Particle Physics and High-Energy Heavy-Ion Physics

Referring to the JINR Road Map, the scientific research in the field of modern elementary particle physics and high-energy heavy-ion physics can be classified into four interrelated directions — the energy-increasing accelerator direction (the Energy Frontier), the intensity-increasing accelerator direction (the Intensity Frontier), the accuracy-increasing non-accelerator direction (the Accuracy Frontier), and the particle astrophysics direction (the Cosmic Frontier). In view of these general directions, within the framework of the new seven-year plan JINR will focus on the following main themes:

1. Particle physics research, including neutrino physics and rare phenomena studies (covering the Energy, Intensity, Accuracy, and Cosmic Frontiers), aimed at extending the Standard Model and discovering new fundamental laws of Nature.
2. High-energy heavy-ion physics research (Energy and Intensity Frontiers) aimed at establishing unique properties of hadronic matter under conditions of phase transitions between quark and hadronic states of matter.
3. Development of new-generation detector systems and accelerator complexes, theoretical support of current and planned experimental investigations, development and maintenance of high-performance telecommunication links and computing facilities at JINR, aimed at providing a comprehensive support for realization of the scientific tasks envisioned by the seven-year plan.

The new seven-year plan in the field of particle and high-energy heavy-ion physics will be implemented by efforts of four JINR Laboratories (VBLHEP, DLNP, LIT, and BLTP) both on the JINR in-house facility base, which includes the **Nuclotron-M** accelerator and the **NICA** collider, and within the framework of international partnership programmes at the world’s largest accelerator facilities like the Tevatron (FNAL), RHIC (BNL), LHC and SPS (CERN), FAIR (GSI) in the experiments with essential contribution made by the Institute’s staff.

JINR also participates in both accelerator and detector activities within the **ILC** project. In particular, Dubna is officially considered to be one of the possible places for ILC siting. The natural continuation of this effort is the involvement in the R&D for detectors and preparation of the ILC physics programme. VBLHEP and DLNP plan to continue the R&D work on construction of free-electron laser elements, construction of ILC photoinjector prototype (in collaboration with DESY and KEK), commissioning of the LINAC-800 based test-bench with electron beams, RF and diagnostic systems, built-in equipment, metrological laser complex, design of the fourth generation cryogenic modules, technology of bimetallic explosion welding of cold mass elements (collaboration with VNIIEF (Sarov)). The JINR groups have also joined in developmental work for the international projects **FLASH** and **XFEL**. It is planned to participate in the development of diagnostic systems of ultra-short bunches in the linear accelerator, experimental study of coherent radiation, construction of units for X-ray laser irradiation diagnostics, development of diagnostics for large cryogenic systems.

In 2010–2016, the **Veksler and Baldin Laboratory of High Energy Physics** (VBLHEP) will preserve its main directions of research in high-energy heavy-ion physics and modern particle physics which, in particular, include investigations of the nucleon spin structure, tests of the Standard Model, search for new physics, and the study of CP violation. During the same period the **Dzhelepov Laboratory of Nuclear Problems** (DLNP) will also continue its investigations in elementary particle physics, in particular, in the traditional for JINR field of neutrino physics and rare processes. DLNP will take part in the development of JINR’s new domestic basic facilities as well.

The **research in high-energy heavy-ion physics at JINR** will be carried out at the VBLHEP accelerator complex (Nuclotron-M and NICA) the construction of which is the primary objective of this Laboratory. At this complex, within the **MPD** project, an experimental study of the 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 will be performed at the energy of colliding particles up to $\sqrt{s_{NN}}$ =11 GeV.

The degree of involvement of VBLHEP groups in research on **high-energy heavy-ion physics at the world's accelerator laboratories** will be defined by the progress of activities on the NICA/MPD project and the emerging opportunities for work at the **Nuclotron-M/NICA** accelerator complex. At the same time, VBLHEP scientists will participate in the study of the properties of nuclear matter in states with extremely high density and temperature, in the search for manifestations of quark deconfinement and possible phase transitions within joint research on heavy-ion physics in the experiments **STAR** at the RHIC collider (BNL), **NA61** (SPS) and **ALICE** (LHC) by investigating the production of various hadrons including light vector mesons and heavy quarkonia, as well as in measurements of direct photon and dilepton yields.

Under the **FASA** project at the **Nuclotron-M** until 2011–2012, experiments are planned to study the processes of multiple emission of medium-mass fragments using relativistic beams of light ions. It is expected to determine the mechanism of multifragmentation and obtain information about nuclear phase transitions of the liquid-fog and liquid-gas types.

