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RESEARCH PROGRAMME AND MAIN RESULTS IN 2006 OF THE LABORATORY OF PARTICLE PHYSICS

Report to the 101st Session
of the JINR Scientific Council
January 18–19, 2007

Dubna 2006

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The activity of LPP in 2006 was concentrated on the current particle physics experiments and preparation of the new ones, R&D of particle detectors, and various acceleration systems.

1. ONGOING EXPERIMENTS

The HERA collider continued operation after the luminosity upgrade in 2006. The **H1** experiment accumulated luminosity of 150 pb^{-1} (or 350 pb^{-1} for period of 2004–2006) in collisions of 920 GeV protons with 27.5 GeV longitudinally polarized electrons/positrons. The polarized lepton beam allows HERA experiments to constrain further parton densities of the proton by measurements of polarization asymmetries, and test the electroweak part of the Standard Model. The LPP JINR group participating in the H1 experiment has made major contribution to the following physics results:

1. Measurement of diffractive structure function F^D_2 in diffractive deep-inelastic scattering (DIS) in processes with a large rapidity gap [1] and processes with a leading proton detected in the H1 Forward Proton Spectrometer (FPS) [2].

2. The differential cross section as a function of the squared four-momentum transfer at the proton vertex t in the range of low fractional proton momentum loss x_{IP} has a dependence of approximately $d\sigma/dt \sim e^{6t}$, independently on Bjorken scaling variable x and photon virtuality Q^2. The FPS data are consistent with the hypothesis of proton vertex factorization for diffractive ep DIS processes [2].

3. Comparison of the leading proton structure function obtained by H1 FPS with the result of an analogous measurement by the ZEUS experiment and F^D_2 obtained by H1 from the data with a large rapidity gap in the central detector shows good agreement between the two experiments and two methods. The result proves small contribution of the proton dissociation in the large rapidity gap data.

4. Diffractive parton density functions (PDFs) for quark singlet and gluon are extracted from a NLO DGLAP QCD fit to high statistics of large rapidity F^D_2 data [1]. The QCD predictions based on the diffractive PDFs describe new H1 data on high p_T dijet and open charm production in diffractive deep-inelastic scattering [3, 4]. A combined NLO QCD fit to F^D_2 and diffractive dijet cross sections constrain the

diffractive gluon density in a wide range of the fractional momentum [3, 5].

The recent physics results have been presented by the LPP JINR group representative, Dr. M.Kapishin on behalf of the H1 collaboration at the 33rd International Conference On High Energy Physics ICHEP-06 [3]. Members of the LPP JINR group are co-authors of 10 articles published on behalf of the H1 collaboration in physics journals in 2006.

Within the upgrade program of the H1 experiment the LPP JINR group is responsible for the upgrade, installation and operation of three important detectors: the Forward Proton Spectrometer, Backward Proportional Chamber and Plug detector.

In 2007 the H1 LPP JINR group plans to perform the upgrade and operation of the FPS spectrometer, Backward Proportional Chamber and Plug detector during HERA-II running period. The LPP JINR group contributes to the laboratory equipment and components of the FPS, BPC and Plug detectors and provides experts for upgrade, hardware and software support of detector operation. After the end of HERA-II operation in July 2007 the LPP JINR group will provide calibration, alignment and data reconstruction for these detectors.

In 2007, the LPP JINR group will also contribute to the physics analysis of deep-inelastic scattering and photo-production processes on the base of new high statistics HERA-II experimental data obtained using FPS, BPC and PLUG detectors. There are plans to run HERA in 2007 at reduced proton energy of 460 GeV to measure longitudinal structure function F_L. The LPP JINR group plans to contribute to the measurement of diffractive longitudinal structure function F^D_L and diffractive high p_T dijet production in processes with a leading proton in the final state.

An LPP group has taken part in analysis of the **HERMES** data collected in 1995–2004, and performed technical maintenance of the mini-drift vertex chambers. The main HERMES results obtained in 2006 are the following:

1. Precise measurements [6] of the polarized spin structure function $g_1(x,Q^2)$ of the proton and deuteron are presented over the kinematic range $0.0041 < x < 0.9$ and $0.18\ GeV^2 < Q^2 < 20\ GeV^2$. The data were collected at the HERMES experiment at DESY in deep inelastic scattering of 27.6 *GeV* longitudinally polarized positrons off longitudinally polarized hydrogen and deuterium gas targets internal to the HERA storage ring. The neutron spin structure function g^n_1 is extracted by combining the proton and deuteron data. The integrals of $g_1^{p,d}$ at $Q^2 = 5\ GeV^2$ are evaluated over the measured x range. Neglecting any possible contribution to the g^d_1 integral from the region $x < 0.021$, a value of $0.330 \pm 0.011(\text{theor.}) \pm 0.025(\text{exp.}) \pm 0.028(\text{evol.})$ is obtained for the flavor-singlet axial charge a0 in a leading-twist NNLO analysis.

2. The first measurements [7] of double-hadron production in deep-inelastic scattering within the nuclear medium were made with the HERMES spectrometer at HERA using a 27.6 *GeV* positron beam. By comparing data for deuterium medium with those for nitrogen, krypton and xenon nuclei, the influence of the nuclear medium on the ratio of double-hadron to single-hadron yields was investigated. Nuclear effects on the additional hadron are clearly observed, but with little or no difference among nitrogen, krypton or xenon, and with smaller magnitude than the effects seen on previously measured single-hadron multiplicities. The data are compared with models based on partonic energy loss or pre-hadronic scattering, and with a model based on a purely absorptive treatment of the final state interactions. Thus, the double-hadron ratio provides an additional tool for studying modifications of hadronization in nuclear matter.

3. Single spin asymmetries [8] in the semi-inclusive production of charged pions in deep-inelastic scattering from transversely and longitudinally polarized proton targets are combined to evaluate the subleading-twist contribution to the longitudinal case. This contribution is significantly positive for π^+ mesons and dominates the asymmetries on a longitudinally polarized target previously measured by HERMES. The subleading-twist contribution for π^- mesons is found to be small.

