MINERνA
Status & Reconstruction

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NuFact 11
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On Behalf of the MINERνA Collaboration

Outline

- Introduction to MINERνA: ν-nucleus scattering.
- Detector & Operations.
  - See M. Kordosky's talk for a discussion of our beamline.
- Current Analysis Efforts - Reconstruction Status. Emphasis on methodology.
  - See presentations by B. Ziemer and J. Devan for application of these techniques.

The MINERνA Collaboration

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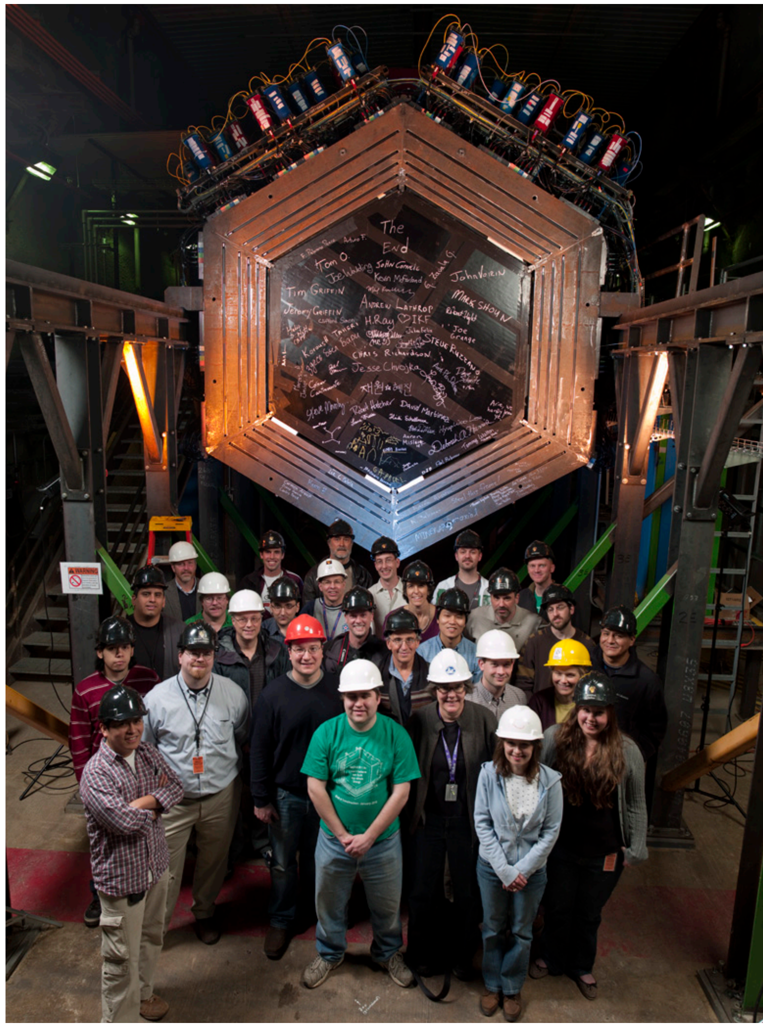


MINERνA

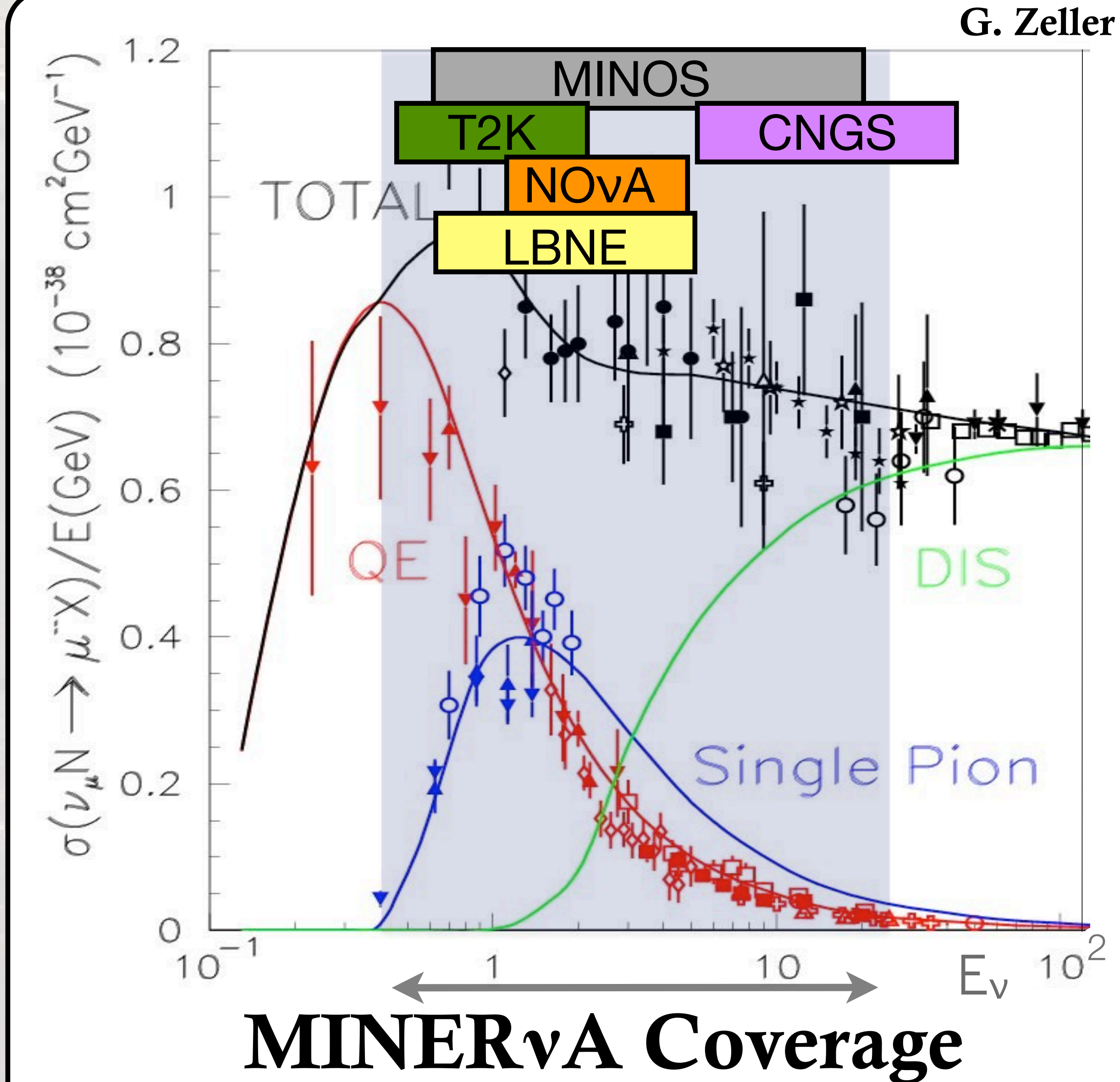
(Main INjector ExpeRiment ν-A)

- ***What***: **On-axis neutrino-nucleus cross-section experiment in the wide-band NuMI (Neutrinos at the Main Injector) beamline at Fermilab. Located directly in front of the MINOS Near Detector.**

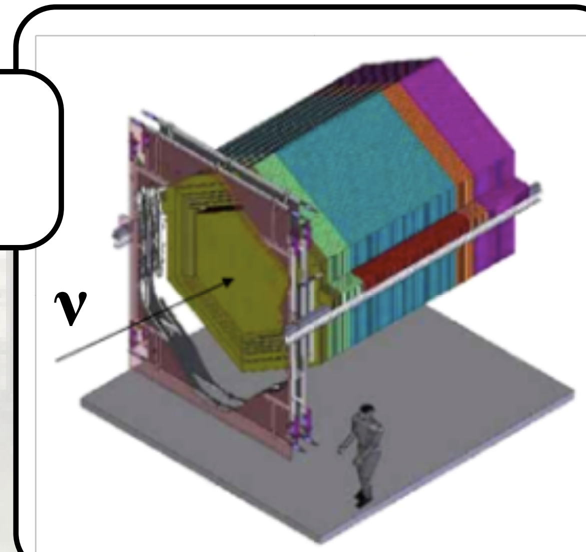
- ***Why***: **Some tensions in low energy (less than 10 GeV) cross-sections; many measurements are bubble-chamber era with low statistics and large uncertainties.**

- ***Why***: **Provides critical input to future neutrino oscillation experiments.**

- ***Why***: **Unique (weak-only) probe of the nucleus. Many quantities of interest: axial form factors as a function of A and momentum transfer (Q^2), quark-hadron duality, x-dependent nuclear effects, etc.**



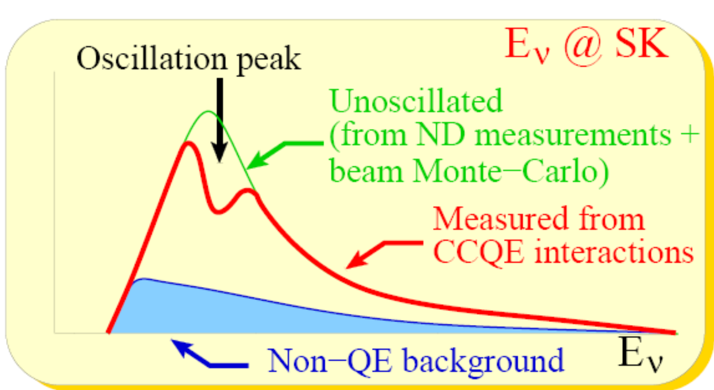
No MiniBooNE results on this plot, but hold that thought…

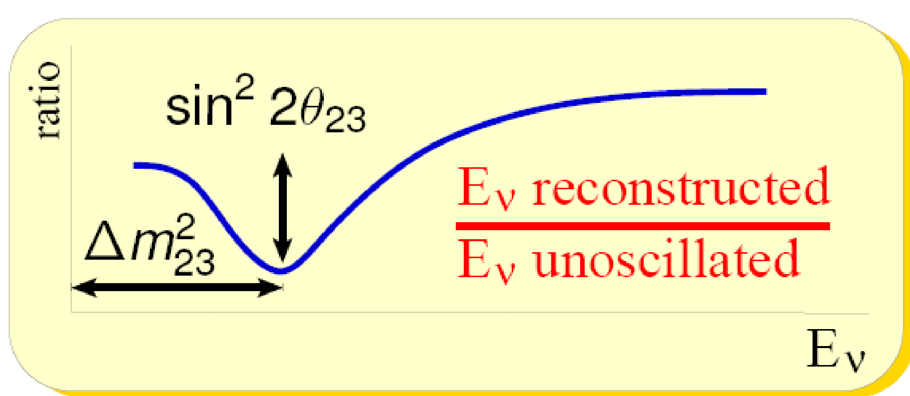


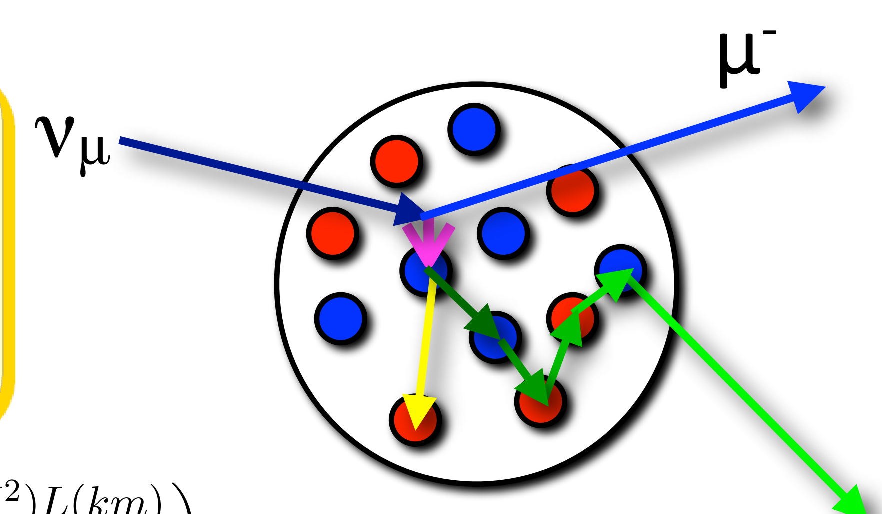
MINERνA

Oscillation Measurement: ν_μ Disappearance

- Recall oscillation probability depends on E_ν.
- However, experiments measure E_{vis}, usually with Quasi-Elastics.
- E_{vis} depends on flux, cross-section, and detector response.
  - Final state interactions are important! ν interacts in dense nuclear matter, and products do not always cleanly exit the nucleus.
- E_{vis} is not equal to E_ν!
- Near/Far detector ratios cannot handle all the uncertainties because the E_{Near}/E_{Far} spectra are different due to matter & oscillation effects, etc.





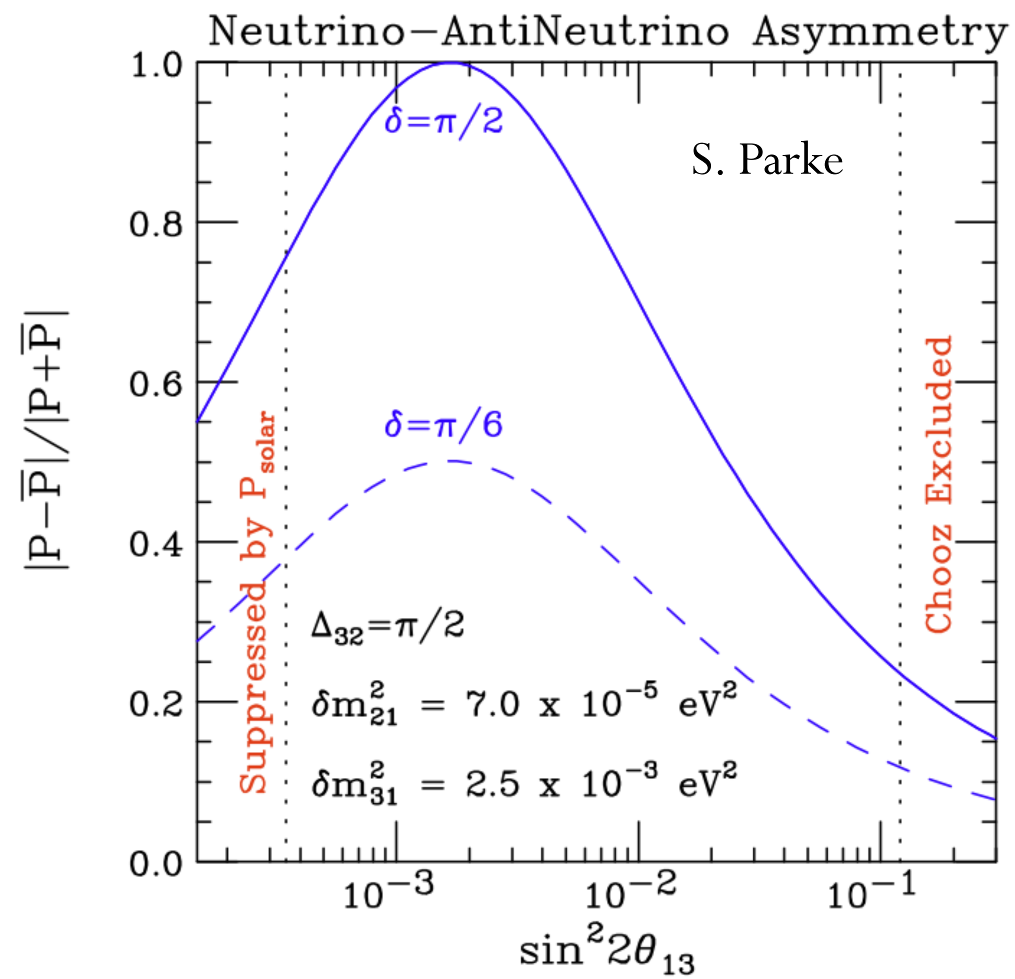


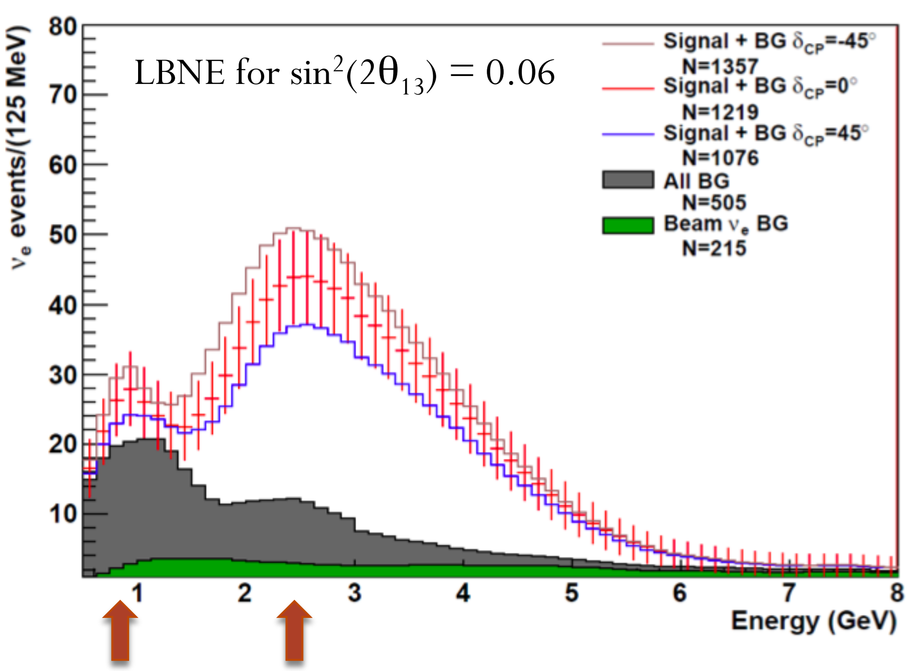
Courtesy of T2K (V. Paolone).

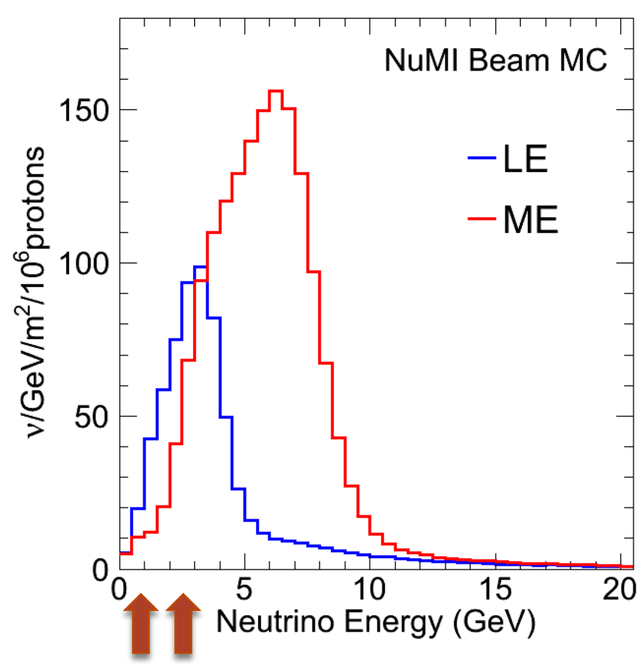
$$P(\nu_\mu \to \nu_\mu) = 1 - \cos^4\theta_{13}\sin^2 2\theta_{23}\sin^2\left(\frac{1.27\Delta m^2_{23}(eV^2)L(km)}{E_\nu(GeV)}\right) - ...$$

Recent Hints of "Large" θ_{13}

- **Good news, but lower statistical errors means increased emphasis on systematic errors.**
- **Larger θ_{13} means smaller ν/anti-ν asymmetries for a given value of δ_{CP}.**
- **MINERνA measurements are very useful here, especially in the NuMI low energy tune!**

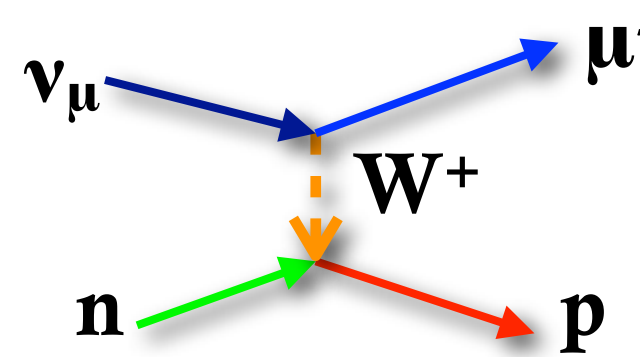




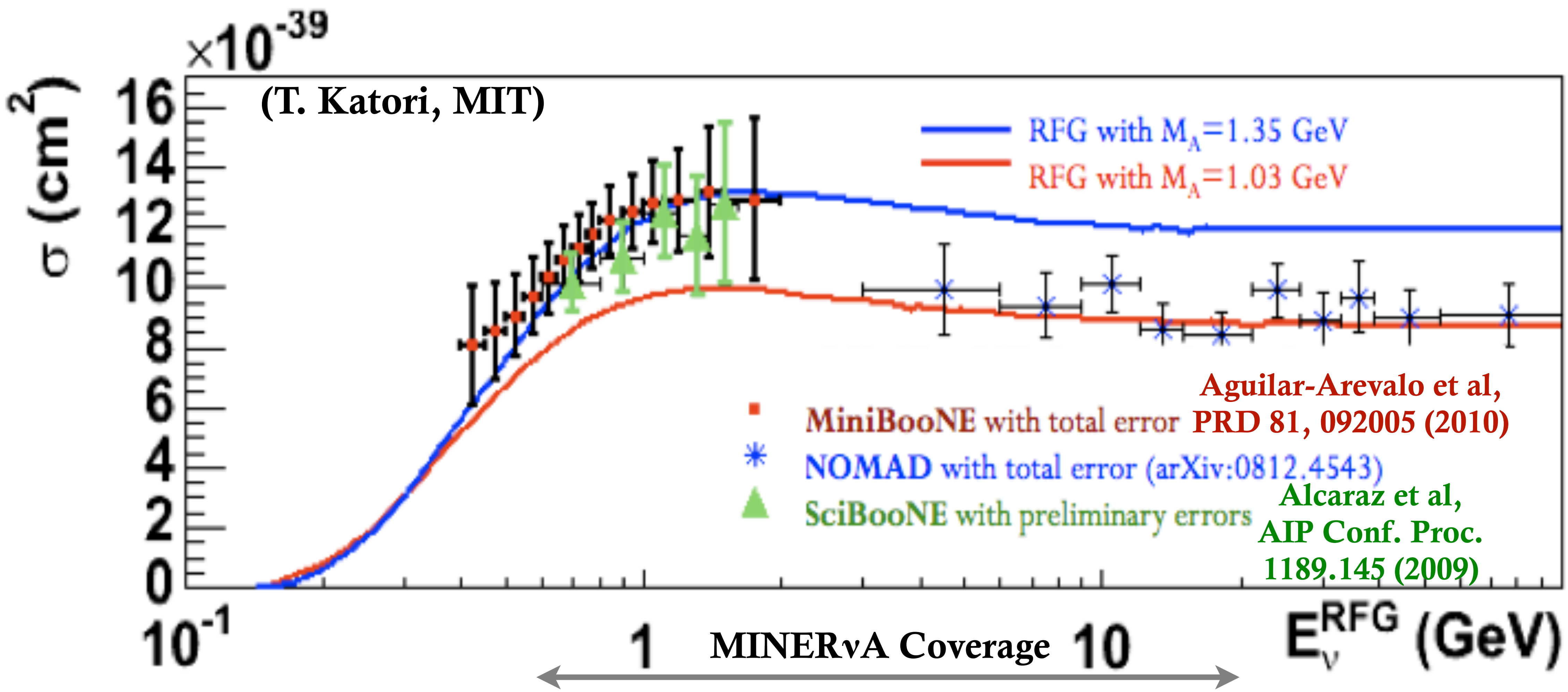


First and Second Oscillation Maxima; LBNE & NuMI.

