VEKSLER AND BALDIN LABORATORY OF HIGH ENERGY PHYSICS

The activity of the V. I. Veksler and A. M. Baldin Laboratory of High Energy Physics in 2013 was focused on the implementation and further development of the NICA project (the Nuclotron-NICA, MPD and BM@N subprojects) and the participation in current researches in various world-class accelerator centers.

THE MOST IMPORTANT RESULTS IN THE DEVELOPMENT OF THE ACCELERATOR COMPLEX

Development and Running of the Basic Facilities

Development of LHEP's accelerator complex in 2013 was aimed at construction of systems and elements for newly created accelerator facilities of the NICA complex.

There were two Nuclotron runs (the 47th and the 48th) in 2013 with the total duration of 2000 hours. The proposed physics research programme, for which 60% of the beam time was allocated, is almost completed. During acceleration shifts of the runs, there were carried out works aimed both to enhance the capabilities of the accelerator complex for the current physics research programme implementation and to test the equipment and operation modes of the newly created facilities of the NICA complex — the booster and collider.

Nuclotron-NICA

Among the most significant achievements obtained during the runs, there are the following:

• A new quench detection system was put into operation [1].

• A new source of light ions on the base of modern Nd-YAG solid-state laser was put into test operation during Run 48.

• Works on the stepwise increase of the ion energy were continued. In the course of Run 47, the beam extraction for the experiments within the framework of the physics research programme was accomplished at the energy of 4.8 GeV/nucleon. The experiments with carbon nuclei were carried out at the energy of 5.15 GeV/nucleon during Run 48. At the end of the run, a beam of carbon nuclei was accelerated to the maximal design field of the dipole magnets — 2 T, which corresponds to the energy of about 5.7 GeV/nucleon.

• Field pulsations on the plateau were reduced by more than an order; it was demonstrated that it is possible to obtain the direct current ratio of about 90%

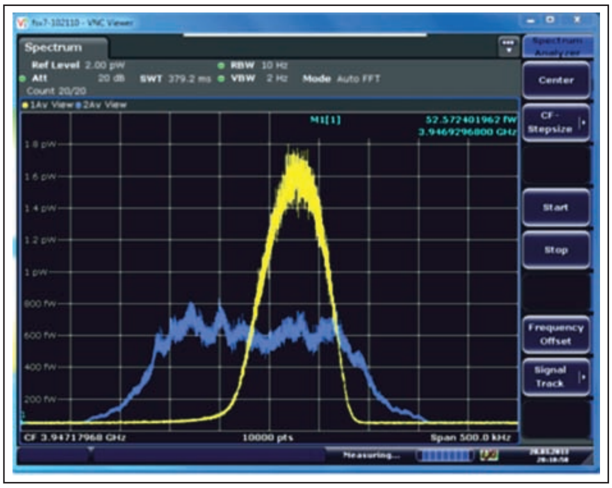

Fig. 1. Spectrum of the longitudinal shot noise of the beam at the 3048th revolution harmonic frequency. The bottom curve (blue) — immediately after the injection, yellow curve — after 8 minutes of cooling. Deuteron energy is 3 GeV/nucleon, beam intensity is 10^9 particles

at slow extraction. The possibility of slow extraction at the spill duration of up to 20 s was also demonstrated.

• A segment of the NICA complex's ACS based on the Tango software complex was put into test operation.

• Elements of the acceleration system and diagnostics devices dedicated to the NICA complex's Booster were tested.

• During Run 47, stochastic cooling for longitudinal degree of freedom of a coasting deuteron beam using the method of notch filter was implemented for the first time in Russia (Fig. 1). In Run 48, the works on cooling were continued with carbon nuclei — cooling was carried out for a coasting beam as well as for a focused one.

NICA

The year 2013 was a crucial one in the sense of the NICA construction. The State Expertise for the NICA civil construction has been successfully fulfilled. For the first time, an international tender for the construction company has been organized. The works on the building site preparation for the NICA complex have been started.

The following main results were achieved in construction of new elements for the NICA complex:

• Testing a new source of polarized particles was started.

• In April–May 2013, the first run was carried out with the test source of multicharged heavy ions KRION-6T and the work at this source has been going on almost uninterruptedly since August. Gold beam generation was demonstrated in the charge state of 30^{+}–32^{+} required for injection into the Booster at the level of 50% of the designed value. The source is being prepared for acceleration of heavy ions at the Nuclotron.

• In 2013, the BEVATECH company produced and prepared sections of the HILac heavy ion linear accelerator for copper plating. The start of the equipment delivery to JINR is expected in May of 2014. Redesign was elaborated of the building dedicated for the HILac allocation; renovation works were started.

• It is planned to do major repairs of Building 1 in order to prepare it for placing the magneto-optical structures, systems and equipment of the Booster. Initial data for technical design specification were prepared, and repairs design elaboration was put out to tender.

• Production of accelerating stations of the Booster is near completion at the BINP, SB of RAS, check assembly was performed and testing was started. In order to provide conditions for stations testing at JINR, there was renovated a building where the test bench will be placed.

• Works on preparation for mass production of the Booster magnets were actively conducted. Building 217 was renovated and the necessary transport connection between the building and LHEP's cryogenic complex was laid.

