

# Status of NO $\nu$ A

NNN12 – Fermilab  
October 4, 2012

Christopher Backhouse  
Caltech

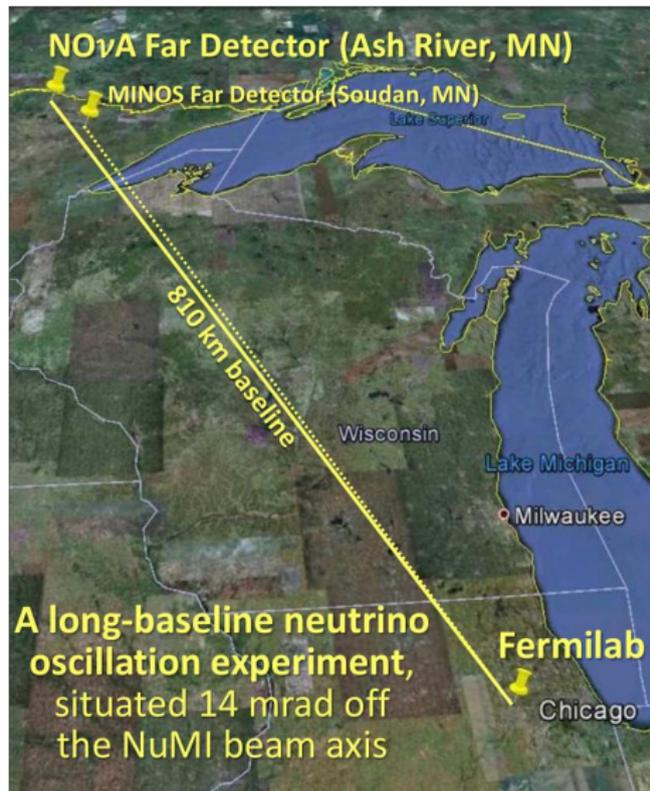
for the NO $\nu$ A Collaboration



## Physics goals

$$\nu_{\mu} \rightarrow \nu_e$$

- ▶ Measure  $\theta_{13}$  via  $\nu_e$  appearance



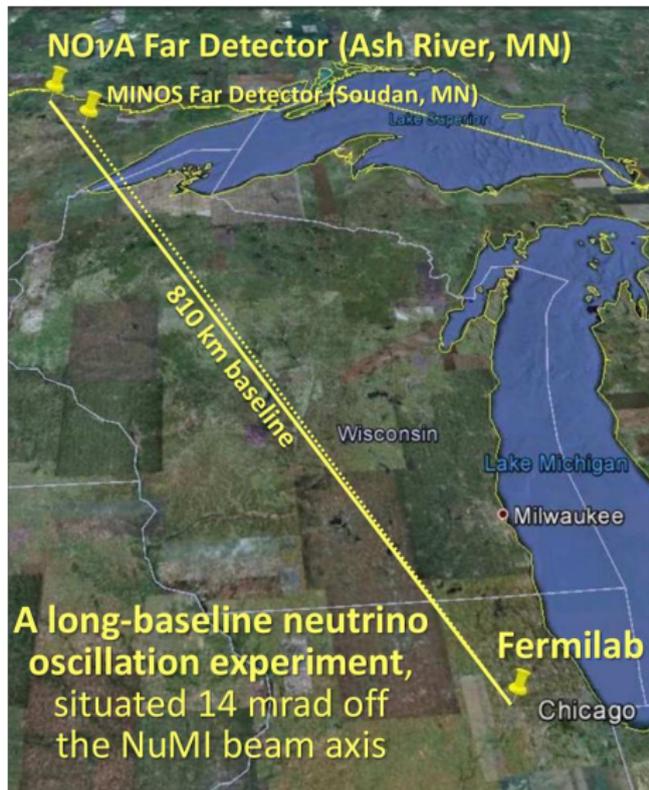
# Physics goals

$$\nu_\mu \rightarrow \nu_e$$

- ▶ Measure  $\theta_{13}$  via  $\nu_e$  appearance

$$\nu_\mu \rightarrow \nu_\mu$$

- ▶ Precision measurements of  $|\Delta m_{\text{atm}}^2|$  and  $\theta_{23}$
- ▶ Could exclude maximal mixing



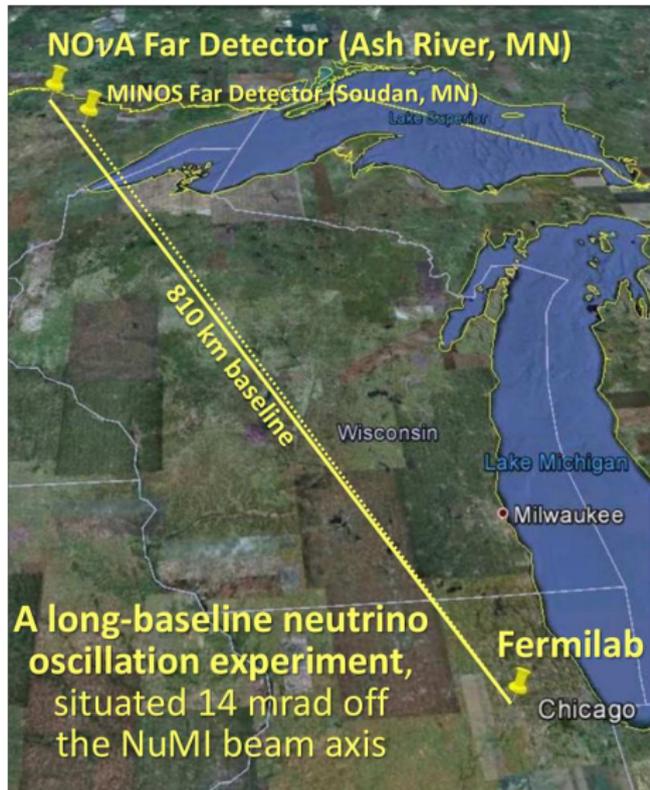
# Physics goals

$$\nu_\mu \rightarrow \nu_e$$

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- ▶ Determine the  $\theta_{23}$  octant

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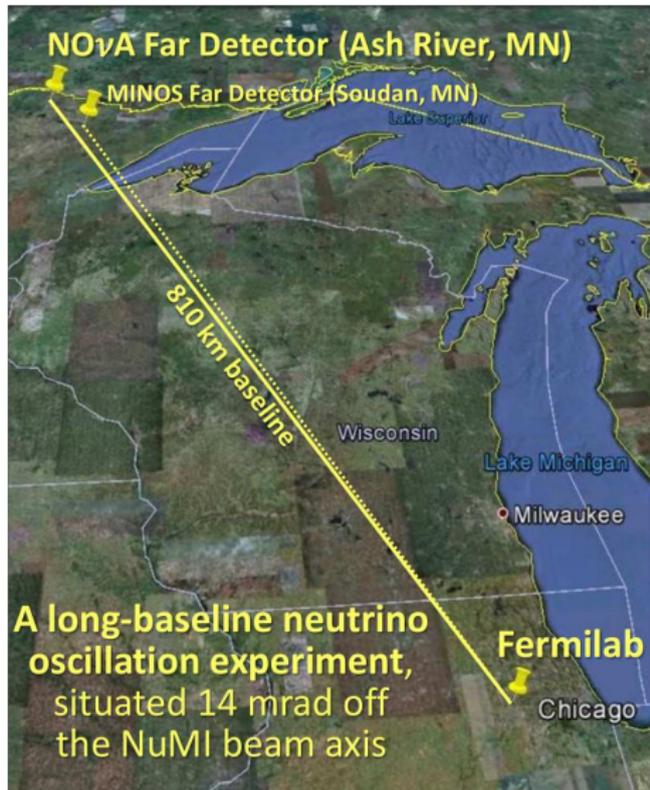
## Physics goals

$$\nu_\mu \rightarrow \nu_e \text{ and } \bar{\nu}_\mu \rightarrow \bar{\nu}_e$$

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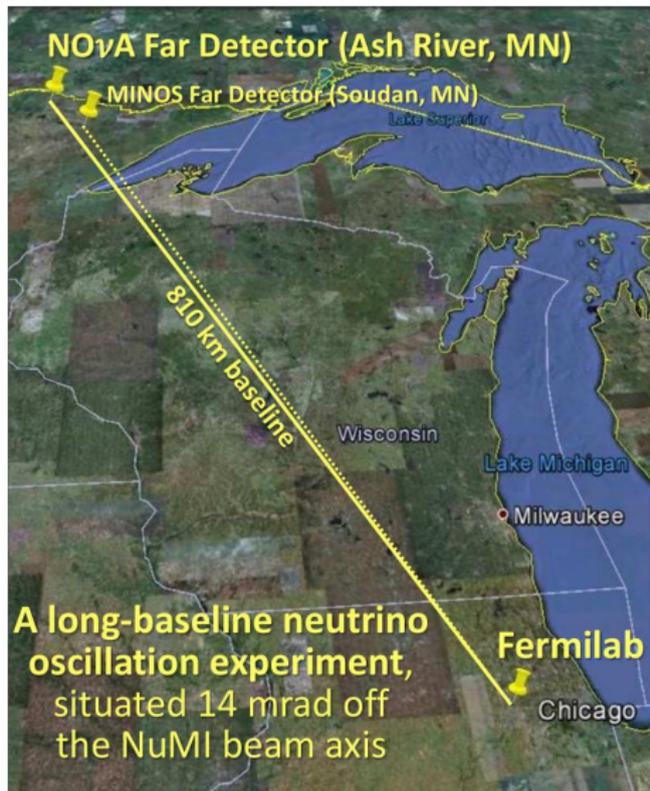
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$$\nu_\mu \rightarrow \nu_e \text{ and } \bar{\nu}_\mu \rightarrow \bar{\nu}_e$$

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- ▶ Determine the  $\theta_{23}$  octant
- ▶ Determine the mass hierarchy
- ▶ Search for  $\delta_{CP} \neq 0$

$$\nu_\mu \rightarrow \nu_\mu \text{ and } \bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$$

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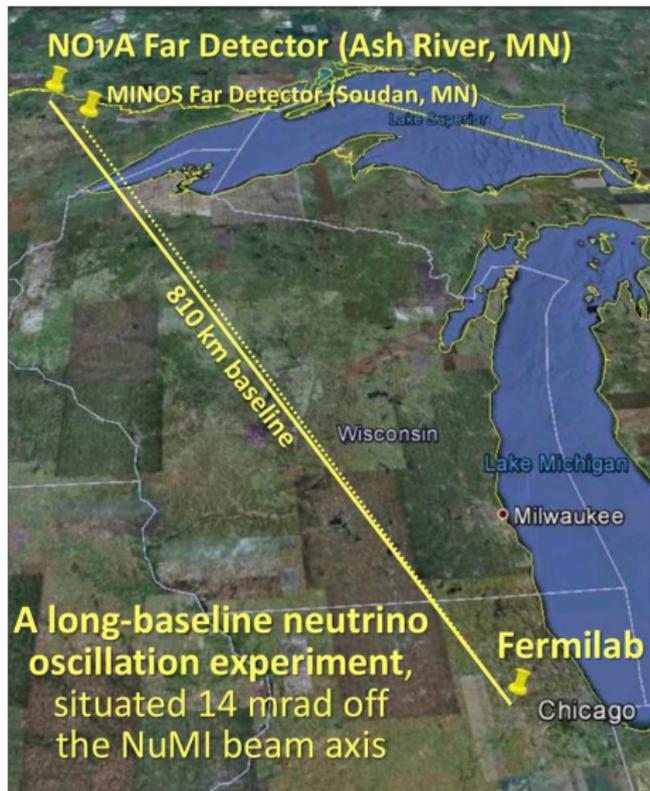
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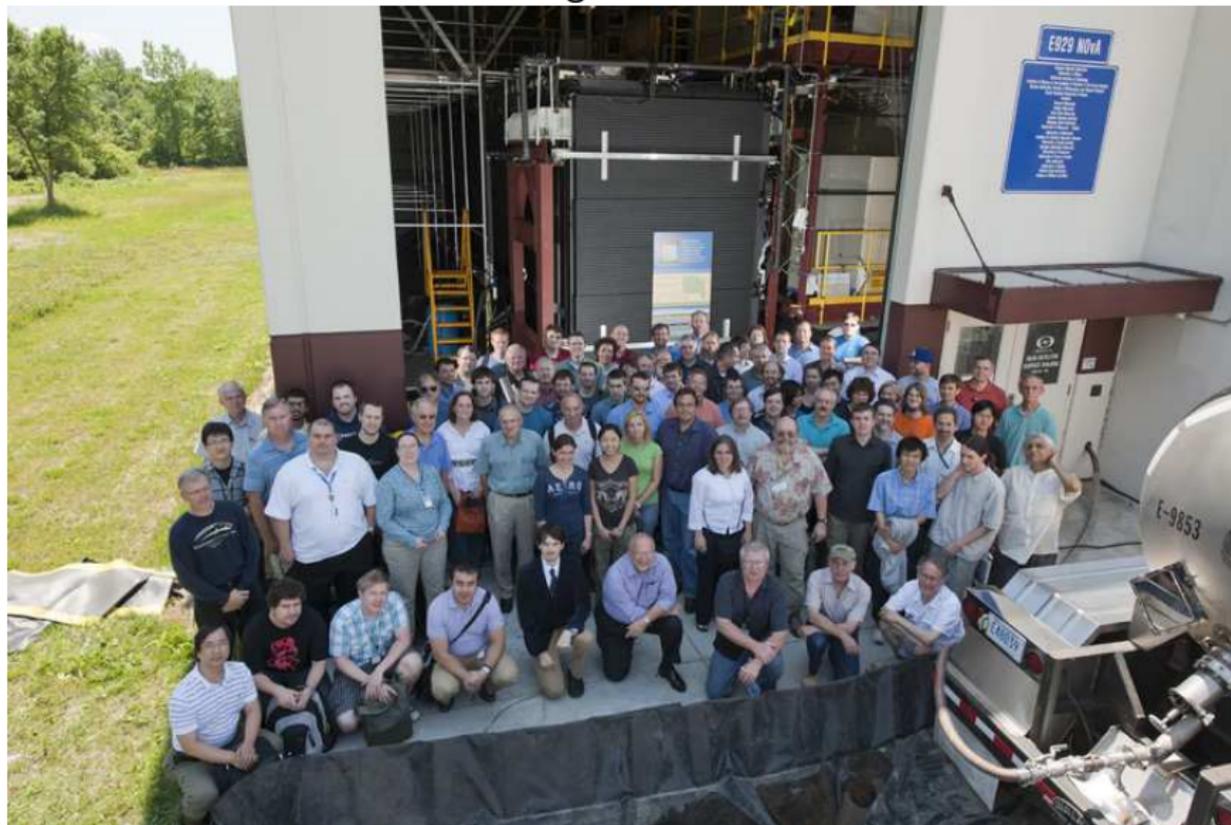
## And...

