THE NOvA EXPERIMENT

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for the NOvA collaboration

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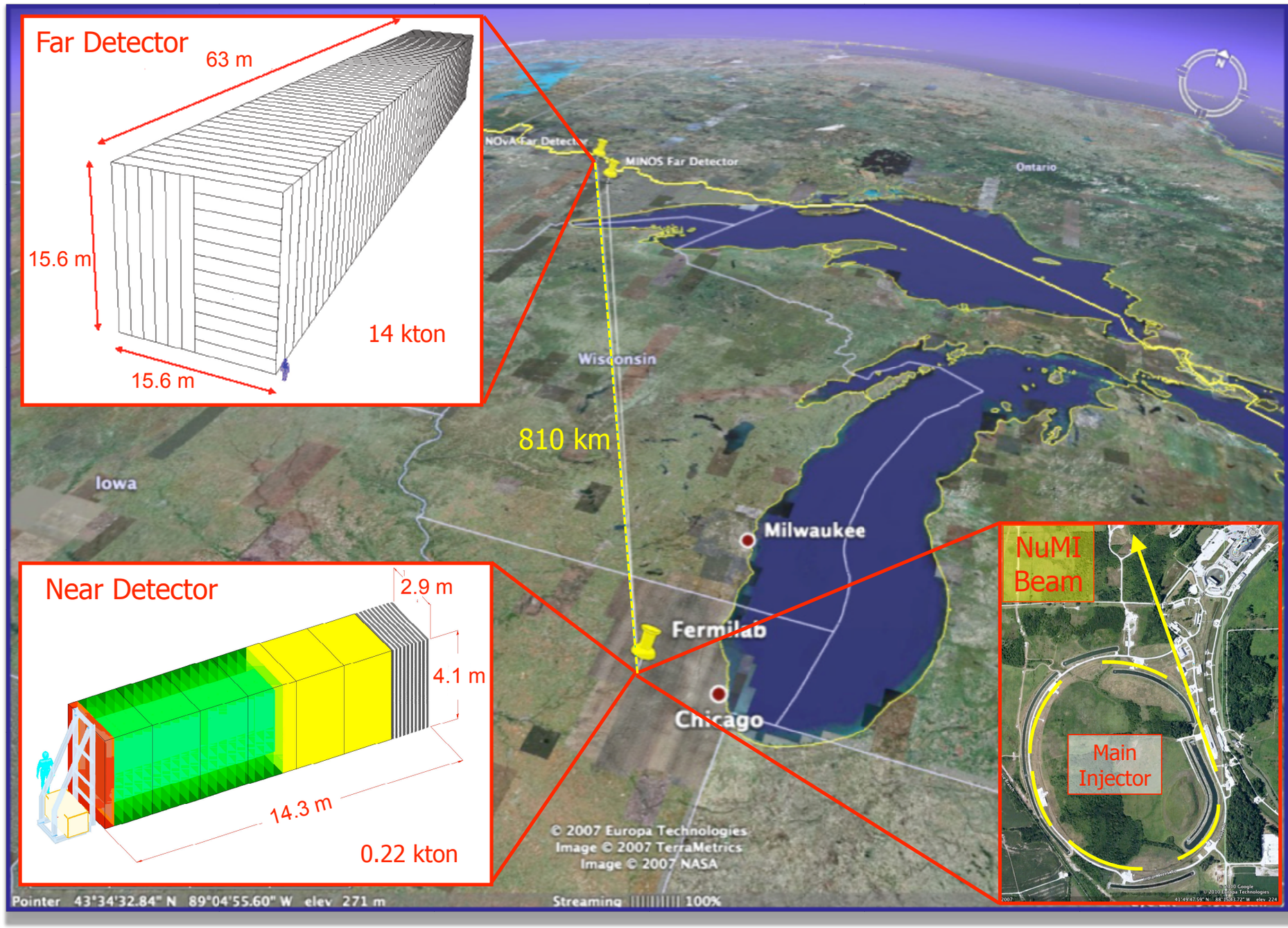
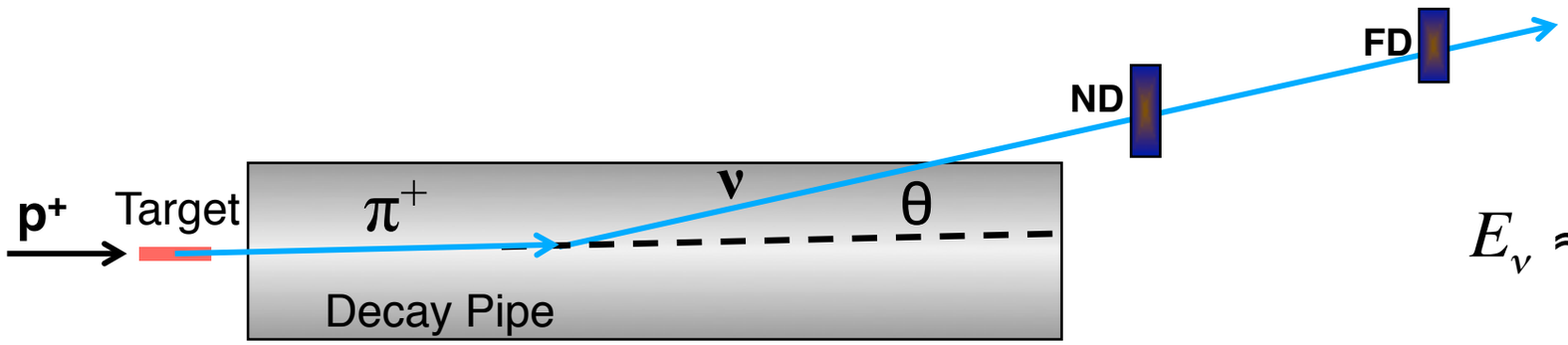
9-12 November 2011, Seoul National University

The NOvA experiment

- 810 km baseline from Fermilab to Ash River, Minnesota
- 700 kW NuMI neutrino beam
- Near and Far detectors placed 14 mrad off the NuMI beam axis
- Physics goals:
  - Search for $\nu_\mu \rightarrow \nu_e$ transitions (with both neutrinos and antineutrinos)
  - measure/limit θ_{13}
  - precision measurement of $|\Delta m^2|$, θ_{23}
  - Determine mass hierarchy
  - Constrain CP violating phase

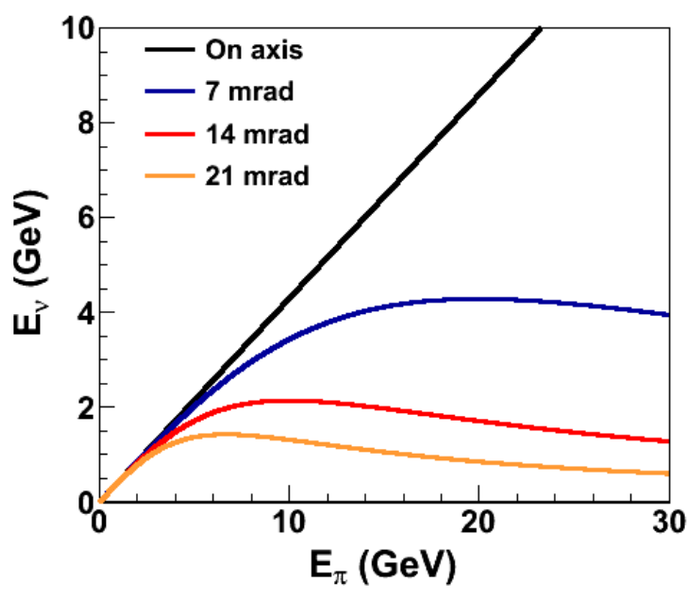


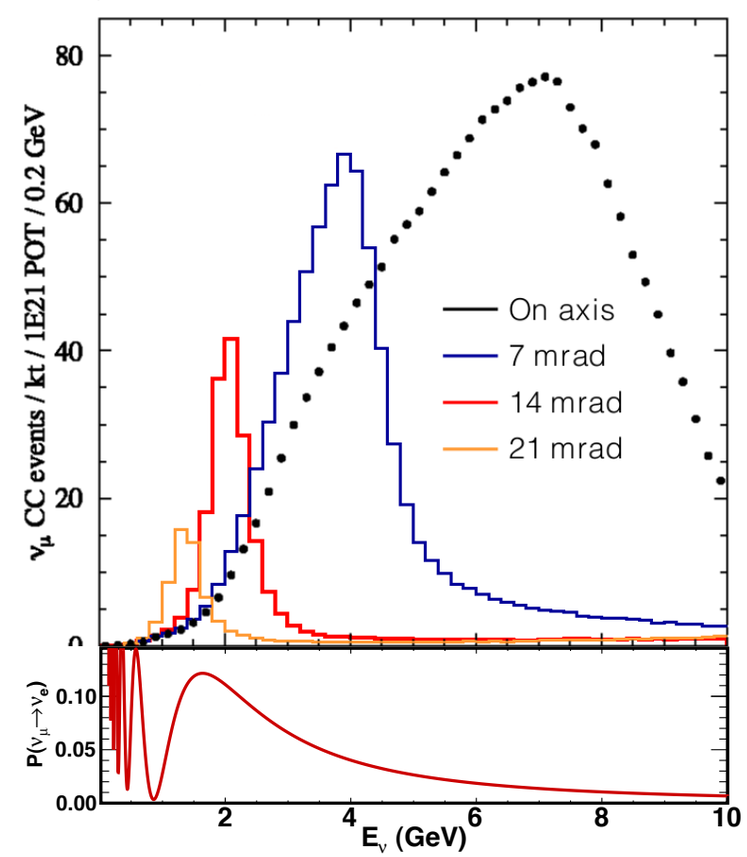
Off-axis Beam



$$E_\nu \approx 0.43 \frac{E_\pi}{1+\gamma^2\theta_\nu^2}$$

- Medium Energy NuMI configuration most favorable to look for $\nu_\mu \rightarrow \nu_e$ oscillations over 810 km baseline
- At 14 mrad off-axis, narrow band beam peaked at E_ν=2GeV
  - Near oscillation maximum
  - Removes high energy NC background events

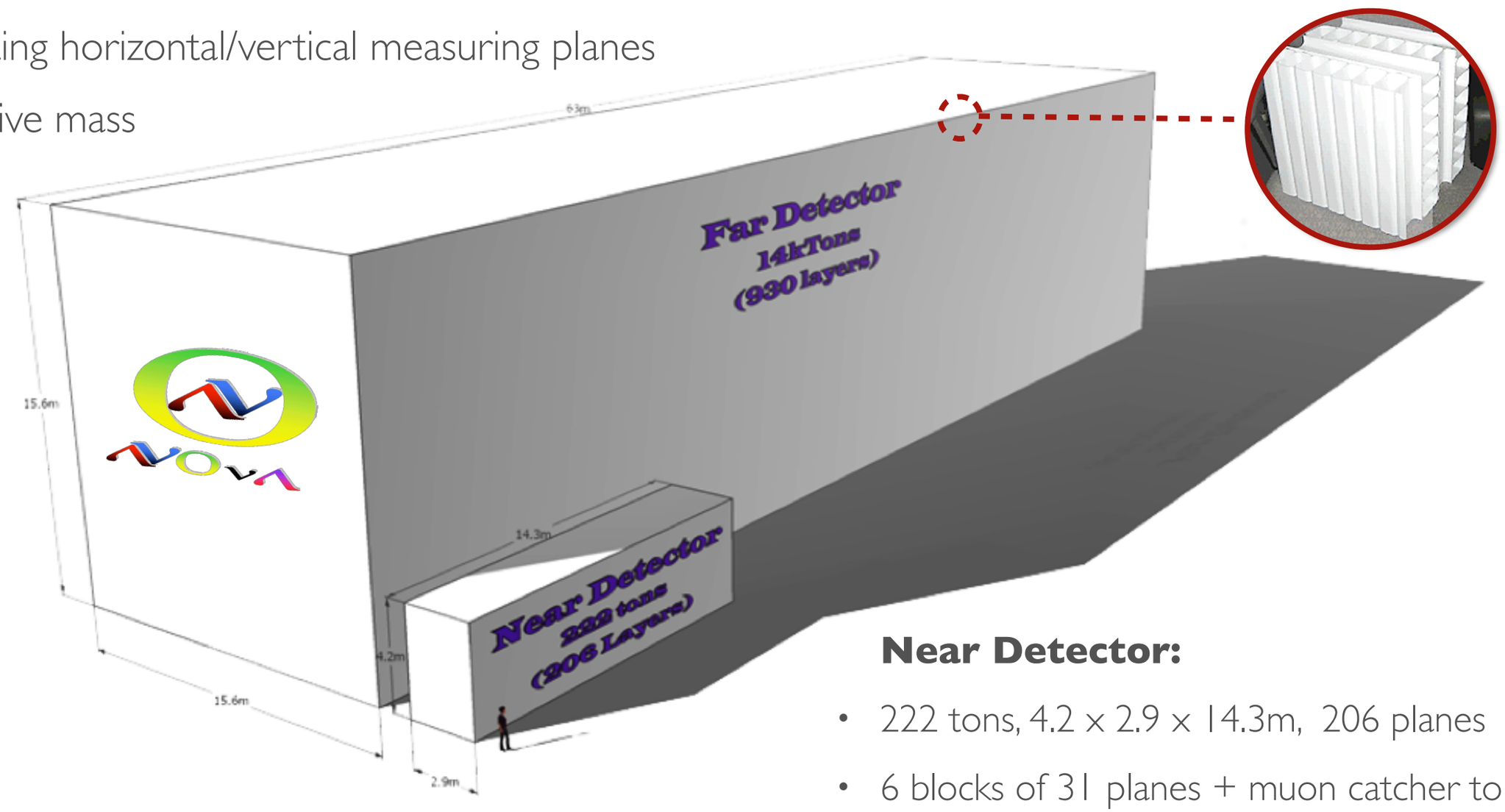




NOvA Detectors

Far Detector:

- 15 ktons, 15.6 x 15.6 x 67m, 930 planes arranged in 30 blocks of 31 planes for assembly
- Alternating horizontal/vertical measuring planes
- 65% active mass

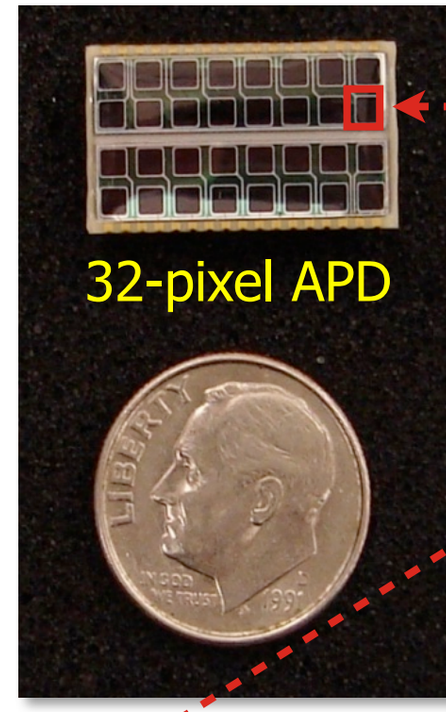


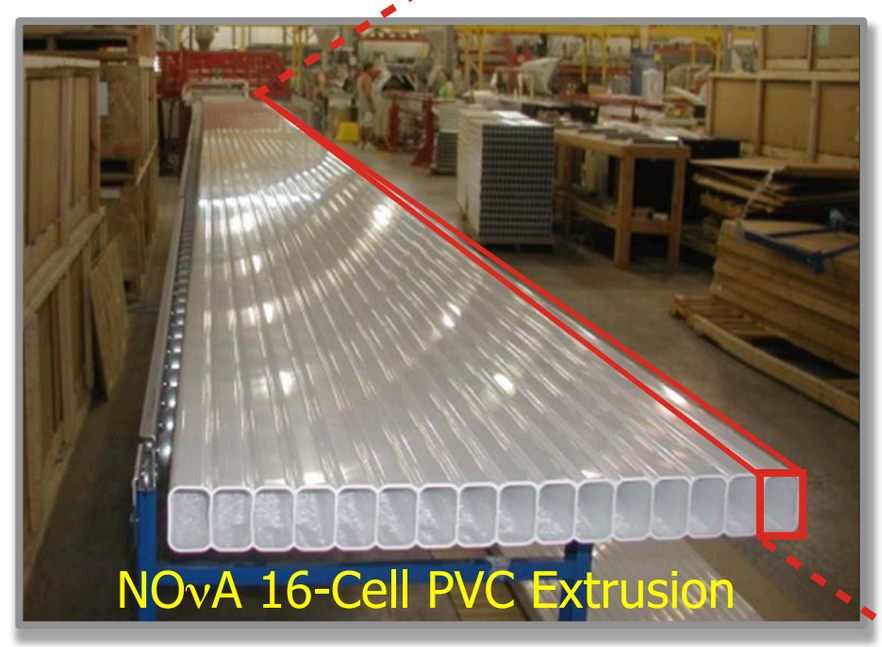
Near Detector:

