Pandora Reconstruction for the DUNE Far Detector

Ryan Cross for the DUNE Collaboration

Lancaster University

DUNE

The Deep Underground Neutrino Experiment (DUNE) is a next-generation neutrino experiment that is in the construction phase. It is designed to measure δ_{CP}, which controls CP violation in the neutrino sector. It is expected to start taking data in 2026.

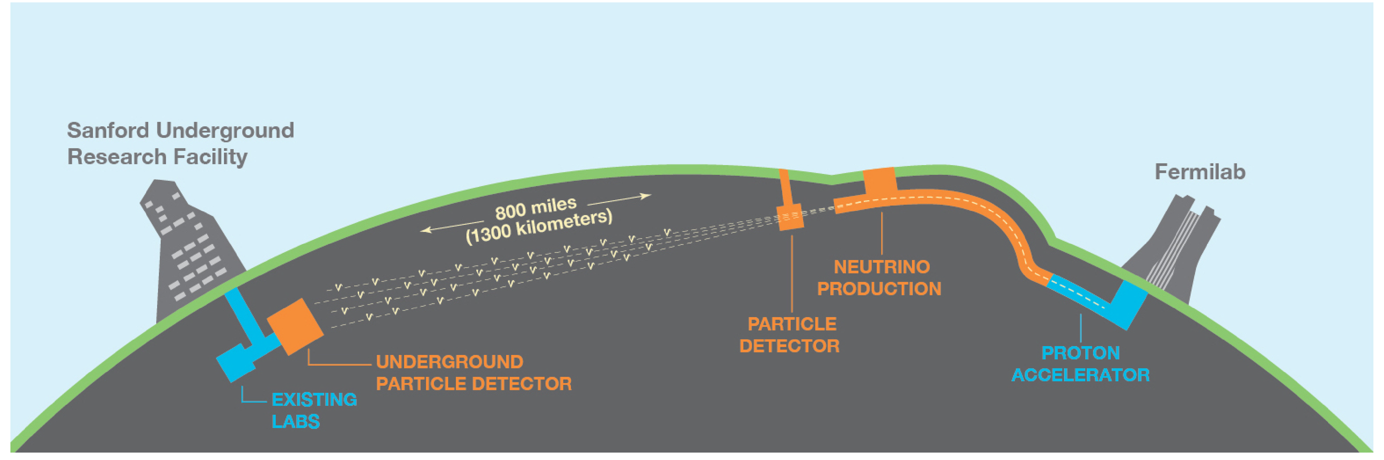


Figure 1. The DUNE Baseline, showing the beam facility, near detector and far detector.

It will consist of four 10 kt fiducial mass modules, which will be located 1480 m underground at the Sanford Underground Research Facility (SURF), South Dakota. The main detector technology is the Liquid Argon Time Projection Chamber.

The Long-Baseline Neutrino Facility (LBNF) at Fermilab will produce a neutrino beam for the far detector at SURF 1300 km away, first passing through a near detector complex.

