The NuMI Off-axis ν_e Appearance Experiment (NOνA)

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IPA 2013, 2013/05

Outline

NOνA Experiment
- NuMI Beam
- The NOνA Detectors
- Current Status

NOνA Physics Reach

Summary

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- Current Status

NOνA Physics Reach

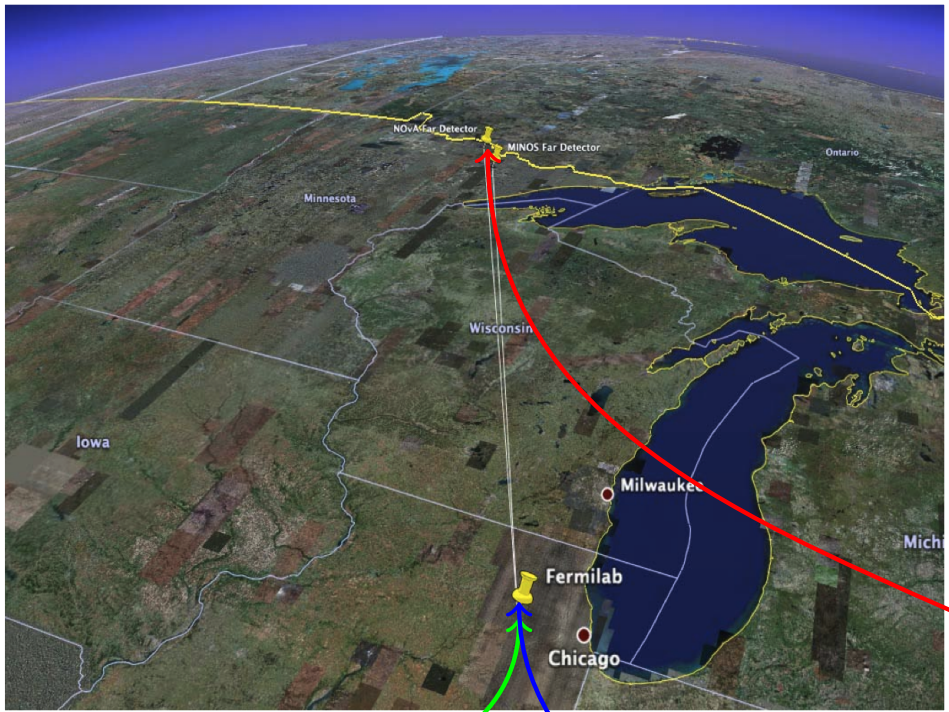
Summary

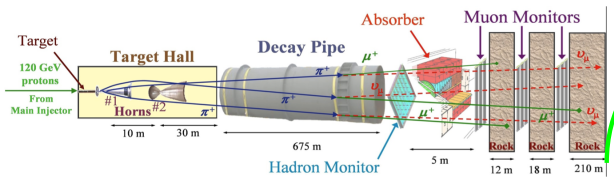
The NOνA Experiment

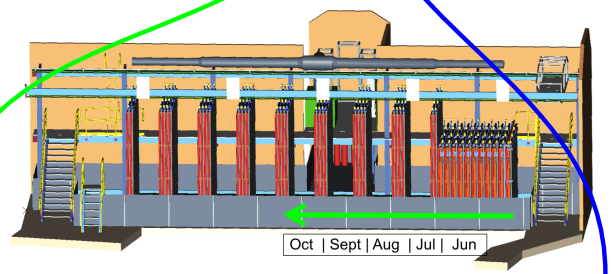
- Intense medium energy ν beam - 700 kW
- Off-axis narrow band beam peaks at $\sim$2 GeV (suppress backgrounds)
- Long baseline 810 km (more matter effect)
- 73% active near and far detectors
- 14 kt total far detector mass

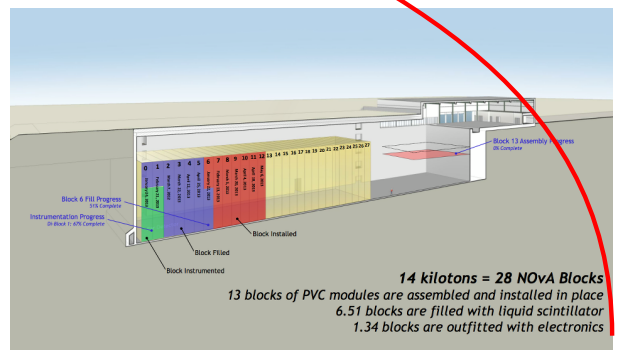
- Precision measurements of θ_{13}, θ_{23}, and $|\Delta m^2_{32}|$
- Determine the θ_{23} octant
- Determine the mass hierarchy
- Search for δ_{CP}
- Exotic physics, *etc.*

