Input of Nuclear Physics Section, Division of Physical Sciences of the Russian Academy of Sciences to European Strategy for Particle Physics Update

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Abstract

This document summarizes the discussions of representatives of research institutes of the Russian Academy of Sciences, Joint Institute for Nuclear Research (international organization, Dubna) and Russian universities concerning the European Strategy for Particle Physics Update. The details of concrete projects are submitted by individual institutions and collaborations. This document does not, however, overview the input of National Research Center "Kurchatov Institute" which is being submitted separately and independently.

1 Introduction

The present situation in particle physics is both intriguing and challenging. The last element of the Standard Model, the Higgs boson, has been discovered at the LHC, and its properties, as of today, agree with the predictions of the Standard Model. Indeed, except for neutrino sector, all data of laboratory experiments are described by the theory layed down half a century ago. Yet we know that the Standard Model is incomplete, as it cannot explain dark matter and baryon asymmetry of the Universe as well as the tiny values of neutrino masses. Theoretical hypotheses on the extension of the Standard Model are numerous, and it is fair to say that none of them is entirely convincing. On the hadronic physics front, we still do not fully understand quark-gluon medium produced in heavy ion collisions, and possibly even in other hadronic collisions, and have troubles in interpreting exotic hadronic states involving heavy quarks.

Particle physics is again experimental science.

It is impossible to predict where and when the discoveries of New Physics will be made, whether breakthrough will come from experiments at highest energies, or at highest intensities, or at highest precision, or in the domain of astroparticle physics. This calls for the emphasis on the **diversity** of experimental and also theoretical research. The breadth of approaches implies also geographical diversity, with experiments at various laboratories complementing each other. In this regard, the coordination of research and, in particular, the Upgrade of ESPP is very welcome.

Recommendation. **This ESPP Upgrade should emphasize the diversity of research in particle physics, the complementarity of studies at large international laboratories (CERN, JINR) and smaller scale facilities at national labs and universities, the integrity of particle and astroparticle physics.**

Russian and JINR particle physics community considers itself an integral part of European and world-wide community and is committed to work together towards new discoveries. We look forward to the new CERN–Russia Agreement that will provide new opportunities for the collaboration between Russia and CERN. We consider highly valuable the mutual observer status of CERN and JINR. Of great importance are also bilateral agreements at governmental and institutional levels between Russia and other European countries and between JINR and European countries and institutions.

2 Energy frontier

With the completion of the Standard Model, search for deviations from it as well as for entirely new phenomena at the highest energies is certainly a priority. The case for New Physics at either LHC energies of at energies of the next hadron collider is still strong.

Russia/JINR particle physics community is proud of contributing to the success of the LHC and its experiments. JINR and Russian institutions involved in the discussions are unanimously committed to the continuation of their participation in the LHC experiments, and look forward to making substential contributions to the upgrade towards HL-LHC and participating at the HL-LHC phase.

On the other hand, the moment of this Strategy Update is crucial for the future of the field. The decision on the next particle collider at CERN should be made soon, in order that the timely R&D program of appropriate scale gets started. Russia/JINR community is going to actively participate in the discussions of this issue, within both this Strategy Update process and other frameworks. Russian research institutes and technology centers, as well as JINR, will contribute to the design of key elements of the machine and detectors, including development of high field magnets.

Recommendation. **This Update of ESPP should reaffirm that HL-LHC is the highest priority. This Update should also give start to a full scale R&D program towards the future high energy collider at CERN.**

3 Hadron/quark-gluon physics

Experiments with heavy ions at Brookhaven and CERN, notably ALICE, and also ATLAS and CMS, with strong participation of Russian and JINR physicists, revealed many unexpected and often controversial properties of quark-gluon and hadron matter at high temperatures and densities. Continuation of these studies at CERN is expected to lead to new insights. Importantly, under construction are new facilities – NICA at JINR, Dubna, and FAIR at Darmstadt, which will give very valuable and complementary information on the properties of quark-gluon matter, especially at high baryon number density. The construction of NICA heavy ion collider facility is well under way, and the international collaboration at NICA is strong and growing. The experiments at NICA will make crucial contributions to our understanding of the nuclear matter equation of state, the onset of deconfinement and/or chiral symmetry restoration, phase transition, mixed phase and the critical end-point, possible local parity violation in strong interactions. The second phase of NICA involves the studies of the nucleon spin problem and polarization phenomena in polarized proton and deuteron interactions at high intensity and high polarization ($> 50\%$) of the colliding beams.

