RECOMMENDATIONS OF THE JOINT SESSION OF THE PAC FOR PARTICLE PHYSICS AND THE PAC FOR NUCLEAR PHYSICS FOR THE ASSESSMENT OF THE JINR NEUTRINO PROGRAMME

On 22 January 2019, the PAC for Particle Physics and the PAC for Nuclear Physics held a joint session for the assessment of all projects and research themes carried out at JINR in the area of neutrino physics, astrophysics and dark matter, hereinafter referred to as the JINR Neutrino Programme.

The PACs thank DLNP Director V. Bednyakov for the comprehensive overview of the JINR Neutrino Programme.

The JINR Neutrino Programme was already reviewed by the PACs in June 2014. The PACs reiterate all the recommendations of the previous joint session, in particular:

– "neutrino physics and astrophysics constitute one of the main research activities at JINR. This research direction is of strategic importance and has very intriguing potential for discoveries and exciting results in the near and further future;

– the PACs encourage the DLNP Directorate to accelerate their efforts towards reduction of research topics of lower priority and concentration of all possible resources (human, financial, intellectual) in selected directions as far as the JINR Neutrino Programme is concerned;

– in particular, DLNP is encouraged to prioritize all the neutrino projects in which JINR is involved according to the following criteria: (i) scientific merit and discovery potential, (ii) resources involved (manpower and finances), (iii) visibility of JINR participation, (iv) competitiveness and timeliness with other international projects".

Recently, six projects of this Programme were evaluated separately by the PAC for Nuclear Physics in January 2018 whereas seven other projects were reviewed by the PAC for Particle Physics.

At the present session, all projects of the JINR Neutrino Programme have been jointly evaluated by the PAC for Particle Physics and the PAC for Nuclear Physics with the ultimate goal to classify them into three categories A, B or C, based on the scientific merit of the project and the performance of the JINR group involved:

Category A: excellent projects, which should be fully funded with adequate resources and encouraged to continue and expand their impact;

Category B: very good projects, but with some weaknesses. They should be funded together with a strong recommendation on where improvement is needed;

Category C: good projects, which demonstrate relatively low performance.

The project leaders were requested to answer a common questionnaire prepared by representatives of the two PACs in coordination with the JINR management. The PACs thank the project leaders for the timely submission of the answers and appreciate the work that has been done in preparing them. Each project was reviewed by one referee from the PAC for Particle Physics and one from the PAC for Nuclear Physics. The questionnaire itself and both the questionnaire answers and the referee reports are uploaded to the Indico webpage of the joint session. The final assignment of each project into category A, B or C has been done taking into account the opinions of the two relevant referees and the subsequent discussion of the project.

COMET. The purpose of the experiment at the J-PARC accelerator in Japan is a sensitive search for the lepton flavor violating neutrinoless conversion of muons into electrons in the nucleus field ($\mu^- + N \rightarrow e^- + N$). A measurement at the level of 10^{-17} for conversion is a factor of 10000 better than the current experimental limit. The technical support and contributions by JINR to the construction of the electromagnetic calorimeter (ECAL, now with LYSO crystals) and the straw tube tracker are very important and decisive for the success of COMET. Nevertheless, with about 30 scientists, the JINR group should be much more ambitious. If JINR wants to get credits on the future results and to obtain a strong scientific visibility, more commitments must be taken for running the full apparatus, data taking and analysis of the experiment, and more resources may be necessary at this stage.

Daya Bay/JUNO. The research includes participation in the Daya Bay neutrino reactor experiment in China and in its larger scale follow up JUNO project. Daya Bay has discovered a non-zero θ_{13} angle, while JUNO is expected to make a sensitive measurement of the neutrino mass hierarchy. Both are unique experiments representing in their respective fields an absolute scientific reference. The JINR contribution to the Daya Bay experiment is significant and includes development of selection algorithms, data analyses for the most precise determination of θ_{13} and Δm^2_{32}, and more precise measurements of the reactor antineutrino energy spectra. For the future of JUNO, the tasks of the group are also significant and include realization of testing facilities for the PMTs, R&D work on the tracking detector and manufacturing the HV power supply. For the future, the group is encouraged to focus on major data analysis topics. Although most of the group is involved in the preparation of JUNO, one should not neglect the potential scientific output of Daya Bay, mostly in relation to the possibility of high-quality student theses.

