2x2 Chicago Meeting

March 19, 2024

Angela White and Elise Hinkle

2x2 Paper Update

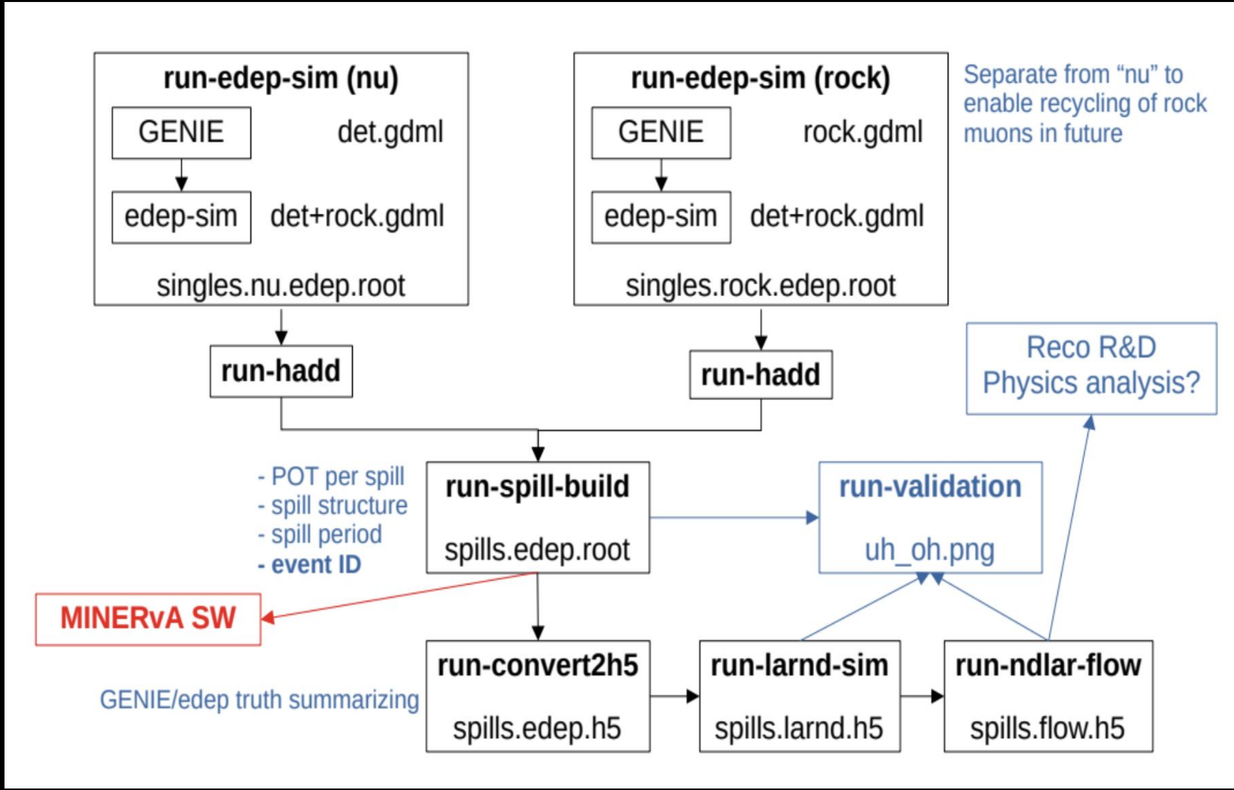
Link to Overleaf Draft:
https://www.overleaf.com/8458358216drvhjgctvqpr#7b24bd

- Meeting with leadership 11am CT this Friday

Will discuss:

- First draft of paper
- Finalized list of plots
- Also: **Fermilab** is planning a **press release**: “DUNE’s first Neutrinos (from 2x2)”
    - This is known, but will mention in meeting
    - Ed: make sure a few people (not just Jen) read it first: ask Jen if if Chicago group can be looped in to make sure not in conflict with paper

2x2 Analysis Chain Overview

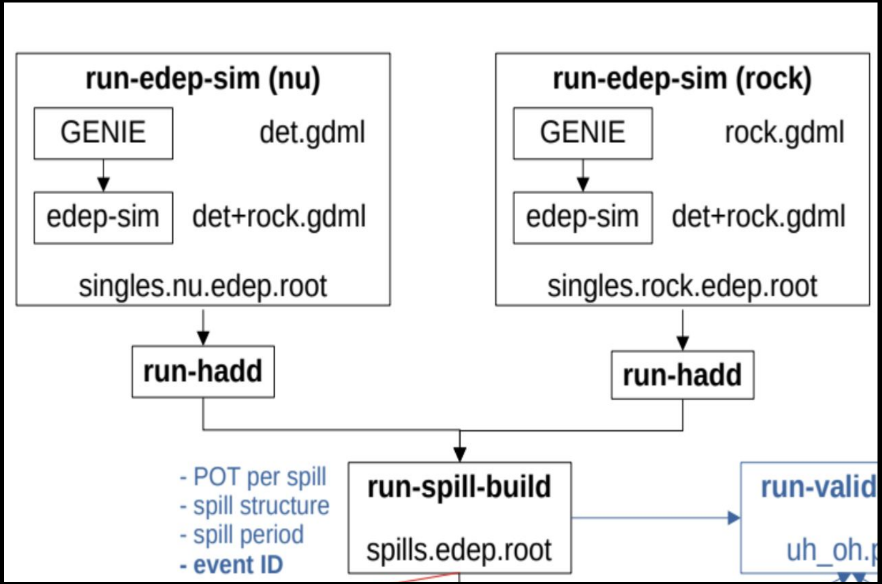


Steps:

1. edep-sim
2. spill-build
3. convert2h5
4. larnd-sim
5. ndlar-flow

EDEP-SIM

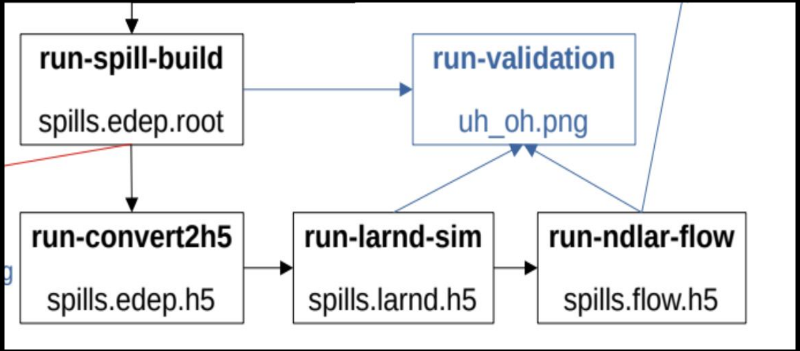
- **GENIE**: The event generator–takes NuMI flux files + geometry description to generate neutrino interactions.
    - Run for rock (+ hall) geometry and detector geometry separately
- **Edep-sim**: Geant4 wrapper.
    - Takes outgoing GENIE particles, propagates them through the geometry, records the particle trajectories and energy deposited in active ("sensitive") detector volumes.
- **hadd**: From ROOT
    - merges edep-sim outputs



