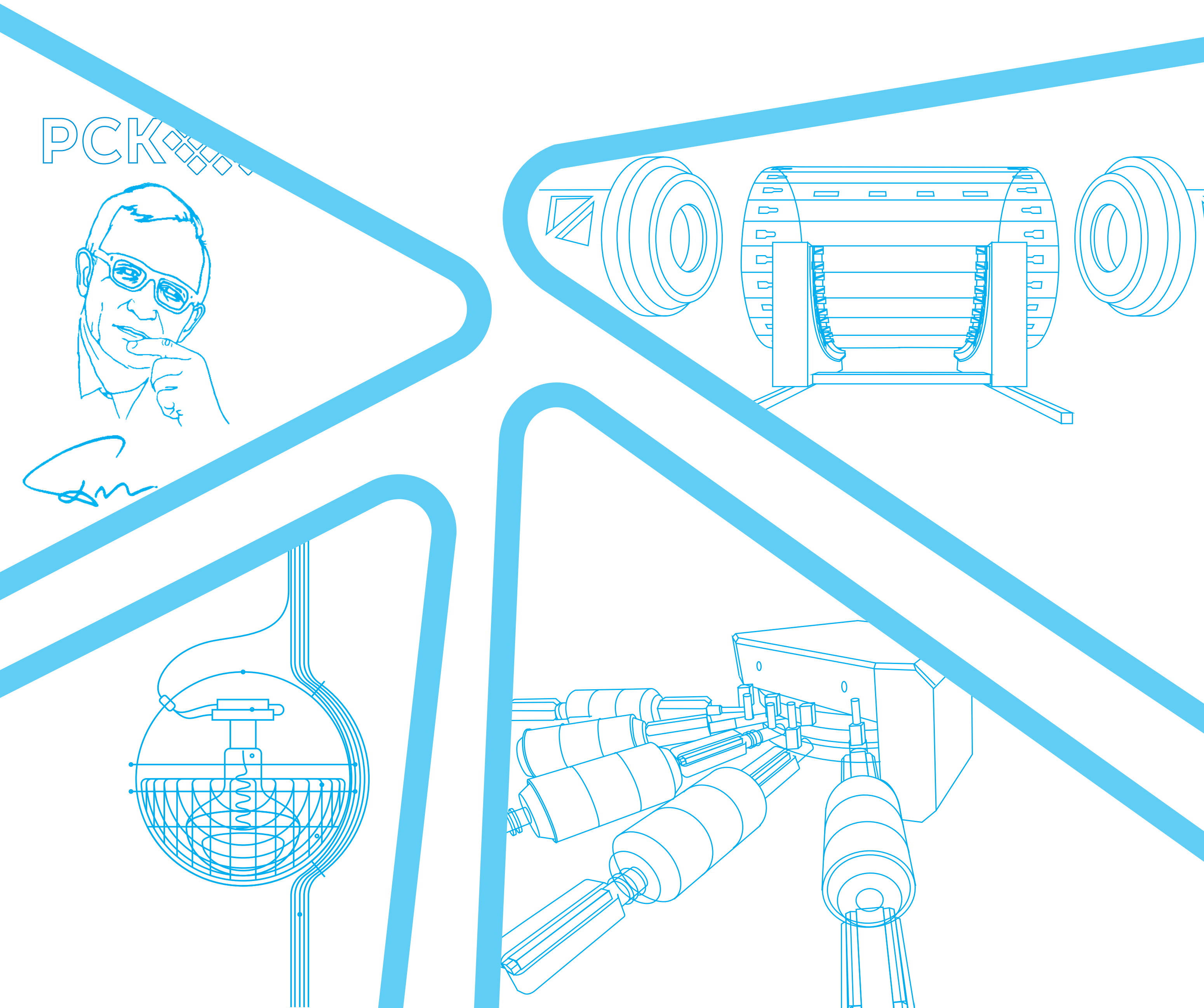
JOINT INSTITUTE FOR NUCLEAR RESEARCH 2017-2023

A BRIEF REVIEW OF SCIENTIFIC ACHIEVEMENTS AND DEVELOPMENT OF RESEARCH INFRASTRUCTURE



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Dubna, 2024

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INTRODUCTION

At the 134th session of the JINR Scientific Council (21–23 September 2023), the results of implementation of the Seven-Year Plan for the Development of JINR for 2017–2023 were summarized. The adopted resolution emphasized that during this period JINR achieved impressive results both in development of a vast research infrastructure and in scientific research on its basis. The incontestable achievements opening a new stage in the organization of scientific research in Dubna are: the creation of the Superheavy Element Factory, the commissioning of the Govorun supercomputer, the increase in the Baikal-GVD neutrino telescope effective performance to a record high, entering the final stage of the NICA megaproject and using it as a basis for extensive international experimental collaborations BM@N, MPD, SPD and ARIADNA based on the JINR large research infrastructure. Along with the development of its own research programme, JINR took an active part in international collaborations at a number of scientific centres around the world, building up its intellectual potential, which made it possible to obtain significant scientific results in a wide range of areas.

JINR's educational programmes are being enhanced, new formats of cooperation and attracting young people are being introduced, and the social infrastructure is being vigorously updated.

The Institute has substantially expanded its international partner network. Cooperation with scientific organizations of JINR Member States and Associate Members was strengthened. In 2021, the community of legitimate JINR Member States welcomed a new country — the Arab Republic of Egypt. Ties with China, Mexico, India, and Brazil are flourishing.

A landmark event was the signing of the Sofia Declaration, a document that emphasizes the special value of international integration for the peaceful scientific, technological, socio-economic and cultural development of countries on all continents of the planet Earth, and contains an appeal to interested States and organizations to join the multilateral scientific cooperation implemented by JINR.

The Institute was deeply involved in the International Year of Basic Sciences declared by the UN, and actively participated in the Decade of Science and Technology in the JINR host country.

JINR scientists, engineers and specialists managed to achieve brilliant results, thanks to which the Institute was able to secure its role as one of the leaders in the world scientific community. All Institute activities are drenched with the principle "Science Brings Nations Together". All this enables us to look confidently into the future.

The November session of the JINR Committee of Plenipotentiaries (2023) approved the new ambitious Seven-Year Plan for the Development of JINR for 2024–2030. It covers a wide range of projects and scientific areas. The main goal of the new seven-year plan is establishing a long-term bright and appealing scientific research programme as well as accumulation of intellectual human capital, provided with infrastructural and financial resources. The new stage involves conducting intensive scientific research with the expectation of new achievements at the forefront of science.

G. TRUBNIKOV
Director
Joint Institute for
Nuclear Research

Almaty (Kazakhstan), 10 November 2023.
Participants of the JINR CP visiting session

In November 2023, the session of the Committee of Plenipotentiaries of the Governments of the JINR Member States, held in Almaty (Kazakhstan), noted the impressive results achieved at JINR in 2017–2023 both in the development of a large research infrastructure and in scientific research, despite the difficult working conditions associated with the limitations of COVID-19 and the sharp deterioration of the geopolitical situation. The significant contribution of JINR to international cooperation, especially at CERN, and the steady growth of the Institute's human resources potential were also noted.

The CP welcomed the successful development of JINR as an international intergovernmental scientific organization establishing new integration links with a wide range of countries in different regions of the world, as well as the creation and continuous development of international experimental collaborations.

In general, these achievements have created a very solid foundation for the further development of the Institute in the new seven years.

The JINR Committee of Plenipotentiaries approved a new Seven-Year Plan for the Development of JINR for 2024–2030. The Plan contains a large-scale multidisciplinary research programme that meets the objectives of the development of science and technology in the JINR Member States, aimed at increasing the intellectual potential of the Institute, as well as strengthening JINR as one of the world's largest international scientific organizations.

A bird's eye view of the NICA complex

The cornerstone task of the Institute in 2017–2023 was the implementation of the **NICA** infrastructure megaproject for the development of the accelerator complex of the JINR Laboratory of High Energy Physics.

The polarized proton acceleration mode was performed for the first time in the JINR Nuclotron accelerator in 2017, which is a fundamental step in the implementation of the spin physics programme at the NICA complex.

Prime Minister of the Russian Federation M. Mishustin launched the Booster

During the implementation of the NICA project, work was carried out on the installation and commissioning of a superconducting ring accelerator (with a perimeter of 210 m) — a Booster for the NICA complex. All elements of the magnetic cryostat system of the Booster were manufactured at JINR using original technology. The technological launch of the superconducting booster synchrotron was carried out by Prime Minister of the Russian Federation Mikhail Mishustin on 20 November 2020, upon completion of commissioning of all objects of the injection complex of the project, including sources of polarized, light and heavy ions and a linear accelerator for heavy ions.

NICA Project Development in 2017–2023

2017

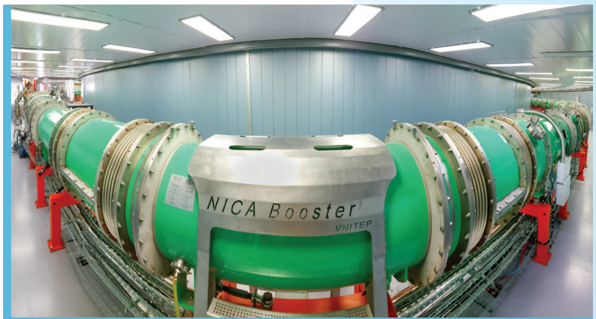
The construction site of the NICA complex

2018

HILac commissioning

2019

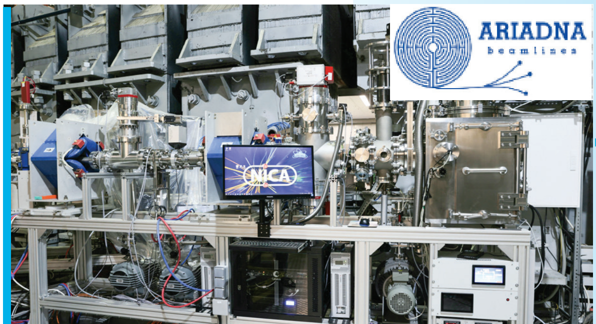
2020



Booster commissioning

NICA collider tunnel

2021



ARIADNA — applied researches

2022

4th Technical Run
(2022-2023):
HILac + Booster + Nuclotron

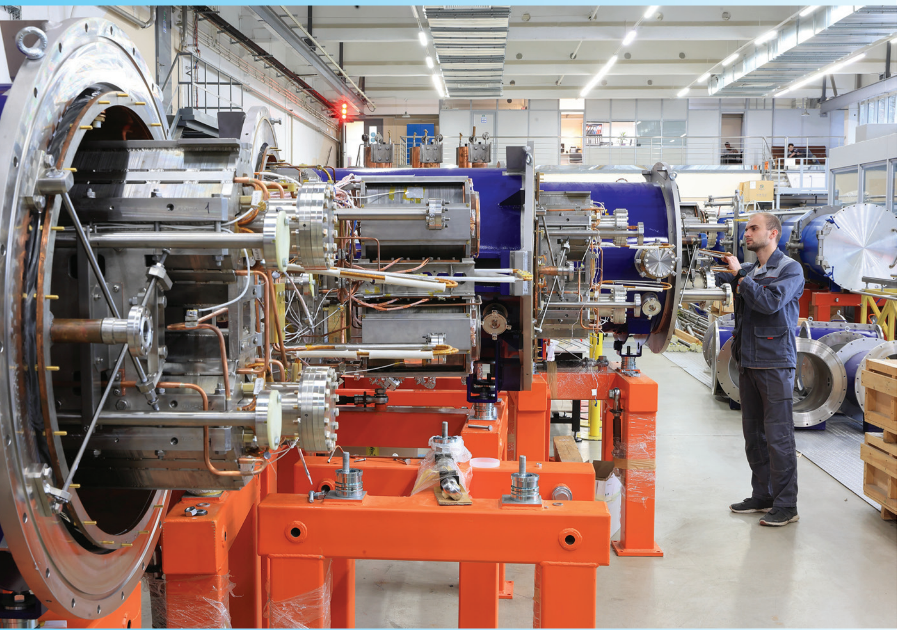
Commissioning of the
NICA injector complex

2023

40 MW — now available

Successful 5th commissioning run
at NICA in 2023 (4 months)

- **490** scientific papers
- **240** reports at conferences
- students practice



Factory of superconducting magnets

On 19 December 2020, singly charged helium ions were injected into the Booster and stable beam circulation was obtained. A beam of singly charged He ions with an energy of 3.2 MeV/amu circulated in the accelerator channel with an intensity of about 10^9 ions/revolution.

In September 2021, the booster synchrotron systems were brought to their design parameters. A beam of iron ions was accelerated in the booster ring for the first time to a design energy of 578 MeV/nucleon. The run also included a full launch of the booster electron cooling system equipment, and electron cooling of a heavy ion beam was achieved. The beam cooling experiment was carried out with $^{56}Fe^{14+}$ ions at an injection energy of 3.2 MeV/nucleon.

By autumn 2022, the most important stage of the NICA project was completed — a heavy ion chain was created and the collider injection complex was put into operation, which includes unique facilities that have no analogues in the world: a cryogenic source and a linear accelerator for heavy ions, cryogenic synchrotrons Booster and Nuclotron, as well as a system of beam transport channels. Commissioning of the electron cooling of ion beams made it possible to double the number of particles accelerated in the Nuclotron. It was possible to obtain the required parameters and ensure stable operation of the complex for 4 months. A record intensity was obtained for extracted beams of accelerated xenon ions.

A technological transfer of the MPD 800-ton solenoid

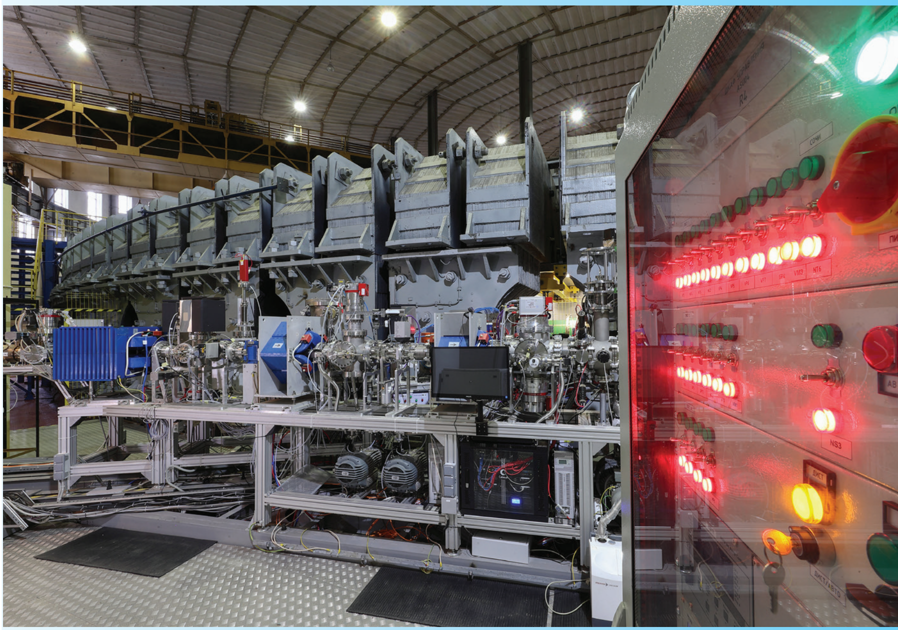
By the end of 2023, the installation of collider magnets was completed. On 5–6 December 2023, a technological transfer of the MPD experiment solenoid magnet with a diameter of more than 5 m and a weight of 800 t was carried out in the pavilion of the multipurpose detector of the NICA accelerator complex. The detector, along with the side platform of the electronics, was moved to the operating position — the beam location.

In the 2022–2023 run, the international collaboration BM@N conducted research using extracted beams, recording more than half a billion collisions of xenon ions with a nuclear target. The accumulated data is being analyzed.

