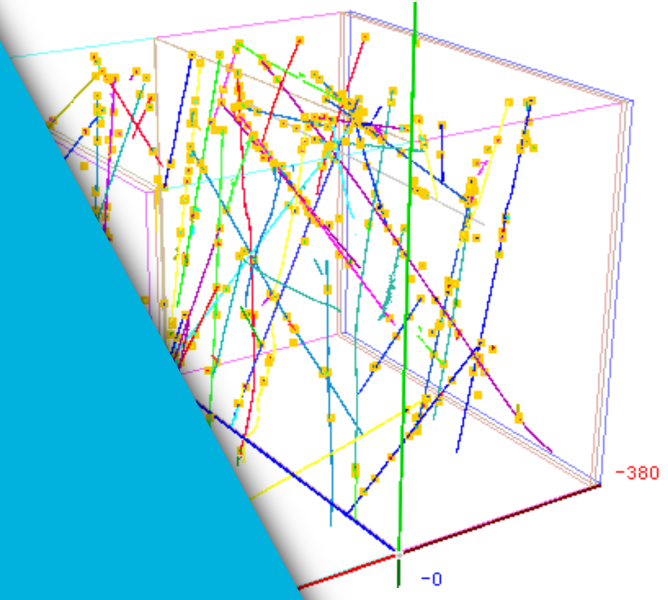
Reconstruction outputs

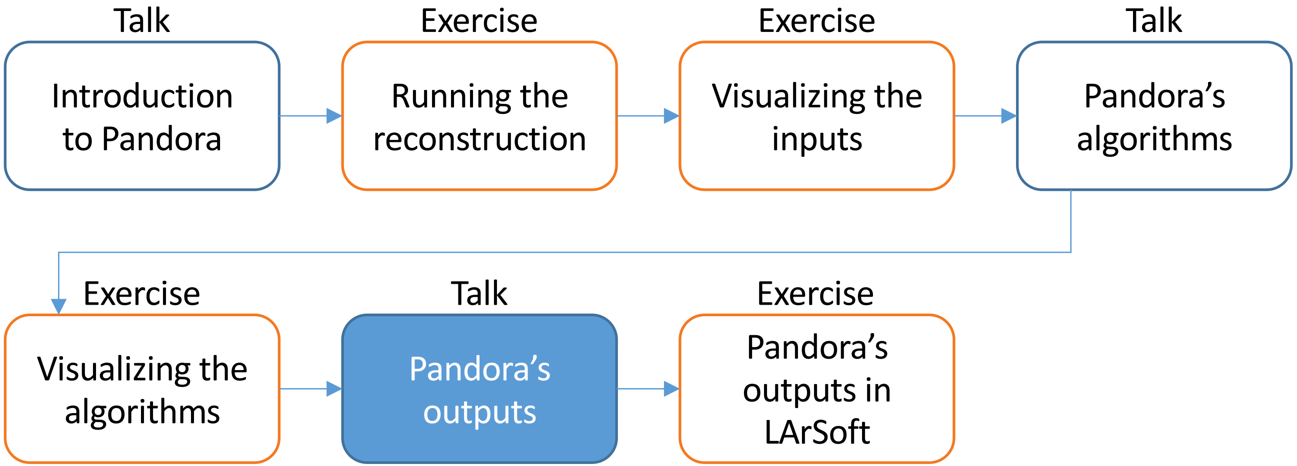


Maria Brigida Brunetti for the Pandora team

09/11/2022

7th UK LArTPC Software and Analysis Workshop

Reconstruction session



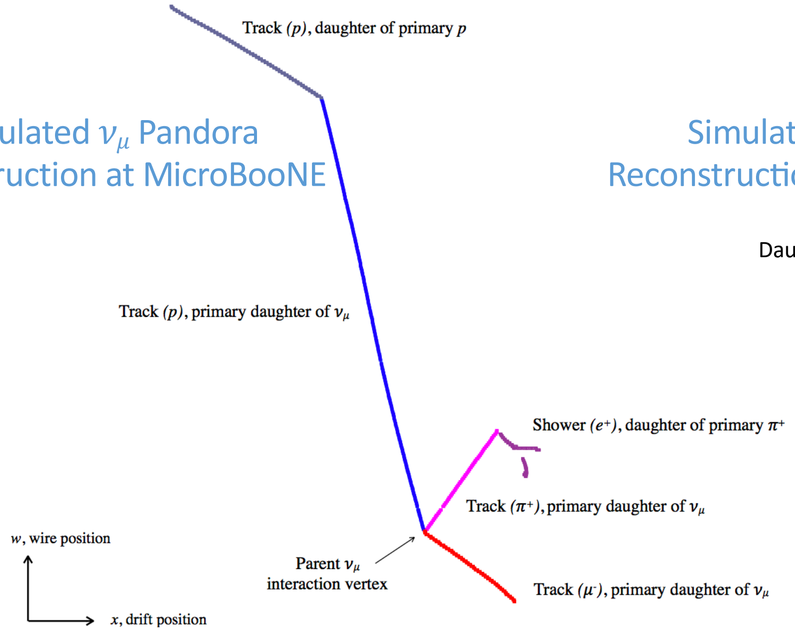
Credit: These slides are based on previous LArSoft workshop slides by John Marshall

