Status of Detecting Final State Nucleons in the NOvA Near Detector

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Final State Nucleons Workshop

Fermilab

January 19, 2017

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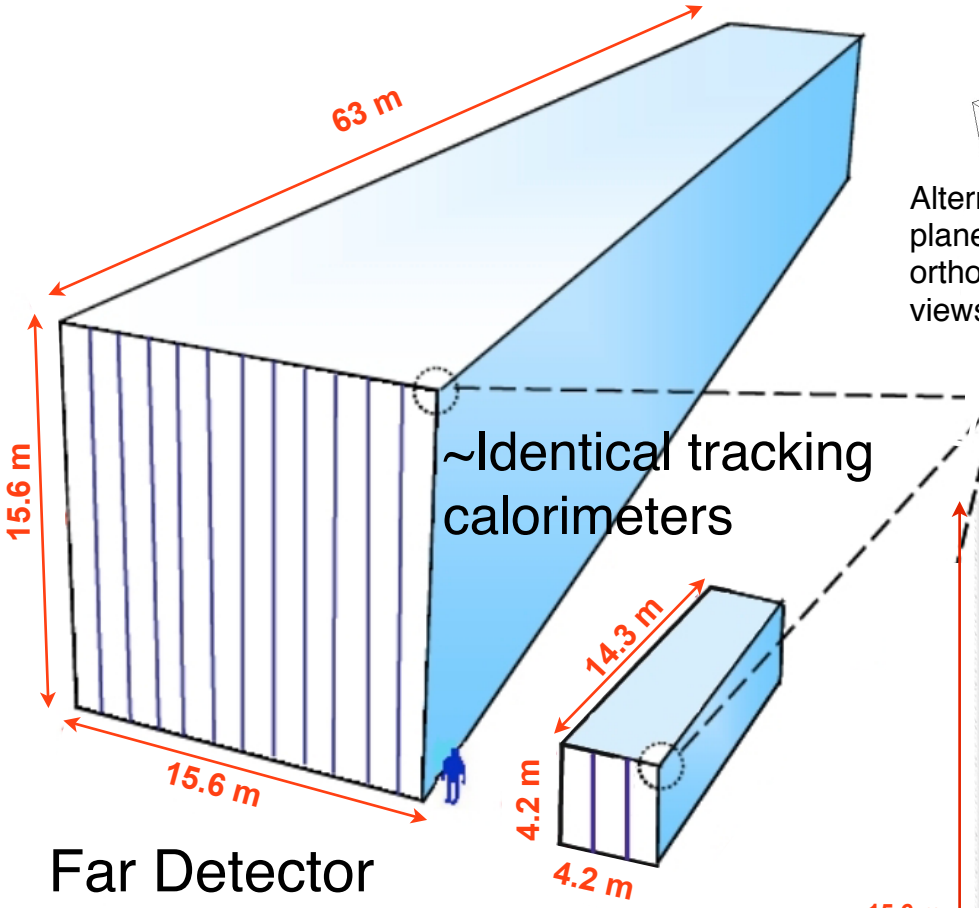
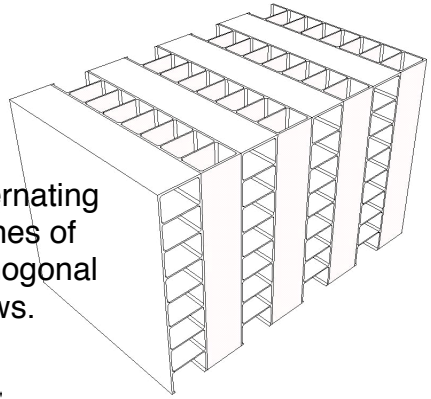
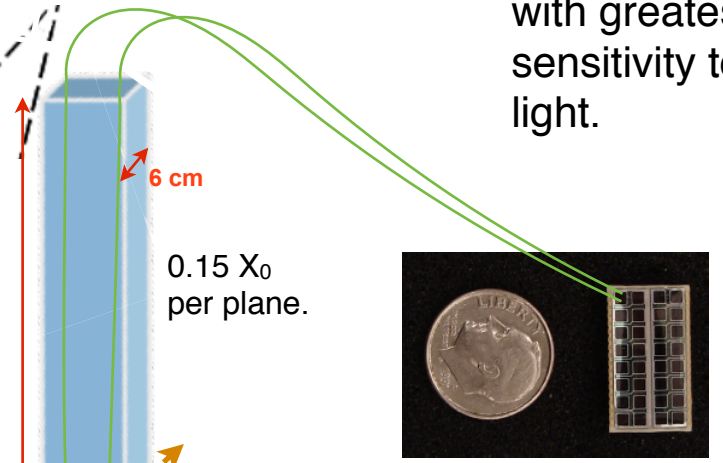
A Reminder of How the NOvA Detectors Work



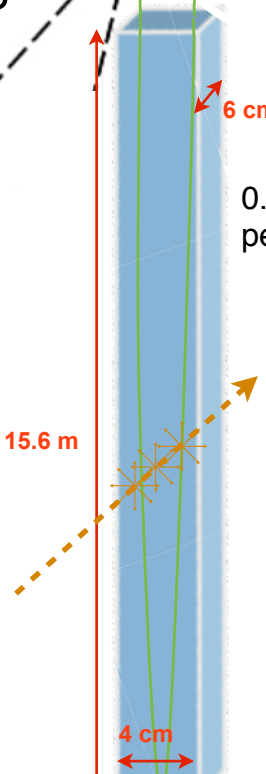


Wavelength-shifting fibers routed to a single cell on an Avalanche Photodiode (APD) made of materials with greatest sensitivity to green light.



Tracking calorimeter:

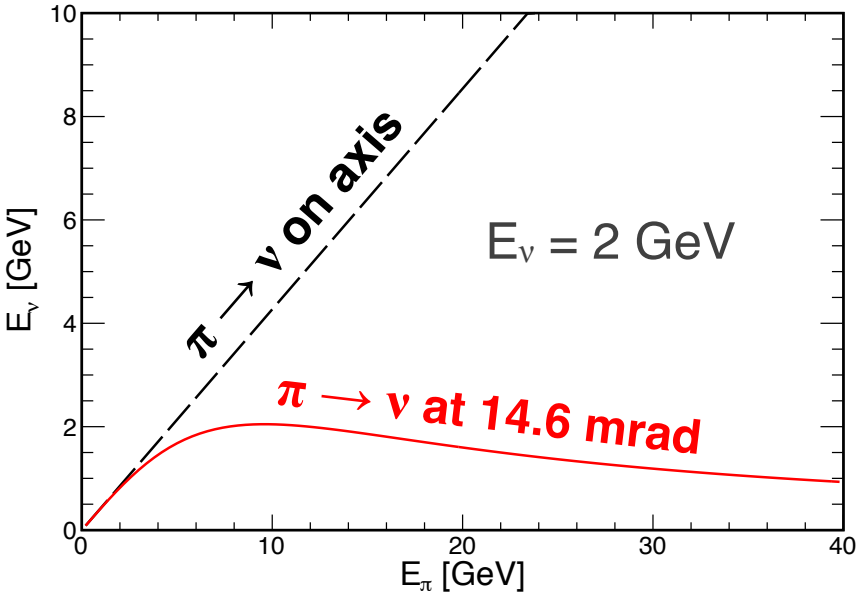
- ~70% active
- muon energy resolution (range): few %
- Moliere radius is ~2.5 cell widths
- EM shower max at ~5 X_0

