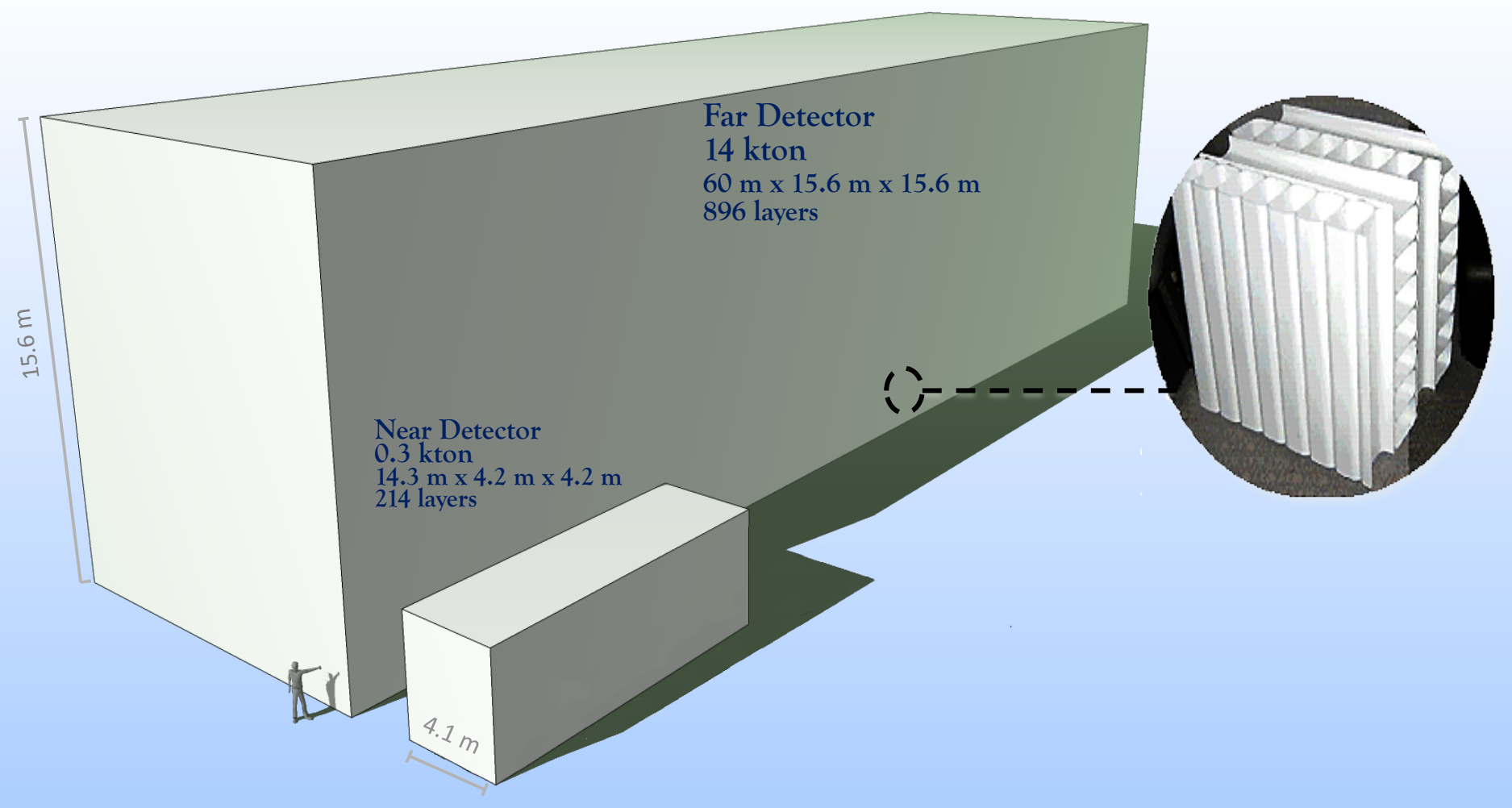
Event Reconstruction with the NOvA Far Detector

Michael Baird – mibaird@indiana.edu
for the NOvA Collaboration

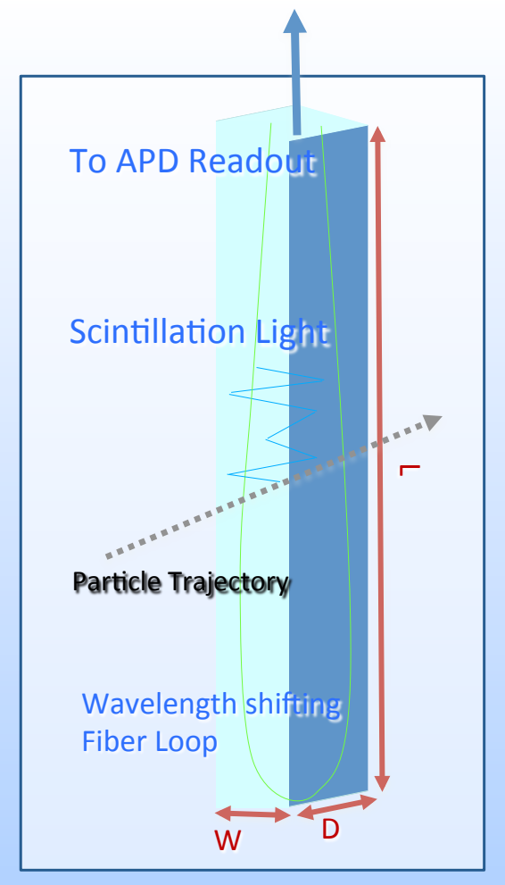
Background

NOvA is a long-baseline neutrino oscillation experiment based out of Fermilab that uses the newly upgraded NuMI beam line and two functionally identical detectors to measure the neutrino rates at a near location, and 810 km away at a far location.



The NOvA detectors are made from planes of extruded PVC cells. Each cell is 4 cm x 6 cm x 15 m (shown at the right) for the far detector, and 4 cm x 6 cm x 4 m for the near detector. These cells are read out at one end from a fiber connected to an avalanche photo diode. The planes alternate between being horizontally and vertically oriented to provide 3D tracking of particles in the detector.

Our reconstruction algorithms are designed to take position, time, and charge information from cell hits and construct interaction vertices and particle tracks.



