Pandora for Cosmics

An Overview & Future Improvements

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2023/03/27

WARWICK
THE UNIVERSITY OF WARWICK

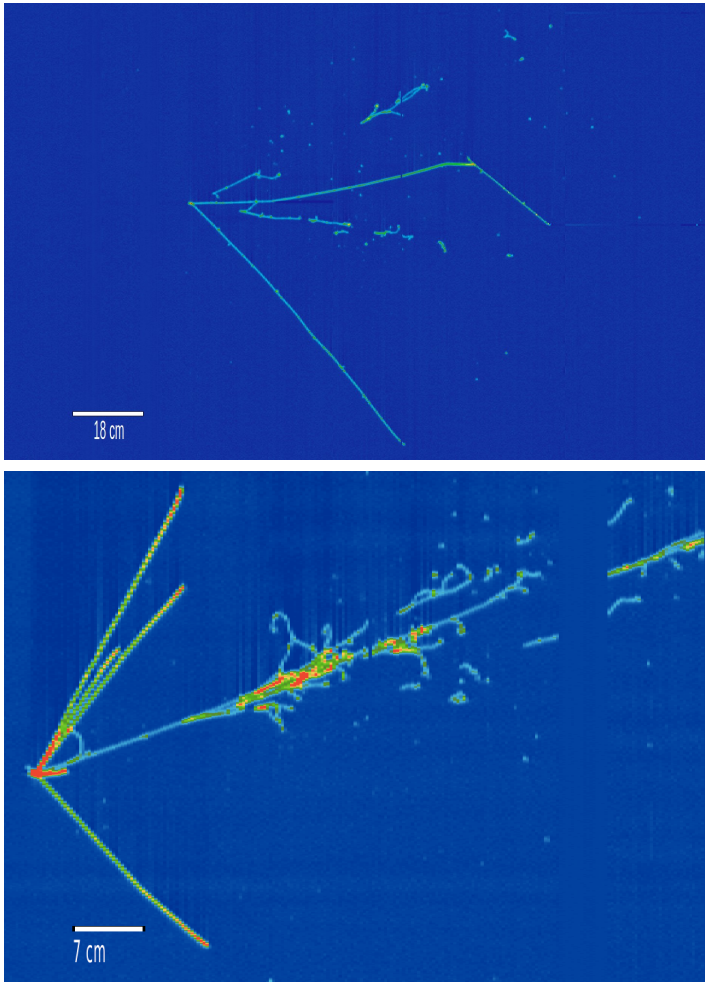
Overview

This talk will cover:

1. **An overview of Pandora.**
2. **Pandora Cosmic**
3. **Pandora Neutrino**
4. **Improving Pandora's Reconstruction of Cosmic Rays**

LArTPC Event Reconstruction

There are many steps in the conversion of raw LArTPC images to analysis-level quantities:



- Low Level Reco:
  - Noise Filtering
  - Signal Processing
- Pattern Recognition:
  - The most 'visual' step
  - Images -> 2D Hits
  - Sparse 2D Hits -> Clusters
  - 2D Clusters -> 3D Particle Representation
  - Produce a full 3D particle flow hierarchy
- High-level Characterisation:
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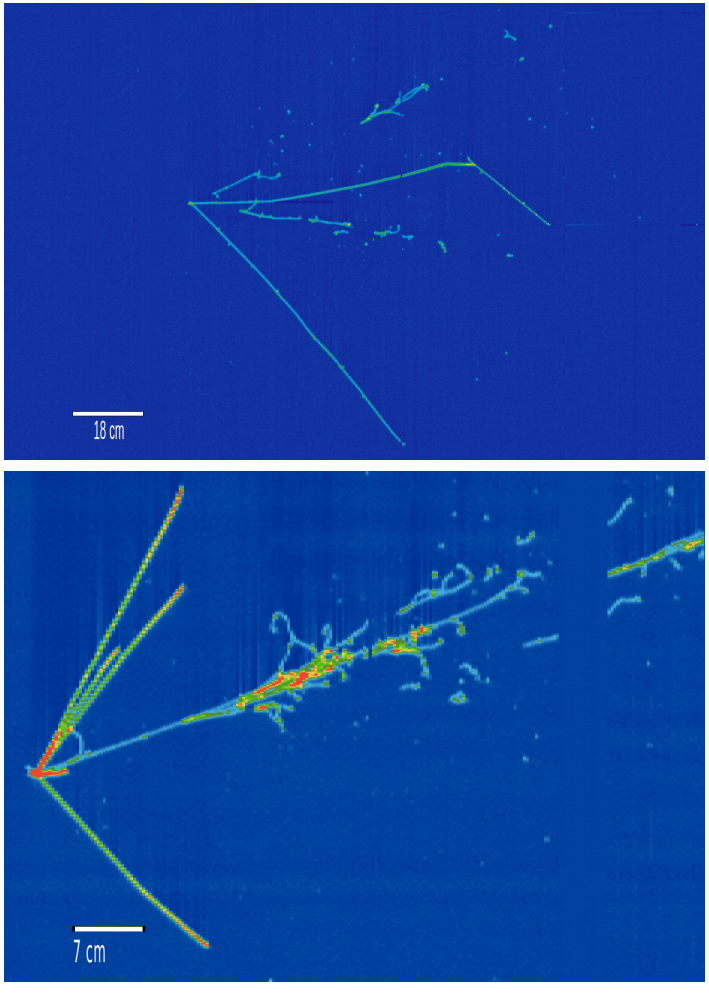

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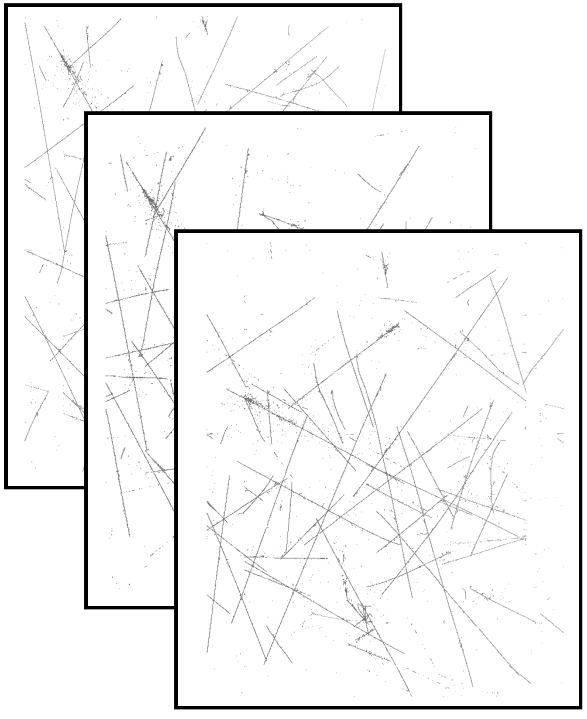
Pattern Recognition

During the Pattern Recognition step, there is a few main goals:

- Produce 3D reconstructed particles, from the input 2D images.
- Build up a 3D particle-interaction hierarchy, starting from the initial neutrino or test beam.



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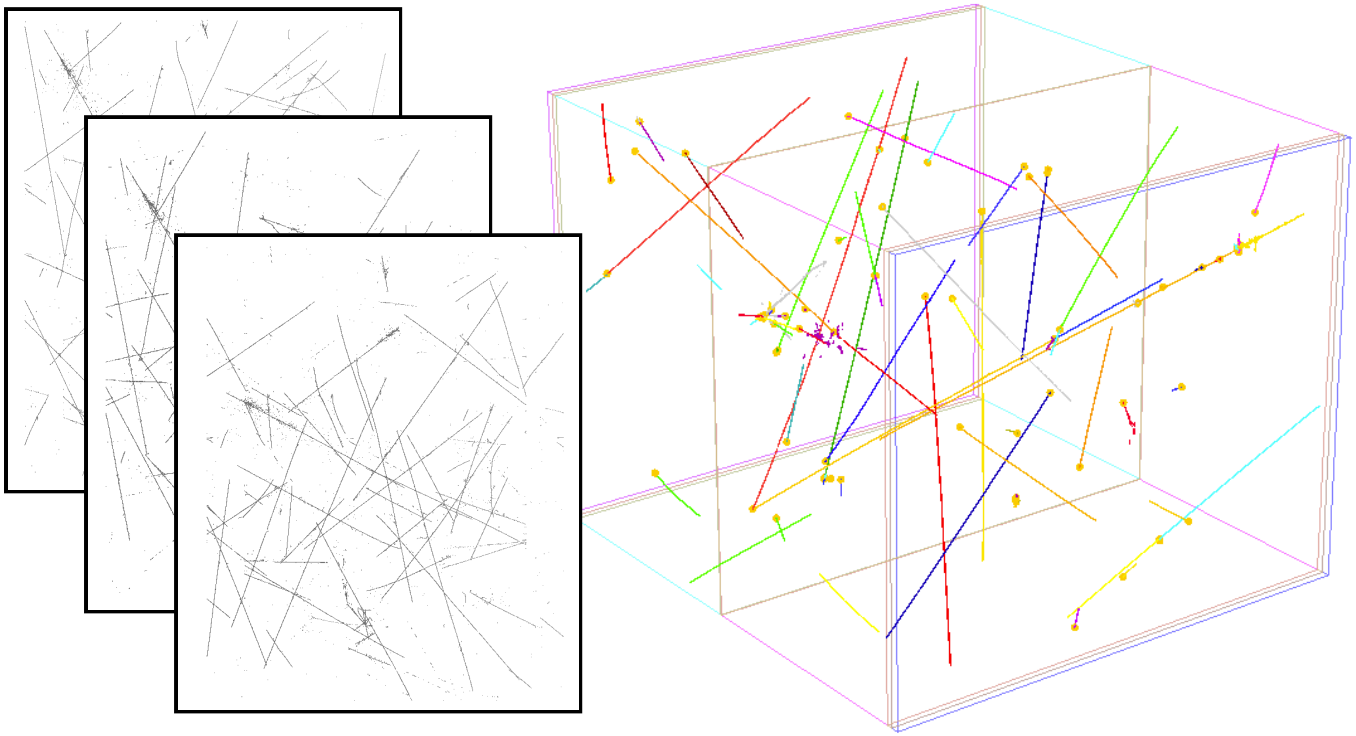

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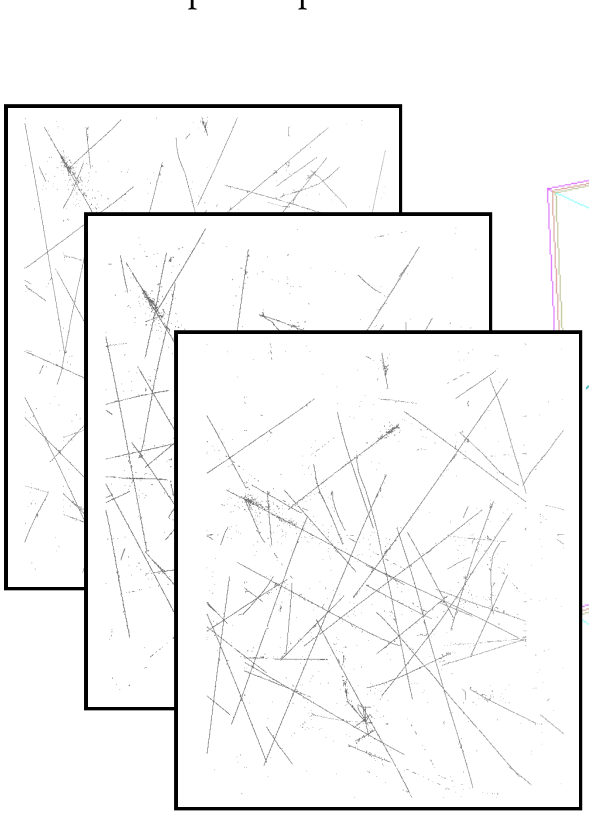

