Neutrino event reconstruction in DUNE using Pandora

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for the DUNE Collaboration

DEEP UNDERGROUND NEUTRINO EXPERIMENT

UNIVERSITY OF CAMBRIDGE

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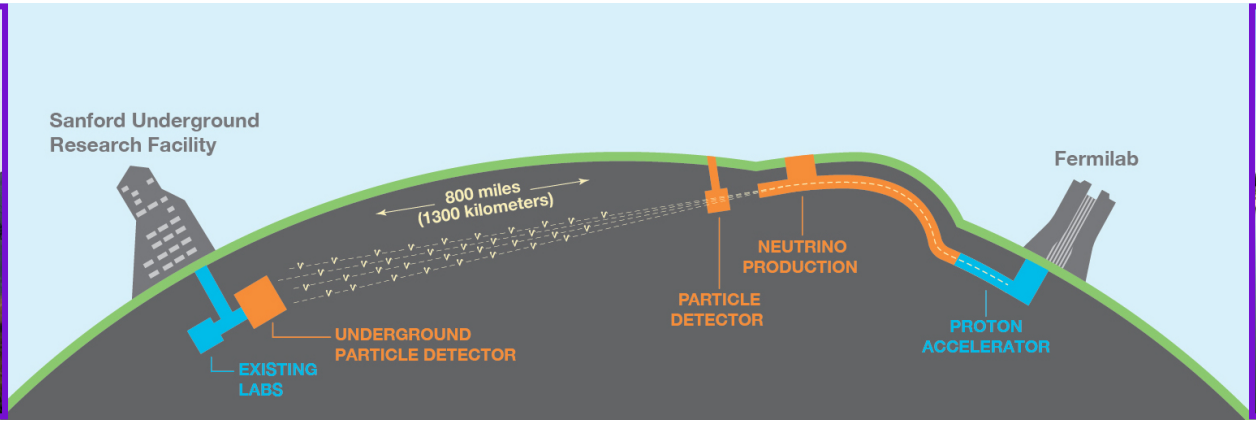
Overview

- Introduction to the Deep Underground Neutrino Experiment (DUNE)
- Introduction to Pandora
- Pandora reconstruction performance
  - DUNE Far Detector
  - ProtoDUNE-SP
- Summary

Introduction to DUNE

- DUNE is a next-generation neutrino oscillation experiment



South Dakota

Illinois

- Wide physics programme
  - Neutrino oscillations:
    - Measurement of CP violation in the neutrino sector
    - Neutrino mass hierarchy
    - High precision measurement of oscillation parameters
  - Proton decay, supernova neutrinos, sterile neutrinos, etc

Introduction to DUNE

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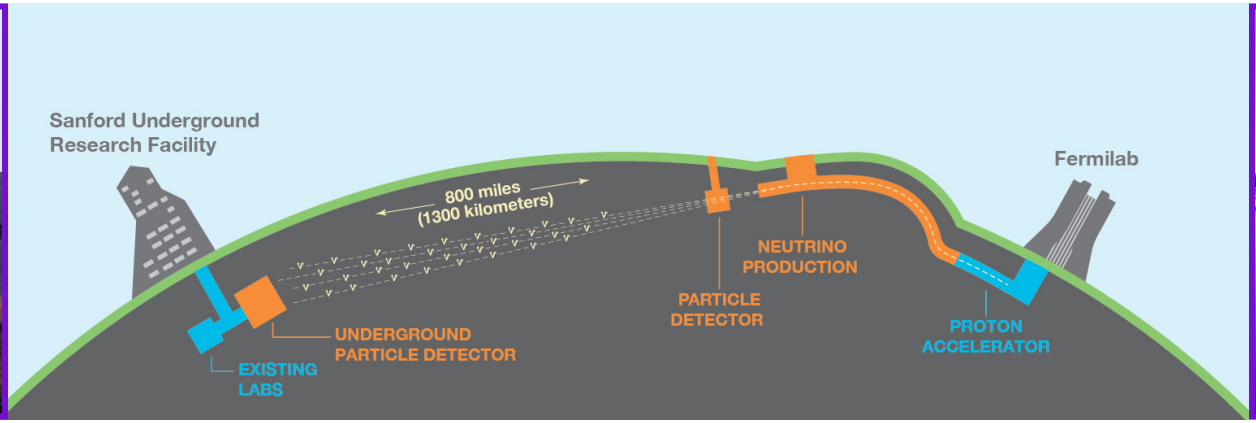


