Initial Performance from the NOvA Surface Prototype Detector

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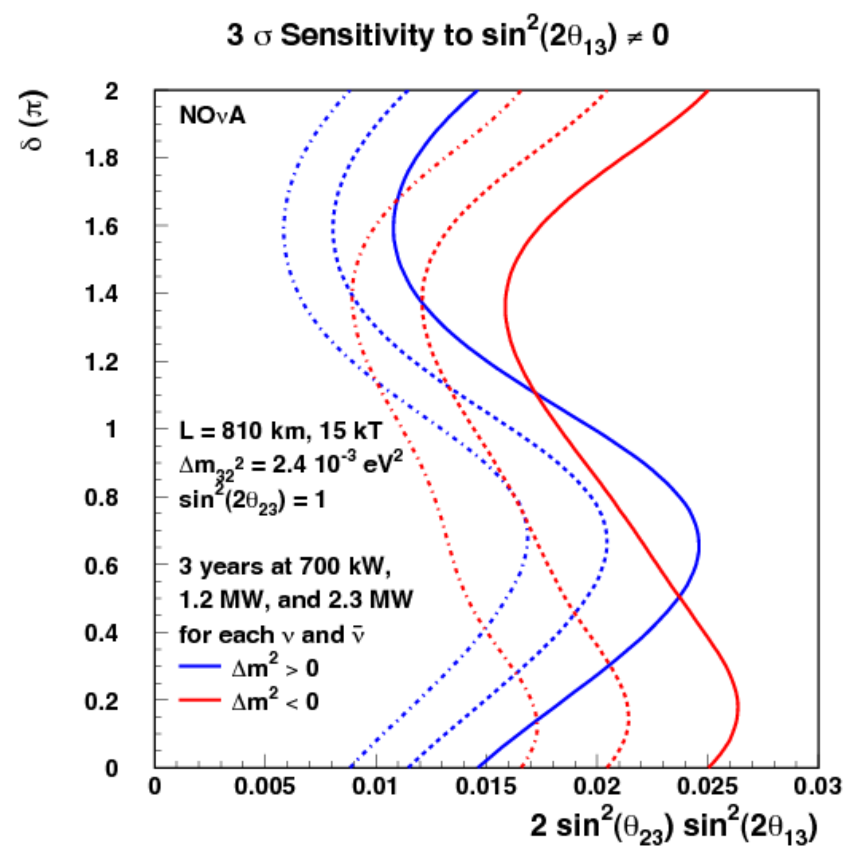
The NOvA Experiment

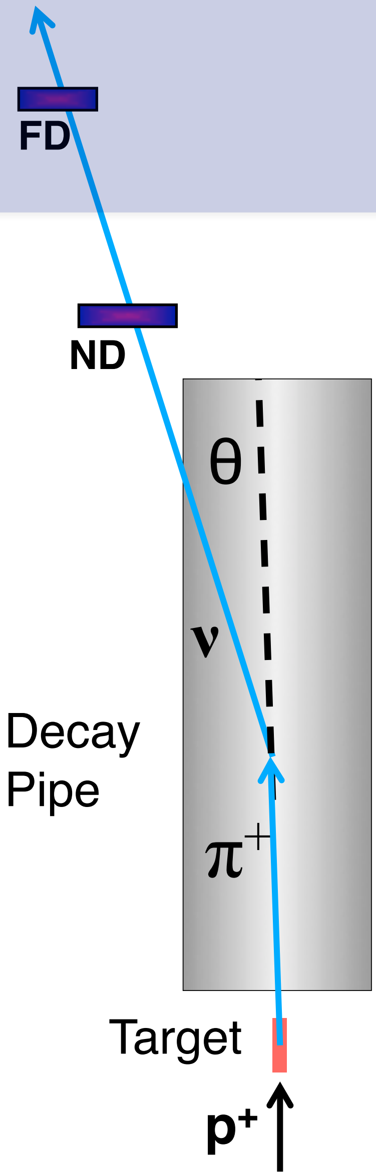
- Long baseline neutrino oscillation experiment:
  - Near and far detector pair.
  - Off-axis ν @ L/E ~ 400 km/GeV
- Goals:
  - **Search for $\nu_\mu \rightarrow \nu_e$ transitions**
  - measure/limit θ_{13}
  - determine mass hierarchy
  - constrain CP violating phase
  - precision measurements of $|\Delta m^2|$, θ_{23}
  - compare $\nu/\overline{\nu}$ oscillations

Design Criteria

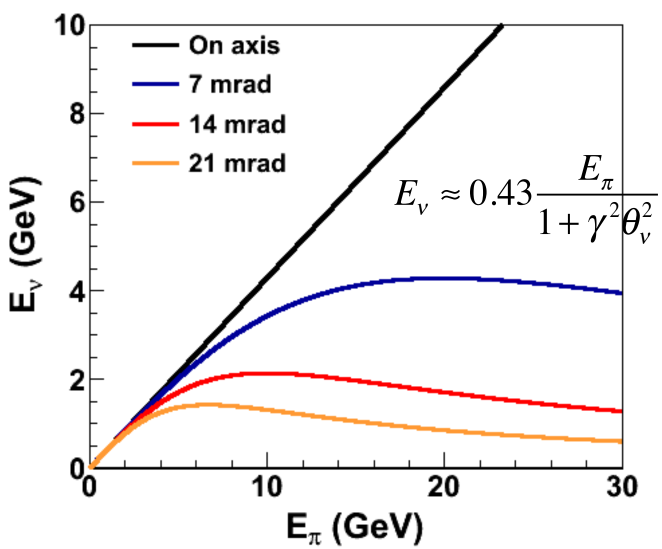
- Experimental Sensitivity: Order of magnitude improvement in θ_{13} limit.
- Energy resolution for ν_e Charged Current events: Less than 8% at 2 GeV
- Energy resolution for Quasi-Elastic ν_μ Charged Current events: Less than 4% at 2 GeV

