The NOνA Experiment

HEPAP Meeting

13 November 2008

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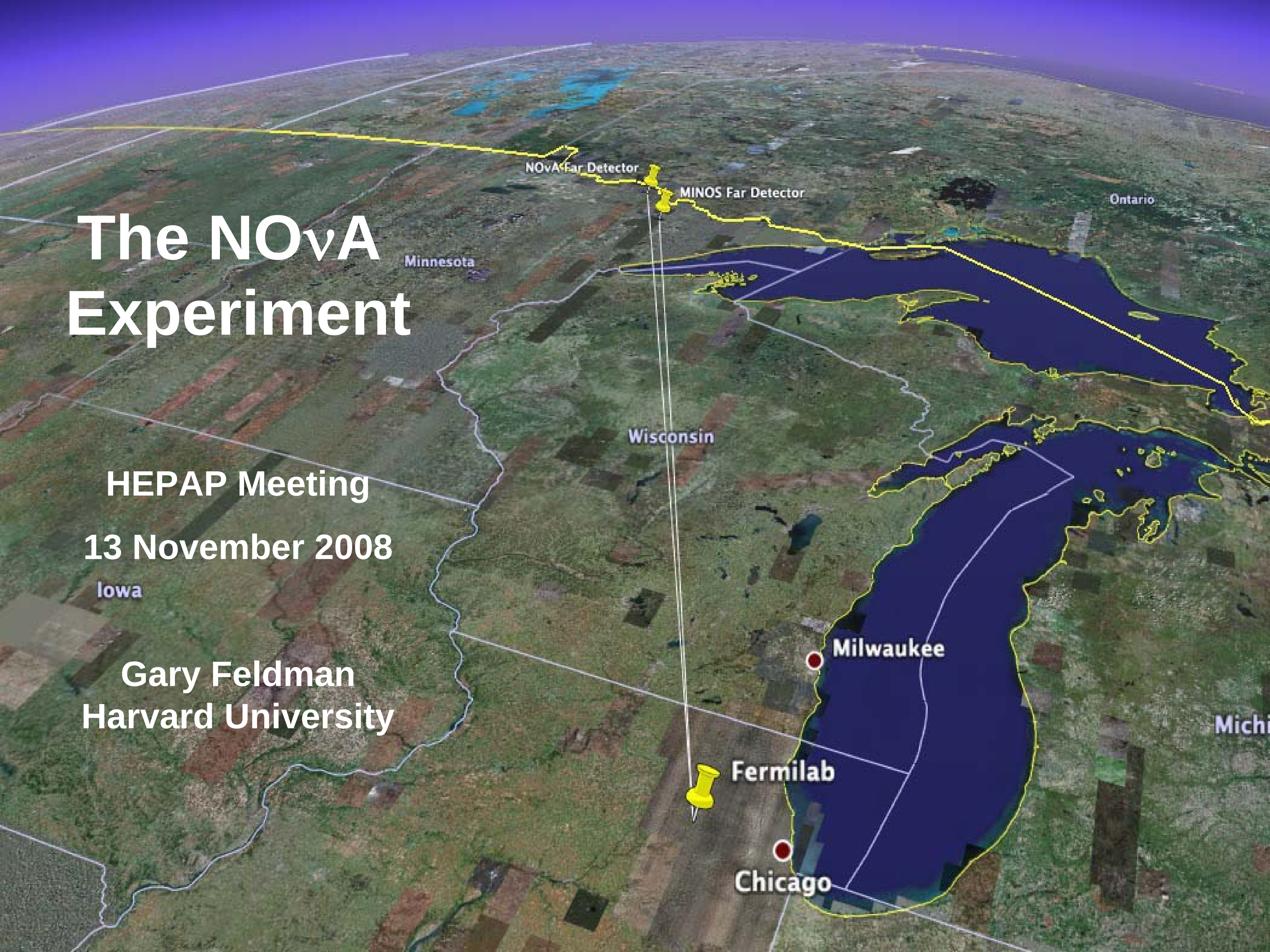
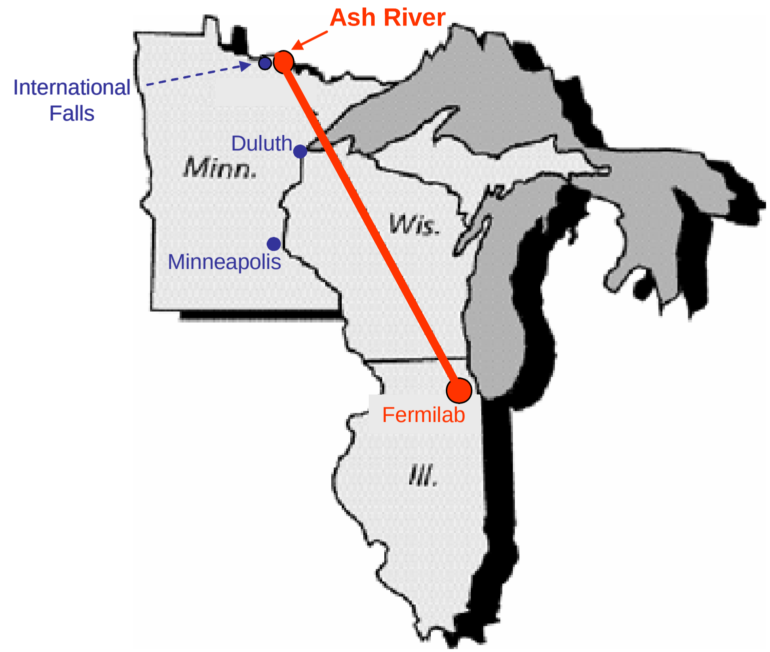
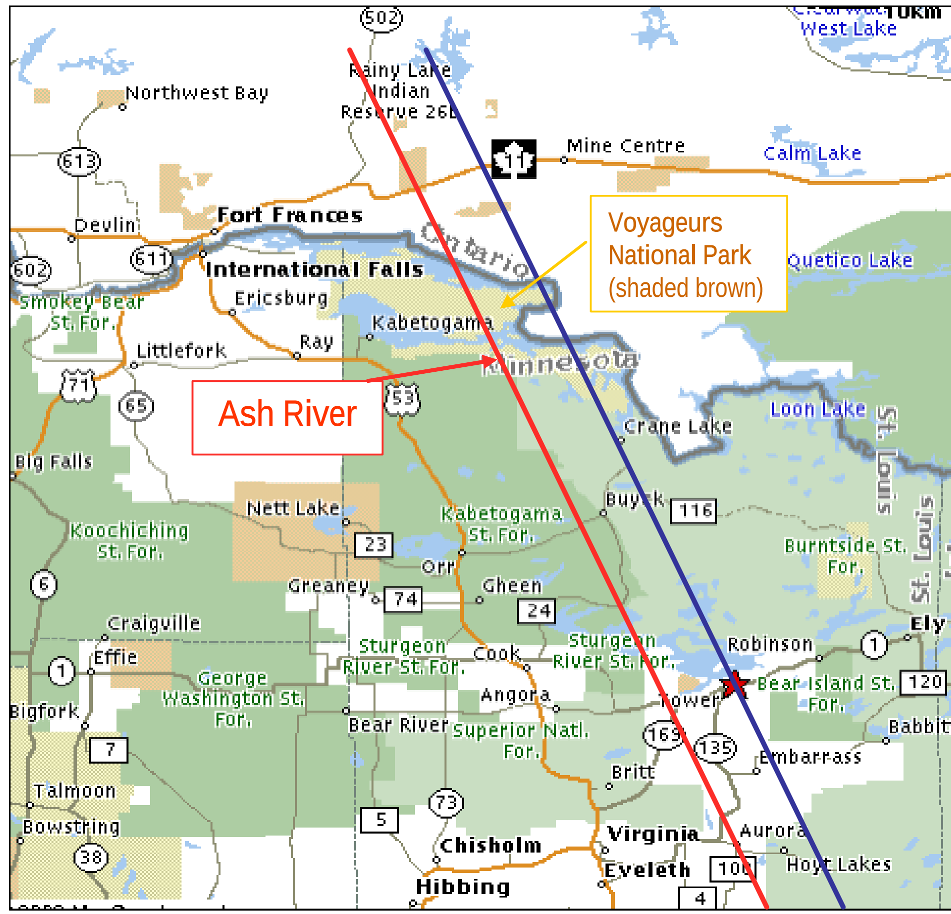


What is NOνA?

