# Exploring scalar NSI effects in long baseline neutrino experiments

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# Outline

- Introduction
- Formalism of Scalar NSI in neutrino interactions
- Methodology
- Results
- Concluding Remarks

# Non standard interactions in neutrinos

- Neutrino oscillations, which also indicate non zero masses of the neutrinos, is beyond the SM of Particle Physics.
- In matter: neutrinos experience a matter potential which has impact on the oscillations. MSW resonances occur at certain matter density and neutrino energy combination.
- Non-standard interaction terms are introduced in neutrino matter effect: vector, axial vector
- The impact of NSI on oscillation probability: an interesting sector to probe new physics.

# Non standard interactions in neutrinos

- Neutrino coupling with scalars is interesting, as neutrinos have mass.
- Matter effect due a neutrino-scalar coupling may be modulated in different ways.
- A new approach in Phys. Rev. Lett. 122, 211801 (2019), we mostly follow it in this work.

# Neutrino Oscillation in matter

- The Hamiltonian for neutrino oscillation in matter is given by :

$$H = E_\nu + \frac{MM^\dagger}{2E_\nu} + V_{SI}$$

Where,

$$V_{SI} = \begin{pmatrix} V_C + V_N & 0 & 0 \\ 0 & V_N & 0 \\ 0 & 0 & V_N \end{pmatrix},$$

and, $V_C = \pm\sqrt{2}G_F n_e$ and $V_N = \sqrt{2}G_F n_n$

# Formalism of a scalar NSI

- No longer a matter potential, but appears as correction/addition/perturbation to the mass term.
- The new Hamiltonian

$$H = E_\nu + \frac{(M + \Delta M)(M + \Delta M)^\dagger}{2E_\nu} + V_{SI}$$

- The oscillation probability can feel the matter density variations along the baseline as $\Delta M$ scales with matter density.

# Formalism of a scalar NSI

- The scalar NSI is generalized as a $3 \times 3$ matrix :

$$\Delta M = \sqrt{\Delta m^2_{31}} \begin{pmatrix} \eta_{ee} & \eta_{e\mu} & \eta_{e\tau} \\ \eta_{\mu e} & \eta_{\mu\mu} & \eta_{\mu\tau} \\ \eta_{\tau e} & \eta_{\tau\mu} & \eta_{\tau\tau} \end{pmatrix}$$

- $\eta_{\alpha\beta}$ elements are dimensionless
- They quantify the strength of scalar NSI

# Methodology

- Exploring the effect of scalar NSI on the oscillation probabilities.
- Exploring the effect of scalar NSI for long baseline neutrino detection

# Methodology

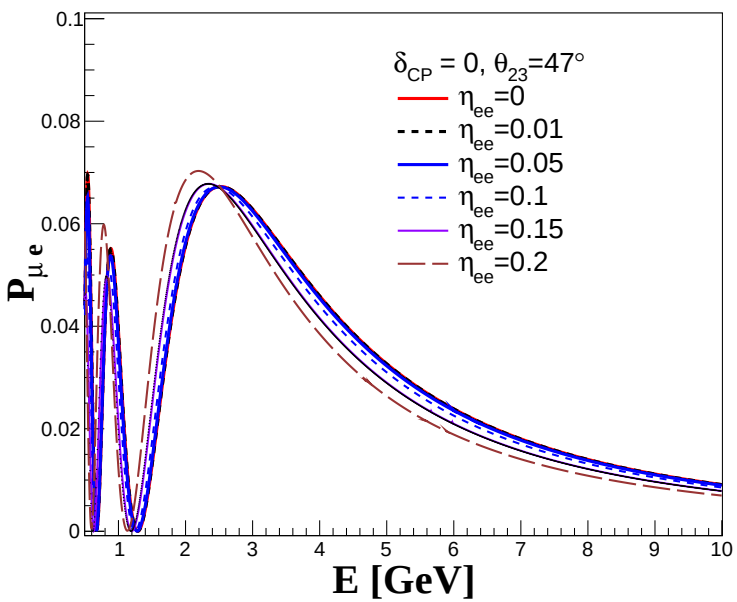
- Probability calculator algorithm: We modify the Hamiltonian and include the scalar NSI matrix.
- The oscillation probability is then studied for different choices of the Scalar NSI elements.
- Baseline used: 1300 KM (DUNE)
- Unless otherwise stated, results are shown for NH.
- A preliminary $\chi^2$ analysis is performed using GLoBES package to explore scalar NSI sensitivity at DUNE

