Commissioning and performance of the TOF detector for the T2K ND280 Upgrade

Emanuele Villa[a] and Lorenzo Giannessi[b] for the T2K collaboration. *Contact*: emanuele.villa@cern.ch

EUROPEAN PHYSICAL SOCIETY EPS HEP2025 MARSEILLE
07-11 JULY, 2025
PALAIS DU PHARO
MARSEILLE, FRANCE

T2K and its Near Detector Upgrade

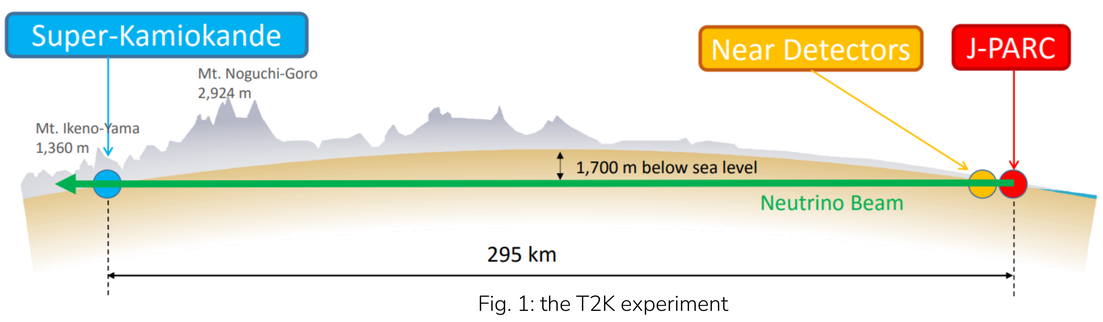


Fig. 1: the T2K experiment

T2K is a long-baseline neutrino oscillations experiment in Japan, where the J-PARC proton accelerator is used to produce a ν_μ or anti-ν_μ beam directed to Super-Kamiokande.
It computes **oscillation parameters** by observing ν_μ **disappearance** and ν_e **appearance**.

ND280 is an off-axis near detector used to characterize the unoscillated flux at the Near Detector site.

ND280 has been recently **upgraded**, by replacing the upstream section with **three new** sub-detector modules:

- two High-Angle Time Projection Chambers (**HATs**)
- the Super Fine Grained Detector (**SFGD**), an active neutrino target,
- six Time-Of-Flight (**TOF**) planes around HATs and SFGD

ND280 Upgrade **goals**:

- improve **proton** detection
- include **high-angle** tracks in selections
- reconstruct **neutron kinematics** from time-of-flight
- improve **sample purity**
- increase the collected **statistics**

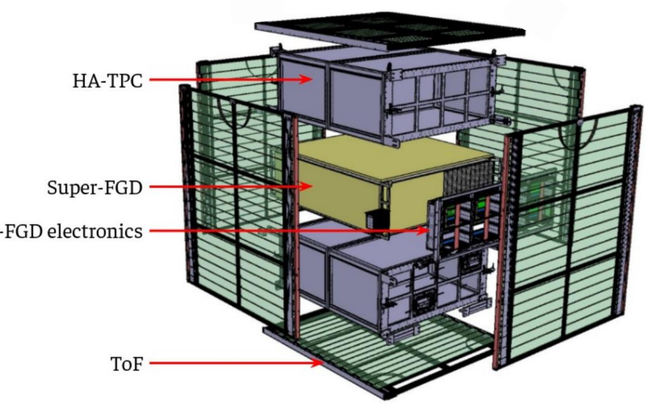


Fig. 2: exploded view of ND280 Upgrade.

The Time-Of-Flight detector

TOF detector **purposes**:

- Precise **time reference** for each track crossing the detectors, contributing to PID and HAT time reconstruction.
- Rejection of **out of the fiducial volume** particles, reducing a major background for neutrino selections.
- **Cosmic trigger** for SFGD and HATs.

TOF consists of **six** similar **plane modules** assembled in a cube (Fig. 2), almost **4π** enclosure for inner detectors.
Each plane 2.2 m, features 20 plastic **scintillator bars,** 2.2m long and read out by an array of **8 SiPMs on each side** (Fig.4).

