Status and Prospects of the NOνA Experiment

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Heavy Quarks and Leptons 2014
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Outline

Overview

NOνA Physics

NOνA Technology

Current Status

NOνA: **N**uMI **O**ff-Axis ν_e **A**ppearance Experiment

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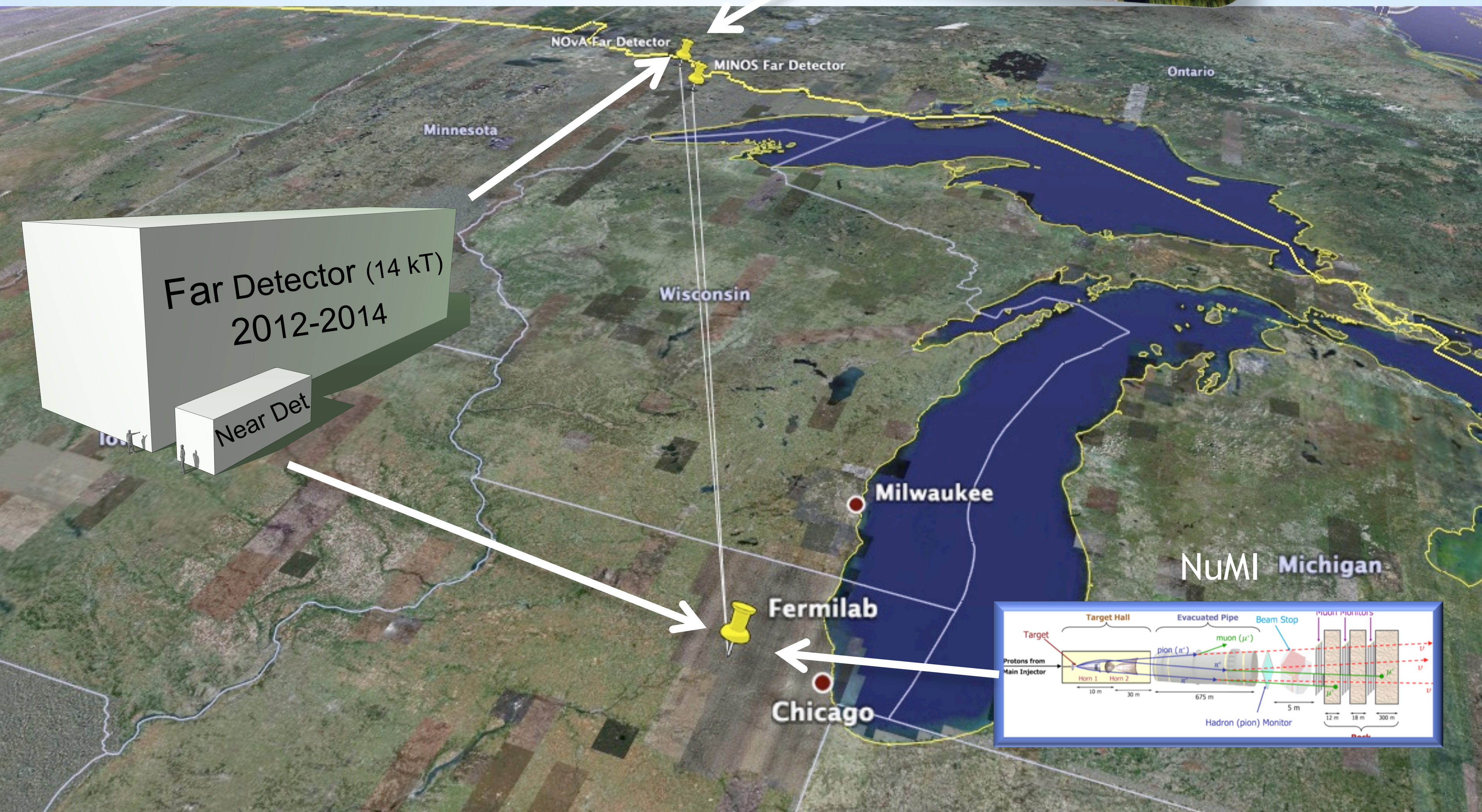
Neutrinos at the Main Injector


The NOνA Collaboration
38 Institutions from 7 Countries
205 members

Neutrino Beam from Fermilab to Minnesota



NOνA Physics Impact

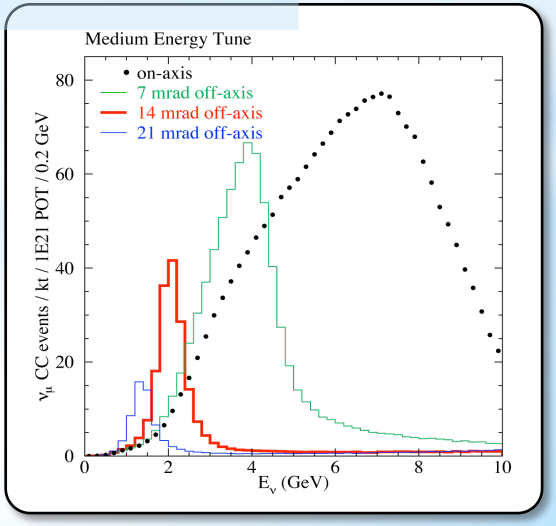
- Mass Hierarchy from Matter Effect on ν_e Appearance
- CP Violation from δ in the PNMS matrix
- Improved Atmospheric Oscillation Parameters from ν_μ Disappearance
- Tests of 3 Flavor mixing paradigm (ν_s?)
- θ_{23} Octant
- Supernova ν's

NOνA Technique

Off-Axis position of detector results in a Narrow band beam peaked at ~2 GeV

At 810 km from source the L/E is optimal for electron neutrino appearance.

Beam upgrades that increase power from 320 kW to 700 kW (in progress)



NOνA Oscillation Measurements

* Survivial Probability $P(\nu_\mu \rightarrow \nu_\mu)$
* Appearance Probability $P(\nu_e \rightarrow \nu_e)$
* Neutrinos and anti-neutrinos
* Sensitive to Hierarchy, θ_{13}, θ_{23}, δ_{CP} and Δm_{31}
  * Reactor experiments do not have all of these dependencies.

$$P(\overset{(-)}{\nu}_\mu \rightarrow \overset{(-)}{\nu}_e) \approx \sin^2 2\theta_{13} \sin^2 \theta_{23} \frac{\sin^2(A-1)\Delta}{(A-1^2)}$$

$$\overset{(+)}{-} 2\alpha \sin\theta_{13} \sin\delta_{CP} \sin 2\theta_{12} \sin 2\theta_{23} \frac{\sin A\Delta}{A} \frac{\sin(A-1)\Delta}{A-1} \sin\Delta$$

$$+ 2\alpha \sin\theta_{13} \cos\delta_{CP} \sin 2\theta_{12} \sin 2\theta_{23} \frac{\sin A\Delta}{A} \frac{\sin(A-1)\Delta}{A-1} \cos\Delta$$

Where: $\alpha = \frac{\Delta m_{21}^2}{\Delta m_{31}^2} \quad \Delta = \Delta m_{31}^2 \frac{L}{4E} \quad A = \overset{(-)}{+} G_f N_e \frac{L}{\sqrt{2}\Delta}$

ν_e Appearance in Matter

$$P(\nu_\mu \to \nu_e) \simeq \left| \sqrt{P_{Atm}} e^{-i(\Delta_{32}+\delta)} + \sqrt{P_{Sol}} \right|^2$$
$$= P_{atm} + P_{sol} + 2\sqrt{P_{atm} P_{sol}} (\cos\Delta_{32}\cos\delta \mp \sin\Delta_{32}\sin\delta)$$

$$\sqrt{P_{atm}} = \sin\theta_{23}\sin 2\theta_{13}\frac{\sin(\Delta_{31} - aL)}{\Delta_{31} - aL}\Delta_{31}$$
$$\sqrt{P_{sol}} = \cos\theta_{23}\sin 2\theta_{12}\frac{\sin(aL)}{aL}\delta_{21}$$
$$a = G_F N_e/\sqrt{2} \simeq 1/3500 \text{ km}$$

