The T2K experiment & the upgrade of its near detector ND280

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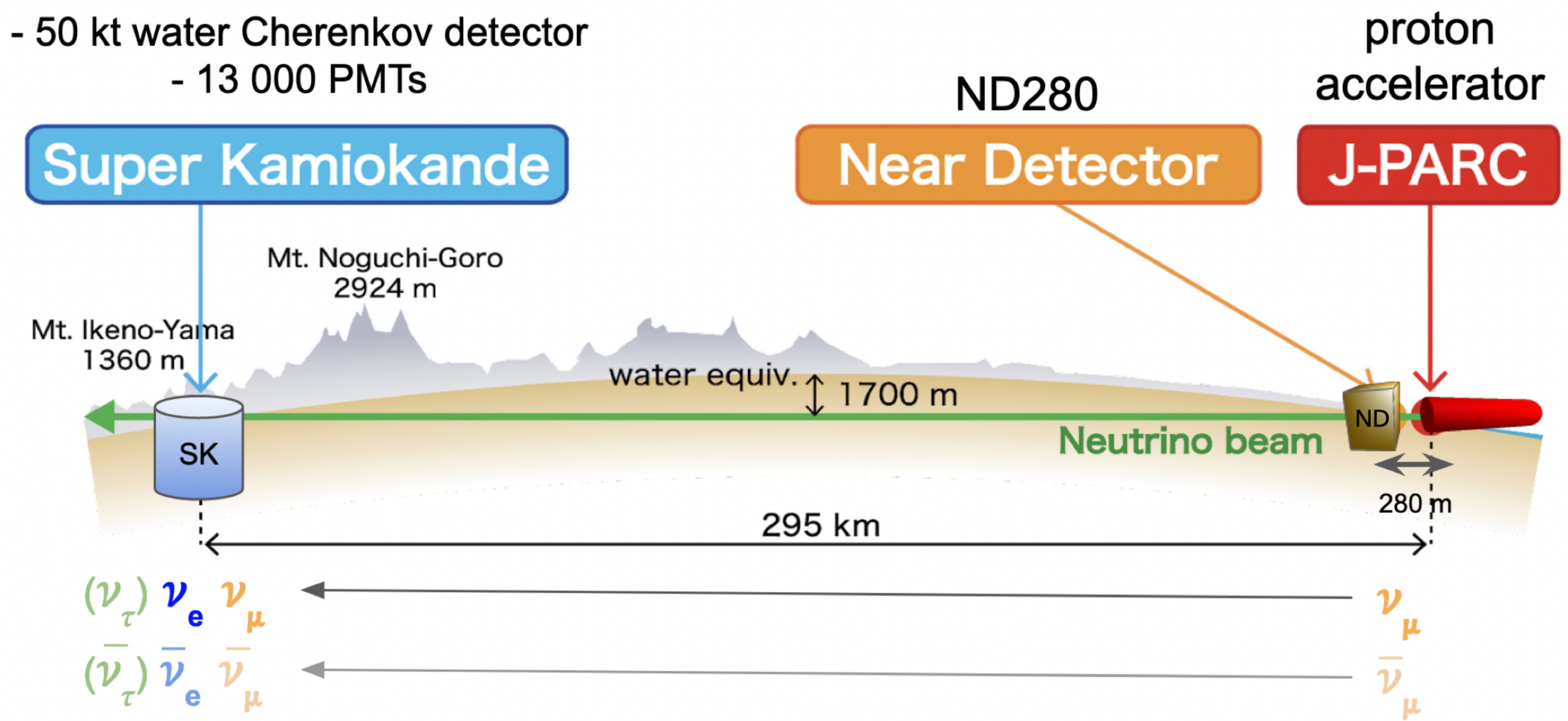
On behalf of the LPNHE neutrino group

