"The interpretation of data is the key to unlocking the secrets of the universe."

– *Carl Sagan*

5

Scalar NSI: A Unique Approach to Constrain Absolute Neutrino Masses through Neutrino Oscillations

Neutrino mass measurements hold profound significance in the landscape of particle physics and cosmology. For decades, neutrinos were considered massless within the framework of the Standard Model, but the discovery of neutrino oscillations shattered this notion, proving that neutrinos have finite masses and can change between different flavors. Accurate measurements of neutrino masses not only provide insights into the nature of neutrinos themselves but also have far-reaching implications. Neutrinos are among the most abundant particles in the universe and played a crucial role in its early evolution. Their masses influence the dynamics of cosmic structures, such as galaxies and galaxy clusters, affecting the large-scale structure of the universe. Furthermore, neutrino mass measurements can shed light on the elusive phenomenon of neutrinoless double-beta decay, a process that, if observed, would have implications for understanding the matter-antimatter asymmetry in the universe and the nature of neutrinos as Majorana particles. In both fundamental physics and cosmology, neutrino mass measurements thus offer a gateway to unraveling the mysteries of the cosmos and the particles that inhabit it.

5.1 Neutrino Mass Measurement

Global scientific endeavors are continuously engaged in a collective effort to establish stringent limitations on the masses of neutrinos [172–174]. Various data sources, including cosmological observations [175–177], neutrino oscillation studies [24], and beta decay processes [178, 179], contribute to the endeavor of constraining neutrino masses [180]. One such limitation is established by cosmological observations, yielding an upper bound of $\sum m_i < 0.12$ eV (at 95% confidence level) [181–185]. However, inherent degeneracies and cosmological assumptions hinder the attainment of a robust constraint on the absolute mass of neutrinos via the cosmological route. Overcoming this limitation necessitates the application of two distinct approaches: direct and indirect. In the direct approach, the estimation of neutrino mass revolves around measuring the endpoint of the electron energy spectrum in the β-decay process. The recent result from the KATRIN experiment, employing this method, establishes a limit of $m_\nu \leq 0.8$ eVc^{-2} at a 90% confidence level [186]. In contrast, the neutrinoless double-beta decay ($0\nu\beta\beta$) constitutes an indirect avenue for neutrino mass determination. This approach exploits the mass difference between parent and daughter nuclei in the $0\nu\beta\beta$ process to impose constraints on neutrino mass. The feasibility of $0\nu\beta\beta$ decay hinges on neutrinos being Majorana particles, allowing it to offer a constraint via $m_{\beta\beta} = \sum U_{ei}^2 m_i$; the current limit stands at $m_{\beta\beta} < 75$ - 180 meV [187–189].

Neutrino masses are exceedingly minute compared to other Standard Model fermions, differing by five orders of magnitude. The determination of ν mass and its underlying mechanism promises illumination of various fundamental enigmas within particle physics. Nonetheless, measuring absolute ν masses is beset with challenges. The feeble interaction of neutrinos with matter poses a formidable obstacle to achieving high-precision ν mass measurements. Intrinsically high background noise plagues mass measurement experiments, and the intricate nature of neutrino experiments gives rise to substantial systematic errors. Despite these hurdles, notable progress is evident in constraining ν masses. Recent years have witnessed crucial achievements, including the primary direct measurement of the squared ν mass difference and the most stringent constraints on the half-life of $0\nu\beta\beta$ decay [190].

Neutrino oscillation experiments are proficient in probing neutrino mass-squared differences but lack sensitivity to absolute masses. Nevertheless, scalar non-standard interactions (NSIs) can establish a direct correlation between absolute ν masses and neutrino oscillations [7, 11, 145, 146, 191]. The coupling of neutrinos through a scalar medium is of interest as it influences the ν mass term, which can be leveraged to restrict the absolute neutrino masses. Previous research [8, 9] has highlighted the significant impact of scalar NSIs (SNSIs) on the sensitivity of long baseline experiments and their potential to introduce parameter degeneracies. SNSIs present an avenue to explore absolute ν masses uniquely and play a role in explaining beyond-the-standard-model physics.

This study introduces an interesting endeavor to constrain the lightest ν mass through investigations of neutrino oscillation experiments. By comprehensively exploring the influence of SNSIs in a model-independent manner, we seek to restrict ν masses for both neutrino mass hierarchies. The linear relationship between SNSI contributions and matter density makes long baseline experiments, such as DUNE [192–195], well-suited to detect their effects. We emphasize that SNSI elements can marginally enhance the capability to constrain ν mass for the normal hierarchy (NH) compared to the inverted hierarchy (IH). Furthermore, the choice of SNSI elements slightly affects the constraining capability at DUNE. The outcomes of our analysis hold promise for estimating absolute ν masses in ν oscillation experiments and contribute significantly to unraveling neutrino nature and beyond-standard-model physics.

In this study, we have undertaken an examination of the potential to restrict the absolute masses of neutrinos by delving into the impacts of scalar non-standard interactions (SNSIs). Taking into account the established cosmological constraint $\sum m_i < 0.12$ eV (95% confidence level) [181–185], we derive upper boundaries for the least massive neutrinos (m_1 and m_3 for NH and IH respectively) as shown in Table 5.1. The reference values for neutrino oscillation parameters used throughout our analysis are as follows [25]: $\theta_{12} = 34.51°$, $\theta_{13} = 8.44°$, $\theta_{23} = 47°$, $\delta_{CP} = -\pi/2$, $\Delta m^2_{21} = 7.56 \times 10^{-5} eV^2$, $\Delta m^2_{32} = -2.497 \times 10^{-3} eV^2$, and $\Delta m^2_{31} = 2.55 \times 10^{-3} eV^2$.

