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Distinguishing Non-Standard Interaction and Lorentz Invariance Violation at P2SO experiment

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Introduction

- Non-standard interactions (NSIs) of neutrinos with matter can affect the neutrino oscillation.
- NSI can be through charge-current as well as through neutral-current processes.
- We have considered only neutral-current NSI present during propagation of neutrinos in earth matter.
- Lorentz Invariance is one of the fundamental symmetries of QFT related to space and time, and it could be possible to observe its violation in the low energy theories.
- Also lorentz invariance violation (LIV) could lead to CPT violation nature.
- Impacts of LIV parameters can be studied through long-baseline experiments.

Objectives

There is a fundamental difference in the origin of LIV and NSI i.e., NSI is an exotically matter dependent property while LIV doesn't depend on matter.

NSI and LIV affect the neutrino propagation Hamiltonian in a very similar way. Discrimination between the effects of NSI and LIV is important for neutrino oscillation studies.
One can distinguish NSI and LIV based on:

A. Variation of matter density over various baseline lengths.

B. Present and future bounds of the NSI and LIV parameters at long-baseline experiments.

- In this work, we have attempted to distinguish between the two scenarios at Deep Underground Neutrino Experiment (DUNE) and Protvino to Super-ORCA (P2SO) experiments.

Simulation Details

- We have used GLoBES [3, 4] software package for simulation.
- For simulation of P2SO experiment, we refer Ref.[5] and for DUNE, we use the configuration as mentioned in the technical design report [6].
- Values of neutrino oscillation parameters used as mentioned in NuFIT 5.1 (2021).

Conclusion

A. DUNE and P2SO experiments are capable of distinguishing the effects of LIV from NSI parameters.

B. At probability and sensitivity levels, the discrimination improved by considering future bounds of NSI parameters compared to present bounds.

C. Best sensitivity of discrimination obtained for $\mu\mu$ sector and worst sensitivity for ee and $\tau\tau$ sector.

Theoretical Background

The effective Hamiltonian for neutrino in the presence of neutral current NSI [1] is

$$H_{NSI} = \sqrt{2}G_F N_e \begin{pmatrix} \epsilon_{ee} & \epsilon_{e\mu} & \epsilon_{e\tau} \\ \epsilon^*_{e\mu} & \epsilon_{\mu\mu} & \epsilon_{\mu\tau} \\ \epsilon^*_{e\tau} & \epsilon^*_{\mu\tau} & \epsilon_{\tau\tau} \end{pmatrix}, \quad (1)$$

where $\epsilon_{\alpha\beta}$ are the effective NSI parameters, representing the strength of NSIs.

Considering only CPT violating LIV parameters, the contribution of LIV effects to the effective Hamiltonian [2] of neutrino is

$$H_{LIV} = \begin{pmatrix} a_{ee} & a_{e\mu} & a_{e\tau} \\ a^*_{e\mu} & a_{\mu\mu} & a_{\mu\tau} \\ a^*_{e\tau} & a^*_{\mu\tau} & a_{\tau\tau} \end{pmatrix}, \quad (2)$$

where $a_{\alpha\beta}$ are the effective LIV parameters.
From Eqns. (1) and (2), one can correlate NSI parameters with LIV parameters as

$$a_{\alpha\beta} = \sqrt{2}G_F N_e \epsilon_{\alpha\beta} = 3.75 \frac{\rho \times 10^{-23}}{(\text{g/cm}^3)} \epsilon_{\alpha\beta} \text{ GeV}, \quad (3)$$

where ρ is the matter density. The matter density ρ is nearly same for long-baseline experiments, indicates that NSI and LIV are identical.

★ The bounds on NSI and LIV parameters are not equivalent and do not follow the Eqn. 3. Hence, there is a possibility of discriminating between NSI and LIV.