- **Spill-build**: overlays edep-sim events into spills
- **Convert2h5**: adjusts units, axes labels and file type for rest of chain

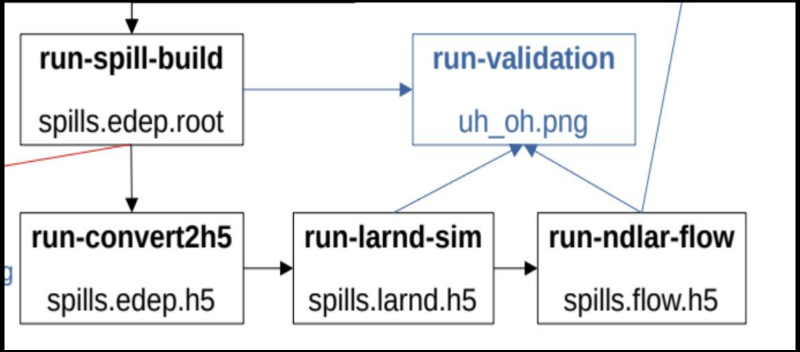
LARND-SIM

- **Larnd-sim:** The detector simulation for the charge (LArPix) and light readout.
  - Written in Python but with the "heavy lifting" compiled to GPU (CUDA) binary using Numba.
- Calculates recombination, pixel response, SiPM response, etc.



NDLAR-FLOW

- **Ndlar-flow:** Calibration and low-level reconstruction.
  - Written in numpy-based Python using "h5flow" framework
- Used to process data, as well
- Outputs simulation files in data-like formatting



Follow-Up: ML-Based 3D Reconstruction

From Google: "Semantic segmentation is a deep learning algorithm that **associates a label or category with every pixel in an image.** It is used to recognize a collection of pixels that form distinct categories."

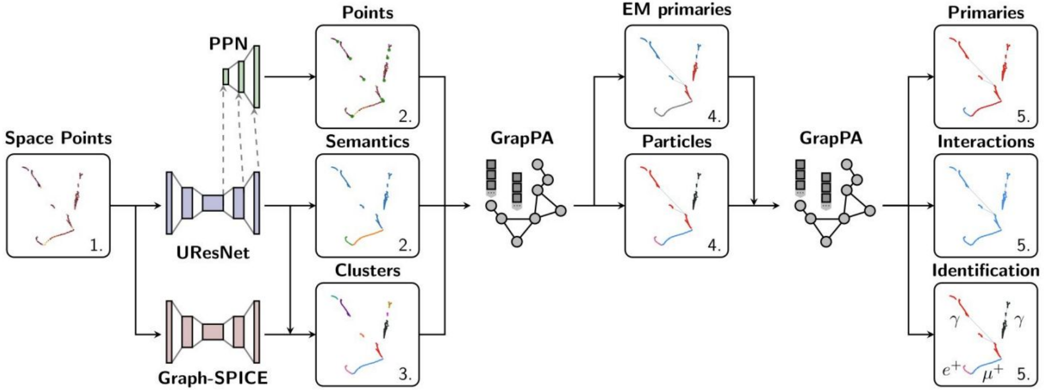
More info on ML Reco for LArTPCs here (may not be specifically for pixel-based detectors, but from SLAC group involved for 2x2)

ML Reconstruction Chain

SLAC NATIONAL ACCELERATOR LABORATORY

Reconstruction flow:

1. Voxel semantic classification, point identification (**CNN**: UResNet+PPN, **L. Dominé**)
2. Dense clustering (Smart DBSCAN, **CNN**): Graph-SPICE, **D.H. Koh**)
3. Particle aggregation, shower primary identification (**GNN**: GrapPA-Track/Shower)
4. Interaction aggregation, particle identification, primary identification (**GNN**: GrapPA-Interaction)



ML-Based Reconstruction for 2x2, F. Drielsma (SLAC)

Recap – Preview of ML Reco Benchmarking

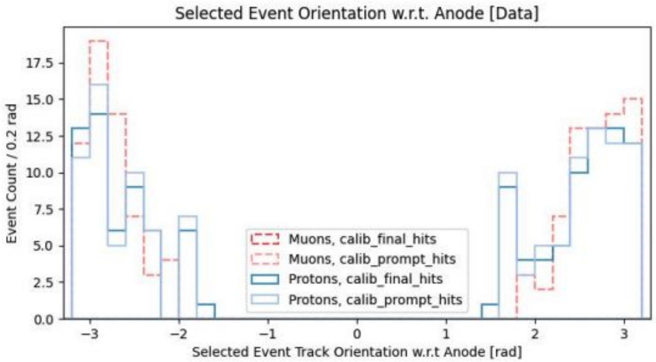
Last week: Showed initial studies looking at reconstructed charged tracks and protons vs. their truth matched particles

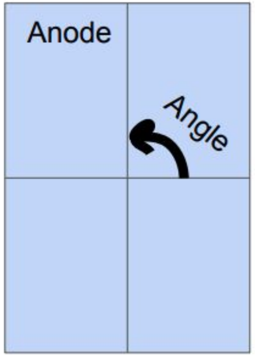
This week: Additional plots shown at analysis and reconstruction meetings last week (+ comments I received)

Previous Work □ January Workshop

- At January Workshop, we showed preliminary particle kinematic data/MC comparisons for hand-scanned proton-like and muon-like track samples from Bern Module data and simulation flow files
  - **Benchmarking charged, track-like particle reconstruction is essential** for the CC $\bar{\nu}_{\mu}$-Ar mesonless cross section analysis and the charged track multiplicity analysis

