

NOvA neutrino experiment

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On behalf of the NOvA Collaboration



XXXth International Workshop on High Energy Physics

IHEP Protvino, Russian federation

June 26, 2014



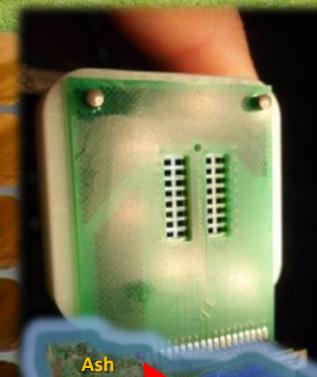
7 countries, 38 Institutions, 204 collaborators



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·Indian Institute 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

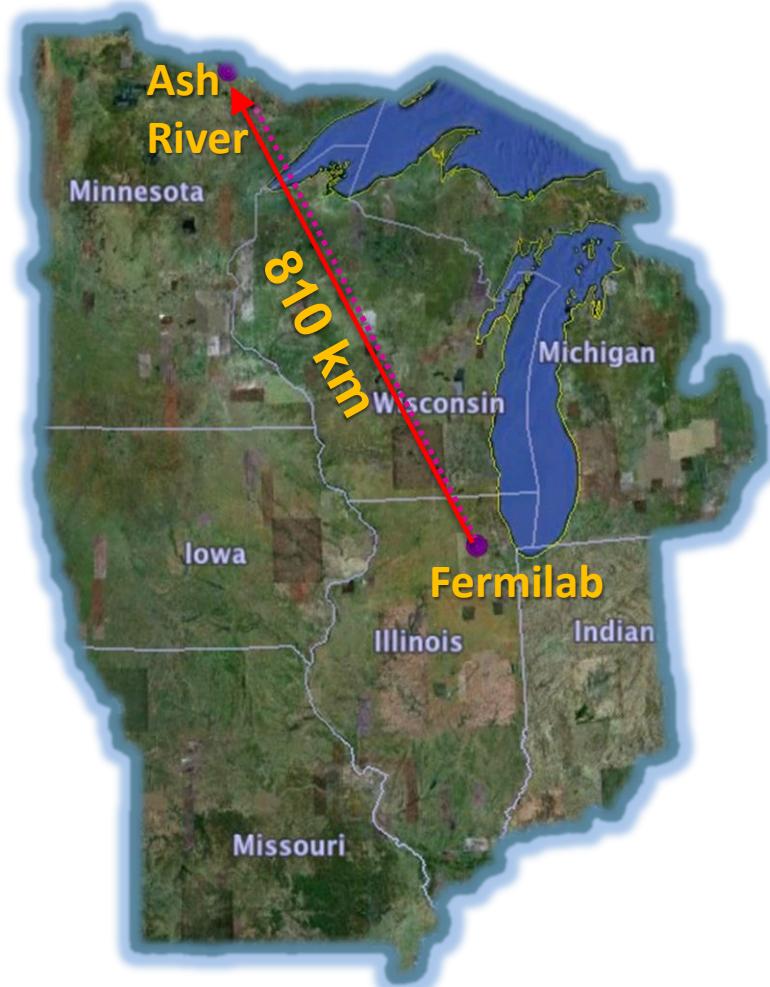
NOvA status – Outline

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



NuMI Off-axis ν_e Appearance Experiment

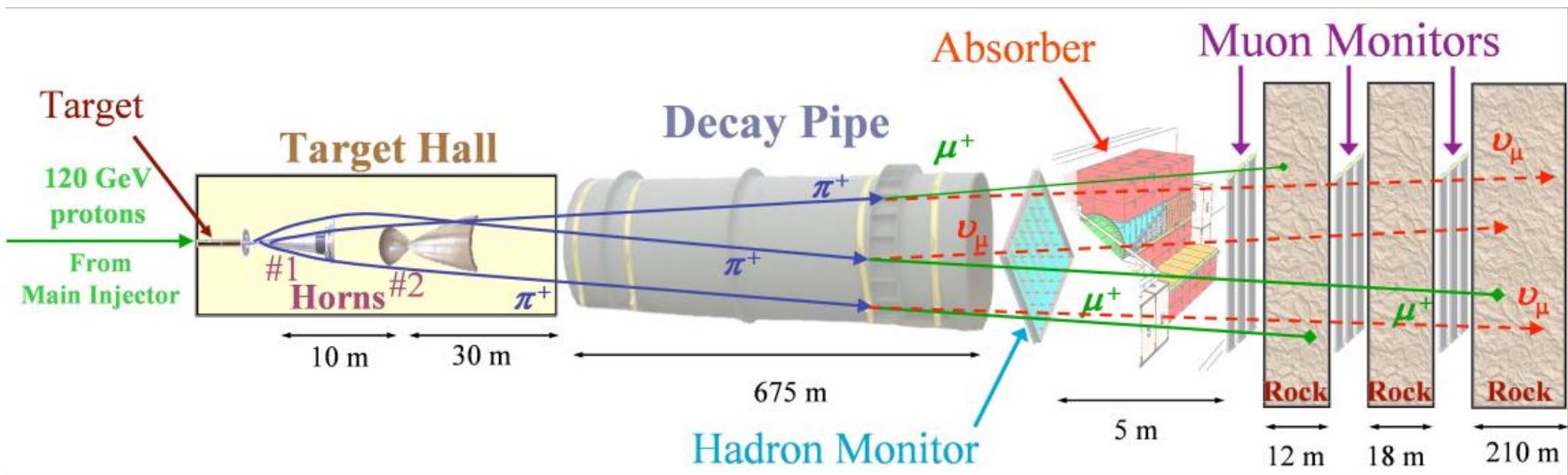
- Long-baseline, two-detector ν oscillation experiment
- Looking for ν_e in ν_μ NuMI beam
- 14 mrad off-axis
- 2 liquid scintillator detectors
- FD (14 kton), ND (0.3 kton)
- Cooled APD readout



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 μ s beam spill every 1.3 s
- Beam back from Sept 4, 2013 (300 \rightarrow 700 kW)
- 500 kW limit until Booster RF system upgrades complete
- 4.9×10^{13} POT/pulse – 6×10^{20} POT/year

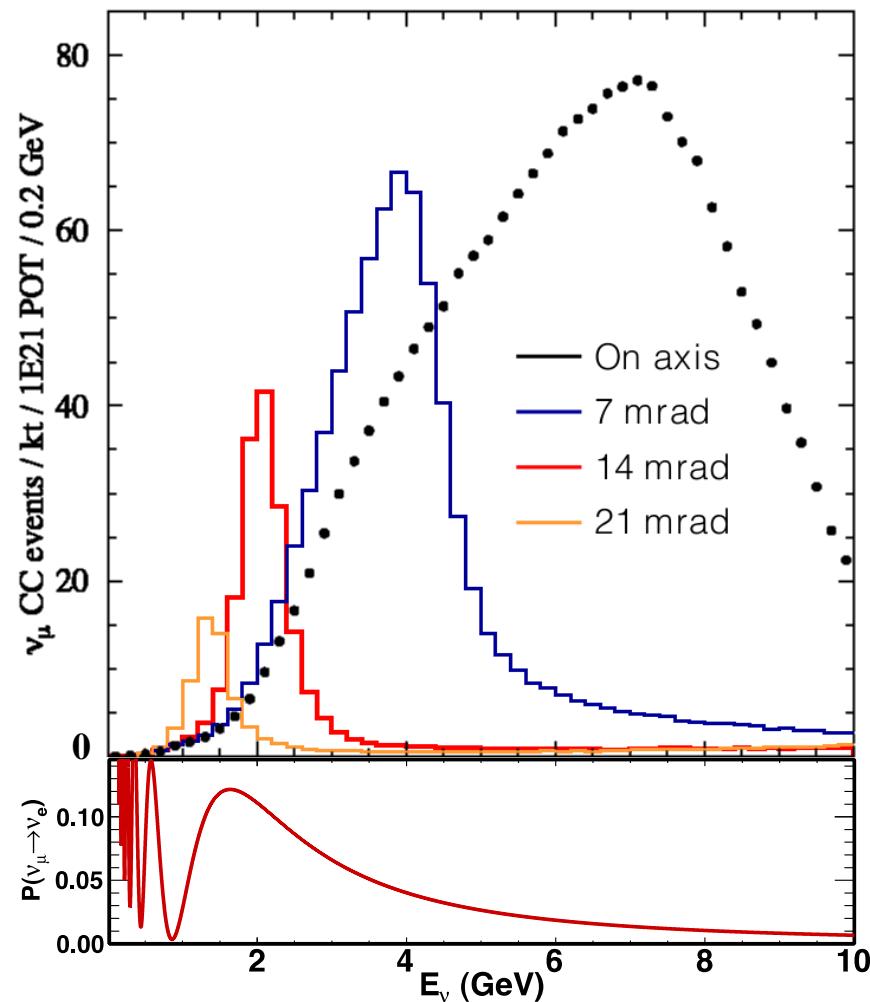


Why off-axis?