NOvA. The NOvA experiment at Fermilab aims at a detailed study of neutrino oscillations with main goals being the determination of the neutrino mass hierarchy and checks for CP violation phase of the PMNS mixing matrix. The JINR group provided several excellent contributions in electronics and liquid scintillator test benches in house, a Remote Operation Centre at JINR for monitoring and shift operation, and a GRID/Cloud infrastructure for data processing. JINR scientists are also involved in some mainstream and exotics data analyses. The number of talks at conferences is sufficient for a group of 24 scientists. The group should focus on a higher impact role in relation to the future operation of the experiment by participating in some of the forthcoming leading analyses, and in some of the many exotics studies that could be proposed and carried out from the huge data statistics.

BOREXINO. The main goals of the BOREXINO experiment at the Gran Sasso underground laboratory is the study of solar neutrino fluxes and measurements of the solar fluxes with improved precision in the experiment Phase-II. The JINR group contributed in the past to several activities: construction of a prototype of the BOREXINO detector (CTF) and its further exploitation, development and operation of the PMT test facility, operation of the main detector and some data analysis activities. The group intends to work on future data analysis, in particular on the improvement of the studies on the ^{7}Be spectrum, on geoneutrinos and on CNO neutrinos. All conference talks were given by two members of the group and most of the talks were not given at important international conferences. The group is rather small (9 people with 4.6 FTE) and is going to be further reduced with the departure of the graduating PhD student, which contributes 0.5 FTE.

TAIGA. The main goal of the Gamma ray Observatory TAIGA is to study gamma-radiation and charged cosmic rays in the energy range of 10^{13} eV – 10^{18} eV. It is an international scientific project searching for the origin of sources of Galactic cosmic rays with energies above 1 PeV. The northernmost location of the facility gives it some advantages compared to other experiments with similar scientific goals. The first phase of TAIGA will begin observations in 2020, a few years earlier than other competing projects. The JINR team has full responsibility in the imaging atmospheric Cherenkov telescopes (IACT) design, mechanical manufacturing and tests; it is also responsible for tests of all 1200 PMTs for two IACT telescopes. The PACs recommends expanding the group activity to the analysis of specific physics problem. The group should increase the number of publications in the refereed journals (including also methodological results) and the number of PhD students.

Mu2e, g-2. The JINR group is involved in two Fermilab's experiments at the forefront of the international research in the field, both looking for small deviations from the Standard Model: Mu2e is searching for the highly suppressed ($\mu^- + N \rightarrow e^- + N$) reaction, while g-2 is aiming at a precise measurement of the muon anomalous magnetic moment, i.e. to establish the observed deviation from the SM at the 5σ level. The main contribution of the group is the participation in the construction of the cosmic ray veto system and in some work for the crystal ECAL for Mu2e. However, the visibility and the level of commitment in the two projects should be improved. Moreover, the consumable/equipment budget for the next 2 years (~320 K$) is not sufficient to provide a sensible construction contribution for the two large collaborations. Finally, the group does not have an adequate number of scientific and managerial responsibilities within the collaborations.

SuperNEMO. The SuperNEMO Demonstrator, which is the first module of the SuperNEMO experiment, is mounted in Modane underground laboratory (France) and aims at searching for neutrinoless double-beta decay (0νββ) of ^{82}Se in order to unveil the nature of the neutrino. The new-generation SuperNEMO detector will have a modular design (20 modules) with the ability to measure simultaneously several isotopes at a sensitivity level to the half-life of $T_{1/2}$ (2β0ν) ≥ 10^{26} years. The JINR contribution includes production of plastic scintillators, calorimeter and tracker construction, development of a new facility for radiochemical purification of the enriched ^{82}Se, purchase of the detector components and participation in the data analysis. The JINR has a long and successful history of involvement in the NEMO experiments. The current output in the form of talks at international conferences and PhD theses should be improved. The JINR group should strive to have the same impact on the SuperNEMO analysis as on NEMO-3. The involvement of young people on data analysis will allow JINR to have a sizable impact commensurate to the level of hardware development and investment.

GEMMA-III. The GEMMA project aims at investigating fundamental properties of neutrinos such as the Magnetic Moment of Neutrino (MMN) and Neutrino Coherent Scattering on Nucleus. The first phase of the project (GEMMA-I) set the world best upper limit for the MMN of < $2.9 \cdot 10^{-11} \mu B$ (90% CL). GEMMA-III is expected to improve this limit by a factor of 5. The GEMMA-III experimental set-up is installed at 10 m from the centre of the reactor core of the Kalinin Nuclear Power Plant (KNPP) under an antineutrino flux of more than 5.10^{13} $\nu/cm^2/s$. First results with an initial set-up consisting of four low threshold HPGe detectors (total mass 1.6 kg) are expected mid-2019. Thanks to the successful development of the detectors and the location in the KNPP, the project is visible in the global competition on the search for neutrino scattering on nucleus and on the limit on MMN. In view of the competing experiments, the team is encouraged to increase the detection volume much more than anticipated, thus reducing the running time of many years and achieving the objectives in a competitive time scale. For that, the team should be enlarged in terms of FTE. The team should also be encouraged to publish more.

