Selection of Antineutrino CC Interactions with photons in the final state using the T2K Near Detector

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1. The T2K Experiment and the Off-Axis Near Detector (ND280)

- The Tokai-to-Kamioka (T2K) experiment is a long-baseline neutrino experiment located in Japan.
- A muon (anti) neutrino beam is produced at J-PARC which is then measured at a suite of near detectors, 280 m downstream, and at Super-Kamiokande, 295 km downstream.
- Super-Kamiokande is located at 2.5^o off the beam axis which gives a more narrow neutrino energy spectrum, peaked at 600 MeV.
- T2K measures ν_μ ($\overline{\nu}_\mu$) **disappearance and** ν_e ($\overline{\nu}_e$) **appearance**.

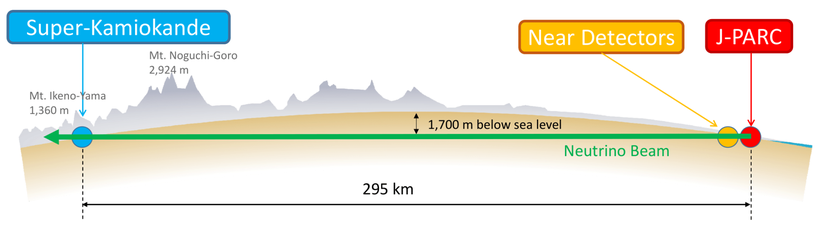


Figure 1: Schematic of neutrino path from J-PARC, through the near detectors, to the far detector, Super-Kamiokande.

- ND280 tracker, Figure 2, contains **two Fine Grained Detectors** (FGD) which are sandwiched between **three Time Projection Chambers** (TPC).
- FGDs provides the target material of the ND280.
- TPCs measures charge, momentum and particle identification (PID).
- Tracker is surrounded by an **Electromagnetic Calorimeter** (ECal).
- ND280 subdetectors are contained within a magnetic field of 0.2 T.

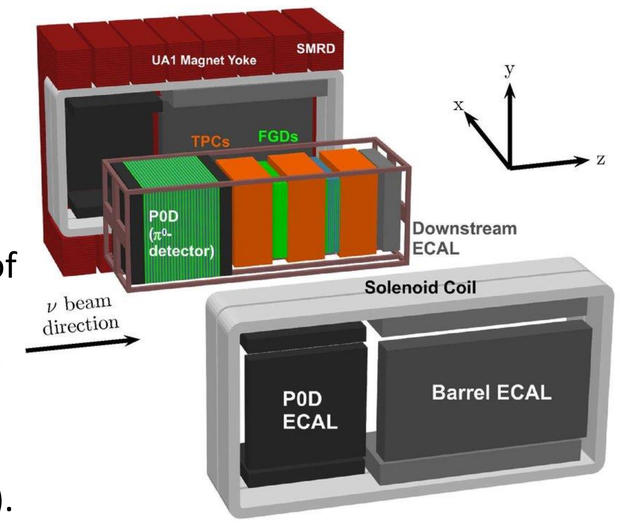


Figure 2: The ND280 detector, including all subdetectors.

2. T2K Analysis Strategy

- **Flux and cross section parameters are constrained** by fitting the near detector Monte Carlo (MC) samples to the data. This decreases the systematic uncertainty on the extrapolated far detector samples and the overall oscillation analysis results e.g the **systematic for muon rings in $\overline{\nu}_\mu$ mode, decreases from 11.8% to 2.9% with the addition of a near constraint** [1].
- T2K uses three topological charged current (CC) samples as near detector inputs for the neutrino oscillation analysis: the **CC0π**, **CC1π** and **CCOther** samples.
- They are defined based on the number of charged pions in the final state, zero, one, or greater than one, respectively.
- A significant number of these CCOther events contain **at least one photon producing particle** (π^0, η, Λ and K) in the final state.
- A new **antineutrino photon** sample has been developed.

3. Selection Process

Two categories of photons are included in the sample.

1. Tagged π^0s in the TPCs.
2. Photons identified in the ECal, diagram shown in Figure 3.

TPC π^0s

- Photons produced by a π^0 are inferred by the detection of electrons, assumed to originate from photon conversion [2].