Key references: [Pandora ProtoDUNE paper](#)
[Pandora MicroBooNE paper](#)

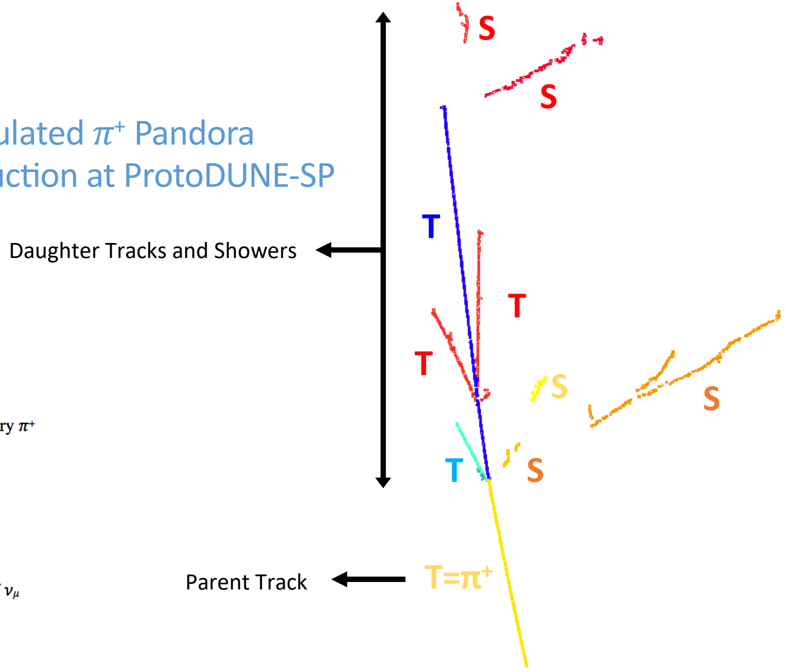
Reminder: Particle Hierarchy Reconstruction

- Use 3D clusters to organise particles into a hierarchy, working outwards from interaction vtx:

Simulated ν_μ Pandora Reconstruction at MicroBooNE



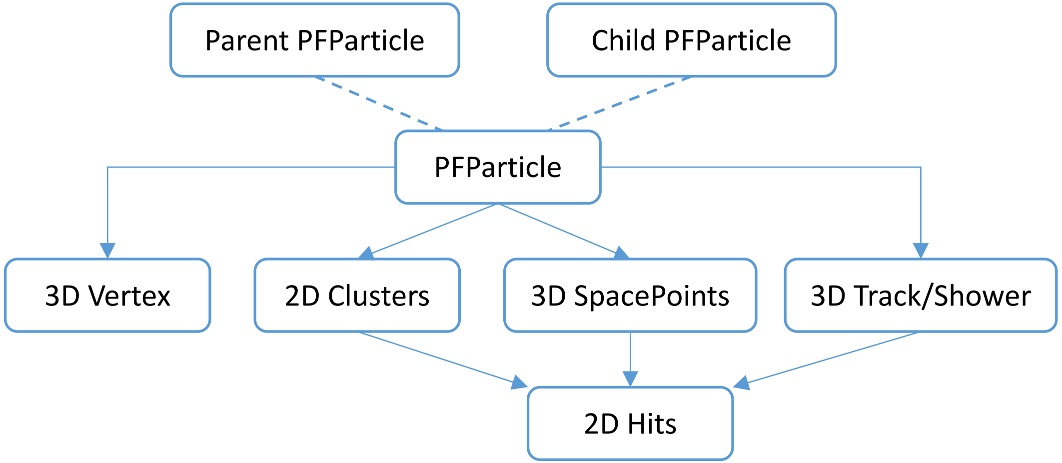
Simulated π^+ Pandora Reconstruction at ProtoDUNE-SP



