Monitoring and Commissioning the NOvA Far Detector

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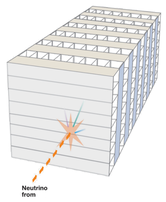
Monitoring

- NOvA's far detector has 344,064 (4 cm x 6 cm x 15.6 m) PVC cells.
- Cells contain a looped fiber and ~8 gallons of liquid scintillator .
- Cells are arranged into 896 planes of alternating view.
- Charged particles deposit energy creating scintillation light.
- Light is collected by the fiber and routed to readout electronics.
- A simplified 3-D view of the detector is shown at right.



- Hit rates and photo-response are displayed in real time for data quality assessment.
- Initial physics is studied on diblocks **more than 99% live** for at least 1 week.
- Higher level tracking and beam metrics are available minutes after data collection.

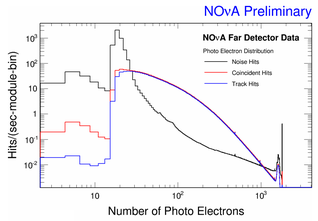
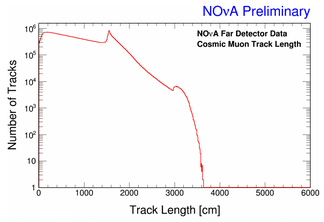


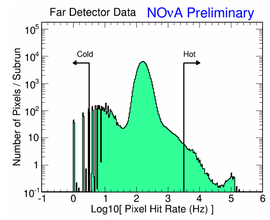
Photo electron distribution for noise, coincident and track hits. Normalized to 1439.91 seconds of live time and 7 DB.



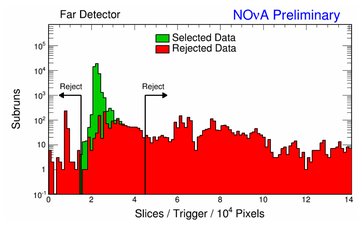
Track length distribution of cosmic muon tracks. Total live time is 1439.91 seconds.

Data Selection

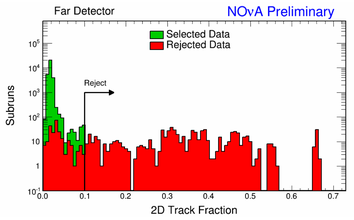
- Low level hit and reconstruction metrics (shown below) are evaluated to select data appropriate for extended studies.
- Figures below contain data collected between Feb. 3 and April 28, 2014.
- Arrows indicate rejection cuts for metrics. Color indicates final selection.



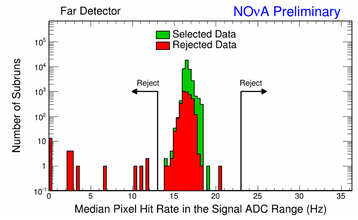
Single pixel (channel) rate averaged over several minutes (subrun) normalized by the total number of subruns. Data with at least 2 consecutive kTons with better than 87.5% channels in the selection window are flagged for analysis.



Number of slices (correlated time and spatial activity) per trigger (500 us window) per 10^4 active pixels.

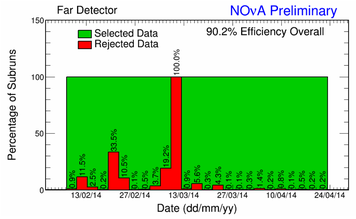


Fraction of tracks (straight line) that were reconstructed in only one view. This metric is sensitive to failures in the data acquisition on portions of the detector.



Median pixel "MIP" hit rate. The "MIP" range is defined as 175 ≤ ADC ≤ 3200 (about 75 < PE < 1390).

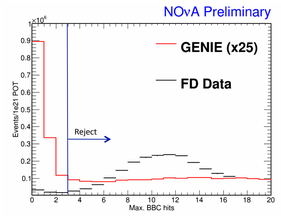
- Continued commissioning efforts and increased numbers of live channels have improved good data output.
- **Physics quality data selection now better than 99%.**



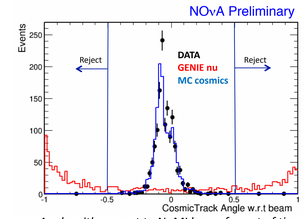
Percentage of selected and rejected data as a function of time. Each entry represents a period of 3 days.