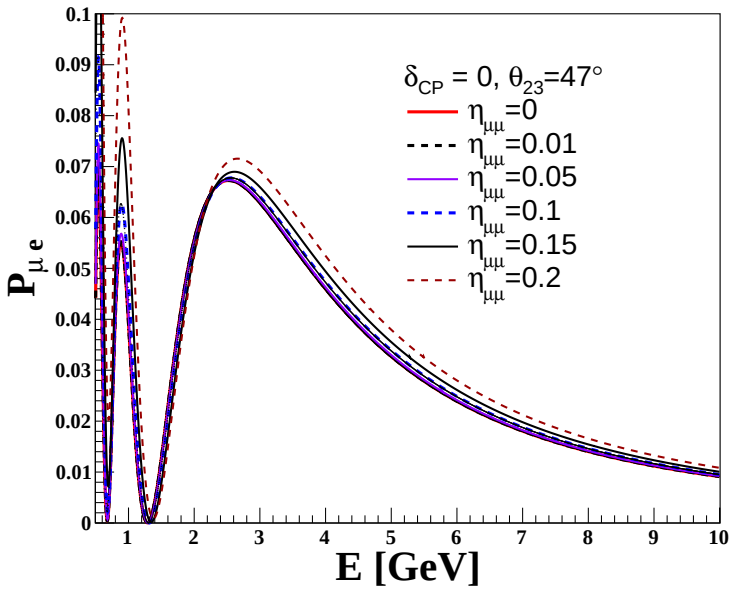
The mixing parameter values used are :

| $\sin^2\theta_{12}$ | $\sin^2\theta_{13}$ | $\delta_{CP}$ | $\Delta m^2_{21}$ | $\Delta m^2_{31}$ |
|---|---|---|---|---|
| 0.308 | 0.0234 | [ -$\pi$, +$\pi$] | $7.54\times10^{-5}$ | $2.43\times10^{-3}$ |

# Results: impact on oscillation probabilities

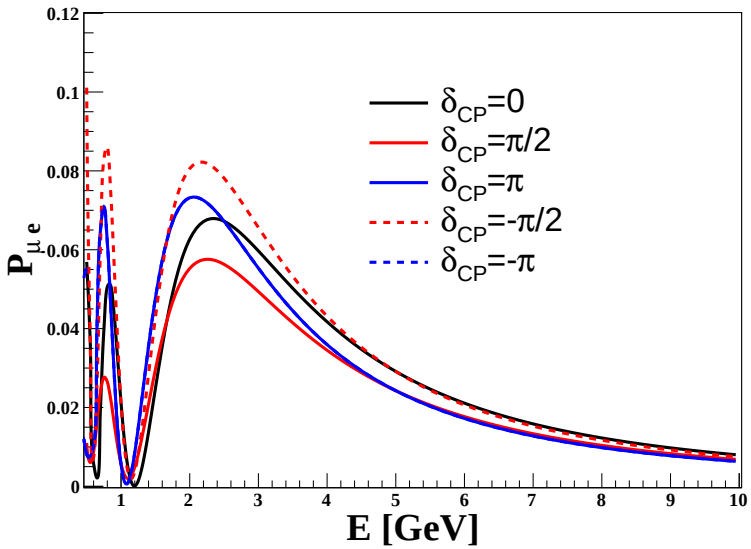
- $P_{\mu e}$ as a function of E at DUNE baseline
- Different choices of the scalar NSI matrix

