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Constraining NSIs with NC events at LBL exper.

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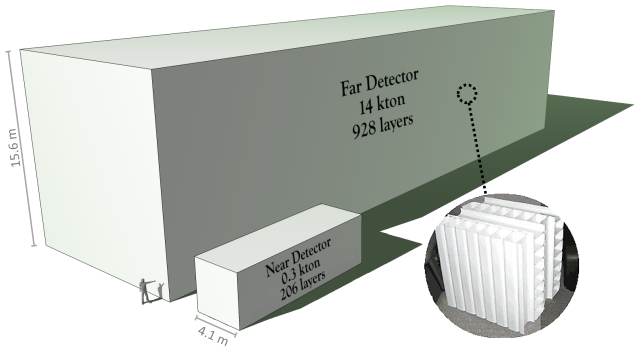
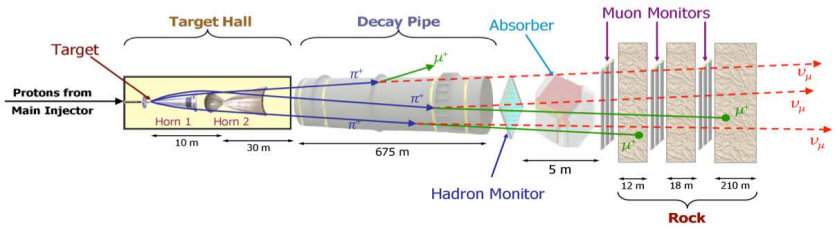
March 24, 2025

LBL

- LBL detect neutrinos over macroscopic distances; accelerator-based experiments use artificial neutrino beams.
- Main goal: observe ν_μ **dis** and ν_e **app** ;
- Near Detector (**ND**) normalizes flux/reduces systematics; Far Detector (**FD**) detects oscillations (ν_μ, ν_e CC) and monitors flux via NC events.
- **Charged Current (CC) Events:** $\nu N \to \ell N'$, producing a charged lepton;
- **Neutral Current (NC) Events:** $\nu N \to \nu N$, leaves no charged lepton;



