
# 2022

JOINT
INSTITUTE
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RESEARCH


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Joint Institute for Nuclear Research

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# JINR MEMBER STATES

## JINR MEMBER STATES

Republic of Armenia

Republic of Azerbaijan

Republic of Belarus

Republic of Bulgaria

Republic of Cuba

Czech Republic

Arab Republic of Egypt

Georgia

Republic of Kazakhstan

Democratic People's Republic of Korea

Republic of Moldova

Mongolia

Republic of Poland

Romania

Russian Federation

Slovak Republic

Ukraine

Republic of Uzbekistan

Socialist Republic of Vietnam

## AGREEMENTS ON GOVERNMENTAL LEVEL ARE SIGNED WITH THE FOLLOWING STATES:

Federal Republic of Germany

Hungary

Italian Republic

Republic of Serbia

Republic of South Africa

# GOVERNING AND ADVISORY BODIES OF THE JOINT INSTITUTE FOR NUCLEAR RESEARCH

## COMMITTEE OF PLENIPOTENTIARIES OF THE GOVERNMENTS OF THE JINR MEMBER STATES

**Republic of Armenia** – S. Hayotsyan

**Republic of Azerbaijan** – A. M. oglu Gashimov

**Republic of Belarus** – S. Shlychkov

**Republic of Bulgaria** – Ts. Bachiyski

**Republic of Cuba** – A. Díaz García

**Czech Republic** – M. Vyšinka

**Arab Republic of Egypt** – M. Sakr

**Georgia** – A. Khvedelidze

**Republic of Kazakhstan** – S. Sakhiyev

**Democratic People's Republic of Korea** – Not appointed

**Republic of Moldova** – V. Ursachi

**Mongolia** – S. Davaa

**Republic of Poland** – M. Waligórski

**Romania** – F.-D. Buzatu

**Russian Federation** – V. Falkov

**Slovak Republic** – F. Šimkovic

**Ukraine** – B. Grynyov

**Republic of Uzbekistan**– B. Yuldashev

**Socialist Republic of Vietnam** – Trần Tuấn Anh

## FINANCE COMMITTEE

One representative of each JINR Member State

## SCIENTIFIC COUNCIL

Chairman: **G. Trubnikov**
Co-Chairman: **S. Kilin (Belarus)**
Scientific Secretary: **S. Nedelko**

- **N. A. Alamanos –** French Republic
- **A. Aprahamian –** United States of America
- **F. Azaiez –** Republic of South Africa
- **Ts. Baatar –** Mongolia
- **C. Borcea –** Romania
- **Bum-Hoon Lee –** Republic of Korea
- **N. Burtebaev –** Republic of Kazakhstan
- **A. M. Cetto Kramis –** United Mexican States
- **A. El-hag Ali –** Arab Republic of Egypt
- **R. Granada –** Argentine Republic
- **S. Kalmykov –** Russian Federation
- **S. Kilin –** Republic of Belarus
- **M. Kovalchuk –** Russian Federation
- **G. Lavrelashvili –** Georgia
- **Lễ Hồng Khiếm –** Socialist Republic of Vietnam
- **Li Jiangang –** People's Republic of China
- **P. Logatchov –** Russian Federation
- **S. Maksimenko –** Republic of Belarus
- **V. Matveev –** Russian Federation
- **Sh. Nagiyev –** Republic of Azerbaijan
- **D. L. Nagy –** Hungary
- **A. Nersessian –** Republic of Armenia
- **N. Nešković –** Republic of Serbia
- **I. Padrón Díaz –** Republic of Cuba
- **Yu. Palii –** Republic of Moldova
- **D. Peres Menezes –** Federative Republic of Brazil
- **R. Rashkov –** Republic of Bulgaria
- **I. Sadikov –** Republic of Uzbekistan
- **A. Sergeev –** Russian Federation
- **M. Spiro –** French Republic
- **Ch. Stoyanov –** Republic of Bulgaria
- **Gh. Stratan –** Romania
- **Trần Chí Thành –** Socialist Republic of Vietnam
- **G. Trubnikov –** Russian Federation
- **R. Tsenov –** Republic of Bulgaria
- **I. Tserruya –** State of Israel
- **V. Voevodin –** Russian Federation
- **Wang Yifang –** People's Republic of China
- **B. Yuldashev –** Republic of Uzbekistan
- **Zhao Hongwei –** People's Republic of China

## PROGRAMME ADVISORY COMMITTEES

### PAC for Particle Physics

Chairperson: I. Tserruya (Israel)
Scientific Secretary: A. Cheplakov

### PAC for Nuclear Physics

Chairperson: To be approved
Scientific Secretary: N. Skobelev

### PAC for Condensed Matter Physics

Chairperson: D. L. Nagy (Hungary)
Scientific Secretary: O. Belov

# INTERNAL ORGANIZATION OF THE JOINT INSTITUTE FOR NUCLEAR RESEARCH

## Bogoliubov Laboratory of Theoretical Physics

**Director D. Kazakov**

Research in

- interactions and symmetry properties of elementary particles, field theory structure and its applications
- properties of exotic nuclei and nuclear systems, low-energy and relativistic nuclear dynamics, nuclear astrophysics
- mathematical models of complex systems, complex materials and nanostructures
- integrable systems, supersymmetry, quantum gravity and string theory

## Veksler and Baldin Laboratory of High Energy Physics

**Acting Director A. Butenko**

Research in

- interactions of multicharged ions in a wide energy range
- relativistic nuclear physics
- structure of nucleons
- strong interactions of particles
- resonance phenomena in particle interactions
- electromagnetic interactions
- particle acceleration techniques
- applied science at NICA complex based on the ARIADNA infrastructure

## Dzhelepov Laboratory of Nuclear Problems

**Director V. Bednyakov**

Research in

- neutrino physics and rare phenomena
- strong, weak and electromagnetic interactions of particles
- nuclear spectroscopy
- charged particle acceleration techniques
- applied research and radiobiology

## Flerov Laboratory of Nuclear Reactions

**Director S. Sidorchuk**

Research in

- synthesis of superheavy elements
- properties of heavy and superheavy elements, mechanisms of nuclear reactions with heavy ions
- reactions with radioactive-ion beams, structures of nuclei at the borders of nucleon stability
- interactions of heavy ions with condensed matter
- heavy-ion acceleration methods

## DIRECTORATE

Director **G. Trubnikov**
Vice-Director **S. Dmitriev**
Vice-Director **V. Kekelidze**
Vice-Director **L. Kostov**
Chief Scientific Secretary **S. Nedelko**
Chief Engineer **B. Gikal**

### Frank Laboratory of Neutron Physics

**Director V. Shvetsov**

Research in
- neutron-induced nuclear reactions
- fundamental properties of the neutron
- structure and dynamics of functional materials
- nanomaterials for energy storage
- materials by neutron scattering, neutron activation analysis, neutron radiography and complementary methods
- dynamic characteristics of the IBR-2 pulsed reactor and advanced neutron source

### Meshcheryakov Laboratory of Information Technologies

**Director V. Korenkov**

Research in
- provision of operation and development of the JINR network, information and computing infrastructure
- optimal usage of international computer networks and information systems
- integration of the heterogeneous computing resources
- modern methods of computer physics, development of standard software
- digitalization of scientific and administrative activities of JINR

### Laboratory of Radiation Biology

**Director A. Bugay**

Research in
- molecular radiobiology
- radiation genetics and cytogenetics
- medical radiobiology
- radiation physiology and neuroradiobiology
- radiation biophysics and mathematical modeling
- astrobiology

### University Centre

**Acting Director A. Verkheev**

Main activities:
- academic programme for senior students, preparation of Bachelor, Master, and PhD theses
- running of international student practices and schools
- popularization of achievements in modern science
- running of scientific schools for physics teachers
- career guidance for schoolchildren
- advanced training of the Institute personnel

### Central Services

- central scientific and information departments
- administrative and economic units
- manufacturing units

# INTRODUCTION


The year of 2022 is marked in the history of the Institute by many events and achievements. We can be proud of bright scientific experiments and important technical achievements of the international community of scientists. During the whole year, the Joint Institute for Nuclear Research continued to enlarge its potential, investing capital to the construction of new facilities. However, the situation in the world affected all spheres of our lives. In this uneasy and turbulent time, the community of JINR showed solidarity, endurance and commitment to the scientific tasks, overcoming all challenges with dignity. Important efforts were made to preserve stability and unity of JINR and to strengthen the scientific mission of the Institute.

In 2022, the regular session of the Committee of Plenipotentiaries of the Governments of JINR Member States was held for the first time on the African continent — in Egypt. A draft of the new Seven Year Plan for 2024–2030 was adopted, regulations on grants and programmes of Plenipotentiaries were approved, and the JINR Postdocs and JINR Fellowship programmes aimed at attracting young scientists to JINR and at strengthening the status of JINR as an international organization were adopted.

We learnt with great regret about the decision of the Czech Republic, Poland and Ukraine to quit JINR and of Slovakia to suspend its membership. These countries have made a tremendous contribution to the development of the Institute and to the achievements of JINR over many decades: intellectually, materially and in terms of staff. We respect the opinions and points of view of the governments of these countries, but the community of JINR hopes that the full-scale cooperation will be restored as soon as possible.

Summing up the year, I would highlight several of the most important scientific results obtained in the main areas of the Institute's research activities.

The fourth and longest commissioning cycle at the NICA accelerator complex was successfully completed, in the course of which three main accelerators of the NICA complex operated simultaneously. The international team of this megascience project achieved bright results. A record intensity was obtained at the extracted beams of accelerated xenon ions. The BM@N experiment became the first Russian nuclear physics experiment at the accelerator complex held with electronic cooling of ion beams. The general construction works at NICA were about 98 percent complete by the end of the year.

In experiments on the synthesis and studies of SHE properties at the Factory of Superheavy Elements, a record number of 238 synthesized atoms of superheavy elements was observed. New isotopes of moscovium, lawrencium, hassium, seaborgium and darmstadtium were discovered. An experiment was started on the chemistry of elements 114 and 112. These achievements confirmed the leadership of the Institute in the synthesis of superheavy elements.

In April 2022, the efficient volume of the deep water Baikal neutrino telescope reached 0.5 $km^3$. In the short time the Baikal-GVD discovered 11 events connected with superhigh energy neutrinos — absolutely unique exotic signals from the active nucleus of our Galaxy, which was preliminarily confirmed by the observation of an astrophysical neutrino flux at the IceCube observatory in the Southern Hemisphere.

Dubna scientists obtained important results in visiting projects to measure the photoproduction cross section of vector mesons in Pb–Pb and Xe–Xe collisions at the LHC energies at the ALICE facility, to search for "dark matter" in the CMS experiment and the "dark photon" in the NA64 experiment, etc. It is necessary to note the successful activities and the

high level of JINR's readiness to execute its responsibilities under the programme of the second phase of refurbishment of the detectors ATLAS, CMS and ALICE at the LHC in CERN. In addition, the Joint Institute's teams actively work in collaborations at FNAL (USA), Tsukuba (Japan) and JUNO (China).

Interesting findings were made by JINR theoreticians in a wide range of fields of theoretical physics. They discovered a new type of anomalous transport phenomenon in the turbulent and accelerated medium. This effect was called a kinematic turbulent effect. In the general case of particles with spontaneous spin, the theorem was proved on the connection of this effect with microscopic properties of matter, namely, with gravitational chiral quantum anomaly. Energies of the lowest $2^+$ states were predicted in even-even superheavy nuclei. These eneries are maximal in the isotopes of Fl and Og, pointing to their almost spherical shape. It was shown that symmetry violation with respect to time reversal in a two-dimensional system of strongly correlated electrons leads to the topological Hall effect — the integer quantum Hall effect in the absence of the external magnetic field.

The active development of fundamental and applied research related to life sciences and condensed matter physics was continued on the basis of the elaboration of an interlaboratory programme of studies based on the International Innovation Centre of Nuclear Technologies being established at the Institute.

JINR scientists were the first to study in detail the mechanisms of the crystallization process of membrane proteins in meso, which provides an empirical basis for the use of this type of crystallization in rational design of medications. The efficiency of a very cold neutron reflector based on nanodiamond powder to enlarge fluxes extracted from the source was also shown experimentally for the first time. In the Neutron Activation Analysis and Applied Research Group, research was conducted using the IREN facility. The most exciting results were obtained in the studies of the meteorite Orgueil, ancient Russian frescoes, heavy metal fallout, cell membranes, processes of programmed cell death, and structure-magnetic properties of new materials. At the IBR-2 reactor, the plan of activities to replace heat exchangers and to form a complete package of documents for getting a license was implemented.

In experiments with animals, radiobiologists of JINR, together with colleagues from the Tsyb Centre of Medical Radiology (Obninsk), founded and patented a principally new method of selective damage of tumour stem cells — a method of enhancing the radiosensitivity of tumour cells using DNA synthesis inhibitors due to which the death of the majority of the population of tumour stem cells is observed after just one fraction of irradiation. In proton irradiation, this mechanism is more effective than in photon beam irradiation.

In 2022, as a result of the modernization of the Govorun supercomputer, its computing power increased by 23.5%, allowing it to reach peak performance. The supercomputer is in the top 20 in the world ranking in terms of performance and efficiency of big data processing.

On the whole, the development of the JINR MICC, including the modernization of the Govorun supercomputer, the successful work of the centre Tier1 of the CMS collaboration, as well as big involvement of Tier1 in tasks of the NICA–MPD collaboration, together with elaboration of methods, algorithms and software for simulation of physical systems, mathematical processing and analysis of experimental data, ensured the Institute's leading position in this field, both in Russia and in other Member States.

Great progress was achieved in the construction of the platform "JINR Digital Ecosystem", which will provide integration of existing and prospective services of support of the scientific, administrative and social activities, as well as the maintenance of engineering and IT infrastructures of the Institute.

In 2022, together with the active development of fundamental and applied science, the Institute continued to expand the international cooperation, including with countries in Latin America, with Serbia, China, Israel, India, and South Korea.

Based on the principles and values, cheif among which is scientific cooperation, the Joint Institute has accumulated unique experience that allows us to move forward on the path to further scientific achievements. The efficiency of new initiatives to strengthen JINR's international scientific and technological cooperation with Member States and partners has been repeatedly confirmed by the organization of regular JEMS practices, events to develop instruments of science diplomacy "Science, Dialogue and Society", and large-scale expansion of the JINR information centre network.

The Institute took an active part in holding the International Year of Basic Sciences declared by the United Nations and vigorously participated in the implementation of initiatives of the Decade of Science and Technology in the country of JINR's location by holding in 2022 several large and representative scientific events.

Immense attention was paid to the development and enlarging of the educational and scientific-educational components. In 2022, the Joint Institute initiated a branch of the Lomonosov Moscow State University in Dubna, which continued the work of the MSU department of SRINP and two chairs of the MSU Physics Faculty.

Remarkable results were achieved by the JINR University Centre, basic chairs of MSU, MIPT, MEPhI, Kazan Federal University, SPbSU, Dubna University: 342 students from Member States had probations and practices at JINR. The annual summer student programme of JINR received a new name START — STudent Advanced Research Training at JINR. Students and postgraduates from all over the world who specialize in natural sciences, engineering and IT take part in it. Many programmes on work with school students, online lectures and excursions for

the growing community of JINR information centres were started.

The year 2022 has proved that even in such a difficult time the key to our success is the results of the scientific programme, new opportunities, the pace of development and stability of JINR due to the preservation of the unique environment for Member States and partner countries that promotes the scientific cooperation and mutual cultural enrichment. Entering the new year with new strength, we are confident in future, we believe in our fascinating science and ambitious projects and, of course, we believe in the talented, industrious and united community of JINR, full of brave ideas and big plans.

G. TRUBNIKOV
Director
Joint Institute for Nuclear Research


# GOVERNING AND ADVISORY BODIES

# COMMITTEE of PLENIPOTENTIARIES of the GOVERNMENTS of the MEMBER STATES of JINR

## STATEMENT OF THE COMMITTEE OF PLENIPOTENTIARIES OF THE GOVERNMENTS OF THE MEMBER STATES OF THE JOINT INSTITUTE FOR NUCLEAR RESEARCH ON PRESERVING THE UNITY OF THE INSTITUTE, ITS SCIENTIFIC MISSION AND INTERNATIONAL PARTNERSHIPS WITHIN A PEACEFUL ENVIRONMENT

In our joint efforts to maintain the unity of the Institute, we, the Plenipotentiaries of the Governments of the JINR Members States, are deeply concerned and regret the current events in Ukraine with widespread and tragic consequences leading to dramatic loss of life and critical international security challenges. Therefore, we call for peace and immediate and concerted actions to find an urgent resolution to this extraordinary situation through dialogue and diplomacy.

Science transcends borders. We urge all Member States of the Institute to stand together and act by joining forces to preserve the stability and unity of JINR. More than ever, reinforcing JINR's mission in the peaceful pursuit of science, it is of utmost importance to continue the support provided for the research and educational activities of the Institute aimed at the benefit of the whole mankind. The members of the JINR Committee of Plenipotentiaries, reunited in an extraordinary meeting on 17 and 21 March 2022, declare the following:

1. We reconfirm our full commitment to the Charter of the Institute, reasserting that all our common resources are used solely for peaceful purposes and the benefit of humankind. Along with implementing its major objective — studies of the fundamental laws of matter, JINR has created and sustains a unique environment for its Member States and partner countries, facilitating scientific cooperation and mutual cultural enrichment.

2. We reiterate our commitment to ensure the unity of the Institute and to support further development of JINR as an international intergovernmental research organization, providing a valuable platform for multilateral scientific communication and collaborations. JINR should remain a distinctive scientific bridge between nations for resolution of global challenges confronting humanity — according to the Institute's Charter and in alignment with the Sofia Declaration of the Committee of Plenipotentiaries on the value of international integration in science and technology, which we adopted in Bulgaria in November 2021.

3. We underline the importance for JINR to continue its close cooperation with international research organizations and in particular with CERN. We emphasize the special role and mission resting with two largest international research organizations in the field of Particle and Nuclear Physics — CERN and JINR, which over the last 65 years have proved their commitment towards strengthening peace and stability.

## SESSION OF THE COMMITTEE OF PLENIPOTENTIARIES, 25 May 2022

A regular session of the Committee of Plenipotentiaries of the Governments of the JINR Member States was held on 25 May in the hybrid format of participation. It was chaired by F.-D. Buzatu, a representative of Romania.

Having heard and discussed the report presented by G. Trubnikov, Director of JINR, the CP took note of the information from the JINR Directorate about the recommendations of the 131st session of the JINR Scientific Council, the implementation of the current Seven-Year Plan for the Development of JINR, the efforts of the Member States towards realization of JINR's large projects, the new scientific and technological results obtained, and about the most important events related to JINR's research and educational activities and international cooperation. The CP noted with satisfaction the organizational measures being taken to ensure a high pace of the Institute's

Dubna, 25 May. Session of the Committee of Plenipotentiaries of JINR



work towards implementing the objectives of the JINR Long-Term Development Strategic Plan up to 2030 and beyond.

The CP endorsed in general the principles, goals and rules for organizing the financing of JINR research and educational activities in the form of cooperation programmes and grants of the Plenipotentiaries of the Governments of the JINR Member States, presented in the draft Regulations on cooperation programmes and grants of the Plenipotentiaries of the Governments of the JINR Member States, and commissioned the JINR Directorate to present the final version of the corresponding Regulations at the next session of the CP.

The CP took note of the Regulations on social support for persons who terminated employment relations with JINR, presented by the JINR Directorate.

The CP endorsed the work accomplished by the JINR Directorate on the execution of the JINR budget in the current year to implement the Topical Plan for JINR Research and International Cooperation in force majeure circumstances of the first quarter of 2022.

The Committee supported JINR's readiness to continue fulfilling all current obligations in accord-

ance with the Cooperation Agreement, protocols, addenda and other documents signed with CERN and collaborations, noting the high value of mutual intellectual exchange over many decades between JINR and CERN for the development of global science.

Having heard and discussed the report "Execution of the JINR budget for 2021 and draft of the revised budget of JINR for 2022" presented by N. Kalinin, Head of the JINR Budget and Economic Policy Department, the Committee of Plenipotentiaries:

— took note of the information on the execution of the JINR budget and on the overpayment of contributions by JINR Member States for 2021;

— approved the consolidated final adjustment of the JINR budget expenditure for 2021 as well as the revised budget of JINR for 2022 with the total income and expenditure amounting to US$ 293 362.6 thousand;

— authorized the Director of JINR, in 2022, to make adjustments to the JINR budget, including adjustments to expenditure items of salaries and international cooperation, within the approved budget in compliance with the Regulations for the Introduction of Adjustments to the Budget of JINR.

Having heard and discussed the report "Concept of the Seven-Year Plan for the Development of JINR for 2024–2030, taking into account the adjustments of the JINR long-term scientific strategy, the optimization of the structure of the JINR Topical Plan as well as the financing and staffing of research projects" presented by G. Trubnikov, Director of JINR, the CP noted with satisfaction that the concept presented fully reveals the architecture and logic of JINR's strategic development formulated in the JINR Long-Term Development Strategic Plan up to 2030 and beyond.

The CP supported the main lines of the concept of the Seven-Year Plan for the Development of JINR for 2024–2030 and commissioned the JINR Directorate to submit a draft of the Seven-Year Plan for consideration by the JINR Scientific Council at its session on 29–30 September 2022.

Having heard and discussed the report "Results of the meeting of the JINR Finance Committee held on 23 May 2022" presented by A. Khvedelidze, Chair of the Finance Committee and Plenipotentiary of the Government of Georgia, the CP approved the Protocol of this meeting. Given the practice of accounting personal income tax (PIT) used in most international organizations, the CP commissioned the JINR Directorate to work with the financial authorities of the Member States on the issue of cancelling Section V of the decision of the JINR CP meeting of 23–25 September 1956 and of ending the practice of withholding PIT from JINR employees against the payment of contributions.

The CP approved the LLC "FinExpertiza" as JINR's auditor for 2021 as well as the Plan for auditing the financial activities of JINR for 2021, presented by the JINR Directorate.

The Committee heard the statement by the Plenipotentiary of the Government of the Slovak Republic, F. Šimkovic, the statement by the Plenipotentiary of the Government of Romania, F.-D. Buzatu, and also noted the official letter from the Plenipotentiary of the Government of the Republic of Bulgaria, Ts. Bachiyski, on the special form of participation of these countries in the activities of the Institute.

Having heard and discussed the report "Proposals for changes in the membership of the JINR Scientific Council" presented by G. Trubnikov, Director of JINR, the CP elected the following members to the JINR Scientific Council for a term of 5 years based on the results of open voting (unanimously): Ana María Cetto Kramis (Mexican Physical Society, Mexico City, Mexico), Trần Chí Thành (Vietnam Atomic Energy Institute, Hanoi, Vietnam), and Zhao Hongwei (Institute of Modern Physics of the Chinese Academy of Sciences, Lanzhou, China).

Considering that the mandate of the current membership of the JINR Scientific Council expires in 2023, the CP commissioned the JINR Directorate to prepare proposals on the new composition of the Scientific Council for the next session of the CP in accordance with the Rules of Procedure of the JINR Scientific Council.

Having heard and discussed the report "Membership of the JINR Scientific Council" presented by S. Nedelko, Chief Scientific Secretary of JINR, the CP, taking into account the force majeure nature of the current circumstances, considered it appropriate in holding the next session of the Scientific Council to proceed from the membership of the Council without including in it those members of the Scientific Council who have announced their temporary or complete withdrawal from its membership.

## SESSION OF THE COMMITTEE OF PLENIPOTENTIARIES, 23 November 2022

A regular session of the Committee of Plenipotentiaries of the Governments of the JINR Members States was held on 23 November in Hurghada (the Arab Republic of Egypt) in a mixed format of participation under the chairmanship of A. Khvedelidze, a representative of Georgia.

Having heard and discussed the report "On the participation of the Republic of Bulgaria and Romania in JINR" presented by L. Kostov, Vice-Director of JINR, the Committee of Plenipotentiaries agreed with the suspension of the participation of the Republic of Bulgaria and Romania in the work of the Committee of Plenipotentiaries of the Governments of the JINR Member States and the JINR Finance Committee and will not take into account the Republic of Bulgaria and Romania when determining the quorum

and voting on agenda items, maintaining the validity of the Charter of the Joint Institute for Nuclear Research for the above states in the rest of it.

Having heard and discussed the report "On the participation of the Czech Republic, the Republic of Poland, and Ukraine in JINR" presented by L. Kostov, Vice-Director of JINR, the Committee of Plenipotentiaries took note of the information about the withdrawal of the Czech Republic, the Republic of Poland, and Ukraine from the Joint Institute for Nuclear Research from 1 January 2023 and commissioned the Working Group under the CP Chair for JINR Financial Issues and the Directorate of JINR to prepare proposals for the settlement of financial issues related to the withdrawal of the Czech Republic, the Republic of Poland, and Ukraine from JINR and submit them for consideration by the meeting of the Finance Committee and the CP session in March 2024 after the approval of the report on the execution of the JINR budget for 2022.

Having heard and discussed the report "On the Procedure for the practical implementation of the decision by the JINR CP on the suspension of the rights, privileges and obligations of the Slovak Republic in JINR" by A. Kharevich, Head of the JINR Legal Department, taking into account the fulfillment by the Slovak Republic of all its financial obligations to JINR for the year 2022, the Committee of Plenipotentiaries commissioned the Working Group under the CP Chair for JINR Financial Issues, together with the JINR Directorate and authorized representatives of the Slovak Republic, to finalize the Procedure for the practical implementation of the decision and submit it for consideration at the meeting of the Finance Committee and the session of the Committee of Plenipotentiaries of the Governments of the JINR Member States in March 2023.

Having heard and discussed the report presented by G. Trubnikov, Director of JINR, about the recommendations of the 132nd session of the JINR Scientific Council, the implementation of the current Seven-Year Plan for the Development of JINR, the efforts of the Member States towards realization of JINR's major projects, the new scientific and technical results obtained, and about the most important events of JINR's scientific and educational activities and international cooperation, the CP noted with satisfaction:

— the progress in implementation, beginning in September 2022, of the fourth technological cycle of the NICA accelerator complex;

— the progress in the production of magnets and their installation in the NICA collider tunnel, the completion of the installation of all dipoles in the collider tunnel arches;

— the work carried out by the MPD collaboration and the VBLHEP team on constructing the MPD detector, and the progress in the production of all detector components required for a technological launch in 2023;

— the successful progress of work and the high level of JINR's readiness to fulfill its obligations under the programme for the second phase of the upgrade of the ATLAS, CMS and ALICE detectors at the LHC at CERN (Geneva);

— the progress in developing the Baikal neutrino telescope for observing natural neutrino fluxes, which in April 2022 reached an effective volume of the deep-water detector of 0.5 $km^3$;

— the successful continuation of experiments at the Factory of Superheavy Elements at the GNS-2 separator, in particular, on the synthesis of a new darmstadtium isotope $^{276}Ds$ in the reaction $^{48}Ca + ^{232}Th$;

— the progress of implementation of the work plan at the IBR-2 reactor to replace heat exchangers with new ones and prepare a complete package of documentation for licensing;

— the further active development of fundamental and applied areas of research related to life sciences and condensed matter physics, based on the development of an interlaboratory research programme on the basis of the Laboratory of Radiation Biology and the International Nuclear Technology Innovation Centre being established at the Institute.

— the successful development of the JINR MICC, including the modernization of the Govorun supercomputer carried out in 2022, and the successful operation of the Tier1 centre for the CMS and NICA–MPD collaborations;

— the significant progress in the creation of the JINR Digital Ecosystem platform;

— the effectiveness of new initiatives to strengthen international scientific and technical cooperation between JINR and JINR Members and Partner Countries;

— the efforts of the JINR Directorate on working with Partner Countries and the intention to raise the status of their participation in JINR, in particular, with the People's Republic of China, Mexico, Brazil, India, Israel, South Korea, and others.

The CP approved the Regulations on Cooperation Programmes and Grants of the Plenipotentiaries of the Governments of the JINR Member States.

The CP noted the timeliness and relevance of the new programmes proposed by the JINR Directorate: JINR Fellowship Programme and JINR Postdoctoral Programme, aimed at increasing the intellectual capital of the Institute and the Member States.

Having taken into account the information from the JINR Directorate about the objective circumstances which affect the time of commissioning of the main facilities of the NICA complex, the CP agreed with the need to extend the period of the general contractor agreement with JSC STRABAG and endorsed the efforts of the Directorate aimed at shortening the deadlines for completing the construction of the NICA complex.

The CP agreed with the basic principles for establishing a regulation on the share of direct staff costs in the contribution of Member States, proposed by the JINR Directorate, and commissioned the JINR Directorate and the Working Group under the CP Chair for JINR Financial Issues to work out this proposal

Hurghada (Egypt), 23 November. Session of the JINR CP




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and submit a draft for consideration at the meeting of the Finance Committee and for approval at the session of the Committee of Plenipotentiaries of the Governments of the JINR Member States in March 2023.

The CP approved the recommendations of the 131st and 132nd sessions of the JINR Scientific Council, as well as the Topical Plan for JINR Research and International Cooperation for 2023.

Having heard and discussed the report "Draft budget of JINR for the year 2023" presented by N. Kalinin, Head of the JINR Budget and Economic Policy Department, the Committee of Plenipotentiaries approved the JINR budget for the year 2023 with the income amounting to US$ 203 485.9 thousand and the expenditure amounting to US$ 245 256.6 thousand, taking into account the positive opening balance amounting to US$ 20 583.9 thousand.

The CP authorized the Director of JINR to make adjustments to the JINR budget for 2023, including adjustments to the expenditure items "Salaries" and "International cooperation", within the approved budget in compliance with the Regulations for making adjustments to the budget of JINR.

The CP approved the scale of contributions of the JINR Member States for the year 2023, which includes the shares of the states leaving JINR (the Czech Republic, the Republic of Poland, and Ukraine) and the states with suspended membership (the Democratic People's Republic of Korea and the Slovak Republic), in order to study in more detail the issue of revising the scale of contributions of the Member States, taking into account the withdrawal of a number of states from JINR. The CP approved the contributions of the JINR Member States for the year 2023, calculated on the basis of the scale of contributions for the year 2023.

The CP did not include the contributions of the states withdrawing from JINR and of the states with suspended membership in the JINR budget for the year 2023.

In connection with the withdrawal from JINR of the Czech Republic, the Republic of Poland, and Ukraine, the CP commissioned the JINR Directorate and the Working Group under the CP Chair for JINR Financial Issues to submit proposals for revising the scale of contributions of the Member States and proposals on the size of the JINR budget in income and expenditure, as well as provisional contributions of the Member States for 2024, 2025 and 2026, for consideration at the meeting of the Finance Committee and the session of the Committee of Plenipotentiaries of the Governments of the JINR Member States in March 2023.

The CP approved the budget for the year 2023 on the construction and exploitation of the NICA complex of superconducting rings for heavy-ion colliding beams with the special-purpose funds of the Russian Federation, provided in accordance with the Agreement between the Government of the Russian Federation and JINR, in the amount of 2 958 845.6 thousand rubles.

The CP approved the consolidated adjustment of the JINR budget for the year 2022 over 9 months; authorized the Director of JINR to index the salary and tariff parts of the compensation package of the staff members, taking into account the possibilities of the JINR budget for 2023, in accordance with the JINR Collective Bargaining Agreement for 2020–2023; and took note of the information on the draft expenditure of the Seven-Year Plan for the Development of JINR for 2024–2030.

Having heard and discussed the report "Results of the meeting of the JINR Finance Committee held on 21 November 2022" presented by A. Omelchuk, Chair of the Finance Committee, the Committee of Plenipotentiaries approved the Protocol of the meeting.

Having taken note of the letter of the Plenipotentiary of the Government of the Republic of Uzbekistan on proposals for the payment of the restructured arrears of the Republic of Uzbekistan which arose prior to 1 January 2002 and the arrears which arose during 2002–2003, the CP commissioned to settle this issue after paying off the current arrears in full and paying the restructured arrears in accordance with the schedule approved by the CP in November 2020.

The CP commissioned the JINR Directorate to prepare a new structure of the JINR budget for budget planning, starting in 2024, and send it to the Plenipotentiaries for comments and proposals as part of the organization of the regular meetings of the Finance Committee and the Committee of Plenipotentiaries in March 2023.

The Working Group under the CP Chair for JINR Financial Issues established by the CP included representatives of the Republic of Belarus, the Republic of Cuba, Georgia, the Republic of Kazakhstan, Mongolia, the Russian Federation, and the Socialist Republic of Vietnam.

The CP approved the audit report based on the results of the audit of JINR's financial activities for the year 2021 and took note of the information on the implementation, by the JINR Directorate, of the Action Plan following the results of the audit of JINR's financial activities for the years 2020 and 2021.

Having heard and discussed the report "Draft Seven-Year Plan for the Development of JINR for 2024–2030" presented by G. Trubnikov, Director of JINR, the Committee of Plenipotentiaries noted that the presented Draft fully complies with the architecture and logic of the JINR Long-Term Development Strategic Plan up to 2030 and beyond and contains an ambitious, competitive international scientific programme, as well as the optimal requested staff and financial resources.

The CP adopted the presented Draft Seven-Year Plan for the Development of JINR for 2024–2030 and commissioned the JINR Directorate to submit its final version at the next session of the JINR CP in March 2023.

The CP asked the Plenipotentiaries of the Governments of the JINR Member States to work with

the governments of their states on the issue of an annual, at least 5%, increase in the amount of contributions of the Member States to financially support the Seven-Year Plan for the Development of JINR for 2024–2030.

Having heard and discussed the report "On the membership of the JINR Scientific Council" presented by S. Nedelko, Chief Scientific Secretary of JINR, the Committee of Plenipotentiaries took note of the list of members of the JINR Scientific Council appointed to the new composition of the Scientific Council by the Plenipotentiaries of the Governments of the JINR Member States and based on the results of open voting (unanimously), approved the candidacies of elected members of the Scientific Council as members of the Scientific Council for a term of 5 years. The new membership of the Scientific Council shall take office from the 133rd session of the JINR Scientific Council.

The CP thanked the members of the Scientific Council of the previous composition for their successful work accomplished during 2018–2022.

For the term of office of the new membership of the Scientific Council, the CP established its maximum number equal to 50 members.

Having heard the scientific report by M. Sakr, Plenipotentiary of the Government of the Arab Republic of Egypt to JINR, the Committee of Plenipotentiaries expressed its gratitude to Professor M. Sakr for his interesting and informative report.

The Committee of Plenipotentiaries thanked V. Korenkov, Director of the Meshcheryakov Laboratory of Information Technologies, for the interesting presentation "JINR Digital Ecosystem".

# SCIENTIFIC COUNCIL

## 131st SESSION OF THE JINR SCIENTIFIC COUNCIL, 24–25 February 2022

The 131st session of the JINR Scientific Council was held on 24–25 February. It was chaired by JINR Director G. Trubnikov and Deputy Chairman of the Presidium of the National Academy of Sciences of Belarus S. Kilin.

G. Trubnikov delivered a comprehensive report covering the highlights for JINR in 2021, the decisions of the latest session of the Committee of Plenipotentiaries of the Governments of the JINR Member States (Bansko and Sofia, Bulgaria, November 2021), the priority research programmes suggested for inclusion in the Seven-Year Plan for the Development of JINR for 2024–2030, as well as recent events in JINR's international cooperation.

The recommendations of the Programme Advisory Committees were reported by I. Tserruya (PAC for Particle Physics), M. Lewitowicz (PAC for Nuclear Physics), and by D. L. Nagy (PAC for Condensed Matter Physics).

The Scientific Council considered the concept of the Seven-Year Plan for the Development of JINR for 2024–2030 in the major areas presented in the reports by V. Kekelidze (particle physics and high-energy heavy-ion physics, and information technologies), S. Dmitriev (nuclear physics, and applied and innovation research), and by L. Kostov (condensed matter physics and radiobiology).

The Scientific Council heard the best reports by young scientists as recommended by the Programme Advisory Committees and a number of scientific reports on the results of 2021.

The Scientific Council considered the Directorate's proposals on awarding the title "Honorary Doctor of JINR", the recommendations of the juries on awarding the B. Pontecorvo Prize and on awarding JINR annual prizes for best papers in the fields of scientific research, methodology research, and applied technology research.

The election of Director of the Veksler and Baldin Laboratory of High Energy Physics took place at the session. Vacancies of positions in the Directorates of JINR Laboratories were announced.

The Scientific Council adopted the following Resolution.

### General Considerations

Having heard the report by JINR Director G. Trubnikov, the Scientific Council noted the significance and timeliness of the Sofia declaration on the value of international integration in science and technology adopted at the session of the Committee of Plenipotentiaries, which, in particular, emphasized the importance of basic sciences and the value of an open international scientific dialogue for resolution of global challenges confronting humanity, and supported the UNESCO initiative and the UN General Assembly decision to proclaim the International Year of Basic Sciences for Sustainable Development in 2022.

The Scientific Council welcomed the accession to JINR of the Arab Republic of Egypt as a full member, which occurred at the session of the Committee of Plenipotentiaries in November 2021, and the pre-accession actions undertaken by the Republic of Serbia to enter JINR as well.

The Scientific Council took note of the appointment of A. Nersesyan (Armenia) and A. El-hag Ali (Egypt) as new members of the Scientific Council, by decisions of the respective Plenipotentiaries of Member States.

### Recommendations in Connection with the PACs

The Scientific Council took note of the recommendations made by the PACs at their meetings in January 2022, as reported at this session by I. Tserruya, Chair of the PAC for Particle Physics, M. Lewitowicz, Chair of the PAC for Nuclear Physics, and D. L. Nagy, Chair of the PAC for Condensed Matter Physics. The Scientific Council requested the JINR Directorate to consider these recommendations while preparing the Topical Plan for JINR Research and International Cooperation for the year 2023.

***Particle Physics.*** The Scientific Council congratulated the NICA Booster team on achieving the design parameters and accelerating a beam of iron ions to an energy of 578 MeV/nucleon. Electron cooling of a heavy-ion beam was first-ever achieved in Russia in the NICA Booster, and the development of the beam

extraction and transport channel systems from the Booster to the Nuclotron was successfully completed in collaboration with the Budker Institute of Nuclear Physics. The Scientific Council acknowledged the start of operation of the SOCHI station equipment — an important component of the NICA applied research and innovations programme — designed for irradiating microchips using ion beams extracted from the HILAC. The Scientific Council also congratulated the NICA team on the installation of the first superconducting magnet in the collider tunnel.

The Scientific Council noted with satisfaction the progress in the infrastructure development, including the admission to the operation of eleven 6-kV modernized substations with a total capacity of up to 33.6 MW, the installation of a helium liquefier with a capacity of more than 1000 litres per hour, a helium refrigerator for cooling the Booster of 2000 W capacity at a temperature of 4.5 K, and four compressed helium purification units, and commissioning of large-scale cryogenic equipment located outdoors.

Congratulating the MPD team on launching the tests of the large superconducting solenoid, the Scientific Council welcomed the plan to produce 800 ECal modules in Russia and another 800 in China.

The Scientific Council appreciated the progress in preparing the BM@N detector for the forthcoming runs with heavy-ion beams scheduled for 2022. The Scientific Council noted the successful implementation of the PAC's longstanding recommendation of having a vacuum beam line in front of BM@N in order to reduce the otherwise huge background.

The Scientific Council endorsed the PAC's recommendations to approve the SPD CDR and asked the SPD team to proceed with the TDR preparations.

Together with the PAC, the Scientific Council noted with satisfaction the growing visibility and the increased involvement of the JINR teams in physics analyses in the ALICE, ATLAS, and CMS experiments at the LHC.

***Nuclear Physics.*** The Scientific Council took note of the report, considered by the PAC for Nuclear Physics, on the scientific and methodological work carried out at FLNP during 2020–2022 under the theme "Investigations of Neutron Nuclear Interactions and Properties of the Neutron", which includes the TANGRA and ENGRIN projects.

In cooperation with physicists from the Czech Technical University in Prague, measurements of rare modes of spontaneous fission of $^{252}$Cf with a highly active sample (~400 kBq) were carried out.

Significant progress was achieved in the development of first-ever efficient reflectors for ultracold neutrons based on powders of diamond nanoparticles.

A wide range of activities was carried out using various nuclear physics techniques to solve problems in ecology, materials science, archeology, art history, and medicine in cooperation with a large number of scientists from research centres of JINR Member States.

The Scientific Council supported the PAC recommendation to extend the theme "Investigations of Neutron Nuclear Interactions and Properties of the Neutron" until the end of 2023.

In 2021, three series of experiments were performed at the new gas-filled separator DGFRS-2 of the Factory of Superheavy Elements at the Flerov Laboratory of Nuclear Reactions. The fusion reactions of $^{243}$Am, $^{242}$Pu, and $^{238}$U isotopes with $^{48}$Ca ions accelerated at DC-280 with the formation of Mc, Fl, and Cn isotopes and their daughter nuclei were used to determine the parameters of the new separator.

During the experiments, it was shown that the new gas-filled separator DGFRS-2 was operating within design parameters, which makes it possible to conduct new experiments on the study of superheavy nuclei at a higher sensitivity level.

The Scientific Council congratulated the FLNR team for the spectacular results obtained at the SHE Factory on the synthesis and decay of superheavy nuclei, and encouraged the FLNR Directorate to publish the first results of these experiments as soon as possible.

***Condensed Matter Physics.*** The Scientific Council noted the progress in replacing air heat exchangers of the secondary cooling circuit of the IBR-2 reactor and the preparation for obtaining a license to operate this facility. The Scientific Council supported the FLNP plans to manufacture a new fuel load for IBR-2 in order to provide the conditions required for extending its service life for a period after 2032, as well as the FLNP activity on studying the mechanism of fluctuations in the IBR-2 power pulses, and recommended continuing this work.

The Scientific Council supported the establishment of the User Committee and welcomed a closer exchange of opinions between this committee and the PAC.

The Scientific Council was pleased to note the further upgrade of the SKAT and EPSILON diffractometers, in particular, during the temporary suspension of the IBR-2 operation.

The Scientific Council encouraged the joint activity for developing the new facility for neutron radiography and tomography at the WWR-SM reactor (INP, Tashkent, Uzbekistan).

The Scientific Council took note of the recent progress in developing the new neutron source at JINR, noting, in particular, the studies carried out to calculate the vibrational stability of the projected NEPTUNE reactor (IBR-3) with neptunium-nitride fuel, as well as to optimize the composition of the reactivity modulator of the NEPTUNE reactor by introducing additional reflectors to be made of nickel or beryllium. The Scientific Council recommended proceeding to the next stage in the design of the NEPTUNE reactor, noting the necessity for the R&D work to optimize the reactor vessel and reactivity modulator to be carried out jointly with the NIKIET Institute of the Rosatom State Corporation.

The Scientific Council welcomed the recent progress in developing the SOLCRYS Structural Research Laboratory at the SOLARIS National Synchrotron Radiation Centre, noting that various parts of the laboratory were at different phases of accomplishment.

***Common Issues.*** The Scientific Council was pleased to note the activity of the PAC for Condensed Matter Physics on the elaboration of an approach to appointing reviewers for JINR themes and projects, expecting to be informed on further PAC experience in application of anonymous peer review.

***Reports by Young Scientists.*** The Scientific Council followed with interest the reports by young scientists, selected by the PACs for presentation at this session, and thanked the respective speakers: V. Zhaketov (FLNP), P. Goncharov (MLIT), A. Slivin (VBLHEP), and M. Tezekbayeva (FLNR), welcoming such selected reports in future.

## Membership of the PACs

As proposed by JINR Director G. Trubnikov, the Scientific Council appointed M. Block (GSI, Darmstadt, Germany) as a member of the PAC for Nuclear Physics for a term of three years. The Scientific Council thanked S. Hofmann (GSI) for his dedicated work as member of this PAC since 2005 and for his outstanding contribution to the cooperation with FLNR in research on superheavy elements.

## Concept of the Seven-Year Plan for the Development of JINR for 2024–2030

The Scientific Council heard with interest the concept of the next plan for the development of JINR (2024–2030) presented in the reports by Vice-Director V. Kekelidze (particle physics and high-energy heavy-ion physics, and information technologies), Vice-Director S. Dmitriev (nuclear physics, and applied and innovation research), and by Vice-Director L. Kostov (condensed matter physics and radiobiology).

Noting with satisfaction that these reports on the major areas revealed in full the architecture and logic of the strategic development of JINR as proposed by Director G. Trubnikov in his report, the Scientific Council endorsed the concept presented as a whole and requested the JINR Directorate to continue work towards developing a detailed draft plan and to present it at the next session of the Scientific Council.

## Scientific Reports on the Results of 2021

The Scientific Council heard with interest the reports "Biohybrid nanocomplexes and their potential application in biomedicine" by Yu. Gorshkova (FLNP) and "Multiple facets of multiloop calculations" by A. Bednyakov (BLTP), and thanked the speakers.

## Awards and Prizes

The Scientific Council congratulated M. Waligórski (Poland) on the award of the diploma "Honorary Doctor of JINR".

The Scientific Council approved the proposal by JINR Director G. Trubnikov to award the title "Honorary Doctor of JINR" to C. Bréchignac (France) and E. Burzo (Romania).

The Scientific Council approved the recommendations of the Jury presented by its Chair, A. Olshevskiy, to award the B. Pontecorvo Prize to T. K. Gaisser (USA) for his significant contributions to neutrino, astroparticle and high-energy cosmic-ray physics, in particular, to the atmospheric neutrino flux calculation from its early stage development.

The Scientific Council approved the Jury's recommendations, presented by JINR Vice-Director S. Dmitriev, on awarding JINR annual prizes for best papers in the fields of theoretical and experimental research, methodology and technology research, and applied technology research.

## Election and Announcement of Vacancies in the Directorates of JINR Laboratories

The Scientific Council elected A. Kisiel Director of the Veksler and Baldin Laboratory of High Energy Physics (VBLHEP) for a term of five years and thanked V. Kekelidze and R. Lednický for their successful tenures as Directors of this Laboratory during 2014–2021 and 2021–2022, respectively.

The Scientific Council announced the vacancies of positions of VBLHEP Deputy Directors. The endorsement of appointments will take place at the 132nd session of the Scientific Council in September 2022.

The Scientific Council announced the vacancies for positions of Directors of the Frank Laboratory of Neutron Physics and of the Meshcheryakov Laboratory of Information Technologies. The elections will take place at the 133rd session of the Scientific Council in February 2023.

# 132nd SESSION OF THE JINR SCIENTIFIC COUNCIL, 29–30 September 2022

The 132nd session of the JINR Scientific Council was held on 29–30 September. It was chaired by JINR Director G. Trubnikov and Deputy Chairman of the Presidium of the National Academy of Sciences of Belarus S. Kilin.

G. Trubnikov presented a comprehensive report which highlighted the decisions of the latest sessions of the JINR Committee of Plenipotentiaries (of 17, 21 March and 22 May 2022), implementation of the current Seven-Year Plan for the Development of JINR

(2017–2023) and the latest events in international cooperation of the Institute.

The Scientific Council took note of the draft of the Seven-Year Plan for the Development of JINR for 2024–2030 introduced by JINR Director G. Trubnikov.

The Scientific Council heard the information about work of the JINR Programme Advisory Committees planned in 2023 and proposals on the changes in their structure presented by JINR Vice-Director V. Kekelidze.

The Scientific Council considered the decision of the Jury on awarding the V. Dzhelepov Prize. Annual JINR Prizes were awarded for the best scientific, scientific-methodical and scientific-technological applied research.

Elections to the position of BLTP Director were held, vacancies for the positions in the Directorates of the JINR Laboratories were announced.

The Scientific Council heard the scientific report "Programme of Scientific Research at MPD" presented by V. Ryabov.

The Scientific Council adopted the following resolution.

## General Considerations

The Scientific Council took note of the comprehensive report by JINR Director G. Trubnikov, covering the decisions of the latest sessions of the Committee of Plenipotentiaries of the Governments of the JINR Member States on preserving the unity of the Institute, its scientific mission and international partnerships within a peaceful environment, adopted at the extraordinary session of the CP on 17, 21 March 2022.

Taking into account the information about the session of the JINR Committee of Plenipotentiaries on 22 May 2022, the Scientific Council noted with satisfaction the progress in implementing the current plan of research and development of the scientific infrastructure at JINR, namely:

— the successful completion of the third cycle of commissioning the NICA accelerator complex in the first quarter of 2022, during which critical tasks were accomplished to ensure the simultaneous operation of the three main accelerators of the NICA complex and to accelerate and extract a beam with an energy up to 3 GeV/nucleon;

— the progress in production of magnets and their installation in the NICA collider tunnel;

— the successful realization of the physics run during which the SRC collaboration accumulated more than 185 million interactions of carbon with a hydrogen target;

— the significant progress in constructing the Baikal neutrino telescope, which led to an increase in the effective volume of the deep-water detector to 0.5 $km^3$;

— the continuation of experiments at the Factory of Superheavy Elements using the DGFRS-2 separator, in particular, the synthesis of new darmstadtium isotope $^{276}$Ds in the $^{48}$Ca + $^{232}$Th reaction;

— the ongoing preparations for the first experiment to study the chemical properties of elements $^{114}$Fl and $^{112}$Cn at the DGFRS-3 (GRAND) separator, scheduled for the end of 2022;

— the progress in the status of the IBR-2 reactor: the affected heat exchangers have been replaced with new ones and the whole package of documentation for licensing is being formed;

— the further active development of fundamental and applied areas of research related to life sciences and condensed matter physics, based on the development of an interlaboratory research programme at the Laboratory of Radiation Biology and of an International Nuclear Technology Innovation Centre being established at the Institute.

The Scientific Council noted the results of the JINR groups under the cooperation agreements, protocols, addenda and other documents signed with research organizations all over the world, particularly with CERN and collaborations.

The Scientific Council took note of the election by the JINR Committee of Plenipotentiaries of A. M. Cetto Kramis (Mexico), Trần Chí Thấnh (Vietnam), and Zhao Hongwei (China) as new members of the Scientific Council.

## Draft Seven-Year Plan for the Development of JINR for 2024–2030

The Scientific Council took note of the Draft Seven-Year Plan for the Development of JINR for 2024–2030. The Draft Plan fully follows the architecture and logic of JINR's strategic development formulated in the concept of this Seven-Year Plan, presented and discussed at the 131st session of the Scientific Council in February 2022 and at the CP session on 25 May 2022.

The Scientific Council endorsed this Draft of the Seven-Year Plan for the Development of JINR for 2024–2030 and recommended that the JINR Directorate submit it for consideration at the next CP session in November 2022.

## Discussions of the Director's Reports

In the course of the discussions of the reports by JINR Director G. Trubnikov, members of the Scientific Council made the following recommendations:

— to find a way to keep cooperation between CERN and JINR, including, in particular, organization of the traditional CERN–JINR School of Physics for young scientists, with possible participation of IUPAP;

— to pay extra attention to coordination and harmonization of the JINR Seven-Year Plan with the NuPECC Long-Range Plan and other strategic documents worldwide;

— to carry out a careful analysis of the existing risks that may hinder the implementation of the Seven-Year Plan and include a special chapter on risk assessments and corresponding scenarios of updates to the Plan;

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— to continue and enhance the activities aimed at strengthening the intellectual, material and financial basis of JINR and involving new associate and full Member States from different regions worldwide, including countries with strong economies, for instance, China.

## Activities of the JINR PACs in 2023 and Proposals for Changes in Their Memberships

The Scientific Council appointed the following new members of the PAC for Particle Physics for a term of three years:

— M. Djordjević (University of Belgrade, Serbia);
— A. Kotzinian (ANSL, Yerevan, Armenia);
— S. Kuleshov (UNAB, Santiago, Chile);
— Yu. Tikhonov (BINP SB RAS, Novosibirsk, Russia).

The Scientific Council terminated the mandate of the current membership of the PAC for Nuclear Physics and appointed the following new members of this PAC for a term of three years:

— D. Balabanski (ELI-NP, IFIN-HH, Bucharest, Romania);
— D. Eremenko (SINP MSU, Moscow, Russia);
— M. Gaidarov (INRNE BAS, Sofia, Bulgaria);
— K. Hahn (CENS, Daejeon, Republic of Korea);
— D. Janseitov (INP, Almaty, Kazakhstan);
— D. Klinov (IPPE, Obninsk, Russia);
— V. Kuzminov (BNO INR RAS, Neutrino, Russia);
— J. Lubián Ríos (INCT-FNA, UFF, Niterói, Brazil);
— I. Mazumdar (TIFR, Mumbai, India);
— Zhi Qin (IMP CAS, Lanzhou, China).

The Scientific Council assumed that members of the PAC for Nuclear Physics who had suspended their participation could be invited to join a new committee to resume their work, if they agreed.

The Scientific Council appointed the following new members of the PAC for Condensed Matter Physics for a term of three years:

— M. Tashmetov (INP AS RUz, Tashkent, Uzbekistan);
— D. Tayurskii (KFU, Kazan, Russia);
— I. Ushakov (FMBC, Moscow, Russia);
— N. Verga (UMF CD, Bucharest, Romania).

In order to determine the required quorum, the Scientific Council resolved to proceed from the memberships of the PACs without including in them those members who had announced their temporary or complete withdrawal from the PACs.

## Scientific Report

The Scientific Council heard with interest the scientific report "Experimental programme at MPD" presented by V. Ryabov (NRC KI PNPI, Gatchina) and thanked the speaker.

## Awards and Prizes

The Scientific Council approved the Jury's recommendations on the award of the V. Dzhelepov Prize to P. Apel (FLNR, JINR) for the development of a new generation of track membranes and their applications in medicine and ecology.

The Scientific Council congratulated the winners of JINR annual prizes for best scientific, methodological, technological, and applied research papers.

## Election and Announcement of Vacancies in the Directorates of JINR Laboratories

The Scientific Council elected D. Kazakov Director of the Bogoliubov Laboratory of Theoretical Physics (BLTP) for another term of five years.

The Scientific Council announced the vacancies of positions of BLTP Deputy Directors. The endorsement of appointments will take place at the 133rd session of the Scientific Council in February 2023.

The Scientific Council announced the vacancy of the position of Director of the Dzhelepov Laboratory of Nuclear Problems. The election will take place at the 134th session of the Scientific Council in September 2023.

The Scientific Council noted that A. Kisiel, since his election as Director of the Veksler and Baldin Laboratory of High Energy Physics (VBLHEP) at the previous session of the Scientific Council in February 2022, was unable, due to force majeure circumstances, to assume his office; therefore, the endorsement of appointments of VBLHEP Deputy Directors could not take place at this session and should be postponed. The Scientific Council agreed with the proposal by JINR Director G. Trubnikov to announce the vacancy of the position of VBLHEP Director again and to hold a new election at the 134th session of the Scientific Council in September 2023. Until the new election, the Scientific Council gave the JINR Director the right to appoint Acting Director and Deputy Directors of VBLHEP, proceeding from the major task to make maximum efforts and organize all work on NICA in order to start the technical launch of the collider by the end of 2023.

# FINANCE COMMITTEE

## MEETING OF THE JINR FINANCE COMMITTEE, 23 May 2022

A meeting of the JINR Finance Committee was held on 23 May, via videoconference. It was chaired by A. Khvedelidze, a representative of Georgia.

The Finance Committee heard a report by JINR Director G. Trubnikov and recommended that the CP:

— take note of the information from the JINR Directorate about the recommendations of the 131st session of the JINR Scientific Council, the implementation of the current Seven-Year Plan for the Development of JINR, the efforts of the Member States towards realization of JINR's large projects, the new scientific and technological results obtained, and about the most important events related to JINR's scientific and educational activities and international cooperation;

— endorse the work accomplished by the JINR Directorate on the execution of the JINR budget in the current year to implement the Topical Plan for JINR Research and International Cooperation in force majeure circumstances of the first quarter of 2022;

— support the main lines of the concept of the Seven-Year Plan for the Development of JINR for 2024–2030 and recommend that the JINR Directorate, while preparing a detailed draft of the Seven-Year Plan, pay special attention to balancing the content of the research and infrastructure development programme with its provision with the necessary financial and material resources, assessing with particular care the existing and estimated risks.

Concerning the report "Execution of the JINR budget for 2021 and draft of the revised budget of JINR for 2022" by N. Kalinin, Head of the JINR Budget and Economic Policy Department, the Finance Committee recommended that the CP:

— take note of the information on the execution of the JINR budget for 2021, approve the consolidated final adjustment of the JINR budget expenditure for 2021, and approve the revised budget of JINR for 2022 with the total income and expenditure amounting to US$ 293 362.6 thousand;

— authorize the Director of JINR, in 2022, to make adjustments to the JINR budget, including adjustments to expenditure items of salaries and international cooperation, within the approved budget in compliance with the Regulations for the Introduction of Adjustments to the Budget of JINR;

— take note of the information on the clarification of calculations for the receipt of funds from countries participating in JINR's activities on the basis of a bilateral Agreement on science and technology cooperation (the Arab Republic of Egypt, the Republic of Serbia, and the Republic of South Africa).

Concerning the report "Proposal for selecting an organization for auditing JINR's financial activities for the year 2021" by L. Kostov, Vice-Director of JINR, the Finance Committee recommended that the CP approve the LLC "FinExpertiza" as JINR's auditor for 2021, as well as the Plan for auditing the financial activities of JINR for 2021 presented by the JINR Directorate.

Concerning the report "Results of the meeting of the Working Group under the CP Chair for JINR Financial Issues held on 19 May 2022" by A. Issadykov, Chair of the Working Group, the Finance Committee recommended that the CP consider the possibility of commissioning the JINR Directorate, given the practice of accounting personal income tax (PIT) used in most international organizations, to work with the financial authorities of the Member States on the issue of cancelling Section V of the decision of the JINR CP meeting of 23–25 September 1956 and of ending the practice of withholding PIT from JINR employees against the payment of contributions.

The Finance Committee recommended that the CP commission the JINR Directorate to continue applying the current procedure for offsetting PIT against the contributions, in doing so:

a) to fix the amount of a Member State's overpayment which arose in the previous financial year when approving the revised budget for the current year at the spring session of the CP;

b) to determine the amount of contributions of the Member States for the next financial year in accordance with the current methodology at the autumn session of the CP;

c) in JINR's letter on the payment of contributions in the next financial year, sent to the Member States, to indicate the amount of the estimated contribu-

tion, the amount of the overpayment fixed, and the amount payable. This principle applies to Member States which have an overpayment for the estimated year and do not have current accumulated arrears in paying contribution to the JINR budget at the end of the estimated year.

It is advisable to start clarifying the amount of a contribution payable beginning in 2023, taking into account the amount of the overpayment that arose and was fixed following the payment of the contribution for 2021.

Concerning the report "Proposals for improving the standard regulation of cooperation programmes and grants of the Plenipotentiaries of the Governments of the JINR Member States" by S. Nedelko, Chief Scientific Secretary of JINR, the Finance Committee recommended that the CP endorse in general the principles, goals and rules for organizing the financing of JINR research and educational activities in the form of cooperation programmes and grants of the Plenipotentiaries of the Governments of the JINR Member States, presented in the draft Regulations, and commission the JINR Directorate to present the final version of the corresponding Regulations at the next session of the CP.

The Finance Committee thanked V. Korenkov, Director of the Meshcheryakov Laboratory of Information Technologies, for his interesting and informative report "Digital platforms for JINR research projects".

## MEETING OF THE JINR FINANCE COMMITTEE, 21 November 2022

A regular meeting of the Finance Committee was held on 21 November in Hurghada (the Arab Republic of Egypt) in a mixed format under the chairmanship of A. Omelchuk, a representative of the Russian Federation.

Concerning the report "On the participation of the Republic of Bulgaria and Romania in JINR" by L. Kostov, Vice-Director of JINR, the Finance Committee recommended the Committee of Plenipotentiaries:

— to agree with the suspension of the participation of the Republic of Bulgaria and Romania in the work of the Committee of Plenipotentiaries of the Governments of the JINR Member States and the JINR Finance Committee and not to take into account the Republic of Bulgaria and Romania when determining the quorum and voting on agenda items;

— to maintain the validity of the Charter of the Joint Institute for Nuclear Research for the above states in the rest of it;

— to make a decision on the resumption of full membership of the Republic of Bulgaria and Romania after sending an appeal from the Plenipotentiaries of these states addressed to the CP Chair and the Director of JINR, in which the readiness to fully fulfill their obligations in compliance with the JINR Charter will be expressed.

Concerning the report "On the participation of the Czech Republic, the Republic of Poland, and Ukraine in JINR" by L. Kostov, Vice-Director of JINR, the Finance Committee recommended that the Committee of Plenipotentiaries:

— take note of the information about the withdrawal of the Czech Republic, the Republic of Poland,

Hurghada (Egypt), 21 November. Meeting of the JINR Finance Committee

and Ukraine from the Joint Institute for Nuclear Research from 1 January 2023;

— commission the Working Group under the CP Chair for JINR Financial Issues and the Directorate of JINR to prepare proposals for the settlement of financial issues related to the withdrawal of the Czech Republic, the Republic of Poland, and Ukraine from JINR and submit them for consideration by the meeting of the Finance Committee and the CP session in March 2024 after the approval of the report on the execution of the JINR budget for 2022.

Concerning the report "On the Procedure for the practical implementation of the decision by the JINR CP on the suspension of the rights, privileges and obligations of the Slovak Republic in JINR" by A. Kharevich, Head of the JINR Legal Department, taking into account the fulfillment by the Slovak Republic of all its financial obligations to JINR for the year 2022, the Finance Committee recommended that the Committee of Plenipotentiaries approve the proposed Draft Procedure taking into account the views expressed by the members of the Finance Committee.

The Finance Committee commissioned the JINR Directorate to take into account the balance of financial resources for 2022 provided in JINR's budget for grants and programmes of the Slovak Republic in accordance with the Agreement between the Directorate of JINR and the Plenipotentiary of the Government of the Slovak Republic, when financing research cooperation between JINR and scientists of the Slovak Republic in the subsequent period after the resumption of full membership of the Slovak Republic.

Concerning the report by G. Trubnikov, Director of JINR, on the recommendations of the 132nd session of the JINR Scientific Council, the implementation of the current Seven-Year Plan for the Development of JINR, the efforts of the Member States towards realization of JINR's major projects, the new scientific and technological results obtained, and about the most important events related to JINR's scientific and educational activities and international cooperation, the Finance Committee recommended the Committee of Plenipotentiaries:

— to endorse the work carried out by the JINR Directorate on the execution of the JINR budget for the current year for the implementation of the Topical Plan for JINR Research and International Cooperation in force majeure circumstances of 2022;

— to note that the main parameters of the Draft Seven-Year Plan for the Development of JINR for 2024–2030 fully comply with the previously presented concept of the Seven-Year Plan for the Development of JINR for 2024–2030 and the logic of the JINR Long-Term Development Strategic Plan up to 2030 and beyond. The presented Draft contains a competitive international scientific programme, and the requested staff and financial resources seem to be optimal;

— to adopt the presented Draft Seven-Year Plan for the Development of JINR for 2024–2030, taking into account the comments made, and to commission the JINR Directorate to submit the revised version at the next meeting of the CP in March 2023;

— to agree with the basic principles for establishing a regulation on the share of direct staff costs in the contribution of Member States, proposed by the JINR Directorate and to commission the JINR Directorate and the Working Group under the CP Chair for JINR Financial Issues to work out this proposal and submit the Draft Regulation on the share of direct staff costs in the contribution of Member States for consideration at the meeting of the Finance Committee and for approval at the session of the Committee of Plenipotentiaries in March 2023.

Concerning the report "Draft budget of JINR for the year 2023" by N. Kalinin, Head of the JINR Budget and Economic Policy Department, the Finance Committee recommended the Committee of Plenipotentiaries:

— to approve the JINR budget for the year 2023 with the income amounting to US$ 203 485.9 thousand and the expenditure amounting to US$ 245 256.6 thousand, taking into account the positive opening balance amounting to US$ 20 583.9 thousand;

— to allow the JINR Director in 2023 to introduce adjustments to the JINR budget, including adjustments to the expenditure items "Salaries" and "International cooperation", within the approved budget in accordance with the Regulations for the Introduction of Adjustments to the JINR Budget;

— to approve the scale of contributions of the JINR Member States for the year 2023, which includes the shares of the states leaving JINR (the Czech Republic, the Republic of Poland, and Ukraine) and the states with suspended membership (the Democratic People's Republic of Korea and the Slovak Republic), in order to study in more detail the issue of revising the scale of contributions of the Member States, taking into account the withdrawal of a number of Member States from JINR;

— to approve the contributions of the JINR Member States for the year 2023, calculated on the basis of the scale of contributions for the year 2023;

— in connection with the withdrawal from JINR of the Czech Republic, the Republic of Poland, and Ukraine, to commission the JINR Directorate and the Working Group under the CP Chair for JINR Financial Issues to submit proposals for revising the scale of contributions of the Member States and proposals on the amount of the JINR budget in income and expenditure, as well as on provisional contributions of the Member States for 2024, 2025 and 2026, for consideration at the meeting of the Finance Committee and the session of the CP in March 2023;

— in order to fulfill the plans for the implementation of the scientific programme of the current Seven-Year Plan for the Development of JINR (2017–2023), ask the Plenipotentiaries of the Governments of the JINR Member States to take measures for paying their contribution arrears to the JINR budget;

— to approve the budget for the year 2023 on the construction and exploitation of the NICA complex of

superconducting rings for heavy-ion colliding beams with the special-purpose funds of the Russian Federation, provided in accordance with the Agreement between the Government of the Russian Federation and JINR, in the amount of 2 958 845.6 thousand rubles;

— to approve the consolidated adjustment of the JINR budget for the year 2022 over 9 months;

— to allow the JINR Director to index the salary and tariff parts of the compensation package of the staff members, taking into account the possibilities afforded by the JINR budget in 2023, in accordance with the JINR Collective Bargaining Agreement for 2020–2023;

— to establish a Working Group under the CP Chair for JINR Financial Issues, consisting of representatives of the Republic of Belarus, the Republic of Cuba, Georgia, the Republic of Kazakhstan, Mongolia, the Russian Federation, and the Socialist Republic of Vietnam.

Concerning the report "Results of the meeting of the Working Group under the CP Chair for JINR Financial Issues held on 25 October 2022" by A. Issadykov, Chair of the Working Group under the CP Chair for JINR Financial Issues, the Finance Committee recommended the Committee of Plenipotentiaries:

— to take note of the appeal (letter) of the Plenipotentiary of the Government of the Republic of Uzbekistan on proposals for the payment of the restructured arrears of the Republic of Uzbekistan which arose prior to 1 January 2002 and the arrears which arose during 2002–2003 and to consider the issue of their settlement after paying off the current arrears in full and paying the restructured arrears in accordance with the schedule approved by the CP in November 2020;

— to agree with an annual 5% increase in the amount of contributions of the Member States for 2024–2030 in order to implement a global-level international research programme, to continue developing the experimental base for a wide range of promising scientific research, due to the increase in operating costs for maintenance of basic setups, the development of engineering and technical infrastructure for attraction of highly qualified scientists and specialists, to ensure wage indexation taking into account forecast inflation for maintaining a competitive level of wages;

— to commission the JINR Directorate to prepare a new structure of the JINR budget for budget planning beginning in 2024 and send it to the Plenipotentiaries for comments and proposals as part of the organization of regular meetings of the Finance Committee and the Committee of Plenipotentiaries in March 2023.

Concerning the report "Results of the audit of the financial activities of JINR performed for the year 2021 and analysis of implementation by the JINR Directorate of the Plan of activities resulting from the audit of the financial activities of JINR performed for the year 2020" by I. Krasilnikov, Project Manager of the FinExpertiza audit company, the Finance Committee recommended that the Committee of Plenipotentiaries approve the audit report based on the results of the audit of JINR's financial activities for the year 2021 and take note of the information on the implementation by the JINR Directorate of the Plan of measures on the follow-up of the audit of JINR's financial activities for the years 2020 and 2021.

The Finance Committee thanked A. Bugay, Director of the Laboratory of Radiation Biology, for his interesting and informative report "Radiobiological research at JINR in application to the problems of space research and nuclear medicine".

# PROGRAMME ADVISORY COMMITTEES

## 55th MEETING OF THE PAC FOR CONDENSED MATTER PHYSICS, 20–21 January 2022

The 55th meeting of the Programme Advisory Committee for Condensed Matter Physics was held on 20–21 January. It was chaired by Professor D. L. Nagy.

The Chair of the PAC presented an overview of the implementation of the recommendations taken at the previous meeting. JINR Vice-Director L. Kostov informed the PAC about the Resolution of the 130th session of the JINR Scientific Council (September 2021) and the decisions of the Committee of Plenipotentiaries of the Governments of the JINR Member States (November 2021).

The PAC took note of the progress report on the replacement of air heat exchangers of the secondary cooling circuit of the reactor and preparation for obtaining a license to operate the IBR-2 facility, presented by V. Shvetsov. The PAC supported the FLNP plans for the next seven years, including manufacturing a new fuel load for IBR-2 in order to provide the conditions required for extending its service life for the period after 2032. The PAC also supported the FLNP activity on studying the mechanism of fluctuations in the IBR-2 power pulses and recommended continuing this work.

The PAC supported further development of the FLNP User Programme, the statistics on which was presented by D. Chudoba.

The PAC urged the JINR Directorate to take care of continuation of experiments, especially those with participation of students due to the temporary shutdown of IBR-2.

The PAC took note of the information on the EPSILON and SKAT experiments operated by German universities (Karlsruhe Institute of Technology and the University of Bonn, respectively) within the framework of the BMBF–JINR collaboration, as presented by F. Schilling. The PAC supported the presented upgrade programme for the SKAT and EPSILON diffractometers.

The PAC took note of the report on the status and further plans for the development of the new neutron source at JINR, presented by M. Bulavin. The PAC appreciated the importance of the studies carried out in 2021 to calculate the vibrational stability of the projected NEPTUNE reactor (IBR-3) with neptunium-nitride fuel. Calculations were also carried out to optimize the composition of the reactivity modulator of the NEPTUNE reactor by introducing additional reflectors (material — nickel or beryllium). To proceed to the next stage in the design of the NEPTUNE reactor (preliminary design stage), the PAC recommended that the R&D work on optimizing the reactor vessel and reactivity modulator be carried out jointly with NIKIET of the Rosatom State Corporation.

The PAC recommended that a progress report on the work for developing the new neutron source made under the JINR–VNIINM and JINR–NIKIET contracts be presented at the PAC meeting in January 2023.

The PAC took note of the recent progress within the theme “Development of the SOLCRYS Structural Research Laboratory at the SOLARIS National Synchrotron Radiation Centre” as presented by N. Kučerka, and noted that various parts of the SOLCRYS structural research laboratory were currently at different phases of accomplishment. The PAC recommended that the theme team present a detailed report at the next PAC meeting, including the financial aspects for the expired period of the theme and a proposal for its extension.

The PAC heard a report on the design and technical parameters of the new facility for neutron radiography and tomography at the WWR-SM reactor (INP, Tashkent, Uzbekistan), as well as on the first results obtained in the experiment, presented by B. Abdurakhimov. The PAC considered that the obtained technical parameters of the jointly developed neutron imaging facility at the WWR-SM reactor met the requirements of a wide range of interdisciplinary research in the field of materials science, engineering sciences, and cultural heritage of the Republic of Uzbekistan.

Following the motion passed at the previous meeting, the PAC discussed the principles for assigning reviewers for themes and projects submitted for the PAC’s consideration. The PAC recommended using well-defined templates in assessment exercises. This practice should be used, for the first time, for themes and projects to be assessed at the 56th PAC meeting in June 2022.

The PAC reviewed 14 virtual presentations made by young scientists in condensed matter physics and life science research. The presentation "Investigation of superconductivity and magnetism in layered nanostructures by polarized neutron reflectometry with secondary radiation registration" by V. Zhaketov was selected as the best presentation of the meeting. The PAC also noted two more high-quality virtual presentations: "High-pressure effect on internal structure and atomic dynamics of pharmaceutical compounds" by N. Belozerova and "Search for biomarkers in UV-induced NETosis" by Ye. Arynbek.

