# First Results from T2K's Upgraded Near Detector (ND280)

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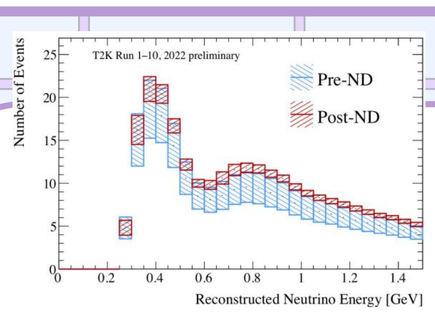
## The T2K Experiment

Tokai to Kamioka is a long-baseline neutrino experiment measuring $\nu_\mu$ ($\bar{\nu}_\mu$) disappearance and $\nu_e$ ($\bar{\nu}_e$) appearance to measure oscillation parameters $\delta_{CP}$, $\theta_{13}$, $\theta_{23}$ and $|\Delta m^2_{23}|$.

1

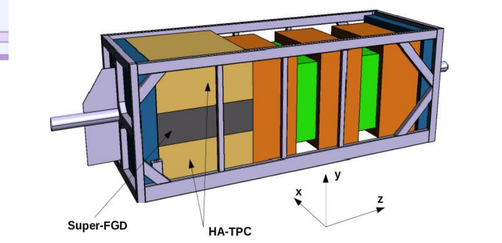



*SK neutrino mode 1 ring muon sample spectrum before and after ND fit*

## ND280 Motivation

ND280 constrains $\nu$ flux and cross sections, but propagation from ND to FD is limited by reduced angular acceptance, scalability of cross sections between different materials, and detection thresholds.

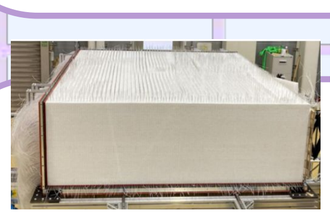
2



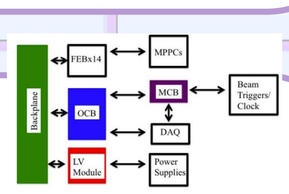

## ND280 Upgrade Impact

Three new sub-detector types (SFGD, HAT, TOF) for better reconstruction: lower proton detection threshold, higher detection efficiencies, higher angular acceptance, and neutron kinematics from time-of-flight.

3



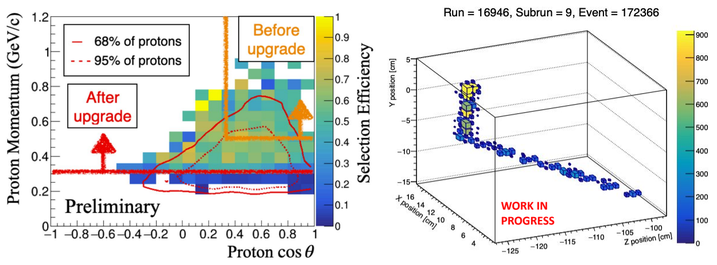
*SFGD during assembly*




*Overview of the SFGD electronics system*

## SFGD

**S**uper **F**ine **G**rained **D**etector to improve final state identification.

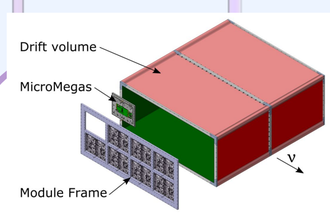




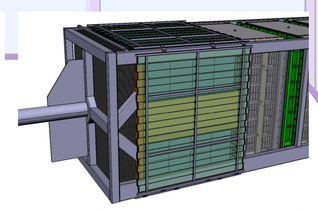


*Left: Proton selection efficiency as a function of polar angle and momentum for legacy and upgrade ND280. Right: Candidate Charged-Current (CC) νμ interaction with stopping proton in the SFGD. Voxel size proportional to the hit charge*

