Status and Prospects of the NOνA Experiment

Peter Shanahan - Fermilab
Neutrino 2006
June 17, 2006 - Santa Fe
For the Collaboration

~150 Scientists from 28 Institutions

Some of us in International Falls, MN - May 2006

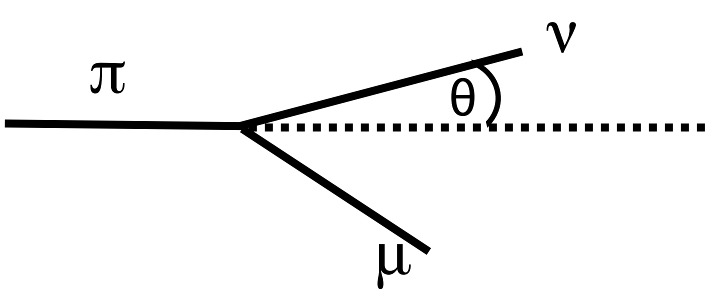
Argonne, Athens, Caltech, College de France, Fermilab, Harvard, Indiana, ITEP, Michigan State, Minnesota-Twin Cities, Minnesota-Duluth, Northern Illinois, Ohio, Ohio State, Oxford, Rutherford, Rio de Janeiro, South Carolina, SMU, Stanford, Texas, Texas A&M, Tufts, UCLA, Virginia, Washington, William and Mary

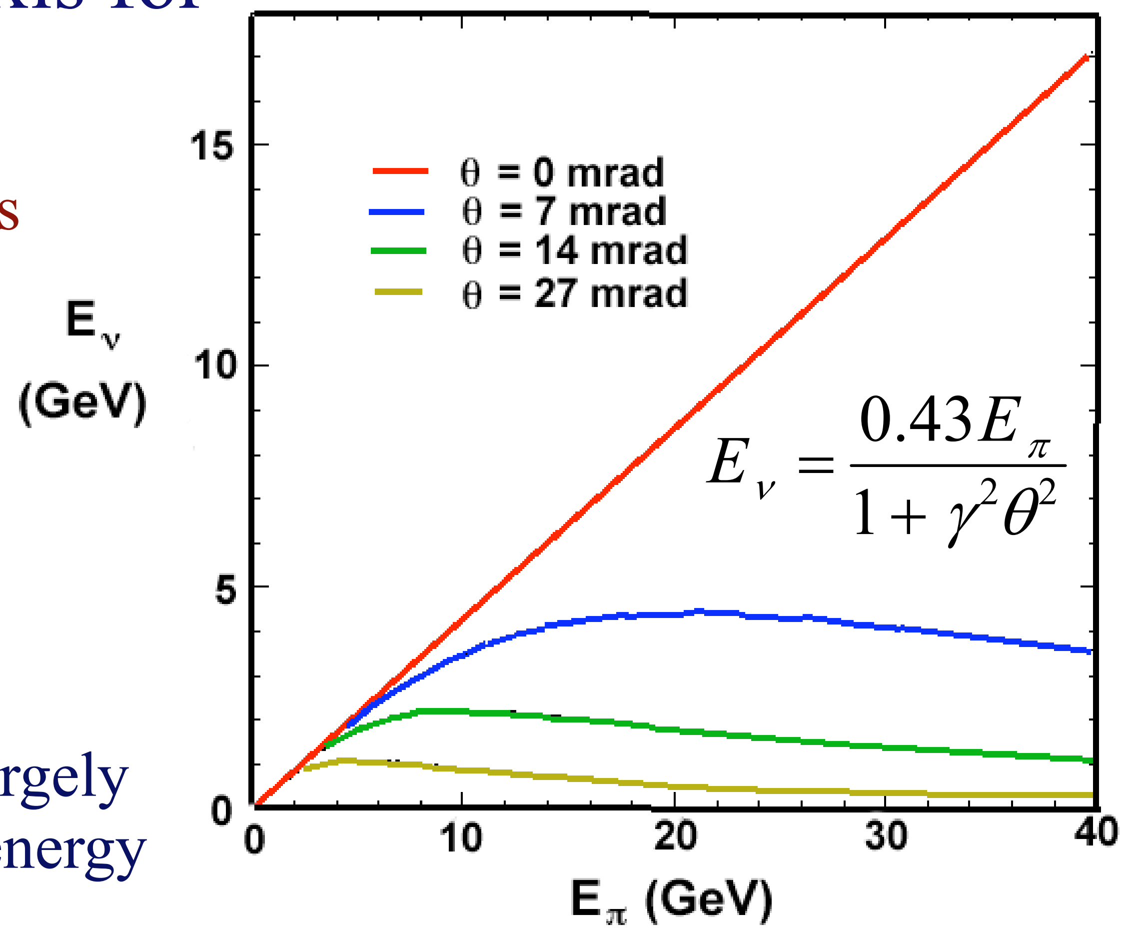
Introduction

- NOνA: NuMI Off-Axis ν_e Appearance
- Study $\nu_\mu \rightarrow \nu_e$:
  - search for $\sin^2(2\theta_{13})$ with a sensitivity a factor of ~14 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 for Background Suppression

