The NOνA Experiment - Overview and Status

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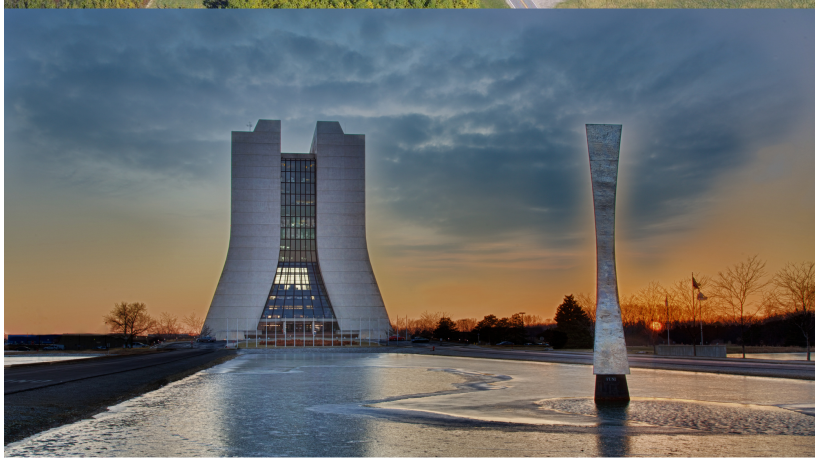
NOνA Collaboration

36 Institutions from 7 countries
181 collaborators

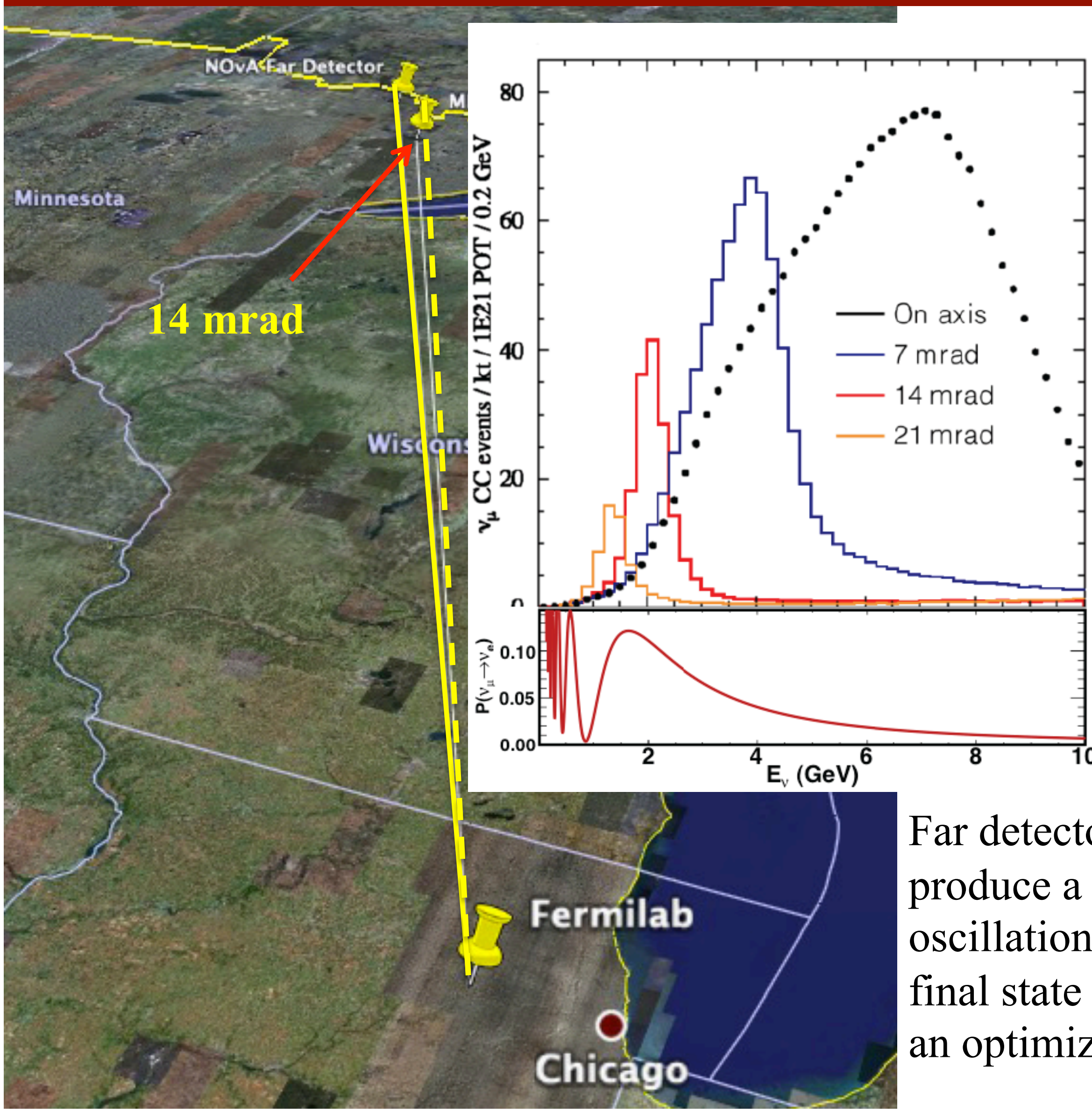
- Argonne National Laboratory·University of Athens·Banaras Hindu University·California Institute of Technology·Institute of Physics of the Academy of Sciences of the Czech Republic·Charles University, Prague·University of Cincinnati·Czech Technical University·University of Delhi·Fermilab·Federal Univ. of Goias · IndianInstitute of Technology, Guwahati·Harvard University·Indian Institute of Technology·University of Hyderabad·Indiana University· Iowa State University·University of Jammu·Lebedev Physical Institute·Michigan State University·University of Minnesota, Crookston·University of Minnesota, Duluth·University of Minnesota, Twin Cities·Institute for Nuclear Research, Moscow·Panjab University·University of South Carolina·Southern Methodist University·Stanford University·University of Sussex·University of Tennessee·University of Texas at Austin·Tufts University·University of Virginia·Wichita State University·Winona State University·College of William and Mary

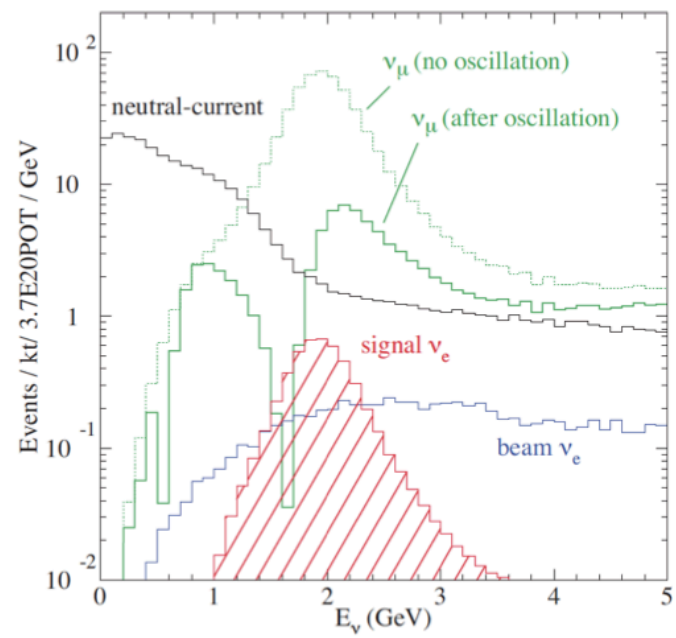
NuMI Off-Axis ν_e Appearance Experiment



- NOνA is a 2-detector ν oscillation experiment, optimized for ν_e identification.
- Upgrading NuMI muon neutrino beam at Fermilab (700 kW).
- Construct a 14 kt liquid scintillator far detector at a distance of 810 km (Ash river, Minnesota) to detect the oscillated beam.
- Functionally identical ~300 ton near detector located at Fermilab to measure unoscillated beam ν to estimate backgrounds in the far detector.

NuMI Off-Axis ν_e Appearance Experiment





Far detector is sited 14 mrad off-axis to produce a narrow-band beam around the oscillation maximum region. Combining with final state interaction cross sections, provides an optimized signal/background separation.

NOνA Physics Goals

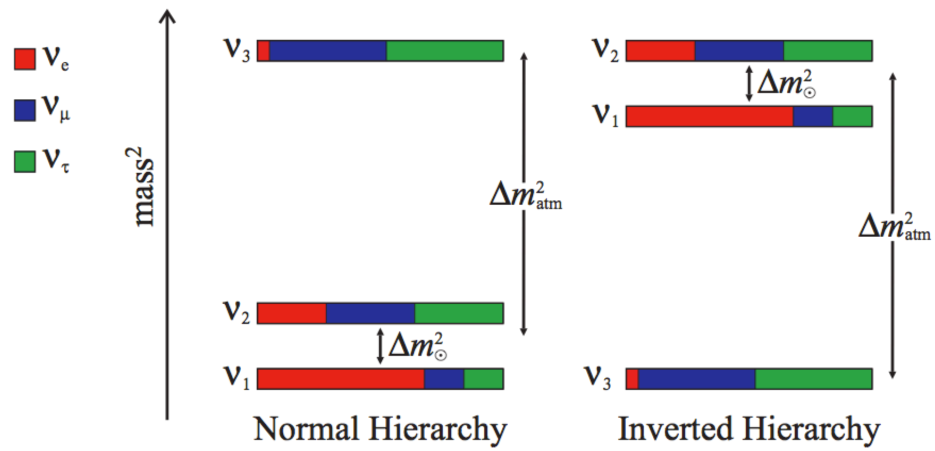
Measuring ν_e appearance probability and ν_μ disappearance probability with ν_u and anti-ν_u beam.