NuMI Off-axis ν_e Appearance

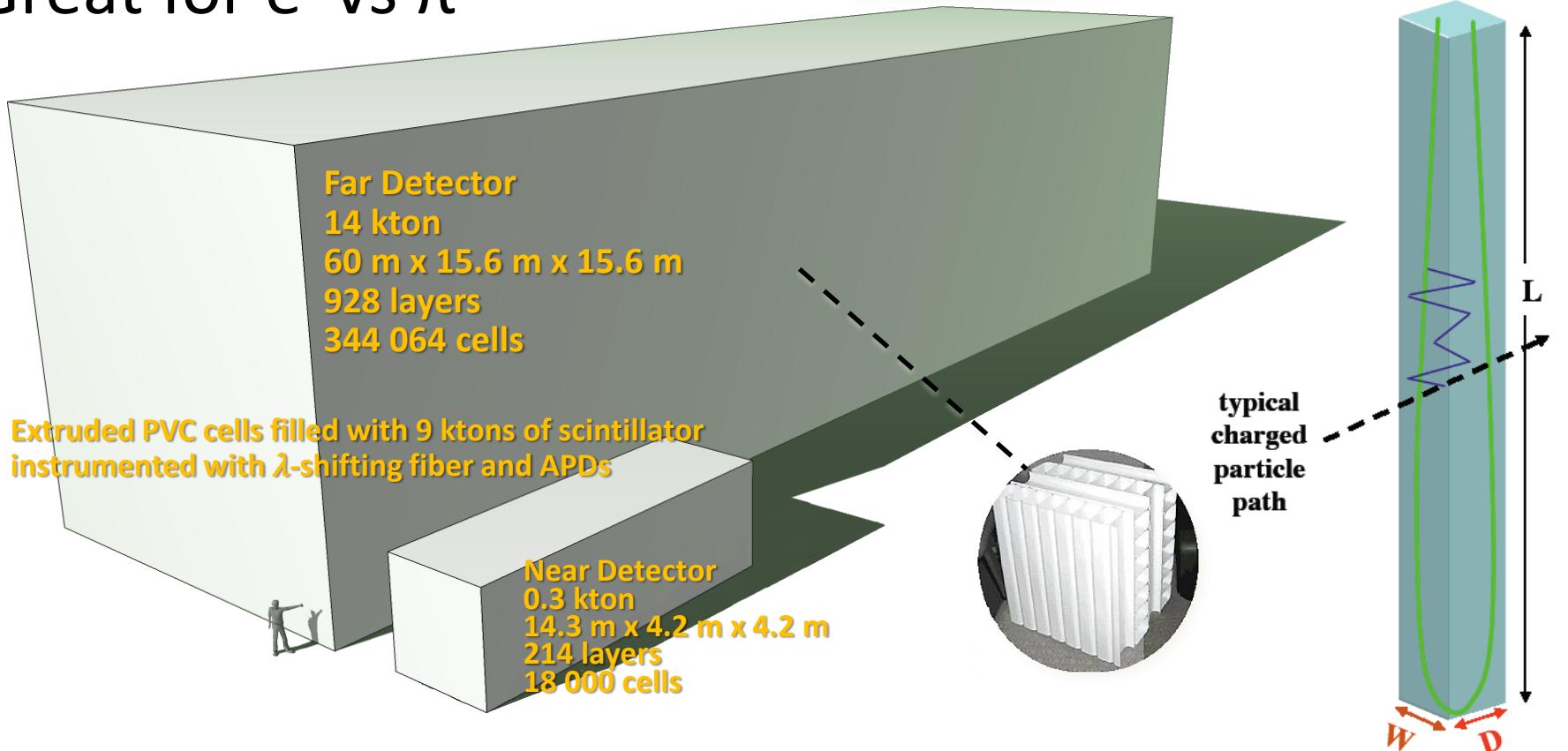
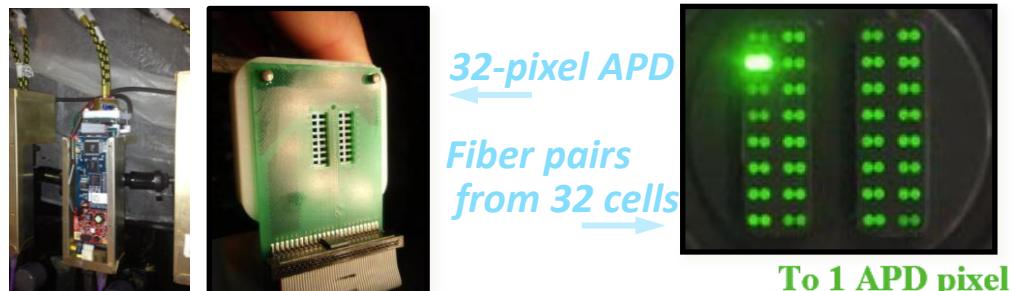
The choice of a 14 mrad off-axis position from the NuMI beam for the NOvA detector, allows for a narrow band beam which in conjunction with topology of final state particles, allows one to more easily reject potential backgrounds

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 just $0.15 X_0$
Great for e^- vs π^0



The NOvA detectors



Near Detector On Surface

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



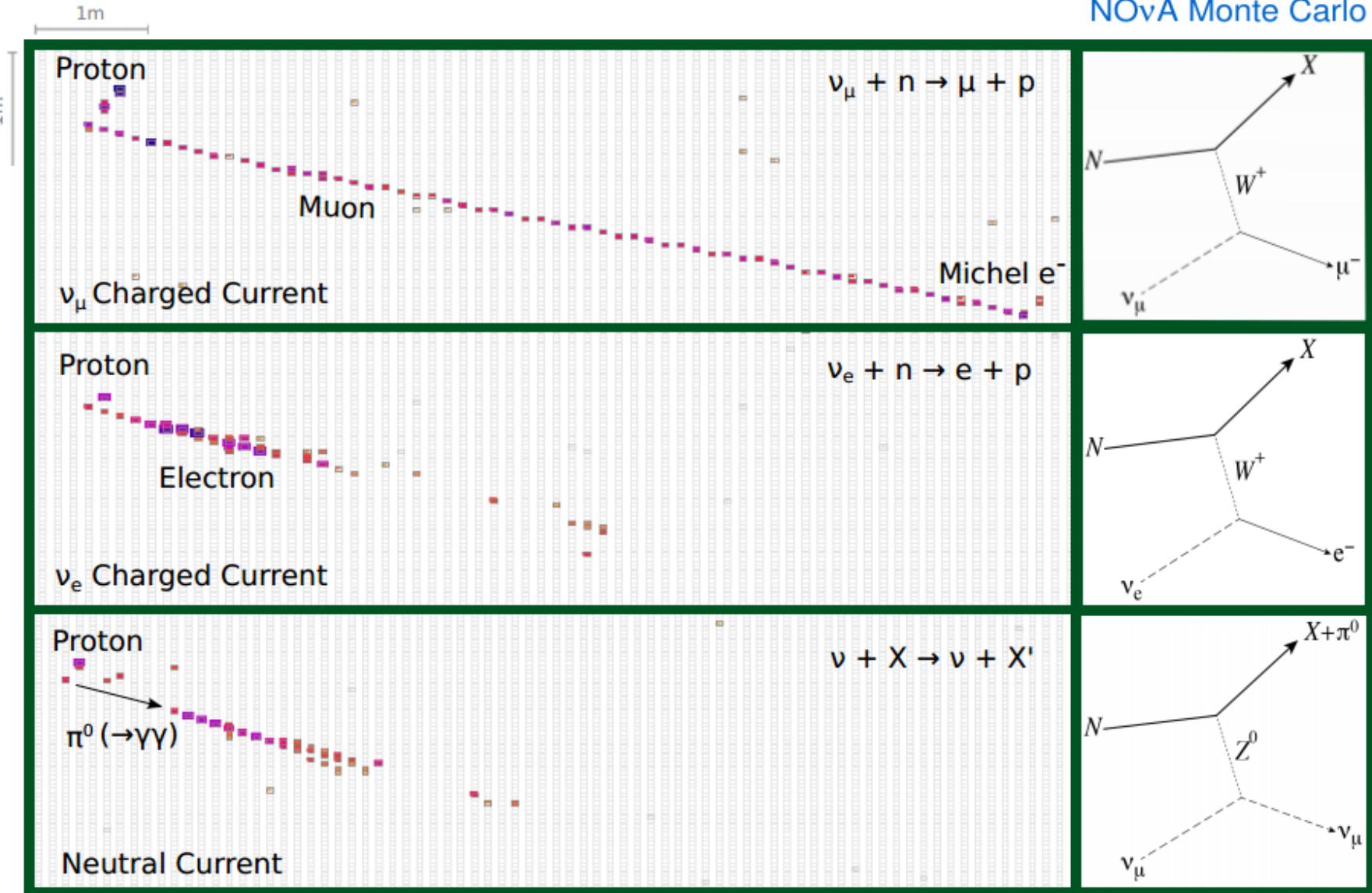
Near Detector On Surface

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NOvA Neutrino Event Topologies

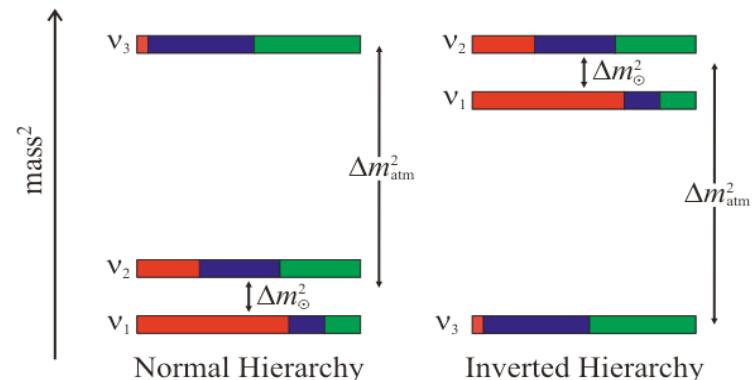
NOvA Monte Carlo





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 $|\Delta m^2_{32}|, \theta_{23}$
 - 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)



u up quark sp6 SLAC	c charm quark sp6 Brookhaven & SLAC	t top quark MPS Fermilab	g gluon MPP Münich University	2012: H CERN
d down quark sp6 SLAC	s strange quark sp6 Brookhaven	b bottom quark sp6 Fermilab	γ photon sp6 CERN	
ν_e electron neutrino sp6 Fermilab	ν_μ muon neutrino sp6 CERN & Fermilab	ν_τ tau neutrino sp6 SLAC	W W boson sp6 CERN	
e electron sp6 CERN Laboratory	μ muon sp6 CERN & Fermilab	τ tau sp6 SLAC	Z Z boson sp6 CERN	

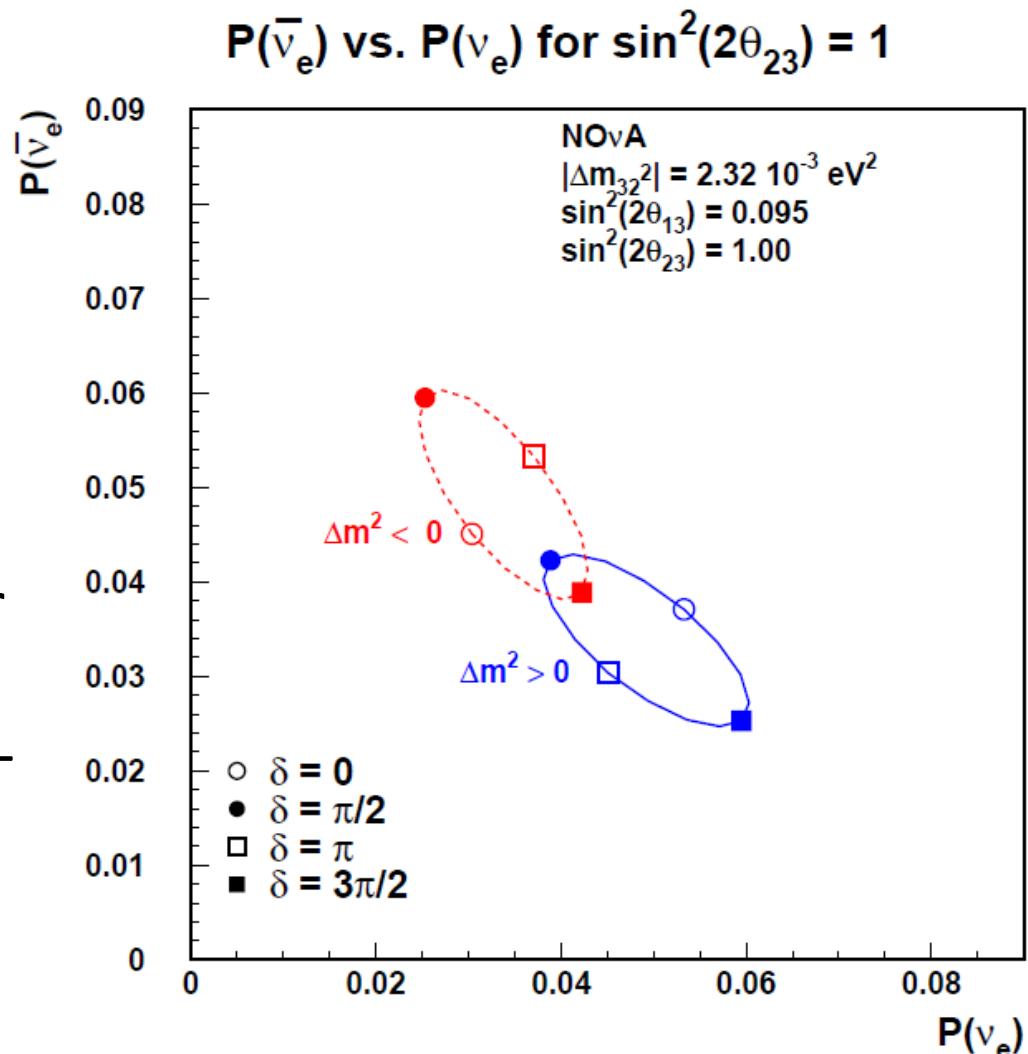
ν_e appearance in NOvA

- 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} is good news for NOvA. It reduces the overlap between these bi-probability ellipses, reducing the likelihood of degeneracies