Off-Axis

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

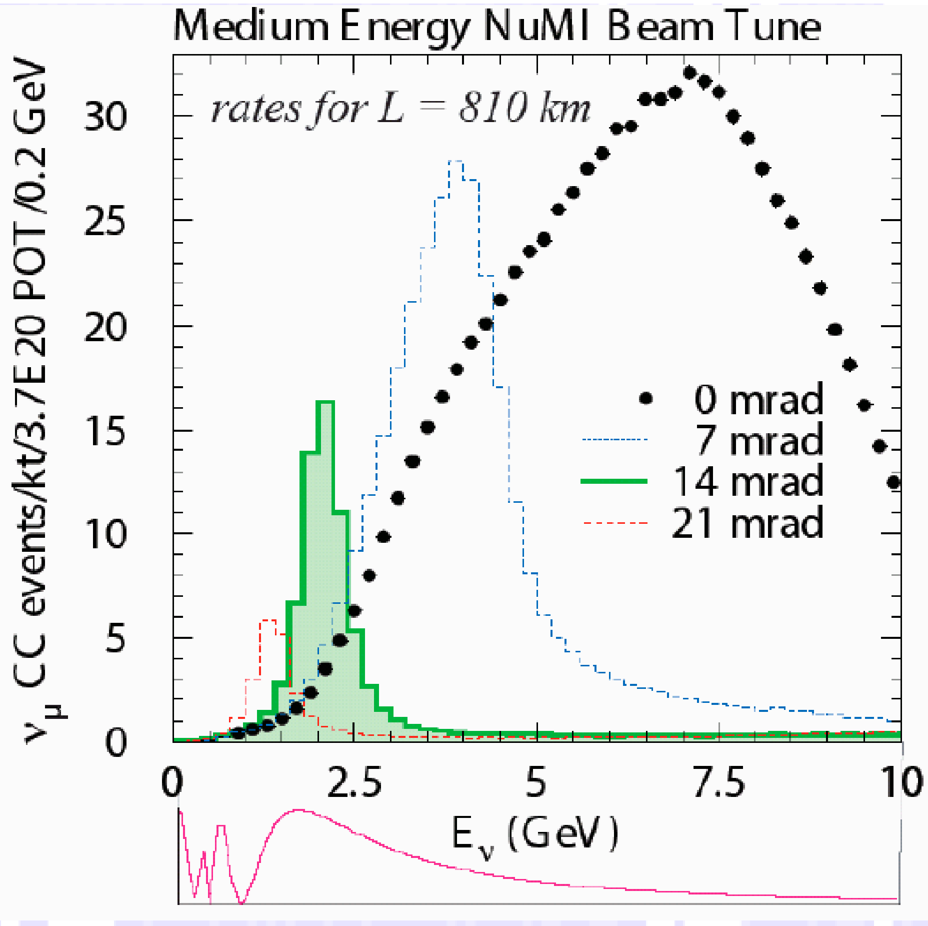




Off-axis: neutrino energy largely independent of parent pion energy

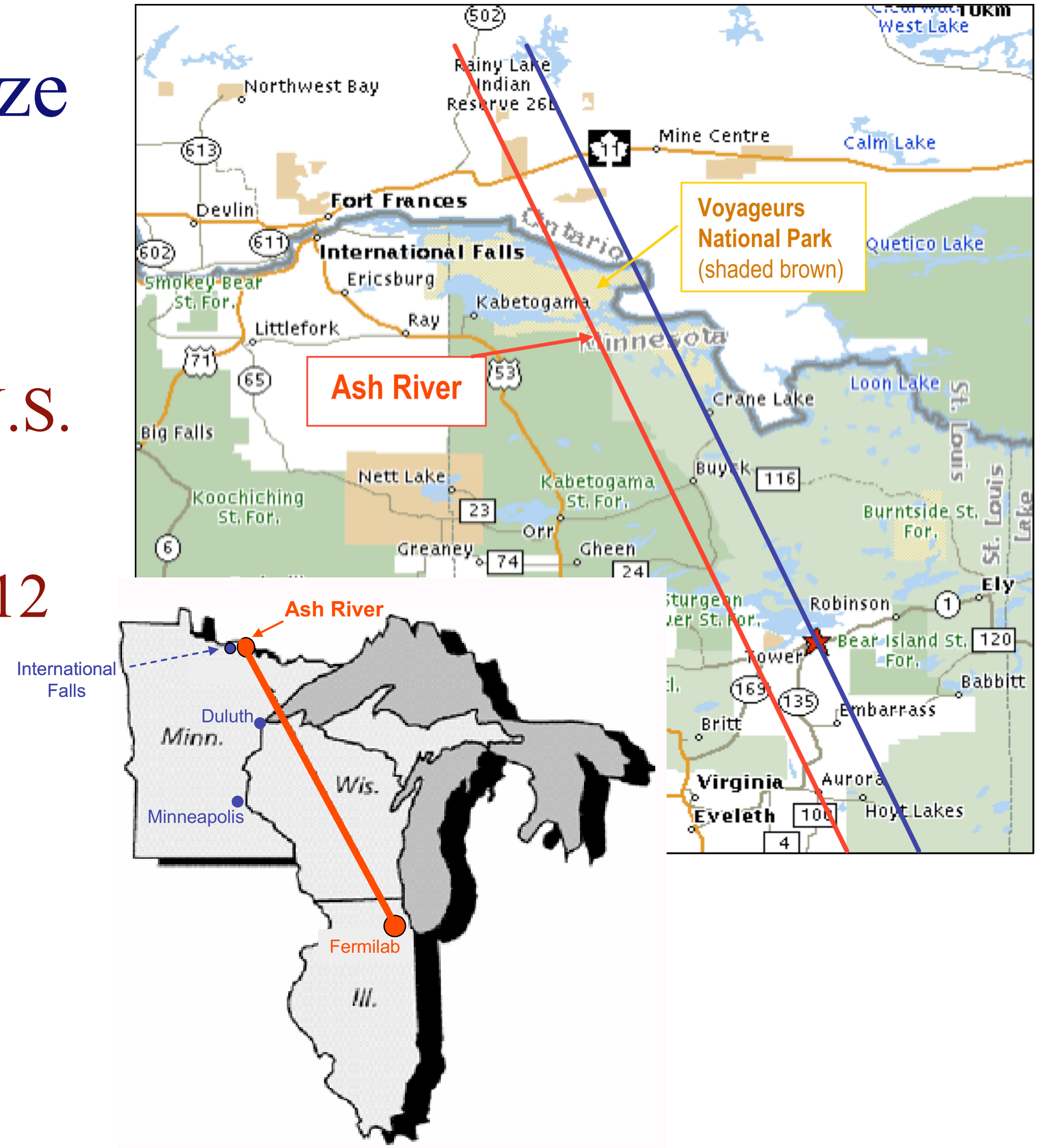
Off-Axis Spectra

- 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)

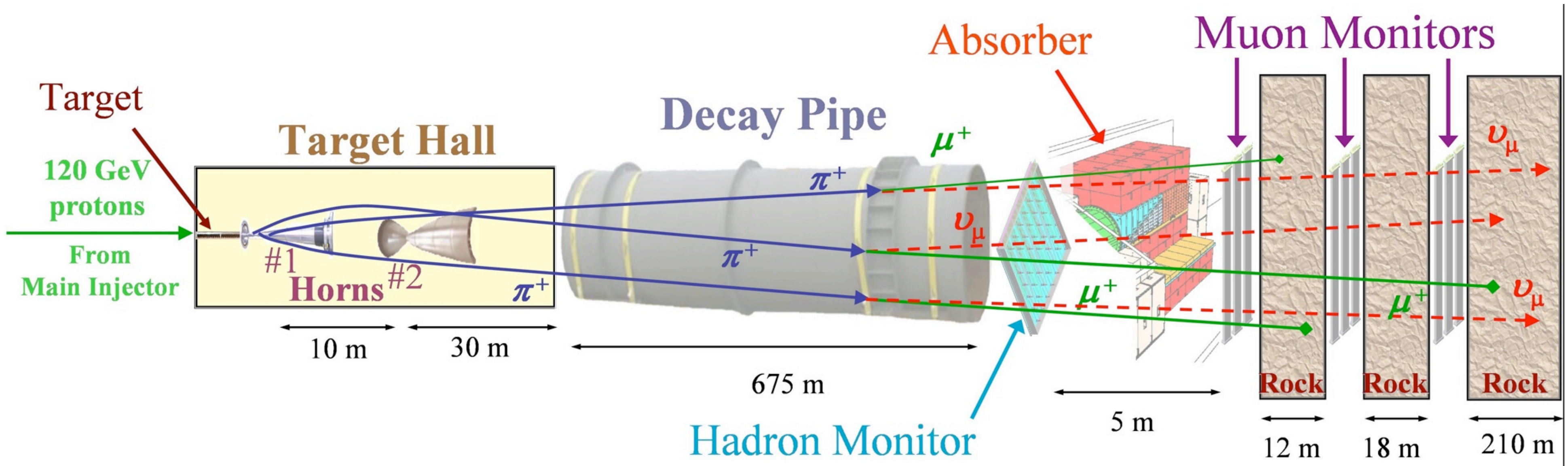


Location

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



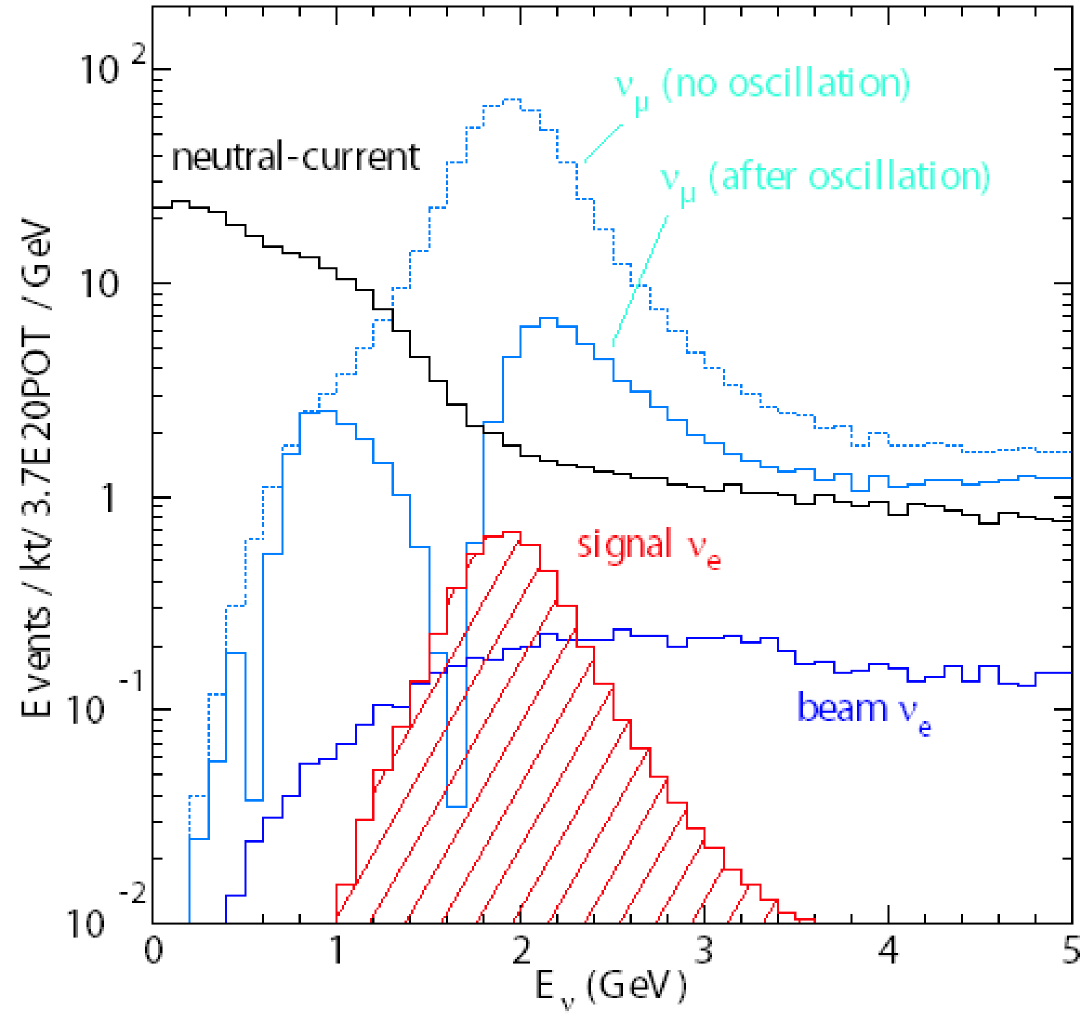
NuMI Beam



- NuMI Experiments:
  - MINOS - Jeff Nelson's talk
  - NOνA
  - MINERνA - Proposed high precision neutrino scattering experiment - Jorge Morfin's talk

Detector Requirements

- **Large! 10's of kT**
- **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**