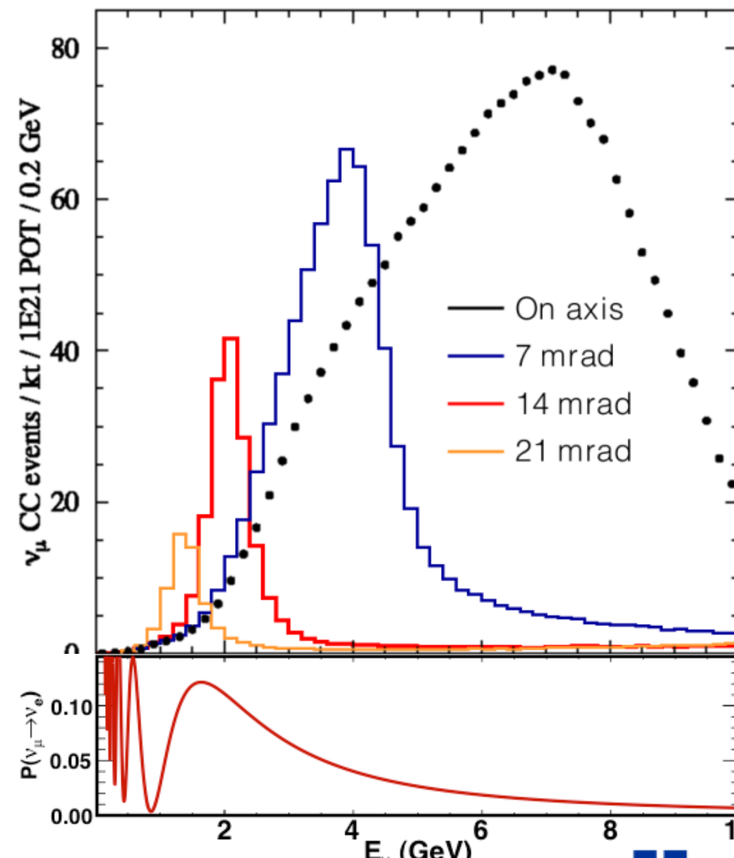


Off-Axis Beam

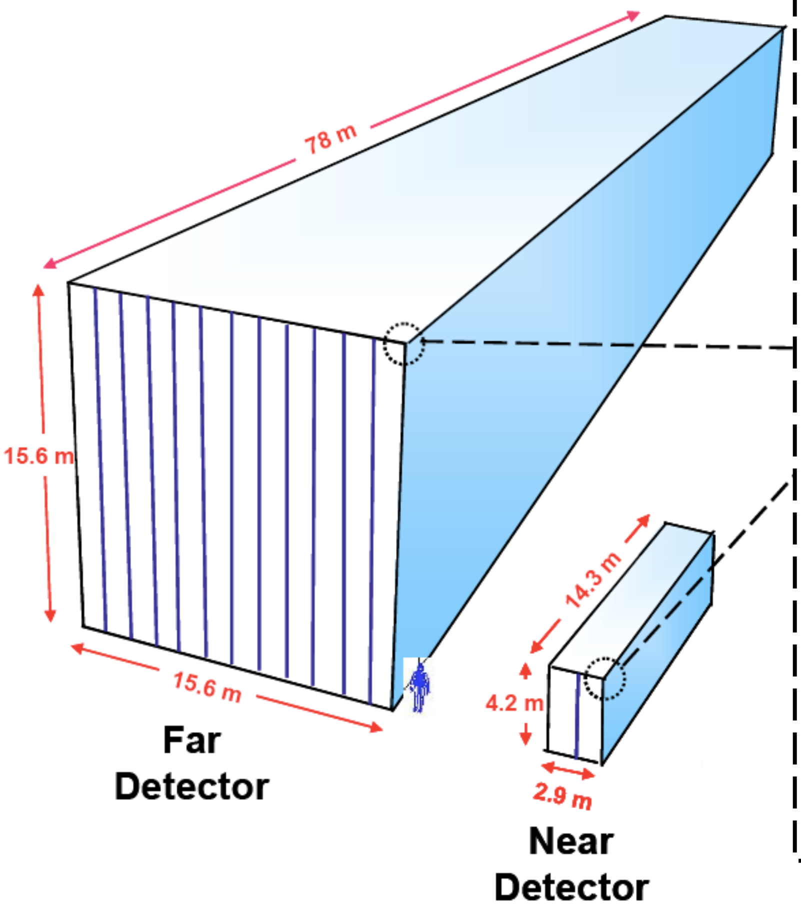


- At 14 mrad off-axis, narrow band beam peaked at 2 GeV
  - Near oscillation maximum
  - Few high energy NC background events