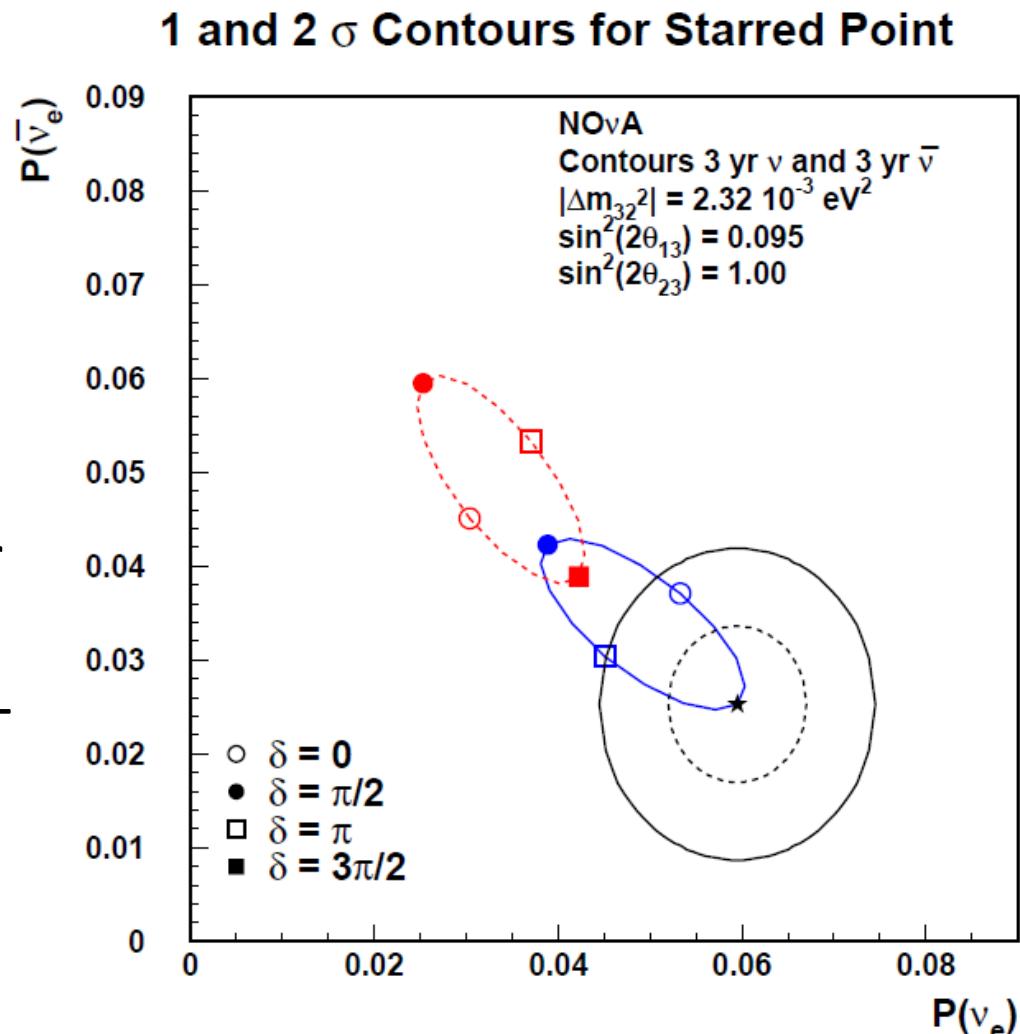
ν_e appearance in NOvA

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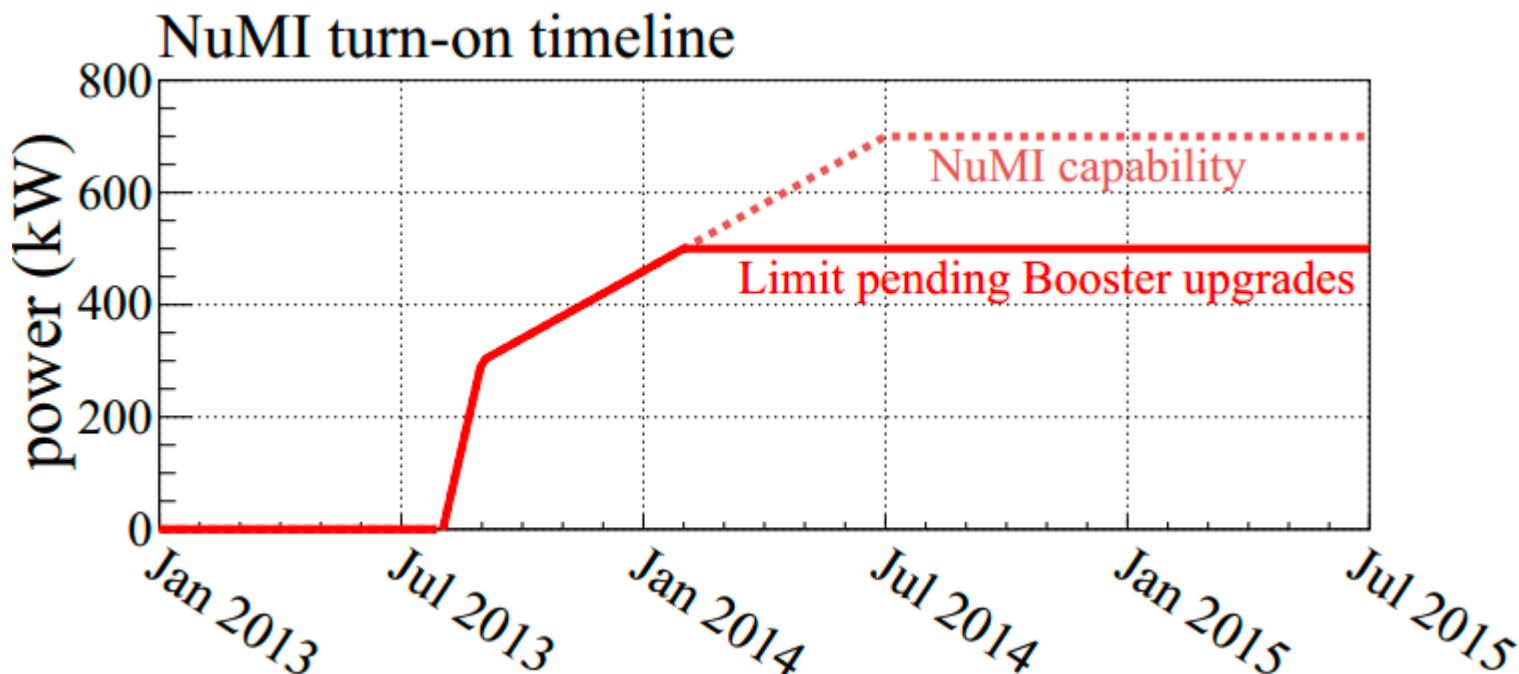
$P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$ at 2 GeV

- Example of 6y NOvA result
- Large θ_{13} is good news for NOvA. It reduces the overlap between these bi-probability ellipses, reducing the likelihood of degeneracies

