Liquid Argon Reconstruction with PANDORA

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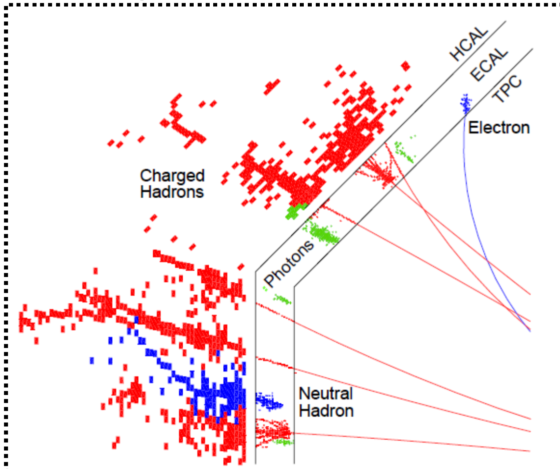
LBNE software meeting,
1st February 2014.

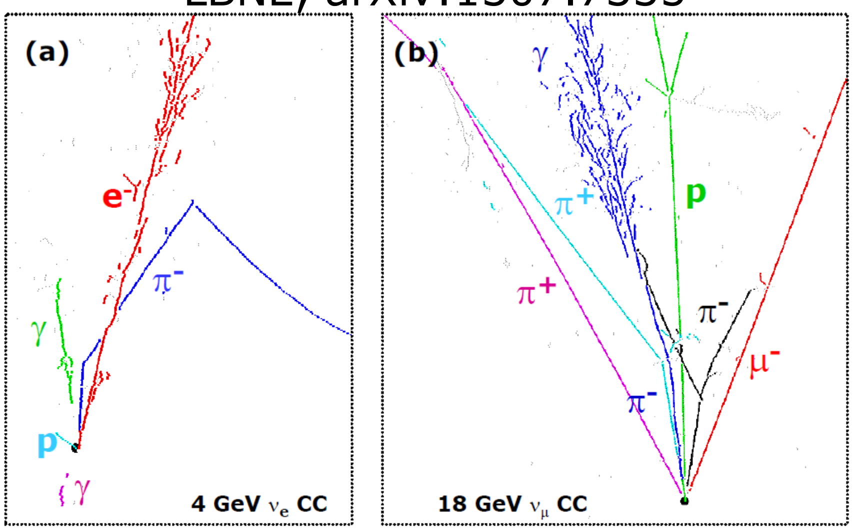
(on behalf of AB, John Marshall, Mark Thomson – Cambridge University)

PandoraPFA

CLIC, arXiv:1209.4039



LBNE, arXiv:1307.7335

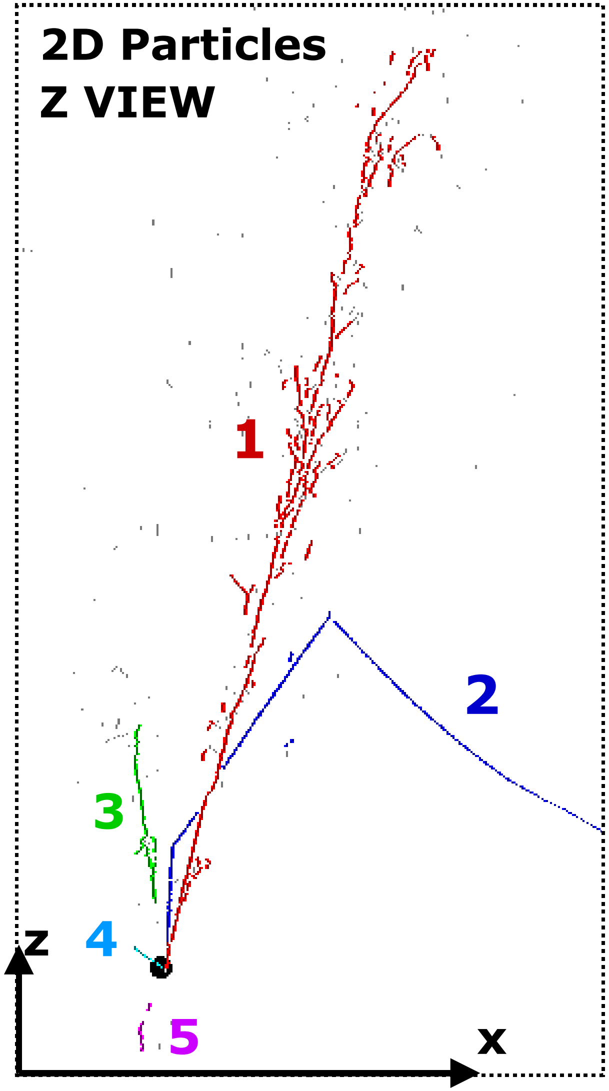


- **PandoraPFA is a toolkit of pattern recognition algorithms for fine-grain detectors.**
  - Developed at Cambridge by John Marshall and Mark Thomson.
  - Initially written for linear collider. Has become central to ILC/CLIC physics studies.
- **The tools are fast, flexible and reusable – readily applicable to automated event reconstruction in Liquid Argon.**
- **Have now developed a chain of 3D algorithms for Liquid Argon.**
  - Applicable to cosmic muons and neutrinos in MicroBooNE and LBNE.

Reconstruction Strategy

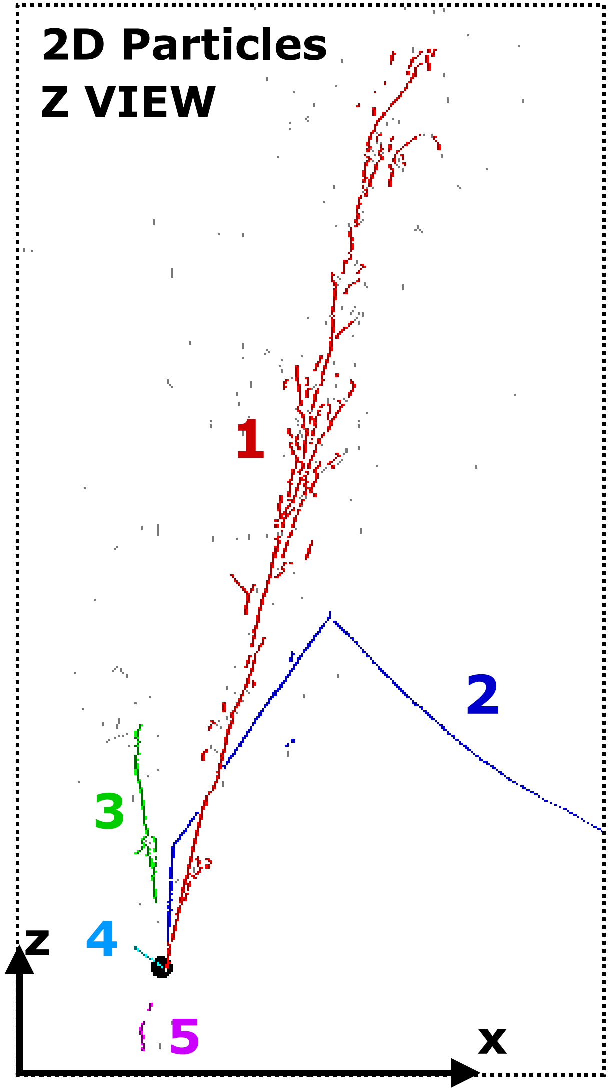
- **Basic strategy: pattern recognition algorithms are based on topological associations between hits and clusters.**
  - Grow events by forming and analysing associations between hits and clusters.
- **Reconstruction chains are highly modular.**
  - Grow events slowly and carefully using many algorithms, each with specific purpose.
    - ◇ Aim for many complementary algorithms where possible.
    - ◇ Algorithms are all re-usable, allowing iterative approach.
  - Try not to make incorrect joins! (much easier to merge hits together than to break clusters apart).
- **Pandora provides a built-in set of tools and algorithms for pattern recognition.**
  - Excellent development environment and visualisation.
- **Also, Pandora is FAST!**