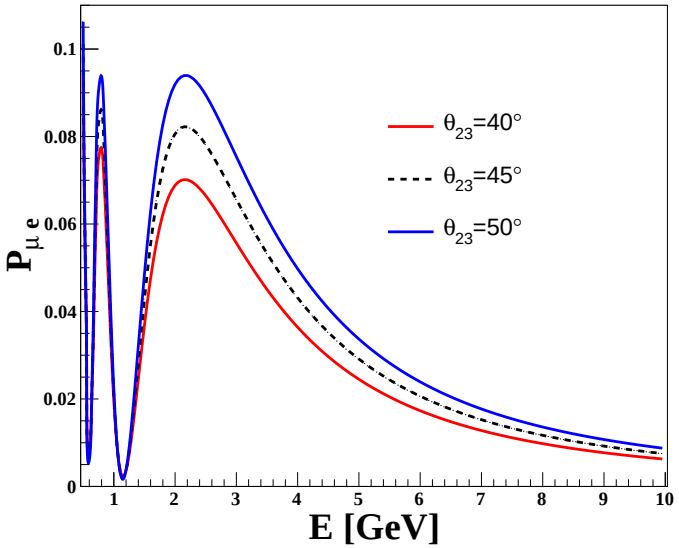


# Results: impact on oscillation probabilities

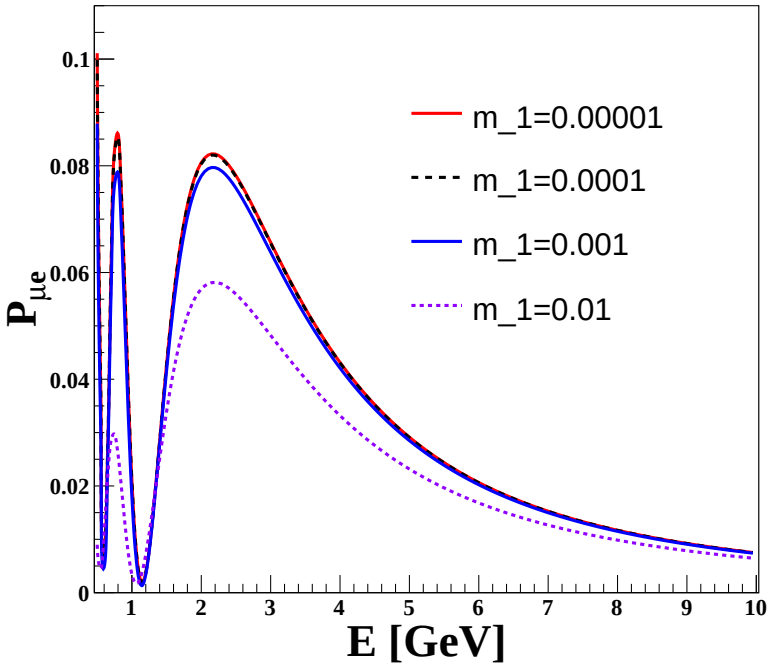
- $P_{\mu e}$ as a function of E at DUNE baseline
- Different choices of $\delta_{CP}$, $\theta_{23}$



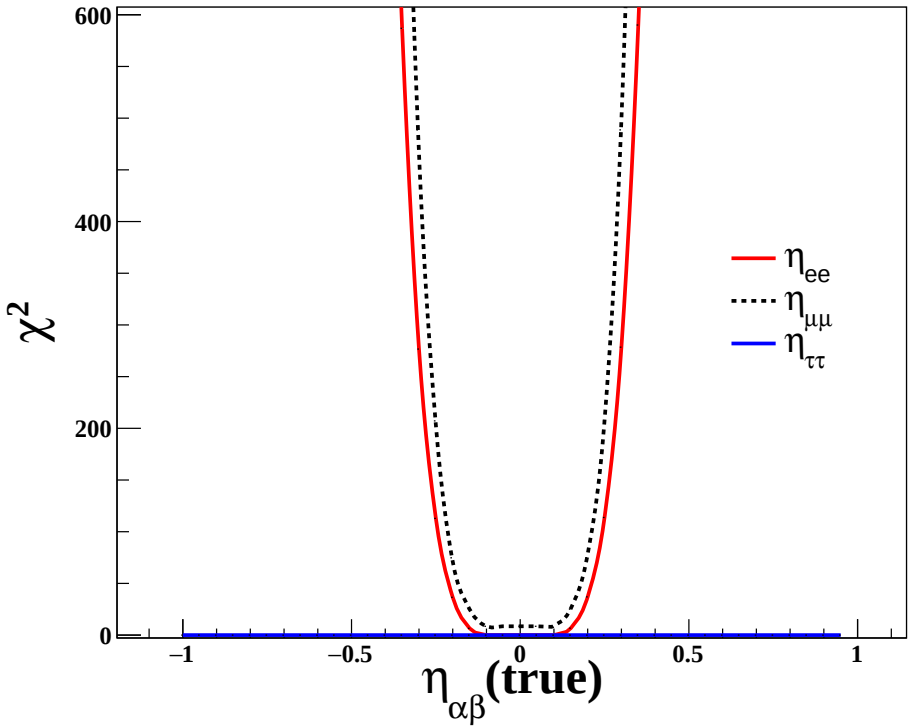
# Results: effect on oscillation probabilities

- $P_{\mu e}$ as a function of E at DUNE baseline
- Impact from the elements of mass matrix



# Results: $\chi^2$-analysis, preliminary

- Fixed parameter, Dune: 5($\nu$) y + 5($\bar{\nu}$) y
- Subtle: for $\eta_{\alpha\beta} < |0.1|$



# Concluding Remarks

- Neutrino scalar coupling and its effect on the neutrino interactions and oscillations is an interesting one, and needs exploration.
- It may lead to new physics beyond SM.
- Being a correction to the mass term, can be explored for mass matrix studies.

*Thanks for the kind attention!*