3-flavor neutrino oscillations in NOvA

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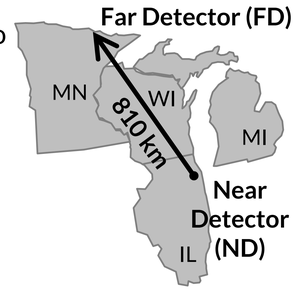
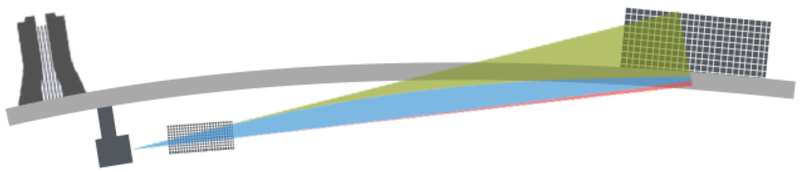
The NOvA experiment

NOvA is a long-baseline, off-axis neutrino oscillation experiment, using the NuMI muon neutrino (or anti-neutrino) beam from Fermilab.

It consists of two functionally identical liquid scintillator detectors: the 0.3 kton ND, which characterizes the unoscillated beam, and the 14 kton FD, 810 km away.

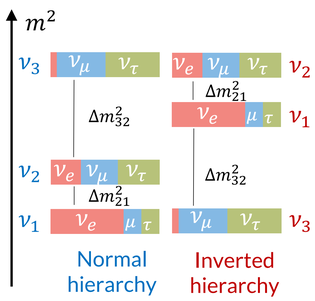




3-flavor neutrino oscillations are transitions in-flight between the flavor neutrinos ν_e ν_μ ν_τ . They are caused by non-zero ν masses and ν mixing.

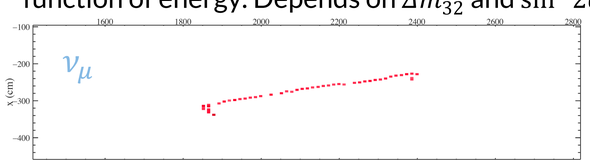
The oscillation probabilities depend on:

- Neutrino energy (E_ν)
- Source-detector distance (L)
- Osc. parameters ($\theta_{12}, \theta_{13}, \theta_{23}, \delta_{CP}$)
- Mass squared differences (Δm^2_{21}, Δm^2_{32})



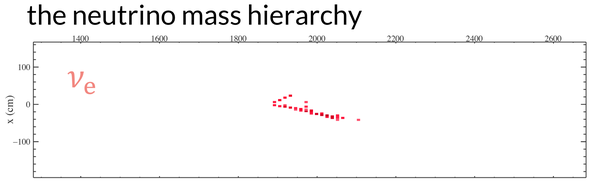
The dominant oscillation modes at the NOvA baseline and energy are:

- **ν_μ/ $\bar{\nu}_\mu$ disappearance:** A suppression of ν_μ-CC events as a function of energy. Depends on Δm^2_{32} and $\sin^2 2\theta_{23}$



Top view of a ν_μCC candidate selected in the FD, with the typical long muon track.

- **ν_e / $\bar{\nu}_e$ appearance:** i.e. $\nu_\mu \to \nu_e$ oscillations. Depends on θ_{13}, θ_{23}, and δ_{CP}. Due to matter effects, this channel is sensitive to the neutrino mass hierarchy

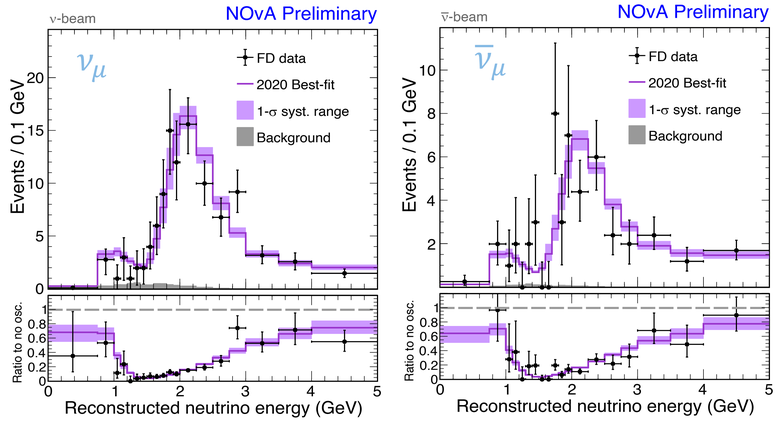


Top view of a ν_eCC candidate selected in the FD, with the typical electromagnetic shower.

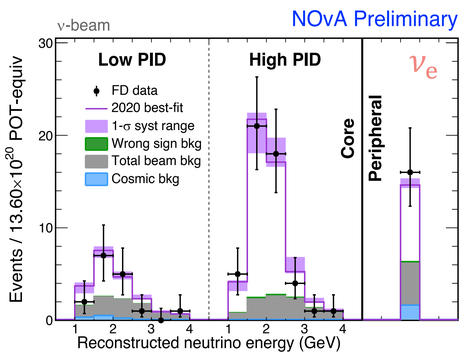
2020 analysis results

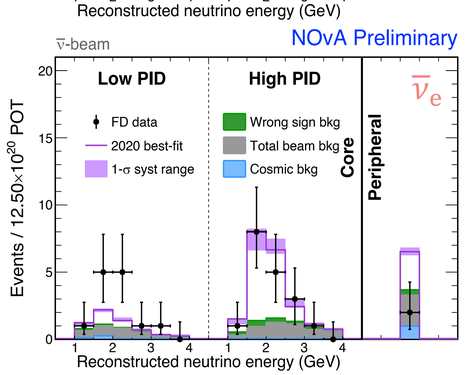
NOvA's latest 3-flavor oscillation results are based on the combined analysis of neutrino and anti-neutrino datasets ($\nu_\mu \to \nu_\mu, \nu_\mu \to \nu_e, \bar{\nu}_\mu \to \bar{\nu}_\mu, \bar{\nu}_e \to \bar{\nu}_e$) with an exposure of ~13e20 protons-on-target in each beam mode.