• An area for superconducting winding production was prepared. A 15 kA current source for testing magnets was produced in Slovakia, delivered to JINR and tested. A satellite refrigerator was produced in Germany, delivered to JINR and prepared for starting-up. In cooperation with GSI a system for magnetic field measurement was developed. Start of serial production of the Booster magnets is scheduled for the first half of 2014.

ILC

The main results achieved by the team participating in the preparation of the project in 2013 are:

Linac-200 Test Bench

Commissioning of the second Linac-200 segment (50 MeV) is under completion. The first launch of the IR FEL prototype based on the electron linac and undulator was performed. An electron beam with the energy of about 18 MeV passed through the undulator. IR radiation with the wavelength of about 14 um and power of 30 mW was registered. Commissioning of the electron beam diagnostics for energy and phase parameter measurement was finished. The upgrade of the temperature control system of the first segment was performed Commissioning of the FEL prototype on the base of the electron linac and wiggler is being developed.

DC Photoinjector Test Bench

The start-up of the DC photoinjector prototype was carried out. The prototype consists of a 12 kV photogun; a focusing magnet with correction coils; the first station of the electron bunch emittance measurement system; a video monitor; a Faraday cup and driver lasers ($\lambda = 266$ nm, $\tau_{\rm pulse} = 75$ ps, $\tau_{\rm pulse} = 15$ ns). Using a 75-ps laser driver ($E_{\rm pulse} = 1$ mJ) the charge of 1.2 nC (corresponding current of ~ 16 A) was extracted from the holed photocathode (metal mesh).

THE MOST IMPORTANT EXPERIMENTAL RESULTS

CMS

The major efforts of the JINR group participating in the CMS experiment have been focused on studying various processes involving muon-pair production in order to test the Standard Model (SM) predictions and on the search for new physics beyond it.

The dimuon mass spectrum was studied; the forward–backward asymmetry of muon pairs was defined as well as differential cross section of their production in the Drell–Yan process in the range of invariant masses from 15 to 1500 GeV. The measured values are in good agreement with the NNLO theoretical predictions of the SM.

Combined analysis of the data on production of dimuons and dielectrons allowed one to exclude with 95% confidence level the existence of new neutral gauge bosons from the extended gauge sector with Standard-Model-like couplings $M_{\rm ZSSm} < 2950$ GeV and for the superstring-inspired Z_ψ below 2600 GeV. The RS1-graviton mass limits made up about 2390 and 2030 GeV for the couplings $c = 0.10$ and 0.05, respectively.

Based on the 2012 data, the analysis of QCD multijet events was carried out aimed at search for microscopic semiclassical and quantum black holes predicted at the TeV-scale. The obtained values of the minimal mass of a black hole were 4.7–6.3 TeV depending on the formation and evolution mechanisms for the values of fundamental multidimensional Planck mass $M_D \leqslant 5$ TeV.

The Higgs boson properties were investigated further. The analysis of data on the channel of its decay into 2 neutral gauge bosons and the further decay into 4 leptons allowed for the more precise measuring of the Higgs mass, which made up $m_{\rm H} = (125.8 \pm 0.5\,({\rm stat.}) \pm 0.2\,({\rm syst.}))$ GeV; for a combined analysis of channels of the decay into a photon pair and 4 leptons — $m_{\rm H} = (125.7 \pm 0.3\,({\rm stat.}) \pm 0.3\,({\rm syst.}))$ GeV [2]. The analysis of angular distributions of Higgs decay products allowed excluding almost all the states with the spin and parity inconsistent with the SM Higgs boson.

ALICE

The JINR group taking part in the ALICE experiment is focused on studying Bose–Einstein correlations. In 2013, ALICE took data with the minimum bias trigger ($6 \cdot 10^7$ events) of p–Pb collisions at 5.02 TeV. The first results of the femtoscopic correlation analysis were obtained for charged kaon pair production in p–Pb collisions at 5.02 TeV per nucleon pair (Fig. 2). The special experimental analysis of charged kaon purity selection in Pb–Pb at 2.76 TeV was performed and new results for femtoscopic $R_{\rm inv}$ were obtained. New results for $\phi \to K^+K$ production were obtained [3].

ATLAS

The LHEP team involved in the experiment is participating in several analyses, in particular, in the analysis of the associative WH/ZH production.

The ongoing work is aimed at improving criteria of the signal event selection and at optimizing the list of variables to be used for background suppression. The achieved results were reported at the meetings of the ATLAS Higgs working group. The joint efforts of the working group members on cut-flow analysis of the available experimental data did not show any confident excess of events over the SM background. The invariant mass spectrum of two b-jets is presented in Fig. 3