- NOνA is a second-generation experiment on the NuMI beamline, which is optimized for the detection of $\nu_\mu \rightarrow \nu_e$ oscillations.
  - It will give an order of magnitude improvement over MINOS in measurements of ν_e appearance and ν_μ disappearance.
- NOνA is a "totally active" tracking liquid scintillator calorimeter, sited off-axis to take advantage of a narrow-band beam.
- The NOνA project also includes accelerator upgrades to increase the Main Injector beam power from 400 kW to 700 kW.
- NOνA's unique feature is its long baseline, which gives it sensitivity to the neutrino mass ordering.
- NOνA is complementary to both T2K and Daya Bay.

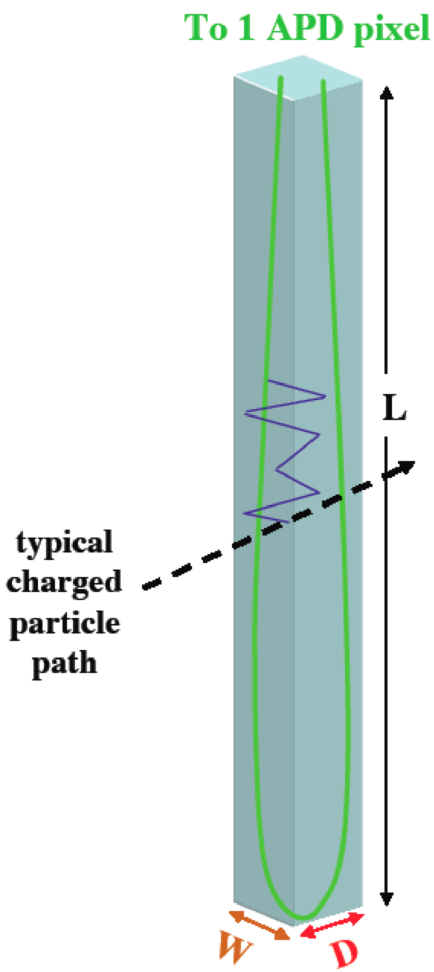
NOνA Far Detector Site





The Ash River site is the furthest available site from Fermilab along the NuMI beamline. This maximizes NOνA's sensitivity to the mass ordering.

NOνA Basic Detector Element

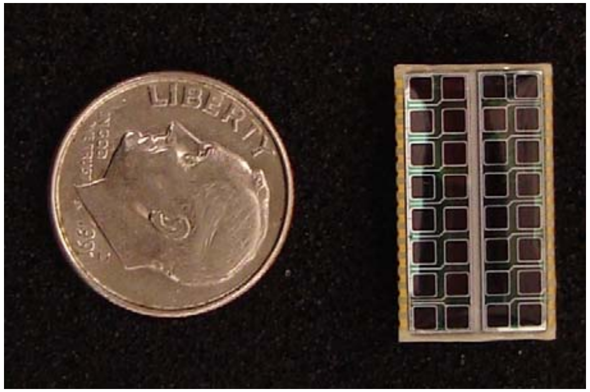


Liquid scintillator in a 4 cm wide, 6 cm deep, 15.7 m long, highly reflective PVC cell.

Light is collected in a U-shaped 0.7 mm wavelength-shifting fiber, both ends of which terminate in a pixel of a 32-pixel avalanche photodiode (APD).

The APD has peak quantum efficiency of 85%. It will be run at a gain of 100. It must be cooled to -15°C and requires a very low noise amplifier.

Fiber stringing machine at the Minnesota factory



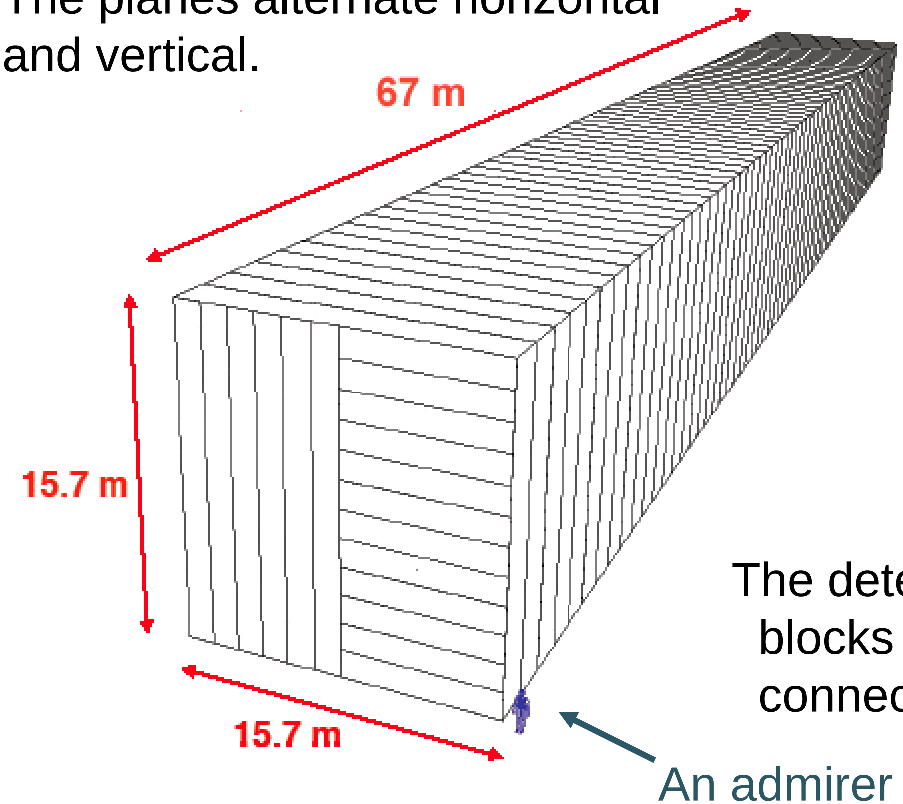
Custom 32-channel APD

Far Detector

The cells are made from 32-cell extrusions.

12 extrusion modules make up a plane. The planes alternate horizontal and vertical.