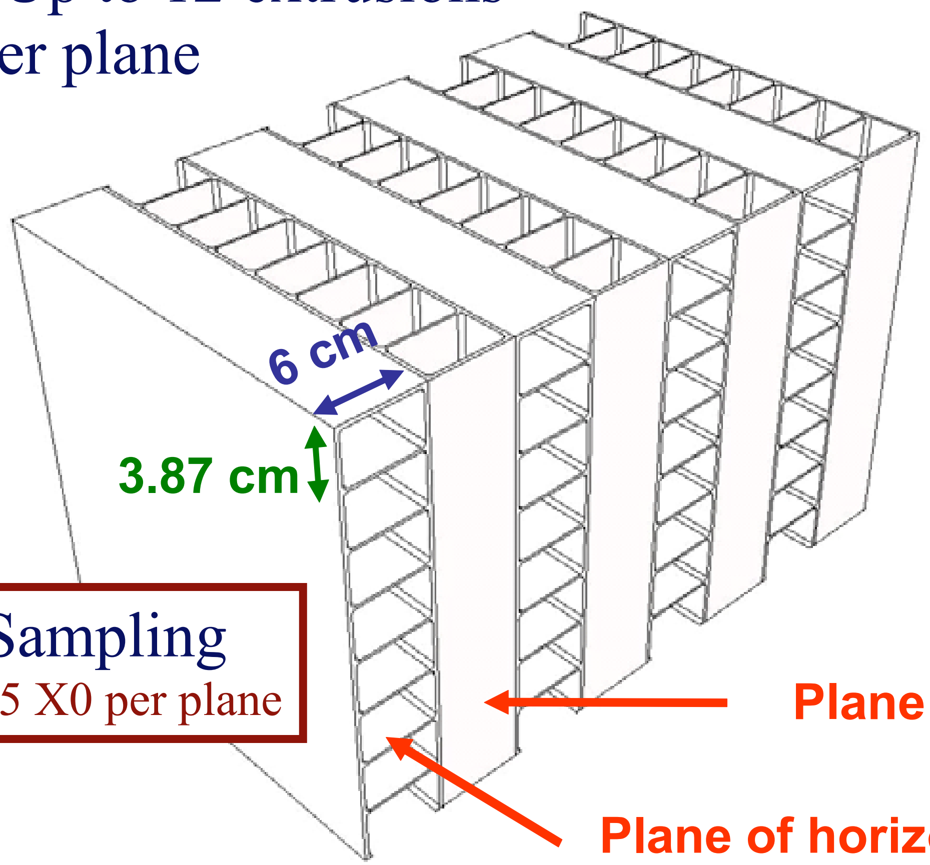


Interaction spectra at 810km, 12km off-axis.
Oscillations: Δm^2=2.5x10^{-3}eV^2, $\sin^2(2\theta_{13})$=0.01

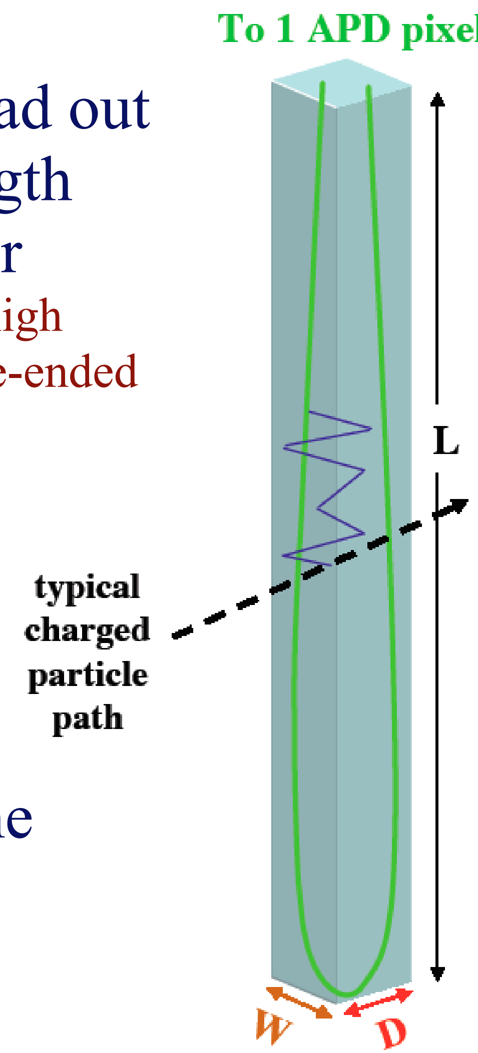
Scintillator and PVC

- PVC extrusions with 15% TiO_2
- 32 cells per extrusion
- Up to 12 extrusions per plane

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



Scintillator:
Mineral Oil with 5% Pseudo-cumene



Sampling
0.15 X0 per plane

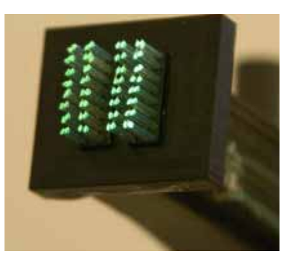
Readout

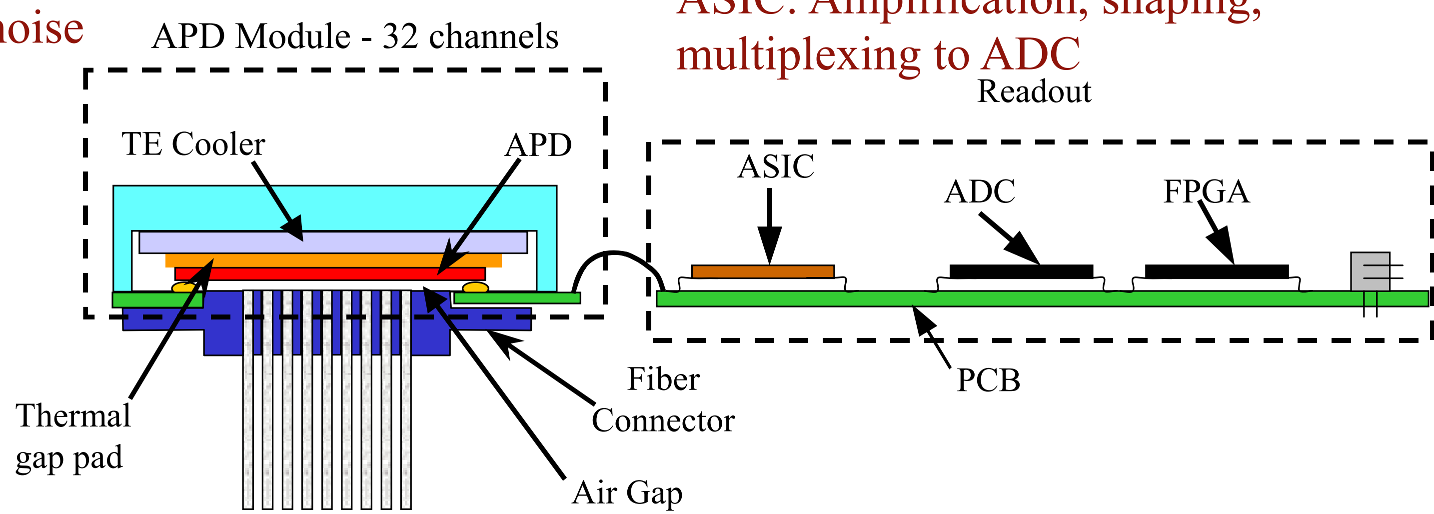
- Wavelength shifting fibers into APDs
  - 0.8mm diameter, “U”-shaped for highly efficient single-sided readout
  - Alternate readout side in horizontal planes for more uniform coverage

Response:
- 20 Photo Electrons for Muon at far end of Cell
- 2.5 PE equivalent noise

Avalanche Photo Diodes: Gain~100, cooled to -15C for 2PE dark noise

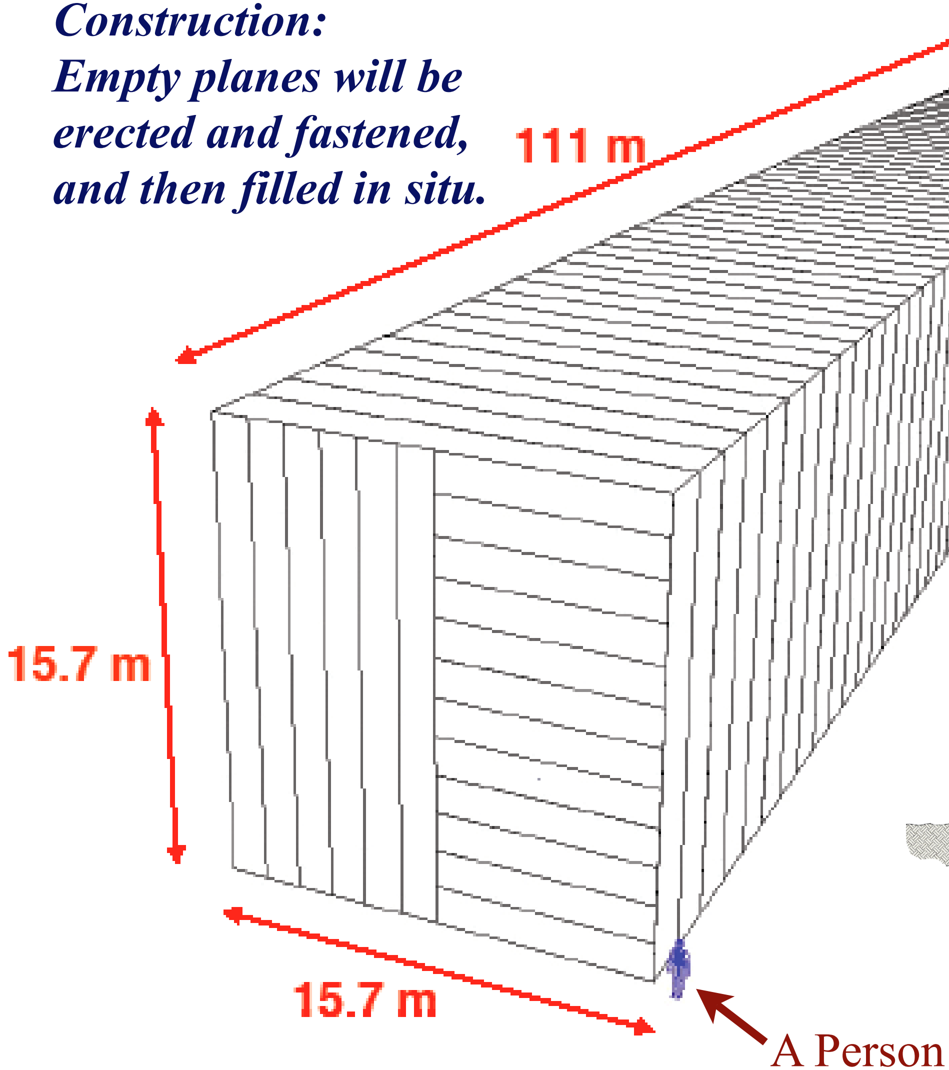
ASIC: Amplification, shaping, multiplexing to ADC