ν_e appearance:

- Measure θ_{13}
- Determine neutrino mass hierarchy
- Resolution of the θ_{23} octant.
- Constrain CP violation phase (δ_{CP})

ν_μ disappearance:

- Precise measurements of $|\Delta m_{32}^2|$, θ_{23}
- (Details see Baird's talk)

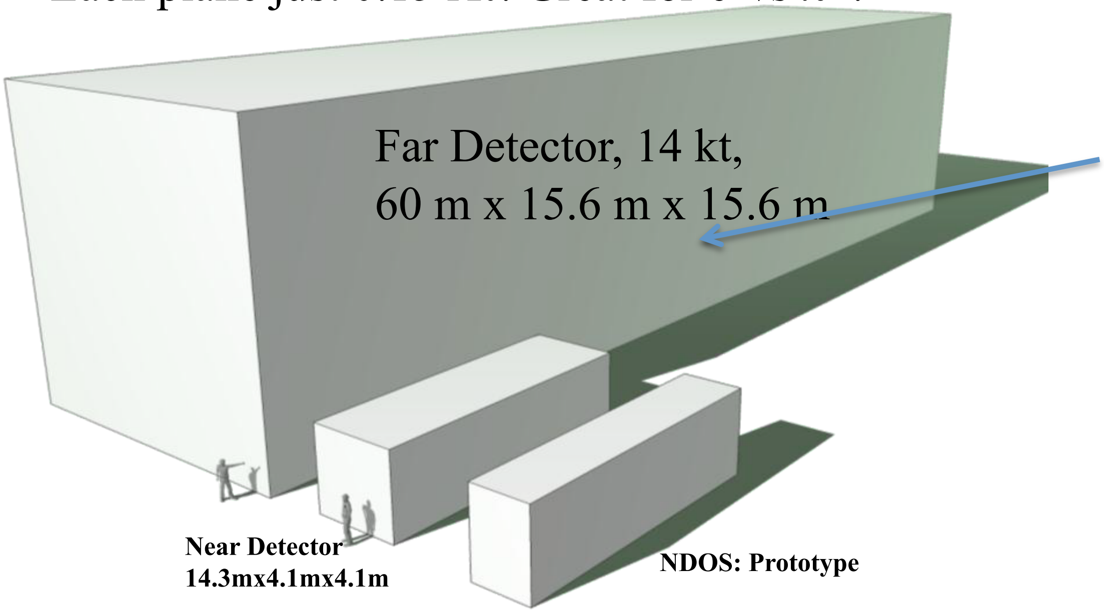


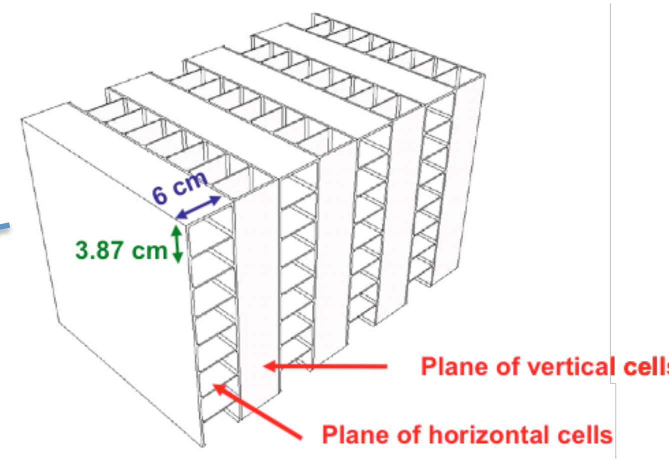
As well as:

- ν_μ cross sections.
- Neutrino magnetic moment.
- Supernova and monopoles.
- Sterile neutrinos.
- Non-standard neutrino interactions.

The NOνA Detectors

- 14-kton Far Detector (~3x MINOS).
- 9-kton active detector.
- 344,064 detector cells read by APDs.
- 0.3 kton Near Detector 18,000 cells/channels.
- Each plane just 0.15 X_0. Great for e^- vs π^0 .

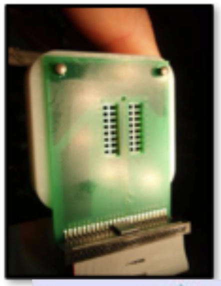




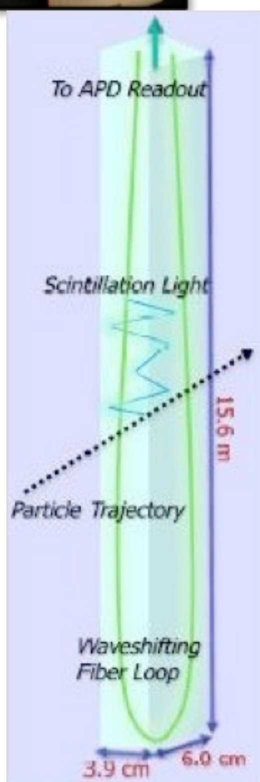
Consist of plastic (PVC) extrusions filled with liquid-scintillator, with wavelength shifting fibers (WLS) connected to avalanche photodiodes (APDs). Assembled in alternating layers of vertical and horizontal extrusions.

Detectors readout

32-pixel APD

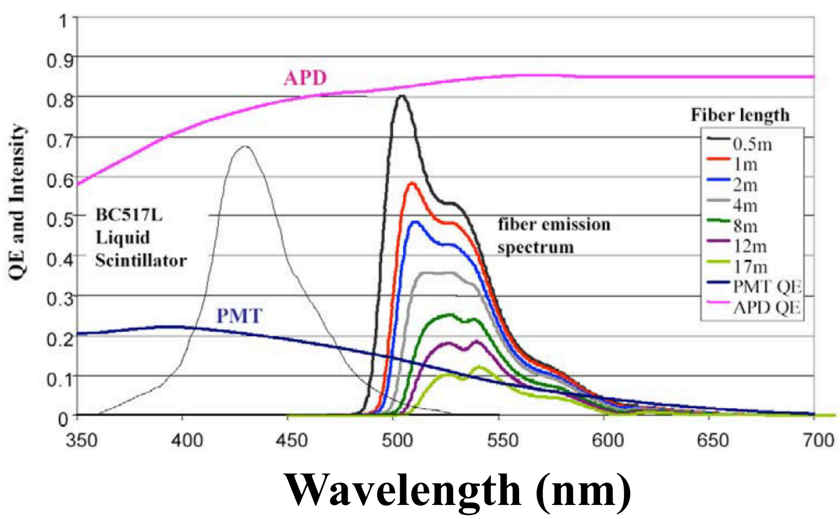


Fiber pairs from 32 cells



NOvA basic cell

Each cell has a wavelength-shifting fiber routed an Avalanche Photodiode (APD). Scintillation light emitted isotropically and captured in wavelength - shifting fibers that convert wavelength to APD's sensitive region.

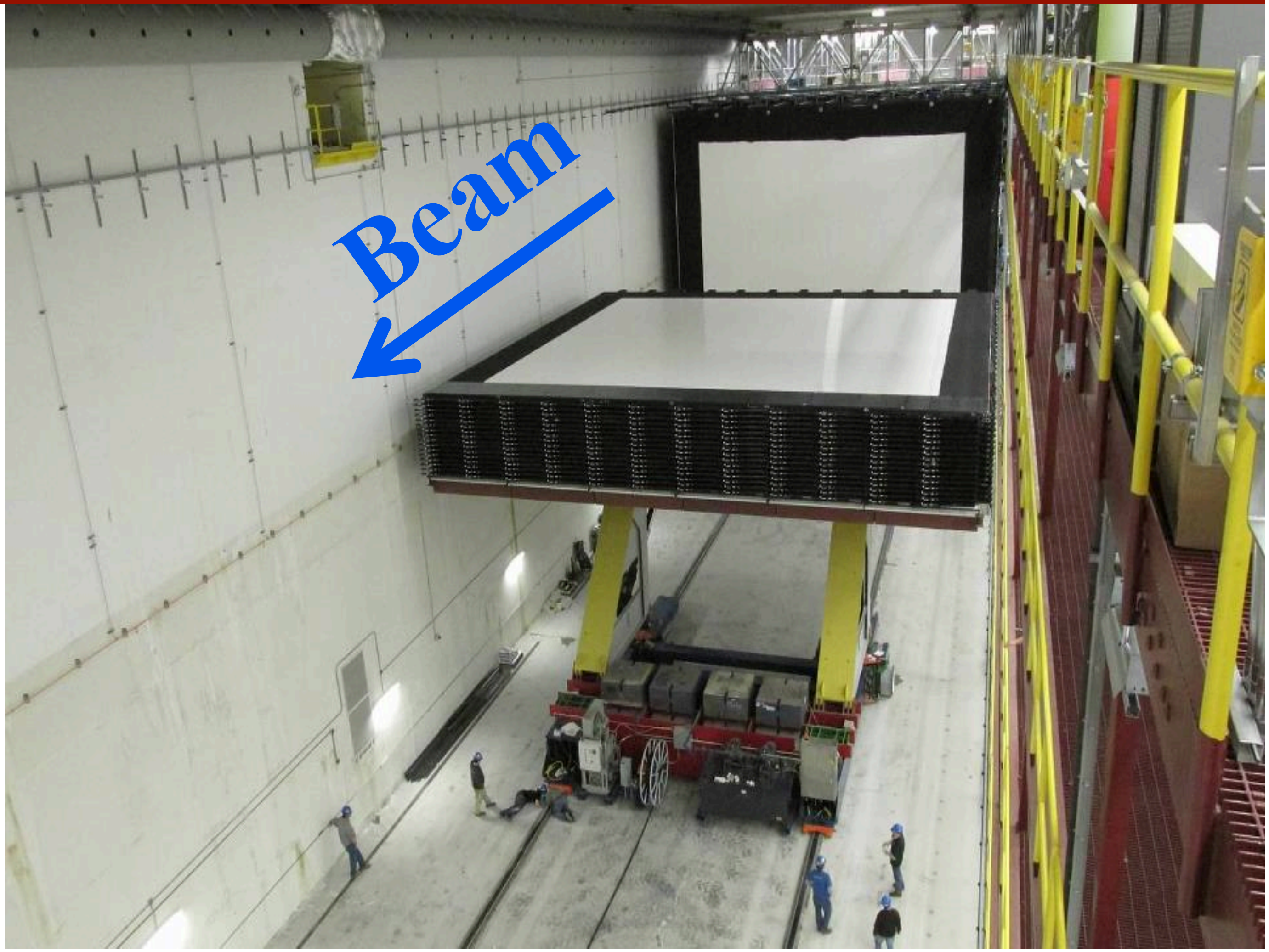


APDs have high quantum efficiency and uniform spectral quantum efficiency. This enables the use of very long scintillator modules, thus significantly reducing the electronics channel count.

