NOνA Detector Performance and Physics Capabilities

June 4, 2007

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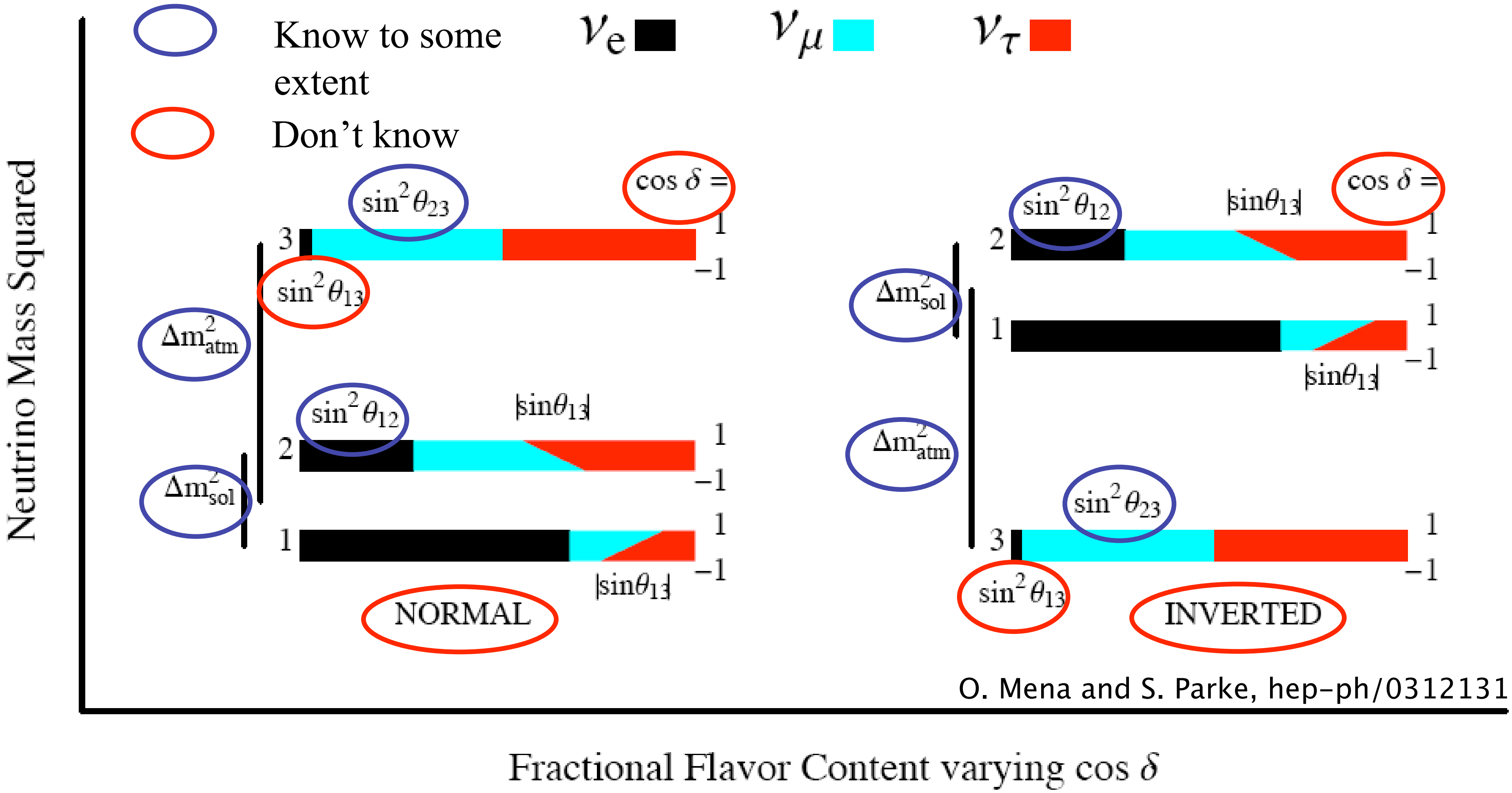
NOνA Physics Goals

- Primary: Study of $\nu_\mu \rightarrow \nu_e$ oscillations to determine θ_{13}, the sign of Δm_{32}, and the CP-violating phase δ.
- Secondary: Improved measurements of θ_{23} and $|\Delta m_{32}|$.
- Tertiary: Other measurements and searches, including
  - Search for sterile neutrinos (improve SK limits by a factor of 2)
  - Measurement of NC cross sections at 2 GeV
  - Measurement of neutrinos from a galactic supernova

What We Know and What We Don’t Know



O. Mena and S. Parke, hep-ph/0312131

$P(\nu_\mu \rightarrow \nu_e)$ (in Vacuum)

- $P(\nu_\mu \rightarrow \nu_e) = P_1 + P_2 + P_3 + P_4$
  - $P_1 = \sin^2(\theta_{23}) \sin^2(2\theta_{13}) \sin^2(1.27\, \Delta m_{13}^2\, L/E)$ "Atmospheric"
  - $P_2 = \cos^2(\theta_{23}) \sin^2(2\theta_{12}) \sin^2(1.27\, \Delta m_{12}^2\, L/E)$ "Solar"
  - $P_3 = \mp J \sin(\delta) \sin(1.27\, \Delta m_{13}^2\, L/E)$
  - $P_4 = J \cos(\delta) \cos(1.27\, \Delta m_{13}^2\, L/E)$

  $\Big\}$ Atmospheric-solar interference

  where $J = \cos(\theta_{13}) \sin(2\theta_{12}) \sin(2\theta_{13}) \sin(2\theta_{23})$ x

  $\sin(1.27\, \Delta m_{13}^2\, L/E) \sin(1.27\, \Delta m_{12}^2\, L/E)$

P($\nu_\mu \rightarrow \nu_e$) (in Matter)

- In matter at oscillation maximum, P_1 will be approximately multiplied by (1 ± $2E/E_R$) and P_3 and P_4 will be approximately multiplied by (1 ± E/E_R), where the top sign is for neutrinos with normal mass hierarchy and antineutrinos with inverted mass hierarchy.

$$E_R = \frac{\Delta m_{13}^2}{2\sqrt{2}G_F \rho_e} \approx 11\,\mathrm{GeV} \text{ for the earth's crust.}$$

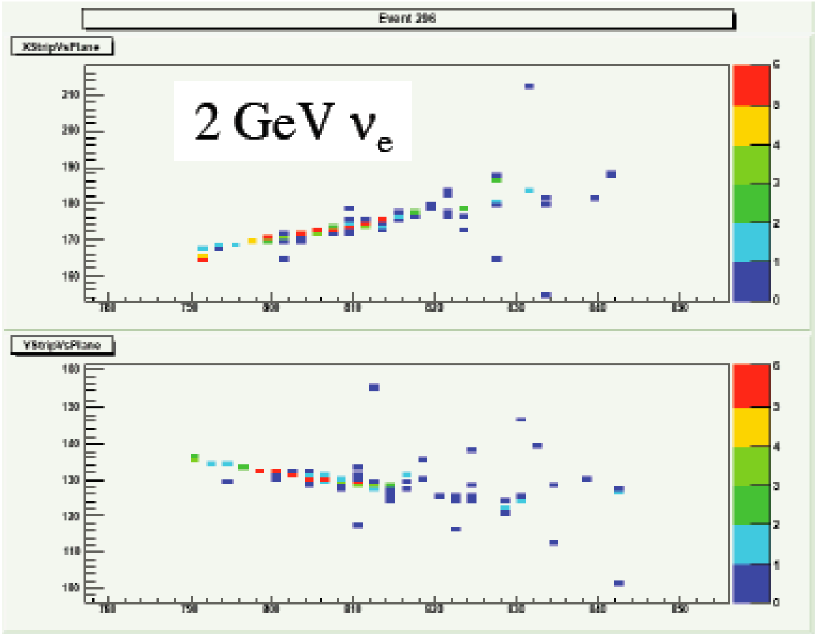
About a ±30% effect for NuMI, but only a ±11% effect for T2K.