4. The transfer of polarization from a high-energy positron to a Λ^0 hyperon produced in semi-inclusive deep-inelastic scattering has been measured [9]. The data have been obtained by the HERMES experiment at DESY using the 27.6 *GeV* longitudinally polarized positron beam of the HERA collider and unpolarized gas targets internal to the positron (electron) storage ring. The longitudinal spin transfer coefficient is found to be $D^{\Lambda}_{LL'} = 0.11 \pm 0.10\ (\text{stat.}) \pm 0.03\ (\text{syst.})$ at an average fractional energy carried by the Λ^0 hyperon of $\langle z \rangle = 0.45$. Dependences

of $D^{\Lambda}_{LL'}$ on both the fractional energy z and the fractional longitudinal momentum x_F are presented.

Throughout this reported period the JINR LPP (Dubna) group has performed technical maintenance of the Drift Vertex Chambers (DVC) during the HERMES data taking. The DVCs were removed for a shutdown that lasted from November 2005 till January 2006; then they were reinstalled for the 2006–2007 data taking period. The DVCs have operated stably till now.

The JINR LPP group participates in the HERMES data analysis. The effort was focused on the analysis of the semi-inclusive 1996-2000 polarized data aiming to extract the polarized quark distributions and its moments in NLO. The analysis is based on a new method [10–14] which needs the data from difference and sum pion asymmetries. The obtained results were presented at HERMES collaboration meetings in March and July of 2006 [15–20].

After the SPS shutdown of 2005, **COMPASS (NA58)** has resumed the data taking in 2006, with the muon beam using a new polarized target and new upgraded/improved detectors. The 2006 run took place from June till November. JINR participants have perfomed more than 200 eight-hour shifts. The new polarized target has a three times larger solid angle for outgoing particles, and three cells in which the material (^{6}LiD) can be polarized in opposite directions. Operation with this target will allow COMPASS to improve substantially the statistical precision of the results, at the same time reducing systematic uncertainties. Among the new detectors there is a so called RICH WALL, a tracking detector located behind the RICH constructed with the JINR (LNP) participation.

The analysis of data collected in 2002–2004 has been continued. A large number of results has been released, presented at various international conferences (49 talks, including [21–25] by JINR physicists), published [26, 27] and will be submitted for publications in 2006 [28, 29]. The current status of the analysis is summarized in 11 internal notes, three of which are written with JINR participants. Main results of the analysis are summarized below.

1. New results of the deuteron spin asymmetry $A_1^d(x,Q^2)$ and the spin-dependent structure function $g_1^d(x,Q^2)$ covering the range $1<Q^2<100$ GeV^2 and $0.004<x<0.7$ have been obtained [26] with a 2.5

times larger statistics than previously published. These data provide an accurate evaluation of $\Gamma_1^d(Q_0^2)$, the first moment of $g_1^d(x,Q_0^2)$, and the singlet axial current, a_0:

$$\Gamma_1^d\left(Q_0^2=3GeV^2\right)=0.050\pm0.003(stat)\pm0.003(evol)+0.005(syst),$$
$$a_0\left(Q_0^2=3GeV^2\right)=0.35\pm0.03(stat)\pm0.05(syst).$$

The new COMPASS measurements of $g_1^d\left(x,Q^2\right)$ and all world data on g_1 have been fitted [26, 25] using two different QCD evolution formalisms (for the first time) in the next-to-leading-order (NLO). The first formalism, based on the numerical solutions of the famous DGLAP evolution equations for parton distribution functions (PDF), was developed by the SMC collaboration [30]; the second one, based on analytical solutions of the equations for PDF moments, was developed by Dubna participants [31]. Both methods of the QCD analysis have produced consistent results with similar χ^2 for two solutions for PDF parameters. One solution gives a set of PDF parameters for the case when $\Delta G>0$, and another solution for $\Delta G<0$, where ΔG is the first moment of the polarized gluon distribution in nucleon. The precision of existing data on g_1 is not sufficient to choose between these solutions. Although the gluon distributions strongly differ in two solutions, the fit parameters, characterizing ΔG, or the total contribution of gluons to the spin of nucleon, are both small and almost equal in absolute value: $|\Delta G|\approx0.2\div0.3$. So, the gluon contribution to the nucleon spin is rather small. The direct measurements of the gluon polarization $\Delta G(x)/G(x)$, where $G(x)$ is PDF of unpolarised gluons, could help to choose between the two solutions for ΔG. The available data, including three values measured by COMPASS

$\dfrac{\Delta G}{G}=-0.57\pm0.41\pm0.058$ from open charm production,

$\dfrac{\Delta G}{G}=0.016\pm0.058\pm0.055$ from production of high p_T hadron pairs with $Q^2<1$ GeV^2,

$\frac{\Delta G}{G} = 0.06 \pm 0.31 \pm 0.06$ from production of high p_T hadron pairs with Q^2>1 GeV^2, are compared to the other data and to the QCD fitted $\Delta G(x)/G(x)$. The most precise COMPASS point is closer to the $\Delta G>0$ solution, although it is only 1.3σ away from $\Delta G<0$. Further improvement of the precision is needed. Contrary to the gluon PDF, the polarized strange quark distributions obtained from two solutions are almost identical for $\Delta G>0$ and $\Delta G<0$. The first moment of this PDF, found from fits at $Q_0^2 = 3GeV^2$, is

$(\Delta s + \Delta \bar{s}) = -0.10 \pm 0.01(stat) \pm 0.01(evol)$, where the evolution error is estimated from results obtained by two methods of the QCD analysis.

2. The study of longitudinal polarization of Λ and $\bar{\Lambda}$ hyperons in the deep-inelastic scattering (DIS) is important for understanding the role of the strange quarks in the nucleon. The preliminary analysis of data collected during the 2003 run was accompished. The data sample comprises about $8.7 \cdot 10^7$ DIS events with Q^2>1 (GeV/c)^2. After the selection cuts, the total data sample contains about 31000 Λ and 18000 $\bar{\Lambda}$, which is significantly larger than the data sample of the 2002 run analyzed earlier which comprises about 9000 Λ and 5000 $\bar{\Lambda}$.

The results on longitudinal polarization of Λ and $\bar{\Lambda}$ for data taken during the 2003 run are presented in [24]. The polarization of Λ and $\bar{\Lambda}$ is the same except, probably, the region of small $x<10^{-2}$ and large y, where there is an indication that polarizations of Λ and $\bar{\Lambda}$ are different. The statistical precision is not sufficient for a definite conclusion, but an indication on different mechanisms of Λ and $\bar{\Lambda}$ production and polarization exists. Theoretical calculations of Λ and $\bar{\Lambda}$ longitudinal polarizations in COMPASS conditions are highly desirable.

