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REPORT ON ACTIVITY IN 2003–2009 OF THE VEKSLER AND BALDIN LABORATORY OF HIGH ENERGY PHYSICS

Report to the 107th Session
of the JINR Scientific Council
February 18–19, 2010

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The goal of this report is to give information on the scientific results achieved at the Particle Physics and High Energy Laboratories in 2003-2008, and at their successor – the Veksler and Baldin Laboratory of High Energy Physics which was founded on the 4th of May 2008.

Development and modernization of the JINR Accelerator Complex

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

Nuclotron-M

The Nuclotron is a basic JINR accelerator facility in high energy heavy ion and particle physics. Its modernization was started in 2007 in frame of the Nuclotron-M project. The goal of the project is to provide stable and safe operation of the Nuclotron magnetic system at the bending field of about 2T and to provide acceleration of heavy ions ($A > 100$) at maximum achievable intensity. It requires full-scale modernization of the cryogenic system, upgrade of the power supply and quench protection systems, vacuum condition improvement, optimization of the ion source KRION-2 for the heavy ion generation, upgrade of the injection complex, development of the beam diagnostics and minimization of particle losses at all stages of the beam acceleration. To prepare the accelerator complex for operation as a part of the NICA facility design and construction of the new ion source KRION-6T, a design of a new heavy ion linac and development of a new source of polarized particles are required. At the end of 2009 the main part of the work was completed for 70-80%. The project completion is scheduled for the end of 2010.

The main obtained results concerning the subsystems of the accelerating complex are:

1. Modernization of the cryogenic system

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

2. Modernization of the vacuum system

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

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

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

3. Modernization of the power supply systems

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

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

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

4. Linear pre-accelerator Linac

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

- alignment of all 59 drift tubes;
- mounting of new power supplies for corrector magnets;
- commissioning of the new synchronization system for all linac control channels.

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

The Technical Design Report for a new heavy ion linear accelerator was prepared by IHEP (Protvino). Construction of the first accelerating section has been started.

5. Heavy Ion Source KRION

Four runs (each about 1 month) were performed in 2008 at the electron-string ion source KRION-2 with a solenoid magnetic field of 3T, another four runs were carried out in 2009. They were aimed at the parameters optimization and preparation for the heavy ion acceleration scheduled for the beginning of 2010.

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

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

6. Development of the polarized deuteron source

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

7. Engineering infrastructure development

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

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

NICA/MPD

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

- ion-ion collisions from *pp* to *pAu* in beam momentum range 1 ÷ 4.5 GeV/u at luminosity ~$1 \cdot 10^{27}$ $cm^{-2} \cdot c^{-1}$),
- collisions of polarized proton-protons in the range of 5 ÷ 12.6 GeV and deuteron-deuterons at 2 ÷ 5.8 GeV/u. For the polarized beam the luminosity designed to be >10^{30} $cm^{-2} \cdot c^{-1}$.

During 2007-2009 enormous amount of work was done on the design of the new accelerator complex. The first considerable step was finished in January 2008, when the Conceptual Design Report [1] of the **NICA** was issued.

In a year, in 2009, the 1st version of the Technical Design Report [2] was prepared and presented to the PAC expertize.

The complex will consist of:

- superconducting heavy ion source KRION of the electron string ion source (ESIS) type,
- source of polarized protons and deuterons,
- "old" linac LU-20,
- new heavy ion linear RFQ accelerator,
- new Booster-synchrotron (that will be placed inside the yoke of the decommissioned Synchrophasotron),
- the existing heavy ion synchrotron Nuclotron (being developed presently to match the project specifications),
- two new superconducting storage rings of the collider,
- new set of transfer channels.

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

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

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

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

MPD detector construction requirements:

- Performance with frequency up to 10 kHz, with multiplicity up to 1500 charged particles in the event;
- Effective recovery of particles in the maximal interval of quasi-rapidity (up to |η|~3) with the sufficient momentum and angle resolutions;
- Reconstruction of impact parameter;

- Identification of charged particles and possibility of detection of e^-, γ and π^0;
- Precise measurement of charge asymmetries in the studied reactions.

The concept of the MPD involves the deployment of a central set of recording equipment in the solenoidal magnetic field and forward detectors outside. Construction of the set-up takes 3 steps:

- starting minimum (the barrel part contains TPC and ECAL or (and) RPC; ZDC and BBC are operating);
- put IT into the barrel and make the end-cup running;
- Forward-detectors are operating.