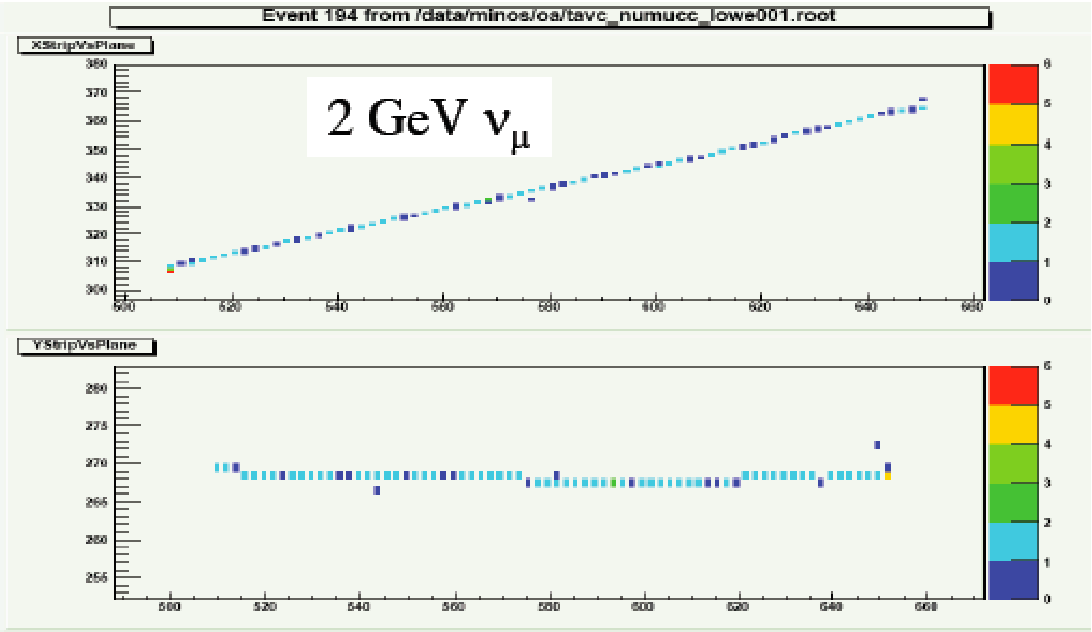
However, the effect is reduced for energies above the oscillation maximum and increased for energies below.

Event Quality

Longitudinal sampling is 0.15 X_0, giving excellent e/μ separation.

A 2 GeV muon is 60 planes long.





