Probing the effects of scalar Non Standard Interactions at Long Baseline Experiments

Abinash Medhi*, Debajyoti Dutta and Moon Moon Devi

* amedhi@tezu.ernet.in
* Department of Physics,
Tezpur University, Assam-784028, INDIA

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Outline

Introduction

- Neutrino oscillations essentially confirms neutrinos have masses.
- It provides the first experimental evidence of physics beyond Standard Model (BSM).
- The models describing BSM physics often comes with some additional unknown coupling of neutrinos.
- These interactions are called Non Standard Interactions (NSIs), as it can't be explained within the framework of SM.

Non standard interactions in neutrinos

- NSI can introduce matter effect in neutrino oscillations (L. Wolfenstein, Phys. Rev. D 17 (1978) 2369–2374).
- The impact of NSI on oscillation probability: an interesting sector to probe new physics.
- Neutrinos coupling with a scalar is an excellent probe to study new physics in Long Baseline experiments (S.-F. Ge and S. J. Parke, Phys. Rev. Lett. 122 (2019)).

Neutrino Oscillation in matter

- The weakly interacting neutrinos might interact with matter via charged-current (CC) or neutral-current (NC) when they pass through matter.
- The Hamiltonian for neutrino oscillation in matter is given by :

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

Where

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

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

Scalar Non Standard Interactions

- The Lagrangian of such interactions can be formulated as :

$$\mathcal{L}_{\text{eff}}^{\text{S}} = \frac{y_f y_{\alpha\beta}}{m_\phi^2}(\bar{\nu}_\alpha(p_3)\nu_\beta(p_2))(\bar{f}(p_1)f(p_4))$$

- The corresponding neutrino Hamiltonian modifies as:

$$\mathcal{H} \approx E_\nu + \frac{(M+\delta M)\,(M+\delta M)^\dagger}{2E_\nu} \pm V_{\text{SI}}$$

δ M = $\sum_f \frac{n_f y_f y_{\alpha\beta}}{m_\phi^2}$

- The effect appears as correction/addition/perturbation to the neutrino mass term.

Formalism and Methodology

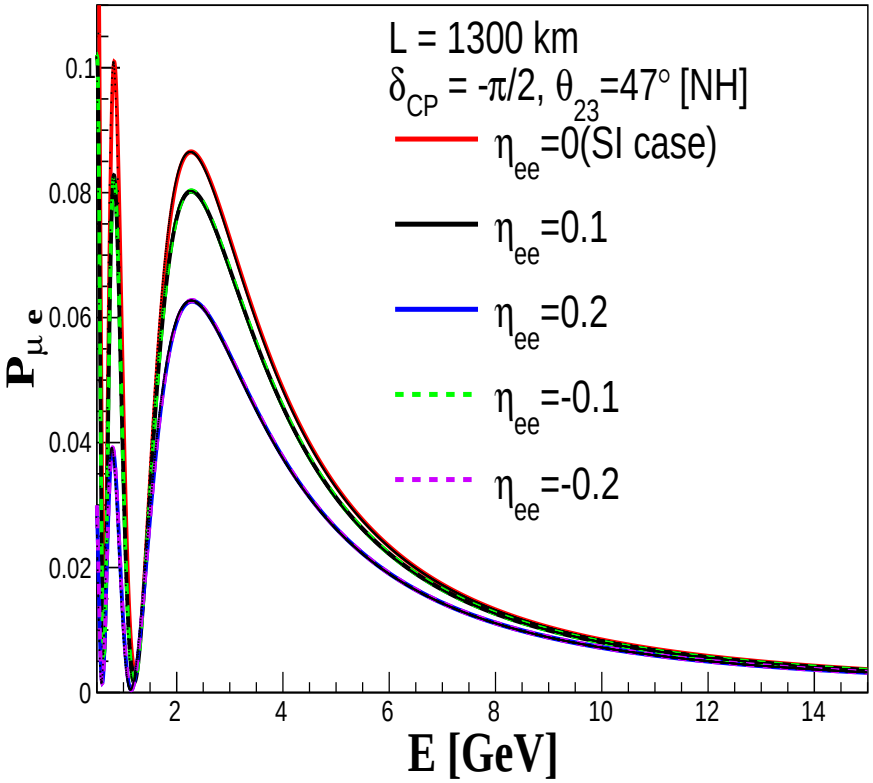
- The effect of scalar NSI can be parametrize as a 3×3 matrix :

