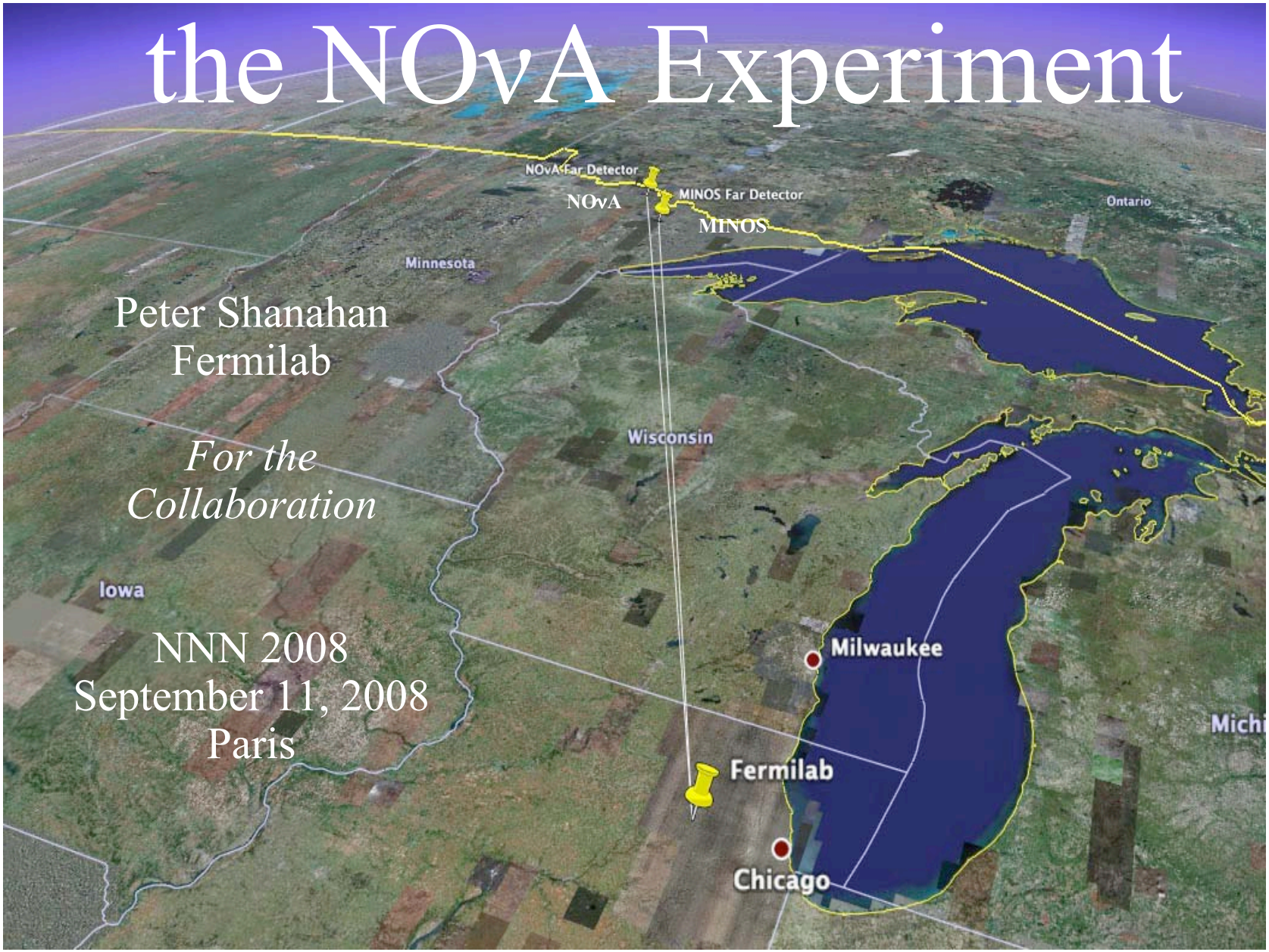
Status and Prospects of the NOvA Experiment



Peter Shanahan
Fermilab

For the Collaboration

NNN 2008
September 11, 2008
Paris

APC, Argonne, Athens, Caltech, Fermilab, Harvard, Indiana, Lebedev Physical Institute, Michigan State, Minnesota-Twin Cities, Minnesota-Duluth, T U München, Northern Illinois, Ohio State

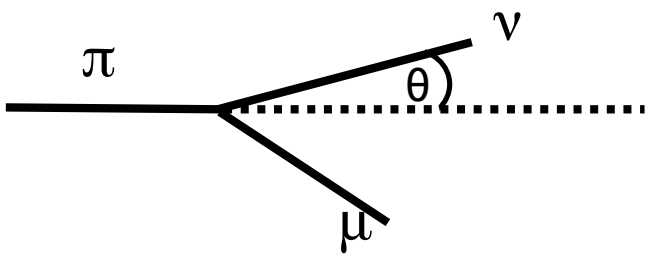
P.U.C. Rio de Janeiro, South Carolina, SMU, Stanford, SUNY Stony Brook, Texas-Austin, Texas-Dallas, Texas A&M, Tufts, UCLA, Virginia, William and Mary

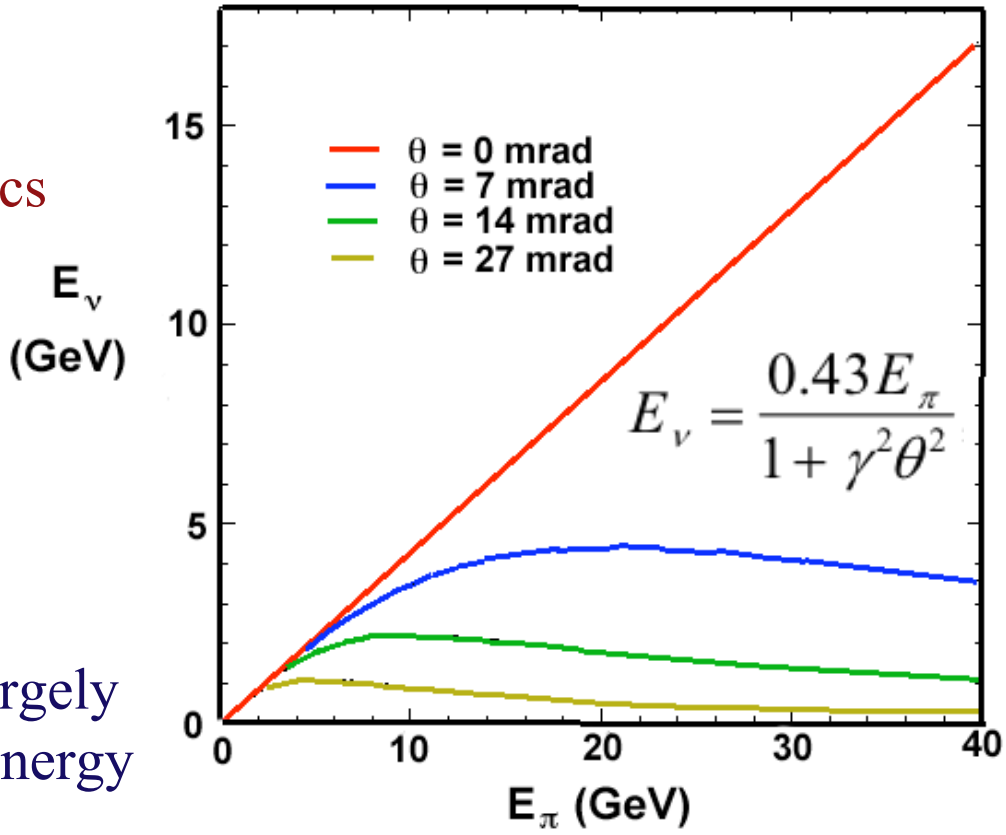
Introduction

- NOνA: NuMI Off-Axis ν_e Appearance
- Study $\nu_\mu \rightarrow \nu_e$:
  - search for $\sin^2(2\theta_{13})$ with a sensitivity an order of magnitude beyond current limits
  - sensitivity to Mass Hierarchy for a significant fraction of parameters
  - search for effect of CP violating phase δ
- Two detectors with a 810 km baseline using the NuMI Neutrino Beam from Fermilab
- Near and Far Detectors optimized for ν_e charged-current detection
- Located Off the Beam Axis