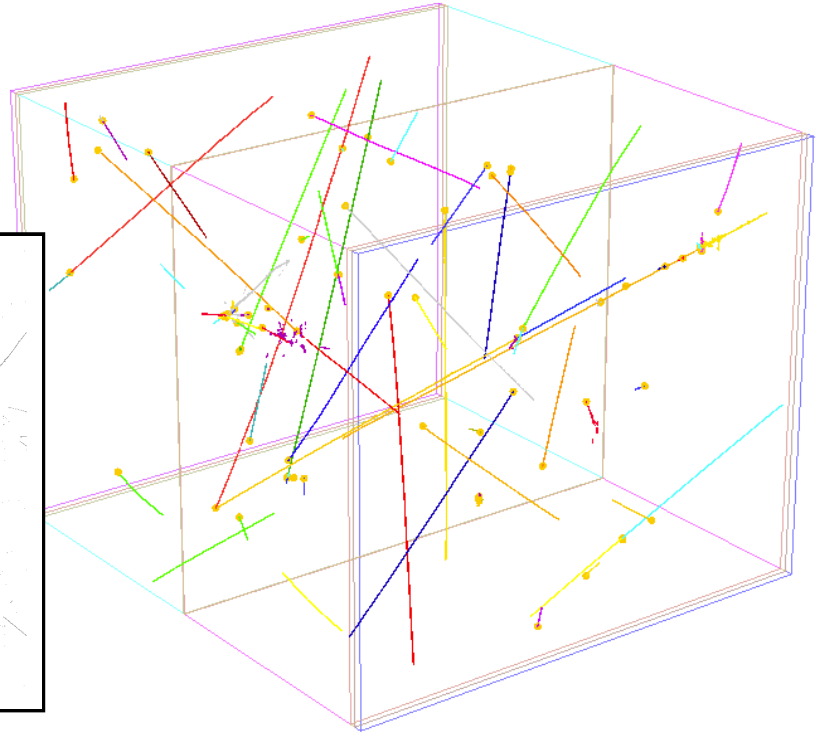

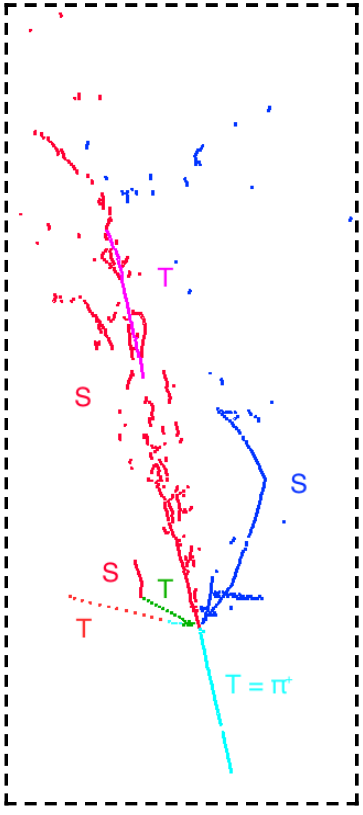

Challenges for LArTPC Pattern Recognition

It is a significant challenge to develop automated, algorithmic LArTPC pattern recognition.

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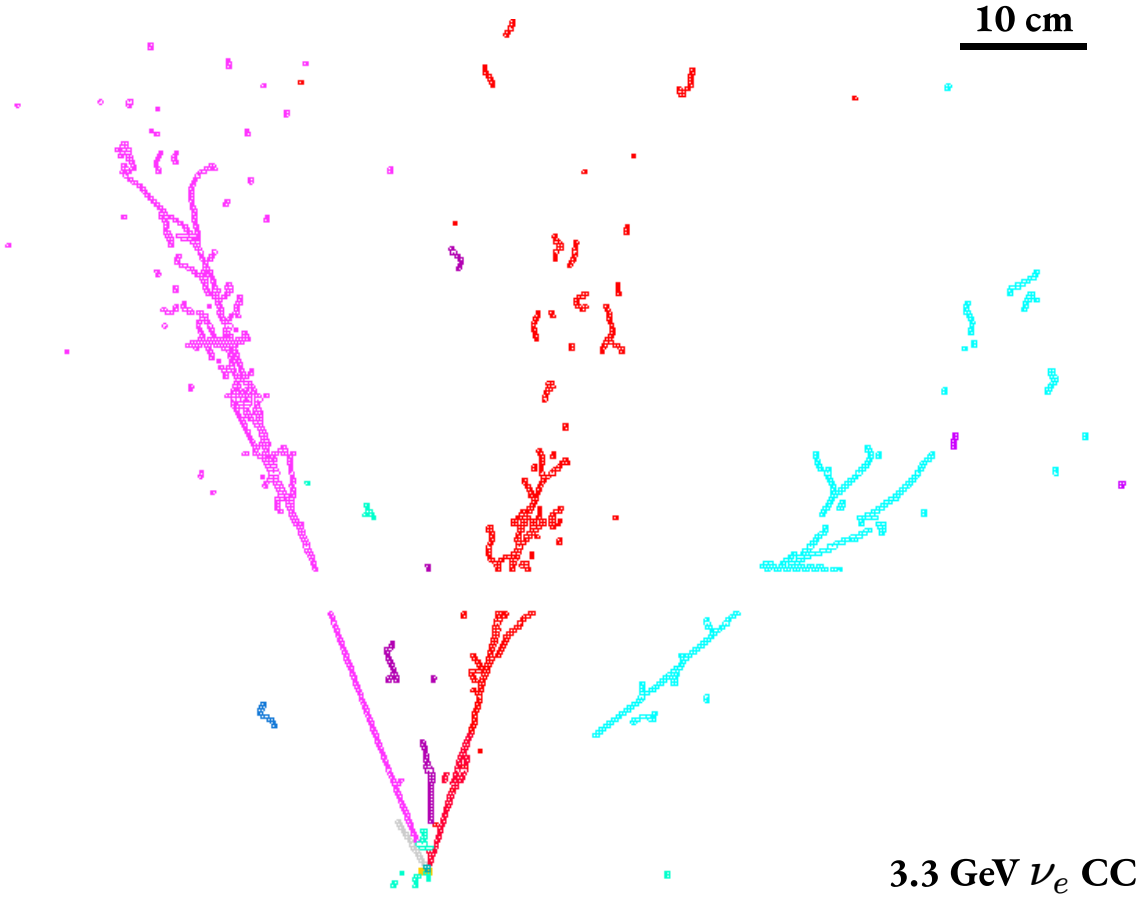

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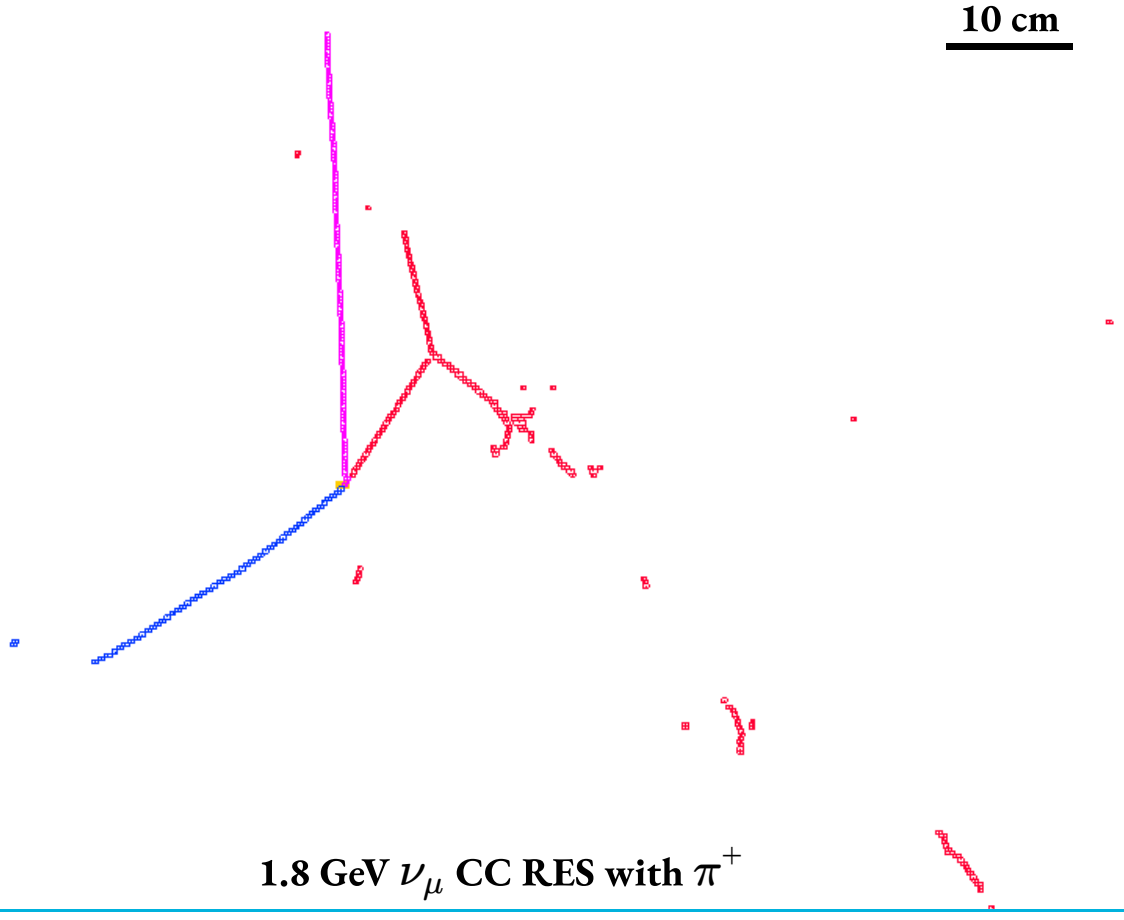

1.8 GeV ν_μ CC RES with π^+

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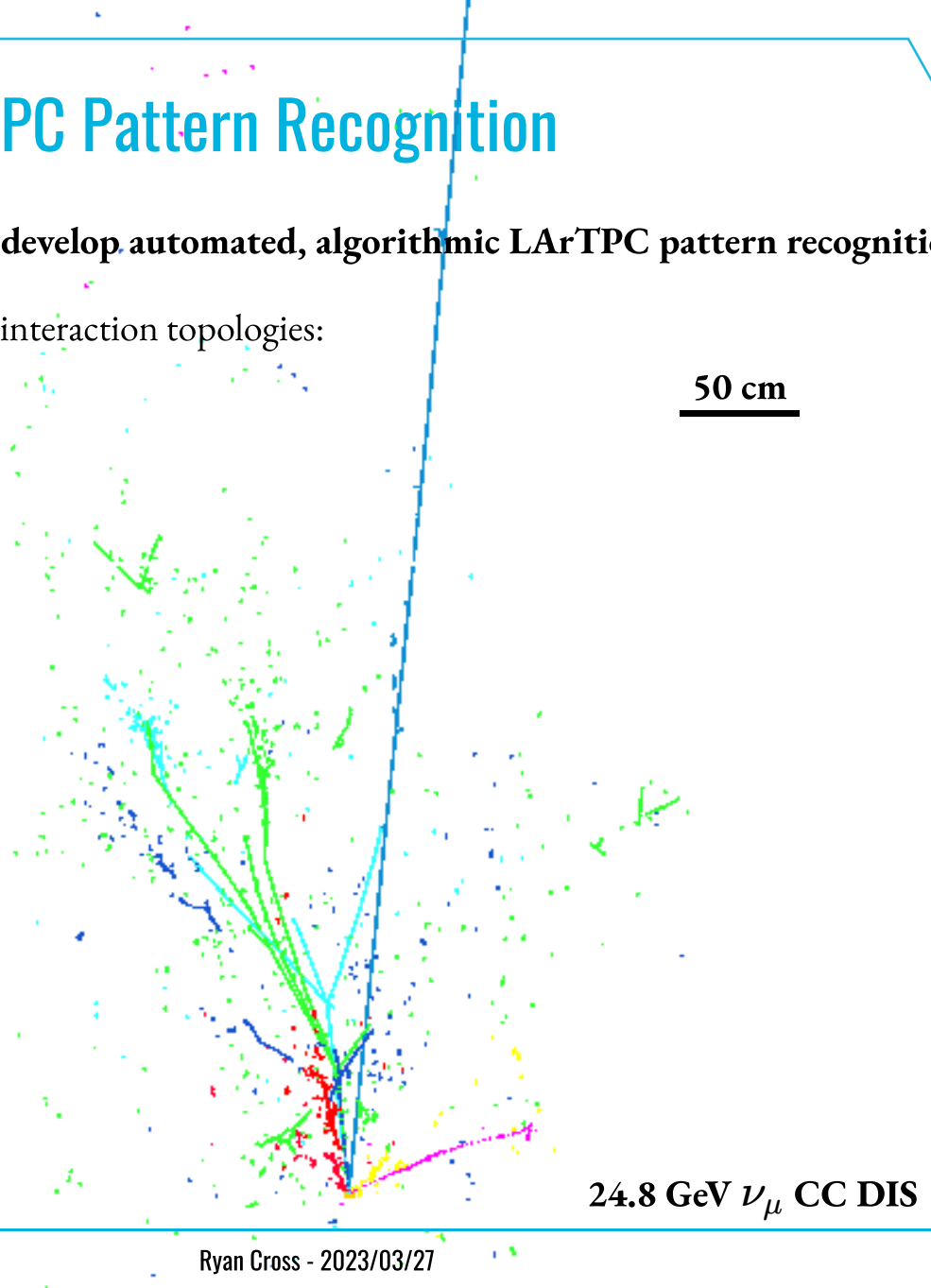

