Участие ОИЯИ в эксперименте T2K

Проект
T2K-II

02-2-1144-2021/2023

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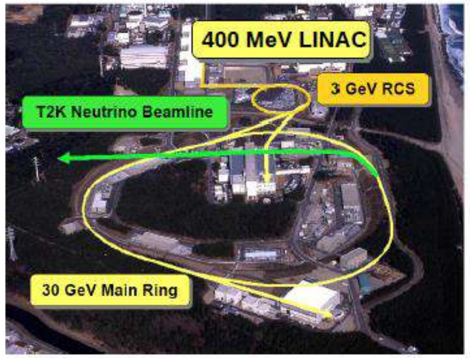
РУКОВОДИТЕЛИ ПРОЕКТА В.В. Глаголев, Ю.И. Давыдов

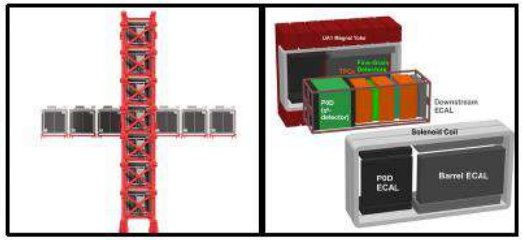
ДАТА ПРЕДСТАВЛЕНИЯ ПРОЕКТА В НОО _________

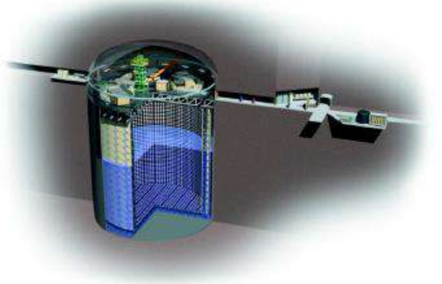
ДАТА НТС ЛАБОРАТОРИИ 30.06.2022 НОМЕР ДОКУМЕНТА _________

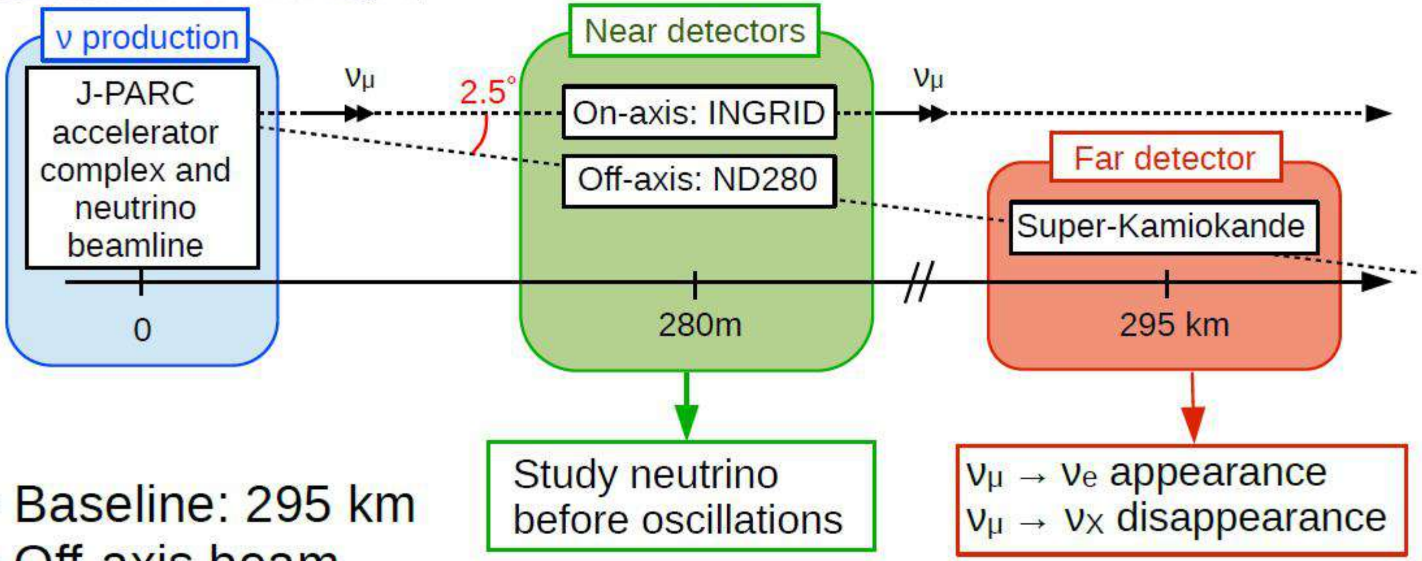
ДАТА НАЧАЛА ПРОЕКТА ____2022_____

ДАТА СЕМИНАРА В ЛАБОРАТОРИИ 15.12.2021, 29.06.2022









- Baseline: 295 km
- Off-axis beam

Vladimir Glagolev

June 29 2022

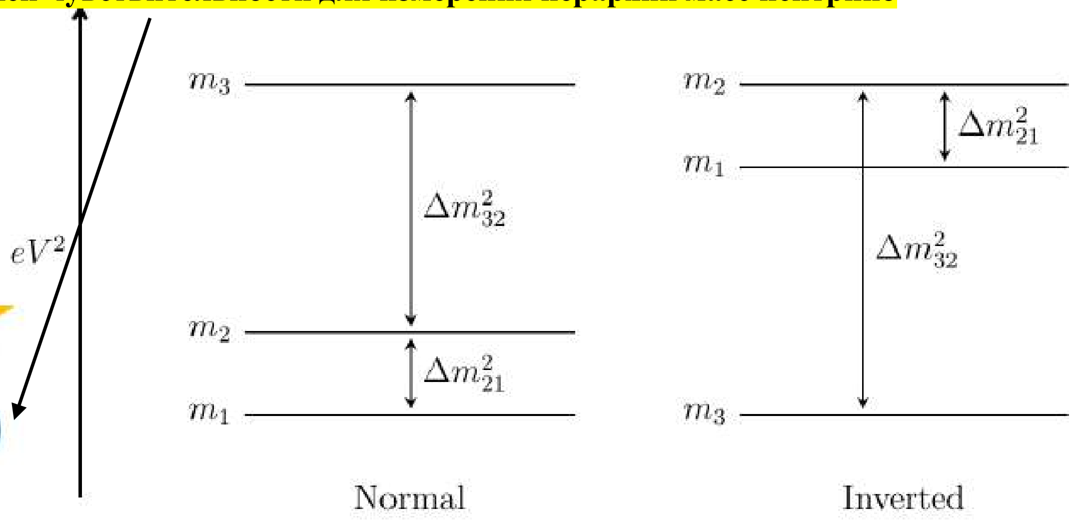
What is T2K trying to measure?

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \times \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta_{CP}} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta_{CP}} & 0 & c_{13} \end{pmatrix} \times \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

T2K aims to measure the 6 parameters which describe neutrino oscillation probability

- Three mixing angle, θ_{23}, θ_{13}, θ_{12}
- Two mass splittings: Δm^2_{32}, Δm^2_{13}
- Complex-phase δ_{CP}

Для NOvA эффект вещества 30 %, против 10% для T2K что приводит к большей чувствительности для измерения иерархии масс нейтрино



Key questions to answer:

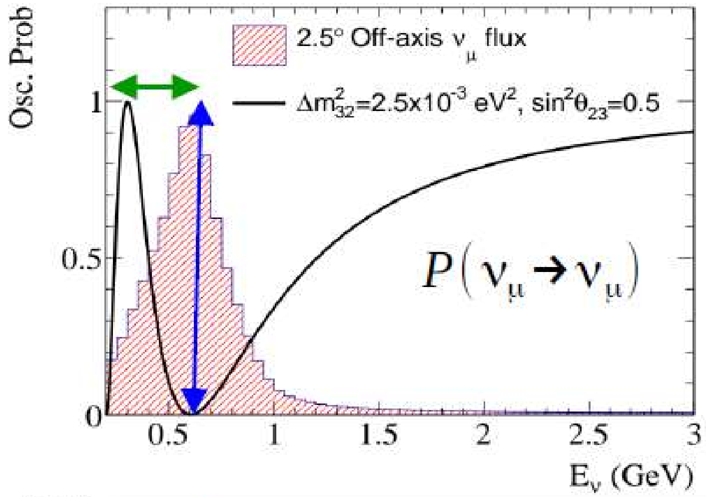
- **Discovery of CP violation (δ_{CP} not 0 or π)**
- **Determination of mass ordering ($\Delta m^2_{32} > 0$?)**
- **Octant of θ_{23} ($\sin^2\theta_{23} > 0.5$?)**
- **Precise measurements of δ_{CP}, θ_{23}, Δm^2_{32}**

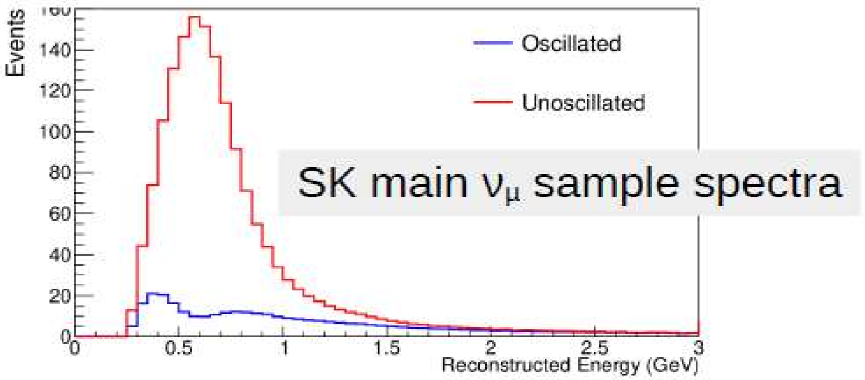
T2K can measure these!

