T0 reconstruction for cosmics in ProtoDUNE LArTPC

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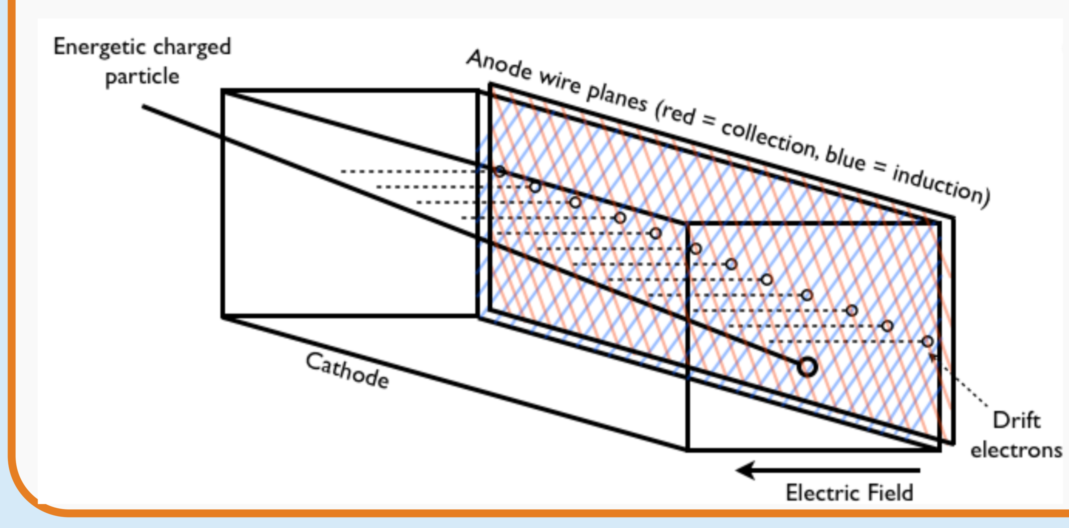
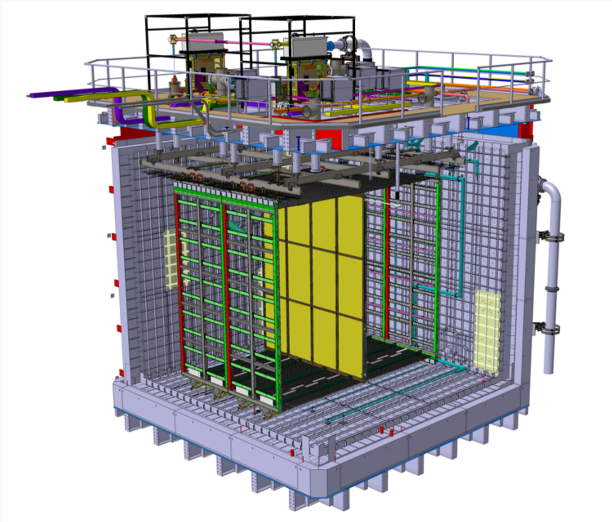
1. DUNE & ProtoDUNE

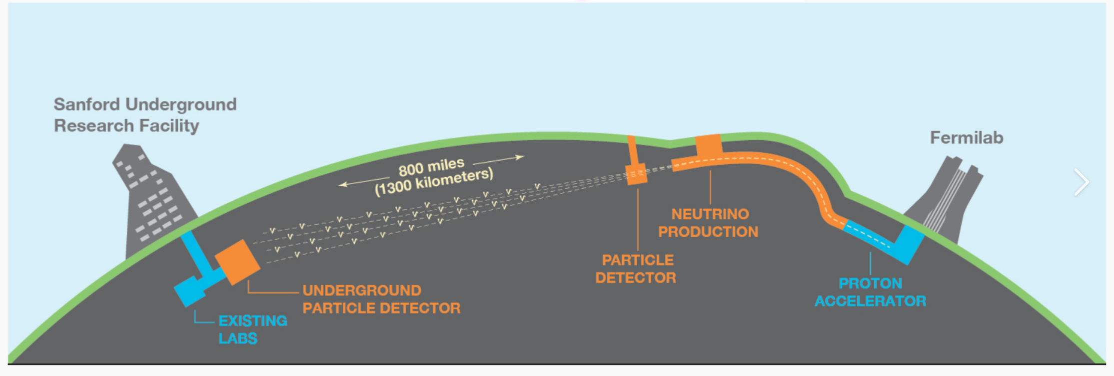
- DUNE (Deep Underground Neutrino Experiment), main goals include measurement of CP violation and observation of neutrinos from supernova burst
- DUNE consist of 3 main parts: a high intensity neutrino source, Far Detector, Near Detector
- Far Detector will consist of 4 separated liquid argon time projection chamber (LArTPC) detector modules each embedded in the standalone cryostat
- ProtoDUNE-HD - LArTPC technology prototype tested at CERN in 2024, [4]
- LArTPC: ionization electrons drift toward readout anode wire planes
- scintillation light is collected by Photon Detection System





