NOvA neutrino experiment

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On behalf of the NOvA Collaboration

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7 countries, 36 Institutions, 181 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

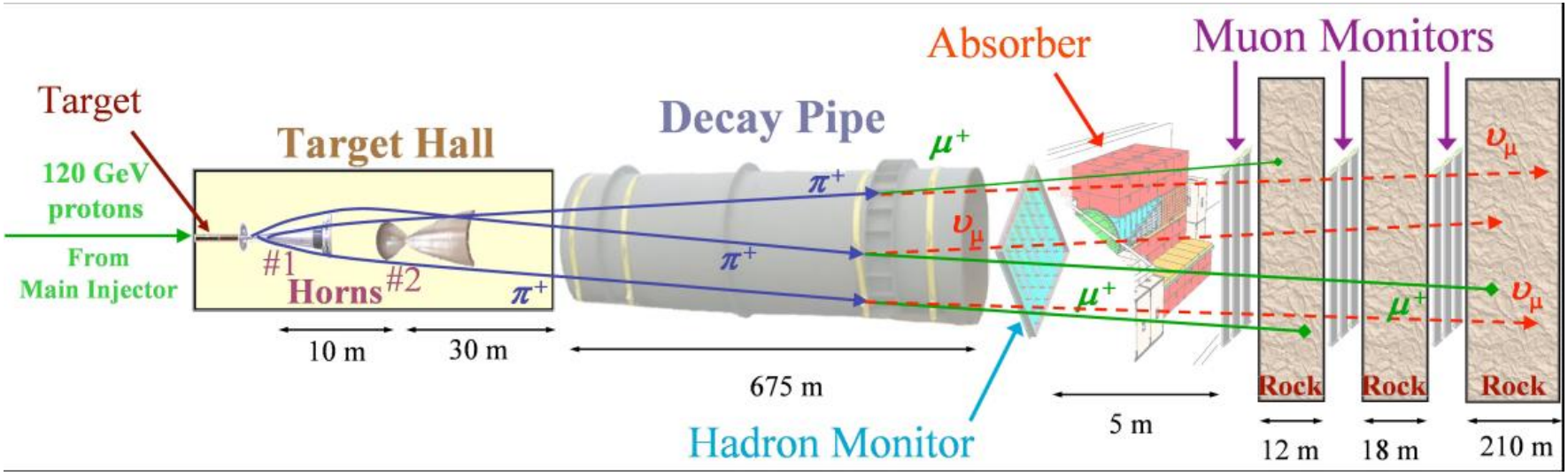
NuMI Off-axis ν_e Appearance Experiment

- Long-baseline, two-detector ν oscillation experiment
- 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 μs beam spill every 1.3 s
- Beam back from Sept 4, 2013
- 500 kW limit until Booster RF system upgrades complete
- 4.9×10^{13} POT/pulse – 6×10^{20} POT/year

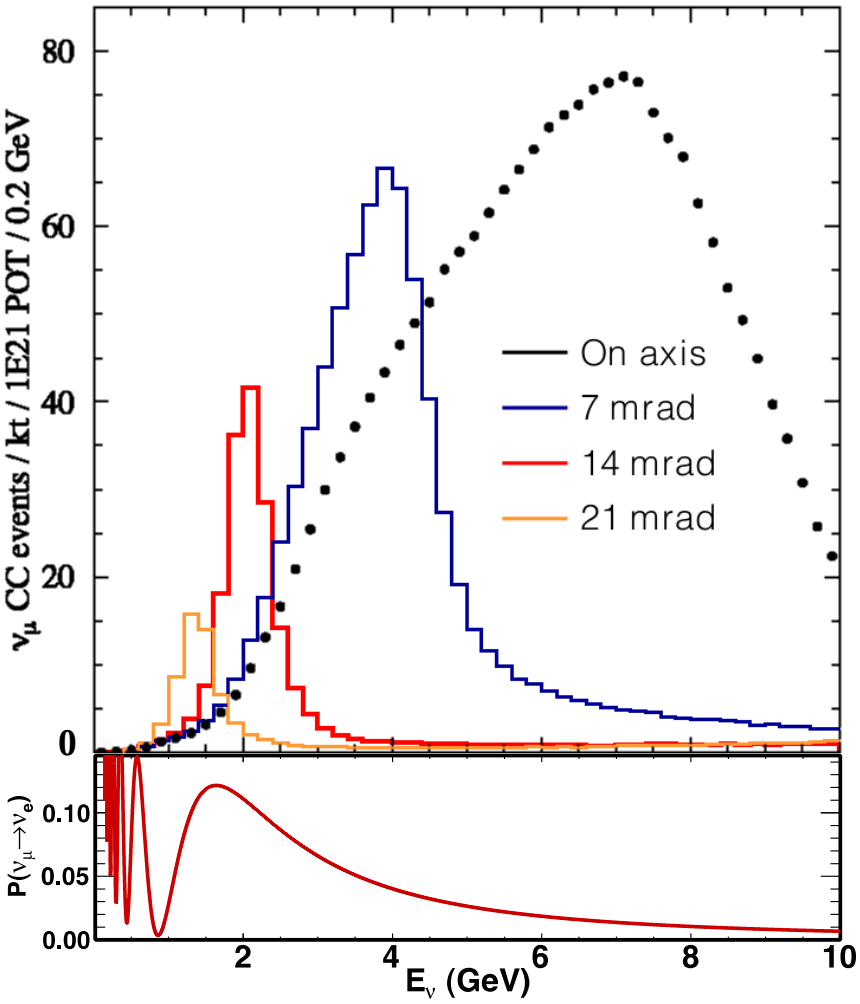


Why off-axis?

