Characterizing an Electron-Neutrino Event Reconstruction Performance Towards Electron-Neutrino Cross Section Measurement in the Upgraded T2K Near Detector

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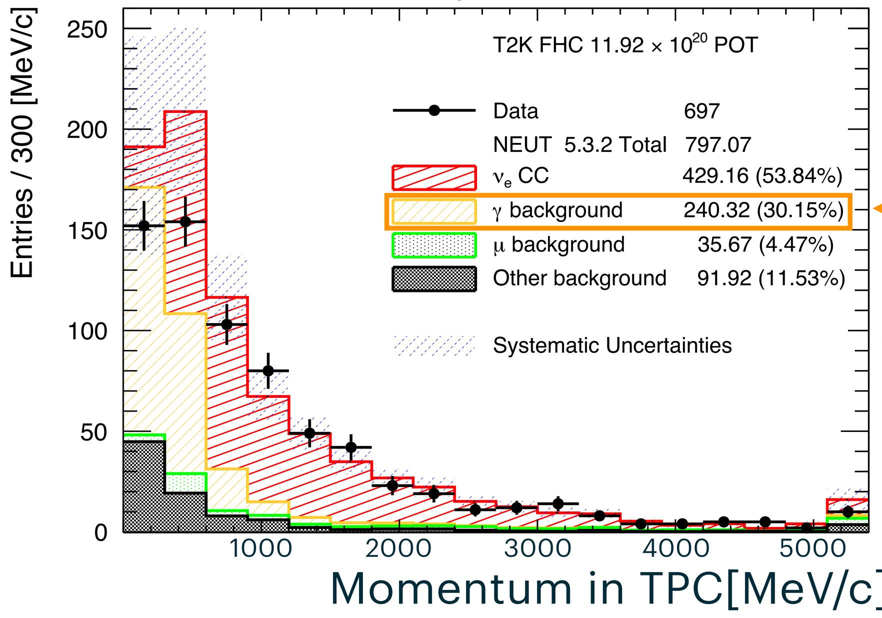
T2K

1. Motivation for ν_e measurement

- The uncertainty of the ν_e cross-section is one of the major systematic uncertainties in the T2K oscillation analysis [1].
- In the ν_e cross-section measurement with ND280, γ-induced backgrounds account for 30% of the events, limiting the sensitivity, especially below 1 GeV/c (around the peak energy of the T2K neutrino beam)[2].

