Gradignan, January,18 2021

Report on Non-Accelerator Neutrino Physics and Astrophysics theme

The "Non-Accelerator Neutrino Physics and Astrophysics" theme is conducted at JINR by the Department of Nuclear Spectroscopy and Radiochemistry. It has a long and strong expertise on nuclear spectroscopy, neutrino physics and related technical development. The team has focused a part of its activities on the search of rare events to tests neutrino properties and to have better understanding of our Universe by detecting high energy neutrino from astrophysical objects in Baikal lake and to look for dark matter under the form of Weakly interactive Massive particles.

Double beta decay program.

It concerns two experiments SuperNEMO and LEGEND. The goal of these experiments is to determine the nature of the neutrino and possibly to measure the mass of the neutrino looking for neutrinoless double beta decay. There is a strong international competition on this field. The present lack of prediction from the theory to predict the most favorable nucleus and the favorized process (light neutrino exchange, majoron exchange, heavy neutrino exchange, decay to excited states or exotic modes) oblige to study various techniques and various isotopes.

SuperNEMO

The team participate to SuperNEMO with the unique feature to measure the full kinematics of the double beta decay (individual energy of the 2 emitted electrons, angular distribution) allowing to reduce background and to access to exotic decay as well as to a large range of isotopes. The contribution of the team is impressive: enriched selenium, purification of selenium source, scintillators, photomultipliers, electronics, shielding…. It must be noted also the strong involvement of the team in the analysis of NEMO3 where the JINR analysis has been very often the reference for the publications. NEMO3 has obtained the best world limit for several double beta decay emitter on the neutrinoless double beta decay and measured several 2-neutrino double beta decay periods. The group has developed new universal method of purification for double beta decay isotope. It has also initiated the R&D for the enrichment by centrifugation of ^{150}Nd et ^{96}Zr which could open a new window for double beta decay search. In order to have a strong involvement in the data analysis of SuperNEMO and to ensure a full return on investment, the team should consider to attract more young people and to have more presentation in conference by JINR staff.

I recommend to support this experiment with the highest priority.

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GERDA (LEGEND)

The participation to LEGEND is also very visible. This experiment is based on the use of Germanium diodes enriched in ^{76}Ge. Such detectors have very good energy resolution. The collaboration has already showed its capabilities to reduce drastically the background with the GERDA experiment, predecessor of LEGEND. GERDA has obtained the best world limit in term of half-live and one of the best limits on neutrino mass. The LEGEND project will have a first phase with 200 kg and the final goal is to accommodate 1 ton of enriched germanium. LEGEND-200 should improve by a factor 10 the present limit on 76Ge and LEGEND-1000 should improve it by 2 order of magnitude if background improvements are successful. JINR Dubna contributes on the procurement of raw material, R&D for the detector, part of the detector to reduce external and internal contamination during installation and operation, responsibilities on the muon veto system,… The team was also involved in the data analysis of GERDA and must be also a major actor for the LEGEND analysis allocating enough manpower.

I recommend to support this experiment with the highest priority.

Monument

The Monument (Muon Ordinary capture for the Nuclear Matrix elements in ββ decays) project is of great interest for neutrinoless double beta decay search and very complementary with the participation of the SuperNEMO and LEGEND experimental programs. Indeed, an issue for the theory in double beta decay is the nuclear matrix calculation to predict the most favorable nucleus et to have a correct interpretation of the data to estimate related parameter (neutrino mass, Majoron coupling,…). Since several decades, the JINR group is involved at PSI in muons capture based experiments. This project lead by. JINR aims to use muon capture to populate nuclear level of the intermediate nucleus and to measure the emitted gamma-rays to extract information to improve theoretical predictions. A by-product of such experiment is also the measurement of x-rays associated to the capture to identify target nucleus. JINR provide all experimental equipment as well as the isotopically enriched targets. The program of measurement is large and may be some priorities should be presented.

Tests at PSI in 2019 have demonstrated the feasibility of such experiment. This project will provide essential data for theory in double beta decay nuclear matric element calculation.

I recommend to support this experiment with the highest priority.

High energy neutrino detection

BAIKAL-GVD experiment

The Baikal lake is a unique place with fresh water to install a neutrino telescope to detect high energy neutrinos from astrophysical objects and from the atmosphere. Recent progress in gravitational waves detection, gamma-astronomy have opened the era of multi-messenger physics to characterize astrophysical sources. In this picture, the detection of high energy neutrino is essential to understand fundamental process occurring in these objects, in particular the way to accelerate particles.

The JINR is the leader of the Baikal -GVD experiment with a strong involvement on construction, installation, operation, simulations and data analysis. Presently 7 clusters are installed and final setup with

12 clusters should be in operation in 2023. The performance reached by this first phase will determine the possibility of a second phase and the attractivity to enlarge the collaboration.

I recommend to support this experiment with the highest priority.

