Neutrino Physics at the NOvA Experiment

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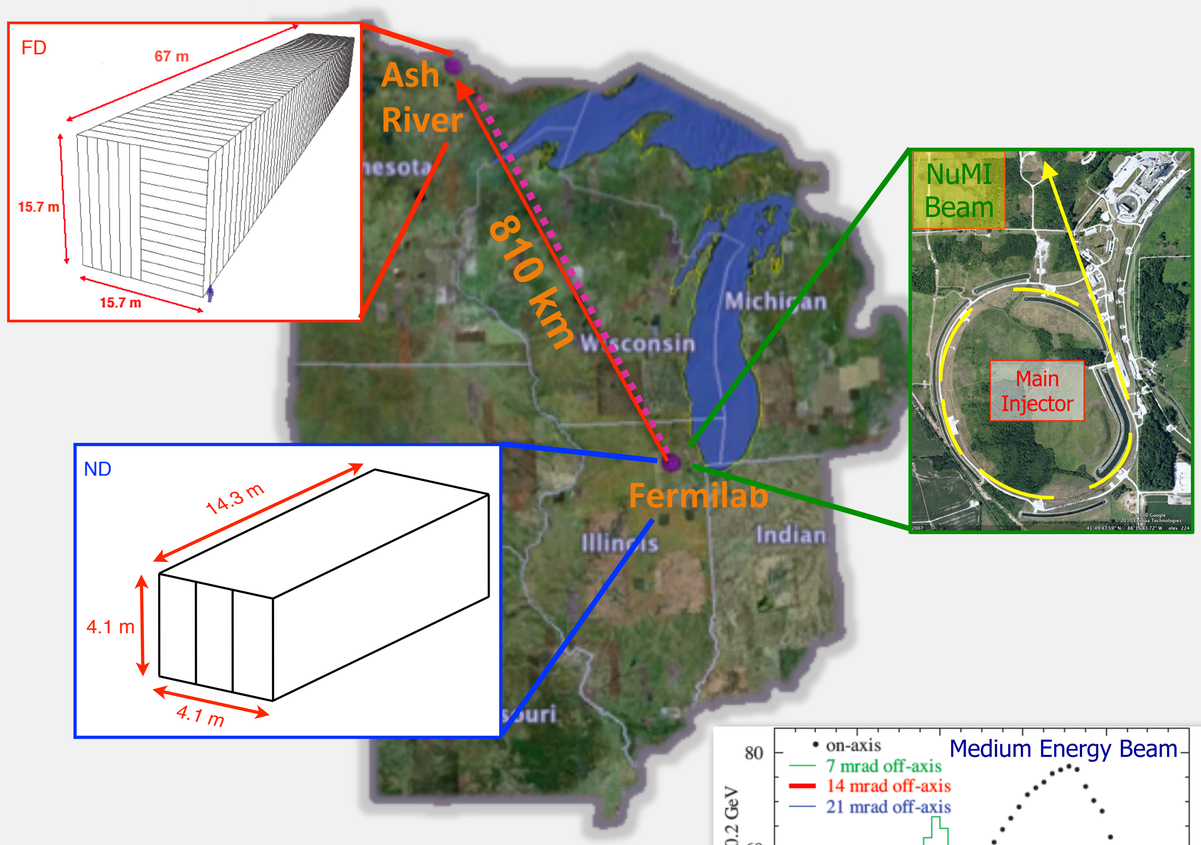
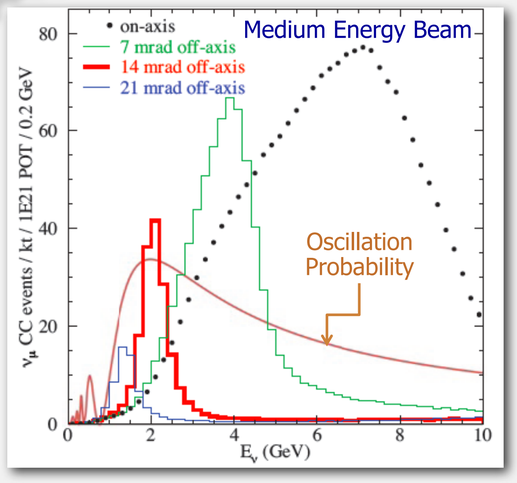
on behalf of the NOvA collaboration

The NuMI Off-Axis ν_e Appearance Experiment





NOvA is a next generation long baseline neutrino experiment using the NuMI beam using a two off-axis detector setup.