From Tokai to Kamioka: the T2K experiment



- T2K: long baseline neutrino oscillation experiment located in Japan
- ν_μ or $\bar{\nu}_\mu$ beam produced at J-PARC accelerator
- Near detector ND280: characterizes (anti) neutrino flux and cross-section before neutrino oscillations
- Far detector Super-Kamiokande (SK): detects ν_μ ($\bar{\nu}_\mu$) and ν_e ($\bar{\nu}_e$) charged current interactions through Cherenkov effect
- Off-axis techniques: ND280 and SK at 2.5°from beam for a narrower band beam peaked at 0.6 GeV

The contributions of the LPNHE group

- Design, production and tests of ND280 Upgrade HA-TPC front end electronics, see Fig.1
- The HA-TPC data acquisition system based on MIDAS
- The HA-TPC simulation and reconstruction (track fitting) software: the new use of resistive MicroMegas technology requires adapting the full software chain
- Analysis of HA-TPC prototypes: test-beam data at CERN in 2018 [1] and at DESY in 2019 [2] and 2021 [3]
- New methods for track reconstruction in the HA-TPCs (log Q method, machine learning)

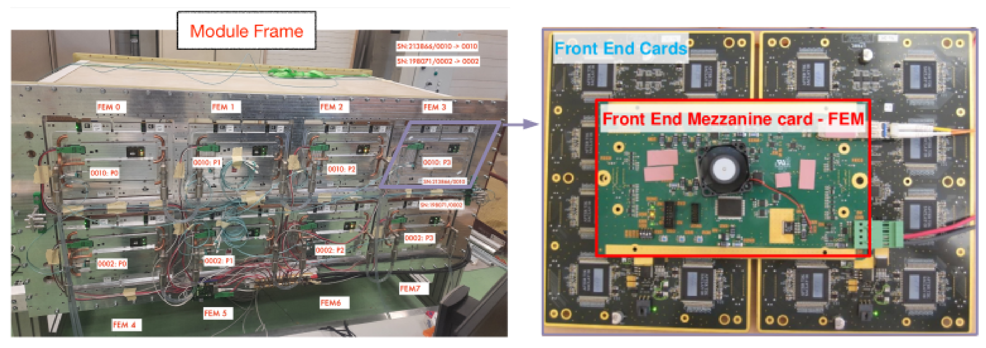
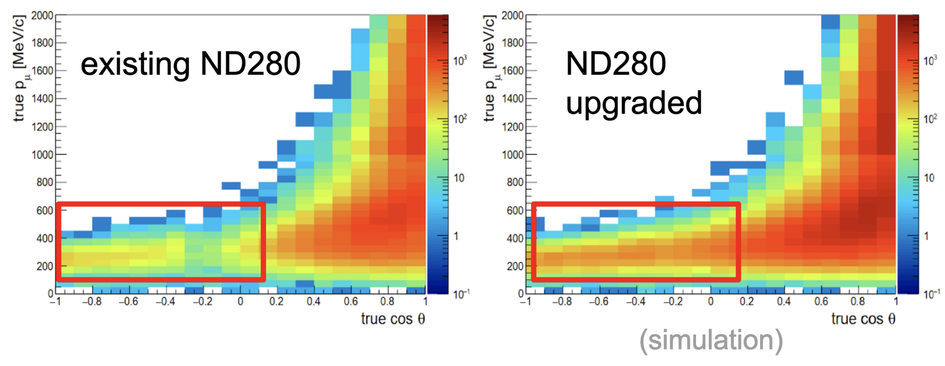


Figure 1. HA-TPC field cage equipped with 8 ERAMs (left), each readout by 2 Front-End Cards (FEC) and 1 Front-End Mezzanine (FEM) (right)

The upgrade of the Near Detector ND280

Reasons for the upgrade:

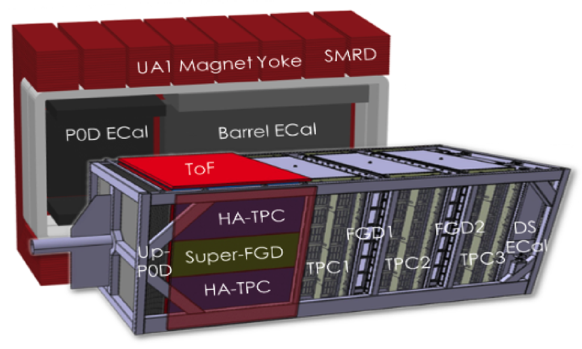


1. Increase angular acceptance (limited phase-space coverage of the current ND280)
2. Reduce systematic uncertainties via better measurements of neutrino interactions