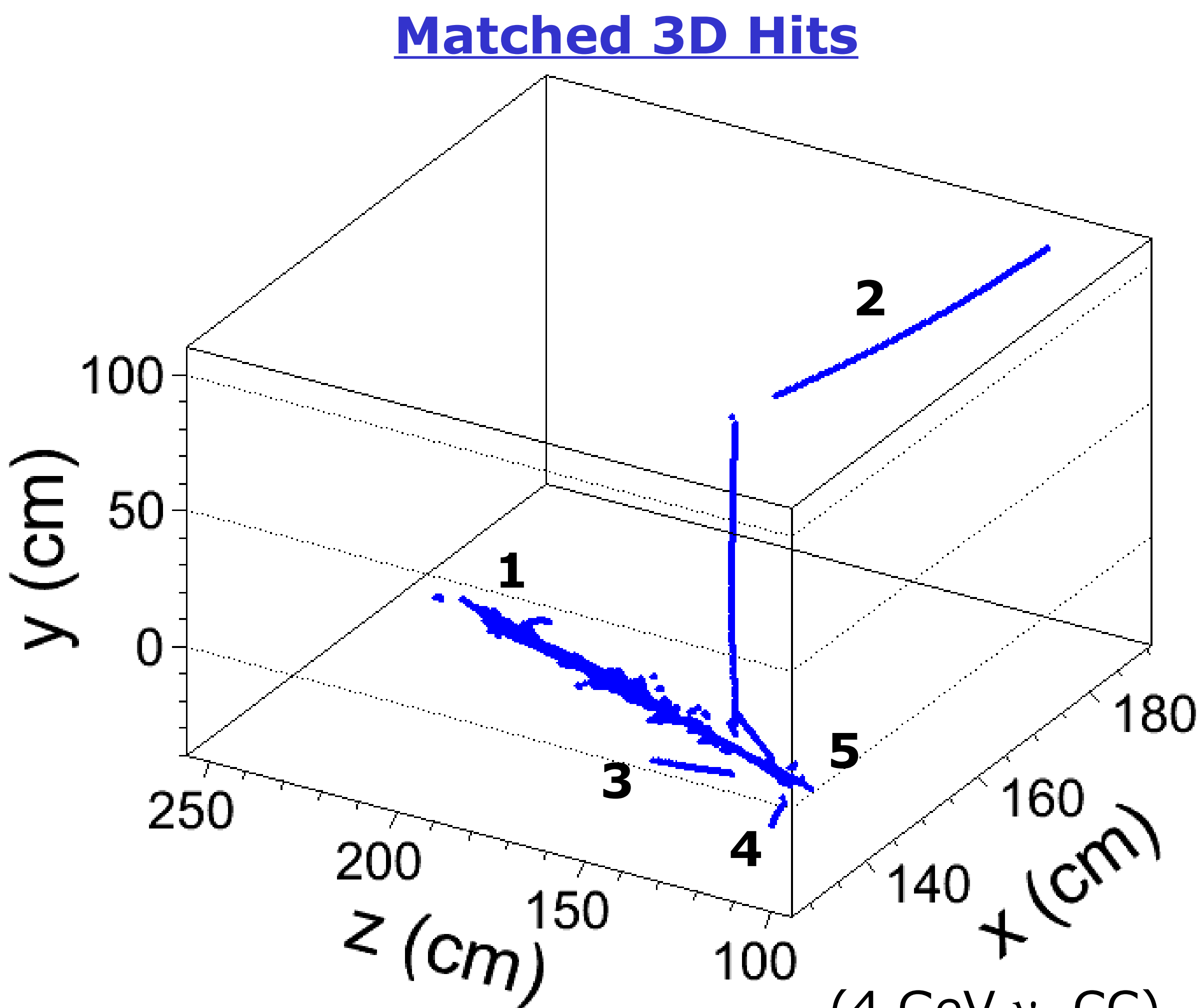
Reconstruction Chain



- **Effort is now fairly advanced: have developed a 3D chain of Liquid Argon pattern recognition algorithms.**
  - Input: 2D hits.
  - Output: 3D particles [without PID].
- **Since last collaboration meeting, reconstruction chain has been incorporated into LArSoft.**
  - Two new packages in LArSoft, containing all our algorithms, and an ART Producer module.
  - 3D particles are outputted as recob::Cluster objects.
  - Currently assumes MicroBooNE geometry (but LBNE next).

Reconstruction Chain





(4 GeV ν_e CC)

Current Algorithms

- **Right: current standard reconstruction chain.**
  - Developed for neutrinos using LBNE spectrum.
  - First run 2D algorithms, then build 3D particles.
- **Uses 21 algorithms.**
  - Each algorithm has a particular purpose. (The names roughly indicate the purpose!)
  - They inherit from 14 base algorithms.
- **Provides a first-pass 3D reconstruction.**
  - But development continues at pace!

1. Create 2D clusters

ClusterCreation
LongitudinalAssociation
TransverseAssociation
LongitudinalExtension
SplitClustersAtKinks

2. Identify 3D vertex

VertexFinding
SplitClustersAtVertex

3. Build 2D particles.

ParticleSeedsFromVertex
ParticleSeedsFromLength
ParticleLengthGrowing
ParticleBranchGrowing
ParticleMerging
ParticleRelegation

4. Add remaining hits to 2D particles

ParallelMerging
BoundedBoxMerging
ConeBasedMerging
IsolatedHitMerging

5. Build 3D Particles

3DParticlesSeedsFromTracks
3DParticlesSeedsFromShowers
3DParticlesSeedsFromTwoViews
3DParticleConsolidation

Pandora & LArSoft

Code has been distributed in Fermilab repositories:

- **Pandora core software is distributed as part of NuSoft.**
- **Liquid Argon reconstruction chain is incorporated into LArSoft as two new packages:**

(1) LArPandoraAlgorithms

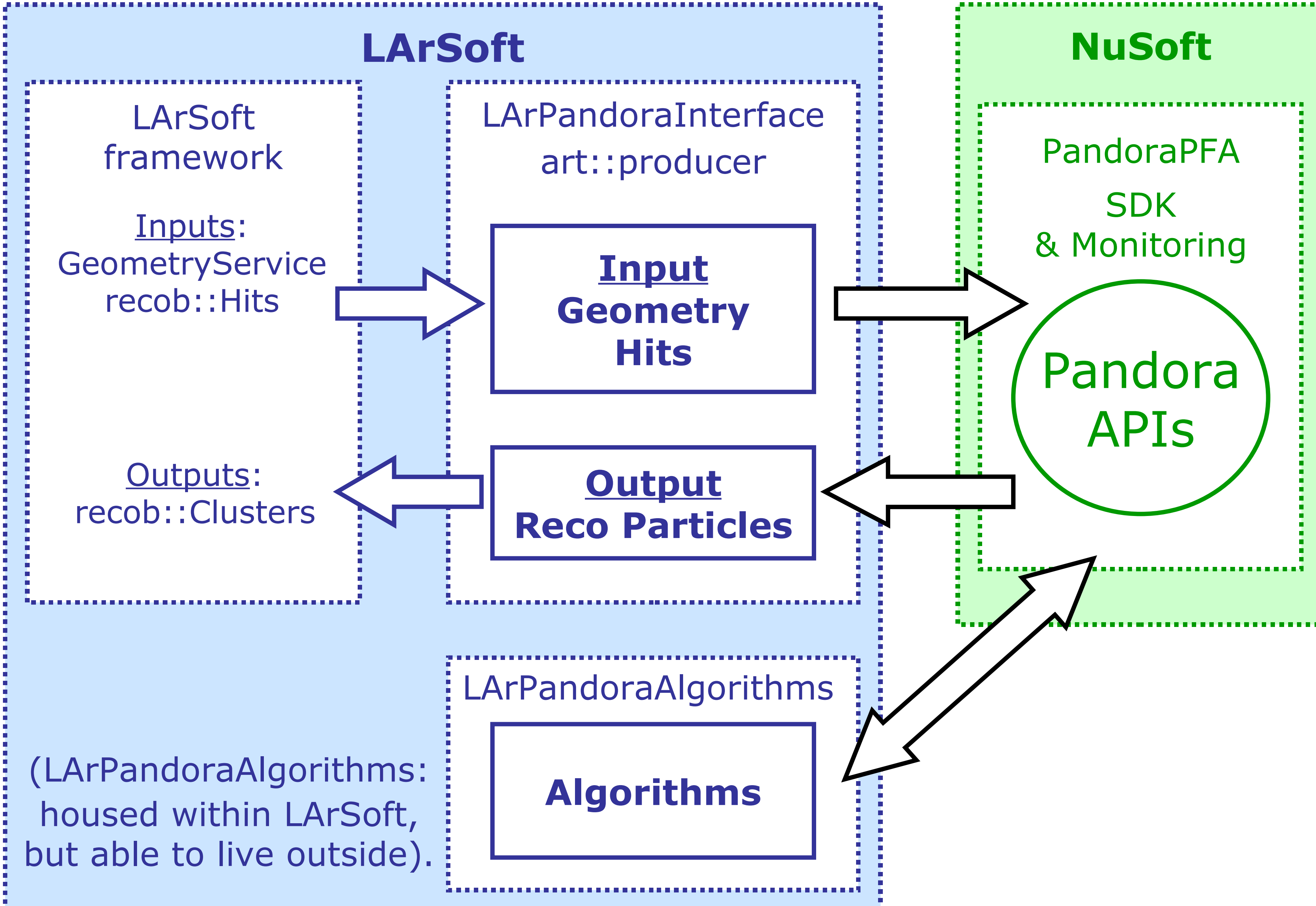
- Contains all the algorithms used in the reconstruction chain.