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

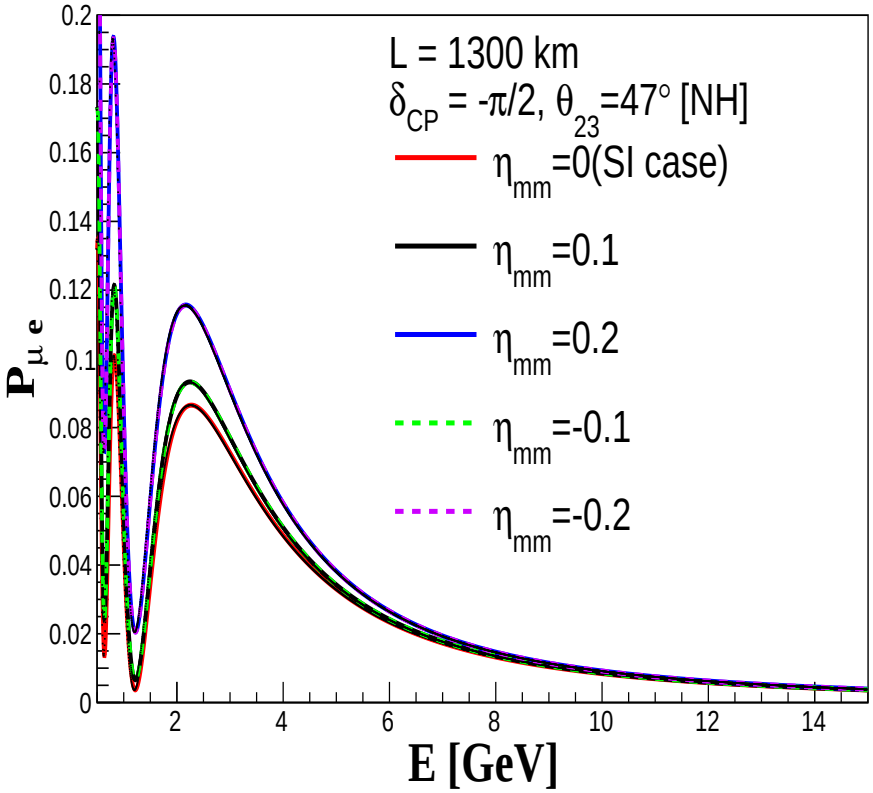
- $\eta_{\alpha\beta}$ elements are dimensionless and quantifies the size of scalar NSI.
- A framework is made with the modified Hamiltonian in GLoBES with baseline = 1300 km (DUNE).
- The values of mixing parameters used in the analysis :

$\sin^2\theta_{12}$	$\sin^2\theta_{13}$	$\sin^2\theta_{23}$	δ_{CP}	$\Delta m^2_{21}(eV^2)$	$\Delta m^2_{31}(eV^2)$
0.308	0.0234	0.5348	$-\pi/2$	7.54×10^{-5}	2.43×10^{-3}

