VEKSLER AND BALDIN LABORATORY OF HIGH ENERGY PHYSICS

The main task of VBLHEP is to carry out researches in particle and high-energy heavy-ion physics both on the JINR in-house facility base and within the framework of international partnership programmes in the world's largest accelerator centres. Concerning home facilities, it is assumed to modernize the existing accelerator Nuclotron and build up a new collider facility NICA.

DEVELOPMENT AND MODERNIZATION OF THE JINR ACCELERATOR COMPLEX

The Nuclotron-M

The Nuclotron is a basic JINR accelerator facility in high-energy heavy-ion and particle physics. Its modernization was started in 2007 in the framework of the Nuclotron-M project. It requires full-scale modernization of the cryogenic system, upgrade of the power supply and quench protection systems, vacuum condition improvement, optimization of the ion source KRION-2 for the heavy-ion generation, upgrade of the injection complex, development of the beam diagnostics and minimization of particle losses at all stages of the beam acceleration. To prepare the accelerator complex for operation as a part of the NICA facility, design and construction of the new ion source KRION-6T, a design of a new heavy-ion linac and development of a new source of polarized particles are required. At the end of 2009 the major part of the work was completed for 70–80%. The project completion is scheduled for the end of 2010.

The main results obtained in 2009 concerning the subsystems of the accelerator complex are the following:

1. Modernization of the Cryogenic System

The upgrade of the accelerator complex cryogenic supply system has been completed. It included heavy repair and full-scale modernization of all low-temperature aggregates of the KGU-1600/4.5 facility, liquid helium rectifier aggregates MO-800, oil separators, and other equipment. The upgraded equipment was tested, commissioned and used during the 39th Nuclotron run without problems. The term of work of the upgraded equipment has sufficiently been prolonged and it already meets the requirements of the NICA/MPD project.

2. Modernization of the Vacuum System

Two stages of the vacuum system upgrade were completed: improvement of the vacuum in the ring and creation of the automatic control system for the ring vacuum equipment.

The average vacuum value in the ring before modernization was $\sim 5 \cdot 10^{-7}$ Torr (nitrogen equivalent at the room temperature). The average vacuum value measured in the 38th run (June 2008) was $\sim 5 \cdot 10^{-9}$ Torr.

The developed automatic control system provides remote switch «on/off» of the equipment, measurements of its parameters, information transfer to the control room, and protection of the equipment in case of accidents. The system was made in collaboration with Czech firms (Vacuum Praha, FOTON). During the 40th run the system was commissioned and put into experimental operation.

3. Modernization of the Power Supply Systems

Modification of the power supply system scheme is in progress now. It includes upgrade of the existing powerful supply units, construction of new cable lines, construction of a new quench detection system and energy evacuation keys. During the 39th run the successive test of the power supply and quench protection system was performed at a magnetic field of about 1.5 T, all the equipment is ready to be tested at the nominal field value.

Development of new power supply units for the orbit correction system was started in cooperation with Electro-Technical Research and Design Institute, Dubnica (Slovak Republic). The experimental sample of the supply unit was tested at the cryogenic test bench and during the 40th run at the Nuclotron ring.

The upgrade of the electrostatic septum (ES) power supply is in the final stage. The goal of this work is to improve the exploitation parameters to increase the voltage up to 200 kV, which will permit one to extract the beam at the Nuclotron designed energy. On 3 January 2010 the system was successfully tested up to 220 kV.

4. Linac

Modernization of the LU-20 has been done. It included:

• alignment of all 59 drift tubes;

• mounting of new power supplies for corrector magnets;

• commissioning of the new synchronization system for all linac control channels.

The achieved deuteron current from the laser source is more than 5 mA (before it was ~ 3 mA).

5. Heavy-Ion Source KRION

Four runs were performed in 2009 at the electron-string ion source KRION-2 with a solenoid magnetic field of 3 T. These were aimed at the parameters optimization and preparation for the heavy-ion acceleration scheduled for the beginning of 2010.

In October 2009, ions $^{124}Xe^{+41}$, $^{124}Xe^{+42}$, $^{124}Xe^{+43}$ and $^{124}Xe^{+44}$ were produced. $^{124}Xe^{+42}$ was extracted with about $3 \cdot 10^7$ particles per pulse in terms of the single chosen charge state.

The vacuum and cryogenic vessels for the new source KRION-6T have been constructed, assembled and tested. Construction of the 6 T solenoid is in progress.

6. Development of the Polarized Deuteron Source

This work is in progress in close collaboration with INR (Troitsk). TDR documentation and first commissioned elements are to be completed in 2010.

