NOνA: Present & Future

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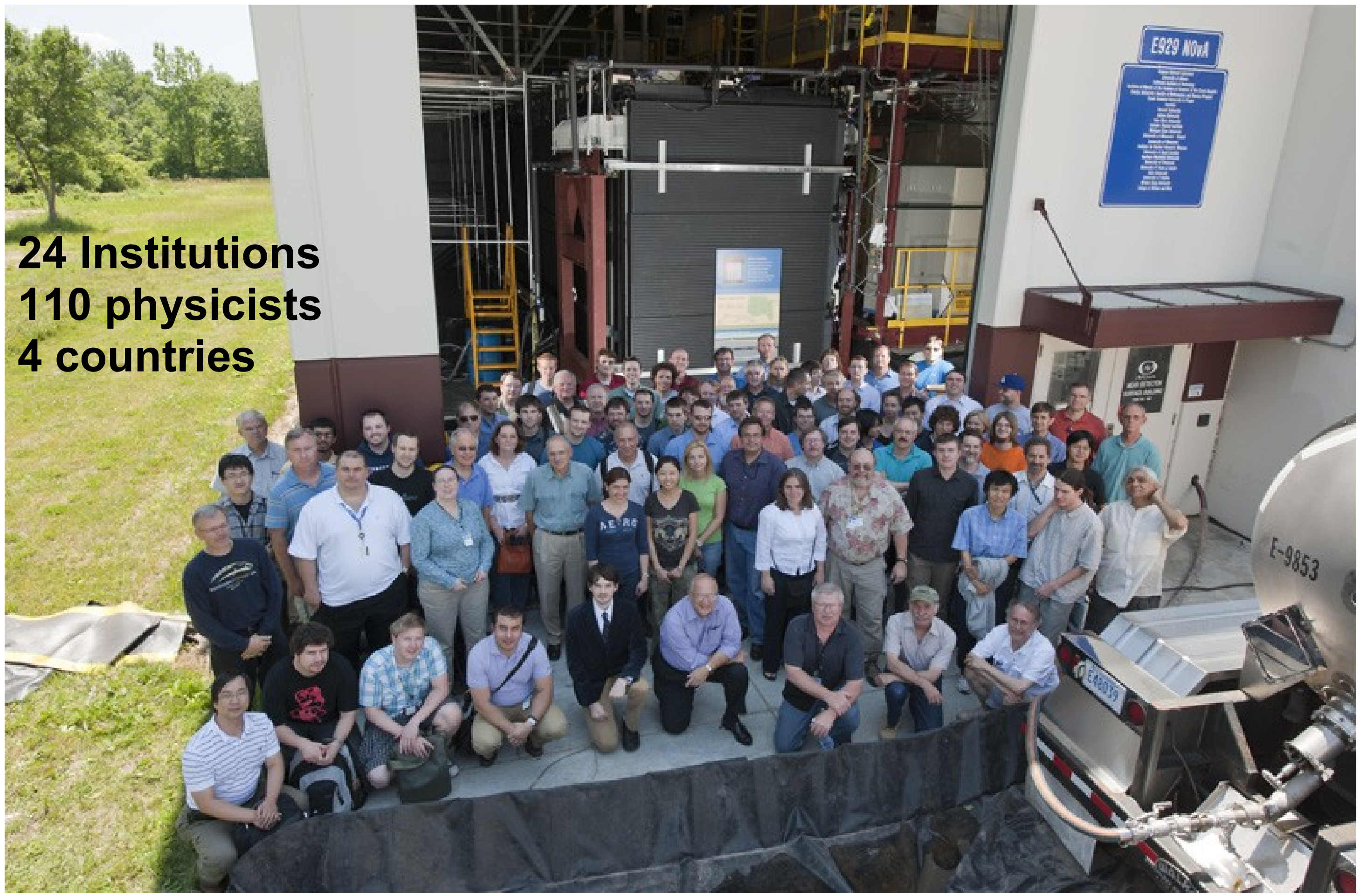
for the NOνA Collaboration

DPF 2011: Brown University, Providence, RI

August 9th – 13th 2011

The NOνA Collaboration

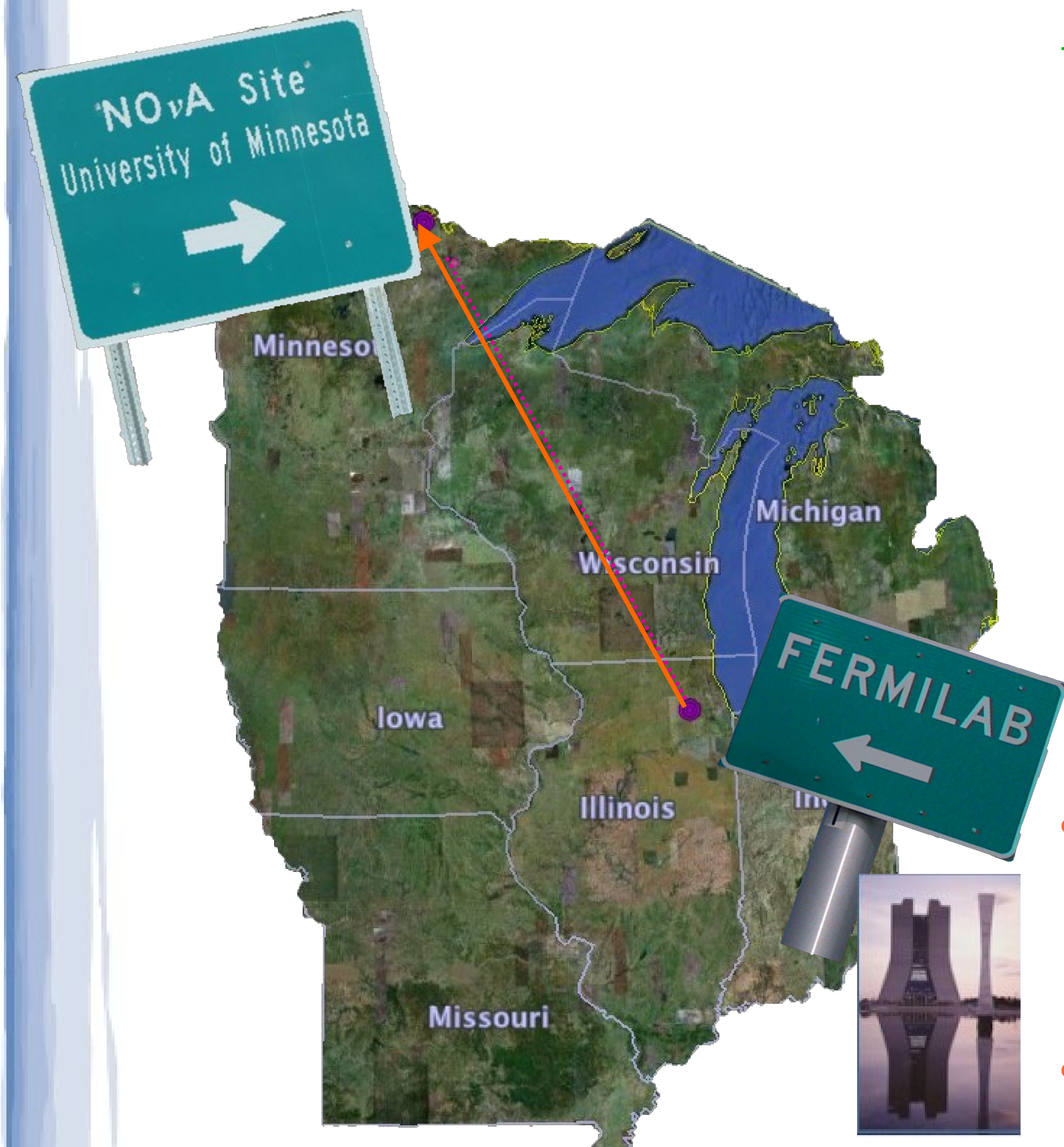
NuMI* Off-axis ν_e Appearance



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

* Neutrinos at the Main Injector

The NOνA Experiment



Physics Goals:

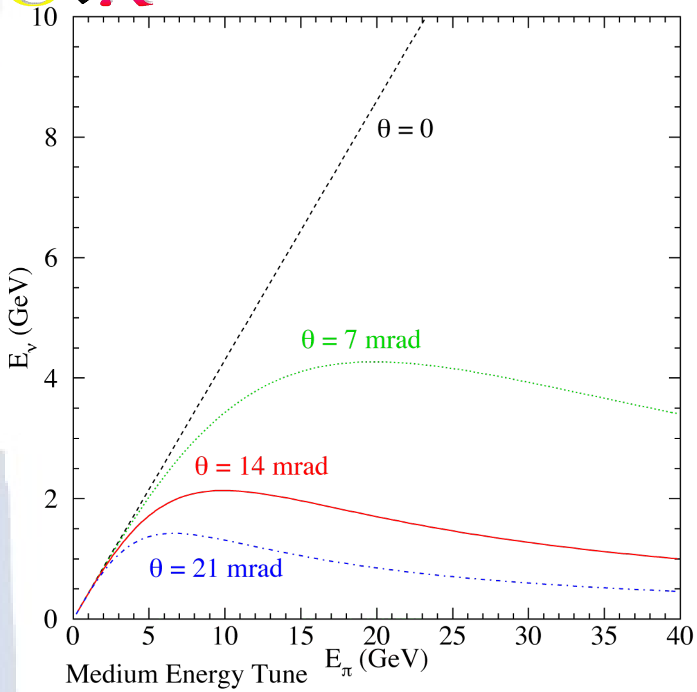
- Search for oscillations

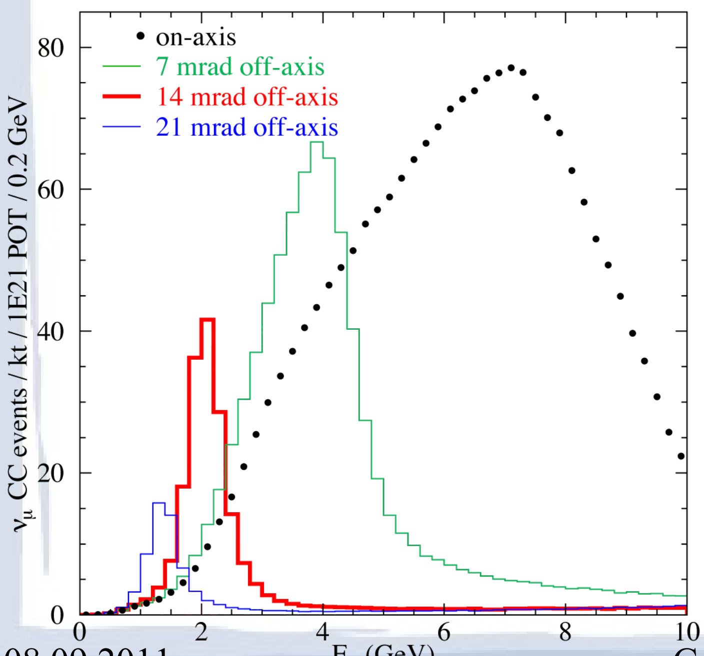
  $\nu_\mu \rightarrow \nu_e$ and $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$

- Measure θ_{13}
- Constrain δ_{CP}
- Determine neutrino mass hierarchy
- Precision measurements of Δm^2_{32}, θ_{23}

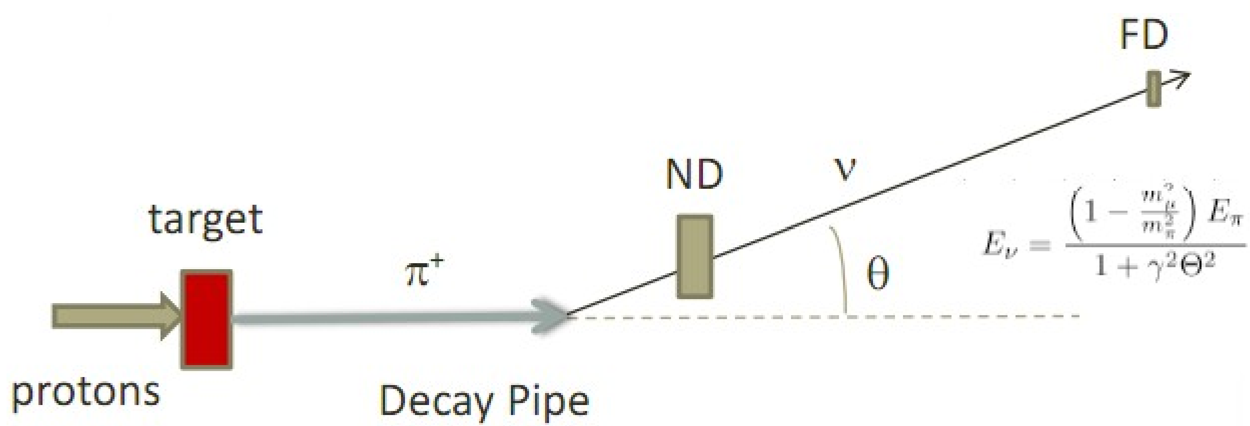
- 810 km baseline from Fermilab to Ash River, MN
  - Near and Far Detectors
- 700 kW upgraded NuMI beam
- Off-axis (14 mrad) detectors