The NOvA Detectors



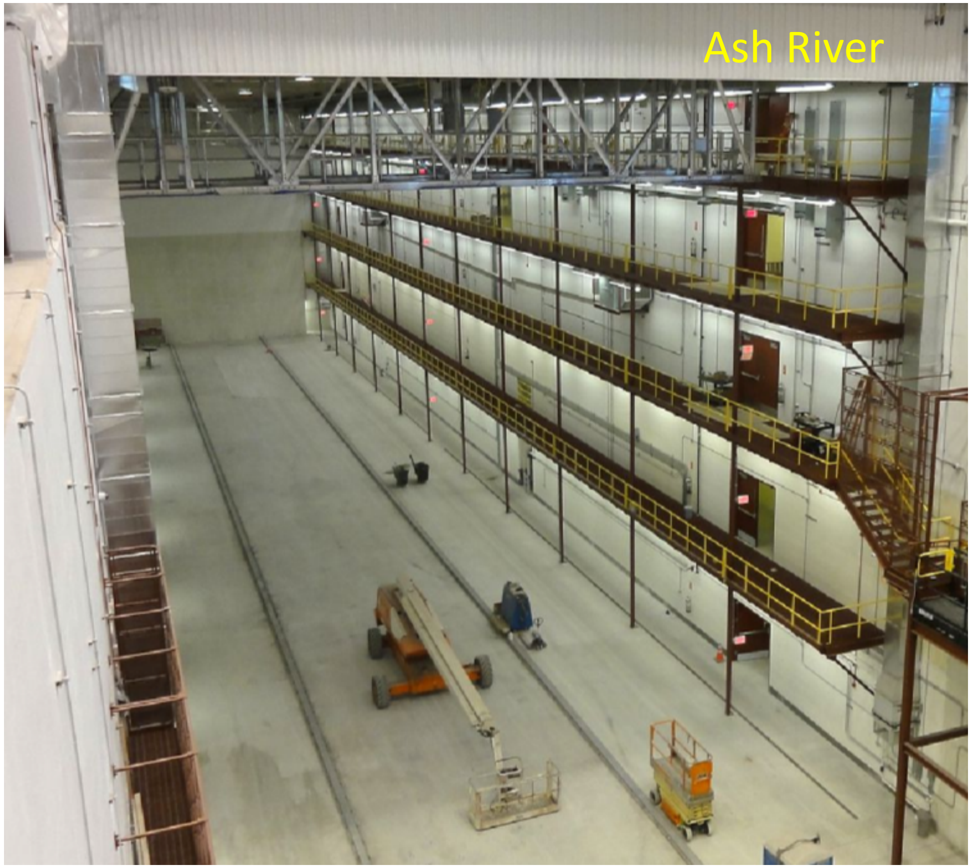
- Near Detector:
  - 220 tons, 1 km from NuMI
  - 105 m underground
- Far Detector:
  - 14 kton, 810 km baseline
  - Overburden >10 rad. Length
- Common Technology:
  - Reduced systematics
  - Low Z ; 65% Active Volume
  - Operational surface prototype near detector (NDOS)

Status and Timeline

Beam Upgrade to 700 kW:
- Accelerator shutdown: March 2012

Far Detector:
- Construction: Jan 2012
- 1 block by shutdown start
- 50% by end of shutdown
- Complete by early 2014

Near Detector:
- Cavern excavation during shutdown
- NDOS: Running now!!



Near Detector on the Surface

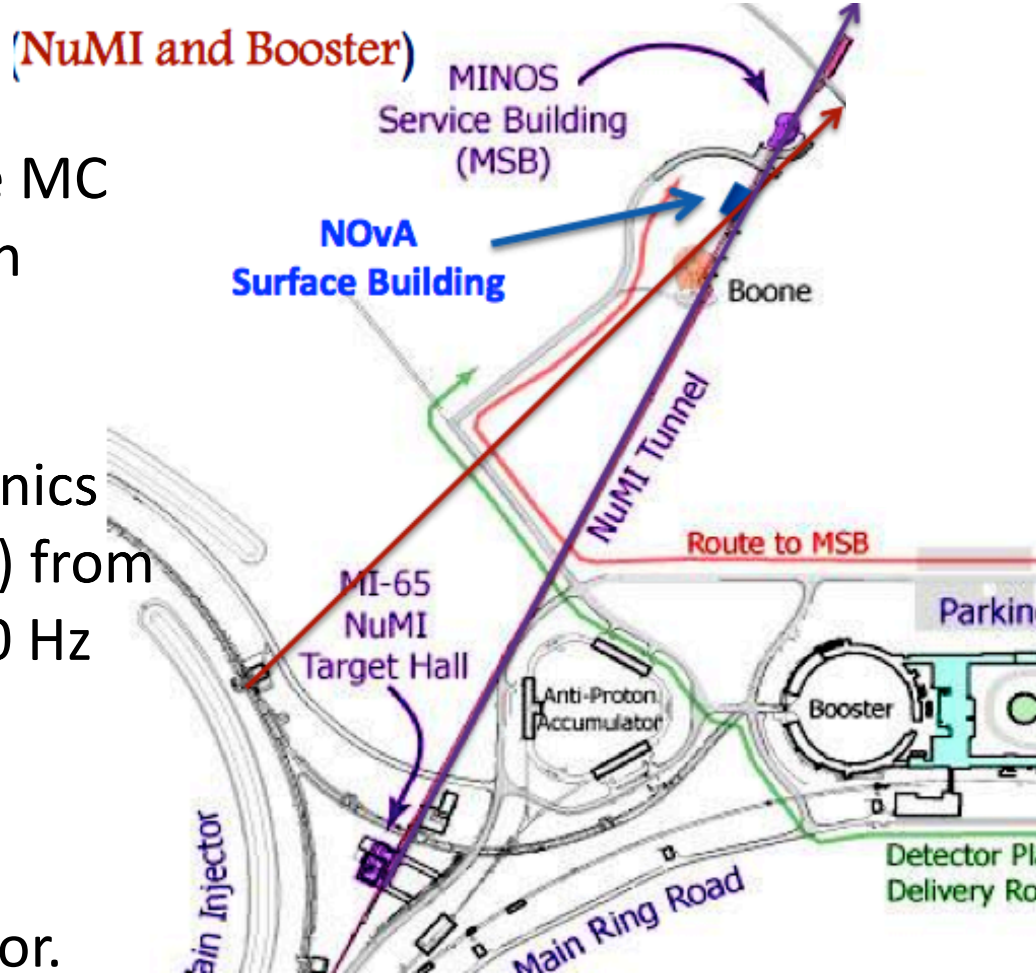
•Full size prototype Near Detector constructed and assembled to mimic far detectors operations as closely as possible.

