Appendix 1

Form No. 24

Project

T2K-II / Hyper-Kamiokande

DLNP: Artikov A.M., Baranov V.Yu., Boikov A.V., Brazhnikov A.O., Budagov J.A., Davydov Yu.I., Demin D.L., Glagolev V.V., Khomutov N.V., Kirichkov N.V., Kiseeva V.I., Kolesnikov A.O., Krasnoperov A.V., Limarev K.K., Malyshev V.L., Popov B.A., Shaikovskiy A.V., Sinitsa A.A., Suslov I.A., Tereschenko V.V., Tereschenko S.V., Vasilyev I.I.,
BLTP: Kozlov G.A., Matveev V.A.

Joint Institute for Nuclear Research, Dubna, Russia

Khabibullin M.M., Khotjantsev A.N., Kudenko Yu.G., Mineev O.V.

Institute for Nuclear Research of the Russian Academy of Sciences

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

SCIENTIFIC PROJECT LEADER J.A. Budagov

DATE OF SUBMISSION OF PROPOSAL OF PROJECT TO SOD _________

DATE OF THE LABORATORY STC 1.04.2021 DOCUMENT NUMBER _________

STARTING DATE OF PROJECT 2022

(FOR EXTENSION OF PROJECT — DATE OF ITS FIRST APPROVAL) _________

Date of the Lab seminars 17.03.2021, 30.03.2021

Appendix 2

Form No. 25

PROJECT ENDORSEMENT LIST

T2K-II / Hyper-Kamiokande

V.V. Glagolev, Yu.I. Davydov

APPROVED BY JINR DIRECTOR

ENDORSED BY

JINR VICE-DIRECTOR

CHIEF SCIENTIFIC SECRETARY

CHIEF ENGINEER

HEAD OF SCIENCE ORGANIZATION DEPARTMENT

LABORATORY DIRECTOR

LABORATORY CHIEF ENGINEER

PROJECT LEADER

PROJECT DEPUTY LEADERS

ENDORSED

RESPECTIVE PAC

T2K-II / Hyper-Kamiokande

Table of Contents

Abstract

The main goal of this project is to facilitate the full participation of the JINR physicists in the very significant Japanese experimental program on neutrino physics[1][2]: the ongoing T2K experiment and the Hyper-Kamiokande project currently under preparation.

The already approved T2K-II experimental program will allow to extend the T2K running time until 2026 and to collect a statistics of up to 20×10^{21} 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, θ_{23} and Δm_{32}^2 , with a precision of 1.7^0 or better and 1%, respectively [3]. In order to achieve these goals upgrades of the J-PARC accelerator complex[4] and of the near detector – ND280[5] – are being performed.

Further goals include the group's participation in the new generation Hyper-Kamiokande project which will follow up the T2K-II experiment and will use the same set of near detectors.

The nearest goal of the Project is to build a very unique active target Super Fine Granularity Detector (SuperFGD) consisting of about 2 million scintillation cubes pierced by scintillation fibers in three mutually perpendicular directions. This target is needed for the upgrade of the magnetized ND280 detector. Due to its fine-grained geometry surrounded by TOF detectors and two High Angle Time Projection Chambers (HA-TPCs), the SuperFGD has a unique capability to reconstruct short tracks and to detect fast-neutrons, which is required for the reconstruction of (anti)neutrino energy as well as for improved reconstruction efficiency for outgoing charged particles produced at large angles (almost perpendicular and backward) with respect to the incoming (ani)neutrino direction. This would also allow to lower the momentum threshold for pions and knocked-out nucleons produced in (anti)neutrino interactions.

Methods and technology for creating the new SuperFGD target include studying the properties of individual scintillation elements (cubes) with reflective edges, cross-talks between elements, light output, testing the target prototype and performing data analyses. A system is being developed for calibrating all fiber channels and SiPM using a system of LEDs. It is also necessary to note the structural difficulties of creating such a target - a box, mainly made of fiberglass, all the edges of which must have holes for fibers with a step of 1 cm and devices for such box assembly. A procedure for assembling and further equipping the target with electronic boards for read-out and calibration is being developed.

Project participants have extensive experience in the creation and maintenance of scintillation detectors (CDF muon counters, Mu2e CRV modules and crystal calorimeter elements), electronic board design and programming (OPERA, Mu2e, COMET), the data simulation and analysis (CDF, Mu2e), design of various objects.

The requested financing for 3 years is about 600 k$.

Introduction

The phase II of the T2K experiment is expected to start in 2022 and to last until 2026. It will be followed by the Hyper-Kamiokande (HK) experiment which will use the same neutrino beam produced by the J-PARC accelerator and the same set of near detectors. The physics goals of T2K-II are measurements of the neutrino oscillation parameters θ_{23} and Δm^2_{32} with a precision of 1.7° and 1%, respectively, as well as a confirmation at the level of 3 σ or more of the matter-antimatter asymmetry in the neutrino sector in a wide range of possible true values of δ_{cp} - the parameter responsible for the CP (matter-antimatter) asymmetry. Achievement of these goals requires reduction of the statistical and systematic errors, and thus a significant upgrade of the beamline and the ND280 detector, as well as improvements in the software and analysis methods.

The current design of the near detector ND280 is well optimized for the detection and reconstruction of forward-going particles (mainly charged leptons: muons and electrons), but it also has a number of limitations, like low reconstruction efficiency of particles produced almost perpendicular and backward w.r.t. the direction of the incoming neutrino, as well as too high momentum threshold to reconstruct a large part of produced pions and knocked-out nucleons (protons and neutrons). It is essential to optimize the detector to be sensitive to additional low-momenta particles produced via nuclear effects, reducing the systematic error in the neutrino oscillations analysis associated with models of neutrino interactions.