The upgraded detector:

- 1 Fine Grained Detector (SuperFGD) sandwich between
- 2 **High-Angle Time Projection Chambers** (HA-TPC) instrumented with resistive MicroMegas

→ ongoing installation in Tokai!



The Encapsulated Resistive Anode Micromegas (ERAM) technology

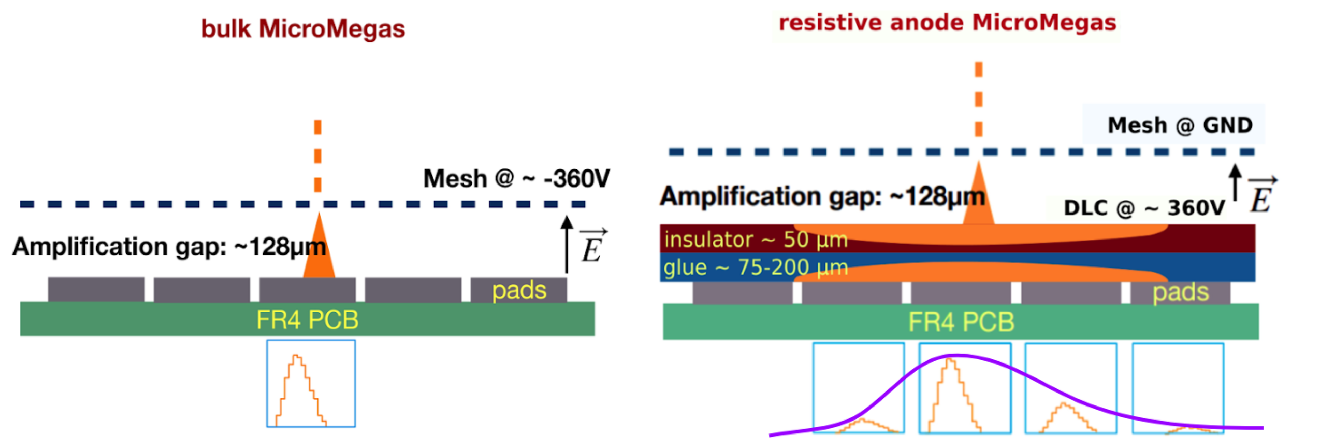


Figure 2. Previous bulk micromegas (left) and new encapsulated resistive anode micromegas technology (right)

Charge deposited spread on adjacent pads with Gaussian behavior:

→ Larger e^- avalanche + time information

→ Improved spatial resolution: **200 µm for horizontal tracks** [3] (vs 600 µm with bulk MicroMegas)

First tracks and HA-TPC installation

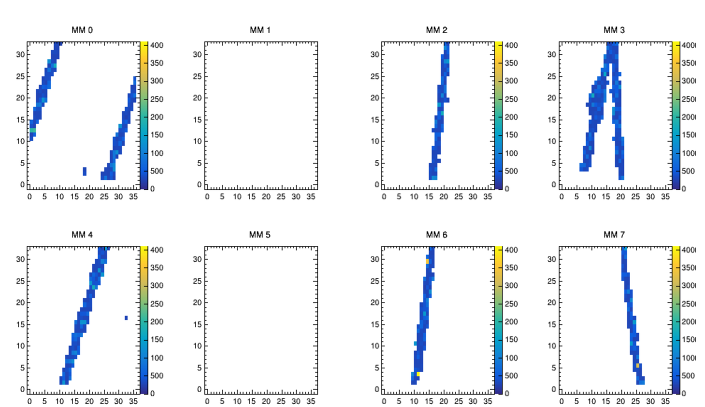


Figure 3. First cosmic tracks at CERN (April 2023)