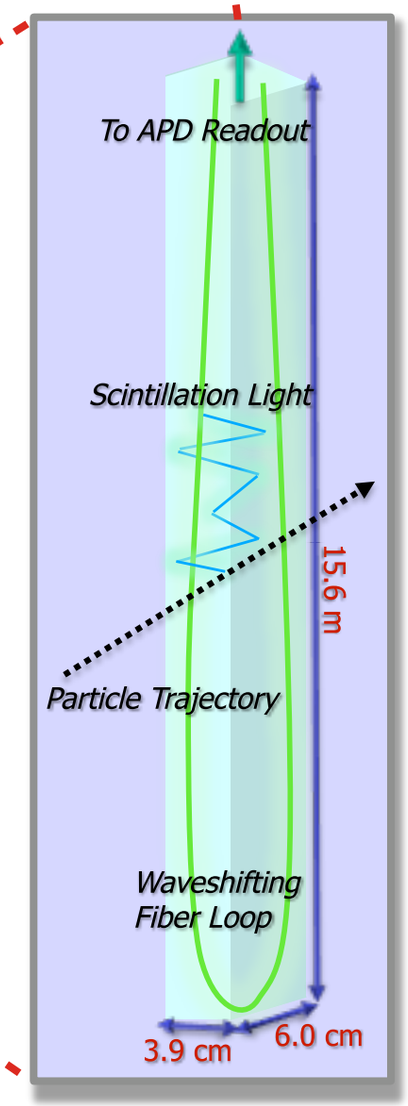
- 222 tons, 4.2 x 2.9 x 14.3m, 206 planes
- 6 blocks of 31 planes + muon catcher to range out muons
- To be placed 14 mrad off-axis next to MINOS ND

Detector Technology

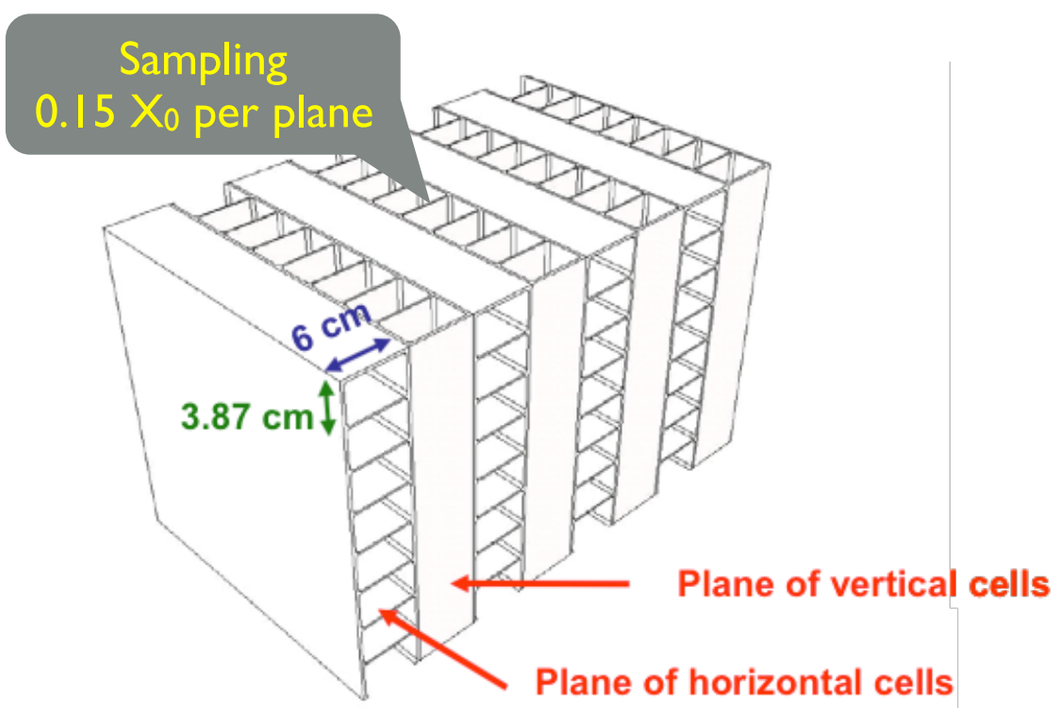
- Near and Far detectors composed of highly reflective 16-cell PVC extrusions (15% TiO_2)
  - Two extrusions glued together into 32-cell module
  - 24 extrusions/plane in Far detector (384 cells/plane)
  - 357'120 cells in Far Detector
- Extrusions filled with liquid scintillator (mineral oil + 5% pseudocumene)
- Each cell read out by a wavelength-shifting fiber into one pixel of a 32-pixel avalanche photodiode (APD)
  - 30-38 p.e. from far-end of cell into APD





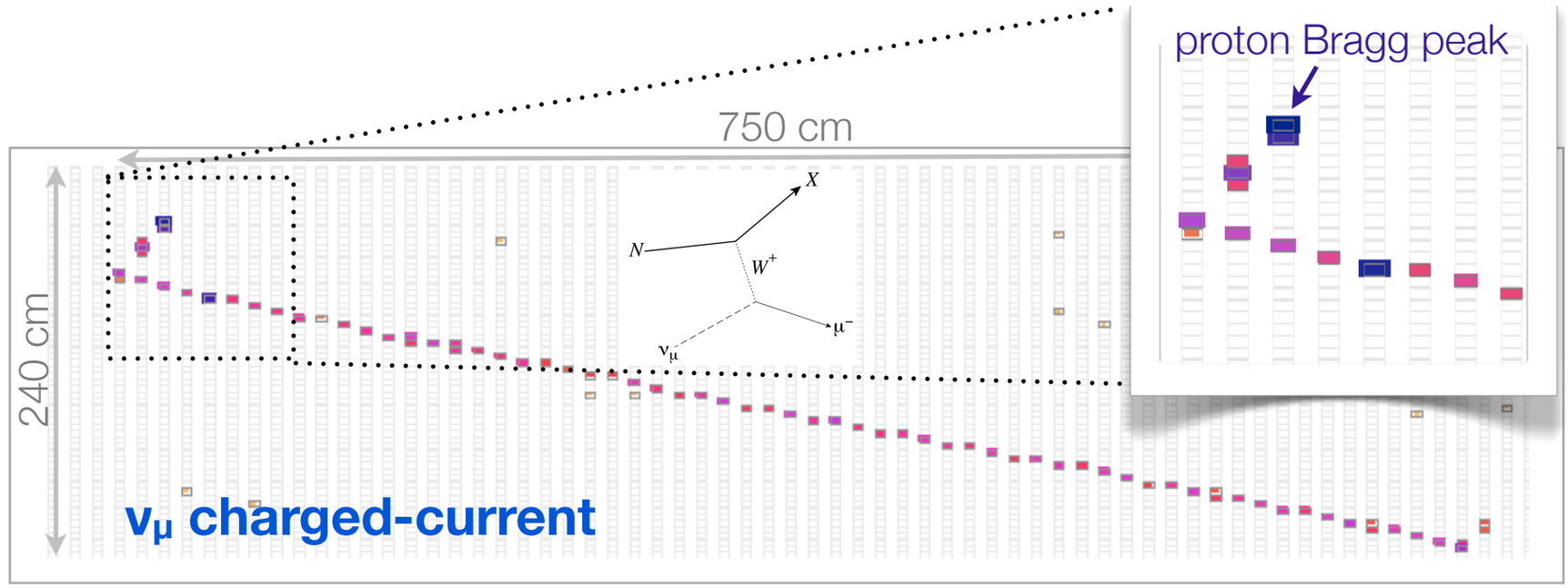


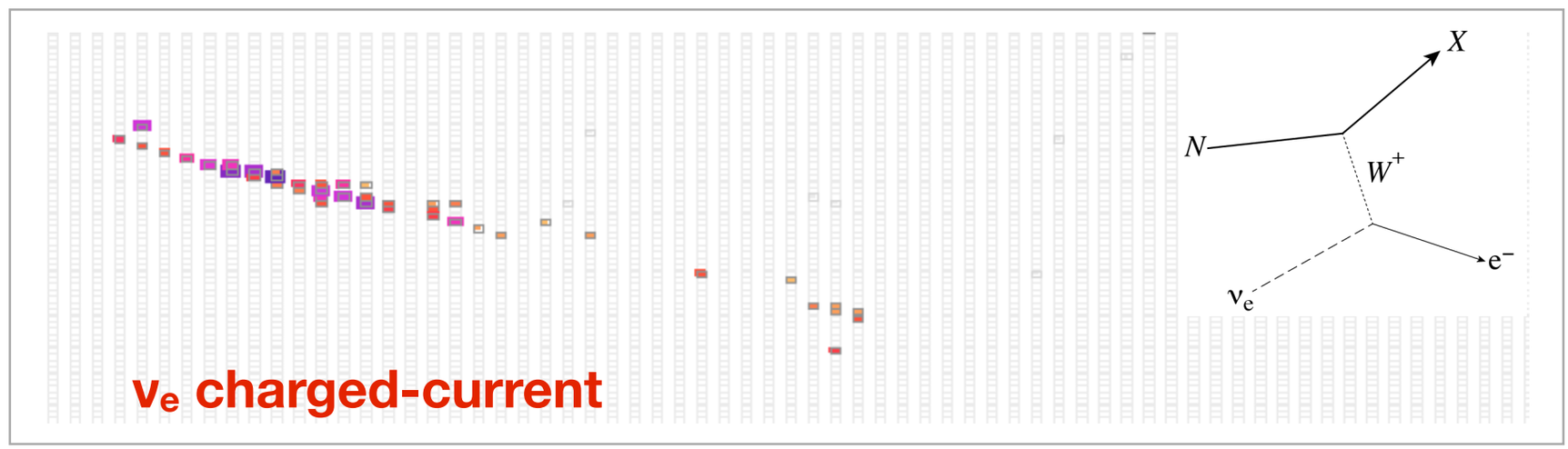
Scintillator cell with looped WLS fiber

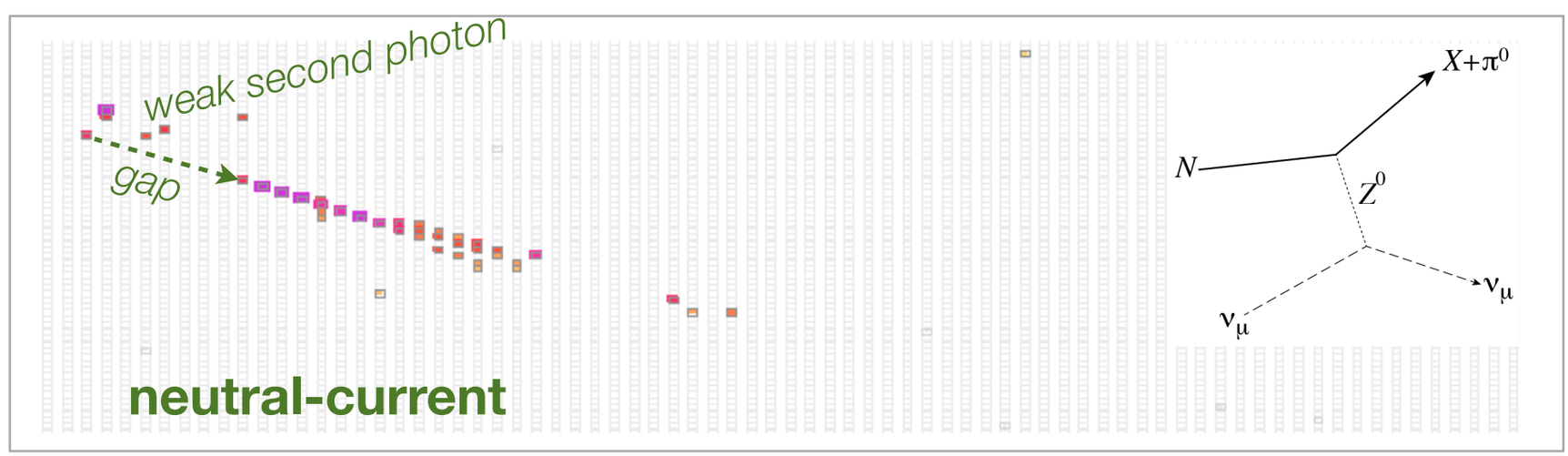


MC Events

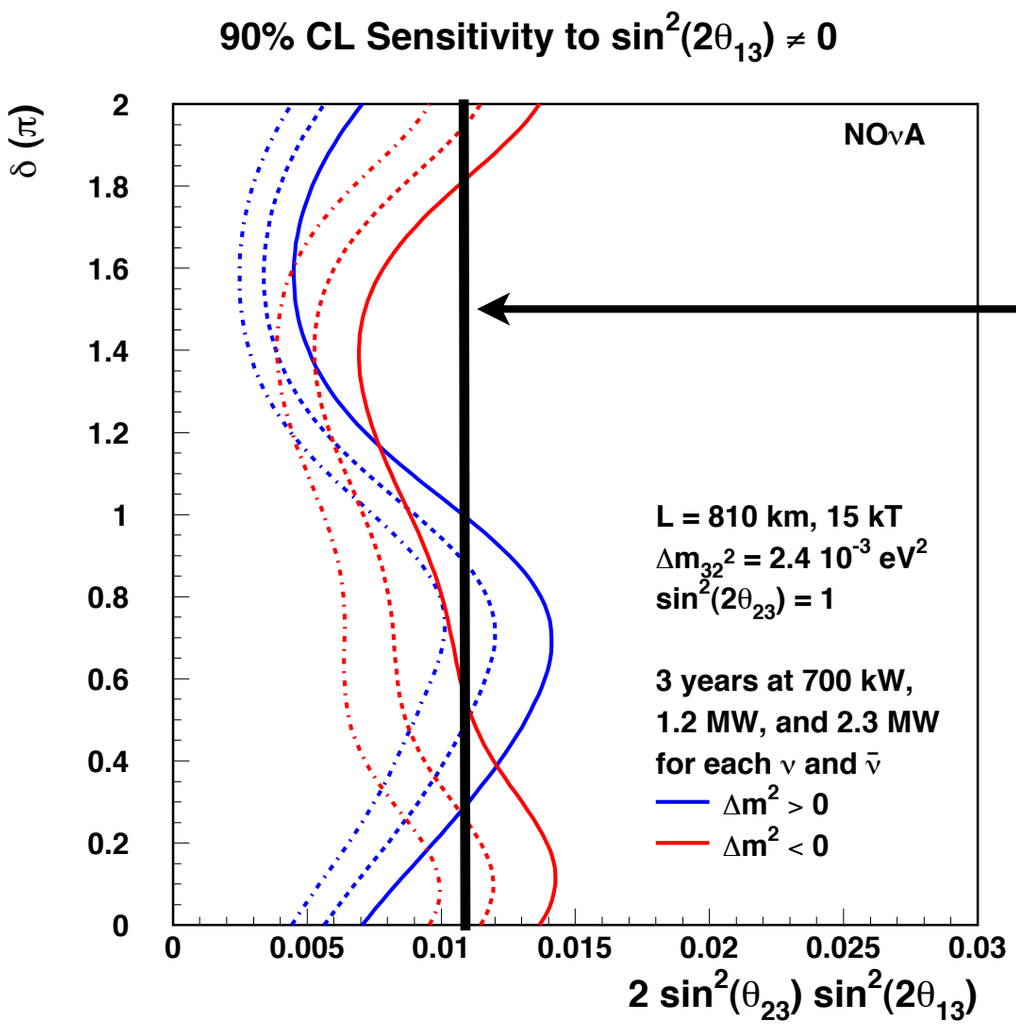
- Topologies of basic interaction channels simulated in the NOvA detectors
- Each "pixel" is a single 4 cm x 6 cm x 15 m cell of liquid scintillator
- Need >1000:1 rejection against background
- Detector challenge: Achieve large target mass (10's+ kilotons) while maintaining high granularity to avoid confusing the detection channels
- NOvA achieves 35% efficiency for ν_e CC while limiting NC→ν_e CC fake rate to 0.1%