7. Engineering Infrastructure Development

During 2009 the upgrade of the water cooling system was continued: new self-rectified filters were installed onto two water lines of the technological systems of the accelerator complex (the Nuclotron ring and cryogenic supply system) and tested during spring «high water» with good results.

A large volume of repairing and construction work was performed at the VBLHEP site.

THE LHC PROJECTS START UP

In 2009 the **ALICE**, **ATLAS** and **CMS** experimental setups were successfully started up with the serious contribution of VBLHEP physicists. An example of the real event is shown in Fig. 1.

NICA/MPD

The goal of the NICA project is the construction and commissioning of a new JINR accelerator facility to provide experimental studies on the frontier of the modern science to investigate properties of hot and dense hadronic matter, and search for the so-called «mixed phase» of such matter, i.e., a mixture of quark–gluon and hadron states, as well as for a possible phase transition.

In 2009 the first version of the Technical Design Report [1] was prepared and presented to the PAC expertise.

The collider rings design is based on the Nuclotron-type 2 T magnets. Two interaction points are presumed for the **MultiPurpose Detector** (**MPD**) to study heavy-ion physics and for the **Spin Physics Detector** (**SPD**) to work with polarized beams.

In January 2010, at the 32nd session of the PAC, the Machine Advisory Committee (MAC) confirmed feasibility of the NICA project and strongly supported its realization.

The design works for the main elements of the NICA complex are in progress.

The MPD is proposed to study hot and dense baryonic matter in collisions of heavy ions over the atomic mass range $A = 1-197$ at a centre-of-mass energy up to $\sqrt{s_{NN}} = 11$ GeV (for Au^{79+}), detection of possible formation of the «mixed phase», as well as the detection of violations of P- and CP-parity in strong interactions.

Two important steps in the MPD project preparations were done in 2009:

• May 2009 — the first version of the MPD CDR [2] was issued;

• June 2009 — the first version of the NICA physics programme review «White Paper» was prepared.

R&D on the MPD subsystems are in progress.

The 4th **Round Table** dedicated to the NICA physics programme and detectors performance was organized and held at JINR in September.

IREN, LUE-200

The employees of the VBLHEP Accelerator Division started up the linear accelerator of the electrons LUE-200 which is the basic part of the pulse resonance neutron source IREN, JINR's basic facility for the wide-range fundamental and applied investigations in nuclear physics.

The JINR involvement in the **ALICE** project is devoted to the following major directions:

• design and prototyping of the large dipole magnet, construction of the iron yoke;

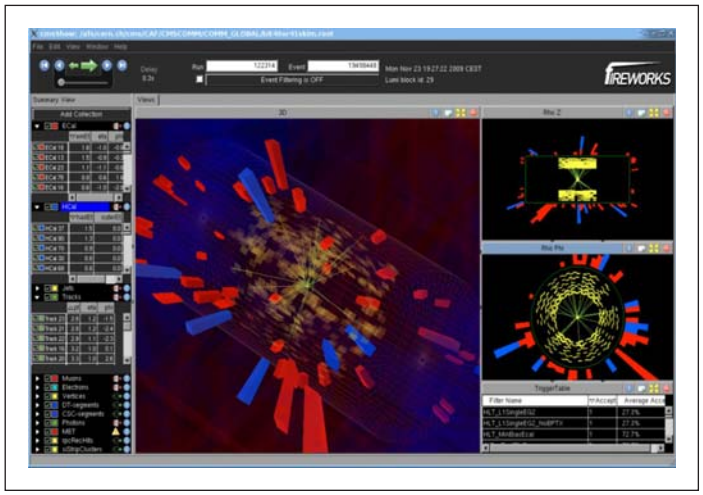

Fig. 1. An example of the event of pp collisions at 450 GeV in the CMS detector

• procurement and testing of lead tungstate crystals for the photon spectrometer;

• construction and testing of 125 drift chambers for the transition radiation detector.

First data on the particle production at a collision energy of 900 GeV obtained during the 2009 test run were analyzed and submitted for publication to «European Physics Journal».

In the **ATLAS** experiment VBLHEP scientists fulfilled all obligations on the construction of the following subsystems and putting them into operation:

• 34 straw wheels (3072 channels in each) for the Transition Radiator Tracker;

• 40% of the liquid argon end-cap calorimeter.

In the **CMS** project VBLHEP group was responsible for:

• Endcap Hadron Calorimeters (HE);

• the first Forward muon Stations (ME1/1).

JINR also participates in the construction of the Endcap pre-shower (ES).

The personnel of the VBLHEP Accelerator Division made a substantial contribution to the accelerator startup.