## 56th MEETING OF THE PAC FOR PARTICLE PHYSICS, 24 January 2022

The 56th meeting of the Programme Advisory Committee for Particle Physics took place on 24 January. It was chaired by Professor I. Tserruya.

The Chair of the PAC presented an overview of the implementation of the recommendations taken at the previous meeting. JINR Vice-Director V. Kekelidze informed the PAC about the Resolution of the 130th session of the JINR Scientific Council (September 2021) and the decisions of the Committee of Plenipotentiaries of the Governments of the JINR Member States (November 2021).

The PAC heard the progress report on the implementation of the Nuclotron–NICA project presented by A. Sidorin and noted with satisfaction that the Booster synchrotron systems were brought up to the design parameters and that an iron beam was accelerated for the first time to the design energy of 578 MeV/nucleon. The electron cooling of a heavy-ion beam was first-ever achieved in Russia in the NICA Booster, and the development of the beam extraction and transport channel systems from the Booster to the Nuclotron was successfully completed in cooperation with the Budker Institute of Nuclear Physics. The PAC acknowledged the start of operation of the SOCHI (Station Of CHip Irradiation) station equipment — an important component of the NICA applied research and innovation programme — designed for irradiating microchips using ion beams extracted from the HILAC. The PAC congratulated the NICA team on the installation of the first superconducting magnet in the collider tunnel.

The PAC took note of the progress report on the infrastructure developments at VBLHEP presented by N. Agapov. The Committee noted with satisfaction the achievements in reconstruction of the power grids up to a total capacity of 33.6 MW and in commissioning of new cryogenic equipment: helium liquefier, helium refrigerator, nitrogen liquefier and recondenser, helium and nitrogen gas holders.

The PAC heard the report on the implementation of the MPD project presented by A. Kisiel. The production of all components of the MPD first-stage detector configuration is progressing well. The commissioning of the time-projection chamber and time-of-flight system with their readout electronics is on track to be completed within 2022. By the end of 2022, 800 modules of the electromagnetic calorimeter will be produced in Russia and another 800 in China. This represents 16 ECal sectors out of the 25 needed for full azimuthal coverage. The PAC urged the MPD team and the JINR management to develop a plan ensuring that the remaining nine ECal sectors are manufactured as soon as possible. The PAC congratulated the Collaboration on launching the tests of the MPD large superconducting solenoid.

The PAC appreciated the progress in the implementation of the BM@N project, as presented by M. Kapishin. The team is focused on preparing the detectors for the forthcoming runs with heavy-ion beams scheduled for 2022. The Silicon Beam Tracker detectors and beam profilers are being manufactured, the GEM detectors for the central tracking system have already been tested, and their installation is scheduled for spring 2022. The new ZDC forward hadron calorimeter is already installed at BM@N. The PAC noted the successful implementation of its longstanding recommendation of having a vacuum beam line in front of BM@N in order to reduce the background.

The international Detector Advisory Committee (SPD DAC) was formed in April 2021, chaired by A. Bressan (University of Trieste, Italy). On behalf of the SPD DAC, he presented an evaluation report at the PAC meeting. As a result of fruitful interactions between SPD participants and DAC members, the improvements in the SPD conceptual design with respect to the original Conseptual Design Report (CDR) were made. Namely, it was decided to change the magnet location to be outside the ECal and was proposed to consider MAPS technology for the internal tracker. On the basis of all that and following the recommendation of the DAC, the PAC approved the SPD CDR and asked the SPD team to move forward to the Technical Design Report (TDR) preparation. The PAC appreciated the important role of the DAC in the SPD project evaluation and requested periodic DAC reports.

The PAC took note of the reports on the scientific results obtained by the JINR groups participating in the LHC experiments, presented by E. Rogochaya (ALICE), E. Khramov (ATLAS), and V. Karjavin. The PAC noted with satisfaction the growing visibility and the increased involvement in physics analyses of the JINR groups as well as their significant contributions to the detector upgrade programmes.

The PAC reviewed 28 posters presented in Zoom breakout room mode by young scientists from VBLHEP, MLIT, and DLNP, and selected two best reports: "Deep learning methods and software for the reconstruction of elementary particle trajectories" by P. Goncharov and "Construction of ARIADNA applied stations based on the NICA accelerator complex" by A. Slivin.

## 55th MEETING OF THE PAC FOR NUCLEAR PHYSICS, 27 January 2022

The 55th meeting of the Programme Advisory Committee for Nuclear Physics was held on 27 January. It was chaired by Professor M. Lewitowicz.

The Chair of the PAC presented an overview of the implementation of the recommendations taken at the previous meeting. JINR Vice-Director S. Dmitriev informed the PAC about the Resolution of the 130th session of the Scientific Council (September 2021) and about the decisions of the Committee of Plenipotentiaries of the Governments of the JINR Member States (November 2021).

The PAC heard the report on the implementation of the theme "Investigations of Neutron Nuclear Interactions and Properties of the Neutron" for 2020–2022, presented by E. Lychagin, and a proposal for its extension until the end of 2023. Within the framework of the theme, three projects are being realized: TANGRA (since 2017), ENGRIN (since 2022) and the modernization of EG-5 accelerator (since 2022). In the study of neutron-induced nuclear reactions, a detailed analysis was carried out of the results from the previously performed measurements of *P*-even and *T*-odd correlations in the fission of $^{236}$U compound nuclei at neutron energies of 0.06 and 0.27 eV, which made it possible for the first time to compare the rotation angles of the fission axis at different neutron energies.

Within the TANGRA project, angular distributions and yields of gamma rays in the (*n*, *n*'γ) reaction for 14-MeV neutrons for C, O, Mg, Al, Si, Cr, Fe nuclei were measured using the Romasha detector system consisting of 18 BGO detectors and a HPGe (high-purity germanium) detector.

In cooperation with physicists from the Czech Technical University in Prague, measurements of rare modes of spontaneous fission of $^{252}$Cf with a highly active sample (~400 kBq) were carried out. Timepix detectors with upgraded electronic boards were used to detect light particles. The main goal of the study was to detect the quaternary fission of $^{252}$Cf.

The PAC noted that significant progress was achieved in the development of first-ever efficient reflectors for slow neutrons based on powders of diamond nanoparticles at FLNP.

A wide range of activities was carried out using various nuclear physics techniques to solve problems in ecology, materials science, archeology, art history, medicine, research of objects of extraterrestrial origin, etc. These studies were implemented in cooperation with scientists from research centres of JINR Member States and are planned to be continued. The PAC recommended extending the theme until the end of 2023.

The PAC heard with interest the report "Update on the experiments at the SHE Factory" presented by N. Kovrizhnykh. In 2021, three series of experiments were performed at the new gas-filled separator DGFRS-2 of the SHE Factory. The fusion reactions of $^{243}$Am, $^{242}$Pu, and $^{238}$U isotopes with $^{48}$Ca ions accelerated at DC-280 with the formation of Mc, Fl, Cn isotopes and their daughter nuclei were used to determine the parameters of the new separator.

In the $^{243}$Am + $^{48}$Ca reaction at five $^{48}$Ca energies with an intensity up to 1.3 pμA, six new chains of $^{289}$Mc (2*n* channel), 58 chains of $^{288}$Mc (3*n* channel), two chains of $^{287}$Mc (4*n* channel) were synthesized and a new isotope $^{286}$Mc (5*n* channel) was produced. In previous experiments, $^{287}$Mc was observed only in three chains and daughter nuclei of $^{286}$Mc in two chains.

The α decay of $^{268}$Db was detected for the first time, its branch and half-life were measured, and a new isotope $^{264}$Lr was produced. The spontaneous fission of $^{279}$Rg was registered for the first time. It was shown that the transmission of DGFRS-2 was two times higher than that at DGFRS-1.

In the experiment with $^{242}$Pu using intense beam of $^{48}$Ca, 25 and 69 decay chains of $^{286}$Fl and $^{287}$Fl were synthesized correspondingly.

In irradiation of $^{238}$U, the intensity of $^{48}$Ca reached 6.5 pμA. During September–October 2021, 16 decay chains of $^{283}$Cn were observed.

In the entire series of experiments, 177 decay chains of Mc, Fl, and Cn were registered, the decay properties of about 30 isotopes of elements from Rf to Mc were measured with higher precision, and the reaction cross sections were measured at different $^{48}$Ca energies. During the experiments, it was shown that the new gas-filled separator DGFRS-2 was operating within design parameters, which makes it possible to conduct new experiments on the study of superheavy nuclei at a higher sensitivity level. The PAC congratulated the FLNR team for the spectacular results obtained at the SHE Factory on the synthesis and decay of very heavy nuclei. The PAC encouraged the FLNR Directorate to publish the first results of these experiments as soon as possible.

The PAC heard the scientific report "The double γ-decay width of the nuclear $2^+_1$ state" presented by A. Severyukhin.

The PAC reviewed eight reports in the field of nuclear physics research by young scientists from FLNR. The best reports selected were: "Detailed study of radioactive decay properties of No isotopes with α-, β-, γ-spectroscopy method" by M. Tezekbayeva, "Construction of a set-up and development of a method for studying symmetric combinations in multinucleon transfer reactions ($^{238}$U + $^{238}$U)" by K. Novikov, and "Production of radioactive targets for the first experiments at the SHE Factory" by A. Bodrov.

# JINR PRIZES

*The B. Pontecorvo Prize* was awarded to Professor T. K. Gaisser (University of Delaware, USA) for his significant contributions to neutrino, astroparticle and high-energy cosmic-ray physics, in particular, to the atmospheric neutrino flux calculation from its early stage development.

## WINNERS OF THE JINR SCIENTIFIC AND RESEARCH WORKS COMPETITION

### For Theoretical Research Papers

*First Prizes*

"The Anomalous Josephson Effect".

*Authors:* Yu. Shukrinov, I. Rahmonov, K. Kulikov, M. Nashaat, A. Mazanik.

"New Methods in Classical and Quantum Field Theory with Extended Supersymmetry".

*Authors:* E. Ivanov, I. Buchbinder, B. Merzlikin, K. Stepanyantz.

*Second Prize*

"Superoperator Approach to the Theory of Hot Nuclei and Astrophysical Applications".

*Authors:* A. Vdovin, J. Wambach, A. Dzhioev, D. Kosov, K. Langanke, G. Martínez-Pínedo, V. Ponomarev, Ch. Penev Stoyanov.

### For Experimental Research Papers

*First Prize*

"SHE Factory: First Results".

*Authors:* Yu. Oganessian, S. Dmitriev, F. Abdullin, D. Ibadullayev, A. Polyakov, R. Sagaidak, V. Utyonkov, Yu. Tsyganov, M. Shumeiko, N. Kovrizhnykh.

*Second Prizes*

"Magnetism of Ferromagnet-Superconducting Heterogeneous Layered Structures".

*Authors:* V. Aksenov, V. Zhaketov, Yu. Nikitenko, A. Petrenko, Yu. Khaidukov.

"New Data on the Spectra of Superheavy Isotopes of Hydrogen $^{7}$H, $^{6}$H and the Detection of Spontaneous Decay Mode with the Emission of 4 Neutrons".

*Authors:* A. Bezbakh, L. Grigorenko, A. Gorshkov, S. Krupko, I. Muzalevskii, E. Nikolskii, G. Ter-Akopian, A. Fomichev, V. Chudoba, P. Sharov.

### For Methodology, Research and Technology Papers

*First Prizes*

"The *v*GeN Experimental Setup for the Investigation of Reactor's Antineutrino Properties".

*Authors:* V. Belov, I. Zhitnikov, S. Kazartsev, A. Lubashevskiy, D. Medvedev, D. Ponomarev, S. Rozov, K. Shakhov, E. Shevchik, E. Yakushev.

"Creation of Systems of Ion Beam Transfer to the Booster and Nuclotron Synchrotrons of the NICA Accelerator Facility".

*Authors:* A. Butenko, A. Galimov, S. Kolesnikov, O. Kunchenko, K. Levterov, V. Seleznev, A. Sidorov, A. Tuzikov, A. Fateev, V. Shvetsov.

*Second Prize*

"The New Gas-Filled Separator DGFRS-2".

*Authors:* V. Bekhterev, G. Ivanov, A. Voinov, V. Konstantinov, D. Kuznetsov, O. Petrushkin, A. Podshibiakin, A. Popeko, D. Solovyev, V. Shubin.

### For Applied Research and Technology Papers

*First Prize*

"Hyperconverged Govorun Supercomputer for the Implementation of the JINR Scientific Program".

*Authors:* D. Belyakov, A. Vorontsov, E. Druzhinin, M. Zuev, V. Korenkov, Yu. Migal, A. Moshkin, D. Podgainy, T. Strizh, O. Streltsova.

*Second Prizes*

"Structural Reorganization in a Lipid Membrane Triggered by Amyloid-Beta Peptide and Temperature".

*Authors:* O. Ivankov, N. Kučerka, T. Murugova, E. Ermakova, A. Rogachev, A. Kuklin, V. Skoi, Kh. Kholmurodov, D. Badreeva, E. Dushanov.

"Non-Destructive Microstructural Analysis of Promising Cement Materials for the Construction of Radioactive Waste Storage Facilities and Civil Facilities: Results of Neutron Radiography and Tomography".

*Authors:* S. Kichanov, K. Nazarov, D. Kozlenko, M. Balasoiu, A. Bekhzodjon, B. Savenko, I. Zel, M. Kenessarin.

## Encouraging Prizes

"Study of Vector Meson Photoproduction Processes in the ALICE (CERN) Experiment".

*Authors:* V. Pozdnyakov, Yu. Vertogradova, B. Rumyantsev, E. Kryshen, J. Contreras Nuno, D. Horak.

"Applying the Neutron Activation Analysis for the Assessment of the Levels of Elements in Mussels from Different Regions of the World Ocean for the Characterization of Connection with their Environment".

*Authors:* P. Nekhoroshkov, M. Frontasyeva, I. Zinicovscaia, D. Nikolayev, T. Lychagina, A. Pakhnevich, K. Vergel, O. Chaligava, D. Grozdov, J. Bezuidenhout.


# RESEARCH AND EDUCATIONAL PROGRAMMES

# BOGOLIUBOV LABORATORY of THEORETICAL PHYSICS

In 2022, at the Bogoliubov Laboratory of Theoretical Physics (BLTP), studies were carried out on the following four themes: Fundamental Interactions of Fields and Particles; Theory of Nuclear Systems; Theory of Complex Systems and Advanced Materials; Modern Mathematical Physics: Gravity, Supersymmetry and Strings. An important component of the BLTP activities is theoretical support of experimental research to be carried out within major international projects with the participation of JINR as well as Dubna-based experimental programmes of JINR Laboratories. The research resulted in about 350 publications in peer-reviewed journals and proceedings of international conferences, 61 articles of large international collaborations with the participation of BLTP researchers, and 2 monographs. Most of the results were obtained in cooperation with scientists from the JINR Member States, Brazil, China, Egypt, France, Germany, India, Italy, South Africa, and other countries.

Every year BLTP is a venue for scientific events of the highest level: seven conferences and workshops and two schools for students and young scientists were organized by BLTP in 2022. These events were held in person or in a mixed format (in person/remote). BLTP researchers gave over 210 talks at more than 70 conferences and workshops, both in person and online. Besides, 76 BLTP researchers and visitors made reports at the Laboratory seminars.

International collaboration was supported by grants of the Plenipotentiaries of the Governments of Belarus, Kazakhstan, Poland, and the JINR Directorate, by joint projects with Egypt, Serbia, and South Africa, and by special Heisenberg–Landau (Germany) and Bogoliubov–Infeld (Poland) collaboration programmes. The Bogoliubov Laboratory of Theoretical Physics has collaboration agreements with APCTP (South Korea) and ITP CAS (Beijing) as well as active cooperation with theorists from CERN. Five research projects were supported by the RFBR grants and five research projects — by the RSF.

Traditionally, much attention was paid to recruiting young researchers, students, and post-graduate students to the Laboratory within the research and education project “Dubna International Advanced School of Theoretical Physics (DIAS-TH)”. The Laboratory plays the role of the training centre for young scientists and students from many countries. Currently, about one third of the BLTP scientific staff are young scientists and PhD students. In 2022, 10 candidate and one doctoral theses were defended by BLTP researchers.

A permanent photo exhibition was opened in the lobby of the Conference Hall of the Laboratory, presenting photographs of a large number of BLTP researchers from the moment of its foundation to the present day.

## SCIENTIFIC RESEARCH

### Fundamental Interactions of Fields and Particles

Theoretical investigations in 2022 were carried out in the framework of the following projects:

- Quantum field theory and physics beyond the Standard Model;
- QCD and spin/3D hadron structure;
- Strong interaction phenomenology and precision physics;
- Theory of hadronic matter under extreme conditions;
- Theory of electroweak interactions and neutrino physics.

Based on recent calculations of four-loop propagators in the heavy-quark effective theory (HQET), an analytic four-loop expression for the QCD cusp anomalous dimension was obtained for the first time. The result is given in the form of the small-angle expansion. In addition, it was found that by means of the maximal transcendentality principle one can obtain the four-loop bremsstrahlung function in the $N = 4$ supersymmetric Yang–Mills theory, which is known to all orders [1].

The six-loop result for anomalous dimensions of $\varphi^Q$ with an arbitrary fixed charge $Q$ was obtained in the scalar $O(N)$ model. The computation was based on the combination of known results derived in

20 December. Solemn opening of the photo gallery dedicated to the scientists of the Bogoliubov Laboratory of Theoretical Physics

the large-charge expansion and explicit perturbative computations of diagrams for operators with $Q$ = 1, ..., 5. At the critical point, the resummed critical exponents in three dimensions were compared with results of Monte Carlo simulations and large-$N$ predictions [2].

An approach based on the solution of differential equations for master integrals in terms of generalized power series was developed. It turned out that for polylogarithmic and some non-polylogarithmic master integrals that are interesting from the point of view of application, the recursions on the coefficients were given by nonhomogeneous difference equations of the first order. The latter can be solved both exactly and as a series in the regularization parameter. This procedure was used to calculate nonplanar elliptic vertex and several massive two-loop three- and four-point functions. It was demonstrated that the generalized power series, exact with respect to the regularization parameter, can be further written in terms of generalized hypergeometric and generalized Kampé de Fériet functions [3].

A generalized renormalization group equation was constructed that describes the leading divergences for an arbitrary effective potential with the interaction of scalar fields of a general form, including for nonrenormalizable interactions. The main solutions were obtained and their numerical analysis was performed [4].

The effects of identical leptons in the final state of the $B^+ \to \ell^+\ell^-\ell^+\overline{\nu}_\ell$ decay were studied. The $B^+ \to \ell^+\ell^-\ell^+\overline{\nu}_\ell$ amplitude contains both the direct ($M_a$) and the exchange ($M_b$) diagrams. A number of differential distributions were calculated. In particular, an interesting observable was proposed that can be readily measured experimentally — the differential distribution over the invariant mass of a pair of leptons of the same charge, $\ell^+\ell^+$. The good news is that the interference between $M_a$ and $M_b$, $dB_{ab}$, was found to be at the level of less than 1% in all considered differental distributions and therefore can be neglected in the full kinematic region of this decay [5].

The transition frequency of ($n$, $l$) = (17,16) $\to$ $\to$ (16,15) in pionic helium-4 was calculated to an accuracy of 4 ppb (parts per billion), including relativistic and quantum electrodynamic corrections up to $O(R_\infty\alpha^5)$. In addition, collisional effects between pionic helium and target helium on transition frequencies were estimated. Once measurements reach the ppb level, then the accuracy of determining the pionic mass will increase by 2–3 orders of magnitude. Such a high precision value of $m_\pi$ can impose direct experimental constraints on the mass of the antineutrino of muon flavor [6].

In addition to the standard method of searching for antimatter by excess flux of gamma quanta with energies in the 500-MeV range, an alternative method of identifying antistars in the Galaxy by narrow X-ray lines in the 1–10 keV range emitted during de-excitation of proton–antiproton atoms (similar to positronium) was developed [7].

A new class of transverse-momentum-dependent functions was introduced. They can be manifested in the Drell–Yan-like processes. The presented functions resemble the well-known Boer–Mulders function associated with the quark spin asymmetry, but in contrast, they are sensitive to the transverse motion of partons inside the hadron which is generated by the collective alignment of quark spin. A detailed analytical and phenomenological analysis was implemented. Within the archetypal and proven factorization procedure, as a practical application, new single-spin asymmetries related directly to the gluon poles and new-found functions were predicted and proposed for further experimental studies [8].

A systematic method for deriving a system of partial differetial equations for the Feynman integrals was proposed. The initial set of the Lorentz invariants and masses can be arbitrarily constrained, down to one or more free parameters. This method does not rely on integration-by-part relations and it is applicable also for non-integer propagator indices [9].

Explicit expressions for the elements of the {$\beta$}-expansion for the nonsinglet Adler function and polarized Bjorken sum rules $S_{Bjp}$ in the NNNNLO were derived. This was achieved by using Chetyrkin's recent results for these quantities computed within extended QCD including any number of fermion representations. The properties of the {$\beta$}-expansion and $S_{Bjp}$ at higher orders were analyzed in connection with the Crewther and Broadhurst–Kataev relations [10].

A new type of anomalous transport phenomenon was discovered in a vortical and accelerated medium. This effect is called the Kinematic Vortical Effect. In the general case of particles with an arbitrary spin, a theorem was proved on the connection of this effect with the microscopic properties of matter, namely with the gravitational chiral quantum anomaly. The resulting simple formula was verified using an independent method for the case of fields with spin 1/2 [11].

In the Nambu–Jona-Lasinio model within the 1/$N$ approximation, sum rules were obtained that relate the phenomenological values of the masses of pseudoscalar mesons to the mass ratios of light quarks. It was shown that the joint use of new sum rules with experimental data on the decay width $\eta \to 3\pi$ makes it possible to calculate masses of quarks and also to establish limits for their ratios: $0.41 < m_u/m_d < 0.59$ and $18.60 < m_s/m_d < 19.84$. The inequalities are valid up to the first correction in 1/$N$ inclusive [12].

The total cross section for electron–positron annihilation into a pair of lambda hyperons was calculated in the energy range close to the charmonium mass $\psi(3770)$. It was shown that both mechanisms (three-gluon and $D$-meson) make a significant contribution to the cross section, but only the three-gluon one makes it possible to correctly describe the behavior of the cross section in the vicinity of the charmonium resonance. It is important to note that agreement with the BESIII experimental data for the production of a pair of lambda hyperons was obtained using the model parameters fixed earlier

for the case of annihilation into a proton–antiproton pair, which was done before the publication of the latest data. No additional adjustments were made [13].

Using the parton–hadron–string dynamics (PHSD) transport model, the hyperon polarization induced by the local vorticity of the medium created in heavy-ion collisions at collision energies from 2.3 to 11.5 GeV was calculated [14].

Based on the three-fluid model, the global Λ polarization in Au + Au collisions at $2.4 \le \sqrt{s_{NN}} \le 7.7$ GeV including its rapidity and centrality dependence was calculated. Contributions from the thermal vorticity and meson-field term to the global polarization were considered. It was found that thermal vorticity results in a quite strong increase in polarization from the midrapidity to forward/backward rapidities, while the meson-field contribution considerably flattens this dependence and results in good agreement with the experimental rapidity dependence [15].

The behavior of the critical temperatures of the chiral crossover and confinement/deconfinement crossover in rotating QCD was studied within lattice simulations. The calculations were carried out for clover-improved Wilson fermions ($N_f$ = 2) with the ratio of pseudo-scalar to vector meson masses in the range 0.65, ..., 0.85. From the results of calculations it follows that the critical temperatures increase quadratically with angular velocity. It was shown that separate rotations of gluonic and fermionic degrees of freedom have opposite effects on the critical temperature: rotating gluons tend to increase it, whereas rotating fermions lead to its decrease. The results confirm the importance of the contribution from rotating gluons for understanding the properties of a rotating quark–gluon plasma [16].

## Theory of Nuclear Systems

In 2022, investigations were carried out in accordance with four projects:

- Microscopic models for exotic nuclei and nuclear astrophysics;
- Low-energy nuclear dynamics and properties of nuclear systems;
- Quantum few-body systems;
- Relativistic nuclear dynamics and nonlinear quantum processes.

The properties of the isoscalar giant monopole resonance (ISGMR) for the double magic nucleus $^{48}$Ca were analyzed in the framework of a microscopic model based on Skyrme-type interactions. A method for simultaneous taking into account the coupling between one-, two-, and three-phonon terms in the wave functions of $0^+$ states was developed. The inclusion of three-phonon configurations leads to a shift of about 1% of the total ISGMR strength into the lower energy region ($E_x$ < 10.0 MeV) and 3% into the higher energy region ($E_x$ > 25.5 MeV). The ISGMR strength distribution obtained with the inclusion of the three-phonon configurations is in good agreement with the data from the ($\alpha$, $\alpha'$) experiments [17].

A recently proposed microscopic version of the Bohr–Mottelson collective model, defined by the following dynamical symmetry chain Sp(12,R) ⊃ ⊃ SU(1, 1) ⊗ SO(6) ⊃ U(1) ⊗ $SU_{pn}$(3) ⊗ SO(2) ⊃ SO(3) of the proton–neutron symplectic model (PNSM), was applied to the microscopic shell-model description of the low-lying collective excitations in a typical strongly deformed nucleus $^{158}$Gd and two transitional-like nuclei $^{104}$Ru and $^{192}$Os. A good overall description of the ground, $\gamma$ and $\beta$ was obtained without using an adjustable kinetic-energy term and effective charge [18].

Experimental data on the isoscalar monopole (IS0) excitations in strongly deformed nuclei (prolate $^{24}$Mg and oblate $^{28}$Si) from iThemba Labs (South Africa) in the ($\alpha$, $\alpha'$) reaction were analyzed in the framework of the self-consistent quasiparticle random-phase approximation method with a representative set of the Skyrme forces. The best description of the IS0 data was obtained using the force SkP$^d$ with low nuclear incompressibility $K_\infty$ = 202 MeV. It was shown that below the main broad giant IS0 resonance, there appears a strong narrow IS0 peak (13–14 MeV in $^{24}$Mg and 17–19 MeV in $^{28}$Si) caused by a significant deformation-induced coupling of monopole and quadrupole modes. Analysis showed that in deformed nuclei, a simultaneous description of monopole and quadrupole excitations indicates the correctness of the energy density functional [19].

The method of superoperators in the Liouville space was applied to study spectral properties of hot nuclei. It was shown that properly defined fermionic superoperators allow one to generalize the equation of motion method to hot nuclei. Equations of thermal quasiparticle random phase approximation were derived which allow calculating the spectral densities and strength functions of charge-exchange and charge-neutral excitations of hot nuclei in a thermodynamically consistent way. Within the quasiparticle–phonon nuclear model, a thermodynamically consistent way to take into account the interaction of thermal phonons was proposed. Using the Donnelly–Walecka method, expressions for cross sections of semileptonic weak reactions with hot nuclei were obtained [20].

The Coriolis matrix elements responsible for mixing of the $1^+$, $K$ = 1 and $1^+$, $K$ = 0 states were calculated in the framework of the Quasiparticle Phonon Model for several Gd and Dy isotopes. The results obtained indicate that Gd isotopes could be more suitable for finding deviations from the Alaga rules in M1 transitions from $1^+$ state to the states of the ground band [21].

A review article was written on optimal reactions for producing superheavy nuclei. The production cross sections of superheavy nuclei with charge numbers 119 and 120 in complete fusion were predicted for future experiments [22].

The energies of the lowest $2^+$ states in even-even superheavy nuclei were predicted. These energies are maximal in Fl and Og isotopes, which indicates their almost spherical shape [23].

For $^{48}$Ca and Ra/actinide-based complete fusion reactions, the excitation functions for the production of isotopes of superheavy nuclei with charge numbers 108–116 were calculated and compared to the available experimental data. The calculated production cross sections clearly indicate that Ds is the border nucleus between the island of stability of superheavy nuclei and the mainland with a relatively large number of neutrons [24].

Excitation functions were predicted for the production of isotopes of a superheavy nucleus with charge number $Z$ = 112 in the (2−5)$n$-evaporation channels of the complete fusion reactions $^{48}$Ca + $^{233,235}$U for future experiments. The calculated production cross section of the $^{277}$Cn isotope in the hot fusion reaction $^{48}$Ca + $^{233}$U was compared with the experimental one in the cold fusion reaction $^{70}$Zn + $^{208}$Pb. A strong correlation between fusion probability and asymmetry in the entrance reaction channel was revealed. The possibility of filling the gap between the isotopes of superheavy nuclei with $Z$ = 112 produced in cold and hot fusion reactions was indicated [25].

The effect of Coriolis mixing on the gamma decay of one-quasiparticle isomeric states was examined for transfermium nuclei with neutron number $N$ = 153. It was shown that mixing of states sharply increases if the isomeric state closely approaches the rotational state with the same angular momentum but built on another quasiparticle state. The model explains three orders of magnitude enhancement of the decay rate of the $K_\pi = 7/2^+$ isomeric state in $^{251}$Cf, in comparison with the decay of a similar state in $^{249}$Cm. The proposed mechanism is of general importance for the isomer decay properties in a wide range of heavy odd-mass nuclei [26].

Nuclear level densities in fissioning nuclei, as well as those for neutron, proton, and α-particle emission residues, were calculated for isotopic chains of superheavy nuclei with $Z$ = 112–120. The deformations leading to the breaking of intrinsic reflection and axial symmetries were taken into account. The influence of shell effects on the energy dependence of the ratios of level-density parameters corresponding to different decay modes was studied [27].

The cross sections 3–8 pb of the evaporation residues $^{288–289}$Mc in the $^{48}$Ca + $^{243}$Am reaction were reproduced to verify the predictions for the synthesis of element 119 in the $^{54}$Cr + $^{243}$Am reaction. The drastic decrease in the cross section to 0.032 pb in the last reaction is defined by a stronger competition with quasifission [28].

The half-lives of even-odd nuclei Cm, Fm, Rf with mass numbers from 242 to 258 were calculated. The dependence of the hindrance factor on the parent nucleus spin was revealed, and an analytical formula was proposed for a simplified approximate estimation of the spontaneous fission hindrance factor. The half-lives of superheavy even-even and even-odd nuclei from $^{265}$Rf to $^{286}$Fl were calculated [29].

The astrophysical $S$ factor was analyzed within the quantum diffusion approach for various reactions. For the reactions of astrophysical interest, the $S$ factor shows a clear maximum in the sub-barrier energy range $E_s \sim (0.6–0.86)V_b$. An analytical expression was proposed to predict the dependence of the $S$-factor maximum on the mass and charge numbers of colliding nuclei. It was shown that at collision energies below $E_s$, a strong dependence of the $S$ factor on $E_{c.m.}$ leads to a considerable reduction of stellar burning rates [30].

A quantum-classical method was developed for quantitative investigation of halo nuclei breakup. For the first time, with this approach the breakup cross sections of $^{11}$Be on Pb were calculated up to 5 MeV/nucleon including low-lying resonances [31].

The evolution was investigated of not a single state but the whole (possibly infinite-dimensional) subspace of the system states that are subject to the Schrödinger evolution. By using the concept of maximal angle between subspaces, several optimal bounds on the speed of such a quantum subspace evolution were etablished. One of these bounds may be viewed as a natural generalization of the Mandelstam–Tamm estimate to the case of quantum subspaces [32].

A new algorithm for calculating sub-barrier fusion in a coupled-channel approximation of the adiabatic approach was proposed. Using the created FORTRAN program, a good description of the experimental data for a number of reactions was obtained [33].

An experimental and theoretical study of the angular and energy distributions of an electron and an ion was performed during the Compton double ionization of a helium atom by 40-keV photon using the COLTRIMS detector. The agreement between theory and experiment was achieved only with significant allowance for electron correlations in helium wave functions [34].

The relativistic study of elastic $pD$ backward scattering based on the one-nucleon exchange diagram was performed. Calculations were carried out using relativistic deuteron wave functions obtained by solving the Bethe–Salpeter equation in the Minkowski space with the relativistic separable potentials Graz-II and MY6. The unpolarized differential cross section was calculated, as well as some polarization observables of the reaction for initial proton momentum up to 7.3 GeV [35].

Possible manifestations of the color transparency (CT) effect were studied in the hard knockout reaction $d(p, pp)n$ where the incident proton and both outgoing protons are fast and can experience soft elastic rescattering by a slow neutron. The corresponding partial amplitudes were calculated using the generalized eikonal approximation based on the pole diagrams. The CT effects were introduced within the framework of the quantum diffusion model with coherent inclusion of contributions from the quark counting and Landshoff mechanisms in the hard $pp$ scattering amplitude. The nuclear transparency and tensor analyzing power of the deuteron were calculated in the range of the incident proton momentum

6–75 GeV/$c$ ($\sqrt{s_{NN}}$ = 3.6–11.9 GeV). An estimate of the event rate for NICA SPD was given [36].

The general formalisms of the $q$-dual statistics, the Boltzmann–Gibbs statistics, and three versions of the Tsallis statistics known as Tsallis-1, Tsallis-2, and Tsallis-3 statistics were considered in the canonical ensemble. It was rigorously proven that the Tsallis-1 statistics is invariant under the uniform energy spectrum translation at a fixed temperature. This invariance demonstrates that the Tsallis-1 statistics is consistent with the fundamentals of the equilibrium statistical mechanics. The same results were obtained for the probability distributions of the Tsallis-3 statistics, the Boltzmann–Gibbs statistics, and the $q$-dual statistics. However, the Tsallis-2 statistics is not invariant under the overall shift in energy [37].

In the framework of the Nambu–Jona-Lasinio model, a study of the pion damping width at a finite temperature was carried out. It was shown that with increasing temperature, the damping width increases, reaching its maximum value at $T \sim 0.15$ GeV, but then, before the phase transition temperature, it decreases again. This behavior of the damping width is due to the fact that the scattering amplitude, which appears in the interaction integral, depends on the four-pion interaction constant, which is determined by the box diagram and which decreases near critical temperatures. The pion spectral function was obtained for various temperatures [38].

## Theory of Complex Systems and Advanced Materials

Theoretical investigations in 2022 were carried out in the framework of the following projects:

- Complex materials;
- Nanostructures and nanomaterials;
- Mathematical models of statistical physics of complex systems;
- Methods of quantum field theory in complex systems.

An exciton Hamiltonian from interpair correlations between the constituent carriers-fermions of two excitons in monolayer transition metal dichalcogenides was derived. Identifying excitons by irreducible representations of their point symmetry group, their pairwise interaction depending on interacting excitons' symmetry was found. It is generally repulsive, except for the case of excitons from different valleys, which attract each other to form an intervalley biexciton. A semianalytical relationship was established between the biexciton binding energy with exciton mass and dielectric characteristics of the material and surroundings. This theoretical model covers the exciton interaction properties permitting an inclusive description of the structure and energy features of the intervalley biexciton in monolayer TMDs [39].

Scattering exponents arising in small-angle scattering from power-law polydisperse surface and mass fractals were considered. It was shown that a set of fractals, whose sizes are distributed according to a power law, can change its fractal dimension when the power-law exponent is sufficiently large. As a result, the scattering exponent corresponding to this dimension appears due to spatial correlations between positions of different fractals. For large values of momentum transfer, correlations do not play any role, and the resulting scattering intensity is given by a sum of intensities of all composing fractals, which leads to the well-known Martin formulas for the scattering exponents of the polydisperse fractals. Thus, both the considered exponents and Martin ones are observed in different ranges of momentum transfer [40].

A theory of two-component quantum Bose mixtures was developed for arbitrarily strong interactions between atoms. The spectrum of excitations and thermodynamic properties was studied. The conditions of stability and stratification of the mixture were derived. The phase transition between normal and superfluid states was analyzed. Detailed numerical calculations were presented [41].

Numerical analysis of materials relevant for radiation research at the facilities available at JINR was performed. The focus was on getting parameters relevant for the positron annihilation studies, which can shed light on the structural changes caused by irradiation. The study involved boron carbide $B_4C$ and $W_2B$ [42].

By considering two *ab initio*-based complementary approaches, the electronic structure of $BaCo_2(AsO_4)_2$ was analyzed, and effective spin models were extracted. Both methods show that the dominant direct hopping makes the bond-dependent Kitaev term negligible, diverting the material away from the sought-after spin-liquid regime. As a result, a simple three-parameter exchange model was presented to describe the interactions of the lowest doublet of the honeycomb cobaltate $BaCo_2(AsO_4)_2$. Remarkably, it is the third-neighbor interactions, both isotropic and anisotropic, that are responsible for the standout double-zigzag ground state of $BaCo_2(AsO_4)_2$, stabilized by quantum fluctuations. A significantly large third-nearest-neighbor hopping, observed *ab initio*, supports the importance of the third-neighbor interactions in the stabilization of the unique ground state of $BaCo_2(AsO_4)_2$ [43].

The particle current in the asymmetric avalanche process on a ring was considered. This process is known to exhibit a transition from intermittent to continuous flow at the critical density of particles. The exact expressions for the first two scaled cumulants of the particle current were obtained in the large time limit via the Bethe ansatz and a perturbative solution of the TQ equation. The results were presented in an integral form suitable for the asymptotic analysis in the large system size limit. In this limit, the first cumulant (the average current per site or the average velocity of the associated interface) is asymptotically finite below the critical density and grows linearly and exponentially times power-law prefactor at the critical density and above, respectively. The scaled second cumulant per site (the difu-

sion coefficient or the scaled variance of the associated interface height) shows the decay expected for models in the Kardar–Parisi–Zhang universality class below the critical density, while it is growing as power law and exponentially times power-law prefactor at the critical point and above. Also, the crossover regime was identified and the scaling functions were obtained for the uniform asymptotics unifying the three regimes. These functions were compared to the scaling functions describing the crossover of the cumulants of the avalanche size obtained as statistics of the first return area under the time–space trajectory of the Vasicek random process [44].

A family of quantum states of the Schrödinger cat type was described as superpositions of the harmonic oscillator coherent states with the coefficients defined by the quadratic Gauss sums. These states emerge as eigenfunctions of the lowering operators obtained after canonical transformations of the Heisenberg–Weyl algebra associated with the ordinary and fractional Fourier transformation. The first member of this family is given by the well-known Yurke–Stoler coherent state [45].

It was shown that the complex hypergeometric function describing 6*j* symbols for the SL(2,C) group is a special degeneration of the *V* function — an elliptic analogue of the Euler–Gauss 2F1 hypergeometric function constructed by Spiridonov in 2003. For this function, the mixed difference-recurrence relations were obtained as limiting forms of the elliptic hypergeometric equation, and some symmetry transformations were derived. At the intermediate steps of computations, there emerges a function describing 6*j* symbols for the Faddeev modular double and the corresponding difference equations, and symmetry transformations were derived for it. The obtained results confirm the status of the *V* function as a universal special function of mathematical physics [46].

General reduction of the elliptic hypergeometric equation to the level of complex hypergeometric functions was considered. The derived equation was generalized to the Hamiltonian eigenvalue problem for new rational integrable *N*-body systems emerging from particular new degenerations of the elliptic Ruijsenaars and van Diejen models [47].

Time-reversal symmetry breaking in a two-dimensional system of strongly correlated electrons was shown to recover the topological quantum Hall effect — integer Hall effect in the absence of an external magnetic field [48].

The thermal conductivity and electrical conductivity behaviour in perspective nanomaterial — polycrystalline graphene — was investigated theoretically. It was shown that the role of grain boundaries can be important in suppression of heat transport in a wide temperature range with decreasing size of a grain. It was also found that the heat and electrical transport can be suppressed significantly even at room temperature if grain boundaries have breaks in misorientation angles along the grain line. Besides, it was shown that the experimentally observed increase in Young's modulus in single-layer graphene with low density of point defects can lead to a noticeable enhancement of the heat transport [49].

The possibility of controlling the dynamics of magnetic precession with a superconducting current opens up a wide scope for applications in superconducting electronics and spintronics. A new method was found for controlling the dynamics of magnetic precession. The indirect capture of the magnetic pre-

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cession in the SFS junction by the Josephson oscillations under the action of an external periodic signal was demonstrated for the first time, which was reflected by the appearance of synchronization steps in the dependence of the magnetization on the current through the junction. The position of the step is determined by the radiation frequency and the shape of the resonance curve. In junctions with a strong spin–orbit coupling, states with negative differential resistance appear on the IV characteristics, resulting in an additional locking step. It was shown that the corresponding oscillations had the same frequency as the oscillations at the first step, but they had a different amplitude and a different dependence on the radiation frequency. This makes it possible to control not only the frequency but also the amplitude of the magnetic precession in the locking region [50].

The renormalization group and epsilon expansion method was used to calculate the dynamic critical index $z$, which determines the rate of relaxation of the order parameter of a ferromagnet in the vicinity of the phase transition point (critical slowing down). The calculations were performed in the fifth order of the epsilon expansion. The value of this index obtained as a result of resummation was in good agreement with both the results of computer simulation and experiment [51].

Using the formalism of time-dependent Green's functions at finite temperature, it was shown that the correct model for describing the dynamics of the phase transition to the superfluid state is the two-component A model of stochastic dynamics, and not the F or E models as previously assumed. Thus, the dynamic index $z$ of the given phase transition was determined [52].

## Modern Mathematical Physics: Gravity, Supersymmetry and Strings

The topics of main focus in the theme in 2022 were:

- Quantum groups and integrable systems;
- Supersymmetry;
- Quantum gravity, cosmology and strings.

Holographic temporal Wilson loops in the Schwarzschild–$AdS_5$ and Kerr–$AdS_5$ black holes were considered, which are holographically dual to the nonrotating and rotating $N = 4$ SYM quark–gluon plasma, respectively. Interquark potentials were extracted from holographic temporal Wilson loops which have the Coulomb behavior at temperatures above the phase transition temperature. It was found that the interquark distance decreases with increasing rotation, which is also observed with increasing temperature. At high temperatures and for certain values of the parameters, the potentials in the Schwarzschild–AdS and Kerr–AdS geometries are close to those calculated in the AdS black brane with a flat horizon. Holographic light-like Wilson loops were also investigated, from which jet-quenching parameters for fast parton were found. It was shown that rotation increases the values of the jet-quenching parameters and at high temperatures the jet-quenching parameters have a cubic dependence on temperature similar to an AdS black brane [53].

With the use of the method of nonlinear realizations, superconformal generalizations of the Schwarzian derivative (or just the Schwarzian) — SL(2) invariant nonlinear differential operator of the third order — were constructed, with arbitrary high supersymmetry, as well as the Schwarzian mechanics with $N = 1, 2, 3, 4$ supersymmetries. It was shown that in an algebraic approach, super-Schwarzians are related to the superalgebras $osp(N|2)$, $su(1, 1|2)$, $D(1, 2, \alpha)$ and appear if the Cartan forms of the respective groups are subjected to the conditions partially expressing them in terms of invariant forms on the "boundary" superspace. For $N = 1, 2, 3, 4$ supersymmetries, super-Schwarzians are also superfield Lagrangians of the respective mechanics. By analyzing the Maurer–Cartan equations, it was shown that in each case, all not directly constrained Cartan forms are expressed in terms of Schwarzians and their derivatives. Also, bosonic generalizations of the

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Schwarzian were studied in the case of the Maxwell and *su*(1, 2) algebras [54].

Manifestly, 4*D*, *N* = 2 supersymmetric and gauge invariant off-shell cubic couplings of matter hypermultiplets to the higher integer spin gauge *N* = 2 multiplets introduced in [JHEP. 2021. V. 12. P. 16] were constructed. The hypermultiplet is described by an analytic harmonic 4*D*, *N* = 2 superfield $q^+$ with the physical component spins $s = (1/2, 0)$ and an infinite number of auxiliary fields. For odd *s*, the gauge group generators and couplings are proportional to the $U(1)_{PG}$ generator of the internal $SU(2)_{PG}$ symmetry of the hypermultiplet and therefore do not exist if $SU(2)_{PG}$ is unbroken. All these features can directly be extended to the case of *n* hypermultiplets with the maximal internal symmetry $USp(2n) \times SU(2)$ [55].

The classical static soliton solutions of the Skyrme model with a false vacuum potential were considered. By using fully three-dimensional relaxation calculations, global energy minimizers in the sectors of topological degrees from $Q = 1$ to $Q = 6$ were constructed. These solutions may be metastable, they contain a domain of true vacuum inside the core. Further, small regions of negative topological charge density which appear for the Skyrmions of degrees $Q = 3, 5, 6$ were explored [56].

A relativistic generalization of the rational Calogero model was obtained by using the deformation of a gauging matrix system with extra semi-dynamical variables. The Hamiltonian of this system was derived by imposing the gauge fixing conditions and eliminating gauge degrees of freedom. The integrability of the proposed relativistic model was proven [57].

Models of coupled semi-dynamical (spin) and dynamical mirror multiplets of $N = 4$, $d = 1$ supersymmetric mechanics were constructed. Specifically, a semi-dynamical mirror multiplet (3, 4, 1) was considered which is coupled to dynamical mirror multiplets (1, 4, 3) and (2, 4, 2). The couplings yield equations for spin variables with the bosonic components *x* and *z* of the dynamical multiplets as evolution parameters [58].

The scattering problem for a null string was solved. It was shown that, like massive strings, null strings affect the momentum and angular momentum of other massive objects, such as black holes; the impacts were quantified for physically interesting configurations. Caustics formed on the world sheet of the null string are regions with an energy density tending to infinity, which hypothetically can lead to intense short-wave gravitational radiation from this region. The information about objects (for example, mass, angular momentum), with which zero strings interact, is fully preserved on the world sheet of the string [59].

A new method for estimating the decay probability of false vacuum via regularized instantons was developed. The case was considered where the potential is either unbounded from below or the second minimum corresponding to true vacuum with a depth exceeding the height of the potential barrier. In this case, the materialized bubbles dominating the vacuum decay naturally have a thick wall and the thin-wall approximation is not applicable. It was proven that in this case, the main contribution to the action determining the decay probability comes from the part of the solution for which the potential

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term in the equation for instantons can be neglected compared to the friction term. It was shown that the developed approximation exactly reproduces the leading order results for a few known exactly solvable potentials. The proposed method can be applied to generic scalar field potentials in an arbitrary number of dimensions [60].

In the modified teleparallel theories of gravity with perfect fluid as matter source, the Bianchi I spaces were investigated. It was found that the Universe becomes isotropic very soon during expansion without any additional assumptions. Moreover, the existence of a huge number of bouncing solutions can prevent the problem of initial singularity in such theories. It was demonstrated that the current acceleration of the Universe can be simulated for a specific setup [61].

An approach was developed that provides an easier way to calculate the Feynman rules for general relativity and non-supersymmetric matter minimally coupled to gravity. It was implemented in the FeynGrav package which automates such calculations. The applicability of the package was tested with $2 \to 2$ on-shell tree level graviton scattering, polarization operators, and one-loop scalar-gravitational interaction structure [62].

## DUBNA INTERNATIONAL ADVANCED SCHOOL OF THEORETICAL PHYSICS (DIAS-TH)

In the framework of the DIAS-TH educational programme, two schools for students and young scientists were held in 2022. Regular seminars for students and postgraduates were organized, computer processing of video records of lectures was continued, and website of DIAS-TH was supported.

The XVII DIAS-TH Winter School "Supersymmetry and Integrability" organized by BLTP was held from 31 January to 4 February. Introductory lectures were given on supersymmetric classical field theory, field theory in D-dimensional anti-de Sitter space and its generalization to higher spins. Also, basic information about the twister formalism and symplectic geometry was presented, quantum integrable models and geometric quantization of classical mechanical systems with compact phase space were discussed. More than 80 people from 11 countries (Armenia, Azerbaijan, Belarus, Bulgaria, France, Germany, Russia, Serbia, Slovakia, Spain, and Turkey) took part in the School.

Moscow International School of Physics was held from 24 July to 2 August in collaboration with the P. N. Lebedev Physical Institute of RAS, the National Research University Higher School of Economics and the Skolkovo Institute of Science and Technology (Skoltech). The School was intended for students and young scientists working in the field of high-energy physics. The School programme included lectures on modern experimental and theoretical high-energy physics, cosmology, and machine learning. The event

15 December. Seminar dedicated to the 85th anniversary of the birth of Academician V. Kadyshevsky

was attended by 83 young scientists from universities and research centres of Dubna, Minsk, Moscow, Saint Petersburg, Samara, Tomsk, and Vladivostok.

An educational series of lectures "Gravitational Waves and Their Role in Modern Physics" was organized at BLTP.

## CONFERENCES AND MEETINGS

Seven conferences and workshops and two schools for students and young scientists were organized in 2022: XVII International DIAS-TH Winter School "Supersymmetry and Integrability" (31 January – 4 February, Dubna); International Workshop "Elementary Particles and Nuclear Physics" (24–30 April, Almaty, Kazakhstan); XVIII International Conference "Symmetry Methods in Physics" (10–17 July, Yerevan); International Conference "Quantum Field Theory, High-Energy Physics, and Cosmology" (18–21 July, Dubna); Moscow International School of Physics (24 July – 2 August, Dubna); International Workshop "Supersymmetries and Quantum Symmetries" (8–13 August, Dubna); VII International Conference "Models in Quantum Field Theory" dedicated to anniversaries of the birth of Professor A. N. Vasiliev and Professor V. D. Lyakhovsky (10–14 October, Saint Petersburg, Russia); III International Workshop "Lattice and Functional Techniques for QCD" (10–14 October, Saint Petersburg, Russia); International Conference "Modern Problems of Condensed Matter Theory" (17–22 October, Dubna).

## COMPUTER FACILITIES

In 2022, 10 new PCs with 11–12th generation Intel processors were installed at workplaces. A server equipped with two 18-core Intel processors Xeon Gold 6354 and 1000 GB of RAM was purchased. The latest versions of Wolfram Mathematica, Maplesoft Maple, OriginLab OriginPro were installed and subscriptions for updates and technical support were extended for a year. Network switches damaged during a summer thunderstorm were replaced. More convenient Saramonic Blink 500 radio microphones were purchased to equip two BLTP auditoriums.

## REFERENCES


1. *Grozin A. G., Lee R. N., Pikelner A. F.* // JHEP. 2022. V. 11. 094.
2. *Bednyakov A., Pikelner A.* // Phys. Rev. D. 2022. V. 106. 076015.
3. *Bezuglov M. A., Onishchenko A. I.* // JHEP. 2022. V. 04. 045;
   *Beguzlov M. A., Kotikov A. V., Onishchenko A. I.* // JETP Lett. 2022. V. 116. P. 61.
4. *Kazakov D. I., Iakhibbaev R. M., Tolkachev D. M.* arXiv: 2209.08019 [hep-th].
5. *Ivanov M. A., Melikhov D.* // Phys. Rev. D. 2022. V. 105. 094038.
6. *Zhi-Da Bai, Korobov V. I., Zong-Chao Yan, Ting-Yun Shi, Zhen-Xiang Zhong.* Precision Spectroscopy of the Pionic Helium-4 // Phys. Rev. Lett. 2022. V. 128. 183001.
7. *Bondar A. E., Blinnikov S. I., Bykov A. M., Dolgov A. D., Postnov K. A.* // JCAP. 2022. V. 03. 009;
   *Dolgov A. D.* // Moscow Univ. Phys. Bull. 2022. V. 77. P. 89.
8. *Anikin I. V., Szymanowski L.* // Eur. Phys. J. A. 2022. V. 58. P. 160;
   *Anikin I.V., Szymanowski L.* // Prog. Theor. Exp. Phys. 2022. Iss. 11. 113B03.
9. *Bytev V. V., Kniehl B. A., Veretin O. L.* Specializations of Partial Differential Equations for Feynman Integrals // Nucl. Phys. B. 2022. V. 984. 115972.
10. *Baikov P. A., Mikhailov S. V.* // JHEP. 2022. V. 185. P. 1.
11. *Prokhorov G. Y., Teryaev O. V., Zakharov V. I.* // Phys. Rev. Lett. 2022. V. 129. 151601.
12. *Osipov A. A.* // JETP Lett. 2022. V. 115. P. 305.
13. *Bystritskiy Yu. M., Ahmadov A. I.* // Phys. Rev. D. 2022. V. 105. 116012.
14. *Tsegelnik N. S., Kolomeitsev E. E., Voronyuk V.* arXiv: 2211.09219 [nucl-th].
15. *Ivanov Yu. B., Soldatov A. A.* // Phys. Rev. C. 2022. V. 105. 034915.
16. *Braguta V. V., Kotov A. Y., Roenko A. A., Sychev D. A.* // Proc. of Science. 2022. V. 430.
17. *Arsenyev N. N., Severyukhin A. P.* // Phys. At. Nucl. 2022. V. 85. P. 580.
18. *Ganev H.* // Intern. J. Mod. Phys. E. 2022. V. 31. 2250047; Eur. Phys. J. A. 2022. V. 58. P. 182.
19. *Bahini A., Nesterenko V. O. et al.* // Phys. Rev. C. 2022. V. 105. 024311.
20. *Dzhioev A. A., Vdovin A. I.* // Phys. Part. Nucl. 2022. V. 53. P. 885.
21. *Shirikova N. Yu., Sushkov A. V., Jolos R. V.* // Eur. Phys. J. A. 2022. V. 58. P. 98.
22. *Adamian G. G., Antonenko N. V.* // Eur. Phys. J. A. 2022. V. 58. P. 111.
23. *Shirikova N. Yu., Sushkov A. V., Malov L. A., Kolganova E. A., Jolos R. V.* // Phys. Rev. C. 2022. V. 105. 024309.
24. *Hong J., Adamian G. G., Antonenko N. V., Kowal M., Jachimowicz P.* // Phys. Rev. C. 2022. V. 108. 014614.
25. *Hong J., Adamian G. G., Antonenko N. V., Jachimowicz P., Kowal M.* // Eur. Phys. J. A. 2022. V. 58. P. 180.
26. *Shneidman T. M., Minkov N., Adamian G. G., Antonenko N. V.* // Phys. Rev. C. 2022. V. 106. 014310.

27. *Rahmatinejad A., Shneidman T. M., Adamian G. G., Antonenko N. V., Jachimowicz P., Kowal M. //* Phys. Rev. C. 2022. V. 105. 044328.
28. *Kayumov B. M., Ganiev O. K., Nasirov A. K., Yuldasheva G. A. //* Phys. Rev. C. 2022. V. 105. 014618.
29. *Rogov I. S., Adamian G. G., Antonenko N. V. //* Phys. Rev. C. 2022. V. 105. 034619.
30. *Sargsyan V. V., Adamian G. G., Antonenko N. V., Lenske H. //* Phys. Lett. B. 2022. V. 824. 136792.
31. *Valiolda D., Janseitov D., Melezhik V. S. //* Eur. Phys. J. A. 2022. V. 58. P. 34.
32. *Albeverio S., Motovilov A. K. //* J. Phys. A: Math. Theor. 2022. V. 55. 235203.
33. *Chuluunbaatar O., Gusev A. A., Vinitsky S. I., Abrashkevich A. G., Wen P. W., Lin C. J. //* Comput. Phys. Commun. 2022. V. 278. 108397.
34. *Kircher M. et al. //* Phys. Rev. Lett. 2022. V. 128. 053001.
35. *Bondarenko S., Yurev S.* arXiv:2207.03768 [nucl-th].
36. *Larionov A. B. //* Phys. Rev. C. 2023. V. 107. 014605.
37. *Parvan A. S. //* Physica A. 2022. V. 588. 126566.
38. *Goderidze D., Kalinovsky Yu. L., Friesen A. V. //* Phys. Part. Nucl. Lett. 2022. V. 4. P. 337; Intern. J. Mod. Phys. A. 2022. V. 37. 2250135.
39. *Hoang Ngoc Cam, Nguyen Thanh Phuc, Osipov V. A. //* npj 2D Mater. Appl. 2022. V. 6. P. 22.
40. *Cherny A. Yu., Anitas E. M., Osipov V. A., Kuklin A. I. //* Phys. Rev. E. 2022. V. 106. 024108.
41. *Rakhimov A., Abdurakhmonov T., Narzikulov Z., Yukalov V. I. //* Phys. Rev. A. 2022. V. 106. 033301.
42. *Donkov A. et al. //* Nanomaterials. 2022. V. 12. 2644; *Donkov A. et al. //* Nucl. Mater. Energy. 2022. V. 31. 101201.
43. *Maksimov P. A. et al. //* Phys. Rev. B. 2022. V. 106. 165131.
44. *Trofimova A. A., Povolotsky A. M. //* J. Phys. A: Math. Theor. 2022. V. 55. 025202.
45. *Spiridonov V. P. //* Theor. Math. Phys. 2022. V. 212. P. 1237.
46. *Derkachov S. E., Sarkissian G. A., Spiridonov V. P. //* Theor. Math. Phys. 2022. V. 213. P. 1406.
47. *Sarkissian G. A., Spiridonov V. P. //* J. Phys. A. 2022. V. 55. 385203.
48. *Ferraz A., Kochetov E. //* Phys. Rev. B. 2022. V. 105. 245128.
49. *Krasavin S. E., Osipov V. A. //* Sci. Rep. 2022. V. 12. 14553.
50. *Abdelmoneim S. A., Shukrinov Yu. M., Kulikov K. V., El-Samman H., Nashaat M. //* Phys. Rev. B. 2022. V. 106. 014505.
51. *Adzhemyan L. Ts., Evdokimov D. A., Hnatič M., Ivanova E. V., Kompaniets M. V., Kudlis A., Zakharov D. V. //* Phys. Lett. A. 2022. V. 425. 127870; Physica A. 2022. V. 600. 127530.
52. *Honkonen J., Komarova M., Molotkov Yu., Nalimov M., Trenogin A. //* Phys. Rev. E. 2022. V. 106. 014126.
53. *Golubtsova A. A., Tsegel'nik N. S.* arXiv:2211.11722 [hep-th].
54. *Kozyrev N., Krivonos S. //* JHEP. 2022. V. 03. P. 120; Rhys. Rev. D. 2022. V. 105. 085010.
55. *Buchbinder I., Ivanov E., Zaigraev N. //* JHEP. 2022. V. 05. P. 104.
56. *Livramento L. R., Shnir Ya. //* Phys. Rev. D. 2022. V. 105. 125019.
57. *Fedoruk S. A. //* Phys. Part. Nucl. Lett. 2022. V. 19. P. 331.
58. *Ivanov E., Sidorov S. //* Phys. Rev. D. 2022. V. 105. 086027.
59. *Davydov E. A., Fursaev D. V., Tainov V. A. //* Phys. Rev. D. 2022. V. 105. 083510.
60. *Mukhanov V. F., Sorin A. S. //* JHEP. 2022. V. 07. P. 147.
61. *Tretyakov P. V. //* Mod. Phys. Lett. A. 2022. V. 37. 2250046.
62. *Latosh B. //* Class. Quant. Grav. 2022. V. 39. 165006.

# VEKSLER and BALDIN LABORATORY of HIGH ENERGY PHYSICS

In 2022, the activity of the Veksler and Baldin Laboratory of High Energy Physics was aimed at construction, development and commissioning of separate units of the accelerator complex "Nuclotron–NICA" and MPD, BM@N and SPD experimental facilities. Experiments were also continued at external accelerators.

## MOST IMPORTANT RESULTS IN THE IMPLEMENTATION OF THE NUCLOTRON–NICA PROJECT

From 2 January to 1 April, the ***third commissioning cycle*** was performed at the NICA complex with acceleration of carbon ions produced by the laser source. The following work was carried out sequentially:

— tuning of the Booster cycle, including adiabatic capture at injection (the 5th harmonics), recapture at 65 MeV/nucleon (the 1st harmonics); the intensity of the $^{12}C^{4+}$ ion beam accelerated up to an energy of 263 MeV/nucleon was equal to $3 \cdot 10^9$ particles per spill;

— single-turn beam extraction from the Booster, tuning of the Booster–Nuclotron transport channel with stripping of $C^{4+}$ ions to $C^{6+}$;

— commissioning of the new injection kicker and the Lambertson magnet, tuning of the beam injection system from the Booster into the Nuclotron;

— adiabatic capture of the beam injected from the Booster into the Nuclotron at the 5th harmonics, its acceleration to an energy of 2.8 Gev/nucleon; the achieved transfer efficiency of the beam at acceleration from the ion source to the Nuclotron output was about 25%;

— stable slow extraction during 6 s;

— launch of new power supply, diagnostic and control systems of the beam transport channel to the BM@N zone;

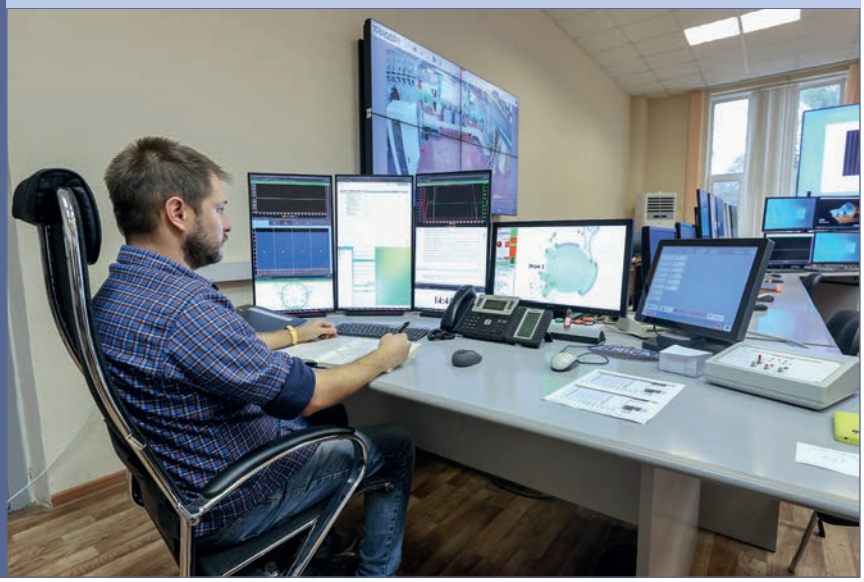
— stable operation of the complex for the SRC experiment for 24 d.

On 20 September, ***the fourth commissioning cycle*** began aimed at accelerating Ar and Xe ion beams from the Krion-6T source. The following work was performed during the run:

15 April. Celebratory meeting dedicated to the 65th anniversary of the Synchrophasotron launch

March. The construction site of the NICA collider.
General construction works have been completed by 80%

The control room of the NICA Booster



— optimization of Krion-6T together with HILAC for producing and accelerating Ar and Xe ions with different charges;

— testing of the Station Of CHip Irradiation (SOCHI) with $Ar^{12+}$ ion beams; the ion beam with a diameter of 100 mm was produced with homogeneity of dose distribution higher than 10% on a 20 × 20 mm chip; the microchips XC6SLX16 were irradiated, and the cross section of single-event effects (SEE) was $1.9 \cdot 10^{-2}$ $cm^{-2}$ at an ion fluence of $3.5 \cdot 10^4$ ion/$cm^2$;

— tuning of the Booster for $Ar^{12+}$ and $^{142}Xe^{28+}$ beam acceleration, dynamic correction of the beam orbit during the entire acceleration cycle; the intensity of the accelerated $^{142}Xe^{28+}$ beam was about $2 \cdot 10^7$ particles per spill;

— sequential testing of two stripping targets made of copper and titanium; the Booster–Nuclotron transport channel was optimized for transporting fully stripped $Xe^{54+}$ ions;

— obtaining a beam circulation in the Nuclotron ring;

— acceleration of the beam at the 4th harmonics of accelerating RF voltage to an energy of about 4 GeV/nucleon; the intensity of the accelerated $^{142}Xe^{54+}$ beam was up to $1 \cdot 10^7$ particles per spill;

— slow extraction of the Xe beam during 2 s (Fig. 1);

— irradiation of emulsions according to the BECQUEREL project;

— calibration of the new diagnostic system; the vacuum system of the extracted beam channel was installed;

— transportation of the beam to the BM@N zone; the beam's intensity was up to $5 \cdot 10^5$ particles per spill according to BM@N triggers, which meets the requirements of the experiment.

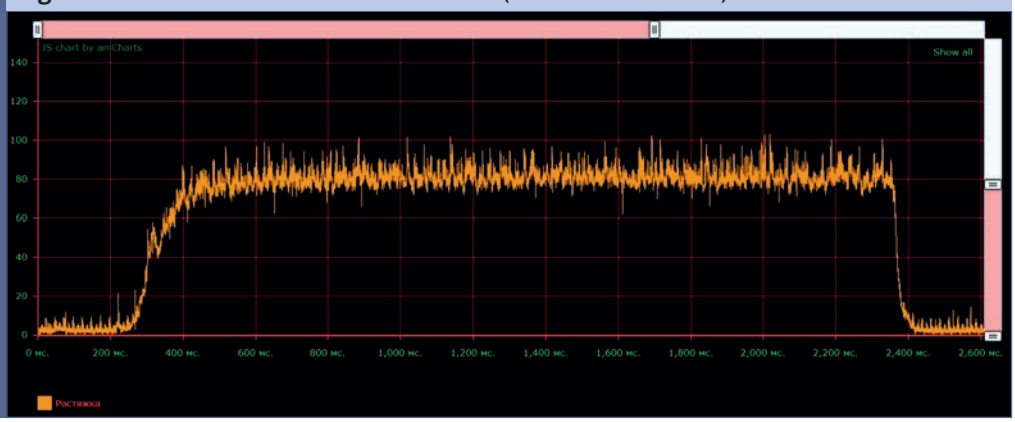
Experiments were conducted on electron cooling of the $^{142}Xe^{28+}$ beam in the Booster at an injection energy. Optimization of the slow beam extraction mode and preparations for research under the BM@N programme are underway.

Manufacturing of equipment for the beam transport channel from the Nuclotron into the collider is being performed by the French company SigmaPhi. The equipment of most subsystems is produced: part of it was delivered to JINR, and another part is stored in SigmaPhi. The exceptions are part of the power supply equipment, profilometers made of scintillation fiber, monitoring and control systems for channel equipment. Negotiations on their delivery are actively ongoing.

All arc dipole magnets of the collider are installed and adjusted inside the tunnel, the production and testing of other magnets are in the final stage. Installation work was suspended until the completion of the building engineering infrastructure located in the main premises.

Renovations of the measurement hall for applied research are in progress. To coordinate the activities within the **ARIADNA** Collaboration, Applied Research and Innovation Committee (NICA ARIC) was established. The Committee includes internationally

**Fig. 1.** Extraction time of the $^{142}Xe^{54+}$ beam (13 December 2022)



Dipole magnets installed inside the collider's tunnel


The NICA accelerator complex


recognized scientists in the fields of research related to the purpose of the channels and irradiation stations being constructed. NICA ARIC is aimed at facilitating the development of a scientific and technical policy for the implementation of applied research at ARIADNA channels, as well as expert evaluation of user proposals for conducting experiments. Stations ISCRA and SIMBO for conducting applied research were constructed and tested.

The main results obtained in 2022 were published in papers [1–13].

## MPD Project

The key element of the MPD facility is a large-sized ***superconducting solenoid magnet***. To put it into operation at $T$ = 4.5 K and start magnetic measurements, a large amount of work needs to be carried out. It includes conducting strength and leak tests, electrical tests, assembling and testing the cryogenic system, as well as assembling and connecting the water cooling of the solenoid power supply systems. The solenoid tests include checking the vacuum volume of the solenoid, the nitrogen thermal shield loop, as well as the loop of liquid helium circulation for strength and leakage. For conducting these tests, a test bench was constructed, the solenoid vacuum system was adapted for testing. A program was developed for automatic control of the vacuum system that prevents equipment failure or solenoid loss of sealing during tests.

While testing, a leakage in the nitrogen shield loop, in the welded joint of the copper pipeline, was discovered and stopped. At the same time, specialists of the MPD Engineering Support Sector, together with ASG representatives, tested the performance of connectors from which control and information signals are transmitted to the monitoring and control system. Temperature and voltage sensors were also tested. In total, about 450 cables were tested for integrity. Preparations are ongoing to measure the magnetic field of the solenoid.

Based on the information about connection from all detector groups (FFD, ECal, ToF, TPC), a control and monitoring system for MPD detector subsystems is being developed. It will be located on a special platform next to the solenoid. A life-size test bench was designed and produced, which is made up of a sector consisting of three magnetic circuit plates and elements of the solenoid and the support frame installed above them.

The test bench allows simulating the position of any of the magnetic circuit gaps due to the movable structure of the support frame. This makes it possible to estimate the volumes filled with cables and pipes in the required area, as well as to easily perform mechanical manipulations during their laying and to record the obtained results for further use directly at the MPD facility.

The production of the **TPC** frame was completed, leak tests are being performed. Twenty-four serial ROC chambers and four spare ones were produced and tested. The TPC gas system was put into trial operation with a test volume. A laser calibration system based on two UV lasers is produced and stored in a test mode. All thermal stabilization panels and radiators for the electronics of the TPC + ECal cooling system were purchased. A total of 537 cards of the readout system were produced, cards and a controller prototype are being tested. Thirteen EASY3000 crates (CAEN) were received for the low-voltage (LV) and high-voltage (HV) power supply system, 6 km of LV cables with a cross section of 120 and 50 mm$^2$ and a HV cable were purchased. A contract was signed for the supply of 60 CAEN modules.

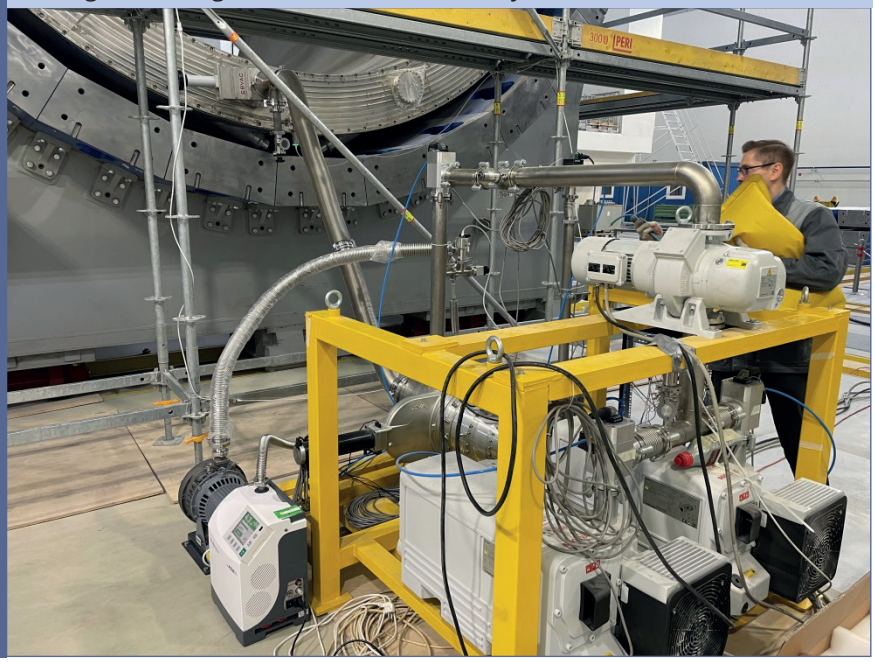
In 2022, the assembly of MRPC detectors and **MPD ToF** modules continued. Earlier, all readout and power supply electronics were produced, and all materials for the assembly of detectors and ToF modules were purchased. The production and test-

Installation of the last three beams of the magnetic core of the MPD detector

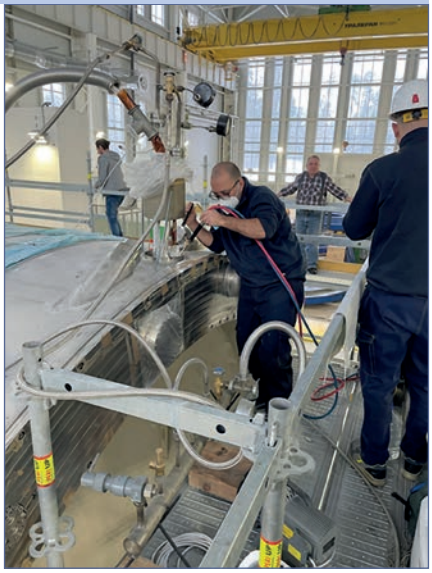
ing of the detectors were fully completed. By the end of 2022, 320 detectors were produced, the required amount was 280. Twenty-five out of 28 ToF modules were assembled.