EPJC (2018) 78:82

Reconstruction Output

- Must translate output from Pandora Event Data Model to LArSoft Event Data Model. The key output is the PFParticle (PF ⇒ Particle Flow):
  - Each PFParticle corresponds to a distinct track or shower and is associated to 2D clusters.
  - 2D clusters group hits from each readout plane, and are associated to the input 2D hits.
  - PFParticles also associated to 3D spacepoints and a 3D vertex.
  - PFParticles placed in a hierarchy, with identified parent-daughter relationships.
  - PFParticles flagged as track-like or shower-like.

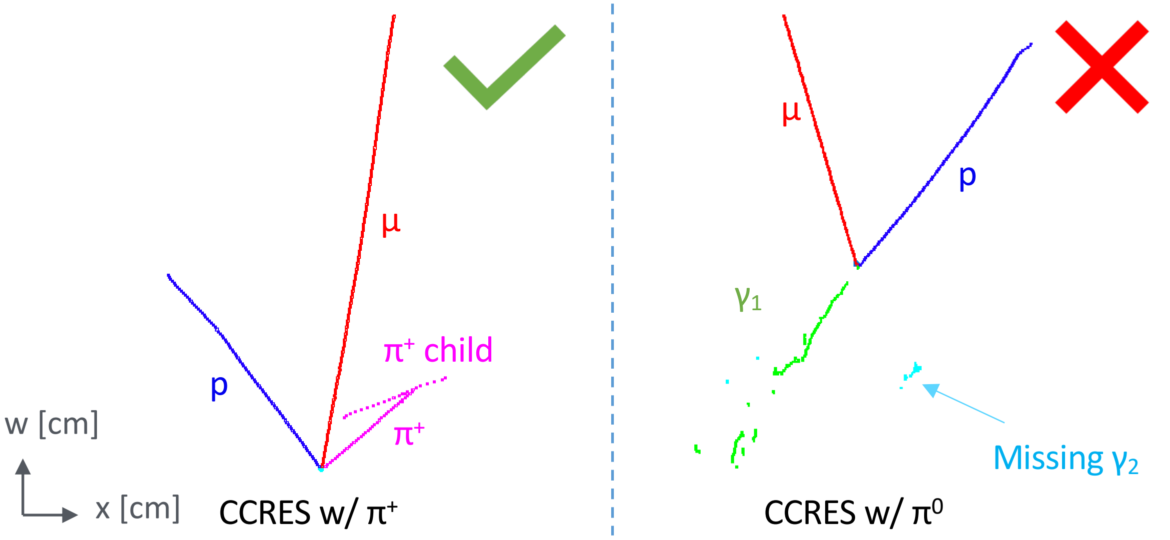


Just the most important outputs shown here

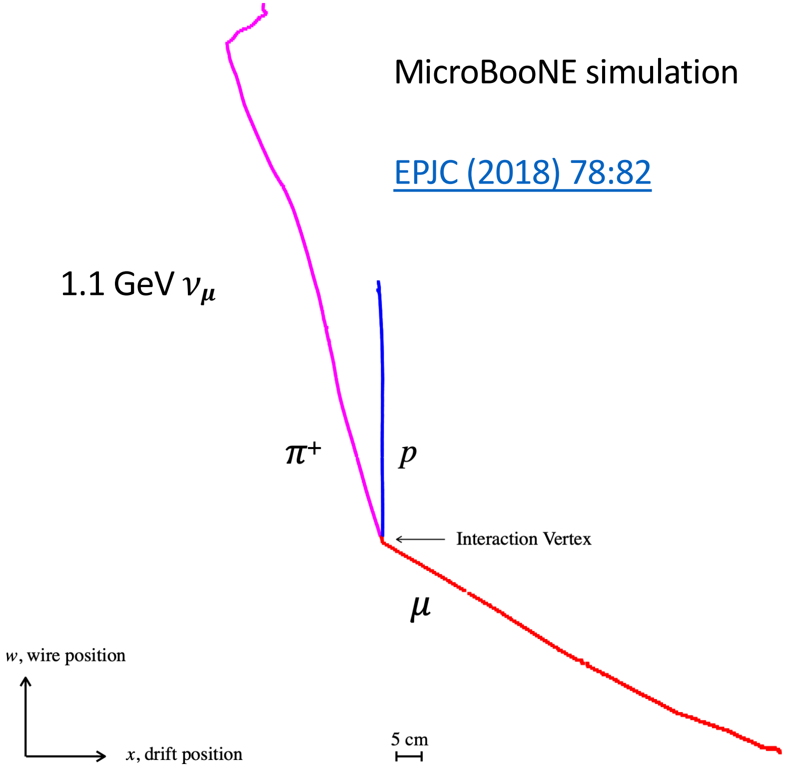
Will work with these products in the analyzer tutorial