Far detector construction

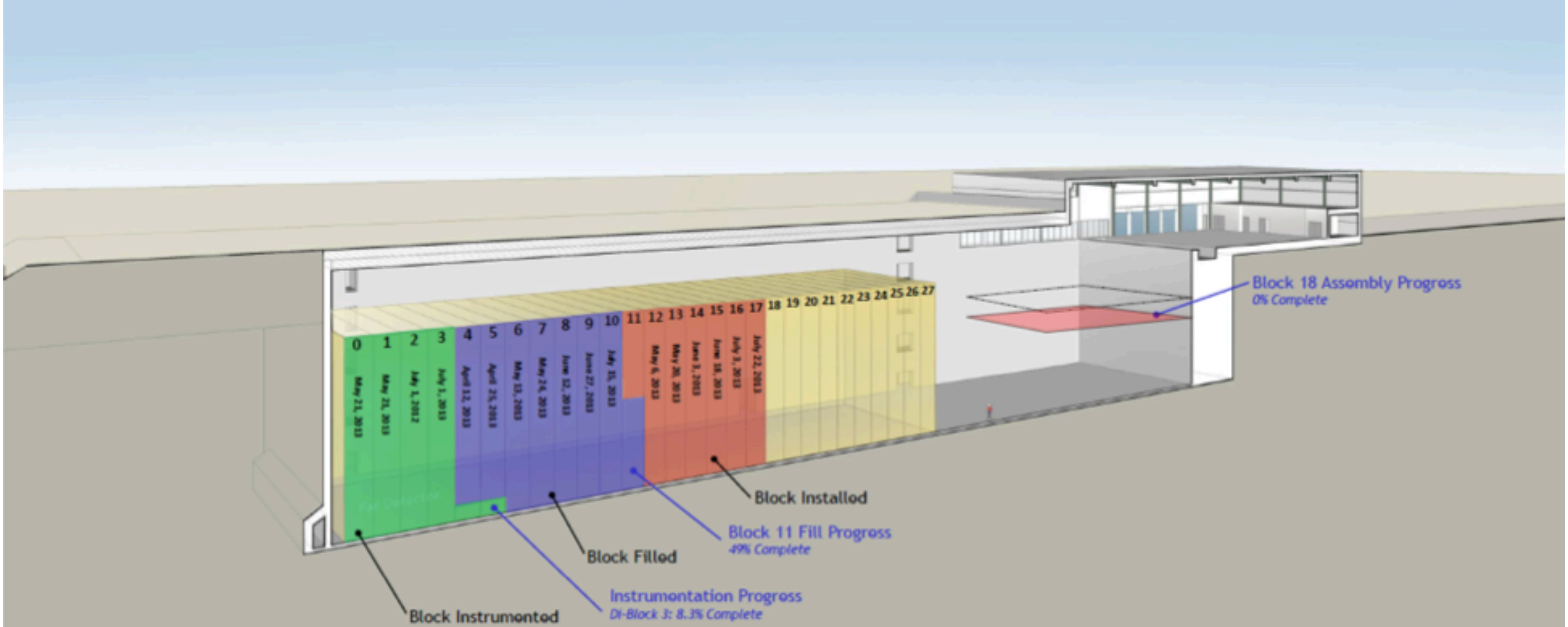
Far Detector:

- The site at Ash River was completed last year.
- 64% blocks have been installed, 41% of the detector has been filled, 15% blocks have been outfitted with electronics (July22, 2013).
- Completion expected by May, 2014.



Far detector construction

status date: July22, 2013



14 kilotons = 28 NOvA Blocks

18 blocks of PVC modules are assembled and installed in place

11.49 blocks are filled with liquid scintillator

4.17 blocks are outfitted with electronics

Near detector construction

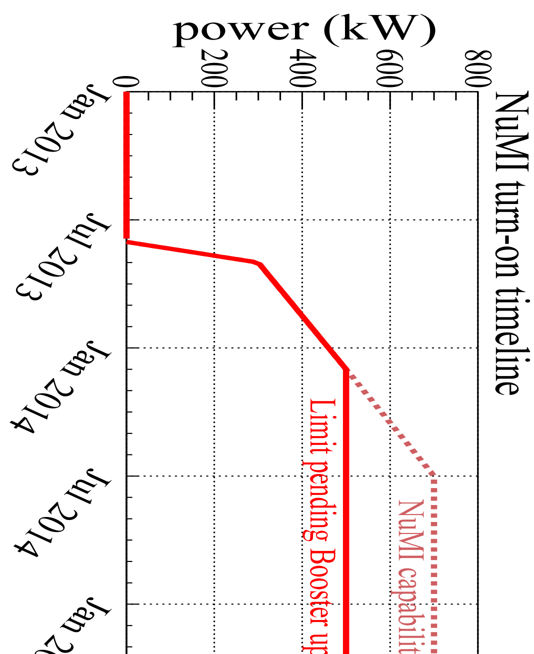
Near Detector:

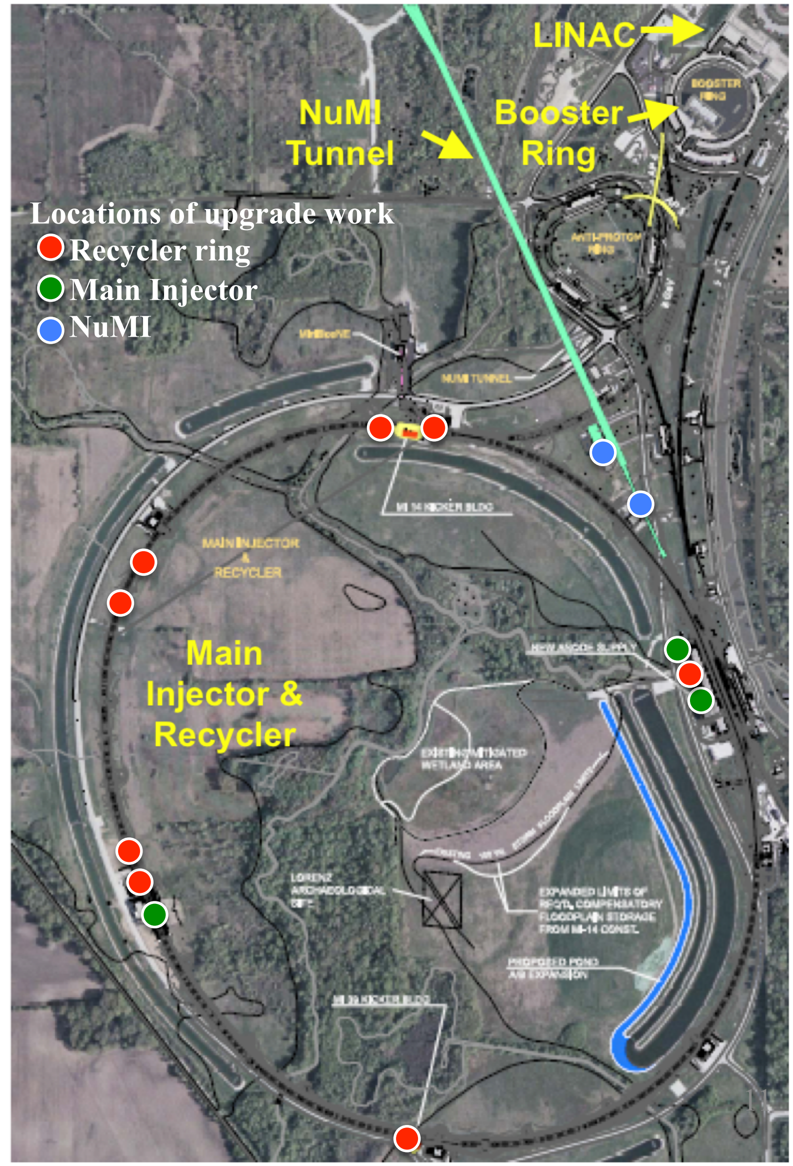
- Cavern excavation is complete.
- Muon catcher installed Aug. 1, 2013
- First half to be installed by end of this year.
- Second half to be installed by summer 2014

Accelerator and NuMI Upgrades

- Fermilab has completed a series of upgrades to the Main Injector and Recycler Rings to reduce the cycle time from 2.2 s to 1.3 s
- Intensity increased from 300 to 700 kW
- Neutrino beamline optimized for NOvA

- Commissioning of accelerators is now underway; routine operation of neutrino beam is expected in September
- Intensity will ramp to 500 kW this year and later to 700 kW