Past ND280 ν_e measurement

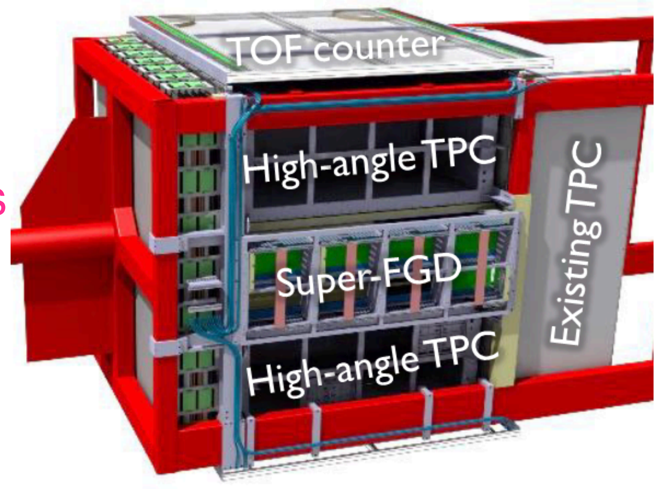


Efficiency : 26%
Purity : 54%
Large γ contaminations esp. below 1 GeV/c

2. ND280 upgrade [3]

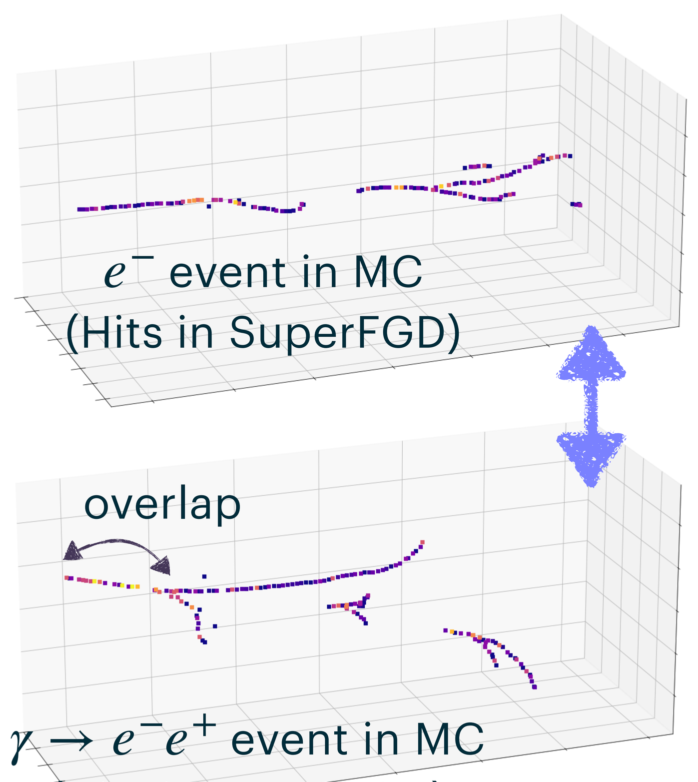
Upgrade detectors

- SuperFGD[4] : active target
  - 2 million scintillator cubes
- High Angle-TPC (HA-TPC)[5]
  - Momentum, PID
- Time Of Flight detector
  - surrounds SuperFGD&HA-TPC



The upgraded ND280 can measure short tracks with 4π solid angle acceptance.
→offers better understanding of neutrino interactions

e.g. Measuring of the intrinsic ν_e component in the beam and the ν_e cross-section without significant backgrounds.



Using hit information with SuperFGD granularity,

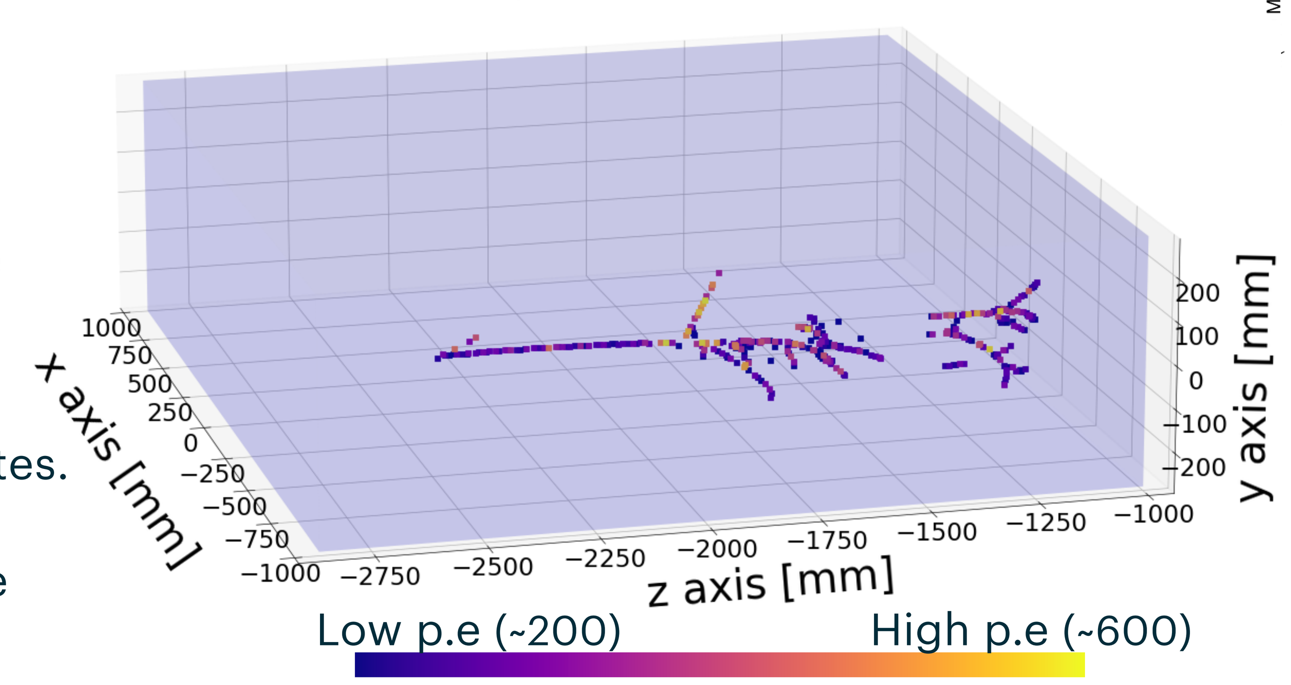
- Reconstruct EM-showers
- Reject γ backgrounds by detecting $\gamma \to e^- e^+$ overlaps