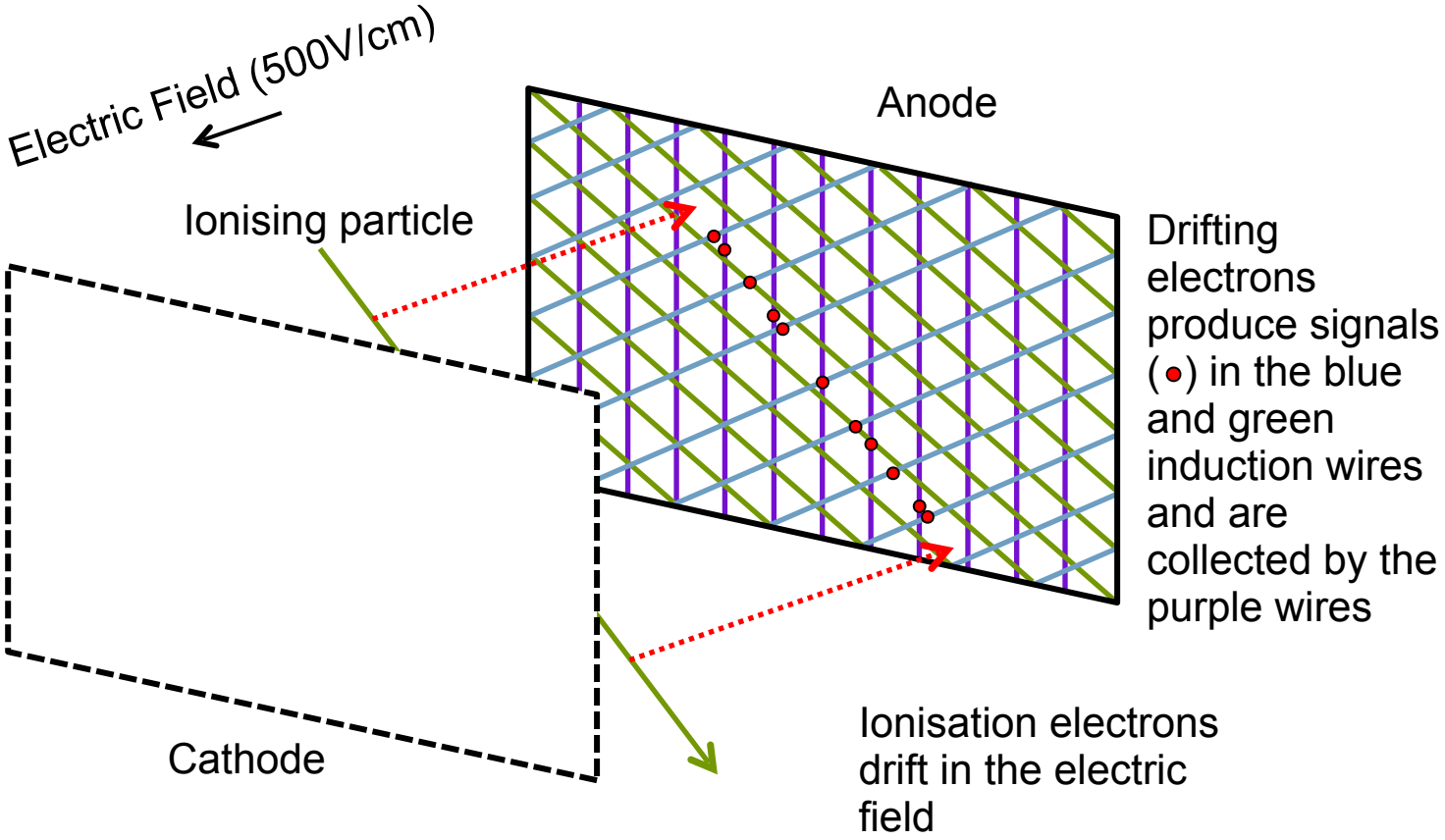
South Dakota

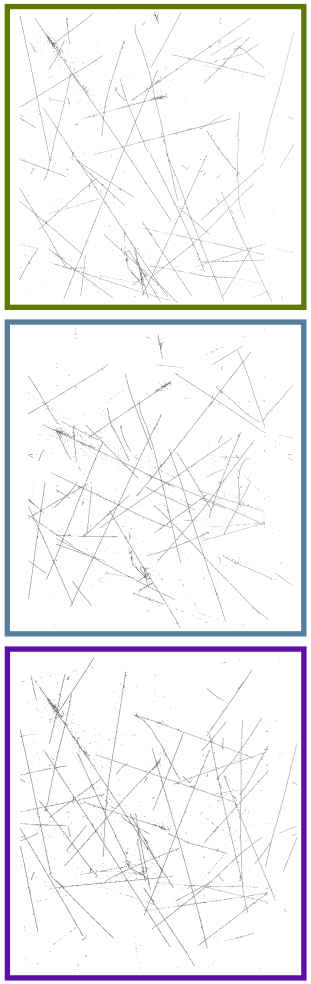
Illinois

- High power neutrino beam produced at Fermilab
- Neutrino beam characterised by a suite of Near Detectors
- Far Detectors measure the oscillated neutrino beam
  - Four 17kt liquid argon time projection chambers (LArTPCs)
  - Focus on the single-phase TPC design in this talk
  - Three views of each neutrino interaction from wire readout planes