- ▶ Cross-sections from the ND
- ▶ Steriles, supernovae, exotica

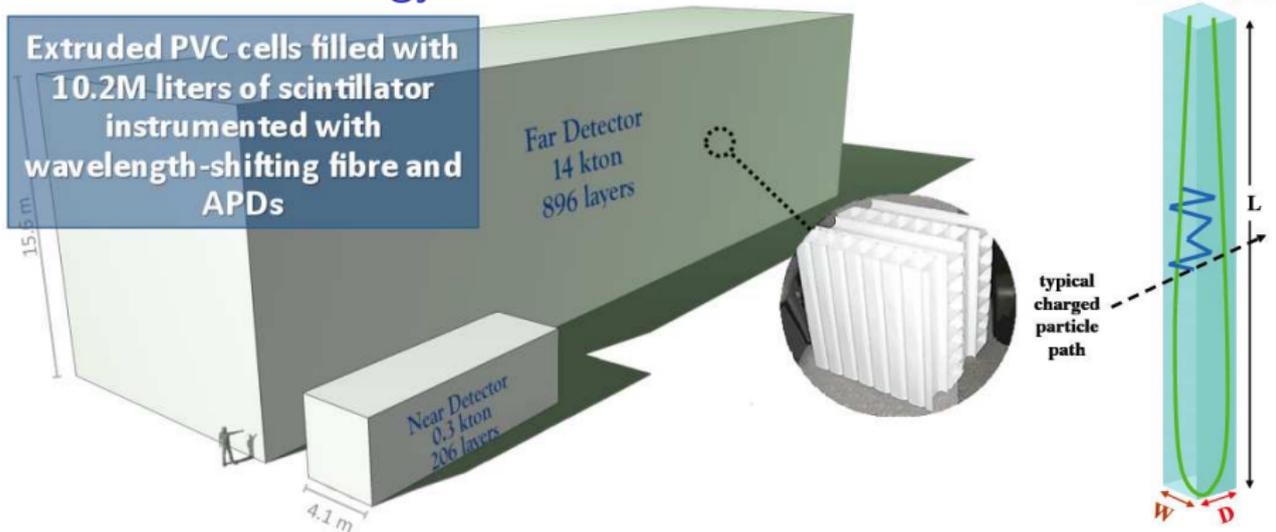


# The NO $\nu$ A Collaboration

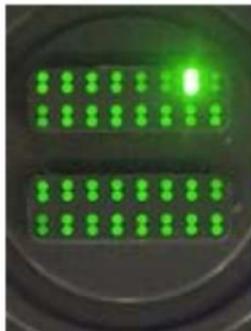
$\sim$ 200 scientists and engineers from  $\sim$ 30 institutions



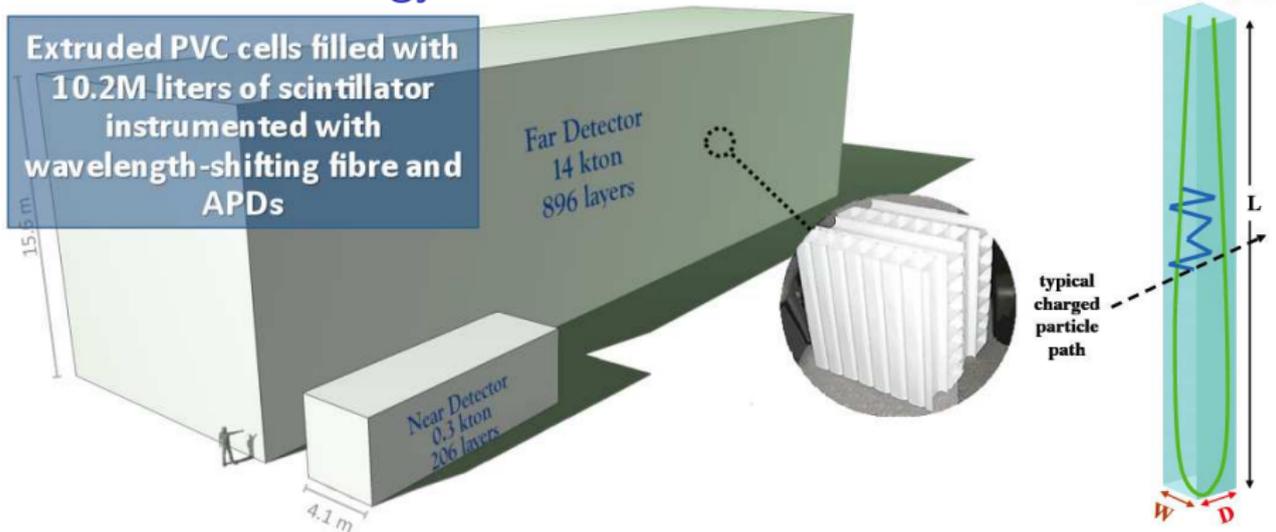
# Detector technology



- ▶ Fine-grained low-Z, highly active, tracking calorimeter
- ▶ 64% liquid scintillator by mass
- ▶ WLS fibres looped in 4x6cm cells of PVC extrusion
- ▶ Each to one of 32 pixels of Hamamatsu APD
- ▶ ~85% quantum eff. Gain ~100×. Cooled to  $-15^{\circ}\text{C}$



# Detector technology



## Far Detector

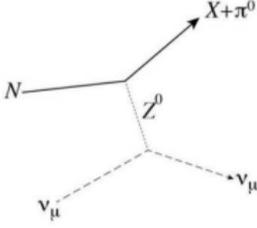
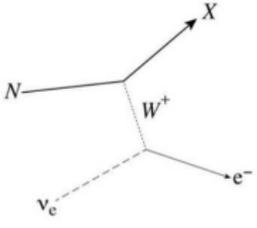
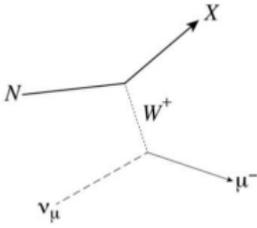
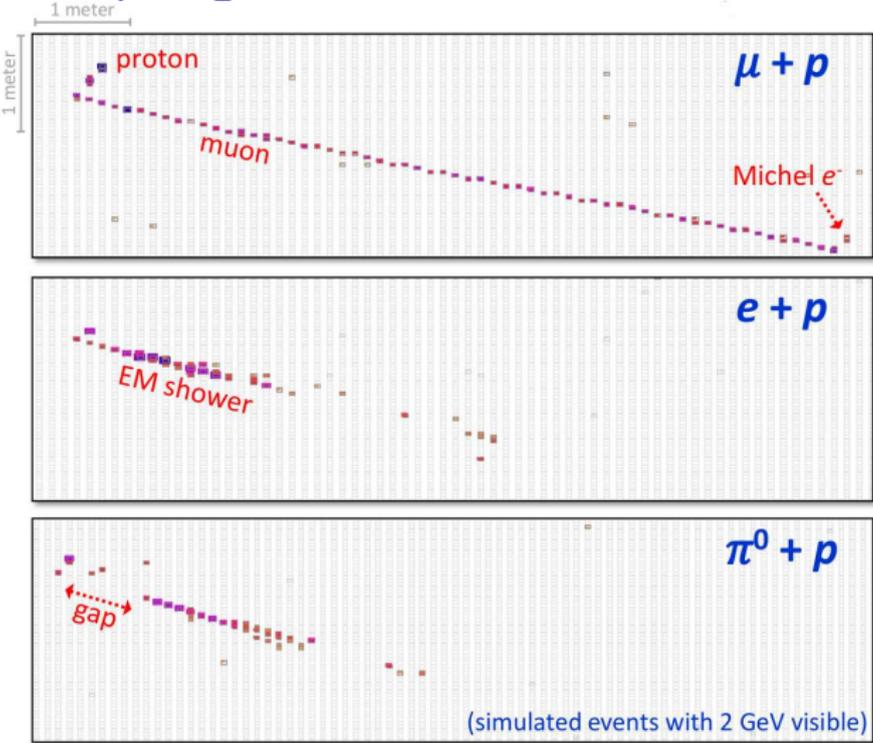
- ▶ 14 kton
- ▶ 344,000 channels

## Near Detector

- ▶ 0.3 kton
- ▶ 18,000 channels



# Event topologies



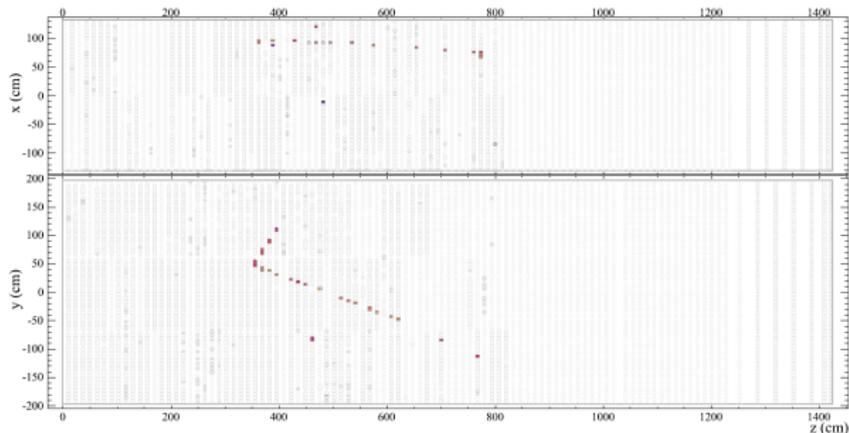
- ▶ Very good granularity, especially considering scale
- ▶  $X_0 = 38\text{cm}$  (6 cell depths, 10 cell widths)

## Near Detector prototype (NDOS)



- ▶ Operating since April 2011
- ▶ Test component production and integration
- ▶ DAQ development
- ▶ Calibration, simulation, reconstruction development with real data

# Near Detector prototype (NDOS)



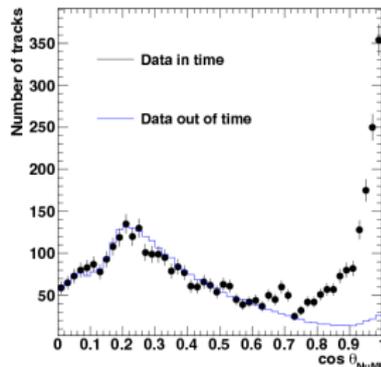
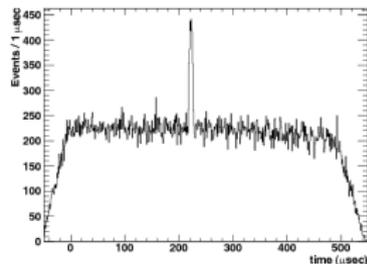
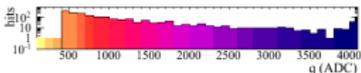
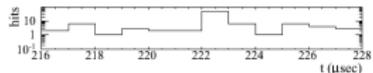
NO $\nu$ A - FIAL E929

Run: 11230/10

Event: 441526

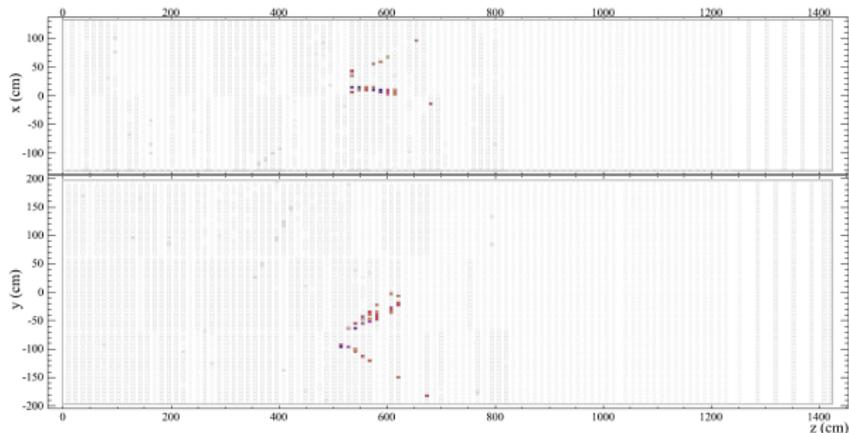
UTC Sun Jan 16, 2011

10:45:34.898617984



- ▶ We have collected a large number of neutrino events from the NuMI and Booster beams