(2) LArPandoraInterface

- Holds ART Producer module and Pandora/LArSoft interfaces.
- Also contains steering files:
  ‘runpandora_example.fcl’ for ART
  ‘PandoraSettings_MicroBooNE_Standard.xml’ for Pandora.

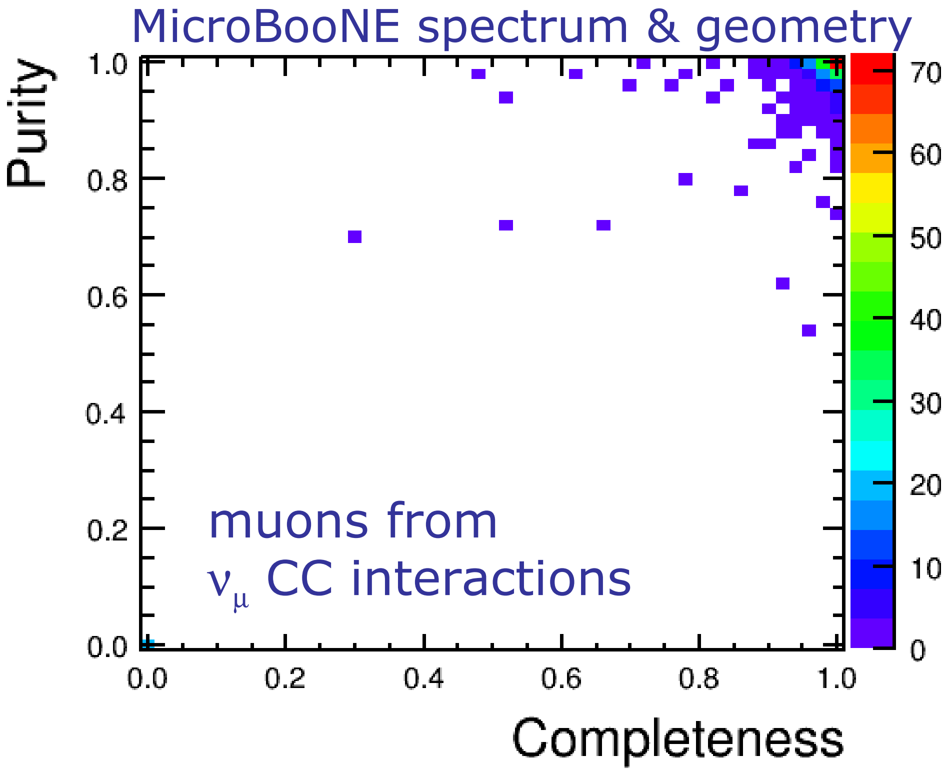
- **Note: need to learn how to use new git/mrb framework! These packages live in the ‘larpandora’ repository.**

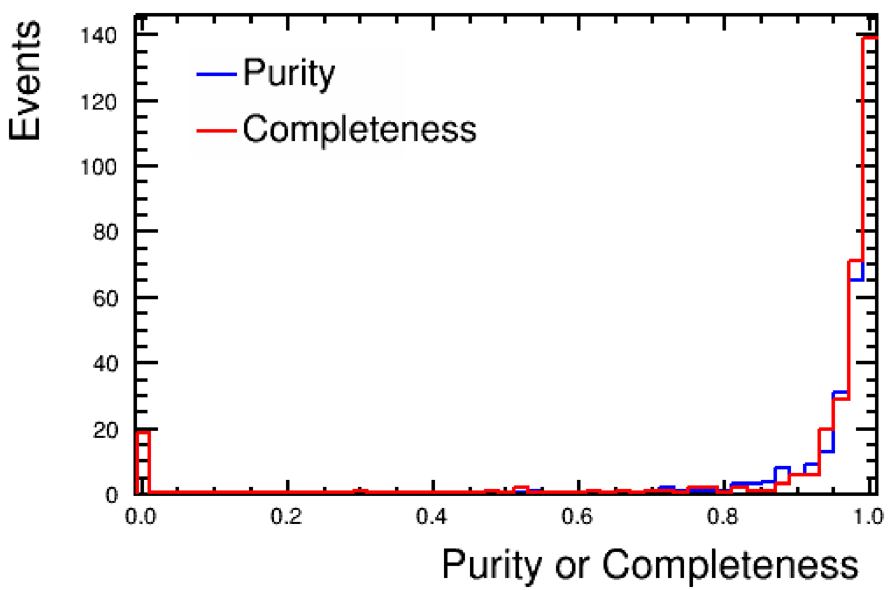
LArSoft/Pandora Interface



Performance

- **We've recently begun to characterise the performance of our algorithms.**
  - Previously relied on event scanning (although this is still incredibly useful, and Pandora has a great event display!).
  - Now have an automated system as well.
- **Start by calculating simple performance metrics.**
  - Use the 2D hit $\leftrightarrow$ MC particle truth information provided by the 'BackTracker' service in LArSoft.
  - Match true hits and reconstructed hits from muon tracks in ν_μ CC interactions.
  - Calculate 'purity' and 'completeness' performance metrics.
- **Initial performance studies are based on MicroBooNE spectrum and geometry.**
  - Reconstruct 500 neutrino interactions with full 3D chain.
  - Study 'out-of-box' performance for MicroBooNE neutrinos.





- **First performance metrics:**
  - For true ν_μ CC interactions, compare the true muon with its nearest reconstructed 3D particle.
  - Define:
    - ◇ 'True hits' in the true muon.
    - ◇ 'Reco hits' in the reco particle.
    - ◇ 'Matched hits' that are in both true muon and reco particle.
  - Calculate two metrics:

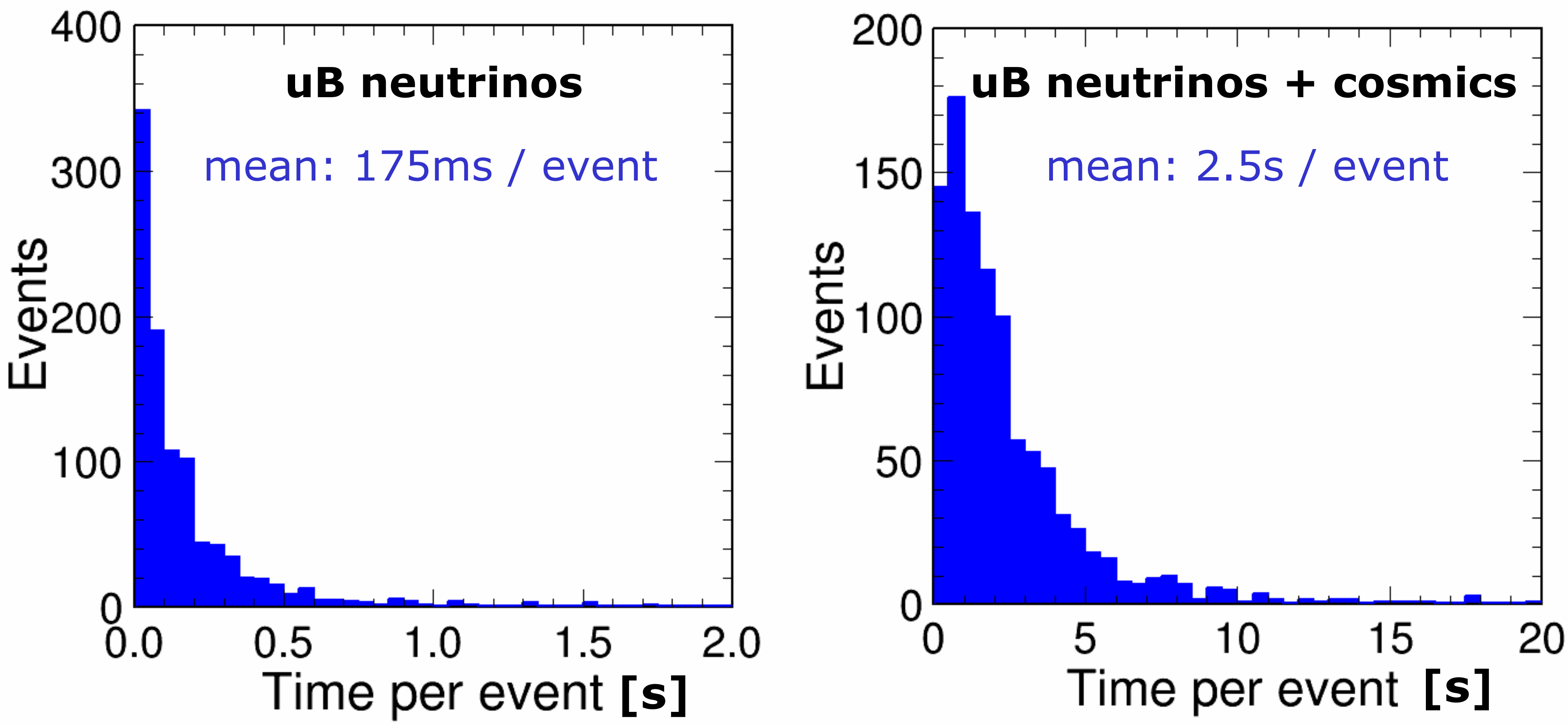
$$\textbf{Completeness} = \frac{\textbf{Matched hits}}{\textbf{True hits}}$$