NuMI Off-axis ν_e Appearance

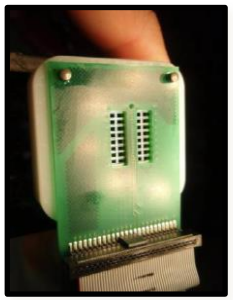
The choice of a 14 mrad off-axis position from the NuMI beam for the NOvA detector, allows for a narrow band beam which in conjunction with topology of final state particles, allows one to more easily reject potential backgrounds

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



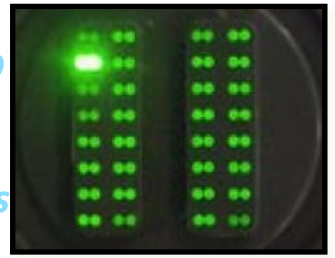
The NOvA detectors

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



32-pixel APD

Fiber pairs from 32 cells



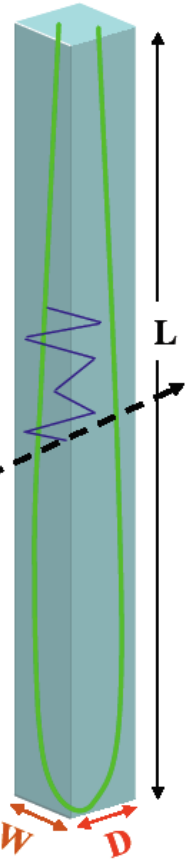
To 1 APD pixel

Far Detector
14 kton
60 m x 15.6 m x 15.6 m
928 layers
344 064 cells

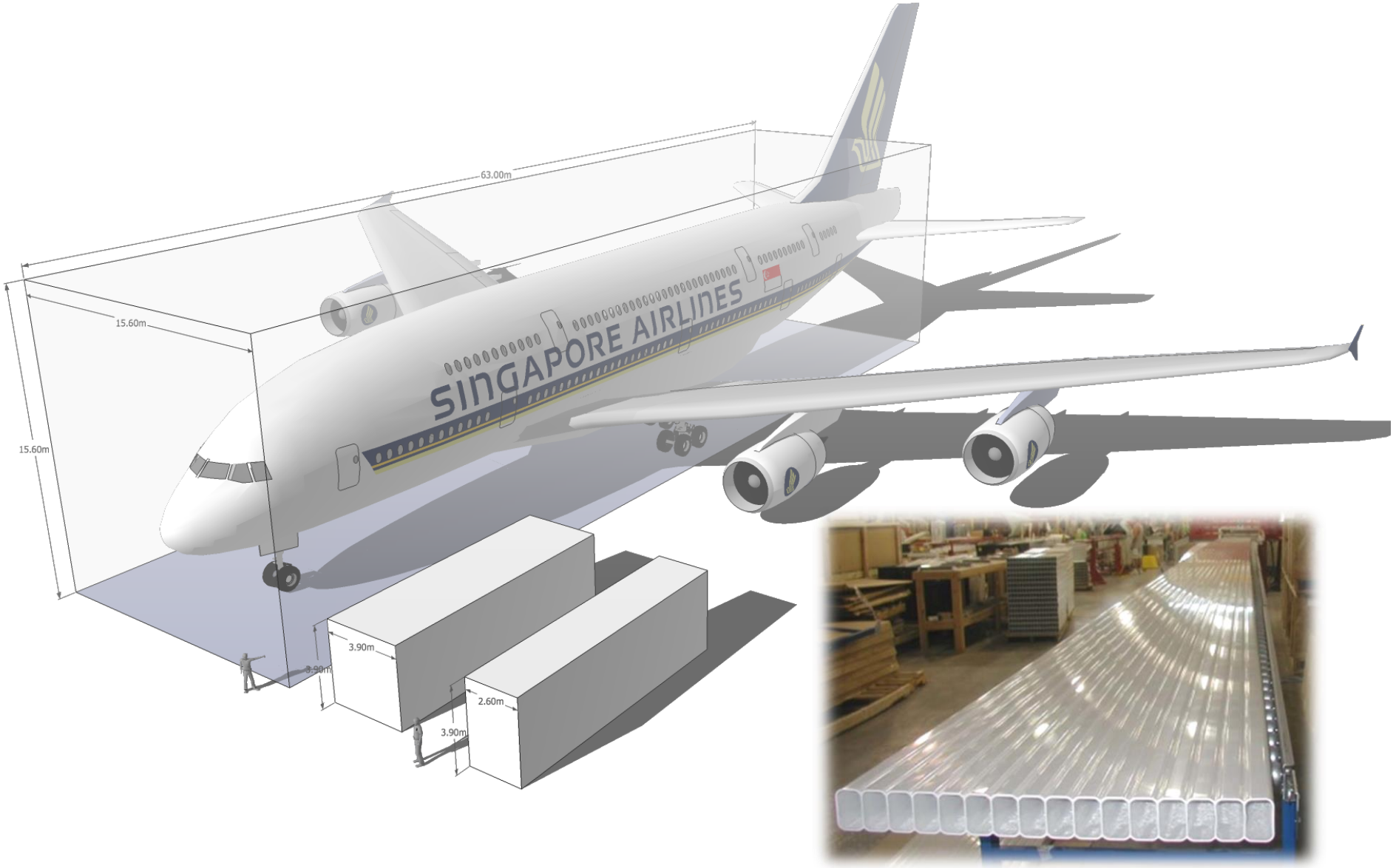
Extruded PVC cells filled with 9 ktons of scintillator instrumented with λ-shifting fiber and APDs