Off-Axis

- Place Detector Off-axis for narrow-band beam
  - π 2-body decay kinematics

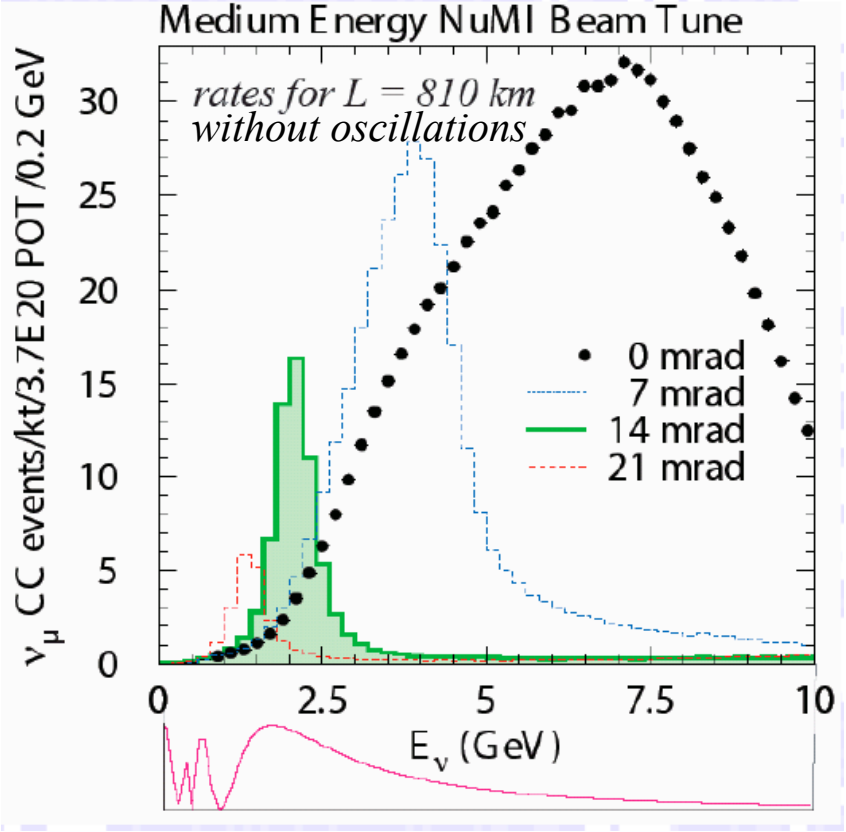




Off-axis: neutrino energy largely independent of parent pion energy

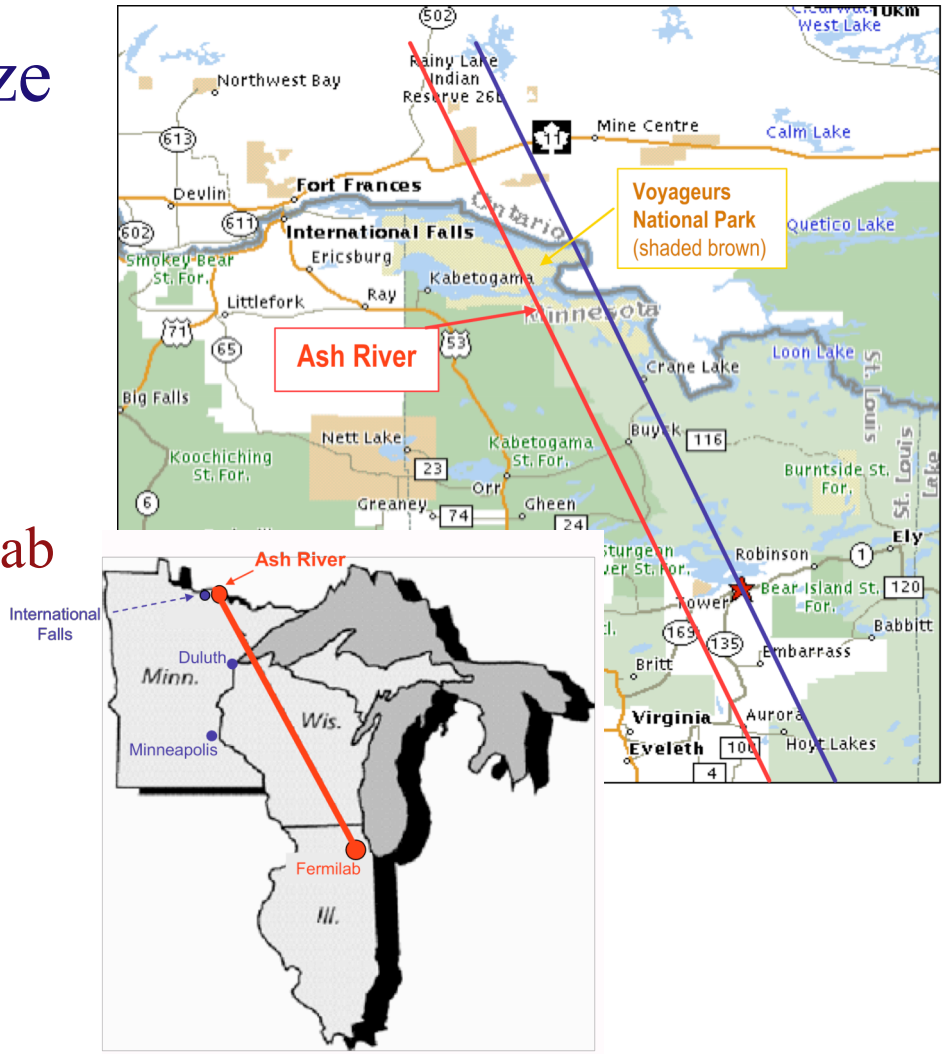
Off-Axis Spectra

- Benefits of off-axis spectrum:
  - More flux near oscillation maximum
  - Reduction of High Energy Tail reduces NC Feed-down
  - Concentration of ν_e from oscillation relative to intrinsic beam ν_e (from 3-body K and μ decay)

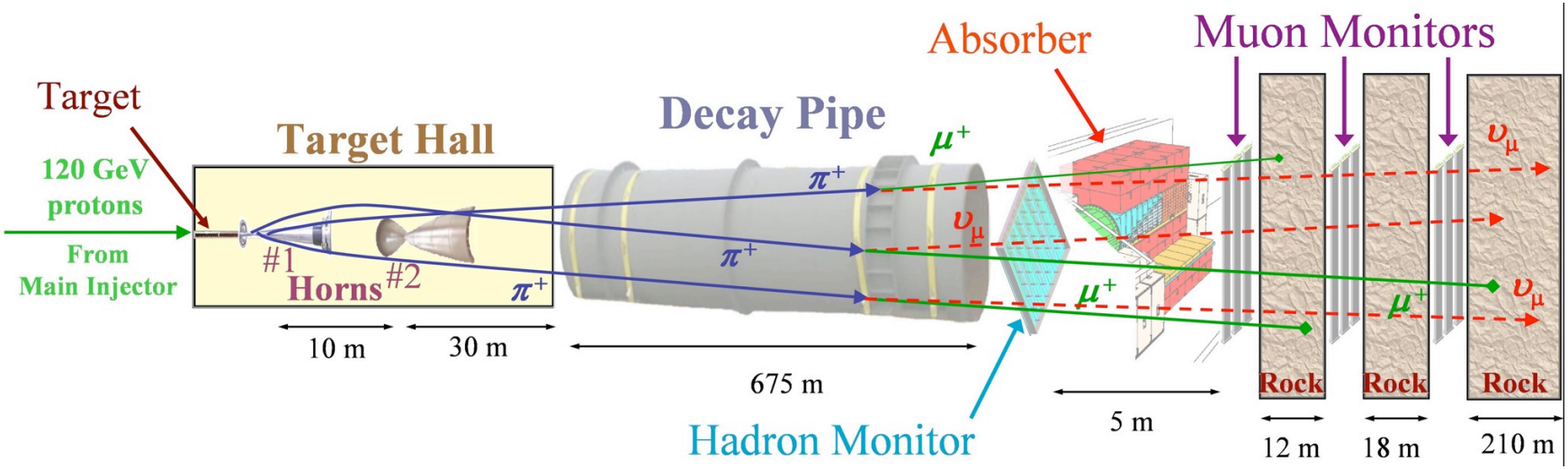


Location

- Optimization: Maximize sensitivity to Mass Hierarchy via Matter Effect
  - Maximize baseline within U.S. - 810 km from Fermilab
  - Optimize off-axis location: 12 km from beam axis
  - Ash River, MN



NuMI Beam

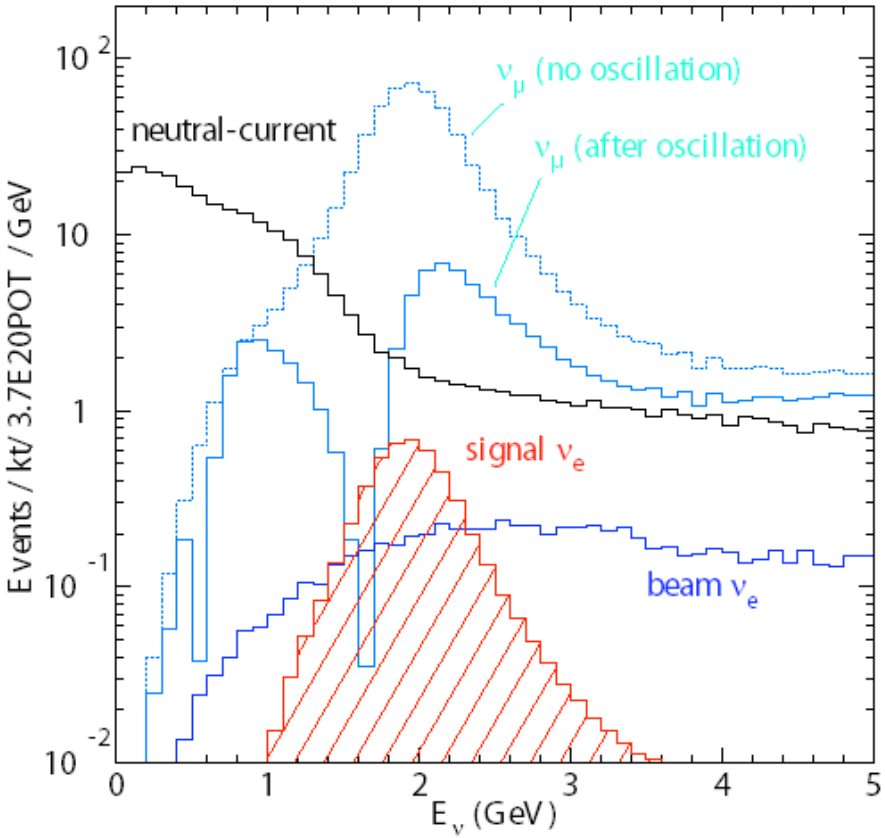


- Beam spectrum tuned with horn currents and relative horn-target placement
- 10 μs spill
- Operating since 2005

- Other NuMI Experiments
  - MINOS - Alex Sousa's talk
  - MINERvA - Proposed high precision neutrino scattering experiment
  - ArgoNeuT - Mitch Soderberg's talk

Detector Requirements

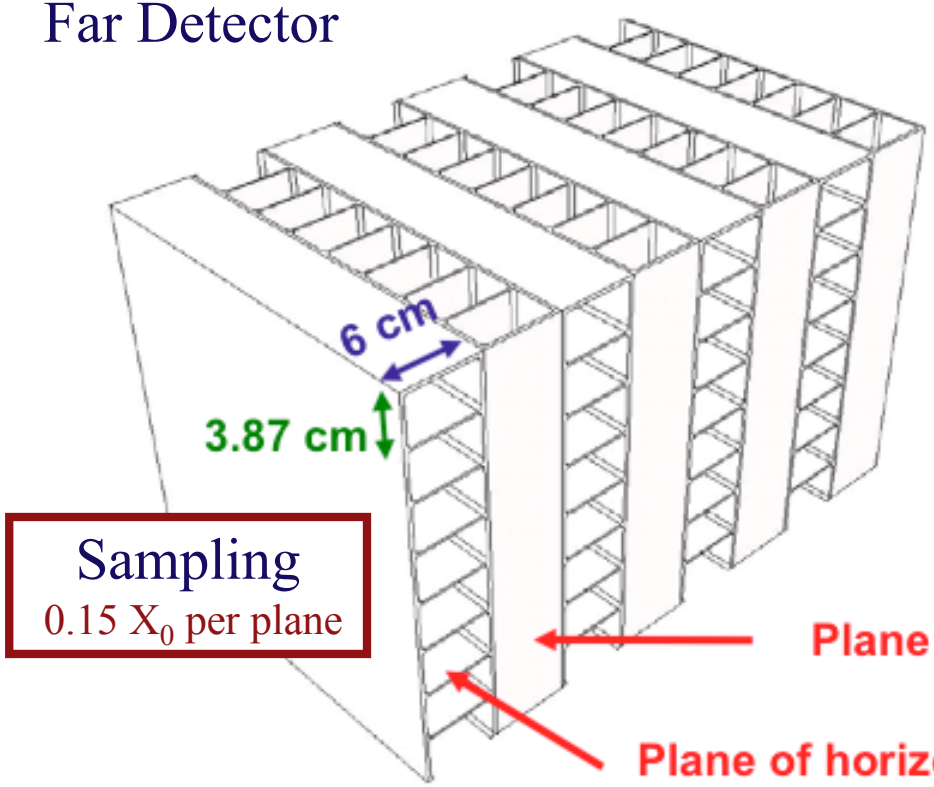
- **Large: 15 kT**
- **Required background suppression**
  - ~50:1 for ν_μ CC (easy!)
    ~100:1 for NC
  - Maximize Hadronic/EM Separation ➠ *Low Z, Fine Sampling per Radiation Length*
- **Energy Resolution**
  - Small compared to width of signal peak
- **⇒ Liquid Scintillator in PVC Structure**



Interaction spectra at 810km, 12km off-axis.
Oscillations: $\Delta m^2=2.5\times10^{-3}eV^2$, $\sin^2(2\theta_{13})=0.01$

