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Investigation of scalar Non-Standard Interactions at P2SO and DUNE

Dinesh Kumar Singha[1], Rudra Majhi[1], Lipsarani Panda[2], Monojit Ghosh[3], and Rukmani Mohanta[1]
University of Hyderabad, India[1] , National Institute of Science Education and Research, India[2] and Ruder Bošković Institute, Croatia[3]
dinesh.sin.187@gmail.com

1 Introduction

- Neutrino oscillation experiments provide us a unique platform to explore new physics beyond the Standard Model.
- One such new physics scenarios can be the non-standard interactions (NSIs) of neutrinos with earth matter. In this context vector mediated NSI is more popular in literature.
- Generally, vector mediated NSI appears in Hamiltonian as a matter potential term.
- However, NSIs can be mediated by scalar fields (SNSI) also via Yukawa interactions.
- Hence, SNSI parameters modify the neutrino masses.
- As the NSIs are matter dependent $\longrightarrow$ we have studied their effects in two neutrino oscillation experiments with high baselines (P2SO and DUNE).

2 Theoretical Background

The effective Lagrangian for SNSI can be written as

$$\mathcal{L}_{\rm eff} = \frac{y_f y_{\alpha\beta}}{m_\phi^2}(\bar{\nu}_\alpha \nu_\beta)(f\bar{f}), \quad (1)$$

where m_ϕ is the mediator scalar mass, and y's are the Yukawa couplings.
The Dirac equation in the presence of SNSI can be expressed as

$$\bar{\nu}_\beta\left[i\partial_\mu\gamma^\mu + \left(M_{\beta\alpha} + \frac{\sum_f N_f y_f y_{\alpha\beta}}{m_\phi^2}\right)\right]\nu_\alpha = 0, \quad (2)$$

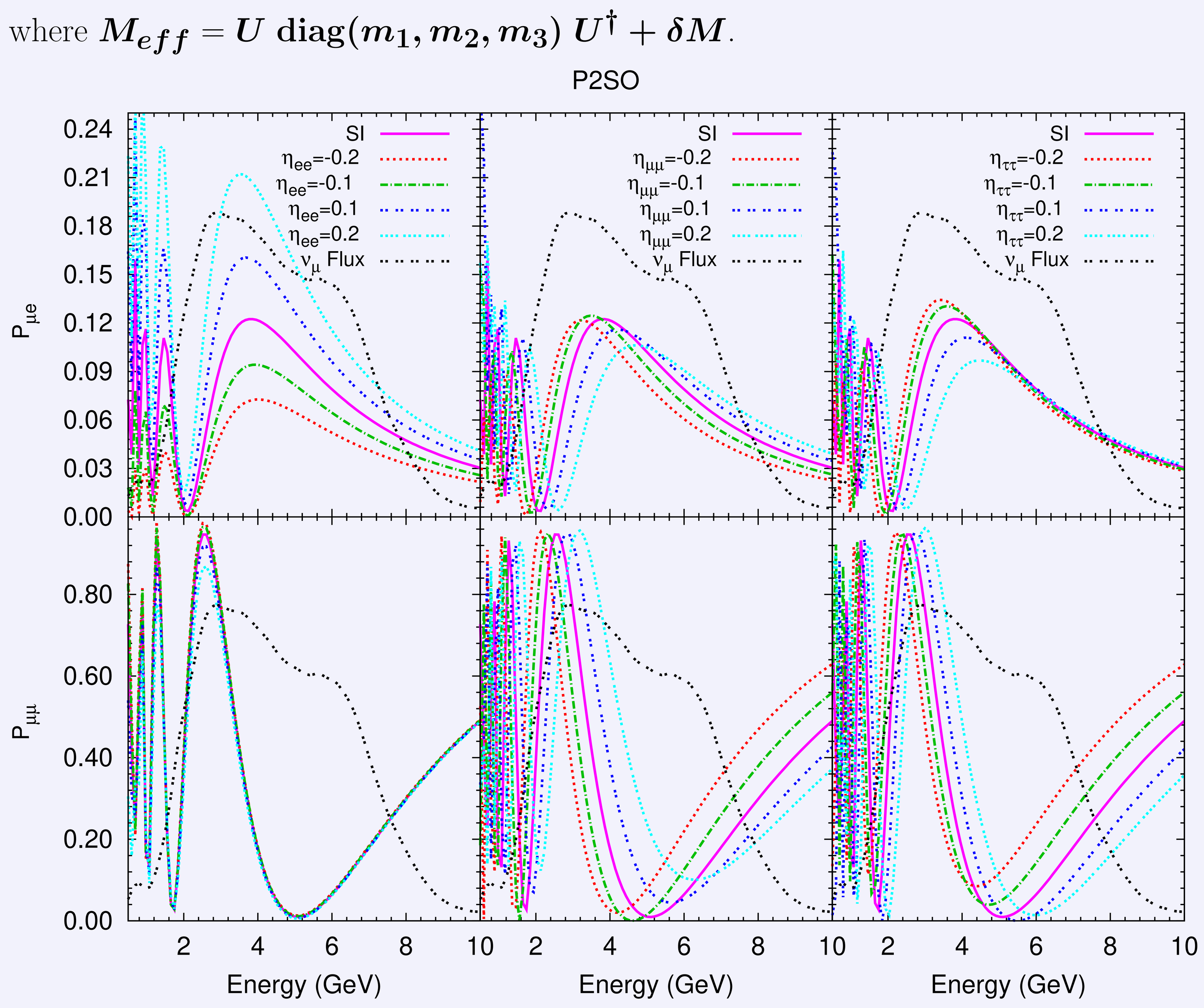
here $M_{\beta\alpha}$ is the neutrino mass matrix and N_f is the number density of the fermion in the earth.
The contribution of SNSI can be parameterized by the matrix