Near Detector
0.3 kton
14.3 m x 4.2 m x 4.2 m
214 layers
18 000 cells

typical charged particle path



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

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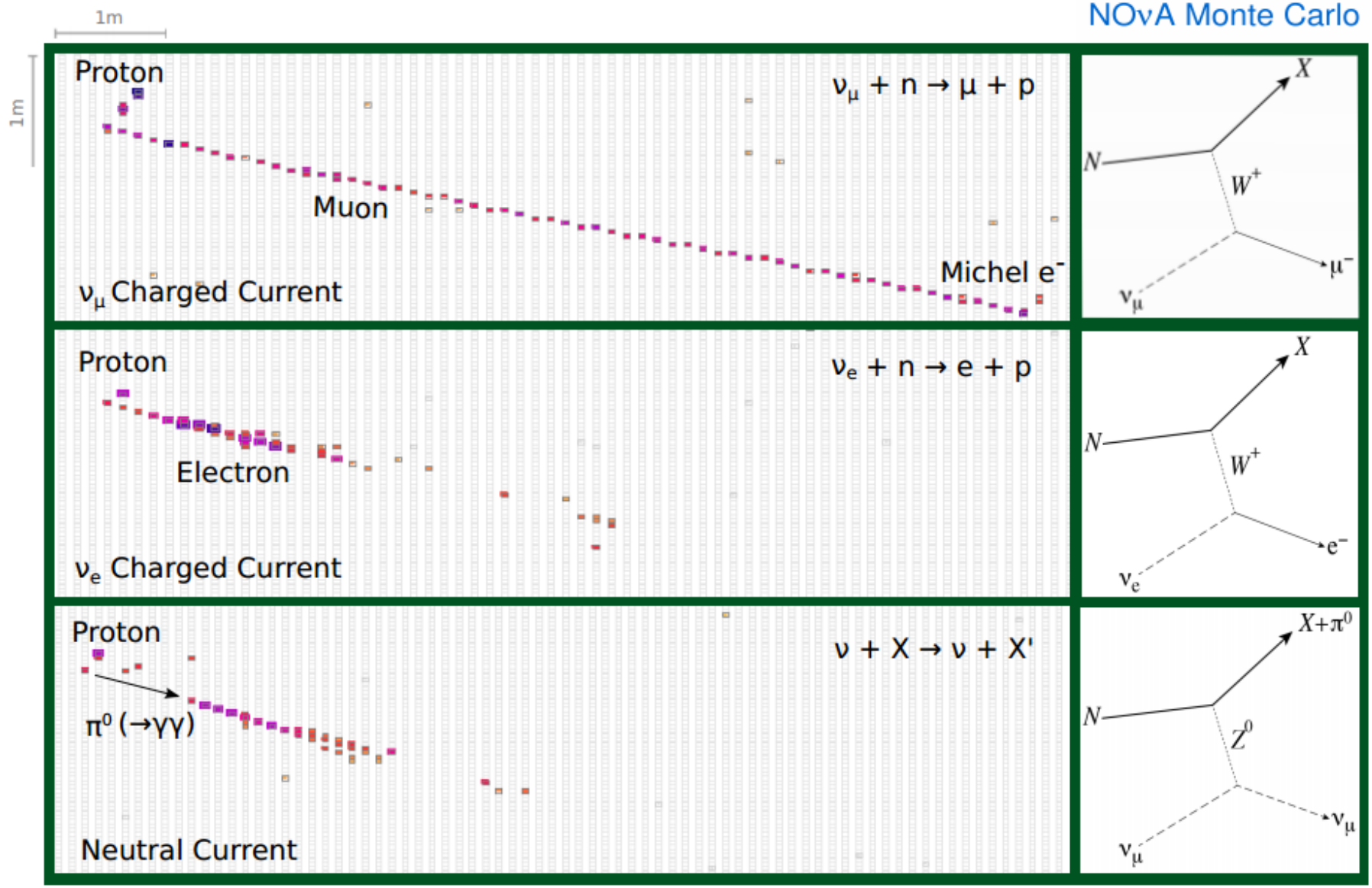
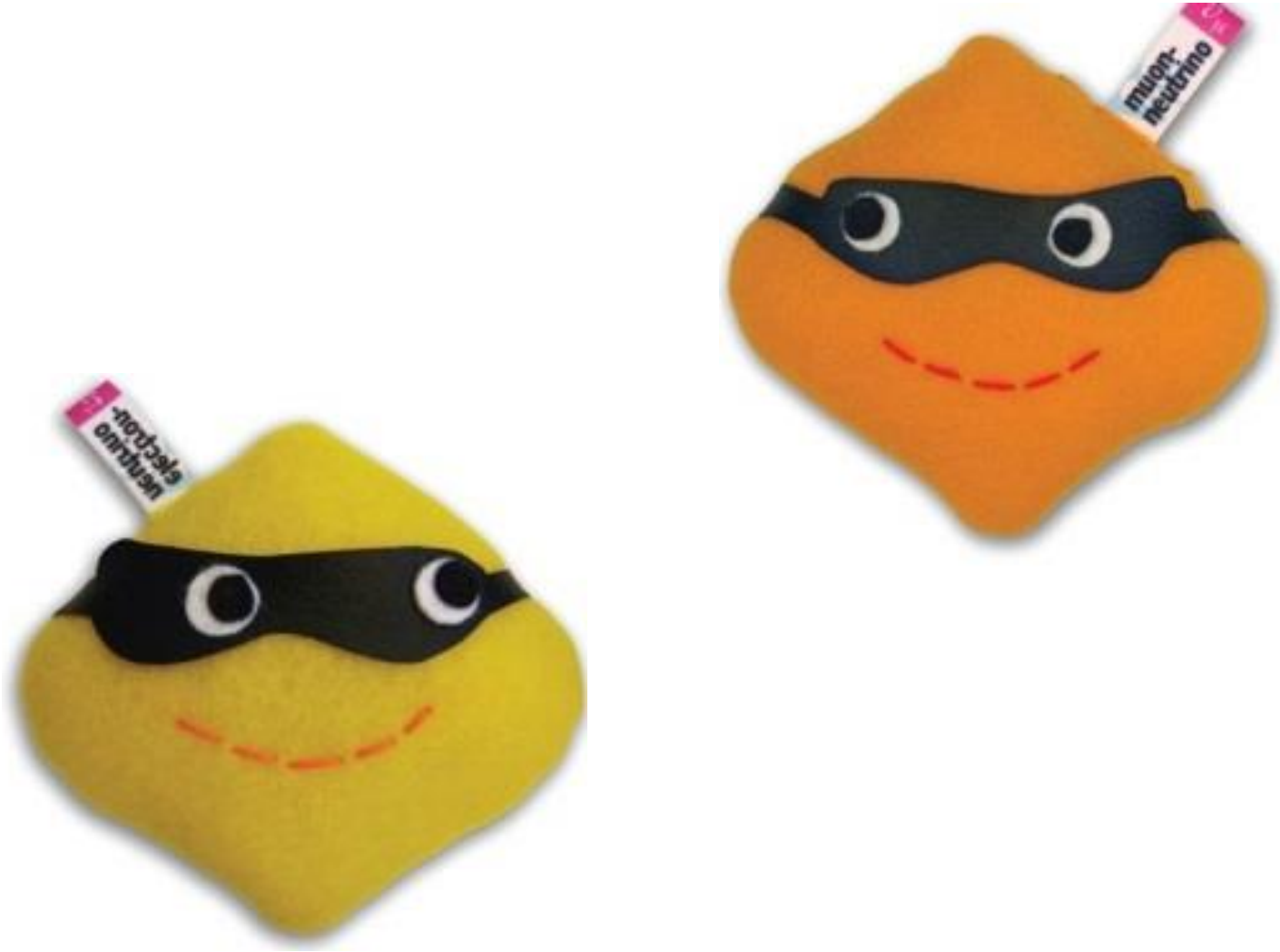
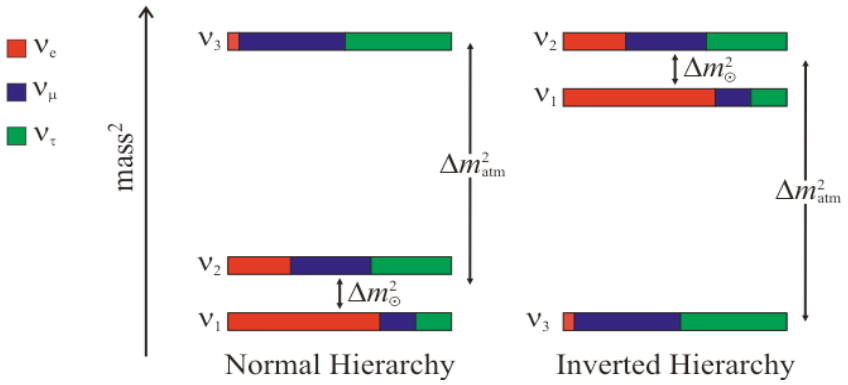
NOvA Neutrino Event Topologies




muon-
neutrino
electron-
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)

