A window to standard model precision tests and new physics searches through neutrino-electron scattering Cases

S. Parhi[1],* V. Singh[1], and L. Singh[1]
[1]*Department of Physics, Central University of South Bihar, Gaya, Bihar, 824236, India.*

Introduction

Over the past decades, significant progress has been made in understanding the lepton sector of the Standard Model (SM). Key parameters of the active neutrino sector includes mass-squared differences, mixing angles, and the CP-violating phase, which have been measured or constrained. In parallel, precision studies of muon and electron dipole moments continue to advance. Recently, the lepton sector has also emerged as a promising portal to physics beyond the SM (Beyond Standard Model (BSM))[1].

A well-motivated BSM extension of the SM is the $U(1)_{L_\mu - L_\tau}$ gauge symmetry, under which the second- and third-generation leptons have charges $+1$ and -1, respectively. This symmetry is anomaly-free without right-handed neutrinos and, once spontaneously broken, predicts a new neutral gauge boson that can address open questions such as neutrino masses, dark matter, the muon $(g-2)$ anomaly, the Hubble tension, and leptogenesis [2].

An especially sensitive probe of the $U(1)_{L_\mu - L_\tau}$ framework is neutrino-electron elastic scattering ($\nu + e^- \rightarrow \nu + e^-$). This process is theoretically clean, with well-understood cross sections in the SM, and can be precisely measured in current and future neutrino experiments. Any deviation from the predicted rates or energy spectra could provide evidence of new gauge interactions mediated by the $L_\mu - L_\tau$ boson. In particular, the enhanced sensitivities of near detectors at long-baseline neutrino facilities, such as DUNE, offer an excellent opportunity to test these interactions at unprecedented precision [3] [4] [5] [6].

In the present work we have evaluated the differential cross-section of neutrino-electron elastic scattering (E_ν^{ES}) is calculated for both SM and BSM aspects.

Differential Cross-Section for E_ν^{ES} in SM and BSM

The differential cross-section for anti-neutrino-electron elastic scattering is given by

$$\frac{d\sigma_{e-\bar{\nu}_\alpha}}{dT_e} = \frac{m_e}{4\pi}\left[G_+^2 + G_-^2\left(1 - \frac{T_e}{E_\nu}\right)^2 - G_+G_-\frac{m_eT_e}{E_\nu^2}\right], \quad (1)$$

where T_e represents the kinetic energy of the final-state electron, $G_\pm$ describe the gauge boson exchanges and E_ν is the energy of incident neutrino.

For the SM,

$$G_\pm = \sum_{j:\,\text{diagrams}} (c_j - d_j)\left(\tilde{c}_j \pm \tilde{d}_j\right), \quad (2)$$

where c_j, d_j, $\tilde{c}_j$, and $\tilde{d}_j$ represent the vector coupling, axial-vector coupling, conjugate of the vector coupling, and conjugate of the axial-vector coupling constants, respectively.

$$G_+^{\text{SM}} = -2\sqrt{2}\,G_F\,s_W^2, \quad (3)$$

$$G_-^{\text{SM}} = \begin{cases} -2\sqrt{2}\,G_F\,\left(s_W^2 + \frac{1}{2}\right), & \text{for } \nu_e \\ -2\sqrt{2}\,G_F\,\left(s_W^2 - \frac{1}{2}\right), & \text{for } \nu_\mu, \nu_\tau \end{cases} \quad (4)$$

*Electronic address: `subhasis@cusb.ac.in`

in which G_F is the Fermi constant. The differential cross-section versus recoil energy for SM is shown in Figure 1.

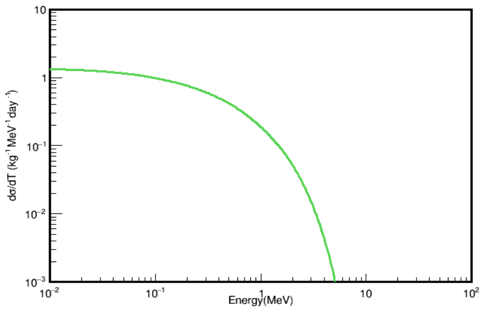

FIG. 1: Differential cross-section (E_ν^{ES}) versus electron recoil energy in the SM.

In Figure 1, the spectrum decreases monotonically with energy and vanishes above a few MeV, as expected in SM. At low energies ($E \lesssim 1$ MeV), where the rate is largest, potential new physics such as light mediators (new vector boson Z'), additional $U(1)$ gauge bosons, or a neutrino magnetic moment could produce observable deviations. Thus, precise measurement of the low-energy recoil spectrum provides a sensitive probe of BSM physics.

For BSM, differential cross-sections are calculated for W, Z, and $V^{(n)}$ exchanges adopting Reference [1]. Figure 2 shows the differential cross-section for W, Z, and $V^{(n)}$ exchanges with total BSM contribution.

Currently, we have calculated the differential cross sections for W, Z, and $V^{(n)}$ exchanges, as well as the total differential cross section for BSM scenarios. We are now working on the differential rate, $\frac{dR}{dT_e}$ where T_e is the recoil energy of electron. Our goal is to optimize the coupling constants c_j, d_j, $\tilde{c}_j$, and $\tilde{d}_j$ for the **T**aiwan **EX**periment **O**n **N**eutrin**O** (TEXONO) experiment by performing a standard χ^2 test statistics.

Discussions

Among the three mediators considered, the differential cross section for neutrino-electron elastic scattering is found to be largest for W boson exchange and smallest for $V^{(n)}$ boson exchange. For clarity, all spectra have been normalized, allowing a direct comparison of the relative contributions. The results shown in Figure 2 demonstrate the sequential increase of contributions from individual exchanges, culminating in the total BSM cross section. These observations highlight the role of different mediators in shaping the recoil spectrum and provide insight into possible new physics signatures.

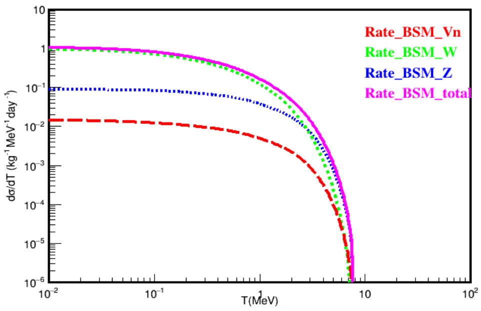

FIG. 2: Total differential cross-section for BSM including W, Z, and $V^{(n)}$ exchanges.

Acknowledgments

The authors acknowledge DST-FIST, DST-PURSE, and UGC-India for financial support.

References

[1] D. Chakraborty et al., Phys. Rev. D **110**, 095030 (2024).
[2] K. Asai et al., Prog. Theor. Exp. Phys. **2024**, 073E01 (2024).
[3] P. Bakhti et al., Phys. Rev. D **99**, 055019 (2019).
[4] V. De Romeri et al., Phys. Rev. D **100**, 095010 (2019).
[5] P. Ballett et al., J. High Energy Phys. **03**, 111 (2020).
[6] P. Coloma et al., Eur. Phys. J. C **81**, 78 (2021).