The T2K experiment and the upgrade of its near detector ND280

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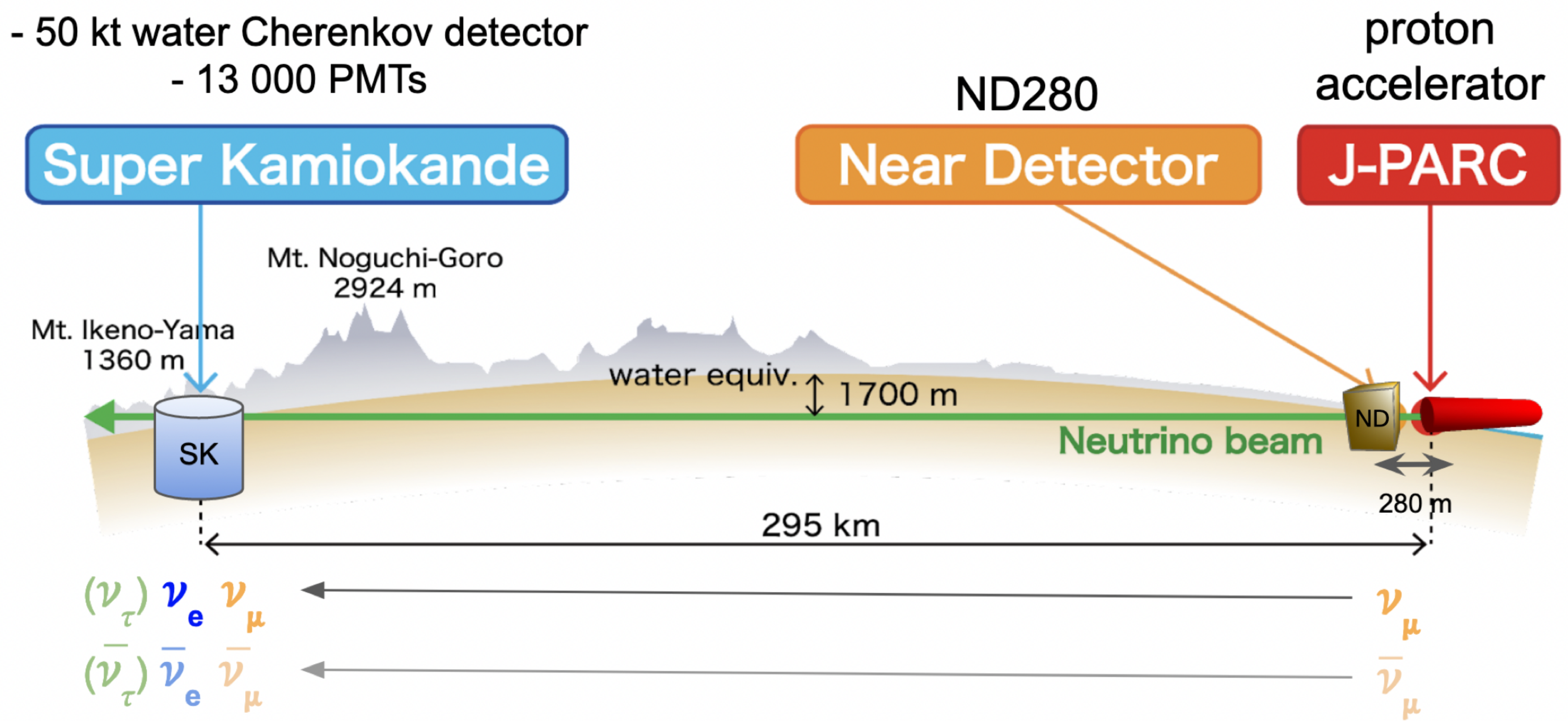
From Tokai to Kamioka: the T2K experiment



- 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 use of **new 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 [4]
- Track reconstruction **new methods** in the HA-TPCs (log Q method, machine learning)

