# This is A Tribute To The Best TN of All Time

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**Abstract**

This is the abstract

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# 1 PØD Samples and Selections

This section describes the development of $\nu_\mu$ and $\overline{\nu}_\mu$CC-Inclusive selections in RHC beam configuration for PØD-based analyses. For a further discussion of the PØD, the reader is referred to the following sections Reference other PØD sections here. These selections are the continuation of previous works that developed $\nu_\mu$CC-Inclusive selections between the PØD and TPC1.

A description of the PØD, the "Global" reconstruction software, and selection flow is presented below.

## 1.1 The PØD

The PØD, short for $\pi^0$ (Pi-Zero) Detector, is a plastic scintillator based tracking calorimeter inside the ND280 basket. The PØD is constructed as many sandwiches of active and inactive materials designed to fully contain $\pi^0$decay photons. The four primary regions inside the PØD in order of upstream to downstream of the neutrino beam are the upstream ECal (USECal), upstream water target (WT), central WT, and central ECal (CECal). A representation of the entire PØD can be seen in Figure 1. Each active module, also called a PØDule, consists of two orthogonally oriented sheets of triangular, scintillator-doped plastic bars as shown in Figure 2. The ECal regions are designed to contain decay photons inside the PØD by alternating the scintillator planes with Lead sheet. The WT regions, as compared to the lead sheet in the ECals, alternate a thin brass sheet and water target between the PØDules. A unique feature of the PØD is that the water can be drained out resulting in two detector configurations: water-in and water-out.

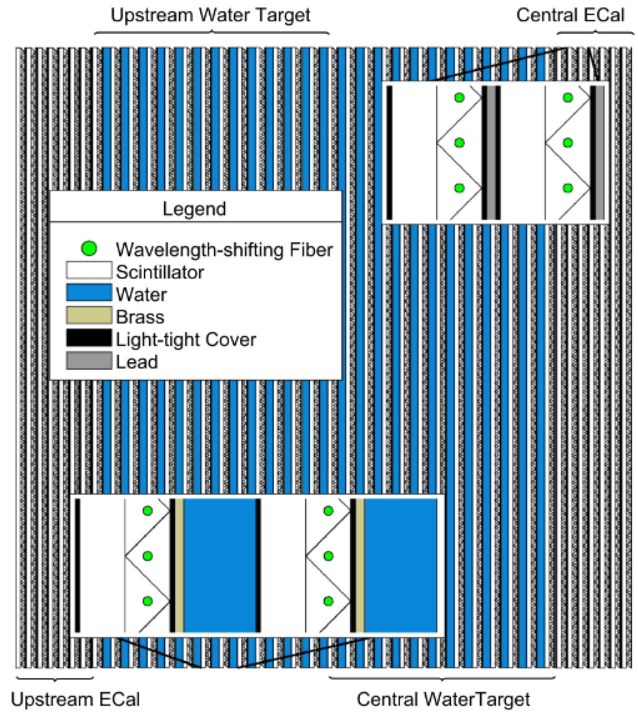


Figure 1: This cartoon illustrates the concept design of the PØD where the neutrino beam is approaching from the left.

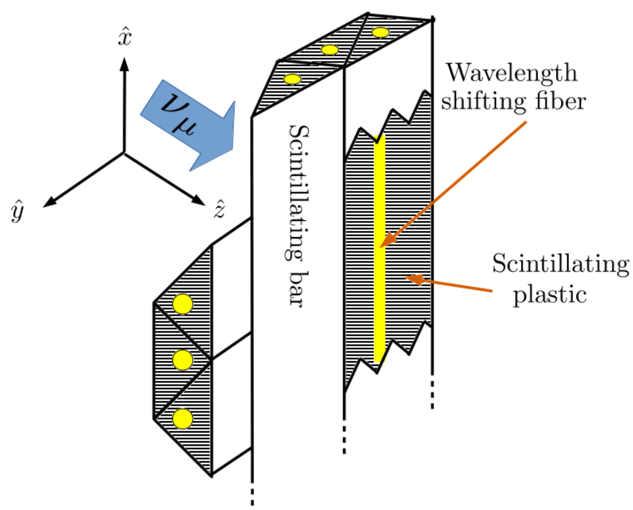


Figure 2: This cartoon illustrates the design of a PØDule with orthogonal layers of scintillating, triangular bars. When a charged particle travels through the bar such as a muon from CC interaction, the scintillation light is captured and wavelength shifted inside a fiber bored in the center of each bar. The wavelength shifted light is later observed by a photon counter.

## 1.2 Global Reconstruction

The task of the Global reconstruction is to combine ND280 sub-detector reconstruction into an single reconstructed object. It was originally designed to analyze CCQE-like events in the Tracker region and has been extended with all of ND280. Global attempts to match and re-fit individual sub-detector objects using a Kalman filter while correcting for energy loss and multiscattering. A vertex associated with the re-fit object is also extracted using a different Kalman filter. A detailed description of the track matching and vertex finding algorithms for Global is described in T2K-TN-46[3].