Single Phase LArTPC

- Detector fully submerged in liquid argon





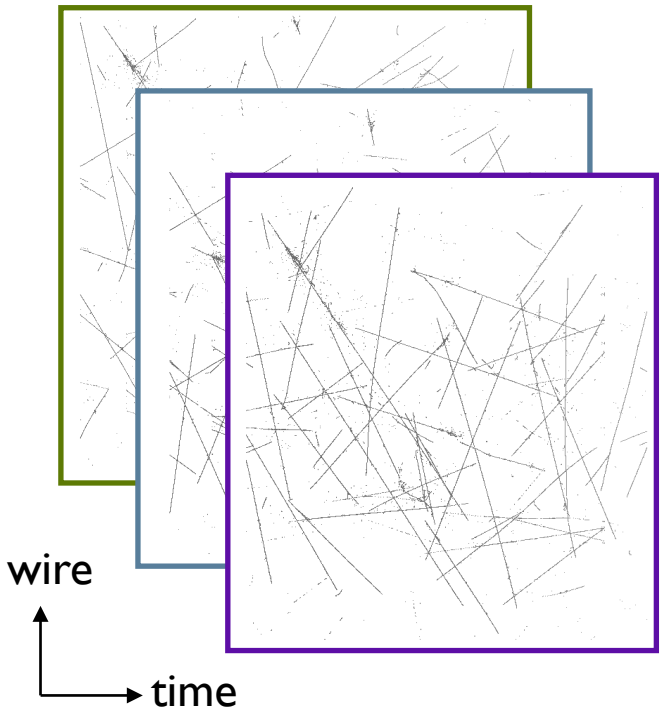
Introduction to Pandora

- Pandora is a software development kit for automated event reconstruction
  - Originally for the ILC 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

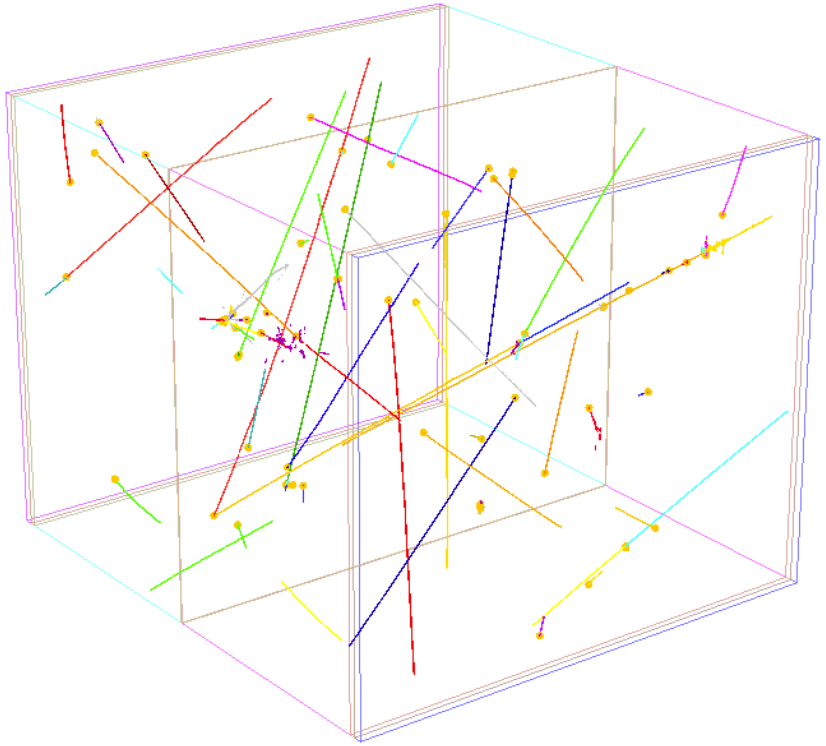
Key references: Eur. Phys. J. C (2018) 78: 82 and Eur. Phys. J. C (2015) 75: 439