In 2022, the production of equipment for the integration of ToF modules into MPD was completed. Rails for the installation of ToF modules are also produced and installed on the support frame. The assembly of gas supply and gas mixture distribution equipment for the ToF system is already underway in the MPD experimental hall in Building 17. The fully automated ToF gas system with recirculation and purification of the gas mixture is a very complex service subsystem. The main equipment of the gas supply system is being prepared for installation at its operating position.

Testing and tuning of the vacuum solenoid system



Localization and repair of the nitrogen loop of the solenoid thermal shield



Testing the integrity of superconducting cables of the solenoid winding

In 2022, the production of the first batch of ***electromagnetic calorimeter (ECal)*** modules was completed by JINR. In total, 800 modules were produced, with 16 towers in each. A test bench was constructed for testing the readout electronics for light signals from module towers. All available 600 boards were tested, and the voltage operating point for each SiPM light detector was determined. A site was constructed for preliminary testing and calibration of modules using cosmic muons calculating the possibility of simultaneous testing of 32 modules. This will ensure the continuous operation of the site where modules are put together into clusters. All 800 modules were tested, 20 of them were sent for modification (for various reasons) and returned for testing and further to the cluster making site. No modules were rejected. Calibration data are constantly being analyzed, and the distribution of calibration coefficients is being studied. A comparison of calibration coefficients for different types of modules and modules from different manufacturers is being carried out.

A site for gluing modules into clusters of 16 pieces was constructed. Holding frames were produced for gluing modules with maximum accuracy. Two teams in a short time put together all available 800 modules, of which 50 clusters were assembled. A holding frame for the final assembly of half-sectors was modified and equipped with auxiliary mechanisms, its geodetic alignment was carried out. The test assembly of the half-sector baskets started, and four baskets of calorimeter modules were installed.

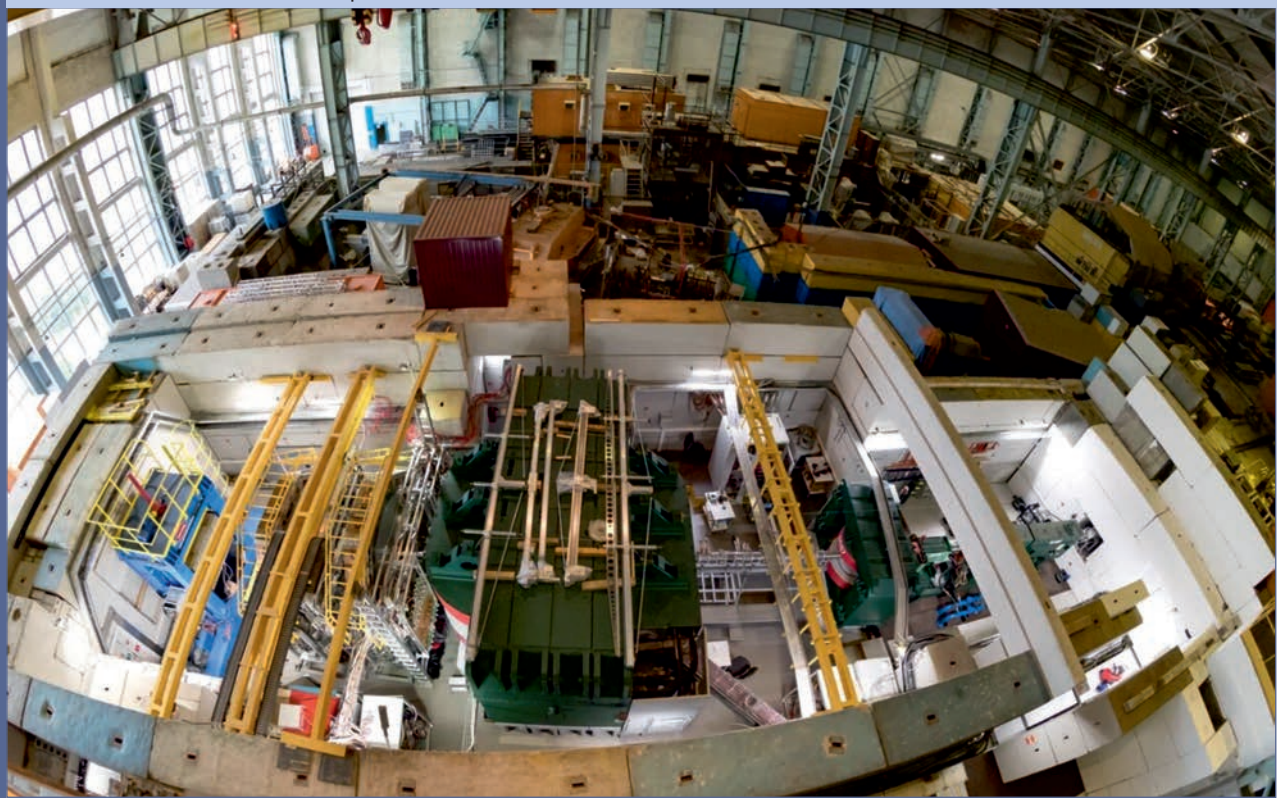
In 2022, two out of three planned batches of modules were delivered from China. In the near future, it is planned to receive all 800 modules from China. The already started testing of the modules shows their good quality. The calibration coefficients are identical with the modules produced in Russia. Preparations are currently underway to start producing a new batch of modules in Russia so that by the time the MPD is assembled, 37 half-sectors will be ready. It will make up 75% of the total calorimeter. The air-cooling system of electronics in clusters is being tested. Using the developed monitoring system, the stability of calorimeter operation is being checked at the cluster level. It is planned to prepare at least 33 baskets (66% of the total number) for installation into MPD. The team is making every effort to increase the number of baskets ready for installation to 41.

In 2022, the MPD Collaboration uniting more than 450 participants from 10 countries published an extensive review presenting the status and physics results expected at the initial stage of the experiment [14].

## BM@N Experiment

The BM@N experiment is aimed at studying the dynamics of reactions and the properties of hadrons in dense nuclear matter, studying the production of strange hyperons near the threshold, and search-

General view of the BM@N experimental zone (autumn 2022)



ing for hypernuclei in the interactions of extracted Nuclotron ion beams with fixed targets. In 2022, the analysis of experimental data collected in interactions of argon ions with a kinetic energy of 3.2 *A* GeV with Al, Cu, Sn, Pb nuclei was carried out. Using the data of the central and outer tracking systems and ToF, charged $\pi^+$, $K^+$ mesons, as well as protons and light nuclear fragments $^3$He, *d*/$^4$He, and *t*, were identified. Figures 2 and 3 illustrate the results presented in paper [15] on studying the production of $\pi^+$ and $K^+$ mesons in argon–nucleus interactions.

Implementation of the BM@N physics programme on studying interactions of heavy nuclei began in 2022 with an experimental run with Xe ion beams of up to 3.9 *A* GeV kinetic energy. The plan is to collect $2 \cdot 10^9$ interactions of Xe with the CsI target.

**Fig. 2.** *a*) Rapidity spectra (*y*) of $K^+$ mesons produced in Ar + Sn interactions. The results are given for bins of the transverse momentum. The predictions of the DCM-SMM, UrQMD and PHSD models are shown by colored lines. *b*) Invariant transverse momentum spectra ($p_T$) of $\pi^+$ mesons produced in Ar + Sn interactions. Results are given for bins of $\pi^+$-meson rapidity

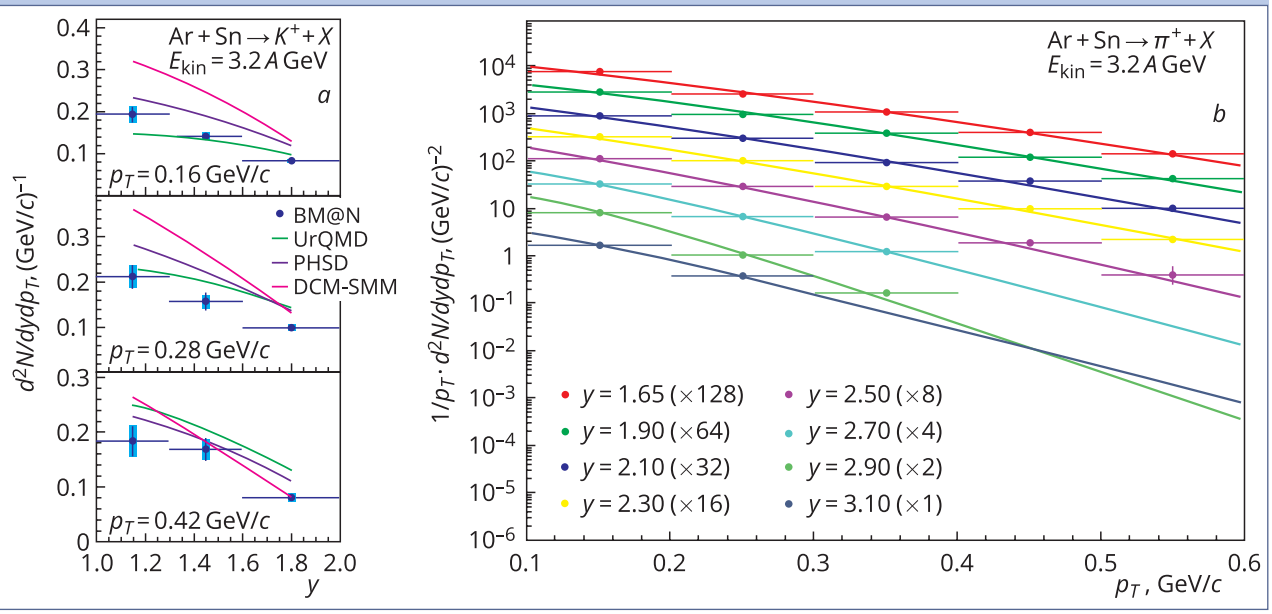


**Fig. 3.** Rapidity dependence ($y$) of the inverse slope $T_0$ extracted from the fits of the invariant $p_T$ spectra of $\pi^+$ mesons ($a$) and $K^+$ mesons ($b$) produced in Ar + Sn interactions. The predictions of the DCM-SMM, UrQMD and PHSD models are shown by colored lines

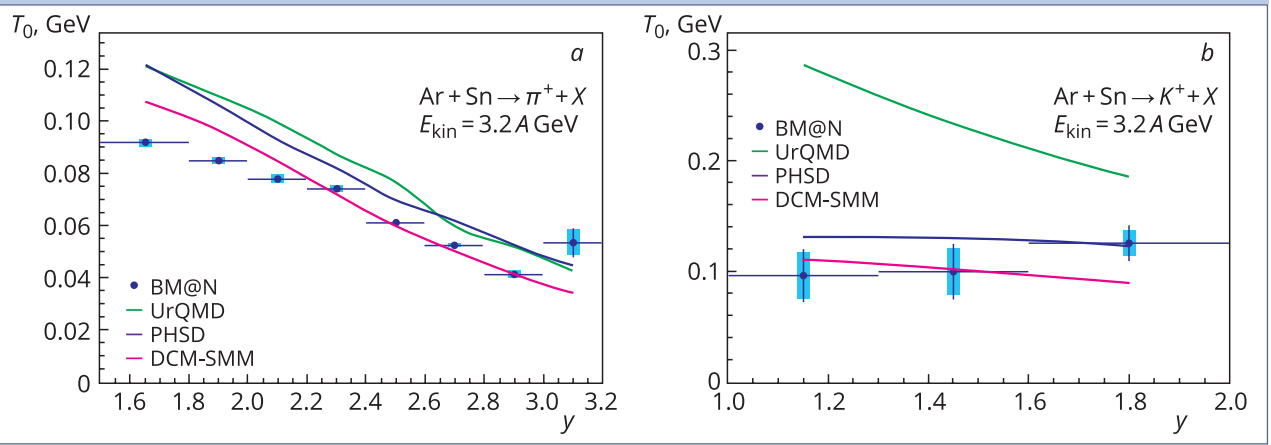



**Fig. 4.** Full configuration of BM@N detectors for the implementation of the research programme with heavy ion beams

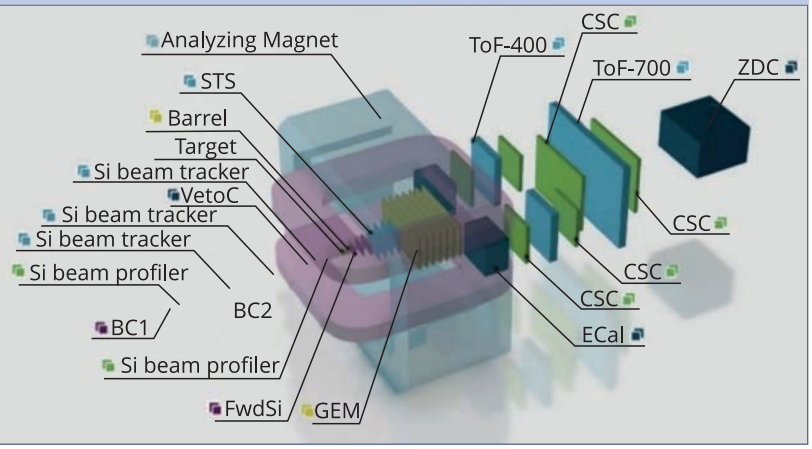
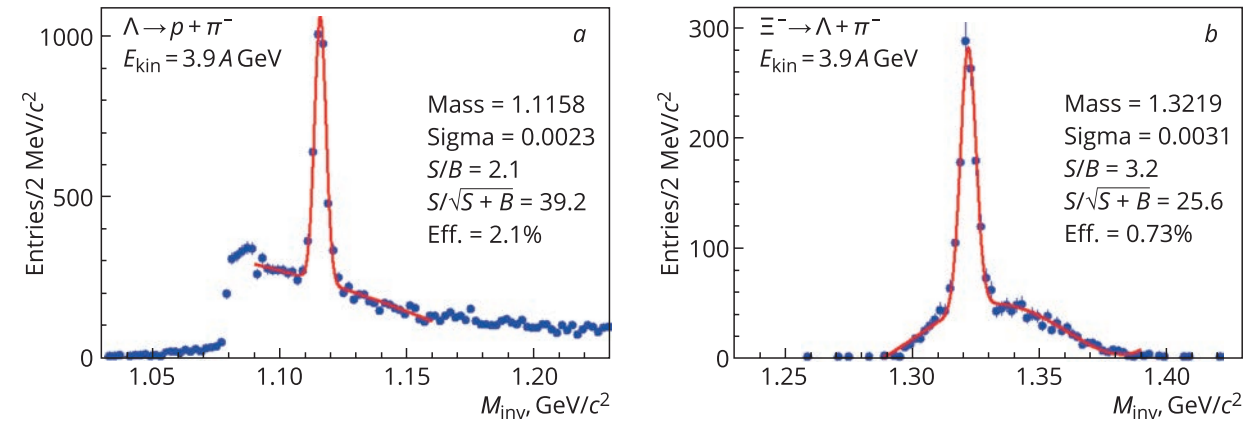



**Fig. 5.** Invariant mass spectra showing signals of Λ ($a$) and $\Xi^-$ ($b$) hyperons reconstructed with the BM@N central tracking system




The results obtained in 2022 by the BM@N Collaboration are published in [15–18].

Detectors of the full BM@N configuration for operation with heavy ion beams were developed and installed into the facility (Fig. 4). The BM@N facility is made up of the following elements: silicon tracking system (STS), forward silicon tracking detectors (FwdSi), tracking stations consisting of gaseous electron multiplier (GEM) detectors, time-of-flight systems (ToF-400 and ToF-700), medium and large cathode strip chambers (CSC) and drift chambers of the outer tracking system, the zero degree calorimeter (ZDC), the forward hadron calorimeter (FHCAL) and scintillator tiles in front of ZDC, trigger detectors (the

barrel detector, the silicon multiplicity detector, the forward trigger detector, beam counters), the target station, the vacuum ion beam pipe in front of the target and the carbon fiber vacuum ion beam pipe inside the BM@N tracking system, the trigger system and the DAQ system.

Studies were performed to prove feasibility of reconstruction of hyperons produced in Xe + CsI interactions at a 3.9 *A* GeV beam kinetic energy. Figure 5 shows signals of Λ and $\Xi^-$ hyperons reconstructed using the BM@N central tracking system.

## SRC Project

Within the framework of the SRC programme, studies of short-range correlations of nucleons that are in close proximity to each other within the nucleus for a short time are carried out. The experiment studies the processes of hard break-up of correlated nucleon pairs by knocking out one of the paired nucleons and reconstructing the kinematics of the reaction. The use of beams extracted from the Nuclotron in combination with the hydrogen target provides a possibility to study such reactions in inverse kinematics. High beam energies and large momentum transfer in the interactions simplify the detection of the correlated recoil partner and allow completing reconstruction of the event kinematics.

In March 2022, the international SRC Collaboration conducted an experiment with the $^{12}C$ ion beam with a momentum of 3.75 GeV/*c*/nucleon using the BM@N spectrometer. This was a continuation of the successful pilot experiment of 2018. It is expected to significantly increase the statistics of useful events, measure absolute cross sections for studying the structure of the $^{12}C$ nucleus and identifying the SRC pairs. To accomplish these tasks, the configuration of the experimental setup was significantly upgraded (Fig. 6).

The components additionally installed into the experimental setup include a new hydrogen target system, beam ion and nuclear fragment counters with improved time and charge resolution, new tracking detectors in the forward spectrometer, as well as cathode strip chambers and time-of-flight calorimeters in the two-arm spectrometer.

During the 2022 run, about 185 million physics events were collected, which amounts to a nearly five-fold increase compared to the previous run. These data are now being analyzed [19, 20]. The performed run completed the planned SRC programme at the BM@N facility. After the run, the detector systems constructed by the SRC Collaboration were transferred to the HyperNIS beamline.

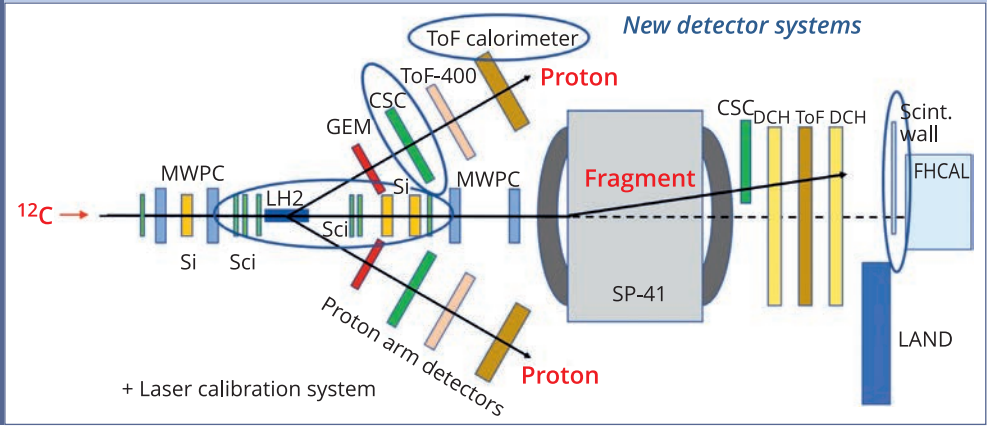
## SPD Project

The main accomplishment of the SPD Collaboration in 2022 was the completion of the technical design of the SPD experiment. It is based on the results obtained while producing and studying the properties of prototypes of the SPD detector elements and subsystems. The most significant change in the design of the SPD facility compared to its CDR is using the classical installation of the solenoid magnet for detectors of this type.

The SPD ***Muon*** Group carried out extensive methodological work on the construction of prototypes for tests with the Nuclotron test beam and for technological purposes. Assembly and tuning of a prototype of the RS run (muon) system with a full number of MDT detectors (68 pcs) and connected analogue electronics based on ADB-32 boards for 1344 readout channels were completed. Optimization of the analogue electronics for readout wire and strip signals was continued. A test batch of Ampl-8.52 and Ampl-8.11R amplifiers (Rash cascade) was produced in cooperation with the JSC "Integral" (Minsk).

Technical development of all major areas of the SPD ***cryogenic system*** was performed. For the helium system, two types of the cryogenic plants were calculated, refrigeration and liquefaction, due to the two possible designs of the superconducting detector winding. All cryogenic and warm pipelines were laid, and documentation is being prepared for route approval. The overall design is ahead of the SPD cryogenic system work plan.

**Fig. 6.** Configuration of the detectors in the SRC experiment at the BM@N facility during the 2022 run



3 October. Participants of the 3rd meeting of the Collaboration of the SPD experiment at the NICA complex


The ***electromagnetic calorimeter*** geometry and layout were optimized to be placed inside the new solenoid cryostat. Sixteen modules consisting of 64 cells with dimensions 55 × 55 mm and 180 layers of the sampling (0.5 mm Pb + 1.5 mm scintillator) were produced and tested with cosmic muons.

Work continues on selecting a concept for the readout electronics of the SPD ***Straw Tracker***. The existing ASICs (VMM3/3a and TIGER) are being studied. Prototypes of new ASICs are being developed in close cooperation with Minsk, Moscow Engineering Physics Institute (MEPhI) and Zelenograd that best meet the requirements for the SPD Straw Tracker readout electronics.

The first stage of the Monte Carlo simulation for the TDR **BBC** design was performed for *pp* collisions at 10 and 27 GeV. The simulation for *pd* and *dd* collisions also began. Tests of scintillation counters prototypes with ToT, DANSS, FERS5200 and NINO-based FEE were performed. Prototypes developed by Mexican and Chile groups were tested with cosmic muons. A new design of the BBC MCP detector for SPD was produced to avoid the development of RF instabilities in circulating beams of the NICA collider. The design was approved by the accelerator team. Simulations proved its applicability for circulating beams of the NICA collider. Prototypes of the MCP-based detectors for SPD were tested at the Nuclotron beams and the electron beams of the linear accelerator Linac-200.

As part of prototyping the DSSD-based ***Silicon Vertex Detector***, the static characteristics (I-V) and (C-V) of large-size silicon detectors (63 × 93 mm), jointly developed under the JINR–ZNTC (Zelenograd) contract, were measured. The concept of the Micromegas-based Central Tracker for the first stage of SPD operation was developed, and tests of the prototypes began.

Hardware and logical interfaces between the ***trigger-less/streaming DAQ*** and the front-end electronics of Range System (FEE RS) were fully formalized. Work is underway to produce a prototype of the FEE RS card of the system and a first-level concentrator. Together with St. Petersburg Polytechnic University, the terms of reference for the use of the White Rabbit Precision Time Protocol in the SPD detector synchronization system were developed. Work is ongoing on the possibility of developing specialized microcircuits for front-end electronics (ASICs) in Russia and Belarus. The relevant agreements were already signed.

A prototype of an online filter framework and a prototype of an offline ***software*** based on the GAUDI framework were developed. Work is underway to construct a detector model using the GeoModel package. A prototype of the SPD distributed computing system based on PANDA and RUCIO was produced.

The first stage of the SPD ***Test Zone*** development was completed. The infrastructure for detector testing was constructed including the experimental room and the gas system required for operation of detectors. The process of signing Memoranda of Understanding with 32 institutes participating in the SPD Collaboration is in full swing. Throughout 2022, JINR SPD Collaboration members gave 18 talks at international conferences, eight papers were published or submitted to journals.

5 March. Scheduled meeting of the general contractor of the NICA project STRABAG JSC and the JINR Directorate

### DSS Project

Within the framework of the DSS project, in 2022 work was carried out to restore the performance of the Nuclotron internal target and the equipment of the DSS project. Experimental data were obtained for three-particle correlations in C + C, C + Al, C + Ag and C + W collisions at the internal target. Preparations for measurements with Xe and Kr beams at the Nuclotron internal target were performed.

The results of the analysis of experimental data on the angular dependences of the deuteron analyzing powers $A_y$, $A_{yy}$, and $A_{xx}$ of elastic deuteron–proton scattering at a deuteron energy of 1300 MeV, the interpretation of data within the framework of the relativistic multiple scattering model taking into account the excitation of the delta isobar in the intermediate state, as well as the results of studying the angular dependences of the analyzing power $A_y$ of the quasi-elastic proton–proton scattering reaction at energies 200–650 MeV/nucleon were presented at such international conferences as Nucleus-2022, ICPPA-2022, and AYSS-2022.

## PARTICIPATION IN EXPERIMENTS AT EXTERNAL ACCELERATORS

### ALICE

The main efforts of the JINR group in the data analysis and physics simulation in the ALICE experiment at LHC were focused on studying femtoscopic (due to the Bose–Einstein and final-state interaction) correlations, the production of light vector mesons in Pb + Pb ultra-peripheral collisions (UPC) and on the development of the theoretical model for hadron production in $p + p$ and Pb + Pb collisions [21–24]. In particular, a preliminary indication was obtained of an increase in kaon source size for more central events and smaller transverse pair momenta. While analyzing four pions ($\pi^+\pi^+\pi^-\pi^-$) coherent photoproduction in the Pb + Pb UPC collisions at an energy of 5.02 TeV, the manifestation of interference in the spectrum of their invariant mass distribution was studied. The analysis of femtoscopic correlation functions for $K^+K^-$ pair production in Pb + Pb collisions at 2.76 TeV was completed within the framework of the FSI model using free parameters for $f_0(980)$. The source radii of kaon emission versus particle transverse pair momentum, as well as the mass and width values were obtained. The development of the three-component model for the momentum spectra and the ratios of hadrons and flows produced in $p + p$, Pb + Pb and Xe + Xe collisions at different LHC energies continued.

Due to the upcoming upgrade of the ALICE detectors, the problem of replacing photodetectors and electronics was solved to improve the time resolution of the electromagnetic calorimeter PHOS with-

out deterioration of the energy resolution. A photodetector was developed that has a time resolution for photons with 1-GeV in-crystal energy of about 140 ps, which improves the present one by a factor of 15.

## CMS

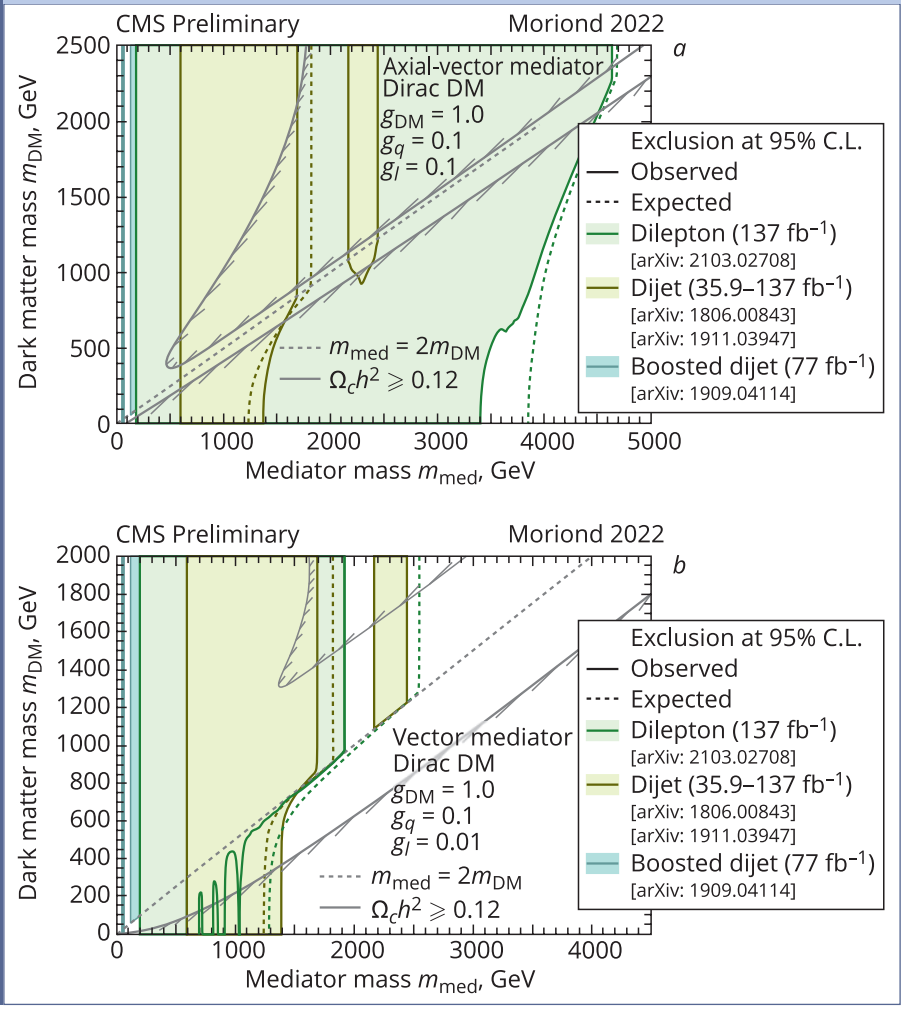
The JINR group taking part in the CMS experiment carried out processing and physics analysis of data collected during LHC Run-2 (2015–2018) with proton beams at an energy of 13 TeV. 95% C.L. observed and expected exclusions were set for combined dijet and dilepton searches in the simplified dark matter (DM) scenario. The mass limits are presented in the plane of the Dirac DM particle $m_{DM}$ and mediator $m_{med}$ (Fig. 7). The exclusions are computed for leptophilic scenarios with the axial-vector mediator (a universal quark coupling of $g_q = 0.1$, lepton coupling $g_l = 0.1$, and a DM coupling of $g_{DM} = 1.0$) and for leptophobic scenarios with the vector mediator (a universal quark coupling of $g_q = 0.1$, lepton coupling $g_l = 0.01$, and a DM coupling of $g_{DM} = 1.0$).

The JINR group is actively involved in the second stage of the CMS upgrade programme for operation under high-luminosity conditions HL–LHC. JINR physicists participate in the construction of a high-granularity end-cap calorimeter (HGCal) and the upgrade of the forward muon station ME1/1. As part of the fulfillment of JINR's obligations, two prototypes of the HGCal cooling system were developed and produced, which are planned to be tested at a special test bench at CERN. The JINR team took part in studying the performance of cathode strip chambers (CSC) at the GIF++ facility at CERN.

The JINR GRID infrastructure, represented by the Tier-1 and Tier-2 centres, was actively used for simulating, processing and storing data from the CMS experiment. In 2022, the Tier-1 data processing system was increased to 18 656 cores providing an overall performance of 1 497 365,628 kHS06. More than 274 million events were processed in 2022. This is 19% of the total number of processed events and 21% of the total successfully performed tasks of all Tier-1 centres for the CMS experiment.

In 2022, JINR physicists made a decisive contribution to the preparation of 22 scientific papers and one patent, 38 reports were made at various conferences [25–30].

**Fig. 7.** 95% C.L. observed and expected exclusion regions in $m_{med}$–$m_{DM}$ plane for dijet and dilepton searches from CMS Run-2 (2015–2018) in the axial-vector (*a*) and vector (*b*) models



21 April. Visit to JINR of national experts in science diplomacy; on tour of the Laboratory

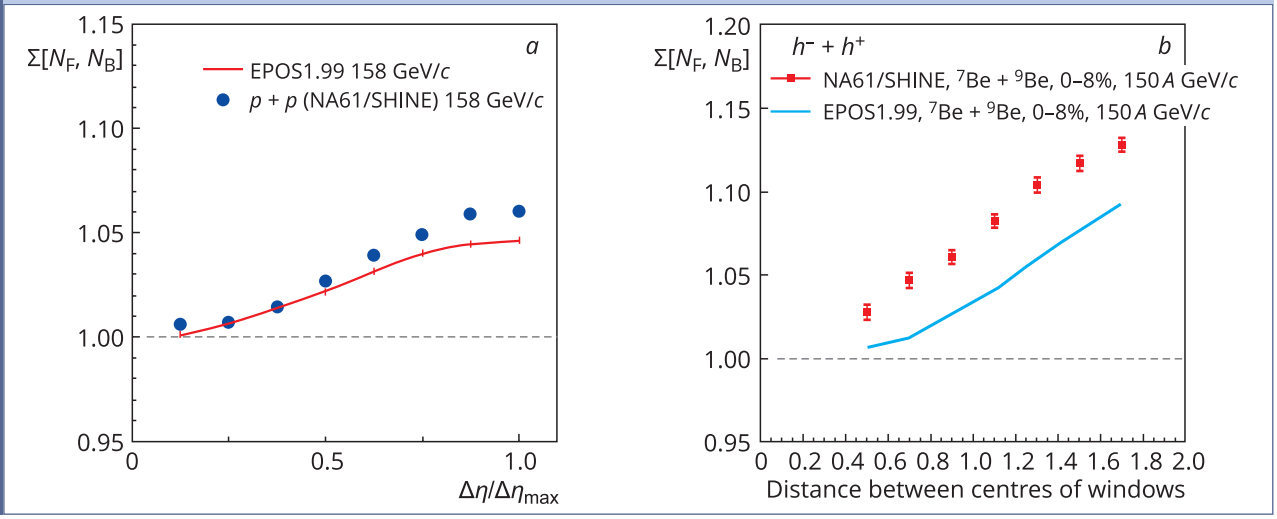
## NA61

The research programme of the NA61/SHINE experiment includes several directions. One of them is the search for the critical point of strongly interacting nuclear matter in relativistic nucleus–nucleus collisions at SPS energies by scanning the phase diagram on both temperature and baryonic chemical potential. In the vicinity of the critical point, the system is unstable and must experience fluctuations. Characteristic signs could be seen in fluctuations of the multiplicity of charged particles [31].

An example of a fluctuation probe is the following value: $\Sigma[N_F, N_B] = [\langle N_F\rangle\omega[N_B] + \langle N_B\rangle\omega[N_F] - 2(\langle N_F N_B\rangle - \langle N_F\rangle\langle N_B\rangle)]/[\langle N_F\rangle + \langle N_B\rangle]$.

It describes the function of the distance between the forward (F) and backward (B) pseudorapidity inter-

**Fig. 8.** $\Sigma[N_F, N_B]$ as a function of the distance between the forward and backward pseudorapidity intervals in inelastic $p + p$ reactions (*a*) and 8% most central Be + Be collisions (*b*) at a beam momentum of 158 GeV/*c* and 150 *A* GeV/*c*, respectively. The dots represent experimental data for all charged particles, the lines show the EPOS1.99 results in the NA61/SHINE acceptance



vals, where $N_F$ and $N_B$ are the corresponding multiplicity and $\omega[N_{F,B}] = \langle N^2_{F,B}\rangle - \langle N_{F,B}\rangle^2/\langle N_{F,B}\rangle$ (Fig. 8).

The change in the pseudorapidity acceptance for $\Sigma[N_F, N_B]$ corresponds to the scan in the baryon chemical potential $\mu_B$ at the freeze-out stage. The developed approach means that $\Sigma[N_F, N_B]$ should be exactly 1 for the Poisson distributions of $N_F$ and $N_B$ in the independent source model and 0 — for the absence of $N_F$–$N_B$ fluctuations. The results on the multiplicity fluctuations $\Sigma[N_F, N_B]$ in $p+p$ and Be + Be data do not show any nonmonotonic behavior. The study of data on negatively charged particles and with a total charge in $p+p$ interactions does not reveal any significant gap either, which could be expected if the system was approaching a critical point.

Currently, the analysis of the collected NA61/SHINE data with other nuclei and energies continues. Eight scientific papers were published. In particular, a satisfactory description of the NA61/SHINE data for the output ratios $K^+/\pi^+$ and $K^-/\pi^-$ as a function of $\sqrt{s}$ in Be + Be collisions is shown. The similarity of these observables with those observed for $p+p$ collisions in a wide range of initial energies is shown [32].

## NA62

The NA62 experiment at CERN SPS is aimed at studying a very rare charged kaon decay into the charged pion, neutrino, and antineutrino. In addition to participating in the development, production, calibration and maintenance of the NA62 magnetic spectrometer, development of software for simulation and reconstruction of events, the JINR group analyzes the data of the NA48/2 and NA62 experiments. In 2022, the team presented seven reports at international conferences.

The data taken in the NA62 experiment at CERN SPS in 2017–2018 were analyzed including a sample of $2.8 \cdot 10^4$ $K^+ \to \pi^+\mu^+\mu^-$ candidates with negligible background [33]. The measured model-independent branching fraction is $(9.15 \pm 0.08) \cdot 10^{-8}$, which is three times more precise than the previous measurements.

Preliminary results of analyzing the rare decay $K^{00}_{\mu 4}$, which has never been observed earlier, were presented at the international conferences [34, 35]. Out of 2437 detected signal candidates with the $S/B$ ratio of about 6 (Fig. 9), the branching ratio of the decay is determined with high precision. In the region of squared dilepton mass above 0.03 GeV$^2/c^4$, the branching ratio was equal to $BR(K^{00}_{\mu 4}, S_l > 0.03) = (0.65 \pm 0.03) \cdot 10^{-6}$. The result $BR(K^{00}_{\mu 4}) = (3.4 \pm 0.2) \times 10^{-6}$ for the full phase space, depending on the decay model extrapolation, is in a reasonable agreement with the $R$ form factor prediction from 1-loop Chiral Perturbation Theory.

## NA64

The JINR group taking part in the NA64 experiment at SPS is responsible for the coordinate detectors based on thin-walled straw tubes and participates in the development of the software system for their online monitoring and DAQ, simulation and reconstruction and analysis of data aimed at searching for the dark photon and other dark matter manifestations.

In 2022, two data taking runs were carried out at SPS, namely with muon and secondary electron beams. The analysis of the previously collected data continued [36–38]. In addition to searching for light dark matter (LDM) and its mediator — dark photon, the NA64 data allow probing for the suggested LDM

**Fig. 9.** The NA48/2 distribution of the missing mass squared for the $K^{00}_{\mu 4}$ signal data events shown together with the results of the background fit

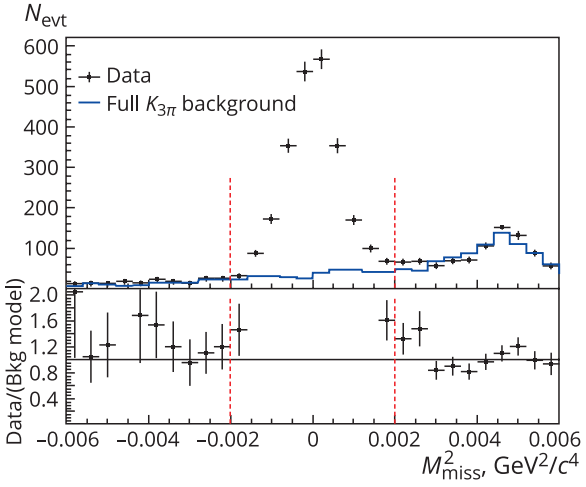
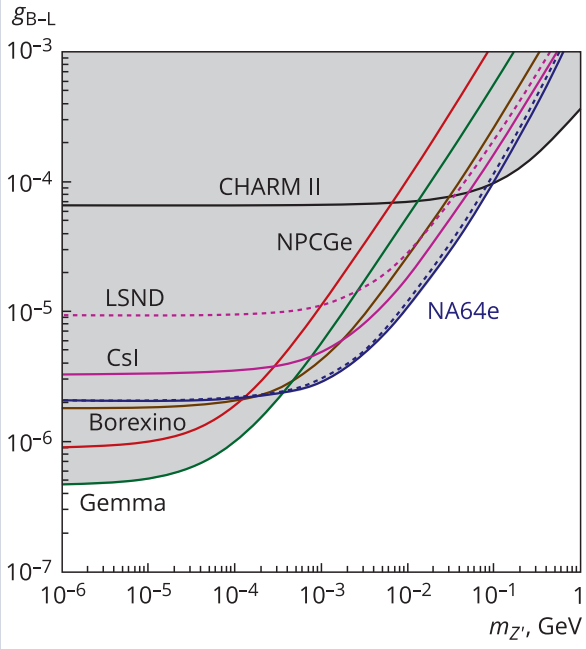
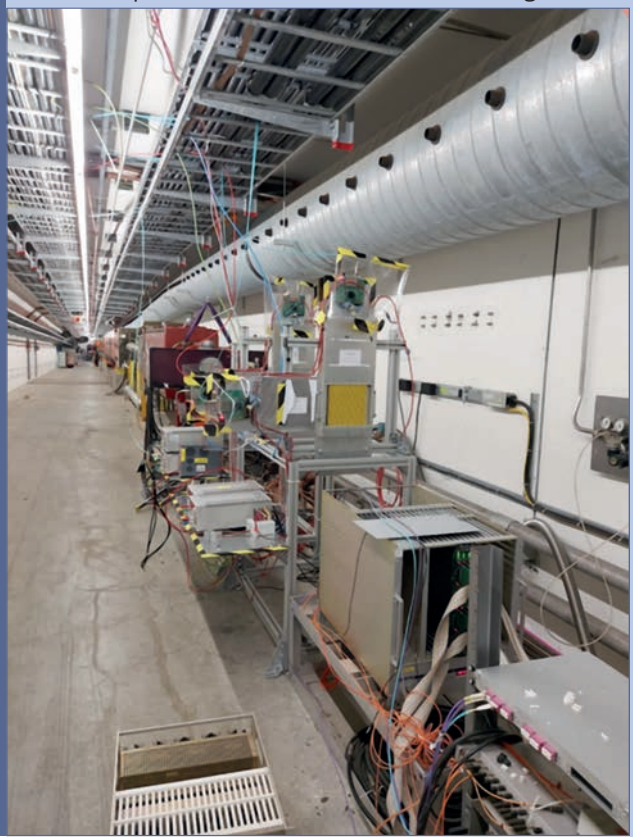



**Fig. 10.** The NA64 90% C.L. exclusion region in the $(m_{Z'}, g_{B-L})$ plane for the unbroken and broken $U(1)_{B-L}$. Constraints from the results of neutrino–electron scattering experiments obtained with nuclear-reactor neutrinos at TEXONO and Gemma, solar neutrinos at Borexino, and accelerator neutrino beams at LSND and CHARM II are also shown



CERN (Geneva, Switzerland).
NA64 setup at the muon (left) and electron (right) lines of the SPS



parameter space in keV–GeV mass range, as well as several SM extensions involving feebly interacting and relatively short-lived particles ($A'$, $Z'$, axion-like particles, etc.). A search for a new $Z'$ gauge boson associated with (un)broken baryon–lepton (B–L) symmetry in the keV–GeV mass range was carried out with $3.4 \cdot 10^{11}$ eot collected during the 2016–2021 runs. Such a boson can be produced after the collision of 100-GeV electrons with the nuclei through the dark bremsstrahlung reaction. Once it is produced, it can invisibly decay into a pair of neutrinos, and the resulting missing energy can be measured in the NA64 experiment. No signal events were found from the analysis of the data. This allows deriving new constraints on the $Z'$–$e$ coupling strength, which for the mass range $0.3 < m_{Z'} < 100$ MeV are more stringent compared to those obtained from the neutrino–electron scattering data (Fig. 10).

## COMPASS

The JINR group involved in the COMPASS experiment at CERN SPS participated in a run with a muon beam with a momentum of 160 GeV/$c$ scattered off a transversely polarized $^6$LiD target. The team ensured stable operation of the MW1 scattered muon identification system and the HCAL1 hadron calorimeter. The obtained data will complete the study of quark contributions to the transverse spin structure of the nucleon. The team obtained preliminary results for the longitudinal double-spin asymmetry in the exclusive production of $\rho^0$ meson from proton and deuteron COMPASS data and for the $F_{3\pi}$ coupling constant from the exclusive reaction $\pi^- A \to \pi^- \pi^0 A$.

In 2022, the JINR group presented two reports at international conferences and published two scientific papers [39, 40].

## STAR

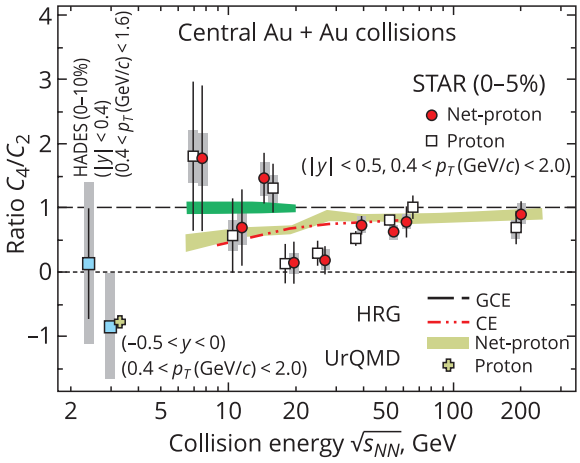
In 2022, the first run with transversely polarized protons with an energy of 510 GeV took place as part of the Cold QCD Programme. New capabilities of the STAR facility after its upgrade allowed performing measurements in the pseudo-rapidity range of $-1.5 < \eta < 1.5$ (mid-rapidity) and $2.8 < \eta < 4.2$ (forward rapidity). It corresponds to the range of the Bjorken variable $0.005 < x < 0.5$. This makes it possible to study the Sievers distributions, transversity, Collins fragmentation functions in previously inaccessible regions, as well as to expand the programme for analyzing the asymmetries of $W^{\pm}$- and $Z^0$-boson production.

The analysis of experimental data obtained in BES-I and BES-II programmes at STAR was performed:

— the femtoscopic correlations of identical pions in Au + Au collisions at energies $\sqrt{s_{NN}} = 3.0$ and 3.2 GeV/nucleon were investigated during the fixed-target (FXT) programme;

— the net-proton fluctuations at $\sqrt{s_{NN}} = 3$ GeV in Au + Au interactions were studied to search for the

**Fig. 11.** The ratio of proton cumulants $C_4/C_2$ at different energies




critical point; proton high-order cumulants were measured [41]. It was shown that the hadronic transport UrQMD model reproduces the ratio $C_4/C_2$ (Fig. 11). This means the dominance of hadron interactions at this energy, therefore, the QCD critical region could only exist at energies higher than 3 GeV.

## HADES and CBM

Within the framework of the HADES experiment, work continued on upgrading the OPER model for simulating $pp \to pp\pi^+\pi^-$ and $np \to np\pi^+\pi^-$ processes at energies of 3.0–4.5 GeV. Software for kinematic analysis of reactions was developed.

An experimental test bench was constructed based on the TRB3 module for working with FE electronics for information readout from SiPM and MRPC. A 16-channel board with SiPM readout for CBM calorimeter system was tested. A paper on the results of optimizing the protection of photomultipliers of the RICH detector was submitted for publication. Two prototypes of 50 × 50 cm straw detector with readout electronics based on the AST1-1 microcircuit were prepared for the CBM muon system.

## REFERENCES


1. *Khodzhibagiyan H., Kekelidze V., Merkuriev A. et al.* Quadrupole Superconducting Model for Update of the Nuclotron Synchrotron // IEEE Trans. Appl. Superconductivity: A Publication of the IEEE Superconductivity Committee. 2022. V. 32, No. 6. P. 1–4.
2. *Anchugov O., Shvedov D., Kiselev V. et al.* A Kicker Magnet for Beam Extraction from the Booster into the Booster–Nuclotron Beamline of the NICA Complex // Instrum. Exp. Techn. 2022. V. 65, No. 3. P. 474–481.
3. *Khodzhibagiyan H., Kotova A., Kuznetsov G. et al.* Solenoid for Spin Physics Detector at NICA from the Nuclotron-Type Superconducting Cable // Phys. Part. Nucl. Lett. 2022. V. 19, No. 4. P. 326.
4. *Kozlov O., Kostromin S., Melnikov S. et al.* Actual Problems of Studying Beam Dynamics in the NICA Collider // Phys. Part. Nucl. 2022. V. 53, No. 5. P. 1220–1273 (in Russian).
5. *Alfeev A., Gurylev I., Yemelianenko V., Mikhailov V., Tsvetkova Yu.* Geodetic Control of Structural Magnets of the Accelerator Complex of VBLHEP JINR // Phys. Part. Nucl. Lett. 2023. V. 20, No. 4 (in Russian).
6. *Filatov G., Slivin A., Syresin E. et al.* Progress in Creating New Channels for Applied Research of the NICA Complex // Phys. Part. Nucl. Lett. 2022. V. 19, No. 5. P. 412–417 (in Russian).
7. *Slivin A., Agapov A., Butenko A. et al.* Construction of Stations for Applied Research at the NICA Accelerator Complex // Phys. Part. Nucl. Lett. 2022. V. 19, No. 5. P. 421–425 (in Russian).
8. *Kotova A., Nikiforov D., Khodzhibagiyan H.* Thermodynamic Characteristics of Doublets of Quadrupole Magnets of the Booster Synchrotron of the NICA Accelerator Complex // Phys. Part. Nucl. Lett. 2022. V. 19, No. 6. P. 643–650 (in Russian).
9. *Filatov G., Slivin A., Agapov A. et al.* Beam Lines and Stations for Applied Research Based on Ion Beams Extracted from Nuclotron // Proc. of the IPAC2022, Bangkok, Thailand, 2022. P. 3096–3098.
10. *Syresin E., Butenko A., Kostromin S. et al.* Challenges of Low Energy Hadron Colliders // Proc. of the IPAC2022, Bangkok, Thailand, 2022. P. 1825–1828.
11. *Slivin A., Agapov A., Baldin A. et al.* Commissioning of the SOCHI Applied Station Beam and Beam Transfer Line at the NICA Accelerator Complex // Proc. of the IPAC2022, Bangkok, Thailand, 2022. P. 3099–3101.
12. *Syresin E., Brovko O., Butenko A. et al.* NICA Ion Collider and Plans of Its First Operations // Proc. of the IPAC2022, Bangkok, Thailand, 2022. P. 1819–1821.
13. *Syresin E., Butenko A., Kostromin S. et al.* Conception of High Intensity Polarized Proton Beam Formation in NICA Collider // Proc. of the IPAC2022, Bangkok, Thailand, 2022. P. 1822–1824.
14. *MPD Collab.* Status and Initial Physics Performance Studies of the MPD Experiment at NICA // Eur. Phys. J. A. 2022. V. 58, No. 7. P. 140.
15. *Merts S. (BM@N Collab.).* Studies of Dense Baryonic Matter with the BM@N Experiment at the Nuclotron // LXXII Intern. Conf. “Nucleus-2022: Fundamental Problems and Applications”, Moscow, July 11–16, 2022.
16. *Mamaev M. (BM@N Collab.).* The Baryonic Matter@ Nuclotron Experiment: Upgrade and Physics Program Overview // 6th Intern. Conf. on Particle Phys. and Astrophys. (ICPPA-2022), Moscow, Nov. 29 – Dec. 2, 2022.
17. *Baranov D. et al.* Feasibility Studies of Strangeness Production in Heavy-Ion Interactions at the BM@N Experiment Using Monte Carlo Simulations // Phys. Scripta. 2022. V. 97, No. 8. 084003.
18. *Guber F. et al.* Study of the Spectator Matter in Heavy Ion Collisions at the BM@N Experiment // Phys. Part. Nucl. 2022. V. 53, No. 2. P. 626–630.

19. *Atovullaaev T. et al.* Magnetic Shielding for the PMTs at the Two-Arm Spectrometer for the SRC Project at BM@N // Phys. Part. Nucl. Lett. 2022. V. 19, No. 4. P. 408–411.
20. *Driuk A., Merts S., Nemnyugin S.* Global Tracking in the BM@N Experiment // Phys. Part. Nucl. 2022. V. 53. P. 552–555.
21. *Romanenko G. (ALICE Collab.).* Identical Charged Kaons Femtoscopic Analysis in PbPb Collisions at 5.02 TeV in ALICE // LXXII Intern. Conf. "Nucleus-2022: Fundamental Problems and Applications", Moscow, July 11–16, 2022.
22. *Pozdnyakov V. (ALICE Collab.).* Photoproduction of Vector Mesons in Ultra-Peripheral Heavy-Ion Collisions with ALICE // 56th Rencontres de Moriond, La Thuile AO, France, March 19–26, 2022.
23. *Pozdnyakov V. (ALICE Collab.).* Recent Results on Ultra-Peripheral Heavy Ion Collisions with ALICE at the LHC // 14th Conf. on the Intersections of Part. and Nucl. Phys. (CIPANP 2022), Orlando, Florida, USA, Aug. 29 – Sept. 4, 2022.
24. *ALICE Collab.* $K^0_S K^0_S$ and $K^0_S K^+$-Femtoscopy in *pp* Collisions at $\sqrt{s_{NN}} = 5.02$ and 13 TeV // Phys. Lett. B. 2022. V. 833. 137335.
25. CMS Exotica Summary Plots for 13 TeV Data Moriond2022; https://twiki.cern.ch/twiki/bin/view/CMSPublic/SummaryPlotsEXO13TeV#DM_summary_plots.
26. *Barducci D. et al.* Search for a $\mu^+\mu^-$ + *b*-jet Event Excess at the Dimuon Mass of 28 GeV in *pp* Collisions at 13 TeV Using Full Run II Dataset. Analysis Note AN-21-089. Geneva: CERN, 2021. Version of Nov. 2022.
27. *Zykunov V.* Effects of Electromagnetic Radiative Corrections during the Production of Lepton Pairs in a Photon–Photon Fusion at the LHC // Phys. At. Nucl. 2022. V. 85, No. 5. P. 366–380 (in Russian).
28. *Shmatov S.* Searches for New Physics with the CMS Experiment at the LHC // Intern. Conf. on Quantum Field Theory, High-Energy Physics, and Cosmology, Dubna, July 18−21, 2022.
29. *Savina M.* Dark Matter Search at the LHC // Intern. Conf. on Quantum Field Theory, High-Energy Physics, and Cosmology, Dubna, July 18−21, 2022.
30. *Lanyov A.* Physics with Dimuons in the CMS Experiment at the LHC // The Workshop "The Physics of the Dimuons at the LHC" (Dimuons-2022), Dubna, June 23–24, 2022.
31. *Prokhorova D. (NA61/SHINE Collab.).* Fluctuations and Correlations Study at NA61/SHINE // Acta Phys. Polonica B. Proc. Suppl. 2022. V. 14, No. 3.
32. *Lykasov G., Malakhov A., Zaitsev A.* Ratio of Kaon-to-Pion Production Cross-Sections in BeBe Collisions as a Function of $\sqrt{s}$ // Eur. Phys. J. A. 2022. V. 58. P. 112.
33. *Cortina Gil E. et al. (NA62 Collab.).* A Measurement of the $K^+ \to \pi^+\mu^+\mu^-$ Decay // JHEP. 2022. V. 11. 011.
34. *Madigozhin D. (NA48/2 Collab.).* Precise Measurement of the Decay $K^\pm \to \pi^0\pi^0\mu^\pm\nu$ // XLI Intern. Conf. on High Energy Physics (ICHEP 2022), Bologna, Italy, July 6–13, 2022.
35. *Korotkova A. (NA48/2 Collab.).* First Measurement of the $K^\pm \to \pi^0\pi^0\mu^\pm\nu$ ($K^{00}_{\mu 4}$) Decay // 56th Recontres de Moriond, La Thuile AO, France, March 19–26, 2022.
36. *NA64 Collab.* Search for a New B–L $Z'$ Gauge Boson with the NA64 Experiment at CERN // Phys. Rev. Lett. 2022. V. 129, No. 16. 161801; arXiv: 2207.09979 [hep-ex].
37. *NA64 Collab.* Search for a Light $Z'$ in the $L_\mu$–$L_\tau$ Scenario with the NA64-e Experiment at CERN // Phys. Rev. D. 2022. V. 106, No. 3. 032015; arXiv: 2206.03101 [hep-ex]5.
38. *NA64 Collab.* Leptonic Scalar Portal: Origin of Muon g–2 Anomaly and Dark Matter? // Phys. Rev. D. 2022. V. 106, No. 1; arXiv: 2202.04410 [hep-ph].
39. *COMPASS Collab.* Probing Transversity by Measuring Λ Polarisation in SIDIS // Phys. Lett. B. 2022. V. 824. 136834.
40. *COMPASS Collab.* The Exotic Meson $\pi_1(1600)$ with $J^{PC} = 1^{-+}$ and Its Decay into $\rho(770)\pi$ // Phys. Rev. D. 2022. V. 105, No. 1. 012005.
41. *STAR Collab.* Measurements of Proton High-Order Cumulants in $\sqrt{s_{NN}} = 3$ GeV Au + Au Collisions and Implications for the QCD Critical Point // Phys. Rev. Lett. 2022. V. 128. 202303.

# DZHELEPOV LABORATORY of NUCLEAR PROBLEMS

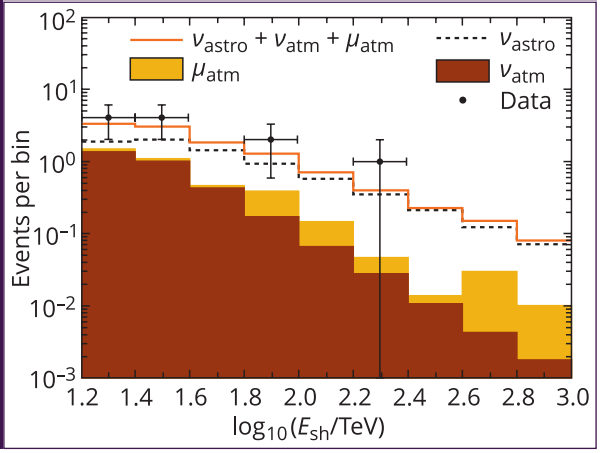
## NEUTRINO PHYSICS AND RARE PHENOMENA, ASTROPHYSICS

With the commissioning of two new clusters in April 2022, the working volume of the deep-sea neutrino telescope **Baikal-GVD** reached a value of ≈ 0.5 km$^3$. The detector contains 10 clusters of deep-sea strings with recording and control equipment (2916 optical modules) and is the largest neutrino telescope in the Northern Hemisphere.

When analyzing the data obtained during the operation of the detector in the configurations of 2018–2021, 11 cascade events with an energy above 15 TeV, initiated by neutrinos of astrophysical nature, were selected, which confirms at a confidence level of 3$\sigma$ the results of the first observation of the flux of high-energy astrophysical neutrinos on the Antarctic detector IceCube (Fig. 1) [1].

The **Daya Bay** experiment was shut down in 2020. In 2022, the measurement of the neutrino oscillation parameters based on the complete dataset was finished. The results $\sin^2 2\theta_{13} = 0.0851 \pm 0.0024$ and $\Delta m^2_{32} = 2.466 \pm 0.060$ ($-2.571 \pm 0.060$) eV$^2$ for the normal (inverted) neutrino mass ordering are currently the most precise [2] and for $\sin^2 2\theta_{13}$ it will remain such for at least 10–15 years.

**Fig. 1.** The Baikal-GVD experiment. Energy distributions of experimental and theoretically expected events in the analysis of cascade events from under the horizon: black dots are the experimental events; the dashed histogram is the distribution of events expected from the diffuse neutrino flux of astrophysical nature; yellow and brown painted areas are background events from atmospheric muons and atmospheric neutrinos; the orange histogram is the total number of expected signal and background events




Within the **JUNO** experiment, the algorithms for the reconstruction of the positron energy in the JUNO detector were developed. It is shown that the algorithms may reach the desired energy resolution of $\sigma = 3\%$ at 1 MeV [3]. It is shown that JUNO will be able to measure the neutrino oscillation parameters $\Delta m^2_{31}$, $\Delta m^2_{21}$, and $\sin^2 2\theta_{12}$ with a precision below 1% during 100 days of data taking [4]. Moreover, the precision of 1% will be reached after 100 days of data taking. A new estimation of the JUNO sensitivity to neutrino mass ordering was obtained with allowance for the recent knowledge of the detector and experimental setup. It reached 3$\sigma$ after six years of data taking.

New oscillation measurements by the **NOvA** experiment were analyzed using improved techniques and simulations. A joint fit to the data within the 3-flavor neutrino oscillation framework continues to yield a best-fit point in the normal mass ordering and the upper octant of the $\theta_{23}$ mixing angle [5]. The data disfavor combinations of oscillation parameters that give rise to a large asymmetry in the rates of electron neutrino and antineutrino appearance. This includes values of the charge parity (CP) symmetry violating phase in the vicinity of $\delta CP = \pi/2$, which are excluded at the confidence level of $> 3\sigma$ for the inverted mass ordering, and values around $\delta CP = 3\pi/2$ in the normal ordering, which are disfavored at the level of confidence of $> 2\sigma$.

Within the **Borexino** experiment, after analyzing the complete Phase-III dataset, the flux of solar neutrinos resulting from the CNO-cycle thermonuclear reactions has been refined [6]. The measured flux was $6.6^{+2.0}_{-0.9} \cdot 10^8$ cm$^{-2} \cdot$ s$^{-1}$, and the hypothesis of the absence of the neutrino CNO signal is excluded with about 7$\sigma$ C.L. The obtained result allowed evaluation of the carbon and nitrogen abundances in the Sun with respect to the hydrogen abundance to be performed for the first time with neutrinos. The ra-

Baikal (Russia), March. Ice camp. Optical modules prepared for installation of the new cluster, the ninth one

Baikal (Russia), April. Joint photo of participants of the expedition after the mission is completed

FNAL (Batavia, USA). Participants of the DUNE Collaboration meeting

tio NCN = $5.78^{+1.86}_{-1.00} \cdot 10^{-4}$ . In parallel, it is shown that determination of the direction to the source (in this case, to the Sun) in a large liquid scintillation detector using neutrino radiation is basically feasible [7]. The search for neutrino events in the Borexino detector in correlation with the most intense fast radio bursts (FRB) has also been completed [8]. No statistically significant excess over the background was observed.

The **EDELWEISS** project is now searching for New Physics in three directions: direct search for Dark Matter (DM) [9], precision studies of CE$\nu$NS (Ricochet), and investigation of double beta decay of $^{100}$Mo with $Li_2MoO_4$ scintillation crystals in the EDELWEISS cryostat (Cupid-MO) [10].

In 2022, work was carried out to launch test measurements for the Ricochet phase in ILL (Grenoble, France) [11]. JINR participates in building the cryogenic low-background setup ($^3$He–$^4$He dilution cryostat), the testing of which has begun at IP2I (Lyon, France), selecting low-background materials, performing background measurements, and creating the active veto system. Creation and testing of the newest detectors-bolometers were continued in the conditions of the EDELWEISS cryostat (low-background environment in the deep underground LSM Laboratory) with simultaneous search for light DM.

The ***ν*GeN** experiment is aimed at the precise investigation of neutrino properties at the reactor of the Kalinin Nuclear Power Plant (KNPP) under an enormous neutrino flux of about $5 \cdot 10^{13}$ cm$^{-2} \cdot$ s$^{-1}$. The comparison of the spectra taken with the reactor ON and OFF did not reveal the expected signal from coherent neutrino scattering. This allows the upper limit on the quenching parameter in germanium to be set at $k < 0.26$ [12]. The data taking continues.

In 2022, the analysis of the **GERDA** experimental data was continued [13, 14]. The LEGEND Collaboration with the decisive participation of JINR specialists carried out a step-by-step commissioning of the LEGEND-200 experiment at the Gran Sasso National Laboratory (Italy). In summer, the first 60 kg of enriched $^{76}$Ge detectors were installed. The complete liquid argon instrumentation developed and built by a joint team of scientists from JINR and Technical University of Munich is mounted. To date, 101 germanium detectors are assembled in LEGEND, and data collection has begun. The mass of the enriched $^{76}$Ge isotope is now ~ 140 kg.

The **NEMO-3** results for the double beta decay of $^{150}$Nd to the $0^{1+}$ and $2^{1+}$ excited states of $^{150}$Sm are published [15]. The data recorded during 5.25 y with 36.6 g of the isotope $^{150}$Nd were used in the analysis. For the first time, the signal of the $2\nu\beta\beta$ transition to the $0^{1+}$ excited state is detected with the statistical significance exceeding $5\sigma$. The corresponding half-life is measured to be $T_{1/2} = \left(1.11^{+0.19}_{-0.14}(\text{stat.})^{+0.17}_{-0.15}(\text{syst.})\right) \cdot 10^{20}$ y. Limits are set on the $2\nu\beta\beta$ decay to the $2^{1+}$ level and on the $0\nu\beta\beta$ decay to the $0^{1+}$ and $2^{1+}$ levels of $^{150}$Sm.

The aim of the **MONUMENT** project is experimental measurements of muon capture on several daughter candidates for neutrinoless $2\beta$ decay. The results would be drastically important for checking the accuracy of theoretical calculations of the nuclear matrix elements. In fall 2022, the orbital muon capture measurements were carried out with isotopically enriched $^{100}$Mo at the PSI meson factory (Switzerland). The measurement of this isotope is associated with the study of the role of neutrinos in formation of supernovae and, particularly, in the synthesis of heavy isotopes. The analysis of the data obtained with the enriched $^{100}$Mo target has begun.

## ELEMENTARY PARTICLE PHYSICS

Within the **ATLAS** project, DLNP scientists participate in the search for potential *cccc* tetraquarks decaying into a pair of charmonium states in the four-muon final state, which is carried out using *pp* collision data at $\sqrt{s}$ = 13 TeV corresponding to an integrated luminosity of 139 fb$^{-1}$. Statistically significant excesses are seen in the di-$J/\psi$ channel consistent with a narrow resonance at 6.9 GeV and a broader structure at lower mass. A statistically significant excess is also seen in the $J/\psi + \psi(2S)$ channel. The fitted masses and decay widths are reported in [16].

Within the **BES-III**, the study of the semileptonic decay $\Lambda_c^+ \to \Lambda e^+ \nu_e$ was carried out [17]. In the analysis of this decay, the partial width $\mathrm{Br}(\Lambda_c^+ \to \Lambda e^+ \nu_e)$ was precisely measured, which allowed improving the world average for this value by more than threefold. This measurement combined with the lattice calculations probes $|V_{cs}|$ and is consequently important for testing the Standard Model and searching for the physics beyond it. In addition, the decay form factors were measured for the first time, which allows validating current lattice QCD calculations.

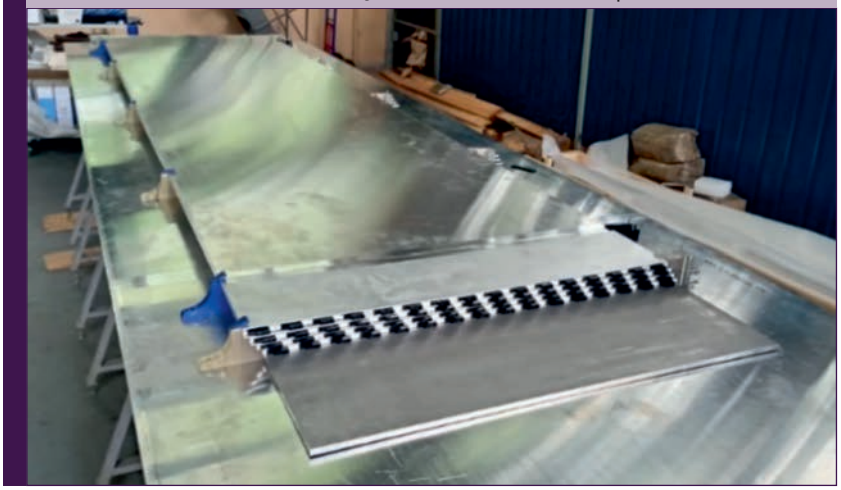
Within the **COMET** project, optical parameters (relative light yield, energy resolution, decay time) of LYSO:Ce and LYSO:Ce, Ca (double doped) crystals from Saint-Gobain (France) were studied and compared. The following results were obtained: the mean scintillator response non-uniformity is ~ 4.6% for LYSO:Ce crystals and ~ 1.1% for LYSO:Ce, Ca; the energy resolution scatter at the middle of the length is ± 0.21% for the entire group of LYSO:Ce crystals and ± 0.19% for LYSO:Ce,  Ca. The light yield scatter near the crystals end surface is ~ 26% and 20% for LYSO:Ce and LYSO:Ce, Ca, respectively. The decay time of LYSO:Ce crystals is 8 ns longer than that of LYSO:Ce, Ca [18].

The first COMET CRV subsystem module, the so-called SCRV-LS-0, was designed and built. It consists of four layers of scintillation strips, 16 strips in each layer, with aluminum sheets separating these layers to reduce the effect of background events under high-radiation conditions.

Within the **COMPASS** project, an important result for the transverse-spin-dependent azimuthal asymmetries in the pion-induced $J/\psi$ production was obtained from the 2015 and 2018 session data. In general, all TSAs were found to be small and compatible with zero within the experimental errors [19].

The main achievement in 2022 is the finalization of the **SPD** Technical Design Project. The SPD project is expected to be implemented in two stages: at the first stage, the basic configuration of the facility for measurements with polarized proton and deuteron beams at low collision energies and luminosities well below the nominal ($10^{32}$ cm$^{-1} \cdot$ s$^{-1}$) will be constracted. It will comprise a muon system, a straw tracker, a central detector based on Micromegas cameras, zero-degree calorimeters, and beam collision detectors. The complete configuration, including a silicon vertex detector, a time-of-flight system, an electromagnetic calorimeter, and an aerogel detector needed to perform the main task of the SPD — studying the polarized gluon structure of nucleons — is planned to be built at the second stage of the project.

SCRV-LS-0 module created at JINR for the COMET experiment



Plastic lens with a diameter of 820 mm for the prototype detector of the TAIGA experiment

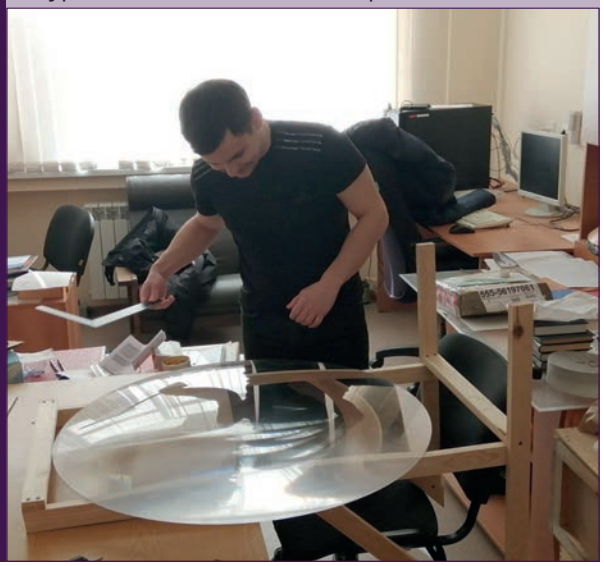
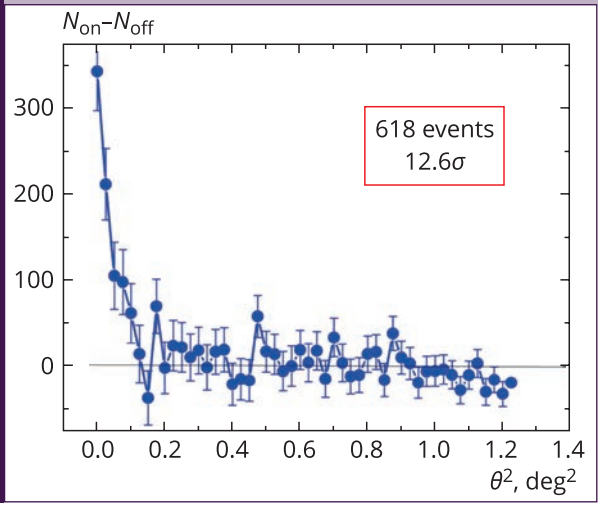


**Fig. 2.** Signal from a source in the Crab Nebula. Θ is the angular distance from the arrival direction of the shower in the image plane to the centre of the field of view




Within the **TAIGA** project, *s* signal from a source in the Crab Nebula with a reliability of 12.6σ was received (Fig. 2) [20]. The mechanical part of the fourth Cherenkov telescope was manufactured at JINR, shipped and assembled at the test site. A prototype of a wide-angle lens Cherenkov telescope was also developed and manufactured at the test site. The lens with a diameter of 600 mm was manufactured at JINR.