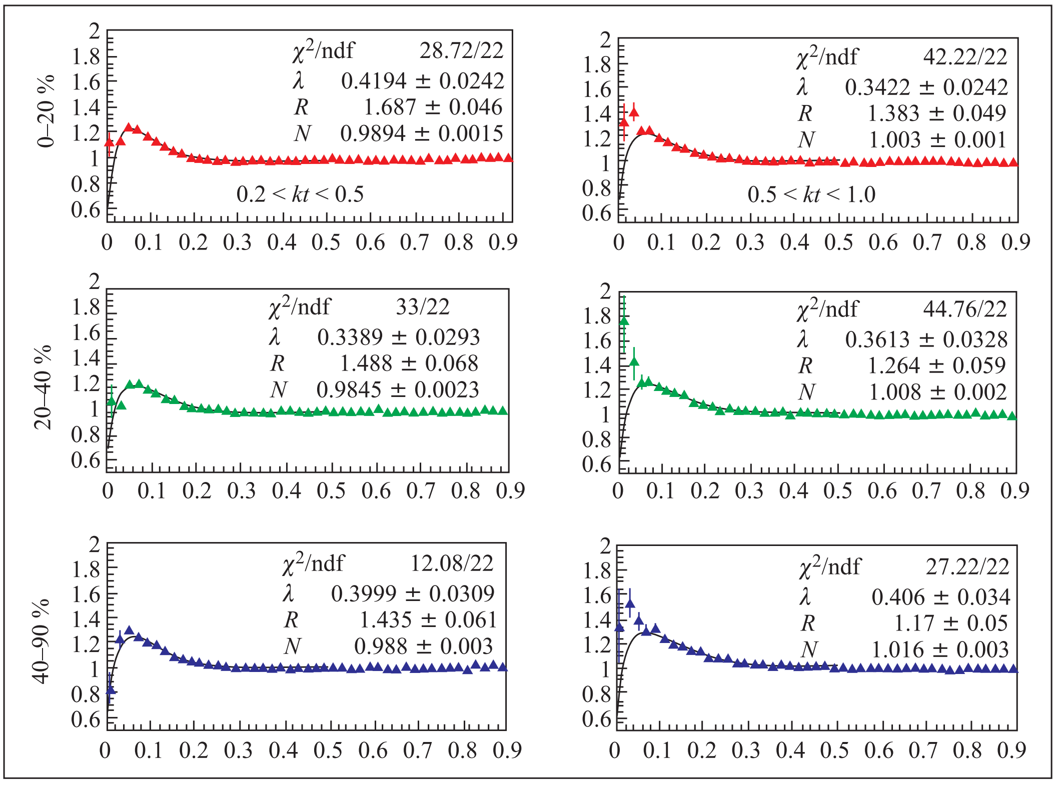

Fig. 2. Correlation functions versus $q_{\rm inv}$ for charged kaon pairs obtained in p–Pb collisions at 5.02 TeV, at different transverse momentum of the pairs and event centrality 0–20%, 20–40%, 40–90%. The curves are the special fit results

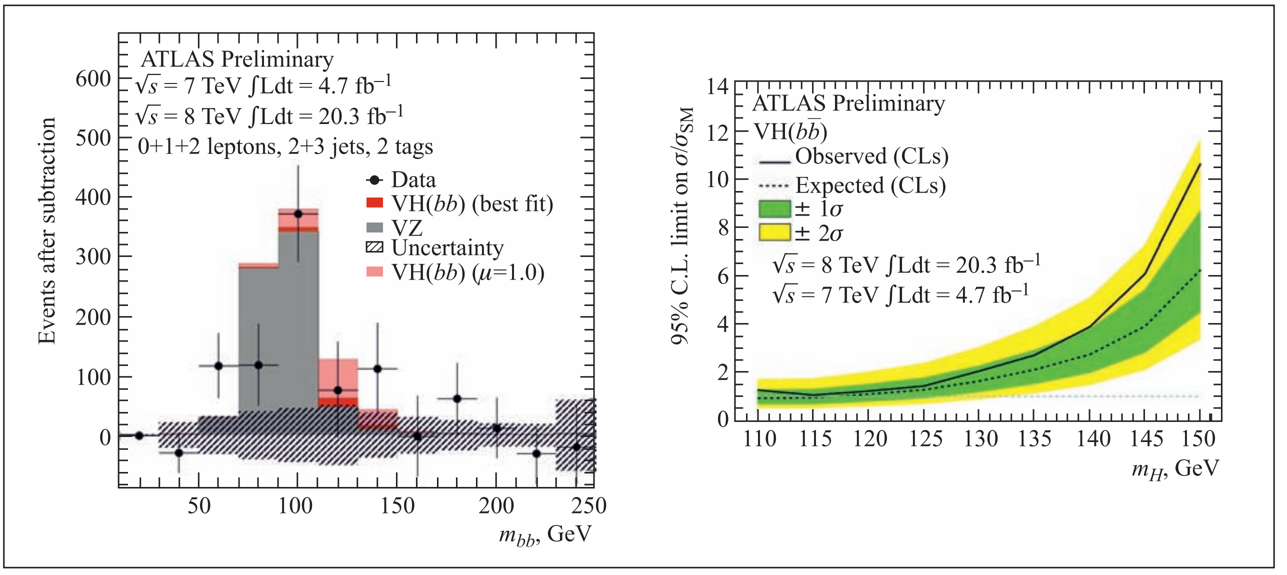

Fig. 3. Invariant mass of two b-jets (left) and 95% C.L. upper limit for the Higgs boson production in VH processes (right)

with all the backgrounds subtracted except the di-boson processes

The upper limit for cross section of the Higgs boson production in association with a vector boson is 1.4 times higher than that predicted by the SM.

The results of this work were presented at conferences and published [4].