Event reconstruction goal

- From hits on wires to reconstructed 3D particle hierarchies



Input hits from the three readout planes



Pandora fully reconstructed event

Example simulated interaction in the DUNE prototype: ProtoDUNE-SP

Multi-algorithm approach

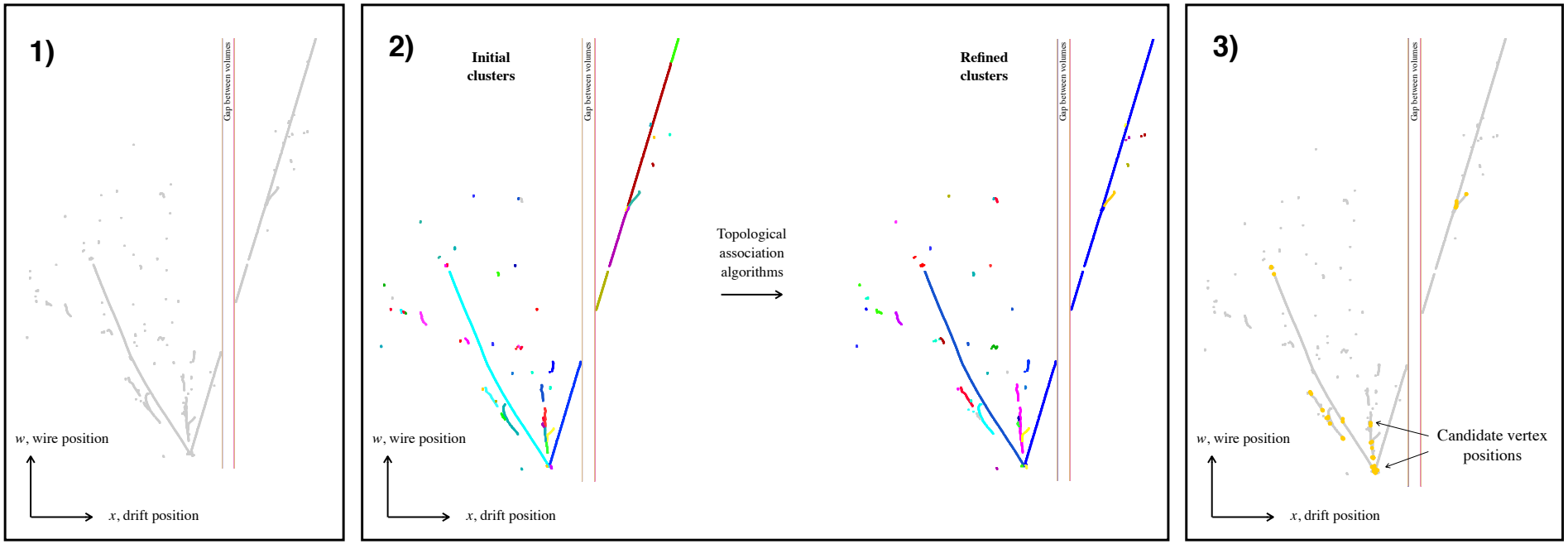
- Break down problem into many smaller steps, and gradually build up features in events