3. Analysis of 2002 data with transversely polarized deuterium target [32] has shown that the so called Collins and Silvers asymmetries in azimuthal distributions of hadrons produced in semi-inclusive DIS processes are small and consistent with zero in the whole regions of kinematic variables x and p_T. These results are confirmed by the overall data of 2002–2004 [27] with the statistics increased by a factor of ~7. The most likely interpretation, taking into account the corresponding

measurements of HERMES on a proton target, is that in the COMPASS isoscalar target there is a cancellation between the proton and the neutron asymmetries. This is confirmed by the theoretical analysis by A.V. Efremov presented at the SPIN 2006 conference [33].

The sequence of experiments **NA48, NA48/1, NA48/2** and preparation for the new experiment in the K^+ beam (proposal P326) carried out by the NA48 collaboration are devoted to search for and precise measurement of direct CP-violation parameters in kaon decays, and to study of kaon and hyperon rare decays. The main goals of the NA48 and NA48/1 experiments have been fulfilled. Data analysis is continued to search for and to study rare kaon decays with a sensitivity of about 10^{-9}. The main goals of the NA48/2 experiment are the search for direct CP-violating charge asymmetry in $K^\pm \to \pi^+\pi^-\pi^\pm$ and $K^\pm \to \pi^0\pi^0\pi^\pm$ decays with a precision of one order of magnitude better than existing data, and to measure the $\pi\pi$ scattering length, a basic parameter of the χPT theory, using more than a million K_{e4} decays (a record statistics). The data were accumulated in 2003 and 2004 runs at the CERN SPS, and analyzed in 2005 and 2006. The collaboration has started of a new program (P326) at the CERN SPS, which is devoted to study a very rare decay of charged kaon into pion and two neutrinos. The responsibility of JINR in the framework of this program is related to R&D of straw detector operating in vacuum. The following results are obtained using the data accumulated in 2003-2004 in the framework of the NA48/2 experiment.

- A final result on the charge asymmetry measurement in $K^\pm \to \pi^+\pi^-\pi^\pm$ decays based on the 2003 data is: $A_g^c = (1.7 \pm 2.1_{stat} \pm 1.4_{stat(trig)} \pm 1.4_{syst}) \cdot 10^{-4} = (1.7 \pm 2.9) \cdot 10^{-4}$ [34]. This result is compatible with the SM predictions, and has already an order of magnitude better precision than similar previous measurements. Preliminary results on this asymmetry based in 2003–2004 data: $A_g^c = (-1.3 \pm 1.5_{stat} \pm 0.9_{trig(stat)} \pm 1.4_{syst}) \cdot 10^{-4} = (-1.3 \pm 2.3) \cdot 10^{-4}$ was presented [35] and published as a JINR report [36].
- The preliminary result for asymmetry measurement in the "neutral" mode $K^\pm \to \pi^0\pi^0\pi^\pm$ based in the 2003 data has been obtained: $A_g^0 = (1.8 \pm 2.2_{stat} \pm 1.0_{trig(stat)} \pm 0.8_{syst} \pm 0.2_{ext}) \cdot 10^{-4} = (-1.8 \pm 2.6) \cdot 10^{-4}$ [37].

This result does not indicate to a CP-violation at the precision level, which is one order of magnitude better than other experiments. A more precise result was obtained using also the statistics accumulated in 2004, and presented at the 33th Rochester conference in Moscow by a JINR representative S.Balev.

- A study of a partial sample of $2.3\cdot10^7$ $K^\pm \to \pi^0\pi^0\pi^\pm$ decays. An anomaly was discovered in the spectrum of the invariant mass of the $\pi^0\pi^0$ subsystem (M_{00}) in the region around $M_{00}=2m_+$, where m_+ is the charged pion mass. This anomaly, never observed in previous experiments, can be interpreted as an effect due mainly to the final state charge exchange scattering process $\pi^+\pi^- \to \pi^0\pi^0$ in the $K^\pm \to \pi^+\pi^-\pi^\pm$ decay [38]. It provides a precise determination of $a_0{-}a_2$, the difference between the $\pi\pi$ scattering lengths in the isospin I=0 and I=2 states. A best fit to a rescattering model corrected for isospin symmetry breaking gives $(a_0-a_2)m_+ = 0.268 \pm 0.010_{stat} \pm 0.004_{syst}$, with additional external uncertainty of ±0.013 due to $K_{3\pi}$ branching fractions and theoretical uncertainties. Obtained results were presented at many international conferences, including 6 presentations of JINR group representatives [35, 39–43].

In 2007 the LPP group plans to perform the following activities:

- The analysis of experimental data will be continued and new results on the estimation of CP-violation effect in charged kaon decays is planned to be obtained based on the whole accumulated statistics.
- A number of charged kaon rare decays is planned to be investigated.
- The mass production of the Monte Carlo simulation corresponding to the statistics accumulated in 2003–2004 will be continued for the precision study of systematical effects for various charged kaon decays.
- New results on the neutral kaon and hyperon rare decays are expected.
- Preparation of the new project (P326) will continue in order to clarify and fulfill the following issues:
  - Operation of the straw detector in high vacuum environment;
  - Choice of gas mixture to optimize resolution and drift time in the straws;

- Construction of a small prototype consisting of ~100 straws and its test in cosmic rays and in the CERN SPS beam in 2007.

The **THERMALIZATION** project has started in 2003 at the **Protvino** accelerator, and is aimed to study the collective behavior of particles in the process of multiparticle production in pp interaction pp $\to n_\pi \pi + 2N$ at the beam energy of E_{lab}=70 GeV.

The SVD-2 setup modernization was continued in order to carrying out physical run in December, 2006. An upgrade of vertex detector electronics has been made. A batch of preamplifiers was purchased at JINR expense, and mounted into the vertex detector. Spare planes with inoperative strips replaced were made. Vertex detector tests have found a remarkable reduction of noise level. The drift tracker is prepared. Faults of the data acquisition system were eliminated. Replacement of the electronic elements manufactured in Belarus has been accomplished. Trigger tests with radioactive sources were made. Simulation of the scintillator hodoscope producing trigger signal for a high multiplicity events was fulfilled. Its test was carried out in the channel with the created noise equipment. Defects in liquid helium filling system from transport vessel of Duar in a stationary bulk were removed. Suggested measures of thermo-acoustical vibrations removal agree to make fulfilling of bulk in the total volume. Preparation of the gamma-detector for running has begun.