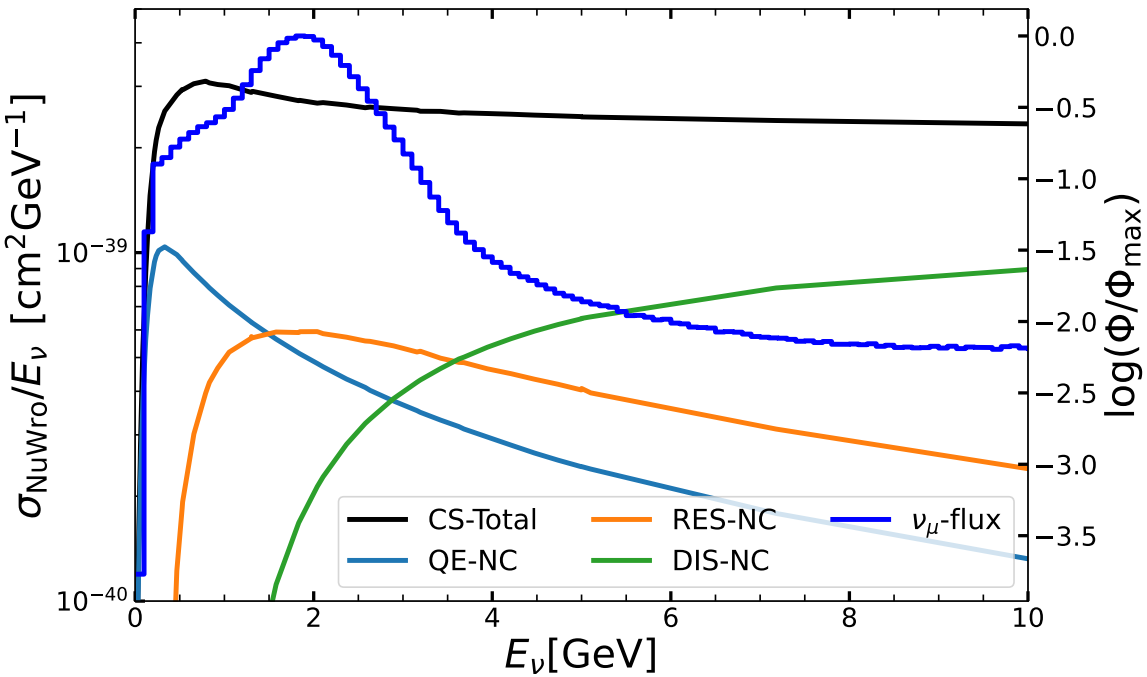
Near and Far detectors



Neutrino Beam Schematic

Neutral Current Neutrino-Nucleon Interactions: Cross Sections

- **Quasi-Elastic Scattering (QE):**
  - Low energy ($E_\nu < 3$ GeV).
  - Example: $\nu + N \to \nu + N$.
- **Resonant Scattering (RES):**
  - Intermediate energy (1 GeV $< E_\nu <$ 6 GeV).
  - Example: $\nu + N \to \nu + N^* \to \nu + N + \pi$.
- **Deep Inelastic Scattering (DIS):**
  - High energy ($E_\nu > 3$ GeV).
  - Example: $\nu + N \to \nu + X$, where X is a hadronic shower.



Non-Standard Interactions - Oscillation and Scattering Effects

The Lagrangian for neutral current non-standard interactions (NC-NSI) considered is:

$$\mathcal{L}_{\text{NSI,NC}} = -2\sqrt{2}\, G_F \sum_{f,P,\alpha,\beta} \epsilon^{f,P}_{\alpha\beta} (\bar{\nu}_\alpha \gamma^\mu P_L \nu_\beta)(\bar{f} \gamma_\mu P f) \,.$$

Oscillation and **Scattering**

NSI effects
Potential modifying the Hamiltonian.

↓

Easy to implement (propagation only)

↓

Effect is very small/Earth matter effects

Modifying scattering amplitudes during detection.

↓

High impact effect

↓

Difficult to implement/large systematics

Dealing with NSI cross section

J Gehrlein, P Machado, **J P Pinheiro** (arXiv:2412.08712)

Events with $Q^2 \to 1$ GeV^2: **Almost** Free Nucleons
(we are working on improving this part)

$$N_{\rm ev}^{\rm free} \propto \sum_{\alpha,\beta}^{e,\mu,\tau} \left(N_p \rho_{\alpha\beta} \sigma_p^{\alpha\beta} + N_n \rho_{\alpha\beta} \sigma_n^{\alpha\beta} \right)$$

Approx of NC events at detector:

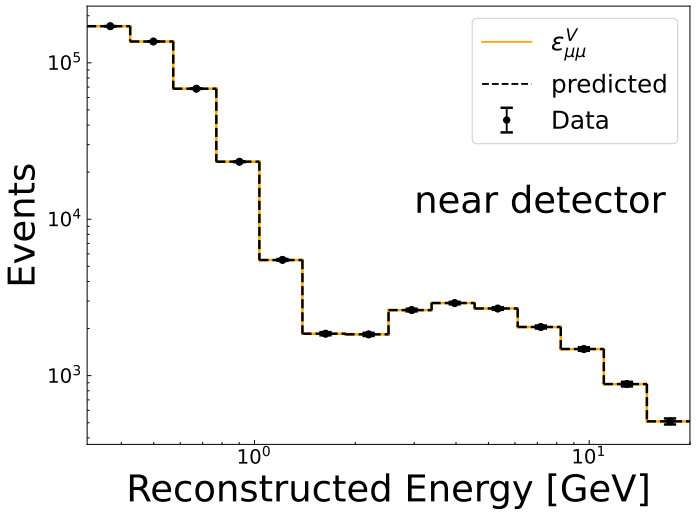
$$N_{\rm ev} \propto \frac{(N_{\rm ev}^{\rm free})_{\rm BSM}}{(N_{\rm ev}^{\rm free})_{\rm SM}} \sigma_{\rm NuWro},$$

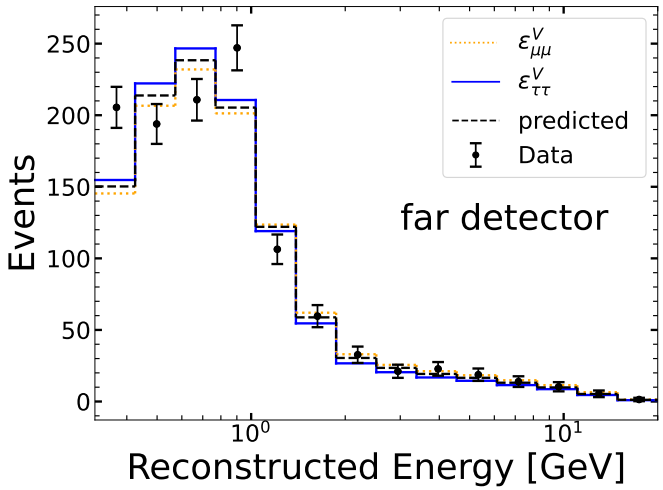
Interpretation:

- Reweighting by NSI prefactor adjusts predictions for NSI contributions.
- NSI can enhance or suppress cross sections, modifying event rates.
- Off-diagonal terms allow interference between flavors, altering the overall interaction probability.