- 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

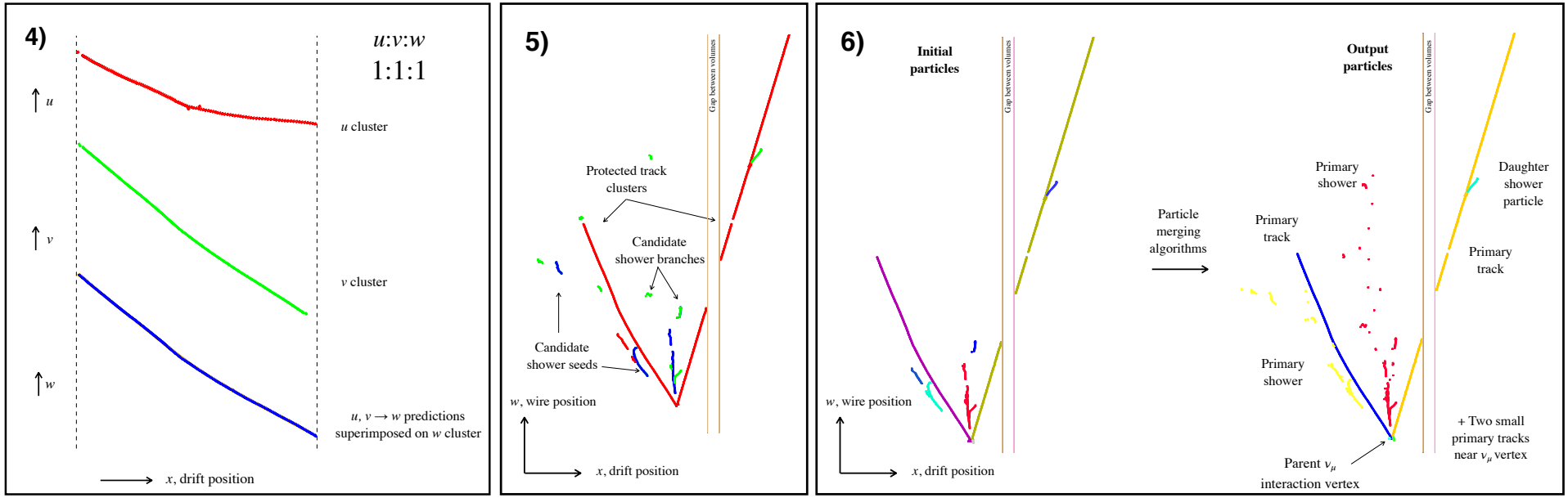
- Build up events in stages



- 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

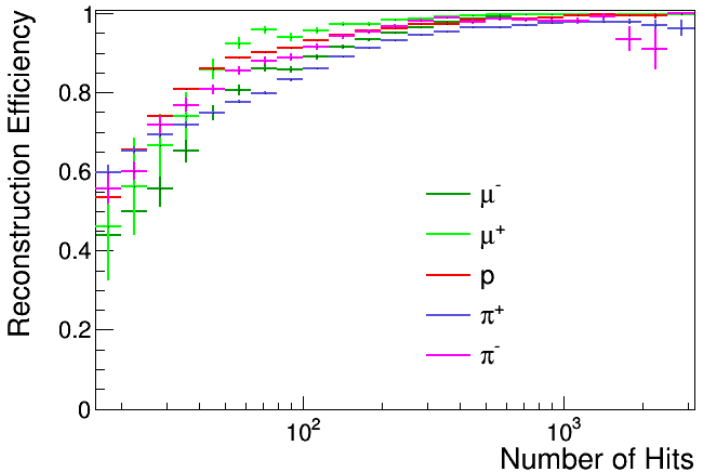
- Move to 3D to fully reconstruct the interaction

