

Event Reconstruction with Pandora

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(on behalf of the Pandora team)

LBNC Meeting

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Overview

- In this talk I will cover these four topics:
 - Introduction to Pandora
 - Current status of Pandora for ProtoDUNE
 - Current status of Pandora for DUNE
 - New Pandora work and development

Introduction

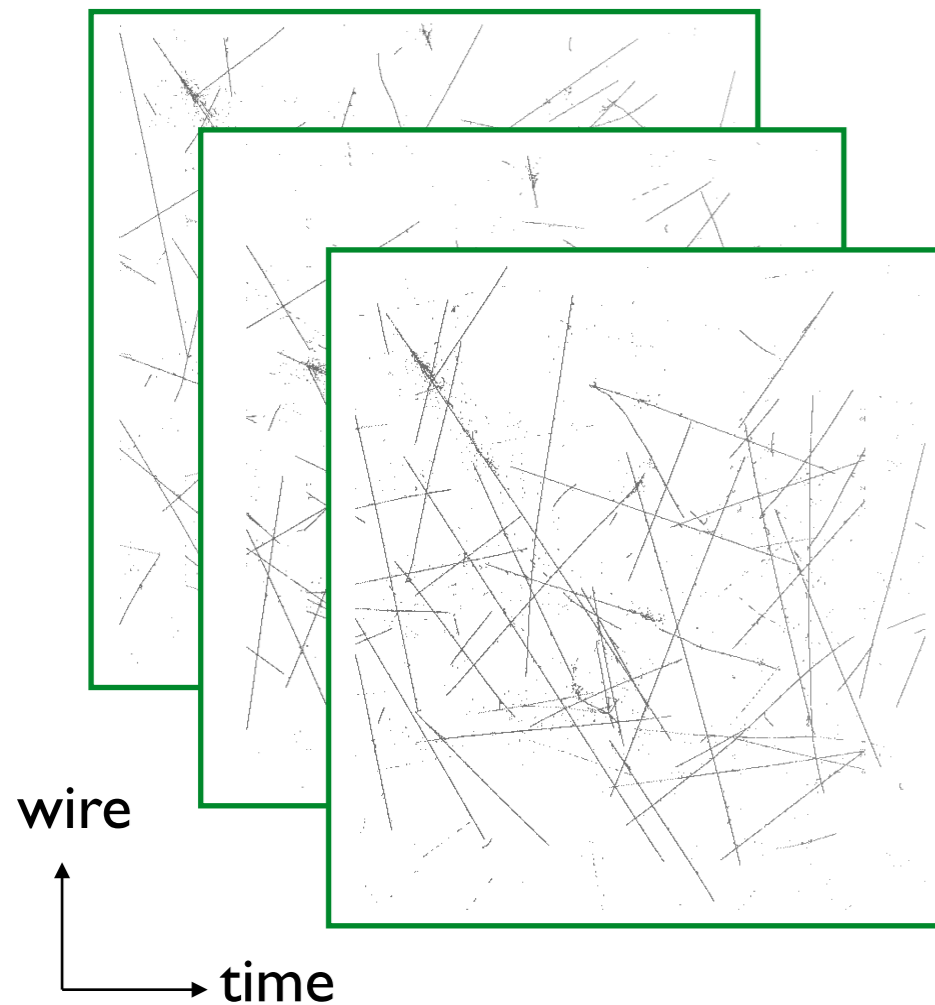
- Pandora is a software development kit for automated event reconstruction
 - Originally for the CLIC detectors
 - Now applied to a number of LArTPC neutrino experiments
- Collaboration between a number of UK institutes
 - New members and collaborators welcome!
- UK long-term Pandora plan for DUNE defined for 7 years
 - Staff, PhD students, postdocs
 - Four post-doc FTEs (Warwick x2, Cambridge, Lancaster)
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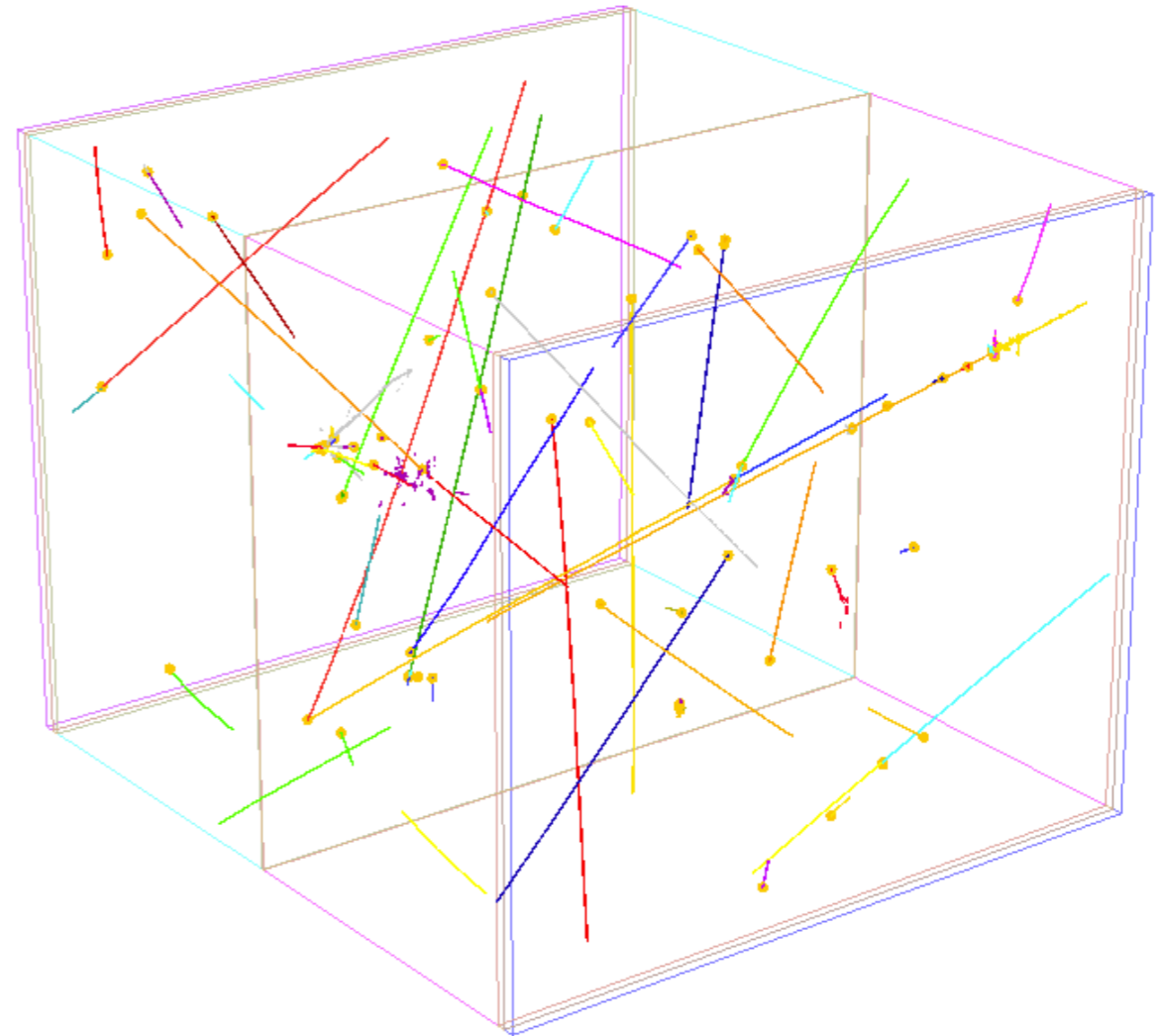
Key references: Eur. Phys. J. C (2018) 78: 82 and Eur. Phys. J. C (2015) 75: 439

Pandora

- The aim is to go from hits on wires to fully reconstructed 3D particle hierarchies



Input hits



Pandora fully reconstructed event

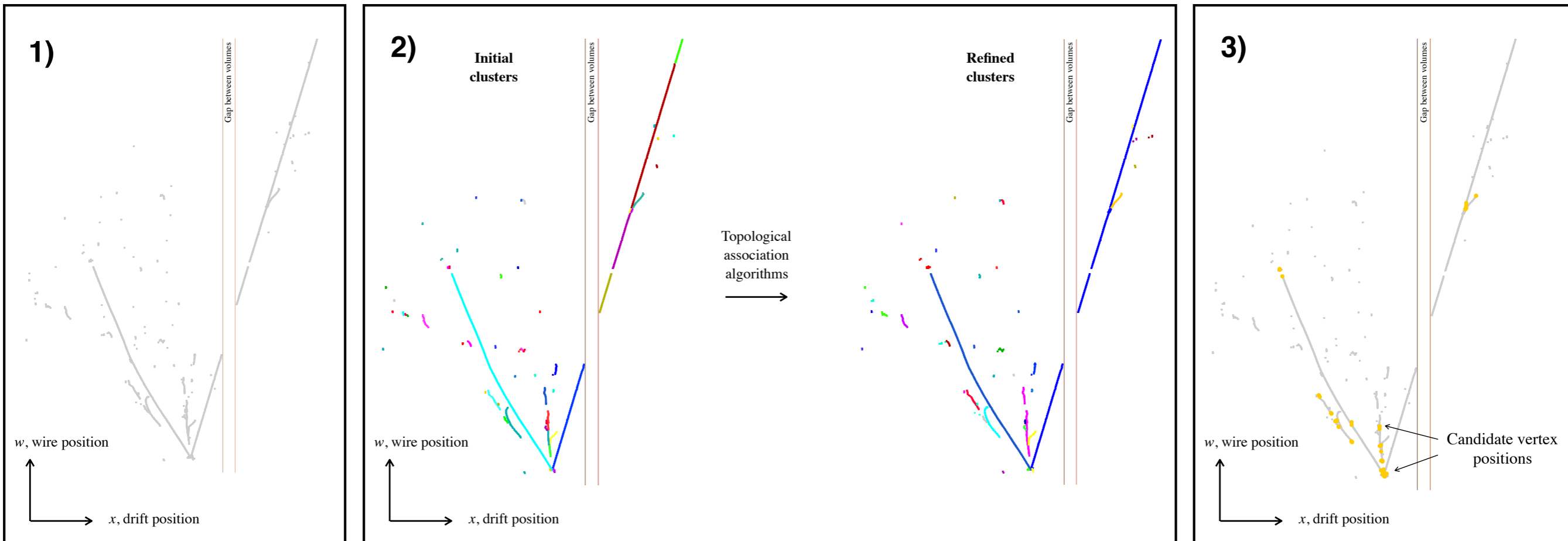
Example simulated interaction in ProtoDUNE-SP