Challenges for LArTPC Pattern Recognition

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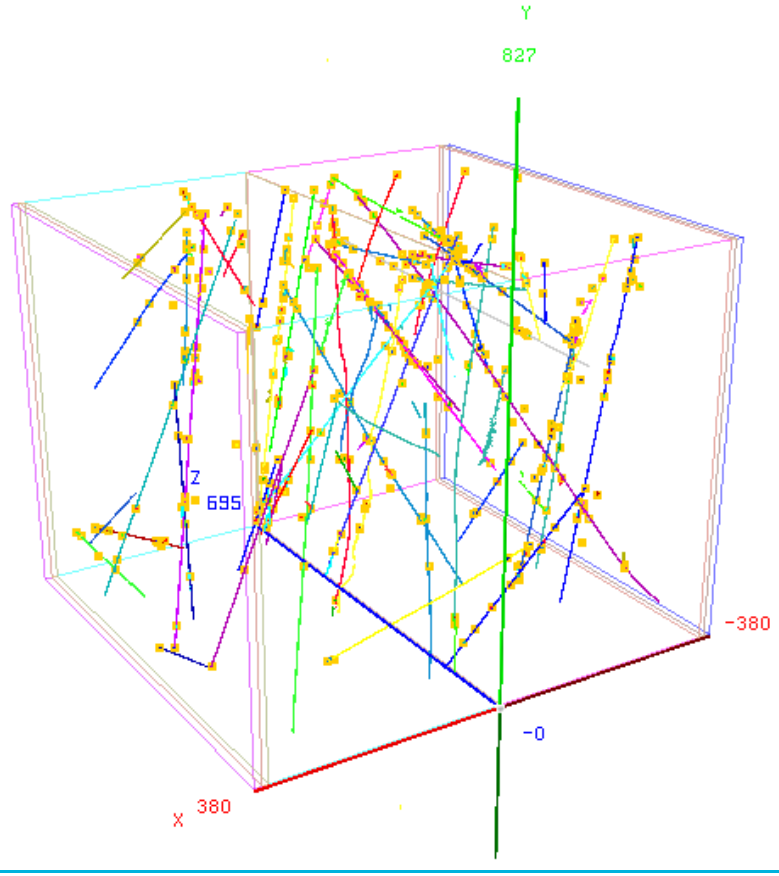
Also, due to the long readout times of the detector technology, surface based detectors have significant cosmic-ray muon backgrounds.

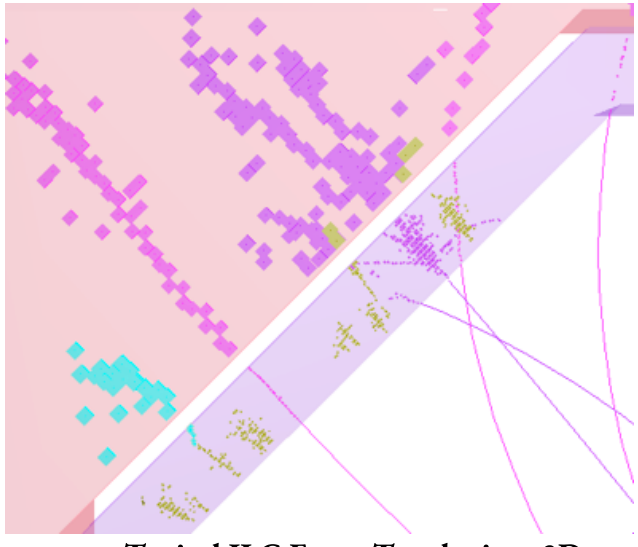


Pandora Multi-Algorithm Approach

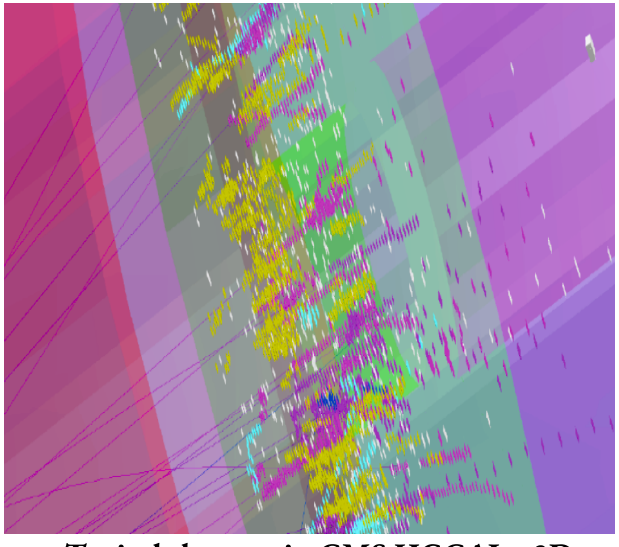
A single approach to clustering is unlikely to work for the complex topologies in a LArTPC, with a mix of track-like and shower-like clusters.

Pandora project has tackled similar problems before, utilising a multi-algorithm approach:

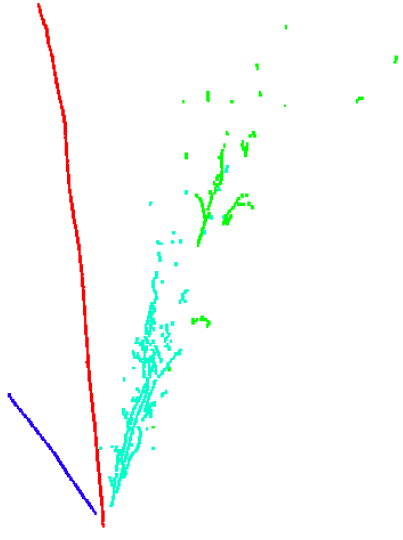
- Build up events gradually.
- Use incremental steps, avoiding mistakes.
- Deploy more sophisticated algorithms as the event picture develops.
- Integrate Physics and Detector knowledge into algorithms.



Typical ILC Event Topologies - 3D
NIMA.2009.09.009 NIMA.2012.10.038



Typical showers in CMS HGCAL - 3D
LHCC-P-008



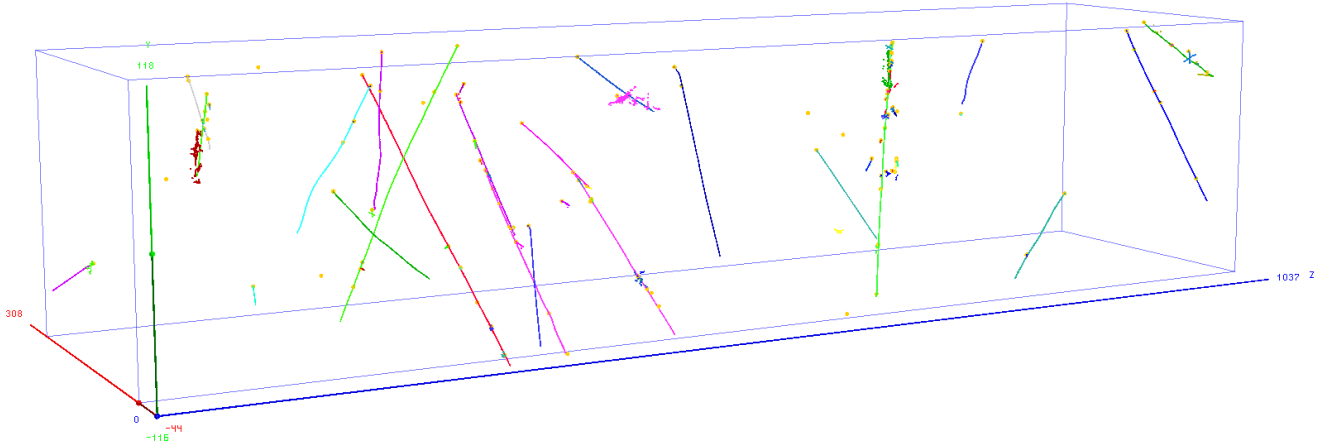
BNB Interaction at MicroBooNE - 3 x 2D

Pandora Multi-Algorithm Approach

Pandora is a flexible reconstruction framework, in use across a wide variety of LArTPC experiments, each with different needs and concerns.

For example, MicroBooNE as a surface based detector has a much greater concern with cosmic rays compared to DUNE. However, a DUNE FD module is much larger and in a higher energy beam, so algorithms that work at MicroBooNE will need additional tuning at DUNE to account for these differences.

This, again, lends itself very strongly to the multi-algorithm approach taken by Pandora. Algorithms can be swapped in and out as needed in config files to address the specific concerns of an experiment with new algorithms or tuning of existing ones.



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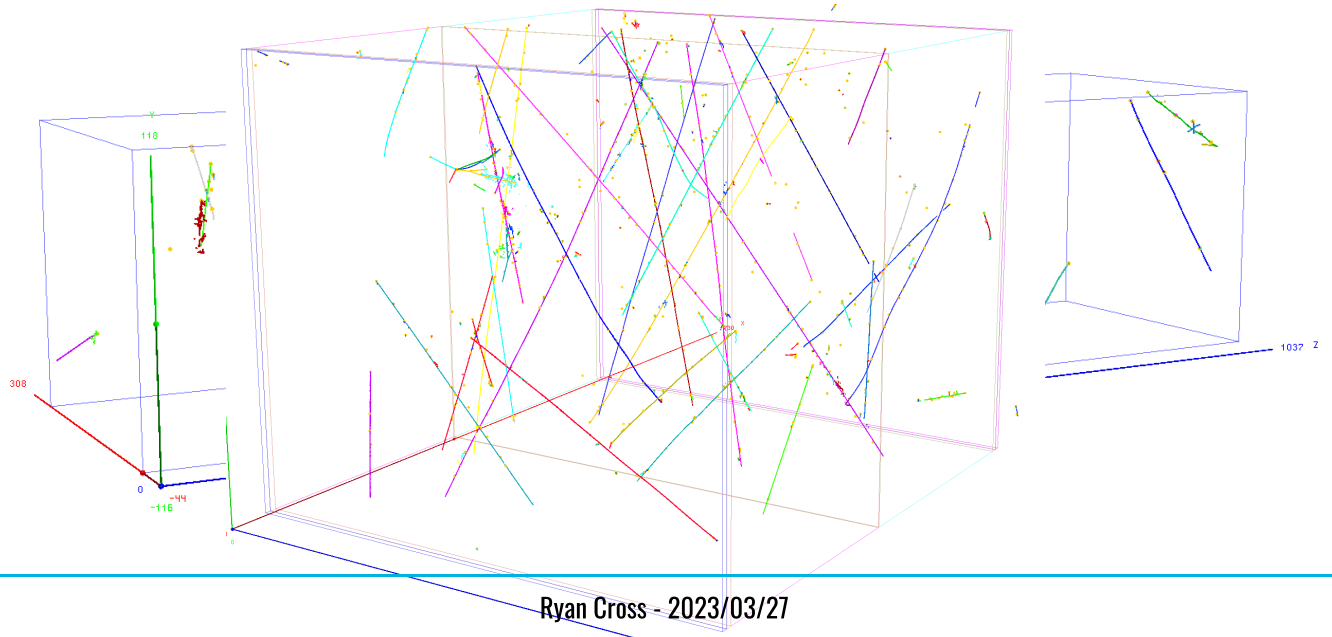
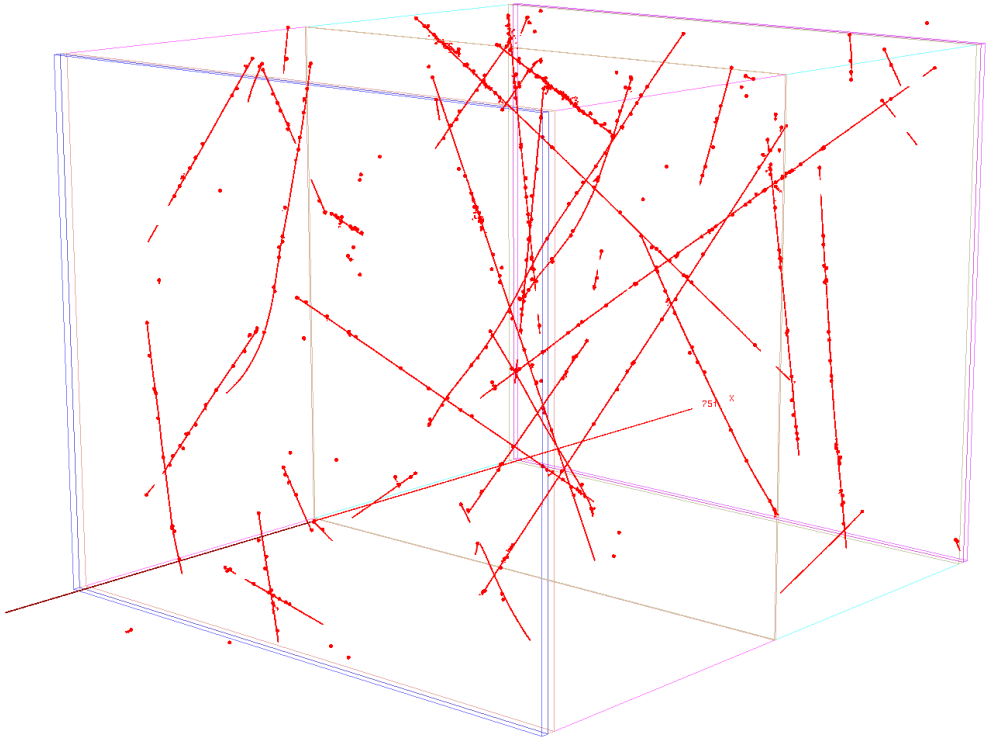