The installation of the **LHC Damper** system [3] aimed at stabilizing the high-intensity beam against coupled bunch transverse instabilities in a frequency range from 3 kHz to 20 MHz and at the same time at damping injection oscillations originating from steering errors has been completed successfully, as well as the injection kicker ripple.

The **LHC beam monitors** used during the accelerator startup were produced and installed by JINR.

THE MOST IMPORTANT RESULTS IN PHYSICS

The activities of the **COMPASS** collaboration in 2009 were concentrated on the two items:

• performing the data taking with a hadron beam;

• analysis of the data obtained with the muon beam in 2002–2007 and with a hadron beam in 2008.

The major obtained results are:

1. A partial wave analysis for the diffractive dissociation of π^- into the $\pi^-\pi^-\pi^+$ final state [4] has been performed on a sample of 420 000 events taken at values of the squared 4-momentum transfer t' between 0.1 and 1 GeV^2. The well-known resonances $a_1(1260)$, $a_2(1320)$, and $\pi_2(1670)$ have been confirmed with record statistics. The collected data have shown a significant natural parity exchange production of a resonance with spin-exotic quantum numbers $J^{\mathrm{PC}} = 1^{-+}$ at 1.66 GeV decaying to $\rho\pi$. The resonant nature of this wave is evident from the mass-dependent phase differences to the $J^{\mathrm{PC}} = 2^{-+}$ and 1^{++} waves. From a mass-dependent fit a resonance mass of $(1660 \pm 10^{+0}_{-64})$ MeV and a width of $(269 \pm 21^{+42}_{-64})$ MeV are deduced (Figs. 2 and 3).

2. In 2009, COMPASS presented a LO evaluation of helicity densities of valence, $\Delta u_v + \Delta d_v$ nonstrange sea, $\Delta\bar{u}_v + \Delta\bar{d}_v$, and strange quarks, Δs (assumed to be equal to $\Delta\bar{s}$) [5]. They have been obtained from the inclusive asymmetry $A_{1,d}$ and the semi-inclusive asymmetries $A^{\pi+}_{1,d}$, $A^{\pi-}_{1,d}$, $A^{K+}_{1,d}$, $A^{K-}_{1,d}$ measured in polarized deep inelastic muon-deuteron scattering. The data cover the range $Q^2 > 1$ GeV^2 and $0.004 < x < 0.3$. The nonstrange densities are found to be in a good agreement

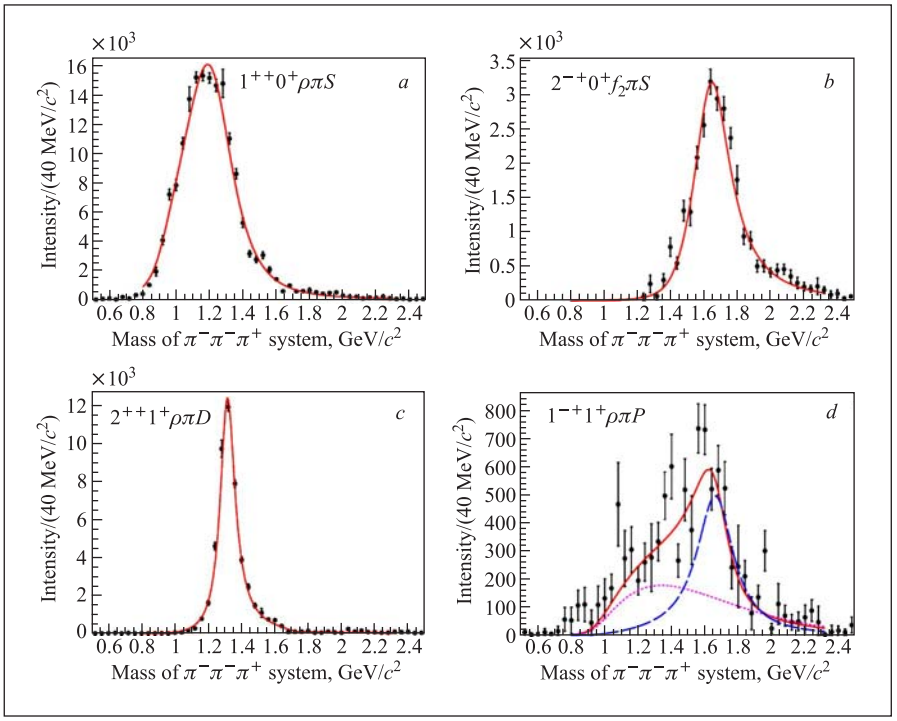

Fig. 2. Intensities of major waves $1^{++}\ 0^+\ \rho\pi S$ (*a*), $2^{-+}\ 0^+\ f_2\pi S$ (*b*), and $2^{++}\ 1^+\ \rho\pi D$ (*c*), as well as the intensity of the exotic wave $1^{-+}\ 1^+\ \rho\pi P$ (*d*). The lines represent the result of the mass-dependent fit