Discrimination at Probability Levels

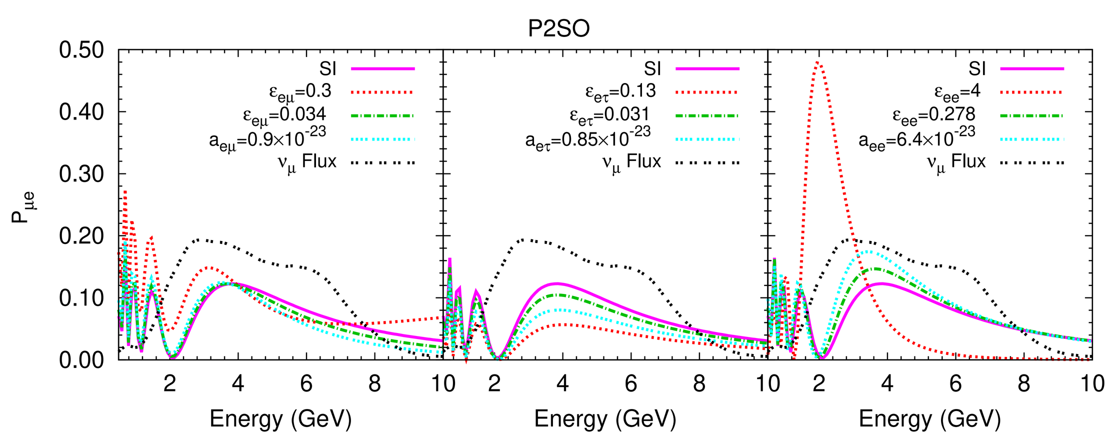

Figure 1: Appearance probability as a function of Neutrino Energy for P2SO experiment in presence of NSI and LIV parameters.

- Cyan curve is always sandwiched between the magenta and red curves but it is mostly outside the region between the magenta and green curves.
- The difference between SI and NSI is higher (lower) as compared to the difference between SI and LIV for present (future) bound of the NSI parameters.
- Distinction between NSI and LIV would be higher for future bounds of NSI parameters compared to their current bounds.