The SuperFGD is a 2m x 2m x 0.5m detector consisting of approximately 2 million 1 cm^3 scintillating polystyrene cubes. The cubes are woven with a series of optical fibers designed to detect the light emitted by the particles produced during the interactions in the target. Unlike the current FGDs, the SuperFGD has a three-fold projective 2D readouts providing a quasi-3D readout. This readout configuration increases the detection of short tracks almost uniformly in all directions. Due to its geometry and coupled with the TOF and the High Angle Time Projection Chambers (HA-TPCs), the SuperFGD has the capability to detect fast-neutrons, which is needed in the reconstruction of the antineutrino energy.

On the strength of a double Nobel prize winning experiment (Super)Kamiokande and an extremely successful long baseline Japanese neutrino programme, the third generation Water Cherenkov detector, Hyper-Kamiokande, is being developed by an international collaboration as a leading worldwide experiment based in Japan. It will address the biggest unsolved questions in physics through a multi-decade physics programme that will start in the middle of this decade.

The science that will be developed will also be able to shape the future theoretical framework and generations of experiments. Hyper-Kamiokande will be able to measure with the highest precision the leptonic CP violation that could explain the baryon asymmetry in the Universe. The experiment also has a demonstrated excellent capability to search for proton decay, providing a significant improvement in discovery sensitivity over current searches for the proton lifetime. The atmospheric neutrinos will allow to determine the neutrino mass ordering and, together with the beam, able to precisely test the three-flavour neutrino oscillation paradigm and search for new phenomena. A strong astrophysical programme will be carried out at the experiment that will also allow to measure precisely solar neutrino oscillation. A set of other main physics searches is planned, like indirect dark matter.

State-of-the-art of the science case proposed

T2K [1] is a currently-operating experiment which uses the well-known Super-K as a far detector to measure (anti)neutrinos produced in the J-PARC accelerator. Hyper-K will use much of the existing infrastructure produced for T2K, particularly the beam line and near detectors. Hyper-K will also benefit from any improved data analysis techniques developed for T2K. Several important T2K upgrades and improvements are planned for the coming years, and this will have a direct impact on improved Hyper-K performance.

The T2K experiment uses the ND280 near detector suite. Future analysis improvements in the ND280 detector aim to reduce the (anti)neutrino cross section and flux uncertainties.

In June 2015, the Super-Kamiokande Collaboration approved the SK-Gd project. This project is an upgrade of the detector's capabilities, achieved by dissolving 0.2% gadolinium sulfate into Super-K's water in order to enhance detection efficiency of neutrons from neutrino interactions. Therefore, following the prompt detection of a positron, the accompanying inverse beta decay (IBD) neutron can be identified in SK-Gd by a delayed gamma cascade, the result of the neutron's capture on gadolinium. As a result of this positive identification of true IBD events, a strong improved separation between signal and background can be achieved. As Super-K is the first example of gadolinium loading in a large-scale water Cherenkov detector, this will be a template for any future possibility of loading gadolinium into Hyper-K.

It is possible to determine the neutrino mass hierarchy by comparing the absolute values of the effective mass squared differences determined by reactor ($\overline{\nu_e}$ disappearance) and accelerator (ν_μ disappearance) with high precision [1],[7]. It is expected, around the year 2025, the mass hierarchy could be determined at ~(3-4)σ or more by combining the future data coming from the ongoing experiments such as NOvA[19], T2K and reactor experiments, Daya Bay [8], RENO [9], Double Chooz [10], and proposed future experiments such as JUNO[11], RENO-50 [12], ICAL [13], PINGU [14], and ORCA [15] where the last three projects will use atmospheric neutrinos to determine the mass hierarchy.

The magnitude of the charge-parity (CP) violation in neutrino oscillation can be characterized by the difference of neutrino oscillation probabilities between neutrino and anti-neutrino channels [16,17]. The current data coming from T2K [18], when combined with the result of the reactor θ_{13} measurement, prefer the value around $\delta_{cp} \sim -\pi/2$ (or equivalently, $\delta_{cp} \sim 3\pi/2$) for both mass hierarchies though the statistical significance is still small. Interestingly, the Super-K atmospheric neutrino data also prefers similar δ_{cp} values with a similar statistical significance [20].

If CP is maximally violated ($|sin\delta_{cp}| \sim 1$), CP violation ($sin\delta_{cp} \neq 0$) could be established at ~(2-3)σ CL by combining the future data coming from T2K and NOvA as well as with data coming from the reactor θ_{13} measurements.

One of the main T2K goals also is a search for sterile components in ν_μ disappearance by observation of neutral-current events (as neutral-current events are produced by all flavours of active neutrinos, a deficit would indicate an oscillation into sterile neutrinos).

In Hyper-K the neutrino oscillation parameters will be measured using two neutrino sources which can provide complementary information. Both atmospheric neutrinos, where neutrino oscillations were first confirmed by Super-K, and a long baseline neutrino beam, where electron neutrino appearance was first observed by T2K, will be employed.

With a total exposure of 1.3 MW × 10^8 sec integrated proton beam power (corresponding to 2.7×10^{22} protons on target with a 30 GeV proton beam) to a 2.5-degree off-axis neutrino beam, it is expected that the leptonic CP phase δ_{cp} can be determined to better than 23 degrees for all possible values of δ_{cp}, and CP violation can be established with a statistical significance of more than 3σ(5σ) for 76% (57%) of the δ_{cp} parameter space.

Hyper-K will be a multipurpose neutrino detector with a rich physics program that aims to address some of the most significant questions facing particle physicists 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.

The Deep Underground Neutrino Experiment (DUNE), formerly LBNE [21], 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 ^{40}Ar, 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.