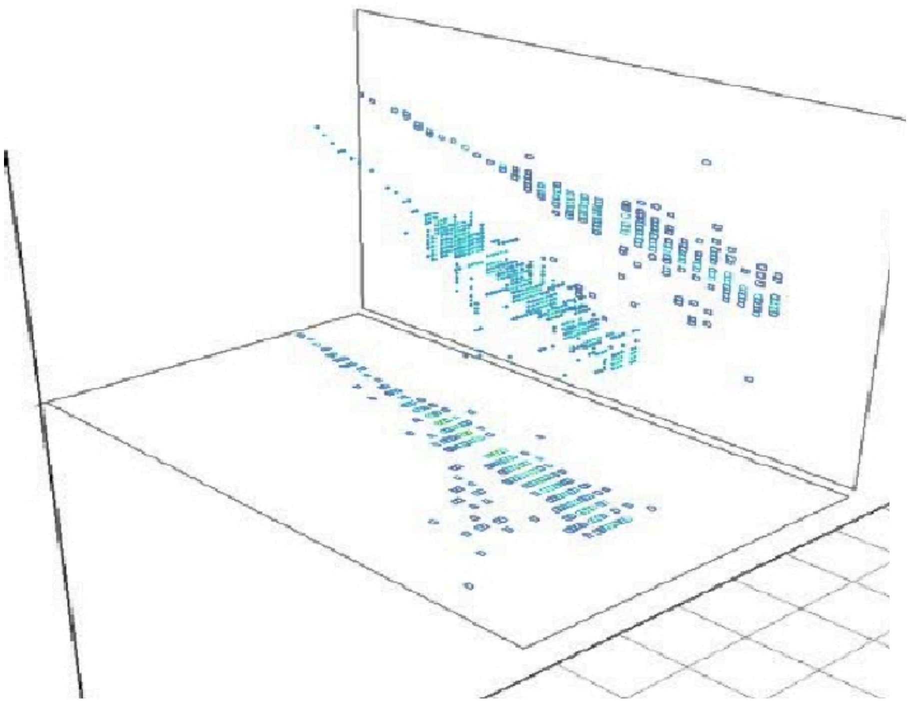


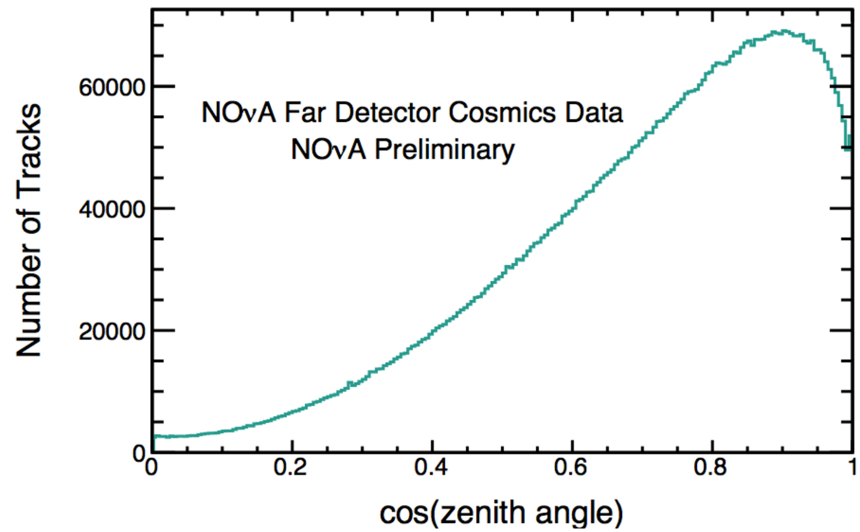


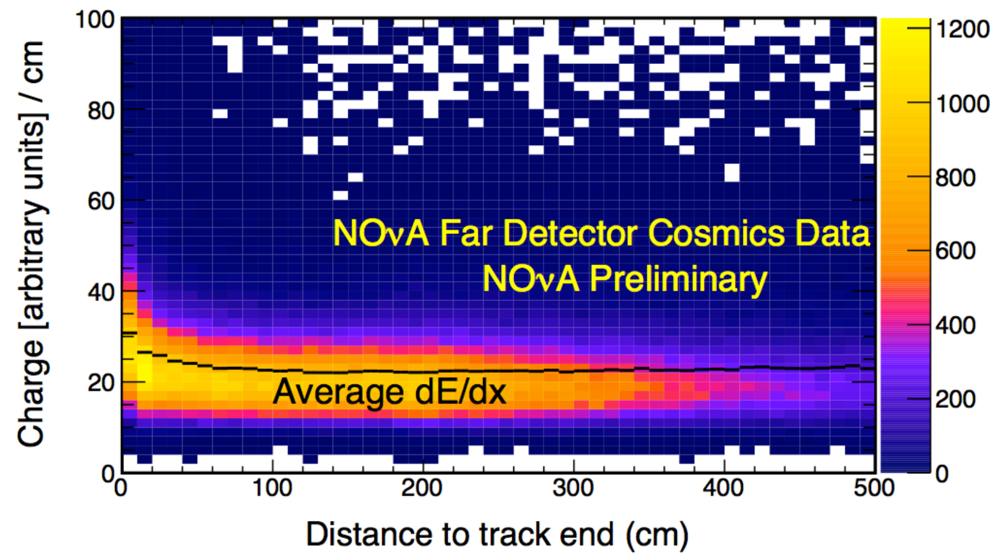
Cosmic ray data – 1st kT FD

First kT has been instrumented May 21, 2013. Reconstruction algorithms already tested on these data.

3D Event display for a cosmic event







ν_e appearance at NOνA

$$P(\nu_\mu \to \nu_e) \approx \sin^2 2\theta_{13} \sin^2\theta_{23} \frac{\sin^2(A-1)\Delta}{(A-1)^2}$$

$$+2\alpha \sin\theta_{13} \cos\delta \sin 2\theta_{12} \sin 2\theta_{23} \frac{\sin A\Delta}{A} \frac{\sin(A-1)\Delta}{(A-1)} \cos\Delta$$

$$-2\alpha \sin\theta_{13} \sin\delta \sin 2\theta_{12} \sin 2\theta_{23} \frac{\sin A\Delta}{A} \frac{\sin(A-1)\Delta}{(A-1)} \sin\Delta$$

$$A \equiv \pm \frac{G_f n_e L}{\sqrt{2}\Delta} \approx \frac{E}{11 \text{ GeV}}$$

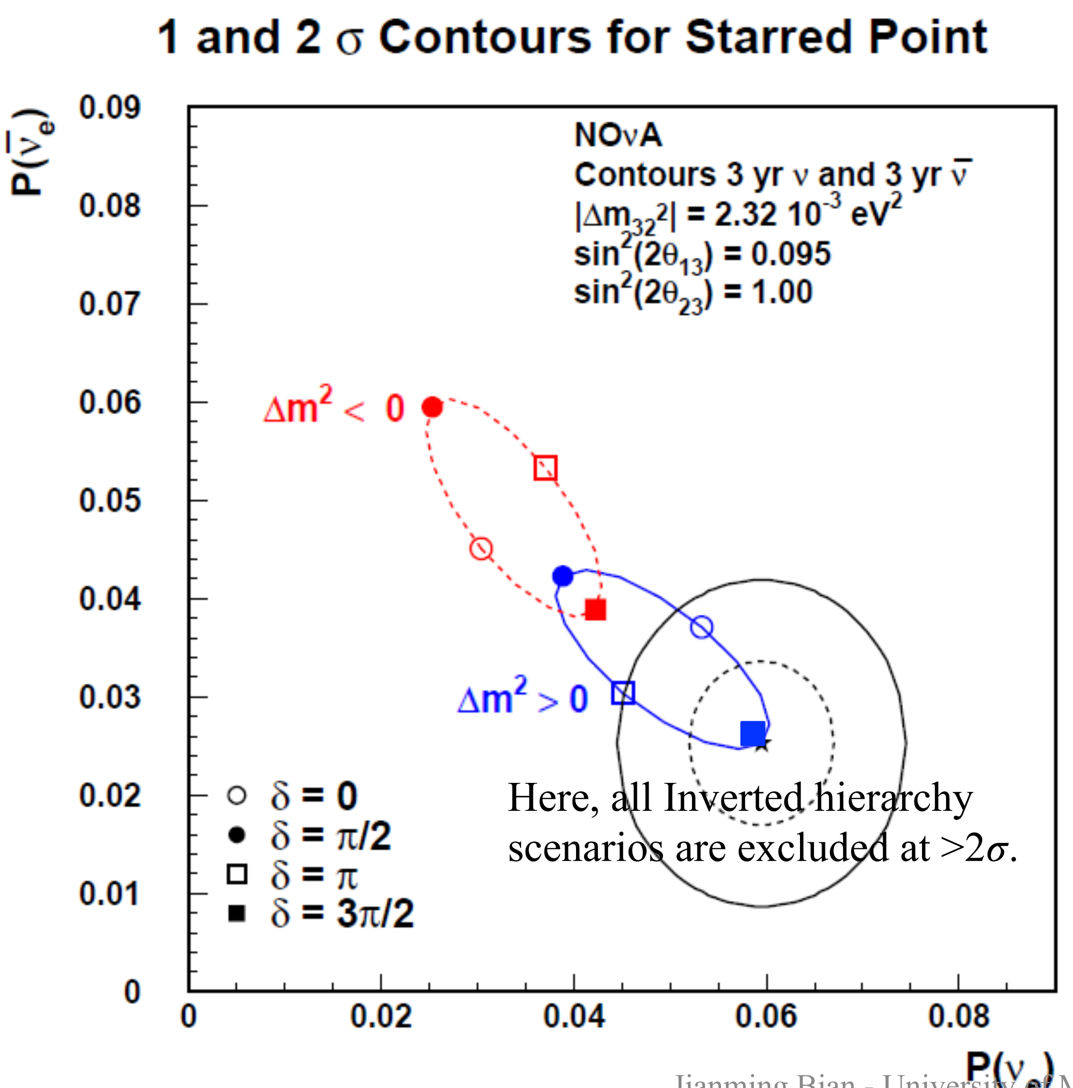
$$\Delta \equiv \frac{\Delta m^2_{31} L}{4E}$$

- We can investigate mass hierarchy due to θ_{13} is not zero.

- We have some sensitivity for δ_{CP} since θ_{13} is not zero.

- Probability is enhanced or suppressed due to matter effects which depend on the mass hierarchy as well as the sign of A which is determined by neutrino vs. anti-neutrino running.

ν_e appearance at NOνA



- Because the $P(\nu_e)$ and $P(\bar{\nu}_e)$ depend on mass hierarchy and δ_{CP} in different ways, a measurement of the probabilities might allow resolving the mass hierarchy and provide information on δ_{CP}.
- The precision of probabilities measurement depends on θ_{13}. Large θ_{13} also reduces the overlap area of NMH and IMH ellipses. So it is good news for NOνA that θ_{13} is large.