The NOνA Experiment

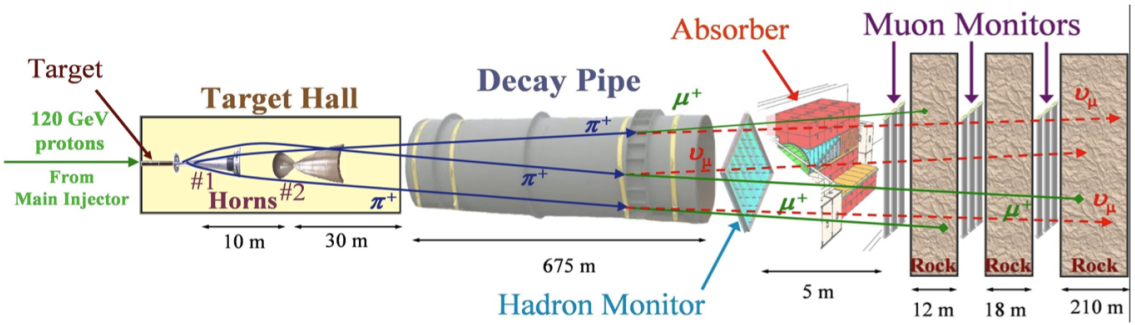




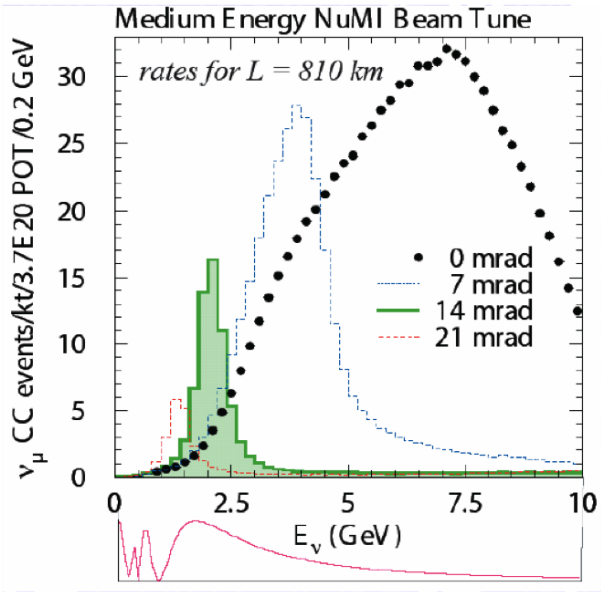




NuMI (Neutrinos at the Main Injector) Beam

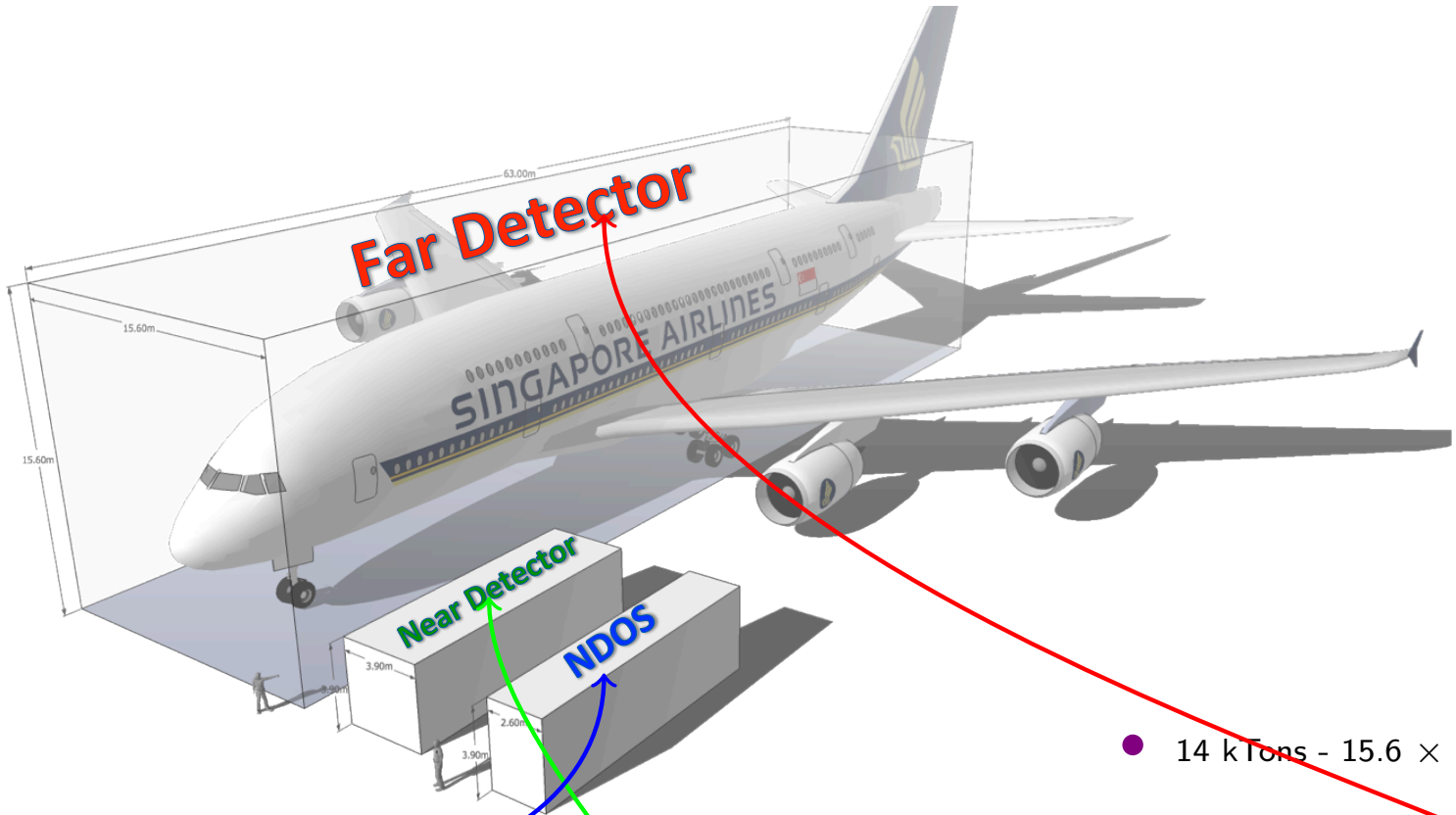


- Beam Spectrum tunable by horn currents, relative placement of target horns
  - ν or $\bar{\nu}$ predominant beam depending on horn current polarity
- 10 μs beam spill every 1.33 sec
- Operating since 2005
  - MINOS, MINERνA, ArgoNEUT
- Turn on in June with low power, $\sim$500 kW in 5 months, expect 5e20 POT in July 2014, 1e21 POT in July 2015



- 14 mrad off-axis medium energy peaks at $\sim$2 GeV, the 1$^{\text{st}}$ oscillation maximum
- Low contamination
  - 4% $\bar{\nu}_\mu$ of ν_μ-enhanced beam
  - 30% ν_μ of $\bar{\nu}_\mu$-enhanced beam
- Narrow Band Beam suppresses backgrounds (NC, τ)

The NOνA Detectors



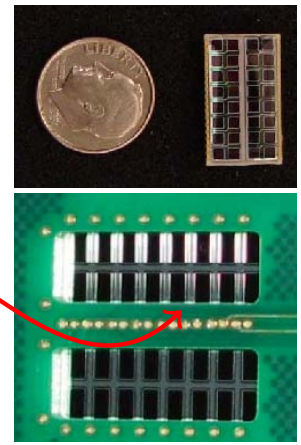
- 225 Tons - 4.1 $\times$ 2.9 $\times$ 14.3 m
- Each plane just 0.15 X_0 ($X_0 = 38$ cm), great for electrons

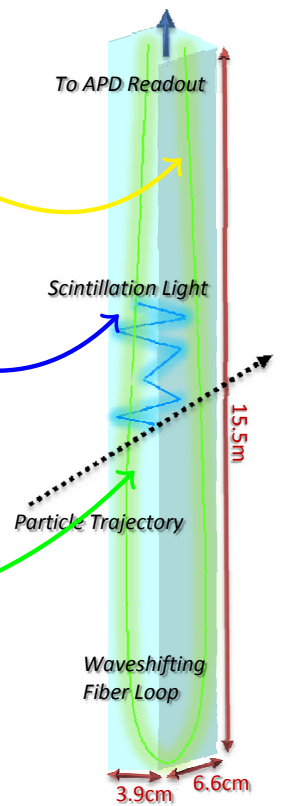
- 300 Tons - 4.1 $\times$ 4.1 $\times$ 14.8 m
- Includes muon catcher for ranging out μ's

- 14 kTons - 15.6 $\times$ 15.6 $\times$ 60 m
- Alternating X/Y measuring planes for 3D reconstruction
- Over 344,000 independent measurement cells
- $>$ 70% of total mass is active

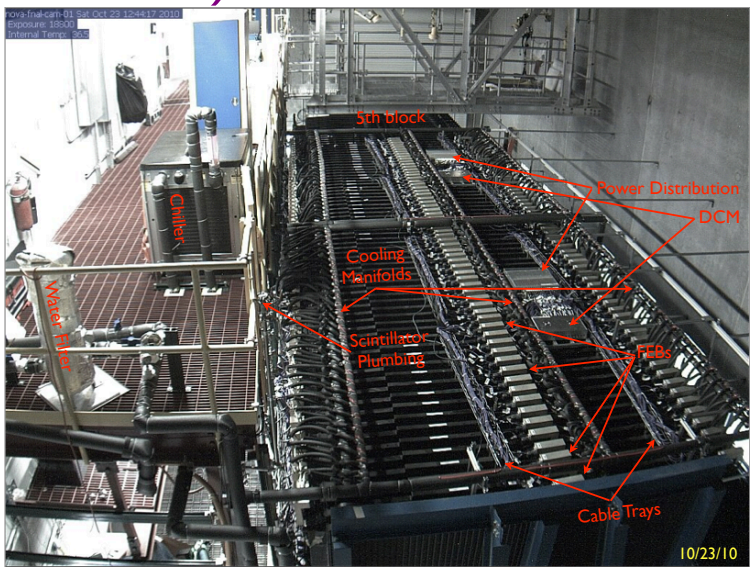
Detector Components

- Avalanche photodiode (APD) converts light to electrical signal (11,160 devices, each 32 pixels)
  - Operated at -15°C, with Gain $\sim$ 100 and quantum efficiency 85%
- Liquid Scintillator (3 million gallons)
  - Contained in 3.9 cm$\times$6.6 cm$\times$15.6 m cells
  - 6.6 cm as seen by the beam
- Cell walls are rigid PVC (5 kilotons)
  - Loaded with 15% anatase form of titanium dioxide
- Looped wavelength-shifting fiber collects light (11,160 km)
  - Fiber diameter 0.7 mm
  - Fiber shifts wavelength to $\sim$ 520-550 nm along the fiber



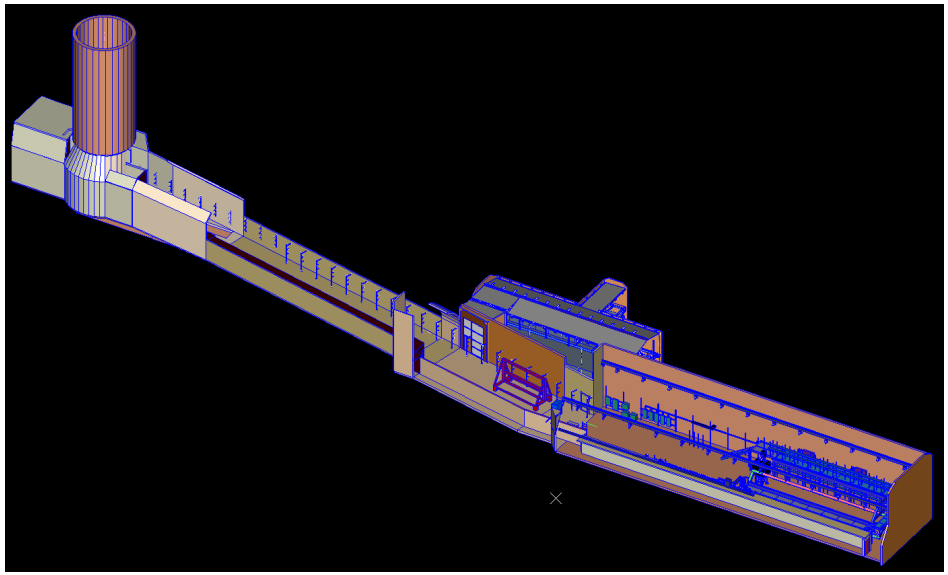


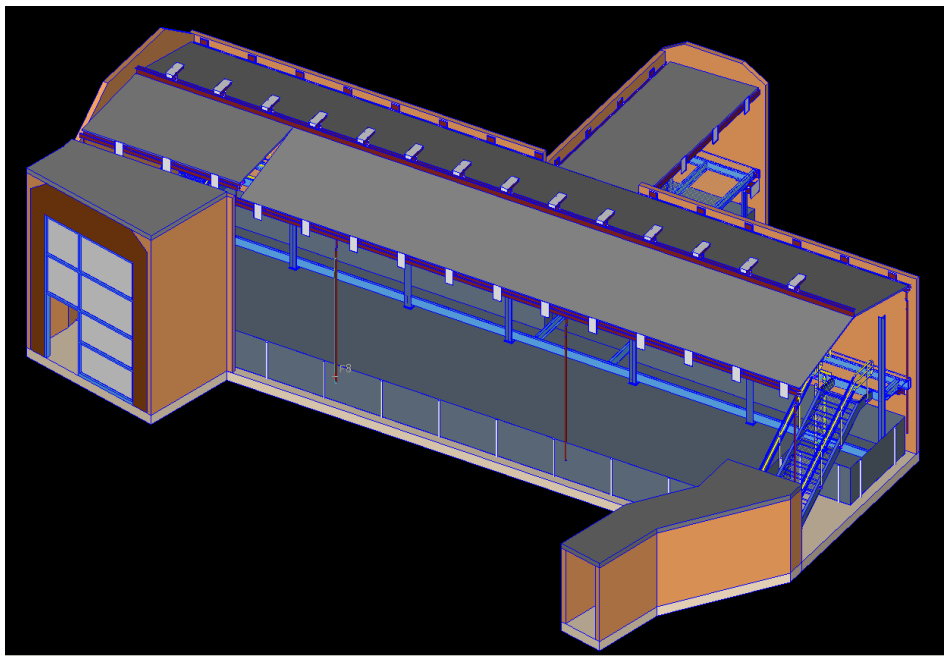
Near Detector on the Surface (NDOS)