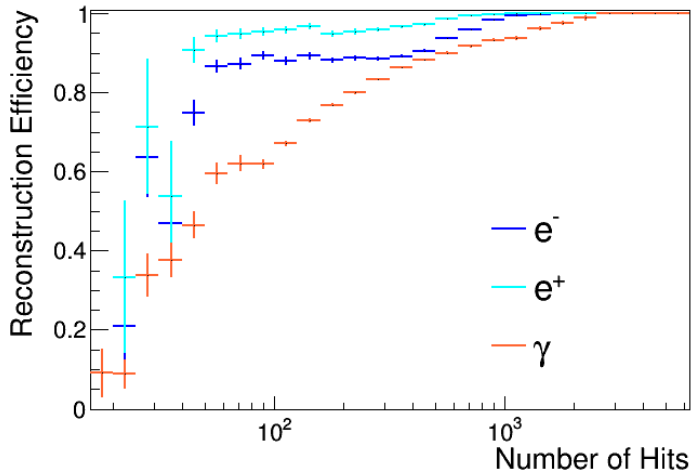


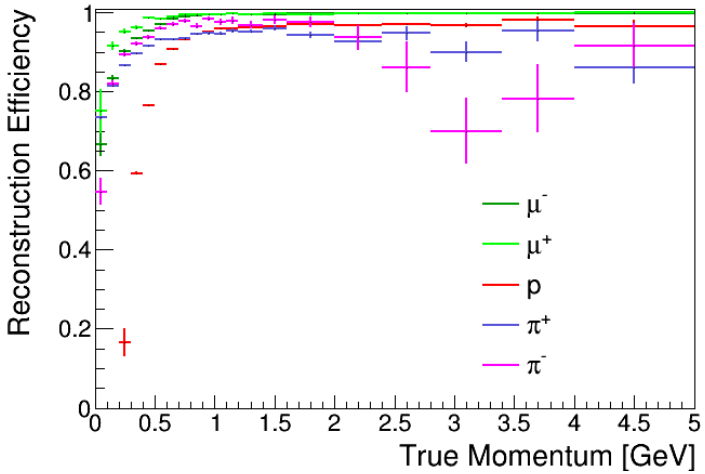
- Form tracks in 3D by matching between 2D views
- Identify tracks and showers
- Refine particle creation in 2D and 3D
- Build the events and hierarchy

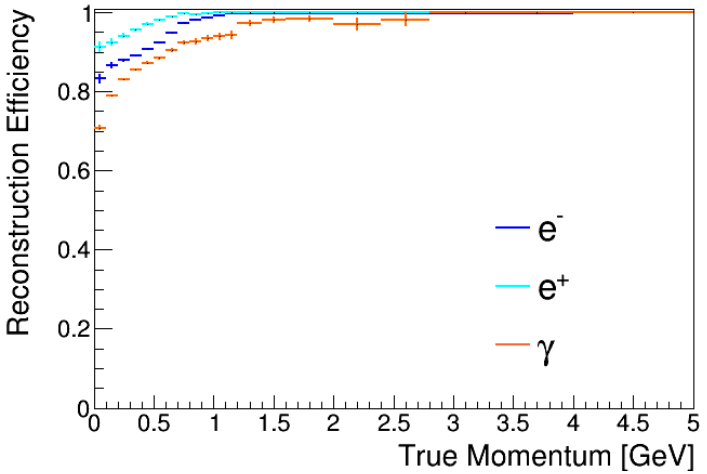
Far Detector performance

- Performance benchmarked in the DUNE TDR









DUNE Technical Design Report Volume II: https://arxiv.org/abs/2002.03005

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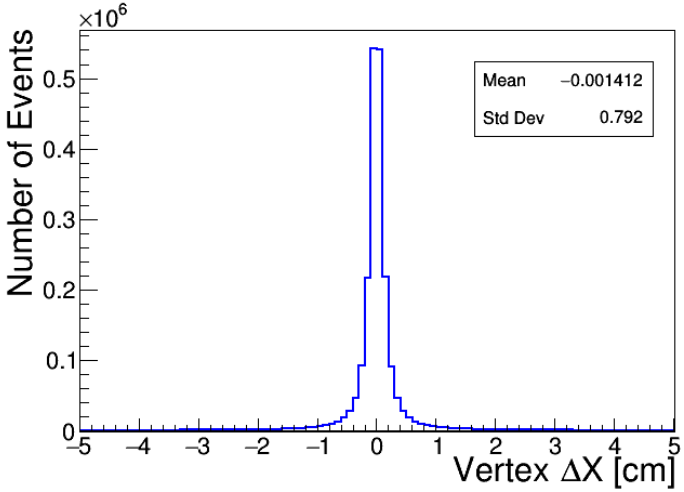

