

# Overview of ML-based Neutral Pion Reconstruction at ProtoDUNE-SP

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**On behalf of the ML  $\pi^0$  Team**

ProtoDUNE EM Shower Task Force Meeting

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- ◆ Neutral pions are key to unlocking the electromagnetic (EM) shower energy scale for DUNE
  - Well-defined mass allows for understanding of energy scale of EM showers (photons) using data:  $M(\pi^0) = \sqrt{2E_1E_2(1 - \cos(\theta_{12}))}$
  - May be differences between data and simulation (e.g. interplay of reconstruction method and thresholding effects)
  - In my opinion, essential to study for pinning down EM shower energy scale systematic → one of most important systematics in  $\delta_{CP}$  measurement!
- ◆ Careful calibration essential for this analysis!
  - Space charge effects are especially impactful
- ◆ Launching machine learning (ML) based effort to identify and reconstruct EM showers from  $\pi^0$  at ProtoDUNE-SP

- ◆ Have launched coherent development effort: “Deep Learning based full data reconstruction chain for LArTPCs” for ProtoDUNE
  - Identify and reconstruct  $\pi^0$  from beam using ML techniques
  - Group is also planning on studying  $\pi^0$  reco. at 2x2 demonstrator
- ◆ Team: CSU + LBNL + SLAC (6 to 8 GS/PD/Scientists supported by dedicated DOE funding for ML-based data reconstruction for SBN/DUNE)
  - Leads: Mike Mooney (CSU) and Patrick Tsang (SLAC)
- ◆ Workshops: a monthly code sprint since June (twice at SLAC, once at CSU), great time/place to join effort
  - Contact Mike and Patrick to get plugged in if you’d like to contribute to the effort!

- ◆ Different groups (SLAC, LBNL, CSU) bring different strengths to group
- ◆ SLAC: primary source of ML expertise, principally from Patrick and Kazuhiro Terao (SLAC scientists) and postdocs/students working with them
- ◆ LBNL: expertise with characterization of ProtoDUNE beam events
- ◆ CSU: expertise with LArTPC calibrations, including space charge effects, electron lifetime, and signal processing
- ◆ LBNL and CSU are picking up expertise with ML from this collaborative effort

- ◆ Reconstruction chain is repurposed from generic reconstruction chain R&D (for both SBN and DUNE)
- ◆ Input: 3D reconstructed points (Cluster3D, SPSolver, WireCell, etc.)
  - Starting with Cluster3D for first pass
  - Semi-equivalent chain in 2D under development
- ◆  $\pi^0$  ID: U-ResNet (ref) to remove isochronous ghost points + classify track vs. shower, PPN (ref) to identify shower start point, apply clustering algorithms (non-ML, CNN-based, GNN-based).
- ◆  $\pi^0$  selection: find a cluster (shower) pair originating from a  $\pi^\pm$  trajectory (via backward projection of shower direction)