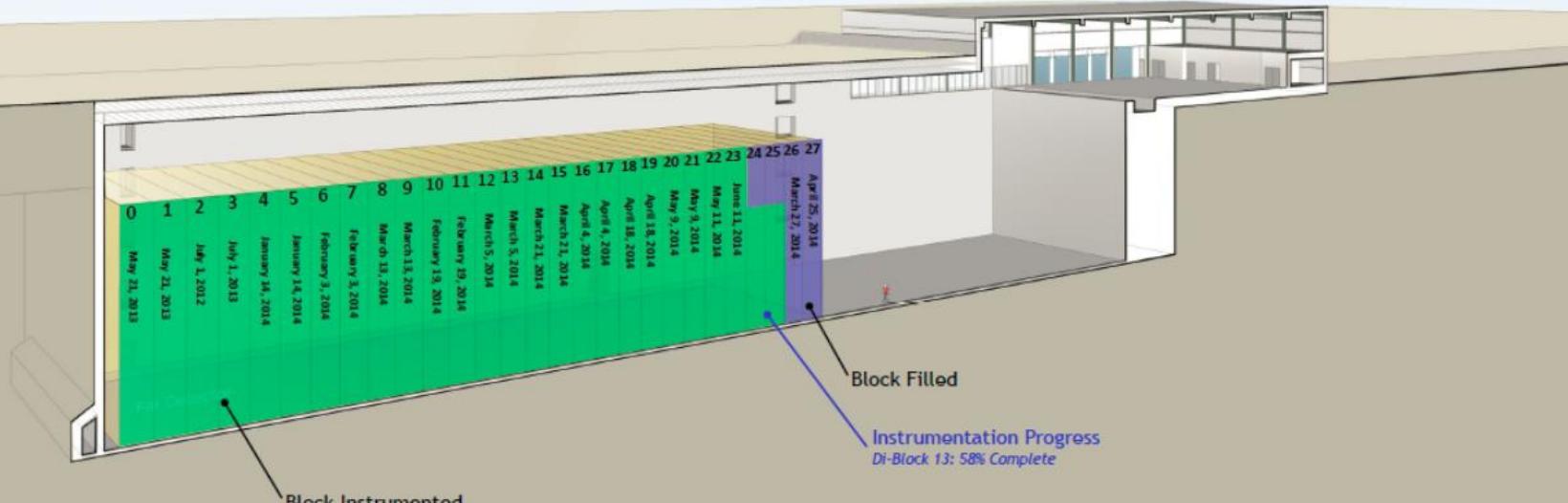


Beam status

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

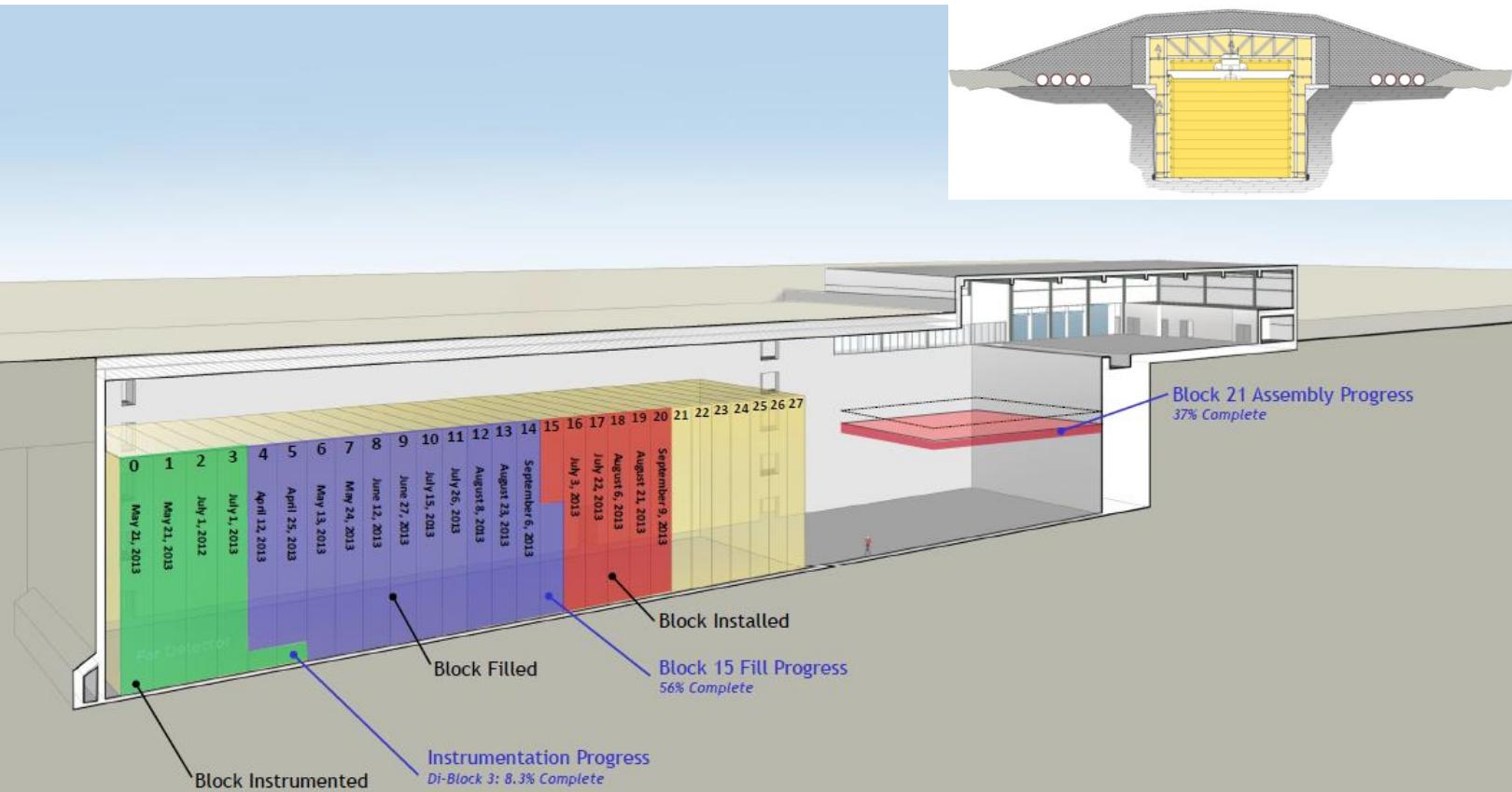


FD construction status



14 kilotons = 28 NOvA Blocks
28 blocks of PVC modules are assembled and installed in place
28 blocks are filled with liquid scintillator
25. 16 blocks are outfitted with electronics

FD construction status



14 kilotons = 28 NOvA Blocks

21 blocks of PVC modules are assembled and installed in place

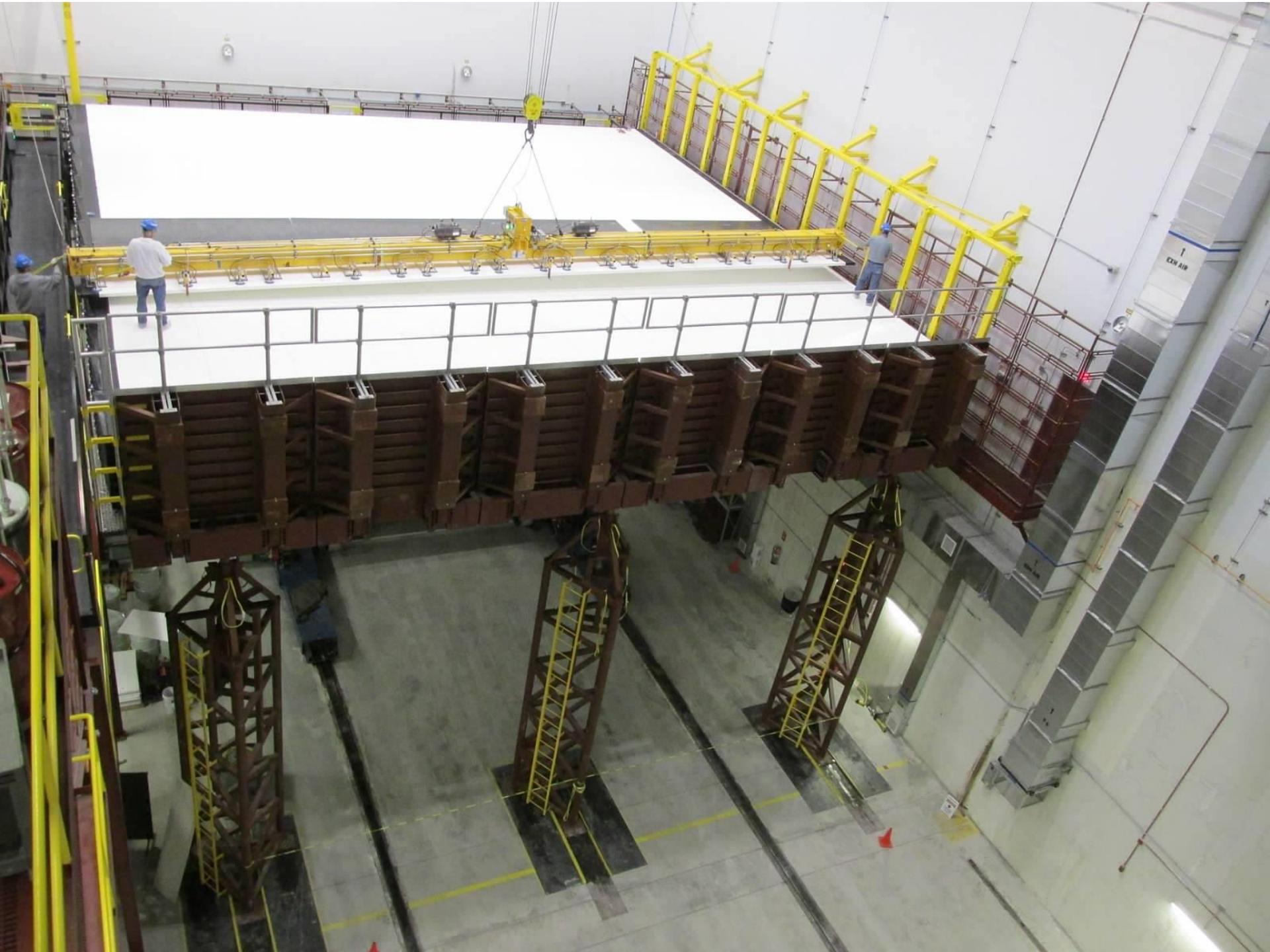
15.56 blocks are filled with liquid scintillator

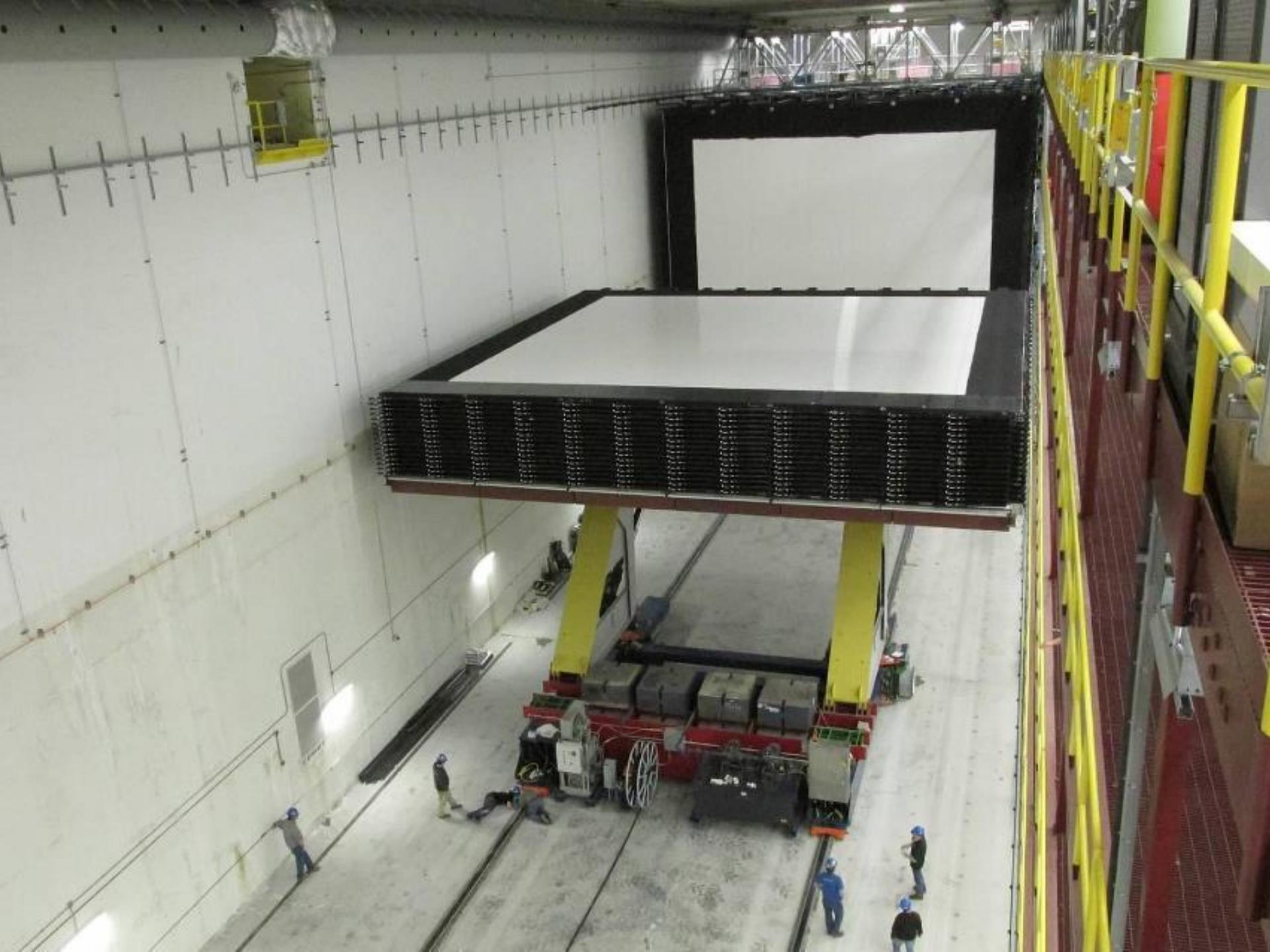
4.17 blocks are outfitted with electronics





Empty Hall





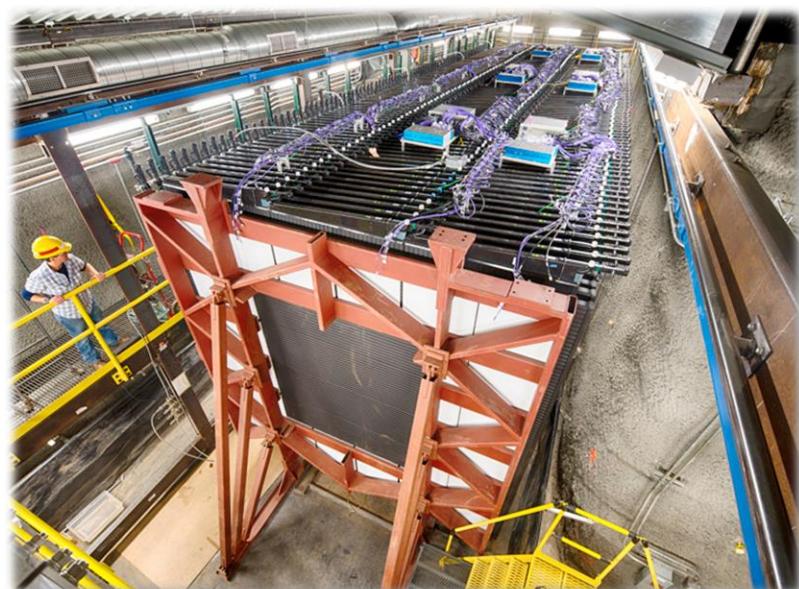






ND Construction Progress

- First block installed Aug 2013
- Whole detector complete and filled
- Waiting for the final batch of APDs



