**Questionnaire (for new projects):**

**T2K-II / Hyper-Kamiokande**

**A. Scientific merit**

1.   Goals of the experiment:

1a. Give a short description of the goals of the experiment

The already approved T2K-II experimental program will allow to extend the T2K running time until 2026 and to collect a statistic of up to 20x1021 protons-on-target (p.o.t.), aiming at initial observation of CP violation with 3σ or higher significance for the case of large CP violation and measurements of neutrino mixing parameters, and  , with a precision of or better and 1%, respectively. In order to achieve these goals upgrades of the J-PARC accelerator complex and of the near detector – ND280– are being performed.

Profiting from the most precise predictions of (anti)neutrino fluxes in accelerator-based experiments and the improved acceptance of the near detector ND280, T2K will be able to perform (anti)neutrino cross-section measurements with unprecedented precision.

T2K’s unique experimental setup will provide a possibility to perform novel searches for exotic phenomena, including Lorentz violation, sterile neutrinos, and neutral heavy leptons.

Hyper-Kamiokande will be a multipurpose neutrino detector with a rich physics program that aims to address some of the most significant questions particle physicists are facing today. Oscillation studies from accelerator, atmospheric and solar neutrinos will refine the neutrino mixing angles and mass squared difference parameters and will aim to make the first observation of asymmetries in neutrino and antineutrino oscillations arising from a CP-violating phase, shedding light on one of the most promising explanations for the matter-antimatter asymmetry in the Universe. The search for proton decays will probe one of the key tenets of Grand Unified Theories. In the case of a nearby supernova, Hyper-K will observe an unprecedented number of neutrino events, providing much needed experimental results to researchers seeking to understand the mechanism of the explosion. Finally, the detection of astrophysical neutrinos from sources such as dark matter annihilation, gamma ray burst jets, and pulsar winds could further improve our understanding of some of the most spectacular, and least understood, phenomena in the Universe.

1b. Explain what the project adds to the international scenario.

The aim of the ND280 upgrade is to overcome the two main limitations of the current ND280 design: the different angular acceptance between ND280 (mostly forward) and Super-Kamiokande (4pi efficiency) and the relatively large threshold to reconstruct charged hadrons produced in neutrino interactions. The ND280 upgrade will achieve a much better uniformity of acceptance as a function of polar angle, by reconfiguring the geometry with a fully active newly proposed scintillator detector acting as neutrino target, disposed along the plane including both the beam direction and the magnetic field. The scintillator detector, called Super-FGD, consists of ~2x10^{6} scintillator cubes of 1 cm^3 each read-out by three WLS fibers thus allowing a 3D reconstruction with excellent granularity. On the top and on the bottom of the Super-FGD, two new TPCs will measure charge, momenta and deposited energy of charged particles exiting the scintillator detector. In addition, 6 planes of time-of-flight (ToF) will surround the new Tracker system, allowing to reject events entering from outside of fiducial volume. Such configuration, combined with the existing tracker system, will allow to select with similar efficiencies outgoing charged leptons emitted in any direction with respect to the beam giving a better handle to distinguish among different neutrino cross-section models and to better constrain the parameters in these models. In addition, the large mass of the detector (~2 tons) and the improved reconstruction efficiency will allow to select clean samples of nu\_e interactions and of final state nu\_mu interactions in which most of the emitted particles will be fully reconstructed. The successful completion of the ND280 Upgrade project is also mandatory for the Hyper-Kamiokande physics program.