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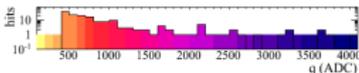
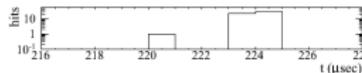
NO $\nu$ A - FIAL E929

Run: 11125/0

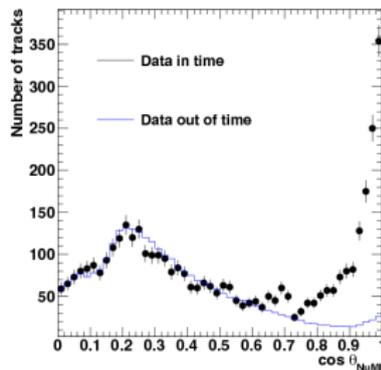
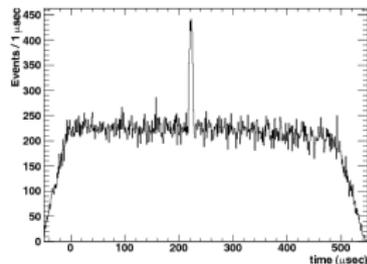
Event: 37594

UTC Thu Jan 6, 2011

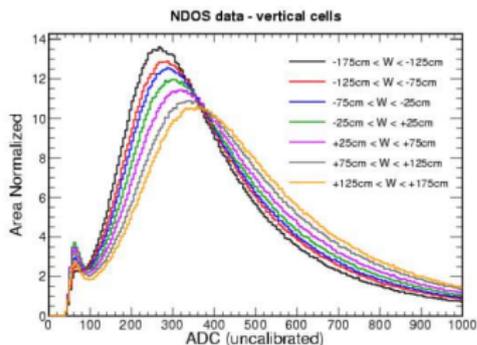
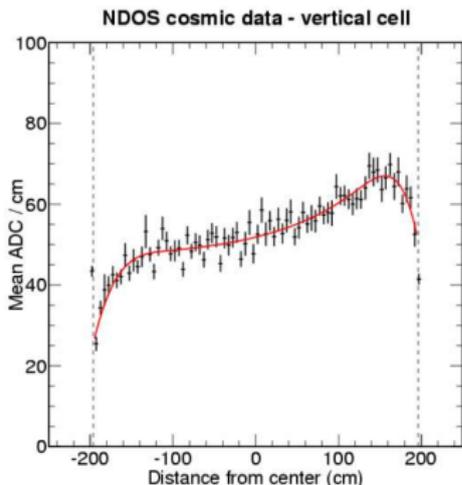
18:17:48.144070054



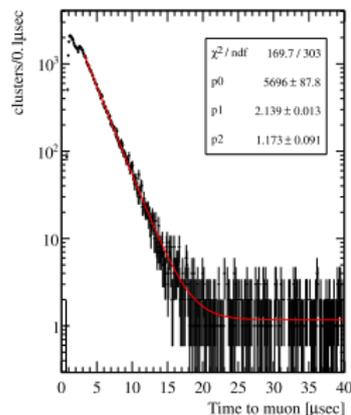
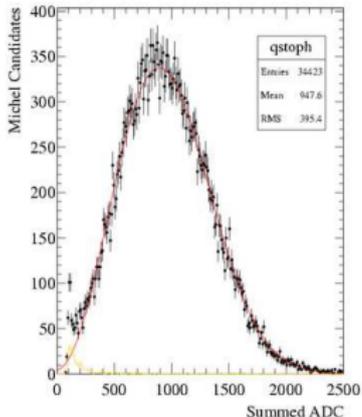
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# Calibration



C. Backhouse (Caltech)

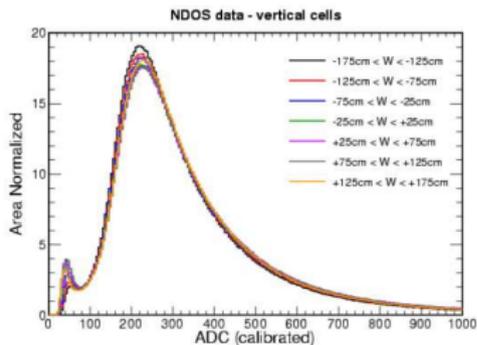
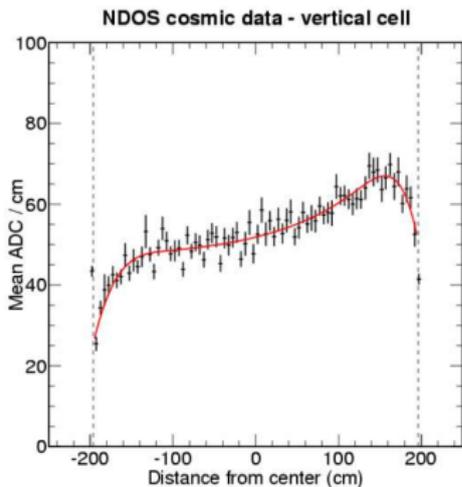


- ▶ Use cosmic muons to measure attenuation and light-level in situ
- ▶ #15 Enrique Arrieta Diaz “Calibration and Reconstruction in the NOvA Detectors”
- ▶ Large sample of Michel electrons from stopping muons
- ▶ Study low-energy modelling

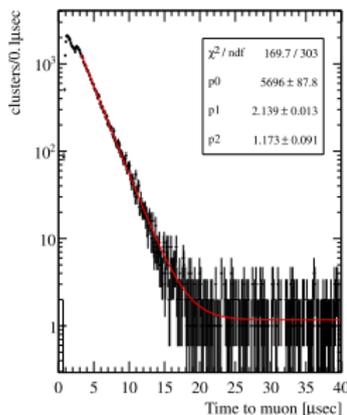
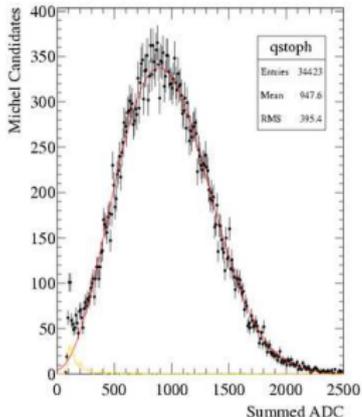
NOvA

8 / 21

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NOvA

8 / 21

## Near Detector underground



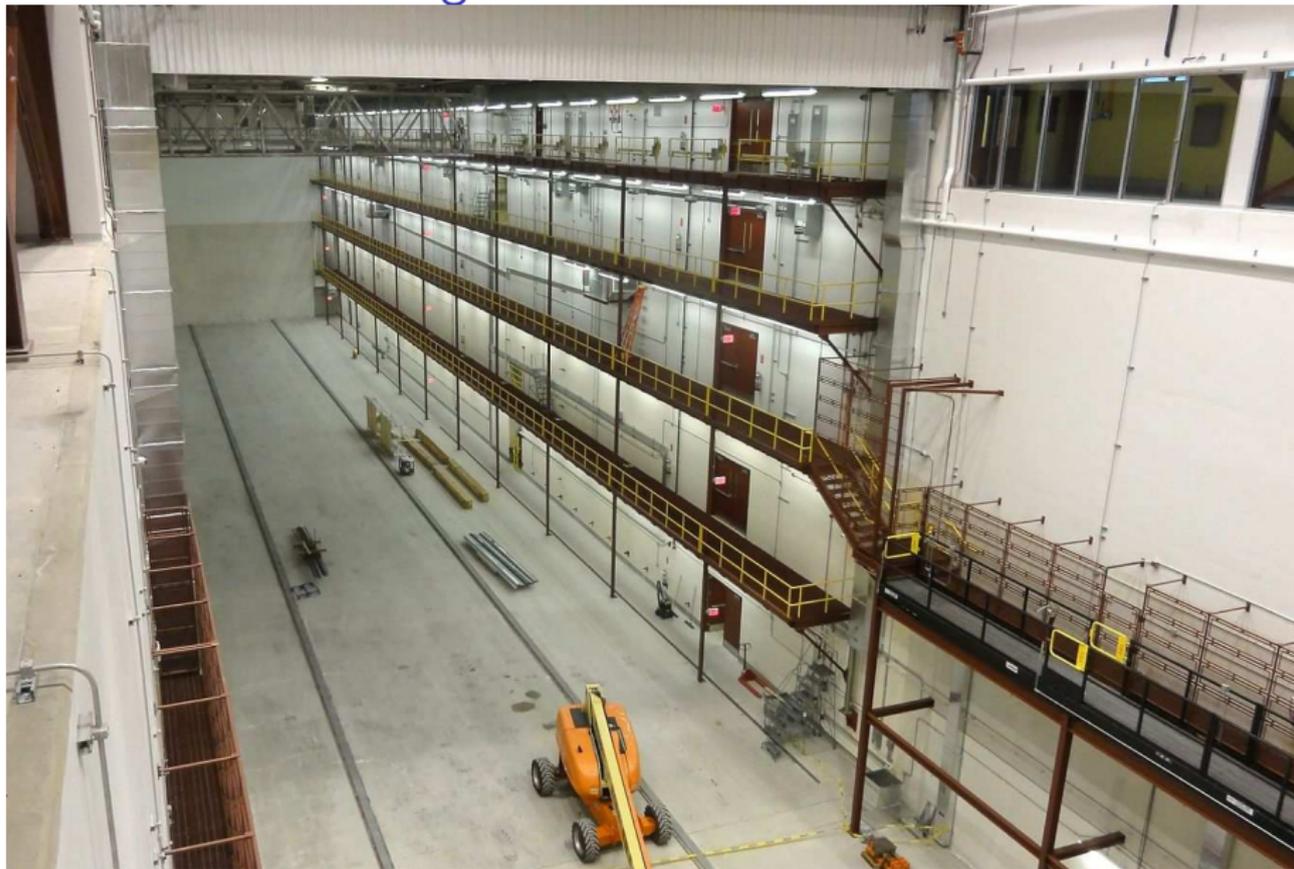
- ▶ Work started on cavern excavation
- ▶ Possible access March 2013

## Near Detector underground



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- ▶ Possible access March 2013

# Far Detector building



## First Far Detector block

**Each detector block:  
190 metric tons**

of extruded and laminated PVC

<http://www.youtube.com/watch?v=gFpK00WJI90>  
#14 Mathew Meuther “NOvA Construction Status”

## First Far Detector block



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**Block Construction:  
4 Weeks**

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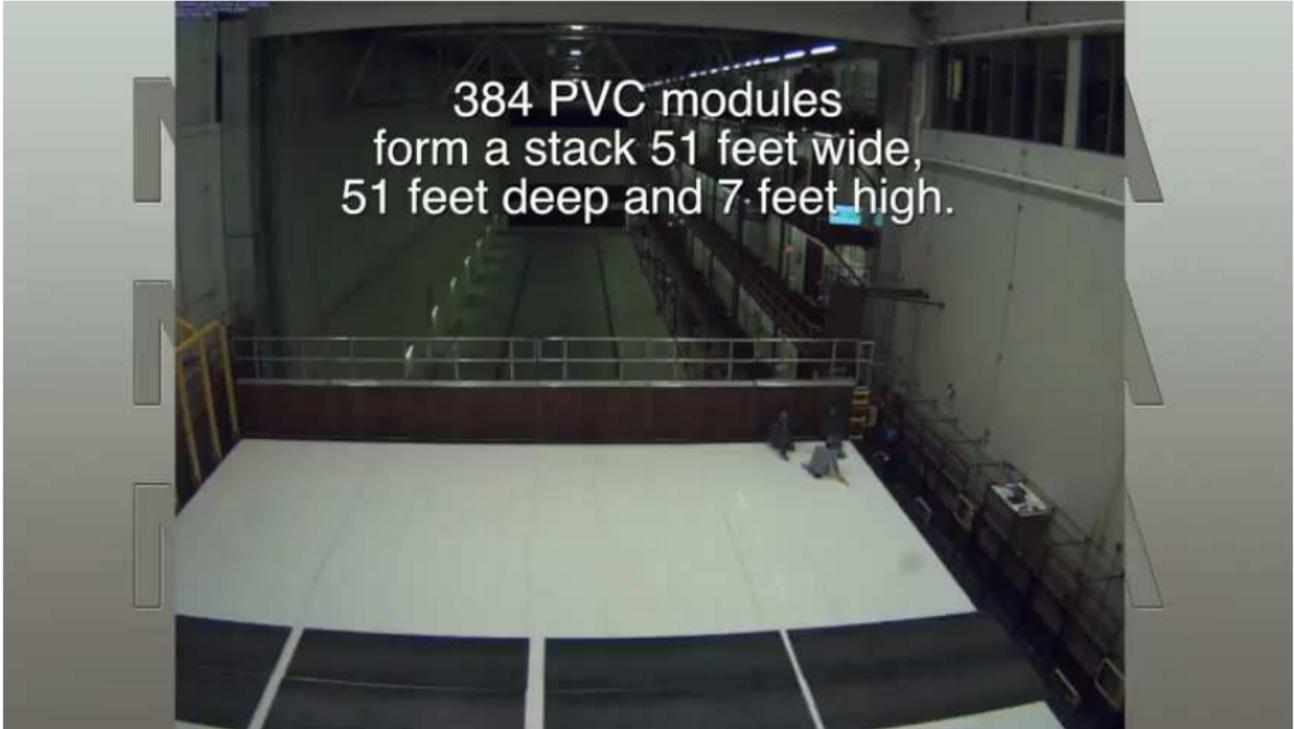
Stacking Modules