Pandora Algorithm Chains - Pandora Cosmic

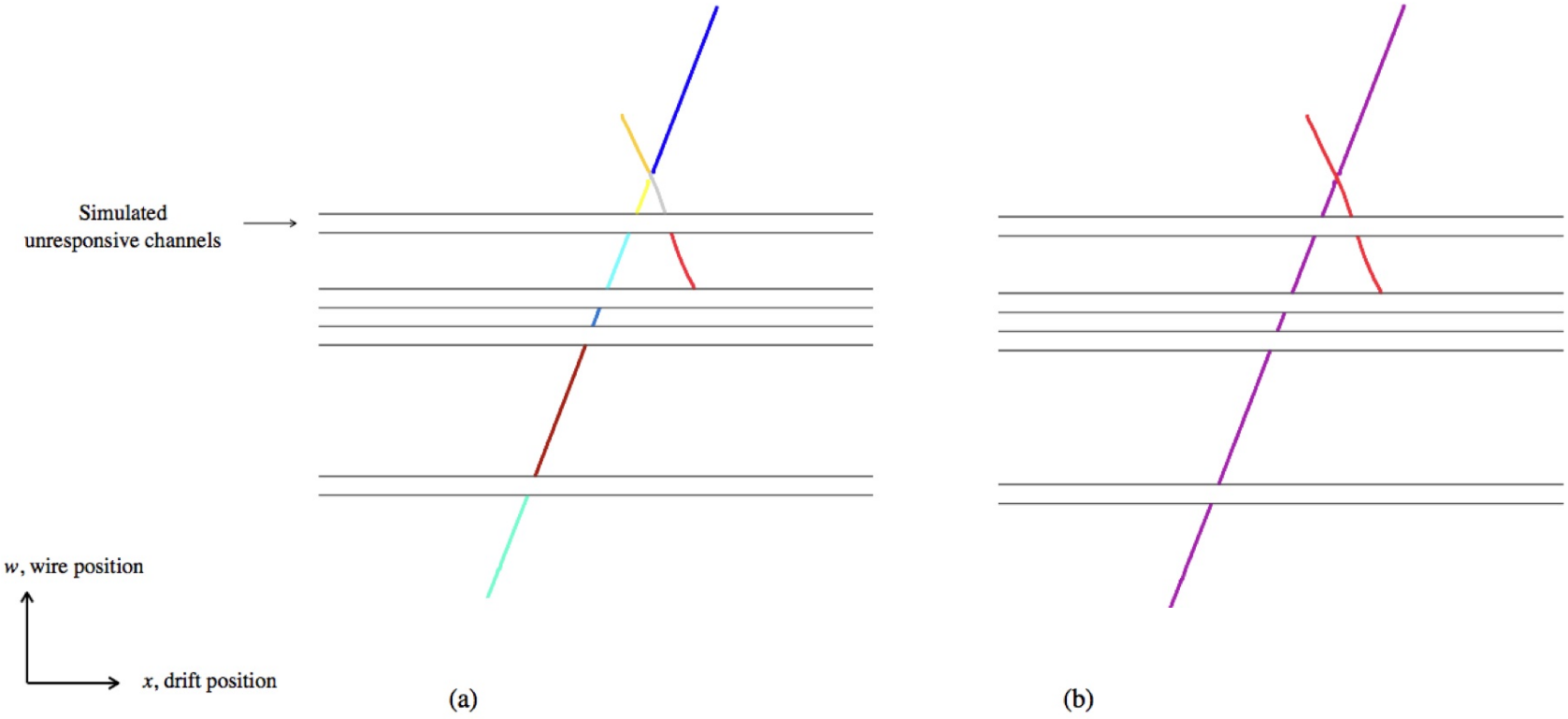
Pandora Cosmic is optimised for the reconstruction of cosmic rays, such that it is much more track focused than the neutrino reconstruction pass, and has different assumptions baked in compared to the neutrino reconstruction, such as the direction a particle is moving.

Broadly, this chain is targeted towards dealing with a high multiplicity of track-like particles in an event, and to effectively remove the most obvious cosmic rays.



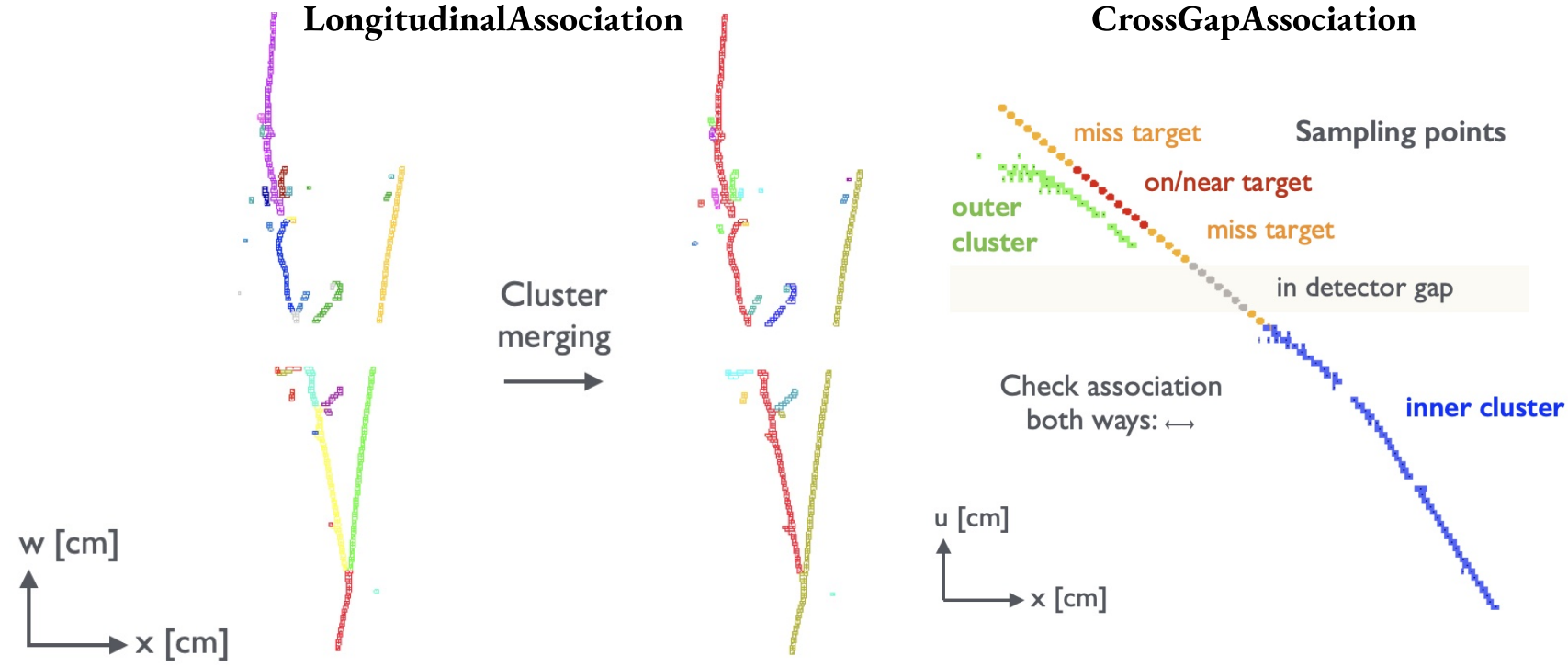
Pandora Cosmic - 2D

For each plane, a list of 2D clusters is produced that represents any continuous lines unambiguously connected hits. This is then refined and improved with iterative algorithms, either merging or splitting clusters as needed.



Pandora Cosmic - 2D

This is followed by algorithms that identify associated between distinct clusters and merge between them, improving the completeness of particles. This needs to be done with a full event context, not just per-cluster.

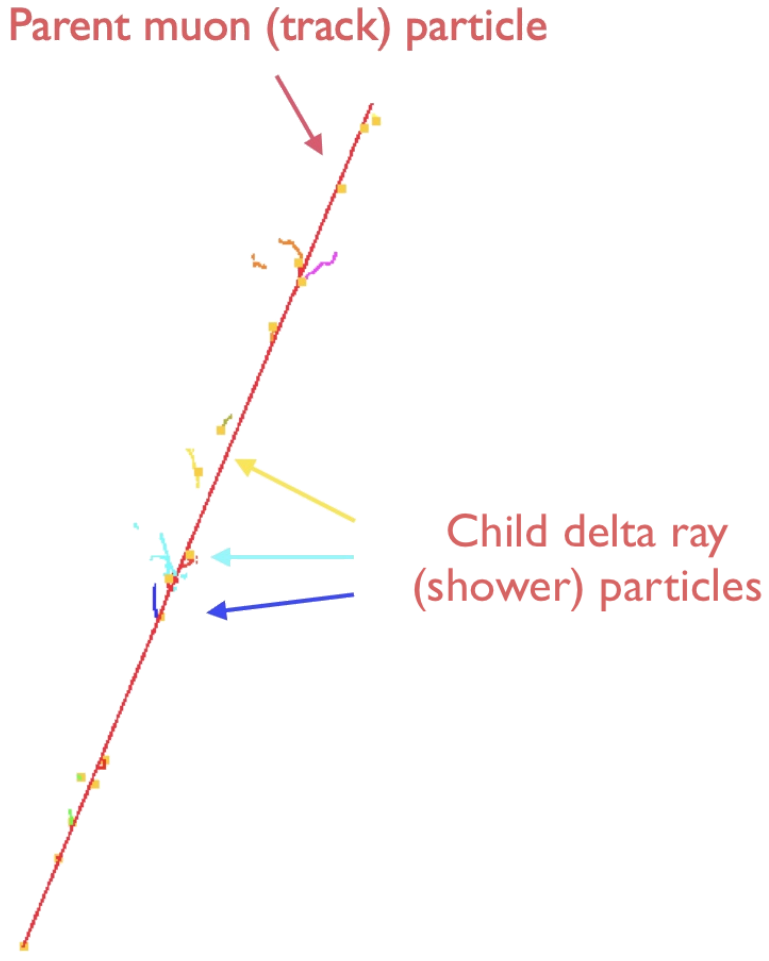


Pandora Cosmic - Delta Rays

The merged and grown clusters are then compared across each view, to find matching positions and build up a full 3D representation of the cosmic rays.

With this 3D information, the remaining hits in the event can be processed under a delta ray hypothesis, to attach them to the relevant cosmic ray.