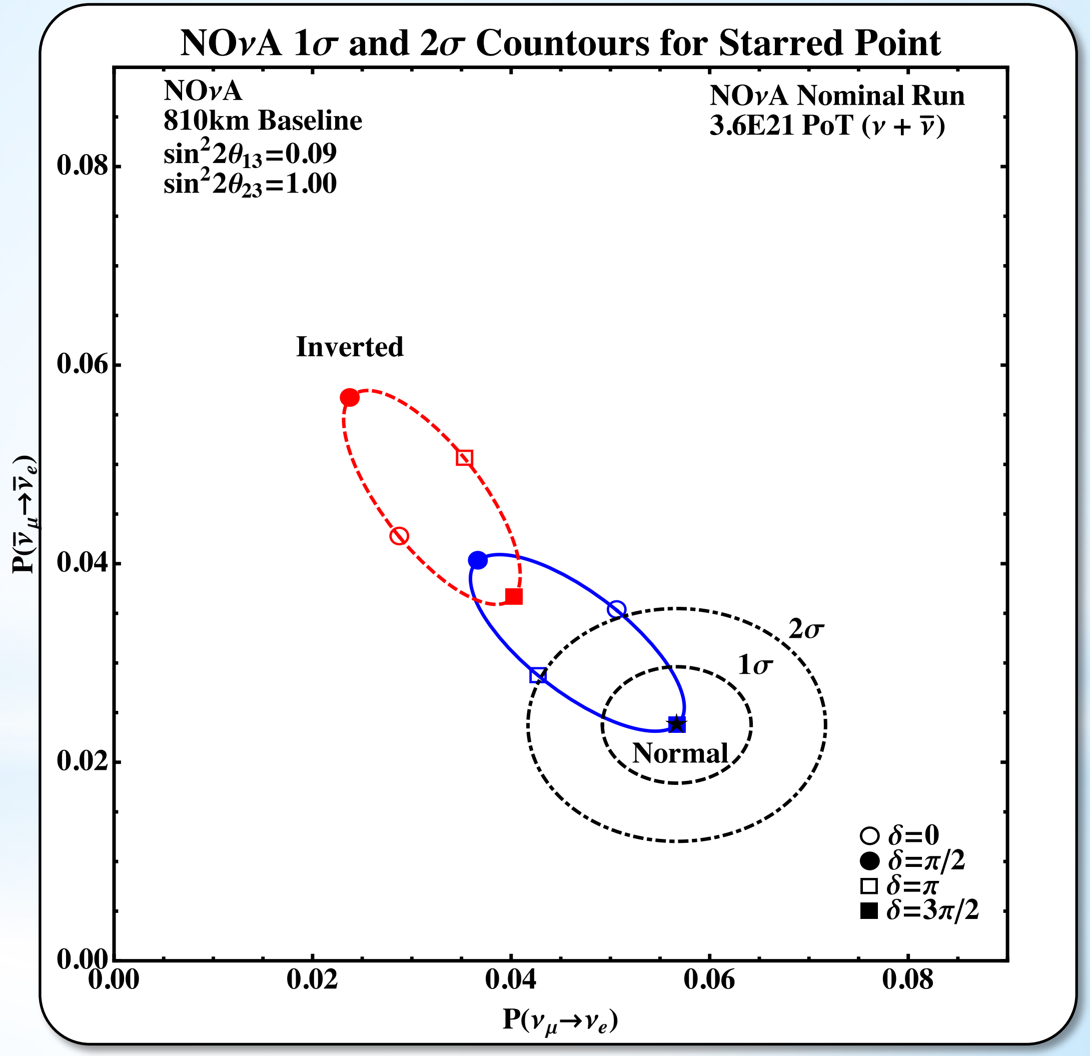
This term has a dependence on the relative sign of Δ_{31}

Effect increases with the baseline:

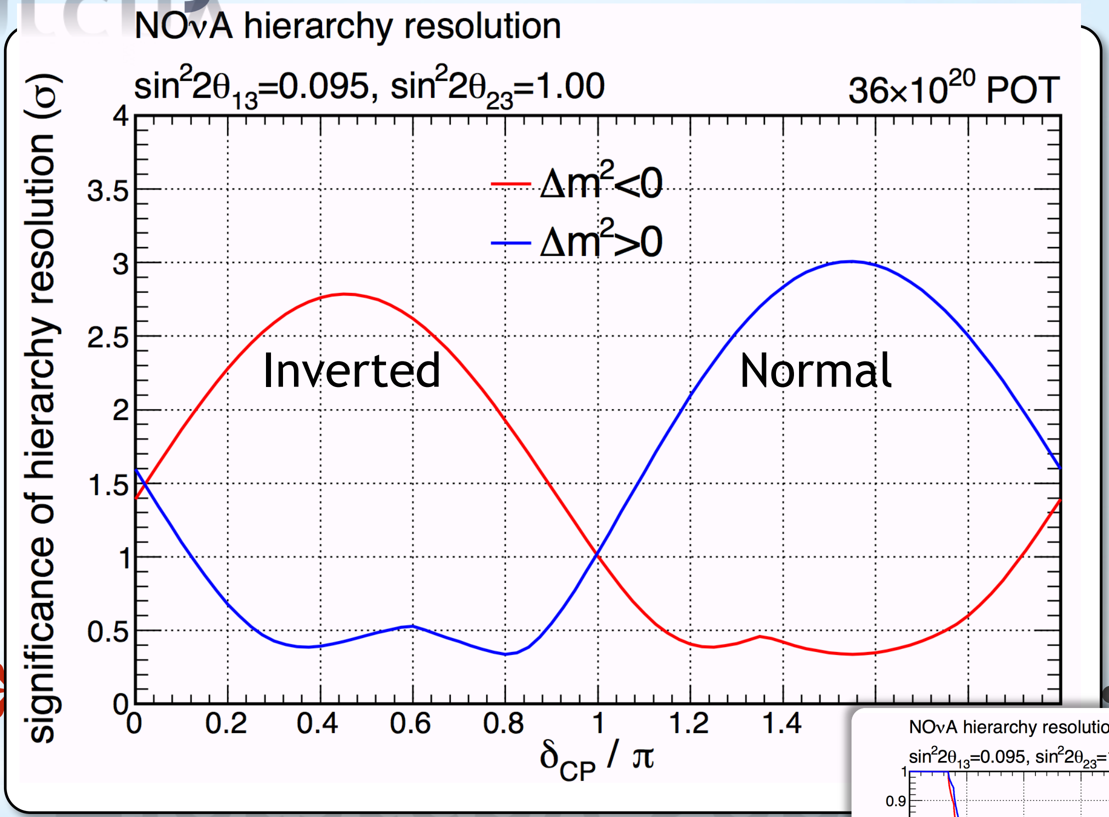
$aL = 0.08$ for $L = 295$ km
$aL = 0.23$ for $L = 810$ km

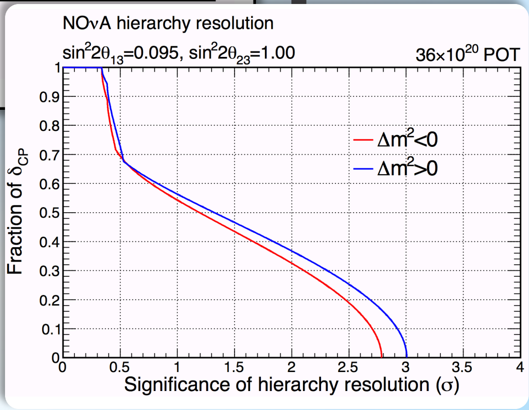
This gives NOvA a method of determining the mass order for ν_1 / ν_3

Measuring the Hierarchy



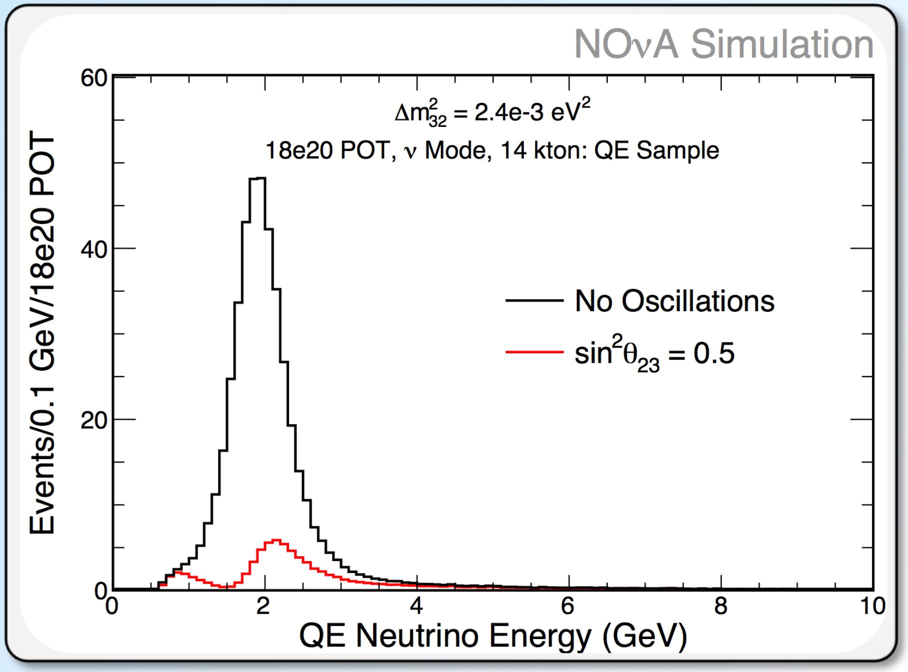
Measuring the Hierarchy





For a maximal θ_{23}, NOvA's sensitivity to the resolution of the hierarchy reaches 95% CL over a third of δ_{CP}

