NOvA neutrino experiment

Filip Jediný, CTU in Prague
On behalf of the NOvA Collaboration

The 20th International Conference on Particles and Nuclei
Hamburg University, Germany
August 28, 2014

7 countries, 38 Institutions, 205 collaborators

Argonne National Laboratory·University of Athens·Banaras Hindu University·California Institute of Technology·Institute of Physics of the Academy of Sciences of the Czech Republic·Charles University, Prague·University of Cincinnati·Czech Technical University University of Delhi·Fermilab·Federal Univ. of Goias· IndianInstitute of Technology, Guwahati·Harvard University·Indian Institute of Technology University of Hyderabad·Indiana University· Iowa State University·University of Jammu·Lebedev Physical Institute Michigan State University·University of Minnesota, Crookston·University of Minnesota, Duluth·University of Minnesota, Twin Cities, Institute for Nuclear Research, Moscow·Panjab, University·University of South Carolina·Southern Methodist University·Stanford University, University of Sussex·University of Tennessee·University of Texas at Austin·Tufts University·University of Virginia·Wichita State University·Winona State University·College of William and Mary

NOvA status – Outline

- Experiment overview
- Detector design
- Physics reach
- Current status

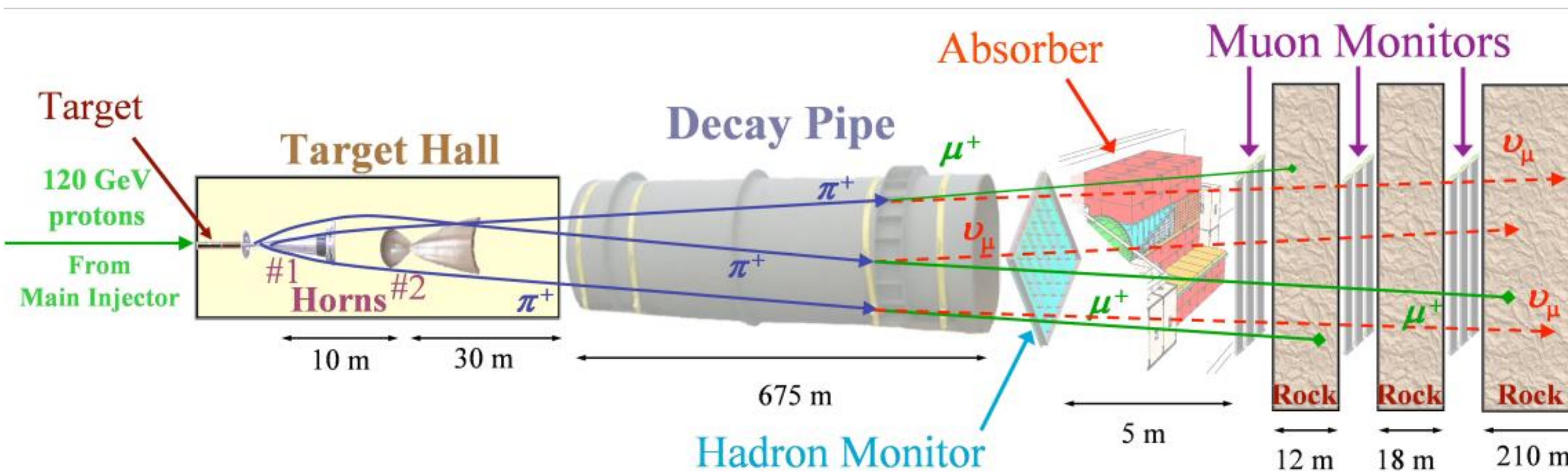
NuMI Off-axis ν_e Appearance Experiment

- Long-baseline, two-detector ν oscillation experiment
- Looks for ν_e in ν_μ NuMI beam
- 14 mrad off-axis
- 2 liquid scintillator detectors
- FD (14 kton), ND (0.3 kton)
- Cooled APD readout

How to make a neutrino beam

NuMI Off-axis ν_e Appearance

- NuMI - Neutrinos at the Main Injector, both ν_μ and $\bar{\nu}_\mu$
- Series of upgrades - 10 μs beam spill every 1.33 s
- Beam back from Sept 2013 (300 -> 700 kW)
- 500 kW limit until Booster RF system upgrades complete
- 4.9×10^{13} POT/pulse – 6×10^{20} POT/year

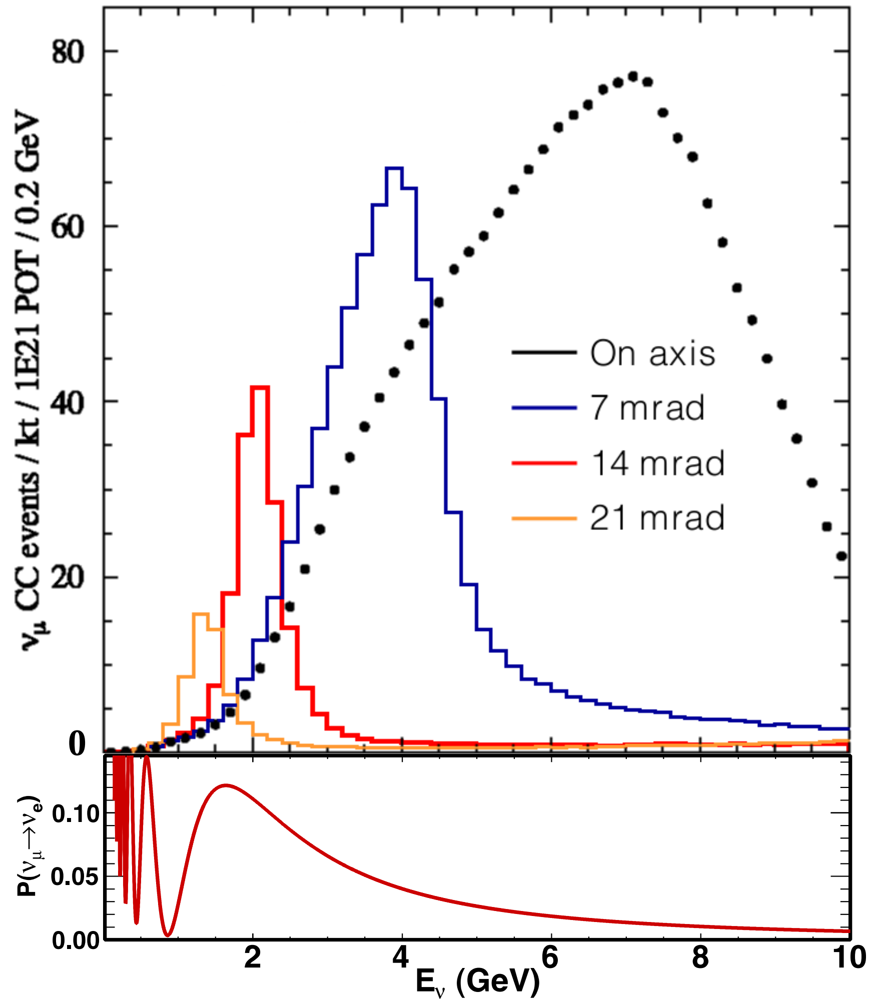


Why off-axis?

NuMI Off-axis ν_e Appearance

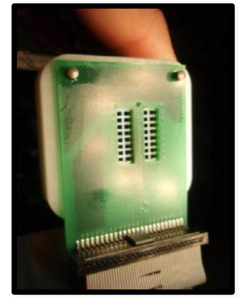
The choice of a 14 mrad off-axis position from the NuMI beam for the NOvA detector, allows for a narrow band beam which in conjunction with topology of final state particles, allows one to more easily reject potential backgrounds

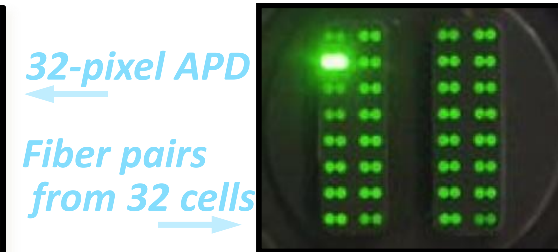
The peak of the beam coincides with the oscillation maximum for electron neutrino appearance for the 810 km distance