The performance of the ATLAS liquid argon hadronic end-cap calorimeter was carried out taking into account the expected degradation of the read-out electronics at the total integrated luminosity of 3000 fb^{-1}. The experimental data obtained in irradiation tests with protons (Zurich) and neutrons (Rez and Dubna) were used as the input parameters for the analysis. Degradation of the preamplifier's gain and its nonlinearity were parameterized as the function of the collected doze which changes depending on the motherboard location inside the ATLAS cryostat. A full GEANT-4 based Monte-Carlo simulation was performed for di-jet events including effects of the preamplifier's degradation. The obtained results demonstrate that radiation damage of preamplifiers results in significant deterioration of the signal, therefore the exchange of the HEC cold electronics is required for operation at the HL-LHC environment.

NA62 and NA48/2 Experiments

The NA62 experiment is devoted to studying the very rare charged kaon decay into charged pion and two neutrinos. The responsibilities of JINR in this experiment (together with CERN) are R&D and full production of straw tracker detectors working with a high spatial resolution in vacuum environment, development of simulation and reconstruction of software for the straw tracker. In addition, the data analysis of the NA48/2 experiment and of NA62 special runs of 2007–2008 is continued.

The main results obtained in 2013 are:

1. The mass production of straw tubes is finished at JINR. More than 6500 straws were manufactured; the long-term overpressure test is in progress. About 15% of the straw tubes are completely tested and delivered to CERN.

2. Work on assembling, testing and delivering the chamber modules to CERN is in progress according to the schedule.

3. Tests of the 64-straw prototype with cosmic rays aimed to measure straw resolution and to study new front-end and read-out electronics are continued. Analysis of the 2012 experimental data from the 64-straw prototype working in vacuum environment is in progress.

JINR team has been continuing the NA48/2 experiment data analysis.

With the determining contribution of the JINR scientists, the first experimental observation of new decay channel $K^{\pm} \to \pi^0\pi^{\pm}e^+e^-$ was obtained. Preliminary branching ratio measurement result agrees with the theoretical prediction, based on SM. The data analysis is in progress (Fig. 4).

The $K^{\pm} \to \pi^{\pm}\gamma\gamma$ rare decay width was measured and its dynamic properties were studied based on the world's largest statistics — 149 decay candidates with the background at 10% level. Branching ratio in the full kinematic range assuming a particular chiral perturbative theory description is measured to be $\text{Br} = (0.910 \pm 0.075) \cdot 10^{-6}$.

A series of NA48/2-NA62 publications devoted to high precision test of the lepton universality in charged kaon decays was nominated in 2013 for the JINR prize. The result of the ratio $R_K = \Gamma(K_{e2})/\Gamma(K_{\mu 2})$ measurement, based on about 150000 reconstructed $K^{\pm} \to e^{\pm}\nu$

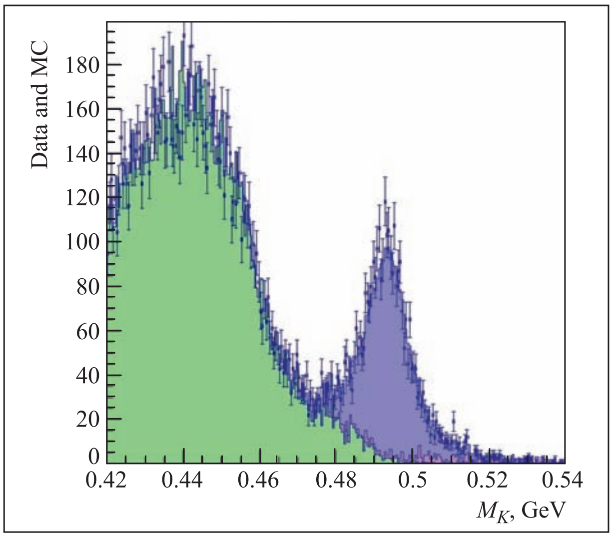

Fig. 4. The first observation of the charged kaon decay to $\pi^0\pi^\pm e^+e^-$

decays collected in 2007 and 2008 with 11% background, is in agreement with the SM calculation: $R_K = (2.488 \pm 0.010) \cdot 10^{-5}$.

High precision measurements of these decays allow us to test the SM and search for new physics beyond it as well as to contribute to the Perturbative Chiral Model development [5].

COMPASS Experiment

In 2013, the activities of the JINR team were focused on preparing the detector to the Drell–Yan process measurements, which are planned to be performed in 2014–2015, and on the study of the General Parton Distributions (GPD), which are planned to be done in 2016. JINR responsibilities in COMPASS consist in production of the main part of the new electromagnetic calorimeter (ECAL0).

The JINR team has been continuing data analysis. In 2013, the COMPASS collaboration presented the results on gluon polarization measured via spin asymmetries from open charm production [6] (Fig. 5). These results were obtained in scattering 160 GeV polarized muons off longitudinally polarized protons and deuterons. The data were taken by the COMPASS collaboration between 2002 and 2007.

At leading order QCD accuracy, the average gluon polarization is determined as $\langle \Delta g/g \rangle$ LO $= -0.06 \pm 0.21\,(\text{stat.}) \pm 0.08\,(\text{syst.})$ at the scale $\langle \mu^2 \rangle \sim 13$ GeV^2 and an average gluon momentum fraction $\langle x \rangle \sim 0.11$. For the first time, the average gluon polarization was also obtained at next-to-leading order QCD accuracy as $\langle \Delta g/g \rangle$ NLO $= -0.13 \pm 0.15\,(\text{stat.}) \pm 0.15\,(\text{syst.})$ at the scale $\langle \mu^2 \rangle \sim 13$ GeV^2 and $\langle x \rangle \sim 0.20$.