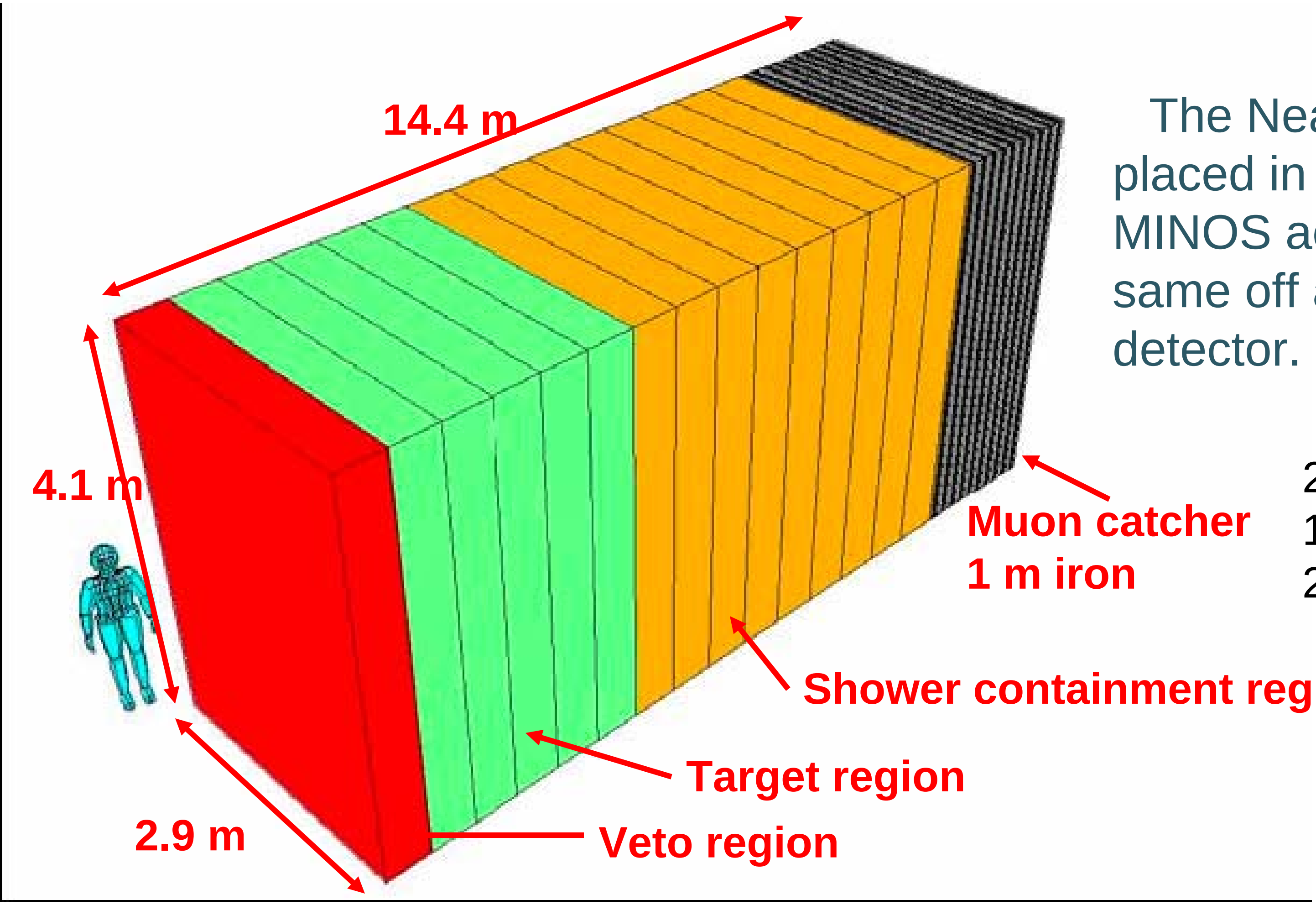
Full length extrusions



There are a minimum of 930 planes, for a total mass of 14 kT. There is enough room in the building for 18 kT, which can be built if we can preserve half of our contingency.

The detector can start taking data as soon as blocks are filled and the electronics connected.

NOνA Near Detector



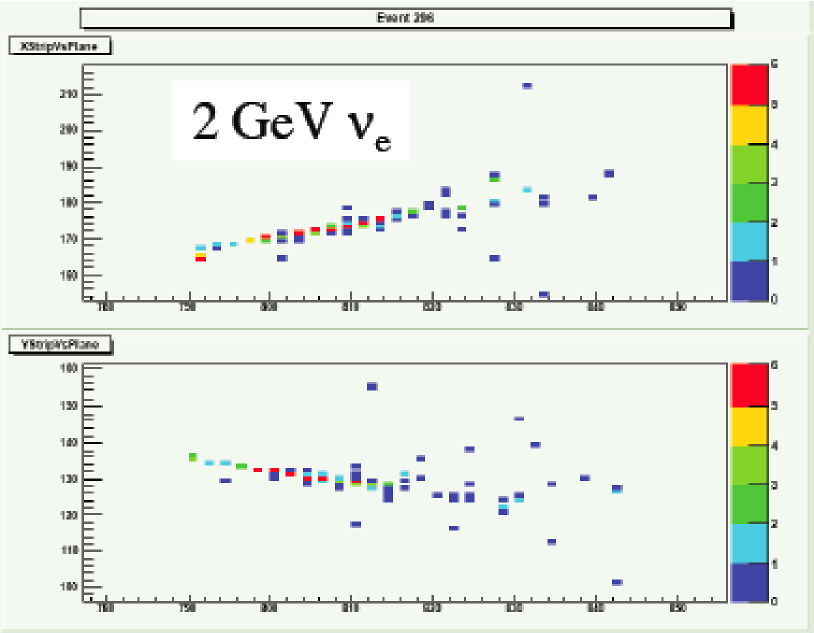
The Near Detector will be placed in a cavern off of the MINOS access tunnel on the same off axis line as the far detector.

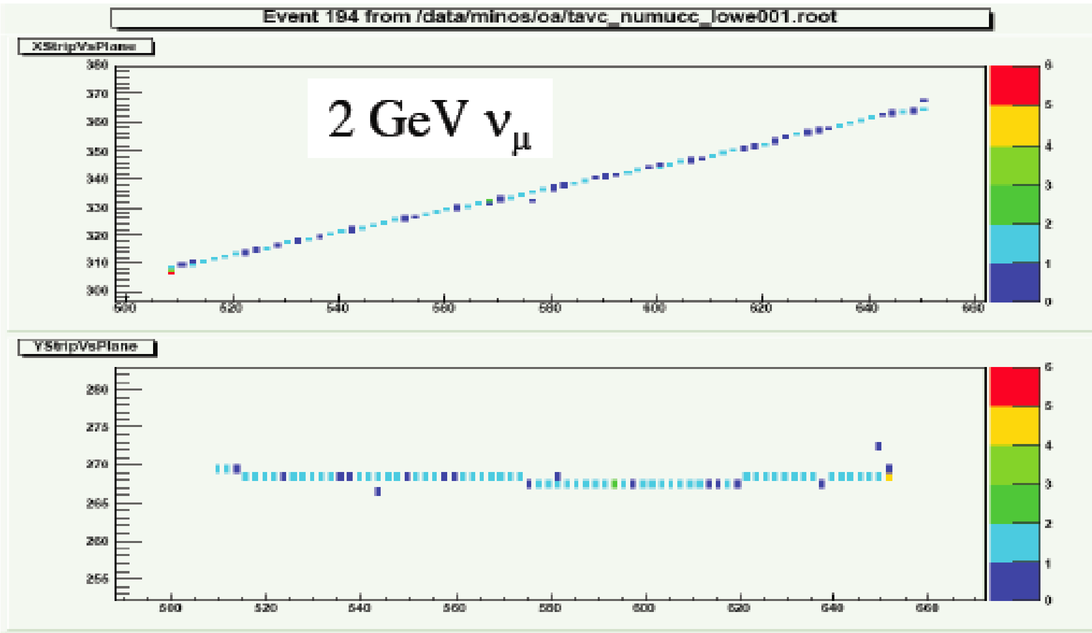
209 T
126 T totally active
23 T fiducial

Event Quality

Longitudinal sampling is 0.15 X0, which gives excellent μ-e separation.

A 2-GeV muon is 60 planes long.