Summary

- Both detectors are **completed**, instrumentation through July
- NuMI beam upgraded, **v observed** in both detectors
- Reconstruction/analysis tools are in place for first results in 2014
- 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



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@NOvANuZ



jediny@fnal.gov



www-nova.fnal.gov

NuMI Off-axis ν_e Appearance Experiment



BLK:07 PLN:12 POS:02

OP:180

BLK:07 PLN:12 POS:02



NOVA Point #1
For Information: JASON CALDIA
404-557-1182
Sue Ladd
2000
2000
2000
2000
2000

WH 07th from Calmar Rd
650-370-9888

Emergency
Non-Emergency
Toll-Free
1-800-222-1222
Fax: 650-370-9889
DCS - 3221
Control Room - 3221
Control Room - 3221

ESNET:
510-423-9220
886682 #

NOvA physics goals

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

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

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

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

mixing angle θ_{13}

mass hierarchy

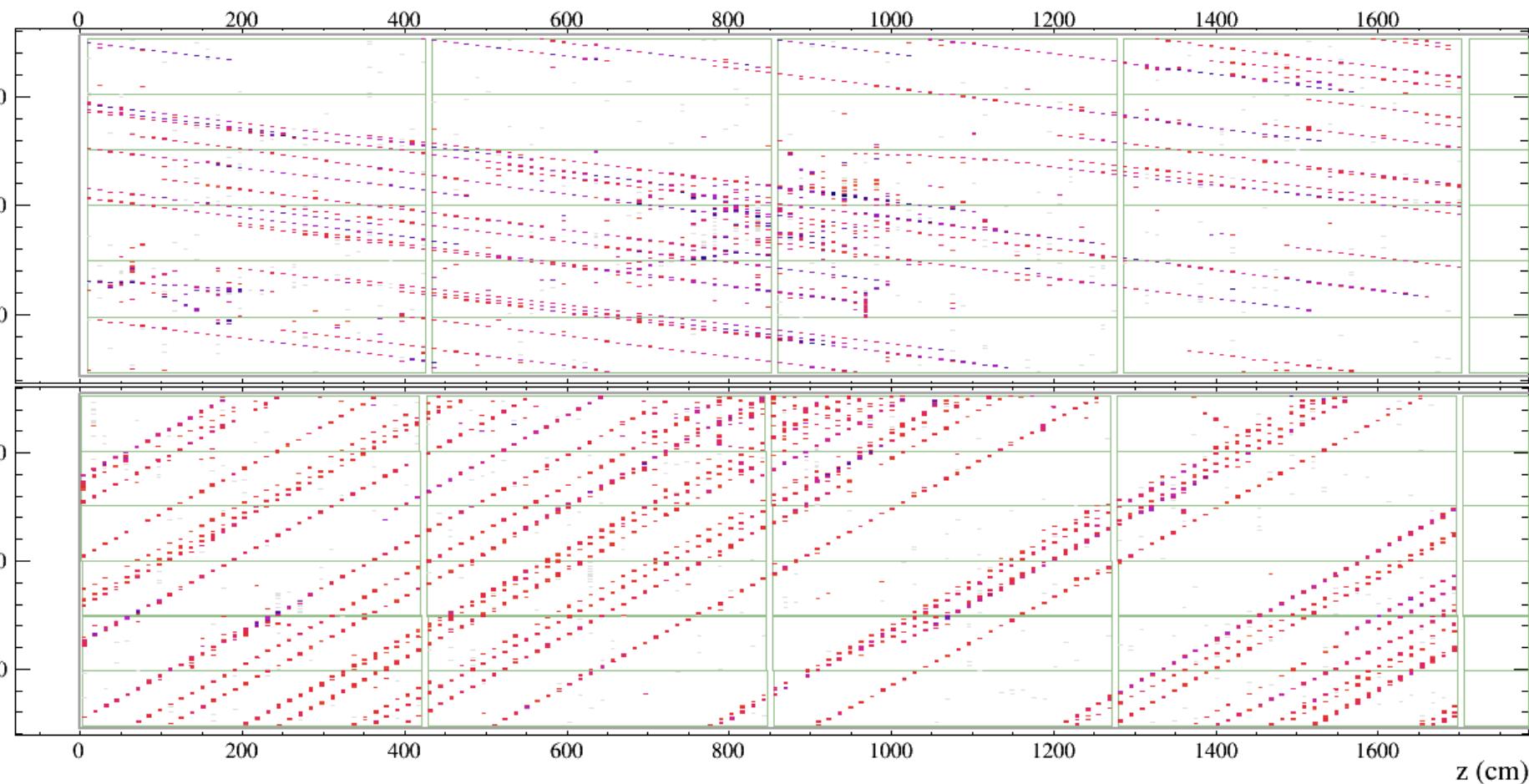
CP violation

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...).



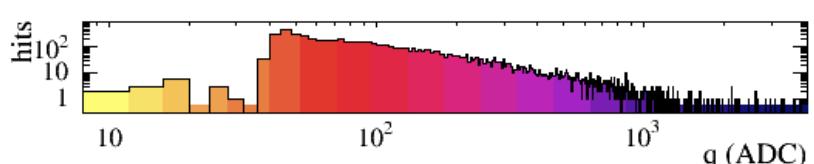
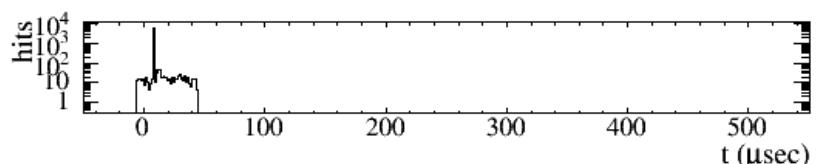
NOvA - FNAL E929

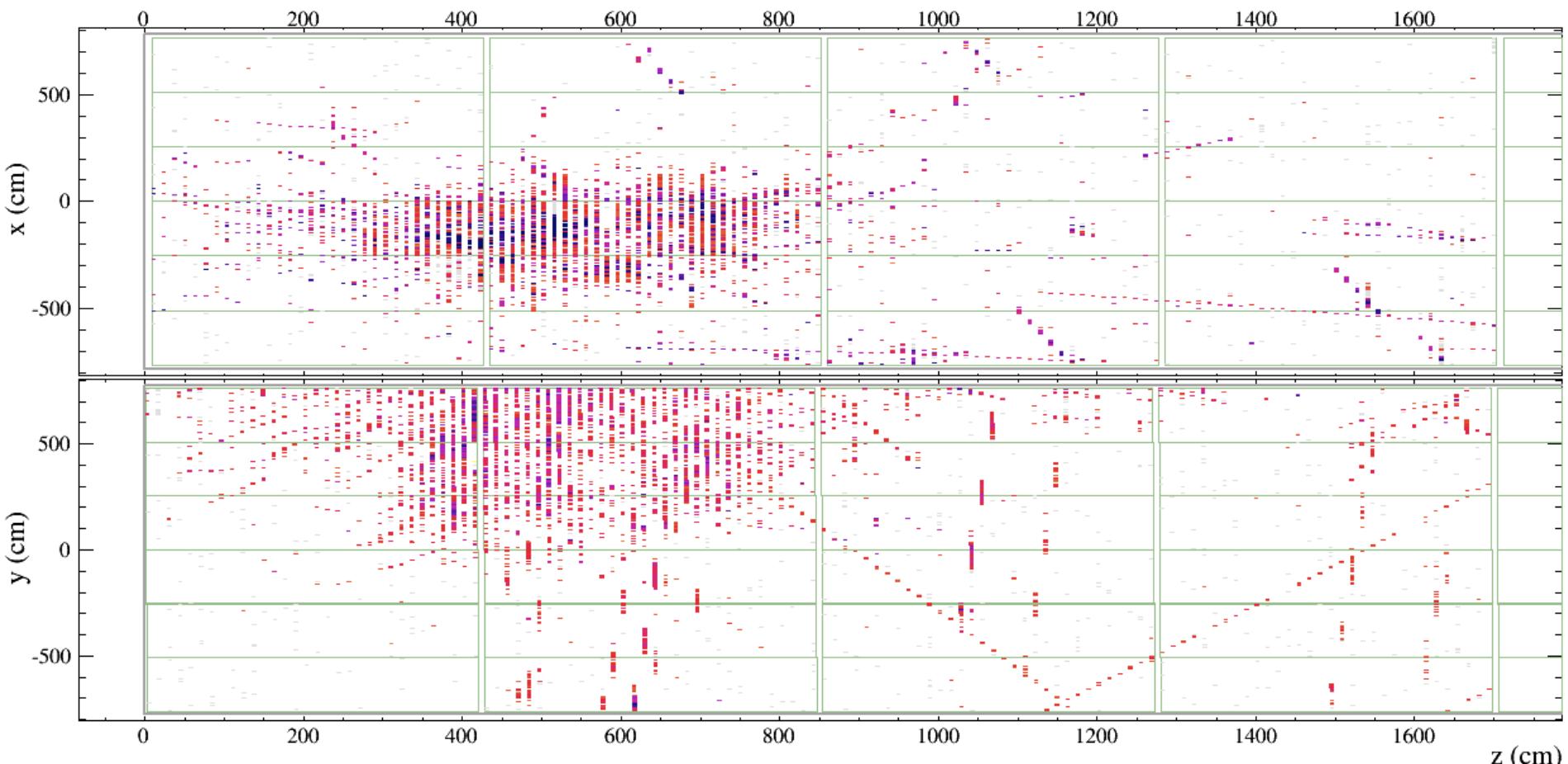
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Event: 273462

UTC Wed Mar 26, 2014

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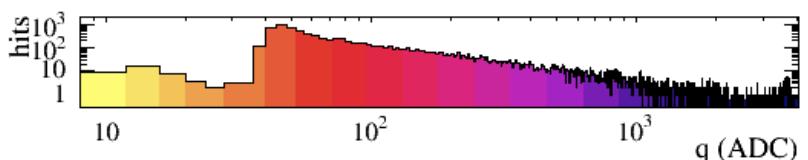
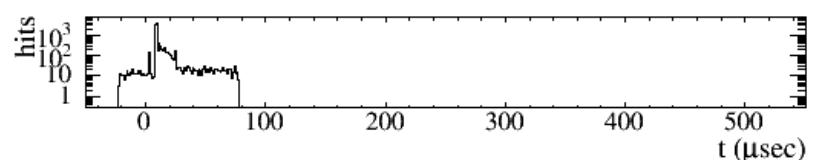