$$\textbf{Purity} = \frac{\textbf{Matched hits}}{\textbf{Reco hits}}$$

- **2D scatter, and 1D profiles, are shown left.**
  - Most events have >95% purity and completeness.

Speed Test

- **Speed test: process a sample of events at Fermilab.**
  – Reconstruct 1000 neutrinos (MicroBooNE beam spectrum), with and without cosmics, using full 3D chain of algorithms.

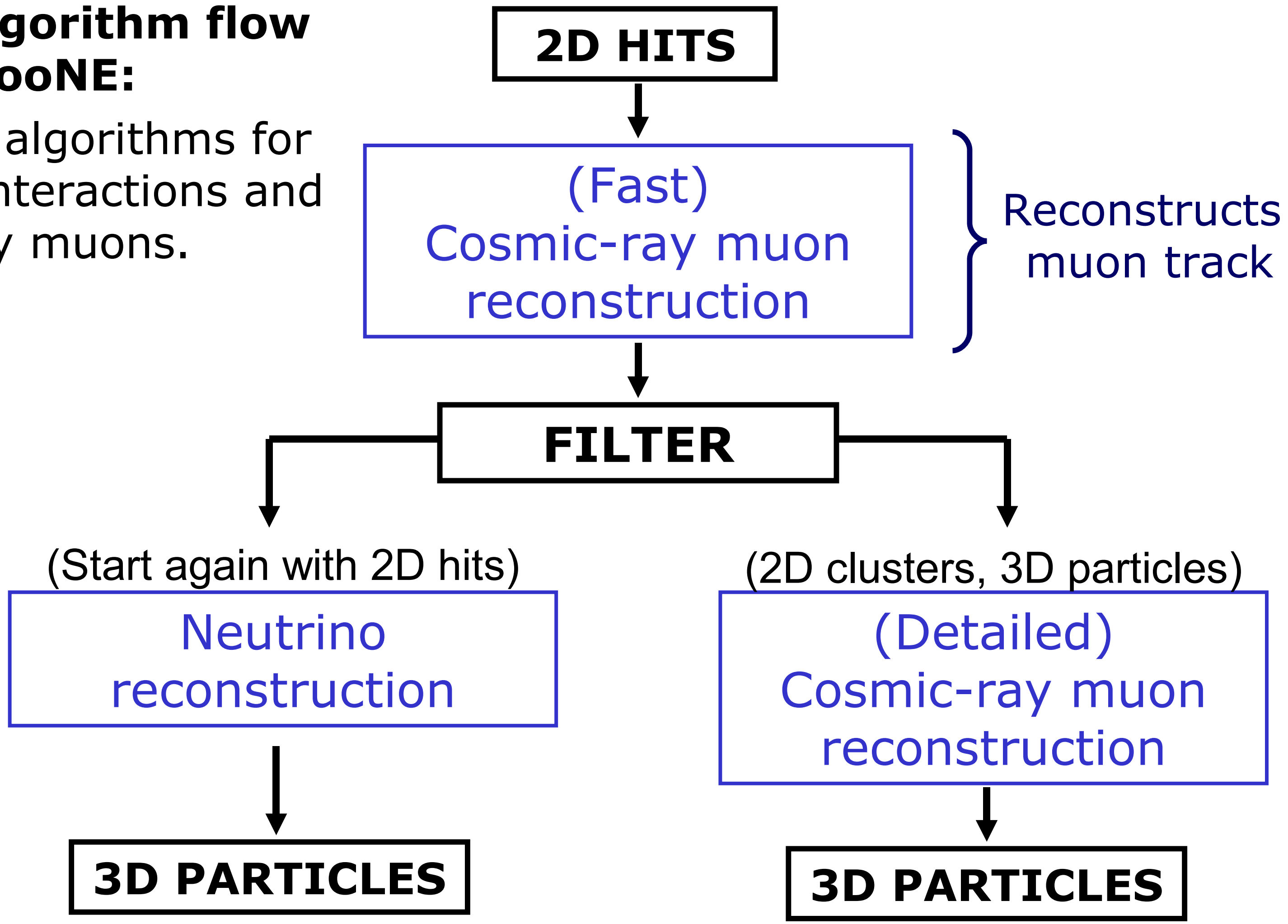


Cosmic-ray Muons

- **Most recent effort has been focused on reconstruction of cosmic-ray muons.**
  - The current chain of algorithms was developed using LBNE accelerator neutrinos.
  - Out-of-box performance for cosmic-ray muons is reasonable, but not optimised.
  - Need high-quality reconstruction of cosmic-ray muons for both MicroBooNE and LBNE!
- **Have now developed a dedicated 3D reconstruction chain for cosmic-ray muons.**
  - Some common algorithms, shared with neutrinos.
  - Some dedicated algorithms, specific to cosmic-ray muons.
- **Following slides are based on MicroBooNE geometry… but plan to apply algorithms to LBNE too.**

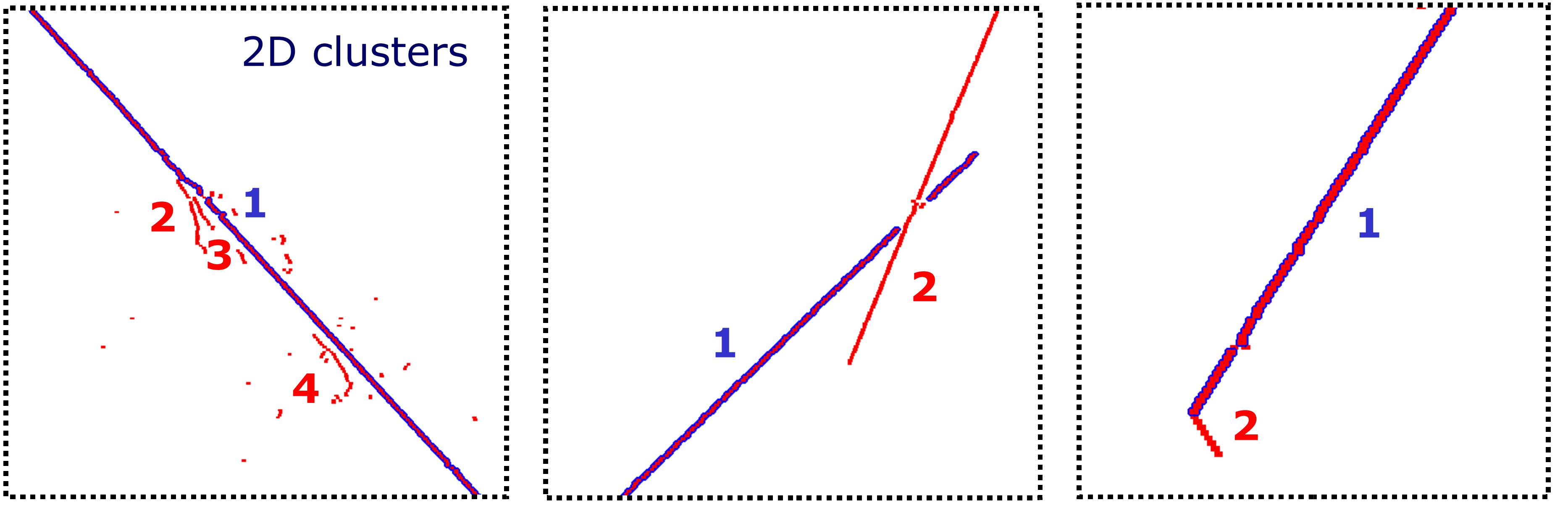
New Reconstruction Chain

- **Possible algorithm flow for MicroBooNE:**
  – Dedicated algorithms for neutrino interactions and cosmic-ray muons.