# ML Reco. Flow Chart

1. Data loader

2. Semantic seg.

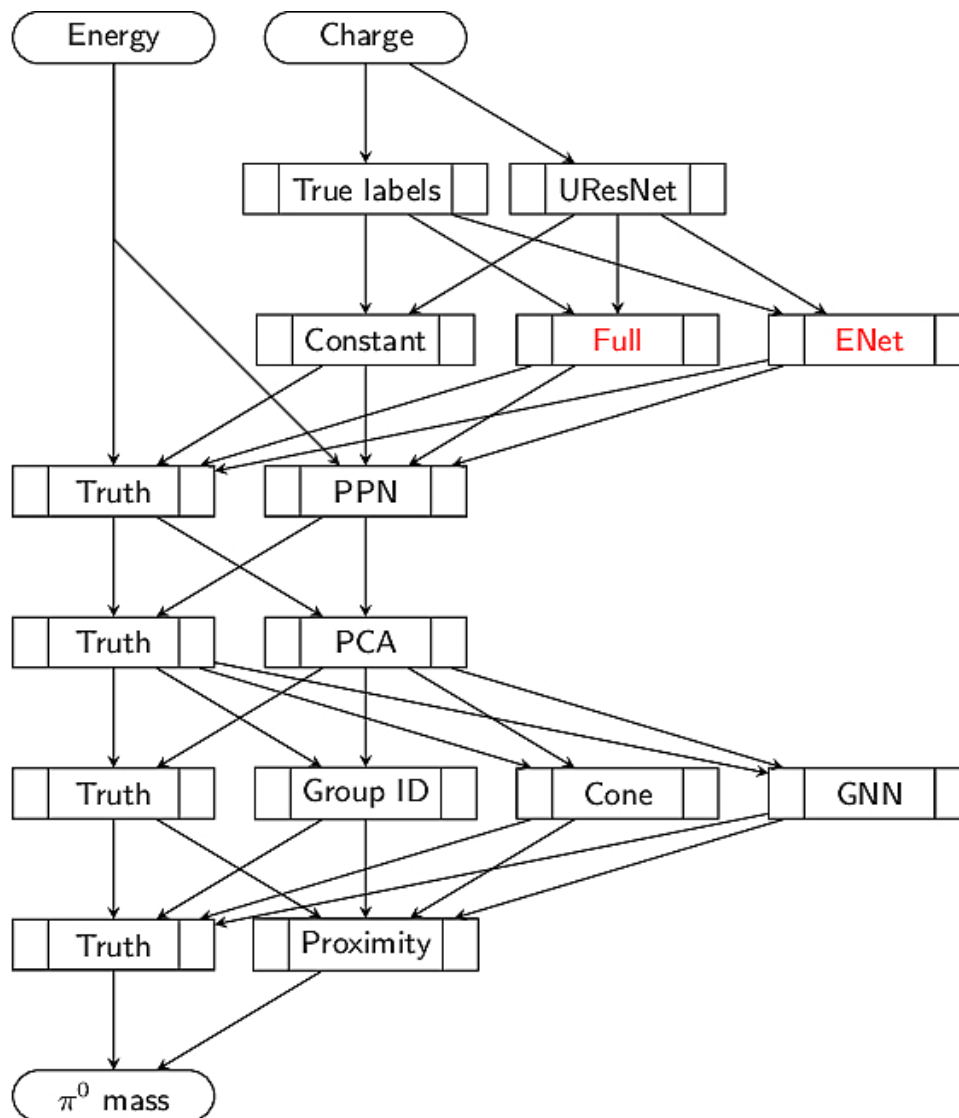
3. Detecor response

4. Shower start

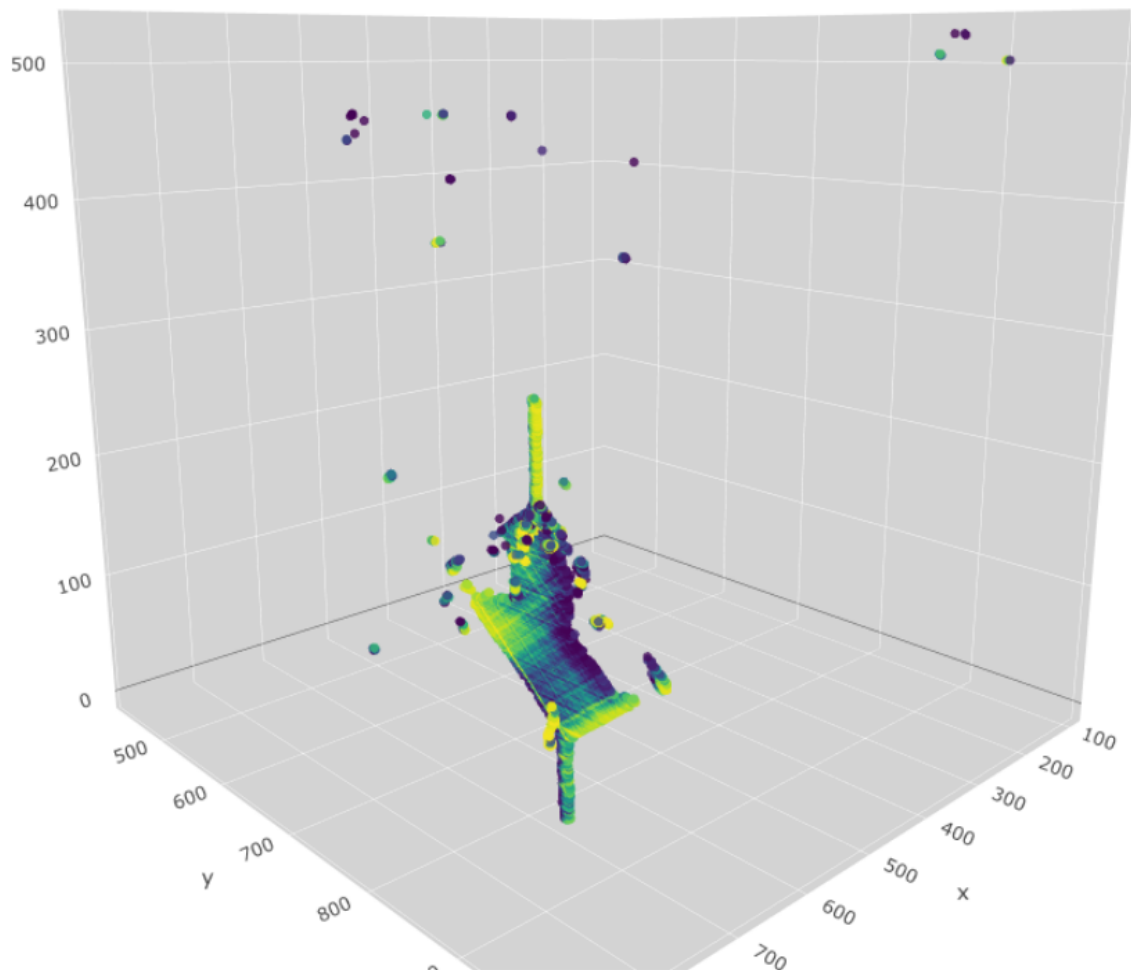
5. Shower direction

6. Shower clustering

7.  $\pi^0$  identification