The software working for December 2006 run and the processing of data taking in 2002 run have been performed. At the expense of project theme and grant (RFBR 06-02-81010-Бел_а) the new equipment for the computing facility was purchased this year. The alignment package was designed, and included into the software of project. By the beginning of the year, the development of the track reconstruction software without magnetic field has been finished. During the run the packages developed by SINP MSU taking into account the magnetic field will be used as well. Drift chamber calibration was performed, and the software for track reconstruction in the drift tracker was developed. The software for the setup elements used in the first run (drift tracker and gamma-quantum detector) was developed. Multiplicity distributions in pA (C, Si and Pb) collisions are obtained from data processing of run, 2002.

The experimental indications to ring event manifestation were founded at pseudo-rapidity distributions on Pb-target.

The theoretical approach was developed for high multiplicity events. Further development of gluon dominant model confirms cluster mechanism of multiparticle production and permits to interpret the obtained results within the modern framework of quark-gluon matter and the recent results about its phase diagram. A group of collaborators (BITP, Kiev) have studied the possibility of Bose-Einstein condensate detection (BEC) in pp collisions with high multiplicity at beam energy equal to 70 GeV (project Thermalization). They have shown at high multiplicity secondary pions more than mean multiplicity the experimental manifestation of BEC may be founded by the sharp increase of neutral meson multiplicity fluctuations at fixed total multiplicity. The above results are published in [44–53].

The LPP participates in the experiment on the 4π-detector **STAR** at the RHIC collider at the Brookhaven National Laboratory (**BNL**). The following tasks were completed by the LPP group during the reported period:

1. The paper "Transverse momentum and centrality dependence of high-pT nonphotonic *electron suppression in Au+Au collisions at* $\sqrt{s_{NN}} = 200$ *GeV*" has been prepared for publication [54].
2. Inclusive yields of the low-pT photons produced in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV at RHIC has been studied using the STAR TPC conversion method, more work on low-pT direct photon production at RHIC is expected in the following year.
3. *"Crystal R&D proposal for Soft Photon Measurement at STAR"* is the joint effort of Laboratory of Particle Physics (JINR), University of California at Los-Angeles (USA) and Institute of Modern Physics at Lanzhou (China) for soft photon measurement at STAR experiment at RHIC. A new specialized crystal detector (CRD) for ultra low-p_T photon measurements is proposed. During the pre-R&D phase the LPP group studied the background conditions, detector response and photon rates and yields using the full MC simulations of the proposed detector.

4. The LPP group has participated in visualization software development for physics studies, and in the development of the new Open Science GRID tools.
5. The development of a program tool for correlator analysis of STAR data has been continued. First results obtained for Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV.
6. Also two papers entitled "Neutral Kaon Interferometry in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV" [55] and "A Fast Hadron Freeze-out Generator" [56-59] were prepared for publication.

In 2007 the LPP group plans to complete the following studies:

1. Heavy flavor production.

During the upcoming period the group is planning to continue J/ψ, Upsilon studies as these are considered as primary probes of the early phases of the possible QGP formation at RHIC. The $\chi_c \to J/\psi + \gamma$ decay measurement may serve as good baseline for 'feed-down' J/ψ produced in heavy ion collisions. Possibility of such decay reconstruction at STAR will be investigated in upcoming period.

2. Electromagnetic probes.

Soft photon studies via TPC conversion method will allow the LPP group to investigate the following physics ideas: new information about early stages of possible QGP formation at RHIC, e.g. thermal photons from QGP and HRG stages. A study of the $\Sigma^0 \to \Lambda + \gamma$ decay reconstruction possibilities at STAR will be performed.

3. Femtoscopic correlations and collective variables.

Studies of femtoscopic correlations in various particle systems including strange particles will be done to get an insight in the space-time evolution of particle production at RHIC. Studies of collective variables (e.g. correlators) to reveal production dynamics at RHIC will be also performed.

The New proposal "Crystal Detector R&D proposal for Soft Photon Measurement in STAR" will be prepared by the Laboratory of Particle Physics (JINR), University of California at Los-Angeles (USA) and

Institute of Modern Physics at Lanzhou (China). The LPP group plans to perform the following studies in the upcoming period:

1. Algorithms and methods:
   1.1. Photon reconstruction and cluster-finder algorithms using the CRD and TPC information – development and testing.
   1.2. Detailed efficiency and purity of the reconstructed soft photon sample.
   1.3. Improvement of the existing algorithms of the background subtraction (e.g. from charged tracks and other sources).
2. Background studies:
   2.1. Shower shape analysis and its usage for background suppression.
   2.2. Possibilities for hardware improvement of the background suppression (veto).
   2.3. Detailed studies of the surrounding BEMC modules-based background (albedo).
3. Performance studies:
   3.1. Various leakages, e.g. leakages to neighbourhood towers and energy resolution effects.
   3.2. Pileup studies in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV, $\sqrt{s_{NN}}$ = 500 GeV.
   3.3. CRD performance optimizations for p+p, d+Au, Cu+Cu, Au+Au systems.

2. PREPARATION OF NEW EXPERIMENTS

JINR participates in the **CMS** project in framework of the Russia and Dubna Member states CMS collaboration (RDMS). The main effort of JINR in the CMS Project is concentrated on the construction of the CMS inner endcap detectors, with RDMS bearing the full responsibility on Endcap Hadron Calorimeters (HE) and First Forward muon Stations (ME1/1). Also JINR participates in Endcap Preshower (ES). In summer 2006, the magnet yoke was closed first time, and magnet current was ramped up to achieve design goal of 4 Tesla. JINR group took a part in a cosmic test of the whole CMS Detector (MTCC), equipped with 60

degree readout, trigger and DAQ, in magnetic field in the surface hall. Second stage of the cosmic test and field mapping was completed in October. Putting the detectors into the underground experimental hall was started in November 2006 with a goal to be ready for a pilot LHC run on September 1, 2007. In line with commissioning of the detectors, JINR actively participates in the development of long-term physics research program within CMS sub-systems: Physics, Reconstruction and Selection (PRS subsystem) and Computing and Core-Software (CCS subsystem).

