Probing BSM Oscillatory Signals with the DUNE Detectors and the LBNF Neutrino Beam: NSI and Sterile Neutrino Sensitivities

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DEEP UNDERGROUND NEUTRINO EXPERIMENT

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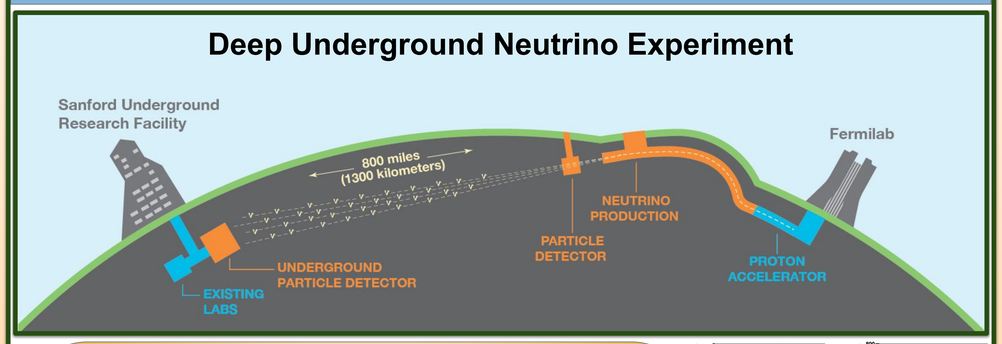
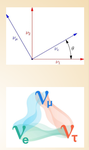
Neutrino Oscillations and DUNE

Deep Underground Neutrino Experiment

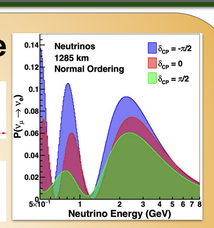


Neutrino states do oscillate

$$\begin{pmatrix} |\nu_e\rangle \\ |\nu_\mu\rangle \\ |\nu_\tau\rangle \end{pmatrix} \doteq \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu1} & U_{\mu2} & U_{\mu3} \\ U_{\tau1} & U_{\tau2} & U_{\tau3} \end{pmatrix} \begin{pmatrix} |\nu_1\rangle \\ |\nu_2\rangle \\ |\nu_3\rangle \end{pmatrix}$$

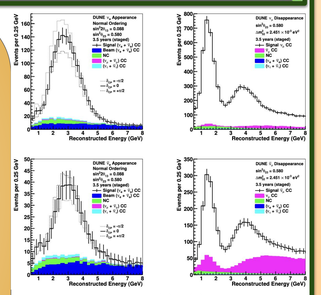


$$P_{\nu_\mu \to \nu_e} \simeq 4 \sin^2(\theta_{13}) \sin^2(\theta_{23}) \sin^2\left(\frac{\Delta m^2_{32} L}{4E}\right)$$



Important questions to be answered by DUNE

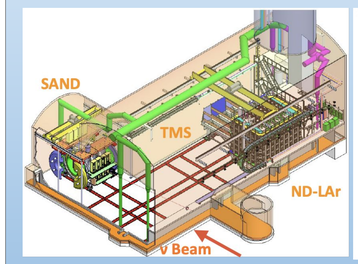
- Is there Charge-Parity violation in the lepton sector? $\delta_{CP} = ?$
- What is the neutrino mass ordering? is $m_3 > m_1$ (NO) or $m_1 > m_3$ (IO)?
- Is the 3-neutrino paradigm the whole picture? Is there a 4th neutrino?
- Can we observe more physics beyond the standard model?



DUNE simulated $\bar{\nu}_e$ / $\bar{\nu}_\mu$ (left/right) FD events from the LBNF neutrino (top) and antineutrino (bottom) beam modes.

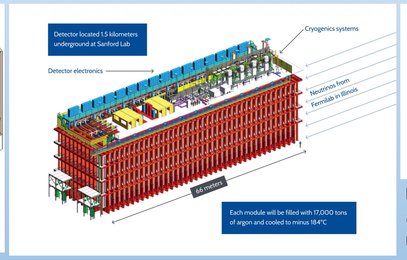
3rd generation, long-baseline Liquid Argon TPC neutrino detector

Near Detector

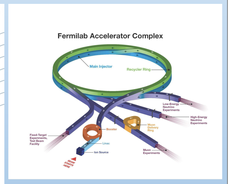


- ND-LAr 150 ton
- 574 m from beam production
- $\mathcal{O}(10^7)$ neutrinos per year
- Constrains the initial flux
- Rich non-oscillation physics

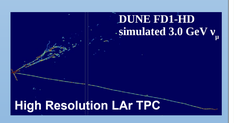
Far Detector



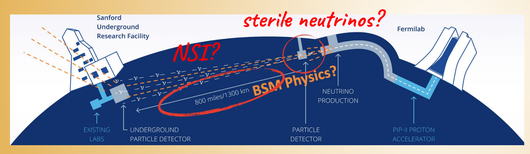
- 17 kton total mass per FD module
- 4 modules, 10 kton fiducial mass each
- 4,850 ft (1,500 m) underground
- 1,300 km from the ND
- Measures the oscillated spectra