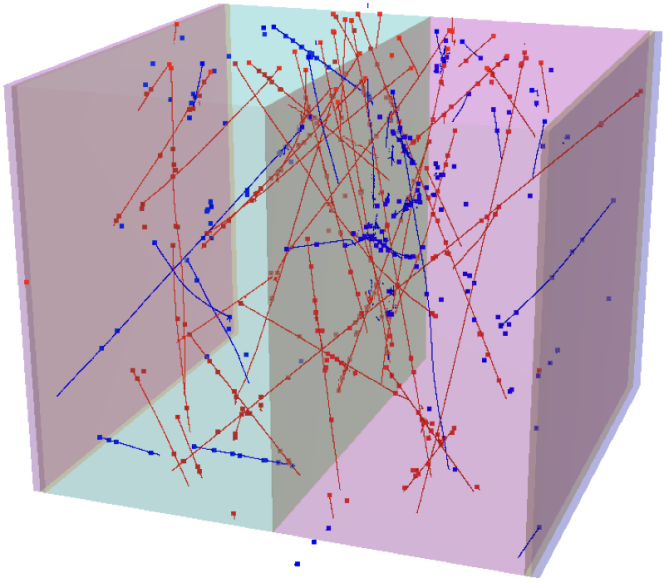
Matches between views are made, and delta-ray shower particles are made, then associated with parent muon particles.



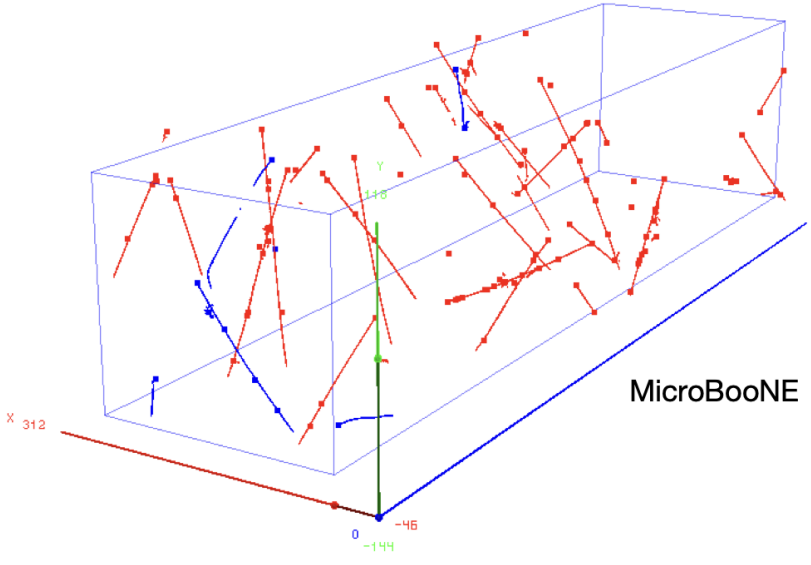
Pandora Neutrino - Overview

To contrast that, there is the Pandora Neutrino configuration chain, which is optimised for the single neutrino or test beam interactions.

Many of the steps are very similar to the cosmic ray reconstruction, so I'll focus on the critical stages that are unique to the neutrino reconstruction.



ProtoDUNE-SP



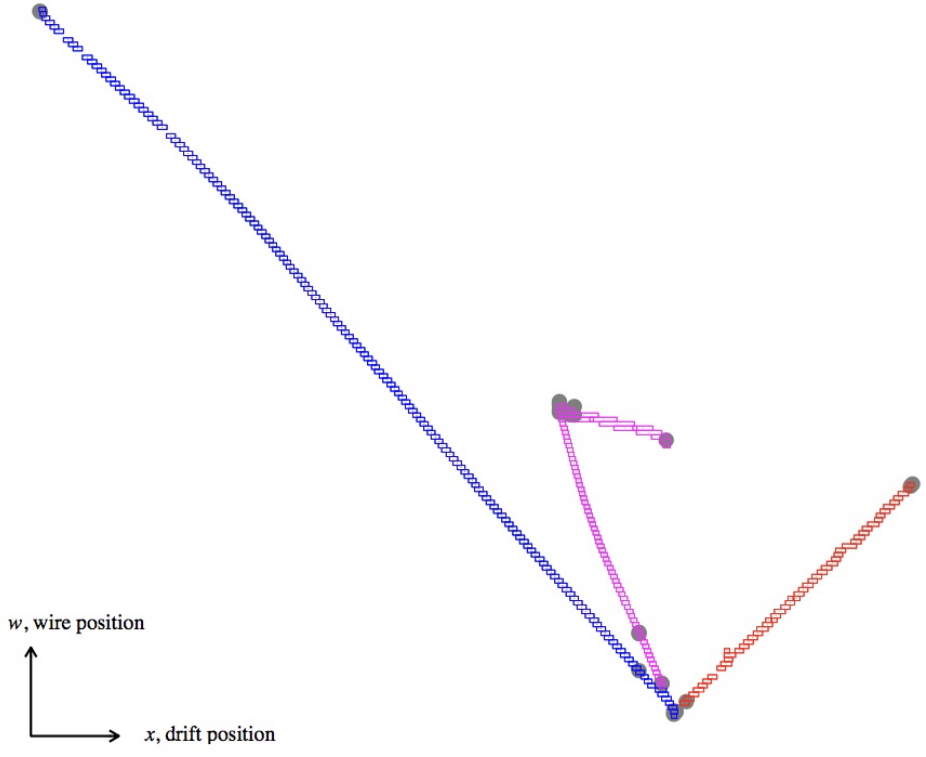
Clear cosmic-ray muons

Ambiguous particles

Pandora Neutrino - Vertex Reconstruction

The most critical part of the neutrino reconstruction is the early deduction of an interaction vertex.

At MicroBooNE, this currently is achieved through the production of many potential interaction points, which are subsequently scored by an SVM to pick a primary interaction location. This will be replaced by a DL-based approach from DUNE in the near future.



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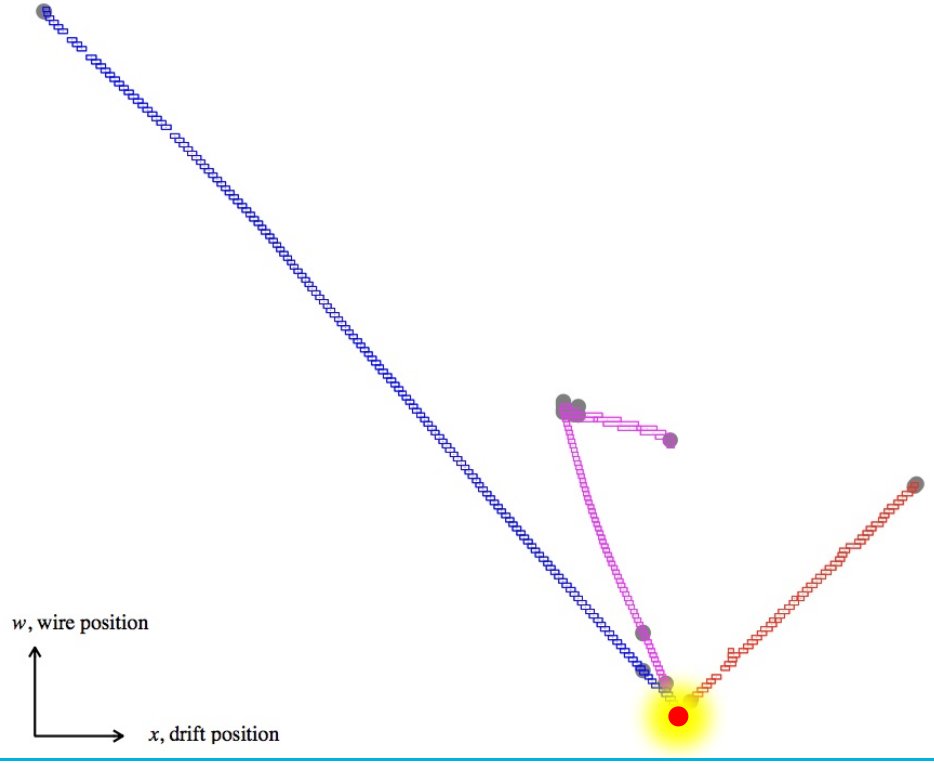
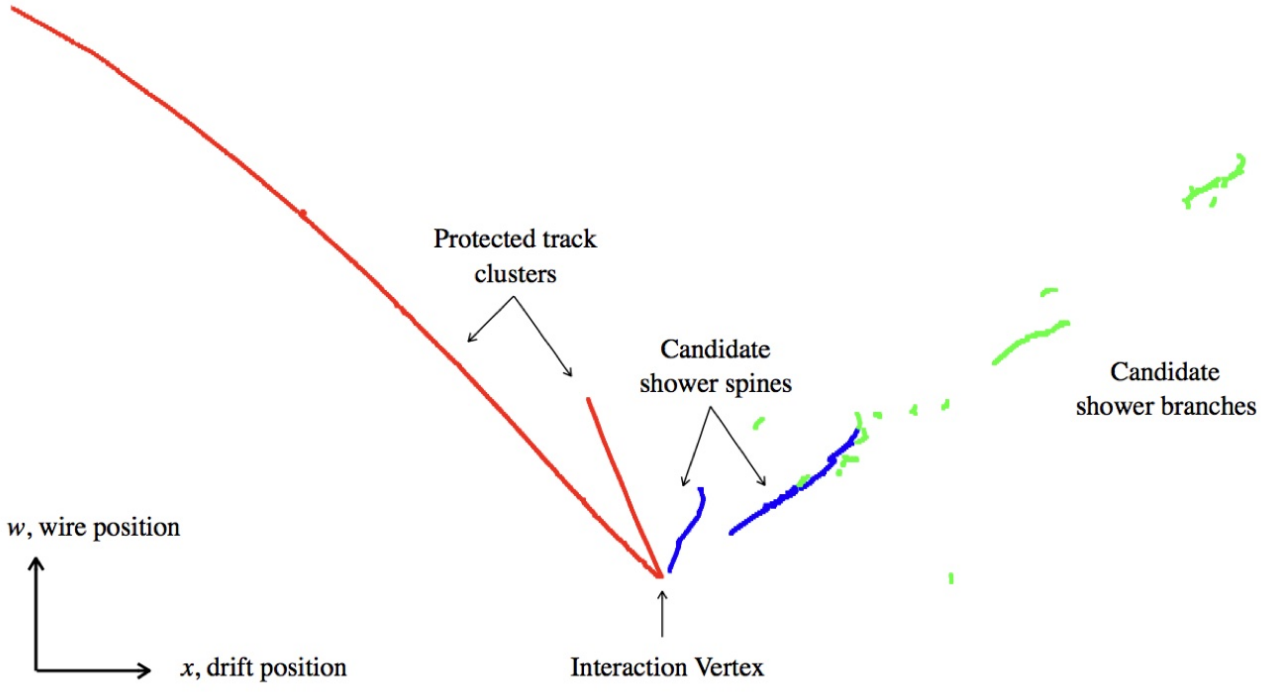


Pandora Neutrino - Shower Reconstruction

Whilst the track reconstruction is mostly identical to Pandora Cosmic, the neutrino configuration also attempts to reconstruct primary electromagnetic showers. This is achieved through early classification of clusters as shower or track-like, before passing through the chains of relevant algorithms.

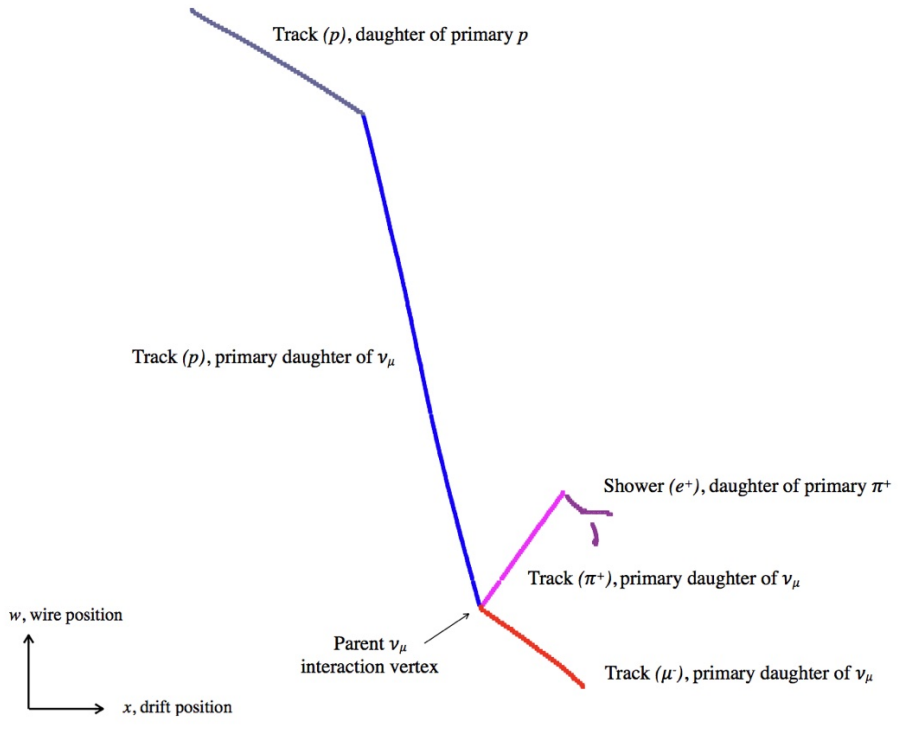
For showers, Pandora slowly builds up shower spines and iteratively attaches branch candidates to these spines and on and on, until a full shower is formed.