## APPLIED RESEARCH AND ACCELERATOR PHYSICS

The Compact-sized Precision Laser Inclinometer (CPLI) has established itself as a high-precision reliable instrument for recording angular oscillations of the Earth's surface. The achieved instrumental accuracy is $10^{-9}$ rad [21].

During 2022, six CPLIs were assembled. Installation of CPLIs in Russia and foreign scientific centres began. Two CPLIs are installed in the MPD detector hall of the future NICA collider. For several months, monitoring of angular microseisms from industrial noise and natural phenomena was carried out. The largest microseisms reach amplitudes of 4 μrad. Possible ways to suppress industrial noise to stabilize the collider beam focus are the introduction of feedback into the control system of the collider magneto-optic equipment and/or the use of piezo stackers.

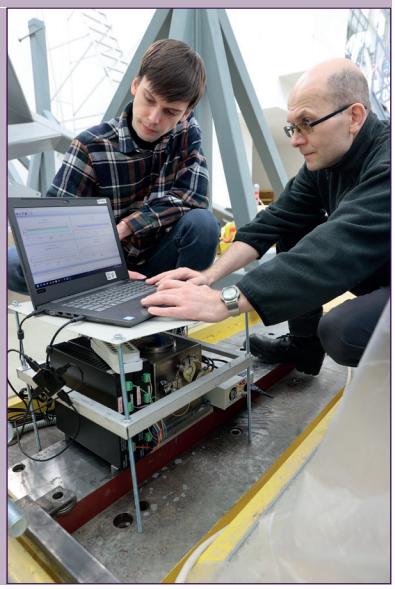
On the basis of the **Medico-Technical Complex (MTC)**, the cytotoxic and cytogenetic effects of gold nanoparticles on a human cell culture under the influence of radiation with various LTE (photons, protons) were investigated. The aim of the research was to study the possibility of the increase in the effectiveness of radiation therapy due to the ability of metal nanoparticles to enhance the radiation effect on cells irradiated in the presence of gold nanoparticles. Modifications induced in the human lung carcinoma cell line A549 by protons and gamma irradiation after treatment with gold nanoparticles were studied. A decrease in survival and an increase in the frequency of micronucleus formation in A549 cells were observed after irradiation in the presence of nanoparticles [22].

Together with colleagues from the Institute of Theoretical and Experimental Biophysics of RAS (Pushchino), experiments were continued with a proton beam in the flash-radiotherapy mode. In the course of these studies, more than 100 laboratory mice and a number of cultures were irradiated. The purpose of the experiment was to study the nature of the flash-effect manifestation after exposure of biological objects to ionizing radiation of ultrahigh dose rate. The results of the experiments are being processed [23].

In the **DLNP Sector of Molecular Genetics of the Cell**, a new microbial species *Cytobacillus pseudoceanisediminis* sp. nov. has been discovered. These bacteria live in a deep salty underground spring in an unused part of the tunnel of the Baksan Neutrino Observatory, INR of RAS. The new microorganism is able to utilize methanol and is highly resistant to heavy metals, which makes it a good candidate for use in bioremediation of polluted waters and soils and in biotechnology [24].

Within the **RADIOGEN** project, DNA sequencing of *γ*- and neutron-induced inherited mutations at the cinnabar gene of *Drosophila melanogaster* has been completed. A comparative analysis of the results of sequencing of inherited mutations of two genes (cinnabar and black) induced by $^{60}$Co *γ* rays or 0.85-MeV neutrons showed that six different types

The Veksler and Baldin Laboratory of High Energy Physics.
Installation of two compact-sized precision laser inclinometers in the MPD NICA hall



Adjustment of the vacuum system of the LINAC-200 electron accelerator

of DNA changes regularly occur with the frequency that markedly varies depending on the genes and the type of radiation. For *y* rays, calculations were made of the frequency of identical DNA changes detected by sequencing of individual mutant genes and the genome as a whole, which showed that the frequency of these changes at the genome level is four orders of magnitude higher than at the level of five studied genes [25].

## REFERENCES


1. *Allakhverdyan V. A. et al. (Baikal-GVD Collab.).* Diffuse Neutrino Flux Measurements with the Baikal-GVD Neutrino Telescope. 2211.09447 [astro-ph.HE]; Phys. Rev. D. 2022 (submitted).
2. *An F. P. et al. (Daya Bay Collab.).* Precision Measurement of Reactor Antineutrino Oscillation at Kilometer-Scale Baselines by Daya Bay. arXiv:2211.14988 [hep-ex]; Phys. Rev. Lett. (submitted).
3. *Gavrikov A. et al.* Energy Reconstruction for Large Liquid Scintillator Detectors with Machine Learning Techniques: Aggregated Features Approach // Eur. Phys. J. C. 2022. V. 82. P. 1021.

4. *Abusleme A. et al. (JUNO Collab.).* Sub-Percent Precision Measurement of Neutrino Oscillation Parameters with JUNO. arXiv:2204.13249 [hep-ex].
5. *Acero M. A. et al. (NOvA Collab.).* Improved Measurement of Neutrino Oscillation Parameters by the NOvA Experiment // Phys. Rev. D. 2022. V. 106, No. 3. 032004.
6. *Appel S. et al. (Borexino Collab.).* Improved Measurement of Solar Neutrinos from the Carbon–Nitrogen–Oxygen Cycle by Borexino and Its Implications for the Standard Solar Model // Phys. Rev. Lett. 2022. V. 129, No. 25. 252701.
7. *Agostini M. et al. (Borexino Collab.).* First Directional Measurement of Sub-MeV Solar Neutrinos with Borexino // Phys. Rev. Lett. 2022. V. 128, No. 9. 091803.
8. *Appel S. et al. (Borexino Collab.).* Search for Low-Energy Signals from Fast Radio Bursts with the Borexino Detector // Eur. Phys. J. C. 2022. V. 82, No. 3. P. 278.
9. *Armengaud E. et al.* Search for Sub-GeV Dark Matter via the Migdal Effect with an EDELWEISS Germanium Detector with NbSi Transition-Edge Sensors // Phys. Rev. D. 2022. V. 106. 062004.
10. *Augier C. et al. (Cupid-MO Collab.).* New Measurement of Double Beta Decays of Mo to Excited States of Ru with the CUPID-Mo Experiment // Phys. Rev. C. 2022 (submitted); https://arxiv.org/pdf/2207.09577.pdf.
11. *Augier C. et al. (Ricochet Collab.).* Fast Neutron Background Characterization of the Future Ricochet Experiment at the ILL Research Nuclear Reactor // Eur. Phys. J. 2022 (submitted); https://arxiv.org/pdf/2208.01760.pdf.
12. *Alekseev I. et al.* First Results of the *ν*GeN Experiment on Coherent Elastic Neutrino–Nucleus Scattering // Phys. Rev. D. 2022. V. 106. L051101.
13. *GERDA Collab.* Pulse Shape Analysis in GERDA Phase II // Eur. Phys. J. C. 2022. V. 82. P. 284.
14. *GERDA Collab.* Search for Exotic Physics in Double-$\beta$ Decays with GERDA Phase II // J. Cosmol. Astropart. Phys. 2022. V. 12. P. 012.
15. *Arnold R. et al.* Measurement of Double Beta Decay of $^{150}$Nd to the $0^{1+}$ Excited State of $^{150}$Sm in NEMO-3. arXiv:2203.03356v1 [nucl-ex].
16. *Eletskikh I. et al.* Observation of an Excess of di-Charmonium Events in the Four-Muon Final State with the ATLAS Detector. ATLAS-CONF-2022-040. 2022.
17. *Ablikim M. et al. (BESIII Collab.).* Study of the Semileptonic Decay $\Lambda_c^+ \to \Lambda e^+ \nu_e$ // Phys. Rev. Lett. 2022. V. 129. 231803.
18. *Kalinnikov V., Velicheva E.* Measurements of the Electromagnetic Calorimeter Prototype Parameters of COMET Experiment Using Cosmic Muons // Phys. Part. Nucl. Lett. 2022. V. 19, No. 3. P. 225–234.
19. *COMPASS Collab.* Double $J/\psi$ Production in Pion–Nucleon Scattering at COMPASS // Phys. Lett. B. 2022. (submitted).
20. *Vasyutina M. et al.* Gamma/Hadron Separation for a Ground Based IACT in Experiment TAIGA Using Random Forest Machine Learning Methods // Proc. of Science. 5. Ser. "5th Intern. Workshop on Deep Learning in Comput. Phys. (DLCP 2021)". 2022.
21. *Budagov Yu. A. et al.* Position-Sensitive Measurements of a Single-Mode Laser Beam Spot Using the Deviding Plate Method // Part. Nucl. Lett. 2022. V. 19, No. 6. P. 589–615.
22. *Rzyanina A. V. et al.* Investigation of the Efficiency and Formation of Cytogenic Lesions in A549 Cells during Irradiation with a Proton Beam // Med. Phys. 2022. No. 1. P. 65 (in Russian).
23. *Gritskova E. A. et al.* Flash Method of Proton Therapy // Phys. Part. Nucl. Lett. 2022. V. 19, No. 6. P. 774–784.
24. *Tarasov K. et al. Cytobacillus pseudoceanisediminis* sp. nov., a Novel Facultative Methylotrophic Bacterium with High Heavy Metal Resistance Isolated from the Deep Underground Saline Spring // Curr. Microbiol. 2023. V. 80. P. 31. https://doi.org/10.1007/s00284-022-03141-8.
25. *Aleksandrov I. P. et al.* Radiation Biology of Structurally Different *Drosophila melanogaster* Genes. Report 9. General Patterns and Locus-Specific Features of Radio-Mutability of Sex-Linked and Autosomal Genes // Rad. Biol. Radioecol. (in press) (in Russian).

# FLEROV LABORATORY of NUCLEAR REACTIONS

## OPERATION AND DEVELOPMENT OF FLNR ACCELERATOR COMPLEX (DRIBs-III)

The construction of new and the upgrade and optimization of the existing accelerators of the DRIBs-III complex continued in 2022.

### DC-280

The basic facility of the SHE Factory, the DC-280 cyclotron, provided 6000 h of beamtime for research in 2022, including 4000 h for experiments on the synthesis of superheavy elements and study of their chemical properties using the DGFRS-2 and GRAND set-ups.

After adjusting the acceleration modes for $^{48}$Ca, $^{54}$Cr, and $^{48}$Ti ions, the intensity of the accelerated beams was 7.73 p$\mu$A for $^{48}$Ca, 3.8 p$\mu$A for $^{54}$Cr, and 2.13 p$\mu$A for $^{48}$Ti. To reduce time for maintenance and to make the cyclotron operation more reliable, the components that duplicated those requiring regular service were manufactured. The currently used deflector was improved, and a new tool with an upgraded structure was manufactured and commissioned. Moreover, a reserve buncher block was fabricated. The commissioning of the flat-top system and beam phase motion monitor system is currently underway.

Moscow, 14 December. Presentation of the first Sber Scientific Prize, the winner of which was the world-famous scientist, Scientific Leader of FLNR JINR, Academician Yu. Oganessian (*photo by Sber Press Office*)

## U-400M

As part of the U-400M upgrade, work on the cyclotron magnetic system was completed: magnetic field strength measured by generating a magnetic field map; first harmonic of the magnetic field corrected using a special set of shims; valley shims added for increasing the magnetic field at the extraction radius. Furthermore, a new magnetic channel for the extraction system was developed and manufactured, a vacuum chamber was assembled and tested, RF generators were upgraded, and a new vacuum pumping system was assembled. The windings for the correction coil were fabricated in collaboration with the specialists from the Department for Superconducting Magnet Research and Technologies of the Veksler and Baldin Laboratory of High Energy Physics.

## U-400

A wide variety of scientific and applied investigations in heavy-ion physics were conducted using the U-400 cyclotron. In 2022, the cyclotron provided over 6400 h of beamtime. Experiments with the beams of $^{6}$Li (MAVR), $^{16}$O (CORSET), $^{22}$Ne (VASSILISSA), $^{48}$Ca (CORSET, VASSILISSA, MAVR, SHELS), $^{24,\ 26}$Mg (CORSET, SHELS), $^{90}$Zn and $^{209}$Bi (CORSET) were carried out. Some experiments were dedicated to applied research with the beams of Ne, Ar, Kr, and Bi ions.

## IC-100

The IC-100 cyclotron, used for applied research, provided over 2500 h of beamtime. Ions from O to Xe accelerated at IC-100 up to the energies of 1.0–1.2 MeV/nucleon were used for irradiating the samples of graphene, AlN, $Si_3N_4$, MgO, $MgAl_2O_4$, ODS steeles, high-temperature titan-based superconductors (in collaboration with the South Africa, Poland, Serbia, Belarus, Kazakhstan, and the Czech Republic), and for *in situ* studies of the optical properties of radiation-resistant dielectrics under ion irradiation.

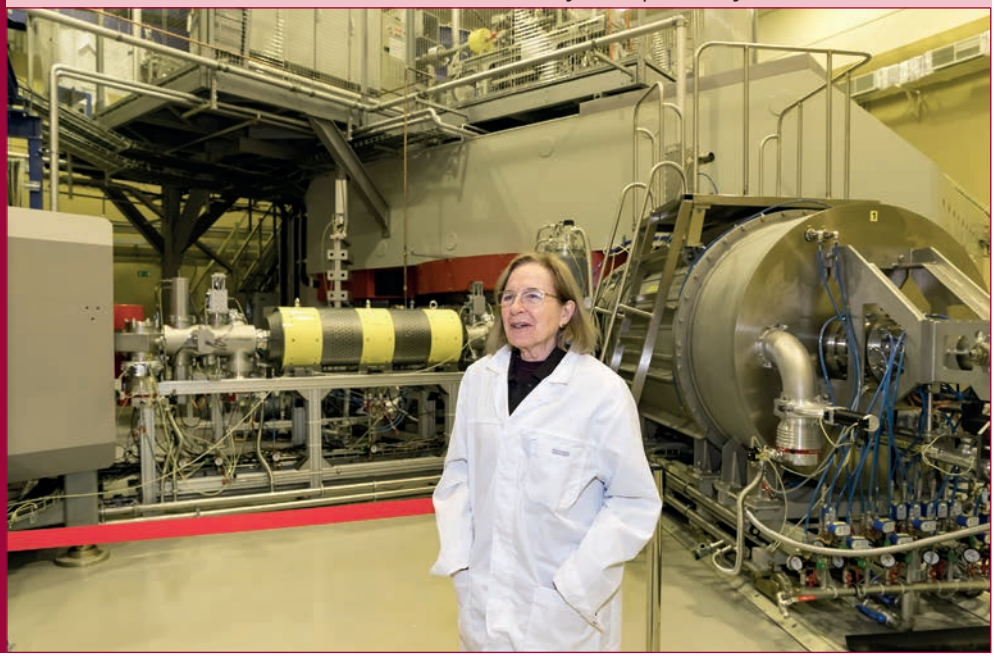
## MT-25

The MT-25 electron accelerator ran for 1200 h. The facility was employed in irradiation of biological samples for the Laboratory of Radiation Biology of JINR and Voronezh State University. Electron components were tested in cooperation with NIIKP and SPE Detector LLC. The promising potential for the use of rare-earth oxides as matrices in practical applications, such as the disposal of radioactive waste, was explored in collaboration with N. I. Lobachevsky State University of Nizhny Novgorod. In addition, ceolits were studied in cooperation with a group of researchers from Vietnam. In a joint effort with the Dzhelepov Laboratory of Nuclear Problems of JINR, methods for measuring the electron energy were worked on.

## DC-140

The implementation of the DC-140 project for applied research at FLNR is ongoing [1]. The premises of Building 101 were prepared for constructing a new accelerator complex and allocating engineering systems. The design documentation was prepared for building the premises, allocating and integrating engineering systems of the new accelerator complex into the existing infrastructure. Construction documents for the cyclotron components and experimental set-ups are ready. The equipment is manufactured, some being already constructed and delivered to FLNR.

25 February. A visit to JINR of the President of the Mexican Physical Society Dr. A. M. Cetto Kramis. An excursion to the Factory of Superheavy Elements



## Experiment at the Dubna Gas-Filled Recoil Separator (DGFRS-2)

A series of experiments was carried out using the gas-filled separator DGFRS-2 of the Factory of Superheavy Elements at FLNR JINR. The studies of the reaction of $^{48}$Ca with $^{243}$Am target nuclei were continued with a view to thoroughly exploring the properties of Mc isotopes and their daughter nuclei and measuring the reaction excitation function in a wide $^{48}$Ca beam energy range (Fig. 1). A new $^{286}$Mc isotope was synthesized, and the cross section for the 5*n* evaporation channel was measured. Four new decay chains of $^{289}$Mc (2*n* channel), 55 decay chains of $^{288}$Mc (3*n* channel), and four decay chains assigned to $^{287}$Mc (4*n* channel) were detected. In addition, the spontaneous fission of $^{279}$Rg was observed for the first time. The *α* decay of $^{268}$Db was confirmed, its branch and half-life being more precisely specified. The decay properties of 21 isotopes from $^{287–289}$Mc to $^{266–268}$Db, including those of $^{264}$Lr, were measured with greater precision.

First experiments on the synthesis of Ds isotopes in the $^{232}$Th + $^{48}$Ca reaction were conducted. Their properties are crucial for identifying new element 120 in the reactions $^{249}$Cf($^{50}$Ti, 3–4*n*)$^{295,296}$120 and $^{245}$Cm($^{54}$Cr, 3–4*n*)$^{295,296}$120 because the *α* decays of nuclei under consideration lead to the $^{275,276}$Ds isotopes. Moreover, the predicted fission barriers of the $^{232}$Th + $^{48}$Ca reaction products, governing the survival probability of excited compound nuclei, are lower than those of the isotopes of element 120. The cross section for the reaction with $^{232}$Th target nuclei will allow more accurate predictions of the production cross sections for the isotopes of element 120. Six decay chains of the new isotope $^{276}$Ds were synthesized for the first time at two $^{48}$Ca beam energies. The *α* decay of $^{276}$Ds led to the discovery of two more isotopes, $^{272}$Hs and $^{268}$Sg (Fig. 1). The reaction cross sections were 70 fb and 0.7 pb at the projectile energies of 231 and 238 MeV, respectively.

The results of the experiments are presented in [2–5].

## Spectroscopy of Heavy and Superheavy Nuclei

Following the replacement of the first triplet of quadrupole lenses of the SHELS separator, first test experiments were conducted aimed at defining the separation efficiency of reaction products formed in complete fusion reactions of the $^{22}$Ne, $^{40}$Ar, $^{48}$Ca ions with the target nuclei of Pb and U. Figure 2 shows a comparison of spectra in the focal plane of the separator prior to and after the replacement. As is seen, the background conditions were substantially improved. It should be noted that an increase in the transmission did not exceed 5%.

The novel GABRIELA-2 detection system comprising five “clover” high-purity germanium *γ* detectors was assembled and will help determine with record efficiency the characteristics of *γ* transitions in heavy short-lived nuclei synthesized at SHELS. Having a minimum tranformation time of 1 μs, the electronic CAMAC-based data acquisition system was replaced with a digital detection system from National Instru-

**Fig. 1.** *a*) Nuclei synthesized at DGFRS-2 in 2022. New isotopes ($^{286}$Mc, $^{276}$Ds, $^{272}$Hs, $^{268}$Sg, $^{264}$Lr) and those that were observed to undergo a novel type of decay ($^{279}$Rg and $^{268}$Db) are marked in red. *b*) Excitation functions of the $^{243}$Am + $^{48}$Ca and $^{232}$Th + $^{48}$Ca reactions

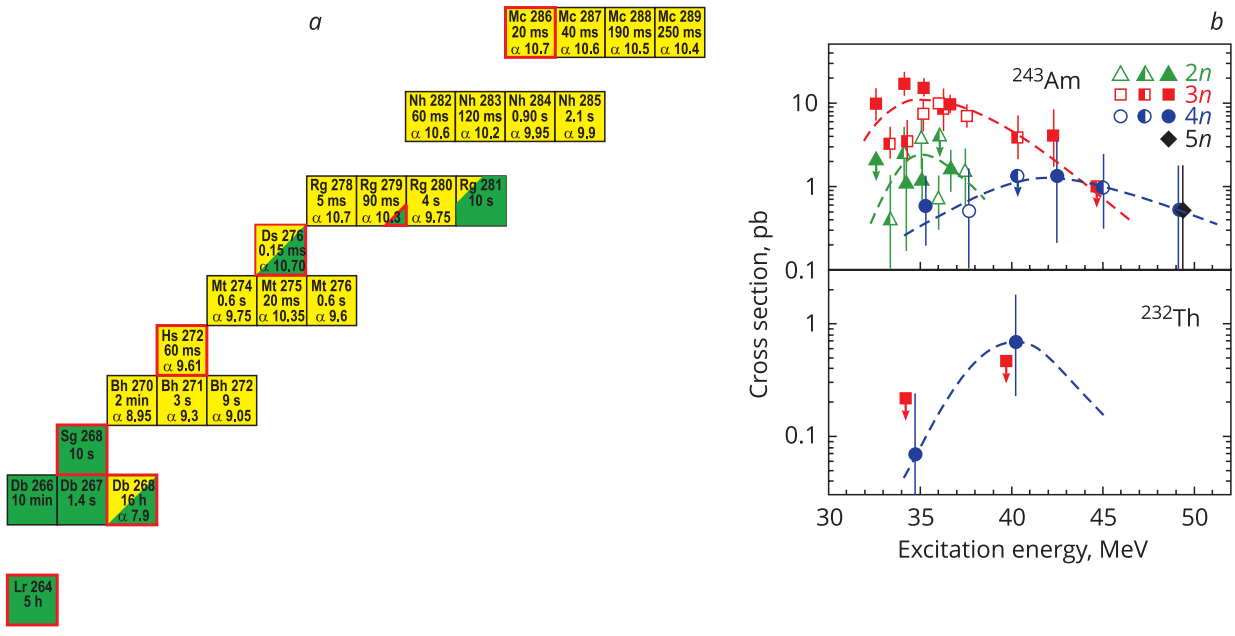
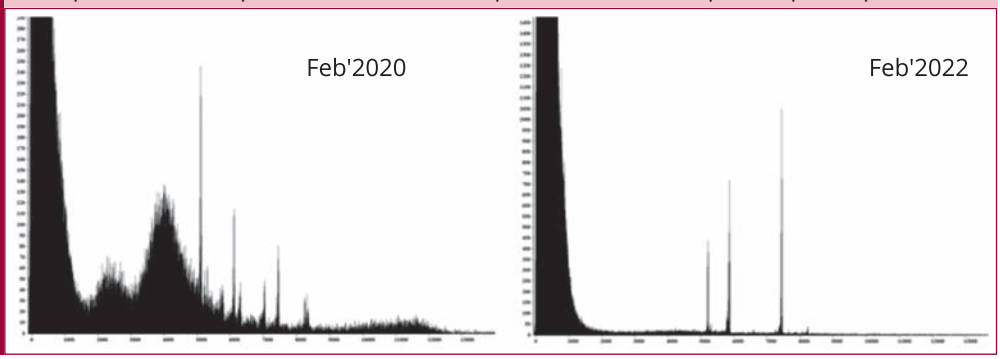


**Fig. 2.** Comparison of the reaction product spectra from $^{40}Ar + ^{208}Pb \rightarrow 2n + ^{246}Fm$ in the focal plane of SHELS prior to and after the replacement of the triplet of quadrupole lenses




ments. The novel system whose distinctive feature is a minimum transformation time of 8 ns provides an advantage in detecting the exotic short-lived states of excited nuclei. New components of the detection system were tested using the $^{26}Mg + ^{206}Pb$ complete fusion reaction, which is of peculiar interest owning to the formation of a new isotope $^{227}Pu$ in the 5*n* evaporation channel. Experimental results are processed.

## Chemistry of Transactinides

In 2022, preparations were well advanced for the first experiments aimed at studying the chemical properties of superheavies. The GRAND separator (DGFRS-3) was commissioned, key separator systems were tested, and transmission was measured (50% for such reactions as $^{48}Ca + ^{206,208}Pb$). In addition, the cryodetector was tuned using the $^{40}Ar$ and $^{48}Ca$ beams.

First experiments were carried out at the novel experimental complex of the SHE Factory combining the physics separator (GRAND) and a chemical set-up (a cryodetector). We pursued studies of the Fl behaviour, presumably in the elemental state, by gas adsorption thermochromatography during irradiation at the DC-280 heavy-ion accelerator. The short-lived radionuclide $^{287}Fl$ with a half-life $T_{1/2} = 0.36$ s was synthesized online in the $^{242}Pu(^{48}Ca, 3n)^{287}Fl$ reaction. Reaction products were preseparated using the new gas-filled GRAND separator and collected in a gas catcher, a recoil transfer chamber installed in the focal plane and separated from the gas volume of the separator by a thin mylar film. Only highly volatile elements (e.g., Hg, Rn) or their compounds were transported from the gas catcher at a temperature of 20 °C to the chemical set-up via a teflon capillary in a carrier gas, a mixture of additionally purified inert gases He/Ar. As a preseparator for the cryodetector, GRAND allowed by 3–4 orders of magnitude better purity of separated Fl atoms from unwanted byproducts (short-lived isotopes of transplutonium elements). This significantly improves the statistical reliability of spectometric data, setting a new standard for SHE chemistry research. In addition, the preseparator allowed one to place the cryodetector measurement system near the focal plane of the separator and the detecting module at a minimum possible distance of 25 cm from the gas catcher, thereby reducing the time needed for gas transport to the chemical detector to 0.1 s. Volatile Fl atoms were studied by adsorption thermochromatography on the surface of gold-plated semiconductor detectors in the He/Ar gas mixture over the temperature range from 20 °C to –170 °C. For this purpose, a linear temperature gradient of –6 °C/cm was obtained for the first time in the thermochromatographic module of the cryodetector. In research at DC-280 in December, two decay chains of $^{287}Fl$ were detected in the cryodetector at the temperatures of approximately –100 °C and –70 °C, which preliminary confirms the previously made conclusions about the high volatility and chemical inertness of elemental Fl. The analysis of the experimental data is pursued. A mobile adsorption model developed at FLNR and the acquired chromatographic data will allow conclusions to be made regarding the thermodynamic properties of Fl.

## Dynamics of Heavy-Ion Interaction, Fission of Heavy and Superheavy Nuclei

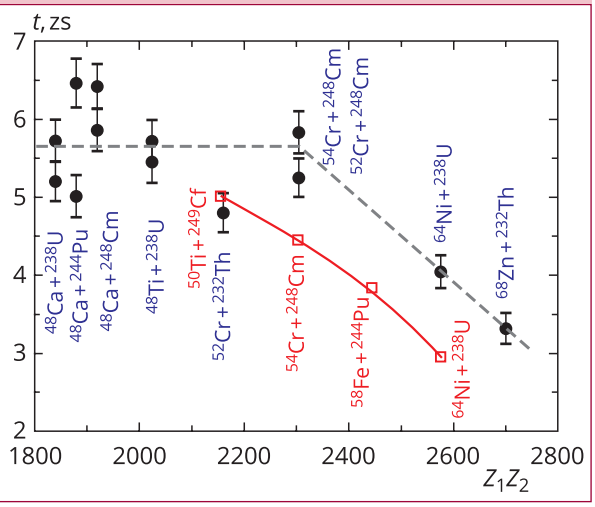
In 2022, mass and energy distributions of fragments formed in the $^{54}Cr + ^{208}Pb$, $^{232}Th$, $^{238}U$ reactions were measured at near-barrier energies for determining the probability of complete fusion of nuclei under investigation. The analysis of the experimental data showed that in transitioning from $^{48}Ca$ to $^{54}Cr$ incident ions, the formation probability of a compound nucleus decreases by more than two orders of magnitude in all the reactions under consideration.

A systematic investigation of the properties of fusion–fission and quasifission was made on the basis of a comprehensive analysis of the experimental data reported earlier in [6]. By analyzing experimental mass distributions, asymmetric quasifission was found to occur over time scales of 5–7 zs in systems with $Z_1Z_2 < 2000$, whereas in those with $Z_1Z_2 > 2000$, the lifetime of the composite nuclear system was found to decrease with increasing $Z_1Z_2$ (Fig. 3).

Multimodal fission studies continued. The proton structures at $Z = 36$ and $Z = 45$ were found to affect the formation of fission fragments of neutron-deficient pre-actinide nuclei ($^{178}Pt$, $^{180,182,183}Hg$,

The Bogoliubov Laboratory of Theoretical Physics, 26 May.
Grand All-Institute seminar to mark the 65th anniversary
of the Flerov Laboratory of Nuclear Reactions

**Fig. 3.** Estimated time for asymmetric quasifission in the reactions of the $^{48}$Ca, $^{48}$Ti, $^{52,54}$Cr, $^{64}$Ni, and $^{68}$Zn ions with actinide nuclei as a function of the Coulomb factor $Z_1Z_2$ at energies near the Coulomb barrier




$^{184}$Pb) [7]. In studying the fission properties of heavy antinide nuclei $^{248}$Cf, $^{254,256}$Fm at an excitation energy of 40–60 MeV, a multimodal fission was found to manifest at all measured excitation energies, though the liquid-drop behaviour dominated. The structural peculiarities of mass and energy distributions attributed to shell effects become less prominent exponentially as the excitation energy of the fissioning nucleus increases [8].

Pursued are the studies of multinucleon transfer reactions that could provide a means of synthesizing new, first and foremost neutron-rich isotopes of transuranium elements [9]. The results of the theoretical modeling revealed the regularities in the dependence of the cross sections for the synthesis of new nuclei on the reaction partners, energy, and detection angles, which have to be taken into consideration when planning experiments.

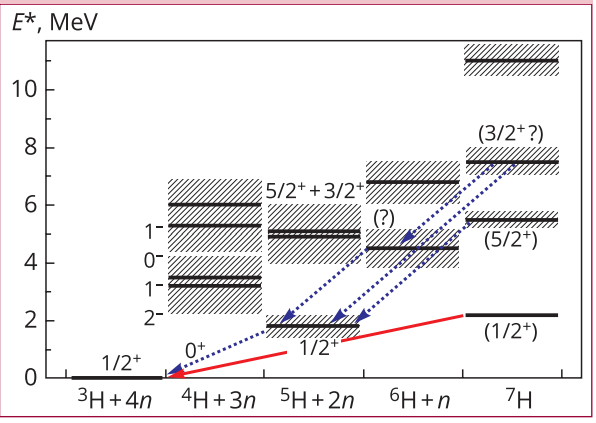
## Structure of Exotic Nuclei

First experiments at the novel ACCULINNA-2 fragment separator [10] were of decisive importance in nuclear physics in that they resulted in the detection of superheavy $^{6}$H and $^{7}$H isotopes [11, 12], resolving one of the key issues that has long been posing challenges to experimentalists and thereby allowing advancements in the exploration of a new mode of spontaneous nuclear decay accompanied by a simultaneous emission of four neutrons.

Suggested earlier in [11], a technique for setting up the experiment allowed the studies of the states in $^{6}$H populated via the $^{2}$H($^{8}$He, $^{4}$He)$^{6}$H reaction [12]. Analogous to $^{7}$H, the detection of $^{4}$He in coincidence with high-energy tritons was assumed to serve an indicator of one or several sequential $^{6}$H decays. The reference measurement of the $^{2}$H($^{10}$Be, $^{4}$He)$^{8}$Li reaction confirmed the effectiveness of the method used for studying the mechanism of the ($d$, $\alpha$) reaction. The missing mass spectrum of $^{6}$H was reconstructed from low-energy $^{4}$He recoils detected in coincidence with $^{3}$H and neutrons. The simulations and data showed that the energy resolution in the missing mass spectrum was better than 2 MeV. Thereto, record-breaking statistics for the $^{6}$H system was collected in the experiment [12]: over 4000 double $^{4}$He–$^{3}$H coincidences and about 130 triple $^{4}$He–$^{3}$H–$n$ concidences. In the reconstructed $^{6}$H spectrum, an important finding was the absence of possible states at the energy $E_T < 3.5$ MeV above the $^{3}$H + 3$n$ decay threshold. This result disagrees with those from previous experiments [*Aleksandrov D. V. et al.* Observation of Nonstable Heavy Hydrogen Isotope $^{6}$H in the Reaction $^{7}$Li($^{7}$Li, $^{8}$B) // Yad. Fiz. 1984. V. 39. P. 513] that reported for the first time on the observation of the $^{6}$H resonance state at the energy $E_T = 2.7(4)$ MeV. A bump observed in previous studies may be accounted for by an order of magnitude higher cross section for populating the $^{5}$H ground state in the $^{7}$Li($^{7}$Li, $^{9}$B*)$^{5}$H reaction.

After processing the experimental data by using the correlation analysis, with due regard for triple $^{4}$He–$^{3}$H–$n$ coincidences, two possible states of the $^{6}$H isotope were found at $E_T \sim 4.5$ (g. s.) and 6.8 MeV. The previously proclaimed $^{6}$H ground state at ~ 2.6–2.9 MeV above the $^{3}$H + 3$n$ threshold was not observed in the experiment involving the $^{2}$H($^{8}$He, $^{4}$He)$^{6}$H reaction with a cross section limit $d\sigma/d\Omega_{cm} < 5$ μb/sr. A scheme of levels and decays of the $^{7}$H and $^{6}$H isotopes (Fig. 4) obtained in the experiments [11, 12] allows a conclusion that the decay of the $^{7}$H ground state may be accompanied by a simultaneous emission of four neutrons (a "true" five-particle decay $^{3}$H + 4$n$). This is the first proven case for the existence of such a nuclear decay mode.

**Fig. 4.** Scheme of levels and possible decay channels for $^{6,7}$H




## Reactions with Beams of Light Stable and Radioactive Nuclei

In 2022, two experiments were conducted at the U-400 cyclotron employing the high-resolution magnet analyzer MAVR. In an experiment with the beams of the $^{48}$Ca and $^{56}$Fe ions accelerated to 10 MeV/nucleon and directed to the Au and $^{238}$U tar-

gets, the differential cross sections were measured for the emission of alphas and other light charged particles at an angle of 0°. The spectra revealed fast $\alpha$ particles with energies close to the kinematic limit for the two- and three-body exit channels. Correlation experiments with fission fragments pointed out the possibility of forming weakly excited heavy nuclei in the reactions under consideration. The analysis of the experimental data using a moving source model indicated several sources for the formation of high-energy nonequilibrium particles. The mechanism of the emission of nonequilibrium $\alpha$ particles from the target nucleus could be attributed to complete or incomplete fusion of nuclei. The main experimental results were published in [13, 14].

## CONSTRUCTION OF NEW AND DEVELOPMENT OF EXISTING EXPERIMENTAL SET-UPS

### Construction of a Separator Based on Resonance Laser Ionization (GaLS Set-Up)

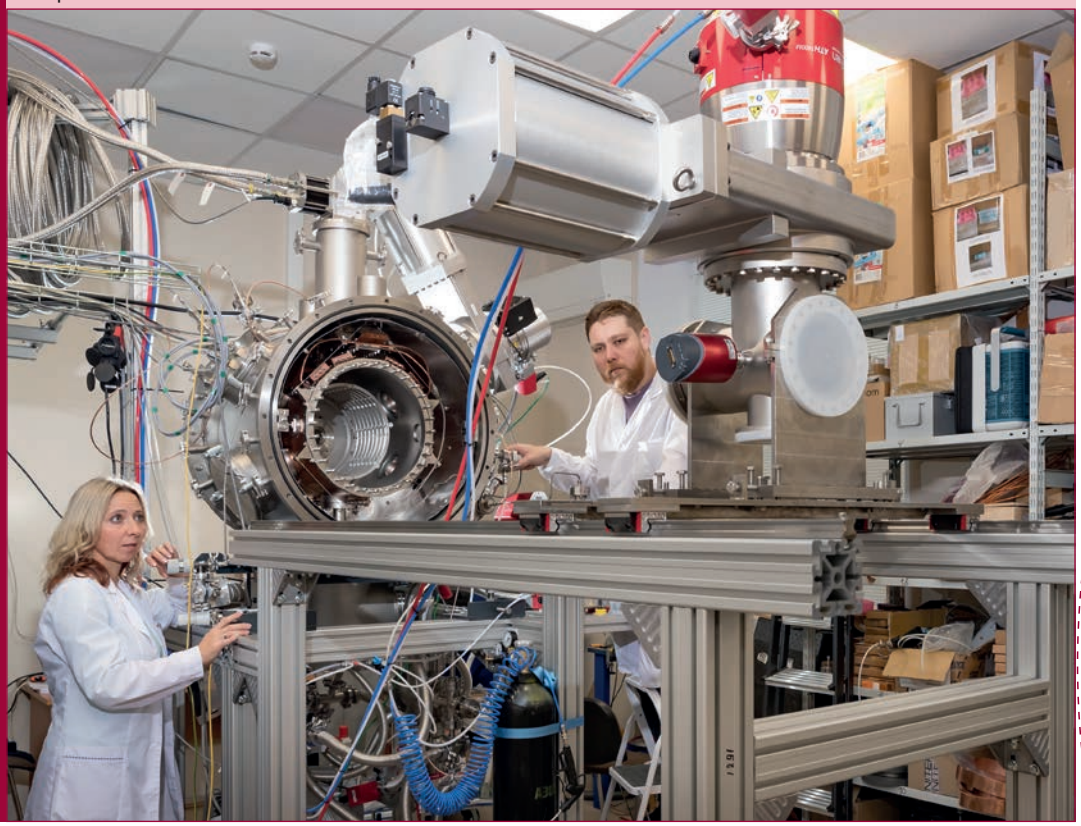
The GALS set-up under construction is intended for the separation and study of the products of multinucleon transfer reactions. The following main results were achieved in 2022:

1. A novel reaction chamber was manufactured to search for and study the optimal levels of atomic transitions for optimal ionization efficiency. In addition, a transport system based on grid electrodes and a registration system were constructed. The upgrade of the evaporative laser for the reference chamber of the GALS set-up is on track to be completed.

2. A detailed scheme on the basis of CAEN software and electronic components were developed for the detection system of the GALS set-up. All the necessary electronic components and primary configuration control programmes were purchased. The mechanical part of the tape station was manufactured in collaboration with iThemba LABS (South Africa).

3. A lab for off-line experiments was prepared, including the installation of engineering systems (power supply, a distillate system, a gas system, etc). A scheme was developed for guiding optical beams within the laser laboratory and for transmitting laser radiation to new experimental set-ups. A possibility of transporting laser radiation from the laser lab to the experimental set-ups by using optical fibers was analyzed. The required single- and multimode fiber sets were chosen and technical specifications were outlined for the sets and input/output devices.

Stand of a cryogenic gas-filled ion catcher for a future facility for precision measurement of nuclear masses



## Gas Ion Catcher

The construction of the cryogenic gas ion catcher, a new set-up for the SHE Factory, continued in 2022. The warm and cold vacuum chambers of the catcher were assembled and evacuated to a pressure of less than $10^{-7}$ Torr. The multi-electrode system for transporting reaction products to the supersonic nozzle was assembled. The copper sheath of the cold chamber, including the gas cooling coil, was manufactured and installed. The system of vacuum pumping control and temperature control of the cold chamber (and the gas in it) was assembled and debugged. Designed for measuring the composition of residual gases in the gas cell, a system based on the mass spectrometer PrismaPro (Pfeiffer) was adjusted. The cooling system of the inner chamber was launched, and a temperature of 48 K was attained at a helium pressure of 10 mbar.

By using specially developed software and performing simulations, the efficiency and extraction time from the cryogenic gas ion catcher were determined for products synthesized in the following complete fusion reactions: $^{40}Ar + {}^{144}Sm \rightarrow {}^{184}Hg^*$, $^{40}Ar + {}^{166}Er \rightarrow {}^{206}Rn^*$, $^{48}Ca + {}^{197}Au \rightarrow {}^{245}Es^*$, $^{48}Ca + {}^{208}Pb \rightarrow {}^{256}No^*$, $^{48}Ca + {}^{209}Bi \rightarrow {}^{257}Lr^*$, $^{48}Ca + {}^{242}Pu \rightarrow {}^{290}Fl^*$. To test the gas catcher without a beam by using an $\alpha$ source, the efficiency and the extraction time of the $\alpha$ decay daughter products were measured.

In collaboration with the Institute for Analytical Instrumentation of RAS (Saint Petersburg) and under a grant from the Ministry of Science and Higher Education of the Russian Federation No. 075-10-2020-117 ("Superheavy Nuclei and Atoms: Mass Limits of Nuclei and the Borders of Mendeleev's Periodic Table" [15]), work continues on the design of the multiple-reflection time-of-flight mass spectrometer intended for the precision measurement of the isotope masses of heavy and superheavy nuclei. In 2022, a preliminary design was completed. Tender documents for manufacturing the mass spectrometer are being prepared. A contract for fabricating a calibrant ion source of the mass spectrometer is underway.

# RADIATION EFFECTS AND PHYSICAL BASES OF NANOTECHNOLOGY, RADIOANALYTICAL AND RADIOISOTOPE INVESTIGATIONS AT FLNR ACCELERATORS

Using high-resolution transmission electron microscopy and computer simulation (molecular dynamics), the parameters of latent tracks in nano- (n-$Si_3N_4$) and polycrystalline (p-$Si_3N_4$) silicon nitride were determined in a wide range of electronic stopping levels [16]. The effects of the formation of swift heavy-ion tracks in the $Si_3N_4$ and AlN crystals and in nanocrystalline $Y_4Al_2O_9$ and $Y_2Ti_2O_7$ were also studied.

The mechanical properties of ODS steels irradiated with swift heavy ions were determined by small specimen compression testing whose results showed that strength properties depended on the structural state of material.

A target device was fabricated for uniform ion doping of metal samples with helium using a method based on the in-depth stop zone scanning of accelerated ions. The device was designed for producing samples for subsequent TEM studies of the structural changes in reactor materials simulated by helium implantation under long-term neutron irradiation.

Heavy-ion irradiation was established to result in the formation of nanopores and ultra-long nanochannels in graphene oxide of nearly any thickness: from single-layer graphene oxide to films of several microns in thickness. The pores of films comprising over 3–4 layers are cylindrical, on average having a narrow size distribution of ~ 6 nm. The experimental studies and modeling by reactive molecular dynamics showed that the pore size depends, to a significant extent, on the composition and the functionalization degree of graphene oxide and on the electron ion energy loss. The pore periphery is electrically conductive owning to the partial restoring of the graphitic structure and contains nitrile groups [17].

Pursued were the studies of the properties of track ion-selective membranes [18, 19] aimed at deep understanding of the mechanism governing the formation of ion-selective channels in polyethylene terephthalate films irradiated with heavy ions and subjected to mild photolysis. The results are crucial for the development of membranes for efficient ion separation.

Track-etched membranes with ultra-small pores were used in experiments aimed at fulfilling tasks related to the structure of electrical double layer in nanopores. Time-resolved measurements of streaming potential were performed. The surface charge density and a number of properties of a hypothetical gel layer on the pore walls of track-etched membranes were defined in the framework of the space charge model. A successful attempt was made for the first time to employ highly asymmetric track-etched membranes in the liquid–liquid membrane contractor. The studies paved the way for further developments of novel membrane purification and separation technologies.

A technology was developed for producing a composite material comprising a track membrane and a layer of polymer nanofibers made from chitosan, collagen, and polylactide. An intermediate layer of titanium provides the adhesion of the fiber

layer to the track membrane. The functionalization of the nanofiber layer with various agents gives composite membranes specific properties, thereby allowing their use in energy-saving water purification technologies, in regenerative medicine applications, such as next-generation wound dressings, and in cellular engineering practical applications [20].

For studying membrane distillation, composite track membranes coated with a 500-nm-thick super hydrophobic polytetrafluoroethylene layer by electron beam dispersion were developed. The track membranes proved to be highly selective in desalinating sodium chloride aqueous solution.

Research continued in the production of modified track membranes that can be used as flow sensors based on the surface-enhanced Raman scattering (SERS). Indeed, the track membranes coated with thin layers of silver by magnetron and thermal sputtering followed by self-assembly of nanoparticles due to the heat treatment have high gain coefficients of an order of $10^{-6}$ with respect to the compounds under investigation. Furthermore, immobilization of aptamers on membrane surfaces, affine to the proteins of the influenza A virus, allows the detection of up to $4 \cdot 10^3$ viral particles per a millimeter using SERS, which is comparable to the sensitivity of a PCR test.

## REFERENCES


1. Reports at the XIV Intern. Sci. Workshop on Problems of Charged-Particle Accelerators. Alushta, Crimea, Sept. 20–25, 2022; https://indico.jinr.ru/event/2945/.
2. *Oganessian Yu. Ts., Utyonkov V. K., Popeko A. G., Solovyev D. I., Abdullin F. Sh., Dmitriev S. N., Ibadullayev D., Itkis M. G., Kovrizhnykh N. D., Kuznetsov D. A., Petrushkin O. V., Podshibiakin A. V., Polyakov A. N., Sagaidak R. N., Schlattauer L., Shirokovsky I. V., Shubin V. D., Shumeiko M. V., Tsyganov Yu. S., Voinov A. A., Subbotin V. G., Bekhterev V. V., Belykh N. A., Chernyshev O. A., Gikal K. B., Ivanov G. N., Khalkin A. V., Konstantinov V. V., Osipov N. F., Paschenko S. V., Protasov A. A., Semin V. A., Sorokoumov V. V., Sychev K. P., Verevochkin V. A., Yakovlev B. I., Antoine S., Beeckman W., Jehanno P., Yavor M. I., Shcherbakov A. P., Rykaczewski K. P., King T. T., Roberto J. B., Brewer N. T., Grzywacz R. K., Gan Z. G., Zhang Z. Y., Huang M. H., Yang H. B.* DGFRS-2 — A Gas-Filled Recoil Separator for the Dubna Super Heavy Element Factory // Nucl. Instr. Meth. A. 2022. V. 1033. P. 166640.
3. *Oganessian Yu. Ts., Utyonkov V. K., Ibadullayev D., Abdullin F. Sh., Dmitriev S. N., Itkis M. G., Karpov A. V., Kovrizhnykh N. D., Kuznetsov D. A., Petrushkin O. V., Podshibiakin A. V., Polyakov A. N., Popeko A. G., Sagaidak R. N., Schlattauer L., Shubin V. D., Shumeiko M. V., Solovyev D. I., Tsyganov Yu. S., Voinov A. A., Subbotin V. G., Bodrov A. Yu., Sabel'nikov A. V., Lindner A., Rykaczewski K. P., King T. T., Roberto J. B., Brewer N. T., Grzywacz R. K., Gan Z. G., Zhang Z. Y., Huang M. H., Yang H. B.* Investigation of $^{48}$Ca-Induced Reactions with $^{242}$Pu and $^{238}$U Targets at the JINR Superheavy Element Factory // Phys. Rev. C. 2022. V. 106. 026412.
4. *Oganessian Yu. Ts., Utyonkov V. K., Kovrizhnykh N. D., Abdullin F. Sh., Dmitriev S. N., Ibadullayev D., Itkis M. G., Kuznetsov D. A., Petrushkin O. V., Podshibiakin A. V., Polyakov A. N., Popeko A.G., Sagaidak R. N., Schlattauer L., Shirokovsky I. V., Shubin V. D., Shumeiko M. V., Solovyev D. I., Tsyganov Yu. S., Voinov A. A., Subbotin V. G., Bodrov A. Yu., Sabel'nikov A. V., Khalkin A. V., Zlokazov V. B., Rykaczewski K. P., King T. T., Roberto J. B., Brewer N. T., Grzywacz R. K., Gan Z. G., Zhang Z. Y., Huang M. H., Yang H. B.* First Experiment at the Super Heavy Element Factory: High Cross Section of $^{288}$Mc in the $^{243}$Am + $^{48}$Ca Reaction and Identification of the New Isotope $^{264}$Lr // Phys. Rev. C. 2022. V. 106. L031301.
5. *Oganessian Yu. Ts., Utyonkov V. K., Kovrizhnykh N. D., Abdullin F. Sh., Dmitriev S. N., Dzhioev A. A., Ibadullayev D., Itkis M. G., Karpov A. V., Kuznetsov D. A., Petrushkin O. V., Podshibiakin A. V., Polyakov A. N., Popeko A. G., Rogov I. S., Sagaidak R. N., Schlattauer L., Shubin V. D., Shumeiko M. V., Solovyev D. I., Tsyganov Yu. S., Voinov A. A., Subbotin V. G., Bodrov A. Yu., Sabel'nikov A. V., Khalkin A. V., Rykaczewski K. P., King T. T., Roberto J. B., Brewer N. T., Grzywacz R. K., Gan Z. G., Zhang Z. Y., Huang M. H., Yang H. B.* New Isotope $^{286}$Mc Produced in the $^{243}$Am + $^{48}$Ca Reaction // Phys. Rev. C. 2022. V. 106. 064306.
6. *Itkis M. G. et al.* // Eur. Phys. J. A. 2022. V. 58. P. 178.
7. *Kozulin E. M. et al.* // Phys. Rev. C. 2022. V. 105. 014607.
8. *Saiko V., Karpov A.* Multinucleon Transfer as a Method for Production of New Heavy Neutron-Enriched Isotopes of Transuranium Elements // Eur. Phys. J. A. 2022. V. 58. P. 41.
9. *Banerjee T. et al.* // Phys. Rev. C. 2022. V. 105. 044614.
10. *Fomichev A. S. et al.* The ACCULINNA-2 Project: The Physics Case and Technical Challenges // Eur. Phys. J. A. 2018. V. 54. P. 97.
11. *Muzalevskii I. A. et al.* Resonant States in $^{7}$H: Experimental Studies of the $^{2}$H($^{8}$He, $^{3}$He) Reaction // Phys. Rev. C. 2021. V. 103. 044313.
12. *Nikolskii E. Yu. et al.* $^{6}$H States Studied in the $^{2}$H($^{8}$He, $^{4}$He) Reaction and Evidence of an Extremely Correlated Character of the $^{5}$H Ground State // Phys. Rev. C. 2022. V. 105. 064605.
13. *Penionzhkevich Yu. E.* Characteristics of Nucleus–Nucleus Reactions with Emission of Fast Charged Particles: A New Approach to Reactions of Fusion of Cold Nuclei // Phys. Part. Nucl. 2022. V. 53. P. 45.
14. *Penionzhkevich Yu. E., Samarin V. V., Lukyanov S. M., Maslov V. A., Naumenko M. A.* Emission of High-Energy Alpha Particles in Nuclear Reactions of $^{48}$Ca and $^{56}$Fe Ions on $^{181}$Ta and $^{238}$U Targets // Chin. Phys. C. 2022. V. 46. 114002.
15. *Yavor M. I., Gall N. R., Muradymov M. Z., Pomozov T. V., Kurnin I. V., Monakov A. G., Arsenev A. N., Oganessian Yu. Ts., Karpov A. V., Rodin A. N., Krupa L., Dickel T., Plaß W. R., Scheidenberg C.* Development of a Mass Spectrometer for High-Precision Mass Measure-

ments of Superheavy Elements at JINR // J. Instrum. 2022. V. 17. P11033.
16. *van Vuuren A. J., Mutali A., Ibrayeva A., Sohatsky A., Skuratov V., Akilbekov A., Dauletbekova A., Zdorovets M.* High-Energy Heavy Ion Tracks in Nanocrystalline Silicon Nitride // Crystals. 2022. V. 12. 1410.
17. *Jovanovic Z., Gloginjic M., Mravik Z., Olejniczak A., Bajuk-Bogdanovic D., Jovanovi S., Pašti I., Skuratov V.* Mechanistic Insights into Ion-Beam Induced Reduction of Graphene Oxide: An Experimental and Theoretical Study // Rad. Phys. Chem. 2022. V. 199. 110355.
18. *Apel P. Y., Blonskaya I. V., Ivanov O. M., Polezhaeva O. A., Dmitriev S. N.* Do the Soft-Etched and UV-Track Membranes Actually Have Uniform Cylindrical Subnanometer Channels? // Rad. Phys. Chem. 2022. V. 198. 110266.
19. *Apel P., Koter S., Yaroshchuk A.* Time-Resolved Pressure-Induced Electric Potential in Nanoporous Membranes: Measurement and Mechanistic Interpretation // J. Membrane Sci. 2022. V. 653. 120556.
20. *Markov P. A., Vinogradov I. I., Kostromina E., Eremin P. S., Gilmutdinova I. R., Kudryashova I. S., Greben A., Rachin A. P., Nechaev A. N.* A Wound Dressing Based on a Track-Etched Membrane Modified by a Biopolymer Nanoframe: Physical, Chemical, and Biological Characteristics // Eur. Polym. J. 2022. V. 181. 111709.

# FRANK LABORATORY of NEUTRON PHYSICS

The Frank Laboratory of Neutron Physics celebrated its 65th anniversary in 2022

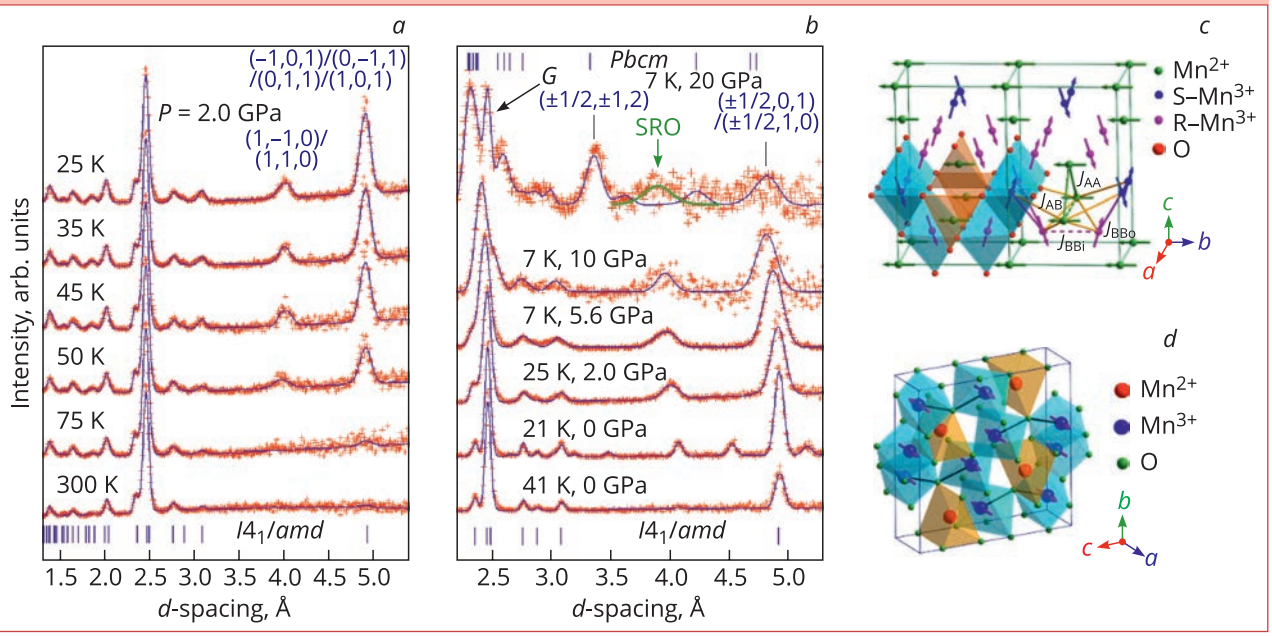
In 2022, the scientific programme of the Frank Laboratory of Neutron Physics was aimed at obtaining new results within the framework of seven research themes of the JINR Plan for Scientific Research and International Scientific and Technical Cooperation: in condensed matter physics ("Investigations of functional materials and nanosystems using neutron scattering", 04-4-1142-2021/2025, leaders — D. P. Kozlenko, V. L. Aksenov, and A. M. Balagurov; "Modern trends and developments in Raman microspectroscopy and photoluminescence for condensed matter studies", 04-4-1133-2018/2023, leaders — G. M. Arzumanyan and N. Kucerka); in neutron nuclear physics ("Investigations in the field of nuclear physics with neutrons", 03-4-1128-2017/2022, leader — E. V. Lychagin); in the development of the FLNP basic facilities ("Development of the IBR-2 facility with a complex of cryogenic neutron moderators", 04-4-1105-2011/2022, leaders — A. V. Belushkin, A. V. Vinogradov, and A. V. Dolgikh); in the development of the IBR-2 spectrometers and computation complex ("Scientific and methodological research and developments for condensed matter investigations with IBR-2 neutron beams", 04-4-1143-2021/2025, leaders — V. I. Bodnarchuk and V. I. Prikhodko); in the development of the design of a new neutron source ("Development of the conceptual design of a new advanced neutron source at JINR", 04-4-1140-2020/2022, leaders — V. N. Shvetsov and M. V. Bulavin); in the development of the SOLCRYS structural research laboratory in Poland ("Development of the SOLCRYS Structural Research Laboratory at the SOLARIS National Synchrotron Radiation Centre", 04-4-1141-2020/2022, leader — N. Kucerka).

## CONDENSED MATTER PHYSICS

### Structure Investigations of Novel Oxide, Intermetallic and Nanostructured Materials

Magnetic oxide $Mn_3O_4$ is an unusual geometrically frustrated functional material with a tetragonally distorted spinel-type structure, in which significant magnetocaloric, magnetoelastic, and magnetodielectric effects are observed. The presence of competing magnetic interactions on the A and B sublattices with tetrahedral and octahedral oxygen environments of $Mn^{2+}$ and $Mn^{3+}$ ions in combination with Jahn–Teller distortions on the B sublattice causes the formation of complex modulated magnetic states in this compound. With decreasing temperature and atmospheric pressure, three magnetic phase transitions are observed in $Mn_3O_4$ at $T_{N1} \approx 43$ K, $T_{N2} \approx 39$ K, and $T_{N3} \approx 33$ K. Below $T_{N1} \approx 43$ K, a ferrimagnetic state of the Yafet–Kittel type occurs, in which the magnetic moments of $Mn^{3+}$ on the B sublattice located in the *bc* plane symmetrically cant towards the *b* axis, which leads to the appearance of magnetization directed antiparallel to the magnetization of the ferromagnetic A sublattice formed by $Mn^{2+}$ magnetic moments. The second phase transition at $T_{N2} \approx 39$ K is related to a change in the symmetry of the magnetic order of $Mn^{3+}$ ions due to the formation of two

**Fig. 1.** Neutron diffraction patterns of $Mn_3O_4$, measured at selected pressures and processed by the Rietveld method (*a*, *b*). Schematic representation of the magnetic structure of ambient pressure phase (*c*), as well as high-pressure phase (*d*)




independent R and S sublattices. On the R sublattice and the sublattice of $Mn^{2+}$ ions, the magnetic order remains the same as in the Yafet–Kittel-type phase, and on the S sublattice, an incommensurate conical structure with the propagation vector $k = (0, \sim 0.47, 0)$ is formed along the *b* axis. During the subsequent phase transition at $T_{N3} \approx 33$ K, the magnetic order on the S sublattice becomes commensurate with the propagation vector $k = (0, 1/2, 0)$. At high pressures $P > 11$ GPa, $Mn_3O_4$ undergoes a structural phase transition to a marocite-like $CaMn_2O_4$ phase.

The crystal and magnetic structure of $Mn_3O_4$ was studied using the DN-6 diffractometer in the pressure range up to 20 GPa and temperatures of 15–300 K (Fig. 1) [1]. At pressures above 2 GPa, the suppression of low-temperature modulated phases and the stabilization of the ferrimagnetic phase of the Yafet–Kittel type were observed. In this case, the magnetic ordering temperature sharply increases from $T_{N1} \approx 43$ to 100 K in the pressure range of 0–10 GPa. The magnetic structure of the orthorhombic high-pressure phase was determined. In this phase, at $T_N = 275$ K, a long-range AFM order is formed with the propagation vector $k = (1/2, 0, 0)$ on the $Mn^{3+}$ sublattice, while the $Mn^{2+}$ sublattice remains magnetically disordered. Additional theoretical DFT calculations were carried out to analyze the relationship between changes in competing magnetic interactions and observed magnetic phase transitions.

## Investigations of Magnetic Fluids and Nanoparticles

The structural organization of magnetic nanoparticles near the metal surface in an electric field was studied by neutron reflectometry (GRAINS reflectometer) [2]. The experiments were performed at the liquid-solid interface, where the liquid phase was a classical ferrofluid containing magnetite nanoparticles stabilized with oleic acid in transformer oil, and a thin (50 nm thick) copper electrode on a planar crystalline silicon substrate was used as a solid. The structural organization in the presence of an electric field of various strengths was studied.

Starting with a single wetting layer of magnetic nanoparticles on the electrode surface in the absence of an electric field, the evolution of the interface structure with increasing electric field intensity was followed by analyzing changes in the scattering length density profiles obtained from neutron specular reflection curves. At a sufficiently strong electric field, the formation of the second adsorption layer was observed. This layer became even more saturated with nanoparticles than the first one. The observed effects are associated with the polarization of particles in an electric field and, accordingly, with their dipole–dipole interaction. Relaxation measurements (after turning off the field) show that the local electric field created by strongly interacting electric dipoles in concentrated adsorption layers is an important feature that determines the enhanced adsorption of nanoparticles.

## Investigation of Biological Nanosystems, Lipid Membranes and Lipid Complexes

Membrane proteins play an important role in processes occurring in living cells, such as ion transport across the membrane, energy conversion, and signal transduction. One third of the human genome encodes membrane proteins. Due to their important role in human physiology, membrane proteins are targets for about 60% of currently used drugs. The

most widely used method for obtaining high-resolution protein structures is X-ray crystallography, which requires high-quality protein crystals. However, the crystallization of membrane proteins still remains a major challenge. Unique structures of membrane proteins account for only ~ 1% of all unique high-resolution protein structures in the Protein Data Bank. One of the *in meso* methods is crystallization in a bicellar mixture. Until now, the mechanism of the crystallization process remains unclear, and the application of this technique is based on trial-and-error experiments.

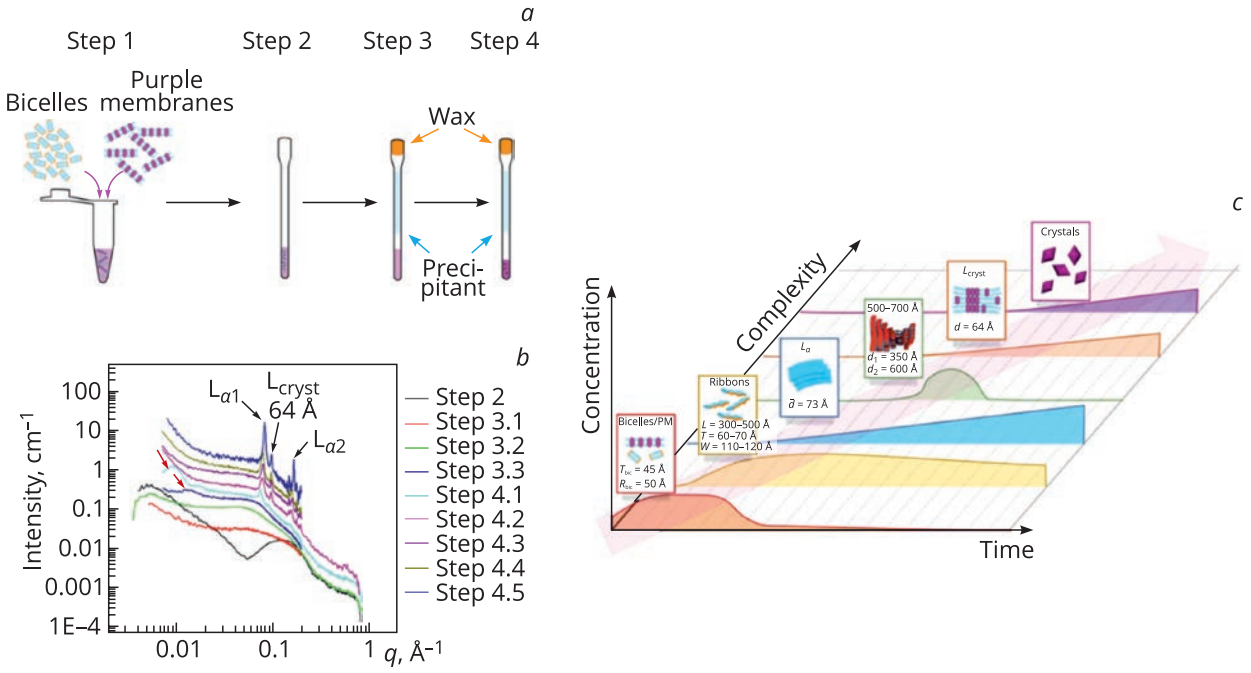
To study the mechanisms of crystallization of membrane proteins, structural rearrangements that occur in the crystallization system during the formation and growth of protein crystals were investigated [3]. For this purpose, a technique was developed for protein crystallization in capillaries suitable for small-angle X-ray scattering experiments. Bacteriorhodopsin from *Halobium salinarum* was taken as a membrane protein. According to the existing paradigm, crystallization occurs in bicelles. However, experiments showed that protein crystallization occurs after the formation of a gel-like phase, which is bicellar only at the initial stages of the experiment, and then it forms ribbon-like interconnected lamellae. The connection of lamellae between each other helps the protein to migrate between the membranes to the site of crystal growth. The formation of a multilamellar phase $L_{cryst}$ during crystallization was also found, the volume of which increases in proportion to the growth of crystals (Fig. 2). The existence of such a local lamellar phase in contact with the crystal surface contributes to crystal growth. The obtained results make it possible to reveal the mechanisms of the process of crystallization of membrane proteins *in meso* and to create an empirical basis for this type of crystallization to use the results in the future for the rational design of drugs.

In the framework of established cooperation with the ophthalmological centre "Vostok-Prozreniye" (Moscow), the possibility of controlling the physical, structural and biological properties during dehydrothermal stitching of stromal corneal grafts based on the Corneoplast material was studied. Structural studies were carried out by small-angle X-ray scattering at the USAXS/SAXS/WAXS Xeuss 3.0 station. The results obtained made it possible to reveal shortening of fibrils along the axis by 3 nm in the intersection zone, occurring at a temperature of 140 °C, which is considered critical and leads to the loss of strength. Changes in the amorphous phase were also detected, which may indicate its significant decrease at 140 °C and, possibly, is associated with the thermal destruction of polysaccharides. All this leads to a decrease in elasticity, strength of the graft, an increase in hydrophobicity, a decrease in biocompatibility and water permeability. As a consequence, collagen samples processed at 140 °C are unsuitable for use in ophthalmic surgery. In addition, Corneoplast grafts failed the epithelialization test after treatment at 140 °C. Corneoplast treated at a temperature of 100 °C and below retains the properties of biointegration.

## Investigation of Polymer Materials, Systems with Surfactants and Gels

Structural studies of hydrogels based on a polymer network of polyethylene oxide (PEO) and polyoxypropylene (POP) with cationic and anionic surfac-

**Fig. 2.** Schematic representation of the process of crystallization of bacteriorhodopsin in bicelles (*a*). Changes in SAXS spectra (*b*) and evolution of the crystallization matrix in real time at different stages of crystallization (*c*)



Xeuss 3.0 X-ray scattering station, which makes it possible to investigate nanoparticles using X-ray small-angle scattering, as well as to study the crystal structure by X-ray diffraction


tants $C_{14}$TAB (mirestyltrimethylammonium bromide) and SDS (sodium dodecyl sulfate) were carried out using small-angle neutron scattering (SANS) (YUMO spectrometer) [4]. The measurements were performed in a wide range of surfactant concentrations. A feature of the microstructure of these gels is the formation of nanophases (even in the absence of surfactants). The reason for this phenomenon is the different nature of the interaction of PEO and POP with water, as well as the different lengths of these polymers. As a result, the hydrogel contains phases saturated with water (with an excess of PEO) and phases in which there is less water (with an excess of POP). The addition of ionic surfactants to the system leads to new effects, which were also studied.

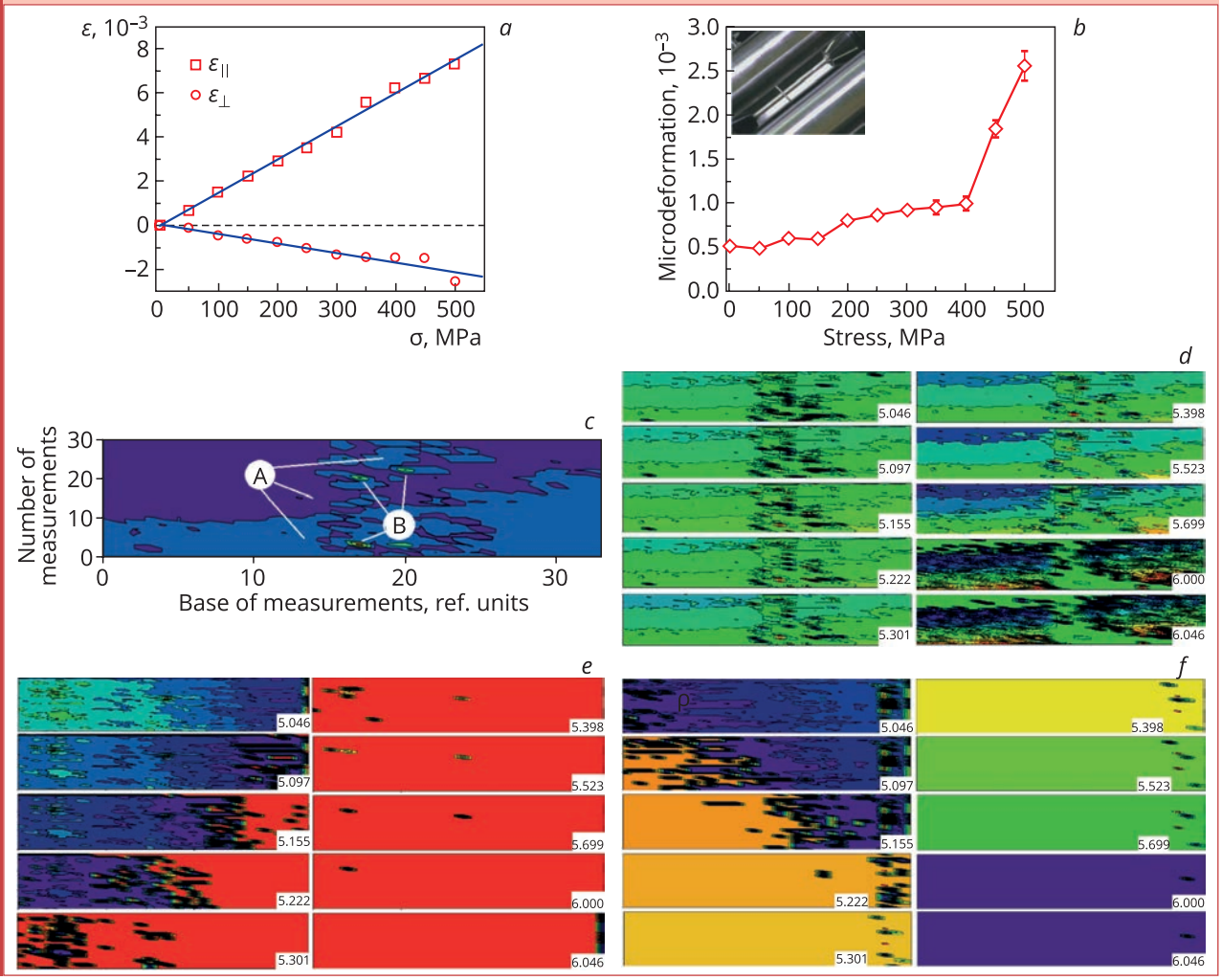
With an increase in the surfactant concentration in the hydrogel structure, a transition was observed from a two-phase structure with water-saturated and water-unsaturated regions to a structure in which surfactant micelles are arranged in a strongly swelling polymer network. It was shown that for SDS surfactant, the swelling of the hydrogel is much greater than for $C_{14}$TAB. The features of the structural organization were studied using SANS curve fitting in the SasView package. The parameters of the microstructure, including the average size of inhomogeneities and micelles, were determined.