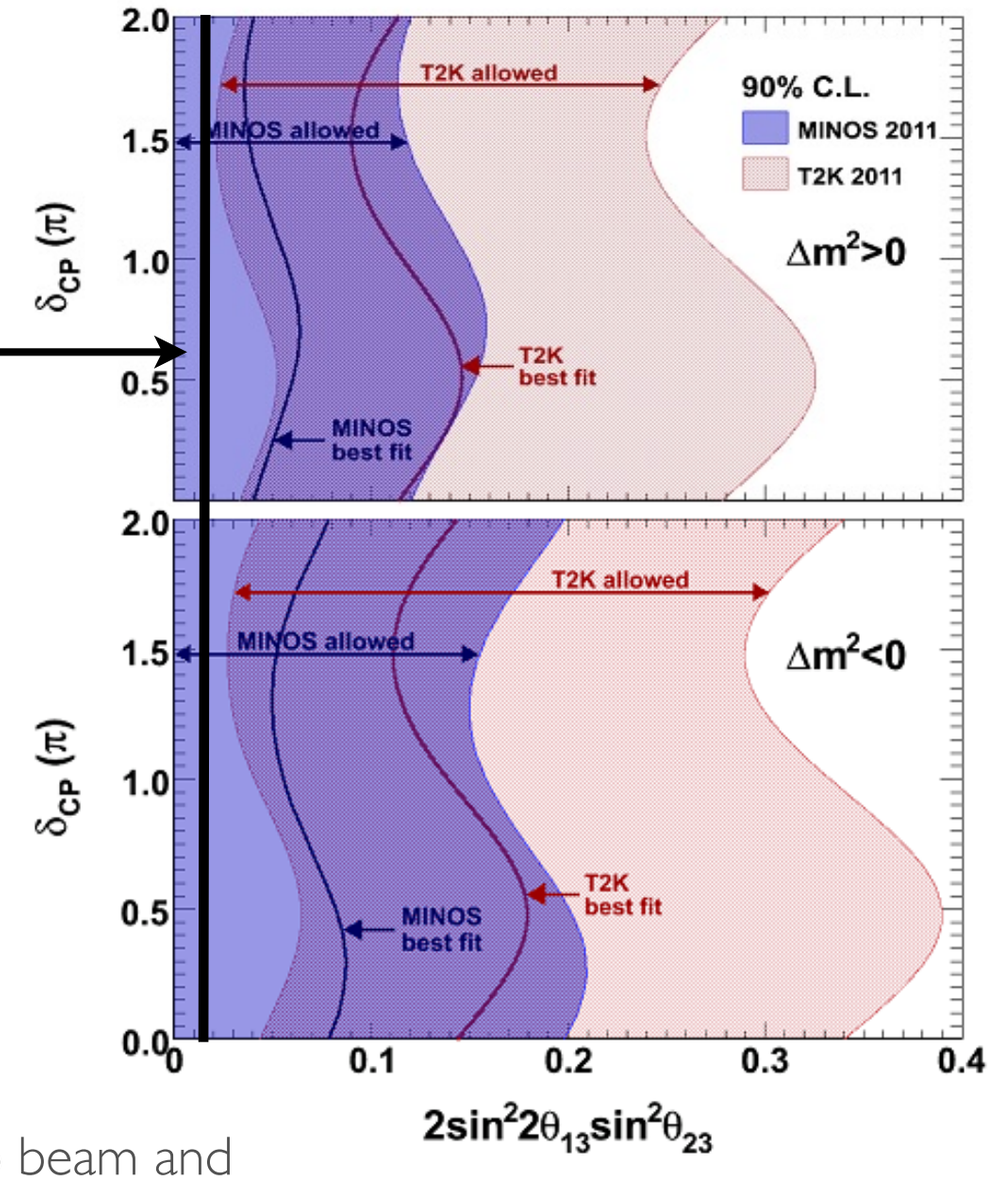






Sensitivity to θ_{13}

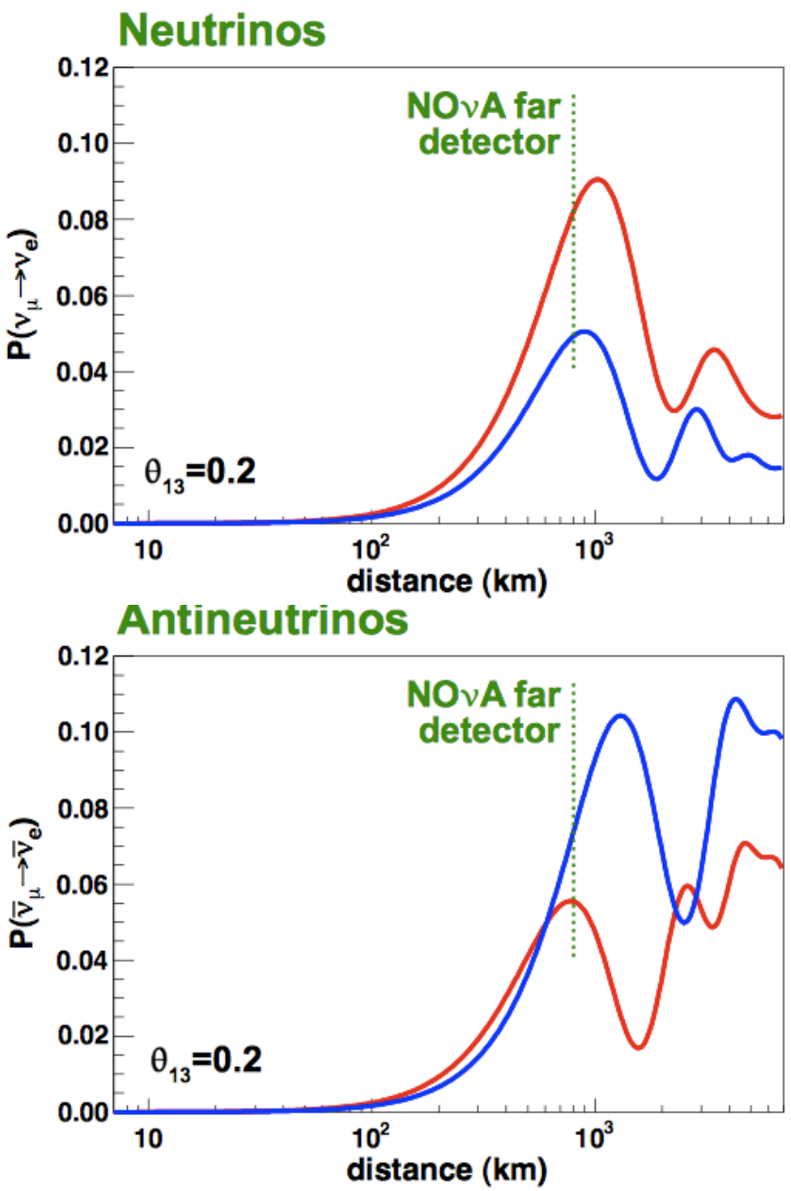


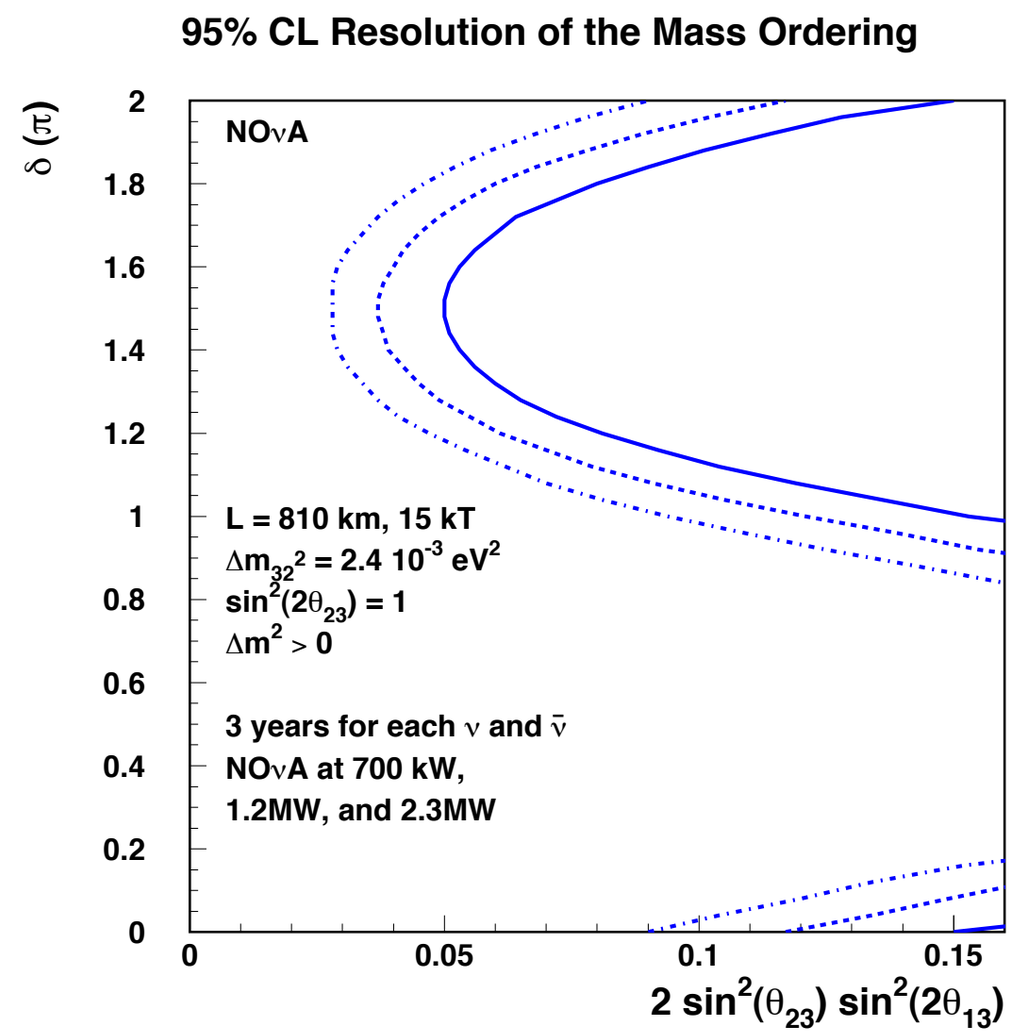


- Sensitivity to $\sin^2(\theta_{13})$ after 3 years each of neutrino beam and antineutrino beam (18×10^{20} POT each)
- NOvA's sensitivity to θ_{13} is one order of magnitude better than the limit from CHOOZ ($\sin^2 2\theta_{13} < 0.15$, 90% CL)

PRL 107, 181802 (MINOS)
PRL 107, 041801 (T2K)

Mass Hierarchy



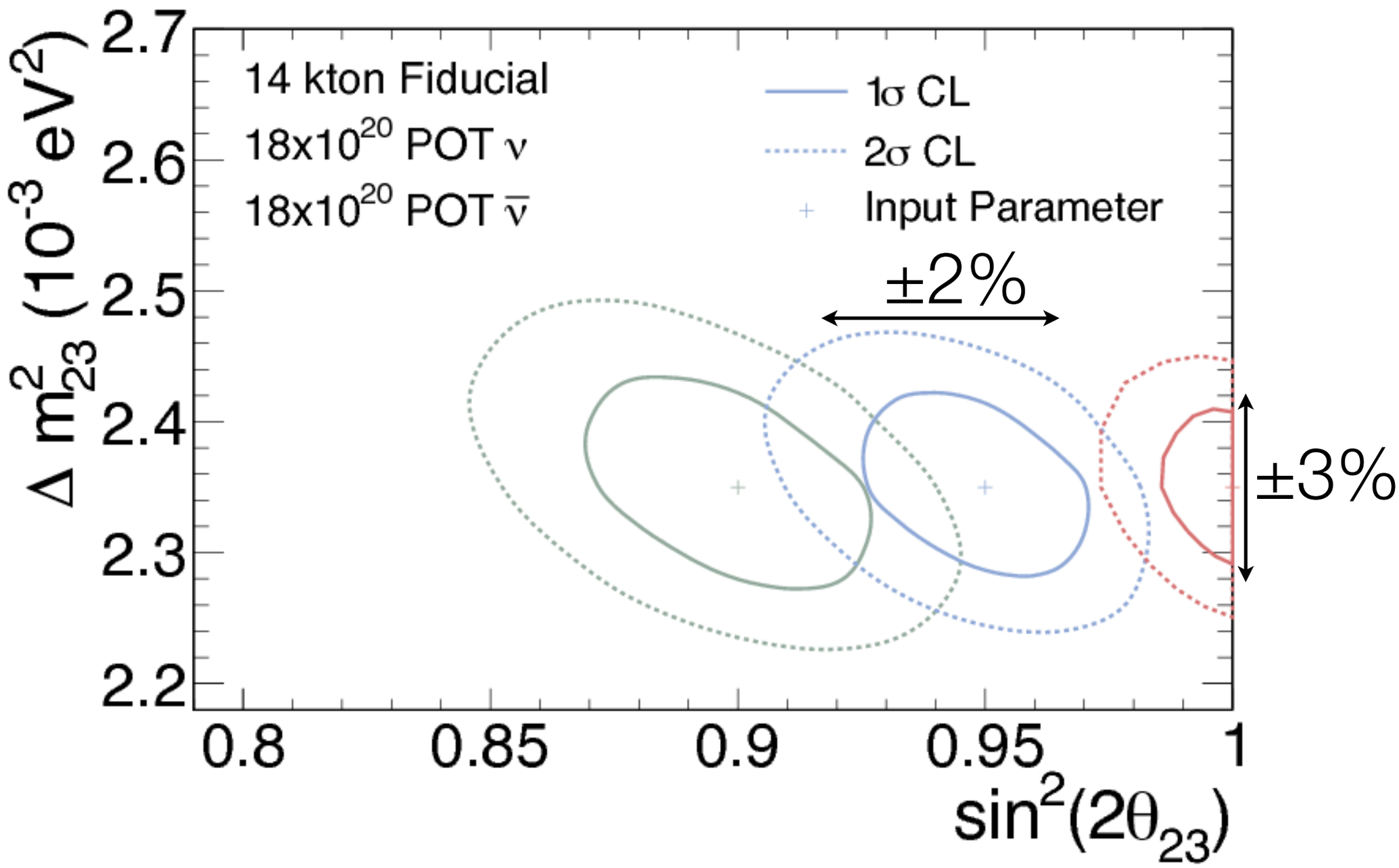


- NOvA plans to run for 3 years in neutrino and 3 years in antineutrino mode
- Take advantage of large matter effects => 30% enhancement/suppression of $\nu_\mu \to \nu_e$ / $\bar{\nu}_\mu \to \bar{\nu}_e$ probability (11% in T2K)

- NOvA is able to resolve ordering of neutrino mass hierarchy for large enough values of $\sin^2 2\theta_{13}$
- 95% CL resolution of mass hierarchy for values of $\sin^2 2\theta_{13}$ to the right of the curves

θ_{23} and Δm^2_{32} Measurements

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

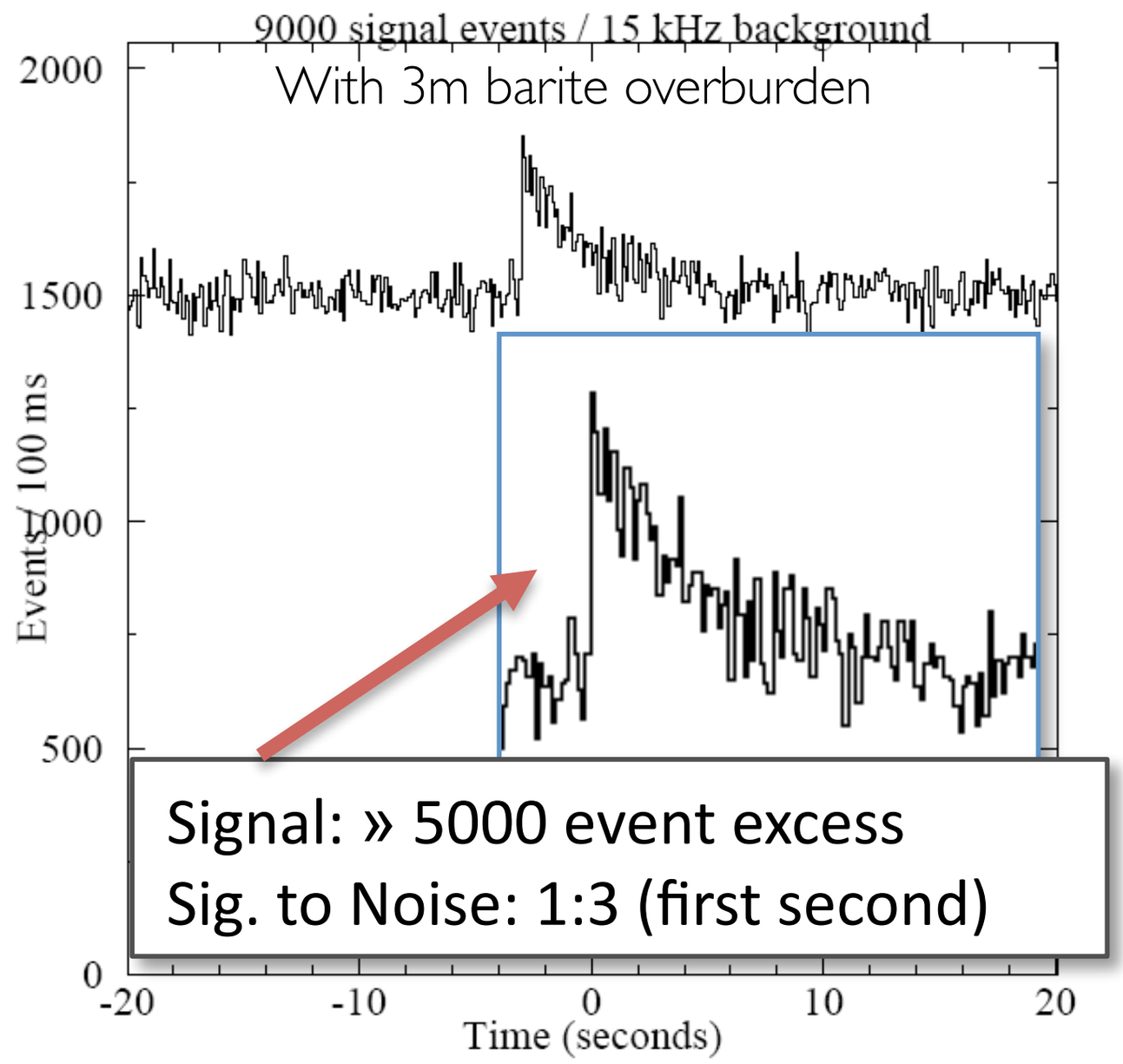


Supernova Signal

- Primary supernova signal:

$$\bar{\nu}_{\mathrm{e}} + p \rightarrow e^{+} + n$$

- For a supernova at 10kpc the total signal is expected to contain:
  - 5000 total interactions over a time span of ~10s
  - Half the interactions in the first second
  - Energy peaks at 20MeV and falls off to ~60MeV
- Challenge is triggering in real time
  - Need data driven open triggering
  - Long event buffering (~30sec)



