The **Pandora** Reconstruction for **Dual-Phase** Liquid Argon **TPCs**

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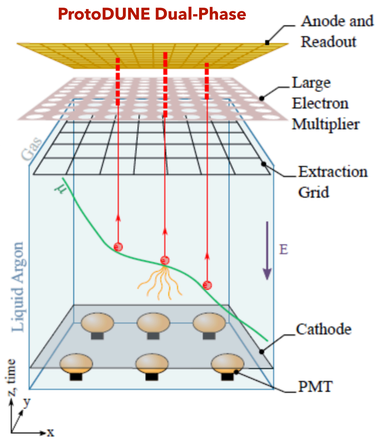
- **TPC Active volume**: (6 x 6 x 6) m^3
- **Ionization event → 3D position**
  Ionization electrons drift vertically along E field towards extraction grid and *sandwiches* of **large electron multipliers** + **anode** (two strip-based collection views each forming a 2D image): **Charge readout planes**
- The peaks of waveforms of charge deposited in the strips are reconstructed as **hits**
- **Scintillation light → event timing**
  Array of 36 photomultiplier tubes (PMTs) below cathode



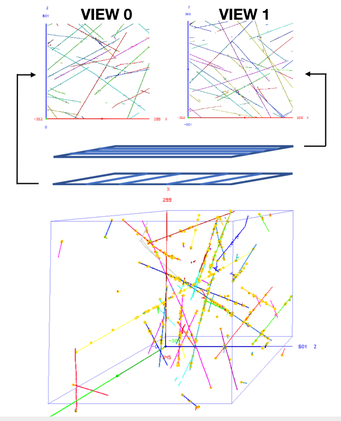
Dual-Phase (DP) **LArTPC**:
a candidate technology for the DUNE far detector

ProtoDUNE-DP: a 300 t prototype at CERN

Pandora [1,2]: a **multi-algorithm reconstruction** based on advanced particle flow techniques

New Dual-Phase specific features

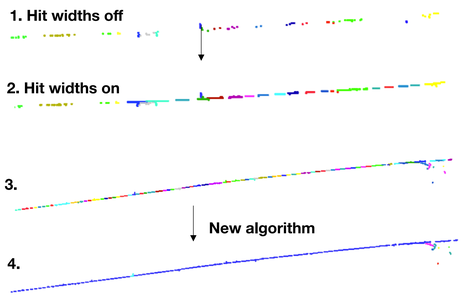
- Large number of algorithms to reconstruct particles in each event
- Two algorithm chains for **cosmic** and **test beam** particles, including:
  - 2D pattern recognition
  - 2D → 3D matching
  - 3D reconstruction
- Particles not tagged as clear cosmic rays are grouped in *slices*
- Each slice reconstructed with both cosmic and test beam algorithm chains, then best output selected



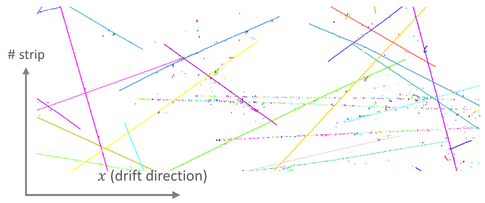
Starting from two 2D-images from the two collection views, 2D → 3D matching and 3D algorithms allow full 3D particle reconstruction

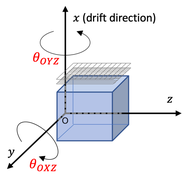
2D reconstruction performance

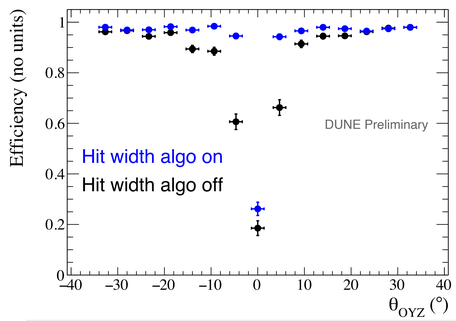
- 2D pattern recognition tested in simulated cosmic ray environment
- Reconstruction efficiency > 90% except for *sparse* tracks parallel to readout strips
- New algorithm making use of the width of charge deposition waveforms (**hit widths**) improves performance



In the above example, separate clusters are represented by different colours. First, the effect of turning hit widths on in the simulation is shown (2 → 3), followed by the improvement due to a new cluster merging algorithm using hit widths information (3 → 4), which leads to all adjacent collinear clusters being merged together.