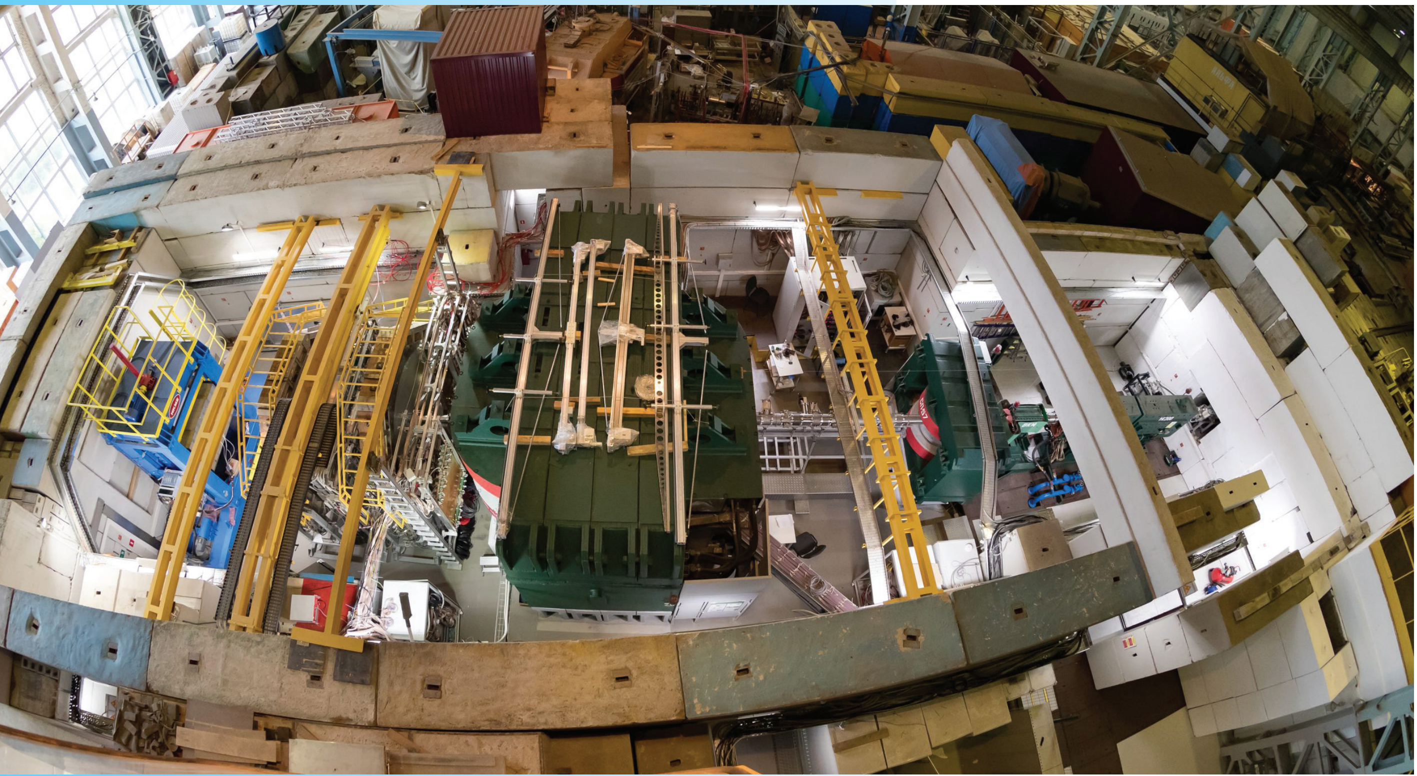
Tunnel of the NICA collider

Participants in the **ARIADNA** collaboration have carried out a number of experiments as part of the applied research programme implemented at JINR.

The achieved results summed up the long-term coordinated work of the JINR team of accelerator physicists and engineers in cooperation with many scientific organizations of the JINR Member States and partner countries.



ARIADNA — Applied Research Infrastructure for Advanced Development at NICA fAcility



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

Participants of the BM@N collaboration meeting

240 participants from **21** institutes from **11** countries

In 2018, the **BM@N** (Baryonic Matter at the Nuclotron) collaboration conducted the first run of the physics programme of the experiment. More than 2 million events were recorded in the interaction of a beam of carbon ions with an energy of 4 GeV/*c* per nucleon with a liquid hydrogen target as part of the short-range correlation research programme and detected almost 200 million events in beams of argon and krypton ions with kinetic energies of 3.2 and 2.3 *A* GeV, respectively.

The BM@N international collaboration includes 240 physicists and engineers from 21 research institutes from 11 countries, including Germany, France, the USA and Israel.

During the run in 2022–2023, 508 million interactions of ^{124}Xe ions with CsI target at an energy of 3.8 *A* GeV and 48 million at an energy of 3.0 *A* GeV were recorded in the experiment using the extracted Nuclotron beams.

Intensive work is nearing completion on the creation of the **MPD** (Multi-Purpose Detector) facility, designed to study the properties of dense baryonic matter formed in collisions of heavy ions at the NICA collider. The MPD international collaboration brings together over 500 participants from 38 institutes from 12 countries.

Participants of the MPD collaboration meeting

500 participants from **38** institutes from **12** countries

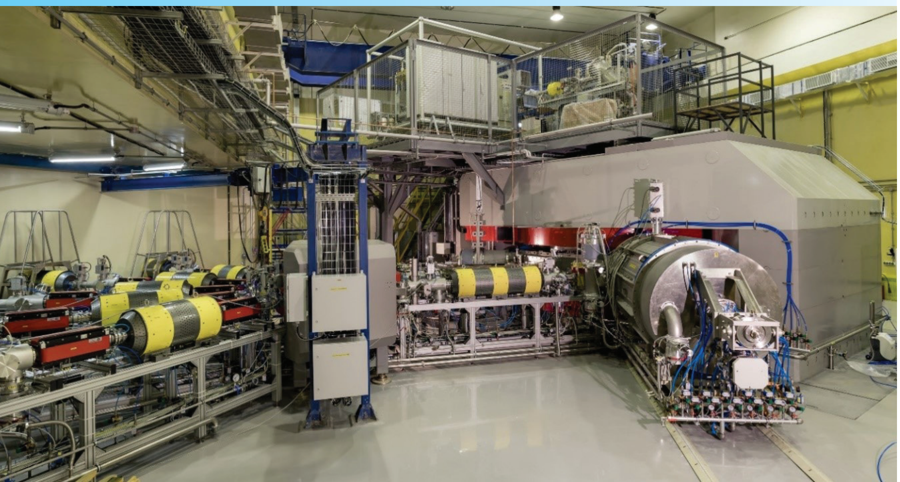
The Spin Physics Detector (**SPD**) is the second facility at the NICA collider, built by 300 collaboration members from 35 institutes from 15 countries. The participants' efforts are currently focused on preparing TDR and testing detector prototypes.

Participants of the SPD collaboration meeting

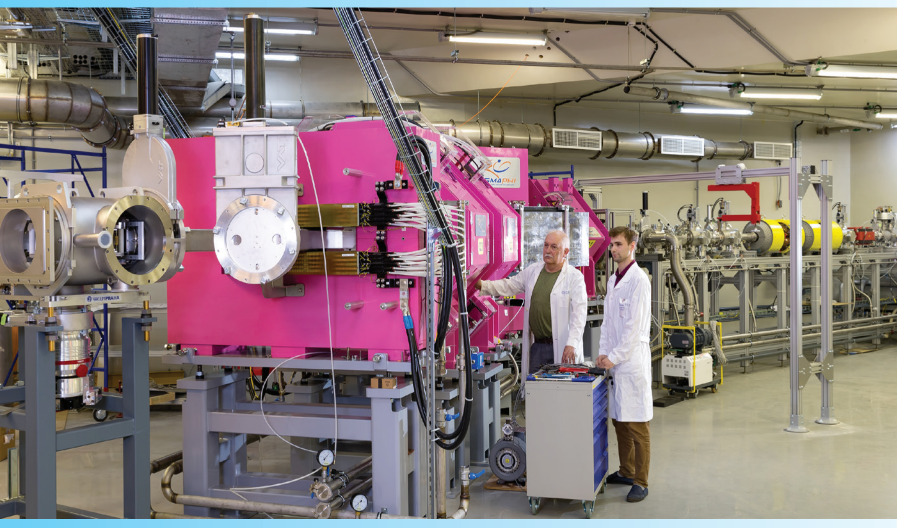
300 participants from **35** institutes from **15** countries

Superheavy Element Factory

Experimental building of the SHE Factory



DC-280 cyclotron, SHE Factory



Gas-filled separator GRAND, SHE Factory

The priority task in 2017–2023 was the construction and commissioning of the Superheavy Element Factory and the construction of a complex of cutting-edge experimental setups for synthesizing superheavy elements and studying their properties.

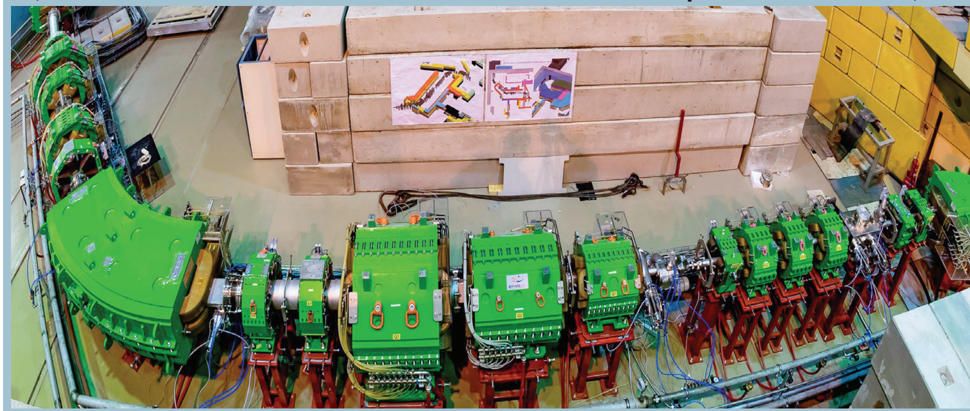
The SHE Factory was created on the basis of the new DC-280 heavy-ion accelerator, the world leader among accelerators of this type. The accelerator was designed at JINR. Its components were manufactured in JINR Member States. The designed intensity of calcium-48 ion beams delivered by the DC-280 accelerator is 10 pμA, which is 10 times higher than the intensities provided by its predecessors.

Two gas-filled separators were constructed and put into operation: DGFRS-2 and GRAND. The DGFRS-2 is designed to solve problems related to the synthesis of new superheavy elements 119 and 120, the synthesis of new SHE isotopes and study of their radioactive decay properties. The GRAND separator is aimed at studying the structure of superheavy nuclei and the chemical properties of SHE.

In 2017–2023, the construction of two promising setups of the SHE Factory began: the multiple-reflection time-of-flight mass spectrometer for the precision measurement of the masses of the heaviest nuclei and the novel GASSOL separator based on a superconducting gas-filled solenoid for studies of the chemical properties of SHE with lifetimes up to tens of milliseconds.

2017

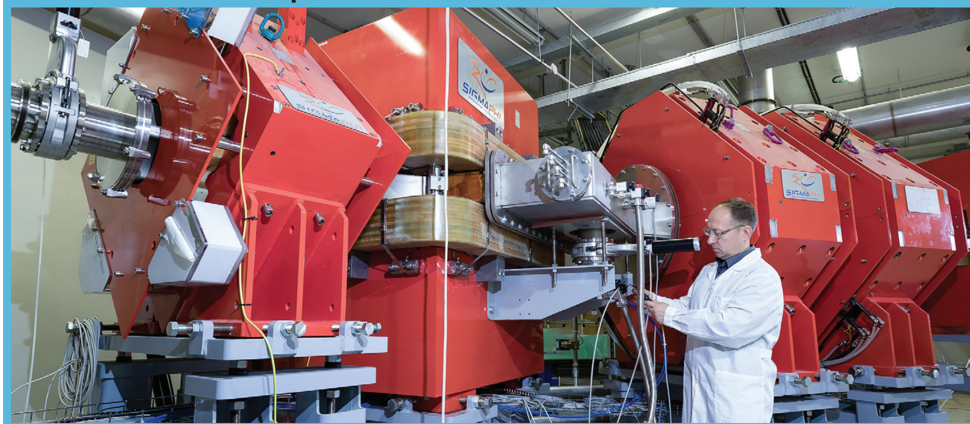
ACCULINNA-2 fragment separator at the U-400M cyclotron (Under modernization. Scheduled to be back in operation in 2024)



Main areas of research:
study of the structure of exotic nuclei near and beyond the neutron drip-line in the direct reactions

2020

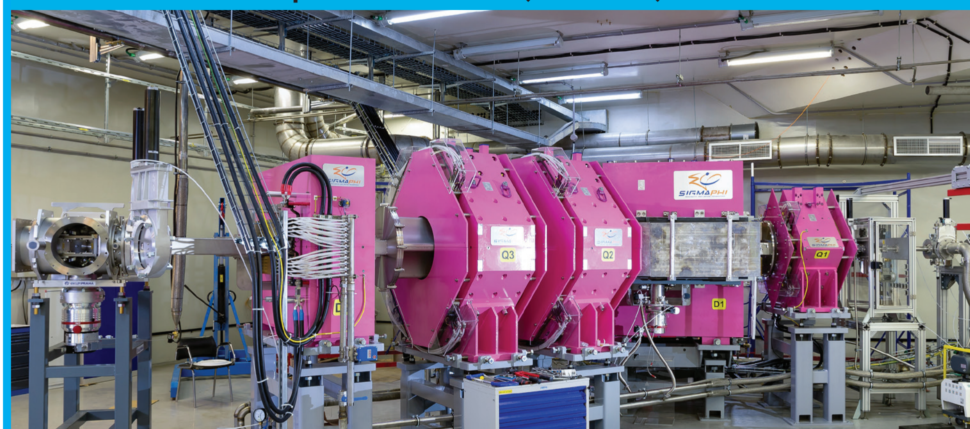
Gas-filled recoil separator DGFRS-2



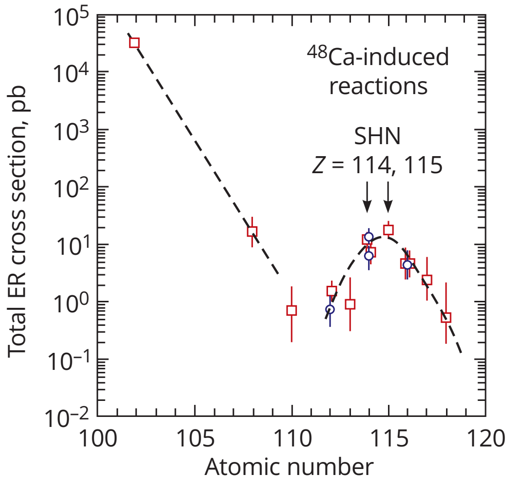
Main areas of research:
· detailed study of already known superheavy elements;
· synthesis of elements 119 and 120

2022

Gas-filled recoil separator GRAND (DGFRS-3)



Main areas of research:
· experiments on nuclear and mass spectroscopy of SHE;
· studying their chemical properties



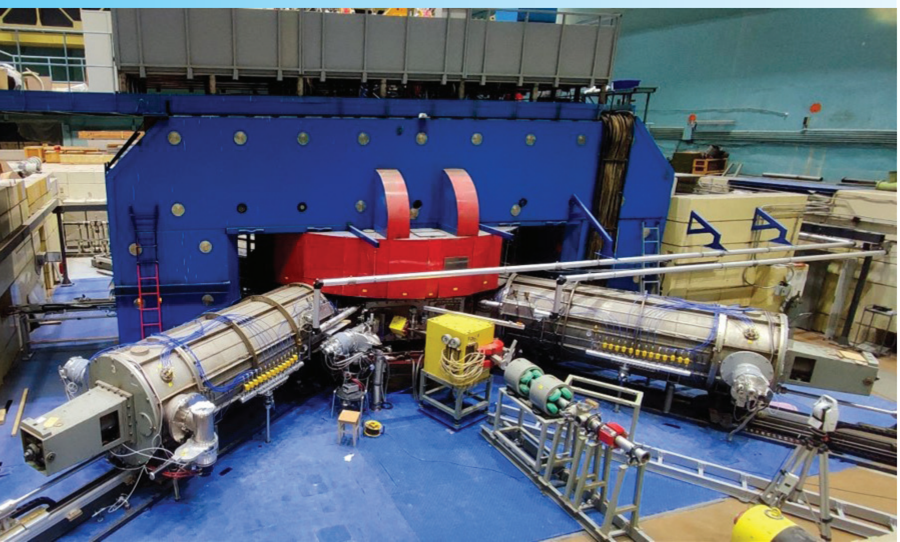
Behavior of the production cross section of the heaviest nuclei in fusion reactions of ^{48}Ca with actinides

With a view to preparing for experiments aimed at synthesizing new SHE, the fusion reaction ^{48}Ca + ^{232}Th leading to the isotopes of element 110 was studied. Experiments carried out at an extremely low cross section, 70 fb, were shown to be feasible, which is of fundamental significance for launching experiments aimed at the synthesis of new elements.

In 2020–2023, the following experiments were conducted with ^{48}Ca and ^{40}Ar beams: ^{232}Th + ^{48}Ca → ^{280}Ds*, ^{238}U + ^{40}Ar → ^{278}Ds*, ^{238}U + ^{48}Ca → → ^{286}Cn*, ^{242}Pu + ^{48}Ca → ^{290}Fl*, ^{243}Am + ^{48}Ca → ^{291}Mc*. Around 250 events of superheavy nuclei formation were observed; the decay properties of 40 nuclei ranging from lawrencium (Z = 103) to moscovium (Z = 115) were studied. Six isotopes were synthesized and studied for the first time: ^{286}Mc, ^{264}Lr, ^{275}Ds, ^{276}Ds, ^{272}Hs, and ^{268}Sg.

In 2023, an experiment on the synthesis of the isotopes of element 116 in the ^{54}Cr + ^{238}U reaction was conducted for the first time. The experiment was aimed at measuring the cross-section reduction factor upon passing from reactions with the ^{48}Ca beam to those with a heavier ^{54}Cr beam, as well as at maintaining the high current of the ^{54}Cr beam. Two synthesis events of a new isotope of element 116, ^{288}Lv, were registered. The experiment has continued in 2024.