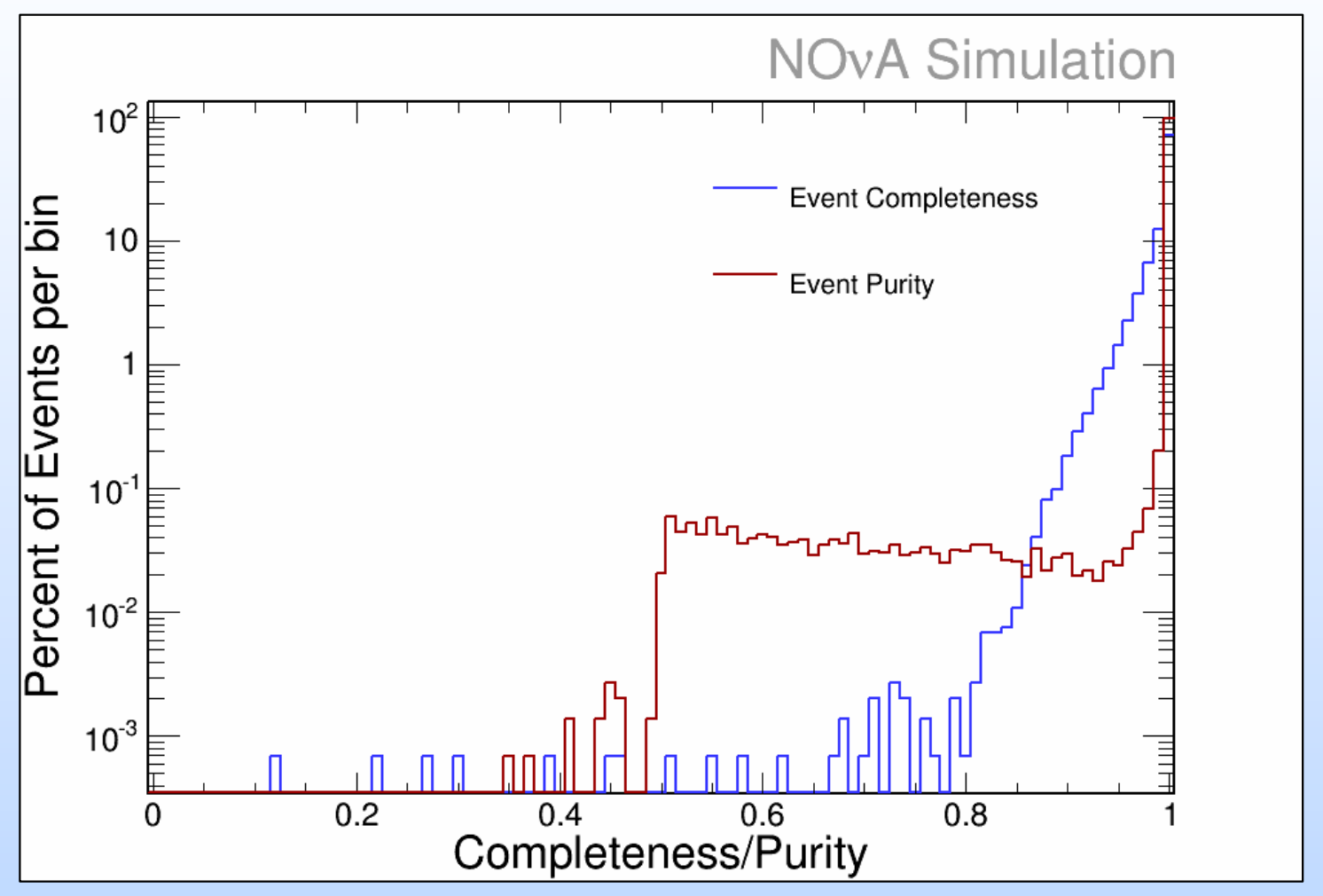
Step 1: Event Separation

The first step in our reconstruction is to separate hits into groups that represent independent physics events (cosmic rays or neutrino interactions.) This is done by applying a density based clustering technique based off of an algorithm called DBSCAN.

For each pair of hits in the detector, we compute a "neighbor score" based on how causally related they are. This computed score takes into account both the spatial and temporal separation of the hits. Next, hits with good scores are grouped together using an expanding clustering algorithm. All other hits not associated with a group are then labeled as "noise."

M. Ester, et. al., A Density-Based Algorithm for Discovering Clusters in Large Spatial Databases with Noise (1996)

Performance:



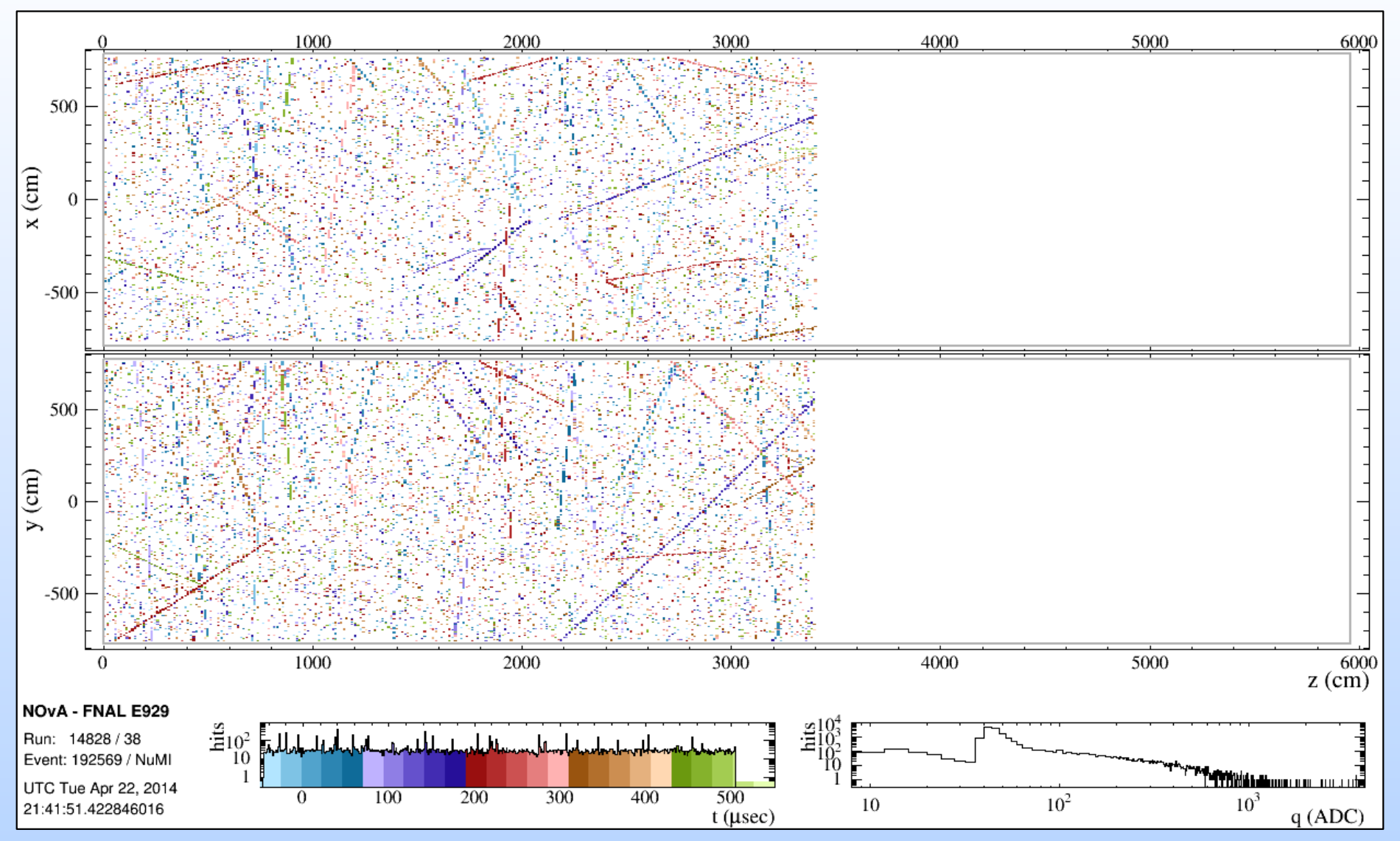
Completeness for a group of hits is defined as the energy from a given physics event within the hit group, divided by the total energy deposited by the physics event in the detector.

Purity for a group of hits is defined as the energy from a given physics event within the hit group, divided by the total energy deposited by all physics events within that hit group.

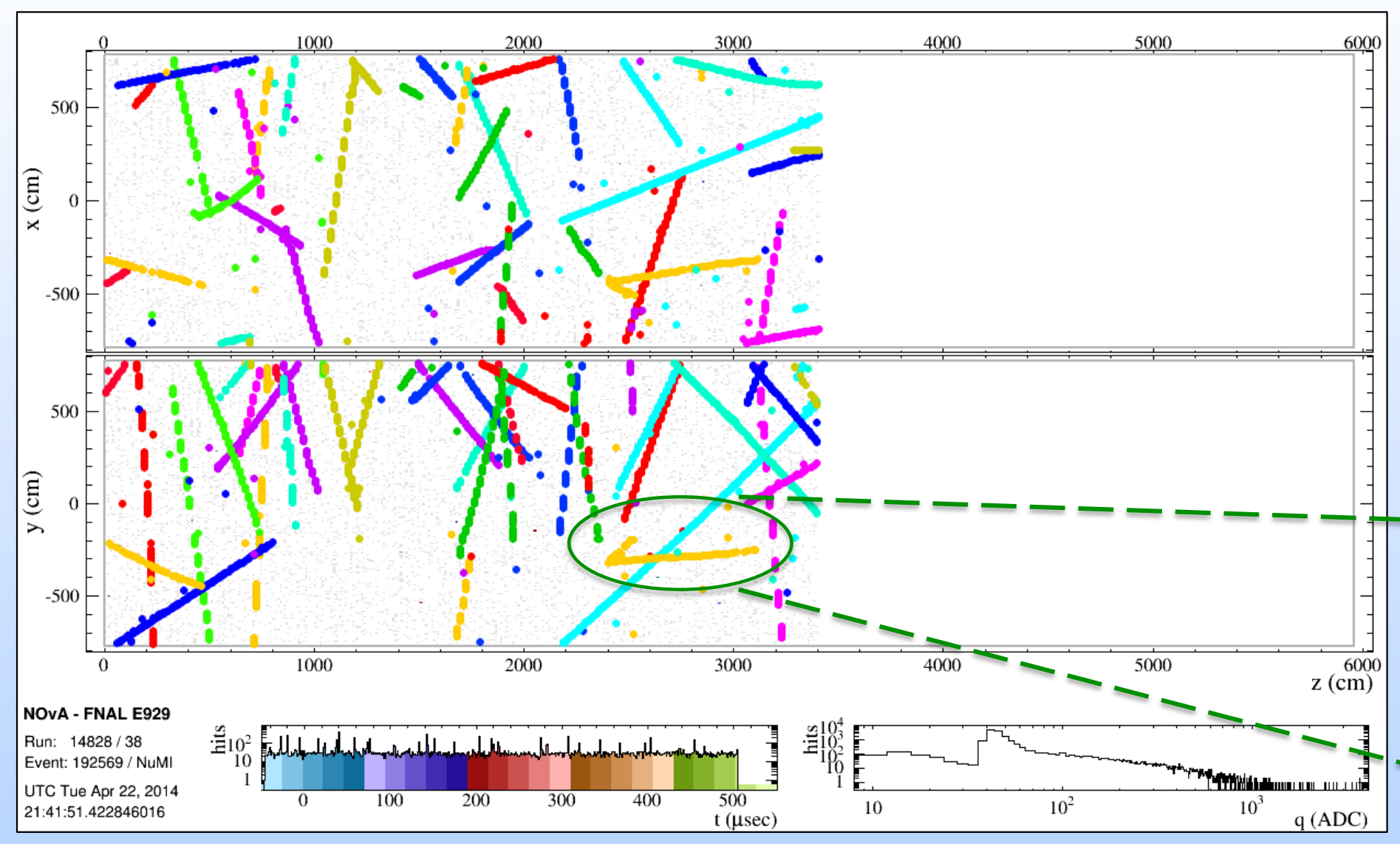
The above plot was made from simulated cosmic ray events.