$P(\nu_\mu \rightarrow \nu_\mu)$

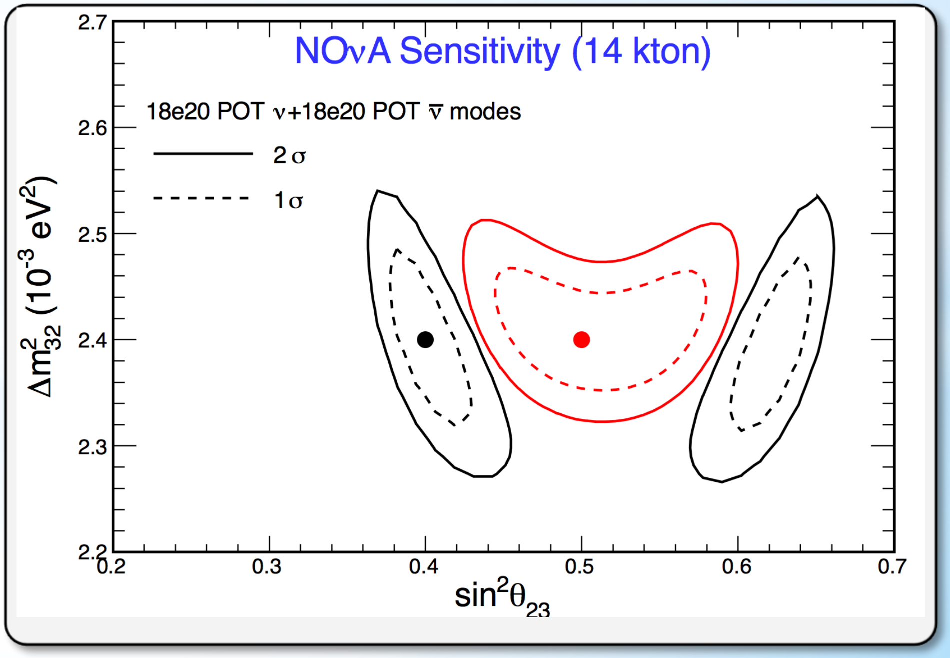


Sensitivities to non-maximal θ_{23} now include cosmic rejection efficiencies

For baseline exposure, any value θ_{23} the NOvA measurements will improve on current best fit values

Energy resolution on ν_μ CC Events from current detector performance & reconstruction techniques:

- 4.5% energy resolution for QE events
- 6% resolution for non-QE events

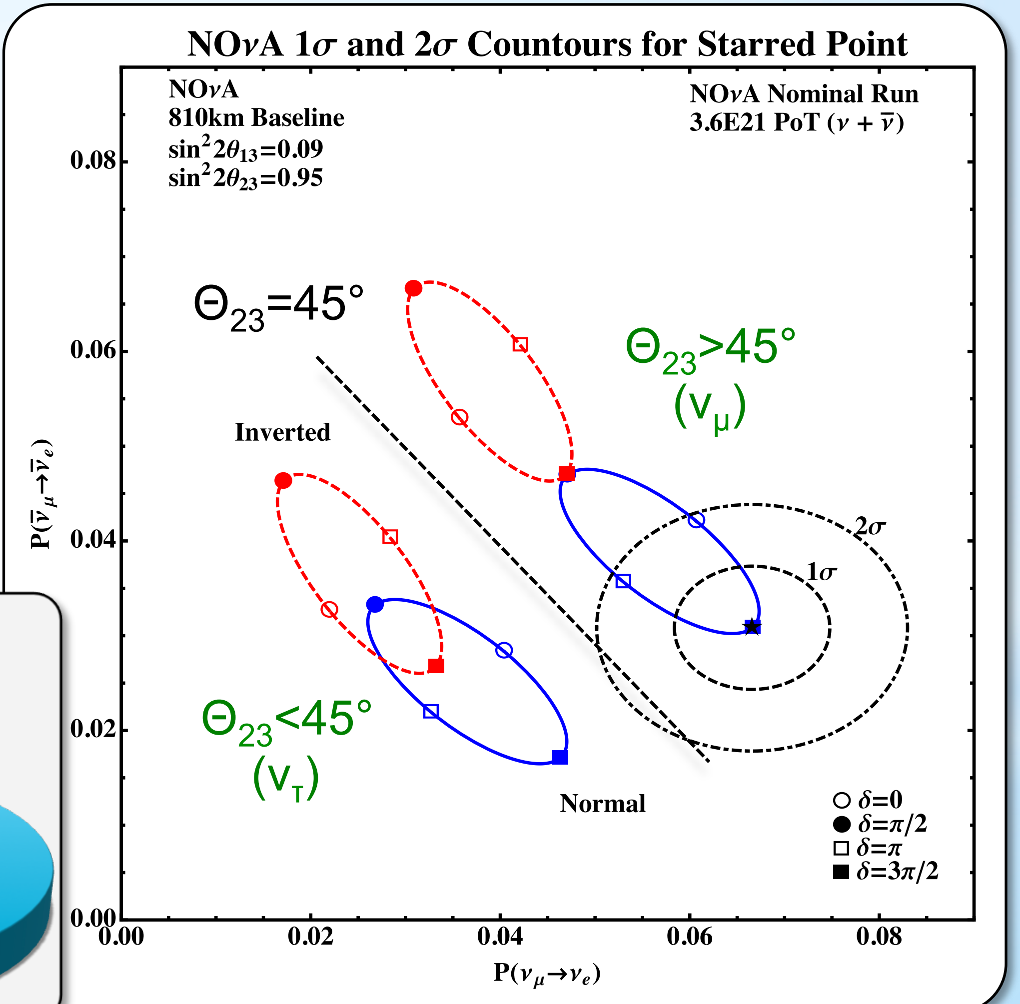


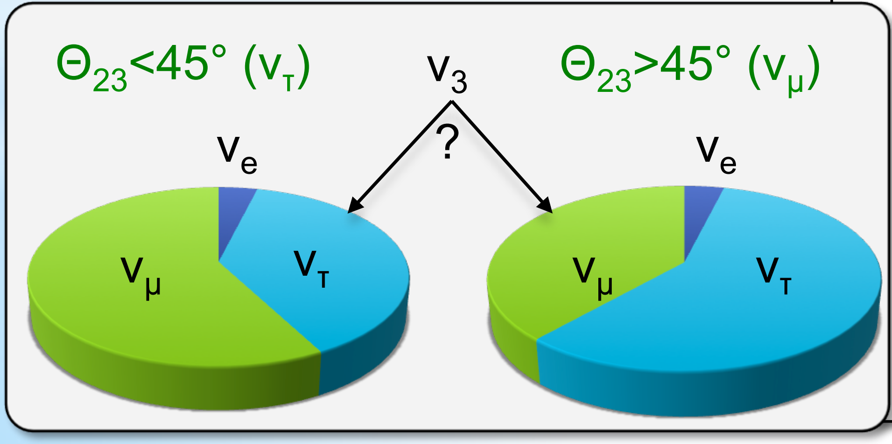
Non-Maximal θ_{23}

NOvA will make a precision measurement of $P(\nu_\mu \rightarrow \nu_\mu)$ which has the potential to establish $\theta_{23} \neq 45°$ based on the $\sin^2\theta_{23}$ dependence of the oscillation probability.

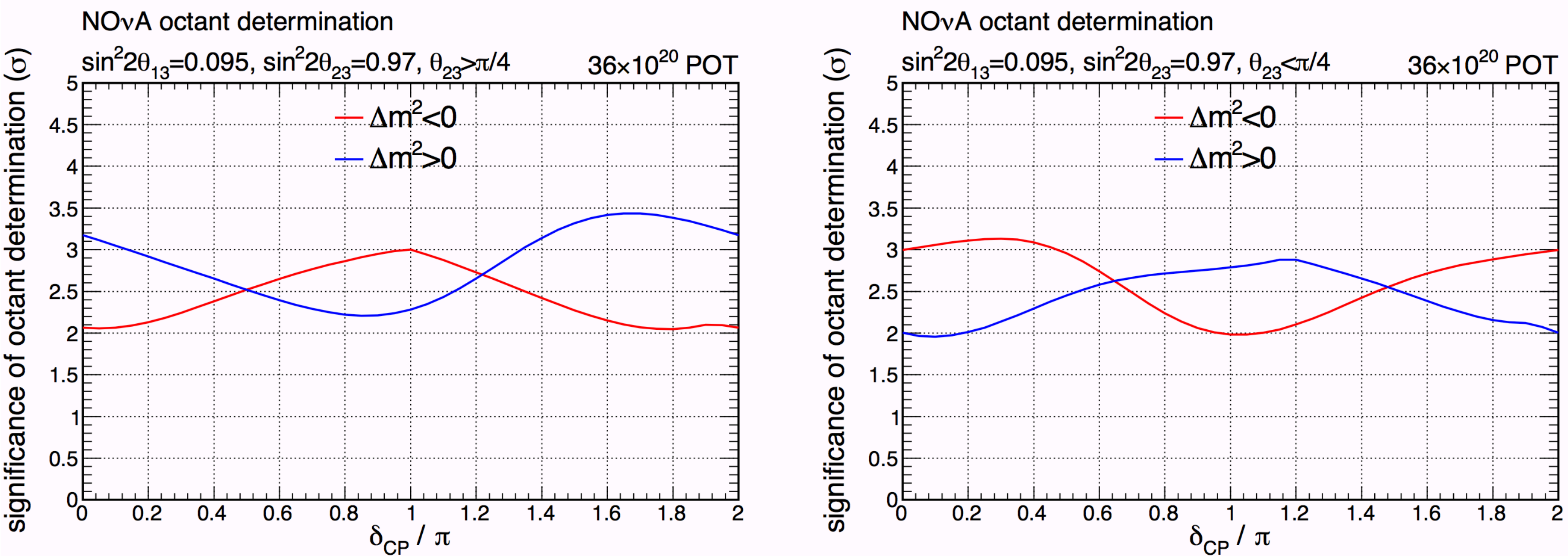
If this is the case then the $P(\nu_\mu \rightarrow \nu_e)$ ellipses shift based on how far θ_{23} differs from 45°.