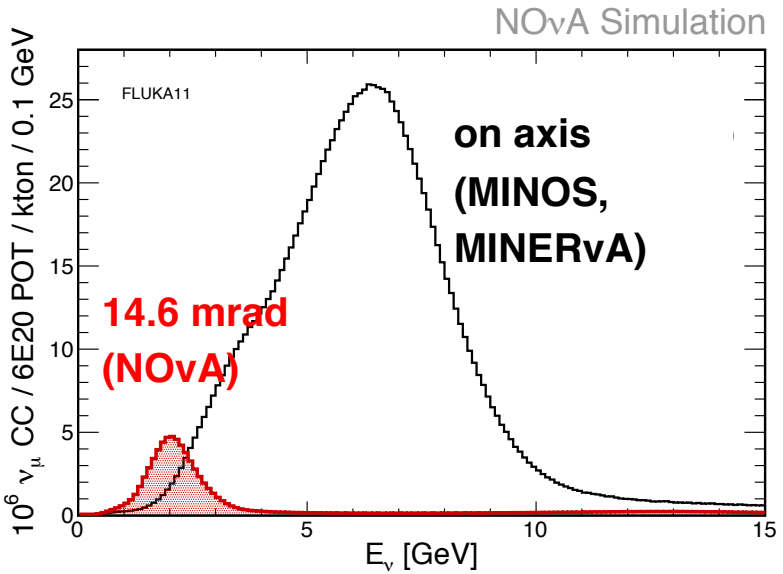


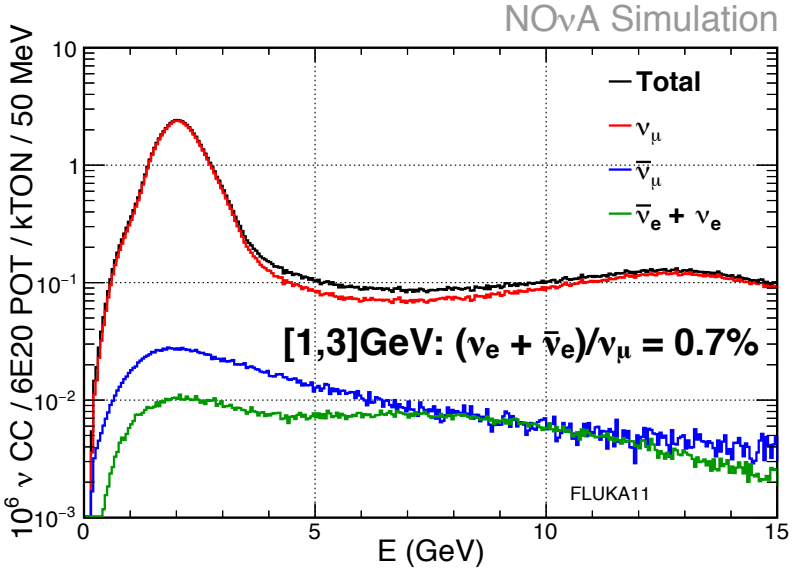
Scintillation light (mostly blue wavelengths) emitted isotropically and captured in wavelength shifting fibers that convert blue light to green.

A Reminder of the Beam at NOvA

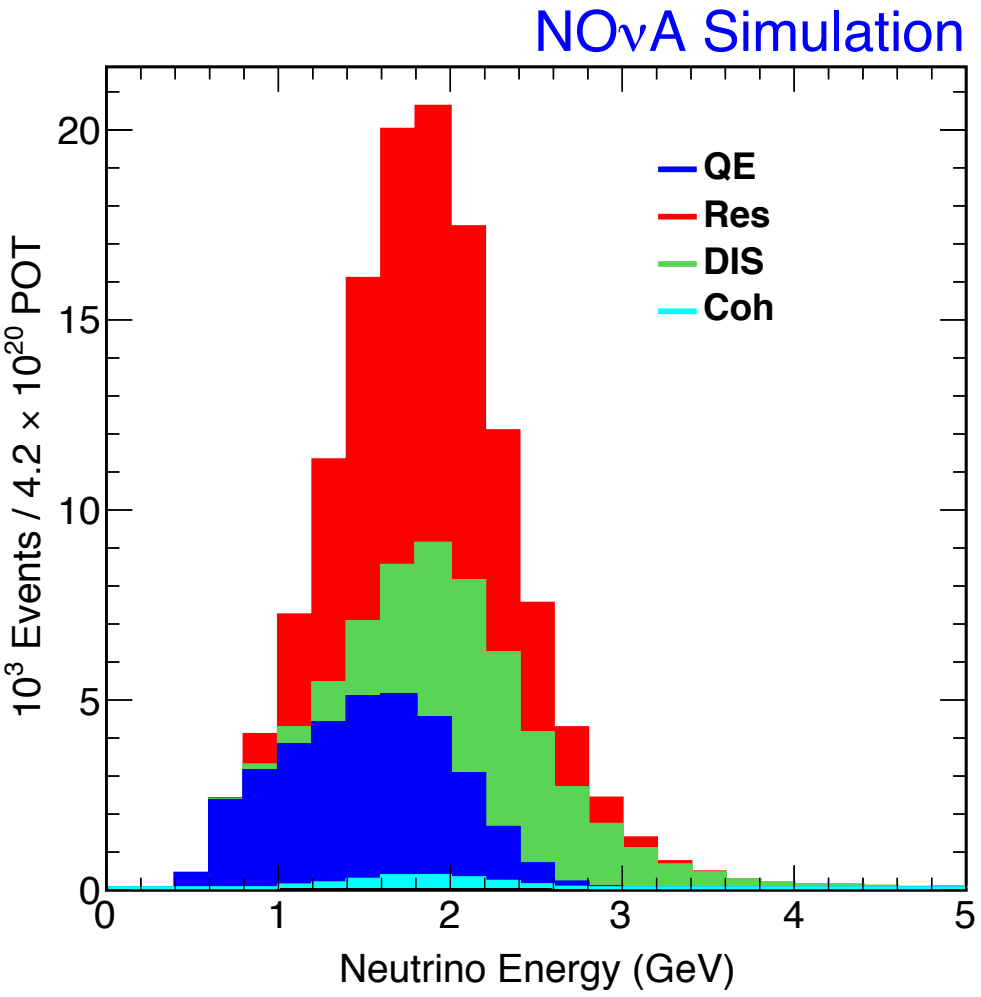
$$E_\nu = \frac{1-(m_\mu/m_\pi)^2}{1+\gamma^2\tan^2\theta}E_\pi$$