Description of the proposed research

T2K ("Tokai to Kamioka") is a particle physics experiment studying the oscillations of the accelerator neutrinos (Fig.1). The experiment is conducted in Japan. T2K was the first experiment which observed the appearance of electron neutrinos in muon neutrino beam [22], it also provided the world best measurement of oscillation parameter θ_{23} [23] and a hint of a significant matter-antimatter asymmetry in neutrino oscillations[2]. The measurement of the neutrino-antineutrino oscillation asymmetry may bring us closer to the explanation of the existence of our matter-dominated Universe

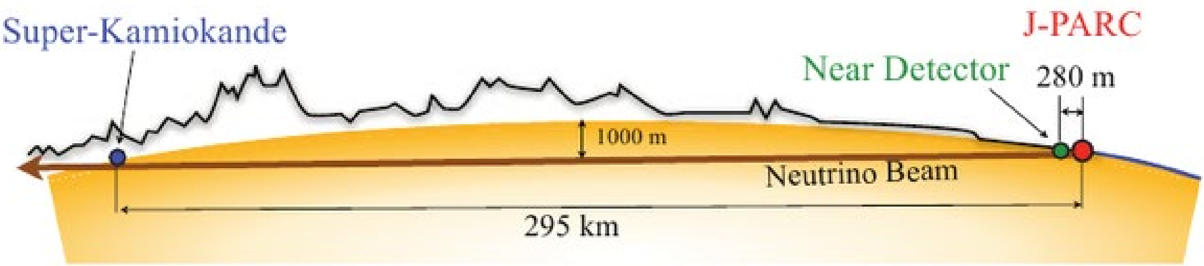

Fig. 1: The intense beam of muon neutrinos is produced in the J-PARC facility (Japan Proton Accelerator Research Complex) in Tokai on the east coast of Japan. The beam is directed towards the Super-Kamiokande far detector located 295 km away in the city of Hida, Gifu prefecture. The properties and composition of the neutrino flux are first measured by a system of near detectors (ND280) located 280 m from the beam production place at the J-PARC site, and then again in the Super-Kamiokande detector.

The T2K-II neutrino experiment will accumulate 20×10^{21} protons-on-target, that is 6 times the present exposure. This aims at initial observation of CP violation at the 3σ level or higher significance if the CP violation is maximal. A further increase by a factor 10 will come with the Hyper-Kamiokande detector, increasing the far detector mass from 22.5 kt to more than 200 kt [24].

While the present configuration of ND280 leads to systematic errors of the order of 6%, the goal is to bring this number down to ~ 4% for T2K-II [5], and to ~ 3% or below for Hyper-Kamiokande.

We plan to improve the performance of ND280 by adding a new highly granular, 3D scintillator detector, Super-FGD composed of small plastic scintillator cubes, read out by WLS fibers in the three orthogonal directions. Above and below this detector are two High-Angle atmospheric pressure TPCs. These three detectors form approximately a cube with 2m-long sides (Fig. 2). It is positioned in the upstream part of the ND280 magnet and is surrounded by six thin Time-of-Flight scintillator layers. This configuration achieves a full polar angle acceptance for muons produced in charged current interactions. The tracking of charged particles in the Super-FGD is also very efficient.

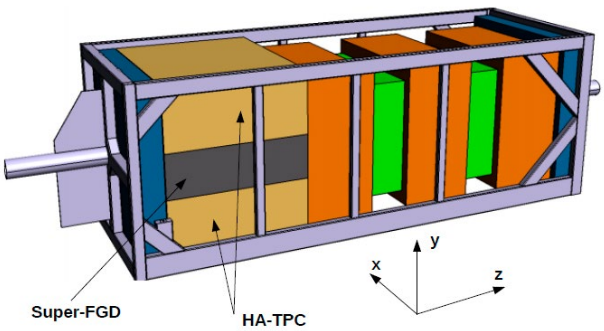

Fig. 2: CAD 3D Model of the ND280 upgrade detector. In the upstream part (on the left in the drawing) two High-Angle TPCs (brown) with the scintillator detector Super-FGD (gray) in the middle will be installed. In the downstream part, the tracker system composed by three TPCs (orange) and the two FGDs (green) will remain unchanged. The TOF detectors are not shown in this plot. The detector is mechanically mounted on the basket, a steel beam structure (light gray), supported at both ends.The beam is parallel to the z axis, the magnetic field is parallel to the x axis

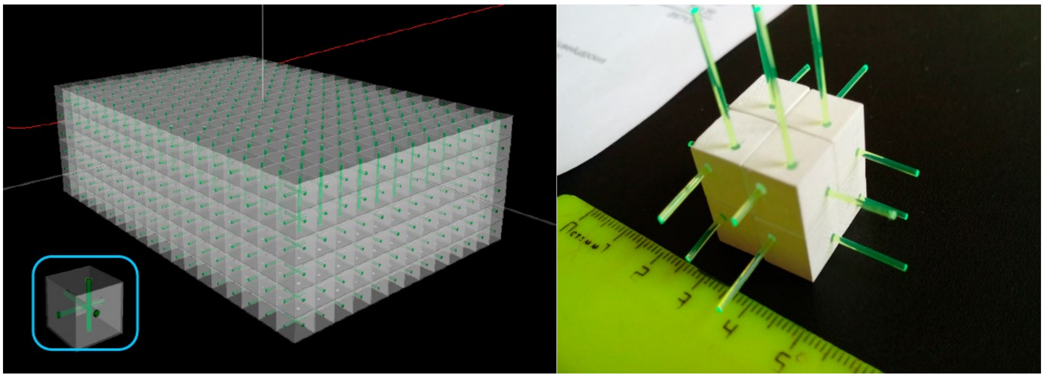

Fig. 3: Left: Schematic view of Super-FGD detector. Right: picture of a small prototype of the Super-FGD.