This corresponds to the mass state ν_3 coupling more to ν_τ or ν_μ





Octant Determination



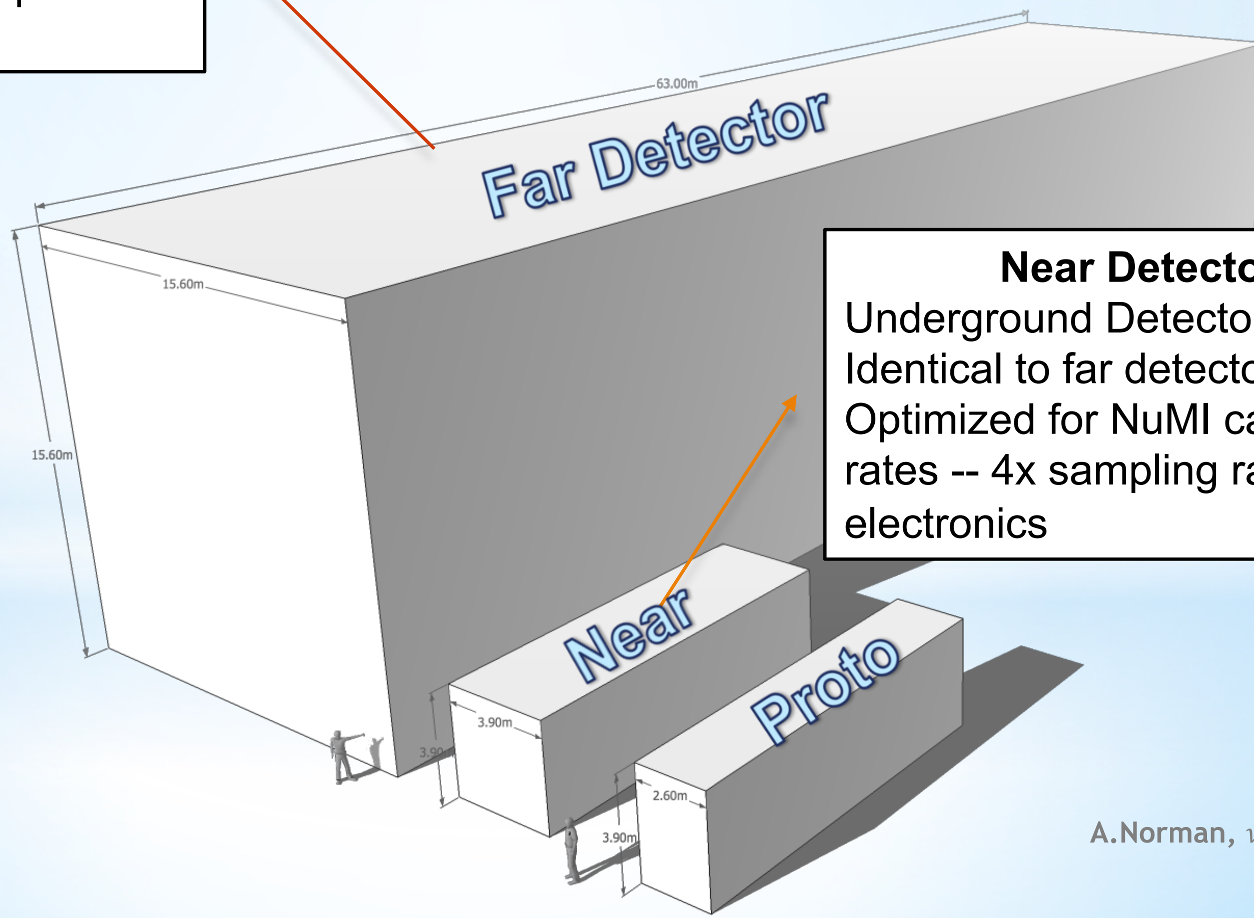
For Non-maximal θ_{23} octant determination by NOνA

- For $\sin^2 2\theta_{23}$=0.97
- > 95% CL for all values of δ_{CP}

NOvA Detectors

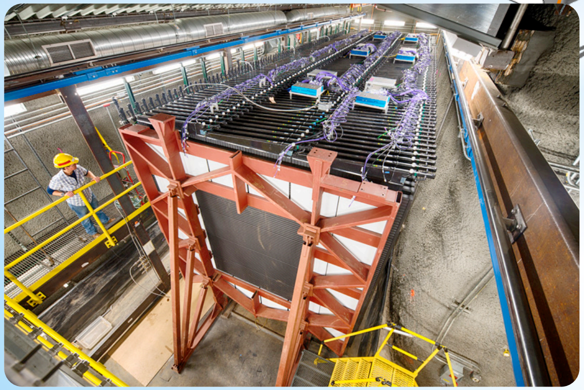
Far Detector

- *Surface Detector*
- 14 kt "Totally Active", Low Z, Range Stack/Calorimeter
- Liquid Scintillator filled PVC
- 896 alternating X-Y planes

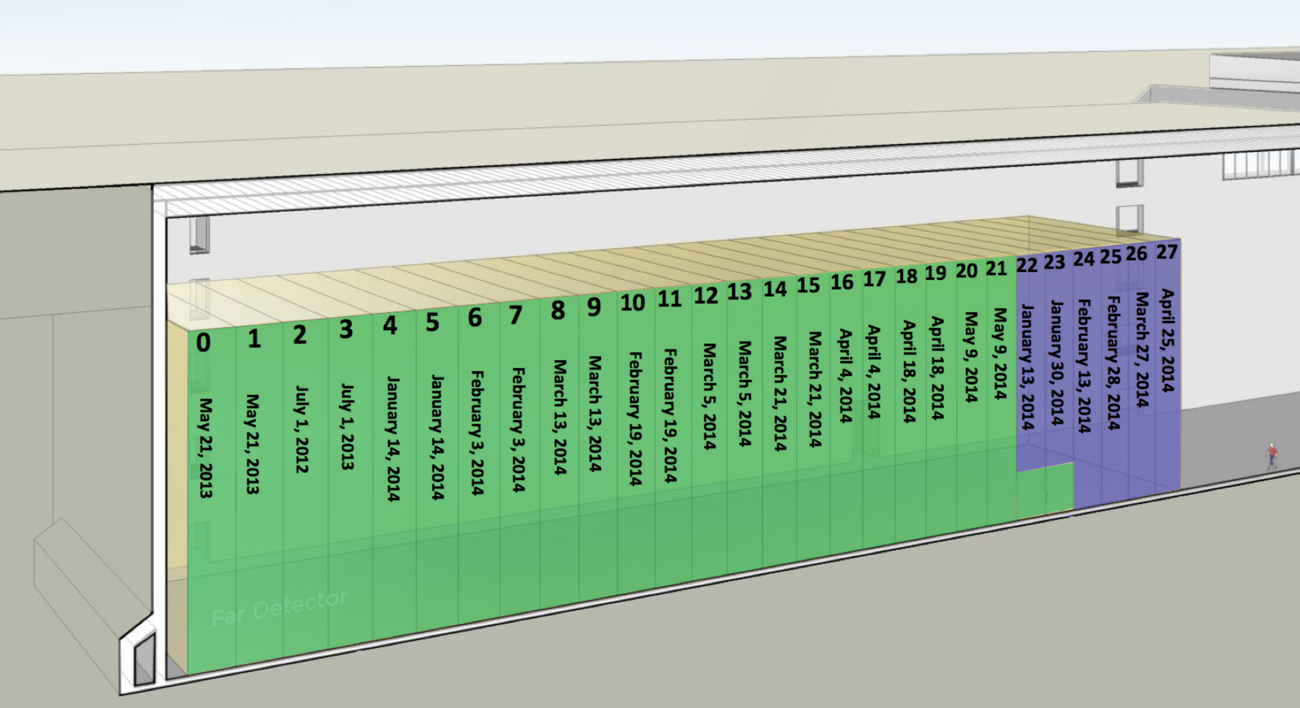


Near Detector

Underground Detector
Identical to far detector
Optimized for NuMI cavern rates -- 4x sampling rate electronics