•Collecting data since October 2010

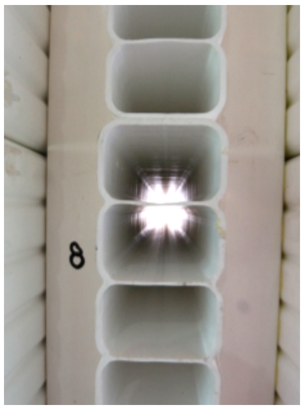
•Virtually all detector subsystems have benefited as we move closer to Far Detector. (Highlighting the major ones here.)

Near Detector On the Surface

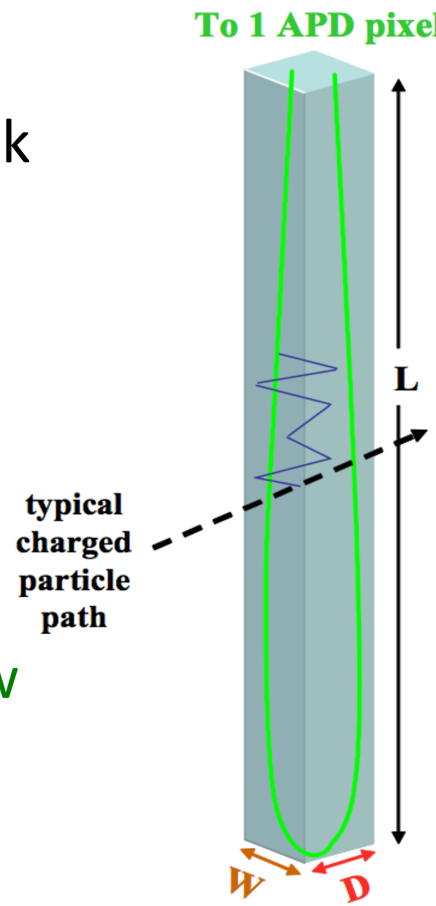
- 6 blocks of 31 alternating orthogonal planes and the MC are installed and filled with scintillator.
- ~75% of the detector is instrumented with electronics
- Gets triggers (500 μs wide) from NUMI and Booster, plus 10 Hz pulser.
- No overburden.
- We are in in the process commissioning this detector.



NOvA Cell

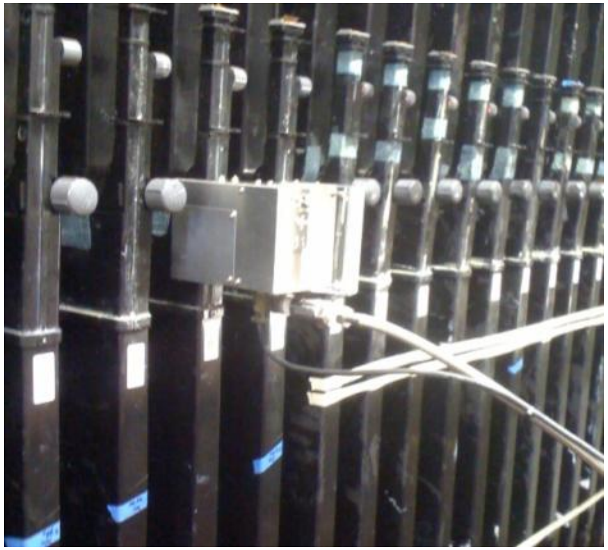


- NOvA cell:
  - 3.8 cm X 5.9 cm X 15.5 m; ~4 mm thick
  - Titanium dioxide loaded PVC (~90% reflectivity at 430 nm)
  - 8 reflections on average
  - 0.15 radiation length per layer filled
  - ~385,000 for 15 kTon. 32 in a sealed module.
- NDOS: Experience in QA/QC. Leaning how to ship, handle, repair. (~20% of delivered manifold covers cracked.) Fed back into design for production pieces. (Add'l talk)