Results : effects on oscillation probabilities

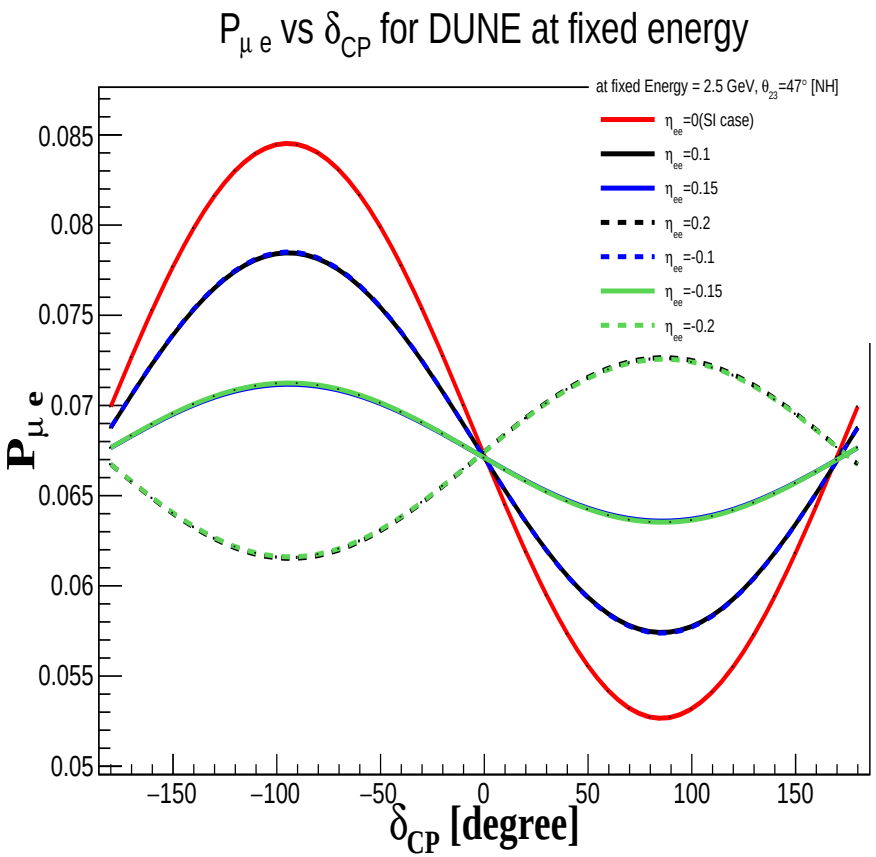


(a) $P_{\mu e}$ vs E for different η_{ee}

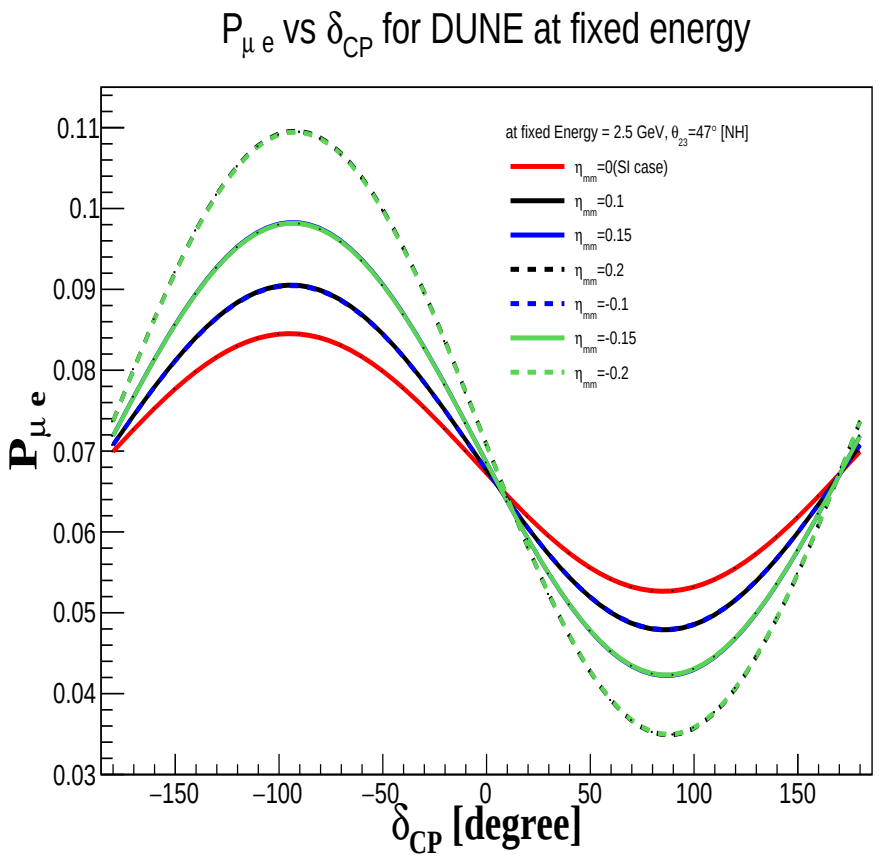


(b) $P_{\mu e}$ vs E for different $\eta_{\mu\mu}$