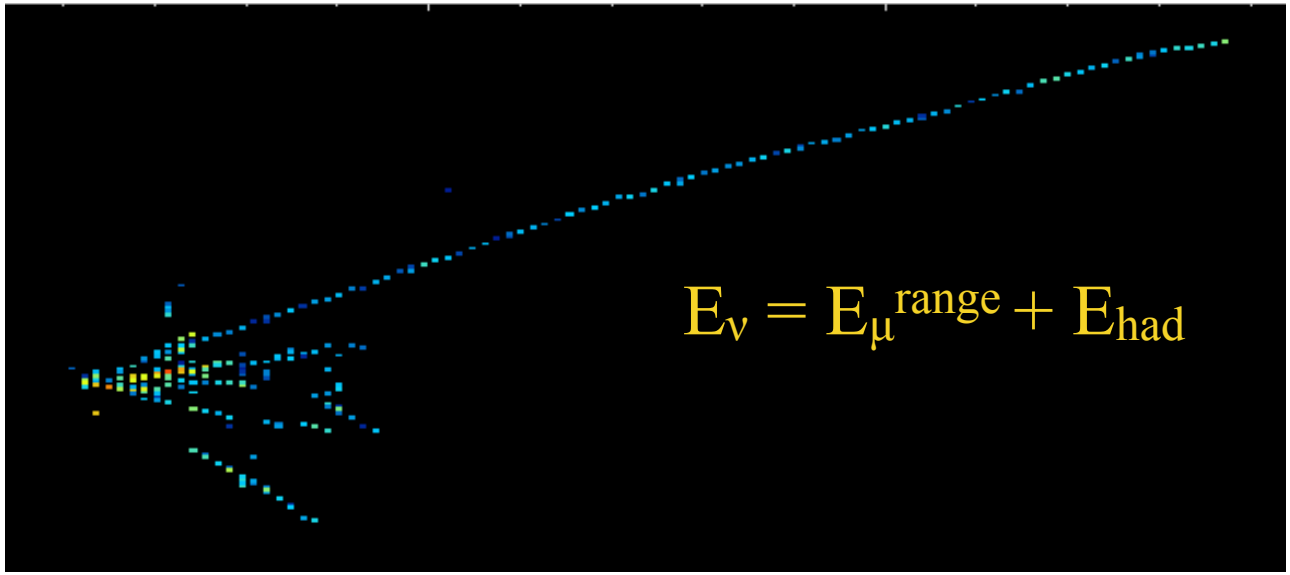


A Reminder of the Beam at NOvA

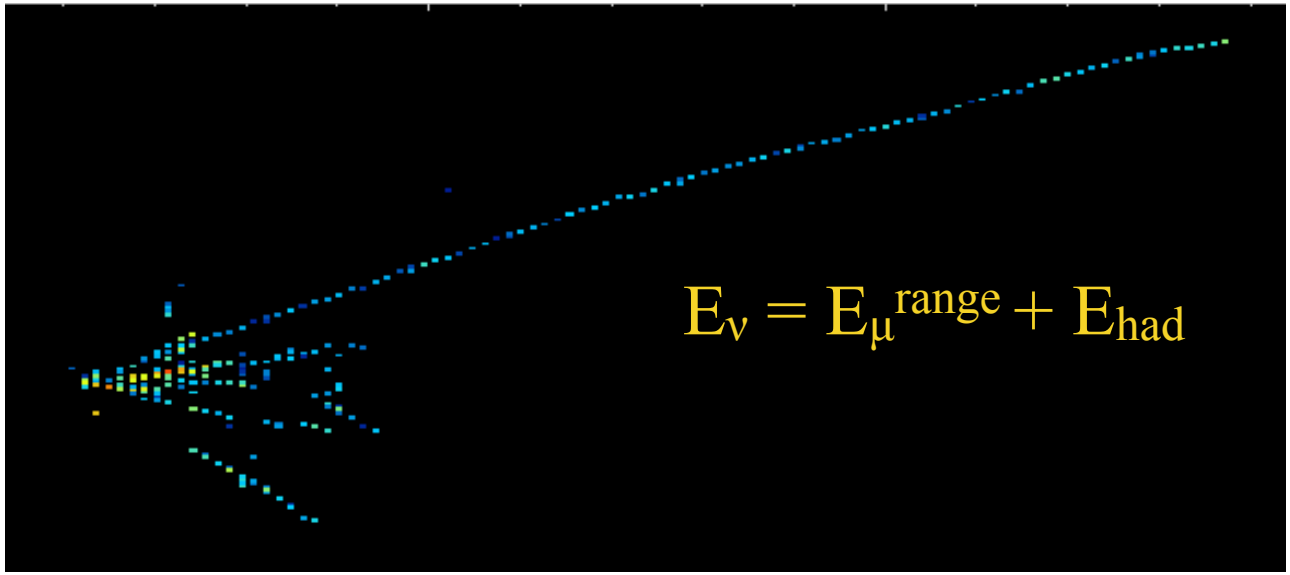


- Even with a narrow band beam, NOvA is still sensitive to many different nu+A interaction channels.
- The ND “sees” approximately equal amounts of interaction channels. However, the QE and RES components in the FD are strongly shaped by oscillations.

Neutrino Energy Reconstruction



Neutrino Energy Reconstruction



We rely on the simulation, which has models for cross sections and final state interactions (FSI), to calibrate measured visible hadronic energy to true hadronic energy.