Preliminary Comparisons: μ vs. p, final vs. prompt hits



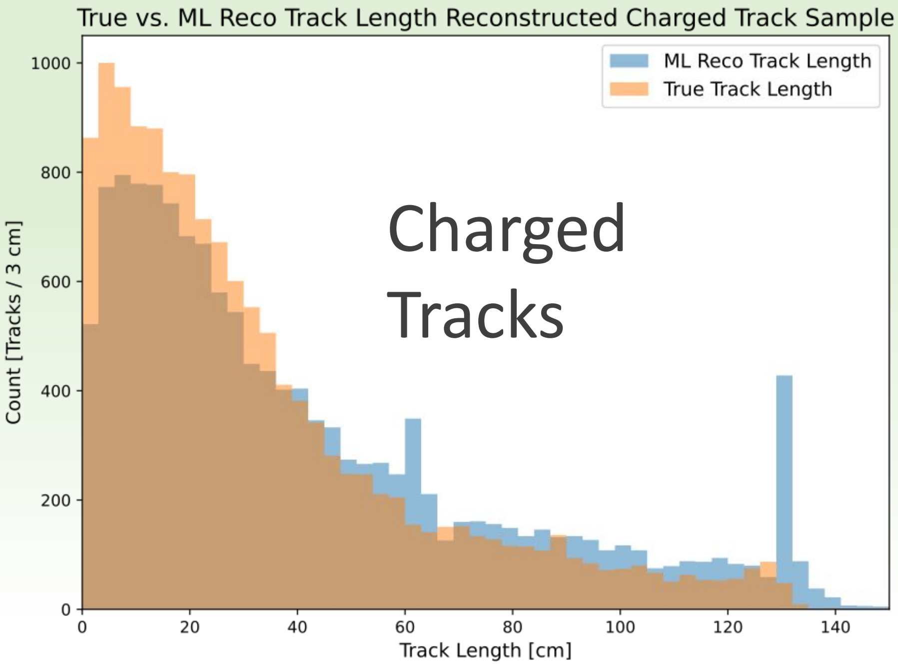


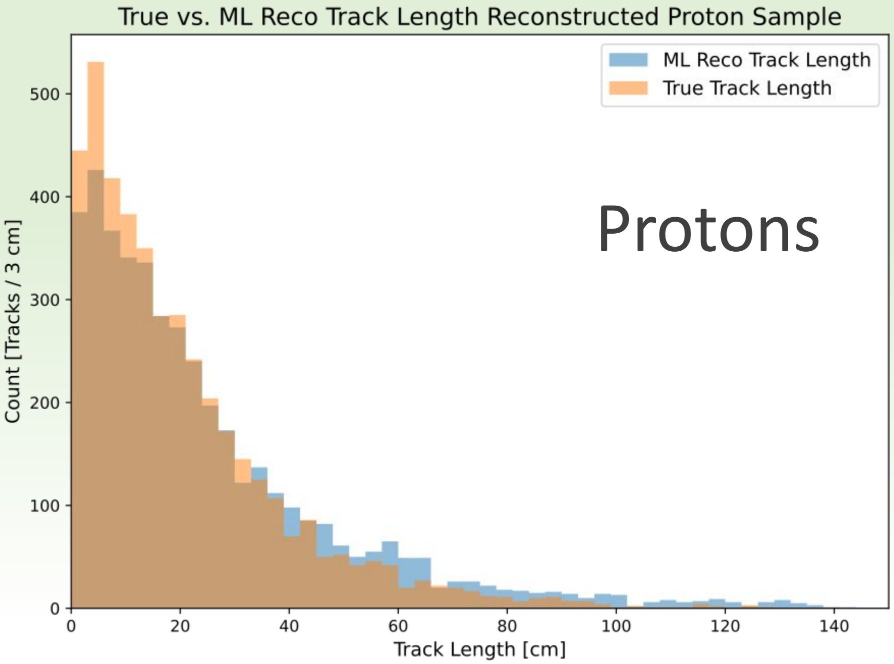
- Small differences in proton angles in prompt vs. final hits datasets
- Indicates difference in how tracklets are formed using the two datasets

Current Work – Full Reco Benchmarking

- Still want to look at calibration-file-level comparisons of data/MC using Bern Module data and simulation (see my presentation yesterday for update on Bern module cosmics simulation status)
- Also want to investigate **full proton reconstruction using CAFs** by comparing reco and true particle kinematics
- As CAFs currently only contain **ML Reco** information, this is the reconstruction I'm evaluating
- **Sample:** MiniRun4.5 Beta 2 CAFs (300 files)
- As ML Reco has some known PID issues, I look at all **reconstructed** charged track-like particles and also just **reconstructed** protons in comparison to **best match true particles**
- Cut on ML Reco "Overlap" variable such that **require reco/true match to have >=0.5 overlap**