2. Motivation

- combine LArTPC ionization signals with Photon Detection System scintillation light in order improve energy reconstruction of low energy events - O(10MeV)
- measure supernova neutrino energy spectra
- as a proxy we will use Michel electrons of muons that stopped in ProtoDUNE



3. T0 tagging algorithms

T0 = reconstructed time of muon arrival at the TPC

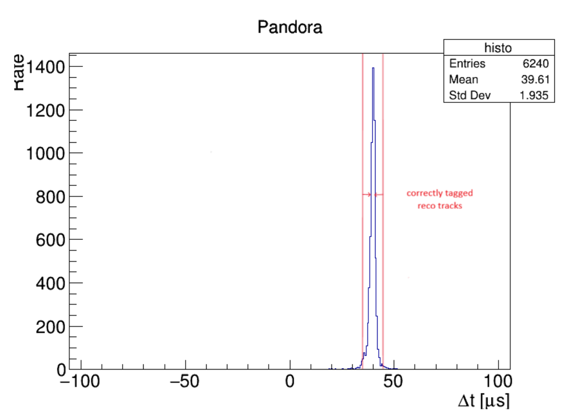
X0 = distance in drift coordinate between shifted track and true trajectory of the same particle

tagged tracks = tracks with reconstructed T0

stitching = connecting tracks reconstructed independently in neighboring parts of TPC track

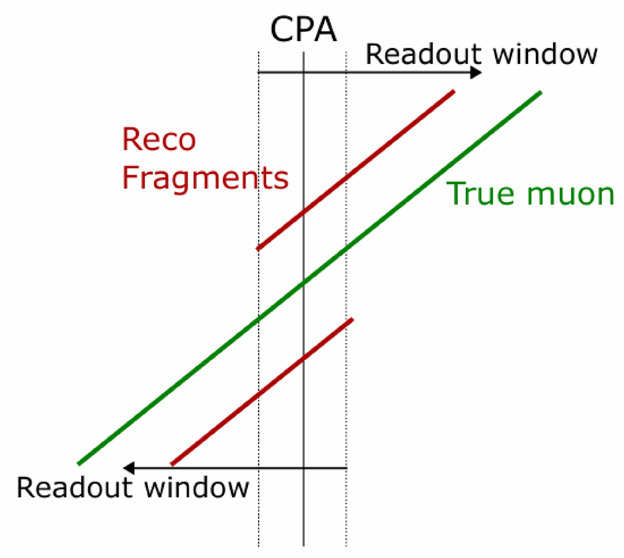
$\Delta t = \mathrm{T0} - \mathrm{T}_{\mathrm{true}}$