Staging Modules

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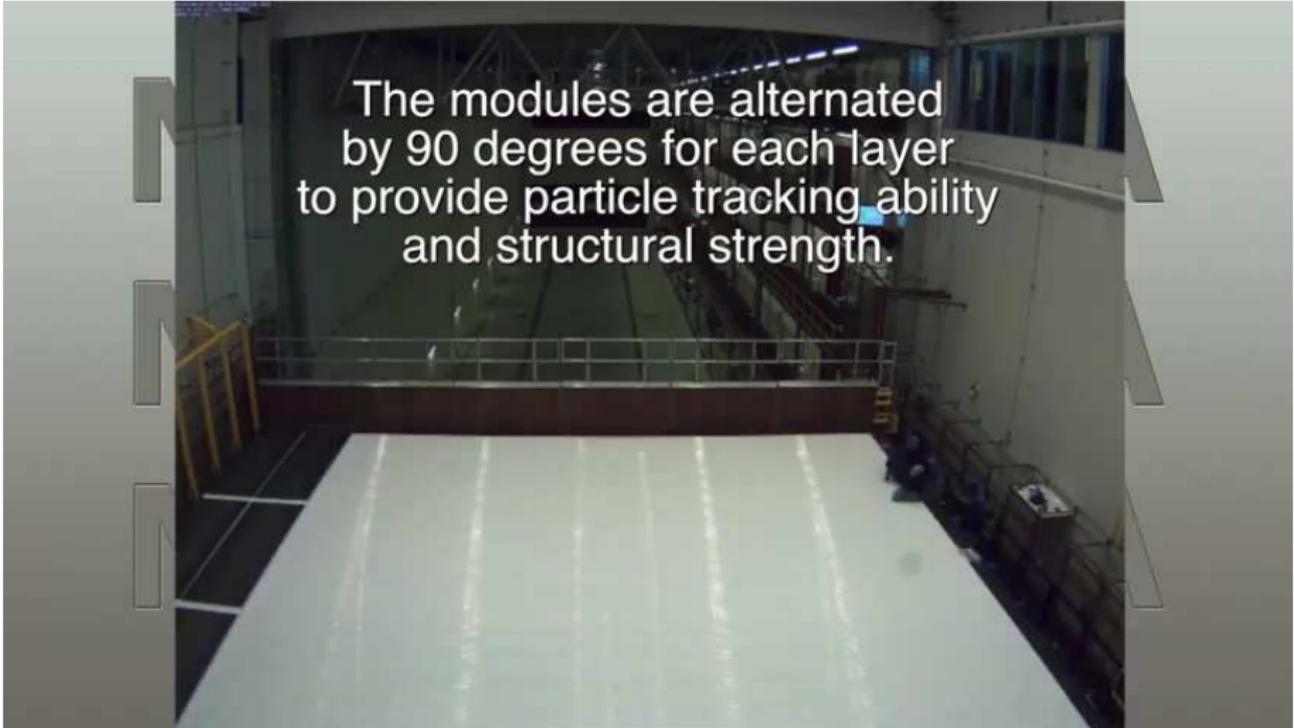
## First Far Detector block



384 PVC modules  
form a stack 51 feet wide,  
51 feet deep and 7 feet high.

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#14 Mathew Meuther "NOvA Construction Status"

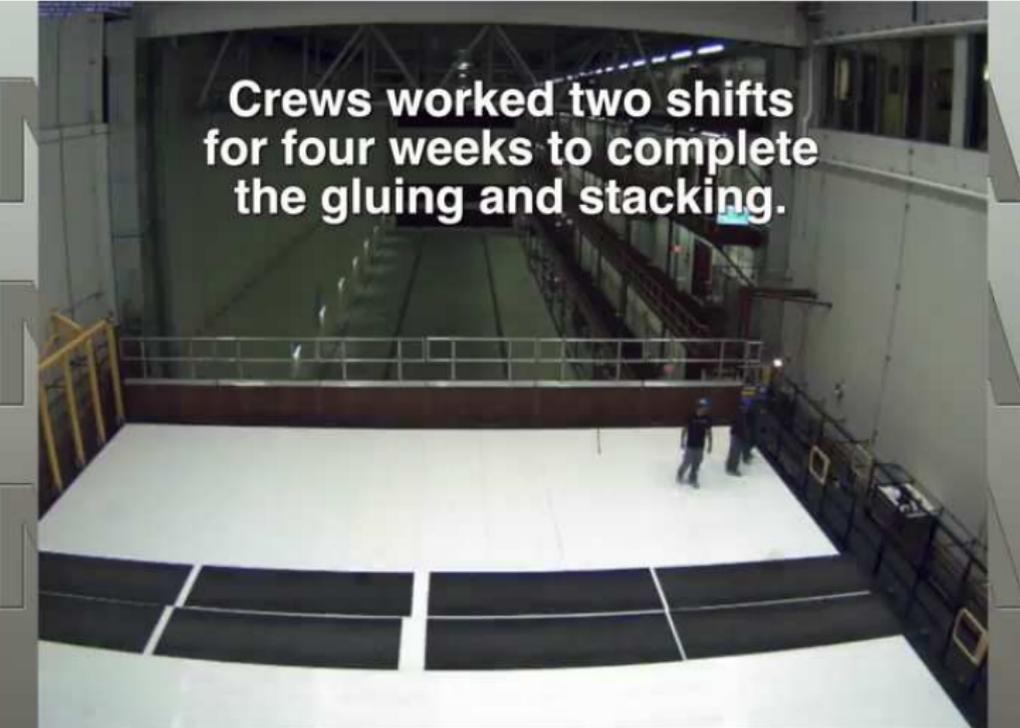
## First Far Detector block



The modules are alternated by 90 degrees for each layer to provide particle tracking ability and structural strength.

<http://www.youtube.com/watch?v=gFpK00WJI90>  
#14 Mathew Meuther "NOvA Construction Status"

## First Far Detector block



**Crews worked two shifts  
for four weeks to complete  
the gluing and stacking.**

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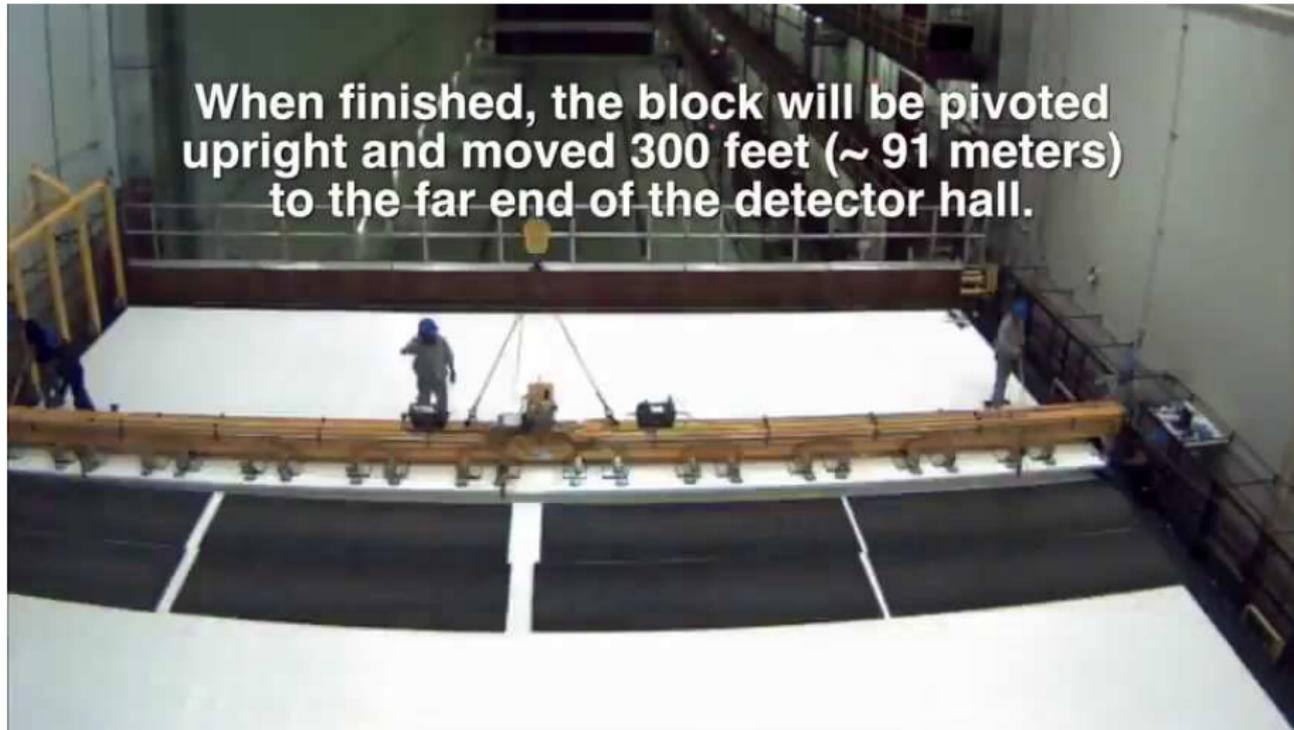
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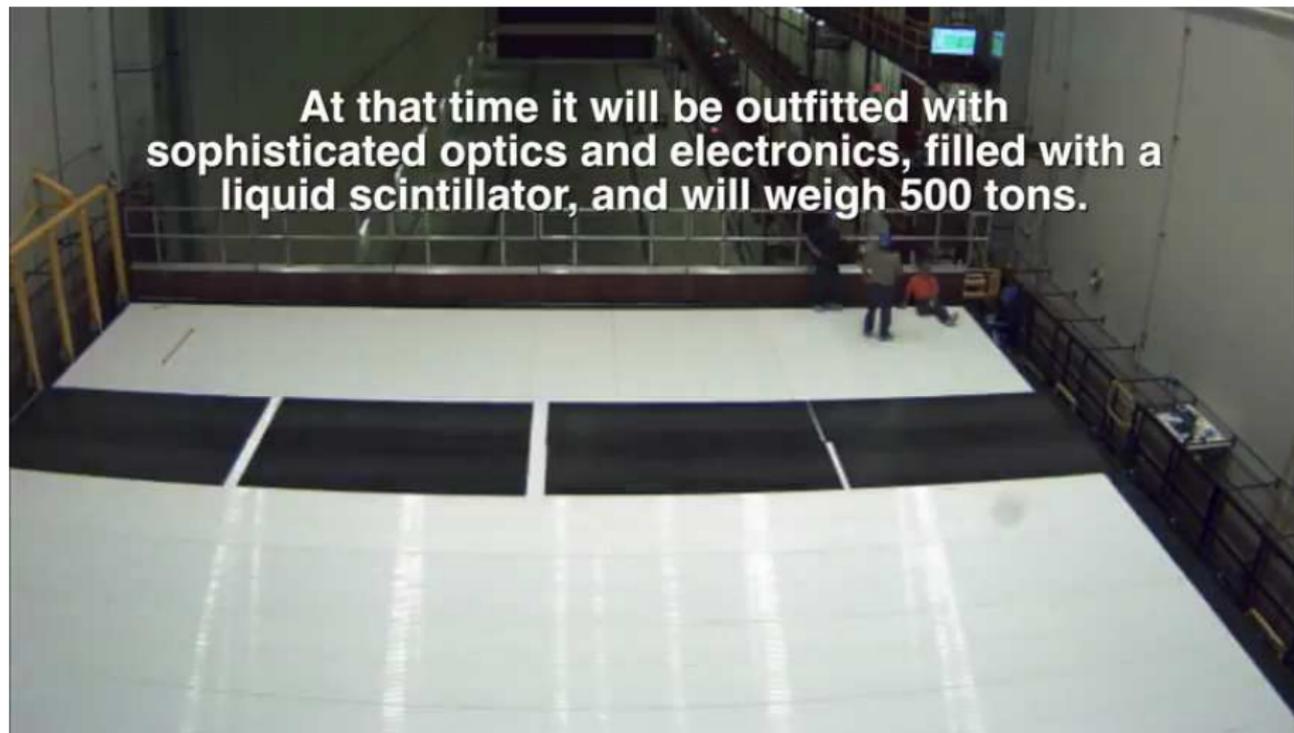
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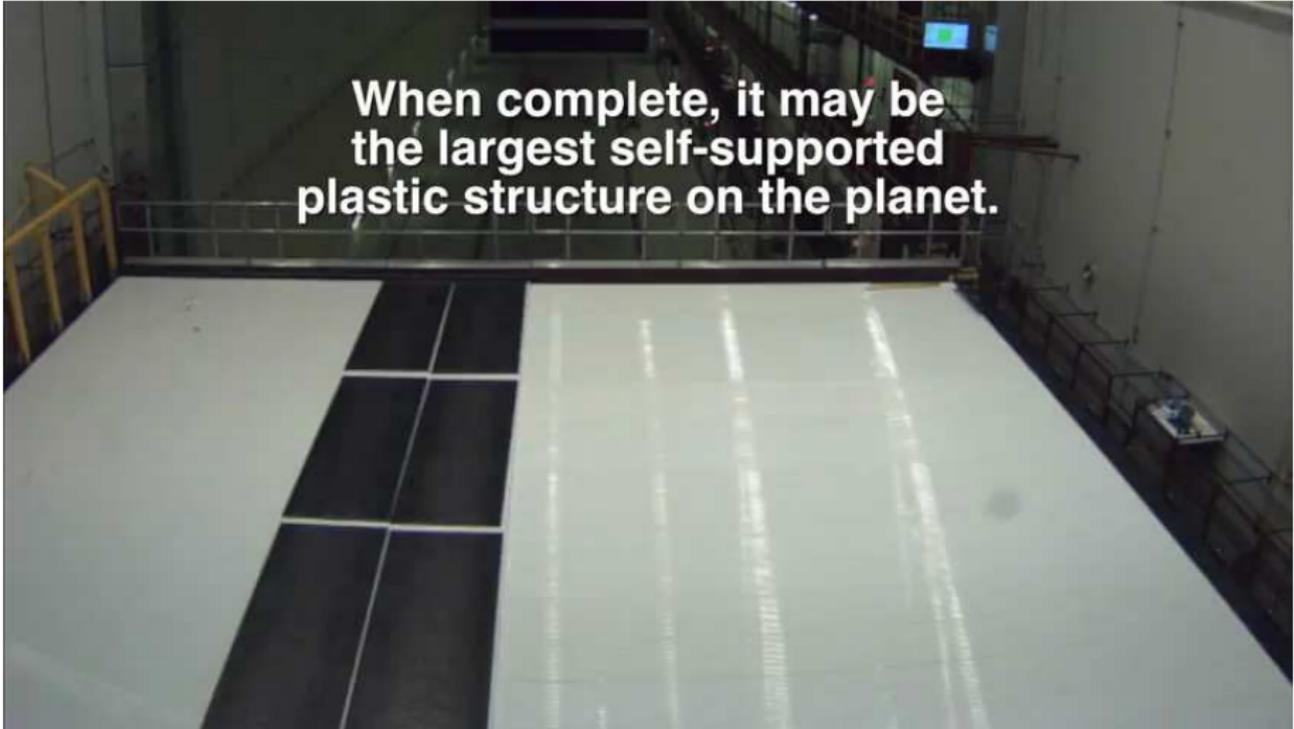
## First Far Detector block



