

# 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 2011 was concentrated on the realization and further development of

the NICA project (Nuclotron-NICA, MPD subprojects and the fixed target programme) and participation in current researches in the world-class accelerator centers.

## THE MOST IMPORTANT RESULTS IN THE DEVELOPMENT OF THE ACCELERATOR COMPLEX

### Nuclotron-NICA

During the 43rd [1] and 44th runs the total operation of the Nuclotron was about 1700 hours and the following tasks were fulfilled:

1. New power supply and quench protection systems of the Nuclotron structural (dipole and quadrupole) magnets have been commissioned;

2. The average vacuum value in the Nuclotron ring was estimated by measuring the deuteron beam lifetime at  $E = 5$  MeV/u. The vacuum pressure was not worse than  $4 \cdot 10^{-10}$  Torr;

3. Together with specialists from Bulgaria, Germany, and Slovakia, a new digital system for on-line beam orbit measurements and an automatic beam orbit correction system have been installed;

4. For the first time the ion ( $d, {}^{6+}C$ ) beam at  $E = 4$  GeV/u has been slowly extracted and the beam intensity reached the value of up to  $5 \cdot 10^{10}$  (deuterons at energy  $E = 300$  MeV/u);

5. While preparing the heavy ions fixed target programme, the deuteron beam (with intensity  $I = 10^6$ , momentum up to  $P = 8.5$  GeV/c, duration  $t = 1$  s) was extracted to the channels БП6 and 6B of experimental hall No. 205;

6. Modernization of the cryogenic complex is in progress. A new turbo compressor has been commis-

sioned. The cooling power of the system has been doubled. The design of the new helium liquefier is in good progress;

7. Two test solenoids for the new heavy-ion source KRION-6T were fabricated and successfully tested. The main solenoid was fabricated. The commissioning of the KRION-6T is planned for the spring of 2012;

8. Preparation for commissioning the new source of polarized ions has started.

### NICA

The following tasks were fulfilled in the framework of the NICA project realization:

1. The Booster dipole magnet and quadrupole lens prototypes have been constructed. Booster dipole magnet has been tested;

2. The collider twin-aperture dipole magnet prototype has been constructed. Twin quadrupole lens is under assembly;

3. The infrastructure for the mass-production of new models and prototypes of the superconducting magnets for NICA and FAIR has been developed;

4. The technical design of the collider rings has been prepared;

5. The NICA collider stochastic cooling prototype has been constructed and installed at the Nuclotron. The commissioning is in progress.

## THE MOST IMPORTANT RESULTS IN PHYSICS

The most significant results obtained by LHEP scientists in 2011 refer to the experiments carried out at CERN.

### Participation in the LHC Projects

LHC operation in 2011 admitted the highlight of the year in the particle physics. LHEP scientists have

taken part in ALICE, ATLAS, and CMS experiments at CERN LHC.

### ALICE

In 2011, ALICE carried out data taking with proton beams at 7 TeV and heavy ions (Pb-Pb) at 2.76 TeV.

The  $p-p$  run was characterized by a new mode of operation for ALICE — it was data taking at a relatively high rate applying selective triggers based on muon detectors and the electromagnetic calorimeter.

The main results obtained with the active participation of the JINR group are presented below.

The JINR team analyzed the data obtained in  $p-p$  interactions at 7 TeV to study two-pions and two-kaons Bose–Einstein correlations. The results for the kaon pair correlation have shown that the invariant radius was increasing with multiplicity and decreasing with the increase of the transverse momentum  $k_T$  (see Fig. 1). This behavior has been predicted in hydrodynamics for  $A-A$  collisions taking into account collective effects in the nuclei. This result has demonstrated that the collective effects also exist in the  $p-p$  collisions.

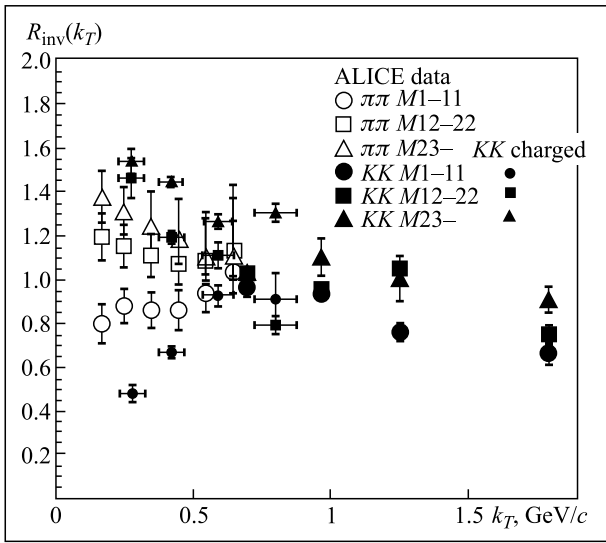


Fig. 1. Invariant radii versus transverse momentum of particle pairs and charged particle multiplicities ( $M$ ) extracted from femtoscopic correlations for  $p-p$  collisions at 7 TeV. The symbols  $\pi\pi$  denote charged pions,  $KK$  charged — charged kaons,  $KK$  — neutral kaons

The analysis of Bose–Einstein correlations of the charged kaon pairs in Pb–Pb collisions is in progress.