Assessing Pattern-Recognition Performance

- Assess performance for simulated MicroBooNE events, using a selection of event topologies.
- Examine fraction of events deemed “correct” by strict pattern-recognition metrics:
  - Consider exclusive final-states where all true particles pass simple quality cuts (e.g. nHits)
  - Correct means exactly one reco primary particle is matched to each true primary particle



Example, CC RES: $\nu_\mu + Ar \rightarrow \mu^- + p + \pi^+$



- Three-track topology: CC ν_μ interactions with resonant charged pion production:

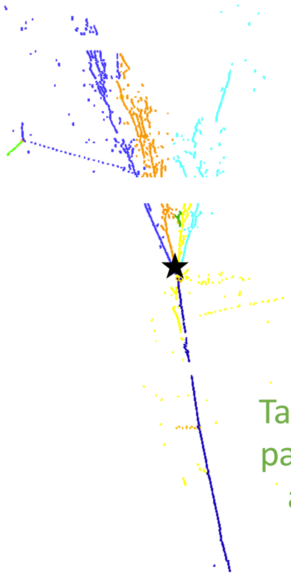
#Matched Particles	0	1	2	3+
μ	3.5%	95.1%	1.4%	0.0%
p	9.0%	86.8%	4.0%	0.3%
π^+	6.9%	80.9%	11.4%	0.8%

47,754 events, 70.5% have exactly one reco particle matched to each target.

- Performance for μ and p similar to that reported for quasi-elastic events.
- π+ interactions can lead to hierarchy of visible particles. If reconstructed separately (without parent-daughter links), π+ is reportedly split.

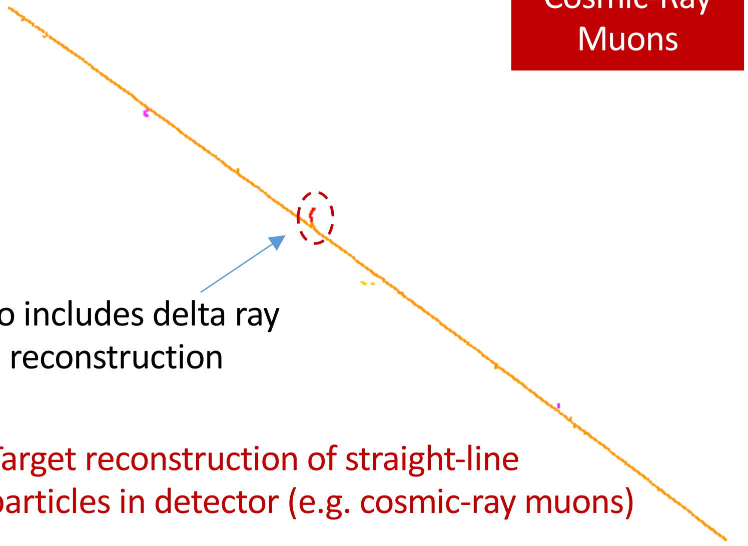
Consolidated reconstruction

- We have used a multi-algorithm approach to create two algorithm chains:
- Consolidated reconstruction uses these chains to guide reconstruction for all use cases:
- Cosmic rays ✔, Multiple drift volumes ✔, Arbitrary wire angles ✔, 2 or 3 wire planes ✔



Neutrino (or TestBeam)

