Non-Standard Scenarios at DUNE

(DUNE-India Meeting, TIFR)

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Research Interests:

- Neutrino Physics
- Detector Simulation & Instrumentation
- Cosmic Rays & Extensive Air Showers
- ML algorithms for Reconstruction in HEP Experiments

Experimental Collaborations:

- Hyper-Kamiokande
- WCTE, IWCD
- GRAPES-3
- INO-ICAL

Current Grants:

- DST-SERB(ANRF) CRG/2021/002961
- DST-JSPS Indo Japan Collaborative grant 2021

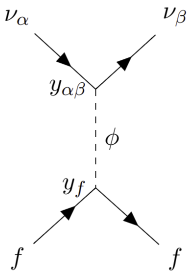
Arnab **Dharitree** **Priyankush**
Current Research Scholars
(NS physics effects in neutrinos, ML)

Abinash (Alumni)
(PhD Thesis on NSI in neutrinos, detector simulation)

Scalar Non-Standard Interaction

SNSI appears as medium-dependent correction to ν-mass matrix:

$$\mathcal{H}_{\mathrm{SNSI}} \approx \mathbf{E}_\nu + \frac{(\mathbf{M}+\delta\mathbf{M})(\mathbf{M}+\delta\mathbf{M})^\dagger}{\mathbf{2E}_\nu} \pm \mathbf{V}_{\mathrm{SI}} \qquad \delta\mathbf{M} = \sum_{\mathbf{f}} \frac{\mathbf{n_f y_f Y}_{\alpha\beta}}{\mathbf{m}_\phi^2} = \mathbf{S_m}\begin{pmatrix} \eta_{ee} & \eta_{e\mu} & \eta_{e\tau} \\ \eta_{e\mu}^* & \eta_{\mu\mu} & \eta_{\mu\tau} \\ \eta_{e\tau}^* & \eta_{\mu\tau}^* & \eta_{\tau\tau} \end{pmatrix}$$



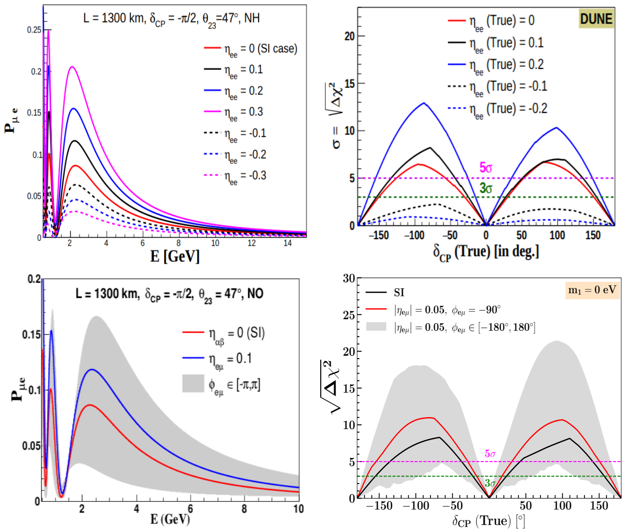
$$\begin{aligned} P_{\mu e}^{(\eta_{ee})} = \Bigg[& 2s_{13}\sin 2\theta_{12}\sin 2\theta_{23}\cos(\delta_{\mathrm{CP}}+\Delta)\frac{\sin[(A_e-1)\Delta]}{A_e-1}\frac{\sin[A_e\Delta]}{A_e}(\mathbf{m_2}-\mathbf{m_1}) \\ & + 2\alpha\, c_{23}^2\sin^2(2\theta_{12})\frac{\sin^2[A_e\Delta]}{A_e^2}(\mathbf{m_2}-\mathbf{m_1}) + 8s_{13}^2 s_{23}^2\frac{\sin[(A_e-1)\Delta]}{A_e-1}\Bigg(\frac{\sin[(A_e-1)\Delta]}{A_e-1}\,\mathbf{m_3} \\ & + \frac{1}{A_e-1}\left[2\Delta\cos[(A_e-1)\Delta]-(A_e+1)\frac{\sin[(A_e-1)\Delta]}{A_e-1}\right]\times\left(\mathbf{m_1c_{12}^2}+\mathbf{m_2s_{12}^2}\right)\Bigg)+\ldots\Bigg]\times\left(\frac{S_m}{\Delta m_{31}^2}\right)\eta_{ee}\,. \end{aligned}$$