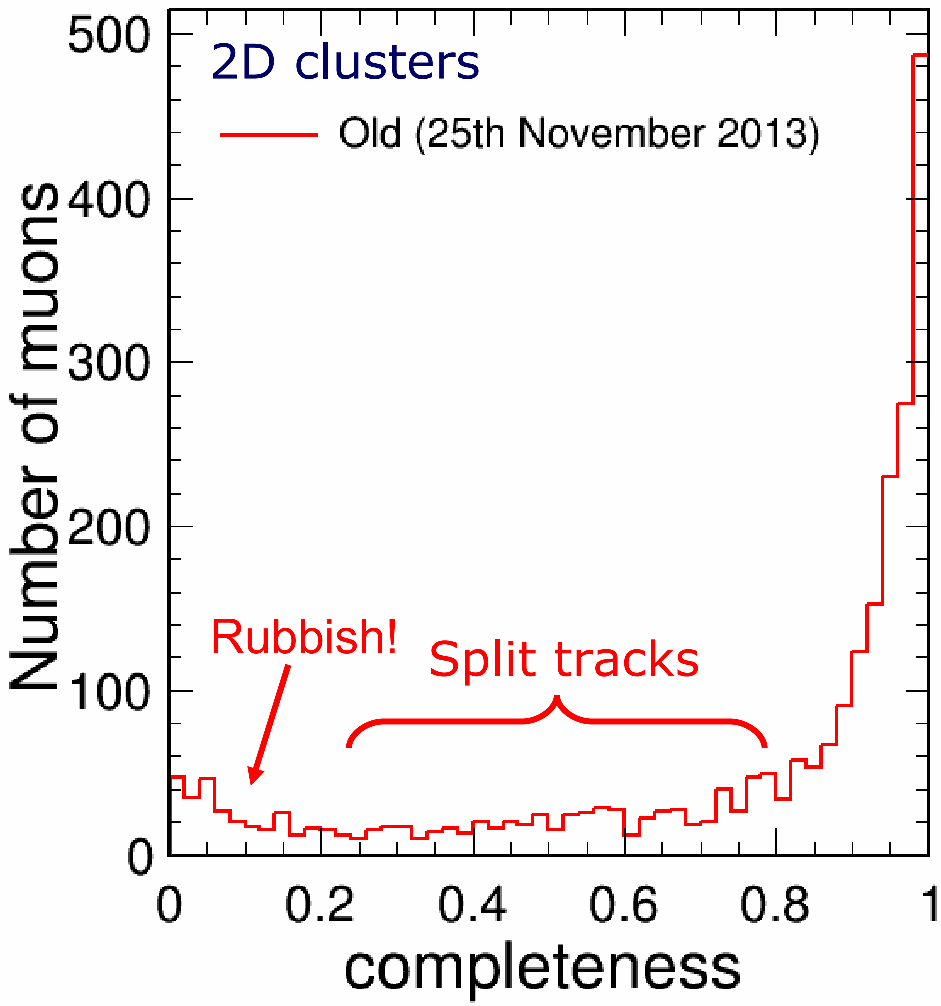
Out-of-box Performance

- **Out-of-box performance is reasonable for cosmic muons:**



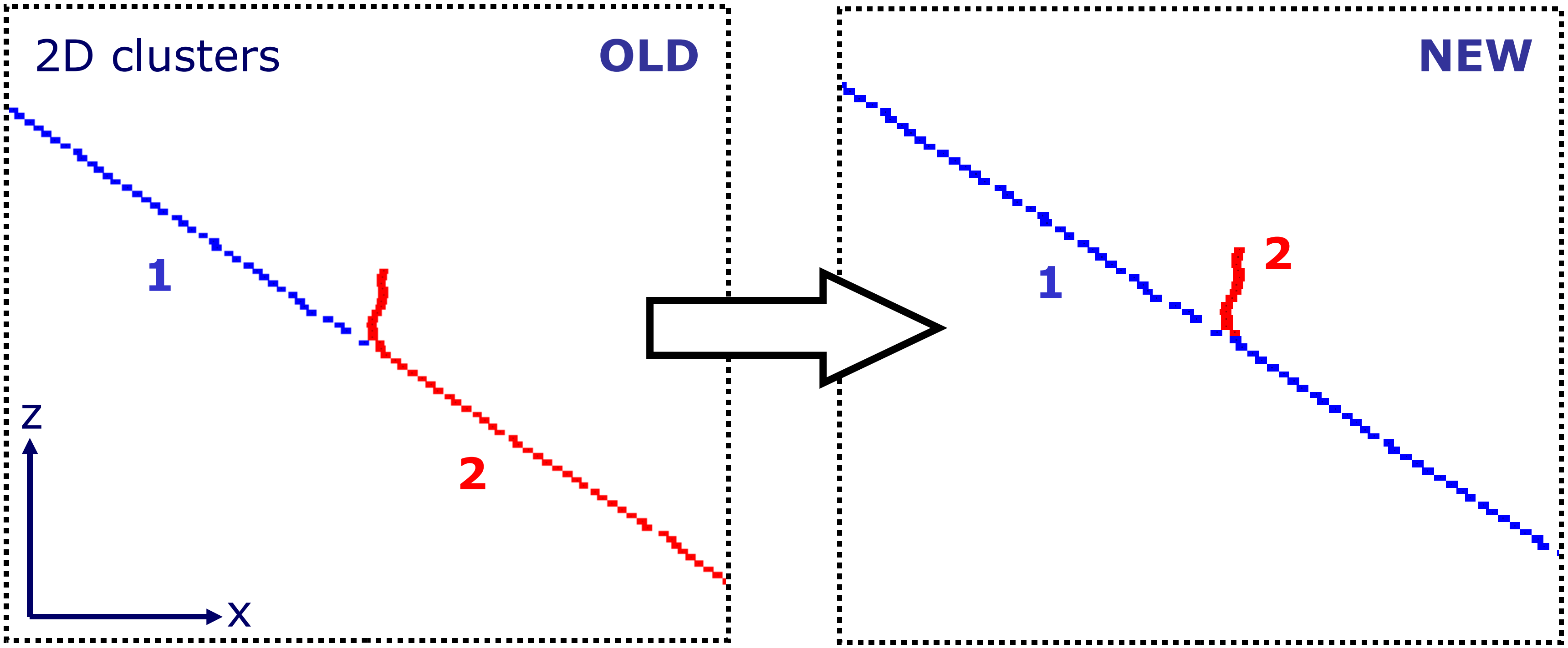
- **The majority of cosmic muon tracks are straight and clean, and are well-reconstructed.**
- **A number of difficult topologies: delta rays, cross-over tracks, showers, decay electrons etc… Also, tracks parallel to wires can be difficult… This leads to reconstruction pathologies.**