Target reconstruction of particles emerging from an identified vertex ★

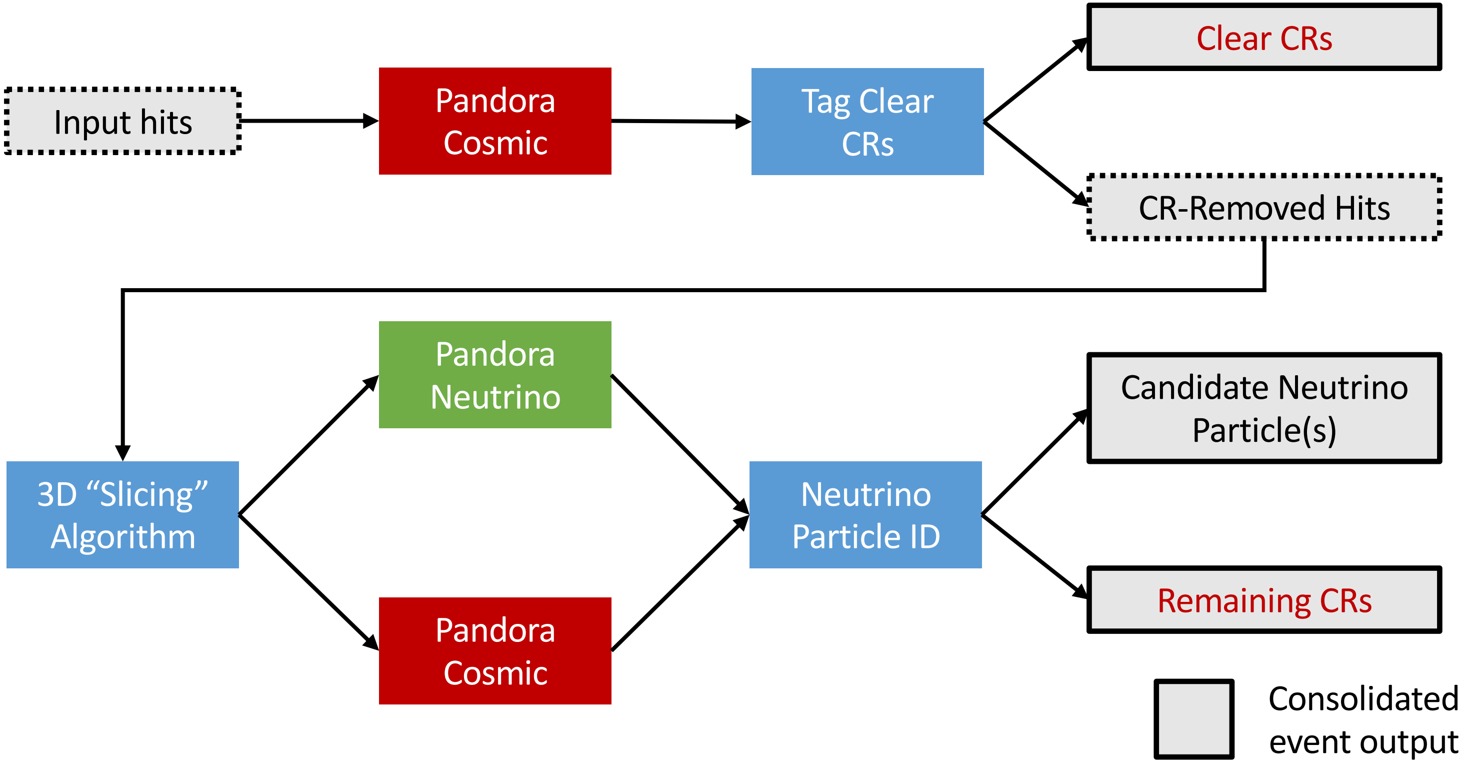


Cosmic-Ray Muons

Also includes delta ray reconstruction

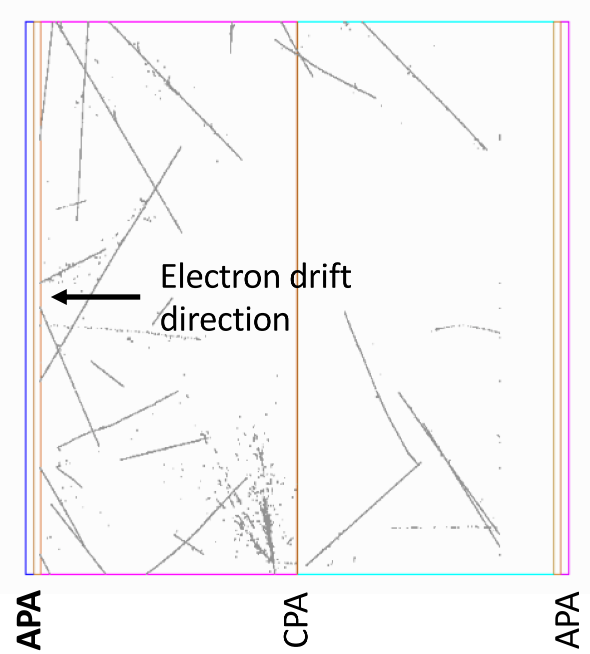
Target reconstruction of straight-line particles in detector (e.g. cosmic-ray muons)