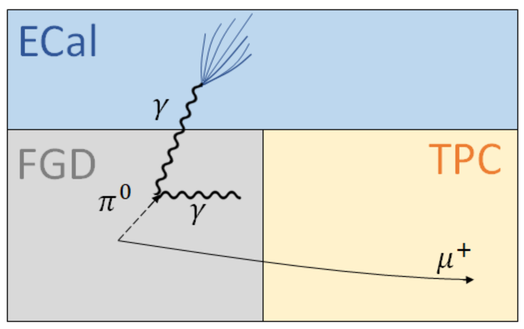


Figure 3: Example of a CC event where a π^0 decays into two photons. One of the photons showers in the ECal and is detected, the other is not detected.

ECal Photons

- Find all isolated objects in the ECal.
- Apply two cuts to determine if the isolated objects are photon-like.

PIDEmHip - Determines how Electromagnetic or highly ionising the ECal object is.

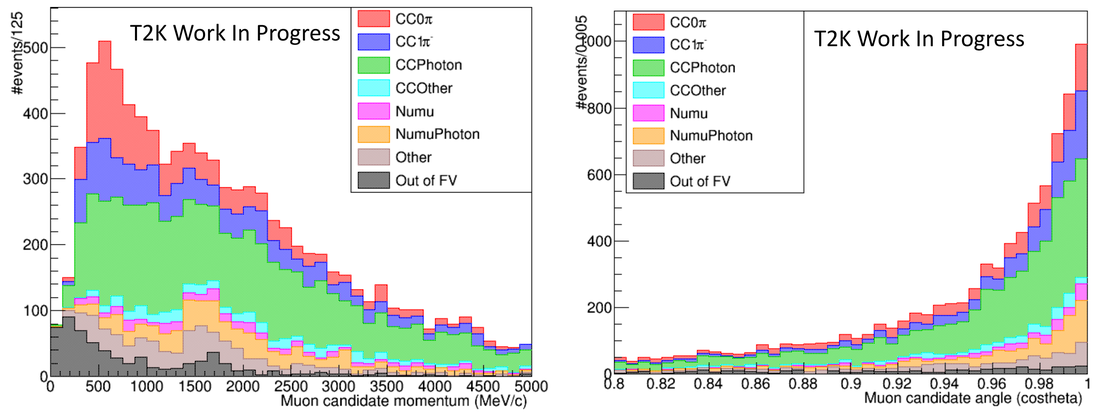
Innermost ECal Layer Hit - The photon should shower close to the central detectors, in the first few layers of the ECal. This cut reduces pileup from charged current quasielastic (CCQE) events.

Multivariate Analysis of Muon Candidate Particle Identification

- Four Boosted Decision Trees (BDTs) developed to reduce background from muon candidate PID wrongly assigning a proton or pion as the muon candidate.
- Two types of BDT trained using single particle MC: one for pions and muons, and another for protons and muons.
- All BDTs use reconstructed TPC and FGD variables as input variables, and two of these BDTs also use ECal variables.
- **Proton background is reduced by approximately 82% and pion background is reduced by approximately 73%.**

4. Photon Sample

- Photon sample requires at least one photon is detected in the final state from either the TPC π^0 tagging, or ECal photon sample. Figures 6 and 7 show the composition of the antineutrino CCPhoton sample as a function of the muon candidate momentum and angle.



Figures 6 and 7: The antineutrino CCPhoton sample as a function of the muon candidate momentum (left) and muon candidate angle (right).

- **CCPhoton sample has an efficiency of approximately 33% and purity of approximately 43%.**
- The CC0π and CC1π samples increase in purity.

5. Conclusion and Future Work

- A new charged current sample has been developed using the Electromagnetic Calorimeter and Time Projection Chambers of the near detector, ND280 at T2K. This sample is determined based on the presence of **at least one photon in the final state.**
- Systematic uncertainties will be evaluated for the new selection.
- The final antineutrino CC photon sample has an **efficiency of approximately 33% and a purity of approximately 43%.**

References

[1] K. Abe et al. (T2K), Phys Rev D vol. 103, p. 112008 (2021).

[2] K. Abe et al. (T2K), Phys. Rev. D vol. 96 p. 092006 (2017).