Sensitivity to oscillations
Atmospheric parameters

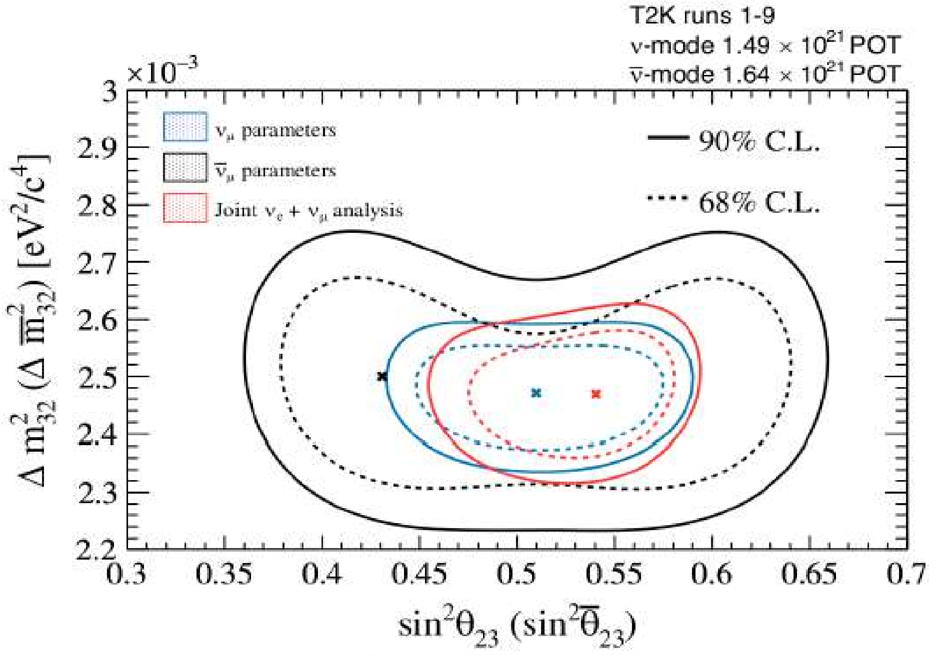
- Muon (anti-)neutrino disappearance gives sensitivity to $\sin^2(2\theta_{23})$ and $|\Delta m^2_{32}|$
- θ_{23} octant sensitivity from appearance channel

$$P(\nu_\mu \to \nu_\mu) \approx 1 - \sin^2(2\theta_{23}) \sin^2\left(1.27 \frac{\Delta m^2 L}{E}\right)$$





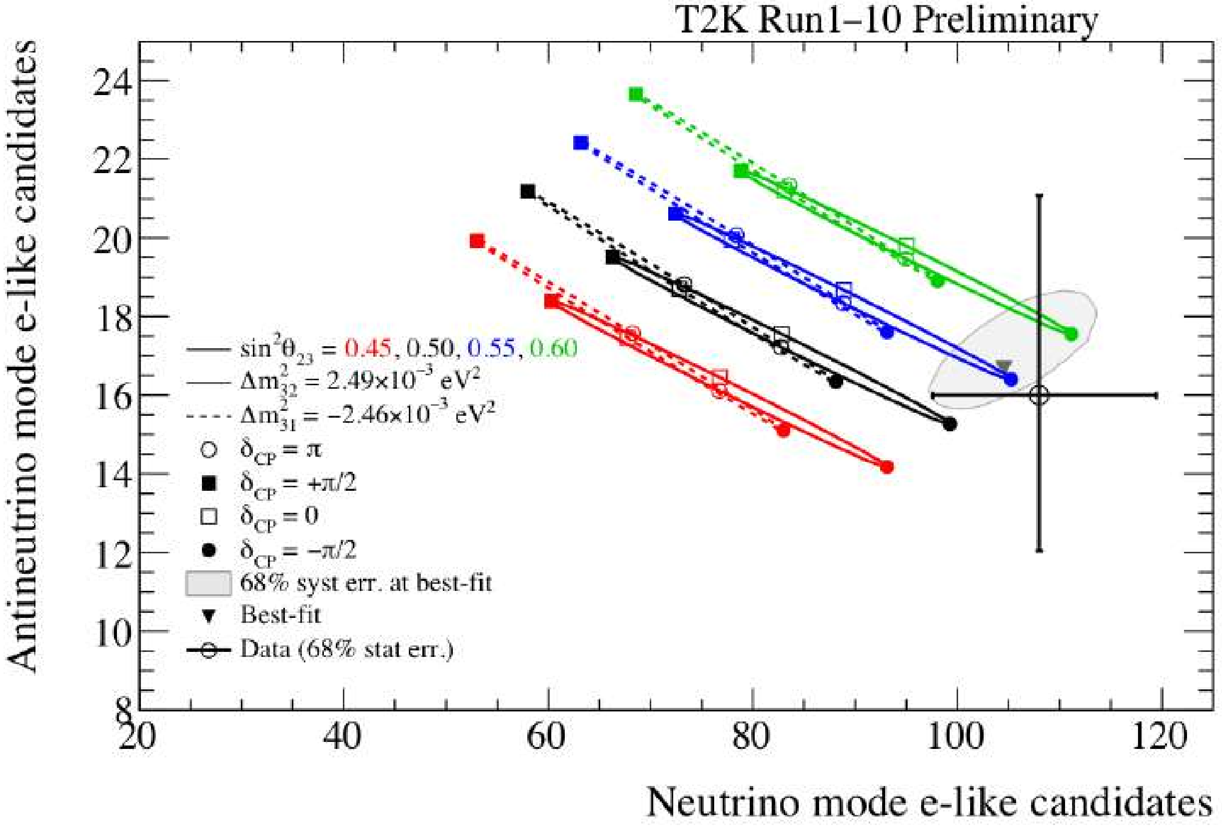
$$P(\nu_\mu \to \nu_e) \approx \sin^2(\theta_{23}) \sin^2(2\theta_{13}) \sin^2\left(1.27 \frac{\Delta m^2 L}{E}\right)$$

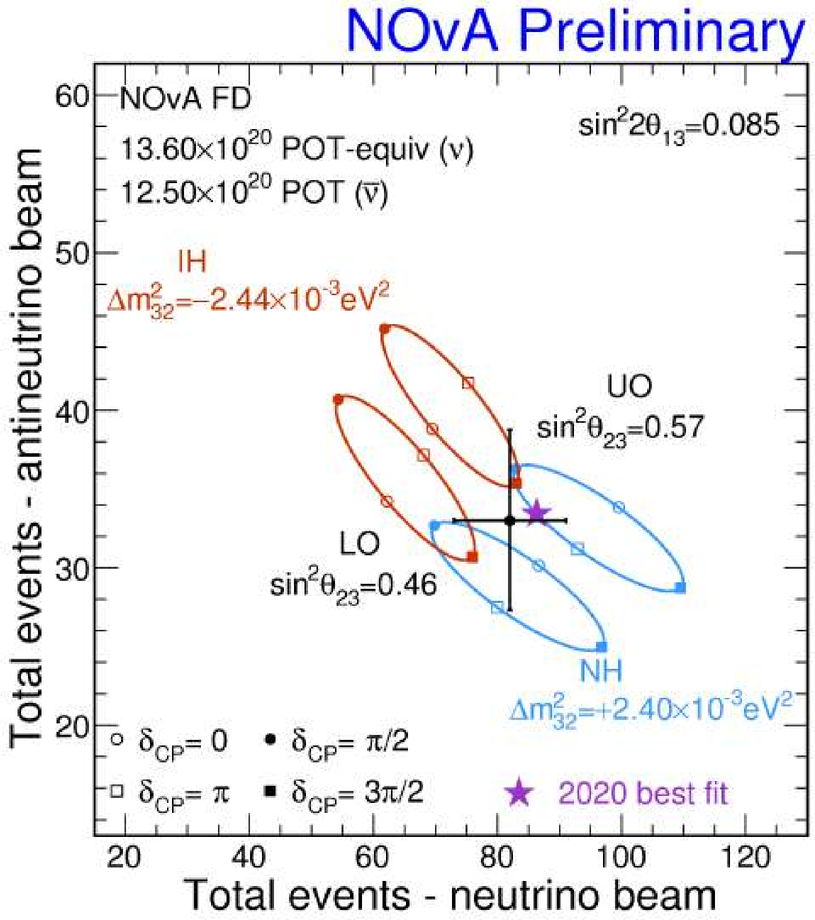


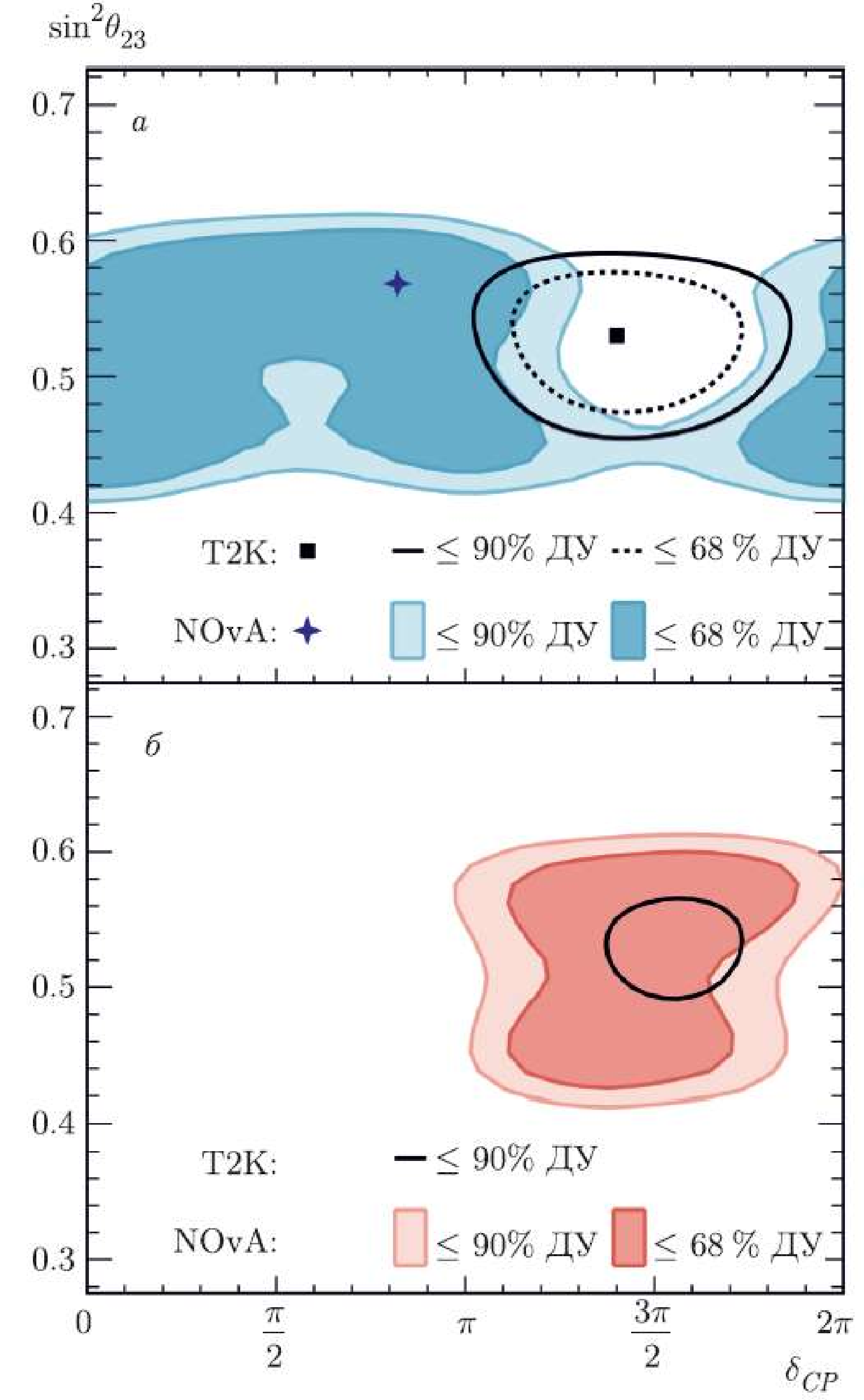
Phys. Rev. D 103, L011101 (2021)