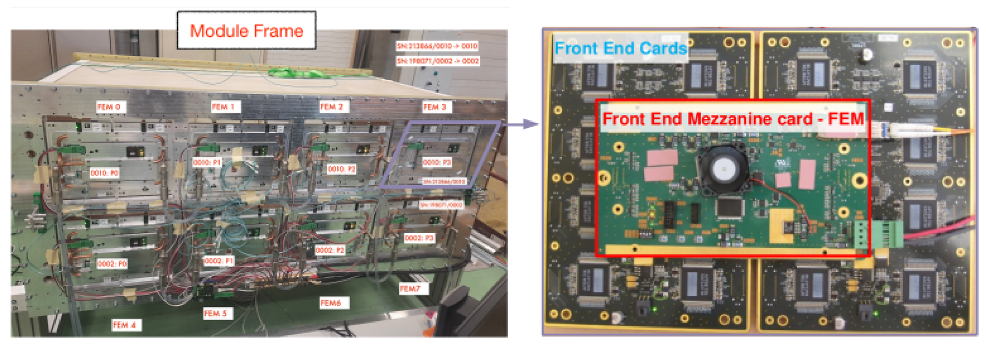
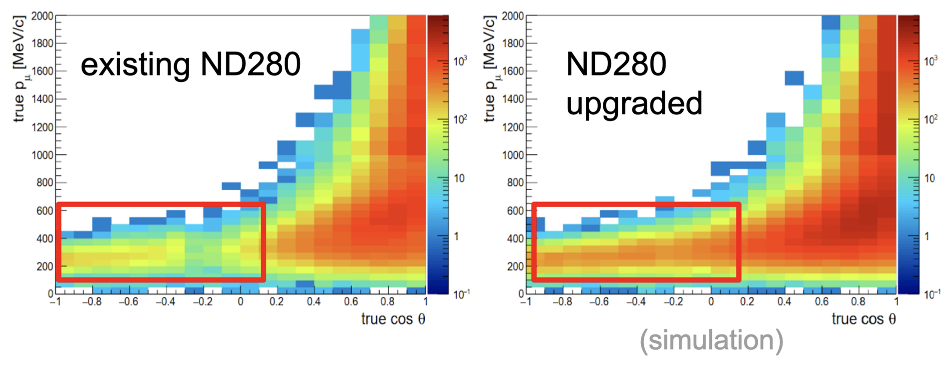


Figure 1. HA-TPC field cage equipped with 8 ERAMs (left), each readout by 2 Front-End Cards (FEC) and 1 Front-End Mezzanine (FEM) (right)

The upgrade of the Near Detector ND280

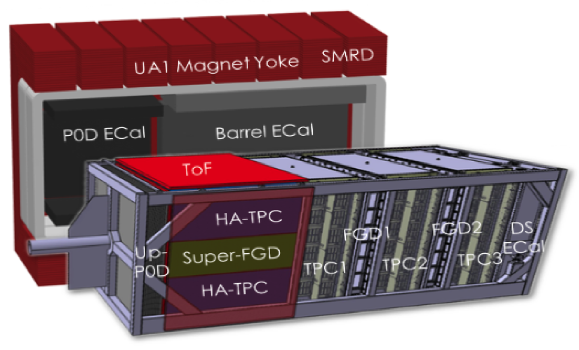
Reasons for the upgrade:



1. Increase angular acceptance (limited phase-space coverage of the current ND280)
2. Reduce systematic uncertainties via better measurements of neutrino interactions [3]

The upgraded detector:

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



The High-Angle TPC Reconstruction Software

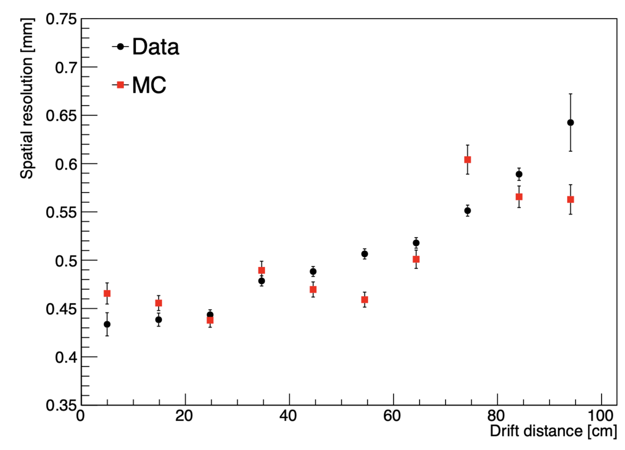


Figure 5. Spatial resolution as a function of drift distance

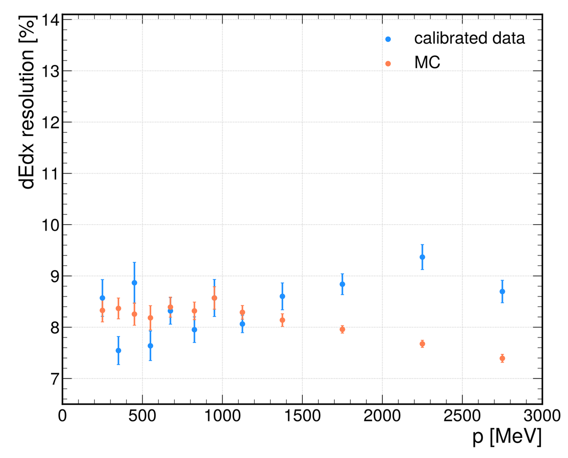


Figure 6. dE/dx resolution as a function of momentum

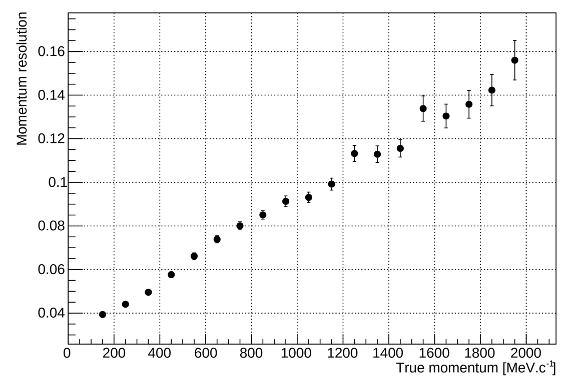


Figure 7. Momentum resolution as a function of the true momentum (vertical μ^-)

- At LPNHE we have developed the full HA-TPC reconstruction chain and tested on both cosmics data and MC. The two are in good agreement with:
  - Spatial resolution of ≈ 500 µm
  - dE/dx resolution better than 10%
- Such performances ensure a resolution on the reconstructed momentum better than 10% for tracks with momenta smaller than 1.2 GeV/c.

