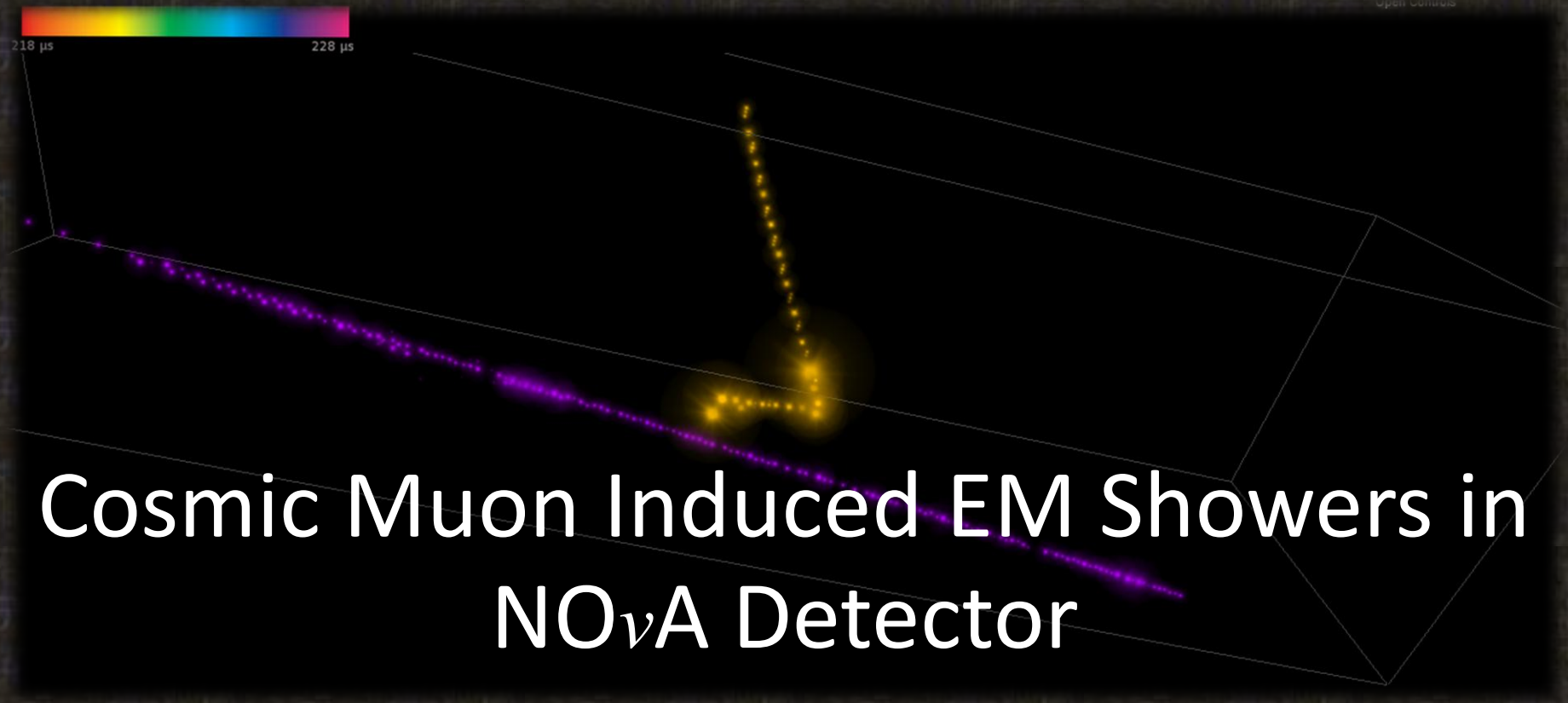

Cosmic Muon Induced EM Showers in NOνA Detector

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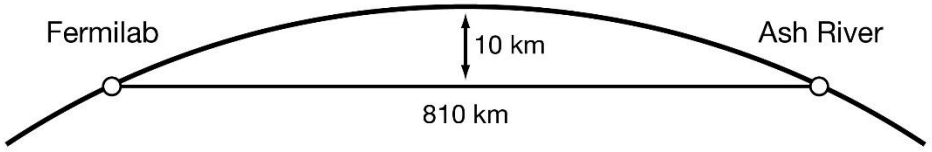
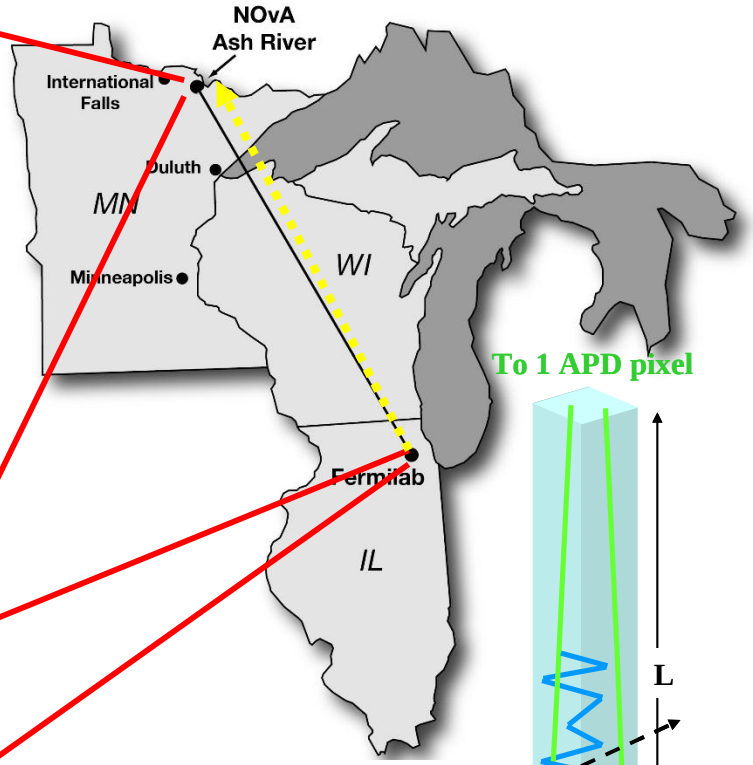
NOνA (NuMI Off-Axis ν_e Appearance)

- NOνA is a long baseline neutrino oscillation experiment, near detector at Fermi Lab and the far detector at Ash River with a baseline of 810 km.
- Two functionally identical detectors differ in size.
- Uses a 2 GeV ν_μ beam of intensity 450 kW currently.
- Looks for oscillations in ν_e appearance and ν_μ disappearance mode.