Multi-algorithm approach

- Break down problem into many smaller steps, and gradually build up features in events
- Pandora is a software framework to facilitate this **multi-algorithm** approach
 - Each step is incremental and aims to avoid mistakes (hard to undo!)
 - As the event develops employ more sophisticated algorithms
- Over 100 algorithms and tools for LArTPCs
 - Use cluster-based pattern recognition where it works well
 - Machine (and deep) learning approaches to help make key decisions
 - Build **physics** and **detector** knowledge into the algorithms

Reconstruction Steps I

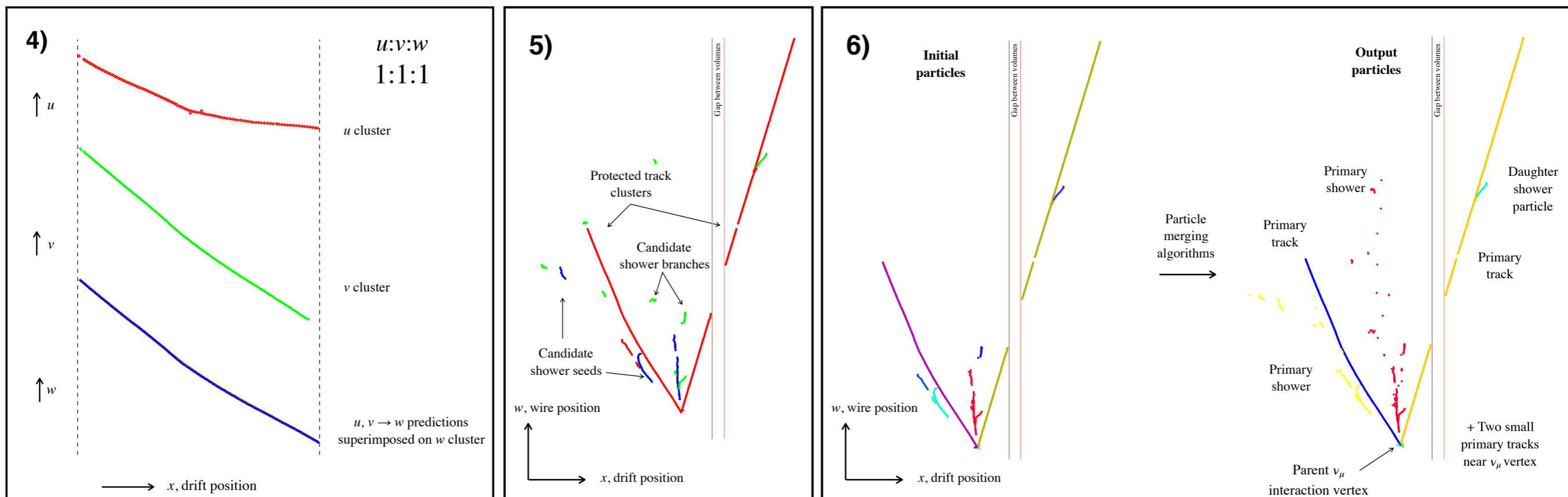
- Build up events in stages



- Form basic clusters in 2D and then merge them together topologically
 - Detector geometry gives information such as gaps between volumes
- Form candidate 3D vertices

Reconstruction Steps II

- Move to 3D to fully reconstruct the interaction

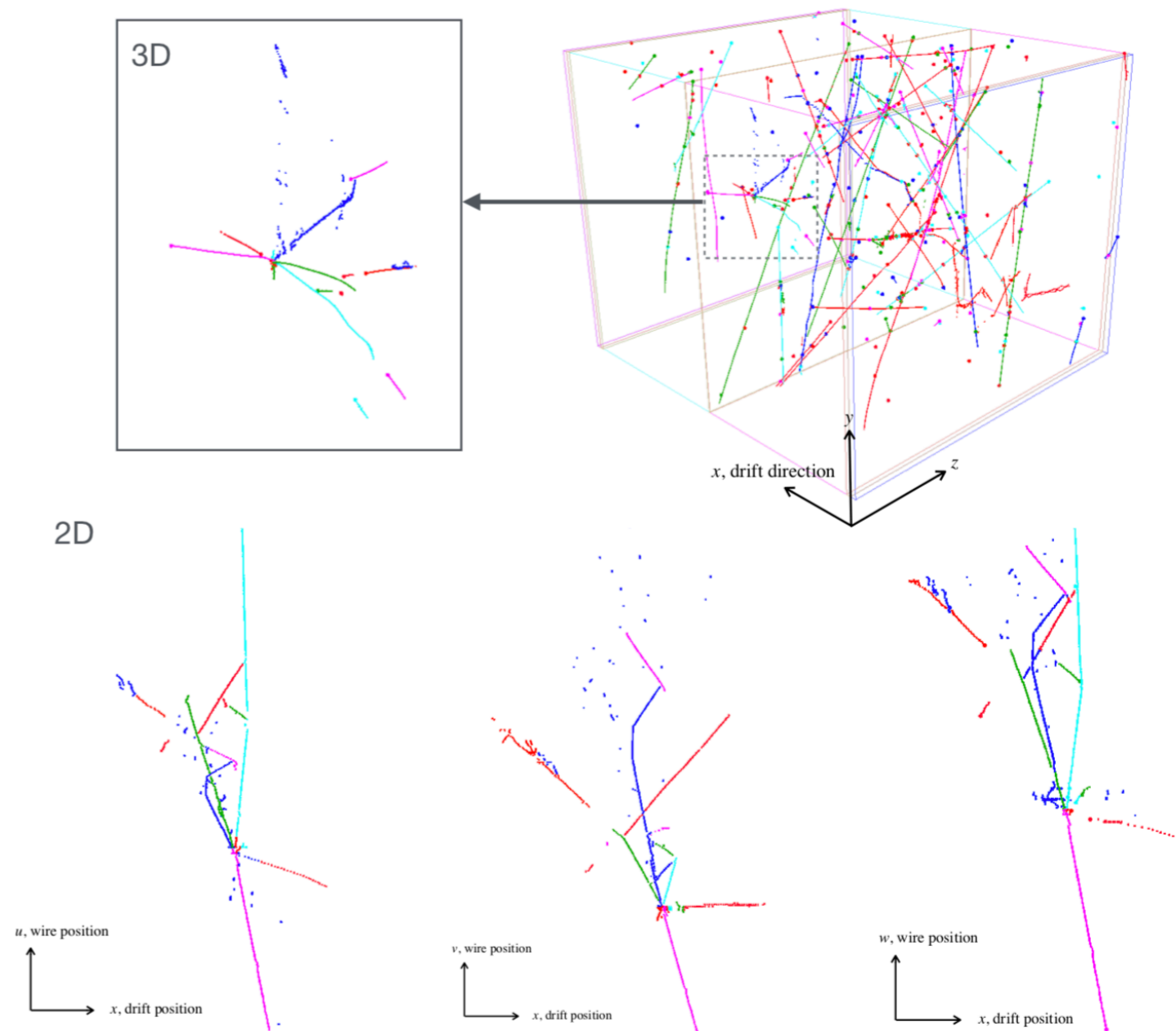


- Form tracks in 3D by matching between 2D views
- Identify tracks and showers
- Refine particle creation in 2D and 3D
- Build the events and full **3D particle hierarchy**

Pandora in ProtoDUNE

Pandora in ProtoDUNE-SP

- Pandora is the primary reconstruction used in ProtoDUNE-SP
- Suite of analysis tools to best use the Pandora outputs
- Used across many calibration and physics analyses
- Feedback from analysers