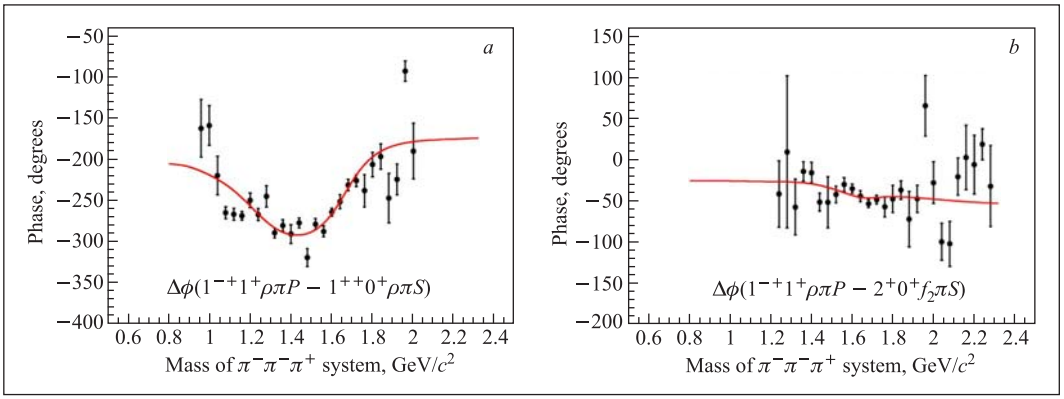

Fig. 3. Phase differences of the exotic $1^{-+}\ \rho\pi P$ wave to the $1^{++}\ 0^+\ \rho\pi S$ (*a*) and the $2^{-+}\ 0^+\ f_2\pi S$ (*b*) waves

with previous measurements (Fig. 4). The distribution of $\Delta s(x)$ is compatible with zero in the whole measured range in contrast to the shape of the strange quark helicity distribution obtained in most of the LO and NLO QCD fits.

3. The longitudinal polarization transfer from μ to Λ and $\bar{\Lambda}$ hyperons, $D_{LL}^{\Lambda(\bar{\Lambda})}$, has been studied in deep inelastic scattering on the unpolarized isoscalar target [6]. The spin transfers to Λ and $\bar{\Lambda}$ produced in the current fragmentation region exhibit different behaviour as a function of x and x_F. The measured x and x_F dependences of D_{LL}^{Λ} are compatible with zero, while $D_{LL}^{\bar{\Lambda}}$ tends to increase with x_F, reaching values of 0.4–0.5. The resulting average values are $D_{LL}^{\Lambda} = -0.012 \pm 0.047 \pm 0.024$ and $D_{LL}^{\bar{\Lambda}} = 0.249 \pm 0.056 \pm 0.049$ (Fig. 5).

The **NA48** Collaboration has started a new programme preparation, **NA62**, at CERN SPS, which is devoted to study of a very rare decay of charged kaon into a charged pion and two neutrinos. The responsibility of JINR in the framework of this programme is R&D of a straw detector, working in vacuum and providing a high spatial resolution in track reconstructions. The activities of the NA48/NA62 collaborations in 2009 were concentrated on two items:

- R&D on the straw detector;
- analysis of the data obtained in NA48 experiment.