Out-of-box Performance



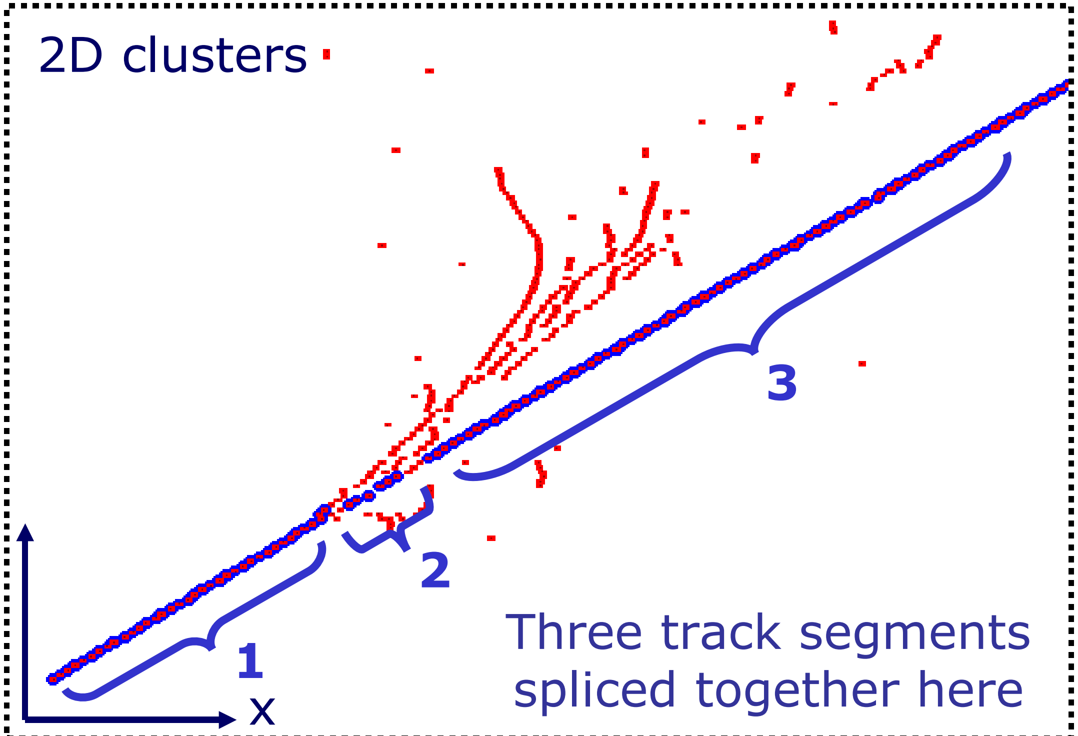
- **Use 'completeness' variable to assess performance of standard 2D algorithms.**
- **Reasonable performance, but many muons are not completely reconstructed.**
  - Many fragmented muons.
  - Typical 2D pathologies:
    - ◇ Failure to track through delta rays or showers.
    - ◇ Failure to track muons parallel to wires.
  - Note: some events can be fixed by 3D reconstruction, but most require additional 2D reconstruction.

Splitting Delta Rays



- Most common pathology: 2D track follows delta ray rather than muon.
- Address this by writing two complementary sets of algorithms:
  - Improved 2D clustering that doesn't go round sharp corners!
  - Algorithms that 'split and splice' segments into a single track.
- New algorithms fix many events (and also help neutrino reconstruction).

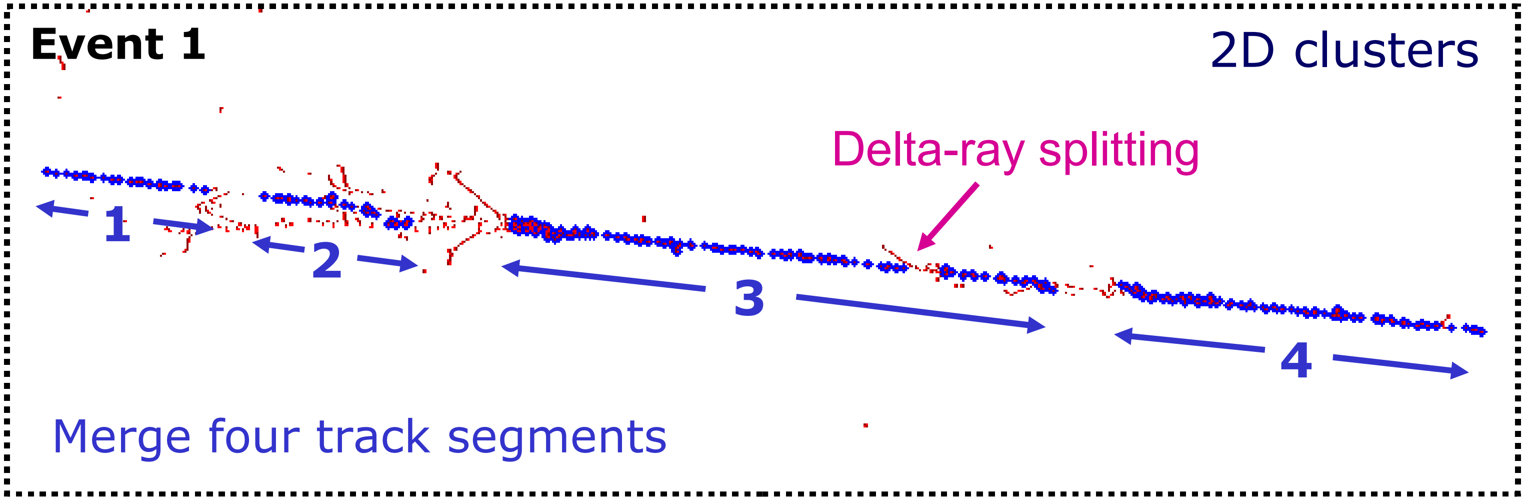
Splicing Track Segments

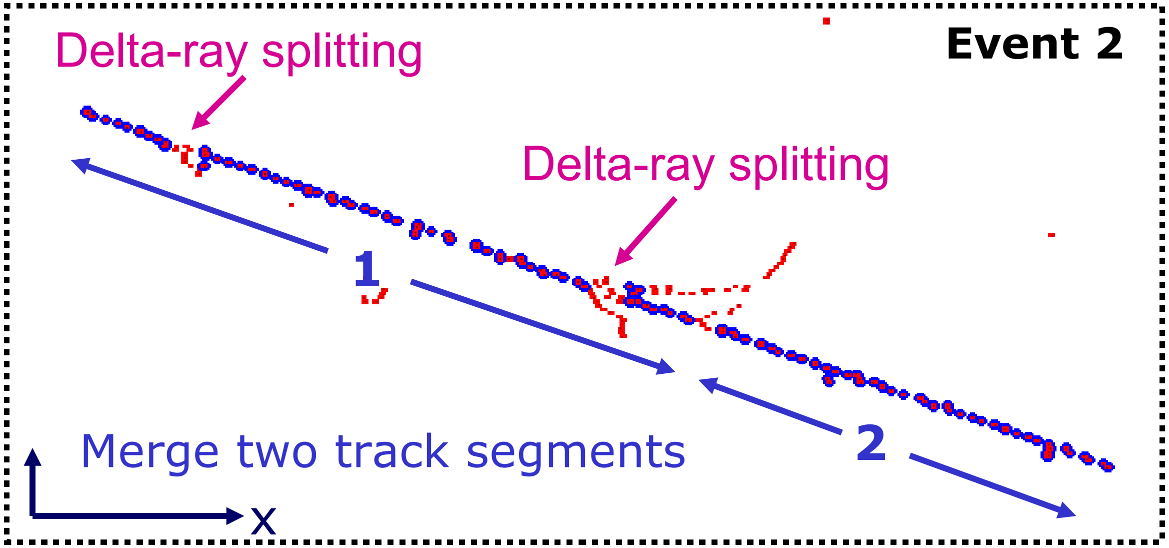


- **Second most common pathology:**
  - 2D algorithms identify clean track segments but fail to join them together.
  - Address this with a new set of algorithms that splice together track segments into a single track.

