Reconstruction algorithms

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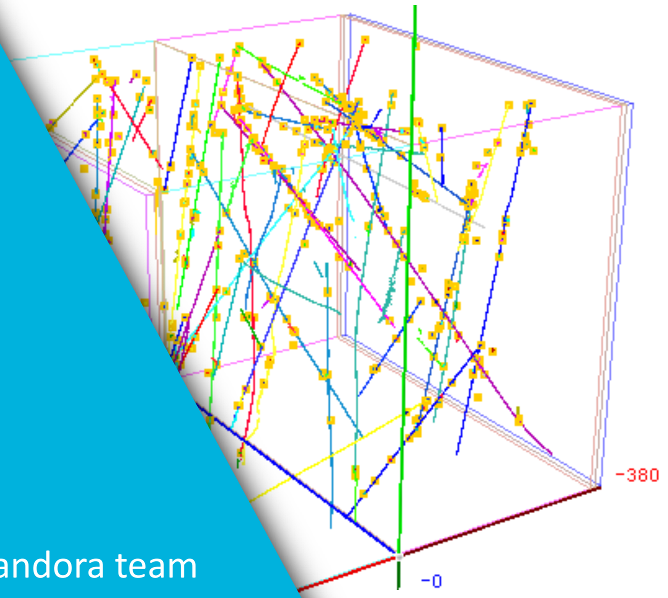
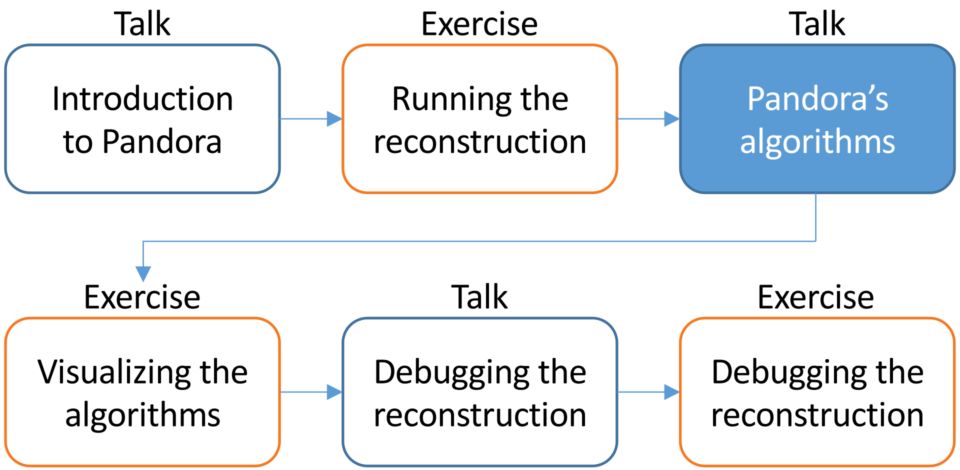
8th UK LArTPC Software and Analysis Workshop



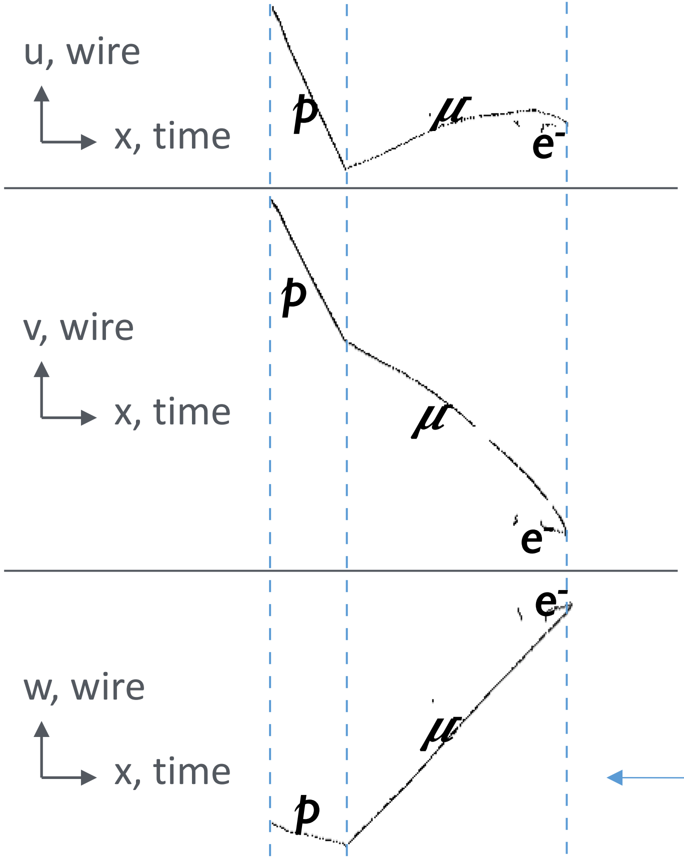
Reconstruction session



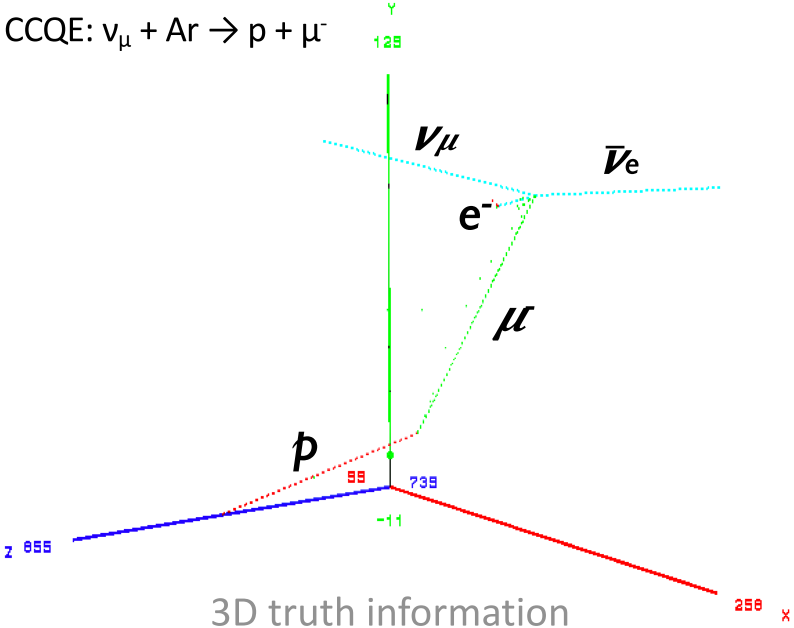
Credit: These slides are based on previous LArSoft workshop slides by Andrew Smith