In 2011, the LHEP physicists gave three talks at international conferences.

## ATLAS

In 2011, the LHEP group activities in the ATLAS experiment could be listed as follows:

- QCD analysis of DIS including the lepton pair production;
- Data quality monitoring of calorimeter responses; the LAr calorimeter upgrade programme;
- Analysis of minimum bias events;
- Search for charged supersymmetric Higgs boson in the trilepton decay mode;
- Search for Standard Model (SM) Higgs boson produced in association with  $W$  boson;

In the framework of the QCD analysis, the scheme for incorporating the Drell–Yan data obtained for small and intermediate values of the momentum transfer into the QCD analysis in the nonsinglet approximation was developed.

The LHEP group participated in the data analysis of the experiment carried out at the extracted proton beam of U-70 synchrotron at IHEP in Protvino to establish the upper radiation loading for the linear response of the ATLAS liquid argon endcap calorimeters. It has been shown that the electromagnetic and hadron calorimeters do not change their calibrations and may be used at the super-LHC.

The experimental data for minimum bias events in  $p-p$  interactions at 7 TeV cms energy were compared with the Monte-Carlo predictions for transverse and longitudinal momenta, rapidity and multiplicity of charged particles. A satisfactory agreement was shown for invariant variables ( $Q^2$  and  $x$ ) as well as for the missing mass value which has been interpreted as a quasi-elastic origin of the selected collisions. The correspondence

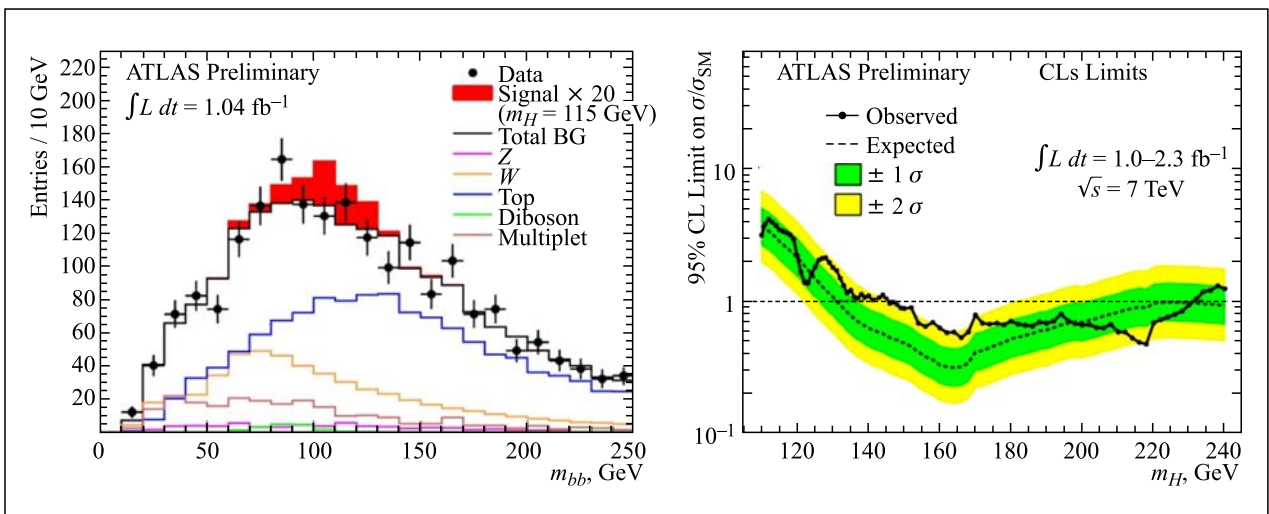


Fig. 2. Two  $b$ -jet invariant mass spectrum for  $WH$  process (on the left) and the combined upper limit of the Standard Model Higgs boson production cross section divided by the Standard Model expectation as a function of  $m_H$  (on the right)

has been also established between the ratio of the transverse mass ( $M_T$ ) to the total energy ( $E$ ) and the time intervals ratio in the moving system ( $\Delta\tau$ ) to the one measured at the rest frame ( $\Delta t$ ):  $M_T/E = \Delta\tau/\Delta t$  or  $M_T\Delta t = E\Delta\tau$ . This correspondence brings another meaning to Plank's hypothesis of the particle energy quantization and allows one to estimate the space-time parameters of the interaction processes:  $M_T\Delta t = E\Delta\tau = h$ .

The programme aimed at searching for the SUSY charged Higgs boson has been developed. The analysis of the data collected in 2010 did not show signal-like events.

The LHEP group actively participated in the search for SM Higgs boson produced in association with  $W$  boson. Preliminary results [2] are presented in Fig. 2. The analyses exclude Higgs boson at the 95% confidence level in the mass intervals of 146–230, 256–282, and 296–459 GeV. The low mass region is the most difficult area due to the low signal level and huge background.