The Encapsulated Resistive Anode Micromegas (ERAM) technology

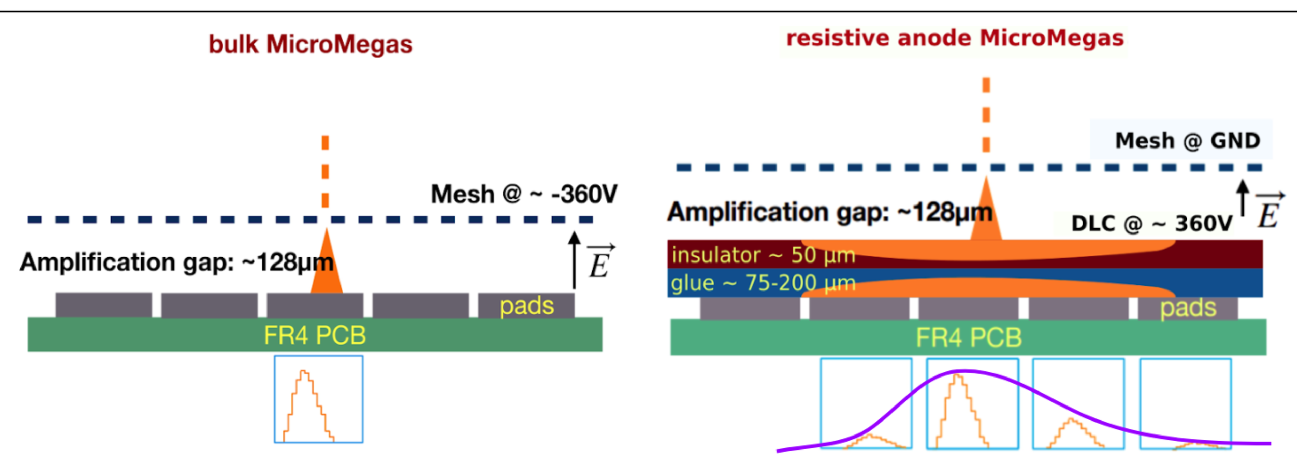


Figure 2. Previous bulk micromegas (left) and new encapsulated resistive anode micromegas technology (right)

Charge deposited spread on adjacent pads with Gaussian behavior:

→ Larger e^- avalanche + time information
→ Improved spatial resolution: **200 µm for horizontal tracks** [4] (vs 600 µm with bulk MicroMegas)

Neural networks for HA-TPC track reconstruction

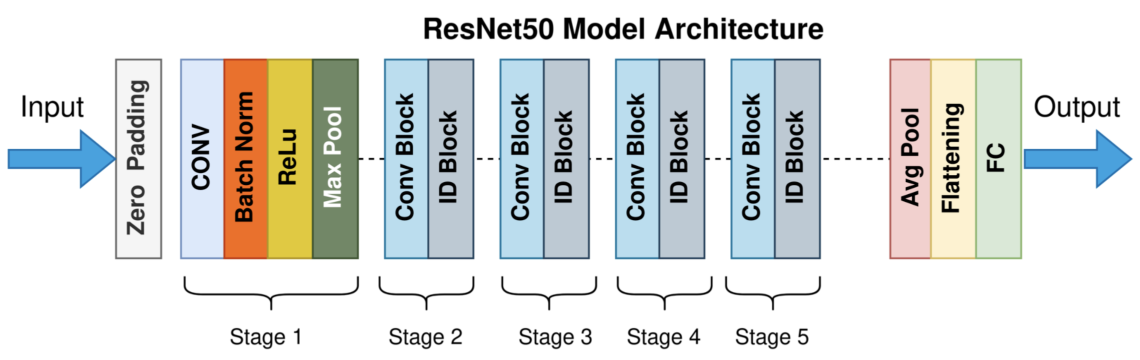


Figure 8. Standard architecture using convolution operation widely used for image recognition, fed with HA-TPC images of deposited charge (MC simu)

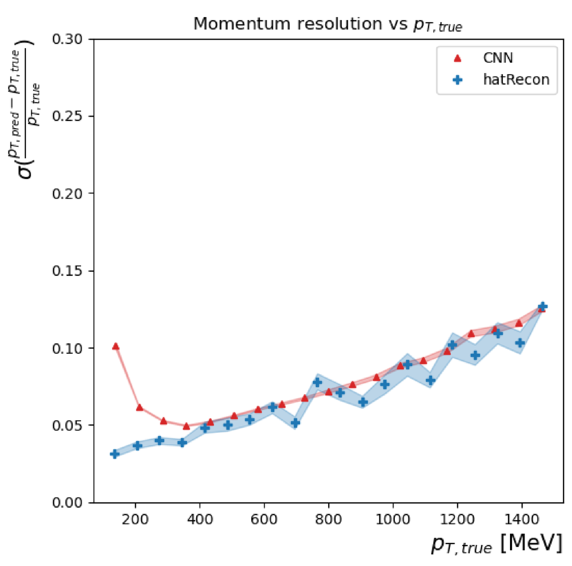


*Figure 9. Reconstructed **momentum resolution** vs p_{true} using CNN or classical algorithm*