Average hit group completeness:	0.9925
Average hit group purity:	0.9952

Examples:

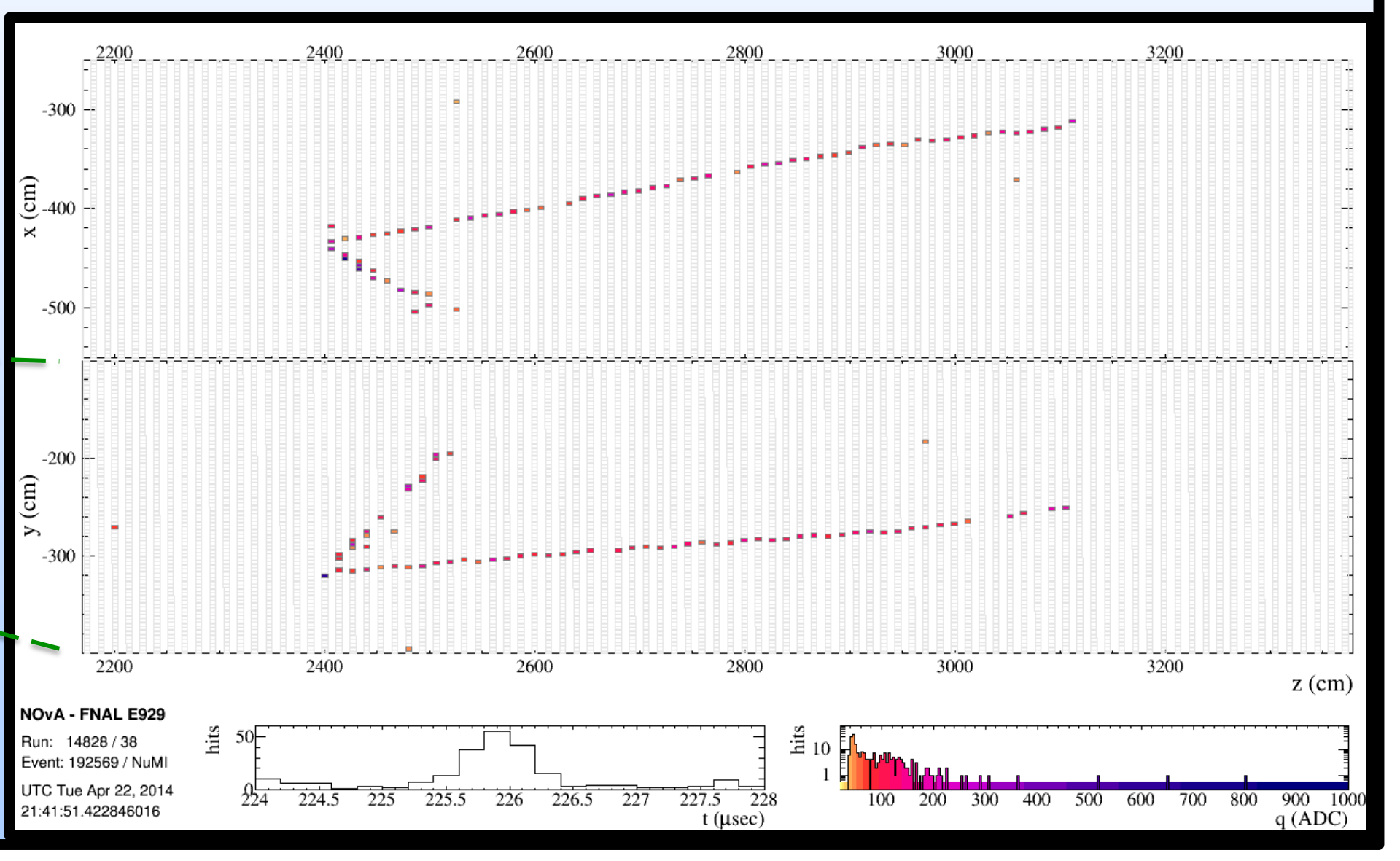


Shown above are all hits within 550 µsec, colored by time. This is data taken during a time when the far detector was not yet fully instrumented.



Now showing the hits that were grouped together by the event separating algorithm (colors denote hits within the same group.) Hits determined to be noise are drawn in light gray.

After events have been separated from the noise and from each other, we can identify potential neutrino candidate events. Shown below is an event well contained within the detector that occurs with the NuMI beam spill window (a neutrino candidate event.)



Step 2a: Vertexing

The next step in reconstructing an event is to determine the location of the neutrino interaction vertex. One approach to event reconstruction has been to identify the large, global features first, and then to build outward to reconstruct the event.

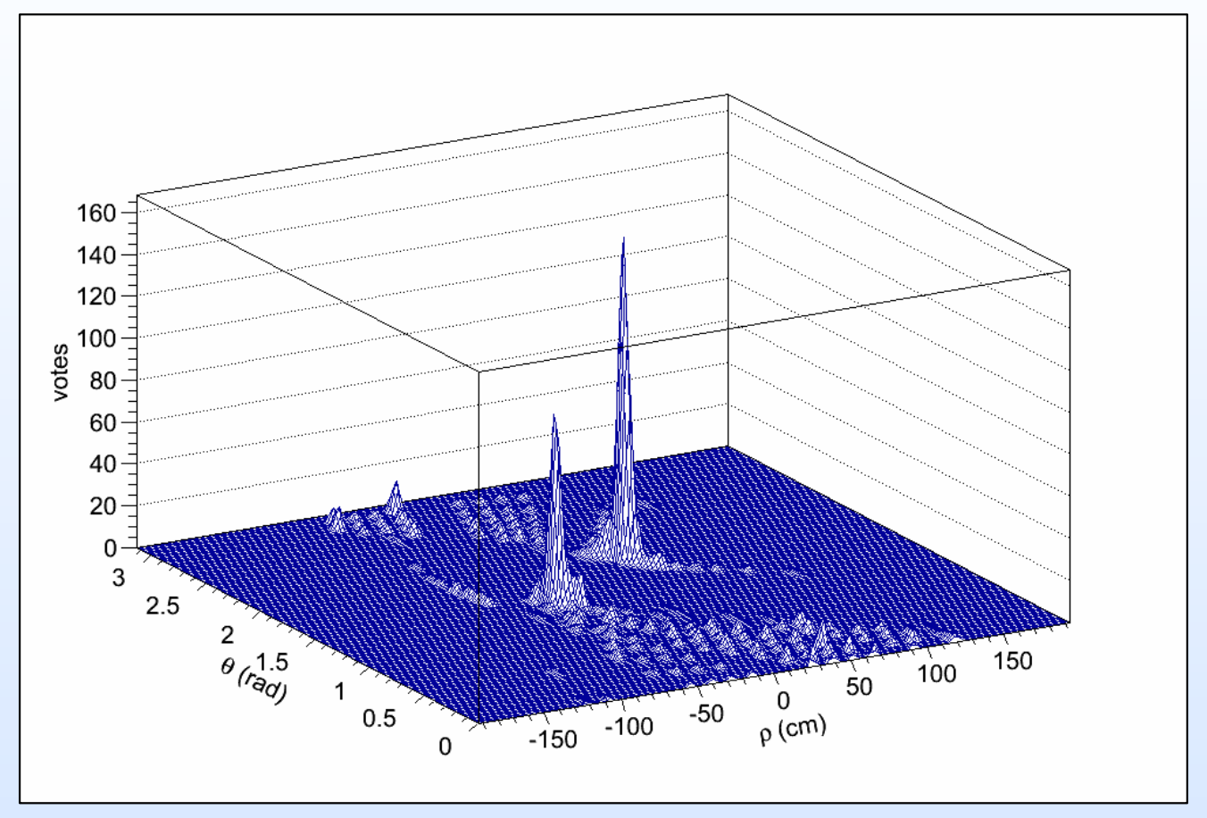
This process begins with a modified, two point Hough transform which produces sets of two dimensional lines (one set for each view in our detector) that are reflective of the major features in our event. Each pair of hits in the event calculates a Gaussian-smeared vote for the line that passes through those two points and casts that vote in a 2D parameter space (called a "Hough-space map.") Major lines are then identified as peaks in the Hough-space map (see the example plot at the right.)