U-400M Cyclotron Complex



Upgraded U-400M accelerator

The new fragment separator ACCULINNA-2 designed for producing beams of radioactive nuclei was commissioned at the U-400M accelerator in 2017. The separator is equipped with a radio-frequency filter for additional purification of secondary beams, a magnetic spectrometer for reaction product separation, a cryogenic target complex of hydrogen and helium isotopes, an array of neutron detectors based on stilbene crystals, and systems for the registration of charged particles. Test experiments confirmed the main design ion-optical parameters of the setup for certain radioactive beams (^{14}B, ^{12}Be, ^{9,11}Li, ^{6,8}He, etc.). The yields of these isotopes were, on average, higher by a factor of 25 compared to those produced at ACCULINNA-1 that has been operating in FLNR since 1996.

In the first experiments at the novel ACCULINNA-2 fragment separator in 2018–2020, it was possible to solve one of the long-standing landmark problems of experimental nuclear physics — the detection of superheavy isotopes of hydrogen — ^{6}H and ^{7}H, as well as advance towards studying a new mode of spontaneous nuclear decay with simultaneous emission of four neutrons. In July 2020, The U-400M cyclotron was upgraded to improve the reliability and stability of the accelerator, as well as the intensity of heavy-ion beams.

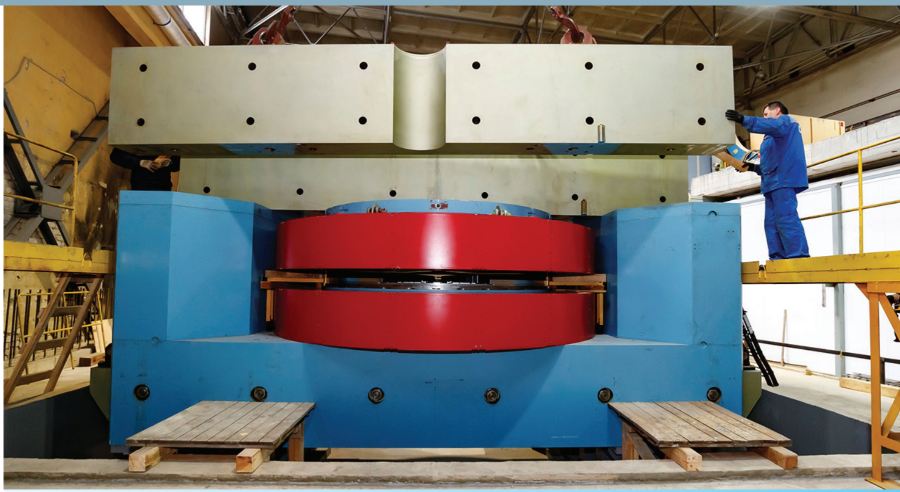
Reconstruction of the U-400(R) Cyclotron Complex

The main goal of the reconstruction of the U-400 complex, converting it to U-400R, is to expand the range of accelerated ions from helium to uranium, decrease the energy spread of accelerated ions, enable smooth ion energy variation within a range of 0.8–25 MeV/nucleon, reduce electric power consumption, and to increase the cyclotron long-term operation stability.

27 July 2023. The first pile was driven into the construction site of the experimental building of the U-400R cyclotron

Pouring the foundation of the U-400R experimental building

DC-140 Accelerator Complex



Installation of the DC-140 cyclotron

The DC-140 cyclotron is being created for fundamental research and application of heavy ion beams in the field of solid state physics, surface modification of materials, in the production of track membranes, as well as in testing the electronic component base for resistance to single radiation effects.

The DC-140 cyclotron is designed for producing beams of ions from oxygen to bismuth accelerated up to 4.8 and 2.1 MeV/nucleon. The 4.8-MeV/nucleon beams will enable ion penetration in Si up to 55 μm and linear energy transfer in Si up to 100 MeV·cm^2/mg for ensuring efficient testing of electronics. The 2.1-MeV/nucleon beams will allow the production of track membranes using polymer films up to 30 microns in thickness.

Dubna, 16–19 September 2019. The participants of the 2nd International Workshop “Theory of Hadronic Matter under Extreme Conditions”

The employees of the Bogoliubov Laboratory of Theoretical Physics at the discussion of scientific problems

More than **3200** papers have been published based on the results of the research conducted over 7 years.

In 2017–2023, the world’s largest Laboratory of Theoretical Physics of JINR conducted research in a wide range of areas of modern theoretical and mathematical physics: Fundamental Interactions of Fields and Particles; Theory of Nuclear Systems; Theory of Complex Systems and Advanced Materials; Modern Mathematical Physics: Gravity, Supersymmetry and Strings. New projects were opened and actively developed: “Theory of Hadronic Matter under Extreme Conditions” and “Quantum Field Theory Methods in Complex Systems”. An important component of the BLTP activities was the theoretical support of experimental research at JINR and other research centres with JINR participation.

The 7 years of research resulted in more than 3200 publications in peer-reviewed journals and proceedings of international conferences. Fifty-eight conferences and 17 schools were organized in Dubna and the Member States. Special attention was paid to recruiting young researchers, students, and postgraduate students to the Laboratory within the research and education project “Dubna International Advanced School of Theoretical Physics” (DIAS-TH).

New methods have been developed and striking results have been obtained in the quantum field theory of nonrenormalizable interactions, the study of the ultraviolet behavior of a number of supersymmetric gauge models of quantum field theory, in the renormalization group analysis of models of new physics, the study of the transport properties of quark–gluon plasma, critical phenomena at non-zero baryon density, and effects of relativistic rotation on phase transitions in hadron matter by lattice QCD methods, hydrodynamic and statistical models of critical phenomena in strongly interacting matter, the medium-field approach in the theory of confinement, the realization of chiral symmetry and hadronization in QCD.

Dubna, 18–21 July 2022. The International Conference on Quantum Field Theory, High-Energy Physics and Cosmology

New approaches have been developed to describe the properties of nuclei far from the stability line, reaction conditions have been proposed and cross sections for the synthesis of superheavy nuclei have been calculated, including taking into account channels with evaporation of charged particles, calculations have been made on the structure of nuclei from the lightest to superheavy, nuclear processes important for explaining astrophysical phenomena have been investigated, and rare nuclear disintegrations in different mass areas have been described.

A number of outstanding works have been carried out on the study of high-temperature superconductivity and the search for promising materials, the study of Josephson transitions, the analysis of graphene properties depending on the presence of impurities, the study of two-pair correlations of interest for the development of semiconductor technologies and optoelectronics, and the study of universal models of statistical physics.

Research has been carried out to solve fundamental problems of modern theoretical physics related to the development of superfield methods in gauge theories with extended supersymmetry in various dimensions, including supersymmetric models of higher spin fields and models of supersymmetric mechanics. The problems solved are due to the modern development of theoretical and mathematical physics and are organically connected by the unity of methods and approaches.

58 conferences

and **17** schools

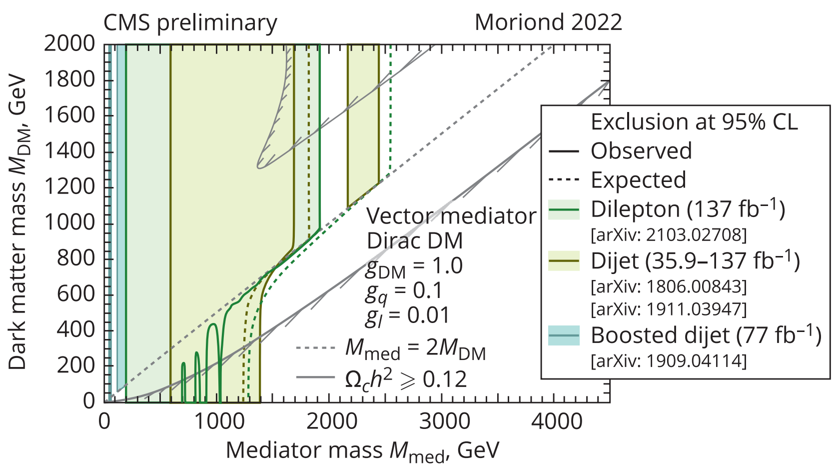
were organized in Dubna and JINR Member States.

JINR physicists in the **COMPASS** experiment (CERN) initiated a programme to search for a new possible mechanism for the production of exotic charmoniums — photoproduction on a nuclear target. A detailed analysis of the decay kinematics of the observed particle suggested that the detected signal may belong to a new particle, which is a partner particle of *X*(3872), has a similar mass, but differs from *X*(3872) in a set of quantum numbers.

A number of interesting results were obtained by the JINR group in the **ALICE** experiment at the LHC (CERN). A new analysis of femtoscopic correlations for pairs of identical charged pions and kaons in *pp* collisions at 13 TeV was performed separately for spherical and jet-like events. A decrease in source radii with increasing transverse momentum of the pair was observed not only for jet-like events, but also for spherical events, which demonstrate non-trivial behavior of collective-like particles, expected only in collisions of heavy ions with possible formation of quark–gluon plasma.

In the **ATLAS** experiment at the LHC (CERN), with the active participation of JINR employees, studies were carried out to search for decays of the Higgs boson of the Standard Model into a pair of *b* quarks produced in association with a *W* or *Z* boson. The analyzed data were obtained in proton–proton collisions at $\sqrt{s} = 13$ TeV. The measured excess of observed events over expected background events in the associative production channel with only a vector boson corresponds to a significance of 5.3σ, which is comparable to the significance of 4.8σ predicted within the SM.

Preparing the reading panel before assembling the MicroMegas detector for the ATLAS experiment



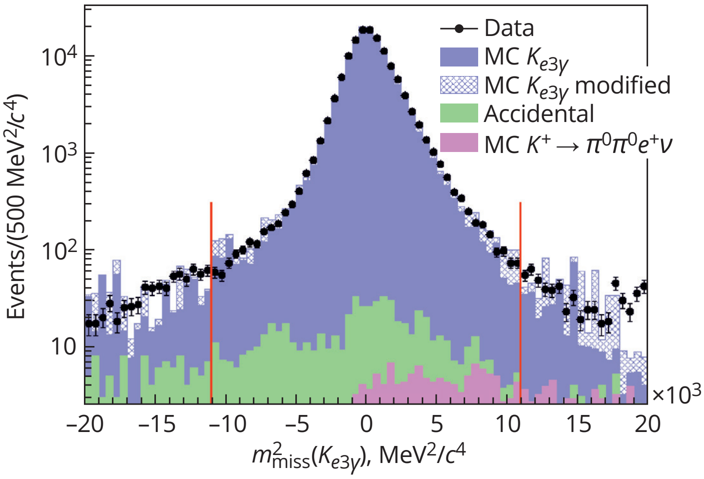
Upper limits at 95% CL on the masses M_{DM} of the Dark Matter particle, which is assumed to be a Dirac fermion, and its associated vector mediator M_{med}, for dijet and dilepton searches from the CMS experiment (LHC Run 2). The painted areas represent the excluded regions

In 2023, within the ATLAS project, a search for quantum black holes (QBH) in the lepton + jet invariant mass spectrum was performed with 140 fb^{-1} of the data collected from $\sqrt{s} = 13$ TeV *pp* collisions. The resulting lower QBH mass threshold limit is 9.2 TeV in the ADD model and 6.8 TeV in the RS model.

The JINR physicists involved in the **CMS** experiment took an active part in searches for new physics beyond the Standard Model using events with a pairs of leptons or *b* quarks. The experimental data of LHC Run 2 with the colliding proton beams at $\sqrt{s} = 13$ TeV were used. The new stringent limits were set on the model parameters of new physics scenarios, namely, the masses and couplings of the dark matter particle candidates, extra scalar states of the extended Higgs models, multidimensional gravitons, new gauge bosons.
A search was performed in the CMS experiment for signals of quantum black holes in lepton-flavor violation channels with $e\mu$, $e\tau$, $\mu\tau$, ee, $\mu\mu$ final states. The mass limits for quantum black holes range from 3.6 to 5.6 TeV/c^2, depending on the model and the number of extra dimensions *n*.

The JINR group actively participates in the construction of the CMS high granularity calorimeter HGCal and the upgrade of the muon system within CMS Phase-2 Upgrade for operation at the High Luminosity LHC. In collaboration with INP BSU (Minsk), the technology of manufacturing HGCal cooling plates was developed, low-temperature rooms and the large-area plastic scintillator trigger planes of the HGCal cassettes test bench were constructed, assembled and tested at CERN. The upgrade of the detectors and readout electronics was successfully completed for the forward muon station ME1/1 of the endcap muon system.

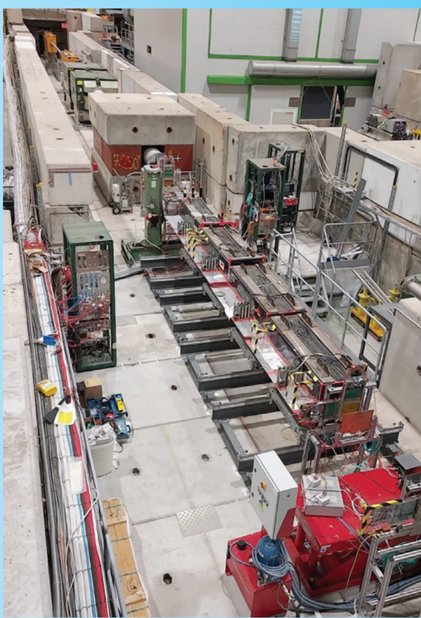
As part of the search for New Physics in rare kaon decays, the **NA62** experiment at SPS (CERN), with the participation of JINR physicists, discovered 17 candidates for the ultra-rare decay of a charged kaon $K^+ \to \pi^+\nu\bar{\nu}$. This allowed us to make the world's best estimate of the relative probability of the decay $BR(K^+ \to \pi^+\nu\bar{\nu}) = (11.0^{+0.4}_{-3.5} \pm 0.3_{syst}) \cdot 10^{-11}$, which is consistent with the prediction of the Standard Model.



Distribution of the squared missing mass of combinations of registered particles $\pi^0 e^+\nu\gamma$ for selected experimental events (points), as well as for the expected signal and background (histogram)

The JINR team in the **NA64** experiment (CERN) is actively involved in upgrading the installation and conducting data acquisition sessions at the SPS accelerator with a beam of muons with an energy of 160 GeV and electrons with an energy of 100 GeV. A search was carried out for the first time for the light Z' boson arising in expansion models of the Standard Model associated with the breaking of baryon-lepton symmetry. The mechanism of dark bremsstrahlung in the reaction of scattering of 100-GeV electrons on a nuclear target $eZ \to eZZ'$ is responsible for the generation of Z'. The result of the analysis, at a 90% confidence level, excluded this mechanism of Z'-boson formation in the mass range from 1 keV to 1 GeV.

The most interesting region of parameters of models of scalar and fermionic thermal dark matter with sub-Gev mass (LDM), produced by a mediator — a new vector boson — dark photon A', was studied for the first time during NA64 operation in 2016–2022. No dark matter formation signals were detected, which made it possible to establish more accurate limits on the interactions of A' with photons.



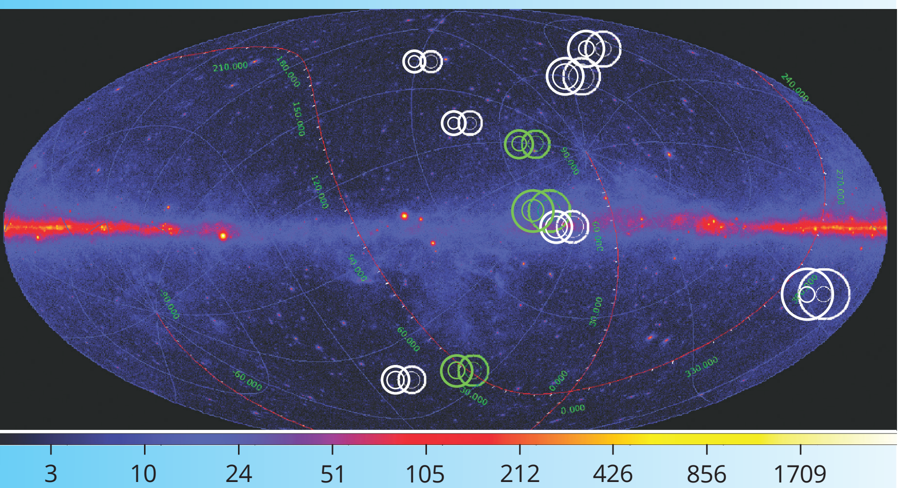
CERN (Geneva). NA64 installation on the muon (left) and electron (right) channels of the SPS accelerator

Within the **BESIII** (IHEP, Beijing) project, the tests of CP symmetry in entangled Ξ^0–$\bar{\Xi}^0$ pairs were carried out. The decay parameters α_Ξ, ϕ_Ξ of Ξ^0 and $\bar{\Xi}^0$ are simultaneously measured with unprecedented accuracies. The most precise values for CP asymmetry observables A^{Ξ}_{CP} and $\Delta\phi^{\Xi}_{CP}$ of Ξ^0 decay are obtained. For the first time, the weak and strong phase differences $\xi_P - \xi_S$ and $\delta_P - \delta_S$ are determined, which are the most precise results for any weakly decaying baryon.