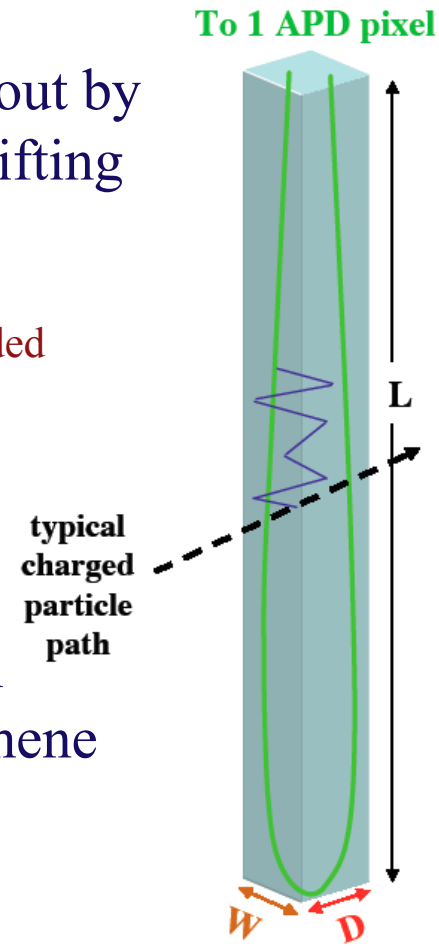
Scintillator and PVC

- PVC (polyvinyl chloride) extrusions with 15% TiO_2
- 32 cells per extrusion
- 12 extrusions per plane in Far Detector



Sampling
0.15 X_0 per plane

Basic unit:
Each cell read out by Wavelength shifting fiber
- U shaped for high efficiency single-ended readout

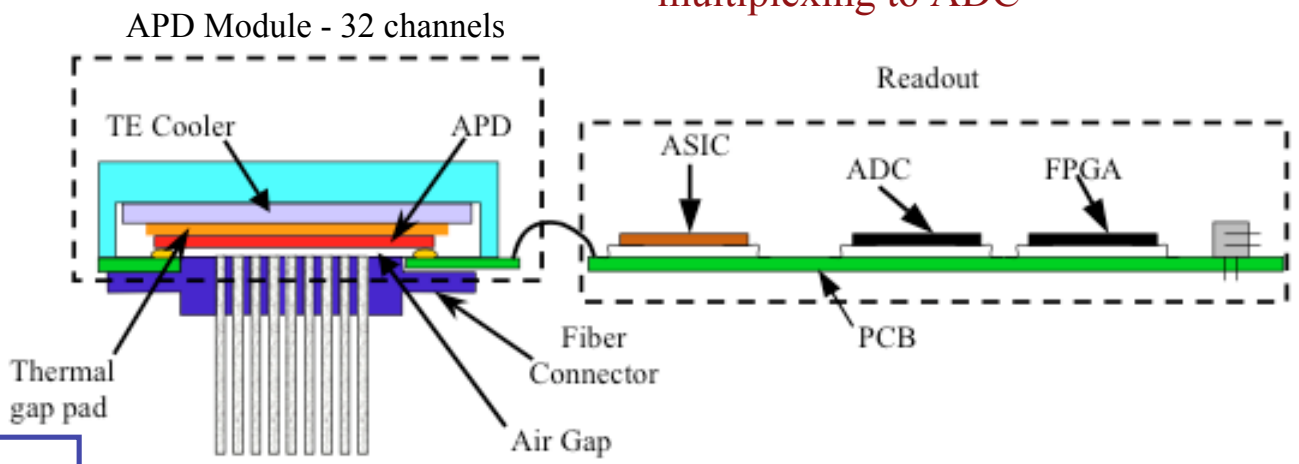


Scintillator:
Mineral Oil with 4.1% Pseudocumene

Readout

- Wavelength shifting fibers into APDs

ASIC: Amplification, shaping, multiplexing to ADC

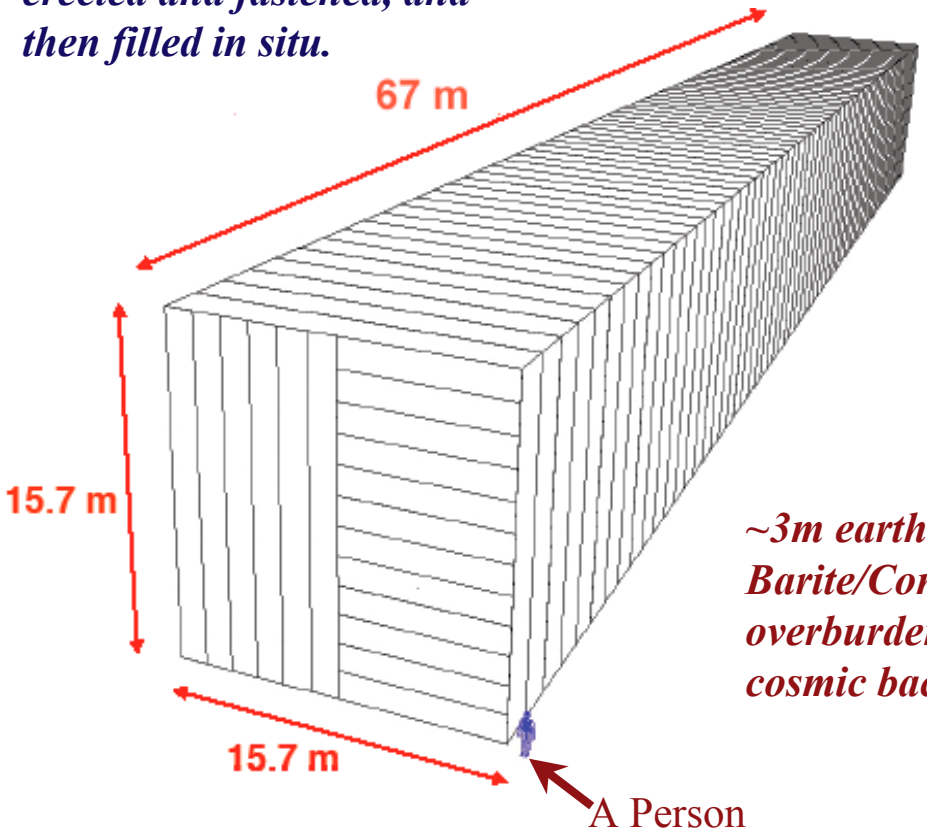


Avalanche Photo Diodes:
- 85% Quantum Efficiency
- Gain~100
- cooled to -15C for 2PE dark noise

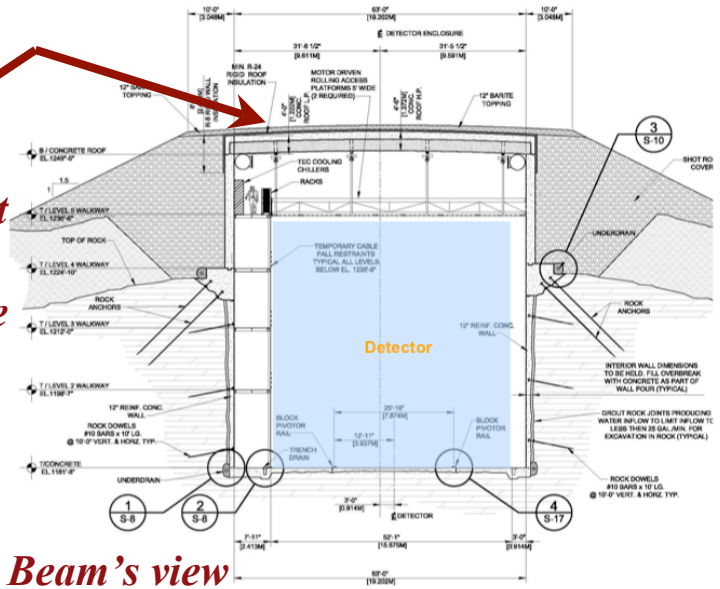
Response:
- 20-30 photo-electrons from μ at far end of cell
- 4 P.E. total noise

Far Detector

Construction:
Empty planes will be erected and fastened, and then filled in situ.



~3m earth equivalent Barite/Concrete overburden to reduce cosmic backgrounds



Beam's view

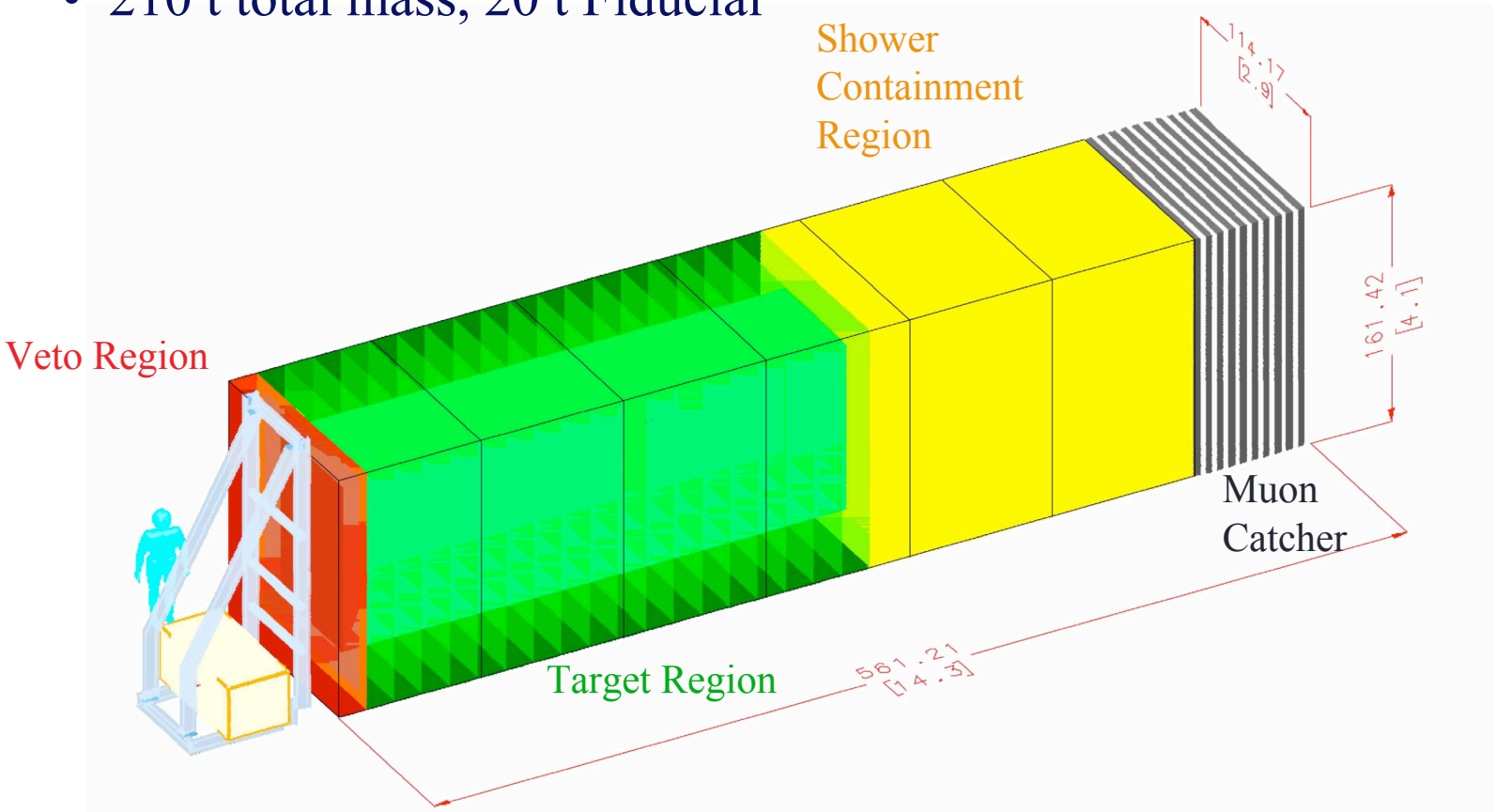
15kT Total Mass
(70% Scintillator)