Off-axis

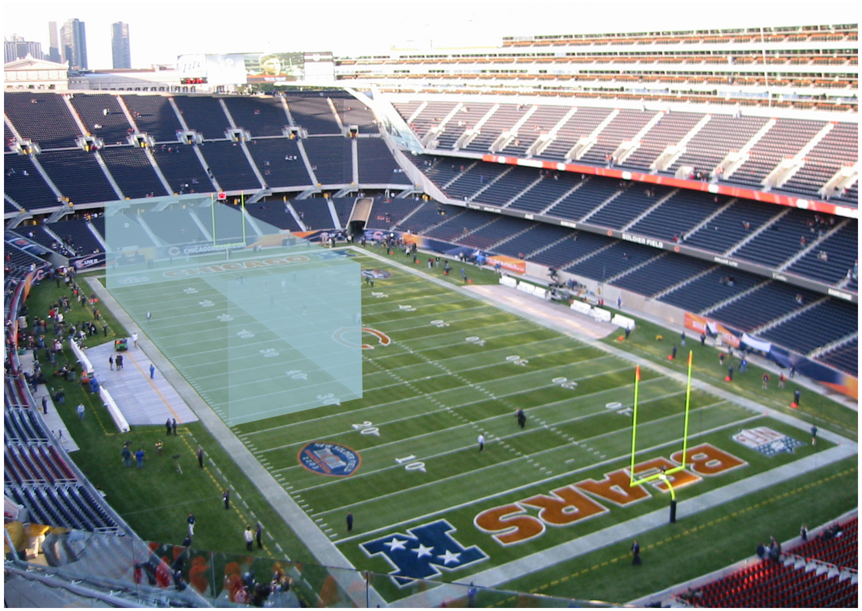




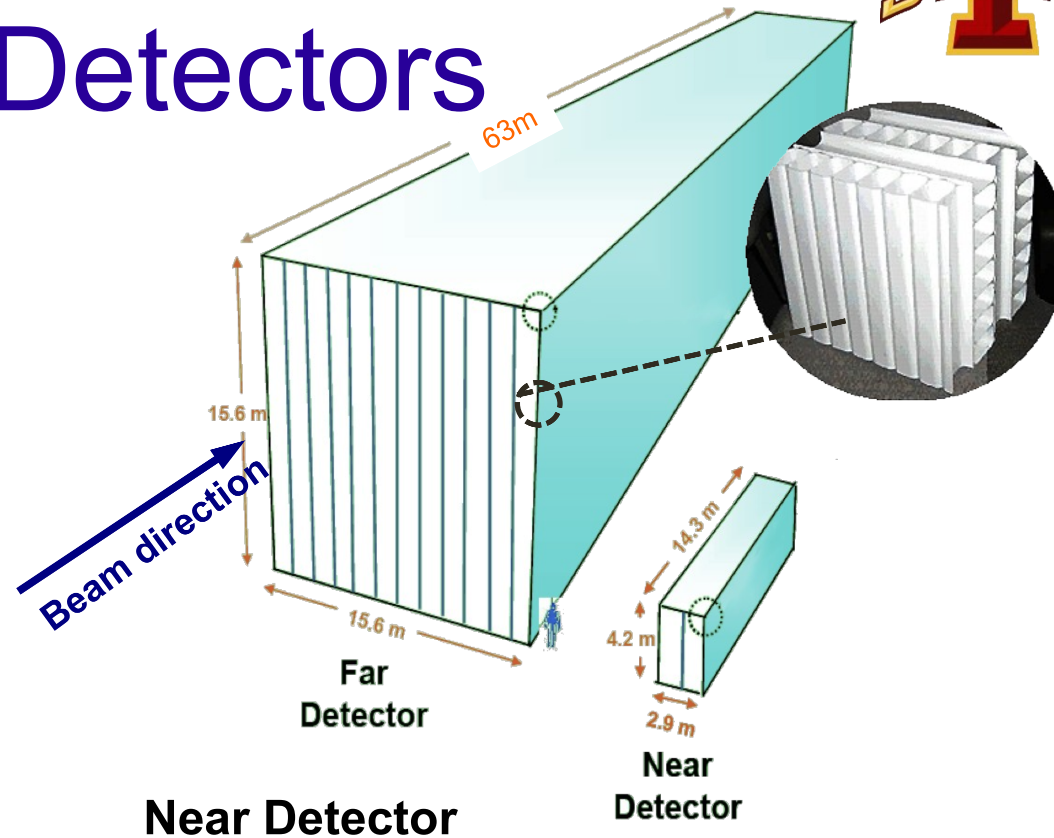
- Medium Energy NuMI beam favoured
- 14 mrad off-axis
- Essentially all pion decays yield neutrinos in 1-3 GeV range
  - Narrow band beam peak at 2 GeV
  - Near oscillation maximum
  - Reduction of NC backgrounds



NOνA Detectors



Far Detector superimposed in SoldierField



Far Detector

- 928 Planes (15.6 m x 15.6 m)

- 14kTon
- ~360000 cells
- Cosmic Ray Muon Rate:
  ~200 kHz (2-3 m overburden)
- Neutrino Rate:
  1400 ν_e beam events/year

Near Detector

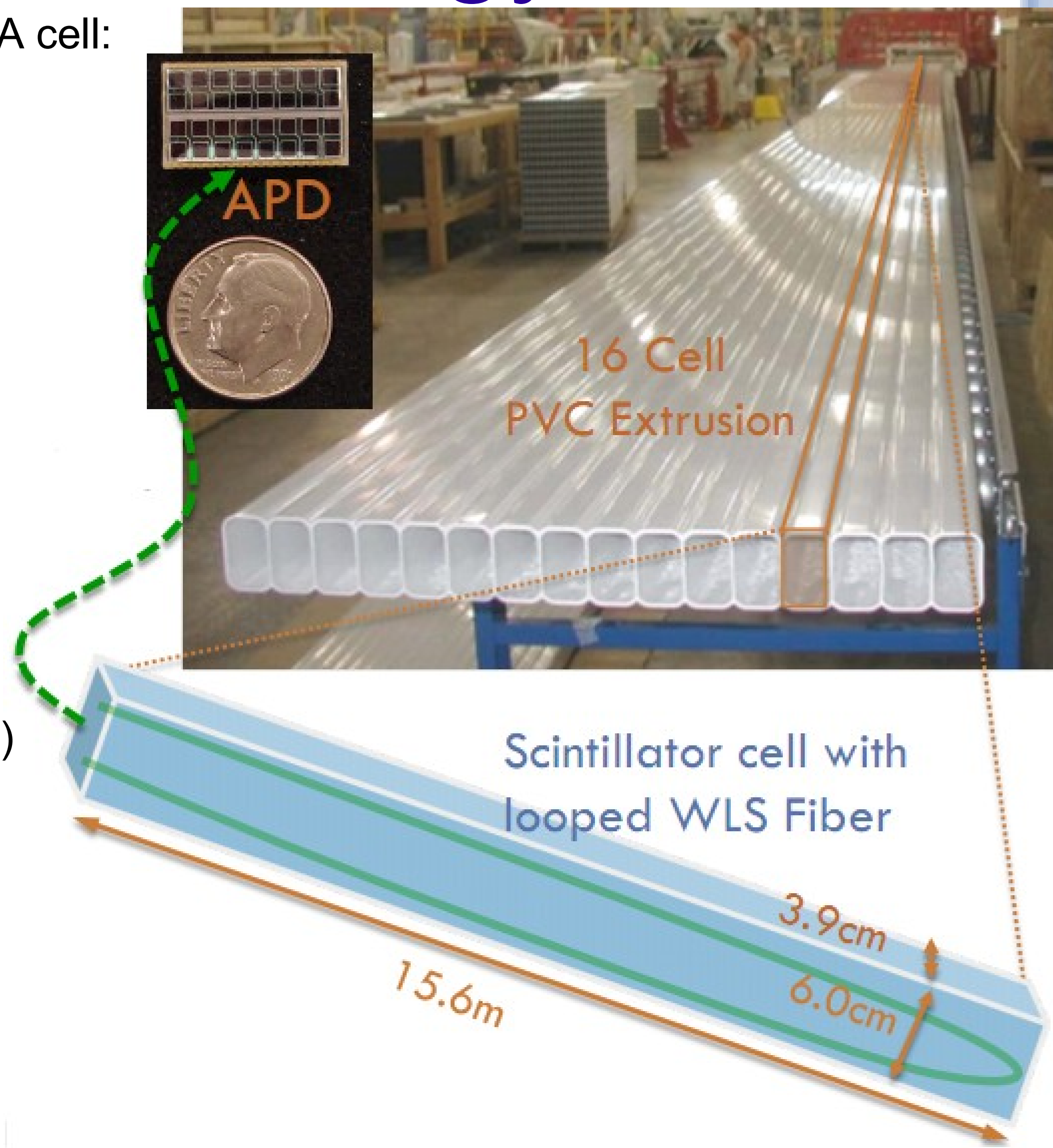
- 196 Planes (2.9 m x 4.2 m)

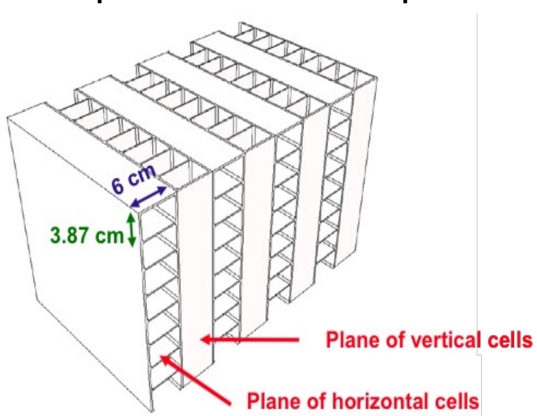
+ 10 Steel/Scint Plane Pairs (“MuonCatcher”)

- 220 Ton
- 16000 cells
- Cosmic Ray Muon Rate:
- ~50 Hz (105 m overburden)
- Neutrino Rate:
  10 μs spill duration every 1.33 s
  30 neutrino events/spill

Detector Technology

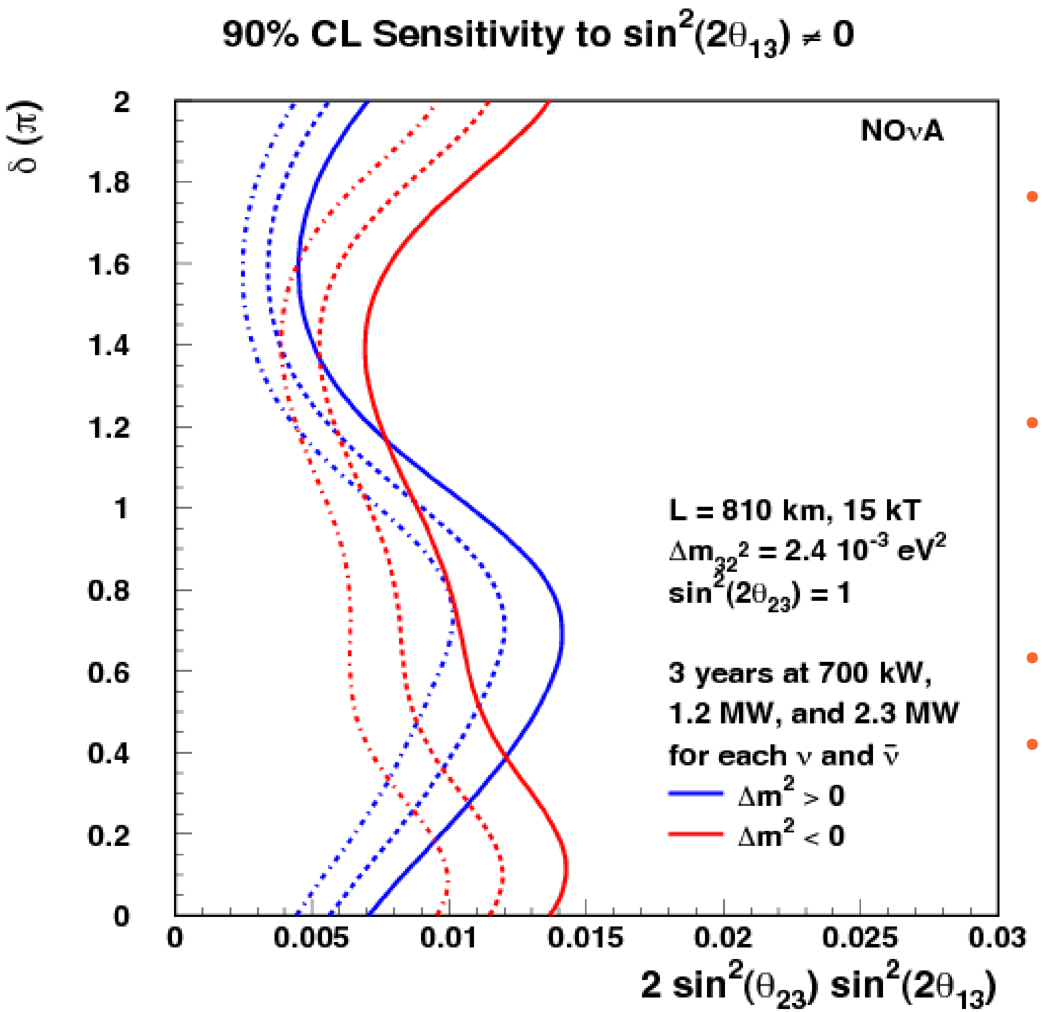
- 16-cell PVC extrusions (15% TiO_2). Each NOvA cell:
  - 3.9 cm x 6.0 cm x 15.6 m (FarDet)
  - ~90% reflectivity at 430 nm
  - 8 reflections on average
- ~360,000 cells (Far), ~16,000 (Near).
- 32 in a sealed module. Alternating X/Y planes.
- Filled with liquid scintillator
  - mineral oil + ~5% pseudocumene
- Read out by wavelength-shifting fiber into one pixel of a 32-pixel avalanche photodiode (APD)