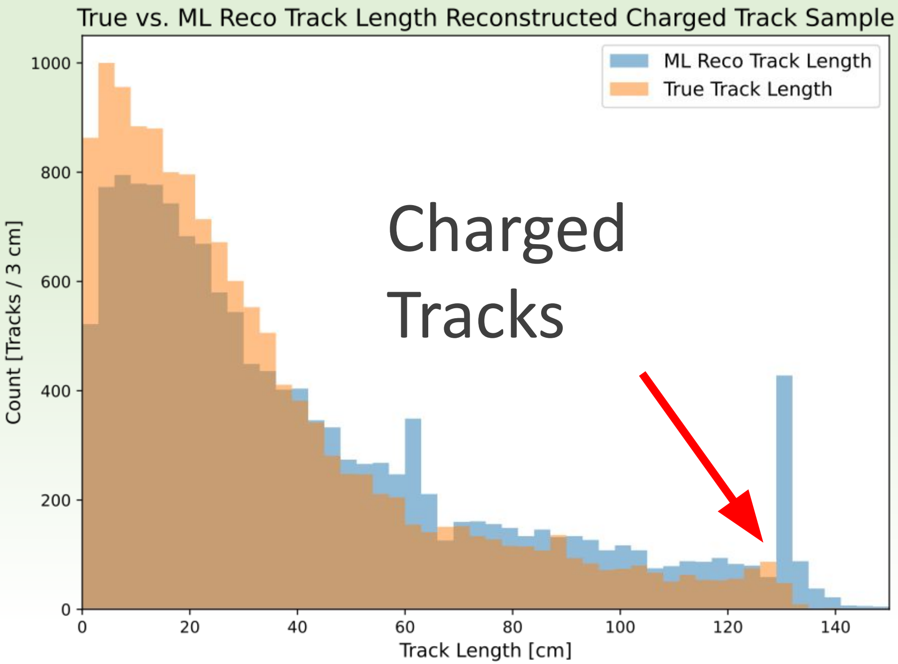
Charged Track and Proton Length





- Longer tail on ML Reco track length distributions
- More short true tracks

Charged Track and Proton Length

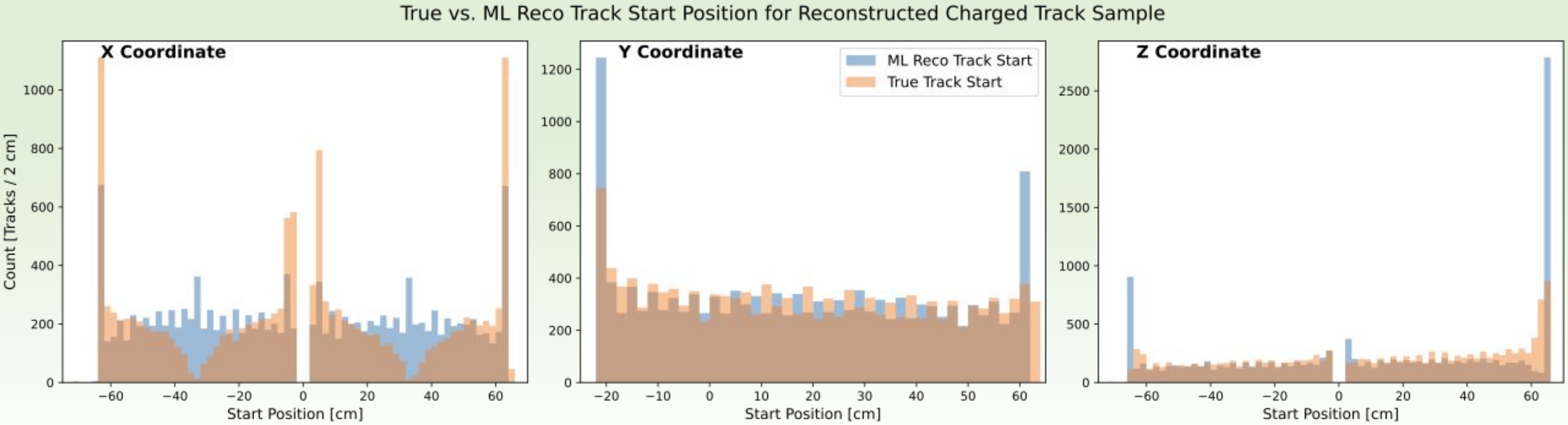


Comments from ML Reco Team:

- Look into peak in track length near end of detector for charged tracks
- Look at difference in reco vs. true track length
- Look at 2D histogram of reco vs. true track length

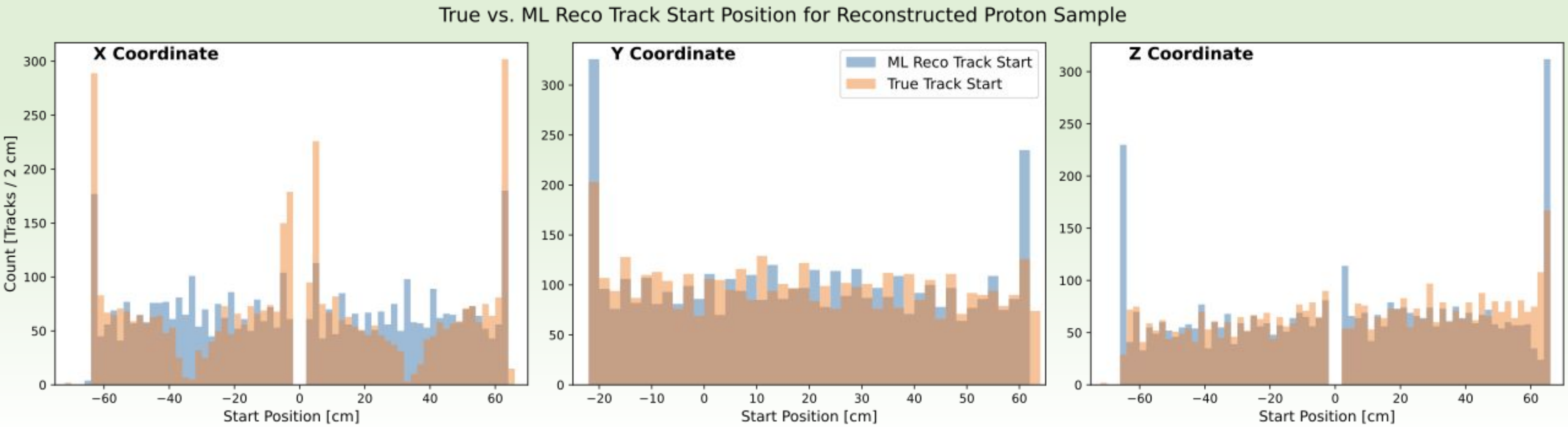
- Longer tail on ML Reco track length distributions
- More short true tracks

Charged Track Start Position



- Significant differences in x-coordinate distribution
- Large spikes at edges for ML Reco

Proton Start Position



- Significant differences in x-coordinate distribution
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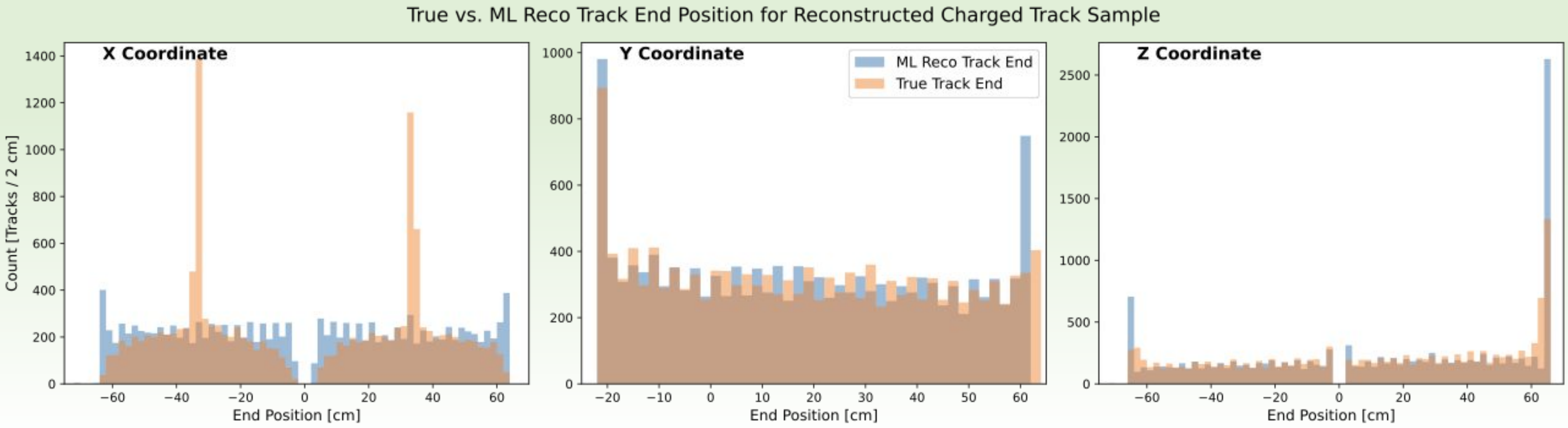
DEEP UNDERGROUND NEUTRINO EXPERIMENT