4




*Schematic view of the HAT*

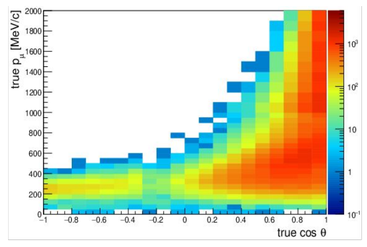


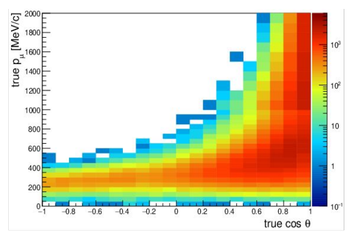
*Technical drawing of TOF planes attached to the exterior of ND280 basket*

## HAT, TOF

2 **H**igh-**A**ngle **T**ime Projection Chambers for high-angle tracks.

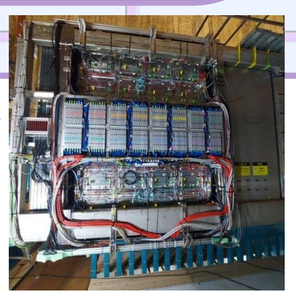
6 **T**ime-**o**f-**F**light detector planes for time reference, background rejection.



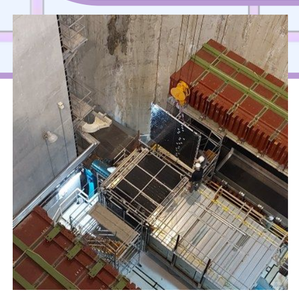




*Distribution of selected νμ CC events in legacy (left) and upgraded (right) ND280 configurations, in neutrino mode, as a function of true muon momentum and polar angle*

5



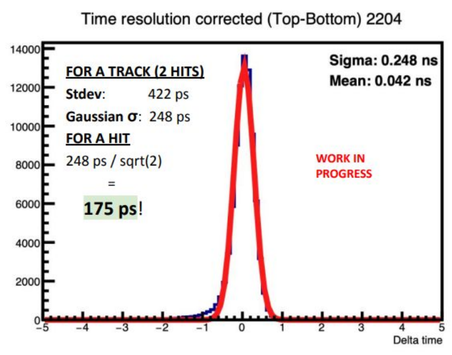
*Upgrade detectors before side TOF installation*

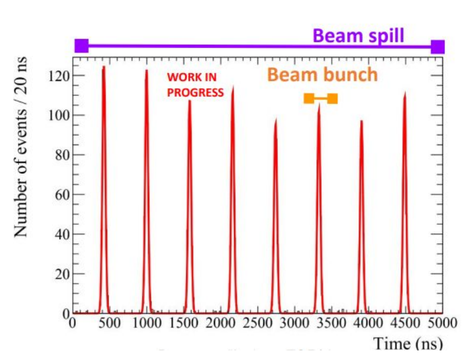


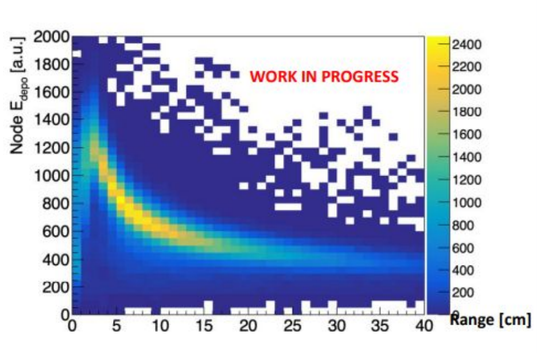
*Installation of last side TOF*

6

## Preliminary Sensitivities and Performance



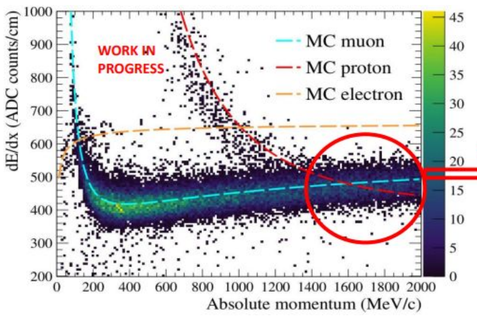




*Left: TOF time resolution, using cosmics, after calibration. Right: Beam profile from TOF hits*