The study of processes occurring in collisions of heavy nuclei at the energies up to 2 GeV/n by way of lepton pair detection is being performed by VBLHEP scientists with the help of the **HADES** wide-aperture spectrometer at the **SIS-18** accelerator (GSI). After the start-up of the **SIS-100** accelerator, work at HADES will be continued at the energies of this accelerator (~10 GeV/n).

The **CBM** set-up is being constructed to study high-energy heavy-ion interactions at the new international accelerator centre **FAIR** (Facility for Antiproton and Ion Research) in Darmstadt, Germany. The CBM experimental complex is intended for investigations associated with the programme on the search for and study of the mixed phase in the "fixed target" experiment scenario. Experiments with CBM are complementary to those with the MPD facility at the NICA collider. The JINR team is involved in designing and building a part of the track detectors for CBM and actively participates in the simulation of elements of this set-up and in the elaboration of the physics programme.

The goal of the **THERMALIZATION** project conducted at the modernized SVD facility is to study the collective behavior of secondary particles produced in pp interactions at the proton beam energy of 70 GeV (Protvino). The programme of investigations includes measurements of partial cross sections of pp interactions at a high number of secondary charged particles, study of multiparticle correlations, search for turbulence signals for the excited hadron matter, etc. The project is planned to be completed in 2011.

The study of the nucleon spin structure will be carried out by JINR scientists at the VBLHEP accelerator complex and at CERN and BNL. A series of experiments are planned to be conducted with the extracted polarized beams of the Nuclotron-M, particularly, using a movable polarized target. These investigations are associated with preparations for implementing the spin programme of the NICA project and are aimed at creating effective polarimetry as well as at developing technology for polarized targets and polarized particle sources. Under this programme, during the period up to 2011–2012, it is expected to carry out investigations on the measurement of polarized observables using the **DSS** and **ALPOM-2** facilities.

The **DSS** experiment conducted in collaboration with RIKEN is aimed at measuring spin-dependent observables in the $^3He(d,p)^4He$ reaction at the energies T_d=1.0–1.75 GeV, which corresponds to the core area in the deuteron, using the polarized deuteron beam at the Nuclotron and polarized ^3He-target fabricated at the CNS (Japan). The goal of the **ALPOM-2** project is to measure the analyzing power in the $p+CH_2$ reaction at momenta of polarized proton beams from 3 to 6 GeV/c. These data are necessary for the planned experiments on the measurement of the ratio of nucleon electric and magnetic form factors at a large four-momentum transfer.

The investigation of the hadron structure and hadron spectroscopy using high-intensity muon and hadron beams is the purpose of the **COMPASS** experiment (CERN, SPS). The JINR team will take part in measurements of generalized parton distributions, in the study of the

Matveev-Muradyan-Tavkhelidze-Drell-Yang (MMTDY) processes as well as in the study of the longitudinal and transverse structure of the nucleon. In 2010–2016, JINR will participate in data taking, processing, and analysis. The scientific programme of the COMPASS experiment will be continued at the **NICA** accelerator complex under the **SPD** project whose start-up is expected to take place in 2016–2017.

The spin programme of the **STAR** project is targeted at measurements of spin-dependent structure functions of nucleons and nuclei using polarized beams of the **RHIC** accelerator (BNL). The JINR team plans to continue participating in this programme of the STAR experiment until the SPD facility has been put into operation at NICA.

Test experiments to validate the anti-proton polarization method are in progress at COSY (Jülich) and AD (CERN) with DLNP's participation. If successful, the PAX project at FAIR to perform spin physics measurements will be elaborated.

In the next seven years, JINR's most important activity in particle physics will concern **verification of the Standard Model, search for new phenomena beyond its realm and study of fundamental symmetry violations**. These investigations are already carried out and will be continued by DLNP and VBLHEP groups within large international collaborations at the world-best accelerator complexes, in experiments with significant or dominant contribution made by JINR scientists. These are nowadays the experiments at the proton-antiproton **Tevatron** collider (FNAL), where DLNP physicists participating in the research work with the CDF and D0 detectors have already obtained physics results of fundamental importance. Data analysis will continue till 2012. The experience gained by these scientists at the Tevatron will be extremely important for JINR's effective participation in future experiments at the LHC.