To find the best vertex, hits are fit to a template of N straight-line prongs emerging from a single space point. The three spatial and 2*N angular parameters required for this model are seeded using the results of the Hough transform and then optimized using a procedure of deterministic annealing. The annealing is employed to help guide the fit toward the global optimum and avoid local optima.

L. Fernandes and M. Oliveira, Pattern Recognition, 41 (2008) 299-314.

M. Ohlsson, C. Peterson, Computer Physics Communications, 71 (1992) 77-98.

Hough-Space Map:



Above: Example of the Hough-space map. Spikes occur when many pairs of hits vote for the same line.

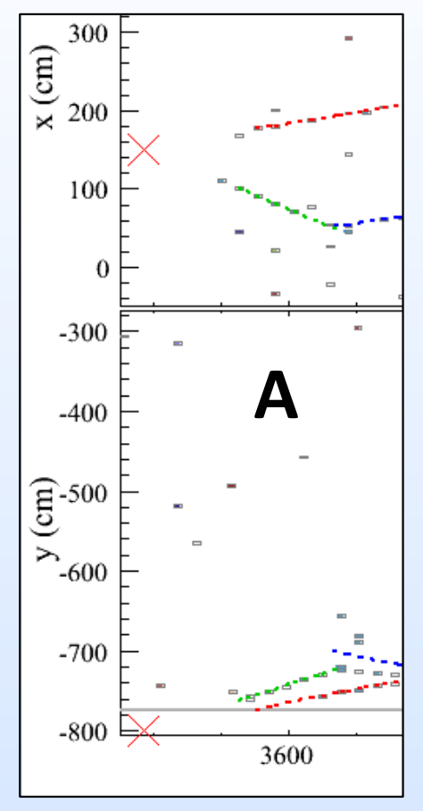
Right: Vertexing performance is judged by the 3D distance between reconstructed and true vertices.

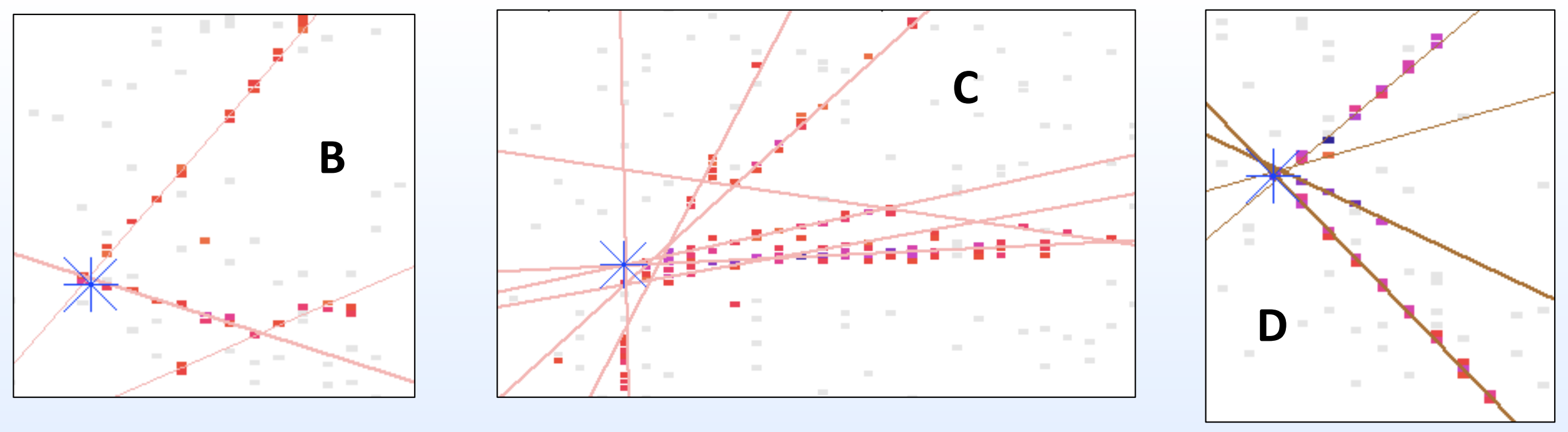
For ν_e CC, average vtx. res. = 10.9 cm (68% are w/in 10 cm)

For ν_μ CC, average vtx. res. = 11.6 cm (68% are w/in 10 cm)

For NC, average vtx. res. = 28.8 cm (68% are w/in 38 cm)

Examples:

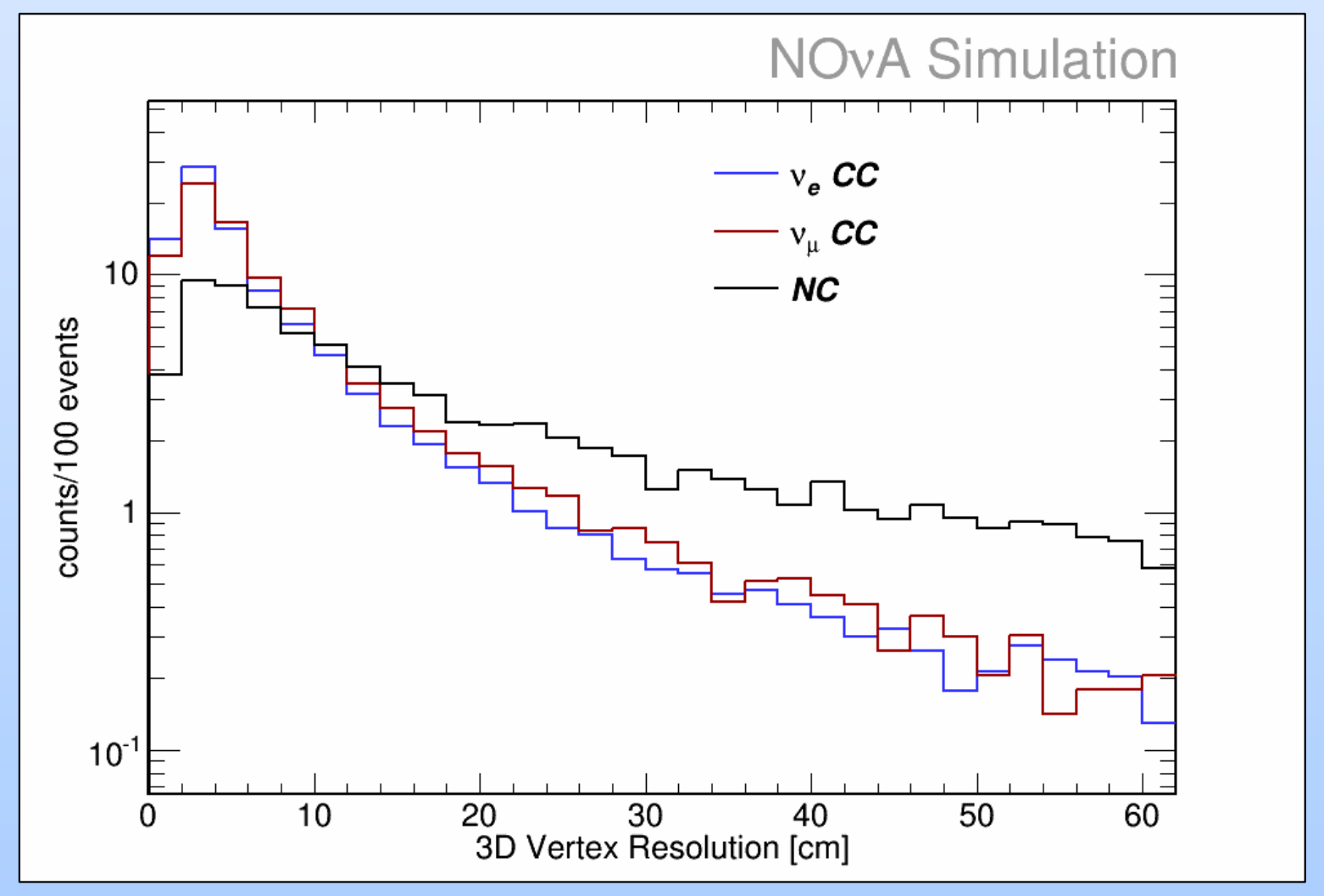




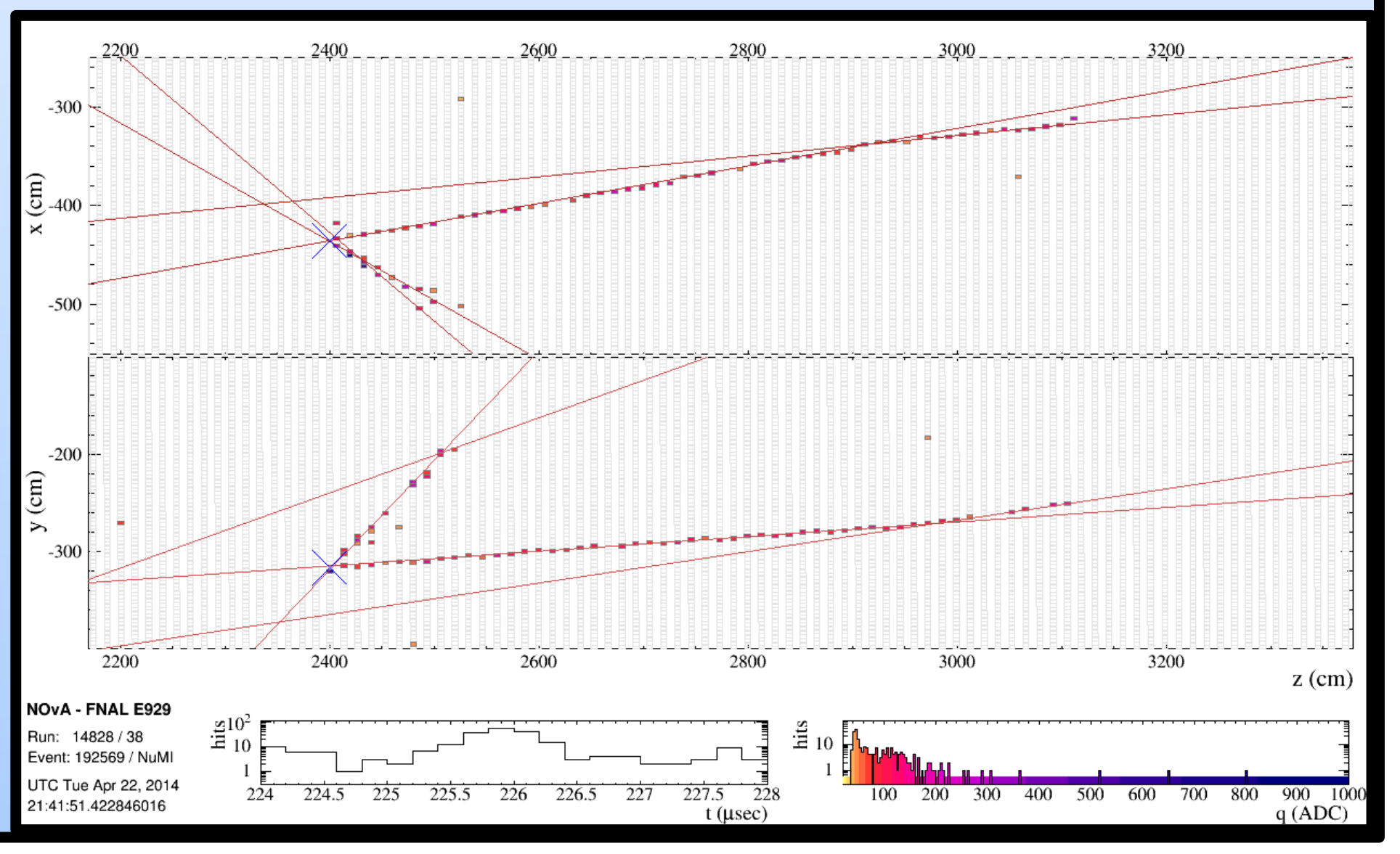
Example A: Simulated neutrino interaction outside the detector.
Example B: Simulated ν_μ CC event.

Example C: Simulated high energy NC event.
Example D: Simulated ν_μ CC event.

Performance:



Below: Red lines are lines from the modified 2-point Hough transform. The blue X is the reconstructed vertex.



Step 2b: Tracking

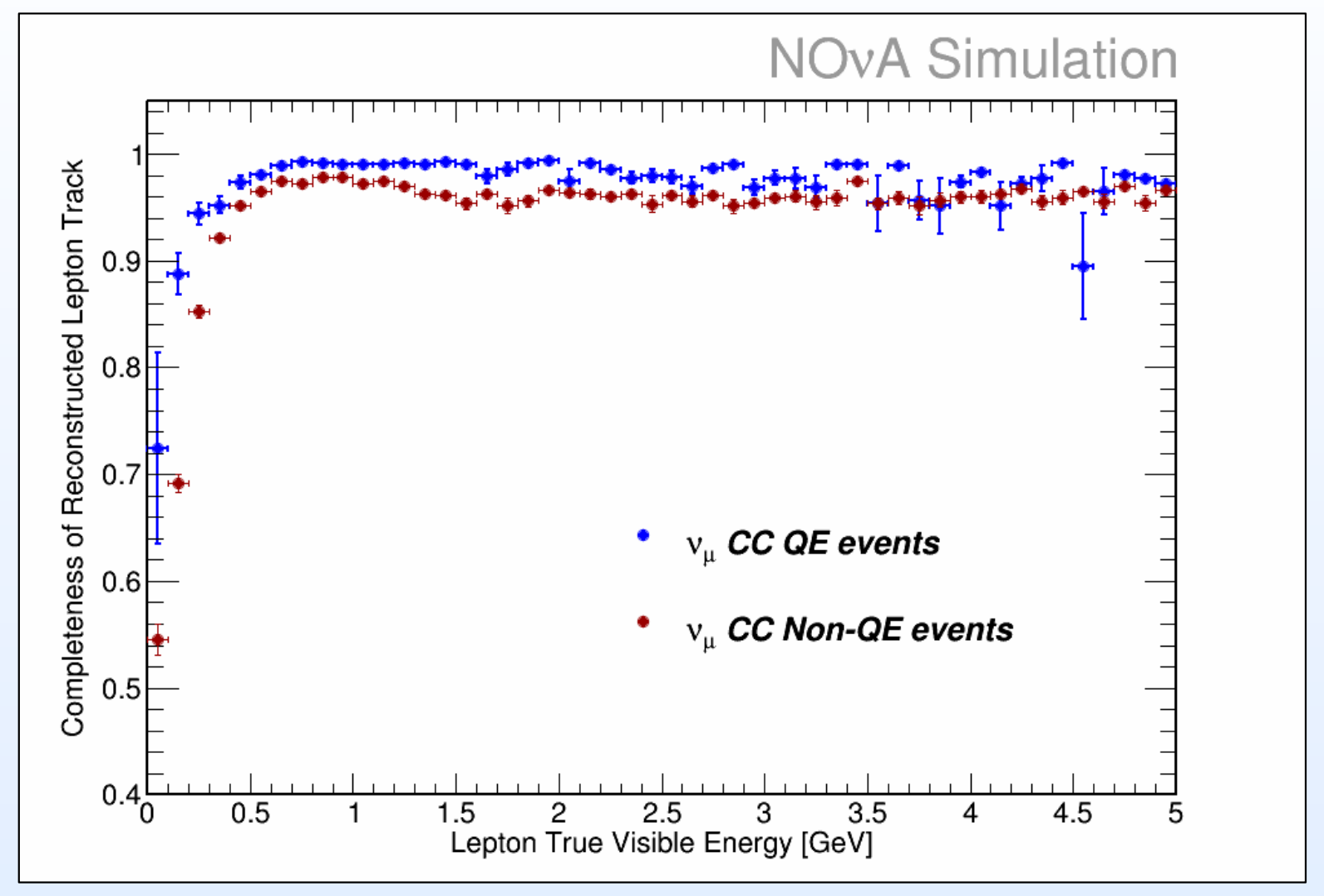
An alternate reconstruction path is to create particle tracks immediately after the event separation step. This method is employed primarily for the purpose of tracking muons (used in the ν_μ CC disappearance analysis) and uses a algorithm based on a Kalman filter.