Recommendation. **Along with ALICE, the Strategy Update should give high priority to NICA and FAIR in the domain of hadronic physics and encourage even stronger participation of European hadronic physics community in these projects.**

4 Intensity/precision frontier

4.1 Flavor physics

It is quite conceivable that New Physics will show up in precision studies of b-quarks, τ-leptons and/or c-quarks. The complementary studies in this domain at e^+e^- machines in operation or under construction and at LHC-b have strong potential in revealing the new phenomena. Furthermore, the discovery of exotic charmonium states $X(3872)$, $Y(4260)$, $Z(3900)$, etc., became a surprise and calls for their precise and systematic measurements.

The continuation of the study of rare kaon decays, notably, at NA62 experiment at CERN, is also promising from the viewpoint of the search for New Physics. Overall, vigorous program on flavor physics at CERN and elsewhere deserves strong support.

Russian and JINR physicists are committed to continue collaboration in these experiments. A new player in this area may become Super Charm-Tau Factory proposed and developed at Budker Institute for Nuclear Physics, Novosibirsk. This is a e^+e^- collider in the c.m. energy range from 2 GeV to 6 GeV with unprecedented luminosity 10^{35} cm^{-2}s^{-1}. Construction of this machine would give an excellent opportunity to search for New Physics, notably, in rare τ-decays, and investigate hadronic physics with charmonia, open charm mesons and charmed baryons.

Recommendation. **Vigorous program on flavor physics at CERN and elsewhere should be maintained and strengthened. Super Charm-Tau Factory project at Novosibirsk should be supported.**

4.2 Search for weakly interacting particles

Search for weakly interacting particles has profound motivation by the existence of dark matter in the Universe. Revealing the nature of dark matter is the challenge to particle and astroparticle physics community, whose scale is similar to the scale of the discovery of New Physics at high energies.

Search for "traditional", heavy WIMPs has not exhausted its potential. JINR physicists are committed to continue their participation in international collaborations in this area, notably at Gran Sasso (Dark Side) and Modane (EDELWEISS). On the other hand, the emphasis of search for dark matter constituents is shifting towards light and very weakly interacting particles, such as axions and axion-like particles, sterile neutrinos, dark photons, etc. Given the huge uncertainties in theoretical expectations, a broad program of search for such particles is a must. Russian physics community is interested in participation in both relatively small projects (TASTE and IAXO – search for axion-like particles, Troitsk nu-mass – search for sterile neutrinos, etc.) and larger scale experiments, notably, SHiP. At the same time, R&D program in this domain is to be extended.

Recommendation. **The Strategy Update should emphasize the importance of this area and welcome both smaller scale projects and larger experiments including SHiP.**

5 Neutrino physics

Russian and JINR physics community has strong involvement in experiments in neutrino physics ranging from search for neutrinoless double beta decay (in particular, with germanium detectors) to neutrino mass measurement (KATRIN) to reactor and accelerator long baseline experiments (JUNO, T2K/T2H, DUNE) and search for sterile neutrinos (DANSS experiment at Kalinin Nuclear Power Plant, BEST experiment at Baksan Neutrino Observatory of INR RAS). This area of research is of great interest not only for particle physics but also for cosmology (neutrino masses are of direct relevance to structure formation in the Universe; CP-violation in neutrino transitions would support, albeit in a model-dependent way, the leptogenesis mechanism for the generation of baryon asymmetry, etc.). The world-wide neutrino program is reasonably well defined and has ambitious, but well identified targets, among which particularly challenging but extremely important are the determinations of the type (Majorana or Dirac) and values of neutrino masses.