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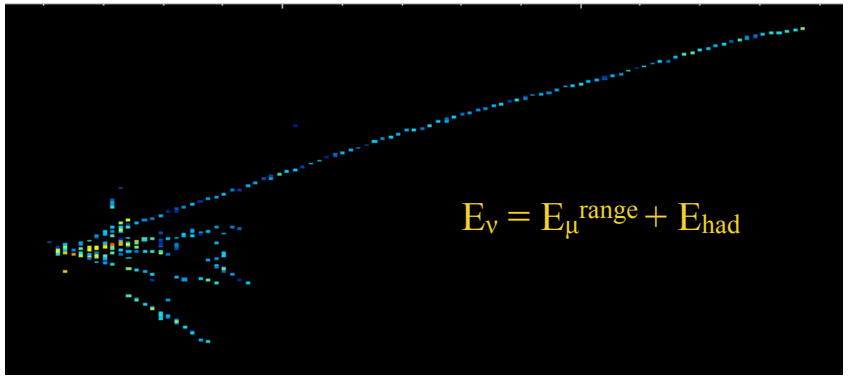
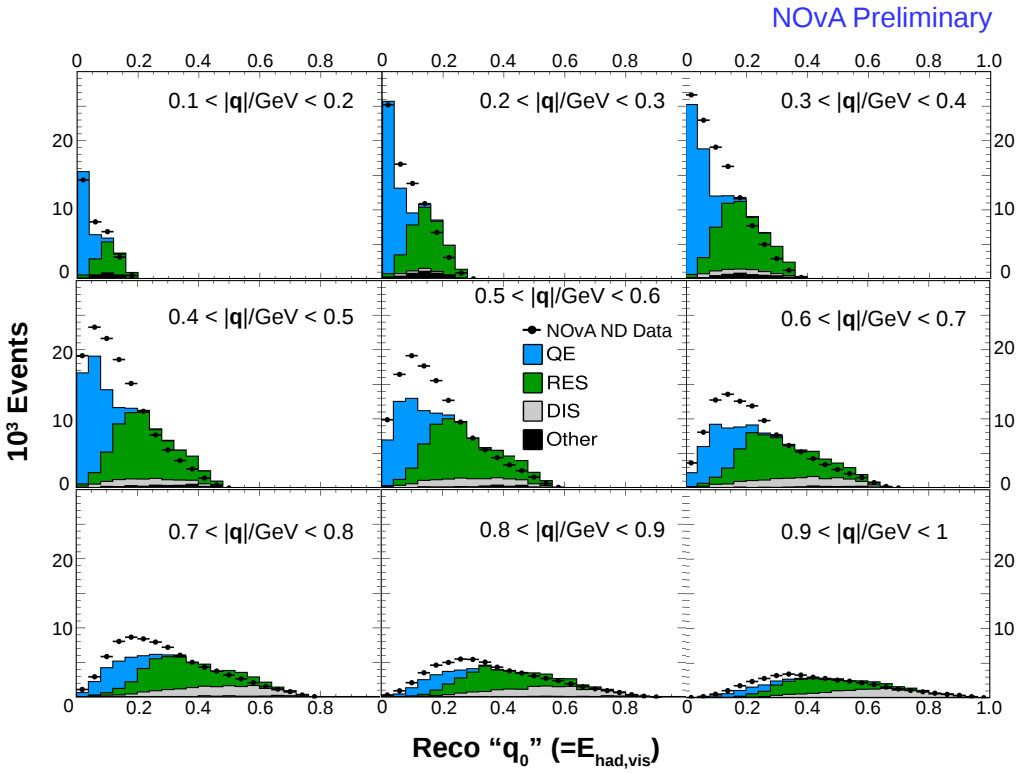
Neutrino Energy Reconstruction





Sizable differences in hadronic energy distributions between data and MC.

Here the MC is GENIE v2.10.4.

$$q_0 = E_{had}$$
$$E_\nu = E_\mu + E_{had}$$
$$Q^2 = 2E_\nu \left(E_\mu - p_\mu \cos(\theta_\mu) - M_\mu^2\right)$$
$$|\vec{q}\,| = \sqrt{Q^2 + q_0^2}$$

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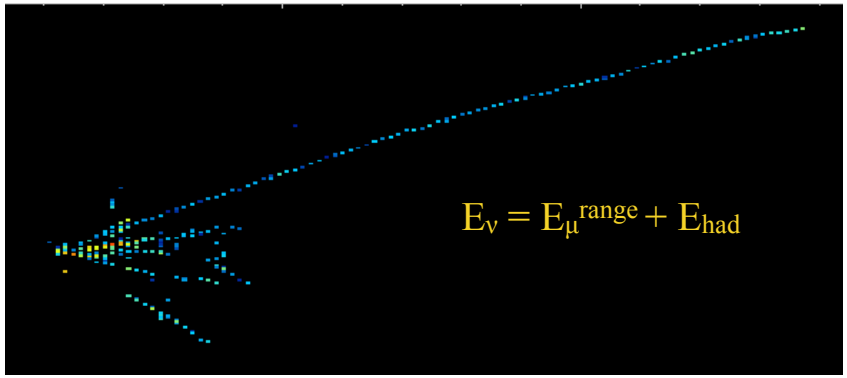
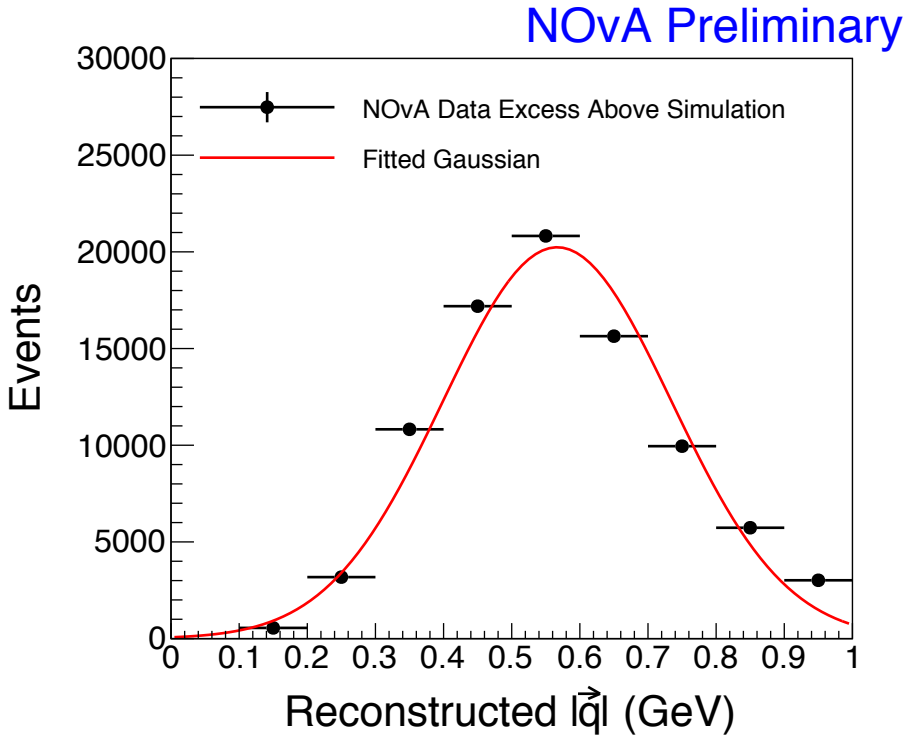
Neutrino Energy Reconstruction