- Probability has three different absolute mass-dependent terms:
  - **mass summation terms:** (m_1+m_2),$(m_1c_{12}^2+m_2s_{12}^2)$/ $(m_1s_{12}^2+m_2c_{12}^2)$
  - **mass difference term:** (m_2-m_1)
  - m_3 **term**

D. Bezboruah et al., JHEP 12 (2025) 222

CPV sensitivity at DUNE

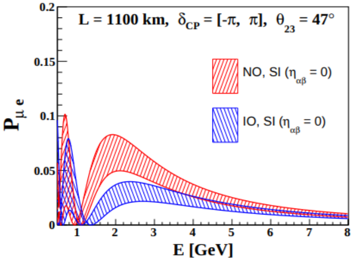
- Positive (negative) η_{ee} enhances (suppresses) oscillation probability.
- CP violation sensitivity mostly gotv enhanced (suppressed) in the presence of η_{ee}.
- Presence of off-diagonal $\eta_{e\mu}$, suppresses $P_{\mu e}$. $\phi_{e\mu}$ has significant impact.
- Enhancement in sensitivity if SNSI phase $\phi_{e\mu}$ is fixed at $-90°$.

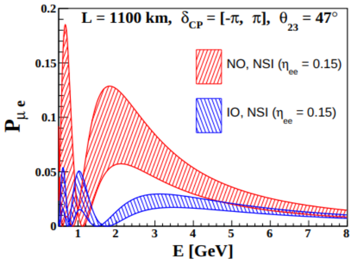


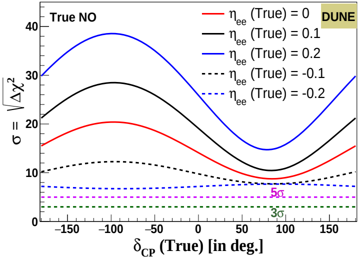
A. Medhi et al., JHEP 06 (2022) 129
A Medhi et al., JHEP 01 (2023) 079
A. Sarker et. al., arXiV:2406.15307

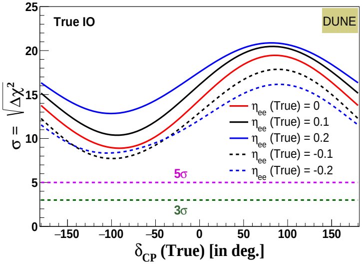
MO Sensitivity at DUNE

- DUNE baseline can distinguish NO and IO in the standard scenario.
- Presence of η_{ee} widens the separation.
- For true NO, positive (negative) η_{ee} enhance (suppress) MO sensitivities.







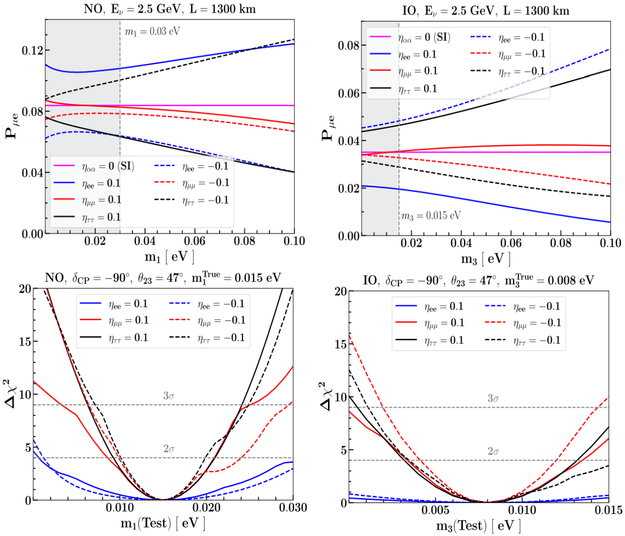


A. Sarker, et. al., JHEP 06 (2024) 128

Absolute Mass Dependence of SNSI

- With increase in the strength of SNSI parameter dependency on the neutrino masses becomes more prominent for both NO and IO.
- **NO:** m_l constrained at 3σ for positive and negative $\eta_{\mu\mu}$, $\eta_{\tau\tau}$; weak for η_{ee}.
- **IO:** Constraints at 2σ for for positive and negative $\eta_{\mu\mu}$, $\eta_{\tau\tau}$; η_{ee} weaker.