Upcoming long-baseline neutrino experiments are poised to unveil novel effects in the realm of new physics and impose more stringent constraints on the parameters governing neutrino mixing. The nature of scalar non-standard interactions (SNSIs), which demonstrate a linear relationship with matter density, renders long-baseline experiments particularly adept at probing their manifestations. Consequently, this endeavor holds the potential to establish bounds on SNSI parameters, consequently contributing to the restriction of absolute neutrino masses. A prominent example of such an experiment is the Deep Underground Neutrino Experiment (DUNE) [192–195] [see chapter 2 for details]. The projected operation spans 7 years (3.5 years of neutrinos and 3.5 years of antineutrinos). DUNE's primary objectives encompass precise measurements of neutrino oscillation parameters, the exploration of CP-violation, and the determination of the neutrino mass hierarchy. Notably, due to its linear scaling with environmental matter density, DUNE presents a promising avenue for investigating SNSI effects.

Normal Hierarchy			**Inverted Hierarchy**		
$m_1(eV)$	$m_2(eV)$	$m_3(eV)$	$m_3(eV)$	$m_1(eV)$	$m_2(eV)$
0.005	0.009	0.050	0.004	0.050	0.051
0.01	0.013	0.051	0.006	0.050	0.051
0.015	0.017	0.052	0.008	0.050	0.051
0.02	0.022	0.053	0.01	0.051	0.052
0.025	0.026	0.056	0.012	0.051	0.052
0.03	0.031	0.058	0.014	0.051	0.052

TABLE 5.1: Table representing the restricted range of neutrino masses for normal and inverted hierarchy

Our investigation employs the GLoBES simulation package [138, 196] to compute numerical probabilities and establish a statistical framework conducive to exploring the experiment's physics sensitivities.

In the following sections, we present a comprehensive overview of our analysis outcomes. Initially, we delve into the repercussions at the probability level, followed by an examination of the influence of scalar NSI at the sensitivity level. Conclusively, our efforts are directed toward constraining the neutrino mass through probing the scalar NSI parameters.

5.2 Effects on oscillation probabilities with varying ν-mass

Figure 5.1 shows the influence of varying admissible values for the lightest neutrino mass on the probabilities $P_{\mu e}$ for different scalar non-standard interaction parameters, namely η_{ee} (left-panel), $\eta_{\mu\mu}$ (middle-panel), and $\eta_{\tau\tau}$ (right-panel), specifically within the context of the DUNE experiment. We list our findings of the study as follows,

- For normal hierarchy, we observe marginal deviation as the scale of absolute neutrino mass shifts to a higher value. The effect on $P_{\mu e}$ for different values of m_1 are different for positive and negative values of η_{ee}. In presence of positive (negative) $\eta_{\mu\mu}$ (top-middle panel), we observe a suppression (enhancement) of oscillation