Key references: Pandora ProtoDUNE paper
Pandora MicroBooNE paper

Inputs to Pandora



CCQE: $\nu_\mu + Ar \rightarrow p + \mu^-$



3D truth information

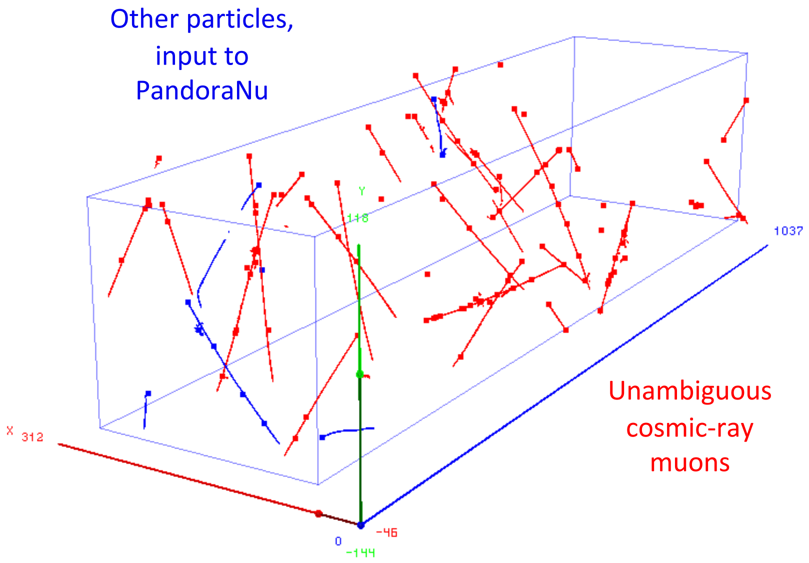
Three 2D representations with common x coordinate, derived from drift time

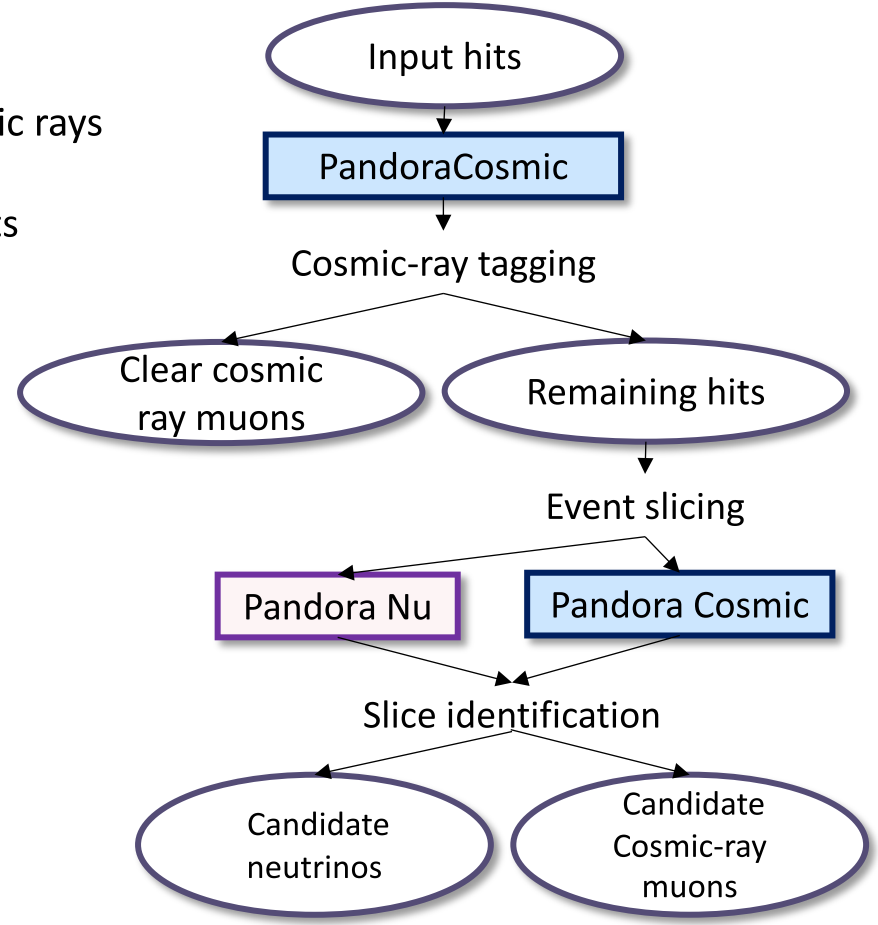
Pandora consolidated reconstruction

A two-pass approach

1. Run cosmic reco, put aside hits from clear cosmic rays

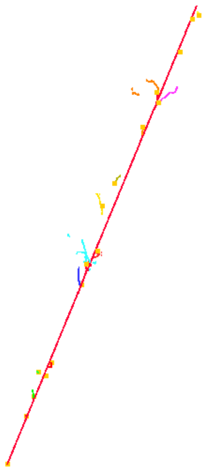
2. Run cosmic and neutrino chain on remaining hits

