On the Long Term Strategy for JINR Development

Preface

The concept of strategy for further development of JINR (till 2030 and further on) as an *international* intergovernmental *scientific organization* should be based on the Charter-defined *main objective* of JINR, which is to unify the efforts, scientific and material potentials of the Institute Member States for investigations of the fundamental properties of matter.

The objective-attaining strategy unavoidably involves consolidation and augmentation of the unique JINR status of being one of the few major organizations in the world where basic research has been successfully and effectively carried out at the world's top level in an unprecedentedly wide range of important scientific directions for as long as 60 years [1].

The experience of the past hard years and logic of science development indicate that successful future of JINR is based on its unique traditions and fruitful unity of scientific research directions underlain by the time-proven pillars of fundamentality, internationality and multidisciplinarity.

The goal of this document is to develop an *image of JINR* attractive for the JINR Member States (*financial agencies, scientists, engineers, and students*) and beyond.

The image must be reliable, directed to the future, and attractive in all possible aspects –highest-quality science, education, innovations, comfortable and secure living conditions, atmosphere of mutually beneficial scientific creativity, etc. A JINR Member State should see clear advantage and benefit from investment of financial and human resources into JINR.

The conceptual target of the JINR scientific policy and development strategy is moving the current knowledge frontiers to new, unexplored areas, which is the goal of any basic research. Specificity of this new knowledge is to a large extent determined by the currently most important objectives of ***elementary particle physics***, a science of the most fundamental laws of Nature [2].

A strategic goal of elementary particle physics (together with astrophysics and cosmology) is to find the laws that govern the behavior of matter and its fundamental constituents, free from "disadvantages" of the modern Standard Model of weak, electromagnetic, and strong interactions.

The Standard Model cannot be considered as a consistent fundamental theory. It is only the "low-energy limit" of a more fundamental theoretical concept valid at all energy scales, including the Planck scale (10^{19} GeV) [3]. Therefore, the main sources of the decisive information for creating a ***new understanding of elementary particles*** (new picture of the world) are now considered to be the following:

- **Search for manifestations of new physics** at the energy frontier (supersymmetry, extra dimensions of space, new forces, new particles, etc.), first of all at the Large Hadron Collider (LHC) and later at new-generation accelerators and colliders (ILC, FCC, etc.).

- Clarification of the **dark matter** and **dark energy** nature.
- Astrophysical Studies **(through neutrinos and multi-messenger astronomy)**.
- **Indirect search for manifestations of new physics**, in particular by high-precision studies of lepton and hadron transformations breaking (**flavour**) family symmetry, and **precision neutrino physics.**

- Of great importance is the matter structure problem, which is now supposed to be solvable within **nonperturbative quantum chromodynamics**.

Elementary particle physics takes the central place in the JINR research programme due to its fundamentality and underlies both the world view and the methodology of all researches carried out at JINR, ranging from quarks, nucleons, and nuclei to molecules and entirely new materials. Particle physics stimulates the work of the JINR scientists in such related fields as information, communication, and computing technologies, radiochemistry, polymer, condensed matter, and complex compound physics, radiobiology, genetics, etc [4].

I. Flagship first priority projects

The 1st main strategic flagship project of JINR in the field of elementary particle physics *(accelerator particle physics of high energy)* is **NICA** (treated elsewhere)

The 2nd strategic flagship project is to obtain, through full-scale participation in the international ATLAS and CMS experiments at the **LHC collider**, fundamentally important results concerning the nature of the Higgs boson, properties of elementary particles (top quark), structure and main characteristics of quark–gluon QCD matter, existence of new physics at the TeV energy scale, such as supersymmetry, extra dimensions of space, and new types of particles and interactions.

In the longer term (after the LHC, beyond 2030) the JINR objective in the field of ultra-high energy particle physics is double faceted.

1) Looking for fundamentally new methods for production of particles with extremely high energies, with the aim of constructing an entirely new advanced accelerator complex for record man-made energies on its territory (after FCC and ILC). This will ensure high attractiveness of JINR for both the Member States and the whole world.