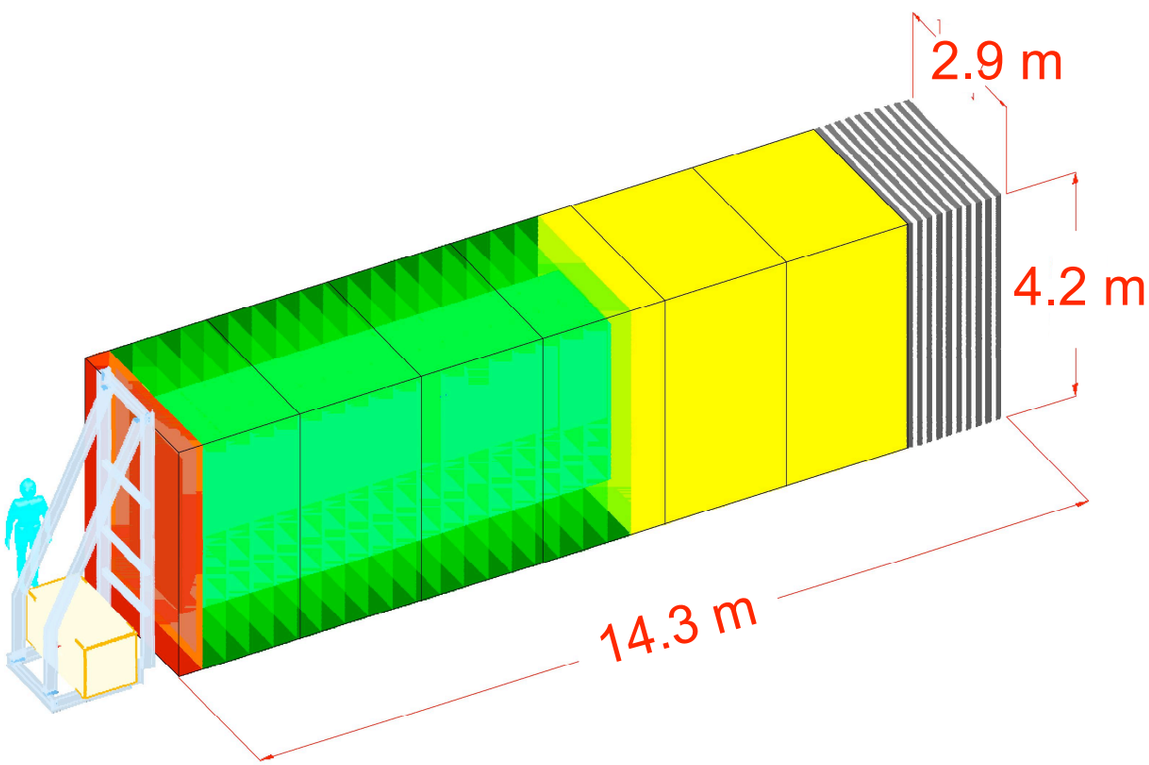
Project Timeline

- Beam
  - March 2012 Accelerator shutdown to install upgrade for 700kw beam
  - Horn1 and target design complete
  - Kicker for Booster-Recycler in use
  - First recycler injector magnet installed
- FD
  - Jan 2012 Start construction
  - 1 block ready by August 2012
  - 50% detector ready by end of shutdown
  - complete by early 2014
- ND
  - Cavern excavation during shutdown
  - Prototype now in operation at FNAL on surface

Far detector laboratory entrance

NDOS

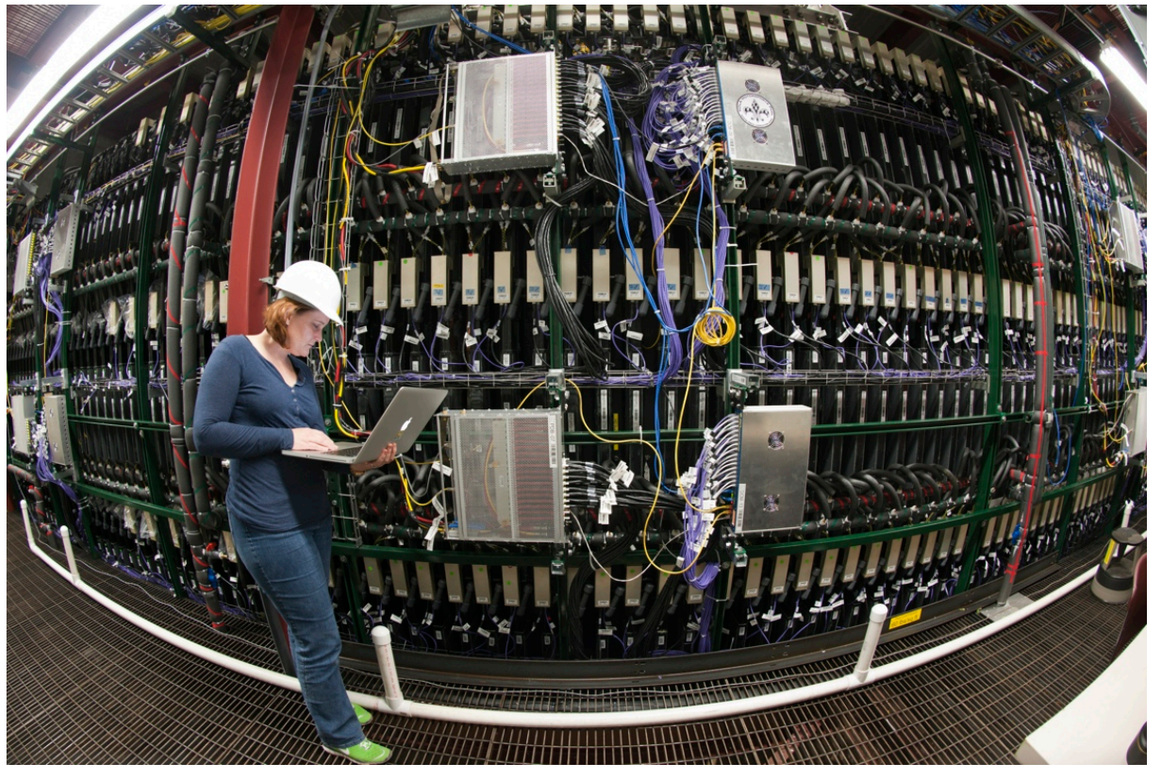
- Designed to prototype all detector systems prior to installation at Ash River as a full end-to-end test of systems integration and installation
- Muon Catcher: PVC + scintillator planes interleaved with iron plates
- Installation completed May 9, 2011.
- Commissioning and data collection ongoing 11/2010 - present



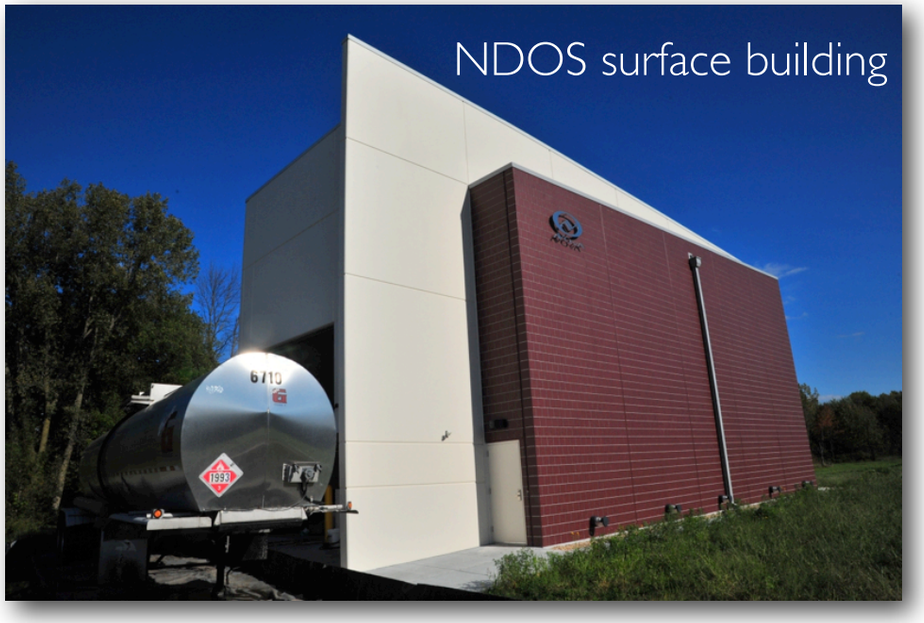
NDOS

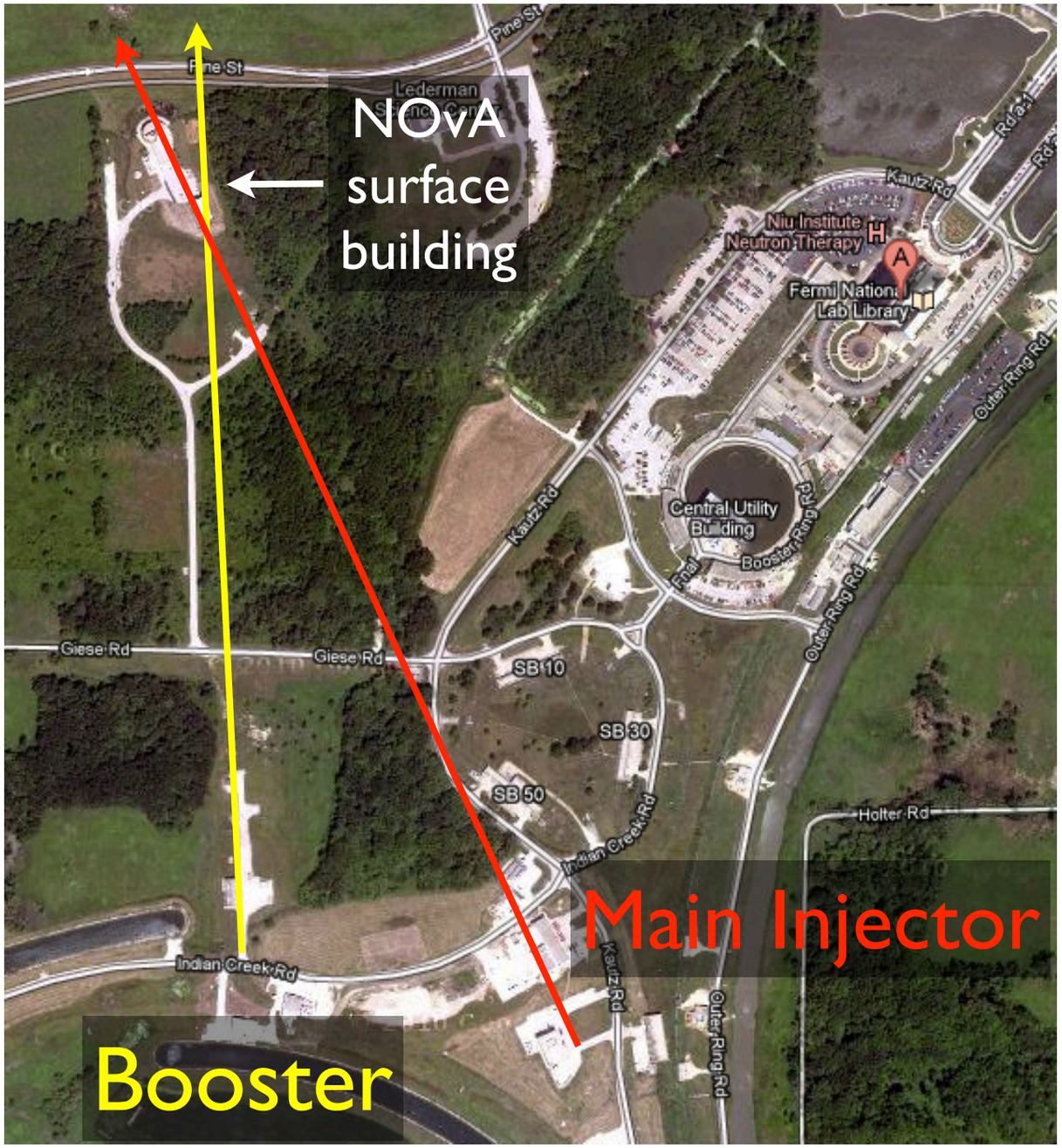
RUN GOALS

- Testing
  - Test detector design and installation procedures
  - Exercise calibration scheme
  - Benchmark MC
  - Demonstrate electron neutrino selection, background suppression
  - Verify cosmic background suppression
- Physics
  - Study nuclear hadronization models
  - Quasi-elastic cross section at 2 GeV
  - Constrain neutrino flux
  - Booster short-baseline oscillations