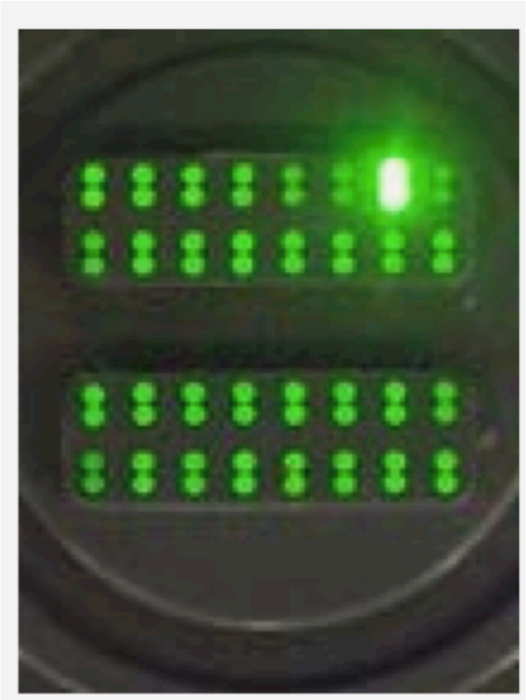
Liquid Scintillator

- 70% of detector mass
- Mineral oil with 5% pseudocumene and wave length shifters producing light at 400 – 450 nm
- Light in a NOvA cell is captured locally by a wavelength-shifting fiber within about one meter at less than 80% attenuation.
- 3.9 million gallons of liquid scintillator at far site.



•NDOS: Experience qualifying scintillator. Refined filling procedure for record keeping and cleanliness. Found internal obstructions preventing complete fills.

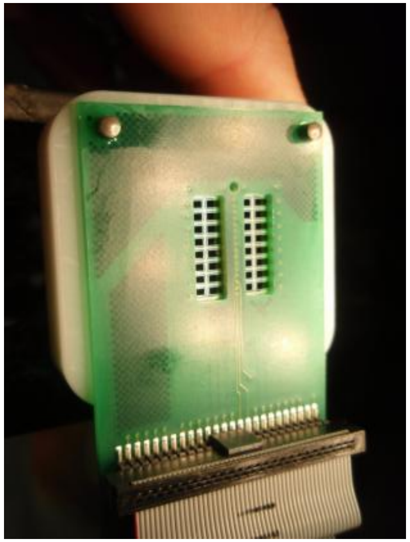
Fibers



- Single sided readout from 0.7 mm diameter looped fiber
- Shifts light to green 490 - 550 nm.
- Light is attenuated by about a factor of ten with red light (520 – 550 nm) preferentially surviving.
- 13,000 kilometers of wavelength shifting fiber for far detector.
- NDOS: Experience in stringing modules. Reworked spooling techniques to minimize tangles. Experience with in-module QA.

APD (Avalanche Photo Diode)

- 85% QE for 520 – 550 nm light.
- Gain of 100 @ 375 volts.
- Actively cooled to -15 C.
- Signals pass though low-noise on-board amplified
- Require 20 pe signal from MIP at far end of cell with 10-15 pe threshold. (We expect 38 pe.)
- ~12,000 APDs on FEBs
- NDOS: Cleanliness issues during installation led to noisy channels. New surface coating under-investigation.