ν_e CC event

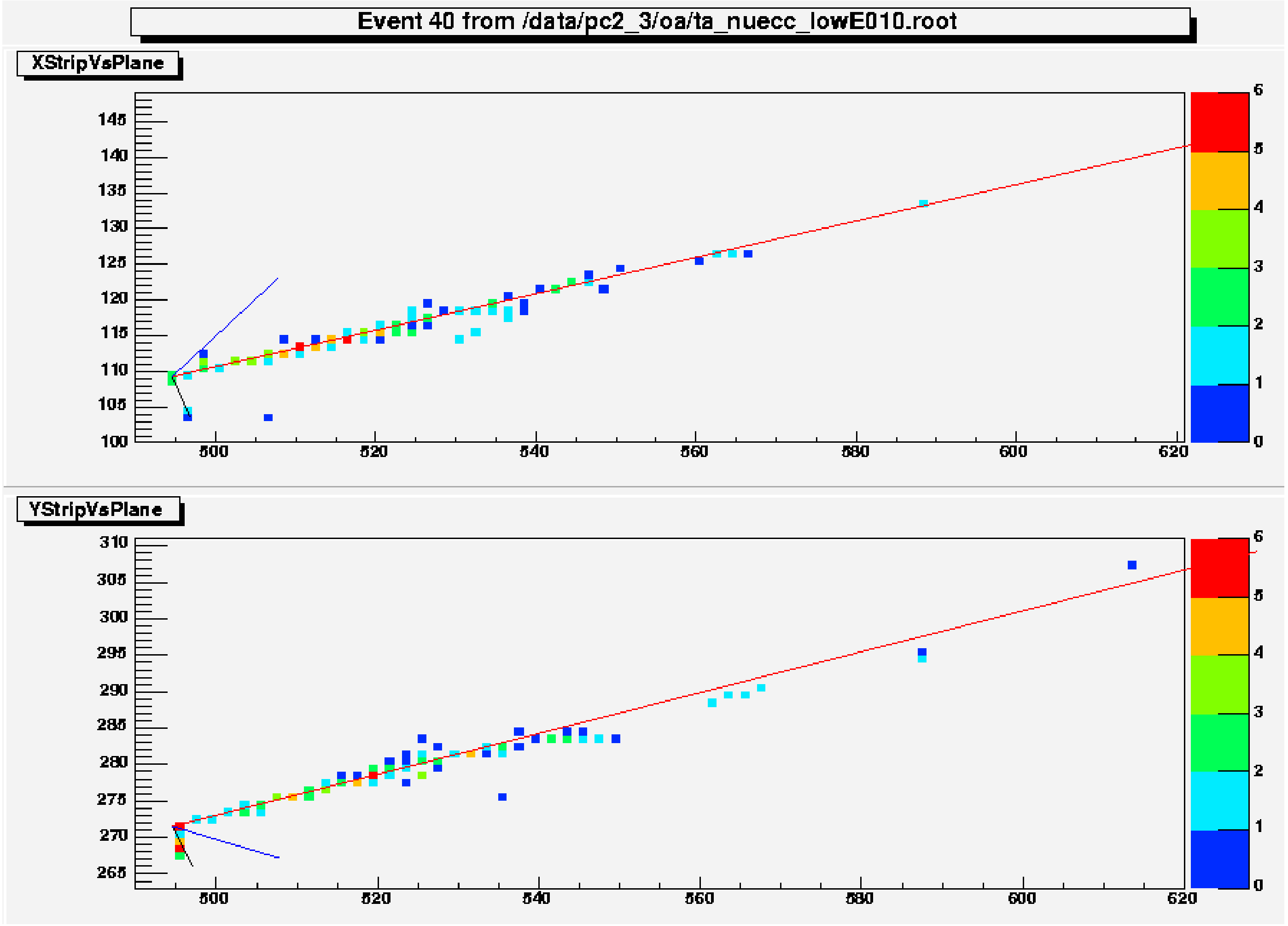
$\nu_e p \rightarrow e^- p \pi^+$

E_ν=2.5GeV

E_e=1.9GeV

E_p=1.1GeV

E_π=0.2GeV



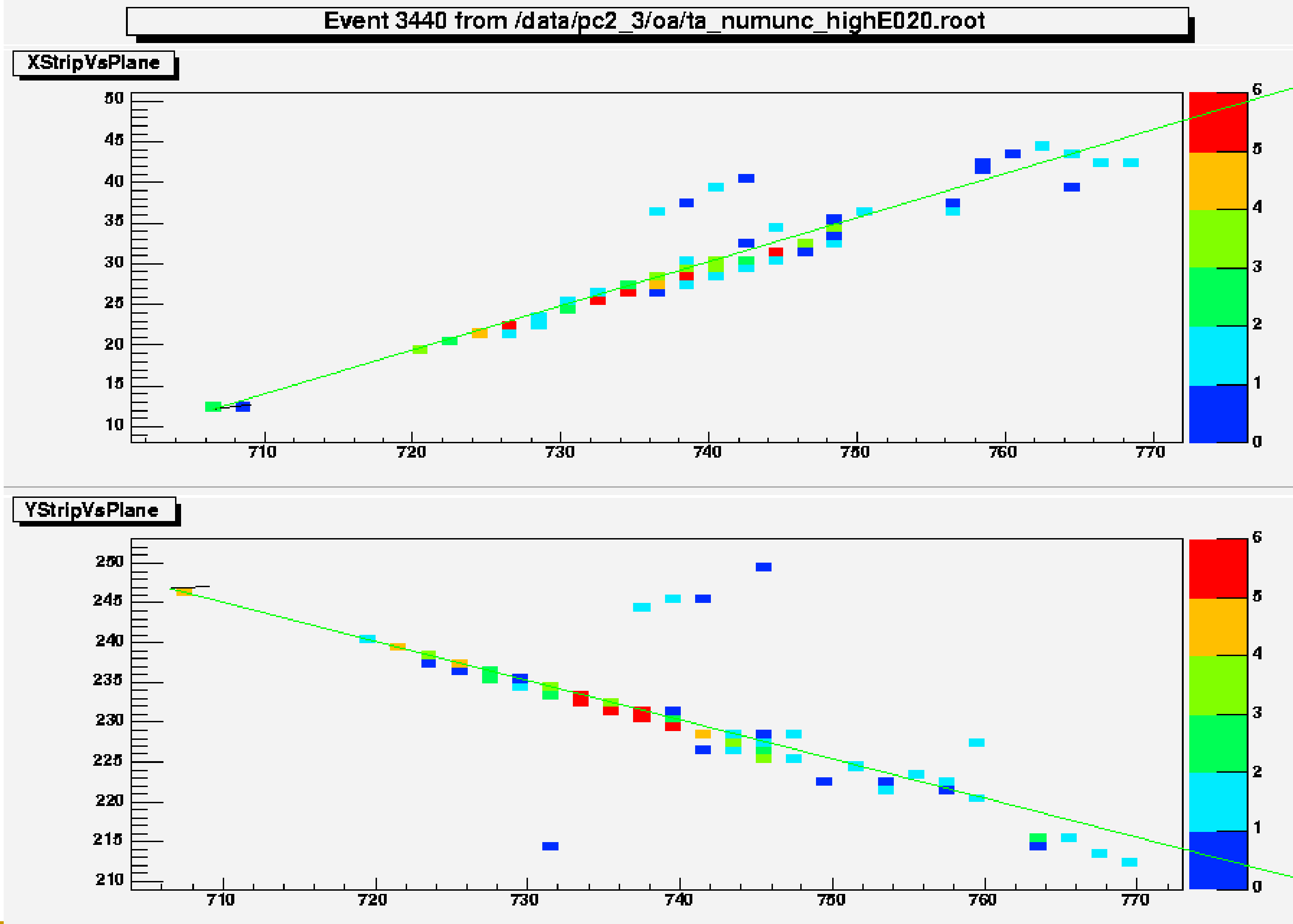
Background NC event

$\nu_\mu N \rightarrow \nu_\mu p \pi^o$

E_ν=10.6 GeV

E_p=1.04GeV

$E_{\pi o}$ =1.97GeV

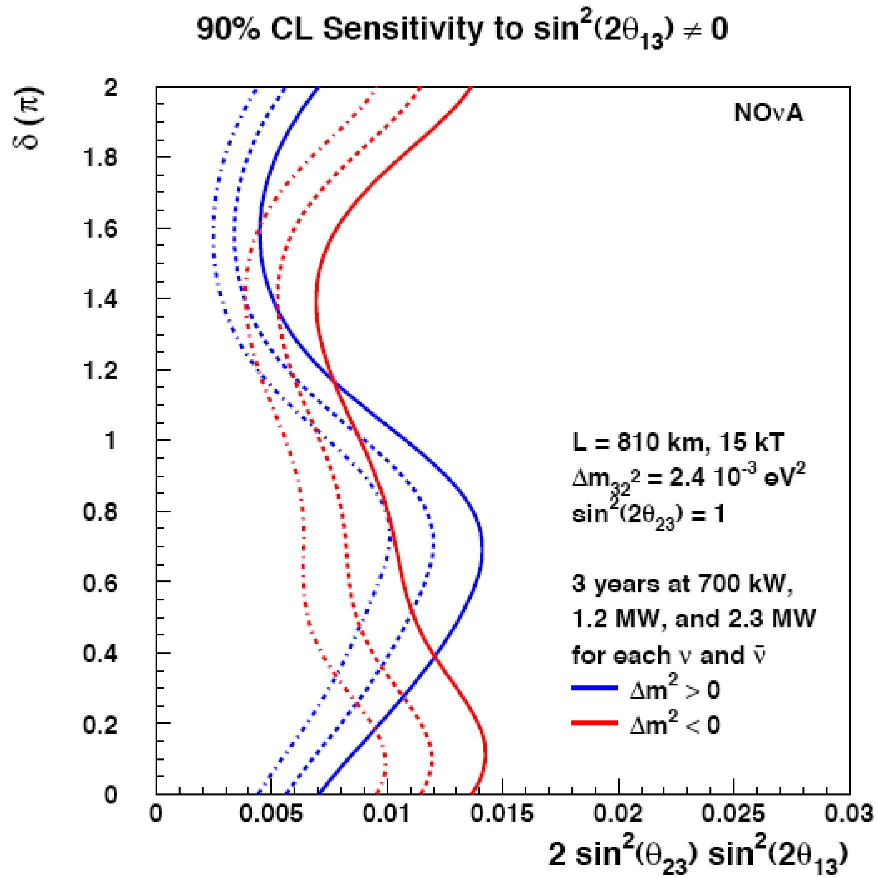


P5 Questions for the Future

- In its May 2008 report, P5 raised 8 "Questions for the Future" concerning neutrinos:
  - "As the first chapter in the study of neutrino oscillations comes to an end, a new chapter begins. The great progress in neutrino physics over the last few decades raises new questions and provides opportunities for major discoveries. Among the compelling issues today:"
- NOνA addresses 7 of these 8 questions.

