Project Review

Neutrino Oscillation Research in the JUNO Experiment (JINR Participation) Project Prolongation for 2021-2023

The JUNO experiment has a wide scientific programme, including the determination of neutrino mass hierarchy, measurement of lepton mixing parameters, search for proton decay, study of Supernova (SN) neutrinos, and also neutrinos from other sources. All these questions are of high priority in contemporary particle physics, and their solving will enable scientists to fill in the “blank spots” within the Standard Model, and maybe even reach beyond it.

The JUNO experiment represents a high-sensitivity neutrino detector located 52 km away from the Yangjiang and Taishan Nuclear Power Plants (NPPs) with total power of 26.6 GW tuned to detect a neutrino flux and to reconstruct their energy spectrum. The Central Detector (CD) comprises 20 tonnes of liquid scintillator in the acrylic sphere with the diameter of 35 m, and 78% of the sphere surface are viewed by 18 000 20” photomultiplier tubes (PMTs) and 26 000 3” PMTs. The above-installed Top Tracker (TT) controls a muon flux. The CD allows reconstructing neutrino energy spectra with characteristic resolution of 3% at 1 MeV.

The experiment also includes the detector of the Taishan Antineutrino Observatory (TAO) located 30 m away from the centre of the Taishan NPP reactor. The detector makes it possible to take into account the structure of the NPP antineutrino energy spectrum to improve the experiment sensitivity to the parameters being measured. This detector contains 2.8 tonnes of liquid scintillator, and ~10 square metres of its surface are viewed by silicon PMTs (SiPMTs). It allows the almost ultimate possible energy resolution to be reached in liquid scintillator when reconstructing antineutrino spectra.

The JUNO experiment precision makes it possible to gain cutting-edge results in neutrino physics research. The main task to determine the mass hierarchy within three standard deviations can be completed in eight years. And this is second only to the capabilities of the DUNE accelerator neutrino experiment. In the JUNO experiment, the precision of the parameters measured to date, mass differences of neutrinos of three generations and their mixing angles, will be significantly improved (many orders of magnitude). The limits of the proton decay probability will be lowered compared to the Super-Kamiokande results, the statistics of the detected SN neutrino will be multiply increased and those of geoneutrinos, atmospheric and solar neutrinos will be improved.

Therefore, high scientific significance and competitive ability of the JUNO experiment is beyond question.

The participation of the JINR group in this project logically follows from its active cooperation in the Daya Bay reactor neutrino experiment where a discovery of great importance has been made. For the first time, the non-zero mixing angle of leptons of the 1st and 3rd generation was measured, and so prospects of searching for the phase responsible for the CP-violation in the lepton sector appeared.

In 2018—2020, still analyzing the Daya Bay experimental data, the JINR group started working on the JUNO project (Topic 1099) using the major part of internal resources. At this stage, the prolongation of these activities in 2021—2023 is under discussion.

The JINR group contributes a lot to the development and construction of many detector components and plays a major role within the JUNO project:

- is responsible for development and manufacturing of high-voltage units (HVUs) for PMTs;
- takes part in the design of the Top Tracker detector, including a mechanical support system, and in the elaboration of hardware and software to monitor scintillators, and also of the track reconstruction and DAQ system;
- participates in tests of large PMTs;
- is engaged in development and construction of the TAO detector;
- develops the Global Neutrino Analysis (GNA) software package;
- puts into operation a data processing centre intended for acquisition, storage and Monte Carlo analysis of the data; this centre will be one of three European data processing centres managing the JUNO data.

By the end of 2020, 25000 HVUs for PMTs are scheduled to be produced, and afterwards, assembly and tests of electronics will be controlled. The Slow Control software will also be developed.

The Top Tracker detector is being constructed from modules composed of plastic scintillators previously produced by the JINR group and already employed in the OPERA experiment. This was considered as a JINR in-kind contribution to the JUNO experiment. A special system was developed that provides continuous remote monitoring of characteristics of scintillator panels, which change with time due to aging. The JINR group takes part in the development and construction of the 140-tonne detector framework, as well as is in charge of elaborating the DAQ system software that should ensure efficient detector data taking. The assembly, installation and commissioning of the Top Tracker detector will be launched with the direct participation of JINR experts in 2021.

The JINR group contributes a lot to PMT mass testing. A Dark Room with a scan station at JINR and two Dark Rooms with two scan stations on the test site in China were constructed and put into operation. To date, about 3900 scans have been performed, and some 2500 PMTs (350 Hamamatsu and 2200 NNVT) have been tested. The JINR group also cooperates in designing and producing a system for shielding PMTs from the Earth's magnetic field. In addition to the basic system, Helmholtz coils, different materials able to provide proper magnetic shielding are being probed.

The main JINR contribution to the TAO detector is the purchase of a half of silicon PMTs (SiPMs), the provision of all 4500 SiPMs with power supplies, and also the Slow Control software development. At the same time, a real challenge should be solved combining SiPMs to some structural modules, "tiles", which later must cover the scintillator surface as tightly and uniformly as possible. At DLNP, a facility was invented that allows the study of SiPM characteristics at the operating temperature of -50˚C, and it will be used for selection and mass testing of SiPMs.

Over the period of three years (2021—2023), 39 JINR staff members will be involved in the work within the project, not exceeding, however, 20 FTE a year. About one third of the participants are students and postgraduates. Engineers make up an equal part.

In the course of the Daya Bay experiment and the JUNO project preparation, the JINR group demonstrated its expertise in elaborating and constructing detectors and engineering systems, developing software, and processing and analyzing physics data. Just in the past five years, 19 papers were published by JINR researchers in authoritative scientific journals using the materials of the above-mentioned experiments, and also 30 reports were given at different international conferences. No doubt, the group will fulfill all the responsibilities taken on the project and greatly contribute to future scientific results both financially and intellectually.

Indeed, the participation in the experiment of such a high scientific level is very valuable for JINR. First of all, it will enable obtaining impressive scientific results, which will strengthen the scientific reputation of the project participants and the credibility of the Institute on the whole. The preparation and conduct of the experiment of this kind plays a significant role in fostering highly skilled professionals at JINR, scientists and engineers. To prove this, we have to mention that five dissertations based on the results of the above neutrino experiments, three of them were doctoral, were successfully defended. Now, while preparing the JUNO experiment, an infrastructure is being established at DLNP that will allow elaboration and design of advanced detectors. This in turn will ensure a substantial foundation for preparing other projects.

I believe that an active role of the JINR group in the Global Neutrino Analysis (GNA) is of great importance. In my opinion, this case is not sufficiently specified in the project.

In total, the international JUNO collaboration numbers about 650 participants from 77 institutions. The JINR group is second, considering the scientists involved, to the Institute of High Energy Physics (Beijing) and is in charge of a large amount of responsibilities within the project. The submitted materials do not provide a complete overview to evaluate whether the JINR responsibilities are objectively balanced in comparison with other collaboration participants.

There are no further remarks on the project.

On the whole, the participation of the JINR group in the JUNO project should be greatly appreciated, and it is advisable to prolongate the project and consider it further as a first priority.

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