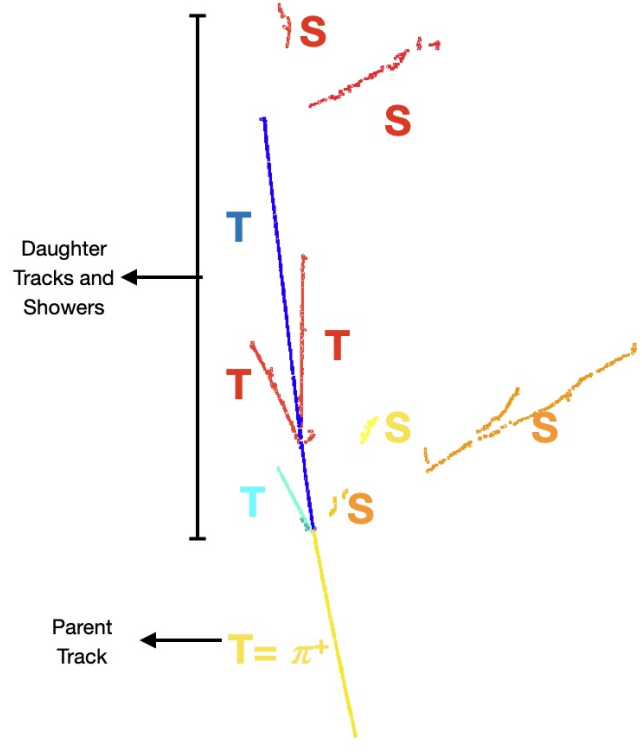
Pandora Neutrino - Hierarchy Reconstruction

With the showers and tracks in an event reconstructed, including a similar matching process for 2D showers to produce 3D showers, the 3D representation of the event can be used to build an interaction hierarchy, started from the found 3D vertex.

Simulated ν_μ Pandora Reconstruction at MicroBooNE



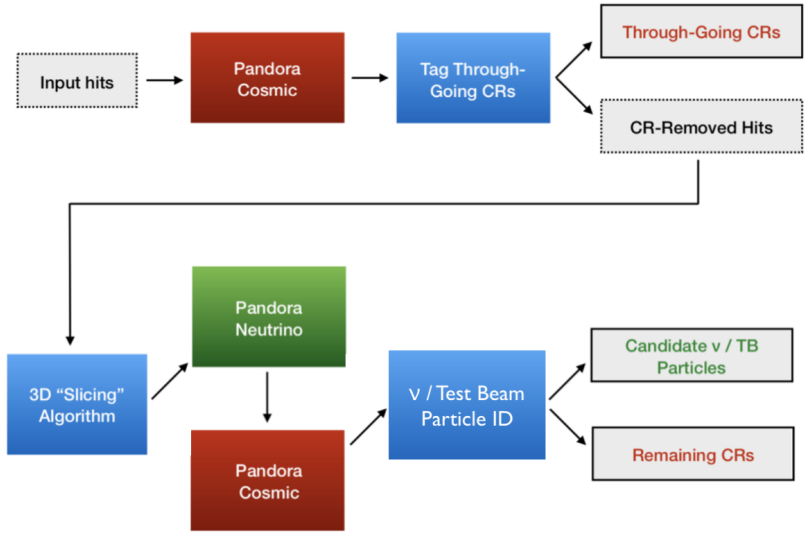
Simulated π^+ Pandora Reconstruction at ProtoDUNE-SP



Pandora for Detailed Cosmic Ray Reconstruction

With the context behind the two main reconstruction chains in Pandora for MicroBooNE, we can start to talk about levelling up the cosmic ray reconstruction.

As the workflow diagram outlines, cosmic rays in the default reconstruction chain are mostly a nuisance, a thing to be removed quickly and completely, to get the best physics we can out of the beam interaction.



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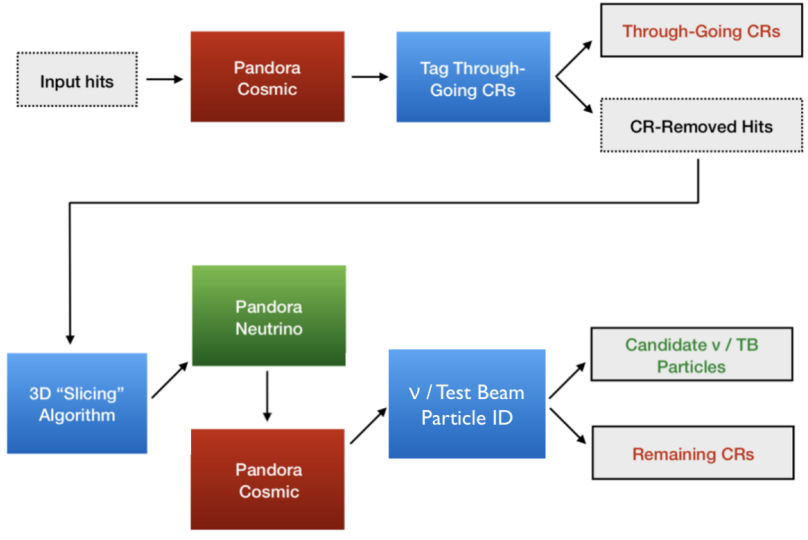


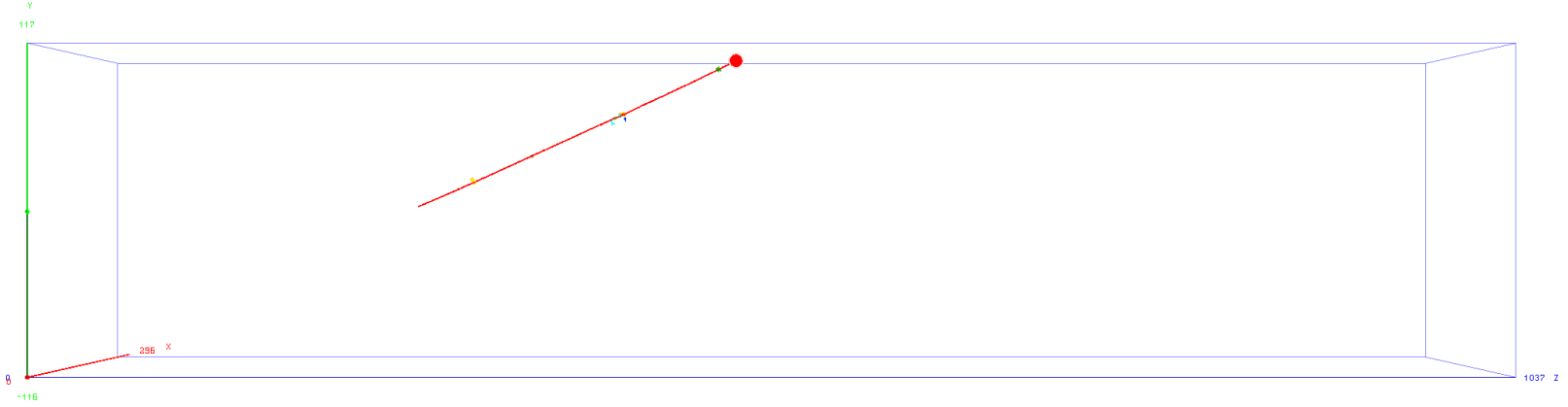
Instead, we can think of a new paradigm for more detailed cosmic ray reconstruction: Passing cosmic rays through an algorithm chain similar to the neutrino reconstruction, to get detailed interaction information such as a vertex, hierarchy, and improved reconstruction of any cosmic-induced interactions.

Pandora for Cosmics - Vertexing

The most basic change that can be made is to bring over more parts of the neutrino algorithm chain into the cosmic reconstruction context.

That does come with its own sets of complications though, as there is different concerns and tunings needed for a cosmic interaction, as compared to a beam interaction.

For example, the SVM based vertex scoring is likely to have some amount of beam-bias, which will make the vertex selected less than ideal. It is possible that a re-tuning for this context could help, though it is more likely that the DL-based vertexing algorithm from DUNE will be much better here, as it has already been tested with retuning for atmospheric samples, which have the beam-bias removed.



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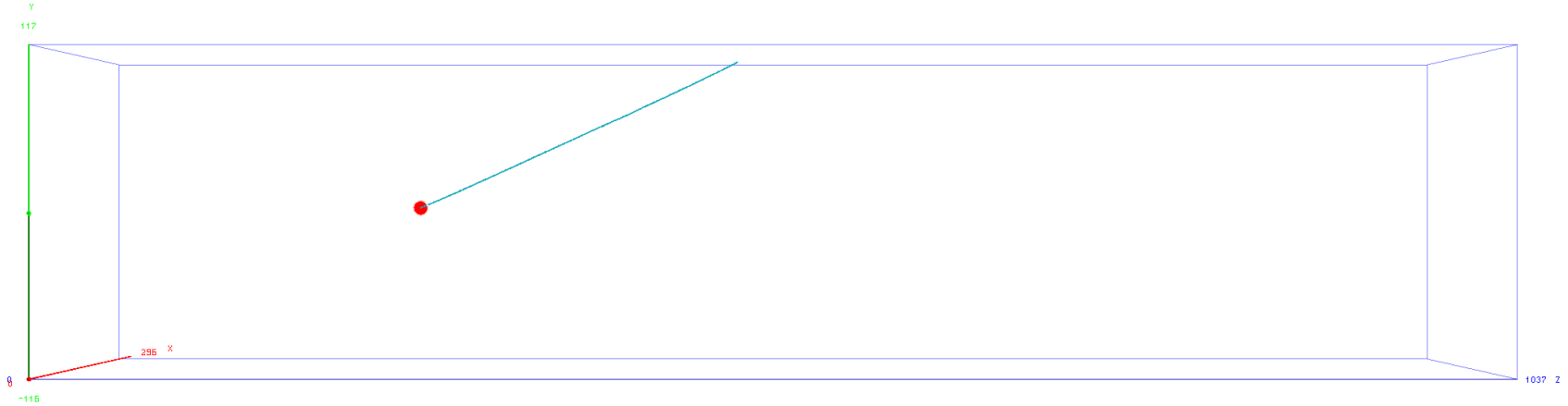
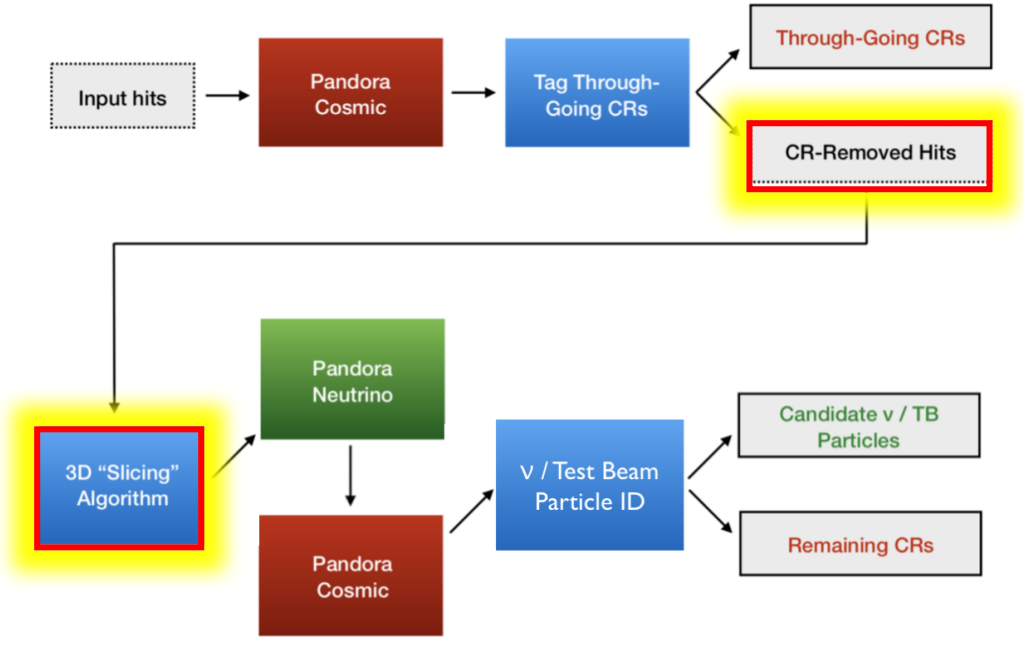


Pandora for Cosmics - Complications

However, there is some open questions that make this more difficult than "move algorithms over, retune for non-beam context".