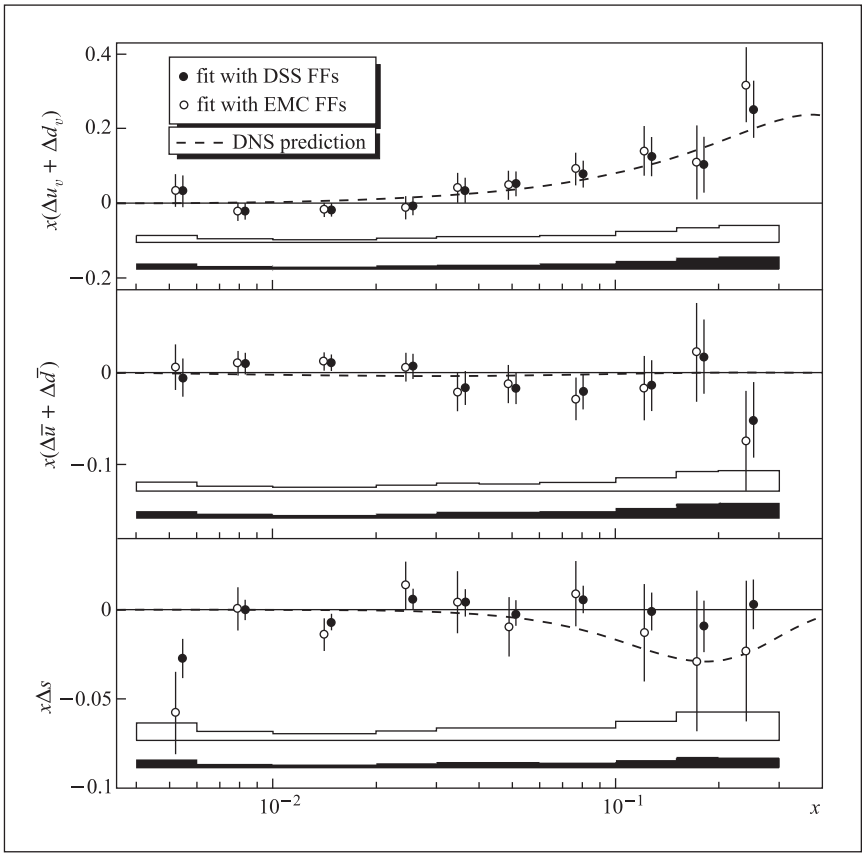

Fig. 4. The quark helicity distributions evaluated at common value $Q^2 = 3$ GeV^2 as a function of x for two sets of fragmentation functions

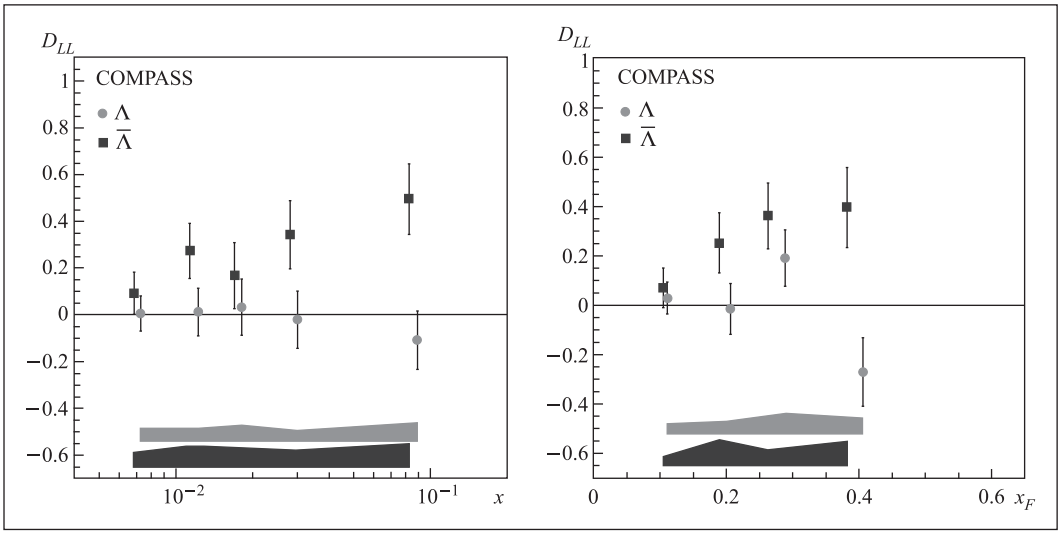

Fig. 5. The x (left panel) and x_F (right panel) dependence of the longitudinal spin transfer Λ and $\bar{\Lambda}$. The shaded bands show the size of the corresponding systematic errors

The major obtained results are:

1. Preliminary results of the lepton universality test [7, 8] have been obtained. The branching ratio $P_K = \Gamma(K^\pm \to \varepsilon^\pm\nu)/\Gamma(K^\pm \to \mu^\pm\nu)$, which is calculated in the Standard Model with the excellent accuracy ($R_K^{\rm SM} = (2.477\pm0.001)\cdot10^{-5}$), has been measured with the record precision, approaching the precision of the theoretical calculation: $R_K^{\rm SM} = (2.500 \pm 0.0016)\cdot10^{-5}$. World results of R_K measurement are shown in Fig. 6 together with the preliminary NA62 ones.

