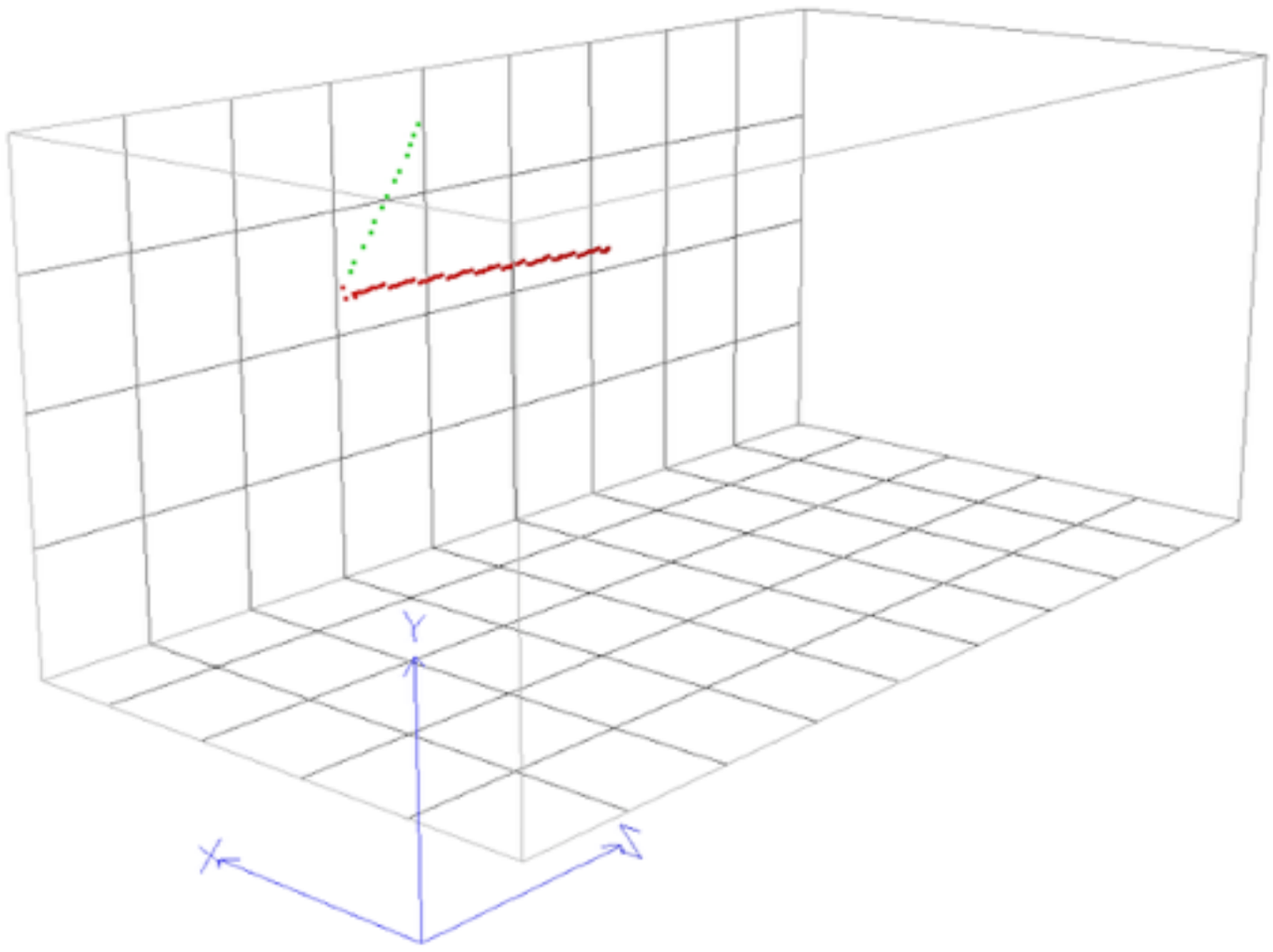


Reconstruction

T. Yang
FNAL

LArTPC14, July 7, 2014

Outline

- Goal of reconstruction
- Specific algorithms
    - Clustering
    - Track reconstruction
    - Shower reconstruction
    - Calorimetry and particleID
    - Optical reconstruction and cosmic removal
    - Pandora
- LBNE-specific issues

Reconstruction in LArTPC

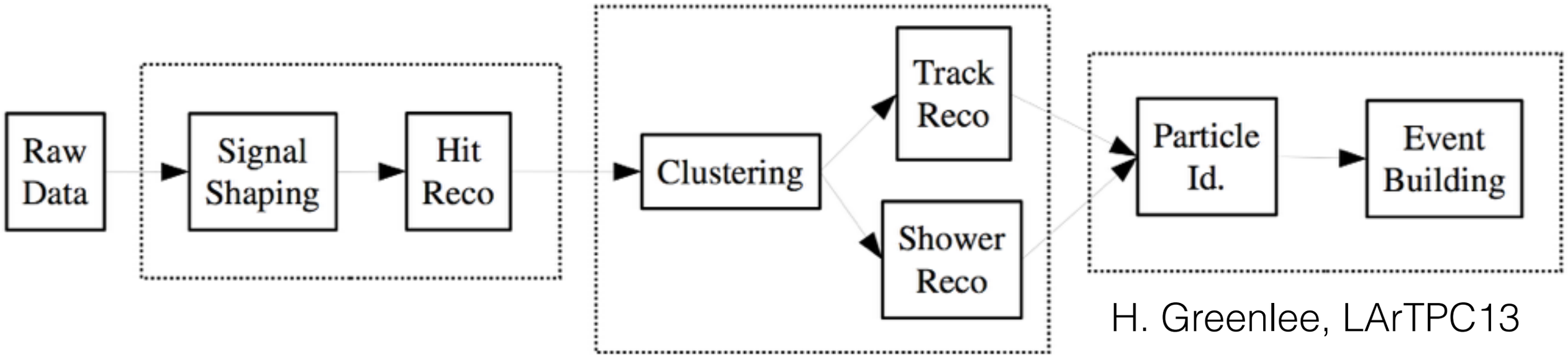
- I will give an overview of reconstruction algorithms in LArSoft - a project for LArTPCs at Fermilab.

- Reconstruction aims to reconstruct 3D particles out of raw signals.
    - The 3D particles can be track-like or shower-like.

- Identify particles using calorimetry/topology information.
    - Select signal events: ν_e from oscillations, ν_e from supernova, K from proton decay.

- Measure energy/momentum using calorimetry, range, multiple scattering (or curvature if magnetized).

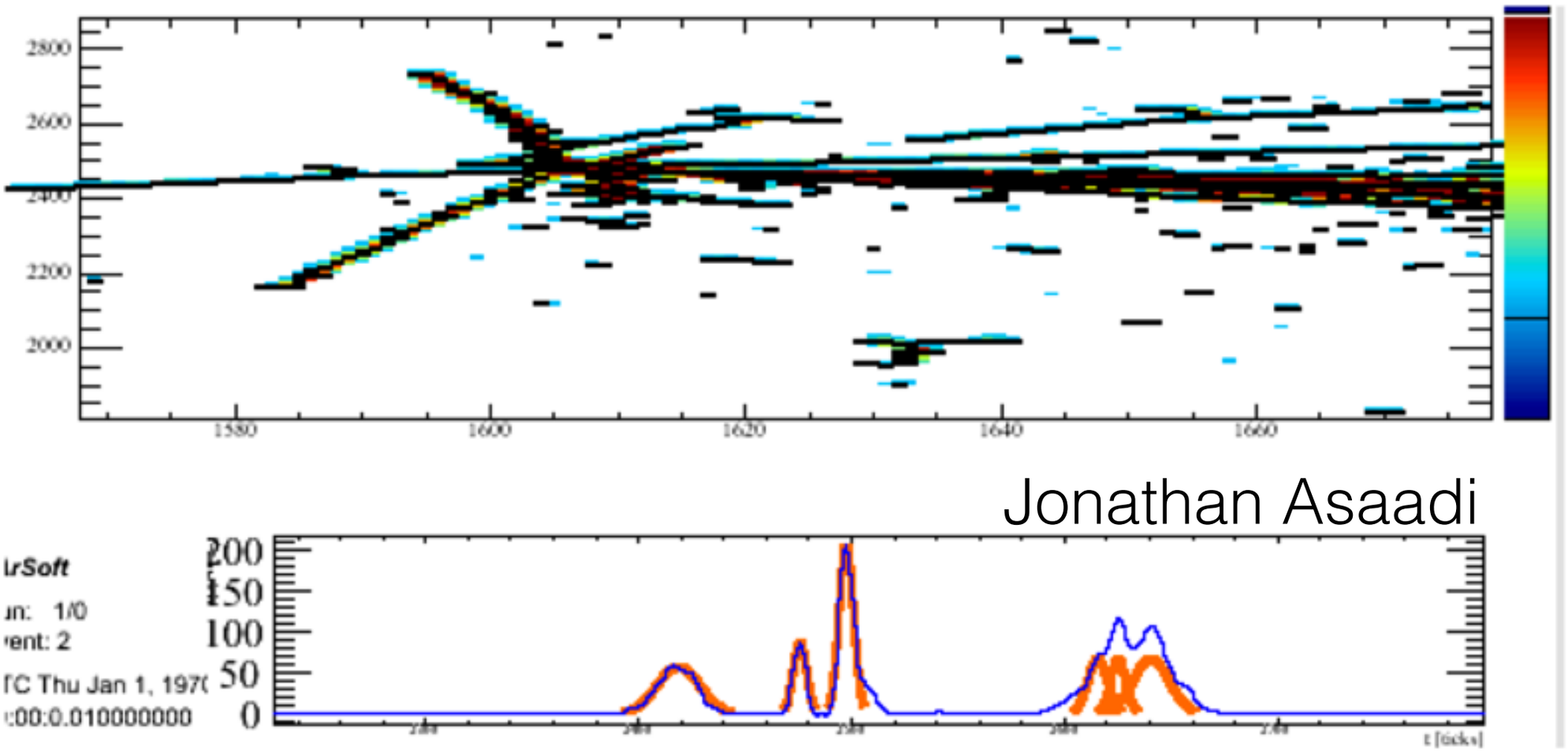
Reconstruction chain



H. Greenlee, LArTPC13

- Bruce has covered the signal shaping.
- I will focus on the rest of reconstruction chain
  - Hit reco, clustering, track reco, shower reco, calorimetry and PID.

Hit reconstruction



- Hit finding is the task of finding and characterizing peaks above baseline in the shaped readout waveform.