Lake Baikal, 13 March 2021. The signing of the Memorandum of Understanding between the RF Ministry of Science and Higher Education and JINR on the development of the Baikal deep underwater neutrino telescope, during the ceremonial launch of the Baikal-GVD telescope

The deep underwater neutrino telescope **Baikal-GVD** is one of the three largest in the world and the largest in the Northern Hemisphere in terms of effective area and volume for observing natural neutrino fluxes.

From 2017 to 2023, 11 clusters of the Baikal telescope were installed; its working volume exceeded ≈ 0.5 km^3 in the task of recording events from high-energy neutrinos (over 100 TeV). The detector contains 12 clusters of deep-sea strings of recording and control equipment (3456 optical modules).



Position of the first ten candidates for astrophysical neutrino events in Baikal-GVD on a celestial map with FERMI-LAT sources in the galactic coordinate system. The inner and outer circles around the events correspond to the 50 and 90% detection probability

The first ten events were selected as astrophysical neutrino candidates after the analysis of the 2018–2020 data. The data were analyzed, and the first results of the search for events from neutrinos on the Baikal-GVD detector associated with the alerts of the Antarctic IceCube detector were published.

In 2022, 11 cascade events with an energy of over 15 TeV initiated by neutrinos of astrophysical nature were selected, which confirms at a confidence level of 3σ the results of the first observation of the flux of high-energy astrophysical neutrinos on the Antarctic detector IceCube.

In 2023, correlations with radio-bright blazars of cascade events with energies exceeding 100 TeV were investigated.

Baikal expedition

Optical modules prepared for installation of the next Baikal-GVD telescope cluster

Participants of the Baikal-GVD project working meeting at the ice camp at the site of the next expedition to deploy a deep-sea neutrino telescope.
Photo: © Irkutsk State University

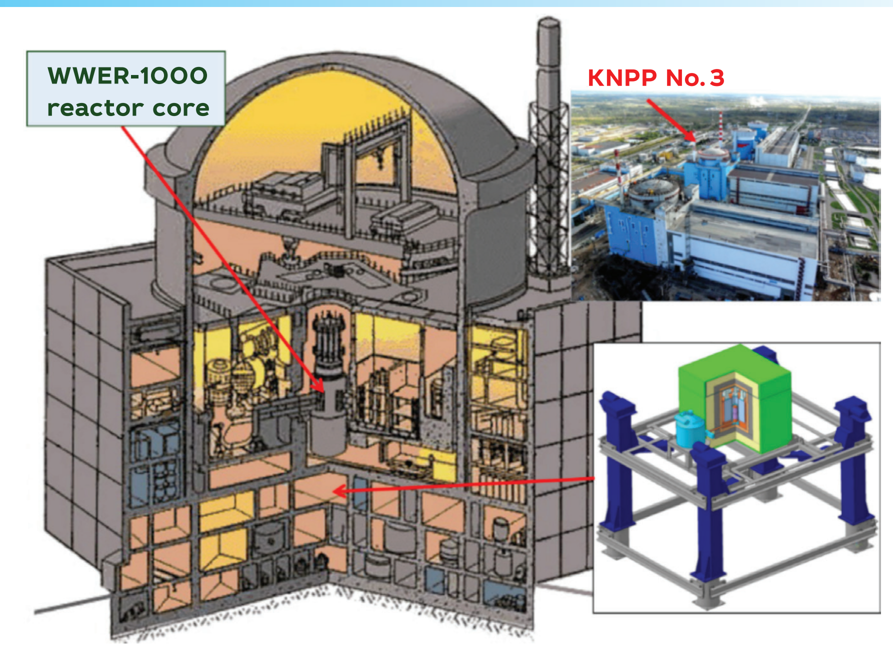
Two experiments are being conducted at the Kalinin Nuclear Power Plant (KNPP) aimed at studying the fundamental properties of neutrinos: ***ν*GeN** and **DANSS**.

In 2021, the work on equipment optimization of the *ν*GeN experimental facility was completed. The possibility of detecting events with an energy above 250 eV with an efficiency of 80% was demonstrated.

The first results on the search for coherent neutrino scattering and other interactions were obtained. A comparison of the data collected while the reactor was ON and OFF (154 and 39 days, respectively) has not yet revealed signs of the expected signal from coherent neutrino scattering. This made it possible to impose a limit on an important parameter of ionization losses in germanium (quenching) at the level of $k < 0.23$ (90% CL).

Kalinin NPP

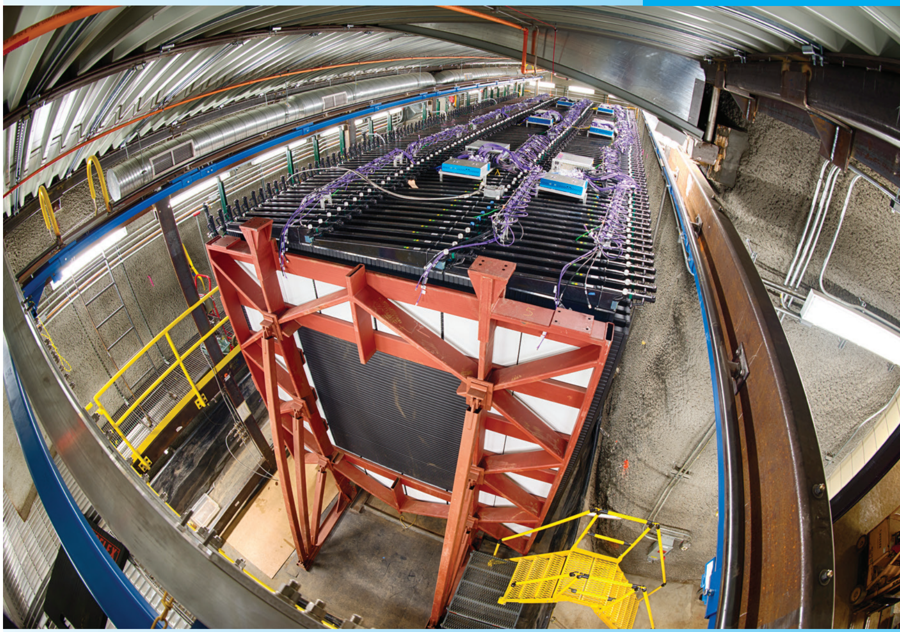
The DANSS detector has started to operate at unit 4 of the KNPP. It registers about 4000 neutrinos per day with a background less than 2–3% (both values are the world's best now). In 2019, an updated full-scale analysis of the 2016–2019 data was performed. The world's best model-independent restriction on the existence of a sterile neutrino was obtained.



Schematic layout of the DANSS detector

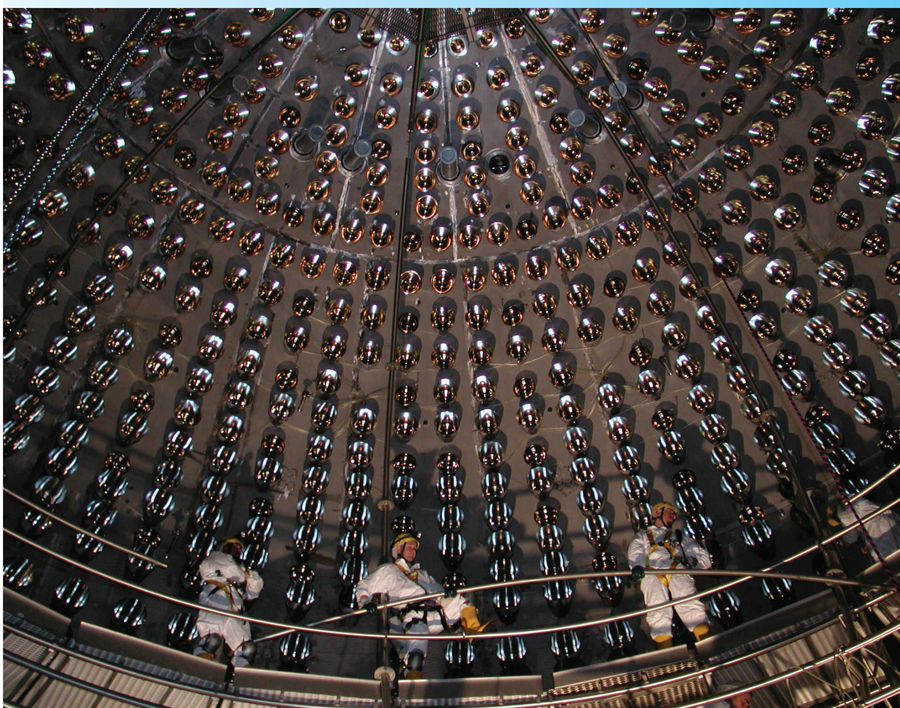
In 2020, the **NOvA** (USA) experiment performed data analysis with an increased exposure. The joint interpretation of the various oscillation channels allowed one to conclude that a combination of oscillation parameters leading to symmetry between neutrinos and antineutrinos is preferable, while the opposite combinations are rejected at levels $>3\sigma$ and $>2\sigma$, respectively.

In 2022, within the participation of JINR physicists in the NOvA experiment, new results were obtained for measuring neutrino oscillations using advanced data analysis and modeling methods. 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 θ_{23} mixing angle.



NOvA detector

In 2018, with the participation of JINR scientists, the **Borexino** (Italy) collaboration presented the results of the most comprehensive analysis of neutrino fluxes accompanying the thermonuclear processes in the Sun at that time. The uncertainty of the “beryllium” neutrino flux is reduced to 2.7%, two times better than existing theoretical prediction. This made it possible for the first time to experimentally clarify the details of thermonuclear processes inside the Sun.



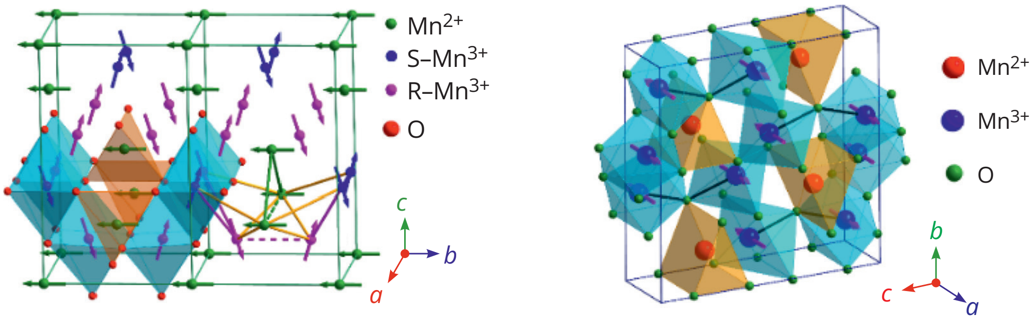
Detector of the Borexino experiment

Experimental hall of the IBR-2 reactor

In 2017–2021, the **IBR-2** reactor operation was organized in 7 or 8 cycles per year. Since October 2021, the nuclear facility has been switched to temporary shutdown mode for equipment replacement and obtaining a new license for the right to operate the IBR-2.

Linde 1800 refrigerator

In 2020, a second source of cold neutrons at the IBR-2 reactor was put into trial operation. Linde 1200 and Linde 1800 refrigerators are used to cool the moderator. The cold moderator provides continuous stable operation for 11 days and gives a gain in the range of long-wavelength neutrons of up to 9 times (depending on the beamline and the region of the neutron spectrum) at a moderator material temperature of ~25 K.

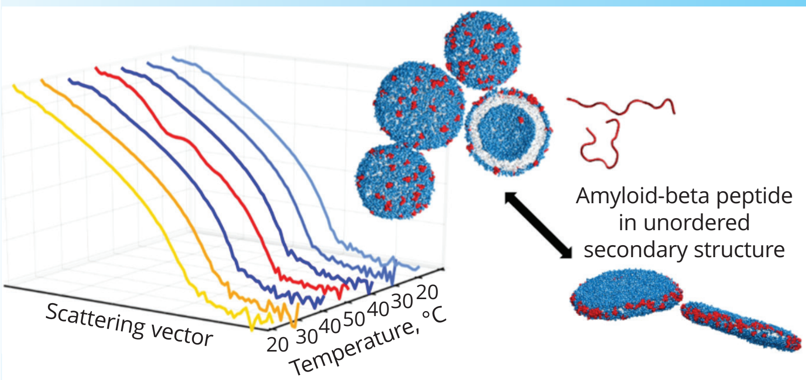


Schematic representation of the modulated magnetic structure occurring below T_{N3} ~ 33 K at ambient pressure and of the geometry of competing magnetic interactions (left), as well as the magnetic structure of high-pressure orthorhombic phase (right)

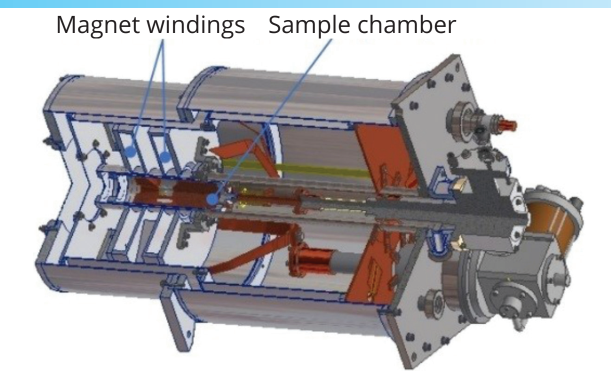
The crystal and magnetic structure of Mn_2O_3, Mn_3O_4 was studied using neutron diffraction in the pressure range up to 20 GPa and temperatures of 15–300 K. At pressures above 2 GPa, the suppression of low-temperature modulated phases and the stabilization of the ferrimagnetic phase were observed. The magnetic structure of the high-pressure orthorhombic phase at P = 20 GPa was determined. The temperature of magnetic ordering under pressure increases by more than a factor of 6, which is a unique case among known magnetic materials.

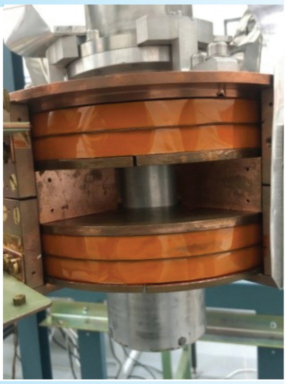
Installation for magnetron sputtering of boron carbide films on substrates made of various materials

The interaction of model biological membranes with amyloid-beta peptide was studied using small-angle neutron scattering. For the first time, the results showed a rearrangement of the overall membrane shape between spherical vesicles and flat nanodiscs in the presence of amyloid-beta peptides. This process clearly points to the destructive effect of the peptide. Interestingly, the observed mechanism could be directly related to the destruction of neuronal cells in Alzheimer's disease.



SANS curves demonstrating the destructive effect of amyloid-beta peptide on the model membrane by changing its shape from large vesicles to small vesicles and nanodiscs. The results of molecular dynamics simulations illustrate the morphological changes



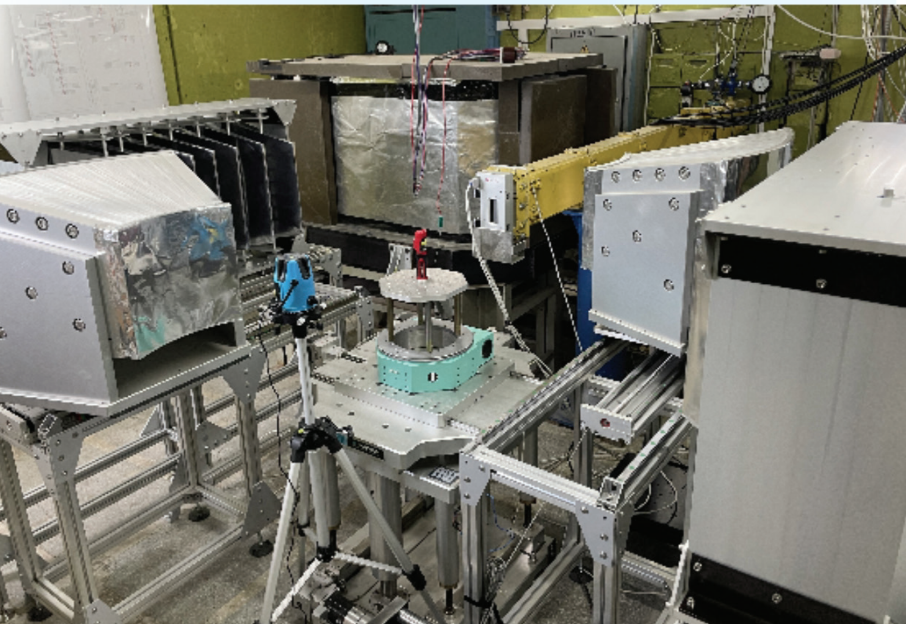


Left: 3D model of a cryomagnetic system based on the SRDK408S cryocooler. Right: External view of the cryomagnet implemented in the form of a Helmholtz pair, where a high-temperature superconductor tape 12 mm wide and 0.1 mm thick with a compensation layer of copper is used as a conductor

In cooperation with the National Institute of Research and Development in Electrical Engineering (ICPE-CA, Bucharest, Romania), a cryomagnetic sample environment system for the **DN-12** diffractometer of the IBR-2 reactor has been developed and constructed. The system consists of a magnet based on a high-temperature superconductor in a cryostat and a cryostat insert with a high-pressure chamber with a sample.