EDELWEISS-LT. The experiment conducted in the underground laboratory of Modane (France) is focused on the direct search for weakly interacting massive particles (WIMP) from the galactic halo considered to be the main candidate of dark matter. The JINR group is responsible for the low background radon/neutron/alpha detectors — their development, operation, maintenance, data acquisition, monitoring and analysis of data. It plans to continue these activities for the next stage of the experiment. The total FTE of the group of 12 researches and engineers is 5. The research staff, including students, involved in data analysis should be higher in order to ensure a more visible impact on the collaboration and a larger share in the number of conference talks.

G&M (GERDA). The GERDA (GERDA&MAJORANA) is dedicated to search for the neutrinoless double-beta decay of ^{76}Ge with open Ge-detectors directly immersed in liquid argon. This project is part of a large international collaboration located at Gran Sasso in Italy. Observation of neutrinoless double-beta decay would be a major breakthrough in the current understanding of the laws of physics. The JINR group is responsible for design, production, testing and installation of the plastic muon veto system. It is participating in the development of LAr instrumentation, in the analysis of GERDA data, and is playing leading roles in the detector upgrade and its operation.

However, the output of the large team (17 scientists) in the form of talks at international conferences could be improved, and the number of PhD degrees (no degrees awarded) is insufficient and not up to standards.

BAIKAL-GVD. The project aims at the detection of high-energy galactic and extragalactic neutrino events in Lake Baikal water instrumented at depth with optical sensors. It detects the Cherenkov radiation from secondary particles produced in interactions of high-energy neutrinos inside or near the instrumented volume. The special features of BAIKAL-GVD compared to other running (IceCube) or planned (KM3NeT) international projects are the complementarity of the experimental set-up, the ability of looking at a different portion of the sky, and the contribution to the Global Neutrino Network by adding valuable statistics to the other projects. It is a flagship JINR project with large involvement and level of commitment. Many hardware aspects are under the leadership of the JINR group, such as the work on the optical modules, the readout and synchronization systems. The future plans include, in particular, realization of a test facility for optimization of the module construction. The relatively low number of publications reflects the present phase of the experiment. For the future, one should expect a more visible participation with talks given at major international conferences. Efforts should be made to attract more internal resources and mostly young and motivated students. For projects like BAIKAL-GVD it is essential that the financial plan be ambitious enough to stay well above the threshold to have a meaningful and rewarding contribution from the JINR group.

DANSS. The DANSS spectrometer is mounted at the Kalinin Nuclear Power Plant. In addition to the initial goal of reactor monitoring, the detector has the capability to search for short-range neutrino oscillation to a sterile state. The main contributions to the detector are coming from JINR. They include 2500 scintillators strips associated to 2500 SiPMs, an active muon veto, slow control, shielding and acquisition electronics. It is planned to develop and construct two new neutrino detectors S^3 (S-cube) using better scintillator material with 4 times more light output. Presently, the DANSS experiment obtained the best limits on the reactor neutrino oscillation to sterile neutrino parameters. The DANSS project and the plans of the group in the future are worth being pursued till solution of the sterile neutrino issue. The group should concentrate its efforts on the running and analysis of the DANSS and S^3 experiment in order to secure its globally leading position before it considers other projects.

<u>NA64.</u> The NA64 experiment is a fixed-target experiment at the CERN SPS specially designed for a direct search for the dark photon decay process A’ → invisible. The JINR group is responsible for the design, production, tests and installation of 14 straw tube chambers, together with their data acquisition software, raw data decoding, online monitoring and visualization, reconstruction and Monte-Carlo simulation. The members of the group participated in the data taking runs and took care of the operation of the straw tube detector. Excellent progress has been made by the team in the process leading to the installation and final preparation for the data taking stage. However, it would be most encouraging to see a plan put forward for potential student participation leading to PhD theses. It would also be encouraging to see the JINR team playing a leading role in physics analyses. Furthermore, the relative number of FTE (4.7 for the team of 13) should be higher for a visible and more efficient impact.

Finally, after this evaluation carried out jointly by the PAC for Particle Physics and the PAC for Nuclear Physics on the basis of scientific merit of the projects and the performance of the JINR group involved, the projects in the area of neutrino physics, astrophysics and dark matter were classified as follows:

Category A: BAIKAL-GVD, DANSS, Daya Bay/JUNO, NOvA;

Category B: COMET, EDELWEISS-LT, GEMMA-3, GERDA, NA64, SuperNEMO, TAIGA;

Category C: BOREXINO, Mu2e, g-2.

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