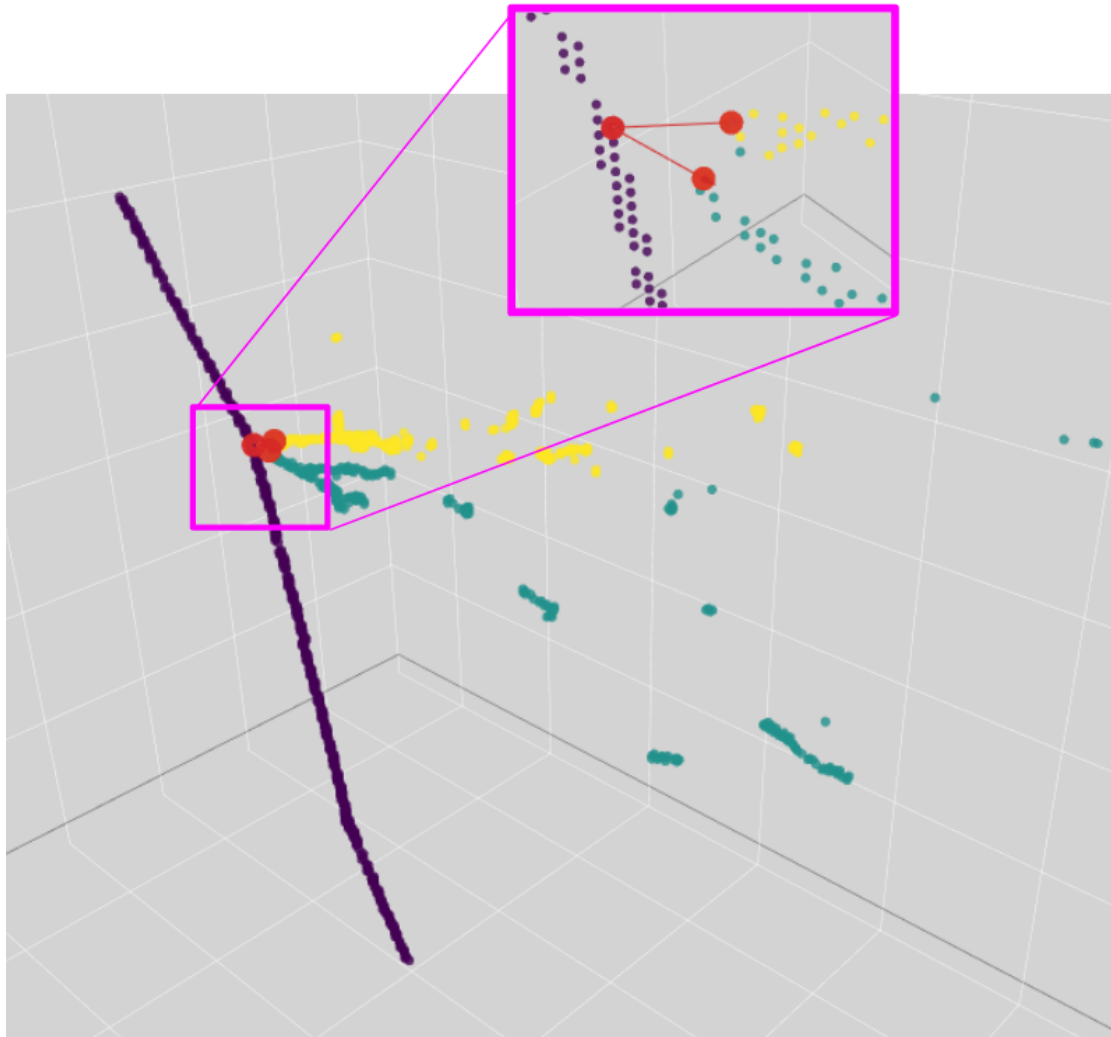


# Example Input



3D points reconstructed using Tracy Usher's Cluster3D algorithm. Shown is a charged pion trajectory with two  $\pi^0$  decay gamma rays (MC). The color scale represents reconstructed charge magnitude.