Charged Track End Position



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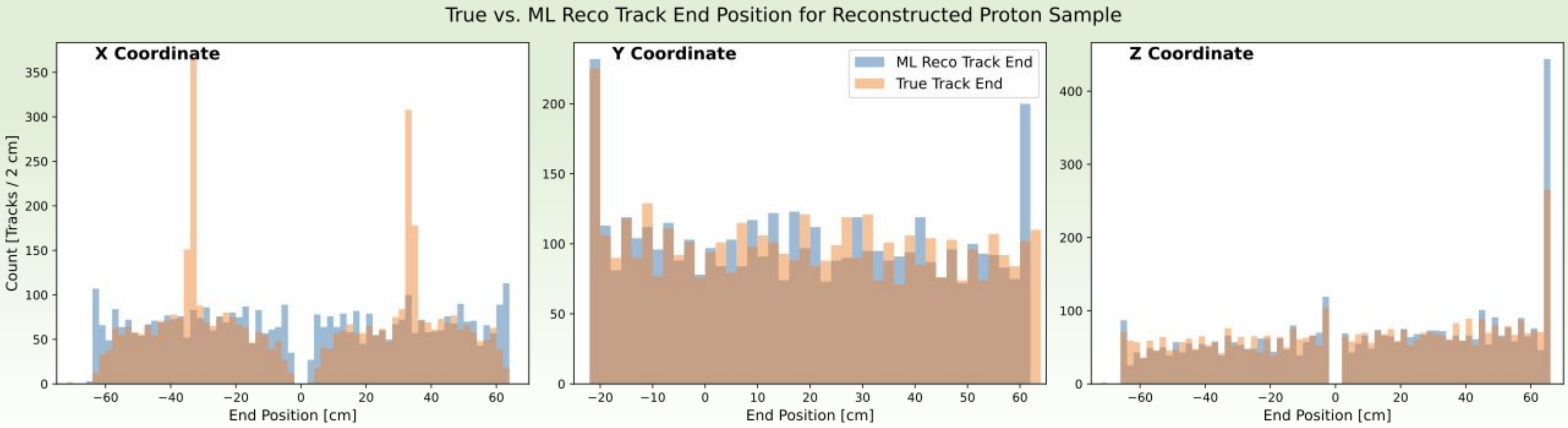
Proton End Position



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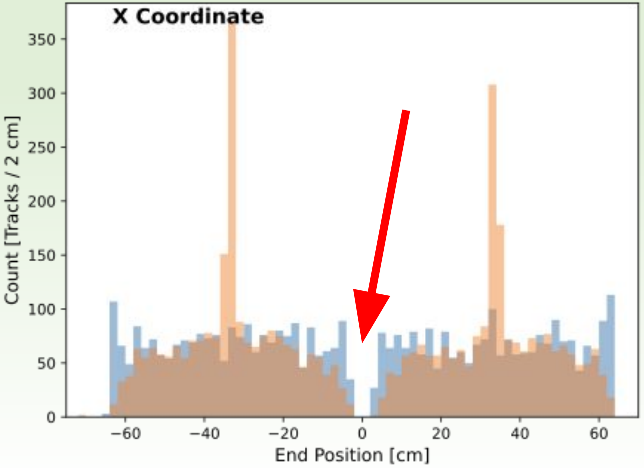
Proton End Position

True vs. ML Reco Track End Position for Reconstructed Proton Sample



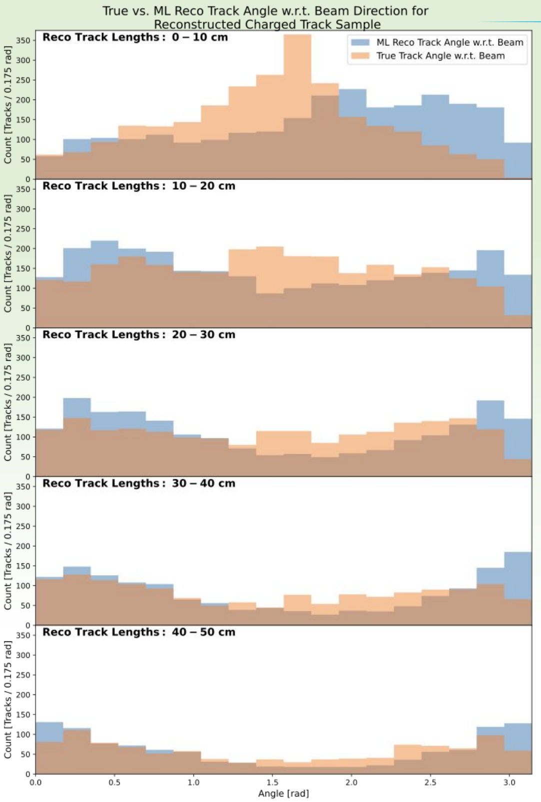
200
150
100
50
0

Comments from ML Reco Team:

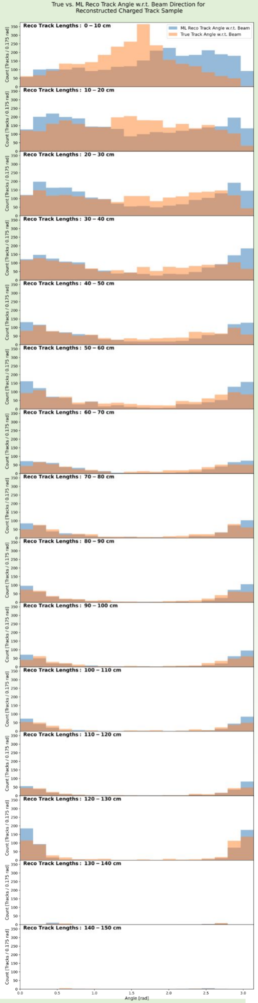
- Look into why there is no peak at gap between modules for track length

- Significant differences in x-coordinate distribution
- Large spikes at edges for ML Reco

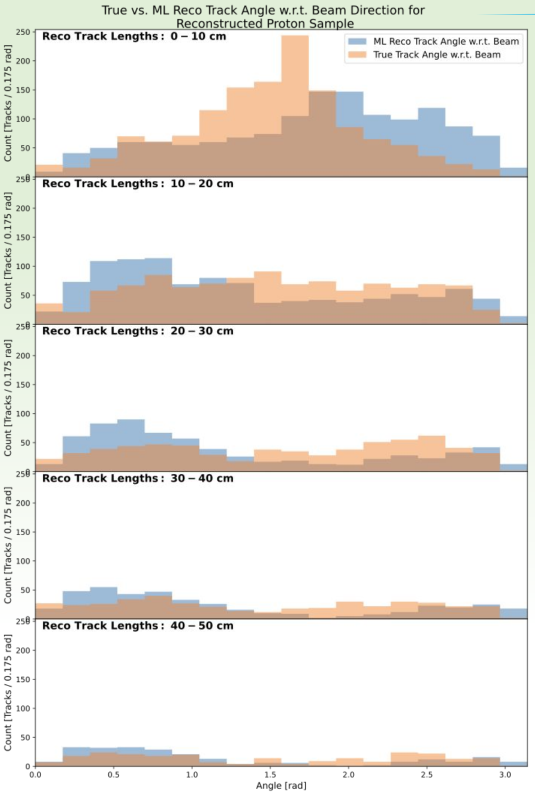
Charged Track Angle w.r.t Beam



- Binned by reconstructed track length in 10 cm bins
- For shorter tracks, clear difference in true vs. reco distributions