ν_e analysis tools

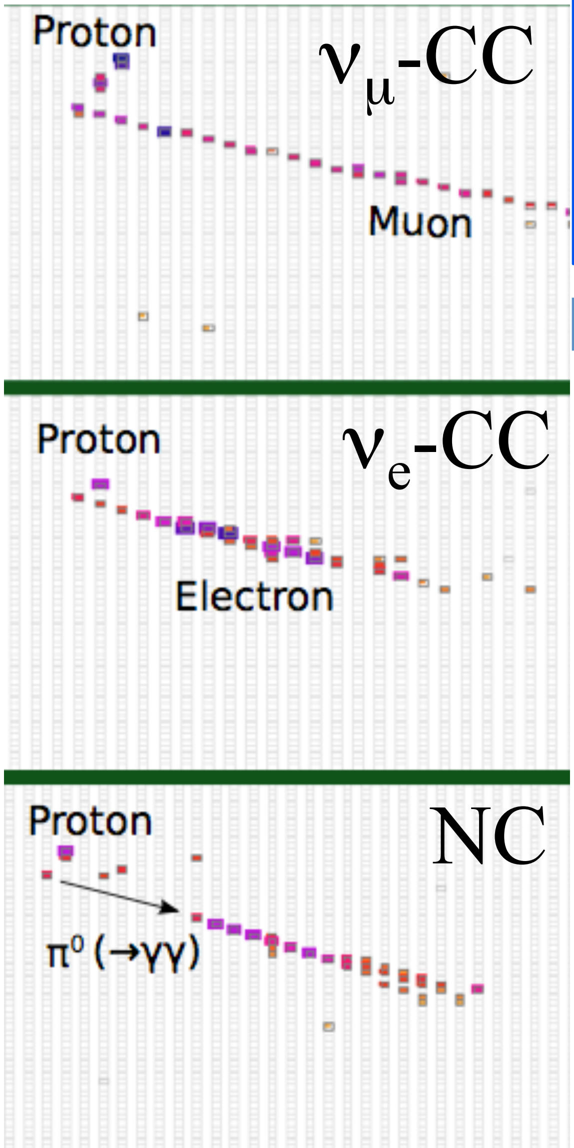
- Reconstruction chain for cell, track, shower and vertex is well developed and shows good performance.

Currently we have three ν_e identification algorithms which can meet with the physics requirement:

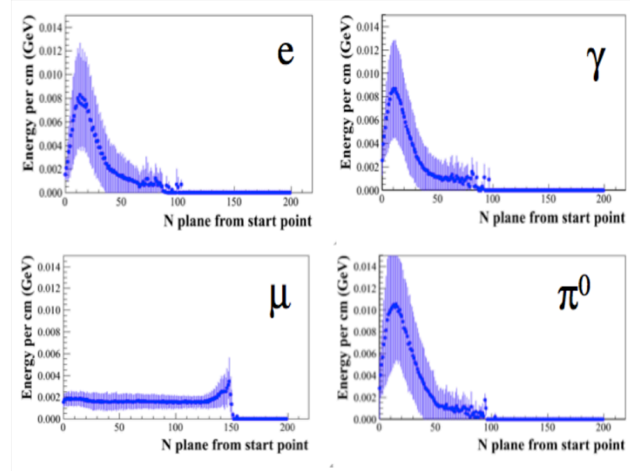
- ANN: Artificial neural network using shower shape based likelihood for particle hypotheses.
- LEM: Matching events to a Monte Carlo library.
- BDT: boosted decision tree on simple reconstructed quantities.

- We also have tools to determine backgrounds in the near detector and extrapolate them to the far detector (see Sachdev's talk).
- Fitting algorithms are in place.

ν_e identification (ANN)

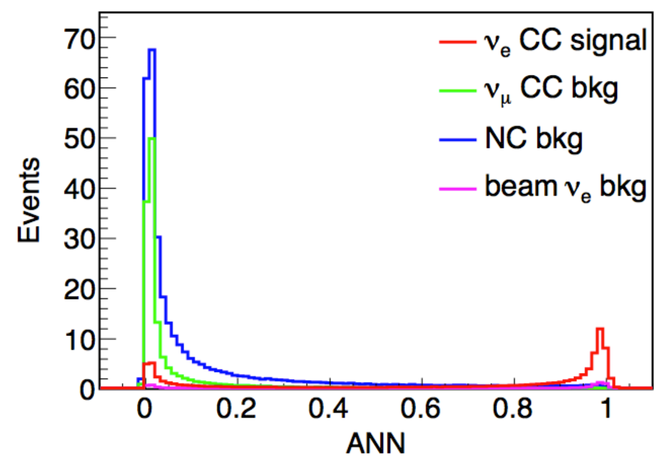


Parameterize energy profile by transverse/longitudinal dE/dx, then likelihood for particle hypotheses.

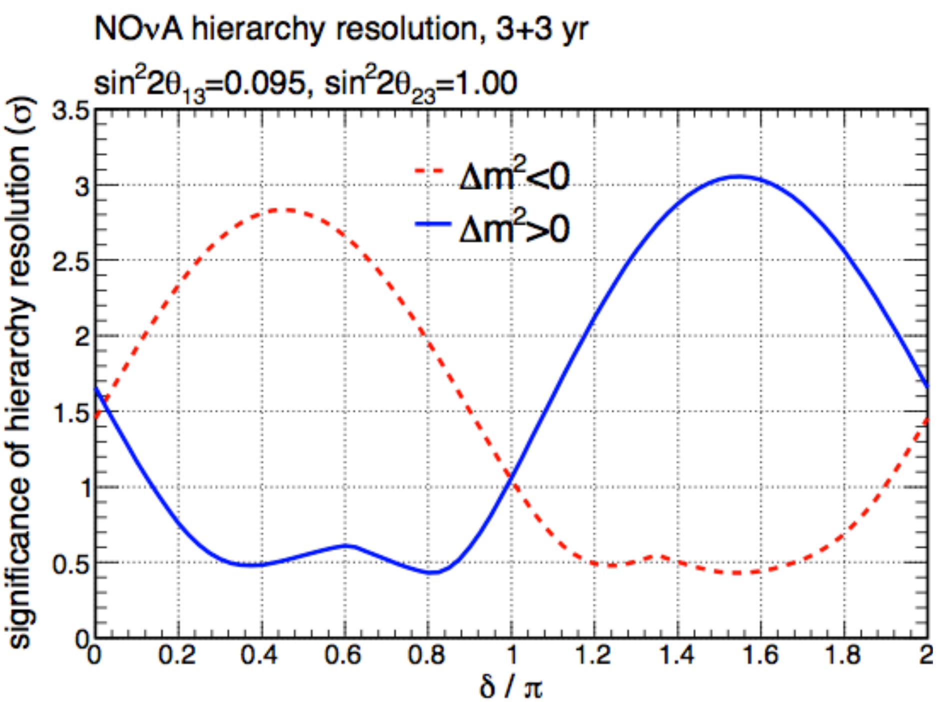


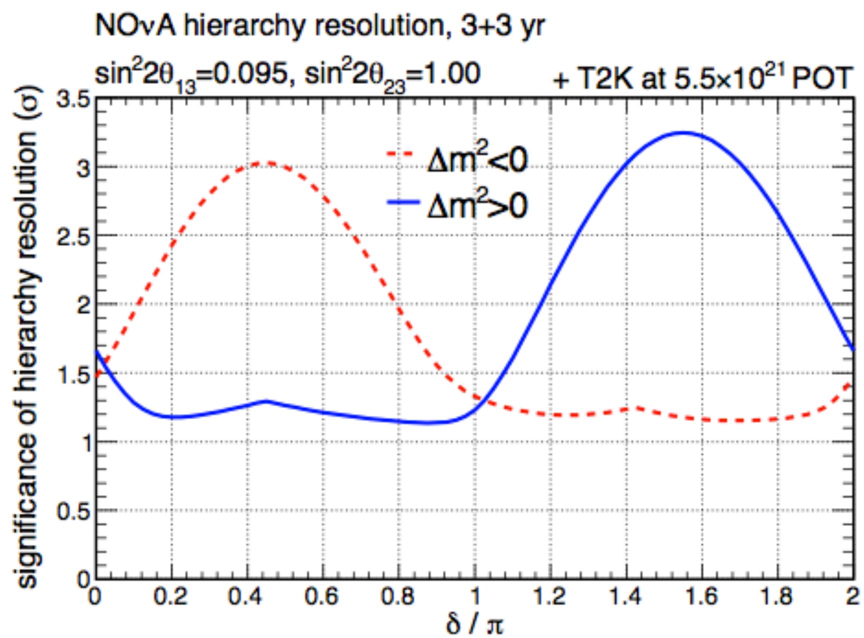
Combine shower shape information with an artificial neural network.

Because NOvA has fine-grained detectors, we are able to see details of energy profiles for different particles.