ν_e CC event

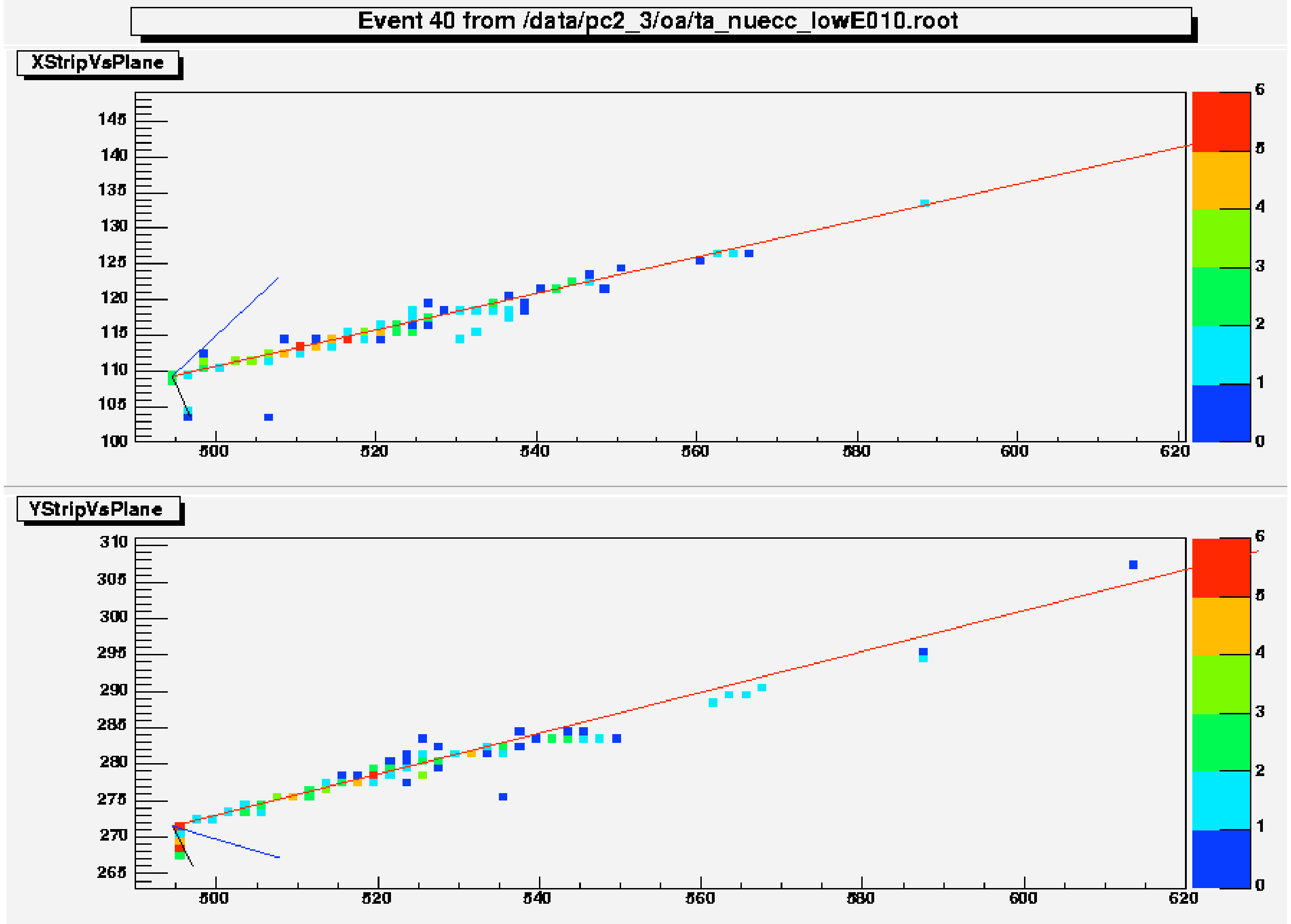
$$\nu_e p \rightarrow e^- p \pi^+$$

$$E_\nu = 2.5\ \text{GeV}$$

$$E_e = 1.9\ \text{GeV}$$

$$E_p = 1.1\ \text{GeV}$$

$$E_\pi = 0.2\ \text{GeV}$$



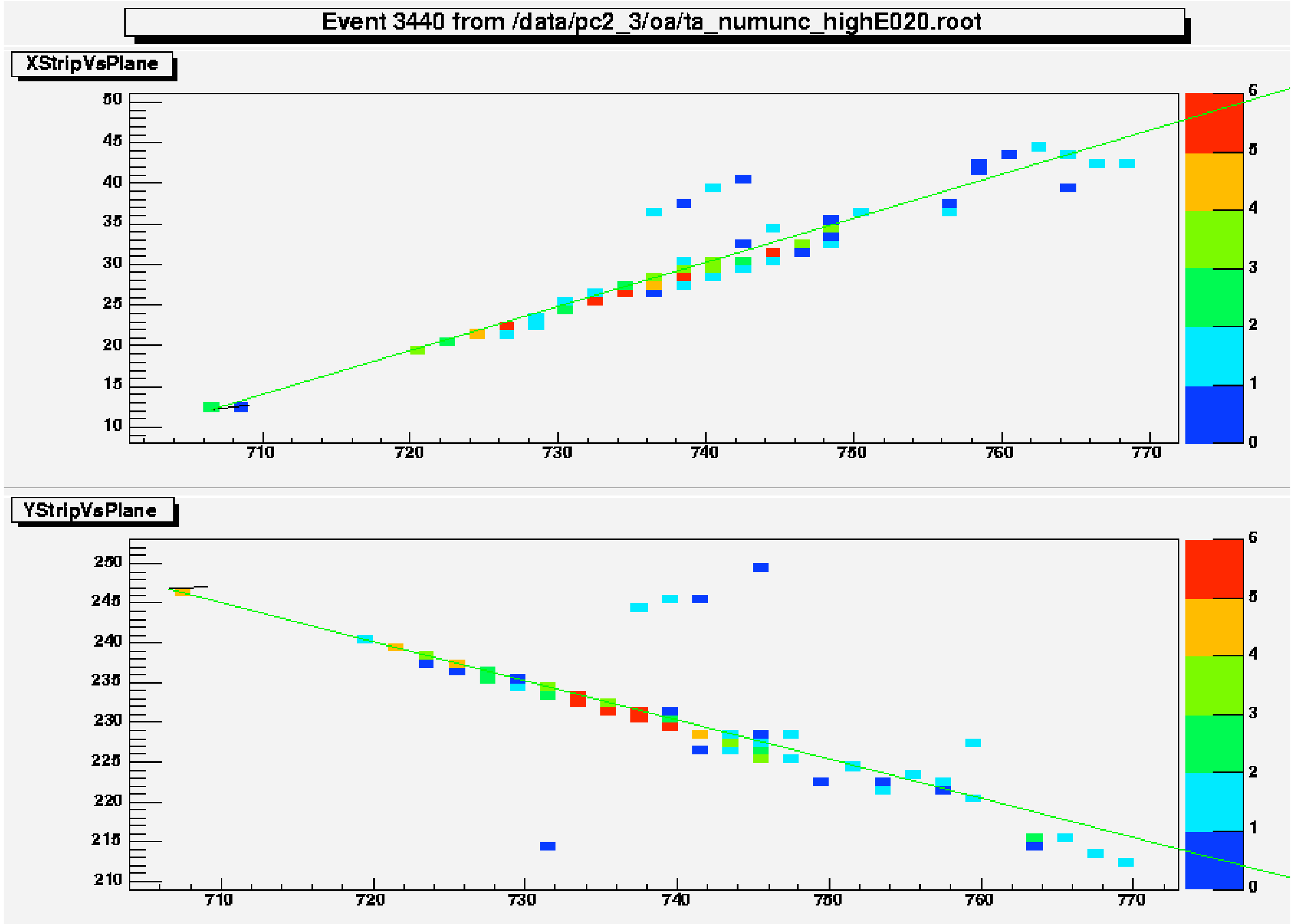
Background NC event

$$\nu_\mu N \to \nu_\mu p \pi^0$$

$$E_\nu = 10.6\ \mathrm{GeV}$$

$$E_p = 1.04\ \mathrm{GeV}$$

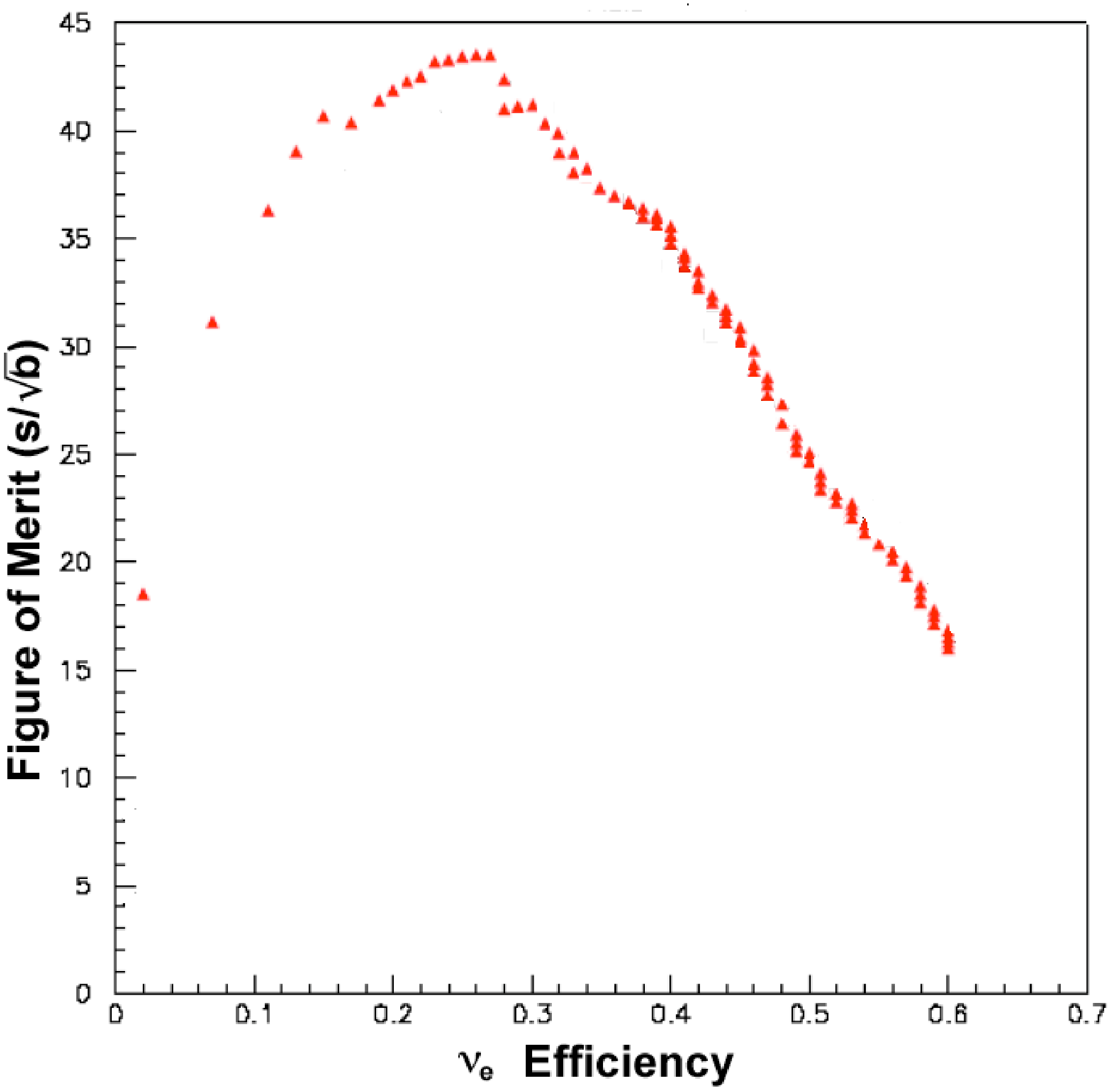
$$E_\pi = 1.97\ \mathrm{GeV}$$



Simulations

- All of the $\nu_\mu \rightarrow \nu_e$ oscillation results come from a full simulation of the Far Detector starting with raw data (signal + background), followed by reconstruction, and event identification via an artificial neural net.
- This is work in progress and we expect some improvements as we become more sophisticated in our reconstruction and identification code.