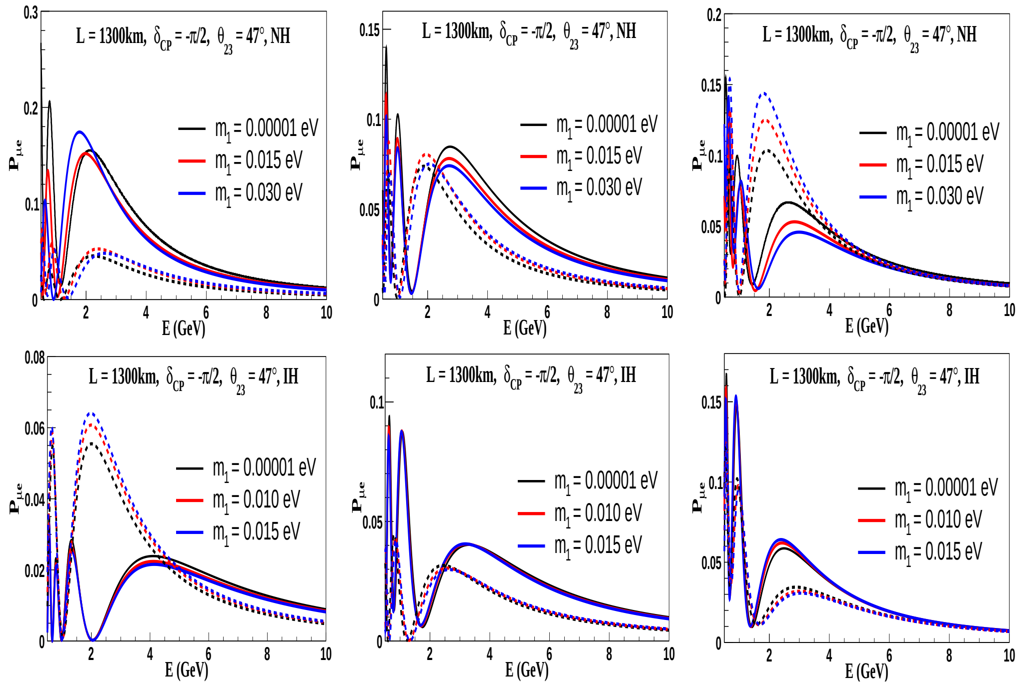

FIGURE 5.1: Appearance probabilities for different values of lightest neutrino mass with $\eta_{ee} = \pm 0.2$ (left-panel), $\eta_{\mu\mu} = \pm 0.2$ (middle-panel) and $\eta_{\tau\tau} = \pm 0.2$ (right-panel) for normal hierarchy (top-panel) and inverted hierarchy (bottom-panel). The solid (dashed) line represents a positive (negative) value of $\eta_{\alpha\beta}$. Also, we consider δ_{CP} = -$\pi/2$ and $\theta_{23} = 47°$ to generate the plots.

probability for higher values of neutrino mass. We observe a significant suppression (enhancement) of $P_{\mu e}$ for positive (negative) values of $\eta_{\tau\tau}$ as shown in the top-right panel.

- For inverted hierarchy, in presence of positive η_{ee} (top-left panel), we observe a suppression for higher values of neutrino mass m_3 while for negative η_{ee} an enhancement is seen. For positive (negative) $\eta_{\mu\mu}$, a marginal shift of the second peak towards lower (higher) energy is noticed for increasing neutrino mass. We observe an enhancement (suppression) of $P_{\mu e}$ with neutrino mass for positive (negative) values of $\eta_{\tau\tau}$ as shown in the bottom panel.

5.3 Effect of SNSI with varying δ_{CP} and ν-mass

In our analysis, we delve into the intricate behavior of neutrino oscillation probabilities with respect to two crucial variables: the Dirac CP-violation phase (δ_{CP}) and the lightest neutrino mass, encompassing both the normal and inverted hierarchies. To systematically evaluate the influence of scalar non-standard interaction (SNSI) elements on these oscillation probabilities, we introduce a parameter $\Delta P_{\mu e}$, which is defined as the disparity between the appearance probabilities with and without the presence of NSI. Specifically, $P_{\mu e}^{NSI}$ denotes the probability of neutrino flavor transition that includes the effects of NSIs, while $P_{\mu e}^{SI}$ stands for the corresponding probability under the assumption of standard interactions.

In figure 5.2, we offer an in-depth exploration of the impact of SNSIs in relation to varying δ_{CP} and the neutrino mass, considering the valid range of parameter values. The oscillation parameter values employed are detailed in the methodology section of this work. For this analysis, we keep the neutrino energy constant at $E = 2.5$ GeV and set the SNSI parameter to a fixed value of $\eta_{\alpha\beta} = 0.2$. With these parameters established, we proceed to systematically adjust the neutrino mass within the permissible range while allowing δ_{CP} to span the range $[-\pi, \pi]$. The outcomes of this analysis are depicted in Figure 5.2, wherein we present the parameter $\Delta P_{\mu e}$ as a function of varying δ_{CP} and neutrino mass. The left, middle, and right panels of the figure correspond to the SNSI parameters η_{ee}, $\eta_{\mu\mu}$, and $\eta_{\tau\tau}$ respectively. Each of these SNSI parameters is assessed separately to comprehend its distinct effects. Furthermore, the top panel of the figure pertains to the scenario of the true normal hierarchy (NH), while the bottom panel corresponds to the true inverted hierarchy (IH). In analyzing the plot, we see that,