Charged Current Quasi-Elastic (CCQE) Scattering on Carbon

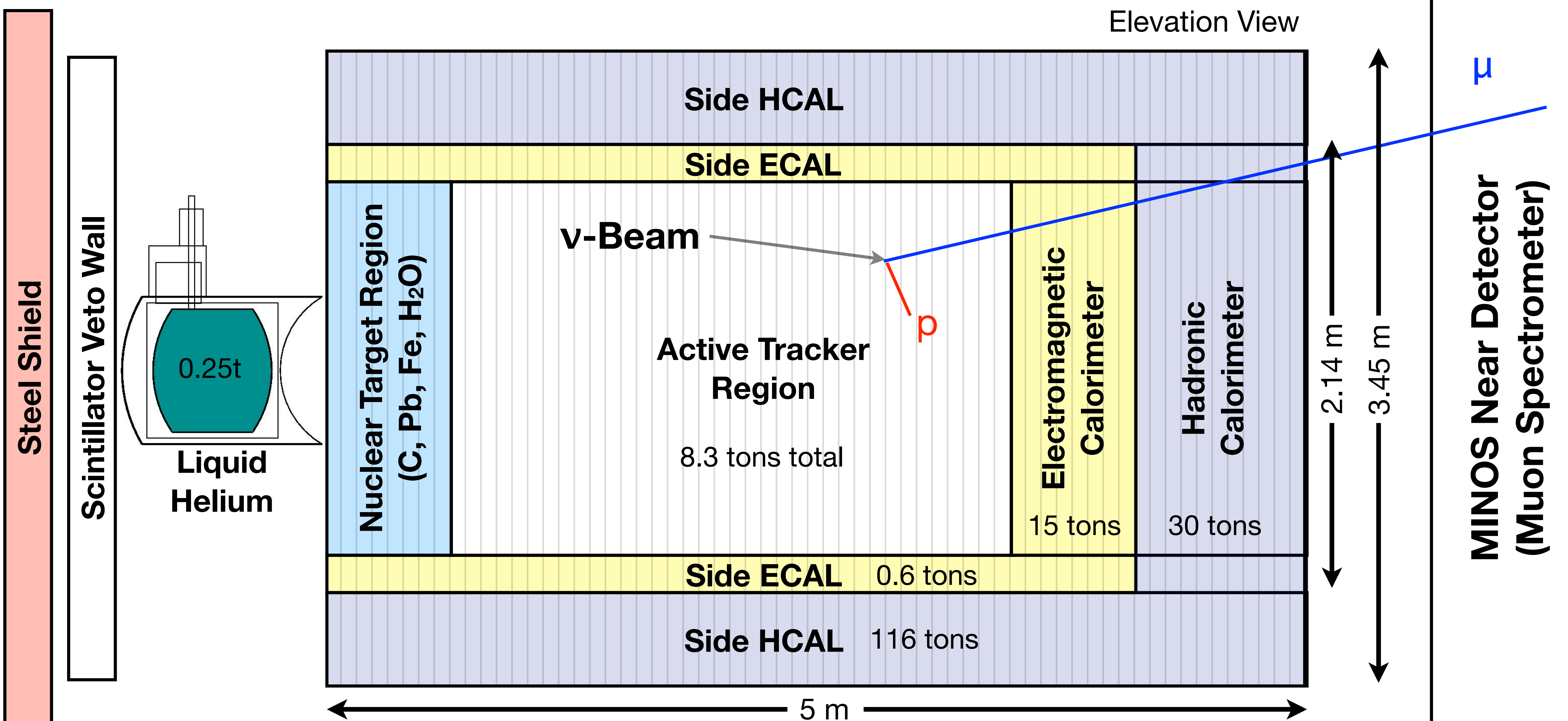


- Open questions in interaction physics abound. For example:
  - MiniBooNE & SciBooNE are in agreement, but conflict with NOMAD data at higher energy.
  - We need ONE detector that can easily do both a "MiniBooNE style" measurement (one track + X) and a "Nomad style" measurement (two tracks).
  - Need to examine multi-nucleon final states (meson exchange currents).



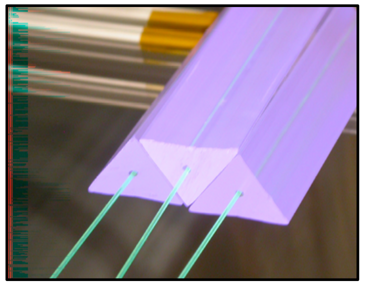
We will fill this gap!

The Best Thing Since Sliced Bread…

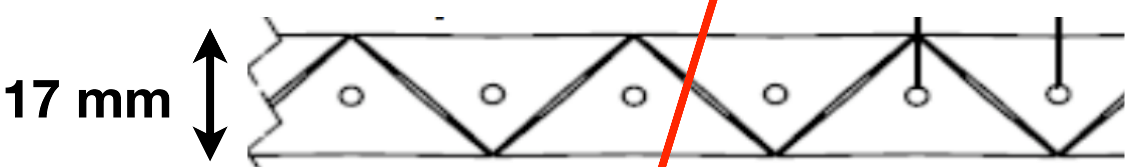


The MINERνA detector is comprised of a stack of MODULES of varying composition, with the MINOS Near Detector acting as a muon spectrometer. It is finely segmented (~32 k channels) with multiple nuclear targets (C, CH, Fe, Pb, He, H_2O).

Plastic Scintillator Strips: The Active Detector Elements.



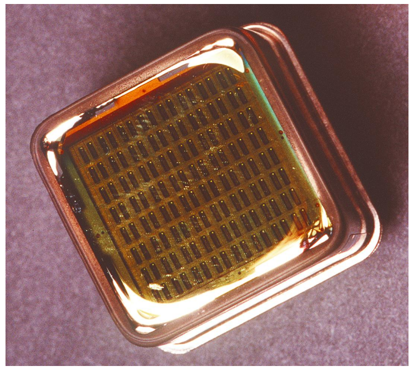
Extruded scintillator & wavelength shifting fibers.

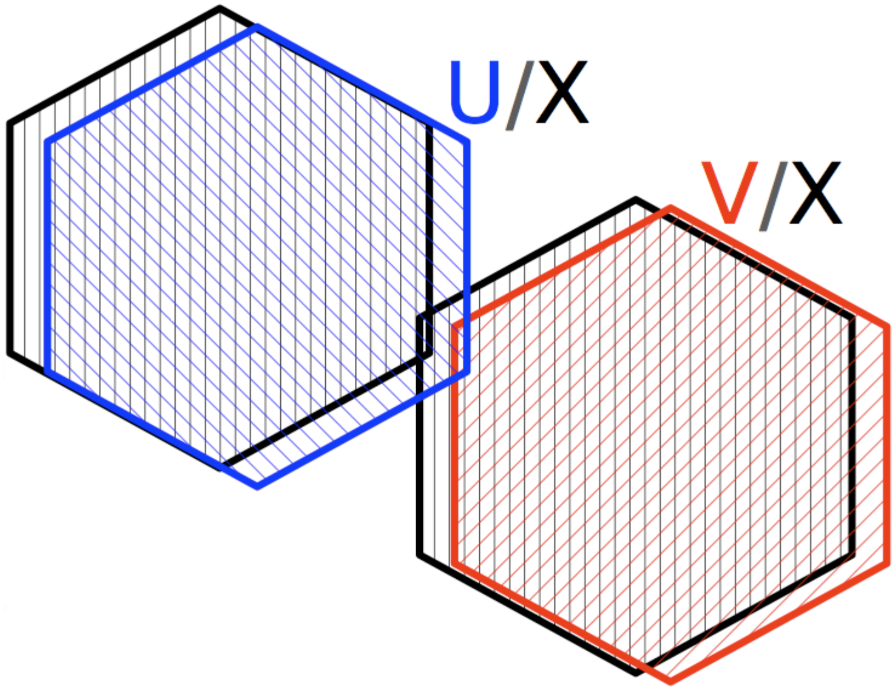


Charge-sharing for improved position resolution (~3 mm).

Strips are bundled into PLANES to provide transverse position location across a module.

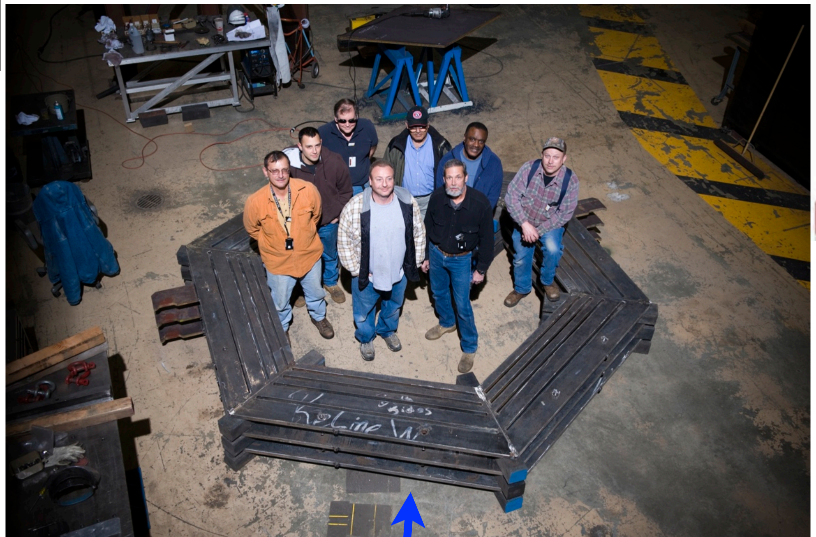
Fibers bundled into cables to interface with 64 channel multi-anode PMTs.

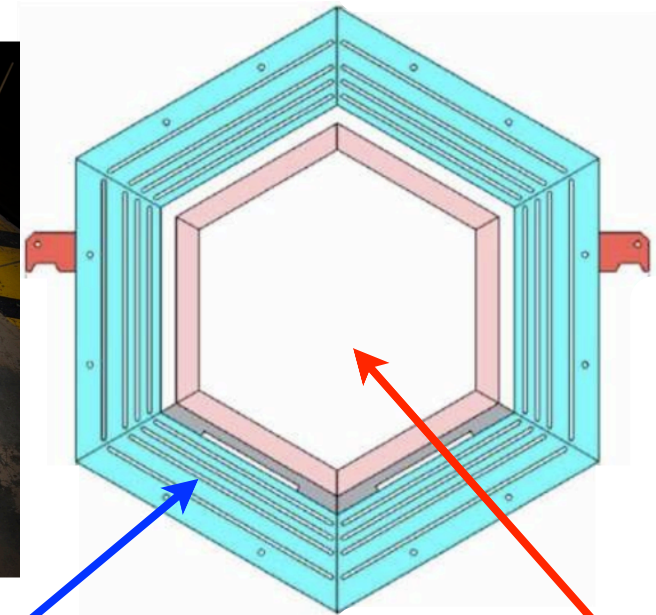


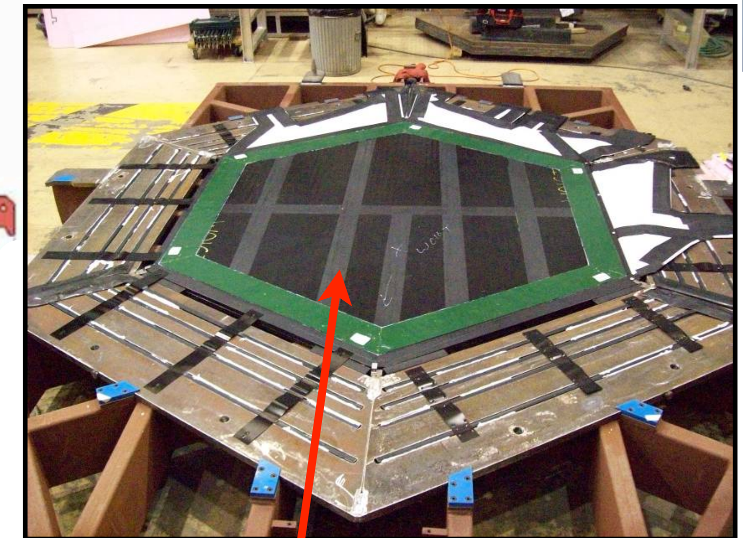


Planes are mounted stereoscopically in UX or VX orientations for 3D tracking. There are typically two planes per module.

MINERνA Modules







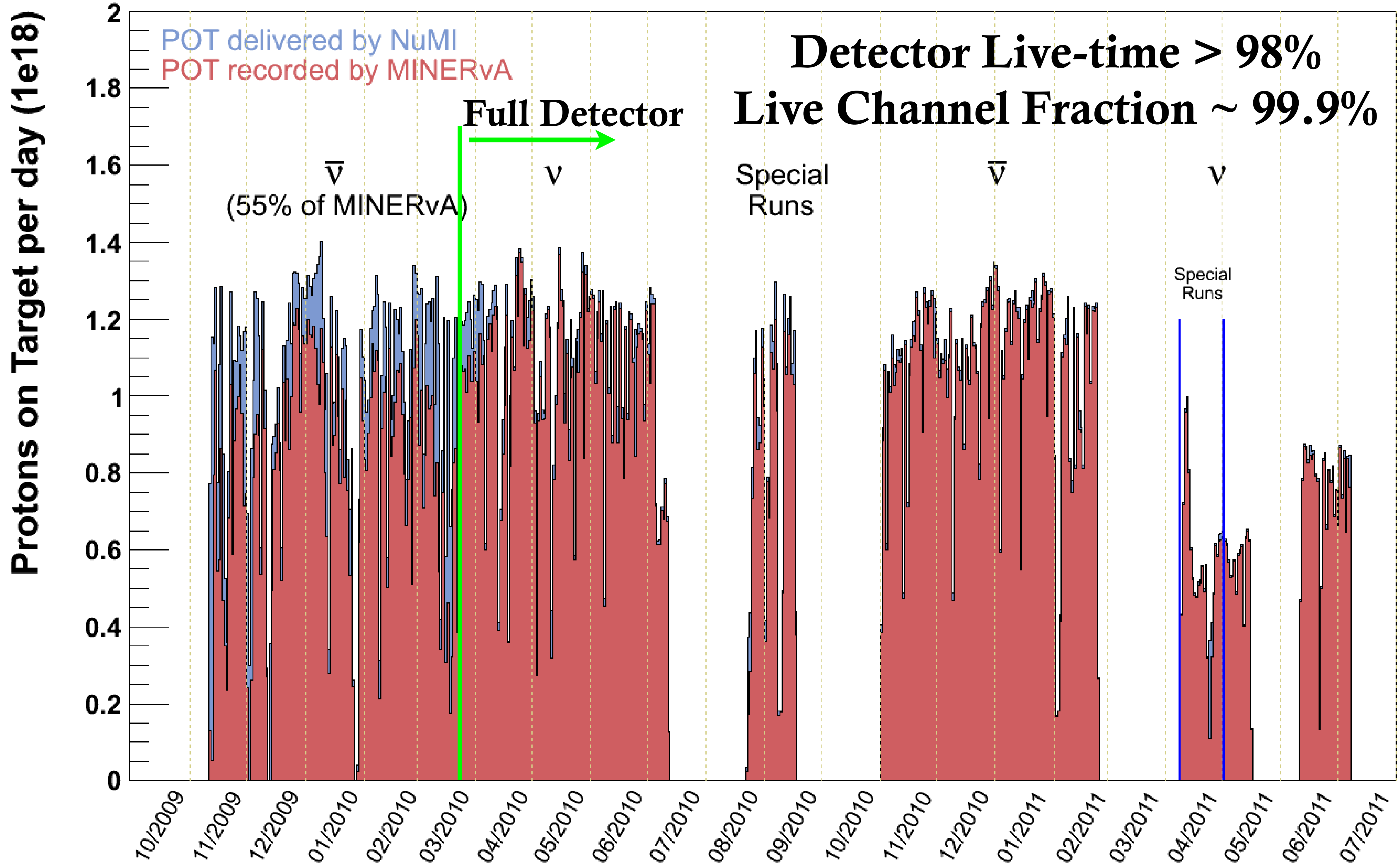
Modules have an outer detector frame of steel and scintillator…

…and an inner detector element of scintillator strips and absorbers/targets.

- Four basic module types:
  - Tracker: two scintillator planes in stereoscopic orientation.
  - Hadronic Calorimeter: one scintillator plane and one 2.54-cm steel absorber.
  - Electromagnetic Calorimeter: two scintillator planes and two 2-mm lead absorbers.
  - Nuclear Targets: absorber materials (some with scintillator planes).
- Instrumented outer-detector steel frames.
- 120 Total Modules: 84 Tracker, 10 ECAL, 20 HCAL, 6 Nuclear Targets.

Data Collection

- Completed full detector installation in March, 2010.
- Running in NuMI "Low Energy" mode.



MINERνA Event Rates

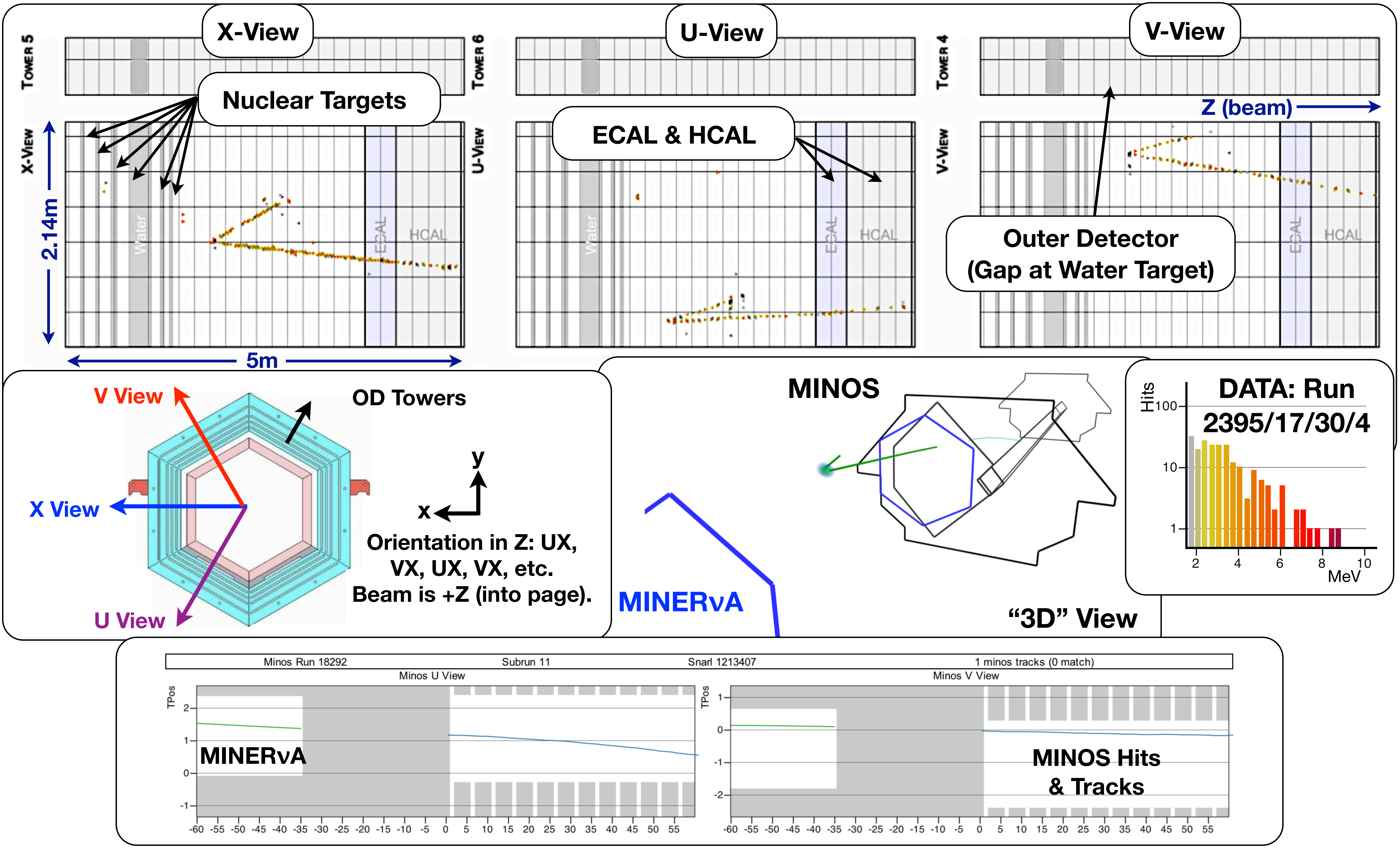
Current Data Sample (GENIE 2.6.2 Generator Raw Events)*

Target Masses: CH Fiducial = 6.43 tons, C = 0.17 tons, Fe = 0.97 tons, Pb = 0.98 tons w/ 90 cm vertex radius cut.
(* http://www.genie-mc.org)

	1.2e20 POT Low Energy Neutrino Mode (Run Plan: 4e20 POT LE)	1.2e20 POT Low Energy Anti-neutrino Mode
Coherent Pion Production	4k	3k
Quasi-Elastic	84k	46k
Resonance Production* (Will likely use a smaller fiducial volume.)	146k	62k
Carbon Target	10.8k	3.4k
Iron Target	64.5k	19.2k
Lead Target	68.4k	10.8k
Scintillator (CH) Tracker	409k	134k

MINERνA Event Displays

- Stereoscopic: 3 views X (view from above), U, V (60^0). X views are twice as dense!
- STRIP (Transverse) vs. PLANE (Longitudinal) for the Inner Detector, TOWER (Radial) vs. PLANE (Longitudinal) for the Outer Detector.