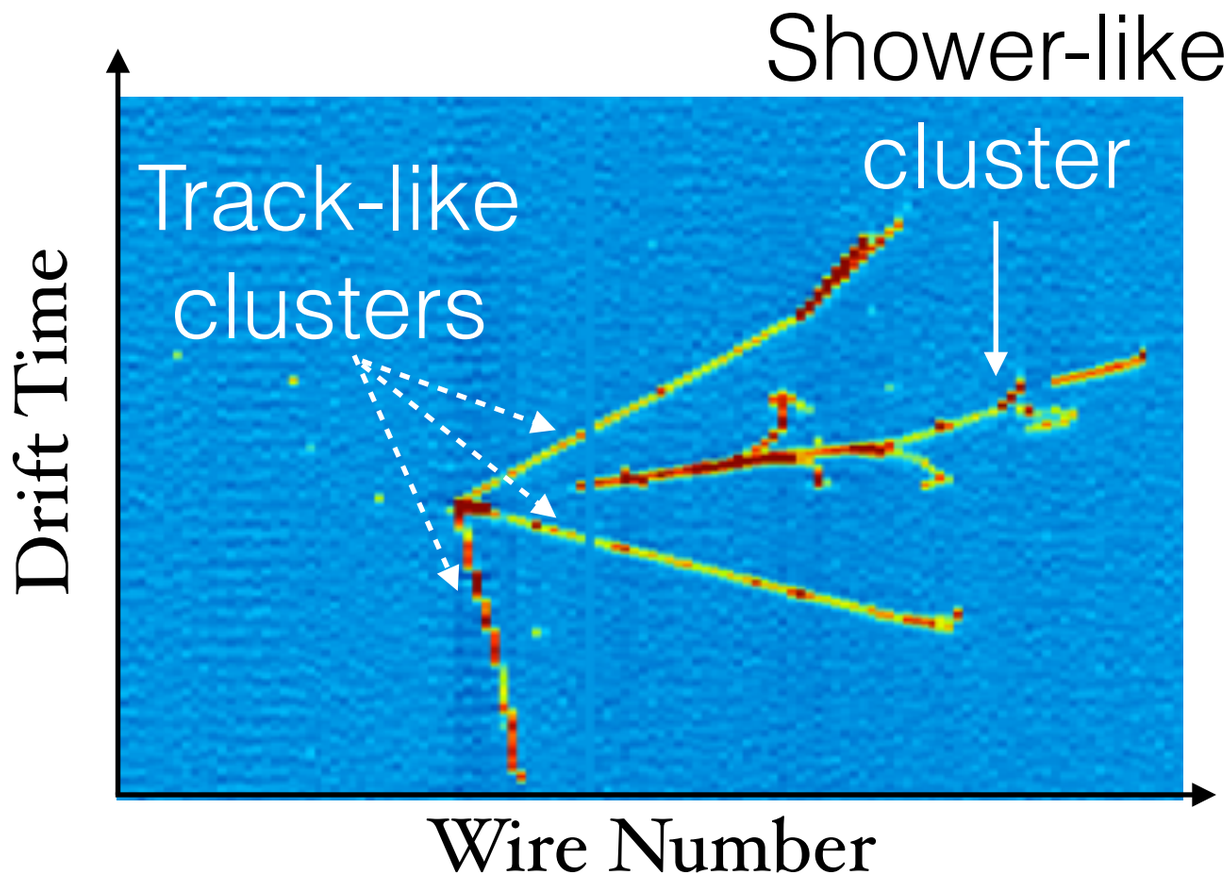
- Hits are characterized by position, height and width.

Cluster reconstruction

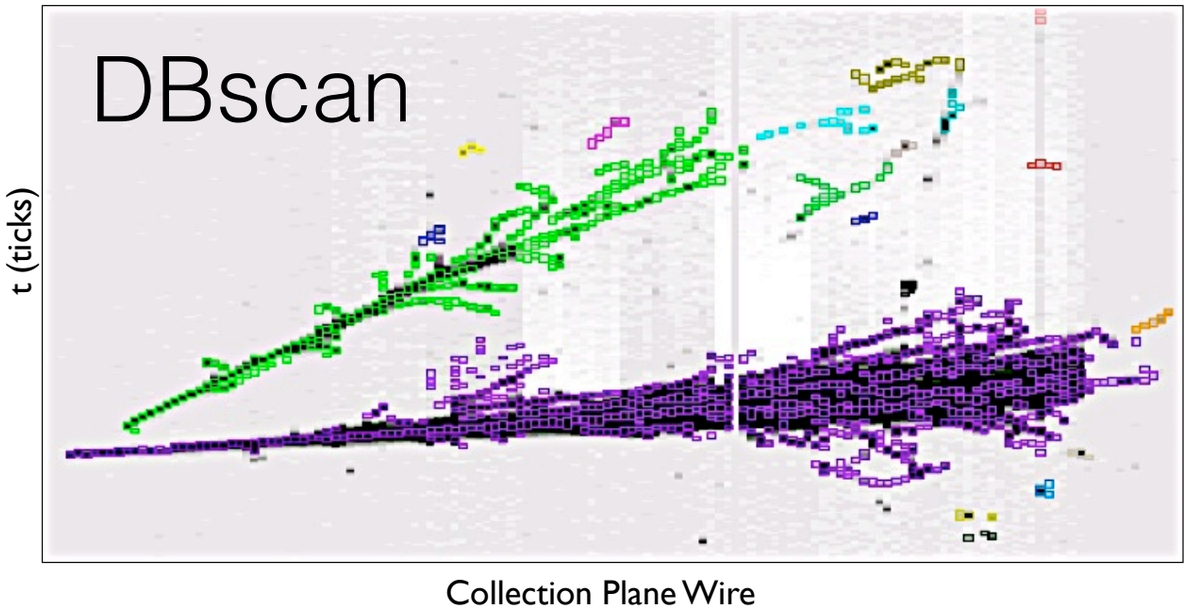
- Hits caused by the same primary particle (within one plane view) are called one cluster.

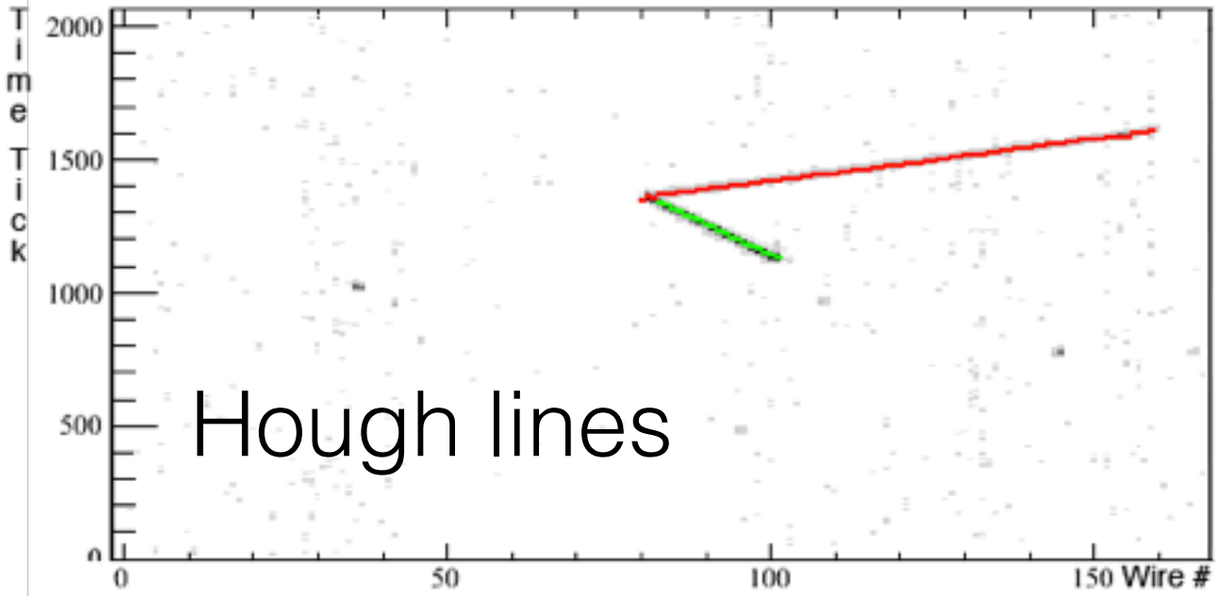
- Cluster reconstruction is normally straightforward because of the proximity of hits caused by the same particle.

- Clustering algorithms
  - DBscan
  - Hough-line finder
  - Fuzzy clustering (Ben Carls)
  - Cluster Crawler (Bruce Baller)



- **DBscan**
  - Density-based spatial clustering.
  - Good for photon showers.
- **Hough line finder**
  - For small TPC, Hough lines can be used as tracks.
  - For large TPC, tracks are not straight enough to be found as single Hough lines.
  - Hough lines are still useful for finding parts of longer tracks, or track-like substructures in showers.