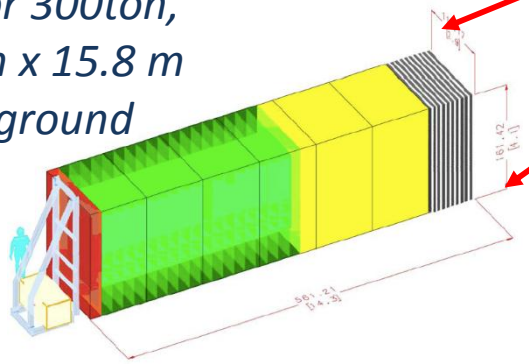


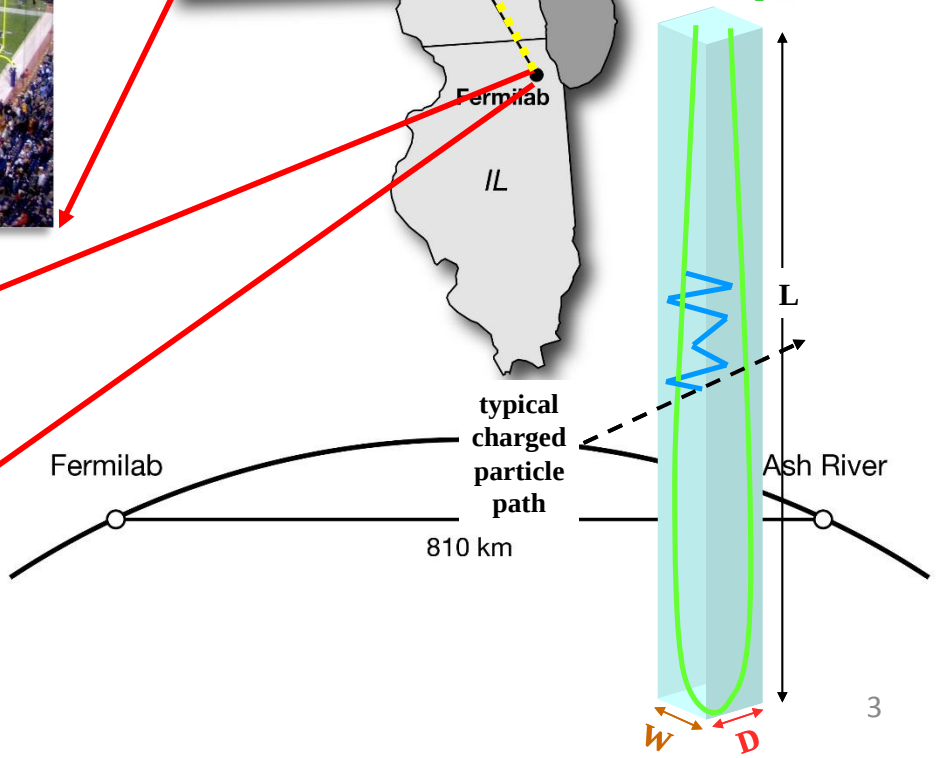
NOνA Detectors

Far Detector 14kton, 15.6 m x 15.6 m x 59.8 m

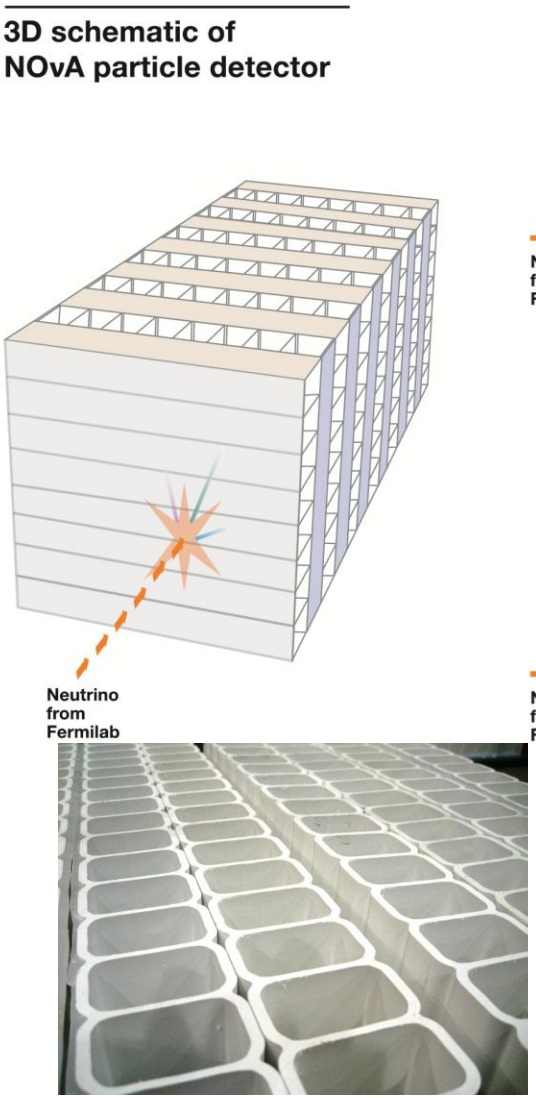


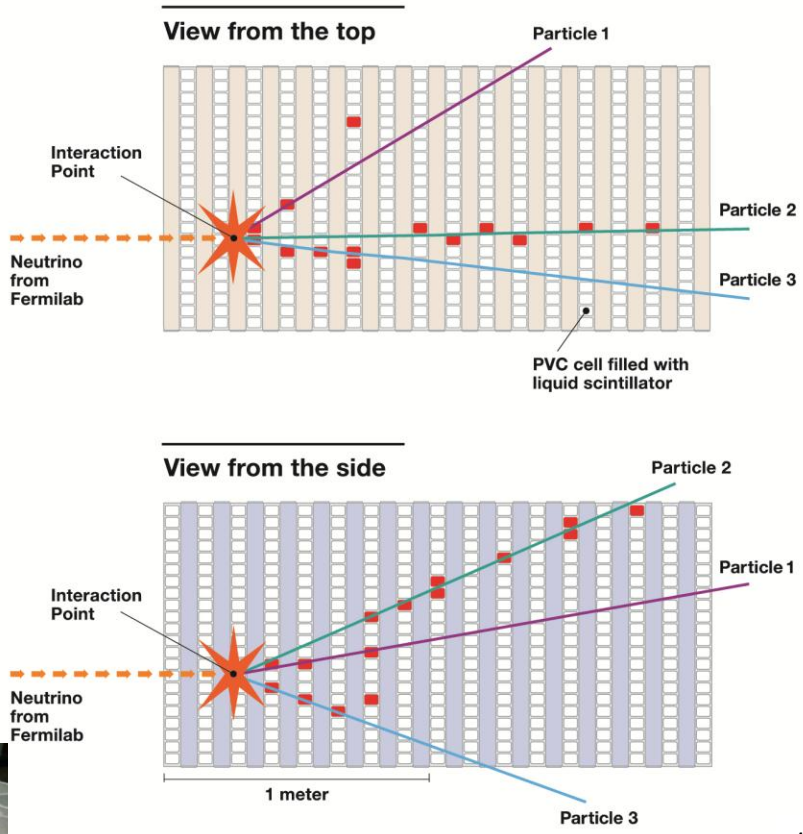
Near Detector 300ton,
4.2 m x 4.2 m x 15.8 m
100 m underground





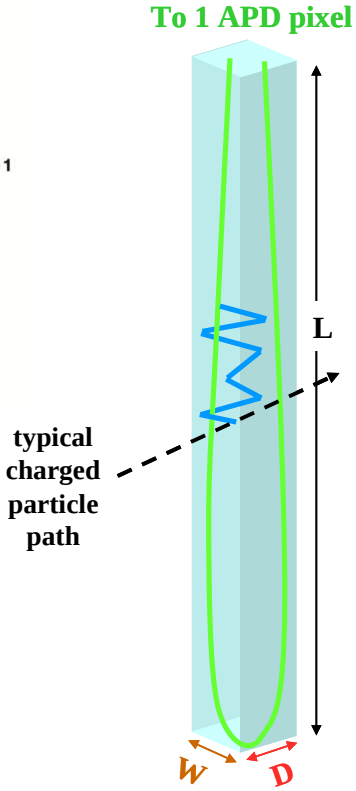
NOνA Detector's capability



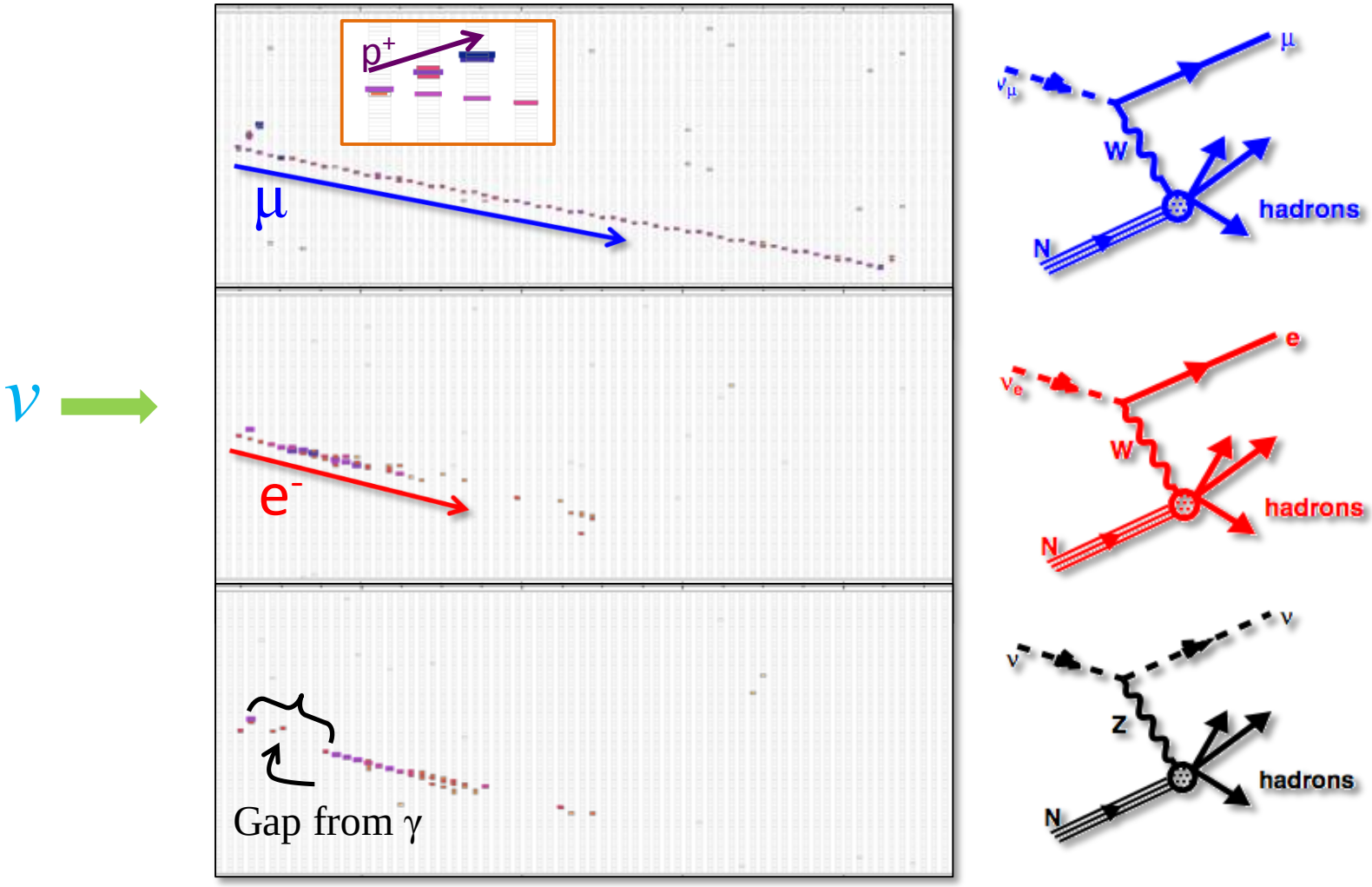


NOvA detectors are finely segmented (1 plane ~0.15 X0), which makes ***it well optimized for electromagnetic shower reconstruction.***