$$\delta M = \sqrt{|\Delta m^2_{31}|}\begin{pmatrix} \eta_{ee} & \eta_{e\mu} & \eta_{e\tau} \\ \eta_{\mu e} & \eta_{\mu\mu} & \eta_{\mu\tau} \\ \eta_{\tau e} & \eta_{\tau\mu} & \eta_{\tau\tau} \end{pmatrix} \quad (3)$$

Here, $\sqrt{|\Delta m^2_{31}|}$ is just a scaling factor and η's are the dimensionless interaction strengths. For our study, we have just focused on the diagonal SNSI parameters η_{ee}, $\eta_{\mu\mu}$ and $\eta_{\tau\tau}$. The Hamiltonian in flavor basis can be written as

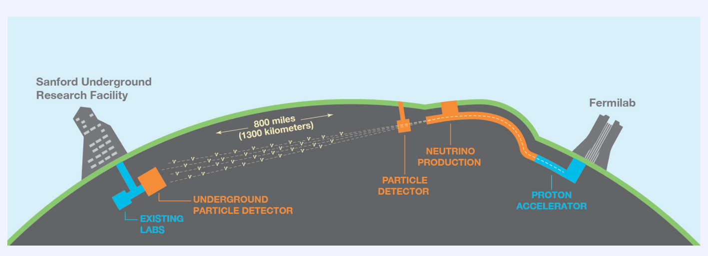
$$H = E_\nu + \frac{M_{eff}M_{eff}^\dagger}{2E_\nu} + V, \quad (4)$$

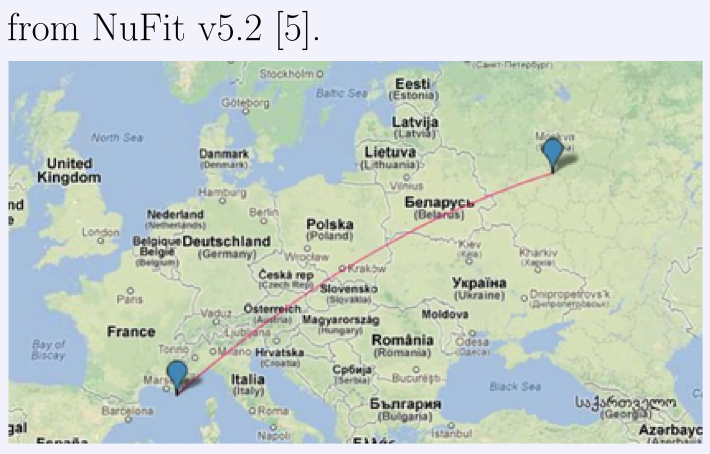
where $M_{eff} = U\ \mathrm{diag}(m_1, m_2, m_3)\ U^\dagger + \delta M$.