NOvA - FNAL E929

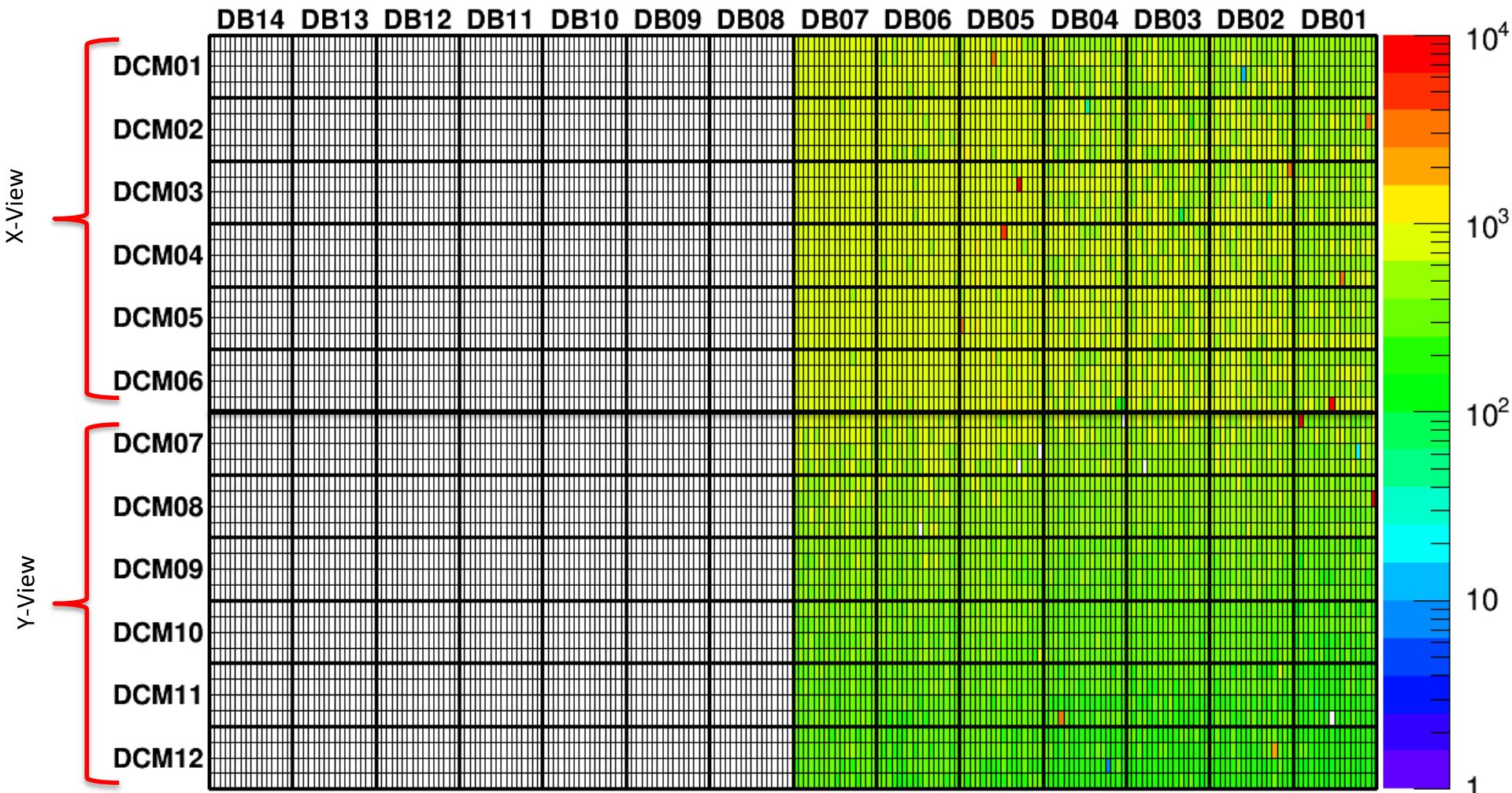
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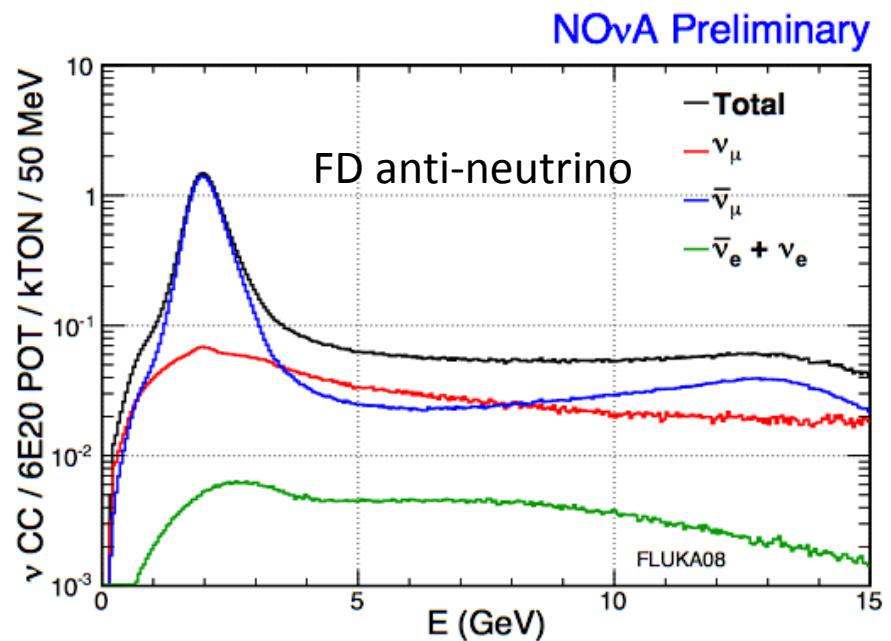
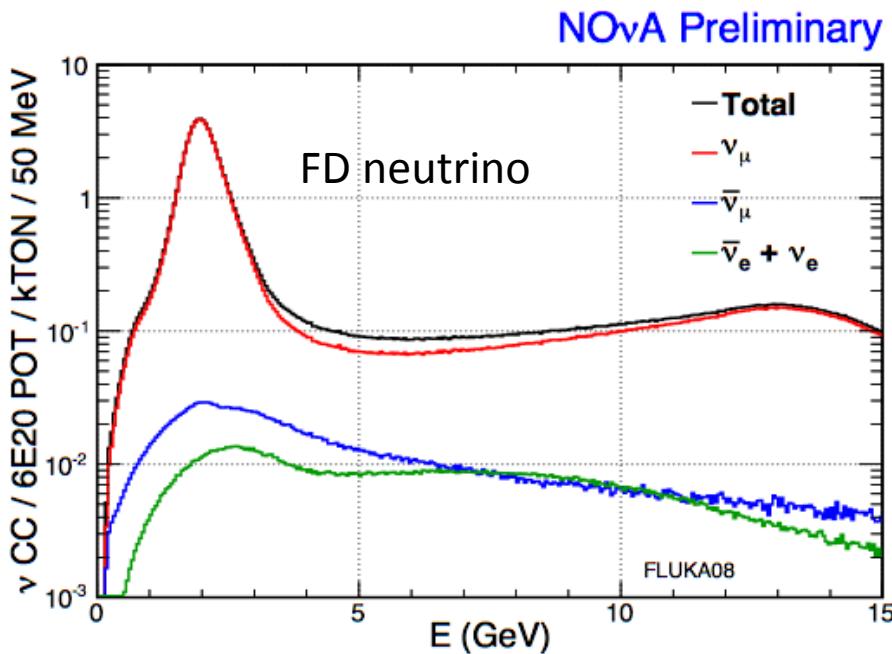
UTC Tue Mar 25, 2014
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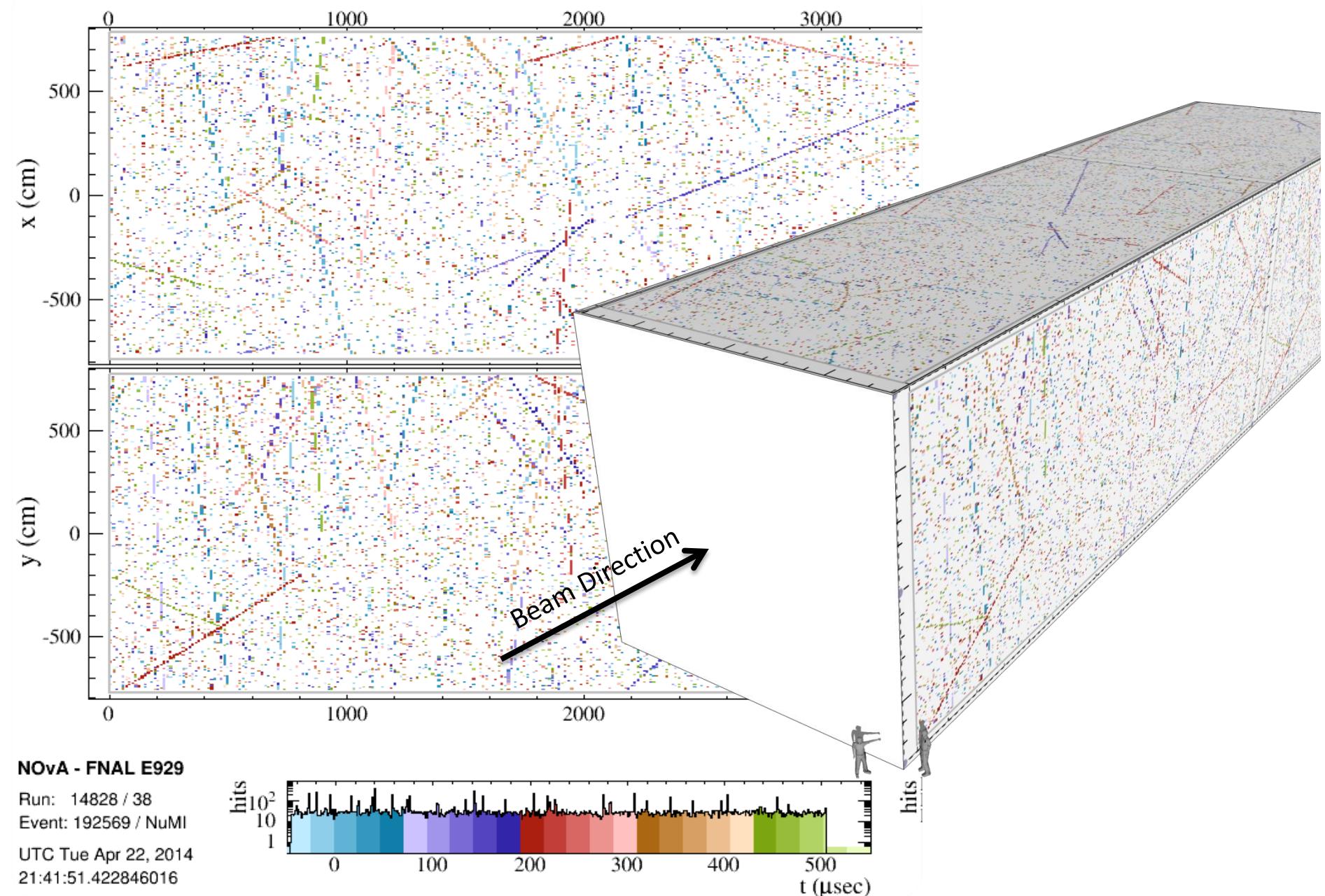
Detector quality