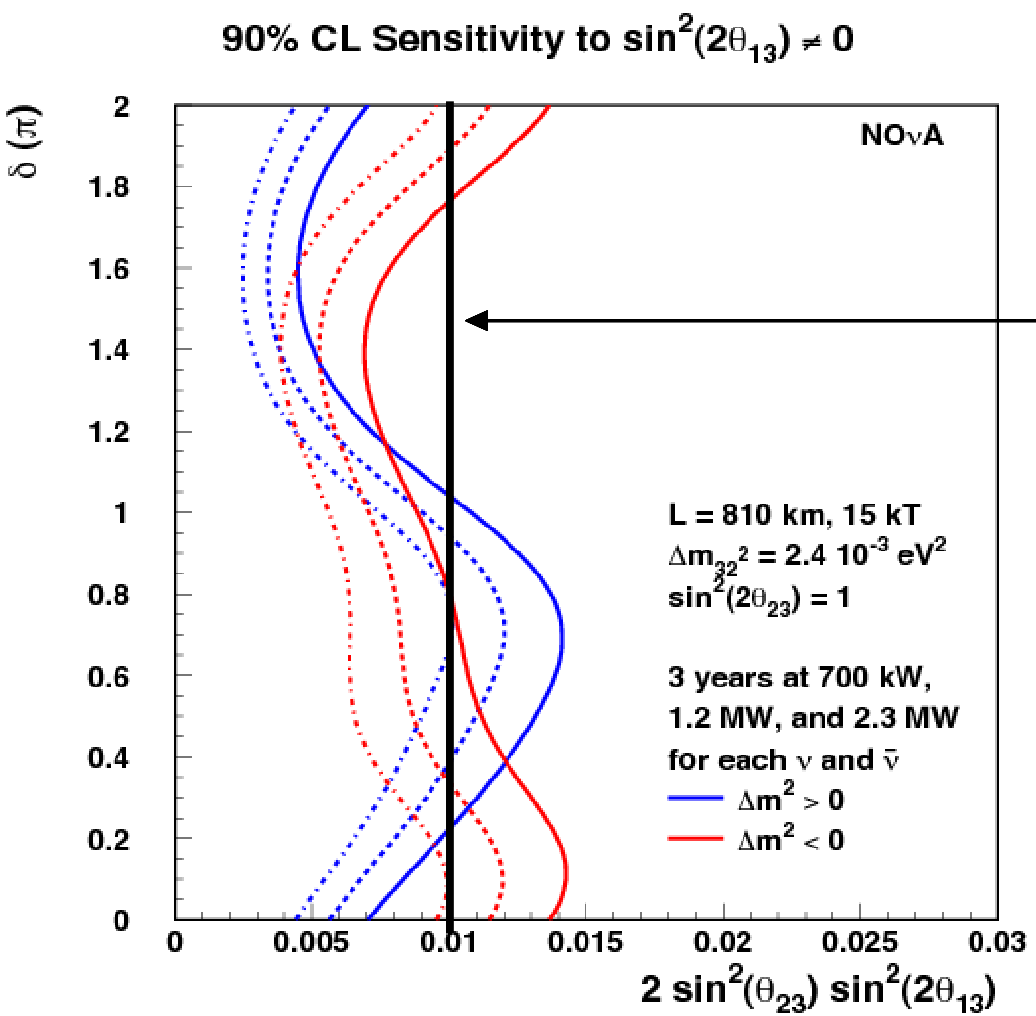
See Xinchun Tian's talk (Friday, 8:20am) for details of the NOvA Data Acquisiton System

Sensitivity to θ_{13}

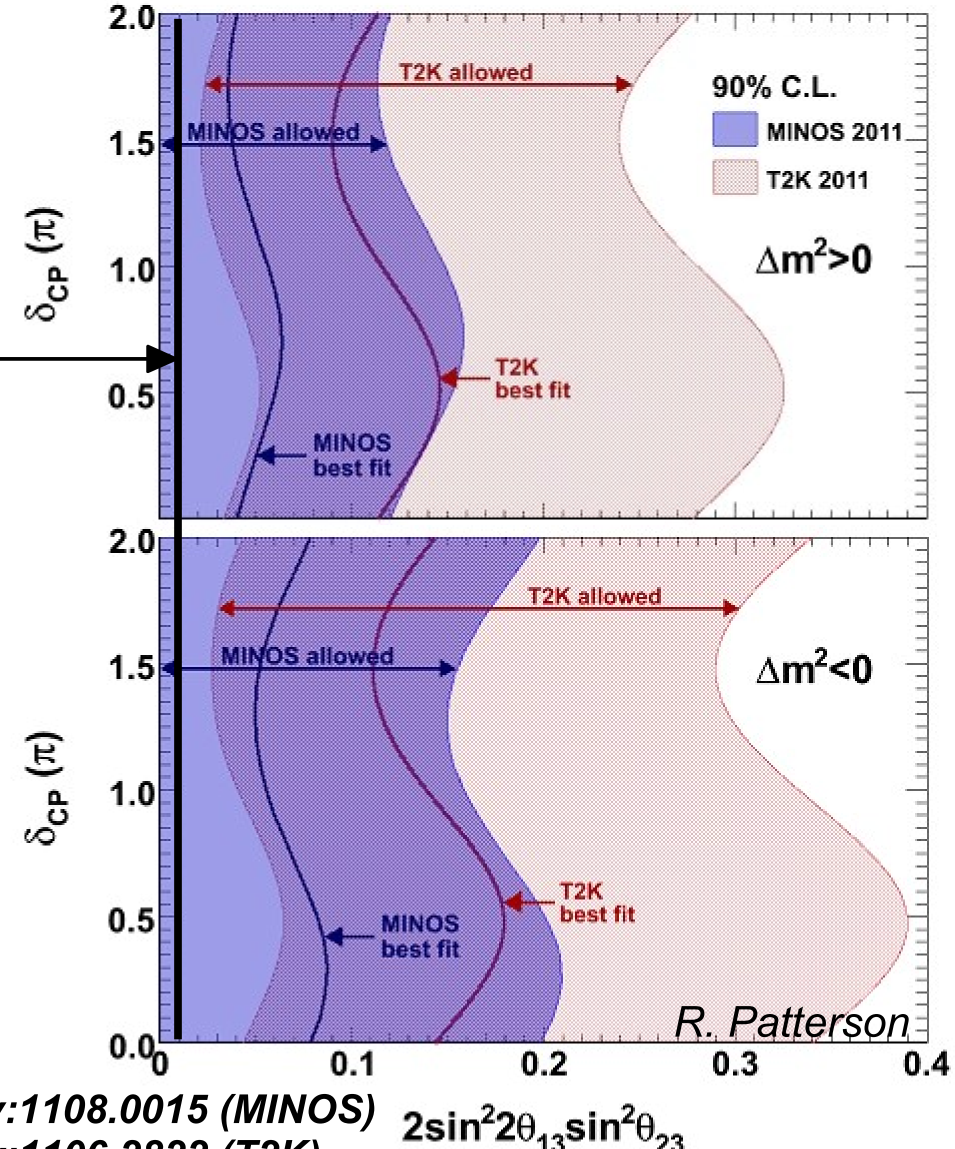


- NOvA is sensitive to electron neutrino appearance down by an order of magnitude at 90% CL.
- Sensitivity to $\sin^2(2\theta_{13})$ after 3 years each of running ν and $\bar{\nu}$ beams
- Contours for different beam upgrades also shown
- 18×10^{20} POT in each neutrino and antineutrino mode

Comparing to recent results



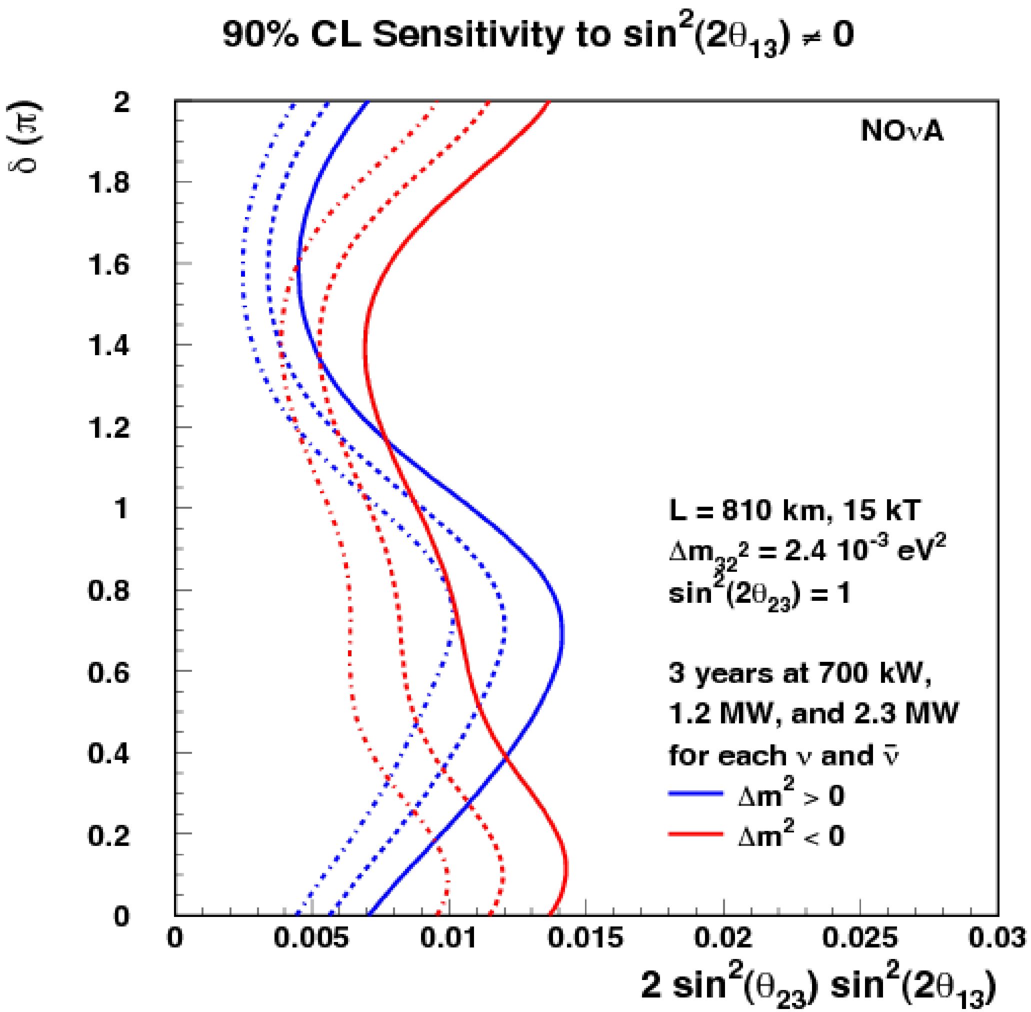
Overlay of MINOS and T2K allowed regions

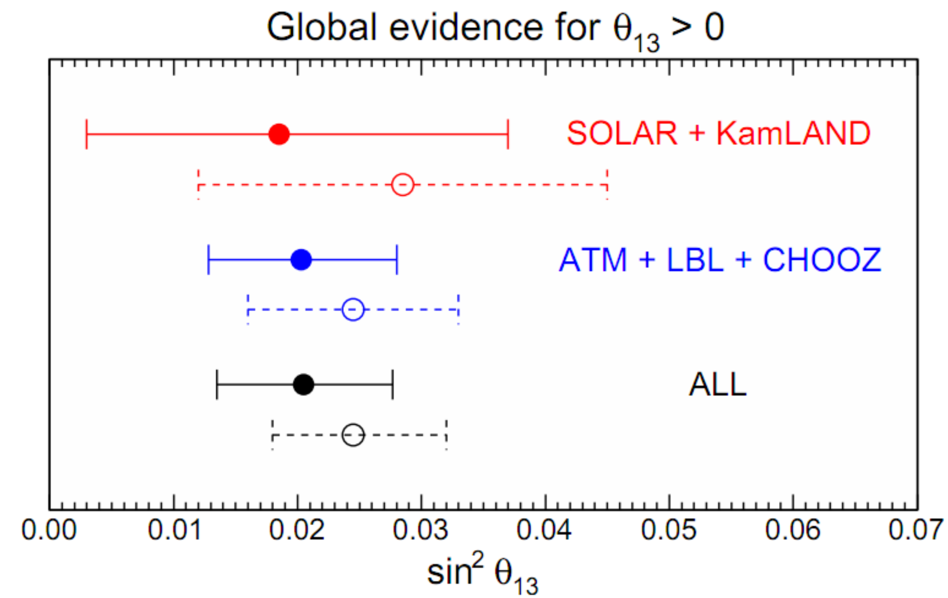


arXiv:1108.0015 (MINOS)
arXiv:1106.2822 (T2K)

Comparing to global picture

- Recent global fit suggests > 3 σ evidence for non-zero θ_{13} (***G.L. Fogli et al., arXiv:1106.6028)***