Comparison of results to NOvA

- NOvA experiment is a long-baseline neutrino experiment in the USA
  - Baseline of 810 km
  - Higher energy and broader neutrino flux







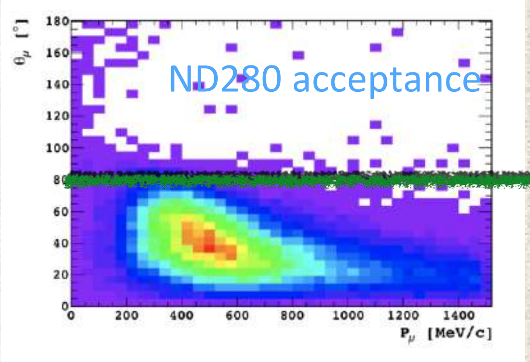
Сравнение результатов T2K и NOvA

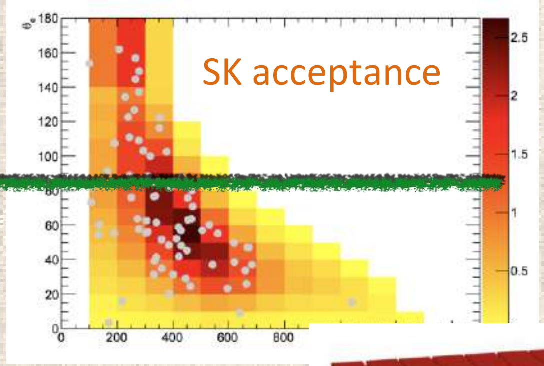
Основным результатом T2K является измерение фазы δ_{cp}, исключающее сохранение CP-инвариантности на уровне 2 сигма, а для некоторых областей на уровне 3 сигма.

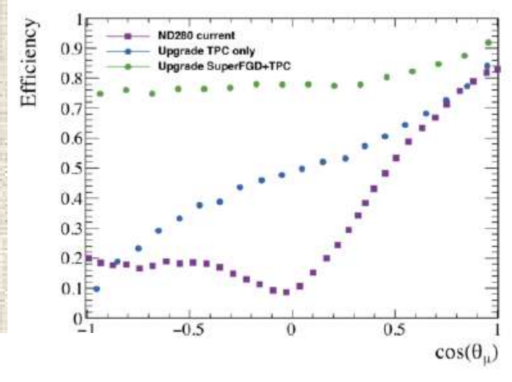
Данные эксперимента NOvA продолжают предпочитать нормальное упорядочивание масс и сохранение CP-инвариантности.

Возможно, совместный анализ данных экспериментов T2K и NOvA приведет к обратному упорядочиванию масс нейтрино и к тому, что максимальное нарушение $\delta_{cp} = 3*\pi/2$ CP-симметрии будет являться общим предпочтительным решением ?

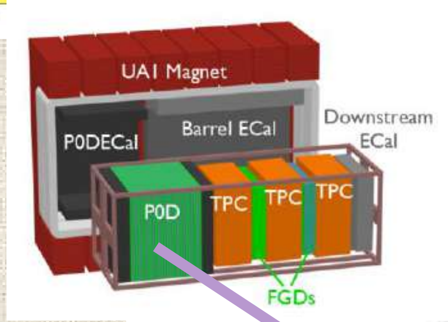
ND280 upgrade

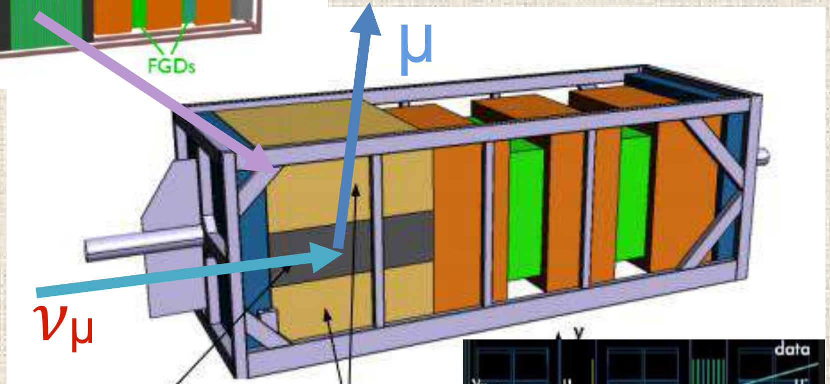


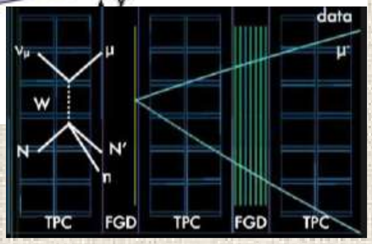




- Main strength of ND280 : magnetized detector → separate ν from $\bar{\nu}$ (cannot be done in SK or HK)
- Main limitation of ND280 : reduced angular acceptance → only forward going tracks are reconstructed with high efficiency
- An analysis dedicated to select tracks with high polar angles → 20% efficiency
- We can do better with an upgrade → Horizontal target and horizontal TPCs
- + Efficiently detect charged particles at any angle
- + The reduction of the protons threshold
- + Measure neutrons in antineutrino interactions
- + As a result, reduce the systematic error from 6 to 4% when counting electronic antineutrinos







Вклад сотрудников ОИЯИ в T2K

- Спроектирована и создана оснастка для сборки активной мишени SFGD, включающая сборочную платформу, систему доступа сверху для монтажа детектора, комплект транспортировочной тары для перевозки массива сцинтилляторов и компонент оснастки.

- Разработан и создан пилотный электронный блок в стандарте NIM для калибровочной системы SFGD.

- Проведено изучение оптических наводок между элементами активной мишени SFGD. Результаты доложены в коллаборации и на семинаре ЛЯП. Статья сдана в печать.

- Проведен анализ систематических погрешностей в ближнем детекторе ND280 восстановления импульсов по пробегам. Результат представлен в T2K Note.

- Изучен выход вторичных частиц с графитовой мишени (replica target at CERN). Улучшена точность определения выхода нейтрино из мишени до ~5%

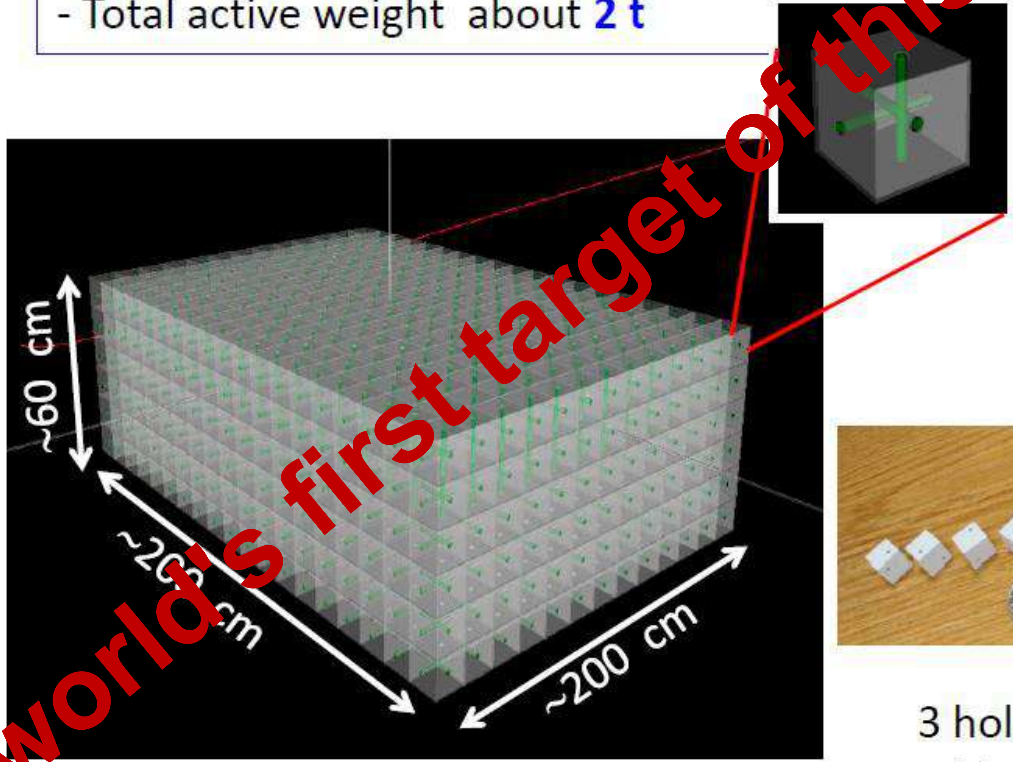
SuperFGD

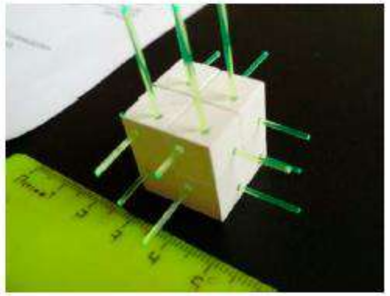
JINST 13 (2018) 02006

- Volume ~200 x 200 x 60 cm^3
- **~2 x 10^6** scintillator cubes , each 1 x 1 x 1 cm^3
- Each cube has orthogonal 3 holes, diameter 1.5 mm
- 3D (x,y,z) WLS readout
- About **60000** readout WLS/MPPC channels
- Total active weight about **2 t**

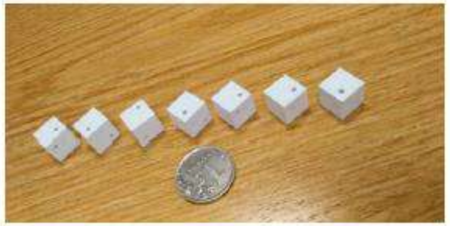
Fully active, highly granular, 4π scintillator neutrino detector with 3D WLS/MPPC readout

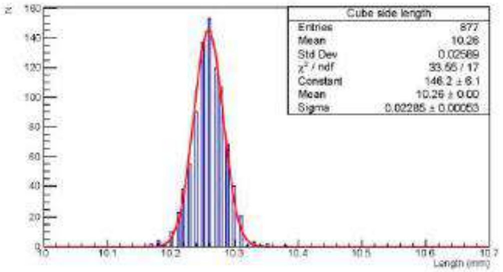
the world's first target of this type





Cubes produced by injection molding
Covered by chemical reflector
Tolerance (each side) about 30 microns