The main JINR obligation on construction of Endcap Hadron Calorimeters is fulfilled. In co-operation with IHEP (Protvino), NC PHEP (Minsk), HTTC NIKIET (Moscow), MZOR plant (Minsk), ISC and NSC KIPT (Kharkov) both HE endcaps were delivered, assembled, dressed with front-end electronics and tested at CERN. Industry of Russia and JINR member states, such as “Krasny Vyborjets” and “Izhorskie Zavody” in St. Petersburg, October Revolution Plant in Minsk, Single Crystal institute in Kharkov, and others were deeply involved into the construction of endcap hadron calorimeters. In particular, a technology of brass production out of artillery case cartridges for calorimeter absorbers was developed by NIKIET (Moscow) in cooperation with St. Petersburg plants. In 2006 both Endcap Hadron Calorimeters are calibrated with LED, laser and radioactive source without magnetic field. Calibration results demonstrate good stability and timing. RMS of tile signals from single readout channel is about 10%. The levelling coefficients for reach channel were extracted. Four HE+ wedges were in operation in MTCC. Data were taken with cosmic muons and radioactive source from calibration with field, and study of magnetic field influence on scintillator brightening is foreseen during second stage of MTCC. Data analysis is going on. Lowering of HE+ is scheduled by the end of 2006.

JINR obligation on proportional chamber construction for ME1/1 muon stations is also fulfilled. All ME1/1 cathode strip chambers are delivered (including spares), installed and tested at CERN. All CSCs were tested repeatedly after transportation, before and after installation. Commissioning of CSC in SX5 without magnetic field is almost completed. A set of six chambers was in operation in MTCC. A combined cosmic test of HE and ME1/1 was performed. Data were taken during a second stage of MTCC with the goal to study magnetic field effects both in ME1/1 and HE, and common operation of two neighbouring detectors as a part of CMS with magnetic field and with final configuration of trigger/DAQ. Mass production of silicon radiation hard detectors 63x63 mm^2 (paid by Russia) in co-operation with RIMST (Zelenograd) will be completed by the end of 2006. A part of the produced detectors was tested for radiation hardness at IBR-2. Detector database was developed at JINR and installed at CERN to manage with the data of the detector measurements. Assembly of detector modules at a Dubna regional center was started. During 2006, the main efforts of JINR physicists in CMS were focused on the development of CMS physics program and the Physics TDR preparation. They made a major contribution to calibration of the endcap hadron calorimeters, development of core and reconstruction software for muon and jet, beam test data analysis, development of data processing and analysis scenarios. The field of a special interest of JINR group is the program for studies of processes with heavy dimuons which is an integral part of the CMS physics program.

The main results based on a full simulation and reconstruction analyses and with taking into account possible systematic effects performed by JINR group are as follows:

1. The detailed studies of the CMS performances for triggering and off-line reconstruction of dimuon pairs have been performed. The total efficiency of triggering including reconstruction and trigger selection efficiency is 98%. There is a significant decrease in trigger efficiency after applying of the Level-2 calorimeter isolation cuts (down by 15%). The off-line reconstruction efficiency for samples with SM Drell-Yan events is about 98–94% for masses 0.2 TeV/c^2–5 TeV/c^2. The overall efficiency of the full reconstruction procedure taking into account trigger and off-line reconstruction inefficiency is 97–93% for a mass range 0.2 TeV/c^2–5 TeV/c^2.

2. The first realistic misalignment scenarios have been developed. These scenarios introduce misalignments for the tracking devices of the CMS (the Tracker and the Muon system). Misalignment is carried out at the reconstruction level (in the ORCA software). This makes possible to use the existing data samples for various misalignment studies. The

First Data scenario corresponds to the situation when the Pixel detector can already be aligned with tracks and when the first optical information is available for the muon system. The Long Term scenario corresponds to the situation of an established running. Misalignment scenarios utilize the mounting precisions of various parts of the CMS as well as the estimated accuracies after the use of optical alignment systems and track based alignment. These numbers are so far rough estimates and will be updated once better estimates become available from alignment studies.

3. The analysis of the experimental data of the combined HE-ME beam test has been carried out. It is shown that muons with energies 30–300 GeV produce 17–27% of events with electromagnetic secondaries which can contaminate the muon track significantly. Most of them originate from the CSC face material (CSC shielding, electronics, cooling plate 9 g/cm^2). Pions at 300 GeV correspond to 17% of the events with punch-through for the EE+HE+ME1/1 configuration. It was found that around 80% of the hadronic punch-through events have up to 1÷5 tracks in the ME1/1 station. The shower radius is about 80 cm. The CMS GEANT4-based simulation reproduces reasonably experimental data both for secondaries and punch-through.

4. The potential of the CMS experiment to measure the cross section and the forward-backward asymmetry for dimuon pairs up to the highest masses that will be accessible at the LHC, and to test the Standard Model up to very high momentum transfers in a new and unexplored energy range was investigated. The total relative systematic uncertainties for the cross section of Drell-Yan pair production are estimated. It is shown that systematic uncertainties from theory are larger than detector effects due to misalignment, acceptance uncertainties etc. The statistical errors dominate for invariant mass larger than 2 TeV/c^2 even for 100 fb^{-1}. For high invariant mass regions the accuracy of the forward-backward asymmetry is limited by the number of events (e.g. 7% for masses above 1 TeV/c^2 and 100 fb^{-1}) and systematic effects (below 7 %).

5. The study of Randall-Sundrum graviton decay into muon pairs has been performed. A mass region of about 1–2 TeV is available for exploration during the LHC startup run with an integrated luminosity

$\int Ldt$ of 1 fb^{-1}. For higher statistics, $\int Ldt$ = 100 fb^{-1}, a RS1 graviton can be observed with a 5σ limit up to the mass values of 1.7–4.1 TeV, depending on the model parameter. Finally, the asymptotic regime of LHC operation $\int Ldt$ = 300 fb^{-1} allows to extend these limits up to 1.9 – 4.5 TeV, respectively. For an integrated luminosity of $\int Ldt$ = 100 fb^{-1}, the spin-1 and spin-2 hypotheses can be discriminated at 2σ level for gravitons with mass up to 1.1–2.5 TeV.