NOvA physics goals

$$P(\overset{(-)}{\nu}_\mu \rightarrow \overset{(-)}{\nu}_e) \approx \sin^2 2\theta_{13} \sin^2\theta_{23} \frac{\sin^2(A-1)\Delta}{(A-1)^2}$$
$$\overset{(+)}{(-)}\, 2\alpha \sin\theta_{13} \sin\delta_{CP} \sin 2\theta_{12} \sin 2\theta_{23} \frac{\sin A\Delta}{A} \frac{\sin(A-1)\Delta}{(A-1)} \sin\Delta$$
$$+\ 2\alpha \sin\theta_{13} \cos\delta_{CP} \sin 2\theta_{12} \sin 2\theta_{23} \frac{\sin A\Delta}{A} \frac{\sin(A-1)\Delta}{(A-1)} \cos\Delta$$
$$\alpha = \Delta m^2_{21}/\Delta m^2_{31} \qquad \Delta = \Delta m^2_{31} L/(4E) \qquad A = \overset{(-)}{(+)} G_f n_e L/(\sqrt{2}\Delta)$$

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…).

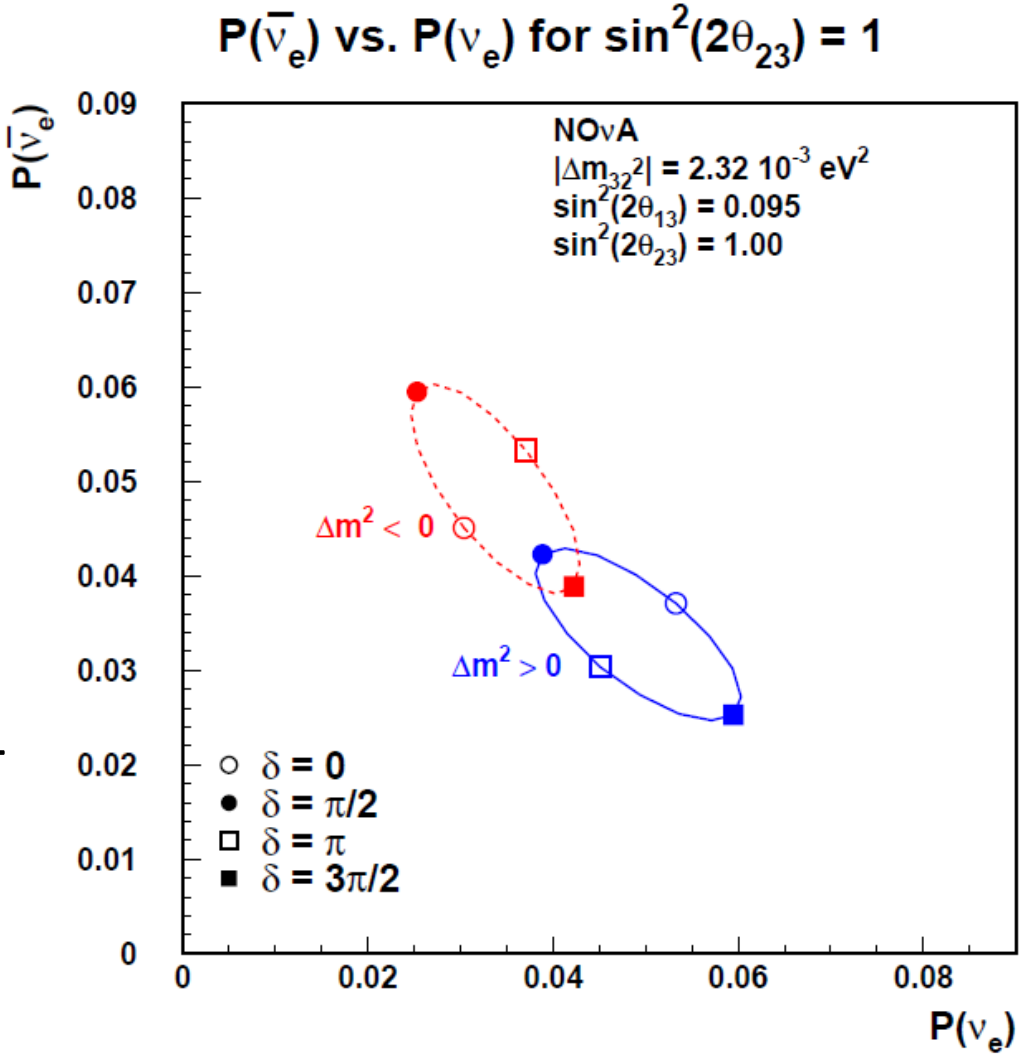
ν_e appereance in NOvA

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



ν_e appereance in NOvA

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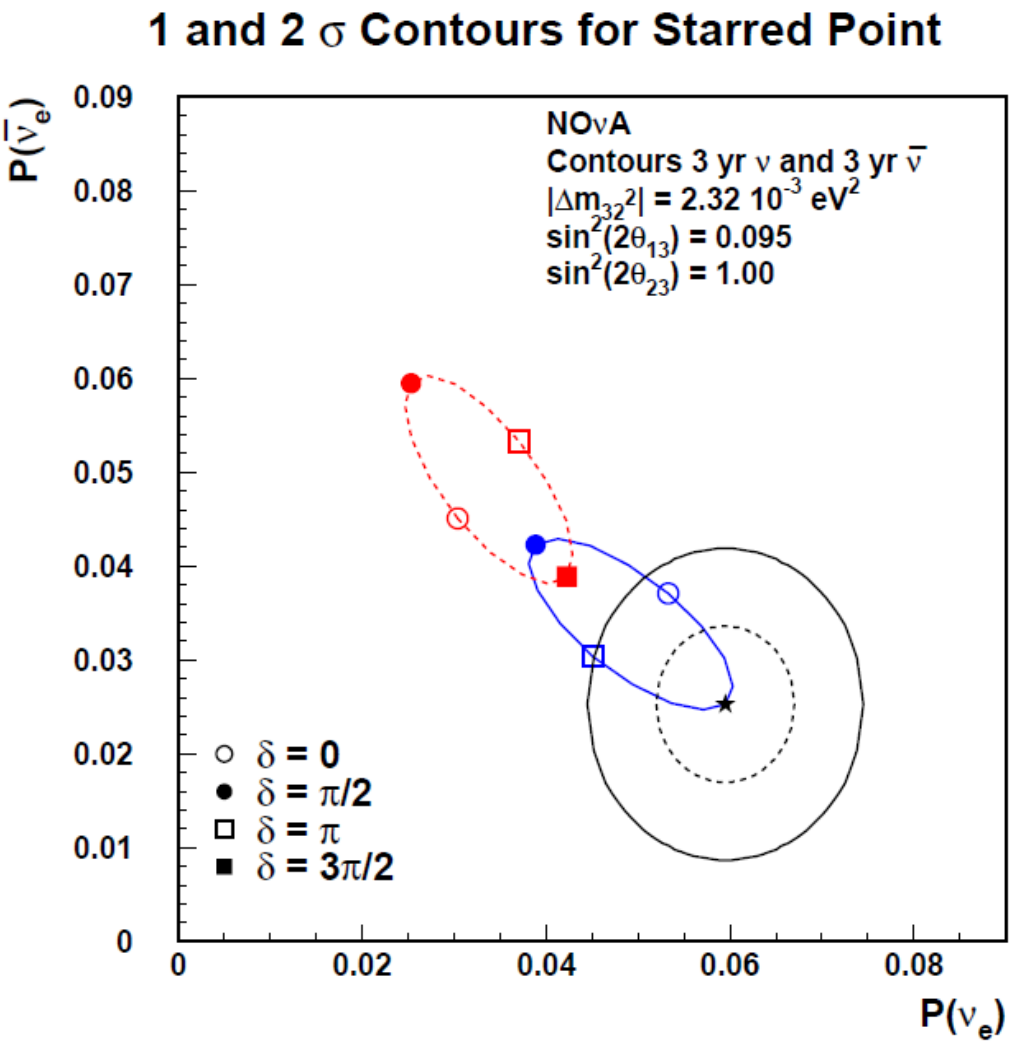
  $P(\nu_\mu \rightarrow \nu_e)$ at 2 GeV and

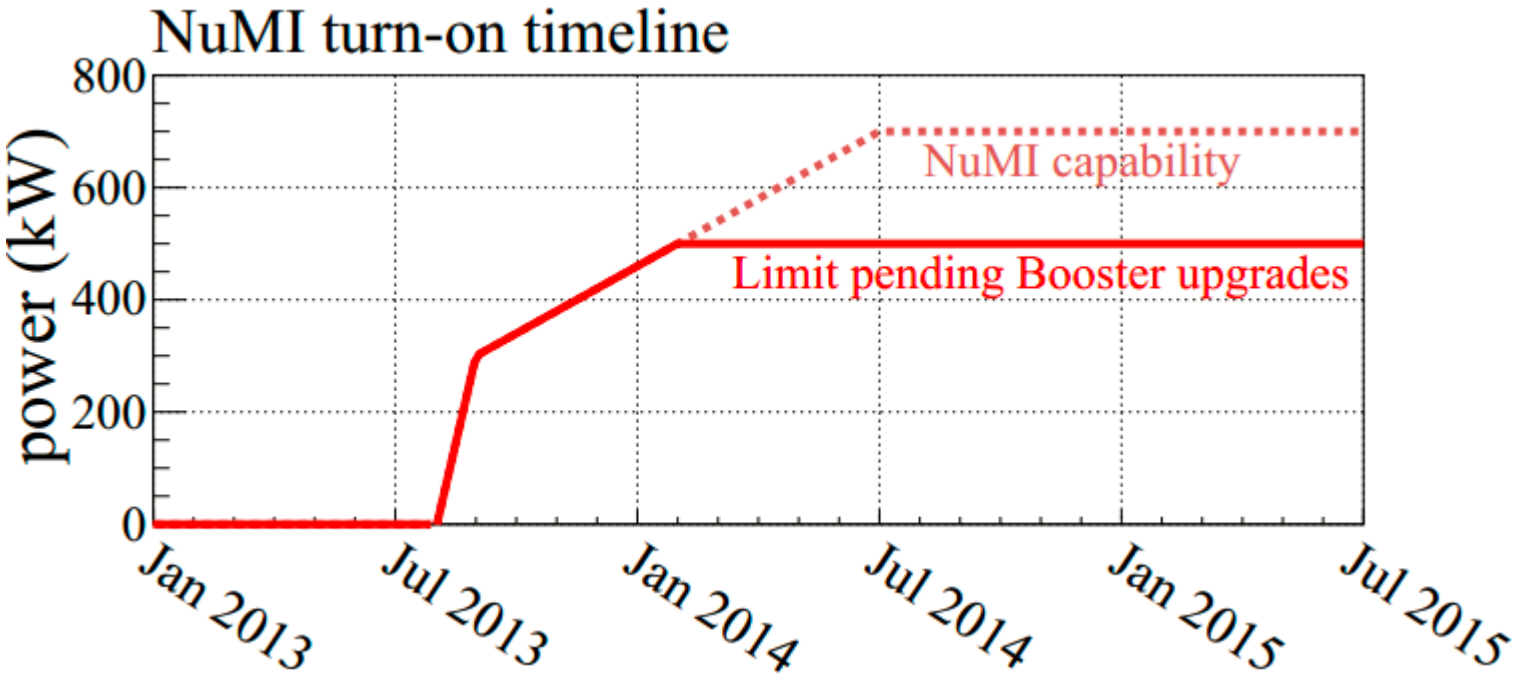
  $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$ at 2 GeV