NOvA employed a modified version of the "empirical MEC" optional model in GENIE v2.10.4 to account for the observed MC discrepancy from data. These MEC events were then reweighted to:

- reverse the linear turn-off of the cross section between 1-5 GeV
- fix a typo to reverse the fraction of n-n to n-p pairs
- apply a momentum-transfer dependent weight derived from the ND data

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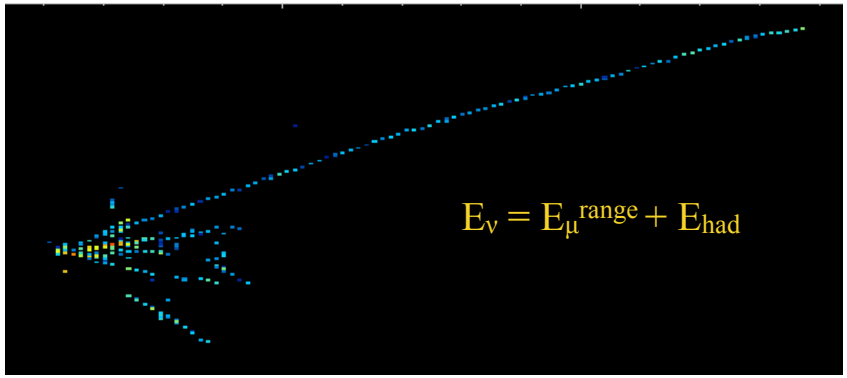
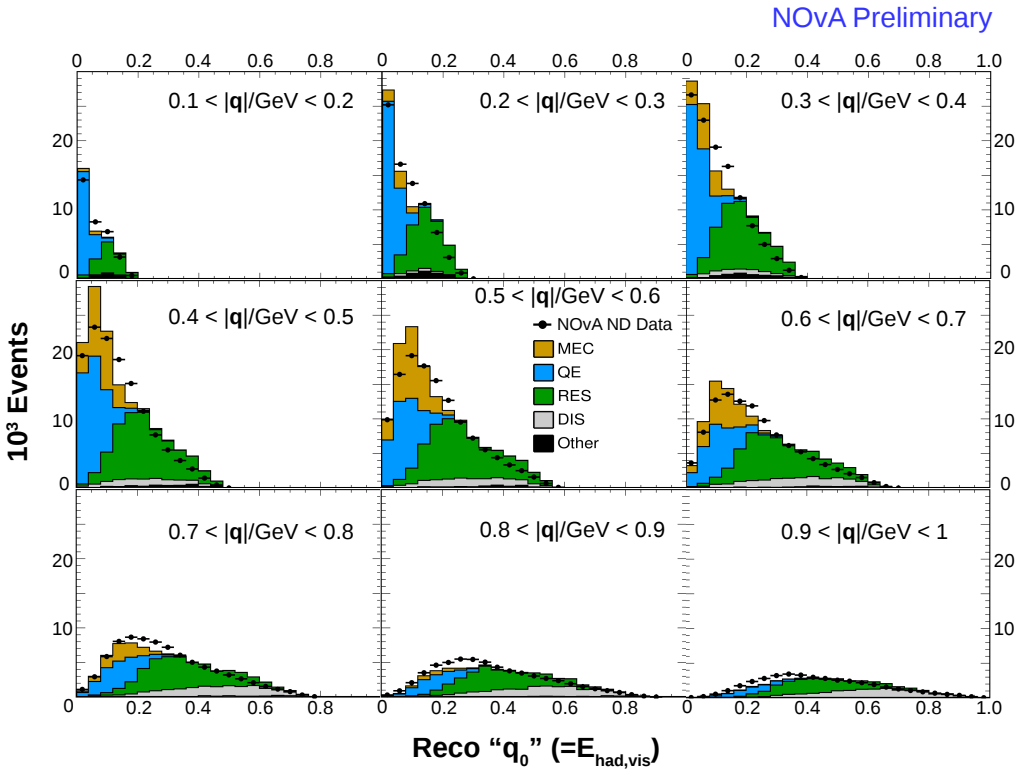
Neutrino Energy Reconstruction





Clear improvement if filling the "gaps", but also far from perfect.

Much more work to do to improve the modeling of nu+A interactions in our detectors, and we expect this will be a long haul.

Direct measurements of final state nucleons are critical to the path forward.

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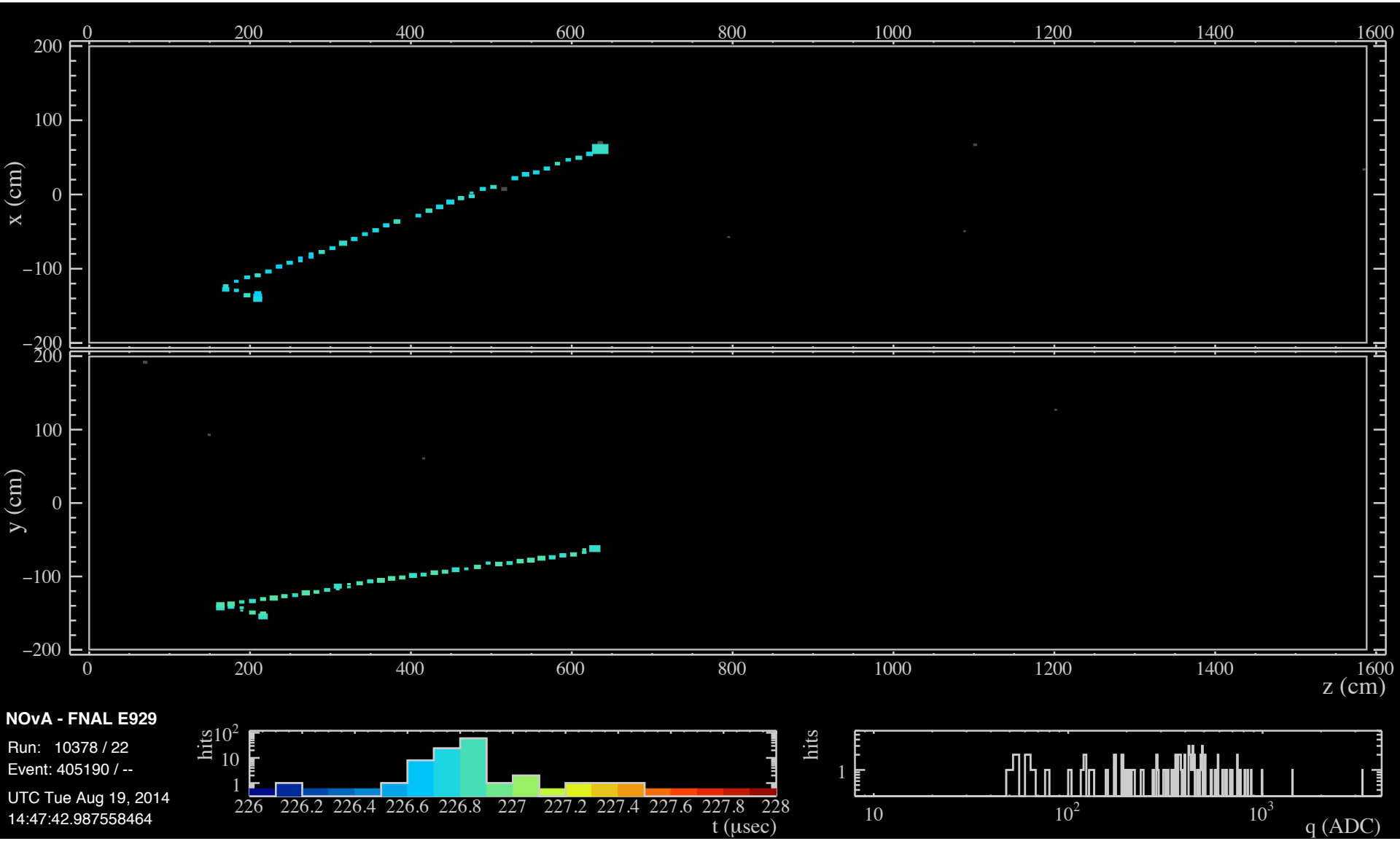
An Injection of Reality