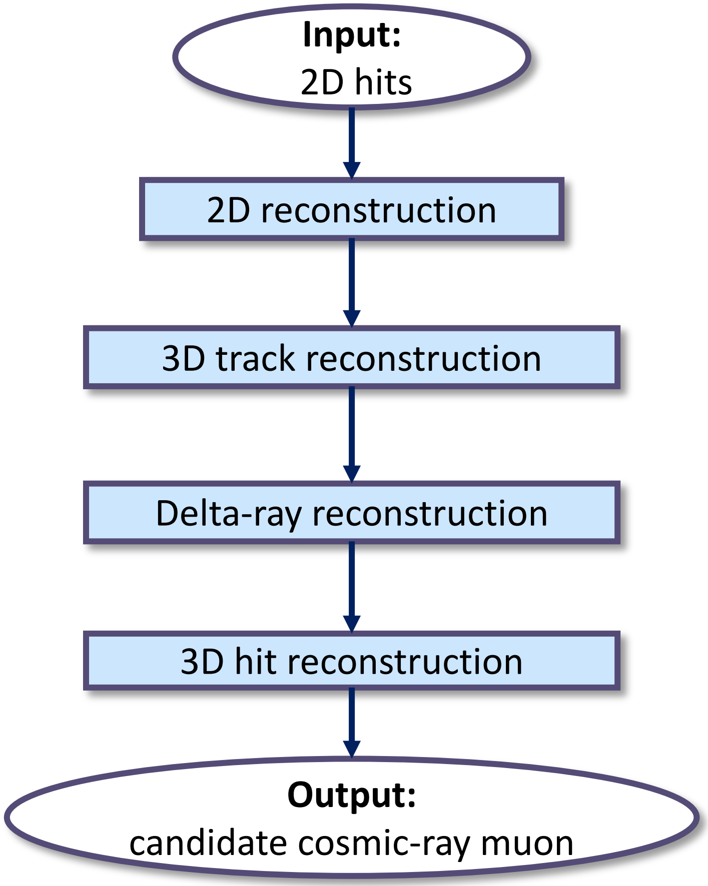




Algorithm chains: **Pandora Cosmic**

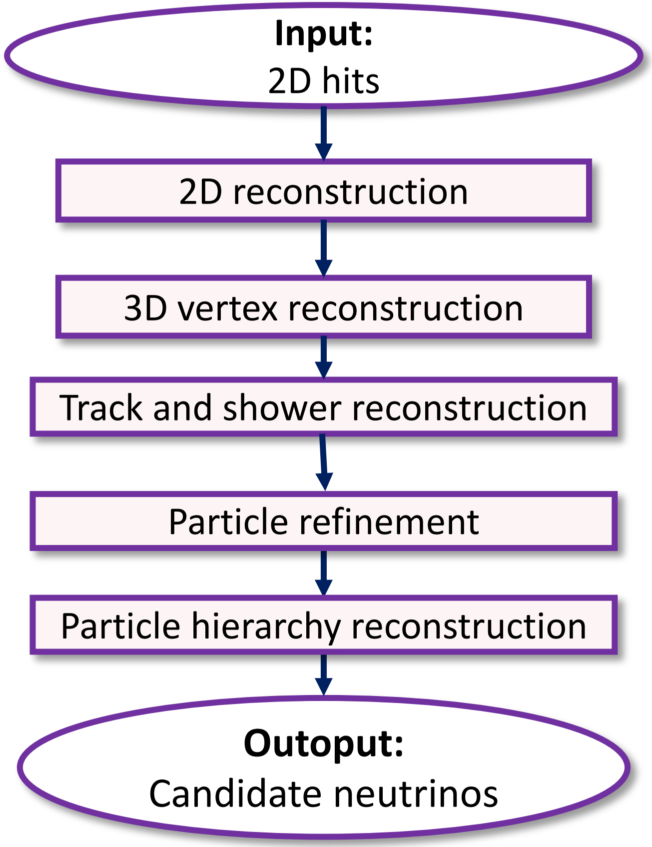
- Two Pandora algorithm chains created for LArTPC use, with many algs in common:
  - **PandoraCosmic:**
  - strongly track-oriented
  - showers assumed to be delta rays, added as daughters of primary muons
  - muon vertices at track high-y coordinate.





Algorithm chains: **Pandora Nu**

- Two Pandora algorithm chains created for LArTPC use, with many algs in common:
  - **PandoraNu:**
  - finds neutrino **interaction vertex** and protects all particles emerging from vertex position
  - Careful treatment to address track/shower tensions.



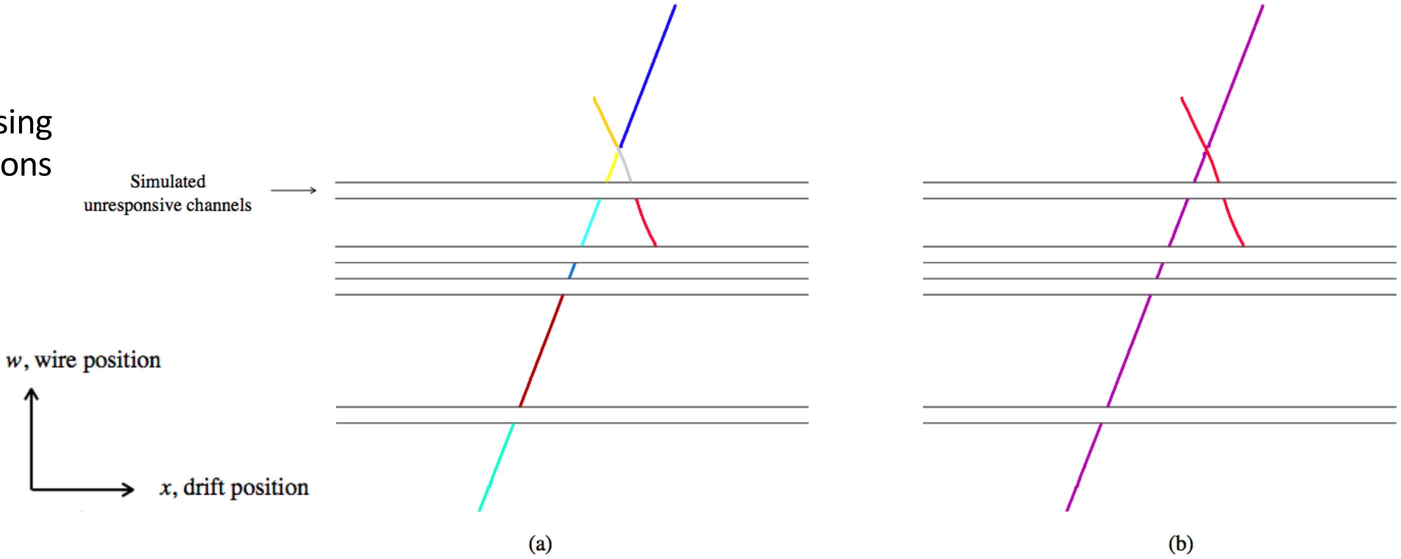
We will now show some **highlights** from the cosmic and nu reco chains

Pandora Cosmic chain

Cosmic-Ray Muon Reconstruction - 2D

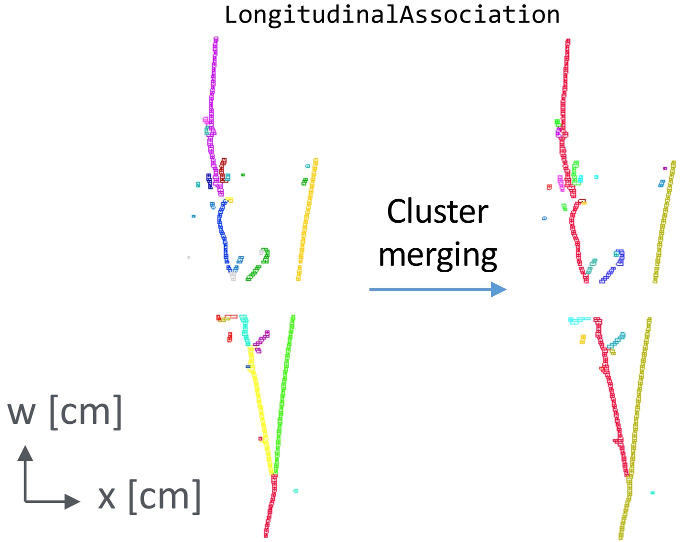
- For each plane, produce list of 2D clusters that represent continuous, unambiguous lines of hits:
  - PandoraCosmic: strongly track-oriented; showers assumed to be delta rays, added as daughters of primary muons; muon vertices at track high-y coordinate.
- Clusters refined by series of 15 cluster-merging and cluster-splitting algs that use topological info.