6. The analysis of the CMS discovery potential to observe the signal from virtual ADD gravitons in the dimuon channel has been carried out. The fundamental Planck scale reachable with the CMS detector has been computed for various values of integrated luminosity. The uncertainties related to misalignment and trigger systematic effects, PDFs, QCD-scale errors, EW and QCD corrections were taken into account. These results show that even the first LHC run with an integrated luminosity of 1 fb^{-1} allows exploration of the new ADD model scale region between 3.9 and 5.5 TeV/c^2 uncovered so far by the other colliders (LEP and TEVATRON). An increase of the collected luminosity up to 100 fb^{-1} makes it possible to probe low-scale gravity with the fundamental Planck scale of 5.7–8.3 TeV/c^2. In the LHC asymptotic regime the CMS sensitivity to the fundamental Planck scale is increased up to values of 5.9–8.8 TeV/c^2.

7. A procedure was developed in details for evaluating the jet energy scale from direct photons in γ+jet events. The systematic shifts obtained on the jet energy scale with this technique are estimated. It is shown that the process γ+jet can provide sufficient statistics for the calibration of jets up to an $E^{jet}_T \approx 1000$ GeV.

All results were included in the CMS Physics TDR, published in the 17 CMS Notes and external journals. Also the results were presented and discussed in 17 talks at 11th RDMS CMS Annual Collaboration conference in Varna on September 12–18, 2006 and 3 presentations at ICHEP2006 Conference, Moscow.

The development of the RDMS LCG regional center was continued. The new CMS software framework was installed in the LIT JINR. The CMS Data Model, data services, and a system of job submission were tested. The important works aimed on development of

CERN–JINR data management system for Magnet Test and Cosmic Challenge and Data Base management were completed. Validation of data transformation chains, Tier-0 -> Tier-1 -> Tier-2 has been performed.

In 2007 LPP group plans to perform the following tasks:

1. Assembly and commissioning of HE and ME1/1 detectors in experimental cavern.

2. Performance of magnet test with cosmic muons and data processing and analysis.

3. CMS start up in LHC pilot run.

4. Development of detector calibration data bases.

5. Participation in beam tests for calorimetry calibration.

6. Development and tests of software for GRID-based distributed system to data processing and analysis. Data transfer from CERN to JINR.

7. Improvement of muon and jet reconstruction algorithms. Development of HCAL calibration methods with physics processes. The respective references on LPP JINR activities in CMS are given in [60–83].

According to the JINR obligations in the **ATLAS** experiment, which is under preparation at CERN, the LPP participates in the construction of the Liquid Argon Hadronic End-cap Calorimeter (LArHEC) and Transition Radiation Tracker (TRT).

The studies on possibility to use the LArHEC modules for case of LHC high luminosity program are started with 70 GeV proton beam at Protvino. All equipment has been tested and installed to perform these studies, the first run will be in December 2006.

The software studies are continued with aim to start the MC analysis of the possibilities to detect the reactions with Higgs bozons and top-quarks produced simultaneously [84–85]. Also the analysis of the results of the LArHEC characteristics measurements is in progress.

The last three 8-layer EC TRT detectors produced in JINR were tested. LPP physicists have participated in installation of the LArHEC and barrel part of TRT/STC in ATLAS experimental set-up. The service systems are under installation. The studies of the time-amplitude characteristics of the "straw" tubes aimed to optimize the dead time for high occupancy was performed. The installation, testing and integration of TRT will be completed in 2007 [86–88].

The experiment **NIS** at the **JINR Nuclotron** is aimed at searching for effects of the hidden polarized strangeness of nucleons. In 2006 the work on NIS project was carried out in two main directions:

1. Development of software tools (online and offline);
2. Hardware development (including production of electronics).

The following work was done:

- New Monte-Carlo tools were developed; the field map was implemented.
- New event reconstruction tools were created: the algorithm was developed and tested; the corresponding codes were developed and implemented.
- Monte-Carlo estimations of the set-up characteristics were revised using new reconstruction tools.

Results of these works were reported at the XVIII International Baldin Seminar on High Energy Physics Problems, "Relativistic Nuclear Physics and Quantum Chromodynamics", JINR, Dubna, 25–30 September, 2006 and will be published. The results were also discussed at the NIS Workshop which was held on November 1–2 in LPP of JINR.

The following works were fulfilled in hardware development:

- Two runs of the set-up were done: in October and in December of 2006. In both runs the NIS equipment was integrated with the GIBS detectors and NIS DAQ system was used for collecting data from all the detectors. The main goal of the October run was achieved, but the run in December was not successful because the required ^{6}Li beam was not obtained.
- Liquid hydrogen target (10 cm in length, 3 cm in diameter) was produced in LHE. Support for it is being produced at the LPP Workshop (final stage). Installation of the target at place is planned for January 2007.
- TOF detectors (RPC) were tested and studied at a test-bench with cosmic rays; the optimal working regime was defined. Two TOF walls from the RPC were mounted at the planned place. Parts of the electronics (TQDC modules) were produced. A part of the high voltage connectors was purchased; a part of the HV supply system was produced. But this work was not completed due to the lack of funding (the HV cells and a part of the necessary connectors could not be funded).
- Proportional chambers with their electronics were prepared for the runs (autumn of 2006) and used in October run.
- Minidrift chamber (MDC) production (gas container) is ongoing in the JINR Workshop, after delay in the 1st half of 2006 due to lack of funding. It is expected that the chamber will be ready in the 1st half of 2007. High voltage supply system was produced. Boards for preamplifiers were re-designed and prepared for production in the JINR Workshop. TDC modules for the MDC1 are produced in amount necessary for the beam tests.
- R&D of start-TOF detector was done; tests of this detector were done in the October run at the Nuclotron.
- Beam profilometer (to be placed before the target) was commissioned and used during beam runs.
- Data acquisition system was prepared; trigger module was produced. The system was tested during preparation for the beam runs and the beam time. All the DAQ electronics as well as the electronics for RPC and MDC was developed and produced by LHE team.

In summary, the commissioning of the set-up started at the end of 2006. Its calibration and production of the necessary electronics are expected to be fulfilled in 2007.