Liquid Argon Time Projection Chambers

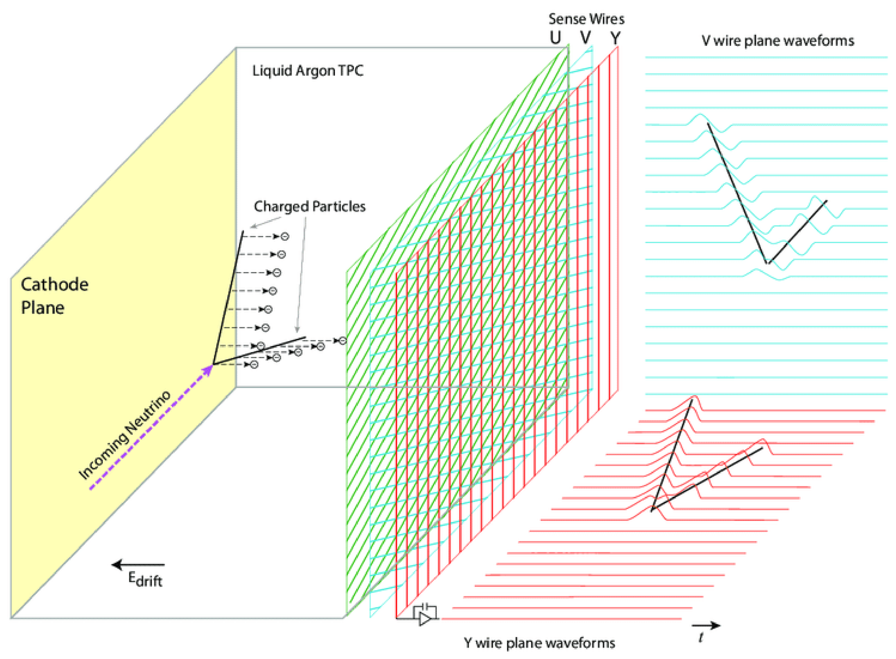


Figure 2. An example of a LArTPC, from MicroBooNE [1].

- Liquid Argon Time Projection Chambers (LArTPCs) work by drifting ionisation electrons from the charged particles ionising the liquid argon.
- The electrons drifting in the electric field then induce signals on wires, which can be read out.
- In the DUNE single-phase design, there are 3 readout planes, giving 3 2D images. These can be combined to reconstruct the 3D event.

Neutrino Event Reconstruction for LArTPCs

Reconstruction

- Reconstruction takes the raw output signals (hits) from the detector and produces Physics-level quantities.
- This includes pattern recognition, particle identification, energy estimation and reconstruction of final-state topology.