Main steps in the MPD project preparations:

- Febr. 2008 – Letter of Intent (LoI) [3] was prepared;
- May 2009 – 1st version of the MPD CDR [4] was issued;
- June 2009 – 1st version of the NICA physics program review "Wait Book" was prepared.

Also four **Round Tables** dedicated to the NICA physics programme and detectors performance were organized and held at JINR.

IREN, LUE-200

The employees of the LHEP accelerator division started up the linear accelerator of the electrons **LUE-200** which is the basic part of the pulse resonance neutron source **IREN**, a new JINR basic facility for the wide range fundamental and applied investigations in nuclear physics.

The Most Important Results in Physics

High precision experiments to search for the direct CP-violation and test of the Chiral Perturbative Theory

The existence of the direct CP-violation in Nature was established, and most precise measurements of CP violation parameters were performed in the series of experiments jointly named **NA48** carried out at the CERN SPS and fully completed with a considerable JINR contribution. According to the current cosmological models, this phenomenon is a crucial component of baryogenesis in the early Universe.

The final results for the CP violation parameters are $Re(\varepsilon'/\varepsilon) = (14.7\pm2.2)\cdot10^{-4}$ from the **NA48** experiment [5], and $A^c_g = (-1.5 \pm 2.2)\cdot10^{-4}$ (for $K^\pm \to \pi^+\pi^-\pi^\pm$) and $A^n_g = (-1.8 \pm 1.8)\cdot10^{-4}$ (for $K^\pm \to \pi^0\pi^0\pi^\pm$) from the **NA48/2** experiment. Here $A_g = (g^+ - g^-)/(g^+ + g^-)$ is the asymmetry of Dalitz plot slope

parameters g^+ and g^-. The above measurements are the most precise ones in neutral and charged kaon decays.

The **NA48/2** experiment has observed for the first time an anomaly (**cusp effect**) in the Dalitz plot distribution of charged kaon decay to one charged and two neutral pions [6] (see Fig.1). This discovery led to the most precise measurement of pion-pion scattering lengths a_0 and a_2 (see Fig.2). Together with the analysis of K_{e4} ($K^\pm \to \pi^+\pi^- e^\pm \nu$) decays (a sample of more than 1.1 million events was collected by the **NA48/2** [7]) these data allow to obtain an explicit self consistent view to experimental measurements of the basic parameters of low-energy QCD. Obtained results are in a good agreement with the ChPT expectations. Analysis of the cusp effect has been completed [6]. An empirical parameterization for the $K^\pm \to \pi^0\pi^0\pi^\pm$ Dalitz plot for the practical implementations, such as MC generators, has been proposed for the use by the PDG.

In addition, new kaon and hyperon rare decay modes have been observed for the first time in these experiments: $K_S \to \pi^+\pi e^+e^-$ [8], $K_S \to \pi^0\gamma\gamma$ [9], $\Xi^0 \to \Sigma^+ e^- \nu \to \pi^+\pi^0\mu^-\nu$ [10] and $K^\pm \to \pi^\pm e^+ e^-\gamma$ [11].

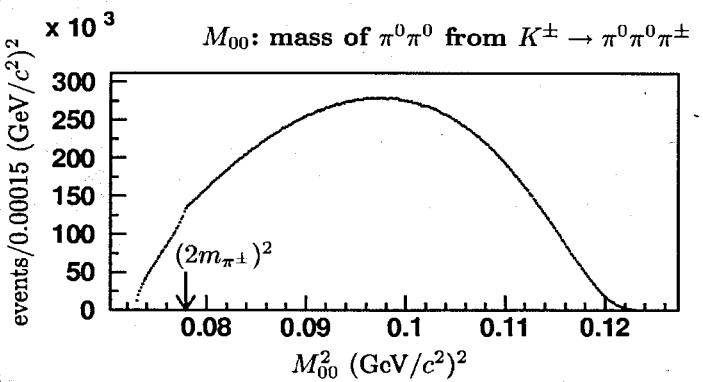

Figure 1. *$\pi^0\pi^0$ mass spectrum from $K^\pm \to \pi^0\pi^0\pi^\pm$ decays.*

Precision measurements of semileptonic charged and neutral kaon decay branching ratios [12] have contributed to the solution of the CKM matrix unitarity problem, which was caused by the outdated measurements of series of previous experiments.