Reactor neutrino program and dark matter search

The neutrino reactor program (*νGEN, DANSS, RICOCHET)* is performed at Kalinin Nuclear Power Plant and at ILL. It aims to measure neutrino coherent scattering at low energy, to search for neutrino magnetic moment and to verify the hypothesis of a fourth neutrino type to explain the measured deficit electronic anti-neutrino flux from nuclear reactors compared to the predictions. The search of dark matter is performed at Modane Underground Laboratory in the frame of EDELWEISS experiment looking for Weakly Interactive Particles interaction in Germanium bolometers. All these experiments are done in a very competitive global context.

Project νGEN

The aim of *νGEN* (Investigation of neutrino properties with the low-background germanium spectrometer) project is the search of non-standard neutrino interactions. It is done by studying coherent neutrino scattering at low energy and by looking for the Magnetic Moment of the Neutrino (MMN). The experimental setup consists in Germanium detectors with a good energy resolution and very low threshold. The first phase allowed to improve the limit on the MMN for neutrino from reactor. It is planned to use a total mass of 5.5 kg with new detectors that could allow to improve MMN limit by at least a factor 2. They will be installed in a shielding at Kalinin Nuclear Power Plant (KNNP) at about 10 m from a commercial reactor with an overburden of 50 meter water equivalent. The electronics will improve as well as the muon veto to improve the background. The same detector will be used to measure the neutrino coherent scattering at low energy to look for deviation from standard model. In the future, developments are planned to reduce background, to lower energy threshold and to increase target mass.

This project has been proposed, developed and realized by JINR group using the unique opportunity to have an access at the KNNP site. It is fully competitive with other projects in the world.

I recommend to support this experiment with the highest priority.

Project DANSS

The DANSS (Detector of the reactor Anti-Neutrino based on Solid state plastic Scintillator) project based at KNNP site. The objective of the project is to check the claim of the existence of sterile neutrino from the re-analysis of the neutrino reactor experiments by G. Mention et Phys.Rev.D83:073006,2011. The JINR has designed and build an experiment based on a segmented detector made of plastic scintillator bars read by an optical fiber connected to a photodetector. The detector is placed on a mobile device allowing to change the distance from the nuclear core by 2 meters to compare the data at different position. DANSS has obtained results excluding the hypothesis of a sterile neutrino for a large part of the expected region in the plot Δm^2_{14} vs $\sin^2\theta_{14}$. The results have been presented in international conferences. It is planned to improved the DANSS-2 detector in particular the energy resolution to enhance the sensitivity. It is expected to be completed mid-2022 and to take data for several years. In parallel, the group collaborate with Czech colleagues to develop a new detector S^3 to study systematics related to the neutrino flux.

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This project lead by JINR group has strong international visibility and the scheduled improvement will allow to keep it in the global competition.

I recommend to support this experiment with the highest priority.

Project EDELWEISS/RICOCHET

The both projects are based on the same detectors: Germanium bolometers recording heat and ionization to distinguish the type of the interacting particle and with high capability of background reduction. Improvement has been done on this detector, in particular for the energy resolution, the background and acquisition. These developments were performed to improve the sensitivity of EDELWEISS detector for the detection of Dark Matter as Weakly Interactive Massive particle. EDLWEISS consists in an array of germanium bolometers installed at Modane Underground Laboratory. The ultimate sensitivity, if the experiment is free of other backgrounds, will be limited by the interaction of solar neutrino in the detector. The project will take advantage that the new Ge bolometers can be used either in EDELWEISS experiment and in the RICOCHET project. The RICOCHET project will measure the low energy neutrino coherent scattering at ILL reactor. The objective is to measure the cross section with an accuracy of 1% to look for deviations compared to the expected cross section predicted by the Standard Model. It gives also the opportunity to characterize neutrino interaction in the detector to better study the response of the detector to neutrino interaction in the view to develop a strategy to reduce potential background from solar neutrino in the Dark Matter search.

The JINR group is collaborating since long-time in the EDELWEISS experiment with contribution on hardware, installation, operation and analysis. The participation to RICOCHET is a very good opportunity to participate to the first measurement of low energy neutrino coherent scattering; complementary to the νGEN experiment done at KNNP. It permits also to prepare the next phase of EDELWEISS for dark matter search by testing the new bolometers and studying neutrino background. The schedule of the project is well defined.

I recommend to support this experiment with the highest priority.

General comments

The proposed program addresses important issues for present particle physics and cosmology. The participation to leading experiments shows the level of expertise reach by this team as well as their international recognition. This team has leadership in several of the experiments presented in this theme. It uses international installations (Gran Sasso, Modane Underground Laboratory, ILL, PSI) as well as national or local infrastructure (Kalinin nuclear power plant, Baïkal lake) to perform their experiments in the best environment. Its scientific strategy is clear and focused on neutrino properties measurement, detection of high-energy neutrino and search of dark matter which are nowadays essential questions in particle physics. This group has strong competences and expertise in experimental techniques for rare events detection related to the low radioactive techniques, photo-detection and Germanium based detectors. The scientific program is based on the complementarity of the experimental approaches as well as the access to local or international facilities. The contributions on each experiment are important

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and for some of them, the JINR group has the leadership (Baikal-GVD, KNNP activities). The group has a strong impact in the data analysis of each project and this potential must be kept and reinforce in the future.

In conclusion I recommend full support to the activities of the theme.

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