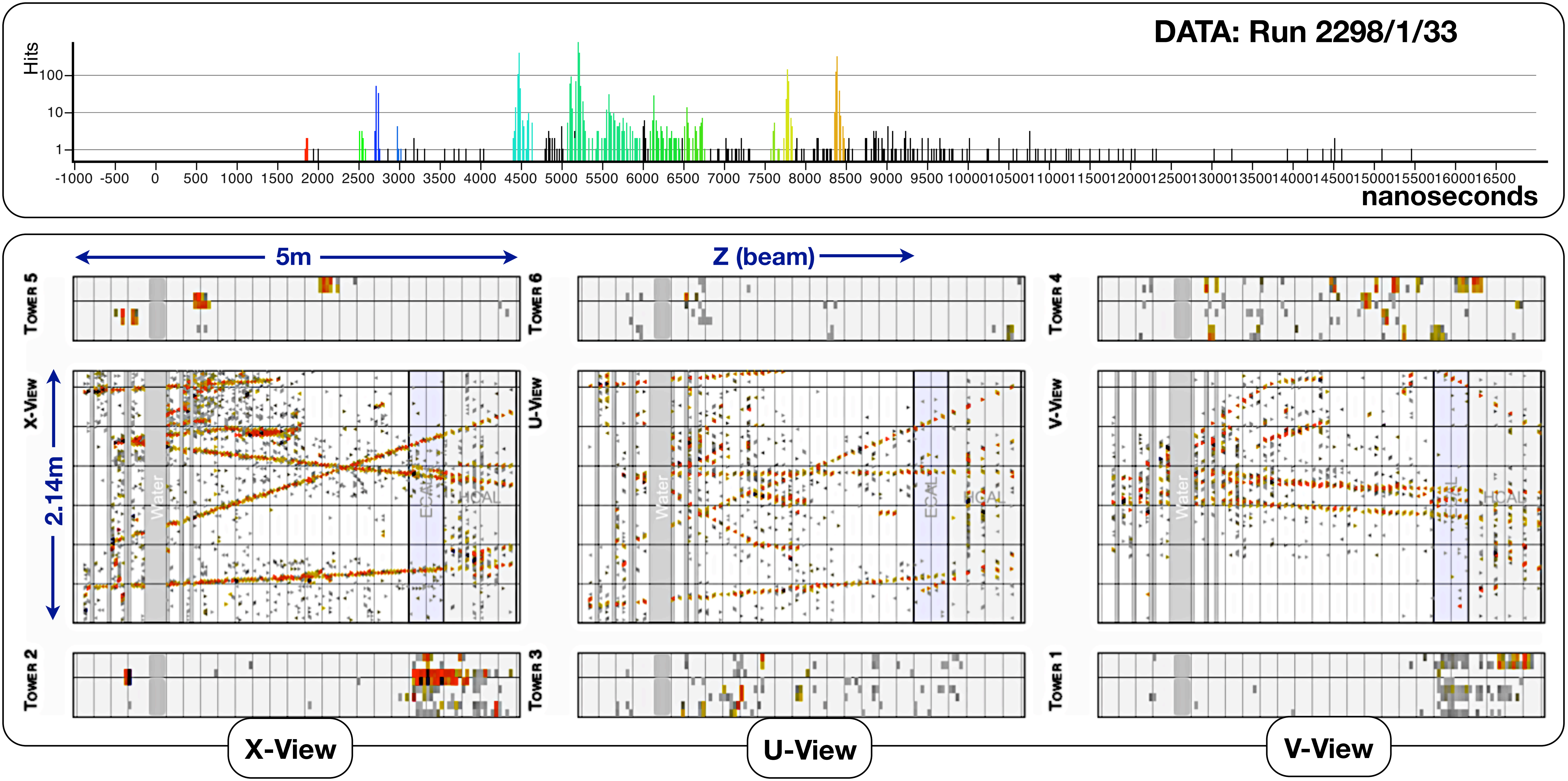


Reconstruction: Qualitative Overview

- Time-Slicing: Peak-finding and bundling hits according to the hit time distribution. MINERνA jargon: build "slices."
- Clustering: Bundle hits within a plane.
- Tracking: Look for the longest tracks first. Match tracks into MINOS for range and curvature reconstruction.
- Vertexing: Bundle tracks together.
- Tracking: Look for shorter tracks (anchored).
- Blobbing: Shower formation - isolated showers and vertex activity.

Time Slicing

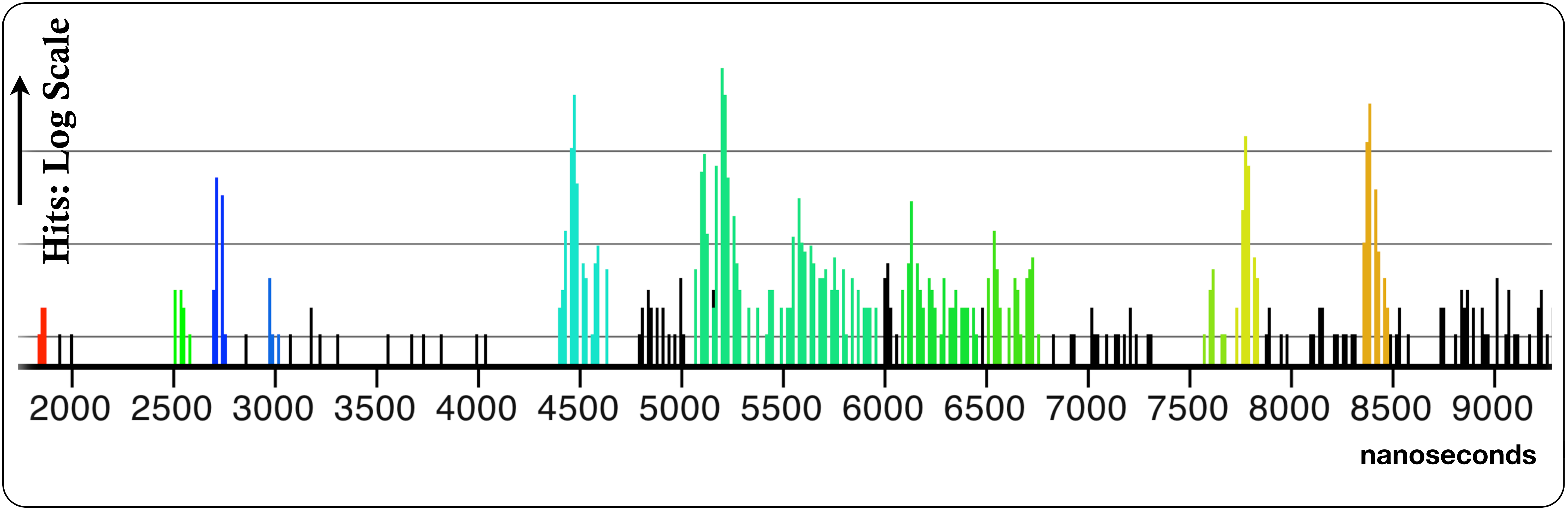
Record entire beam spills… Things look messy!
Timing comes to the rescue!



Bundle hits into "Time Slices." Beam spill is ~10 μs, data gate is ~16 μs. Slices are typically ~100 ns wide.

Time Slicing

Record entire beam spills… Things look messy!
Timing comes to the rescue!

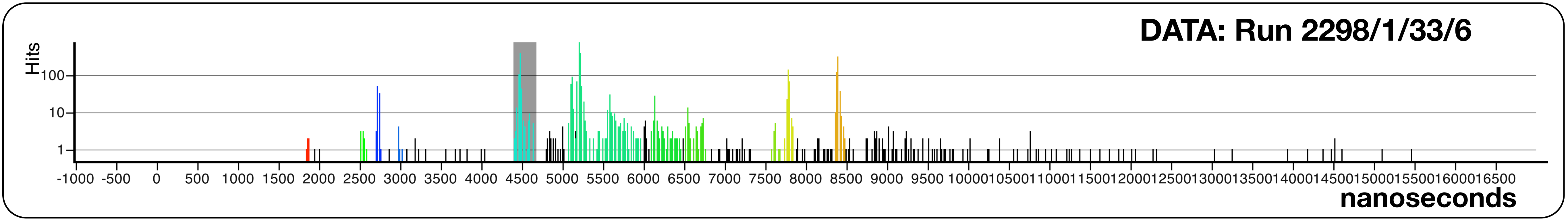


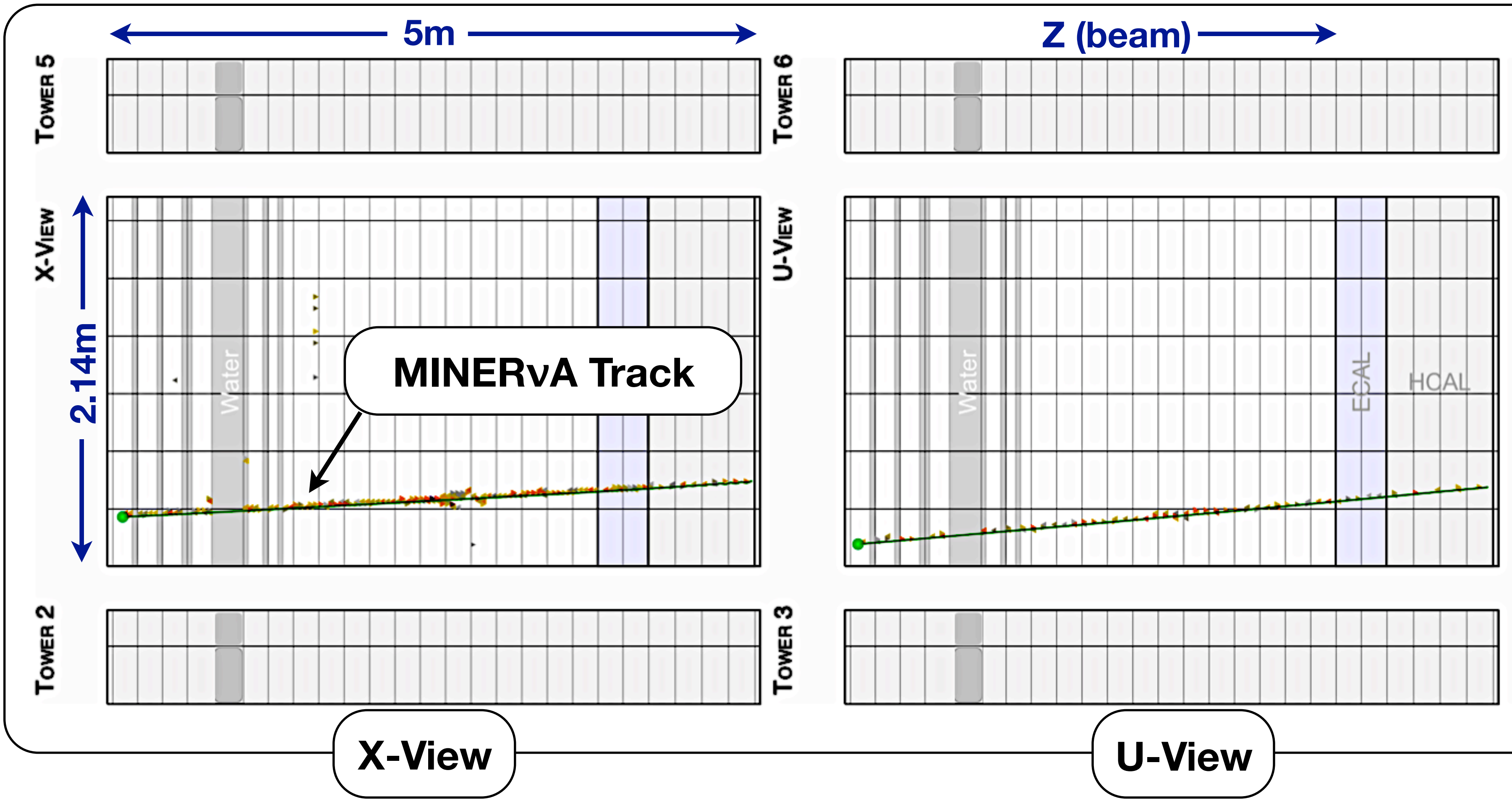
- **Peak-finding in the hit-timing distribution - grow slices forward in time.**
- **Satisfy minimum energy and hit number requirements, grow until gaps appear.**
- **Conservative: Prefer to lump two interactions together and split with reconstruction information than break a real event.**

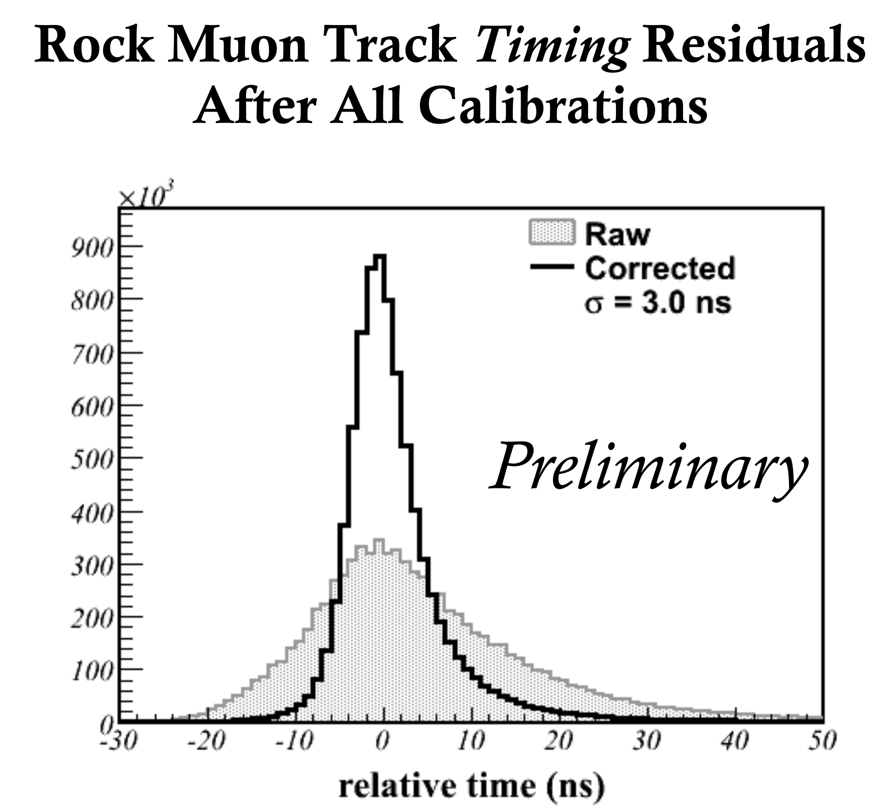
Time Slicing

Can now pick out single interactions easily!

Note: Lot's of through-going "rock muons" in the data…







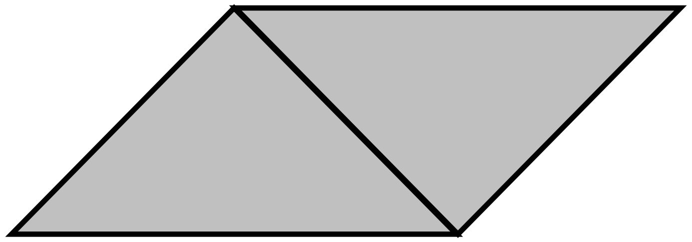
These come from neutrino interactions in the upstream rock and are a valuable calibration tool (no cosmic ray trigger for MINERvA).

Clustering

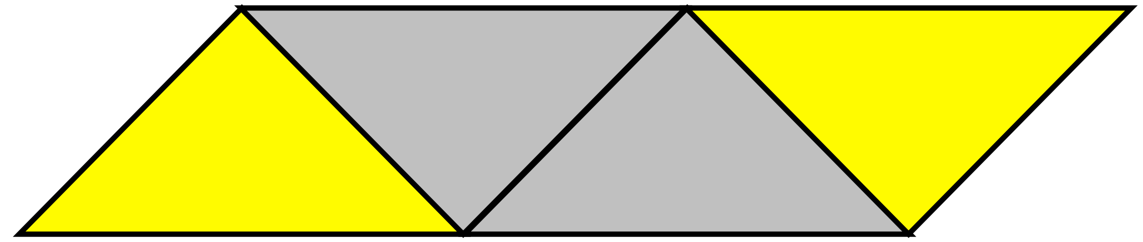
- **Group neighboring hits within a plane.**
- **Study hit topology (size and distribution of hits) *and* hit energy sum:**
  - **"Low Activity" - Hit sum has very low energy.**
  - **"Trackable" - MIP consistent groups: narrow, no more than MIP-like energy 1-8 MeV in each hit *and* no more than 12 MeV in the sum.**
  - **"Heavy Ionizing" - Narrow but high energy: very high energy single digits are allowed. No upper bound on the sum.**
  - **"Superclusters" - Broad or double-peaked, etc. shower-like clusters.**

Cluster Menagerie

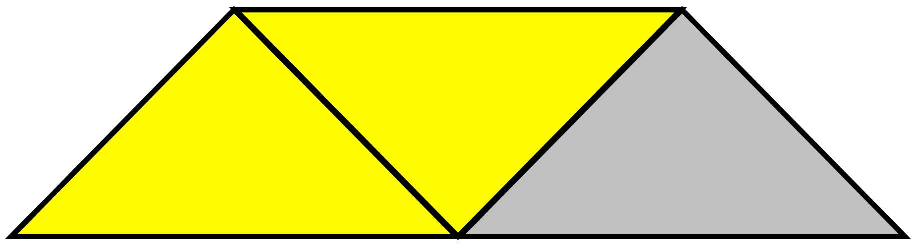
Low E	< 1 MeV
Medium E	1-8 MeV
High E	8+ MeV