The main milestones for 2007 year are: completion of the set-up commissioning, its calibration and start of the physical data taking with limited acceptance.

3. ACCELERATION TECHNIQUES

The **Transverse Damping System at LHC** is constructed at the Laboratory of Particle Physics of JINR in collaboration with the Radio Frequency Group of Accelerators and Beams Department (AB-RF) at CERN. The LHC Damper will be used for preventing transverse coupled bunch instabilities, for damping the transverse injection errors, and for excitation of transverse oscillations for beam measurements. The LHC Damper is in the list of the systems that must operate already for the first beam injection into the LHC. The JINR's obligations in the framework of the CERN-Russia-JINR agreements are the design and construction of 20 deflectors and 20 push-pull wideband power amplifiers for the LHC Damper. The design stage for deflectors and amplifiers was successfully completed at LPP, and its results were accepted by CERN. The 20 vacuum tanks and electrode structures for deflectors as well as the deflectors' supports and alignment devices were manufactured in the Russian industry and at JINR in 2004–2005. After vacuum cleaning of the deflectors' components, the deflectors were assembled by the JINR team jointly with the CERN team in March 2006. Bake-out procedure and vacuum tests at CERN were done for 8 pairs of deflectors in April–May 2006. The obtained pressure limits were from $2.0 \cdot 10^{-10}$ Torr to $1.7 \cdot 10^{-9}$ Torr (all data are better than the expected limit of $2 \cdot 10^{-9}$ Torr). These 8 pairs of deflectors were installed into the LHC tunnel in August–September 2006. The push-pull wideband power amplifier was designed and constructed at LPP in collaboration with AB-RF CERN. Tests of the amplifier were done in June–August 2006 at the specialized tests stand of LPP. Amplitude of ±7.5 kV was obtained on the deflector that corresponds to required magnitude. The measured amplitude-frequency and phase-frequency characteristics of the amplifier in the frequency range from 100 kHz to 30 MHz. Full-scale tests of the push-pull wideband power amplifier have shown that the experimental results correspond to the design specifications. Series production and pre-assembly of push-pull

wideband power amplifiers were completed at JINR in November 2006. The final assembly of 16 amplifiers was done by the JINR team jointly with the CERN team in November–December 2006. These power amplifiers in junction with the preamplifiers and the high voltage power converters were tested at CERN (December 2006) and prepared for installation into the LHC tunnel. Four power amplifiers will be assembled and tested in the beginning of 2007. These 4 amplifiers as well as 4 deflectors will be used in spare units.

Theoretical studies of the transverse feedback systems for modern synchrotrons are being continued [89]. A proposal on a transverse damping system at SIS100 synchrotron, which will be constructed within the framework of new international project FAIR, was presented at the tenth European Particle Accelerator Conference [90].

Future plans of the LPP team are determined by participation in the commissioning of the LHC Damper as well as in the investigations of transverse beam dynamics with the aim of obtaining the ultimate beam parameters at the LHC. The nearest plans in 2007 concern the hardware commissioning of 16 power amplifiers and 16 deflectors installed into the LHC tunnel in junction with the preamplifiers and the high voltage power converters located in the LHC POINT 4 ground hall. Beam commissioning of the LHC Damper is planned at the turn of the year. At the same time first measurements with beam to optimise LHC Damper performance will be started.

In the framework of the **CLIC** project aimed to provide a new level of investigations in the field of particle physics by an electron-positron linear collider of TeV energy range, LPP participates in preparation of the test cavity undergoing the action of 10^6 pulses with the power 2–30 MW and duration of 150–200 ns to study the lifetime of the accelerating structure of the CLIC collider with respect to pulsed repetitive heating. The main results obtained in 2006:

I. The test facility was designed and built to determine the resource of high gradient accelerating structures for linear collider imposed by pulsed heating at operating frequency of 30 GHz. According to second stage requirements the 10^5 pulses were realized with the operating arrangement – a test cavity during the experimental run (the end of 2005 the beginning of 2006). The following conclusions can be formulated:

1) The powering of the test cavity is fulfilled at the frequency of 30 GHz using the high power FEM oscillator.

2) The temperature of an operating range of the test cavity (RTC) was raised during every pulse by 45°C. During the third contract stage it must be provided that the RTC temperature rises by about 120°C in every pulse. According to the run results, the change to the test cavity design was fulfilled to reach the necessary temperature rise. The 120°C temperature rise can be reached without the RF pulse changing. The new test cavity is being manufactured in LPP now to prepare and guide the control experiment. The new master test cavity will be manufactured in CERN.

3) Several technical and physical problems were discovered during the test facility starting and tuning:

- Pulse reflections change the FEM output parameters very much (up to break off the generation).
- RF breakdowns at the power level about 0.3-0.5 were registered at the various regions of the experimental device.
- Operating mode splitting led to RF power reflections from the test cavity.

These problems were not considered in the contract.

The reflection and breakdown problems demanded to carry out the three-dimensional computational modeling, cold measurements and the experiments with the electron beam. As a result the radical changes were done practically in all the equipment elements. The suitable solutions of such problems are discovered now. The operating mode splitting into two modes with the relational frequency distance about 0.1% was observed at the FEM output as well as in cold measurements of the Bragg mirrors. From 30% to 70% of operating pulses can be unsuitable for test cavity feeding due to the splitting effect. An explanation of splitting mode effect is absent now. New more complicated Bragg mirrors (with a calculated profiled form) are tested now to eliminate the splitting effect.

II. The investigations of sub-millimeter range FEM scheme were continued. Experiments with new triple-wave FEM scheme are fulfilled. This scheme was proposed by the scientists from IAP RAN (Nizhny

Novgorod). It is intended to prepare for the statistic beginning on the third contract stage at the first half year 2006 pulses. It is planned to accumulate the statistics of 10^6 pulses in 2006. Four reports at the international conferences were presented and two articles were published at 2006 [91–94].

