

# Scientific programme of the Joint Institute for Nuclear Research

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## Abstract

The Joint Institute for Nuclear Research (JINR) is a large multidisciplinary international scientific centre, in which fundamental research in modern elementary particle physics, nuclear physics, and condensed matter physics using nuclear methods is integrated with the development and application of the newest technologies and university education activity in related areas.

## 1 Introduction

### 1.1 General information about the Joint Institute for Nuclear Research (JINR)

The Joint Institute for Nuclear Research (JINR) in Dubna was established on the basis of the convention signed by the Plenipotentiaries of the governments of the Member States of JINR in March 1956 in Moscow. JINR was created in order to unify the intellectual and material potential of the Member States in order to study the fundamental properties of matter.

Dubna as a town of science was founded immediately after the end of World War II. In 1947 a group of scientists led by Academician I.V. Kurchatov initiated construction of the then largest accelerator of charged particles — the synchrocyclotron. The accelerator was commissioned in 1949. Extensive fundamental and applied investigations into the properties of nuclear matter immediately started at the newly established Institute for Nuclear Problems (INP) with its operating 680 MeV synchrocyclotron, headed by the young physicists M.G. Meshcheryakov and V.P. Dzhelepov, later world-known scientists.

After INP, the Electrophysical Laboratory of the USSR Academy of Sciences (EFLAN), headed by Academician V.I. Veksler, was set up in Dubna. A new accelerator, namely a synchrophasotron with record parameters for that time, was constructed at EFLAN.

In 1954 the European Organization for Nuclear Research (CERN) was established near Geneva to unite the efforts of Western European countries for the study of the fundamental properties of matter.

About the same time, under the stimulus of the government of the USSR, the countries then belonging to the socialist world took the decision to establish the Joint Institute for Nuclear Research in Dubna from the INP and EFLAN laboratories. The same year, specialists from twelve countries (Albania, Bulgaria, China, Czechoslovakia, East Germany, Hungary, Mongolia, North Korea, Poland, Romania, USSR, and Vietnam) came to Dubna. The town became international, and investigations into many fields of nuclear physics of interest for research centres of the JINR Member States were launched there.

Many scientists and engineers from the Member States have been trained in the JINR scientific schools established by N.N. Bogoliubov, D.I. Blokhintsev, G.N. Flerov, I.M. Frank, B.M. Pontecorvo, V.I. Veksler, and other outstanding physicists. The development of different scientific directions at JINR is connected with the names of A. Baldin, A. Logunov, M. Markov, D. Shirkov, A. Tavkhelidze, as well as L. Infeld and H. Niewodniczanski (Poland), G. Nadjakov (Bulgaria), H. Hulubei (Romania), L. Janossy (Hungary), N. Sodnom (Mongolia), Wang Gangchang (China), Nguyen Van Hieu (Vietnam), V. Votruba and J. Kozesnik (Czechoslovakia), H. Pose and K. Lanius (Germany), and others.

The Charter of the JINR was adopted in 1956, the text of which was revised in 1992 and more recently in 1999. In accordance with the Charter, the activities of the Institute are achieved on the basis of its openness, and the mutual and equal co-operation of all the interested parties to participate in research.

The aim of the Institute is

- to carry out theoretical and experimental investigations on adopted scientific topics;

- to organize the exchange of experience when carrying out research and the exchange of information obtained as a result of these investigations through publication of scientific papers, holding of conferences, symposia, etc.;
- to promote the development of the intellectual and professional capabilities of the scientific personnel;
- to establish and maintain contacts with other national and international scientific organizations and institutes to ensure stable and mutual co-operation;
- to use the results of the investigations of an applied nature to provide supplementary financial resources for fundamental research by implementing them into industrial, medical, and technological developments.



**Fig. 1:** N.N. Bogoliubov and D.I. Blokhintsev

The results of investigations carried out at the Institute can be used solely for peaceful purposes for the benefit of mankind. So until the late 1980s, Dubna was a centre that unified the efforts of leading research groups of nuclear sciences from socialist countries and the Soviet Union.

After the disintegration of the USSR, membership of JINR underwent the following changes: the majority of Eastern European countries, such as Poland, the Czech and Slovak Republics, Bulgaria, Romania, and others continue to be Member States and contribute to the budget. Germany remains as an observer and makes a substantial financial contribution. Most of the former Soviet Union republics, which became independent states, entered JINR as new members.

There are different ways to participate in the activities of the Institute: on the basis of the full or associated membership, or bilateral and multilateral agreements in order to perform particular scientific programmes. The JINR Member States contribute financially to the Institute's activities and have equal rights in its management.

At present JINR has 18 Member States: Armenia, Azerbaijan, Belarus, Bulgaria, Cuba, Czech Republic, Georgia, Kazakhstan, D.P. Republic of Korea, Moldova, Mongolia, Poland, Romania, Russian Federation, Slovak Republic, Ukraine, Uzbekistan, Vietnam.

The JINR has special co-operation agreements concluded on the governmental level with:

- Germany (in the fields of theoretical physics, heavy-ion physics, condensed matter physics, and high-energy physics),
- Hungary (in the field of condensed matter physics),
- Italy (in the field of intermediate- and low-energy physics).

Positive preliminary negotiations with scientific officials of the USA, China, Greece, India and other countries are under way to conclude similar governmental agreements with these countries.

Among the major partners with whom JINR has long-term co-operation agreements are

- CERN, in the field of high-energy physics,
- IN2P3 (France), in the field of nuclear and particle physics,
- INFN (Italy), in the field of nuclear and particle physics,
- FNAL, BNL, SLAC and other research centres in the U.S.A.

The activity of JINR in the territory of its host country, the Russian Federation, is carried out in accordance with the Russian Federal Law on Ratification of ‘The Agreement between the Government of the Russian Federation and JINR on the Location and Terms of Activity of JINR in the Russian Federation’. The Federal Law was approved by the Federation Council on 22 December 1999 and signed by the President of the Russian Federation, V. Putin, on 2 January 2000. The Federal Law came into force from the date of its official publication — 6 January 2000.