**This process will be repeated  
28 times to complete the  
detector.**

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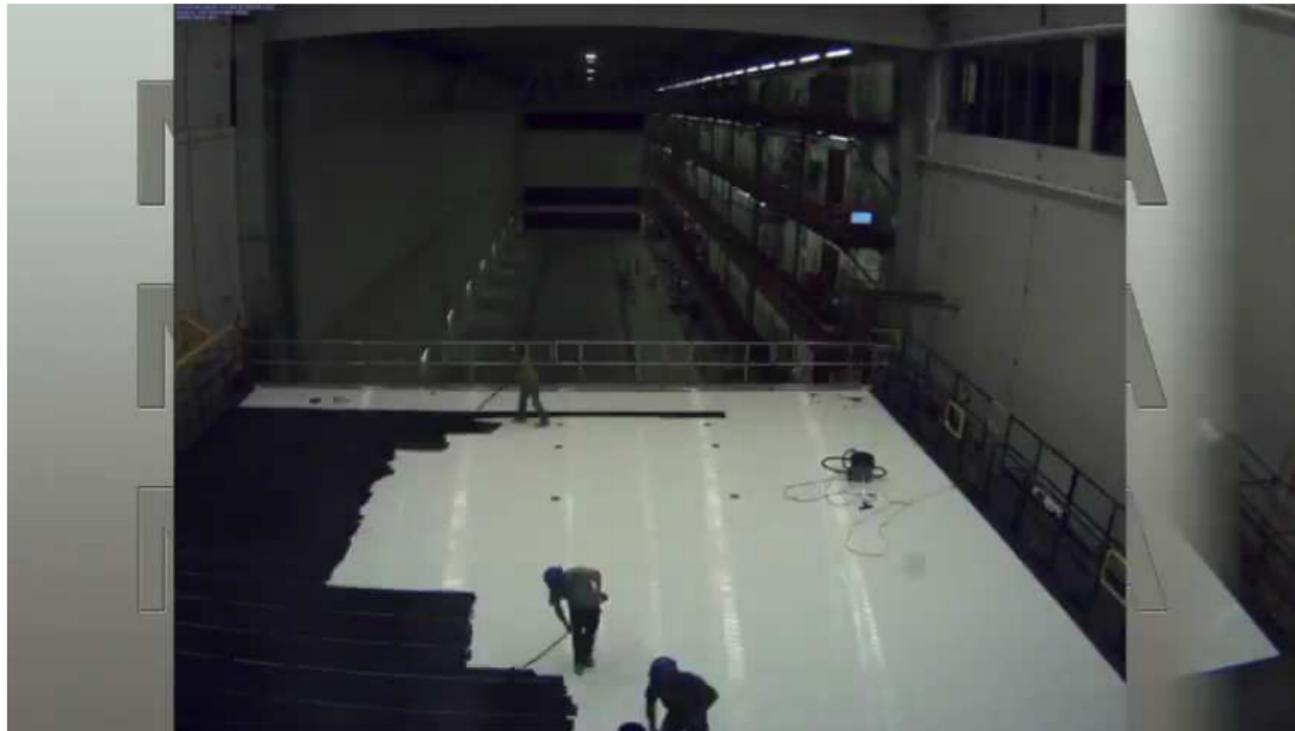
## First Far Detector block



**When complete, it may be  
the largest self-supported  
plastic structure on the planet.**

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#14 Mathew Meuther "NOvA Construction Status"

## First Far Detector block



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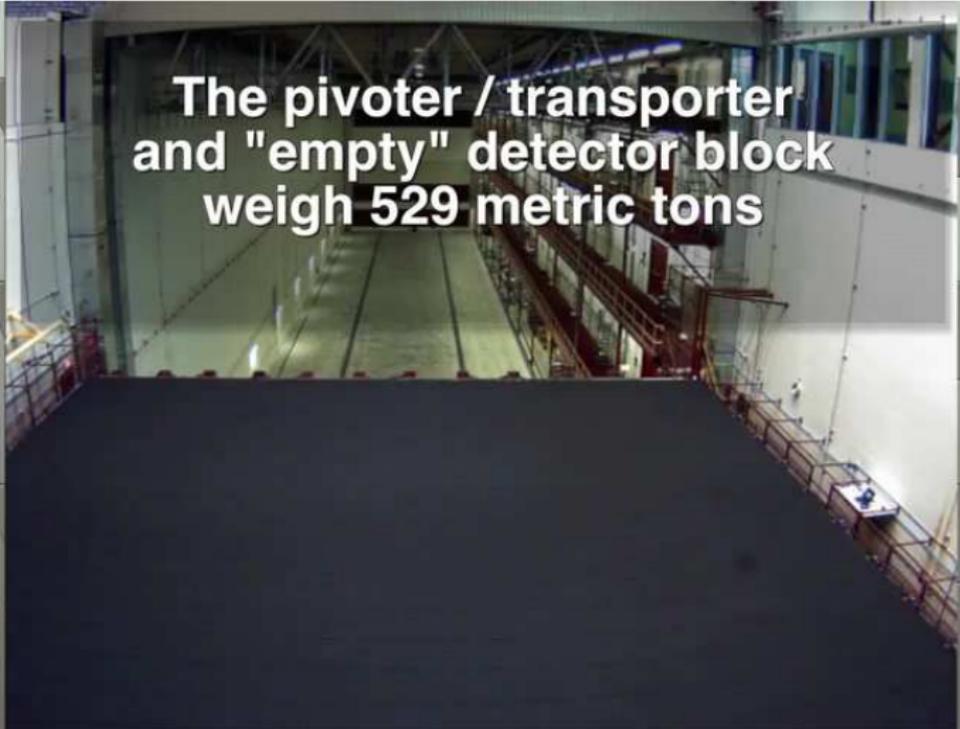
## First Far Detector block



**A light-tight coating  
is applied to the top layer to  
ensure the accuracy of  
the detector's sensitivity.**

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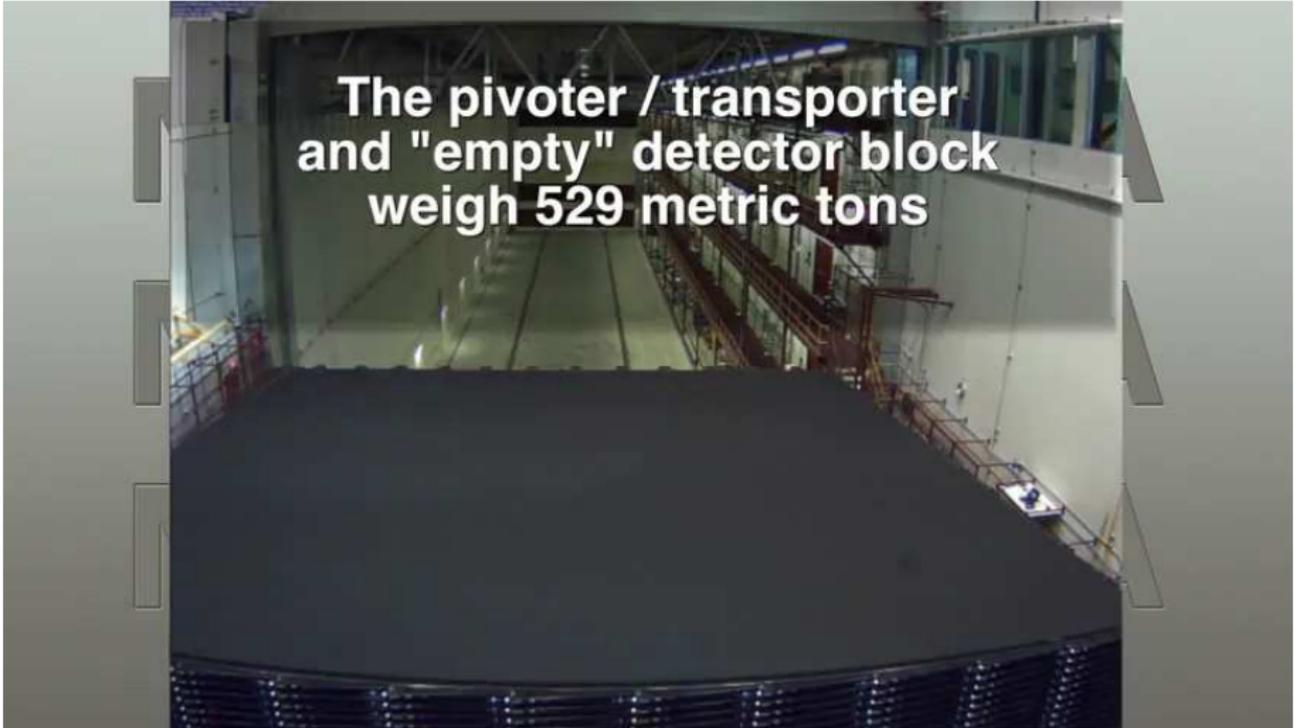
## First Far Detector block