The new device makes it possible to independently vary the parameters on the sample under study during the neutron scattering experiment: the magnitude of the magnetic field, temperature, and pressure.

Works on the development of the ASTRA-M scintillation detector for Fourier Stress Diffractometer (**FSD**) were completed. The main purpose of the spectrometer with the new ASTRA-M detector is the measurement of residual stresses in samples. The total covered solid angle is Ω = 0.55 sr. High spatial resolution is achieved by reducing the size of the scattering volume due to the specific collimation.

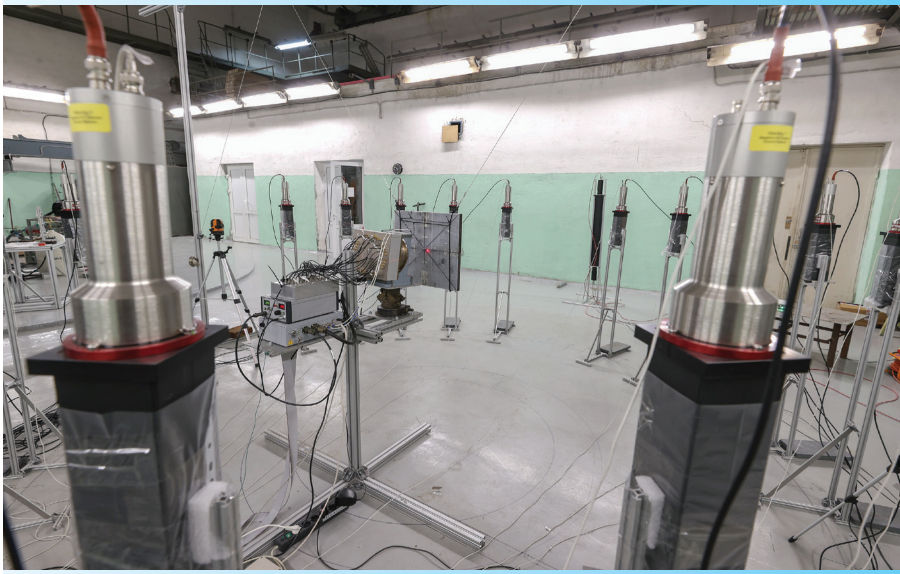


Left: ASTRA-M detector at the FSD spectrometer. Right: External view of individual elements of the ASTRA-M detector. The element is a (Ag)/^{6}LiF scintillator plate, which is shaped like a time-focusing surface with glued wavelength-shifting fibers that transmit the light flux from the neutron capture site to the photomultiplier

The **TANGRA** facility was constructed at FLNP. The facility consists of ING-27 tagged neutron generator and 18 gamma-ray scintillation detectors of γ transitions based on BGO crystals. The obtained data on the characteristic gamma rays are critically important for the development of non-destructive elemental analysis methods using portable tagged neutron generators.

In the framework of the JINR–ITEP–PNPI collaboration, a series of experiments were carried out to measure the T-odd effect of rotation of a fissile nucleus in the angular distributions of prompt γ rays (ROT effect) in the fission of ^{235}U induced by polarized neutrons. The angle of rotation of the nucleus was determined for three values of incident neutron energy: 0.025, 0.06 and 0.3 eV. For the first time, the effect was measured in the low-lying resonance ^{235}U. It was shown that the sign of the observed effect does not change, but its magnitude for the first resonance of ^{235}U (0.3 eV) is 3 times less than that for thermal neutrons.

A series of studies were carried out to measure the cross section of the (n, α) reaction with fast neutrons on ^{35}Cl, ^{91}Zr, ^{40}Ca, ^{63}Cu, ^{58,60,61}Ni nuclei. Data on the reactions ^{60}Ni$(n, \alpha)^{57}$Fe (at E_n below 6 MeV) and ^{61}Ni$(n, \alpha)^{58}$Fe for neutrons in the MeV-range, as well as cross sections for the ^{60}Ni$(n, \alpha)^{57}$Fe and ^{61}Ni$(n, \alpha)^{58}$Fe reactions for the E_n range above 8.0 MeV, and ^{91}Zr$(n, \alpha)^{88}$Sr reaction in the MeV-range were obtained for the first time.

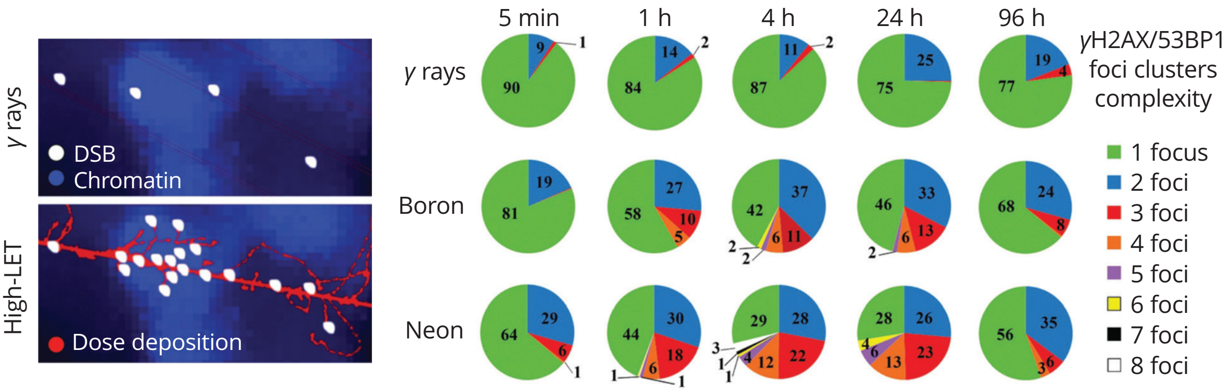


TANGRA facility

The Xeuss 3.0 X-ray facility, which allows nanoparticles to be studied using X-ray small-angle scattering, as well as to study the crystal structure by X-ray diffraction

The possibility of enhanced directional extraction of very cold neutrons (VCNs) from a source surrounded by a nanodiamond reflector was experimentally demonstrated. The gain factor for a narrow solid angle of extraction of VCNs with velocities of 57 and 75 m/s was 10. The gain factor for a wide solid angle was 33 for neutrons with a velocity of 47 m/s. This is equivalent to a multiple increase in the power of a nuclear research reactor. The effect of nanodiamond sizes on the efficiency of reflection of cold neutrons (CNs) at small grazing angles was studied.

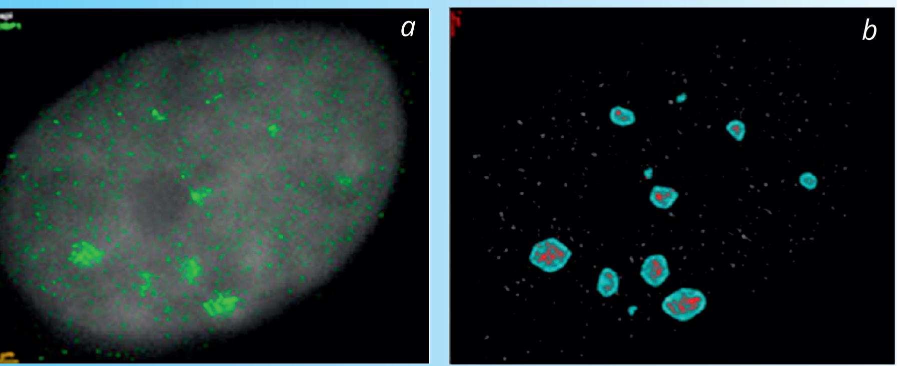
The phenomenon of quasi-specular reflection of CNs from nanopowders can be used to focus or transport CNs to research facilities in cases where other reflectors are destroyed in intense fields of ionizing radiation.



Formation of γH2AX/53BP1 foci clusters of different composition in nuclei of normal human skin fibroblasts after exposure to ^{60}Co γ rays and accelerated ^{11}B and ^{20}Ne ions

Using charged particle beams of JINR accelerators, the mechanisms that determine differences in the lethal and mutagenic effectiveness of radiation with different physical characteristics were clarified at the Laboratory of Radiation Biology.

The induction and repair were studied of clustered DNA double-strand breaks (DNA DSBs) of different composition in mammalian and human cells after exposure to ionizing radiation with different physical characteristics. A new method has been developed to analyze the fine structure of clustered DNA damage with ultra-high resolution.



Visualization of the structure of 53BP1 repair protein clusters in the nuclei of human U87 glioblastoma cells 24 hours after irradiation with accelerated ^{15}N ions (13 MeV/nucleon, 1.3 Gy): *a*) a microscope image; *b*) software post-processing

Radiobiological studies related to the study of the effects of radiation on the behavioral reactions of laboratory animals

A fundamentally new method has been developed and patented for increasing the biological effectiveness of medical proton beams and gamma therapeutic units. The method makes it possible to bring the biological effectiveness of proton irradiation closer to the effectiveness of irradiation with carbon ions.

The molecular and cellular mechanisms were studied of the combined effect of the DNA synthesis inhibitor AraC and proton radiation on the B16 murine melanoma *in vivo*. It has been shown that the introduction of AraC enhances the antitumor effect of proton radiation through several mechanisms, including a decrease in the number of tumor stem cells, inhibition of cell proliferation, and angiogenesis in the tumor against the background of changes in the immune response in the primary focus and its infiltration by lymphocytes.

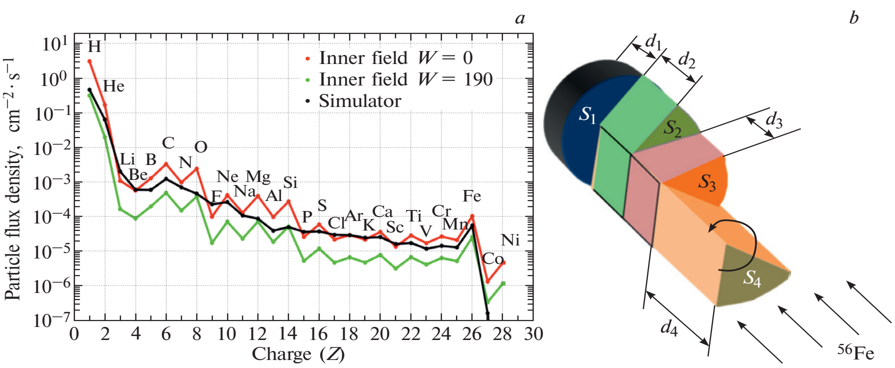
A cytogenetic analysis was performed of the formation of chromosomal aberrations in human carcinoma cells and normal human peripheral blood lymphocytes after irradiation with photons and protons (150 MeV and Bragg peak). For γ-ray exposure, a more effective repair of chromatin breaks was observed in tumor cells compared with normal ones than for proton exposure.

Analysis of chromosomal aberrations in human lymphocytes using the mFISH method

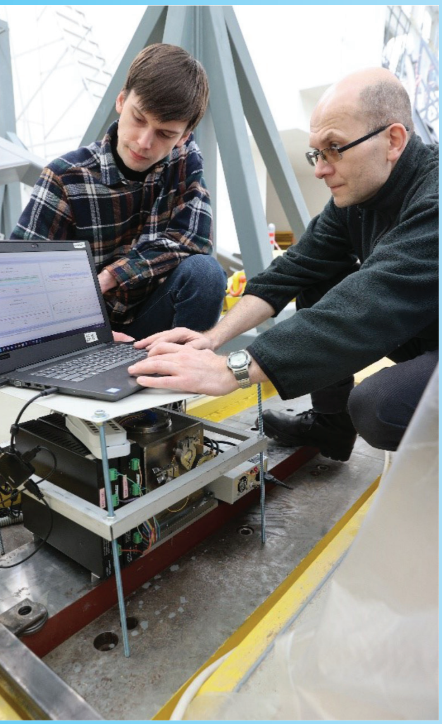
A comparative study was performed of behavioral disorders and morphological changes in the brain of adult female rats after 1 Gy irradiation with γ rays and protons of various energies. Impairments of short-term memory and motor and exploratory activity of animals were observed. Neurodegenerative changes in different brain structures were revealed.

The new SARRP X-ray facility for radiobiological research

A unique simulator of the radiation field inside the habitable module of a spacecraft in deep space has been proposed and patented. It reproduces in the correct ratio all components of the radiation field, averaged over solar activity.



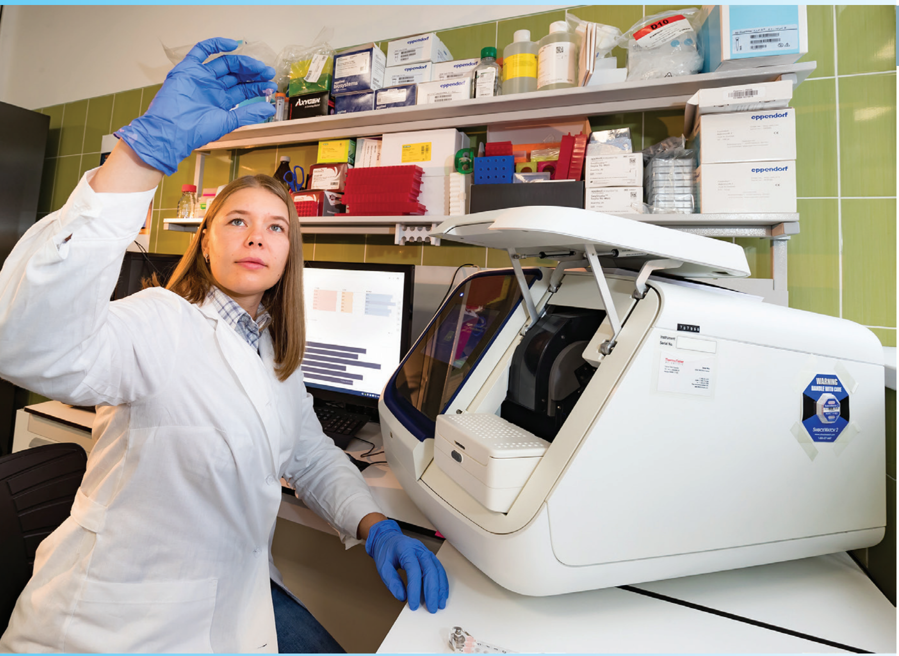
a) Comparison of the calculated charge distributions of the particles of the radiation field inside the spacecraft at the solar activity minimum and maximum and the calculated charge distribution of the particles of the radiation field behind the simulator. *b*) A schematic view of the simulator's converter



Installation of a Compact Laser Inclinometer in the MPD NICA hall

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

During 2022, six new-type CPLIs were created. The placement of CPLIs in scientific centres of JINR Member States has begun. Two units of the CPLI are installed in the MPD detector hall of the NICA collider. For several months, monitoring of angular microseisms from industrial noise and natural phenomena was carried out.



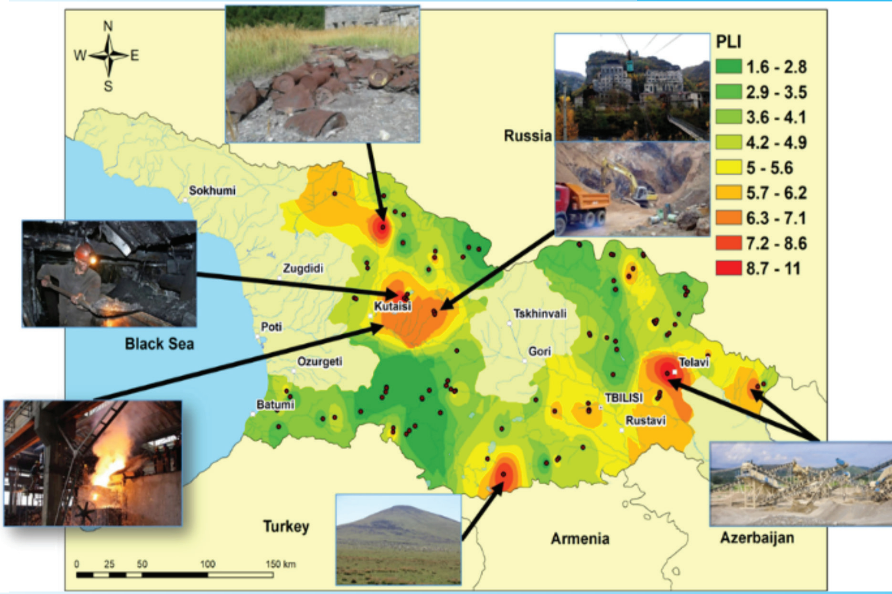
Setting up sequencing reactions to determine the DNA sequence of the 16S RNA gene in new extremophilic species of microorganisms found in the underground hot spring of the Baksan Neutrino Observatory

TARDISS (Cell Genetics)

In 2021, the group of researchers from DLNP JINR performed Stage II of the experiment at the Baksan Neutrino Observatory (BNO) of the INR RAS on the study of ultradeep microbial communities inhabiting the extreme environment near the Elbrus magma chamber.