- 225 tons, 199 plastic planes + 10 steel planes, $\sim$1/3 instrumented
- Serves as a test stand for DAQ HW and SW, installation procedures
- Real data ($\sim 10^{20}$ POT) for calibration, reconstruction and data analysis
  - Expected neutrino candidates - $\sim$ 500
  - Measure ν_μ QE cross section
  - Measure the inclusive cross section of charged current ν_μ for energies $\sim$2 GeV
- The Muon Catcher will be decommissioned and recycled for Near Detector

Near Detector Tunnel and Hall





Near Detector Hall - Beneficial Occupancy on May 10th

Fermilab

BENEFICIAL OCCUPANCY OR USE CERTIFICATE

This is for B.O. of the Building and office move in at second floor

Project Title NOvA Near Detector Hall

Subcontractor Kiewit Infrastructure

Subcontract No. 605581

Construction Project No. 6-7-14

In accordance with Article 27 of the Fermilab Construction Subcontract Terms and Conditions which are part of this subcontract, Fermilab hereby takes use or possession of the following works prior to subcontract completion: **NOvA Near Detector Hall**

Description of subcontractor work areas and/or features (i.e., mechanical equipment, etc.). (Reference additional sheets or drawings as needed.):

The work primarily consists construction of a new test experiment facility/building that includes civil, electrical, mechanical, HVAC and architectural installations. The area for BO is the entire facility.

Prior to taking possession or using any of the work Fermilab shall furnish the subcontractor a list of items of work remaining to be performed or corrected on those portions of the works to be used or occupied. This listing however does not relieve the subcontractor from complying with the terms of the subcontract.

On **May 8, 2013** inspection of the described work was completed and except as noted herein the inspection party found the work to be substantially in accord with the subcontract. A listing of work remaining or to be corrected is attached.

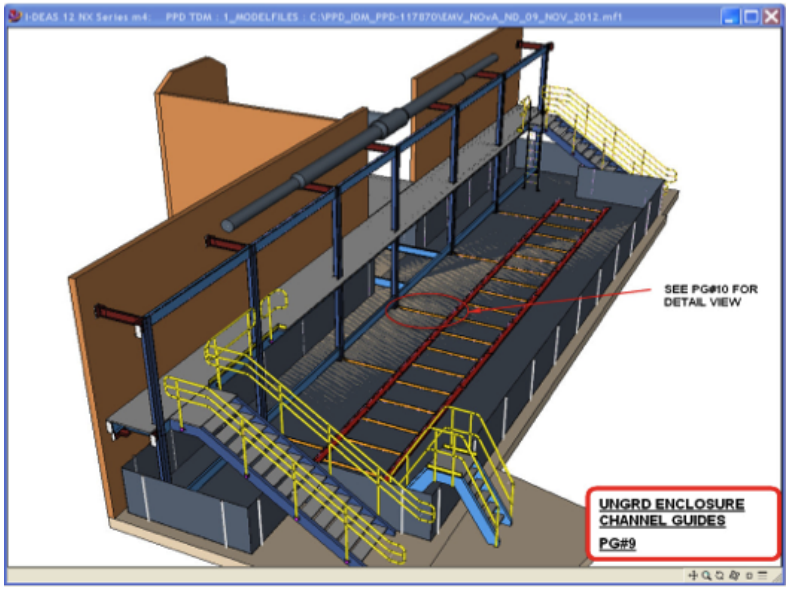
The inspection party consisted of:

A. Subcontractor

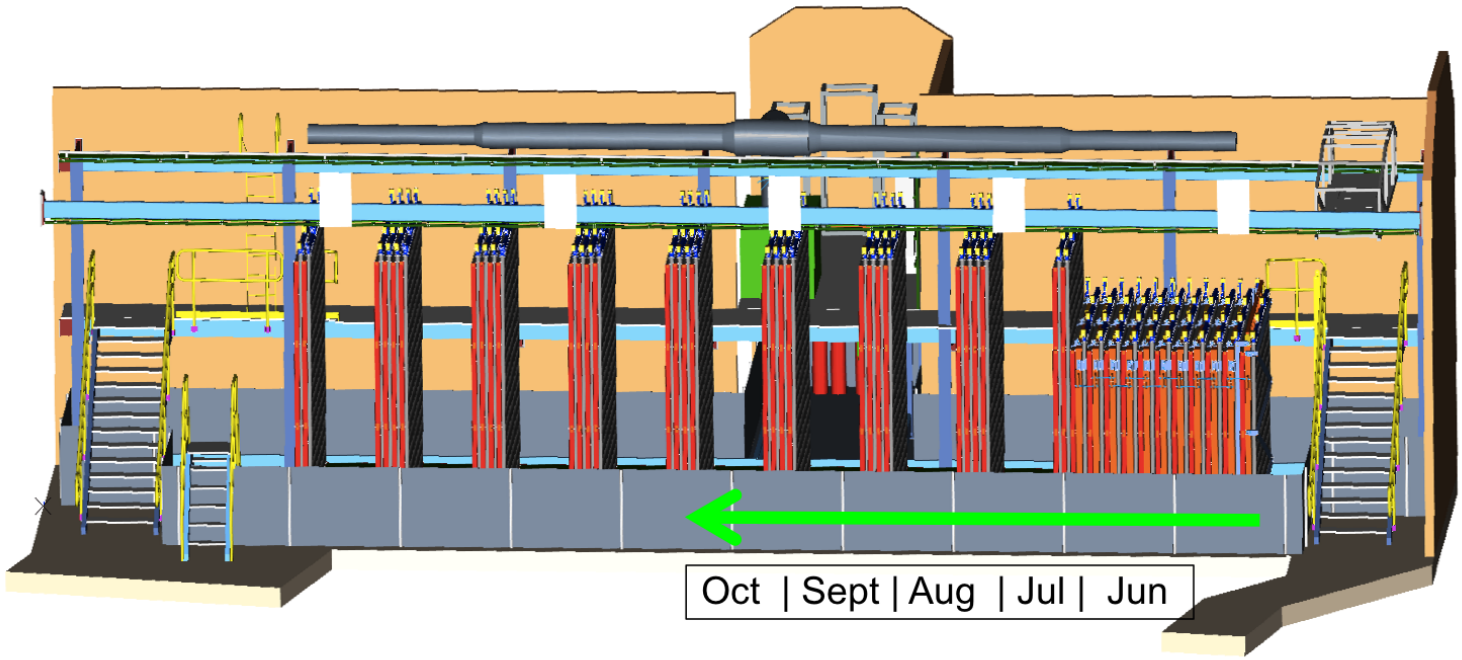
B. Fermilab

FESS/Eng

/ENGINEERING 7/95 Page 1 of 4



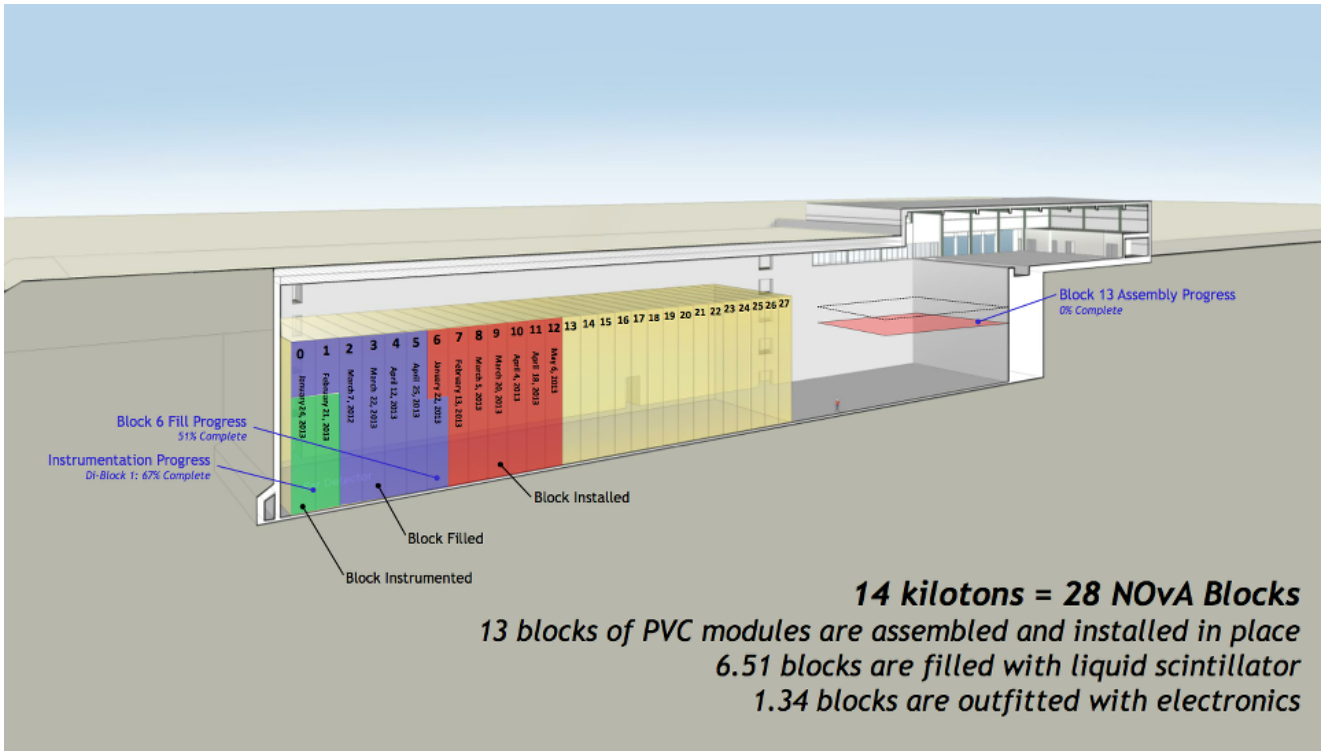
Near Detector Schedule



- Blocks 5-8 [1], and Muon Catcher installation: July - December 2013
  - Steel plates in Muon Catcher are refurbished from NDOS.
- Blocks 1-4: Jan/Feb - May/June 2014