## Applied Research

Defects in the surface layers of metals and alloys play an active role in the process of strain hardening and affect the strength and durability of equipment and products. Such defects under the action of mechanical loads serve as sources of stress concentration. Therefore, control over the condition of the surface layers of critical products is a practically important task both in their manufacture and operation. For this purpose, in cooperation with NRNU MEPhI, the effect of defects after mechanical treatment of the surface of a D16T alloy sample on its tensile hardening in the range of applied loads from 50 to 500 MPa was studied using nondestructive testing methods: thermal neutron diffraction and scanning contact potentiometry (SCP) [5]. Alloy D16T is widely used in aviation, automotive and other industries.

Neutron experiments were carried out with the Fourier stress diffractometer of the IBR-2 reactor. Tensile tests of a D16T alloy sample were performed using the LM-29 tensile testing machine. The roughness of the sample surface before testing was 12.5 $\mu$m. The sample was tested for eleven different stress values: from 0 to 500 MPa with an interval of 50 MPa. The SCP measurements were carried out using a Spectroelph desktop instrument for spectral analysis of electrical signals. Contact with the sample was provided by a conical transducer (probe) made of austenitic steel X18N10T with a cone angle close to 90 deg and a radius of rounded apex of about 0.3 mm. The surface roughness ($R_a$) of the transducer corresponded to a value of 0.15 $\mu$m. The length of the measuring base of the sample for scanning was 53 mm. The potentiograms were built for different levels of SLS fixation (SLS = $|\lg|\varphi||$, where $\varphi$ is the signal amplitude). The surface was successively scanned using the Spectroelph device with a total number of tracks of more than thirty and an average scanning speed of 1.7 mm/s (Fig. 3).

**Fig. 3.** Deformation of the crystal lattice $\varepsilon$ (*a*) and microdeformation (*b*) for D16T alloy as a function of the applied load $\sigma$. Linear-time potentiograms before testing for the level SLS = 2 (*c*), high values of the inhomogeneity fixation level (*d*), loads of 50 MPa (*e*) and 500 MPa (*f*)




The obtained diffraction spectra were processed using the Rietveld profile analysis. The deformation of the crystal lattice was calculated from the relative change in the lattice parameter of the material: $\varepsilon = (a - a_0)/a_0$, where $a$ and $a_0$ are the lattice parameters of the deformed and undeformed material, respectively. From the linear approximation of the data in the elastic region, estimates were made for the elastic modulus and Poisson's ratio: $E = 67$ GPa and $\nu = 0.29$. Comparison of the behavior of the widths of the diffraction peaks of the D16T alloy depending on the interplanar spacing $d_{hkl}$ with the resolution function of the device measured for a reference sample showed that the main contribution to the broadening of the peaks is made by microstrains associated with an increased density of dislocations in the material under study. In this case, the contribution to the broadening of the peaks due to the small sizes of coherently scattering crystallites is practically absent. The microdeformation averaged over all Miller indices (*hkl*) was estimated from the broadening of the diffraction peaks compared to the reference sample. At loads in the range from 0 to 400 MPa, the microdeformation varies slightly with a tendency to some increase. At loads above 400 MPa, a significant increase in the microdeformation of the material was observed due to the development of plastic deformation.

In contrast to the surface potentiograms, the linear-time potentiograms show the distribution of structural inhomogeneities in the linear interval of the control (in this case, along the generatrix of the cylindrical surface of the sample). On the potentiograms, one can see color patterns of reflexes that represent small local volumes — generators of mechanical stress waves (MSW). Figure 3, *c* shows a linear-time potentiogram for the fixation level SLS = 2 obtained before testing. It demonstrates defects after the machining of the sample surface — spots and stripes marked with the letter A, as well as powerful sources (concentrators) of internal stresses (SIS) marked with the letter B. The stripes on the potentiograms correspond to helical groove marks after lathe machining. The latter is known to lead to surface deformation or strain hardening. Subsequent grinding during processing results in the removal

6 June. Participants of Comissions of the Parliamentary Assembly of the Union State of Belarus and Russia on tour of the Laboratory

of the hardened layer and the formation of tensile residual stresses that occur at a depth of several microns from the surface. The surface defects are more clearly seen in Fig. 3, *d* (they are concentrated in the central part of the sample).

The analysis of the measured SCP potentiograms showed that, in the region of elastic deformation at a stress of 50 MPa, machining defects, as in the case of zero load, are concentrated mainly in the middle and along the edges of the sample. Traces of lathe machining and grinding of the surface in the form of corresponding spots and stripes on potentiograms at loads of more than 50 MPa at high levels of fixation are transformed into separate reflexes 1–2 mm in size, which are local areas of a strain-hardened material that generates waves of mechanical stresses. The formation of such groups of reflexes in the central part of the sample indicates the active role of surface treatment defects in the formation of microplastic deformation at the stage of initial hardening. The appearance of numerous stress wave generators at stresses above 200 MPa, and especially in the yield strength region (250–300 MPa), is associated with the unloading of local volumes due to shear processes, leading to an increase in the effect of strain hardening. Also, histograms of the distribution of the amplitude of electrical signals were plotted for all considered test modes, which make it possible to find out the distribution of SIS by the power of the sources. It was found that the constructed histograms correlate with the behavior of the microdeformation of the sample material obtained from neutron diffraction data. At a load of 150 MPa, the histogram shows practically no signals corresponding to the selected fixation level. Figure 3, *b* shows that the microdeformation at this time did not change compared to the previous load. Therefore, one can conclude that at a given load value, active sources of internal stresses do not work, since their activation requires a higher load. With an increase in the load up to 200 MPa, these sources start to generate stress waves more intensely, and further, with a change in the deformation mechanism, this process only intensifies.

The problem of disposal and storage of solid radioactive waste from the nuclear industry is acute for governments and scientific communities of countries that use and develop nuclear technologies. Approaches to the creation of radioactive waste storage facilities are subject to strict regulatory requirements for the mechanical and chemical properties of the specific building materials used. For example, cement materials, as a key element in the disposal of radioactive waste, should have certain criteria for chemical and mechanical stability for about 300 y. Strict requirements for the mechanical strength of the composite cement used for the storage of radioactive waste lead to the need to study and validate these materials, including using neutron tomography. In the framework of neutron studies of cement materials [6], new approaches to the analysis of reconstructed three-dimensional data were proposed to assess the structural and morphological features of cement materials with inclusions or pores.

# MULTIMODAL PLATFORM FOR RAMAN AND NONLINEAR OPTICAL MICROSCOPY AND MICROSPECTROSCOPY FOR CONDENSED MATTER STUDIES

The Biophotonics project is aimed at fundamental and applied research in the field of spontaneous and nonlinear Raman microspectroscopy with a trend in the field of life sciences. The fundamental research is mainly focused on studying the mechanisms and nature of the anomalous ratio of line intensities of anti-Stokes (aSt) and Stokes (St) components in the spectra of surface-enhanced Raman scattering (SERS). The applied work is aimed at the application of Raman spectroscopy and fluorescence microscopy in biomedical research, in particular, in identifying signaling pathways and searching for spectral markers of light-induced NETosis, as well as some features of lipid-protein interaction in various membrane mimetics.

## Detection of Low-Frequency Raman Spectra Using Volumetric Bragg Filters Simultaneously in Stokes and Anti-Stokes Regions

Special filters based on BragGrate volumetric Bragg gratings, which are characterized by high selectivity, were used to separate the low-frequency Raman signal against a strong background of Rayleigh scattering using the CARS microspectrometer of FLNP. The advantages of such filters are their ultranarrow passband (~ 5 $cm^{-1}$), a high degree of attenuation of exciting laser radiation (optical density > 4) and transparency for Raman signals (up to 85%), which allows them to be used to study ultralow frequency spectra (< 50 $cm^{-1}$) in systems with single monochromators. Another advantage of these filters is the possibility of simultaneous detection of Stokes and anti-Stokes components in the Raman spectrum.

As a result of the research, the efficiency of using Bragg volumetric filters in the CARS microspectrometer for recording ultralow-frequency spectra (< 30 $cm^{-1}$) of various materials when samples are excited by a laser at a wavelength of 633 nm was demonstrated.

## Investigation of a Possible Anomaly in the Ratio of the aSt/St Peaks in the SERS Spectra Depending on the Continuous and Pulsed Pumping Modes

Surface-enhanced Raman scattering spectra, along with great signal strength, exhibit a number of distinct features as compared to the spectra of the spontaneous Raman scattering. In particular, this refers to the anti-Stokes-to-Stokes molecular spectral line strength ratios (aSt/St ratios). These ratios in the spontaneous Raman scattering, if far away from electronic resonances, and in case of thermodynamic equilibrium, are defined by the Boltzmann relation.

The formation of AgPs on por-Si samples was carried out by immersion deposition in a 3-mM $AgNO_3$ aqueous-alcohol solution for 70 min. Ag-coated por-Si was chosen as a SERS substrate because it was reported to provide ultrahigh sensitivity (up to the detection limit of a single molecule) in combination with an extremely long shelf life (up to 3 y).

Thus, it was experimentally shown that when the sample is excited by radiation at a wavelength of 785 nm, the ratio of the intensity of aSt/St lines differs significantly depending on the pumping regime. An analysis of the intensity ratios of the aSt/St lines depending on the pumping regime will make it possible to estimate the contributions to these ratios from (i) the plasmon spectral profile of the SERS substrate and (ii) the optical Raman pumping of TNB vibrational states.

## Synthesis of Liposomes/Liposomes with Embedded Proteins and the Study of Their Chemical Structure by the Raman Spectroscopy

The Raman spectra of liposomes with embedded peptides were measured daily for four days to track the kinetics of Raman frequencies. Of particular interest was the Amide I line 1620–1690 $cm^{-1}$, which is sensitive to conformational changes in the secondary structure of the peptide, as well as the spectral region of Raman frequencies in the range 1030–1150 $cm^{-1}$, where three bands characterizing the trans-gauche conformation in lipids are expressed.

The normalized Raman frequencies clearly show that the intensity/spectral weight of the peak at 1671 $cm^{-1}$ ($\beta$ turn, a type of irregular secondary structure in proteins) drops markedly by the fourth day of measurements, which indicates the conformation of the protein into a more stable structure with a characteristic Raman frequency at 1656 $cm^{-1}$ ($\alpha$ helix). It is known that the association of multiple $\beta$ sheets/$\beta$ turns can lead to protein aggregation and fibril formation, which is a precursor to Alzheimer's disease.

The data indicate that on the fourth day of measurements, the spectral weight of the conformational state of the peptide in the $\alpha$ helix increased by at least 1.5 times. This suggests that after balancing the liposome-embedded peptide system, the latter retains its natural conformational state.

28 October. The jubilee seminar dedicated to the 65th anniversary of the Laboratory foundation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## UV-Induced NETosis: Revealing the Dependence of Activation on Irradiation Intensity Using the Raman Spectroscopy and Fluorescence Microscopy

In 2022, the research activities in this area were devoted to the application of methods of the Raman spectroscopy and fluorescence microscopy to study light-induced NETosis under the action of UV radiation (365 nm) at doses of 4, 16, and 32 J/cm$^2$. In neutrophil granulocytes, components of the mitochondrial respiratory chain, in particular, cytochrome *c* oxidase and a membrane-bound heterodimeric flavohemoprotein cytochrome $b_{558}$, which is part of NADPH oxidase and contains redox centres, can be considered effective photoacceptors and transducers of photo signals. Oxidative stress and ROS generation were explored by the Raman spectroscopy. Characteristic Raman frequencies were recorded for two radicals: $H_2O_2$ (878 cm$^{-1}$) and HClO (732 cm$^{-1}$). The results of fluorescence microscopy showed a dose-dependent formation of NETotic cells.

# NEUTRON NUCLEAR PHYSICS

## Investigations of (*n*, *p*) and (*n*, *α*) Reactions with Fast Neutrons

Studies of $(n,p)$ and $(n,\alpha)$ reactions with fast neutrons are of great interest both for assessing radiation damage to structural materials of nuclear facilities and for nuclear physics and astrophysics. The measurements were carried out with monoenergetic neutrons in the neutron energy range of 3.0–10.5 MeV at the accelerators EG-5 (FLNP JINR), EG-4.5 (Peking University, Beijing) and HI-13 (China Institute of Atomic Energy (CIAE), Beijing).

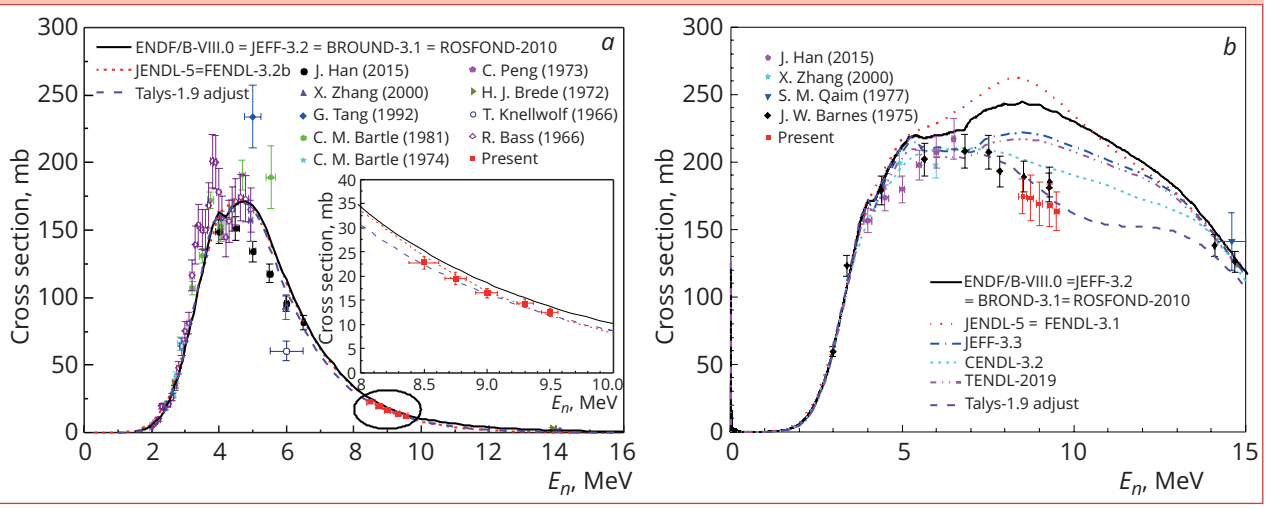
At the EG-5 accelerator (FLNP JINR), measurements of the cross section for the $^{148}$Sm$(n,\alpha)^{145}$Nd reaction in the neutron energy range of 3.3–5.3 MeV are nearing completion.

Experimental data for the $^{91}$Zr$(n,\alpha)^{88}$Sr reaction were processed and published in *Phys. Rev. C* [7]. The cross sections were measured with high accuracy at neutron energies of 3.9, 4.3, 5.0, and 5.3 MeV. This is the first experimental result in the MeV region. The total cross sections were obtained by summing the measured cross section of the reaction $^{91}$Zr$(n,\alpha_0)^{88}$Sr and the partial cross section $(n,\alpha_1)$ obtained in calculations using TALYS-1.9. In addition, the *α* clustering factors were calculated by two methods using the compound-nucleus and "knock-on" mechanisms, which show that *α* clusters are formed after the interaction of neutrons with target nuclei.

Measurements of $^{40}$Ca$(n,\alpha)^{37}$Ar reaction cross sections at five neutron energies in the region of 8.5–9.5 MeV were carried out on the HI-13 tandem accelerator of the China Institute of Atomic Energy (CIAE) [8]. For this reaction, there are relatively many measurements that were performed in previous years for neutron energies below 7 MeV, but the energy range from 7 to 14 MeV remained very poorly studied experimentally due to the lack of reliable sources of monoenergetic neutrons. The small amount of data causes increased interest in new measurements, especially due to the discrepancy between the results of some previous measurements and the recommendations of international nuclear data libraries. The cross sections were measured using a twin gridded ionization chamber. The obtained results are compared with the available experimental data and evaluation data from libraries in Fig. 4.

The TALYS-1.9 code was used for theoretical calculations. These calculation results with the adjusted parameters are in agreement with the measurements and show that the compound mechanism is predominant for the $^{40}$Ca$(n,\alpha)^{37}$Ar reaction in the 8.5–9.5 MeV region. Nevertheless, both the currently measured forward/backward ratios and the calcu-

**Fig. 4.** Cross sections of $^{40}$Ca$(n,\alpha_0)^{37}$Ar (*a*) and $^{40}$Ca$(n,\alpha)^{37}$Ar (*b*) reactions



lations using TALYS-1.9 suggest that the direct and pre-equilibrium mechanisms cannot be neglected.

Also, cross sections of the $^{232}$Th($n$, $f$) reaction were measured at twelve energies in the range of 4.2–11.5 MeV. The experiments were carried out on the EG-4.5 accelerator of Peking University (4.2–5.5 MeV) and the HI-13 tandem accelerator (CIAE, Beijing) (8.5-11.5 MeV) [9]. The results obtained are consistent with the existing experimental data obtained using white neutron sources, whereas the previous cross sections measured using mono-energetic neutron sources are systematically overestimated.

## Development of the Concept of a UCN Source at a Pulsed Reactor

Work continued on the development of the concept of an intense source of ultracold neutrons (UCN) at a pulsed reactor of moderate power. As the main option, a source based on the principle of time focusing and F. L. Shapiro's idea of pulsed filling of a UCN trap was considered.

The analysis showed that the previously proposed creation of a time lens based on the principle of time focusing using nonstationary neutron diffraction on a moving diffraction structure may pose almost insurmountable difficulties. This forced one to turn to an alternative focusing approach based on the principle of nonstationary neutron spin-flip in a magnetic field. In this case, the so-called adiabatic or gradient flipper can serve as a time lens, in which the spin-flip occurs under the action of a high-frequency alternating field directed perpendicular to a strong constant field. When passing through the flipper, the neutron energy changes by $E_D = 2\mu B$, where $\mu$ is the magnetic moment of the neutron, and $B$ is the magnitude of the constant magnetic field.

Since the change in energy in the spin-flipper occurs along the direction of the magnetic field gradient, one of the important tasks is to create such a lens design that this change in energy occurs mainly due to a change in the neutron velocity along the beam. Studies of this problem started.

Later, it was realized that in the case of a large release of neutron energy by the flipper-moderator and, accordingly, a high initial energy and neutron velocity even in the absence of a time lens, the spread of times of flight $\delta t$ from the pulsed source to the flipper-moderator and, accordingly, to the trap, for such neutrons can be much less than the time of flight itself $t = L/V$, where $L$ is the length of the transport neutron guide. Under favorable conditions, $\delta t$ can also be significantly less than the reactor pulse repetition period $T$. In this case, the neutron flux, which, after moderation, will be converted into UCNs that can be stored in a trap, will have a pulsed structure, and the neutron density in the pulse will exceed the average density by a factor of $G = T/\delta t$. The latter result led to the proposal to create the first stage of a UCN source without time focusing, but with a flipper-moderator designed for a great energy release. With a magnetic field of about 20 T, the change in energy will be $E_D = 2.4 \cdot 10^3$ neV, and the neutron velocity before moderation will be about 20 m/s. These fields are achievable in modern superconducting systems.

The use of neutrons with such high velocities provides better conditions for transporting neutrons from the converter and makes it possible to use a more efficient converter.

## Study of Fresco Painting Using Neutron Methods

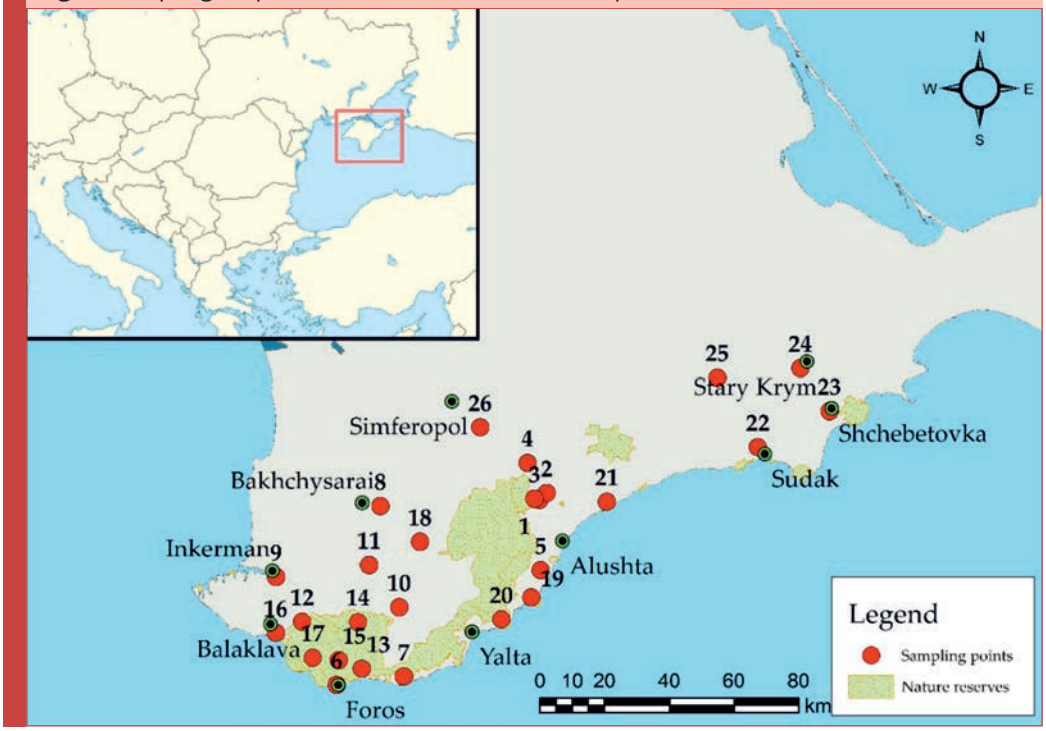
Studies have started on archaeological fragments of frescoes in the Church of St. John the Baptist on Opoki (XII century) and the Resurrection Church of the Derevyanitsky Monastery (XVI and XVII centuries) in Veliky Novgorod.

More than ten complementary methods were applied to study unique pre-Mongolian wall paintings of the XII century from St. George's Cathedral of the Yuriev Monastery in Veliky Novgorod [10]. Both archaeological samples from the main space of the Cathedral and fragments *in situ* in the stair tower of the Cathedral were studied. For the first time in Russia, sensitive neutron methods were used to study the elemental composition of pigments and plasters — neutron activation analysis and prompt gamma activation analysis. The conducted investigations made it possible to determine the elemental and mineral composition of the pigments and plasters used in the creation of wall paintings, to identify the technique of paintings, to make assumptions about the different time of the creation of the paintings in the main space of the Cathedral and in its stair tower, as well as to reconstruct the presumably original appearance of the painting depicting St. George. The discovery of an expensive lapis lazuli pigment testified to the high status of the ktetor of the Cathedral's paintings. The obtained data were compared with Byzantine and Italian church paintings of the same period.

## Biomonitoring of Air Pollution

Within the framework of the international programme "Deposition of Heavy Metals in Europe — Estimates Based on the Analysis of Moss-Biomonitors", a comparative analysis was performed based on the results of two biomonitoring studies conducted in the Republic of Moldova in 2015 and 2020. Analysis of the results showed that the content of most of the elements in mosses collected in 2020 decreased compared to 2015. The most significant decrease was observed for Pb and Cd, the average content of which decreased by 75 and 66%, respectively. The concentration of Cu decreased by 43%, and of V and Cr — by 31% for both elements. The content of Al, Fe, Ni, As, and Sb decreased by less than 30%, while the content of Zn increased by 8.9%. The main sources of air pollution in the country are transport, energy sector, industry and agriculture [11].

**Fig. 5.** Sampling map of moss-biomonitors in the Republic of Crimea




Passive biomonitoring was carried out in the northern and southern parts of Vietnam. The NAA method was used to determine the content of 39 elements in 45 moss samples. Factor analysis made it possible to identify five main components. Factor 1 includes elements of soil origin: Ce, La, U, Al, Fe, Ti, and Zr. Factor 2 is represented by Ni, Sb, Cr, Ba, Co, V, Zr, and Zn, the elevated concentrations of which are associated with fuel combustion and transboundary transport. Elements of Factor 3 (Cl, K, and Na) point to the impact of agricultural activities on air quality. Factor 4 (Th, Zn, As, and Al) includes elements that are regarded as indicators of mining. Factor 5 comprises Sr, Ca, Mg, and Ba and may be related to the chemical composition of water in the studied region [12].

The work on the assessment of atmospheric deposition of heavy metals using moss-biomonitors on the Crimean Peninsula was completed (Fig. 5) [13].

Of the five factors determined using principal component analysis, Factor 1 is a combination of elements (Na, Mg, Al, Sc, Ti, V, Cr, Fe, Co, Ni, Zn, As, Se, Rb, Sb, Cs, La, Ce, Nd, Sm, Eu, Tb, Ta, Th, and U) coming from the weathering of the surface layer of the Earth's crust. Factor 2 includes Br and I, the accumulation of which is associated with the transfer of metal ions from the surface of the Black Sea. Factor 4 is anthropogenic and includes Cl and K elements, while Factors 3 and 5 comprise elements of natural origin.

Active biomonitoring (moss bag technique) was used to assess air pollution in the city of Tula near the Kosogorsky Metallurgical Plant. Three moss species: *Sphagnum fallax*, *Pleurozium schreberi*, and *Dicranum polysetum* were chosen as bioindicators. The values of the relative accumulation factor (RAF) indicated a high degree of pollution of the studied area as a result of industrial activities, mainly by Mn and Fe [14].

## FLNP BASIC FACILITIES

### IBR-2 Reactor

In 2022, the IBR-2 reactor did not operate for physics experiments.

A package of documents was prepared for obtaining a new license for operation of the IBR-2 nuclear research facility (the old one expired on September 30, 2022). The documents were sent to Rostechnadzor in November 2022 and are currently under consideration.

Work started on the manufacture of new air heat exchangers.

Work was carried out on the extension of the service life of IBR-2 systems and equipment, including scheduled preventive maintenance.

### IREN Facility

At the IREN facility, experiments were carried out to optimize the operating frequency of the accelerating system and to match the operating frequencies of the accelerating structures with the natural frequencies of the resonators of the SLED microwave power compression systems. After matching (perhaps not

The IREN facility

yet complete) the frequency of the master oscillator, the operating frequency of the section, and the natural frequencies of the resonators of the SLED systems, it became possible to increase the neutron yield from the nonmultiplying target of the IREN facility, and the obtained particle energy spectra of the accelerator beam confirmed an increase in the energy at the exit of the accelerator to 115 MeV. The obtained results allow one to hope for an increase in the intensity of neutron beams in operation at a frequency of 50–100 Hz.

In 2022, the IREN facility operated for experiments for more than 1000 h, including 450 h at a frequency of 50 Hz, 390 h at a frequency of 25 Hz, and 192 h at a frequency of 2 Hz.

### EG-5

At the EG-5 accelerator, work on its upgrading started. In cooperation with the colleagues from the Budker Institute of Nuclear Physics SB RAS and Novosibirsk State University, calculations of a new accelerator tube were performed. The stages of its manufacture and the creation of a new ion source at INP were outlined. The cosmetic repairs of one of the two experimental halls were carried out.

### New Equipment for the Suite of Spectrometers at the IBR-2 Reactor

For the most part, preparatory work has been completed on the creation of a cryostat with cold top-loading sample exchange for the REMUR spectrometer, cooled by a closed-cycle cryocooler with pumping liquid $^3$He to obtain temperatures of 0.5 K. The cryostat will be equipped with a superconducting HTSC-based vector magnet with a maximum magnetic field of 3 T for experiments with polarized neutrons. The design of the cryostat makes it possible to switch to a $^3$He–$^4$He dilution cycle providing a temperature of 50 mK. The design of the magnet is being worked out and the technological aspects of its manufacturing are being studied.

Due to the availability of equipment for detecting secondary radiation on this spectrometer, it is planned to implement a wide-aperture geometry in the low-temperature part of the cryostat, which allows placing a *γ* detector. The cryostat will be based on a built-in $^4$He liquefier. The design of the cryostat will make it possible to install a nuclear orientation thermometer, an osmotic pressure thermometer ($^3$He in $^4$He), as well as a thermometer based on measuring the saturated vapour pressure of liquid $^3$He.

Further work in this direction will be carried out as a separate project within the framework of this theme.

## NEW NEUTRON SOURCE

In 2022, work continued on the project of a high-intensity pulsed neutron source for conducting research with extracted beams, which should replace the IBR-2 reactor after its service life expires.

In the process of studying the problems of stability and reliability of operation of the NEPTUNE reactor, it was concluded that the main factor negatively affecting the stability and reliability of its operation

in all modes is the dynamic bending of fuel rods and fuel assemblies. The phenomenon of dynamic bending is typical only of pulsed reactors; other factors, according to the calculations, do not significantly affect the dynamics of the NEPTUNE reactor and are fully compensated by negative feedback from the axial expansion of nuclear fuel (fuel rod column).

Work started on going beyond the scope of the oscillator approximation for dynamic bending. The direct approach leads to the construction of a system of partial differential equations, including equations up to the fourth order. A technique for solving such equations by a combined numerical-analytical method using beam functions was developed. The first results of solving such equations were obtained.

On the basis of the obtained results, it became possible to formulate requirements for the optimal design of fuel rods and the configuration of the reactor core, which would ensure stable operation of the reactor at an installed power of 10–15 MW. The preferred option for the core configuration is a variant with a rigid fastening of one of the ends of the fuel rods that are not assembled in a fuel assembly (rod-to-rod assembly) and a fastening that provides limited small transverse and unlimited longitudinal movements of the other end. Provisionally, a rigid fastening is assumed to be at the upper end.

Simultaneously with the search for the best configuration of the reactor core, work is underway to find the optimal arrangement of moderators. Optimization of the thermal (water) moderator of the NEPTUNE reactor was carried out. Calculations performed using the Serpent software package showed that a water moderator thickness of 4 cm is sufficient to convert most of fast neutrons into thermal ones. The maximum thermal neutron flux is achieved at a water moderator thickness of 5.5 cm.

The requirements specification for R&D "Manufacturing of titanium hydride plates for use in structural elements of the reactivity modulator of the NEPTUNE pulsed reactor" was developed.

In cooperation with the Russian Federal Nuclear Centre — E. I. Zababakhin All-Russia Research Institute of Technical Physics (RFNC-VNIITF, Rosatom State Corporation), preparations for performing precision calculations of nonstationary bending of fuel rods, under conditions typical of the NEPTUNE reactor in order to verify the calculation methodology developed at FLNP, were started. The possibility of conducting experimental studies is being explored in order to verify the calculations to substantiate the neutron-physical and dynamic characteristics of the NEPTUNE reactor.

In cooperation with the State Scientific Centre of the Russian Federation — A. I. Leypunsky Institute for Physics and Power Engineering (IPPE JSC, Rosatom State Corporation), discussions are underway on the possibility of modeling the core of the NEPTUNE reactor on the BFS large physical test facility, as well as on performing calculations and modeling the reactivity modulator.

## REFERENCES


1. *Kozlenko D. P., Dang N. T., Kichanov S. E., Thao L. T. P., Rutkaukas A. V., Lukin E. V., Savenko B. N., Tran N., Khan D. T., Truong-Son L. V., Khiem L. H., Lee B. W., Phan T. L., Phan N. L., Truong-Tho N., Hieu N. N., Tran T. A., Phan M. H.* High Pressure Enhanced Magnetic Ordering and Magnetostructural Coupling in the Geometrically Frustrated Spinel $Mn_3O_4$ // Phys. Rev. B. 2022. V. 105. 094430.
2. *Karpets M., Rajnak M., Petrenko V., Gapon I. V., Avdeev M. V., Bulavin L. A., Timko M., Kopcanský P.* Electric Field-Induced Assembly of Magnetic Nanoparticles from Dielectric Ferrofluids on Planar Interface // J. Molecul. Liquids. 2022. V. 362. 119773.
3. *Murugova T. N., Ivankov O. I., Ryzhykau Y. L., Soloviov D. V., Kovalev K. V., Skachkova D. V., Round A., Baeken C., Ishchenko A. V., Volkov O. A., Rogachev A. V., Vlasov A. V., Kuklin A. I., Gordeliy V. I.* Mechanisms of Membrane Protein Crystallization in "Bicelles" // Sci. Rep. 2022. V. 12, Iss. 1. P. 1–17.
4. *Krakovsky I., Tropin T. V., Ivankov O. I., Artikulniy O.P., Petrenko V. I.* Interaction of Ionic Surfactants with Epoxy-Based Hydrogel Investigated by SANS // Colloids and Surfaces A: Physicochem. and Engin. Aspects. 2022 (submitted).
5. *Surin V. I., Bokuchava G. D., Papushkin I. V.* // Information Technologies in Design and Production. 2022. No. 1(185). P. 34–44.
6. *Zel I., Kenessarin M., Kichanov S., Nazarov K., Bălășoiu M., Kozlenko D.* Pore Segmentation Techniques for Low-Resolution Data: Application to the Neutron Tomography Data of Cement Materials // J. Imaging. 2022. V. 8. P. 242.
7. *Zhang G., Sansarbayar E., Gledenov Yu. M., Khuukhenkhuu G., Krupa L., Gustova N. S., Voronyuk M. G., Chuprakov I., Battsooj N., Wilhelm I., Solar M., Sykora R., Kohout Z., Liu J., Hu Y., Cui Z.* Cross Sections of the $^{91}Zr(n, \alpha)^{88}Sr$ Reaction in the 3.9–5.3 MeV Neutron Energy Region // Phys. Rev. C. 2022. V. 106. 064602.
8. *Jie Liu, Haoyu Jiang, Zengqi Cui, Yiwei Hu, Haofan Bai, Jinxiang Chen, Guohui Zhang, Gledenov Yu. M., Sansarbayar E., Khuukhenkhuu G., Krupa L., Chuprakov I., Xichao Ruan, Hanxiong Huang, Jie Ren, Qiwen Fan.* Cross Sections of the $^{40}Ca(n, \alpha_0)^{37}Ar$ and $^{40}Ca(n, \alpha)^{37}Ar$ Reactions in the 8.50–9.50 MeV Neutron Energy Region // Phys. Rev. C. 2022. V. 106. 054610.
9. *Gledenov Yu. M., Zengqi Cui, Jie Liu, Haoyu Jiang, Yiwei Hu, Haofan Bai, Jinxiang Chen, Guohui Zhang, Khuukhenkhuu G., Sansarbayar E., Krupa L., Chuprakov I., Yinlu Han, Xichao Ruan, Hanxiong Huang, Jie Ren.* Cross Section of the $^{232}Th(n, f)$ Reaction in the MeV Neutron Energy Region // Eur. Phys. J. A. 2022. V. 58. P. 86.

10. *Philippova O. S., Dmitriev A. Yu., Tsarevskaya T. J., Dmitrieva S. O.* Comprehensive Study of 12th Century Wall Painting Fragments from the St. George Cathedral of the Yuryev Monastery in Veliky Novgorod (Russia) Using Complementary Physico-Chemical Methods // Heritage Science. 2022. V. 10. P. 49; https://doi.org/10.1186/s40494-022-00680-y; https://rdcu.be/cKYDp.
11. *Zinicovscaia I., Chaligava O., Yushin N., Grozdov D., Vergel K., Hramco C.* Moss Biomonitoring of Atmospheric Trace Element Pollution in the Republic of Moldova // Archives of Environ. Contamination and Toxicol. 2022. V. 82. P. 355–366; https://doi.org/10.1007/s00244-022-00918-7.
12. *Tien D. P. T., My T. T. T., Khiem L. H., Frontasyeva M., Zinicovscaia I., Son N. A., Do V. D.* Studying Airborne Trace Elements in Featured Areas in Red River Delta and South Central Vietnam Using Moss Technique and Neutron Activation // J. Rad. Nucl. Chem. 2022. V. 331. P. 2743–2750; https://doi.org/10.1007/s10967-022-08331-z.
13. *Nekhoroshkov P., Peshkova A., Zinicovscaia I., Vergel K.* Assessment of the Atmospheric Deposition of Heavy Metals and Other Elements in the Mountain Crimea Using Moss Biomonitoring Technique // Atmosphere. 2022. V. 13. P. 573; https://doi.org/10.3390/atmos13040573.
14. *Świsłowski P., Vergel K., Zinicovscaia I., Rajfur M., Wacławek M.* Mosses as a Biomonitor to Identify Elements Released into the Air as a Result of Car Workshop Activities // Ecol. Indicators. 2022. V. 138. 108849; https://doi.org/10.1016/j.ecolind.2022.108849.

# MESHCHERYAKOV LABORATORY of INFORMATION TECHNOLOGIES

Memorial cabinet of M. G. Meshcheryakov

The activity of the Meshcheryakov Laboratory of Information Technologies (MLIT) in 2022 was focused on ensuring the reliable functioning and growth of the JINR network, information and computing infrastructure, as well as on developing mathematical support and software for the research and production activities of the Institute and scientific centres of its Member States on the basis of the JINR Multifunctional Information and Computing Complex (MICC). The research was carried out within two themes: "Information and Computing Infrastructure of JINR" and "Methods, Algorithms and Software for Modeling Physical Systems, Mathematical Processing and Analysis of Experimental Data". A distinctive feature of ongoing research directions is close cooperation with all the Laboratories of the Institute, institutes of the JINR Member States and other countries.

In 2022, the next stage of modernization of the "Govorun" supercomputer took place. The performance of this high-performance system enhanced by 23.5% and reached 1.1 PFlops.

In 2022, the staff of the Meshcheryakov Laboratory of Information Technologies published over 250 scientific papers and 5 monographs, presented more than 100 reports at international and Russian conferences.

## INFORMATION AND COMPUTING INFRASTRUCTURE OF JINR

The Multifunctional Information and Computing Complex, as JINR's large-scale strategic infrastructure project, successfully continued its operation in 2022 and played a decisive role in research asking for modern computing power and data storage systems. The uniqueness of the project is ensured by the use of the reliable engineering infrastructure and state-of-the-art information technologies in the MICC architecture, namely, networks with a bandwidth of up to 4 × 100 Gbit/s, distributed computing and data storage systems based on grid technologies and cloud computing, the hyperconverged "Govorun" supercomputer. Multifunctionality, availability for calculations in 24/7 mode, scalability and high perfor-

mance, a reliable data storage system, information security and an advanced software environment are the major requirements that the MICC meets.

In 2022, the active use of the MICC resources for JINR's research and applied tasks continued. Due to grid technologies (DIRAC Interware), which brought together the dedicated computing resources of all the MICC components, simulation campaigns for the MPD experiment of the NICA complex were successfully held. The Tier-1 grid site for the CMS experiment at the LHC continued to be a leader among similar world sites. Tier-2/CICC provided data processing for the experiments at the LHC, NICA, FAIR and other large-scale experiments, as well as support for users from the JINR Laboratories and the Member States. The cloud environment of JINR and its Member States was mainly used for computing within the JINR neutrino programme. The HybriLIT platform, which includes the basic resource for high-performance computing, the "Govorun" supercomputer, and the education and testing polygon, was actively used by registered users.

## JINR Network Infrastructure

The network infrastructure is a fundamental component of the IT infrastructure of JINR and of the MICC. This is an intricate complex of multifunctional network equipment and specialized software. It is the foundation for the JINR information and computing infrastructure, which was created and is constantly developing, providing access to the Internet, the computing resources and the data storage systems both within JINR and in external scientific organizations cooperating with JINR. The JINR network infrastructure consists of the following functional components: the external optical telecommunication data transmission channel JINR–Moscow, the backbone of the JINR local area network, the local area networks of the Institute's subdivisions.

In 2022, the reliable functioning of the following JINR telecommunication channels was ensured: the Moscow backup channel with a bandwidth of 4 × 100 Gbit/s, the 100 Gbit/s JINR–CERN direct channel and its 100 Gbit/s backup channel, which passes through Moscow and Amsterdam, ensuring the operation of the LHCOPN network for connection between Tier-0 (CERN) and Tier-1 (JINR) and of the LHCONE external overlay network allocated to the JINR Tier-2 centre for communication with the RUHEP Collaboration and the networks of the National Research Computer Network of Russia and RetN using RU-VRF technology [1]. The DWDM (Dense Wave Division Multiplexing) technology is used for data transmission via the external optical telecommunication channel.

The distribution of the incoming and outgoing traffics by the JINR subdivisions in 2022 (exceeding 25 TB by the incoming traffic) is shown in the Table. The traffic of the hotel and restaurant complex (HRC) increased significantly, which is related to the commissioning of a building on 2 Moskovskaya St. after repair, since it was equipped with a network infrastructure and 512 IP addresses.

***Table***

| Subdivision | Incoming traffic, TB | Outgoing traffic, TB |
|---|---|---|
| VBLHEP | 430.2 | 209.23 |
| HRC | 413.24 | 60.25 |
| MLIT | 330.76 | 204.99 |
| DLNP | 229.59 | 113.38 |
| Dubna State University | 139.03 | 39.38 |
| FLNR | 137.7 | 32.69 |
| FLNP | 137.05 | 42.05 |
| JINR Directorate | 96.16 | 53 |
| Remote Access Node | 84.88 | 11.84 |
| UC | 52.97 | 11.51 |
| BLTP | 35.57 | 15.96 |
| LRB | 29.49 | 4.53 |
| SIMO | 27.63 | 2.94 |

The overall incoming traffic of JINR, including the general-purpose servers, Tier-1, Tier-2, the "Govorun" supercomputer and cloud computing, amounted to 29.56 PB in 2022, while the overall outgoing traffic reached 34.19 PB. The traffic with the scientific and educational networks, accounting for 94.5% of the total, is overwhelming.

The local area network (LAN) is based on the JINR backbone network with a bandwidth of 2 × 100 Gbit/s and the distributed multi-node cluster network between the DLNP and VBLHEP sites (4 × 100 Gbit/s).

In 2022, the modernization of the central network virtual cluster of the JINR Network Operation Centre (NOC), which was built on top of the Proxmox VE (Virtual Environment) open source software under the GNU license, was in progress. The NOC cluster ensures the operation of the NOC and JINR services, such as dns, dhcp, proxy, mail, webmail, maillist, ssl, database servers, virtual hosting, nmis monitoring, sshgate, centralized logging, sip telephony, etc.

The NOC regularly updates software on 15–20 servers (webmail.jinr.ru, indico.jinr.ru, mail.jinr.ru, maillist.jinr.ru, mx1.jinr.ru, mx2.jinr.ru, auth-1.jinr.ru (login.jinr.ru), auth-2.jinr.ru, etc.), which keeps the systems up to date.

In 2022, the jinr.int zone was registered, and the mail.jinr.ru mail server was adapted to work with the jinr.int zone.

The work on the improvement of the mail.jinr.ru service was systematically performed: a new hypervisor was prepared and put into operation, scripts were developed, a new adm-mail.jinr.ru server was created for the "cold" copy of mail.jinr.ru. Support for the mailing services (maillist.jinr.ru), "Personal Account", News, VPN, Edurom, Elibs, IPDB was carried out.

In 2022, about 1300 user requests were processed. Since March, an enhanced network protection regime has been provided. More than 80 incidents related to the hacking of the JINR network resources, copyright infringement, etc. were identified and processed. As part of cooperation with

the third-party scientific organizations, VPN access to the network was provided for more than 110 users of the computing resources. A system for monitoring and tracking the status of over 770 network elements was ensured. The sshgate remote access service was put into operation. A mandatory check for vulnerabilities is performed for websites opened for access from the outside.

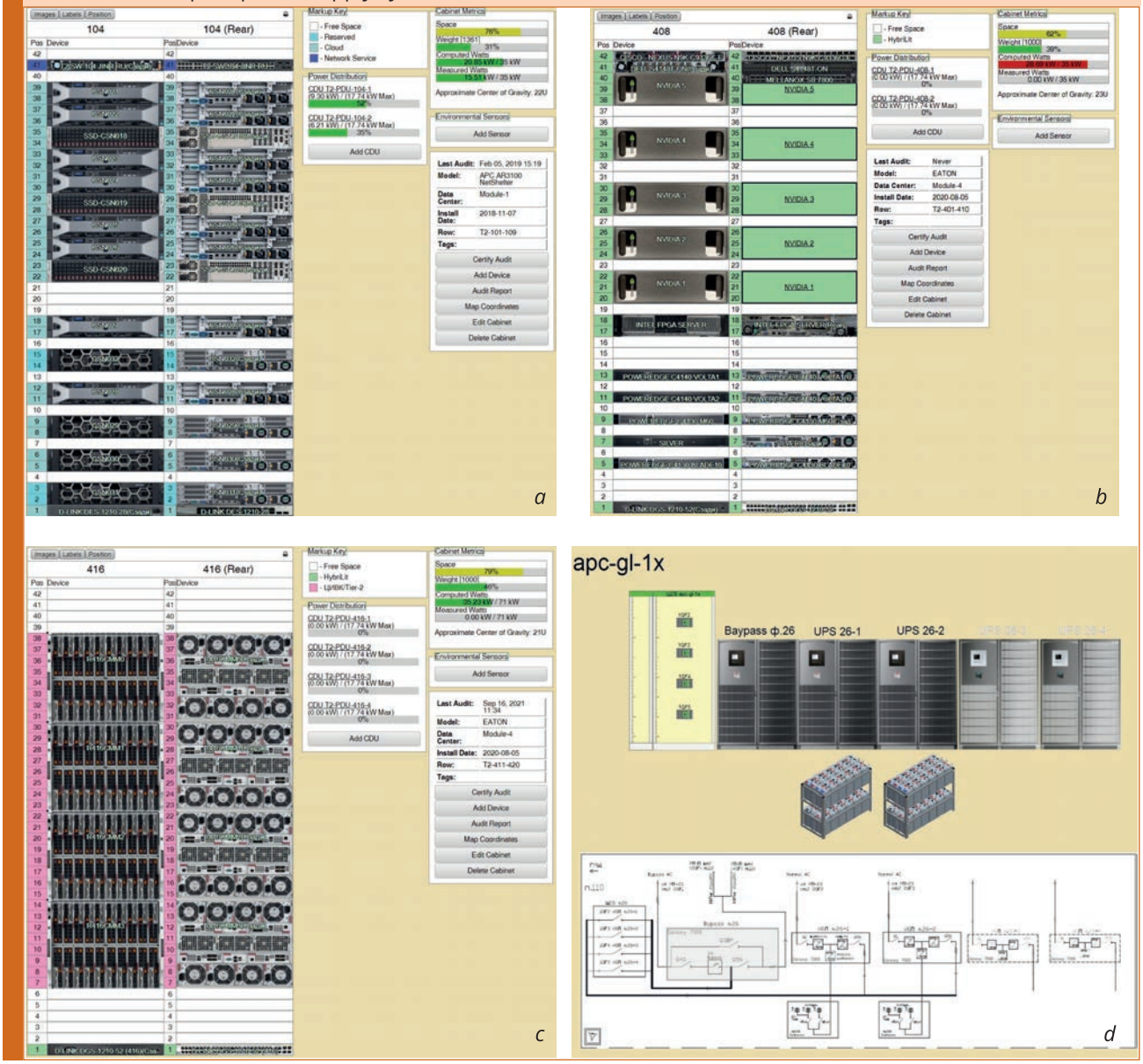
The JINR LAN comprises 9291 network elements and 18 044 IP addresses, 6355 network users, 4477 users of mail.jinr.ru, 1455 users of electronic libraries, 837 users of the remote access service and 111 users of the EDUROAM service.

## MICC Engineering Infrastructure

In 2022, the work on the replacement and enhancement of the MICC engineering infrastructure, designed to ensure the reliable, uninterrupted and fault-tolerant operation of the information and computing systems and the data storage resources, was in progress.

The MICC computing facilities are hosted in one computing hall of 800 $m^2$ of floor space at the 2nd floor of the MLIT building. It currently consists of eight separate IT equipment modules with 2 MW power. All racks are UPS backed up with an autonomy of 10–15 min. Racks are equipped with intelligent (switched and metered) power distribution units, which enable the fine-grained monitoring of power consumption. There are two diesel generator backups in operation to provide the computer centre with electricity in the case of disconnection from external power supply networks. All modules, except for the "Govorun" supercomputer, are air-cooled. The "Govorun" supercomputer is fully "hot" water-cooled, which allows for a power density of 100 kW per rack and PUE = 1.06.

**Fig. 1.** Examples of the equipment visualization system in racks 104 (*a*), 408 (*b*), and 416 (*c*) of the MICC hall and of the uninterrupted power supply system (*d*)



All technological equipment that provides both the guaranteed power supply to the MICC and the cooling system is located at the first and basement floors of the building. Chillers, dry coolers, and diesel generators are located on the territory adjacent to the MLIT building.

The DCIM (Data Centre Infrastructure Management) system is utilized for controlling and accounting the MICC equipment. This software allows one to visualize and control the MICC physical infrastructure on the basis of data on the equipment and its location entered in the DCIM database, to provide management and monitoring services. Figure 1 illustrates examples of equipment visualization.

## JINR Grid Environment (Tier-1 and Tier-2 sites)

In 2022, the successful operation of the JINR grid sites continued, and on average 100% availability and reliability of services was ensured.

For many years, the Tier-1 resource centre was used only to perform jobs of the CMS experiment at the LHC within the participation of JINR and its Member States in this experiment. Since 2021, the introduction of the DIRAC platform has made it possible to utilize the allocated resources of this centre for simulation jobs of the MPD experiment of the NICA project. The amount of resources is regulated by requests from the MPD Collaboration. At present, Tier-1 contains 18 656 cores with a total performance of 297 135.18 HEP-SPEC06. The following software and compilers are used: CentOS Scientific Linux version 7.9, gcc (GCC) 4.8.5, gcc-11.2.1, gcc-c++-11.2.1, gcc-gfortran-11.2.1, C++ (g++ (GCC) 4.8.5, GNU Fortran (GCC) 4.8.5, dCache-6.2 for data storage, Enstore 6.3 for tape libraries and FTS. The total usable capacity of disk servers is 14 PB, and that of tape libraries is 50.6 PB. The long-term data storage system based on the IBM TS4500 library is focused on servicing the NICA complex and CMS experiments. Software for NICA is installed in the CVMFS using GitLab by users/software developers themselves.

In terms of performance, Tier-1 (RU_JINR_T1) is ranked first among Tier-1 world centres for the CMS experiment (Fig. 2, *a*). In 2022, more than 275 million events were processed, which accounts for 18% of the total number of processed events (Fig. 2, *b*) and 25% of the total CPU load of all Tier-1 centres for the CMS experiment.

Figure 2, *c* shows the statistics on the use of the JINR Tier-1 centre by the CMS experiment for different types of data stream processing (reconstruction, modeling, reprocessing, analysis, etc.). Figure 2, *d* il-

**Fig. 2.** Contribution of the world Tier-1 centres to CMS experimental data processing in 2022: *a*) distribution by the normalized CPU time in HEP-SPEC06 h; *b*) number of processed events; *c*) statistics on the use of the JINR Tier-1 centre by the CMS Collaboration by different types of data stream processing; *d*) distribution by the number of jobs completed on Tier-1 by the CMS, BM@N, MPD and SPD Collaborations

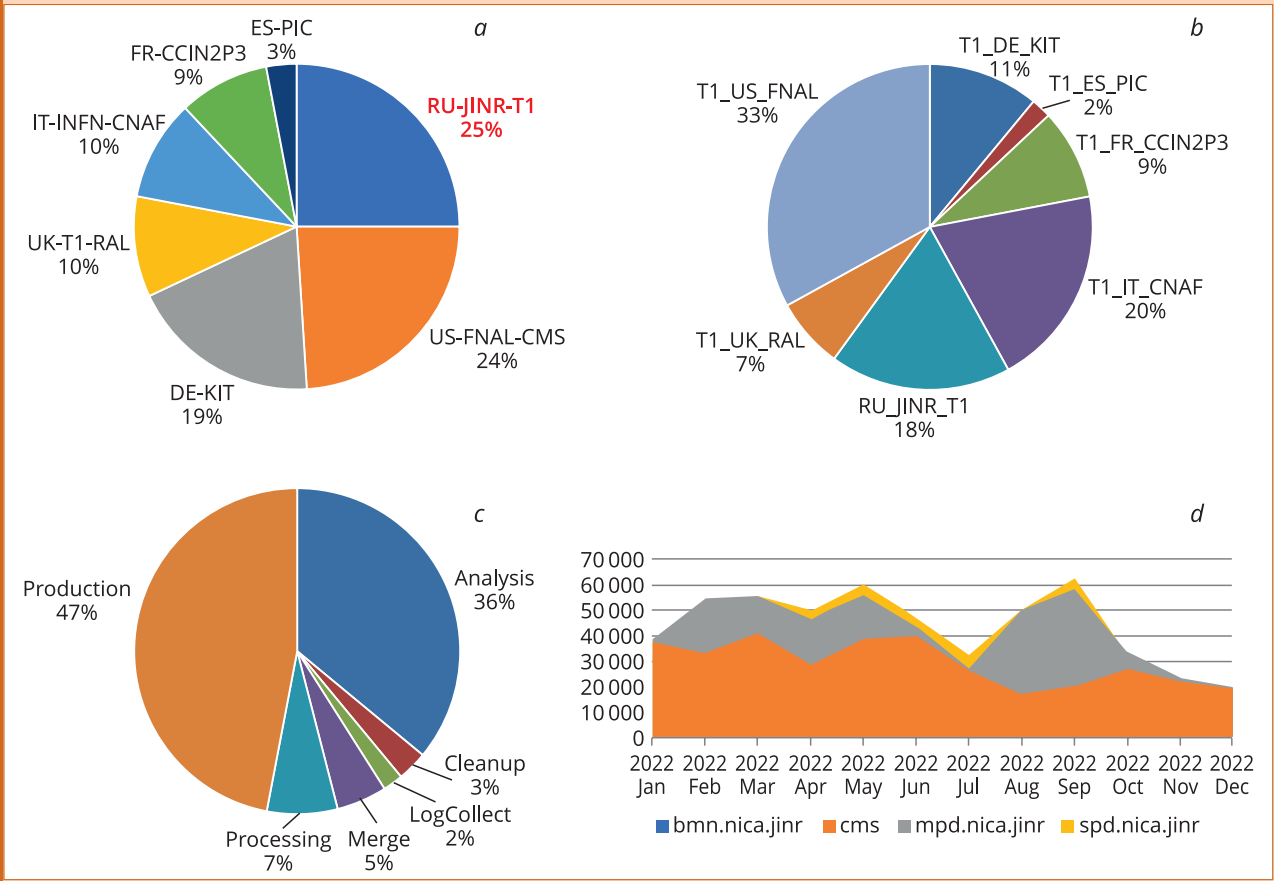
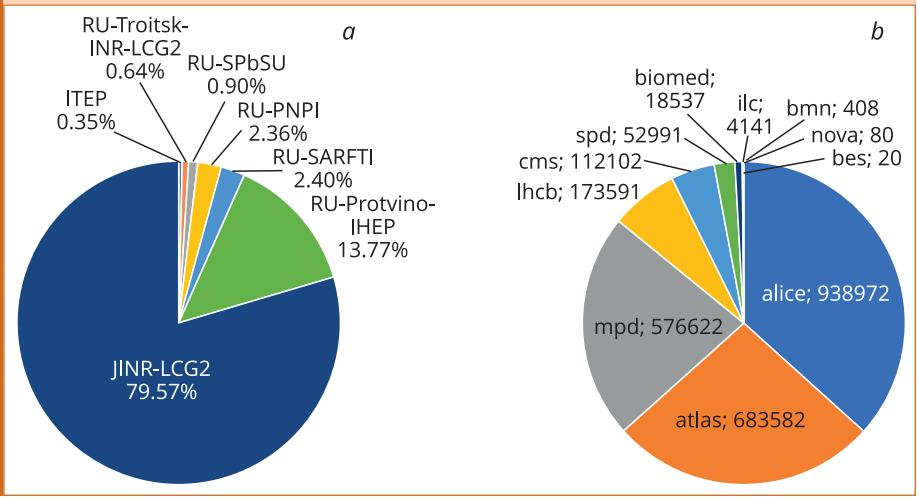


**Fig. 3.** *a*) Distribution of RDIG jobs completed on the grid sites; *b*) use of the JINR Tier-2 site (JINR-LCG2) by virtual organizations within grid projects




lustrates the distribution by the number of jobs performed on Tier-1 by the CMS, BM@N, MPD and SPD Collaborations in 2022.

The JINR Tier-2 output is the highest in the Russian Consortium RDIG (Russian Data Intensive Grid). 80% of the total CPU time in the RDIG is used for computing on this site. In 2022, the computing resources of the Tier-2 centre amounted to 9244 cores, which currently provides a performance of 149 938.7 HEP-SPEC06. The total usable capacity of disk servers is 4763 TB for ATLAS, CMS, and ALICE and 140 TB for other virtual organizations. Figure 3, *a* presents the distribution of jobs performed on the RDIG grid sites. The data on utilizing the JINR Tier-2 site (JINR-LCG2) by virtual organizations within grid projects in 2022 are shown in Fig. 3, *b*.

In 2022, the JINR subdivisions continued to use the EOS-based data storage system with a capacity of 17 PB. Figure 4 demonstrates the statistics on the use of the EOS system.

## Cloud Infrastructure

Figure 5 provides information on the consumption of the cloud infrastructure resources in 2022: the main users are Collaborations of neutrino experiments and MLIT.

In 2022, the work on the development and support of the computing platform for neutrino experiments was underway. Due to the termination of support for the GSI authentication and the transition of the DUNE and NOvA experiments to an authenti-

**Fig. 4.** Statistics on the use of the EOS system by user groups and Collaborations

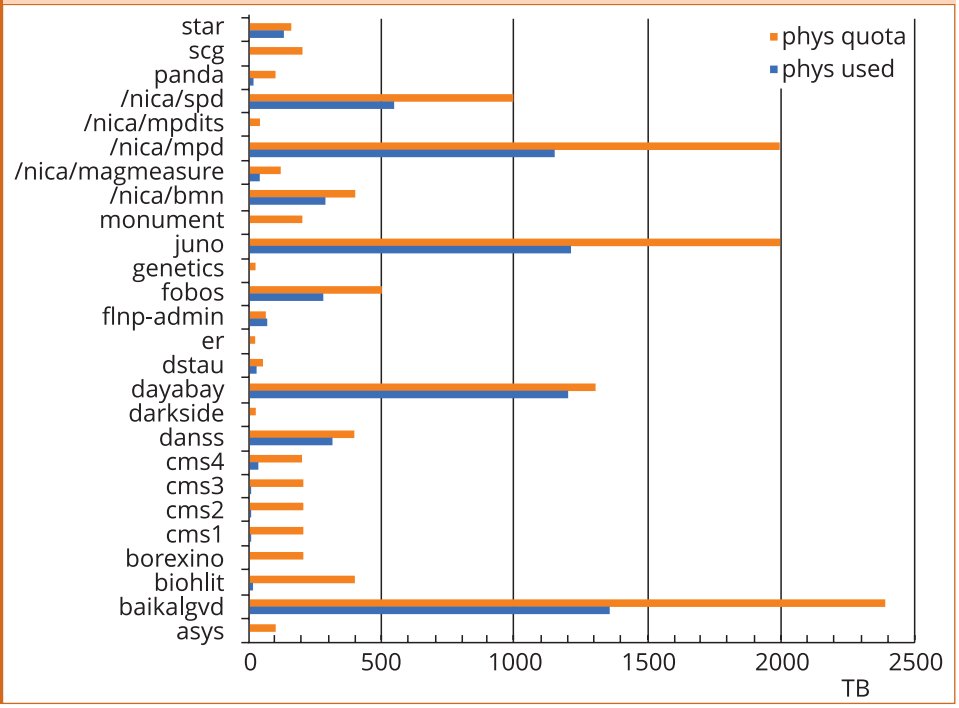
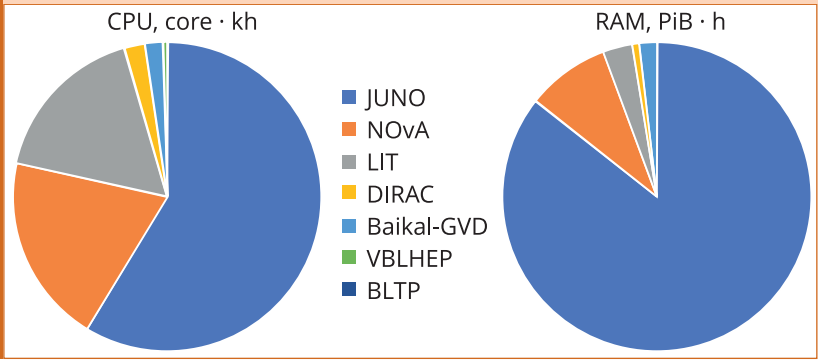


**Fig. 5.** Use of cloud computing by Collaborations and JINR's subdivisions




cation system using tokens, the HTCondor cluster of the cloud neutrino platform was updated to version 9.0, in which support for authentication by JSON web tokens (i.e., JWT) was implemented. For the DUNE experiment, the StashCache caching data storage with a total volume of 1 TB was deployed and connected to the Open Science Data Federation (OSDF).

At the request of the JUNO Collaboration, an exporter of data both on the current load in the batch cluster of the neutrino platform to use this data by the experiment in order to optimize the distribution of computing jobs in the JUNO global grid infrastructure and on the EOS storage used by the experiment and the load of JINR network channels was developed.

In the jupyter.jinr.ru interactive computing service, at the request of users, instead of a set of different images with different software, one universal image based on Datascience Notebook from the Jupyter Docker Stacks set, including all the basic software and modified environment necessary for the correct operation of the ROOT software, was prepared for data analysis.

A server with the NVIDIA A100 Ampere 40 GB graphics card was purchased and put into operation for neutrino computing platform users involved in the development of machine learning algorithms, as well as using the corresponding application software.

In the JINR cloud storage, an additional local replica of modeled and real data sets in the Near and Far Detectors of the NOvA experiment was created to perform the oscillation analysis of the experimental data completely independently of FermiLab infrastructure tools.

About 60 TB of data from the Borexino experiment was copied from the CNAF data centre (Italy) to the EOS storage at JINR. A fairly new approach together with the IAM (Identity and Access Management) service was used to authenticate and authorize the user under whom the data was copied.

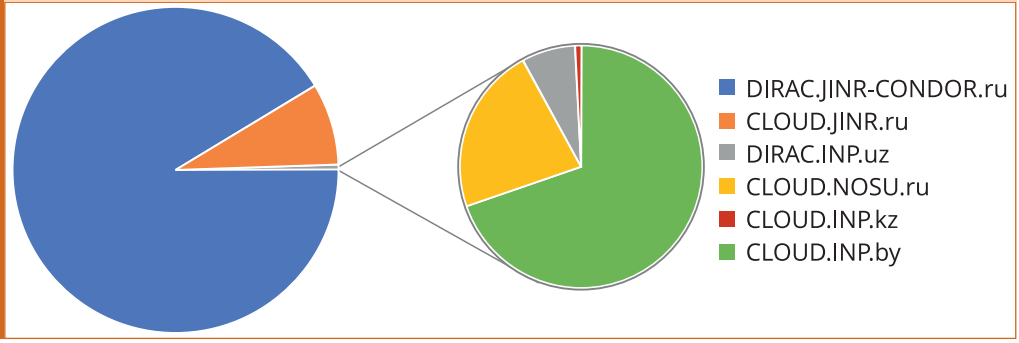
The http:/dice.jinr.ru web portal with information about the participants of the Distributed Information and Computing Environment (JINR DICE), which combines the JINR cloud and cloud infrastructures of the JINR Member States, and about conducted training events on work at the JINR DICE was put into operation. Most of the jobs in the JINR DICE in 2022 were performed on the neutrino computing platform (DIRAC.JINR-CONDOR.ru) (Fig. 6). The main consumer of the JINR DICE resources in 2022 was the Baikal-GVD Collaboration (96%).

In addition, a number of auxiliary cloud services for different JINR scientific experiments were deployed on top of the JINR cloud: several documentation storage systems for experiments and user groups (ad-docs.jinr.ru for the VBLHEP Accelerator Department, spd-docs.jinr.ru and bmn-docs.jinr.ru for the SPD and BM@N experiments, respectively, baikal-docs.jinr.ru for the Baikal-GVD experiment, as well as neutrino-docdb.jinr.ru for joint use by the participants of the JINR neutrino programme; the first version of the ad-operations.jinr.ru electronic journaling system was realized and implemented for the VBLHEP Accelerator Department).

## Heterogeneous Infrastructure

Resource-intensive massively parallel computing and work with Big Data are provided by the JINR MICC heterogeneous infrastructure represented by the HybriLIT platform, which involves the education and testing polygon, the ML/DL/HPC ecosystem [2] and the "Govorun" supercomputer, driven by a common software and information environment. The "Govorun" supercomputer is the key computing part of the HybriLIT platform and has an innovative

**Fig. 6.** Distribution of the number of jobs completed in the JINR DICE by participants



Yu. N. Migal (CJSC “RSC Technologies”) speaks about the current stage of the modernization of the “Govorun” supercomputer

hyperconverged software-defined architecture with unique properties for customization flexibility for the user’s task. The “Govorun” supercomputer comprises a GPU component, a CPU component, and a hierarchical data processing and storage system.

In November, the next stage of modernization of the “Govorun” supercomputer, which is associated with the expansion of the CPU component, implemented as part of a hyperconvergent approach to building a computing complex, underlying the “Govorun” supercomputer, took place. As a result of the modernization, the CPU component was extended to 32 hyperconverged compute nodes. Each node contains two Intel Xeon Platinum 8368Q processors (frequency 2.6 GHz, 38 cores, cache 57 MB, TDP 270 W), eight DDR4 RAM modules (256 GB), eight Intel Optane DC Persistent Memory modules (2 TB), four EDSFF E1.S NVMe SSDs (16 TB) and an M.2 NVMe SSD with a capacity of 128 GB. In addition, each node is equipped with two 100 Gbit/s Intel Omni-Path adapters (Fig. 7).

As a result of the modernization of the CPU component, the performance of the “Govorun” supercomputer increased by 239 TFlops, and the volume of the hierarchical data processing and storage system of the “Govorun” supercomputer was enlarged by 1.6 PB for the “very hot data” DAOS layer and by 8 PB for the “warm data” layer. Consequently, the performance of the “Govorun” supercomputer enhanced by 23.5% and reached 1.1 PFlops, and the total capacity of the hierarchical storage increased to 8.6 PB.

The hyperconvergence of new compute nodes already enabled their use for data mass genera-

**Fig. 7.** Location of new nodes of the “Govorun” supercomputer

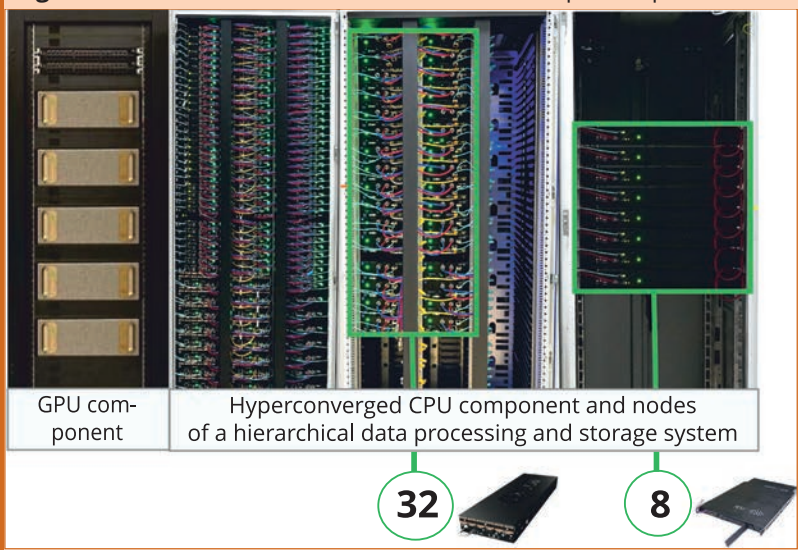
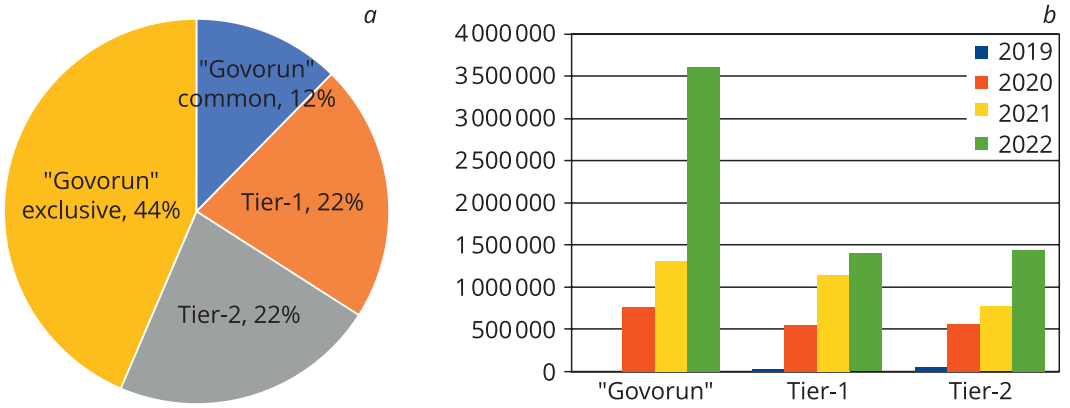


**Fig. 8.** DIRAC-based distributed heterogeneous environment for MPD tasks: *a*) share of use of different MICC components in 2022; *b*) increase in the share of the MICC computing resources in normalized CPU HEP-SPEC06 days




tion and reconstruction tasks within the NICA MPD experiment. It is noteworthy that for a number of MPD tasks, there was a need for a large amount of RAM, which is satisfied by new nodes. The computing resources and the hierarchical data processing and storage system of the "Govorun" supercomputer were integrated into a DIRAC-based distributed heterogeneous environment that includes the resources of JINR and its Member States. The experience of using different computing resources of JINR and other MPD Collaboration institutes has shown that at present, the use of the "Govorun" supercomputer resources is the most efficient (Fig. 8).

Figure 8, *a* shows the diagram of the use of different MICC components in the DIRAC-based distributed heterogeneous environment for MPD jobs. At the same time, the share of those jobs that can only be calculated on the "Govorun" supercomputer was about 44% in 2022, and the total contribution of the "Govorun" supercomputer resources to event mass generation and reconstruction for the MPD experiment was about 56%. Figure 8, *b* illustrates the increase in the share of the MICC computing resources in the heterogeneous environment for MPD jobs. The sharp increase in the share of the "Govorun" supercomputer is related to the modernization carried out in 2022. Thus, over 50 million events were generated on the new nodes.

The above-mentioned modernization of the "Govorun" supercomputer will make it possible to speed up studies in the field of lattice quantum chromodynamics, to qualitatively increase the efficiency of modeling the dynamics of relativistic heavy-ion collisions, to carry out calculations of the radiation safety of JINR experimental facilities and to enhance the efficiency of solving applied tasks. The modernized "Govorun" supercomputer makes it possible not only to perform computing, but also to use the supercomputer as a research polygon for developing software–hardware and IT solutions for JINR tasks.

The total number of users of the "Govorun" supercomputer is currently 323, of which 242 are JINR staff members, and 81 are from the Member States.