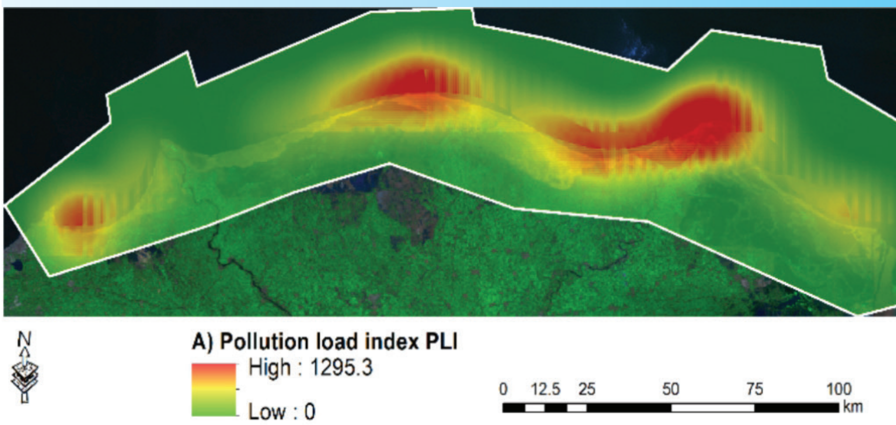
Research to study the effect of low radiation background on model biological objects has been conducted. Analysis of the data indicates that there is no effect of a decrease in the radiation background on a complex model organism.

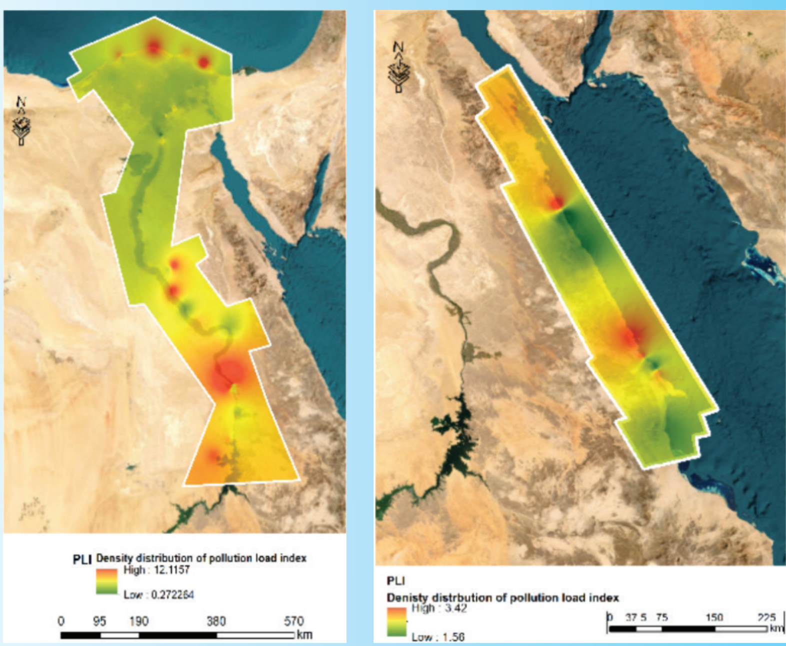
As part of the international UN programme “Atmospheric deposition of heavy metals in Europe — Assessments based on the analysis of moss biomonitors”, work was carried out to assess air pollution in 12 JINR Member States: Armenia, Azerbaijan, Belarus, Bulgaria, Georgia, Kazakhstan, Moldova, Mongolia, Romania, Russia, Slovakia, and Vietnam.



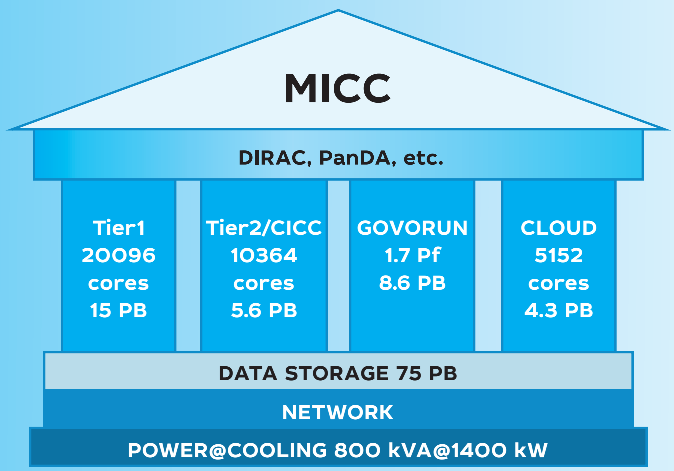
Spatial distribution of the air pollution load index in Georgia in the Atlas of atmospheric deposition of heavy metals

Within the framework of the collaboration between the Academy of Scientific Research and Technology (ASRT, Egypt) and JINR, a comprehensive picture was given on the assessment of the ecological situation in Egypt using soil and sediments samples from Nile River and delta, the coastal areas of the Mediterranean and Red Seas. The characterization of the samples was given using two analytical techniques: neutron activation analysis (NAA) and inductively coupled plasma mass spectrometer (ICP-MS). The characterization of the samples in terms of pollution revealed that this is not uniform and that some sites are relatively more polluted than others, but overall do not pose a significant risk to humans and the environment.



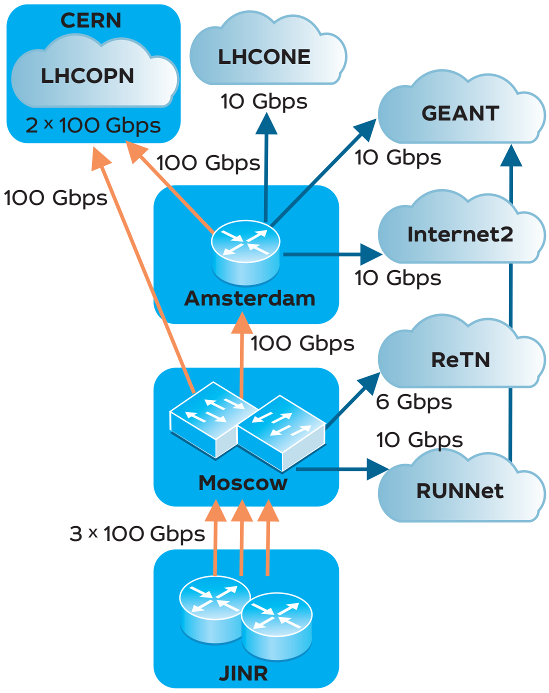


Spatial distribution of the pollution load index (PLI) along the coastal areas of the Mediterranean Sea, Nile River and the delta



JINR Multifunctional Information and Computing Complex

One of MLIT's major areas in the Seven-Year Plan for the Development of JINR in 2017–2023 was the planned development of a world-class Multifunctional Information and Computing Complex (**MICC**) at the Institute.



JINR network infrastructure

JINR network infrastructure

The JINR network infrastructure reached a new technological level. The bandwidth of the Moscow–JINR telecommunication channel was increased from 100 to 3 × 100 Gbps, the capacity of the Institute's backbone was enhanced from 10 to 2 × 100 Gbps, and a distributed computing cluster network was built between the DLNP and VBLHEP sites with a bandwidth of up to 400 Gbps, which meets the requirements of the NICA megaproject.

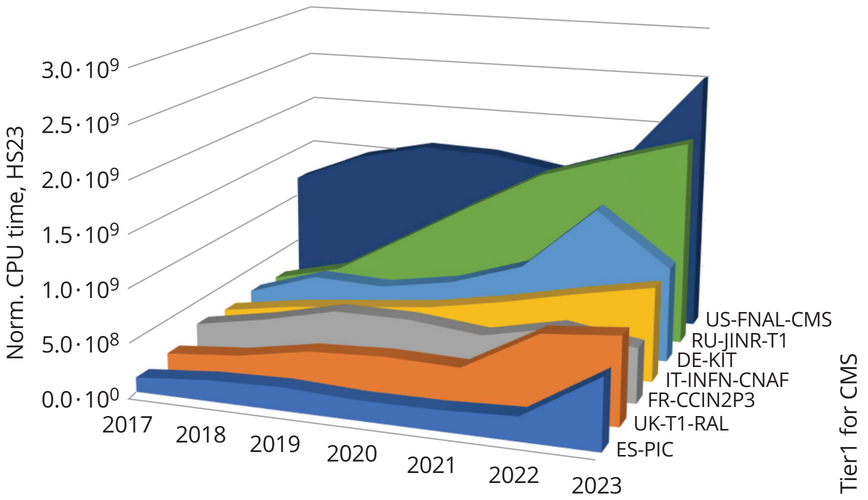
JINR grid environment (Tier1 and Tier2 sites)

The JINR grid infrastructure is represented by the Tier1 centre for the CMS experiment at the LHC and the Tier2 centre for processing data from the NICA, LHC, BES, BIOMED, NOvA, ILC experiments, etc. Both JINR grid sites ensured 100% availability and reliability of the services. The Tier1 processing system for CMS was expanded as planned from 3600 to 20 096 cores, currently delivering the 32 382.54 HS06 performance. The storage system was enlarged. The total usable capacity of disk servers was increased from 4 to 15 PB and from 5.4 to 51 PB for the IBM TS3500 and IBM TS4500 tape libraries. In terms of performance, Tier1 occupies one of the leading places among the other Tier1 centres for the CMS experiment. Since 2021, the resources of the Tier1 centre have also been used to model and process data from the NICA experiments.

The computing resources of the Tier2 centre were expanded as planned from 2470 to 10 364 cores, providing the 66 788.4 HS06 performance. The total usable capacity of disk servers is 5.6 PB. The JINR Tier2 website is the best in the Russian consortium RDIG (Russian Data

Intensive Grid). From 2017 to 2023, the contribution of JINR Tier2 to RDIG's productivity enhanced from 42 to 90%.

The EOS distributed storage system (the so-called "data lake") was successfully integrated into the MICC structure and is employed for storing and accessing large amounts of information. There is 23.3 PB of storage space available for EOS users. The experiments of NICA, of the neutrino programme and other users store data on EOS according to quotas.



Contribution of the world Tier1 centres to CMS experimental data processing for 2017–2023: distribution by the normalized CPU time in HS23 hours

Heterogeneous infrastructure

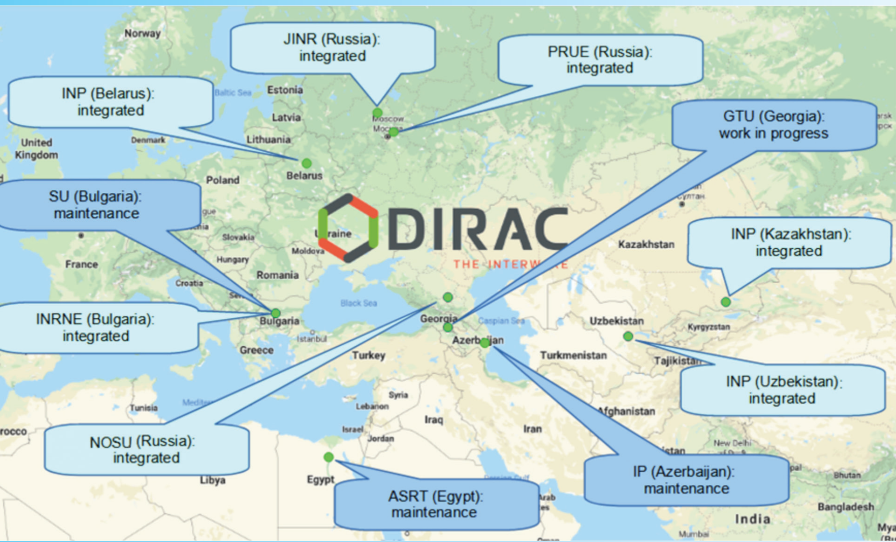
The Govorun supercomputer was created in 2018 on top of the experience gained during the operation of the HybriLIT heterogeneous cluster, which is part of the MICC JINR. HybriLIT has shown its relevance in solving tasks of lattice QCD, radiation biology, applied research, etc. The continuous growth in the number of users and the expansion of the range of tasks led to the creation of a new computing system — the Govorun supercomputer as a high-performance scalable liquid-cooled system with a hyperconverged and software-defined architecture.

Govorun supercomputer

Since its presentation, the overall performance of the Govorun supercomputer has enhanced from 0.5 to 1.7 PFlops for double precision operations, and the total capacity of the hierarchical storage has increased from 288 TB to 8.6 PB.

Since 2021, an information and computing system (ICS) to solve tasks related to the computations of electron shells of superheavy elements has been intensively developed on the HybriLIT platform. The ICS embraces the computing resources of the Govorun supercomputer and a set of IT solutions and software required for modeling electron shells. To calculate the electronic properties of superheavy elements, intensive computing using the AMS and DIRAC software was performed on this system. In addition, to develop quantum algorithms, a testing polygon for quantum computing with installed quantum computing simulators, namely, Cirq, Qiskit, PennyLane, capable of operating on various computing architectures, was deployed in the ICS.

At the end of 2021, a scalable research infrastructure of a new level was created on the basis of combining the supercomputers of JINR, JSCC RAS and SPbPU. It allows the participants to enlarge their local computing power, to provide access to the means for storing and processing large volumes of data, to distributed data storages (data hubs), as well as to utilize each other's capacities in the case of peak loads. Such an infrastructure is also in demand for the tasks of the NICA megascience project.



Clouds of organizations integrated into the JINR distributed information and computing environment (DICE)

Cloud infrastructure

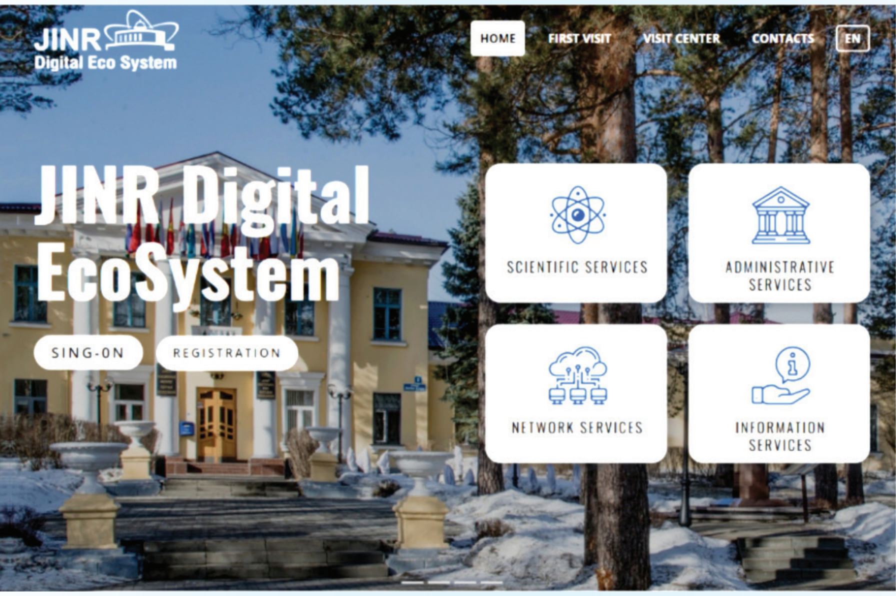
The resources of the cloud infrastructure were enlarged from 330 to 5152 CPU cores and from 840 GB to 61.5 TB of total RAM. The total amount of disk space in the ceph-based software-defined storage was increased to 4.3 PB. The expansion of cloud infrastructure resources was financed within the NOvA/DUNE, JUNO, Baikal-GVD experiments (DLNP), which are the main users of the cloud infrastructure.

During the reporting period, work to integrate the cloud structures of the JINR Member States into the DIRAC-based distributed platform was actively performed.

During the coronavirus pandemic in 2020–2022, DICE resources free from their core activity were utilized to conduct research on the SARS-CoV-2 virus within the Folding@Home platform.

Integration of computing resources

Within the implementation of the Seven-Year Plan, using the DIRAC (Distributed Infrastructure with Remote Agent Control) Interware, the computing resources of Tier1/Tier2, the Govorun supercomputer, the cloud environments of JINR and its Member States' organizations, the NICA cluster, the cluster of the National Autonomous University of Mexico (UNAM), the cluster of the Institute of Mathematics and Digital Technology of the Mongolian Academy of Sciences (IMDT MAS), the National Research Computer Network of Russia and storage resources, namely, dCache, EOS and the Lustre ultrafast data storage system, were combined.



Single access point interface of the Digital EcoSystem

JINR Digital EcoSystem

Since 2022, work has been underway to create the Digital JINR platform, i. e., the JINR Digital EcoSystem, which was put into test operation at the end of March 2023. JINR Digital EcoSystem is a platform providing access to the JINR information services network.