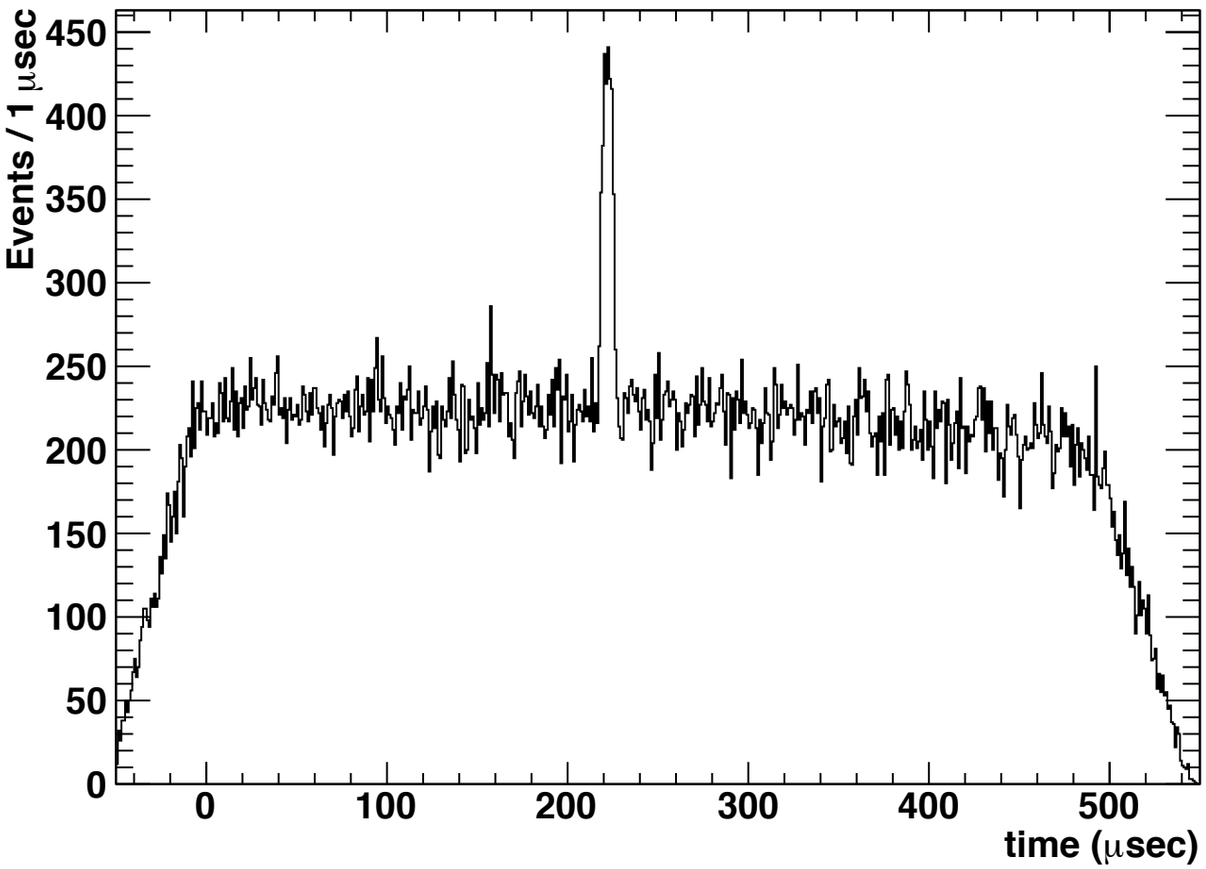
NDOS Location

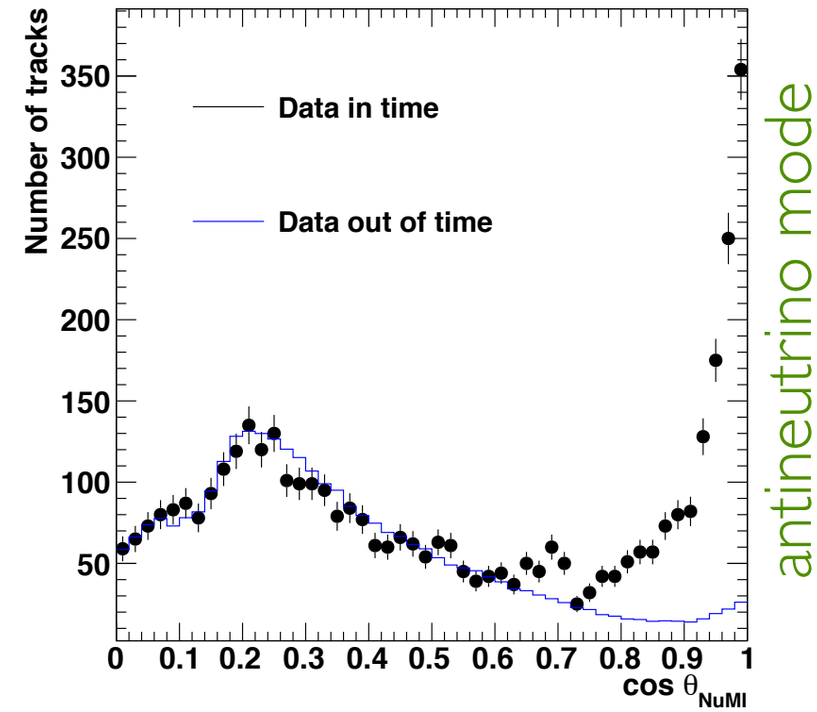


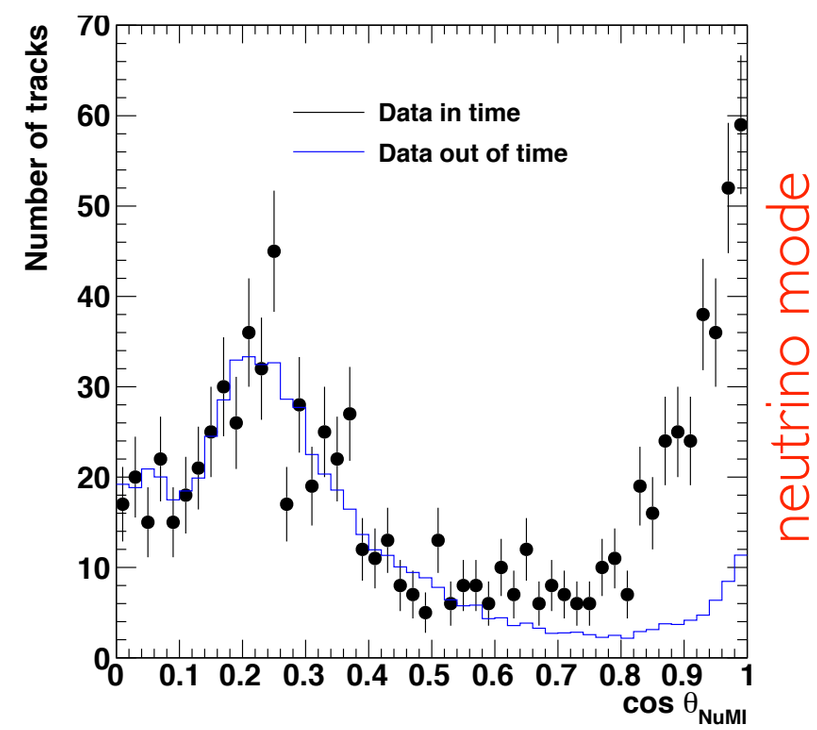


- Located in two neutrino beams providing an early look at data and a chance to tune up DAQ, calibration, reconstruction, and analysis prior to first data from Ash River
- NDOS is located directly above the NuMI neutrino beam line and is oriented parallel to the NuMI beamline. It sees neutrinos at an off-axis angle of 110 mrad.
- NDOS is located on the Booster Neutrino Beam (BNB) line, but the detector axis is rotated 23° with respect to the BNB beamline

Finding NuMI Neutrinos

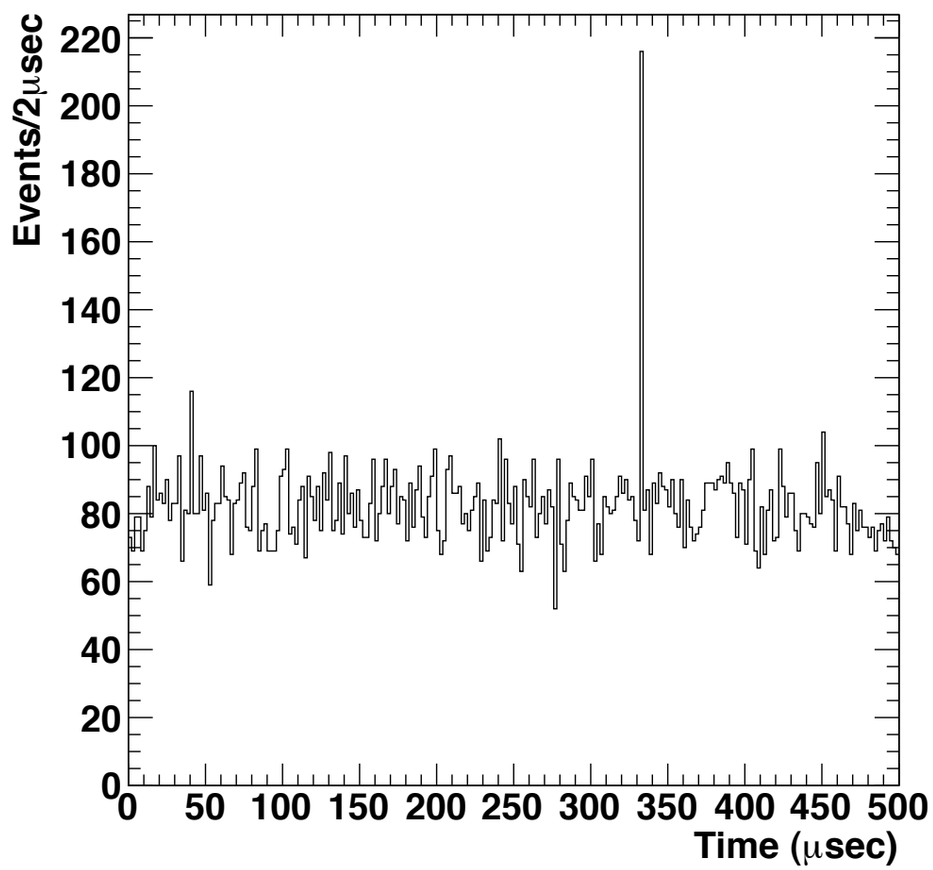


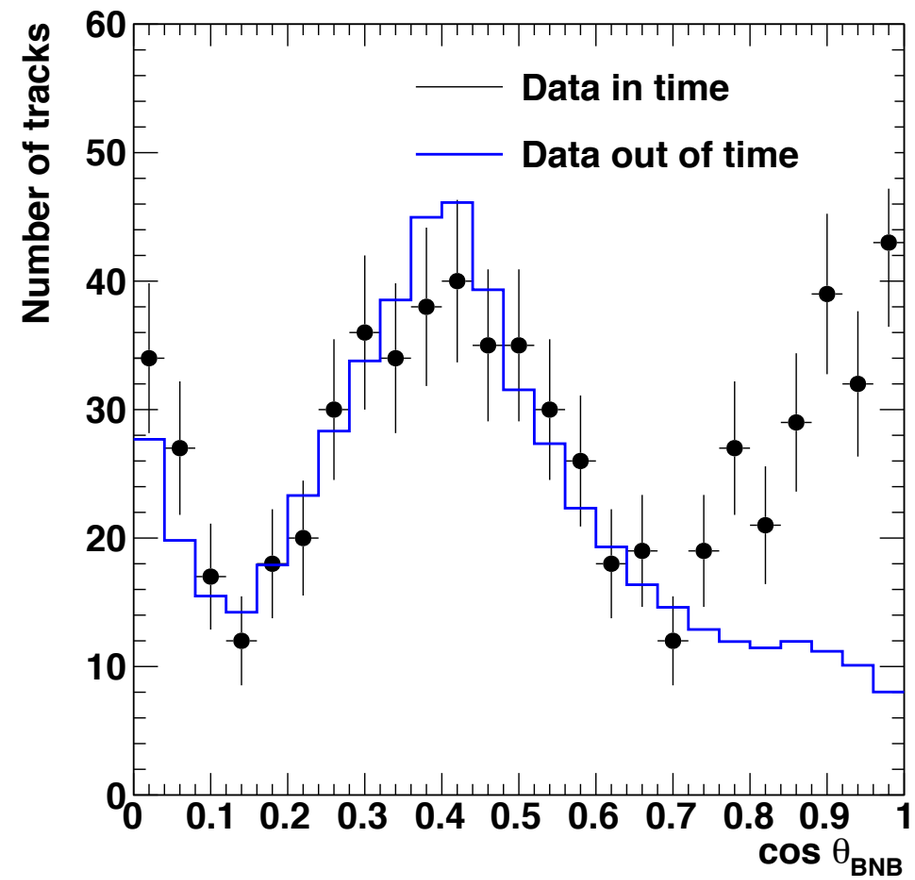




- 110 mrad off NuMI axis
- 5.6×10^{19} POT in antineutrino mode, recorded 1001 events (69 cosmic background)
- 8.4×10^{18} POT in neutrino mode, recorded 253 events (39 cosmic background)

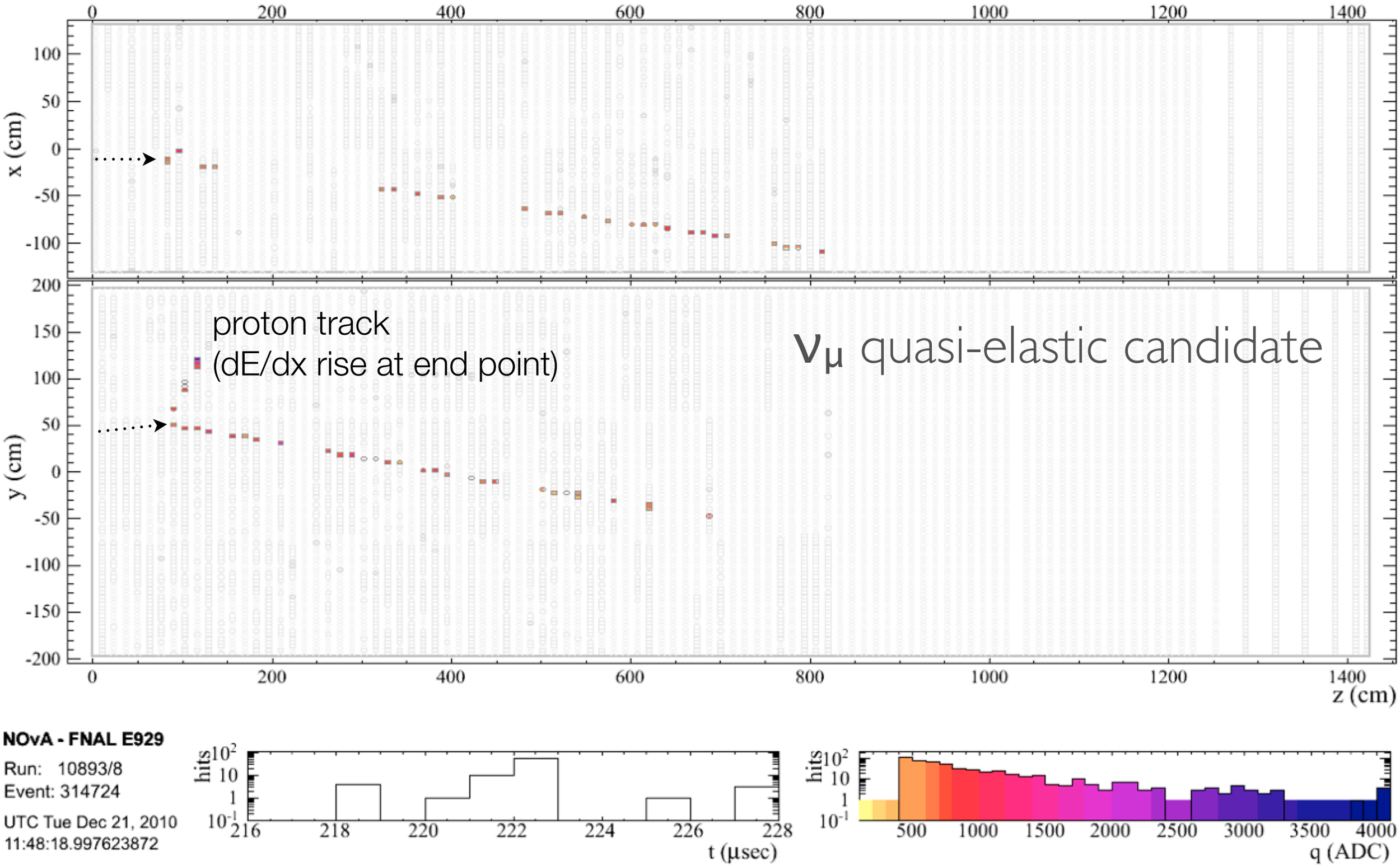
Finding Booster Neutrinos



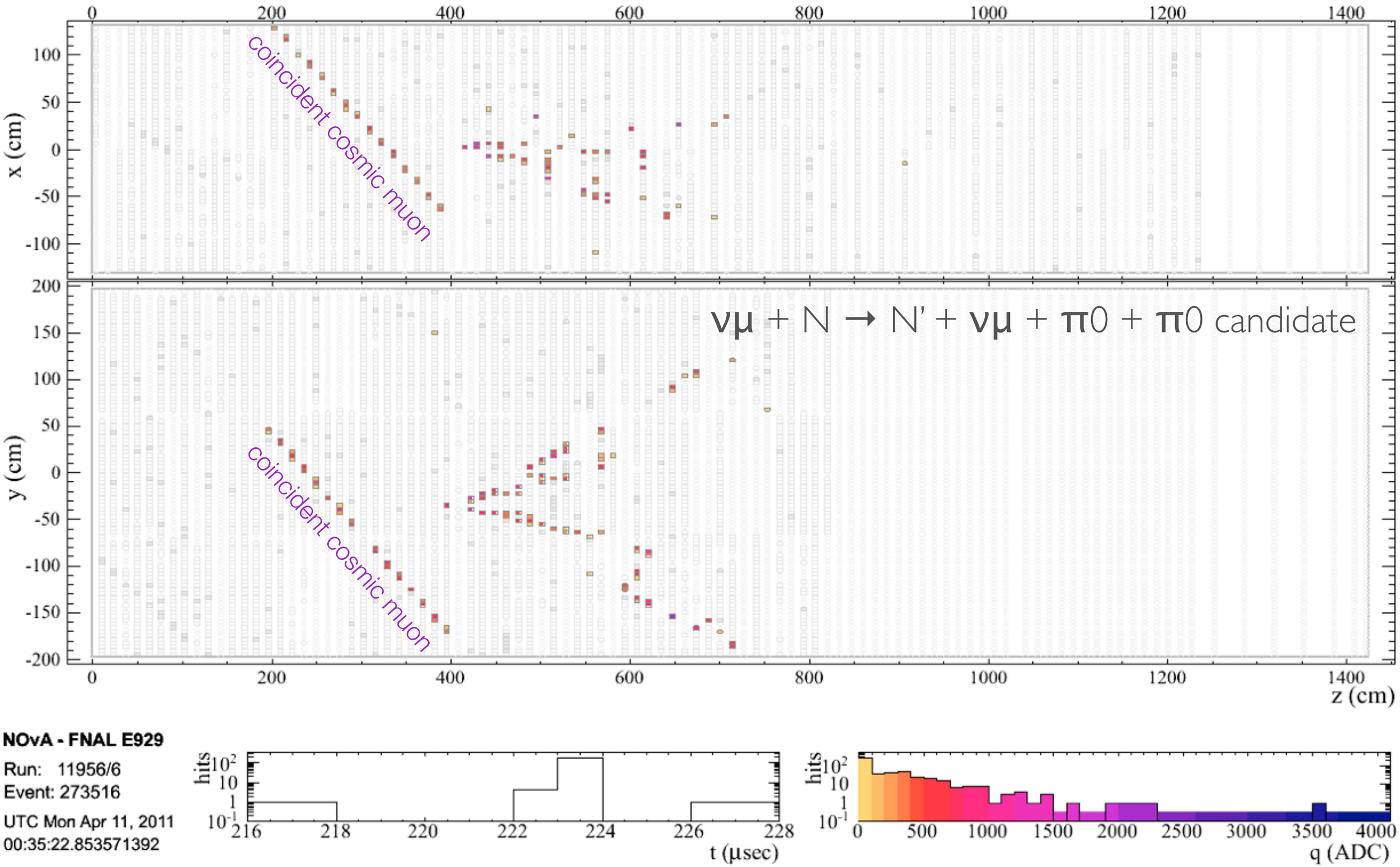


- NDOS nearly on Booster axis
- Recorded 2.7×10^{19} protons on target. Events recorded between 12/24/2010 and 5/22/2011
- 222 events on a background of 92 cosmic ray events.
  5 ν's / 10^{18} POT