NC Event Spectra at NOvA's Detectors

J Gehrlein, P Machado, **J P Pinheiro** (arXiv:2412.08712)





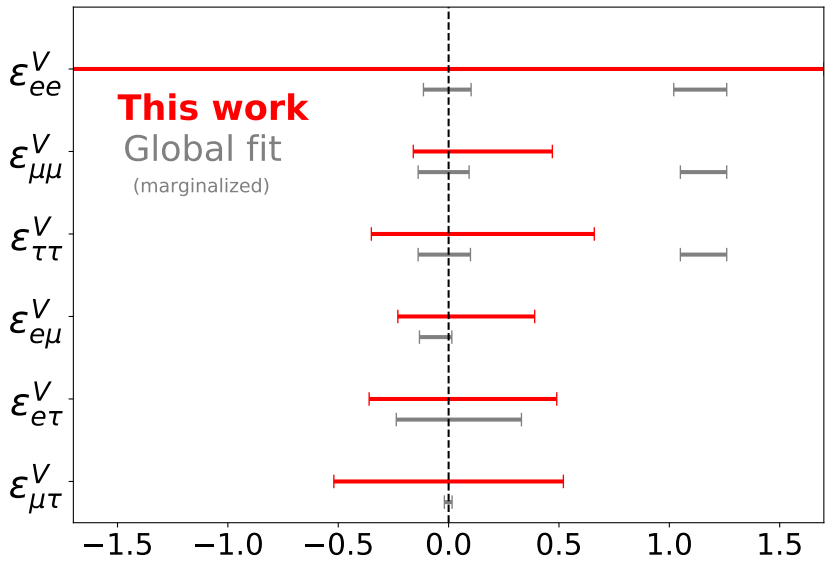
NOvA data with **statistical and systematic uncertainties** overlaid.

- ND spectrum **perfectly fits data**, due to bin-to-bin uncertainties correlated between ND and FD.
- FD spectrum shows deviations in the presence of NSI.

Constraints on NC NSI Parameters at NOvA

J Gehrlein, P Machado, **J P Pinheiro** (arXiv:2412.08712)

Vectorial NSIs results:



- NOvA data **excludes large NSI regions**, addressing the LMA-Dark degeneracy.

Constraints on NC NSI Parameters at NOvA

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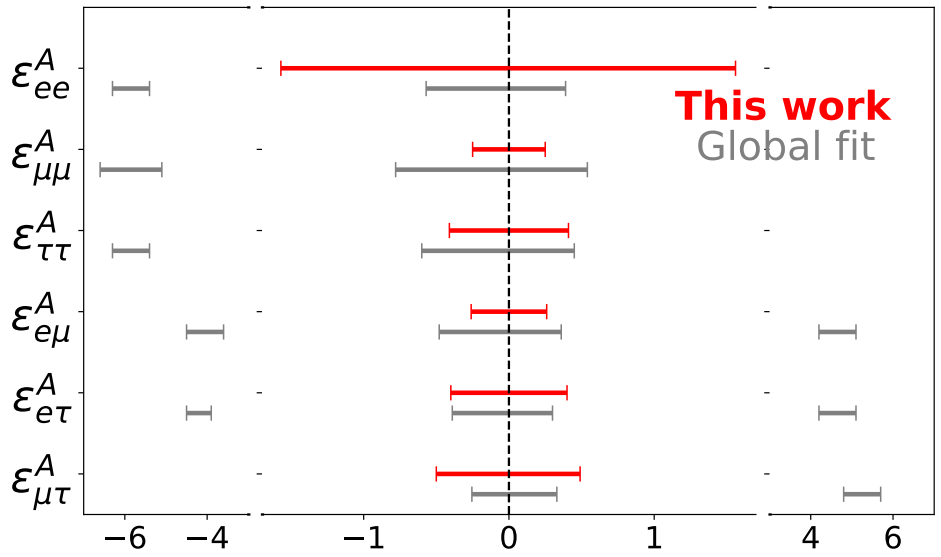
Axial NSIs results:



- NOvA improves constraints on:
$$\varepsilon^A_{\mu\mu},\ \varepsilon^A_{\tau\tau},\ \varepsilon^A_{e\mu}$$
- Helps break degeneracies for:
$$\varepsilon^A_{e\tau},\ \varepsilon^A_{\mu\tau}$$
- Improved sensitivity over axial NSIs.
- **Exclusive bounds for isospin-conserving NSIs**:
$$\varepsilon^A_u = \varepsilon^A_d$$