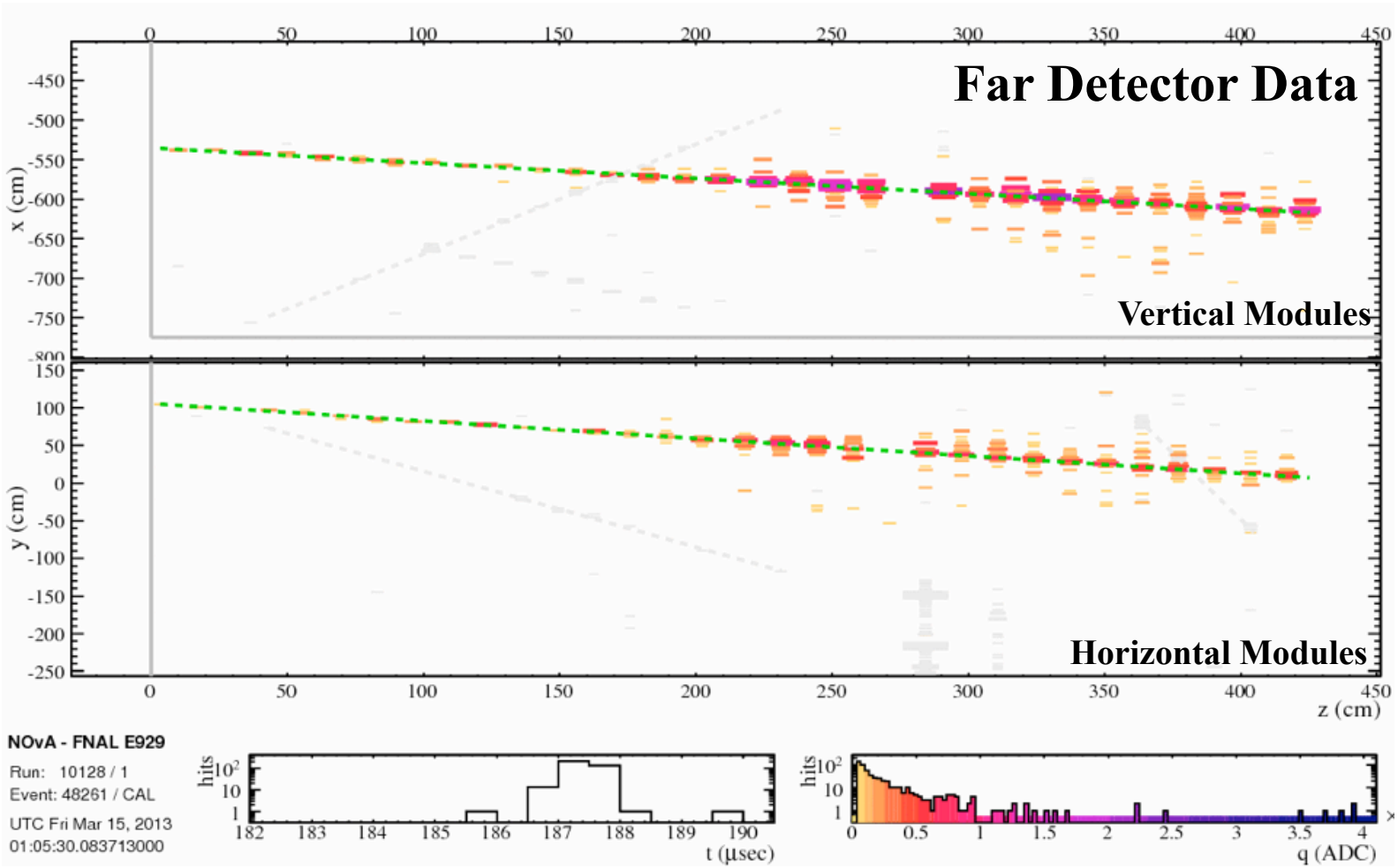
[1] Real detector has no gaps.

Far Detector - May 7, 2013

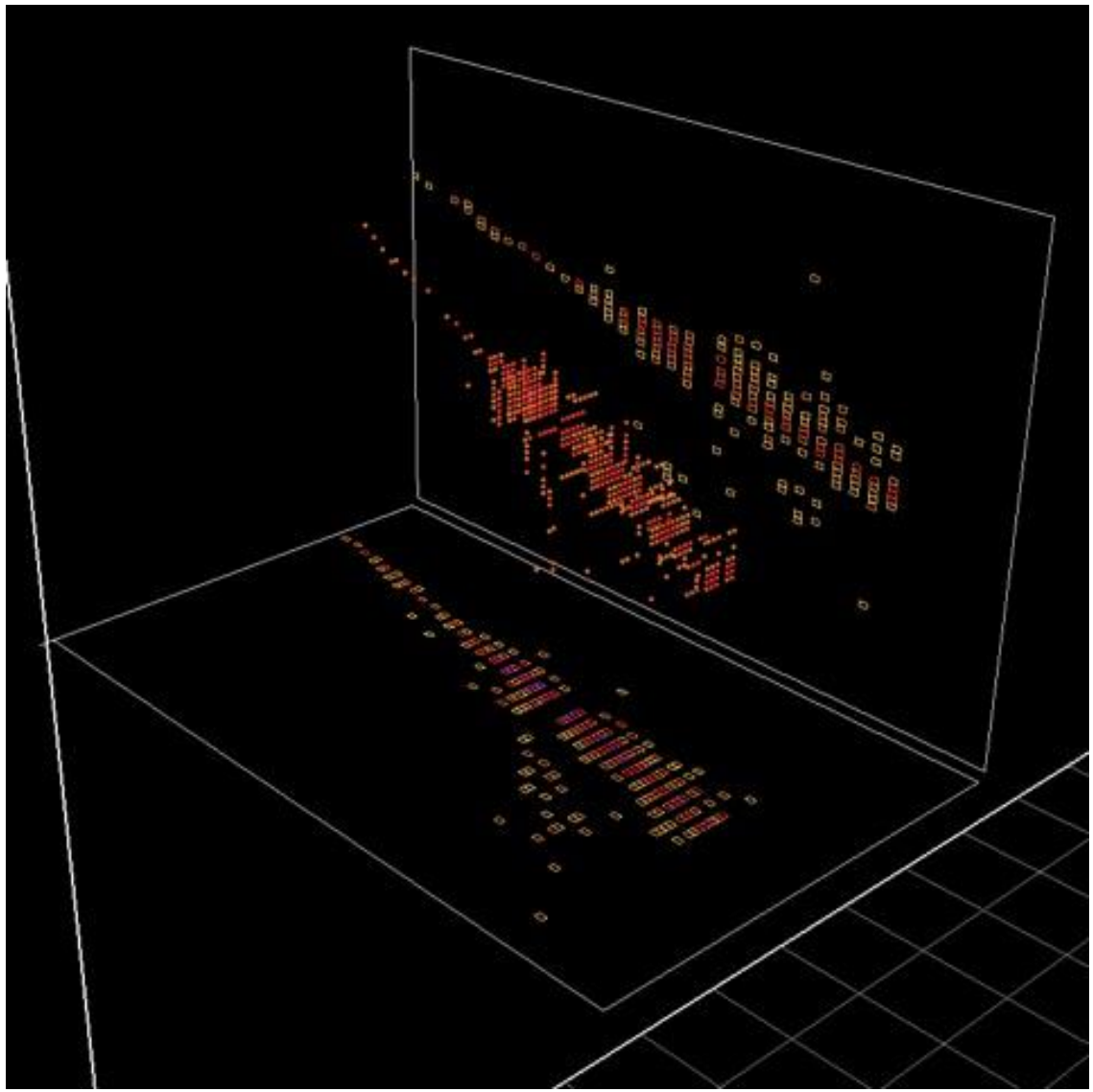


- First block installed on Sept. 10, 2012
- 2.5 kt far detector mass fully instrumented when beam returns in June
- Full detector (14 kt) module assembly will be finished by early 2014, and fully instrumented by August 2014