With the active involvement of the JINR team, the analysis of experimental data on production of Λ, $\Sigma(1385)$ and $\Xi(1321)$ hyperons in muon DIS off a ^{6}LiD target was carried out. The relative yields of $\Xi(1385)^+$, $\Sigma(1385)^-$, anti-$\Sigma(1385)^-$, anti-$\Sigma(1385)^+$,

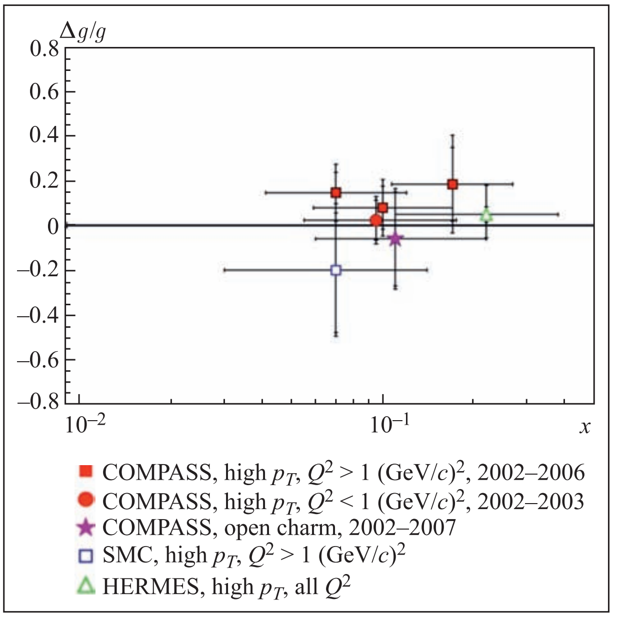

Fig. 5. A compilation of gluon polarization measurements from open charm (star) and high-p_T hadron production

$\Xi(1321)^-$, and anti-$\Xi(1321)^+$ hyperons decaying into Λ(anti-Λ)π were measured. The heavy hyperon to antihyperon yield ratios were found to be in the range from 3.8% to 5.6% with a relative uncertainty of about 10%. The received results were used to tune the parameters of the LEPTO Monte-Carlo generator.

Multiplicities of charged hadrons produced in deep inelastic muon scattering off a ^{6}LiD target were measured as the function of the DIS variables x_{Bj}, Q^2, W^2 and the final state hadron variables p_T and z.

STAR

The JINR group taking part in the STAR experiment at RHIC was actively involved in the energy scanning programme on studying hadron production in Au–Au collisions at the energies $\sqrt{s}_{NN} = 7.7$, 11.5, 19.6, 27, 39 GeV. The statistics was acquired allowing search for signs of phase transitions in nuclear matter and for localization of the critical point. It was found that R_{CP} ratio, elliptic flow for mesons, baryons and their antiparticles; ratio of particle yields in Au–Au collisions depend on the transversal pulse and energy of the collision [7].

The experiment data were processed and preliminary results were obtained on spectra of charged hadron production in Au–Au collisions at the energies $\sqrt{s}_{NN} = 7.7$, 11.5, 19.6, 27, 39 GeV at high transversal pulses.

The participation in the STAR polarization programme was continued by measurement of double-spin asymmetries of jet production and single-spin transversal and longitudinal asymmetries in order to obtain spin-dependent gluon and quark (valence and sea) distributions.

NA61 Experiment

The JINR group involved in the ion part of the NA61/SHINE experiment is carrying out the systematic studying of nucleus–nucleus reactions occurring in Pb–Pb collisions and investigating reactions with medium-sized nuclei (Xe and Ar) as well as with light nuclei (Be). From December 2012 to March 2013 the experiment took data from Be–Be collisions having finished the energy scanning which had been started in 2011 [8].

The first preliminary results were obtained on the ^{7}Be–^{9}Be collision as well as on the p–p reaction. Preliminary data on p–p and p–C (Long Target) reactions at 31 GeV/c required for the neutrino experiment T2K were acquired. The analysis of data on the cosmic ray programme is in progress.

The NA49 collaboration has been investigating a broad range of hadronic reactions at the CERN SPS. The main aim of the experiment is the studying of hadronic matter at the highest temperature and densities in the search for the onset of quark–gluon deconfinement and the QCD predicted critical point of strongly interacting matter.

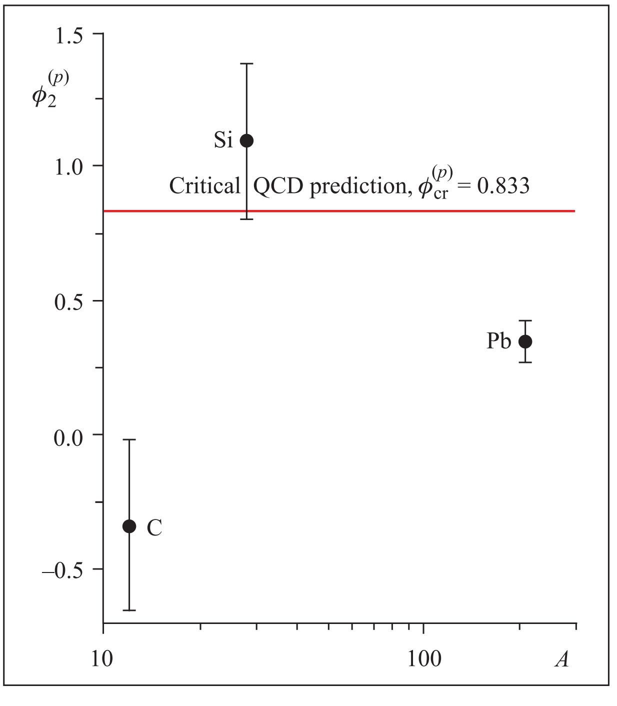

Fig. 6. The obtained value of the proton intermittency ϕ_2 in Si–Si collisions at 158 $A \cdot$GeV indicates fluctuations approaching in size the prediction of QCD