- There may need to be some changes to the control flow outlined below. Simply running the neutrino reconstruction on the full 2D output will be too difficult of a problem. Similarly, trying to run the slicing to split up the cosmics into more easily reco-d parts is also difficult.



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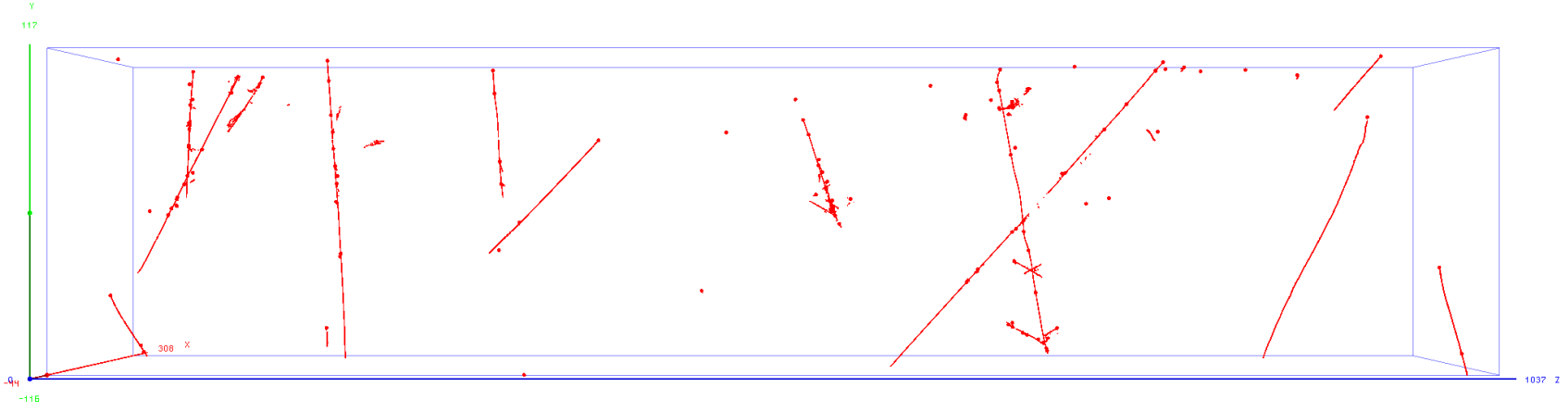

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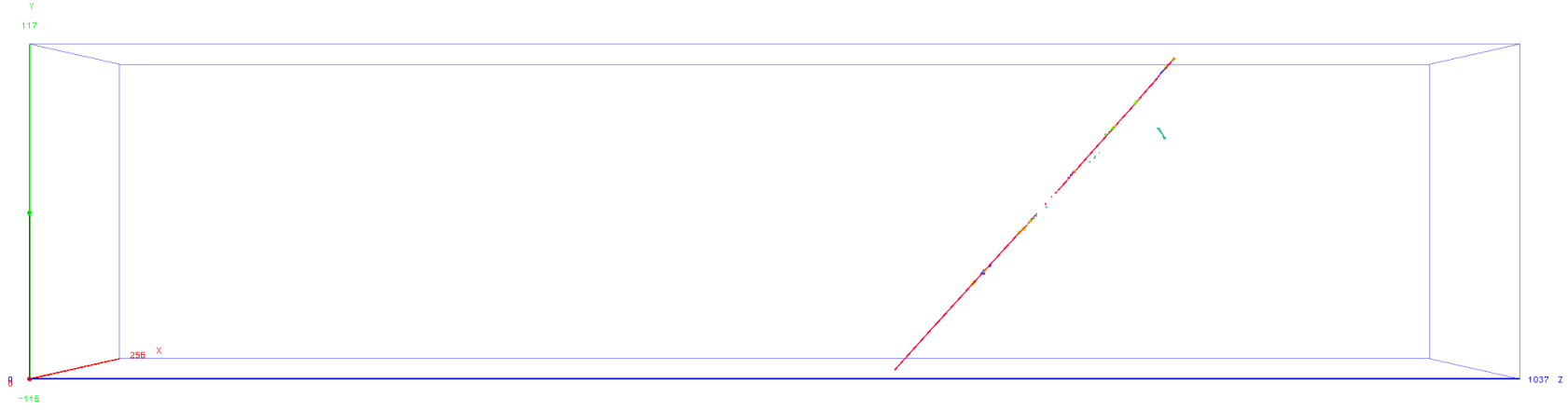

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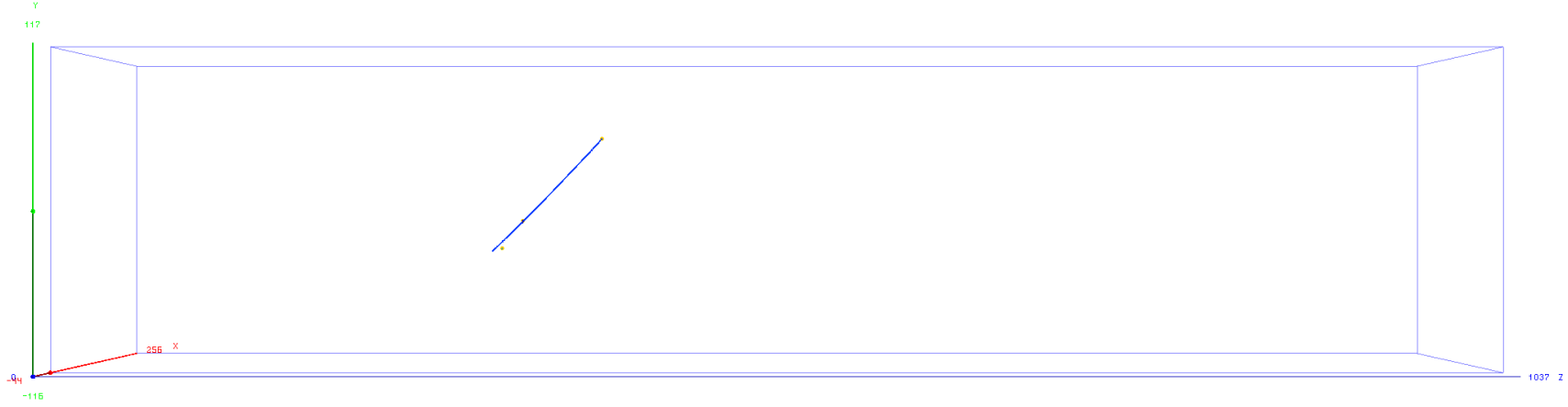

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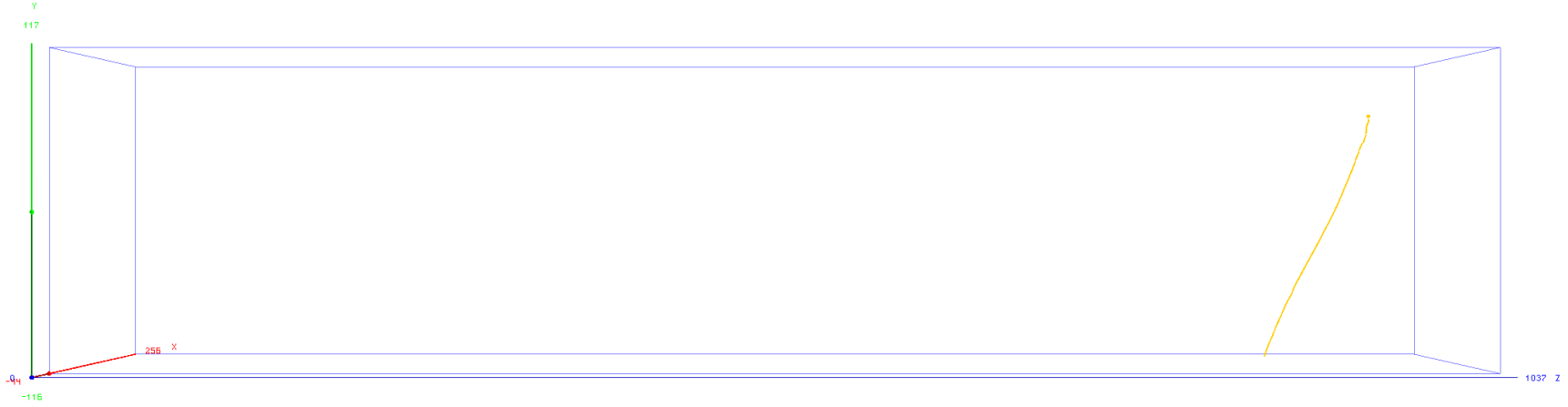

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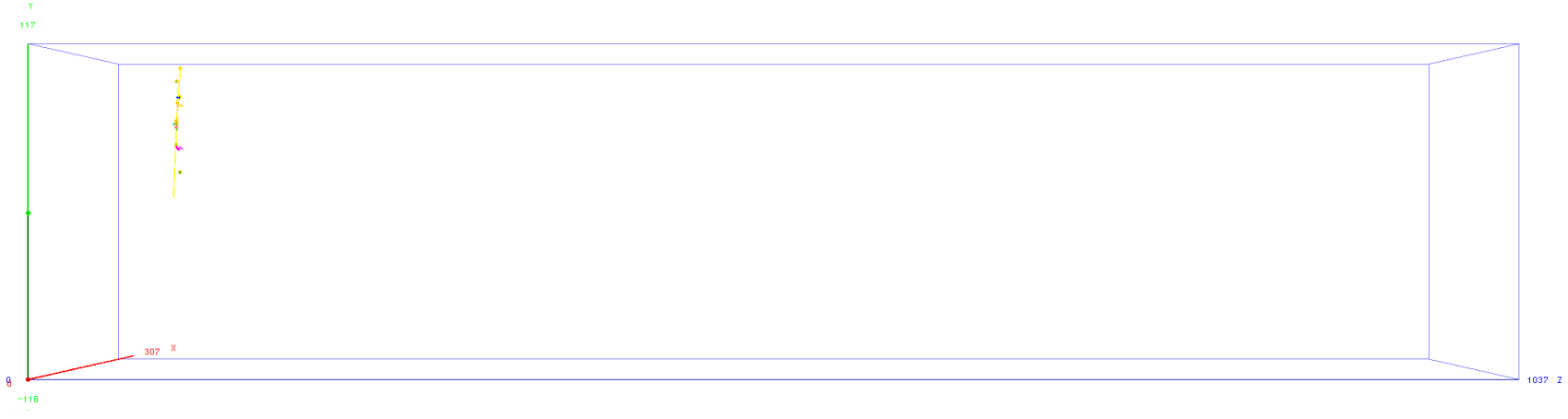
- Instead, we could alter the flow. If we instead run Pandora Cosmic as normal, but instead of throwing the cosmics away, we use that information to then perform a Cosmic-slicing step, we should get very clean slices to then pass to the neutrino reco step.