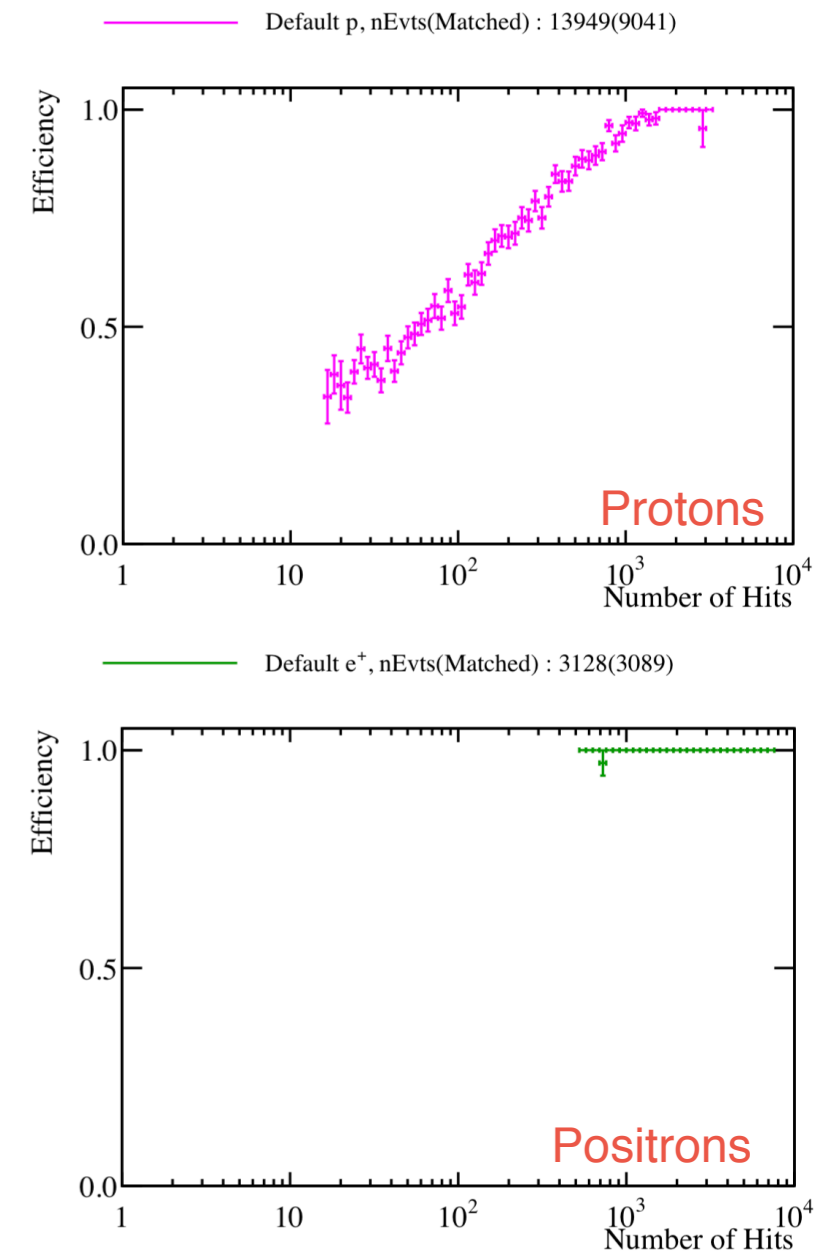
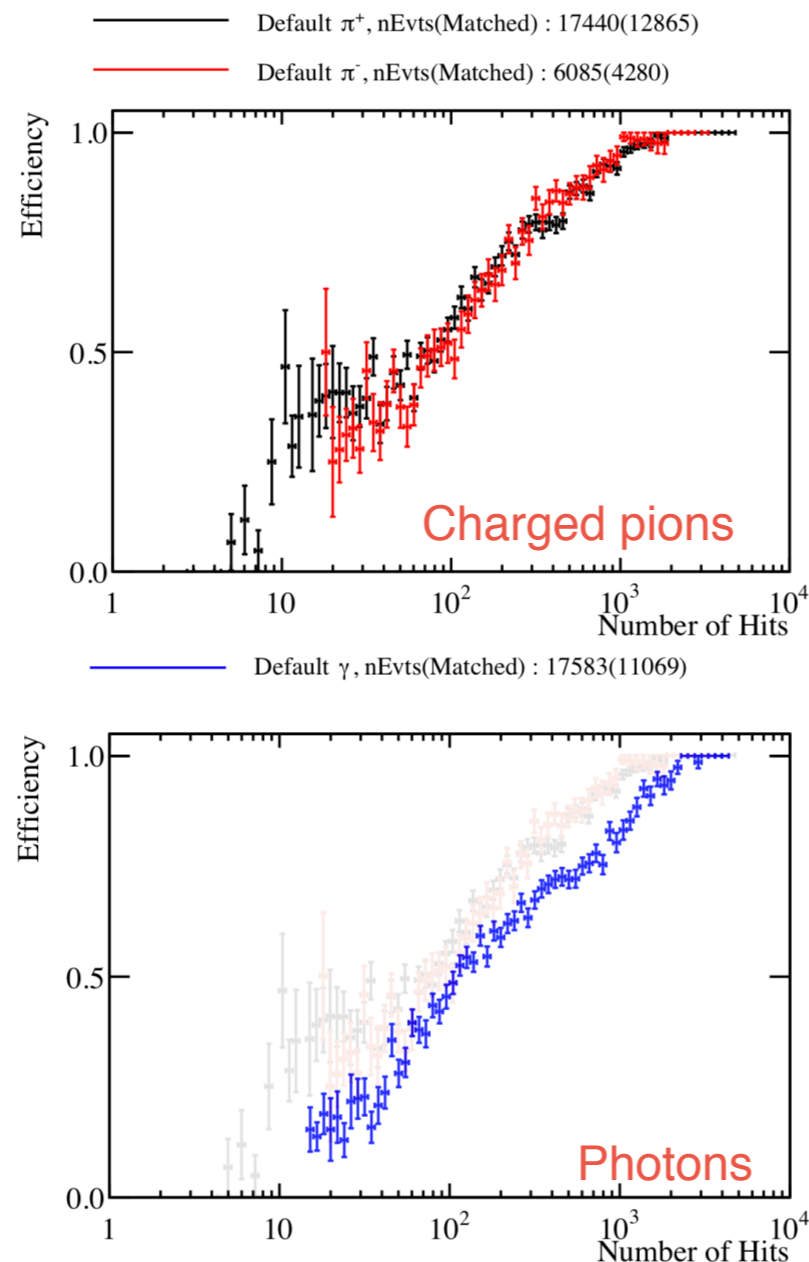


MCC11 Reconstructed Event with correctly tagged test beam particle

Pandora in ProtoDUNE-SP

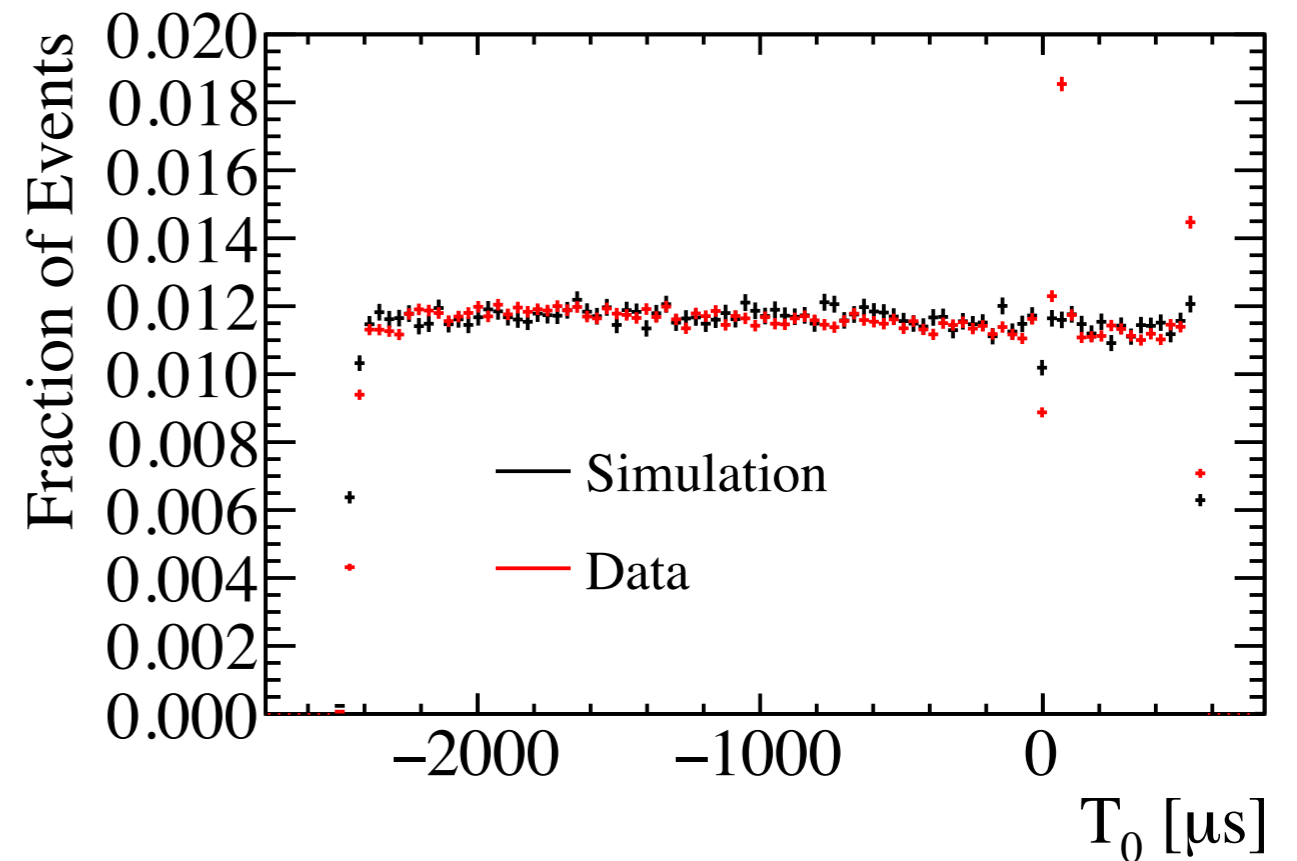
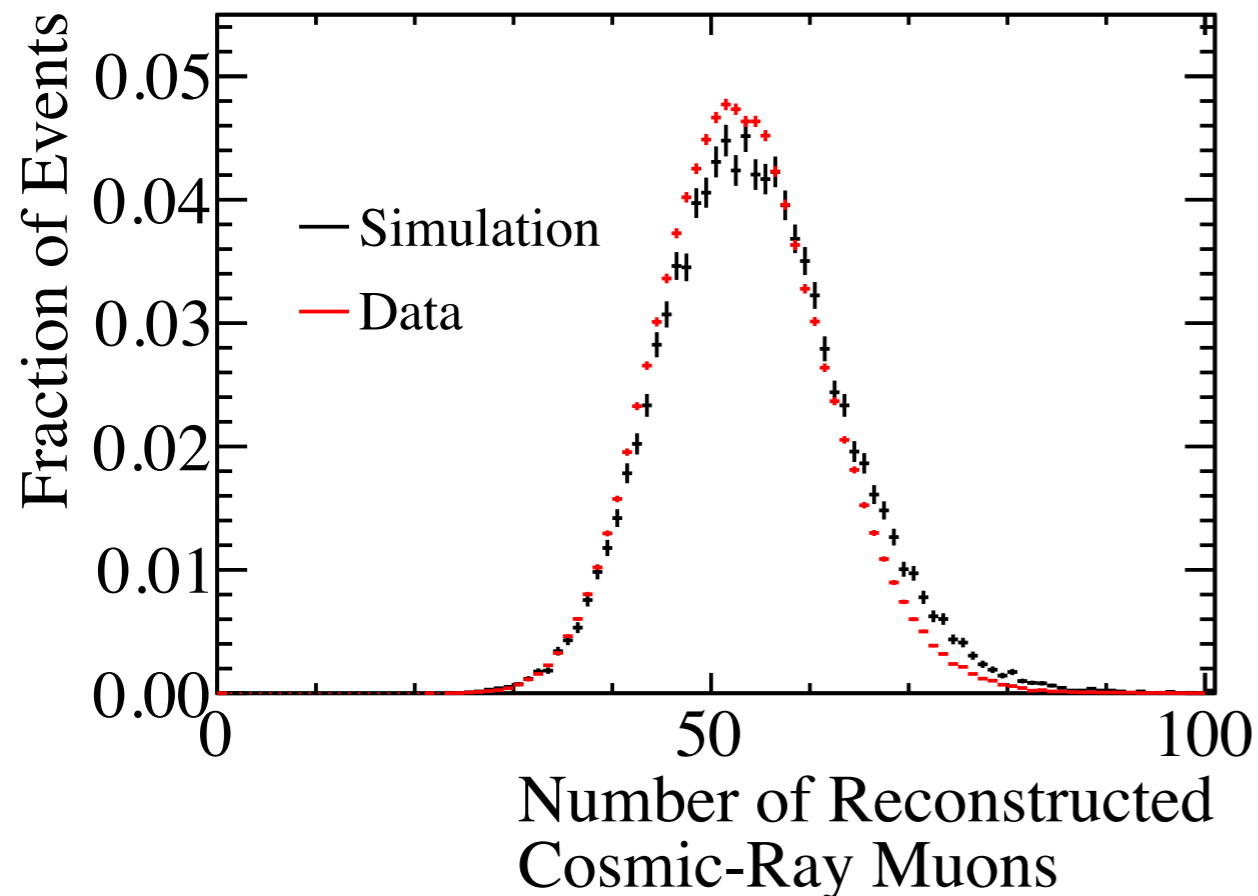
- Reconstruction efficiency of primary and secondary test beam particles in ProtoDUNE-SP