The SuperFGD (Fig. 3) is a novel idea for a fine grained fully-active plastic scintillator detector made of many optically independent 1 cm cubes. The scintillator is a composite of polystyrene doped with 1.5% paraterphenyl and covered by ~ 50μm of chemical reflector. Each cube has three holes of 1.5 mm diameter drilled along their X, Y and Z axes through which WLS fibres are fed. The full detector is about 2×2×0.6 m^3 comprising 2 million cubes and readout through ~60,000 channels. It has twice the resolution of the existing FGD and provides 3D reconstruction.

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 (CERN) hadron beams. This study [25] is being successfully performed for the first stage of the T2K long-baseline neutrino experiment with an active participation of a group of physicists from DLNP JINR.

We plan to perform a new data-taking with the exact replica of the T2K long carbon target. These measurements are crucial for further reduction of (anti)neutrino flux uncertainties in T2K-II/HK.

The group of physicists from DLNP JINR (N.Atanov, A.Krasnoperov, V.Lyubushkin, B.Popov, S.Tereshchenko, V.Tereshchenko) plans to participate in
- data-taking and analysis of experimental data using CERN hadron beams;
- software development for data processing and analysis;
- preparation of scientific publications.

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.

We plan to join the T2K collaboration efforts on oscillation analysis that has the aim to define the neutrino oscillation parameters such as $sin^2\theta_{23}$, $sin^2\theta_{13}$, Δm^2_{32} and δ_{CP} (although T2K sensitivity to $sin^2\theta_{13}$ is much smaller than that of reactor experiments). Currently, constraints exist for the θ_{12} and θ_{13} angles, as well as for the two mass differences Δm^2_{21} and Δm^2_{32}. The θ_{23} angle still has a large uncertainty and it is not yet known whether it has a value of π/4 (corresponding to maximal mixing), or above (below) this value. One more outstanding oscillation parameter is the complex phase δ_{CP}. Any value of δ_{CP} different from 0 or π would lead to CP violation in the leptonic sector, with

±π/2 representing maximal CP violation. One remaining task is the determination of the neutrino mass hierarchy (MH), which can either be normal (NH) or inverted (IH). In addition to these measurements, the consistency of the Pontecorvo–Maki–Nakagawa–Sakata (PMNS) framework is also probed.

The oscillation parameters are extracted from a fit of the predicted event rate to the oscillated data at Super-Kamiokande (SK) while the data at ND280 is used to provide precise predictions for the far detector spectrum. There are three sets of systematic uncertainties that are parameterized to define “nuisance parameters” in the fit:

1) Flux uncertainties. The neutrino flux is simulated with the FLUKA simulation package, and then tuned with external data constraints from the NA61/SHINE hadron production experiment at CERN, to account for mis-modelled hadron interactions in the graphite target.

2) Detector systematic uncertainties which are parameterized according to each detector (ND280 or SK).

3) Neutrino cross-section uncertainties. The neutrino interaction model is tuned to world cross-section data and our understanding of neutrino-nucleus interaction theory.

Data and simulated samples at ND280 are classified according to their final state pion multiplicity, beam mode, and the target in which the interaction occurred. The SK data is categorized in a similar way to that of ND280. Samples are defined according to the Cherenkov ring multiplicity and type. T2K tests the fitting framework and systematic error model through simulated data studies. Alternative models or tunes are used to create mock data sets and are passed through the oscillation analysis procedure. The results are compared to the nominal simulation fit. These studies allow to identify biases and motivate model improvements. In case of a significant deviation this effect is included in the oscillation parameter errors.

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. To be included in the author list for regular physics publications by the T2K collaboration we have to take part in shifts with respect to the institution shift quota.

People involved are Igor Suslov (FTE=100%), Konstantin Limarev (PhD student, FTE=100%) and Viktoria Kiseeva (young researcher, FTE=100%). More PhD students will be involved further. Some expenses are required to purchase the data server and computers.

The near detector ND-280 of the T2K experiment includes a SuperFGD measuring about 2x2x0.6 m^3, composed of about 2 million polystyrene scintillators measuring 1x1x1 cm^3. Each cube is made by injection molding. The cubes have three through holes with which wavelength shifting fibers are passed to pick up signals. Optical isolation of the cubes is ensured by a surface layer formed by chemical etching. However, such a surface does not provide complete light isolation of the cubes, therefore it is important to control the transmission of light through the surface layer and its effect on the reconstruction of tracks in the detector.

The transmission of light through the walls of the cubes and its penetration into neighboring cubes was tested by our colleagues using accelerator beams. We have developed a way to investigate optical light leakage between cubes using LEDs, which provides a fast and reliable way to control light leakage through the cubes' surfaces. For this, a flash from a led diode through an optical fiber was transmitted into one cube through one of three holes. The LED wavelength is 375 nm, which overlaps with the absorption region of the scintillator. The absorbed light is re-emitted by the scintillator at longer wavelengths with a peak at about 425 nm. The light re-emitted in the cube is picked up by an optical wavelength-shifting fiber and recorded using a SiPM. At the same time, the signal is read out from the adjacent cube to measure the light portion that has passed into it through the light insulated walls of two cubes, as shown in Fig. 4.