It is obvious that a new era of fundamental investigations in particle physics will be opened when the **LHC** collider starts operation at CERN. DLNP, BLTP, LIT and VBLHEP scientists will take part in the ATLAS and CMS experiments at the LHC. These two experiments are designed to make excellent measurements of many possible (known and unknown) products of collisions at the unprecedented centre-of-mass energy of 14 TeV. The goal of the **ATLAS** project is to study proton-proton interactions using to the maximum extent the resources and capabilities of the LHC collider to investigate various physics processes with a view to verifying predictions of the Standard Model and search for phenomena beyond its scope. JINR's team is involved in the activities on a number of major physics tasks (top quark, Higgs boson and supersymmetry searches, etc.) and is responsible for maintaining the key subsystems of the experimental facility. JINR is taking part in the **CMS** project within a joint collaboration of Russia and JINR Member States (RDMS CMS). The RDMS collaboration is fully responsible for the endcap hadron calorimeters and forward muon stations. In 2010–2016, the JINR group will participate in data taking, monitoring of the detection systems, maintenance of their operation, data processing with the aim of testing the Standard Model in the MMTDY processes, and in the search for signals from new physics. QCD investigations, study of jet events, measurements of their cross sections for the purpose of verifying gluon structure functions, and a study of production of massive states (gauge bosons, Higgs bosons) will also be performed.

In the **DIRAC** experiment at the PS accelerator at CERN, DLNP scientists continue studies of low-energy QCD parameters followed from chiral symmetry violation. Plans to improve measurements using SPS beam and completion of these studies in 2014 will be considered.

Measurements of CP violation are currently very important for the understanding of the nature of CP violation within the Standard Model. Under the **NA62** project at the CERN **SPS** beam, VBLHEP continues a series of high-precision experiments aimed at investigating the phenomenon of direct CP violation in the kaon decay and a wide range of other properties of these decays with unprecedented accuracy. The NA62 set-up is being developed to enable the study of the ultra-rare decay of a charged kaon into a charged pion and two neutrinos. The measurement of its probability will allow one to significantly improve the parameters of the Cabibbo-Kobayashi-Maskawa matrix and, probably, find manifestations of new physics. The tasks of the JINR team for 2010–2016 include building (jointly with CERN) a track detector of new type, developing software for simulation and reconstruction of tracks in the detector and for the entire NA62 experiment, and participating in experimental data taking, processing, and analysis.

The results, obtained with DLNP's participation in the E391a experiment at KEK on the decay of a neutral kaon into a pion and a neutrino-antineutrino pair, allow one to consider continuation of this research at a higher precision level which may lead to a new understanding of the CP-violation effect. Future DLNP plans are related with the experiment **KLOD** at IHEP (Protvino) and with the NA62 experiment at CERN.

Precision studies of rare muon and pion decays allow one to test the Standard Model of electroweak interaction and μ-e universality. It is proposed by DLNP to conduct a search for the μ^+ decay into $e^+\gamma$ which violates the lepton number conservation law (MEG project). Modern extensions of the Standard Model predict measurable lepton-flavour-violating μ^+ decay into $e^+\gamma$. The proposed experiment with the sensitivity of 10^{-14} (relative to the main decay scheme) at the PSI accelerator provides a good chance to obtain first evidence for existence of new physics beyond the Standard Model.

The search for manifestations of polarized hidden strangeness of nucleons in the production of φ and ω mesons in proton-proton and neutron-proton interactions is the main goal of the **HyperNIS** project at the **Nuclotron-M**. The characteristics of the Nuclotron-M beams provide unique possibilities for the search of hypernuclei and study of their properties. The key task for the near future is to search for neutron-rich ${}^{6}_{\Lambda}H$ hypernuclei using the ^{7}Li beam. This programme of studies is planned to be completed in 2015.

JINR substantially participates in the **FAIR** accelerator and detector activities. The physics programme of the future FAIR facility covers a wide range of topics that address central issues of strong interactions and QCD. The antiproton beam in the momentum range from 1 to 15 GeV/s will allow the **PANDA** experiment to make high-precision measurements which include charmonium and open charm spectroscopy, the search for exotic hadrons and the study of in-medium modifications of hadron masses. During the next seven years JINR plans to participate in the PANDA experiment, contributing to the construction of the muon system, superconducting solenoid, and quartz radiators. It is expected that the main contribution of JINR to FAIR will be financed under the Russia–FAIR agreement.

Neutrino and rare phenomena physics offers promising possibilities to study fundamental, key issues of modern elementary particle physics. The **study of double-beta decay** processes has highest priority at DLNP, and will be carried out within the framework of the NEMO, GERDA-MAJORANA (G&M) and Super-NEMO projects. It is planned by 2016 to achieve with ^{82}Se the limit on an effective neutrino mass, $m_\nu < 0.04–0.11$ eV. The main purpose of the GERDA experiment is to search for the neutrinoless double-beta decay of ^{76}Ge. GERDA will operate with bare germanium semiconductor detectors (enriched in ^{76}Ge) situated in liquid argon. The experiment will be performed in the Gran Sasso Underground Laboratory (Italy).