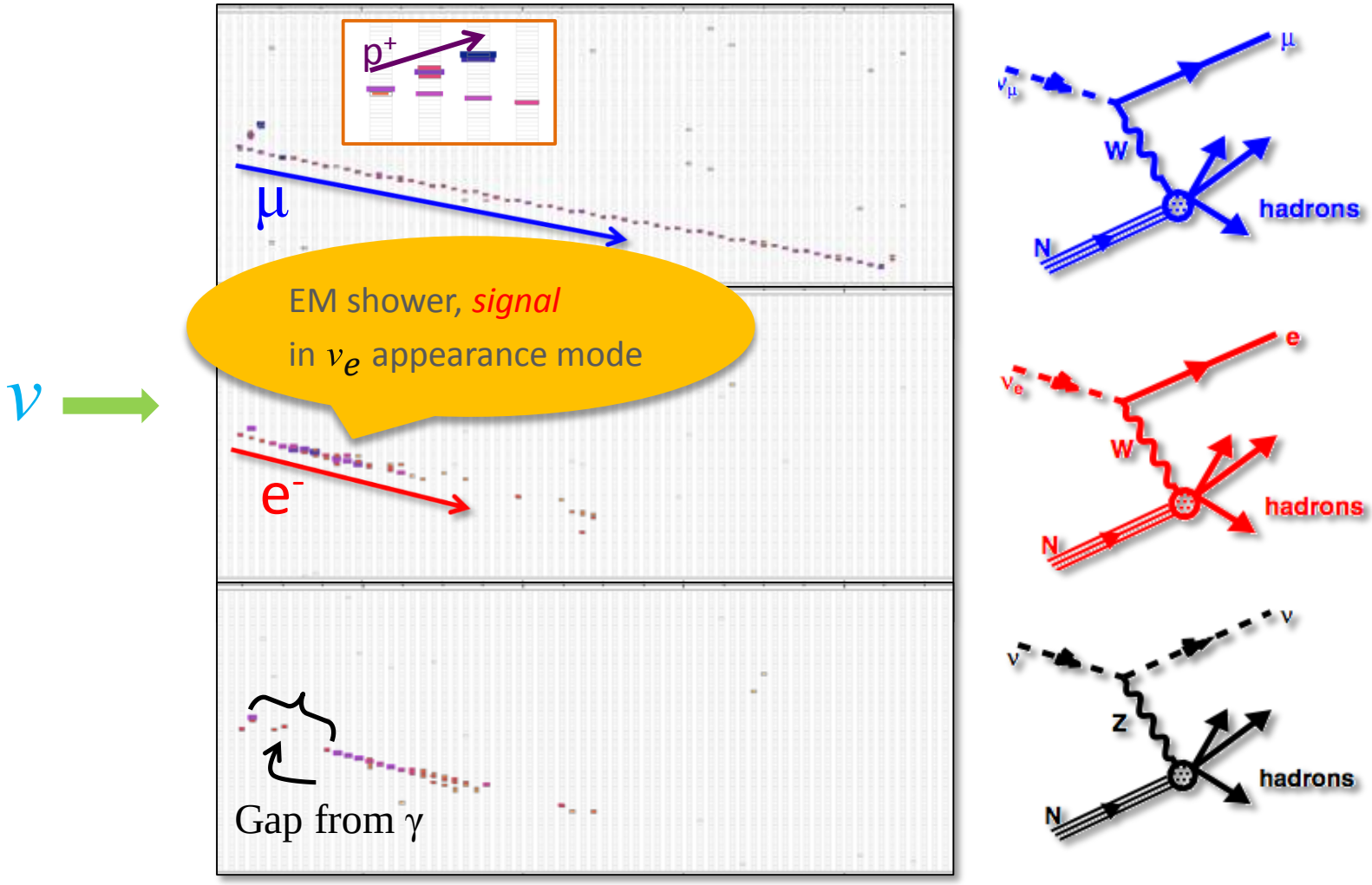
Fine-grained, low-*Z*, highly-active tracking calorimeter allows for differences between "tracky" muons, "showery" electrons, and "gappy" π^0's to be seen.



Event Topologies at NOνA



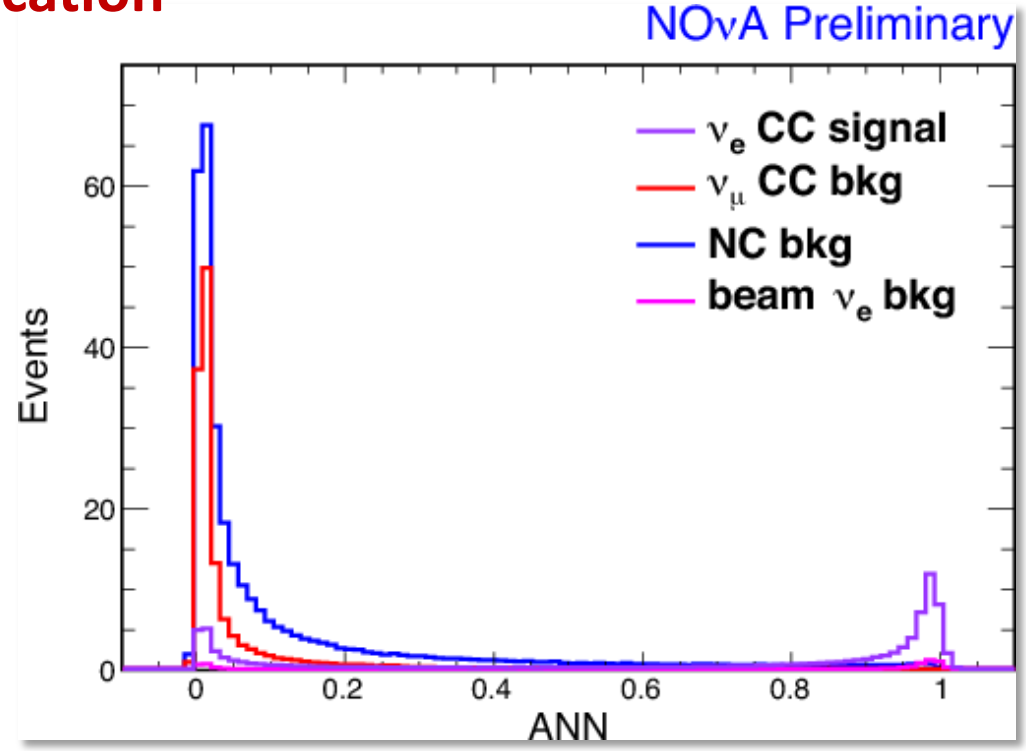
Event Topologies at NOνA



Particle Identifications at NOνA

LID : Longitudinal Identification

- Distribution of Artificial Neural Network (ANN) to identify ν_e CC events.
  - This method uses shower-shape based likelihoods for particle hypotheses calculated from longitudinal and transverse dE/dx information.