Cosmic Event Pictures - 2D



Cosmic Event Pictures - 3D



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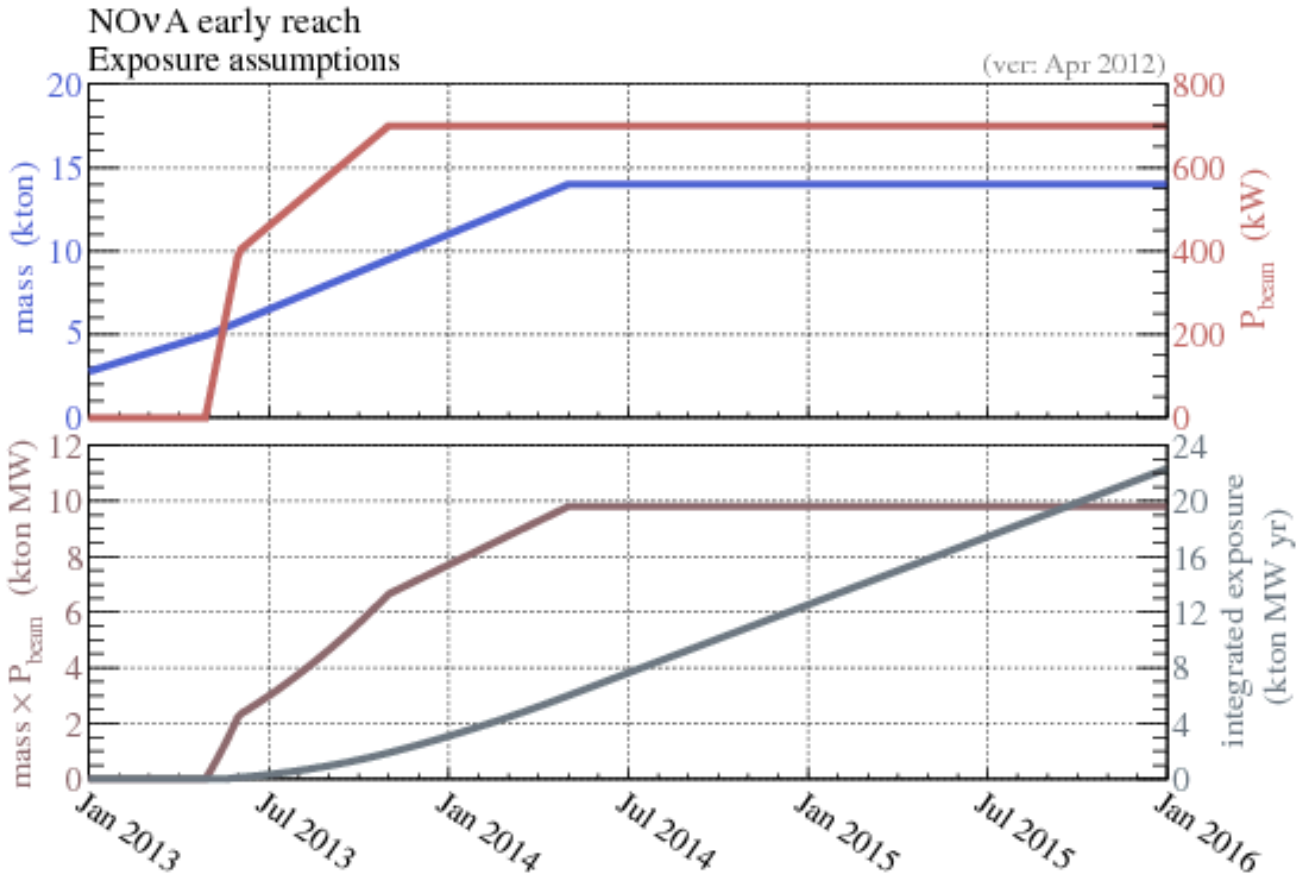
NOνA Physics Reach

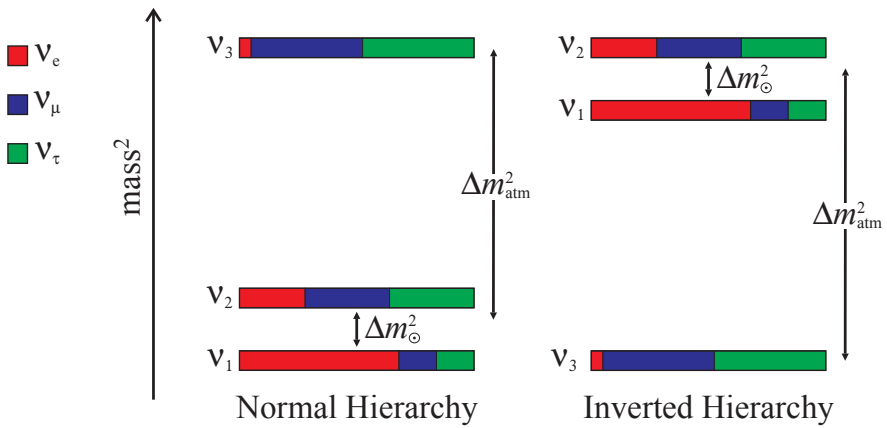
Summary

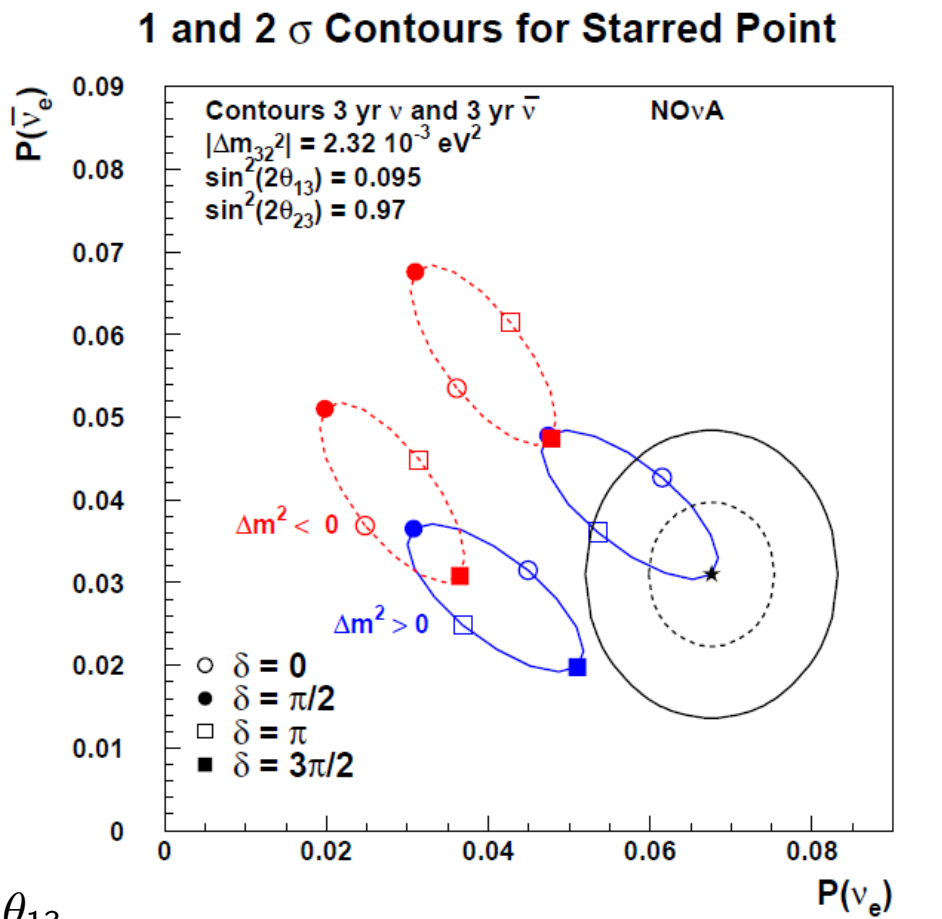
Beam, Mass and Beam $\times$ Mass



- 2.5 kt far detector mass when beam returns in June with low power
- 1 year neutrino running and then antineutrino running