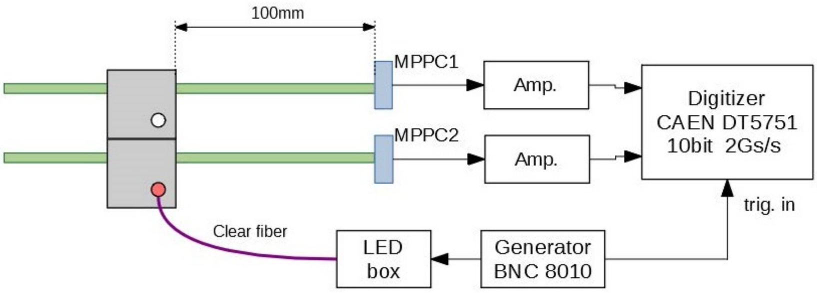

Fig.4: Read-out scheme

We have made comparisons of light leaks at different geometries. Two options are shown in Fig. 5. Here, in one case, light was transmitted into cube "0" and the light leakage into cube "1" (left Figure) was measured, in the other - cube "1" was illuminated and light leakage into cube "0" (right Figure) was measured. Fig. 6 shows the spectra of signals from the cubes, obtained when the cube "0" is illuminated. The left spectrum shows the signal from the illuminated cube "0", and the right one - the signal from the cube "1" due to the light passing from the cube "0". In this case, the ratio of the average signal in the cube “1” to the average signal in the cube “0” is 0.033. This value of the measured light leakage is consistent with the data obtained by our colleagues in measurements with accelerator beams.

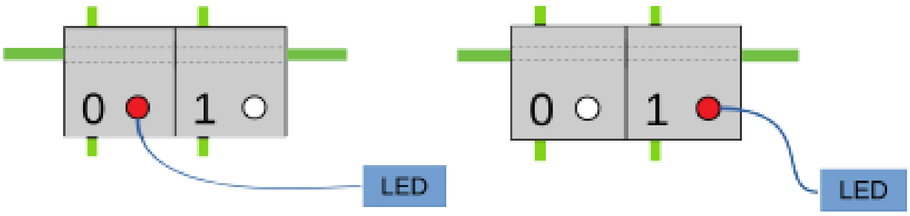

Fig.5: Scheme of the cube tests

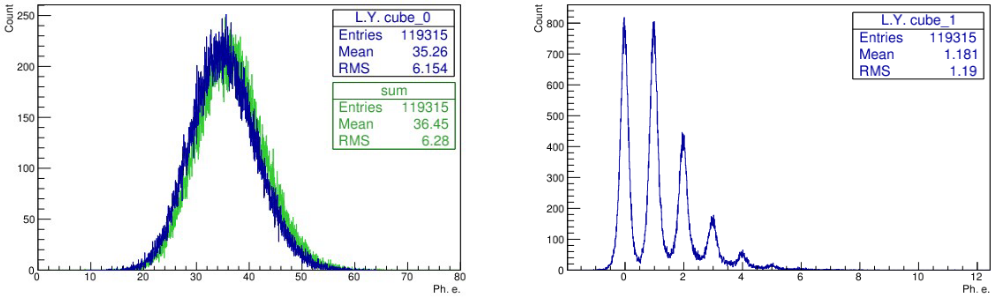

Fig.6: The spectra of signals from the cubes, obtained when the cube "0" is illuminated. The left spectrum shows the signal from the illuminated cube "0", and the right one - the signal from the cube "1"

Of particular note is the difference between the two geometries shown in Fig. 5. In the case of illumination of the "1" cube, the light leakage into the "0" cube is noticeably less and the ratio of the signal in the "0" cube to the signal in the "1" cube is 0.0187. This is due to the different distances from the spot of illumination to the boundaries of the cubes and to the optical wavelength shifting fibers. This effect demonstrates the dependence of light leaks into neighboring cubes on the place of light source and can be used to increase the spatial sensitivity when tracks of charged particles are reconstructed.

Typically, detectors operate under stable conditions and large temperature fluctuations are not expected. Nevertheless, in the conditions of transportation and storage of scintillators, one-time or cyclic temperature changes are possible. To study the effect of elevated temperatures on the light yield and light leakage through the walls of the cubes, we carried out studies of the behavior of cubes with increasing temperature. As a result of research, we did not find a change in the light yield and light leak through the walls of the cubes after cyclic heating of the samples to 60C.

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. Concept of the calibration system is presented on the Fig. 7.

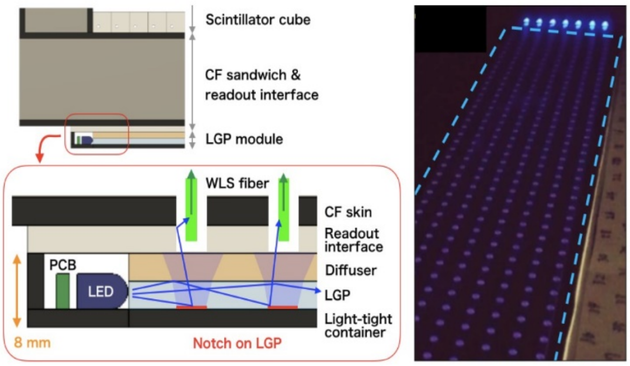

Fig. 7:

Scheme of LGP (left) and a photo of the LGP prototype (right).

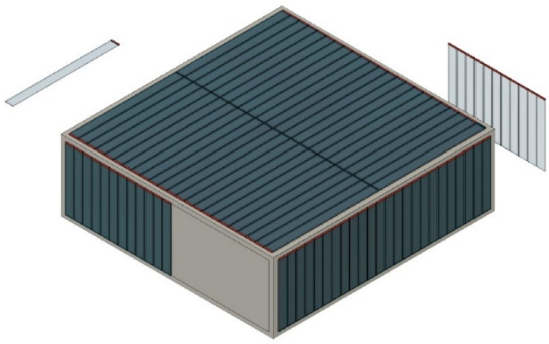

Fig.8: Common view of the mechanical box and the LGP modules attached to the box surface.

Fig.8 shows a common view of the mechanical box and the LGP modules attached to the box surface. The calibration system will be integrated to the mechanical box (Fig.8) 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 (Fig. 9).