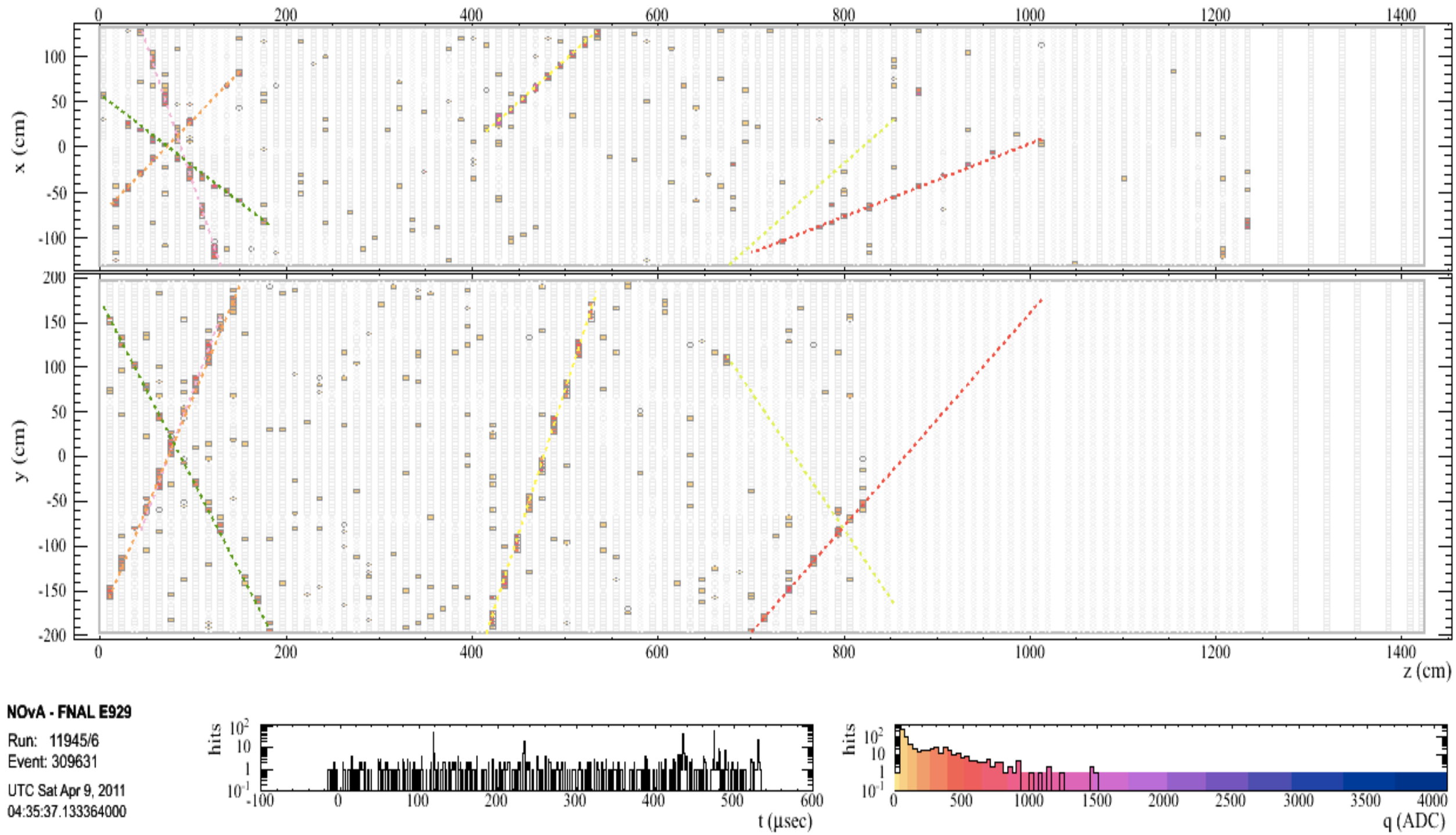
NOvA NDOS NuMI Data



NOvA NDOS NuMI Data

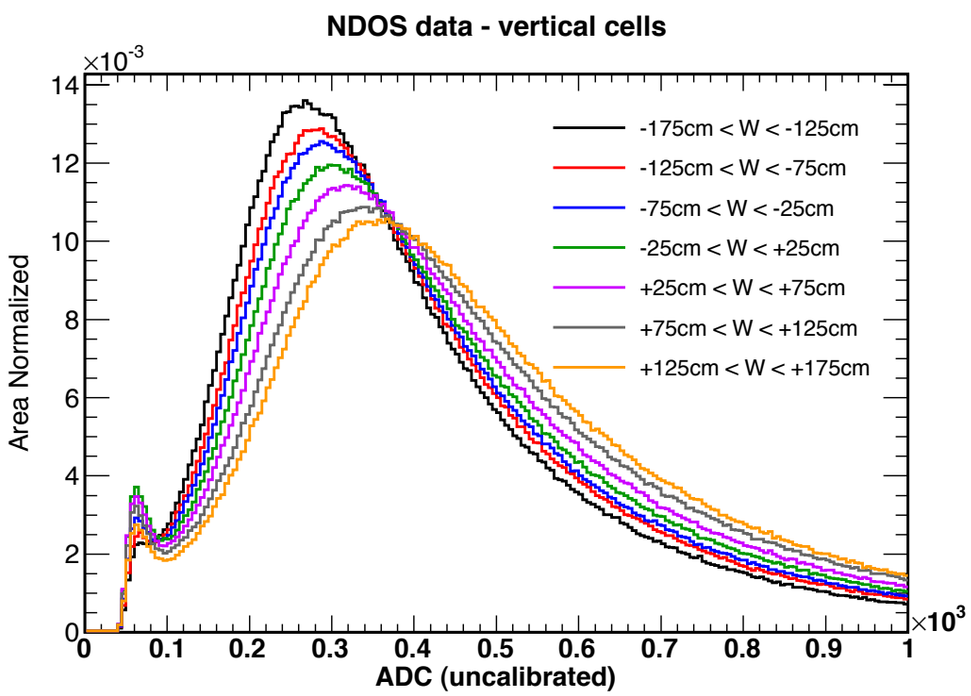


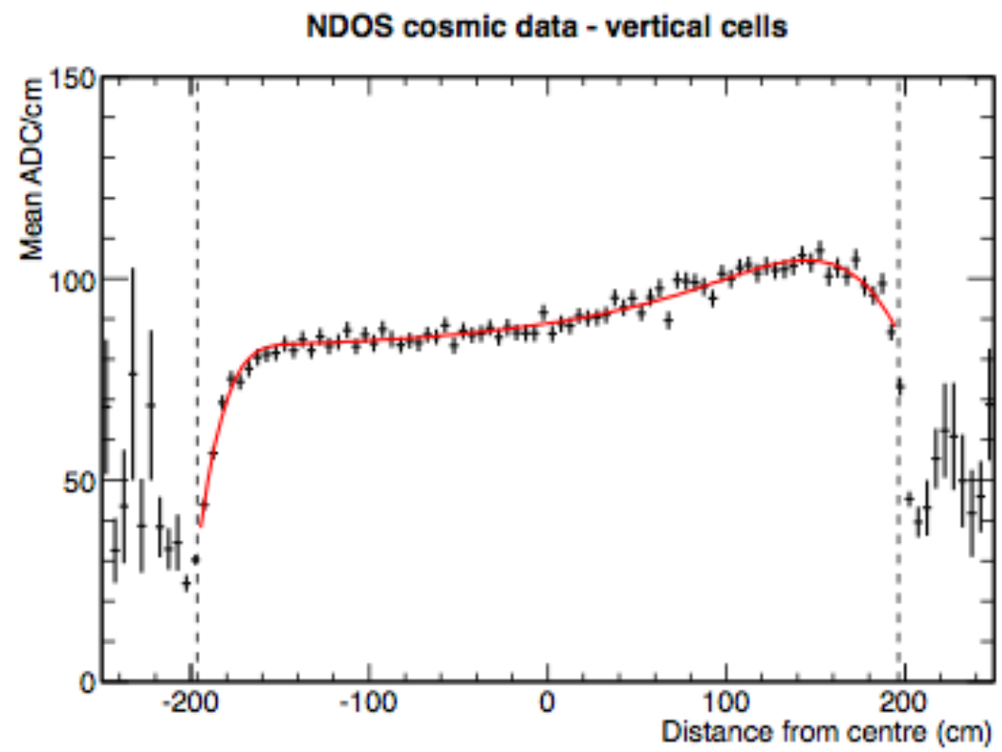
Cosmic Rays in NDOS

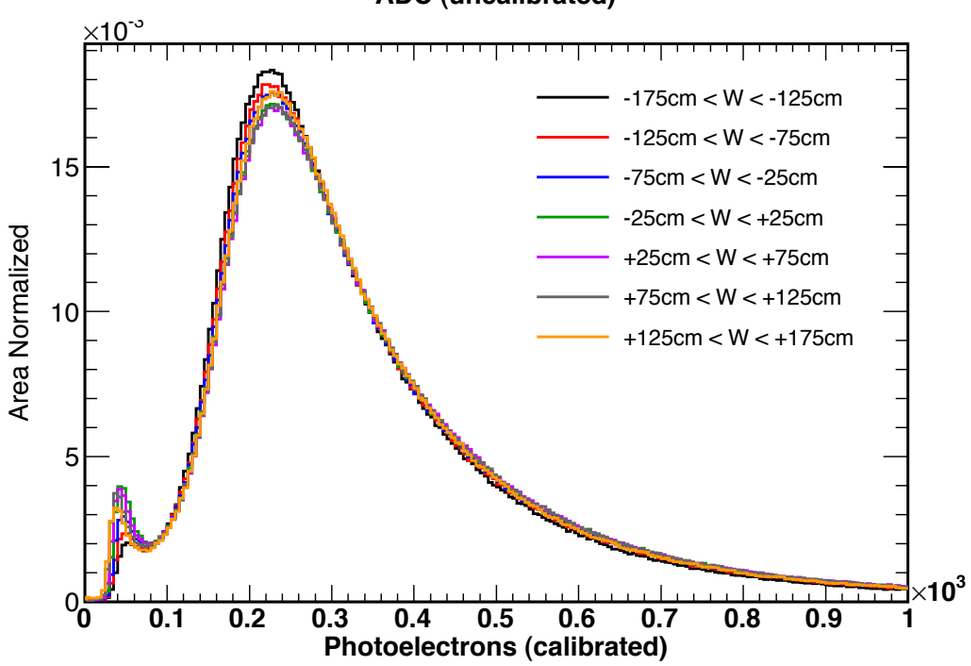


Calibration

- Cosmic muons provide intra detector calibration source



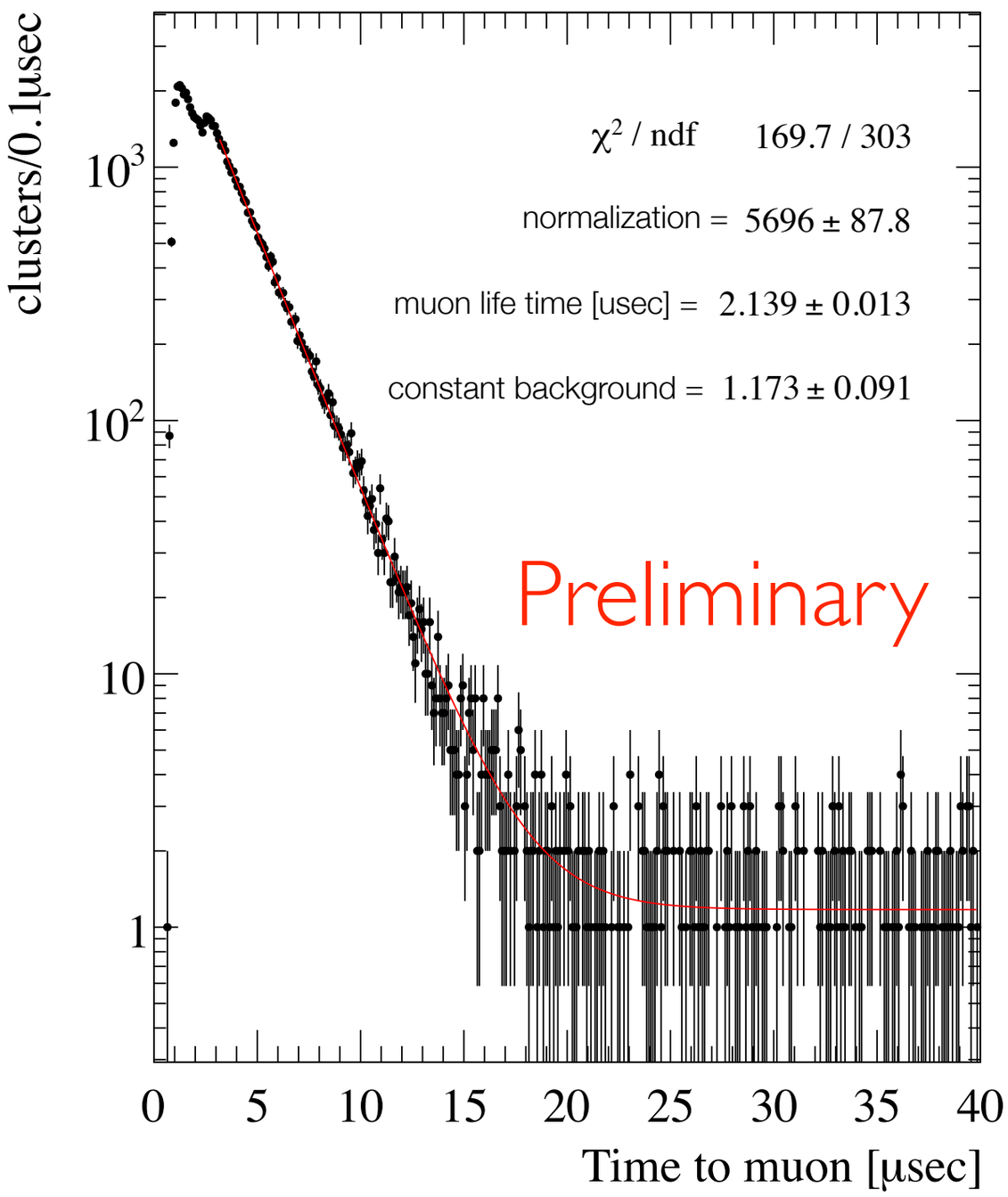


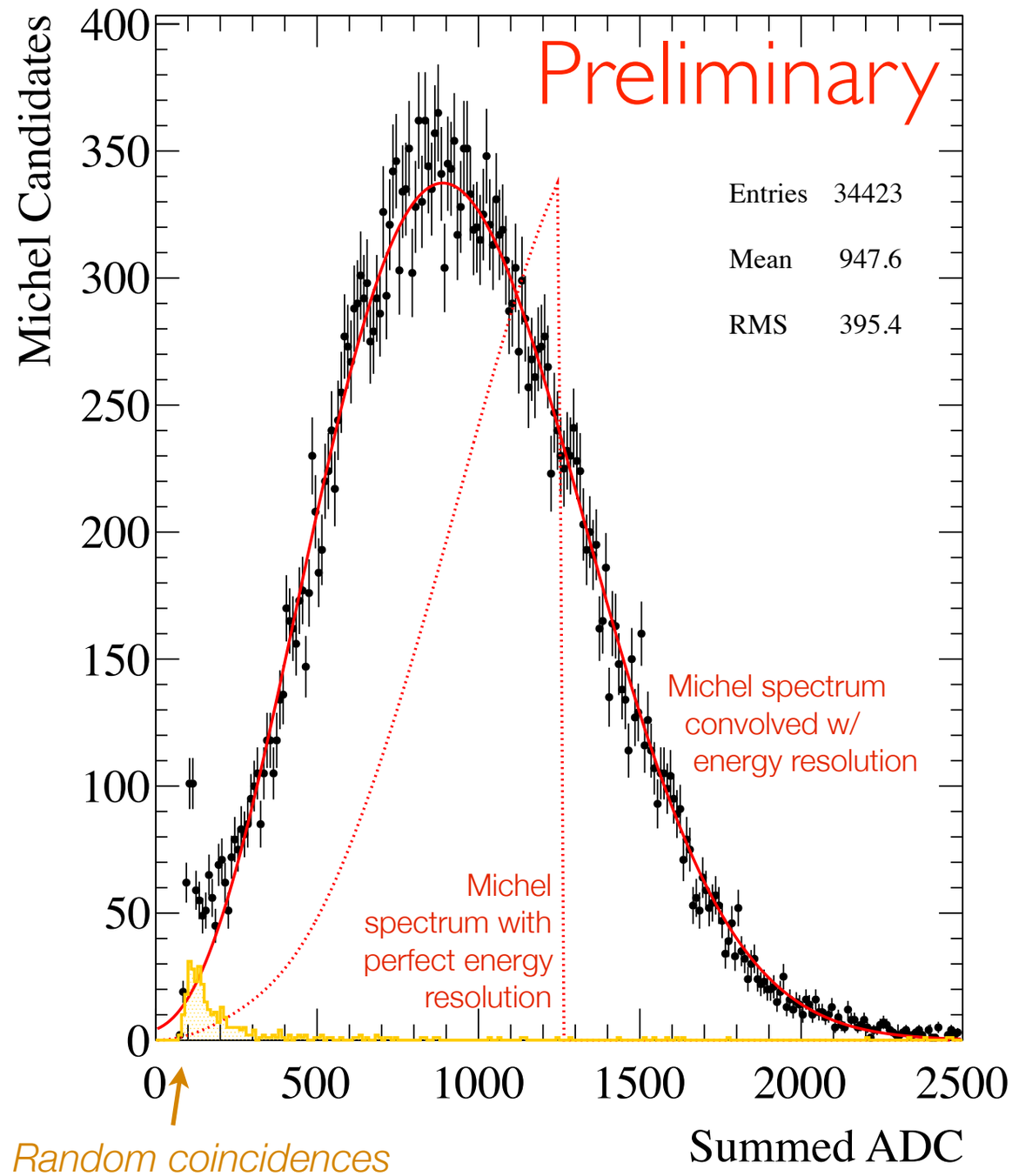


- Top left: Path length corrected muon response for different distances from fiber for a single example cell
- Above: Measured and fitted fiber attenuation for the example cell
- Bottom left: Muon response after attenuation corrections