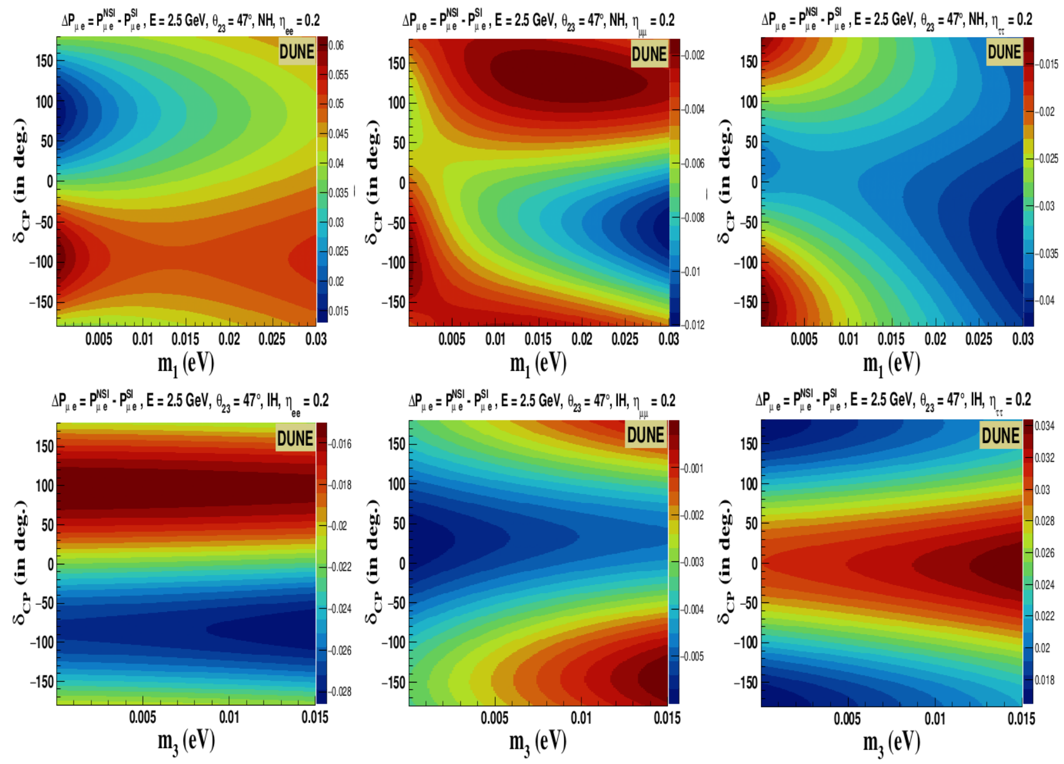

FIGURE 5.2: Effect of SNSI in δ_{CP}–m plane for $\eta_{\alpha\beta} = 0.2$ at DUNE. We plot $\Delta P_{\mu e}$ = $P_{\mu e}^{NSI}$ - $P_{\mu e}^{SI}$ with varying δ_{CP} and ν-mass. The top–panel (bottom–panel) represents NH (IH) for energy = 2.5, $\theta_{23} = 47°$.

- In the context of the normal hierarchy scenario, the SNSI element η_{ee} brings about a discernible enhancement in probabilities across the entire range of δ_{CP}. This enhancement is particularly pronounced within the region of negative δ_{CP} values. Contrarily, both $\eta_{\mu\mu}$ and $\eta_{\tau\tau}$ exhibit a tendency to suppress probabilities across the entire δ_{CP} parameter space. Notably, the suppression effect induced by $\eta_{\tau\tau}$ is more substantial compared to that exerted by $\eta_{\mu\mu}$.

- For the inverted hierarchy scenario, both η_{ee} and $\eta_{\mu\mu}$ contribute to the suppression of probabilities across the complete range of δ_{CP}. However, the degree of suppression is notably more pronounced in the case of η_{ee}. In contrast to the aforementioned effects, the SNSI element $\eta_{\tau\tau}$ engenders an enhancement in probabilities. This enhancement is especially prominent within a specific range of δ_{CP} values spanning from $-60°$ to $40°$.

5.4 Effect of SNSI with varying ν-energy and ν-mass

In Figure 5.3, we delve into the energy range that elicits the most pronounced effect of scalar non-standard interactions for different selections of the lightest neutrino mass within the permissible upper limits. To accurately gauge these effects, we utilize the previously defined parameter $\Delta P_{\mu e}$. Within this analysis, we keep the baseline fixed at $L = 1300$ km and sustain the SNSI parameter at a constant value of $\eta_{\alpha\beta} = 0.2$. We then systematically vary the value of the lightest neutrino mass across the allowable range and simultaneously span the neutrino energy from 0.5 GeV to 10 GeV. The resultant plot showcases $\Delta P_{\mu e}$ as a function of varying neutrino energies and masses. The left, middle, and right panels correspond to distinct SNSI parameters, namely η_{ee}, $\eta_{\mu\mu}$, and $\eta_{\tau\tau}$ respectively. The top and bottom panels of the figure encapsulate scenarios corresponding to the normal hierarchy and the inverted hierarchy respectively. This comprehensive analysis offers insights into the energy domains where the impact of SNSIs is most pronounced for varying choices of the lightest neutrino mass under both the normal and inverted hierarchy scenarios.

- In the scenario of the normal hierarchy, depicted in the top panel, when considering the influence of scalar non-standard interaction elements, a notable pattern of probability enhancement emerges. Focusing on the η_{ee} element (top-left), a substantial enhancement becomes evident, manifesting around an energy value of approximately 1.5 GeV. This enhancement pattern becomes particularly pronounced when the neutrino mass surpasses 0.02 eV. For the other SNSI elements, a contrasting trend of probability suppression is observed, centered around this specific energy value.

- In the context of the inverted hierarchy, as illustrated in the bottom panel, the maximal augmentation in probabilities materializes prominently for the $\eta_{\mu\mu}$ (bottom-middle) and $\eta_{\tau\tau}$ (bottom-right) SNSI elements. These elements distinctly contribute to the enhancement of neutrino oscillation probabilities. Conversely, the presence of the η_{ee} element (bottom-left) instigates a distinct outcome. Here, a substantial suppression of the $P_{\mu e}$ probability becomes evident at lower energy values.

