Electron Neutrino Appearance at NOνA

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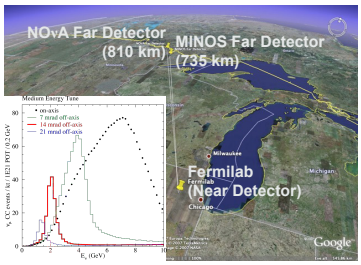
NOνA in a Nutshell

- Long baseline, two detector neutrino oscillation experiment
- Upgrade of NuMI beam from 400 to 700 kW
- Liquid scintillator 14 kton far detector (FD), 0.3 kton near detector (ND)
- Both near and far detector located 14 mrad off axis, leading to narrow 2 GeV neutrino energy band

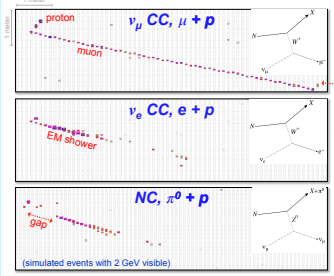


Physics Goals of ν_e Appearance Analysis

- NOνA will observe ν_e and anti-ν_e appearance at 2 GeV
- Parameters NOνA will measure in the ν_e appearance analysis are θ_{13}, δ_{CP}, mass hierarchy, and information on the θ_{23} octant
- Below: Sample detector events before analysis

$$P(\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_e) \approx \sin^2\theta_{13}\frac{\sin^2(A-1)\Delta}{(A-1)^2} + \overset{(+)}{-} 2\alpha(\sin\theta_{13}\sin\delta_{CP})\sin 2\theta_{12}\sin 2\theta_{23}\frac{\sin A\Delta}{A}\frac{\sin(A-1)\Delta}{(A-1)}\sin\Delta + 2\alpha(\sin\theta_{13}\cos\delta_{CP})\sin 2\theta_{12}\sin 2\theta_{23}\frac{\sin A\Delta}{A}\frac{\sin(A-1)\Delta}{(A-1)}\cos\Delta$$

$$\alpha = \Delta m^2_{21}/\Delta m^2_{31} \qquad \Delta = \Delta m^2_{31} L/(4E) \qquad A = \overset{(-)}{+} G_F n_e L/(\sqrt{2}\Delta)$$

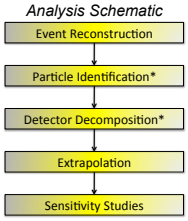


ν_μ CC events feature a long, well-defined muon track. Some ν_μ CC events also have a short proton track.

ν_e CC events feature characteristic E-M shower development.

NC events also have E-M shower, but can sometimes be distinguished by features like gaps.

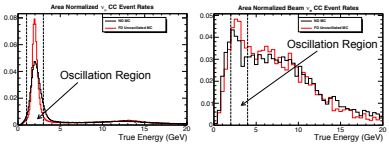
Analysis Schematic



*See Gavin Davies' and Tian Xin's poster for PID Algorithms; see Kanika Sachdev's poster for the MRCC Decomposition

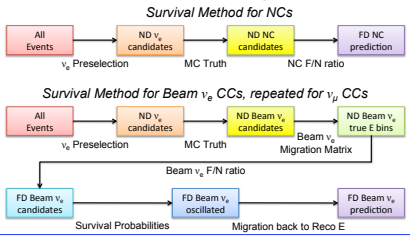
Far Over Near Extrapolation

- NOνA Detectors similarly designed to share event efficiencies and purities, and cancel systematic errors
- Differences in detector flux attributed to kinematic effects encoded in ratio of event rates at FD over ND
- One expected source of difference in detector spectra is the ND is close to the decay pipe and sees neutrino line source, but FD sees an effective point source
- F/N ratios are applied to near detector data to predict far detector spectrum
- All F/N ratios, purities, efficiencies, and migration matrices come from MC truth information

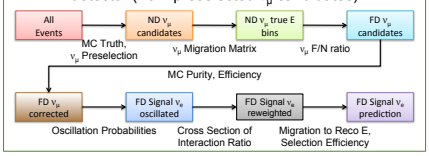


Above: area normalized event rates demonstrate differences in detector spectra shapes. A F/N ratio can be made from the non-normalized versions. These spectra are the true events with no selections applied. The F/N ratios change when various selections or PIDs are applied.