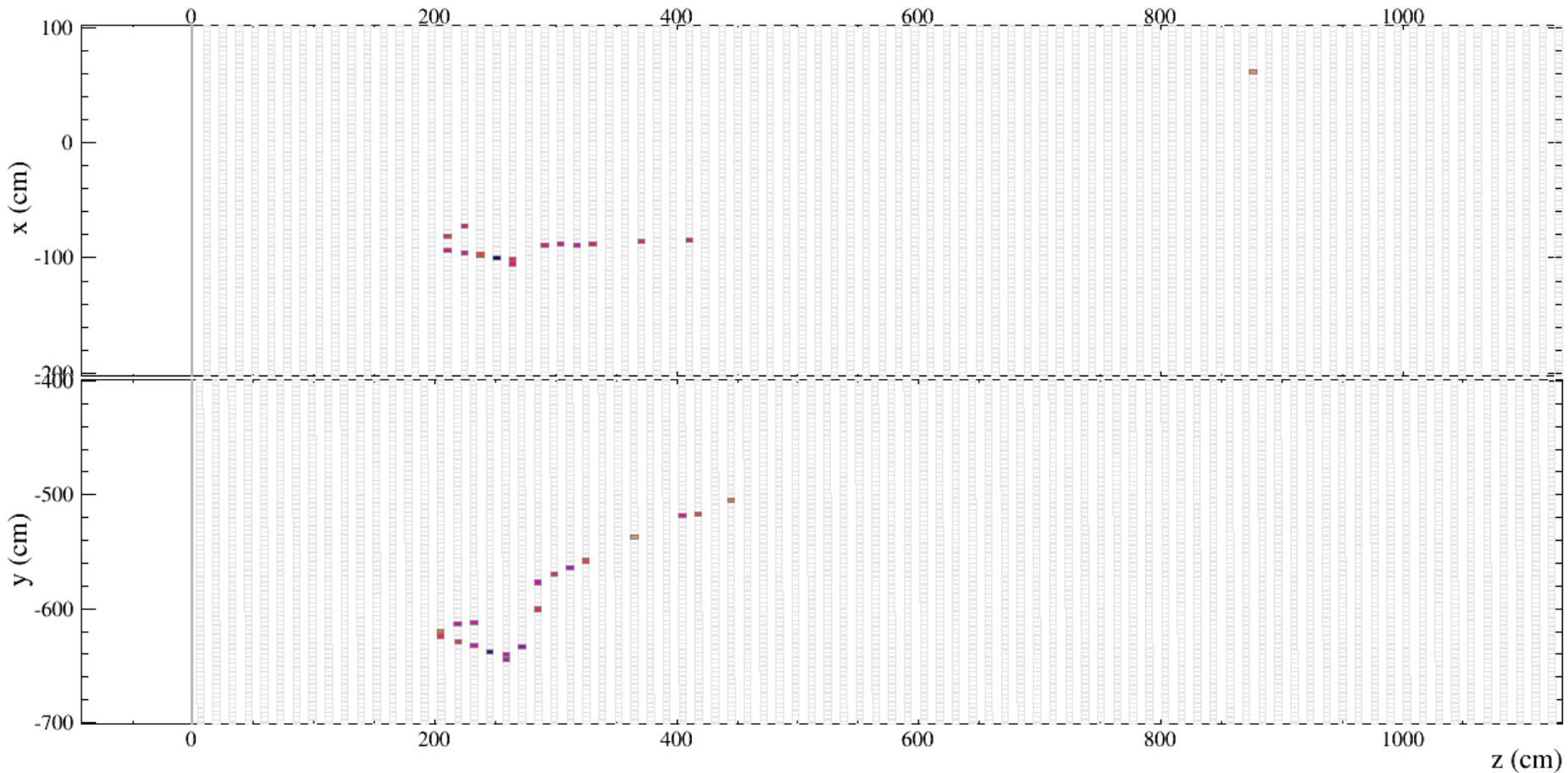
The NuMI Beam spectra: ν_μ and $\bar{\nu}_\mu$



- 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

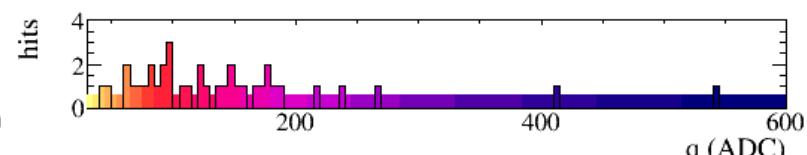
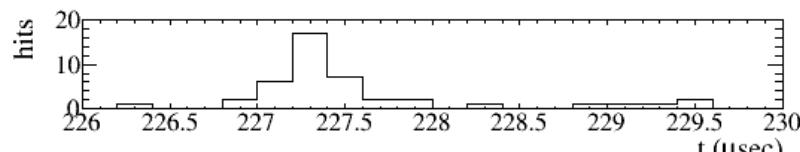


1st neutrino candidate

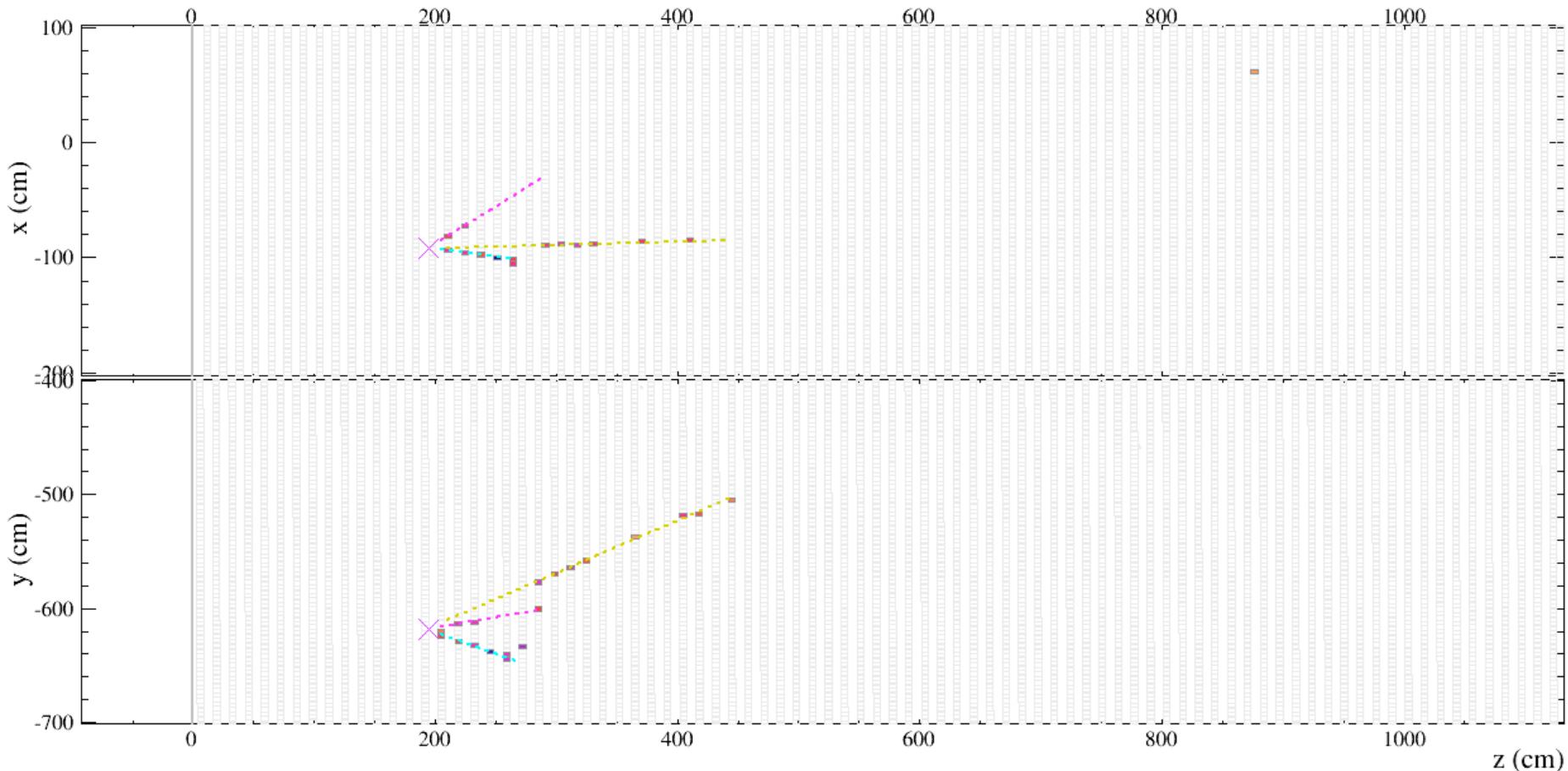


NOvA - FNAL E929

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Event: 77385 / NuMI
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13:25:44.976546176

