SuperFGD - central part of near neutrino detector of T2K experiment

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Abstract

The T2K experiment is a long baseline neutrino experiment in Japan. It is applied to detect neutrino flavor oscillations after traveling 295 kilometers through the Earth crust. The neutrino beam appears in accelerator complex in J-PARC. It produces the neutrino off-axis beam with power of 800kW. The detecting part of experiment consists of two detectors: the near and far ones. The far detector is a water Cherenkov detector Super Kamiokande. The near one is called ND280 and located 280 metres from the accelerator complex. It consists of fine grained detectors, time projection chambers and electromagnetic calorimeters.

Oscillation Parameters

The fundamental neutrino oscillations theory leads to the mixing matrix U_{PMNS}. It connects the active states of neutrino flavors with their mass flavors. This matrix can be parameterized by four parameters and other ones correlating with them.

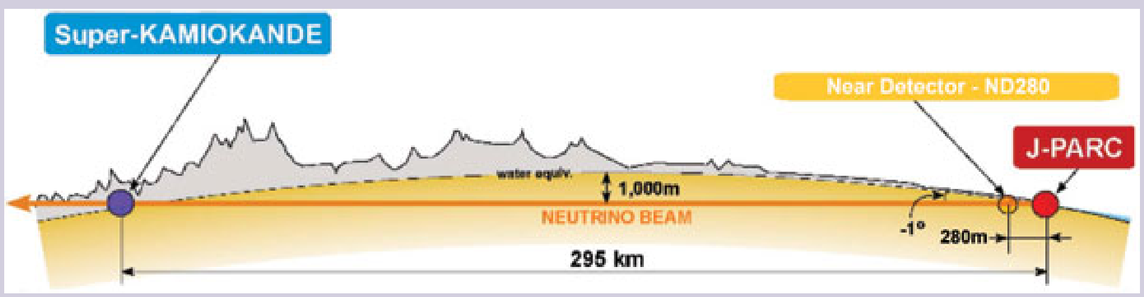
Known parameters:

- Difference between square masses Δm^2_{12}, Δm^2_{23}, Δm^2_{13}.
- Mixing angles θ_{13}, θ_{23}, θ_{12}.

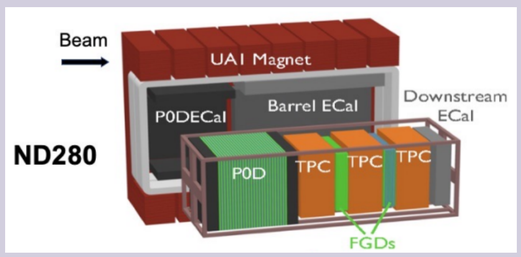
Parameters to measure:

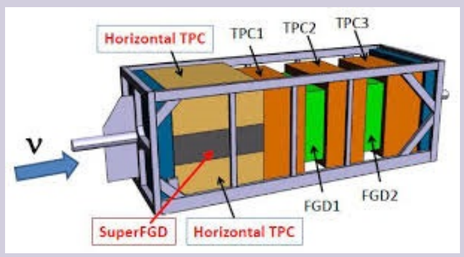
- CP violation phase δ_{CP}
- Mass hierarchy

Experiment T2K



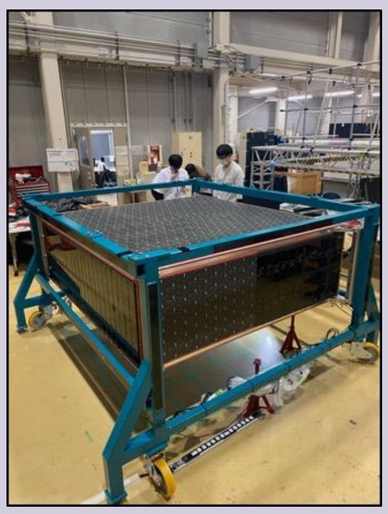
The experiment started take data in 2011. In the 2024 near detector was upgraded. The P0D detector was replaced with SuperFGD and two horizontal TPCs.





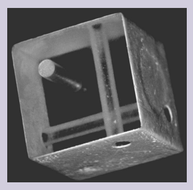
The far detector is Super Kamiokande(SK). It is used to measure the neutrino flux after passing 295 kilometers. The probability of neutrino oscillations can be calculated based on difference of fluxes between near and far detectors.