- **With new 2D algorithms in place, can now reconstruct full length of cosmic-ray muon track.**
  - Will need to fine-tune hits later… Also need a new algorithms that fill in gaps (not done yet…)

Splicing Track Segments

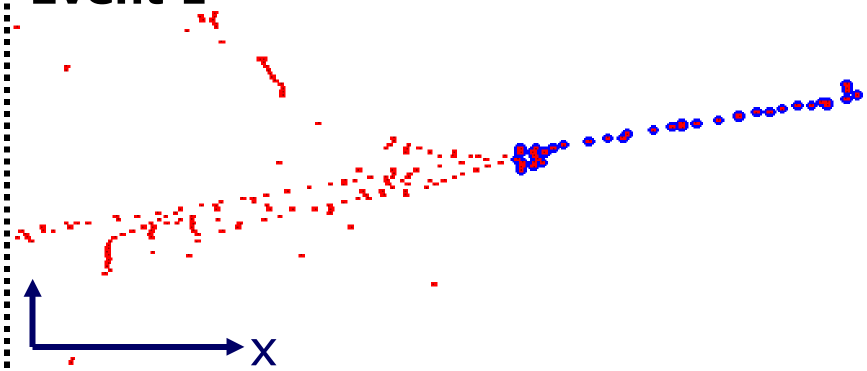




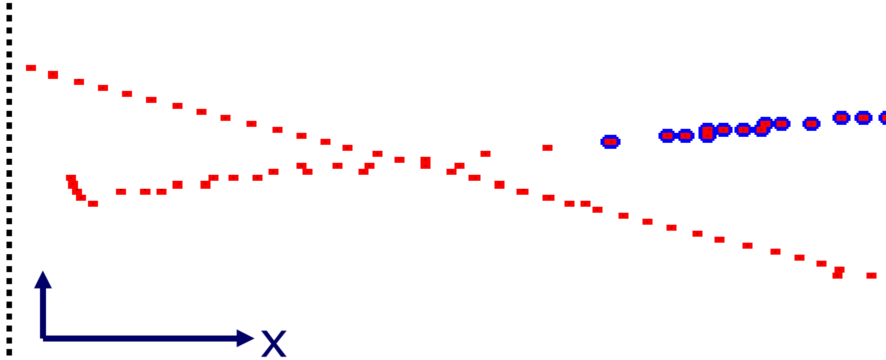
Remaining Pathologies

- **After scanning through many events... With new algorithms, cosmic-ray muon reconstruction now performs well.**
- **Some remaining split events (parallel to wires and difficult):**