Both detectors are totally active tracking liquid-scintillator calorimeters located 14 mrad off the NuMI beam axis:

- Near detector is located at Fermilab, 300 tons, 100m underground and 1km downstream the beam production target
- Far Detector is located at Ash River (Minnesota), on surface, 14 kt, 810 km downstream the beam production target

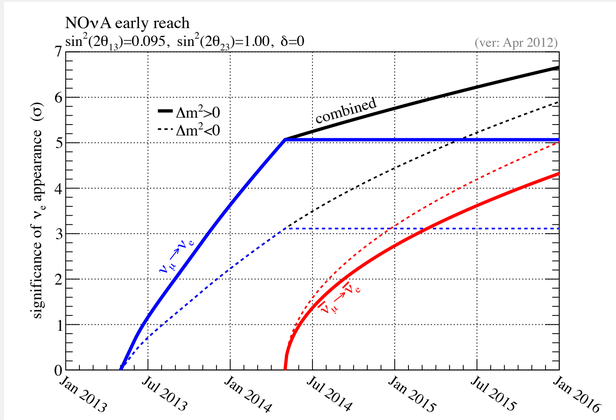
The NuMI beam upgraded from 400 kW to 700 kW, running in the medium energy target-horns configuration gives a narrow band neutrino beam peaked at 2 GeV.

NOvA Physics Goals

ν_e Appearance : $\nu_\mu \rightarrow \nu_e$ oscillations

$$P(\overset{(-)}{\nu}_\mu \rightarrow \overset{(-)}{\nu}_e) \approx \sin^2 2\theta_{13} \sin^2\theta_{23} \frac{\sin^2(A-1)\Delta}{(A-1)^2}$$
$$\overset{(+)}{(-)}\, 2\alpha \sin\theta_{13} \sin\delta_{CP} \sin 2\theta_{12} \sin 2\theta_{23} \frac{\sin A\Delta}{A} \frac{\sin(A-1)\Delta}{(A-1)} \sin\Delta$$
$$+\ 2\alpha \sin\theta_{13} \cos\delta_{CP} \sin 2\theta_{12} \sin 2\theta_{23} \frac{\sin A\Delta}{A} \frac{\sin(A-1)\Delta}{(A-1)} \cos\Delta$$
$$\alpha = \Delta m^2_{21}/\Delta m^2_{31} \qquad \Delta = \Delta m^2_{31} L/(4E) \qquad A = \overset{(-)}{+} G_f n_e L/(\sqrt{2}\Delta)$$

1. Measure $\sin^2(2\theta_{13})$ in a long baseline via ν_e appearance
2. $\sin^2(2\theta_{13})$ is now well measured which allows NOvA to search for neutrino CP violation
3. NOvA can gain information about the θ_{23} octant since $\sin^2(\theta_{23})$ is a coefficient on the leading order term
4. Probability is either suppressed or enhanced due to matter effects which depend on the mass hierarchy, ie. the sign of Δm^2_{31}, and neutrino vs. anti-neutrino running



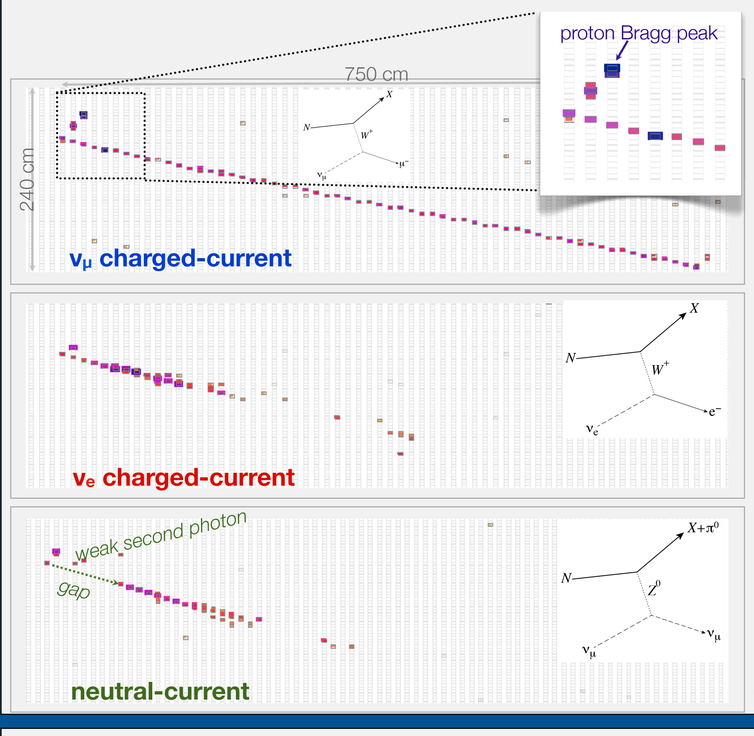
ν_μ Disappearance : $\nu_\mu \rightarrow \nu_\mu$ oscillations

$$P(\overset{(-)}{\nu}_\mu \rightarrow \overset{(-)}{\nu}_\mu) \approx 1 - \sin^2 2\theta_{23} \sin^2(1.27\, \Delta m^2_{32}\, L/E)$$