Consolidated reconstruction



Example: Reconstruction at ProtoDUNE-SP

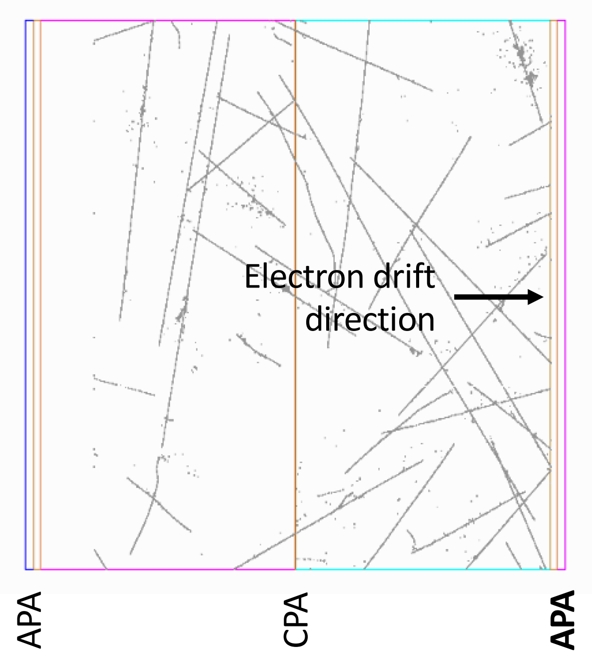
- Single Phase DUNE Far Detector prototype, exposed to test beam at CERN
- Multiple "drift volumes", complex topologies and significant cosmic-ray backgrounds:
  - An ideal testing ground for LArTPC pattern recognition



APA: Anode Plane Assembly
CPA: Cathode Plane Assembly

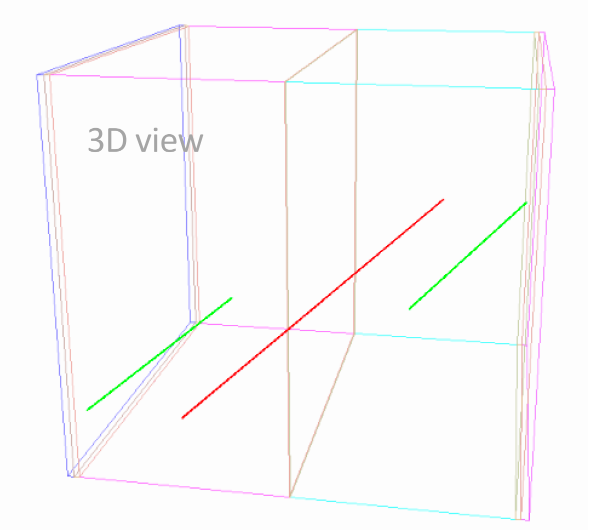
1. Reconstruct cosmic-ray muons independently for each volume of detector

w [cm]
x [cm]