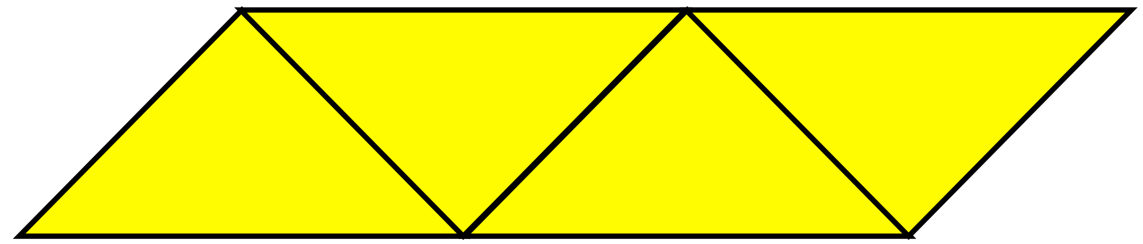
ΣE = 0.9 MeV; LowActivity



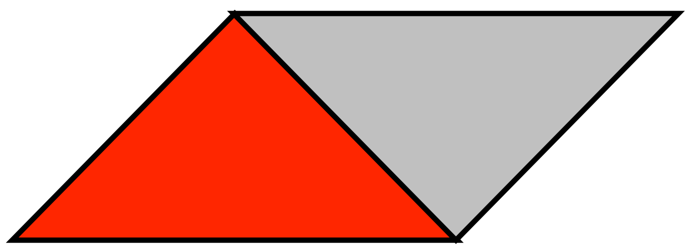
ΣE = 5 MeV; SuperCluster



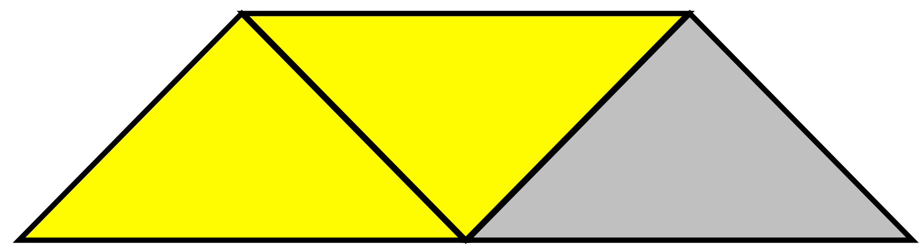
ΣE = 10 MeV; Trackable



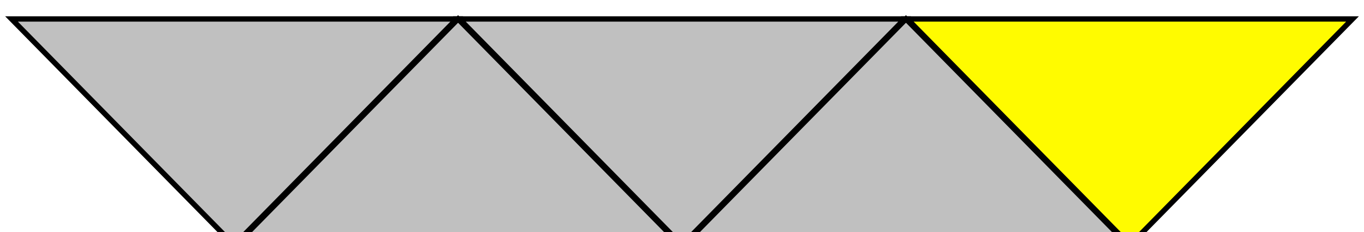
ΣE = 6 MeV; SuperCluster



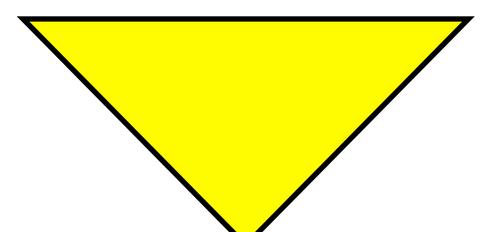
ΣE = 10 MeV; HeavyIonizing



ΣE = 17 MeV; HeavyIonizing



ΣE = 10 MeV; SuperCluster



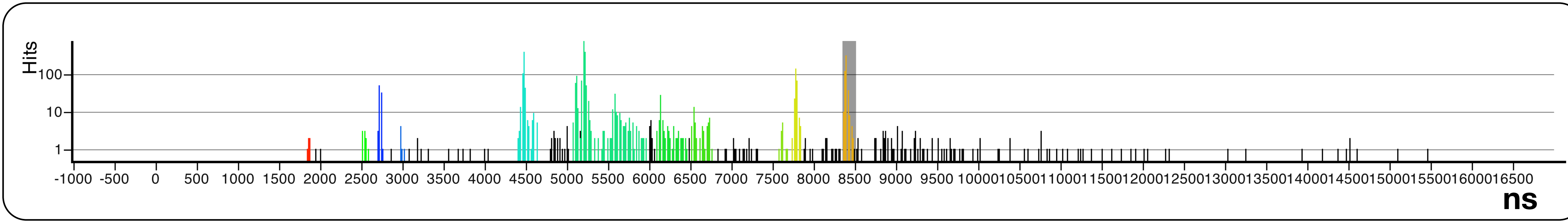
ΣE = 5 MeV; Trackable

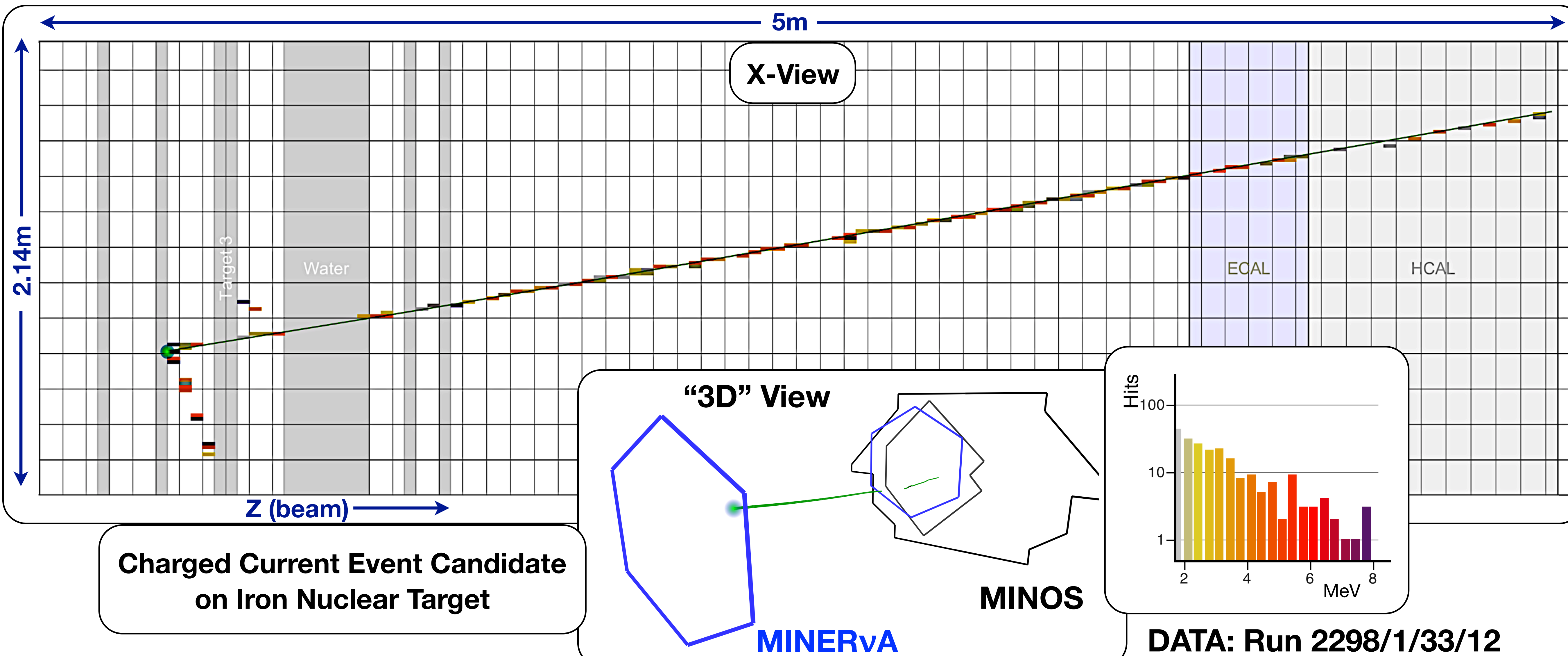
Long Tracking

- Consume Trackable and Heavy-Ionizing clusters only.
- Form 2D seeds with at least three hits in each view (X, U, or V).
  - This enforces an 11-plane (~20 cm in pure plastic) minimum.
- Merge seeds and then look for 3D tracks.
- Fit the track with a custom Kalman Filter (take multiple scattering into account as the track moves through the detector).

Tracking

X-View Close-Up



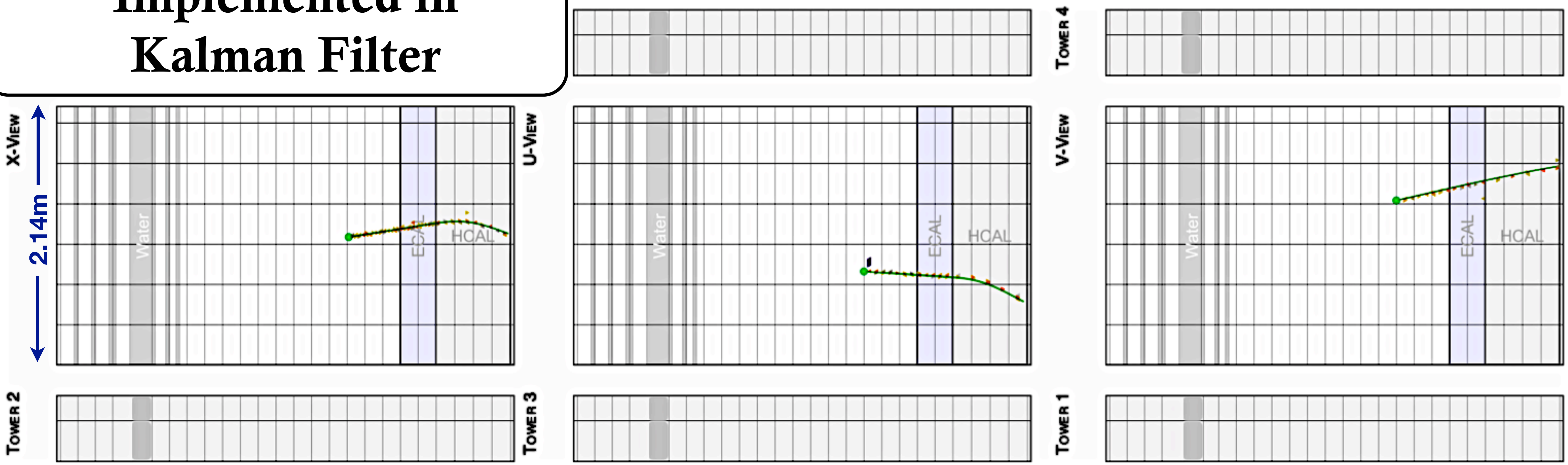


Charged Current Event Candidate on Iron Nuclear Target

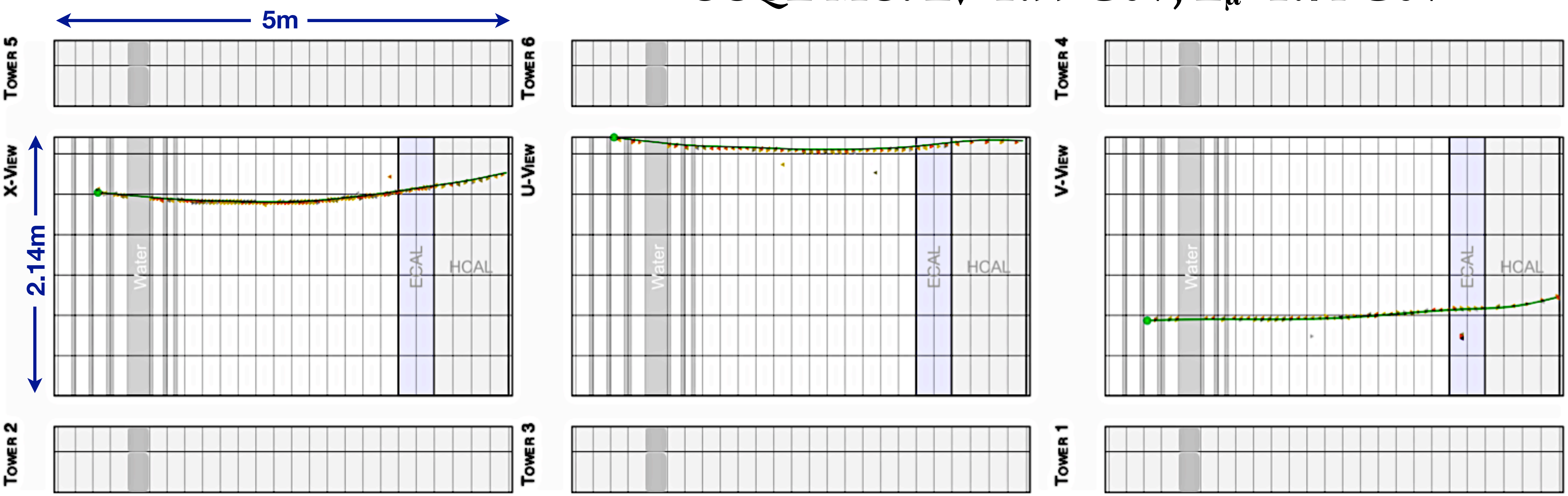
DATA: Run 2298/1/33/12

Multiple-Scattering Implemented in Kalman Filter

CCQE MC: E_ν=1.97 GeV; E_μ=1.73 GeV

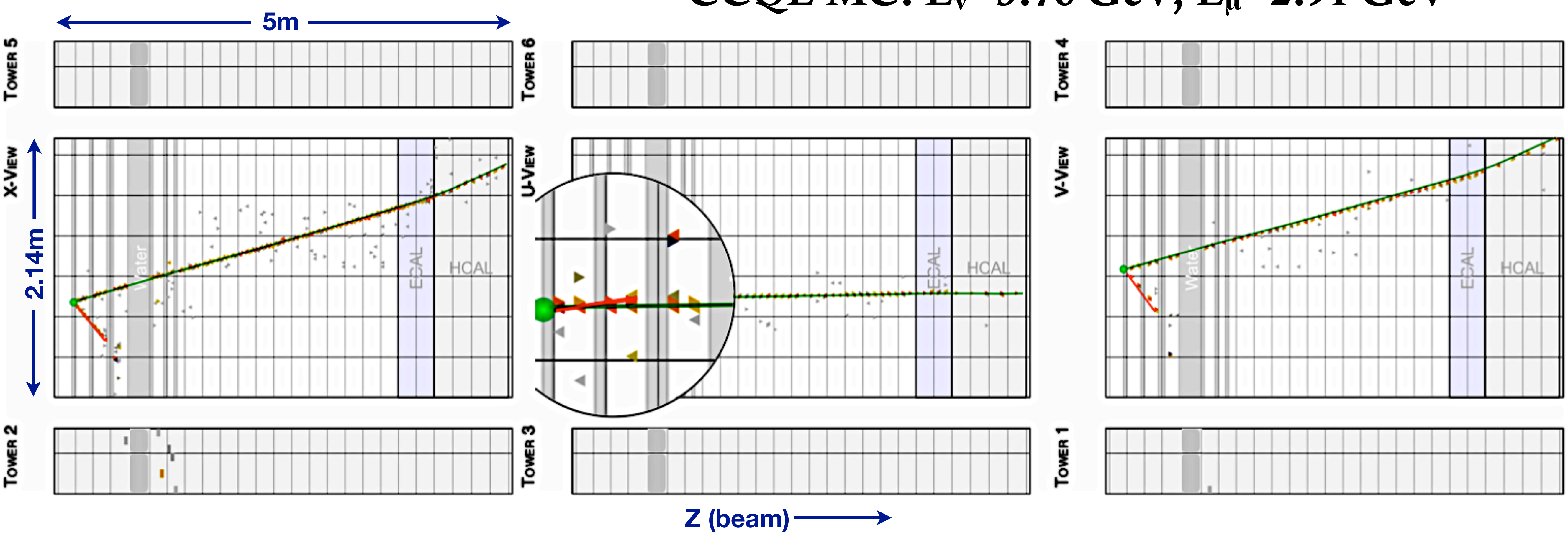


CCQE MC: E_ν=2.99 GeV; E_μ=2.71 GeV



Two-View Tracking

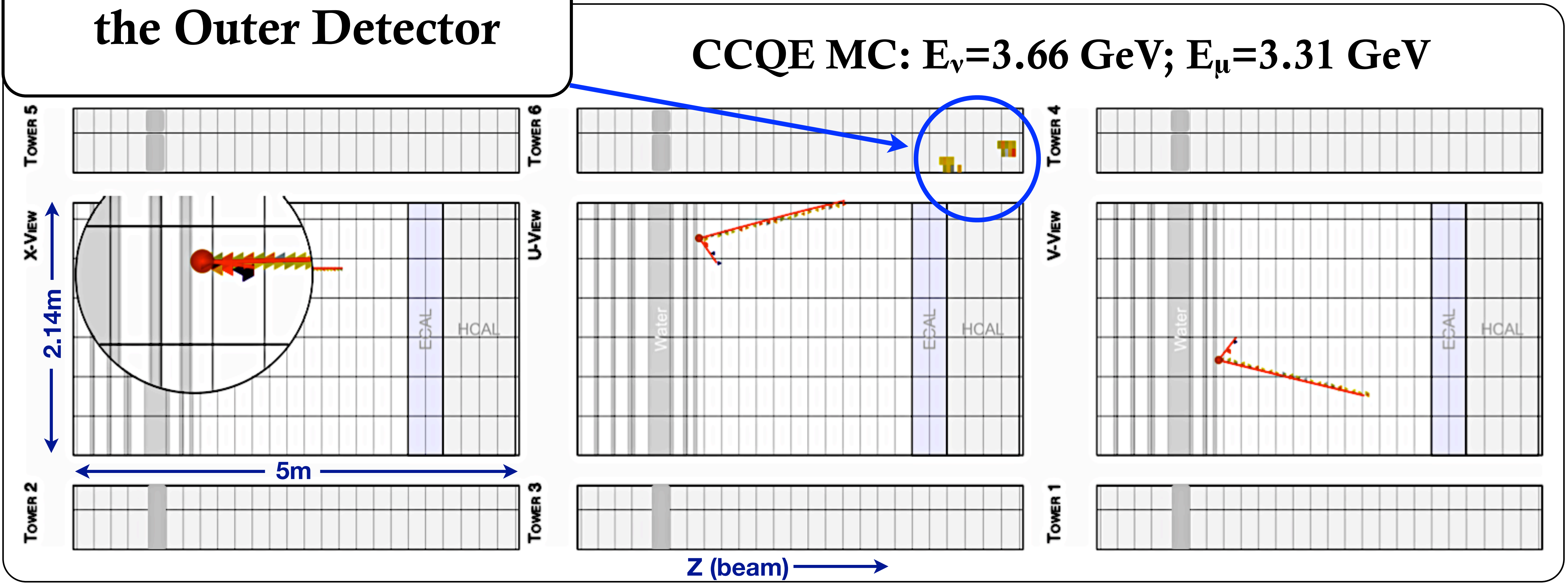
CCQE MC: E_ν=3.76 GeV; E_μ=2.91 GeV

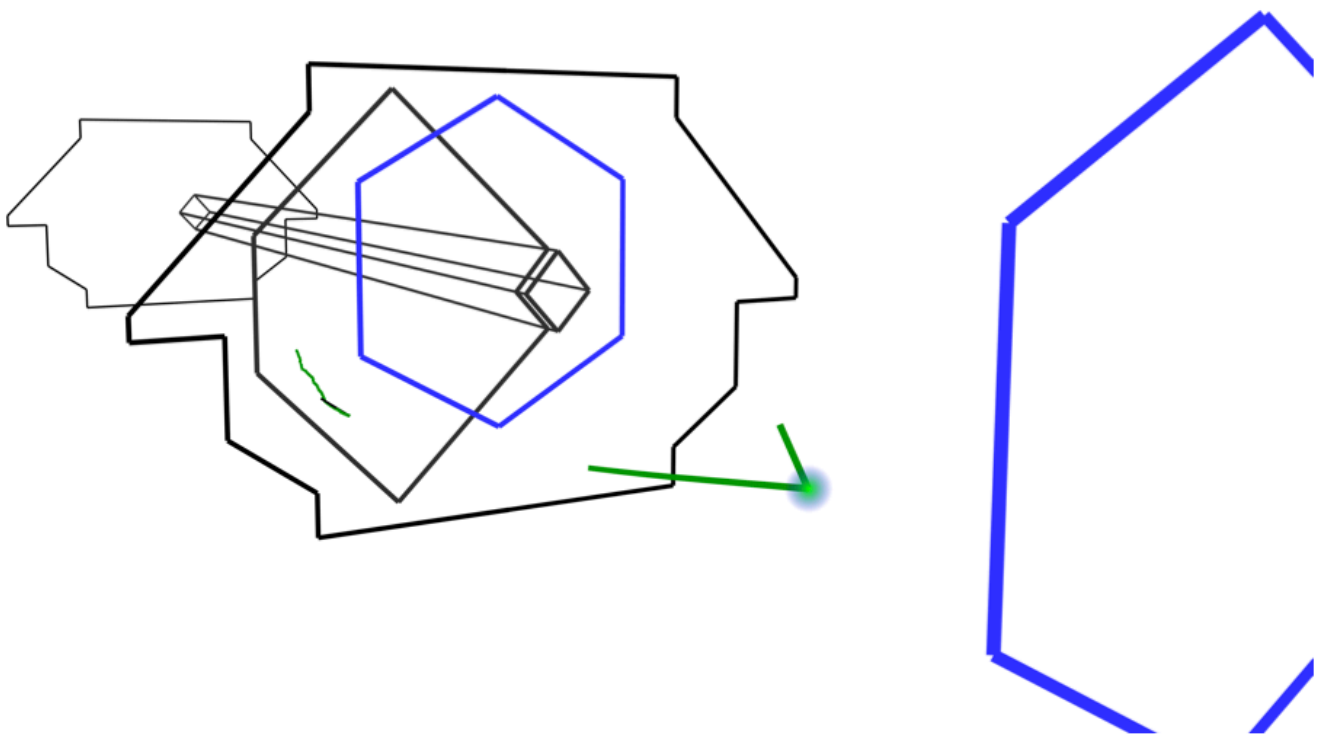


- Two views are sufficient to reconstruct three dimensional information.

