NOνA Electron Neutrino Appearance Measurement

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Physics with the $\nu_\mu \longrightarrow \nu_e$ Oscillation Channel

$$P\left(\overline{\nu}_\mu^{(-)} \rightarrow \overline{\nu}_e^{(-)}\right) \approx \sin^2 2\theta_{13} \sin^2 \theta_{23} \frac{\sin^2(A-1)\Delta}{(A-1)^2}$$
$$+ 2\alpha \sin\theta_{13} \cos\delta_{cp} \sin 2\theta_{12} \sin 2\theta_{23} \frac{\sin(A\,\Delta)}{A} \frac{\sin(A-1)\Delta}{(A-1)} \cos\Delta$$
$$\mp 2\alpha \sin\theta_{13} \sin\delta_{cp} \sin 2\theta_{12} \sin 2\theta_{23} \frac{\sin(A\,\Delta)}{A} \frac{\sin(A-1)\Delta}{(A-1)} \sin\Delta$$

$$A = \mp \frac{G_f n_e L}{\sqrt{2}\Delta} \qquad \Delta = \frac{\Delta m^2_{31} L}{4E} \qquad \alpha = \frac{\Delta m^2_{21}}{\Delta m^2_{31}}$$

For NOνA: L = 810 km
E = 2.1 GeV

❖ Measure $\sin^2 2\theta_{13}$ by observing (anti)electron neutrino appearance in a (anti)muon neutrino beam

❖ In this oscillation channel the value of $\sin^2\theta_{23}$, mass hierarchy and CP violating phase δ all alter the oscillation probabilities

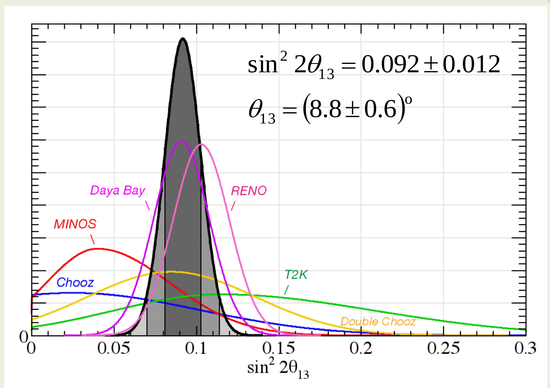
❖ At the NOνA baseline the matter effect has a 30% effect on the oscillation probability. In the normal hierarchy the (anti)electron neutrino appearance probability is (suppressed)enhanced. The reverse is true in the inverted case. This allows the mass hierarchy to be probed by comparing oscillation probabilities

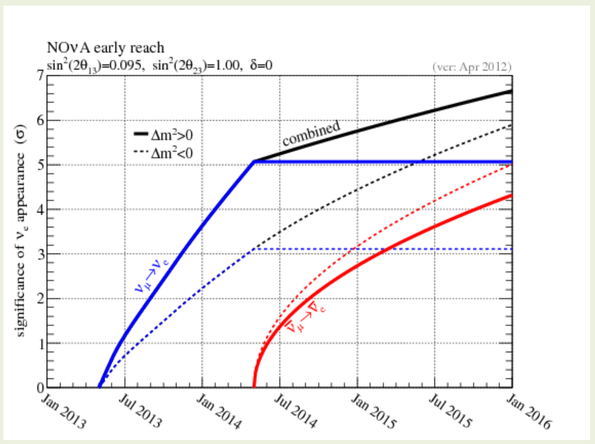
❖ The value of δ_{CP} affects neutrino and anti-neutrino oscillation probabilities differently. NOνA has some reach in measuring this phase.

❖ A non-maximal θ_{23} mixing alters the oscillation probability. For more about NOνA's ability to precisely measure $\sin^2 2\theta_{23}$ see J. Zirnstein's poster.

Early ν_e Appearance Sensitivity

In light of the recent Daya Bay and RENO results, θ_{13} is well constrained to be non-zero and large. This will allow NOνA to very quickly accumulate ν_e appearance statistics.





Beginning in April of 2013 NOνA will begin running with 5 kT of detector while construction continues into 2014. Even with a partial detector and beam power not reaching 700 kW until fall of 2013, a minimum of a 3σ measurement of ν_e appearance is expected in the first year of neutrino running.