In 2022, the overall usage of the resources of the "Govorun" supercomputer amounted to 555 079 jobs, which corresponds to 40 million core hours, and to 455 jobs on the GPU component, which corresponds to 32 890 GPU hours. The average load of the CPU component was 96.2%, while the GPU load was 91.4%.

## Monitoring System

Within the development of the resource management system for the Tier-1 and Tier-2 grid sites, a new accounting system [3] was created at JINR. It enabled to significantly expand the functionality of the original system, as well as to reduce the time of obtaining statistical data due to the creation of automatic data processing by the visualization system. The implemented approach provides the statistical data display directly from SLURM (Simple Linux Utility for Resource Management) and allows accounting for the resources and their use both within the distributed data processing system and locally. The visualization system yielded a powerful tool for analyzing and compiling different reports and presentations. The accounting system was integrated into the general MICC monitoring system, i.e., LITMon, which made it possible to organize a single entry point and combine disparate accountings into a unified structure.

## Information Services

In 2022, a number of works on the development and current maintenance of the "Dubna" Electronic Document Management System (EDMS) were completed. For the further development and optimization of electronic document management, the EDMS software was configured for the process of coordinating technical specifications and design assignments for the development of design and/or working documentation for all capital investment objects of the Institute, for the document management of accounts and acts of work performed under budget items 18 "Design works" and 19 "Construction of

buildings and technological systems", for the document management of accounts and acts of work performed KS-2, KS-3 under budget item 14, paragraphs a, b, etc. A number of works on the adaptation of the "Dubna" EDMS to accommodate the changes in the organization of procurement procedures at JINR were carried out.

The ongoing maintenance and on-demand development of the APT EVM information systems for NICA, CERNDB, ISSC, HR LHEP, ADB2, PIN, ISS, Document Base and Electronic Photo Archive were performed.

The maintenance of a number of the JINR Directorate's sites and programs for accounting for international scientific and technical cooperation (ISTC), etc. was in progress. Certificates of registration of a computer program were received for a number of programs.

In 2022, the work on the creation of the Digital JINR platform started. Its main purpose is to provide a unified environment for the creation and development of digital services, their integration with each other and the analysis of information on all aspects of JINR's activities. The Digital EcoSystem will encompass a wide range of services, from resources for users of basic facilities to handling business trips, vouchers, ordering certificates, etc. The major groups of services are administrative (the area of responsibility of JINR Development of Digital Services Department) and scientific. At present, a prototype of the Digital EcoSystem single access point (https://eco.jinr.ru), a number of network services, a telephone directory and some others were implemented. Access to the system is based on the JINR Single Sign-On (SSO) authentication service.

The work on the maintenance and modernization of central information servers, portals and databases for the information maintenance and software for the activities of MLIT (lit.jinr.ru) and JINR (www.info.jinr.ru, dissertations.jinr.ru, pepan.jinr.ru, etc.) was underway.

The License Management System (LMS, soft-lit.jinr.ru) was put into trial operation. The main purpose of creating the LMS is to automate the management, acquisition, maintenance and use of licensed software products. The LMS comprises the Network Licensing System (NLS), databases and a web interface. The NLS, as one of the main components, implements the automatic granting and issuance of network licenses. The LMS web interface was implemented in the "Dubna" EDMS development environment using the LegoToolkit web application.

## METHODS, ALGORITHMS AND SOFTWARE FOR MODELING PHYSICAL SYSTEMS, MATHEMATICAL PROCESSING AND ANALYSIS OF EXPERIMENTAL DATA

One of the main activities of MLIT is to provide mathematical, algorithmic and software support for experimental and theoretical research underway at JINR. A summary of prominent results is presented below.

To optimize the characteristics of the magnetic system of the CBM experiment (GSI, Darmstadt), the three-dimensional modeling of the protective screen of RICH photodetectors was carried out [4]. For the BM@N magnetic system, the distribution of the field in the magnet working area was analyzed.

The numerical modeling of smooth-irregular liquid-crystal waveguide structures (4-cyano-40-pentylbiphenyl or 5cb) under the action of an external field was performed [5], which made it possible to investigate the inhomogeneous nonstationary regions that arise in this case. It was shown that when the external repetitively pulsed electric field was turned on, the attenuation and size of the inhomogeneities decreased.

It was proposed to replace the Runge–Kutta scheme in numerical calculations of the current-voltage characteristics of long Josephson junctions by an "explicit" second-order scheme [6]. A numerical-analytical algorithm for estimating round-off errors was developed. Their boundedness over the entire calculation interval when using the proposed scheme was proved. The calculations were carried out on the "Govorun" supercomputer with the REDUCE system.

The pion–nucleus scattering data for a number of target nuclei were analyzed on the basis of a microscopic model of the pion–nucleus potential [7]. The obtained numerical results of the elastic scattering cross section $\pi^{\pm} + {}^{40}Ca$ at energies of 116, 163 and 241 MeV confirmed the earlier conclusions about the influence of the nuclear medium on the parameters of the pion–nucleus scattering amplitude.

To study the pion damping width (lifetime) of elementary particles, an algorithm for the calculation of multidimensional collision integrals based on the Monte Carlo method was developed [8]. The algorithm was applied to calculate the pion damping width in hot nuclear matter, which is typical of heavy-nucleus collision processes. The calculations were performed on the HybriLIT heterogeneous cluster. To optimize the computation time, parallel computing based on OpenMP and CUDA technologies was used.

The automation of the assembly, configuration and installation of software (DevOps) for the development and use of MPDRoot was implemented [9]. Typical MPDRoot DevOps operations that used to be cumbersome and time-consuming were reduced to just a few commands, accompanied by a short deployment guide, which greatly minimized the potential for errors on the end user and developer side. The main advantage of the current implementation is its wide compatibility and full modularity that

makes it easier to maintain, upgrade and identify the source of potential problems in the future.

The software models of the track detectors of the BM@N experiment were upgraded and further optimized for the current configuration of the experimental facility (autumn run 2022) [10]. An electrostatic field map was calculated for the current configuration of the GEM detector to enhance the quality of the detailed simulation of processes inside triple gas electron multipliers.

Data reconstruction algorithms were fine-tuned for the SRC configuration at the BM@N facility during the spring run of 2022.

Algorithms based on deep neural networks were developed for event reconstruction on the time interval of the SPD facility under high-luminosity conditions. The TrackNET recurrent neural network, optimized for work on the "Govorun" supercomputer, was enhanced [11]. The data processing performance of up to 2000 events per second with an efficiency of up to 97% and a false track rate of 5% was achieved.

As part of the work on creating a configuration information system [12] for the experiments of the NICA project, a configuration manager, namely, a C++ class library for working with the DDS API, exchanging data with the database and processing REST requests, was developed. The work to transfer the configuration information system to trial operation is underway.

The development of track reconstruction algorithms and methods for estimating the operating parameters of new HGCal detector cassettes of the CMS experiment in a test module on cosmic muons started [13]. The detailed modeling of the test setup with the determination of the optimal dimensions of the trigger and sensitive planes for the subsequent testing of new detectors was performed.

Application of the HIJING, EPOS 1.99, UrQMD and Geant4 FTF models for the analysis of experimental data by the NA61/SHINE Collaboration was considered. It is shown that the Geant4 FTF model describes well the data on $\pi$-meson rapidity distributions in $^{40}$Ar + $^{45}$Sc interactions at $\sqrt{s_{NN}}$ = 5.2 and 6.1 GeV [14].

A series of computational experiments using a number of quantum simulators, such as QuEST, Qiskit, CuQuantum, and the Circ quantum circuit generator, capable of operating on different computing architectures, were performed on the "Govorun" supercomputer [15]. It was shown that the dimension of the state vector grew exponentially with an increase in the number of qubits, and the possibilities for simulating quantum algorithms on the "Govorun" supercomputer (configuration before its modification) were limited to 38 qubits on a CPU, to 31 qubits on one GPU and 34 qubits on eight GPUs [16].

In 2022, the JINRLIB library (http://wwwinfo.jinr.ru/programs/jinrlib/) was replenished with the following programs developed by MLIT specialists: INQSIM, a program for converting PI-type fully symmetric quadrature rules on 2-,...,6-simplexes from compact to expanded forms; FITTER_WEB, a program for fitting experimental data obtained on a small-angle neutron scattering spectrometer, implemented as a web application.

The KANTBP 3.1 program for calculating the energy values, reflection and transmission matrices, and the corresponding wave functions in the adiabatic coupled-channel approach was developed and published in the CPC Program Library [17]. The theoretical cross sections obtained with the KANTBP 3.1 program describe well the experimental data for different heavy-ion fusion and fission reactions.

The momentum distributions of the nucleus and electrons were investigated in the case of the double Compton ionization of a helium atom at a photon energy of 40 keV [18]. It was established that the doubly charged ion momentum distribution was very close to the Compton profile of the nucleus in the ground state of the helium atom, while the momentum distribution of the singly charged ion gave a precise image of the electron Compton profile. The theoretical foundation of the new method is given in [19].

The Bayesian two-rule automatic adaptive quadrature (B2AAQ) of one-dimensional Riemann integrals is critically driven by the *a priori* input provided by the user. Conditions that enable a straightforward elementary input of problem parameters and result in either a single subrange decision tree or a forest of subrange decision trees were defined. This secures the increase of the B2AAQ robustness, reliability and efficiency, together with a significant expansion of its scope, beyond that of the QUADPACK package, which is the core of the computational integration chapters of the major computer libraries worldwide [20].

The numerical study of the fast regulation of the magnetization direction in magnetic nanomaterials, such as magnetic nanomolecules and nanoclusters, was performed [21]. The method can find application in the creation of memory devices and other spintronic appliances.

A mathematical model of multifractal dynamics has been proposed to be used to describe the COVID-19 pandemic. The calculated parameters of the model accurately determine the parameters of the trend and the large jump in daily diseases. The fractal dimensions of various segments of daily incidence in the world and variations in the main reproduction number of COVID-19 were calculated [22].

The $Q_3$ indicator of classicality of quantum states with different symmetries of a three-level quantum system [23], defined as the probability of finding a state with a positive Wigner function within a unitary-invariant ensemble of random states in the Hilbert–Schmidt, Bures and Bogolyubov–Kubo–Mori metrics, was analyzed. As a result of calculations of $Q_3$ indicators in all metrics, a regularity was revealed: the states with a higher symmetry were more classical.

A software and hardware platform was developed on the basis of quantum fuzzy controllers embedded into the control loop to control the pressure and flow of liquid nitrogen of superconducting magnets of the cryogenic system of the NICA accelerator complex [24]. The quantum controller demonstrated the highest speed in achieving the target value, low overshoot and accuracy of achieving the control goal compared to other types of controllers (Fig. 9, blue curve). The design of quantum fuzzy controllers is based on quantum information technologies and is performed using the QSCIT (Quantum Soft Computational Intelligence Toolkit) software toolkit developed by MLIT specialists.

Within the ML/DL/HPC ecosystem [2], using the example of solving a specific problem to investigate the dynamics of magnetization in a Josephson $\varphi_0$ junction, a methodology for developing software modules, which enable not only to carry out calculations, but also to visualize the results of the study and to accompany them with the necessary formulas and explanations, was presented (Fig. 10). A parallel implementation of the algorithm for performing computing for different values of the model parameters based on the Joblib Python library and modules with the integration of the Matlab code into Jupyter Notebook, which make it possible to effectively carry out applied computations for image analysis, were developed.

Within the joint project of MLIT and LRB, the development of the information system for radiation biology tasks on top of the ML/DL/HPC ecosystem was in progress: a module to study the behavioral patterns of small laboratory animals exposed to radiation was developed. The module enables the automation of the analysis of video data obtained when testing rodents in different test systems, one of which is the Open Field. The setup has a form of round arena with chequered-marked sectors and holes. An approach to marking the arena on the basis of determining key points within a neural network approach was proposed [25]. Three neural network models, namely, a simple convolutional model and two models based on the VGG16 and Xception architectures, which were trained using the transfer learning technique, were considered. The neural network architectures showed comparable results, however, the best accuracy was provided by an approach based on the simple convolutional model. The further development of the approach involves expanding the dataset for training and the set of key points to enhance the accuracy of labeling.

**Fig. 9.** Controlling the process of achieving the given level of nitrogen pressure by different types of regulators in cooling mode (blue curve — quantum controller, green — fuzzy controller, red — PID controller)

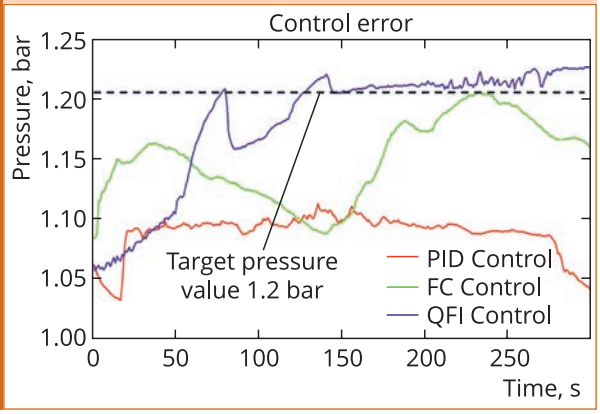



**Fig. 10.** Scheme of software modules for studying systems with Josephson junctions

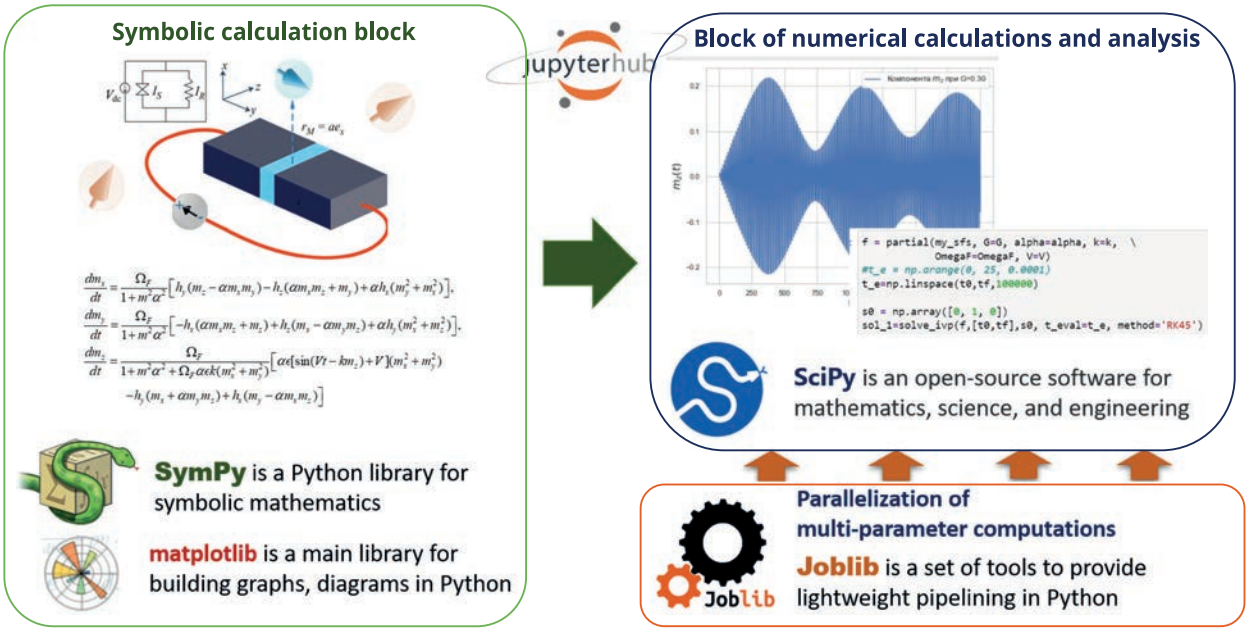
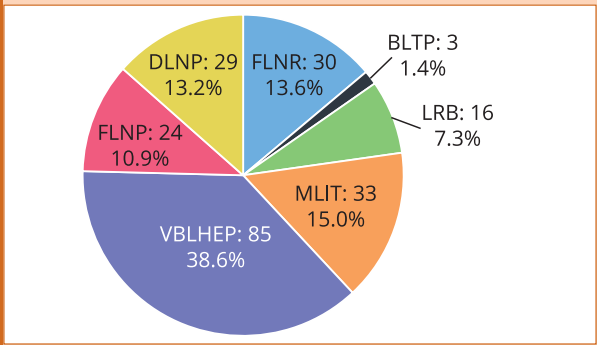


**Fig. 11.** Distribution of the number of excursions in 2022 by the Laboratories




The research performed jointly with FLNP within the UNECE ICP Vegetation international programme for monitoring and forecasting air pollution processes in Europe and Asia was underway. The possibility of using the Earth remote sensing data together with machine learning methods for predicting air pollution by heavy metals was investigated [26]. The average accuracy of the models exceeded 89%. Models of pollution by aluminum, iron, and antimony in the central region of Russia were constructed.

A service for planning and accounting for excursions to JINR (https://jinrex.jinr.ru) was developed together with the UC. The main functions of the service are as follows: saving information on excursions, excursion coordination, demonstration of the workload of visiting points, collecting analytics and demonstration of statistics. To date, over 100 people related to conducting excursions were registered in the system. In 2022, 220 excursions were held at JINR (Fig. 11).

## INTERNATIONAL COOPERATION

In 2022, the cloud of the Institute of Nuclear Physics of the Academy of Sciences of Uzbekistan was put into operation and integrated into the JINR DICE. The server and network hardware for the cloud infrastructure of the Institute of Nuclear Physics (Almaty, Kazakhstan) was purchased and supplied. The work on putting the hardware into operation and expanding the cloud capacity of this organization is underway. At present, Plekhanov Russian University of Economics, the North Ossetian State University (Russia), the Institute of Nuclear Physics (Kazakhstan), the Institute of Physics of the National Academy of Sciences of Azerbaijan, the Institute for Nuclear Research and Nuclear Energy (Bulgaria), Sophia University "St. Kliment Ohridski" (Bulgaria), the Scientific Research Institute for Nuclear Problems of the Belarusian State University, the Institute of Nuclear Physics (Uzbekistan), the Egyptian National STI Network of the Academy of Scientific Research and Technology were fully integrated into the JINR DICE, and the Georgian Technical University is in the progress of integration.

The computing cluster of the Institute of Mathematics and Digital Technologies of the Mongolian Academy of Sciences (IMDT MAS) was integrated into the heterogeneous distributed environment based

Tashkent, 8 October. Launch of a cloud computing cluster created with the assistance of JINR at the Institute of Nuclear Physics of the Academy of Sciences of Uzbekistan

on the DIRAC platform. This makes it possible to utilize available cluster resources in computing for the NICA megascience project.

In 2022, the implementation of the joint project of LRB, MLIT and research centres of the University of Belgrade "Computer Identification, Characterization and Modeling of Histological Data" started within the Cooperation Agreement between JINR and the Ministry of Education, Science and Technological Development of the Republic of Serbia. In April, a workshop "Computational Biology and Physics" (https://indico-hlit.jinr.ru/event/310/) was held. The participants discussed a number of topical issues in neuroradiobiology and radiology, as well as technological and information tools for automating relevant studies and data processing. To implement the project, the BIOHLIT-Serbia web portal (https://it4bio.jinr.ru/) was deployed. The resources of the HybriLIT heterogeneous platform are actively used to solve the computational tasks of the project.

## EDUCATIONAL PROGRAMME ON THE EDUCATION AND TESTING POLYGON

In 2022, the resources of the HybriLIT platform were actively used for educational purposes. This direction is connected both with training courses for JINR staff members and practical classes for students of Dubna State University, Tver State University, etc.

In 2022, practical classes on "Architecture of Computer Systems", "High-Performance Computing Technologies", "Modern Methods for Analyzing Complex Systems", "Machine Learning and Data Mining", "Languages and Technologies for Data Analysis", "Mathematical Apparatus and Tools for Data Analysis" were held using the resources of the education and testing polygon and the ML/DL/HPC ecosystem for more than 800 students, which enabled them to master state-of-the-art technologies for developing parallel algorithms on novel computing hybrid architectures and tools (libraries and frameworks) for machine and deep learning tasks [27].

The resources of the platform were also actively used during the first JINR Autumn School of Information Technologies, which was held on 14–19 November at MLIT. School participants attended training courses on topical issues in the field of distributed and high-performance computing, machine learning and artificial intelligence, mathematical modeling, modern methods and technologies for data processing and analysis.

In 2022, one PhD, eight Master's and four Bachelor's theses were prepared using the resources of the HybriLIT platform.

## REFERENCES


1. *Velikhov V. E. et al.* // 2022 Intern. Sci. and Techn. Conf. "Modern Network Technologies" (MoNeTec). M., 2022. P. 1–4.
2. *Zuev M. I. et al.* // PoS (DLCP2022). 2022. V. 429. P. 027.
3. *Kashunin I. A., Mitsyn V. V., Strizh T. A.* // Phys. Part. Nucl. Lett. 2022. V. 19, No. 6. P. 820–825.
4. *Akishin P. G., Ladygyn V. P.* // Phys. Part. Nucl. Lett. 2022. V. 19, No. 6. P. 792–796.
5. *Ayriyan A. S. et al.* // Soft Matter. 2022. V. 38, No. 18. P. 7441–7451.
6. *Zuev M. I., Serdyukova S. I.* // Comput. Math. Math. Phys. 2022. V. 62, No. 1. P. 1–9.
7. *Lukyanov V. K. et al.* // AIP Proc. (in press).
8. *Friesen A. V., Goderidze D., Kalinovsky Yu. L.* // Phys. Part. Nucl. Lett. 2022. V. 19, No. 4. P. 412–421.
9. *Buša Jr. J. et al.* // Mod. Inform. Technol. & IT-Education. 2022. V. 18, No. 1. P. 176–182.
10. *Baranov D.* // Phys. Part. Nucl. Lett. 2022. V. 19, No. 5. P. 550–553.
11. *Rusov D. I. et al.* // PoS (DLCP2022). 2022. V. 429. P. 005.
12. *Alexandrov E. et al.* // Phys. Part. Nucl. Lett. 2022. V. 19, No. 5. P. 543–546.
13. *Palichik V. V., Voitishin N. N.* // Phys. Part. Nucl. (in press).
14. *Galoyan A., Ribon A., Uzhinsky V.* // Eur. Phys. J. C. 2022. V. 82, No. 181.
15. *Ivancova O. V. et al.* // Quantum Soft Engineering Toolkit. Pt I: Quantum Fast Search Algorithms. Quantum Simulators On Classical Computers. Quantum Control Information Models. M.: Kurs, 2022.
16. *Zrelov P. V. et al.* // Software & Systems. 2022. V. 35, No. 4. P. 618–630 (in Russian).
17. *Chuluunbaatar O. et al.* // Comput. Phys. Commun. 2022. V. 278. P. 108397(1–14).
18. *Kircher M. et al.* // Phys. Rev. Lett. 2022. V. 128. P. 053001(1–6).
19. *Chuluunbaatar O. et al.* // J. Quant. Spectr. Rad. Trans. 2022. V. 278. 108020(1–9).
20. *Adam Gh., Adam S.* // AIP Conf. Proc. (in press).
21. *Yukalov V. I., Yukalova E. P.* // Laser Phys. Lett. 2022. V. 19. 116001.
22. *Tsvetkov V. P. et al.* // Chaos, Solitons and Fractals. 2022. V. 161. 112301.
23. *Khvedelidze A., Torosyan A.* // Zap. Nauchn. Sem. POMI. 2022. V. 517. P. 250–267.
24. *Butenko A. V. et al.* // Phys. Part. Nucl. Lett. 2023. V. 20, No. 2. P.183–199.
25. *Anikina A. I. et al.* // PoS (DLCP2022). 2022. V. 429. P. 017.
26. *Uzhinskiy A., Vergel K.* // Comput. Optics. 2023. V. 47, No. 1. P. 137–151.
27. Collection of Scientific and Project Activity Reports of Graduates of the Intern. School of Inform. Technol. "Data Science". V. 3 / Eds.: V. V. Korenkov et al. Dubna: JINR, 2022 (in Russian).

# LABORATORY of RADIATION BIOLOGY

In 2022, the Laboratory of Radiation Biology (LRB) continued studies within the framework of Themes 04-9-1077-2009/2023 "Research on the Biological Effect of Heavy Charged Particles of Different Energies" and 04-9-1112-2013/2022 "Research on Cosmic Matter on Earth and in Nearby Space; Research on the Biological and Geochemical Specifics of the Early Earth".

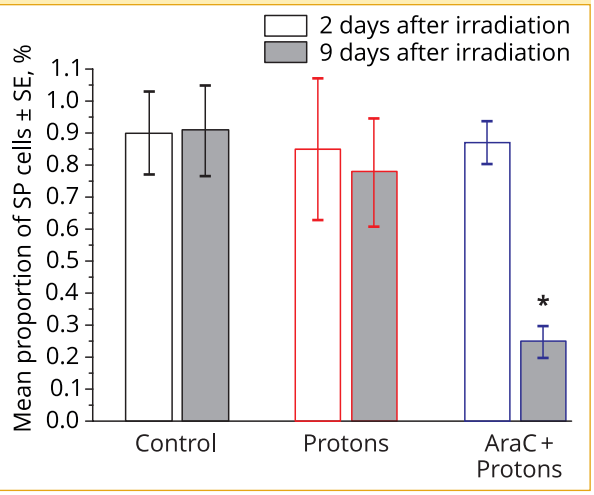
## MOLECULAR RADIOBIOLOGY AND RADIATION CYTOGENETICS

### Research on the Molecular Mechanisms of the Action of DNA Repair Inhibitors

The effectiveness has been evaluated of the combined action of 1-$\beta$-D-arabinofuranosylcytosine (AraC) and proton radiation at a focal dose of 10 Gy on B16 melanoma growth and a number of tumor radiation response processes *in vivo*. The proportion of cancer stem cells (CSCs; SP cells) was determined 2 and 9 days after proton irradiation and combined exposure to AraC and protons. Two days after irradiation, this indicator did not differ in the studied groups and corresponded to the nonirradiated control level, which indicates the absence of a higher resistance of this cancer cell population to proton radiation compared with other cells.

Nine days after proton irradiation, the CSC fraction still remained at the control level, but after combined exposure, it decreased 3.1-fold compared with exposure to proton radiation alone (Fig. 1). Taking into account such action of AraC, it could be assumed that the radiosensitizing effect of this compound would be stronger in cells with more efficient repair of radiation-induced DNA damage, i.e., in CSCs. The results obtained testify in favor of this assumption [1, 2]. A patent for the invention has been obtained (RU 2774032).

**Fig. 1.** The CSC (SP cells) proportion in a primary B16 melanoma focus 2 days and 9 days after proton irradiation and combined exposure to AraC and proton radiation. * — $p = 0.003$ in comparison with the Protons group




Research has been continued on the modifying effect of AraC and hydroxyurea (HU) on the frequency of DNA double-strand break (DSB) formation in various types of tumor cells: human U87 glioblastoma and mouse B16 melanoma after exposure to accelerated protons and nitrogen ions ($^{15}$N) [3–6]. Dependences of the formation frequency of DNA DSBs and the kinetics of their repair have been determined in tumor cells after irradiation with particles of a wide linear energy transfer (LET) range in the presence of modifiers (Fig. 2). The AraC + HU combination has the greatest modifying effect on the DNA DSB yield. The dose change factor in the presence of radiomodifiers is ~ 2. Research on the radioresistance mechanisms of tumor cells and, in particular, glioblastoma cells suggests that their radioresistance is due to adaptation to survive with partially repaired DNA. This may be the result of the loss of important functions during the repair process, i.e., slow repair while maintaining pathways involving the Rad51 and DNA-PK proteins throughout the cell cycle. The slow kinetics of damage repair in U87 cells may also reflect this circumstance [3].

**Fig. 2.** Dose dependences (left) and repair kinetics (right) of DNA DSBs in B16 melanoma cells after proton irradiation under normal conditions and in the presence of modifying agents

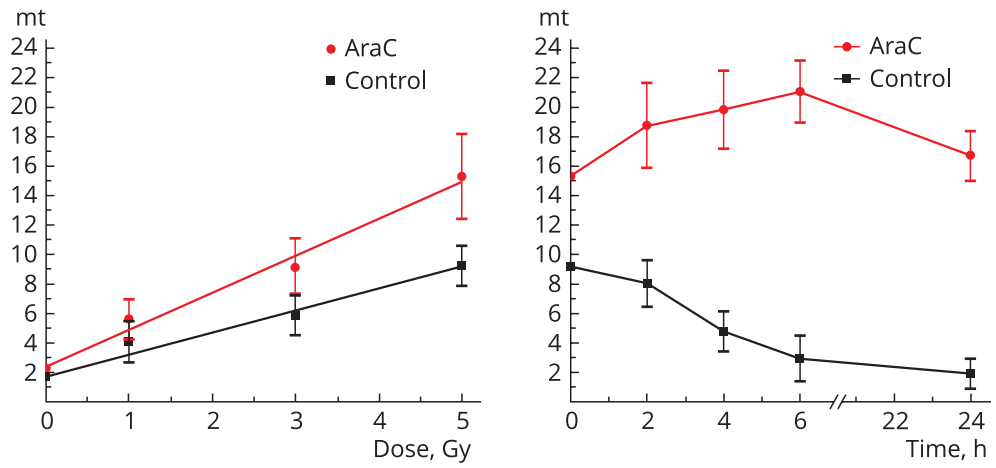



**Fig. 3.** Kinetics of formation and elimination of γH2AX/53BP1 foci in B16 melanoma cells after 1.25-Gy Bragg peak proton irradiation under normal conditions and in the presence of AraC

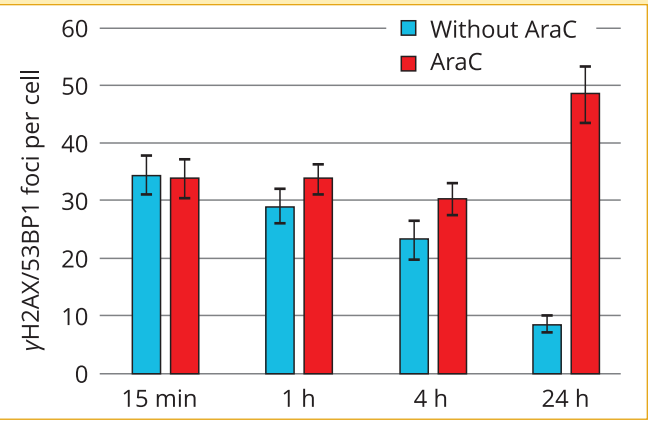
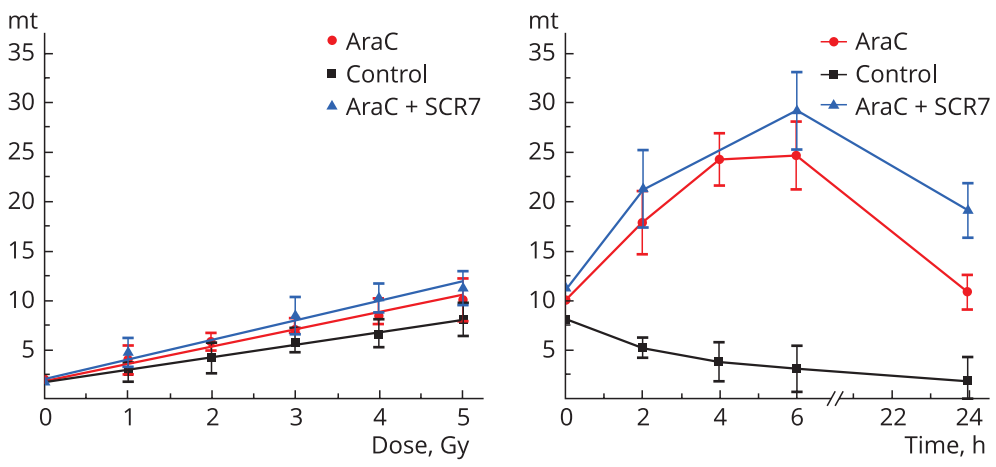



**Fig. 4.** DNA DSB induction and repair in B16 melanoma cells after X-ray irradiation under normal conditions (control) and in the presence of AraC and SCR7



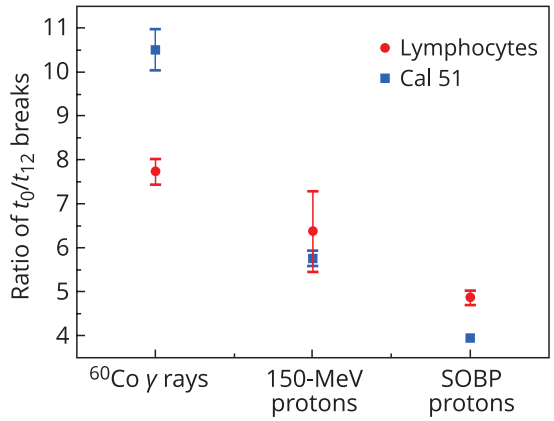
The formation and elimination kinetics of γH2AX/53BP1 foci has been studied in mouse B16 melanoma cells after spread-out Bragg peak proton exposure at a dose of 1.25 Gy in the presence of AraC. The data obtained indicate an increased level of radiation-induced foci under the influence of AraC. The most significant difference in the foci yield in the presence of AraC and without it was observed after 24 h of post-irradiation incubation (Fig. 3) [4].

The DNA DSB induction and repair have been studied in mouse B16 melanoma cells after X-ray exposure in the presence of AraC and SCR7, an inhibitor of ligase IV — the key enzyme of nonhomologous DNA DSB repair. An increase in the DNA DSB yield was observed under the combined action of AraC and SCR7 compared with the use of AraC alone (Fig. 4) [5, 6].

## Studies of Cytogenetic Disorders in Higher and Lower Eukaryotic Cells

A series of studies of the sensitivity of normal and tumor human cells to photon ($^{60}$Co γ) and proton (150 MeV and spread-out Bragg peak) radiation has been completed. In human peripheral blood lymphocytes and Cal51 human breast carcinoma cells, the induction and repair of chromatin breaks were studied with the chemically induced premature chromatin condensation (PCC) technique, and chromosomal aberration induction was investigated with the classical metaphase method (Fig. 5). Aberrations recorded by the standard metaphase method

**Fig. 5.** The effectiveness of PCC break repair estimated as the ratio of the initial break yield ($t_0$) to that after repair completion ($t_{12}$) in lymphocytes and Cal51 cells after photon and proton radiation exposure

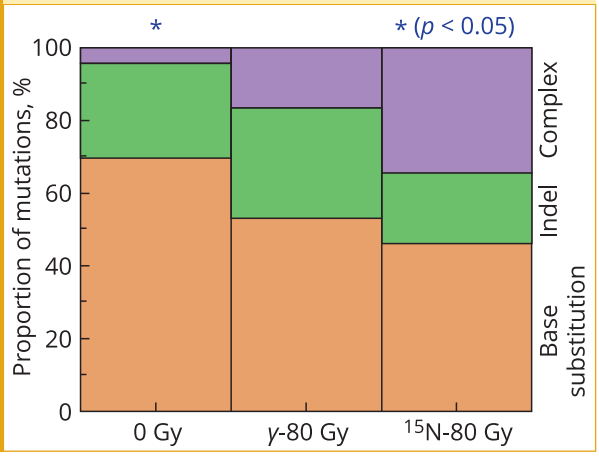



represent the final result of fully completed repair, while PCC is a method for visualizing the initial level of damage and repair kinetics. Both techniques have confirmed the higher biological effectiveness of protons on tumor cells than on lymphocytes.

Research was performed on characteristics of spontaneously immortalized SIM-A9 mouse microglia cells obtained from the brain of newborn C57BL/6 mice. It has been shown for the first time that SIM-A9 cells express a high level of the TSPO protein and CD68, CD11b, and CD45$^{high}$ markers on the cell surface membrane, which corresponds to the phenotype of activated microglia. An mFISH analysis of

**Fig. 6.** *a*) The 21XY karyotype of normal bone marrow cells of C57BL/6 mice; *b*) a typical karyogram of SIM-A9 cells containing 60 chromosomes. Numbers indicate marker chromosomes: 1, 2, 3, 4, 5 — the result of the centromere fusion of two chromosomes 2, 6, and 8, chromosomes 8 and 17, and two chromosomes 18, respectively; 6, 7 — translocations 19*–4–9 and 11*–X (* denotes the part of the chromosome carrying the centromere); 8, 9 — strongly shortened chromosomes 1 and 4; 10 — a separate centromere. Arrows show additional spontaneous chromosomal aberrations: centromere fusion of chromosomes 2 and 15 and a shortened X chromosome with an acentric fragment. The sidebar below shows translocations 6 and 7 in more detail

**Fig. 7.** Spectra of spontaneous mutations and mutations induced by $^{60}$Co γ rays and accelerated $^{15}$N ions (base pair substitutions, deletions/insertions, and complex mutations). The induction of complex mutations by nitrogen ions increases statistically significantly (Fisher's test)




the SIM-A9 line karyotype was made. A relatively stable hypotetraploid female mouse karyotype has been determined: the number of chromosomes per metaphase varied from 50 to 61, while the number of chromosome copies varied from 2 to 5.

About 12 constant marker anomalies of chromosomes have been detected (Fig. 6), as well as nonclonal structural chromosomal aberrations. A high chromosomal instability of the line has been revealed, which is characteristic of all immortalized and tumor lines. The data obtained allow considering the SIM-A9 line as an alternative to primary microglia in the study of the development mechanisms of neurodegenerative diseases and neuroinflammation and research on the effectiveness of potential therapeutic drugs that can regulate the pro- and anti-inflammatory activity of microglia [7].

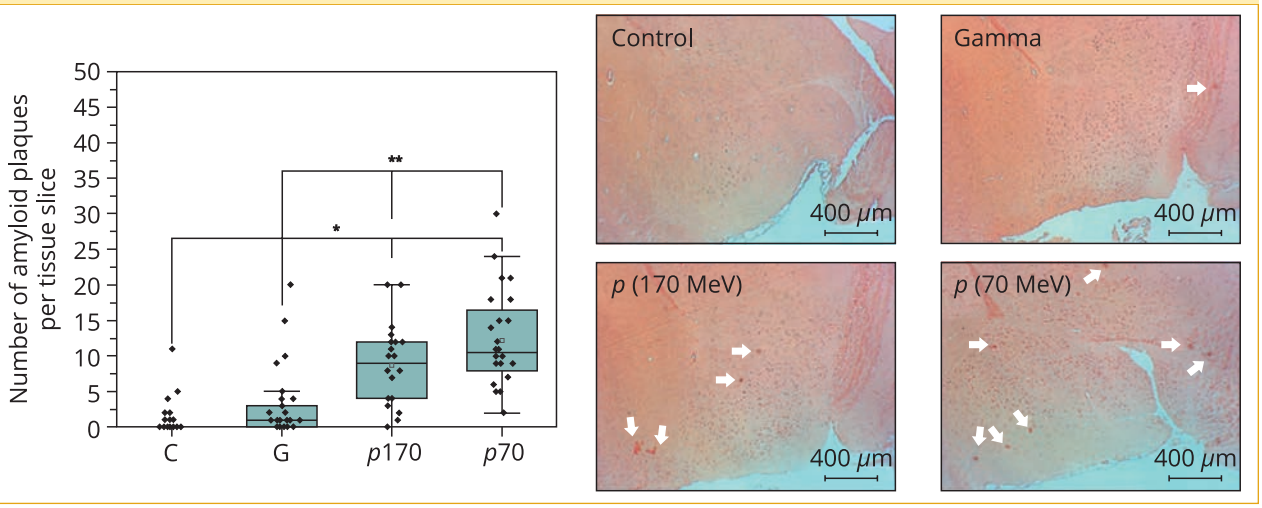
Studies of the induction of chromosomal rearrangements and extended deletions in yeast by heavy ions have been continued. The spectrum of mutations induced by rare ionizing radiation (*γ* rays) and accelerated nitrogen ions (LET 67 keV/*μ*m) was analyzed. It has been shown that ionizing radiation most effectively induces base pair substitutions and less effectively — small deletions and complex mutations (Fig. 7).

## RADIATION PHYSIOLOGY AND NEUROCHEMISTRY

A study of morphological changes in the brain of adult female rats after irradiation with $^{60}$Co *γ* rays and protons of different energies at a dose of 1 Gy was performed. Pathomorphological analysis reveals early amyloidosis (Fig. 8), autolysis of the ependymal layer, neurodegenerative changes in various brain structures, and the development of neuronal hypertrophy. The observed destructive changes increase with particles' LET [8].

The action of 170-MeV protons and $^{60}$Co *γ* rays at doses of 1 to 4 Gy on the visual organs of mice was studied. It has been found that irradiation causes oxidation of retinoids in the retina and retinal pigment epithelium, which was detected by changes in their

**Fig. 8.** Amyloid plaques in the rat forebrain 30 days after irradiation (marked with white arrows on sections). C, G, *p*170, and *p*70 denote, respectively, the control group, gamma radiation, 170-MeV protons, and 70-MeV protons



Researchers of the LRB Radiation Physiology Sector

fluorescence spectra. The phenomenon discovered using a noninvasive diagnostic method for recording fundus autofluorescence can allow assessment of the radiation exposure of the eye tissues and the whole organism [9].

The biological effect of long-term fractionated γ irradiation of female ICR (CD-1) mice at a low total dose was analyzed. Fractionated irradiation of animals with $^{60}$Co *γ* rays was performed for 33 weeks at a total dose of 1.65 Gy. A decrease in the average lifespan of the mice by more than 150 days has been established compared with the control animals [10].

An analytical study was carried out on the selection of new neuroprotective agents effective in the treatment of radiation damage to the central nervous system [11]. The currently used drugs target the biochemical processes of cell apoptosis, radiation toxicity, neuroinflammation, cognitive and behavioral disorders, or other processes resulting from radiation damage. The following drugs have been identified as promising for research: minocycline, fingolimod, ramipril, memantine, and melatonin.

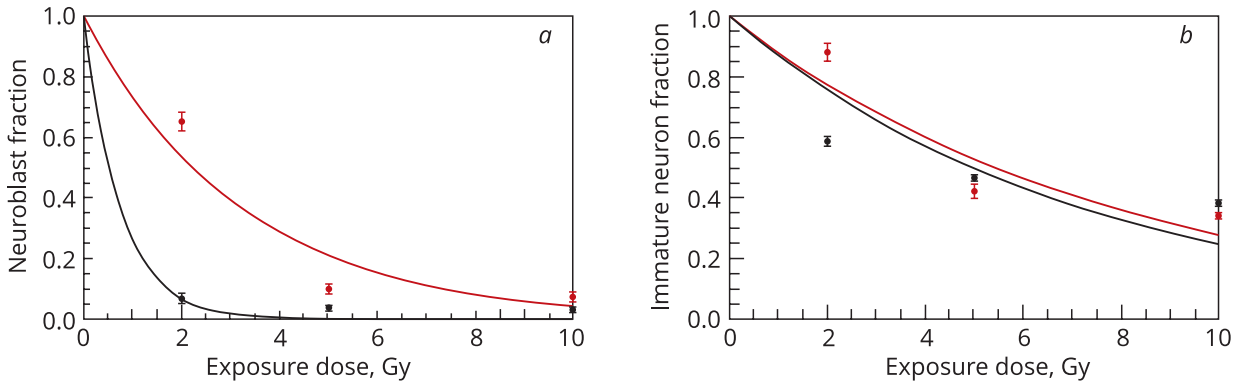
## MATHEMATICAL MODELING OF RADIATION-INDUCED EFFECTS

A mathematical model of radiation-induced impairment of neurogenesis in adult C57BL/6J mice has been developed [12]. The model reproduces experimental data on age-related changes in the number of neural stem cells amplifying neuronal progenitors, neuroblasts, immature neurons, and, for the first time, mature neurons, astrocytes, and oligodendrocytes. Accounting for the death of progenitor cells and immature neurons made it possible to assess the deficit of newly formed mature neurons, astrocytes, and oligodendrocytes after irradiation with X-rays (Fig. 9).

A mathematical description of the main repair pathways of DNA single-strand breaks (SSB), base lesions (BL), and double-strand breaks (DSB) in mammalian and human cells has been proposed [13]. The model approach reflects the key molecular mechanisms of DNA repair: DNA SSB repair, base excision repair, and nonhomologous end joining. The time dynamics of the formation and repair of the key DNA damage types (BL, SSB, and DSB) in human cells induced by accelerated heavy ions with different physical characteristics has been calculated.

A model approach has been proposed to analyze the properties of hippocampal neural networks with different types of NMDA receptors: GluN1/GluN2A, GluN1/GluN2B, and GluN1/GluN2A/GluN2B. Molecular dynamics modeling of the activation of NMDA

**Fig. 9.** Comparison of the fraction of surviving neuroblasts (*a*) and immature neurons (*b*) on the 21st and 60th days of mouse life (red and black lines, respectively) after acute X-ray irradiation. Calculated data — lines, experimental data — dots: 21 days (*Rola R. et al.*, 2004), 60 days (*Mizumatsu S. et al.*, 2003)




receptors' ion channel modified by the action of allosteric modulators was performed. The study of the electrophysiological activity of neurons with an altered structure of NMDA receptors was carried out in models of neural networks of the CA1 and CA3 regions of the hippocampus. Insignificant changes have been revealed in the ion channel conductivity and local potential depending on the subunits that make up the receptor and on the modulator type [14].

The structure of the permease enzyme was analyzed. The positions of amino acid residues, mutations in which inactivate the arginine transporter, have been determined. It has been shown that most of the studied amino acids are localized in conservative regions of the protein [15].

The Springer Publishing House has issued the book "Nonlinear Dynamics of Nanobiophysics", which includes reviews by LRB scientists of soliton excitations and quantum correlation effects in nonlinear DNA models [16, 17].

## ASTROBIOLOGY

Research has been continued on the mechanisms of the formation of prebiotic compounds under the action of accelerated heavy charged particles in the presence of terrestrial rocks as catalysts. These studies provide a model of events associated with chemical and biological processes that were occurring on the early Earth.

A micropaleontological study of the Murchison, Aguas Zarcas, Sutter's Mill, Tagish Lake, Tataouine, and other carbonaceous chondrite meteorites has been continued using a Tescan Vega 3 scanning electron microscope with an X-ray microanalyzer. Framboidal remains of prokaryotic and eukaryotic microorganisms have been found in meteorite samples. New types of microfossils of the Orgueil meteorite have been discovered and described. They are classified as prasinophytes, acritarchs, and fungal spore-like forms.

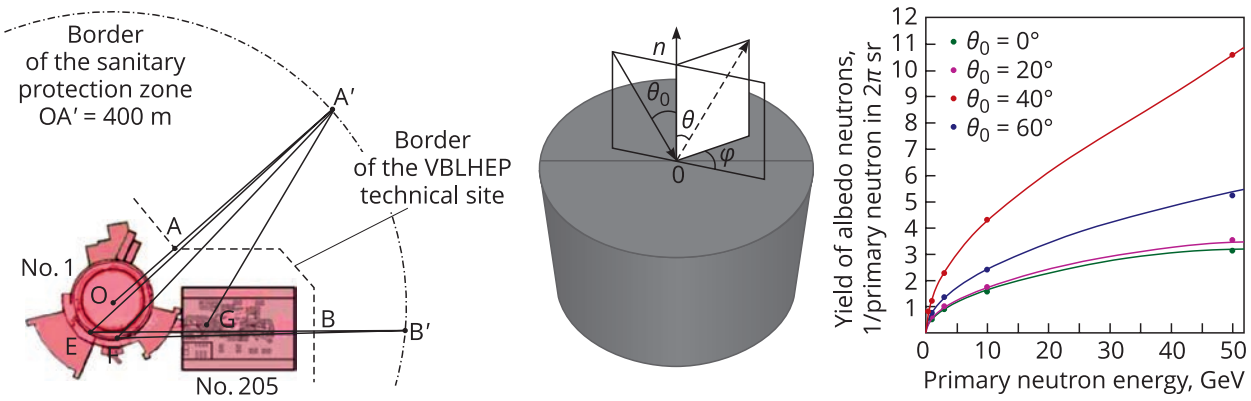
## RADIATION PROTECTION PHYSICS AND RADIATION RESEARCH

In 2022, in cooperation with the Dzhelepov Laboratory of Nuclear Problems (DLNP), experiments at the Phasotron accelerator on the development of instruments for nuclear planetary science were supported, including the ones within the framework of collaboration with the Space Research Institute of the Russian Academy of Sciences.

For the NICA accelerator complex, the borders of the sanitary protection zones have been determined for the operation of the collider in the heavy-ion collision mode and for an additional mode of high-energy proton collision [18]. The differential and total albedo values of relativistic neutrons incident on concrete have been calculated (Fig. 10). Based on the data obtained, an approximation of the energy dependence of total neutron albedo in the energy range up to 50 GeV has been proposed [19].

The year 2022 marked the 25th anniversary of cooperation between the Space Research Institute of the Russian Academy of Sciences and the Joint Institute for Nuclear Research (JINR) in nuclear planetary science [20]. On the JINR side, DLNP and LRB staff participate in the work. During this time, a number of space instruments were developed using gamma and neutron spectroscopy techniques. Detailed ground-based calibrations were carried out

**Fig. 10.** Left: Location of Buildings 1 and 205 (VBLHEP), with critical points A′ and B′ on the border of the sanitary protection zone. The table shows the contribution of different radiation sources to the annual doses of neutrons and $\gamma$ rays ($\mu$Sv) at the points A′ and B′ during the NICA complex operation. Right: A schematic representation of the neutron albedo calculation geometry and total neutron albedo as a function of angle and energy




| Source | Point A′ | Point B′ |
|---|---|---|
| Heavy-ion mode of the collider operation | 15.5 | — |
| BM&N experiment in Building 205 | 11.1 | 19.7 |
| Section of the proton beam extraction to the collider | 0.6 | 0.7 |
| Section of the proton beam slow extraction to Building 205 (with average proton energy 5 GeV) | 33.1 | 40.3 |
| SPD testing zone in Building 205 at the 2-GeV proton beam | 19.6 | 62.7 |
| SPD testing zone in Building 205 at the 12-GeV proton beam | 53.7 | 172.7 |
| *Total* | 133.6 | 296.1 |

with various radiation sources and planetary soil models [21, 22]. Most of this equipment is already successfully operating on board orbital and landing spacecraft, providing unique scientific data on the presence and distribution of water (ice) on the surface of the Moon and Mars and on the elemental composition of the soil.

A monograph by G. N. Timoshenko "Radiation Protection of High-Energy Accelerators" was published [23], which considers the main specifics of the formation of ionizing radiation fields at high-energy proton and heavy-ion accelerators as well as activation of equipment, refrigerants, air, and shielding and the development of radiation monitoring tools.

## NEW FACILITIES

In 2022, two X-ray sources for radiobiological tasks were put into operation.

A CellRad compact irradiator manufactured by Precision X-ray Inc. (the USA) is designed for work with cell cultures. A multifunctional research complex SARRP (Small Animal Radiation Research Platform) manufactured by Xstrahl Ltd. (the United Kigdom) is designed for radiobiological research on small laboratory animals with the possibility of X-ray tomography and highly conformal irradiation.

## CONFERENCES AND EDUCATION

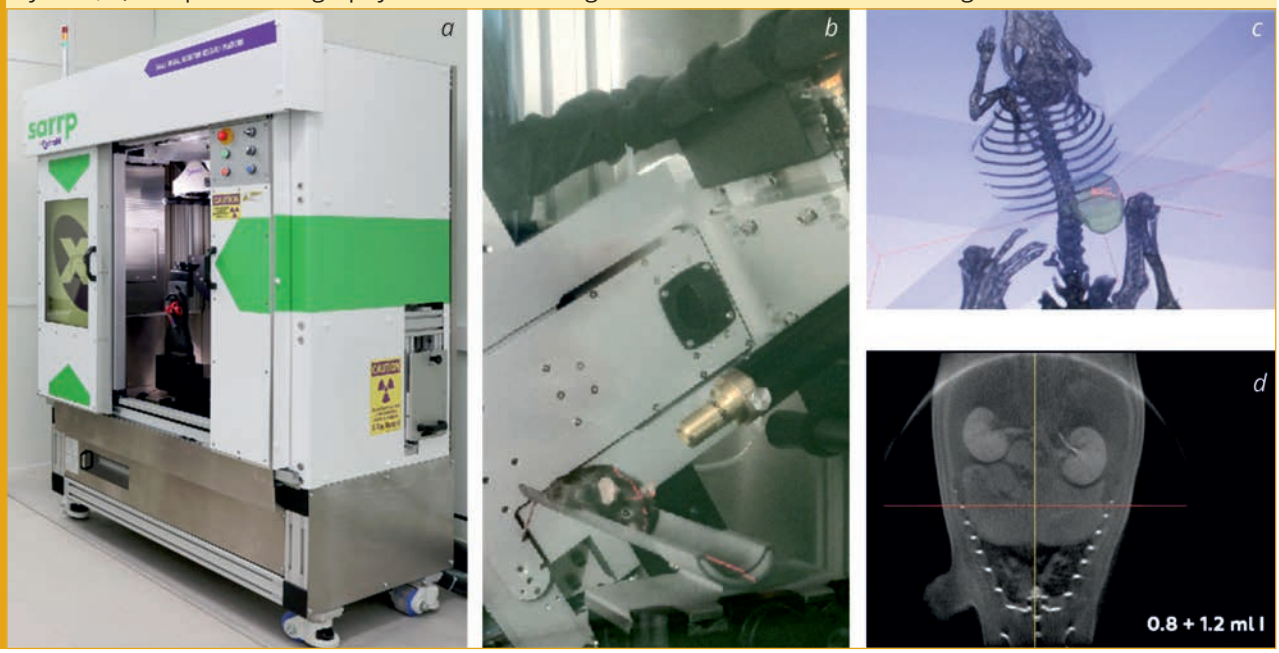
In 2022, LRB staff took part in 30 scientific conferences held in a mixed online and offline format.

On 25–27 October, JINR hosted a mixed-format Conference entitled "Current Problems in Radiation Biology. To the 60th Anniversary of the Establishment of the RAS Scientific Council on Radiobiology". The Conference was participated by more than 100 radiobiologists from Russia, Belarus, and Azerbaijan. By the beginning of the Conference, a book of abstracts was published (Dubna: JINR, 2022. 91 p.). Eighteen plenary reports were heard, and 12 posters presented by young scientists were considered.

The educational process continued at the Department of Biophysics of Dubna State University. The Department's current enrolment is 34 students and seven postgraduates. Six students successfully graduated with a Master's degree in physics.

24 March. A ceremonial commissioning of the new X-ray facility SARRP for radiobiological research

The SARRP facility: *a*) general view; *b*) irradiation of a mouse during an experiment; *c*) irradiation planning system; *d*) computer tomography of the internal organs of a mouse with a contrast agent



Dubna–Moscow, 25–27 October. Jubilee Conference “Current Problems in Radiation Biology. To the 60th Anniversary of the Establishment of the RAS Scientific Council on Radiobiology”


Moscow, 6 December. A solemn ceremony of awarding certificates of honor of the Russian Academy of Sciences (RAS) held at a joint meeting of the Bureau of the Preventive Medicine Section of the RAS Department of Medical Sciences and the RAS Radiobiological Society. In the photo: Academicians I. B. Ushakov, V. V. Zverev, RAS Corresponding Member E. A. Krasavin

## REFERENCES


1. Method for Increasing the Effectiveness of Ionizing Radiation on Melanoma / Zamulaeva I. A., Boreyko A. V., Bugay A. N., Kaprin A. D., Koryakin S. N., Krasavin E. A., Matchuk O. N., Mosina V. A., Selivanova E. I., Chausov V. N. Patent RU 2774032, Russia's Federal Service for Intellectual Property (Rospatent). Published on 14 June 2022. Bull. No. 17 (in Russian).
2. *Zamulaeva I. A., Matchuk O. N., Selivanova E. I., Yakimova A. O., Mosina V. A., Koryakin S. N., Kaprin A. D., Boreyko A. V., Bugay A. N., Chausov V. N., Krasavin E. A.* Radiobiological Effects of the Combined Action of 1-$\beta$-D-Arabinofuranosylcytosine and Proton Radiation on B16 Melanoma *In Vivo* // Phys. Part. Nucl. Lett. 2023. V. 20, No. 1.
3. *Boreyko A. V., Zadneprianetc M. G., Chausov V. N., Khramko T. S., Kozhina R. A., Kuzmina E. A., Tiounchik S. I., Krasavin E. A.* Combined Action of DNA Synthesis Inhibitors and Accelerated Protons on Malignant Tumor Cells // Phys. Part. Nucl. Lett. 2023. V. 20, No. 4 (in Russian).
4. *Zadneprianetc M., Boreyko A., Jezkova L., Falk M., Ryabchenko A., Hramco T., Krupnova M., Kulikova E., Pavlova A., Shamina D., Smirnova E., Krasavin E.* Clustered DNA Damage Formation in Human Cells after Exposure to Low- and Intermediate-Energy Accelerated Heavy Ions // Phys. Part. Nucl. Lett. 2022. V. 19, No. 4. P. 440–450.
5. *Kozhina R. A., Boreyko A. V., Chausov V. N., Erhan S. E., Ilyina E. V., Koryakin S. N., Kuzmina E. A., Matchuk O. N., Selivanova E. I., Tiounchik S. I.* The Effect of DNA Synthesis Inhibitor on DNA Damage Induction in Melanoma Cells after Exposure to Protons // Phys. Part. Nucl. Lett. 2022. V. 19, No. 5. P. 590–593.
6. *Erhan S.-E., Boreyko A. V., Kozhina R. A., Kuzmina E. A., Ilyina E. V., Tiounchik S. I., Chausov V. N.* Induction of DNA Damage in Neuronal Cells of Mice under the Influence of Repair Inhibitors under the Action of Gamma-Rays *In Vivo* // Phys. Part. Nucl. Lett. 2022. V. 19, No. 5. P. 586–589.
7. *Shaposhnikova D. A., Moskaleva E. Yu., Semochkina Yu. P., Vysotskaya O. V., Komova O. V., Nasonova E. A., Koshlan I. V.* Characterization of SIM-A9 Microglial Cells: New Data // Tsitologiya. 2023. V. 65 (in press) (in Russian).
8. *Severyukhin Yu. S., Lalkovičová M., Utina D. M., Lyakhova K. N., Kolesnikova I. A., Ermolaeva M. E., Molokanov A. G., Gaevsky V. N., Komarov D. A., Krasavin E. A.* Comparative Analysis of Behavioral Reactions and Morphological Changes in the Rat Brain after Exposure to Ionizing Radiation with Different Physical Characteristics // Cell. Mol. Neurobiol. 2022; https://doi.org/10.1007/s10571-021-01187-z.
9. *Yakovleva M. A., Feldman T. B., Lyakhova K. N., Utina D. M., Kolesnikova I. A., Vinogradova Y. V., Molokanov A. G., Ostrovsky M. A.* Ionized Radiation-Mediated Retinoid Oxidation in the Retina and Retinal Pigment Epithelium of the Murine Eye // Radiat. Res. 2022. V. 197. P. 270–279.
10. *Bychkova T. M., Nikitenko O. V., Utina D. M., Ivanov A. A.* Influence of Long-Term Fractionated γ-Irradiation on the Lifespan of Mice // Aviakosmich. Ekol. Med. 2022. V. 56, No. 4. P. 77–82 (in Russian).
11. *Lalkovičová M.* Neuroprotective Agents Effective against Radiation Damage of Central Nervous System // Neural. Regen. Res. 2022. V. 17, No. 9. P. 1885–1892.
12. *Glebov A. A., Kolesnikova E. A., Bugay A. N.* Mathematical Model of Radiation-Induced Violation of Neurogenesis // Phys. Part. Nucl. Lett. V. 19, No. 4. P. 338–354 (in Russian).
13. *Vasilyeva M. A., Bugay A. N., Dushanov E. B.* Modeling the Repair of Heavy Ion-Induced DNA Damage in Mammalian Cells // Aktual. Vopr. Biol. Fiz. Khim. 2022. V. 7, No. 4. P. 557–564 (in Russian).
14. *Aksenova S. V., Batova A. S., Bugay A. N., Dushanov E. B.* Effect of Modulators on NMDA Receptor Activation // Aktual. Vopr. Biol. Fiz. Khim. 2022. V. 7, No. 3. P. 418–422 (in Russian).
15. *Koltovaya N. A., Dushanov E. B.* Mutational Analysis of the CAN1 Arginine Permiase Structure in Yeast // Aktual. Vopr. Biol. Fiz. Khim. 2022. V. 7, No. 4. P. 565–569 (in Russian).
16. *Bugay A.* Soliton Excitations in a Twist-Opening Nonlinear DNA // Nonlin. Dynam. Nanobiophys. / Eds. S. Zdravković, D. Chevizovich. Singapore: Springer Nature Singapore Pte Ltd., 2022. Ch. 7. P. 141–172.
17. *Chizhov A. V.* Quantum Correlation Effects in Biopolymer Structures // Nonlin. Dynam. Nanobiophys. / Eds. S. Zdravković, D. Chevizovich. Singapore: Springer Nature Singapore Pte Ltd., 2022. Ch. 9. P. 233–262.
18. *Butenko A. V., Gordeev I. S., Kovalenko A. D., Paraipan M., Syresin E. M., Timoshenko G. N.* Prediction of Radiation Environment around NICA Complex // Phys. Part. Nucl. Lett. 2022. V. 19, No. 2. P. 123–128.
19. *Gordeev I. S., Timoshenko G. N.* Relativistic Neutron Albedo // Phys. Part. Nucl. Lett. 2022. V. 19, No. 4. P. 402–407 (in Russian).
20. *Timoshenko G. N., Litvak M. L., Mitrofanov I. G., Shvetsov V. N.* 25 Years of Cooperation between the Institute of Space Research and JINR // Phys. Part. Nucl. Lett. 2022. V. 19, No. 5. P. 465–483 (in Russian).
21. *Mitrofanov I. G., Litvak M. L., Sanin A. B., Anikin A. A., Mokrousov M. I., Golovin D. V., Nikiforov S. Y., Timoshenko G. N., Shvetsov V. N.* Laboratory Demonstration of Space Gamma-Ray Spectroscopy Experiment with Tags of Galactic Cosmic Rays for Testing Different Types of Martian Regolith // Nucl. Instr. Meth. A. 2022. V. 1028. P. 166364.
22. *Malakhov A. V., Mitrofanov I. G., Litvak M. L., Sanin A. B., Golovin D. V., Djachkova M. V., Nikiforov S. Yu., Anikin A. A., Lisov D. I., Lukyanov N. V., Mokrousov M. I., Shvetsov V. N., Timoshenko G. N.* Physical Calibrations of the FREND Instrument Installed Onboard TGO Martian Orbiter // Cosm. Res. 2022. V. 60, No. 1. P. 23–37.
23. *Timoshenko G. N.* Radiation Protection of High-Energy Accelerators. Dubna: JINR, 2022. 111 p. (in Russian).

# UNIVERSITY CENTRE

## JINR TRAINING

In 2022, the training process for students studying at the JINR-based departments of MSU, MEPhI, MIPT, Dubna State University, St. Petersburg State University, and Kazan (Volga Region) Federal University was organized offline.

In 2022, 52 lecture courses were developed for students studying at the JINR-based departments of MIPT, MSU, and Dubna State University. Their programmes are posted at uc.jinr.ru.

In 2022, 342 students from Voronezh State University, Dubna State University, Moscow State University, National Research Nuclear University "MEPhI", Moscow Institute of Physics and Technology, Omsk State Technical University, Saratov State Technical University, North Ossetian State University, Tomsk Polytechnic University, Ural Federal University, South Russian State Polytechnic University, and other universities of the JINR Member States were trained and did their internships at JINR.

Six students were attached to JINR to prepare their PhD theses without mastering the PhD academic programme.

The JINR UC organizes the passing of PhD specialty exams for JINR employees attached to the JINR-based Department of MIPT "Fundamental and Applied Problems of Microworld Physics". Since 2018, 35 people studying at the Department have passed their PhD exams.

### INTEREST Programme

In 2020, the online Programme INTEREST — INTErnational REmote Student Training — was launched at JINR for undergraduate and postgraduate students specializing in science, engineering, and IT. Since its launch, 260 people have taken part in the Programme. In 2022, two Waves were held. The events were attended by 80 students and postgraduates from Azerbaijan, Belarus, Bulgaria, Cuba, Egypt, Germany, Greece, Hungary, India, Iran, Kuwait, Mexico, Nigeria, Poland, Romania, Russia, Serbia, South Africa, Turkey, USA, and Vietnam. The Programme included work on research projects, lectures, and online excursions.

The Veksler and Baldin Laboratory of High Energy Physics, 2 March.
Participants of the JINR UC student programme on excursion to the Laboratory

## START Programme

In 2022, the JINR Summer Student Programme continued its work under the new name START — STudent Advanced Research Training. This full-time onsite internship programme is held twice a year. Students from all over the world specializing in science, engineering, and IT, who have completed the 3rd year of the Bachelor's course, Master students, as well as PhDs of the 1st year of study, are eligible for participation in the Programme. The Summer Session (July–November) was attended by 47 representatives of Armenia, Azerbaijan, Belarus, Bulgaria, Egypt, India, Russia, Serbia, and Uzbekistan. Fifty-seven JINR specialists became supervisors of research projects.

The Programme helps JINR staff members select university students and invite them to the Institute for a full-time internship for a period of 6–8 weeks. During the internship, students are introduced to the field of their scientific interest and the basic equipment, visit the Laboratories of the Institute, and work on a research project.

## International Student Practice

In 2022, after a long break due to the epidemiological situation in the world, the International Student Practice in JINR Fields of Research was held in March. Twenty-four Master and PhD students, as well as young researchers, from the Arab Republic of Egypt, which became one of the JINR Member States in November 2021, came to take part in the Practice. The three-week event included work on research projects, lectures on the fields of research conducted at JINR Laboratories, and excursions to the basic facilities.

## SA–JINR Summer School

On 21 January – 4 February, the third SA–JINR Summer School in Physics organized by the South African Institute for Nuclear Technology and Sciences (SAINTS) at iThemba LABS was held online. The subjects of the School included accelerator technologies and research, theoretical and computational physics. The event was attended by 18 students from various universities in South Africa.

For two weeks, STEMI (Science, Technology, Engineering, Mathematics, IT) students and postgraduates listened to lectures in various areas of physical research and completed a number of tasks in processing and analyzing experimental data.

## JINR at the 2nd Congress of Young Scientists

On 1–3 December, the JINR delegation took part in the 2nd Congress of Young Scientists in the Sirius Park of Science and Art in Sochi.

At the discussion session "Prospects and Challenges for the International Integration of Infrastructure and Human Resources", JINR was presented as one of the most successful examples of the integration of infrastructure and human potentials. One of the successful examples of cooperation among scientists and the integration of infrastructure and human potentials was the JINR UC INTEREST Programme. The importance of working with young researchers in order to develop the scientific dialogue became one of the key topics of the session.

On 2 December, the discussion session "Development of Popular Science Tourism: First Results and Prospects" was attended by Acting Director of the JINR University Centre Dr A. Verkheev, who spoke about the Institute's experience in outreach.

The Congress of Young Scientists in Sochi was the key event of 2022 as part of the Decade of Science and Technology in Russia. It was visited by representatives of about 40 countries including Russia, Belarus, Kazakhstan, China, India, Egypt, Myanmar, Syria, Uzbekistan, and others. An eventful programme prepared for the participants included round tables,

Dubna, 1 March. Organizers and participants of the First Stage of the International Student Practice in JINR Fields of Research for students from Egypt

Sochi, 1–3 December.
JINR delegation at the 2nd Congress of Young Scientists in the Sirius Park of Science and Art


expert sessions, panel discussions, as well as new informal and unconventional event formats.

## Interaction with JINR Information Centres

The JINR UC actively cooperated with the JINR Information Centres (IC) based in the Kamchatka State University named after Vitus Bering (Petropavlovsk-Kamchatsky), Far Eastern Federal University (Vladivostok), and North Ossetian State University named after K. L. Khetagurov (Vladikavkaz). Online streaming for the Northern (Arctic) Federal University named after M. V. Lomonosov (Arkhangelsk), Yerevan State University, and the National Science Laboratory named after A. I. Alikhanyan (Armenia) was run. In 2022, in cooperation with the JINR Information Centres, 35 events (online lectures and excursions) were held, attended by more than 4000 people.

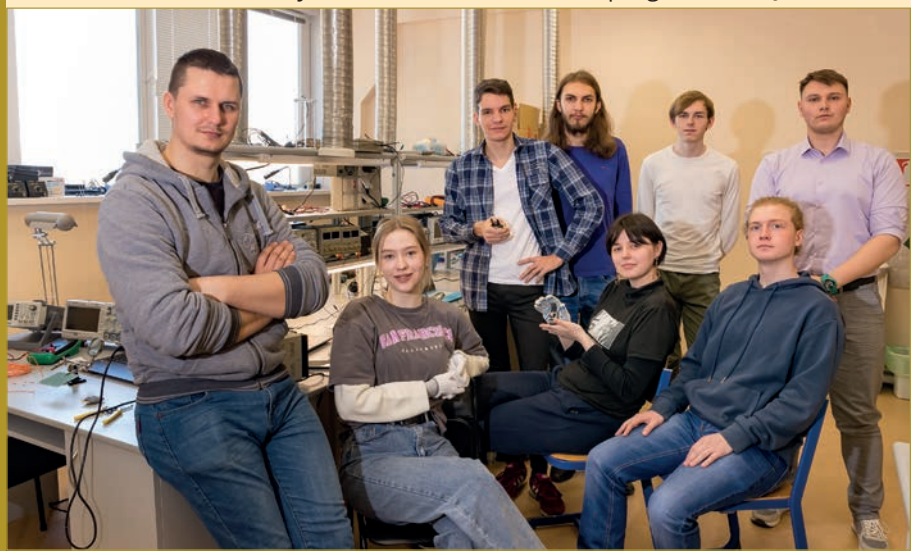
On 9 November, as part of the JEMS-21 internship, a round table "Interaction of JINR with Universities. JINR Information Centres, Educational Programmes of the University Centre" was organized. The heads of the JINR Information Centres at the North Ossetian State University, Far Eastern Federal University, Kamchatka State University, and the Northern (Arctic) Federal University shared their experience of the JINR IC activities organized in their universities, talked about the results achieved, new tasks set and tools to solve them offered by JINR. Among the formats of interaction between universities and JINR, the IC heads and representatives of the universities participating in the round table noted online lectures by the Institute specialists and excursions to the JINR basic facilities, student practices, exchange visits, and the JINR educational portal edu.jinr.ru. Representatives of the Information Centres remarked that, in addition to working with students, an important area of the IC activities was career guidance for schoolchildren and advanced training for teachers. The participants also got acquainted with the JINR UC Engineering and Physics Training.

## Events

In 2022, the JINR UC specialists, together with representatives of the Institute's Laboratories, participated in the organization of exhibitions, lectures, visits, master classes, and physical demonstrations at various events:

- All-Russian Festival "NAUKA 0+" held at the Moscow Central Exhibition Centre "Expocentre" and Moscow State University (7–9 October); at the Northern (Arctic) Federal University in Arkhangelsk (25–29 October); at the Far Eastern Federal University in Vladivostok (6–7 December);
- Festival of Science and Technologies "Geek Picnic" held in the park of arts "Muzeon" in Moscow (30 July);
- Physics Workshop "Element 105" as part of the Summer School (July);
- Day of the JINR-based departments held at Dubna State University (31 January – 4 February);
- MegaScience festival dedicated to the 115th anniversary of Academician V. I. Veksler (online on VK, MEPhI) (4 March);
- Career forum "Career Start: Spring 2022" (online, NRNU MEPhI) (12–16 April);
- MIPT Career Boost (offline, MIPT) (22 April);
- Presentation of the JINR-based department at MIPT (online, MIPT) (28 June);
- MIPT Career Day (offline, MIPT) (28 October).