There is an indication obtained in correlation analysis of the data on Si–Si scattering at 158 GeV, that the proton intermittency ϕ_2 exceeds QCD limit corresponding to the phase transition (Fig. 6).

Experiments at the Nuclotron Carried out during the 2013 Year Runs

About 60% of the beam time of Runs 47 and 48 was used for the current experiments and for the detector beam tests. In particular, the following experiments used this time:

FAZA-3 Experiment

In the framework of the FASA-3 experiment, the total time scale of the multifragmentation process was measured: it happens in 120 fm/s after the collision of a deuteron beam with the Au target. Thus, the time of hot nucleus expansion was measured for the first time [9].

Energy and Transmutation Project

Spectral characteristics of neutrons generated by the deuteron beam at the subcritical Quinta setup, which contains 512 kg of natural uranium, were experimentally investigated in 2012–2013 in the framework of the project.

In order to measure spectral dependences of the neutrons, semiconductor breakdown detectors with threshold converters in the energy range of incident deuterons of 1–8 GeV were used.

The behavior dependences of high-energy part of the spectrum $E_n > 20$ MeV on the energy of incident deuterons were obtained. The experiments demonstrated the following:

• The fission process is going efficiently in the subcritical setup with the uranium mass of 512 kg and the radius of 12 cm; the obtained value of power gain is 2.5. This value achieved plateau in the wide energy range 1–8 GeV (Fig. 7).

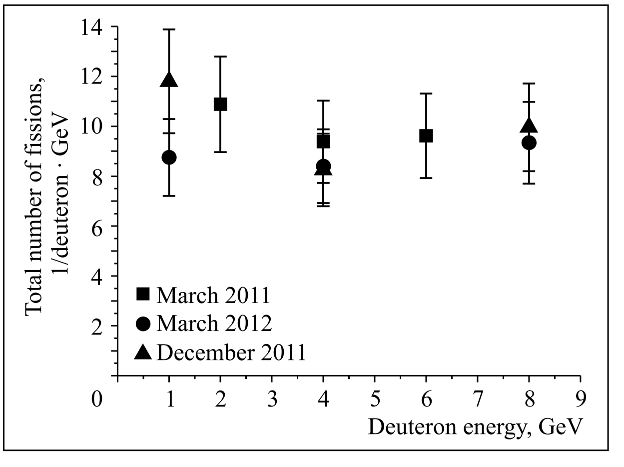

Fig. 7. Power gain as a function of energy in units of fissions per 1 deuteron and per 1 GeV, the 2011–2013 runs

• The total escape of the neutron with the energy $E_n > 20$ MeV was measured; it made up 80%.

• It was discovered that with the deuteron energy getting higher, the content of the fast neutrons (with the energy $E_n > 20$ MeV) in escape was increasing from 6 to 12%.

The transmutation rate of ^{237}Np radioactive isotopes was studied as well as its dependences on the incident particle energy. The increase of the reaction rate with the deuteron energy rise was demonstrated. This result indicates that transmutation efficiency rises with the increase of particles energy.

DSS Project

In the DSS experiment carried out at the inner target of the Nuclotron, there were obtained new experimental data on angular dependence of the cross section of elastic deuteron–proton scattering at the deuteron energies of 1300, 1500 and 2000 MeV.

New experimental data were obtained on deuteron fragmentation reaction with detection of two protons for various kinematic configurations at the initial deuteron energies of 300, 400, and 500 MeV.

Preliminary results were presented at the international conferences HS2013 and EFB22.

The data on tensor analyzing powers A_y, A_{yy}, A_{xx} and A_{xz} were obtained for the $dd \to tp$ reaction at the deuteron energy of 200 MeV [10].

Experiments in Preparation

BM@N Project

The BM@N project is a fixed target experiment which was proposed as implementation of the first stage of the NICA project. In that framework, to advance the BM@N project preparation, the following activities were accomplished in 2013:

• The BM@N experimental zone was cleaned, the zone contour was created. The counting room was ready. The dipole magnet was set to the nominal position and commissioned at the 80% of the nominal current.

• R&D works on the warm resistive plate chambers for the BM@N TOF detector are in progress. For the region of high hit rate ($\sim$ 4 kHz/cm^2) it is proposed to use 12-gap "warm" RPCs with 0.5 mm thick inner glass, gas gap of 220 μm, and 32 strips of 10×160 mm. The expected time resolution is $\sim$ 65 ps, efficiency — $> 94\%$. Operational temperature is 45 °C. For the region of low hit rate ($\sim$ 400 Hz/cm^2) it is proposed to use 10-gap RPCs with 0.7 mm thick glass, gas gap of 300 μm, 16 strips of 18×580 mm and the number of chambers — 36. These planes will have time resolution < 60 ps and efficiency $\sim 98\%$ and will operate at room temperature. An option to use resistive plate chambers produced from low-resistivity glass for the high hit rate range is under development.