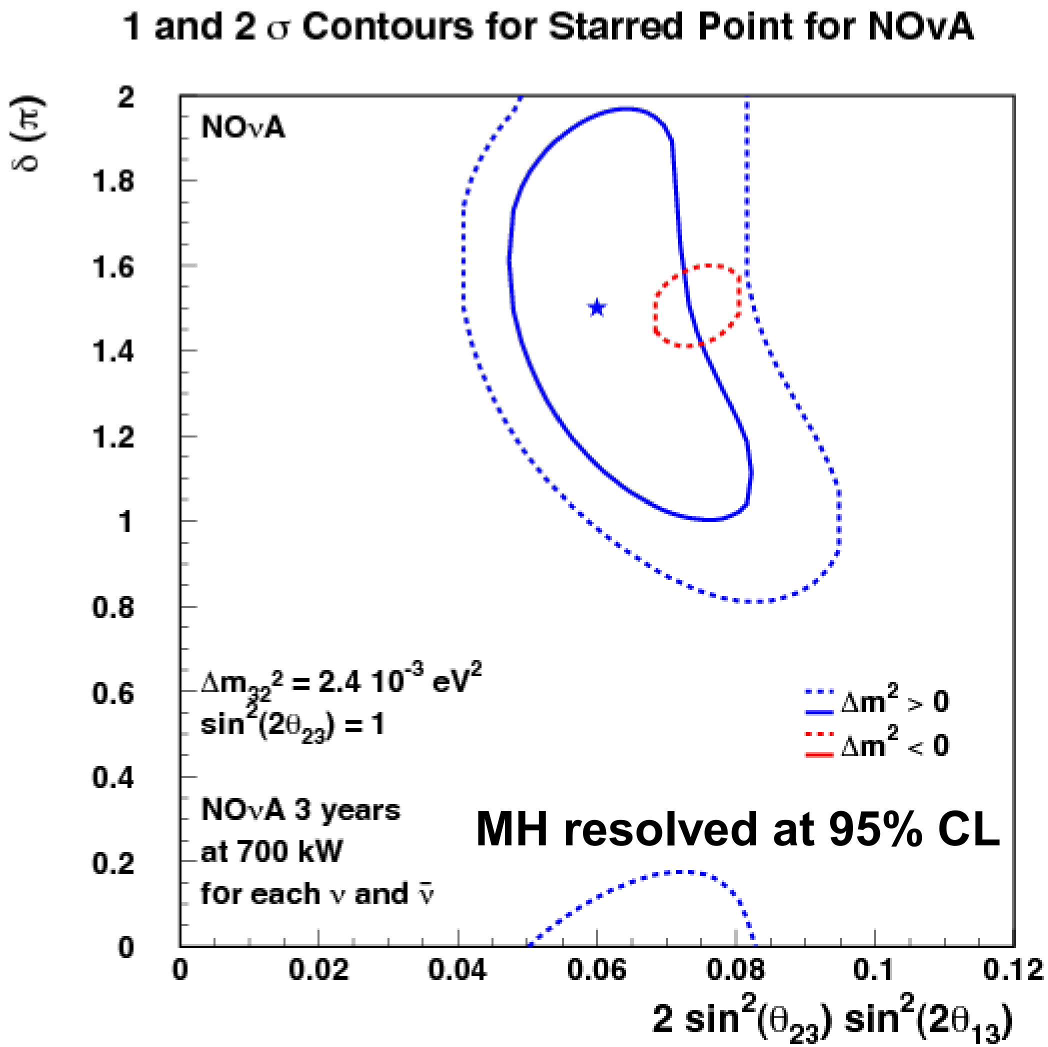


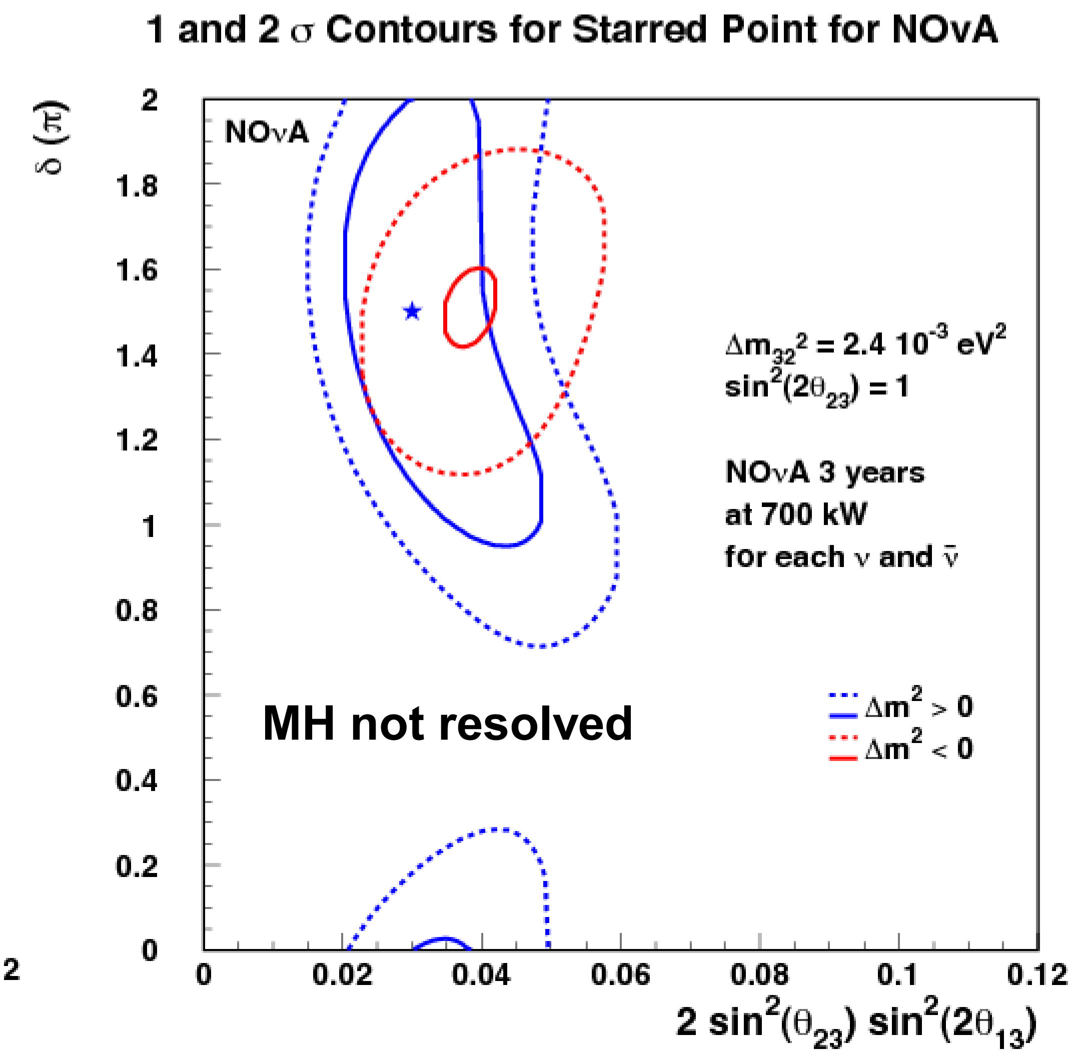


$\sin^2(2\theta_{13}) = 0.098 \pm 0.028$, new reactor fluxes (1σ)

- NOvA is sensitive to an order of magnitude better
- Recent range indicated by T2K/MINOS results is encouraging for NOvA

Constraining δ_{CP}

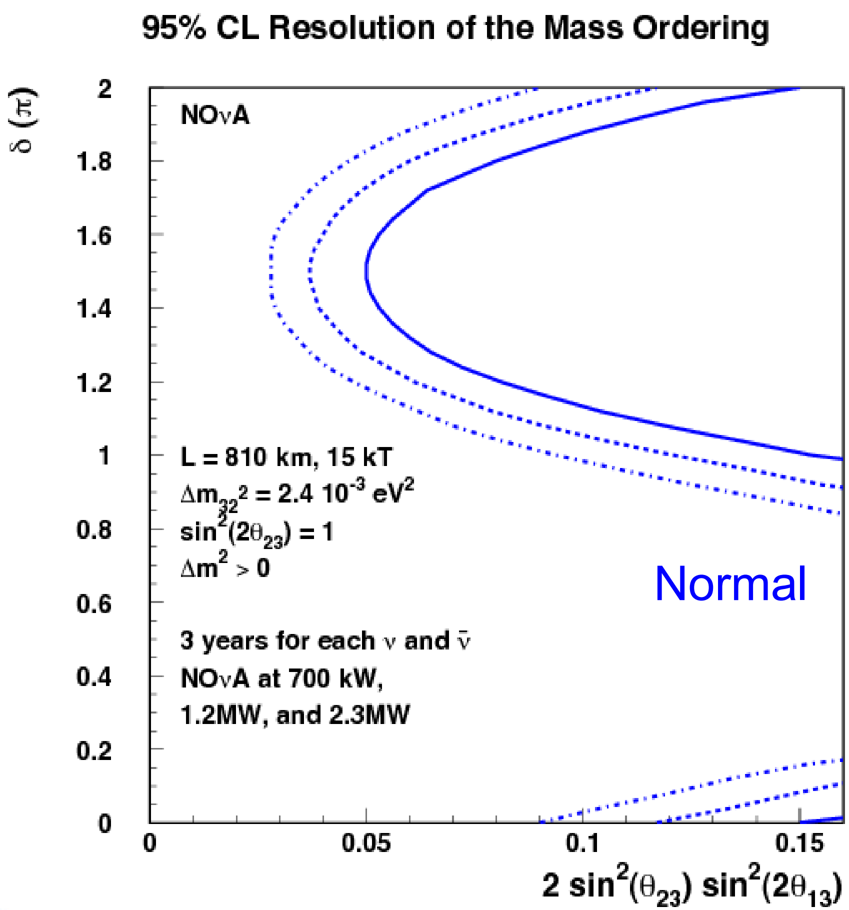


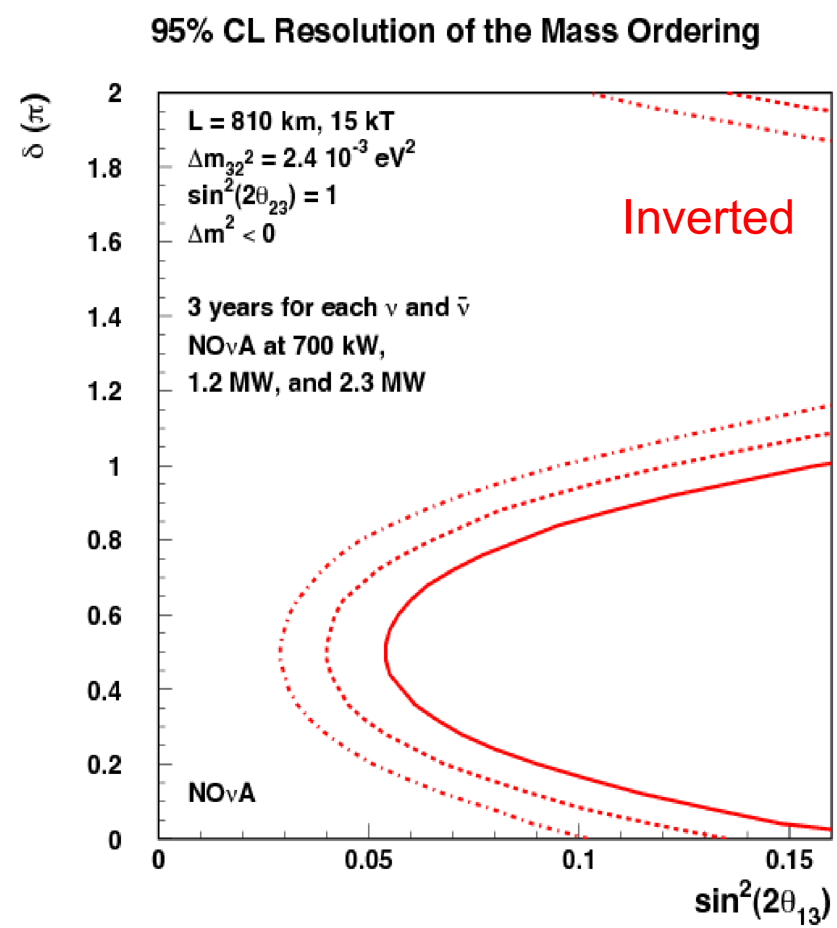


Both scenarios: δ constrained to upper half of plane

Resolving the mass hierarchy

Due to NOvA's 810 km baseline, matter–induced oscillations affect the oscillation probability by 30%.
Matter effects depend on the mass hierarchy sign and change $P(\nu_\mu \rightarrow \nu_e)$ and $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$ differently.

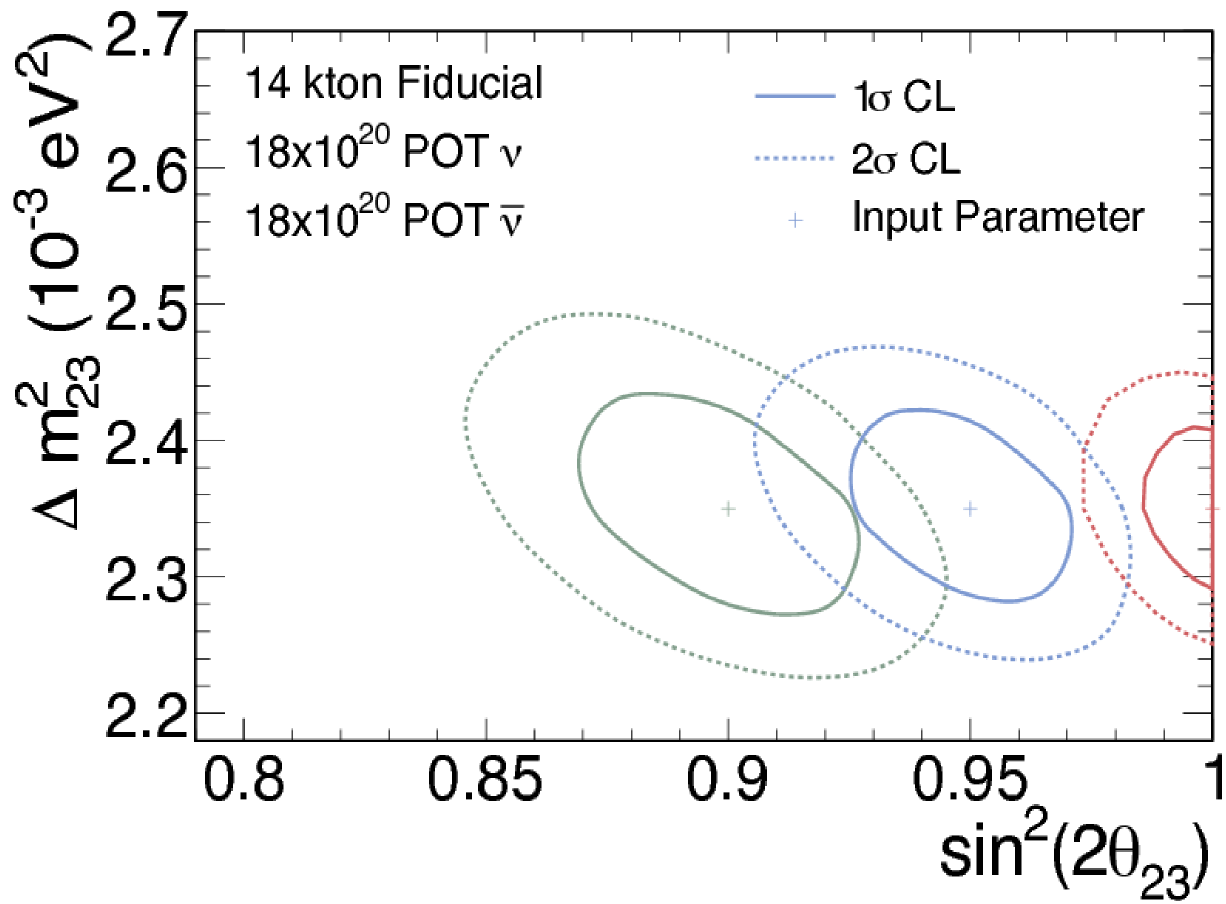




By running for 3 + 3 years (ν and $\bar{\nu}$) NOvA may resolve the mass hierarchy if θ_{13} is large enough