ν_e Efficiency vs. Figure of Merit



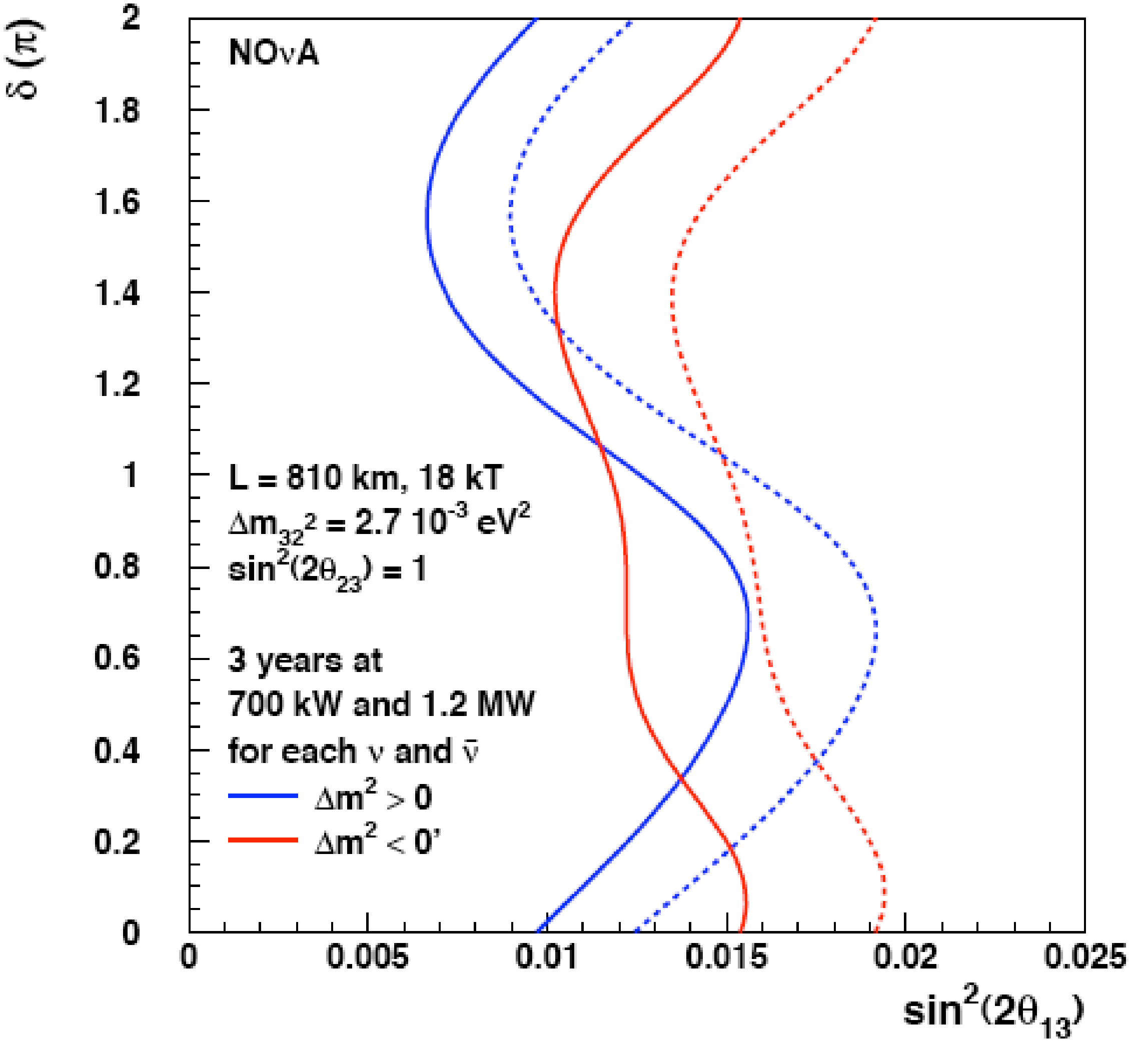
Maximum discovery figure of merit $\left(s/\sqrt{b}\right)$ ⇔ 26% efficiency.

The figure of merit for maximum precision on a signal $\left(s/\sqrt{(s+b)}\right)$ will occur at higher efficiencies.

Running and Beam Assumptions

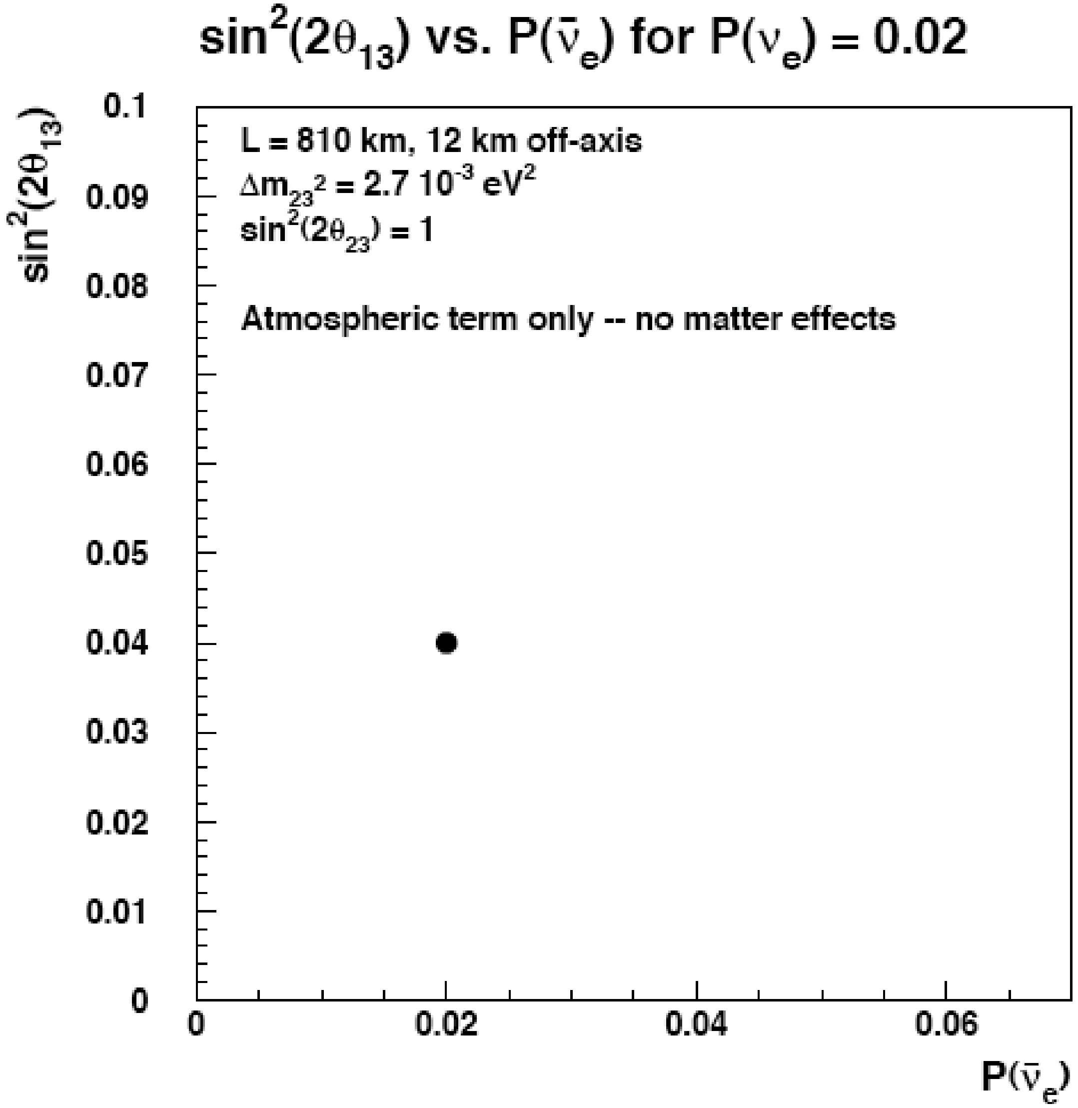
- The calculations will be shown for 3 years of neutrino plus 3 years of antineutrino running for both 700 kW and 1.2 MW (SNuMI) beam power.
- A year is defined as 44 weeks of running with a derating factor of 0.61 for accelerator and NuMI downtime and average-to-peak performance.
- This translates to a total of 36 10^{20} pot for 700 kW and 60 10^{20} pot of 1.2 MW.

