NOvA Constraints on CP-violating Non-Standard Interactions

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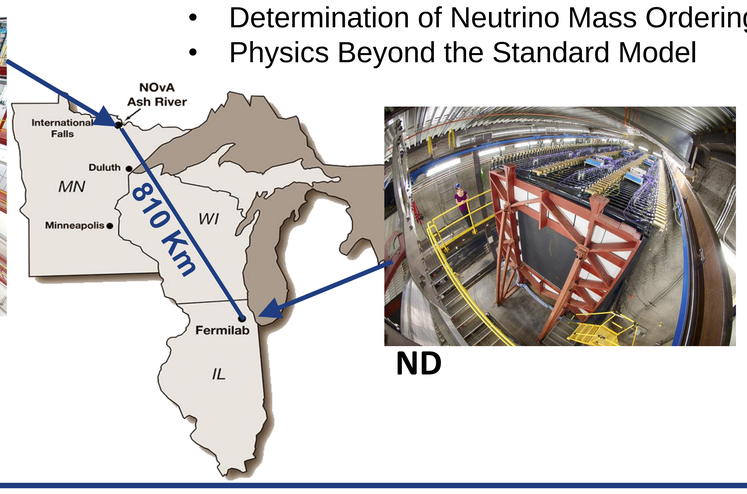
The NOvA Experiment

NOvA is a long-baseline neutrino oscillation experiment at Fermilab using the 700 kW NUMI muon neutrino beam.

Detectors:
- Far Detector (FD): 14 kton; on the surface
- Near Detector (ND): 0.3 kton; underground
- Detectors are liquid scintillators

Goals
- Study the ν_μ ($\overline{\nu_\mu}$) disappearance and ν_e ($\overline{\nu_e}$) appearance.
- Measurement of the oscillation parameters (Δm^2_{32}, θ_{23}, δ_{CP})
- Determination of Neutrino Mass Ordering
- Physics Beyond the Standard Model

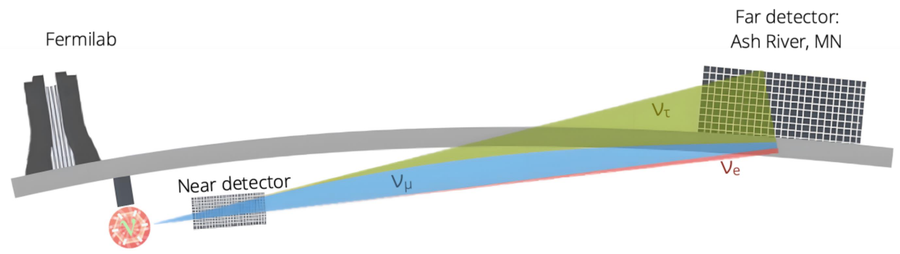
FD



ND

Neutrino Oscillations

As neutrinos propagate, they change flavor



Evolution in matter is governed by an *effective* Hamiltonian

$$H_E = \frac{1}{2E}(U\,\mathbb{M}^2\,U^\dagger + \mathbb{A})$$

$$\mathbb{M}^2 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & \Delta m^2_{21} & 0 \\ 0 & 0 & \Delta m^2_{31} \end{pmatrix} \qquad \mathbb{A} = \begin{pmatrix} A & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

$$A = 2EV_{CC} = 2\sqrt{2}EG_F N_e$$

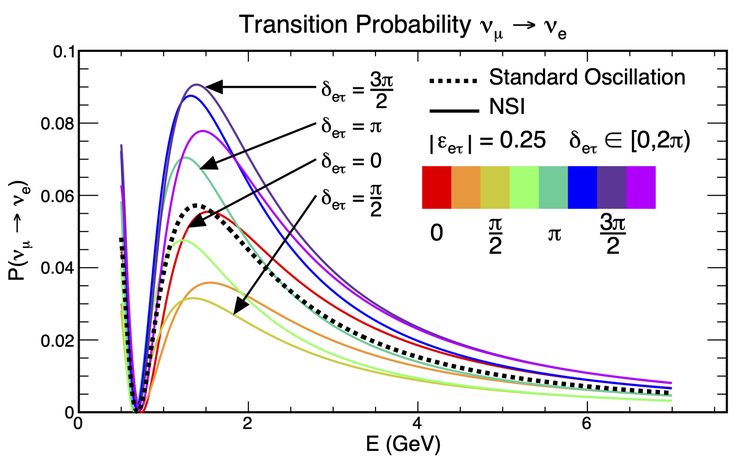
Density of electron cloud which can change based on position. Ultimately leads to resonances when oscillation frequency ~ MSW frequency