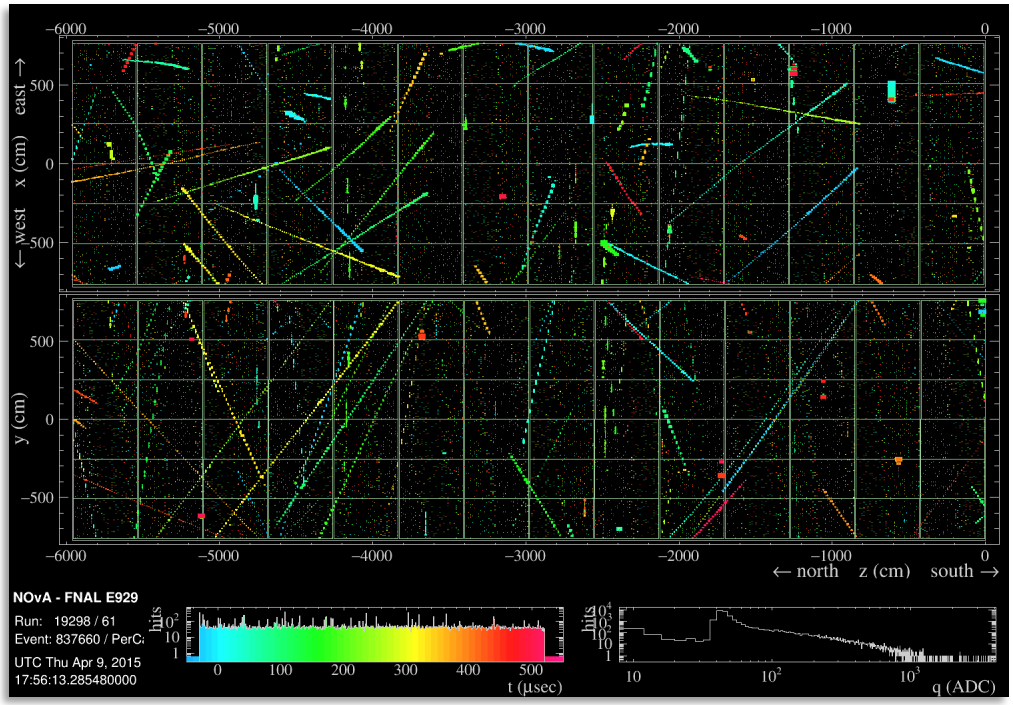


We use data driven technique to benchmark PID algorithms and simulation of EM shower at NOvA

Using Cosmic Rays to Study Electron Selection

- ❖ Cosmic-ray induced showers:
  - Bremsstrahlung(Brem) shower : Energetic muon looses energy via EM interaction in media.
- ❖ Why Cosmic Brem Shower:
  - Plenty of Cosmic EM shower in Nova FD detector, 72kHz
  - EM shower can mimic signal in the ν_e appearance mode.
  - Provide statistically rich test samples of pure EM showers.
  - Check the multivariate ν_e PID algorithm including:
    - Efficiency.
    - Fiducial cut.
    - Monitor detector for EM shower reconstruction.

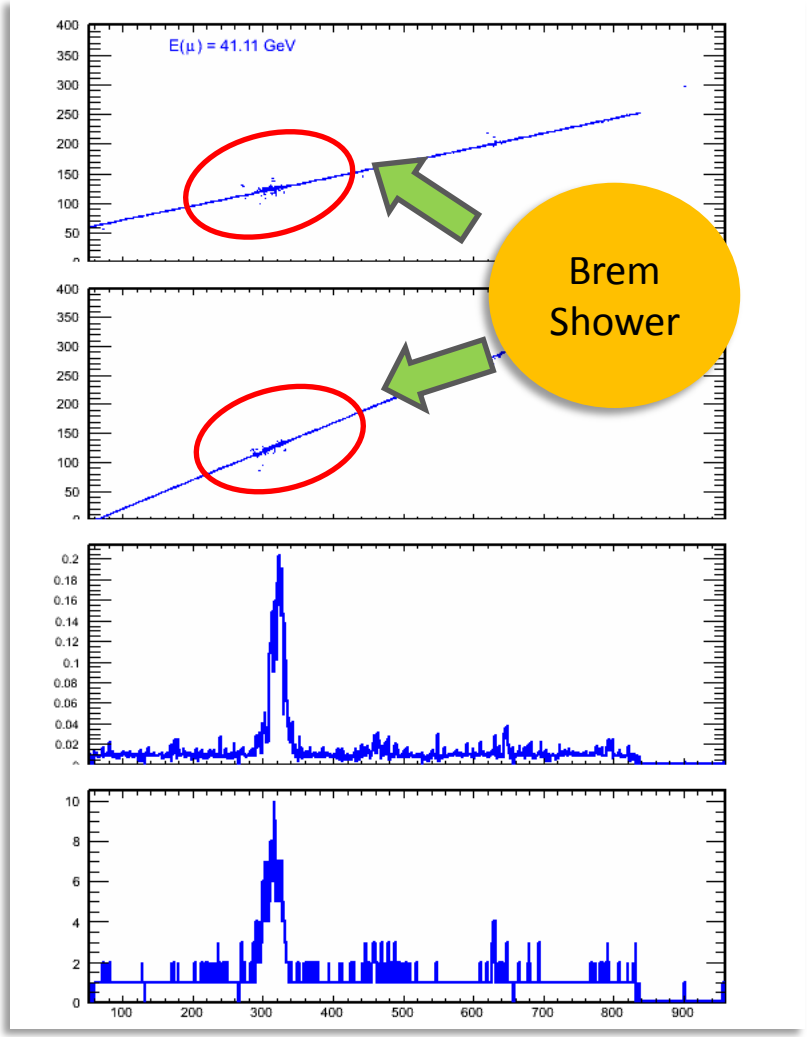
A 500μ sec cosmic trigger event display



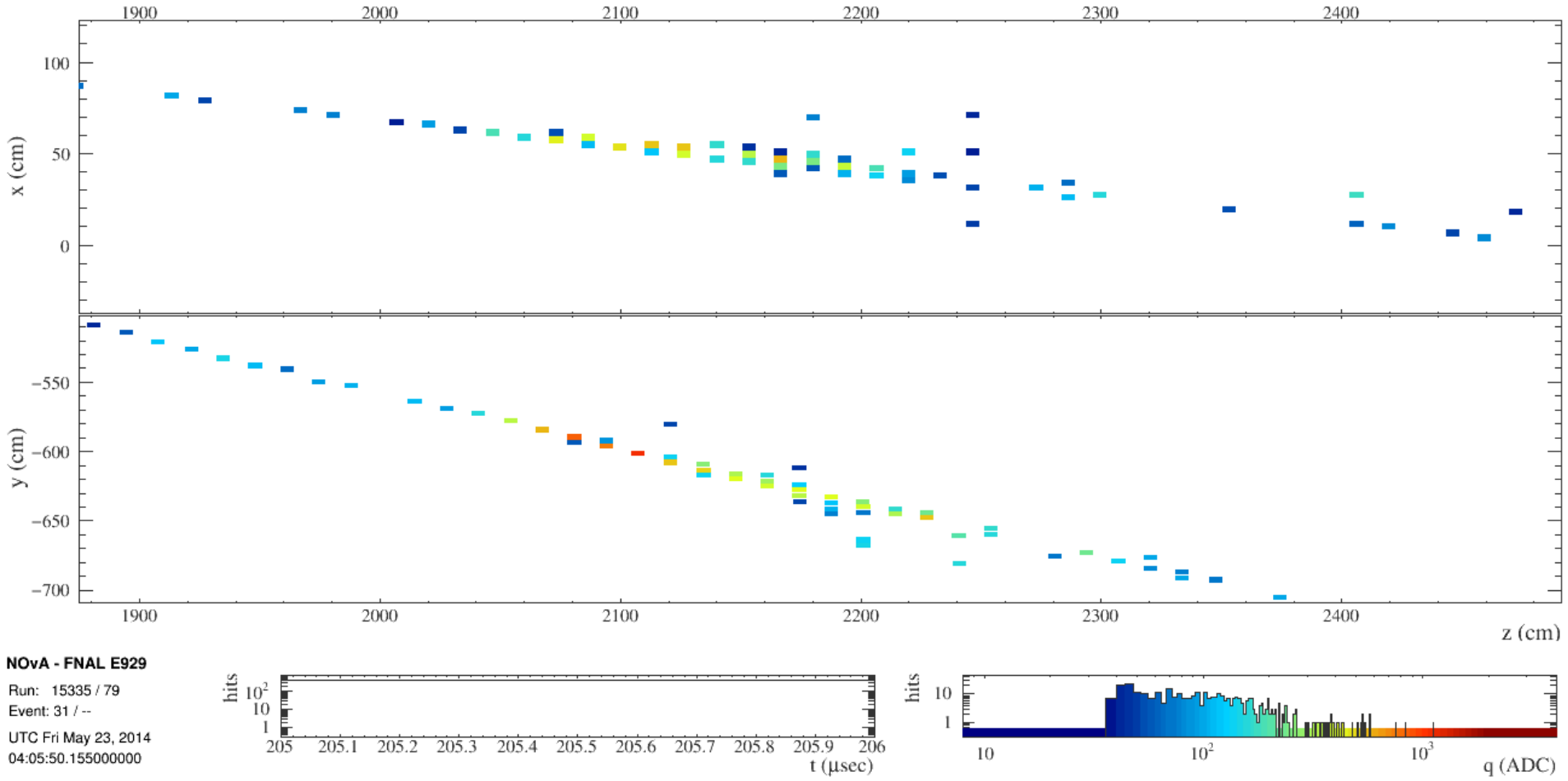
Shower finding and extraction

- **Muon removal:**
  - We developed a criteria based on energy deposition in planes along the muon track.
  - Find shower on basis of energy deposition in planes.
  - Define a shower regions:
    - Shower start.
    - Shower end.
  - Remove all the hits out of the shower regions.
  - Remove only muon *mip* in the shower region.