Far Detector

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



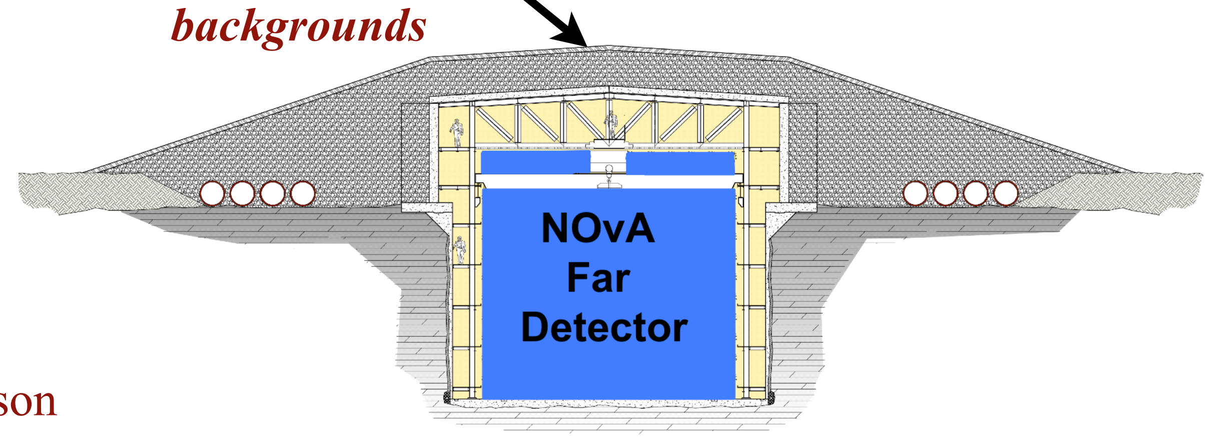
25kT Total Mass
(18.25 kT Scintillator)

Detector supported in blocks of 31 planes

54 blocks = 1654 planes total

635136 cells

3m overburden of excavated rock - reduce cosmic backgrounds

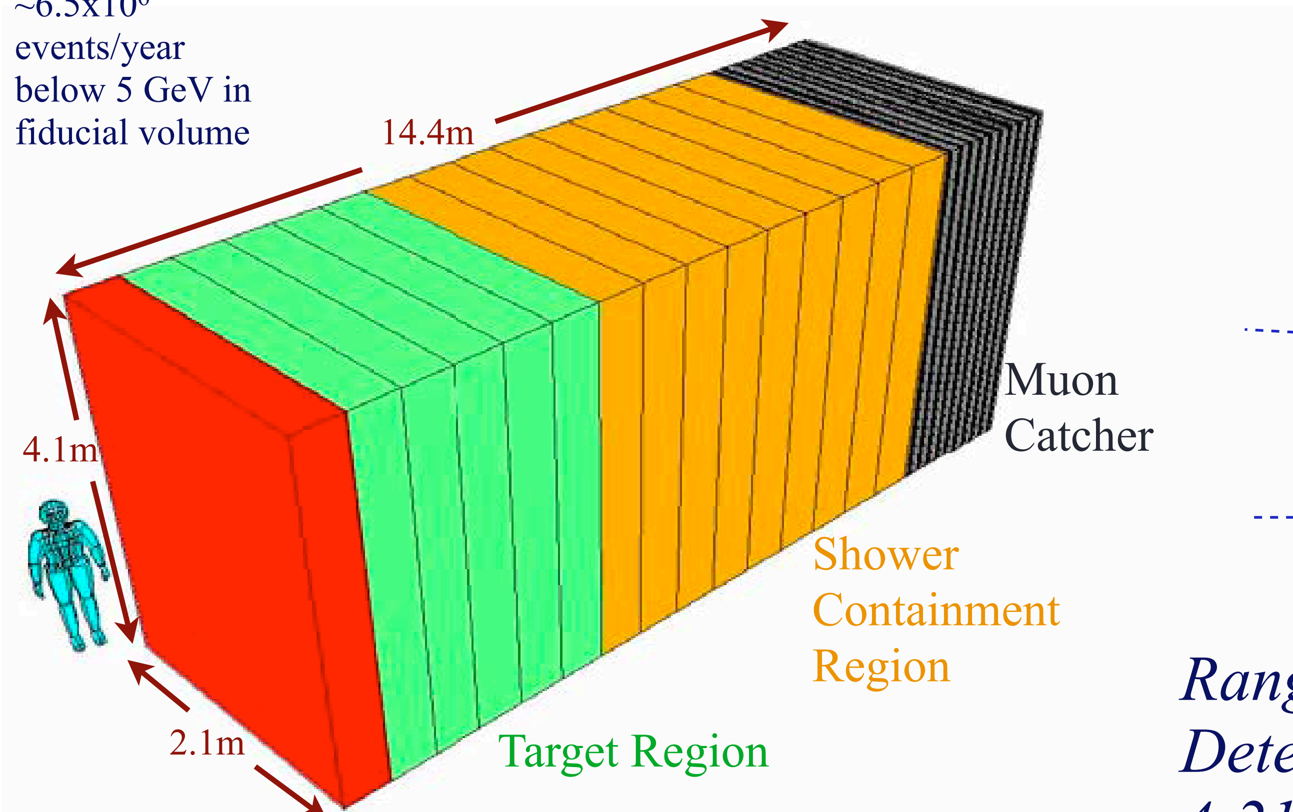


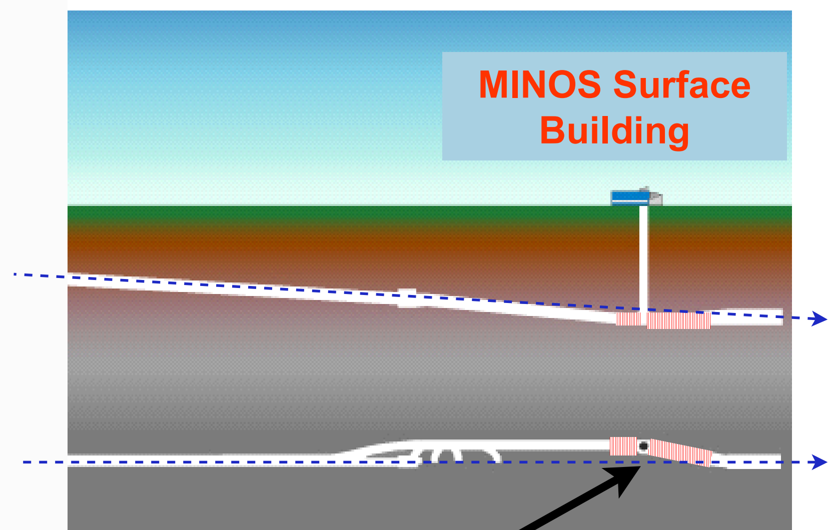
Beam's view

Near Detector

- Characterize intrinsic beam backgrounds
  - Same segmentation and basic structure as Far Detector
  - Sees beam as a line source - Will take exposure in different positions to compensate

~6.5x10^6 events/year below 5 GeV in fiducial volume





Range of Near Detector Locations: 4-21 mrad off-axis

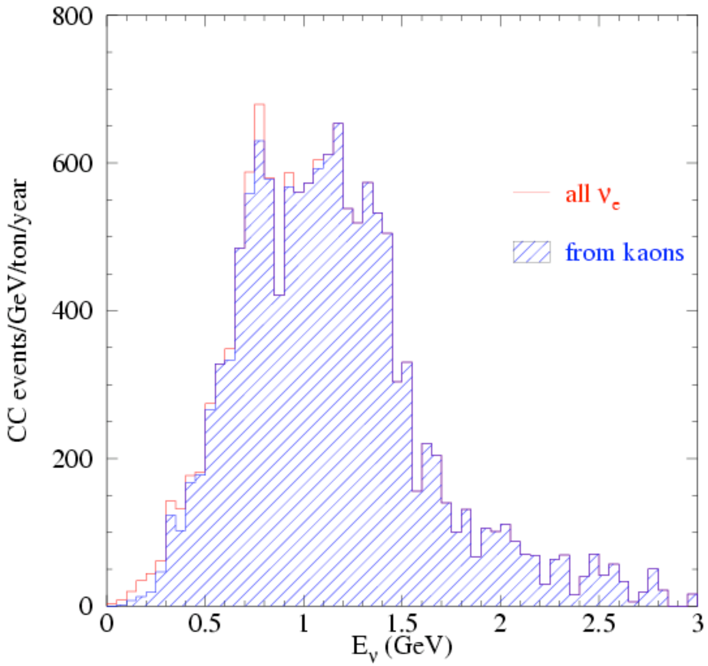
Prototype

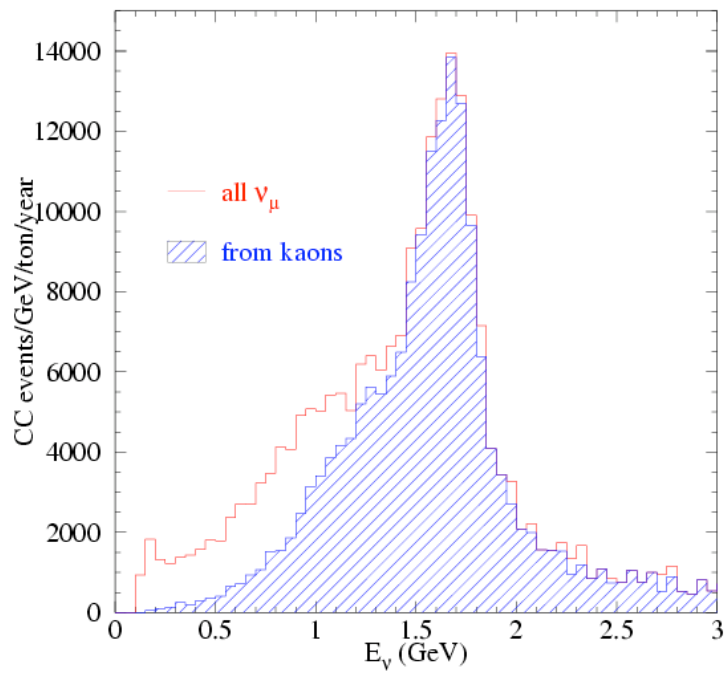
IPND: Integration Prototype Near Detector