Dubna, April. Students of physics of the 2nd and 3rd years from the Far Eastern Federal University (Vladivostok) on an intern programme at JINR



## ACTIVITIES FOR SCHOOL STUDENTS AND TEACHERS

### Schools for Teachers at JINR

On 26 June – 2 July, the Scientific School for Physics Teachers was held at JINR. Teachers from Arkhangelsk, Balashikha, Bryansk, Dzhraovit village (Armenia), Dubna, Irkutsk, Ishimbay, Izhevsk, Kaliningrad, Korolev, Lytkarino, Masis (Armenia), Moscow, Novy Urengoy, Noyabrsk, Petropavlovsk-Kamchatsky, Saratov, Severodvinsk, and Tula took part in the event. The School programme included popular-science lectures on the latest achievements in nuclear physics, particle physics, and accelerator technology delivered by scientists and engineers, as well as excursions to the JINR basic facilities.

On 3–7 October, the Scientific School for Teachers from Primorsky Krai was held at JINR. Ten teachers of physics, mathematics, informatics, and astronomy from Vladivostok, Nakhodka, Ussuriysk, Bolshoy Kamen, and Sovetskaya Gavan took part in the event. The School programme included visits to LRB, FLNR, VBLHEP, MLIT, the exhibition "JINR Basic Facilities", JINR Library, and Dubna State University. A feature of the School programme was introduction to the educational course "Engineers of the Future" and training in the "Virtual Laboratory" and doing a hands-on practicum developed by the specialists of the JINR University Centre. When visiting Dubna

Dubna, 26 June – 2 July. The 11th International Scientific School for Physics Teachers

Dubna, 3–7 October. Teachers from Primorsky Krai — participants of the Scientific School — get acquainted with the "Virtual Laboratory" at the JINR University Centre

State University, the guests got acquainted with the areas of student training and saw laboratories where future physicists and engineers study. At the end of the School, the teachers listened to the lectures on the opportunities that the University Centre and JINR provide for school and university students.

## Science School for Egyptian Schoolchildren

On 12–16 September, the Scientific School for Students of the Children's University of the Egyptian Academy of Scientific Research and Technology was held at JINR. The School introduced the students to JINR, its research, and the current state of physics. To participate in the School, 12 students passed a strict competitive selection held in Egypt.

The programme of the event included visits to FLNR, VBLHEP, and LRB, as well as an excursion to Moscow. The participants also visited Physics and Mathematics Lyceum named after V. G. Kadyshevsky, where they communicated with the Lyceum students and performed a laboratory work.

## Cooperation with the Educational Centre "Sirius"

In 2022, cooperation with the Educational Centre "Sirius" was continued. As part of the signed agreement, the parties joined forces in organizing project research activities for talented schoolchildren, winners of regional and all-Russian olympiads in natural sciences.

In January, the JINR specialists ran the fifth cycle of the project "Lessons of the Present" — "Lessons of Real Nuclear Physics", which was attended by more than 600 school students in grades 7–11 joined in 90 scientific teams from educational institutions representing 41 regions of Russia.

The participants were asked to assemble a model of a charged particle detector — a cloud chamber and, with its help, to observe and record particle tracks in the chamber, as well as make a photo or video report on the work done. An introductory lecture on particle physics and a video instruction on the chamber assembly were given by VBLHEP leading researcher S. Merts and VBLHEP senior engineer D. Klimansky.

In November, for the second time JINR became a co-organizer in one of the cycles of the project "Lessons of the Present" — "Lessons of Real Ecological Studies". The project was presented by Head of the Neutron Activation Analysis and Applied Research Sector of FLNP I. Zinicovscaia. The project participants got acquainted with the existing methods for monitoring the content of heavy metals in environmental objects and also proposed their own methods for monitoring and reducing the environmental stress in their regions. The November programme was attended by 73 teams of schoolchildren from 37 regions of Russia. The best task solutions found by the teams were awarded with JINR souvenirs, as well as certificates and branded souvenirs from the "Lessons of the Present" project.

## JINR at the Nanograd Forum

In June, JINR became a partner of the School League programme. The objective of the event is early career guidance for schoolchildren, development of research and engineering skills, as well as popularization of science and technology among young people. Since 2010, a part of this programme was the Nanograd Forum. The goal of the Forum is to develop the design and research culture among schoolchildren in a high-tech society. In 2022, the Forum was held on 16–26 June in Saint Petersburg.

Dubna, 3–18 July. Participants of the 34th International Computer School (ICS) at the Resort Hotel "Ratmino"

Representatives of the JINR UC and VBLHEP became experts at the poster session, where the participants presented their projects on solving a possible scientific and technological task and developing a communication strategy for its promotion in the market of a certain industry. The participants got acquainted with the fundamental and applied research conducted at the JINR Laboratories and had an online tour of the NICA accelerator complex. A similar event with a lecture and an online excursion was held in December.

## JINR at "Virtual Science Camp"

To popularize science and introduce school students to the achievements and projects of JINR, the University Centre took part in the international lectorium "Virtual Science Camp".

In February, JINR staff members delivered a series of lectures within the framework of this project. N. Anfimov (DLNP) gave a lecture "What is JINR?" for schoolchildren from Brazil, France, Germany, Ireland, Portugal, Romania, Serbia, Slovakia, Spain, and Turkey.

## Physics Days–2022

On 1–3 June, the JINR University Centre, in cooperation with the teachers of the Interschool Physics and Mathematics Open Classroom, Kadyshevsky Lyceum, and Dubna State University, held the traditional Science Festival "Physics Days" in Dubna. Over 150 guests of the Festival from the schools of Dubna, Moscow, and Zaprudnya took part both in team scientific events and in master classes in mathematics, physics, chemistry, and biology.

For the first time, within the framework of the event, an Open Experimental Olympiad in Physics was held for students in grades 7–8. The prize winners of the Olympiad were students of the Kadyshevsky Lyceum and Moscow School No. 1514. Teachers of Dubna State University organized an exciting team game exercising logic, reasoning, and nonstandard vision — the "PRO Chemistry" quiz. Volunteers and guests of the Festival got a chance to visit the exhibition "JINR Basic Facilities" and know more about the NICA complex.

## Robotics Tournament CyberDubna-2022

On 24–26 February, the 11th Robotics Tournament CyberDubna-2022 of the Open Upper-Volga Educational Cybernetic Network was held online for teams of 7–11-grade school students, as well as for students doing their 1st and 2nd year at college and 1st-year students of the universities in the Moscow Region and other regions of Russia.

## Hackathon "Dubna-2022"

Seventeen teams from the North of the Moscow Region and the Tver Region took part in the robot design and programming competition. The best results were shown by school students from Kimry, Taldom, and Dubna. On 24 April, they competed for the main prize in the final of the tournament. Fourty-five children in grades 5–10 took part in the qualifying stage, most of them were students of the 9th grade.

## ICS-2022

On 3–18 July, the 34th International Computer School (ICS) was held at Resort Hotel "Ratmino". Participants of the ICS-2022 were the winners of regional competitive programmes organized by JINR (technical educational and competitive Hackathon on the basics of engineering, the annual open regional tournament on robotics CyberDubna), as well as school students who won in the online distant competition. Fourty-one school students in grades 5–11 from Moscow and the Moscow Region (Dolgoprudny, Dubna, Lobnya, Taldom), Kimry, Saratov, Stavropol, and Ust-Labinsk completed projects in physics, biology, mathematics, information security, applied informatics and programming, and the basics of engineering.

## Interschool Physics and Mathematics Open Classroom

On 9 September, classes in physics, experimental physics, preparation for the Unified State Examination in physics, mathematics, and Olympiad in mathematics began for schoolchildren attending the Interschool Physics and Mathematics Open Classroom. Also, the 1st- and 2nd-year students at Yandex.Lyceum started their studies.

In the 2021/2022 academic year, the prize winners of the regional stage of the All-Russian Olympiad for schoolchildren in the Moscow Region and the Olympiad named after J. K. Maxwell became students in grades 7, 9, and 11 of Lyceum No. 6, School No. 9, and Kadyshevsky Lyceum.

On 14 June, Chernogolovka hosted the team Olympiad "Mathematical Carousel-2022". Seventy-four 5–8 graders from Chernogolovka, Dubna, and Fryazino took part in the event. In the leagues of grades 5–6 and 7–8, the teams of Dubna students of the Interschool Physics and Mathematics Open Classroom won the second prize.

On 23 September, the XXXII Open Olympiad in Physics and Mathematics was held among school students in grades 6–8.

## Lectorium

In 2022, as part of the UC Lectorium, 60 lectures by JINR specialists were delivered for 3500 students. During the summer holidays, demonstrations of physical experiments were organized for 160 schoolchildren in four recreation camps of the city.

## Visits

As part of career guidance work with schoolchildren, students, and teachers, the University Centre organized introductory visits to the territory of the Institute. Every week, several groups of students and teachers visited the Laboratories and basic facilities of JINR, communicated with JINR specialists, and learnt more about the latest scientific achievements. In total, 85 excursions were organized in 2022; 1400 people in 66 groups visited the JINR sites. Due to the online format and the video streaming of the tours, the coverage of the audience who joined 19 online visits to the JINR Laboratories came up to almost 19 000 people.

In August, UC staff members organized an excursion for physics teachers from Nizhny Novgorod. The two-day programme included visits to five Laboratories and introduction to the main projects and research facilities.

On 22 August, JINR was visited by Vietnamese schoolchildren and students studying in the educational institutions of Moscow.

## YaNAO Schoolchildren's Internship at JINR

On 5–9 December, 20 schoolchildren in grades 8–11 from the Yamalo-Nenets Autonomous Okrug (YaNAO), winners of the municipal stage of the All-Russian School Olympiad, had an internship at JINR.

The children visited the interactive exhibition "JINR Basic Facilities", listened to a lecture at the JINR Museum of History of Science and Technology, and took a tour of Dubna. The visit programme also included lectures, excursions and lab works at DLNP, VBLHEP, FLNP, MLIT, and UC. In addition, the schoolchildren visited Dubna State University and the Regional Physics and Mathematics Lyceum named after Academician V. G. Kadyshevsky, where they participated in a physics workshop.

## Schoolchildren from Kamchatka at JINR

At the end of November, 12 schoolchildren from the Kamchatka Territory, winners of the Complex Regional Olympiad "Vitus Bering – 2022" in natural sciences, visited JINR. During the three days spent in Dubna, the students visited the JINR Laboratories, got acquainted with the ongoing scientific projects, took part in a master class on programming, and listened to a series of lectures by JINR specialists. The visit took place as part of the work of the JINR Infocentre opened in May 2022 on the basis of Kamchatka State University named after Vitus Bering (KamSU) in Petropavlovsk-Kamchatsky.

The Complex Regional Olympiad "Vitus Bering – 2022" in natural sciences (physics, chemistry, biology, computer science, mathematics) was organized by KamSU together with Kamchatka Institute for the Development of Education, MIPT, and JINR. Based on the results of two stages, 12 winners were selected among students in grades 8–10. With the support of JINR, the Department of Education of Petropavlovsk-Kamchatsky, and the JINR Infocentre at the Vitus Bering KamSU, the winners of the Olympiad were sent to Dubna.

## ADVANCED TRAINING AND SKILL IMPROVEMENT

In the 2022/23 academic year, 114 JINR employees studied English, and 23 foreign specialists attended the Russian course.

For 162 JINR workers, training courses for personnel maintaining facilities subordinate to Rostechnadzor were held.

Thirty-five students of Dubna University College and Dmitrov Technical School were trained at JINR.

### Engineering Laboratory Works

In 2022, more than 40 people from Russia (Dubna State University, Far Eastern Federal University, MEPhI), Egypt, Poland, and Uzbekistan did the UC engineering lab works on vacuum technology and automation, electronics and RF technology. In cooperation with the Radiation Safety Department and FLNR, the development of a new lab work on dosimetry was in progress. A new layout of the training section of the LINAC-200 accelerator was worked out, installation works and first tests with the beam were started. In addition to the training section, the UC scientific and engineering group was actively involved in the development of the accelerator itself (control and diagnostics, commissioning, preparation for emittance measurements).

## JINR INFORMATION MATERIALS

In 2022, more than 10 new exhibition stands were made for various popular-science events, two photo shoots for the New Year calendar and its distribution among JINR staff members were arranged. Printed information materials (brochures and booklets) about JINR, its flagship projects (in Russian and English), and UC programmes for students and postgraduates, schoolchildren and teachers were updated. Information banners promoting JINR and career prospects for students were updated as well. New design of JINR souvenirs was developed.

### Production and Demonstration of Video Materials

In 2022, JINR staff members (with the participation of UC) prepared 53 episodes of video content on JINR and Dubna intended for demonstration on the interactive billboard at the JINR Club of Scientists.

To update the collection of video tours of the Institute Laboratories, more videos about FLNR, MLIT, and DLNP were made. To make the choice of a specific tour easier, the first series of trailers for the existing video tours was created. Introductory videos about JINR in Russian and English were updated. A total of 54 videos were released in 2022.

# INTERNATIONAL RELATIONS AND SCIENTIFIC COLLABORATION

# COLLABORATION in SCIENCE and TECHNOLOGY

The main results of the international cooperation in science and technology of the Joint Institute for Nuclear Research in 2022 are reflected in the following data:

— joint research was conducted with scientific centres in the Member States, as well as with international and national organizations in other countries, on 42 topics of first priority and one topic of second priority;

— the Joint Institute sent 1194 specialists to solve cooperation issues and issues of participation in scientific meetings and conferences;

— 380 specialists were received for joint work and consultations, as well as for participation in meetings, conferences, and schools held at JINR;

— 24 international scientific conferences and schools, 19 workshops, and 13 meetings were organized and held.

The international cooperation of JINR is presented in agreements and treaties. Its development comprises joint experiments at basic facilities of physics centres, the acquisition of research data, the preparation of joint publications of the joint research results, the supply of equipment and techniques for the interested sides, etc.

**On 13 January**, Plenipotentiary of the Government of the Republic of Uzbekistan to JINR, President of the Academy of Sciences of the Republic of Uzbekistan B. Yuldashev visited JINR. JINR Scientific Leader V. Matveev, JINR Vice-Director L. Kostov and Head of the International Cooperation Department D. Kamanin attended the meeting with the JINR Director Academician G. Trubnikov.

At present, JINR cooperates with nine Uzbek research institutes and universities on 14 themes of the JINR Topical Plan. National scientific centres of Uzbekistan take part collaboratively with JINR in large-scale international projects.

One of the main topics of discussion was the opportunities for deepening cooperation in the field of personnel training: over the entire period of cooper-

Dubna, 13 January. A visit to JINR of Plenipotentiary of the Government of the Republic of Uzbekistan, President of the Academy of Sciences of the Republic of Uzbekistan B. Yuldashev

The Flerov Laboratory of Nuclear Reactions, 14 February.
Participants of the 20th International Training Programme "JINR Expertise for Member States and Partner Countries" at an introductory lecture about the Laboratory

ation, JINR has trained for the Republic of Uzbekistan more than 300 qualified specialists, including more than 20 doctors of sciences and more than 100 candidates of sciences.

**On 18 January**, President of the National Academy of Sciences (NAS) of the Republic of Armenia A. Sagyan visited JINR. At the meeting with leaders of the Institute, A. Sagyan proposed drafting a roadmap on the development of cooperation between NAS institutes and JINR, as well as expressed interest in holding internships for young scientists from Armenia at JINR and the creation of a network model of student training.

One of the bright examples of joint activities of Armenia and JINR is the creation of precision laser inclinometers for the observatory in Garni (Armenia). Active work of scientists from Armenia and MLIT JINR is underway. According to Academician Sagyan, one of the promising fields for scientific cooperation is selective membranes for antiviral applications, which are being developed at FLNR.

The parties discussed the opportunities for conducting joint scientific research in life sciences and bioinformatics, as well as for deepening cooperation in education, in particular, in the area of organizing practices at JINR for the scientific youth of Armenia. As a result of the meeting, a comprehensive roadmap on the development of cooperation will be developed.

Academician A. Sagyan got acquainted with the NICA megascience project and visited the factory of superconducting magnets at VBLHEP, the Factory of Superheavy Elements at FLNR, where he also met with Academician Yu. Oganessian, and LRB.

**On 14 February**, the 20th International Training Programme "JINR Expertise for Member States and Partner Countries" started. Participants of JEMS-20 were heads and specialists from research and educational institutions of Armenia, Slovakia, and Serbia. A representative from North Macedonia took part in the JEMS programme for the first time.

Head of the International Cooperation Department D. Kamanin opened the programme of JEMS with an introductory lecture about JINR. The participants had excursions to the Factory of Superheavy Elements at FLNR, the NICA accelerator complex, and the factory of superconducting magnets at VBLHEP.

On the first day of the training programme, participants had a meeting with JINR Vice-Director L. Kostov, JINR Chief Scientific Secretary S. Nedelko, and heads of departments and scientific laboratories of JINR. The participants shared their expectations from the upcoming week in Dubna, as well as the first impressions of visiting the Institute.

The JEMS programme was divided into thematic sections: Heavy Ion Physics and Accelerator Technologies; Research with Neutrons and the Nanoworld; Theory, Information, Education; Life Sciences on Earth and in Space; and Neutrino. The participants listened to lectures on the areas of scientific studies from leading specialists of JINR and got an idea of international and educational activities, the organization of the JINR social infrastructure. The internship ended on 18 February with a traditional round table with the participation of representatives of the JINR Directorate.

**On 17 February**, a regular meeting of the JINR STC was held online under the chairmanship of Scientific Leader of JINR V. Matveev, where the key topic was the first public presentation of the concept of the Seven-Year Plan for the Development of JINR for 2024–2030.

JINR Director Academician G. Trubnikov started the presentation with a review of the preliminary results of the current Seven-Year Plan. Speaking about the concept of the new seven-year period, he presented the further actions of its discussion, including at the meetings of JINR leadership. Compiling the final version of the Seven-Year Plan for the Development of JINR for 2024–2030, with account of all remarks and comments, is planned for September 2023, and in November 2023 the plan will be considered both in terms of the scientific programme and in budgetary terms.

The JINR Director identified six basic research areas of JINR, including relativistic heavy-ion and spin physics, low-energy nuclear physics, condensed matter and neutron physics, neutrino physics and astroparticle physics, information technologies and high performance computing, life sciences and applied research. The speaker stressed the necessity to attract talented scientists and engineers to JINR and marked the importance of evaluation and selection, during the next seven years, of new large-scale projects for their implementation. G. Trubnikov spoke about plans and tasks and further work to develop the NICA project, the neutrino telescope Baikal-GVD, the Govorun supercomputer, the IBR-2 reactor, the IREN facility and the U-400M cyclotron, and to develop a new neutron source NEPTUNE.

Answering the comments in the active discussion on prioritization of inner and external experiments in the physics of relativistic heavy-ion collisions, particle physics and neutrino physics, the speaker stressed that the focus should be primarily on the development of the research infrastructure and the implementation of modern attractive projects in Dubna.

**On 18 February**, the 32nd meeting of the Joint Committee on the Collaboration IN2P3–JINR was held by video conference. The parties discussed progress in the implementation of scientific projects, prospects for cooperation, which celebrated its half-century anniversary in 2022, as well as a number of joint events scheduled for 2022.

JINR Director G. Trubnikov and IN2P3 Director R. Pain informed participants of the meeting about the latest results and further plans of the organizations. The parties discussed in detail the financial support for cross-participation in projects and the extension of cooperation areas, in particular, in quantum computing, radiobiology, life sciences and innovative research. Besides, participants proposed drafting a joint youth talent academic research programme.

To commemorate the anniversary of the cooperation and further discuss the cooperation enhancement, the participants suggested actively using large-scale conferences held by the parties: a conference in honour of the 65th anniversary of FLNR in May, the 10th EXON Symposium on Exotic Nuclei in Peterhof in early July, etc.

**On 24–25 February**, President of the Mexican Physical Society Dr A. M. Cetto Kramis took part in the 131st session of the JINR Scientific Council as a special guest. On the sidelines of the event, A. M. Cetto Kramis learned about the Institute's scientific infrastructure by visiting VBLHEP, FLNR, FLNP, and LRB.

At the meeting at the Institute's Directorate on 25 February, the parties discussed possible priority fields of scientific cooperation between Mexico and the Joint Institute, a possibility of participation of Mexican scientists in the fulfilment of the Seven-Year Plan for the Development of JINR. The sides discussed prospects of cooperation in theoretical physics, life sciences and applied research. It was noted that in 2019 a Memorandum was signed under which Mexican scientists joined the implementation of the NICA project.

The sides agreed on holding in the near future a meeting to discuss and choose the trends and plans of joint work, as well as on appointing coordinators for cooperation on the Mexican side.

**On 24 March**, the ceremonial commissioning of the SARRP (Small Animal Radiation Research Platform) X-ray irradiation facility manufactured by Xstrahl (Great Britain) and designed for radiobiological studies on small laboratory animals took place at JINR's LRB.

JINR Vice-Director L. Kostov commented on the event on behalf of the Institute's Directorate, "I am delighted to be present at this event — the opening of LRB's first basic facility. It will expand the research capabilities of the laboratory. We are still proud that LRB has the opportunity to use the entire research infrastructure of the Joint Institute: neutron sources, heavy ions of different energies, and gamma rays. We can call the new X-ray equipment the first basic facility of the Laboratory of Radiation Biology."

LRB Director A. Bugay, speaking at the event with the participation of representatives of the JINR Directorate and Laboratory staff, noted that there are a total of one hundred such facilities in the world, used by leading research and cancer centres around the world, mainly in the USA and China. However, this is the only SARRP system installed in the territory of Russia and Eastern Europe, and it will be the first facility of this scale and level at LRB.

SARRP is a multifunctional instrumentation for the complete modelling of the radiation therapy cycle with the help of X rays, which are used in most clinics of the world to treat oncology. The new facility is a unique device that allows not only irradiation, but also preparation for it, treatment planning with dose marking. It makes 3D computed tomography possible, with analyzing it by slices. The device allows one to create a radiation field of the required shape with

high accuracy and irradiate only the desired area of the animal's body, as well as analyze the processes in real time and simulate irradiation, by adjusting the intensity, voltage, and collimation of the X-ray beam.

The SARRP system commissioning will allow the scientists of LRB and JINR Member States to conduct unique research in the fields of fundamental radiobiology, neuroradiobiology, and the development of new radiation therapy methods at a high technical level.

**From 14 to 16 April**, a delegation of the Joint Institute, headed by JINR Director Academician G. Trubnikov, visited the Republic of Armenia by invitation of the National Academy of Sciences of the country (NAS RA). The main purpose of the visit was the participation in the extended meeting of the Presidium of NAS RA on the issues of cooperation between scientific centres of the Republic of Armenia and JINR. The programme of the JINR delegation visit to Armenia included a number of working meetings, a visit to the Alikhanyan National Science Laboratory and opening of an information centre of JINR at Yerevan State University.

At the meeting of the NAS RA Presidium, President of the Academy A. Sagyan presented the key milestones in the JINR–Armenia scientific cooperation to his colleagues representing scientific and educational organizations of the country, noting that it is necessary to work out the mechanisms of cooperation in joint staff training, which may be an additional impetus for the development of research projects. The participants discussed a joint project in the field of studying geodynamic processes in Armenia with the use of precision laser inclinometers, as well as the creation of a network of such devices in the country. Another promising area for interaction is biological studies of membranes, and a separate seminar was devoted to this realm.

A special item in the agenda of the meeting was congratulations extended to FLNR JINR Scientific Leader Academician Yu. Oganessian on his anniversary by colleagues from scientific and educational centres of Armenia. In recognition of his contribution to world science, Yu. Oganessian received the Honorary Order of the Russian–Armenian University at the meeting.

On 14 April, there were a number of working meetings of the JINR delegation with Chairman of the Science Committee of the Republic of Armenia S. Hayotsyan and President of the NAS of Armenia A. Sagyan. On the same day, MLIT JINR Director V. Korenkov met with managers of the Institute for Informatics and Automation Problems of NAS RA. There was also a meeting of representatives of the Ministry of Emergency Situations of Armenia, the Institute of Mechanics of NAS RA, the Institute of Geophysics and Engineering Seismology named after A. Nazarov of NAS RA, as well as other interested institutions, with JINR Director Advisor M. Itkis, Head of the JINR International Cooperation Department D. Kamanin, and Senior Researcher of DLNP JINR G. Torosyan.

Yerevan (Republic of Armenia), 14–16 April. Extended meeting of the Presidium of the National Academy of Sciences of Armenia on cooperation between the scientific centres of Armenia and JINR (*photo: the National Academy of Sciences of Armenia Press Service*)

On 15 April, representatives of JINR, YSU, and the Alikhanyan National Science Laboratory signed an agreement on the opening of the JINR Information Centre. The format of JINR Information Centres that already function in Petropavlovsk-Kamchatsky, Vladivostok, Arkhangelsk, Sofia, Vladikavkaz, and Cairo provides practice courses, online excursions to the Institute's Laboratories, lectures by staff members and is intended to promote academic mobility of the young. Meanwhile, the information centres serve to raise awareness about JINR in regions.

In the ceremonial atmosphere, FLNR Scientific Leader Academician Yu. Oganessian was conferred the title of Honorary Professor of Yerevan State University.

On 15 April, during their visit to Yerevan, JINR Director Academician G. Trubnikov and Scientific Leader of the Flerov Laboratory of Nuclear Reactions Academician Yu. Oganessian were welcomed by N. Pashinyan, Prime Minister of Armenia. Yu. Oganessian and G. Trubnikov told the Prime Minister about the meetings of the Joint Institute's delegation held during the visit to Armenia, about the planned directions for the development of cooperation and its new formats, as well as about the attraction of young Armenian scientists to new programmes of the Joint Institute and the new JINR Information Centre at Yerevan State University. In his turn, N. Pashinyan noted that the Government of Armenia is ready to support further development of scientific cooperation in joint topics of the Topical Plan of JINR and congratulated Yu. Oganessian on his birthday and wished him sound health.

**On 20 April**, a meeting of the JINR Science and Technology Council (STC) was held in the International Conference Hall. The agenda of the meeting included an overview of events related to the Institute's activities held since the previous meeting of the STC and reports by the heads of medical institutions of Dubna — Medical Unit No. 9 and Dubna City Hospital.

At the beginning of his talk, JINR Director G. Trubnikov congratulated LRB Scientific Leader RAS Corresponding Member E. Krasavin, a famous specialist in fundamental, space and medical radiobiology, on his 80th anniversary and wished him sound health and new fruitful ideas.

The JINR Director spoke about the results of the meeting of the Scientific Council, the new Seven-Year Plan for the Development of JINR for 2024–2030 presented at the meeting, the concept of the modernization of the Topical Plan, and work on the Regulations on Grants and Programmes of Plenipotentiaries. The speaker highlighted that topics and projects of the current Seven-Year Plan for the Development of JINR for 2017–2023 were approved for implementation by the end of 2023 at the past JINR Programme Advisory Committees sessions in June 2021 and in January 2022. It provided full expert support of the scientific programme of the Institute.

G. Trubnikov further informed the STC about the extraordinary meeting of the JINR CP held on 17 and 21 March. He also spoke about the Statement on the necessity to preserve the unity of the Institute, its scientific mission, and international scientific partnership in a peaceful environment. The planned execution of the research programme is continued as well as active cooperation with Plenipotentiaries of the Governments of JINR Member States. The Director highlighted some achievements of the JINR Laboratories in the first quarter of 2022. The successful long run at the accelerators of the NICA complex, the installation of two new clusters of the neutrino telescope during the recently completed regular Baikal expedition, the MLIT's well-coordinated work on smooth functioning of all computer resources of the Institute, and the commissioning of the new X-ray irradiation facility SARRP for LRB were among them. The speaker also talked about the modernization of the IBR-2 reactor, the DC-140 accelerator, the preparation of experiments on the study of the properties of elements 112 and 114 at the DC-280 accelerator, and the construction of the medical accelerator.

The Director's report included important statistics: the Institute's budget is filled by 84%, salaries of the staff are increased by 10% and salaries of workers of production units by 20% in 2022. The establishment of the MSU branch in Dubna, the opening of the Information Centres in Arkhangelsk and Yerevan, the start of construction of a modern checkpoint at the site of DLNP, and many other events were among positive ones presented in the report.

Then Acting Head of Medical Unit No. 9 of the FMBA of Russia I. Larionova reported on the work and new opportunities of Medical Unit No. 9. She spoke about mobile teams for visits to enterprises that were created, repairs of premises, the creation of the Industrial Medical Care Centre, as well as about an electronic system for medical examinations in the Medical Unit, palliative and rehabilitation departments, and the issue of establishing a cardiovascular centre.

Chief Medical Officer of the Dubna City Hospital A. Osipov reported on the work and new opportunities of the city medical institution. In particular, he noted with satisfaction that for the first time in many years the Dubna City Hospital was developing in cooperation with Medical Unit No. 9, which gives hope for further improvement of the work of medical organizations in Dubna.

**From 25 to 27 April**, the Veksler and Baldin Laboratory of High Energy Physics of JINR hosted in a hybrid format the 9th Collaboration Meeting of the MPD Experiment at the NICA Facility. More than 140 scientists took part in the meeting, 60 of them were present at the meeting in person. The participants were informed about the progress in implementation of the NICA project and the MPD detector, the schedule of constructing the NICA complex and the start of its operation, and about sessions with particle beams at the facility. The agenda of the event

The Veksler and Baldin Laboratory of High Energy Physics, 25–27 April.
Participants of the 9th Collaboration Meeting of the MPD Experiment at the NICA Facility


included reports on specific values that are planned to be measured in the experiment and plans for publication of the obtained results.

Leader of the NICA project, VBLHEP Acting Director V. Kekelidze opened the event and told the audience about the progress of the NICA project. He spoke about two successful runs at the complex: one in September 2021 and the other, three-month commissioning run, at the beginning of 2022. Almost 90% of superconducting magnets necessary for NICA are ready for further work. Installation of ready magnetic blocks in the collider's tunnel is underway. Construction work on the NICA complex is scheduled to be completed in 2022. There is a slight delay in the timing of the commissioning of cryogenic compressor stations. However, by the autumn of 2022, work on them is to be completed.

Interim Spokesperson of the MPD collaboration V. Riabov (PNPI) reported on the current status of the experiment. Specialists are working on the major systems of the detector: the supercompact solenoid and its yoke, the support structure, time-of-flight and time projection chambers, and the electromagnetic calorimeter. V. Ryabov noted that there are five Physics Working Groups operating within the MPD collaboration. They presented reports on the work done at the current event.

There was also a discussion of the problems that have arisen due to recent world events, sanctions and restrictions. It was stated that, despite the difficulties encounered, the main work to develop and launch the experimental facility was planned to be completed by the end of 2023.

Another issue for discussion was computing and software infrastructure for data processing. The Institute of Physics and Technology of the Mongolian Academy of Sciences was included in the MPD collaboration. The participants of the meeting had an excursion around the NICA complex.

**On 29 April**, a JINR delegation, headed by G. Trubnikov and represented by S. Dmitriev, B. Gikal, G. Shirkov, and S. Yakovenko, visited the Efremov Institute of Electrophysical Apparatus (NIIEFA), St. Petersburg. The goal of the visit was to sign an agreement on the development and production of an accelerator complex based on the MSC-230 superconducting cyclotron for proton radiation therapy of oncological diseases.

JINR Director Academician G. Trubnikov and NIIEFA Director General E. Sakadynets signed the document. The agreement includes four stages and implies drafting of technical documentation, production of components and systems of the accelerator, its assembling, debugging and a test launch at NIIEFA, further transportation to JINR, installation, and full-fledged launch in Dubna in two years.

During the visit, the JINR delegation was introduced to the production opportunities of NIIEFA. The organization is currently one of the most technically developed and advanced producers of electrophysical equipment in Russia.

**On 4 May**, the JINR Information Centre was opened on the basis of Vitus Bering Kamchatka State University in Petropavlovsk-Kamchatsky. On the eve of this, the Government of the Kamchatka Krai held a meeting of the JINR delegation, headed by Chief Scientific Secretary S. Nedelko, with Deputy Chair of the Government of the Kamchatka Krai A. Lebedeva, KamSU Acting Rector E. Merkulov, as well as heads of the Institute of Cosmophysical Research and Radio Wave Propagation of FEB RAS, the Kamchatka branch of the Geophysical Service of FEB RAS, and the Institute of Volcanology and Seismology of FEB RAS.

Greeting the participants of the meeting, A. Lebedeva mentioned in particular an exceptionally important role of the JINR Information Centre in

improving the quality of school education in natural sciences. The parties discussed the prospects of cooperation between JINR and KamSU, as well as research organizations in the region. Head of the JINR International Cooperation Department D. Kamanin spoke about the activity of information centres both in Russia and in other Member States, and noted their features and common tasks. The participants discussed a number of specific initiatives on joint projects and established new working contacts.

Minister of Education of the Kamchatka Krai A. Korotkova took part in the ceremony and noted the need for live communication between schoolchildren and students and representatives of the scientific community to choose a future profession.

On the same day, the opening of the Natural Science School for students and schoolchildren took place, within which JINR specialists gave lectures for schoolchildren and students in various areas of research carried out at the Institute.

**On 26–27 May**, science diplomats from Brazil, South Korea, Uganda, and Vietnam visited JINR. In addition, the delegation of the Analytical Centre for Innovations in Science, Technology, and Education (Moscow) took part in the visit.

The visit became another event on the implementation of the provisions of the Sofia Declaration of JINR, in particular, on strengthening the role of JINR as a unique integration platform for the development of modern tools of the Member States and partners in the fields of science diplomacy, science education, and intercultural exchange.

Welcoming guests, JINR Director G. Trubnikov noted the relevance of the problems of science diplomacy in the light of the current situation. He spoke about the results of the JINR CP session, where a strategy of scientific development of JINR for another seven-year period was adopted.

In their turn, the scientific diplomats highlighted special importance of science and scientific diplomacy today and the important role of JINR in development and expansion of international cooperation.

During the visit, the guests also got acquainted with the NICA megascience project and visited the factory of superconducting magnets, as well as the exhibition "JINR Basic Facilities".

**On 28 May – 4 June**, a large visit of the delegation of the Joint Institute for Nuclear Research to the Far Eastern Federal University took place. It was organized as part of the implementation of agreements on the development of bilateral cooperation in accordance with the agreement on the opening of the JINR Information Centre on the basis of FEFU, signed on 13 May this year. Members of the Institute's delegation, which included representatives of all the Laboratories and the JINR University Centre, gave a series of lectures for students, postgraduates, and scientists of FEFU and institutes of the Far Eastern Branch of the Russian Academy of Sciences. A number of thematic round tables, sessions, and meetings were held, including ones with representatives of the Primorsky Krai administration.

The meeting of the delegation with Acting Rector of FEFU B. Korobets and representatives of the University administration was devoted to discussing priorities of the Information Centre, common tasks of JINR and FEFU partner network's development in the Asia–Pacific region. The objectives for the development of promising areas of cooperation between the University and JINR in fundamental and applied research and training were specified.

The JINR delegation took part in a meeting with representatives of FEFU and the Far Eastern Branch of the Russian Academy of Sciences, dedicated to the exchange of experience in international cooperation in science and education. Areas of possible cooperation in terms of expanding interaction with countries of the Asia–Pacific region were discussed at the meeting with Deputy Vice-Rector of FEFU for International Affairs E. Vlasov.

On 31 May, a review of the main lines of the research programme and the strategy of the JINR development was presented at the meeting of the Scientific Council of FEFU.

On 1 June, the JINR delegation and the FEFU leaders met with representatives of the Primorsky Krai administration with the participation of E. Shamonova, Acting Deputy Chaiperson of Primorsky Krai and Minister of Education of Primorsky Krai, N. Stetsko, Deputy Chairman of the Primorsky Krai Government, who is responsible for economic development, industry, trade, vocational education, employment, project management, and tourism, and S. Dubovitsky, Minister of Vocational Education and Employment of Primorsky Krai. The parties discussed JINR's experience in working with school teachers and students in order to popularize modern science, as well as the role and potential of the JINR Information Centre at FEFU as a coordinator of the Institute's interaction with educational and scientific organizations in the region. Prospects for interactions of the region organizations with the Institute in science were also discussed.

Later that day, a round table was held at the Presidium of the Far Eastern Branch of RAS, where possibilities of bilateral cooperation with a focus on interdisciplinary areas and possibilities of the JINR Information Centre at FEFU were discussed. As a result of the round table, a number of meetings were held between representatives of the JINR delegation and colleagues from the Institute of History, Archaeology and Ethnology of the Peoples of the Far East of FEB RAS, the Far East Geological Institute, the Institute of Applied Mathematics, and the Institute of Automation and Control Processes with Computation Centre, representatives of the Council of Young Scientists of FEB RAS, as well as the management of the University's Education and Science Museum.

The final event of the JINR delegation's visit to FEFU was a round table on the integration of JINR educational opportunities into the educational process of the University, where the basic functionality and

objectives of the JINR Information Centre at FEFU were set.

**On 7 June**, JINR Director G. Trubnikov met with Academician-Secretary of the Department of Physics, Mathematics and Informatics of the National Academy of Sciences (NAS) of Belarus A. Shumilin and Heads of Belarusian scientific centres: the Stepanov Institute of Physics of NAS of Belarus, Minsk Research Institute of Radiomaterials, the Centre for Geophysical Monitoring of NAS of Belarus, Institute of Mathematics of NAS of Belarus, the Scientific-Industrial Centre "Tekhnologia", the Centre "Fundamental Interactions and Astrophysics" of the Stepanov Institute of Physics of NAS of Belarus, who arrived in Dubna as a delegation.

The sides discussed opportunities to widen cooperation, in the sphere of production of superconducting resonators, in particular. This topic was discussed the day before at the joint meeting of the Commission of the Parliamentary Assembly of the Union of Belarus and Russia on Economic Policy and the Commission of the Parliamentary Assembly on Budget and Finance. During the discussion, suggestions were made to develop mutual beneficial cooperation between JINR and Belarusian institutes, and possible topics of joint research, in particular, in laser technology, studies of radioresistance of various technical components, and others were identified. The sides agreed to organize further visits for discussions of details of cooperation.

**On 9 June**, the 13th meeting of the Russia–China Working Group on High Technology and Innovation took place at the site of the Ministry of Science and Higher Education of the Russian Federation in Moscow. A JINR delegation, headed by Vice-Director V. Kekelidze, took part in the section dedicated to the development of scientific and technical cooperation within megascience projects between Russia and China.

V. Kekelidze presented the physical tasks and fields of applied studies of the NICA project, made an overview of the existing cooperation between JINR and Chinese scientific organizations in that field. As a way of development of bilateral relations, V. Kekelidze offered to conclude an agreement between JINR and the Ministry of Science and Technology of China on scientific and technical cooperation and the use of facilities of the Joint Institute. Signing of this agreement will allow JINR to expand and multiply the successful practices of cooperation between JINR and the Chinese side obtained within the NICA project.

**On 20 June**, the opening ceremony of the 15th International Internship for Young Scientists and Specialists from the CIS countries took place. It was organized by the International Innovative Nanotechnology Centre of the CIS countries (InINC CIS), the Joint Institute for Nuclear Research, and the Intergovernmental Foundation for Educational, Scientific and Cultural Cooperation of the CIS (IFESCCO). Young scientists and specialists from Armenia, Azerbaijan, Belarus, Kazakhstan, Kyrgyzstan, Russia, Tajikistan, and Uzbekistan gathered in Dubna for the Internship, which lasted until 19 July.

Internships have been held annually since 2009. More than 300 people have taken part in them over

Dubna, 20 June. Opening ceremony of
the 15th International Internship for Young Scientists and Specialists from the CIS countries

this time. In 2010–2022, more than 150 scientists received the InINC CIS grants for the development of scientific and innovative projects. Participation in Internships in Dubna provides additional opportunities for scientific and career growth of young scientists and specialists from the CIS countries.

During the Internship, the participants visited the JINR Laboratories, the Dubna University and its Digital Production Centre and the Experimental Design Bureau of Electrochemical Technology, JSC Scientific Production Centre "Aspect", the Special Economic Zone "Dubna", and met with representatives of the national groups of their countries in JINR.

The participants worked inside international teams of 4–5 people on joint scientific-technical or innovation projects. As a result of the Internship, projects were defended, and the authors of the brightest works are able to apply for grants from the InINC CIS next year.

**On 8 July**, the opening ceremony of the International Year of Basic Sciences for Sustainable Development (IYBSSD 2022) was held in the UNESCO headquarters (Paris, France). The Joint Institute for Nuclear Research is one of the organizers of IYBSSD 2022 and a member of its Steering Committee. Together with JINR, the organizers of IYBSSD 2022 are its partners, such leading international scientific centres and communities as CERN, the International Union for Pure and Applied Physics (IUPAP), the International Union of Pure and Applied Chemistry (IUPAC), the National Institute for Nuclear Physics (INFN, Italy), and others.

The ceremony in Paris was opened by UNESCO Deputy Director-General Xing Qu. In his speech, Xing Qu stressed that science can change the world, making it more sustainable, and said that UNESCO in its turn wants to make scientific sphere more open, equal and fruitful.

M. Spiro, President of IUPAP, President of the Steering Committee for the proclamation of the International Year of Basic Sciences for Sustainable Development, and Honorary Doctor of JINR, also addresed the ceremony. In his speech, he presented the idea that basic sciences, driven by the thirst for knowledge, are the basis for education and the source of discoveries. Eventually, they find practical applications that serve the inclusive sustainable development of the world.

The Joint Institute held a number of events included in the official list of events of the IYBSSD 2022: 16th international scientific conference "Parallel Computational Technologies " (PCT 2022); International Workshop on Exploring High Baryon Density Matter at the JINR NICA Facility; and X International Symposium on Exotic Nuclei (EXON-2022).

**On 12–13 July**, JINR Vice-Director L. Kostov and FLNP Director V. Shvetsov were on a working visit to Dimitrovgrad, Ulyanovsk Region. They took part in the first meeting of the Advisory Board of the International Research Centre based on the MBIR reactor.

More than 80 scientists, experts, and leaders from more than 30 leading scientific centres of Algeria, Armenia, China, India, Kazakhstan, Russia, Uzbekistan, and Vietnam took part in the first meeting of the Board in person and online. At the meeting, international organizations were represented by JINR and IAEA.

The status of the construction of the MBIR reactor, the issues of joining the MBIR IRC Consortium, the organization of work within the relevant committees as part of the MBIR IRC Advisory Board, as well as the future international programme of experimental research at the facility were discussed. On behalf of JINR, the Board included L. Kostov and B. Sharkov, Special Representative of the JINR Director for Cooperation with International and Russian Scientific Organizations. FLNP Director V. Shvetsov became a member of the Non-Energy Applications of Nuclear Technologies Committee, and Head of the FLNR Sector V. Skuratov joined the Materials and Fuel Research Committee. V. Shvetsov gave a presentation on research on extracted neutron beams.

In reports of the participants, the experience of international centres based on research reactors, as well as approaches to the development of national nuclear projects and advanced research at the MBIR facility in cooperation with Rosatom were considered.

**In July**, a research group from Egypt had a working visit to FLNP within the joint project of the Academy of Scientific Research and Technology of Egypt (ASRT) and JINR "Molecular Modeling and Experimental Neutron Scattering Studies of Interactions of the Condensed Matter and Biological (Lipid Membranes) Systems".

Among the visitors were the co-heads of the project on behalf of Egypt Professor of Physics Kh. al-Hayes, Professor of Applied Spectroscopy and Molecular Modeling at the Spectroscopy Department of the National Research Centre (NRC) M. Ibrahim, as well as a group of Egyptian scientists and specialists.

FLNP Leading Researcher Professor Kh. Kholmurodov is an executive on behalf of JINR. Employees of a sector of the FLNP Department of Neutron Investigations of Condensed Matter and students of the Dubna University participate in the project.

The heads of the joint project met with FLNP Director V. Shvetsov to discuss the status of the cooperation and prospects for its further development.

The project is aimed at creating an economical and environmentally friendly biosensor. Previously, the results of research on interaction between graphene quantum dots (GQDs) and graphene oxide as a substrate and cholesterol as a biological molecule were obtained using quantum mechanical calculations. Egyptian scientists have performed the X-ray structural analysis of the samples at the Xeuss 3.0 facility, and computer modeling will be carried out on JINR's Govorun supercomputer. The results of the project are planned to be published in one of the highly ranked scientific journals.

The next stage of the project involves conducting the computer molecular dynamic modeling on the same model molecules at JINR to confirm the obtained results. One of the trends of the project development will be the verification of the model using the research facilities at FLNP. Understanding the mechanism of interaction in the objects mentioned above is an important step towards the development and implementation of advanced biosensors, which are widely used in various fields such as agriculture, medicine, biological protection, etc.

**On 23–24 August**, the 4th International Meeting of the BRICS Working Group on Research Infrastructure and Megascience Projects took place as part of the Technoprom-2022 Forum, being held in Novosibirsk. The Joint Institute was an active participant of the event. The two-day meeting brought together representatives of ministries, relevant departments, and scientific organizations of the BRICS countries.

JINR Director G. Trubnikov chaired the topical session devoted to update of BRICS countries' policy on research infrastructure. The participants discussed the need for open dialogue between the countries for the benefit of the research infrastructure development.

At the topical session devoted to the Strategic Plan of the BRICS Working Group, Head of the JINR International Cooperation Department D. Kamanin presented its draft. The presentation of the Document aroused an active discussion, at which the participants of the working meeting made many proposals for the elaboration of the Plan.

On the second day of the meeting, the Working Group discussed ways to improve the BRICS GRAIN web platform. In fact, the discussion continued the main topic of the meeting, i.e., the elaboration of the Strategic Plan's draft. On behalf of the Joint Institute, Chief Scientific Secretary S. Nedelko spoke on the topic of the session and presented the aims of the platform, as well as invited the participants to discuss a number of proposals for the BRICS GRAIN development.

During the following topical session, its participants discussed the BRICS Task Force project, which was included in the Strategic Plan and aimed to analyze existing research infrastructure objects of the BRICS Members. D. Kamanin presented the project, milestones of its development, and further plans for its implementation.

Under the Forum's topic "Nuclear technologies and megascience projects", a session dedicated to scientific facilities of the megascience class was held. Academician G. Trubnikov spoke about the NICA accelerator complex, its goals, stages and implementation dates, detailing project management and applications. He noted that great attention is being paid to training personnel for NICA. The project is now actively involving countries located in Latin America, Africa, South Asia, and the Mediterranean region.

**On 30 August**, a JINR delegation took part in the 26th meeting of the Sub-commission for Scientific and Technical Cooperation of the Russian–Chinese Commission for the Preparation of Regular Meetings with Heads of Governments. Director of the Joint Institute G. Trubnikov spoke at the event.

During the meeting, in particular, the parties underlined the high level and broad scope of cooperation between JINR and scientific organizations of the People's Republic of China. They also confirmed the advisability of signing a declaration of intent between JINR and relevant institutions of the People's Republic of China to implement cooperative work in the field of basic scientific research. The parties agreed to hold consultations on agreeing the draft of the document.

Novosibirsk, 23–24 August.
Participants of the 4th International Meeting of the BRICS Working Group on Research Infrastructures and Megascience Projects as part of the forum "Technoprom-2022" (*photo: INP SB RAS*)

Dubna, 2 September. The inauguration of the MSU Branch in Dubna

The Veksler and Baldin Laboratory of High Energy Physics, 7 September.
A delegation of the RF Ministry of Science and Higher Education,
headed by Deputy Minister D. Afanasiev (left), on a visit to JINR

Academician G. Trubnikov spoke about the results and prospects of cooperation within the NICA megascience project. Wu Yan, Deputy Head of the International Cooperation Department of the Chinese Academy of Sciences, who spoke on behalf of China on the same topic, noted that the key components of the NICA complex, developed jointly by JINR and China, had been put into batch production.

Eight research institutes and 13 universities of China participate in JINR research on 20 scientific topics. The first superconducting cyclotron, which was created through the joint efforts of China and Dubna, was launched at the Institute of Plasma Physics in Hefei.

**At the end of August**, JINR hosted a round-table meeting of representatives of the Rosatom State Corporation, RASU JSC, Germanium JSC, Germanium and Applications LLC, Science and Innovation JSC, Giredmet JSC, and Tver State University, organized within the framework of the protocol on cooperation between JINR and Institute of Physical and Technical Problems JSC. With the active participation of staff members of VBLHEP JINR, the parties discussed the development of production of the high-purity germanium and cooperation in this area.

Germanium is used in fiber and thermal imaging optics, photonics, microelectronics, and chemical industry. The high-purity germanium is necessary in nuclear physics to create detectors of X-ray and gamma radiation.

The participants paid special attention to the restoration of the production of the monocrystalline germanium and the key requirements for raw materials. The technical conditions for the production of detector-quality germanium single crystals in a large volume were discussed.

**On 12 September**, on the sidelines of the 28th International Nuclear Physics Conference (INPC 2022) in Cape Town (RSA), the 21st meeting of the Joint Coordination Committee on Cooperation of the Republic of South Africa with JINR was held.

JINR Director G. Trubnikov headed the delegation of the Institute at the event. Deputy Chief Executive Officer of the National Research Foundation (NRF) C. Nxomani co-chired the South African party.

A number of topical issues of cooperation were considered at the meeting of the Committee: current work on joint projects and the upcoming competition for new ones; student practices in 2023 and the SAINTS Summer School; issues of financing and management structure of joint projects.

The central issue was the discussion of the strategy for the development of cooperation and, in particular, projects on accelerator technologies and radiobiology, which were approved during this meeting, as well as on participation of South Africa in the SPD experiment, on information technologies and radiochemical laboratory. During the meeting, the issue of opening the JINR Information Centre at the National Cyclotron Laboratory iThemba LABS was raised. The participants of the meeting outlined a programme of joint activities for the next year.

**From 26 to 30 September**, the 35th meeting of the International Association of Academies of Sciences (IAAS) Council took place in Moscow and St. Petersburg. A JINR delegation, under the joint leadership of JINR Director G. Trubnikov and JINR Scientific Leader V. Matveev, took part in it.

The Joint Institute became a full member of IAAS in 2020. Among the participants of the event were representatives of the governing bodies of the National Academies of Sciences of many countries, including the JINR Member States. The main topic of the meeting was summing up the IAAS work in

Cape Town (RSA), 12 September. Participants of the 21st meeting of the Joint Coordination Committee on Cooperation of the Republic of South Africa with JINR

2017–2022, with the key focus on the integration of science in the Eurasian space.

At the meeting of the IAAS Council, reports were presented on the development of research in various key areas and plans of IAAS for the next few years. During the session, elections for the position of Head of the Association for 2022–2027 took place. A representative of the JINR Member State, Chairman of the Presidium of the NAS of Belarus V. Gusakov, was re-elected to this position by the decision of participants.

On 26 September, Deputy Chairman of the JINR AYSS Council A. Nezvanov took part in the meeting of the IAAS Council of Young Scientists. Participants from different countries shared their experiences in supporting young professionals, talked about the challenges they face, and discussed future projects.

At the IAAS Council meeting, G. Trubnikov, a full member of IAAS, was awarded a badge and a diploma as an IAAS Academician.

**On 27 September**, as part of the IV International Scientific Forum "Nuclear Science and Technologies" in Almaty (Kazakhstan), a round table was held dedicated to the 65th anniversary of the Institute of Nuclear Physics (INP) of the Ministry of Energy of the Republic of Kazakhstan and the 30th anniversary of cooperation between JINR and the Republic of Kazakhstan. The participants of the event discussed current issues and prospects for the development of cooperation in the main cooperation areas and formats, primarily in the field of large-scale research infrastructure, scientific activities and staff training.

The work of the round table was opened by the speech of INP Director S. Sakhiyev. Speakers at the round table were, in particular, JINR Director Academician G. Trubnikov, who acquainted the participants with the current results of JINR research activities, and FLNR Deputy Scientific Leader M. Itkis, who presented a report on the history of long-term cooperation between JINR and INP.

Based on the considerable experience of fruitful mutually beneficial cooperation between Kazakhstan and JINR, the participants of the round table discussed the feasibility of developing and expanding the range of unique experimental facilities of both institutes. It was also noted that the establishment of the JINR Information Centre in Kazakhstan could become a further impetus to the cooperation enhancement of JINR with both the scientific community of the Republic of Kazakhstan and its universities.

**On 27 September**, an updated version of the Framework Agreement on Cooperation between JINR and the International Atomic Energy Agency (IAEA) was signed. The signing ceremony took place at the IAEA headquarters in Vienna (Austria) within the 66th annual IAEA General Conference. JINR Vice-Director L. Kostov on behalf of JINR and the IAEA Deputy Director General M. Chudakov on behalf of IAEA put signatures under the document.

According to the Agreement, JINR and IAEA are going to actively enhance cooperation and hold joint events for the sake of the interests of their Member States. That is staff training and research infrastructure improvement, operation and use of nuclear research reactors and particle accelerators, including the qualified support in the development of new facilities. The cooperation will develop in nuclear physics and the development of nuclear data for reactions caused by heavy ions, neutrons and gamma radiation. In addition, JINR and IAEA will contribute to the spread of information about nuclear field in the industrial sector and to the use of the INIS document collection.

Moscow, 26–30 September. The 35th meeting of the IAAS Council with participation of JINR representatives

Vienna (Austria), 27 September. Signing of the Framework Agreement on Cooperation between JINR and IAEA by JINR Vice-Director L. Kostov and IAEA Deputy Director General M. Chudakov


In 2022, the General Conference was devoted to the topic of global cooperation in the nuclear field. Among the participants of the event were representatives of 175 IAEA Member States. During the conference, the JINR delegation held a number of working meetings.

**On 30 September**, JINR Director G. Trubnikov took part in a meeting with President of the Republic of Kazakhstan K.-J. Tokayev, aimed at discussing prospects for the development of nuclear science.

The conversation at the highest level took place during the visit of JINR Director G. Trubnikov to the International Scientific Forum "Nuclear Science and Technologies", which was held in Almaty on 26–30 September. The forum was dedicated to the 65th anniversary of JINR's long-term partner — the Institute of Nuclear Physics of the Ministry of Energy of the Republic of Kazakhstan, and to the 30th anniversary of cooperation between JINR and the Republic of Kazakhstan.

During the meeting with the President of the Republic of Kazakhstan, the participants of the meeting exchanged their opinions on the development of atomic energy in Kazakhstan, the use of modern nuclear technologies, practical training of highly qual-

Almaty (Kazakhstan), 30 September. The meeting of JINR Director G. Trubnikov with President of the Republic of Kazakhstan K.-J. Tokayev (centre)

ified employees. President of the Chiyoda Technol Corporation (Japan) A. Inoue and Leading Researcher of the Institute Laue–Langevin (ILL, France) V. Nesvizhevsky were participants of the event as well. The leaders of foreign scientific organizations expressed their interest in close cooperation with Kazakhstan.

On the same day, G. Trubnikov met with Minister of Energy of the Republic of Kazakhstan B. Akchulakov, as well as visited the branch of the Institute of Nuclear Physics in Astana based on the Gumilyov Eurasian National University.

**On 4–8 October**, during the visit of the delegation of the Joint Institute to the Republic of Uzbekistan, the agreements were signed with the National University of Uzbekistan, Tashkent State Technical University, and Namangan Institute of Engineering and Technology, which are aimed at training staff and conducting joint research on nuclear energy and medicine, ecology, nuclear and nanotechnologies, electronics, and computer technologies.

On 4–5 October, the JINR delegation, headed by Director G. Trubnikov, took part in the scientific forum "Physics-2022" in Namangan. More than 250 participants from 13 countries discussed the status and prospects for physics development. During plenary sessions, JINR scientists presented reports on research carried out at the Laboratories of the Institute. JINR Vice-Director L. Kostov delivered a report at the forum. Two sessions were chaired by Deputy Scientific Leader of FLNR M. Itkis and Director of LRB A. Bugay.

On 7 October, the delegation of the Joint Institute visited the Institute of Materials Science of the NGO "Physics-Sun" of the AS RUz in Parkent.

In Tashkent, the JINR delegation met with rectors, representatives of the teaching staff, and students of the National University of Uzbekistan, Tashkent State Technical University, Tashkent University of Information Technologies, and Tashkent Medical Academy. The Chairman of the working meeting was B. Yuldashev, Plenipotentiary of the Government of the Republic of Uzbekistan to JINR, President of the Academy of Sciences of Uzbekistan. The participants discussed issues of student and academic exchange between universities of the country and JINR, opportunities for practical training and dissertation defence in Dubna. Interest was expressed in carrying out joint work on biogenetic technologies, hydrogen energy, diagnostic radiology, laser metrology, and information technologies.

The meeting at the Academy of Sciences was attended by scientists from the Institute of Nuclear Physics, the Institute of Materials Science, the Arifov Institute of Ion-Plasma and Laser Technologies, the Institute of Mechanics and Seismic Stability of Structures, the Institute of Energy Problems, representatives of the executive authorities of Uzbekistan, interested ministries, university rectors, and heads of the Academy of Sciences of the Republic Uzbekistan. The long-standing scientific cooperation between Uzbekistan and JINR, the high qualification of Dubna scientists, and the strongest scientific school of the Institute were noted.

On 8 October, a cloud computer cluster created in cooperation with specialists of MLIT JINR was launched at the Institute of Nuclear Physics of the Academy of Sciences of Uzbekistan, which will integrate the INP AS RUz into the JINR computing network for computing that requires significant resourc-

Republic of Uzbekistan, 4–8 October. Participants of the working meeting at the Academy of Sciences of Uzbekistan (*photo: the Academy of Sciences of Uzbekistan*)

Vladivostok, 10 October.
Signing of the quadripartite agreement between the Government of Primorsky Krai, JINR, FEFU and FEB RAS during the visit of the JINR delegation to Vladivostok (*photo: FEFU press service*)

es, as well as participation in computing for such JINR megascience projects as NICA and Baikal-GVD.

During the meeting dedicated to the opening of the cloud computer cluster, President of the Academy of Sciences of Uzbekistan B. Yuldashev presented JINR Director G. Trubnikov with the Samarali Faoliyati Uchun (for productive activities) badge of the Institute of Nuclear Physics.

**On 10 October**, a quadripartite agreement was signed at the Primorsky Krai Government between the Primorsky Krai Government, the Joint Institute for Nuclear Research, the Far Eastern Federal University (FEFU), and the Far Eastern Branch of the Russian Academy of Sciences (FEB RAS).

The agreement provides for personnel training for developing nuclear physics research in the region: the opening of new departments at FEFU and training of specialists for the Russian Photon Source synchrotron under construction, and also includes provisions on the implementation of innovative projects in the field of megascience, materials science, information technology, nuclear medicine, radiobiology, life sciences, biomedicine, theoretical physics, ecology, and archaeology. The parties also outlined the possibility of cooperation in scientific tourism, nature-like technologies and other projects useful for the economy of the region.

On the same day, at the FEB RAS Presidium, the JINR and FEFU representatives held a round table "Megascience facilities: Science and technology for macro-regional development". JINR Scientific Leader V. Matveev welcomed the participants and stressed the importance of developing an interest in science among young people. JINR Director G. Trubnikov made a report on the JINR scientific programme at the round table.

The JINR delegation visited the Institute of Automation and Control Processes of the FEB RAS and the Elyakov Pacific Institute of Bioorganic Chemistry of the FEB RAS, where, as a result of the discussion, a number of areas of joint work were outlined.

During the visit to Vladivostok, the JINR representatives took part in the 2nd Far Eastern Forum of Young Scientists and Innovators "Vostok. Nauka". Chairman of the JINR AYSS V. Rozhkov represented the scientific youth of the Institute at the forum. As part of the forum, round tables were organized to discuss the issues of international cooperation, popularization of science, as well as interaction in the field of education, science and technology. An interactive exhibition dedicated to the JINR activities and achievements of modern science was opened on the platform of the forum. The exhibition became one of the events of the JINR additional programme for the International Year of Basic Sciences for Sustainable Development (IYBSSD 2022). JINR is one of the IYBSSD organizers. More than 200 researchers from the Russian Far East attended the forum.

Within the meeting, diplomas were awarded to physics teachers of Primorsky Krai who participated in the internship held at the JINR University Centre.

**On 11 October**, the official opening of the JINR Information Centre took place at the FEFU on Russky Island (Vladivostok) on the basis of an agreement signed on 13 May 2022 in Dubna. The Infocentre is designed to create new opportunities for students, postgraduates and young specialists of the University to get acquainted with the unique scientific infrastructure and research projects of the Institute.

The opening of the new Infocentre was preceded by a comprehensive preparation for the fulfillment of its main task — to educate students and attract them to science. FEFU students have already visited JINR Laboratories for excursions and practices, and a series of online lectures by JINR scientists has been organized, attended by about 1000 listeners.

**On 14 October**, a working meeting of representatives of the consortium "International Centre for Research MBIR" with the Directorate of the Joint Institute was held where the sides discussed the international component of the MBIR project, JINR experience of organizing scientific collaborations, and areas of mutual scientific interests, in particular, the idea of extending the project collaboration within BRICS.

The project in Dimitrovgrad is at the stage of creating a scientific programme and establishing a user policy. Here, according to MBIR representatives, the expertise of JINR's Frank Laboratory of Neutron Physics and its relevant experience with the IBR-2 research reactor can be a solid support. The participants proposed to draw up a single neutron programme, which will involve different types of reactors: the future PIK reactor, the JINR FLNP IBR-2 pulsed reactor, and the MBIR reactor. The parties identified research using ultracold neutrons and neutron capture therapy as areas of mutual scientific interest.

**On 25–28 October**, the JINR delegation headed by Special Representative of the JINR Director Academician B. Sharkov was on a working visit to the Socialist Republic of Vietnam (SRV). The purpose of the visit was to consider further steps to develop the JINR–Vietnam cooperation, in particular, as part of the agreement on the participation of the Institute in the creation of the first research reactor in the SRV.

On 25 October, the JINR representatives met with heads of the Vietnam Atomic Energy Institute (VINATOM). The delegation members visited the site of the future research reactor near Ho Chi Minh City.

On 26 October, jointly with colleagues from the Vietnam Academy of Sciences and Technology (VAST) and scientific institutes of the VINATOM system, the JINR delegation visited the Vietnam National University Ho Chi Minh City. At the event, JINR presented major fields of its scientific programme, objects of the scientific infrastructure and corresponding principles of the user policy, as well as ongoing international staff training programmes. JINR's representatives spoke about the joint work with VINATOM on the development of a scientific programme and experimental tools for the future research reactor of Vietnam and about the targeted training programme for Vietnamese specialists being implemented at the Institute.

The Vietnamese side expressed their great interest in using the JINR research infrastructure for training programmes aimed at students, master students, and postgraduates. In particular, such thematic fields were highlighted as biology, materials science, geophysics, engineering physics, information technologies, etc.

Ho Chi Minh City (Socialist Republic of Vietnam), 26 October.
Participants of the meeting at the Vietnam National University Ho Chi Minh City during a working visit to the SRV of the JINR delegation headed by Special Representative of the JINR Director Academician B. Sharkov

Head of the VAST International Cooperation Department Lê Quỳnh Liên expressed readiness of the Academy, which coordinates the participation of Vietnam at JINR, to take into account this interest when planning joint work with the Institute on training programmes and to support in general broad involvement of the Vietnam National University Ho Chi Minh City and its international partners in the JINR activities.

On the same day, a meeting was held with VINATOM President Professor Trần Chí Thành and representatives of a number of divisions of VINATOM at the Vinagamma R&D Centre for Radiation Technology being part of VINATOM. As a result of the meeting, the Vietnamese side selected two specialists to work at JINR, namely, at FLNP, as coordinators.

On 27 October, the JINR delegation started its work at Hanoi University of Science and Technology (HUST), one of the universities included in the VAST system. The JINR representatives took part in the work of the International Scientific Symposium on Origin of Matter and Evolution of Galaxies (OMEG16) and held a number of working meetings. A group of JINR employees, headed by Yu. Panebrattsev, displayed a multimedia exhibition dedicated to the history of the development and the basic facilities of JINR at the University. More than 300 people, mostly young scientists, visited the exhibition, arranged with the active assistance of VAST and HUST.

The JINR scientific infrastructure, the history of and prospects for the Vietnam–JINR cooperation, as well as the scientific areas of joint research with the VAST institutes, were also presented for HUST students and postgraduates. JINR's Vietnamese employees in Dubna took part in the meeting via a teleconference. They shared their experience of participating in international research projects of the Institute. The audience expressed great interest in the presentations, which concluded with a round table moderated by HUST Vice-Rector Tran Dinh Phong and Head of the JINR International Cooperation Department D. Kamanin.

On the same day, the JINR delegation visited the Institute of Geophysics of VAST. At the meeting, during the discussion of prospects for cooperation, Director of the Institute Nguyen Xuan Anh made a number of proposals for the development of relations with JINR. In particular, the Institute of Geophysics would be interested in using the resources of MLIT's supercomputer to process data obtained by the Vietnam national seismological network, as well as in training IT specialists in this field. The JINR delegation visited one of the stations of the system for studying the physical nature of lightning and atmospheric aerosols, as well as the children's scientific school.

On 28 October, the JINR delegation visited the Institute for Nuclear Science and Technology (INST), one of the institutes of the VINATOM system, where there was a meeting with its Directorate and researchers. In addition, JINR's representatives got acquainted with the major research areas of the INST scientific programme, visited its laboratories, including a cyclotron laboratory for the production of medical isotopes. Deputy Director of INST Nguyen Huu Quyet headed the meeting, which was held in the format of a round table and brought together heads of the departments. The discussion resulted in a proposal to organize a working visit of the representatives of the Institute to JINR to establish direct contacts with relevant scientific groups.

A series of working visits of the JINR delegation to the universities and scientific organizations of VINATOM and VAST in Hanoi and Ho Chi Minh City was completed by a meeting with the Plenipotentiary of the Government of Vietnam, Vice-President of VAST Tran Tuan Anh, which was attended by President of VINATOM Trần Chí Thành, as well as by the directors of the Institute of Physics, the Institute of Geophysics, and HUST. The participants of the meeting confirmed great mutual interest in the further development of cooperation in scientific and technological issues, and in personnel training programmes.

**On 7–11 November**, a regular international training programme "JINR Expertise for Member States and Partner Countries" (JEMS-21) was held in Dubna. This time, the participants of the programme were representatives of Russian educational institutions and scientific organizations from Arkhangelsk, Moscow, Petropavlovsk-Kamchatsky, Rostov-on-Don, Tomsk, Tula, Vladivostok, Voronezh, and Yakutsk.

Head of the JINR International Cooperation Department D. Kamanin opened the programme of JEMS with an introductory lecture about JINR. The JEMS-21 programme included thematic blocks on internship days: Heavy Ion Physics and Accelerator Technologies; Research with Neutrons and the Nanoworld; Theory, Information, Education; Life Sciences on Earth and in Space; and Neutrino. The participants visited the Laboratories and facilities of the Institute, listened to lectures in the areas of current research from leading specialists of JINR, got acquainted with the principles of international cooperation of the Institute and the organization of social infrastructure.

On 9 November, as part of the JEMS-21, a round table "Interaction between JINR and universities. JINR Information Centres, educational programmes of UC" was organized. The participants of the internship shared their own tasks and opportunities, which resulted in a lively discussion about systemic issues of interaction between science and education. The format of JINR Information Centres was actively discussed. The round table was attended by the directors of the existing Information Centres, who spoke about the experience of JINR Information Centres in their universities, the results achieved, new tasks and tools offered by JINR to solve them. A great response from the participants was caused by an introduction to the UC engineering workshop.

On 10 November, a detailed discussion of the work of Information Centres and prospects for open-

Dubna, 7–11 November. JINR training programme "JINR Expertise for Member States and Partner Countries" (JEMS-21)

ing new ones was continued at the second workshop of directors of JINR Information Centres "Organizational issues and tasks of IC: Experience exchange", which was held in a mixed format. During the discussion, the directors of the existing ICs located both in Russia and in the Member States, namely, Bulgaria, Armenia, and Egypt, provided detailed information about their work and shared plans for the future. The meeting was attended by the representatives of scientific groups from South Africa, Uzbekistan and Vietnam, who expressed interest in creating infocentres in their countries.

On 11 November, the JEMS-21 finished with a traditional round table with the participation of representatives of the JINR Directorate, at which the results of the internship were summed up.

**On 14–15 November**, Rector of the North Ossetian State University (NOSU) A. Ogoev visited JINR. A number of working meetings were held with the leadership of the Institute and the Directors of the Laboratories participating in joint scientific and educational projects. In addition, A. Ogoev, together with a delegation of employees and students of NOSU, took part in the JINR Autumn School of Information Technologies, which took place at MLIT.

The results of five-year JINR–NOSU cooperation, the development of scientific and innovative cooperation between the organizations and other partners in southern Russia were discussed at the meeting with JINR Director G. Trubnikov. In particular, cooperation between NOSU and JINR on personnel training, scientific interdisciplinary projects and applied research was noted.

**On 12 December**, a JINR Information Centre opened for Tomsk scientists, students, and schoolchildren at Tomsk Polytechnic University (TPU). The Centre is located in a multifunctional classroom in one of the academic buildings of TPU. The classroom is equipped with computer workplaces with necessary information materials and multimedia equipment. The Centre will become an "information window" into the work of the Institute and achievements of Russian and world science. Scientific and educational, as well as popular science events in the field of modern physics will be held there.

The Centre also housed a photo exhibition "Do Science in Dubna", dedicated to the work of JINR's young scientists and specialists.

The opening of the JINR Infocentre took place during the visit of a delegation of Dubna scientists to TPU. On 13 December, leading JINR specialists held a school for young scientists of Tomsk at TPU and also presented a series of popular science lectures for schoolchildren of the city.

**On 17–18 December**, a JINR delegation, led by Special Representative of the Director of the Institute for Cooperation with International and Russian Scientific Organizations B. Sharkov, took part in the Forum for Foreign Graduates of Soviet and Russian Universities, Representatives of the Education System in the Middle East and North Africa (MENA) in Cairo (Egypt), organized by the Federal Agency for the Commonwealth of Independent States, Compatriots Living Abroad, and for International Humanitarian Cooperation (Rossotrudnichestvo).

B. Sharkov made an overview report on JINR and moderated a round table on the interaction of science, education, and industry. Head of the national group of Egyptian employees at JINR W. Badawy continued the topic with a report "Training and information activities of JINR in cooperation with Egypt".

During a plenary session and round tables held within the forum, issues related to the prospects for cooperation of Russian educational and scientific organizations with the countries of the Middle East

and North Africa, the potential of graduates of Soviet and Russian universities as a driving force of regional cooperation, as well as the possibilities of Russian educational and research organizations for training personnel for Partner Countries from the MENA Region were discussed. E. Badawy, representing the International Cooperation Department, made a presentation at the round table on opportunities of JINR in this area.

Within the forum, B. Sharkov took part in a meeting with the Ambassador Extraordinary and Plenipotentiary of the Russian Federation to the Arab Republic of Egypt, G. Borisenko. The delegation also held a number of talks with representatives of universities and research organizations in Egypt and heads of alumni associations of Soviet and Russian universities in the Middle East and North Africa region, as well as with representatives of Rosatom and partners from Tomsk Polytechnic University, on whose platform the JINR Information Centre was opened on 12 December. During the meetings, agreements were reached on the development of partnership in research, educational activities, and personnel training of JINR, Rosatom, and TPU.

During their stay in Cairo, the JINR delegation met with Plenipotentiary of the Govrnment of Egypt to JINR, President of the Egyptian Academy of Scientific Research and Technology M. Sakr, as well as with Head of the Egyptian Atomic Energy Authority, member of the Scientific Council of the Institute A. El-hag Ali to discuss the implementation of the decisions of the 12th meeting of the Joint Coordination Committee of JINR–ARE (November 2022) in Hurghada on the sidelines of the visiting session of the Committee of Plenipotentiaries, the preparation of cooperation programmes, etc.