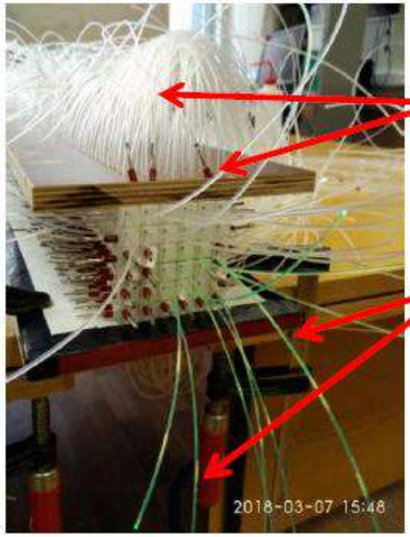




3 holes in each cube drilled
with the tolerance of 50-70 microns

Assembly procedure

Baseline method: 1- assembly of planes and whole detector using fishing lines
2 - replacement of fishing lines by WLS fibers

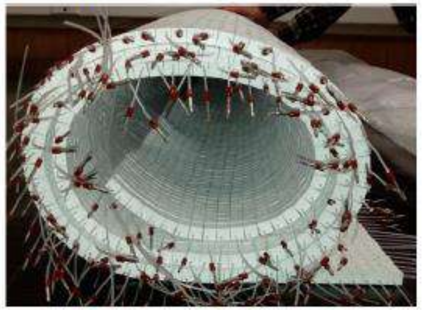


Fishing lines

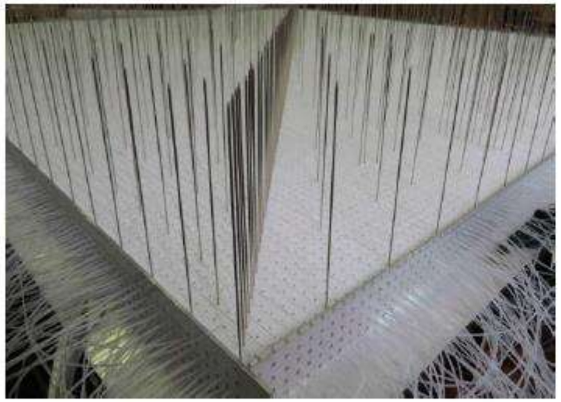
Y11 WLS fibers

Method was tested with small prototypes

Swiss roll made of a plane of cubes



Four panes assembled with fishing lines and stainless steel needles



Packing cube layers: box #1

- Move every cube layer + polyethylene film using wooden bars (~4x4 cm cross section, ~ 3 m long);
- A strong and light pipe can be used instead of a bar (better to cover by a polyethylene)

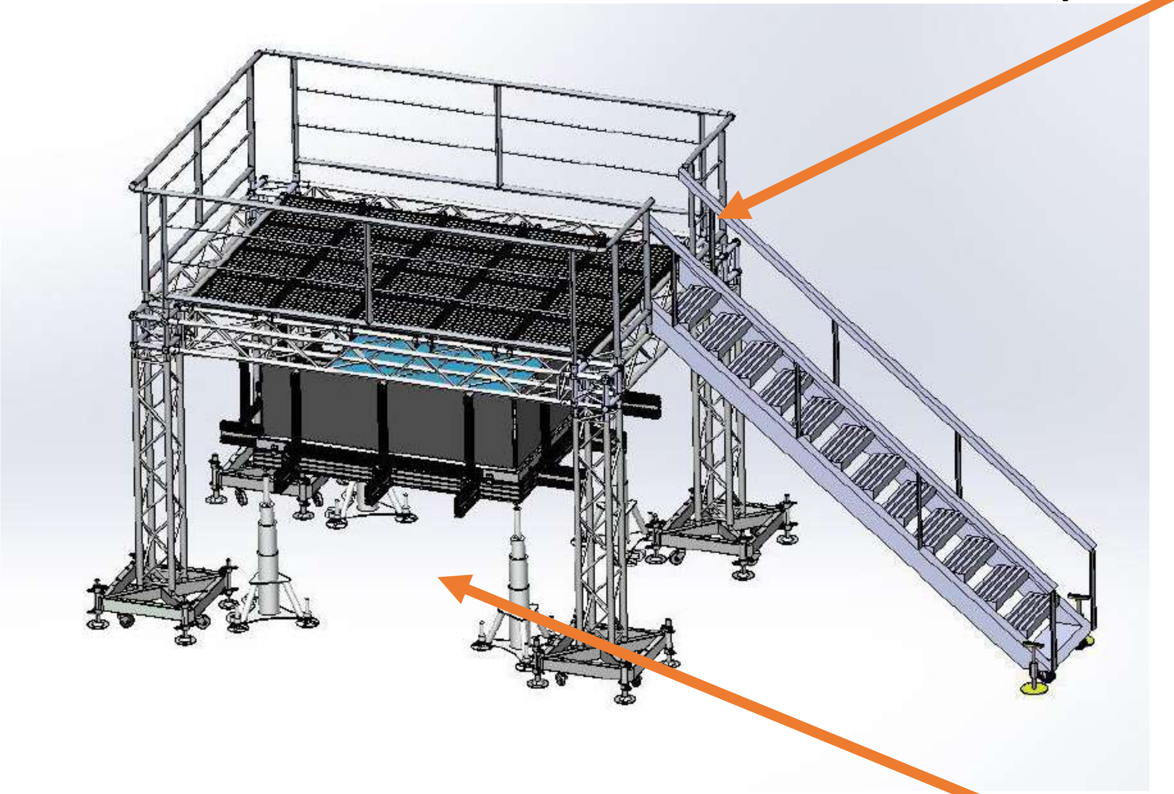
Joint Institute for Nuclear Research

Cubes shipment

- 6/June/2022: from INR to Vnukovo airport (VKO)

The assembly platform

Top access system



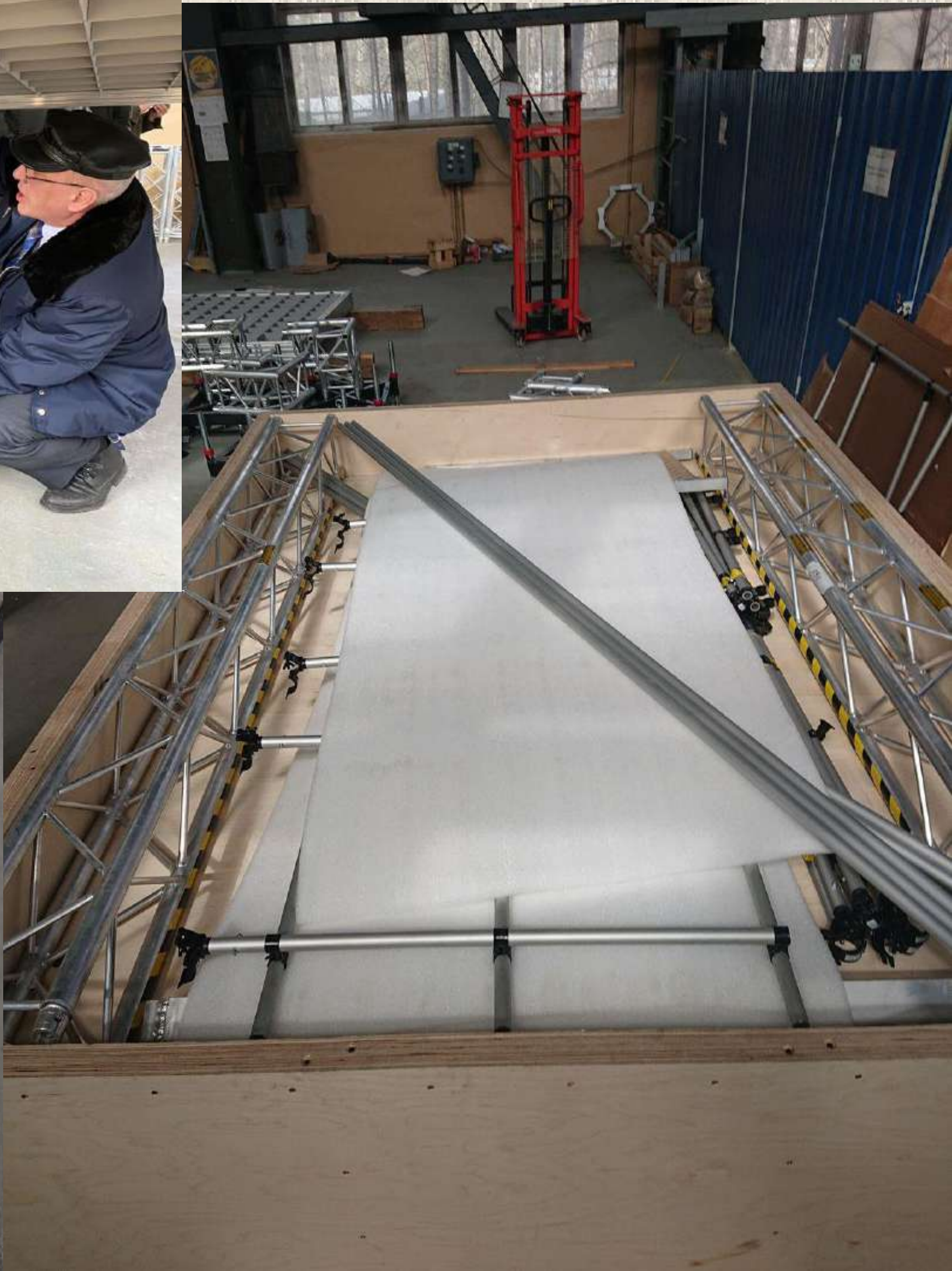
Support system

June 2022: shipment of the platform elements from JINR to INR

May-July 2022: paperwork for platform shipment (INR)