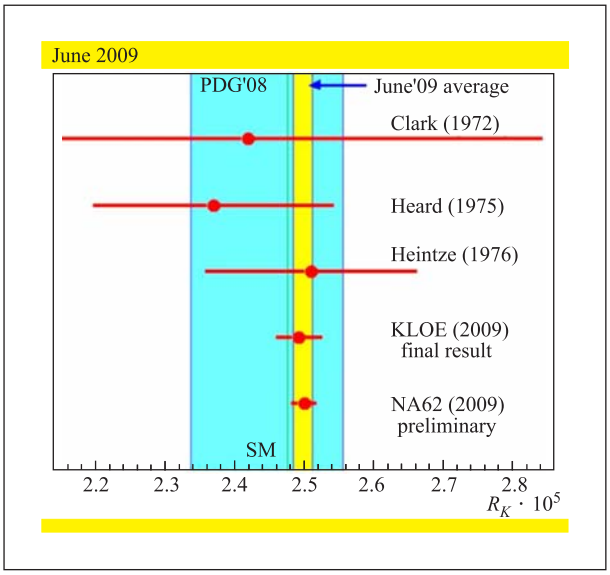

Fig. 6. Summary of R_K measurements

2. The 2007–2008 experimental data from the first straw detector prototype [9] were analyzed to measure resolution and efficiency of a straw in different conditions and with different readout electronics. A good spatial resolution (< 100 μm, see Fig. 7) was obtained for the region of the straw with a radius larger than 0.5 mm; good efficiency ($> 99\%$) was obtained in the inner straw region starting 0.2 mm from the straw wall.

3. More than 100 million triggers were collected to choose the optimal gas mixture, electronics usage and study aging, noises, efficiency and resolution at high particle rate. The data analysis is now in progress.

4. A full-scale straw detector design and its integration into the NA62 experimental setup are in progress.

The results obtained with the data accumulated in 2003–2004 in the **NA48/2** experiment are:

1. A sample of 7253 $K^{\pm} \to \pi^+ e^+ e^-$ decay candidates with 1.0% background contamination has been collected by the NA48/2 experiment at the CERN SPS, allowing a precise measurement of the decay properties. The branching ratio in the full kinematic range was measured to be $\mathrm{BR} = (3.11 \pm 0.12) \cdot 10^{-7}$, where the uncertainty includes also the model dependence. The shape of the form factor $W(z)$, where $z = (M_{ee}/M_K)^2$, was parameterized according to several models. A possible CP-violating asymmetry of K^+ and K^- decay widths was investigated, and a conservative upper limit of $2.1 \cdot 10^{-2}$ at 90% CL was established.

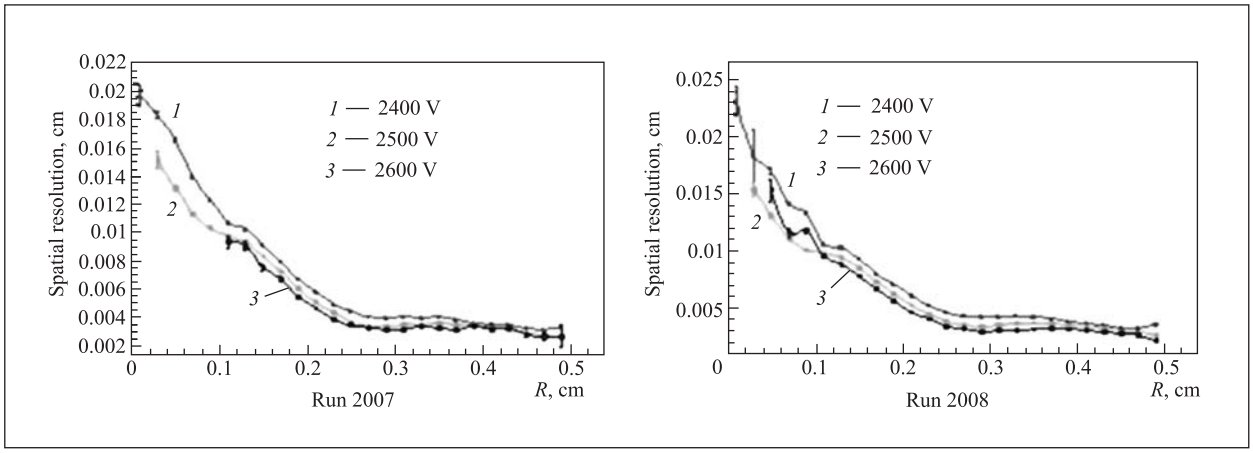

Fig. 7. Spatial resolution of a straw for different HV vs straw radius

2. Analysis of the cusp phenomena in $K^{\pm} \to \pi^0\pi^0\pi^{\pm}$ and a new measurement of the K_{e4} decay $K^{\pm} \to \pi^+\pi^- e^{\pm}\nu$ wave been done. The most precise measurements of the pion–pion scattering lengths have been obtained on a base of «cusp effect» and K_{e4} decay (see Fig. 8).