Results : effects on oscillation probabilities

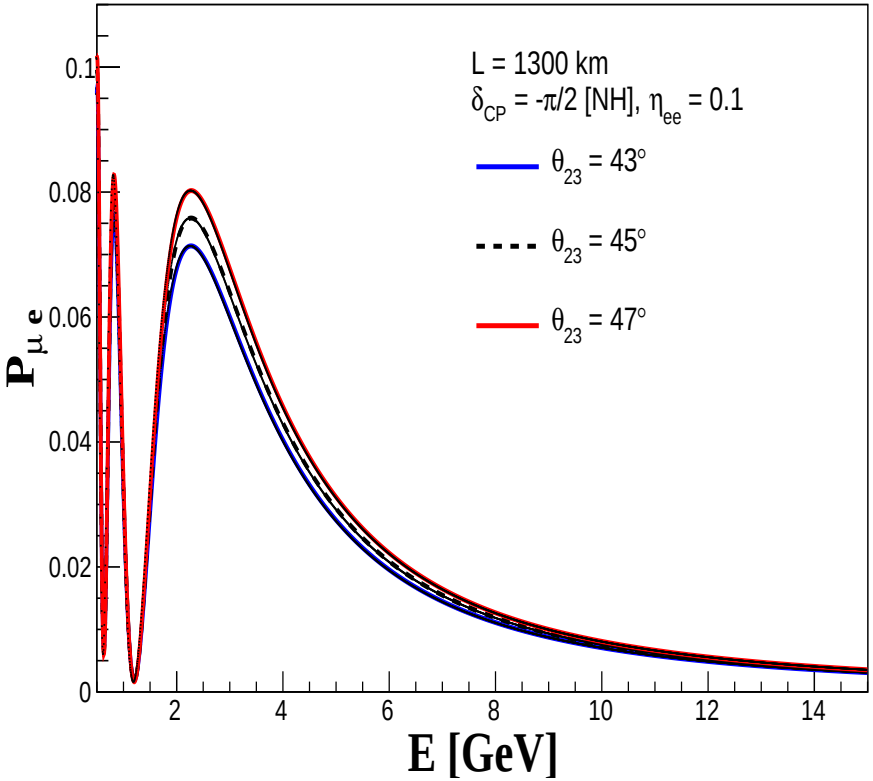


(a) $P_{\mu e}$ vs δ_{CP} for different η_{ee}

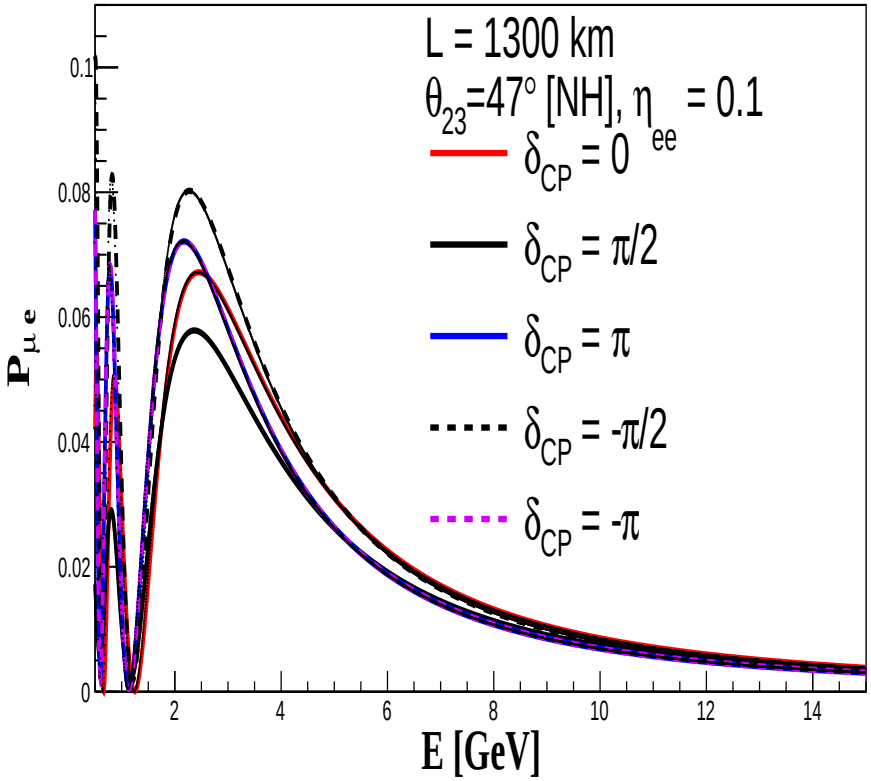