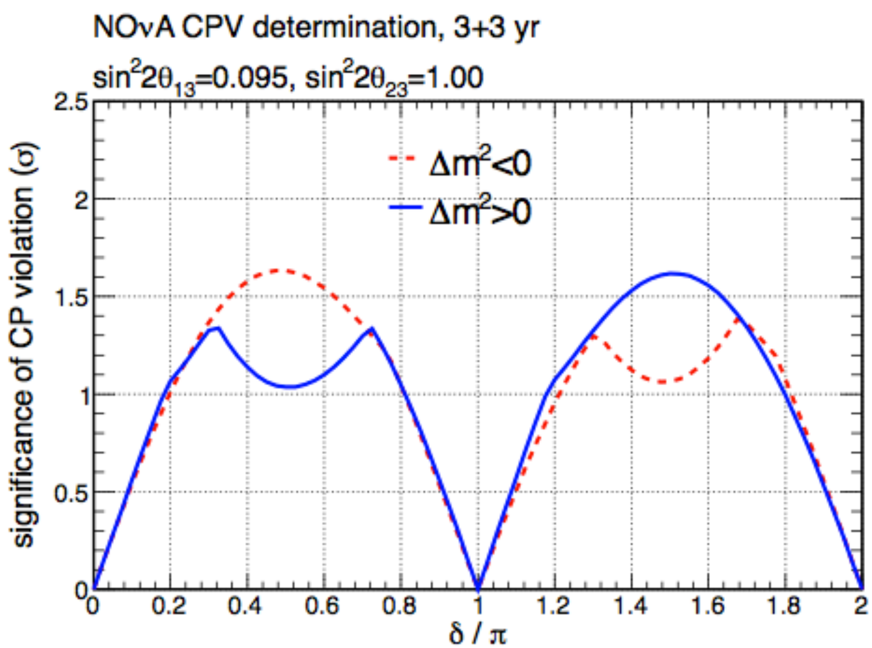
Significance to resolve mass hierarchy

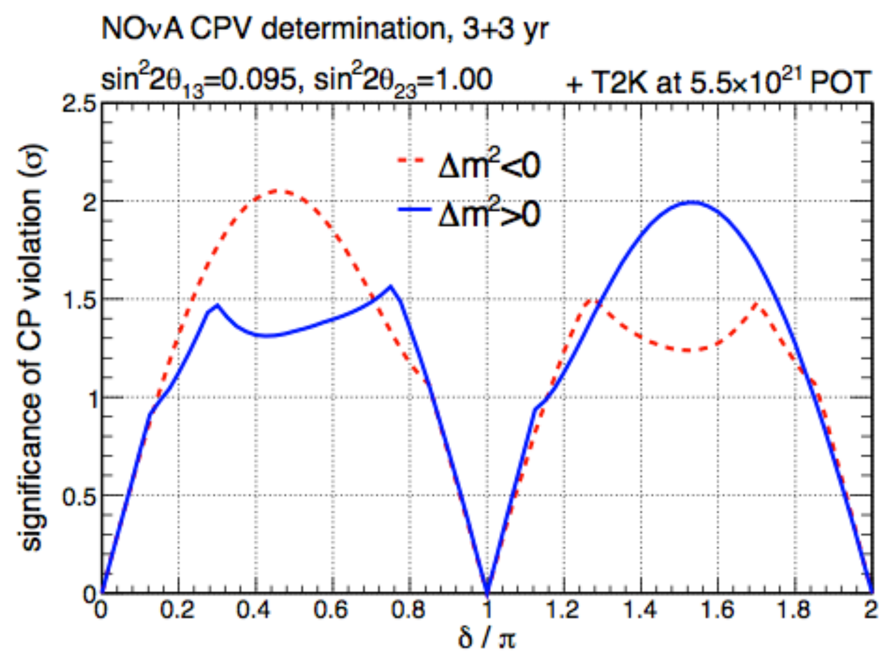




- Results from full simulation, reconstruction, selection, and analysis framework.

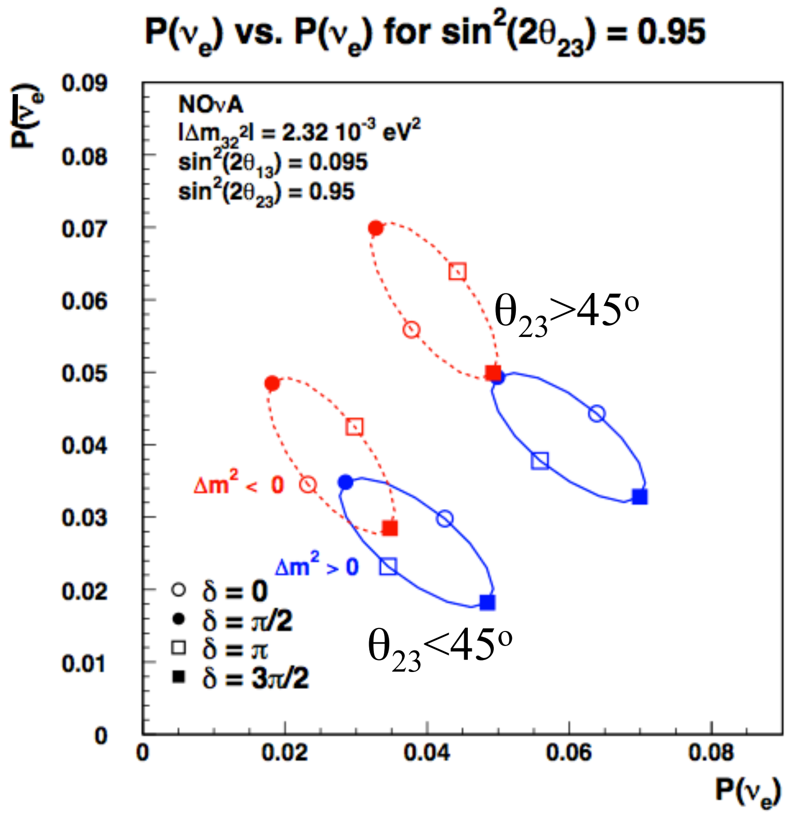
CP violation phase

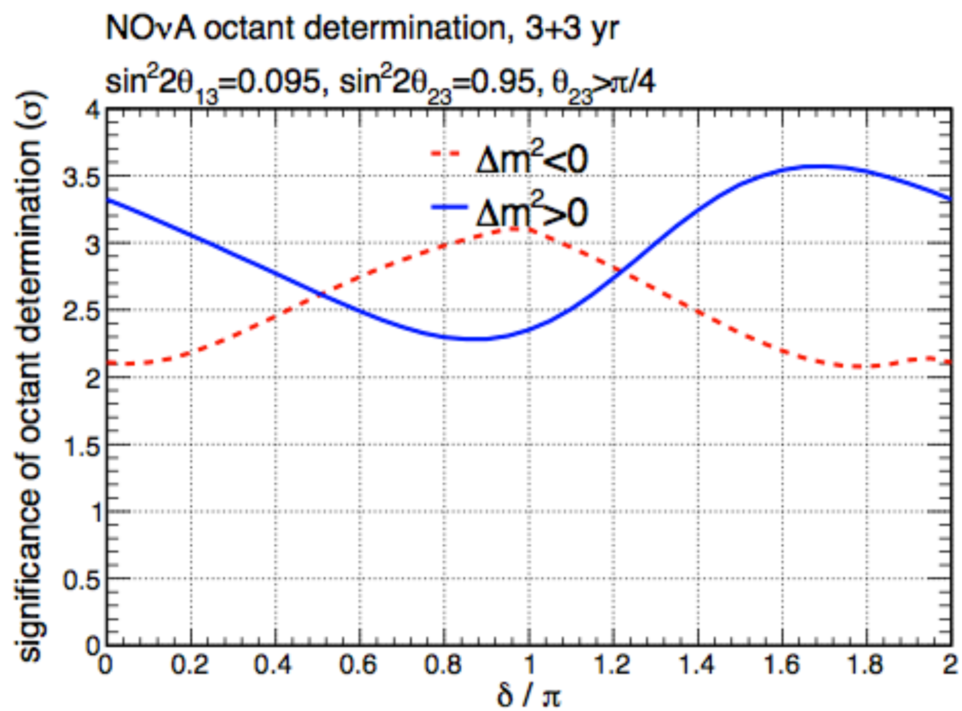




- Results from full simulation, reconstruction, selection, and analysis framework.

Octant of θ_{23}





- If $\sin^2(2\theta_{23})$ is not maximal there is an ambiguity as to whether θ_{23} is larger or smaller than 45°.
- The $\sin^2(\theta_{23})$ term is crucial in comparing accelerator to reactor experiments.
- $\sin^2(2\theta_{23})$ is measured in ν_μ disappearance.
- Because $P(\nu_\mu \rightarrow \nu_e)$ is in proportion to $\sin^2(\theta_{23})\sin^2(2\theta_{13})$, it can be used to determine θ_{23} octant.

Summary

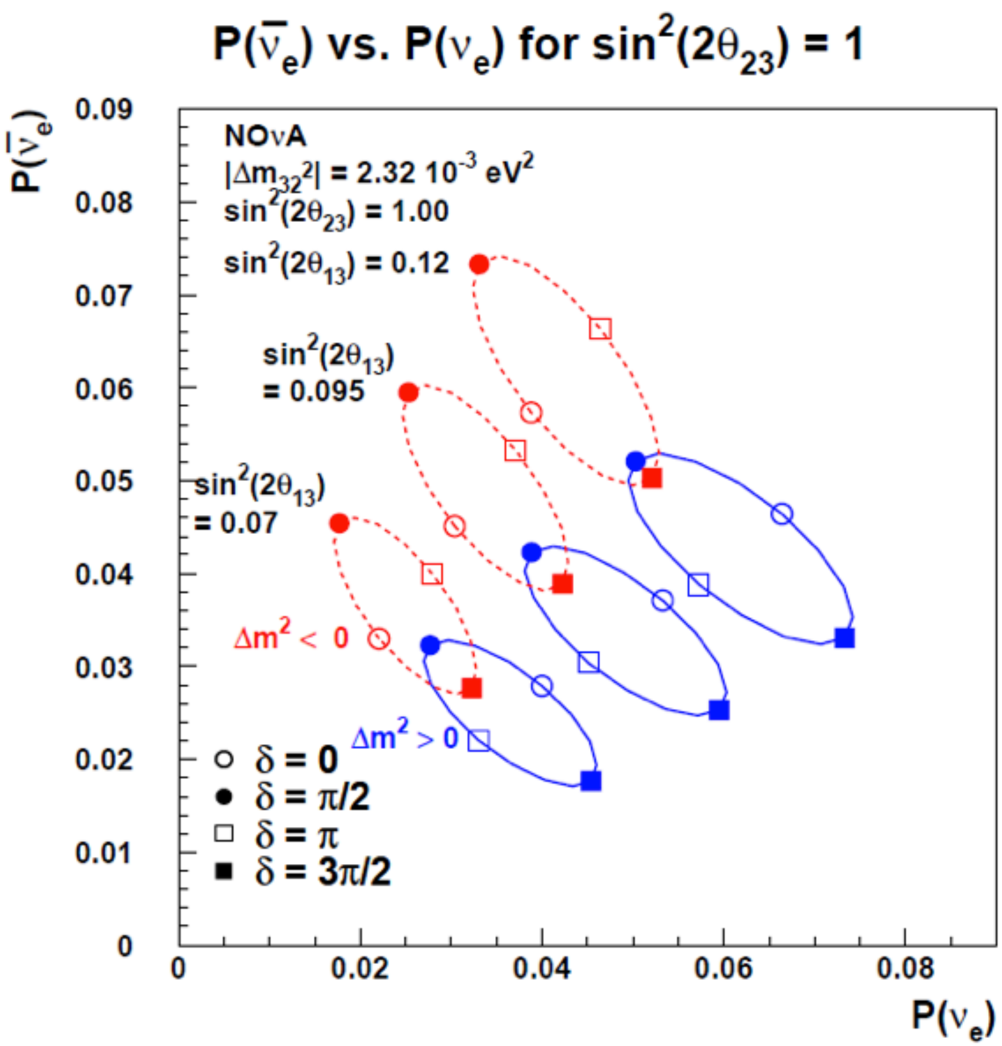
- Physics reach:
  - NOνA has the best chance to investigate mass hierarchy.
  - Can determine θ_{23} octant.
  - Provide first information on CP violation.
  - Look at other physics such as supernova, neutrino magnetic moment, monopoles and non-standard neutrino interactions.