Long Term ν_e Sensitivities

❖ Below are representative numbers for the ν_e appearance analysis. These numbers depend greatly on the specific oscillation parameters.

	signal	total bkgd	NC bkgd	ν_μ CC bkgd	ν_e CC bkgd
ν (3 yrs)	68	32	19	5	8
$\bar{\nu}$ (3 yrs)	32	15	10	<1	5

❖ Assuming a nominal run plan of 3 year ν + 3 year $\bar{\nu}$ with 6x10^{20} POT/year and a 14 kT detector.

❖ Using an earlier analysis approach based on an artificial neural net for particle identification, but including the new information on θ_{13}

❖ Using a 45% signal efficiency and ~10% uncertainty on the background and 0.1% neutral current leakage

For more about the NOνA experiment:

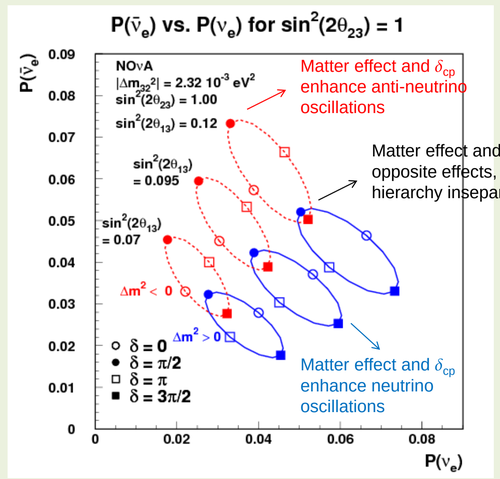
Posters
J. Liu: The NOνA Experiment
E. Arrieta-Diaz: Calibration and Reconstruction in the NOνA Detectors
J. Zirnstein: NOνA Muon Neutrino Disappearance Measurement
J. Nowak: Non-Oscillation Measurements with the NOνA Detectors

New Perspectives Talks
M. Betancourt: Status of Quasi-elastic studies in the NOνA Near Detector Prototype

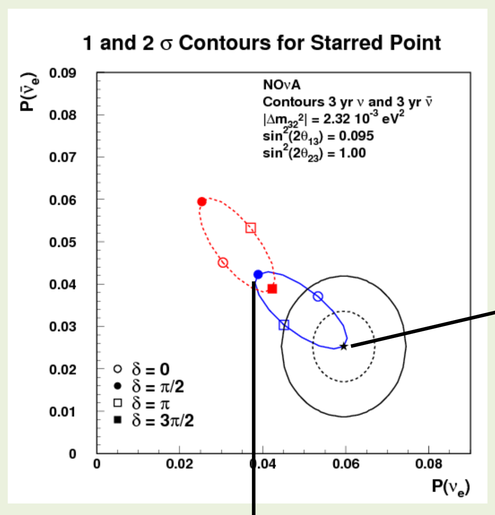
T. Kutnink: Status of the NOνA Near Detector Prototype

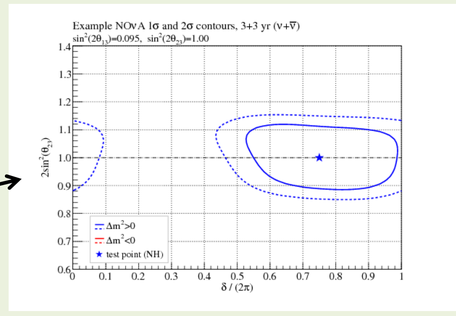
Resolving the Mass Hierarchy

By running in both neutrino and anti-neutrino mode, the oscillation probabilities can be plotted as shown. For a given value of θ_{13}, and assuming θ_{23} is maximal, an ellipse can be drawn in probability space for each mass hierarchy.

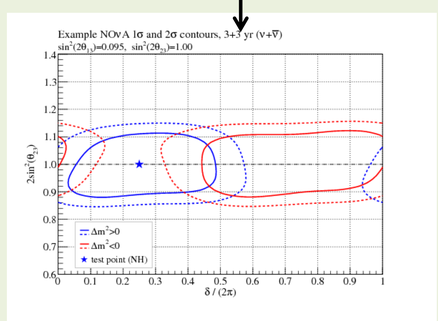


For Example





If NOνA measures the oscillation probabilities at the starred point, the normal hierarchy can be distinguished.