- Largest source of inefficiency is cosmic ray muon contamination



Pandora in ProtoDUNE-SP

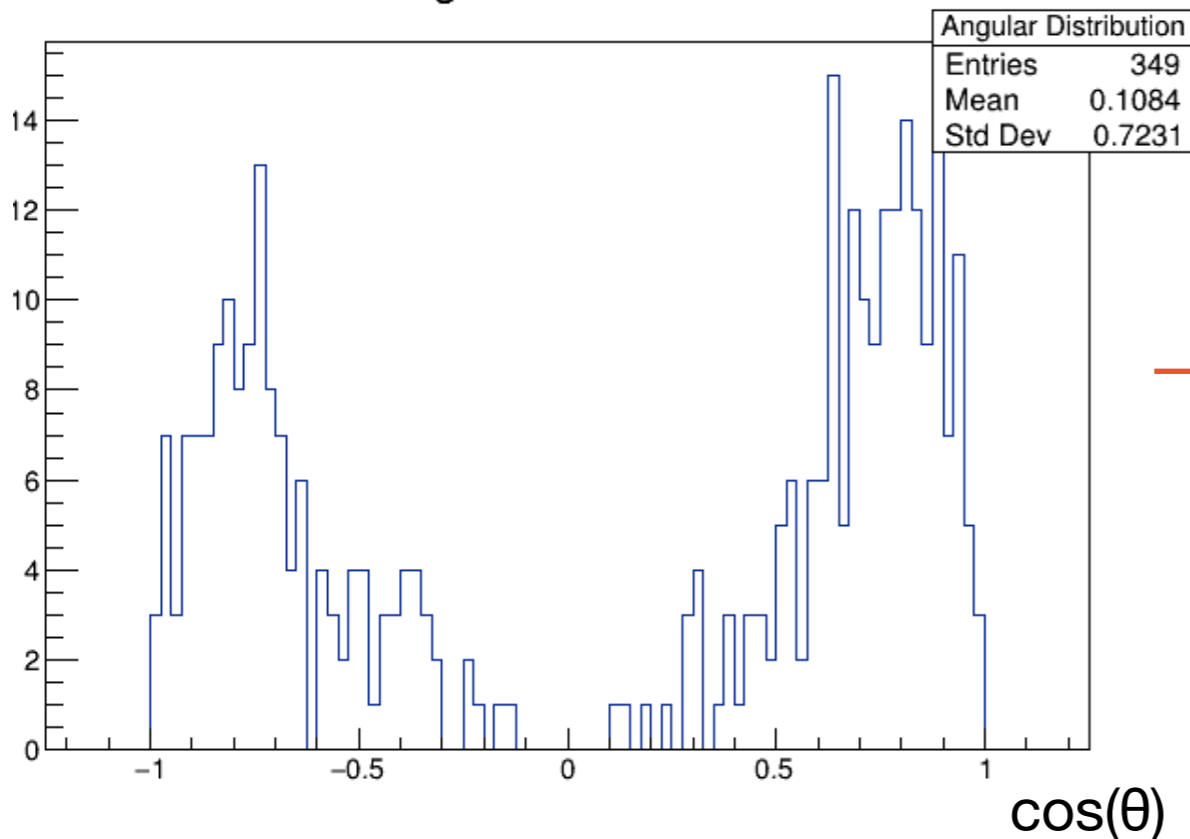
- ProtoDUNE-SP cosmic data and MC from the TDR
 - One new feature for ProtoDUNE-SP was **track stitching**:
 - Two collinear tracks either side of the CPA or APA can be joined together by an equal and opposite shift in the drift direction
 - Enables us to measure the T_0 for this subset of tracks



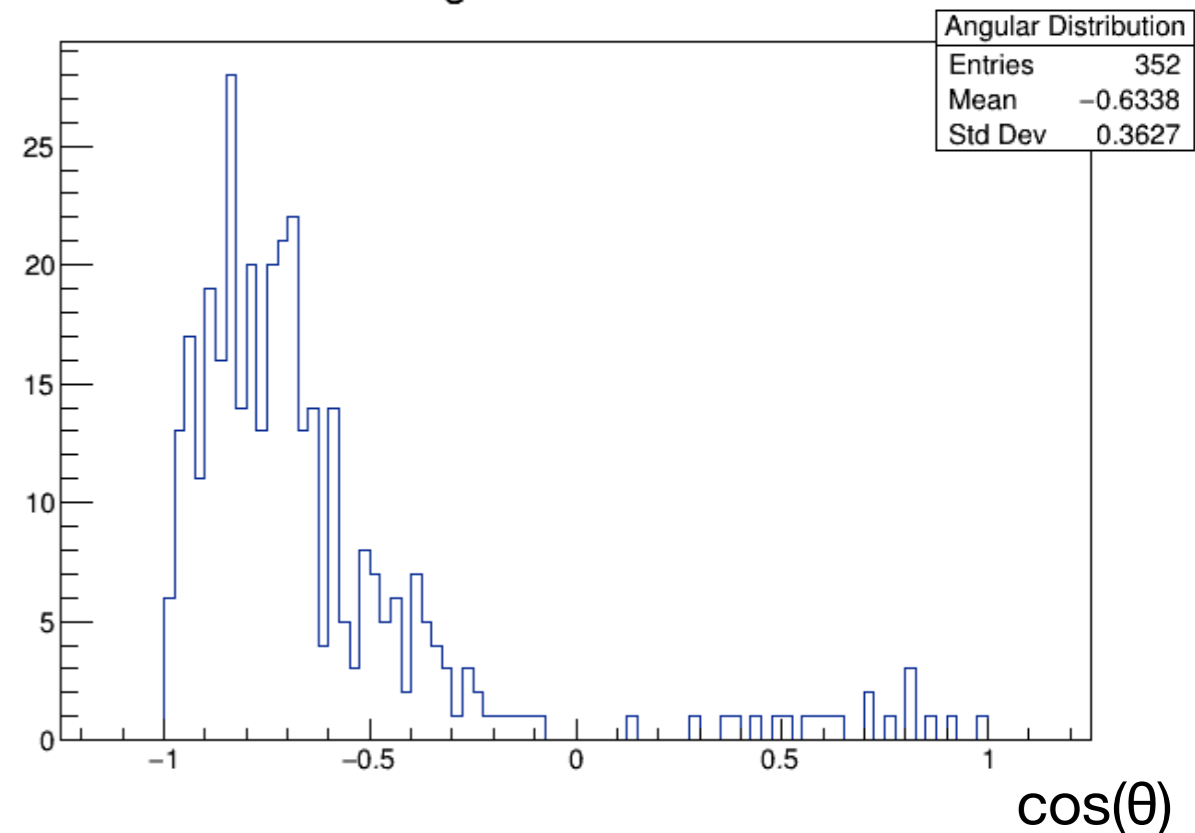
Pandora in ProtoDUNE-DP

- Efforts have started on adapting Pandora for **dual phase**
 - Drift direction is vertical, not horizontal
 - Ensure coordinates are correct for cosmic ray reconstruction to get the correct angular distribution