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

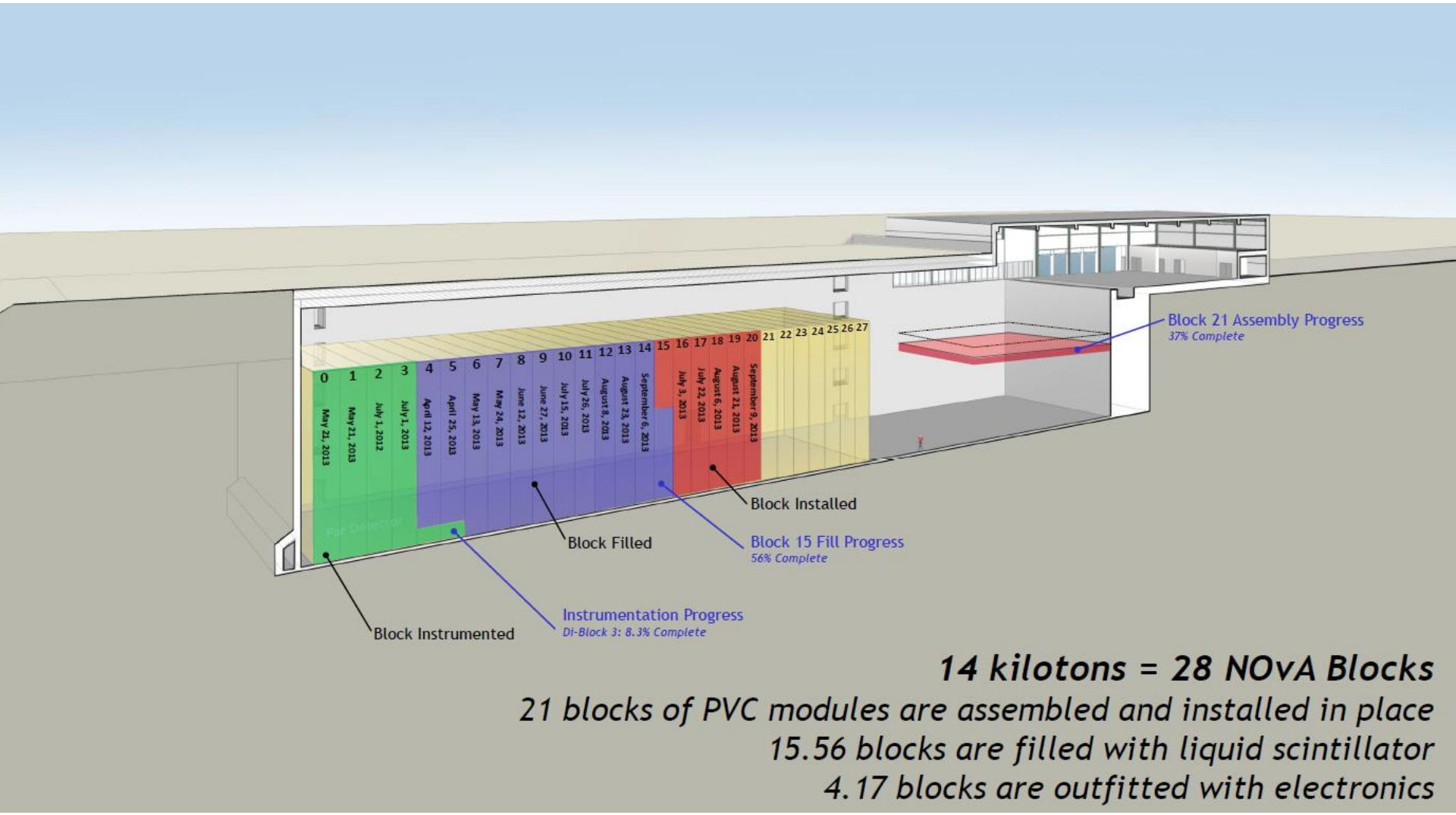


Beam status

- **First beam on September 4, 2013**
- Need Booster upgrades to reach 700kW
- Started looking for neutrinos, stay tuned!