Neutrino Oscillations with Non-Standard Interaction (NSI)

NSI are a beyond standard model extension of the standard matter effect

$$\mathcal{H} = \left(\frac{1}{2E}\right)\left[U\begin{pmatrix} 0 & 0 & 0 \\ 0 & \Delta m^2_{21} & 0 \\ 0 & 0 & \Delta m^2_{31} \end{pmatrix}U^\dagger + A\begin{pmatrix} 1+\varepsilon_{ee} & \varepsilon_{e\mu} & \varepsilon_{e\tau} \\ (\varepsilon_{e\mu})^* & \varepsilon_{\mu\mu} & \varepsilon_{\mu\tau} \\ (\varepsilon_{e\tau})^* & (\varepsilon_{\mu\tau})^* & \varepsilon_{\tau\tau} \end{pmatrix}\right],$$

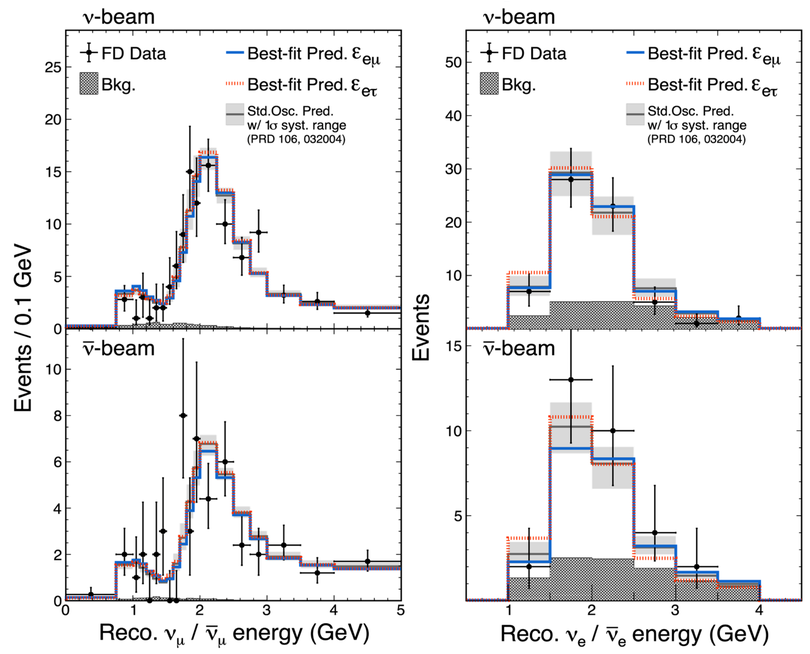
With $\varepsilon_{\alpha\beta} = |\varepsilon_{\alpha\beta}|e^{i\delta_{\alpha\beta}}$, where $\delta_{\alpha\beta}$ are a new CP-violating phases associated with each NSI amplitude.



Oscillation probability $P(\nu_\mu \to \nu_e)$ for neutrinos traveling 810 Km through the Earth. The standard oscillation prediction (black–dashed line) is compared with the NSI model with $|\varepsilon_{e\tau}| = 0.25$ and different values of its corresponding phase, $\delta_{e\tau}$. The sensitivity to δ_{CP} is weakened for both neutrino mass orderings, while the constraints on $\sin^2\theta_{23}$ are scarcely modified.

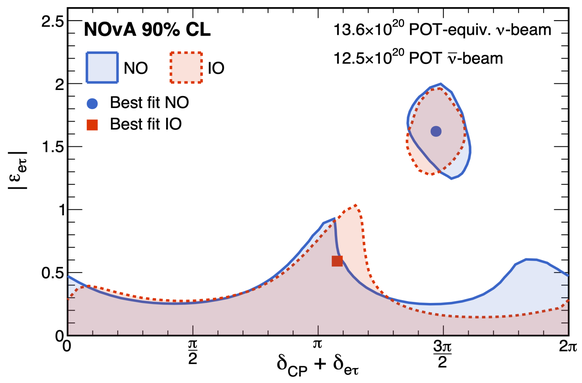
The standard three-flavor oscillation parameters are set to the best-fit values reported in [1].