### CMS

During 2011, the JINR group participated in data taking, processing, and physics analysis of the first proton beam collisions at the energy of proton beams of 7 TeV. The commissioning and maintenance of the inner endcap detectors, where RDMS bears a full responsibility on Endcap Hadron Calorimeters (HE) and First Forward Muon Stations (ME1/1), in the experimental CMS cavern, were carried out. The operational efficiency for HE was about 100%, while for ME1/1 it was 98.3%. The integrated luminosity of  $5.2 \text{ fb}^{-1}$  had been collected by the end of data taking with the efficiency of above 91%. The shifts, including the fast detector monitoring and data quality check, were partially carried out in the JINR remote operation centre.

The spatial resolution of ME1/1 chambers was derived using the 2010 and 2011 data. The mean value of the resolution reached about  $62 \mu\text{m}$  and varied from 58 to  $68 \mu\text{m}$  according to the requirements of the Technical Design Project for ME1/1 ( $75 \mu\text{m}$ ).

The calibration of the endcap hadron calorimeter was also performed with CMS required accuracy  $\sim 3\%$  in the azimuthal direction. Different systematic effects were analyzed. The total value of the systematic shifts was computed to have reached 10%. Uncertainties of the jet energy scale after corrections were within 3% for the jet energy of above 30 GeV.

The main efforts of the JINR group in the CMS physics programme were focused on research of the muon pairs and multiple jet production, on check of the standard model predictions, and on search for physics beyond SM [3]. The dimuon mass spectrum was studied for different invariant masses (Fig. 3).

A search for a new high-mass resonance decaying to muon pairs was performed on the base of the data taken

in 2010–2011, and corresponded to an integrated luminosity of  $40 \text{ pb}^{-1}$  for 2010 and  $1.1 \text{ fb}^{-1}$  for 2011 of the CMS data collected at 7 TeV. The upper limits on the inclusive cross section of heavy dilepton resonances are predicted in theoretical models with extra gauge bosons ( $Z'$ ) or as Kaluza–Klein graviton excitations ( $G_{KK}$ ) in the Randall-Sundrum model. At the 95% confidence level these limits exclude a  $Z'$  with standard-model-like couplings ( $Z_{SSM}$ ) below 1780 GeV, the superstring-inspired  $Z_\psi$  below 1440 GeV. The mass limits  $G_{KK}$  were below 1240 (1640) GeV for values of the coupling parameter  $k/M_{\text{Pl}}$  of 0.05 (0.1). The combined analysis using the dimuon and dielectron events significantly increases these limits up to 1940 (1620) GeV for  $Z_{SSM}$  ( $Z_\psi$ ) and 1450 (1780) GeV for RS1-graviton.

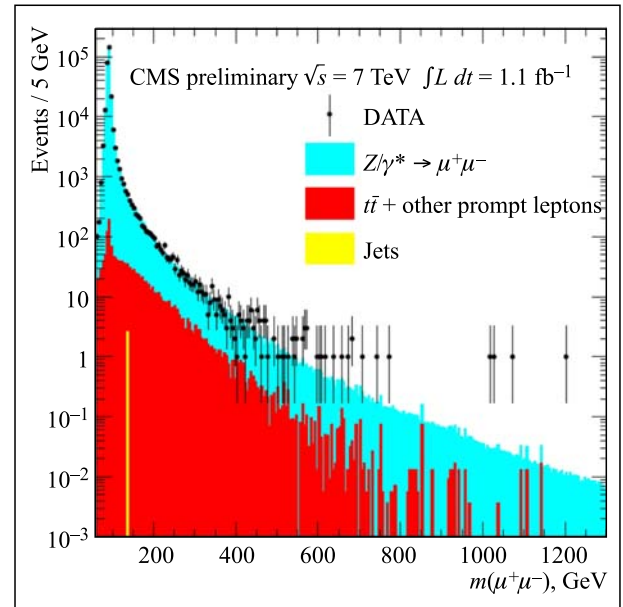


Fig. 3. The dimuon mass spectrum. Different backgrounds are given

In general the JINR physicists contributed to seven CMS physics analyses based on the CMS data of 2010–2011 and four CMS papers published in scientific journals.

### The Common ATLAS and CMS Search for SM Higgs Boson

The combined analysis of both ATLAS and CMS experiments excluded the SM Higgs boson in the mass range of 141–476 GeV (see Fig. 4).

«... The main conclusion is that the Standard Model Higgs boson, if it exists, is most likely to have a mass constrained to the range 116–130 GeV by the ATLAS experiment, and 115–127 GeV by CMS. Tantalising hints have been seen by both experiments in this mass region, but these are not yet strong enough to claim a discovery». Rolf Heuer

Among the accomplished studies world recognized there are as follows:

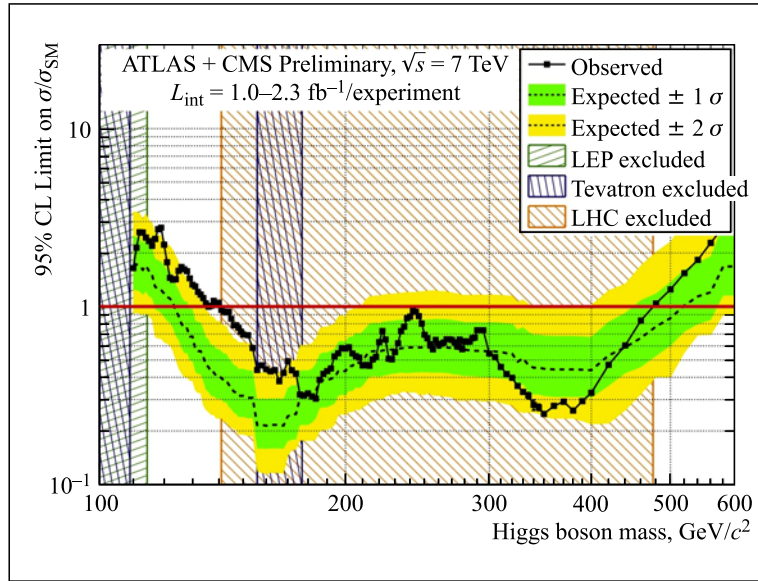


Fig. 4. ATLAS and CMS combined data on the SM Higgs boson search

### NA62 and NA48/2 Experiments

The NA62 Collaboration has finished main R&D stages on the basic detectors performance, prepared a Technical Design Report of the experiment devoted to study very rare charged kaon decays into pion and two neutrinos and started detector production.

The responsibility of the JINR team is to design and construct the main track detector of the experiment — a straw tracker working with a high spatial resolution in vacuum, and develop the simulation and reconstruction software for this detector.

The main results obtained in 2011 in the framework of the NA62 experiment preparation:

1. The prototype of 64 straws was tested with the radioactive gamma source and at the SPS pion beam with different gas mixtures (Ar/CO<sub>2</sub> (80:20) and CO<sub>2</sub>/isoC<sub>4</sub>H<sub>10</sub>/CF<sub>4</sub> (90:5:5)) at the gas gain range  $G = (6-10) \cdot 10^4$ . As a result, the base line technology has been chosen to construct the full-scale module-0 of the straw tracker;

2. Straw tube mass-production was started at LHEP. About 1500 tubes were manufactured. Technical parameters correspond to the specification;

3. Assembly of the module-0 was started at CERN. Preparation for the assembly and quality control at LHEP is in progress;

4. Software for the straw tracker fast simulation has been modified to include the leading and trailing time of the straw response;

5. A proposal to measure the  $\pi-\mu$  atom yield in the framework of the NA62 experiment has been prepared.

Analysis of the NA48/2 experimental data in 2011 [4]:

$K^\pm \rightarrow \pi^\pm l^+ l^-$  decay modes have been analyzed in terms of four different sets of model form factors, including the model of meson dominance that was proposed by the JINR group of theoreticians. The most precise form-factor measurements have confirmed that the new model adequately describes the data (see Figs. 5 and 6).

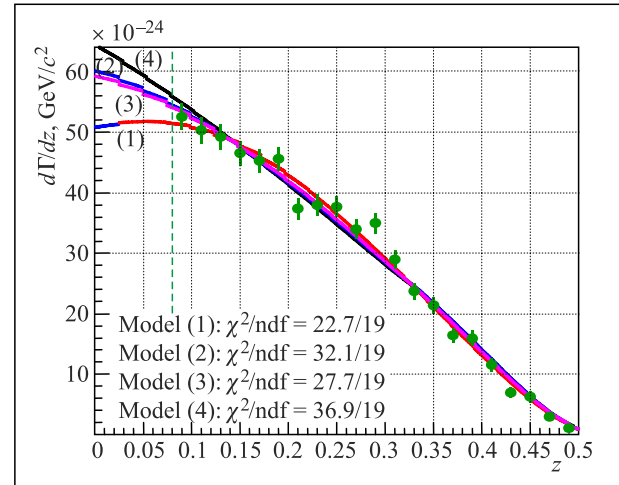


Fig. 5. NA48/2 results obtained in study of the  $K^\pm \rightarrow \pi^\pm l^+ l^-$  decays compared with the used models

The branching ratios were measured with the best precision for  $K^\pm \rightarrow \pi^\pm \mu^+ \mu^-$  and  $K^\pm \rightarrow \pi^\pm e^+ e^-$  decays (see Fig. 5):  $\text{Br}(K^\pm \rightarrow \pi^\pm \mu^+ \mu^-) = (9.62 \pm 0.25) \cdot 10^{-8}$  and  $\text{Br}(K^\pm \rightarrow \pi^\pm e^+ e^-) = (3.11 \pm 0.12) \cdot 10^{-7}$ .

For the first time the upper limit for the  $CP$ -violated charged asymmetry in decays  $K^\pm \rightarrow \pi^\pm e^+ e^-$  ( $< 0.021$ );  $K^\pm \rightarrow \pi^\pm \mu^+ \mu^-$  ( $< 0.029$ ) (CL 90%) has been determined.