**The pivoter / transporter  
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weigh 529 metric tons**

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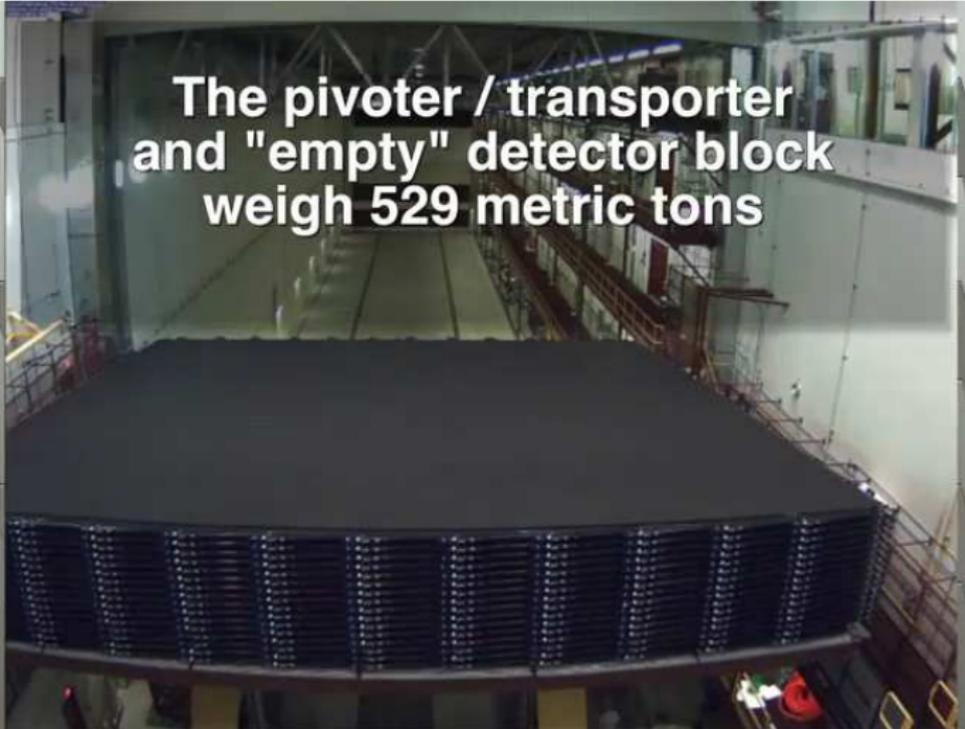
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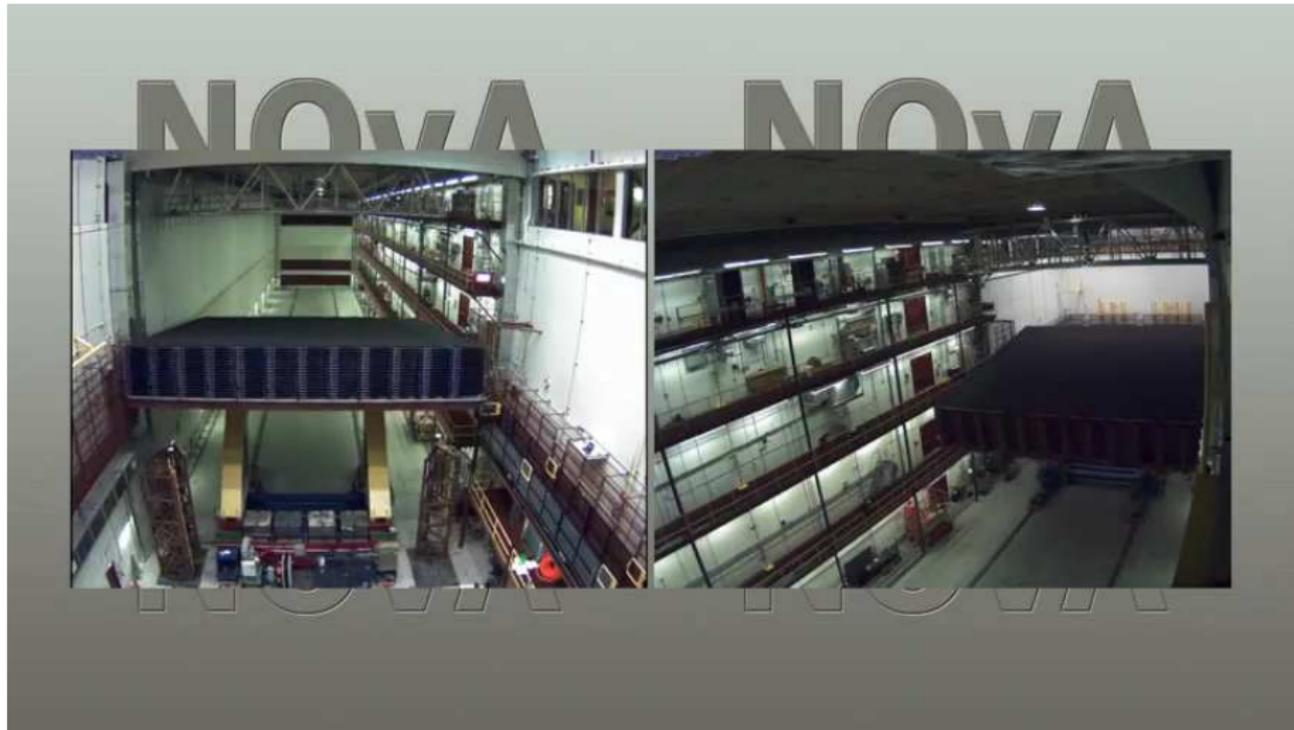
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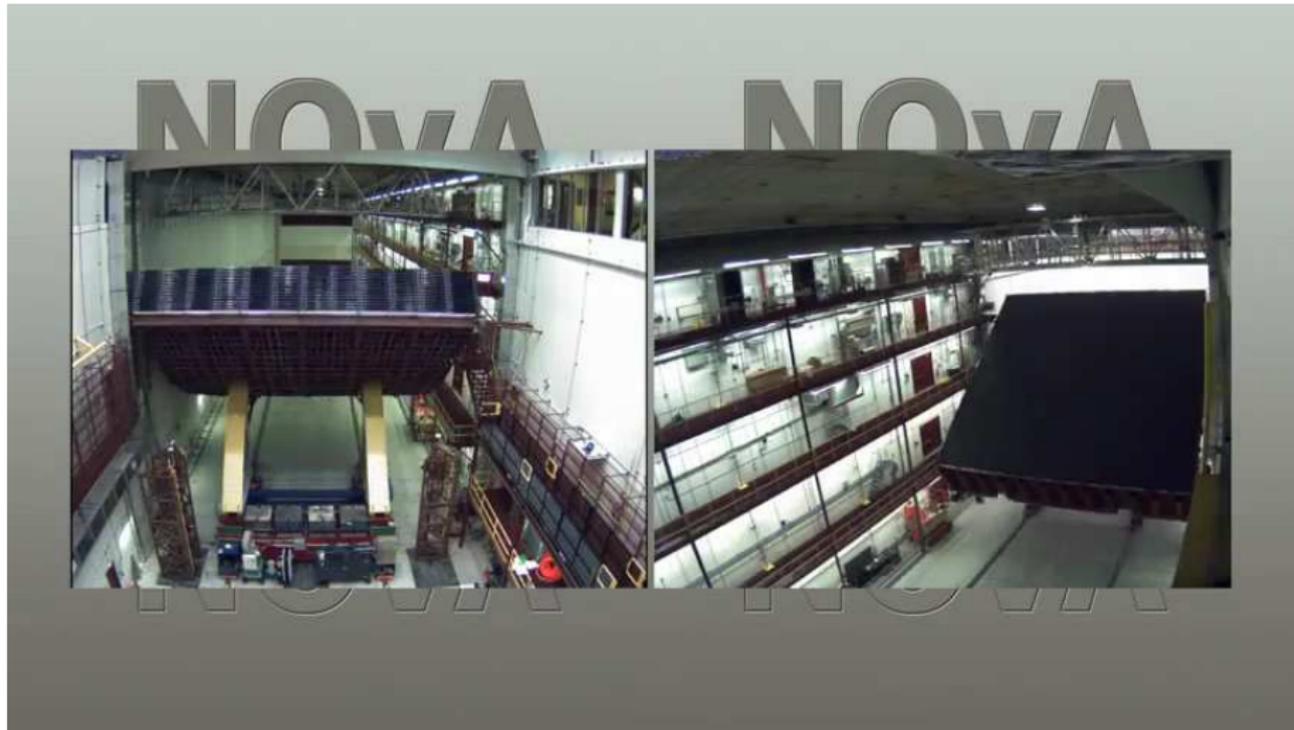
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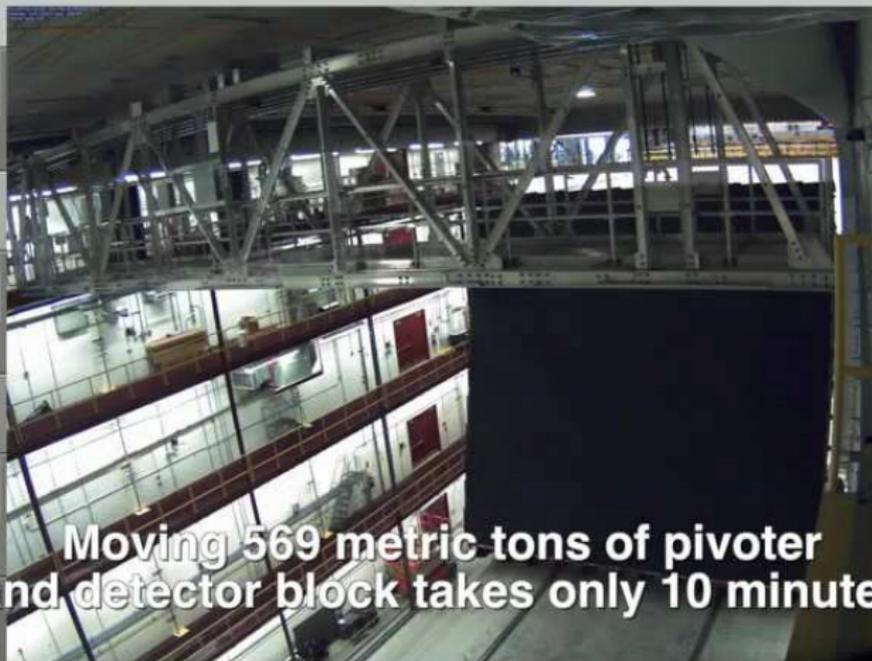
## First Far Detector block



Moving 569 metric tons of pivoter  
and detector block takes only 10 minutes

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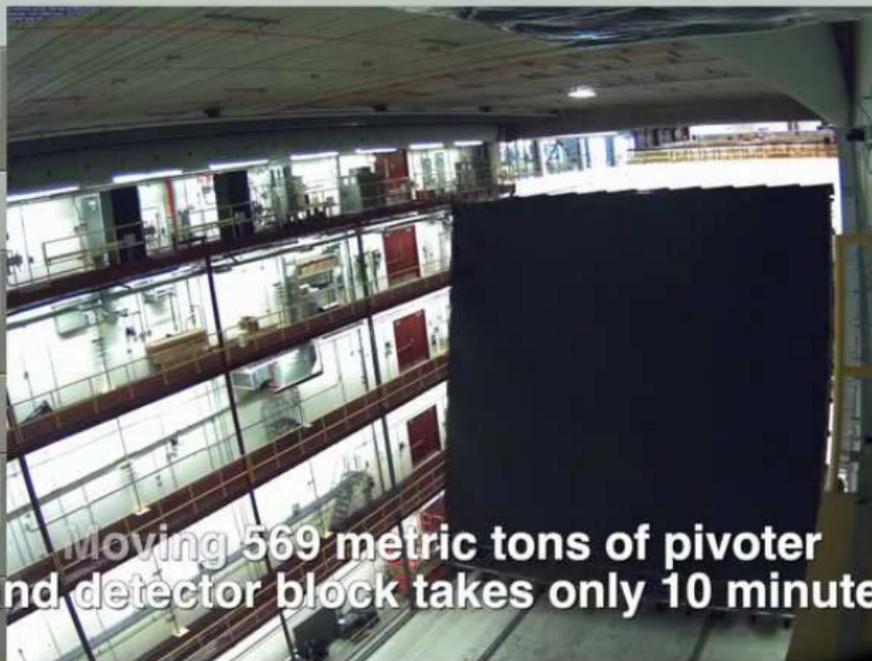
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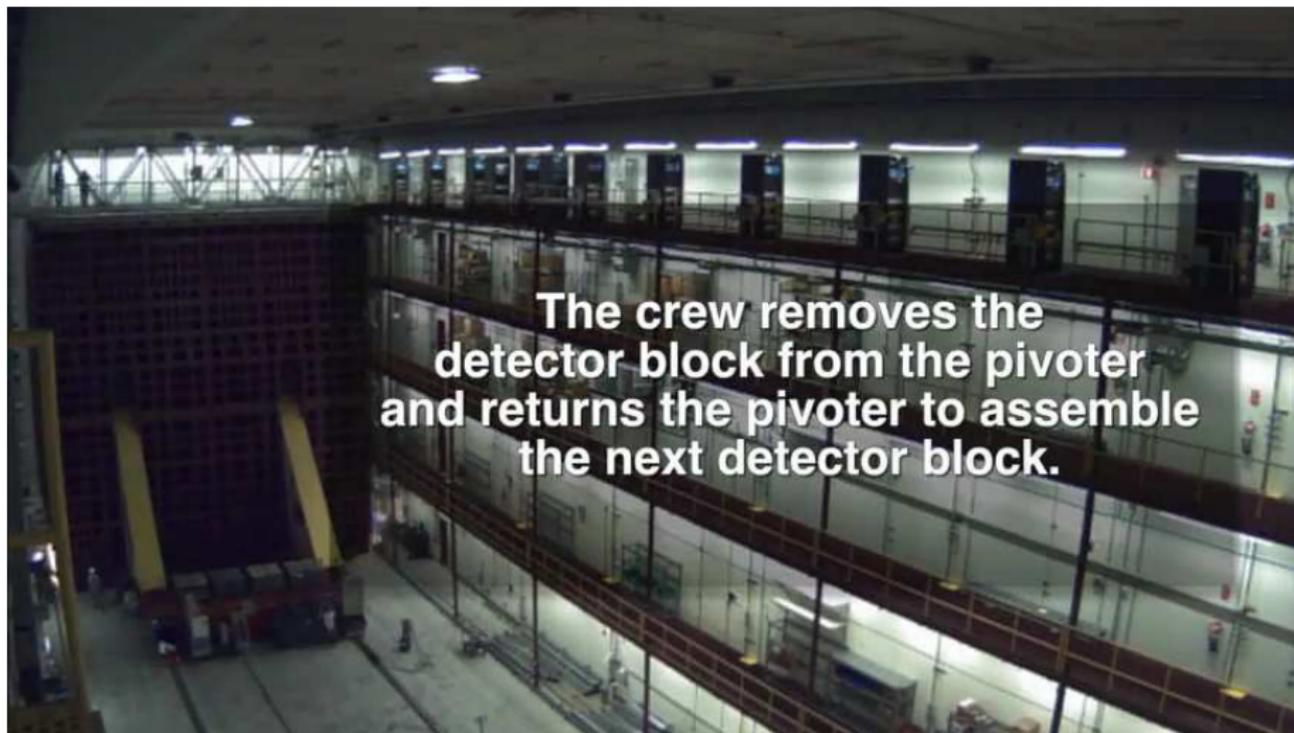
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## First Far Detector block