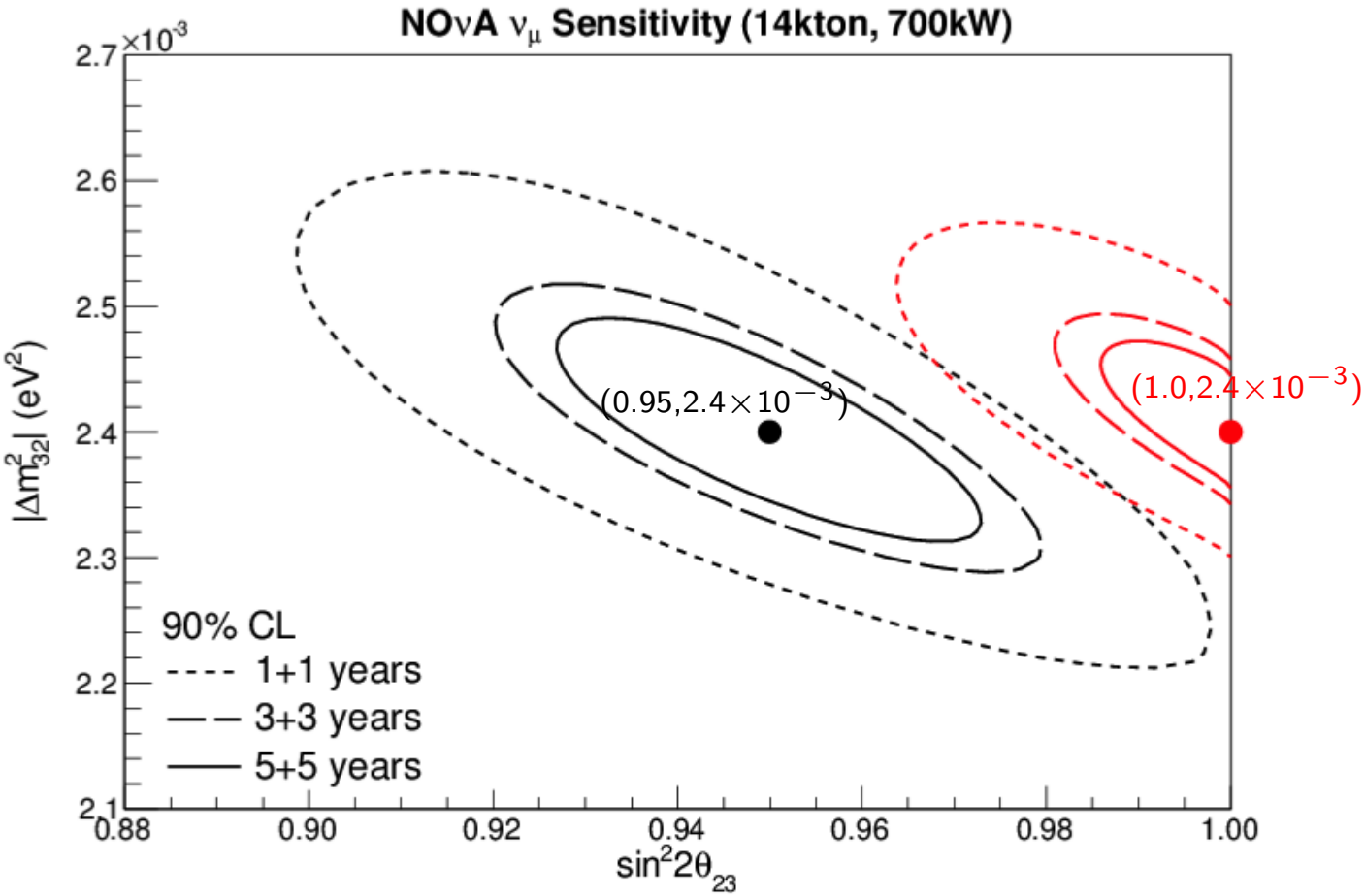
NOνA Physics Reach





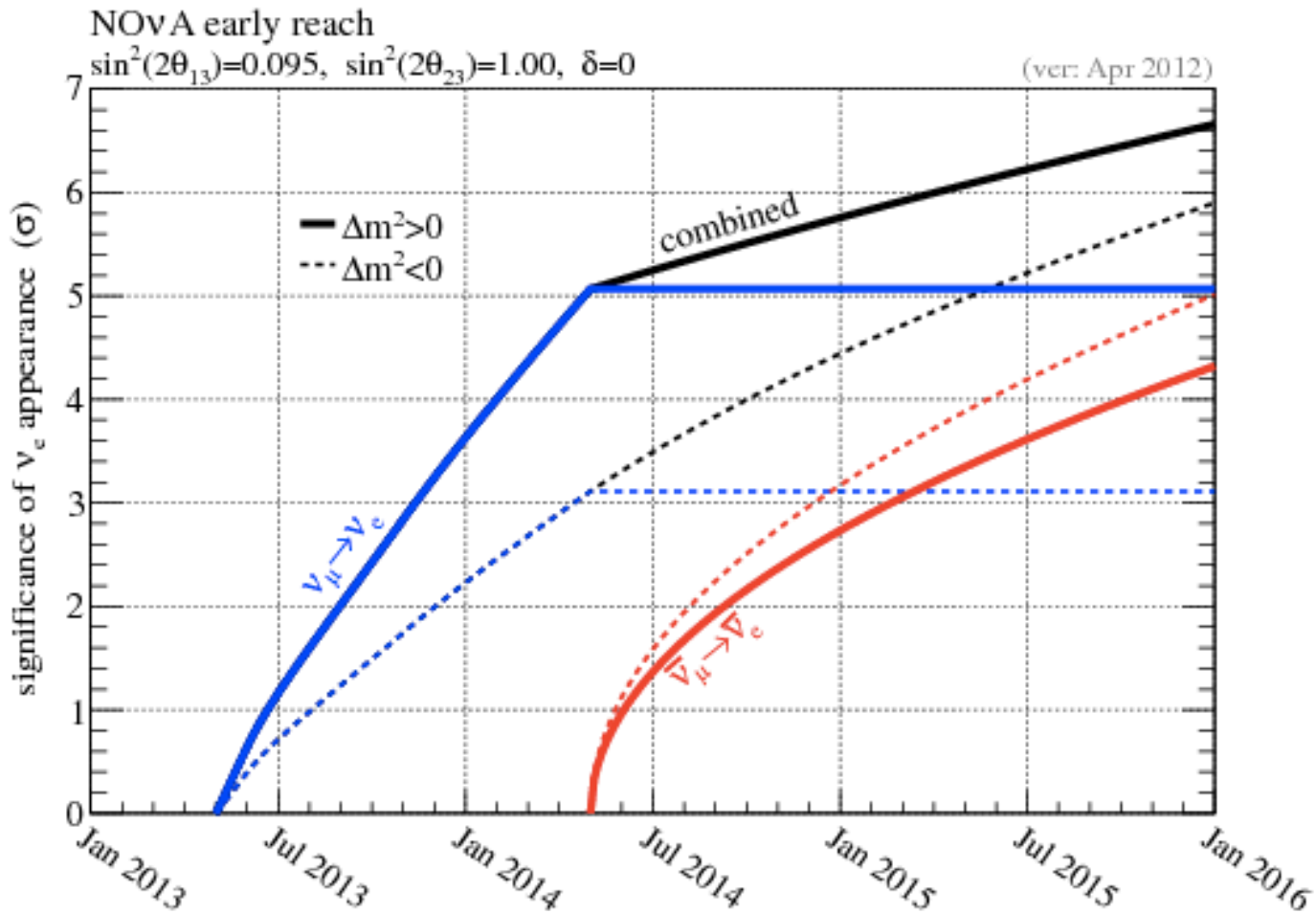
- Precision measurements of θ_{23}, $|\Delta m^2_{32}|$, θ_{13}
- Determine mass hierarchy
- Probe δ_{CP}
- Determine θ_{23} octant

NOνA Physics Reach - θ_{23}



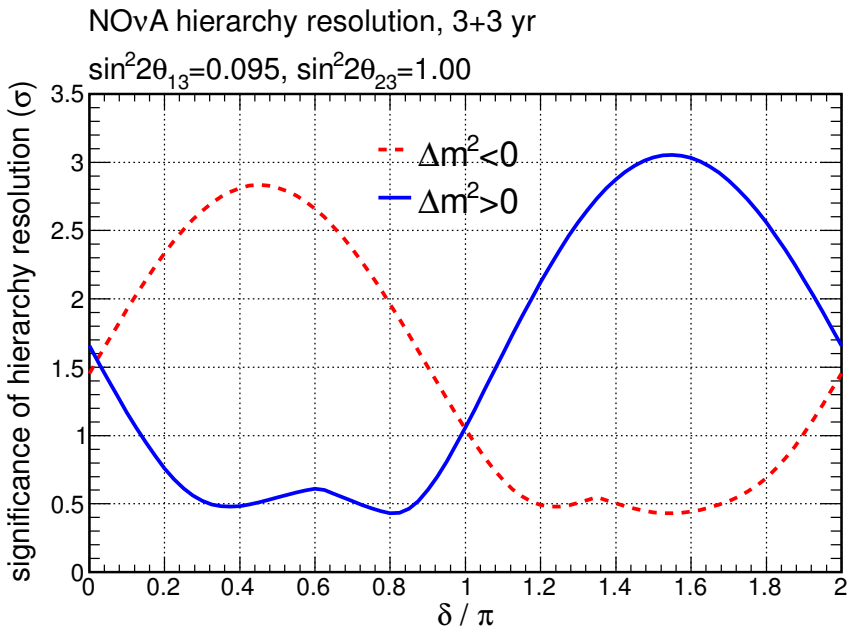
- Statistics only and Systematics is small

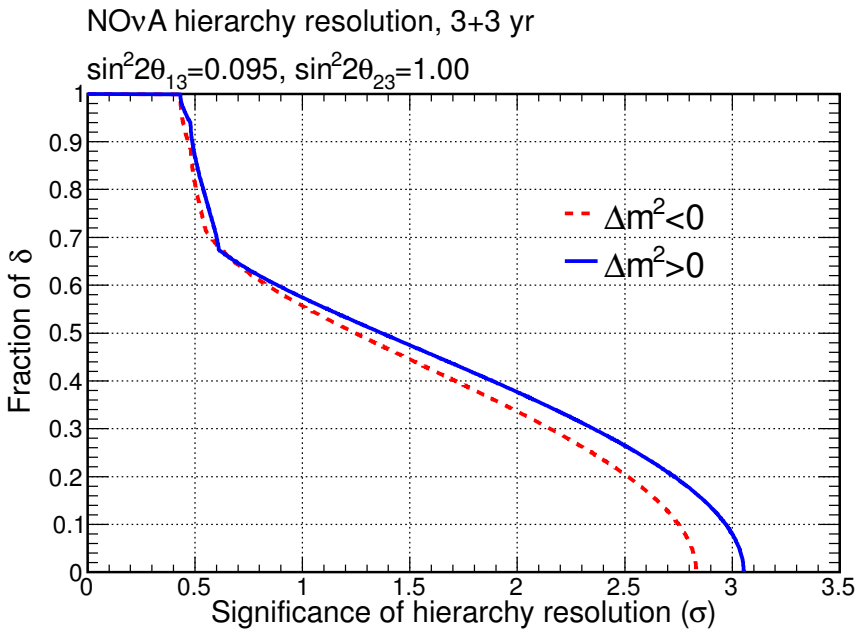
NOνA Physics Reach - θ_{13}



- 5σ (3σ) of ν_e appearance within first year for NH + $\delta_{CP} = 0$ (IH + $\delta_{CP} = 0$).