Q1: What is the value of θ_{13}?

- "What is the value of θ_{13}, the mixing angle between first- and third-generation neutrinos for which, so far, experiments have only established limits? Determining the size of θ_{13} has critical importance not only because it is a fundamental parameter, but because its value will determine the tactics to best address many other questions in neutrino physics."

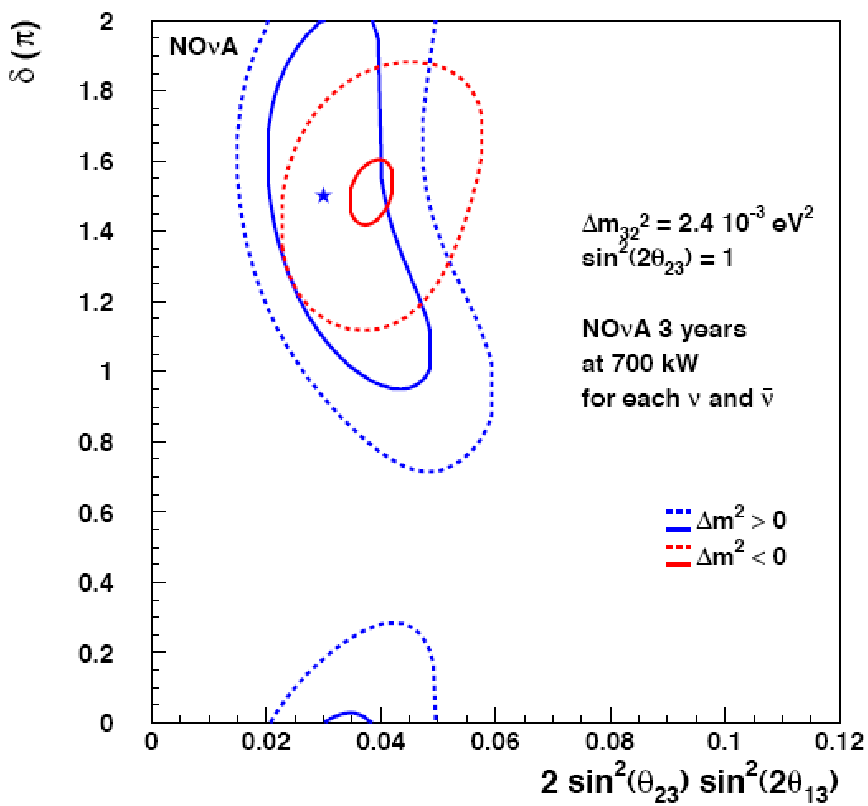


NOνA searches for ν_e appearance down to ~0.01 at the 90% c.l.

Q2: Do neutrinos violate CP?

- “Do neutrino oscillations violate CP? If so, how can neutrino CP violation drive a matter-antimatter asymmetry among leptons in the early universe (leptogenesis)? What is the value of the CP violating phase, which is so far completely unknown? Is CP violation among neutrinos related to CP violation in the quark sector?”

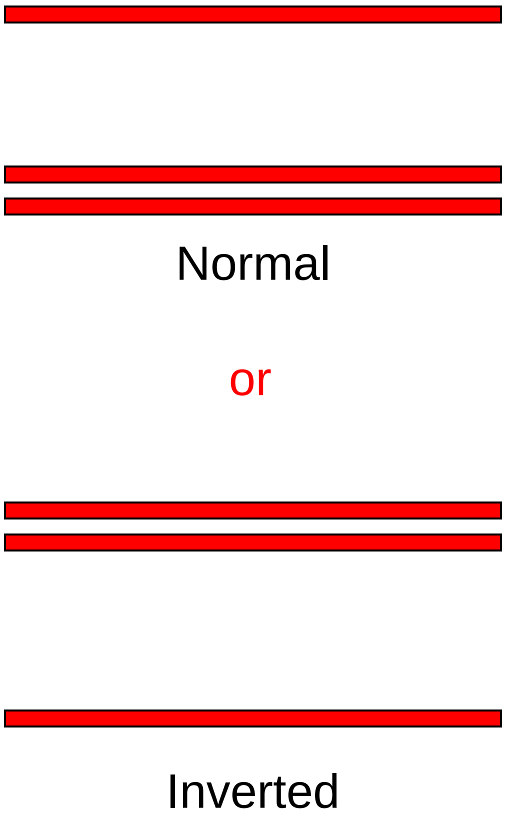
1 and 2 σ Contours for Starred Point for NOνA



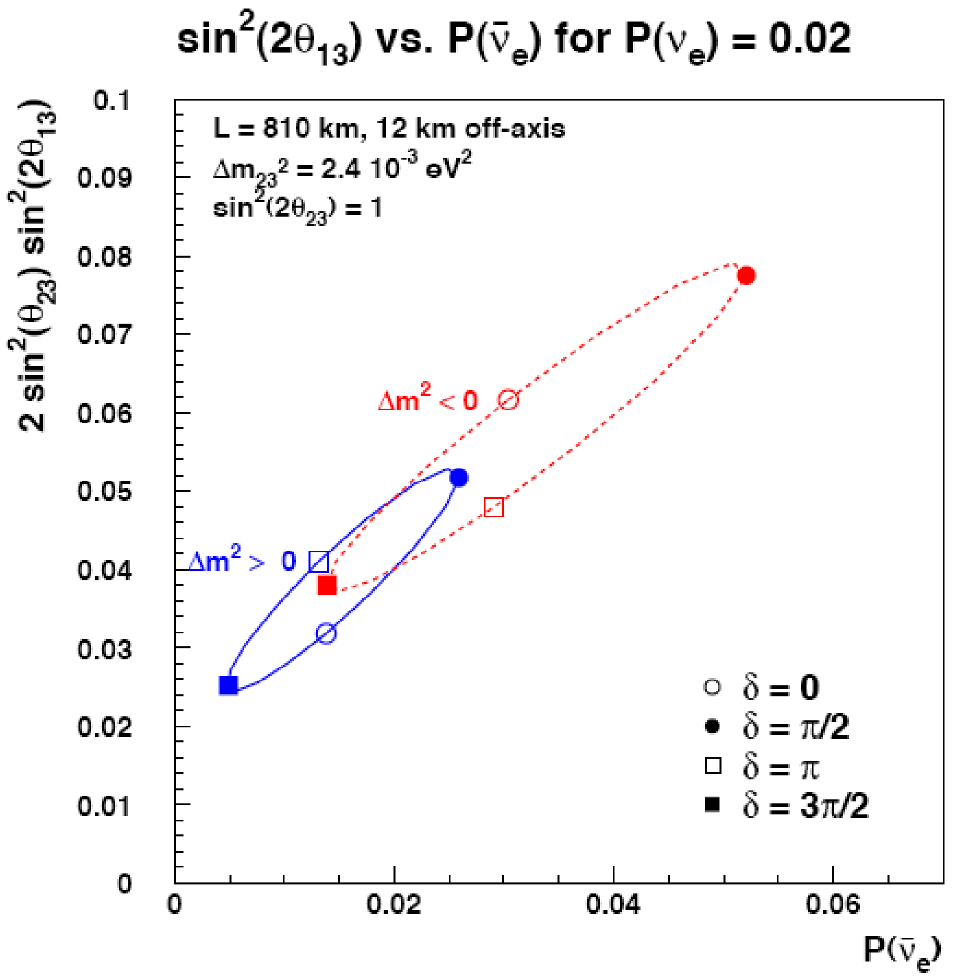
NOνA provides the first look at the CP-violating parameter, even at relatively small θ_{13}.