This Agreement underlines the international legal capacity of JINR and grants it privileges and immunities in compliance with established practice for international intergovernmental organizations.

## 1.2 Governing and Advisory Bodies of JINR

JINR has a number of Governing and Advisory Bodies.

- Committee of Plenipotentiaries of the JINR Member States
- Finance Committee
- Scientific Council
- Programme Advisory Committee for Particle Physics
- Programme Advisory Committee for Nuclear Physics
- Programme Advisory Committee for Condensed Matter Physics.

The Committee of Plenipotentiaries of the Governments of the Institute Member States is the supreme body of the JINR and carries out its activities in the session order. Each member of the Institute has one representative in the Committee of Plenipotentiaries.

The scientific policy is developed and coordinated by the Scientific Council, whose members are eminent and well-known scientists from the Member States, as well as from CERN, Germany, Greece, France, Italy, China, India, and other countries.

Three Programme Advisory Committees (PACs) for Particle Physics, Nuclear Physics and Condensed Matter Physics are advisory bodies of the JINR Directorate and to the JINR Scientific Council in specific fields of research. The PACs hold their meetings twice a year.

## 1.3 JINR’s structure and the main fields of research activities

The internal organization of the JINR is determined by scientific specialization. There are seven Laboratories at JINR. On account of the scope of scientific activities each is comparable to a large research institution:

- Bogoliubov Laboratory of Theoretical Physics (BLTP)
- Veksler–Baldin Laboratory of High Energies (VBLHE)
- Laboratory of Particle Physics (LPP)
- Dzhelapov Laboratory of Nuclear Problems (DLNP)
- Flerov Laboratory of Nuclear Reactions (FLNR)
- Frank Laboratory of Neutron Physics (FLNP)
- Laboratory of Information Technologies (LIT).

There are two more all-Institute subdivisions in the JINR structure:

- Division of Radiation and Radiobiological Research
- University Centre of JINR.

Several associate experimental physics workshops are also part of the Institute. The personnel of the Central Workshop totals about 400. It is equipped with everything necessary for manufacturing large-sized non-standard facilities, electronics, and has technological production lines for the construction of detectors for physics.

In the past four decades JINR has grown into a large multidisciplinary physics centre. It employs over 6000 people, including 1100 scientists and about 2000 engineers and technicians. The main fields of the Institute's activities are the following:

### ***1.3.1 Theoretical physics***

Quantum field theory and modern mathematical physics; fundamental symmetries; Standard Model and beyond; astroparticle physics; nuclear structure near the dripline; dynamics of few-body systems; exotic properties of nuclear matter; systems with strong correlations; integrability; self-organization; disordered structures.

### ***1.3.2 Elementary particle physics***

Origin of mass; nature of spin; fundamental symmetries (including chiral symmetry); nature of dark matter; neutrino mass; deconfinement; search for supersymmetry.

### ***1.3.3 Relativistic nuclear physics***

Non-perturbative QCD; spin effects in hadronic processes; quark–gluon degrees of freedom; asymptotics in nuclear collisions; mechanism of hadronization and confinement; heavy-ion collisions; multiple production; nuclear multifragmentation processes; hypernuclei and  $\eta$  nuclei; cumulative effects; spin structure of light nuclei; physics of resonances; Nuclotron; superconducting magnet technology.

### ***1.3.4 Heavy-ion physics***

Nuclear reactions induced by beams of stable and radioactive nuclei; synthesis and properties of transuranium and superheavy nuclei; properties of nuclei close to proton and neutron drip-lines; chemistry of actinides and transactinides; radioanalytical investigations; heavy-ion accelerators; production of secondary beams; interaction of heavy ions with condensed matter.

### ***1.3.5 Low- and intermediate-energy physics***

Fundamental physics phenomena and processes in nuclear physics; rare decays of elementary particles and nuclei; non-accelerator particle physics; nature and properties of the neutrino.

### ***1.3.6 Nuclear physics with neutrons***

Violation of fundamental symmetries in neutron-induced reactions; beta-decay and electromagnetic properties of the neutron; ultracold neutrons; nuclear data for science and technology; ecological study with neutrons.

**1.3.7 Condensed matter physics**

Strongly correlated electron systems; low-dimensional systems; heterostructures; quantum wells and dots; quantum liquids; chaos; self-organization; disordered systems; polymers; biopolymers; biomembranes; nanomaterials; physics of surfaces.

**1.3.8 Radiation and radiobiological research**

Radiobiology; radiation genetics; mutagenesis; chromosomal aberration; biophysics of photobiological processes; target therapy; radiation protection; dosimetry; neutron spectrometry; radiation transport through matter.

**1.3.9 Networks, computing and computational physics**

Distributed high-performance computing infrastructure; high-speed networking; information, algorithmic, and software support; modelling of physical systems; data processing and analytic calculations for physics problems; JINR's GRID segment and global GRID structures.

**1.3.10 Educational programme**

University-type education; continuous education 'secondary school – higher education institution — research institution'; postgraduate programmes; extension of specialties; collective use centres; international schools; JINR-based educational departments.

A unique choice of experimental facilities is available at this Institute. Apart from the still operational early accelerators — the 680 MeV Phasotron and the 10 GeV Synchrophasotron (terminated in 2003) — they include: the Nuclotron, a new, superconducting synchrotron for nuclei and heavy ions up to 6 GeV/n intended for relativistic nuclear physics studies; the U400 and U400M cyclotrons used for experiments on the synthesis of heavy and exotic nuclei, on the studies of their properties and heavy-ion reaction mechanisms; the IBR-30 neutron booster and the IBR-2 reactor (mean power 2 MW, peak power 1500 MW) used for nuclear physics research with neutrons and condensed matter studies. Also, several new facilities are being constructed at JINR, namely IREN — a new source of resonance neutrons and DRIBs — Dubna Radioactive Ion Beams project.

**1.4 Three 'pillars' of JINR**

The Institute has preserved its integrity thanks to its three 'pillars':

- internationally recognized traditions of scientific schools,
- the status of an international intergovernmental organization, and
- basic facilities that have unique performance allowing topical problems to be solved in many fields of physics.