Tracking Through the Outer Detector

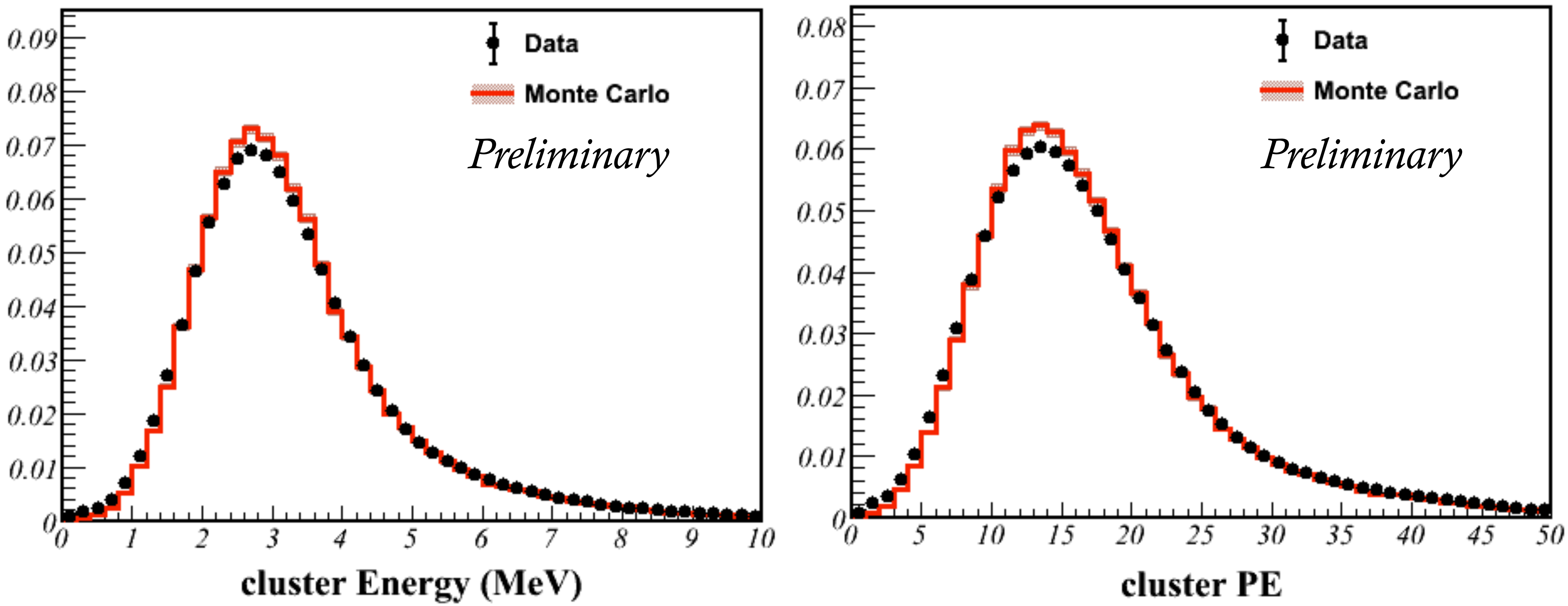
CCQE MC: E_ν=3.66 GeV; E_μ=3.31 GeV





- Tracking through the Outer Detector is effective for tracks originating in the Inner Detector.

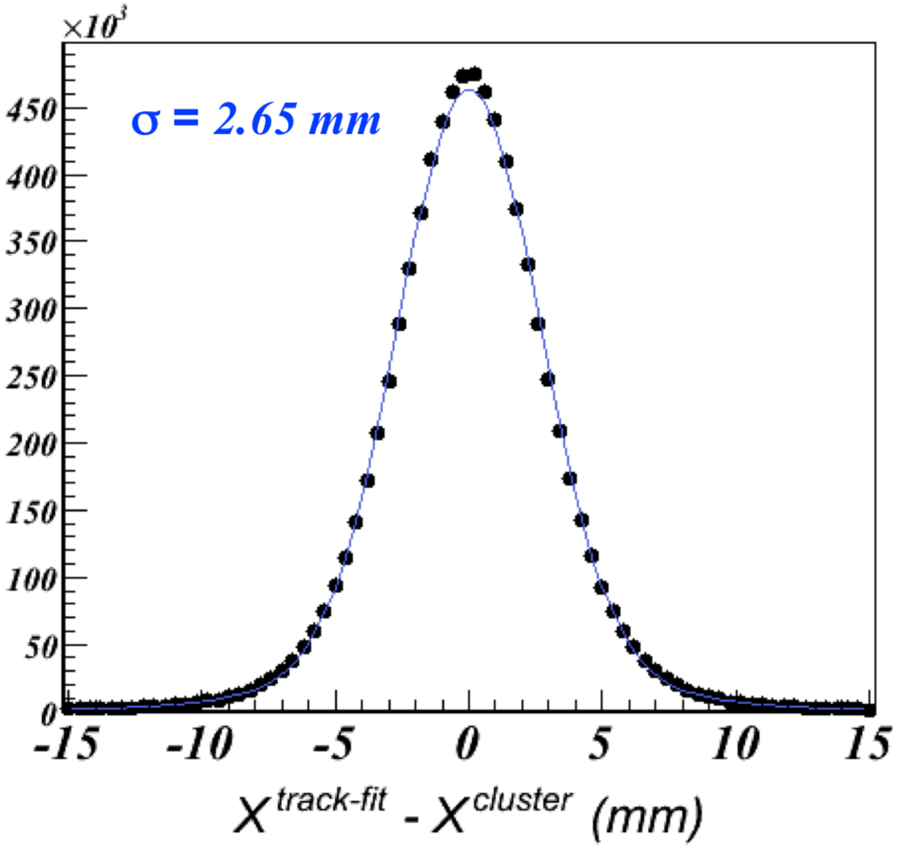
Clusters and Tracking

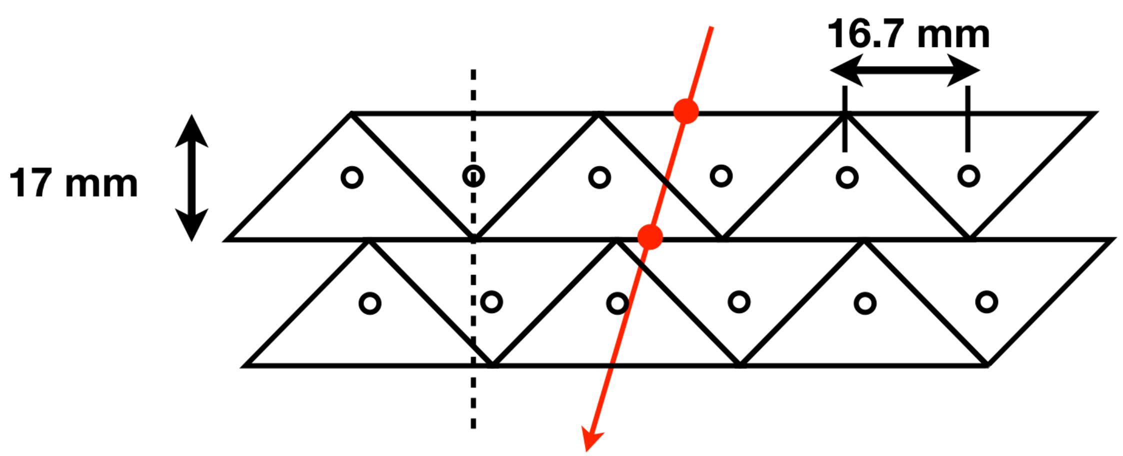


- **Data/MC comparison of cluster energies on a track.**

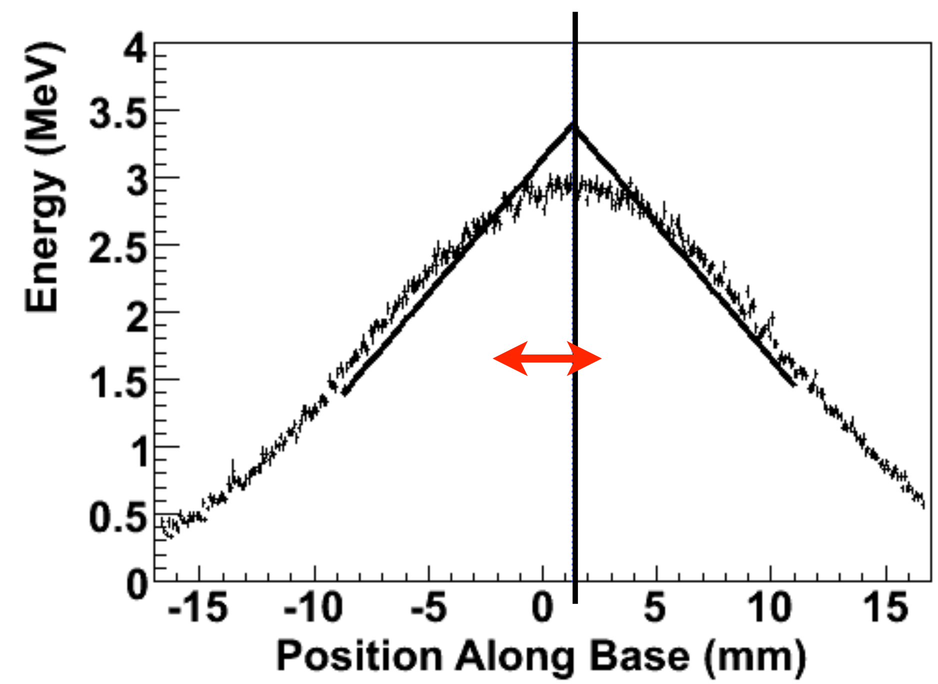
Tracking Calibrations: Strip-to-Strip

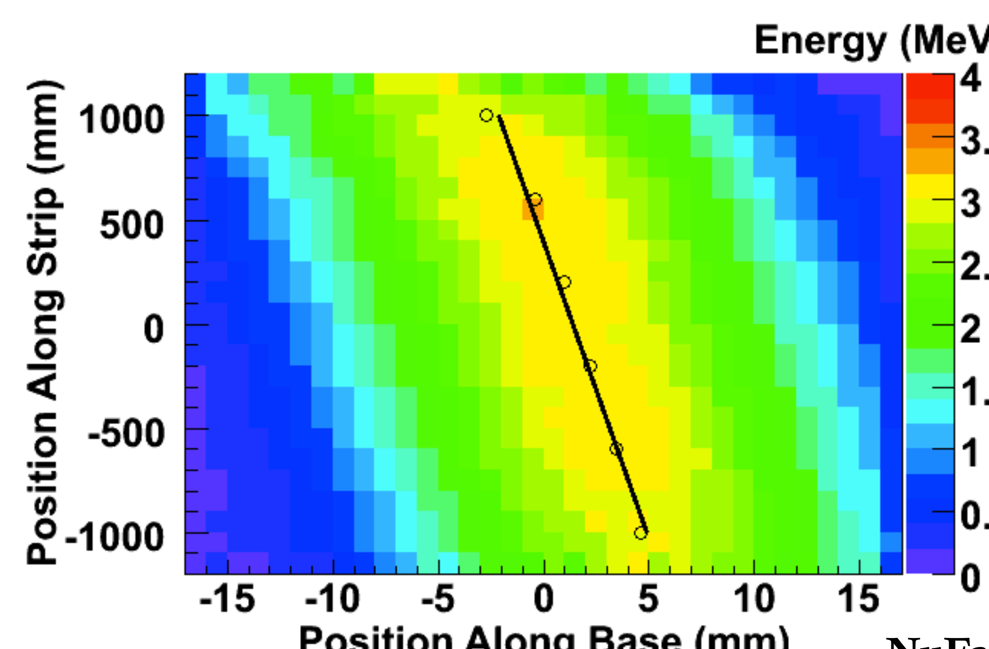
Leverage good residuals, triangular strip shape.





Find deviations along the strip for rotations & offsets.



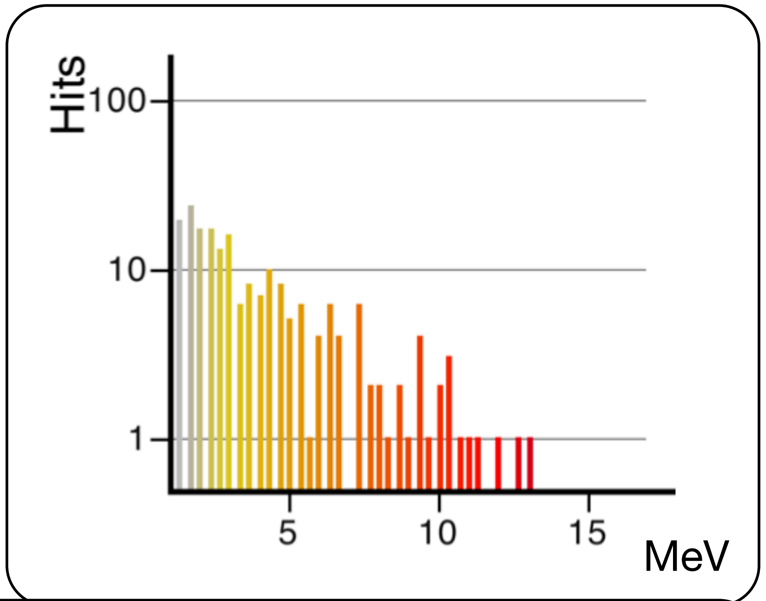


Shower Reconstruction

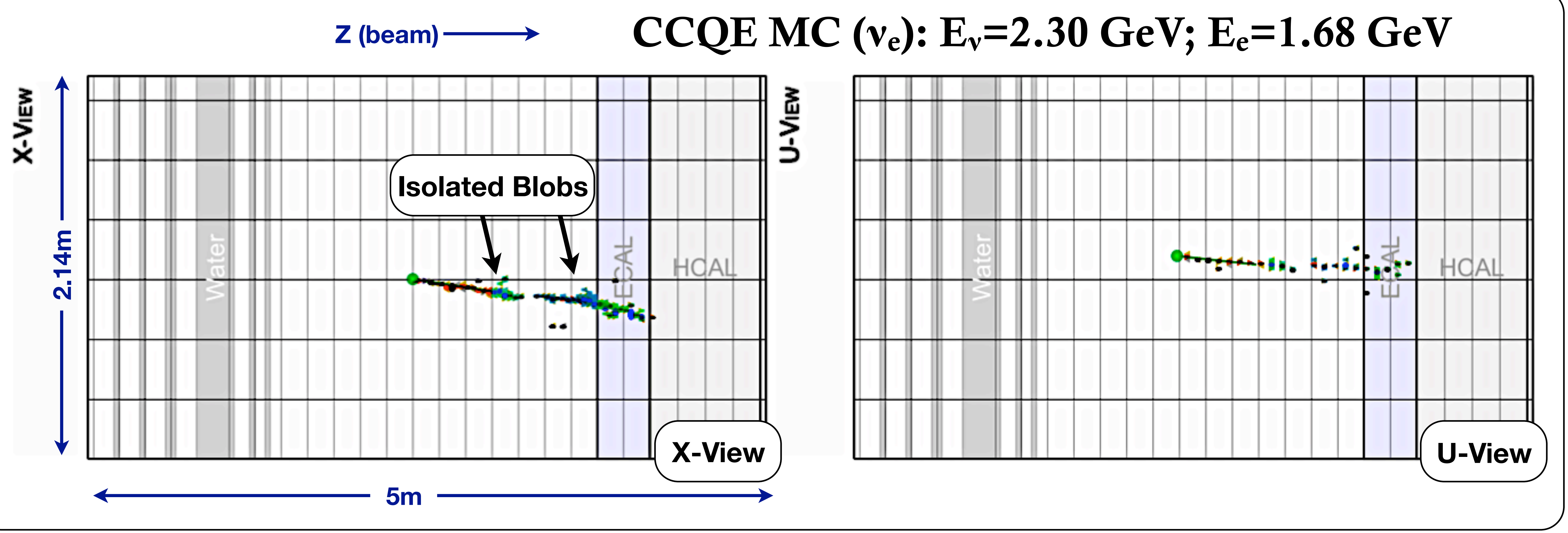
- **MINERνA Jargon: *Blobbing.***
- **Several algorithms: peak-find-and-grow, cone algorithms, spatially anchored searches, etc.**
- **Active current development is aimed at:**
  - **electromagnetic final states (showers),**
  - **vertex activity.**

Shower Reconstruction

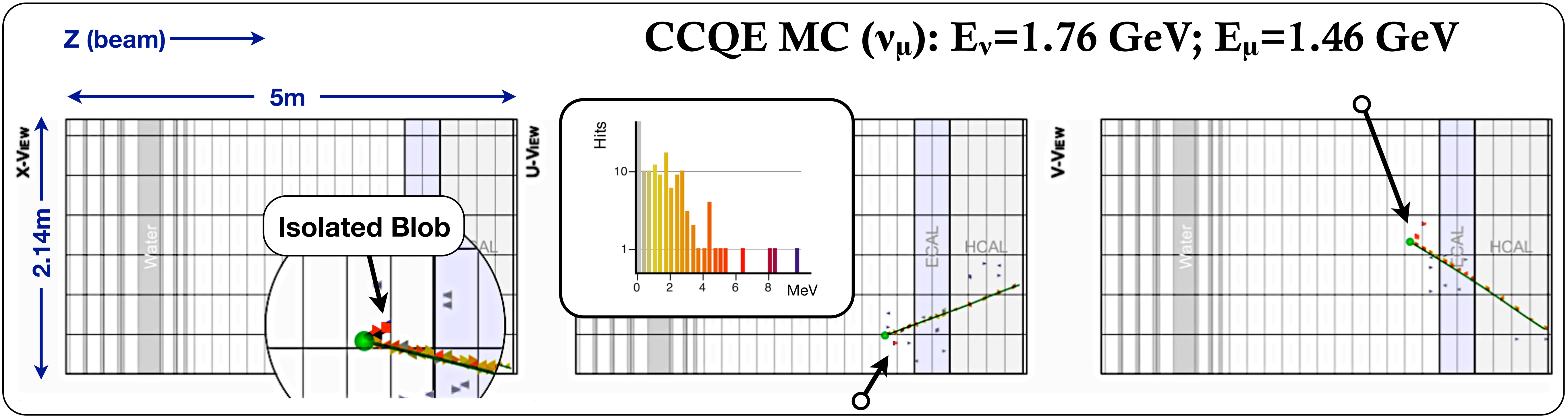
- Low to medium energy electrons reconstructed by seeding a cone with a track, and attaching isolated "blobs."
- Isolated blobs built by a peak-finding algorithm that searches each view, and then combines the 2D objects into a 3D object.



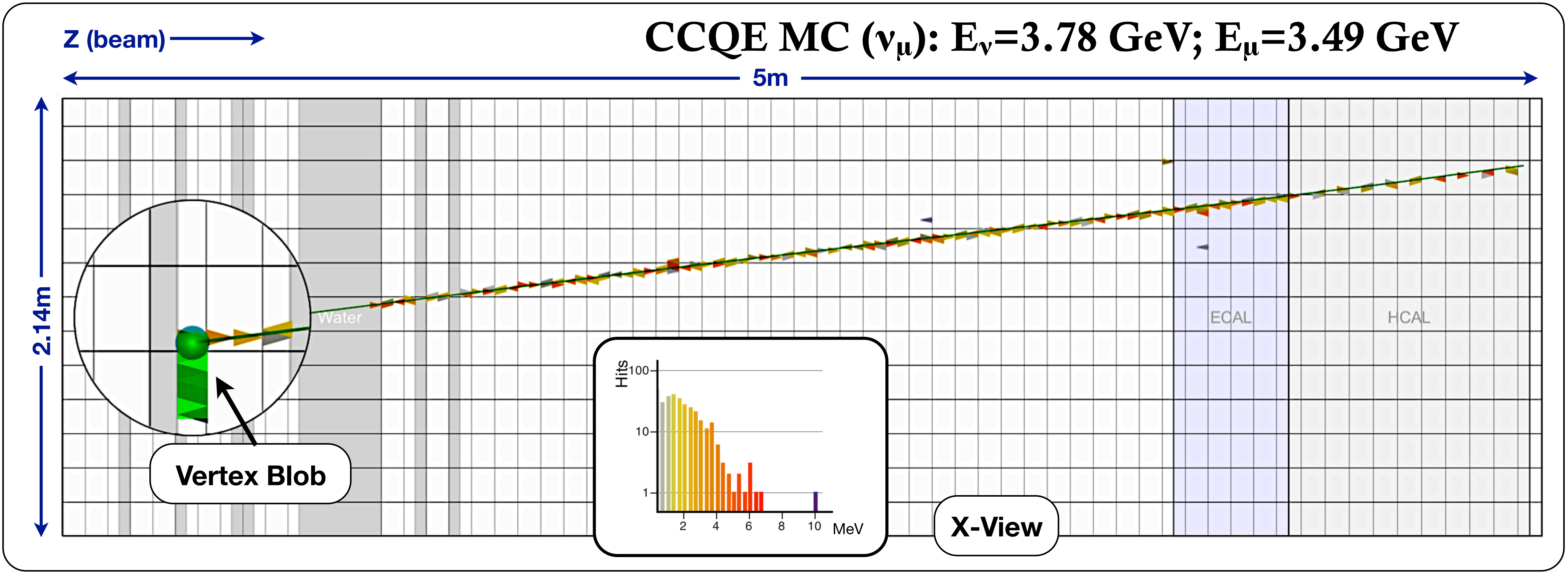
CCQE MC (ν_e): E_ν=2.30 GeV; E_e=1.68 GeV



Blobs are how we currently handle un-trackable activity.