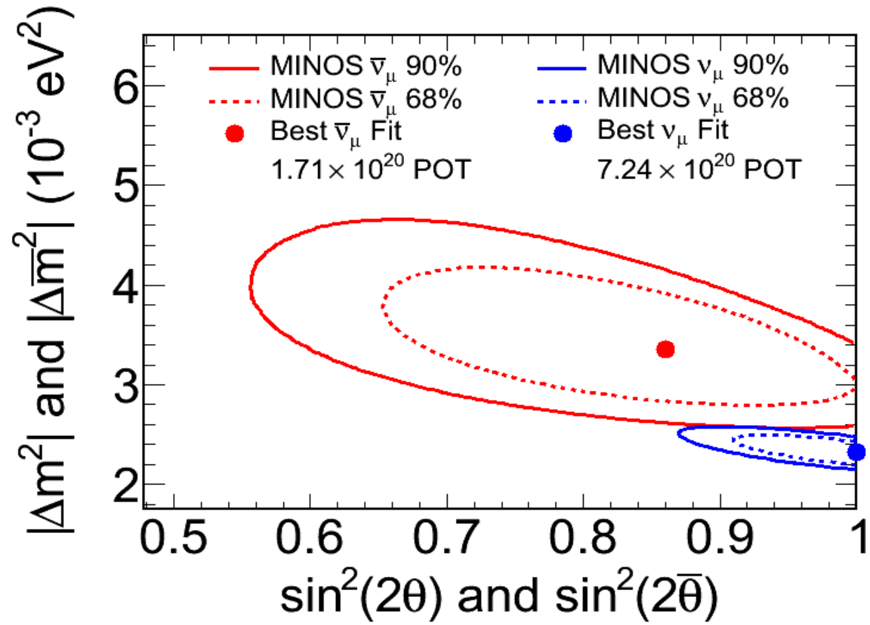
Precision measurements of Δm^2_{32}, θ_{23}

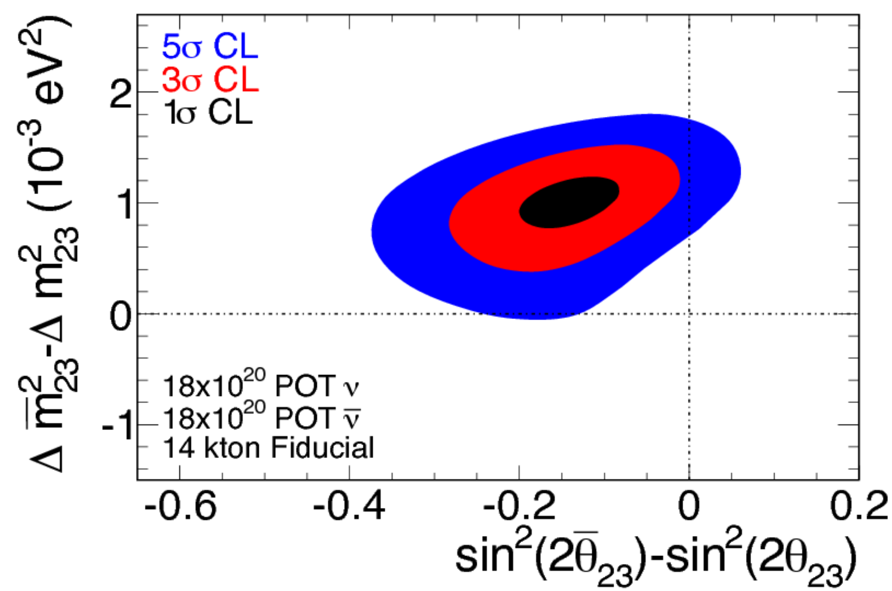
- Sensitivity to Δm^2_{32}, θ_{23} after 3 years each of neutrino and antineutrino beam
- Contours for Δm^2_{32} at the fit value of 2.35×10^{-3} eV^2 and different values for $\sin^2(2\theta_{23})$
- NOνA will improve the MINOS measurement of Δm^2_{32} and can measure $\sin^2(2\theta_{23})$ to better than 2% due to large detector mass and excellent energy resolution of charged current events $(\nu_\mu + n \rightarrow \mu + p)$
- More precise test whether $\sin^2(2\theta_{23})$ is maximal



ν and $\bar{\nu}$ Disappearance Parameters

- MINOS reported a ~2σ difference between best fit values for ν and $\bar{\nu}$ disappearance parameters (arXiV:1103.0340)
- NOνA intends to run for 3 years in neutrino mode and 3 years anti-neutrino
- **Top**: MINOS result for anti-neutrino (red) and neutrino (blue) disapperance. The solid (dashed) curves give the 90% (68%) contours.
- If MINOS central values are correct, NOνA will establish the difference with 3σ significance in 2 years, 5σ in 6 years
- **Bottom**: NOνA results after full 6 year run, 3+3 years in neutrinos+ antineutrinos.





Status and Timeline

NuMI Beam:
- Upgrade from 320 kW to 700 kW
- In order to achieve this...
  - Accelerator shutdown: March 2012

Far Detector:
- Construction starting January 2012
- 50% completion by end of shutdown
- Complete by early 2014

Near Detector:
- Cavern excavation during shutdown
- NDOS: Running since October 2010...

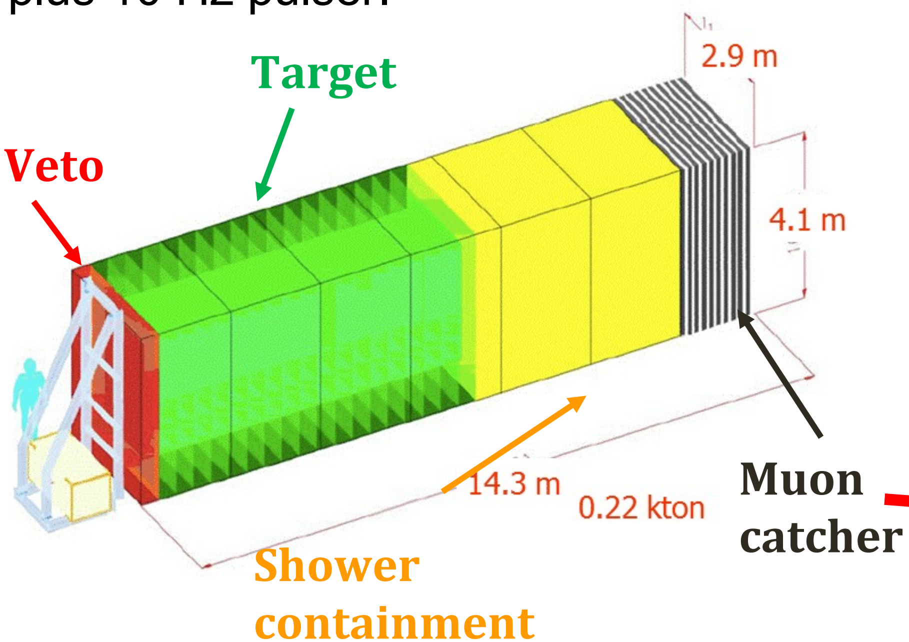
Far Detector laboratory entrance

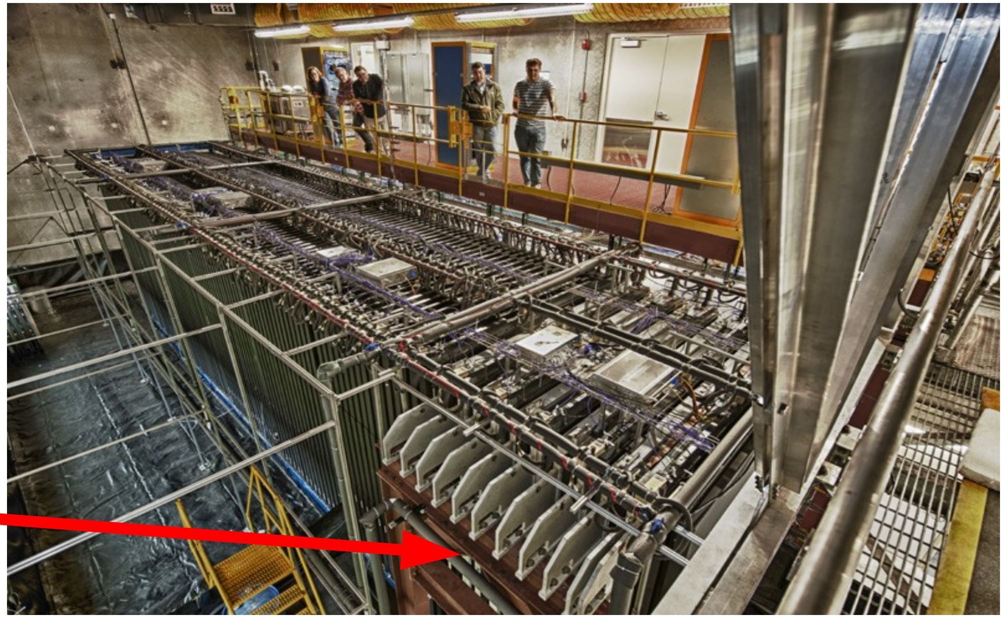
Far Detector

Far Detector laboratory complete!
Beneficial occupancy of Ash River laboratory on April 13th 2011

NDOS:
Near Detector On the Surface

- Prototype Near Detector collecting data since October 2010
- 6 blocks of 31 alternating orthogonal planes and a muon catcher are installed and filled with scintillator.
- ~50% of the detector is instrumented with electronics
- Gets triggers (500 μs wide) from NuMI (6.4° off-axis) and Booster (~on-axis) beams, plus 10 Hz pulser.

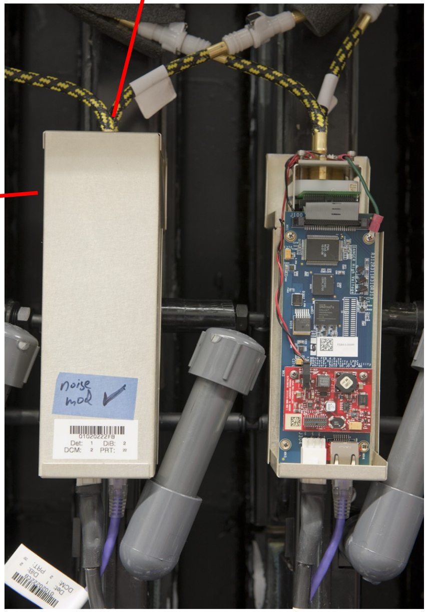




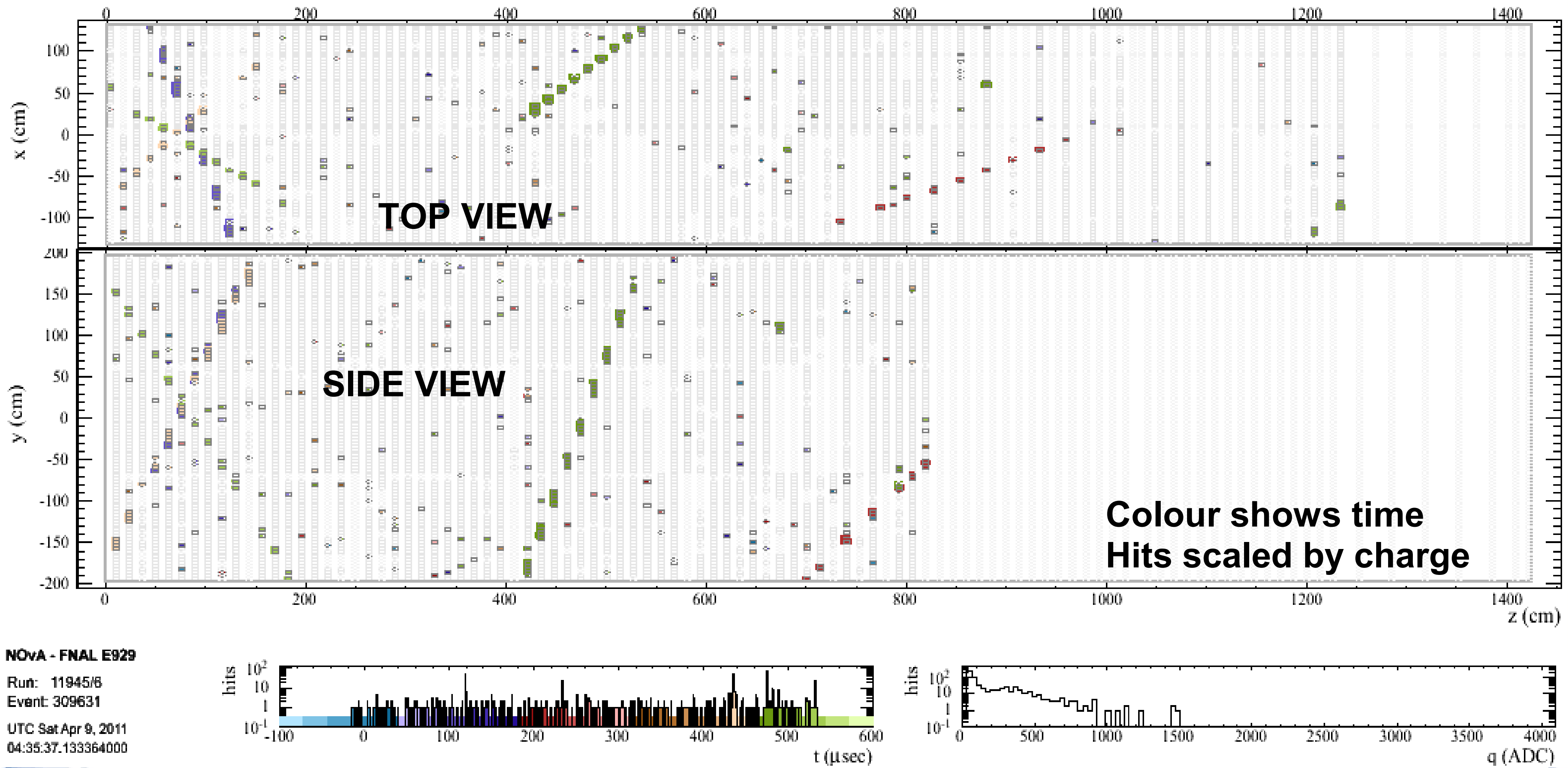
See Susan Lein's talk (Friday, 8:00am) for details of NDOS performance