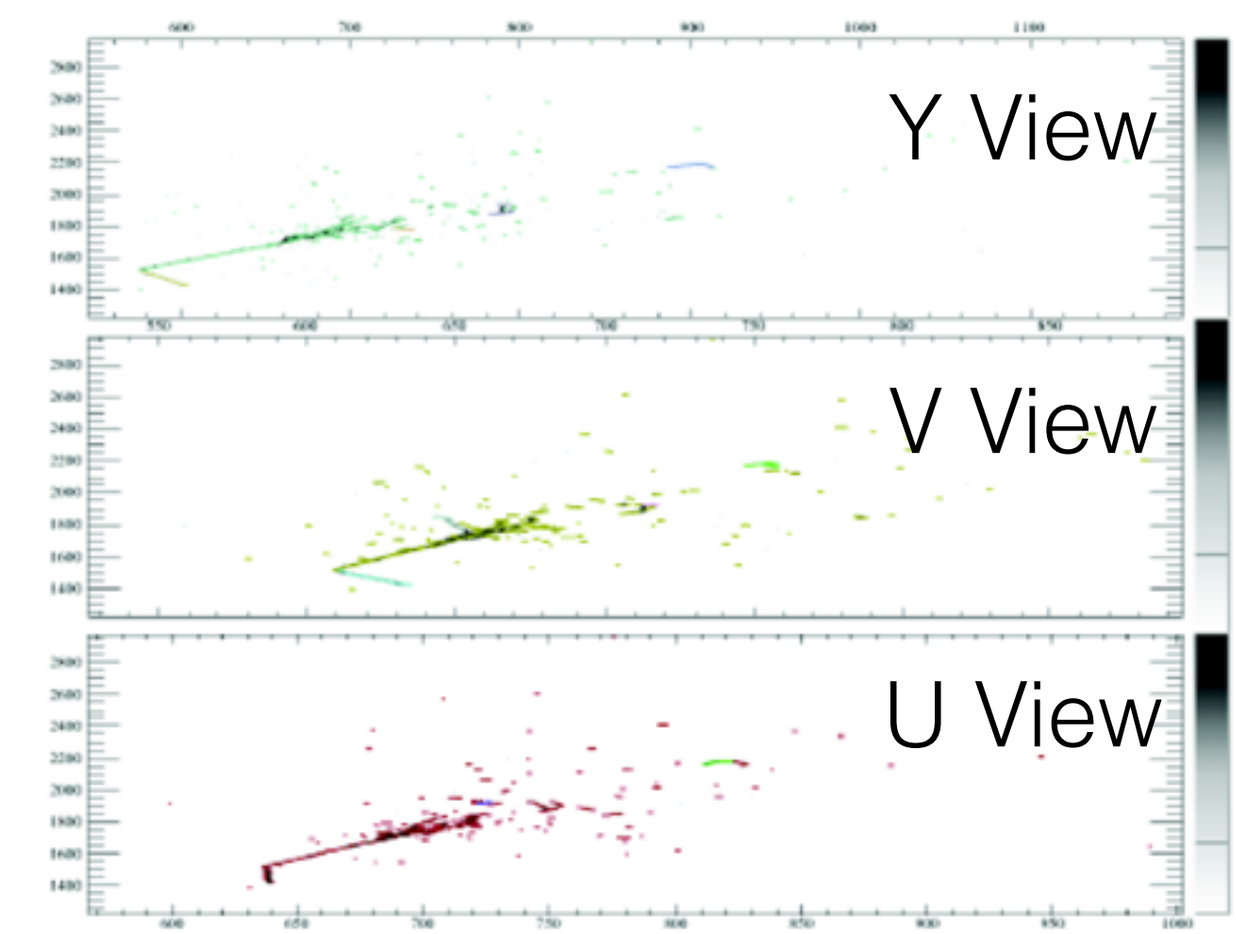


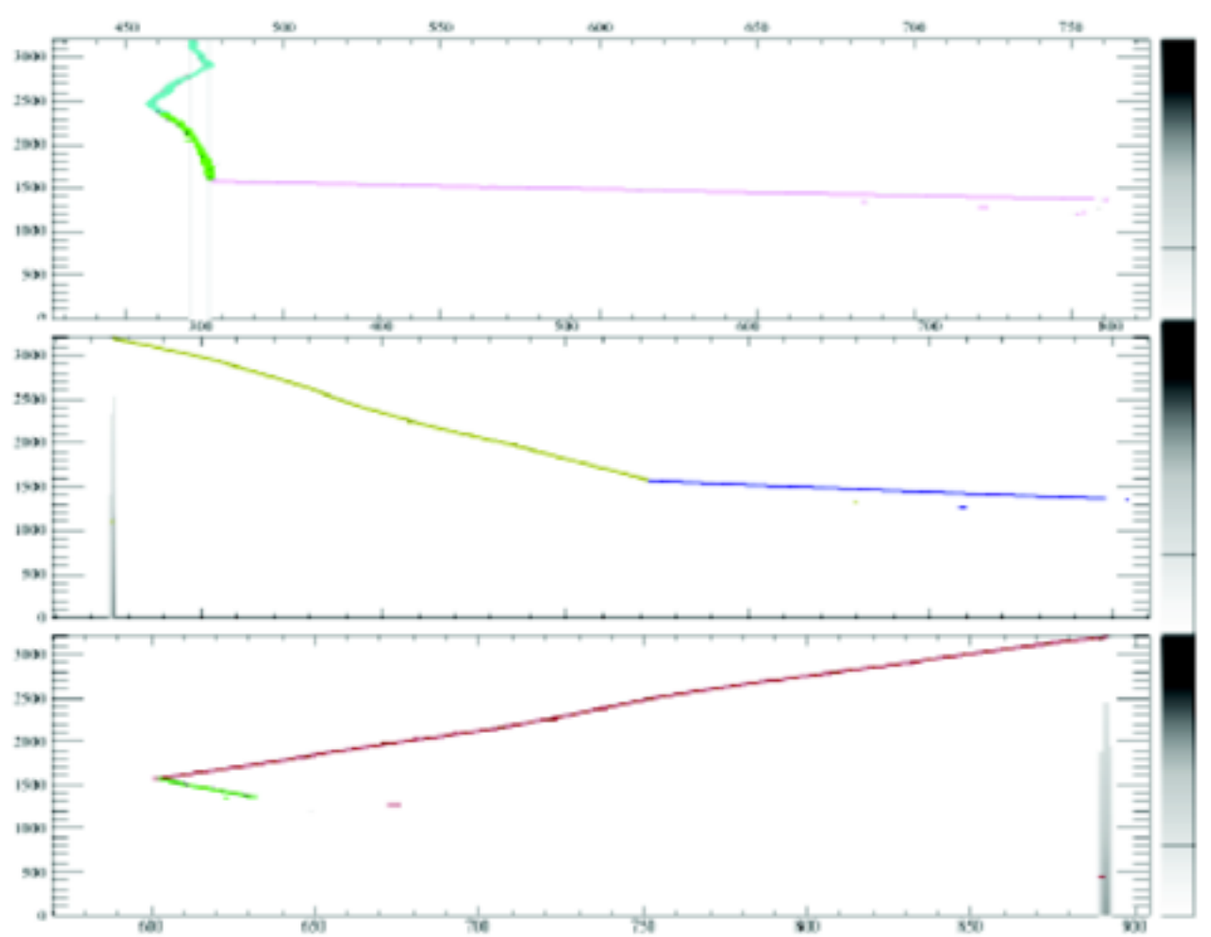
Developed for early ArgoNeuT analysis: 1205.6747.

Fuzzy clusters

Ben Carls

- Fuzzy clustering + line finding + merging
- Basic idea is to merge Hough lines based on proximity in space and angle (rather than just space, as with dbscan), then merge remaining nearby isolated hits.
- Reconstruct both track-like and shower-like clusters.



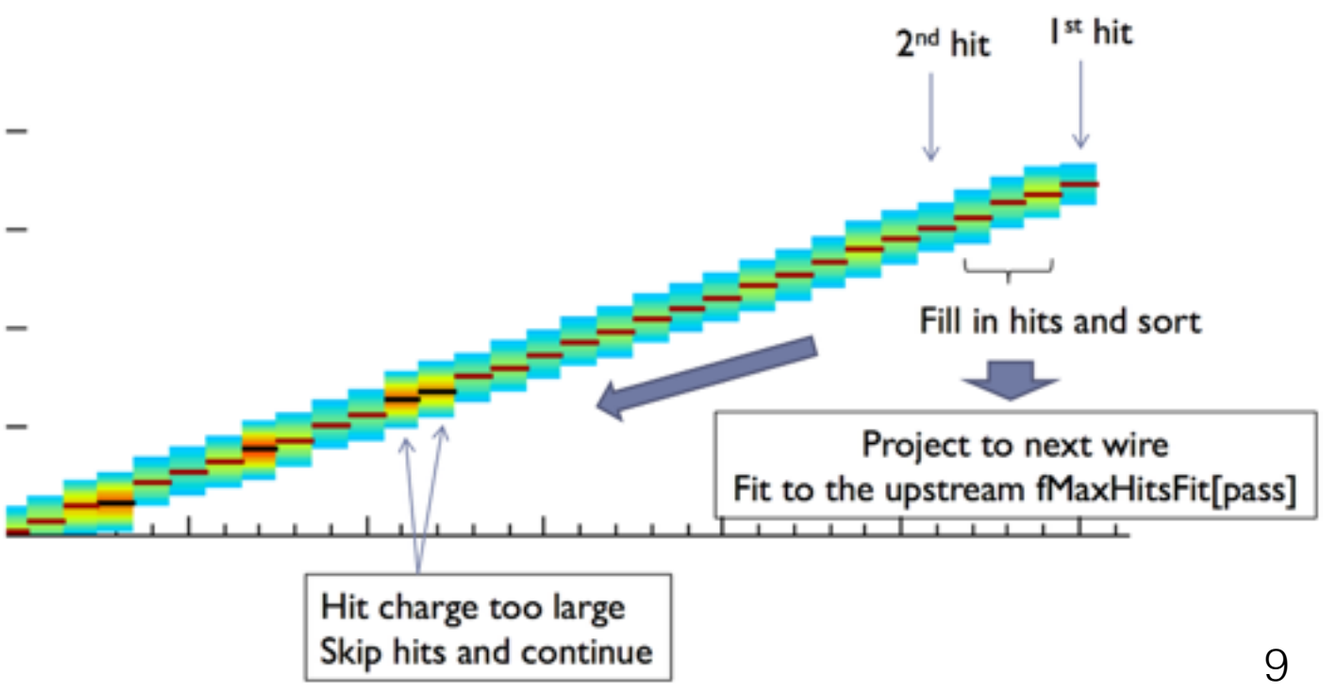


Bruce Baller

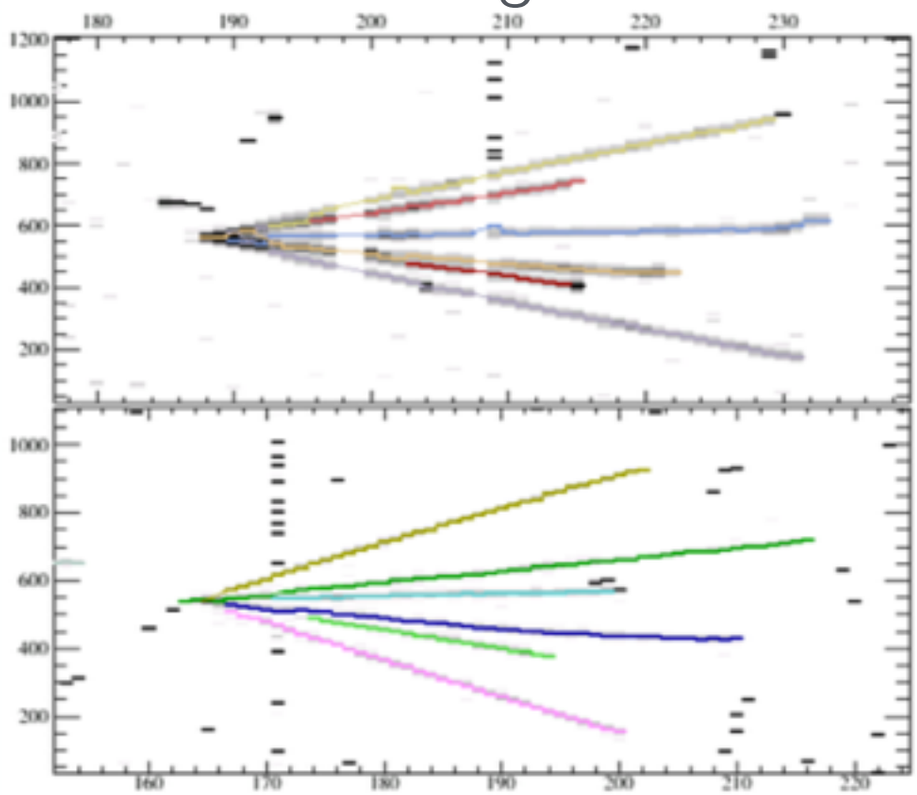
Cluster Crawler

- Clusters are found in each wire plane view by projecting short "seed" clusters formed in regions of low hit density into higher hit density regions.

- Hits are appended to the seed cluster if the projected hit position and hit charge are consistent with the seed cluster hits.