FD construction status



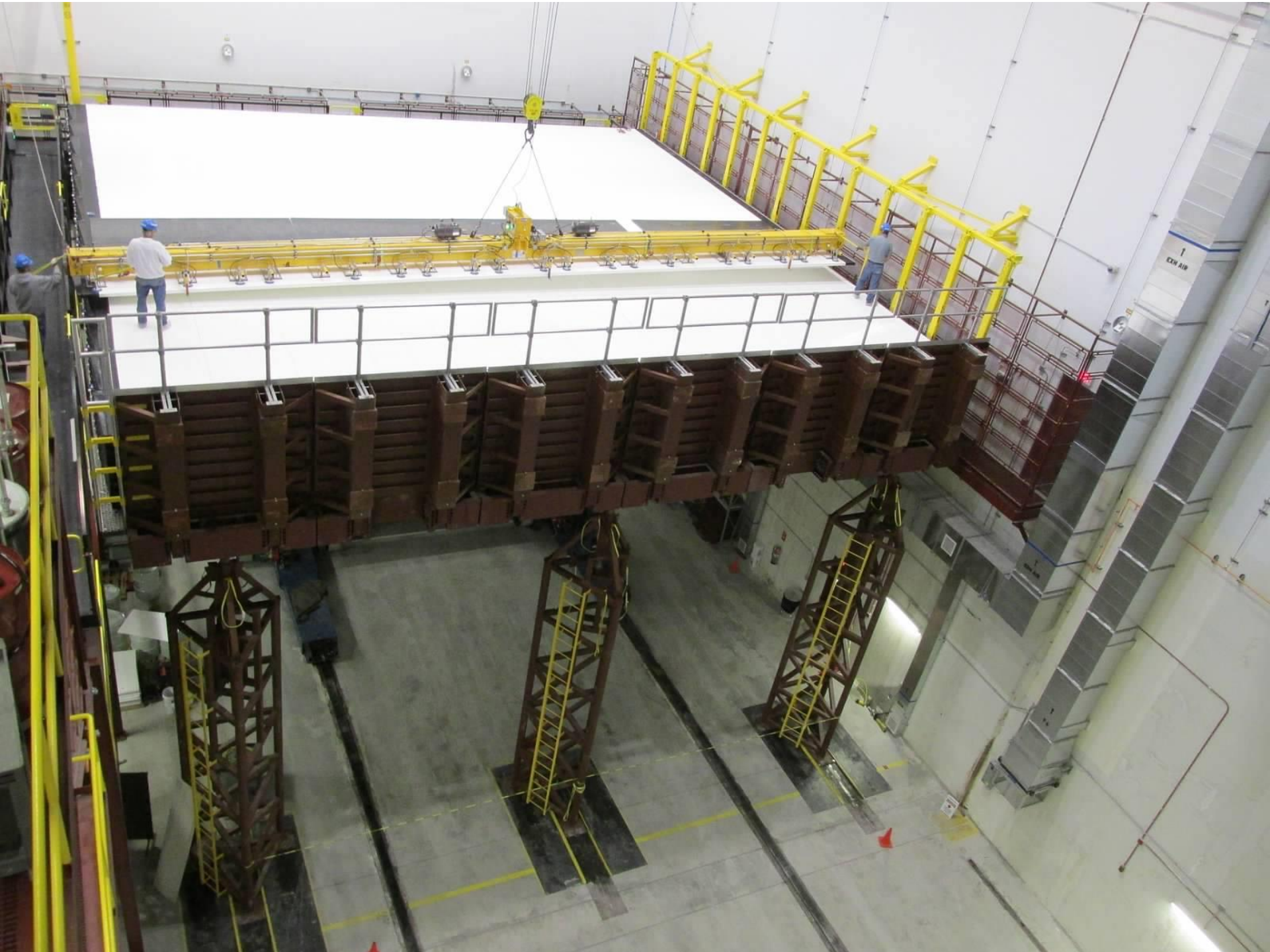
14 kilotons = 28 NOvA Blocks

21 blocks of PVC modules are assembled and installed in place

15.56 blocks are filled with liquid scintillator

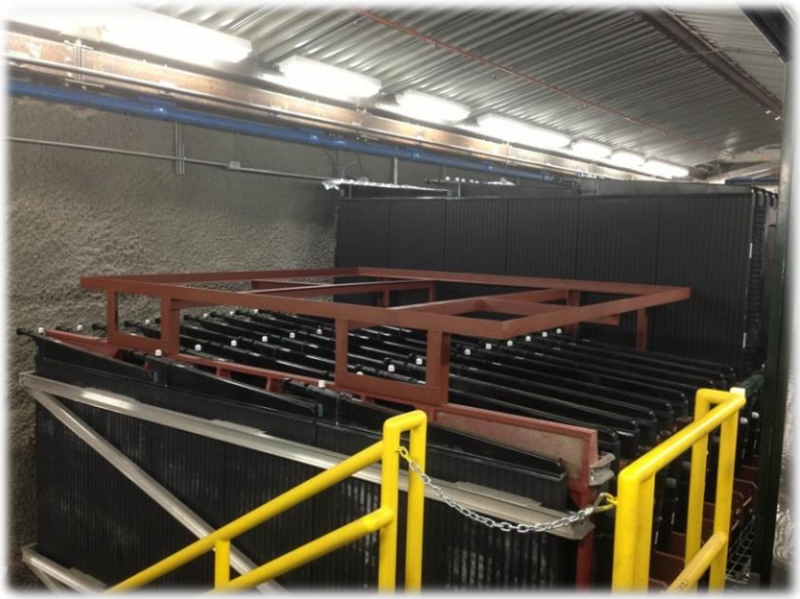
4.17 blocks are outfitted with electronics


Empty Hall



ND Construction Progress

- ND Muon Catcher installed Aug 1st
- First block installed Aug 21st 2013
- First (downstream) half of ND to be installed by the end of this year
- Second (upstream) half to installed by summer of 2014



Summary

- NOvA will make many important contributions to neutrino physics:
  - Measurement of θ_{13}
  - Important first information on the neutrino mass hierarchy and CP violation
  - Determination of the θ_{23} octant
  - More precise measurements of $|\Delta m^2_{32}|$ and $\sin^2(2\theta_{23})$
- First FD blocks have been outfitted and now collecting cosmic ray data, ND muon catcher installed, first half of detector will be completed by end of 2013
- NuMI beam is back
- Collaboration is very focused on commissioning of Far Detector
- Reconstruction/analysis tools are in place for first results in summer of 2014

Stay tuned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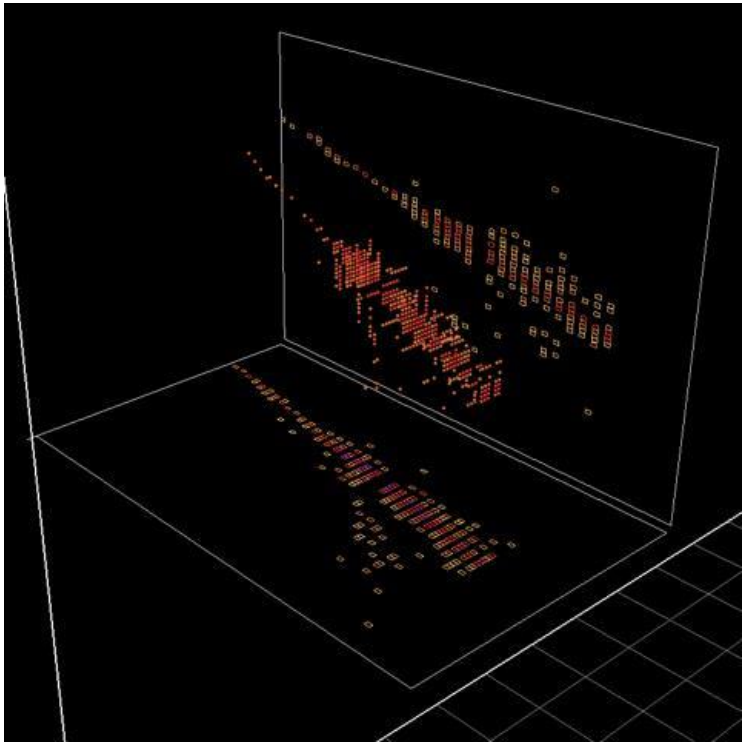
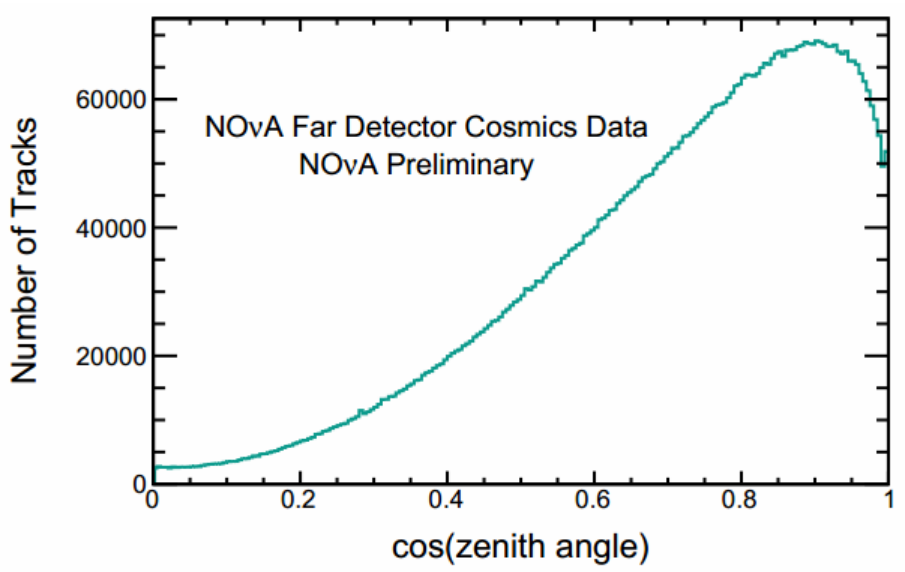
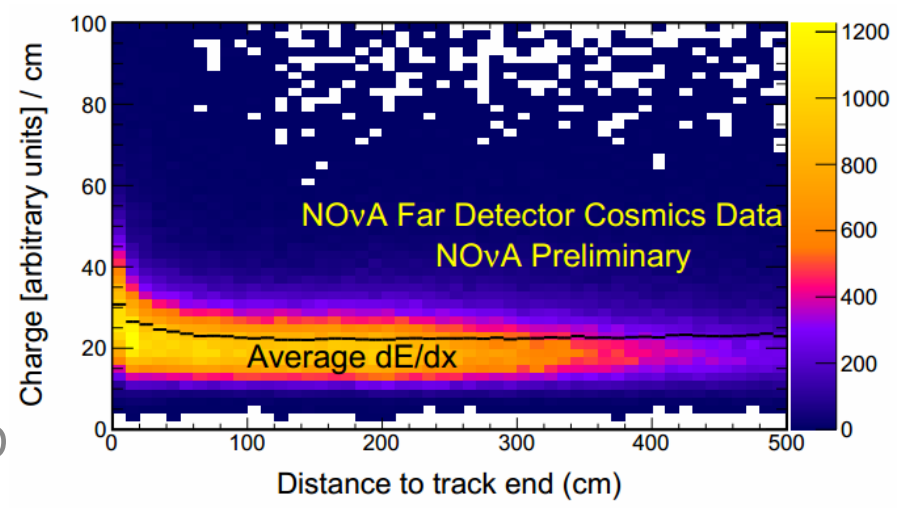
First FD cosmic data