- A muon with brem shower

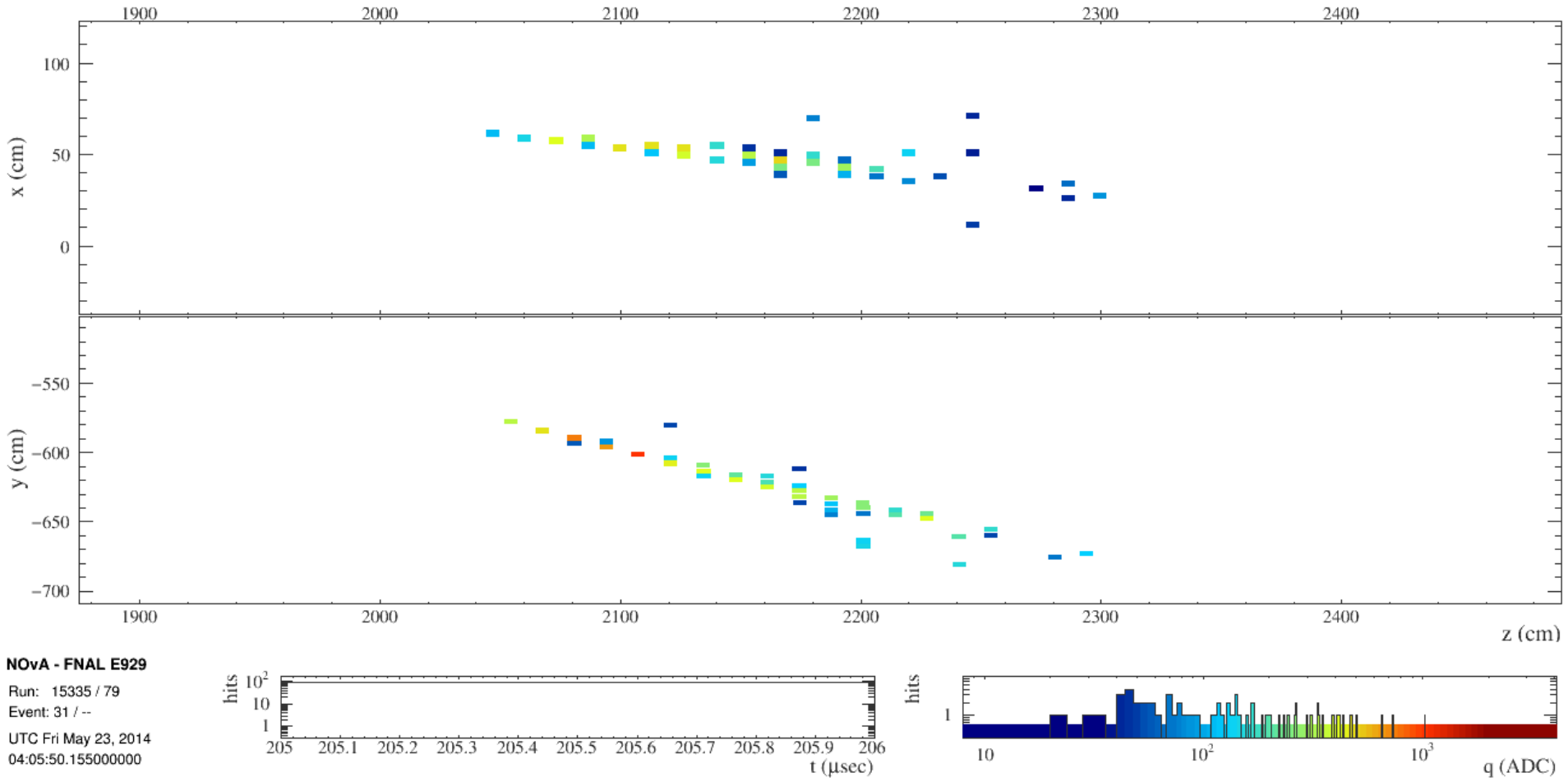


Brem shower example



Event display of hits of a cosmic muon candidate with Electromagnetic (EM) Bremsstrahlung (Brem) Shower.

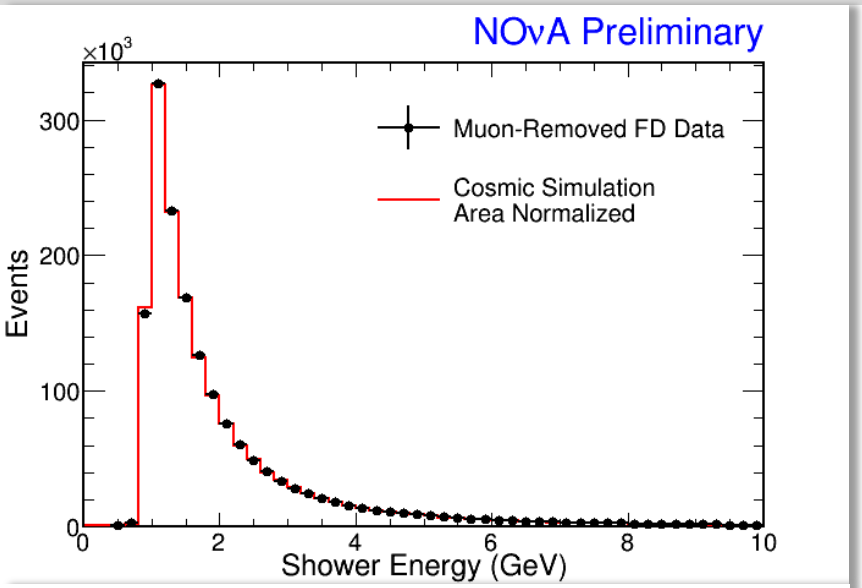
Brem Shower hits extracted



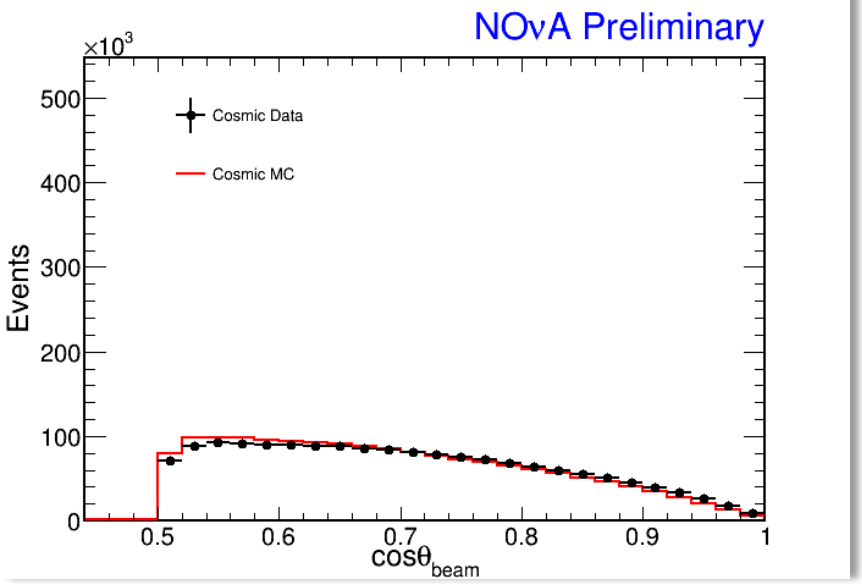
Event display of hits of the EM shower after the removal of hits associated with the muon track from NOvA simulations.

Extracted Brem Shower's variables

- Data and MC comparison of shower energy after reconstruction. Good agreement between Data and MC.

