Investigating Improvements to the NOvA Event Selection Efficiency for Events in the Mass-hierarchy-sensitive Energy Range

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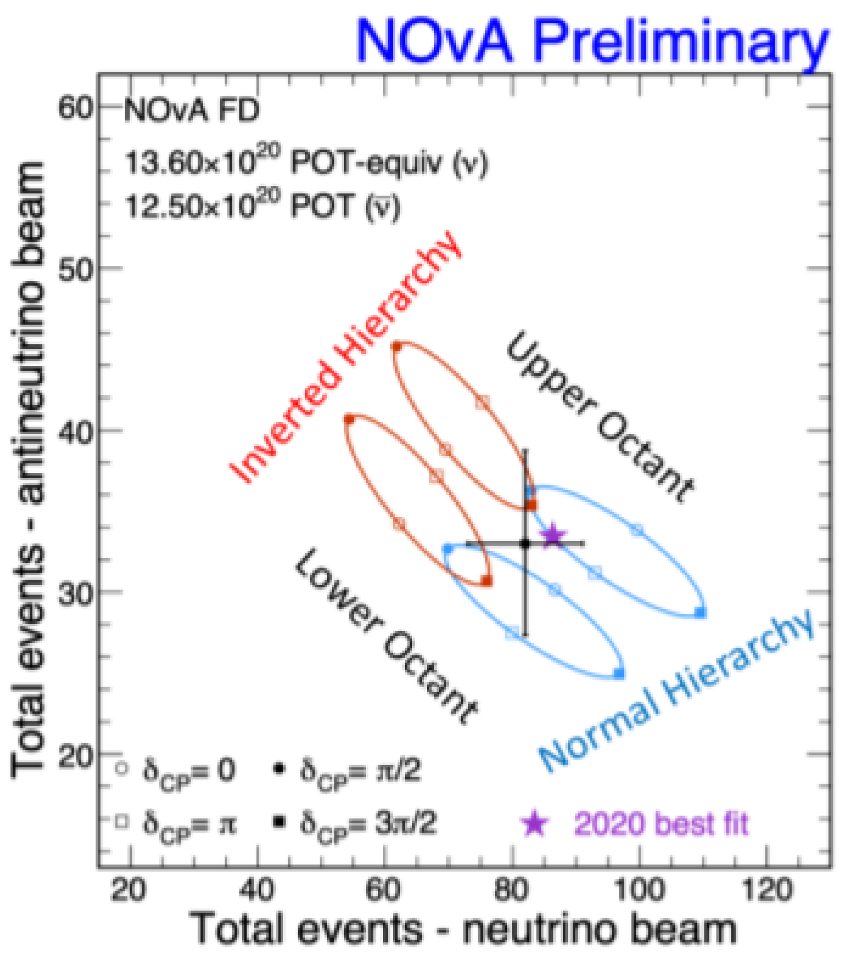
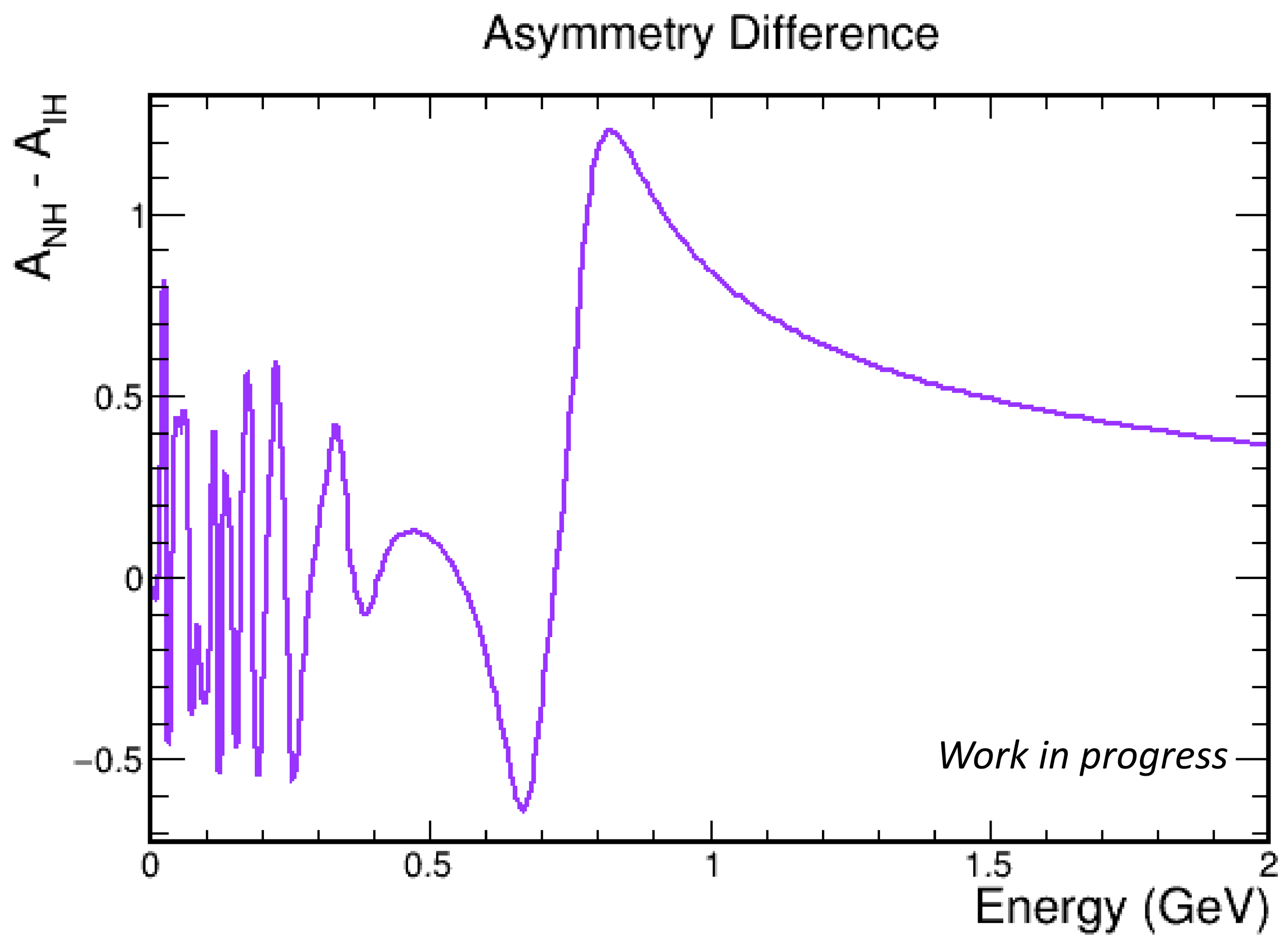
NOvA studies neutrinos with muon neutrino and antineutrino beams originating from Fermilab.