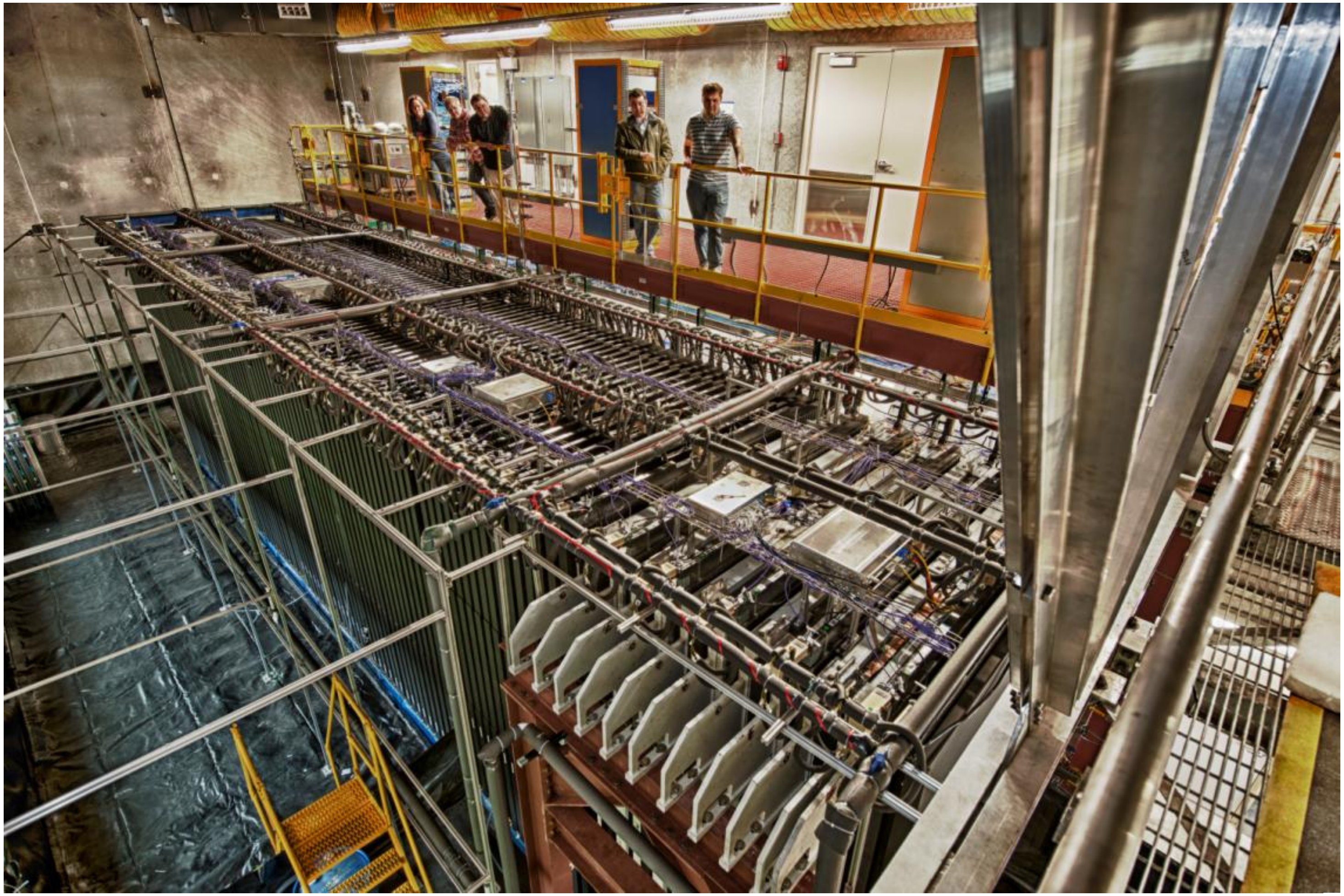


DAQ

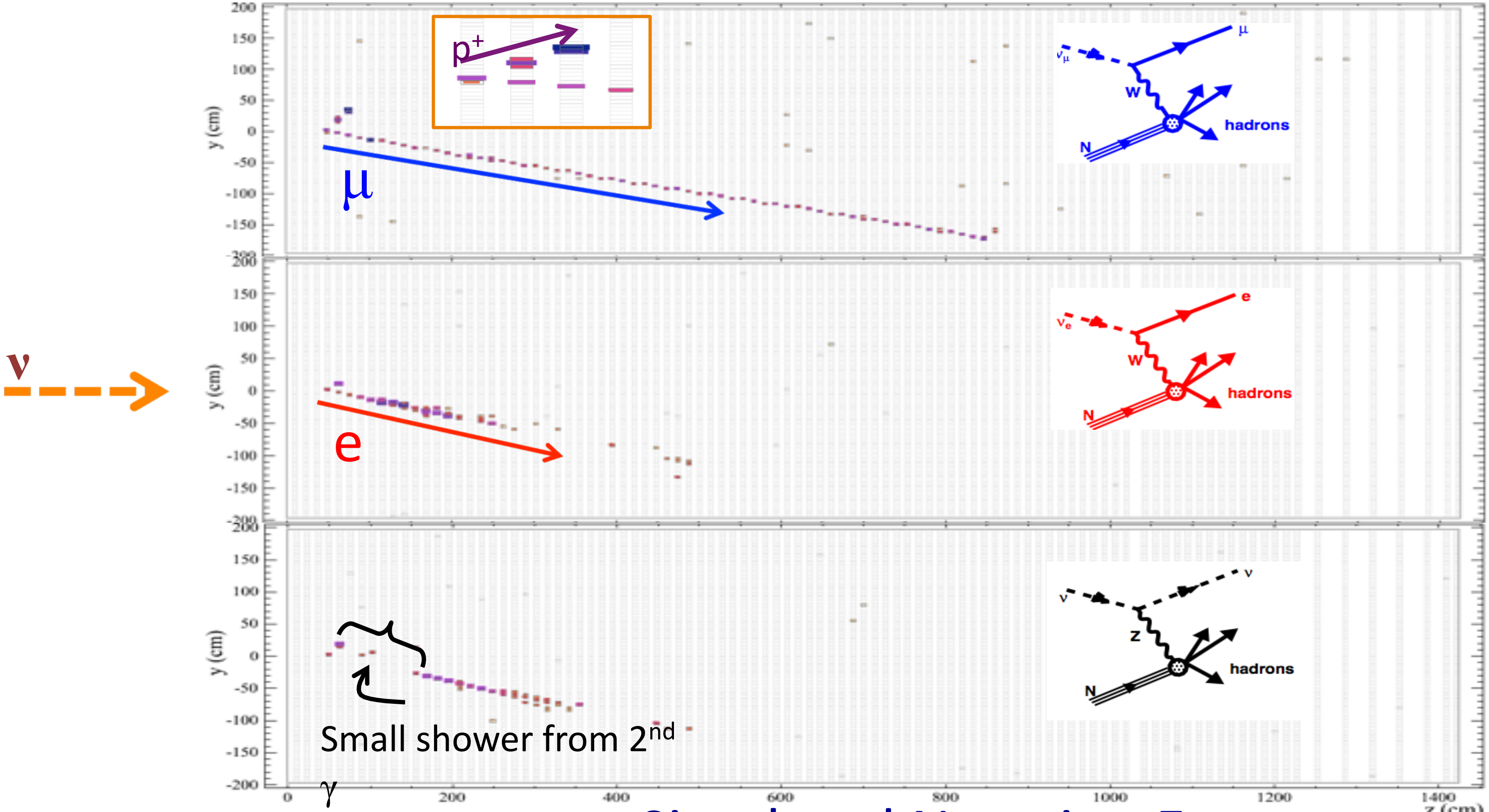
- Front-end electronics operate in continuous digitization mode.
- Data from the ADC is processed on-board with correlated sampling.
- 64 FEBs feed a Data Concentrator Module which passes the data to a processing farm.
- Data is buffered until the arrival of a software spill trigger.
- Data rate driven by cosmic ray muons (0.5 GB/s) (Mimicked at NDOS).
- NDOS: Since deployment updates to the software have doubled real throughput.