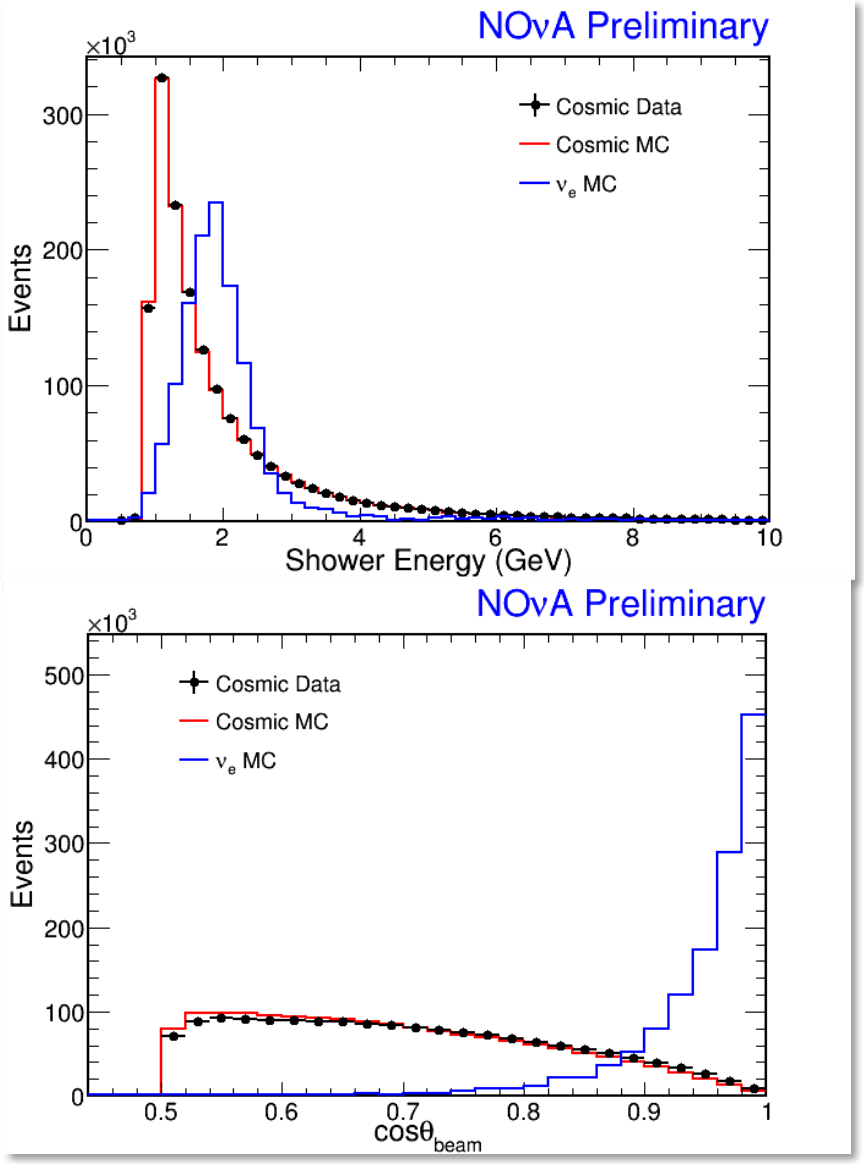


- Data and MC comparison of shower angle. Good agreement between Data and MC.



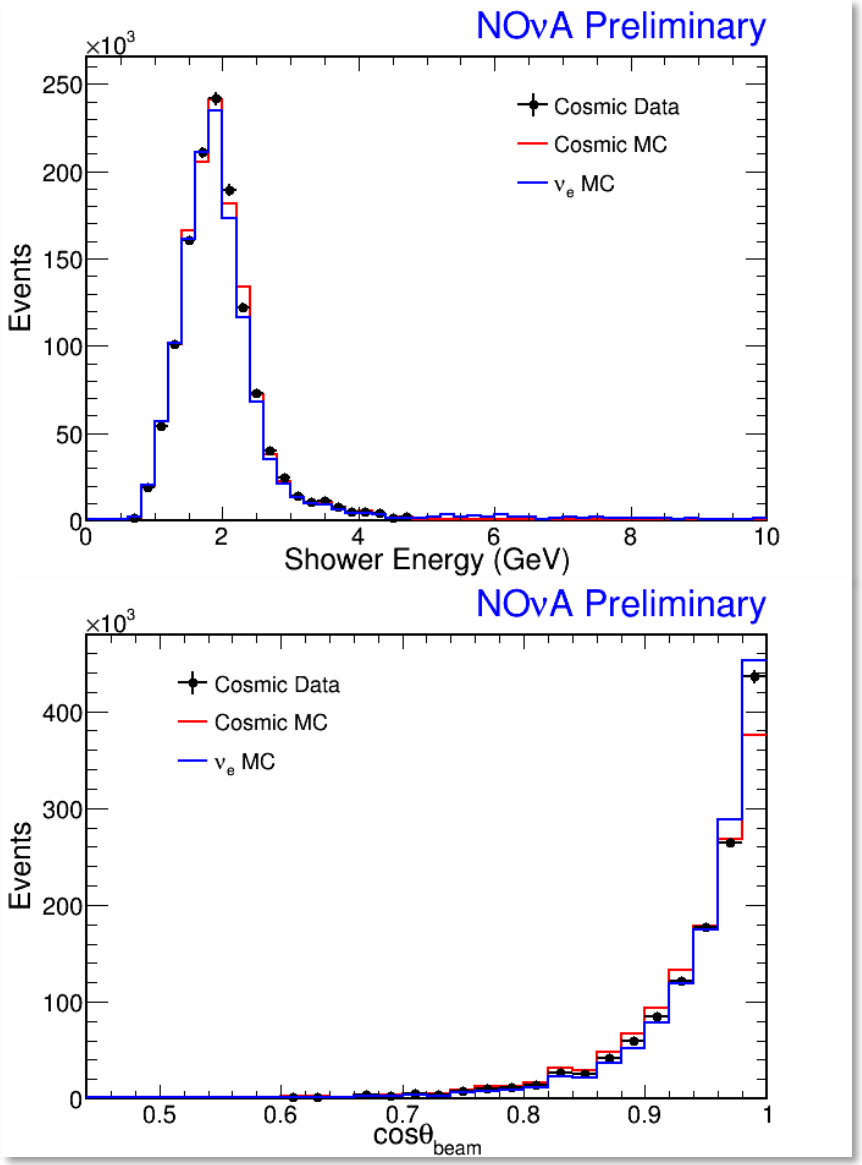
Shower variables vs ν_e

- Data and MC comparison of shower energy after reconstruction. Good agreement between Data and MC.
- Brem shower energy in comparison with ν_e MC events. Brems are less energetic to ν_e events.
- Brem shower angle in comparison with ν_e MC events. Brems are more perpendicular to direction of beam than ν_e events.



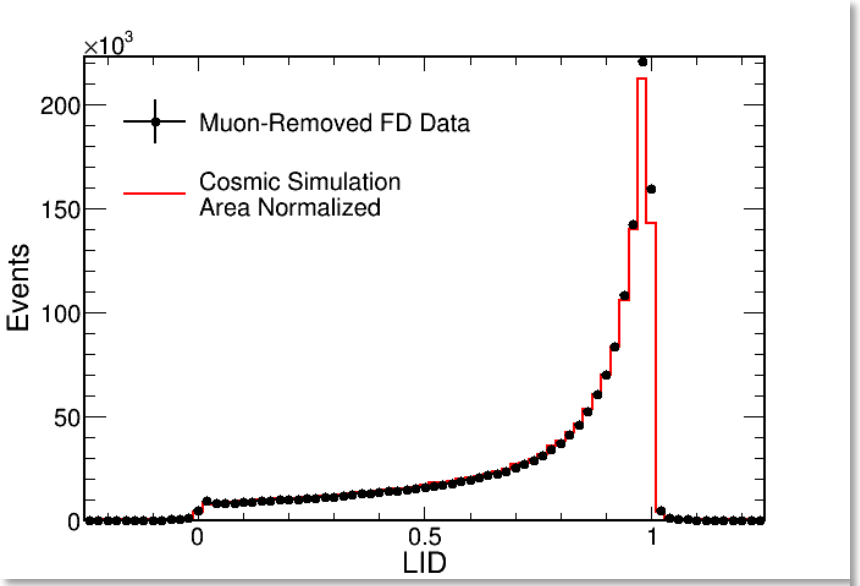
Shower reweighted to ν_e

- Most of the difference in Brem events and ν_e events comes from difference in energy and angle distributions.
- A 2D reweighting matrix is constructed and used to reweight Brem shower energy and angle to ν_e CC events to make for these differences.