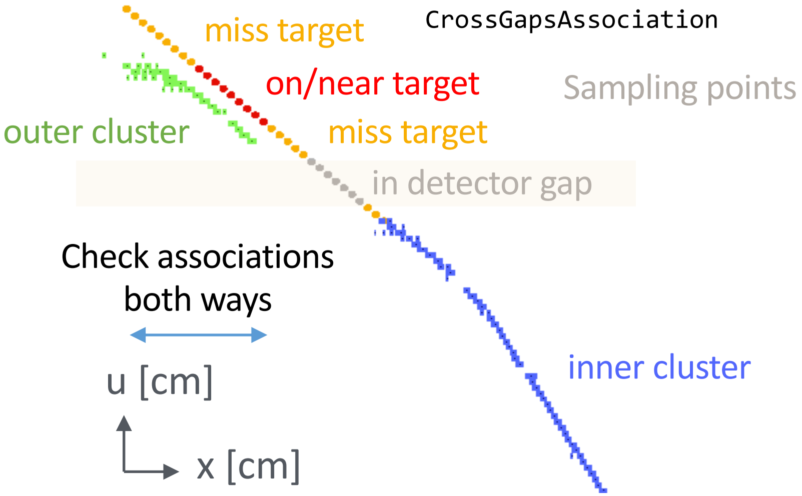
Example: Crossing cosmic-ray muons



Topological Association - 2D

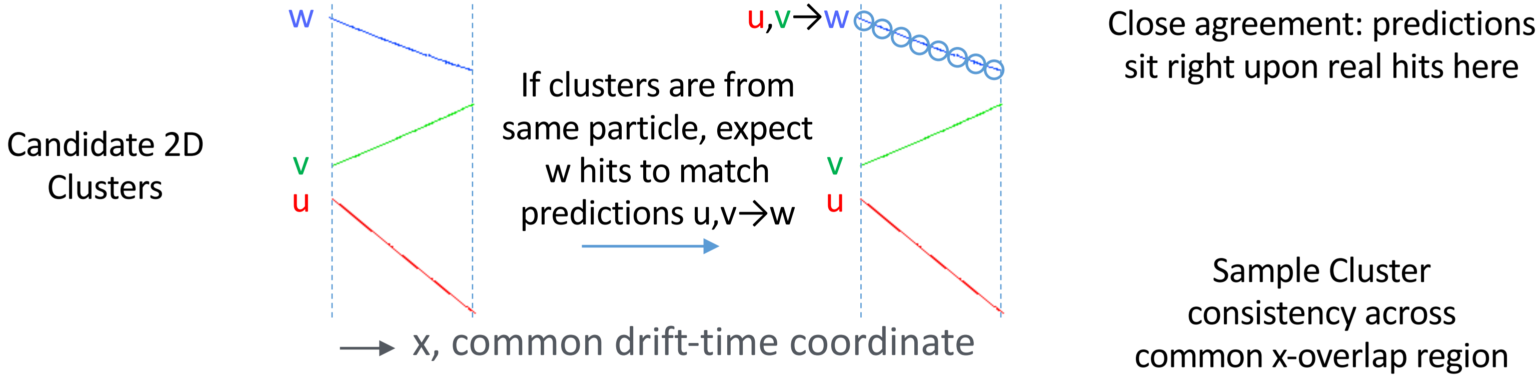
- Cluster-merging algorithms identify associations between multiple 2D clusters and look to grow the clusters to improve completeness, without compromising purity.
  - The challenge for the algorithms is to make cluster-merging decisions in the context of the entire event, rather than just considering individual pairs of clusters in isolation.
  - Typically need to provide a definition of association (for a given pair of clusters), then navigate forwards and backwards to identify chains of associated clusters that can be safely merged.





Track Pattern Recognition - 3D

- Our original input was 3x2D images of charged particles in the detector.
- Should now have reconstructed three separate 2D clusters for each particle:
  - Compare 2D clusters from u, v, w planes to find the clusters representing same particle.
  - Exploit common drift-time coordinate and our understanding of wire plane geometry.
  - At given x, compare predictions {u,v→w; v,w→u; w,u→v} with cluster positions, calculating χ^2

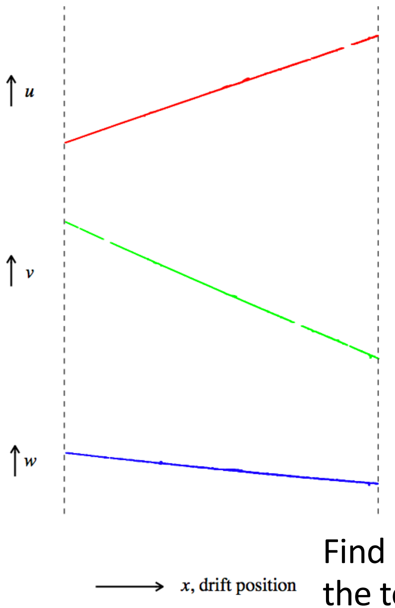


Store all results in a "tensor", recording x-overlap span, no. of sampling points, no. of "matched" sampling points and χ2. Documents all 2D cluster-matching ambiguities.

Track Pattern Recognition - 3D

Tensor stores overlap details for trios of 2D clusters. Tools make 2D reco changes to resolve any ambiguities. If a tool makes a change (e.g. splits a cluster), all tools run again.

ClearTracksTool



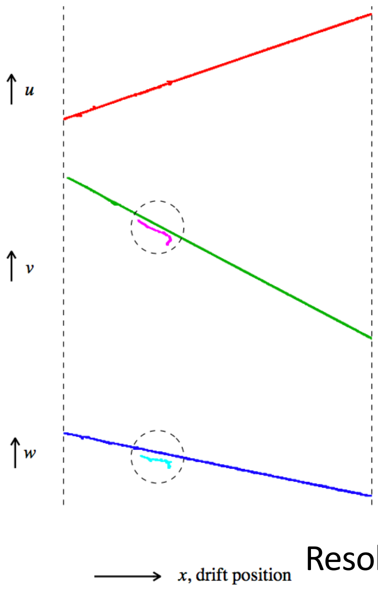
u:*v*:*w*

1:1:1

No. of associated 2D Clusters u:v: w

Find unambiguous elements in the tensor, demanding that the common x-overlap is 90% of the x-span for all three clusters.