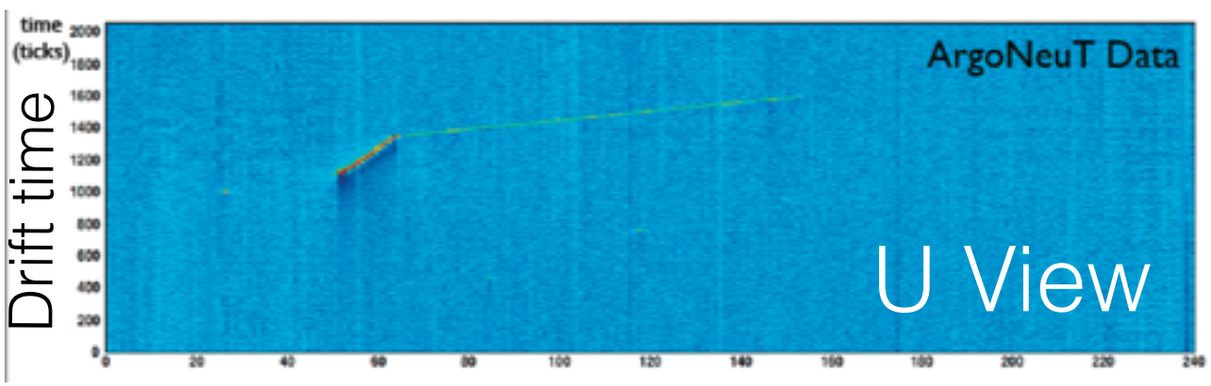


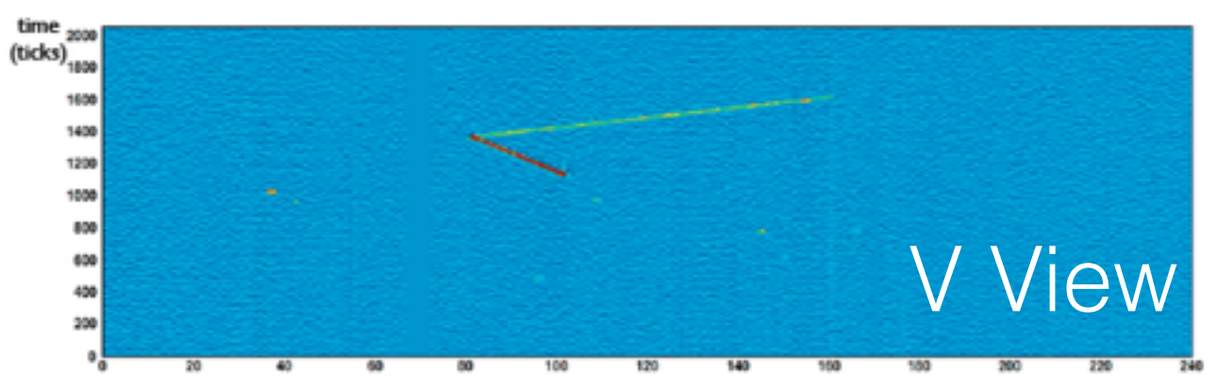
ArgoNeUT data



From 2D to 3D

- Hits and clusters contain 2D information: wireID and drift time.
- The next step is to reconstruct 3D objects (track or shower) using hits/clusters in different plan views.
- The key is to match hits with common drift time
  - Drift time gives $x = v_0 * t$.
  - Wire crossing gives y and z.
  - Difficult for tracks parallel to wire planes.





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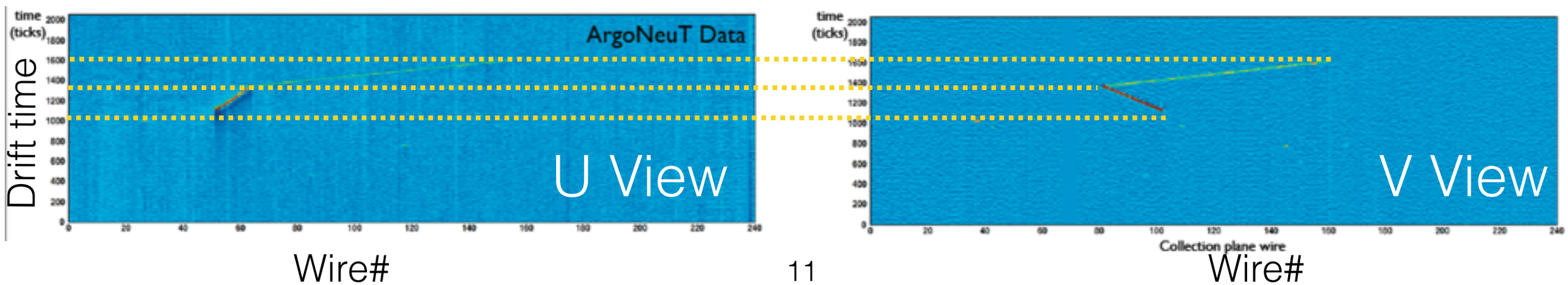
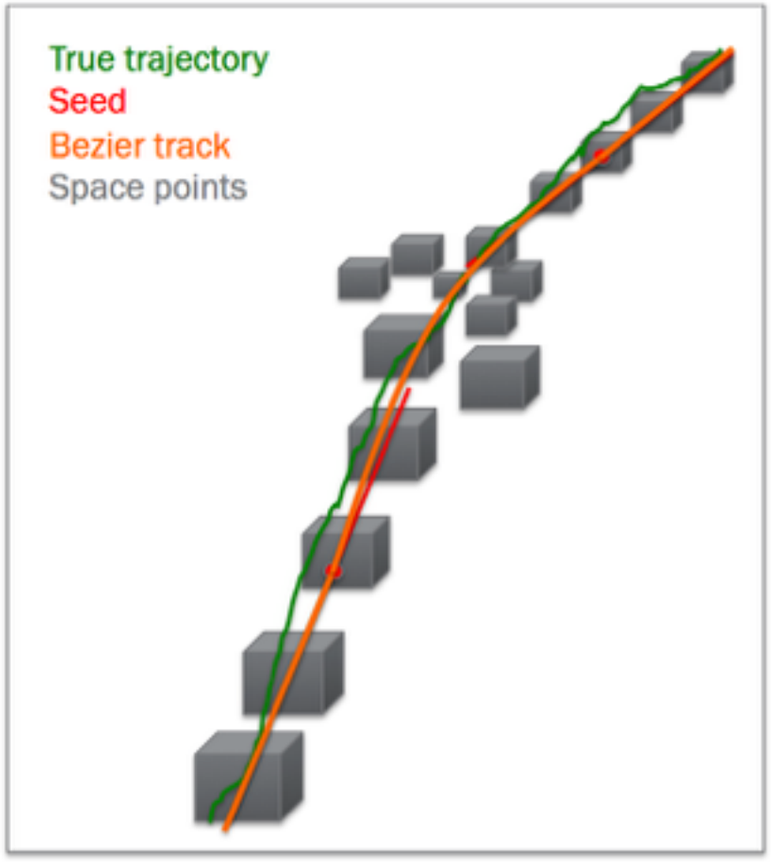


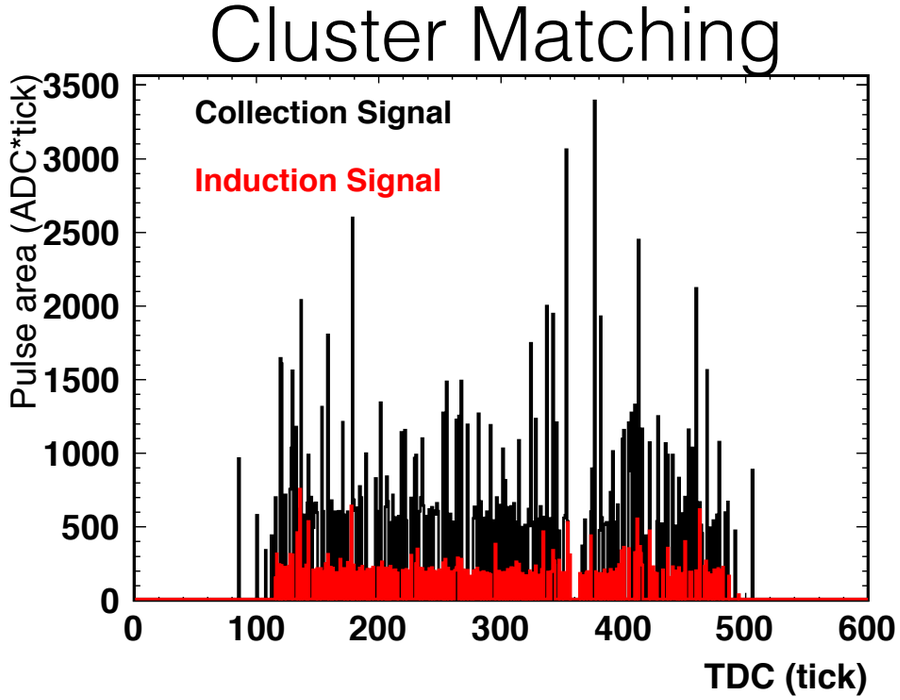
Tracking algorithms in LArSoft

- Non-Kalman-filters
  - Bezier Tracking
  - CosmicTracker
- Kalman filters
  - TrackKalmanHit
  - TrackKalmanSPS

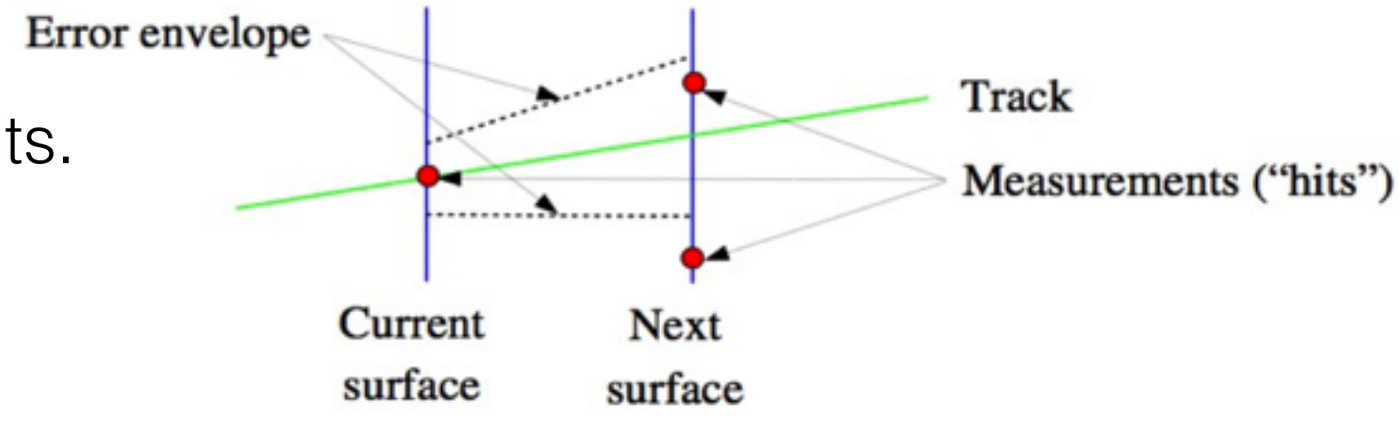
- **Bezier Tracking** - Ben Jones
  - Reconstruct seeds (3D point with direction) using clean hits.
  - Runs a smooth track through set of seeds interpolating through 2D hits.



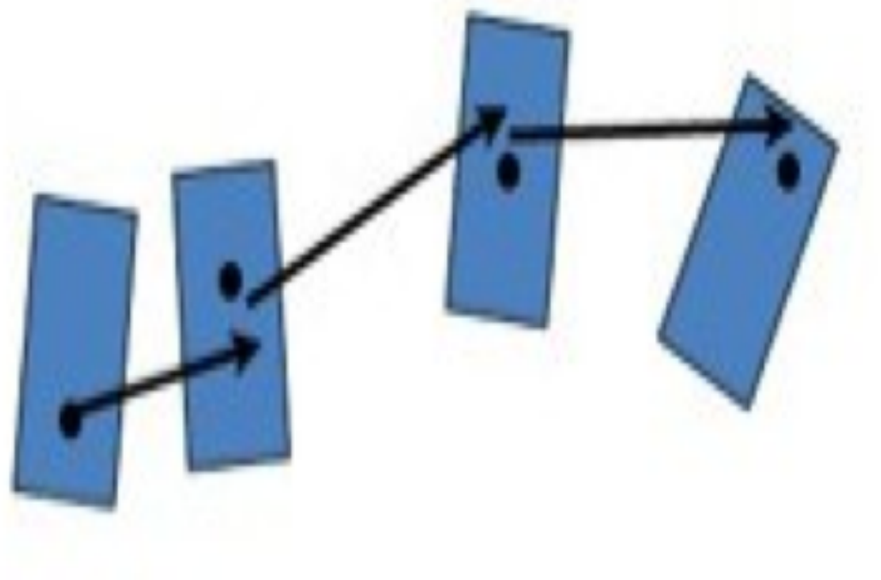
- **CosmicTracker** - Tingjun Yang
  - Match clusters based on time and charge.
  - Reconstruct 3D space points using hits on matched clusters.
  - Used in ArgoNeuT CC-inclusive measurement with cluster crawler: PRD **89**, 112003 (2014)



- **TrackKalmanHit** - Herb Greenlee
  - 3D track finding directly using hits.
  - Starts from 3D seed tracks, use Kalman filter to define a road for adding hits.
  - Does not rely on clusters directly, 90% efficiency to reconstruct cosmic tracks.