One of the most important goals is to preserve and enhance this significant foundation of JINR.

**2 JINR's scientific activity and basic facilities****2.1 World-wide recognized traditions of scientific schools**

The Institute is proud of the prominent scientists who worked at JINR. They made outstanding contributions to JINR's research programme and established scientific schools at Dubna. Among them is the famous theoretical physics school founded by N. Bogoliubov, D. Blokhintsev, and M. Markov.

Another school on neutrino physics was founded by B. Pontecorvo who made the supposition about neutrino oscillations.

Academician V. Veksler, a distinguished scientist, is the author of the phase stability principle, being a base for modern accelerators.

Academician G. Flerov, a prominent scientist and founder of heavy-ion physics at JINR.

Laureate of the Nobel and State Prizes, Academician I. Frank made important contributions to the formation and development of various directions in physics: electrodynamics of a moving charged relativistic particle; nuclear and especially neutron physics and others.

Relativistic nuclear physics is a new scientific direction established in Dubna by Academician A. Baldin.

A very big contribution to the formation of the JINR scientific schools was made by the prominent scientists from the JINR Member States (see introduction). Our obligation and key strategic goal is to preserve the traditions of JINR's schools, and to train young scientists in the spirit of these traditions.

## 2.2 International collaborations

Over its 47 years of existence, first-class theoretical and experimental research programmes accomplished at JINR have led to a significant enrichment of fundamental nuclear science. JINR accounts for a half (about 40) of the total number of discoveries in particle and nuclear physics, registered in the former Soviet Union. About 500 research papers and reports representing approximately 3000 authors are submitted every year by JINR to editorial boards of journals in many countries and to organizing committees of conferences. JINR publications are sent to over 50 countries.

The Institute carries out theoretical and experimental research using its own basic facilities and those of other major scientific centres throughout the world. These facilities provide ample and unique opportunities for research in high-energy physics as well as in low- and intermediate-energy physics. Widely used are novel information technologies and computational physics methods, which, on the whole, maintain a modern level of research.

Here I would like to recall the words of the great Russian writer A. Chekhov, who wrote:

Science cannot be national, in the same way that a multiplication table cannot be national.  
If a science becomes national, it ceases to be a science.

JINR is a perfect illustration of this idea.

Broad international co-operation is one of the most important principles of JINR's activities. Almost all investigations are carried out in close collaboration with the JINR Member States scientific centres, as well as international and national institutions and laboratories of the world. JINR collaborates with nearly 700 research centres and universities in more than 60 countries, including Germany, France, Italy, Japan, Switzerland, and the USA.

### 2.2.1 Co-operation with CERN

Our long-standing scientific partner is CERN. For more than 40 years the co-operation between JINR and CERN has been very fruitful and mutually beneficial. Though the general agreement between JINR and CERN was signed in 1992, nevertheless, the real co-operation between the two international organizations has a long and rich history. JINR scientists and engineers are actively involved in the current CERN experiments as well as in the preparation of the future LHC project. Today JINR participates in about twenty projects at CERN. Among them: ATLAS, CMS, ALICE, LHC (accelerator complex), DELPHI (data analysis), DIRAC, HARP, NA45, NA48 (data analysis), NA48/1, NA48/2, NA49, NA58 (COMPASS), NOMAD (data analysis), and others.

### 2.2.1.1 *The ATLAS project*

Here we have performed a large amount of work, unusual even for our large Institute: in co-operation with Belarus and Slovak Institutes and industry we manufactured about 300 000 units of steel absorber plates with very high mechanical tolerances (about 50 microns).

In June 2002, the Joint Institute completed one of its international obligations for the ATLAS project. The last of the 65 twenty-one-ton modules for the ATLAS Hadron Barrel Tile calorimeter was transported to CERN to join its ‘co-brothers’.

### 2.2.1.2 *The CMS project*

JINR is participating in the CMS project in the framework of the Russia and Dubna Member States Collaboration (RDMS). The involvement of the Member States in this activity through RDMS has given them an opportunity to play leading roles and to contribute significantly to the preparation of the hadron calorimeter, electromagnetic calorimeter, and the muon detector.

For example, the Belarusian scientists and industry have developed and manufactured a special electronics scheme (for proportional chambers) which successfully passed radiation tests at CERN. Belarus and Bulgaria are responsible for CMS end-cap calorimetry.

### 2.2.1.3 *The ALICE project*

JINR is playing an important role also in the ALICE project. We have a large number of commitments in this project:

- construction of the iron yoke for the warm dipole magnet,
- production of large-scale chambers for transition radiation detectors,
- production of lead tungsten crystals for the ALICE photon spectrometer,
- participation in the GRID activity.

The first 10 lead tungsten crystals have been delivered to CERN and successfully passed the test under the electron beam.

### 2.2.1.4 *The LHC Damper*

JINR specialists in the field of accelerator R&D also participate in the construction of the Transverse Damping System at the LHC.

I would like also to comment on some scientific results obtained in CERN experiments in co-operation with JINR scientists. You already know about an impressive result obtained in 2000 and connected with the discovery of a new state of matter — the so-called ‘quark–gluon plasma’. That was a result of combined data coming from the seven experiments ongoing in the frame of CERN’s Heavy-Ion Programme. It is remarkable that physicists from the JINR Laboratory of High Energies are participating in three of them, namely NA49, NA45 and WA98, and have significantly contributed to obtaining this result that pertains to relativistic nuclear physics. This trend was also developed in Dubna by the community of scientists headed by Academician A. Baldin who initiated the idea to use the Dubna accelerators (synchrotron, Nuclotron) for relativistic nuclei acceleration.

The interpretation of the CERN experimental results was not completely clear and definite. However, recently, the new exciting effect called ‘jet quenching’ from deuteron–gold collisions was discovered at BNL (RHIC) with the participation of the JINR scientific group. This result strengthens scientists’ confidence that RHIC collisions of gold ions have created unusual conditions and that they are on the right path to discovering a form of matter called the quark–gluon plasma.