- Probes CP violation and measures neutrino parameters by observation of ν_e appearance in ν_μ beams by oscillation
- NOvA is a mature experiment but still is statistics limited, motivating exploration of ways to increase sample sizes



NOvA uses two detectors, one at Fermilab and one in northern MN, to make observations of neutrinos originating from Fermilab in order to measure neutrino parameters like the mass hierarchy.

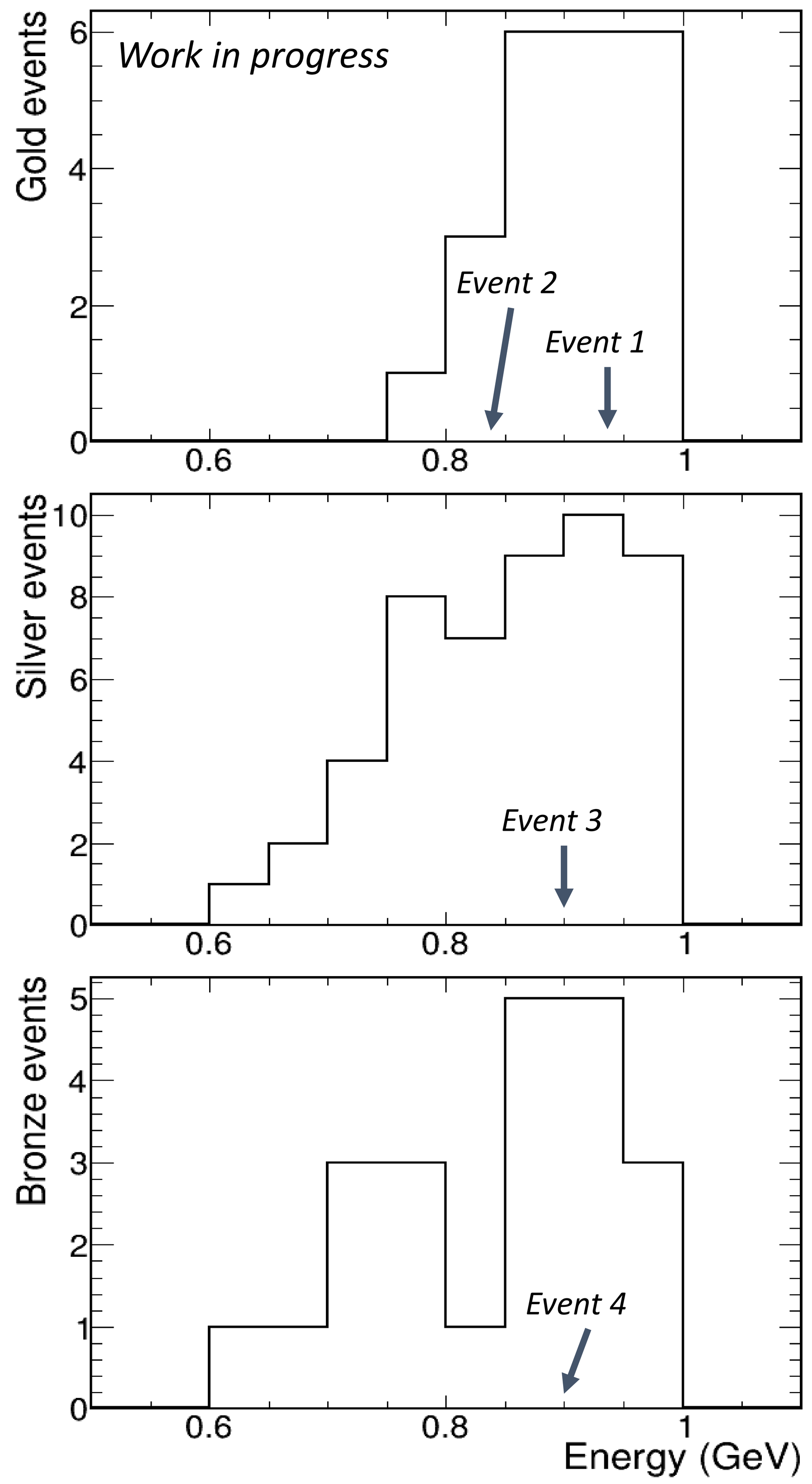
Neutrinos oscillate between flavor states by propagating through mass states. The neutrino mass hierarchy, the ordering of mass states, can be measured by observing flux differences of ν_e and $\overline{\nu_e}$ appearances. This project probes quality checks for opportunities to allow new events to enter the experimental sample without compromising signal-to-background. Focus is on the energy range most sensitive to mass hierarchy.



With $A = \frac{P_\nu - P_{\overline{\nu}}}{P_\nu + P_{\overline{\nu}}}$, the mas hierarchy produces an asymmetry in ν and $\overline{\nu}$ oscillations. The highest differences occurred at low energies, providing motivation for investigating reconstruction efficiencies there. Only a general energy range was desired, so just ν_e and $\overline{\nu_e}$ appearance frequencies were considered.

The project's first pass workflow involves:

- Gathering ~100 simulated ν_e events near the center of the detector with appropriate energies
- Hand-scanning events and ranking them either Gold, Silver, or Bronze by overall quality
  - Most Gold events should pass quality checks (multiple tracks, long tracks, etc.) (Event 1)
  - Most Bronze events should not pass quality checks (unclear vertices, short tracks, long EM shower gaps, etc.) (Event 4)
- Exploring energies, particle IDs, and quality check results by rank as a signal-only study



Energy histograms by rank for the project sample point toward 0.8 GeV for a reasonable new energy threshold.