*NOvA Detectors are BIG



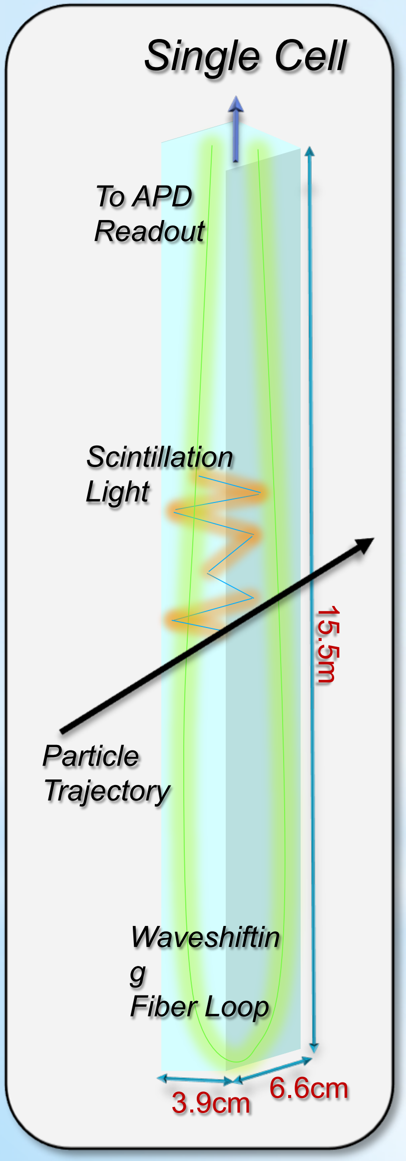
NOvA By the Numbers:

Over:

- ✓ 11 millon liters of scintillator
- ✓ 10.4 million meters of Wavelength Shifting Fiber
- ✓ 305,000 meters of PVC Extrusion
- ✓ 11,000 Detector Modules, Front End Boards & APDs

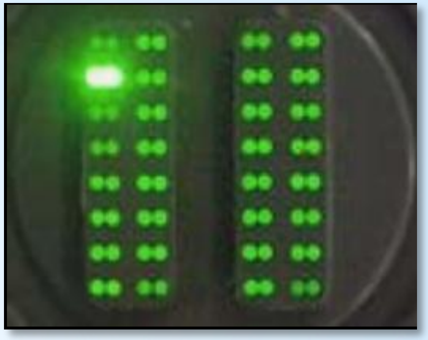
Construction Completed:
Apr 25, 2014 (14 kt)
Electronics:
80% complete (11.25 kt)
Estimated Completion:
July 2014

The Readout Cell

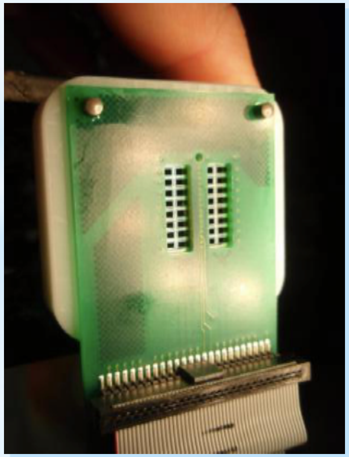


NOvA Detection Cell

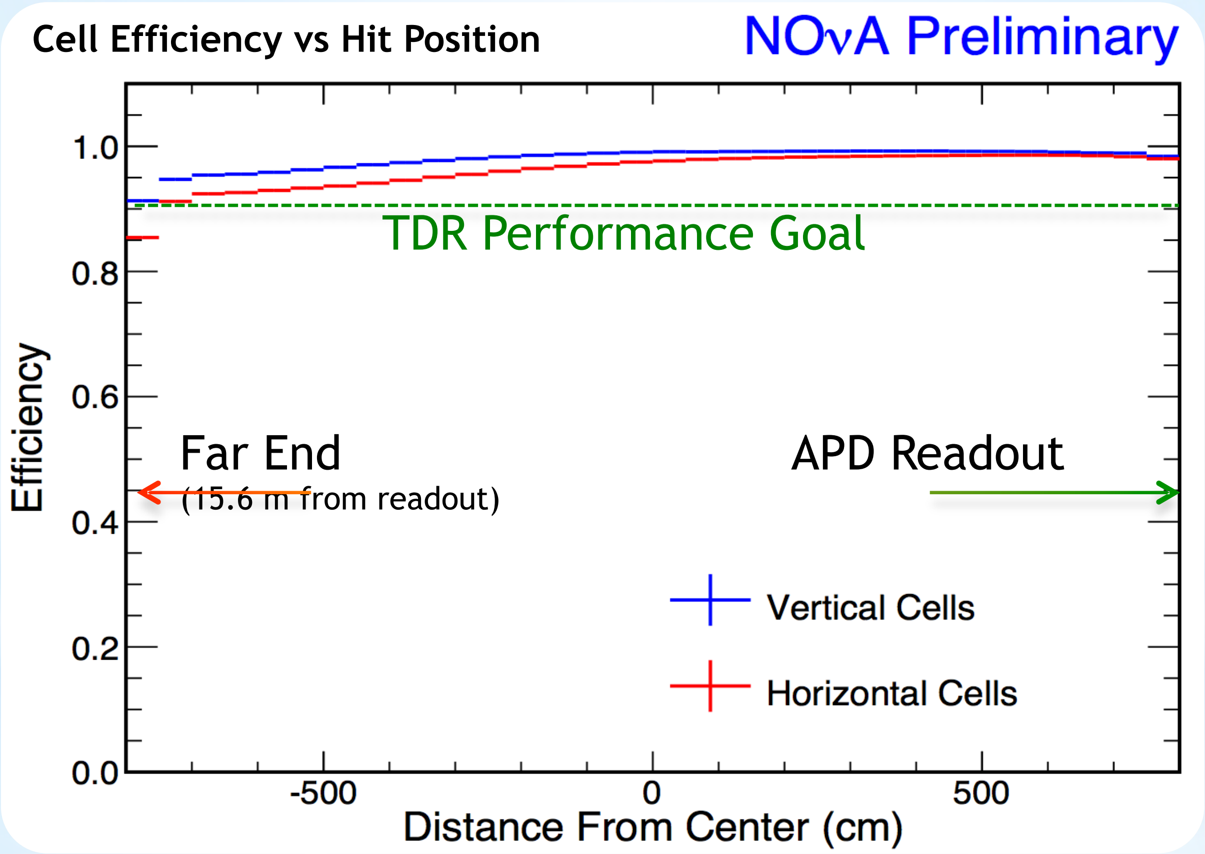
- 15.5 m long, 3.9x6.6cm tube,
- Made of reflective PVC structure,
- Filled with liquid scintillator,
- Wavelength shifting fiber for light transport,
- Read out by an avalanche photodiode
  - Passage of MIP through the cell results in dE/dx ≈12.9 MeV across the cell.
- Need the light output to be 30-38 p.e. from the **FAR END** end to give a 10:1 signal/ noise