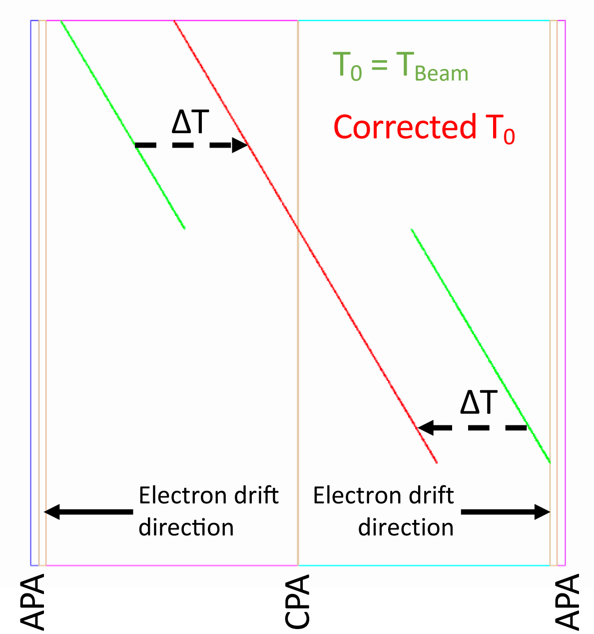


Stitching and T_0 Identification

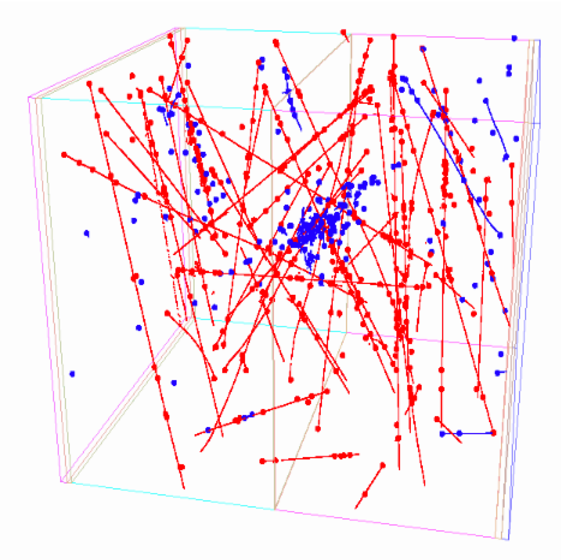
- In a LArTPC image, one coordinate derived from drift times of ionisation electrons:
  - But, only know electron arrival times, not actual drift times: need to know start time, T_0
  - For beam particles, can use time of beam spill to set T_0, but unknown for cosmic rays
  - Place all hits assuming $T_0 = T_{Beam}$, but can identify T_0 for any cosmic rays crossing volumes



2. Stitch together any cosmic rays crossing between volumes, identifying T0



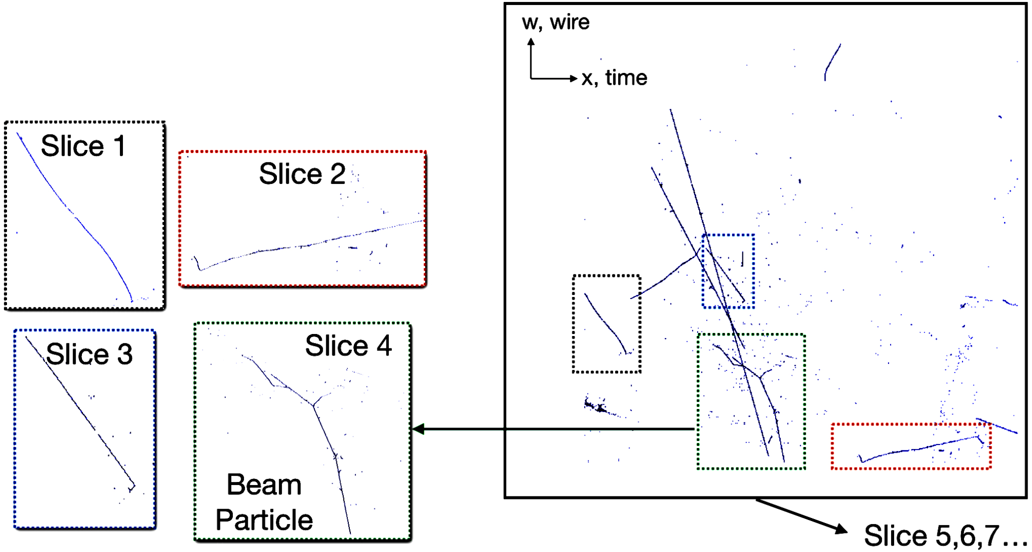
Cosmic Ray Tagging and Slicing



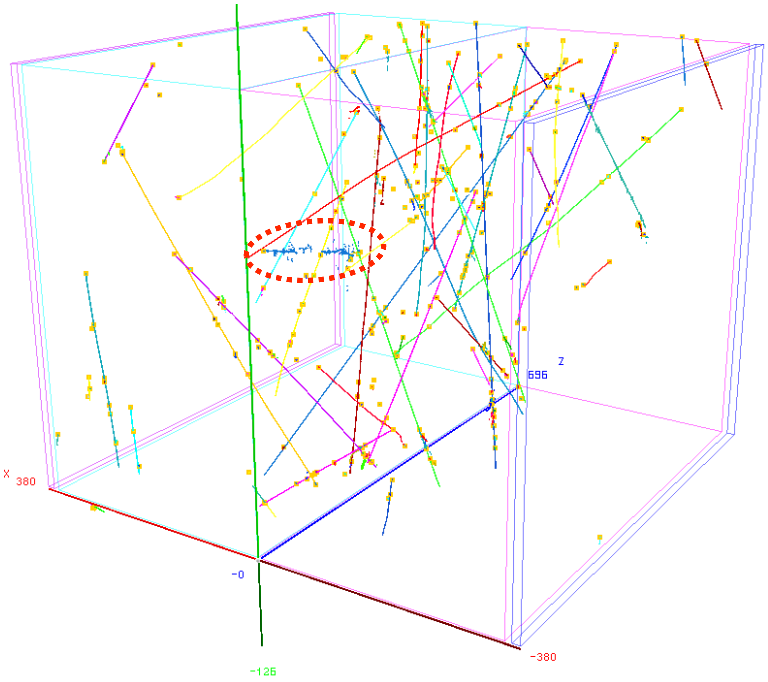
3. Identify clear cosmic rays (red) and hits to reexamine under test beam hypothesis (blue)