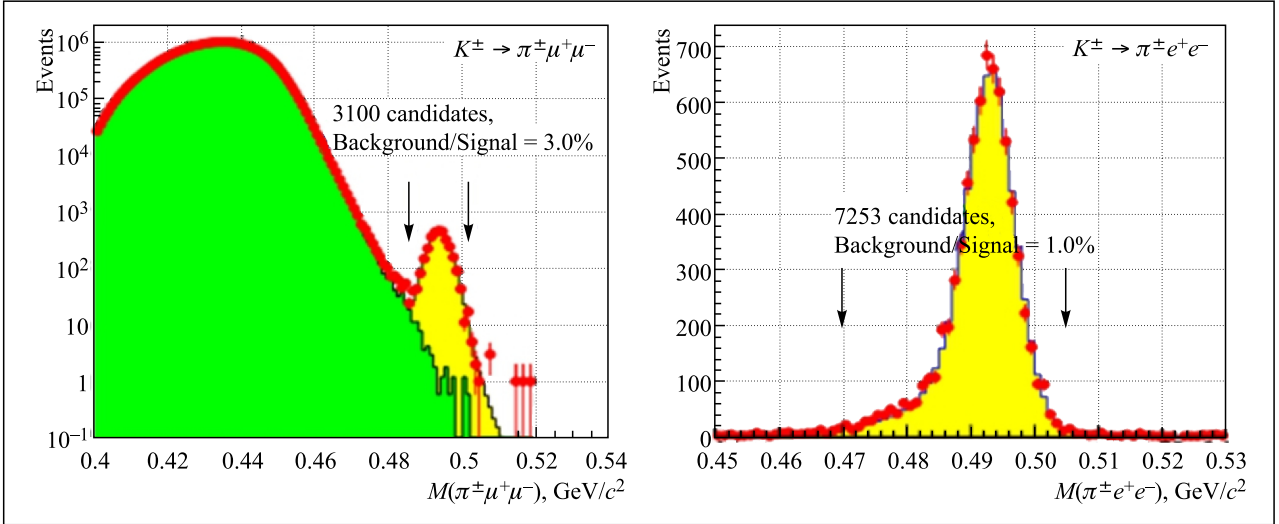


Fig. 6. The selection of the signal from data samples in analysis of the  $K^\pm \rightarrow \pi^\pm l^+ l^-$  decays

### COMPASS Experiment

In 2011, **COMPASS** performed data taking with the muon beam. All components worked well. The analyses of the data taken with the muon (2002–2007) and hadron beams (2008–2010) using the deuterium and hydrogen targets were in general completed. The main results are given below.

Double spin asymmetries for production of charged pions and kaons in semi-inclusive deep-inelastic polarized muon scattering off the proton and deuteron polarized targets have been extracted from the experimental data. A leading order evaluation of the helicity distributions for the three lightest quarks and antiquark flavours has been derived from these asymmetries [5] (presented in Fig. 7). The resulting values of the sea quark distribu-