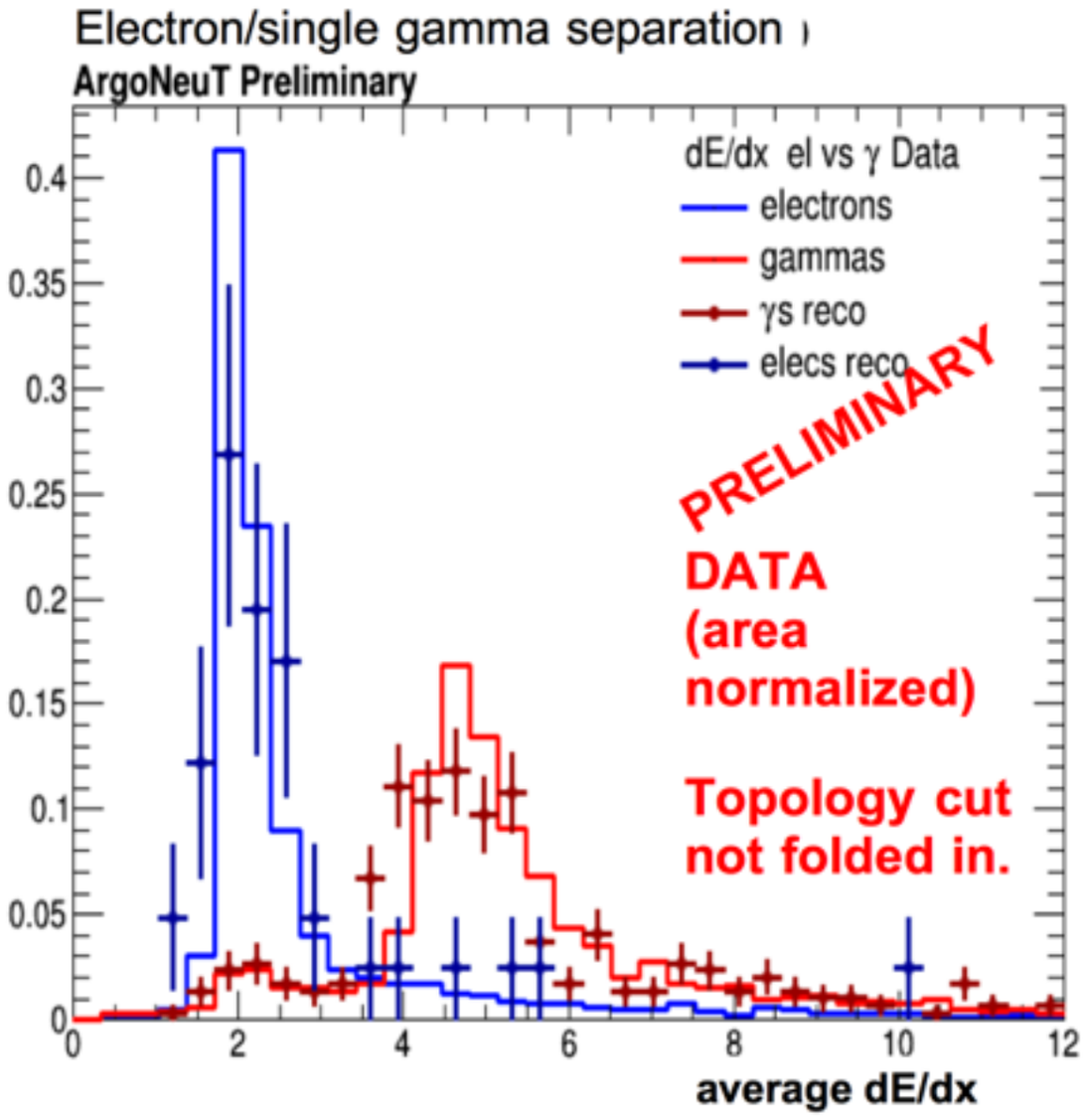
- **TrackKalmanSPS** - Eric Church
  - Reconstruct 3D space points using hits
  - Run Kalman filter through space points.



Shower reconstruction

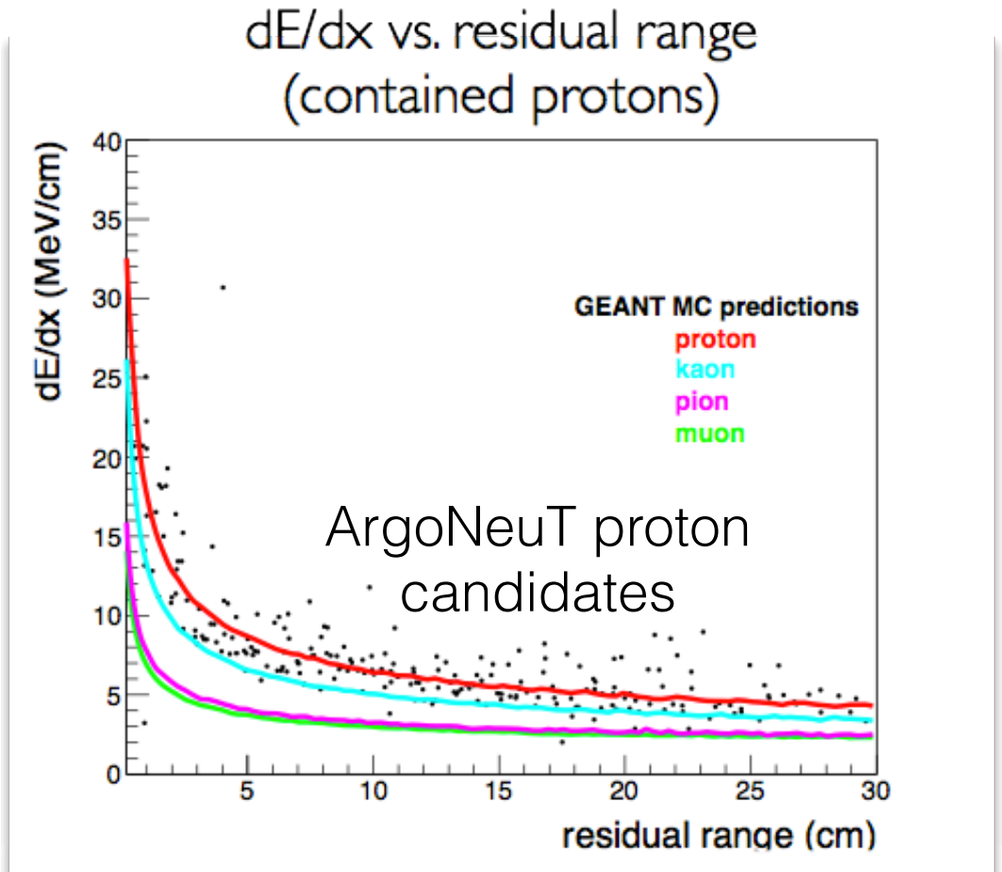
- Start with 2D clusters
  - Calculate 2D start points, angles
  - Select shower like clusters
  - Match clusters between different plane views
- Reconstruct 3D shower objects using matched 2D clusters
  - 3D shower axis
  - dE/dx and shower energy
- Current focus is on refining cluster reconstruction

Andrzej Szelc



Calorimetry and PID

- dQ/dx -> dE/dx
  - Electronics calibration factor
  - Electron lifetime correction
  - Recombination correction (Birks model or Modified Box model)
- Calorimetry based particle ID
  - dE/dx vs residual range for contained tracks



Optical reconstruction and cosmic removal

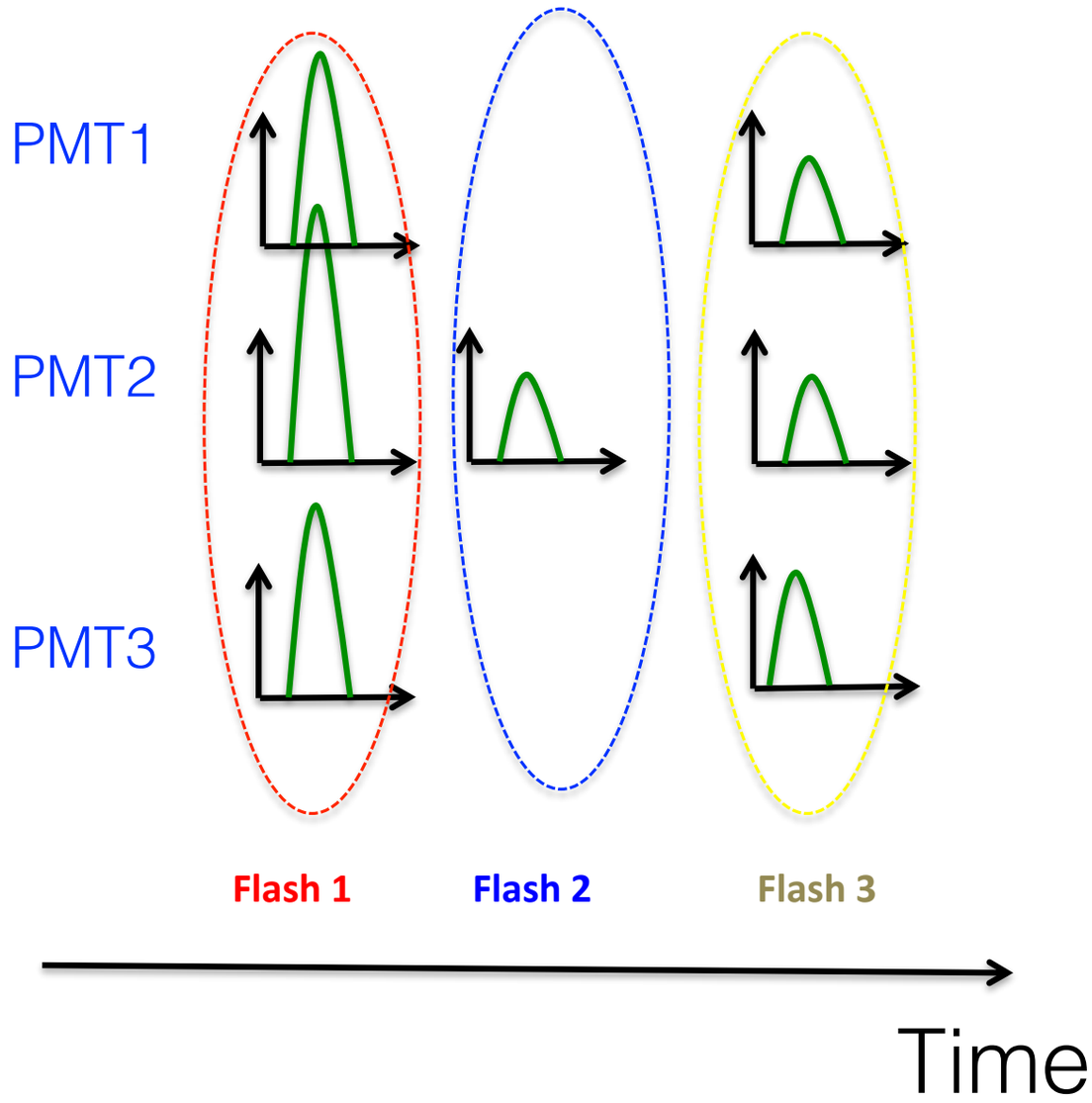
Ben Jones
Kazu Terao
Wes Ketchum

- Flash: a group of PMT pulses that happened at the same time.