SuperFGD

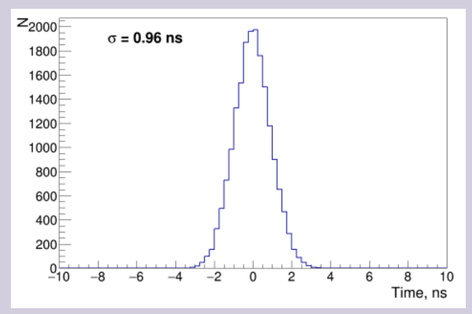


SuperFGD is a fine grained scintillating detector. It consists of almost 2 billion plastic cubes. Every cube has the light reflection layer to minimize the light transmission to near cubes. The parameters of detector are:

- Size of cube is 1x1x1 cm
- The cubes are made of polystyrene
- Sizes of detector are 192x182x56 cm
- Mass is around 2 tons

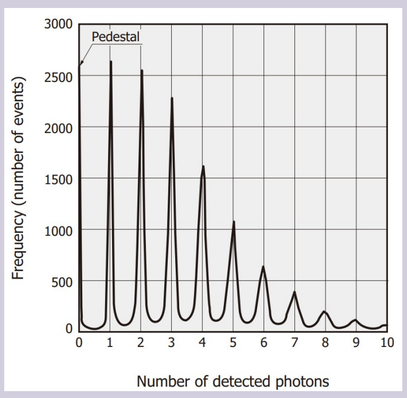


Three orthogonal wavelength shifting fibers are passed through every cube. This geometry provide the possibility to detect photoelectrons in three dimensions.
Also the plot of the time resolution for one channel is presented. The mean value is 0.96 ns.



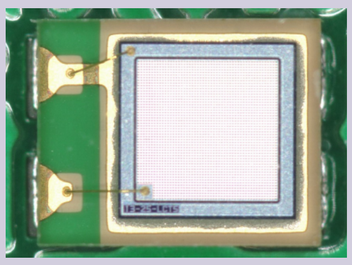
MPPC

When a particle pass the detector medium it emits photons. These photons are registered by multi pixel photon counters(MPPC). The configurations of this photodetectors is presented here:



- Model: Hamamatsu - S13360-1325PE
- Gain is 7×10^5
- 2668 pixels on each MPPC
- Photo detection efficiency(PDE) is 25%
- Effective area is 1.3mm $\times$1.3mm
- Crosstalk probability 1%

The MPPC spectrum helps to determine the number of photoelectrons hit the detector. With this information, the energy losses in each cube can be measured with high accuracy. After adding up these losses, whole particle energy can be reconstructed. This is applicable for particles stopped in SuperFGD.

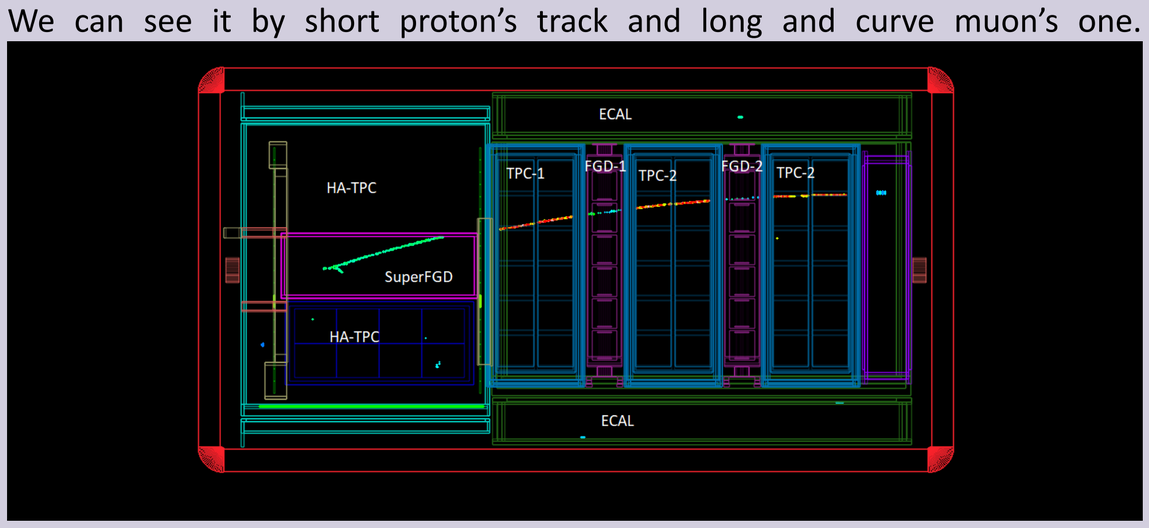


Track example

There is a track from off-axis near detector. Here can be noticed that the neutrino interacted with neutron in the medium of detector and proton and muon are produced.

$$\nu_\mu + n \rightarrow p + \mu^-$$

We can see it by short proton's track and long and curve muon's one.



Results

- Measurements of ν_μ oscillations in ν_e lead to the conclusion that mixing angle $\theta_{13} \neq 0$. It was confirmed by such experiments as Daya Bay, Double Chooz.
- For now the T2K collaboration made the upgrade of the near off-axis detector ND280. There was added superFGD that was applied for 4π particle track reconstruction. Also were added two TPCs(Horizontal TPC). They are applied to detect particles on high angles relative to μ^- direction.
- The main current task of the experiment is to search δ_{CP} which can explain the baryon asymmetry of the universe.

Reference

Yu.G. Kudenko Neutrino oscillations: recent advances and future prospects - Physics-Uspekhi - 2018 - Phys. Usp. - 61 - p. 739–747
S Fedotov et al Scintillator cubes for 3D neutrino detector SuperFGD - J. Phys.: Conf. Ser. - 2022 - 2374 - 012106
Supported by RSF grant 24-12-00271