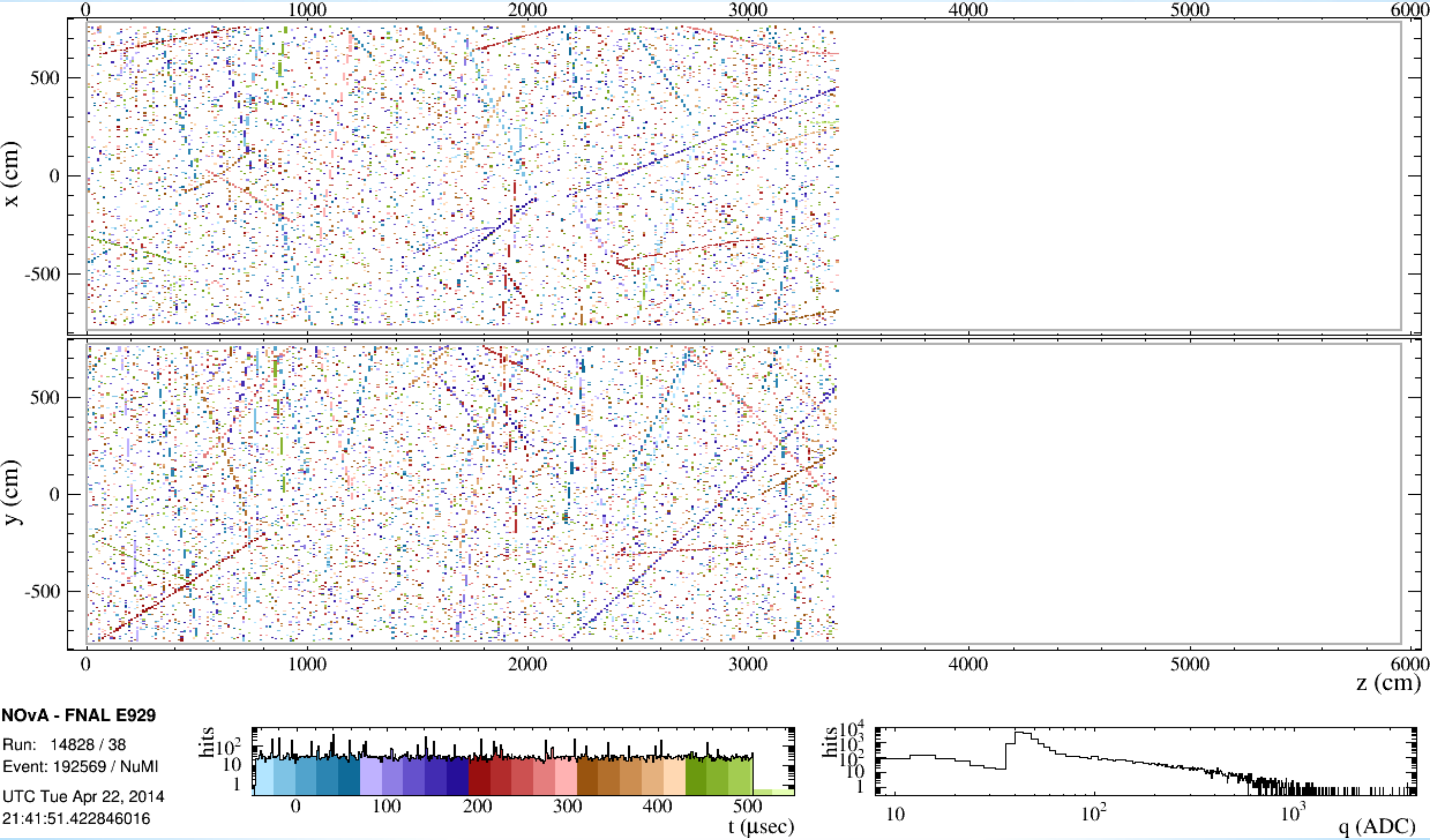
Waveshifting fiber readout and 32pixel APD used for cell digitization



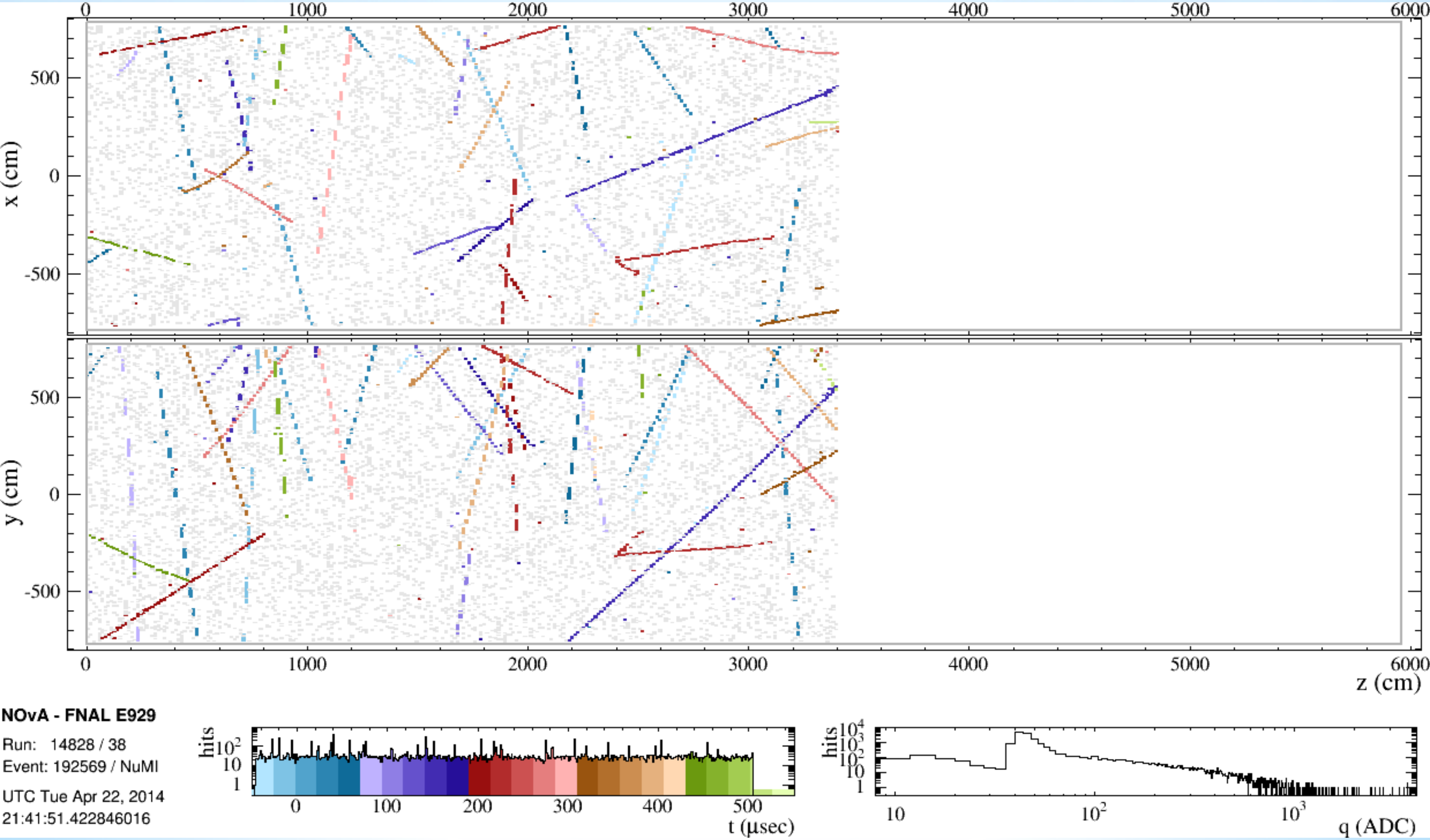
NOνA Cell Efficiency



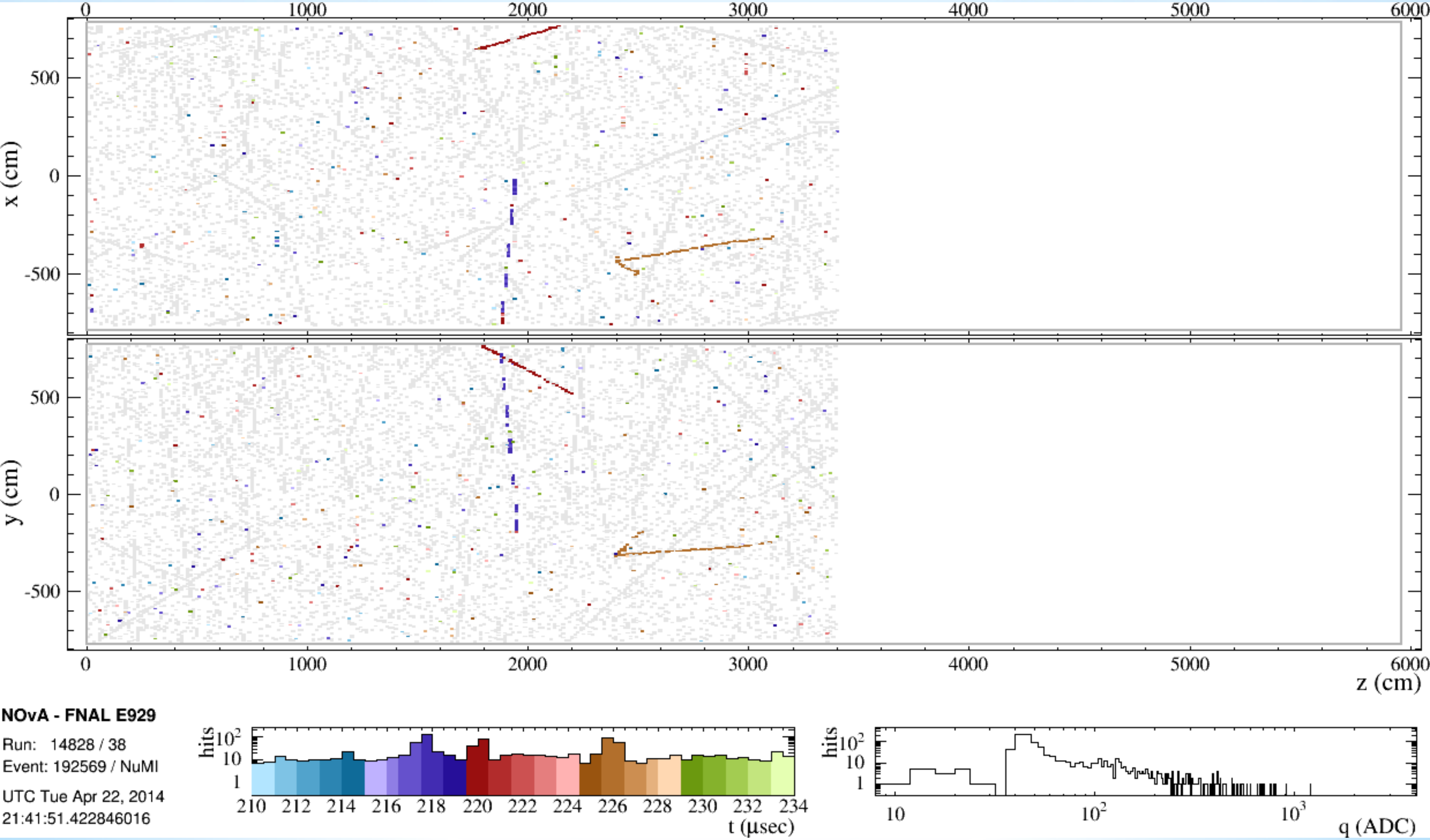
Life on the surface: Cosmic ray rate ~120k Hz