- Each flash represents a neutrino or cosmic interaction.

- Current FlashFinder is almost 100% efficient for protons above 40 MeV.

- Matching flashes with tracks gives t0 information of each track, thus help to remove cosmic ray background.



Pandora

Andy Blake
John Marshall
Mark Thomson

- Starting from hits, pandora is a toolkit for doing all of the steps involved in pattern recognition, in 2D and 3D.

- Development of Pandora reconstruction chain for MicroBooNE has now reached an advanced stage.

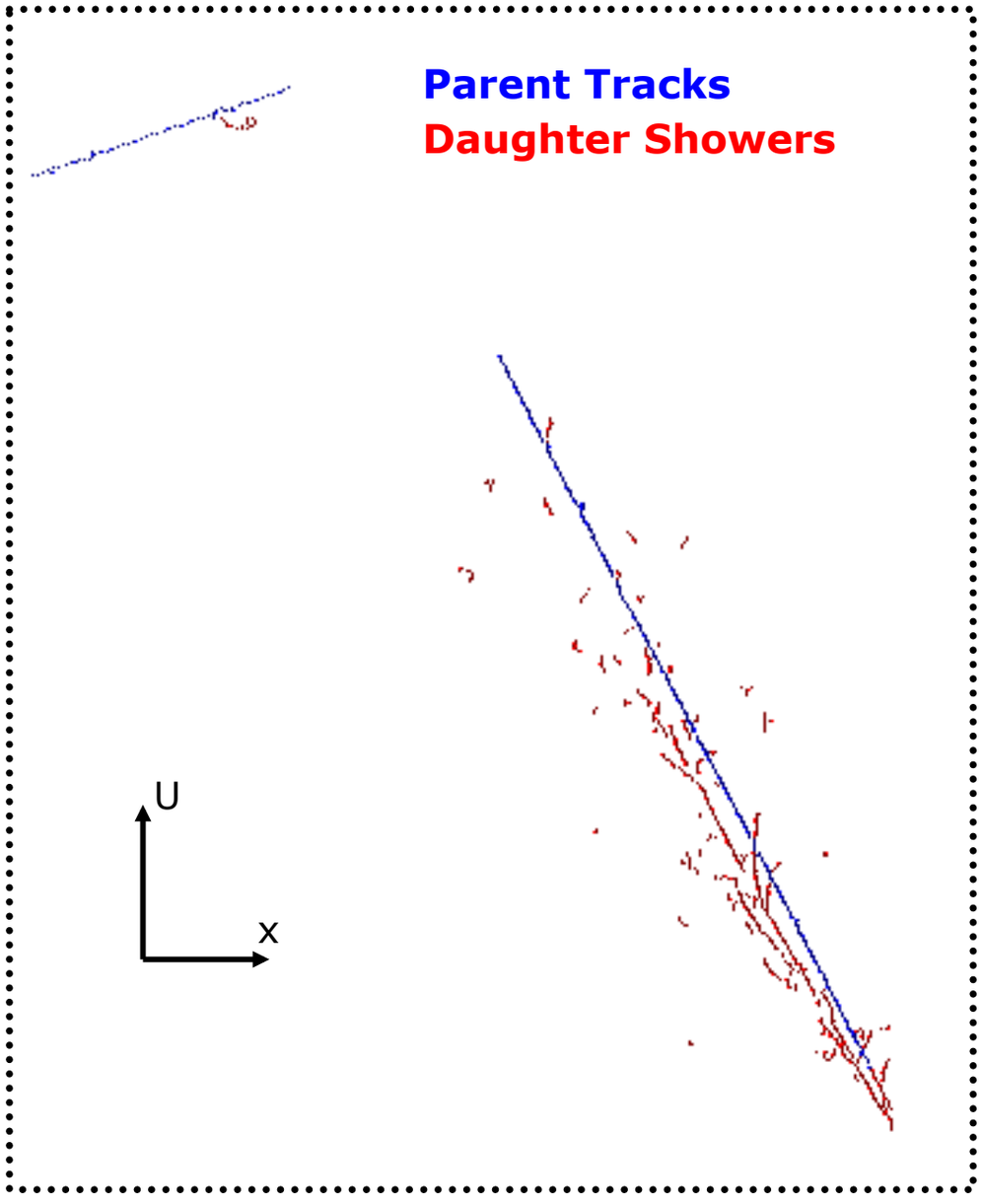
- In particular, a ‘complete’ chain of algorithms for muon track reconstruction and cosmic-ray reconstruction.

  - Efficiency close to 100% above ~100 hits.

- Current focus:

  - Shower reconstruction.

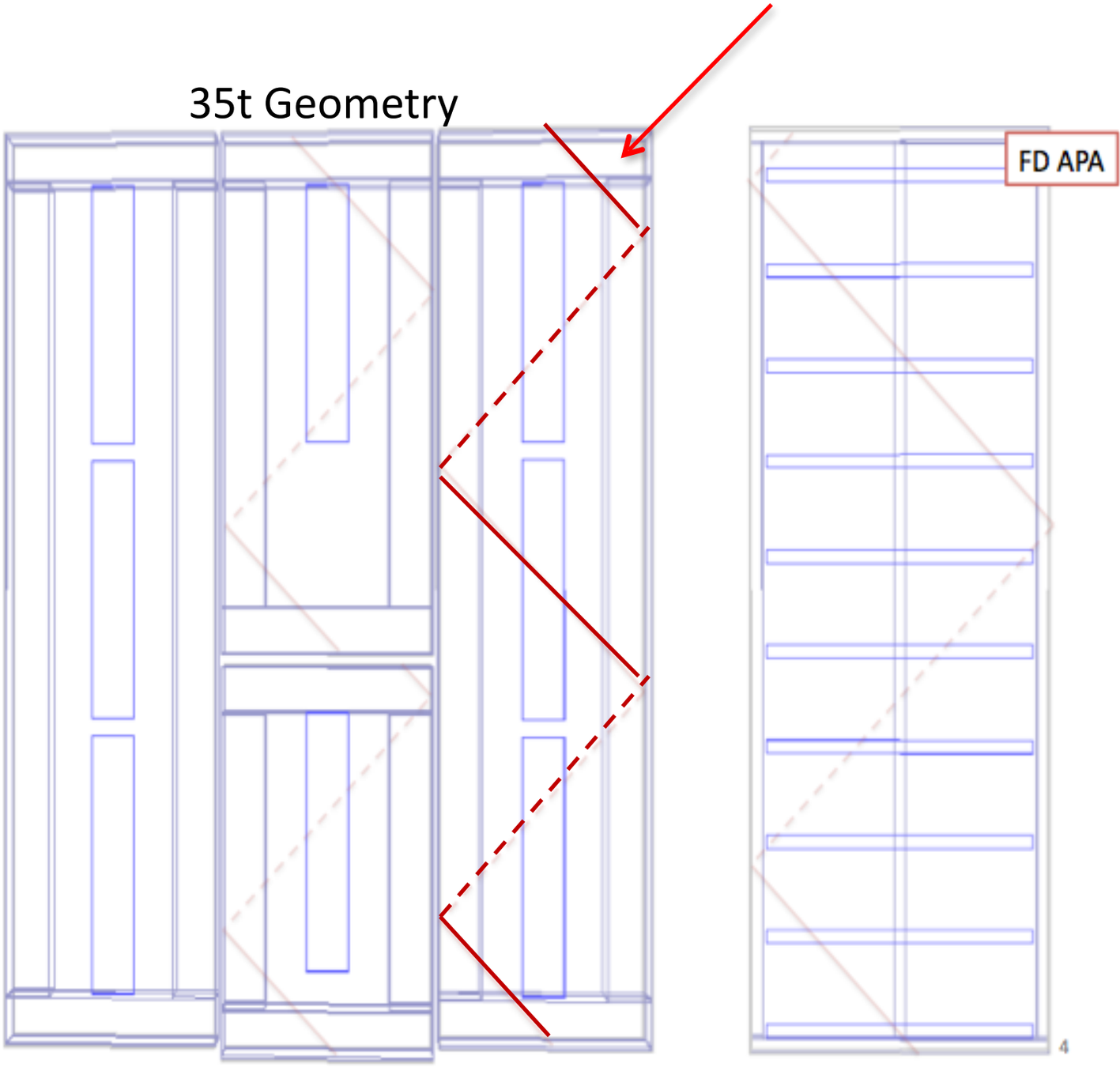
  - Propagate the reconstructed objects through LArSoft.



LBNE-specific Problem: 35t and Far Detector Induction-Plane Hits are Ambiguous

Five wire segments connected to the same electronics channel

- Disambiguation is associating a hit to a single wire segment using other hits in the same region.
- Easier problem to solve in the far detector than the 35ton
- May need to use external counter information



Breaking LBNE's Ambiguities

Tom Junk

If hits are unique in time, then they can be associated between views based on time (J. Kim).