Recommendation. **The Strategy Update should support long baseline experiments and at the same time give high priority to neutrinoless double beta decay search and direct measurement of neutrino mass.**

6 Astroparticle physics

Rapidly developing field of astroparticle physics is tightly connected with particle physics proper. The reasons are numerous: both aim at discovering the most fundamental properties of our world; both have very much in common in the experimental methods they use; both require development of large scale infrastructure, as well as computer resources; individual scientists, both in theory and experiment, often move from one field to another, so that particle physics and astroparticle physics communities have substantial overlap. And, indeed, a number of discoveries in particle physics came out from astroparticle domain (a relatively recent example is neutrino oscillations first observed in solar and atmospheric neutrino experiments).

Russia/JINR physics community is particularly strongly involved in multimessenger astrophysics. One of the messengers – high energy neutrinos – is studied at large scale underwater and under-ice detectors Baikal-GVD (Gigaton Volume Detector), KM3Net and IceCube. These three are integrated into Global Neutrino Network. In particular, Baikal-GVD collaboration with the leading role of Institute for Nuclear Research of the Russian

Academy of Sciences (INR RAS) and JINR includes a number of institutes and universities from Russia, Slovakia, Czech Republic and Germany. Baikal-GVD construction is well underway, with 3 of its clusters already in operation and the first phase totaling 8 clusters (volume 0.4 cubic kilometers) planned for 2020. The second phase is foreseen in 2021-2025 at which the number of clusters will increase to 20 and volume to 1 cubic kilometer. Together with KM3Net, Baikal-GVD will have excellent opportunities to study high energy neutrinos, notably, to determine their arrival directions with high precision. Thus, we are witnessing a major breakthrough in high energy neutrino astrophysics which started with the first detection of cosmic high energy neutrinos by IceCube.

Gamma ray detectors are dedicated to the study of the second messenger – high energy photons. Among these are Carpet array at Baksan Neutrino Observatory of INR RAS whose first phase is in operation and the second phase is due to start in 2019, international project TAIGA at Tunka Valley in Siberia, with leading role of the Moscow State University and JINR, and CTA. In particular, TAIGA observatory will have excellent sensitivity to cosmic photons with energy exceeding 100 TeV, with applications to the study of sources of high energy photons, gamma-ray absorption on the intergalactic background radiation, searches for axion-photon transitions, hidden photon/photon oscillations etc. Its prototype is due to be operational also in 2019.

The third messenger – ultra-high energy cosmic rays (UHECR) – have the longest history of its studies. Currently, research on UHECR is dominated by Pierre Auger Observatory and Telescope Array (the latter with Russian participation). The next step may be the construction of K-EUSO cosmic ray observatory onboard of the International Space Station, the project lead by the Moscow State University. The feasibility of the detection of UHECR from space has been demonstrated already by TUS experiment onboard of Lomonosov satellite.

Among other facilities on Russian territory is the complex NEVOD at Moscow Institute for Physical Engineering which already has good opportunities for studying muons originating from cosmic rays and whose substantial development is proposed for 2019 – 2026.

Finally, INR RAS has proposed the New Baksan Neutrino Telecope (NBNT) to be built at its Baksan Neutrino Observatory. It is a 10 kt liquid scintillator detector located at depth of 4760 meters water equivalent. This is the only large volume underground detector proposed in Europe, and its scientific capabilities are outstanding, indeed. This is due, in particular, to its unique location deep underground and away from nuclear power stations. It is foreseen that NBNT will become a part of network of deep underground neutrino detectors which will include HyperKamiokande, JinPing, JUNO, SNO+.

Recommendation. **The Strategy Update should include astroparticle physics section as its integral part. In particular, Baikal-GVD and TAIGA should be supported. The progress with K-EUSO should be welcomed, as well as the development of NEVOD. The R&D program towards NBNT should be encouraged.**