3. Electron-neutrino event selection

ν_e event reconstruction scheme

Find vertex
↓
Muon rejection using TPCs
↓ Select EM-shower | ↓ Select e^- track using TPCs
↓ Reject γ conversion (Use Gradient Boosted Decision Tree (BDT))
↓
① "EM-shower-like" ν_e (16.4% of ν_e interactions are selected) | ② "Track-like" ν_e (3.6% of ν_e interactions are selected)

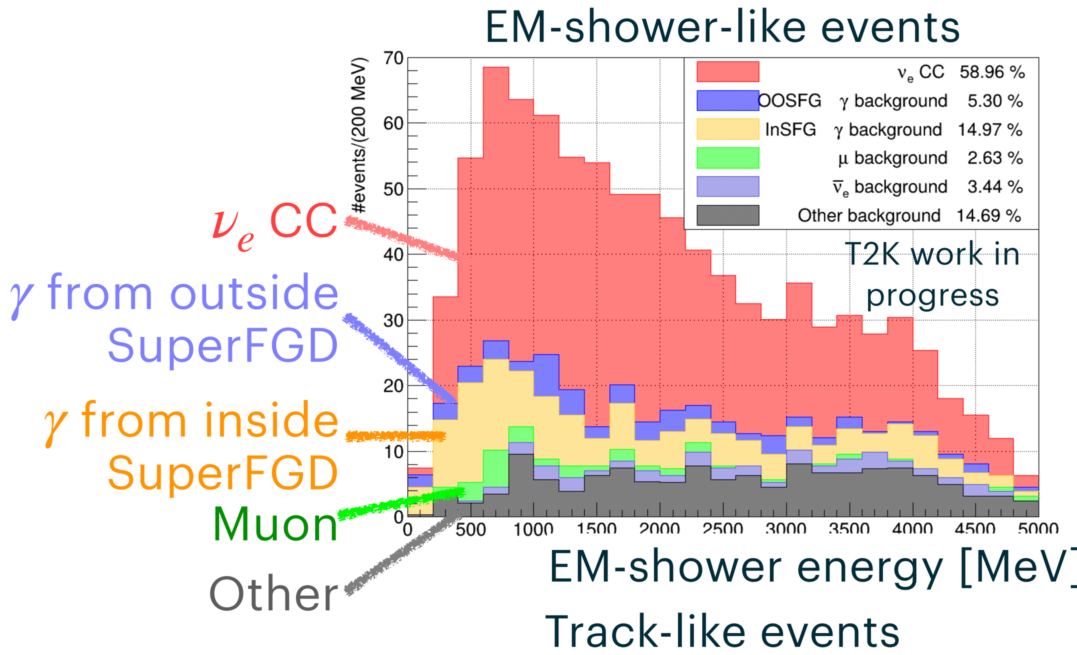
ν_e-CCQE candidate in 2024 data→
EM-shower-like e^- and proton candidates.
Shaded area: SuperFGD volume



The ν_e event selection results with normalizing 10^{21} POT in the neutrino mode MC.