5. NOvA can measure precisely $\sin^2 2\theta_{23}$ and the magnitude of $|\Delta m^2_{32}|$ of the surviving ν_μ energy spectrum

Topologies of basic interaction channels in the NOvA detectors

The NOvA detectors are optimized for detection of ν_e charged-current interactions:
1 plane ~ 0.15 X_0, Molière radius = 10 cm



ν_μ Charged-Current

Long well-defined muon track, proton is a short track with large energy deposition at the track end (2 GeV muon traverses ~60 planes)

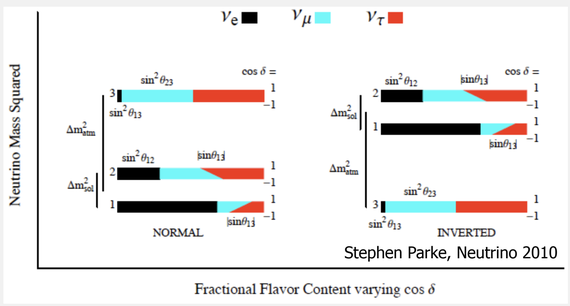
ν_e Charged-Current

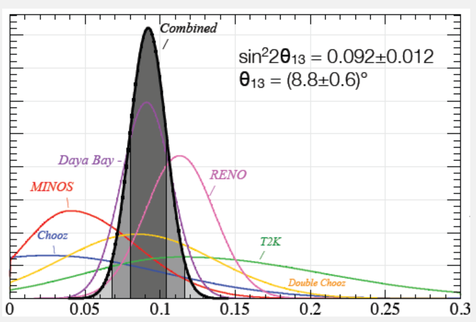
Single shower with characteristic e-m shower development (selection efficiency ~35%)

NC with π^0 production

Single shower with characteristic e-m shower development (NC background contamination ~0.1%)

Resolving the Mass Hierarchy



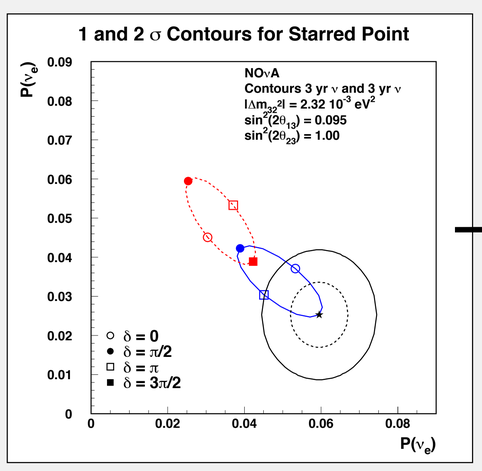


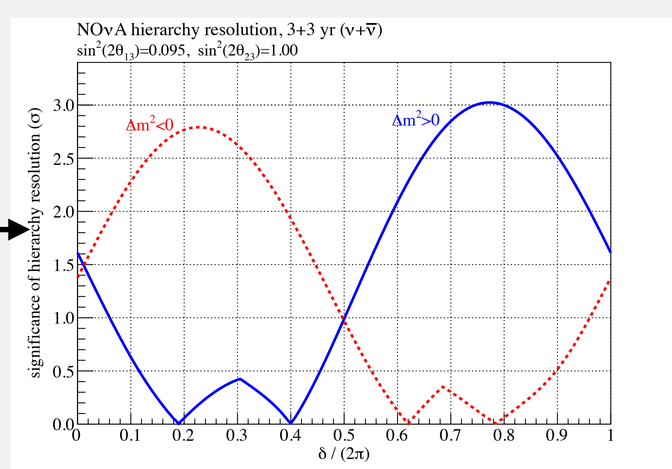
Due to NOvA's long baseline, matter effects modify the electron appearance probability by 30%.

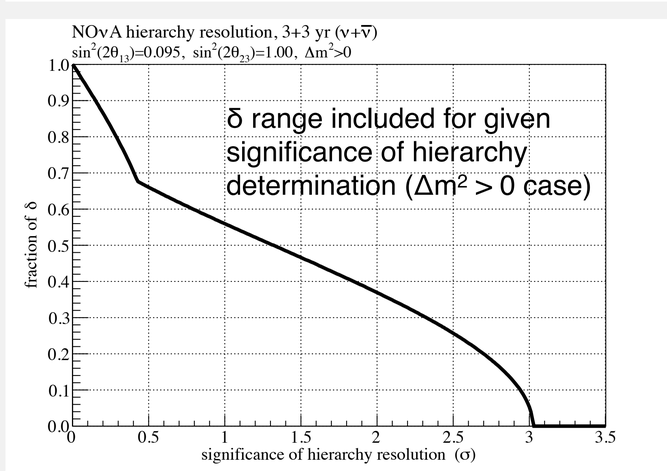
Matter effects depend on the mass hierarchy sign and change $P(\nu_\mu \rightarrow \nu_e)$ and $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$ differently.