The Deep Underground Neutrino Experiment (DUNE), formerly LBNE, is a 40-kiloton liquid argon neutrino experiment that is projected to begin taking data about the same time as Hyper-K is operated. Because DUNE will use a different target material than that of Hyper-K (liquid argon rather than water), many complementary measurements can be made, including nucleon decay measurements and supernova neutrino detection. Information about the neutrino signature from supernovae is much sought after, and Hyper-K and DUNE will each add to the overall picture. The primary reaction channel for these neutrinos in Hyper-K is the inverse beta decay channel, in which only electron antineutrinos will take part. In DUNE, the reaction channel will be the charged-current reaction on 40Ar, which measures electron neutrinos. Taken together, these measurements will be able to determine the relative abundance of neutrinos to antineutrinos. Furthermore, DUNE will be able to better determine some features of the neutrino spectrum which are dominated by the electron neutrino signal, such as the neutronization burst that occurs during early times, while Hyper-K will better measure features where there is an antineutrino signal, such as the accretion and cooling phases that occur at late times. Due to the fact that the baseline between the accelerator facility and Hyper-K will be shorter than the proposed baseline for the DUNE experiment, the two experiments will have some complementarity in the information they can extract from their accelerator programs. The longer baseline in the DUNE experiment means their measurement will be more affected by matter effects, which will give them more sensitivity to the mass hierarchy. The shorter baseline of Hyper-K experiment means less sensitivity to matter effects, which should lead to an increased sensitivity to the measurement of the CP-violation phase.

Hyper-Kamiokande will be using a well-established experimental technique of Water Cherenkov detectors. Due to its much larger fiducial mass compared to other experiments, including DUNE, and unique sensitivity to the p->e+pi0 decay channel the Hyper-Kamiokande project has a significantly better sensitivity to the proton decay.

HK is also a unique observatory for neutrinos from astrophysical sources, such as supernovae (SN) neutrinos. Hyper-Kamiokande will detect thousands of anti-nu\_e (via inverse beta-decay) and nu\_e (via elastic scattering) from SN bursts in the galactic center. Thanks to the elastic scattering events it will be possible to reconstruct the direction towards a Supernova at a distance of 10 kpc with an accuracy of about 1 degree. The events observed in Hyper-Kamiokande will allow to provide detailed information about the time profile and the energy spectrum for inspecting Supernova explosion mechanism. In addition, it will be possible to detect neutrinos also from extra-galactic Supernova explosions. Even for distances of 4 Mpc, we will observe few tenths

of neutrinos in Hyper-Kamiokande and, at such distances, one Supernova is expected every three years. Hyper-Kamiokande will also be able to detect the Supernova relic neutrinos (SRN) that are neutrinos produced by all Supernova explosions since the beginning of the universe. Such neutrinos fill the present universe and have a flux of few tens/cm^2/sec. The observation of SRN would allow to understand how heavy elements have been synthesized in stellar formation.

**C. Plans and requests**

2.   Plans

Describe the plans of the JINR group within the project, in physics analysis, data taking, software development. detector R&D, detector operation and maintenance, upgrade activities… for the requested period of time of the project.

We plan to participate in T2K oscillation analysis, which involves analyzing new data obtained with the upgraded ND280 detector, developing event selection methods, and performing studies on various types of systematic uncertainties to better understand and reduce them. On the first stage (year 2022) we expect to join to the ongoing T2K analyses and focus on adapting and developing their methods with respect to the upgraded ND280 detector. This activity implies performing MC studies and developing software tools for analysis. Here, the close cooperation with the INR RAS group is planned. As soon as the new data from the upgraded T2K arrives and is available (years 2023 and 2024), we are going to participate in the analysis and in obtaining physical results. Also, this activity implies the participation to the T2K publication preparation process and in the scientific conferences.