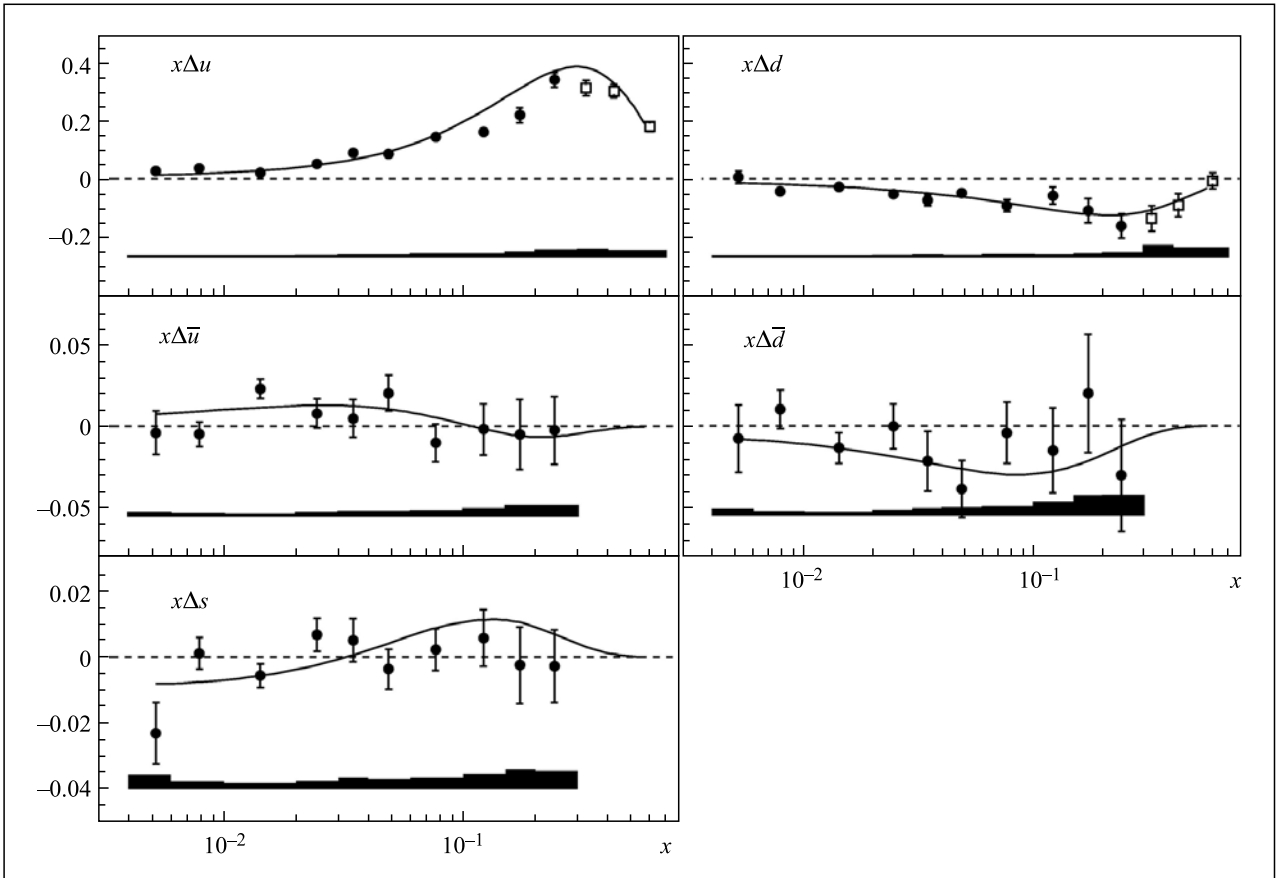


Fig. 7. The quark helicity distributions  $x\Delta u$ ,  $x\Delta d$ ,  $x\Delta\bar{u}$ ,  $x\Delta\bar{d}$ , and  $x\Delta s$  at  $Q_0^2 = 3 \text{ GeV}^2$  as a function of  $x$

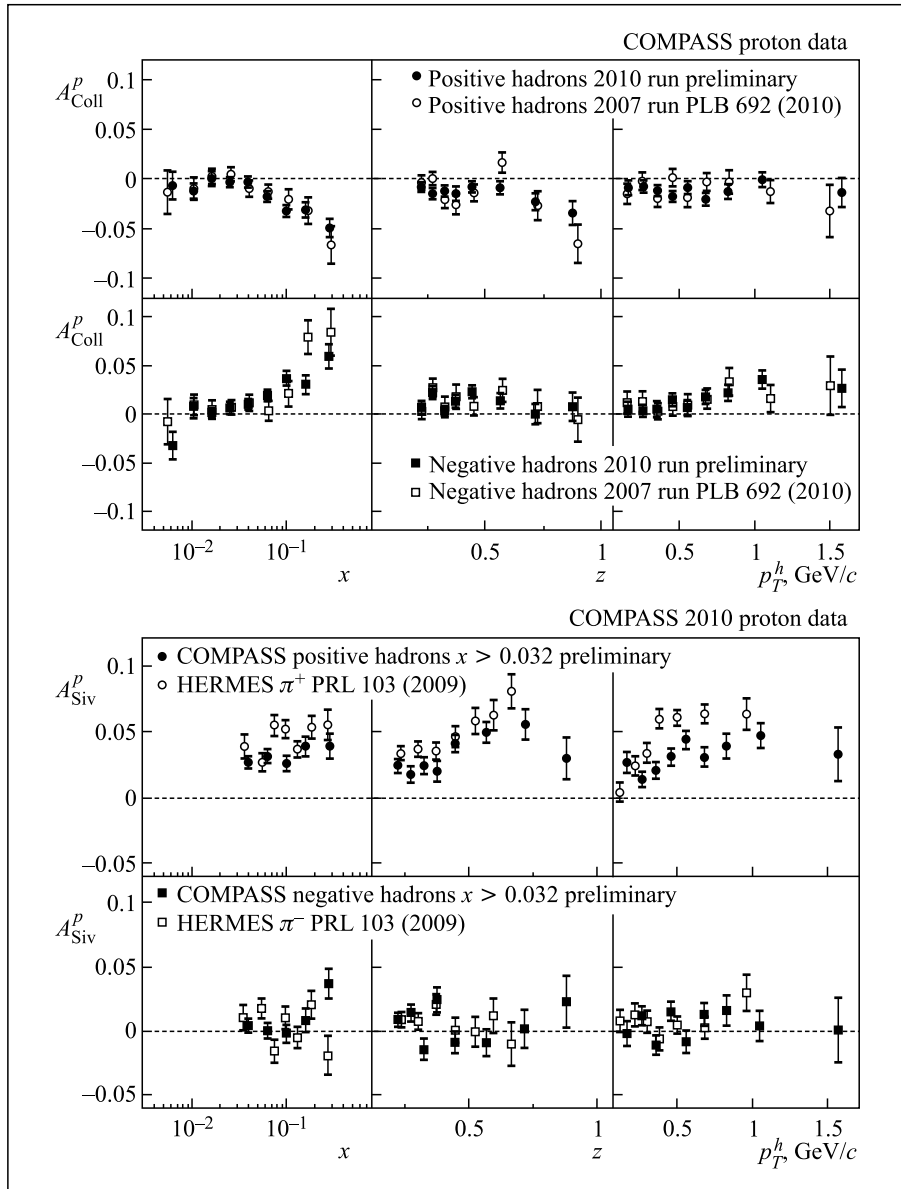


Fig. 8. Collins (upper plots) and Sivers (lower plots) asymmetries

tions are small and do not show any sizable dependence on  $x$  in the range of the measurements. No significant difference has been observed between the strange quark and antiquark helicity distributions, both are compatible with zero. The integrated value of the flavour asymmetry of the helicity distribution of the light-quark sea,  $\Delta u - \Delta d$ , has been found to be slightly positive, about 1.5 standard deviations from zero.