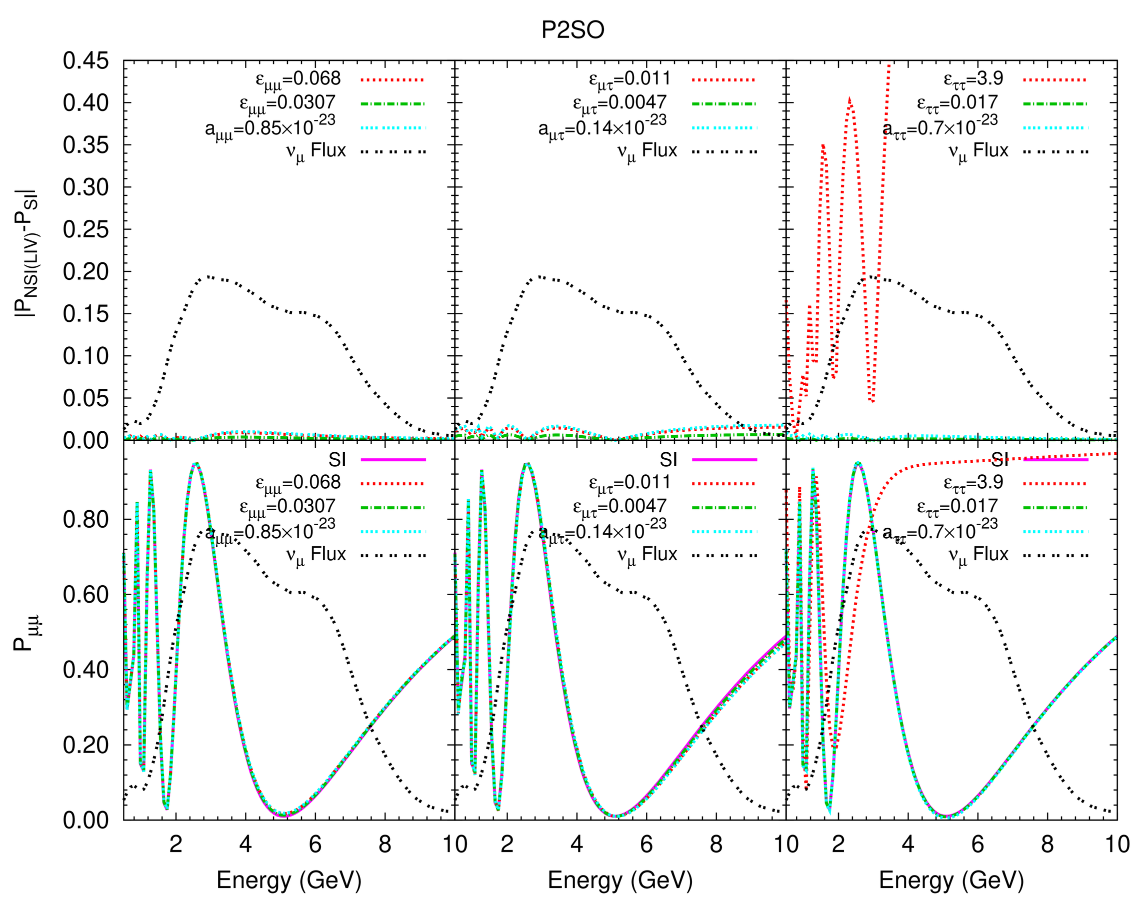

Figure 2: Survival probability as a function of Neutrino Energy for P2SO experiment in presence of NSI and LIV parameters.

■ Similar to appearance channel, we expect to have better separation between LIV and NSI for future bounds of NSI compared to their current bounds in disappearance channel.

Elimination of Degeneracies

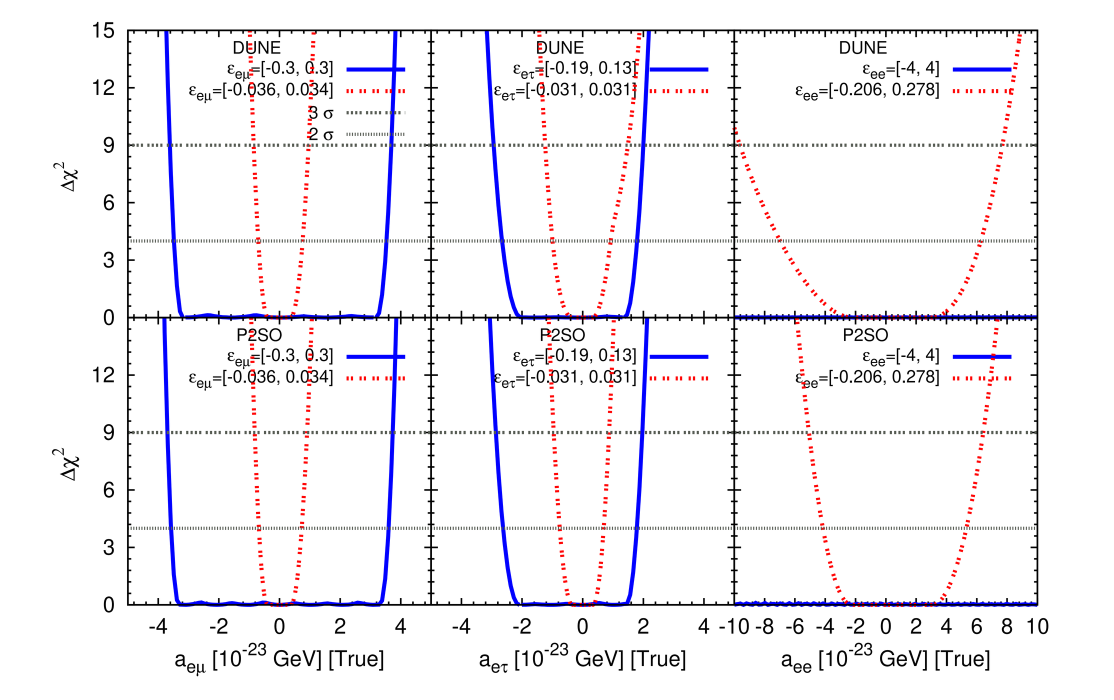

Figure 3: Sensitivity as a function of true LIV parameters $a_{e\mu}$, $a_{e\tau}$ and a_{ee} for P2SO and DUNE experiments.