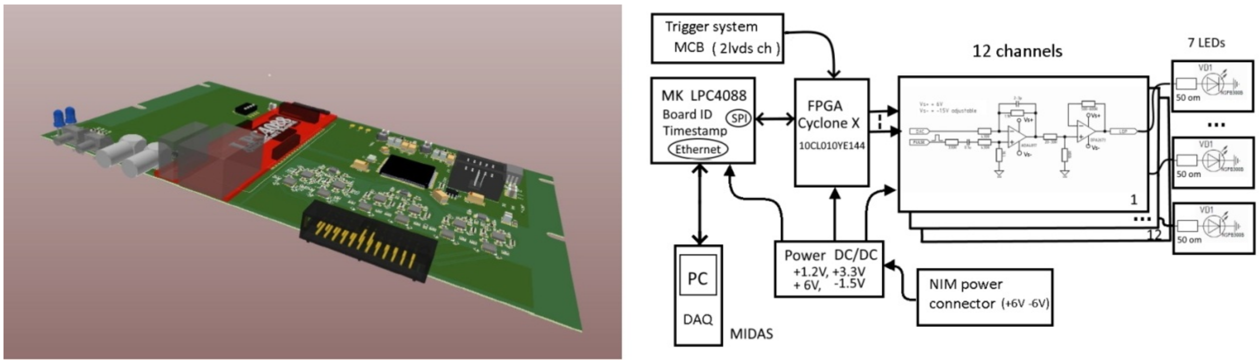

Fig.9: Special electronic board for LGP modules.

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 early 2022, we need to install and configure a calibration system on the SuperFGD.

One of the areas 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.

The SuperFGD platform (Fig. 10) is designed for:

- assembly of the SuperFGD detector with the fishing lines at the first stage, which is an assembly of the detector array, consisting of scintillation cubes 1 cm^3 in size arranged in layers, 192x184 cubes in size and 56 cubes high in accordance with the assembly technology (2021-2022) ;

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

In terms of application, the platform refers to special-purpose ground support facilities and is intended for use in industrial-type premises, laboratories, capital residential and other similar premises.

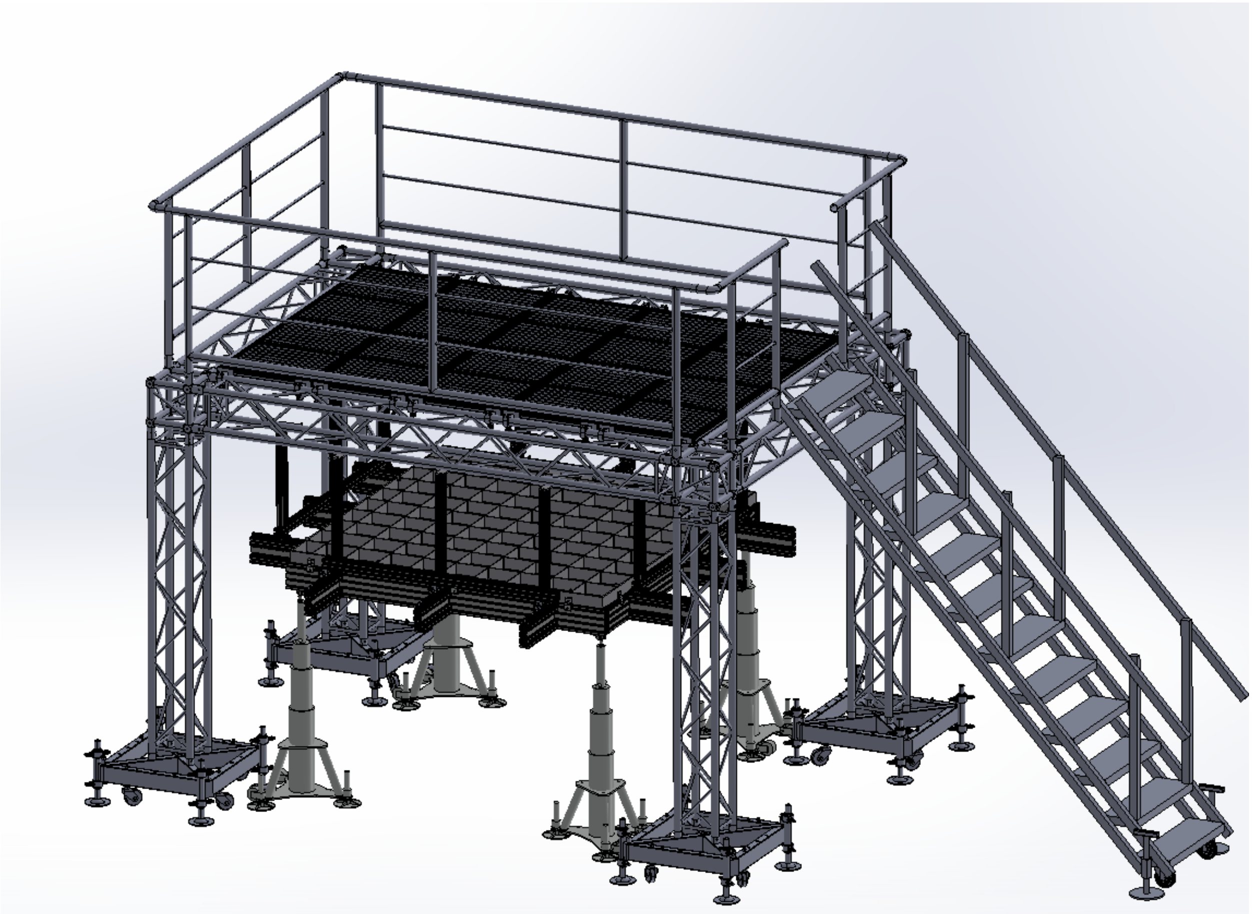

Fig.10: General view of the platform.