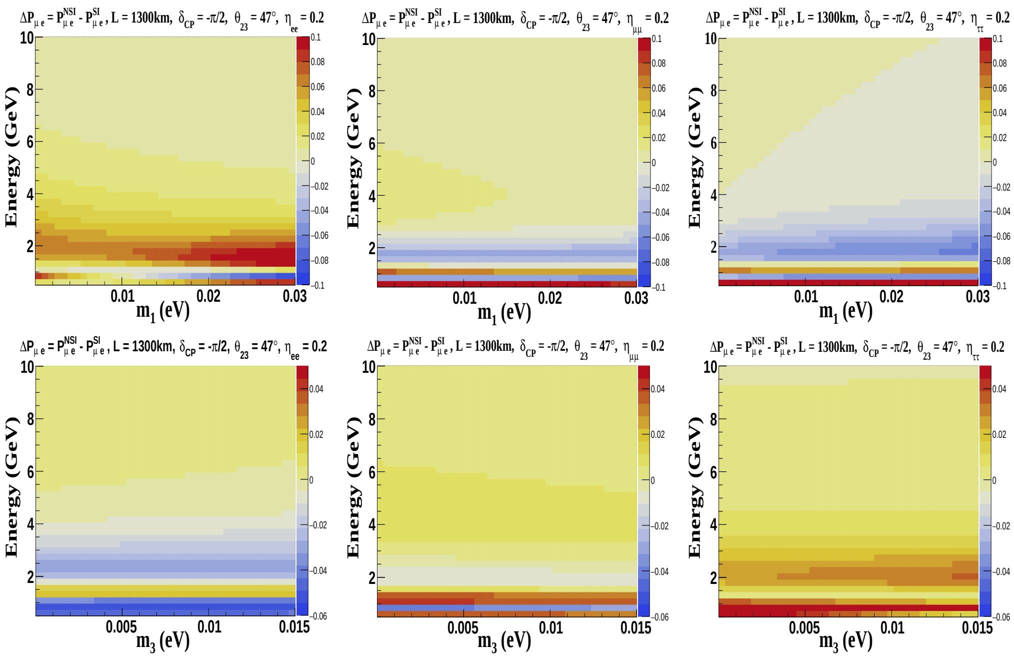

FIGURE 5.3: Plot of $\Delta P_{\mu e} = P_{\mu e}^{NSI} - P_{\mu e}^{SI}$ for varying neutrino energies and masses for NH and IH. The top (bottom) panel showcases the effects of normal (inverted) hierarchy. The left, middle and right panels represent the effect of SNSI parameters η_{ee}, $\eta_{\mu\mu}$ and $\eta_{\tau\tau}$ respectively.

We then present our findings regarding the determination of the absolute masses of neutrinos, accounting for both hierarchies, in the presence of Non-Standard Neutrino-Self Interaction effects. Our study employs the Deep Underground Neutrino Experiment (DUNE) as a specific illustrative case. Our approach involves imposing constraints on the neutrino masses while considering individual diagonal elements ($\eta_{\alpha\beta}$) of the NSI matrix at a time. To achieve this, we investigate the impact of the NSI parameter $\eta_{\alpha\beta}$ on the appearance channel ($P_{\mu e}$) for various chosen values of the lightest neutrino mass. Specifically, our attention is directed towards analyzing the SNSI parameters

η_{ee}, $\eta_{\mu\mu}$, and $\eta_{\tau\tau}$, with a focus on understanding DUNE's potential to narrow down the range of possible neutrino masses. Furthermore, we delve into the intricate relationship between the lightest neutrino mass and the SNSI parameters. It is important to note that throughout our analysis, we adopt the same values for the neutrino oscillation parameters as previously specified.

In our pursuit of constraining the absolute neutrino masses, we introduce a statistical measure [as discussed in Chapter 2] that serves as an indicator of sensitivity. This measure quantifies our ability to narrow down the possible neutrino mass values, taking into account the interplay between NSI effects and neutrino oscillations.

5.5 Constraining the neutrino masses

Illustrated in figure 5.4, we showcase the adeptness of the Deep Underground Neutrino Experiment in the endeavor to confine the absolute masses of neutrinos, accounting for both mass hierarchies. Upon inspecting the SNSI Hamiltonian, it becomes evident that the Non-Standard Neutrino-Self Interaction parameters wield a direct influence on the conventional neutrino mass matrix. This distinct connection allows for an exploration that enables the establishment of limitations on the neutrino masses. To quantify this constraint-imposing potential, we introduce the notion of sensitivity, captured by the parameter $\Delta\chi^2$. This measure is instrumental in delineating the extent to which the smallest neutrino masses can be confined through a meticulous investigation of the interplay between SNSI effects and neutrino mass characteristics.

$$\Delta\chi^2 = min\big[\chi^2\left(\eta_{\alpha\beta}^{test} \neq 0, m_{lightest}^{test}\right) - \chi^2\left(\eta_{\alpha\beta}^{true} \neq 0, m_{lightest}^{true} \neq 0\right)\big]. \tag{5.1}$$

We systematically explore the impact of varying the test value of the lightest neutrino mass within an admissible range, while maintaining a fixed true neutrino mass at $m_1^{true} = 0.02$ eV for the Normal Hierarchy (NH) and $m_3^{true} = 0.01$ eV for the Inverted Hierarchy (IH). This investigation is underpinned by a comprehensive process of marginalization over the oscillation parameters θ_{23} and δ_{CP} within the fit data. The sensitivity measurement, denoted as $\sqrt{\Delta\chi^2}$, is exhibited across a permissible span of the lightest neutrino mass values. Here, the solid lines signify scenarios with positive values of the SNSI parameters $\eta_{\alpha\beta}$, while the dashed lines correspond to instances featuring negative values of $\eta_{\alpha\beta}$.