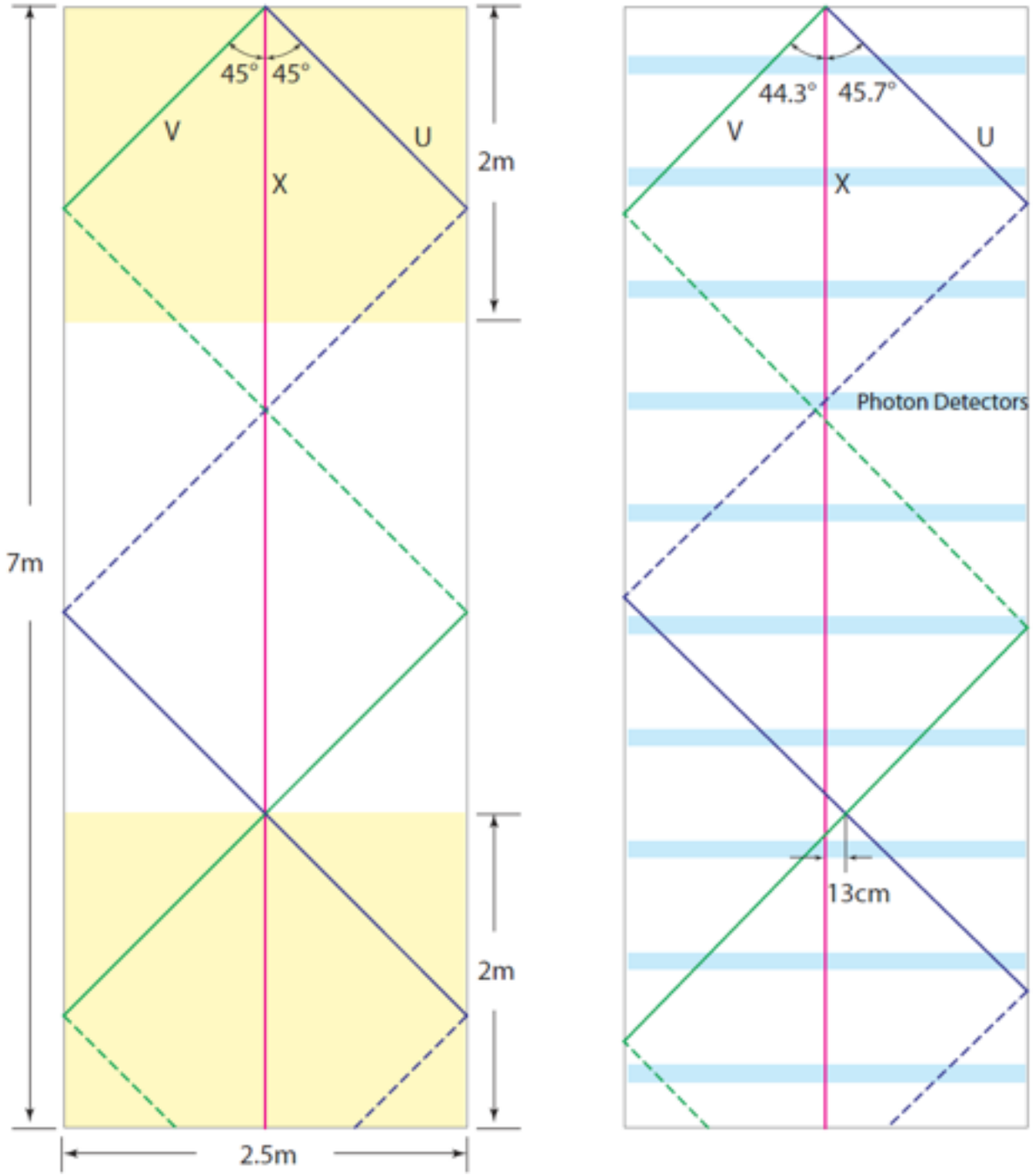
Wire angle choice of

U: +45.707°
V: -44.275°

Mean that triplets of U, V, and Z wires intersect just once.

But ...

- Many hits arrive close in time for many events
- One hit in one view may correspond to several hits in another (foreshortening)
- Hits may be lost
- Hit timing may not be precise
- Performance based on just timing is not perfect



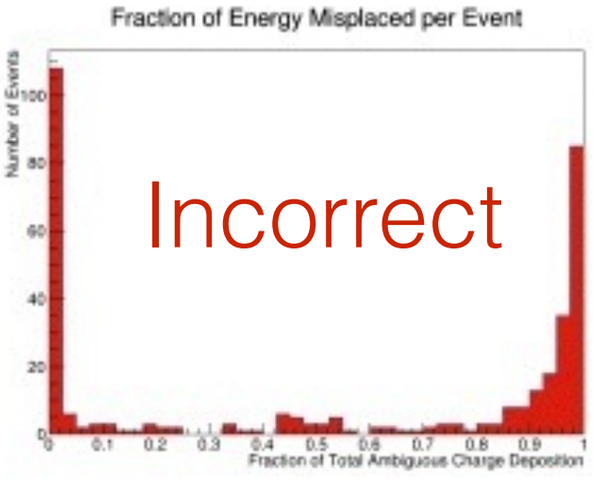
Far Detector angle skew example.

Right and Wrong Fractions with 45° vs. 36° Wires

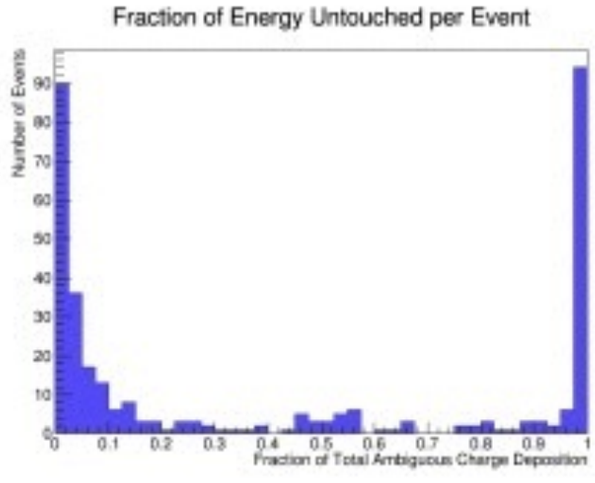
Tom Junk

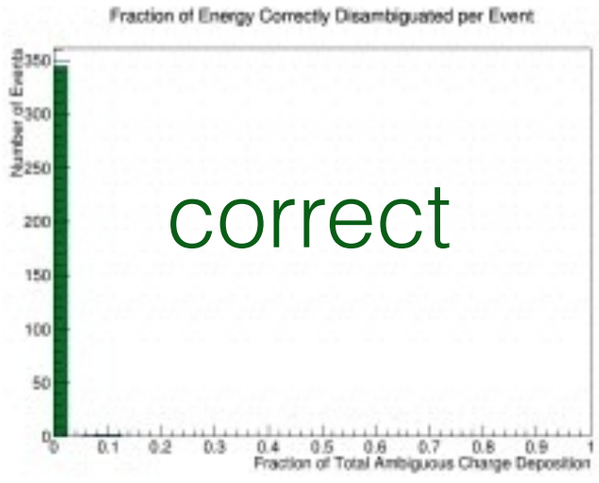
T. Alion, DocDB 8452

incorrect
missed
correct



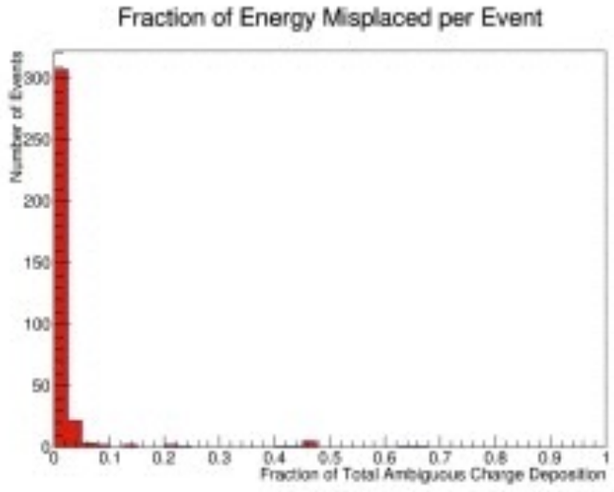
Incorrect

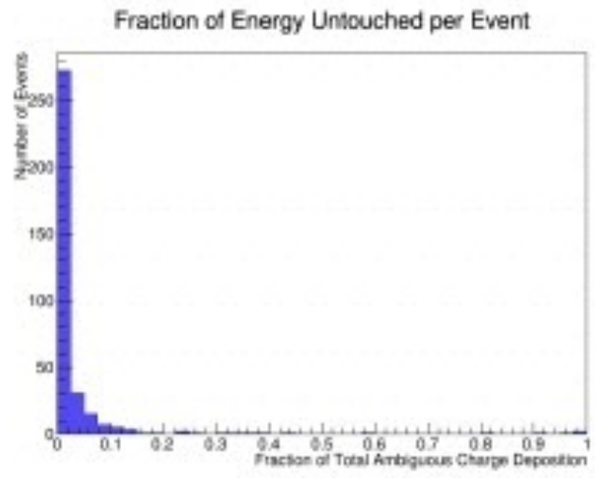


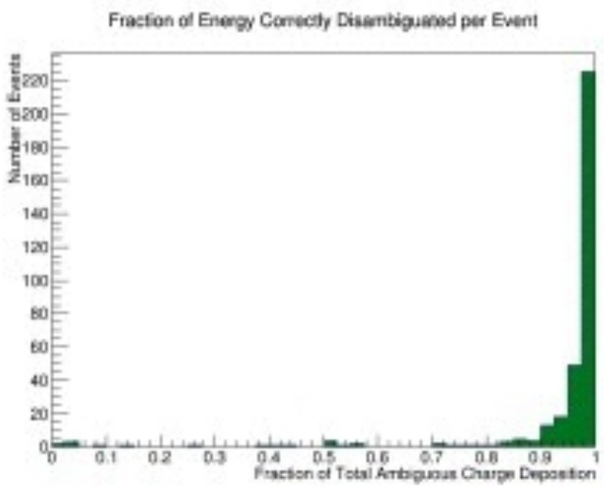


correct

350 Nue events in 45°







350 Nue events in 36°

Algorithm not optimized for 45° -- all hits either misassigned or not assigned.
We prefer the smaller angle! But algorithm optimization may show that 45° isn't so bad.

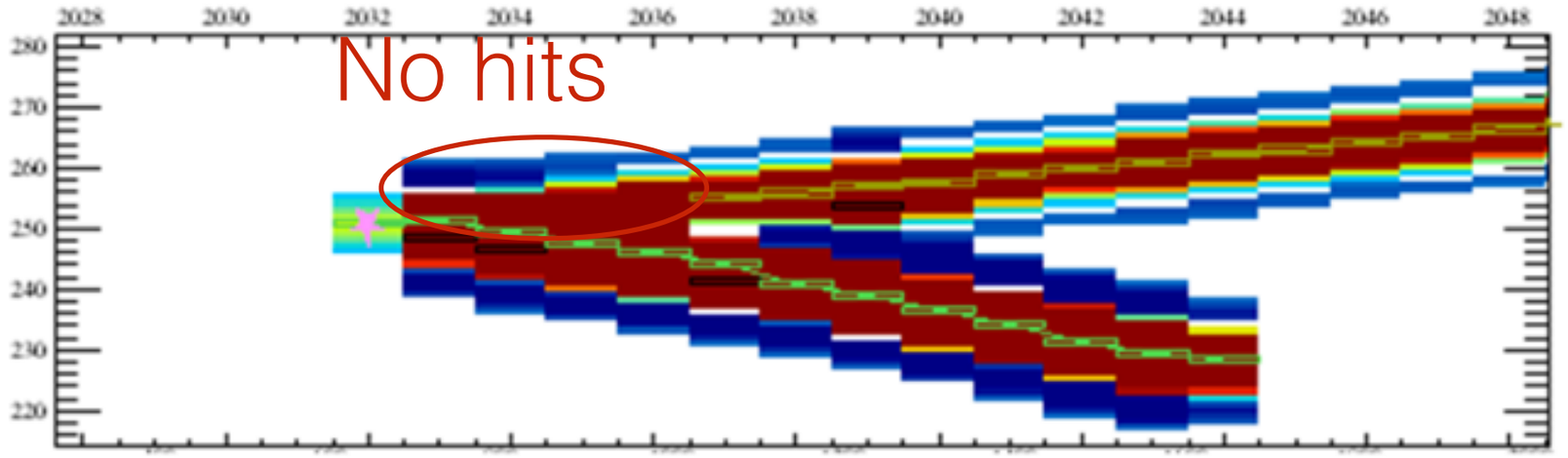
Likely some residual of ambiguous events in 45° that hurt physics, like proton decay