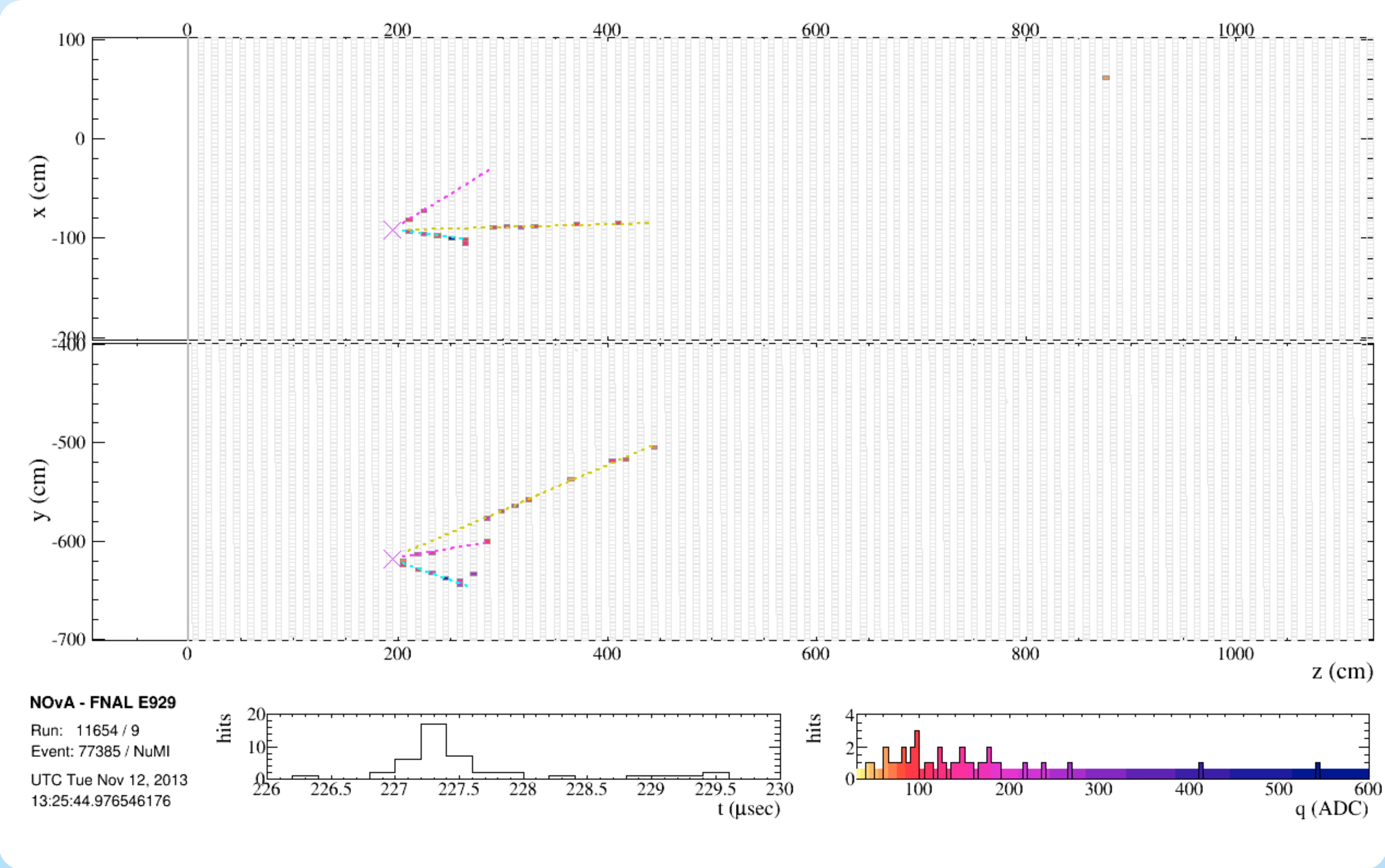
Life on the surface: Reconstructed tracks



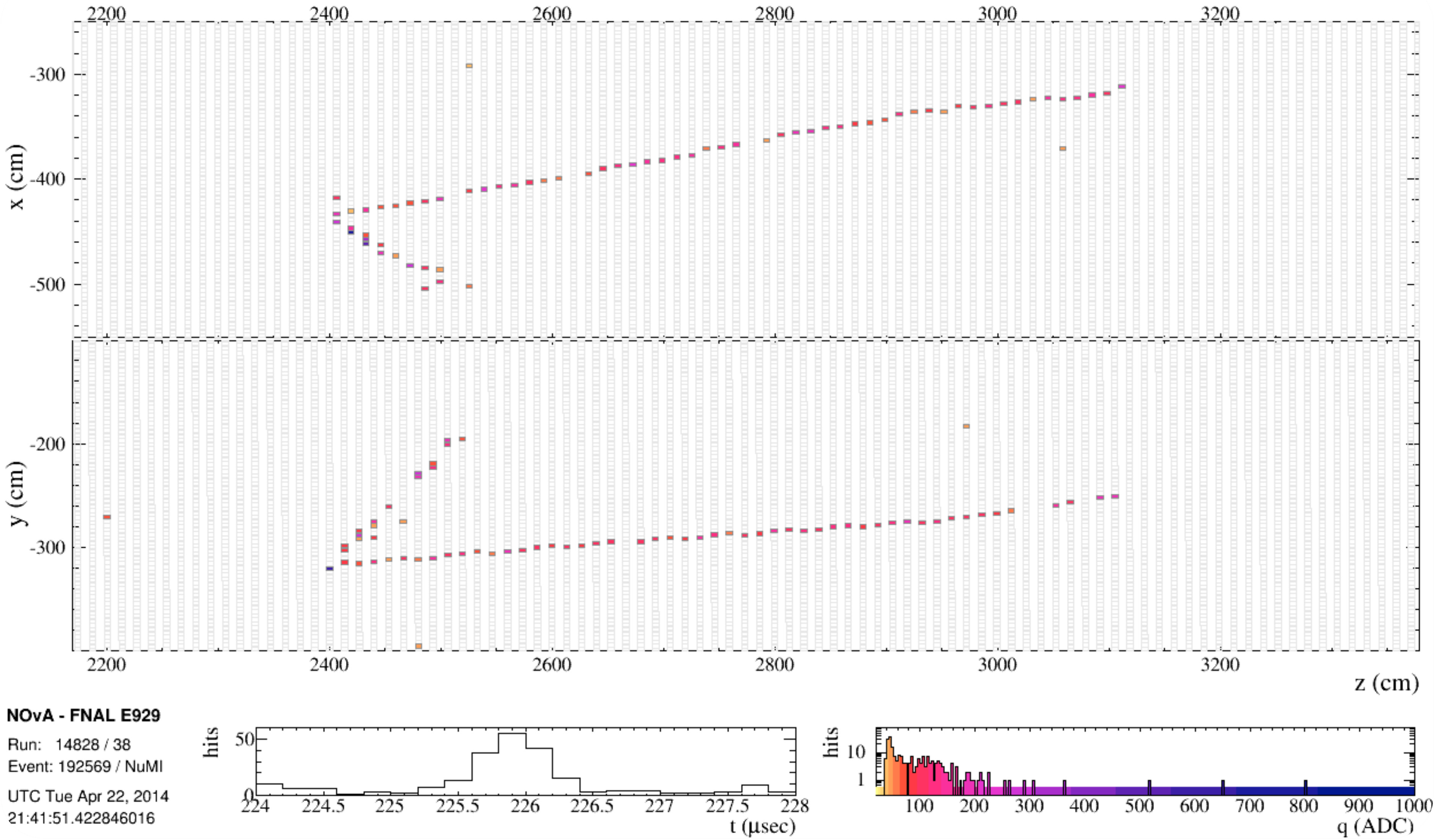
Life on the surface: In time with accelerator signal