Q3: What are the relative masses of the three known neutrinos?

- "What are the relative masses of the three known neutrinos? Are they "normal," analogous to the quark sector, (m3 > m2 > m1) or do they have a so-called "inverted" hierarchy (m2 > m1 > m3)? Oscillation studies currently allow either ordering. The ordering has important consequences for interpreting the results of neutrino-less double beta decay experiments and for understanding the origin and pattern of masses in a more fundamental way, restricting possible theoretical models."



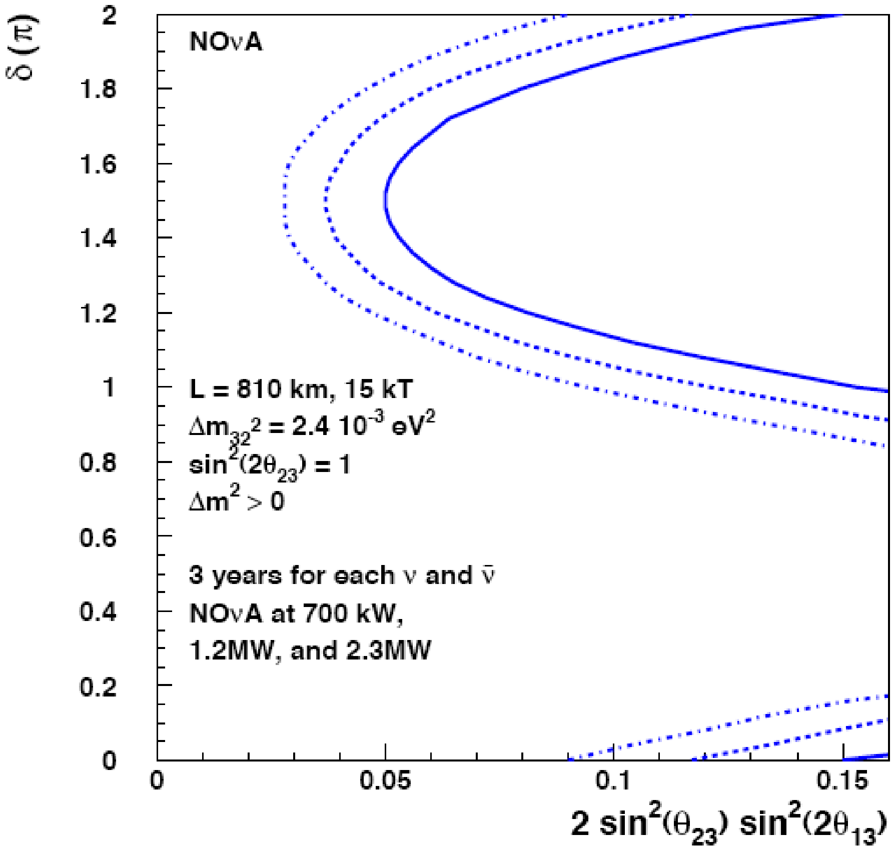
Parameters Consistent with a 2% $\nu_\mu \rightarrow \nu_e$ Oscillation Probability



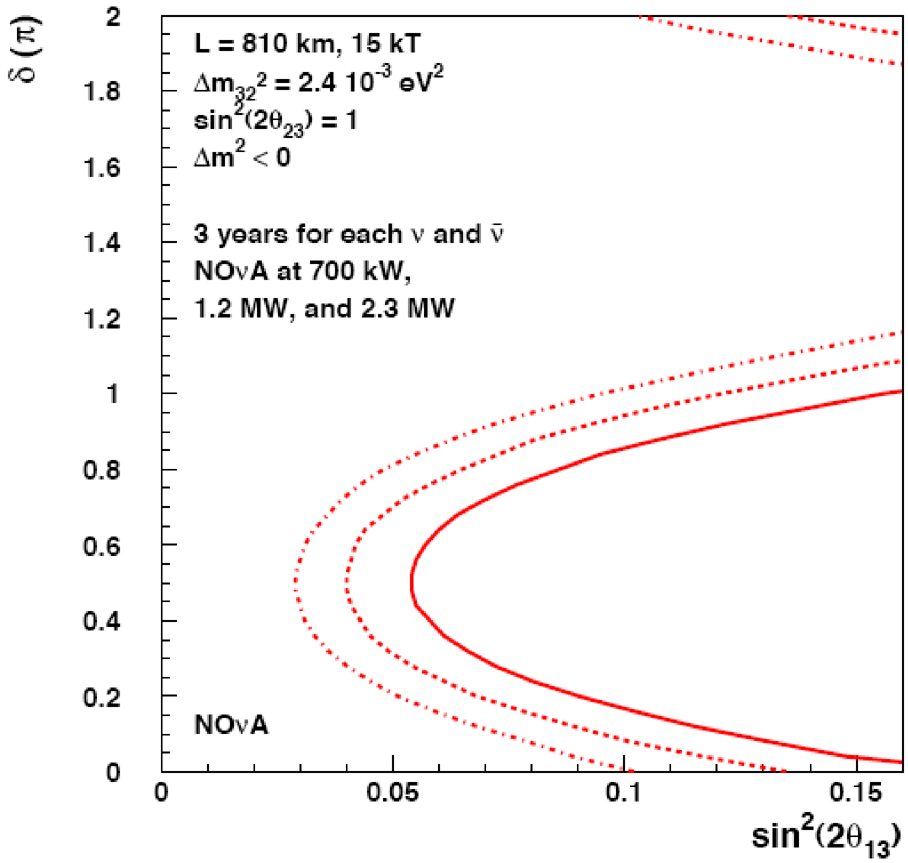
Strategy for Determining the Mass Ordering

- If the CP-violating term goes in the same direction as the matter effect, then there is no ambiguity and NOνA can determine the mass ordering by itself, given sufficient integrated beam.
- If the CP-violating term goes in the opposite direction as the matter effect, then there is an inherent ambiguity and NOνA cannot determine the mass ordering by itself. But it can be determined, in principle, by comparing NOνA and T2K.
  - If the neutrino oscillation probability is larger in NOνA than in T2K, it is the normal mass ordering; if the opposite, it is the inverted mass ordering.