First preliminary results on azimuthal asymmetries in hadron-pair production in deep-inelastic scattering of muons on transversely polarized  $\text{NH}_3$  targets, obtained with the major contribution of the JINR group, were presented by COMPASS in 2011 [6]. The data were taken in 2010 and 2007 with the COMPASS spectrometer using the muon beam of 160 GeV/c at the CERN SPS. These asymmetries (Fig. 8) are related to the transversity distribution functions  $h_1^q(x)$ . They pro-

vide an independent access to the well-known Collins and Sivers effects in DIS with single hadron production. The results presented in this letter have shown sizeable asymmetries for the  $\text{NH}_3$  target, indicating a nonvanishing  $u$ -quark transversity.

## STAR

In 2011 the research activity of the VBLHEP group in the framework of the STAR experiment was focused on solving two tasks:

1. Participation in the programme of energy scanning on the collider RHIC. To reach this goal, measurements were carried out at BNL at the energy of 7.7; 9.2; 11.5, and 39 GeV;

2. Performance of experiments by using polarized protons at the energy of 200 and 500 GeV to obtain new more precise information on spin distributions of quarks

and gluons. Investigations at the energy of 500 GeV are carried out for the first time and open a unique opportunity of studying the spin distribution function in the processes with  $W$ -boson production;

Figure 9 shows the measured asymmetry in comparison with theoretical predictions based on total summing up (rhicbos) and calculations of NLO (CHE) [7]. The CHE calculations used DSSV08 of the polarized PDF, in the meantime the rhicbos calculations are shown in addition to the previous DNS-K and DNS-KKP PDF. The results of the CHE and rhicbos calculations are in good agreement.

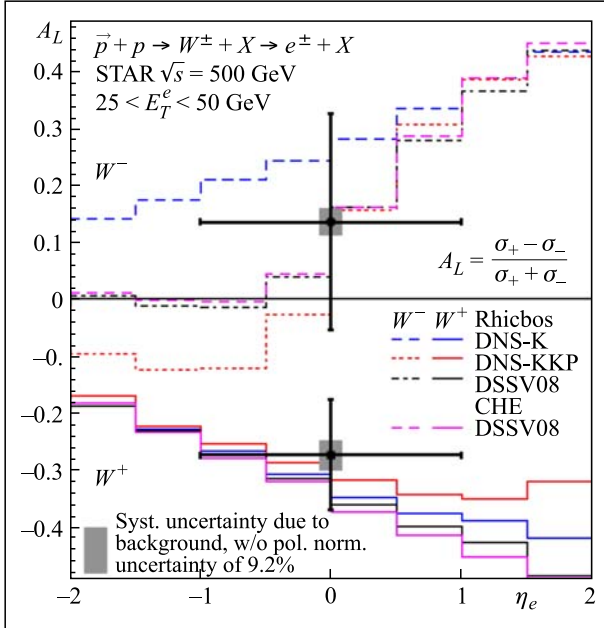


Fig. 9. Longitudinal single-spin symmetries for events with  $W$  bosons

The range covered by the DNS-K for DNS-KKP for  $\Delta\bar{d}$  and  $\Delta\bar{u}$  approximately coincides with the corresponding estimation of the DSSV08 uncertainty. In the field of middle rapidities the  $W^{+(-)}$  production is a good probe for polarization of  $u$  and  $d$  ( $d$  and  $u$ ) quarks, and  $A_L^{W^{+(-)}}$ , as it is expected, will be negative (positive).

The measured  $A_L^{W^+}$  is indeed negative that stresses the direct tie of  $u$  quark with polarization. Value  $A_L^{W^-}$  is positive in the centre as it was expected with a big statistic uncertainty. The results of our measurements of  $A_L$  agree with the predictions made by means of

## PROGRESS WITH THE MPD SUBSYSTEMS

In 2011, the MPD Collaboration worked at further development of the detector subsystems in the frame of the Technical Design Report (TDR) preparation. In particular, the following results were achieved.

1. **TOF.** The first beam tests were carried out for the time-of-flight detector manufactured by collaboration of

the polarized quark and antiquark PDF, obtained from measurements of inclusive and semi-inclusive pDIS, as it was expected, from the universality of polarized PDF.

The STAR measurement of the single spin asymmetry violating the parity for decays of  $W^+$  and  $W^-$  produced in longitudinally polarized  $p-p$  interactions with the energy of  $\sqrt{s} = 500$  GeV, into positrons and electrons of the rapidity central area,  $|\eta_e| < 1$ , opens a new and direct way of studying the spin structure of the proton by using the weak interaction violating the parity in the collisions of polarized  $\vec{p} + p$ .