LongTracksTool



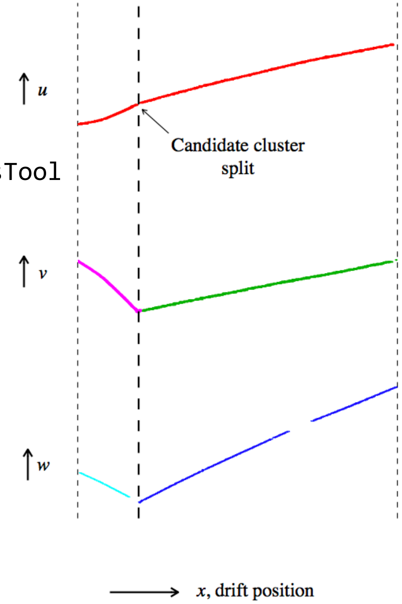
u:*v*:*w*

1:2:2

Resolve obvious ambiguities: clusters are matched in multiple configurations, but one tensor element is much “better” than others.

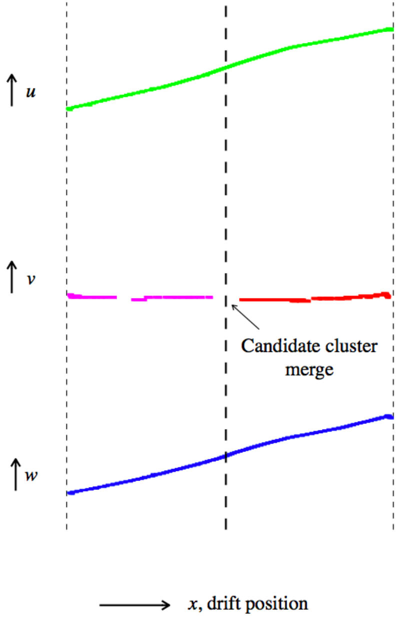
Track Pattern Recognition - 3D

OvershootTracksTool



u:v:w
1:2:2

Two clusters in w and v, matched to common u cluster. Split ***u*** cluster.



u:v:w
1:2:1

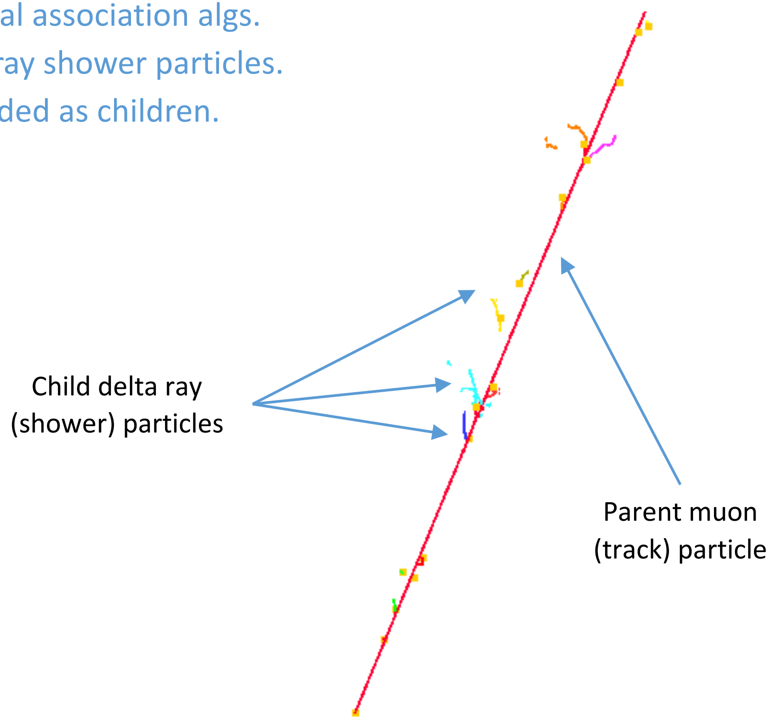
UndershootTracksTool

Two clusters in v view, matched to common clusters in u and w views. Merge ***v*** clusters.

- Use all connected clusters to assess whether this is a true 3D kink topology.
- Modify 2D clusters as appropriate (i.e. merge or split) and update cluster-matching tensor.
- Initial ClearTracks tool then able to identify unambiguous groupings of clusters and form particles.

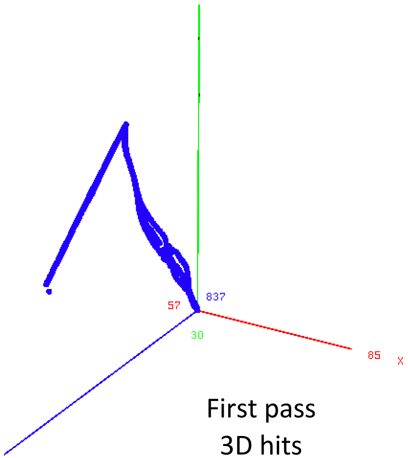
Delta-Ray Reconstruction - 2D, 3D

- Assume any 2D clusters not in a track particle are from delta-ray showers:
  - Simple proximity-based reclustering of hits, then topological association algs.
  - Delta-ray clusters matched between views, creating delta-ray shower particles.
  - Parent muon particles identified and delta-ray particles added as children.