- NOνA is ready to take physics data
  - Starting cosmic ray data.
  - Detector construction is proceeding well.
  - Many analysis tools are in place.
  - We are focusing on commissioning our far detector and working towards first physics results in summer 2014.

Thank you!

Backup

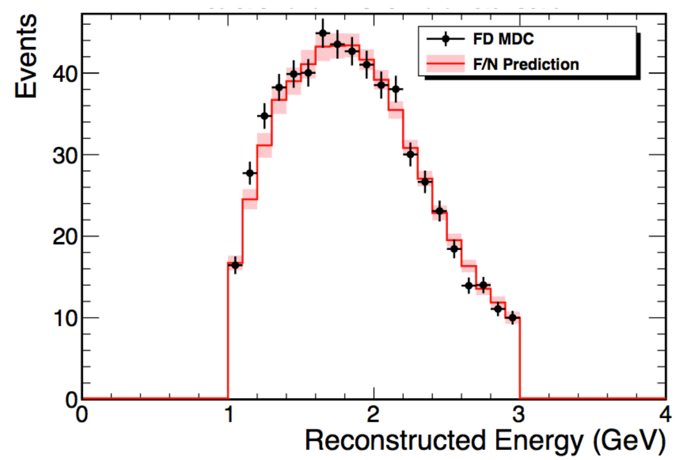
$P(\nu_e)$ vs. $P(\overline{\nu}_e)$ with different θ_{13} assumptions



Extrapolation from the Near Detector (ND) to the Far Detector (FD)

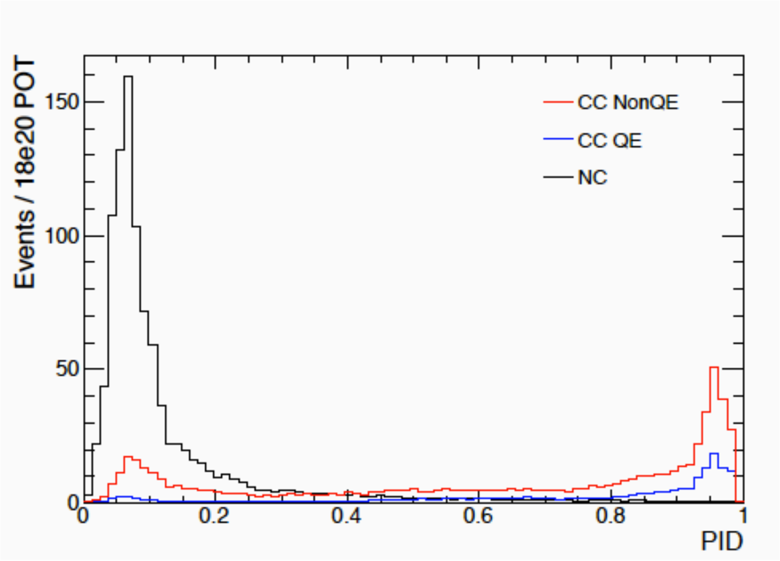
- There are ν_μ-CC, NC and beam ν_e-CC backgrounds which we want to identify in the ND and extrapolate to the FD:
  - Extrapolate identified nm-CC and me-CC in the ND to the FD
  - Use muon removed ν_μ-CC events in data to simulate NC events. (MRCC, see Kanika's talk)
  - Extrapolate identified backgrounds in the near detector to the far detector.

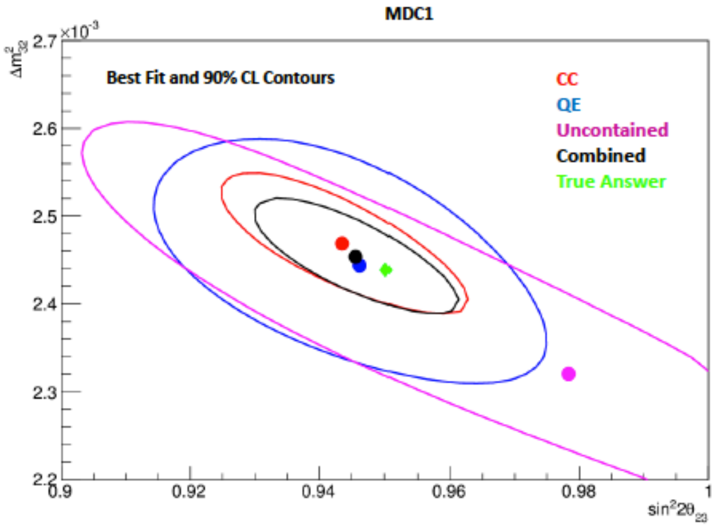
Extrapolation from the ND to the FD



Mock data challenge – ν_μ analysis

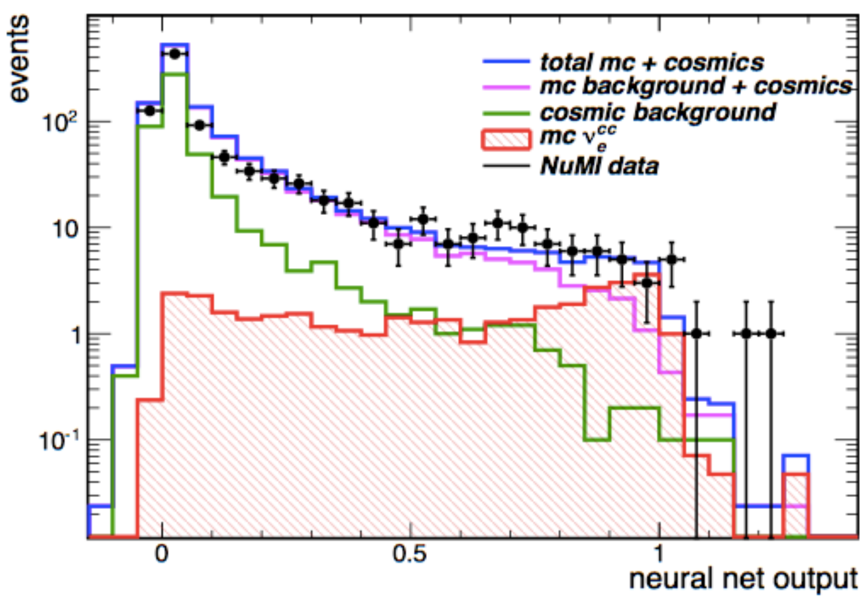
Similar situation to the ν_μ analysis:
One good PID, based on maximum likelihood analysis.
Concerns are QE identification, energy resolution and cosmic rejection.

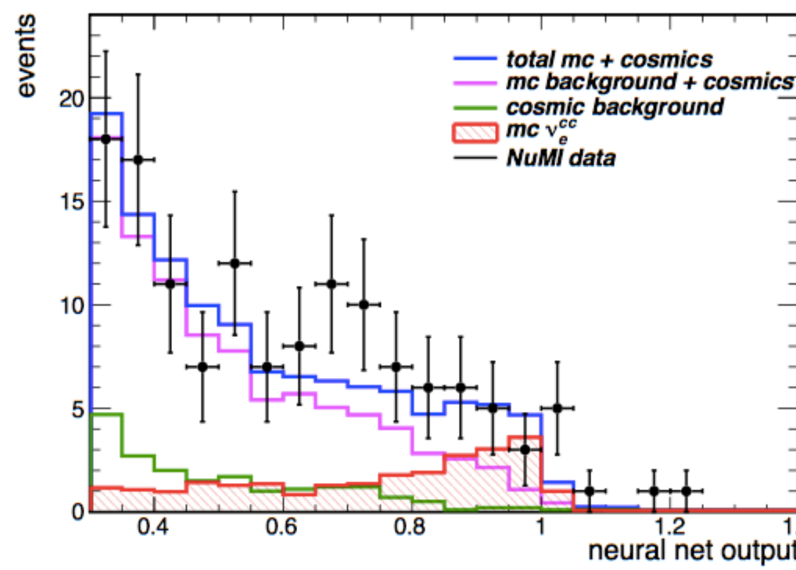




ν_e identification in the prototype detector (NDOS)

- We ran the analysis chain on the NuMI data recorded at the prototype detector (NDOS).
- Measured the electron neutrino component of the beam.