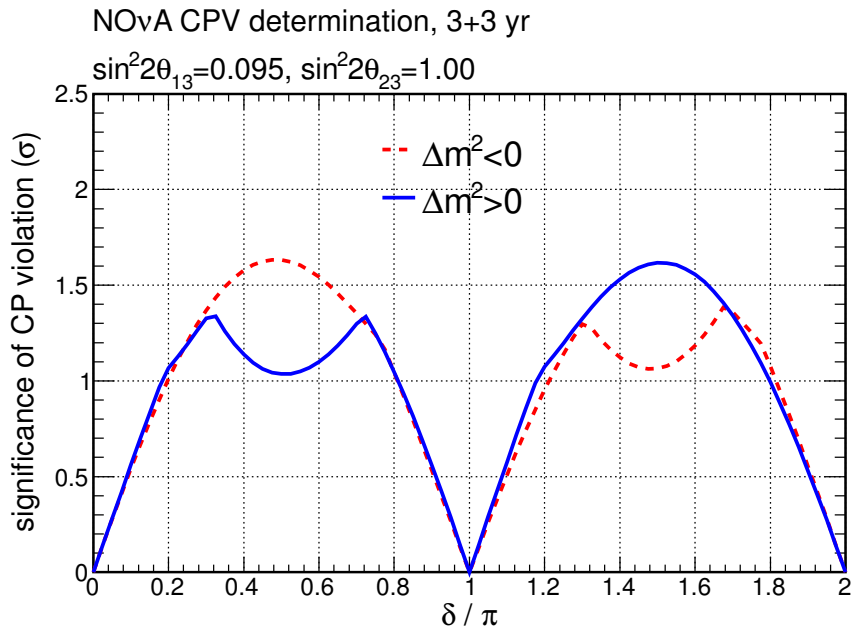
NOνA Physics Reach - Mass Hierarchy

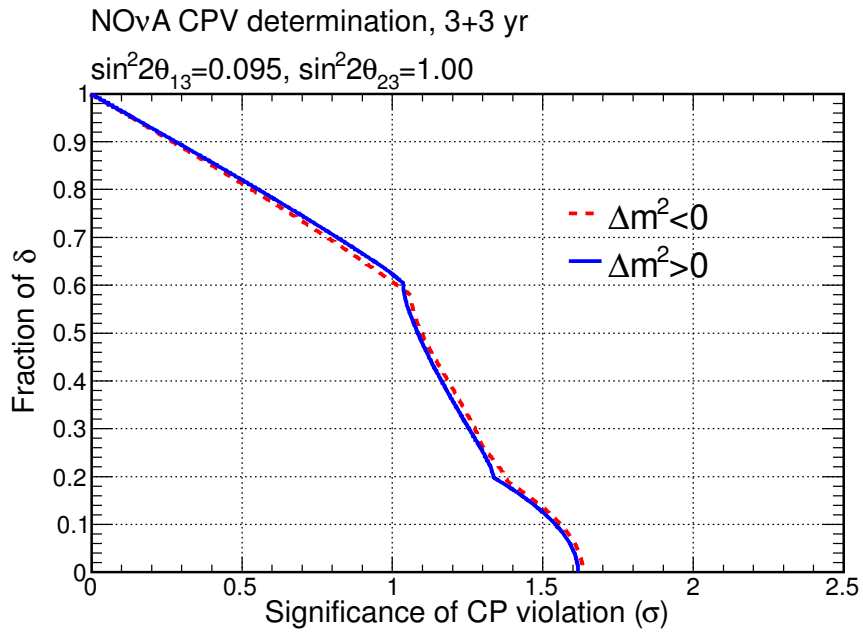




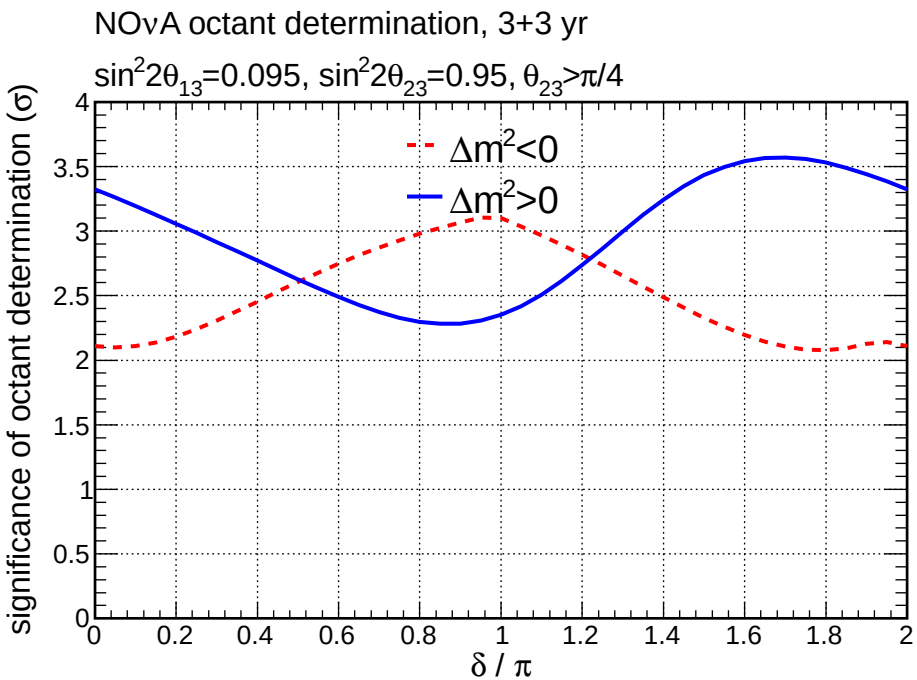
- The hierarchy is resolved and CP phase is constrained for particular values of delta at the 2-sigma level.