NDOS

NDOS

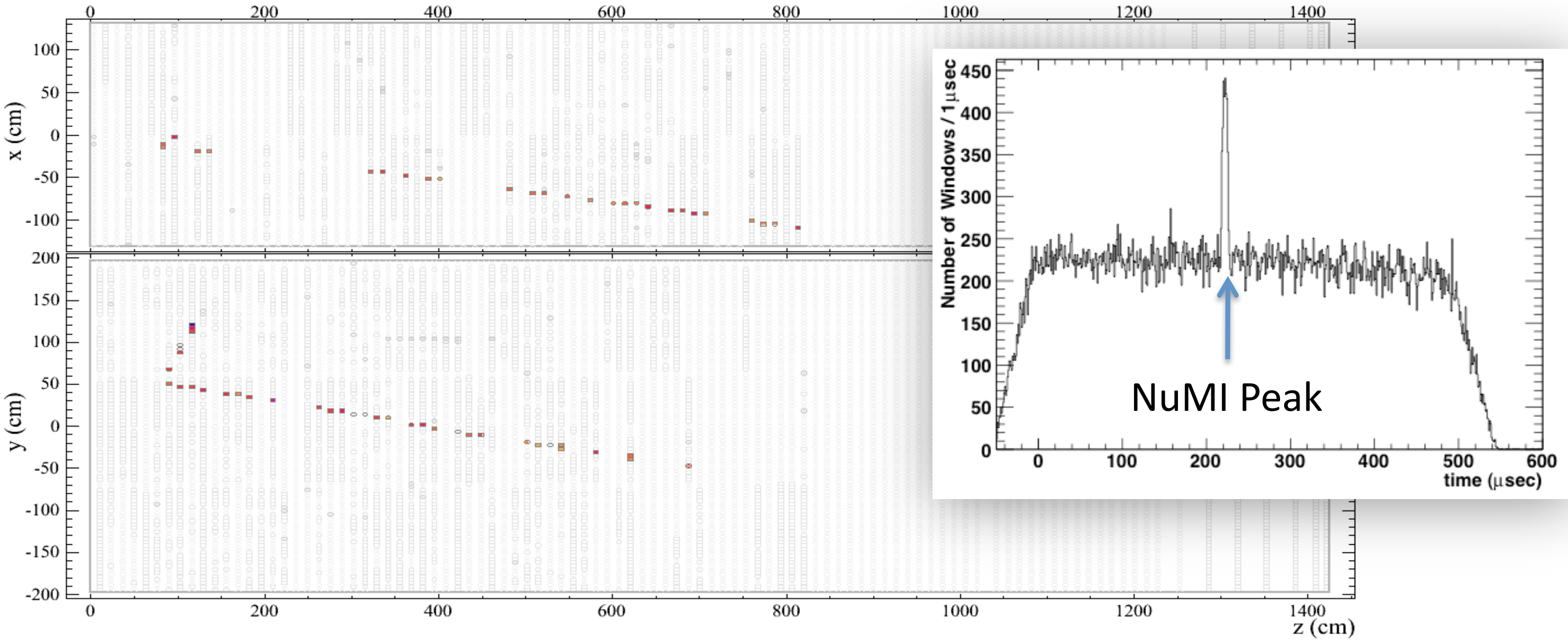


Early Analysis from Actual Neutrinos



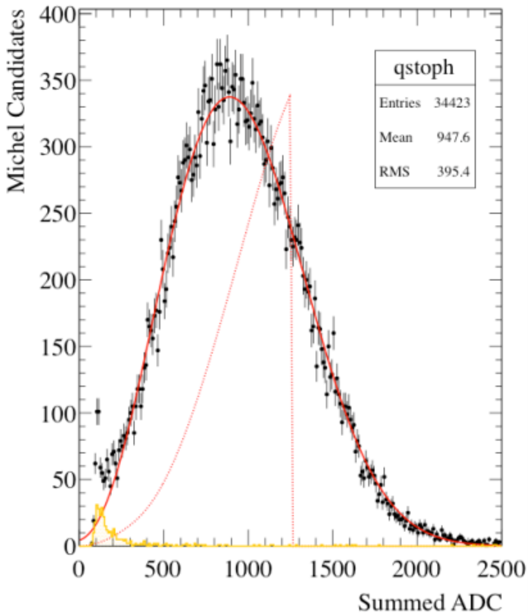
Simulated Neutrino Events

Early Analysis from Actual Neutrinos

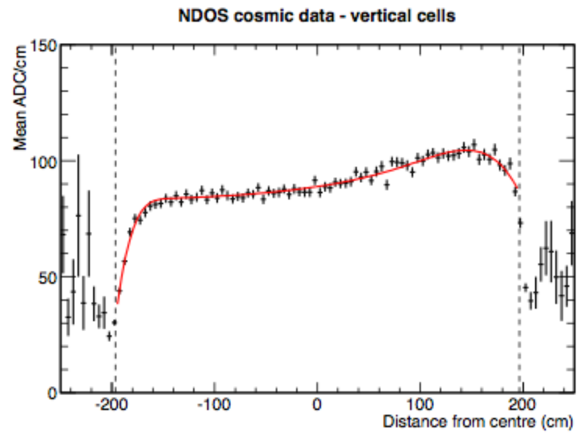


- 5.6x10^{19} POT reverse horn current beam, 1001 NuMI events (69 cosmic BG)
- 8.4x10^{18} POT forward horn current beam, 253 NuMI events (39 cosmic BG)
- 3x10^{19} POT, 222 booster events (92 cosmic BG)