Initial 1.2 MW Beam
$\mathcal{O}(10^{21})$ POT/year
Upgradeable to 2.4 MW



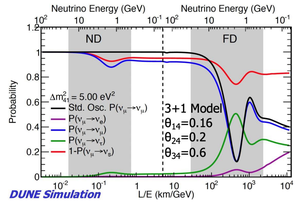
Uniquely positioned to test physics beyond the standard model

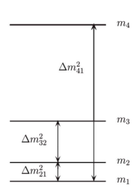


- ND close to beam source can probe anomalous short-baseline oscillations: existence of sterile neutrinos?
- Long baseline implies on extended exposure to matter effects: NSI?

Sterile Neutrinos

A 4th, non-weakly interacting and massive neutrino that mixes with the 3-Flavor neutrinos





Extension of the PMNS matrix

$$U = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} \\ U_{\mu1} & U_{\mu2} & U_{\mu3} & U_{\mu4} \\ U_{\tau1} & U_{\tau2} & U_{\tau3} & U_{\tau4} \\ U_{s1} & U_{s2} & U_{s3} & U_{s4} \end{pmatrix}$$

A massive new state that can produce anomalous ν_e and ν_τ appearance at the ND. Sensitive also through NC-disappearance.

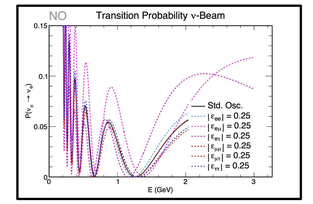
Non-Standard Interactions

Extension of the standard matter effect potential

$$\mathcal{H} = U\mathcal{H}_0 U^\dagger + \mathcal{H}_{\text{matter}} + \mathcal{H}_{\text{NSI}}$$

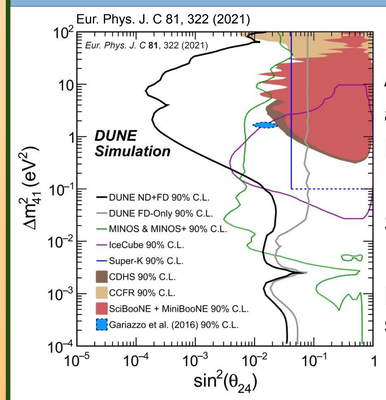
$$\mathcal{H}_{NSI} \doteq \pm\sqrt{2} G_F N_e \begin{pmatrix} \varepsilon_{ee} & \varepsilon_{e\mu} & \varepsilon_{e\tau} \\ \varepsilon_{\mu e} & \varepsilon_{\mu\mu} & \varepsilon_{\mu\tau} \\ \varepsilon_{\tau e} & \varepsilon_{\tau\mu} & \varepsilon_{\tau\tau} \end{pmatrix}$$

$$\varepsilon_{\alpha\beta} = |\varepsilon_{\alpha\beta}| e^{i\delta_{\alpha\beta}}$$



NSI may alter the oscillation probability pattern by inducing NC-like flavor changing. Potential impact on the PMNS parameters.

DUNE Steriles and NSI Sensitivities



Large Δm^2_{41}: ND dominated

Active-to-sterile oscillations at the ND.

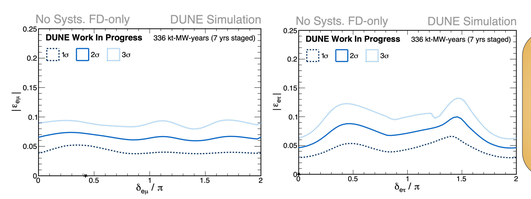
ND systematics are dominant.

Small Δm^2_{41}: FD dominated

FD statistics are dominant.

ND provides flux and systematic constraints.

Long 1,300 km baseline gives DUNE strong sensitivity to matter effects, and consequently to NSI.



Current 90% C.L. (NOvA)

Phys. Rev. Lett. 133, 201802

$|\varepsilon_{e\mu}| \lesssim 0.3$

$|\varepsilon_{e\tau}| \lesssim 0.4$

Robust constraints on NSI parameters affecting ν_e appearance at the FD. Work in progress sensitivities using current DUNE CAFAna software, pioneered by the Cincinnati group.

Conclusions and Next Steps

- ➢ DUNE is well equipped to perform world-class standard and non-standard neutrino oscillation physics.
- ➢ Present DUNE sterile neutrinos and NSI sensitivities only available through GLoBES.
- ➢ The Cincinnati group is pioneering the next round of sensitivities using full DUNE software.
  - NSI sensitivities work in progress; sterile neutrinos following up.
- ➢ Inclusion of systematic uncertainties and ND MC samples are expected next.

Fermilab Acknowledgements

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