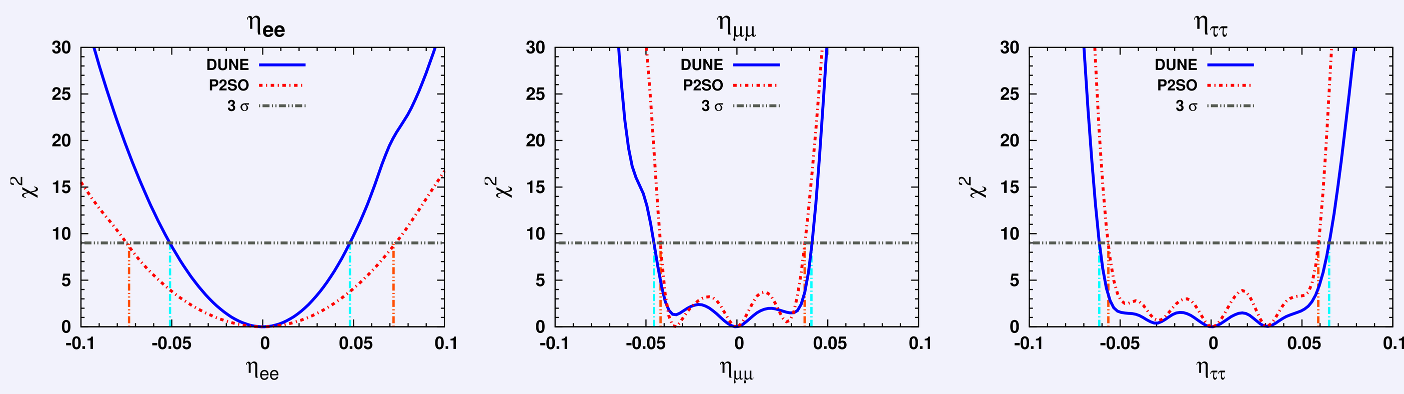
3 Experimental Details

- We have used General Long Baseline Neutrino Experiments (GLoBES) [1,2] software and additional plugins to simulate the experiments Protvino to Super-ORCA (P2SO) and Deep Underground Neutrino Experiment (DUNE) and to incorporate SNSI.
- *P2SO configuration* $(3\nu + 3\bar{\nu})$ [3]:
  - Beam power of 450 KW corresponding to POT = 4×10^{20} per year.
  - Super-ORCA is an upgraded water Cerenkov detector with 10 times more denser detector geometry compared to ORCA.
- *DUNE* $(6.5\nu + 6.5\bar{\nu})$ [4]: Beam power of 1.2 MW corresponding to POT = 1.1×10^{21} per year with a liquid argon time projection type detector.
- Values of oscillation parameters are taken from NuFit v5.2 [5].





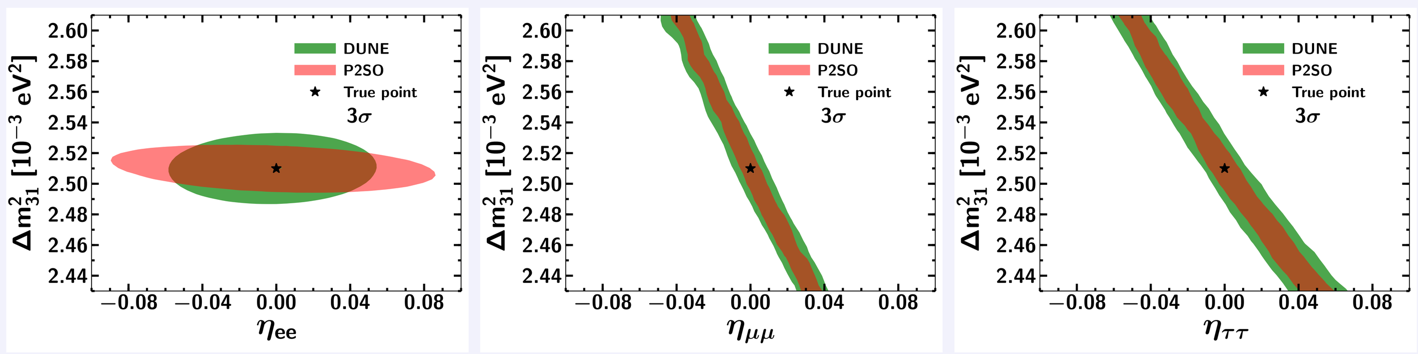
4 Bounds on SNSI parameters



- The above plots show the bound on SNSI parameters η_{ee}, $\eta_{\mu\mu}$ and $\eta_{\tau\tau}$ at P2SO and DUNE experiments at 3σ C.L.