• A new option for the inner tracker based on the GEM technology was proposed and now is under consideration. The preliminary simulation for GEM-based inner tracker demonstrated the possibility to select hyperons. A triple GEM detector prototype of 10×10 cm (250×250 $X{-}Y$ strips, 400 μm pitch) produced by the CERN workshop will be tested during the next Nuclotron run.

• The prototype module of Zero Degree Calorimeter successfully passed beam and cosmic ray tests with several PMT and HV dividers. Technical design of the ZDC support was prepared. The support will be produced by NKMZ (Kramatorsk, Ukraine). 50% (65 k$) is paid in December 2013. Delivery time is October 2014.

• The work on putting outer tracking system elements into operation is in progress.

• Three housings for 12×12 cm scintillation fiber hodoscope were delivered in October 2013 from Dechin, Czech Republic. Two detectors are under construction.

• Two Cherenkov T_0 detectors are produced and are ready for tests.

Progress with the MPD Subsystems

A substantial progress has been recently achieved in the TPC manufacturing, fabrication of ECAL modules, completion of the R&D stage for the TOF and TOF TDR preparation.

A step forward was made in evaluating the MPD technical project. The TDR preparation was discussed at the last MPD-AC meeting. The MPD TOF technical project will be presented in June 2014.

The following results were achieved in the development of subsystems:

MPD Magnet

The technical design of the MPD solenoid is completed (JINR and Neva-Magnet Ltd. (St.-Petersburg)). The technical description and assembly drawings passed the international expert evaluation led by T. Tailor (CERN), who noted high-level professional knowledge and excellent drawing quality. The next steps which are planned for 2014 — the international tender opening and start of the construction.

TPC

In 2013, the design, construction and tests of prototypes for TPC elements (RoC; FEE; laser, gas and cooling systems) were fulfilled. Production of the TPC Field Cage and RoC was started.

ECAL

In 2013, the facility for the ECAL module production was established by JINR and the Institute for Scintillation Materials (Kharkov, Ukraine). The technology for production of a trapezoidal ECAL module has been proven. The certification procedure for MAPD wafers was developed. Production of photodetector units was organized. The feasibility of mass production of ECAL modules was investigated. The first study of the ECAL performance with particle beams and cosmic rays was performed.

During the beam test in December, the performance of two ECAL modules with different WLS-fibers was studied; ECAL read-out electronics (amplifiers and

ADCs) was tested and energy scan with electron beam ($E_e = 1.6$ GeV) was performed.

TOF

The main results achieved in 2013:

• The design of the TOF geometry and module was optimized.

• The Nuclotron beam line for tests was upgraded.

• mRPC performance: efficiency, rate, capability and time resolution were studied (Fig. 8).

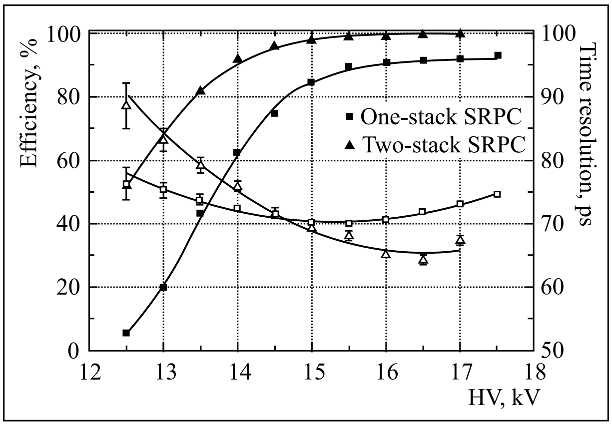

Fig. 8. Time resolution (□, △) and efficiency (■, ▲) for an MPD TOF mRPC with strip read-out. Results of the Nuclotron'13 beam tests

• TOF TDR has been prepared.

• The experimental area and counting room were fully equipped with instrumentation for test measurements and data analysis.

Straw Tubes

The following items were performed in 2013:

• development and production of the outside ring for the engineering wheel prototype were finished,

• development and production of two flexible 24-channel mother-boards (MB),

• assembling of the fragment of the outside gas manifold for one of the MBs,

• study of the straightness of the 60 cm long straws.

FFD

• There was purchased a full set of photomultipliers produced by the Photonis company for FFD modules production.

• The final mechanical design of FFD modules was developed.

• Under the agreement between the V. G. Khlopin Radium Institute (Saint-Petersburg) the modules were developed and tested with the final version of the electronics.

• The full set of quartz radiators was produced for detector modules.

• The system of time calibration of FFD channels with picosecond laser was elaborated and the main parts were purchased for its production.

• The prototypes of the system of low-voltage power supply and LVDS signal receiving from electronics of detector modules were developed, produced, and tested.

• In cooperation with the TOF group, there was performed a study of characteristics of the produced FFD modules at the Nuclotron deuteron beam (March and December runs, 2013).

MPD Simulation Group

A large amount of work on simulation of the MPD subsystems and different reactions was performed in 2013. The software packages were heavily modernized. In particular: the realistic MPD magnetic field map was installed into reconstruction software; the system of distributed data storage and processing was deployed at the computer clusters of LHEP and LIT; new algorithm for the search for the clusters on the TPC pad place was prepared, tested, and installed in the MPD software.