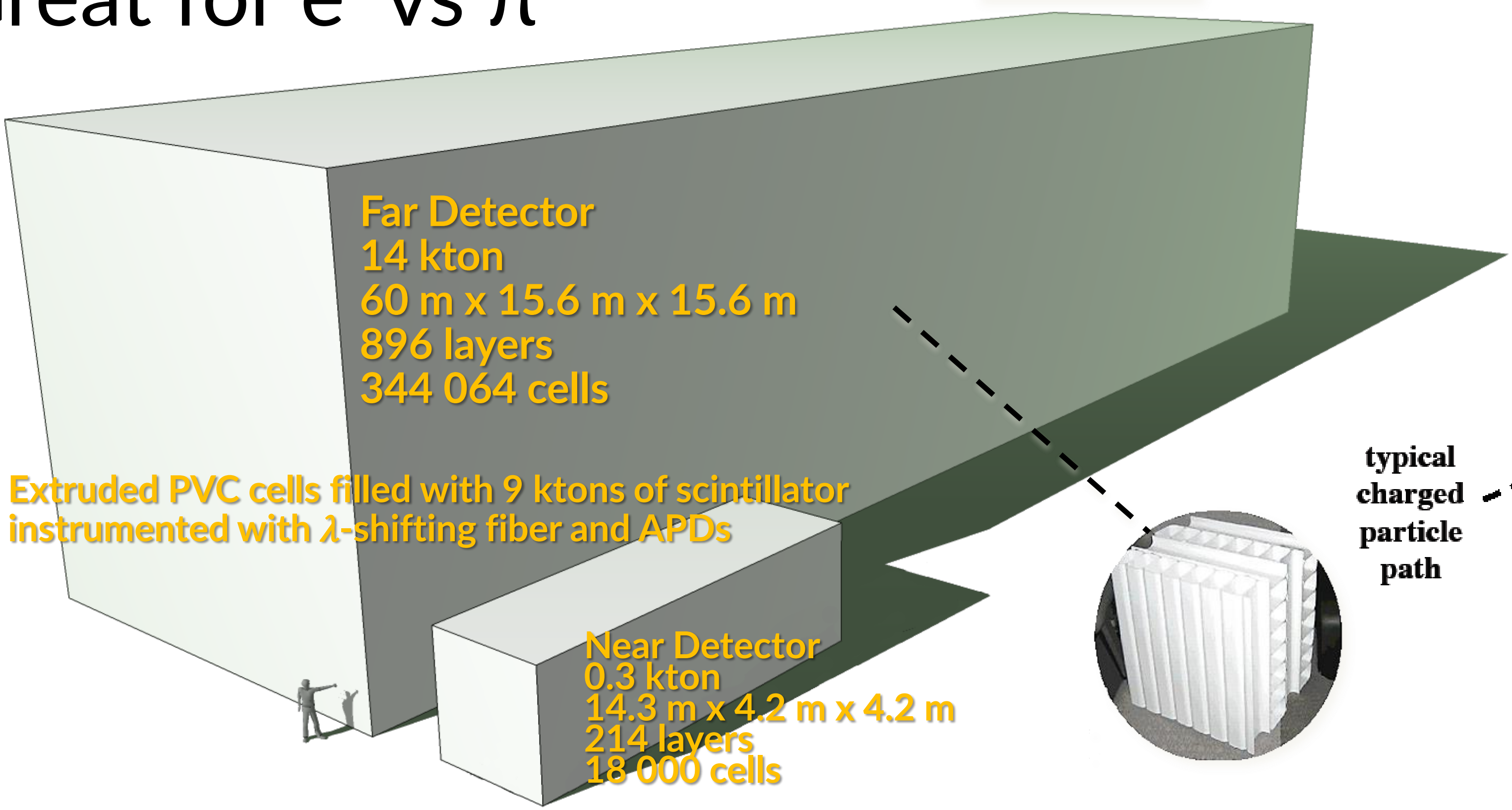


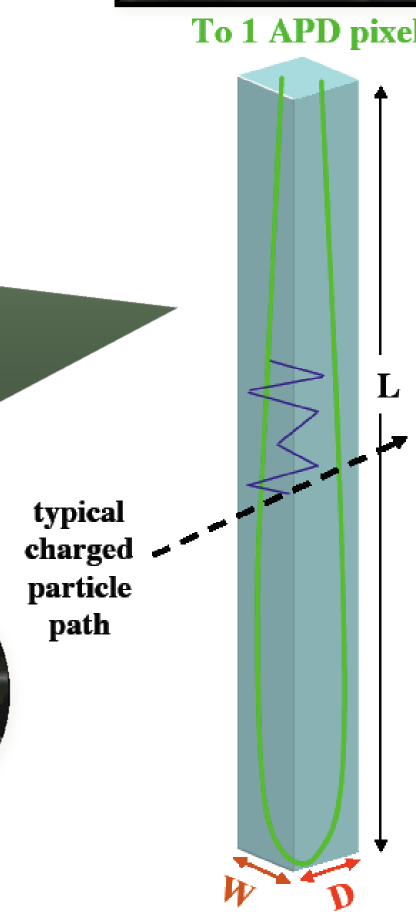
The NOvA detectors

- 64% active detector
- Each plane 0.15 X_0
  Great for e^- vs π^0

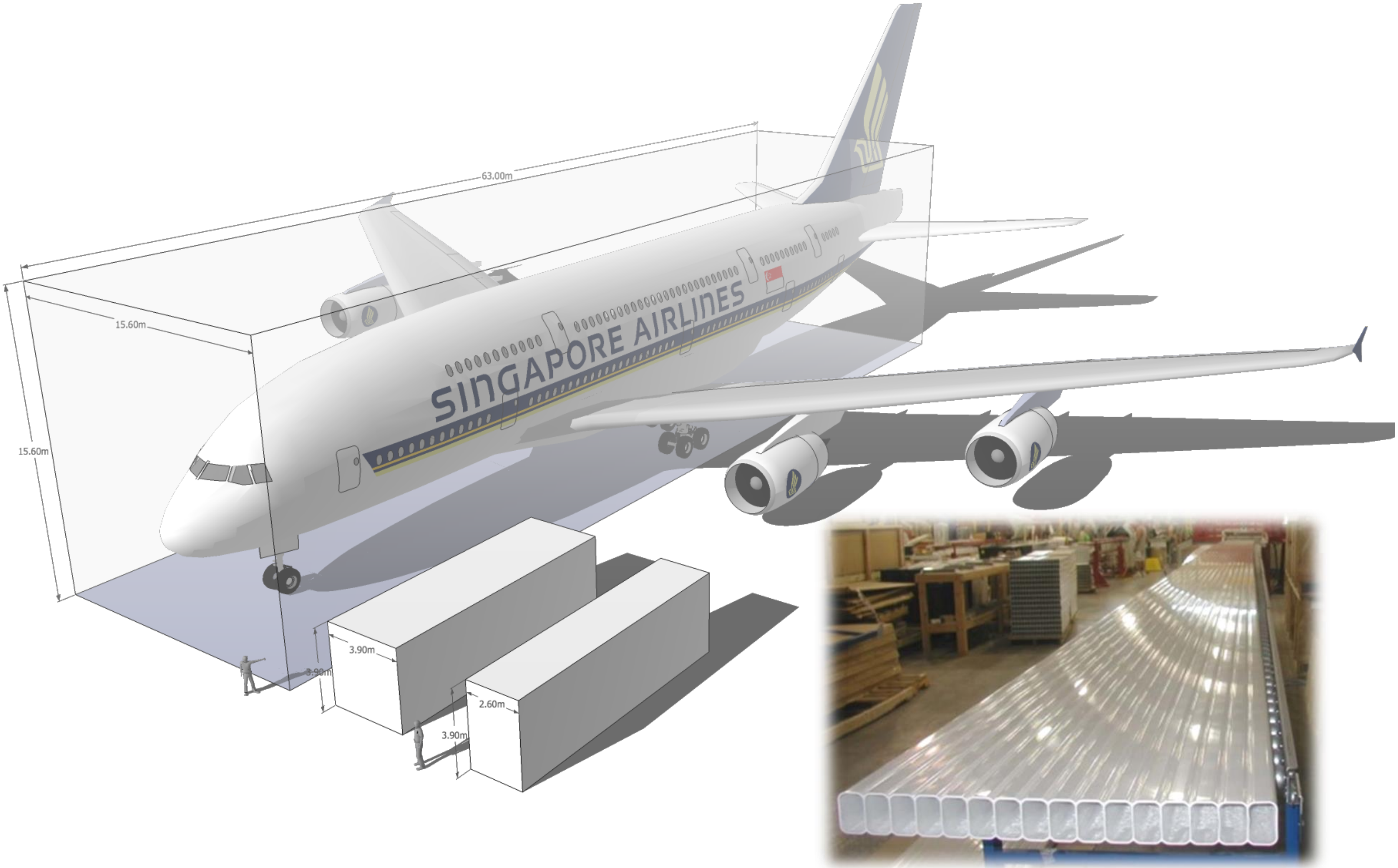








The NOvA detectors



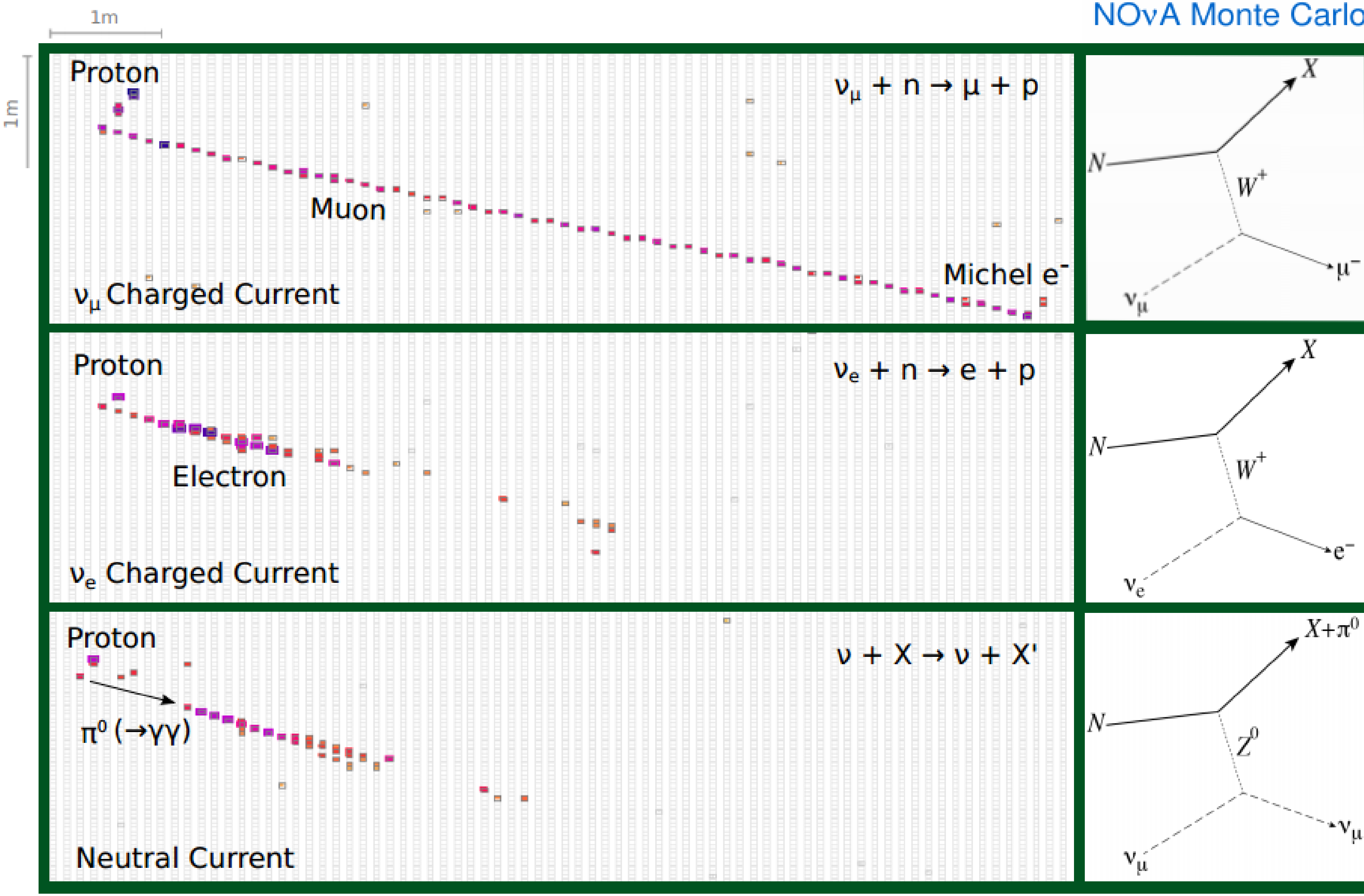
Near Detector On Surface

- 200 t NDOS
- Tested detector design, installation procedures, electronics, DAQ.
- Collected beam data from two neutrino beamlines from December 2010 to April 30th 2012 and from Sept 4 2013
- Analyzed Data, performed calibrations

Near Detector On Surface

- 200 t NDOS
- Tested detector design, installation procedures, electronics, DAQ.
- Collected beam data from two neutrino beamlines from December 2010 to April 30th 2012 and from Sept 4 2013
- Analyzed Data, performed calibrations