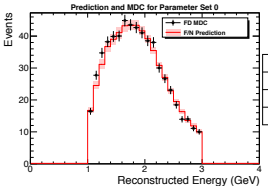
Survival Method used for events that occur in both detectors (from preselected ν_e candidates)



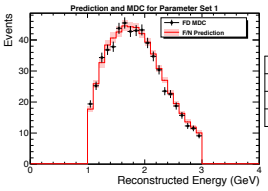
Appearance Method used for signal ν_e CCs and background ν_μ to ν_τ CCs, events which only occur at far detector (from preselected ν_μ candidates)



- Mock Data Challenge (MDC) samples, or MC with built in oscillation parameters, used for validation
- Two different MDC samples were compared to F/N predictions



Δm^2_{32}	0.00236 eV^2
$\sin^2(2\theta_{23})$	1.00
$\sin^2(2\theta_{13})$	0.09
δ_{CP}	5π/4



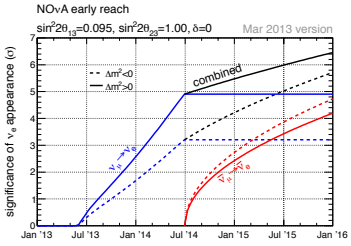
Δm^2_{32}	0.00244 eV^2
$\sin^2(2\theta_{23})$	0.95
$\sin^2(2\theta_{13})$	0.098
δ_{CP}	05π/4

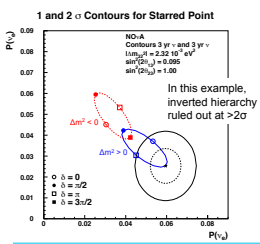
Errors shown are only statistical

Common parameters for both samples: $\Delta m^2_{21} = 7.59 \times 10^{-5}$ eV^2, $\theta_{12} = 0.601$, density of crust = 2.75 g/cm^3, MC scaled to 18×10^{20} POT

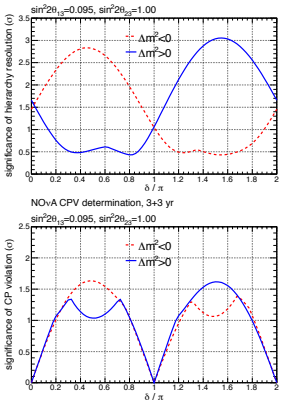
Sensitivities

- The nominal run plan for NOνA is 3 years of neutrino running and 3 years of anti-neutrino running
- All following results based on reconstruction and PIDs; decomposition and extrapolation were still under development
- Appearance probability modified by 30% due to matter effects
- Large θ_{13} reduces overlap of bi-probability ellipses, lowering likelihood of degeneracy
- Significance of ν_e appearance will be 3σ or 5σ (depending on mass hierarchy) after only one year

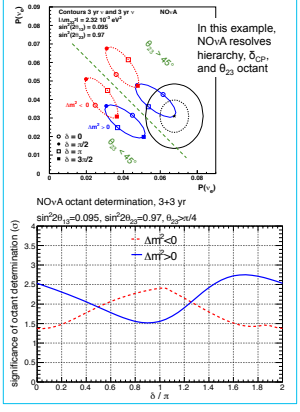




Including energy fit information improves the significance at degenerate points



For non-maximal θ_{23}, NOνA gets simultaneous octant, hierarchy, and CP phase information



The NOνA Collaboration

Argonne National Laboratory, University of Athens, Banaras Hindu University, California Institute of Technology, Institute of Physics of the Academy of Sciences of the Czech Republic, Charles University, Prague, University of Cincinnati, Czech Technical University, University of Delhi, Fermilab, Indian Institute of Technology, Guwahati, Harvard University, Indian Institute of Technology, University of Hyderabad, Indiana University, Iowa State University, University of Jammu, Lebedev Physical Institute, Michigan State University, University of Minnesota, Crookston, University of Minnesota, Duluth, University of Minnesota, Twin Cities, Institute for Nuclear Research, Moscow, Panjab University, University of South Carolina, Southern Methodist University, Stanford University, University of Sussex, University of Tennessee, University of Texas at Austin, Tufts University, University of Virginia, Wichita State University, College of William and Mary