Observation of **neutrino oscillations** requires neutrinos to have mass and lepton-flavor non-conservation. DLNP is taking part in leading experiments on neutrino oscillations such as the OPERA experiment (Gran Sasso), whose aim is to detect tau neutrino appearance with muon-neutrino beam from CERN's accelerator, and the Daya Bay reactor neutrino experiment.

At the GEMMA spectrometer situated at the Kalinin Nuclear Power Plant, experiments on measurement of the **neutrino magnetic moment** are performed. With the unique parameters of this instrument, the sensitivity is expected to be at the level of $3.5\cdot10^{-11}$ μ_B after data taking up to 2009. At the end of 2010, the new detector GEMMA-2 will start to operate with an increased neutrino flux from the reactor. It is planned to achieve with GEMMA-2 the sensitivity on the neutrino magnetic moment at the level of $(9–7)\cdot10^{-12}$ μ_B after operation during 2010–2012.

DLNP participates in the study of **ultra-high-energy cosmic rays** (within the projects TUS, NUCLEON and Baikal), in direct and indirect **dark matter search** (within the projects

EDELWEISS and Baikal). A direct observation of the interaction of Weakly Interacting Massive Particles (WIMP) in a terrestrial detector would be of tremendous importance to particle physics and cosmology. The EDELWEISS collaboration is searching for WIMP dark matter using cryogenic detectors. The development of EDELWEISS will be continued in the project called EURECA (European Underground Rare Event Calorimeter Array). The aim is to search for dark matter with the highest accuracy with a target mass of up to one ton. It is planned to begin the EURECA experiment in 2015.

To realize the ambitious JINR programme in particle physics and especially in high-energy heavy-ion physics, a specialized **VBLHEP Accelerator Complex** together with state-of-the-art detection systems will be built. To this end the **NICA** project has been prepared. Its aim is to create the accelerator base and infrastructure required for realization of the key physics task to be addressed by the Laboratory — experimental studies of hadronic (strongly interacting) matter and its phase transitions.

The chief goal of the project is to construct, based on the Nuclotron-M accelerator, a collider that will allow carrying out investigations with colliding beams of high-intensity ions at an average luminosity of $L=10^{27}cm^{-2}s^{-1}$ for Au^{+79} within the energy region $\sqrt{s_{NN}}$ = 4–11 GeV, as well as with polarized proton ($\sqrt{s_{NN}}$ up to 20 GeV) and deuteron ($\sqrt{s_{NN}}$ up to 12 GeV) beams with longitudinal and transverse polarization and with extracted ion beams as well as polarized proton and deuteron beams.

This requires creating a source of highly charged heavy ions, constructing a linear injector accelerator, designing and building a booster synchrotron, developing and constructing two superconducting storage rings, integrating the developed systems and the existing accelerator Nuclotron-M into a collider providing at least two beam intersection points. It is planned to complete the Nuclotron-M project in 2011. The physical start-up of the NICA facility is planned for 2015.

To use effectively the NICA collider opportunities, it is necessary to construct adequate detector set-ups at JINR. Such experimental instruments will be **detectors MPD and SPD** at VBLHEP.

The goal of the **MPD** project is experimental studies of strong interactions in hot and dense hadronic matter and a search for a possible formation of the so-called “mixed phase” of such matter. The design concept of the MPD set-up envisages placing the central complex of detecting equipment in the solenoid magnetic field as well as two forward-backward detectors. Under the MPD project, the DLNP is planning to take responsibility for the construction of a compact high-performance electromagnetic calorimeter (EMC).

The **SPD** facility is being developed at VBLHEP for realization of the second part of the scientific programme for the NICA collider concerning investigations of the interactions of colliding light-ion beams and polarized proton and deuteron beams. This will allow setting up spin physics experiments to continue the JINR research programme in this area at a brand new level.

The successful achievement of the goal, set before VBLHEP, for the construction of the **NICA** accelerator complex and **MPD** and **SPD** detectors requires concentration of essential resources and optimization/minimization of financing for another projects carried out in the Laboratory within the existing JINR obligations.

Funding (k$)*

Activities	2010	2011	2012	2013	2014	2015	2016
Nuclotron+NICA	10 900	25 100	26 700	26 300	6 200	6 600	8 200
Detector MPD	2 100	4 600	8 100	7 600	5 100	650	650
Detector SPD	130	550	750	850	1 050	1 600	2 700
Experiments with Nuclotron beams	165	175	175	175	155	125	90
Physics of neutrino and rare processes	800	1 300	1 800	2 300	2 300	2 300	2 300
Experiments at external accelerators	2 300	2 450	2 450	2 500	3 200	3 700	3 700
Total	**16 395**	**34 175**	**39 975**	**39 725**	**18 005**	**14 975**	**17 640**

* Figures hereinafter do not include personnel, electricity and infrastructure costs.