1003 planes of detector supported in blocks of 31

385000+ cells

Near Detector

- Identical to Far Detector, except smaller, with muon catcher
- Placed and oriented at the same off-axis angle
- Contains 2 GeV ν events
- 210 t total mass, 20 t Fiducial



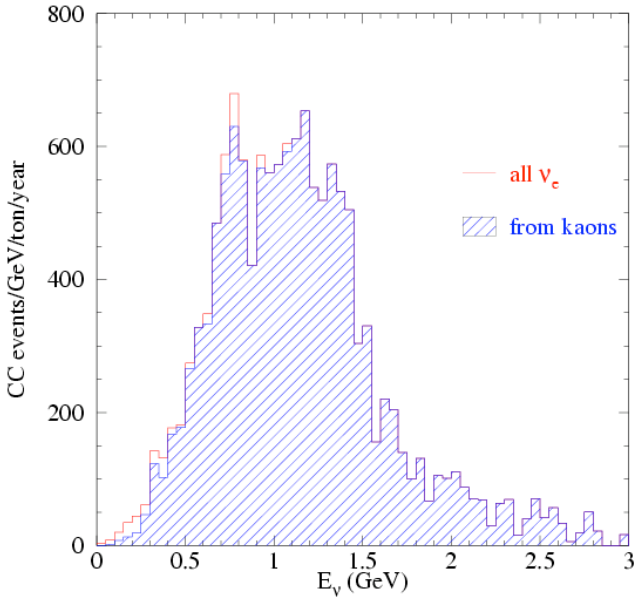
Prototype

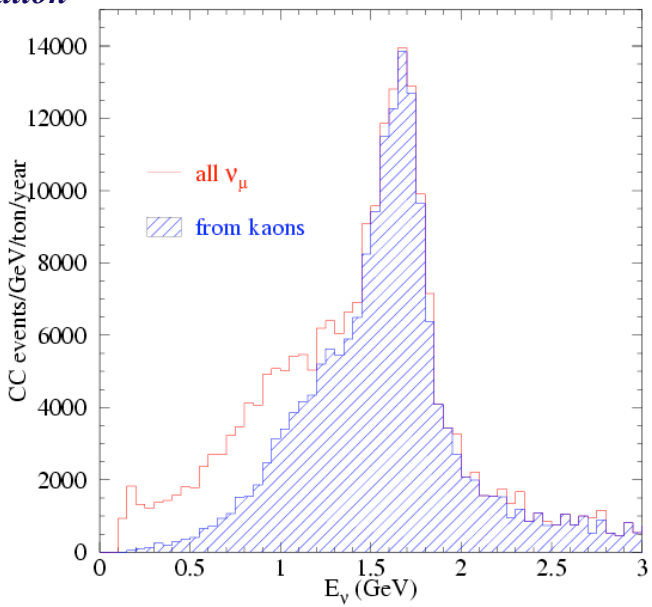
IPND: **I**ntegration **P**rototype **N**ear **D**etector (84 tonnes)

Test scale production of all detector elements

- Test neutrino beam response, cross calibration techniques, cosmic rejection
- To be located on surface near MINOS Service Building
- Data taking early 2010

Low Energy Beam Configuration



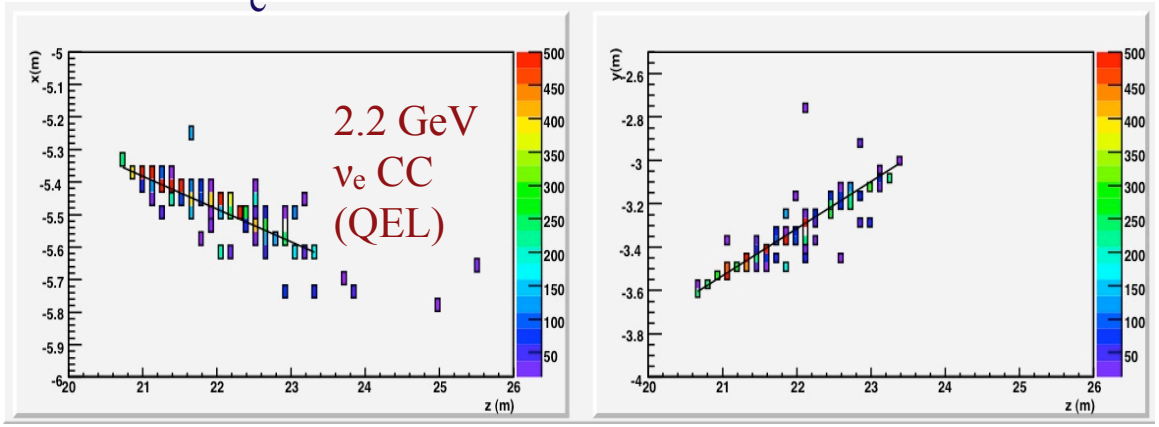


107 mrad off-axis:

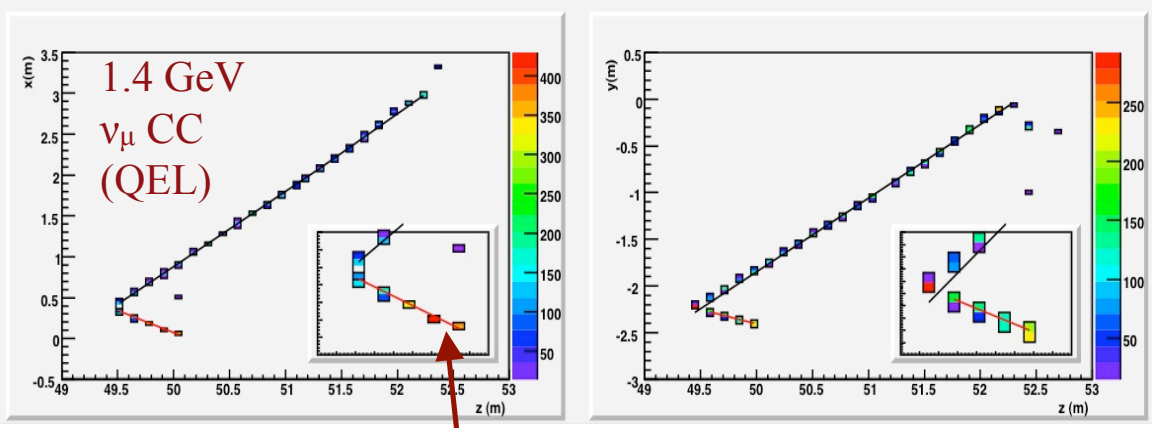
dominated by K decays

Performance

ν_e CC event

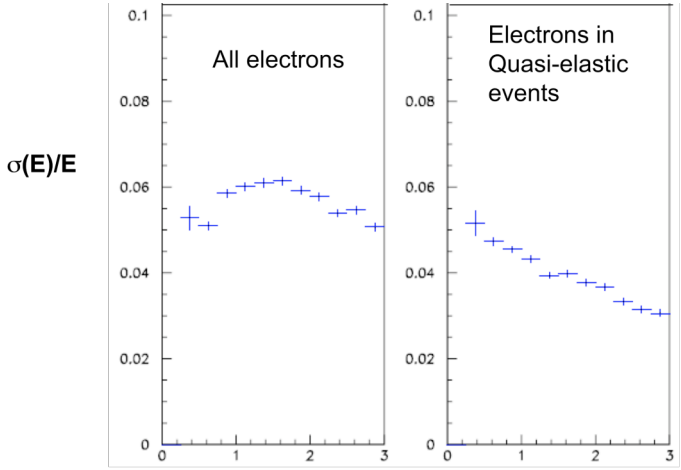


ν_μ CC event

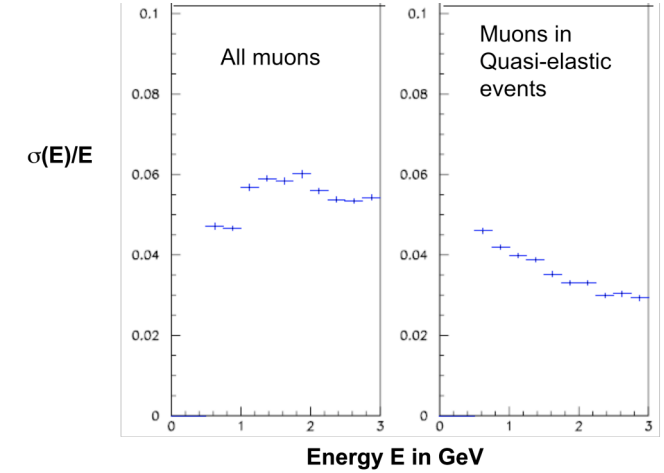


Proton track often distinguishable by pulseheight

Electron: σ(E)/E<6%

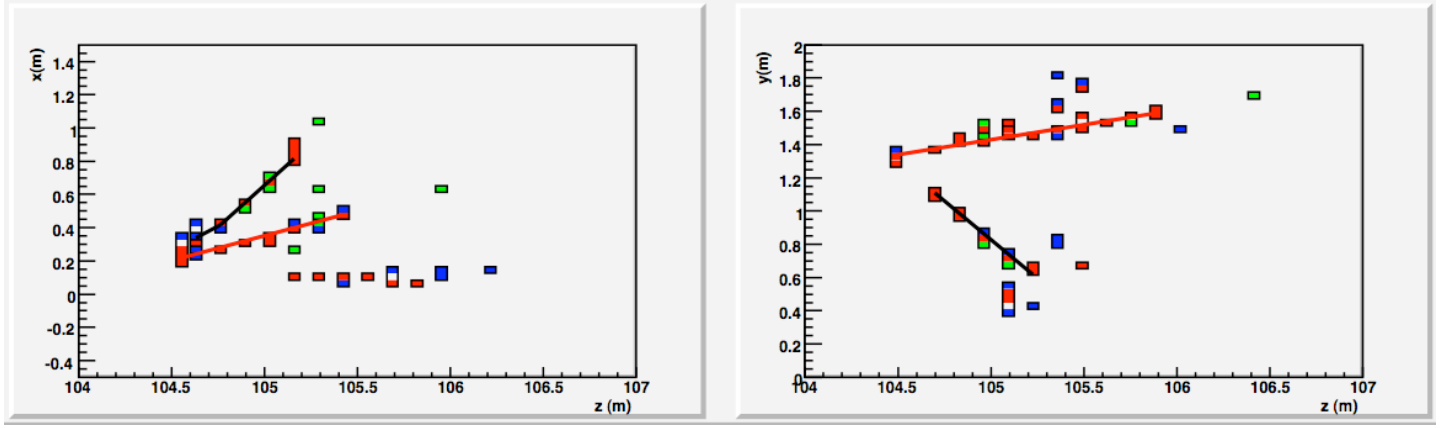


Muon: σ(E)/E<3.5% for 2GeV QE

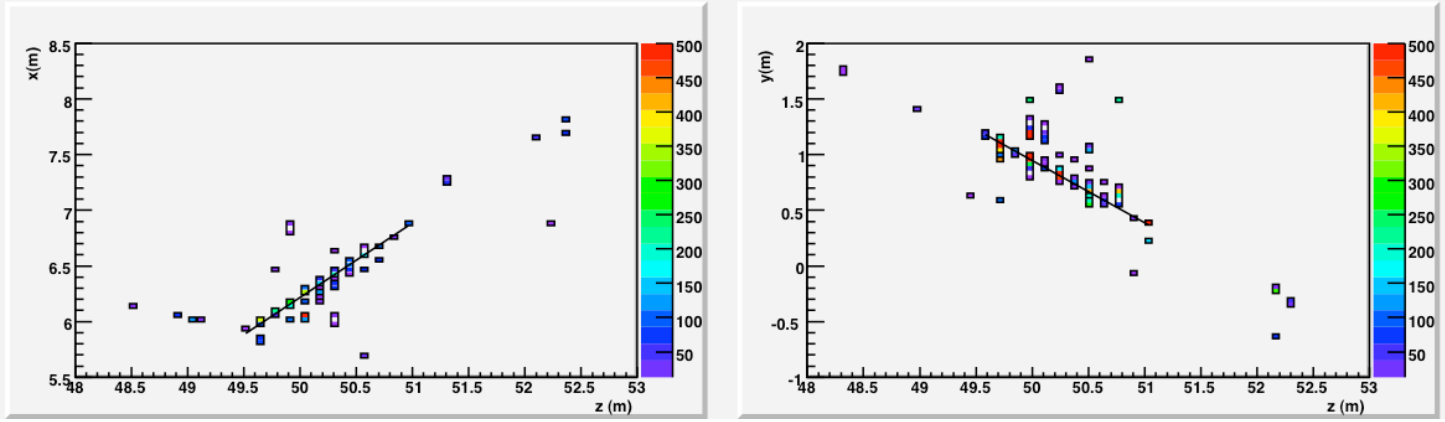


NC Rejection

E_ν=10.3 GeV, y=0.14
Gaps between vertex and showers
Easy case



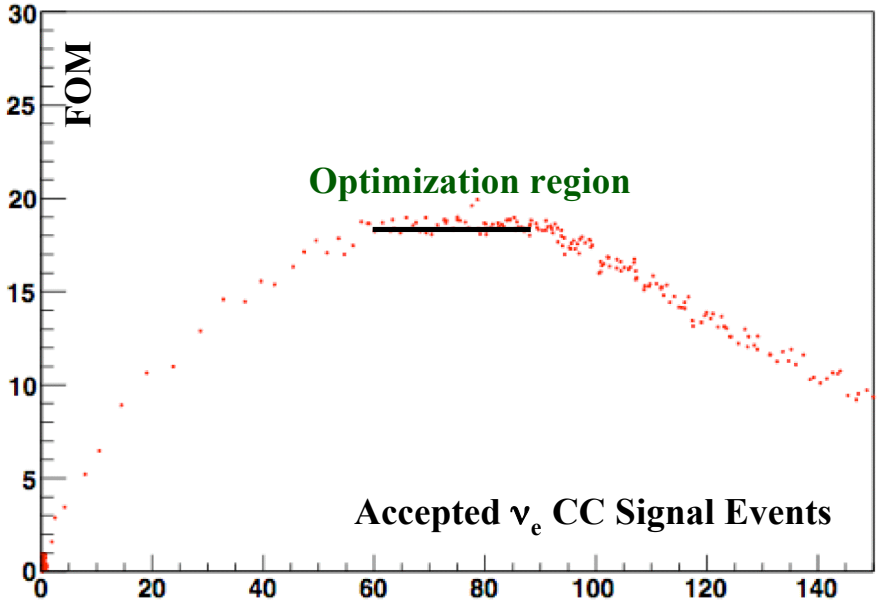
E_ν=8.4 GeV, y=0.27
Highly electromagnetic final state
Hard to reject



Signal Selection

ν_e CC signal selection uses artificial neural net based on reconstructed parameters of the electron and the event:
shape, signal profiles, topology, etc.

ANN cut chosen to maximize Figure of Merit (FOM)=S/√B



3yrs each mode, 15 kT, 700 kW	Neutrino Running	Anti-neutrino Running	Efficiency*
ν_e CC signal	75.0	29.0	36%
Backgrounds	14.4	7.6	
NC	6.0	3.6	0.23%
ν_μ CC	0.05	0.48	0.004%
Intrinsic Beam ν_e	8.4	3.4	14%

* Efficiency includes effect of fiducial cut

Assumptions:
$\sin^2(2\theta_{13})=0.1$
$\sin^2(2\theta_{23})=1.0$
$\Delta m^2=0.0024$ eV^2
$\delta=0$ and no matter effects

Sensitivities

- Assumptions for the following plots:
  - **15 kT detector**
  - **3 years running each for ν and $\bar{\nu}$**
  - **3 beam power scenarios: 700 kW, 1.2 MW, and 2.3 MW**
- Plots made using...
  - **Full simulation of flux, interactions, and detector response**
  - **Event selection based on reconstruction**

NOνA and Reactors

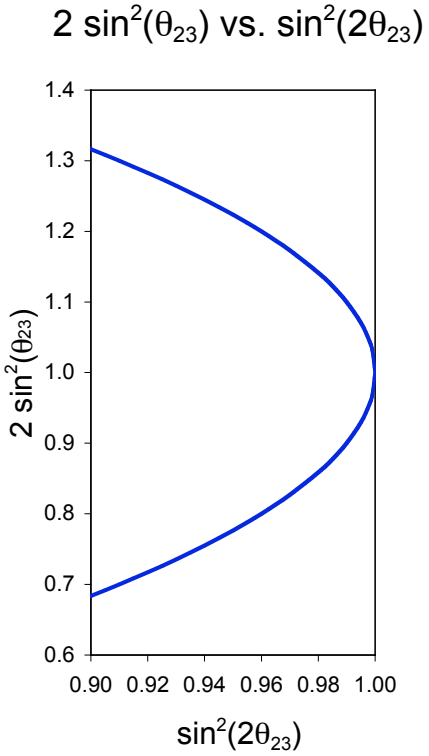
- Dominant term in $P(\nu_\mu \rightarrow \nu_e)$ for long-baseline accelerator is proportional to $\sin^2(\theta_{23})\sin^2(2\theta_{13})$

- But $\sin^2(2\theta_{23})$ is measured in long baseline ν_μ disappearance experiments

  Difference is significant for $\theta_{23} \neq \pi/4$

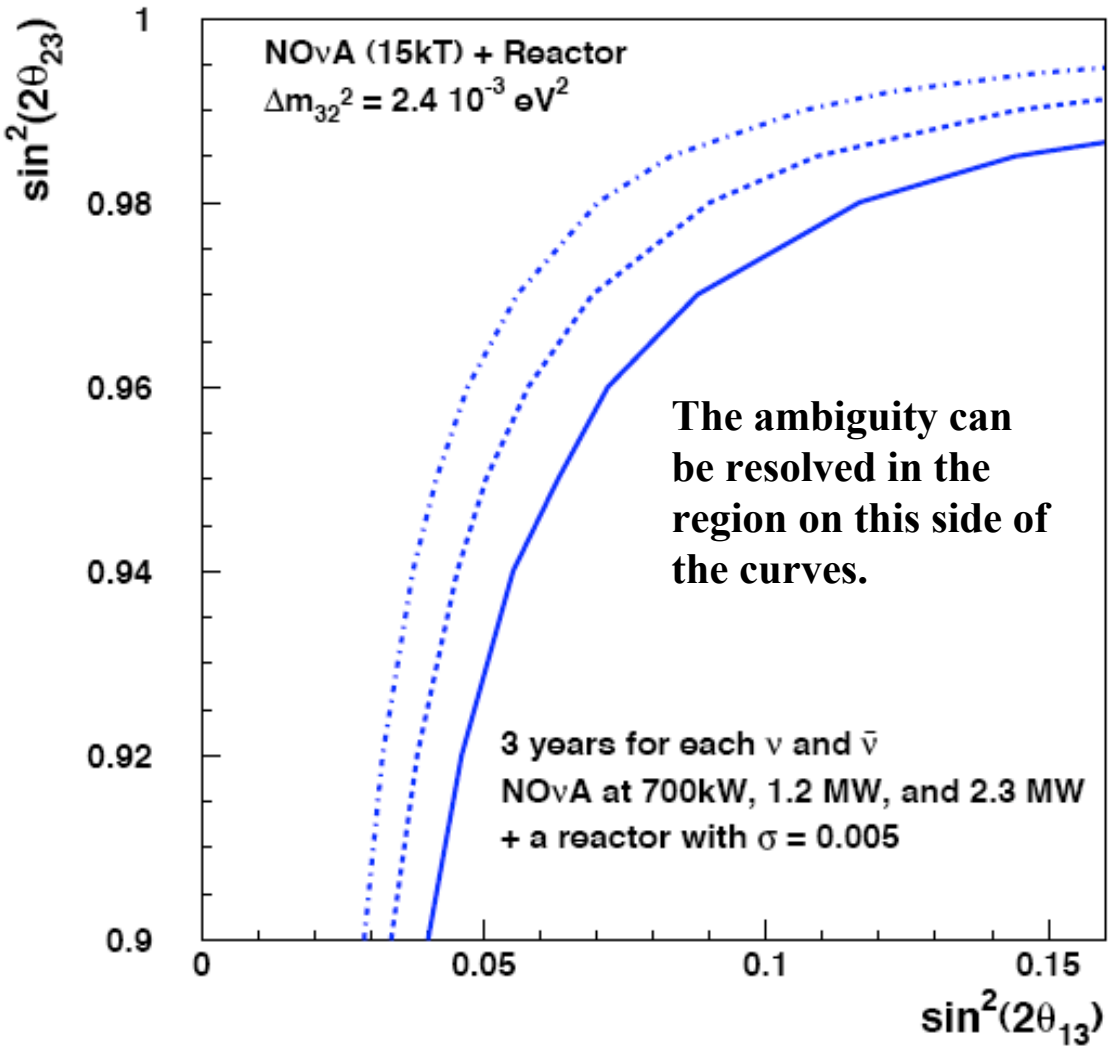
- Fortunately, reactor experiments are sensitive to $\sin^2(2\theta_{13})$

- Comparison of LB appearance and Reactor results can allow resolution ambiguity: does ν_3 couple more to ν_μ ($\theta_{23}<\pi/4$) or to ν_τ ($\theta_{23}>\pi/4$) ?