3σ Sensitivity to $\theta_{13} \neq 0$



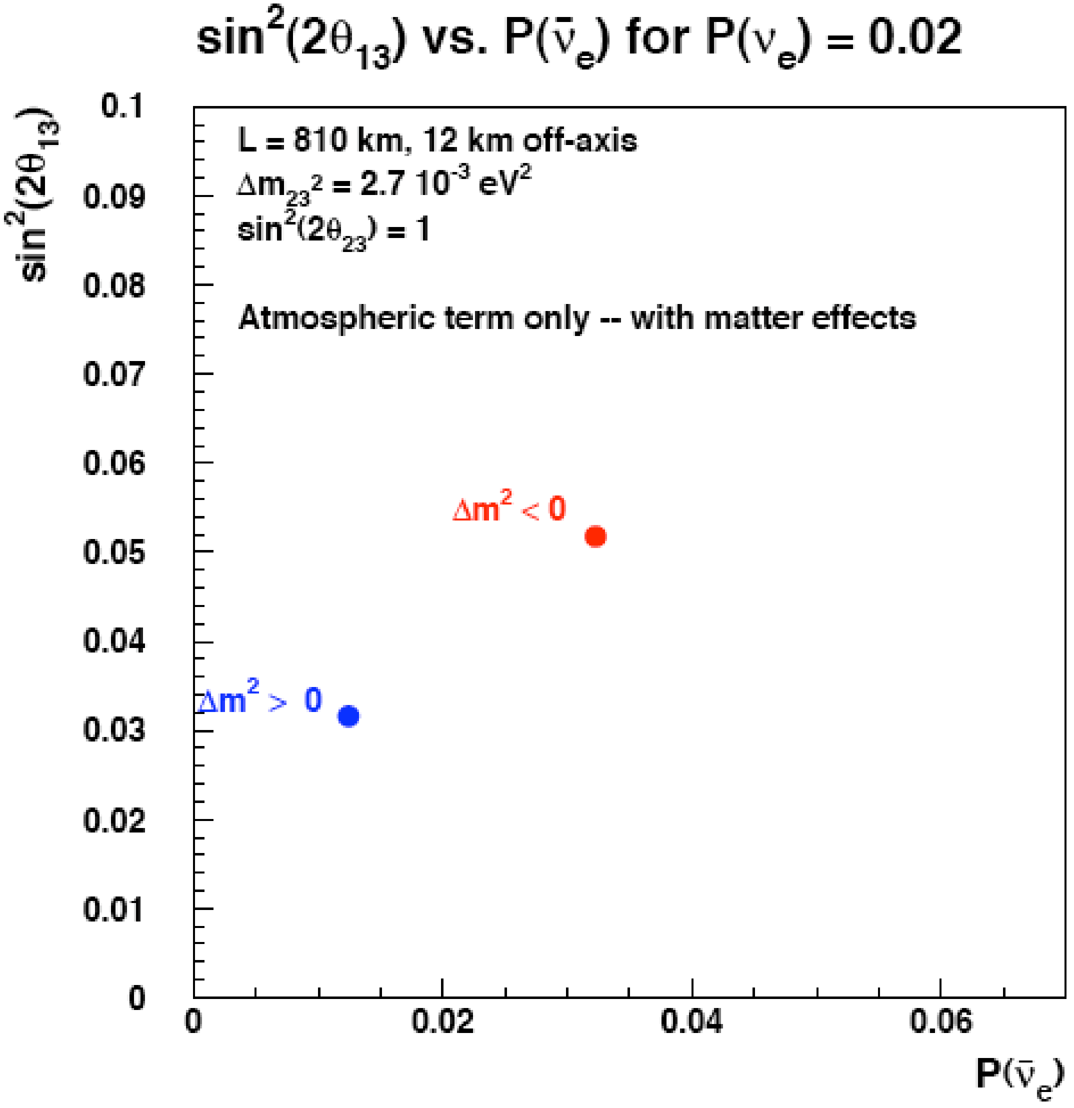
1.2 MW values are about an order of magnitude more sensitive than the 90% CL Chooz limit, or the ultimate 3σ MINOS sensitivity.

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



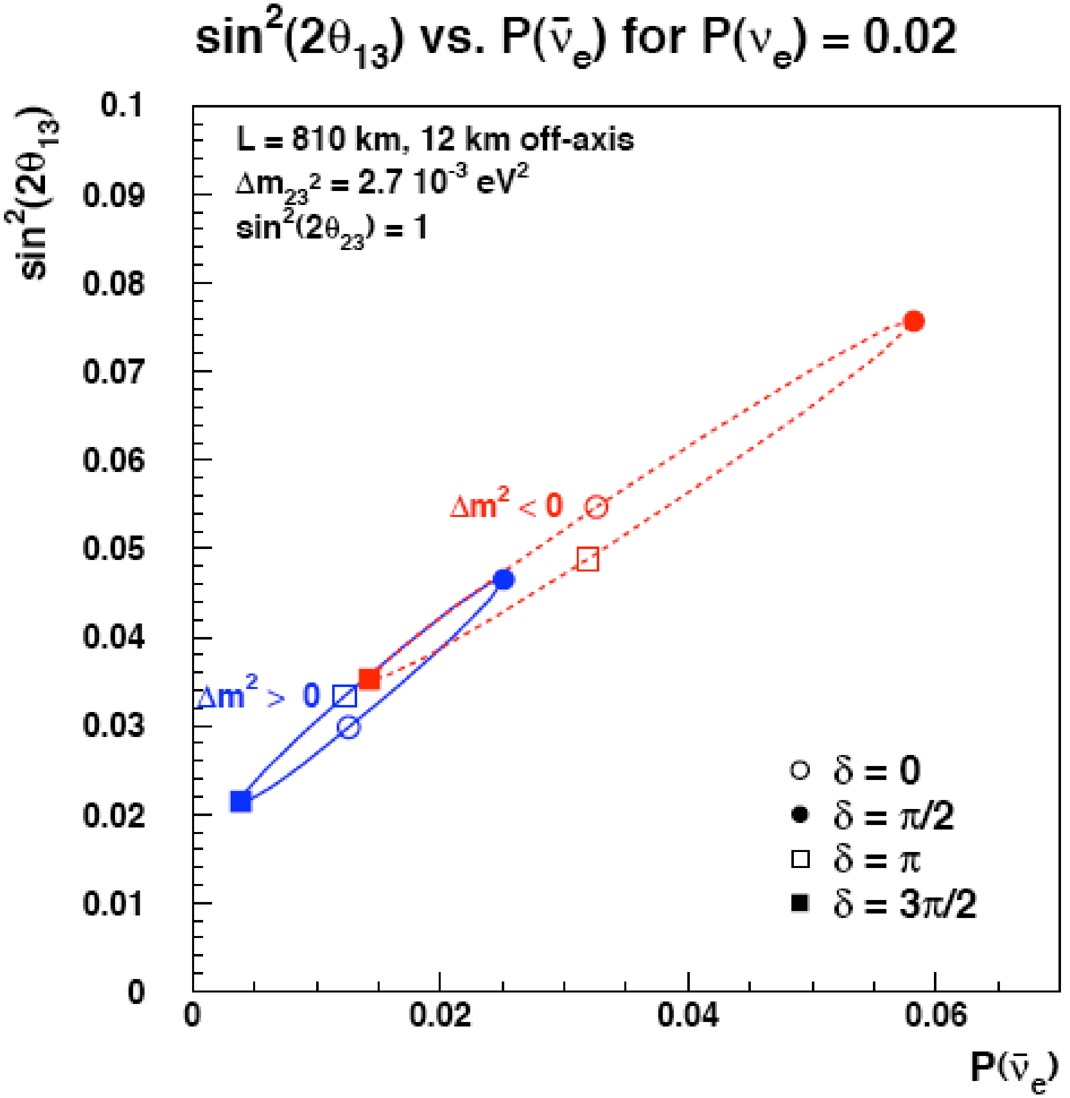
Atmospheric term only – no matter effects