Angular Distribution



Angular Distribution



- Dual phase reconstruction **fully part** of UK Pandora plan

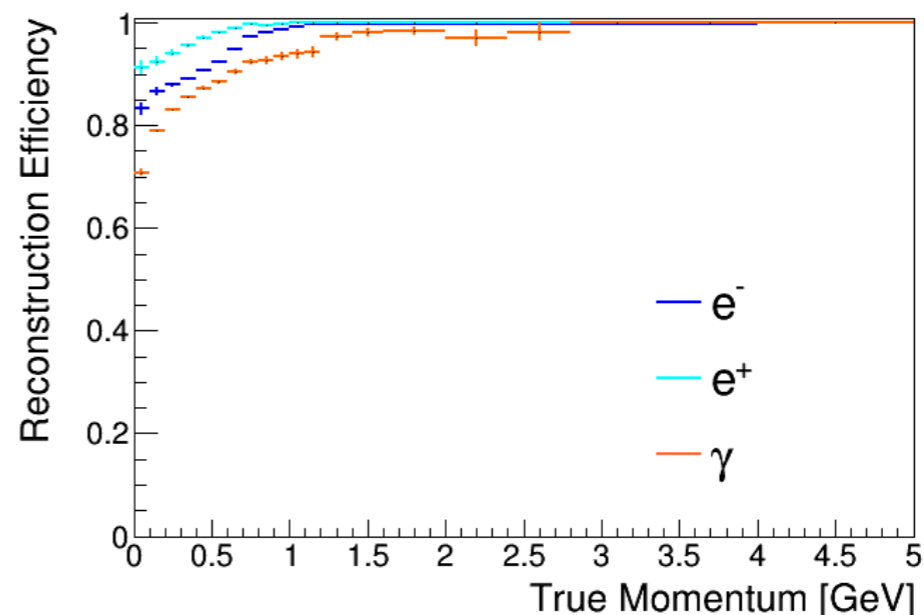
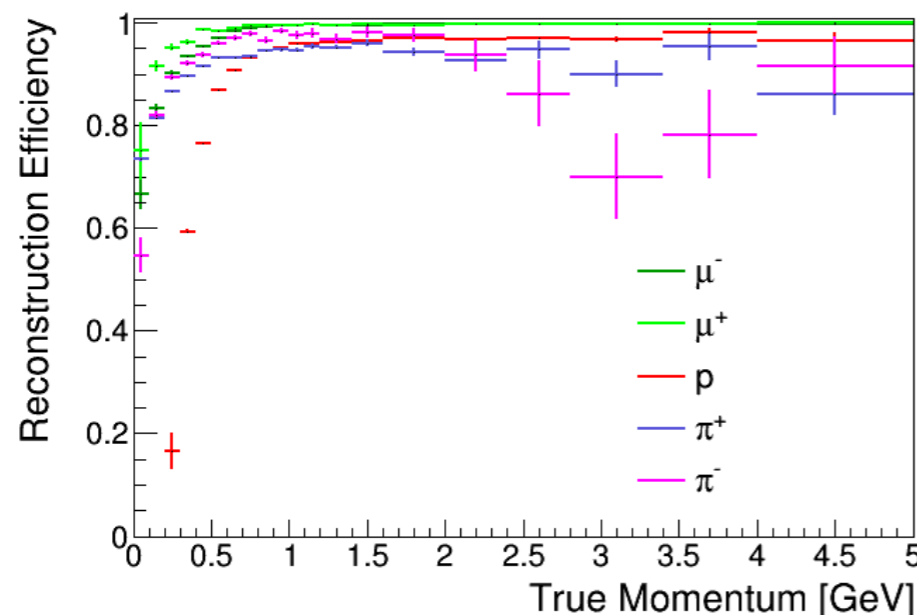
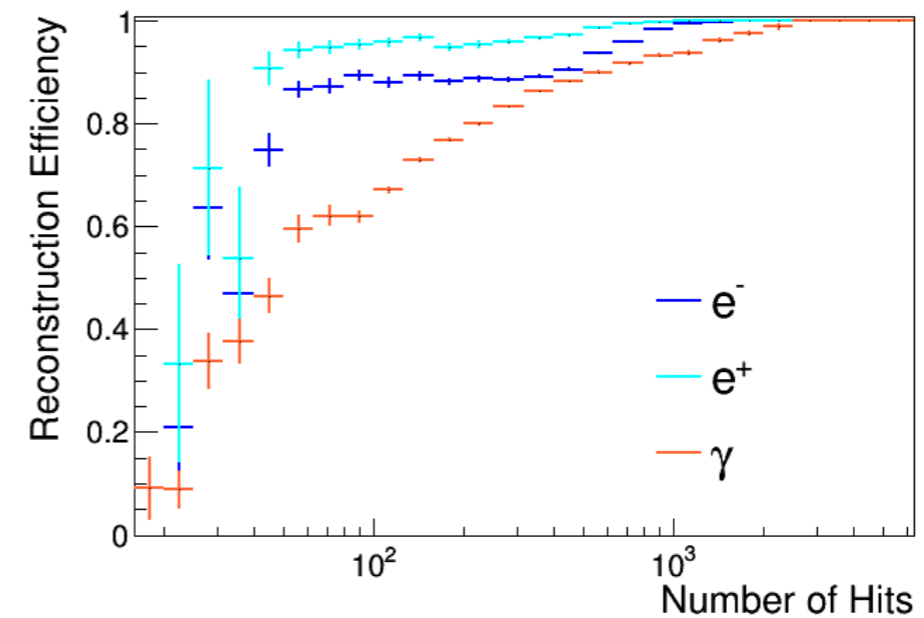
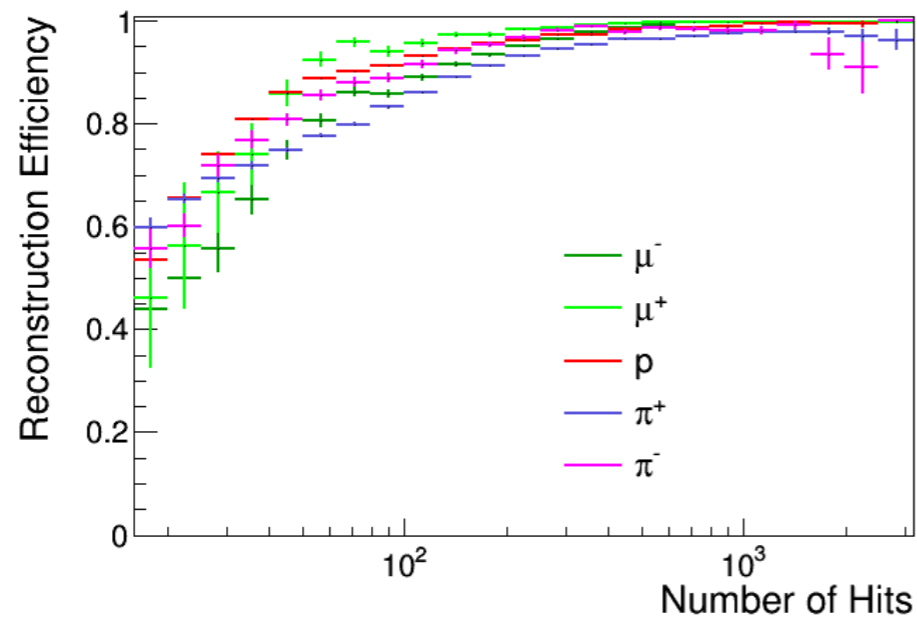
Pandora in DUNE FD

Pandora in DUNE

- The Pandora performance for reconstructing beam neutrino interactions was **fully benchmarked** in the DUNE TDR
- There is a seven year work-plan defined in the UK to develop Pandora further for the DUNE FD
 - Including both **single phase** and **dual phase**
 - **Beam** and **atmospheric** neutrinos
- Many areas of active work on-going