NOvA Neutrino Event Topologies

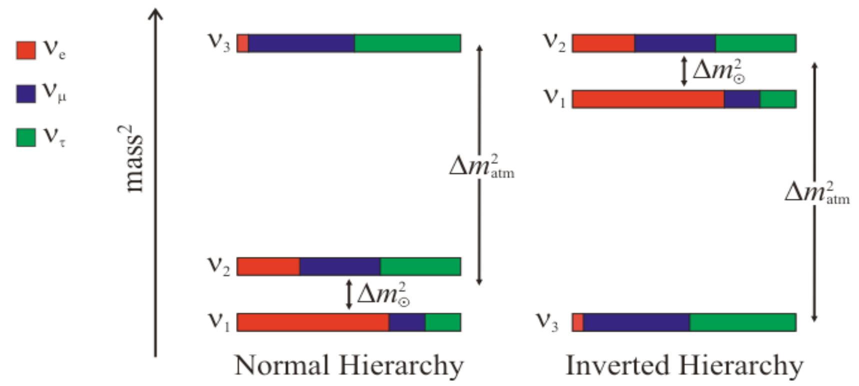



electron-
neutrino


muon-
neutrino

NOvA physics goals

- Observe $\nu_\mu \rightarrow \nu_e$, $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$
  - **Measure θ_{13} via ν_e appearance**
  - **Determine the neutrino mass hierarchy**
  - **Search for neutrino CP violation**
  - **Determine the θ_{23} octant**



- Observe $\nu_\mu \rightarrow \nu_\mu$, $\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$
  - Precision measurements of $|\Delta m^2_{32}|$, θ_{23}
  - Over-constrain the atmospheric sector

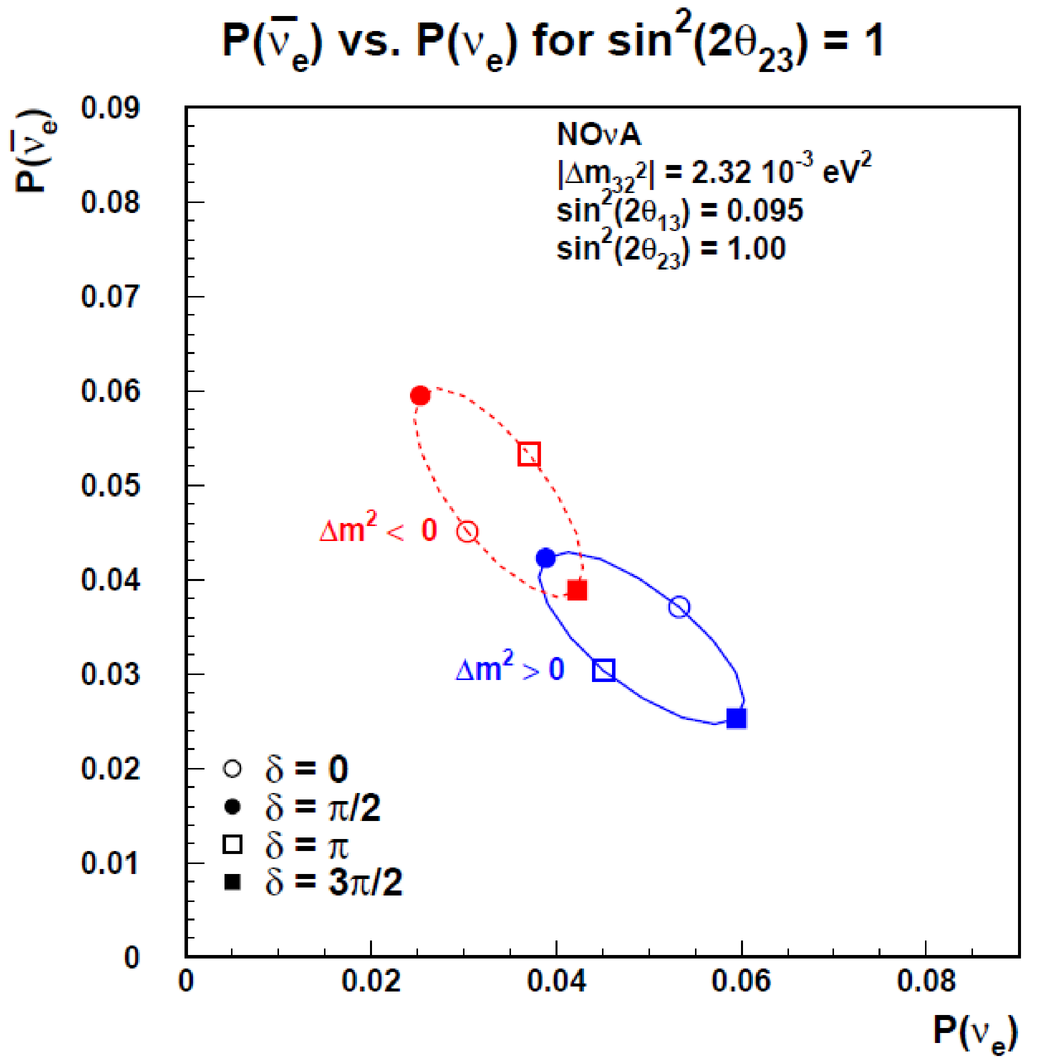
- Non-oscillation physics program
  - Neutrino cross-sections at the Near Detector
  - Sterile neutrinos
  - Supernova neutrinos
  - Magnetic monopoles
  - Non-Standard neutrino Interactions (NSI)

ν_e appereance in NOvA

- NOvA will measure:

  $P(\nu_\mu \rightarrow \nu_e)$ at 2 GeV and

  $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$ at 2 GeV



- Large θ_{13} reduces the overlap between these bi-probability ellipses, reducing the likelihood of degeneracies

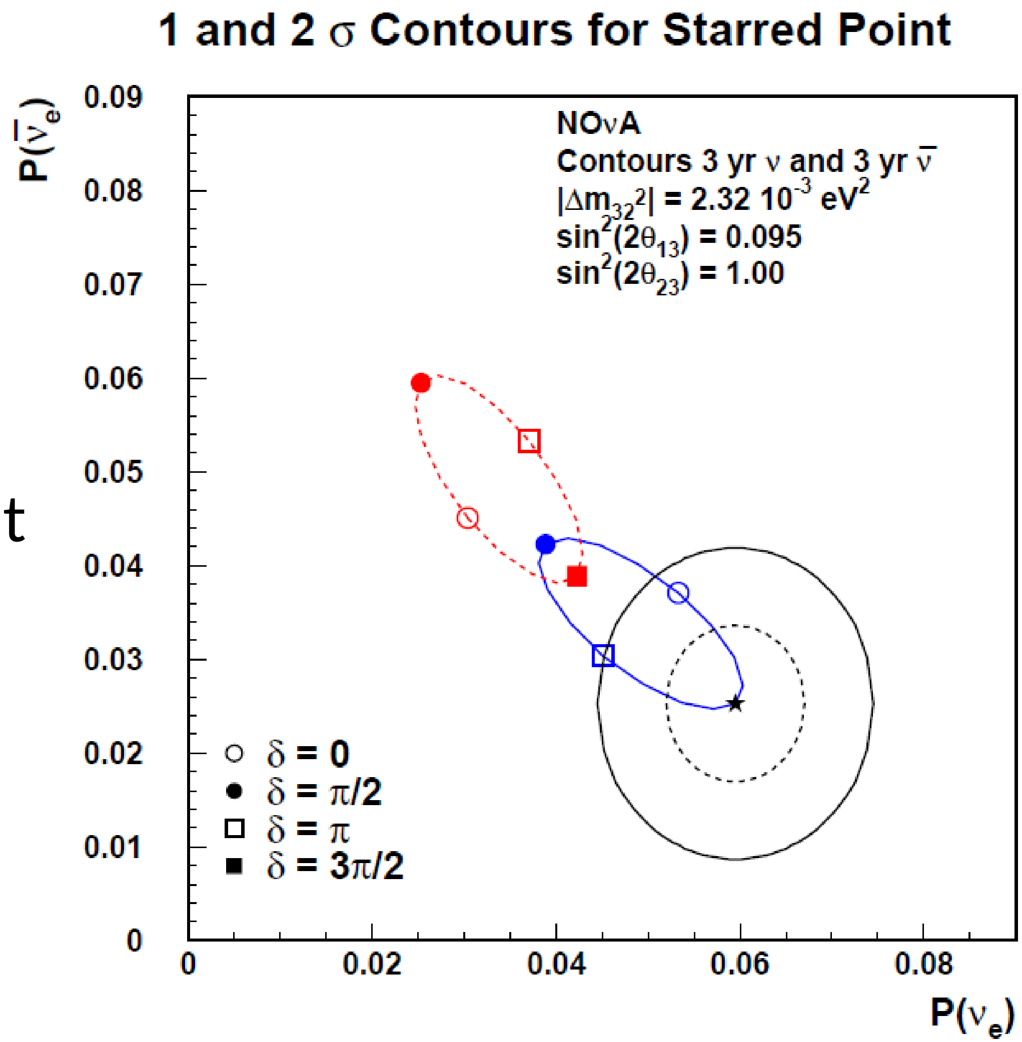
ν_e appereance in NOvA

- NOvA will measure:

  $P(\nu_\mu \rightarrow \nu_e)$ at 2 GeV and

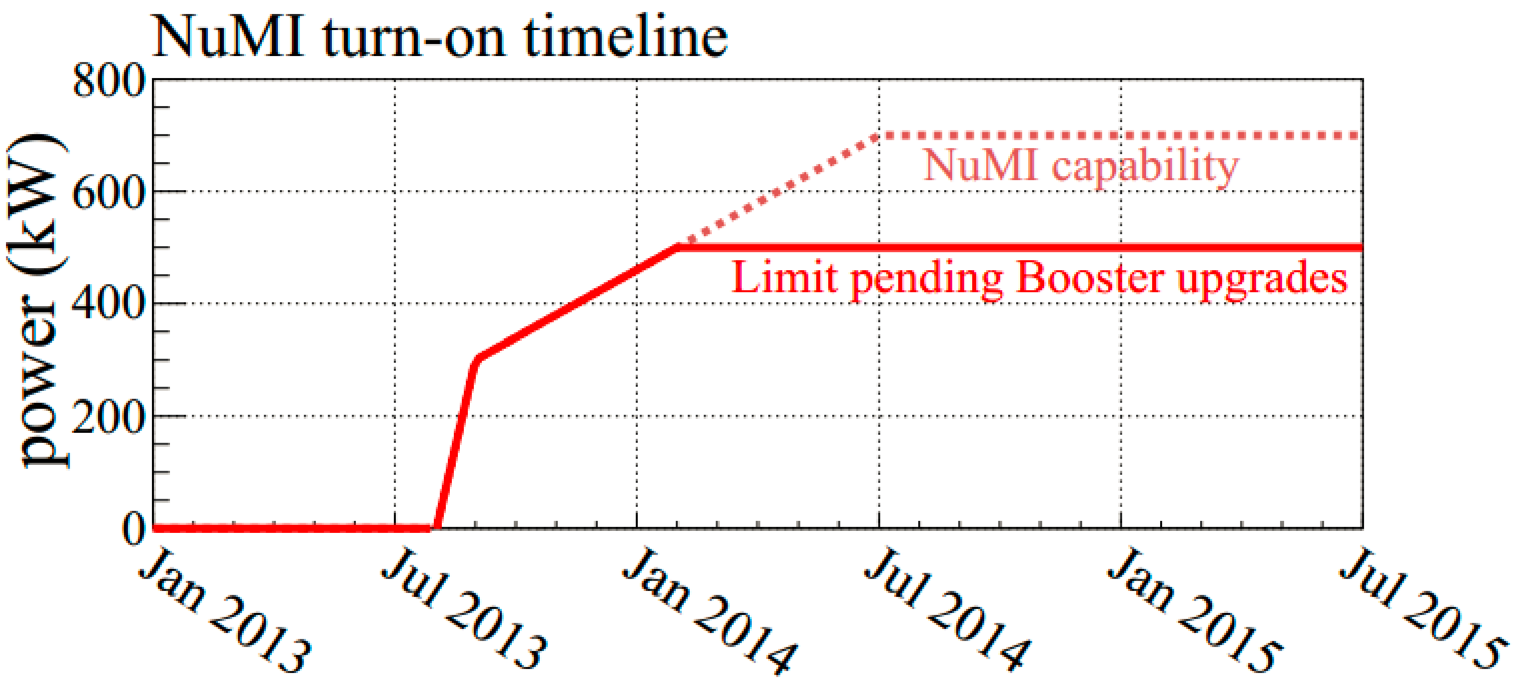
  $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$ at 2 GeV