- A MIP deposits about 10 MeV per cell. Our hit detection threshold in a cell is a few MeV.
- Currently our reconstruction algorithms require 2-4 hits in each view to form 3-d “tracks” or “prongs”.
- In a very low multiplicity event, the lowest energy MIP we could reasonably *reconstruct* is ~40 MeV. Higher for a proton.
- Particle identification typically requires more than a few hits to distinguish pi from p. This will likely raise the threshold to at least 100-200 MeV for a MIP, 300-500 MeV for a proton.
- Identifying final state particles in the NOvA analysis is in a nascent but very active state.
  - We have several ND xsec analyses underway that are developing MVA PIDs for charged particles.
  - Another new, very promising approach is to adopt the same convolutional visual network (CVN) technology used in the oscillation analyses to identifying final state “prongs”.
  - Neutrons are hard, but some progress is also being made in making use of secondary vertices downstream of the primary vertex.


0
200
400
600
800
1000
1200
1400
1600
x (cm)
y (cm)
z (cm)
NOvA - FNAL E929
Run: 10378 / 22
Event: 405190 / --
UTC Tue Aug 19, 2014
14:47:42.987558464
hits
t (μsec)
q (ADC)

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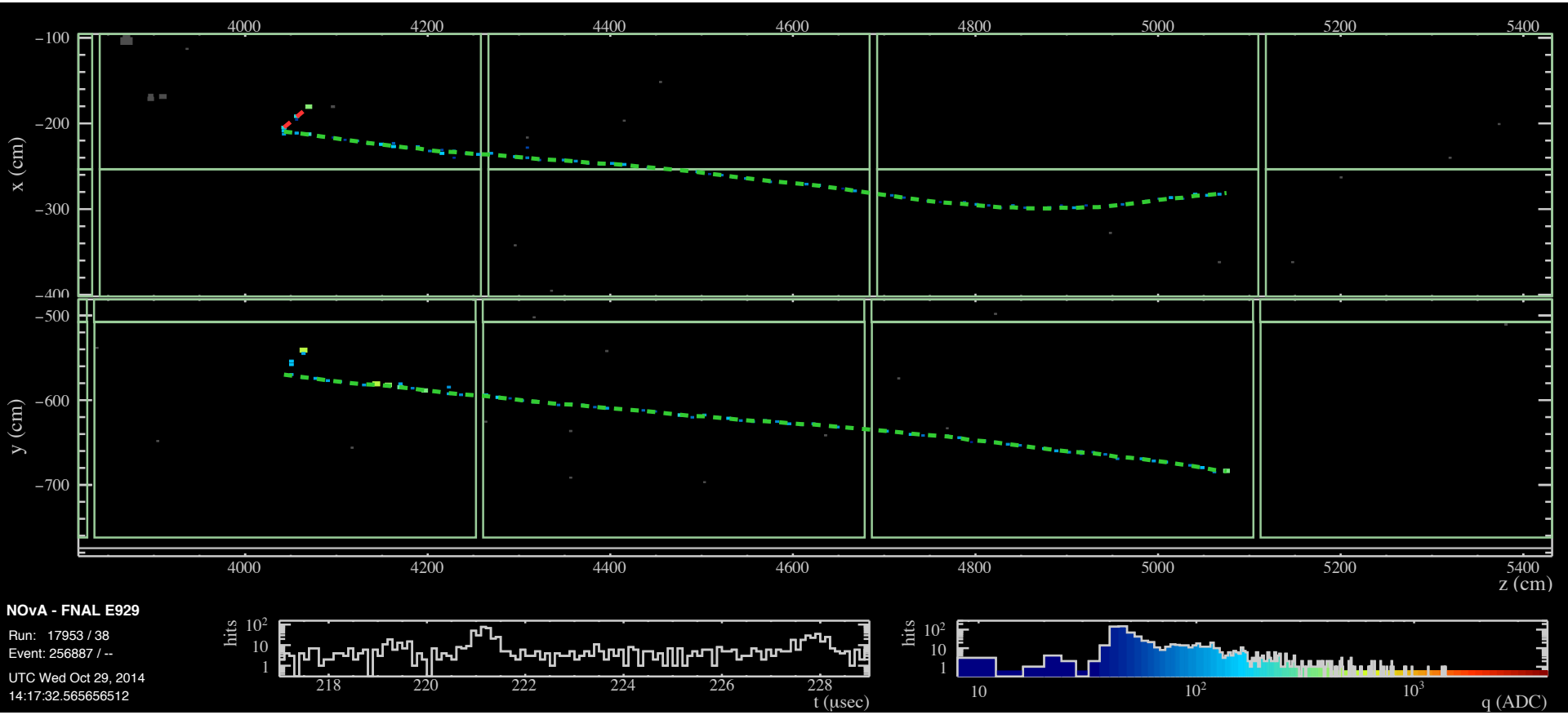
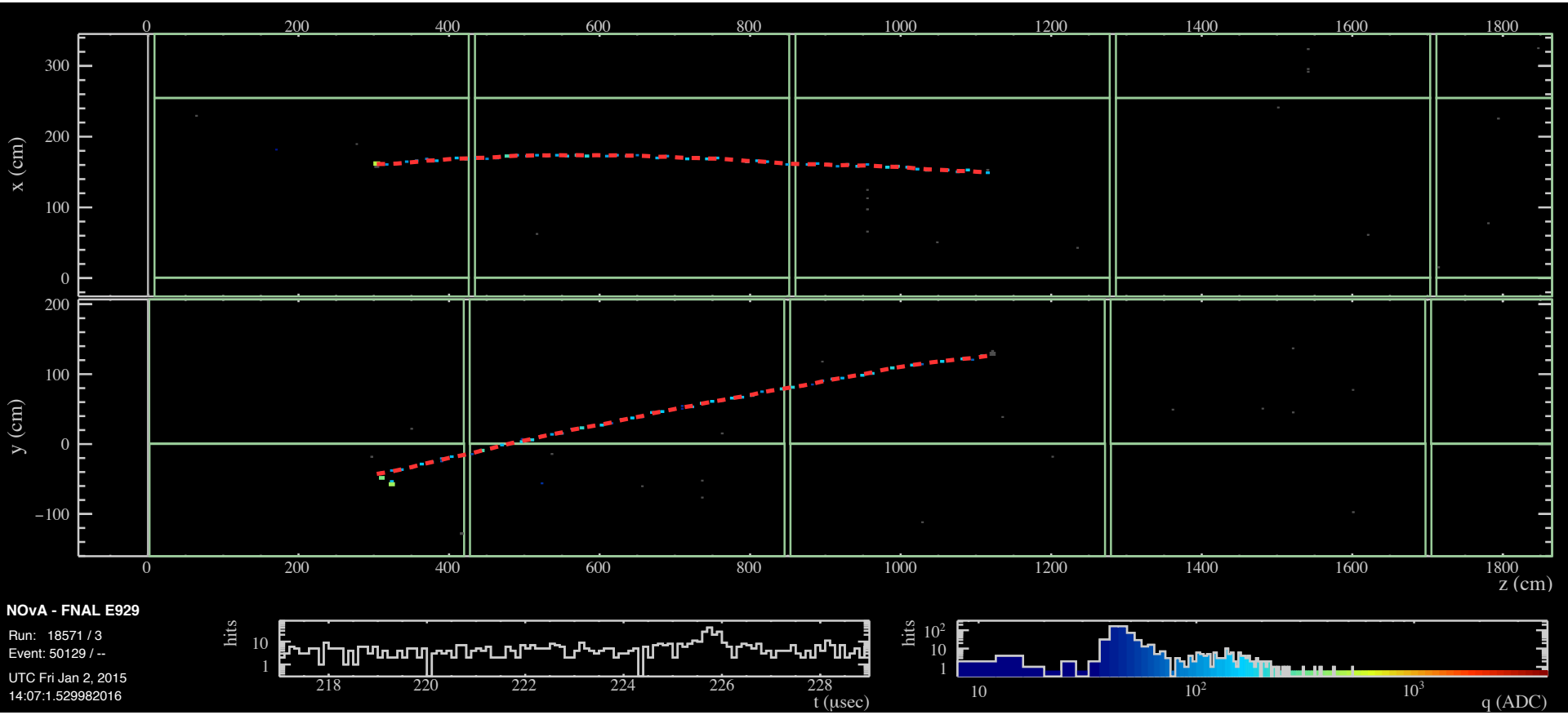
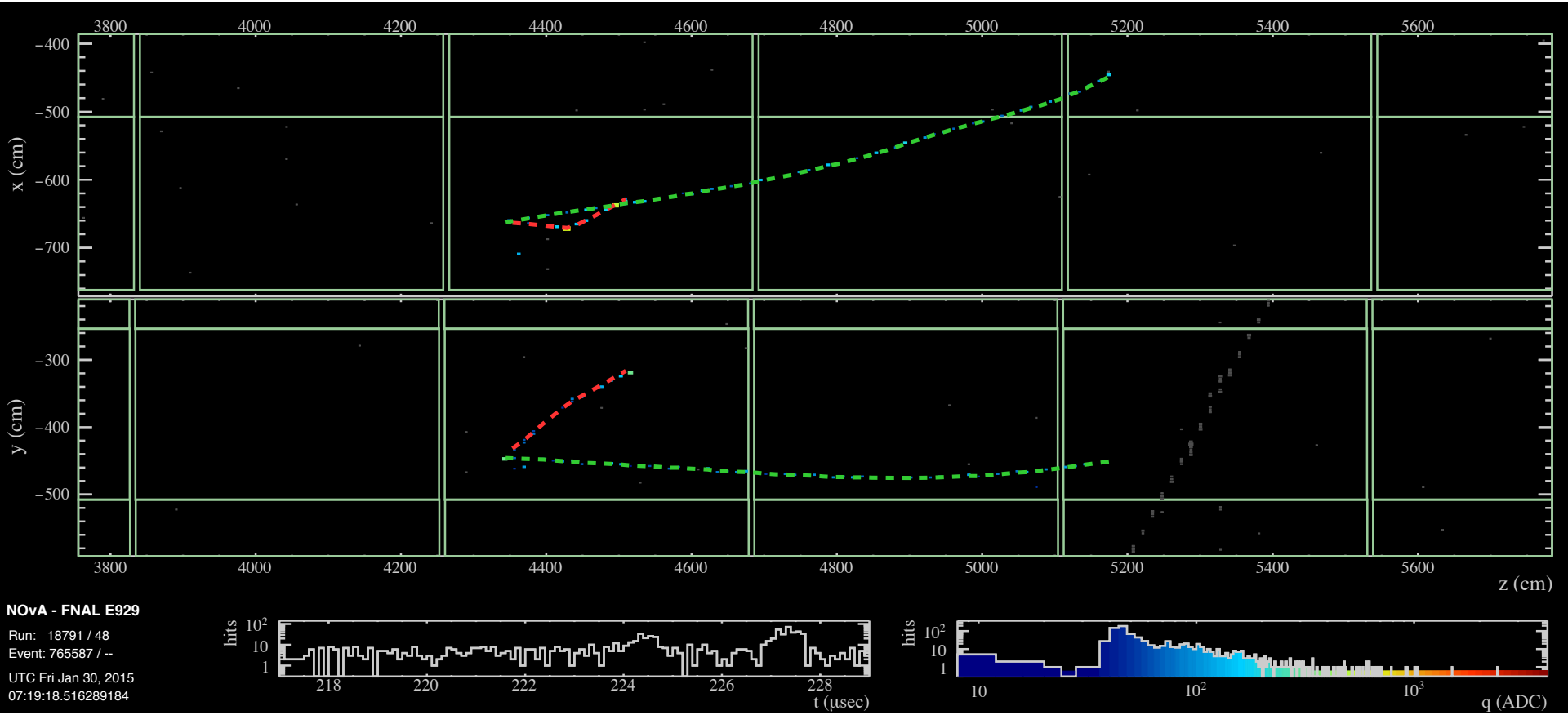