2) Ensuring the effective and visible participation in the top-level international projects at new colliders and new experimental facilities at CERN, in China, United States, Japan, etc. Here the problem of choice is aggravated by low interest of the Member States in investigations at future facilities “through JINR”. One should keep in mind that “JINR shares” at CERN are high now, mainly due to an appreciable contribution from JINR to the LHC machine and detectors.

Next, the **3rd, according to the *JINR Neutrino Programme***, main objective is to ensure the leading position of JINR in neutrino physics and astrophysics, the most fundamental and rapidly developing area of modern physics, both through the astrophysical researches at the **unique BAIKAL–GVD neutrino telescope** and multifaceted (basic, applied) investigations with **antineutrino beams at the Kalinin Nuclear Power Plant** and through creation of the advanced research infrastructure in Dubna.

More specifically, there are a few strategic objectives standing out:

Organization of a real collaboration – GNN (Global Neutrino Network) – between the Baikal project and other large experiments in this field (IceCube, KM3Net) with developing the data exchange protocol and algorithms, holding joint workshops, and creation on this basis of a global network for monitoring space in the neutrino channel with ensuring stable operation of this information channel within the multi-message investigation of space.

> *After being constructed, the Baikal–GVD kilometer-scale neutrino telescope will be used, due to its multifunctional infrastructure, not only for astrophysical objectives within the project, such as determination of ultrahigh-energy comic ray sources and generation mechanisms, but also for a wide range of geophysical, geological, applied, ecological, and other scientific economic objectives.*

Special efforts are needed to develop an ambitious scientific programme (with absolutely new ideas, projects, etc.) which could effectively use unique potential of JINR neutrino infrastructures at Baikal Lake and at the Kalinin Nuclear Power Plant in connection with new opportunities.

II. Flagship partnership

1) CERN

CERN and JINR share a long and successful history of collaboration, extending back to the earliest days of their existence. Most recently, the collaboration has taken place within the framework of the 2010 Co-operation Agreement covering further development of scientific and technical co-operation in their respective research projects.

CERN and JINR have concluded an important number of Protocols for the implementation of their co-operation, covering areas of particle physics, accelerator physics and technologies, educational programmes, administrative and financial tools, publication policies. **The 2010 Co-operation Agreement is directly addressing the desirability of developing a global network of accelerator laboratories.**

Currently, a significant number of countries are member states of both CERN and JINR. There are also examples of member states of JINR being associated members of CERN and vice versa. This “overlap” has a clear tendency of its further extension.

In 2014, CERN and JINR took a decision on the reciprocal granting of the Observer Status to each other in their supreme bodies – the CERN Council and the Committee of Plenipotentiaries of JINR.

Over last years, JINR has taken a number of steps to become integrated, with its projects and facilities, into the European Research Infrastructure within the framework of the ESFRI rules and procedures.

Taking into account all the above and considering the great challenge of building up a next major facility in Europe - the FCC collider, it looks strategically important to grant the FCC the **status of a partnership project of two international centers, CERN and JINR**. This will allow using material and human resources of these centres in the most effective way and also make groundless discussions of the necessity to choose between the two organizations and lay a solid basis for the long-term development of Particle Physics at CERN, JINR, and their partners.

2) Common development and common operation of research facilities and infrastructures (when it is profitable) in JINR Member States. SOLARIS (Poland), Modane LSM (France), and ELI (Extreme Light Infrastructure, Europe) are good examples (so-called Octopus-idea).

3) Participation of JINR in the implementation of the international flagship multipurpose neutrino project DUNE (USA) or in another DUNE-scale project (together with CERN).

III. Diversity (20 to 30% of JINR activities)

An organization like JINR must participate in a variety of important experiments elsewhere. This activity should not constitute more than 20 to 30% of the overall scientific activity. Examples:

1) Contribution of JINR scientists to the advanced international experiments (JUNO, EUREKA, DUNE, etc.) and creation of the advanced research infrastructure in Dubna.

2) Indirect search for new physics is to continue JINR's traditional investigations in flavour physics of quarks and leptons by fully participating in such world-class experiments as the study of the rare CP-violating kaon decay $K\to\pi\nu\nu$ and the precision search for muon-to-electron conversion on nuclei $\mu A\to eA$.