The target will be assembled on the bottom grid (Fig.10), starting from the bottom plate and the two side walls forming an angle. All walls of the target (including top and bottom panels) will have holes with 1 cm period for fibers. The platform will ensure the assembled procedure first on the fishing lines and vertical spokes which will be changed to the optical fibers after assembling full matrix of scintillator cubes and installation other two side walls and top panel.

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.

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 (see the letters in the appendix) 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.

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

Estimation of human resources

Name	FTE	Positon	Work (apart common duties like shifts)
A.M. Artikov	0.5	Head of sector	SuperFGD cube tests
V.Yu. Baranov	1.0	Junior researcher	SuperFGD cube tests
A.V. Boikov	1.0	engineer	SuperFGD calibration system
A.O. Brazhnikov	0.3	design engineer	platform and tooling for SFGD assembly
J.A. Budagov	0.3	Chief researcher	SuperFGD
Yu.I. Davydov	0.8	Head of department	SuperFGD assemble group leader
D.L. Demin	0.3	Head of sector	Tests at DLNP Linak-200
V.V. Glagolev	0.6	DLNP Deputy director	SuperFGD
N.V. Khomutov	0.3	scientist	Firmware development
N.V. Kirichkov	0.3	head of the design department	platform and tooling for SFGD assembly
V.I. Kiseeva	1.0	Young researcher	Monte Carlo, data analyses
A.O. Kolesnikov	0.8	scientist	SuperFGD tests
A.V. Krasnoperov	0.3	scientist	Software support
K.K. Limarev	1.0	PhD student	Monte Carlo, data analyses
V.L. Malyshev	0.5	scientist	SuperFGD tests
B.A. Popov	1.0	Senior scientist	Data analyses
A.V. Shaikovskiy	0.7	design engineer category 1	platform and tooling for SFGD assembly
A.A. Sinitsa	0.4	design engineer category 2	platform and tooling for SFGD assembly
I.A. Suslov	1.0	Senior scientist	Monte Carlo, data analyses
V.V. Tereschenko	0.8	Head of group	SuperFGD calibration system
S.V. Tereschenko	0.6	Engineer	SuperFGD calibration system
I.I. Vasilyev	1.0	Junior researcher	SuperFGD cube tests
Total FTE	**14.5**		

Justification of estimated costs

During 2022-2024, it is planned to carry out research work to create an HK Outer detector, in particular, to choose a suitable large-diameter PMT from 3-4 different types. It is also necessary to carry out a RnD and create a shifting plate, fasteners, cable connections and develop PMT fastenings inside the HK volume. In addition, it is planned to participate in the future upgrade of the near detector ND280.

To ensure the procurement of samples of 3-4 different types of photomultiplier tubes with a large-diameter photocathode (from 7 to 20 cm) for R&D, the following expenses expected to be needed, about kUSD 20-20-10 for 2022-2023-2024 years, respectively.

To equip a stand for testing PMT samples, you will need light insulation, mechanical and electronic components, a computer. The costs in amount of kUSD 30-20-30 are expected for 2022-2023-2024, respectively.

The data analysis and Monte-Carlo simulations will require a data server, 2-3 computers with monitors and laptops. Expenses are expected for 2022-2023-2024 years as 10-15-10 K $.

For the creation of shifter plates for the HK Outer detector PMT, R&D is expected with chemical plants for the production of a plastic scintillator with special additives. Expenses are expected for 2022-2023-2024 years as 20-20-15 K $.

	2022	2023	2024
Simulation and data analysis	Improvement of T2K (anti) neutrino flux uncertainty down to 3-4%. Adapting and developing T2K analysis method with respect of upgraded ND280 detector. $ 8 k	T2K data analysis $ 10 k	T2K data analysis $ 10k
SuperFGD mechanics. Finalize design of the SuperFGD assembly platform.	Assembling of the SuperFGD	Hyper-Kamiokande Outer detector PMT support system design	Hyper-Kamiokande Outer detector PMT support system design
RnD for detector subsystems. SuperFGD properties investigations.	Assembling and start-up of the SuperFGD at near detector facility. Study of the SuperFGD properties. RnD with PMT samples and shifters for Hyper-Kamiokande Outer detector. Materials $ 20 k (scintillators, fibers) Equipment $ 32 k (PMT's, elect. blocks, stand computer)	RnD with PMT samples and shifters for Hyper-Kamiokande Outer detector. Materials $ 20 k (shifters, mech. parts) Equipment $ 30 k (PMT's, elect. blocks)	RnD with PMT samples and shifters for Hyper-Kamiokande Outer detector. Finalize design of the shifters. Materials $ 15 k (shifters, mech. parts) Equipment $ 30 k (PMT's, elect. blocks)
Electronic for SuperFGD LED calibration design and DAQ	Creation, assembly and start-up of the calibration system. DAQ support of the SuperFGD. Equipment $ 20 k	Development of electronics and DAQ for further upgrade of the ND280 and Hyper-Kamiokande (Outer detector) Equipment $ 15k	Development of electronics and DAQ for further upgrade of the ND280 and Hyper-Kamiokande Equipment $ 10 k
SuperFGD/ND280 maintenance, T2K data taking shifts, meetings, conferences	Participation in the SuperFGD start-up, data taking shifts, meetings $ 85 k	SuperFGD/ND280 maintenance, T2K data taking shifts, meetings, conferences $ 85 k	SuperFGD/ND280 maintenance, T2K data taking shifts, meetings, conferences $ 85 k
Operation fee	$ 25 k	$ 35 k	$ 35 k

SWOT Analysis

The **strengths** of the project are undoubtedly its fundamental nature and focus on the missing model parameters of neutrino physics - measuring the neutrino mixing parameter responsible for the CP-parity violation and improved accuracy of neutrino mixing parameters, θ_{23} and Δm^2_{32}.