Proton Angle w.r.t Beam



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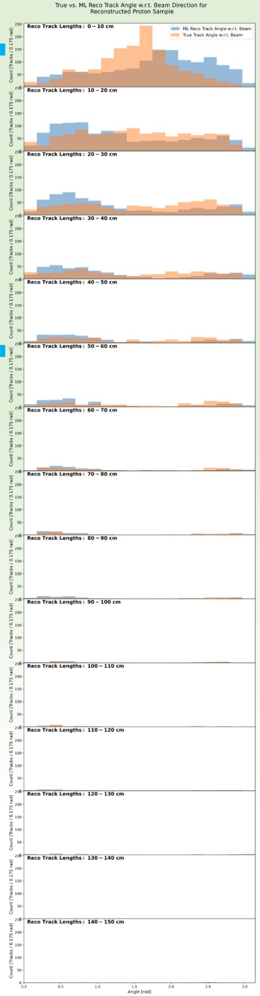

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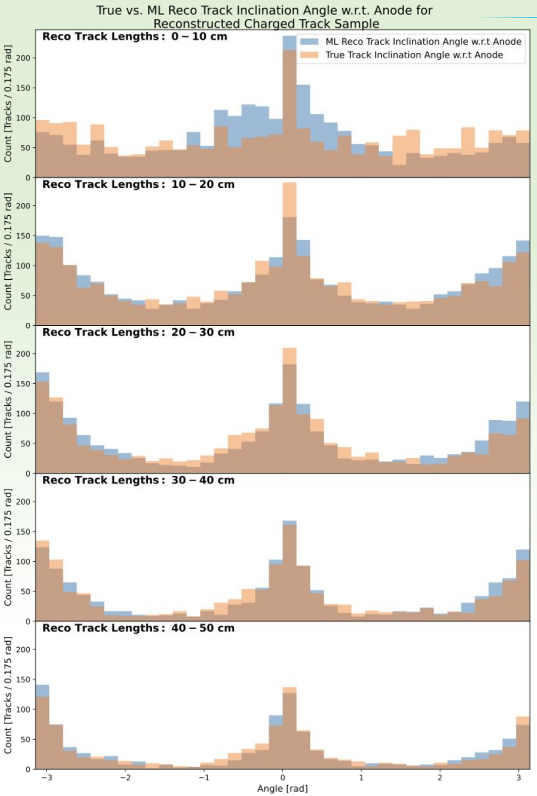
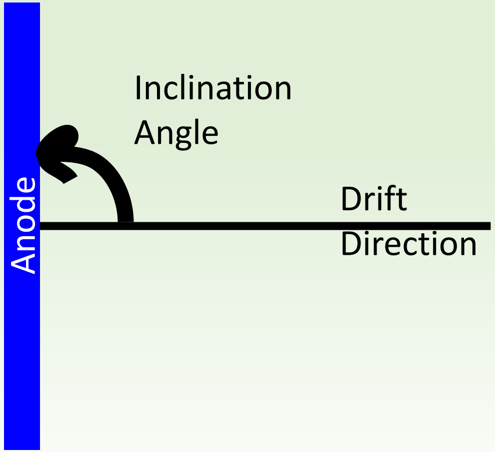
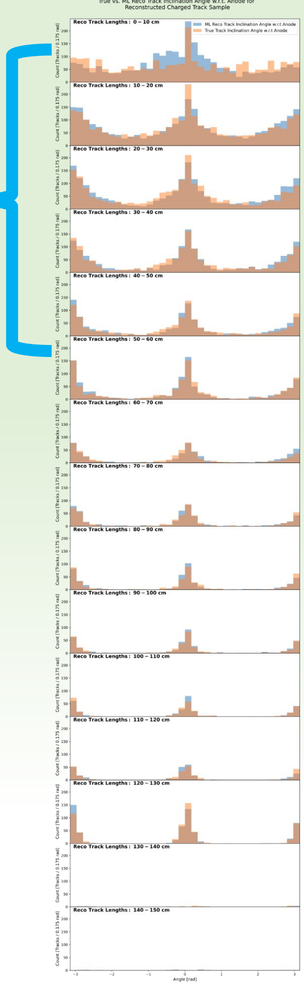
DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

Charged Track Inclination Angle







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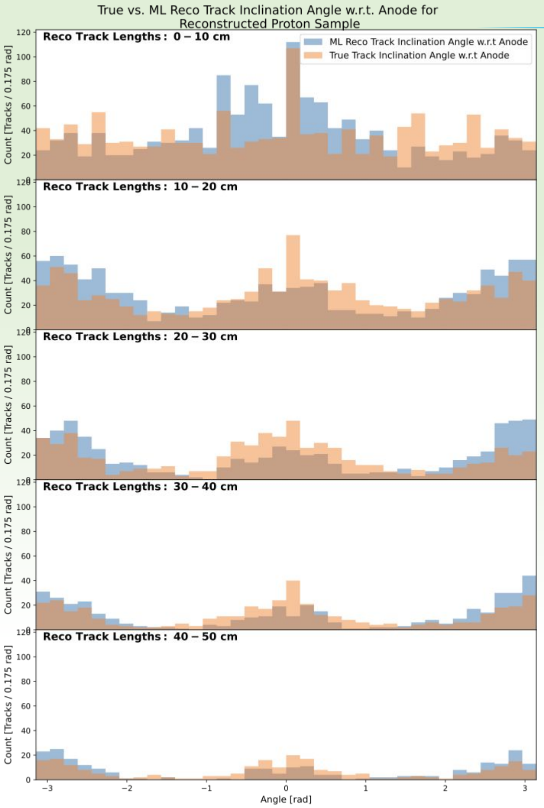
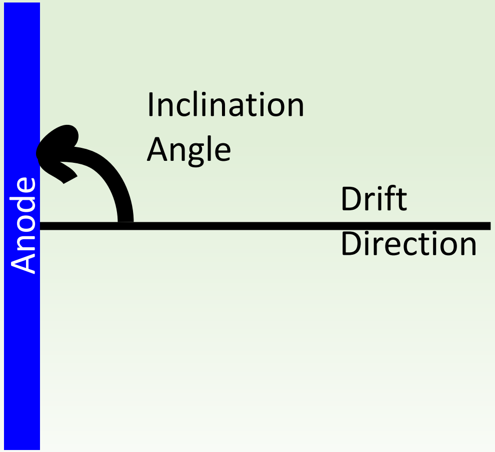
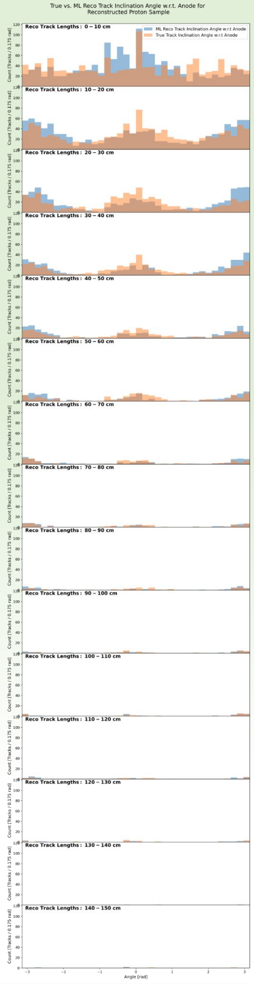
Proton Inclination Angle