Lessons Learned

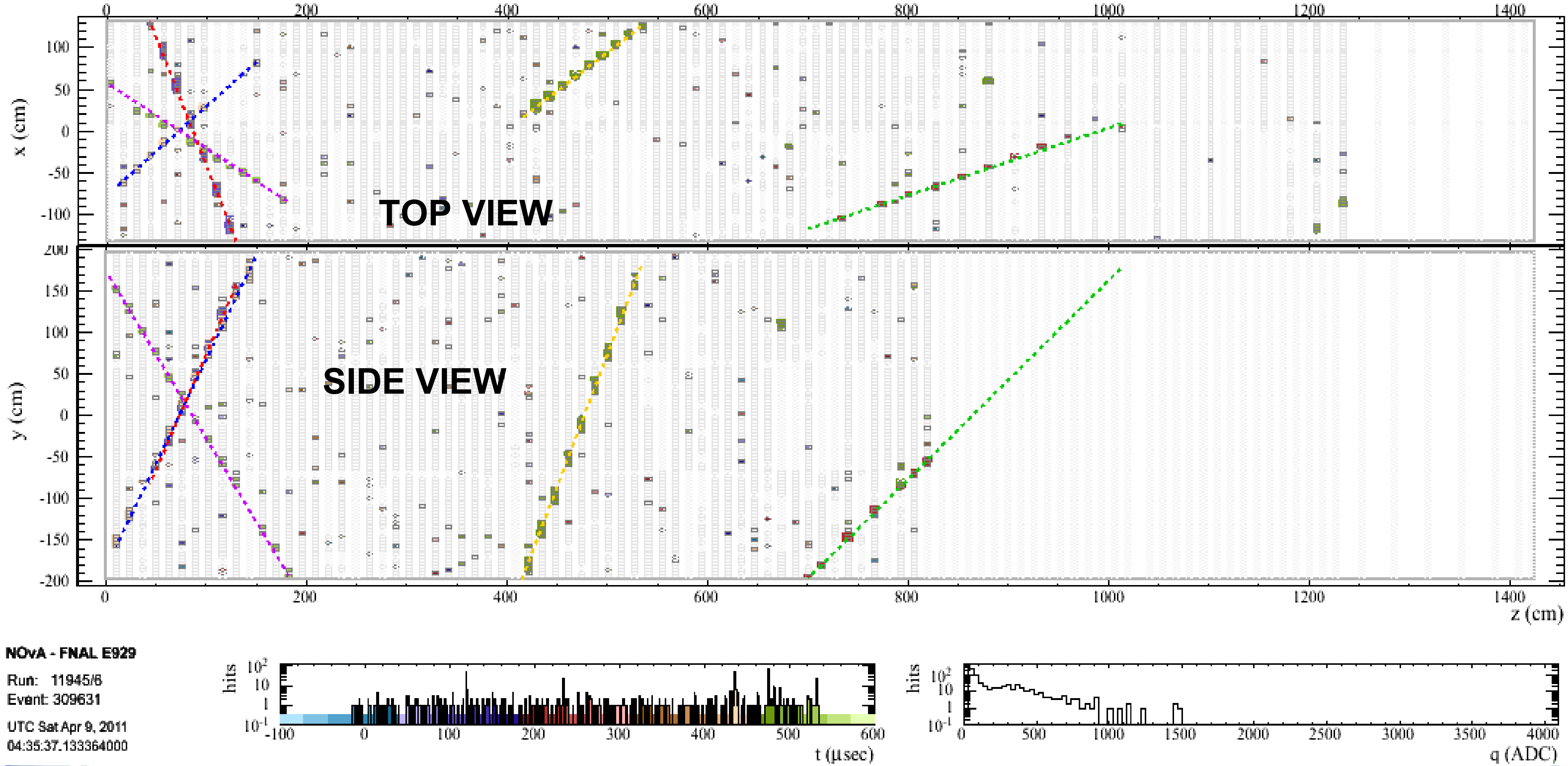
- 22% of module manifolds developed cracks
  - '*Splints*' to fix NDOS; Redesign of manifolds
  - Change module pressure testing procedure
- Experience qualifying and filling scintillating oil
- We are using bare APDs
  - Extremely sensitive to all kinds of contamination
  - Cleanliness issues led to noisy channels
  - New installation procedures
  - New APD surface coating under investigation



Cosmic Rays in NDOS



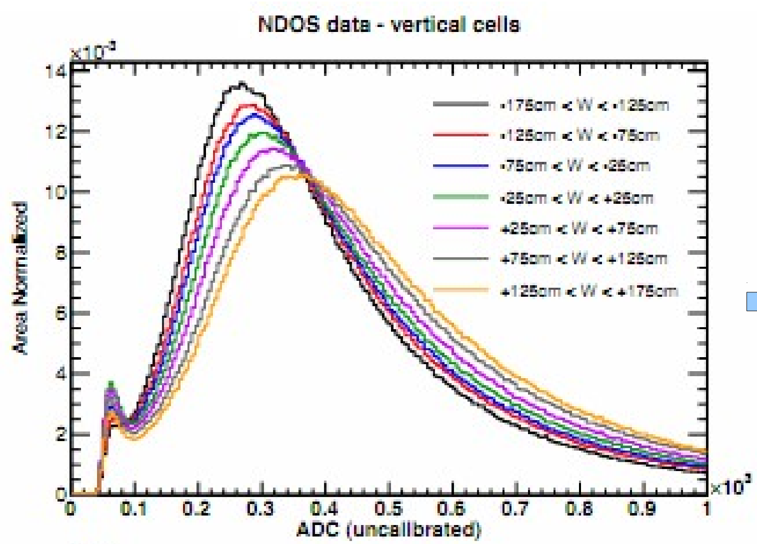
Cosmic Rays in NDOS

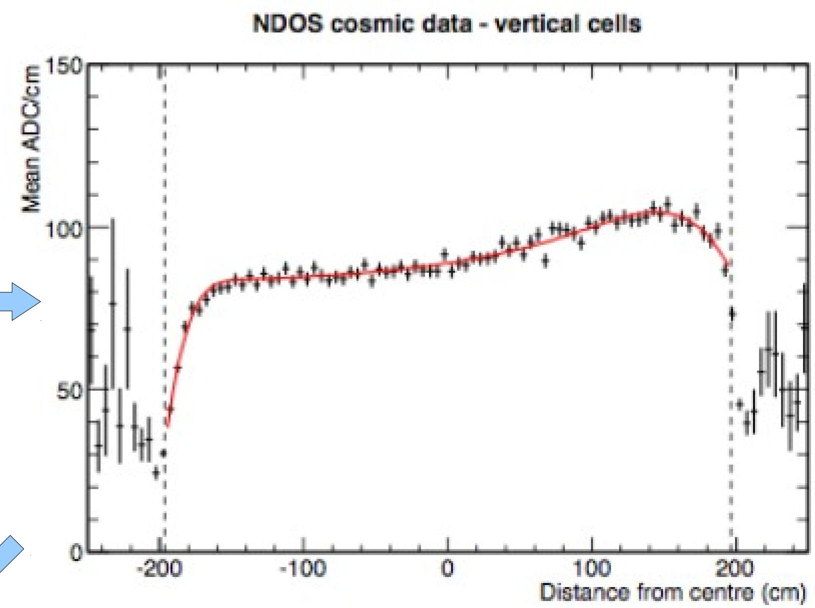


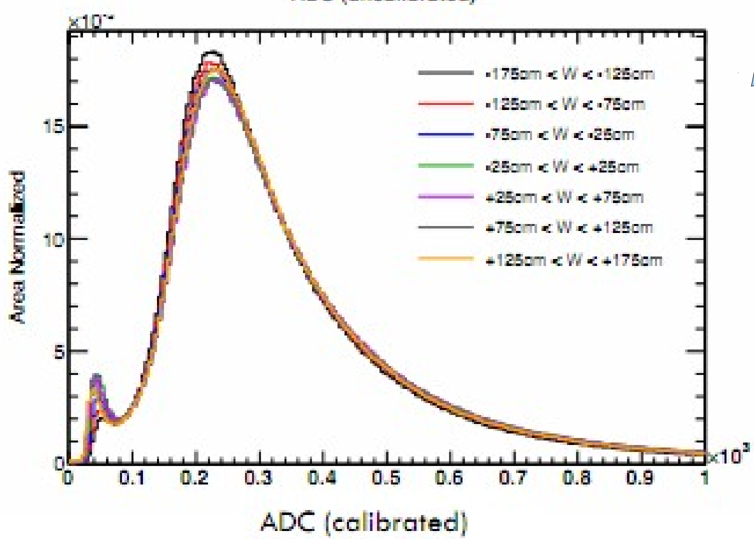
See Nick Raddatz's talk (Friday, 8:40am) for details of particle tracking in NOvA

Calibration

Using cosmic muons as an intra-detector calibration source: Cell-by-cell calibration

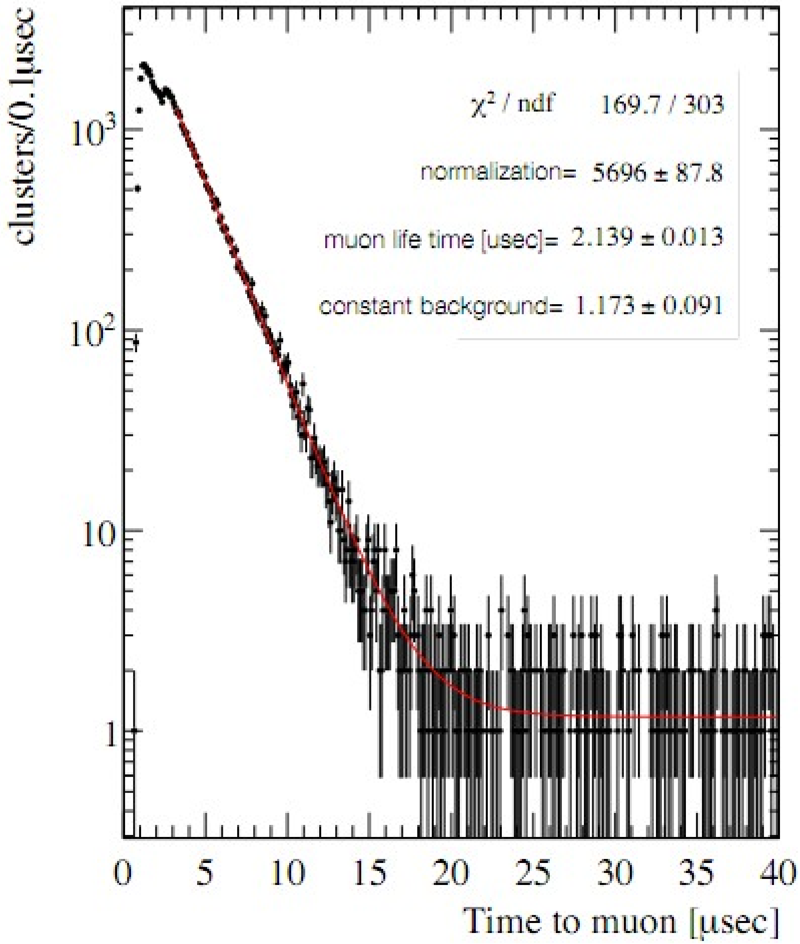


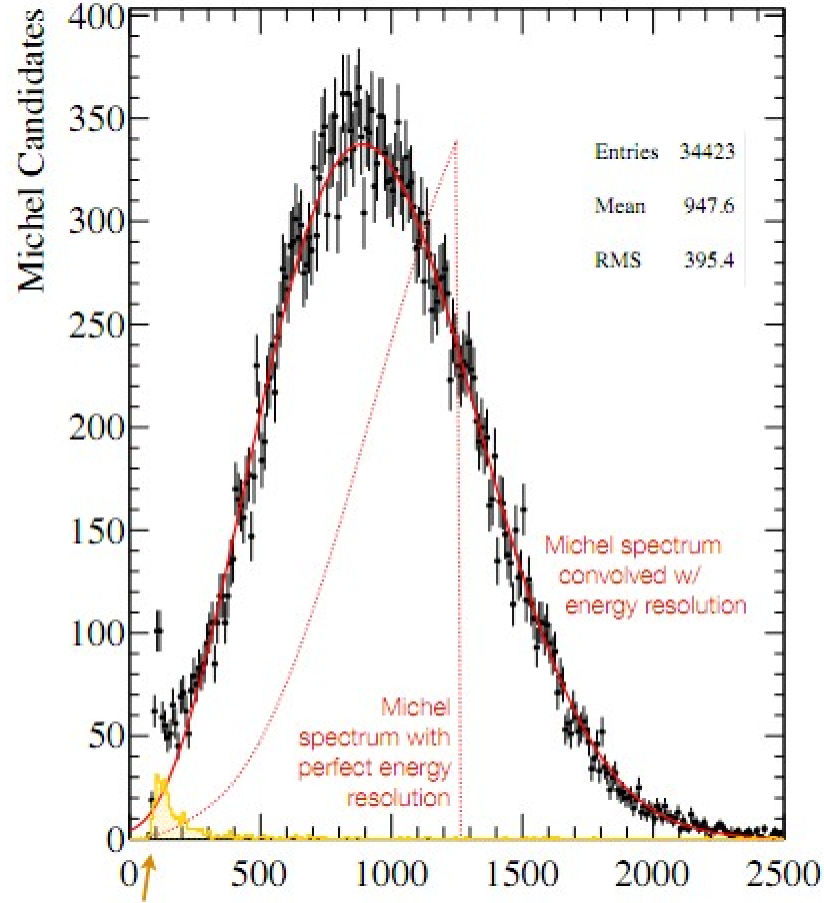




Top left: Path length-corrected muon response for different distances from fiber end for a single example cell
Above: Measured and fitted fiber attenuation for the example cell
Bottom left: Muon response after attenuation corrections