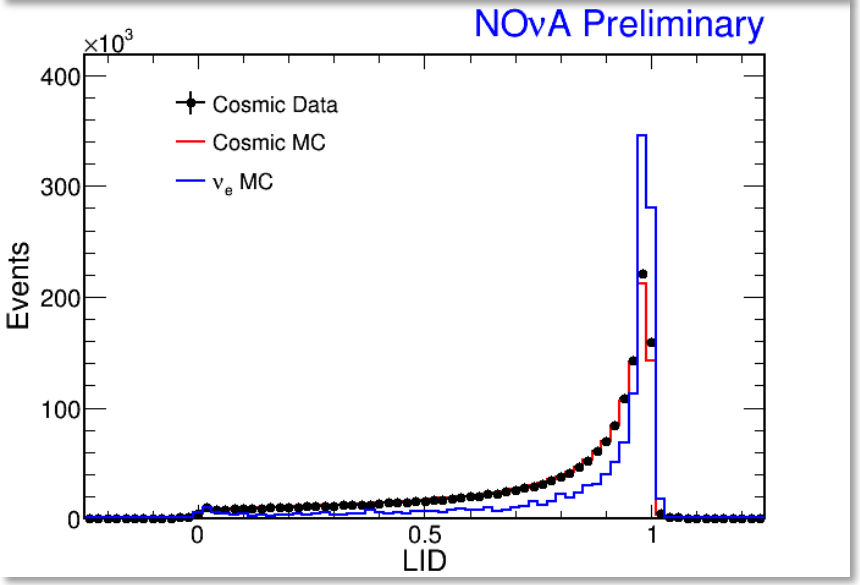


Particle Identification ANN (LID)

- Data and MC comparison of electron identification ANN (LID) . Good agreement between data and MC. Most of the Brem are identified as ν_e like.



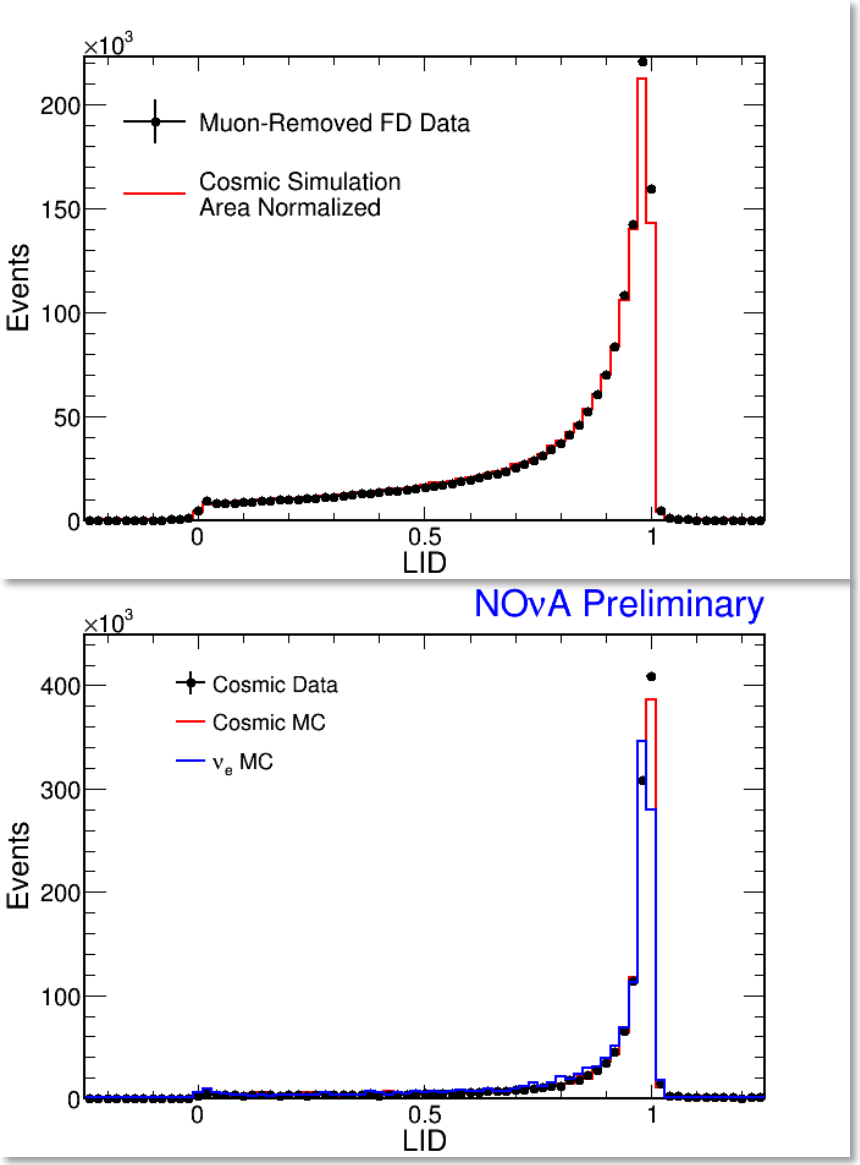
- Brems identification in comparison to ν_e events.



LID after reweight

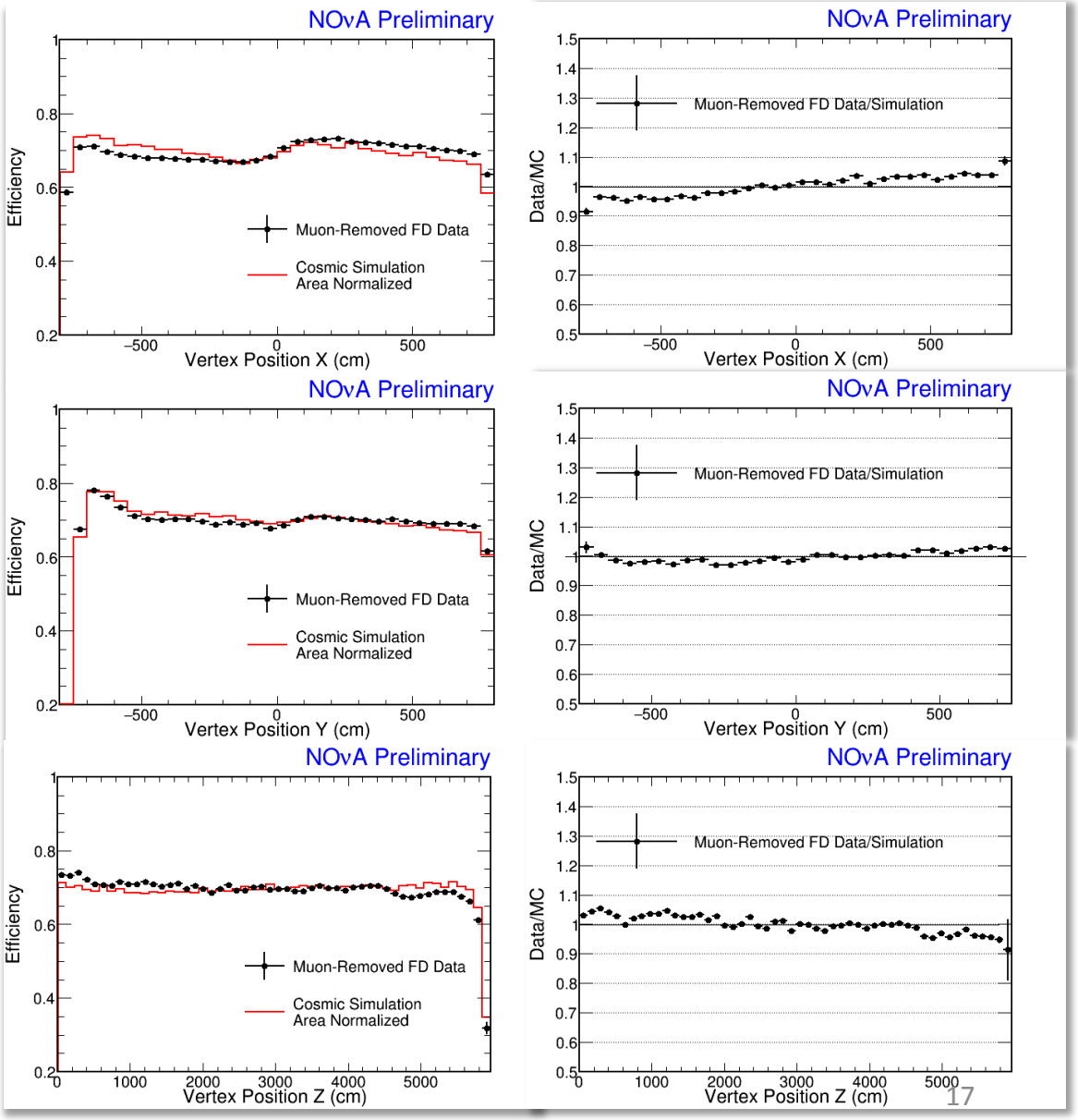
- Most of the Brems are identified as ν_e like. But to benchmark the PID and simulations Brem should reasonably be similar to ν_e . We achieved this by reweighting.

- After reweighting Brem energy and angle to ν_e events, Brems do look more like ν_e events. This convinces us that Brem can be used as data driven benchmark for testing PIDs and EM shower simulations at NOνA



PID Efficiency X, Y and Z in detector.