## Experiments at the Nuclotron Carried out During 2011 Year Runs

The 43rd and 44th Nuclotron runs gave about 50% of the integrated time for the operation of the current experimental setups and R&D. In particular:

- An interaction of the deuterons with the Ag nuclei was studied in 18 points in the energy range from 320 to 372 MeV/u at the registration angle of one charged particle equal to 120 degrees (lab. syst.) The aim of this study was to search for peculiarities of dependence of the pion yield on the energy (setup DELTA, theme 1097). The data are in processing;

- In the framework of the DSS project, a new target control system has been finally commissioned; new methodical results which were needed to reduce systematic errors of measuring the elastic  $d-p$ -scattering cross section has been obtained; the angular dependence of the elastic  $d-p$ -scattering cross section have been measured at the energy of 500 MeV/u. The expected statistical error in the results on the differential cross section is 3–5%;

- A specialized run for biological investigations has been performed. Track detectors CR-39 were exposed to check the beam purity; three rats were irradiated with a dose of 1 Gr, three — in the nondefocused beam, and three rats — with a dose of about 0.7 Gr. The results are analyzed;

- In the framework of the NIS-GIBS project, the methodical run with the deuteron beam aimed at studying the vertex reconstruction precision was carried out;

- In the framework of the BM@N project preparation in the 44th Nuclotron run, the carbon beam with the energy of 3.42 GeV/n was successfully accelerated, extracted, and transported into the BM@N experimental zone.

JINR, Beijing University, and GSI. Three MRPC detectors were studied: two identical prototypes with a working area of  $70 \times 140$  mm having pad read-out and one full-size prototype with a working area of  $600 \times 300$  mm having longitudinal strips (bilateral read-out). Tracking was performed by 3 drift chambers (STRELA). The

detector based on fast FES with quartz radiator (FFD prototype) and sizes of  $75 \times 75$  mm ( $2 \times 2$  «towers») was chosen as a start-up detector.

The deuteron beam energy while measuring was about 1 GeV/u. The MRPC efficiency and time resolution were measured at different voltage on them and different thresholds of the registering electronics. Totally under different conditions 14 points were obtained on the voltage from 9 till 13 kV for MRPC. The collected data are sufficient to determine the time resolution under different conditions. The first results of the TOF MPD operation have been obtained. The data analysis is performed.

**2. Straw Tracker.** A full-scale prototype of the endcap track detector element of the MPD facility has been manufactured.

**3. TPC.** Studies with the Prototype 0 were performed on the gaseous mixture Ar/Methane with the UV laser beam and cosmic irradiation. The RoC chamber with PAD Plane is used for readout. The pad sizes are  $8 \times 12$  mm, the number of the FEE channels is 256. The trigger is based on scintillation counters.

A new Pad Plane prototype has been developed with the pad sizes of  $5 \times 12.5$  mm. The response function in RoC chamber has been determined.

A developed cylindrical Prototype 1 with a drift length of about 80 cm includes the following: Field Cage made on the technology to be applied while TPC constructing, a laser calibration system (2–3 rays), a RoC chamber with the Pad Plane, 256 of the FEE channels. Tests of the Prototype 1 will be carried out on the working gaseous mixture with cosmic rays. A technological prototype FEE (FEB-64) is developed on the basis of 200 microchips ALTRO and PASA received from CERN. The work has been carried out to prepare the equipment and develop the technology of manufacturing in 2012 two cylindrical cells of kevlar with the diameter of 540 mm and 620 mm (3 m long) for the TPC body.

**4. Calorimetry.** Beam tests of the MPD electromagnetic calorimeter were performed at DESY and accelerators PS and SPS (CERN) including also the new detector to register MAPD photons. The main advantages of the latter in comparison with FEA are: compactness and nonsensitivity to the magnetic field.

**5. FFD.** A stand was made for testing with the cosmic muons at the Radium Institute (St. Petersburg). Tests of the modules (version 1) were fulfilled on the proton beam of the Nuclotron (March 2011). The tests and measurements of the time resolution were carried out on the cosmic muons.

## INNOVATIONS

In the frame of the **DVIN** project, the compact detector for drugs and explosive materials detection has been developed. First consignment of the detectors has been fabricated and installed at the railway stations and metropolitan in Moscow, St. Petersburg, and Novosibirsk.

For the first time the «**Energy and Transmutation**» project obtained results which indicate to the possible increase of the energy multiplicity gain of the subcritical uranium assembly in dependence on the deuteron

energy (0.6–6 GeV). The increasing of the relativistic ions energy leads to the increase of the average neutron energy in the subcritical assembly volume. If the results are confirmed, it will allow one to increase the transmutation coefficient of the worked out nuclear fuel as well as to use efficiently  $^{238}\text{U}$  and  $^{232}\text{Th}$  as nuclear fuel.

Deuteron energy, GeV	2	4	6
Total yield of delayed neutrons per one deuteron in arbitrary units	$20 \pm 2$	$50 \pm 5$	$96 \pm 10$

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