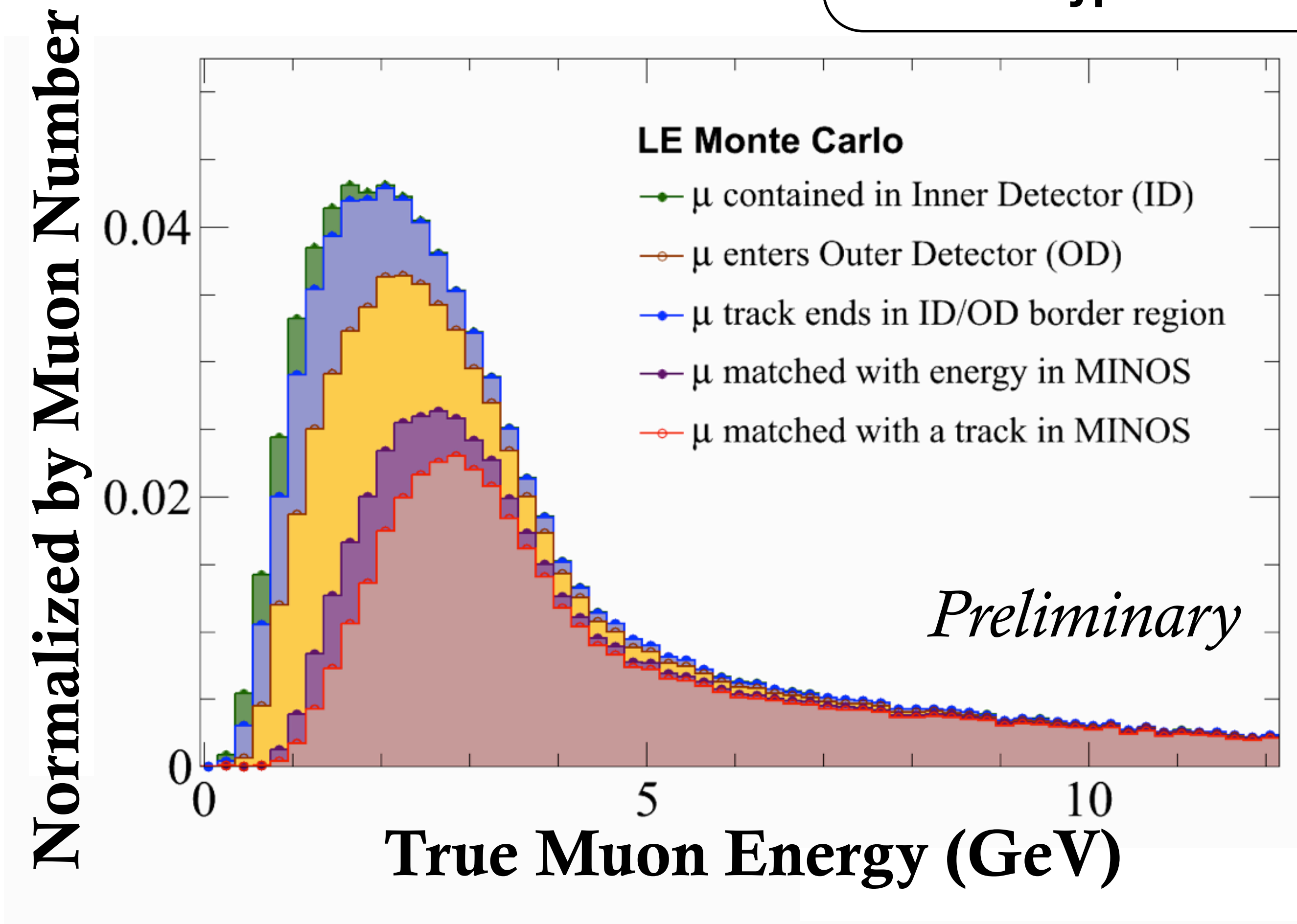
Vertex activity can be 2D.

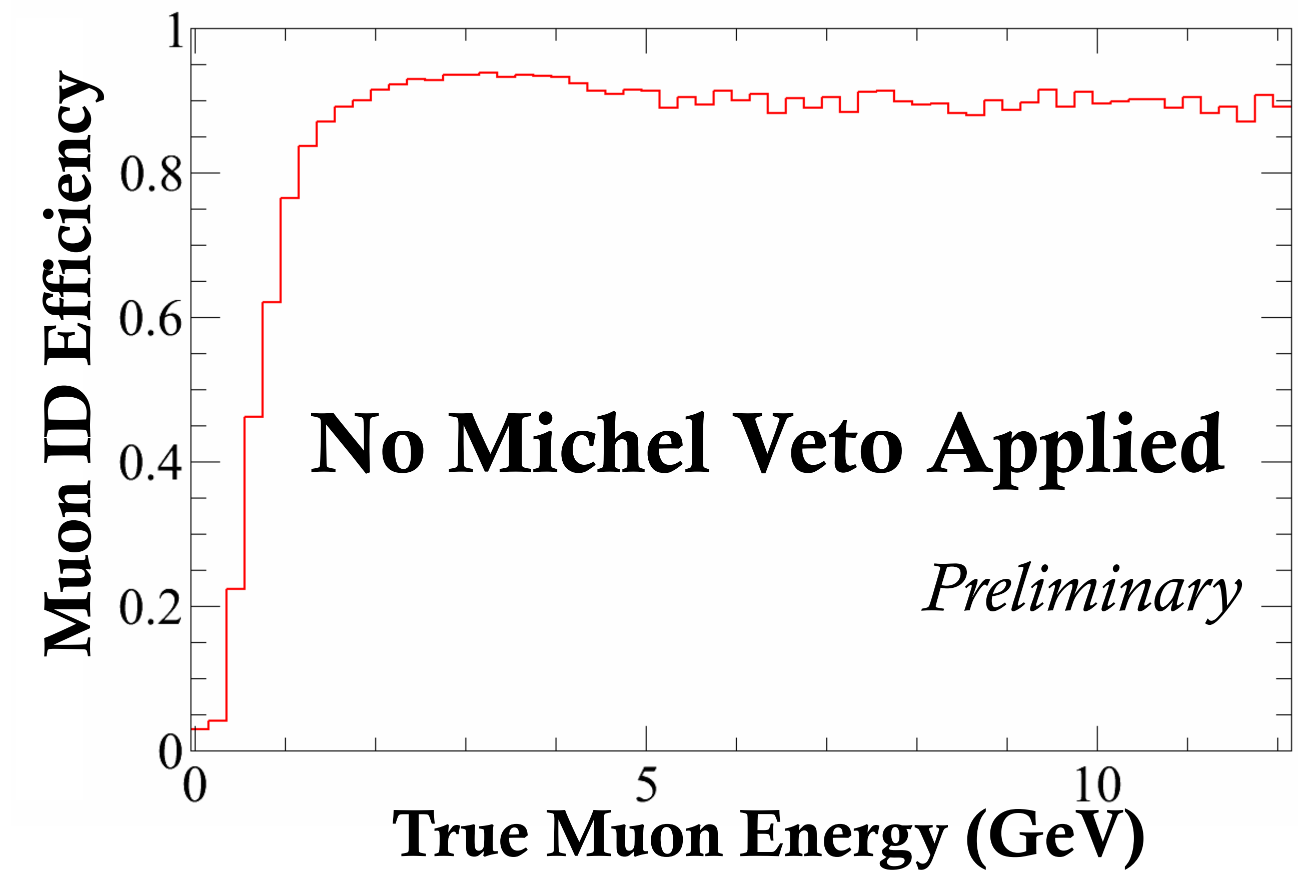


Particle ID

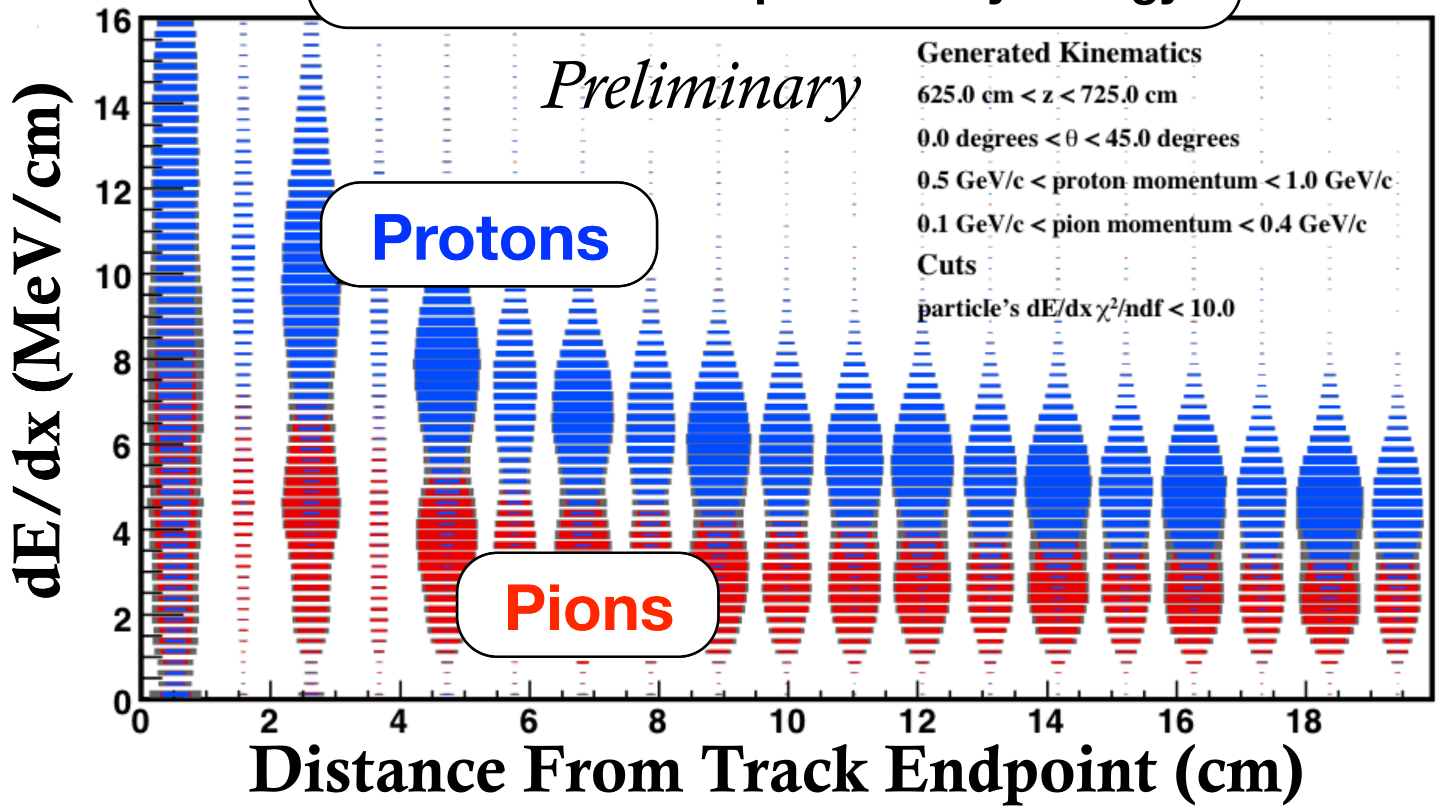
- Current Methods:
  - MINOS-Matching: Assume the particle is a muon.
  - dE/dX Profile Fits: Pion/Proton separation.
    - Also used in a multi-variate PID for stopping muon/pion separation (developmental).
  - Michel Tags.
    - Veto pions in a muon-only CCQE-like analysis (developmental).

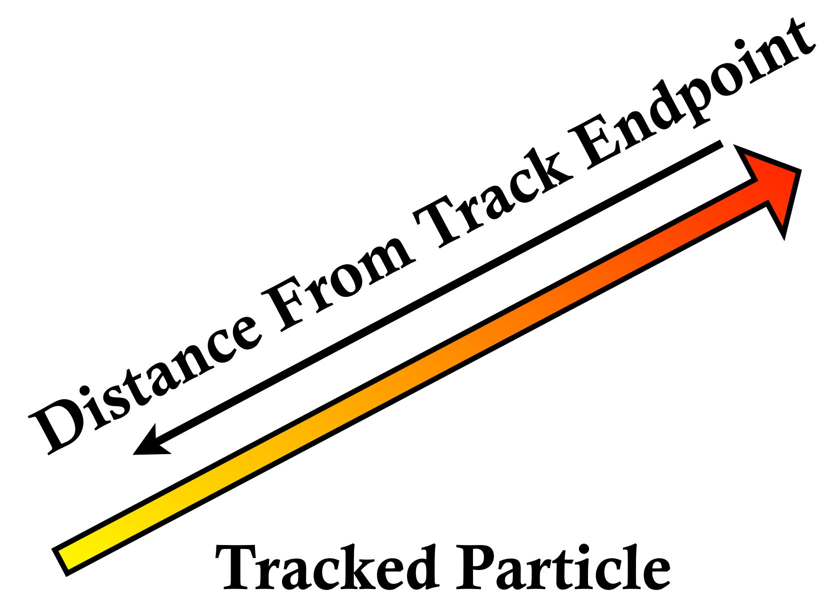
Muon Type & Efficiency by Energy



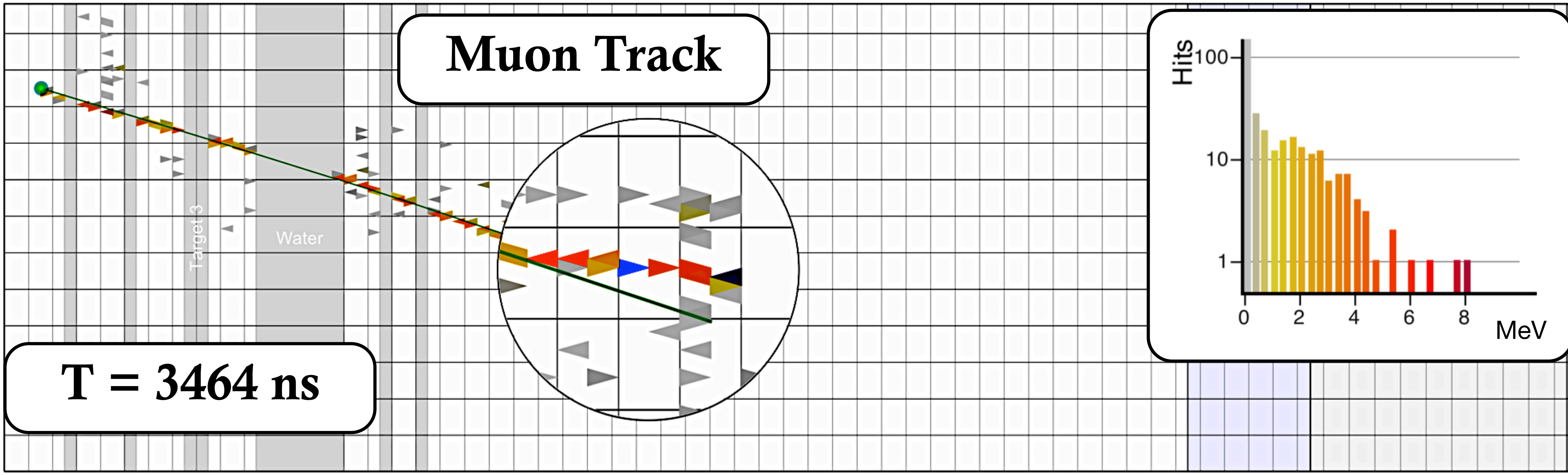


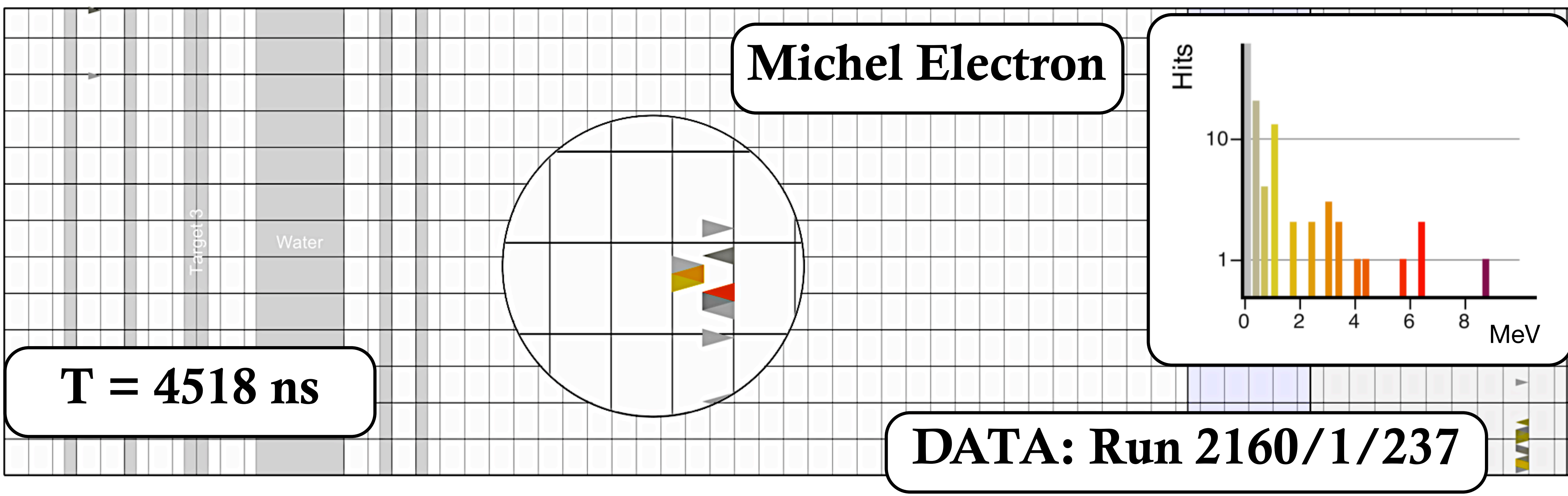
Pion & Proton Separation by Energy





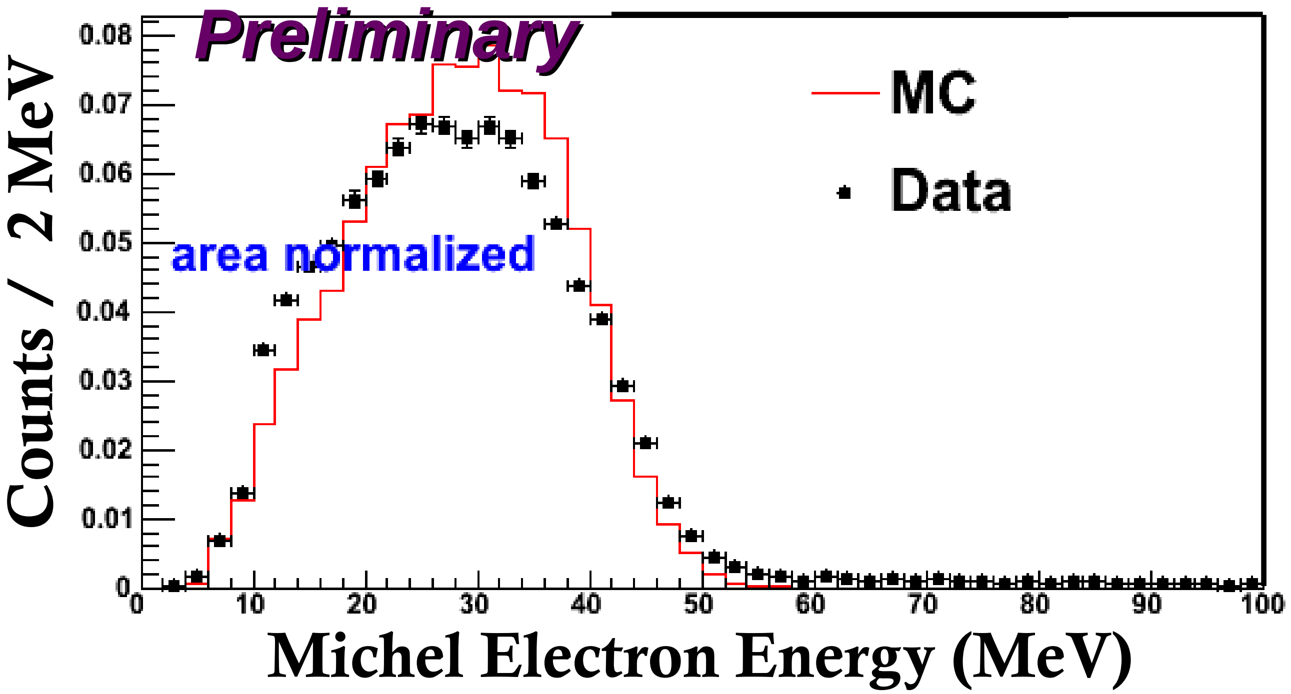
Michel Electrons

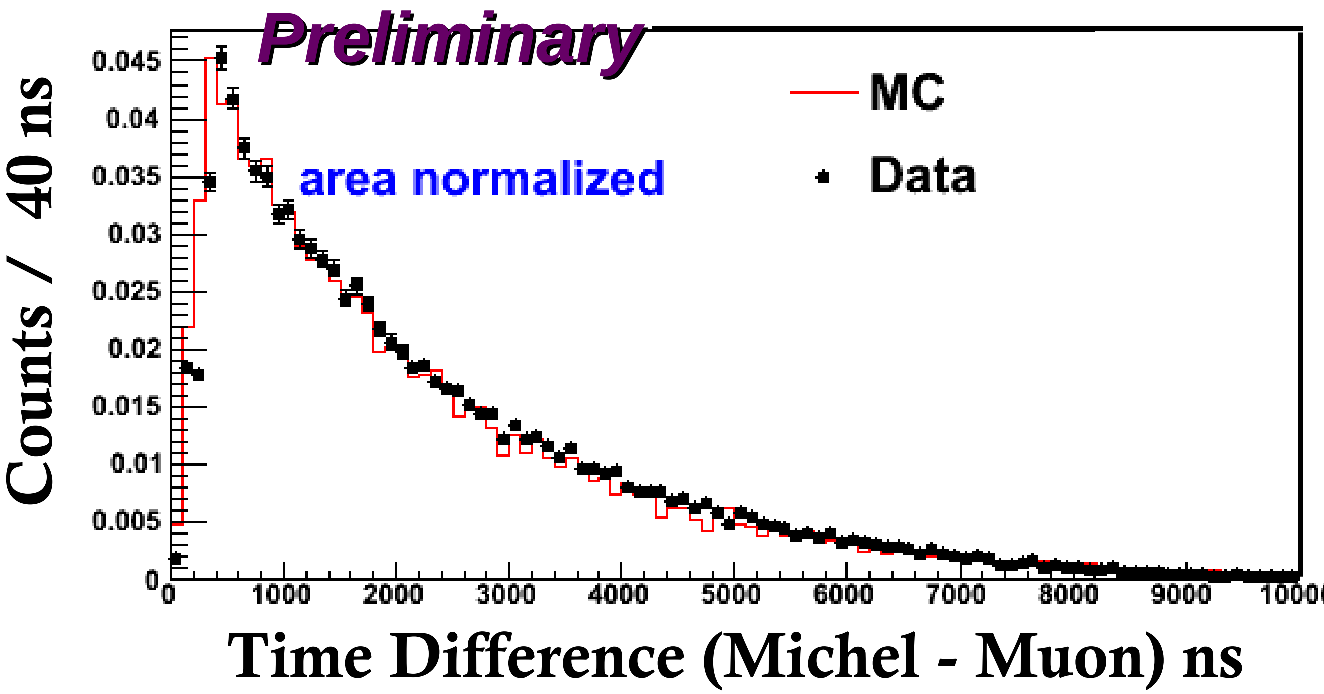




Michel Electrons

Michel Electron Fits	Muon Lifetime in Plastic (ns)
Data	2100 ± 10
MC	2120 ± 20





MC is background free μ^-. Data contains a small μ^+ contamination. Nominal μ^- lifetime in carbon is 2026 ns.