One more example of our fruitful co-operation with CERN is connected with the NA48 experiment. A world-class result was obtained by this Collaboration at CERN. It concerns the most precise

measurements of the parameter  $\varepsilon/\varepsilon'$ , which is related to direct CP violation in neutral kaon decays. JINR has successfully contributed to all stages of this experiment. More than 20 tons of high-purity liquid krypton and the aluminium cryostat with its infrastructure were produced in Russia and delivered to CERN as an original contribution by Dubna. The Dubna group is among those who contributed independently to the evaluation of the final  $\varepsilon/\varepsilon'$  result.

### 2.2.2 *Science bringing nations together*

A special page in our co-operation with CERN is the joint poster exhibition ‘Science Bringing Nations Together’.

Since 1997 when the first joint exhibition of this series was held at the University of Oslo (Norway), CERN and JINR have organized these exhibitions every year. They were already shown at UNESCO in 1998, at the United Nation’s office in Geneva in 1999, in the European Parliament in Brussels in 2000, in the Russia State Duma in 2001, in Romania in 2002, and in August 2003 in Armenia, where the 2003 European School on High-Energy Physics was held.

The dominant theme of the exhibition was that the joining of creative efforts and material resources by scientists from various countries has become another important way for fruitful communication and mutual understanding between peoples.

### 2.2.3 *Co-operation with Russia*

Russia, owing to its status as the host country of the Joint Institute and as the main contributor to the JINR budget, plays a special role in the activity of this international centre. At present JINR has as many as about 150 partner institutions in Russia involved in all the fields of research and educational activities of JINR. This partnership is effectively supported by the Russian Ministry for Atomic Energy, Ministry for Industry, Science and Technology, and by the Russian Academy of Sciences. Since the very beginning of JINR’s existence the Plenipotentiaries of JINR from the USSR and later from Russia have greatly contributed to the development of the Institute. Here are their names in chronological order: E. Slavskii, V. Emelyanov, A. Petrosyants, A. Protsenko, V. Konovalov, B. Saltykov, V. Fortov, V. Bulgak, M. Kirpichnikov.

Effective co-operation is achieved with institutes in Russia such as IHEP (Protvino), Kurchatov Institute (Moscow), Institute of Nuclear Physics (Gatchina near St. Petersburg), ITEP (Moscow), INR (Troitsk), Lebedev Institute of Physics (Moscow), Moscow State University, Budker Institute of Nuclear Physics (Novosibirsk), and others.

JINR–Russia co-operation has promising prospects:

- While putting the main emphasis on the operation and development of its own facilities, JINR will continue its participation in research programmes at major Russian facilities.
- Widening of co-operation in the field of higher education, including special-purpose training of young Russian scientists at the JINR University Centre using the Institute’s facilities.
- Preservation of the ‘common intellectual space’. Establishment of closer links with the International Association of Academies of Sciences, participation in the international project ‘Universities and Research Centres of JINR (Dubna) Member States’ of the Russian Ministry of Science and Technology.

### 2.2.4 *Co-operation with Germany*

The Joint Institute has very fruitful relations with scientific centres in Germany. Since 1991, JINR has concluded a special co-operation agreement on the governmental level—namely BMBF—with Germany. At present JINR cooperates with almost 70 centres in Germany located in 47 cities.



Today the co-operation between JINR and German Scientific Groups is based on

- the BMBF–JINR Agreement, and
- on bilateral agreements concluded between JINR and German scientific groups.

The co-operation in the field of high-energy physics at DESY was included in the JINR–BMBF Agreement in 1995. The Laboratory of Particle Physics of JINR and DESY co-operate in the experimental programme at the HERA electron–proton collider and in the R&D programme for the TESLA linear collider and Free-Electron Laser (FEL). The Dubna group has made important contributions in all fields of this collaboration.

In the HERMES collaboration, the Dubna group has taken an active part in data analysis and detector upgrades. Recently many thousands of events for the deeply virtual Compton scattering processes were collected at HERMES.

### **2.2.5 Co-operation with the U.S.A.**

JINR is implementing a wide scientific collaborative programme with U.S. research laboratories. This co-operation is carried out in the fields of high-energy physics, heavy-ion physics, nuclear physics with neutrons, and accelerator technologies. At present, the Joint Institute for Nuclear Research collaborates with 73 U.S. scientific centres (18 research laboratories and 55 universities) located in 66 cities.

JINR is developing a successful collaboration with FNAL. At this Laboratory, groups of JINR scientists have been taking part in the experiments using the CDF and D0 detectors.

Another good example is the active collaboration with the Brookhaven National Laboratory. JINR scientists are participating in the design and construction of the electromagnetic calorimeters for the STAR detector.

On 23 April 2002, a representative delegation from the U.S. Department of Energy (DOE) headed by the Undersecretary Robert Card visited the Joint Institute for Nuclear Research. The visit concluded with the signing of a joint Declaration of Intent between the U.S. Department of Energy and the Joint Institute for Nuclear Research, where both sides expressed their mutual interest in strengthening the co-operation in the fields of particle physics and nuclear physics. A full-scale DOE–JINR Agreement is now under consideration.

## **2.3 Research programme and basic facilities**

### **2.3.1 Theoretical physics**

Research topics of the Bogoliubov Laboratory of Theoretical Physics (BLTP, director — Professor A. Sissakian) in recent years have covered a wide field of activity in the quantum theory of fields and particles, mathematical physics, the theory of nuclei, and the theory of condensed matter. These topics are traditional for the JINR and have been pursued over many years since its foundation in 1956 thanks to the outstanding scientists D. Blokhintsev, N. Bogoliubov, M. Markov, Ya. Smorodinsky together with the then-young and later famous theoreticians A. Baldin, S. Bilenky, N. Chernikov, S. Gershtein, Zhou Guanzhao (China), Nguyen Van Hieu (Vietnam), V. Kadyshesky, A. Logunov, M. Mateev (Bulgaria), V. Matveev, R. Muradian, V. Ogievetsky, D. Shirkov, L. Soloviev, V. Soloviev, A. Tavkhelidze, I. Todorov (Bulgaria), and others.