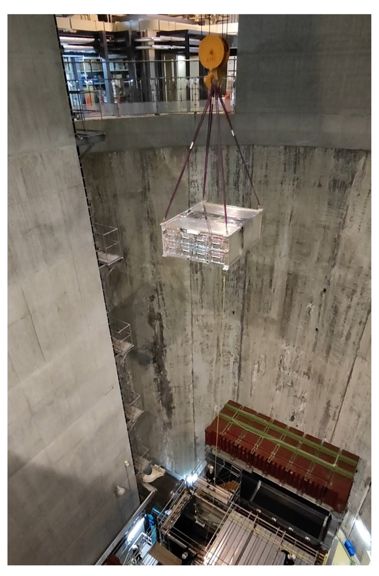
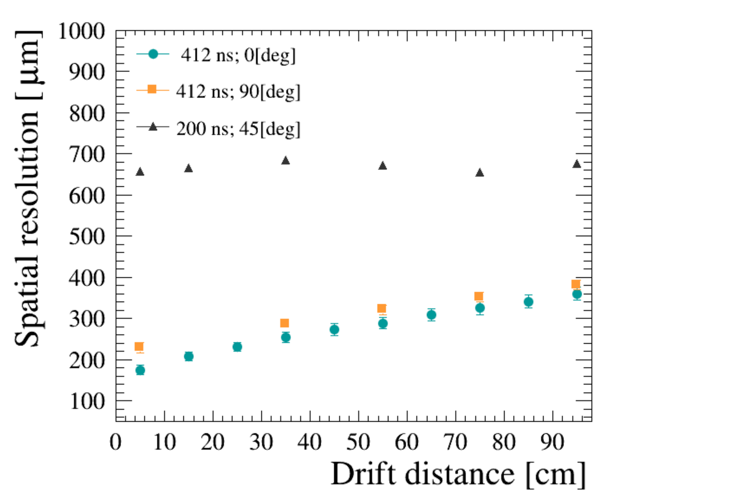
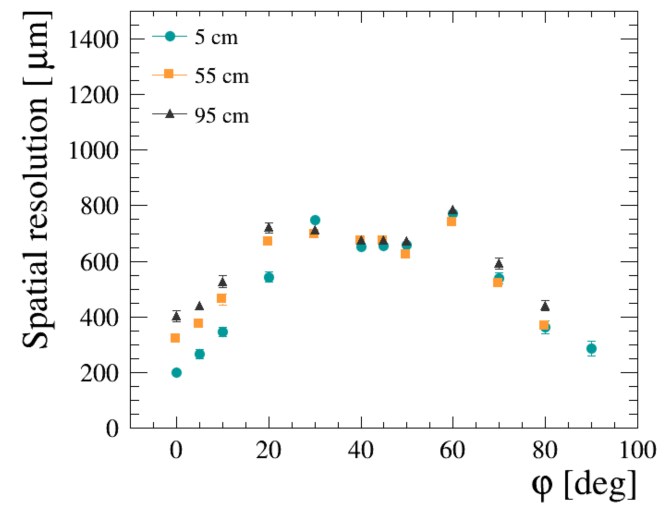


Figure 4. Bottom HA-TPC positioning inside ND280 (September 2023)

The High-Angle TPC Reconstruction Software



(1) Spatial resolution as a function of ionization electrons' drift distance



(2) Spatial resolution as a function of track angle

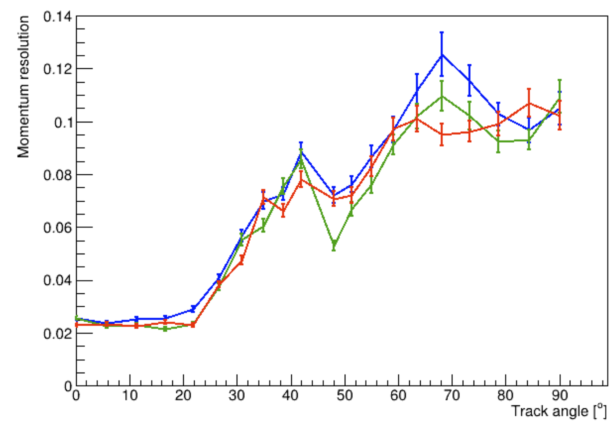


Figure 6. Momentum resolution as a function of the track angle for 800 MeV.c^{-1} muons at 25 cm (blue), 50 cm (green) and 75 cm (red) drift distances