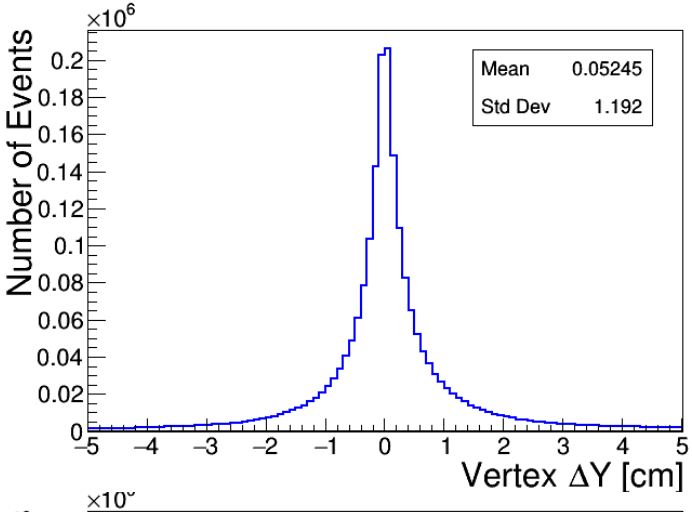

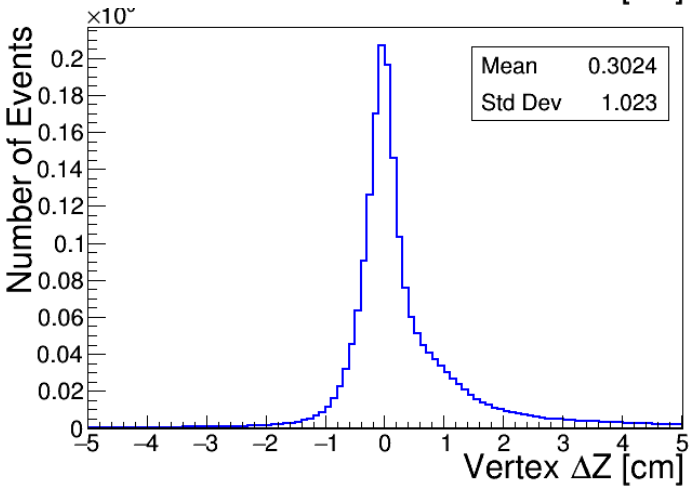

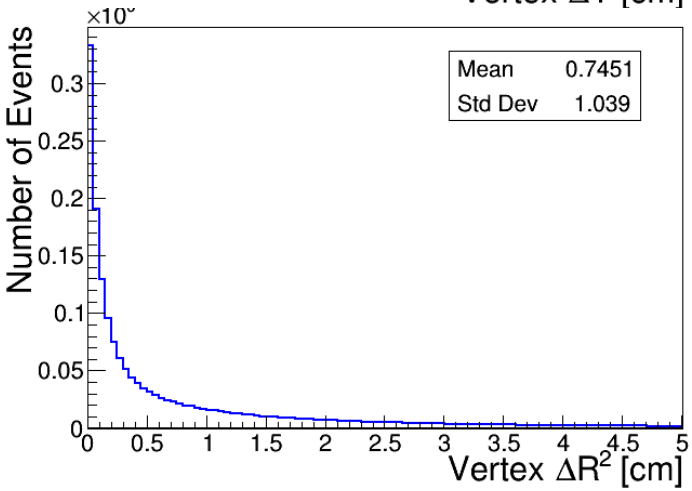

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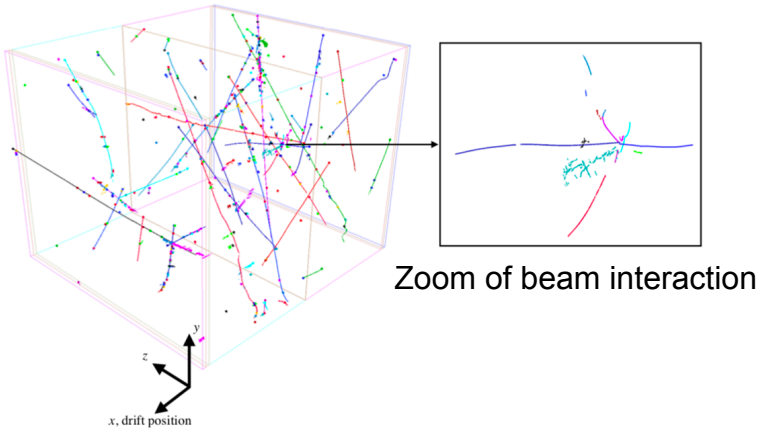
Pandora in ProtoDUNE-SP

- Pandora is the primary reconstruction for ProtoDUNE-SP
- The outputs are used for the large number of analyses
- Suite of analysis tools to best use the Pandora outputs
- Feedback from analysers