Michel Electron Calibration

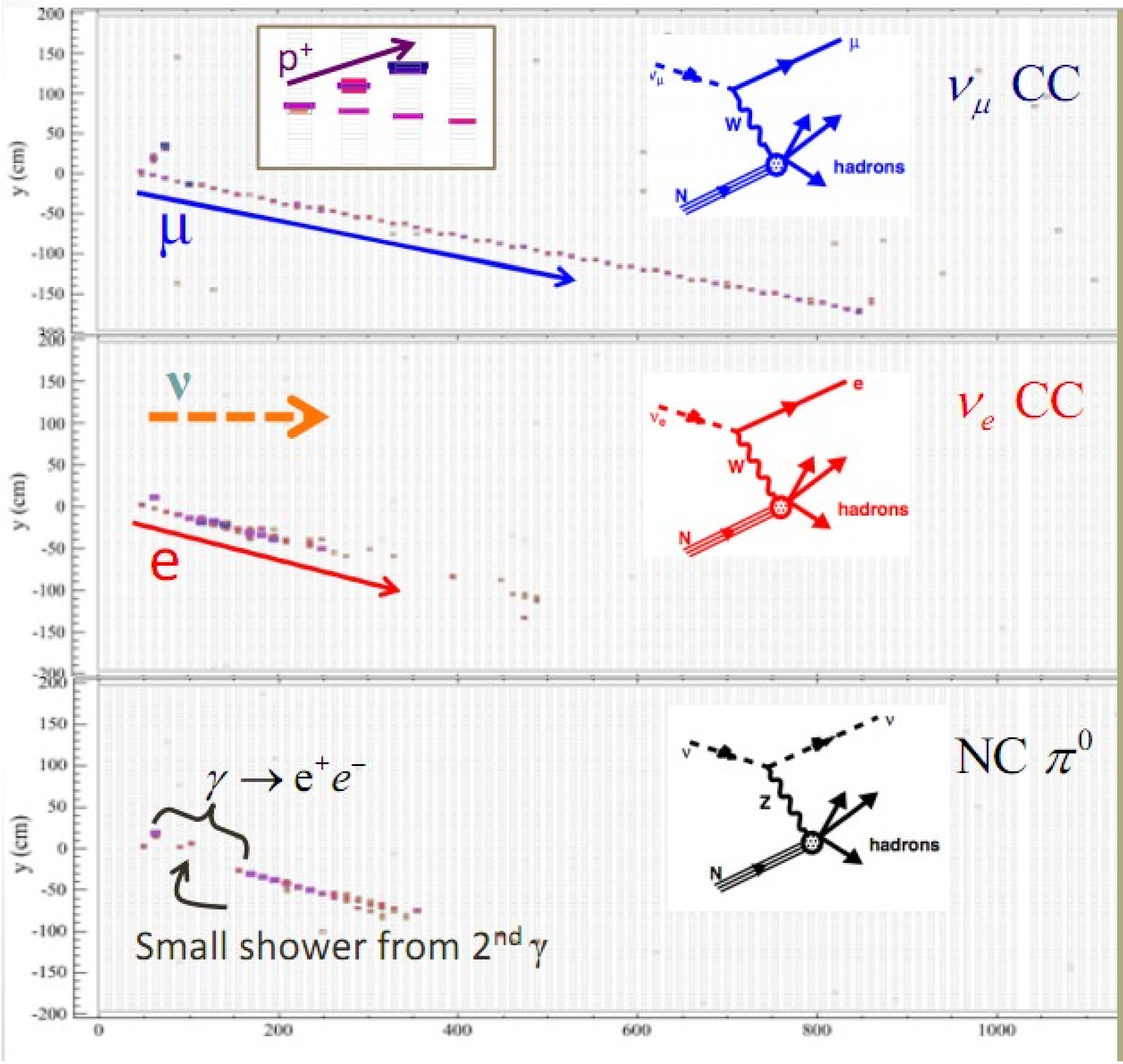




Random coincidences

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

Monte Carlo Neutrino Events



V_μ Charged-current

Long well-defined muon track, proton is a short track with large energy deposition at the track end.

V_e Charged –current

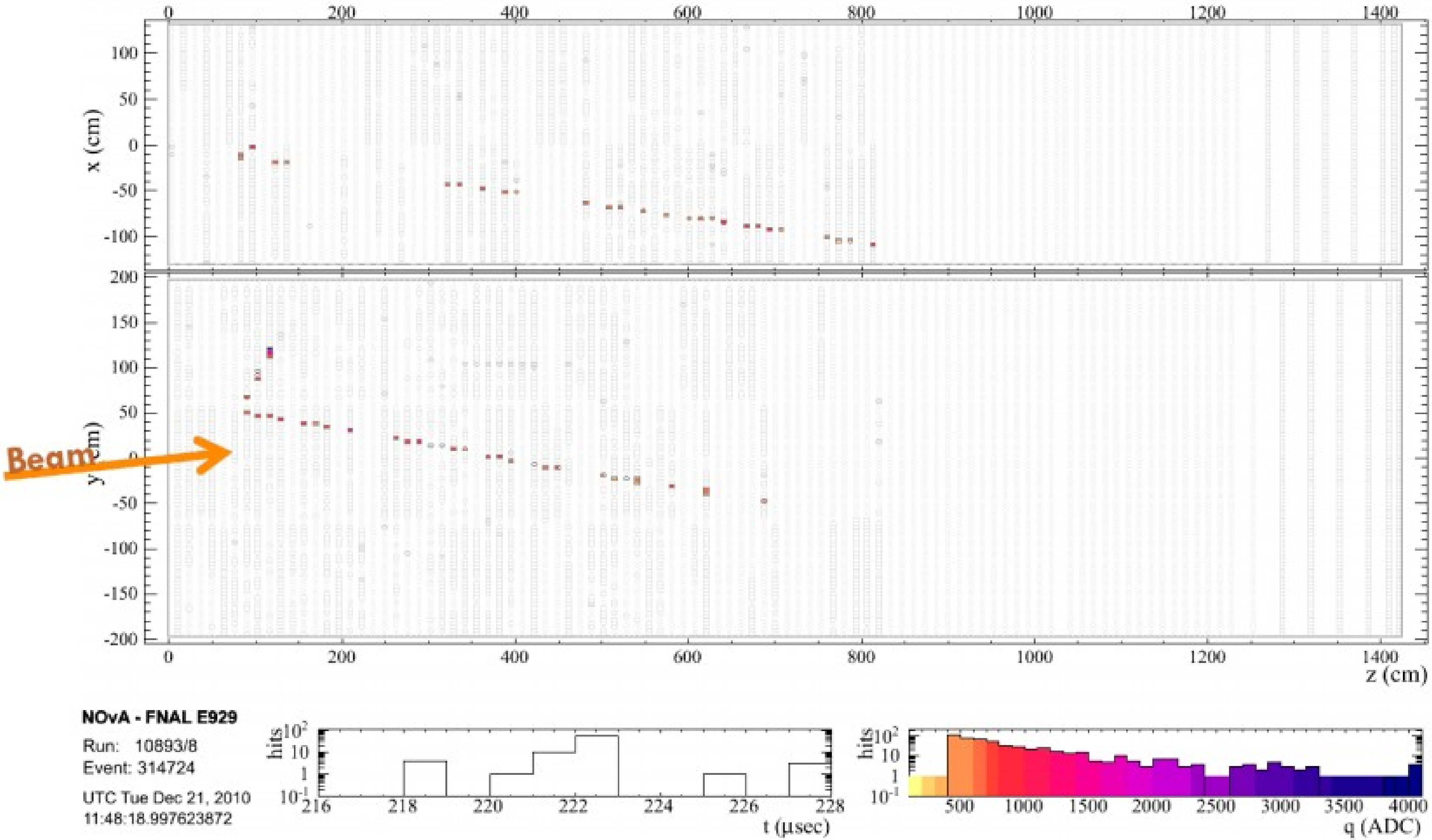
Single shower with characteristic e-m shower development.

NC with π^0 in final state

Possible gaps near event vertex, multiple displaced e-m showers.