Michel Electrons

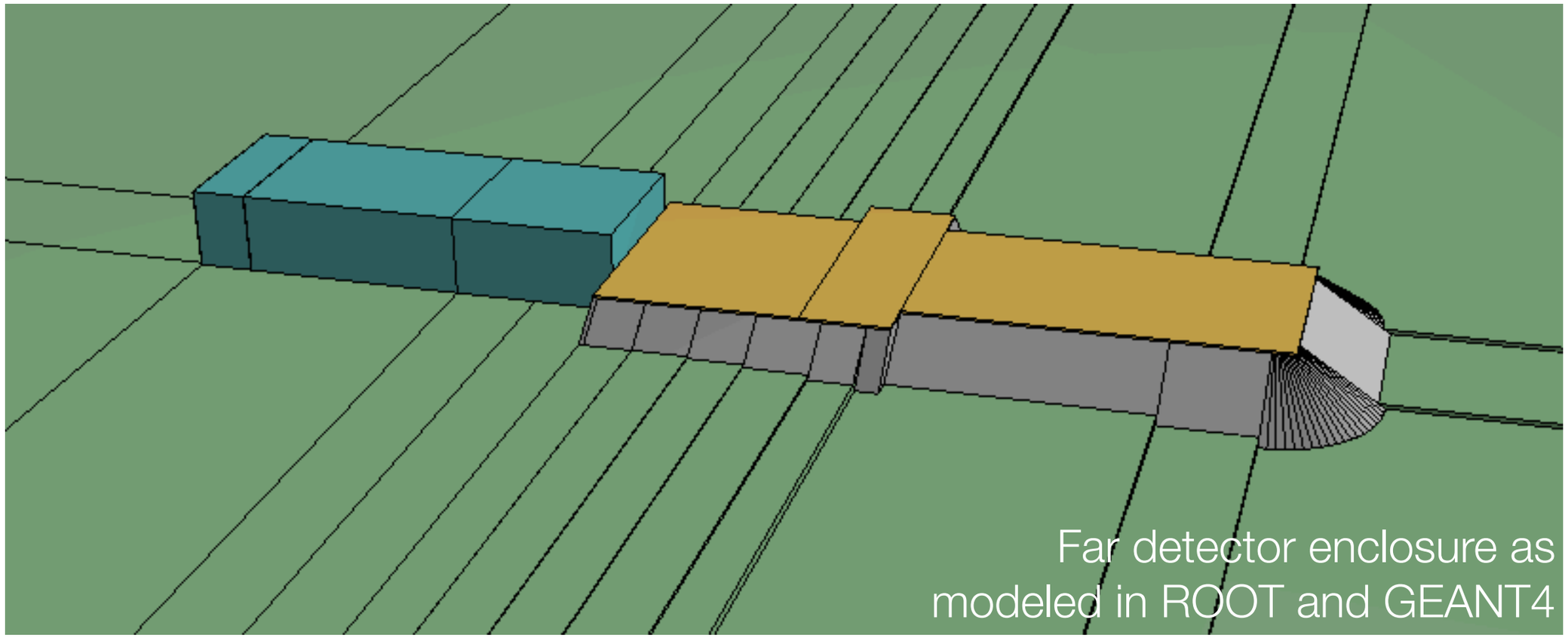
- Use Michel electrons for electro-magnetic energy calibration





Random coincidences
These are clusters that are matched to muons recorded 20 seconds prior to event

NOvA Far Detector

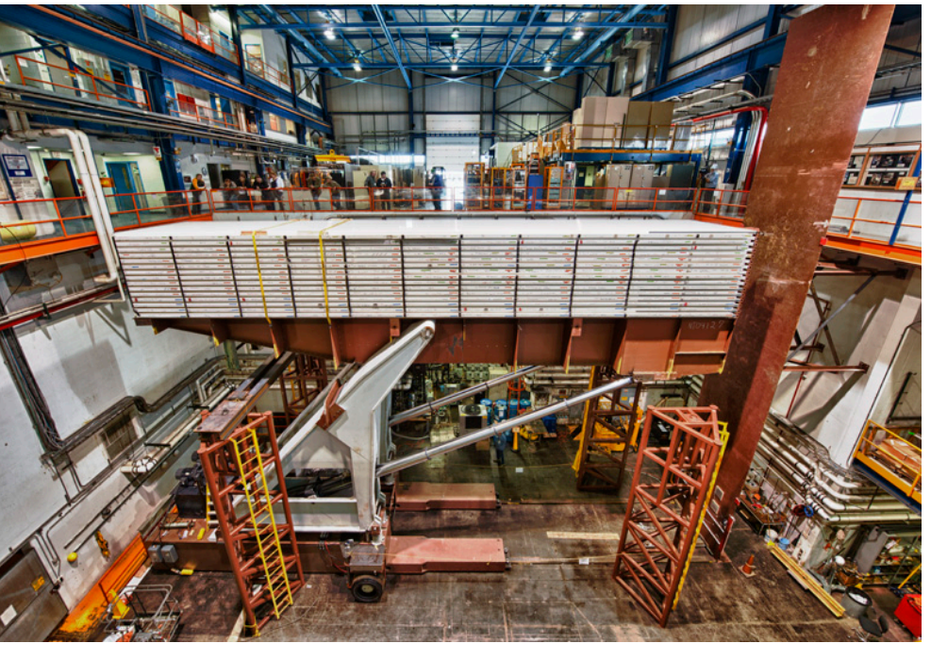


- After many years of looking at this.
  We can now look at this...

Far Detector Laboratory

Beneficial occupancy of Ash River laboratory on April 13, 2011

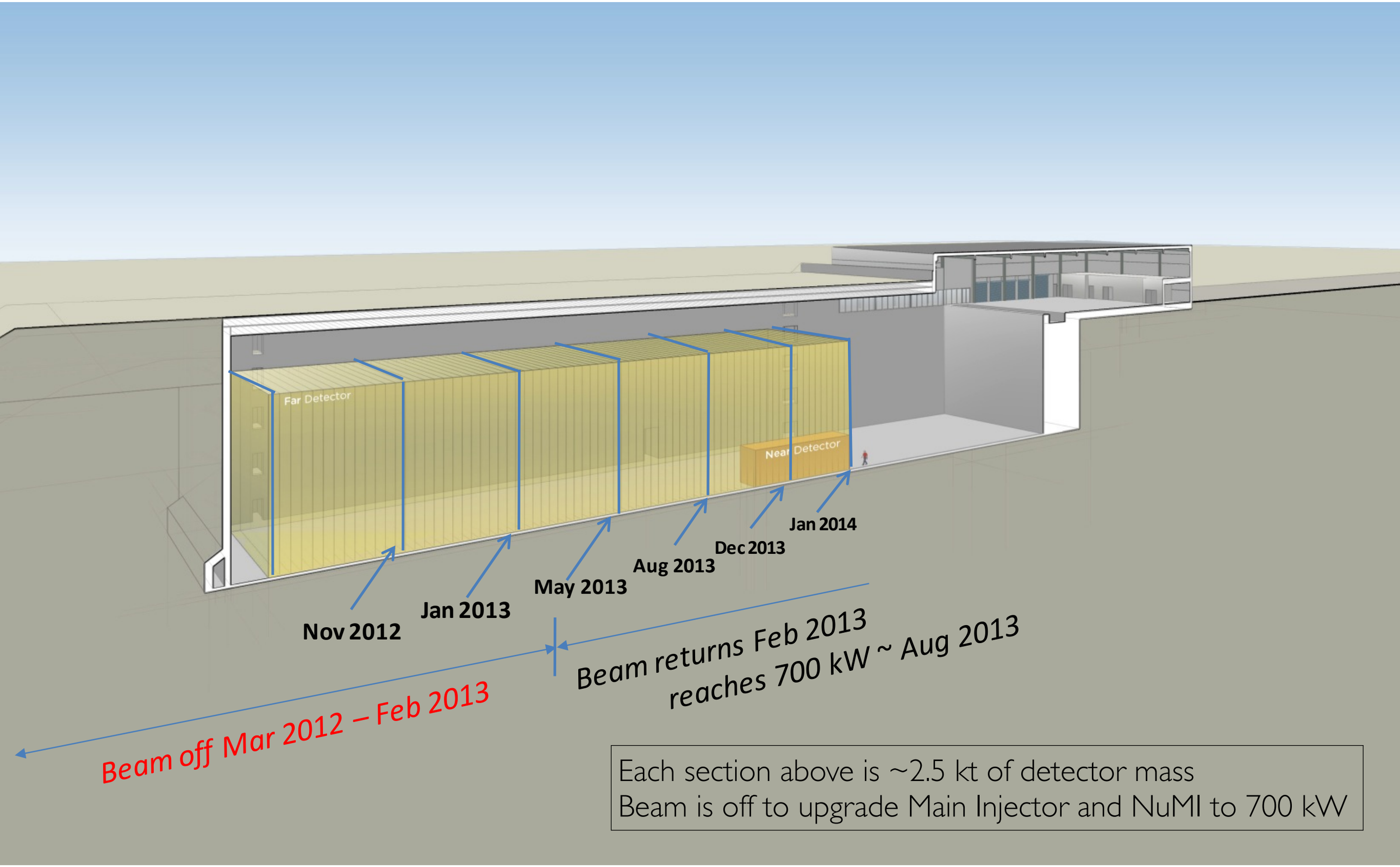
NOvA Far Detector



Inside the detector enclosure looking south

Block Pivoter Prototype @ CDF

NOvA Far Detector



Each section above is ~2.5 kt of detector mass
Beam is off to upgrade Main Injector and NuMI to 700 kW

Summary

- NOvA is the flagship project of Fermilab's Intensity Frontier initiative
- Far detector construction is underway.
  - Far detector laboratory complete
  - NuMI upgrades begin in March of 2012 (possibly May 2012)
  - Plan to have first far detector block in place by August 2012
  - Commissioning of 700 kW beam begins in 2013 with ~5 kt of far detector in place
  - 14 kt complete by end of 2014
- Prototype near detector operational on surface at Fermilab
  - Extremely valuable preparation for construction at Ash River
  - Early look at real cosmic rays and neutrinos

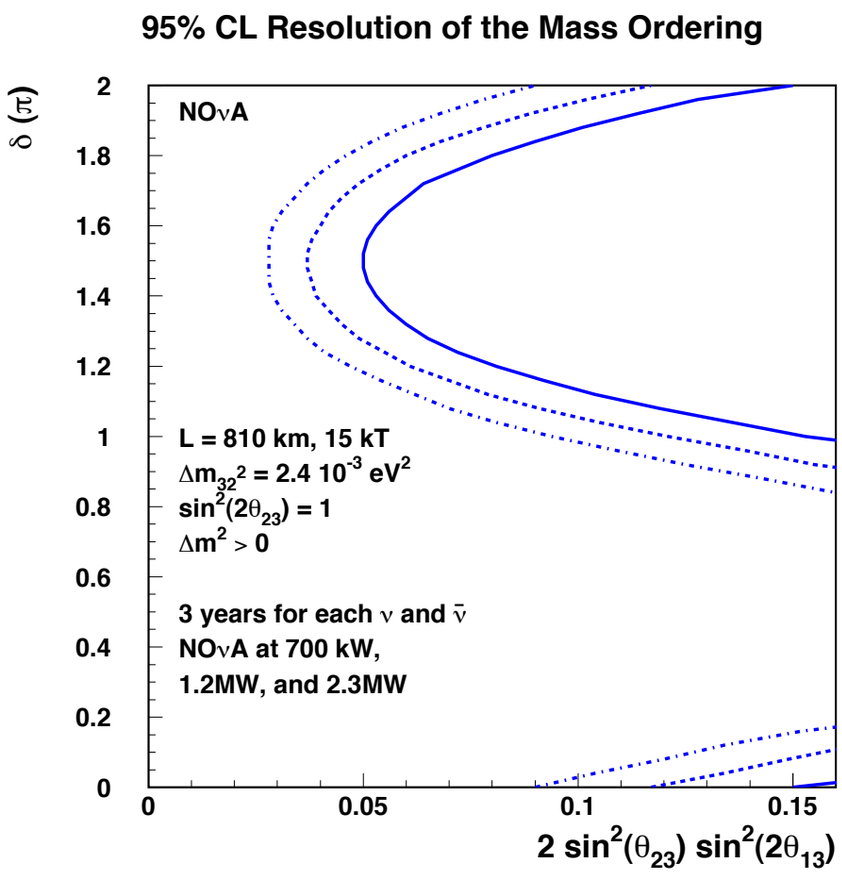
Thank You!