# CONFERENCES and MEETINGS

Ten conferences were the largest among the scientific conferences and workshops held at JINR in 2022.

On 29–31 March, the Meshcheryakov Laboratory of Information Technologies hosted the international scientific conference ***"Parallel Computational Technologies" (PCT-2022)***, the sixteenth in a series of annual conferences dedicated to the development and application of parallel computing technologies and machine learning in versatile areas of science and technology. The conference is organized by the Ministry of Science and Higher Education of the Russian Federation and the Supercomputer Consortium of Russian Universities.

More than 110 scientists from Belarus, Brazil, Egypt, Mongolia, Romania, and Slovakia took part in the conference. Russia was represented by participants from 40 universities, research centres, IT and industrial companies. The conference was organized in nine sessions, where issues associated with the application of cloud, supercomputer and neural network technologies in science and technology, including applications, hardware and software, specific models, languages, libraries and packages, were discussed. Seven plenary, 38 sessional and 10 poster talks were delivered.

JINR Director Academician G. Trubnikov opened the conference with a report on the history of the Institute, its scientific programme, present and future. He underlined that information technology is one of the dynamically developing areas of knowledge, which plays a crucial role in the implementation of JINR's ambitious programme. MLIT Director V. Korenkov spoke in detail about the status and prospects for the development of the JINR computer complex, i.e., the Multifunctional Information and Computing Complex. He also highlighted that MLIT would continue to provide high-quality IT services and support

The Meshcheryakov Laboratory of Information Technologies, 29–31 March.
Participants of the 16th International Conference "Parallel Computational Technologies" (PCT-2022)

to scientists participating in JINR's projects both in the territory of Dubna and beyond.

The talk "Supercomputer technologies, artificial intelligence and Big Data" by V. Voevodin (RCC MSU), a leading Russian specialist in computer technology, high-performance computing and parallel programming, evoked great interest among the audience. The 36th edition of Top50 of the CIS's most powerful computers (http://top50.supercomputers.ru/list) was announced during the report.

At the conference, there were plenary talks on mathematical modeling using supercomputer and parallel technologies. In particular, K. Barkalov (Lobachevsky University, UNN, Nizhny Novgorod) spoke about the kinetic modeling of the reaction of isobutane alkylation with mixed olefins and sulfuric acid using the asynchronous global optimization algorithm. A. Chistyakov (Don State Technical University) presented in his report the methods and algorithms for the predictive modeling of the consequences of natural and man-made disasters in shallow waters, such as the Sea of Azov, as well as for the prediction of the silting of shipping lanes. I. Chernykh (ICM&MG SB RAS) devoted his report to the supercomputer modeling of the carbon burning subgrid process in the problems of the evolution of white dwarfs and the explosion of type Ia supernovae or thermonuclear supernovae.

A number of talks at the conference were made by representatives of the IT industry, leading manufacturers and suppliers of hardware and software, who were sponsors of the conference. Among them were Karma Group and RSC Group. Their reports provided an IT development analysis and presented trends in the development of storage systems, computer communications, novel computing architectures, as well as touched upon the issues of the design of large-scale computing centres. The Special Technological Centre was also the conference partner, and information support was provided by the PARALLEL.RU Centre, the newspaper "Poisk" and the journal "CAD/CAM/CAE Observer" .

A separate session was dedicated to the integrated supercomputer infrastructure (ISI). In September 2021, JINR, the Interdepartmental Supercomputer Centre of the RAS and Peter the Great St. Petersburg Polytechnic University signed an agreement on the integration of their supercomputers into a unified scalable research infrastructure based on the National Research Computer Network of Russia. During the session, there were delivered talks on modern IT solutions for providing shared-use centres, on the implementation of the ISI on the Govorun supercomputer of JINR, on the experience of using the ISI for event generation and reconstruction within the MPD experiment. The session ended with a tour around the Multifunctional Information and Computing Complex (MLIT JINR).

A competition of reports by young scientists under the age of 30 was organized within the conference with the financial support of Karma Group. At the first stage, the Programme Committee of the conference selected the best articles from those submitted to the competition. At the second stage, young scientists presented their works at the youth session of the conference. During this session, the jury chose the winners of the competition, who were awarded diplomas and cash bonuses.

On working days of the conference, there was organized a supercomputer exhibition, where RSC Group and Karma Group presented their latest developments in high-performance computing.

The participants of the conference were impressed by a bus sightseeing tour of Dubna, during which they visited the town's significant places, and by an excursion to the interactive exposition "JINR Basic Facilities" at the Cultural Centre "Mir", where they were able to see the models of JINR's basic facilities and learn the principles of their operation. At the closing of the conference, words of gratitude were expressed to the Organizing Committee for the high level of holding the conference.

From 25 to 29 April, the ***5th International Conference "Condensed Matter Research at the IBR-2"*** was held online at FLNP JINR in order to discuss the results obtained at IBR-2 units, as well as development prospects for further research and experimental facilities. Over 160 researchers from 18 countries took part in the conference. The scientific scope covered a wide range of lines of research with the help of neutron scattering at IBR-2, including the physics of condensed matter, materials science, chemistry, biophysical and geophysical engineering sciences, research in cultural heritage, etc. Twelve plenary papers, 46 talks, and 75 posters were presented.

The current status and plans to modernize the IBR-2 research reactor were addressed in detail by FLNP Director V. Shvetsov, who opened the conference. D. Kozlenko (FLNP) presented a review of the current state of the spectrometers complex for research into condensed matter at the IBR-2 pulsed reactor and plans of its further development. In the final report of the opening section, A. Korsunsky (Oxford University, UK, and Skolkovo Institute of Science and Technology, RF) explored the unique opportunities of researching hierarchical structures of functional materials using complementary methods of neutron scattering, X rays, and electronic microscopy.

The functional and nanostructure materials section was opened by a guest speaker Corresponding Member of RAS S. Streltsov (IMP UB RAS), who considered the theoretical basis for new physical effects in transition metals compounds connected with spin-orbit coupling, and their relation with magnetic and structural properties. Guest speakers S. Rogozhkin (National Research Nuclear University MEPhI) and V. Lebedev (PNPI NRC "Kurchatov Institute") presented the results of using complementary analysis of nanostructures in structural materials and studies of the effect of compression of lanthanide atoms in Ln-endofullerenols and their ordering in solutions. Oral presentations by researchers from MSU, IMET

UB RAS, PNPI NRC KI, FLNP JINR, and RSE INP (Kazakhstan) covered the results of studies of structural properties of a wide range of functional and nanostructured materials, including multiferroics, hydrides, complex magnetic oxides, van der Waals magnets, proton-conducting membranes with nanodiamonds for fuel elements, materials for compact current sources and solar batteries.

In the section dedicated to the development of neutron scattering methods and neutron experiment techniques, guest speaker S. Grigoryev (PNPI NRC KI) presented a project of the compact neutron source DARIA, intended for scientific research and industrial application. In oral presentations, the section participants from FLNP, PNPI NRC KI, and INR RAS discussed promising developments on design of neutron detectors of various types, data acquisition systems, issues related to development and optimization of various options for a cold moderator on a new neutron source at FLNP JINR.

In the soft condensed matter section, A. Angelova (Paris-Saclay University, France) made an invited report on the study of lipid nanocarriers of drugs for the delivery of natural neuroprotectors. In subsequent oral presentations, researchers from PNPI NRC KI, MIPT, FLNP, the Institute of Chemistry of the Academy of Sciences of Moldova (Moldova), and the Centre for Energy Research (Hungary) presented the results of studies of various protein, lipid, micellar nanosystems, biohybrid nanocomplexes and polymers.

In the magnetic nanomaterials section, the invited lecture by S. Kantorovich (University of Vienna, Austria) on soft magnetic materials, current state and new trends in this area of research was met with great interest. The participants from the University of Bucharest (Romania), St. Petersburg State University, PNPI NRC KI, IMET UB RAS, and FLNP discussed the results of studies of magnetic properties of ferrofluids, layered nanosystems and complex biological nanoobjects.

In the section on research into internal stresses and textures in materials, the invited report by V. Em (NRC KI) was dedicated to a review of the current state and prospects of the development of neutron stress diffractometry methods. Participants from the Institute of Electronics of the Bulgarian Academy of Sciences (Bulgaria), FLNP, and Tula State University presented the results of research into texture and stresses in structural materials, rocks and minerals.

In the section on cultural heritage research, S. Kichanov (FLNP), I. Saprykina (IA RAS), and B. Bakirov (KFU and FLNP) discussed the main research areas using neutron radiography and tomography at the IBR-2 reactor and the results of the analysis of the internal structure of ancient and medieval coins.

The conference programme included a new section of using complementary methods for the study of condensed matter, whose use may become relevant due to the temporary shutdown of the IBR-2 reactor for technical reasons. A. Doroshkevich (FLNP) presented an overview of the possibilities and the most important results of condensed matter research at the EG-5 accelerator. A. Savin and R. Steimann from the National Institute of Research and Development for Technical Physics (Romania) introduced the audience to the possibilities of using the electromagnetic method to estimate the degree of defectiveness of cylindrical products and the results of microwave measurements of biological tissues. On the whole, the conference participants evaluated the scientific and technical level of the conference as consistently high.

On 4–8 July, the ***Meeting on Heavy Ion Physics*** was held in Saint Petersburg, which was organized by JINR's Flerov Laboratory of Nuclear Reactions. As part of the meeting, a ***visiting session of RAS Council on Heavy Ion Physics*** took place on 4 July. The meeting was associated with the 65th anniversary of the Flerov Laboratory of Nuclear Reactions. Representatives of the nuclear physics community of Russian scientific institutes and universities, students of MSU and SPbU, as well as scientists from the Rosatom State Corporation's institutes took part in the event.

The meeting was dedicated to theoretical, experimental and technological issues of using heavy ions to study the properties of atomic nuclei. A considerable part of the reports covered the studies performed at JINR's Factory of Superheavy Elements. The agenda also addressed the questions regarding the current work on cooperation among Rosatom institutes and JINR as part of the federal project of a complex programme of development of nuclear science and technologies.

The provisional results of the Russian Ministry of Science and Higher Education's "Superheavy Nuclei and Atoms: Nuclei Mass Limits and Boundaries of Mendeleev Periodic Table" Grant commitments for 2020–2022 were presented by Scientific Secretary of FLNR and Deputy Head of the Grant A. Karpov. Reporting on the grant chart progress, MLIT Director V. Korenkov paid particular attention to employment of digital platforms and quantum computing in JINR scientific projects. Head of FLNR Sector V. Utenkov presented his paper "Superheavy Element Factory: Results and Prospects", whereas Head of Department at SPbU V. Shabayev reviewed the studies on research of nuclear and chemical properties of superheavy elements conducted by a scientific group of SPbU.

The meeting agenda featured prominently the G. N. Flerov Award Ceremony recognizing three outstanding scientists of the Khlopin Radium Institute: A. Rimsky-Korsakov (received by his widow S. Rimskaya-Korsakova), L. Pleskachevsky, and S. Khlebnikov.

RAS Council chaired by FLNR Scientific Leader Academician Yu. Oganessian considered a number of questions on the development of infrastructure and studies in heavy ion physics.

At the Council opening, JINR Director Academician G. Trubnikov presented a Seven-Year Plan for the Development of JINR for 2024–2030. JINR Vice-Di-

rector RAS Corresponding Member V. Kekelidze reported on the progress of the NICA megascience project and the current plans on the experimental programme of the complex. JINR Vice-Director S. Dmitriev presented the development roadmap of the JINR Innovation Centre.

On 6–8 July, the Meshcheryakov Laboratory of Information Technologies hosted the ***6th International Workshop on Deep Learning in Computational Physics (DLCP-2022)***. The workshop was organized together with the Skobeltsyn Institute of Nuclear Physics of the Lomonosov Moscow State University (SINP MSU).

The workshop was devoted to the use of machine learning in particle astrophysics and high energy

Saint Petersburg, 4–8 July. G. N. Flerov Award holders with participants of the Meeting on Heavy Ion Physics and the visiting session of RAS Council on Heavy Ion Physics

The Meshcheryakov Laboratory of Information Technologies, 6–8 July.
Participants of the 6th International Workshop on Deep Learning in Computational Physics (DLCP-2022)

physics, but was not limited to these areas. Both modern machine learning methods in general and their application in natural sciences and education were also discussed.

More than 130 scientists (90 in person, over 40 remotely) from research centres of India, Kazakhstan, Mongolia, Poland, Romania, Serbia, Slovakia, Turkey, and Uzbekistan took part in the workshop. Russia was represented by participants from 15 universities and research centres. The conference was organized in five sessions, one of which was poster. Seven plenary and 34 sessional talks, as well as seven posters, were presented.

MLIT Director V. Korenkov opened the workshop with a report on the IT ecosystem being developed at the Laboratory. It comprises a platform for high-per-

Lipnya (Ivankovo Reservoir), 15–17 July.
Participants of the 26th Summer School for Young Scientists and Specialists “Lipnya-2022”

formance computing, data acquisition and storage, Big Data analysis using artificial intelligence, in particular, deep learning. He also highlighted that there existed a multitude of tasks related to machine and deep learning within computing for different studies underway at JINR.

G. Ososkov, who laid the foundations for applying machine learning methods to JINR tasks, in particular, in high energy physics, delivered a highly interesting talk on the history of the formation of approaches for solving tasks using artificial neural networks and on their application in the tasks of charged particle trajectory reconstruction in high energy physics experiments, of nuclear reaction data analysis, of the prediction of liquid nitrogen flow rate during the operation of reactor, of plant disease detection, etc.

Representatives of SINP MSU spoke about their projects in which machine learning methods are actively applied. L. Dudko talked about the history and major applications of deep neural networks in the CMS experiment at the LHC (CERN). L. Kuzmichev delivered an overview report on the TAIGA astrophysical complex, and Workshop Co-Chairman A. Kryukov dwelled upon machine learning methods for data analysis within the TAIGA experiment, including for event simulation, particle identification and gamma-energy spectrum reconstruction.

The report of O. Streltsova (MLIT) was devoted to the information system (IS), being developed jointly with LRB colleagues, for the analysis of data from radiobiological studies underway at JINR. The algorithmic block of the IS is based on the methods of machine and deep learning, as well as of computer vision.

M. Zuev (MLIT) spoke about the ML/DL/HPC ecosystem deployed on the HybriLIT heterogeneous platform, which provides new opportunities for applied research. The talk by A. Ilyina (MLIT) on the analytical platform for labor market analysis evoked great interest among the audience.

A number of plenary talks were made by representatives of the IT industry, who were sponsors of the workshop. Among them were Softline, RSC Group, and IT Cost. Their reports provided an IT development analysis and presented the specifics of the transition to Russian IT products.

The ***International Conference on Quantum Field Theory, High-Energy Physics, and Cosmology*** was held in Dubna from 18 to 21 July. It was organized jointly by the Bogoliubov Laboratory of Theoretical Physics of JINR, the Institute for Nuclear Research of the Russian Academy of Sciences, and the Skobeltsyn Institute of Nuclear Physics of the Lomonosov Moscow State University.

Thanks to the co-chairs of the conference, D. Kazakov (BLTP JINR), V. Rubakov (INR RAS) and E. Boos (SINP MSU), more than 180 specialists in different fields of modern theoretical physics gathered at BLTP, in the shortest possible time. The broad range of conference topics covered problems of quantum field theory and gravity, dark matter and cosmology, accelerator and non-accelerator physics. In addition, special attention was paid to neutrino physics, the three-dimensional structure of hadrons, and quantum chromodynamics at high temperatures and densities.

The conference was representative and productive. Scientists from Kazan, Moscow, Novosibirsk,

The Bogoliubov Laboratory of Theoretical Physics, 18–21 July.
The International Conference on Quantum Field Theory, High-Energy Physics, and Cosmology

Protvino, Rostov-on-Don, Samara, St. Petersburg, Tomsk and Yaroslavl (Russia), as well as from Bulgaria, France, India, and Ireland took part in the meeting. Review talks were delivered by the well-known experts in particle physics, theory of gravity and cosmology, such as K. Postnov (SAI MSU), D. Gorbunov (INR RAS), S. Troitsky (INR RAS), R. Lee (BINP SB RAS), A. Myagkov (NRC KI – IHEP), A. Olshevskiy (JINR), and A. Leonidov (LPI RAS).

The interest in the conference turned out to be so great that the Organizing Committee received more than 180 applications for oral talks and made every effort to ensure that most of them were included in the schedule. Five parallel sections corresponding to the conference topics were organized. Within four days, 135 parallel talks were given. Most of the speakers managed to come to Dubna in person. It is also worth noting a significant number of young scientists among the participants of the conference. Many of them had the opportunity to give a talk and discuss their results both at the auditoriums and in a more informal setting. A separate poster section for senior students was organized during the coffee breaks.

Interesting talks on modern topics undoubtedly contributed to numerous and, in some cases, heated discussions. They stimulated the exchange of ideas and the establishment of scientific contacts. The participants noted the high level of organization, as well as the warm and friendly atmosphere.

The proceedings of the conference will be published in the journal "Particles and Nuclei, Letters". More information and the talk slides can be found on the website https://indico.jinr.ru/e/qft2022.

On 21–24 September, the traditional ***14th International Scientific Workshop in Memory of Professor V. Sarantsev "Problems of Colliders and Charged Particle Accelerators. Applied Researches on Accelerators"*** was held in the Resort Hotel "Dubna" (Alushta). The seminar has been held in Alushta since 2005. The event was organized jointly by the Joint Institute for Nuclear Research, the Institute of Nuclear Physics of SB RAS, and the Scientific Council for Charged Particle Accelerators of the Russian Academy of Sciences.

The workshop was aimed at exchanging information and discussing issues of accelerator science and technology, physics of beams of charged particles, the development of new projects of lepton and hadron colliders, modernization of operating facilities, the use of accelerators for scientific and applied aims, and the involvement of young scientists in solving problems of accelerator technologies. The current state of the NICA megascience complex and the SKIF synchrotron were widely discussed. On 23 September, on the birthday of V. Sarantsev, a memorable report "Touches to the Portrait of a Scientist" was in the programme.

A total of 49 oral and 62 poster presentations were shown during the workshop. Representatives of the largest accelerator centres of Russia were among speakers.

According to the organizers, the workshop, with its international status, is largely a forum where all Russian accelerator centres present their latest results. In addition, the interest in the current workshop is due to the fact that it takes place against the background of the increasing role of domestic manufacturers of accelerator technology. Selected reports of the seminar will be published in the journal "Particles and Nuclei, Letters" in Russian and English.

On 10–14 October, the traditional ***7th International Conference "Models in Quantum Field Theory"***, dedicated to the 82nd anniversary of Professor A. Vasiliev and the 80th anniversary of Professor V. Lyakhovsky, was held at the Euler International Mathematical Institute in Saint Petersburg. The conference was organized by the Joint Institute for Nuclear Research, Saint Petersburg State University, Euler International Mathematical Institute, and Konstantinov Petersburg Nuclear Physics Institute of the National Research Centre "Kurchatov Institute".

The conference programme covered a wide range of problems in theoretical and mathematical physics. The plenary and section reports presented the results and the latest scientific achievements in the study of high-energy physics problems and complex stochastic classical systems using quantum field theory methods.

In the opening plenary report of the conference, Professor M. Hnatic (JINR) spoke about the outstanding contribution of Professor A. Vasiliev to the development of methods of quantum field theory in the study of phase transitions, turbulence, transport phenomena and other related problems, and about the subsequent development of his ideas in the works of his students and followers who formed the unique "Vasiliev school". In the second plenary report, Professsor D. Kazakov (JINR) reported on his and his students' latest achievements in the study of non-renormalizable theories, and then Professor E. Akhmetov (MIPT and ITEP) spoke about the analytic properties of correlation functions in Minkowski and de Sitter spaces.

Topics related to the physics of elementary particles, quantum gravity, black hole physics were covered in plenary reports by Professors I. Aref'eva (MI RAS), V. Shabaev (SPbSU), V. Braguta (JINR), I. Buchbinder (TSPU), D. Gorbunov (INR RAS), A. Grib (HSPU), and S. Paston (SPbSU). Professors Yu. Pismak (SPbSU), M. Nalimov (SPbSU and JINR), and K. Wiese (LPT ENS, Paris) reported on the features of solving stochastic problems of classical and quantum physics by quantum field theory methods. On the last day of the conference, reports in the field of mathematical physics by Professors A. Isaev (JINR), A. Lachowska (EPFL, Lausanne) and S. Derkachev (POMI RAS) were made. In addition to these 16 plenary presentations, 82 sectional presentations were given. Their high scientific level and the meaningfulness of the results presented are typical for regular con-

ferences dedicated to the outstanding scientist and teacher, Professor of St. Petersburg State University A. Vasiliev. The conference participants were given a collection of memoirs about him, published by the JINR Publishing Department.

The unexpectedly high number of participants — there were more than 130 of them — testifies to the great interest in the subject of the conference. It is gratifying to note that a significant part of those present were young scientists, graduate students and even master's students from different universities. The conference was attended by scientists from Belarus, Brazil, France, Germany, Japan, Mongolia, Russia, Slovakia and Vietnam.

Articles on the best reports, after the standard review process, are planned for publication in the journal "Theoretical and Mathematical Physics". Detailed information about the conference can be found at https://indico.jinr.ru/event/1099/.

On the same dates, St. Petersburg hosted a satellite meeting — ***III International Workshop "Lattice and Functional Techniques for QCD"***, organized by JINR and SPbSU. The participants had the opportunity to attend the presentations of both events.

On 21 October, an international seminar ***"Study of the Properties of Matter in Experiments with Kaons and Baryons"***, dedicated to the 75th anniversary of JINR Vice-Director and Leader of the NICA megascience project V. Kekelidze, was held in the Conference Hall of the Veksler and Baldin Laboratory of High Energy Physics. On this day, his students and colleagues addressed many warm words to him. The reports presented provided a lot of information about experiments and projects led by V. Kekelidze in different years on behalf of JINR.

JINR Director Academician G. Trubnikov presented V. Kekelidze with the Rosatom medal "For Contribution to International Cooperation in the Nuclear Industry". In his speech, JINR Vice-Director L. Kostov indicated that V. Kekelidze made an invaluable contribution to such fields of modern experimental physics as the study of elementary particles, processes of the production and decay of hadrons, and much more.

At the ceremonial part of the seminar, MLIT Director V. Korenkov, VBLHEP Deputy Director for Scientific Work A. Sorin, NRNU MEPhI Rector V. Shevchenko, and Chief Researcher of the Institute of Nuclear Physics and Engineering of NRNU MEPhI A. Petrukhin congratulated V. Kekelidze. VBLHEP Acting Director A. Butenko and Head of VBLHEP's Division of Physics at Colliding Beams D. Peshekhonov congratulated him on behalf of the VBLHEP team. SINP MSU Director E. Boos thanked V. Kekelidze for many years' support of the cooperation, in particular, in the field of the construction of NICA detectors. There were also greetings from the Nuclear Regulatory Agency of Bulgaria and Belarusian colleagues from JSC SOL instruments, the organization involved in the LHC and NICA experiments.

At the seminar, speakers delivered a number of scientific reports. Academician I. Meshkov spoke about the history of the idea and creation steps of the NICA megascience project. Leading Researcher of the Relativistic Nuclear Physics Laboratory of Petersburg Nuclear Physics Institute of the National Research Centre "Kurchatov Institute" (PNPI NRC KI) V. Riabov (MPD), Head of DLNP's Department of Colliding Beam Physics A. Guskov (SPD), and Head of the Department of the Baryonic Matter Investigations at the VBLHEP Nuclotron M. Kapishin ("From physics at HERA to physics at BM@N") dedicated their reports to the three main detectors of the complex. Chairman of the JINR Programme Advisory Committee for Particle Physics I. Tserruya (Weizmann Institute, Israel) presented his report "Dileptons at NICA: Challenges and Opportunities" online. E. Goudzovski (University of Birmingham, UK) spoke about challenges in experiments with kaons via videoconference. P. Hristov (CERN) spoke about multi-quark states.

On 24–28 October, the ***26th International Conference of Young Scientists and Specialists (AYSS-2022)*** was held at MLIT in a mixed format. About 150 young scientists from abroad and Member States took part in the conference personally, and more than 90 participants joined it online.

Scientists gave lectures on the latest theoretical, experimental, and applied research carried out around the world, focusing on the main results obtained at JINR. The conference programme included overview lectures on neutrino astronomy, life sciences, neural networks, particle physics, modern theoretical problems, the status of the MPD experiment, the NICA accelerator complex, and the accelerator complexes of FLNR. There were two poster sessions, one of which was organized online.

Full-time excursions were organized to several Laboratories of the Institute — FLNP, VBLHEP, FLNR, LRB, MLIT, as well as to an interactive exposition "JINR Basic Facilities" at the Cultural Centre "Mir". Remote participants were given the opportunity to get acquainted with JINR's activities in the form of an online tour of the basic facilities.

During the conference, young scientists presented about 150 oral reports in various thematic sections, 20 (10) poster reports in a full-time (online) session. The chairmen of the sections and the jury selected the best reports in different areas. The winners were awarded certificates of honor and backpacks with the symbols of the conference.

On 14–18 November, the ***1st JINR Autumn School of Information Technologies*** was held at MLIT. The Autumn School became the first stage in a series of JINR Schools of Information Technologies.

The JINR School of Information Technologies aims to involve young specialists in solving tasks in various fields of science using state-of-the-art information technologies. More than 60 senior students from 13 Russian universities, including those where JINR Information Centres operate, took part in the event.

The Veksler and Baldin Laboratory of High Energy Physics, 21 October.
The International scientific seminar “Study of the Properties of Matter in Experiments with Kaons and Baryons” dedicated to the 75th anniversary of JINR Vice-Director RAS Corresponding Member V. Kekelidze




13:14


:26


13:35

The teachers of the school were MLIT specialists, as well as invited lecturers from other laboratories of the Institute and universities of Russia. Each day was dedicated to one of the IT areas being developed and applied in JINR projects.

MLIT Director V. Korenkov opened the school. In his welcoming speech, he highlighted that the school involves long-term cooperation of students with the Institute, which will contribute to their professional training as specialists of a very high level.

JINR Director G. Trubnikov introduced the participants of the school to the JINR Long-Term Development Strategy for 2024–2030 and its flagship projects. V. Korenkov devoted his report to the status and prospects of development of MLIT, including the JINR Multifunctional Information and Computing Complex (MICC). V. Voevodin, Director of the MSU Research Computer Centre and the MSU branch in Sarov, a leading Russian specialist in the field of computer technology, presented his report on the supercomputer systems existing in the world and features of algorithm structures. Professor R. Smelyansky (CMC MSU) spoke about the trends in the development of the computing infrastructure, and A. Avetisyan (ISP RAS) delivered a talk on "Computer Security and Secure Software".

A presentation of the modernized Govorun supercomputer, the performance of which enhanced by 23.5% and reached 1.1 PFlops, was also held within the school. A. Moskovsky (CJSC "RSC Technologies") spoke about the creation, modernization and technologies used in the Govorun supercomputer, and D. Podgainy (MLIT) dwelled upon the tasks solved on the Govorun supercomputer.

On other days of the school, its participants learned about distributed and high-performance computing to solve tasks at the NICA accelerator complex and of the JINR neutrino programme. D. Oleynik (MLIT) introduced the listeners to the basics of data processing for high-energy physics (HEP) experiments, and I. Pelevanyuk (MLIT) spoke about distributed computing based on the DIRAC platform. K. Gertsenberger (VBLHEP) and O. Rogachevsky (VBLHEP) delivered talks on information services for supporting the BM@N experiment and on computing for the MPD experiment at the NICA collider. This direction was continued with lectures by J. Busa, Jr., "Automation of Assembling Large Packages on the Example of MPDRoot" (MPDRoot is a platform for data simulation and analysis within the MPD experiment), by F. Prokoshin (DLNP), who shared plans for using the EventIndex catalog implemented for the ATLAS experiment at the LHC and its adaptation for the SPD facility at the NICA collider, and by A. Zhemchugov (DLNP), who spoke about the Geant4 simulation package as the main simulation tool in HEP.

The direction "Mathematical Modeling, Numerical Methods and Algorithms for Solving JINR Applied Tasks" was opened by a lecture of Yu. Kalinovsky (MLIT), who spoke about the modeling of physical processes in a dense and hot nuclear medium, and D. Goderidze (MLIT) acquainted the students with

The Meshcheryakov Laboratory of Information Technologies, 24–28 October.
Participants of the 26th International Conference of Young Scientists and Specialists

The Meshcheryakov Laboratory of Information Technologies, 14–18 November.
1st JINR Autumn School of Information Technologies

the parallel implementation of such algorithms. O. Grigoryan (MLIT) and A. Ayriyan (MLIT) devoted their lecture to neutron star simulation using a neural network approach, and I. Rahmonov (BLTP) described the mathematical modeling of hybrid Josephson structures that consist of superconductors and magnets. Within this area, the students participated in a tutorial on tools based on Python libraries and the Jupyter ecosystem to solve scientific and applied tasks, which was prepared by the Heterogeneous Computing Group of MLIT JINR together with specialists from the Institute's Laboratories (A. Rahmonova, A. Vorontsov, A. Nechaevsky, I. Rahmonov, M. Bashashin, M. Zuev, O. Streltsova, and Yu. Butenko).

The direction "Machine Learning and Artificial Intelligence for Solving JINR Applied and Scientific Tasks" was presented by lectures of Professor G. Ososkov (MLIT) "Applied Aspects in HEP Tasks", of A. Uzhinsky (MLIT) "Machine Learning in Applied Tasks Solved at MLIT" and of V. Papoyan (MLIT) "Methods of Machine Learning in Particle Identification Tasks".

The last day of the school was devoted to Big Data analytics. P. Zrelov (MLIT) introduced the school participants to the subject of the direction, S. Belov (MLIT) and A. Artamonov (Head of the Department of Competitive Systems Analysis, NRNU MEPhI) spoke about Big Data analytics technologies and their practical application. During the tutorial held by E. Antonov, M. Ulizko, R. Tukumbetova (NRNU MEPhI), the students got acquainted with the Kibana data analytics and visualization platform and the ElasticSearch search engine.

Talks on the JINR social infrastructure (A. Tamonov, SIM Office), on the Institute's educational programme (A. Verkheev, UC), and on the activities of the JINR AYSS (V. Rozhkov, DLNP) were delivered specially for the school participants.

The school participants visited exciting excursions: interactive exposition "JINR Basic Facilities" at the Cultural Centre "Mir", where they were able to see the models of JINR's basic facilities and learn the principles of their operation; Factory of Superconducting Magnets at VBLHEP; Govorun supercomputer and JINR Multifunctional Information and Computing Complex at MLIT; and a sightseeing tour of Dubna.

At the end of each day, fruitful discussions were held between the students and the teachers. The students asked questions on the materials of lectures and tutorials, and talked over possible joint work on topics of their graduation theses. At the closing of the school, all participants were awarded personal certificates.

The presentations of the lectures, photos and video materials are available at the school website http://itschool.jinr.ru in the section "JINR Autumn School of Information Technologies".

## Conferences, Schools, and Meetings Held by JINR in 2022*

| No. | Name | Place | Date | Number of participants |
|---|---|---|---|---|
| 1. | 55th Meeting of the Programme Advisory Committee for Condensed Matter Physics (online) | Dubna | 20–21 January | 68 |
| 2. | 56th Meeting of the Programme Advisory Committee for Particle Physics (online) | Dubna | 24 January | 31 |
| 3. | International Student Practice (for South Africa; online) | Dubna | 24 January – 4 February | 27 |
| 4. | 55th Meeting of the Programme Advisory Committee for Nuclear Physics (online) | Dubna | 27 January | 25 |
| 5. | 17th International DIAS-BLTP Winter School "Supersymmetry and Integrability" (hybrid format) | Dubna | 31 January – 4 February | 83 |
| 6. | 20th International Training Programme "JINR Expertise for Member States and Partner Countries" (JEMS-20) | Dubna | 14–18 February | 13** |
| 7. | 32nd Meeting of the Joint Committee on Collaboration IN2P3–JINR (online) | Dubna | 18 February | 16 |
| 8. | 131st Session of the JINR Scientific Council (hybrid format) | Dubna | 24–25 February | 62 |
| 9. | International Student Practice (for Egypt) | Dubna | 28 February – 25 March | 29** |
| 10. | Scientific Seminar Dedicated to the 65th Anniversary of Professor A. Isaev | Dubna | 11 March | 110 |
| 11. | 16th International Conference "Parallel Computational Technologies" (PCT-2022) | Dubna | 29–31 March | 121 |

* A number of conferences were held jointly with other organizations.

** Without participants from JINR.

| No. | Name | Place | Date | Number of participants |
|---|---|---|---|---|
| 12. | Intrenational Workshop on Elementary Particle Physics and Nuclear Physics | Almaty, Kazakhstan | 24–30 April | 42 |
| 13. | 9th Collaboration Meeting of the MPD Experiment at the NICA Facility (hybrid format) | Dubna | 25–27 April | 145 |
| 14. | 5th International Conference "Condensed Matter Research at the IBR-2" (online) | Dubna | 25–29 April | 160 |
| 15. | Meeting of the JINR Finance Committee (hybrid format) | Dubna | 23 May | 46 |
| 16. | Session of the Committee of Plenipotentiaries of the Governments of the JINR Member States (hybrid format) | Dubna | 25 May | 97 |
| 17. | Festive Events Dedicated to the 65th Anniversary of the Flerov Laboratory of Nuclear Reactions | Dubna | 25–27 May | 402 |
| 18. | 11th International Conference of Young Scientists and Specialists (Alushta-2022) | JINR Resort Hotel "Dubna", Alushta, Russia | 5–12 June | 71 |
| 19. | International Scientific Workshop Dedicated to the 20th Anniversary of JINR Participation in Dimuon Physics Programme within the CMS Experiment at the LHC | Dubna | 23–24 June | 73 |
| 20. | 11th International Scientific School for Physics Teachers | Dubna | 26 June –2 July | 21 |
| 21. | 4th Internatioal Summer School for Young Scientists "Modern Information Technologies for Solving Scientific and Applied Problems" | Vladikavkaz, Russia | 29 June – 1 July | 100 |
| 22. | 34th International Computer School (ICS-2022) | Dubna (Ratmino) | 3–18 July | 55 |
| 23. | Workshop on Heavy Ion Physics (with a Visiting Session of the RAS Council on Heavy Ion Physics) | Saint Petersburg, Russia | 4–8 July | 150 |
| 24. | 6th International Workshop on Deep Learning in Computational Physics (DLCP-2022) | Dubna | 6–8 July | 113 |
| 25. | 18th International Conference on Symmetry Methods in Physics (SYMPHYS-XVIII) | Yerevan, Armenia | 10–16 July | 80 |
| 26. | 26th Summer School for Young Scientists and Spesialists "Lipnya-2022" | Lipnya Island, Tver Region, Russia | 15–17 July | 90 |
| 27. | Multidisciplinary School-Seminar "Summer School" (Workshop "Element 105" as part of the school was held from 16 to 26 July) | Recreation Centre "Volga", Tver Region, Russia | 16 July – 20 August | 1300 |
| 28. | International Conference on Quantum Field Theory, High-Energy Physics, and Cosmology (hybrid format) | Dubna | 18–21 July | 184 |
| 29. | Moscow International School of Physics 2022 | Dubna | 24 July – 2 August | 108 |
| 30. | International Workshop "Supersymmetries and Quantum Symmetries" (SQS'22) | Dubna | 8–13 August | 65 |
| 31. | Science School for Egyptian Students of the Children's University of the Egyptian Academy of Scientific Research and Technology | Dubna | 12–16 September | 15* |
| 32. | 9th Collaboration Meeting of the BM@N Experiment at the NICA Facility (hybrid format) | Dubna | 13–16 September | 127 |
| 33. | Virtual Workshop between IMP and FLNR JINR for Superheavy Element Research | Dubna, Lanzhou, China | 15 September | 23 |
| 34. | 14th International Scientific Workshop in Memory of Professor V. Sarantsev "Problems of Colliders and Charged Particle Accelerators. Applied Researches on Accelerators" (hybrid format) | Alushta | 21–24 September | 112 |

* Without participants from JINR.

| No. | Name | Place | Date | Number of participants |
|---|---|---|---|---|
| 35. | 132nd Session of the JINR Scientific Council | Dubna | 29–30 September | 63 |
| 36. | 3rd Meeting of the Collaboration of the SPD Experiment at the NICA Complex | Dubna | 3–6 October | 100 |
| 37. | Scientific School for Teachers from Primorsky Krai | Dubna | 3–7 October | 10* |
| 38. | III International Workshop "Lattice and Functional Techniques for QCD" | Saint Petersburg, Russia | 10–14 October | 60 |
| 39. | 7th International Conference "Models in Quantum Field Theory" | Saint Petersburg, Russia | 10–14 October | 134 |
| 40. | International Conference "Modern Problems of Condensed Matter Theory" | Dubna | 17–22 October | 89 |
| 41. | International Seminar "Study of the Properties of Matter in Experiments with Kaons and Baryons" Dedicated to the 75th Anniversary of V. Kekelidze, Corresponding Member of RAS, JINR Vice-Director | Dubna | 21 October | 250 |
| 42. | Workshop "Close Prospects on Superheavy Element Research" | Dilijan, Armenia | 22–27 October | 12 |
| 43. | 26th International Conference of Young Scientists and Specialists (AYSS-2022) | Dubna | 24–28 October | 356 |
| 44. | Anniversary Conference "Current Problems in Radiation Biology. To the 60th Anniversary of the RAS Scientific Council on Radiobiology" (hybrid format) | Dubna | 25–27 October | 100 |
| 45. | Meeting of the Working Group under the CP Chairman for JINR Financial Issues | Dubna | 25 October | 25 |
| 46. | Scientific Seminar Dedicated to the 65th Anniversary of the Frank Laboratory of Neutron Physics (hybrid format) | Dubna | 28 October | 100 |
| 47. | Workshop on Theoretical Physics | Cairo/Giza, Egypt | 29 October–2 November | 25 |
| 48. | 21st International Training Programme "JINR Expertise for Member States and Partner Countries" (JEMS-21) | Dubna | 7–11 November | 22* |
| 49. | 10th Collaboration Meeting of the MPD Experiment at the NICA Facility (hybrid format) | Dubna | 8–10 November | 166 |
| 50. | 1st JINR Autumn School of Information Technologies (hybrid format) | Dubna | 14–18 November | 110 |
| 51. | Meeting of the JINR Finance Committee (hybrid format) | Hurghada, Egypt | 21 November | 68 |
| 52. | Session of the Committee of Plenipotentiaries of the Governments of the JINR Member States | Hurghada, Egypt | 23 November | 82 |
| 53. | 12th Meeting of the Joint Coordination Committee on the Egypt–JINR Cooperation | Hurghada, Egypt | 24 November | 18 |
| 54. | Baikal Collaboration Workshop | Dubna | 5–9 December | 55 |
| 55. | Intership for Schoolchildren from Yamalo-Nenets Autonomous Okrug | Dubna | 5–9 December | 37 |
| 56. | Seminar Devoted to the 85th Anniversary of the Birth of Academician V. Kadyshevsky | Dubna | 15 December | 90 |

There were 6 meetings of the JINR Science and Technology Council.

JINR was one of the organizers of the Virtual International Workshop on Physics Performance Studies at NICA (NICA-2022), the 22nd Baikal Summer School on Physics of Elementary Particles and Astrophysics, the Natural Science School in Kamchatka, the 28th International Seminar "Nonlinear Phenomena in Complex Systems", the 4th International Scientific Forum "Nuclear Science and Technologies", and other events.

There were also held Physics Days 2022, Training Course for Young Scientists of CIS Countries, Student Programme (research training START), Technical Hackathon "Dubna-2022", Open Robotics Tournament (CyberDubna 2022).

* Without participants from JINR.


# INNOVATIVE ACTIVITY

# INNOVATIVE ACTIVITY

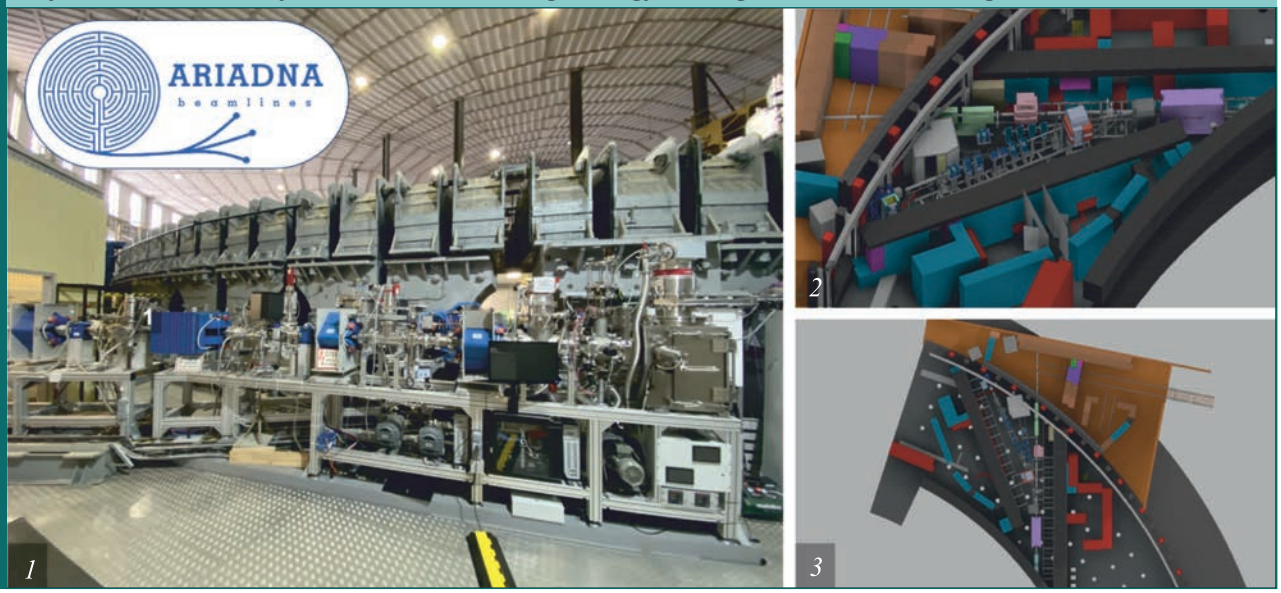
In 2022, the most important practical steps were taken to implement the flagship initiative of the Institute in the development of R&D infrastructure — the creation of an Innovation Centre for Nuclear Physics Research in the field of radiation biology, biomedical technologies, radiation materials science, as well as ecology and information systems, within which researchers and developers will have access to user infrastructure and new installations, having significant potential in terms of obtaining applied results and developing new technologies, such as:

— ARIADNA — user infrastructure based on derived NICA beams (beams with energies from MeV/nucleon to GeV/nucleon): life sciences, biomedical applications, research on radiation resistance of semiconductor electronics, nuclear physical data for new energy;
— an infrastructure for developments in the field of OMICS technologies and neuro-radiobiology: increased radiosensitivity, transgenic systems, targeted delivery (molecular vectors) and radionuclides;
— a complex based on the MSC-230 superconducting proton cyclotron for R&D in the field of beam therapy: the use of radio modifiers, flash therapy, radiation planning; pilot installation for medical centres;
— a complex based on the DC-140 cyclotron for testing electronic components, radiation materials science, development of track membrane technologies and their production;
— a 1st class radiochemical laboratory and a specialized accelerator (40 MeV) for the production of radioisotopes ($^{225}$Ac, $^{99m}$Tc) for nuclear medicine.

While creating the Innovation Centre, the following results were obtained in particular:

— participation of research and production enterprises in the activities of the ARIADNA collaboration based on the innovative infrastructure of the NICA complex, where the first high-energy ion beam ($^{54}$Xe, 3.8 GeV/nucleon) was obtained for applied work; the first irradiation session of samples from five partner organizations was conducted and the data processing was started. Cooperation has been established with industrial partners and developers in the field of research on the properties of innovative composite materials for the space industry, in the field of radiation chemistry and radiation modification of

The Veksler and Baldin Laboratory of High Energy Physics. Irradiation stations as part of the ARIADNA research infrastructure: *1* — Station Of CHip Irradiation (SOCHI); *2* — layout of the Irradiation Station of Components of Radioelectronic Apparatuses (ISCRA) and the Station of Investigation of Medico-Biological Objects (SIMBO); *3* — layout of the Station of High Energy Investigation in Nuclear Energetics (SHINE)



The Flerov Laboratory of Nuclear Reactions, 5–6 April.
A delegation from Northern (Arctic) Federal University named after M. V. Lomonosov (NArFU, Arkhangelsk) headed by Vice-Rector for Innovative Development of NArFU M. Eseev (right) on a tour of the FLNR nanocentre

polymers (together with the Skolkovo resident company), as well as high-temperature superconductivity (for more information, see the VBLHEP section of this Report);

— the stages of work provided for the construction plan of the MSC-230 medical superconducting cyclotron have been implemented in partnership with the NIIEFA of the Rosatom State Corporation. The formation of a research programme based on a medical cyclotron under construction, as well as pre-project work on the creation of a radiological department based on MSC-230, is included in the joint work plan of the Institute and the FMBA of Russia (more detailed information is provided in the DLNP section of this Report);

— the work provided for in the plan for the creation of a specialized cyclotron for applied research DC-140, including work on the preparation of the site for its placement and the manufacture of its parts and assemblies, has been completed. Based on the R&D laboratory of the CAP FLNR (Nanolab), custom-made work has been carried out on the manufacture of track membranes, as well as on the radiation modification of various materials, including for hydrogen energy technologies, water treatment and other applications. Prototypes of products and devices based on track membranes have been developed, including for biomedical applications (for more information, see the FLNR section of this Report);

— the SARRP (Small Animal Radiation Research Platform) X-ray irradiation unit, designed for radiobiological studies on small laboratory animals, has been put into operation. This installation has become an important component of the Institute's infrastructure in the field of OMICS technologies and neuro-radiobiology. The installation allows for a complete simulation of the radiation therapy cycle using X rays.

In order to introduce a small-size precision laser inclinometer developed at JINR's FLNP into the practice of monitoring seismic activity, the use of this device in the Kamchatka region has been started in a test mode.

The main preparatory work for the commissioning of the LINAC-200 accelerator complex at FLNP has been completed. The complex has several electron beam output zones with energies from 5 to 200 MeV for radiation materials science, testing and tuning of measuring and recording equipment, and the creation of innovative particle detectors.

To ensure and coordinate innovation activities at the Institute, the Innovations and Intellectual Property Department (IIPD) has been formed within the framework of the JINR Chief Engineer's Office (JINR CE Office). The functions of the department include the development and implementation of optimal approaches, formats of work with innovative projects, consulting and support of project teams in all aspects and at all stages of preparation and imple-

North Caucasus, 24 May.
Presentation of soil carbon mobile analysis prototype device developed at JINR at the opening of the Way Carbon polygon (*photo: Kadyrov Chechen State University*)

mentation of developments. The innovation group of the department is formed from representatives of Laboratories and managers of large projects of the Institute.

The key objectives of the IIPD are attraction of partners from industry and applied science, project content and development of the integration concept of the Innovation Centre, as well as preparation and support of interlaboratory projects, including in the field of LiveScience, EcoEnergy, BigData and QT, in the field of hydrogen energy.

In 2022, as part of the further development of JINR's technological cooperation with industrial partners, the Institute continued its interaction with research and production resident companies of the Dubna Special Economic Zone, participants of regional territorial clusters and other industrial partners and organizations.

As a result of organizing the interaction of development teams within the Institute, involving business partners in this interaction, a number of applied projects, including interlaboratory projects, were initiated, such as: the development of new-generation biomaterials for ophthalmology and dentistry, including on the basis of track membranes (Flerov Laboratory of Nuclear Reactions, Frank Laboratory of Neutron Physics); development of products based on track membranes functionalized by biomolecules (Flerov Laboratory of Nuclear Reactions, Dzhelepov Laboratory of Nuclear Problems); execution of custom research as part of the development of a new generation of plant protection products by a business partner (Dzhelepov Laboratory of Nuclear Problems, Frank Laboratory of Neutron Physics). Also, structural studies of various micellated preparations provided by one of the residents of the Dubna SEZ were carried out at FLNP. FLNR's Centre of Applied Physics, together with a partner from the SEZ, launched joint experiments aimed at creating products for laboratory diagnostics based on track membranes. In order to develop a project to create a matrix spectroscopic semiconductor X-ray detector operating in the mode of counting single photons (DLNP in cooperation with colleagues from VBLHEP and the Republic of Belarus), cooperation with the developer of a two-beam electron beam computed tomograph has been organized.

Cooperation has been organized with the Dokuchaev Soil Science Institute and the Voronezh State University of Forestry and Technologies named after G. F. Morozov to study the application of the labeled neutron method in the framework of climate projects and rational land use.

In order to optimize the work with the results of intellectual activity (RIA), including in terms of the interaction of the structural units of the Institute, as well as the authors of the RIA, in cooperation with the Internal Audit Service (IAS), the Legal Department and the Accounts Department, a draft Regulation has been drawn up on the organization of accounting and management of intellectual property rights at the Joint Institute for Nuclear Research, created during the implementation of the JINR TP, as well as under contracts, agreements, government contracts, programmes and projects, which are financed by funds supporting scientific, scientific-technical,

innovative activities within relevant agreements on the provision of grants for the implementation of scientific, scientific and technical programmes and projects.

Prerequisites have been created for the implementation of a project approach to the creation of service RIA at JINR, and the elaboration of mechanisms for handling rights to RIA created jointly or with the participation of industrial partners has begun. In cooperation with the Legal Department, the IAS and the Accounts Department, the preparation of a package of model agreements regulating the joint creation of RIA with a partner, the possession, use and disposal of joint RIA, as well as relations with the authors of such RIA, was ensured. The development of this approach was carried out jointly with the FLNR Centre of Applied Physics, as well as within an innovative project in the direction of "Artificial Intelligence and Computer Vision", implemented by LRB and MLIT together with the South Ural State University.

In order to find technological sites for the manufacture of non-standard equipment for JINR installations, the interaction of representatives of the Institute with a world-class scientific and educational centre Tulatech and a number of residents of the Dubna SEZ was organized.

As part of the development of scientific and technical relations and the exchange of experience, scientists and specialists of the Institute and residents of the Dubna SEZ are regularly familiarized with the opportunities that open up mutual access to the research and production infrastructure of JINR and residents of the SEZ.

Representatives of the IIPD took part in the examination and certification of innovative projects of residents of the Digital Garage of the Dubna SEZ.

In order to expand the use of the JINR R&D infrastructure by industrial partners, as well as the use of innovative products of private fast-growing high-tech companies in Russia, the Institute has established cooperation with the association "National Champions: Fast-Growing Technology Companies".

The following results have been achieved in the field of industrial intellectual property protection. Cooperation with the Federal Institute of Industrial Property (FIIP) of the Federal Service of the Russian Federation for Intellectual Property (Rospatent) continued on JINR patent applications that passed the formal examination of the FIIP of Rospatent in 2020–2022.

In order to determine the technical level of new elaborations of JINR employees for patentability, an examination of a number of design elaborations was carried out, including the definition of objects of legal protection and their classification in accordance with the International Patent Classification (IPC), as well as the search for analogues and prototypes. Together with the laboratory staff, reports on patent research were prepared.

For eight elaborations, in collaboration with the authors, packages of submission documents were prepared and forwarded to RF Rospatent for patents on inventions.

Six RF patents for inventions have been received:

— (RU) 2765830 "Method for changing final energy of proton beam used for flash therapy" by S. Dolya, V. Smirnov;
— (RU) 2770864 "Device for resonance charge of capacitor" by S. Dolya, V. Smirnov;
— (RU) 2772969 "Cold neutron storage ring" by Yu. Nikitenko;
— (RU) 2776157 "Compact superconducting cyclotron for proton therapy using beams with ultrahigh dose rate (FLASH)" by G. Karamysheva, O. Karamyshev, I. Lyapin, V. Malinin, D. Popov, G. Trubnikov, G. Shirkov, S. Shirkov;
— (RU) 2776102 "Method for positioning scintillation cells in segmented detectors and apparatus for implementation thereof" by S. Afanasiev, Yu. Ershov, A. Golunov, N. Gorbunov;
— (RU) 2776326 "Method for express analysis of inhibition of living protein molecules" by S. Dolya.

At the end of the year, a positive decision was also received by RF Rospatent for the grant of a patent under application 2022113781 "Device for producing cold and ultracold neutrons" by S. Dolya, Yu. Nikitenko.

Three computer programs were registered in the Register of programs for electronic computers of Rospatent: 2022665357 "JINR staff business trip registration program" by V. Borisovsky, V. Eliseev, T. Tyupikova; 2022665558 "Program of registration of business trips of foreign employees arriving at JINR" by V. Borisovsky, V. Eliseev, T. Tyupikova; 2022667974 "Program of maintaining a directory of organizations associated with JINR scientific research" by V. Borisovsky, V. Eliseev, T. Tyupikova.

Sets of application documents for obtaining registration certificates have been prepared and submitted to RF Rospatent:

— "PLT-Viewer monitoring and data accumulation program for measuring currents of superconducting structural magnets of synchrotron Booster and Nuclotron" by A. Panfilov, V. Karpinsky, S. Kirov, A. Kozlyakovskaya, A. Sergeev, V. Tovstukha;
— "JINR International Cooperation Accounting Database" by V. Borisovsky, V. Eliseev, T. Tyupikova.

Information on patents obtained and registered programs was submitted to the JINR Accounts Department for payment of royalties.

In 2022, 87 JINR patents were supported. Work was carried out with Laboratories to identify patents with a priority of more than 10 years, the need for further maintenance of which is absent.

In the field of patent and information work in 2022, JINR received in electronic form 36 issues of the Rospatent bulletin "Inventions. Utility Models". The information published in these bulletins has been processed taking into account the JINR topics.

The results of processing are presented in 12 issues of the IIPD bulletin “Patents”, which are sent to departments of the Institute to subscribers in both electronic and paper form. The electronic database of the IIPD bulletins is also available on the website of the department (https://oliis.jinr.ru/).

The information sheets of IIPD on the receipt of new patents by the Institute and the state registration of other objects of industrial intellectual property (computer programs and databases) are drawn up. This information is regularly included in the “Patents” section on the JINR website (http://www.jinr.ru/posts/category/patents-ru/), as well as in the sections of the IIPD website “Valid Patents” (https://oliis.jinr.ru/index.php/patentovanie-2/8-russian/25-dejstvuyushchie-patenty-oiyai) and “Computer Programs Registered by JINR” (https://oliis.jinr.ru/index.php/patentovanie-2/8-russian/28-programmy).


# CENTRAL SERVICES

# PUBLISHING DEPARTMENT

In 2022, the Publishing Department issued 69 titles of publications and 44 titles of official documents.

In the spring of 2022, work on the book of diaries of the first director of JINR Dmitry Ivanovich Blokhintsev was completed. The diaries cover the period of D. I. Blokhintsev's life and work from 1955 to 1975, introduce the history of the formation and development of JINR, and reflect the author's personal attitude to events and people. A lot of work has been done on deciphering the diary entries, typing and editing the texts, translating foreign-language fragments, compiling the reference apparatus, and preparing the original layout.

The books published in 2022 include the monograph by G. N. Timoshenko "Radiation Protection of High-Energy Accelerators", the book by N. N. Prislonov "Dubna: Years of Achievements. Essays on the Modern History of the Science City", the book of memoirs by E. P. Shabalin "On the Ship of My Dreams: Notes of a Reactor Specialist", a collection of memoirs about A. N. Vasiliev "Quantum Field Theory: It's a No-Brainer", the book by V. A. Bednyakov "Defender Science", a collection of selected works by A. I. Frank "Problems of Long-Wave Neutron Optics", and memoirs of V. A. Bednyakov "Julian Aramovich Budagov... Promised to Live to Be 100 Years Old".

A Book of Abstracts of the international conference "Condensed Matter Research at the IBR-2" (Dubna, April 25–29, 2022) and proceedings of the conference "Topical Problems of Radiation Biology" (Dubna, October 25–27, 2022) have been issued.

JINR Annual Reports for 2021 (in Russian and English) have been published.

In 2022, six issues of the journal "Physics of Elementary Particles and Atomic Nuclei" (brief name "Particles and Nuclei"), including 122 papers, were published. Issue 2 contains the proceedings of the LXX International Conference "NUCLEUS-2020. Nuclear Physics and Elementary Particle Physics. Nuclear Physics Technologies" (Saint Petersburg, May 26–30, 2020). Issue 4 contains the proceedings of the International Conference on Precision Physics and Fundamental Physical Constants (Stara Lesna, Slovakia, October 4–8, 2021). Six issues of the journal "Physics of Elementary Particles and Atomic Nuclei, Letters" (brief name "Particles and Nuclei, Letters"), which include 131 papers, were published. Issue 3 contains the proceedings of the Fifth International Conference "Modern Problems of Genetics, Radiobiology, Radioecology and Evolution" (GRRE) (Nor Amberd, Armenia, October 5–9, 2021). Issue 5 contains the proceedings of the XXV International Conference of Young Scientists and Specialists of JINR (Almaty, Kazakhstan, October 11–15, 2021).

The information bulletin "JINR News" continued to be published in Russian and English.

In 2022, 51 issues of the JINR weekly newspaper "Dubna: Science, Cooperation, Progress" were published.

Brochures about JINR and the flagship projects of the Institute prepared by the Press Centre, as well as leaflets about JINR, have been printed in Russian and English.

As part of the exchange of scientific publications, the following JINR publications were sent to organizations cooperating with the Institute all over the world: JINR preprints and communications, the information bulletin "JINR News", JINR Annual Reports, the journals "Particles and Nuclei" and "Particles and Nuclei, Letters".

The Publishing Department forwarded 97 papers containing the results of research of Dubna scientists to the editorial boards of journals, to various conferences, symposia, meetings and schools held both in the JINR Member States and in other countries. Papers of JINR staff members were submitted to the journals "Nuclear Physics", "Bulletin of the Russian Academy of Sciences: Physics", "Instruments and Experimental Techniques", "Nuclear Physics and Engineering", "Crystallography", "Journal of Surface Investigation. X-Ray, Synchrotron and Neutron Techniques", etc.

Work continued on placing periodicals and non-periodicals produced at JINR in the Russian Science Citation Index (RSCI) database on the platform of the Electronic Library System of the Scientific Electronic Library.

The Publishing Department fulfilled orders for printing photo posters and poster presentations of the Institute's staff members for submission to scientific forums. Information materials such as programs, notebooks, badges, diplomas and certificates were printed for conferences and meetings.

Publications issued by the JINR Publishing Department in 2022


At the request of the Laboratories and other JINR departments, bookbinding, photocopying and scanning of scientific-technical and engineering-design documentation were carried out. More than 115 thousand various forms have been printed.

New printing equipment, a modern high-performance digital printing machine Konica Minolta AccurioPress 7090, has been purchased.

# SCIENCE and TECHNOLOGY LIBRARY

In 2022, the JINR Science and Technology Library (STL) rendered services to 1770 readers. An electronic loan system has been implemented. Four thousand copies of publications were given out. As of 1 January 2023, the Library stock amounted to 431 171 copies, 195 264 of them being in foreign languages. Via the interlibrary loan system, 121 publications ordered by readers were received. Twenty-six requests from other libraries were completed. On the whole, the library received 1249 copies of books, periodicals, preprints and theses from all acquisition sources, including 137 publications in foreign languages. All the new publications were registered in the central catalogues, branch catalogues and in the information system "Absotheque".

There were 114 issues of the express bulletins "Books", "Articles", and "Preprints" published, including 5515 titles. Electronic versions of the bulletins are available on the page "New Acquisitions" of the JINR STL website and are distributed via e-mail. Subscription is available via the STL website in the section "Services": http://lib.jinr.ru/ntb_mail/newslist.html. The exhibitions of new acquisitions of books, preprints, periodicals and theses were arranged regularly, where 889 publications were displayed. Six topical exhibitions were organized, which displayed 530 publications.

The electronic catalogues of books, journals, articles, preprints and theses are available on Internet at http://lib.jinr.ru:80http://lib.jinr.ru:8080/OpacUnicode/80/OpacUnicode. In the electronic catalogue in the personal account, the readers can order requested literature and look through their reader's register forms.

"The Bibliographic Index of Papers Published by JINR Staff Members in 2021" (1439 titles) was prepared by the JINR STL and published by the JINR Publishing Department. The Index is available in the section "Services" on the Library's website http://lib.jinr.ru/buk/2021/bibl_uk.php.

Three biobibliographic indexes have been prepared. The database of papers of JINR scientists is available online. A total of 3024 JINR preprints and communications have been scanned and added to the electronic catalogue.

The STL received 80 titles of periodicals. Due to the Library subscription to the foreign journals, JINR scientists have access to full-text electronic versions of these journals.

Employees of the JINR Science and Technology Library on the background of the exhibition of new arrivals

Scientific Electronic Library is used by readers very actively. Due to the national electronic subscription of the RFBR, JINR scientists are provided with the electronic access to the full-text versions of journals of the following publishing houses: Elsevier, Springer, American Physical Society, American Institute of Physics, Wiley, IEEE Digital Library, as well as journals "Nature", "Science" and information retrieval databases "Web of Science" and "Scopus".

Within the project "History of JINR and Dubna in Books, Journals and Central Newspapers", 56 new bibliographic records have been introduced. The information system "Literature about JINR Scientists" (1020 records) has been put into service, which is available on the page of the site of JINR STL "Publications about JINR": http://who-is-who.jinr.ru/catalog3/main.html/.

In 2022, in exchange for JINR publications printed by the JINR Publishing Department, the Library received 143 publications from ten countries. Among them 96 issues were from Russia, 27 from Germany, 3 from France, and 4 from Japan.

In 2022, within the information system "Absotheque", the input of documents to electronic catalogue was for: books — 299 titles, journals — 1279 numbers, preprints — 554 titles, theses and author's abstracts — 119 titles, book articles — 486 titles, and journal articles — 4989 titles.

As of 1 January 2023, the total number of records in the information system "Absotheque" was 342 183.

On requirements of the JINR Directorate, briefing notes and statistics of indicators of publication activity of JINR scientists and their co-authors from other countries and organizations with the usage of Web of Science, Scopus, and RSCI have been prepared.

## PUBLICATION ACTIVITY OF JINR STAFF MEMBERS

According to the international database "Scopus" as of 28 December 2022, the total number of publications is 1137.

**Table 1.** Joint publications with authors from JINR Member States

| State* | Number of publications |
|---|---|
| Armenia | 119 |
| Azerbaijan | 99 |
| Belarus | 149 |
| Bulgaria | 122 |
| Cuba | 15 |
| Czech Republic | 118 |
| Egypt | 101 |
| Georgia | 95 |
| Kazakhstan | 37 |
| Moldova | 19 |
| Mongolia | 86 |
| Poland | 288 |
| Romania | 187 |
| Slovakia | 120 |
| Ukraine | 58 |
| Uzbekistan | 142 |
| Vietnam | 231 |

*In alphabetical order.

**Table 2.** Joint publications with authors from JINR Associate Members

| State* | Number of publications |
|---|---|
| Germany | 157 |
| Hungary | 347 |
| Italy | 271 |
| Serbia | 115 |
| South Africa | 95 |

*In alphabetical order.

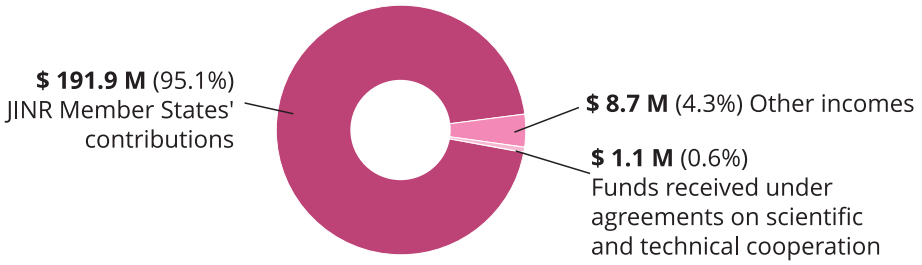
**Table 3.** Joint publications with authors from other states and regions

| State/Region* | Number of publications | State/Region* | Number of publications |
|---|---|---|---|
| United States | 310 | Ireland | 60 |
| China | 274 | New Zealand | 59 |
| United Kingdom | 235 | Sri Lanka | 59 |
| France | 221 | Montenegro | 58 |
| Turkey | 208 | Ecuador | 58 |
| India | 202 | Kuwait | 51 |
| Switzerland | 184 | Israel | 48 |
| Brazil | 175 | Qatar | 48 |
| Thailand | 151 | Hong Kong | 44 |
| Pakistan | 150 | Argentina | 42 |
| Netherlands | 147 | Slovenia | 42 |
| Greece | 146 | Morocco | 41 |
| Austria | 144 | Peru | 36 |
| Sweden | 140 | Philippines | 33 |
| Japan | 140 | Indonesia | 32 |
| Spain | 137 | Puerto Rico | 31 |
| Portugal | 129 | Palestine | 27 |
| Taiwan | 121 | United Arab Emirates | 21 |
| South Korea | 115 | Saudi Arabia | 19 |
| Finland | 106 | Algeria | 6 |
| Mexico | 106 | Uruguay | 5 |
| Colombia | 105 | Tajikistan | 5 |
| Croatia | 104 | Jordan | 5 |
| Australia | 96 | Paraguay | 4 |
| Norway | 81 | Madagascar | 4 |
| Chile | 78 | Nigeria | 2 |
| Denmark | 77 | Nepal | 2 |
| Belgium | 72 | Monaco | 1 |
| Canada | 67 | Lebanon | 1 |
| Iran | 65 | Bosnia and Herzegovina | 1 |
| Malaysia | 63 | Uganda | 1 |
| Cyprus | 63 | Tunisia | 1 |
| Lithuania | 62 | Sudan | 1 |
| Estonia | 60 | Bangladesh | 1 |
| Latvia | 60 | Albania | 1 |

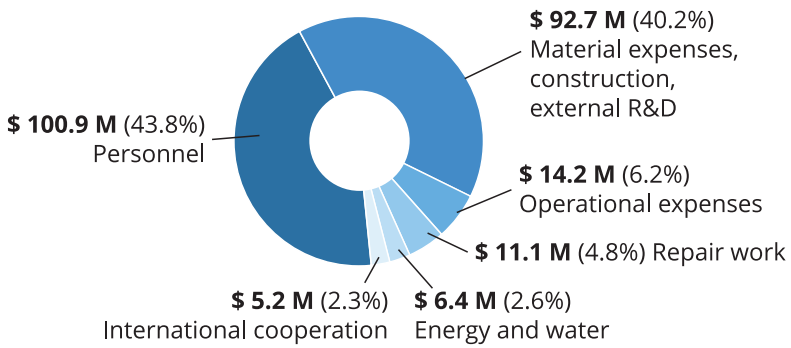
*In decreasing order of the number of publications.

# FINANCIAL ACTIVITIES

Execution of the JINR budget for 2022 in income — a total of **US$ 201.7 million**:




Execution of the JINR budget for 2022 in expenses — a total of **US$ 230.5 million**:




Contributions of JINR Member States for 2022 (in percent)

| State | % | State | % |
|---|---|---|---|
| Republic of Armenia | 0.36 | Republic of Moldova | 0.09 |
| Republic of Azerbaijan | 0.12 | Mongolia | 0.10 |
| Republic of Belarus | 0.73 | Republic of Poland | 5.08 |
| Republic of Bulgaria | 0.73 | Romania | 1.87 |
| Republic of Cuba | | Russian Federation | 80.86 |
| Czech Republic | 1.41 | Slovak Republic | 1.36 |
| Georgia | 0.16 | Ukraine | 1.59 |
| Republic of Kazakhstan | 1.52 | Republic of Uzbekistan | 0.52 |
| Democratic People's Republic of Korea | 0.21 | Socialist Republic of Vietnam | 1.41 |
| *Total:* | | | 100.0 |

In 2022, for the implementation of a number of scientific projects, the staff members of the Joint Institute for Nuclear Research received financial support of the Russian Foundation for Basic Research (RFBR), the Russian Scientific Foundation (RSF), and the Ministry of Science and Higher Education of RF.

RFBR financed JINR projects in the framework of the Competition of Projects of Fundamental Scientific Research (3 projects) and the Competition of the Initiative Projects of Fundamental Scientific Research, Conducted Jointly by the RFBR and the German Research Foundation (2 projects).

RSF rendered financial support to scientific projects of JINR within the following competitions: "Holding of Fundamental Scientific Research and Scientific Research in Separate Scientific Groups" (9 projects), "Holding of Fundamental Scientific Research and Scientific Research in Small Separate Scientific Groups" (1 project), "Holding of Fundamental Scientific Research and Scientific Research by International Scientific Communities — NSPC_China and DFG_Germany" (1 project), "Holding of Initiative Research by Young Scientists" (4 projects), "Holding of Research by Scientific Groups under the Guidance of Young Scientists" (1 project), and "Holding of Research on the Basis of Existing Scientific Infrastructure of the World Level" (1 project).

The RF Ministry of Science and Higher Education financed two projects: "Superheavy nuclei and atoms: Limits of nuclear mass and boundaries of the Periodic Table" and "Development and creation of elements of experimental stations based on pulsed and permanent neutron source".

# STAFF

As of 1 January 2023, the total number of the staff members at the Joint Institute for Nuclear Research was 5156 (without temporary staff members).

Working at JINR are: RAS Academicians V. Matveev, I. Meshkov, Yu. Oganessian, G. Trubnikov, B. Sharkov; RAS Corresponding Members V. Aksenov, A. Belushkin, L. Grigorenko, D. Kazakov, V. Kekelidze, E. Krasavin, A. Starobinsky, G. Shirkov; Members of other state Academies of Sciences B. Yuldashev, O. Chuluunbaatar; 41 Professors, 29 Assistant Professors, 220 Doctors of Science, and 602 Candidates of Science.

In 2022, 589 people were employed and 636 people were discharged because of engagement period expiry and for other reasons.

Dubna, 27 October. Participants of the solemn ceremony of awarding diplomas on conferring academic degrees to the defended applicants

## AWARDS

For the services for JINR and international cooperation, the Honourable Mention of the Mayor of the Dubna city was awarded to 1 staff member; the Honourable Mention of the Governor of the Moscow Region was awarded to 3 staff members; the Honorary Letter of the Governor of the Moscow Region was awarded to 3 staff members; the JINR Honorary Letter was awarded to 14 staff members; the Diploma of the participant of the VIII All-Russian Award "For Loyalty to Science" in the nomination "Science Is Fashionable", I class was awarded to 1 staff member; the Badge "For Services to Dubna" was awarded

to 1 staff member; the Honorary Badge “For International Cooperation in the Nuclear Industry” was awarded to 2 staff members; the Gold Medal of the International Academy of Engineering was awarded to 1 staff member; the Medal “For Loyalty to the Traditions of National Education” was awarded to 1 staff member; the Medal of the Order “For Merit to the Fatherland”, II class was awarded to 5 staff members; the Sber Scientific Prize in the nomination “Physical World” was awarded to 1 staff member; the Order of Friendship was awarded to 1 staff member; the Honorary Certificate of the Mayor of the Dubna city was awarded to 7 staff members; the Honorary Certificate of the Ministry of Investment, Industry, and Science of the Moscow Region was awarded to 4 staff members; the JINR Honorary Certificate was awarded to 30 staff members; the JINR Honorary Diploma was awarded to 6 staff members; the Honorary Title “Honored Scientist of the Moscow Region” was conferred on 3 staff members; the Title “Honorary Professor of the Lomonosov MSU“ was conferred on 1 staff member; the Title “Honorary Member of the Engineering Academy of Armenia” was conferred on 1 staff member; the Title “Honorary JINR Staff Member” was conferred on 2 staff members.

# CONTENTS

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