Physics Response

- In order to understand backgrounds, timing, and confirm response throughout active volume, searches for neutrino-like events from NuMI in the far detector have been conducted over data taken between Oct. 2013 and April 2014.
- Complementary hand scanning and automated analysis based (track quality, event steepness) techniques were used.
- Pre-selections were applied to events in both search paths including minimum cell (20) and plane (4) cuts, fiducial containment 1 m from edges with stray hit exceptions (see below) and angle with respect to the beam > 0.5 or < -0.5.

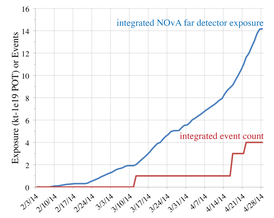


Maximum hit count extending beyond box containment sides for out of time data and GENIE neutrino simulation. Events to the right of the blue line are excluded.

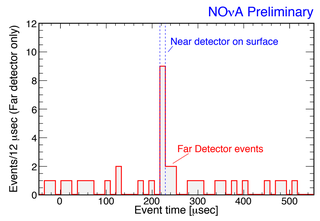


Angle with respect to NuMI beam for out of time data, cosmic simulation and GENIE neutrino simulation.

- Selected events with blinded times were scanned by multiple experts.
- 9 "golden" events have been identified, 7 in the expected beam window. This is a significant excess above the expected 0.5 in-time background events.
- **In-time neutrino candidates have been observed** throughout the detector volume. (Selection shown in the gallery below.)



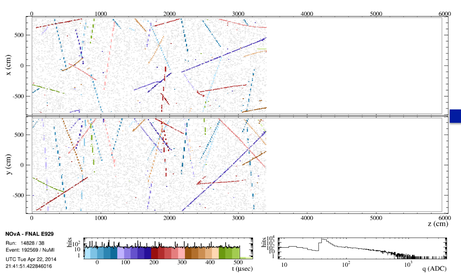
*Total exposure (kilotons * 1e19 POT) for recent scan sample as a function of calendar time. The red curve shows the integrated number of events labeled "gold" by two of 5 scanners or found by the automated analysis.*



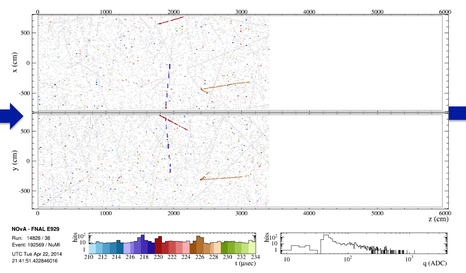
Timing distribution for selected far detector events shown in red. Expected neutrino arrival time based on near detector data is shown in blue.

NOvA Far Detector Event Gallery

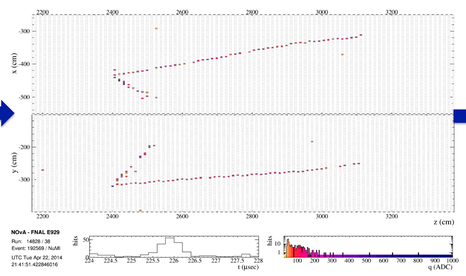
Neutrino Candidates



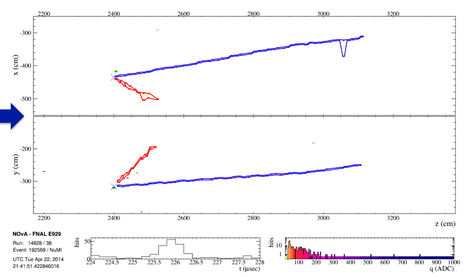
Full event display for neutrino candidate selected by automated and scan-based analyses showing the full (arbitrary) 550 us trigger time window. Hits determined to be noise by clustering algorithm are suppressed. Colors indicate hit times per lower histogram at left. The lower histogram at right shows the ADC distribution.