- HA-TPC prototype exposed to the DESY test beam 2021 showed a spatial resolution better than 800 µm for all the track topologies
- The Geant4 simulations results obtained showed a momentum resolution $\frac{p_{\text{reco}}-p_{\text{true}}}{p_{\text{true}}}$ better than 3% for horizontal tracks and of the order of 10% for vertical tracks because of their shorter length

Neural networks for HA-TPC track reconstruction

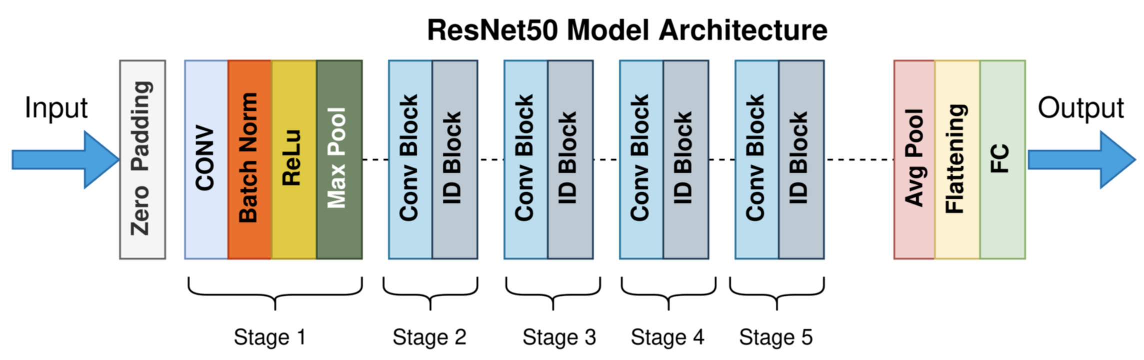
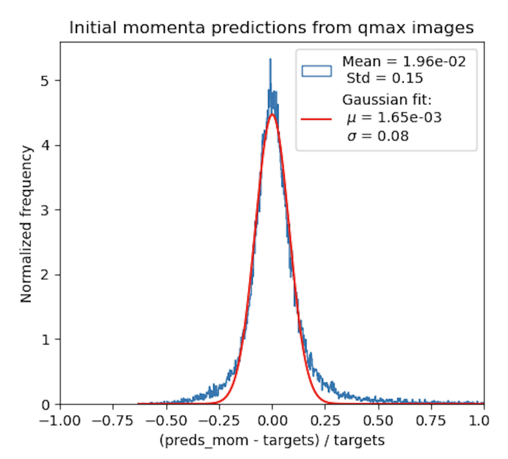


Figure 7. Standard architecture using convolution operation widely used for image recognition



- **ResNet50** fed with HA-TPC images of deposited charge (Monte-Carlo simulations)
- Prediction of track parameters: 8% momentum resolution for 200-1000 MeV muons (vs 7% with standard algorithms)
- Ongoing work to perform PID

References

[1] D. Attié et al. Performances of a resistive Micromegas module for the Time Projection Chambers of the T2K Near Detector upgrade. *Nucl. Instrum. Meth. A*, 957:163286, 2020.

[2] D. Attié et al. Characterization of resistive Micromegas detectors for the upgrade of the T2K Near Detector Time Projection Chambers. *Nucl. Instrum. Meth. A*, 1025:166109, 2022.

[3] U. Yevarouskaya et al. Analysis of test beam data taken with a prototype of tpc with resistive micromegas for the t2k near detector upgrade. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 1052:168248, 2023.

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