Pandora

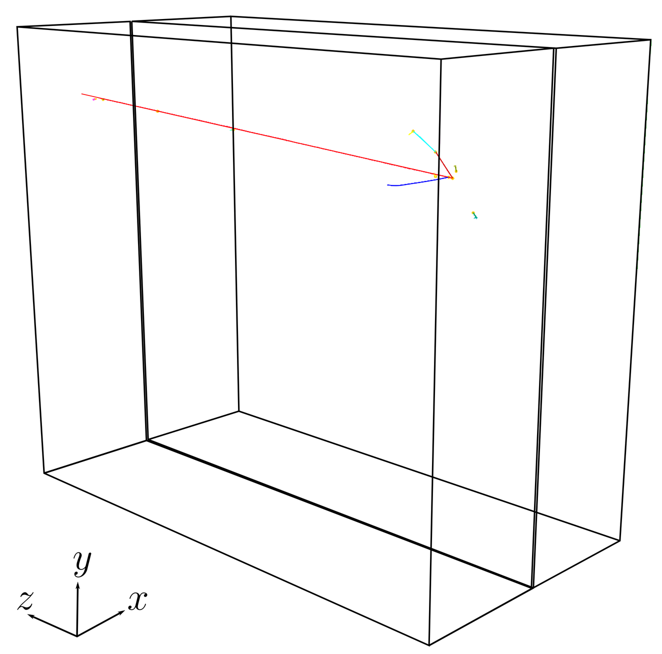
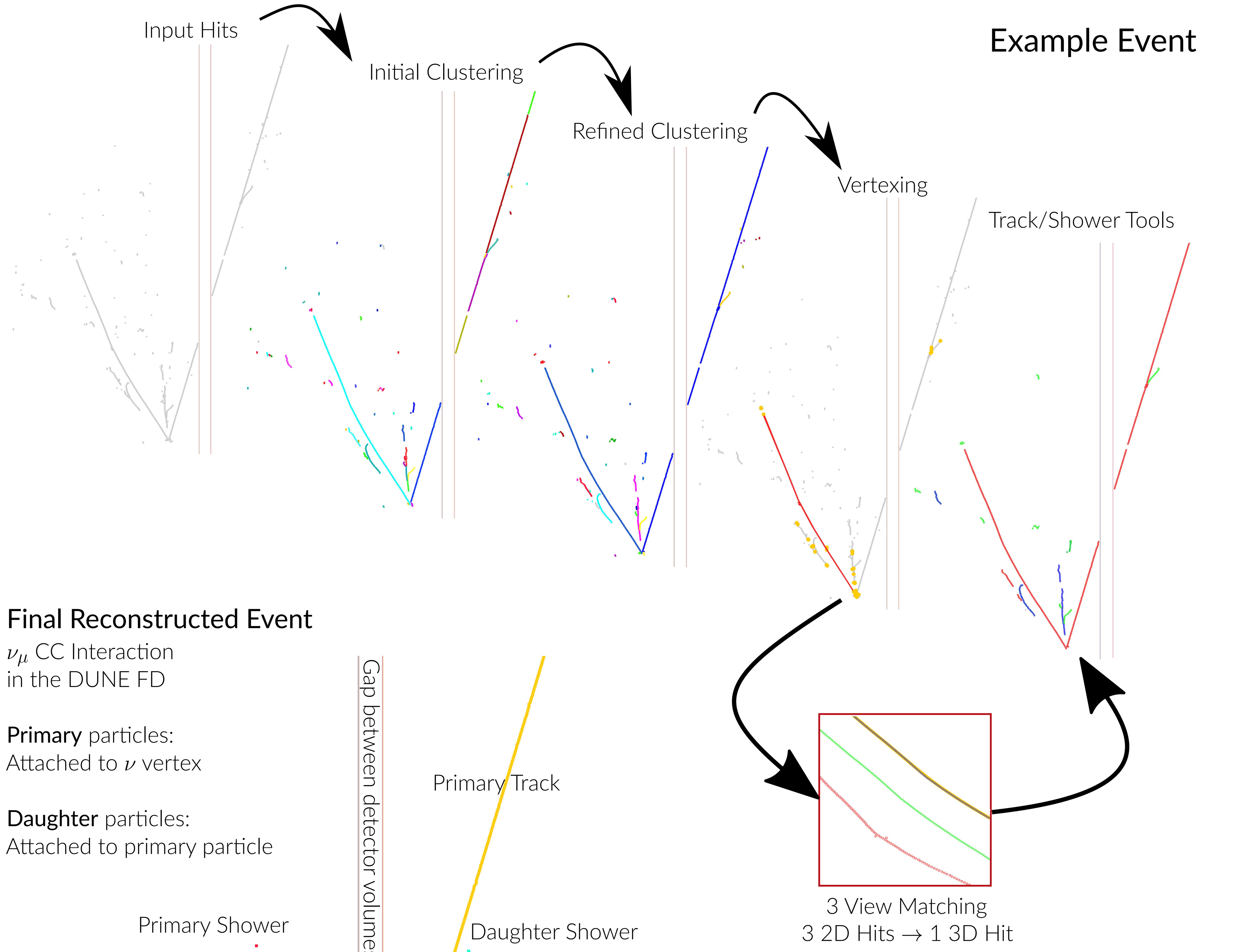