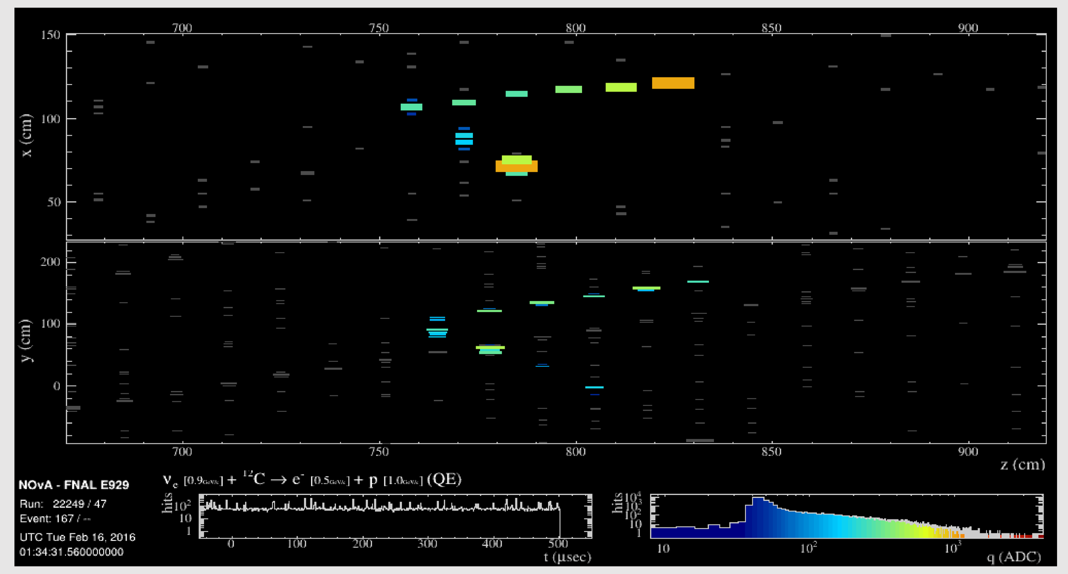
Preliminary results reveal useful signal at low energy. ν_e events in this range fail quality checks because of an energy minimum of 1.0 GeV, enforced because of past poor reconstruction at low energy. With modern reconstruction, particle ID scores remain good at low energy, indicating early potential for safe signal gain by lowering the energy threshold.

A simulation lowered the threshold from 1.0 GeV to 0.8 GeV.

- Considerable increase in favorable signal (Event 2)
- Lower rank events tended to have lower particle IDs, so they were not included in the final sample (Event 3)
- Promise for new low energy signal, but results are signal-only
- No hard data on background effect has been gathered. Other effects of lowering the threshold are unclear

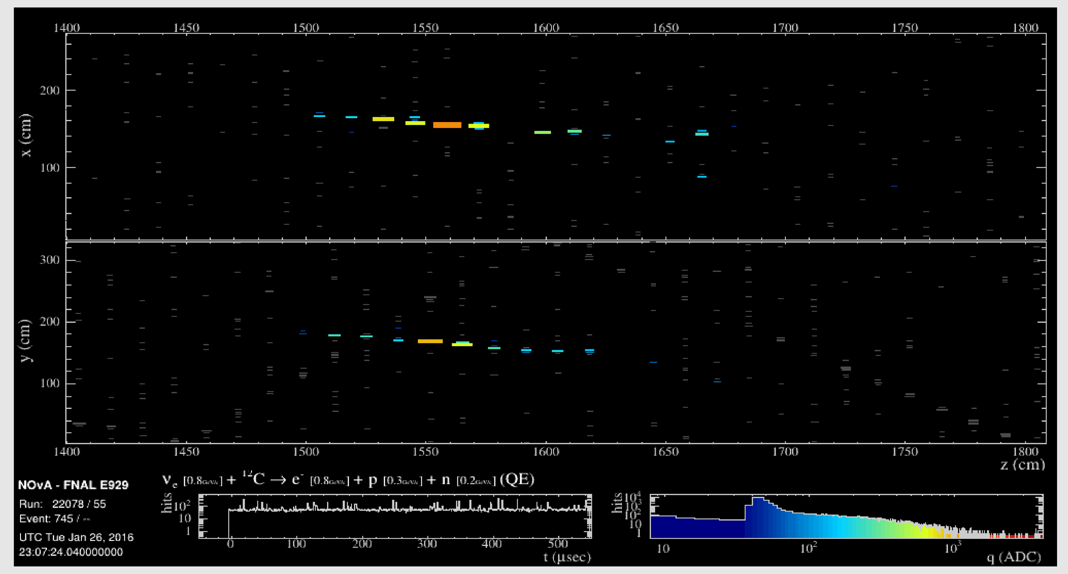
Future work for the project includes:

- Analysis of cosmic rejection and looking for other areas that could benefit from optimization
- A second pass of the workflow with:
  - A larger sample and focused preselection
  - Emphasis on background analysis and effects when including low energy ν_e events



