Report on the project
"*Study of Neutrino Oscillations in JUNO and Daya Bay Experiments*"

The project is oriented on participation of scientists and engineers of the Laboratory of Nuclear Problems (JINR Dubna) in the planned reactor antineutrino experiment JUNO and in the running Daya Bay experiment, both situated in China and realized in the framework of wide international collaboration.

JUNO will belong to the main worldwide experiments, which will measure neutrino oscillations and determine corresponding mixing angles and neutrino mass differences. The main goal of JUNO experiment is to determine neutrino mass hierarchy with sensitivity corresponding to 3-4 standard deviations by 2026. This requires achieving the unprecedented energy resolution of better than 3% at 1 MeV of released energy. If this goal is achieved, then these measurements of neutrino mass differences will become the most precise in the world.

At the present time, the neutrino mass hierarchy is an open question and understanding of this phenomenon is one of the main challenges of neutrino physics and, in a broader context, of high energy physics, because neutrinos are one of the key pillars of the Standard Model.

The ordering of neutrino masses is related to the probability of neutrino oscillations. This relation makes it possible to determine the mass hierarchy in JUNO experiment with reactor antineutrinos.

JUNO is in fact, the multi-purpose experiment. Besides the mass hierarchy determination, the mixing angles will be measured with high precision, geo-neutrinos will be detected, possible observations of Super Nova neutrinos will be realized and measurements of another quantities, as mentioned in Section 2.2, will be carried out.

The activities and responsibilities of JINR group in JUNO/Daya Bay are clearly defined in Sections 1 and Subsection 3.1. They are:

- design and production of high voltage units (HVU) for JUNO small and large photomultipliers (PMTs),
- the construction of the Top Tracker detector (TTD) – the important part of the JUNO muon veto system,
- design and production of a scanning station – a brand new equipment for precise tests and characterization of large PMTs,
- supplying the light sources for mass test of PMTs together with corresponding software development, including DAQ and data analysis,
- calculations of required design of Helmholtz coils needed to ensure shielding of the central detector against the Earth magnetic field,
- research and development (R&D) of liquid scintillator (LS) in the central detector,
- software support realized in the framework of Global Neutrino Analysis (GNA) package.

All of the above responsibilities are crucial for the JUNO experiment, nevertheless considering the most important ones from the point of view of financial, material and technical contribution of JINR, the first four tasks can be considered as having highest priority. **Proposal for HVU was accepted by the JUNO collaboration and contributed to the motivation behind the attached to the PMTs overall design of the whole JUNO electronics.** At present, the prototype design of HVUs thanks to JINR team is in advanced stage of development, and, as it is mentioned in Section 3.2. of the proposal, design and production preparation work is planned to be finished by the end of this year. HVUs itself as well as the activities related to its development, mass production and installation comprise the most expensive part of financial contribution of the JINR group.

On the other hand, this sizeable expense will be balanced by the contribution of JINR into the construction of TTD: the major part of the OPERA tracker constructed in the past with large contribution of JINR, will be reused in TTD and will be accounted as an in-kind contribution of the

JINR team. TTD will precisely identify cosmic muons passing through the JUNO central detector and producing a serious background due to appearance of ^{9}Li/^{8}He unstable isotopes. **The JINR team develops a mechanical support system, hardware and software for monitoring of Top Tracker scintillators, tracks reconstruction and data acquisition system (DAQ).**

Remarkable contribution was already made in testing procedure of PMTs, which have to satisfy crucial requirements to achieve the unique energy resolution of approx. 3% at 1 MeV. The JINR group already constructed a new and sophisticated laboratory for PMT testing by means of scanning station (SC) placed in a dark room. They developed software based on modern IT-technologies for collection, processing and storing the data from SC, which is an original all-sufficient equipment. Four SCs will be constructed for on-site installation in China. SC is also planned as precise complementary equipment for mass testing PMTs.