The JINR physicists participating in the experiments on the detector **STAR** at the Relativistic Heavy-Ion Collider (RHIC) at the Brookhaven National Laboratory (BNL) have carried out the following main tasks:

1. The production of soft photons in the energy interval of 35–160 MeV in Au + Au and d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The substantial excess of photon production in Au + Au collisions has been found in the energy interval of 60–160 MeV, in contradiction with the predictions of the HIJING model.

2. Study of the influence of deformation of Au^{197} and U^{238} nuclei on the elliptic flow (initial eccentricity and eccentricity fluctuations) in Au + Au and U + U collisions. It has been found that deformation of Au^{197} nucleus increases the average eccentricity in central Au + Au collisions. The average eccentricity and eccentricity fluctuations have been studied and predicted for U + U collisions [10].

3. Study of femtoscopic correlations and their consequences for particle production dynamics using various Monte Carlo models [11–15].

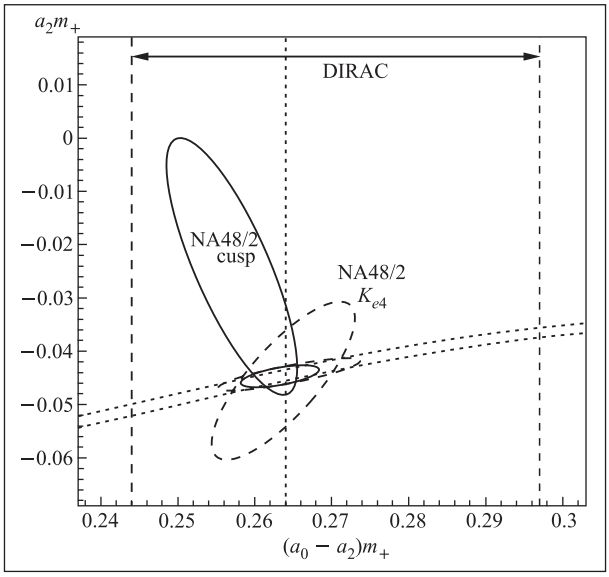

Fig. 8. 68% confidence level ellipses corresponding to the final results of the pion scattering lengths measurement (small solid line ellipse: fit with the ChPt constraint; large solid line ellipse: fit using a_0-a_2 and a_2 as independent parameters), and from K_{e4} decay (small dashed line ellipse: fit with the ChPT constraint; large dashed line ellipse: fit using a_0 and a_2 as independent parameters). Vertical lines: central value from the DIRAC experiment (dotted line) and error limits (dashed lines). The 1-sigma theoretical band allowed by the ChPT constraint is shown by the dotted curves

4. A capability of wavelet analysis to study multiparticle correlations of secondary particles produced in ultrarelativistic heavy-ion collisions has been studied. First, propagation of statistical errors in the wavelet spectra was estimated by the MC method. It was also shown how to correct the wavelet spectra for limited detector efficiency applying the weighting method.

5. Preliminary analysis of STAR data on charged and strange neutral hadrons produced in Au + Au collisions at 9.2 GeV has been performed.

6. Experimental data on transverse momentum spectra of hadrons produced in pp and nucleus–nucleus collisions have been analyzed in the framework of the z-scaling model.

7. A detailed verification of the z-scaling has been performed using the data on hadron production in pp and $p\bar{p}$ collisions and the comparison of pQCD; and z-scaling predictions on asymptotic behaviour of jet production have been done [16–18].

In 2009 the JINR group participating in the **HADES** experiment has performed the following tasks:

• The analysis for dp elastic scattering at large transverse momenta for dp@1.25 GeV data has been performed to study short-range correlations in deuteron. Analysis of the single and double π production in np@1.25 GeV has been started.

• The theoretical analysis of the dielectron production in the d–p reaction at the HADES energy was fulfilled. Similar analysis was done for the πp reaction and the predictions for the future HADES measurements were obtained.

• Upgrade of the drift chambers (plane 2) and front-end electronics.

INNOVATION

In 2009, different systems for the remote nondamaging analysis of forbidden substances were developed on the basis of the tagged neutron method (TNM). The main advantage of TNM is in its sensitivity to the element composition of the hidden substance but not to the contrast of the substance density as in casual X-ray introscopes.

TNM has an opportunity to define the time information which can be used for selection of the events during a certain time interval that results in reducing the background. It has been shown that the usage of gamma/alpha coincidences decreases the signal/background ratio by more than 200 times, which allows one to determine a small amount of the explosive substance. Fast 14 MeV neutrons are convenient to use for identification of the hidden objects because of their high penetration power. These are especially efficient to check the middle-sized (luggage) and large-sized (loading container) objects.