The Charged Lepton Flavour Violation (CLFV) phenomenon is traditionally under investigation at JINR, it is deeply connected with modern neutrino physics, in particular in the common direction of new-physics-search experiments.

Therefore, a strategical goal of JINR could be to gain advantages from simultaneous participation in the COMET (Japan) and Mu2e (USA) projects both (via rather different ways) aimed at muon-to-electron conversion on nuclei. Two very different JINR teams with absolutely different scientific trajectories came to the same idea – search for the mu-to-e conversion in nuclei. This additionally proves importance of the idea and guarantees that JINR will not miss the world important result of this study. Furthermore, a competition between these teams together with availability of results of g-2, mu-2-e-gamma, and mu-2-3e searches will allow reliability of the study. There is also a general possibility for the Mu2e experiment to measure muon-to-positron conversion (violation of lepton number equals 2 unities), which gives direct access to the absolute neutrino mass scale.

This also concerns participation in the most ambitious international experiments aimed at studying hadron, nuclei, and spin structure of hadrons (COMPASS, BES-III, PANDA), continuation of basic research in neutron physics, including measurement of fundamental beta decay parameters of the neutron (its lifetime and electric dipole momentum), and verification of the equality of the inertial and gravitational neutron masses both within the international collaborations at external ultracold neutron sources and at the IBR–2M pulsed reactor (and/or its successor).

It looks conceivable to dream about a completely new paradigm for "individual" hadron-hadron interaction study, instead using particle beams, when, for example, a direct access could be available to an event where one well-separated (ultracold) neutron interacts with another (ultracold) neutron or proton, producing together, say, a new hydrogen nucleus, or destroying a DNA molecule.

IV. Consolidation and attractiveness of JINR

This goes with a reduction of JINR participation in low-scale and low-importance projects in the field.

It is obvious that JINR needs to be renovated. Very modern, attractive, new, and forward looking image, with clear prospects of obtaining important results, especially for young employees, should be developed.

The list of these general steps could be the following:

– Maximum use of the potential of the available basic facilities and those under construction and their integration into the European and global research infrastructures.

– Conversion of JINR into an open international centre concentrating highly intellectual human resources of the world standard and providing adequate working conditions and social infrastructure.
– Enhancement of attractiveness of JINR as a research and education centre for JINR Member States by, for example, direct fusion of science and education, introduction of scientific studies into the educational process, invitation of highest-level scientists for work at JINR and participation in the educational process.
– Priority development of the information, communication, and computing infrastructure for maximum effective attainment of currently important objectives of JINR and physics research centres of its Member States.
– Establishment of a laboratory/centre for novel and interdisciplinary research (radiobiology and medicine, power engineering, etc.) and implementing the results in the Member States [6].
– Access, under certain conditions, to the experimental data from the applied and innovative researches at the JINR facilities [7] and to the technologies developed at JINR [8].
– Take special efforts to reduce the path from JINR basic research and new findings to their applications and use in industry and education [9].

IMPORTANT: Each above item should have its own “driver” responsible for its execution.

References and comments:

[1] *JINR is advanced superheavy elements physics, precision nuclear spectroscopy, materials and condensed matter physics, fundamental neutron studies, ultrahigh-energy particle physics, precision neutrino physics and astrophysics, theoretical and mathematical physics, information technologies, communications, and computing, advanced experimental techniques and instruments, biophysics, environmental studies, radiobiology, etc.*

A unique feature that makes JINR essentially different from CERN is the time-proven constructive triunity of fundamentality, internationality, and multidisciplinarity of the researches. Apart from European scientists, scientists from Asia, Africa, and Latin America have long been full participants in these researches, which extends scientific interests and scientific policy of JINR far beyond Europe.

Long-term stability of successful scientific research ensures extensive experience and high skills of the researchers, which, as a consequence, allows effective sharing of knowledge with the younger generation and guarantees a wide range of activities in applied science and innovation. This makes JINR attractive for young scientists of various nations: everyone finds an activity of interest and high scientific importance. And this is the basis for the future development of JINR.