A sample of 7253 $K^\pm \to \pi^\pm e^+ e^-$ decay candidates with 1.0% background contamination collected by the **NA48/2** experiment [13] allowed the most precise measurement of the branching ratio and the form factor for this decay.

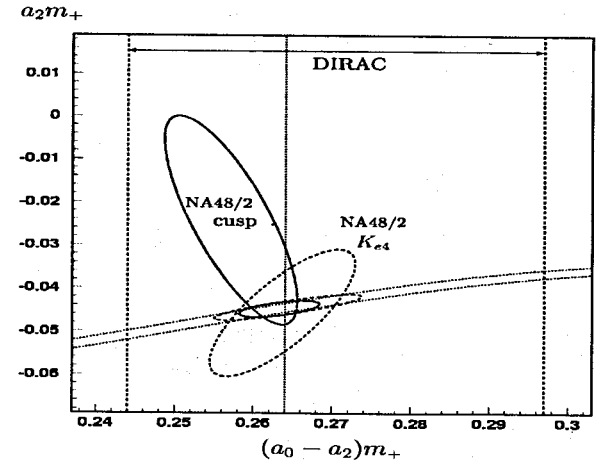

Figure 2. *Solid ellipses corresponding to the final results of the π scattering lengths measurement (small solid line ellipse: fit with the ChPT constraint; large solid line ellipse: fit using a_0-a_2 and a_2 as independent parameters), dashed from K_{e4}. Vertical lines: central value from the DIRAC experiment (dotted line) and error limits (dashed lines). The one-σ theoretical band allowed by the ChPT constraint is shown by the dotted curves.*

Obtained results were presented by the JINR scientists at many international conferences and six candidate theses and a doctoral thesis have been defended.

Study of the nucleon spin structure and test of the fundamental sum rules

In frame of the **COMPASS** and **HERMES** experiments new unique results on the nucleon spin structure approaching the solution of the so called **"Spin Crisis"** problem, were obtained:

- First direct measurements of the gluon polarization value were provided Fig.3. The analysis has shown that a small value of ($|\Delta G/G|<0.3$) is preferred.
- For the first time the full set of polarized Parton Distribution Functions (PDF) **Δu, Δd, $\Delta \bar{u}$, $\Delta \bar{d}$ and Δs** was extracted [14,15] Fig.4.
- Data on the measured inclusive and identified hadron spin asymmetries on the proton and deuteron targets allowing to evaluate the non-singlet

structure function $g_1^{NS}(x, Q^2)$ verify and **confirm the validity of the Bjorken sum rule** with better than one σ precision, were obtained.

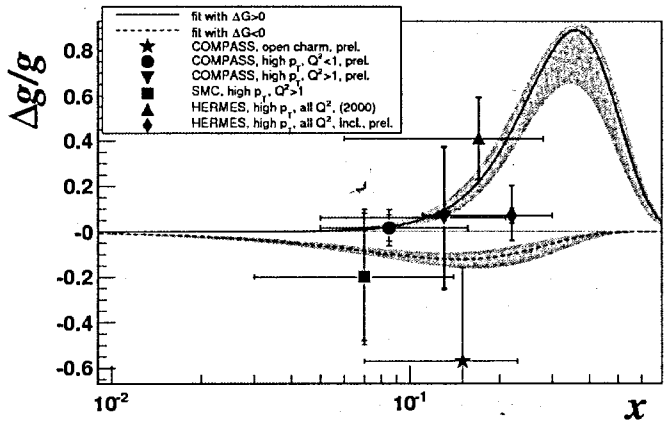

Figure 3. *The Compilation of the <Δg/g> measurements from open charm and high p_T hadron pair production as a function of x [16]. Horizontal bars mark the range in x for each measurement, the vertical ones give the statistical precision and the total errors (if available). The open charm measurement is at a scale of about 13 (GeV/c)², other measurements at 3 (GeV/c)². The curves display parameterizations from NLO QCD analysis in the MS scheme at 3 (GeV/c)² , fits with ΔG > 0 (broken line) and with ΔG<0 (dotted line).*

Moreover the following results were obtained in the HERMES and COMPASS experiments with considerable contributions by the JINR team:

- Measurement of transverse spin structure of the nucleon;
- Study of the exclusive muon production;
- Measurement of the Λ and $\bar{\Lambda}$ polarizations;
- Study of the Primakoff effect.

The results of the analysis were presented by JINR physicists in ~30 talks at various International Conferences on behalf of the Collaboration.