Track seeds are formed assuming pairs of hits ≤ 3 planes apart in their view belong to the same track. These track seeds represent all possible tracks. Propagation of a track occurs by beginning with seeds highest in Z and stepping backwards plane by plane using the current estimate of the track position and slope to estimate the location of expected track hits in the next plane. For hits in the next plane, a probability score is computed and hits with good scores are included in the track. When a hit is added to a track, the track fit is corrected to include the measured information on position and slope. Once a track is complete, this process begins again with a different track seed (ignoring the hits already used) to allow for the inclusion of multiple tracks.

Tracking occurs separately in each view and 2D tracks are then matched between views using a simple score function. Matched tracks are merged into 3D tracks.

R. Fruhwirth, Nucl. Instr. Meth. Phys. Res., A262, 444, 1987.
P. Billoir, Comp. Phys. Com., 57, 390, 1989.
P. Billoir and S. Qian, Nucl. Instr. Meth. Phys. Res., A294, 219, 1990.

Performance:



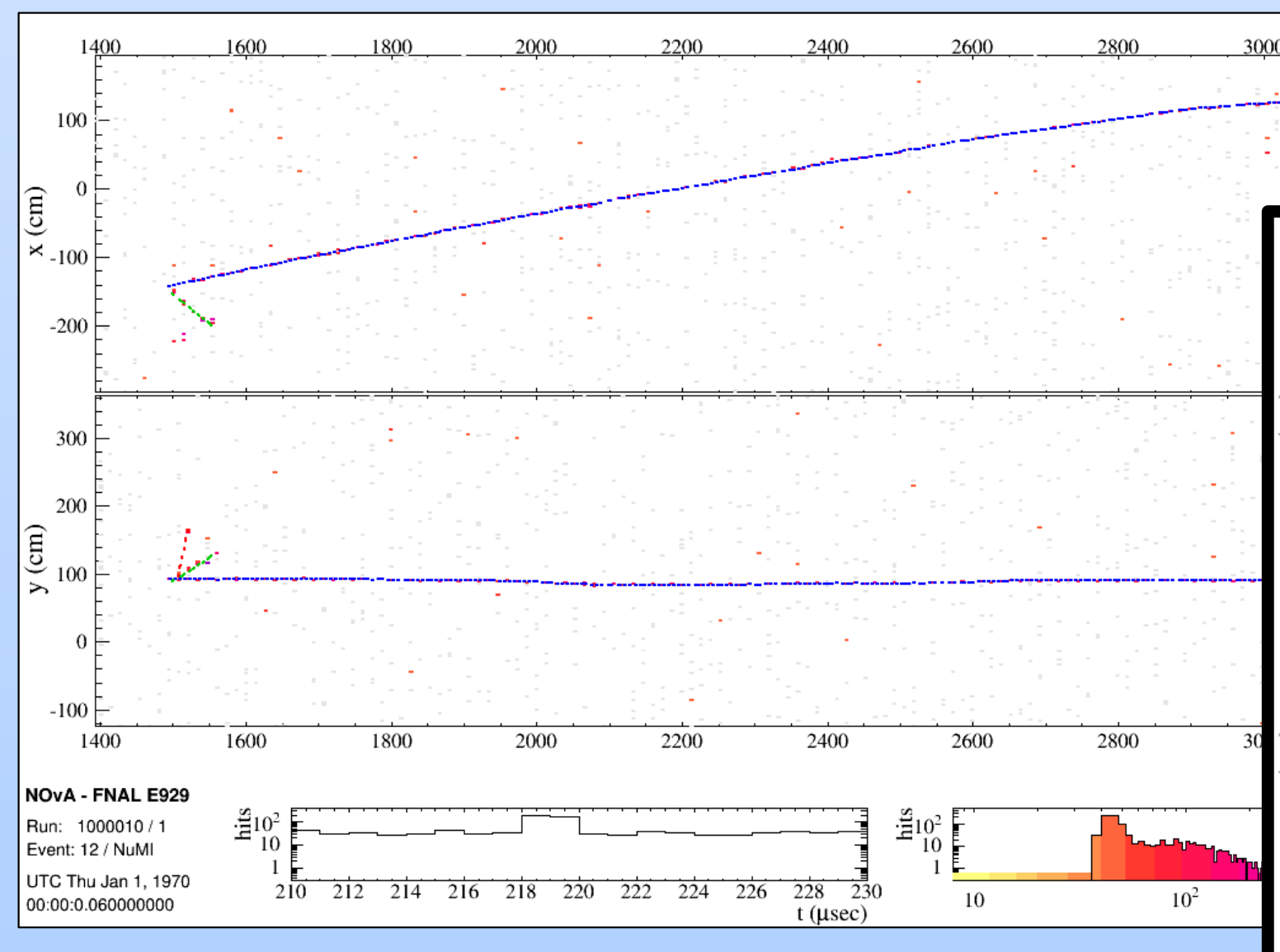
Above: Performance is based off of the completeness of the track matched to the primary lepton.

For all ν_μ CC, ave. completeness = 0.93

For QE ν_μ CC, ave. completeness = 0.98

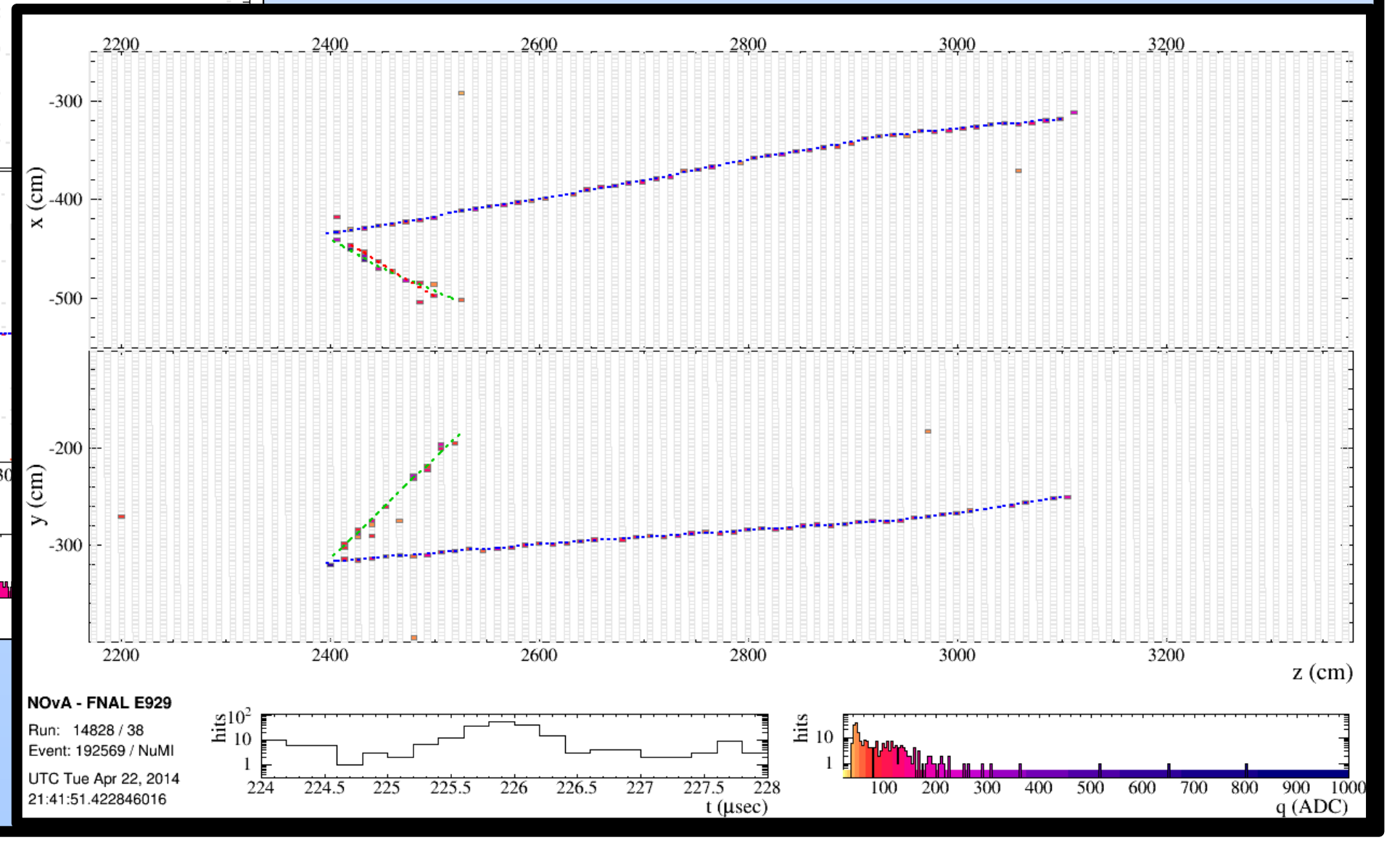
For non-QE ν_μ CC, ave. completeness = 0.92

Examples:



Below: Tracks are drawn as colored dashed lines. Tracks of the same color are matched between each view.

