Scalar-NSI: An unique tool to probe New Physics

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October 16, 2024

Contents

Introduction

- Wolfenstein introduced non-standard interactions (NSI), opening up the possibility of probing New Physics using neutrino oscillation.
- NSI are assumed to be mediated by vector and axial-vector interactions mediated by W and Z bosons.
- In recent studies a new kind of scalar particle is introduced to mediate the interactions.
  Thus, we have two types of NSI namely vector NSI and scalar NSI.
- Vector NSI modifies the potential where as the scalar NSI (SNSI) appears as a correction to the mass term.
  Thus, the Hamiltons can be expressed as:

$$H_{mat}^{V} \sim E_\nu + \frac{MM^\dagger}{2E_\nu} + (V_{SI} + V_{NSI})$$

$$H_{mat}^{S} \sim E_\nu + \frac{M_{eff}M_{eff}^\dagger}{2E} + V_{SI}$$

where $M_{eff} = M + M_{SNSI}$

- The effective Lagrangian in the presence of SNSI:

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

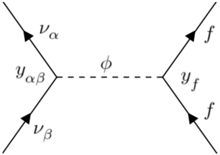


Figure: Feynmann diagram contributing to SNSI.

where

- α, β refer to the neutrino flavors.
- $f =$ e, u, d indicate the matter fermions.
- $y_{\alpha\beta}$ is the Yukawa couplings of the neutrinos with the scalar mediator ϕ.
- y_f is the Yukawa coupling of ϕ with f.

- The effect of scalar NSI appears as an addition to the neutrino mass term.
- The corresponding Dirac equation, taking into account the effect of SNSI:

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

With

$$\delta M = \frac{\sum N_f y_f y_{\alpha\beta}}{m_\phi^2}$$

- The effect of SNSI appears as a correction term:

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

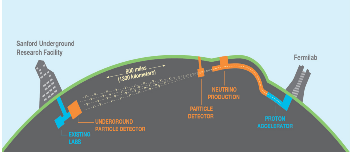
- We will focus on the off-diagonal complex SNSI parameters($\eta_{e\mu}$, $\eta_{e\tau}$ and $\eta_{\mu\tau}$) in this work.

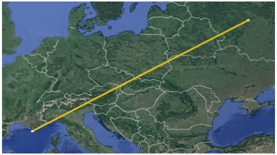
Simulation details

Simulation details:

- DUNE: (Deep Underground Neutrino Experiment)
  - Baseline- 1300 km
  - Beam Power- 1.2 MW $\rightarrow$ 1.1 $\times\ 10^{21}$ POT
  - Run time - 6.5ν + 6.5$\overline{\nu}$
  - $\rho = 2.848\ g/cm^3$

* B. Abi et al. (DUNE), (2021), arXiv:2103.04797 [hep-ex]





- P2SO: (Protvino to Super-ORCA)
  - Baseline- 2595 km
  - Beam Power- 420 KW $\rightarrow$ 4 $\times\ 10^{20}$ POT
  - Run time - 3ν + 3$\overline{\nu}$
  - $\rho = 2.95\ g/cm^3$

*A. V. Akindinov et al., Eur. Phys. J. C 79, 758 (2019).

- We have estimated the sensitivity in terms of χ^2 analysis. We use the Poisson log-likelihood:

$$\chi^2 \sim \frac{\left[N^{\text{true}}(\eta_{\alpha\beta}^{\text{true}}=0) - N^{\text{test}}(\eta_{\alpha\beta}^{\text{test}} \neq 0)\right]^2}{N^{\text{true}}(\eta_{\alpha\beta}^{\text{true}}=0)}.$$

- The true values for our analysis, obtained from NuFIT results.

Parameters	Bestfit value $\pm 1\sigma$	3σ
$sin^2\theta_{12}$	$0.303^{+0.012}_{-0.012}$	0.270 $\rightarrow$ 0.341
$sin^2\theta_{13}$	$0.02225^{+0.00056}_{-0.00059}$	0.02052 $\rightarrow$ 0.02398
$sin^2\theta_{23}$	$0.451^{+0.019}_{-0.016}$	0.408 $\rightarrow$ 0.603
δ_{CP}	$232^{+0.36}_{-0.26}$	144 $\rightarrow$ 350
$\Delta m^2_{21}/10^{-5}eV^2$	$7.41^{+0.21}_{-0.20}$	6.82 $\rightarrow$ 8.03
$\Delta m^2_{31}/10^{-3}eV^2$	$+2.507^{+0.026}_{-0.027}$	+2.427 $\rightarrow$ +2.590

Table: Oscillation parameters from NuFIT 5.2 considering Normal Ordering.