Conclusions

- **MINERνA is functioning well & recording data as NuMI delivers P.O.T.**
- **Reconstruction is under development but reaching critical mass to do interesting physics, particularly for charged current channels, and especially for muon-flavor neutrinos.**

Other MINERνA Talks

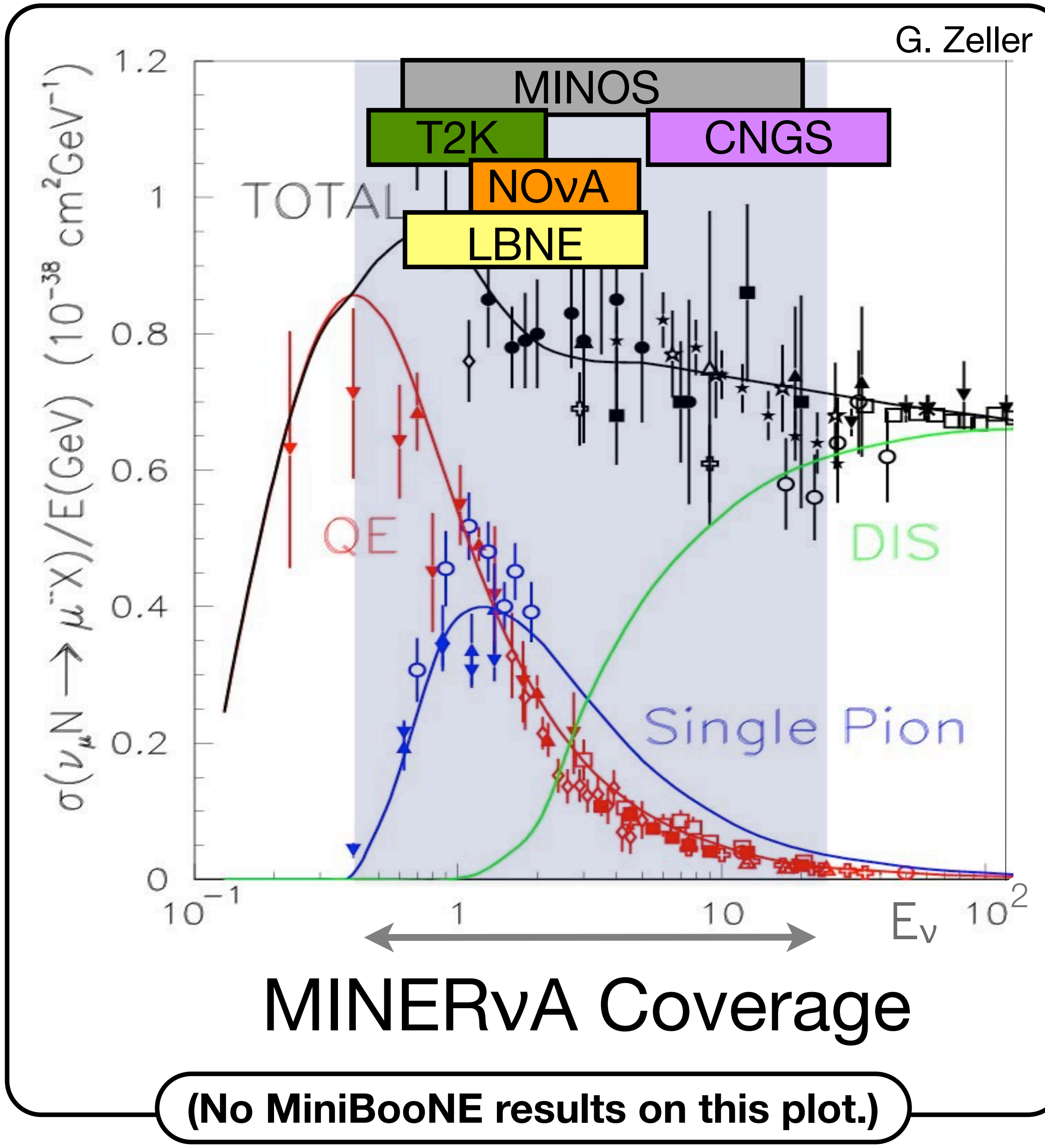
- Elastic Scattering - B. Ziemer, Thursday Morning.
- CC Inclusive Events & Nuclear Targets - J. Devan, Thursday Morning.
- NuMI Flux - M. Kordosky, Thursday Afternoon.

Thank You for Listening!

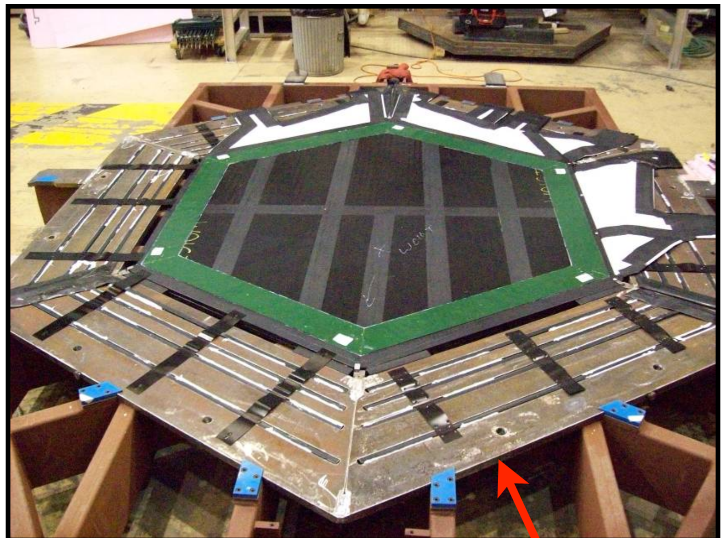
Back-Up

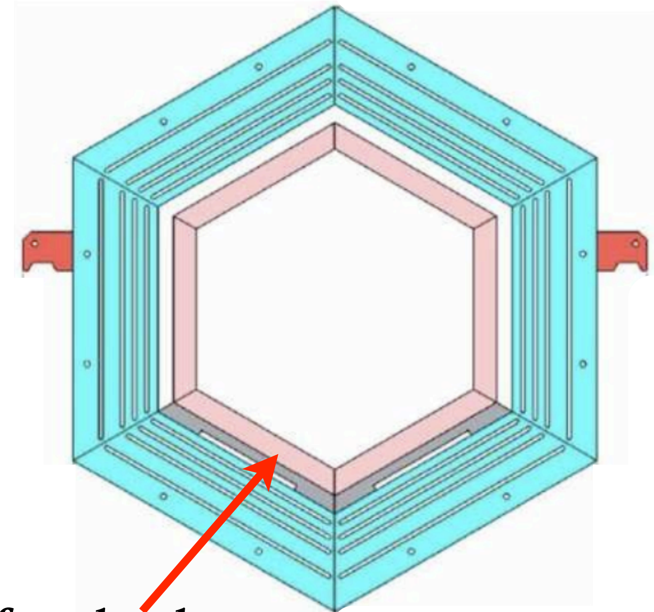
MINERνA Motivations

- We are now entering a period of precision neutrino oscillation measurements.
- To maximize oscillation effects, need $\Delta m^2 \times L/E_{Beam} \sim 1$.
- For $\Delta m^2 \sim 2.5 \times 10^{-3}$ eV^2 and L ~ 100's of km, E_{Beam} ~ few GeV range.
- Therefore, we need precision measurements of neutrino cross sections in this range.

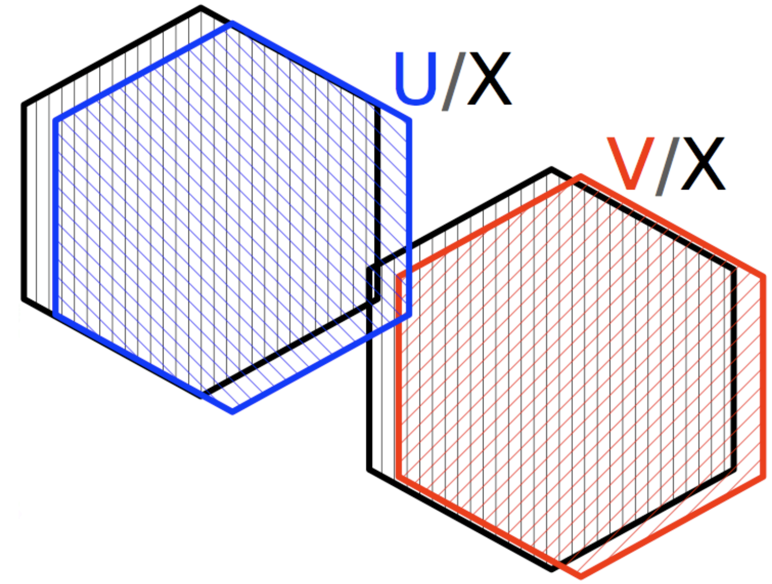


MINERνA Modules

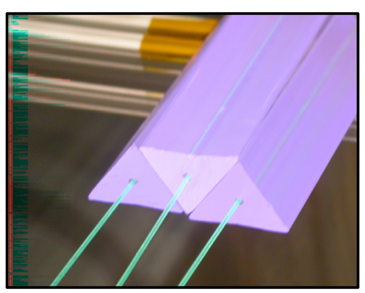




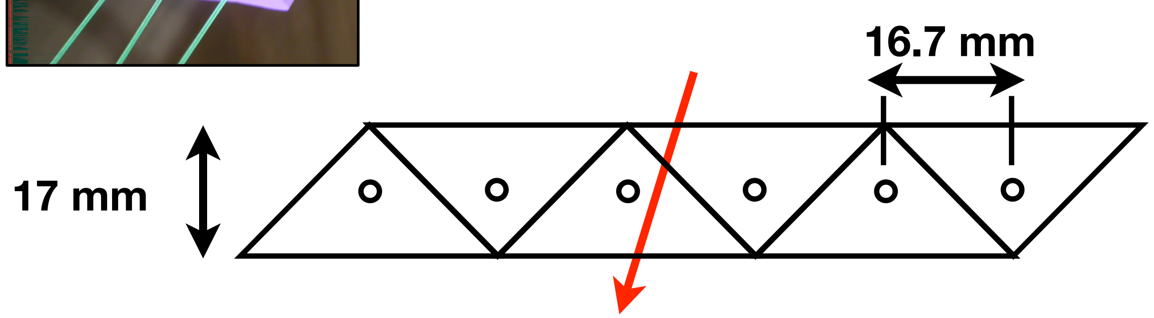
Modules have an outer detector frame of steel and scintillator and an inner detector element of scintillator strips and absorbers/targets.



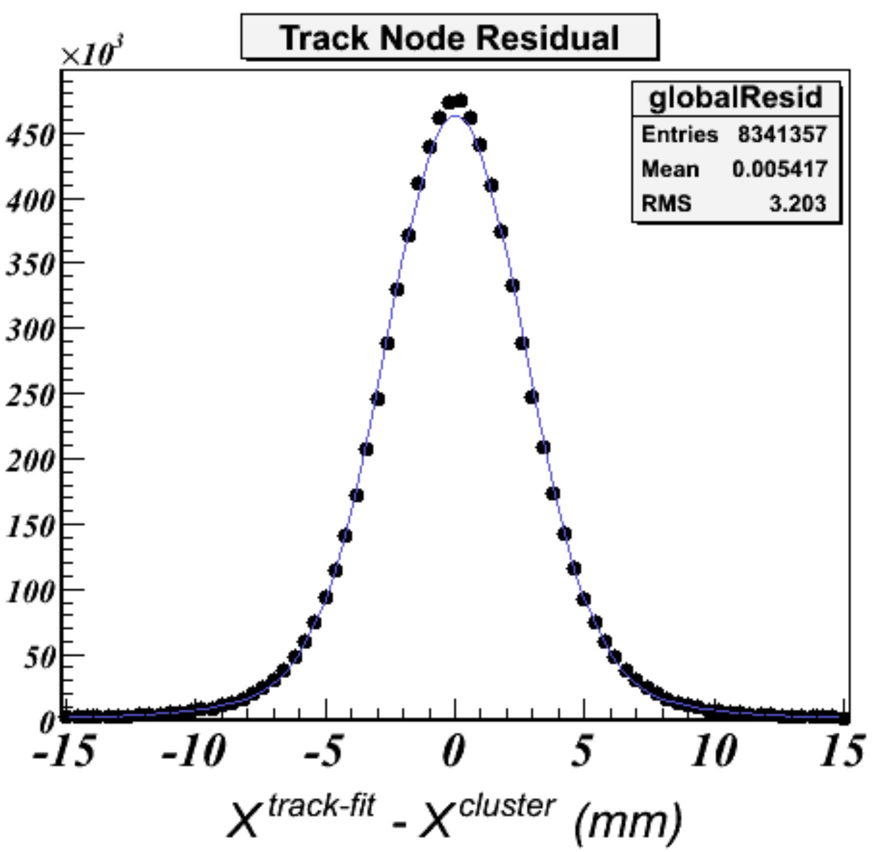
Planes are mounted stereoscopically in XU or XV orientations for 3D tracking.



Extruded scintillator & wavelength shifting fibers.



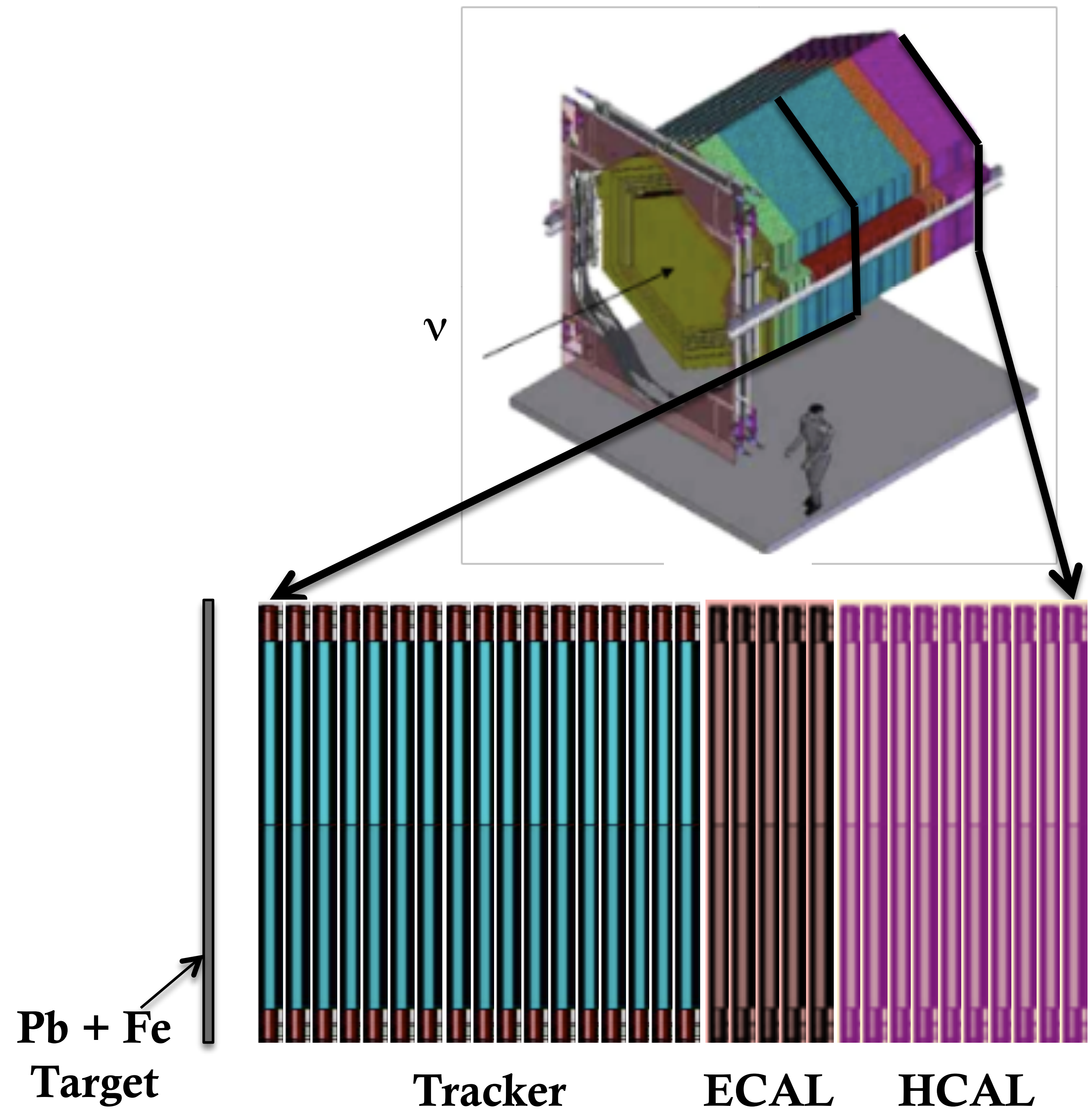
Charge-sharing for improved position resolution (~3.5 mm).



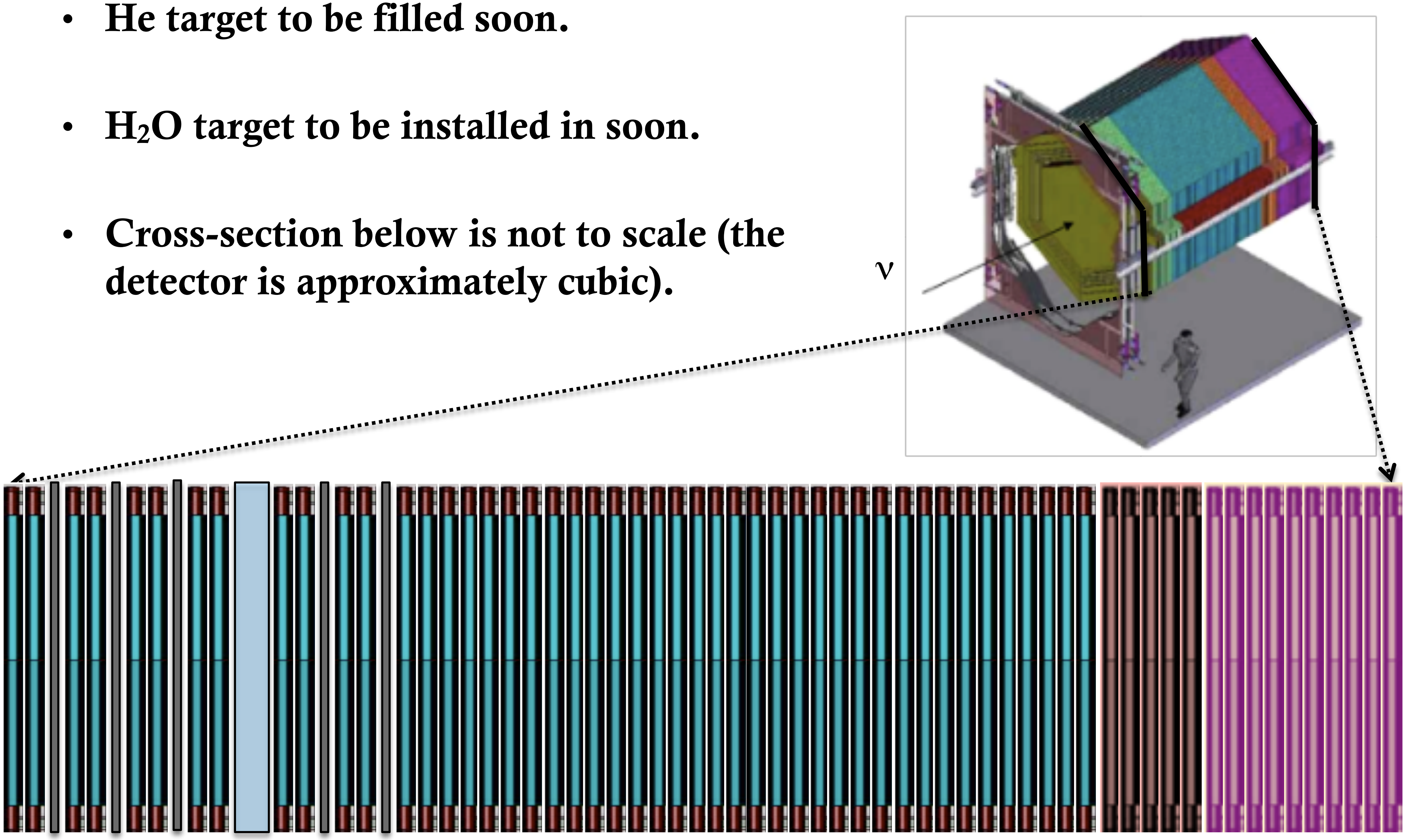
Residual between a fitted position along a track and the charge-weighted hit in that plane for a sample of through-going muons.

MINERνA "Frozen Detector"

- Partial installation of 34 tracking, 10 ECAL, and 20 HCAL (full back calorimetry) completed November 12, 2009.
- Collected data in this configuration until early January, 2010 when we resumed installation (and continued data-taking with the "Downstream Detector").
- One nuclear target module (Fe, Pb) and one module instrumented as veto included for the "Frozen" period.