INNOVATIONS

R&D with the Use of Straw Tubes

Detectors based on thin-wall drift tubes possess a number of advantages: they are transparent in the sense of the material budget, have good space/time parameters and relatively low cost. One of the disadvantages is the spatial resolution which is not good enough in comparison to Micro Pattern Gas Detectors (σ of the MPGD is better than 100 μm).

The conducted R&D demonstrated that the straw can operate in the mode of transition from the limited proportionality (saturation) mode to the high current mode with gas mixture $PrCO_2$ (80/20) at the pressure ranging from ~ 3 to 4 bar. The spatial resolution of the straw in this mode is increasing up to ~ 40 μm [11].

To test the straws' readiness for long-term operation in that transient mode, their radiation stability was checked by X-ray irradiation at the test bench. For ~ 2600 hours of irradiation, the average charge made up 4.2 C per 1 cm of the straw length. Degradation of the energy resolution was not observed.

The study of the transient mode between the low and high current modes for straws filled with $ArCO_2$ gas mixture at the pressure of 3 bar showed its feasibility for high-precision registration of charged particles. The transient mode does not develop in the self-quenching streamer mode at the pressure within this range; and, at the anode diameter of 30 μm or less it also has high stability and enough radiation tolerance.

Two-Phase and Three-Phase Separationless Flow-Meters for Oil Production

The two-phase flow-meter "oil-salty water" for oil production was designed at LHEP. It consists of a gamma-densitometer (GD) with radioactive source ^{137}Cs and a narrowing device. The flow-meter was tested on the test facility "oil-gas-salt water" at the TUV SUD NEL company (Glasgow, Scotland). The results showed [12] that the flow-meter meets the State Standard requirements (GOST R8.615-2005) to determine volumetric and mass flow rates of crude oil in the range of water cuts $0 < w < 95\%$. Such competitive measuring devices are not produced in the Russian Federation.

The obtained experience allowed us to design a three-phase four-component separationless flow-meter for "oil-gas-formation water" mixtures. This is a combination of a spectrometric gamma-densitometer and a combined narrowing device. The characteristics of the flow-meter were studied on the State Special Primary Standard of the Unit of Mass Flow Rate of Gas-Liquid Mixtures GET-195-2011 (VNIIR, Kazan) in November, 2013. The preliminary analysis confirmed the operability of the flow-meter, definiteness of its characteristics and their repeatability in all the ranges of the preset parameters of "oil emulator-water", "oil emulator-gas" and "water-gas" gas-liquid mixtures.

REFERENCES

1. *Ivanov E. V. et al.* The Quench Detection System for Superconducting Elements of Nuclotron Acceleration Complex // Phys. Part. Nucl., Lett. 2013. V. 10, No. 4(181). P. 603–612.
2. *Chatrchayn S. et al. (CMS Collab.).* Combination of Standard Model Higgs Boson Searches and Measurements of the Properties of the New Boson with a Mass near 125 GeV. CMS-PAS-HIG-13-005. Geneva: CERN, 2013.
3. *Abelev B. et al.* Two- and Three-Pion Quantum Statistics Correlations in Pb–Pb Collisions at 2.76 TeV at the LHC. arXiv: 1310.7808. 2013.
4. *ATLAS Collab.* Search for the *bb* Decay of the Standard Model Higgs Boson in Associated $(W/Z)H$ Production with the ATLAS Detector. ATLAS-CONF-2013-079. 2013.
5. *Batley J. R. et al. (NA48/1 Collab.).* A New Measurement of the $K^{\pm} \to \pi^{\pm}\gamma\gamma$ Decay at the NA48/2 Experiment. CERN-PH-EP-2013-197. 2013.
6. *COMPASS Collab.* // Phys. Rev. D. 2013. V. 87. P. 052018.
7. *Adamczyk L. et al. (STAR Collab.)* // Phys. Rev. Lett. 2013. V. 110. P. 142301.
8. *Anticic T. et al. (NA49 Collab.)* // Phys. Rev. C. 2013. V. 87. P. 024902;
   Baatar B. et al. (NA48 Collab.) // Eur. Phys. J. C. 2013. V. 73. P. 2364.
9. *Karnaukhov V. A. (FAZA-3 Collab.).* Properties of Hot Nuclei Produced in Collisions of Light Relativistic Ions with Heavy Targets // Phys. At. Nucl. 2014. V. 77, No. 12. P. 129.
10. *Kurilkin A. K. et al.* Angular Distributions of the Vector A_y and Tensor A_{yy}, A_{xx}, A_{xz} Analyzing Powers in the $dd \to {}^3\mathrm{H}p$ Reaction at 200 MeV // Phys. Rev. C. 2013. V. 87. P. 051001(R).
11. *Davkov V. I. et al.* Spatial Resolution of Thin-Walled High-Pressure Drift Tubes // Nucl. Instr. Meth. A. 2011. V. 634. P. 5.
12. *Kakorin I., Filippov Yu.* Two-Phase Flowmeter on the Base of the Narrowing Device and Gamma Densitometer for Oil-Stratum Water Mixtures // Measurement Technique. 2013. No. 11. P. 33–38 (in Russian).