Our analysis is particularly directed towards the diagonal SNSI parameters, namely η_{ee} (presented in the left-panel), $\eta_{\mu\mu}$ (depicted in the middle-panel), and $\eta_{\tau\tau}$ (illustrated in the right-panel), for both the Normal Hierarchy displayed in the top-panel, and the Inverted Hierarchy showcased in the bottom-panel. Throughout our study, we systematically vary the value of m_1 (or m_3) within the permissible region, depending on whether we are considering the Normal Hierarchy or the Inverted Hierarchy scenario. We see that,

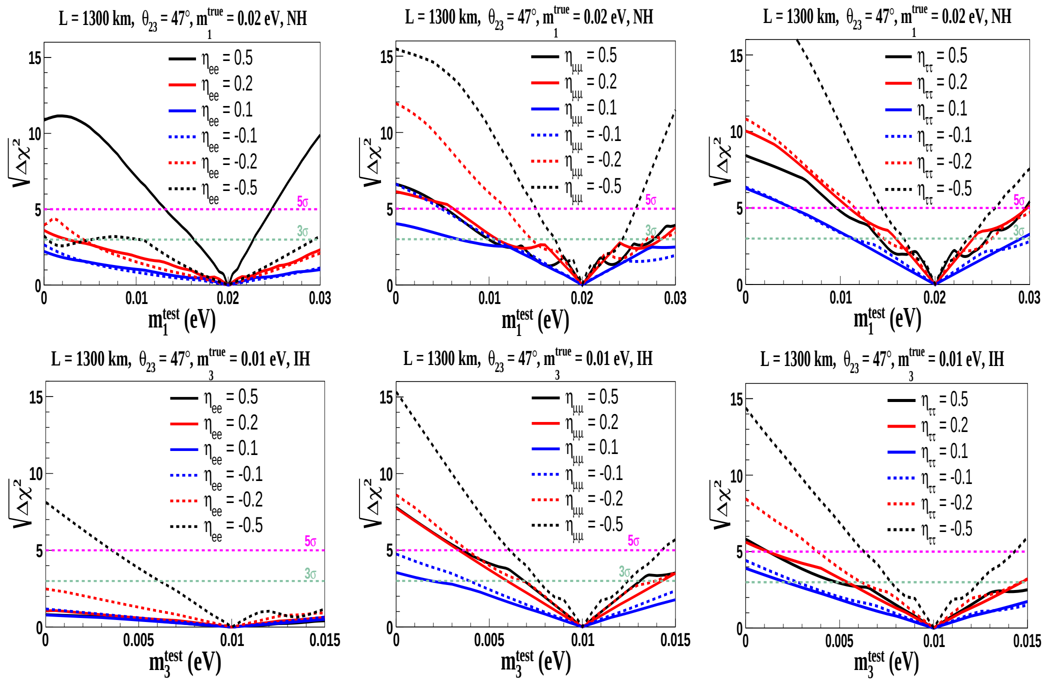

FIGURE 5.4: Constrain on lightest neutrino mass for normal (top-panel) and inverted (bottom-panel) hierarchy for the diagonal NSI parameters η_{ee} (left panel), $\eta_{\mu\mu}$ (middle-panel) and $\eta_{\tau\tau}$ (right-panel). The solid (dashed) lines represent positive (negative) parameter values. The magenta and green dashed horizontal lines represent the 3σ and 5σ C.L.

- For normal hierarchy, the presence of η_{ee} (top-left panel) indicates an increase in the constraining capability with the increase in the strength of the NSI parameter. The improvement is comparatively higher for positive values. For $\eta_{\mu\mu}$ (top-middle panel), we observe a significant enhancement in the sensitivity with the increase in the strength of negative values. A similar improvement is also observed for higher values of negative $\eta_{\tau\tau}$ (top-right panel). In contrast, the effect of positive $\eta_{\mu\mu}$ and $\eta_{\tau\tau}$ is relatively nominal.
- In the bottom panels i.e. for inverted hierarchy, we observe that the constraining capability gets improved for negative η_{ee} (bottom-left panel), though it cannot

be constrained within 3σ CL. The positive η_{ee} shows minimal changes in sensitivities. For $\eta_{\mu\mu}$ (bottom-middle panel), we see an enhancement in sensitivities for the positive and negative values of the NSI parameter. In the presence of $\eta_{\tau\tau}$ (bottom-right panel), a significant improvement can be seen with the increase in the negative strength of the parameter though only nominal changes are seen for the positive values.

In table 5.2, we have summarized the constraints on the lightest neutrino mass at 3σ CL for normal and inverted hierarchy. We observe that the mass of the lightest neutrino can be best constrained in the presence of $\eta_{\tau\tau}$ ($\eta_{\mu\mu}$) for normal (inverted) hierarchy.

NSI Parameter	**Constrain on lightest neutrino mass at 3σ CL**	
	Normal Hierarchy, $m_1[eV]$	**Inverted Hierarchy,** $m_3[eV]$
η_{ee}	$[0.003, 0.03]$	-
$\eta_{\mu\mu}$	$[0.012, 0.028]$	[0.006,0.014]
$\eta_{\tau\tau}$	[0.016,0.024]	[0.005,0.0145]

TABLE 5.2: 3σ allowed range for the lightest neutrino mass in the presence of diagonal NSI parameters. The true neutrino mass is fixed at $m_1 = 0.02$ eV ($m_3 = 0.01$ eV) for NH (IH) with $\eta_{\alpha\beta} = 0.2$.