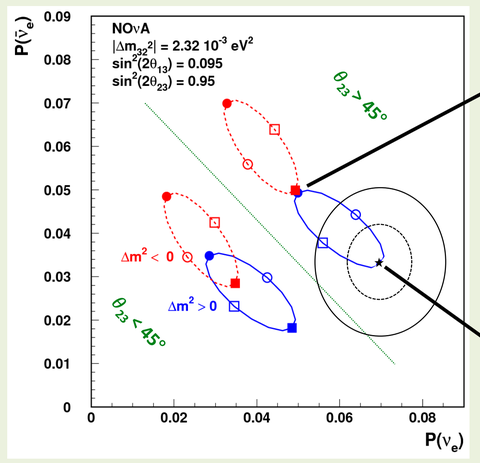


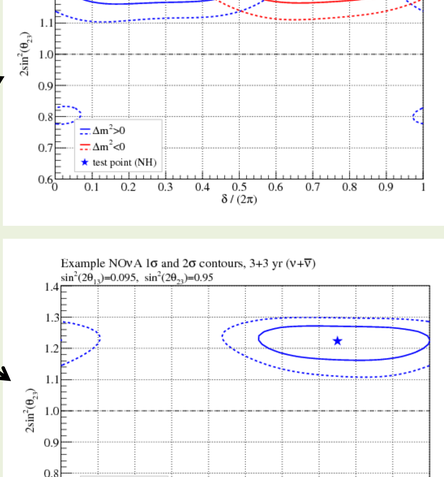
At this point the hierarchy choice cannot be distinguished.

At the end of NOνA's planned run the mass hierarchy can be determined to greater then 2σ for ~35% of the values of δ_{CP}. For a very small region of parameter space a 3σ measurement can be made.

$\theta_{23} \neq 45^o$

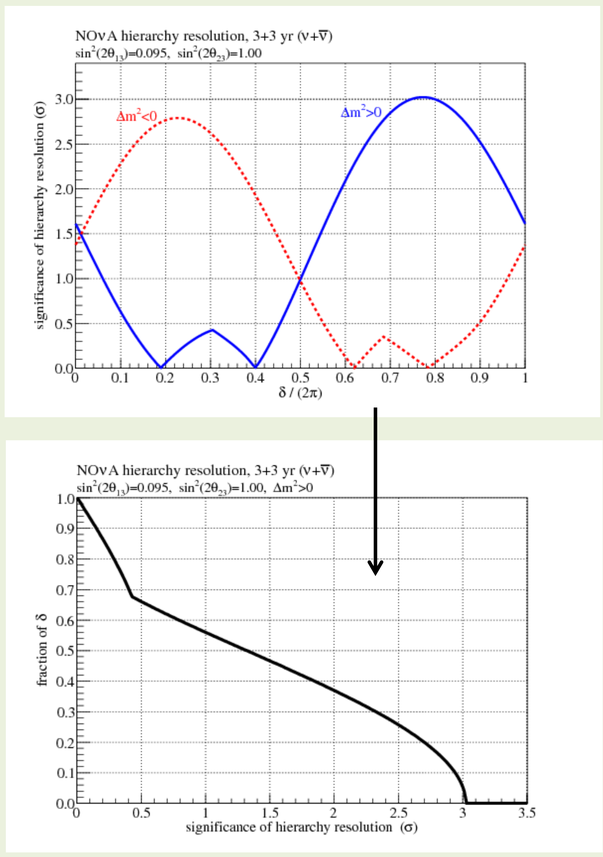
If $\sin^2 2\theta_{23}$ is non-maximal, then there is a question whether θ_{23} is larger or smaller then 45^o. This alters the oscillation probabilities for ν_e appearance and can lead to θ_{23} octant resolution.





In degenerate cases the hierarchy cannot be determined, but the octant can still be resolved.

In the Long Run



Simultaneous hierarchy, CP phase, and octant information.

δ_{cp} Sensitivity

It will take the next generation of experiments to fully determine δ_{CP} . NOνA can provide some clues about the phase, but in the best case scenario is limited to a 1.5σ result.