Another impressive results on the nucleon structure were obtained in **H1** experiment at DESY. With participation of the JINR scientists the most precise measurements of the structure function F_2 in the kinematical range $3\cdot10^{-5}<x<0.8$ and Q^2 up to $3\cdot10^4$ (GeV/c)² were performed [17].

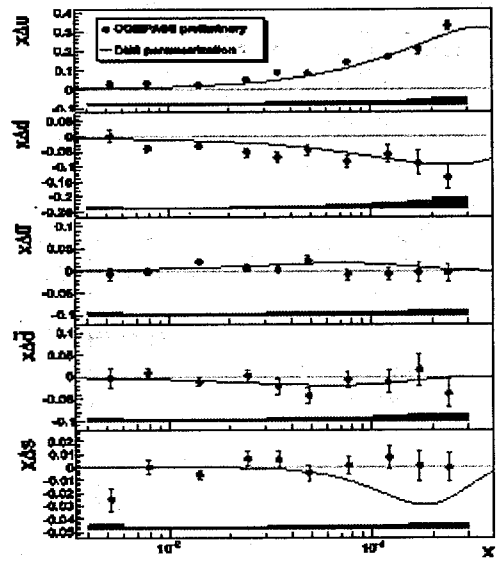

Figure 4. *The quark helicity distributions evaluated at common value $Q^2=3(GeV/c)^2$ as a function of x Bjorken. Bands at the bottom of each graph present systematic uncertainties. Solid markers and bands correspond to COMPASS data.*

Search for the new states of the hadronic matter

In the **STAR** experiment at RHIC with a strong participation of the JINR group the effect of the **high-p_T non-photonic e suppression** in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV has been observed Fig.5. This effect is not explained by the present theory.

The study of femtoscopic correlations has shown that π, K, p and Λ radii have **m_t scaling** pointing to the universal expansion expected in hydrodynamics.

The JINR team contribution to the STAR data analysis includes:

- Soft photons analysis;
- A new theoretical approach to the reconstruction of the reaction plane;
- Fractal Dimension Analysis of STAR events;
- Wavelet analysis to study multiparticle correlations of secondary particles produced in ultrarelativistic heavy ion collisions;
- Comparison of perturbative QCD and z-scaling predictions on asymptotic behavior of jet production at Tevatron and RHIC

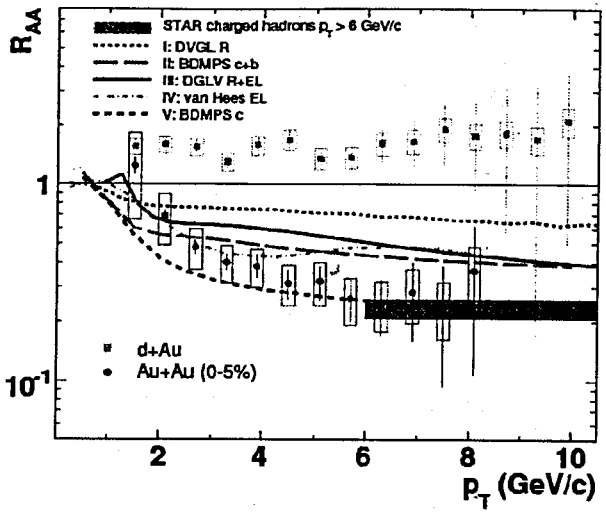

Figure 5. *High p_T non-photonic electron suppression in Au-Au collisions at $\sqrt{s_{NN}}$ = 200 GeV.*

In other searching experiment in this field - **NA49** [18] at CERN SPS, with the main contribution of the JINR team, **anomalous strangeness to pion ratio ("Horn")** Fig.6 was observed in central Pb+Pb collisions. It can be interpreted as an indication on the observation of a new state of strong interacting matter.

In addition to the participation in data taking and analysis, JINR contribution to NA49 was the construction and support of the time-of-flight (TOF) detector.

Other physics results obtained with the principal contribution of the JINR team in NA49 experiment:

- Energy scan in Pb-Pb collisions for 20A, 30A, 40A, 80A and 158A GeV;
- Study of energy dependence of particle production as well as dependence on the collision centrality;
- Measurements of Transverce spectra for $\pi^{\pm}$, $K^{\pm}$, p and anti-p and light nuclei d, anti-d, t and ^{3}He in the energy range 20÷158A GeV.