95% CL Resolution of the Mass Ordering NOνA Alone

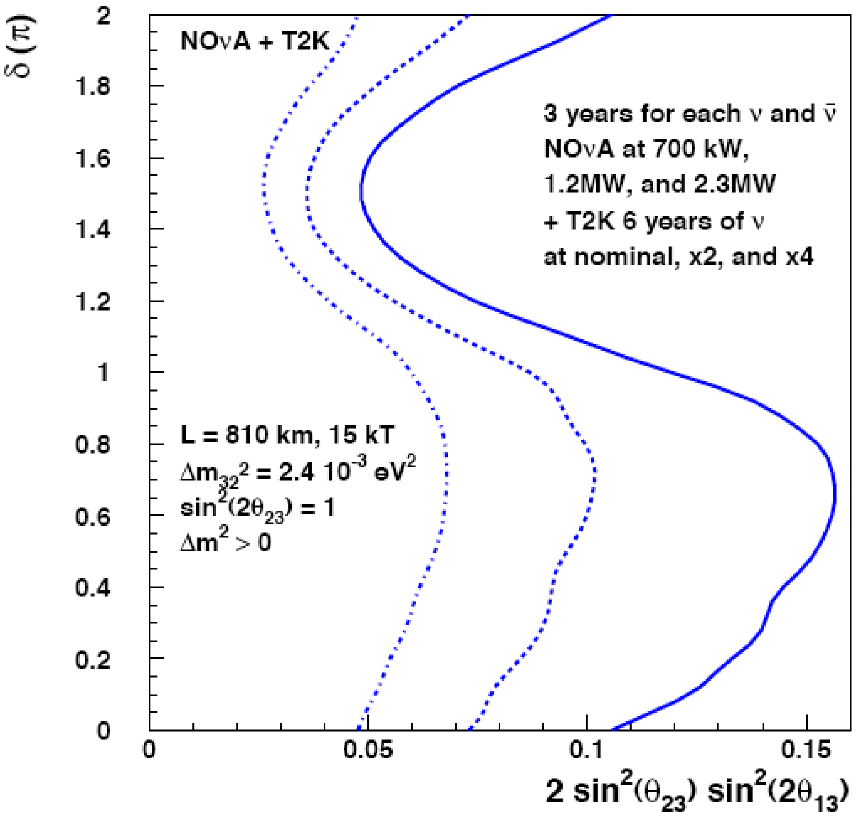


Normal Ordering

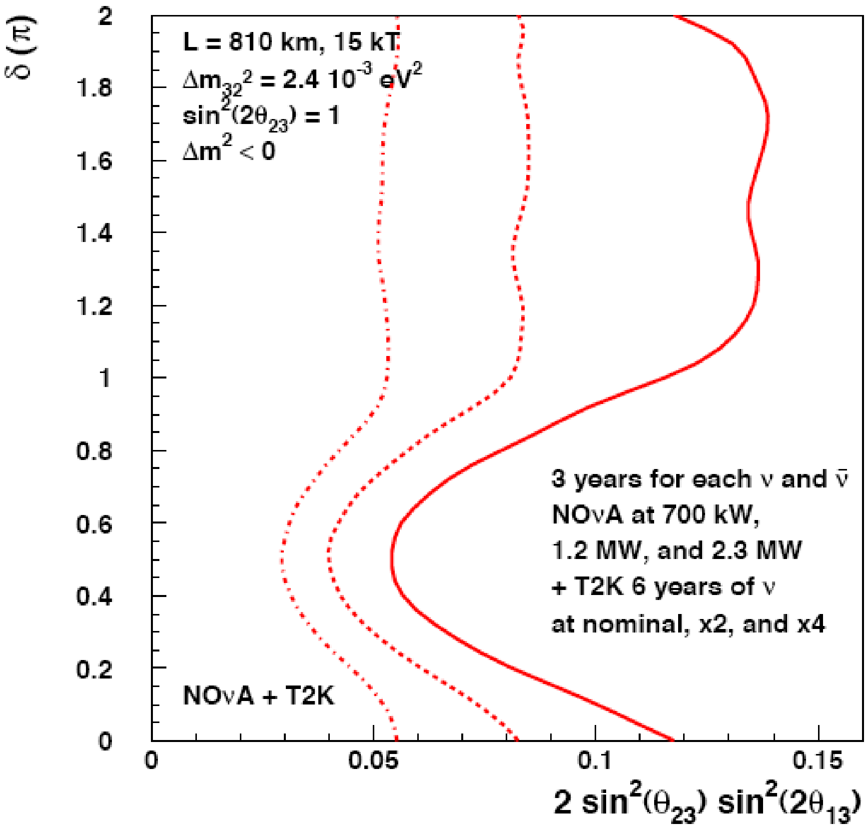


Inverted Ordering

95% CL Resolution of the Mass Ordering NOνA Plus T2K



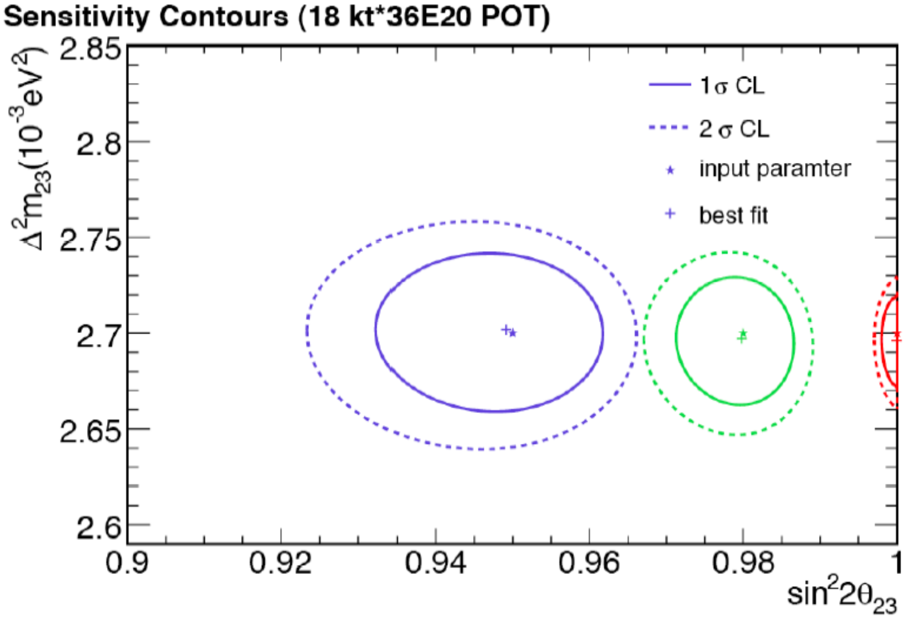
Normal Ordering



Inverted Ordering

Q4: Is θ_{23} maximal (45^o)?

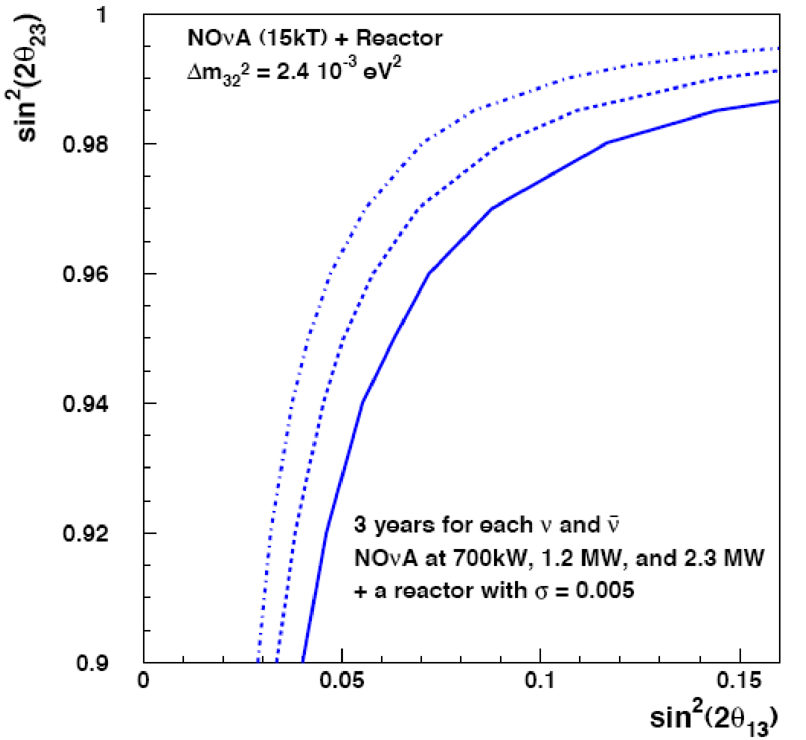
- "Is θ_{23} maximal (45 degrees)? if so, why? Will the pattern of neutrino mixing provide insights regarding unification of the fundamental forces? Will it indicate new symmetries or new selection rules?"



Because of its excellent energy resolution NOνA can make ~1% measurements of ν_μ disappearance using quasi-elastic events.

A related question (which P5 did not ask)

- If θ_{23} is not maximal, does the third mass state couple more strongly to ν_μ or ν_τ?
- This is not (easily) answerable by accelerator experiments alone, but can be resolved by comparing NOνA with a reactor experiment such as Daya Bay. This is because NOνA measures $\sin^2(\theta_{23})\,\sin^2(2\theta_{13})$, while Daya Bay measures $\sin^2(2\theta_{13})$.
- The parameter space for which this question can be answered is to the right and below the curves.



Q5: Are neutrinos their own antiparticles?