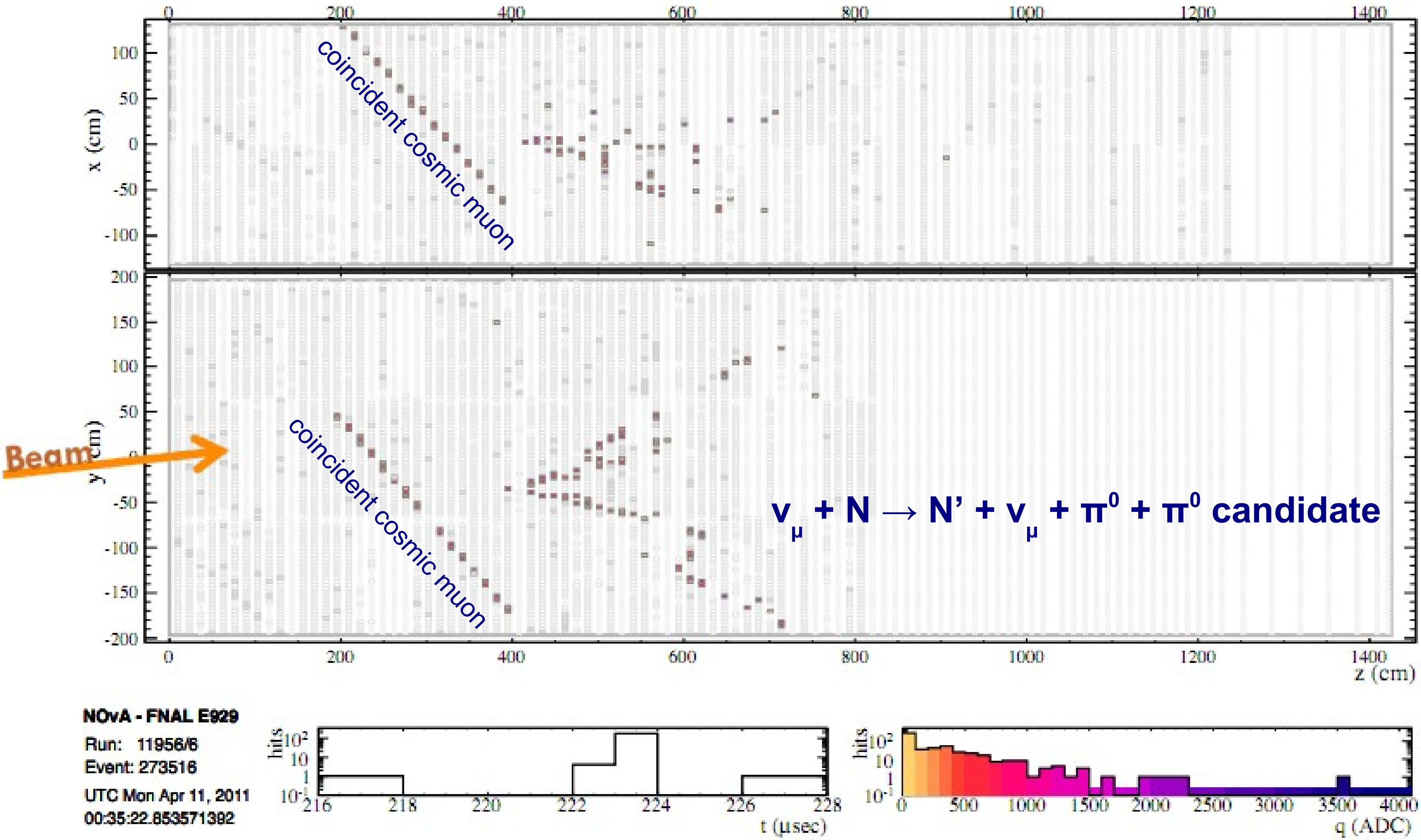
Neutrinos in NDOS

DATA



Neutrinos in NDOS

DATA



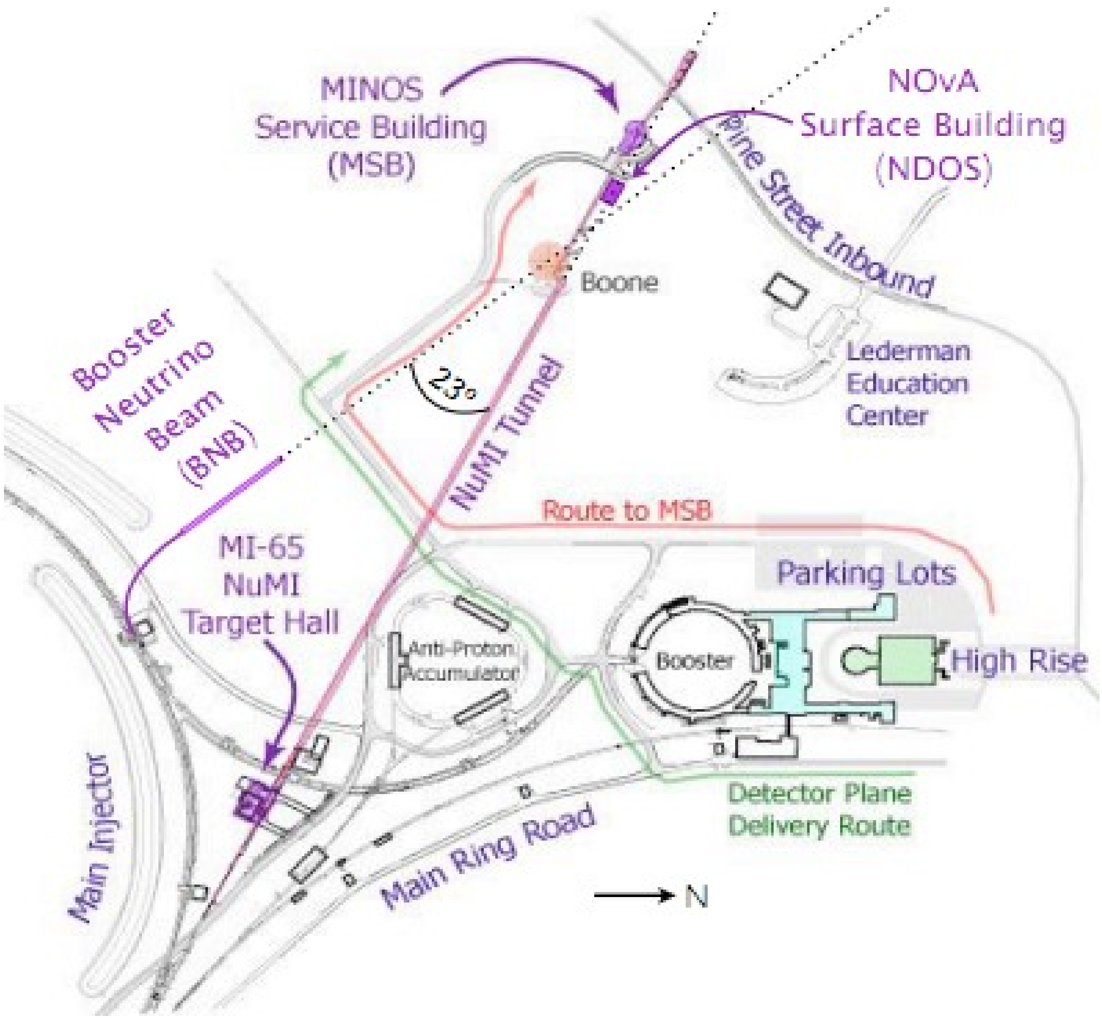
See Jarek Nowak (Thursday, 10:50am) and Minerba Betancourt's (Thursday, 11:10am) talks for details of neutrino interactions and early neutrino data in NOvA's NDOS

Summary

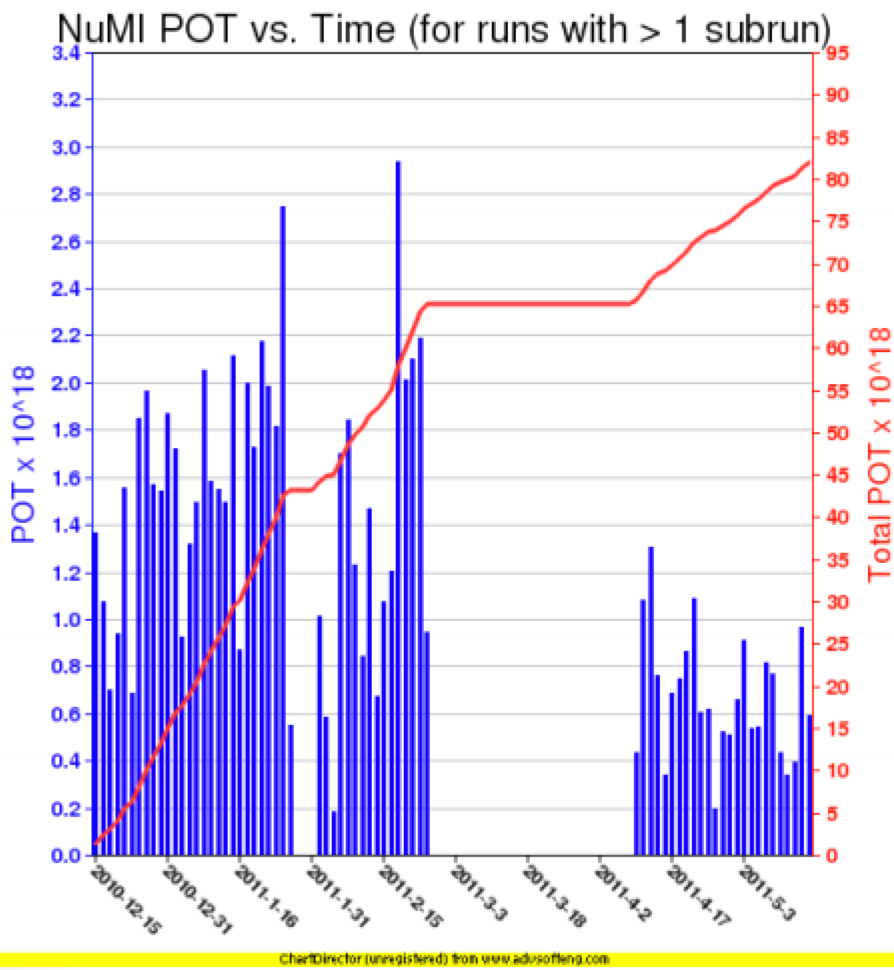
- NOνA is the flagship project of Fermilab's Intensity Frontier initiative
- Recent results from T2K and MINOS are very encouraging for the NOνA goals
- NOνA is on track to make many important contributions to neutrino physics
  - Measurement of θ_{13}
  - Determination of mass hierarchy
  - More precise measurements of Δm^2_{32}, $\sin^2(2\theta_{23})$
- Far detector construction is underway.
  - Far detector laboratory complete
  - 14 kt complete by early 2014
- Prototype near detector (NDOS) operational on surface at Fermilab
  - Extremely valuable preparation for construction at Ash River
  - Early look at real cosmic rays and neutrinos
  - Headstart on calibration techniques and physics analyses
- Reminder: **5 more NOνA talks at this meeting...**

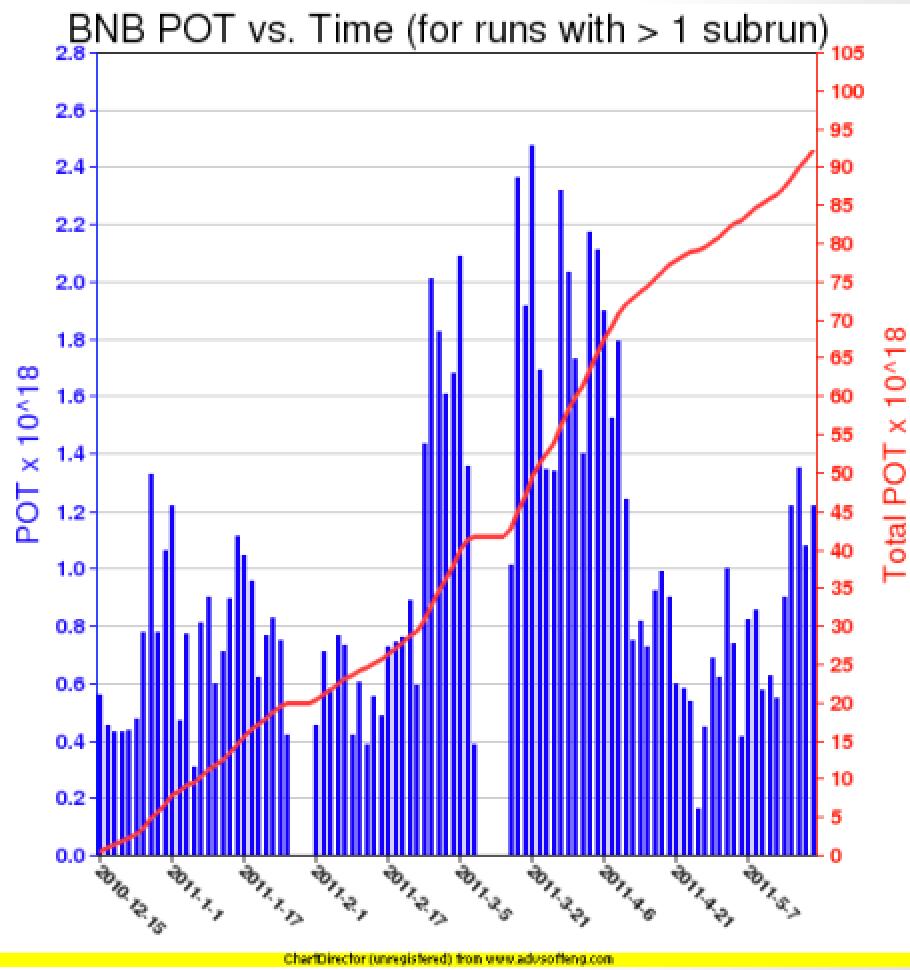
BACKUP SLIDES

NDOS Location

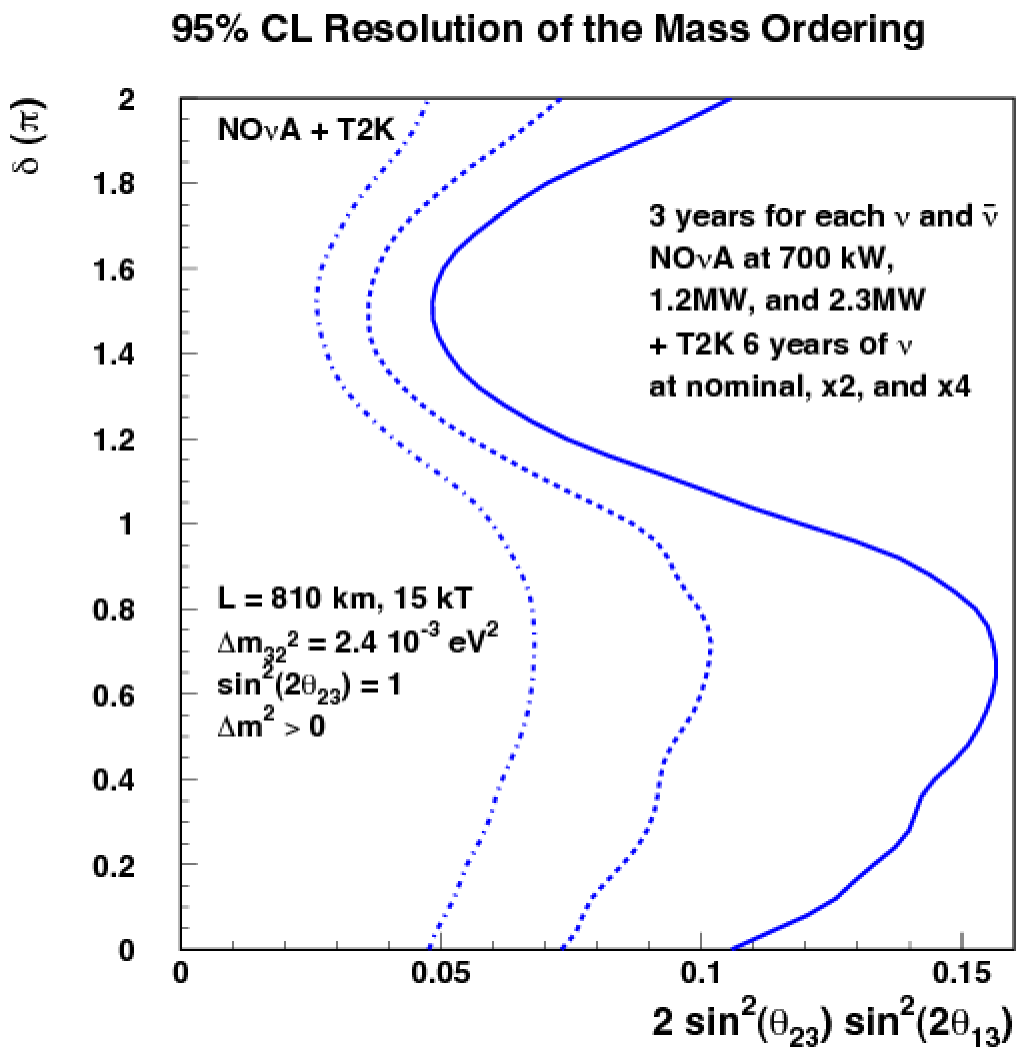


POT accumulated





Resolving the mass hierarchy



NOvA + T2K resolves the neutrino mass hierarchy at 95% C.L or better.

Assumes nature has a normal hierarchy.

For $\delta_{CP} > \pi$, NOvA resolves the hierarchy on its own by comparing measurements using neutrino and anti-neutrinos.

For $\delta_{CP} < \pi$, comparison of T2K's measurement using neutrinos at the first oscillation maximum (limited matter effects) and NOvA's measurement at the first oscillation maximum (matter effects) helps break the ambiguity in the comparison of NOvA's neutrino measurement to its anti-neutrino measurement.

Constraining δ_{CP}

Combining NOvA with T2K in worst case