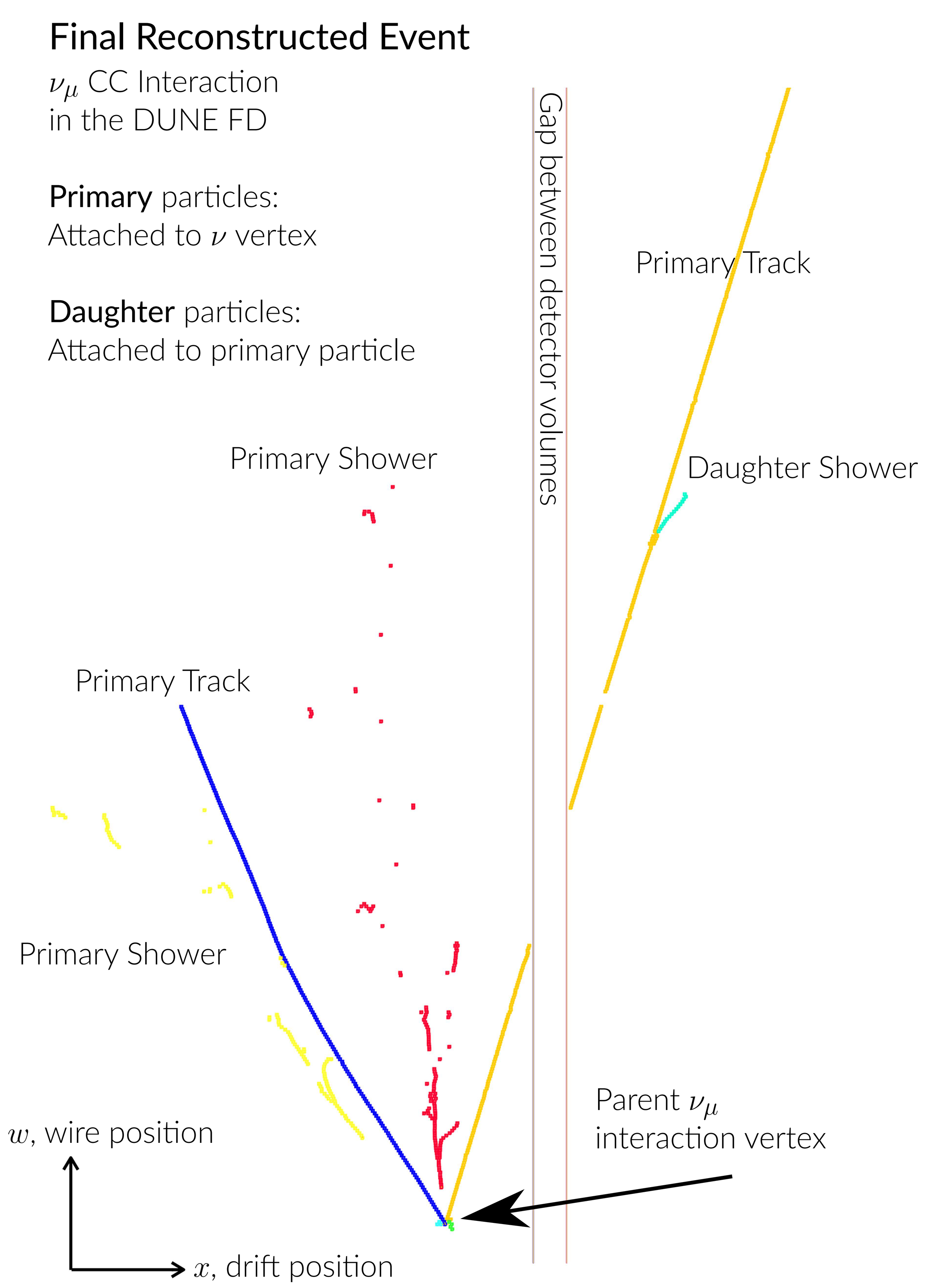
Figure 3. Example 3D reconstruction of a ν_μ interaction in a DUNE Far Detector module.

- Pandora [2] is pattern recognition software that is used across many experiments including DUNE.
- Pandora is responsible for event reconstruction, going from 3 input images to a full event hierarchy.
- The final output contains individual particles, all attached together by parent and daughter links.

Pandora Multi-algorithm approach to LArTPC Pattern Recognition

The multi-algorithm approach to pattern recognition uses many small focused algorithms to build up a complete picture of the full event. A broad outline of this process can be seen below, going from input hits through to a full reconstruction of the event. Each step shown below is made up of many individual algorithms that add a small part to the final event.





[1] R Acciarri et al. In: Journal of Instrumentation 12.02 (2017), P02017.

[2] R Acciarri, et al. In: Eur Phys Jour C 78.1 (2018), p. 82.

[3] Babak Abi et al. In: arXiv:2002.03005 (2020).

Performance for the Single Phase DUNE Far Detector

- The performance of Pandora has been evaluated against simulated accelerator neutrino and antineutrino interactions in the 10 kt DUNE Single Phase module.
- Figures 4 and 5 show the reconstruction efficiency as a function of the number of hits associated with final state particles, for all interaction types except deep inelastic ones.