Test scale production of all detector elements

- Test beam, cross calibration, test cosmic rejection
- To be located on surface near MINOS Service Building
- Taking data late 2007/early 2008

Low Energy Beam Configuration

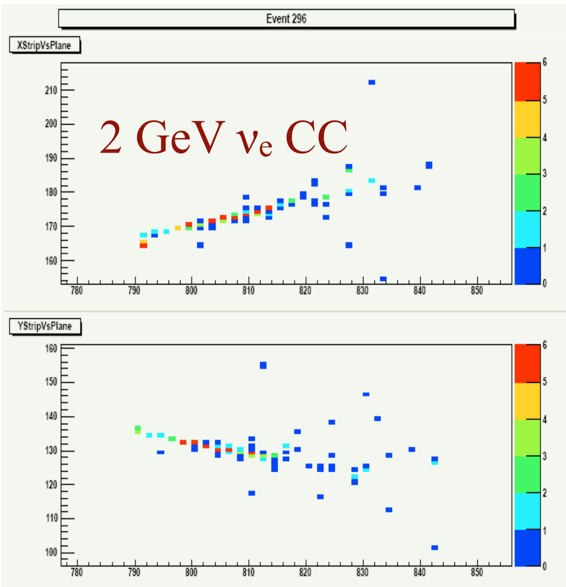




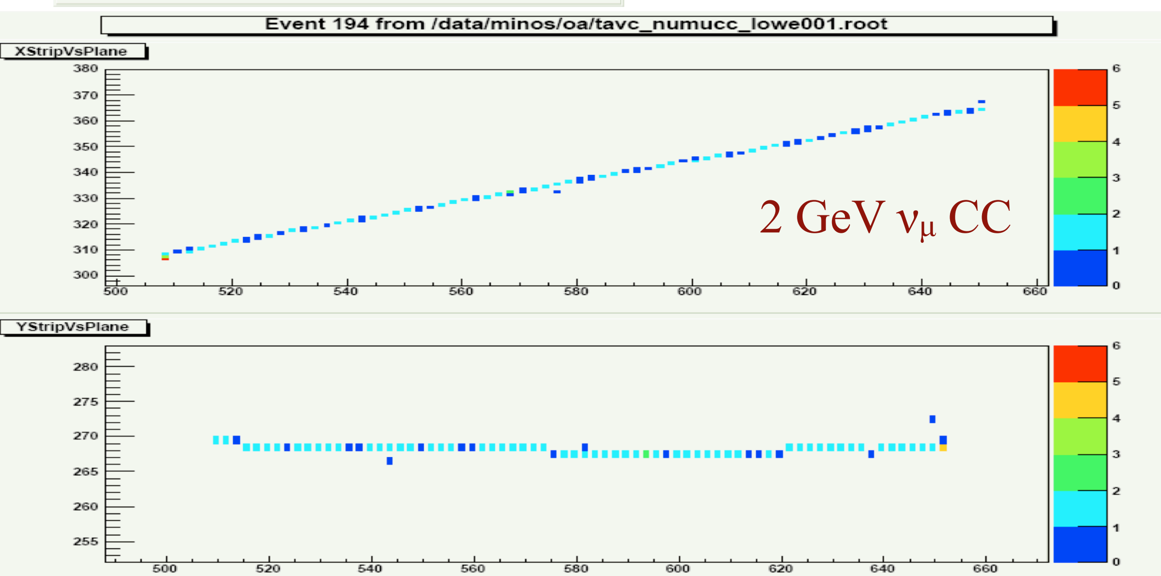
107 mrad off-axis:

dominated by K decays

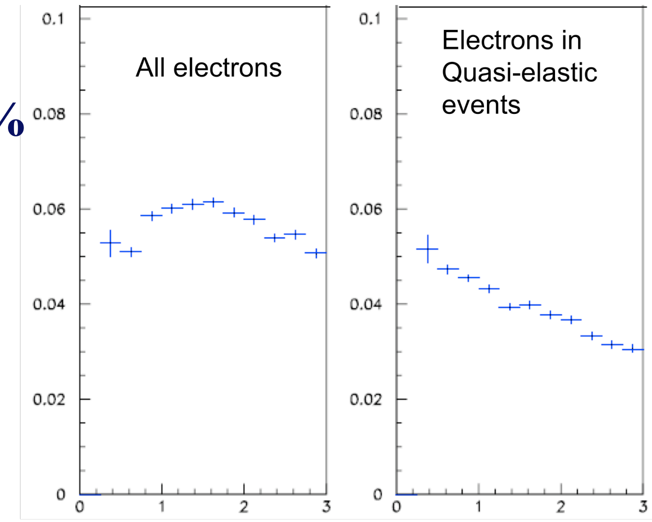
Performance



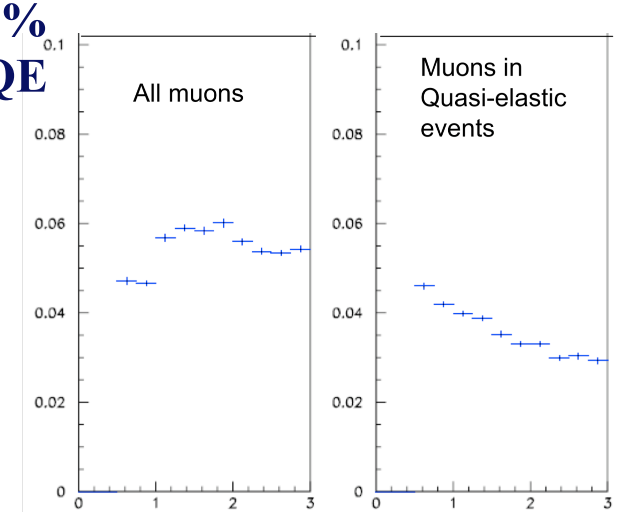
e/μ separation is easy



electron
$\sigma(E)/E<6\%$



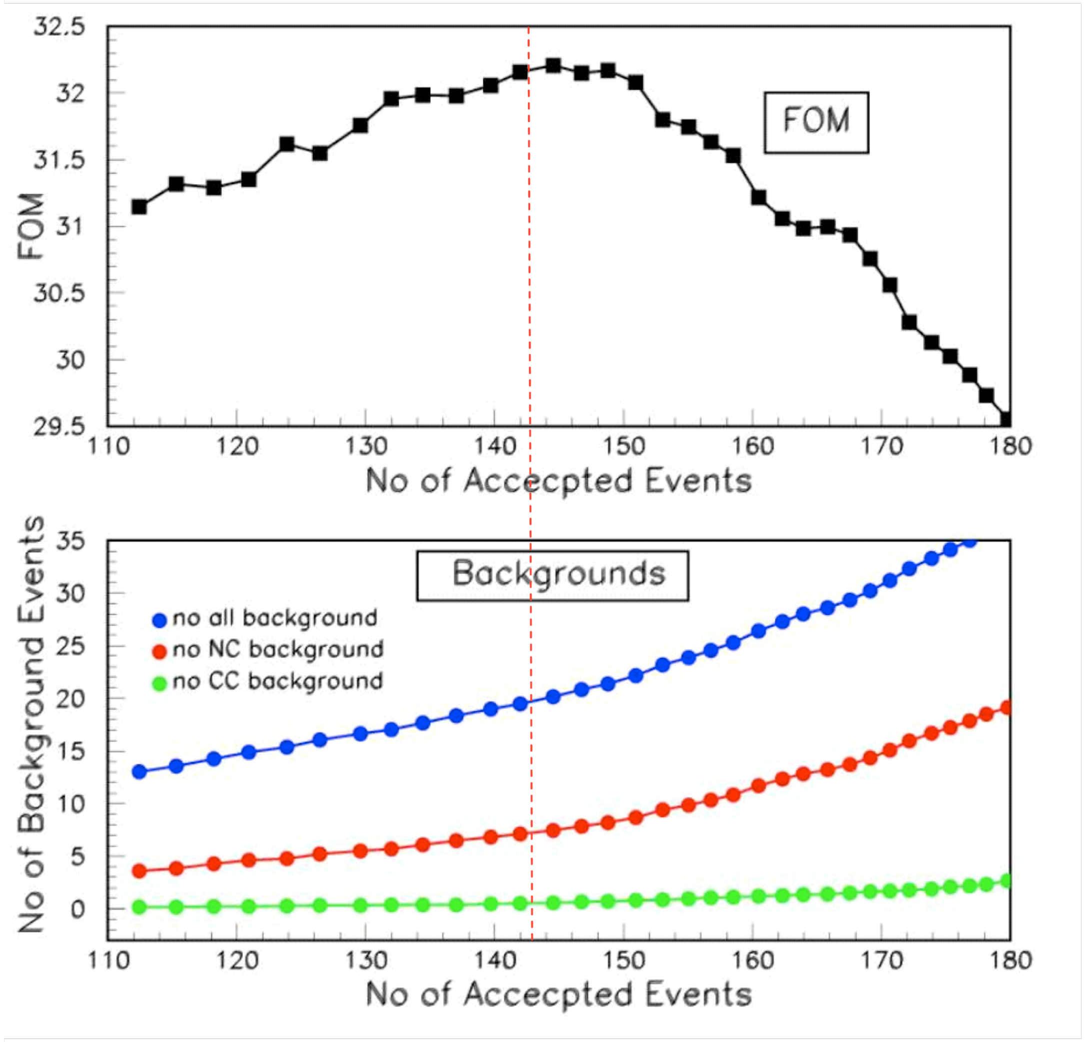
muon
$\sigma(E)/E<3.5\%$
for 2GeV QE



CC/NC Identification

ν_e CC/ NC separation uses likelihood based on reconstructed parameters of the electron and the event:
shape, signal profiles, topology, etc.