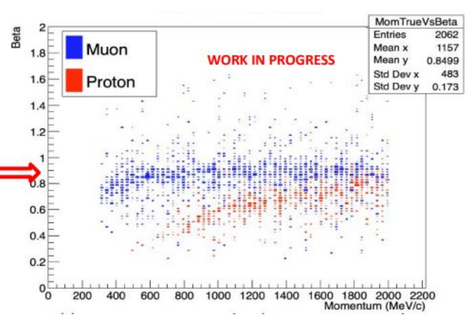
*SFGD Bragg peak studies for particle ID*

Time resolution of TOF at 175 ps: Reject of out of target events, distinguish beam bunches in a spill, precise HAT T0 estimation.

Multivariate analysis to perform particle ID using Bragg peak in SFGD.

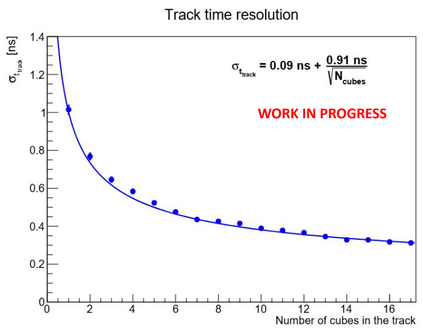


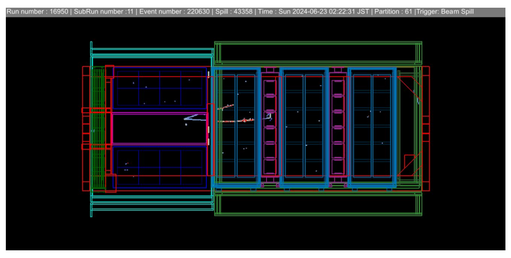

Combine



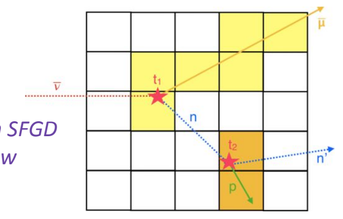

*Left: HAT PID by dE/dx. Right: Muon-proton separation by momentum using TOF-SFGD time of flight (MC)*

HAT dE/dx resolution under 10% allows for particle ID at low momentum. TOF can help distinguish protons and muons at higher momentum.




Sensitive to CC neutron events due to improved timing. Signature: delayed proton track linked to main vertex.

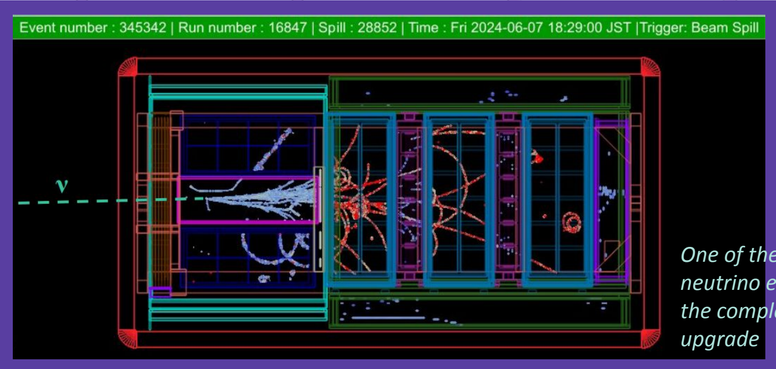



*CC neutron interaction in SFGD cubes, 2D view*

*Left: Time resolution of a single particle track as a function of the number of cubes forming the track, obtained from a selected sample of cosmic rays. Right: Potential neutron event display in SFGD, with neutron KE 27 MeV, lever arm 122 mm, time of flight 1.7 ns*

## T2K runs 13 and 14

- Technical runs in 2023 and 2024
- Upgrade completed in May 2024
- $5.2 \times 10^{20}$ POT (protons on target) collected with upgrade
- $4.4 \times 10^{21}$ POT with T2K ND280 2010-2022
- Beam power increased to 800 kW




*One of the first neutrino events with the completed ND280 upgrade*

## Contact

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Lepton Photon 2025
Madison, Wisconsin, USA

*The T2K collaboration*