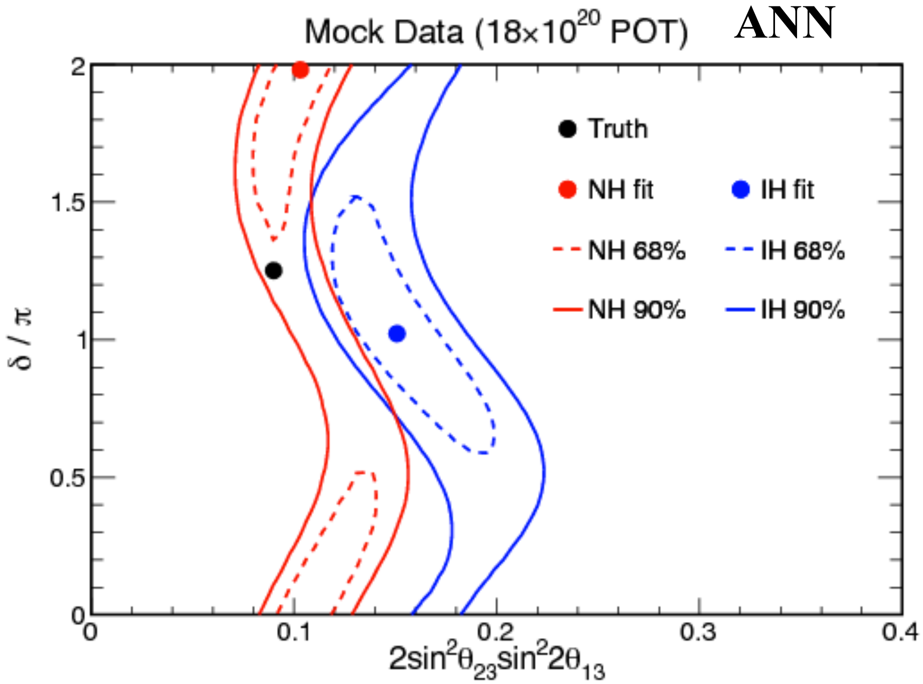




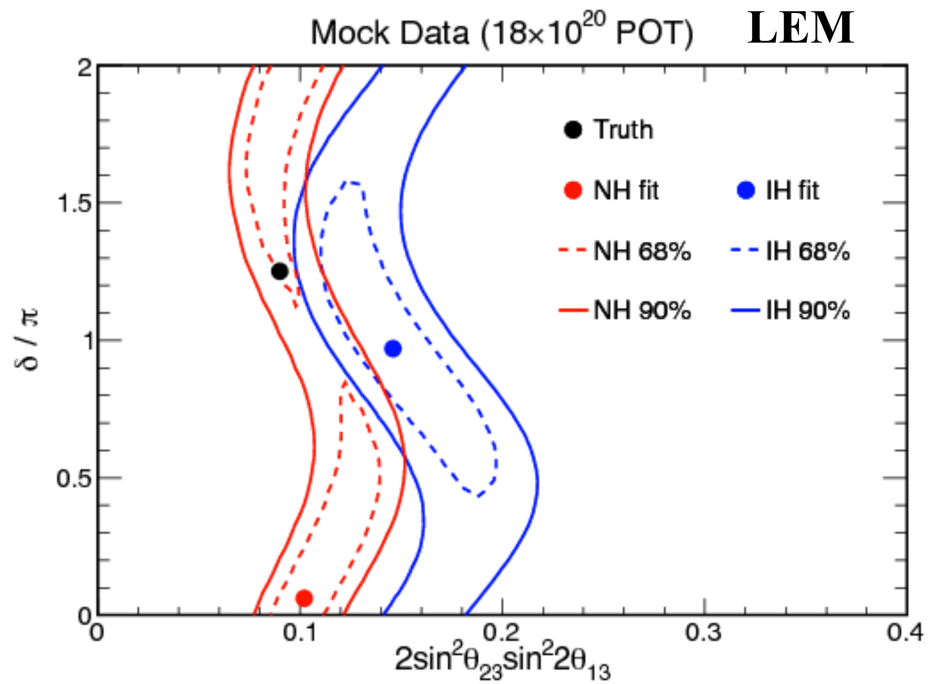
Mock data challenge– ν_e analysis

Mock data challenge for the first 3 years' data taking. Hidden physics parameters were chosen and all truth information was stripped from the Monte Carlo files. The two analysis techniques got identical results, which agreed with the truth within about 1σ.

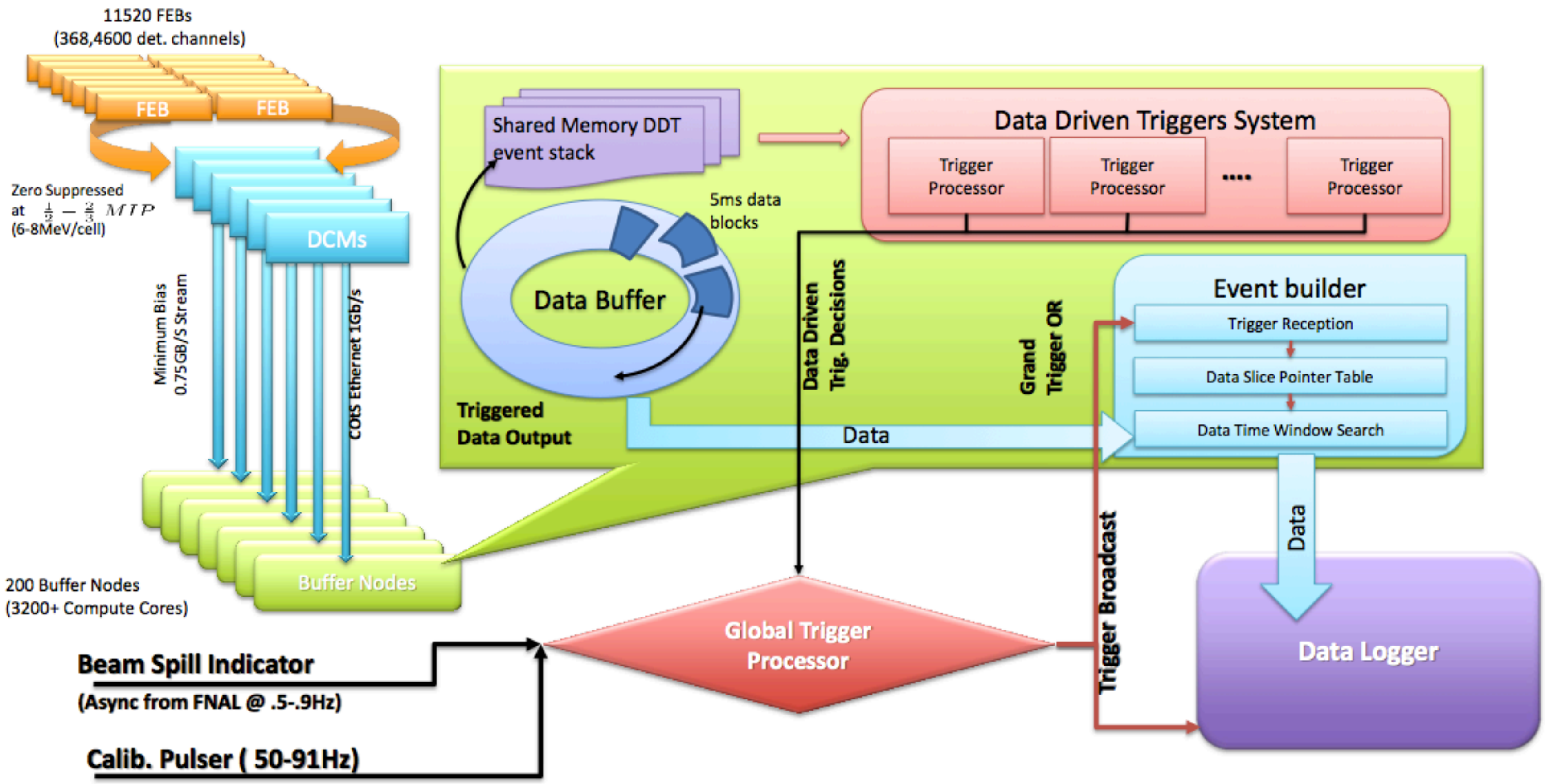
ANN



LEM



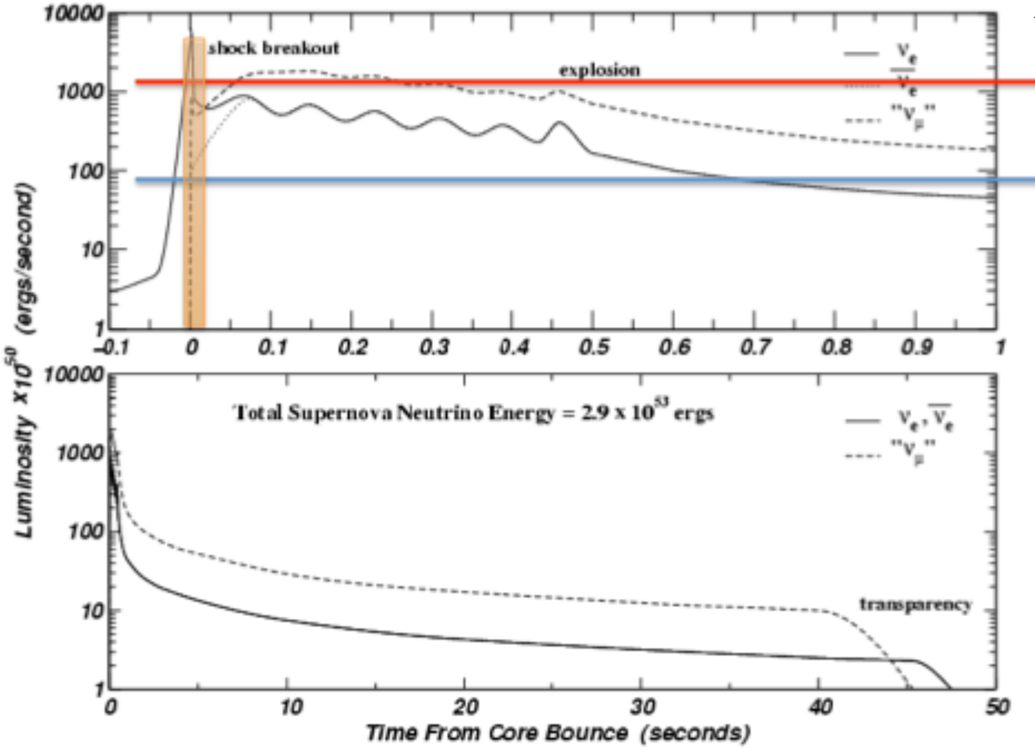
Data-Driven Triggers



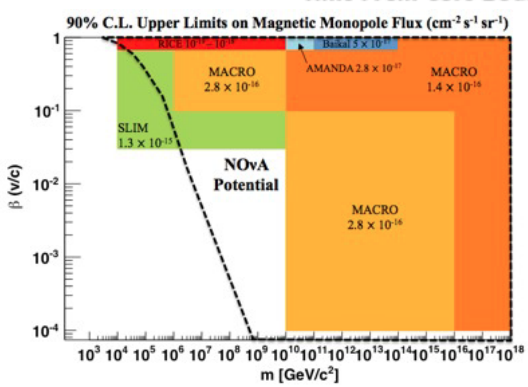
- We cannot record everything that is happening in the far detector due to the 100 kHZ cosmic ray rate. So we have been developing three general classes of data-driven triggers.
- Non-beam physics: exotics, upward atmospheric ν's etc.
- Rarer cosmics useful for calibrations: stopping, horizontal, bremsstrahlung, etc.
- Backup for beam events.

Study other physics at NOvA

Supernova neutrino energy spectrum, A. Dighe, TAUP09



NOvA is not underground, however it is a segmented detector with a very flexible trigger (See Jan Zirnstein's talk). NOvA can measure electron-neutrinos and electron-antineutrinos from supernova, providing information on time profile and energy of SN neutrinos .



A magnetic monopole track is slower and higher ionizing than an energetic muon. Small overburden gives us sensitivity to a low-mass low beta region not probed by other experiments.