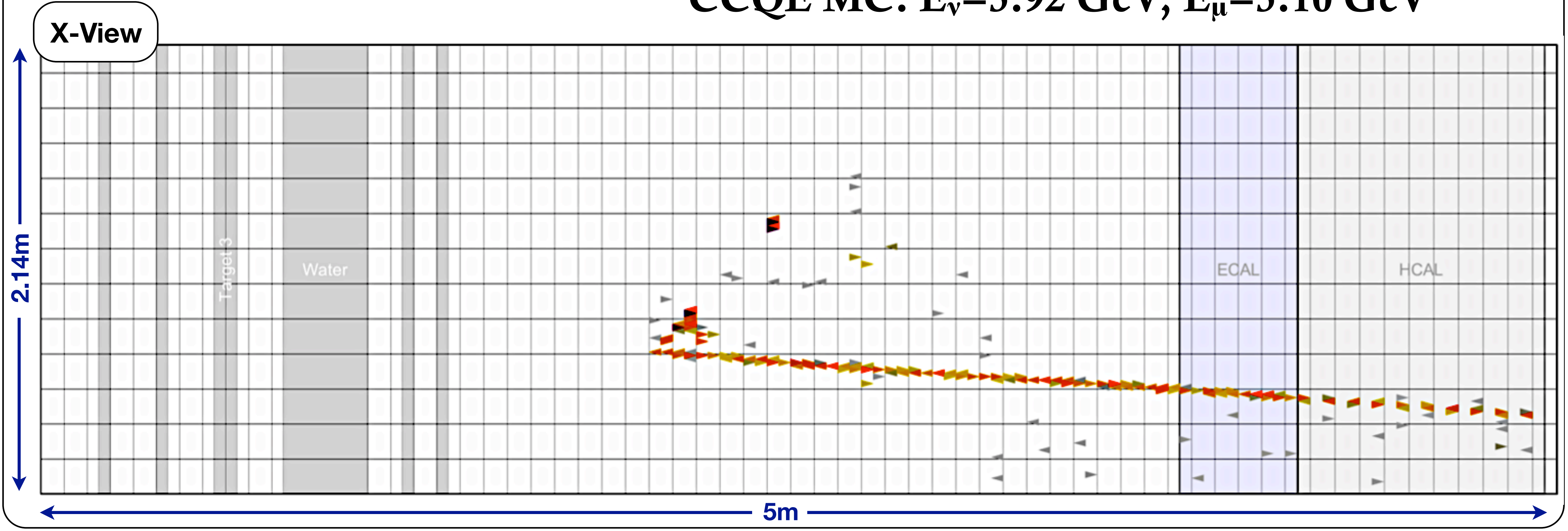
- **MINERνA installation finished in March, 2010.**
- **He target to be filled soon.**
- **H_2O target to be installed in soon.**
- **Cross-section below is not to scale (the detector is approximately cubic).**



Reconstruction

- After time-slicing, we have an isolated interaction.

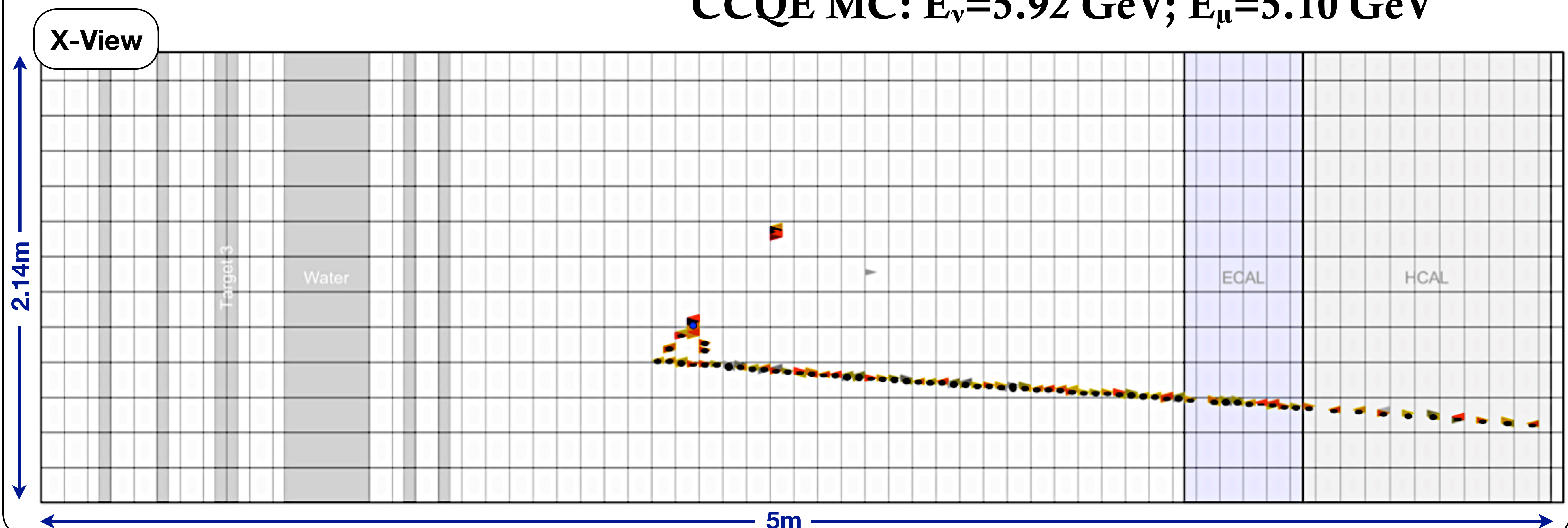
CCQE MC: E_ν=5.92 GeV; E_μ=5.10 GeV



Reconstruction

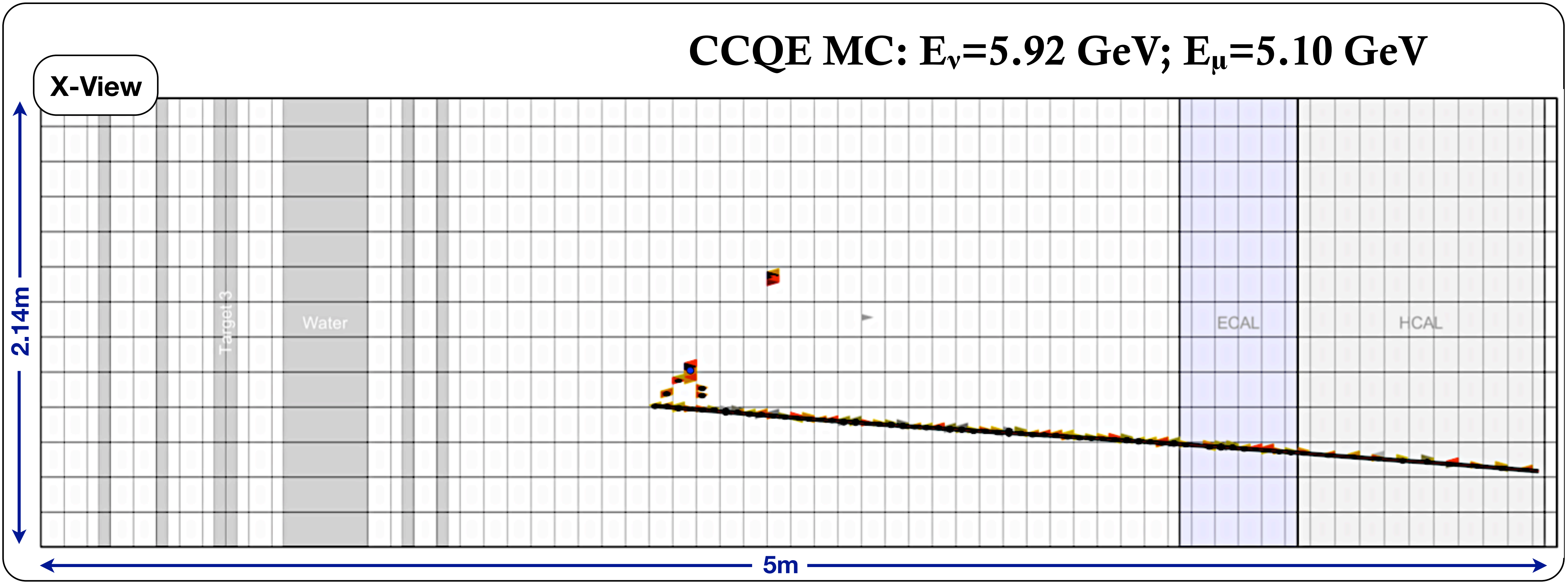
- First, we clean away low significance hits and form clusters (shown here as overlays on the hits).

CCQE MC: E_ν=5.92 GeV; E_μ=5.10 GeV



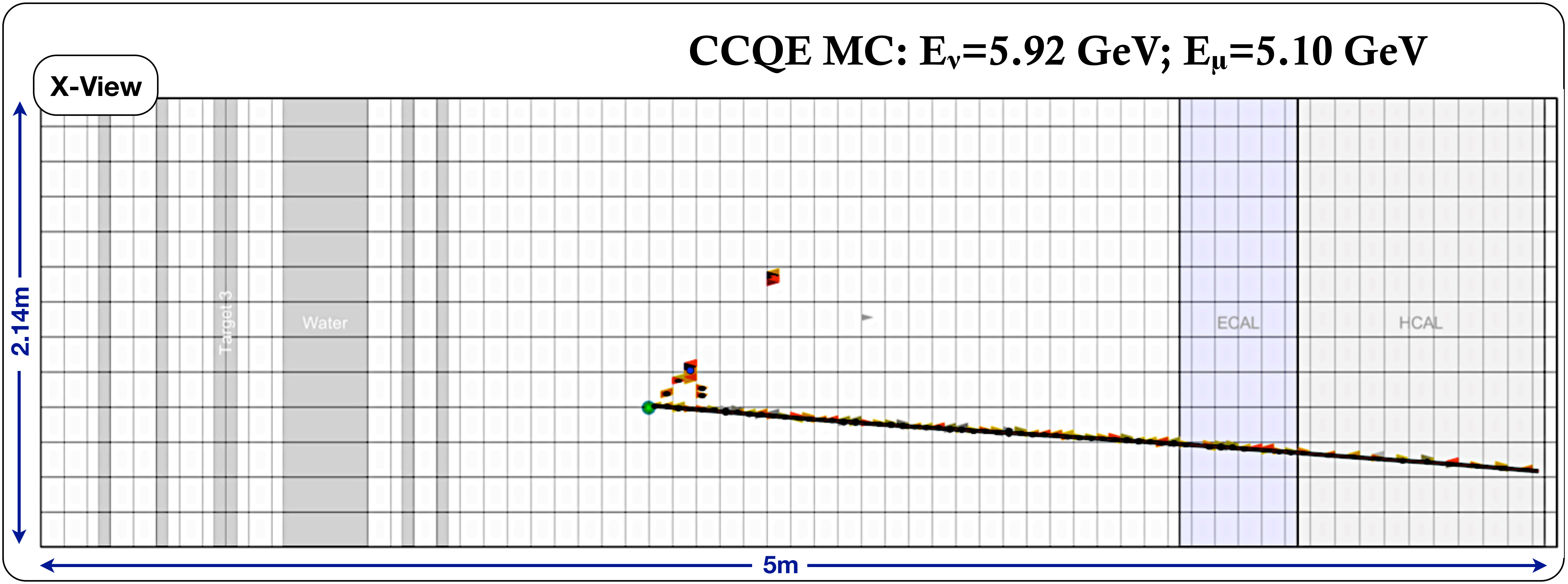
Reconstruction

- After clustering, we run long-track finding.



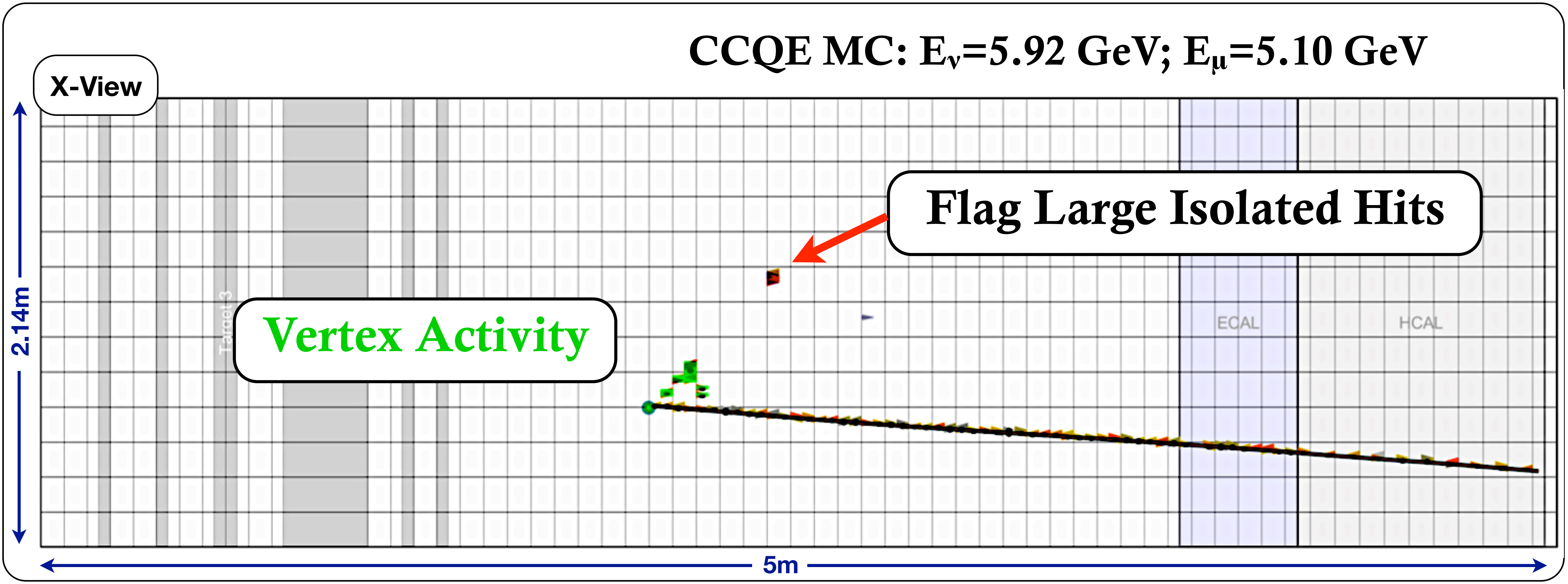
Reconstruction

- With tracks in hand, we can form vertices.



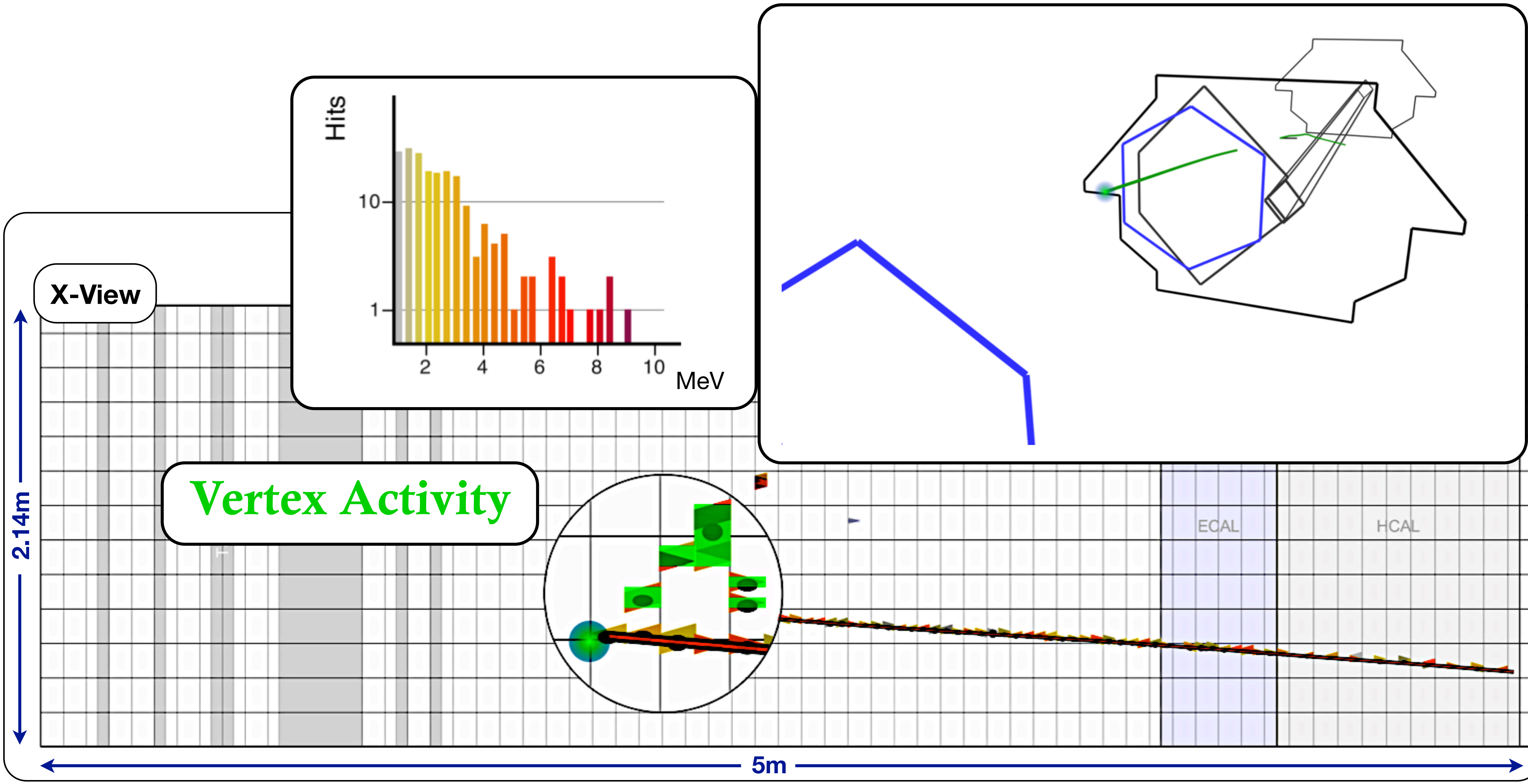
Reconstruction

- We search for activity around the vertex and reconstruct isolated showers away from the vertex.



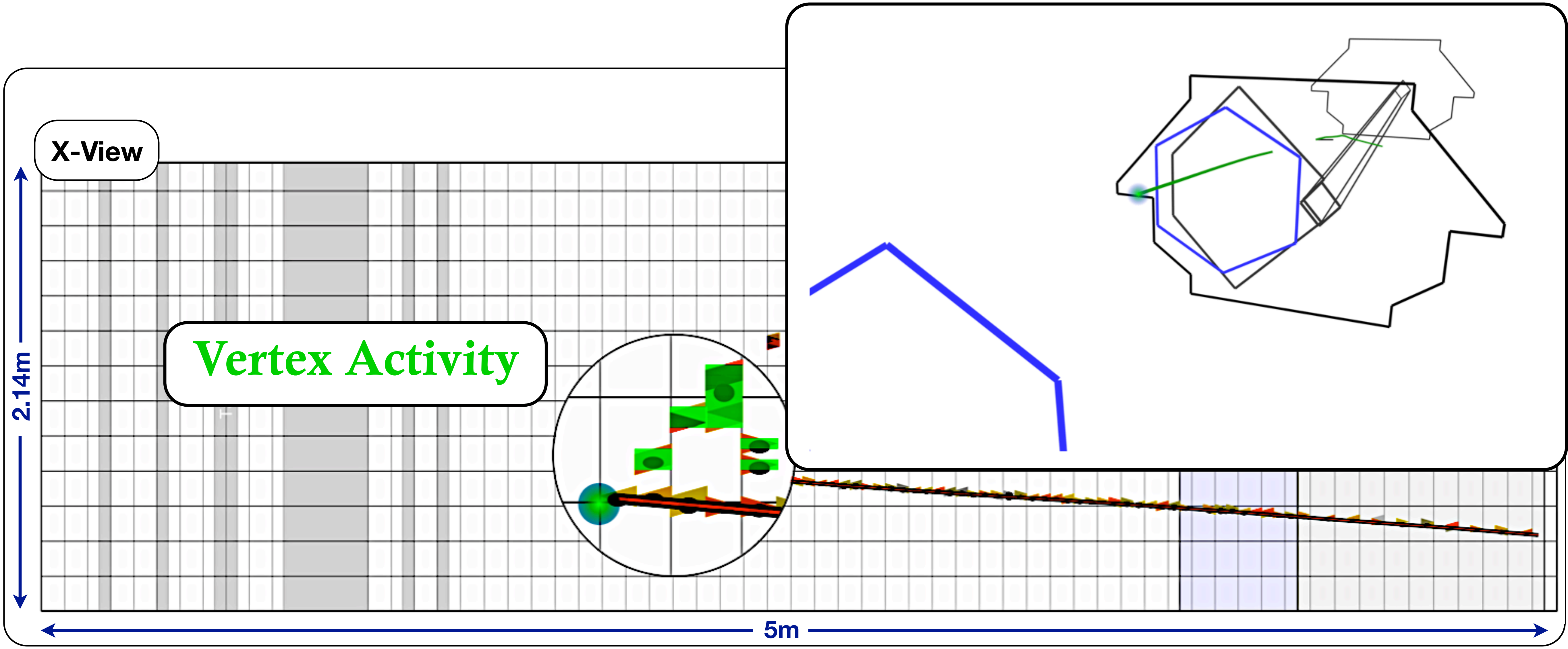
Reconstruction

- (Near) Final Reconstruction Picture, including track matching into MINOS.



Reconstruction: Track Matching

- Estimate tracking & matching efficiency by beginning with a track in MINOS and looking for a track in MINERνA.



Reconstruction: Track Matching

- MC data discrepancy is likely due inadequate dead time and pile-up simulation.