- Example of 6y NOvA result
- Large θ13 reduces the overlap between these bi-probability ellipses, reducing the likelihood of degeneracies



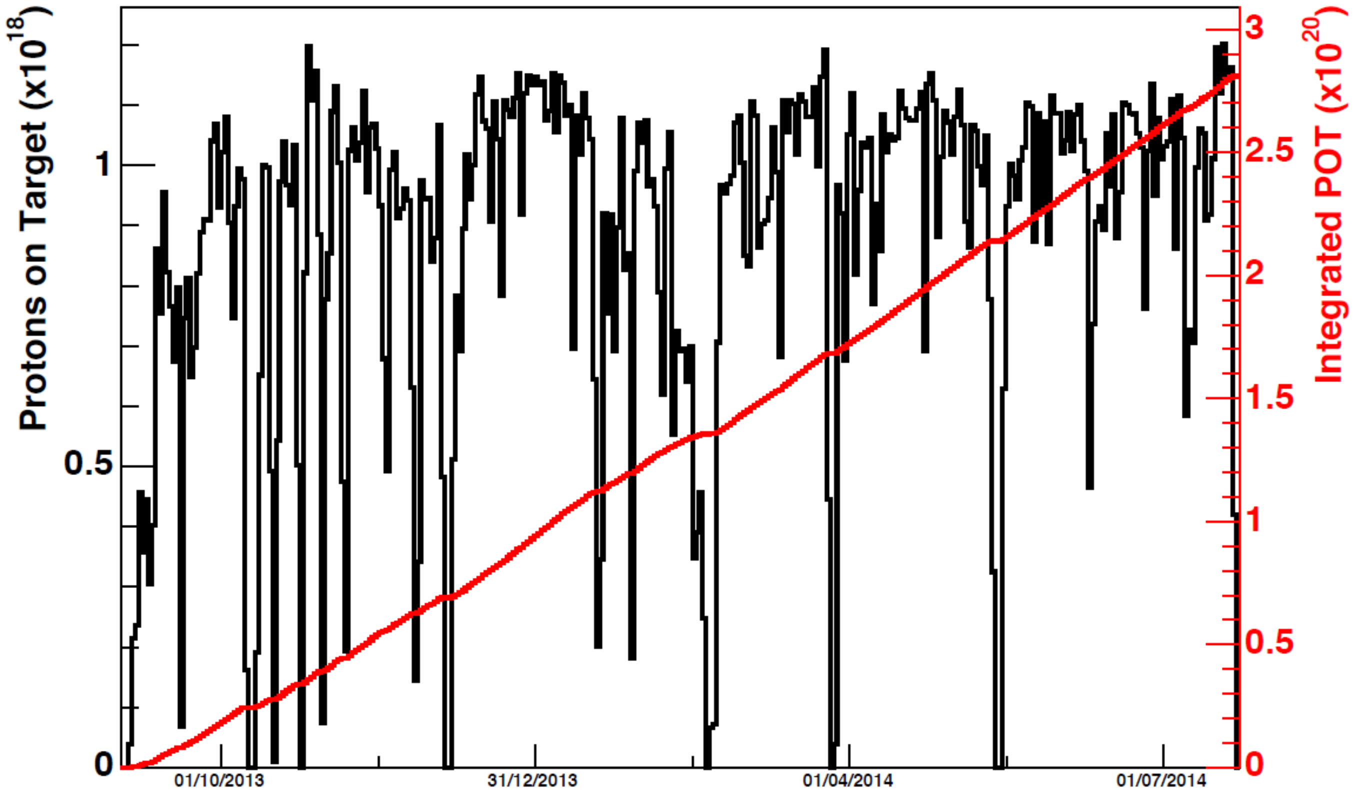
Beam status

- First beam on September 4, 2013
- Need Booster upgrades to reach 700 kW
- We see neutrinos, stay tuned for first results!