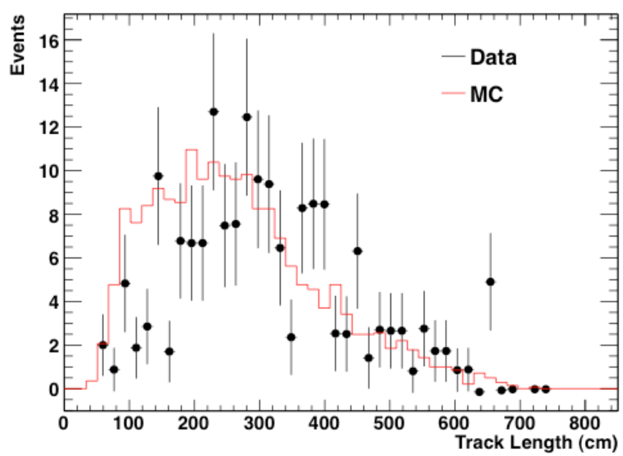
Commissioning/Calibration Experience



- Use Michel electrons for electro-magnetic energy calibration



- Cosmic muons provide intra-detector calibration source

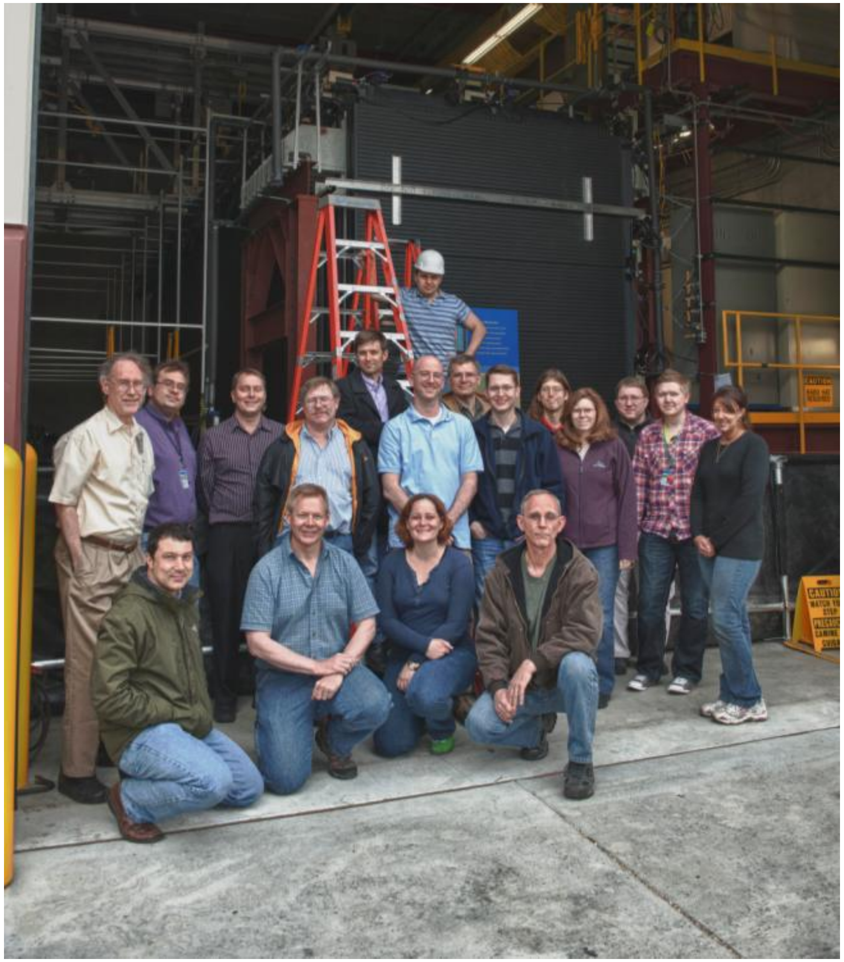


- Early look at contained events indicates NuMI MC event rate agrees with data

Conclusions

- The NOvA NDOS is taking data now and has been vital to the overall program.
- We are learning a lot about our detector as we prepare for the far and near detector construction.
- NOvA offers broad and impactful physics program that is still in early but exciting stages.

… Stay Tuned!



Additional Speakers

For more details please attend these sessions:

Detector for Neutrinos - June 11, 14:00; *Superior A*

- Sarah Phan-Budd, *NOvA PVC Extrusions*
- Alex Smith, *NOvA Module QC/QA*

Trigger and DAQ Systems - June 11, 16:00; *Mayfair*

- Susan Kasahara, *NOvA Data Acquisition Systems and Software*

Physics

$$\begin{bmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{bmatrix} = U^\dagger \begin{bmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{bmatrix}$$

- $\nu_e, \nu_\mu, \nu_\tau \leftrightarrow \nu_1, \nu_2, \nu_3$
  - Flavor States: creation and detection
  - Mass States: propagation

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -\sin\theta_{13}e^{i\delta} & 0 & \cos\theta_{13} \end{pmatrix} \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

(12) Sector: Reactor + Solar and (23) Sector: atmospheric and accelerator are observed.
(13) Sector mixing not yet observed

$$P(\nu_\alpha \rightarrow \nu_\beta) = \left| \sum_j U^*_{\beta j} e^{-i\frac{m_j^2 L}{2E}} U_{\alpha j} \right|^2$$

Oscillation probability depends on: dist. traveled (L), ν energy (E), and difference in the squared masses ($\Delta m^2_{ij} = m^2_i - m^2_j$)

Actual Neutrino Events