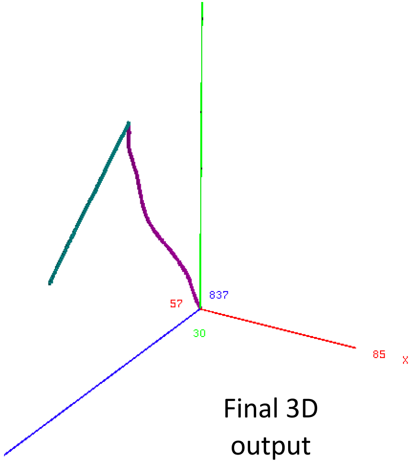


3D Hit/Cluster Reconstruction

- For each 2D Hit, sample clusters in other views at same x, to provide u_{in}, v_{in} and w_{in} values
- Provided u_{in}, v_{in} and w_{in} values don't necessarily correspond to a specific point in 3D space
- Analytic expression to find 3D space point that is most consistent with given u_{in}, v_{in} and w_{in}
  - $\chi^2 = (u_{out} - u_{in})^2 / \sigma_u^2 + (v_{out} - v_{in})^2 / \sigma_v^2 + (w_{out} - w_{in})^2 / \sigma_w^2$
  - Write in terms of unknown y and z, differentiate wrt y, z and solve
  - Can iterate, using fit to current 3D hits (extra terms in χ^2) to produce smooth trajectory



First pass
3D hits

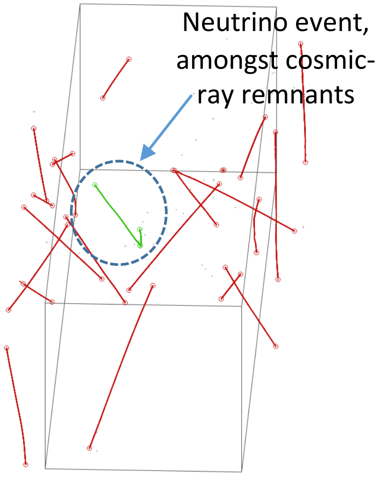


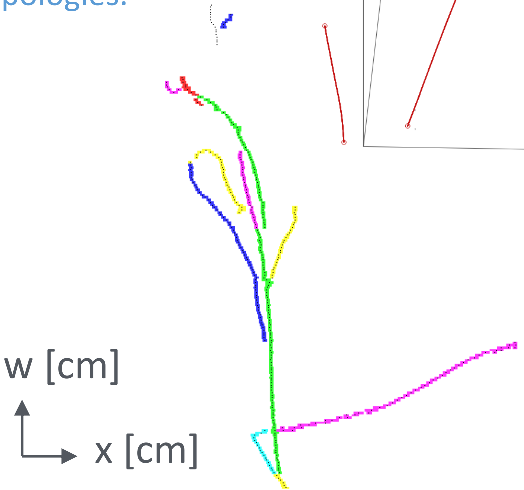
Final 3D
output

Pandora Nu chain

Neutrino Reconstruction

- Must be able to deal with presence of any cosmic-ray muon remnants.
  - Run fast version of reconstruction, up to 3D hit creation
  - “Slice” 3D hits into separate interactions, processing each slice in isolation.
  - Each slice ⇒ candidate neutrino particle.
- Neutrino pass reuses track-oriented clustering and topological association.
  - Topological association algs must handle rather more complex topologies.
  - Specific effort to reconstruct neutrino interaction vertex.
  - More sophisticated efforts to reconstruct showers.

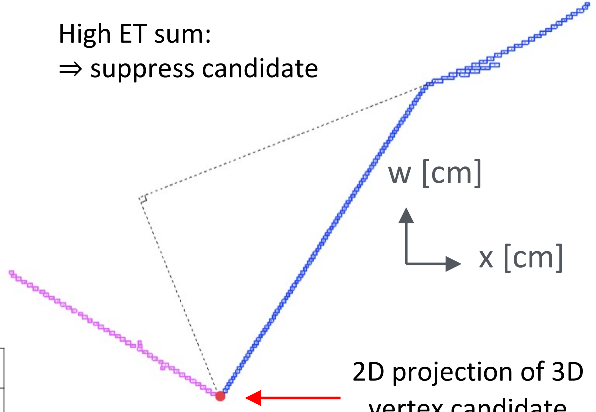




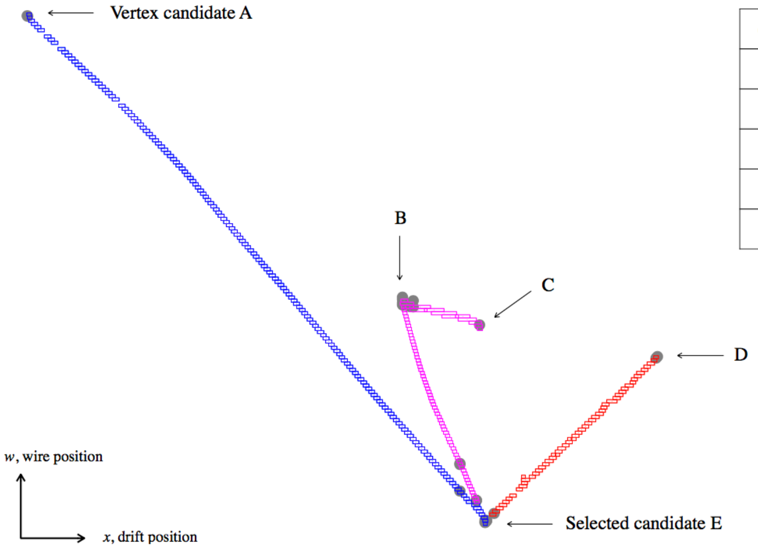
Neutrino Reconstruction

- Search for neutrino interaction vertex:
  - Use pairs of 2D clusters to produce list of possible 3D vertex candidates.
  - Examine candidates, calculate a score for each and select the best.

High ET sum:
⇒ suppress candidate



2D projection of 3D vertex candidate



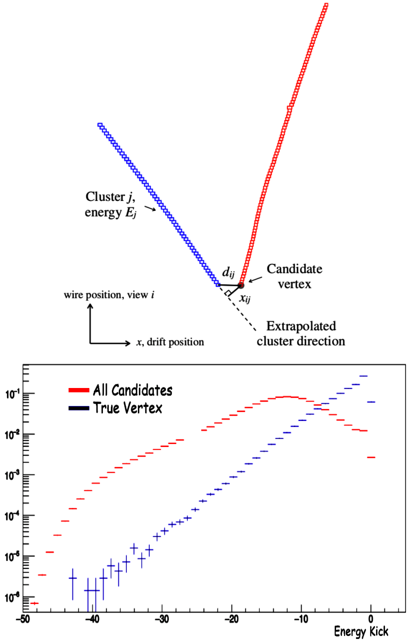
Candidate	S	$S_{\text{energy kick}}$	$S_{\text{asymmetry}}$	$S_{\text{beam deweight}}$
A	4.9E-07	3.5E-06	1.00	0.14
B	1.3E-02	3.1E-02	0.99	0.42
C	1.1E-03	2.4E-03	0.95	0.46
D	5.7E-10	1.1E-09	1.00	0.52
E	9.0E-01	9.0E-01	1.00	0.99