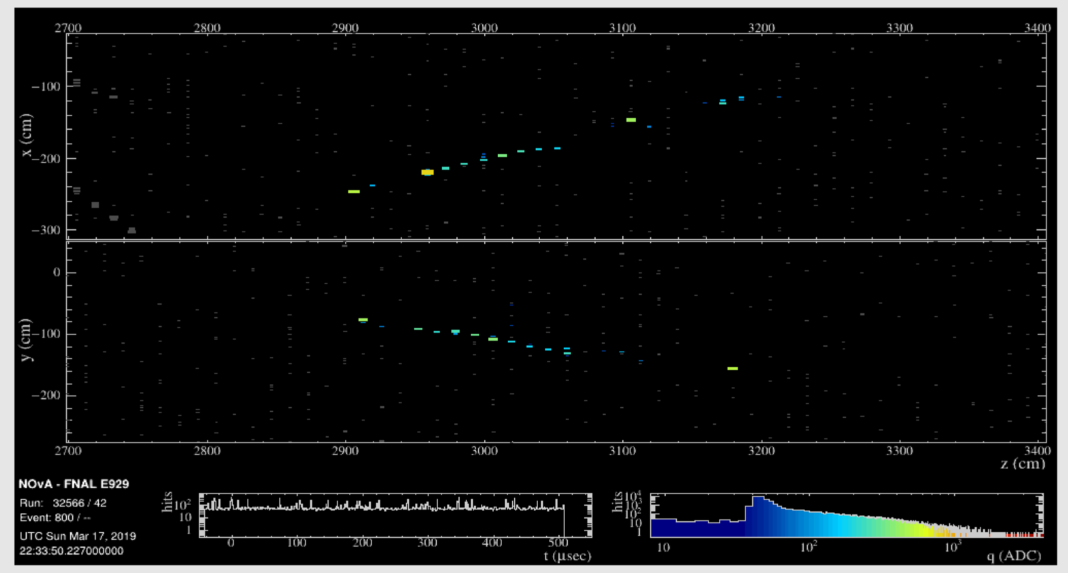
- Gold • E = 0.946 GeV • ν_e score = 0.965

Event 1: Ranked Gold for its multiple tracks and clear vertex.



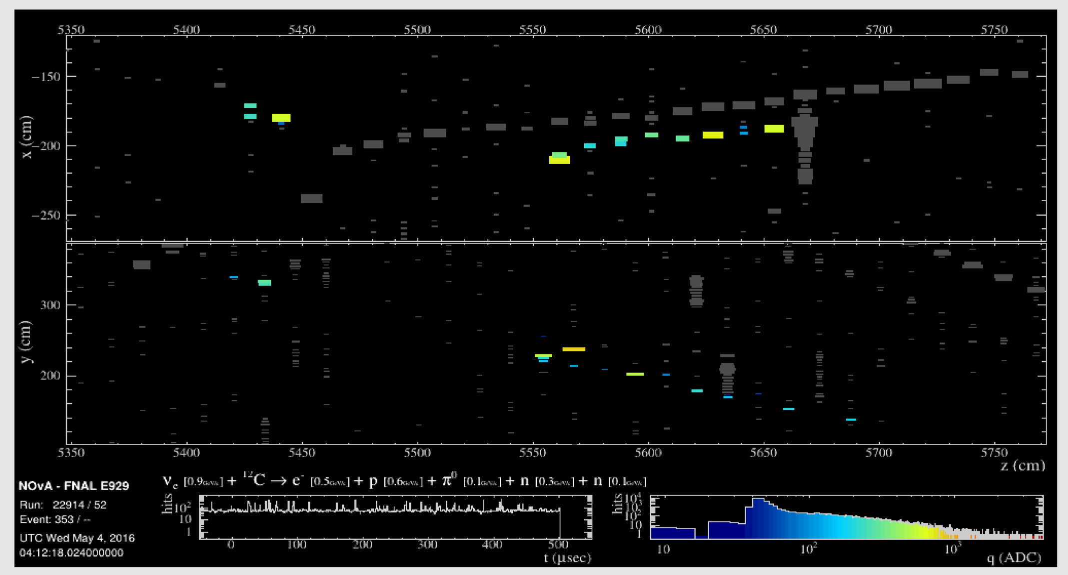
- Gold • E = 0.835 GeV • ν_e score = 0.957

Event 2: Fails current quality cuts but would pass with a lowered energy threshold with high particle ID.



- Silver • E = 0.899 GeV • ν_e score = 0.808

Event 3: Fails current quality cuts and fails with a lowered threshold with poor PID. Future work in background should reveal whether problems would arise from low quality and energy events.



- Bronze • E = 0.899 GeV • ν_e score = 0.785

Event 4: Ranked Bronze for an unclear vertex and strange gaps.

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