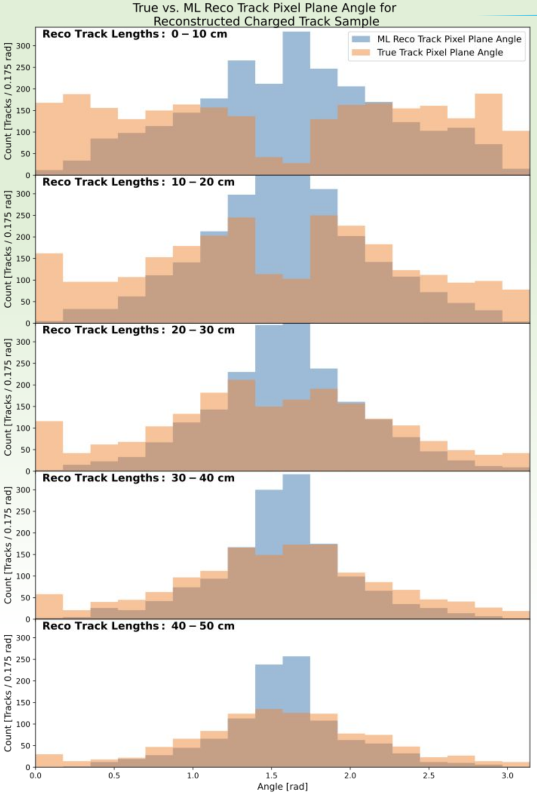


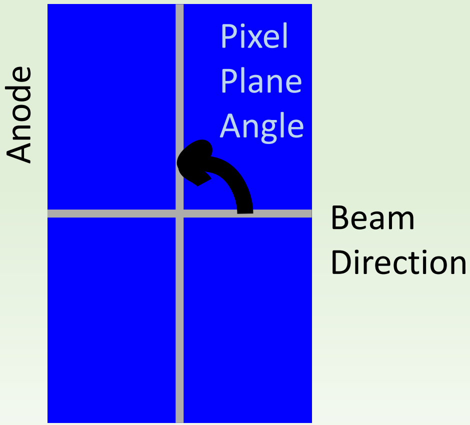




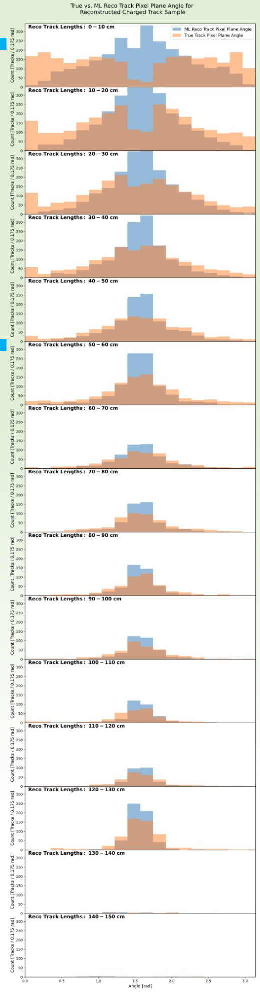
- Binned by reconstructed track length in 10 cm bins