July-Aug 2022: shipment of the platform to KEK/J-PARC

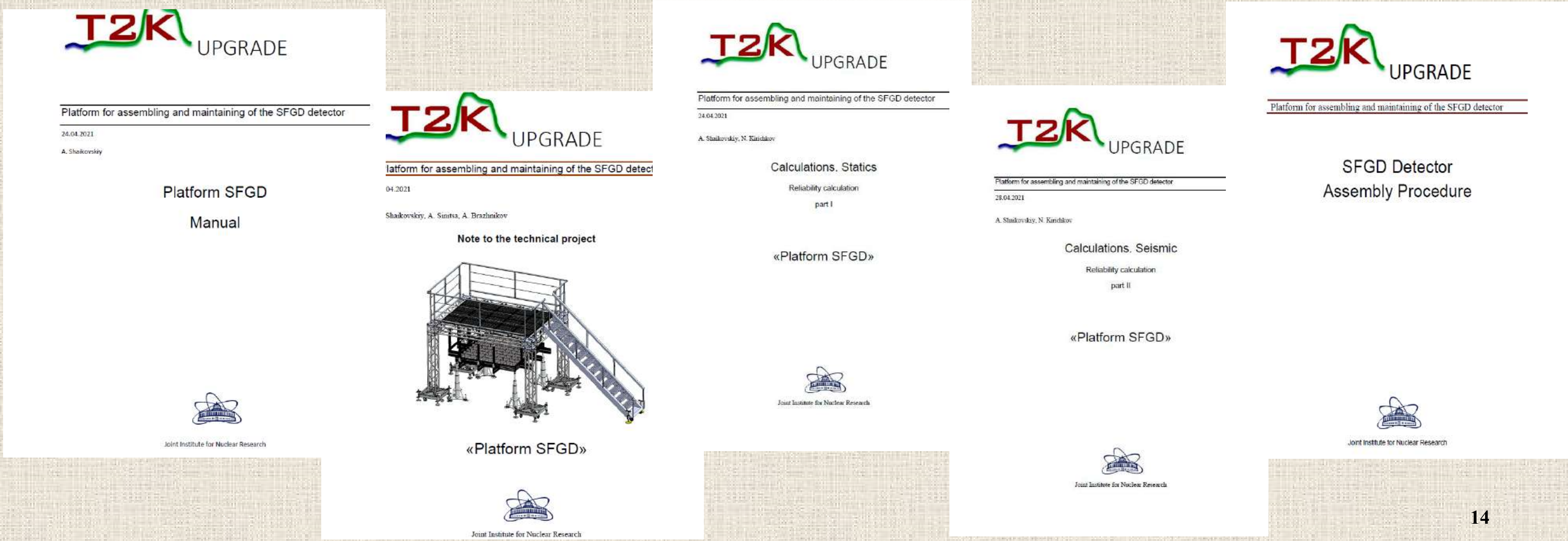
Подготовка платформы и системы доступа сверху к отправке в ИЯИ и далее в J-PARC



Strong contribution of the JINR engineers

- **The SuperFGD assemble platform is developed**
- **Reliability calculations of the assembly platform for the static load and seismic stresses demonstrate that the structure has a good safety margin.**
- **SuperFGD assemble procedure is developed**

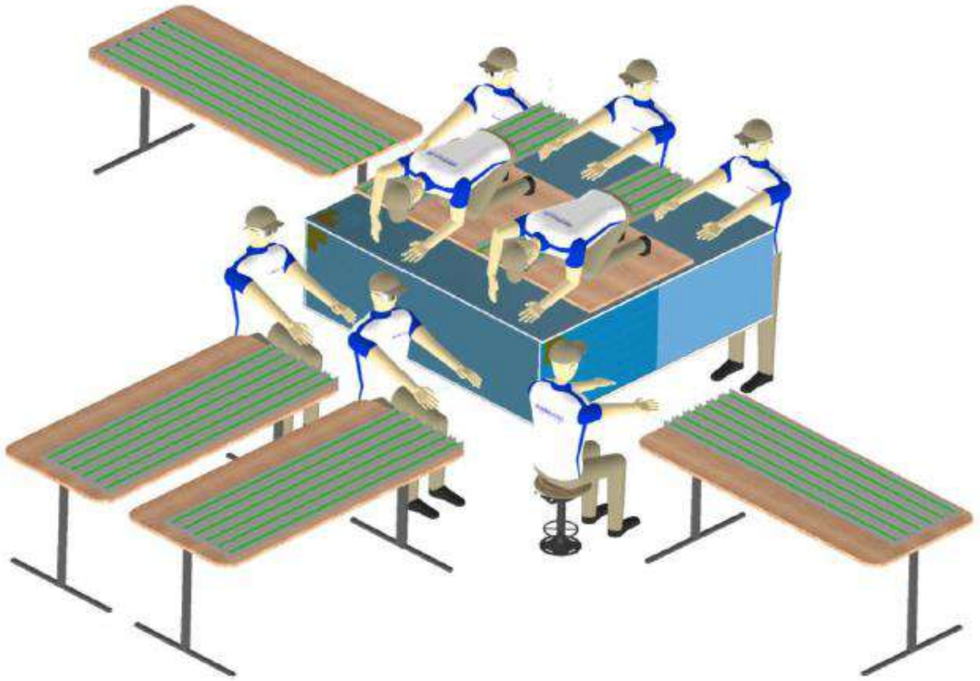
1. Platform for the SFGD assembly. Manual
2. Note to the technical project
3. Calculations. Statics (Reliability calculation. Part I)
4. Calculations. Seismic (Reliability calculation. Part II)
5. SFGD Detector Assembly Procedure



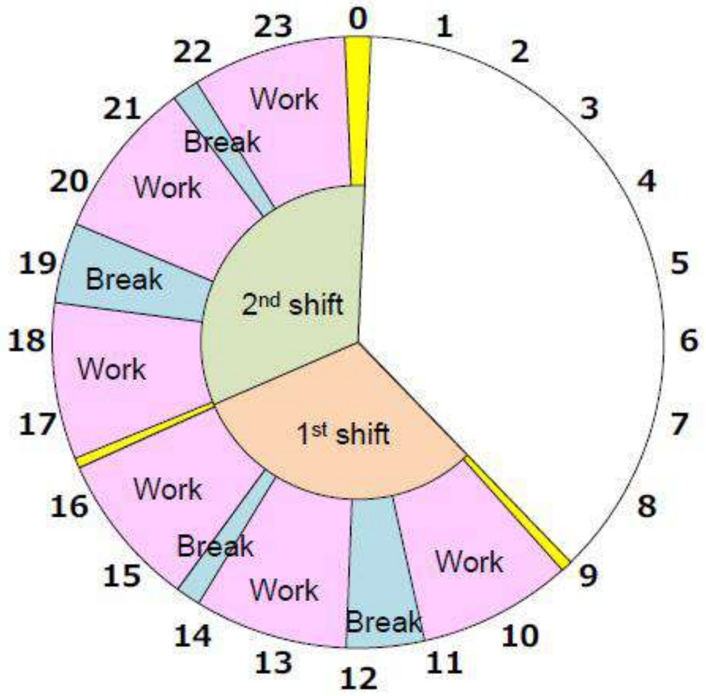
Fiber insertion

- Much person power is needed for the work.
- Eight people will work in parallel.
- First shift will be outsourced to company.