## 1.3 Signal Selection

The selection of CC-Inclusive events use a series of cuts to select the primary lepton. The pre-selection cuts ("precuts") are applied first to extract events that start in the PØD FV. The candidate lepton, also referred to as the "main track", is then selected based upon the measured charge and momentum of all tracks in TPC1.

This following sections will describe the precuts common to all CC-Inclusive selections and the branching of different cuts, after the precuts, to select the main track.

### 1.3.1 Precuts

The precuts were initially developed to select $\nu_\mu$CC-Inclusive using the PØD and TPC sub-detector reconstruction softwares separately[1]. They were then used with the Global reconstruction software for the $\nu_\mu$CC0$\pi$ selection in the FHC beam configuration as described in technical note T2K-TN-258[4]. The description and flow of the precuts are described here as well since there is an incomplete description of the selection precuts.

The precuts are performed on each bunch per beam spill as follows

1. The event has a "good" data quality flag.
    - An event is rejected if any sub-detector or electronics in ND280 reported as "bad" during that bunch.
2. There is at least one (1) track reconstructed in TPC1.
    - A candidate main track is assigned to a specific track for each selection based on a track's charge and momentum measured in TPC1. The highest momentum, negatively-charged track (HMNT) is assigned as the main track to the $\nu_\mu$CC-Inclusive selection. Likewise, the highest momentum, positively-charged track (HMPT) is the main track for the $\overline{\nu}_\mu$ CC-Inclusive selection.
3. The track in TPC1 must have more than 18 nodes.
    - Add description of what a node is.
4. The reconstructed vertex is within the PØD WT FV.

| Corridor Volume | | | T2K-TN-73 WT FV | | |
|---|---|---|---|---|---|
| -988 | $< X <$ | 910 | -836 | $< X <$ | 764 |
| -1020 | $< Y <$ | 1010 | -871 | $< Y <$ | 869 |
| -3139 | $< Z <$ | -900 | -2969 | $< Z <$ | 1264 |

Table 1: The PØD veto corridor volume (left) and WT FV (right) coordinates in ND280. The corridor spans from the 5th (8th) to 40th (80th) PØDule (scintillator layer).

- The PØD FV is defined to include as much as the WT regions as possible. Its X and Y borders are 25 cm away from the PØDule edges while its Z borders intersect the last and first half downstream PØDule in the USECal and CECal, respectively. The enumerated volume edges are shown in Table 1. This volume, while used for track-based analyzes in the past, was optimized for $\pi^0$ and $\nu_e$ analyzes[2].

5. All tracks that enter TPC1 also pass a veto cut

- Any TPC1 track that enters the "corridor" volume rejects the entire event. This cut was designed to eliminate broken tracks between the PØD and TPC1 when the separate sub-detector reconstructions were used[1]. In practice, this cut ensures that Global tracks entering TPC1 away from its X and Y edges. The corridor definition is the same as defined in T2K-TN-208 and shown in Table 1.

# References

[1] T. Campbell and Others. Analysis of Îœ ÎŒ Charged Current Inclusive Events in the P‰D in Runs 1+2+3+4, Mar 2014. T2K-TN-80 v4. 7, 8

[2] K. Gilje. Geometry and Mass of the $\pi^0$ Detector in the ND280 Basket, Apr 2012. https://www.t2k.org/docs/technotes/073. 8

[3] G. Wikström and A. Finch. Global Kalman vertexing in ND280, Feb 2018. T2K-TN-46 v3. 7

[4] T. Yuan, J. Lopez, and A. Marino. Double Differential Measurement of the Flux Averaged $\nu_\mu$ CC0Pi Cross Section on Water, Aug 2016. T2K-TN-258 v4.6.1. 7

# Nomenclature

FGD A **F**ine **G**rain **D**etector is a detector made of closely spaced, small scintillating bars designed to provide precise resolution of charged particle tracks

HMNT The **H**ighest **m**omentum **n**egatively-charged **t**rack in the bunch

HMPT The **H**ighest **m**omentum **p**ositively-charged **t**rack in the bunch

MIP A **M**inimum **I**onizing **P**article

ND280 The **N**ear **D**etector which is **280** meters away from the neutrino source

CECal The **C**entral **ECal** detector which is a part of the PØD inside ND280

PØD The **P**i-zero (**Ø**) Detector

PØDule A collection of two active scintillator bar layers inside the PØD

FV The **F**iducial **v**olume of a detector is the region where the detector response is well understood

TPC A **T**ime **P**rojection **C**hamber is a device that detects and tracks charged particles with the application of strong electric fields

Tracker The region of ND280 consisting of two FGDs and TPCs

Global The Global reconstruction module responsible for making joined tracks between the subdetectors inside ND280

USECal The **U**p**s**tream **ECal** which is a part of the PØD inside ND280