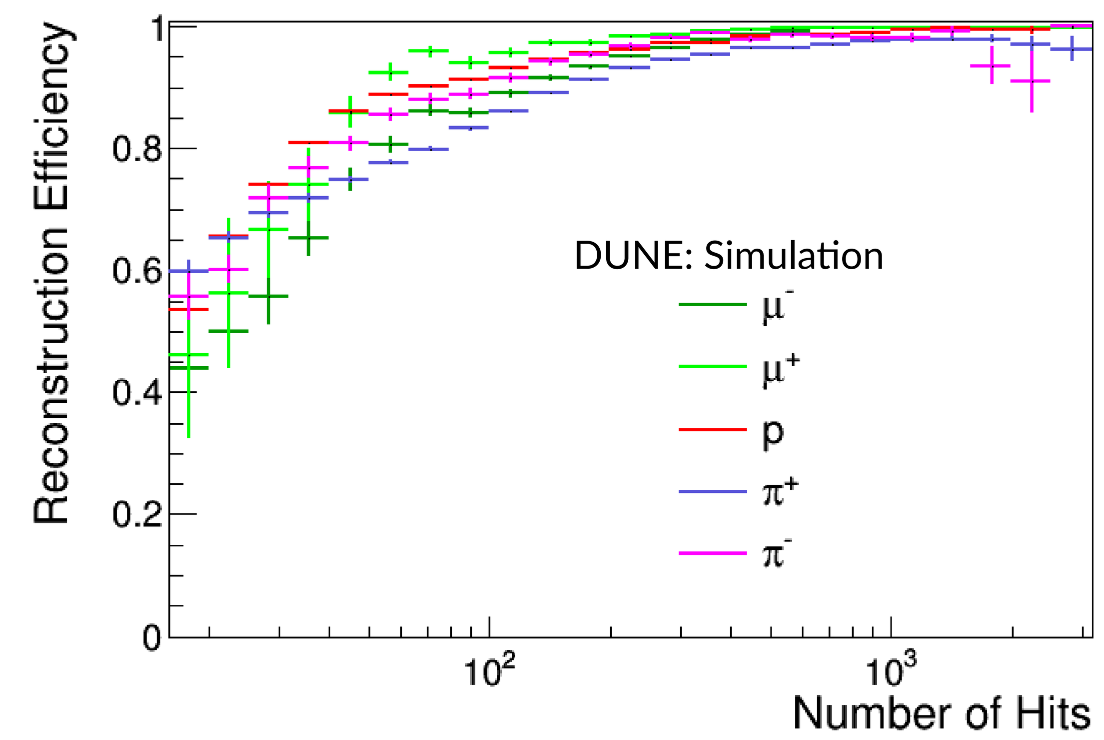


Figure 4. Reconstruction efficiency for tracks [3].