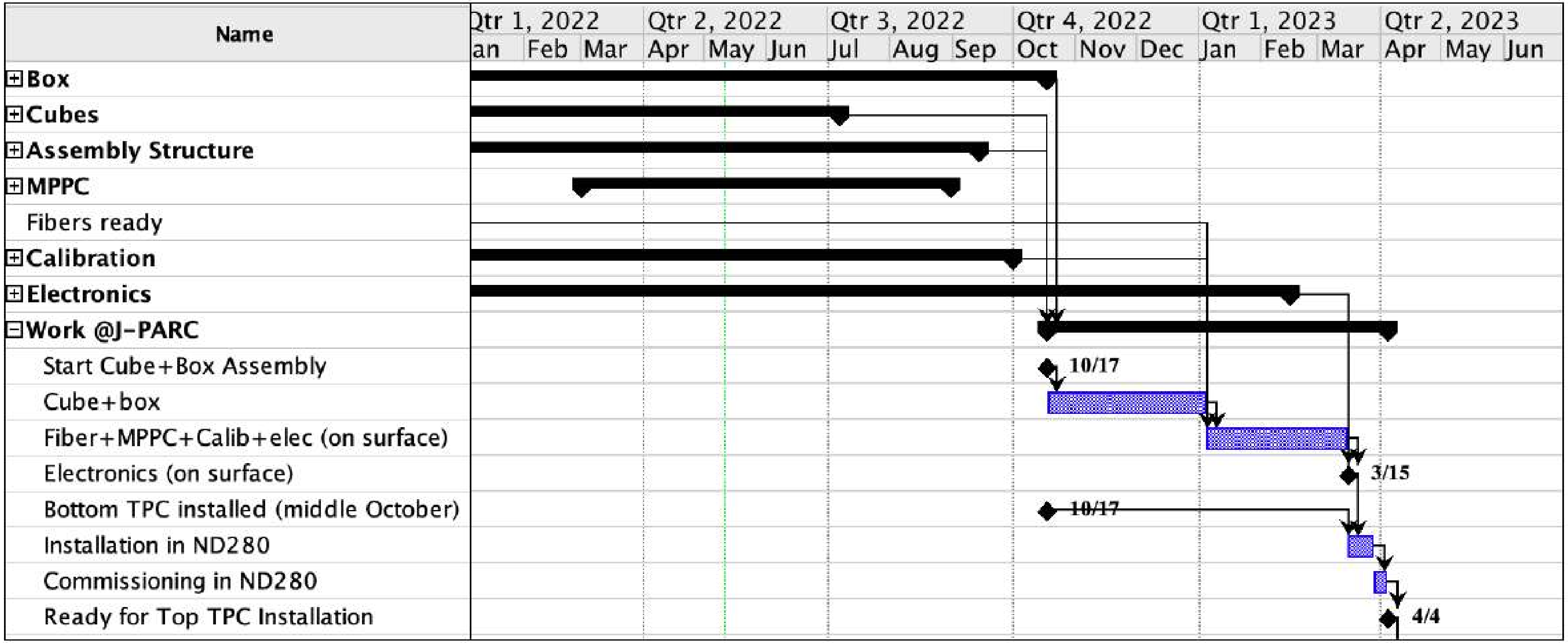
Fiber insertion work with eight people



Daily work schedule



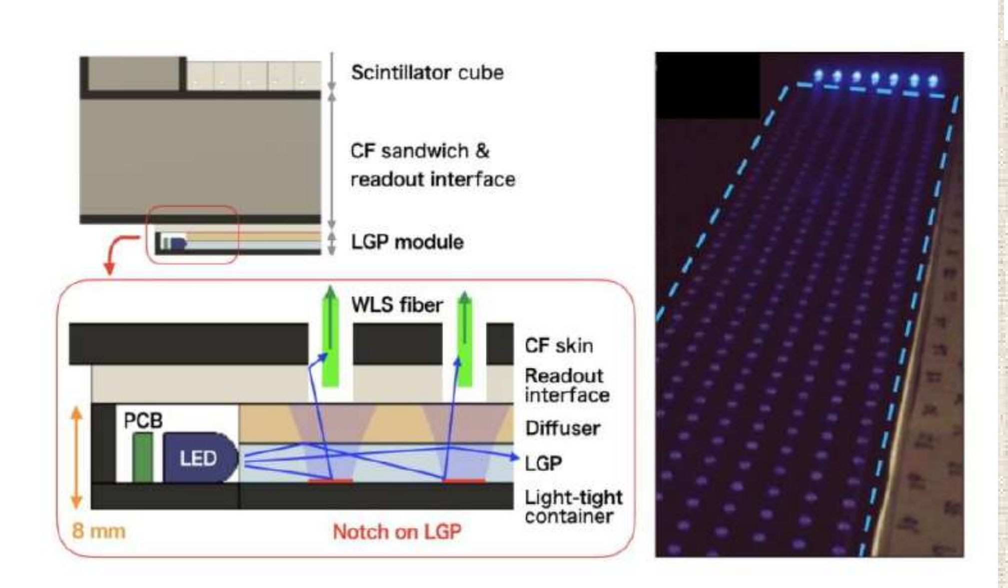
Overall Time Schedule

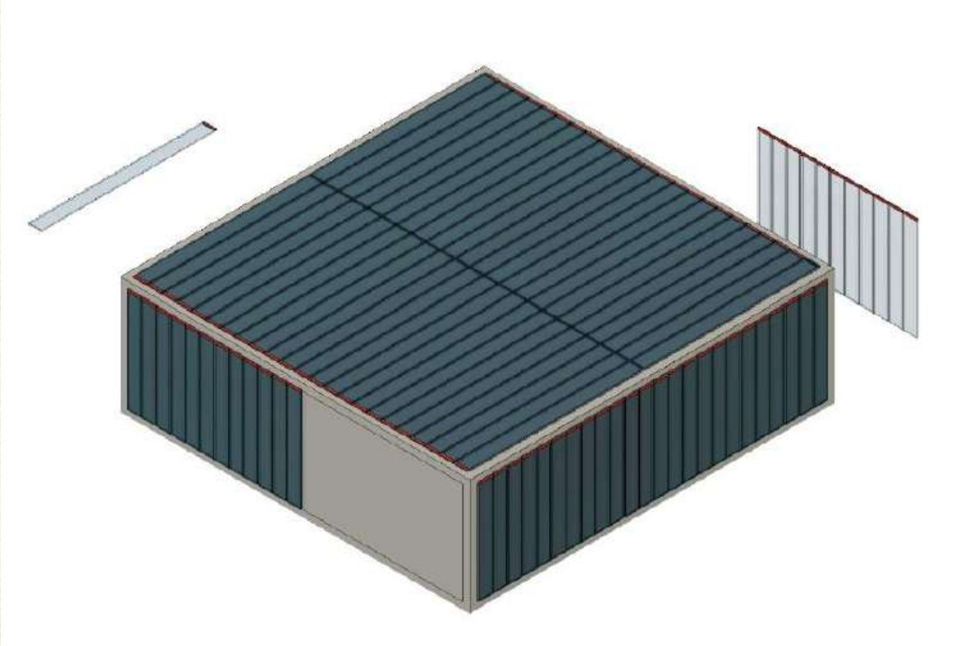


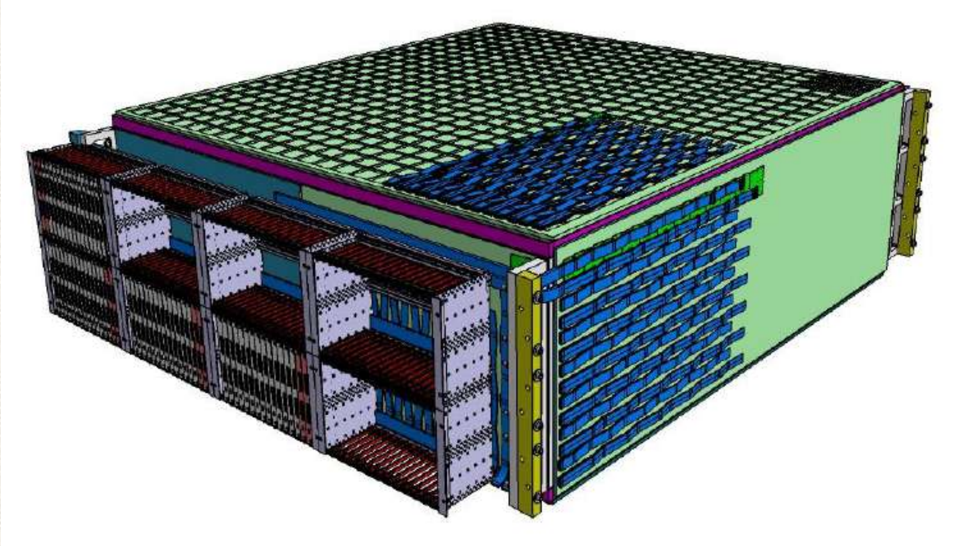
- Overall schedule is not impacted by the various updates

JINR contribution to the calibration system of SFGD

LNP develops electronics for the SFGD calibration system. The Figures show the concept of the calibration system. 93 LGP modules are located around the detector and allow us calibrate all 56k MPPC. Intensity of calibration LED radiation is controlled down to single photons.





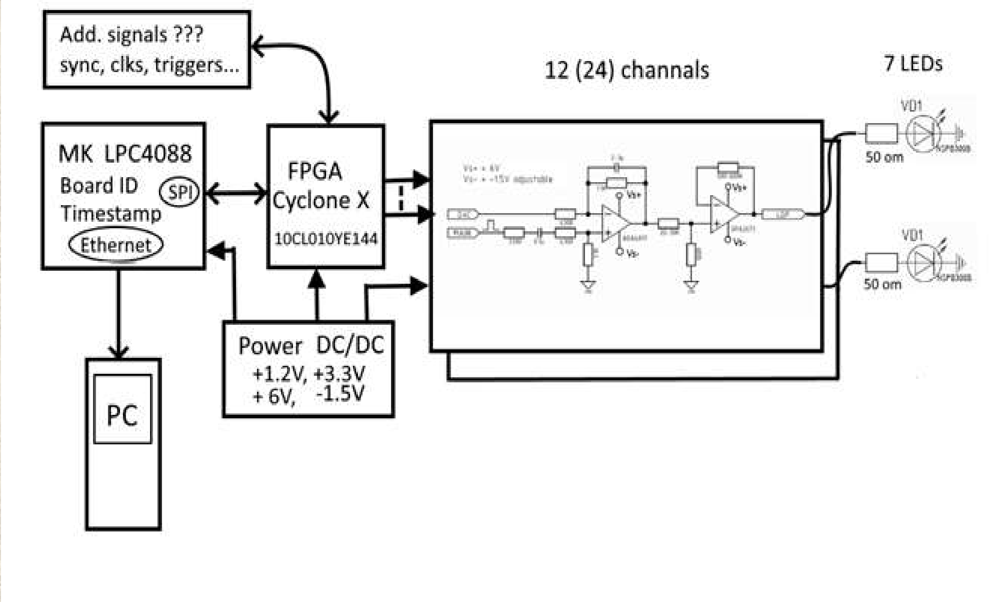


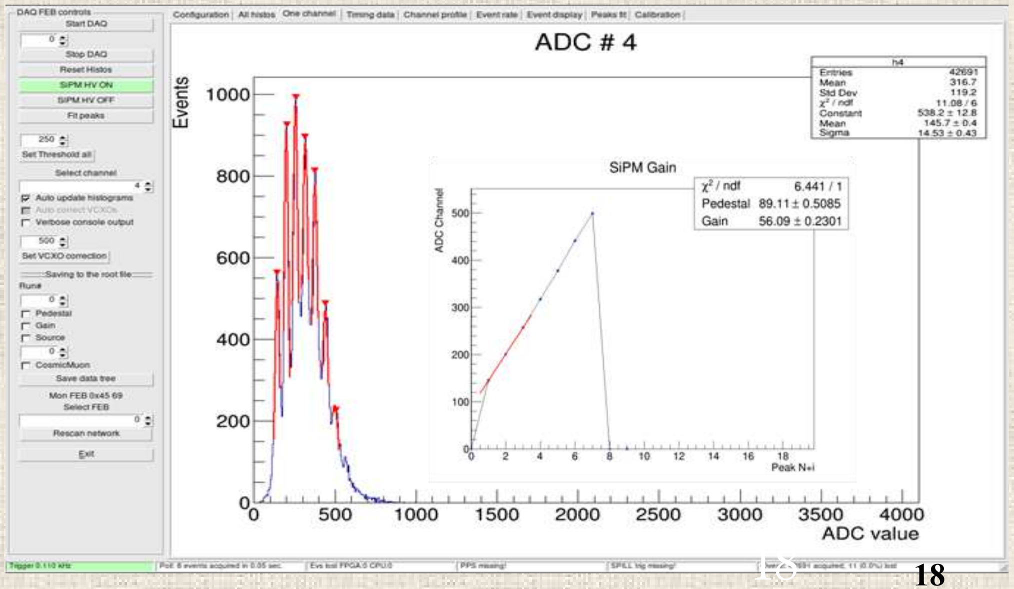
17

JINR contribution to the calibration system of SFGD

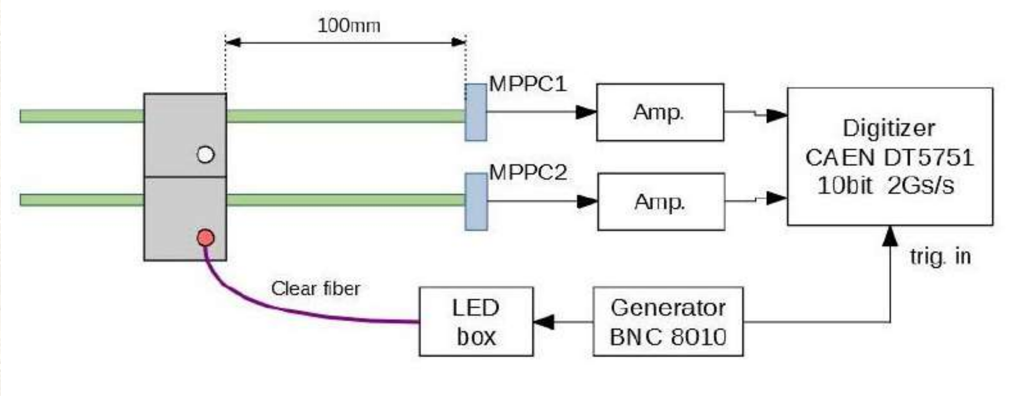
Photo on the left shows a module developed and manufactured in DNLP, which contains 12 channels of SFGD electronics. JINR group is obliged to manufacture 8 such modules up to June 2022.

Upper right picture shows the module's scheme. Lower right picture demonstrates calibration of a single LGP channel with single photons.