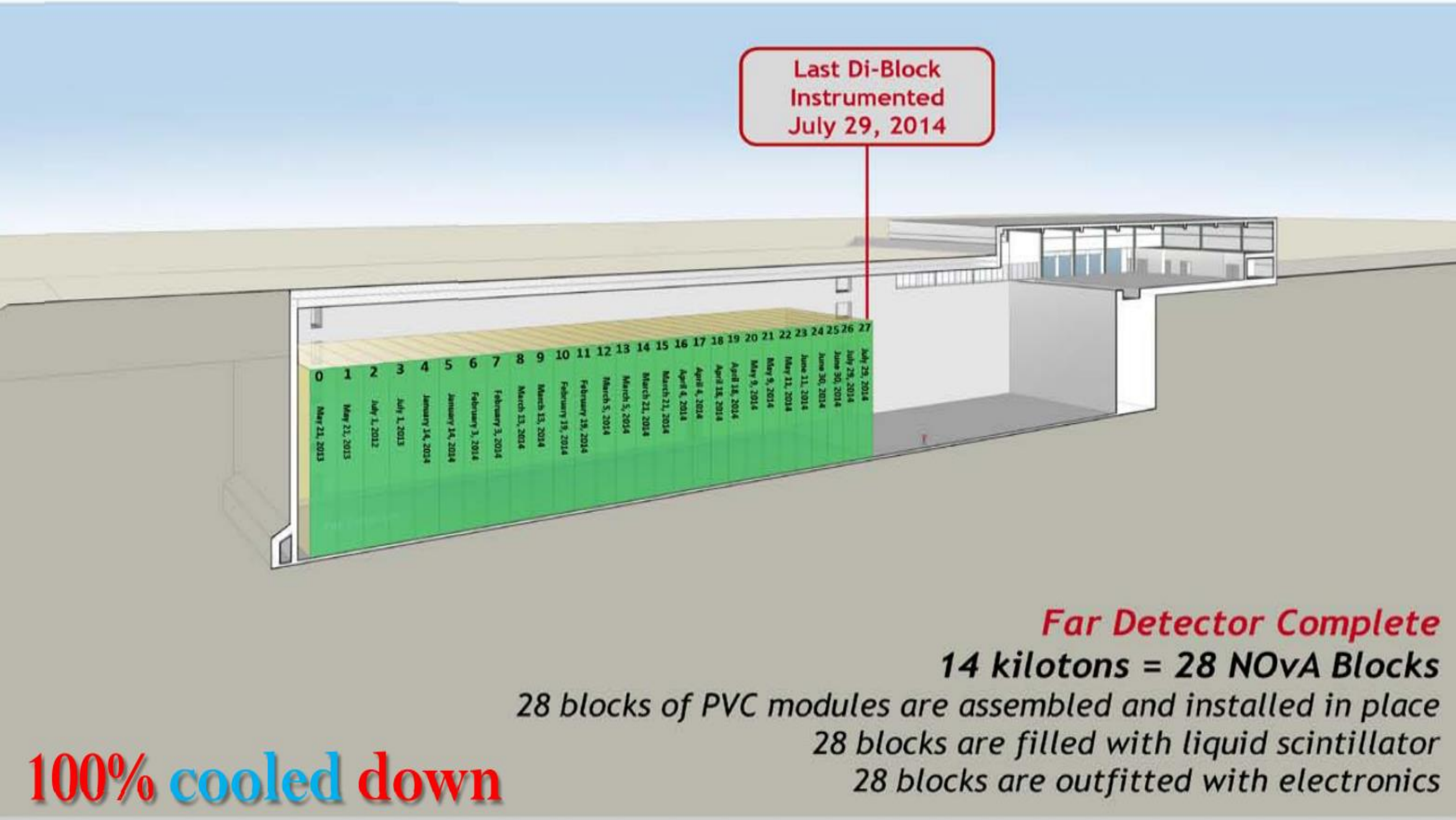


Beam status

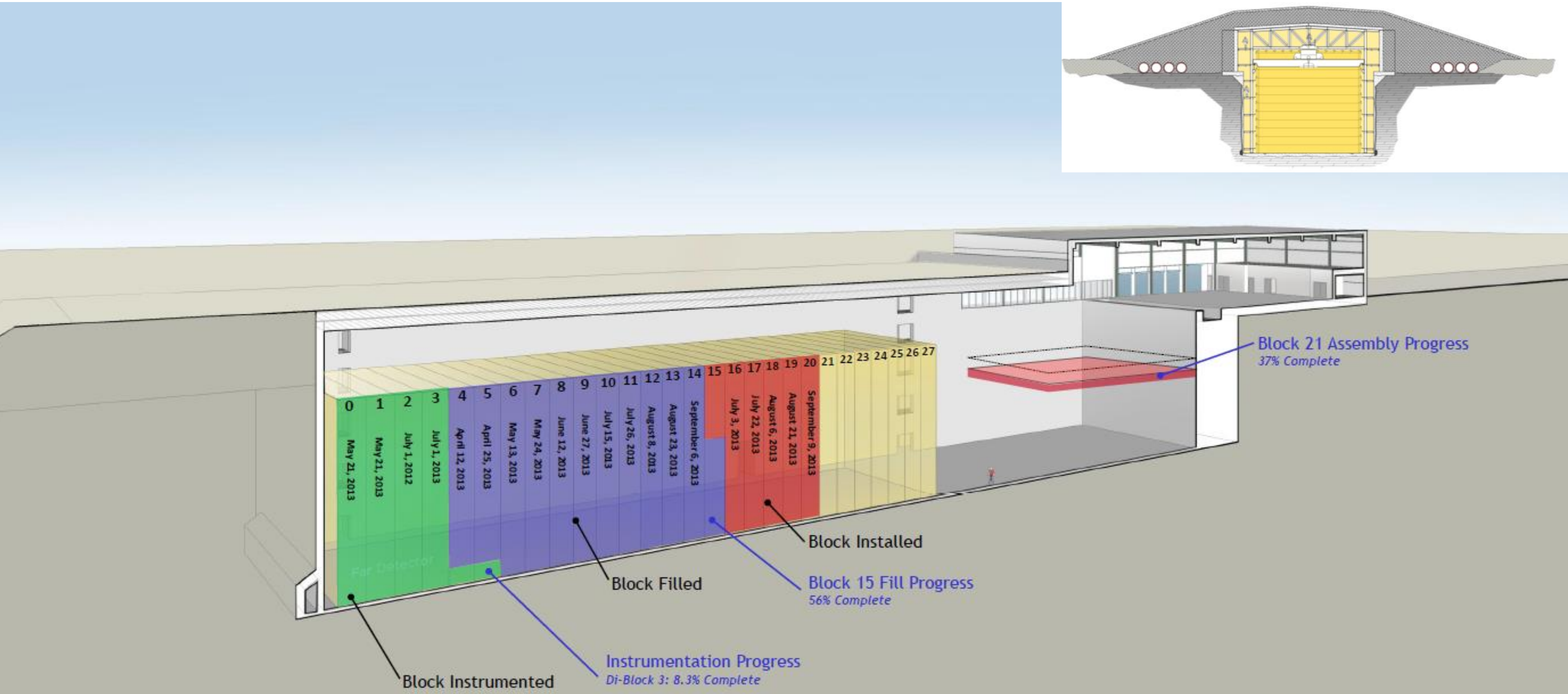
- First beam on September 4, 2013
- Need Booster upgrades to reach 700 kW
- We see neutrinos, stay tuned for first results!



FD construction status



FD construction status



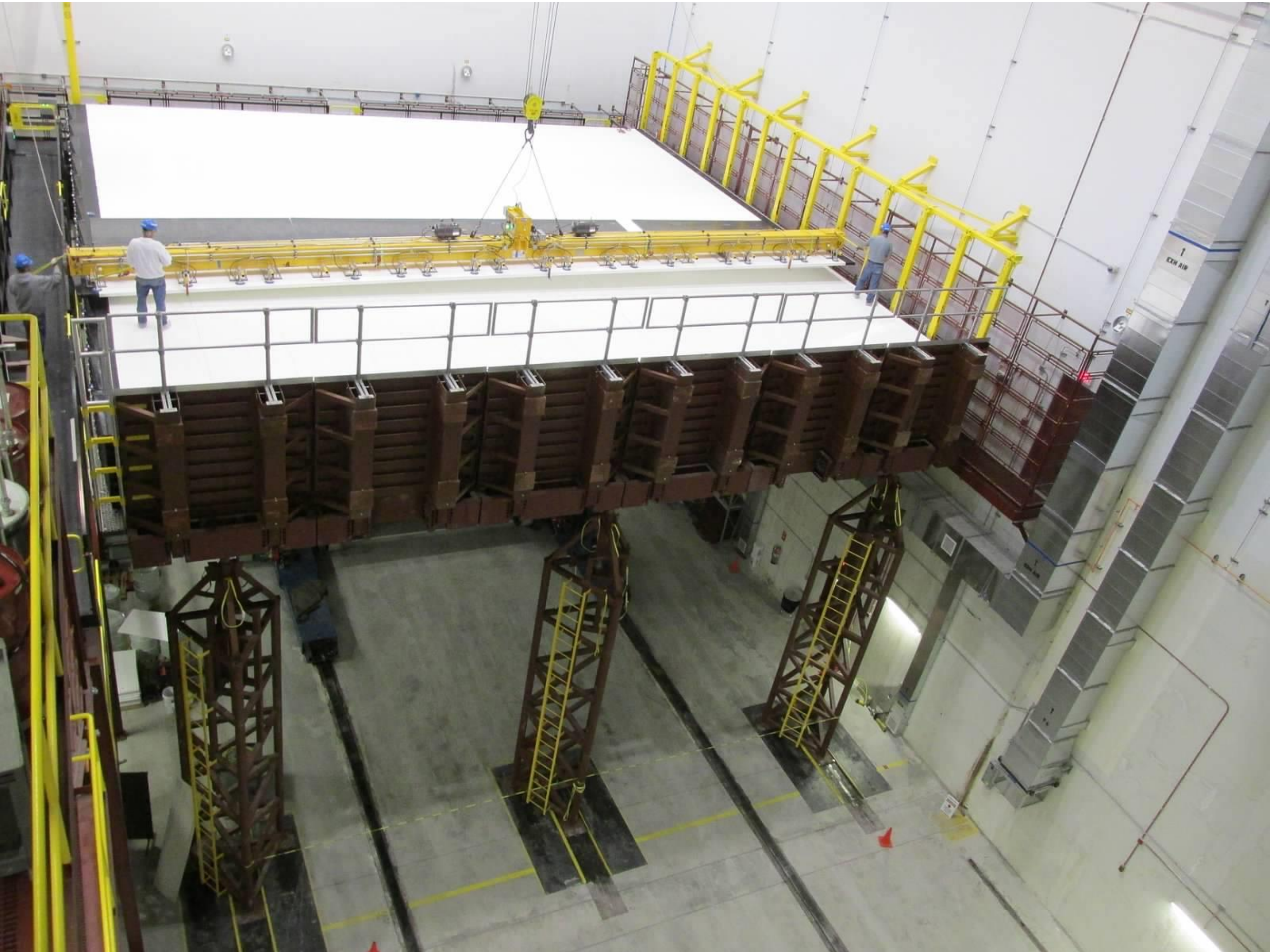
14 kilotons = 28 NOvA Blocks

21 blocks of PVC modules are assembled and installed in place

15.56 blocks are filled with liquid scintillator

4.17 blocks are outfitted with electronics

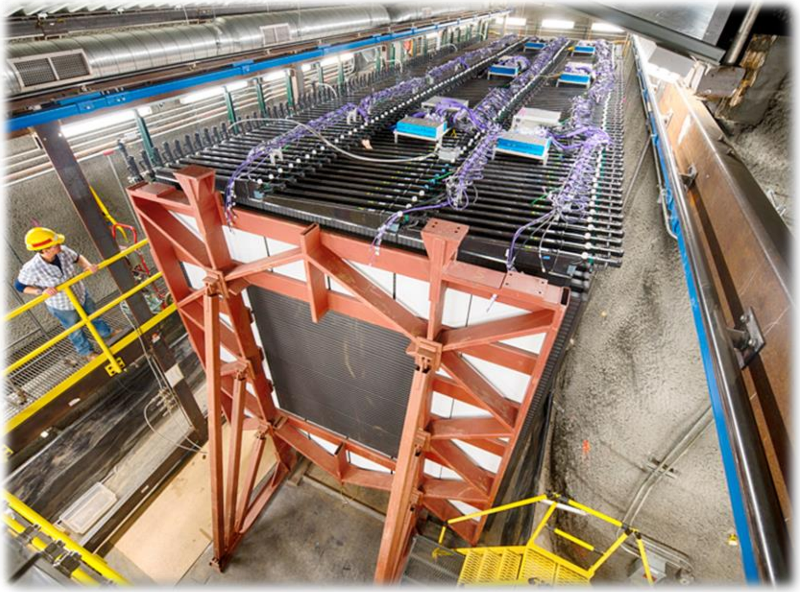

Empty Hall




Di-Block: 01
Position: 06

ND Construction Progress

- First block installed Aug 2013
- Completed just few days ago
- Whole Near detector filled, fully instrumented, cooled
- Taking physics data!



Summary

- Both detectors are **completed**, fully instrumented
- NuMI beam upgraded, **ν observed** in both detectors
- Reconstruction/analysis tools in place for first results in 2014/2015
- NOvA will make many important contributions to neutrino physics:
  - Important first information on the neutrino mass **hierarchy** and **CP violation**
  - Determination of the θ_{23} octant, Measurement of θ_{13}
  - More precise measurements of $|\Delta m^2_{32}|$ and $\sin^2(2\theta_{23})$
  - Cross sections, Magnetic monopoles, …