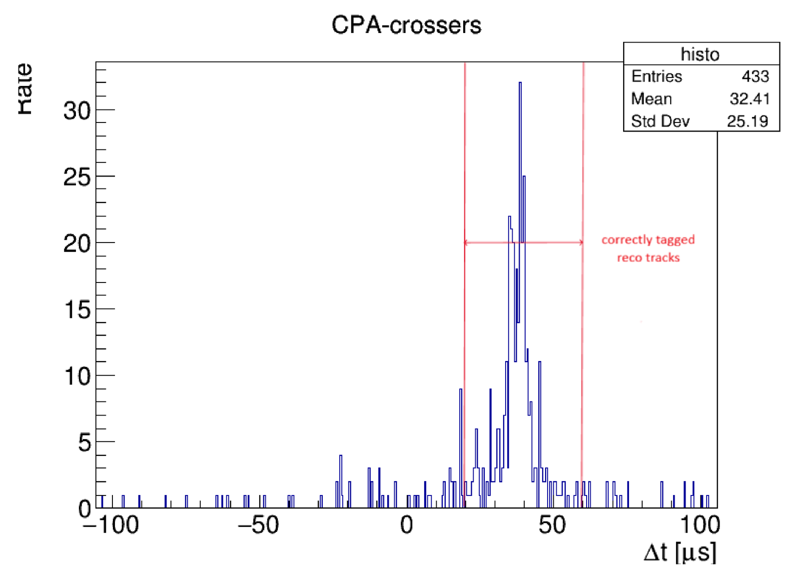
1. Pandora

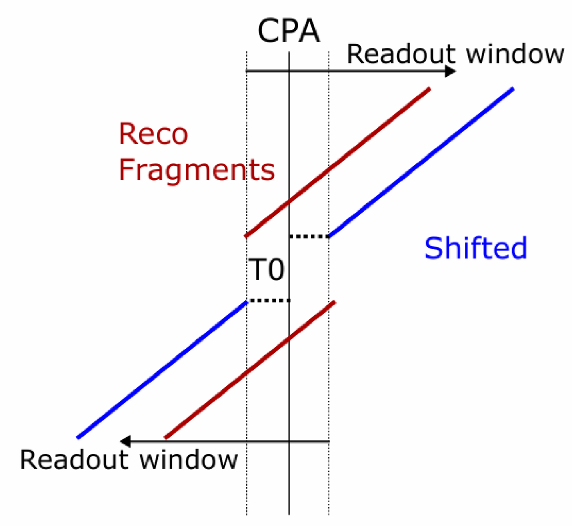


Pandora is able to reconstruct T0 of a tracks that pass through CPA or APA through stitching of two 3D tracks...