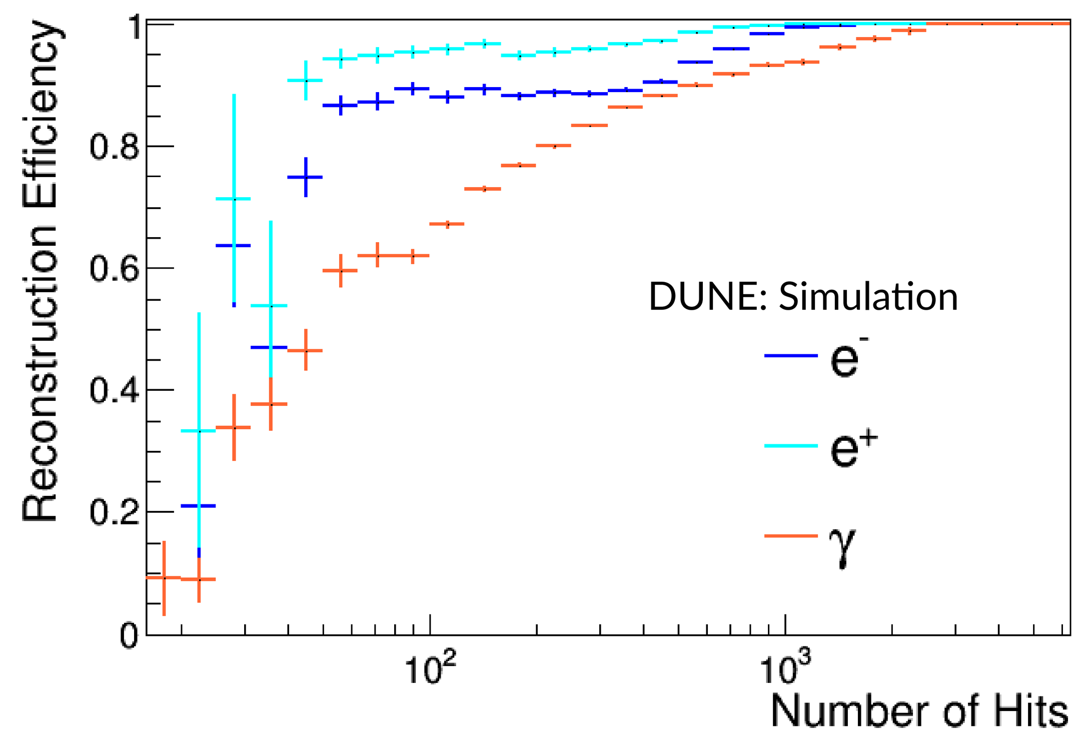


Figure 5. Reconstruction efficiency for showers [3].

Developing the Pandora Reconstruction for DUNE

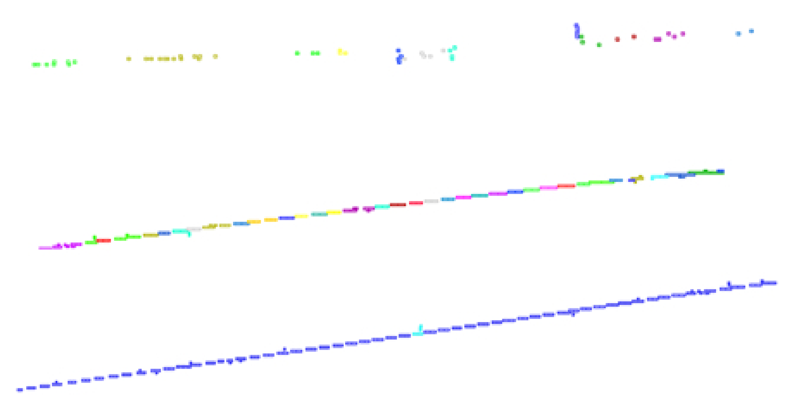


Figure 6. Three stages of hit width usage.

Hit Widths

- Hit widths, the width of the charge deposition waveform, were not being used.
- For final state particles with momenta perpendicular to the wire planes this could result in very sparse hits being used for the reconstruction, causing issues.
- With new algorithms to use this additional information, the reconstruction is improved.

Track vs Shower Identification

- Track / Shower identification is used in many parts of the reconstruction, and any inaccuracies could cause the wrong algorithms to be used for a given particle.
- It has been updated to use additional variables in its decision making, giving increased accuracy.

3D Reconstruction

- The 3D track reconstruction could result in unphysical tracks being produced in certain ambiguous cases.
- The 3D reconstruction pipeline is now being updated to select the most coherent hits from a large set of hits produced from running many 2D → 3D tools.

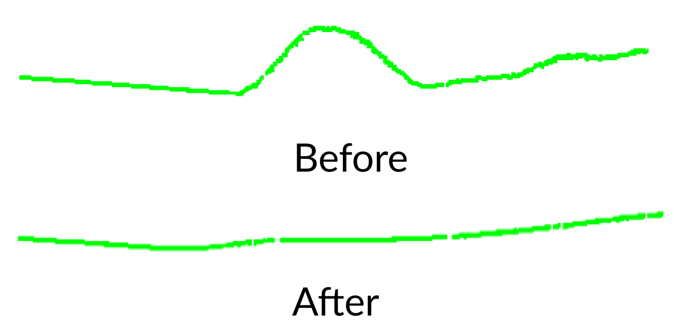


Figure 7. Example before and after of 3D hit improvements.

Vertexing

- Previously, too many candidate vertices were produced.
- Changes were made to both reduce the number of candidates, but also to pick better candidates.
- This is very important, as an accurate vertex is an anchor for many subsequent algorithms.