(b) $P_{\mu e}$ vs δ_{CP} for different $\eta_{\mu\mu}$

Results : $P_{\mu e}$ with varied δ_{CP}, θ_{23}

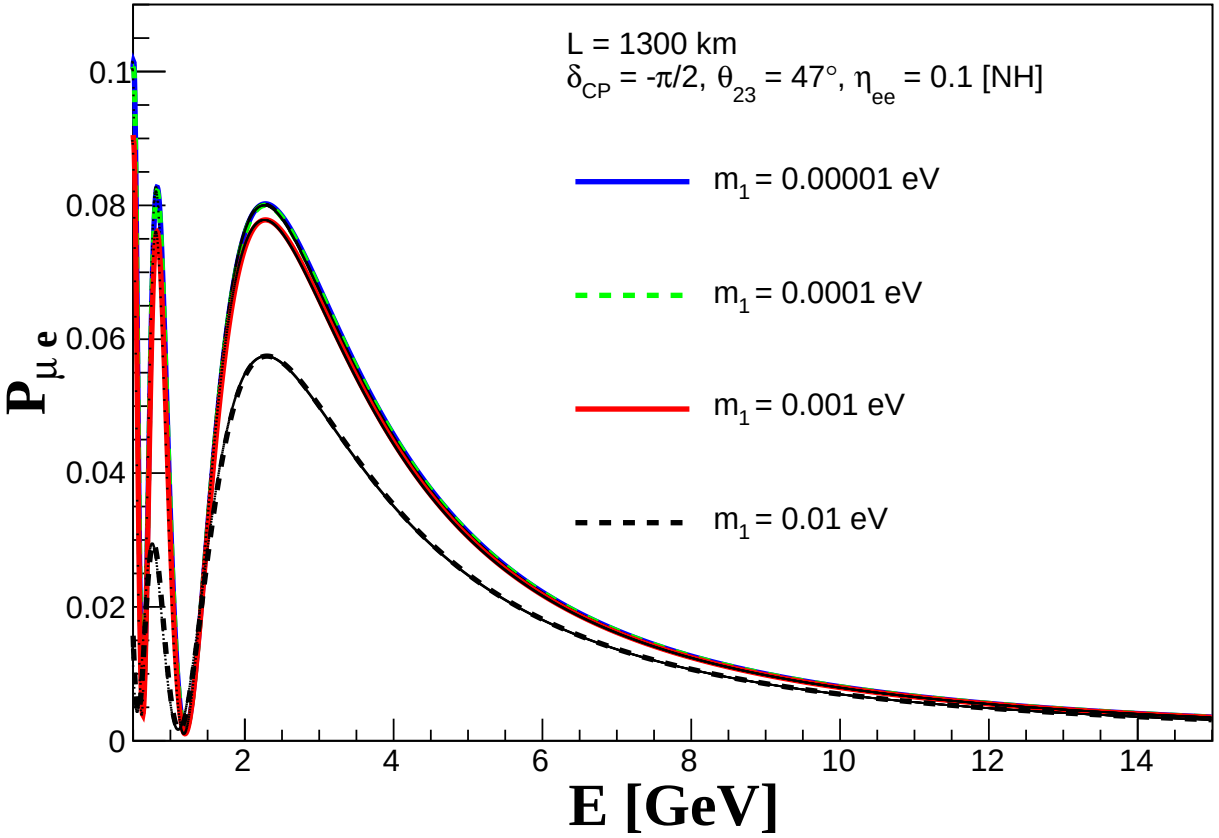


(a) $P_{\mu e}$ vs E for different θ_{23}