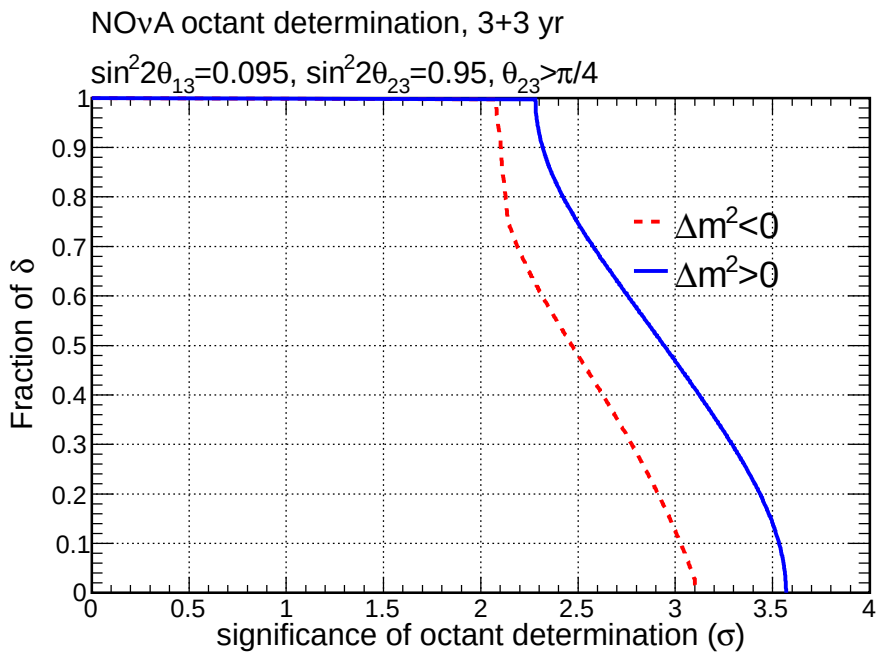
NOνA Physics Reach - CP





NOνA Physics Reach - θ_{23} Octant



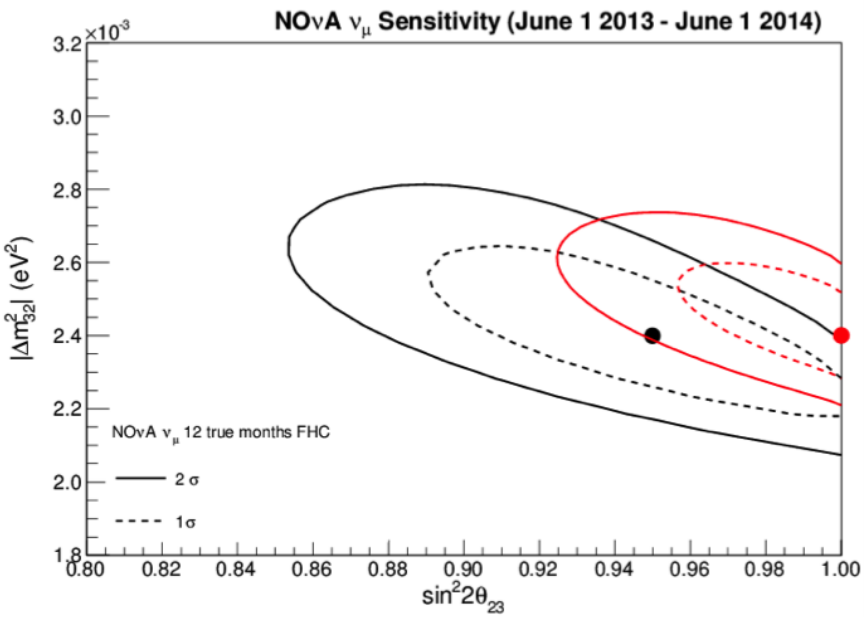


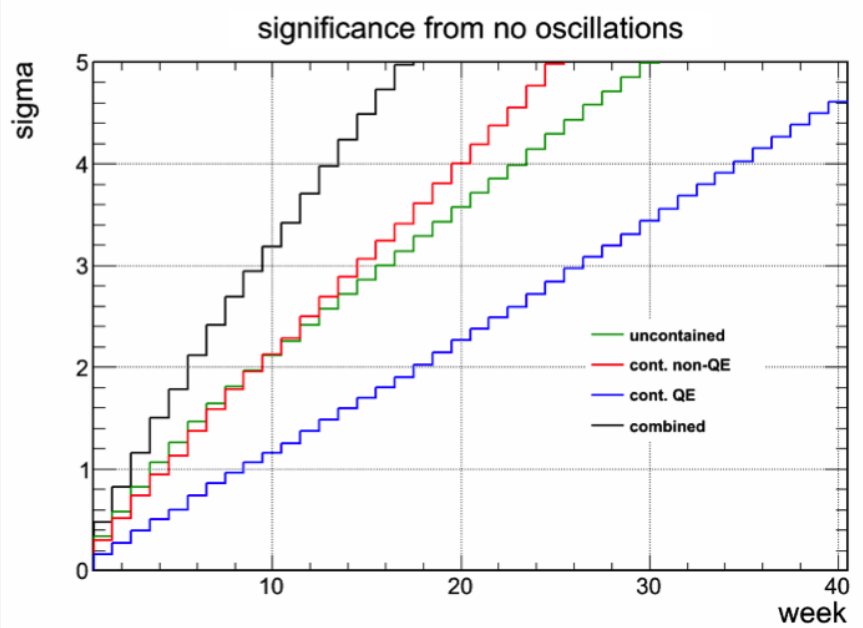
Summary

- Near Detector will have 4 blocks of PVC modules and muon catcher up and running by the end of 2013
- 50% of the Far Detector modules are assembled and installed in place
- Far detector has been recording and analyzing cosmic data
- First beam data in June with 2.5 kt detector mass
- Full detector (14 kt) module assembly will be finished by early 2014, and fully instrumented by August 2014

Backup Slides

ν_μ disappearance Analysis - early reach





ν_μ disappearance Analysis - full reach

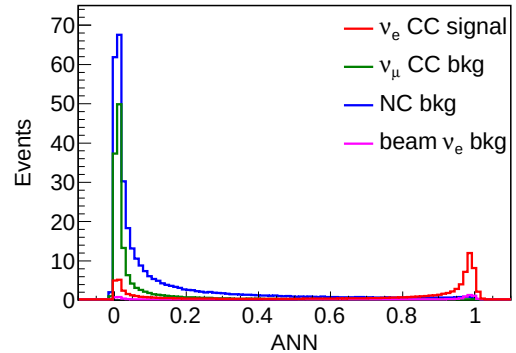
- Expected # event within [0,5] GeV after oscillation in a year (6×10^{20} POT).
  - 150 contained [2] CC.
  - 75 uncontained CC
  - 300 NC per year
  - 1 cosmic muon
- Competitive with current world limits in a year
- Within a few years, precision measurements of θ_{23}, Δm^2_{32} should surpass current limit

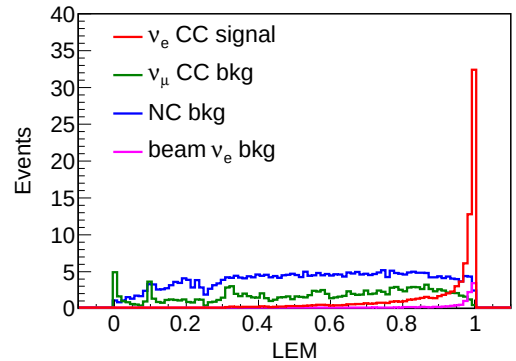
[2] $-750 < x, y < 750$ cm, $5 < z < 5950$ cm

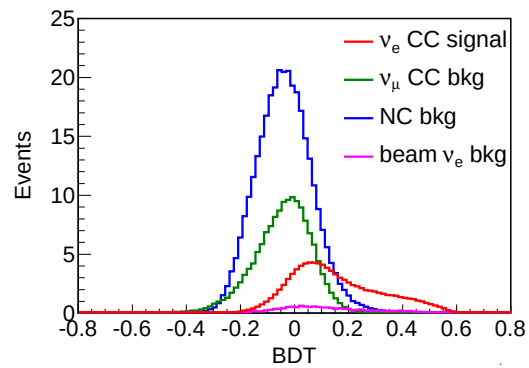
ν_e appearance Analysis - PID

- ν_e PID
  - ANN Likelihood ratios for particle hypotheses
  - LEM Matching to MC library events
  - BDT MVA on simple reconstructed quantities
- Expected event counts

18×10^{20} POT	ν	$\bar{\nu}$
NC	19	10
ν_μ-CC	5	< 1
Beam ν_e	8	5
Total Background	32	15
$\nu_\mu \rightarrow \nu_e$ signal	68	32

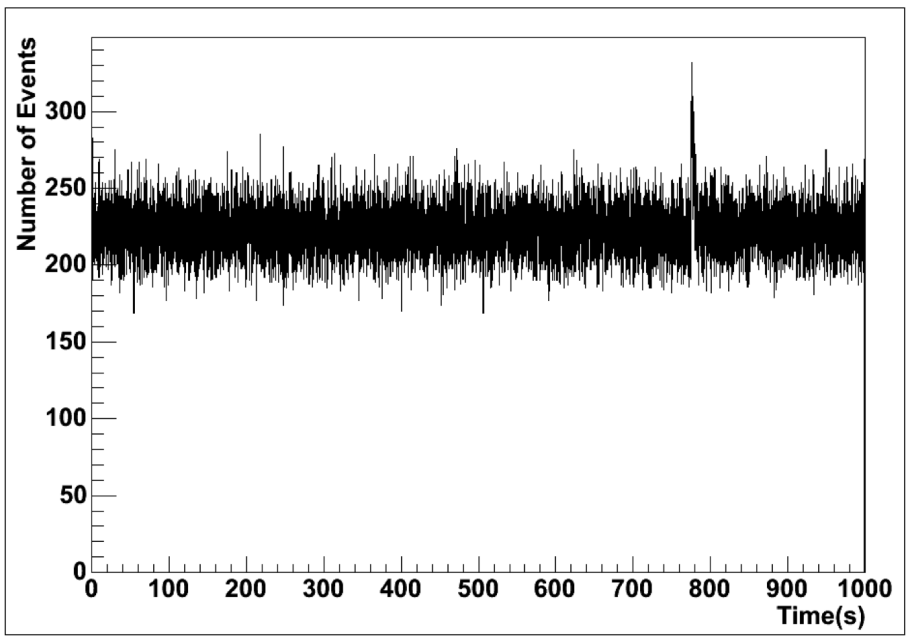


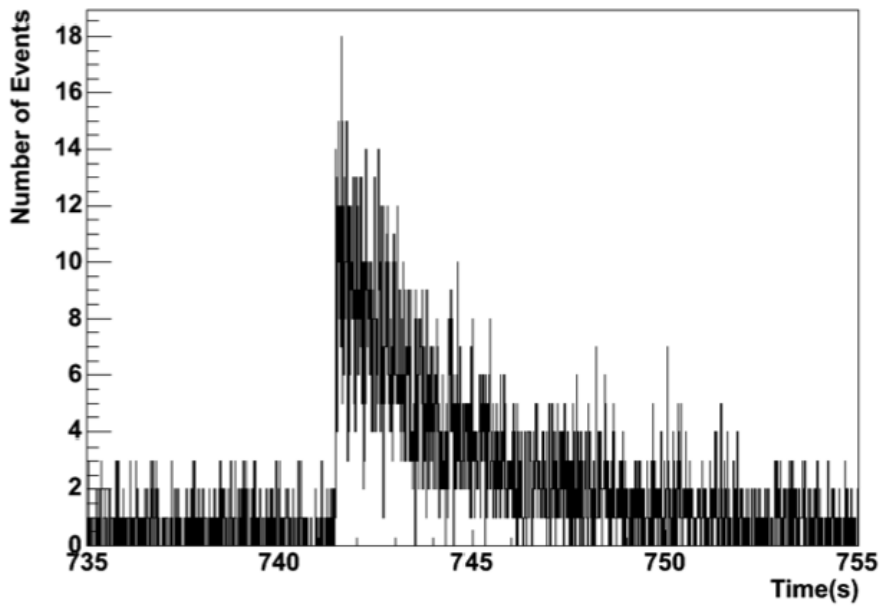




NOνA Physics Potential - Supernova

- 10 second 5000 events burst for a supernova near the center of galaxy





Accelerator & NuMI Upgrades

- Beam in neutrino mode will be turn on June 1^{st} with low power, ramp up to 150 kW in 2 weeks, and 300 kW by July 1^{st}
- Beam will be running at 500 kW from December until summer, then switch to ant-neutrino mode after two months shutdown