Conclusions

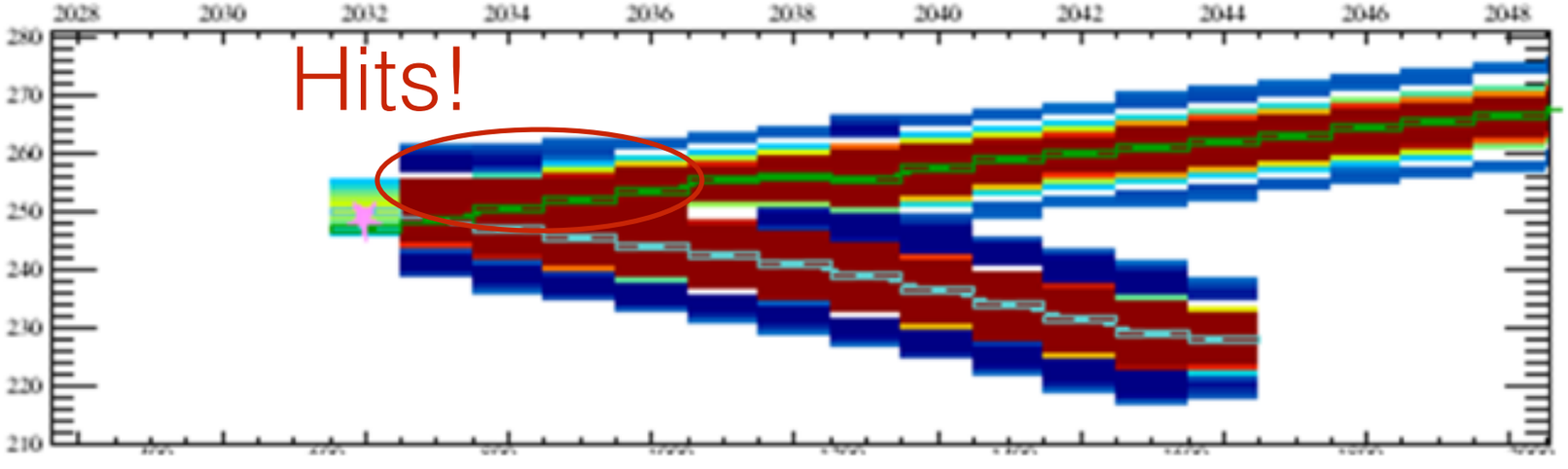
- Cosmic reconstruction is in a pretty good shape.
  - Current focus is track reconstruction in neutrino events.
- Shower reconstruction is under rapid development.
  - Current focus is on optimizing cluster reconstruction.
- Need to understand the reconstruction performance with wrapped wires for LBNE.

- ClusterCrawler module also reconstructs hits and does hit refining around neutrino vertex.

Before



After

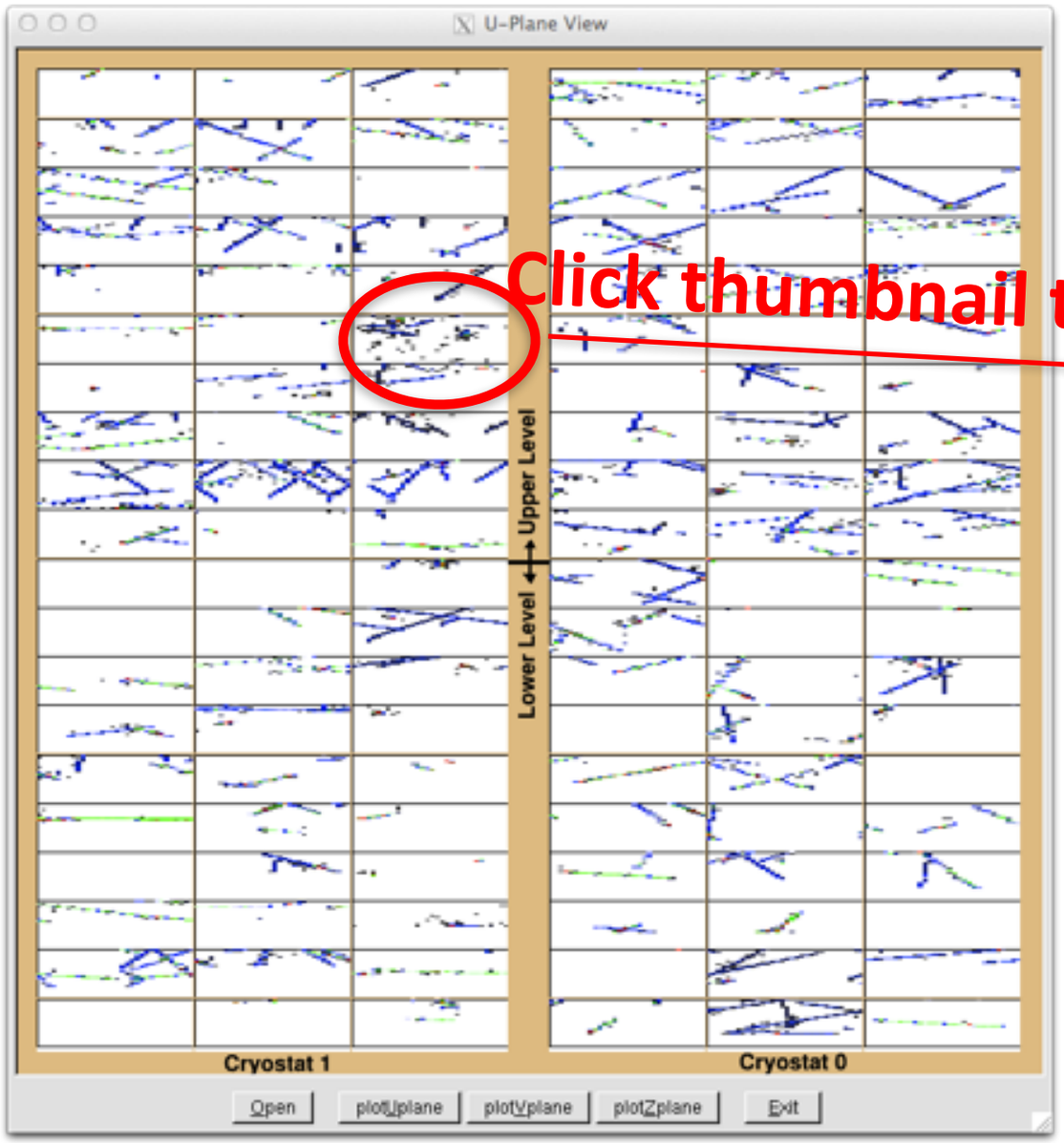


LBNE-Specific Issue: the 10 kt Far Detector is **BIG!**

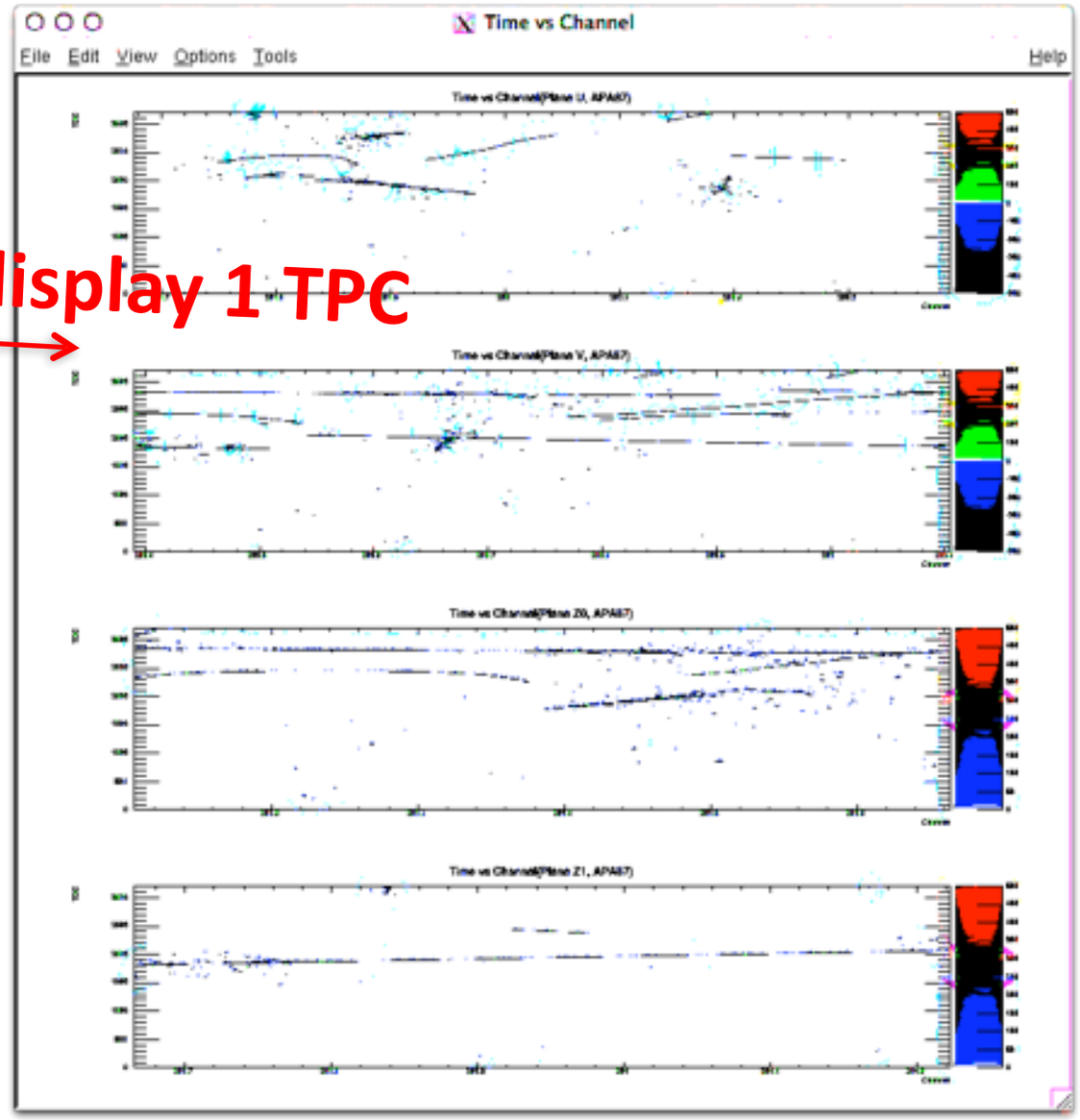
Tom Junk

How do we display the events? (2 GB raw data/event)

Big problem for surface FD design – 70 cosmics on average
in a 3 ms readout window; 0.001 neutrino event on average (just reading out beam spills).



Click thumbnail to display 1 TPC



S. Park (U.T.Arlington)

Scanning events is less of a worry underground – occupancy ~0. But it's good to have the powerful tools nonetheless!

Current Best Disambiguation Strategy

Tom Junk

- Assign ambiguity choices first to those hits with just one solution (“Trivial”)
  Hits separated in time.

- Extrapolate ambiguity choices to hits on nearby channels at nearby times
  “crawling” – Essentially a mini-clustering algorithm used in pattern recognition

- Very efficient for tracks and localized clusters
- Not so good for events that cross the APA frames (algorithm improvement possible)
  or “salt and pepper” events

Black points: all hits
Red points:
correctly disambiguated

T. Alion
J. Kim (Univ. S. Carolina)

Disambiguation cheater available in LArSoft too.