A perspective programme of scientific research is directed to further investigation of the basic problems in the theory of elementary particles by developing the methods of quantum field theory and employing the current tools of mathematical physics. The key tasks here are the elucidation of fundamental symmetries of the physical world, recovering of the basic structure components in elementary particle physics, unification of all the fundamental fields and forces including gravitation. The connection of present-day elementary particle physics with astrophysics and cosmology is of great importance

and this tendency is gaining strength. As before, much attention will be paid to the theoretical investigations aimed at the preparation and justification of future experiments, as well as the theoretical treatment and interpretation of the experimental data already obtained.

The Standard Model is considered to be the basis of the present-day theory of elementary particles. Therefore, it is important to make more precise or determine all its parameters (the total number of which approaches 25) through the calculation of concrete physical processes taking into account higher orders of perturbation theory. The following investigations are of great physical interest: the theoretical studies of the spin and polarization effects in the framework of QCD, investigation of the small- $x$  region in deep-inelastic lepton–hadron scattering, elucidation of the vacuum state in QCD, and physics of heavy quarks. Such interesting directions of theoretical investigations as CP-violation, neutrino physics, processes with very high multiplicity are important not only for the theory of elementary particles, but also for current cosmology and astrophysics.

The attempts to go beyond the scope of the Standard Model, for example, through its supersymmetric extension are also worth while. In this direction it is very interesting to predict the physical characteristics of the supersymmetric partners for known elementary particles, the experimental search for which will start in the near future.

A new approach has been suggested at JINR which describes extremely inelastic, high-energy, hadron interactions, when the multiplicities of the produced hadrons considerably exceed the corresponding mean multiplicity. The approach highlights the rarely investigated region of very high multiplicity. A possibility to test experimentally the theoretical and model predictions in this field is being studied now in a number of collaborations (ATLAS, CDF, STAR and others).

So, the main topics related to the particle physics will be:

- Development of nonperturbative methods: lattice gauge theories, collective variables (instantons, vacuum condensates, chiral approach, etc.), analytical methods and duality;
- QCD-based phenomenology;
- the Standard Model and its extension.

Theoretical support of current and future experiments at JINR, IHEP, CERN, DESY, GSI, FNAL, BNL and other physics centres will be, as before, of first priority at the Institute.

Modern mathematical physics, although formally a new JINR theme, is in reality a tradition in theoretical physics research at the Institute. The main directions here will be fundamental symmetries, unification of fields and forces including gravitation.

Another new project is the Dubna International Advanced School of Theoretical Physics (DIAS-TH) which started its activities in 2003 (rector — Professor A. Filippov).

### 2.3.1.1 *Relativistic nuclear physics*

JINR's home experimental basis in the field of high-energy physics is the accelerator complex of the Laboratory of High Energies (director — Professor A. Malakhov) — the Nuclotron. This accelerator was built over a period of five years and was put into operation in 1993. The **Nuclotron** is based on the unique technology of superconducting magnetic systems, proposed and investigated at the Laboratory. All design, tests, and assembly work were carried out at the LHE. Production of the structural cryomagnetic elements was done by the JINR workshops.

The Nuclotron accelerator complex allows the generation of proton, polarized deuteron (also neutron/proton) and multicharged ion beams in the energy range up to 6 GeV/amu.

The Nuclotron enables an extensive programme of research in relativistic nuclear physics to be performed both in the asymptotic mode and the transmission regime.



**Fig. 2:** The Nuclotron: a superconducting synchrotron for heavy ions up to 6 GeV/n. It has been operating since 1993.

In 1999, a special system for extraction of a nuclear beam from the Nuclotron to external set-ups was completed. Now a large international research programme is being carried out on this machine.

The Nuclotron research programme has three main axes:

- polarization phenomena at relativistic energies,
- effects of nonperturbative QCD in nuclei,
- nuclear structure at relativistic energies.

The energies of accelerated particles at the Nuclotron are good for cumulative relativistic nuclear effects investigations at intermediate energies. Of special interest are *polarized cumulative effects* which can be studied at the Nuclotron. This is a kind of unique possibility of this machine — only in CEBAF is there a similar research programme aimed at the study of polarization phenomena using relativistic electron beams. So, from this point of view, the Nuclotron can be considered as a competitive and complementary facility in the world.

Polarization phenomena at relativistic energies (projects SPHERE, PIKASO, DELTA-SIGMA, STRELA) which are studied include:

- Investigation of the nature and properties of non-nucleon (mesonic, multiquark, etc.) degrees of freedom in nuclei at large  $x > 1$  (cumulative processes).
- Study of the polarization properties of the deuteron at large transfer momentum (complementary to the JLab investigations).
- Search for the role of three-nucleon forces.

In December 2002 the polarized deuteron beam was extracted from the Nuclotron with the energy of more than 2 GeV/n and beam intensity of  $\sim 10^8$  particles per cycle. This is a good background for the continuation of polarized experiments at the Nuclotron.

The other important topic of the Nuclotron scientific programme is the study of effects of nonperturbative QCD in nuclei (projects SPHERE, NIS). For example, the NIS project, proposed by two JINR labs — VBLHE and LPP, is aimed at searching for effects of polarized nucleon strangeness, including violations of the OZI rule, in vector meson production in pp and np interactions near the threshold. If this hypothesis is confirmed, both the ‘spin crisis’ problem and the seeming violation of the OZI rule will find their natural explanation.

The third main topic is the nuclear structure at relativistic energies. The study of the nuclear structure at the level of nucleons and their clusters is deeply associated with astrophysical phenomena.

Research progress on relativistic nuclear beams opens up new approaches to the solution of high-priority problems of nuclear structure from the lightest to the heaviest ones, including such phenomena as nuclear fog, multifragmentation, multiparticle production, etc.

The FASA project explores the mechanism of nuclear multifragmentation which takes place in nucleus–nucleus interactions at intermediate and high energies.

In the BECQUEREL project, the research programme is concentrated on a detailed study of relativistic fragmentation of light radioactive and stable nuclei. The expected results will allow one to answer some high-priority questions of the cluster structure of light nuclei.