(b) $P_{\mu e}$ vs E for different δ_{CP}

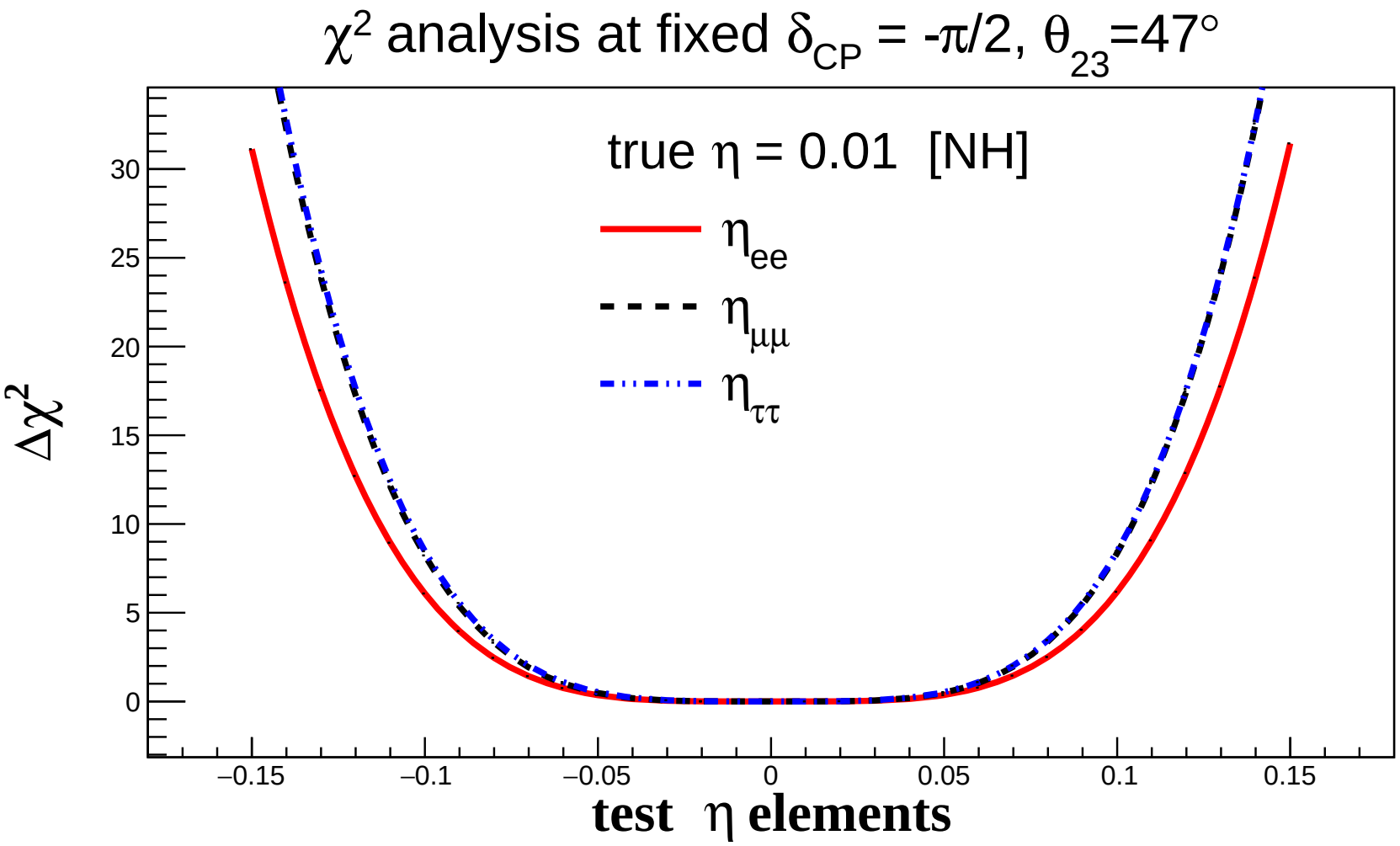
Results: $P_{\mu e}$ with varied ν masses



- Scalar NSI gives a possibility of probing it to various neutrino mass models.