A. Medhi et al., EPJC 85 (2025) 380



Lorentz Invariance Violation

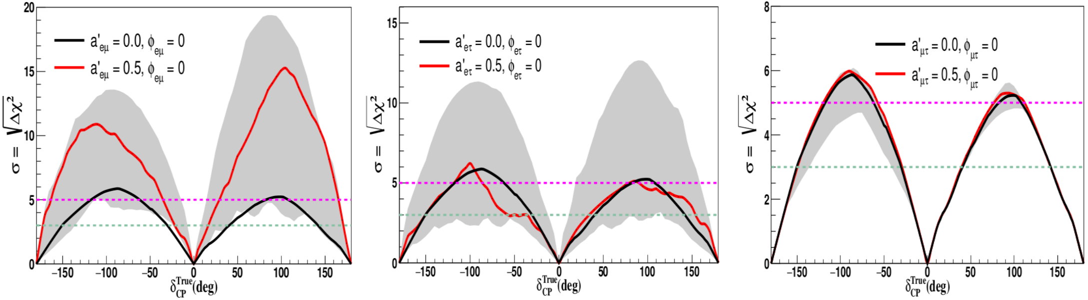
- LIV introduces new effects in neutrino oscillations, beyond the Standard Model.
- The effective Hamiltonian including Lorentz Invariance Violation (LIV) contributions is given by:

$$
\boxed{
\begin{aligned}
H_{\text{eff}} &= H_{\text{vacuum}} + H_{\text{matter}} + H_{\text{LIV}} \\
&= \frac{1}{2E} U \begin{pmatrix} 0 & 0 & 0 \\ 0 & \Delta m_{21}^2 & 0 \\ 0 & 0 & \Delta m_{31}^2 \end{pmatrix} U^\dagger + V_{CC} \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \\
&+ \begin{pmatrix} a_{ee} & a_{e\mu} & a_{e\tau} \\ a_{e\mu}^* & a_{\mu\mu} & a_{\mu\tau} \\ a_{e\tau}^* & a_{\mu\tau}^* & a_{\tau\tau} \end{pmatrix} - \frac{4}{3} E \begin{pmatrix} c_{ee} & c_{e\mu} & c_{e\tau} \\ c_{e\mu}^* & c_{\mu\mu} & c_{\mu\tau} \\ c_{e\tau}^* & c_{\mu\tau}^* & c_{\tau\tau} \end{pmatrix}
\end{aligned}
}
$$

where:

- $a_{\alpha\beta}$ ($\equiv |a_{\alpha\beta}| e^{i\phi_{\alpha\beta}}$) are the CPT-violating LIV terms.
- $c_{\alpha\beta}$ ($\equiv |c_{\alpha\beta}| e^{i\phi_{\alpha\beta}}$) are the CPT-conserving LIV terms.

CPV Sensitivity in Presence of LIV



- Presence of $a_{e\mu}$ shows an improvement in the sensitivity for the entire δ_{CP} range. Significant impact of $\phi_{e\mu}$.
- For $a_{e\tau}$, $a_{\mu\tau}$; the effect on sensitivity is nominal when $\phi_{\alpha\beta} = 0°$.

A. Sarker, et. al., EPJC 83 (2023) 592

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Possible Future Contribution to DUNE

- Further exploration of new physics effects
- Detector simulation (GEANT4) & instrumentation
- Data Analysis, ML for reconstruction and physics studies

Publications related to DUNE

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Thank you for the kind attention!