Before gamma rejection by the BDT

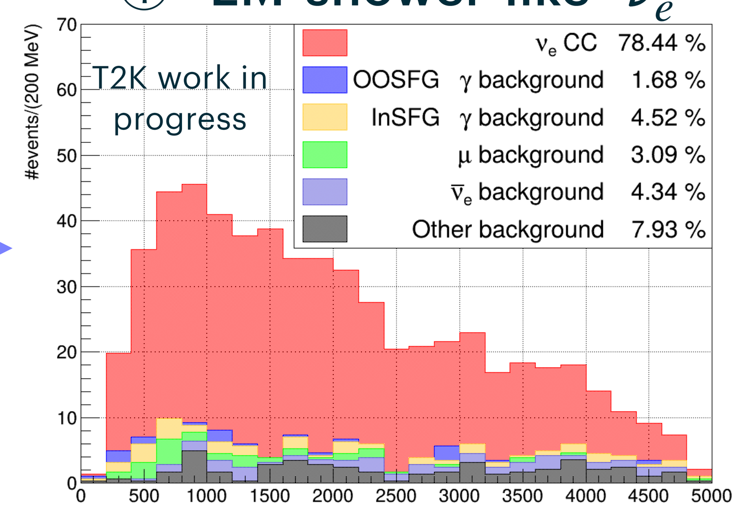
EM-shower-like events



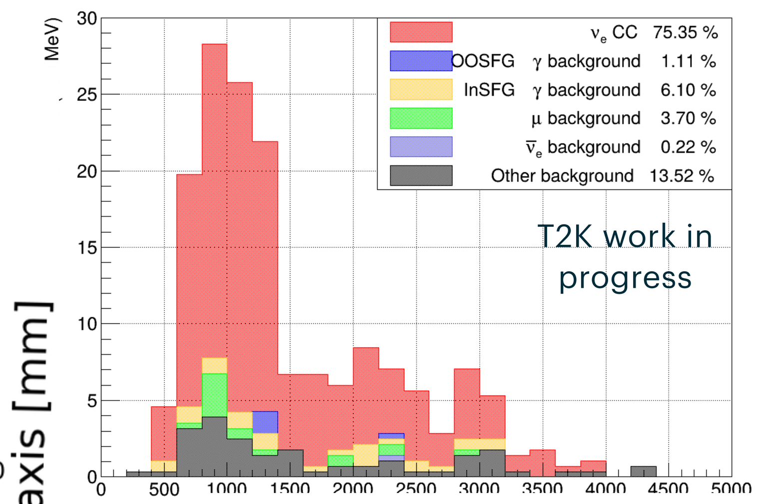
Reject gamma by the e/γ BDT

66% reduction in background events while retaining 87% of ν_e events

After gamma rejection
① "EM-shower-like" ν_e

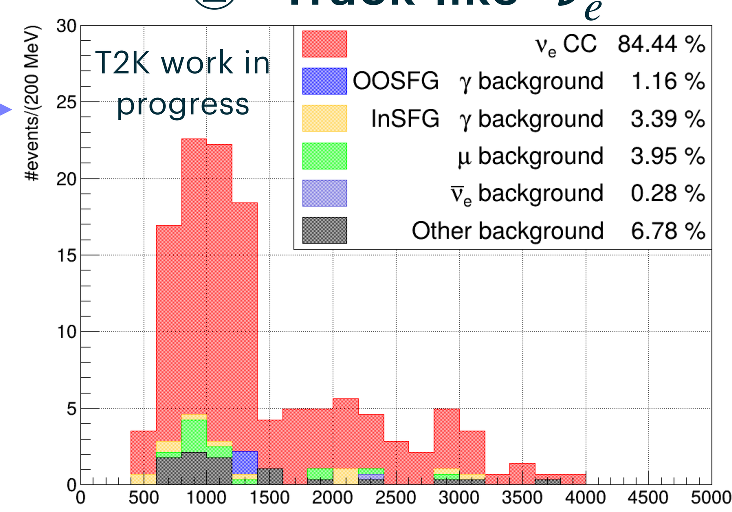


Track-like events



51% reduction in background events while retaining 86% of ν_e events

② "Track-like" ν_e

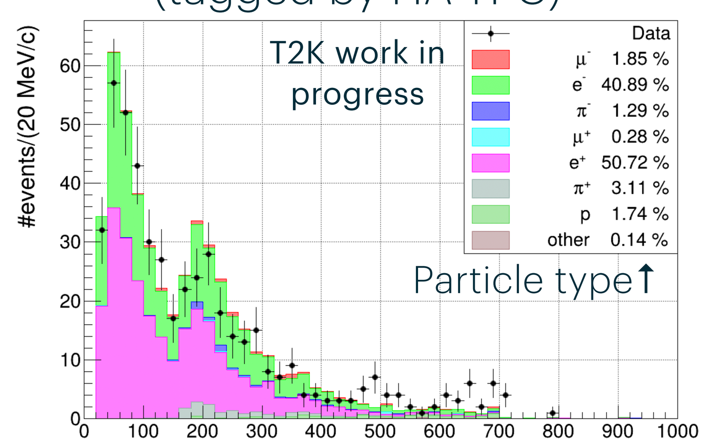


☆As a result of a large reduction in γ backgrounds using the BDT, ν_e events are selected with a purity* of 80% at an efficiency of 20%.
(*defined as the fraction of ν_e events among the selected events.)