Efficiency, as a function of the angle in the horizontal plane OYZ (diagram above for definition), for a sample of single 2 GeV/c muons, with the standard cosmic reconstruction (black) and with the addition of the new hit width-based cluster merging algorithm (blue).

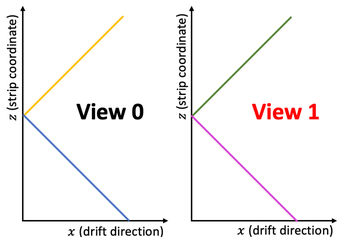
References: [1] Eur. Phys. J. C 78, 82 (2018) [2] Eur. Phys. J. C 75, 439 (2015)

2D → 3D matching with calorimetry

- **Aim:** match 2D clusters across views to reconstruct 3D trajectories
- Only two non-parallel views required, but **redundant information** often necessary to correctly identify matches
- Two-collection view detectors such as ProtoDUNE

Procedure:

1. Find all cluster pairs
2. Identify cluster overlap region in drift coordinates
3. Build fractional charge profiles of clusters
4. Slide a window across the profiles and repeatedly calculate local matching score (*L*)
   - *L* = 1 - p-value (p-value for measuring a correlation coefficient (*r*), assuming true *r*=0)
5. *L* consistently close to 1 indicates correct match

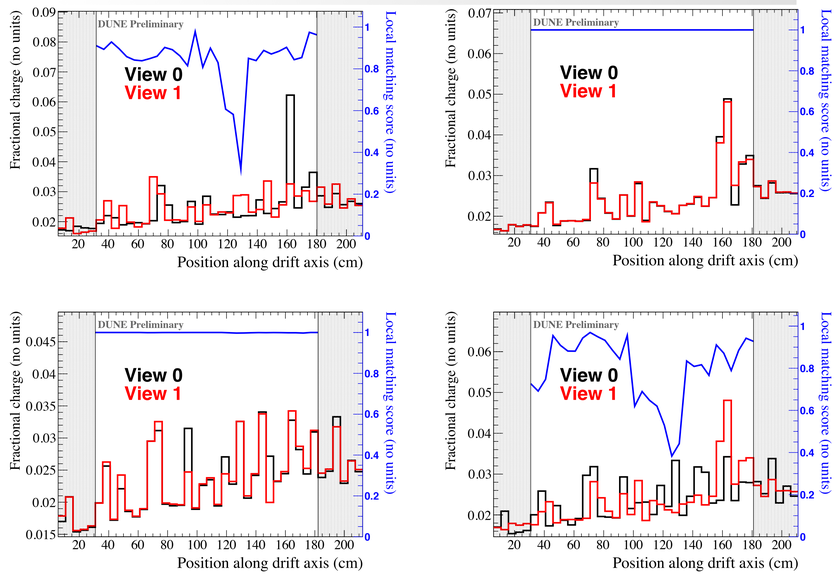


Sketched example of a di-muon particle gun Monte Carlo event simulated in ProtoDUNE-DP.

Two Monte Carlo particle example

- Four possible cluster matches across two views
- Only two matches are correct

Simulation



The local matching score and fractional charge profiles for the four pairwise cluster combinations formed by the example Monte Carlo di-muon event shown to the left. The matching candidates shown in the top-right and bottom-left images are correct matches, according to the simulation.