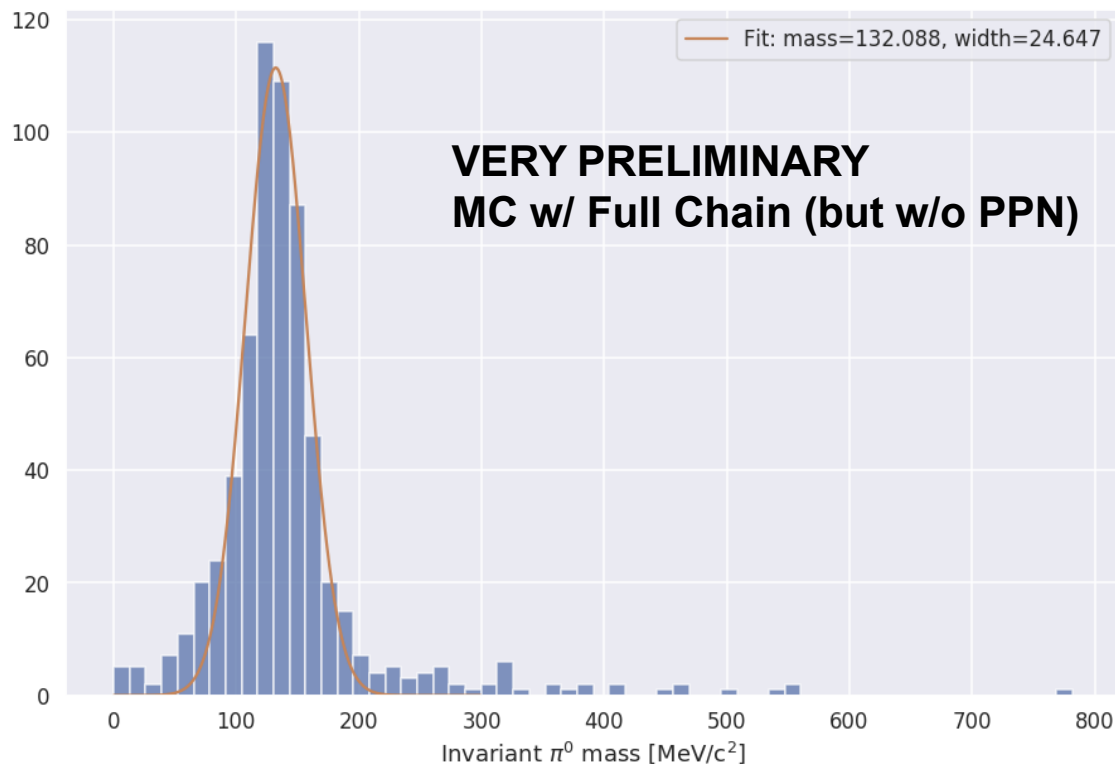
Isochronous “ghost points”, common to all 3D point reconstruction algorithms, are apparent along x-axis.



“Ghost points” are removed using U-ResNet, points are clustered into a particle and colored. Two EM showers resulting from  $\pi^0$  decay are visible.

The shower directions are reconstructed and selected as they point back to the charged pion trajectory.





- ◆ Above plot  $\pi^0$  mass for full reconstruction chain, except PPN not included (using true shower start point for now)
  - Using cone clustering (not GNN), which may be default approach
- ◆ Very preliminary result, but promising!

# BACKUP SLIDES

# Space Charge Effects

- ◆ Looking at cosmic data, notice offsets in track start/end points from top/bottom of TPC
  - Very suggestive of space charge effects (SCE) **as expected** as the ProtoDUNE-SP is near the surface; also seen at MicroBooNE
  - **Space charge:** build-up of slow-moving  $\text{Ar}^+$  ions due to e.g. cosmic muons impinging active volume of TPC (via ionization)
  - Leads to E field distortions, distortions in reconstructed ionization position
    - Both can bias particle  $dE/dx$  and energy! Important to calibrate!