This scientific program is going on in frame of NA61 CERN experiment.

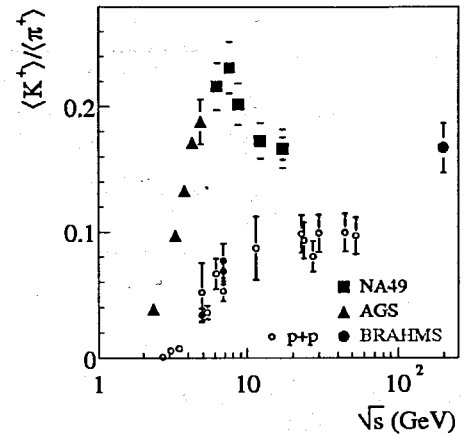

Figure 6. *A maximum in the energy dependence of the strangeness to pion ratio ("Horn") was observed by the NA49 experiment in central Pb+Pb collisions. It may indicate onset of deconfinement at low SPS energies.*

The **HADES** project on SIS (GSI, Darmstadt) is aimed at systematic investigation of the properties and behavior of hadrons in the nuclear medium by studying collisions ranging from π and protons as projectiles to heavy nuclei [19].

The JINR group has performed a very challenging task of design and construction of HADES low-mass Drift Chambers and front-end electronics.

The main scientific achievements from the conducted HADES experiments can be summarized as follows:

- The low-mass pair excess observed by the pioneering **DLS experiment has been fully confirmed** (Fig.7). Moreover, the observed yield of the anomalous pair excess has been shown to scale with the beam energy as π production.
- The origin of the pair excess observed in C+C collisions has been traced back to non-mesonic elementary sources present in N+N collisions (p+p and d+p) with a very strong isospin dependence.
- Preliminary results from a heavier collision system (Ar+KCl), however, have shown stronger than linear apart dependence of the excess yield, which may indicate the onset of medium effects.
- For the first time, a clear $\omega \rightarrow e^+e^-$ signal has been reconstructed at SIS energies in p+p, p+Nb and Ar+KCl collisions.
- For the first time, deep sub-threshold production of Ξ- (1321) has been observed with multiplicities larger than it was expected from the statistical and transport models.

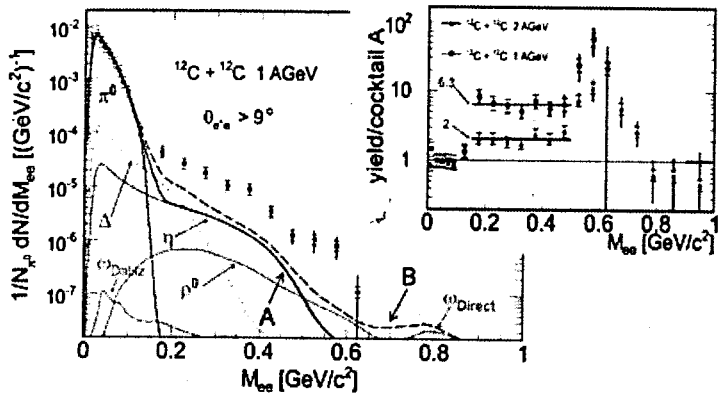

Figure 7. *HADES confirmed the DLS puzzle in C+C, (1 A GeV) experiments. It has shown ~ 6 times excess overproduction of di-electron pairs in the mass region 0.15<M<0.55 Gev. HADES also has shown that for C+C (2 A GeV) this excess value is two times less.*

Participation in the LHC projects

CMS, ATLAS and **ALICE** experimental set ups were constructed, commissioned and successfully started up with the serious contribution of LHEP physicists.

JINR participates in the **CMS** in framework of the Russia and Dubna Member states CMS Collaboration (RDMS). The main effort of JINR in the CMS Project was concentrated on the construction and commissioning of the CMS inner Endcap detectors, where RDMS bears a full responsibility on **Endcap Hadron Calorimeters** (HE) and the **1st Forward muon Stations** (ME1/1). JINR also participates in construction of the **Endcap Preshower** (ES). In line with commissioning the main efforts of JINR physicists in CMS were focused on the development of a long-term CMS physics program and the Physics TDR preparation.

All JINR obligations have been fulfilled; detectors of the JINR responsibility are ready for data taking.

The field of a special interest of the JINR group is the program for studies of processes with heavy di-muons which is an integral part of the CMS physics program.