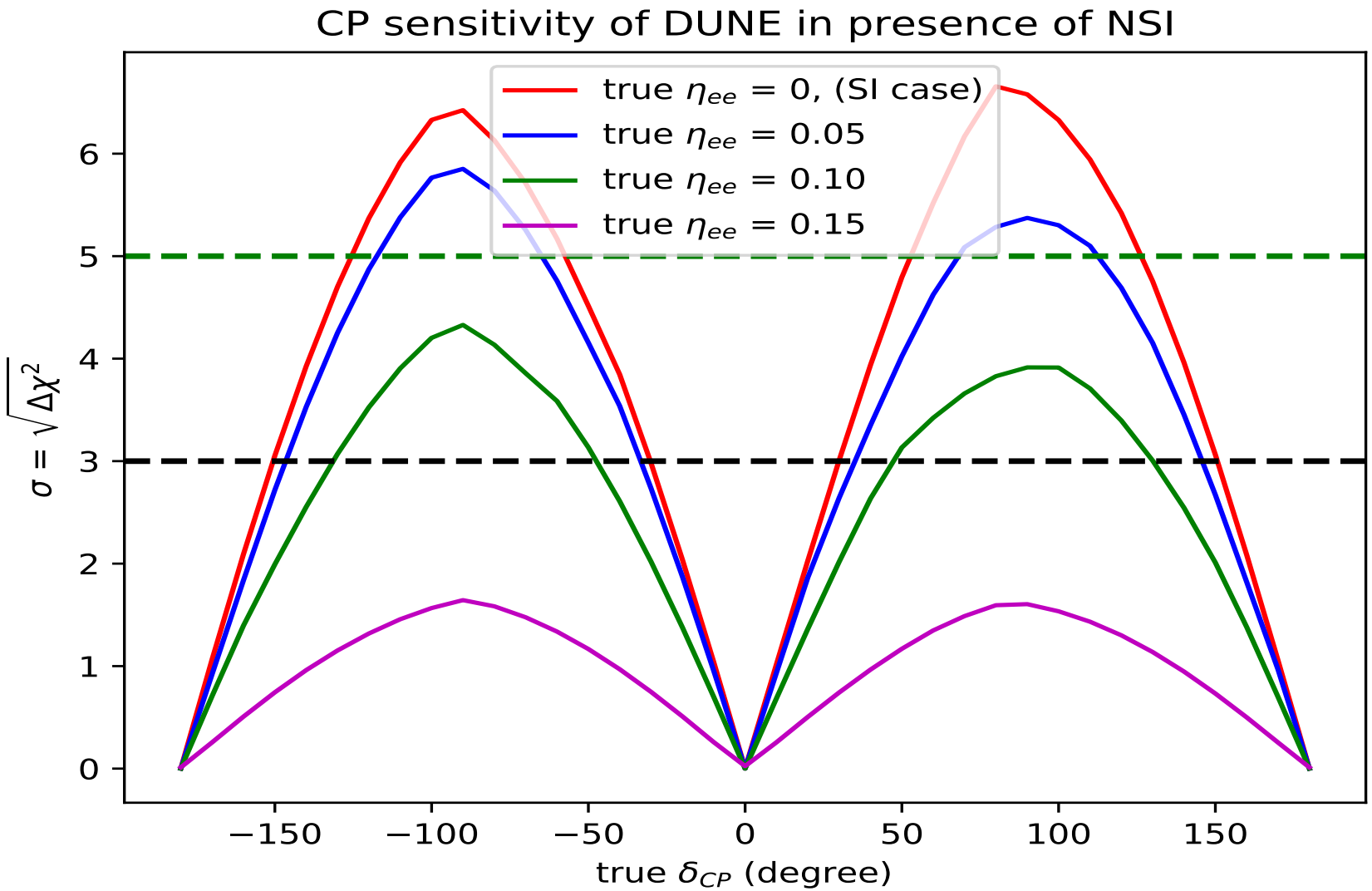
Results : χ^2 - analysis, preliminary

- DUNE: 5 years (ν) + 5 years ($\bar{\nu}$)



Results : Effects on CP sensitivity

- DUNE: 5 years (ν) + 5 years ($\bar{\nu}$)



Concluding Remarks

- Scalar NSI has a notable impact in neutrino oscillations at DUNE.
- The CP sensitivity of DUNE gets spoiled in presence of scalar NSI.
- It is crucial to identify such subdominant effects of neutrino oscillations for accurate interpretation of data.
- A good window to study new physics beyond Standard Model (BSM).
- As it directly effects the neutrino mass term, it can be used to probe various neutrino mass models.

Thank You for your kind attention !