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



History/Schedule

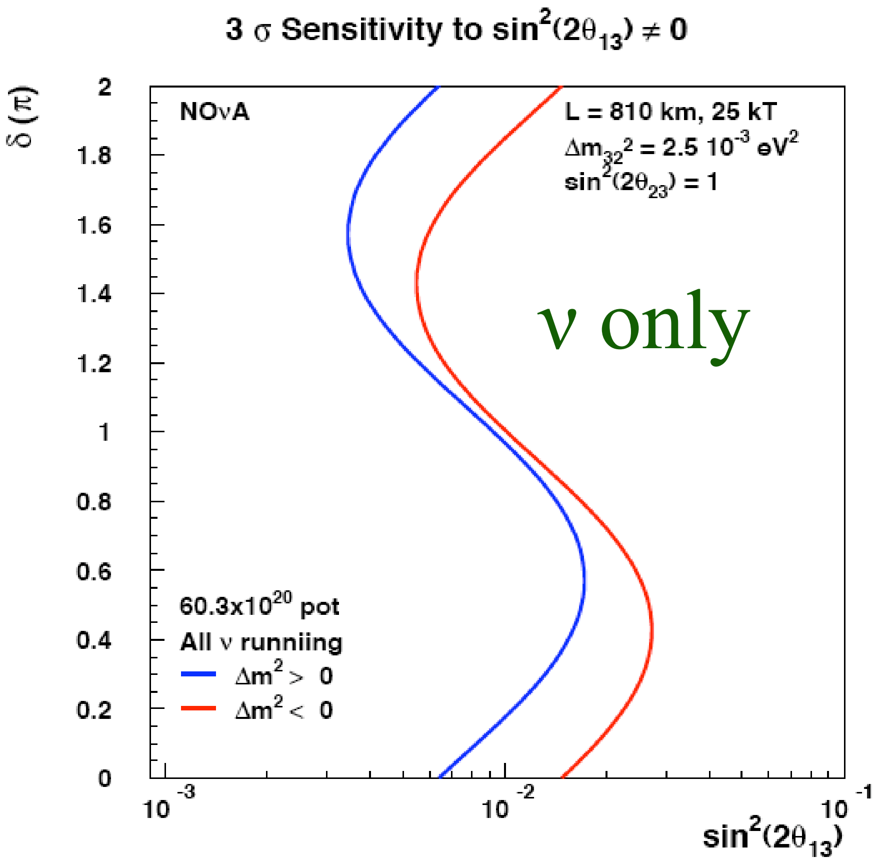
- April 2005: Fermilab PAC approval
- April 2006: DOE CD-1 recommendation
  - "Approve Preliminary Baseline Range"
  - Conceptual Design Report
- Upcoming Reviews:
  - Late 2006/Early 2007: Review for CD-2 ("Approve Performance baseline")/ Technical Design Report
  - by Oct 2007: Reviews for CD-3 ("Approve start of construction")
- Detector construction and running
  - Start Far Detector Assembly in late 2009- start data taking with first 5 kT in late 2010 complete in late 2011

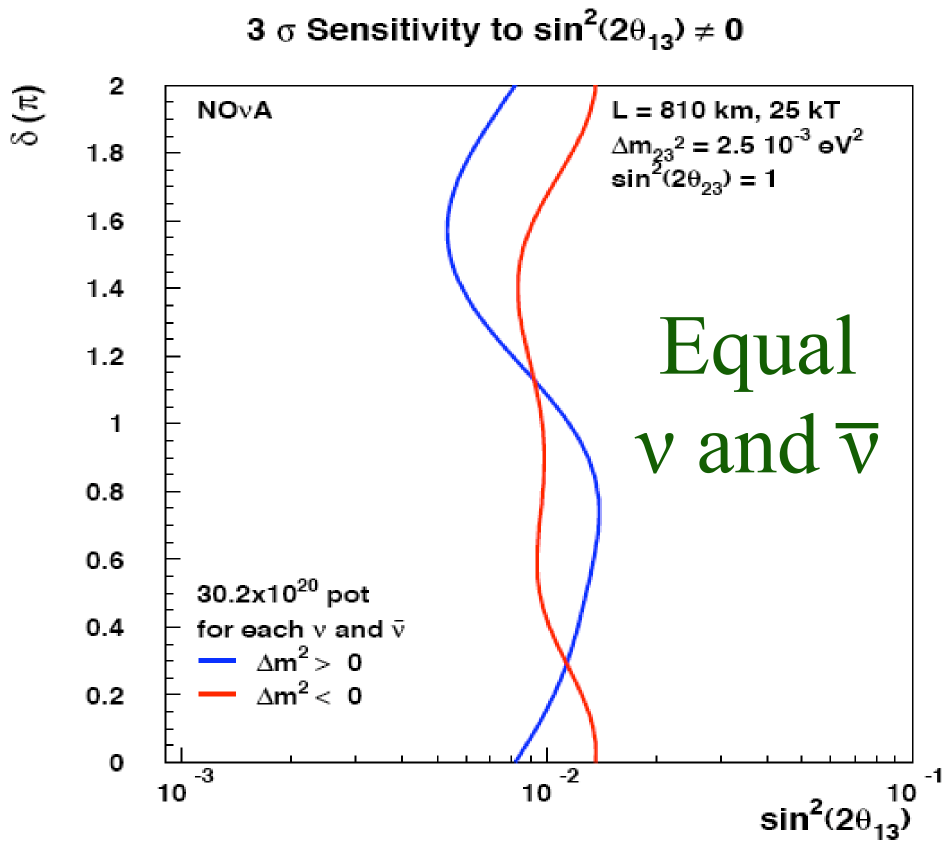
Sensitivities

- Assumptions for the following plots:
  - 60×10^{20} protons-on-target over 6 years with 25 kT detector: includes 1MW NuMI upgrade
  - Operations begin with 1st 5 kT and continue during construction
  - Equal ν and $\bar{\nu}$ running
- Plots made using...
  - Full simulation of flux, interactions, and detector response
  - Event selection based on reconstruction

3σ Sensitivity to $\sin^2(2\theta_{13})\neq 0$

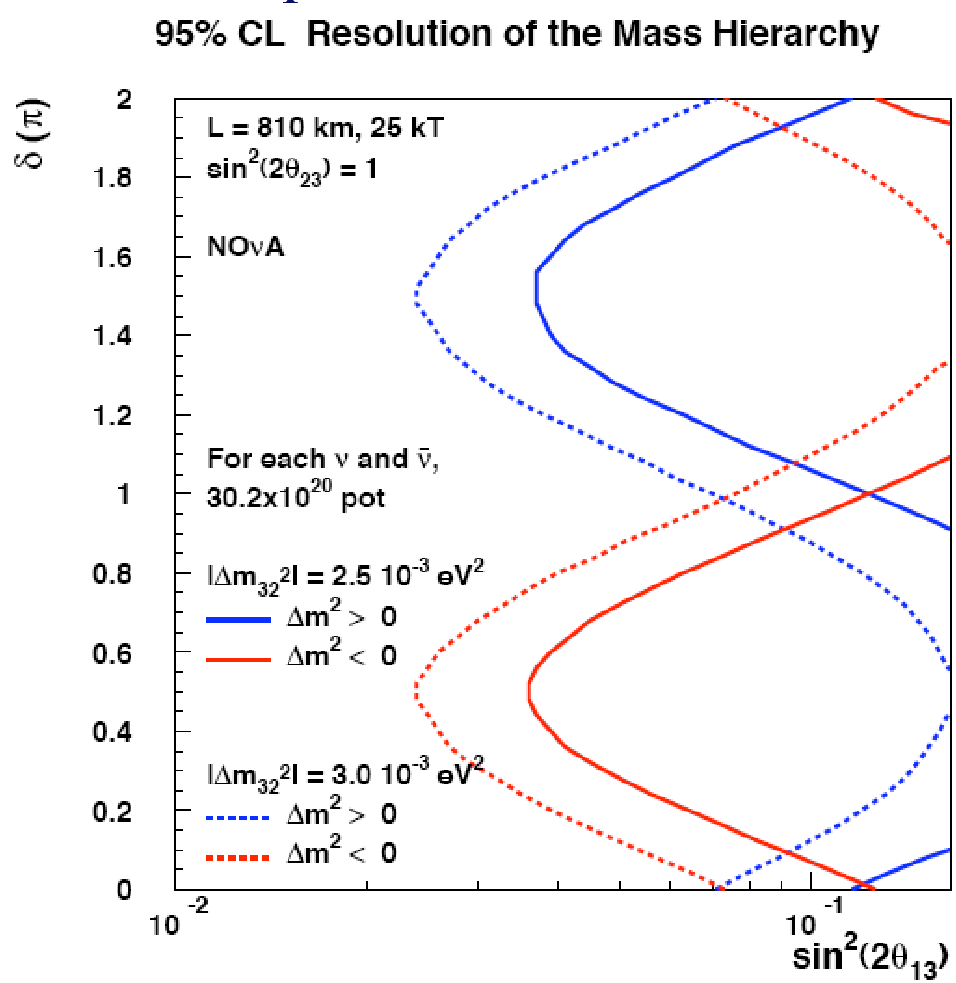
- Advantage to equal $\nu/\bar{\nu}$ running:
  - More consistent reach in $\sin^2(2\theta_{13})$ vs. δ and mass hierarchy