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



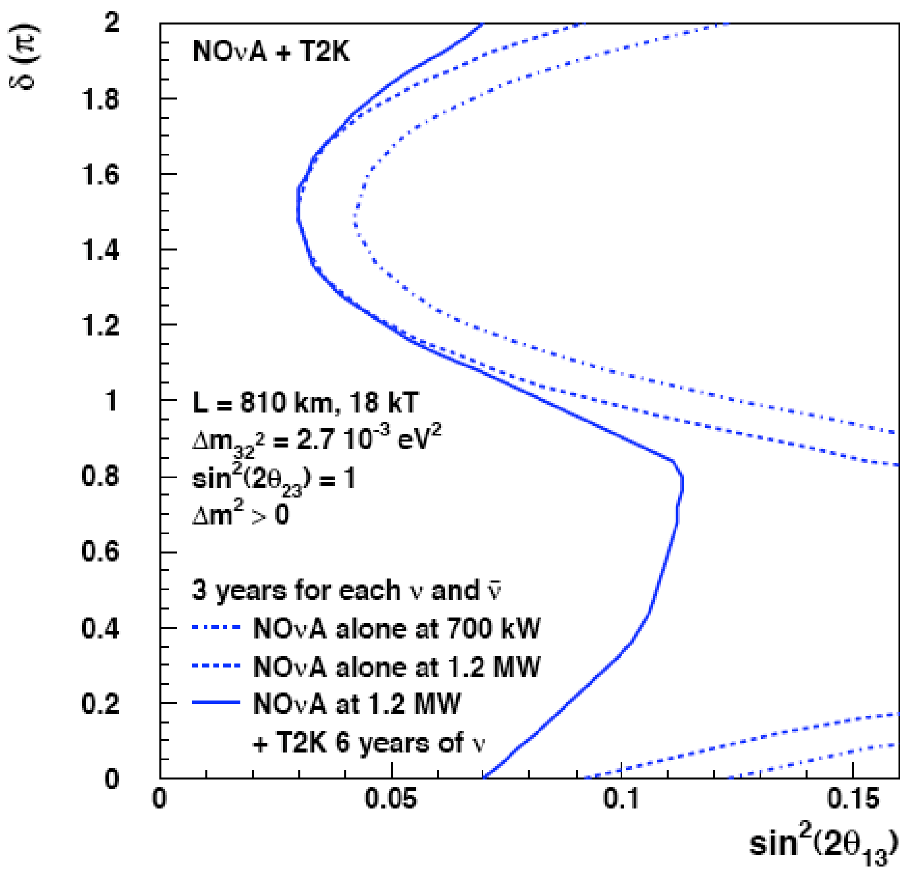
Atmospheric term only – with matter effects

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

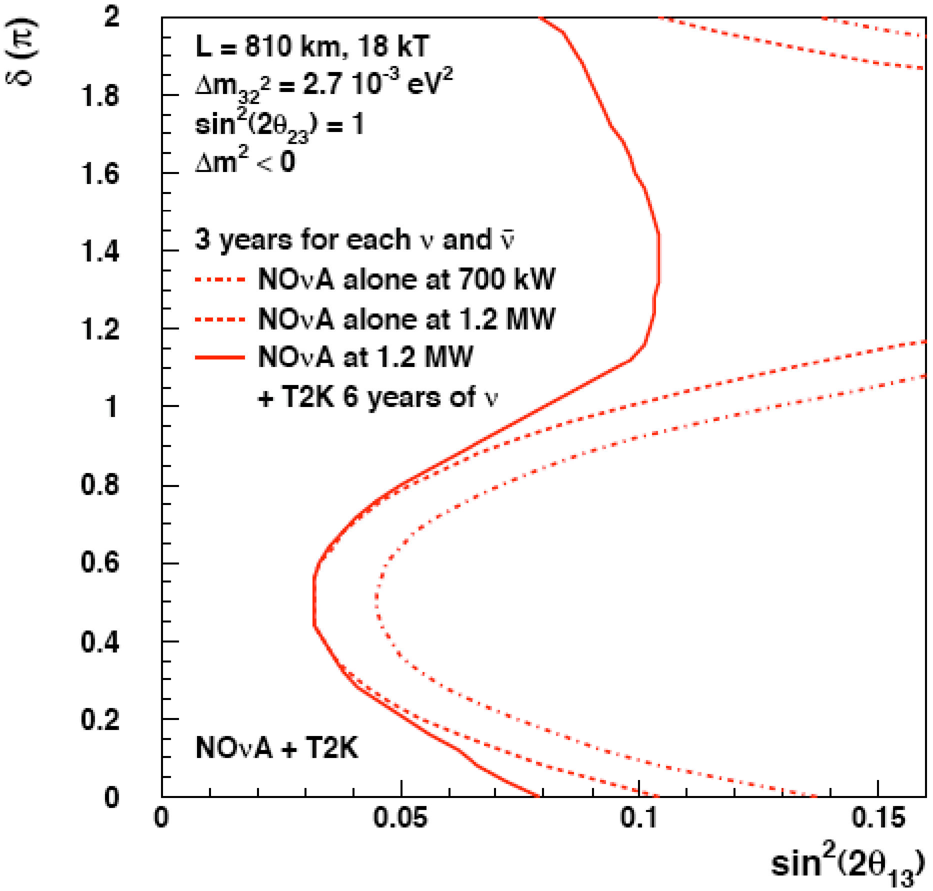


Some CP-violating phases create an inherent ambiguity in resolving the mass ordering.