4000
4200
4400
4600
4800
5000
5200
5400
−100
−200
−300
−400
−500
−600
−700
x (cm)
y (cm)
z (cm)
NOvA - FNAL E929
Run: 17953 / 38
Event: 256887 / --
UTC Wed Oct 29, 2014
14:17:32.565656512
hits
10^2
10
1
218
220
222
224
226
228
t (μsec)
10
10^2
10^3
q (ADC)

Fermilab


0
200
400
600
800
1000
1200
1400
1600
1800
300
200
100
0
x (cm)
200
100
0
−100
y (cm)
z (cm)
NOvA - FNAL E929
Run: 18571 / 3
Event: 50129 / --
UTC Fri Jan 2, 2015
14:07:1.529982016
hits
10
1
218
220
222
224
226
228
t (μsec)
hits
10²
10
1
10
10²
10³
q (ADC)

Fermilab


3800
4000
4200
4400
4600
4800
5000
5200
5400
5600
−400
−500
−600
−700
x (cm)
−300
−400
−500
y (cm)
z (cm)
NOvA - FNAL E929
Run: 18791 / 48
Event: 765587 / --
UTC Fri Jan 30, 2015
07:19:18.516289184
hits
10^2
10
1
218
220
222
224
226
228
t (μsec)
hits
10^2
10
1
10
10^2
10^3
q (ADC)

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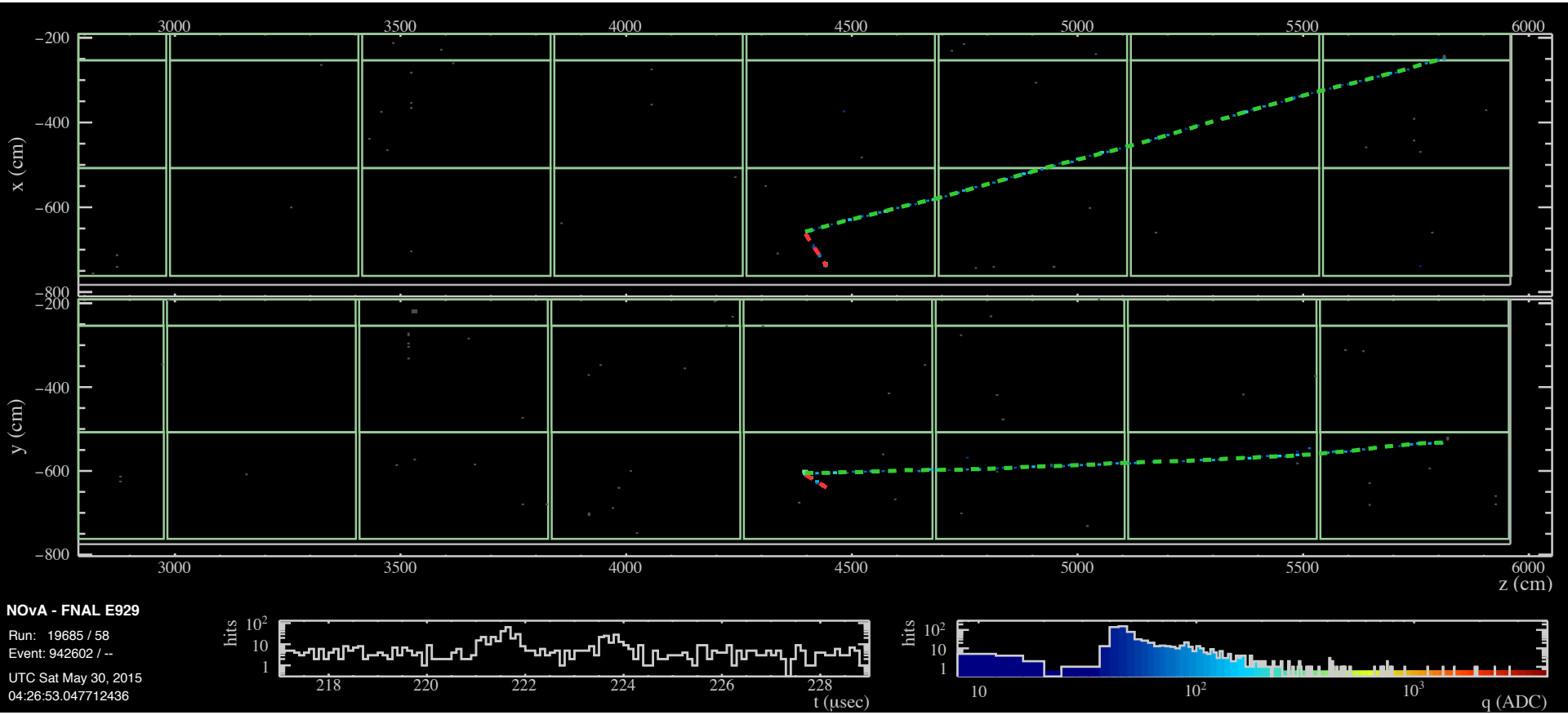
3000
3500
4000
4500
5000
5500
6000
−200
−400
−600
−800
x (cm)
y (cm)
z (cm)
NOvA - FNAL E929
Run: 19685 / 58
Event: 942602 / --
UTC Sat May 30, 2015
04:26:53.047712436
hits
10^2
10
1
218
220
222
224
226
228
t (μsec)
10
10^2
10^3
q (ADC)

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Analyses Underway

- ν_μ CC inclusive
- ν_e CC inclusive
- NC π^0 semi-inclusive
- ν_μ CC π^0
- ν_μ CC 0π
- ν_μ CC 2p2h
- ν_μ CC $\pi^{+/-}$
- ν + e
- ν_μ CC Coherent π^+
- Many more…
- All of the above with antineutrinos

Looking Forward and Summary

- NOvA's high rate of neutrino interactions in the ND and off-axis narrow-band beam provide excellent opportunities to make precision measurements of nu+A interactions.
- Within NOvA there is a growing emphasis in improving the reconstruction and PID (CVN in particular) for ND exclusive channel xsec measurements.
- NOvA will soon begin collecting high statistics antineutrino data.
- Stay tuned!