Resolution of θ_{23} ambiguity at 95% CL

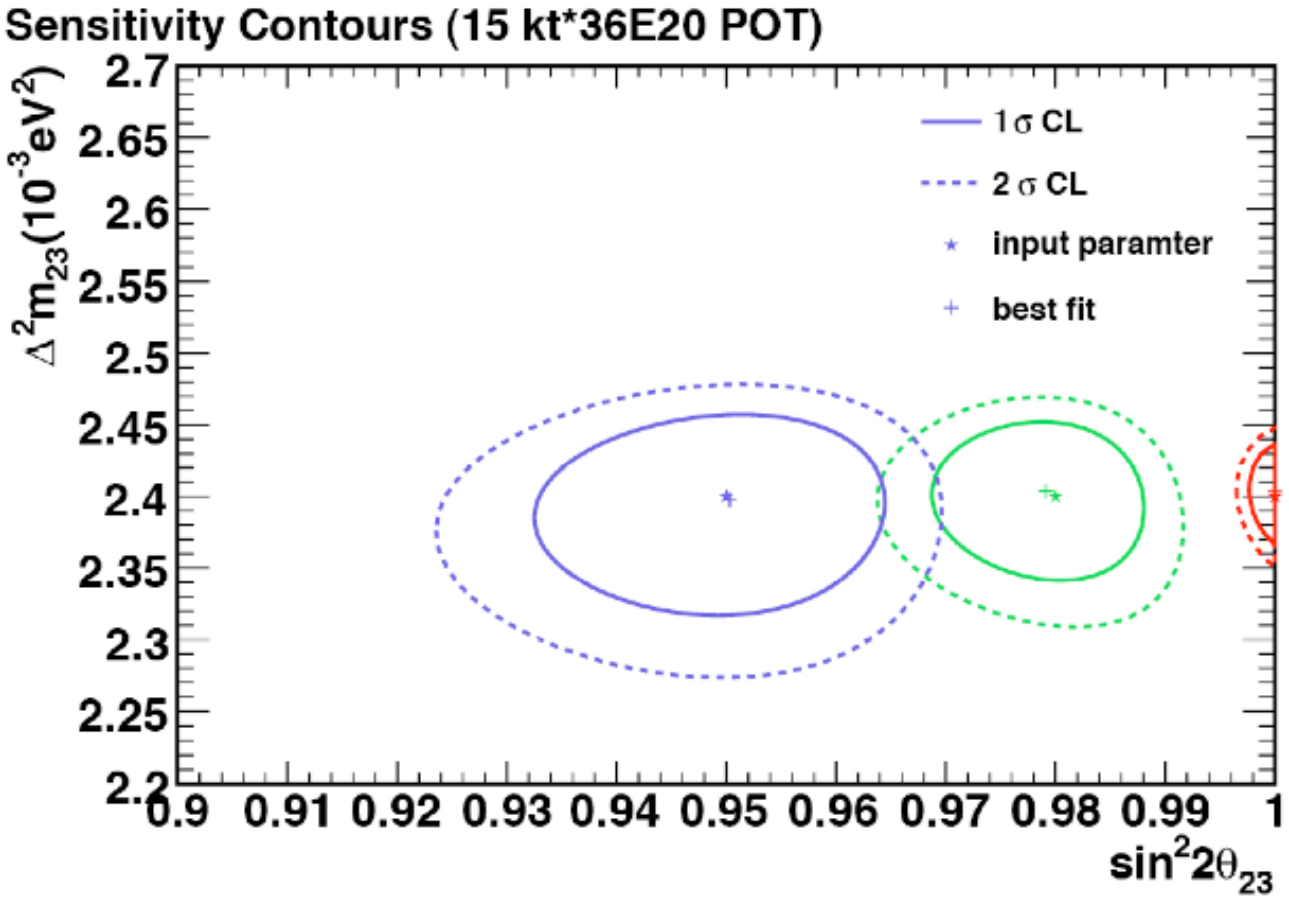
The curves represent an average over mass hierarchy, CP phase δ, and sign of θ_{23} ambiguity.



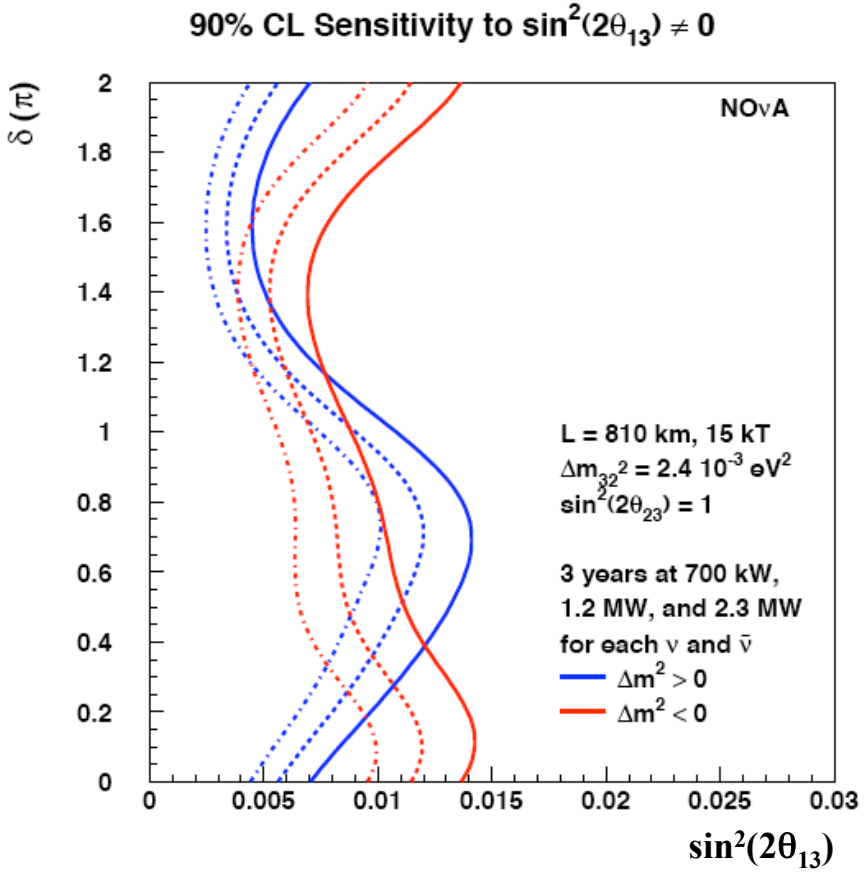
Measurement of $\sin^2(2\theta_{23})$

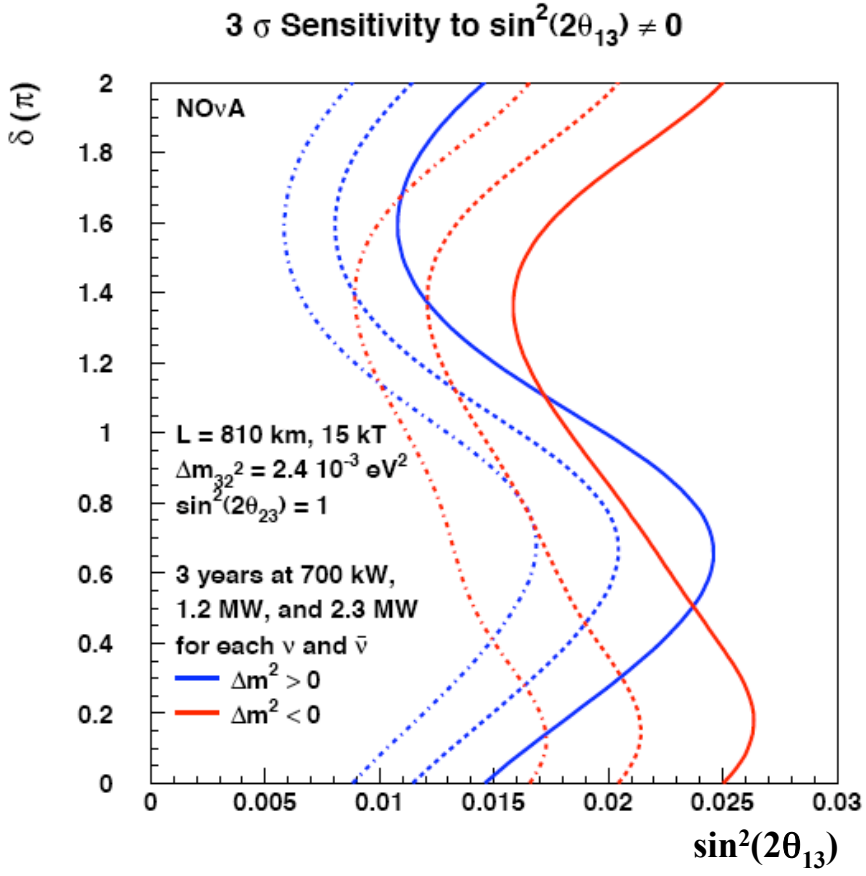
ν_μ Disappearance:

High Precision Measurement of Δm^2_{23} and $\sin^2(2\theta_{23})$ will be possible with QE Channel, using NOνA's excellent energy resolution.



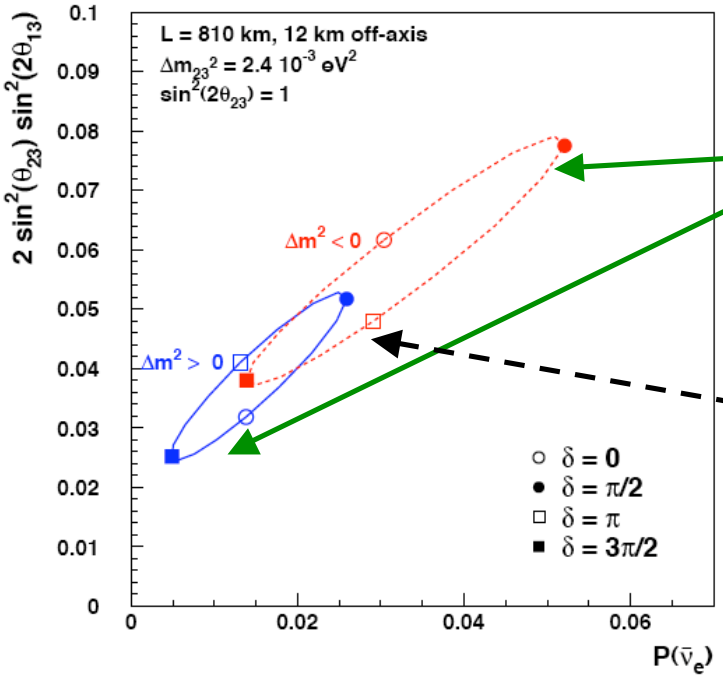
Sensitivity to $\sin^2(2\theta_{13})\neq 0$