Above: The tracker can easily follow long muon tracks through multiple scattering to provide good muon energy resolution.



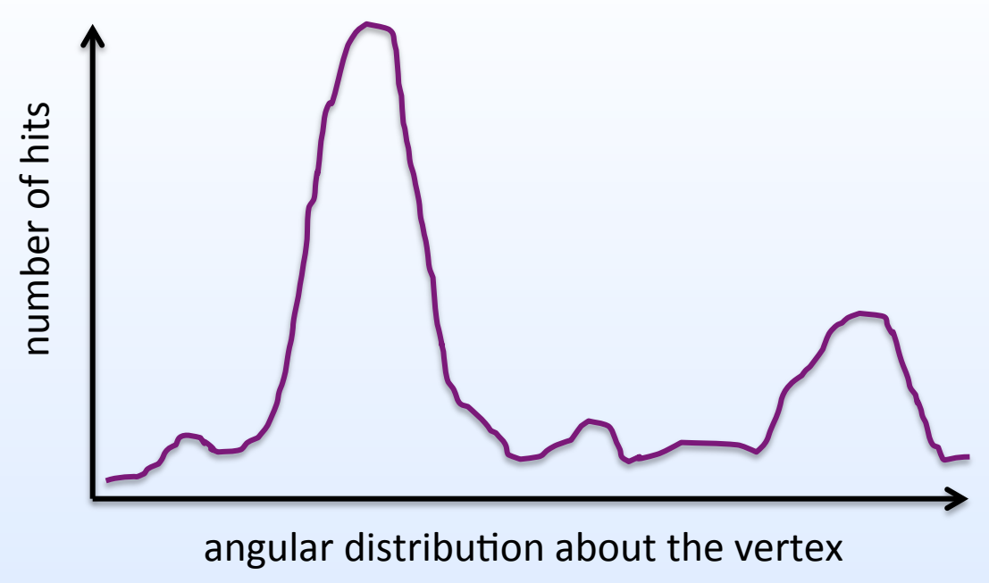
Step 3a: Clustering

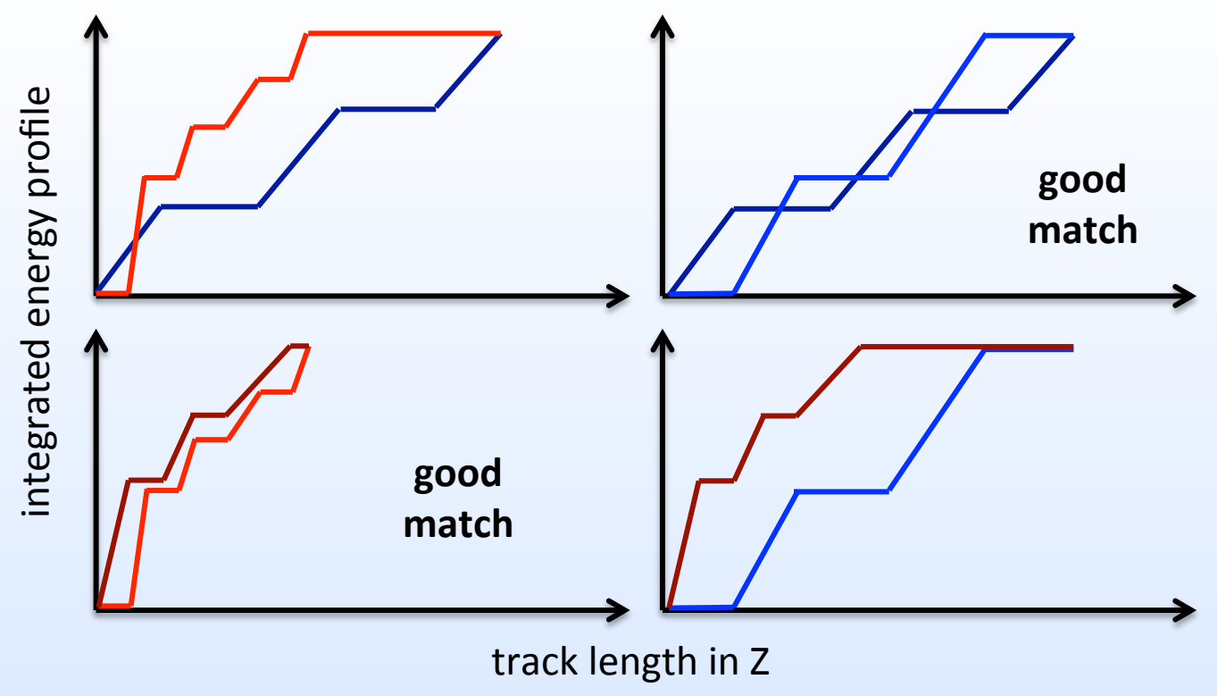
The next step in reconstructing a neutrino event is to create "prongs." A prong is a cluster of hits assumed to be associated with a single particle and has both a start point and a direction associated with it.

To create prongs, cell hits in a physics slice are represented as energy deposition at an angle with respect to the previously produced vertex. Hits are then clustered in this 1D angular space using a k-means clustering algorithm (see example plot at the near right.) Hits are allowed to have membership in multiple clusters and a cluster can be as small as a single hit to account for small neutron deposits.

Clustering is done in each 2D detector view separately and are then matched between views by applying a K-S test on the energy profiles (see example plots at the far right.) These final 3D prongs serve as input to advanced tracking and particle identification algorithms.

M.-S. Yang, K.-L. Wu, Unsupervised possibilistic clustering, Pattern Recognition, 39 (2006), pp. 521.





Above Left: Example of the angular distribution of hits around the vertex within a 2D view. Major prongs show up as spikes in this plot.

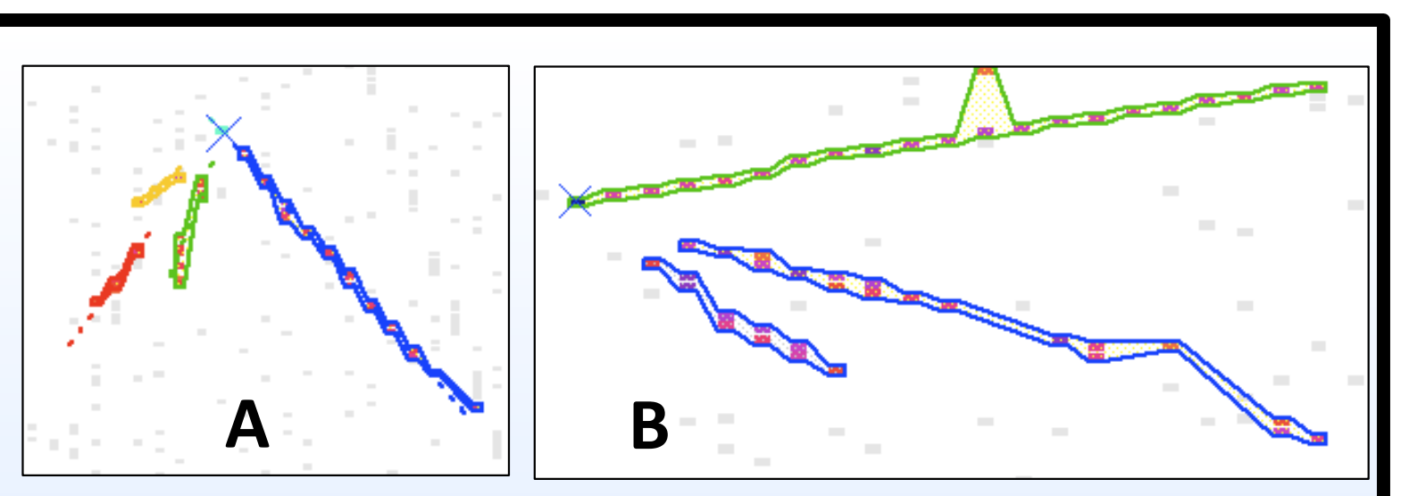
Above Right: Example of K-S test plots made when matching the energy profile for prongs in each view.