Fig. 3: the unmounted ToF planes @ CERN

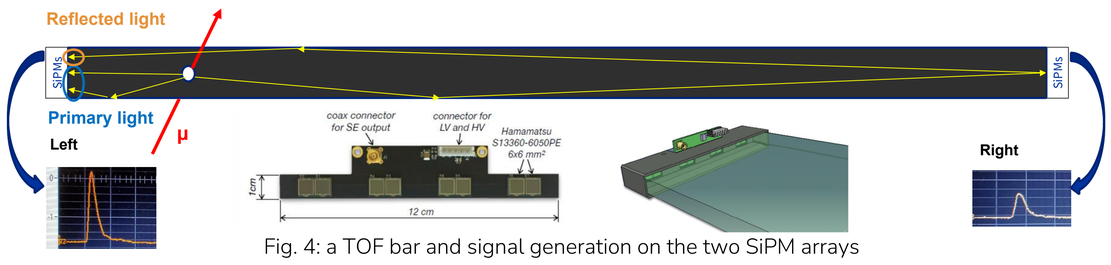


Fig. 4: a TOF bar and signal generation on the two SiPM arrays

Single-bar characterisation

A characterisation of the time response for a **single scintillator bar** was performed using a cosmic test bench**.** The bar has been **scanned** to collect 1000 cosmic events in 21 positions.

Fig. 5 shows the **average waveforms** for each trigger position. Their shape is not trivial: sum of a **primary wave** and a **secondary** one coming from **reflections** on the other side of the bar, see Fig. 4.

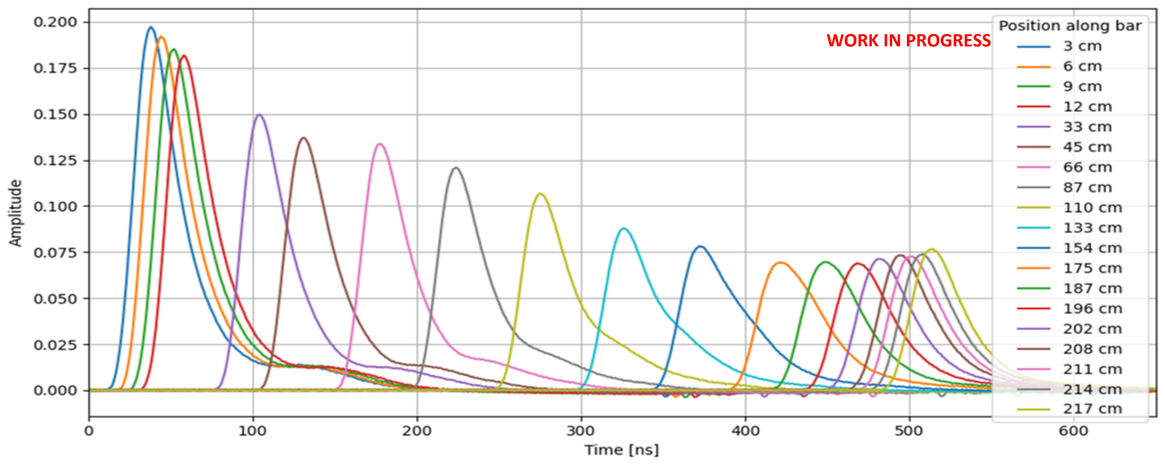


Fig. 5: average waveforms for the readout at one edge of the bar. Arbitrary horizontal spacing.

Since the **rising edge** is used to estimate the time associated to every event, the time resolution is impacted by this phenomenon (despite using a Constant Fraction Discrimination, which only compensates for the shape of the signals).

Using the same dataset and selecting only vertically crossing tracks (the most optimistic scenario), the nominal time resolution was estimated to be at **130 ps**.

The results from this dedicated setup provide an asymptote for the expected resolution of the whole detector.

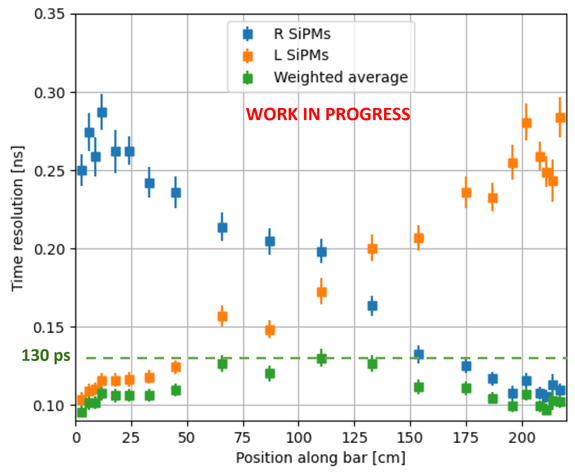


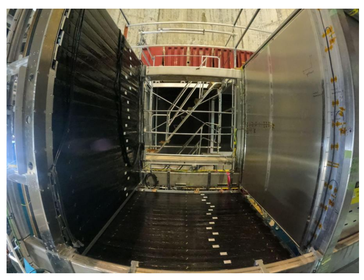
Fig. 6: time resolution along a TOF bar

Installation at J-PARC

TOF installation at J-PARC performed in several steps, interleaved by HATs' and SFGD's.
TOF allows for **flexibility**, planes have been moved several times to give access to other detectors!