Reconstructed Spectra

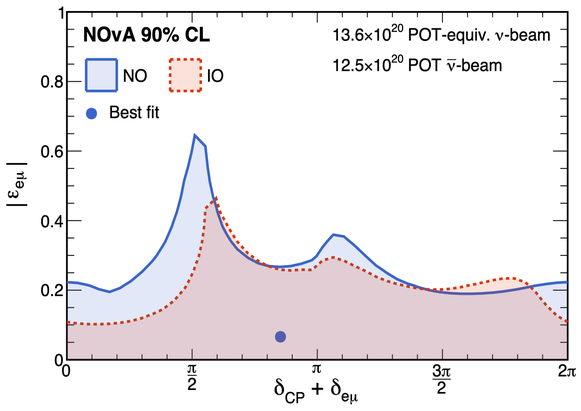


- The standard oscillation prediction (solid black histogram) and its corresponding 1σ systematic uncertainty range are compared with the best-fit predictions of this analysis for $\varepsilon_{e\mu}$ (solid blue line) and $\varepsilon_{e\tau}$ (dotted red line).
- The NSI parameters $\varepsilon_{e\mu}$ and $\varepsilon_{e\tau}$ only have a marginal impact in NOvA [2].

$\varepsilon_{e\tau}$ and $\varepsilon_{e\tau}$ Results

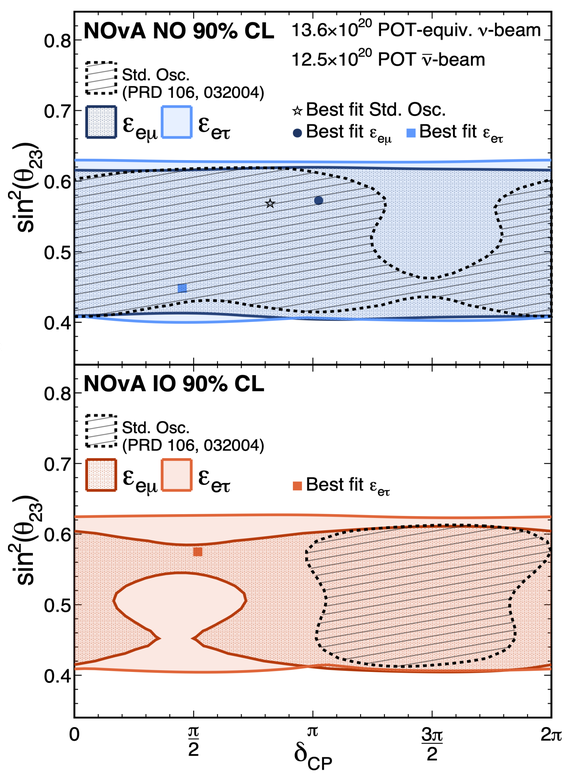


- $|\varepsilon_{e\tau}| < \sim 0.4$
- Upper region due to degeneracy



- $|\varepsilon_{e\mu}| < \sim 0.3$

Effect of NSI on SO Parameters



- The sensitivity to δ_{CP} is weakened for both neutrino mass orderings.
- The constraints on $\sin^2\theta_{23}$ are scarcely modified.

Conclusions

- NSI is not needed to explain NOvA spectra
- The analysis constrains the NSI amplitudes to $|\varepsilon_{e\tau}| < \sim 0.4$ and $|\varepsilon_{e\mu}| < \sim 0.3$
- Hight degeneracy for $|\varepsilon_{e\tau}|$
- Increased difficulty measuring δ_{CP} with non-zero NSI.

References

[1] Acero, M. A., Adamson, P., Aliaga, L., Anfimov, N., Antoshkin, A., Arrieta-Diaz, E., ... & Ryabov, V. (2022). Improved measurement of neutrino oscillation parameters by the NOvA experiment. *Physical Review D*, *106*(3), 032004.

[2] Acero, M. A., Acharya, B., Adamson, P., Aliaga, L., Anfimov, N., Antoshkin, A., ... & Falero, S. S. (2024). Search for CP-violating Neutrino Non-Standard Interactions with the NOvA Experiment. *arXiv preprint arXiv:2403.07266*.

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