- Clear cosmic rays:
  - Particles appear to be "outside" of detector if $T_0 = T_{Beam}$
  - Particles stitched between volumes using a $T_0 \neq T_{Beam}$
  - Particles pass through the detector: "through going"

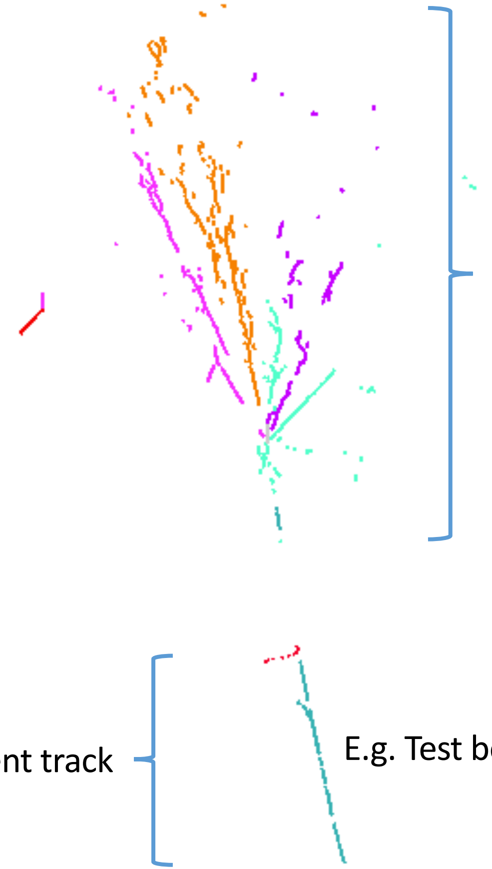
- Slice/divide blue hits from separate interactions
- Reconstruct each slice as test beam particle
- Then choose between cosmic ray or test beam outcome for each slice



Consolidated output



E.g. Reconstruction output: test beam particle (electron)
and: N reconstructed cosmic-ray muon hierarchies



Overall summary

- The use of Liquid Argon technology is one of the cornerstones of the current and future neutrino programmes.
- High-performance reconstruction techniques are required in order to fully exploit the imaging capabilities offered by LArTPCs:
  - Pandora multi-algorithm approach uses large numbers of decoupled algorithms to gradually build up a picture of events.
  - Output is a carefully-arranged hierarchy of reconstructed particles, each corresponding to a distinct track or shower.

We will now try working with the Pandora outputs, creating an analyzer module

Additional information

Performance metrics

Target MCParticles must satisfy quality cuts

Reco/MCParticles matches must satisfy quality cuts.

- Determine target MCParticle associated to each hit
  - Use MCParticle hierarchy to determine primary "targets" for reco
  - Associate hits to target MCParticle making largest E contribution
- Match reco particles to target MCParticles
  - For each combination of reco particle and target MCParticle, find the number of shared hits; fold all child particles, in both reco and MCParticle hierarchies, back into parent primaries
  - Interpret raw/comprehensive matching information to clarify pattern recognition performance:
    1. Find strongest (most shared hits) match between any reco particle and target MCParticle
    2. Repeat step i, using reco and MCParticles at most once, until no further matches possible
    3. Assign any remaining reco particles to target MCParticle with which they share most hits
- Match reco particles to target MCParticles
  - Efficiency: Fraction of target MCParticles with at least one matched reco particle
  - Completeness: Fraction of MCParticle true hits shared with the reco particle
  - Purity: Fraction of hits in reco particle shared with the target MCParticle
- Match exactly one reco particle to each target MCParticle ⇒ Event is "correct"

Performance metrics

- In practice, some MCParticles not reconstructable. Targets must satisfy quality cuts:
- ≥15 hits in total, at least five hits in at least two views.
- Target must deposit >90% E in these hits.
- Plus, ignore all hits which are downstream of far-travelling neutron in MC hierarchy.