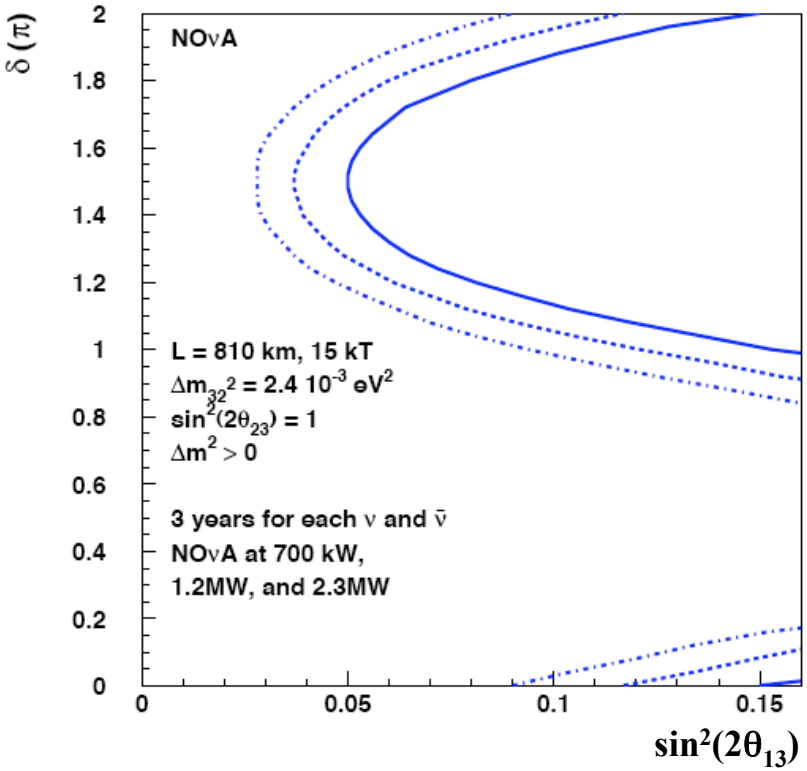
CP Violation and Mass Hierarchy

Parameters consistent with $P(\nu_\mu \rightarrow \nu_e)$=0.02

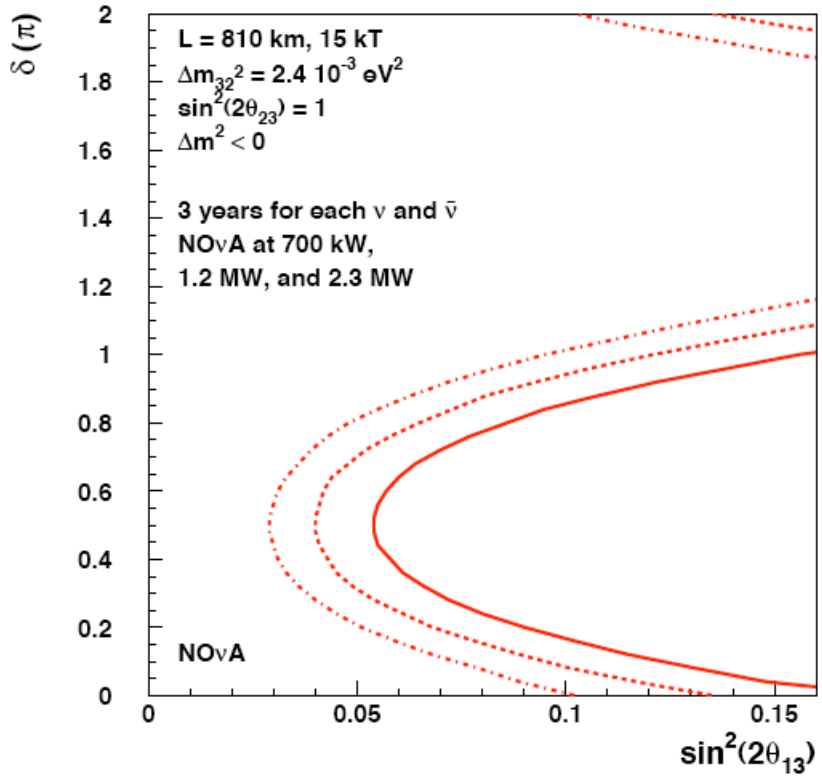


- **CP violation and matter effect change sign between ν and $\bar{\nu}$**
- **If the effects add, NOνA alone may be able to determine the Mass Hierarchy**
- **If they cancel, comparison with T2K may be able to break CP/Mass Hierarchy ambiguity**