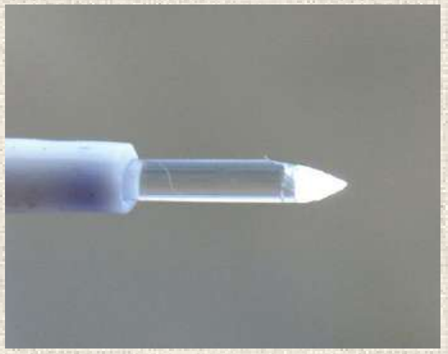




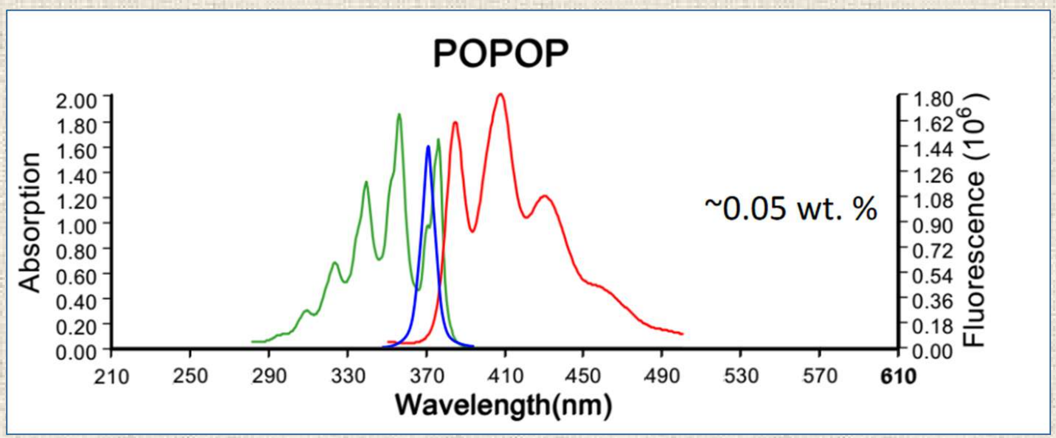
SFGD cubes optical cross talk study using a LED excitation



We have developed a way to study optical light leakage between cubes using LEDs, which provides a fast and reliable way to control light leakage through the surfaces of the cubes.



LED370E wavelength spectrum is peaked around of 375 nm

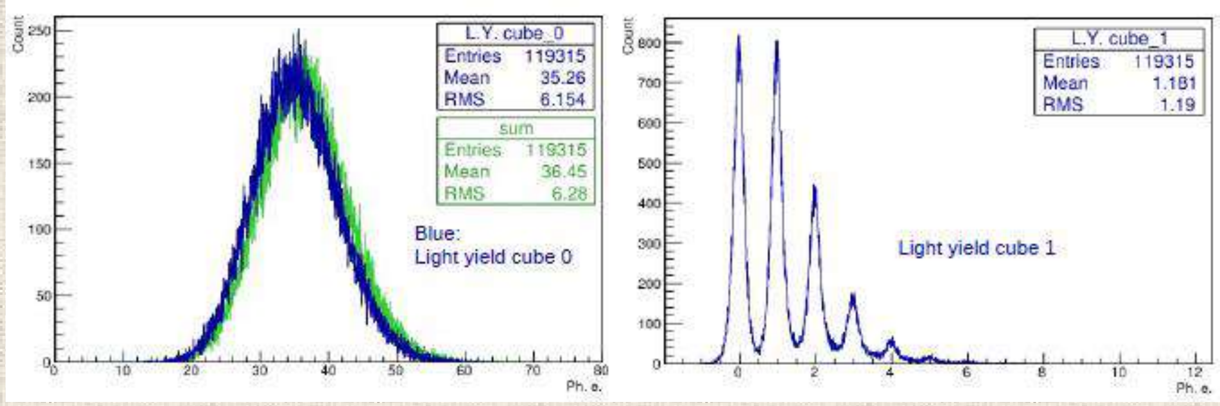


Fiber to illuminate the cubes with a LED light

WLS fibers: 1 mm diameter, open far end

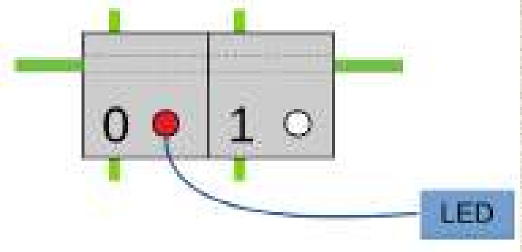
SiPM: Hamamatsu S13360-1350CS 1.3x1.3 mm^2

Cubes optical cross talk measurements



Spectra of signals from 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 leak from the cube "0".

Light leak through one side wall is about 3.3%, it coincides with the data obtained by our colleagues in measurements on accelerators.



$$\frac{L.Y.cube\,1}{L.Y.cube\,0}=0.0335$$

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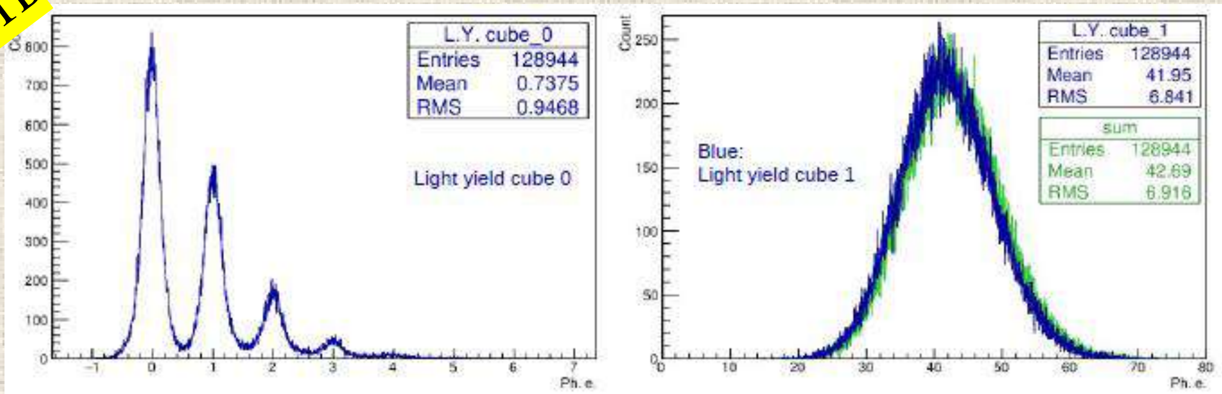
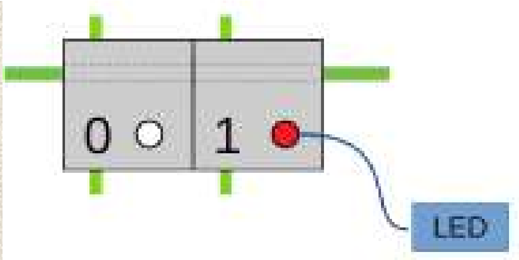


In the case of illumination of cube "1" light leakage into cube "0" is noticeably less and the ratio of the signal in the cube "0" to the signal in the cube "1" is 1.8 % . This is due to the different distance from the illumination spot to the cubes boundary walls.



$$\frac{L.Y.cube\,0}{L.Y.cube\,1}=0.0176$$

This effect can be used to increase the "spatial" sensitivity when reconstructing tracks of charged particles.

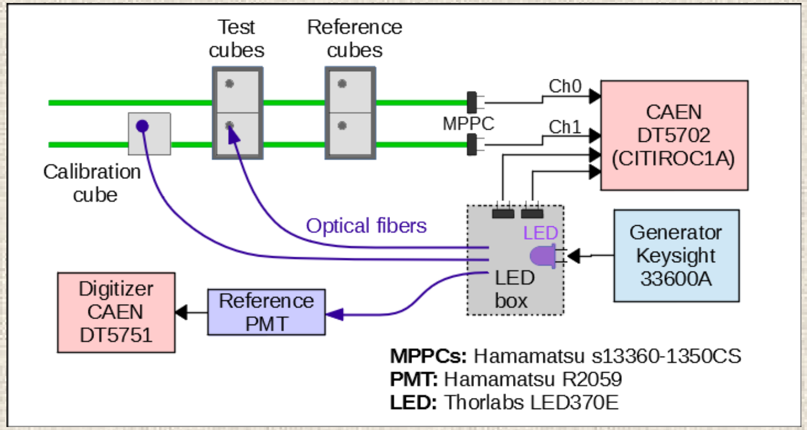
Heating influence on the light yield and crosstalk of the cubes

We want to check how temperature treatment, for example, heating of the transportation container during the transportation of the detector from INR to J-PARC could affect on the scintillating properties of the cubes and on the reflecting coating and consequently crosstalk.

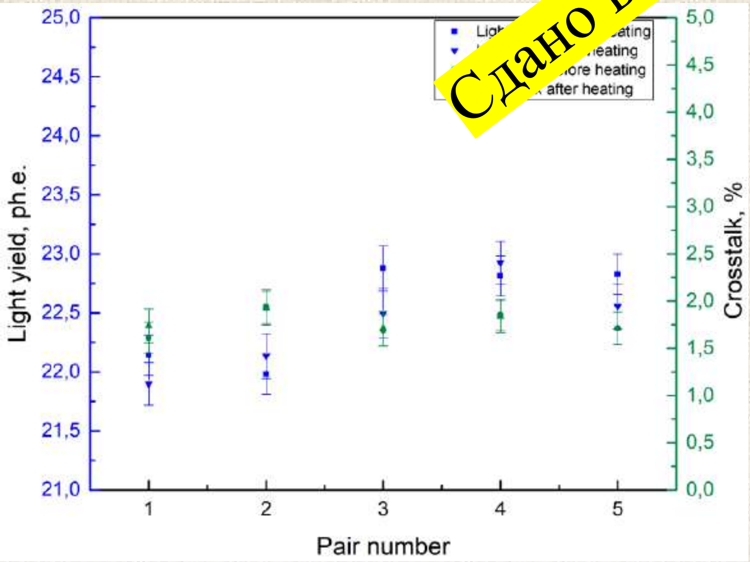
Using the UV LED (λ≈375 nm) light injection into the cubes we can measure the light yield and crosstalk of the cubes before and after heating and compare the results.

Heating of the cubes we are going to do using the industrial thermostabilized chamber.

We have tested 5 pairs of cubes, measured their light yield and crosstalk before and after heating. We put it to the thermostabilized chamber and kept under 60 °C for 24 hours, and then allowed them cool to room temperature for 20 hours before measuring.