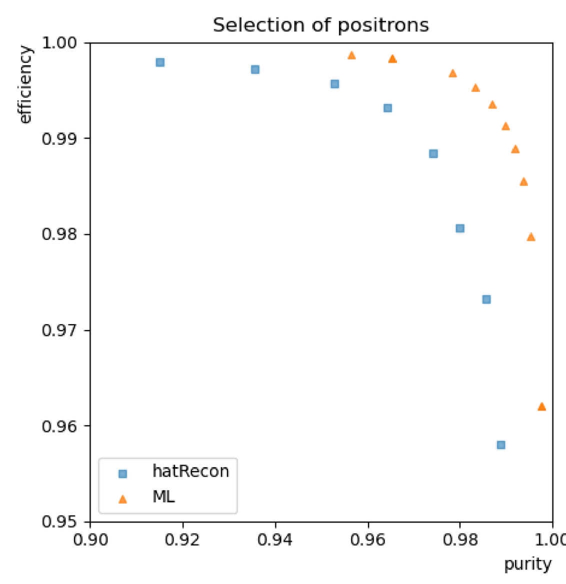


*Figure 10. **PID** with CNN: efficiency vs purity for e^+ selection*

HA-TPC installation and first tracks

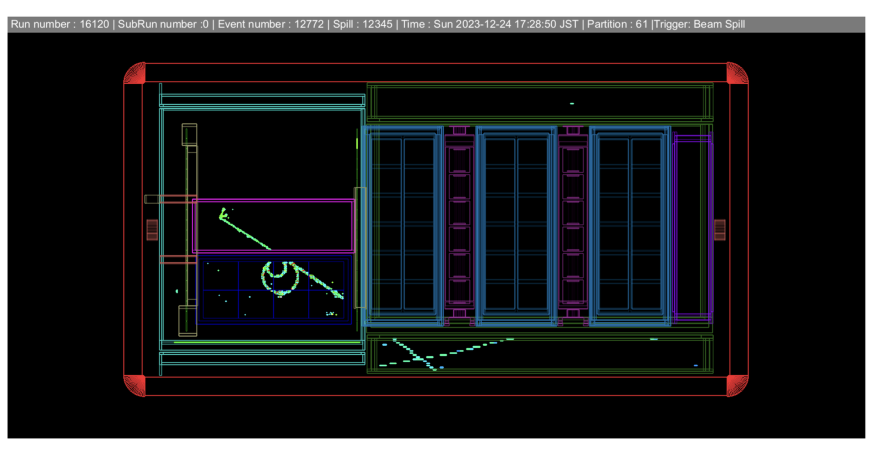


Figure 3. Neutrino interaction in the upgraded ND280 with 2 stopping protons in the SFGD (December 2023)*

*Top HA-TPC and 2/6 TOF panels were not installed yet

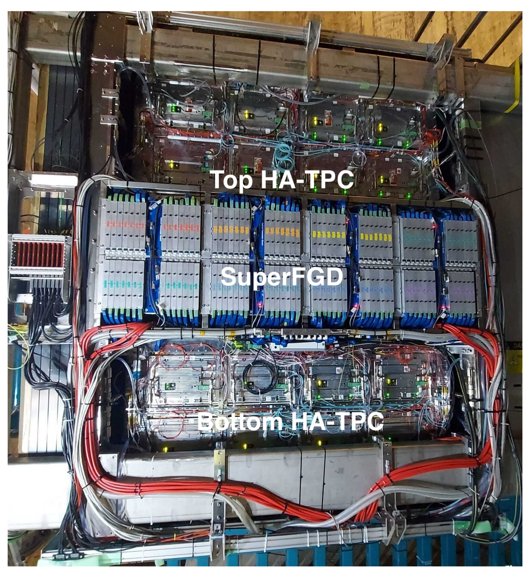


Figure 4. HA-TPCs and SFGD inside ND280 (May 2024)

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] S. Dolan et al. Sensitivity of the upgraded T2K Near Detector to constrain neutrino and antineutrino interactions with no mesons in the final state by exploiting nucleon-lepton correlations. *Phys. Rev. D*, 105(3):032010, 2022.

[4] 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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