We are developing electronics for LED calibration system of the SuperFGD using notched light guide plates (LGP). The calibration system can distribute LED light uniformly to several channels at once and is used for gain calibration and stability monitoring. The module consists of PCB with LEDs’ array, LGP, diffuser, container and electronics unit. The calibration system will be integrated to the mechanical box and a single module with 7 LEDs has to cover 96x8 SuperFGD channels. In total, 93 LGP modules are necessary to cover full detector. A special electronic board was developed at JINR to control the LGP modules. The board consists of LPC4088 microcontroller, FPGA (Cyclone10 LE) and 12 channels of analog drivers. The developed scheme allows us receiving commands via UDP protocol to manage calibration LED pulse duration and amplitude. At the moment, the final debugging of the circuit is being performed before mass production. After that, we will produce the required number of blocks. In 2022-2023, we need to install and configure a calibration system on the SuperFGD

Another area of responsibility of the JINR group is the design of the platform and equipment for assembling the unique superFGD target. It is very likely that the JINR will eventually be tasked with creating this platform and developing a procedure for assembling the target in the J-PARC before placing the target in its place in the experiment. The assembly of the target on this special platform should take place within 2022-2023. The SuperFGD platform is designed for:

- assembly of the unique SuperFGD detector with the fishing lines at the first stage, which is an assembly of the detector array, consisting of scintillation cubes 1 cm3 in size arranged in layers, 192x184 cubes in size and 56 cubes high in accordance with the assembly technology (2022-2023) ;

- assembly of the detector at the second stage, which is the installation of optical fibers, MPPC boards, calibration system and flexible cables for connecting the registration system (2022-2023);

- calibration of the optical channels of the detector and installation of the detector components (2022-2023);

- maintenance of the detector (2023-2024+)

At each stage of the assembly, the platform structure and its component parts provide unhindered access to the detector from all sides and secure fixation of the detector in its regular spatial position.

Our design engineers performed calculation of strength and stiffness of the platform and box support system according to construction standards in seismic regions of the Far East (9 points, 0.65 g) and shown that the construction meets the seismic requirements. Calculations will be continued in accordance with the spectrum of earthquake frequencies provided by the Japanese colleagues.

We emphasize that JINR is responsible for the design of the platform and equipment for the SuperFGD assembly.

In order to achieve a precision of the order of 4-5% in the prediction of neutrino and antineutrino fluxes for the future accelerator neutrino experiments (such as T2K-II, DUNE, T2HK and others) it is necessary to measure the yields of hadrons in proton-nucleus and pion-nucleus interactions using hadron beams.

The nearest plans are :

- 2021/2022: collection of new data with the T2K replica target

- 2022/2023: calibration and analysis of these data; extraction of precise hadron yields from the surface of the T2K replica target

- 2023/2024: usage of these new hadron production measurements for improved predictions of (anti)neutrino fluxes in T2K/HK; better-precision measurements of neutrino oscillation parameters in T2K-II.

Starting from 2022-2023, the JINR participants plan to join the research work on the creation of the Hyper-Kamokande veto detector - Outer detector which is designed to exclude background events caused by cosmic muons. This detector will be equipped with 6,700 ultrasensitive photosensors (PMTs) with a diameter of 20 cm. The JINR group plans to develop a system for mounting PMTs for the Outer detector of the Hyper-Kamiokande facility, create shifters for photomultipliers and corresponding electronic equipment.

Let us emphasize that our group was invited to participate in the T2K experiment by the leaders of the T2K collaboration and J-PARC to carry out a unique assembly and maintenance of a new type of 3D scintillation active target and to participate in data analysis to measure the phase of CP-mixing. We also closely cooperate with INR RAS on the creation of a SuperFGD, about which there is a corresponding protocol on cooperation between JINR and INR RAS.

3.   Group size, composition and budget.

3a. List the JINR personnel involved in the project, including name, status (e.g. PI, researcher, post-doc, student, engineer, technician…) and  FTE. Mention the total number of people in the collaboration.

3b. Present the JINR group budget for the requested period of time of the project, specifying the main budget items (equipment, computing, salaries, common funds, travel…)

3c. Indicate the use or needs of JINR computing resources for the group and for the project if any.



Young JINR colleagues (marked yellow) are 49% FTE and we plan to invite more (PhD) students to participate in the oscillation and astrophysical analysis.