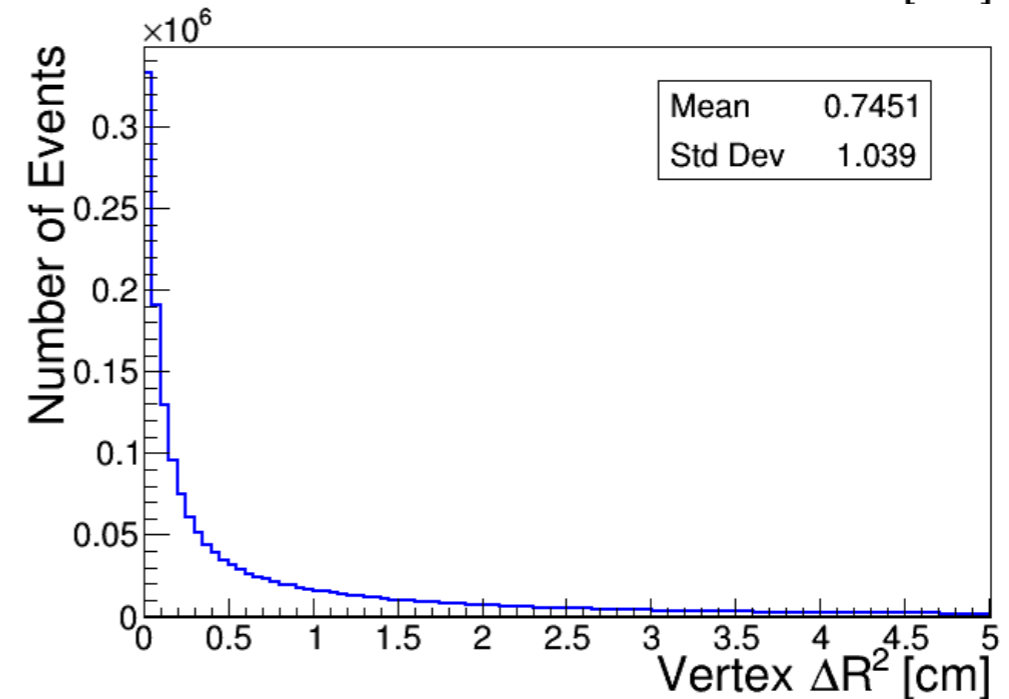
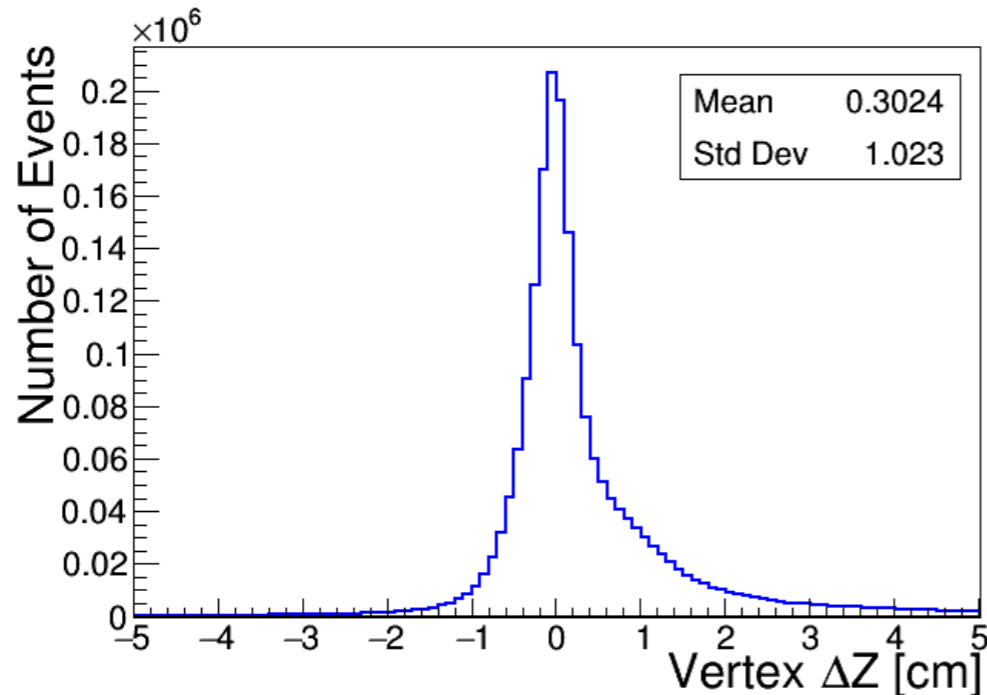
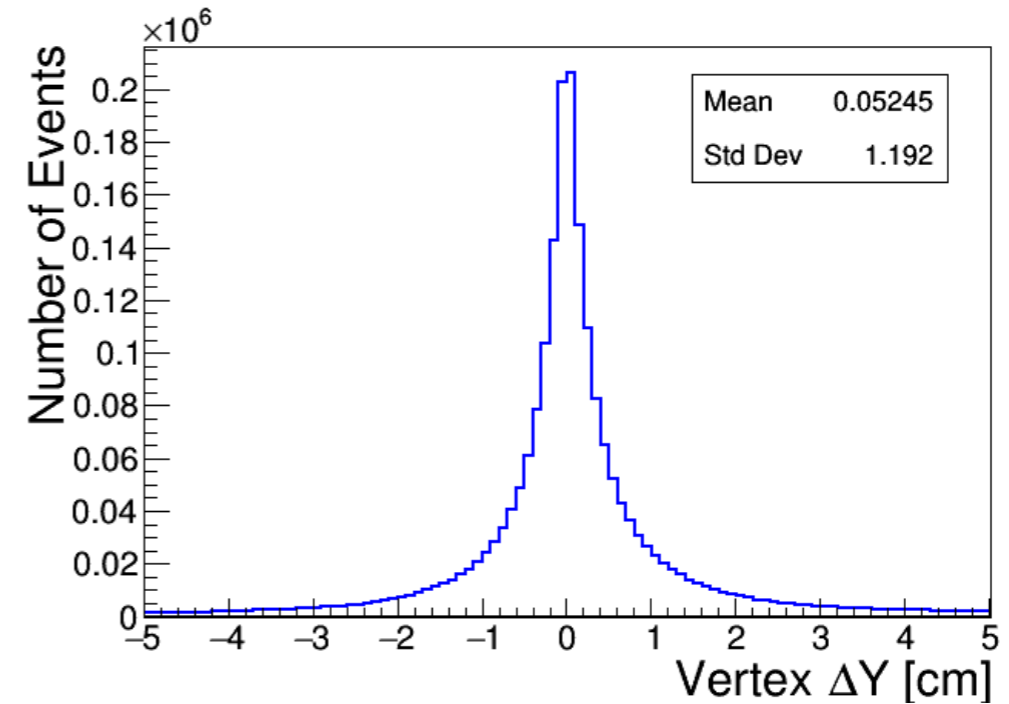
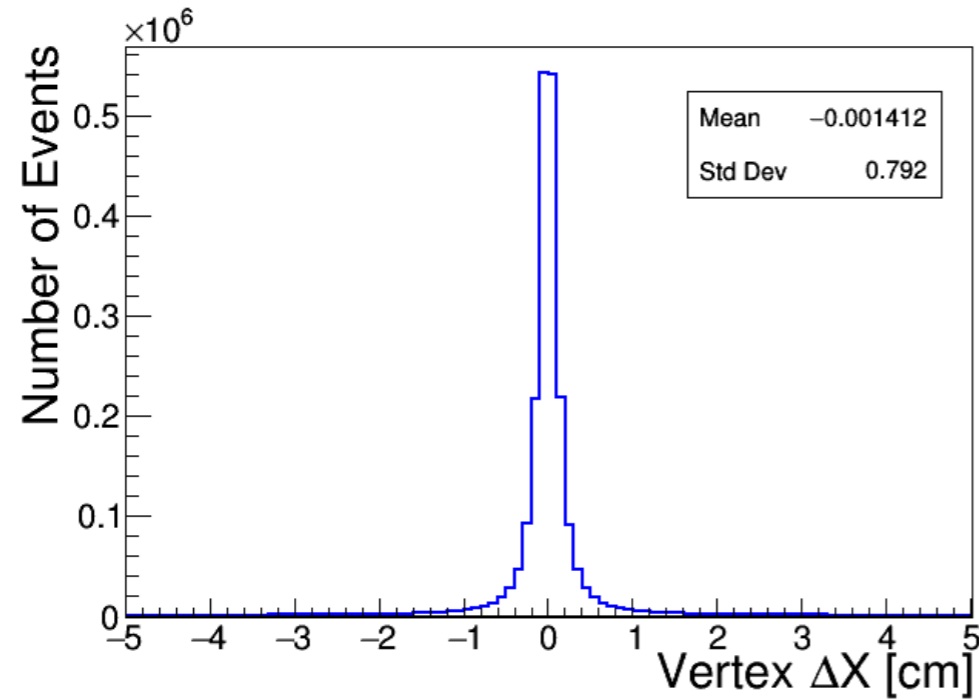
Pandora in DUNE

- Reconstruction efficiency for track- and shower-like particles from neutrino interactions



Pandora in DUNE

- Neutrino interaction vertex resolutions

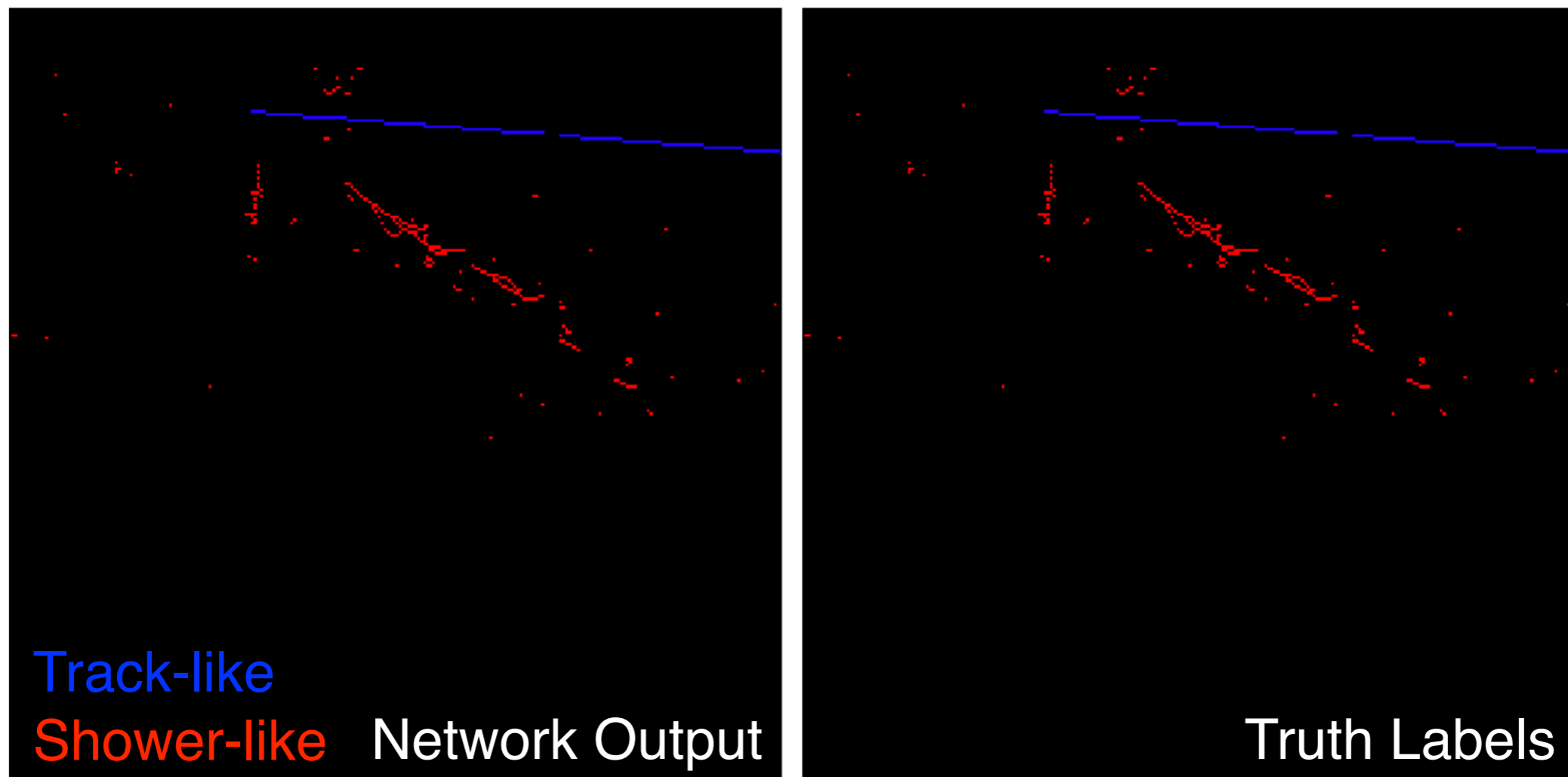


Current Activities

- There is a lot of work now ongoing to improve all aspects of Pandora event reconstruction
 - Updates developed in view of the DUNE FD, but will have applications in ProtoDUNE too
- I will give examples of:
 - Track / shower classification
 - At both the hit-level and particle-level
 - Vertex reconstruction
 - 3D hit creation
 - Additions of charge information