5.6 Correlation in $(\eta_{\alpha\beta} - m)$ parameter space

In figure 5.5 and figure 5.6 we unveil the regions that conform to the allowed confidence levels of 1σ, 2σ, and 3σ in the $\eta_{\alpha\beta} - m$ planes, specifically in the context of the DUNE detector. In figure 5.5 we consider HO (47°) & $\delta_{CP} = -90°$ and In figure 5.6 we consider LO (43°) & $\delta_{CP} = -90°$. The underlying framework for this visualization involves defining the true values of ($\eta_{\alpha\beta}$, m) at (0.2, 0.02 eV) for the NH and (0.2, 0.015 eV) for the IH. Within the ambit of this study, we systematically vary the test values of $\eta_{\alpha\beta}$ within the range of [0.1, 0.3], while simultaneously exploring the permissible range for the lightest neutrino mass in both NH and IH scenarios.

The primary focus of our analysis remains directed towards the diagonal components of the NSI matrix, namely η_{ee} (depicted in the left-panel), $\eta_{\mu\mu}$ (presented in the middle-panel), and $\eta_{\tau\tau}$ (illustrated in the right-panel). These panels are divided based on whether we are considering the Normal Hierarchy in the top-panel or the Inverted Hierarchy in the bottom-panel. The representation of the confidence regions is as follows:

the solid blue, red, and black lines symbolize the 1σ, 2σ, and 3σ confidence intervals, respectively. The true data points are denoted by a black star, serving as a reference against which the distribution of confidence regions can be compared. For both the octant scenarios we mostly see the same trend in the sensitivity plots. In the following we discuss the observations we got from figure 5.5 and figure 5.6.

- For normal hierarchy, we observe that for the parameter η_{ee} (top-left panel), the absolute mass can be constrained as $m_1 \in [0.009, 0.03]$ eV by DUNE at 1σ CL. In the presence of NSI parameter $\eta_{\mu\mu}$ (top-middle panel), DUNE can constrain the absolute mass of neutrino $m_1 \in [0.016, 0.024]$ eV at 1σ CL. For parameter $\eta_{\tau\tau}$ (top-right panel), we observe a similar constrain with $m_1 \in [0.017, 0.023]$ eV at 1σ CL.

- The allowed region for all the diagonal elements $\eta_{\alpha\beta}$ in the inverted hierarchy (bottom panels) is more in comparison to the normal hierarchy (top panels) case. The constraint on the absolute mass in the presence of η_{ee} (bottom-left panel) worsens. For the presence of $\eta_{\mu\mu}$ (bottom-middle panel) and $\eta_{\tau\tau}$ (bottom-right panel), the allowed region at 1σ CL for the absolute mass m_3 is roughly $[0.007, 0.013]$ eV.

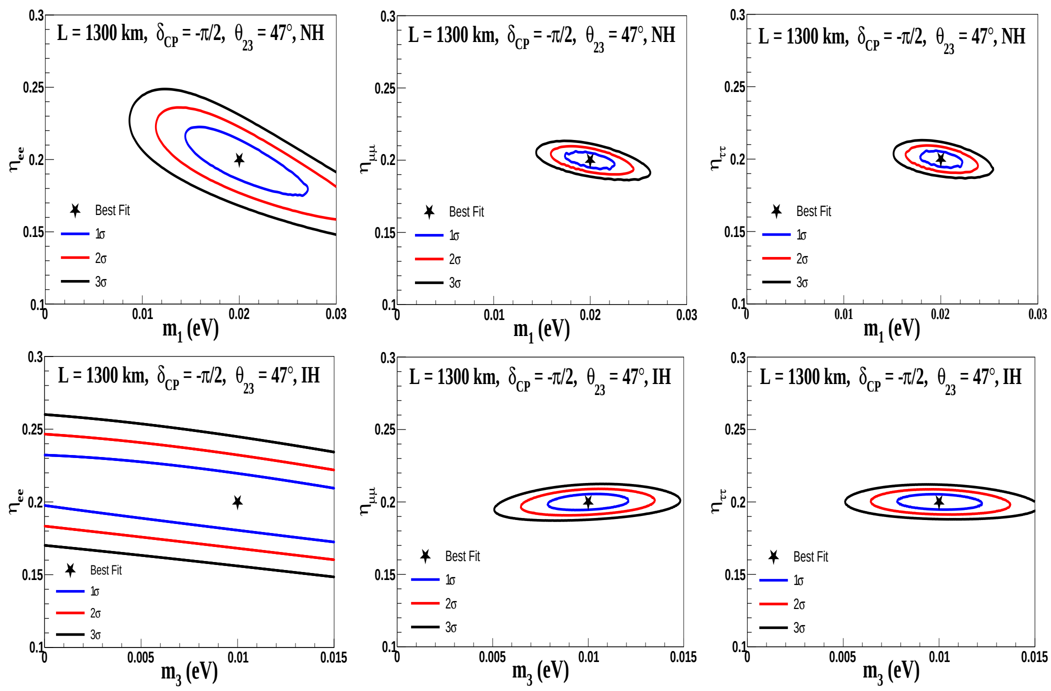

FIGURE 5.5: **HO = 47°; $\delta_{CP} = -90°$:**Allowed region of lightest neutrino mass for normal (top-panel) and inverted (bottom-panel) hierarchy for the diagonal NSI parameters η_{ee} (left-panel), $\eta_{\mu\mu}$ (middle-panel) and $\eta_{\tau\tau}$ (right-panel). The blue, red and magenta lines represent the 1σ, 2σ and 3σ confidence level. The best fit values of $(\eta_{\alpha\beta}, m)$ are $(0.2, 0.02eV)$ and $(0.2, 0.015eV)$ for NH and IH respectively.