The T2K-II experiment is based on a well-developed relatively simple technique for reconstructing Cherenkov light in water and the optimal parameters of the distance to the far detector and neutrino energy for a successful and hopefully the world's first δ_{cp} measurement result.

Further goals include the group's participation in the new generation Hyper-Kamiokande project which will follow up the T2K-II experiment. Hyper-K apart from studying neutrinos from an accelerator will provide wide program of neutrino physics in particular 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.

It should be noted that in comparison to US experiments (NOvA, LBNE), there is a huge advantage here in the absence of the enormous problem of obtaining US visas and the prohibition of access to US national Laboratories for JINR employees.

The **weaknesses** of the Project is the possible delay in implementation due to the pandemic.

The longer baseline in the DUNE experiment means the measurement will be more affected by matter effects, which will give them more sensitivity to the mass hierarchy.

It is expected that measurement of the mass hierarchy could be determined not at the T2K alone but combining the future data coming from the ongoing experiments such as NOvA, T2K and reactor experiments.

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Appendix 3

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	255 k$	85 k$	85 k$	85 k$
	b) rouble zone countries	30 k$	10 k$	10 k$	10 k$
	c) protocol-based				
	Total direct expenses	600 k$	200 k$	205 k$	195 k$

PROJECT LEADER

LABORATORY DIRECTOR

LABORATORY CHIEF ENGINEER-ECONOMIST

Appendix 5

September 6, 2019

Academician Viktor Matveev
Director of the JINR
cc: Professor Vadim Bednyakov
Director of JINR-DLNP
cc: Professor Vladimir Glagolev
Deputy Director of JINR-DLNP

Dear Academician Matveev,

This letter is to express our interest in collaborating with the Joint Institute for Nuclear Research (JINR) within the framework of the T2K experiment at J-PARC (Japan Proton Accelerator Research Complex), Tokai, Japan. J-PARC is the best facility in the world for low and intermediate-energy nuclear/hadron and particle physics experiments.

As you know, the T2K experiment is a long baseline neutrino oscillation experiment and takes a leading position in the world in the study of neutrino physics.

The experiment uses an intense proton beam generated by the J-PARC Main Ring synchrotron, and is composed of a neutrino beamline, a near detector complex (ND280), and a far detector (Super-Kamiokande) located 295 km away from J-PARC.

We welcome the participation of JINR scientists from Dzhelepov Laboratory of Nuclear Problems (DLNP) in the T2K experiment. We are sure that JINR participation in the T2K experiment will be useful for JINR as well as for KEK/J-PARC and will make the cooperation between the two leading world physics scientific centers closer.

Taking into account the great and wide experience and high qualifications of physicists, engineers and technicians from DLNP JINR, we hope that in the case of JINR's participation in T2K, the JINR-T2K group can efficiently become active in the different detector systems, including their construction.

I would be grateful if you could discuss whether or not full participation of JINR's scientists, and financial support for them, in the T2K international collaboration would fit into the research strategy of your institute.

Should you have any questions regarding terms of collaboration, we would be happy to discuss it with you and your experts in the near future.

Your sincerely,

Atsuko K. Ichikawa
Spokesperson of the T2K Collaboration

Federico Sanchez Nieto
International Co-spokesperson of the T2K collaboration

Appendix 6

October 20, 2020

Prof. Victor A. Matveev
Director of JINR
6 Joliot-Curie St.
141980 Dubna, Moscow Region
Russia

Dear Professor Victor Matveev,

We would like to inform you with a great pleasure about the positive decision of the T2K Institutional Board regarding the application of the JINR group led by Dr Vladimir Glagolev to join the T2K collaboration. This group is already made a valuable contribution to the construction of the Super Fine-Grained Detector in the framework of the upgrade program of the near neutrino detector ND280 and now has become a full member of the T2K Collaboration. We are confident in further active work of the JINR group in the T2K experiment and expect that this group will play a significant role in conducting the experiment and in the analysis of the experimental data.

We also take this opportunity to express our deep gratitude to you for your continued support of the participation of Russian scientists in the T2K experiment.

Sincerely Yours,

Prof Atsuto Ichkawa
T2K Spokesperson

Prof Federico Sanchez
T2K International Co-Spokesperson

-

JAPAN PROTON ACCELERATOR RESEARCH COMPLEX
J-PARC

Prof. Naohito SAITO

2-4 Shirakata, Tokai-mura, Ibaraki,
305-1195, Japan

Phone: +81-29-284-4494
FAX :+81-29-284-4571
e-mail: naohito.saito@j-parc.jp

March 2021

Prof. Grigory V. Trubnikov
Director of JINR
6 Joliot-Curie St.
141980 Dubna, Moscow Region
Russia

Dear Prof. Grigory Trubnikov,

I am writing to express our deep respects for the achievements of the group from JINR, led by Dr. V. Glagolev and Dr. Yu. Davydov, in the upgrade of the near detector ND280 of the T2K experiment. We acknowlege the members of the group have great experience in renowned experiments such as CDF, ATLAS. Thanks to their efforts, together with colleagues from INR (Moscow), the creation of a unique SuperFGD target of a new type becomes a reality. The JINR colleagues make a significant contribution to the development of engineering tools and procedures for target assembly, calibration and testing of properties of target elements.

We hope that you and JINR PAC will strongly support the further participation of the JINR group in T2K-II and in the approved Japanese and worldwide leadership Hyper-Kamiokande experiment. We expect that JINR scientists will make a great contribution to data analysis, electronics, DAQ and the construction of the Hyper-Kamiokande detector.

We are looking forward to fruitful scientific results and strengthening scientific cooperation between J-PARC and JINR.

Sincerely Yours,
Director of J-PARC Center
Naohito SAITO
N. Saito

CC:
Dr. Viktor Matveev
Dr. Vadim Bednyakov
Dr. Vladimir Glagolev