Preparation of testing of the complex inclusive scanning station and the dark room can be considered as a comprehensive intellectual and technical contribution of the JINR team to the JUNO experiment.

It is reasonable to mention the software development activities of the JINR team. In Section 3.6 the main features of software development in the Global Neutrino Analysis framework, in the estimation of the background, in simulation of optical properties of photomultipliers are described in detail. Activities of the JINR group in the Daya Bay experiment are described in detail in Section 4. In there, the reader can find interesting tasks connected with searching of sterile neutrino and determination of experimental constraints on the neutrino wave packet parameters. The theoretical concept of neutrino wave packet was elaborated by principal investigators of the project D.V.Naumov and V.A.Naumov. Section 5 contains the time schedule for realization of the tasks in 2018-2020 years.

In last Sections 6–11 the information which characterizes the JINR team and its results – conference presentations, publications, prepared theses, citations, Hirsch index and task responsibilities – is given. **All achieved results indicate high intensity of the scientific activity and professional competence of the team members.**

From the very beginning scientists and engineers from JINR play the key role in the JUNO experiment. Firstly, it is a natural result of the activities of the JINR team in the Daya Bay experiment, where they were involved in the main neutrino oscillation analysis among 5 groups. Secondly, it is a result of their ambitions to participate in the study of all usual and unusual properties of neutrinos which led to their activities related to the enforcement of the idea of realization of the new big project for measurement of neutrino mass hierarchy.

At present, besides planned financial support, activities of the JINR group are highly visible in intellectual, technical, organization and management areas. The leader of the proposed project D.Naumov is a member of Institutional and Executive Boards, A.Olshevsky is a Level 2 Manager in the PMT Instrumentation group and another five researches are Level 3 managers. To manage all the planned activities the JINR team includes 32 members. The average age of the JINR team member is ~40 years. There are 3 bachelor and master students, 6 young scientists in PhD studies, 8 engineers, 11 staff members with PhD degree and 1 professor. **The main part of the team (over 60%) consists of skilled scientists with PhD degree and skilled engineers with rich experience in big experiments.**

Based on these facts I arrived at the following conclusions:

1. The JINR team is at the present moment fully integrated into the preparation of the experiment. Many of the key hardware components already passed initial tests, the testing equipment for the photomultipliers was developed, the software for experimental setups and data processing is in development.
2. The team is a major player in the experiment, the proposed technical, material and software solutions were approved by international collaboration.

3. The full-fledged preparation and realization of the experiment is not possible without JINR's contribution.
4. The team's participation must be backed by financial contribution. I consider the requirement of 3 million USD to be adequate. Additionally, JINR will contribute the equivalent of 750 thousand USD by means of installation of the top tracker detector based on renovated tracker parts from the OPERA experiment. The largest part – 2 million USD – is allocated for the construction of High Voltage Units. The project proponents successfully negotiated lower unit price for HVU than the retail price of analogous commercial devices.
5. The configuration of the team is balanced – apart from experienced engineers and scientists, it also includes students, PhD students and young scientists. This is a big plus – as this is a long-term project, young people will gain invaluable experience and based on the experiment's results they will have opportunity to defend theses for existing degrees – Bachelor, Master, PhD, Doctor of Science.

I have following comments and questions concerning this project:

1. The weaknesses and potential risks of this project are not presented (for example, an increase of prices). Consequently, there are no prepared strategies how to handle the risk scenarios.
2. LNP, some members of which are the project proponents, is a key participant in other important neutrino experiments such as Baikal experiment and experiment in the Kalinin atomic plant. What is the benefit in participating in another big project, what will be the synergistic effect in this triad participation and what will be the added value for JINR being international organization?
3. Young scientists from JINR member states other than the Russian Federation are not included in this project. Are project proponents planning some activity to attract young scientists and engineers from the JINR member states?

Despite these reservations the benefits of this project are undeniable. It will contribute to the success of JUNO and Daya Bay experiments in a significant manner and consequently to the success of JINR in the international scale. I fully support its approval and financing.

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