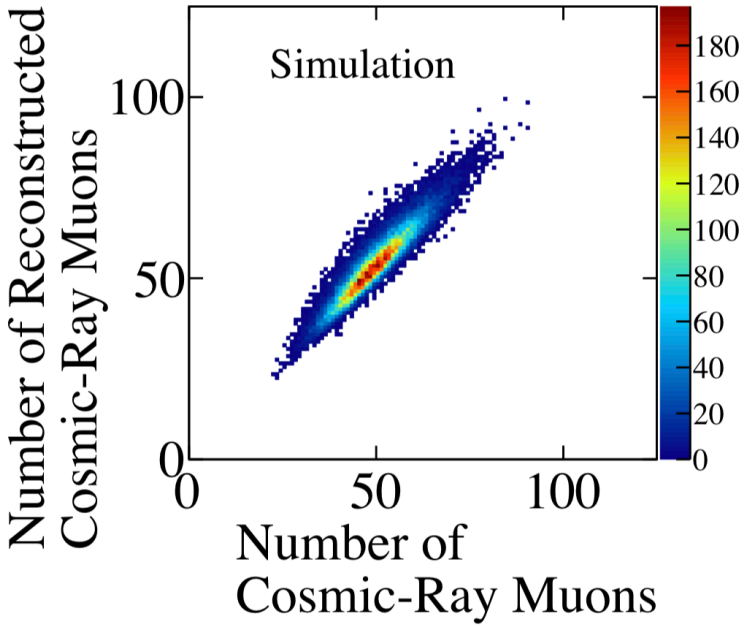
Zoom of beam interaction

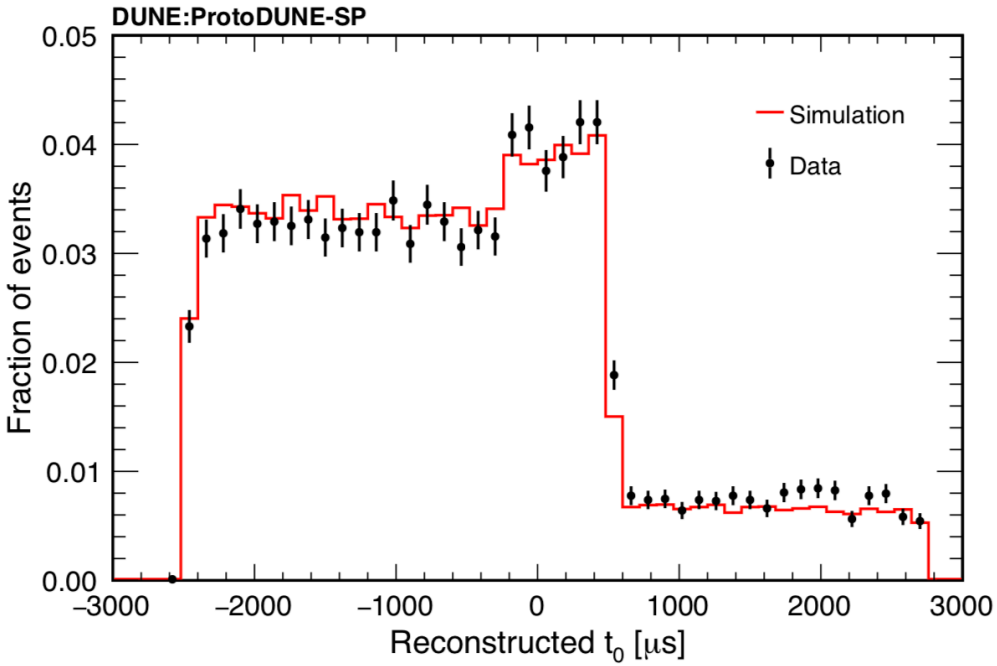
Simulated test-beam interaction in ProtoDUNE

DUNE Technical Design Report Volume II: https://arxiv.org/abs/2002.03005

Pandora in ProtoDUNE-SP

- ProtoDUNE-SP cosmic data and MC
  - Stitch collinear tracks either side of the cathode or anode using an equal and opposite shift in the drift direction
  - Measure the arrival time in the TPC, t0, for this subset of tracks





Left: DUNE Technical Design Report Volume II: https://arxiv.org/abs/2002.03005
Right: ProtoDUNE Performance Paper: https://arxiv.org/abs/2007.06722

New developments

- There is a lot of on-going work to improve all aspects of the event reconstruction
  - Integration of deep learning techniques
    - Convolution Neural Network (CNN) for vertex finding
    - CNN for identifying track- and shower-like hits
  - Increase use of charge information
    - Matching clusters between the different readout planes
    - Feature finding in geometrically ambiguous cases
  - High energy muons
    - Important for calibration in the Far Detectors
    - Improve track finding through large delta-ray showers
    - Stitch tracks across multiple cathodes and anodes

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
- Improvements will be benchmarked on DUNE FD simulation and, where possible, using ProtoDUNE data and simulation
- Strong intention to support DUNE Near Detector 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

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

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