Charged Track Pixel Plane Angle

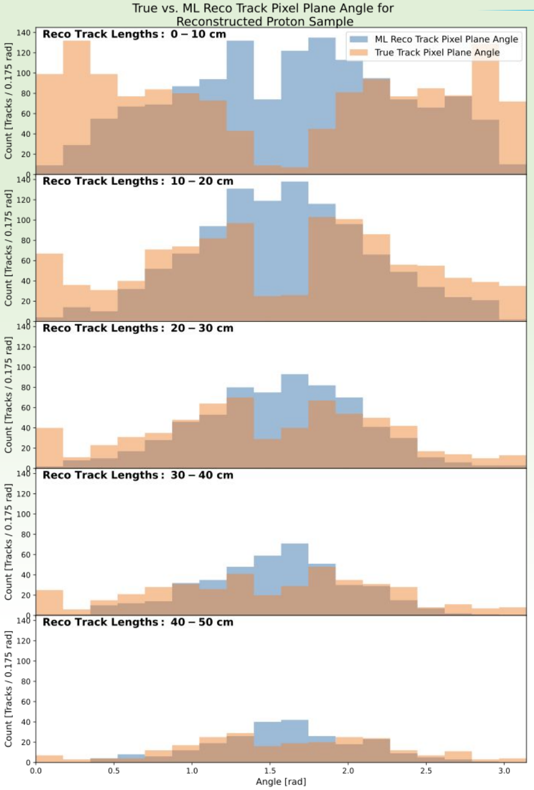


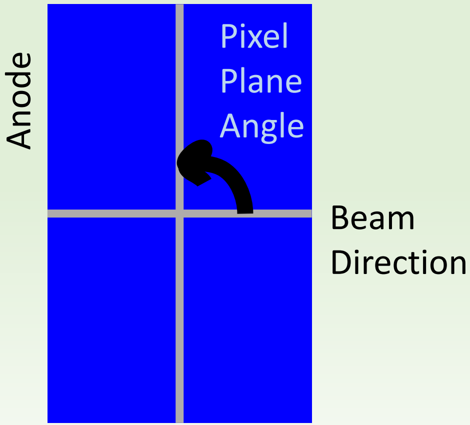


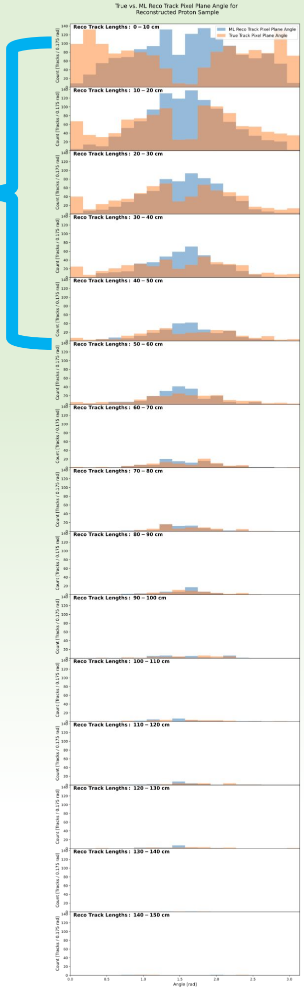
- Binned by reconstructed track length in 10 cm bins
- For all tracks, clear difference in true vs. reco distributions



Proton Pixel Plane Angle







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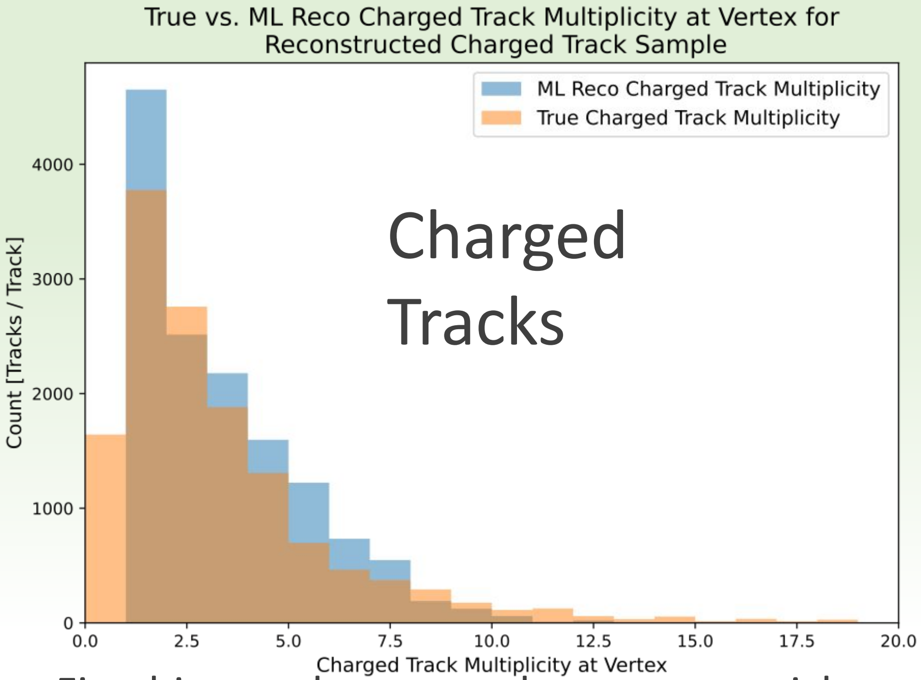
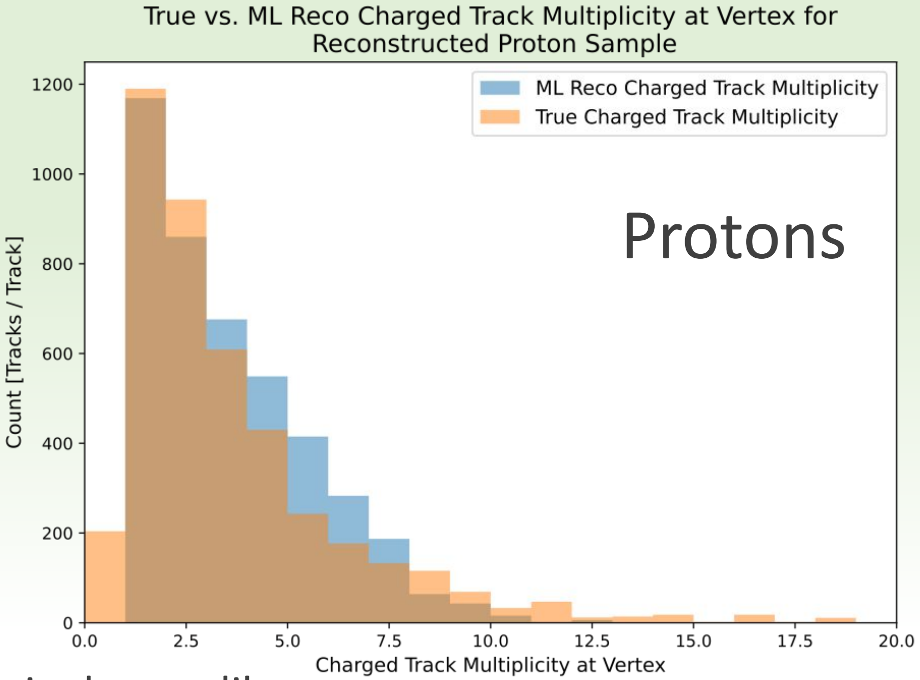
Track Multiplicity at Vertex





- First bin may be cases where true particle match is shower-like
- In the future, will look at kinematics by true track multiplicity at vertex to get a better understanding of reconstruction fidelity in high activity environments

Summary + Future Studies [as presented last week]

- Starting to study proton and charged track reconstruction (ML Reco) using CAFs
- **Some unexpected features in true vs. reco distributions, especially for pixel plane angle**
- Future areas of investigation:
  - Break down some of the plots I showed in terms of different variables (e.g. by charged track multiplicity at the vertex, by start/end position, etc.) to **identify specific failure modes**
  - Similar studies with reflowed Bern data/new Bern cosmics samples run through ML Reco

Additional Comments from Others

- Look at proton thresholds using a sample of true protons
- Create samples of TRUE protons and charged tracks and make plots similar to what I've shown here
- Make efficiency vs. purity plots with reco protons, charged tracks
- Make plots such that they can be easily reproduced for new iterations of ML Reco (i.e. when it is retrained)
- Would be nice to be able to go from "weird feature" to event display (not currently possible)

Announcement – APS April Practice Presentations

I’m giving a general 2x2 talk at APS April and am planning to give practice presentations at:

- UChicago Group Meeting next week (**Tuesday 3/26, 3pm CT**)
- ND-LAr Consortium Meeting next week (**Thursday 3/28, 10am CT**)

One Last Thing …

What happened to the Fermilab UChicago house?