In addition to the names listed in the table, we have strong theoretical support in the person of our theoretical physicists Prof. Viktor Matveev and Dr. Gennady Kozlov.

The T2K collaboration has about 500 members.

The project participants have extensive experience in working with scintillation detectors, including the creation of a part of the muon system of the CDF experiment at the Tevatron (Fermilab), test modules of the e.m. calorimeter and veto system of the Mu2e experiment; measurement of the top quark mass on CDF, simulation for Mu2e, data analysis from NA61/SHINE experiment, creation of the front-end electronics boards for Mu2e calorimeter and electronics for other experiments.

From the point of view of the leading roles of the T2K experiment, we note that Boris Popov is the group leader of data analysis for the T2K experiment, obtained on the graphite target, Yuri Davydov is the SuperFGD target assembly group leader and Vladimir Glagolev is IB representative.

And we have 8 young scientists and engineers working on this Project. Moreover, in the next three years we are going to involve 2-3 or more young PhD students in data analysis of the T2K and further development of the HK project.

Our budget/tasks table and formal Project budget forms for 3 years period are attached below.



In the initial period we will use our department and Lab computing resources as well as INR and T2K one’s. Also, in perspective (2023-2024+) we considering the possibility to use Tier2 resourses from LIT JINR.

Form No. 26

**Schedule proposal and resources required for the implementation of the Project**

**T2K-II / Hyper-Kamiokande**

(Project title)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Expenditures, resources, financing sources | | | Costs (k$)  Resource  requirements | Proposals of the  Laboratory on the distribution of finances and resources | | |
| 1st year | 2nd year | 3rd year | |
| Expenditures | | Main units of equipment, work towards its upgrade, adjustment etc. | 165 | 60 | 55 | 50 | |
| Construction/repair of premises |  |  |  |  | |
| Materials | 55 | 20 | 20 | 15 | |
| Required resources | Standard hour | Resources of  – Laboratory design bureau;  – JINR Experimental Workshop;  – Laboratory experimental facilities division;  – accelerator;  – computer.  Operating costs. | 7000h  600h  420h | 3000h  200h  140h | 2000h  200h  140h | 2000h  200h  140h | |
| Financing sources | Budgetary  resources | Budget expenditures including foreign-currency resources. | 600 | 200 | 205 | 195 | |
| External resources | Contributions by collaborators.  Grants.  Contributions by sponsors.  Contracts.  Other financial resources, etc. | 30  10 | 10  5 | 10  5 | 10 | |

PROJECT LEADERS V.V.Glagolev Yu.I.Davydov

*Appendix 4*

Form No. 29

**Estimated expenditures for the Project**

**T2K-II / Hyper-Kamiokande**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Expenditure items | Full cost | 1st year | 2nd year | 3rd year |
|  | Direct expenses for the Project |  |  |  |  |
| 1. | Accelerator, reactor | 420 h | 140 h | 140 h | 140 h |
| 2. | Computers |  |  |  |  |
| 3. | Computer connection |  |  |  |  |
| 4. | Design bureau | 7000 h | 3000 h | 2000 h | 2000 h |
| 5. | Experimental Workshop | 600 h | 200 h | 200 h | 200 h |
| 6. | Materials | 55 k$ | 20 k$ | 20 k$ | 15 k$ |
| 7. | Equipment | 165 k$ | 60 k$ | 55 k$ | 50 k$ |
| 8. | Construction/repair of premises |  |  |  |  |
| 9. | Payments for agreement-based research (operation fee) | 95 k$ | 25 k$ | 35 k$ | 35 k$ |
| 10. | Travel allowance, including:  a) non-rouble zone countries  b) rouble zone countries  c) protocol-based | 255 k$  30 k$ | 85 k$  10 k$ | 85 k$  10 k$ | 85 k$  10 k$ |
|  | Total direct expenses | 600 k$ | 200 k$ | 205 k$ | 195 k$ |