Large θ_{13} is good news for NOvA as it reduces the overlap between bi-probability ellipses, reducing the likelihood of degeneracies.

NOvA plans on running 3 years with a neutrino beam and 3 years with an antineutrino beam to resolve the mass hierarchy.







In this example:

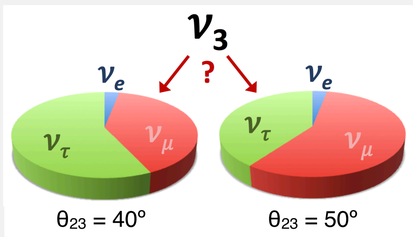
- $\sin^2(2\theta_{13})$=0.095, $\sin^2(2\theta_{23})$=1
- $P(\nu_\mu \rightarrow \nu_e)$ and $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$ at 2 GeV
- 10% background systematic error
- 41% (ν) and 48% (ν̄) signal efficiency
- 18 x 10^{20} POT

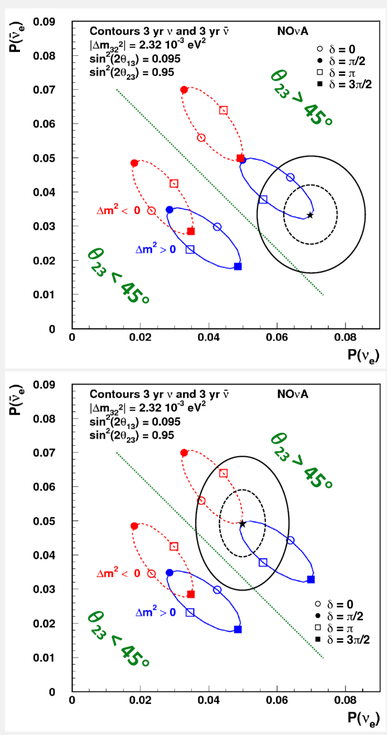
The θ_{23} Octant

If $\sin^2(2\theta_{23})$ is not maximal there is an ambiguity as to whether θ_{23} is larger or smaller than 45°.

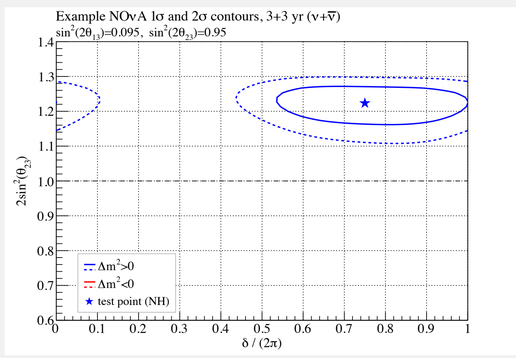
$\theta_{23} < 45°$ implies that ν_3 couples more strongly to ν_τ than to ν_μ. $\theta_{23} > 45°$ implies the opposite.

Contours for two 3 years + 3 years example scenarios:

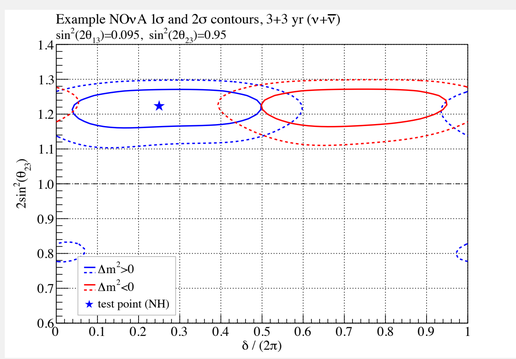




Simultaneous hierarchy, CP phase & θ_{23} octant information from NOvA



In "degenerate" cases, hierarchy and δ information is coupled. θ_{23} octant information is not.



The NOvA Collaboration

www-nova.fnal.gov

ANL, Athens, Caltech, Institute of Physics of the Czech Republic, Charles University, Czech Technical University, FNAL, Harvard, India Universities Consortium, Indiana, Iowa State, Lebedev, Michigan State, Minnesota Duluth, Minnesota/Twin Cities, INR Moscow, South Carolina, SMU, Stanford, Tennessee, Texas/Austin, Tufts, Virginia, WSU, William and Mary.