- PID efficiencies as a function of vertex X , Y and Z direction in NOνA. Efficiencies are reasonably flat and data and MC agreement is well within 5 %. The rest of the difference will be considered as a source of systematic uncertainty.

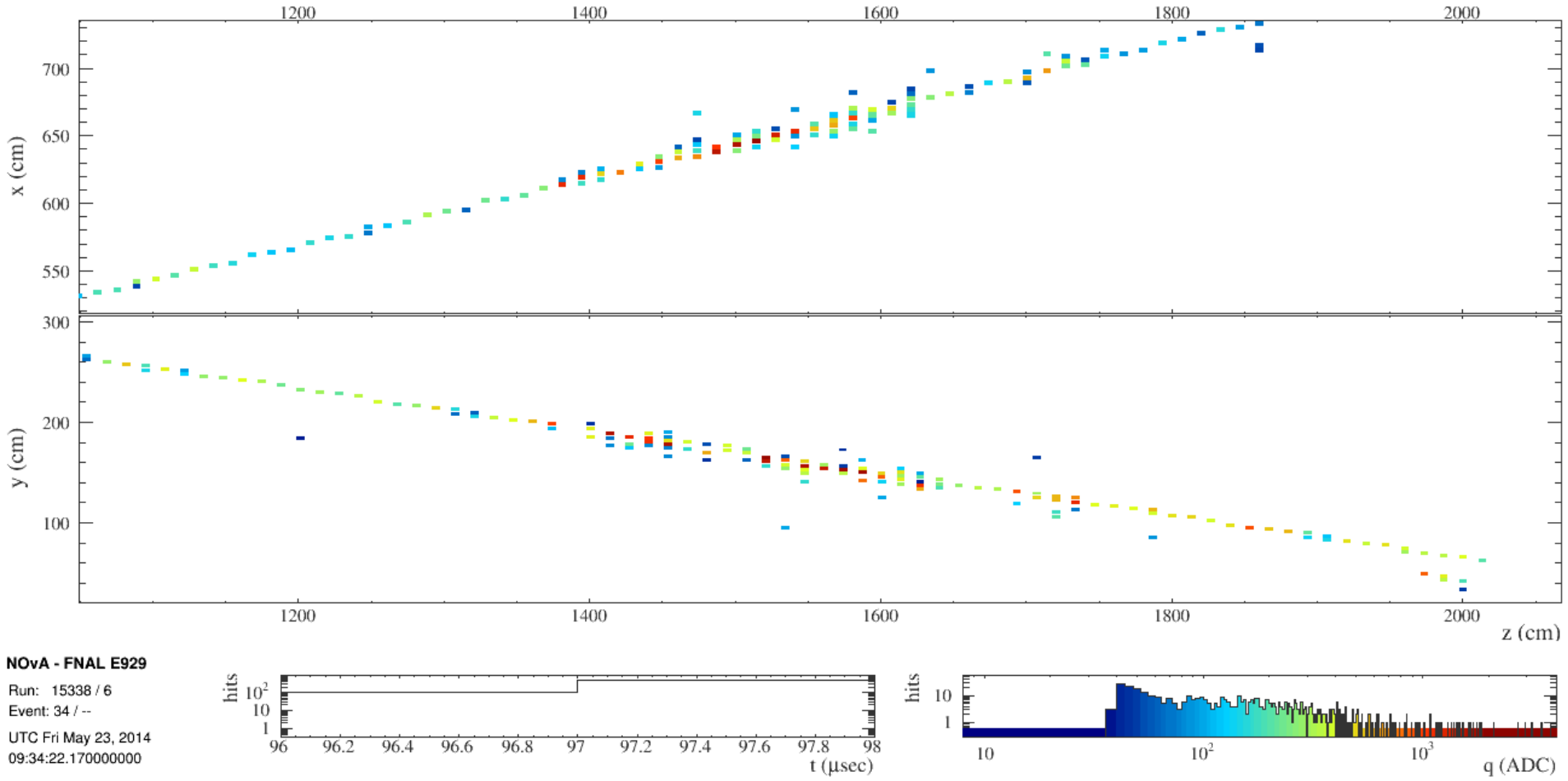


Conclusion

- ✓ Using Muon Removal algorithm we find and isolate EM Shower from cosmic data and MC.
- ✓ A good agreement between data and MC.
- ✓ ν_e reweight method has been developed to make cosmic EM showers resemble beam events.
- ✓ A data-driven technique to benchmark the particle identifications and simulations of EM showers using Brem sample.
- ✓ PID efficiencies as a function of positions across the detector are pretty uniform, indicating calibration effects are well controlled.

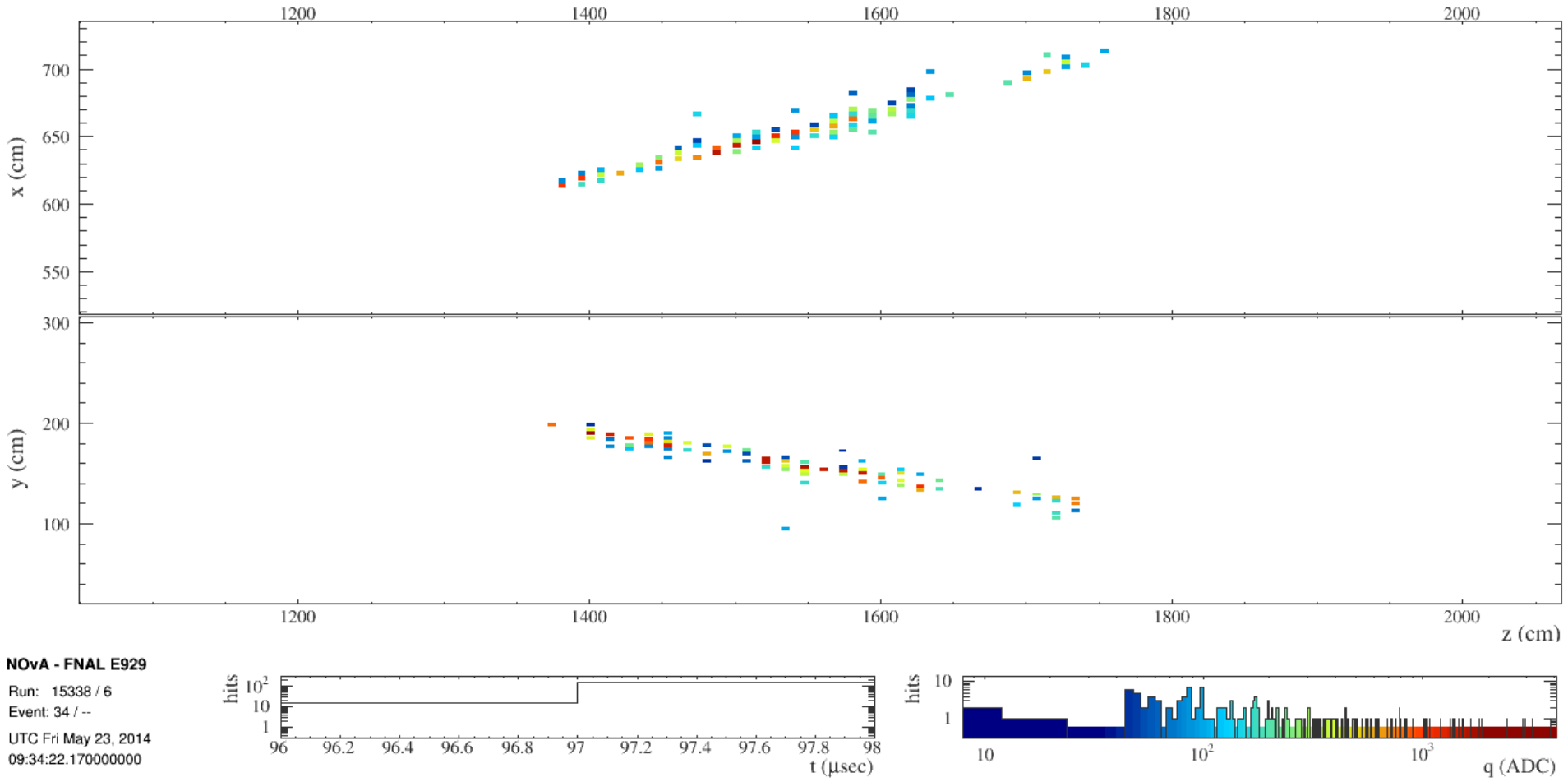
Backup

Brem Shower example



Event display of raw hits of a cosmic track candidate with Electromagnetic (EM) Bremsstrahlung (Brem) Shower from NOvA simulation.

Brem Shower extracted



Event display of hits of the EM shower after the removal of hits associated with the muon track from NOA simulation. What left are hits of Brem shower.