In 2009 the work was carried out on the following projects:

• a stationary system to examine large-sized loads [19]. A prototype of the system was made, its characteristics were studied;

• a movable system to examine cars.

Stands for testing alpha detectors, as well as for the electronics of the data acquisition and gamma detectors, were developed.

The following patents have been obtained:

• #2008129146 «A Device for Identification of the Hidden Substances» — a patent for the used model;

• #2008141464 «A Movable Device for Identification of the Hidden Substances» — a patent for the invention.

REFERENCES

1. Nuclotron-based Ion Collider fAcility (NICA). Technical Design Report. Dubna, 2009.
2. The MultiPurpose Detector (MPD) to Study Heavy-Ion Collisions at NICA. Conceptual Design Report. Dubna, 2009.
3. *Zhabitsky V. M., Höfle W.* LHC Transverse Feedback System: First Results of Commissioning // JINR News. No. 2. P. 11–14.
4. *COMPASS Collab.* Observation of a $J^{\mathrm{PC}} = 1^{-+}$ Exotic Resonance in Diffractive Dissociation of 190 GeV/c π^- into $\pi^-\pi^-\pi^+$. Submitted to «Phys. Rev. Lett.»; CERN-PH-EP/2009-018.

5. *COMPASS Collab.* Flavour Separation of Helicity Distributions from Deep Inelastic Muon-Deuteron Scattering // Phys. Lett. B. 2009. V. 680. P. 217–224.
6. *COMPASS Collab.* Measurement of the Longitudinal Spin Transfer to Λ and $\bar{\Lambda}$ Hyperons in Polarized Muon DIS // EPJC. 2009. V. 64. P. 171–179.
7. *Goudzovski E.* Measurement of the FCNC Decays $K^{\pm} \to \pi^{\pm}\lambda^{+}\lambda^{-}$ from NA48 // Proc. of KAON09, KEK, Tsukuba, Japan, 9–12 June 2009.
8. *Goudzovski E.* Lepton Universality Test with Leptonic Kaon Decays at NA62 // Ibid.
9. *Movchan S.* Straw Tracker Prototype for the Precise Measurement of the Very Rare Decay $K^{+} \to \pi^{+}\nu\bar{\nu}$ (NA62 Experiment at SPS CERN) // Nucl. Instr. Meth. F. 2009. V. 604. P. 307–309.
10. *Abelev B. I. et al. (STAR Collab.).* Energy and System Size Dependence of Phi Meson Production in Cu + Cu and Au + Au Collisions // Phys. Lett. B. 2009. V. 673. P. 183–191.
11. *Abelev B. I. et al. (STAR Collab.).* Pion Interferometry in Au + Au and Cu + Cu Collisions at $\sqrt{s_{NN}} = 62.4$ and 200 GeV // Phys. Rev. C. 2009. V. 80. P. 024905.
12. *Abelev B. I. et al. (STAR Collab.).* Observation of Charge-Dependent Azimuthal Correlations and Possible Local Strong Parity Violation in Heavy-Ion Collisions. arXiv:0909.1717 [nucl-ex].
13. *Zulkarneev R.* JINR Preprint P2-2009-135. Dubna, 2009.
14. *Filip P. et al.* Initial Eccentricity in Deformed $^{197}\mathrm{Au} + {}^{197}\mathrm{Au}$ and $^{238}\mathrm{U} + {}^{238}\mathrm{U}$ Collisions at $\sqrt{s_{NN}} =$ 200 GeV at the BNL Relativistic Heavy-Ion Collider // Phys. Rev. C. 2009. V. 80. P. 054903.
15. *Lednicky R.* Finite-Size Effects on Two-Particle Production in Continuous and Discrete Spectrum // Phys. Part. Nucl. 2009. V. 40. P. 307–352.
16. *Shahaliev E. I. et al.* Can We Define the Centrality in High-Energy Nuclear Collisions within the Random Matrix Theory. To be published in Universal Academy Press, Inc. Japan, 2009.
17. *Vokál S., Orlova G. I., Lehocká S.* Azimuthal Structures of Produced Particles in Heavy-Ion Interactions // Phys. At. Nucl. 2009. V. 72, No. 2. P. 237–242.
18. *Tokarev M., Zborovsky I.* New Properties of z-Scaling: Flavor Independence and Saturation at Low z // Intern. J. Mod. Phys. 2009. V. 24. P. 1417–1442.
19. *Bystritsky V. M.* Stationary Inspection Complex DViN-2 // Part. Nucl., Lett. 2009. V. 6, No. 6(155). P. 586.