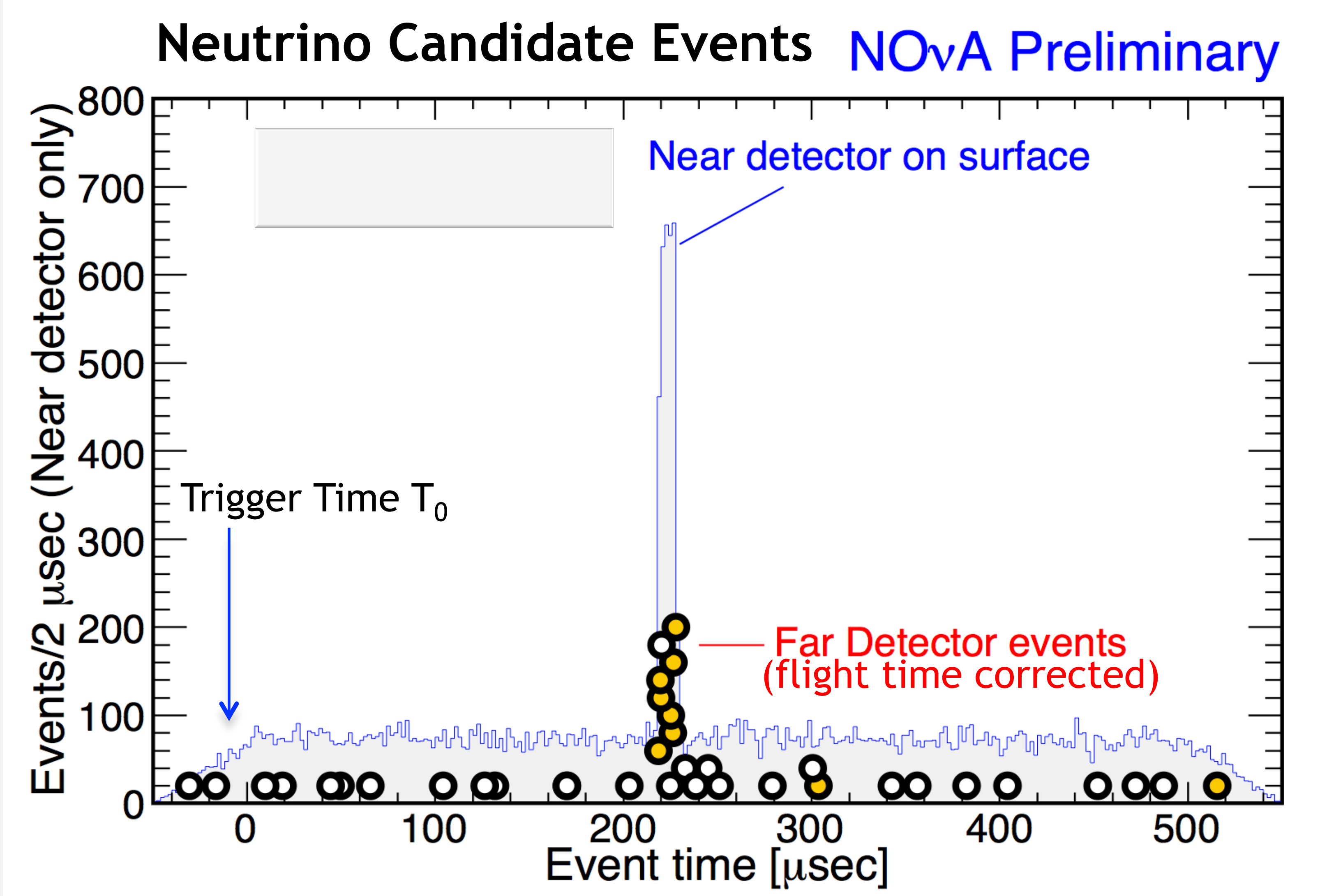
First ν November 12, 2013



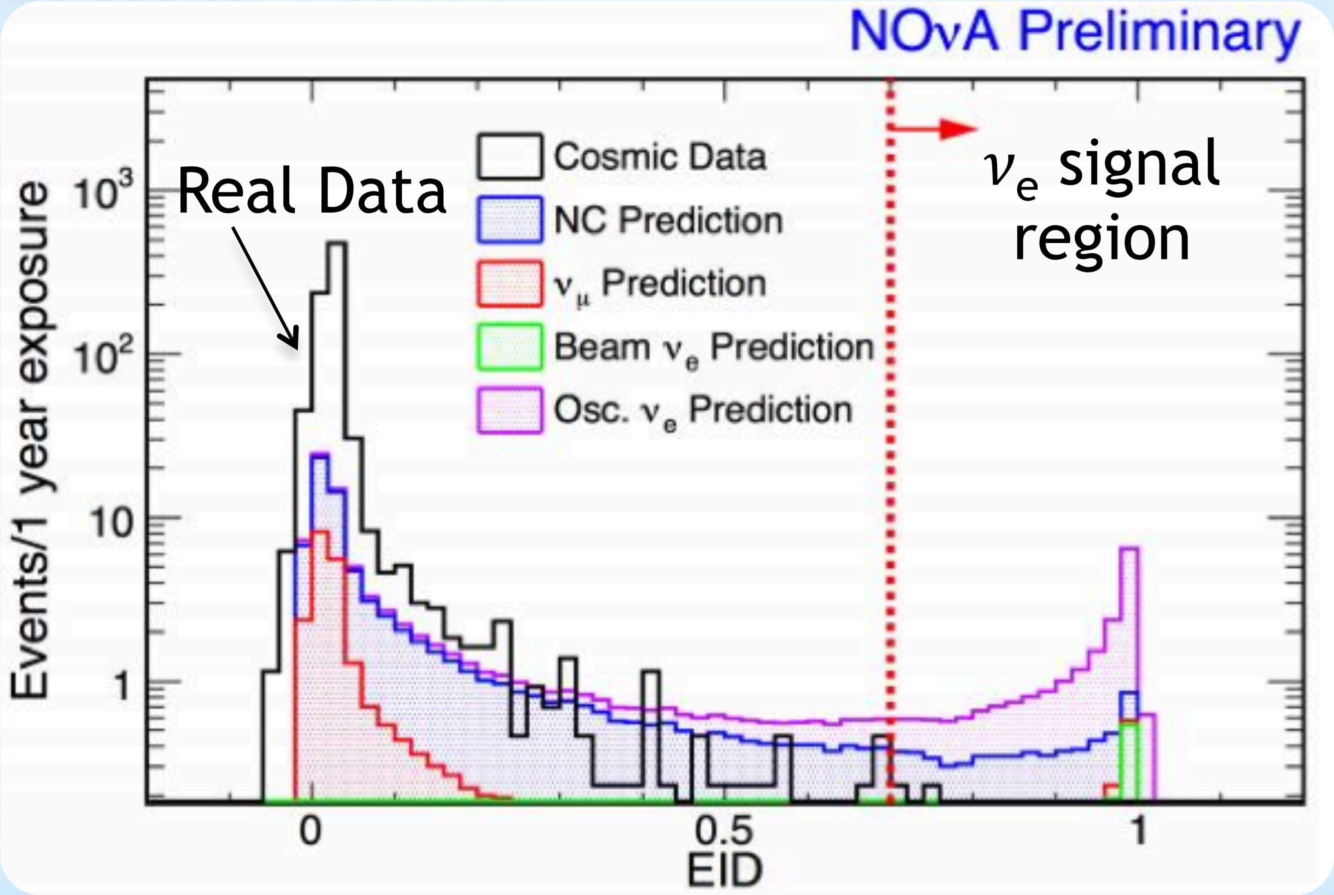
First ν_μ-CC Candidate



Far Detector ν Candidates



ν_e Selection



Complimentary Methods of PID

- EID - Neural net based on EM shower profile
- Library Event Matching (LEM) – Template method based on event topology

ν_e Selection

ν_e Signal and Background Estimates

	Simulation				Data	
Cut	ν_e Signal	NC	Beam ν_e	ν_μ CC	Cosmic Ray	All Background
All Events	36.7	380	28.1	557	19M	19M
Pre-selection	24.7	83.5	2.9	30.0	56k	56k
Vertex Gap	24.6	81.8	2.9	29.6	55k	55k
P_T/P	22.0	59.6	2.6	24.3	1248	1334
Maximum Y	21.2	57.4	2.5	23.0	834	917
Neutral Net	**13.9**	3.9	1.5	0.7	0.5	**6.5**
Library Template	**14.0**	3.5	1.5	1.1	0.9	**7.0**

- Exposure 6×10^{20} POT
- 1 yr at design mass/beam power
- 14 kt total detector mass

- Signal estimates are leading order
- Simple oscillation w/o matter effect
- Averaged over hierarchy and δ_{CP}

Summary

* Near and Far Detectors are complete.
* Detectors functoning as expected.
* We are currently acquiring beam data.
* Accelerator is ramping toward 700 kW.
* By end of year we will have collected the data for our first oscillation results.