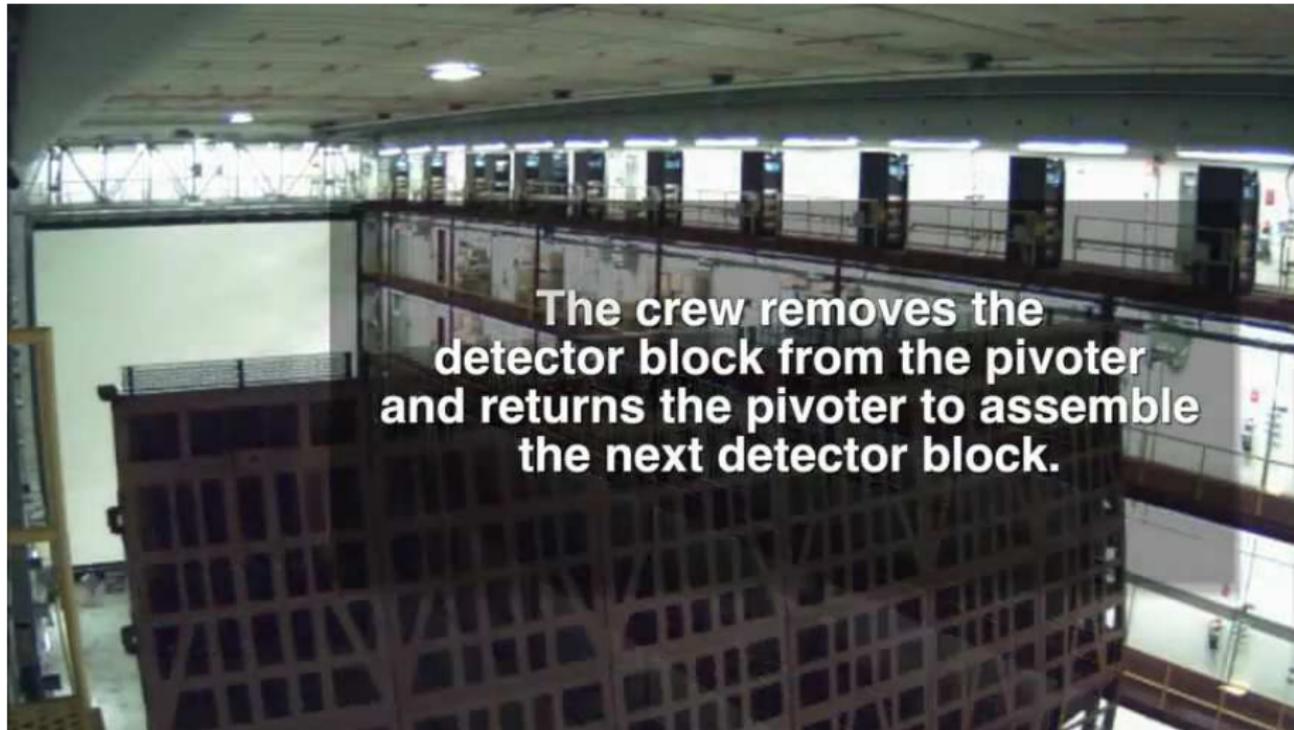
<http://www.youtube.com/watch?v=gFpK00WJI90>  
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## First Far Detector block



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## First Far Detector block



**The crew removes the detector block from the pivoter and returns the pivoter to assemble the next detector block.**

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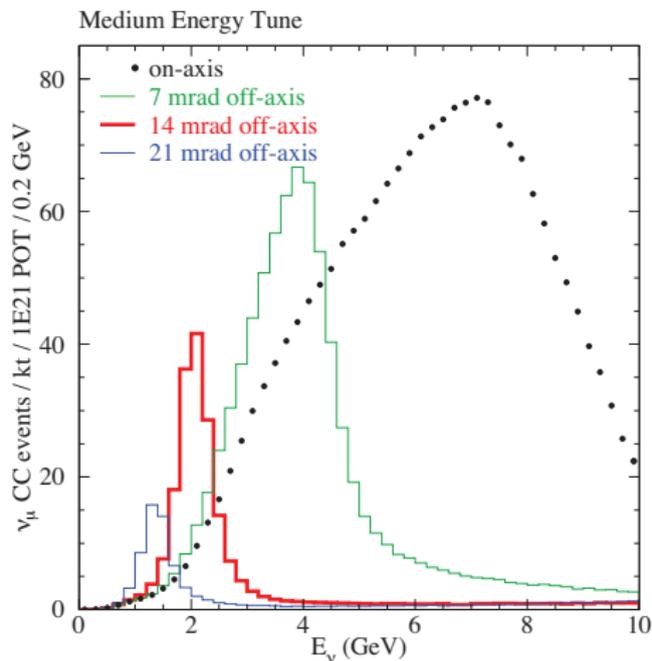
## First Far Detector block



One down, 27 to go!

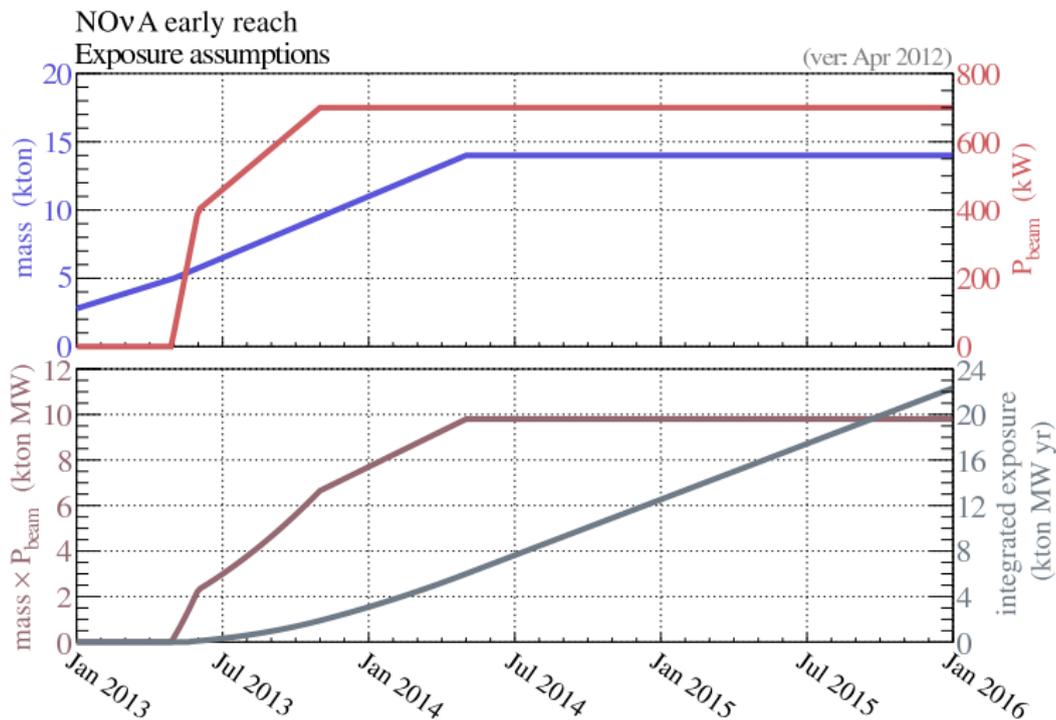
# Accelerator and NuMI upgrades

- ▶ NuMI being upgraded from 350kW to 700kW
- ▶ 1-year shutdown, began May 1
- ▶ Convert Recycler to protons from antiprotons
- ▶ Shorten Main Injector cycle 2.2s→1.33s
- ▶ Overhaul of NuMI target station
- ▶ Beam returns May 2013
- ▶ 6-9 month ramp-up to full power



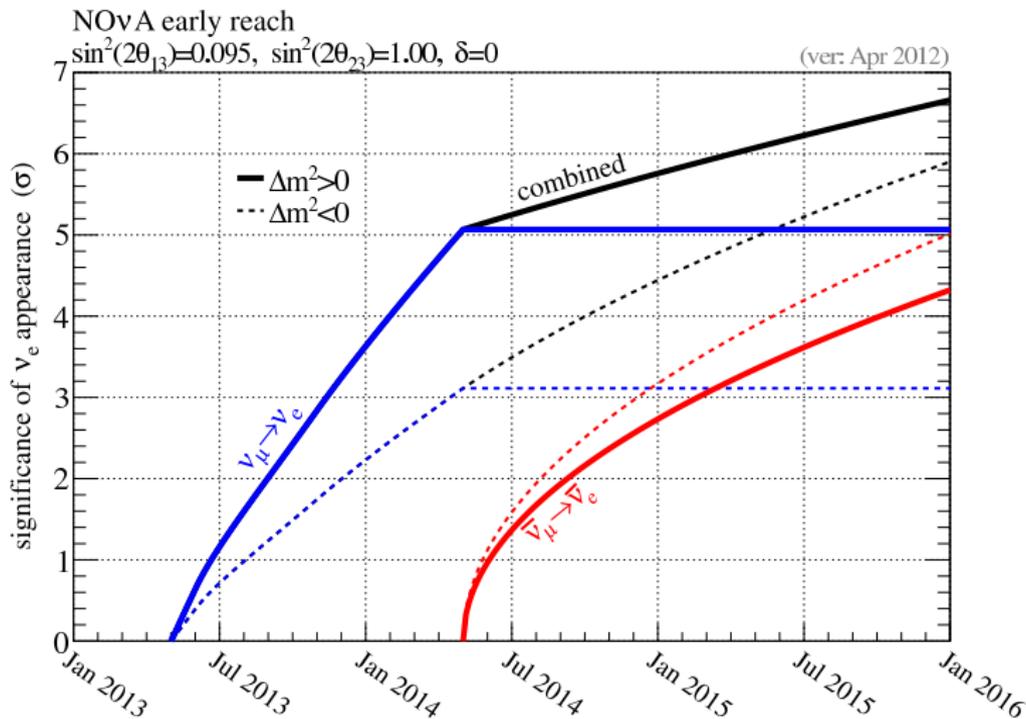
14mrad off-axis beam peaks sharply at 2GeV

# Exposure assumptions and early reach



- ▶ 5kton when beam returns. 700kW in six months. 14kton in May 2014

# Exposure assumptions and early reach



- ▶  $5\sigma$  observation of  $\nu_e$  appearance within first year (assumes NH,  $\delta = 0$ )
- ▶ With detector still under construction and beam commissioning

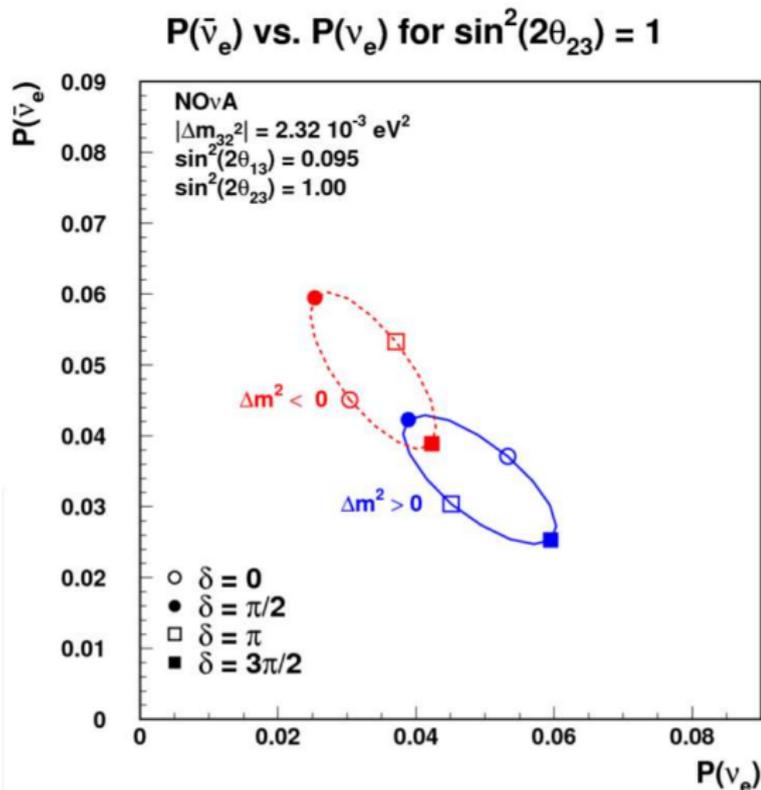
## Sensitivities

- ▶ Assuming 3 years  $\nu$ -mode + 3 years  $\bar{\nu}$ -mode @  $6 \times 10^{20}$  POT/yr
- ▶ Start in neutrino mode
- ▶ Can switch to antineutrinos at any time based on our or others' results
  
- ▶ Take  $\sin^2 2\theta_{13} = 0.095$
  
- ▶ Representative event counts for  $\nu_\mu \rightarrow \nu_e$  analysis
- ▶ Vary depending on specific oscillation parameters

	$\nu$	$\bar{\nu}$
NC	19	10
$\nu_\mu$ CC	5	<1
$\nu_e$ CC	8	5
tot bkg	32	15
$\nu_\mu \rightarrow \nu_e$	68	32