Pandora for Cosmics - Complications

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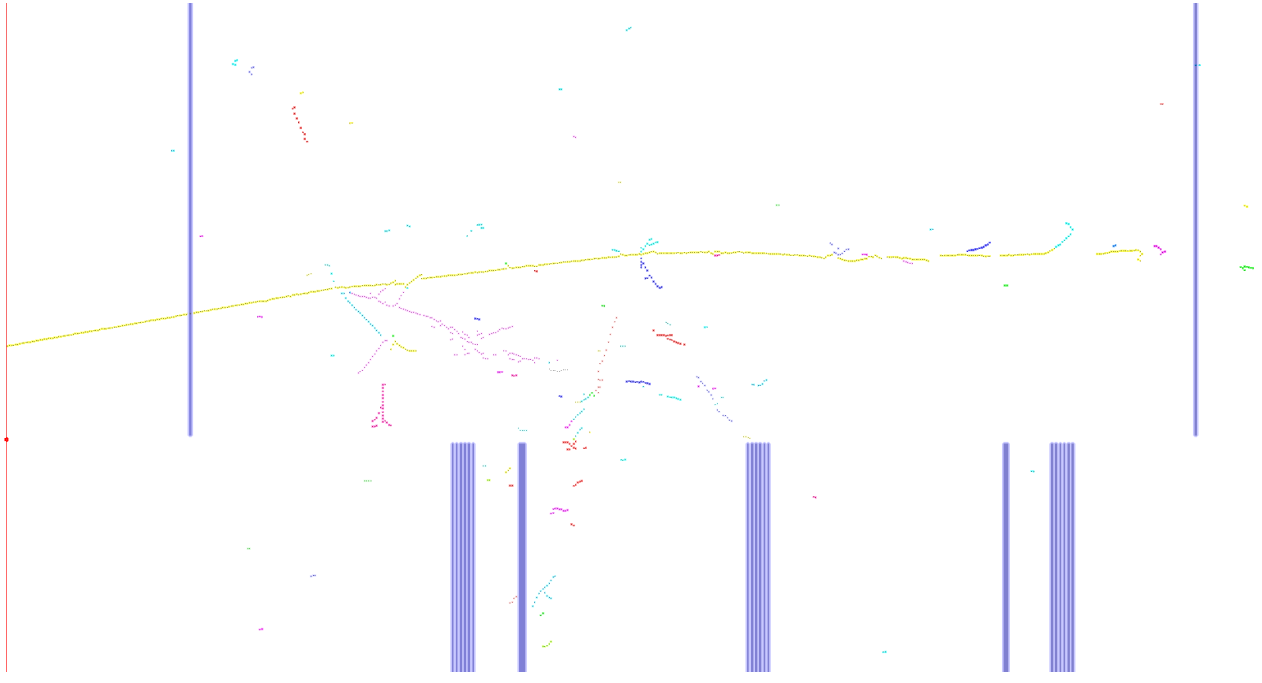

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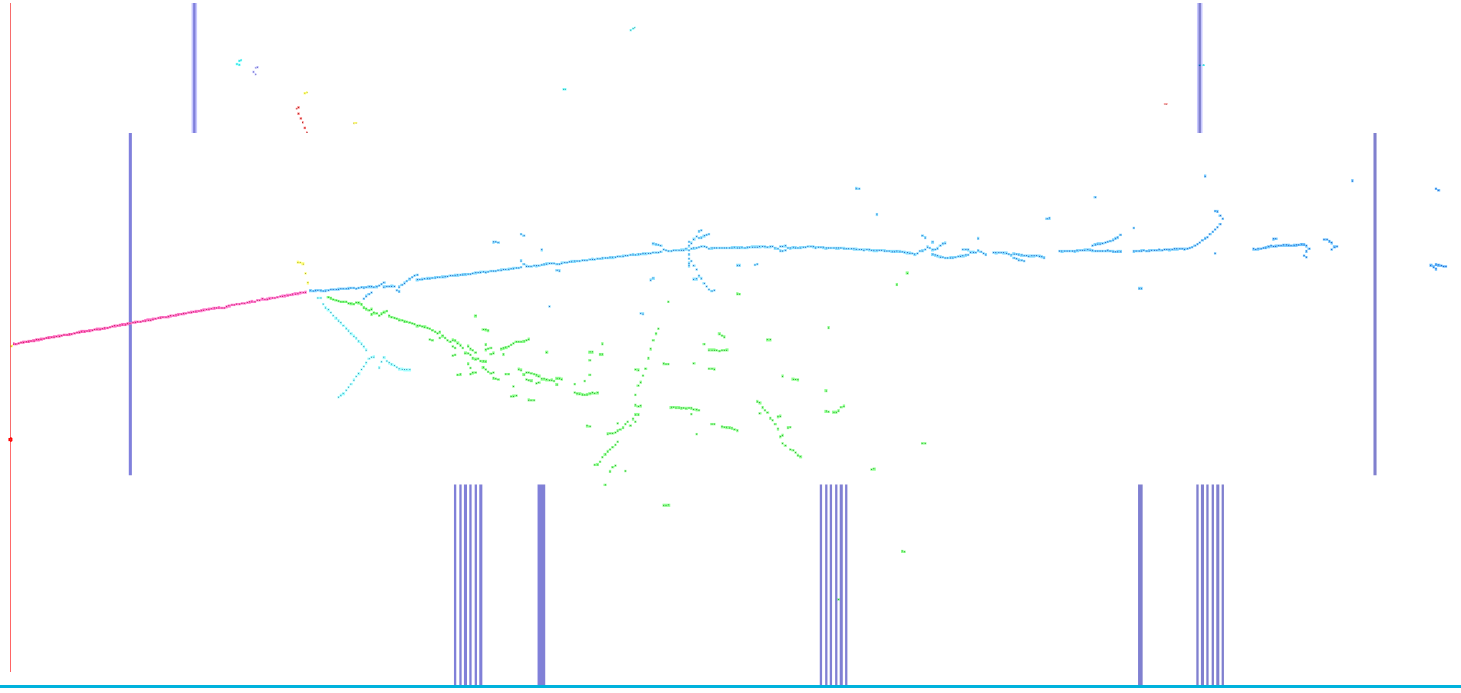

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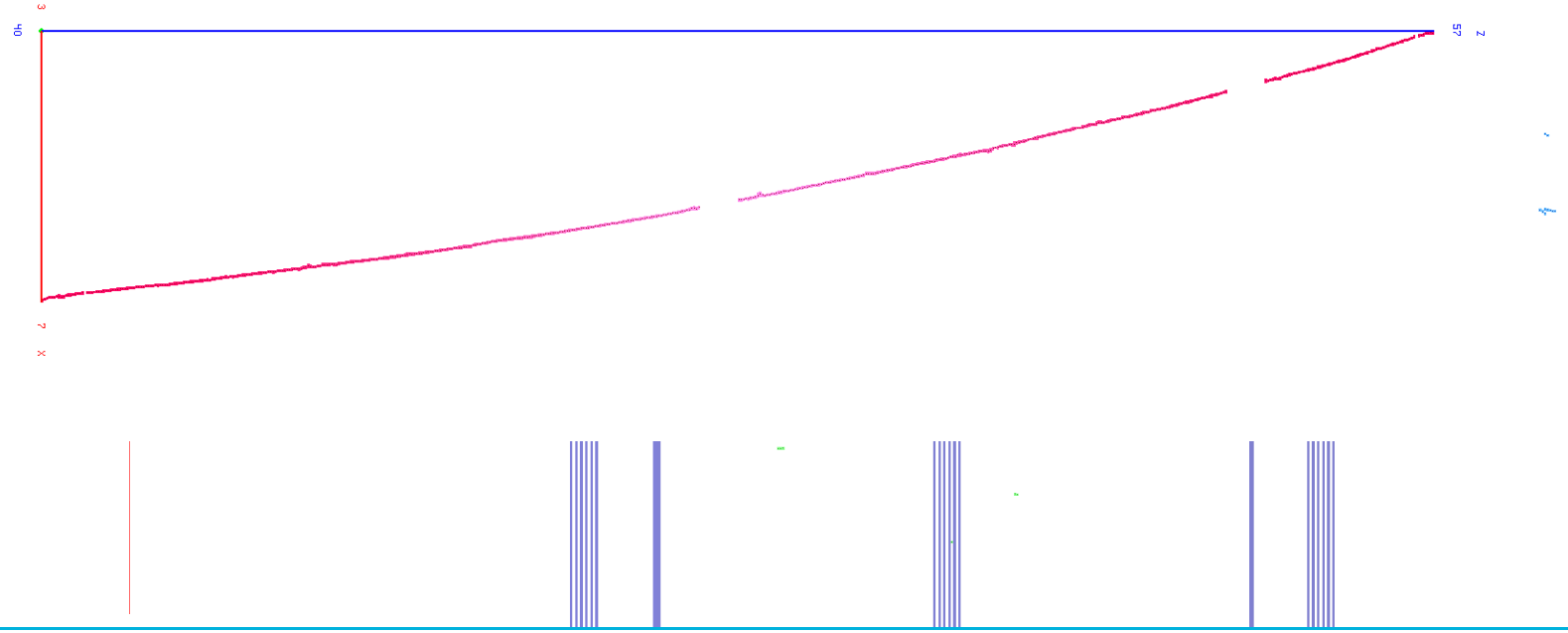

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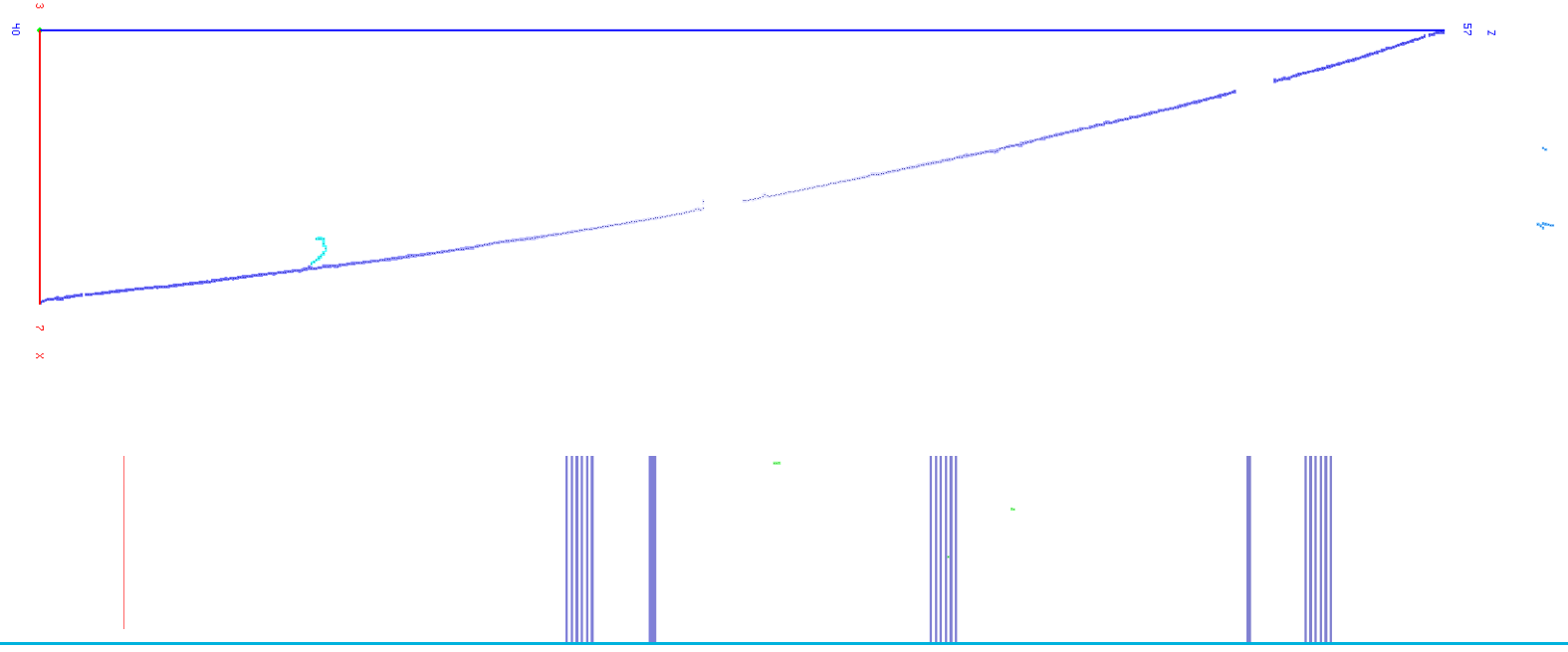

Pandora for Cosmics

So it looks like there is a few good points and a few parts to work on:

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So next steps:

- Get a dedicated data sample to work on this, and develop metrics to quantify how good the current cosmic reconstruction is.
- Implement the slicing properly into Pandora (which may be of use outside of MicroBooNE as well).
- Once both of the above are in place, we can start to work on a dedicated set of algorithms, or tunes of existing algorithms to improve the detail of cosmic ray reconstruction.

Conclusion

In conclusion:

- Pandora is the multi-algorithm approach to pattern recognition, in use across a wide variety of LArTPC experiments.
- In order to effectively target the differing interactions that take place in a LArTPC, Pandora has multiple algorithm chains, tuned for different goals.
- Whilst the Pandora Cosmic chain is effective for the reconstruction of beam neutrinos, it is not optimised for the detailed reconstruction of cosmic interactions.
- There has been some initial exploration into utilising the Pandora Neutrino reconstruction chain on cosmic interactions, to gain increased detail.
- This mode of running has some additional complications and will need further tuning, but has the potential to unlock further physics from cosmic ray interactions in LArTPCs, at MicroBooNE and beyond.

Pandora for Cosmics

An Overview & Future Improvements

Ryan Cross - DM Physics Searches

2023/03/27

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