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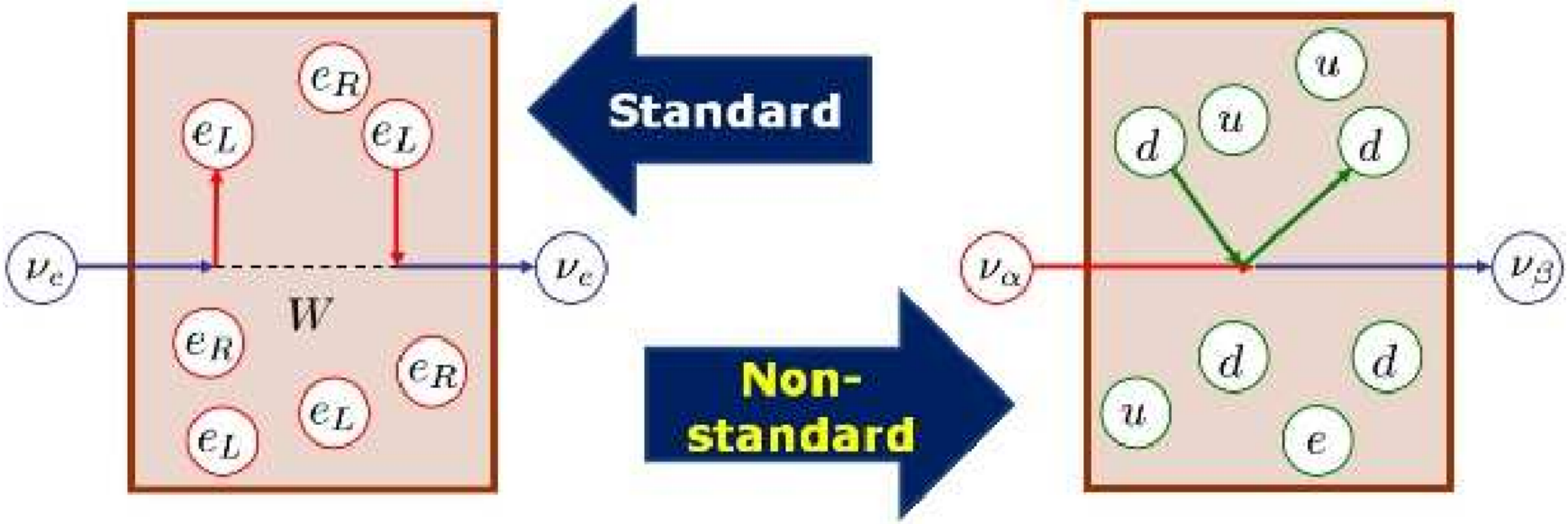
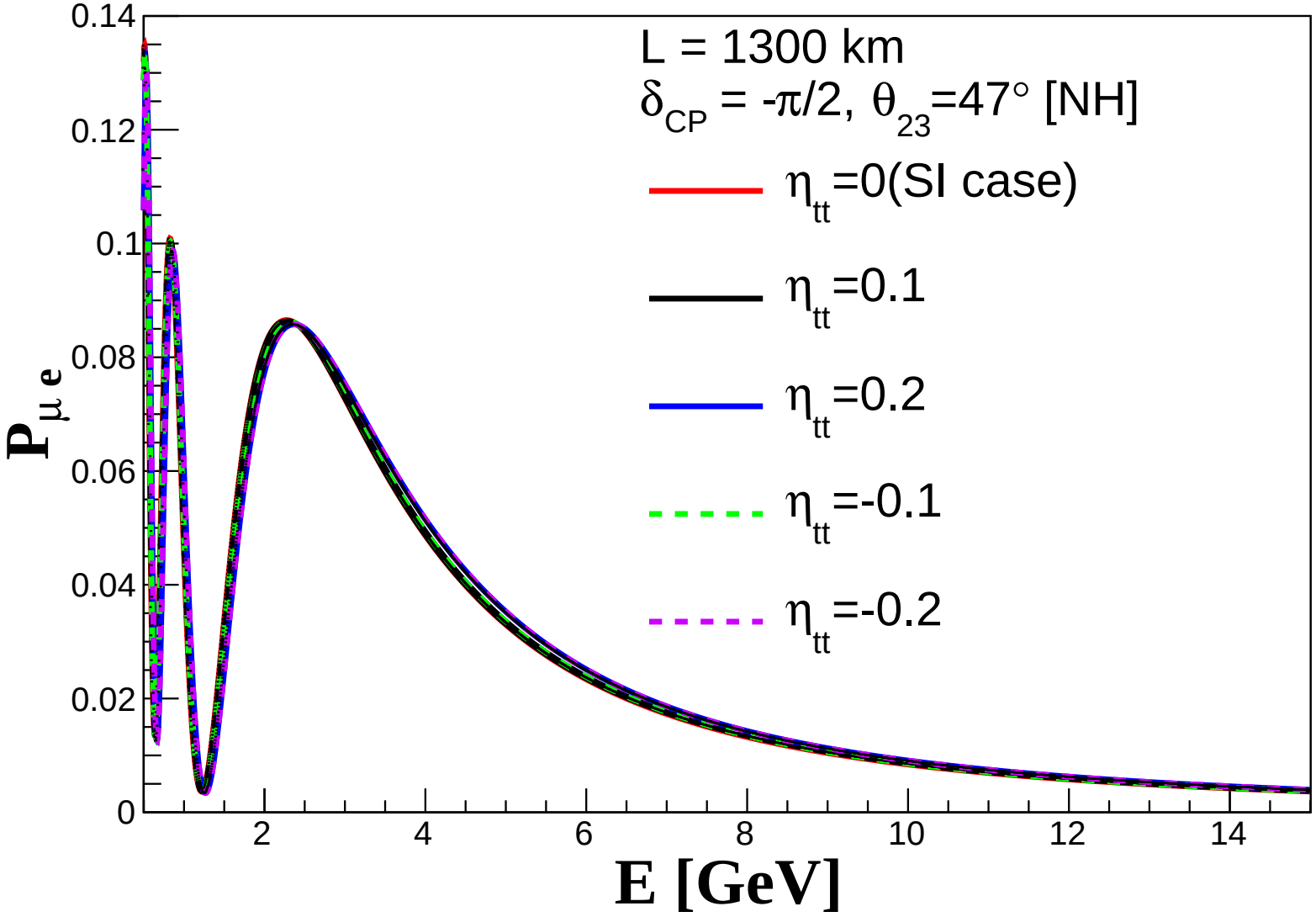
Back up: Schematic representation



Schematic pictures of standard matter effects (left picture) and matter non-standard neutrino interactions (right picture).

Reference: DOI:10.1088/0034-4885/76/4/044201

Back up: effects on oscillation probabilities



(a) $P_{\mu e}$ vs E for different $\eta_{\tau\tau}$