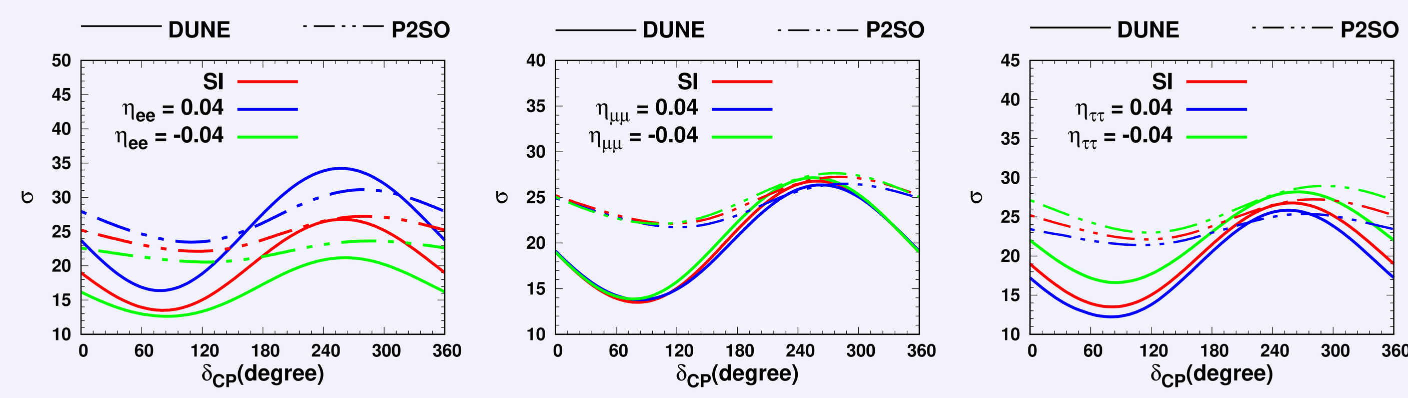
★ P2SO provides stringent bounds on SNSI parameters compared to DUNE experiment except η_{ee}.

5 Allowed region plots



- These plots show the allowed region in $\eta_{\alpha\beta}$ (test) - Δm^2_{31} (test) plane at 3 σ C.L.
- The sensitivity of the experiments to measure Δm^2_{31} depletes in the presence of $\eta_{\mu\mu}$ and $\eta_{\tau\tau}$.

6 Effect on Mass Hierarchy



- The parameter η_{ee} has significant effect on mass hierarchy sensitivity compared to the other SNSI parameters.
- The effect of positive and negative value of η parameters are quite opposite for ee and $\tau\tau$ case.
- Hierarchy sensitivity is not much affected by $\eta_{\mu\mu}$.
- P2SO is more sensitive to mass hierarchy compared to DUNE because of more matter interactions.

7 Conclusion

- Both P2SO and DUNE are sensitive to scalar non-standard interactions.
- Appearance channel is sensitive to η_{ee}, whereas both appearance and disappearance channel are sensitive to $\eta_{\mu\mu}$ and $\eta_{\tau\tau}$.
- Probability for the positive (negative) value of η_{ee} is higher (lower) compared to the standard case. This effect is opposite for $\eta_{\mu\mu}$ and $\eta_{\tau\tau}$.
- Stringent bounds on SNSI parameters can be obtained from DUNE and P2SO.
- The parameters $\eta_{\mu\mu}$ and $\eta_{\tau\tau}$ worsen the measurement of Δm^2_{31}.
- Effect on mass hierarchy is more (less) from η_{ee} ($\eta_{\mu\mu}$) sector.
- In general sensitivity of P2SO experiment is better than DUNE with the exception of η_{ee}.

Acknowledgement

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