JINR responsibilities for the CMS physics analyses:

- Drell-Yan pair production in di-muon channels;

- Extra Dimensions in dimuon channels;
- QCD running coupling measurements;
- Prompt photon measurements.

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

- Physics study and simulation;
- Design and prototyping of the large **dipole magnet;**
- Construction of the iron yoke;
- Procurement and testing of lead **tungstate crystals** for the photon spectrometer;
- Construction and testing of **125 drift chambers for transition radiation detector;**
- Development of the software for the pattern recognition and track reconstruction;
- Testing of the GRID based ALICE simulation and data analysis

The JINR group main activity relates to the vector meson physics, femtoscopy, study of heavy quarkonia production in the dimuon mode.

At the end of 2009 during successful start of LHC proton-proton beam collisions all ALICE sub-detectors constructed with the participation of the JINR team performed according to experimental requirements. First data on the particle production at the energy collision of 900 GeV were analyzed and submitted for publication in European Physics Journal.

In the **ATLAS** experiment LHEP scientists fulfilled all obligations in the construction and putting in operation of the detectors subsystems, which were:

- **34 straw wheels** (3072 channels in each) for the Transition Radiator Tracker ;
- 40% of the **Liquid argon end-cap calorimeter;**
- providing of temperature and radiation tests by means of the IBR-2 neutron reactor.

The personnel of the LHEP accelerator division made a substantional contribution to the accelerator start up.

The **LHC Damper** system [20] was constructed and put in operation. This system stabilizes the high intensity beam against coupled bunch transverse instabilities in a frequency range from 3 kHz to 20 MHz and at the same time it damps injection oscillations originating from steering errors and injection kicker ripple. The LHC Damper includes 4 feedback systems on 2 circulating beams (in other words one feedback system per beam and plane). Every feedback system consists of 4 electrostatic kickers, 4 push-

pull wide band power amplifiers, 8 preamplifiers, two digital processing units and 2 beam position monitors with low-level electronics.

The design and series production of 20 electrostatic kickers wide band and 20 push-pull wideband power amplifiers for the LHC Damper in the framework of the CERN-Russia-JINR Agreements were completed by the Russian industry and JINR in full volume in 2006. 16 amplifiers and 16 kickers were extensively tested in 2007-2009 at the test stand at CERN and in the LHC tunnel. Cleaning of 16 power amplifiers from dust blown into amplifiers with air after the incident in sector 3-4 of the LHC was done as part of the shutdown work in 2009, and additional air filters were installed to increase the amplifiers' reliability.

The hardware commissioning of the LHC transverse damper system has been successfully completed. All the design specifications were fulfilled and the LHC Damper was used with beam in September 2008 and after 20 November 2009, exciting transverse oscillations for the tune measurements.

The LHC beam monitors used during the accelerator start up were produced and installed by JINR.

Participation in development of external accelerator complexes

ILC(CLIC)

Series of R&D were performed in frame of the International Linear Collider (ILC) program. In particular, within of the CLIC project, at the end of 2007 a high frequency (HF) facility was developed and put into operation by the JINR-IAP RAS collaboration for experiments on damage of the cavity wall due to RF pulse heating by using the 30 GHz free-electron maser with the output power of 20 MW, pulse duration of 180 ns and repetition rate 1 pulse per second. The pulse heating of the oxygen-free copper ring reached 35°C-45°C per pulse and the pulse number up to 10^5 in this regime was obtained. Systems of stabilization of the high-voltage modules of the linac (electron gun and modulators) were developed. The accuracy of the stabilization is about 0.2%. The data acquisition system collecting the microwave radiation parameters in several places of the facility as well as electron parameters beam in every pulse of the facility operation was prepared.

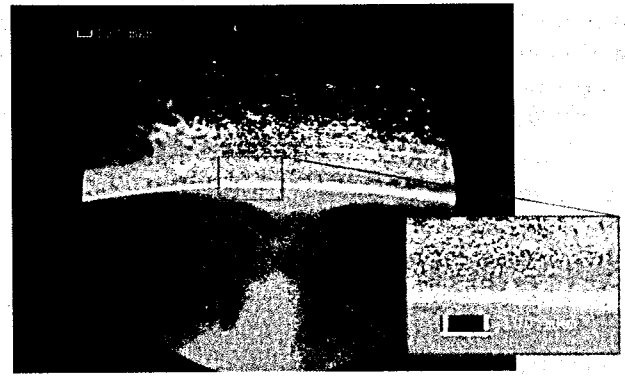

Figure 8. *Study the cavity surface damage due to RF pulse heating.*

The designed parameters – pulse temperature rise of the copper ring about 180°C-200°C was reached in the middle of 2008. The first full-scale experiment (September 2008) showed that the OFE copper ring was damaged after $3{,}2 \cdot 10^4$ pulses at this temperature rise per pulse, Fig.8.