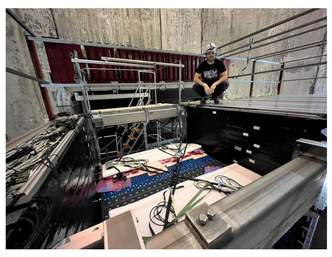
Shipment to Japan (truck+plane)!

Lowering the first plane down to the ND280 pit

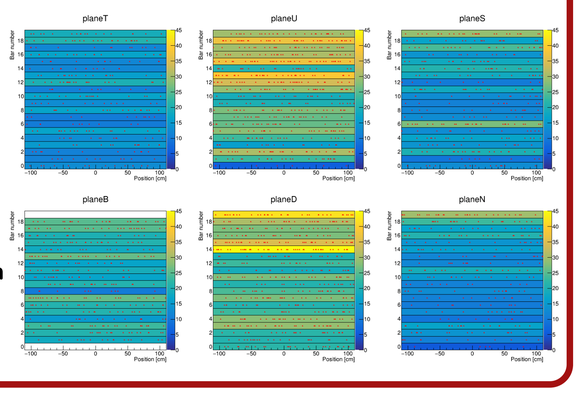


First two TOF planes in the final position in ND280 basket. Ready for HATs and SFGD installation.

TOF installation at 50% progress (+ a satisfied student).



Last side panel in place in May 2024: ND280 Upgrade completed!



Event display of beam data taking: most hits on Upstream and Downstream planes, along beam direction.

Time calibration and resolution

Iterative time calibration procedure, based on Markov chain approach. At each step:

- Assume constant offset per bar (initially zero).
- Calculate Δ_{time} for each hit pair,
- Compute the mean offset over all events, per bar
- For each bar, add *offset* = <Δ_{time}> / *damping_factor*

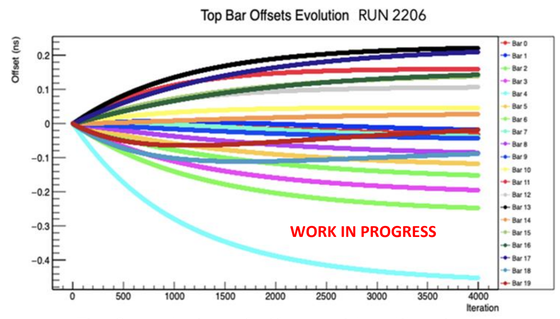


Fig. 9: evolution of offsets with calibration steps

Overall effect on the TOF bars is to **absorb all offsets**, regardless of the origin (geometry, cables, electronics).
Offsets computed from cosmics dataset. Δ_{time} , showed in Fig.10, is corrected for expected time of flight, with ~3cm accuracy of the reconstructed position along the bar (from single-bar studies).

Time resolution improves from ~300ps to **175ps**! (V. Kasturi). Same method being used for SFGD.