### 2.3.2 *Users' centre*

Over the last several years, the model of a users' centre on the basis of the VBLHE accelerator complex has been continuously and successfully tested. It is planned that the scientific policy and practical work at the VBLHE accelerator complex will be oriented to the maximum number of external researchers. This means further development of the Nuclotron as a users' centre of relativistic nuclear beams. The work in this direction is under way now and will be a main focus of attention of the Nuclotron evaluation committees.

One of the strategic goals of the users' centre could be an educational programme for young specialists and engineers of the Member States. A number of routine JINR projects in high-energy physics can serve as a good scientific platform for this purpose.

### 2.3.3 *Elementary particle physics*

Since its foundation in 1956, JINR has developed as a centre of elementary particle physics which is the most direct way to study the structure of matter on the ultra-small space–time scale. Gradually the methods and approaches used in particle physics had an essential influence on other branches of science developed as new research directions at JINR.

Experimental physics of elementary particles is studied at the Laboratory of Particle Physics (director — Professor V. Kekelidze), the Dzhelepov Laboratory of Nuclear Problems (director — Professor A. Olshevsky). The elementary particle physics programme at JINR covers a wide range of fundamental issues to study various phenomena and processes aimed at verifying the predictions of the Standard Model and searching for new phenomena and regularities beyond them:

- verification of predictions, tests of the Standard Model (CP-violation, QCD, Higgs mass, etc.);
- search for the effects beyond the Standard Model (supersymmetry, superstrings, leptiquarks, technicolour, proton decay, compositeness, extra dimensions, CPT and Lorentz violation, dark matter, etc.);
- study of the nature and properties of neutrinos (neutrinoless double beta decay, neutrino oscillations, magnetic moment of the neutrinos, etc.);
- construction of the model of the Universe, etc. (by means of investigation of the new physical phenomena with particles, nuclei, stars, galaxies, etc.).

After 2006, the main experiments in this field will be associated with the LHC. However, before then, JINR physicists have large opportunities for experimental physics at DESY, Tevatron, etc. Also, it is necessary to mention the increasing role of the home site in HEP activities:

- detector production,
- data processing,
- data analysis,
- on-line experiment control,

- videoconferences,
- experiments at the world's best accelerators in the 'remote' mode,
- powerful computing facilities.

Thus JINR can be considered as a kind of cluster in particle physics first of all for its Member States.

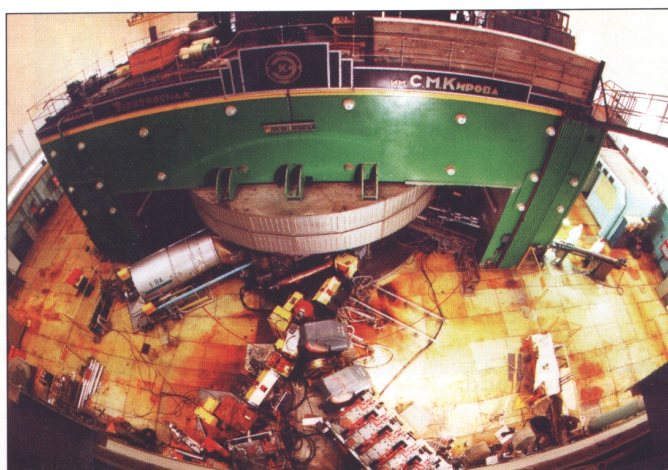
Very important fields of research will be astroparticle physics and cosmology. Along with the theory, a number of experiments are planned in this area. For example, the TUS project is aimed at astrophysical studies on space satellites.

#### **2.3.4 Low- and intermediate-energy physics**

The programme of low- and intermediate-energy physics research is aimed at studying fundamental phenomena and processes in nuclear physics, rare decays of elementary particles and nuclei, and non-accelerator particle physics. The key tasks in non-accelerator particle physics, astrophysics, and cosmology are investigations of the nature and properties of the neutrino. The shortest way of gaining important information in this area is the study of the neutrinoless double beta decay of nuclei. These promising investigations, which lead one to expect findings of fundamental importance, are being conducted and will be continued within long-term projects like NEMO, TGV, GENIUS, and MAJORANA aimed at searching for and detecting neutrinoless and two-neutrino modes of the double beta decay of a variety of nuclei.

Investigations in low- and intermediate-energy physics are planned to be carried out within international collaborations at accelerators both in Russia (JINR's accelerators and high-current accelerator in Tomsk) and in Europe (PSI, COSY, etc.), at the reactor of the Kalinin Nuclear Power Plant, and in the underground laboratories in Baksan (Russia), Gran Sasso (Italy), Frejus (France), and Homestake (USA).

The programme will also include studies of extremely rare electroweak processes to verify predictions and to reveal applicability limits of the Standard Model of particle physics as well as to search for so-called 'new physics', which definitely requires going beyond the present concepts. These investigations will be carried out in the experiments PIBETA (PSI, Switzerland) and FAMILON (at the JINR Phasotron).



**Fig. 3:** The Phasotron accelerator

The internal research programme is implemented at the Phasotron, an accelerator of 680 MeV protons (M.G. Meshcheryakov, V.P. Dzhelepov et al.). It commenced operation in 1949, was reconstructed

in 1984, and is the oldest basic facility of the JINR. Ten beam channels are available at this machine and used to carry out experiments with pions, muons, neutrons, and protons. Five secondary beams are designed to carry out medical investigations.

### 2.3.5 Heavy-ion physics

In recent decades, heavy-ion physics has been the most dynamically developing area of low- and intermediate-energy physics, and JINR has become one of the leading scientific centres in heavy-ion physics. In recognition of the outstanding contribution of JINR scientists to modern physics and chemistry, the General Assembly of the International Union of Pure and Applied Chemistry (IUPAC) in 1997 named element '105' of Mendeleev's periodic table as Dubnium (Fig. 4).