95% CL Resolution of the Mass Ordering

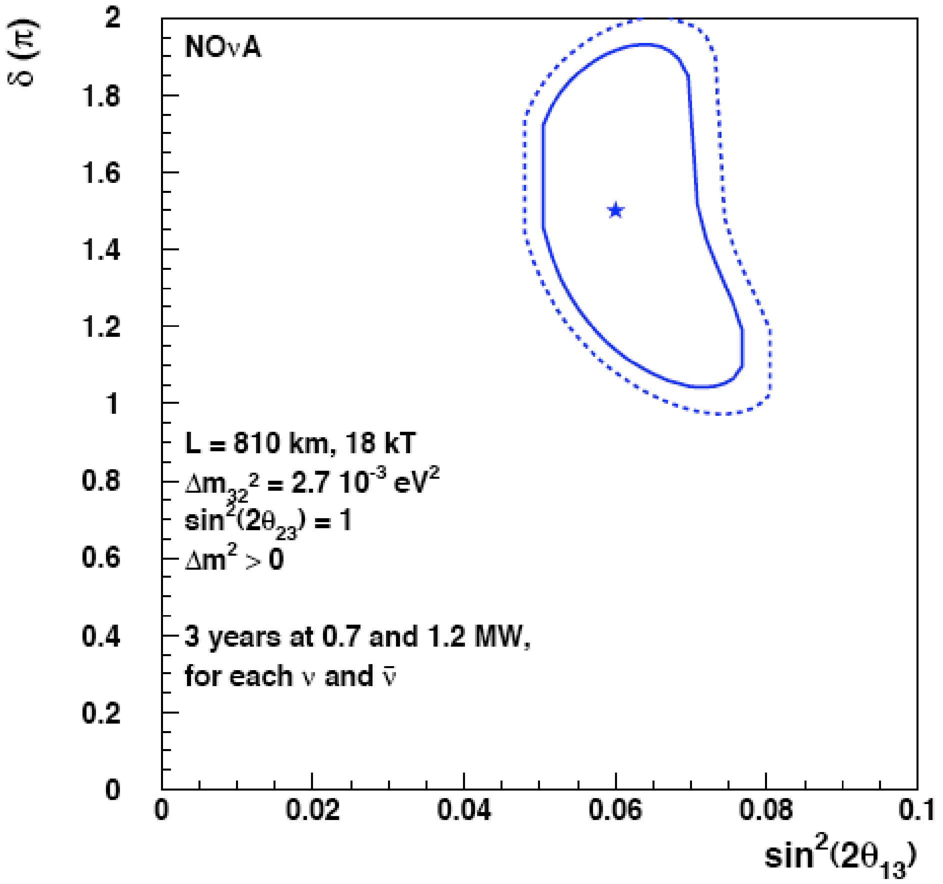


Normal mass ordering

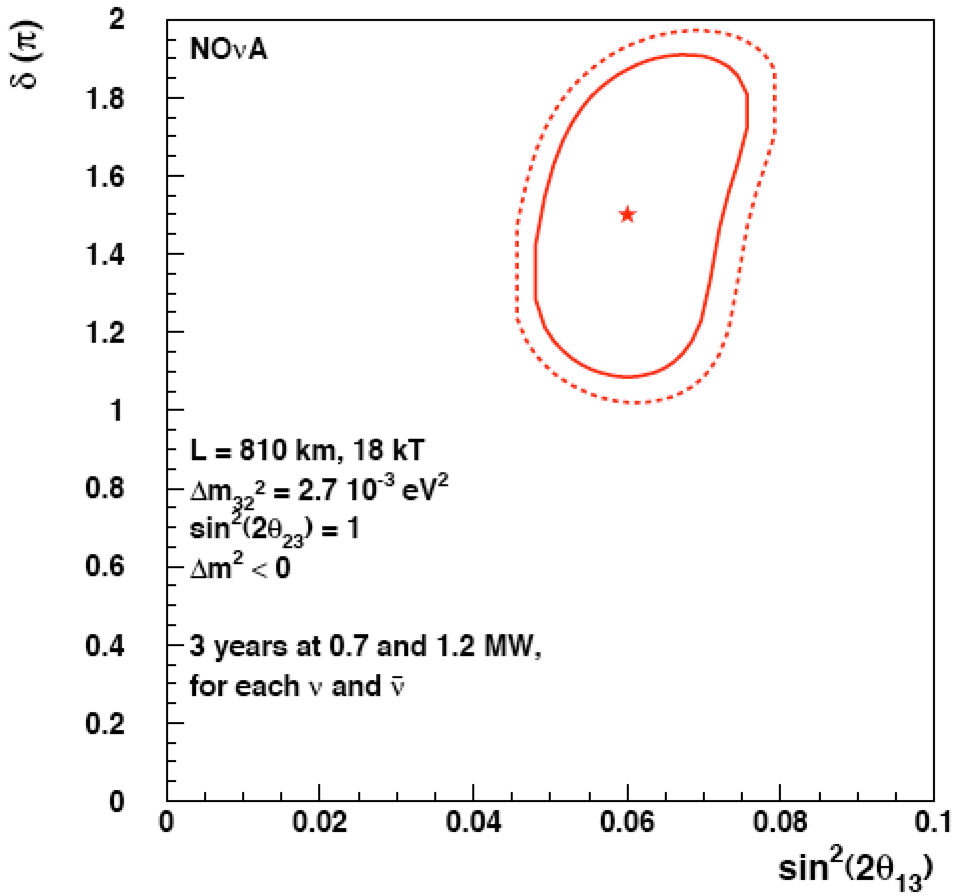


Inverted mass ordering

1σ Contours for Starred Point

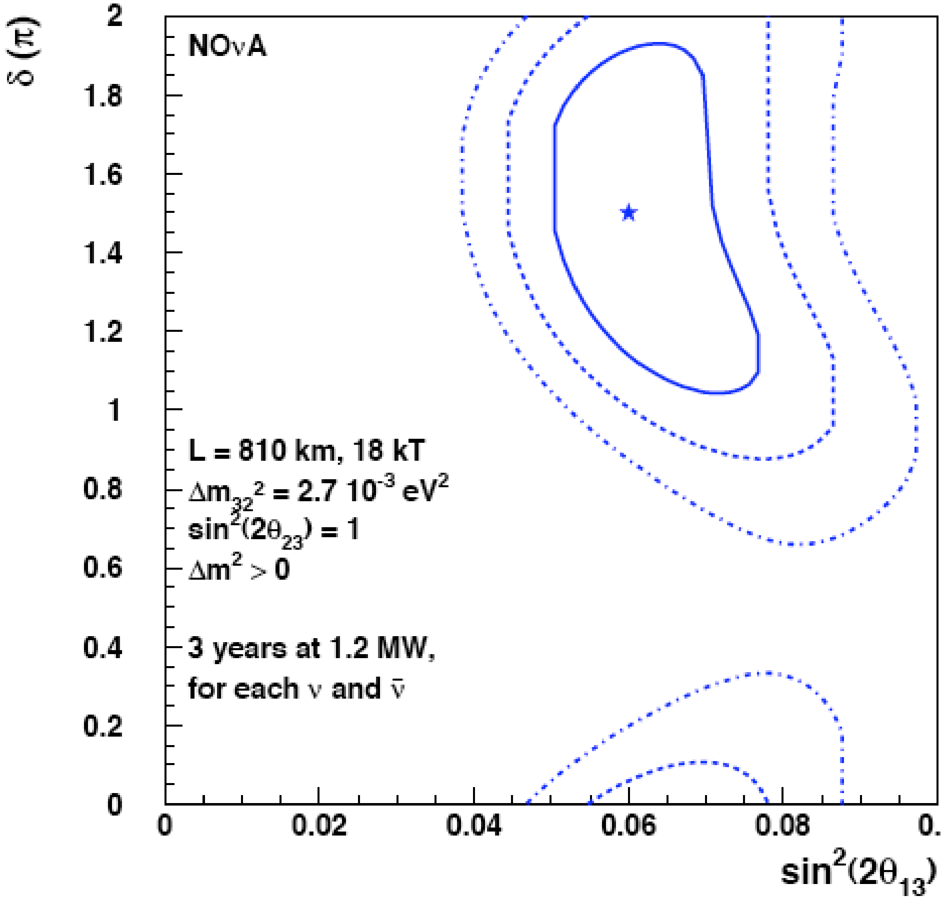


Normal mass ordering

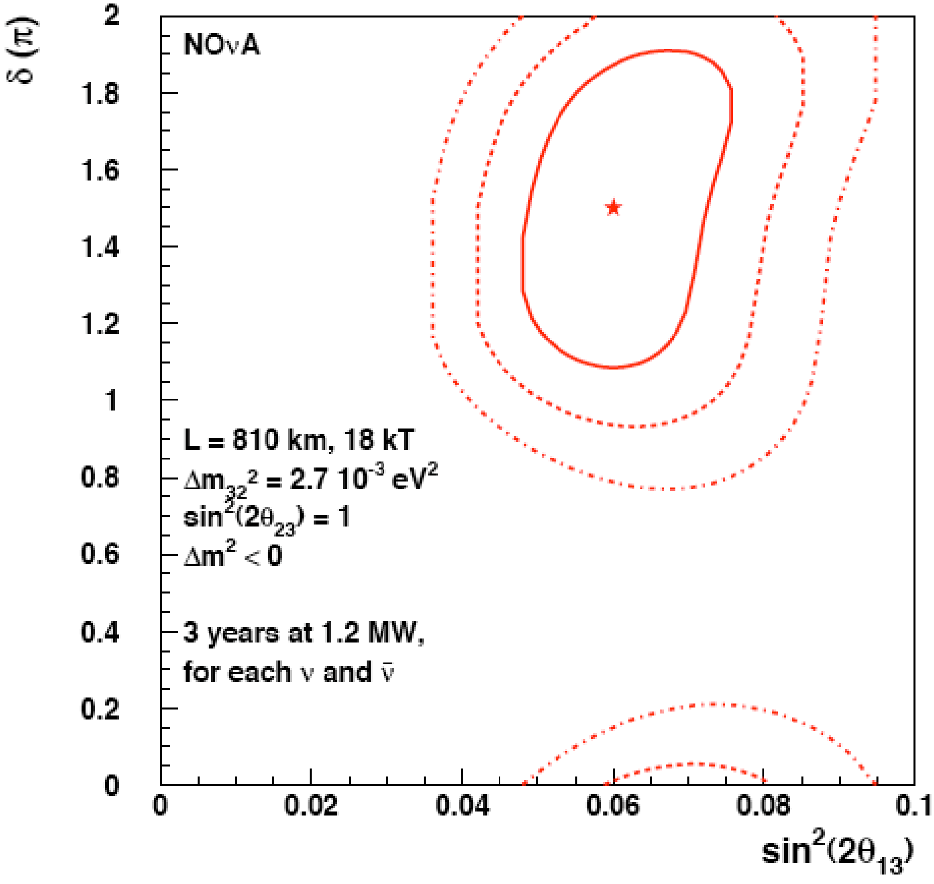


Inverted mass ordering

1, 2, and 3 σ Contours for Starred Point

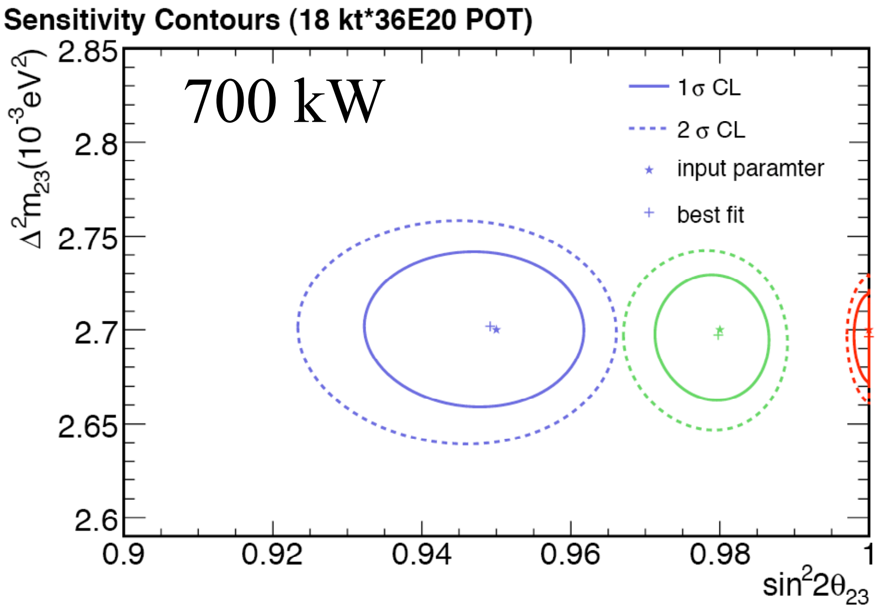


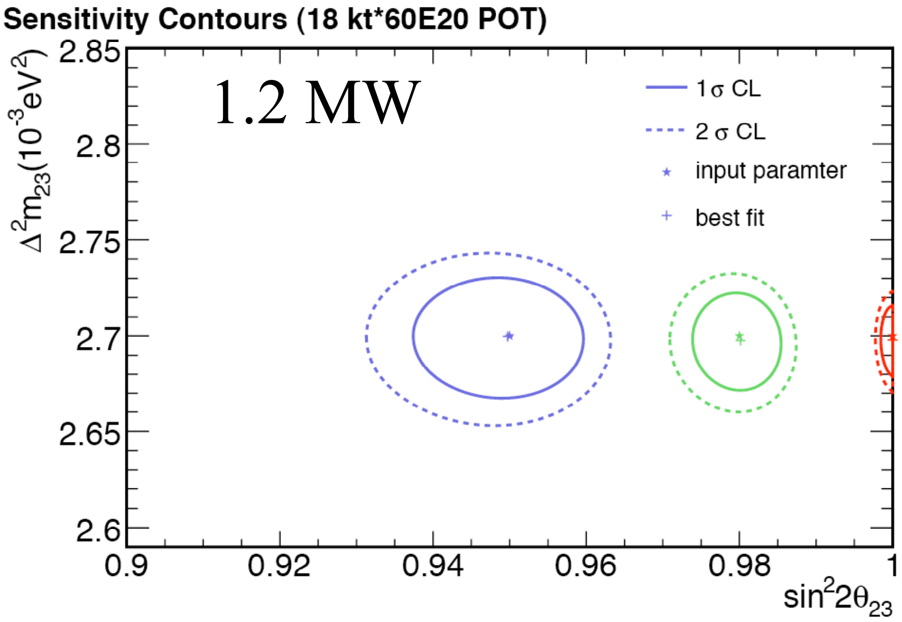
Normal mass ordering



Inverted mass ordering

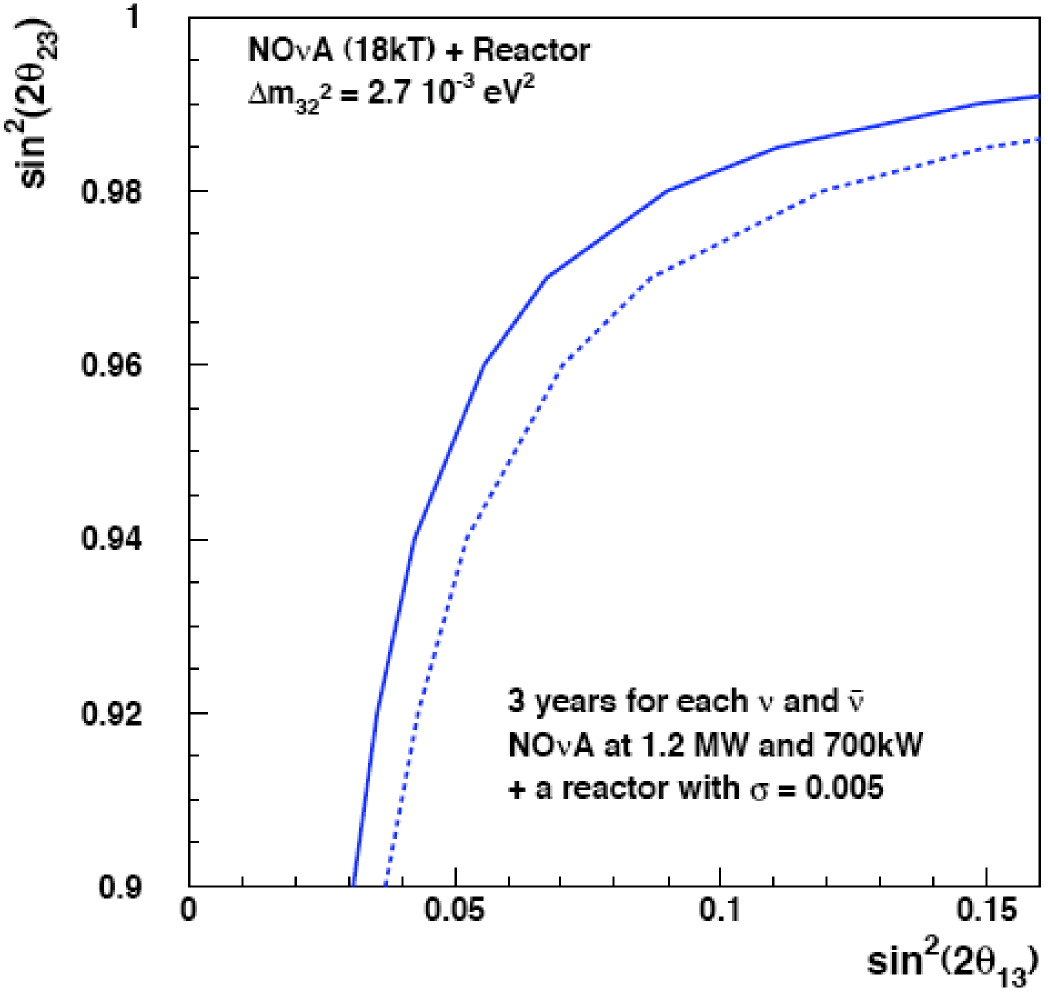
Measurement of $\sin^2(2\theta_{23})$


Sensitivity Contours (18 kt*36E20 POT)


Sensitivity Contours (18 kt*60E20 POT)

Parameterized analysis of quasielastic ν_μ CC events.

95% CL Resolution of the θ_{23} Ambiguity



If $\sin2(2\theta_{23}) \neq 1$, then whether $\theta_{23} > \pi/4$ or $\theta_{23} < \pi/4$ determines whether the 3rd mass state couples more to ν_μ or ν_τ.

This ambiguity can be resolved by comparing NOνA to the Daya Bay reactor experiment.

Summary

- NOνA will provide an order of magnitude improvement in sensitivity to θ_{13} over present experiments.
- NOνA will have unique sensitivity to the mass ordering through matter effects.
- NOνA will obtain information on the CP-violating phase δ, which will be useful in planning future experiments.
- NOνA will improve the precision of $\sin^2(2\theta_{23})$ measurements by an order of magnitude over present measurements.
- NOνA may be able to determine the sign of $\cos(2\theta_{23})$ by comparing its results to those from the Daya Bay reactor experiment.