The main goal of the Digital JINR 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 activities. The Digital JINR is, in fact, a single window service in the JINR digital environment.

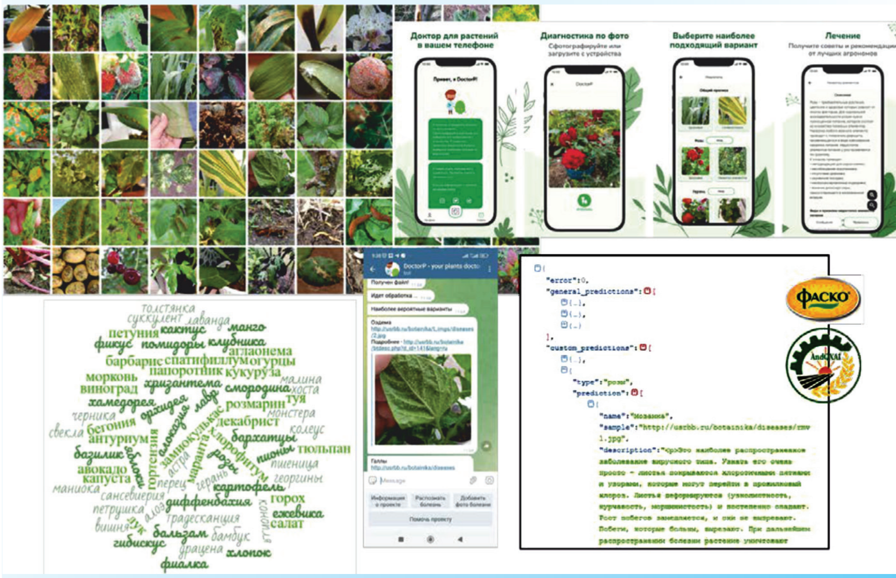
The Digital EcoSystem encompasses a wide range of services, from resources for users of basic facilities to arranging business trips, vouchers, ordering certificates, etc. The main groups of services are administrative and scientific. Access to the system is based on the JINR Single Sign-On (SSO) authentication service via a single access point of the Digital EcoSystem.

Methods, algorithms and software for modeling physical systems, mathematical processing and analysis of experimental data

One of the important activities of MLIT within the implementation of the Seven-Year Plan was to provide mathematical, algorithmic and software support for experimental and theoretical studies underway at JINR, in many of which computing resources are an essential tool for producing significant scientific results. In 2017–2023, more than 1300 scientific papers within research conducted by MLIT staff members and over 700 articles within international collaborations were published. A summary of some prominent results is presented below.

In the course of research conducted jointly with FLNP within the UNECE International Cooperative Program (ICP) Vegetation for monitoring and predicting air pollution processes in Europe and Asia, a cloud platform for managing monitoring data was developed at JINR.

A platform and a mobile application (DoctorP) for detecting plant diseases and pests were elaborated. Both a general model capable of detecting 68 disease classes and specialized models for 30 ornamental and agricultural crops are available. The database contains over 6000 images. The platform can be accessed by third-party applications and services.



Examples of DoctorP platform interfaces

A hardware and software platform was developed on top of quantum fuzzy controllers built into the control circuit to solve the task of controlling the pressure and flow of liquid nitrogen of superconducting magnets of the cryogenic system of the NICA accelerator complex. The operability and effectiveness of the developed intelligent system for the remote control of the technological process of cooling a superconducting magnet with a guaranteed achievement of a stable superconductivity zone were experimentally demonstrated.

Since 2020, on the basis of the ML/DL/HPC ecosystem, a joint project between MLIT and LRB on the creation of an information system (IS) for analyzing and storing data from radiobiological experiments has been developed. Algorithms for experimental data processing on top of machine and deep learning methods and computer vision are implemented in the developed system. The IS embraces reliable modern tools of authentication and hierarchical data access control, a data storage system, as well as components for convenient work and the visualization of data analysis results.

More than

1300 papers

have been published based on the results of the research conducted over 7 years.

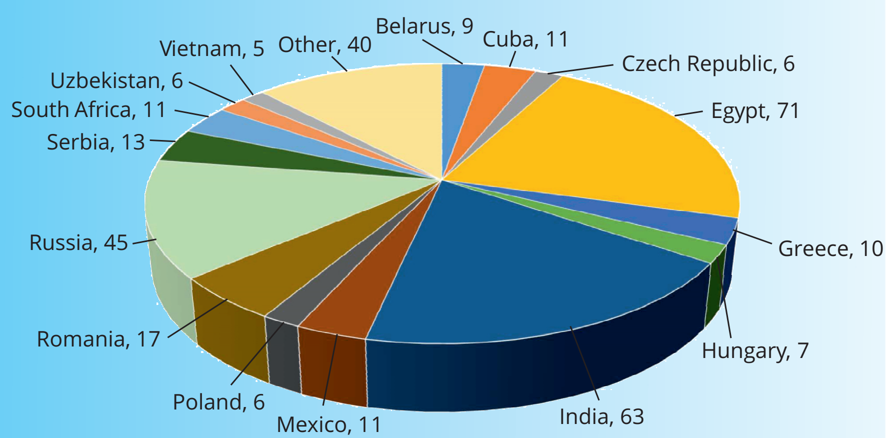
JINR EDUCATIONAL PROGRAMME

The JINR University Centre (UC) organizes an educational process for students from the basic departments of Moscow State University, MEPhI, MIPT, Dubna State University, St. Petersburg State University, and Kazan (Volga Region) Federal University. Around 500 undergraduate and graduate students from universities of JINR Member States annually complete internships and practical training at JINR.

13 basic departments in **6** universities

INTEREST Online Programme

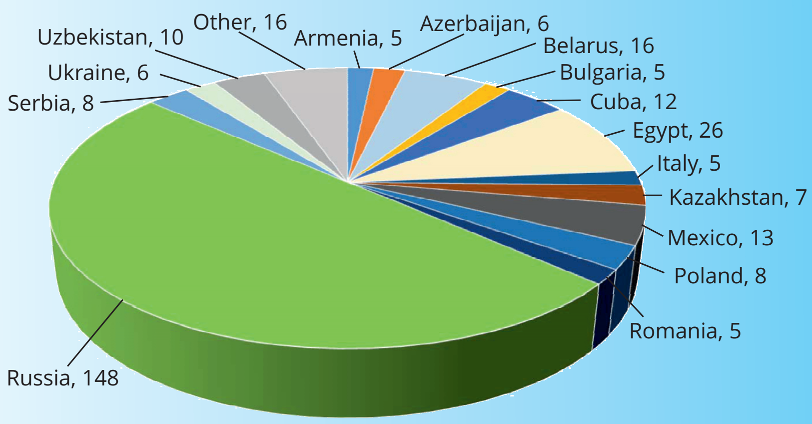
INTEREST (INTErnational REmote Student Training) is an all-year online programme launched in September 2020. It allows students to get acquainted with the main fields of research at the Institute, facilitates the search for a scientific supervisor for qualification work, as well as participation in on-site internships at JINR. The number of programme participants from 37 countries reached 331. Each wave of the programme lasts 4–6 weeks.



331 participants from **37** countries worked on JINR projects in an online format

START Programme

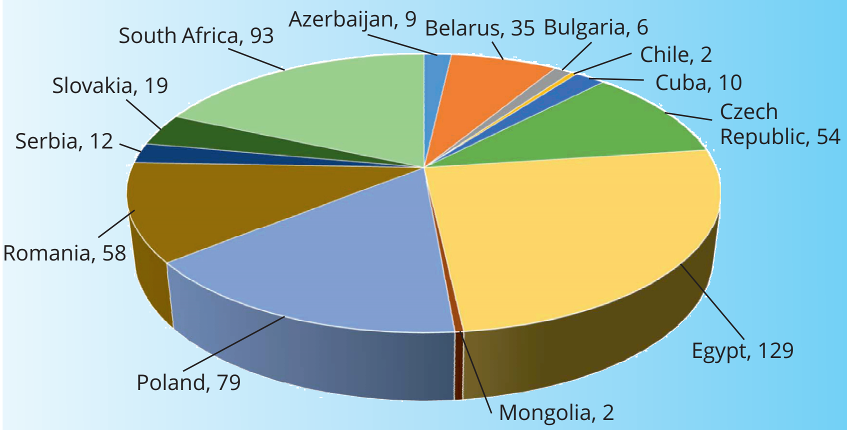
In 2022, the JINR Summer Student Programme was rebranded into START programme — STudent Advanced Research Training. The full-time training programme runs all year round. Students from all over the world specializing in natural sciences, engineering and IT, completing the 3rd year of a bachelor's and master's degree programme, as well as 1st-year PhD students are allowed to participate in the programme. From 2017 to 2023, 296 people from 25 countries took part in START programme. The programme also enables JINR experts to find young specialists who are invited to complete their full-time internship at the Institute for a period of 6-8 weeks.



296
undergraduates and graduate students from **25** countries
completed full-time training in START programme at JINR

International Student Practice

International student practice in the JINR fields of research means three-week full-time programmes. From 2017 to 2023, 508 students participated in the stages of the international student practice. An eventful cultural and educational programme is prepared for the students, although most of the time of each stage is spent carrying out scientific projects under the supervision of JINR specialists.



508 people
from **13** countries
took part in the introductory three-week international student practice

Vocational Guidance Activities

UC employees, together with the representatives of the Institute's laboratories, annually participate in person and online in major Russian science festivals, organizing exhibitions, lectures, excursions, master classes and physical demonstrations at various events, as well as at the JINR Information Centres:

- All-Russian science festival NAUKA 0+ in Moscow at the Expocentre Exhibition Centre and MSU. Programmes presented by JINR included lectures, master classes, demonstrations of models of the Institute's basic facilities and stands with exhibits of research projects;
- Geek Picnic festival of science, technology and art in the Muzeon art park;
- Technosreda Festival on 25-26 September, 2021;
- 19th World Festival of Youth and Students, Sochi, 2017;
- 2nd Congress of Young Scientists, Sochi, 2022;
- International Dark Matter Day, 2019;
- Nanograd Forum of School League programme, St. Petersburg, 2022;
- Physics workshop “Element 105”, Summer School;
- Day of JINR Basic Departments at Dubna University;
- Career Days at MSU, MIPT, MEPhI, SPbSU and Dubna University.

More than **20** events for JINR Infocentres annually

JINR Basic Facilities Exposition

An interactive exposition “JINR Basic Facilities” at the Cultural Centre “Mir” made by the UC staff members was devoted to celebrating the 65th anniversary of JINR. Interactive models' stands are the best way to be introduced to the main facilities of the Institute on interactive models.

JINR Schools for Teachers

200
teachers

from 37 regions of the Russian Federation and 7 JINR Member States took part in International Schools for Physics Teachers organized at JINR and CERN from 2017 to 2023.

Interaction with School Students

The UC organizes events for schoolchildren, teachers and the general public aimed at popularizing scientific knowledge and developing interest in natural and exact sciences, physics and mathematics. The UC annually holds the following events: "Days of Physics" festival, CyberDubna Robotics Tournament, competitions in the design and programming of robots, Technical Hackathon, and the International Computer School (ICS).

Since 2021, there have been organized scientific schools for students of the Children's University under the Egyptian Academy of Scientific Research and Technology. In total, 39 people became participants in the school over 2021–2023.

In 2022, more than 600 school students of 7–11 grades took part in the cycle "Lessons of Real Nuclear Physics", a joint project of the Educational Centre "Sirius" and JINR. Students were distributed in 90 science and technology studios of "Lessons of the Present" based on educational organizations in 41 regions of Russia.

More than
60 group **excursions for school students and undergraduates**
to the JINR Laboratories annually

Dubna, 2 September 2022. The festive opening of the MSU branch in Dubna

Moscow, 20 November 2023. MSU Rector V. Sadovnichy and JINR Director G. Trubnikov signed an agreement on cooperation between JINR and MSU at the joint meeting of the MSU–JINR Scientific Council

In 2022, on the initiative of JINR and Lomonosov Moscow State University, a branch of MSU began its work in Dubna, which took over from the existing subdivision of the Skobeltsyn Institute of Nuclear Physics of MSU and two departments of the MSU Faculty of Physics.

In May 2023, the master's degree programmes "Elementary Particle Physics" and "Fundamental and Applied Nuclear Physics" were updated, and the master's programme "Methods and Technologies of Data Processing in Heterogeneous Computing Environments" was agreed upon.

In cooperation with the JINR Meshcheryakov Laboratory of Information Technologies and the Faculty of Computational Mathematics and Cybernetics of Moscow State University, programmes and a curriculum in the field of Applied Mathematics and Computer Science have been prepared. The disciplines of the IT area being implemented were presented at the section of the International Conference of Moscow State University "Mathematics in the Constellation of Sciences", organized in Dubna.

On 2 March 2017, a festive colloquium dedicated to the **inauguration of the chemical elements of Mendeleev's Periodic Table** was held at the RAS Central Scientists House (Moscow), based on the decision of the International Union of Pure and Applied Chemistry (IUPAC) to assign the names:

- Nihonium and symbol Nh for element 113;
- Moscovium and symbol Mc for element 115;
- Tennessine and symbol Ts for element 117;
- Oganesson and symbol Og for element 118.

At the festive colloquium dedicated to the inauguration of new superheavy elements

In 2019, the European Physical Society (EPS) announced presentation of **awards in the fields of high energy and particle physics** (HEP) to CDF and DZero collaborations for the discovery of *t* quark and a detailed study of its properties.

Staff members of the Dzhelepov Laboratory of Nuclear Problems took part in both experiments.

Members of the CDF collaboration from DLNP: A. Artikov, J. Budagov, V. Glagolev, F. Prokoshin, O. Pukhov, A. Semenov, A. Simonenko, I. Suslov, A. Sissakian, G. Chlachidze, and D. Chokheli. All of them made a substantial contribution to the modernization of the CDF facility in 1992–1999, as well as to the analysis and processing of the experiment's results in 2000–2012.

Members of the DZero collaboration from DLNP: V. Abazov, G. Alexeev, L. Vertogradov, J. Vertogradova, A. Verkheev, G. Golovanov, V. Malyshev, Yu. Merekov, B. Sabirov, N. Skachkov, V. Tokmenin, Yu. Kharzheev, and Yu. Yatsunenko. They created detectors and electronics for the front-end muon systems of the DZero facility, participated in the study of properties of the top quark, made a decisive contribution to the discovery of heavy *b* hyperons and to the study of hadron multiparton interactions.

On 14 October 2020, a staff member of BLTP JINR F. Šimkovic received Slovakia's prestigious **ESET Science Award** in recognition of his considerable contribution to the theory of particle and nuclear physics, especially the physics of neutrino.

ESET Science Award 2020 winners: T. Csanádi, F. Šimkovic (BLTP JINR) and I. Varga. *Photo: esetscienceaward.sk*

Paris. UNESCO–Russia Mendeleev International Prize award ceremony

In 2021, the first winners of the **UNESCO–Russia Mendeleev International Prize** in the Basic Sciences were announced: Yu. Oganessian (Russia) and V. Balzani (Italy).


Staff members of FLNP JINR I. Zinicovscaia, N. Yushin, D. Grozdov, and K. Vergel — winners of the international exhibition Euroinvent-2021

The winners of the 13th European Exhibition of Creativity and Innovation **Euroinvent-2021**, held online on 20–22 May 2021, were young scientists of FLNP JINR Inga Zinicovscaia, Nikita Yushin, Dmitriy Grozdov, and Konstantin Vergel. The researchers won the gold medal for their work "Production of Mineral-Organic Hybrid Adsorbent for Metal Removal from Industrial Wastewater" and the silver medal for the study "Unexpected Reproductive Effect of Prolonged Oral Administration of Silver Nanoparticles in Laboratory Mice".

In June 2022, in recognition of the value of international cooperation between JINR and Mongolia and the contribution to joint research, Advisor to the MLIT Directorate I. Puzynin received the **Order of the Polar Star of Mongolia**, and the **Medal of Friendship** was presented to BLTP JINR Leading Researcher S. Vinitsky upon the decision of the President of Mongolia.

The delegation of the Embassy of Mongolia in the Russian Federation and representatives of the JINR Directorate with staff members of the Institute who were honoured with Mongolian government awards

On 24 November 2022, S. Merts, Senior Researcher of VBLHEP JINR, was awarded the All-Russian Award "**For Loyalty to Science**" for winning the nomination "Science Is Fashionable" in Moscow.

VBLHEP JINR staff member S. Merts — laureate of the Award "For Loyalty to Science"

Awarding the first Sber Scientific Prize to Academician Yu. Oganessian

On 14 December 2022, the first **Sber Scientific Prize** was presented at the Sberbank headquarters. Academician Yu. Oganessian won the Prize for his fundamental work on the synthesis of superheavy elements and contribution to the formation of the accelerator experimental basis that provide the prospect for revolutionary nuclear technologies.