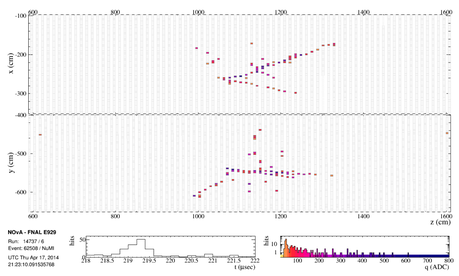
Same event with timing windowed zoomed to 24 us wide and encompassing the expected beam arrival time. The candidate event is visible in brown. Clustering algorithm creates independent objects of the three groups of hits separated in time.



Same event with timing windowed reduced to 4 us wide and zoomed spatially. Hits are colored by ADC value. The event is contained in kTons 5-7.5 of the detector.



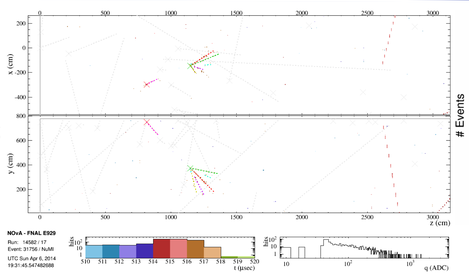
Same event with reconstructed event prongs and vertex drawn.



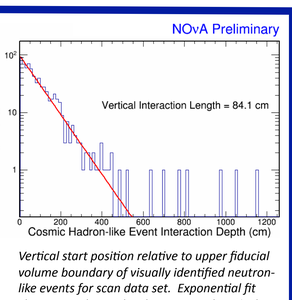
Another zoomed candidate neutrino event. The event is contained in kTons 2.5-5.

Neutron-like

- Neutron-like events entering the top of detector were identified during scanning.
- Many out-of-time neutrino candidates had topologies similar to event shown at right.



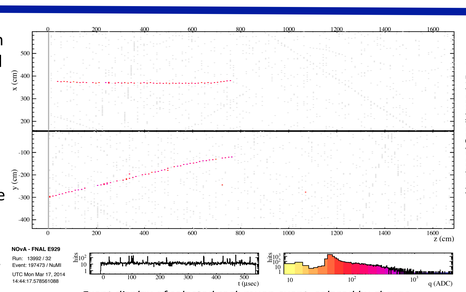
Background event identified in scan analysis. The event is near the top of the detector and has large transverse momentum with respect to the NuMI beam. Reconstructed prongs and vertex are drawn. Hit colors denote time values.



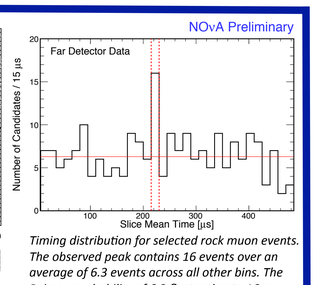
Vertical start position relative to upper fiducial volume boundary of visually identified neutron-like events for scan data set. Exponential fit shown in red provides the measured vertical interaction length.

Rock interaction

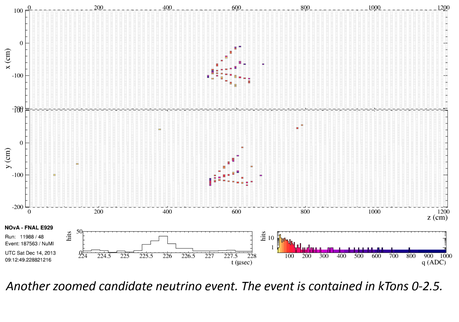
- A separate search for rock generated NuMI activity was conducted.
- Single stopping tracks entering through the front detector face were selected.
- The tracks were required to be up-going along the direction of the beam.



Event display of selected rock muon event, colored by charge



Timing distribution for selected rock muon events. The observed peak contains 16 events over an average of 6.3 events across all other bins. The Poisson probability of 6.3 fluctuating to 16 or more is 0.08%.



Another zoomed candidate neutrino event. The event is contained in kTons 0-2.5.

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