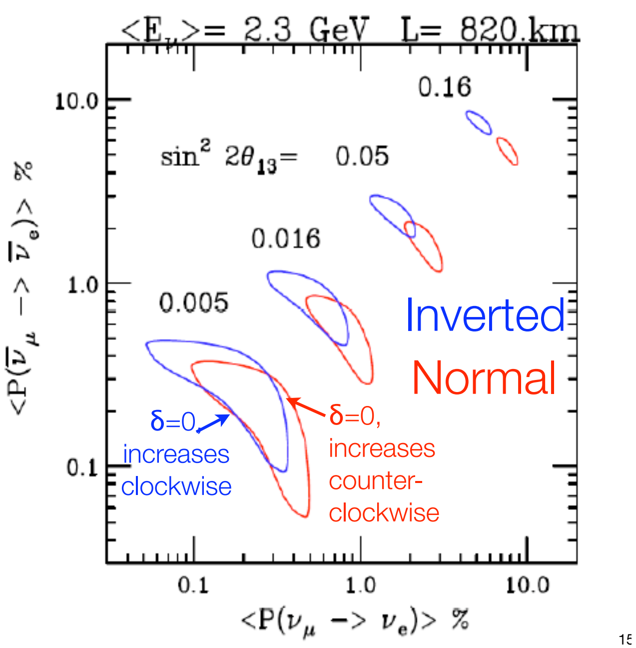


Mass Hierarchy

Effect at a fixed L/E is proportional to baseline: unique reach for NOνA



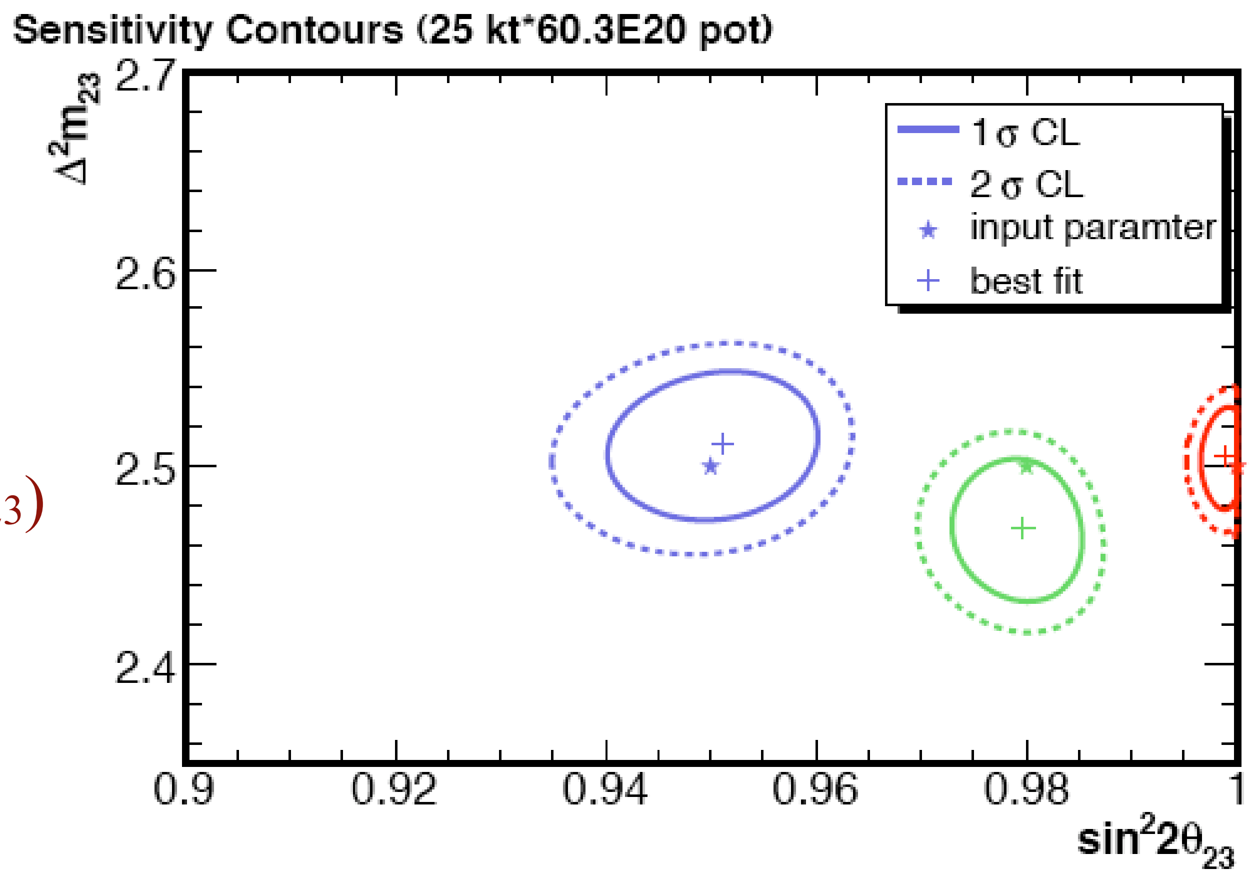
Reminder:
Matter effects enhance (decrease) ν oscillations for normal (inverted) MH, vice-versa for $\bar{\nu}$



Dominant Mixing

ν_μ Disappearance:

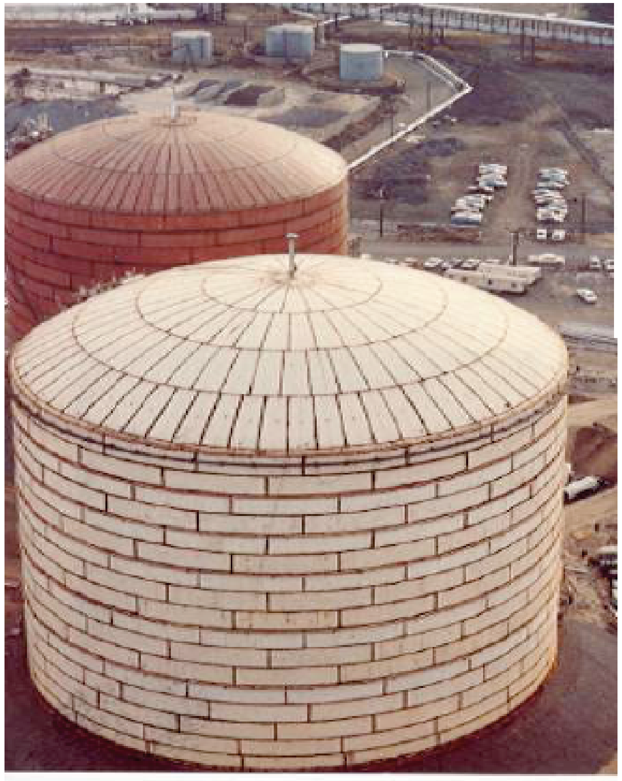
High Precision Measurement of Δm^2_{23} and $\sin^2(2\theta_{23})$ will be possible with QE Channel



Longer Term Future

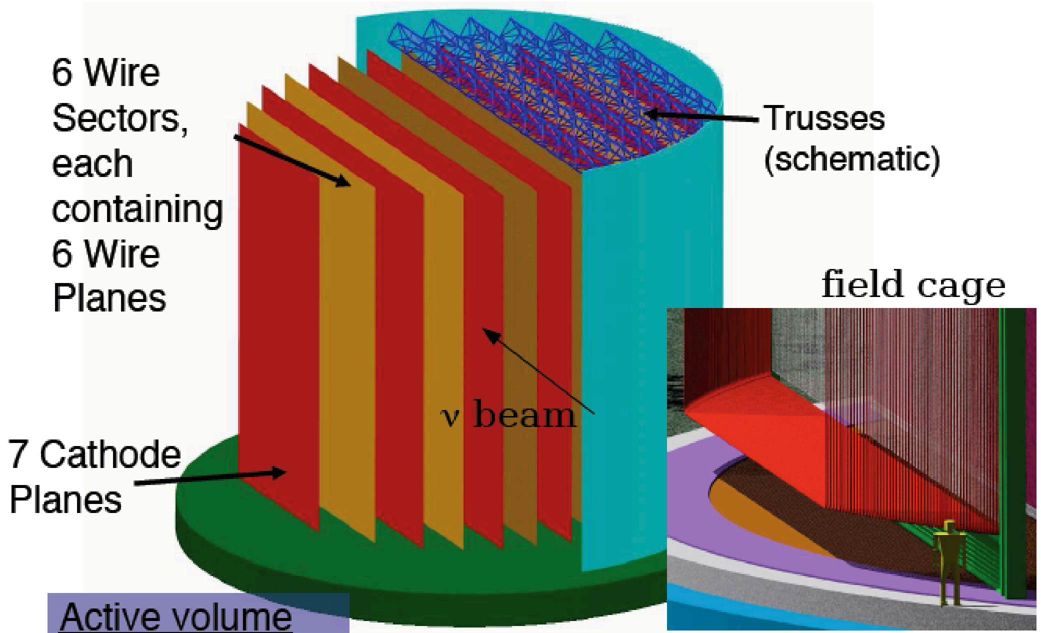
- Liquid Argon TPC study:

Fermilab, Michigan State University, Tufts University, Princeton University, Yale University. UCLA, Texas A&M, York University (Canada)



Bonnie Fleming

Modularized drift regions inside tank



Active volume
Diameter: 40m
Height: 30m

Scalable → 15-50 kTons
4 - 6 wire planes

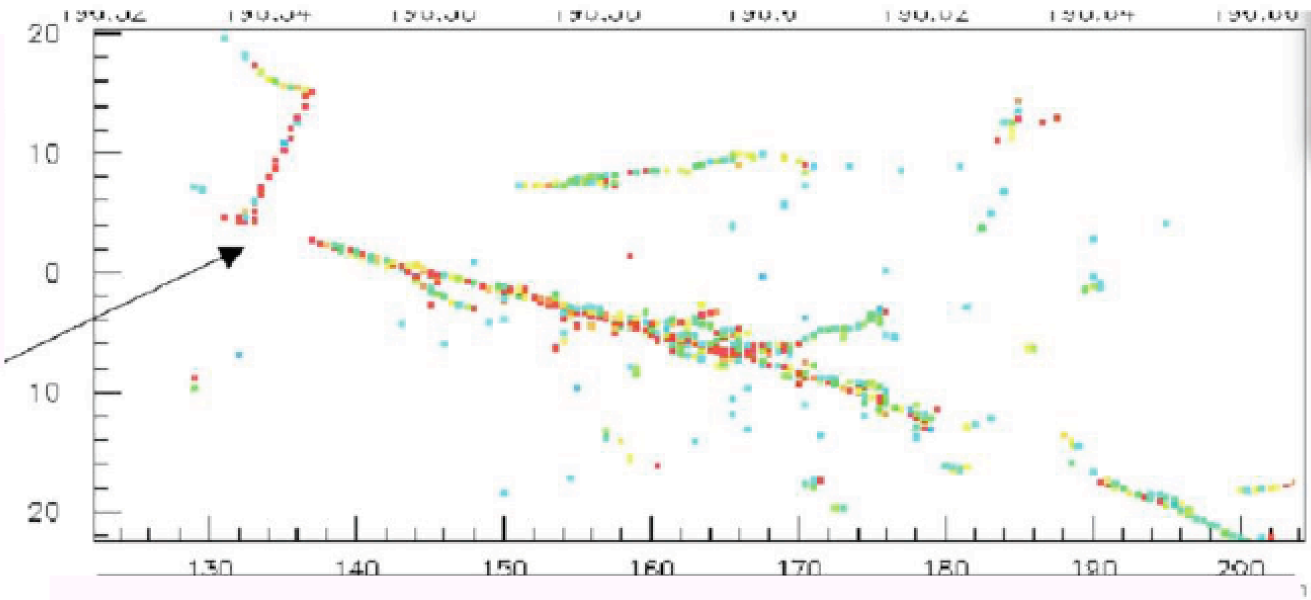
LAr TPC

$$\nu_\mu + \mathrm{n} \rightarrow \nu_\mu + \pi^+ + \pi^- + \pi^0 + \mathrm{n}$$

$$(1\ \mathrm{GeV})\ \pi^0 \rightarrow \gamma + \gamma$$

3.5% X_0 sampling gives excellent NC/ν_e CC separation

4 cm gap



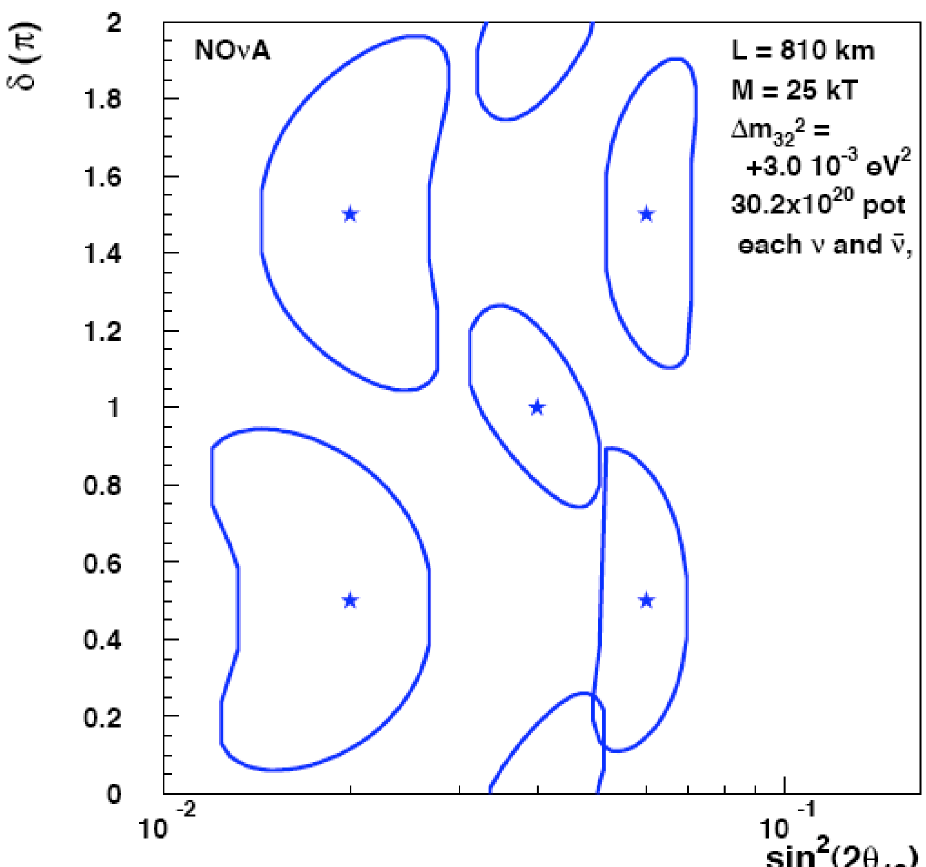
81% efficiency in blind hand-scan, with backgrounds less than 1/2 of intrinsic beam ν_e

Bonnie Fleming

CP Violation

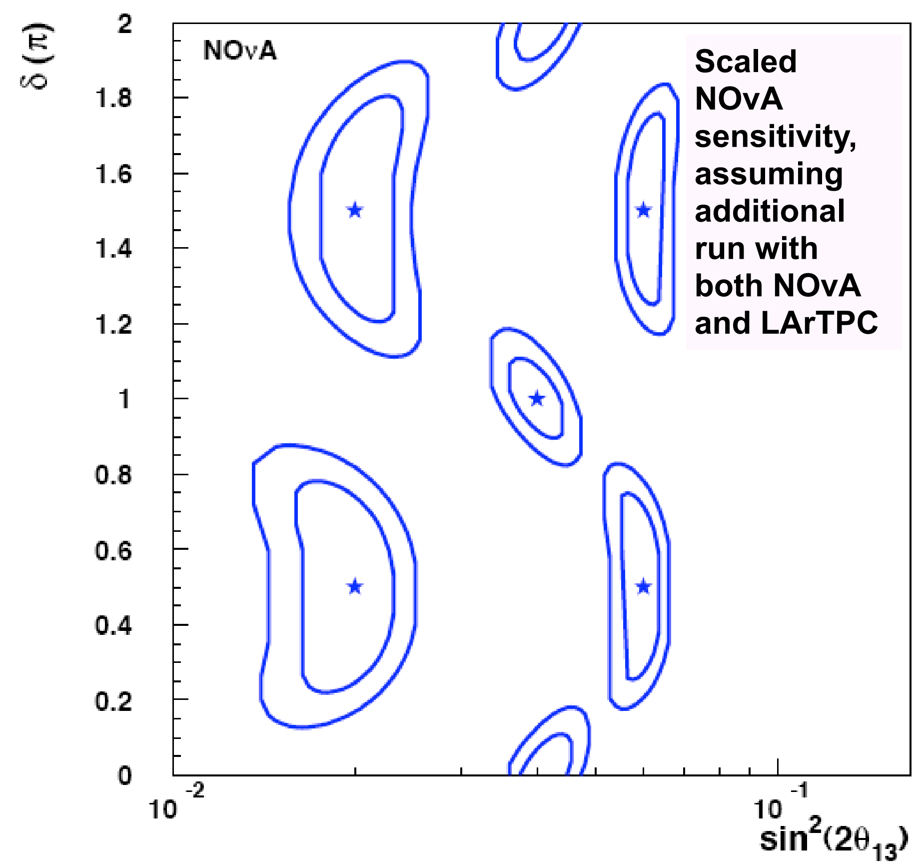
NOνA only: low precision information on phase δ

1 σ Contours for Starred Points



NOνA and LAr Upgrade: greatly improved sensivity to CP violation

1 and 2 σ Contours for Starred Points



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 Mass Hierarchy
    - Matter effects: advantage of long baseline
- A key part of an "internationally coordinated, staged program" in neutrino physics.