OGANESSON Prize winners

On Yu. Oganessian's initiative, the prize money was donated to the OGANESSON Prize Fund. The **OGANESSON Prize** is awarded annually to recognize outstanding achievements in theoretical and experimental studies in physics, chemistry, biology, and applied research, as well as to reward creative educational endeavors and inspirational science promotion. The first winners were announced in 2023: Ana María Cetto Kramis, Professor of Physics at the National Autonomous University of Mexico; Mikhail Efimovich Shvydkoy, Special Representative of the President of the Russian Federation for International Cultural Cooperation; Valeria Pershina, Professor of Chemistry at the GSI Helmholtz Centre for Heavy-Ion Research in Darmstadt, Germany; Vasily Alekseevich Semin, Head of the Scientific and Technological Department of Accelerators of the Flerov Laboratory of Nuclear Reactions, JINR.

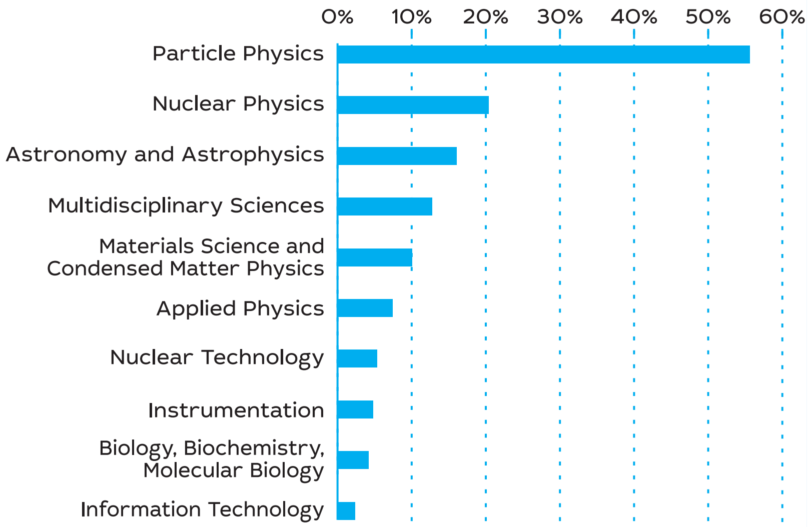
On 28 September 2023, at the Great Hall of the People in Beijing (China), the festive ceremony of awarding the **Friendship Award of the People's Republic of China** (PRC) took place. Among the winners is JINR Director, Academician G. Trubnikov, who was honoured with a prestigious award of the People's Republic of China for his contribution to the development of scientific cooperation between JINR and Chinese research centres in superconducting technologies, nuclear physics facilities, and nuclear medicine.

JINR Director, Academician G. Trubnikov, honoured with the PRC Friendship Award

On 19 December 2023, the first award ceremony of the **Vyzov** National Award for future technologies took place. VBLHEP JINR Deputy Director H. Khodzhibagiyan won the Prize in the Engineering Solution category for the development of magnetic systems based on high-temperature superconductors for charged particle accelerators and ultrahigh power energy storage devices. The co-authors of the work are JINR Director, Academician G. Trubnikov and VBLHEP JINR researcher M. Novikov.

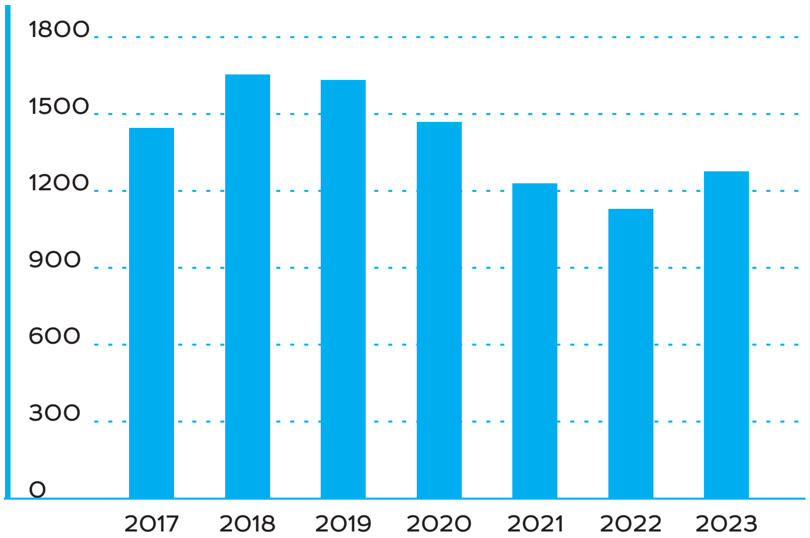
VBLHEP JINR researcher H. Khodzhibagiyan — winner of the Vyzov National Award for future technologies

JINR DEVELOPMENT MONITORING



The distribution of JINR publications for 2023 by scientific fields, according to WoS data (one publication can be attributed to several scientific fields)

JINR scientists conduct research in the field of astrophysics and particle physics, nuclear physics, condensed matter physics, radiation biology, information and computing technologies, theoretical and mathematical physics.



Number of JINR publications according to WoS data

At least

1000 publications

have been published annually for the past 7 years.

	2017	2018	2019	2020	2021	2022	2023
Number of organizations cooperating with JINR	883	908	918	931	1005	998	996
Number of JINR Information Centres	–	1	1	2	4	8	11
Number of collaborations involving JINR	38	38	39	39	39	39	39

The Institute is actively developing its partner network.

JINR uses new formats of international cooperation in order to involve more participants in its scientific and organizational orbit.

5th place

in terms of budget size among international intergovernmental scientific organizations (IISO) in the field of natural sciences

	Name of IISO	Annual budget 2022, thousands of US$
1	CERN	1 472 685
2	European Molecular Biology Laboratory	336 162
3	European Southern Observatory	283 445
4	Square Kilometer Array	270 089
5	JINR	221 600
6	European Spallation Source	143 280
7	European Synchrotron Radiation Facility	122 922
8	Institut Laue–Langevin	113 557
9	World Meteorological Organization	99 547
10	International Institute for Applied Systems Analysis	25 681

2nd place

in terms of the number of staff among IISOs

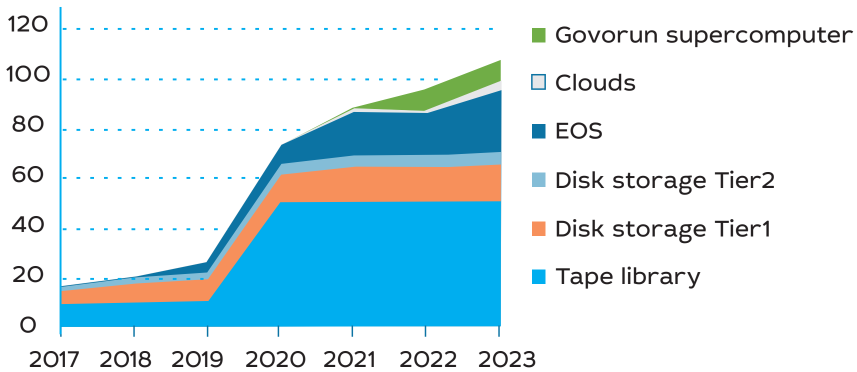
	Name of IISO	Number of staff in 2022, people
1	CERN	12 200
2	JINR	4200
3	Joint Research Centre	2750
4	UNESCO	2200
5	European Space Agency	2200
6	European Molecular Biology Laboratory	1986
7	European University Institute	1212
8	European Synchrotron Radiation Facility	707
9	European Southern Observatory	700
10	Institut Laue–Langevin	536

The IT platform is developing dynamically.

Data storage capacity and computing power have increased

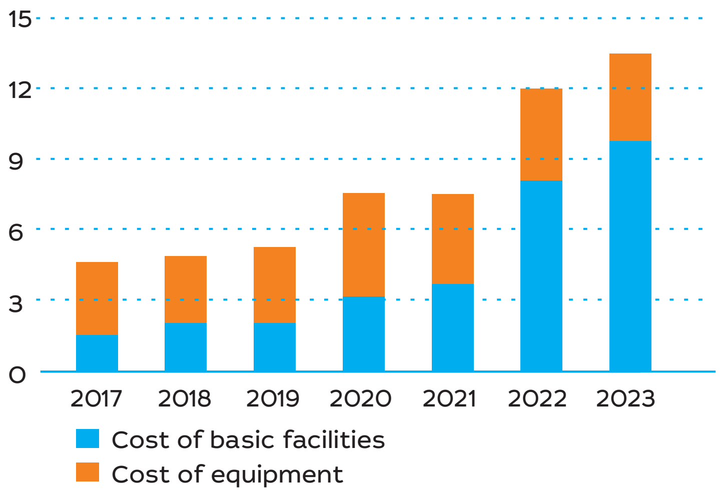
5 times

over the past 7 years.

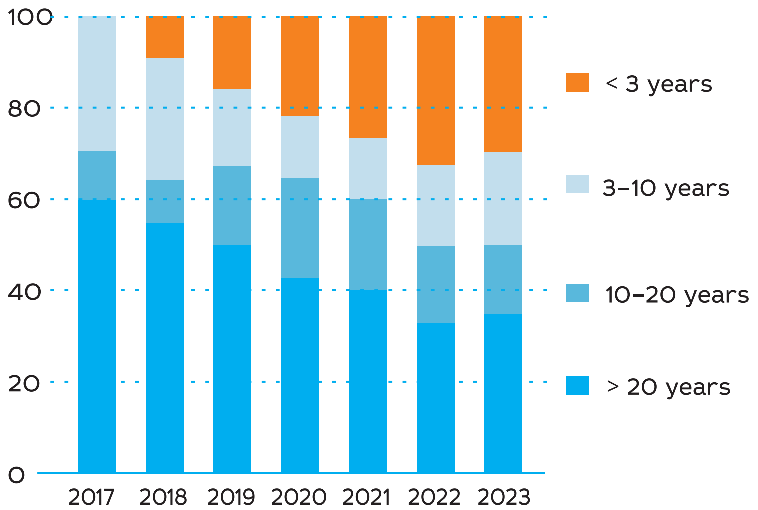


JINR data storage system, PB

The uniqueness of the research conducted at JINR is largely due to the presence and active development of its own infrastructure of experimental physical facilities. The Institute has invested heavily in scientific infrastructure over the previous seven-year period (the cost has increased 3 times). There has been a significant rejuvenation of the basic facilities of the Institute (one third of the basic facilities are younger than 3 years old).

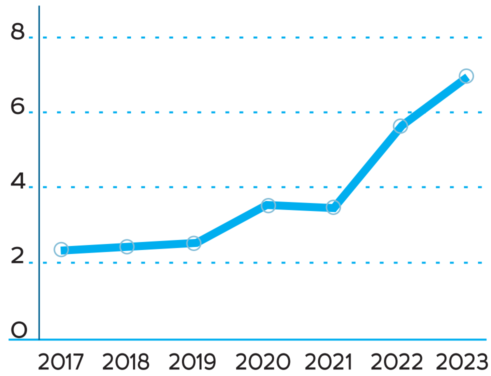


Cost of basic facilities and equipment at the beginning of 2024, billion rubles

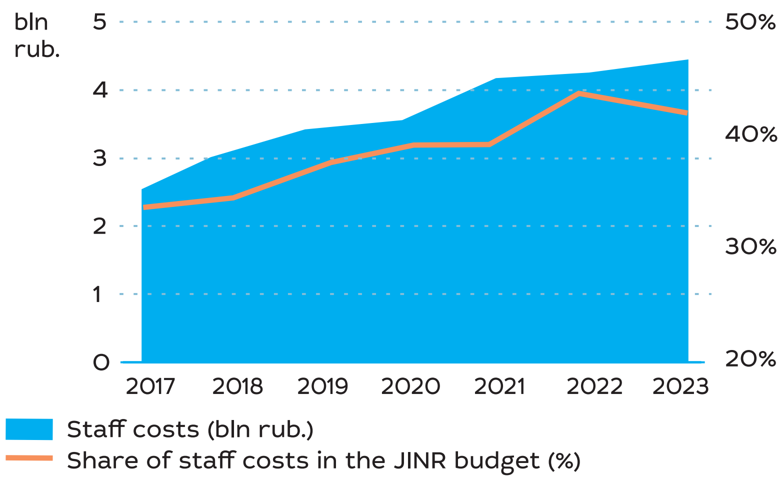


Distribution of the number of basic facilities by their age at the beginning of the year in %

The researchers' capital-labor ratio has increased **3 times**



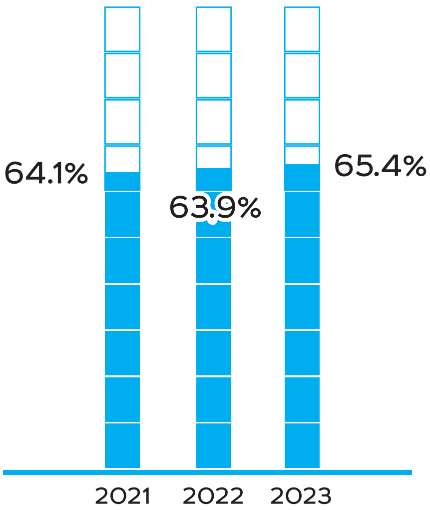
Cost of basic facilities and equipment per researcher at the beginning of the year, million rubles



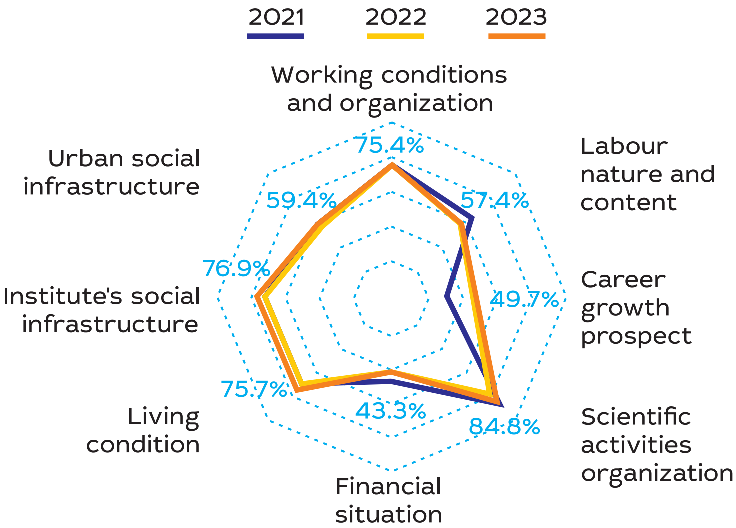
Staff costs and the share of staff costs in the JINR budget (Staff costs include salary costs, insurance premiums and social welfare fund)

Staff costs increased both in absolute terms and as a percentage of total expenses.

According to the annual sociological surveys, staff satisfaction with work at JINR is growing. First of all, the employees are satisfied with the organization of scientific activities, working conditions and organization, and the social infrastructure of the Institute.



The aggregate staff satisfaction index

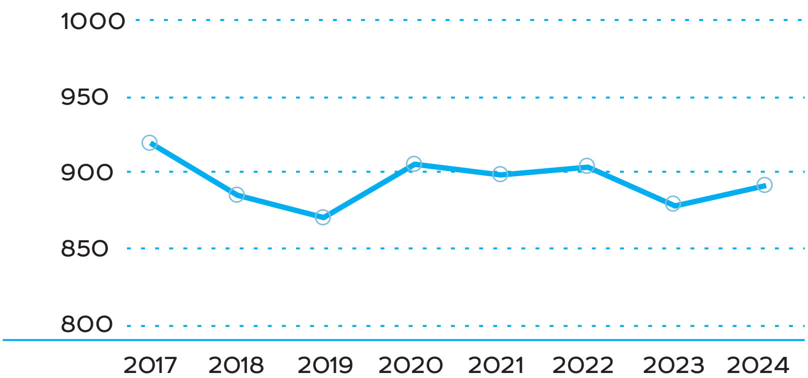


% — the share of those who are rather and quite satisfied of the total number.

Staff satisfaction according to annual sociological surveys

900

Candidates and Doctors of Sciences



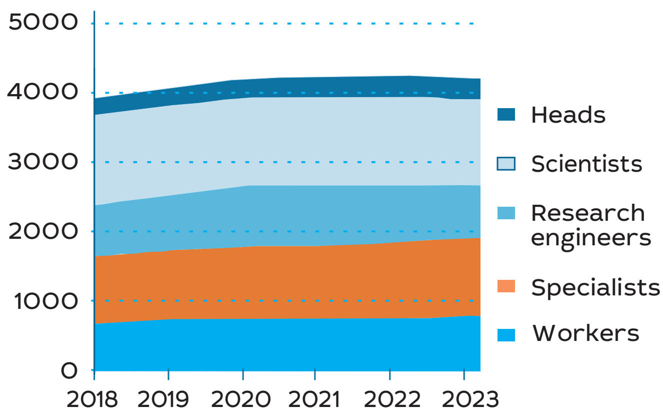
The number of staff with scientific degrees at the beginning of 2024, people

The number of staff without self-supporting units is

4200

people

The staff structure is stable.



Structure of staff by category at the beginning of 2024, people

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