Right: Performance is based off of the completeness of the prong that matches the primary lepton.

For ν_e CC, ave. completeness = 0.88 (0.95 for QE, 0.86 for non-QE)

For ν_μ CC, ave. completeness = 0.93 (0.98 for QE, 0.92 for non-QE)

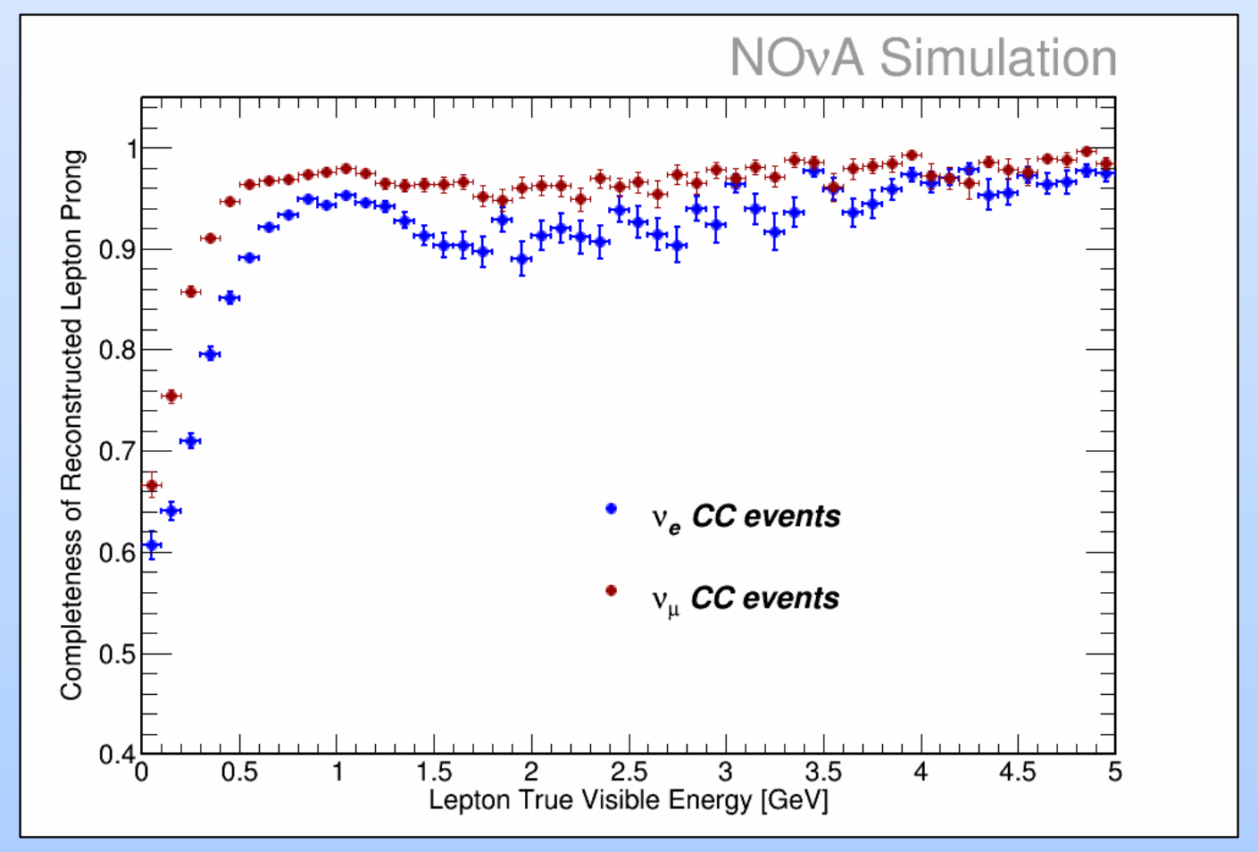
Examples:

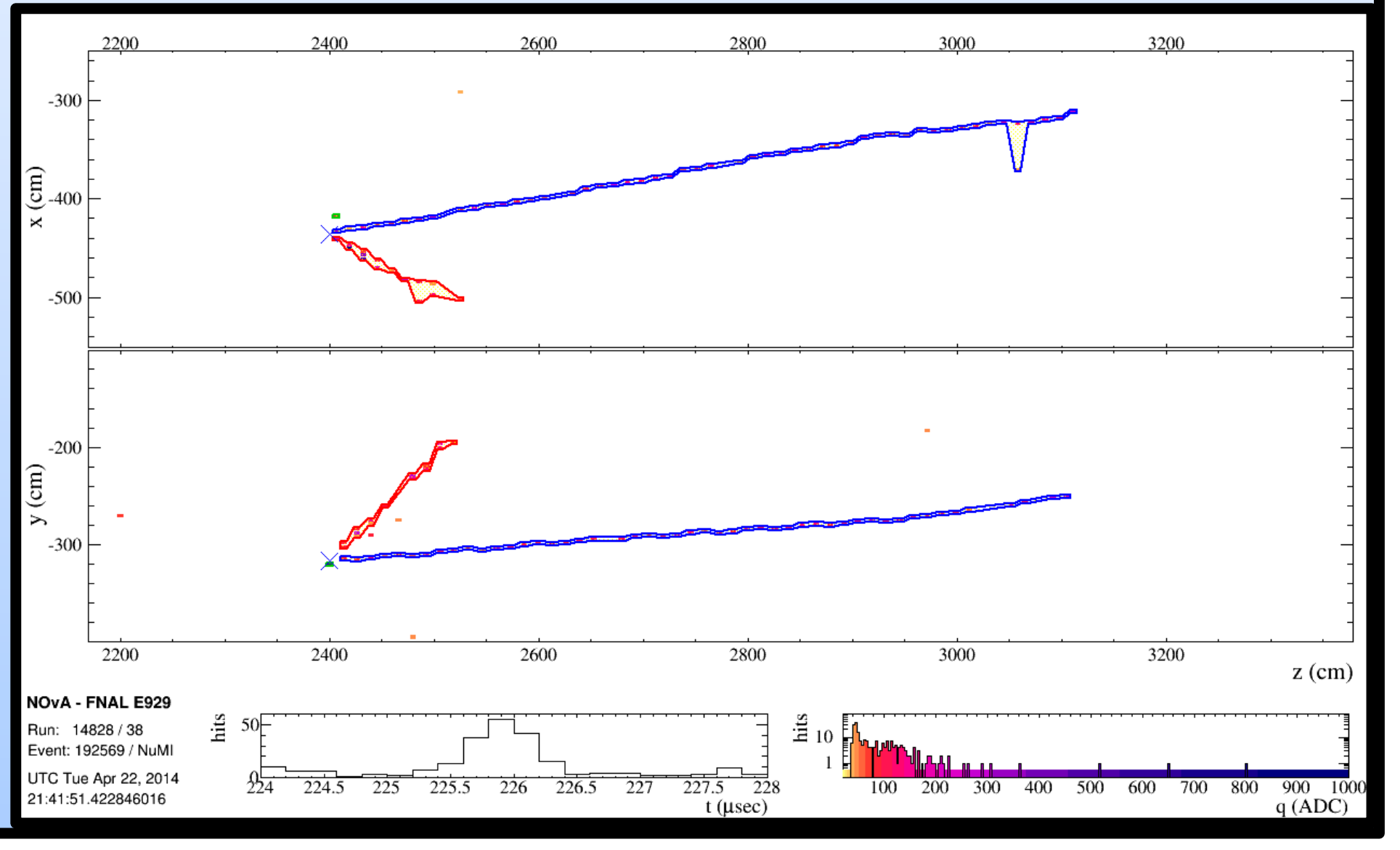


Example A: Data event (cosmic ray neutron.)
Example B: Simulated ν_μ CC event.

Below: Prongs are drawn outlining the cells that belong to them.

Performance:





Further Information on NOvA:

Posters:

- E. Arrieta-Diaz: NDOS charge current cross section analysis
- C. Backhouse: ν_e appearance analysis overview
- K. Bays: ν_μ disappearance analysis overview
- X. Bu: Near Detector assembly and installation
- S. Budd, L. Goodenough: NuMI beam
- G. Davies, T. Xin, J. Bian: Cosmic background rejection
- N. Mayer: Non-oscillation physics
- M. Muether: Far Detector commissioning, performance and monitoring
- E. Niner: Time and Energy Calibration
- L. Suter: Extrapolation techniques
- M. Tamsett: Data-driven trigger system
- Z. Wang: Magnetic monopole search

Talks:

A. Norman: Status of the NOvA Experiment
Wednesday, 9 am

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