2. CPA-crossers

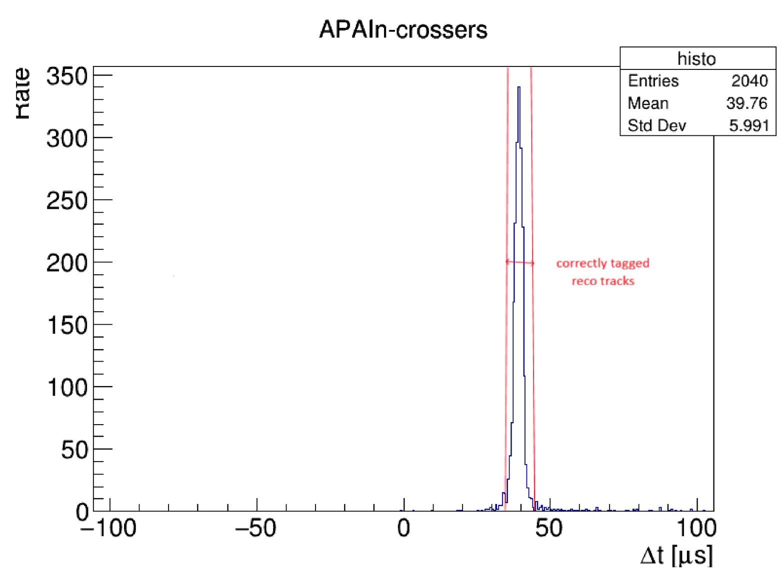


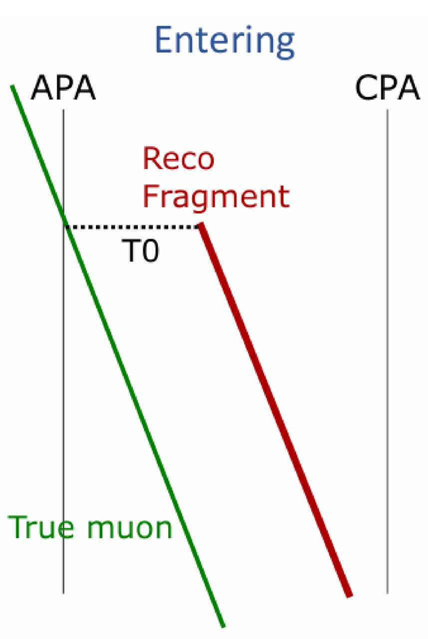


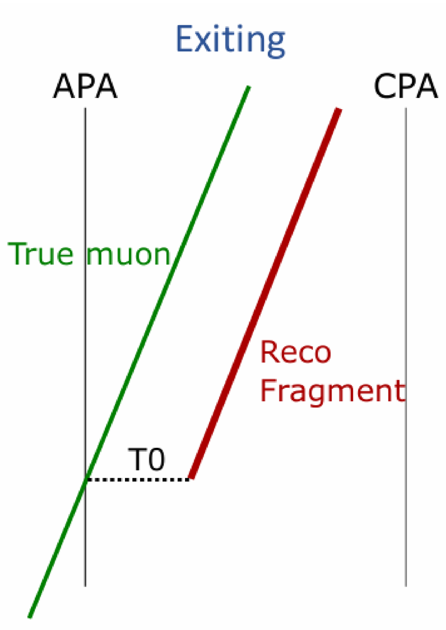


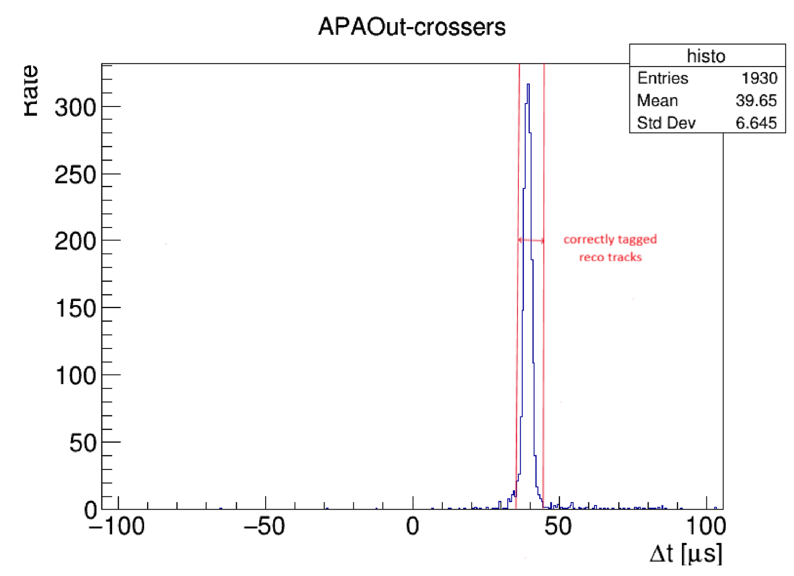
CPA-crossers are tagged stitched tracks that were not stitched by Pandora, pass through CPA, are cut by readout window, have min. track length of 20 cm; and are collinear → the X0 shift of both stitched tracks in ref. to the CPA must be the same → $\mathrm{T0} = \mathrm{X0}/\mathrm{v}_{\mathrm{drift}}$ (1.5 mm/μs). Track schemes are from [3].

3. APAIn-crossers & 4. APAOut-crossers









APAIn-crossers/APAOut-crossers are tagged reconstructed tracks that entered/exited the TPC through anode plane (APA), were not cut by readout window and follow spatial condition.

Spatial condition: the track start point/endpoint is not near front, rear, top/bottom TPC boundaries. Track schemes are from [3].

4. Efficiency and purity

$$\text{efficiency} = \frac{\text{correctly tagged reco tracks}}{\text{true muons w/ reco T0 candidate}} \qquad \text{purity} = \frac{\text{correctly tagged reco tracks}}{\text{tagged reco tracks}} \tag{1}$$

- **tagged reco tracks** - T0 determine by T0 tagging algorithms
- **correctly tagged reco tracks**
  - corresponding true muon $\geq$ 20 cm length & intersects APA/CPA
  - $\Delta t = \mathrm{T0} - \mathrm{T}_{\mathrm{true}}$ lies within the distribution of the main peak
- **true muons w/ reco T0 candidate** - primary muons (length $\geq$ 20 cm) intersecting CPA/APA, with reco tracks matching selection criteria

5. Results

T0 tagging algorithm	efficiency	purity
Pandora	56 %	93 %
CPA-crossers	24 %	49 %
APAIn-crossers	82 %	75 %
APAOut-crossers	78 %	49 %

Reference

[1] Fermilab, DUNE Graphic, https://lbnf-dune.fnal.gov/

[2] Wikipedia, Time projection chamber, https://en.wikipedia.org/wiki/Time_projection_chamber

[3] V. Pec, https://indico.fnal.gov/event/60082/contributions/291939/

[4] The DUNE Collaboration, https://arxiv.org/pdf/2312.03130, The DUNE Collaboration, Schematics of ProtoDUNE-HD https://arxiv.org/pdf/2604.23966