# Principle of the $\nu_e$ measurement

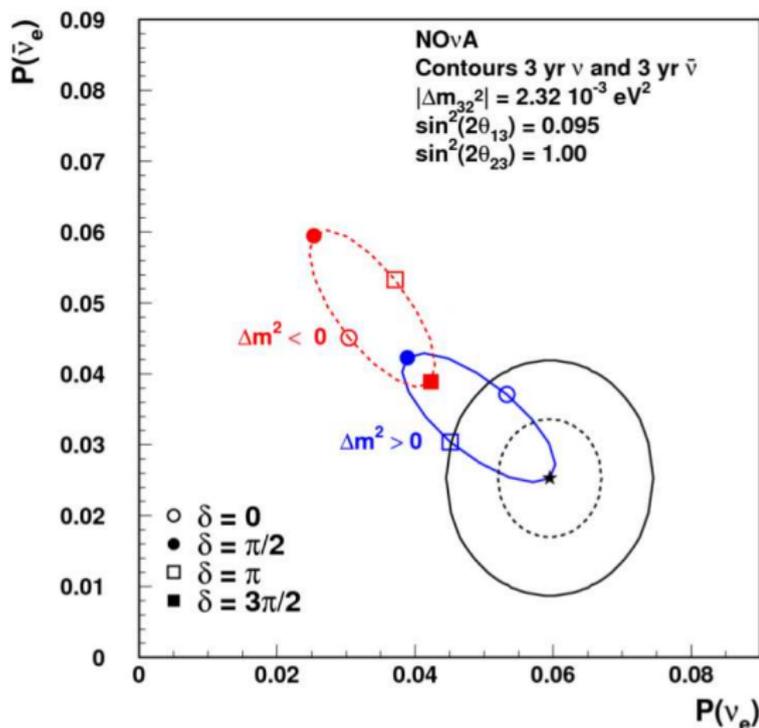
- ▶ To first order, NO $\nu$ A measures  $P(\nu_\mu \rightarrow \nu_e)$  and  $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$  evaluated at 2GeV
- ▶ These depend differently on  $\text{sign}(\Delta m^2)$  and  $\delta_{CP}$
- ▶ #16 Gavin Davies “Neutrino Physics with the NO $\nu$ A Detectors”



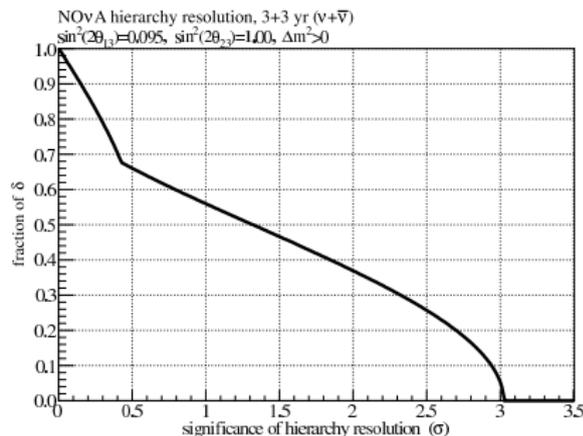
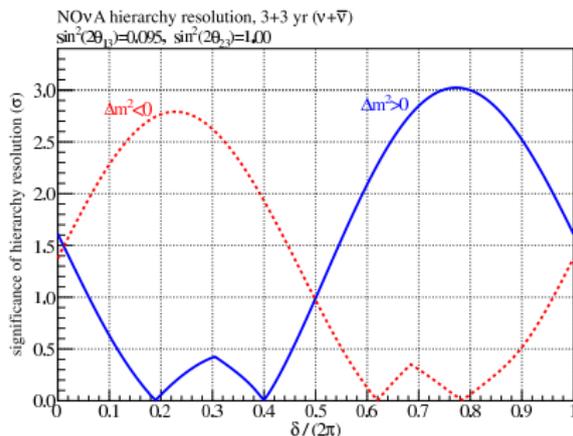
# Principle of the $\nu_e$ measurement

- ▶ Measurements give an allowed region in this space
- ▶ In this case all inverted hierarchy scenarios are excluded at  $>2\sigma$
- ▶ #16 Gavin Davies  
“Neutrino Physics with the NOvA Detectors”

## 1 and 2 $\sigma$ Contours for Starred Point

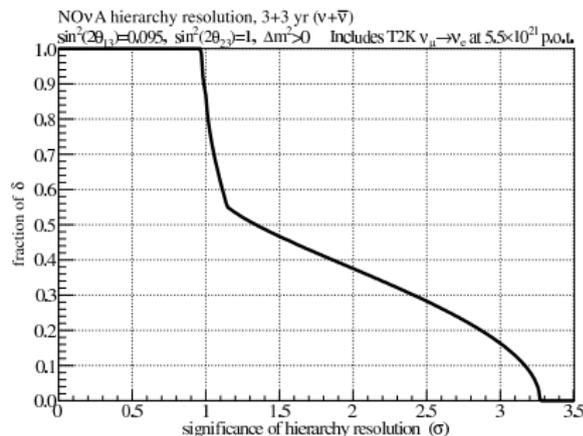
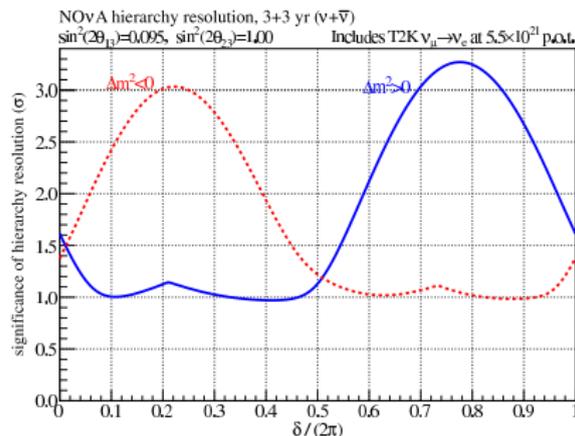


# Significance to resolve hierarchy



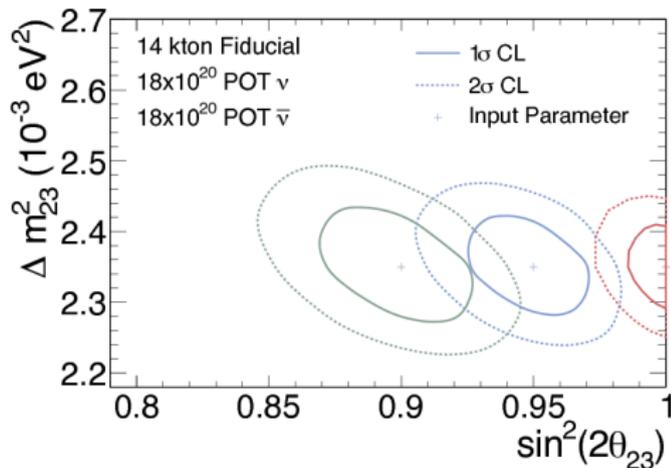
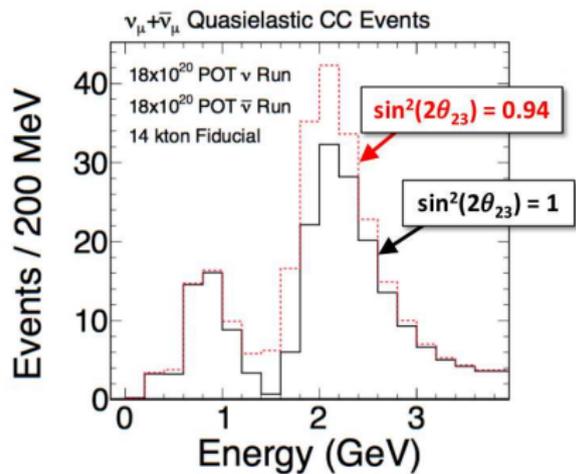
- ▶ For favourable values of  $\delta$  we can measure the hierarchy at high significance
- ▶ There also exist degenerate scenarios

# Significance to resolve hierarchy



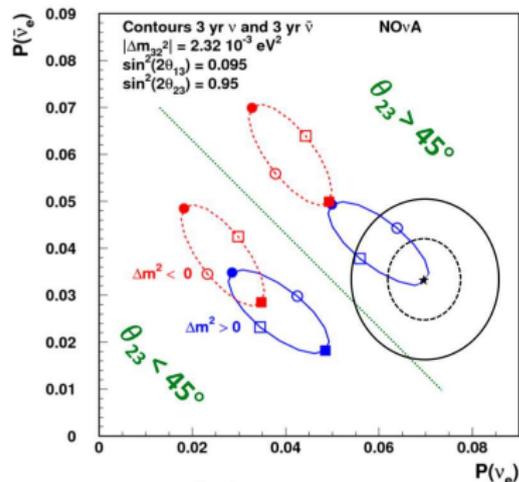
- ▶ For favourable values of  $\delta$  we can measure the hierarchy at high significance
- ▶ There also exist degenerate scenarios
- ▶ Matter effects have a much smaller impact on T2K
- ▶ Help to break the degeneracies

# $\nu_\mu$ analysis



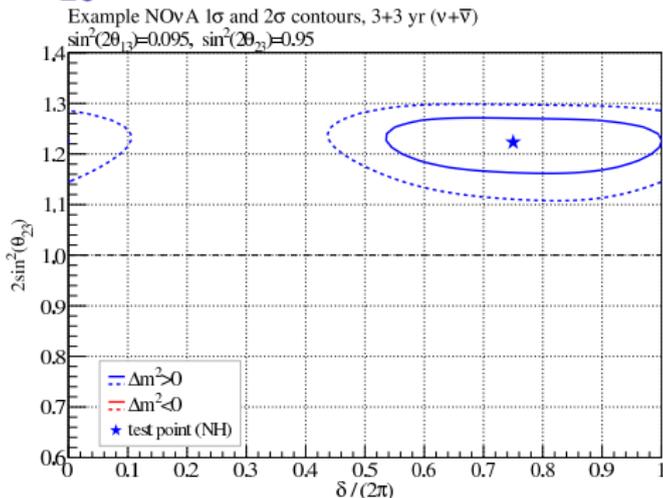
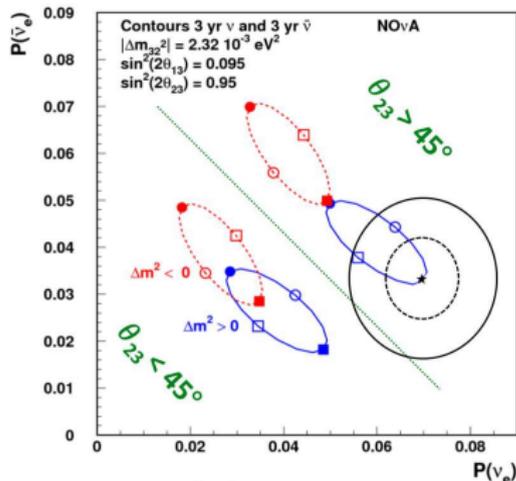
- ▶ Current constraints on  $\sin^2 2\theta_{23} \gtrsim 0.9$
- ▶ NO $\nu$ A can distinguish these cases from maximal mixing

# Determining the octant of $\theta_{23}$



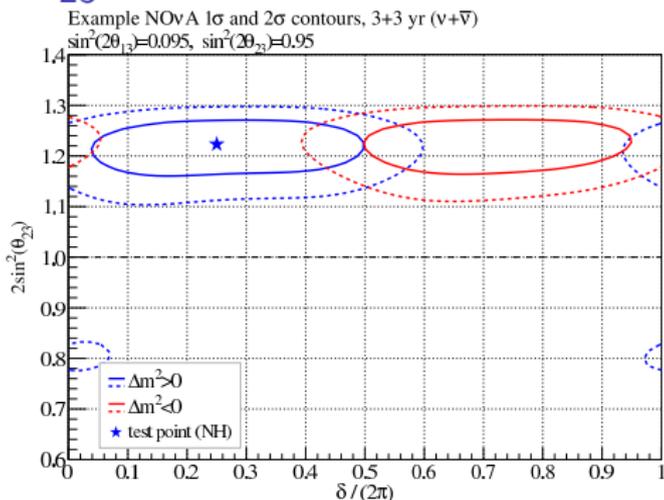
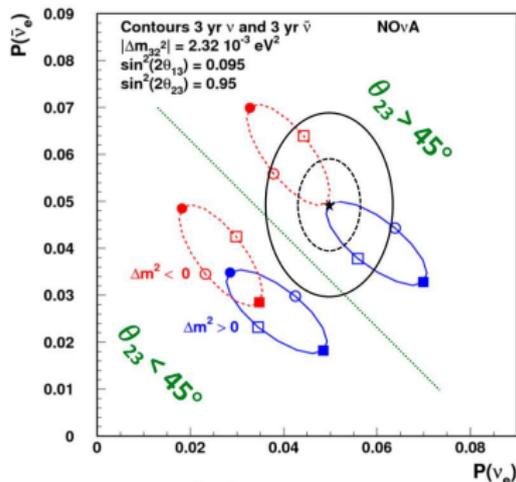
- ▶ If it turns out  $\theta_{23} \neq 45^\circ$ , is it bigger or smaller?
- ▶ Affects  $\nu_e$  probabilities. In same sense, contrasting with hierarchy and  $\delta_{CP}$ 's opposite sense

# Determining the octant of $\theta_{23}$



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- ▶ Here we determine hierarchy and octant ( $>2\sigma$ ) and rule out half of  $\delta_{CP}$  space (at  $2\sigma$ )

# Determining the octant of $\theta_{23}$



- ▶ If it turns out  $\theta_{23} \neq 45^\circ$ , is it bigger or smaller?
- ▶ Affects  $\nu_e$  probabilities. In same sense, contrasting with hierarchy and  $\delta_{CP}$ 's opposite sense
- ▶ In a degenerate case hierarchy and  $\delta$  information are coupled, octant is not

# Conclusion

- ▶ Gained experience with NDOS operation
- ▶ First FD block!
- ▶ NuMI upgrade in progress
- ▶ First neutrino events in partial FD next Spring
  
- ▶ Large  $\theta_{13}$   $\rightarrow$  sensitivity to hierarchy,  $\delta_{CP}$ , and  $\theta_{23}$  octant
- ▶ Developing analyses for first data

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