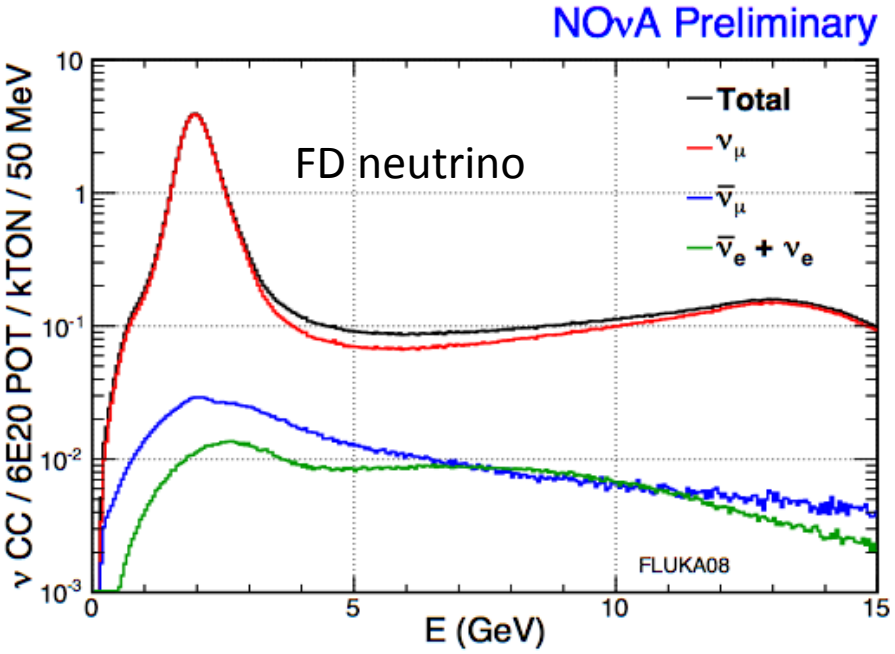


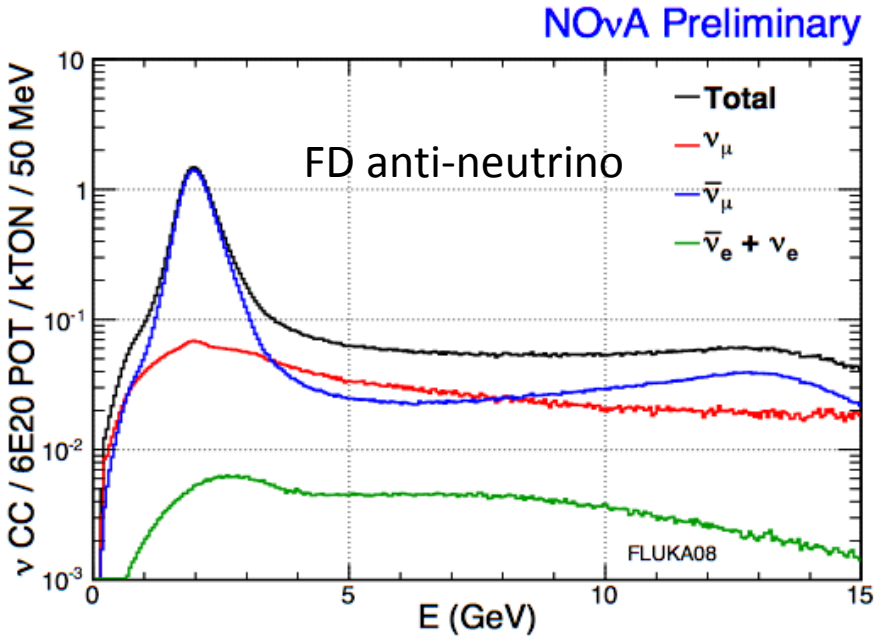




- First kton of the Far Detector was instrumented May 21st 2013
  - Now have two kton instrumented
- Reconstruction algorithms already tested on cosmic ray data collected
- Captured many examples of above 3D display of a cosmic ray event

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

How to make a neutrino beam

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- Series of upgrades - 10 μs beam sp
- Beam back from Sept 4, 2013
- 500 kW limit until Booster RF syste
- 4.9×10^{13} POT/pulse – 6×10^{20} POT/