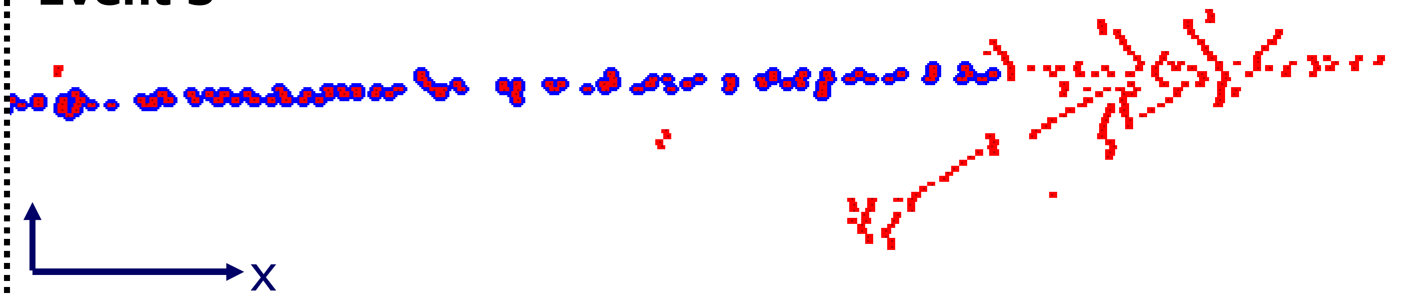
Event 1



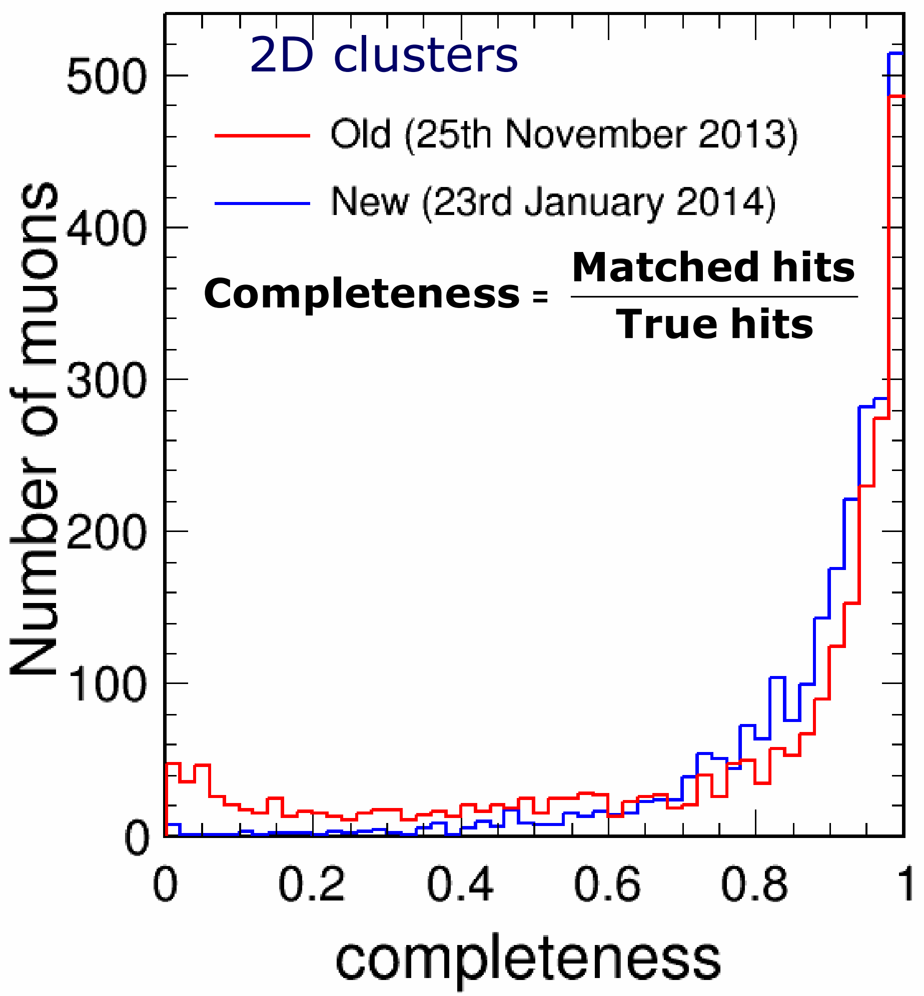
Event 2



Event 3



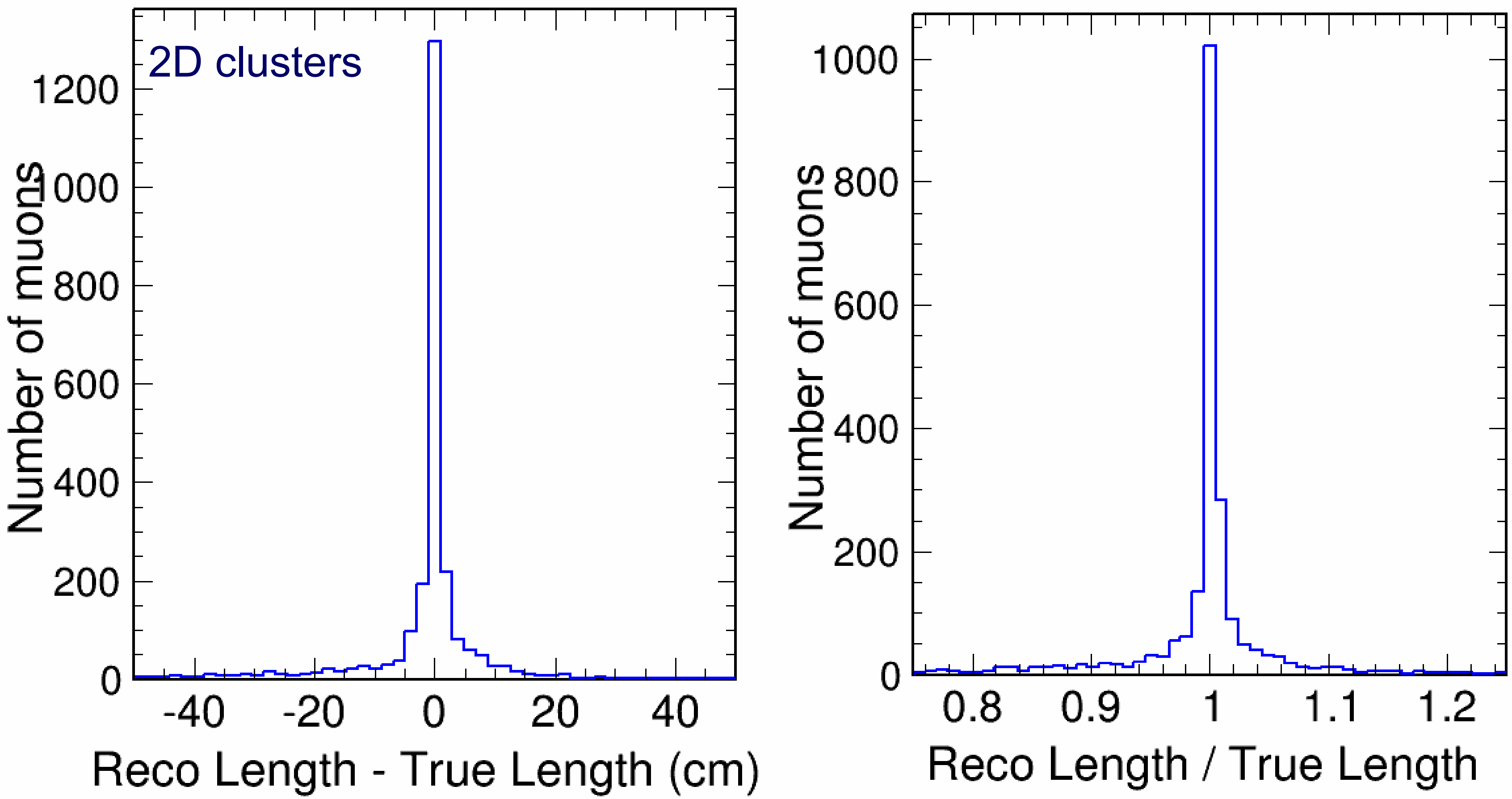
Improved Performance



- **With new algorithms in place, left plot shows new distribution of completeness variable.**
  - Big improvement!
- **However, true performance is undersold by definition of completeness variable!**
  - 'true hits' actually includes delta rays as well as muon.
  - But delta rays not included in reconstructed muon (yet).
  - So, muon reconstruction is penalised by this metric.
- **Scanning studies suggest that actual performance is is better than this…**

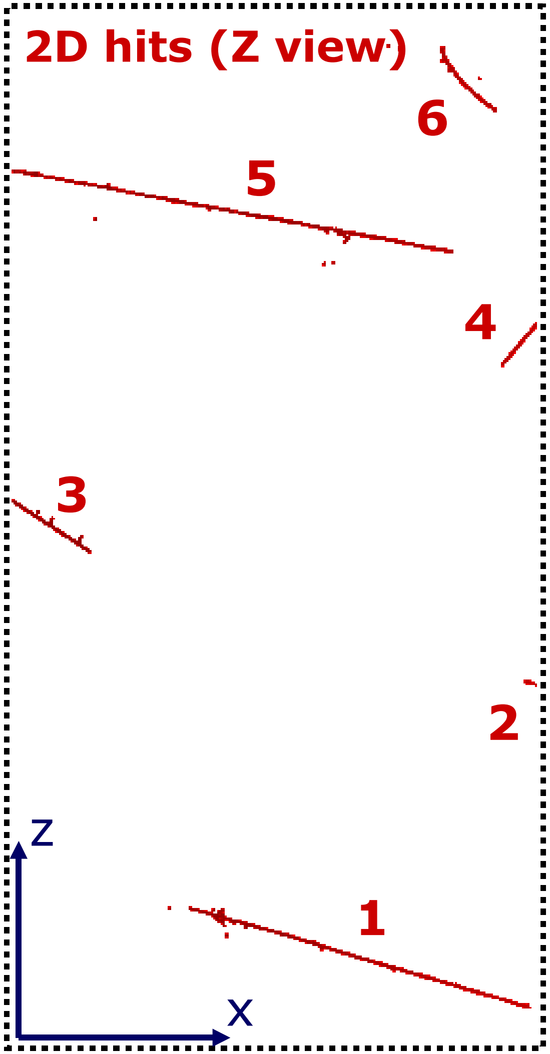
Track Length

- **Try a more robust metric: vertex-to-end distance.**

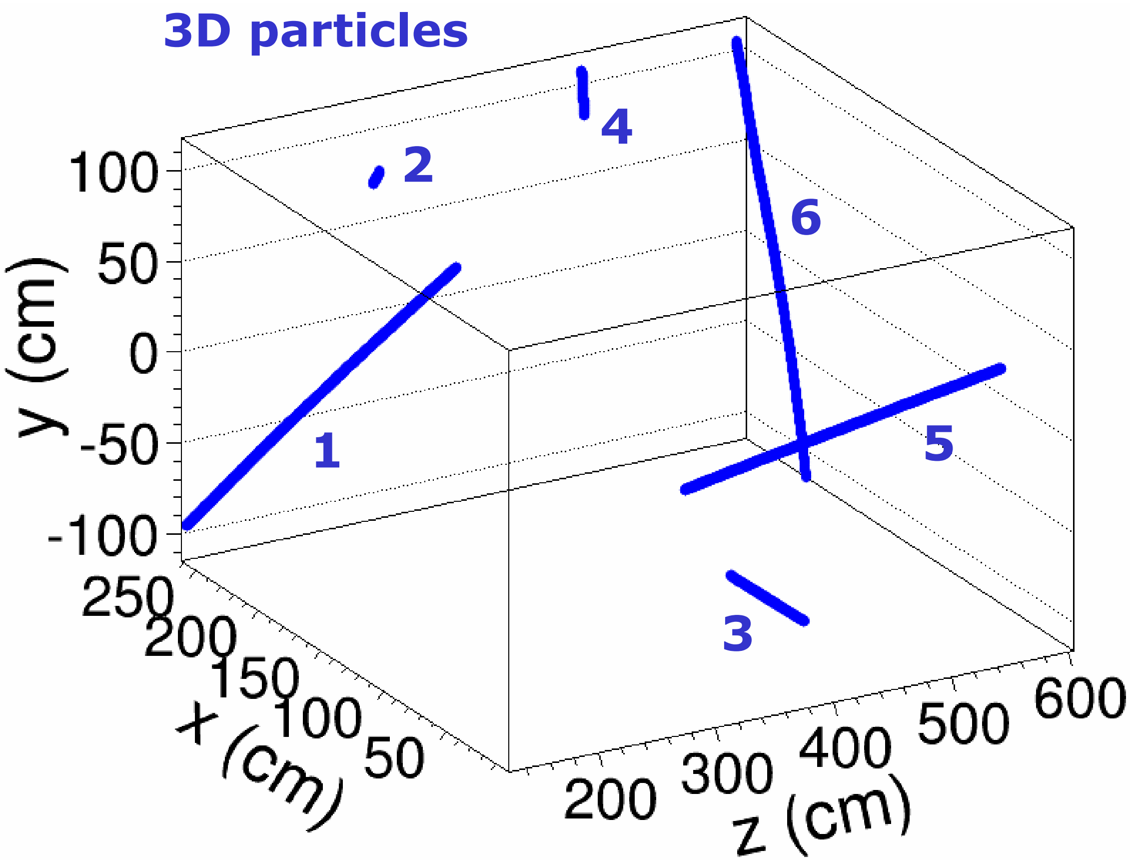


- Best 68% of reconstructed events fall within 2.5 cm of true track length.

3D reconstruction



3D cosmic-ray muon reconstruction is up and running!



LBNE Reconstruction

- **Have developed algorithms using MicroBooNE geometry, but all algorithms are readily applicable to LBNE!**
  - Neutrinos, cosmic-ray muons…
  - Far Detector, 35t prototype…

  } etc…

- **For LBNE, need to adapt algorithms for LBNE geometries. Various issues:**
  - Larger wire pitch (need to understand effect on algorithms).
  - Different transformations between U, V and Z views.
  - Multiple drift volumes.
  - Interface between pattern recognition and disambiguation?
  - etc…

- **Hope to get started on this soon…**

Summary

- **Continuing to make progress on Pandora reconstruction.**
  - Reconstruction is a big topic! But getting there…
- **Have run algorithms on LBNE and MicroBooNE neutrinos, using MicroBooNE geometry.**
  - Performance looks pretty good. Also, pretty fast!
- **Also have dedicated cosmic-ray muon reconstruction.**
  - New 2D reconstruction algorithms give better performance.
  - However, need to put more time into performance metrics.
- **Reconstruction code is now distributed in LArSoft.**
  - New packages: LArPandoraAlgorithms, LArPandoraInterface.
  - Have accumulated a lot of new code recently. Will commit to new git repository as soon as I know how!
- **Effort has been focused on MicroBooNE geometry so far... Need to get started on LBNE geometry!**