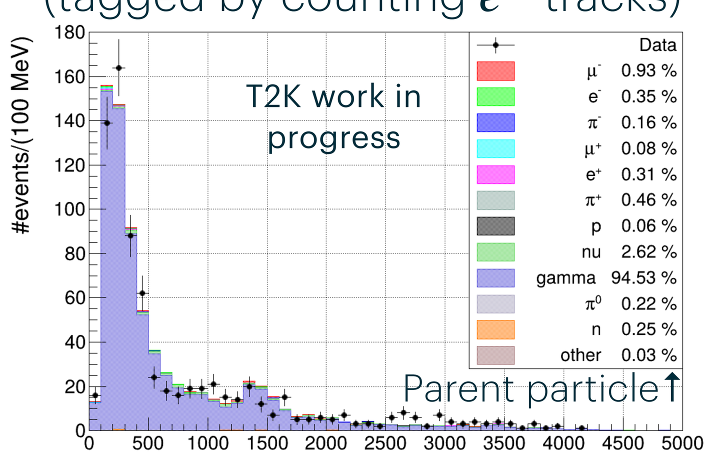
4. e/γ separation performance

- Testing the BDT separation power in control samples (with ~1.57×10^{20} POT)

Electron events (tagged by HA-TPC)



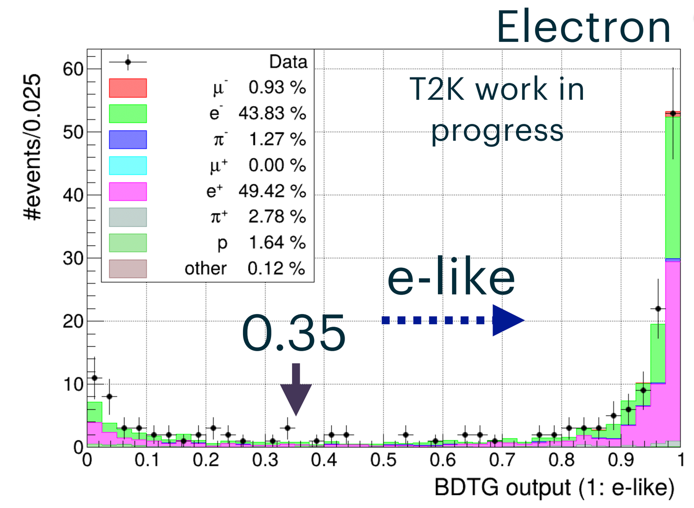
Gamma events (tagged by counting $e^{\pm}$ tracks)

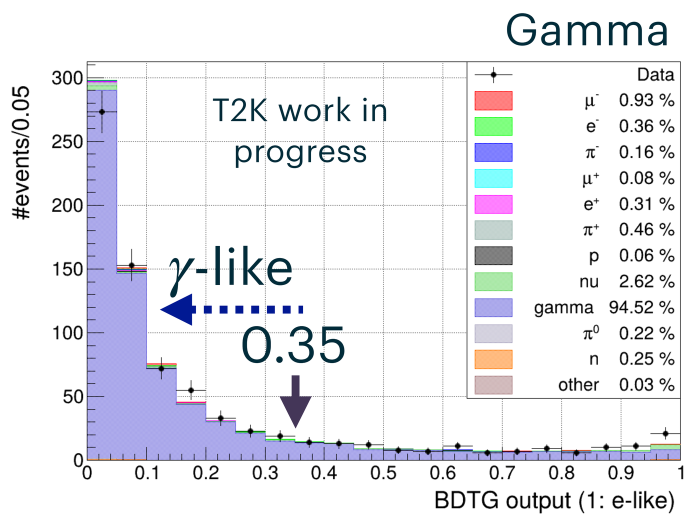


*Both samples are scaled by area.

Applying e/γ separation by the BDT

BDT scores [0.0, 1.0]





☆Good e/γ separation performance is confirmed with data.
→Over 80% of γ events are rejected while retaining ~80% of $e^{\pm}$
(at the threshold at 0.35 : same one as used in the ν_e event selection, tuned via a Monte Carlo study).

e/γ separation efficiencies with the control samples

	MC eff. (%)	Data eff. (%)	Ratio
Electron	84.6±0.4%	81.6±1.8%	0.96±0.02
Gamma	16.0±0.4%	17.7±1.4%	1.10±0.09

5. Conclusions

An electron-neutrino event selection has been developed for the upgraded ND280.

- Monte Carlo studies indicate that ν_e events can be selected with a purity of 80% at an efficiency of 20%.
- A large reduction in gamma-induced backgrounds is achieved.

The e/γ separation using the BDT is tested with the $e^{\pm}$ and γ control samples.

- Over 80% of γ events are rejected while retaining ~80% of $e^{\pm}$.
  (good agreement with data)

Next steps

- Evaluating the systematic uncertainties for measuring ν_e-CC events.
- Increasing the selection efficiency.

References :

[1] Phys.Rev.Lett. 135 (2025) 26, 261801.
[2] J. High Energ. Phys. 2020, 114 (2020).
[3] arXiv:1901.03750 [4] arXiv:2603.14921
[5] Nucl. Instrum. Meth. A, 1088 (2026), 171527