(*JHEP 09, 178(2020), arXiv:2007.14792 [hep-ph])

Results

Bounds on the SNSI parameters:

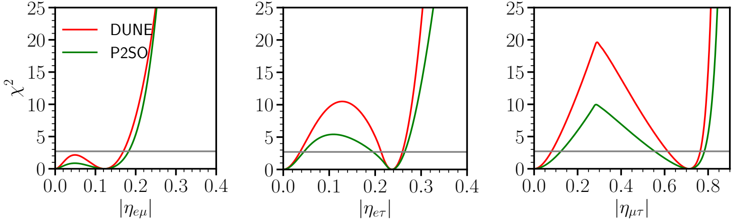
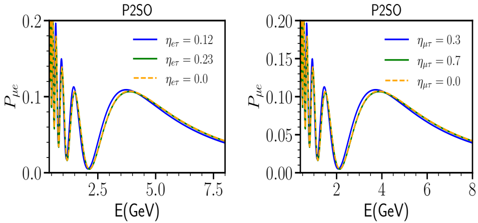


Figure: Sensitivity on the SNSI off-diagonal parameters for P2SO(green) and DUNE(red).



Mass Hierarchy Sensitivity:

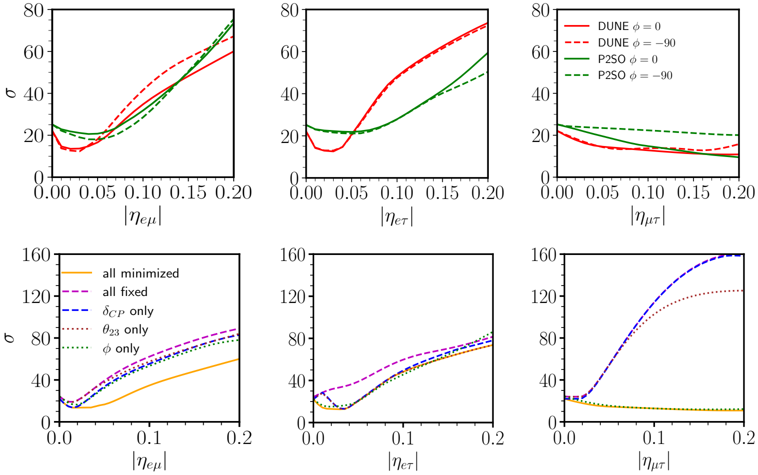


Figure: MH Sensitivity as a function of $\eta_{\alpha\beta}$ for different value of true Phases.

CPV sensitivity:

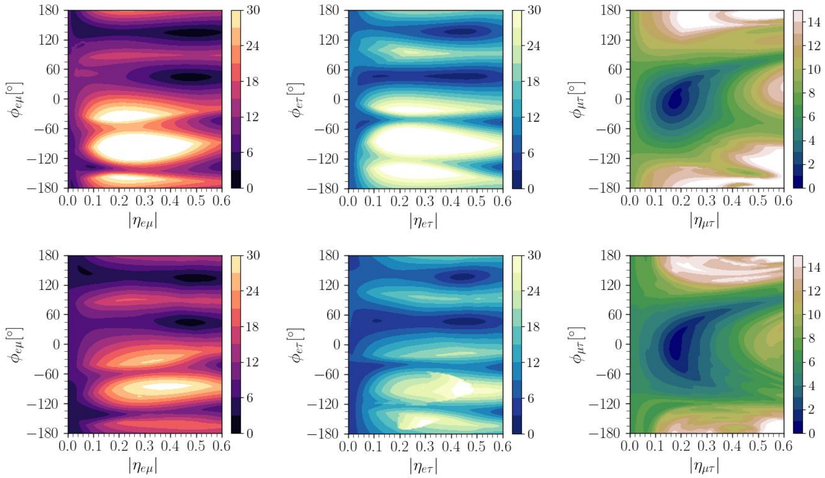


Figure: CP violation sensitivity as a function of $\eta_{\alpha\beta}$ and $\phi_{\alpha\beta}$.

Summary and Conclusion

- We obtained bounds on the SNSI off-diagonal parameters and explained the behaviours by probability plots.
- The SNSI parameter $\eta_{\mu\tau}$ is loosely bound compared to $\eta_{e\mu}$ and $\eta_{e\tau}$.
- Δm^2_{31} plays a very non-trivial role for bounds on these off-diagonal parameters, suggesting utmost care should be taken on Δm^2_{31} minimization.
- In MH sensitivity plots, we obtained similar behaviour from $\eta_{e\mu}$ and $\eta_{e\tau}$. The sensitivity first decreases and then increases linearly.
- We see for certain values of $\eta_{\alpha\beta}$ and $\phi_{\alpha\beta}$, the CPV sensitivity almost reducing to zero.
- We find the SNSI parameter $\eta_{\mu\tau}$ and the corresponding phase are very crucial while determining oscillation parameters.

Thank you for your attention!