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Performance of SuperFGD in the T2K neutrino beam

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T2K experiment



T2K (Tokai-to-Kamioka) experiment is a long-baseline neutrino experiment in Japan studying neutrino oscillations. The main goals of T2K are:

Motivation of the ND280 Upgrade

The uncertainties of current T2K oscillation measurements are dominated by statistics. However, systematics will limit T2K (and Hyper-Kamiokande) sensitivity in the future.

- It is important to measure neutrino interactions in all phase space.
- Precisely detect particles produced at any angle.
- Reduce detection threshold to measure protons with low energy.
- Measure neutrons in anti- v_{μ} interactions.
- Reduce background and obtain better track identification using ToF (Time-of-Flight). • Reduce total systematics to $\leq 4\%$ level (from the current $\sim 6\%$) for appearance modes.
- The probe of CP violation, providing further constraints on the δ_{CP} phase,
- Precise measurements of oscillation parameters (Δm_{23}^2 and θ_{23}) via disappearance studies,
- Measurements of various neutrino interaction cross-sections for different types of targets.

The experiment uses a muon-neutrino beam generated at the J-PARC accelerator in Tokai and sent 295 km to the far detector, Super-Kamiokande, in Kamioka.

SuperFGD (Super Fine-Grained Detector)



Detector design

- SuperFGD is the active target for neutrino interactions in the upgraded ND280 detector.
- It consists of ~ 2 million cubes (192 x 56 x 182 cm³) with 1 cm side. The total mass of SuperFGD is ~ 2 t.
- Cubes are injection molded by Uniplast (Vladimir, Russia).
- Cubes are made of polystyrene, and doped with 1.5% of paraterphenyl (PTP) and 0.01% of POPOP, and coated with a chemical reflector for optical independence.
- SuperFGD provides a 3D readout for each cube via three orthogonal wavelength-



MPPC calibration and gain calculation

■ ~60,000 MPPCs, model S13360-1325PE (Hamamatsu Photonics K.K.), detailed characteristics are available at Hamamatsu website.



- Extract the HG calibration ratio (ADC/p.e.) from MPPC fingerplots. The mean distance between peaks is the **gain** value.
- Several HG values are used to find the pedestal. The intersection point of these graphs is the **pedestal** position.

shifting fibers, each connected to MPPC (Multi-Pixel Photon Counter).

Attenuation length for horizontal WLS fibers



 LY_{S} and LY_{L} – short and long Light Yield coefficients [p.e.], A_S and A_L – short and long attenuation components [cm], *x* – distance from photosensor [cm], **R** – reflection coefficient [%].



L.Y., p.e.





- Real cosmic data were used (only events from horizontal fibers).
- Cosmic trigger.
- Select hits > 40 p.e. matched in all three dimensions.
- Compare mean time of hit to mean time for event.
- Gives ~1.2 ns time resolution.

Time resolution

Example of neutrino event with stopped proton in SuperFGD

First event displays with upgraded ND280





- The detector has been collecting data since May 2024.
- These long particle tracks and multi-track events found in the beam data taken in **June 2024.**

[1] K. Abe et al., The T2K Experiment, Nucl. Instrum. Methods A, vol. 659, pp. 106–135, 2011.

[2] A. Blondel et al., A fully active fine-grained detector with three readout views, JINST, vol. 13, no. 2, P02006, 2018.

[3] S. Fedotov, New 3D fine-grained scintillation detector for the T2K experiment, JINST, vol. 15, no. 7, C07042, 2020.

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