Multidisciplinarity ensures continuous gaining of new experimental results. It underlies deep traditional cooperation of JINR departments and continuous exchange of experience, equipment, and ideas. It unites together all research directions by common values and relation to work, unified striving for fundamental knowledge within the framework of international cooperation defined as necessary and obligatory in the JINR founding documents.

Fundamentality of scientific research, and it alone, inevitably gives rise to new technologies, materials, instruments, thus improving the quality and safety of life.

[2] *Fundamentality of elementary particle physics extends from the structure of the smallest particles of matter to astrophysical scales of Space. The study of mutual transformations between sub-atomic particles gives a clue to the understanding of the laws that govern the Universe. For this reason, being the basis of modern astrophysics and cosmology, elementary particle physics plays a key role in the search for completely new knowledge without which further interplay of man and Nature can hardly be imagined.*

According to Bruno Pontecorvo, it is this most fundamental field that holds a tremendous potential for unexpected discoveries, which, as experience shows, are capable of radically improving the quality of life. Both the advanced methodology and the essentially unique instrumentation of elementary particle physics intrinsically enrich and stimulate development of modern natural science in all its aspects.

[3] *The Standard Model has too many external parameters and internal unsolvable problems, in particular vagueness of the electroweak symmetry breaking mechanism, absence of explanation for the stability of the Higgs boson mass (hierarchy problem), no place for gravitation within the Model.*

There is also a number of experimental data that are considered as indications of New Physics beyond the Standard Model. These are extreme smallness of nonzero neutrino masses (consequence of neutrino oscillations), baryon asymmetry, accelerating expansion of the Universe (dark energy), in which a lot of matter is found to be missing (dark matter), and a few so-called flavour anomalies ($H\rightarrow\mu\tau$, $B\rightarrow K\mu\mu$, $B\rightarrow D^{(*)}\tau\nu$, $B_s\rightarrow\varphi\mu\mu$, g-2, etc.).

[4] *It should be stressed that the particular physics goals of the JINR development concept discussed below are far from being random or arbitrary ("pulled out of a hat"). They are a logical consequence and natural continuation of the 60-year diverse successful research carried out by JINR at the nuclear physics frontier.*

It can be said that these goals have "sufferingly" resulted from hard work and genius of several generations of JINR scientists and engineers, and now, while preserving and augmenting this heritage, it is necessary to start attaining these ambitious goals. Actually, the scientific future of JINR is the improved continuation of its present.

[5] *The nonperturbative component of QCD is that extraordinary component of the Standard Model which is meant to explain from the first principles (e.g., by lattice calculations) the dynamic breaking of chiral symmetry (which generates over 98% of the visible baryon mass of the Universe), confinement effect, and entire nuclear physics. It is necessary to understand how hadrons (pions, kaons, protons, neutrons) are formed, mutually interacting, on the basis of quarks and gluons and how they form the diversity of atomic nuclei.*

It is quite possible that nuclear physics does not uniquely stem from our current understanding of QCD, yet it is obviously bound to rely on QCD for the simple reason that all protons and neutrons, all nuclei, and all matter are "made" of quarks and gluons.

[6] *Ultimately, in the long-term perspective, improvement or even advanced development of the experimental basis for medico-biological, radiological, and genetic research based on nuclear-physics methods (Life Science) seems greatly important for JINR as an international multidisciplinary scientific centre. By 2030, this direction will undoubtedly become one of the most important for JINR.*

[7] *This means granting access to the data obtained at JINR to the researchers who are not participants in the project (e.g., after a certain period). An example is the Hubble telescope. The open data policy has resulted in that the number of papers published by the authors of the project is approximately equal to the number of papers published by independent authors.*

[8] *A few years ago this policy was adopted by CERN. In simplified form, it is free use of technical and technological developments, including working drawings, but with an obligatory citation.*

[9] *Preparation of experiments at new-generation accelerators (ILC, CLIC) requires development of completely new types of detectors capable of operating under high fluxes for a long time while ensuring the required detection accuracy and reliability. Development of these*

detectors is important not only for high-energy physics. The future of biology, materials science, geophysics, and medicine is now closely associated with investigations using sources of synchrotron light and X-rays and other nuclear-physics techniques. This will require high-resolution recording systems and image sensors.

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