Track / Shower Hits

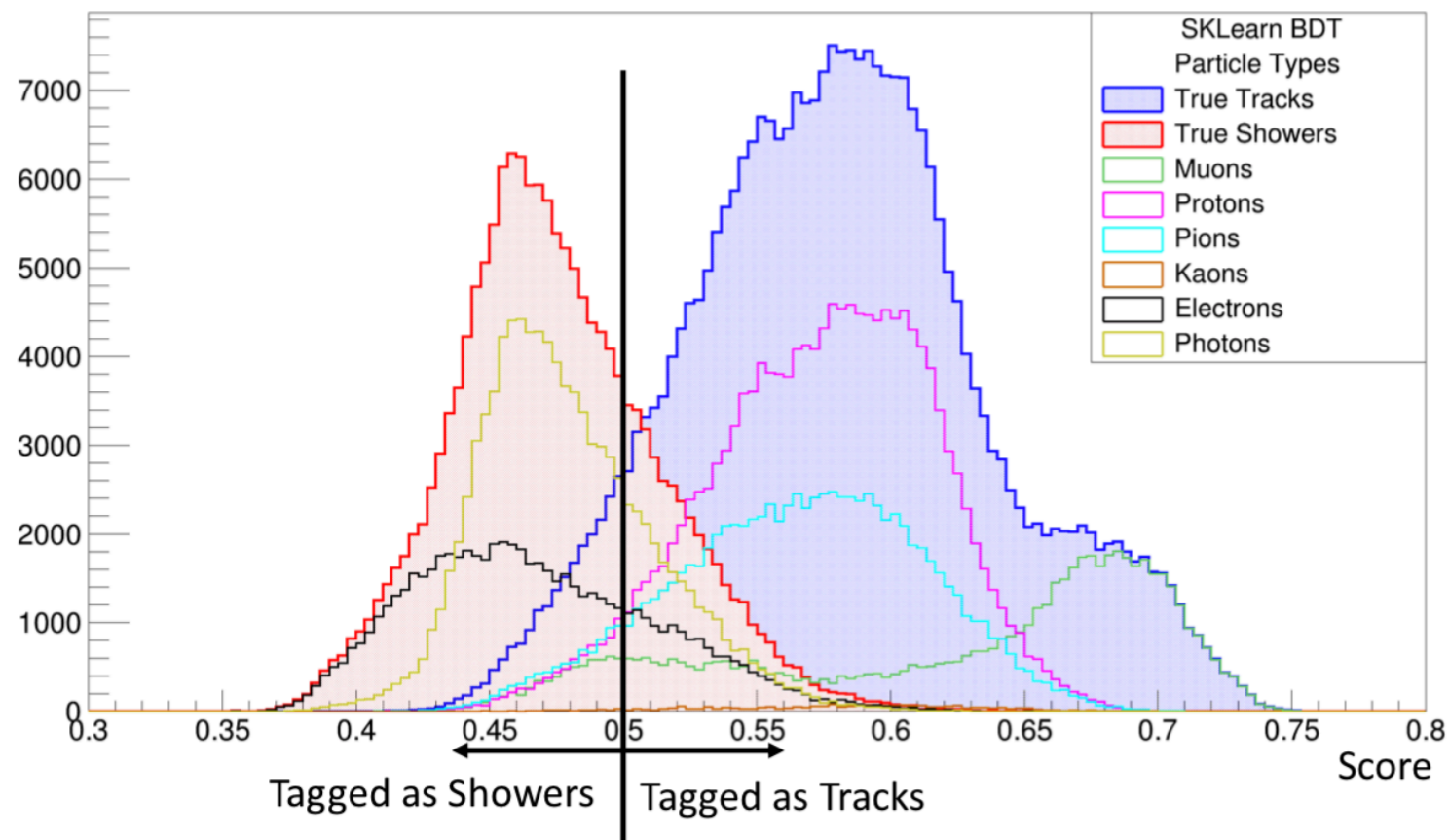
- Goal is to improve clustering by tagging hits as track or shower like early in the reconstruction chain
 - Use **deep learning** image-based semantic segmentation to classify hits



Example CC ν_μ $1\pi^0$ event

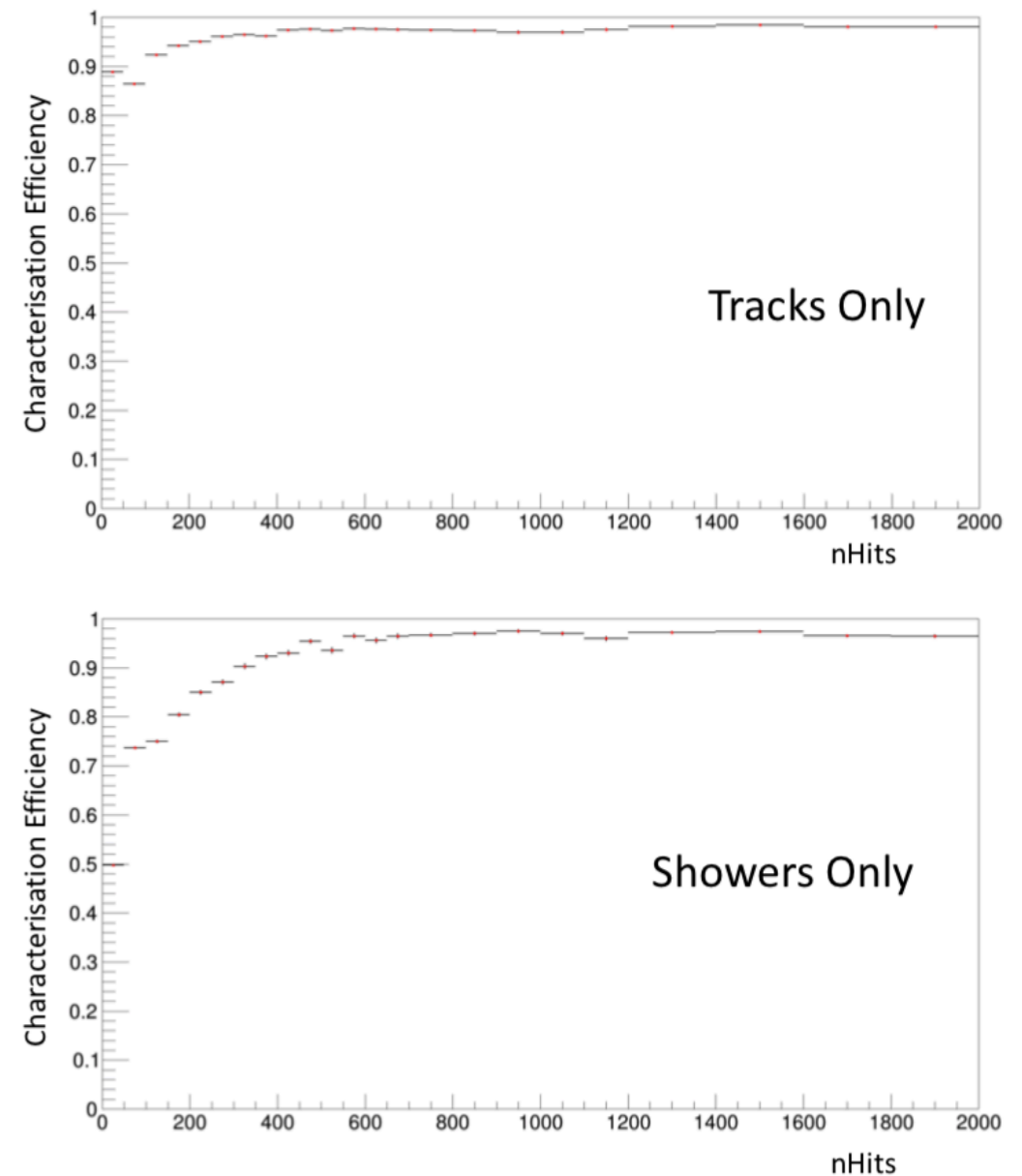
Track / Shower Objects

- Use **machine learning** to correctly identify reconstructed particles as tracks or showers



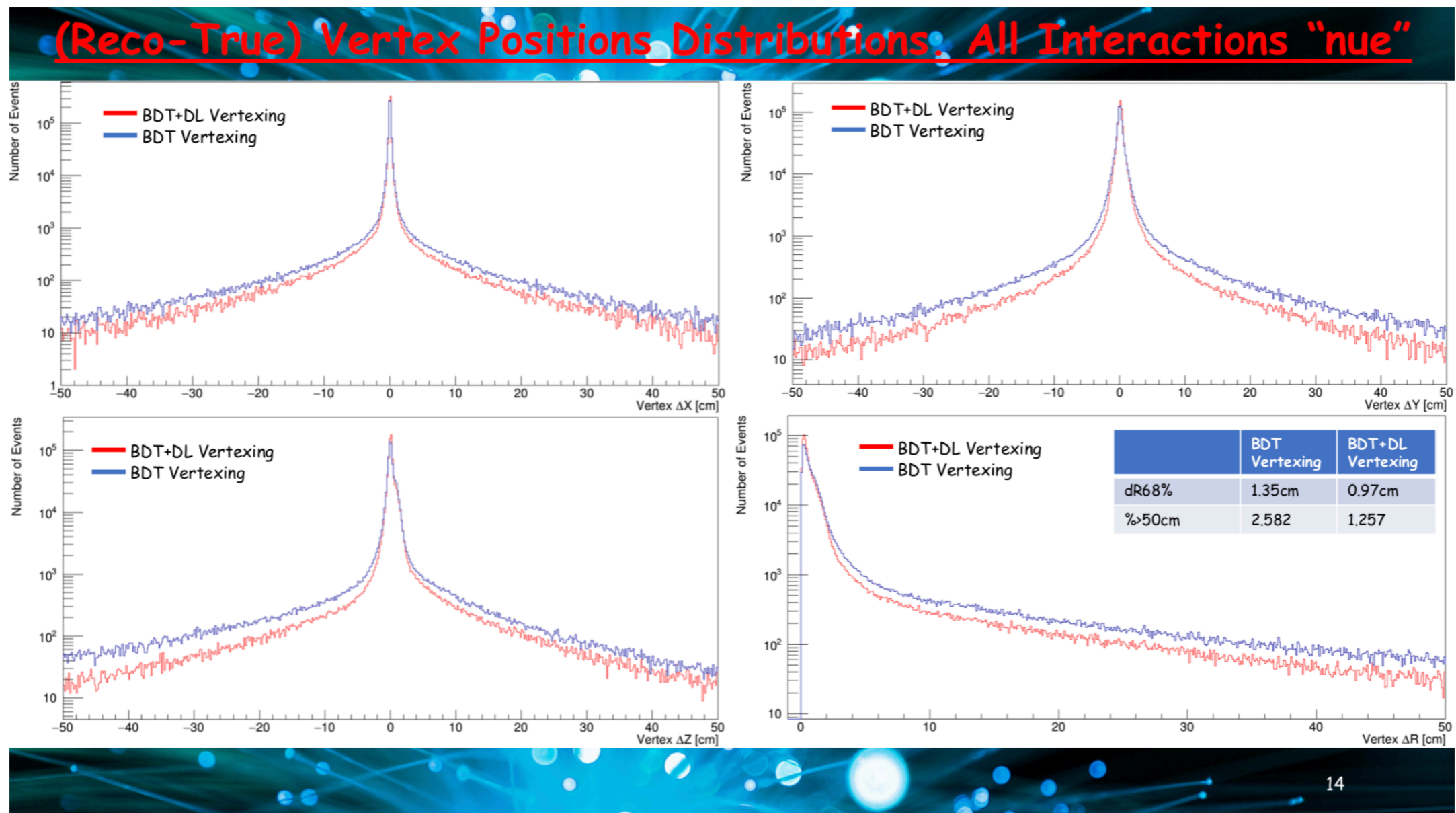
Trained using MCC11 numu and nue beam neutrino interactions