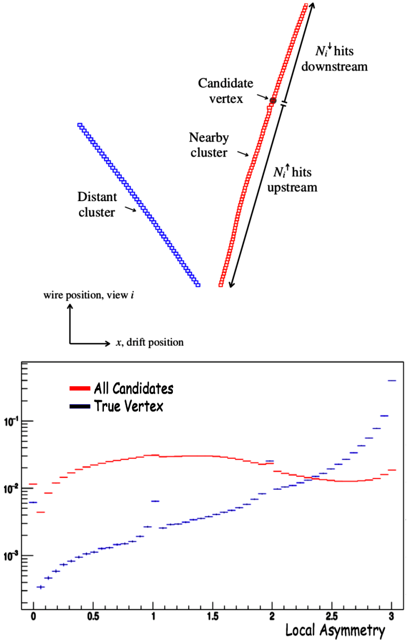
Scores for labelled candidates, with breakdown into component parts:

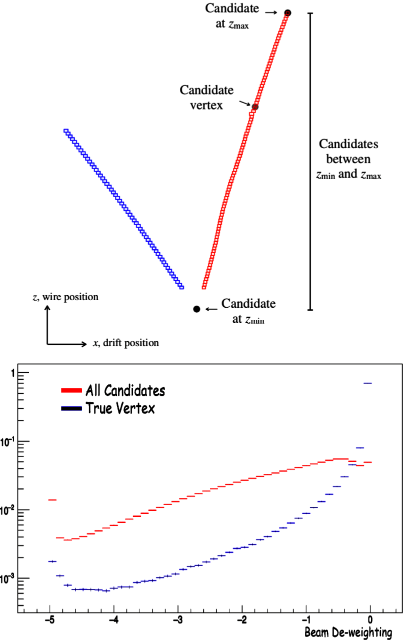
- Downstream usage:
  - Split 2D clusters at projected vertex position.
  - Use vertex to protect primary particles when growing showers.

Vertex Reconstruction – 3D

- Interaction vertex is an important feature point in our LArTPC images:
  - Continued development, ever-more sophisticated approaches to finding 3D vertex position
  - Boosted Decision Trees (BDTs) or Support Vector Machines (SVMs) to select best candidate
  - Exploit Convolutional Neural Networks (CNNs) ⇒ Deep Learning talk/tutorial tomorrow



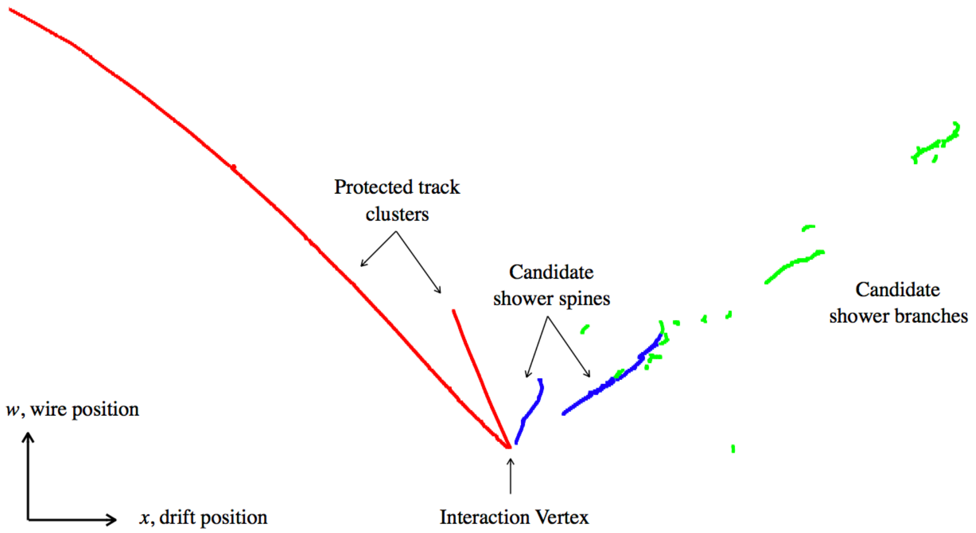




E.g BDT/SVM "features"

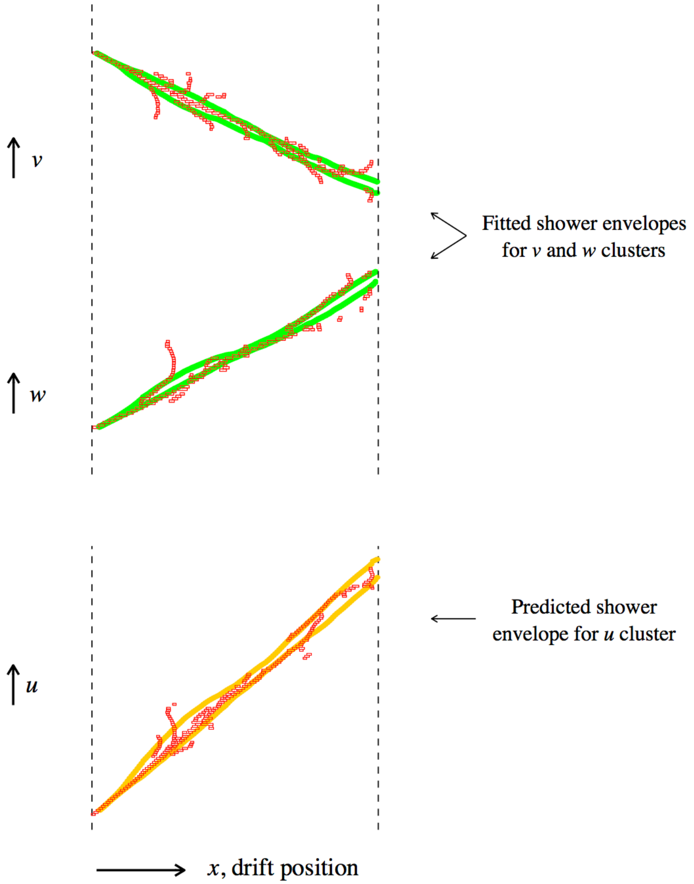
Shower Reconstruction - 2D

- Track reconstruction exactly as in PandoraCosmic, but now also attempt to reconstruct primary electromagnetic showers, from electrons and photons:
  - Characterise 2D clusters as track-like or shower-like and use topological properties to identify clusters that might represent shower spines.
  - Add shower-like branch clusters to shower-like spine clusters. Recursively identify branches on the top-level spine candidate, then branches on branches, etc.