Stay tuned

facebook.com/novaexperiment

@NOvANuZ

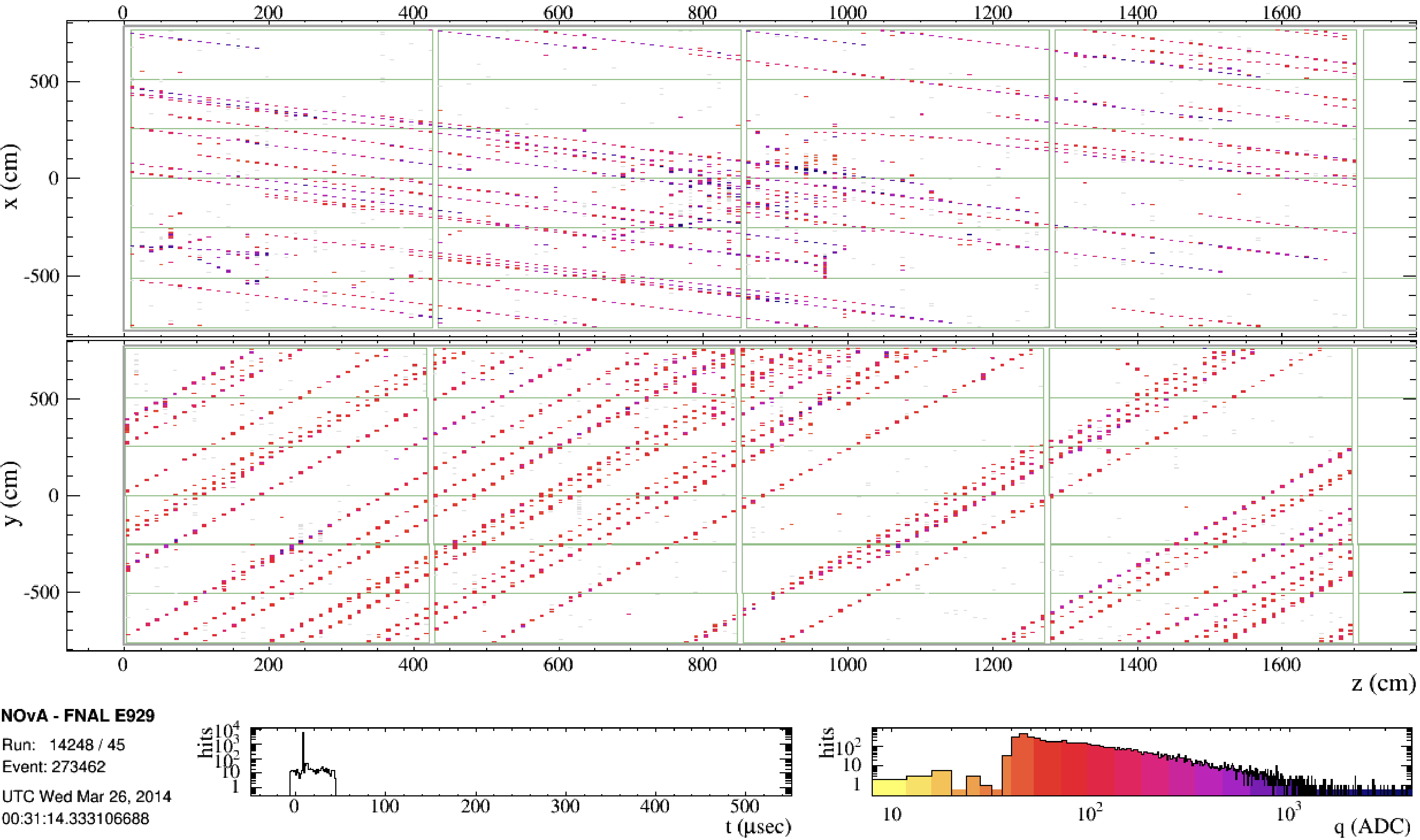
jediny@fnal.gov

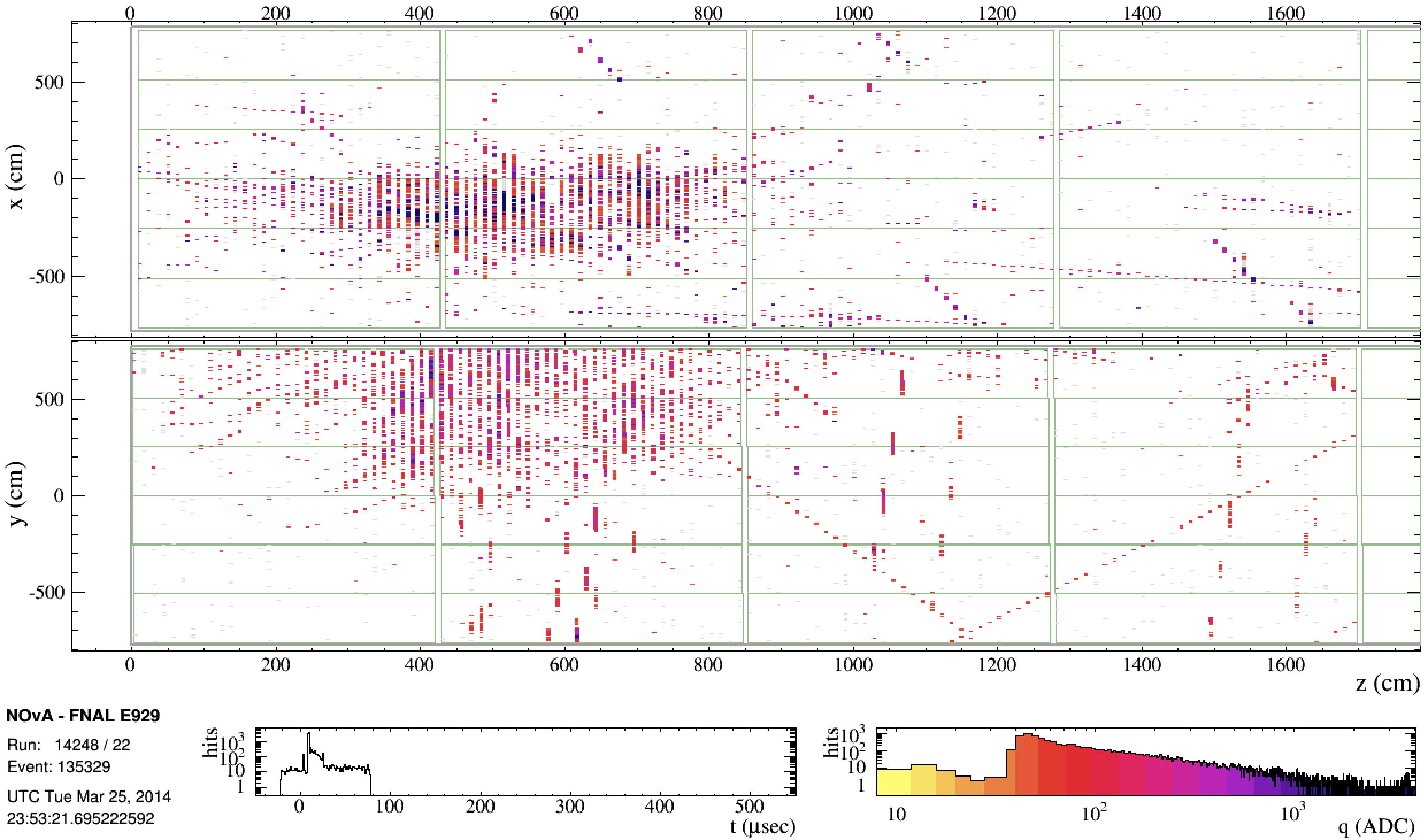
www-nova.fnal.gov

NuMI Off-axis ν_e Appearance Experiment

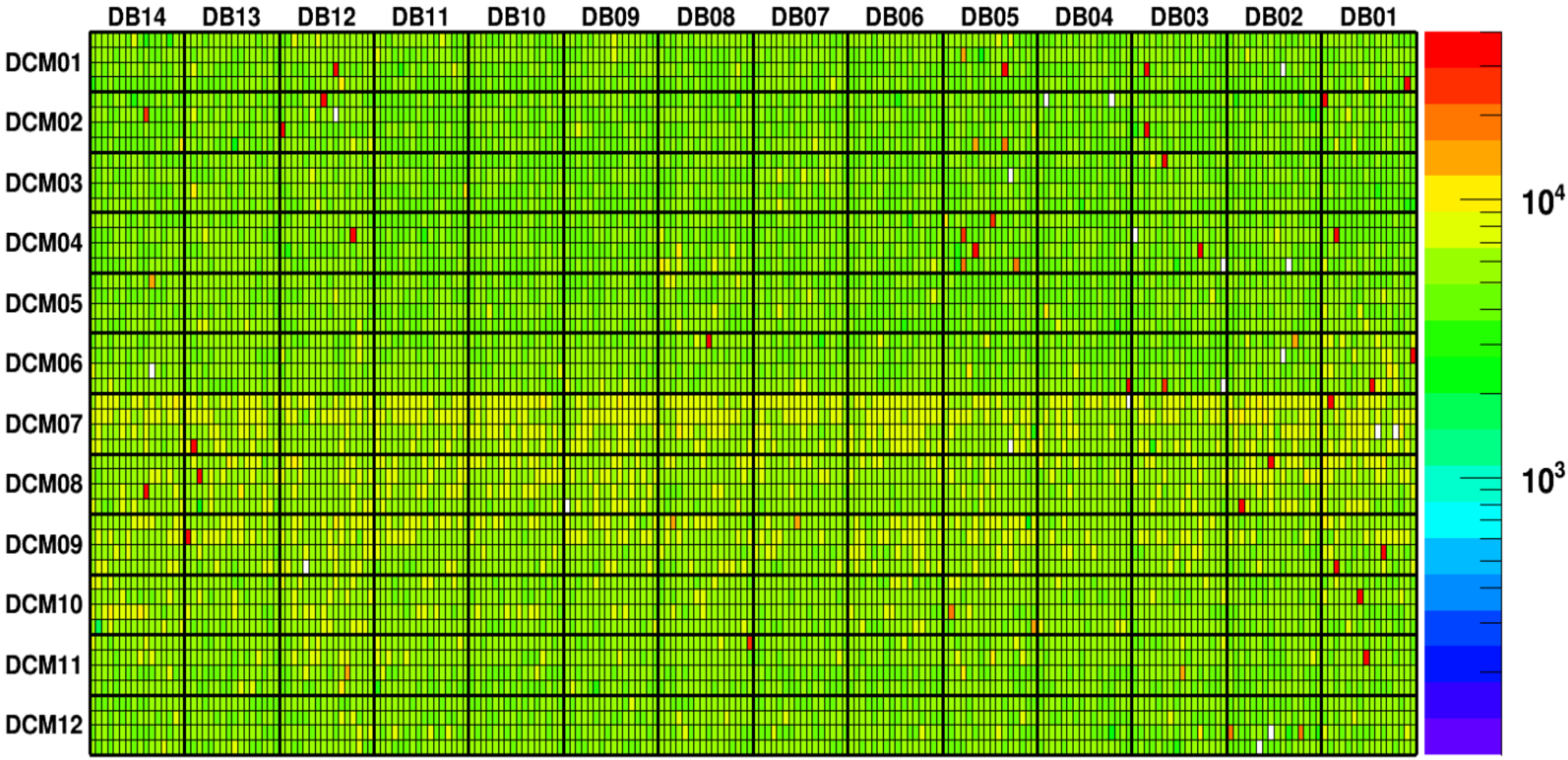

DIBLK:03 GP:180
BLK:07 PLN:12 POS:02


WH 12TH FLOOR CONTROL RM
630-840-4008
SHARED MEMORY SEGMENTS
ESNET:
510-423-9220
886682 #

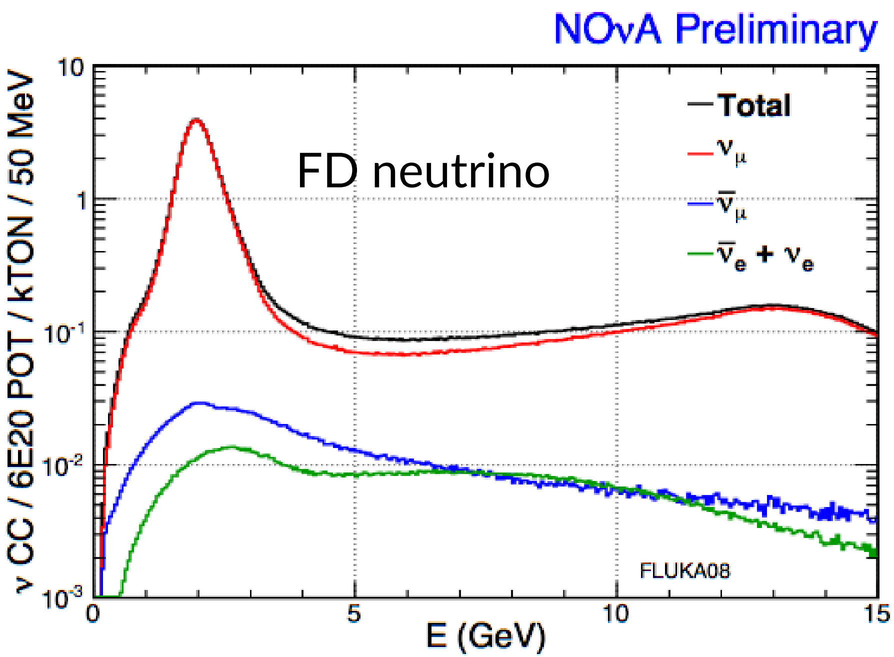

0
200
400
600
800
1000
1200
1400
1600
500
0
-500
x (cm)
y (cm)
z (cm)
NOvA - FNAL E929
Run: 14248 / 45
Event: 273462
UTC Wed Mar 26, 2014
00:31:14.333106688
hits
t (μsec)
q (ADC)