Efficiency vs nHits



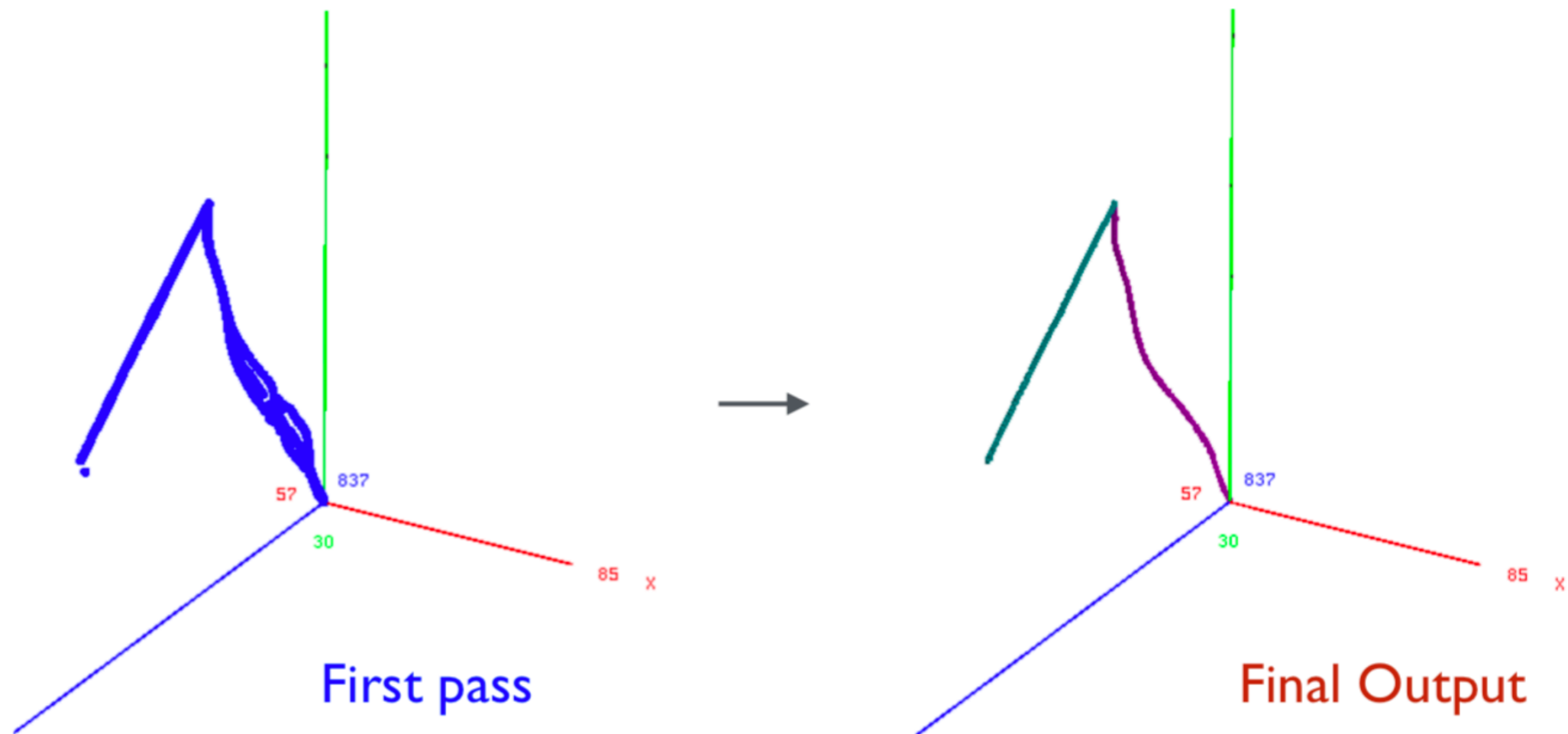
Vertexing Improvements

- Use a **CNN** to perform neutrino interaction vertexing
 - Combine with **BDT** approach for best performance



3D Hit Creation

- 3D hit creation generally works well, but a number of issues will be addressed



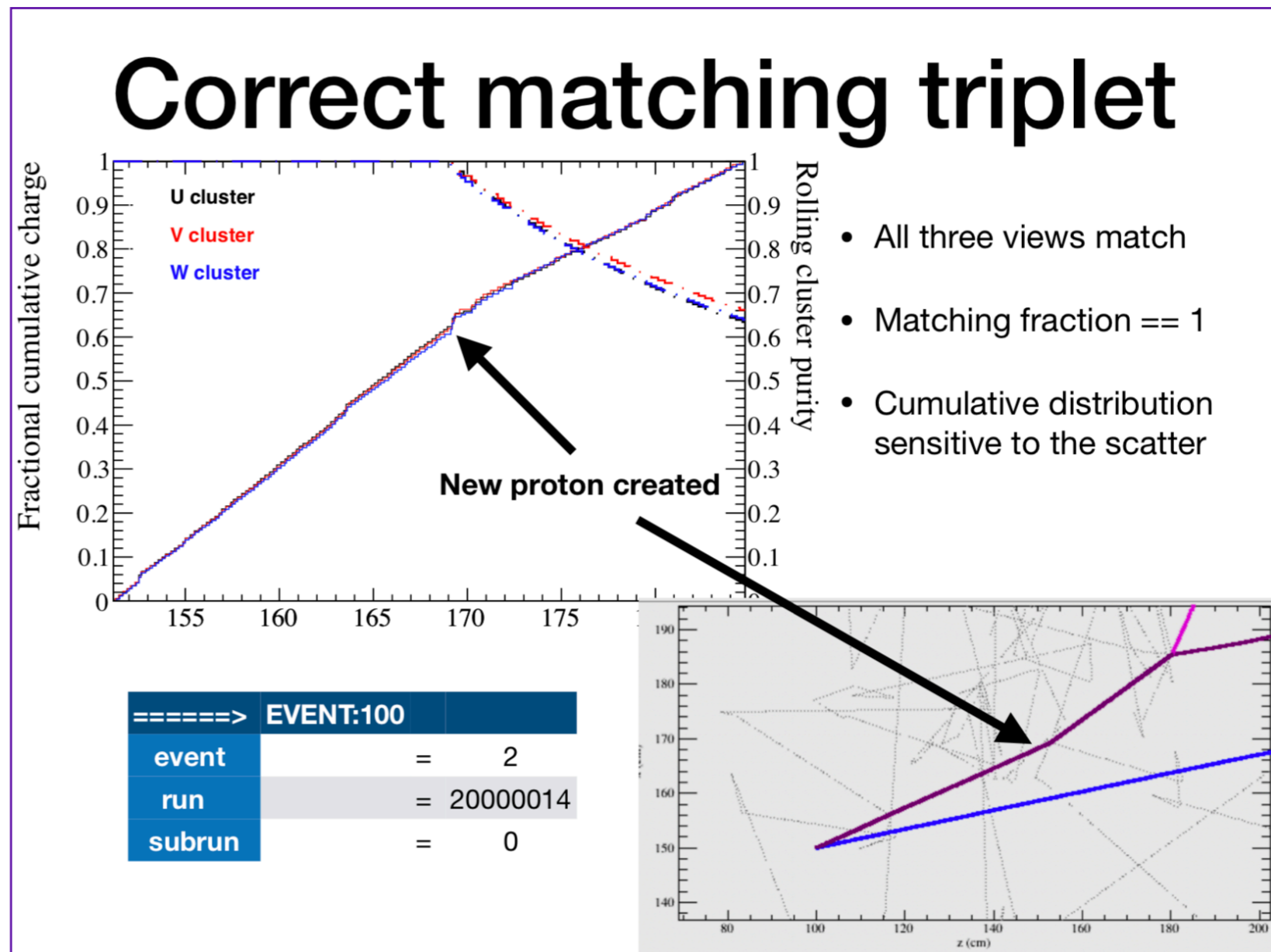
- Resolve ambiguities in matching the three 2D views

Using charge information

- Pandora currently makes little use of charge information
 - Can provide an orthogonal source of information

- Lots of potential use cases throughout the reconstruction chain

- Enhancing the view to view matching
- Feature identification
- Single view mis-clustering
- Cluster splitting



Analysis Utilities

- Produce utilities to provide easy access to the Pandora particle hierarchy
 - These functions help users access the track or shower associated to the particle, etc
- Utility classes will exist for most reconstruction objects in LArSoft
 - PFParticles
 - Tracks
 - Showers
 - Clusters
 - Slices
 - Spacepoints
- Similar utilities proved successful in ProtoDUNE-SP

Summary

- Pandora is performing well for ProtoDUNE-SP and DUNE
 - We are also supporting ProtoDUNE-DP
- Many improvements planned to all steps of the reconstruction chain
 - Incorporate modern deep learning techniques where appropriate
- Improvements will be benchmarked on DUNE FD simulation and, where possible, using ProtoDUNE data and simulation
- Strong intention to support ND reconstruction (3DST, Argon Cube,...)

Pandora

Pandora is an open project and new contributors would be extremely welcome. We'd love to hear from you and we will always try to answer your questions.



<https://github.com/PandoraPFA>



<https://pandorapfa.slack.com>



John Marshall
Andy Chappell
Maria Brunetti
Jhanzeb Ahmed
Mousam Rai
Isobel Mawby

Leigh Whitehead
Lorena Escudero
Steve Green
Jack Anthony
Andy Smith
Stefano Vergani
Alex Moor

Andy Blake
Dom Brailsford
Ryan Cross

ProtoDUNE-DP material from Etienne Chardonnet (Université Paris Diderot / Laboratoire APC)

Pandora SDK: **John Marshall, Mark Thomson** ♦ Core LArTPC algs: **Andy Blake, John Marshall**