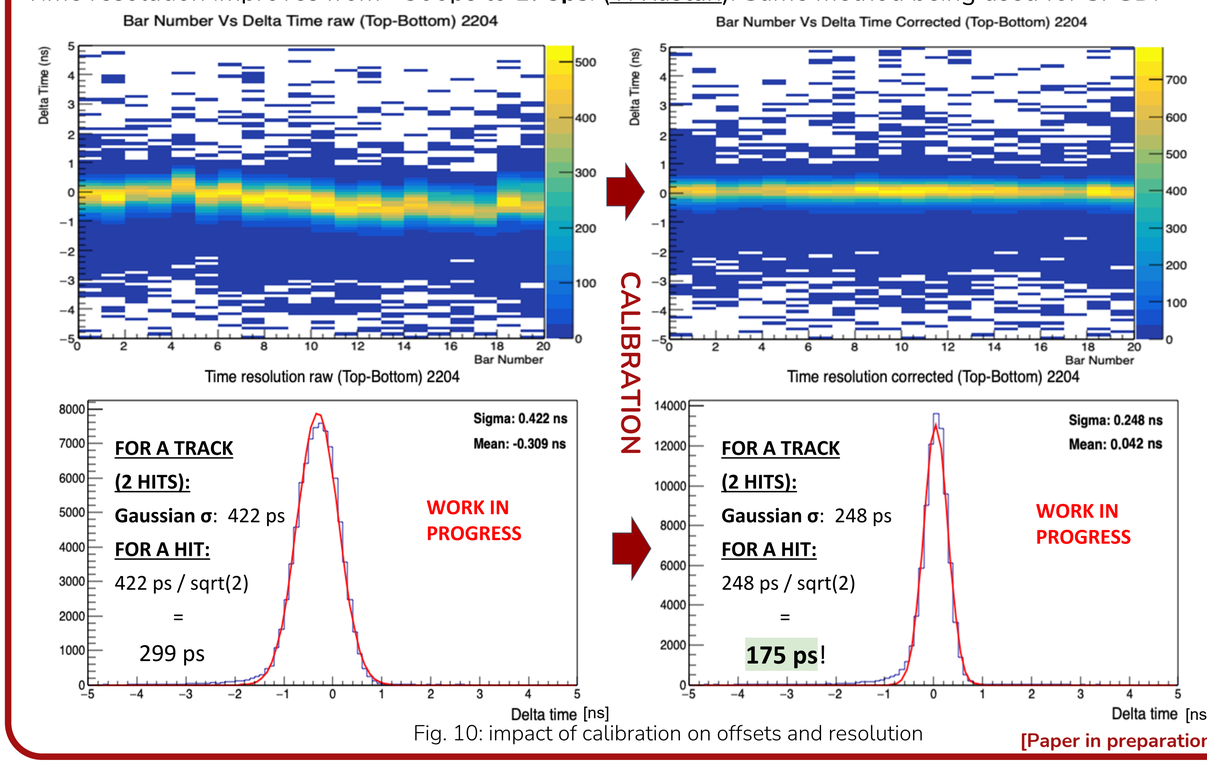


Fig. 10: impact of calibration on offsets and resolution

[Paper in preparation!]

Timing capabilities

First **PID** studies on MonteCarlo show that the combined TOF and SFGD resolution allows for **separation** between muon and protons.

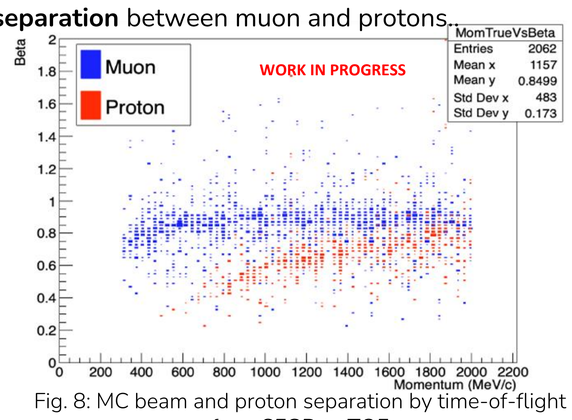


Fig. 8: MC beam and proton separation by time-of-flight from SFGD to TOF

T2K **beam spill** features eight bunches, ~20ns wide (before calibrations), separated by ~580ns. TOF is able to clearly **distinguish the bunches**, providing reference for HAT timing.

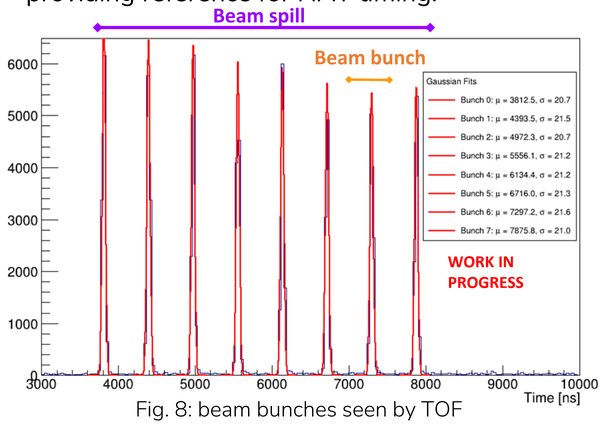


Fig. 8: beam bunches seen by TOF

[Paper in preparation!]

a) Author, CERN and University of Geneva. **b)** Speaker, University of Geneva. **References:** [1] K. Abe et al., *The T2K experiment*, arXiv:1106.1238; [2] K. Abe et al., *T2K ND280Upgrade: technical design report,* arXiv:1901.03750; [3] A. Korzenev et al., *A 4pi time-of-flight detector for the ND280/T2K upgrade,* arXiv:2109.03078.