4. COMPUTING

The goal of the project is to construct a modern computing infrastructure at LPP JINR for ongoing experiments on particle and nuclear physics. The **F-cluster** Project is devoted to the essential development of the informational and computer infrastructure of the Laboratory of Particle Physics as a basic tool for simulation and data analysis of ongoing experiments on particle and nuclear physics with participation of JINR physicists. Development of LPP–LHE computer farm was continued according to the Project [95]. In 2006 the total power of the computers of the farm is about 60K SI2K, and the number of computers is 34. For the moment it is possible to run up to 94 batch jobs by these batch computers simultaneously. On request of ATLAS experts 8 computers are equipped by 1 and more GB of memory. Six CPU switches KVM Master View 9138 (48 ports in total) are used to control all computers of the PC-farm from 1 console. Available disk space for users has been increased up to about 75G bytes. Main part of the disk space is organized as RAID5 by raid controllers:

- 3ware7500 with Seagate 80 GB IDE discs;.
- 3ware8500 with Seagate 200 GB IDE discs;
- 3ware9500S with Seagate 400 GB SATA discs.

The last part of discs is organized as RAID1 and consists of 6 Seagate 750 GB SATA disks. A new air condition system has been mounted and put in operation into the PC-farm hall. IP-telephony has started to be used in the Laboratory. New version of the LINUX operation system: Scientific Linux CERN 3 (SLC3), which has substituted Red Hat Linux 7.3, has been installed at the PC-farm computers. New application software like GEANT4 and Virtual Monte-Carlo system for new OKAPI project has been installed together with experts from DLNP. New application services for organization of scientific actions and managements of document circulation in the Laboratory were introduced [96]. The current situation with the computing at JINR requires the continuation of the works under Project because the existing computing resources are not sufficient to support the ongoing experiment (NA48, COMPASS, STAR). Moreover, accumulated experience during the work under Project shows that for experts of future experiments (OKAPI, CMS, ATLAS and so on) it is more useful and efficient to use the network infrastructure of the Laboratory together with computers and disk servers of the LPP–LHE PC-farm. To enlarge these capabilities it is necessary to prolong the Project within resources requested for its realization at the beginning of works. The main tasks of the Project in 2007–2009 are:

1. To guarantee an increase of power and disc space of the LPP–LHE PC-farm not less than by a factor of 2 with using new computers, new types of discs and disc servers, and a new technologies to join them into the cluster.

2. To enlarge the wireless area for connection of users to JINR local network with high speed. To provide the possibility to deploy the GRID technology on the LPP–LHE computer cluster to use it in the ongoing (NA48, COMPASS, STAR) and future particle and nuclear physics experiment.

4. INNOVATION ACTIVITY

In the framework of the JINR "**Innovation** band" the LPP participates in development of the "Application of Nuclear Physics Methods for Identification of Complex Chemical Substances". The main goal of the project is to develop methods for identification of complex chemical substances by registration of the γ-quanta spectra induced by fast neutrons irradiation. The neutrons are produced in the reaction $d+t \to \alpha+n$. The γ-quanta are registered in coincidence with α particles. For each event the coordinates and the arrival time of α-particles in the alpha-detector are measured as well as amplitudes and arrival time of γ in the γ-detectors. This information allows to find a 3D

position of a object inside an interrogated volume. Investigations of different detectors for α and γ registration will be performed. The data acquisition and data analysis systems will be manufactured. Simulation of the neutrons and γ-quanta interactions in the interrogated volume will be done to optimize the detector. The prototypes of the detector to identify hidden substances will be constructed.

In 2006 the experiments devoted to the study of the properties of the prototype of the device for remote nondestructive identification of illicit substances, based on the API technique, were continued. The Associated Particle Imaging (API) is a technique which could provide a 3D imaging and identification of objects hidden in various containers or in soil. The study of the API method is carried out at the Los Alamos National Laboratory [97], Argonne National Laboratory [98], Bechtel Nevada Special Technologies Laboratory [99], INFN (Italy) [100], JINR [101–104] as well as at other laboratories. The API technique uses fast monochromatic neutrons with energy of 14.1 MeV produced in binary reaction $d+t \to {}^4He+n$. In this reaction the α-particle with the energy of 3.5 MeV flights back-to-back with the neutron (in c.m. system). By measuring the α-particle trajectory, the direction of the corresponding neutron is determined. These «tagged» neutrons interact with the interrogated object and can produce γ quanta in $A(n,\gamma)A'$ reactions with energy spectra which are unique for each chemical element in the object. The characteristic γ-spectra could serve as "fingerprints" to identify the hidden substance. The key feature of the API method is the measurement of the time difference between detection of α particle and γ quantum. It provides the possibility to determine the distance traveled by the neutron before it is inelastically scattered by the nuclei of the interrogated object. It is thus possible to determine a γ-spectrum from the definite localized region in the object. It strongly suppresses the background. A large signal-to-background ratio provided by the API method significantly facilitates the identification of the hidden substances. The unique advantage of the API method is to provide the image of the hidden object in 3 dimensions. The use of the fast 14 MeV neutrons significantly increases the probing depth in the investigated object. An important distinctive feature of the API method pertains to its high sensitivity to chemical composition of the illicit substance. In 2005, laboratory tests for the stationary system for detection of explosives hidden in the small and middle size (600x600x600 mm^3) containers were finished. The system comprises a neutron generator with a 9-pixel silicon α-detector. It allows 9 beams of tagged neutrons to be produced. The γ-spectra are measured by the two BGO gamma-detectors. The DAQ electronics have been created for 16 α- or γ-channels. The decision making software based on the neural net method provides identification of the hidden subjects. The stationary system successfully passed the inspection tests, its experimental exploitation is starting at the demining center. Another stationary system is constructing for the Federal Courier Service. This system is aimed for the detection of the drugs, explosives and other illicit substances. The exploitation will start in 2007. Some results of the work have been published in [105].

In the framework of the innovation activity on **Development of Accelerator for Radiation Technologies** the following works have been done. A series of very simple, compact and cheap accelerators for the radiation technologies based on cold cathodes with threshold emission characteristics, the low-frequency (100 kHz) coaxial resonator and the transistor converter of electrical power from 50 Hz to 100 kHz, has been developed. Experimental investigations of scale models and the prototype of the accelerator, tentative operation of accelerators in Japan and China have confirmed high efficiency of power transformation of an electric network in the electron beam power. The basic directions of works in the future: adaptation of accelerators for concrete technological processes; modernization of accelerator systems to reduce the operation costs and simplify running; increase of the power and energy of electron beams up to 100 kW and 500–700 MeV, respectively.

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