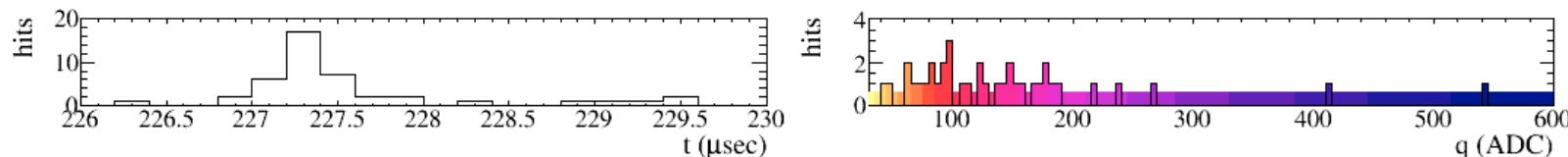


1st neutrino reconstruction

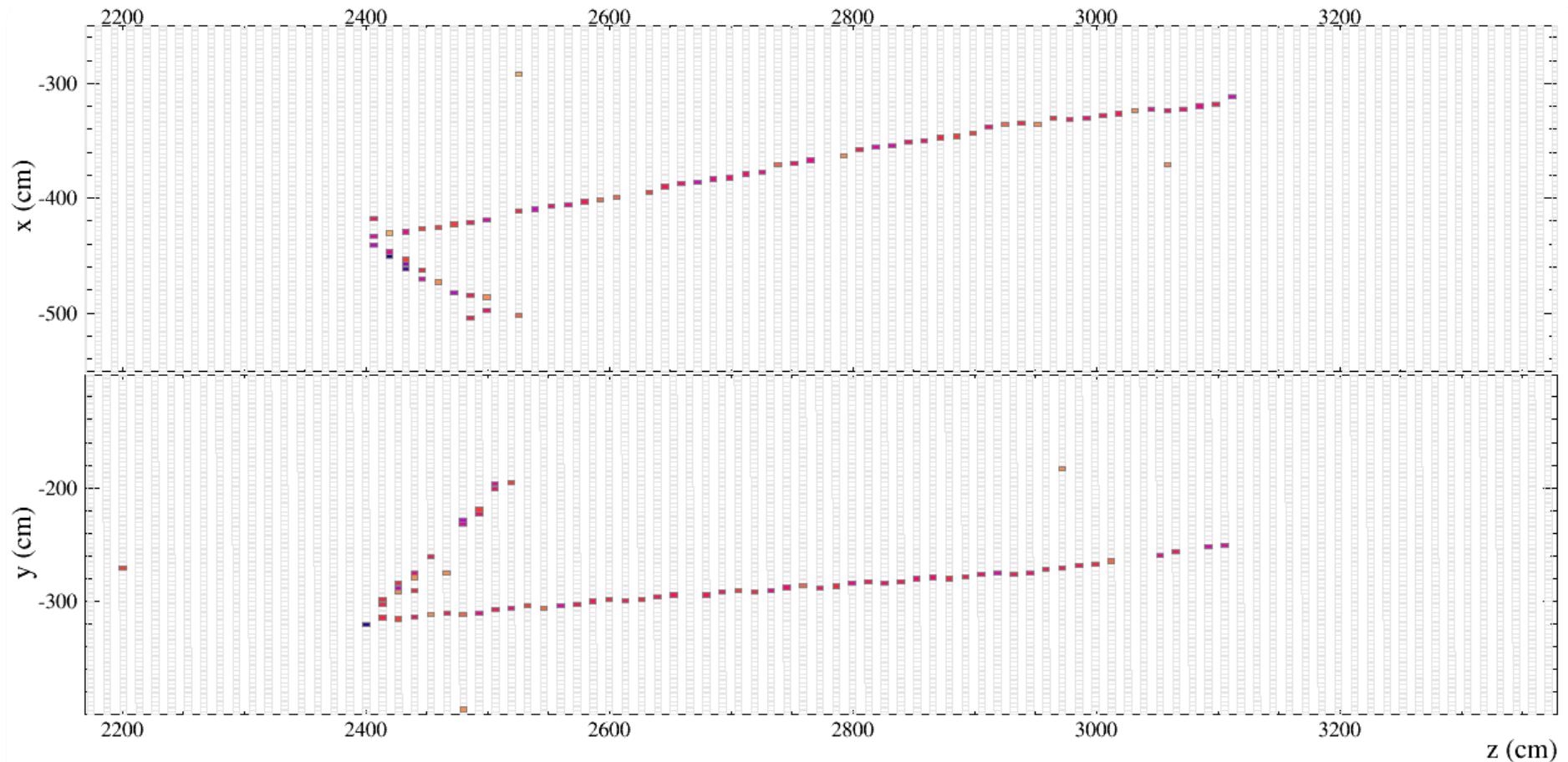


NOvA - FNAL E929

Run: 11654 / 9
Event: 77385 / NuMI
UTC Tue Nov 12, 2013
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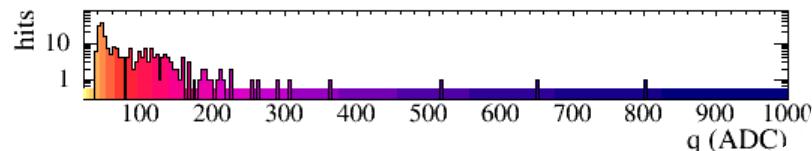
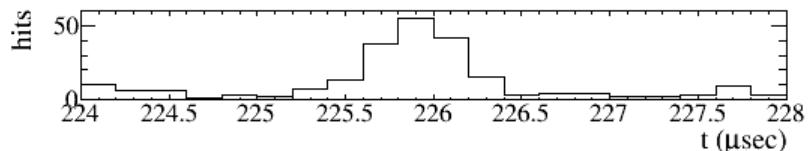


ν_μ CC candidate

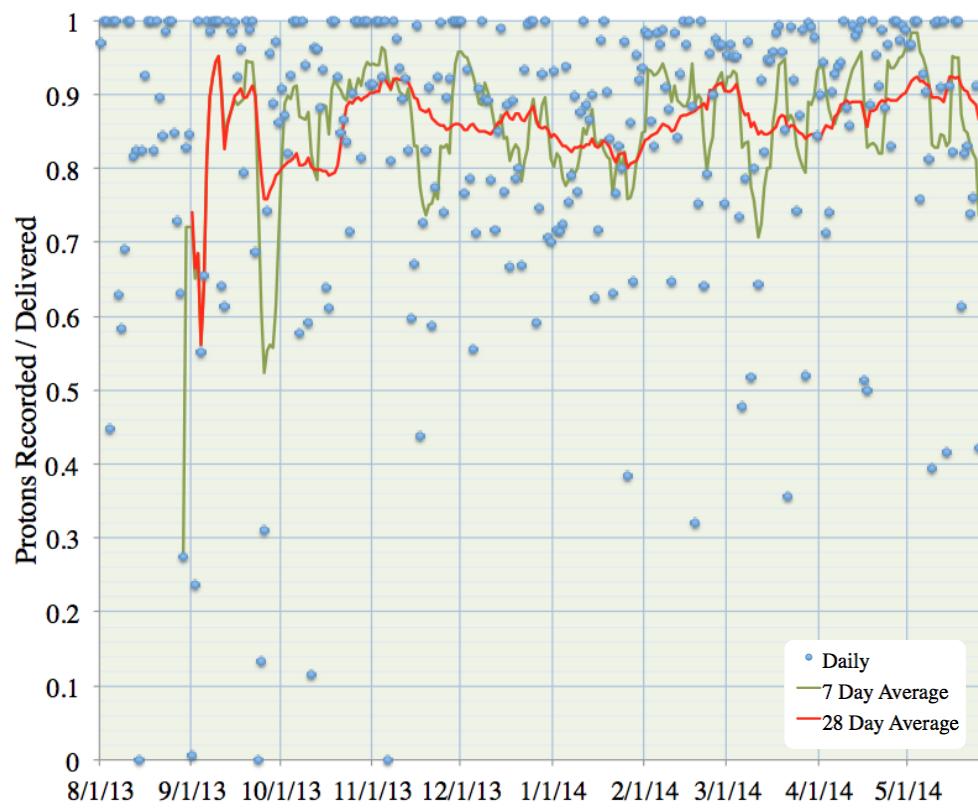


NOvA - FNAL E929

Run: 14828 / 38
Event: 192569 / NuMI
UTC Tue Apr 22, 2014
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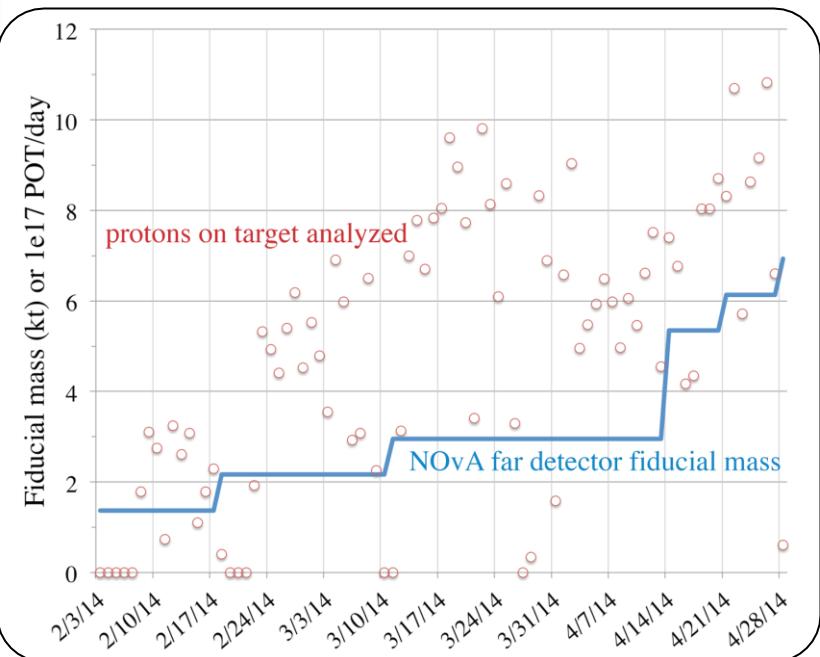
Far Detector Operations

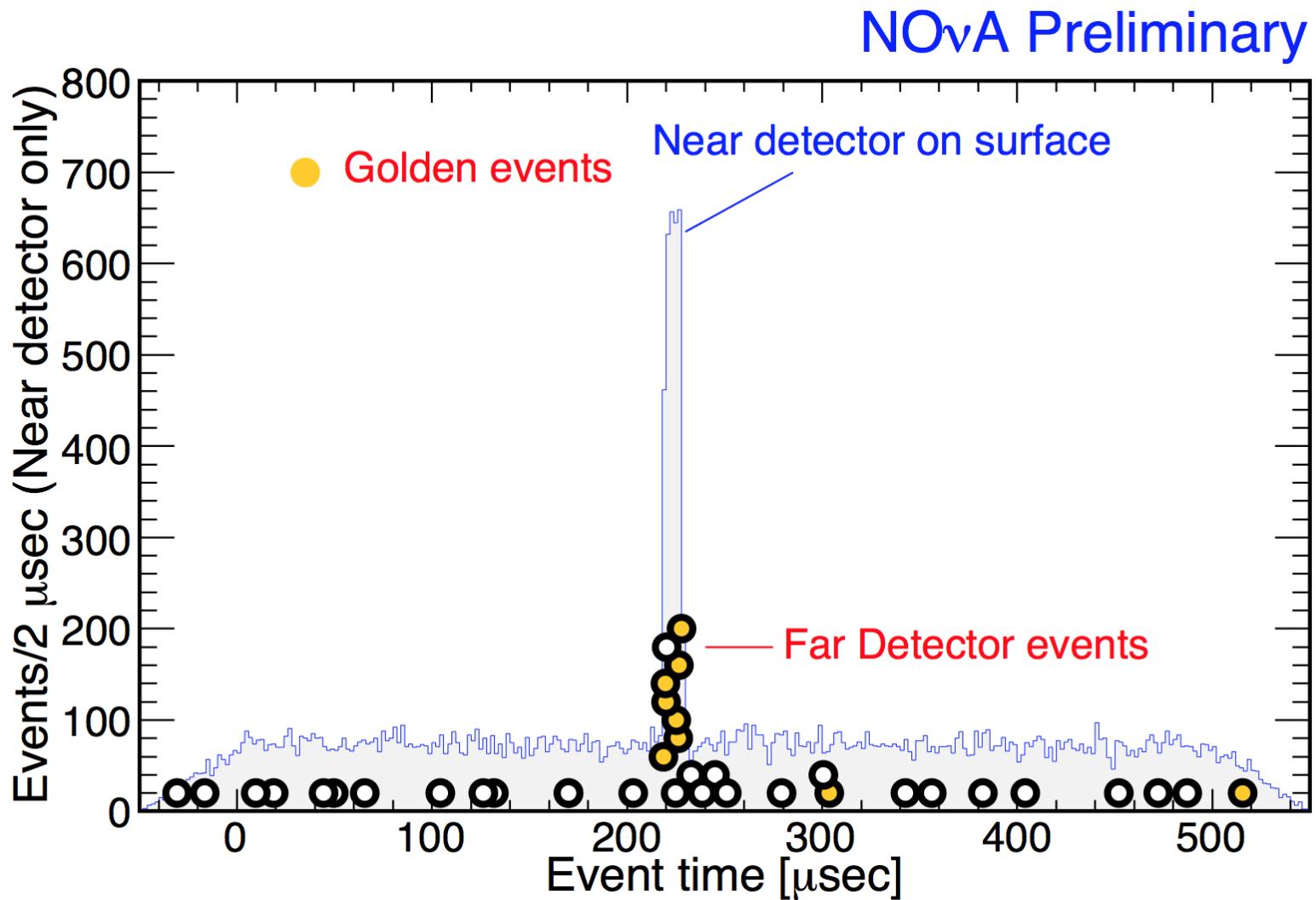


Early physics operations started Feb 3, 2014:

- Have integrated 1.7% of a nominal year at full detector mass and beam power:

$$\frac{1}{3} \text{yr} \times \frac{1}{3} \text{beam} \times \frac{1}{4} \text{detector} \times \frac{3}{4} \text{eff.} \simeq 0.02$$





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 :

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

Neutrino energy E
Baseline L