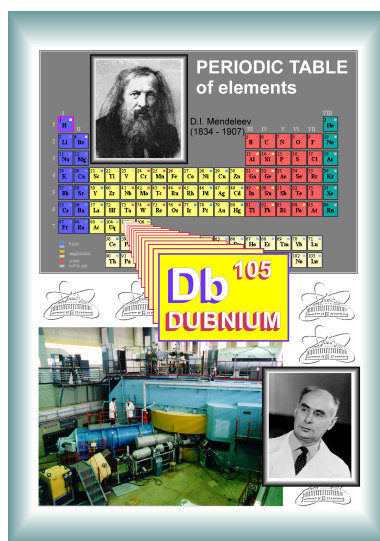


Fig. 4: Dubnium: element 105 of Mendeleev's periodic table

The main experimental base of the Flerov Laboratory of Nuclear Reactions (FLNR, scientific leader — Academician Yu. Oganessian, director — Professor M. Itkis) is the complex of two heavy-ion cyclotrons, U400 and U400M. The isochronous U400 cyclotron was constructed in 1978 and produces ion beams of atomic masses from 4 to 100 and maximum energy up to 25 MeV/nucleon. The U400M is an isochronous cyclotron which commenced operation in 1991–92 to accelerate heavy ions. At the U400M cyclotron, internal ion beams of light elements from He to Ar with energies up to 50 MeV/nucleon have been obtained (the maximum energy is 100 MeV/nucleon).

The Laboratory's research programme involves investigations in a wide region of low- and intermediate-energy heavy-ion physics.

The main topics of research in heavy-ion physics are

- synthesis of new nuclei and study of nuclear properties and heavy-ion reaction mechanisms using ion beams of stable and radioactive isotopes;
- development of the U400+U400M cyclotrons and the MT25 microtron complex for producing intensive beams of accelerated ions of stable and radioactive isotopes (DRIBs project);
- radiation effects and modification of materials, radioanalytical and radioisotopic investigations with heavy ions, applied research.

A fundamental outcome of macro-microscopic theory is the prediction of an 'island of stability' of superheavy elements. This hypothesis, proposed more than 30 years ago and intensively developed since, has recently received experimental confirmation at JINR — five new heavy elements and more

than 30 isotopes of transfermium elements have been discovered (scientific leader — Yu. Oganessian). As a result of investigations performed between 1998 and 2003, decays of the heaviest nuclei with atomic number from 108 to 118 were observed. First experiments on the chemical isolation and identification of element 112 were performed.

### 2.3.6 Condensed matter physics

The programme in the field of condensed matter physics is oriented towards the use of nuclear-physical methods developed at JINR to solve topical problems of present-day natural sciences concerned with the properties of matter in a condensed state. The nuclear-physical methods are versatile and powerful techniques for addressing problems of structural analysis and studying the properties of matter at a microscopic level, making it possible to take advantage of interdisciplinary investigations in full measure.

The main Laboratory of JINR in this area is the Frank Laboratory of Neutron Physics (FLNP; director — Professor A. Belushkin), its basic facility is the IBR-2 reactor (the scientific leader of the reactor complex is Professor V. Aksenov). The key role in the foundation and further development of this Laboratory belongs to Academician I. Frank and Professor F. Shapiro.

IBR-2 (Fig. 5) is a pulsed reactor with an average thermal power of 2 MW, peak power in pulse of 1 500 MW, half-width of the pulse 215  $\mu$ s, pulse repetition rate 5 Hz, thermal neutron flux density in moderator at maximum of the pulse —  $2 \times 10^{16}$  n/cm<sup>2</sup> s.



**Fig. 5:** The IBR-2 reactor

Among the wide variety of topical problems in condensed matter physics, certain issues at present attract the particular attention of researchers:

- strongly correlated electron systems (high-temperature superconductors, compounds with colossal magnetoresistance, and systems with heavy fermions),
- low-dimensional, quasi one-dimensional, and quasi two-dimensional systems,
- heterostructures, and quantum holes and points,
- Bose–Einstein condensation,
- chaos, self-organization, and strange attractors,
- disordered systems, glasses, and liquids,
- liquid crystals, polymers, microemulsions, biomembranes,
- nanomaterials, fullerenes, and nanotubes,

- physics of surfaces, and waves of charge and spin density.

The investigations at the IBR-2 reactor can make a significant, and in some cases decisive, contribution to the solution of a number of the above-mentioned problems. In addition to the investigations using neutron beams at the IBR-2 reactor and at major European sources like ILL, ISIS, LLB, HMI, and PSI, other methods of nuclear physics will be used for solving the problems formulated above.

During the coming 5 to 6 years the IBR-2 pulsed reactor will be completely modernized. As a result JINR will have the only world-class operating pulsed neutron source of JINR Member States. Its unique parameters will allow a rich research programme for another 20 to 30 years. IBR-2 is included in a 20 year strategic programme of neutron scattering research in Europe.

### **2.3.7 Nuclear physics with neutrons**

The scientific programme in the field of nuclear physics with neutrons is oriented towards the preparation and development of new experimental techniques for investigations to be carried out with the IREN neutron source that is under construction. The new pulsed neutron source IREN will be the most intense specialized source in Europe. With a comparable energy resolution it will be second in intensity to the LANSCE source operating in Los Alamos.

Traditional fields of research in nuclear physics with neutrons are as follows:

- experimental and theoretical investigations of the electromagnetic properties of the neutron and its beta-decay,
- studies of spatial parity violation in interactions of neutrons with nuclei,
- research into the highly excited states of nuclei at thermal and resonance neutron captures,
- obtaining new data for nuclear astrophysics,
- experiments with ultracold neutrons.

These investigations have been mainly carried out with beams of the IBR-2 reactor. At the same time, JINR's cooperation with other nuclear centres in Russia, Bulgaria, Poland, the Czech Republic, Germany, the Republic of Korea, France, the USA, and Japan made it possible to use a wide range of modern neutron sources.

In the coming years, the research into fundamental symmetries showing up in reactions with neutrons, studies of the properties of the neutron, and fundamental interactions with participation of neutrons will be of top priority. For example, within the KaTRIn project, time symmetry violation in the interaction of polarized neutrons with polarized nuclei will be investigated using FLNP's unique technique that allows one to reduce to a minimum the systematic effects associated with the polarization of neutrons and target nuclei and the analysis of the transmitted neutron beam polarization.