ANL, Athens, Caltech, Institute of Physics of the Czech Republic, Charles University, Czech Technical University, FNAL, Harvard, Indiana, Iowa State, Lebedev, Michigan State, Minnesota/Duluth, Minnesota/Twin Cities, INR Moscow, South Carolina, SMU, Stanford, Tennessee, Texas/Austin, Tufts, Virginia, WSU, William and Mary

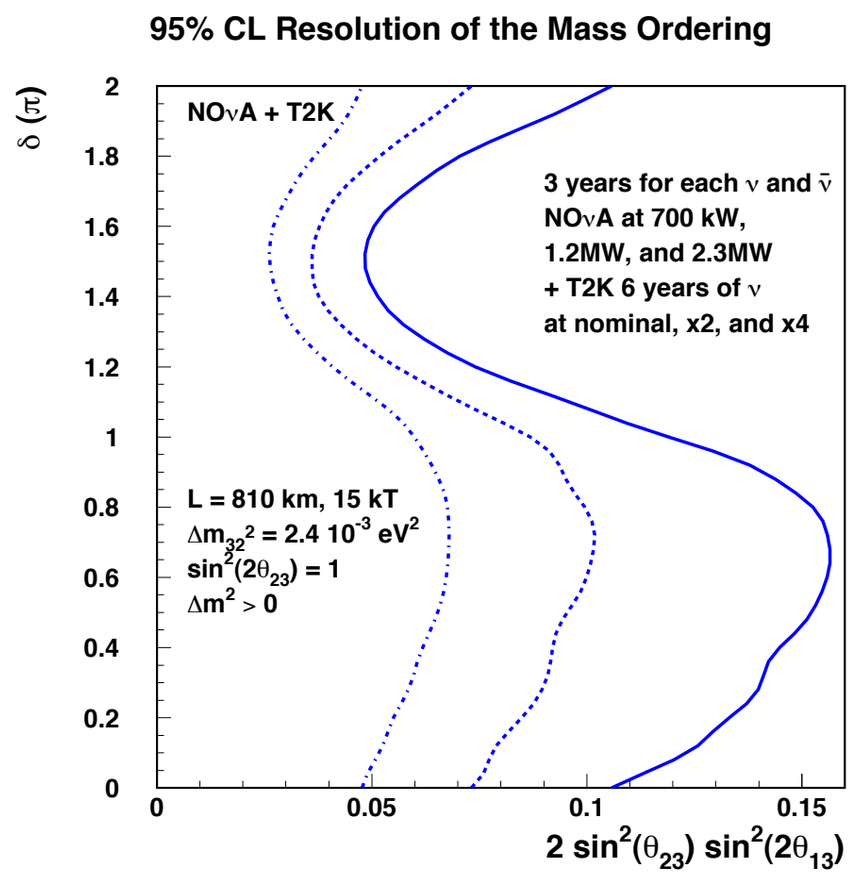
Backup

Mass Hierarchy

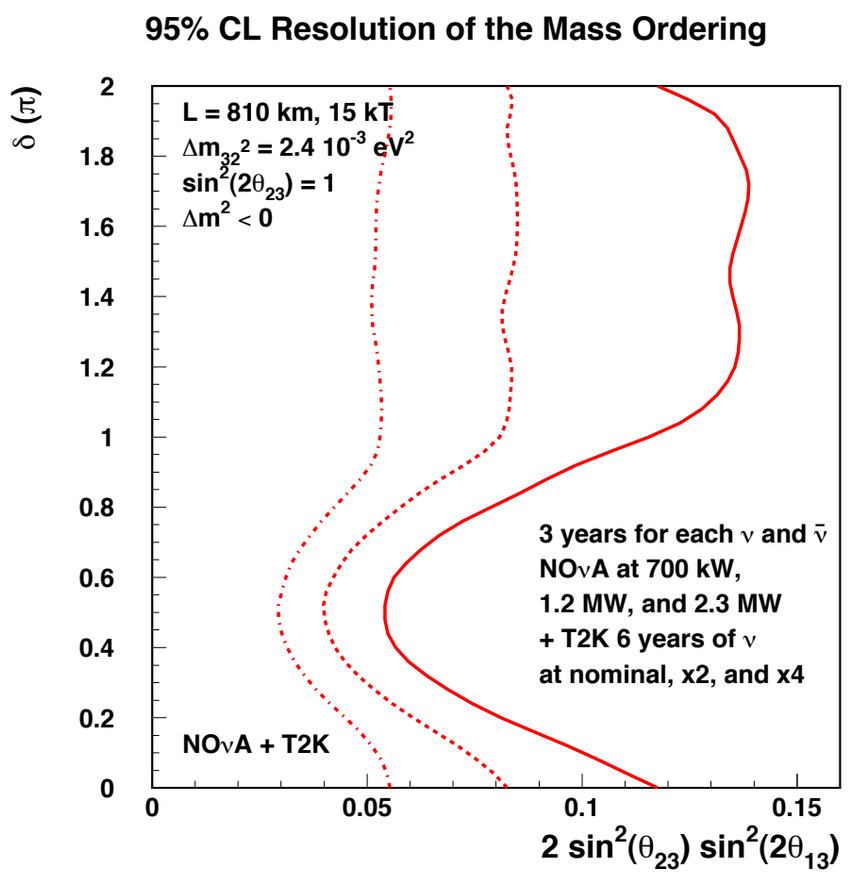
Can improve sensitivity by including additional information from a different baseline



Normal Hierarchy
NOνA alone

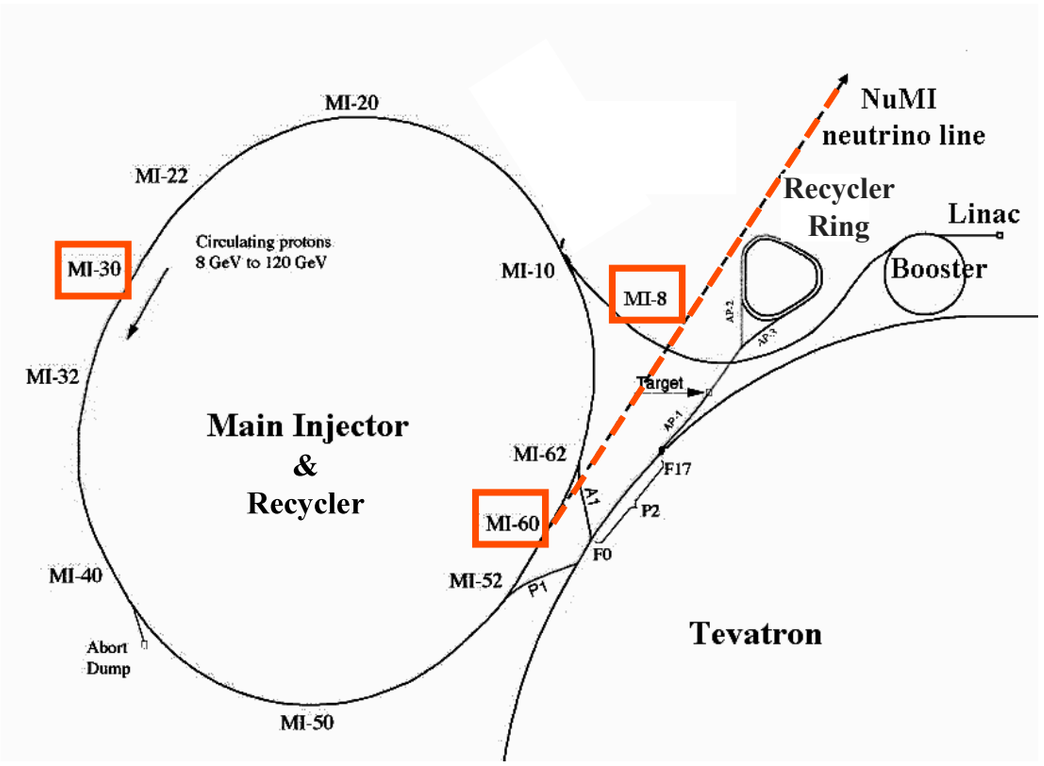


Normal Hierarchy
NOνA+T2K



Inverted Hierarchy
NOνA+T2K

NuMI Upgrade



NuMI will be upgraded from ~320 kW to 700 kW during 2012 shutdown

Reduce cycle time from 2.2 to 1.33 seconds - via slip-stacking in the Recycler prior to Main Injector

Increase intensity/cycle with 12 Booster batches instead of 11 by using new injection kicker magnet

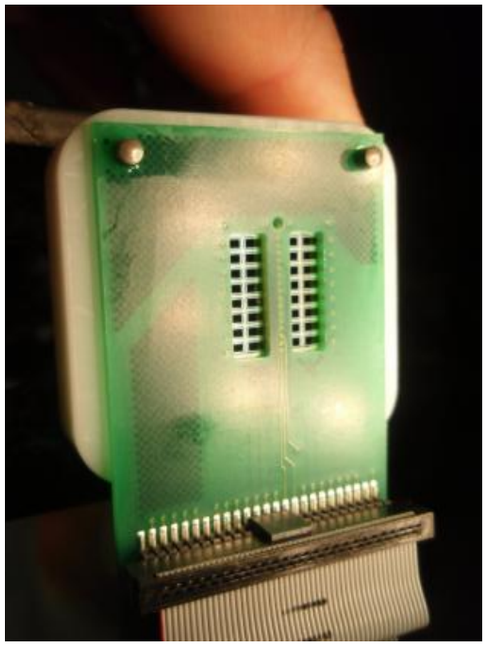
Upgrade beam components, such as target and horns
10 μsec beam pulse every 1.33 sec

4.9×10^{13} POT/pulse => 6.0×10^{20} POT/year of running

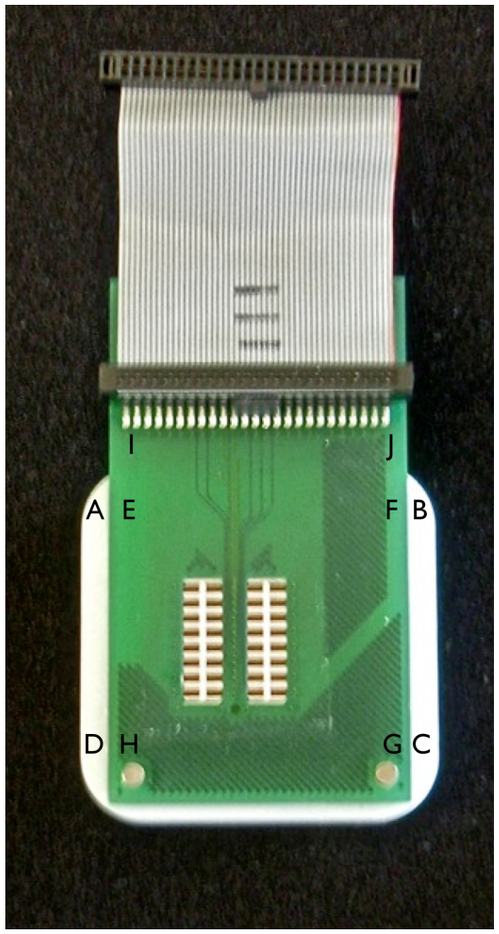
APD

Avalanche photo-diode (APD)

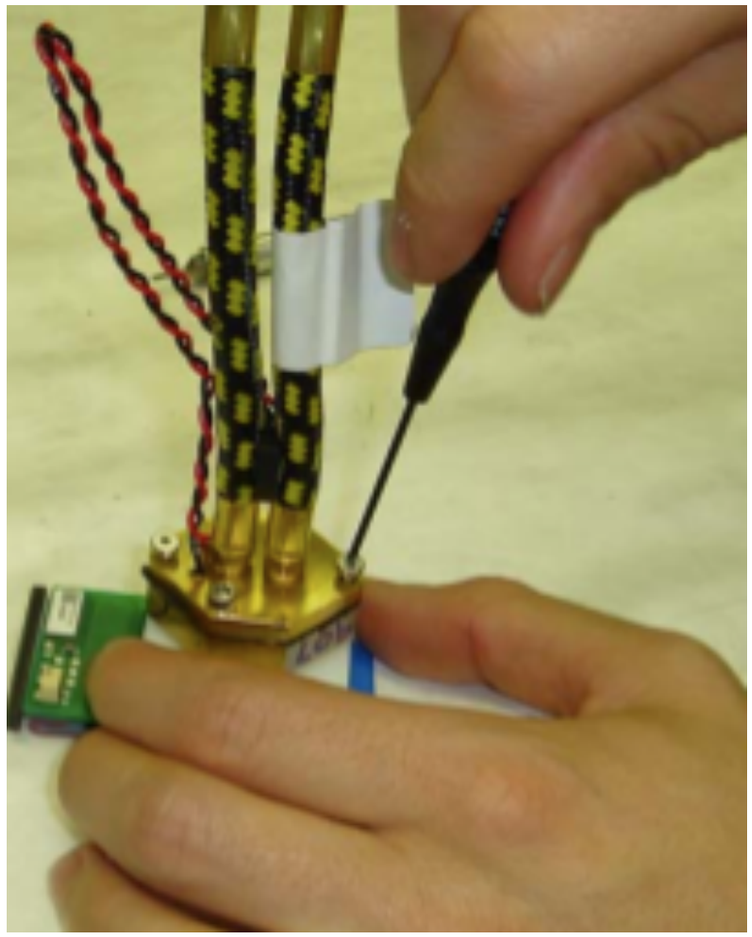
- Made by Hamamatsu
- Relatively cheap (~ $400 a piece)
- Array of 32 pixels
- 85% QE for 520 – 550 nm light.
- Gain of 100 @ 375 volts.
- Actively cooled to -15°C.
- 11,150 APDs at Far detector (496 at Near detector)



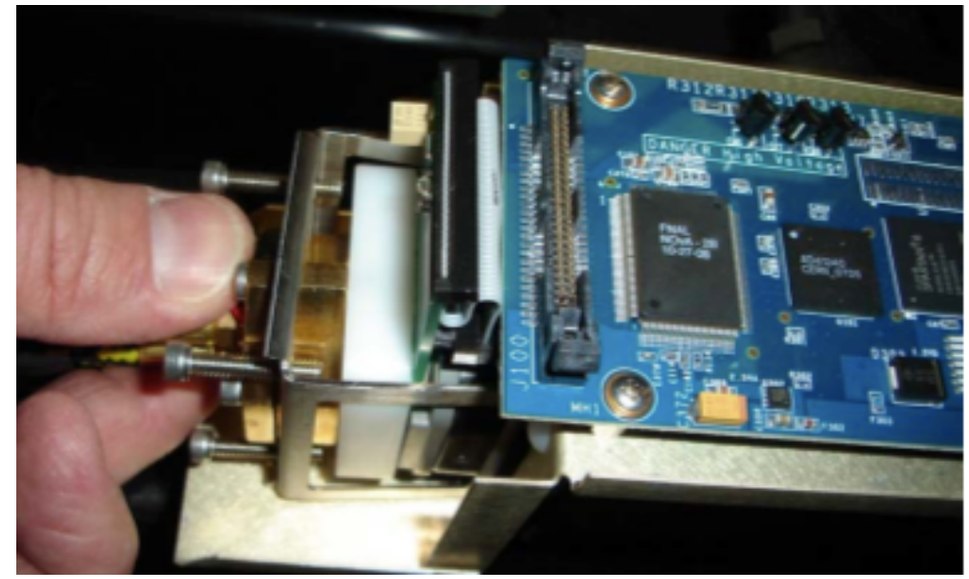
APD Installation



APD and carrier board attached to spacer



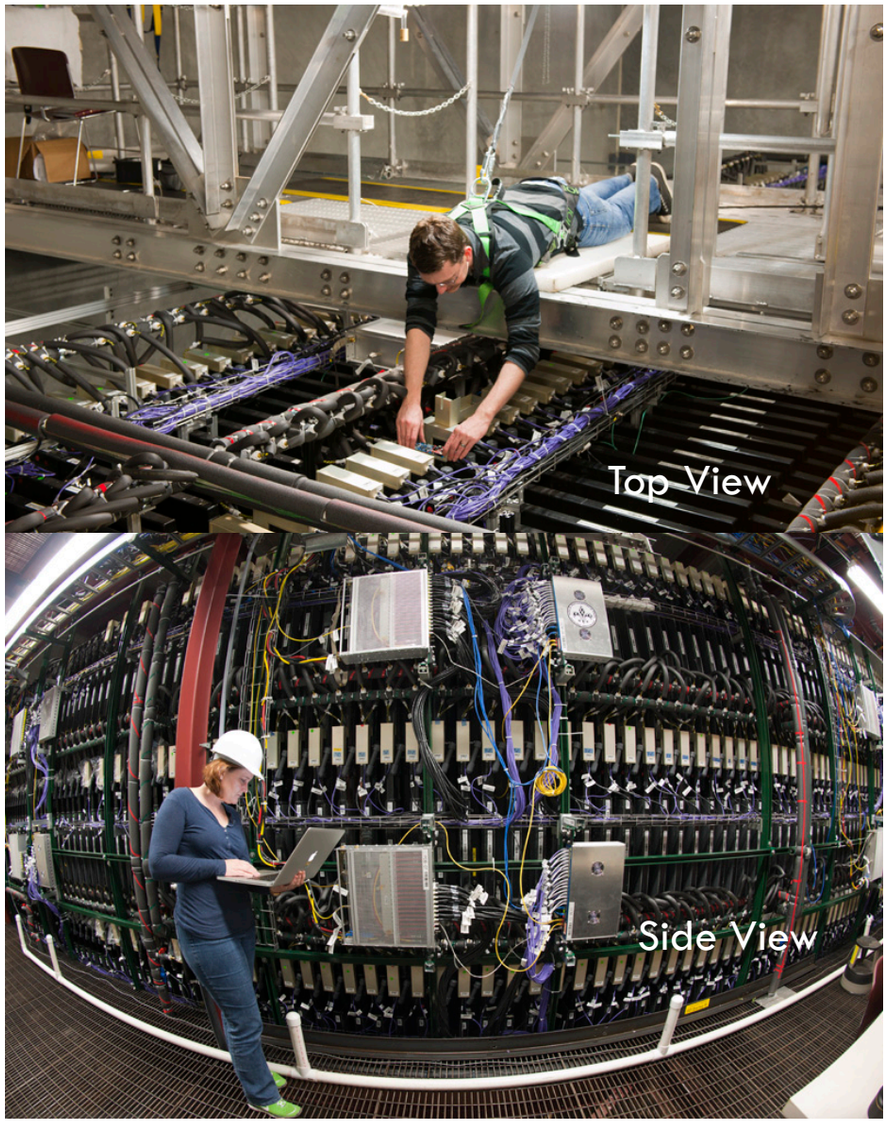
APD attached to heat sink



APD assembly attached to front end board which is preinstalled on the detector

NDOS - Lessons learned

- **22% manifolds developed cracks.**
  - Redesign of manifolds
  - Splints to fix NDOS
  - Changes to pressure testing
- **50% APDs were lost due to a bad installation or sealing issues and a subsequent cooling.**
  - APD assembly in a clean room
  - Strict installation procedures
  - Redesign of the APD module
  - APD and FEB surface coding
  - APD module sealing test
- **Electronics noise induced by a thermo electric cooler controller**
  - Redesign of the TECC board
  - Using ferrite beads



Module Factory