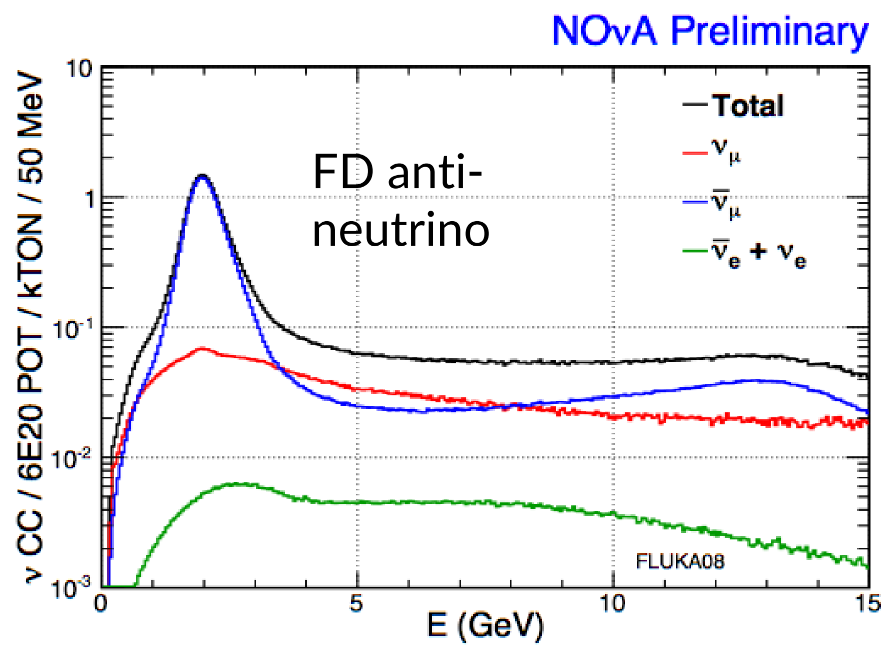

x (cm)
y (cm)
z (cm)
NOvA - FNAL E929
Run: 14248 / 22
Event: 135329
UTC Tue Mar 25, 2014
23:53:21.695222592
hits
t (μsec)
q (ADC)

Detector quality

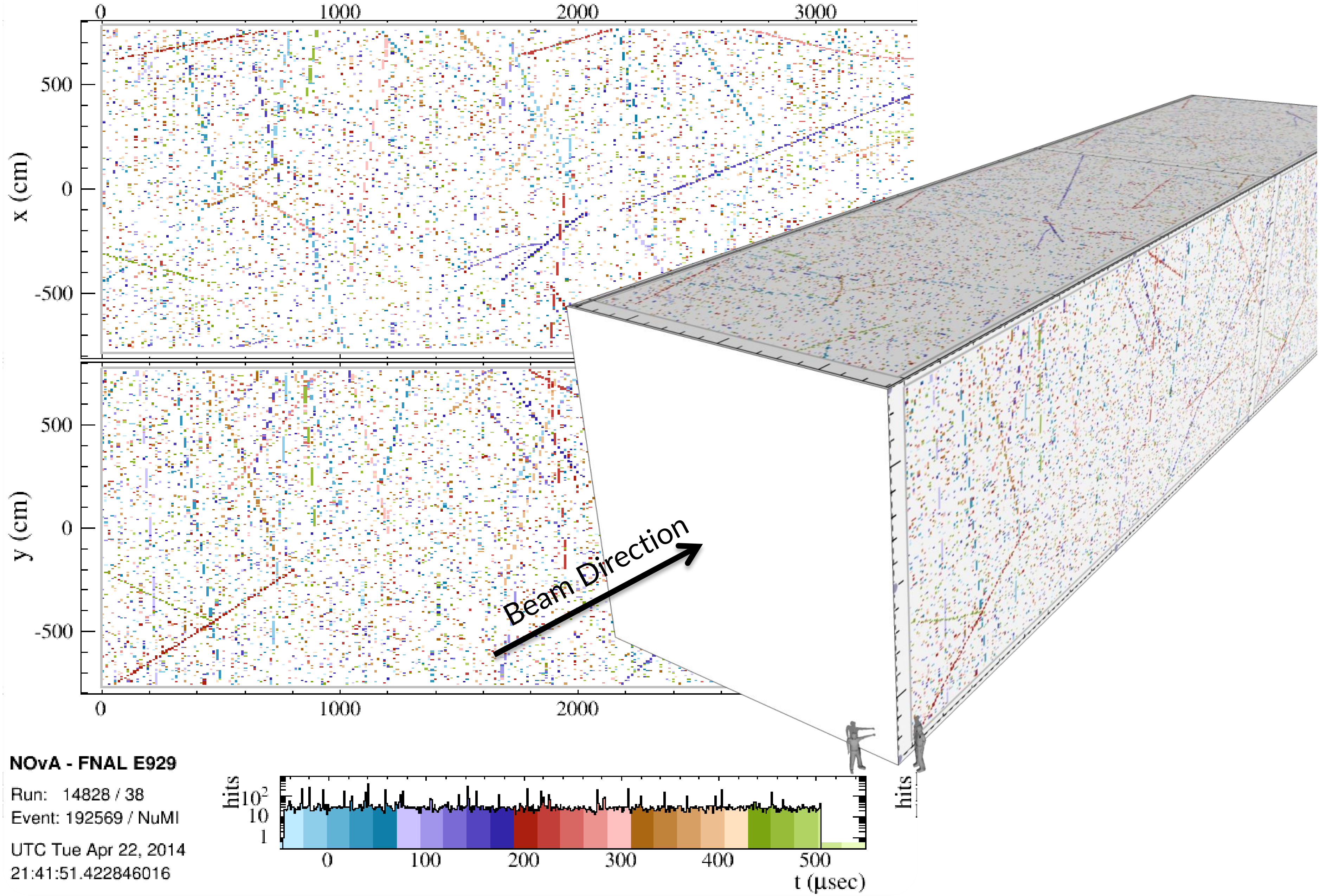


The NuMI Beam spectra ν_μ and $\bar{\nu}_\mu$



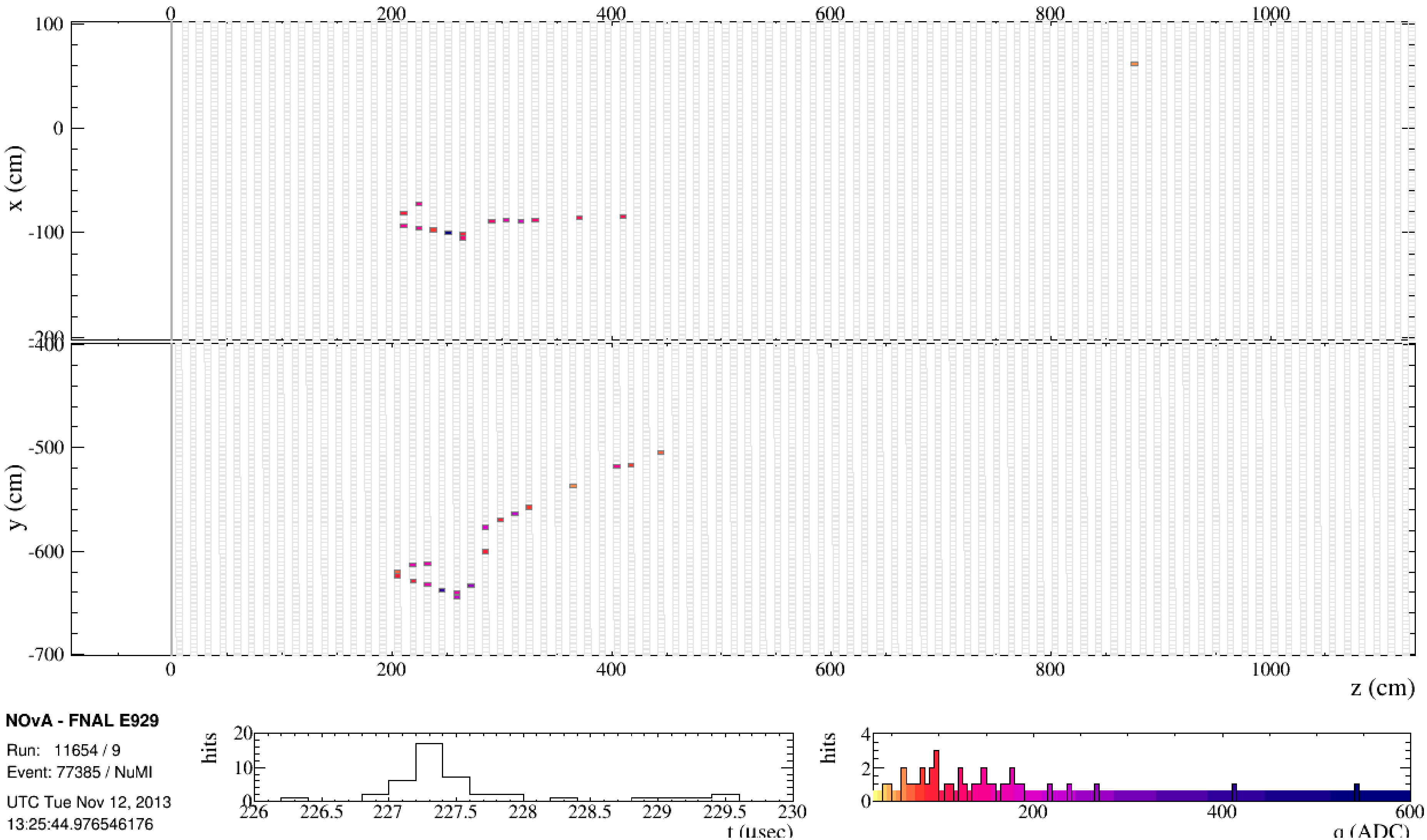


- The NOvA off-axis beam has a peak in the 1-3 GeV signal region with 1.6% wrong sign contamination and 0.6% beam ν_e
- For anti-neutrino configuration has only 10% wrong sign contamination and 0.8% beam ν_e