### **2.3.8 Radiation and radiobiological research**

The programme of radiation and radiobiological research concerns the study of the regularities and mechanisms of the stochastic and determinist effects of low doses of different kinds of ionizing radiation (leaders — Professor E. Krasavin, Professor V. Korogodin, Academician M. Ostrovsky).

The radiation genetics section of the programme is mainly aimed at studying the mechanisms of mutation formation in cells with different levels of genetic apparatus organization and, primarily, the formation of stable chromosome aberrations in human cells that initiate the development of malignant neoplasms as one of the most serious remote consequences of irradiation. The Nuclotron is a tool for decoding the mechanisms of stochastic radiation effects and evaluating the carcinogenic risk of low-dose radiation.



The research into the molecular photo and radiobiological processes in eye structures is aimed at studying the molecular mechanisms of the photodestructive processes whose ground is the pathogenesis of a number of diseases, first of all, malignant skin neoplasms. The latter circumstance prompts the intensive study of the impairing effect of light on the organism in the conditions of the phototoxic influence of different chemical compounds (including medicines), pesticides, and industrial emissions. Another topical task of this section is to elucidate the mechanism of the formation of cataracts due to radiation and to study retinal damage caused by heavy charged particles. This is the central problem of space radiation biology.

### **2.3.9 Networking, computing and computational physics**

In June 2000, the former Laboratory of Computing Techniques and Automation (LCTA; founders: Professor M. Meshcheryakov (first director) and Professor N. Govorun) was reorganized into the Laboratory of Information Technologies (LIT; director — Professor V. Ivanov). The main task of the new Laboratory was the provision of theoretical and experimental research in the JINR Member States with modern telecommunication, network, information and computing resources. For this purpose, a new structure was established for the Laboratory based on a highly skilled research team in the field of information technologies and computational physics.

To provide JINR and its Member States with the information environment adequate to modern international scientific cooperation, it is necessary first of all

- to provide JINR and its Member States with high-speed telecommunication data links and to create a corporate network of JINR and JINR Member-State institutes,
- to create a high-speed, reliable and protected local-area network at JINR,
- to create and provide maintenance of a distributed high-performance computing infrastructure and mass storage resources,
- to provide information, algorithmic, and software support of the Institute's research and technical activities,
- to develop JINR's GRID segment and to provide its connection to the European and global GRID structures,
- to develop mathematical modelling of physical systems,
- to process experiment results and develop new data processing techniques,
- to perform analytic calculations for physical problems.

## **3 Dubna as an educational centre**

The educational programme plays an important role in JINR's activities. It should be stressed that the concept of JINR's development is the integration of fundamental science, technological studies, and education. To achieve this, in 1991 we established the JINR University Centre (head — Dr S. Ivanova) and in 1994, together with the Russian Academy of Natural Sciences, the authorities and management of Moscow Region the Dubna International University for Nature, Society, and Man (president — Academician V. Kadyshevsky, vice-president — Professor A. Sissakian, rector — Professor O. Kuznetsov) (Fig. 6).

Since 1995, the University Centre of JINR has been offering post graduate training. The University Centre offers graduate programmes in the fields of nuclear physics, elementary particle physics, condensed-matter physics, theoretical physics, technical physics, and radiobiology.

Our strategic plan is to develop JINR as a kind of 'superuniversity' centre with the aim of training specialists from the JINR Member States and other countries. These specialists will be engaged in the research activities in Dubna, and may also join future megaprojects like the LHC, TESLA, and others.



**Fig. 6:** V.G. Kadyshevsky and A.N. Sissakian

#### **4 JINR's concept of development and the long-term research programme**

The JINR Programme of Scientific Research and Development for the years 2003–2009 was prepared from a proposal by the Institute's Scientific Council and under the guidance of the JINR Directorate. The full text of the Programme is available at the JINR web-site ([http://www.jinr.ru/years\\_7/](http://www.jinr.ru/years_7/)). This long-term programme of JINR was worked out after a 10-year interval during which only annual or three-year planning was carried out. This new planning points to the increased interest of the Member States in developing the future scientific strategy for JINR.

At present, the partners of JINR in its 18 Member States consist of 247 research and educational institutions, including 71 universities. The Programme is aimed at enhancing the scientific relations with all partners of the Institute, at creating favourable conditions for carrying out research, first of all, at the unique facilities of JINR, and also for supporting those experiments at other research laboratories where JINR staff make major contributions both to instrumentation and physics. This approach contributes to the strengthening of the position of the Joint Institute in those fields of research activities in which the impact of JINR scientists is internationally recognized.

The Programme reiterates that JINR will further develop as a large multidisciplinary international research centre, in which fundamental studies of the structure of matter are integrated with high-technology developments and with university education in related areas of knowledge.

In accordance with the JINR Charter, the fundamental studies will be focused on modern scientific problems in the fields of particle physics, nuclear physics, and condensed-matter physics using advanced experimental techniques. During the next 10 years JINR will meet the demands of a wide science programme, covering all research directions of the Institute.

The Programme is aimed at addressing key issues of natural sciences, including verification of the Standard Model, the search for new physics phenomena and regularities, synthesis of new elements and studies of nuclides close to nucleon stability, investigations in the physics of surfaces, studies of strongly correlated electron systems and of nanomaterials. These investigations will be combined with an effective theoretical, mathematical, and software support of experiments.

The main basic facilities of JINR, as indicated in the Programme, are the Nuclotron, the IBR-2 reactor, the U400-U400M cyclotron complex, and the facilities under construction — IREN and DRIBs.

The success of the long-term Programme greatly depends on the recruitment of young scientists and engineers. Therefore, the Directorate intends to develop a dedicated programme 'Young Staff at JINR'.

## **5 Conclusion**

In conclusion, we understand well that science is united. The methods, experience and knowledge accumulated in high-energy physics research could be useful in other sciences too. We should reflect on this in order to find an appropriate interface with other actively developing branches of knowledge, for instance astroparticle physics and cosmology, informatics, biology, quantum computers and others.

The multidisciplinary character of JINR provides for interesting results in overlapping fields of science. We have the full right to expect that in fundamental science and its application as well as in educational programmes JINR will continue to serve as a brilliant world centre.

## **Acknowledgements**

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