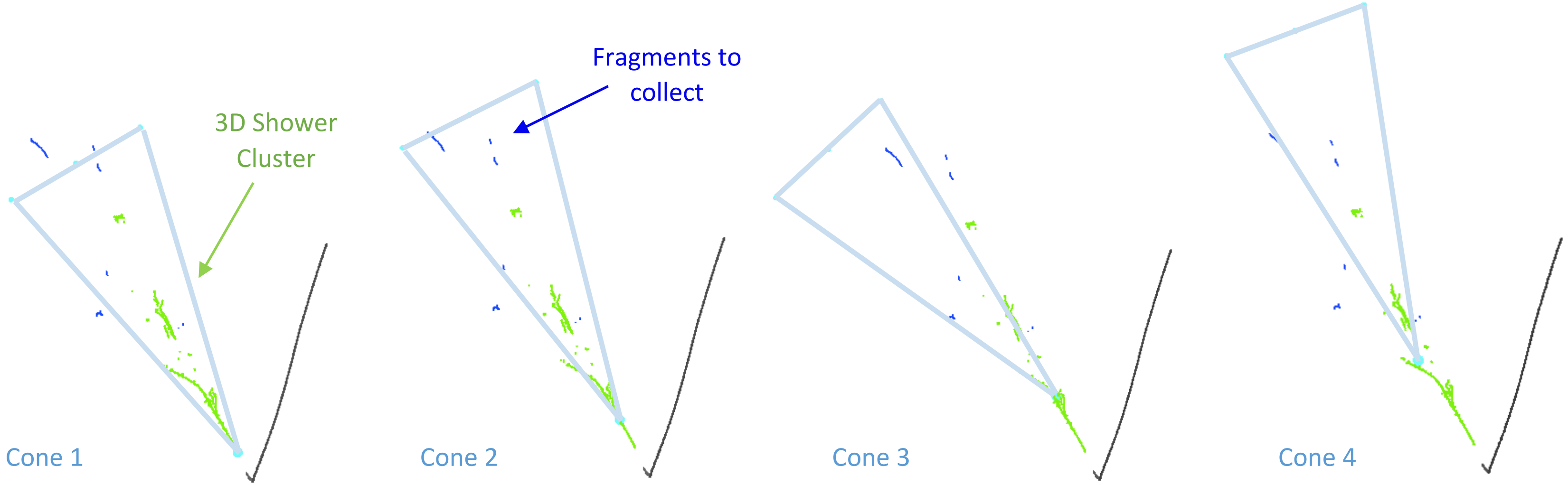
Shower Reconstruction - 3D

- Reuse ideas from track reco to match 2D shower clusters between views:
  - Build a tensor to store cluster overlap and relationship information.
  - Overlap information collected by fitting shower envelope to each 2D cluster.
  - Shower edges from two clusters used to predict envelope for third cluster.



Particle Refinement - 2D, 3D

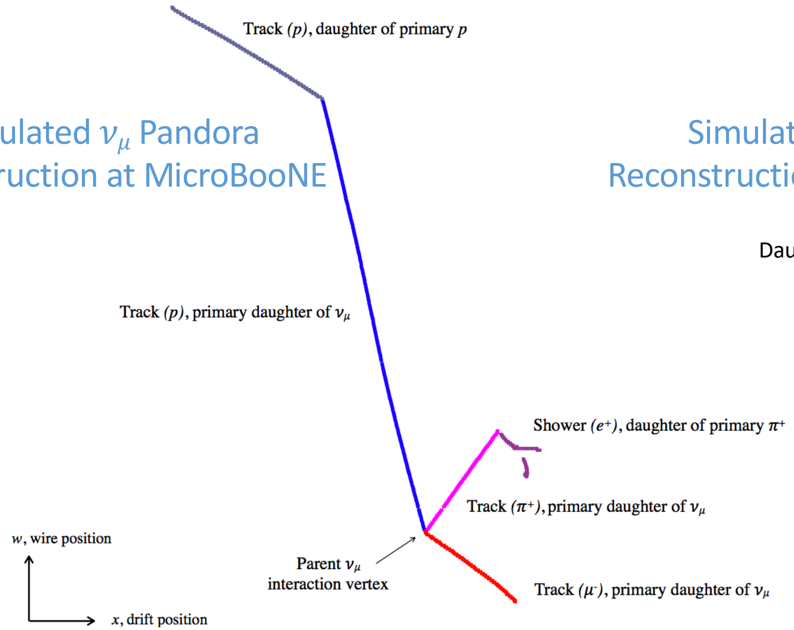
- Series of algs deal with remnants to improve particle completeness (esp. sparse showers):
  - Pick up small, unassociated clusters bounded by the 2D envelopes of shower-like particles.
  - Use sliding linear fits to 3D shower clusters to define cones for merging small downstream shower particles or picking up additional unassociated clusters.
  - If anything left at end, dissolve clusters and assign hits to nearest shower particles in range.



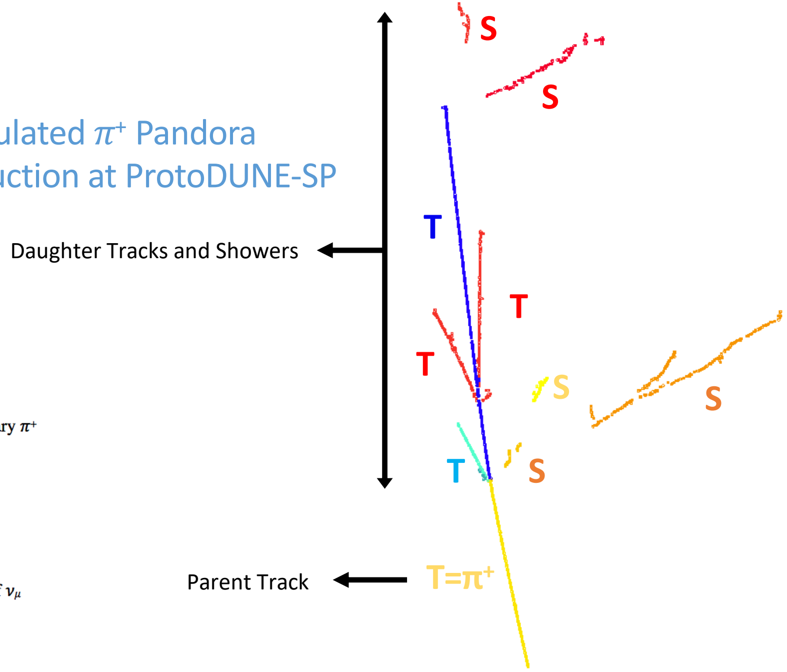
Particle Hierarchy Reconstruction - 3D

- 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



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We will now try visualizing actions of individual algorithms