95% CL Resolution of Mass Hierarchy, NOνA Alone

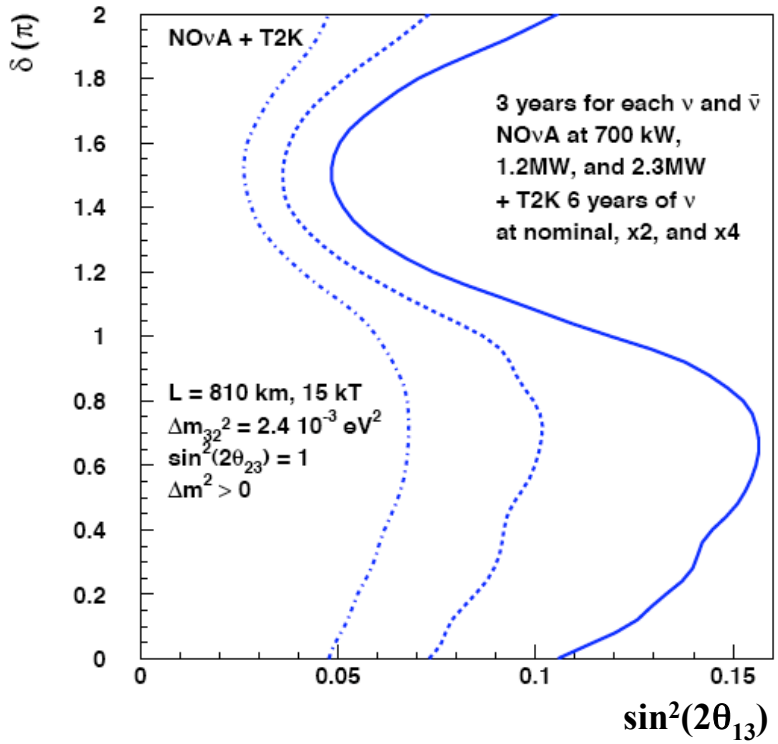


Normal Ordering

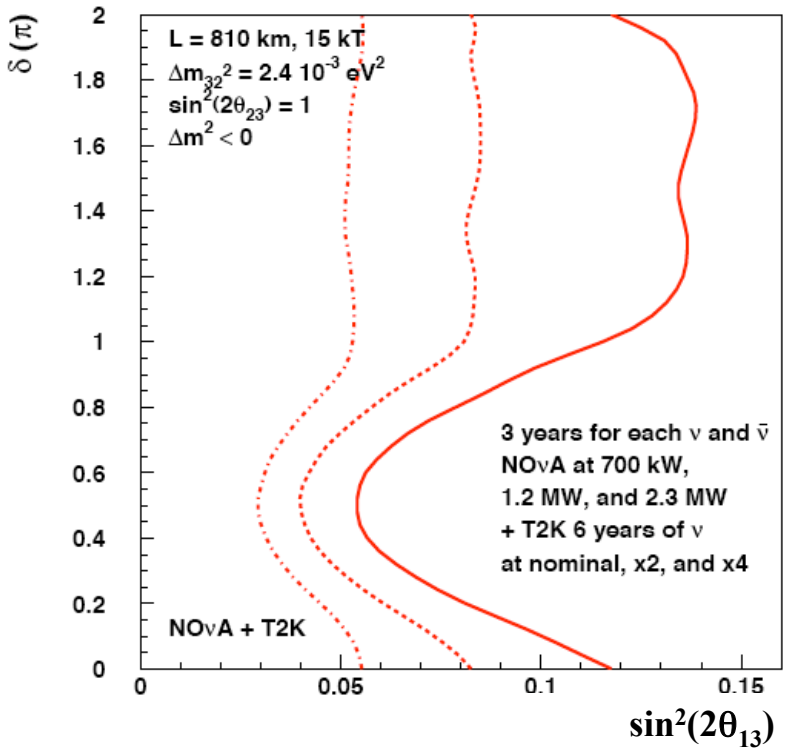


Inverted Ordering

Combining with T2K



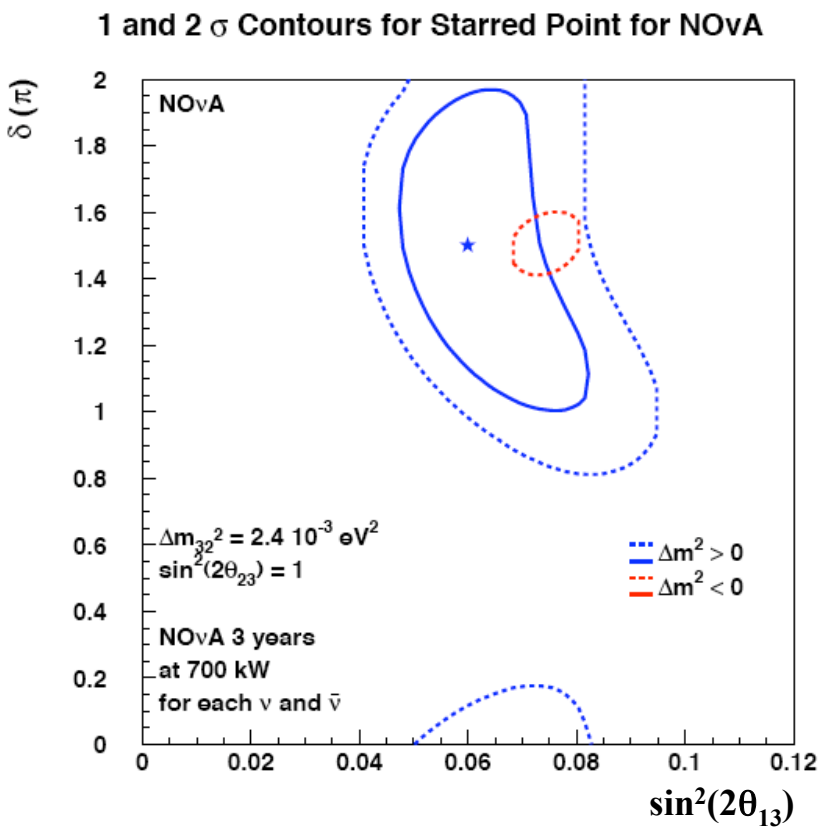
Normal Ordering

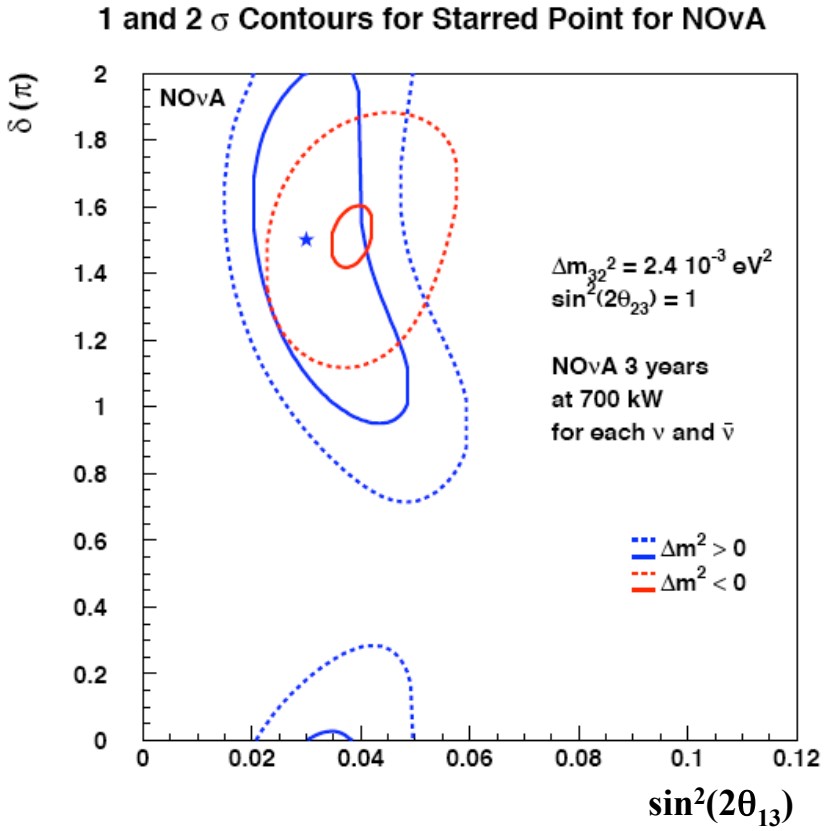


Inverted Ordering

N.B.: assumes T2K runs in neutrino mode only

Best possible δ for Normal MH





NOνA Only

History/Schedule

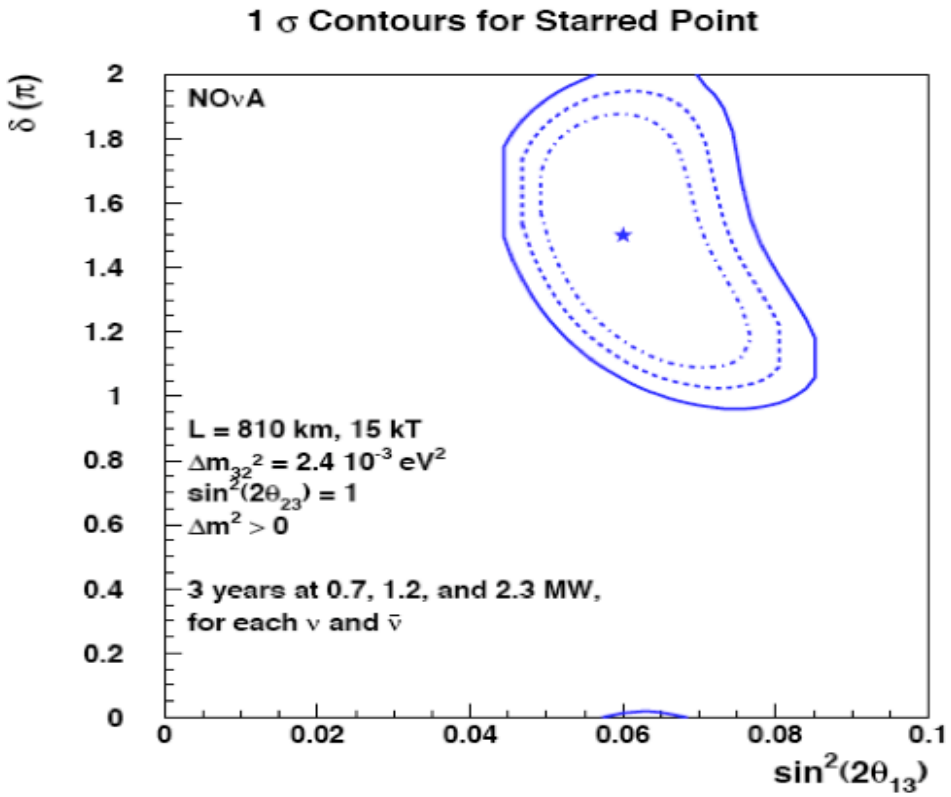
- May 2002: 1st Workshop
- April 2005: Fermilab PAC approval
- April 2006: DOE CD-1 recommendation - "Approve Preliminary Baseline Range"
- November 2007: DOE CD-2 review - Cost, schedule and scope baseline
  - complete ***Technical Design Report***
- December 17, 2007: "Black Monday"
  - US Congress cuts much science funding, including FY2008 NOvA funding
- April 2008: CD-2 re-review, approval recommended
- **July 1, 2008: M$9.23 restored to NOvA FY08 funding - project activities resume**
- Expect CD-2 full approval soon
- Detector construction and running
  - IPND Data taking early 2010
  - Far Detector construction start late 2011, complete mid-2013. Data taking can start with first few kT

Conclusions

- NOνA will have greatly increased sensitivity to $\nu_\mu \rightarrow \nu_e$ over current experiments
  - Fine grained, low Z detector
  - Off beam axis location
- Unique sensitivity to the Mass Hierarchy
  - Matter effects: advantage of long baseline
- Complimentary to both T2K and Reactor Experiments
- NOνA is back on track!

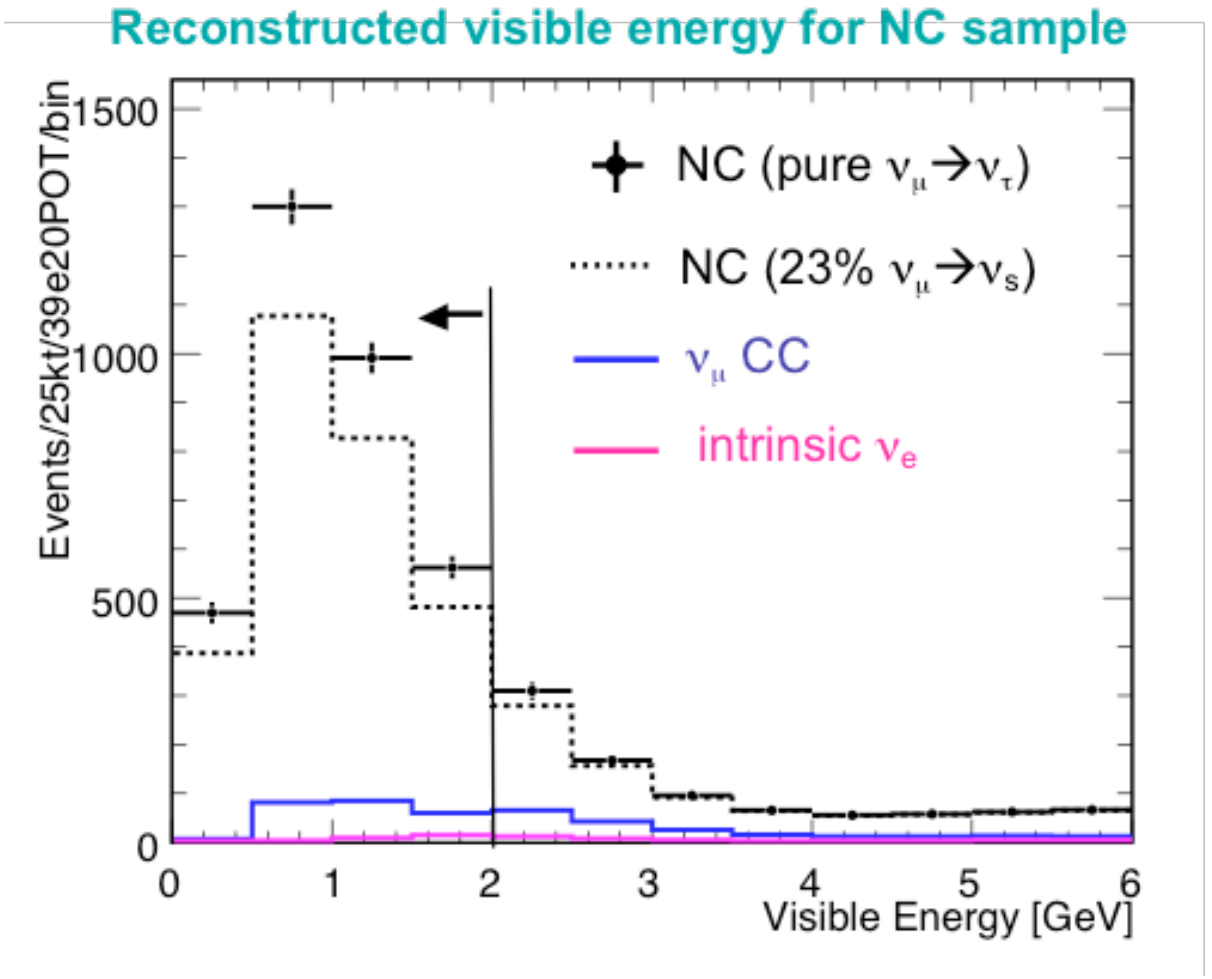
Backup Slides

δ at 1 σ

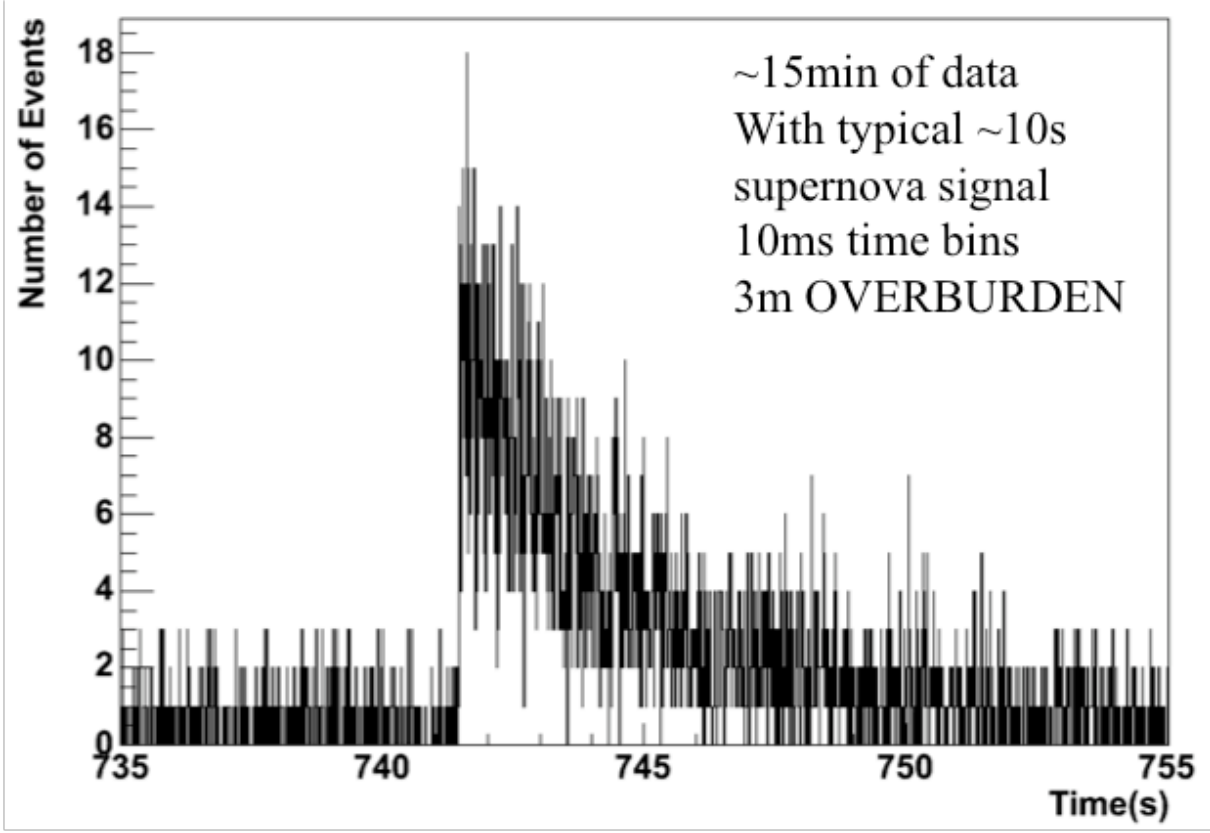

1 σ Contours for Starred Point
NOνA
δ (π)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
L = 810 km, 15 kT
Δm32 2 = 2.4 10-3 eV2
sin2(2θ23) = 1
Δm2 > 0
3 years at 0.7, 1.2, and 2.3 MW,
for each ν and ν̄
0
0.02
0.04
0.06
0.08
0.1
sin2(2θ13)

Sterile Neutrinos

Sensitivity to 11% sterile neutrino admixture at 90% CL



Supernova Sensitivity



NOvA would see burst of 5000 events for a supernova at the center of the galaxy