- We have calculated $\chi^2_{\min}$ considering LIV exists in nature and NSI as the test hypothesis, i.e.,

$$\chi^2 \sim N^{\text{test}}(\epsilon^{\text{test}}_{\alpha\beta} \neq 0, a^{\text{test}}_{\alpha\beta} = 0) - N^{\text{true}}(\epsilon^{\text{true}}_{\alpha\beta} = 0, a^{\text{true}}_{\alpha\beta} \neq 0).$$

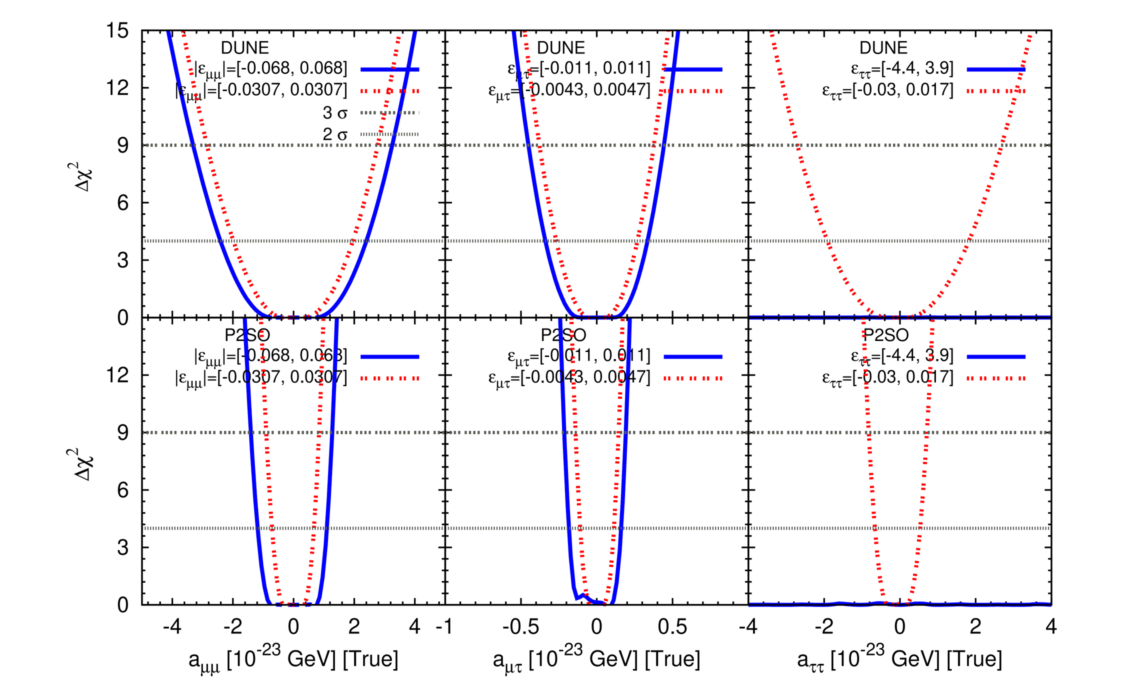

Figure 4: Sensitivity as a function of true LIV parameters $a_{\mu\mu}$, $a_{\mu\tau}$ and $a_{\tau\tau}$ for P2SO and DUNE experiments.

★ Best discrimination between LIV and NSI is possible for the $\mu\mu$ sector and worst sensitivity for ee and $\tau\tau$ sectors.

★ For $a_{e\mu}$, $a_{e\tau}$ and $a_{\mu\tau}$ sectors, discrimination occurs for present bounds of LIV parameters but outside their future bounds.

References

[1] Y. Farzan and M. Tortola. Neutrino oscillations and Non-Standard Interactions. *Front. in Phys.*, 6:10, 2018.

[2] V. Alan Kostelecky and Matthew Mewes. Lorentz and CPT violation in neutrinos. *Phys. Rev. D*, 69:016005, 2004.

[3] P. Huber et al. Simulation of long-baseline neutrino oscillation experiments with GLoBES. *Comput. Phys. Commun.*, 167:195, 2005.

[4] P. Huber et al. New features in the simulation of neutrino oscillation experiments with GLoBES 3.0. . *Phys. Commun.*, 177:432–438, 2007.

[5] Dinesh Kumar Singha et al. Study of light sterile neutrino at the long-baseline experiment at KM3NeT. *Phys. Rev. D*, 107(7):075039, 2023.

[6] B. Abi et al. Experiment Simulation Configurations Approximating DUNE TDR. 3 2021.