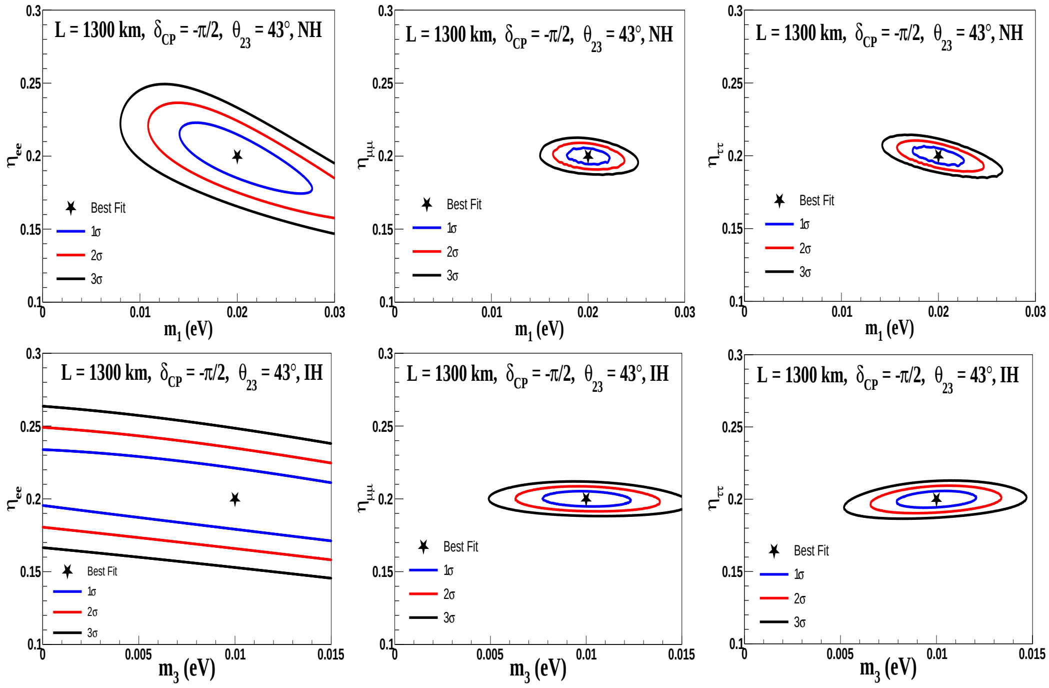

FIGURE 5.6: **LO = 43°; δ_{CP} = −90°:** Allowed region of lightest neutrino mass for normal (top-panel) and inverted (bottom-panel) hierarchy for the diagonal NSI parameters η_{ee} (left-panel), $\eta_{\mu\mu}$ (middle-panel) and $\eta_{\tau\tau}$ (right-panel). The blue, red and magenta lines represent the 1σ, 2σ and 3σ confidence level. The best fit values of $(\eta_{\alpha\beta}, m)$ are $(0.2, 0.02eV)$ and $(0.2, 0.015eV)$ for NH and IH respectively.

The observations made in this section complement what we have also seen in subsection 5.5 for the constraining sensitivity of the lightest neutrino mass. We see that the neutrino mass cannot be constrained in the presence of η_{ee} for IH for both HO and LO cases.

5.7 Chapter summary

In the landscape of contemporary experiments, the precision with which neutrino oscillation parameters are being scrutinized has reached unprecedented levels. Notably, within this context, the influence of sub-dominant factors such as scalar Non Standard Neutrino Interaction takes on a significant role in shaping the sensitivities of detectors. The realm of scalar NSI introduces a captivating avenue through which the exploration of the absolute masses of neutrinos can be facilitated via neutrino oscillations. At the heart of this research endeavor lies the core objective of unveiling the remarkable potential that exists for constraining the lightest neutrino mass. This potential is particularly evident when we integrate neutrino oscillation data within the framework of scalar NSI. The present study constitutes an exploration of these prospects within the confines of a concise letter. An essential consideration in this study is the incorporation of the cosmological constraint pertaining to the sum of neutrino masses. This holistic approach accounts for a comprehensive perspective that encompasses not only the oscillation data but also the cosmological implications.

The most noteworthy finding within this work pertains to the influence of the scalar NSI parameter $\eta_{\alpha\beta}$ on bounding the absolute masses of neutrinos. In a fascinating revelation, it is discerned that the presence of $\eta_{\tau\tau}$ or $\eta_{\mu\mu}$ confers a slightly enhanced capacity for constraining the lightest neutrino masses compared to the impact of η_{ee} in both hierarchical scenarios. The significance of the endeavor to constrain neutrino masses cannot be overstated. This undertaking serves as a pivotal step in unveiling the mechanisms underlying neutrino mass generation. As we navigate this pursuit, the potential breakthrough it holds stands poised to illuminate our understanding of the universe and its fundamental physical underpinnings. In essence, the intricate interplay between neutrino oscillations, scalar NSI, and the constraints on neutrino mass presents a gateway to profound insights that have the potential to reshape our comprehension of the cosmos.