- "Are neutrinos their own antiparticles? Do they give rise to lepton number violation, or leptogenesis, in the early universe? Do they have observable laboratory consequences such as the sought-after neutrinoless double beta decay in nuclei?"

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

If NOνA establishes inverted hierarchy and next generation of $0\nu\beta\beta$ experiments see nothing, then it is very likely that neutrinos are Dirac particles

Q6: What can we learn from neutrinos from a supernova?

- “What can we learn from observation of the intense flux of neutrinos from a supernova within our galaxy? Can we observe the neutrino remnants of all supernovae that have occurred since the beginning of time?”

QuickTime™ and a
TIFF (LZW) decompressor
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NOνA would see burst of 5000 events from a supernova at the center of the galaxy.

Q7: What can neutrinos reveal about other astrophysical phenomena?

- "What can neutrinos reveal about other astrophysical phenomena? Will we find localized cosmic sources of very-high-energy neutrinos?"

Q8: Do sterile neutrinos exist?

- “What can neutrinos tell us about new physics beyond the Standard Model, dark energy, extra dimensions? Do sterile neutrinos exist?”

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are needed to see this picture.

NOνA’s fine segmentation allows for clean neutral-current measurements facilitating searches for sterile neutrinos

NOνA Timeline

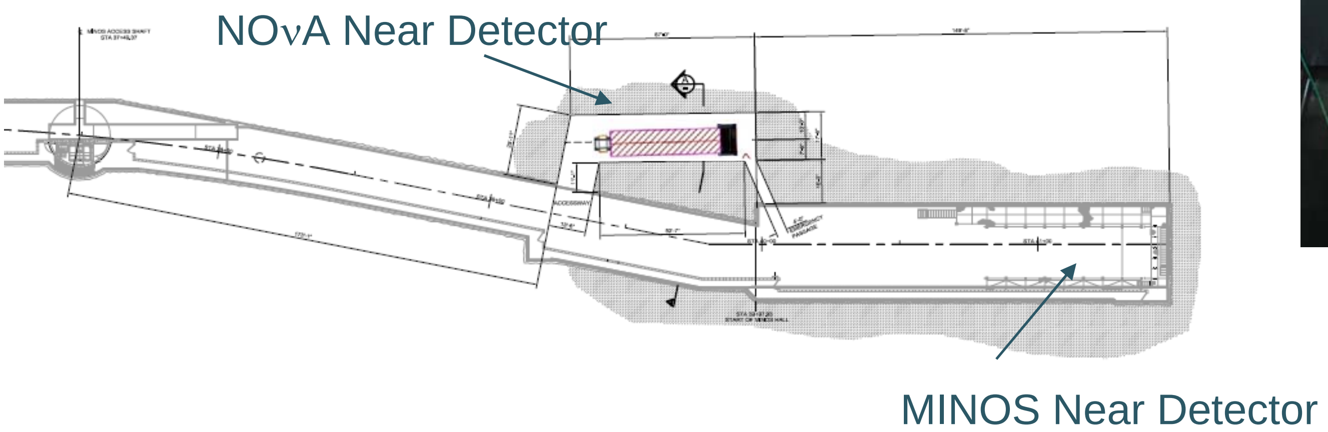
Apr 2005	Fermilab Stage 1 Approval
Nov 2005	CD-0 Granted
Feb 2006	Recommended by NuSAG
Oct 2006	Recommended by P5
May 2007	CD-1 Granted
Oct 2007	Passed CD-2/3a Review
Dec 20 2007	Omnibus funding bill zeros NOνA FY08 funding
Apr 30 2008	Passed Repeat CD-2/3a Review
May 29 2008	Re-recommended by P5 under Scenario B or better
July 1 2008	Supplemental funding bill restores $9.5 M NOνA funding
Sep 15 2008	CD-2 Granted
Oct 24 2008	CD-3a Granted: $23.9 M for long-lead items:
	$10.4 M for far site prep - road and excavation
	$6.3 M for ANU tooling, parts, and instrumentation
	$2.3 M for scintillator wave-shifters (single source)
	$4.9 M contingency

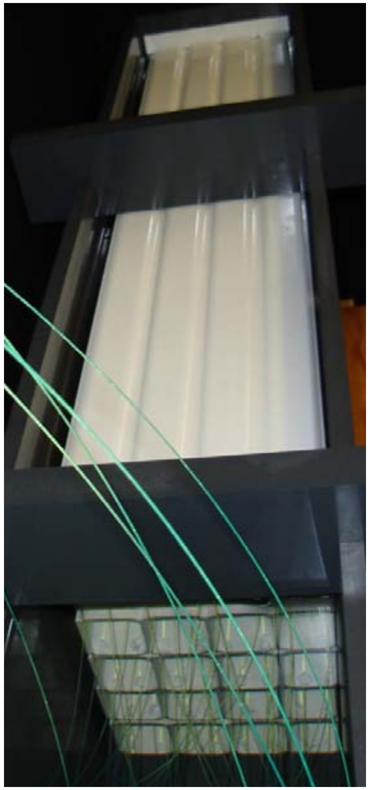
Recent Technical Progress (1)

- Far site building design converging toward RFP in February.
- External review of structure verified buckling stability of a free-standing block.
- Lifting fixture and glue machine prototype at Argonne proceeding.
- The Minnesota factory started outfitting extrusions for a 6 plane full scale assembly prototype at Argonne, to be completed Feb 2009.
- 4,500 gallons of scintillator mixed.
  QC plan converging.

Recent Technical Progress (2)

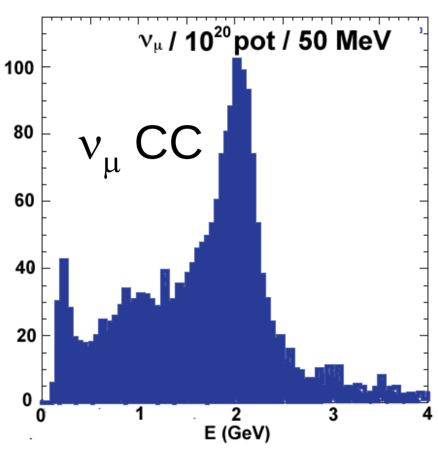
- 35 photoelectrons measured at far end of the Caltech "mini-tracker". Exceeds expectation of 25 pe.
- Offline software moved to a new unified framework. It is beginning to attract new students and postdocs and will form the basis for calibration studies.
- Preliminary engineering study and cost estimate of near detector cavern completed.

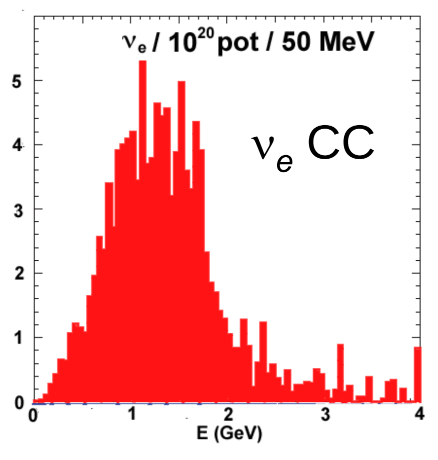




Integration Prototype Near Detector (IPND)

- Planning is continuing for the IPND, which will give NOνA first experience with the all of the components of the experiment.
  - 3 modules high, 2 modules wide, 124 planes long working prototype.
  - Scheduled for completion Feb 2010.
  - It will sit in the MINOS support building 107 mrad off-axis to the NuMI beam to see narrow band ν_μ and ν_e beams from *K* decay.
- The NOνA Calibration Committee is studying the advisability of also placing it in a test beam.





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Schedule

- The restart after the supplemental appropriation as been slower than optimal largely due to the difficulty of pulling back key personnel, who had been assigned to other projects.
- The schedule has probably slipped 12 months compared to the schedule prior to the omnibus funding bill. Future progress will, of course, depend on funding profiles.
- Best estimate of schedule:
  - Apr 2009 — Start of Construction (assumes FY09 funding final before March 6)
  - Jun 2011 — Far Detector Building Beneficial Occupancy
  - Aug 2012 — 1st 2.5 kT of the Far Detector Online
  - Jan 2014 — Full Far Detector Online