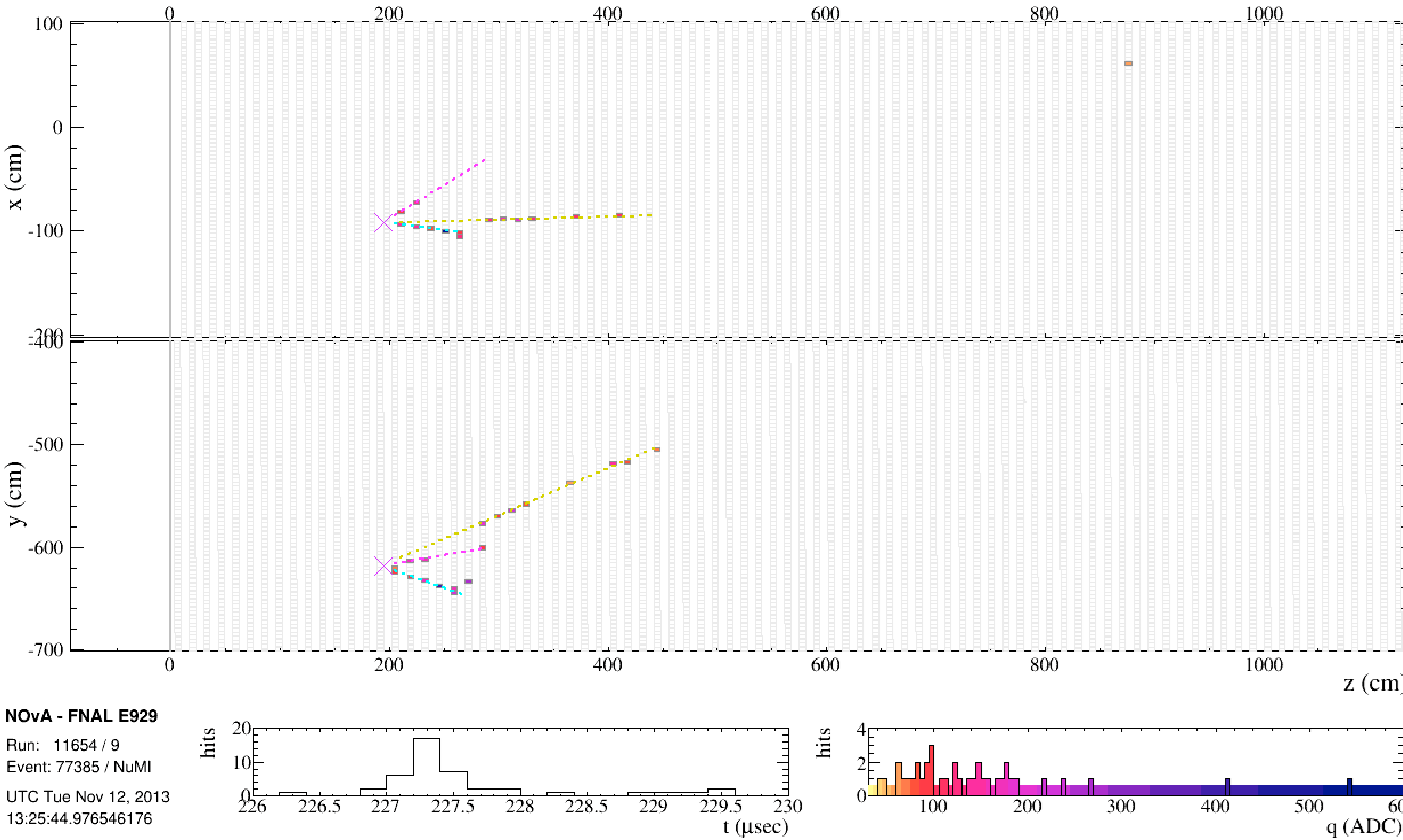


x (cm)
y (cm)
Beam Direction
NOvA - FNAL E929
Run: 14828 / 38
Event: 192569 / NuMI
UTC Tue Apr 22, 2014
21:41:51.422846016
hits
t (µsec)

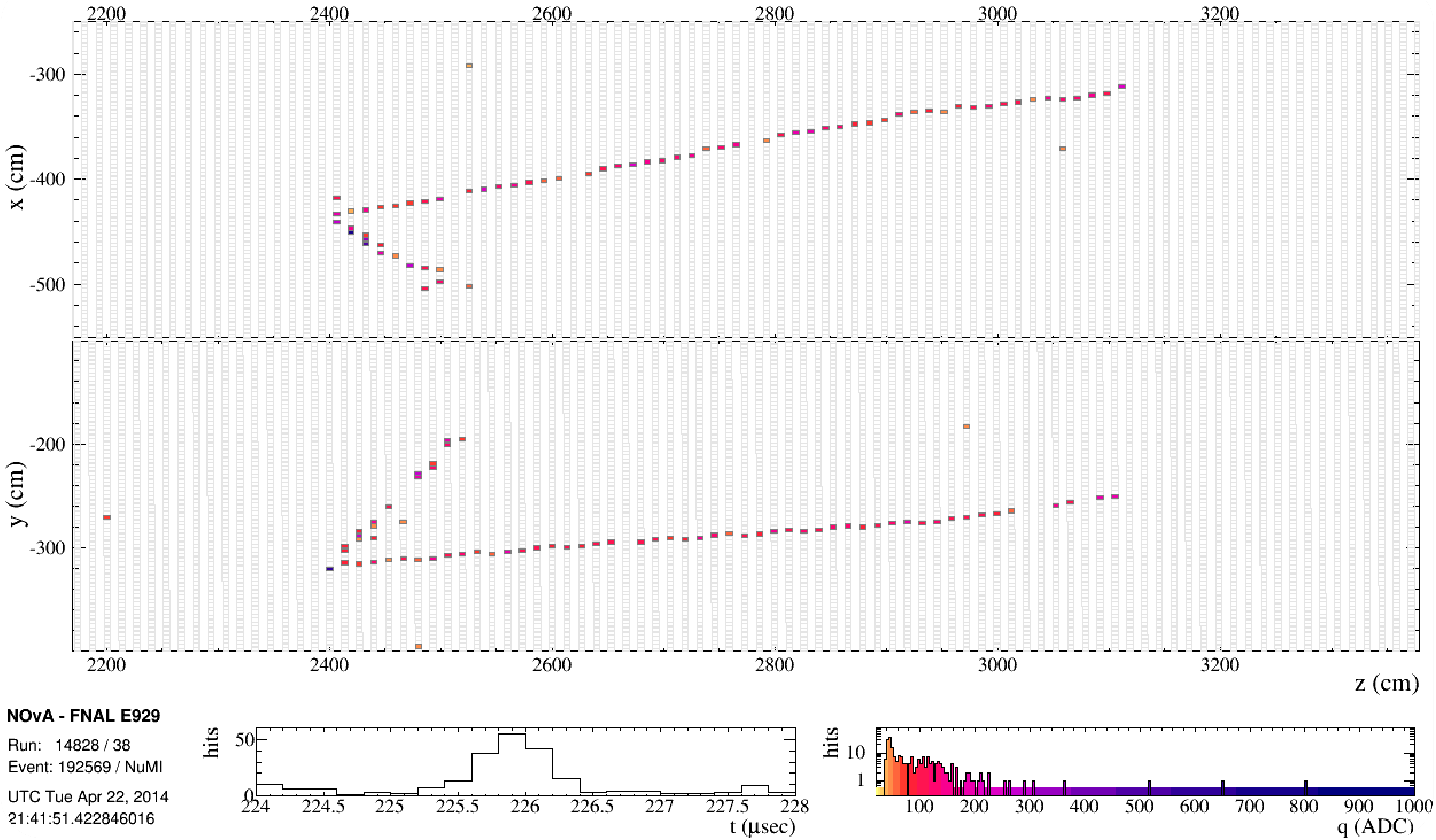
1st neutrino candidate



1st neutrino reconstruciton



ν_μCC candidate



NOvA physics goals

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

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

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

$\alpha = \Delta m^2_{21}/\Delta m^2_{31}$ $\Delta = \Delta m^2_{31} L/(4E)$ $A = \overset{(-)}{+} G_f n_e L/(\sqrt{2}\Delta)$

mixing angle θ_{13}

mass hierarchy

CP violation

θ_{23} octant

$\sin^2(2\theta_{13})$ has been measured at short-baseline and can be accessed in long-baseline search for ν_e events, which allows us to make measurements of **δ_{CP}** (CP violation phase parameter). We can gain information about the θ_{23} octant since **$\sin^2(\theta_{23})$** is a coefficient on the leading-order term.

Probability is enhanced or suppressed due to **matter effects** which depend on the mass hierarchy - the sign of $\Delta m^2_{31} \sim \Delta m^2_{32}$ as well as neutrino vs. anti-neutrino running.

Plus much more non-oscillation topics (cross-sections, sterile neutrinos, monopoles, supernovae, NSI…).

NOvA physics goals

$$P(\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_e) \approx \sin^2 2\theta_{13} \sin^2\theta_{23} \frac{\sin^2(A-1)\Delta}{(A-1)^2}$$
$$\overset{(+)}{-}\ 2\alpha \sin\theta_{13} \sin\delta_{CP} \sin 2\theta_{12} \sin 2\theta_{23} \frac{\sin A\Delta}{A} \frac{\sin(A-1)\Delta}{(A-1)} \sin\Delta$$
$$+\ 2\alpha \sin\theta_{13} \cos\delta_{CP} \sin 2\theta_{12} \sin 2\theta_{23} \frac{\sin A\Delta}{A} \frac{\sin(A-1)\Delta}{(A-1)} \cos\Delta$$

$\alpha = \Delta m^2_{21}/\Delta m^2_{31}$ $\quad \Delta = \Delta m^2_{31} L/(4E)$ $\quad A = \overset{(-)}{+} G_f n_e L/(\sqrt{2}\Delta)$

mixing angle θ_{13}

mass hierarchy

CP violation

θ_{23} octant

$\sin^2(2\theta_{13})$ has been measured at short-baseline and can be accessed in long-baseline search for ν_e events, which allows us to make measurements of **δ_{CP}** (CP violation phase parameter). We can gain information about the θ_{23} octant since **$\sin^2(\theta_{23})$** is a coefficient on the leading-order term.

Probability is enhanced or suppressed due to **matter effects** which depend on the mass hierarchy - the sign of $\Delta m^2_{31} \sim \Delta m^2_{32}$ as well as neutrino vs. anti-neutrino running.

Plus much more non-oscillation topics (cross-sections, sterile neutrinos, monopoles, supernovae, NSI…).

Neutrino Mass Mixing

- Neutrino Flavor Oscillations arise from mixing
  - Flavor eigenstates are mixtures of mass eigenstates

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{-i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 1 & 1 \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

"Atmospheric"/ Long-baseline ν_μ disappearance

Phase δ not yet measured

"Solar" ν_e disappearance

$c_{13} \equiv \cos\theta_{13}, etc.$

Oscillation probability, in the limit of 2 flavors α and β, mixed by angle θ, mass-squared difference Δm^2:

$$P(\nu_\alpha \to \nu_\beta) = \sin^2(2\theta)\sin^2(\frac{\Delta M^2 L}{4E})$$

Neutrino energy E
Baseline L