The light yield and crosstalk did not change significantly after heating



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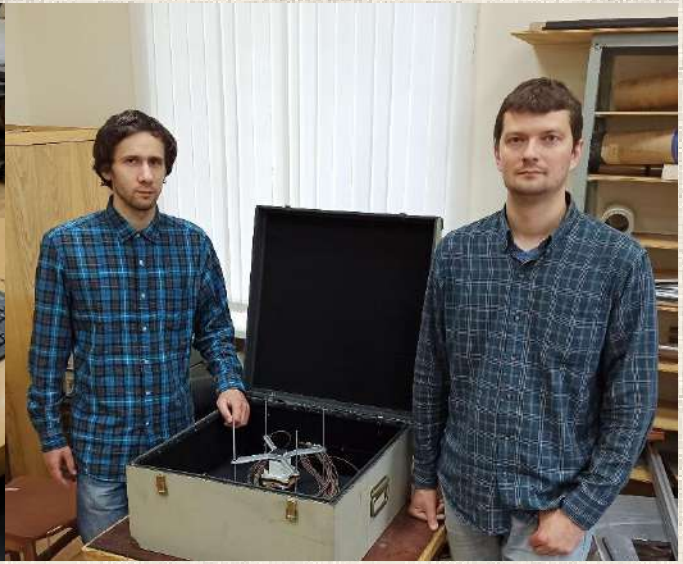
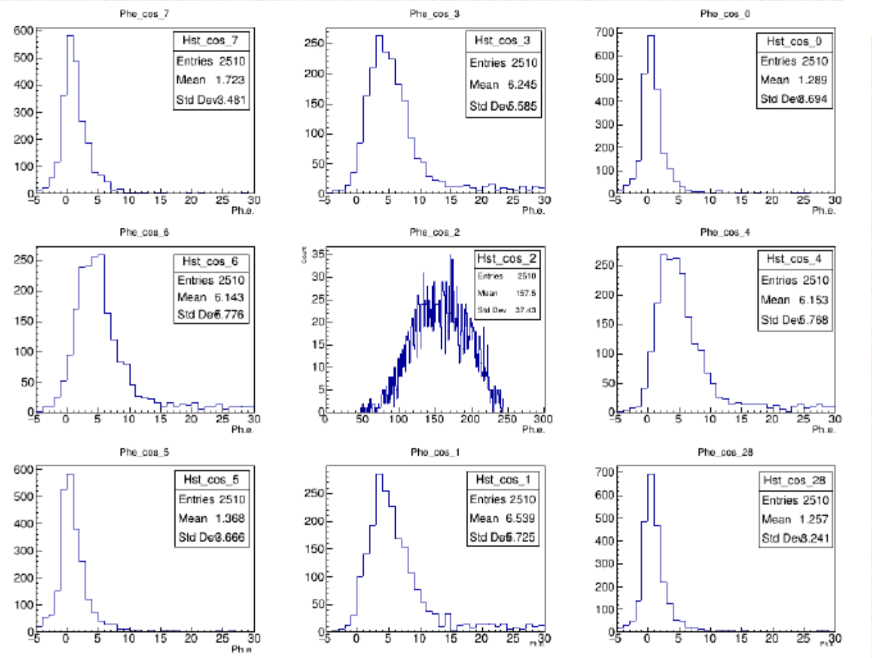
3x3x3 cubes prototype measurements





3x3x3 cubes matrix tests on cosmic muons

Signals from cubes from the central column and cross talk on adjacent columns when cosmic muons pass vertically through the central column

We plan to study the possibility of improving the accuracy of reconstructing the tracks of charged particles in the SFGD taking into account the optical cross talk in adjacent channels. To do this, it is necessary to develop an algorithm to take into account cross talk in cubes.

To test this technique on cosmic muons and on accelerator beams, it is planned to create a prototype detector with a size of about 5x5x10 cubes.

NA61/SHINE для T2K

1. **Hadron production measurements with a thin Carbon and a replica of the T2K target using the NA61/SHINE spectrometer at the CERN SPS**

2. **Prediction of neutrino and antineutrino fluxes in T2K/T2K-II/HyperKamiokande with unprecidented precision**

3. **Upgrade of the NA61/SHINE spectrometer and of the readout system (DAQ rate increased by a factor of 10)**

Основные результаты и планы:

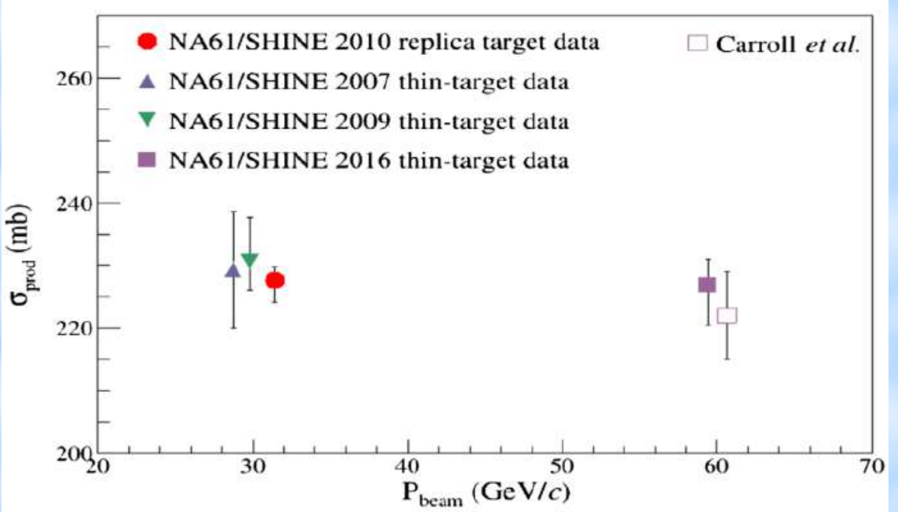
1. Выполнен анализ данных эксперимента NA61/SHINE и опубликованы результаты по измерению выходов адронов и сечению рождения [Phys. Rev. D 103 (2021) 1, 012006] в протон-углеродных взаимодействиях.

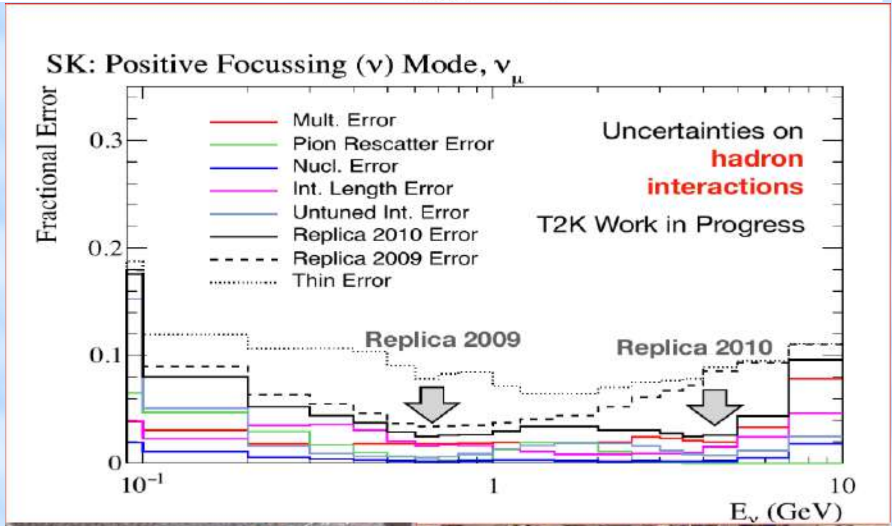
2. Эти данные были использованы для более точного предсказания спектров и потоков (анти)нейтрино в эксперименте T2K: для ускорительных экспериментов получена рекордная точность ~5%.

3. Участие в модернизации спектрометра NA61/SHINE: замена электроники считывания сигналов с время-проекционных камер установки.

4. Подготовка предложений (CERN-SPSC-2021-028 и CERN-SPSC-2022-022) в научный комитет SPSC по созданию и использованию низкоэнергетичной линии пучка H2 совместно с модернизированной установкой NA61/SHINE

5. На лето 2022 года запланирован новый набор экспериментальных данных с точной копией мишени T2K. Это позволит улучшить точность измерения выходов адронов, особенно для заряженных и нейтральных каонов





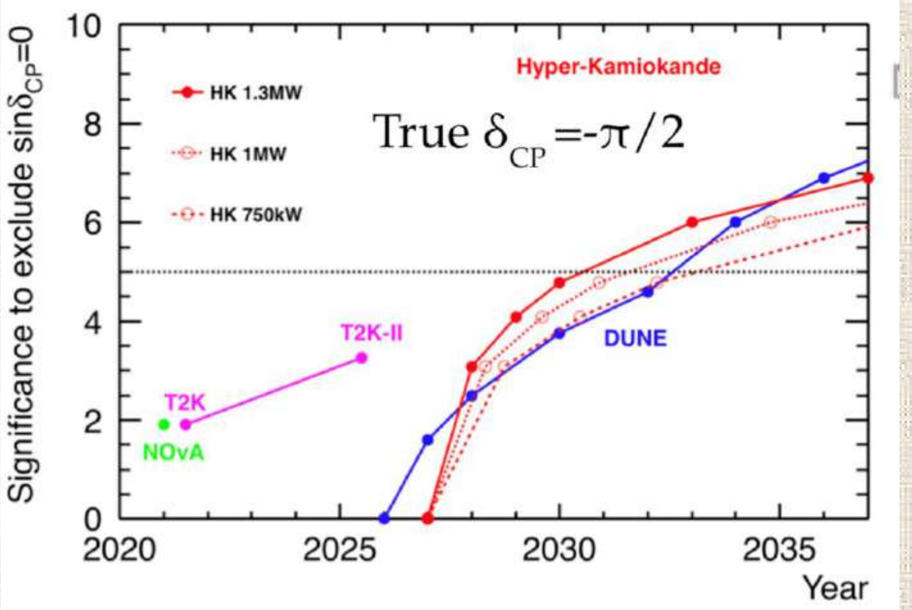
План участия в T2K-II на 2023 г.

- Участие в сборке мишени SFGD в J-PARC на лесках, далее на оптических волокнах. Тестирование оптических каналов в процессе сборки.
- Создание остальных 7 NIM блоков системы калибровки SFGD в J-PARC. Участие в сборке и наладке полной системы калибровки.
- Участие в сеансах набора данных T2K-II
- Поиск «темных» фотонов на данных с ближней мишени эксперимента T2K и T2K-II
- Продолжить изучение выхода вторичных частиц с графитовой мишени (replica target at CERN). Улучшеие точности определения выхода нейтрино из мишени до ~4%

Плавно переходим к докладам Игоря Александровича и Александра Валерьевича

T2K-II

- Upgrade of J-PARC Main Ring (1.3 MW beam)
  - Approved and funded, will be done by 2022
- Goal: collect >10x10^{21} POT by 2026 → 3σ measurement of CP violation if δ_{CP}~-π/2
- Near Detector upgrade to reduce systematics from ~7% to ~4%
  - Installation the new detectors in 2022
  - Use the ND280 Upgrade detector also as initial Near Detector for Hyper-Kamiokande
  - Strong involvement of the JINR group
- Improvements of the Far Detector thanks to the SK-Gd project



Hyper-Kamiokande

- Exclusion of δ_{CP}=0
  - 8σ for δ_{CP} ~ ± π/2
  - >3σ (5σ) significance for 76% (57%) of δ_{CP} space
- Sensitivity will be further enhanced by combination with atmospheric neutrino measurements
- Assume systematics uncertainties of ~4% (currently 7% for T2K)