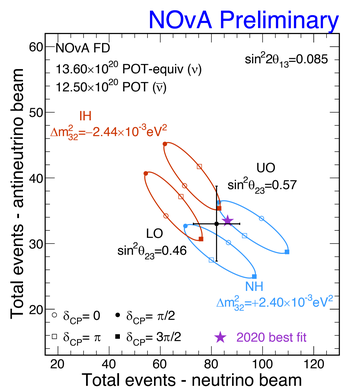
The constraints on neutrino oscillation parameters result from comparisons between the measured spectra and predictions, which are constructed from the simulation and enhanced by data-driven methods.



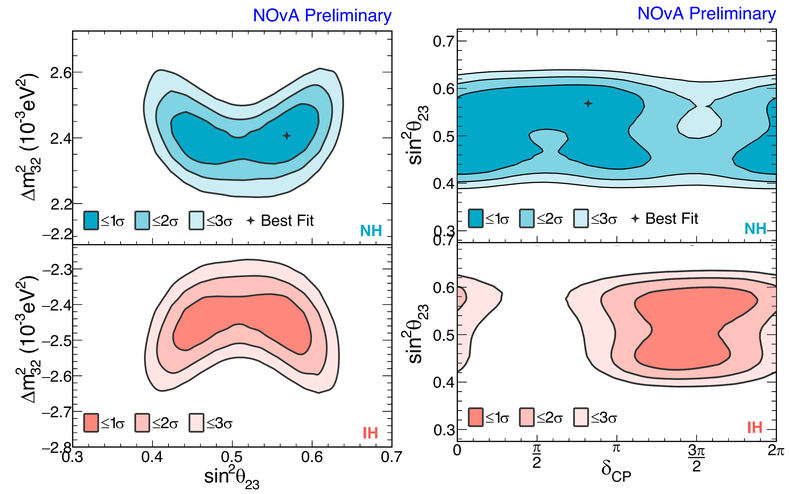
Reconstructed energy spectrum of the FD data and best-fit prediction for $\nu_\mu(\bar{\nu}_\mu)$-selected events. Observed: 211 (105) $\nu_\mu(\bar{\nu}_\mu)$-CC candidates, with an expected background of 8.2 (2.1).





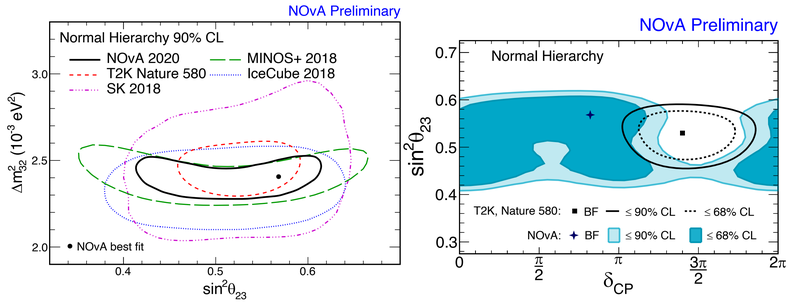


Reconstructed energy spectrum of the FD data and best-fit prediction for $\nu_e(\bar{\nu}_e)$-selected events, in 3 bins of the PID classifier. Observed: 82 (33) $\nu_e(\bar{\nu}_e)$-CC candidates, with an expected background of 33 (14).



Regions of parameter space that are consistent with the 2020 data. The best fit lies in the Normal Hierarchy, with $\Delta m^2_{32} = (2.41 \pm 0.07) \times 10^{-3}$ eV², $\sin^2\theta_{23} = 0.57^{+0.04}_{-0.03}$, $\delta = 0.82\pi$.

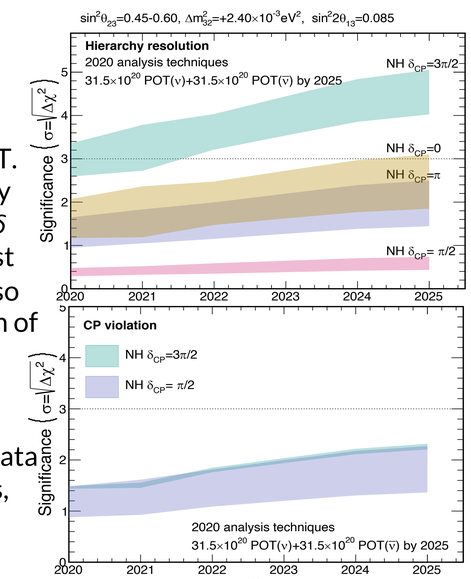
Below: the same results, compared to T2K (Nature 580) and other neutrino experiments.



The future

NOvA is expected to run until 2025, for a total exposure of 63 × 10^{20} POT. We can reach 3σ hierarchy sensitivity for 30-50% of δ values, and ~5σ in the most favorable case. We can also reach a ~2σ determination of CP violation.

Finally, quantifying consistency with T2K requires a joint fit of the data from the two experiments, which is already in the works.



See also: A. Sutton, "Neutrino energy reconstruction in NOvA" (poster); S .Calvez, "Latest results from the NOvA experiment" (talk).

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