The JINR team is strongly involved in the **SIS-100 magnet system** construction based on the dipole and quadrupole Dubna-type 2T super-conductiong magnets.

Experiments at the Nuclotron

In parallel with accelerator facility modernization studies aimed at searching for **non-nucleon degrees of freedom** and **spin effects in few-nucleon systems** were carried out at the Nuclotron in frame of the following projects: ALPOM, STRELA, LNS, PHe3, Delta-Sigma and Delta-2.

The activities were concentrated on the investigation of charge-exchange processes in *dp* interactions. Determination of the forward scattering *NN* amplitudes by measurements of energy dependencies of *np* spin observables at 0^o - $\Delta\sigma_L(np)$, $\Delta\sigma_T(np)$, $A_{00kk}(np)$, $A_{00nn}(np)$ and R_{dp} using longitudinal (L), transverse (T) and unpolarised targets and quasimonochromatic 1-6 GeV neuteron beams. Comparison of the obtained data with QCD motivated calculations. Modernization of the Saclay-ANL-JINR proton polarized target. Study of analyzing power in scattering of polarized protons on carbon, polyethylene and methane. Development of a wide aperture polarimeter ALPOM. Measurement of polarization transfer from deuteron to proton in ^{12}Cd,pX reaction with internal momenta 0.6-0.8 GeV/c. Exclusive measurements of rare processes associated with light mesons creation, interaction and decay.

In frame of the NIS experiment the apparatus aimed at searching for **OZI rule violation** in ϕ and ω production in proton-proton interactions near threshold at the Nuclotron and the Θ-baryon (**pentaquark**) production in proton-proton interactions near threshold, was constructed and put in operation.

Experimental searches for the **hyper-** and **η-nuclei,** and study with technique of nuclear track emulsions were carried out in frame of GIBS, Eta-nuclei and Bequerel projects.

A study of **phase transition in nuclear matter** was investigated in series of experiments **PHASA**, PHASA1, PHASA2 and is continued in PHASA-3 project [21].

Figure 9 presents one of the obtained results: the measurement of tensor polarisability of deuterons while unpolarized deuteron beam was going through the unpolarized target [22].

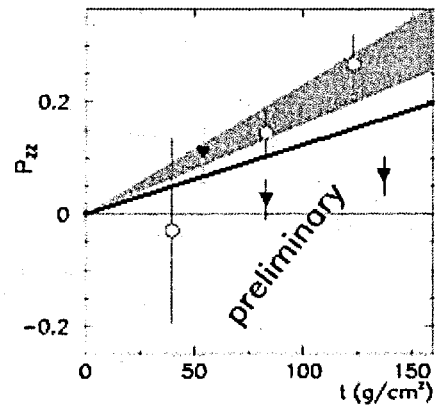

Figure 9. *Tensor polarization of deuterons vs thickness of the target. The dashed region shows the error values, the solid line is the theoretical prediction.*

The innovation programme in the LHE, PPL and LHEP has been conducted in frame of **«MedNuclotron»**, **«Energy and transmutation»**, **«DVIN»** and **«Development of compact accelerators for applied purposes»** projects and includes:

- Research of the programme in molecular biology aimed at studying **changes in the structure of genes under heavy ion irradiation** and work on the **development of the Medical-biological complex** on the base of the Nuclotron proton and ion beams to carry out the research program in medical biology and oncology therapy;
- Studies of **transmutation cross sections of radioactive nuclear wastes**. Study **of fragmentation of light stable and radioactive nuclei;**
- A method of **identification of complex chemical substances** by registration of the gamma-quanta spectra induced by fast neutrons irradiation was developed. **Detector, data acquisition and analysis systems** were developed and manufactured;
- The **electron beam technologies** for modification and development of new materials, sterilization medical tools, disinfection and treatment of medical and industrial wastes, have been developed. An industrial version of the compact accelerator **D-300** has been manufactured. This machine has a unique **high-voltage system with efficiency > 90%.**

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