Constraints on Nonstandard Neutrino Interaction from Neutrino Electron Scattering

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Abstract.
Neutrino-electron scattering is a purely leptonic fundamental interaction and therefore provides an important channel to test the Standard Model (SM), especially at the low energy-momentum transfer regime [1, 2]. In this study Data on $\bar{\nu}_{\rm e} - {\rm e}$ and $\nu_{\rm e} - {\rm e}$ scattering from the TEXONO and LSND experiments, respectively, are used and constraints on neutrino Non-Stardard-Interactions (NSI) couplings depending on model-independent approaches, which are described by a four-Fermi point like interaction and depending on several beyond-Standard-Model-physics scenarios, mediated by massive intermediate particles including (1) an extra Z-prime gauge boson, (2) a new light spin-1 boson (NLS1B), (3) Dark Photon (DP), and (4) a charged Higgs boson (CHB), are placed via the neutrino-electron scattering channel to test the SM at a low energy-momentum transfer regime. The relevant parameter spaces are extended by allowing light mediators.

1. Introduction

NSI of neutrinos are important not only for phenomenological, but also for experimental point of view since the measurements and found evidences can suggest new physics or favor one of the existing new physics theories Beyond the Standard Model (BSM). The seesaw mechanisms, R-parity-violating supersymmetry (SUSY), TeV scale loop mechanisms, extra dimensions, and string theory are the most popular proposals attempting to answer these questions and explain the origin of neutrino mass. However, in the underlying new physics BSM, it is mostly expected that the structure of electroweak charged and neutral currents of the Standard Model (SM) would also change. Such changes in the neutrino sector lead to NSI of neutrinos. In many works on NSI, new interactions are generally mediated by new particles, which are assumed to be heavier than the electroweak scale. Hence, these are carried out in the form of effective four-fermion interaction at low energy. Furthermore, it is also possible mediated new particles can have relatively low masses.

2. Scalar, Pseudo-scalar and Tensorial NSI of Neutrino

Phenomenological studies of Flavor-Conserving (FC) and Flavor-Violating (FV) NSI of neutrino have been extensively carried out with a variety of interaction channels and neutrino sources. Experimentally new bounds for FC coupling of $\varepsilon_{\rm ee}^{\rm eL,R}$ and FV coupling of $\varepsilon_{\rm e\tau}^{\rm eL,R}$ NSI parameters were derived and existing bounds were improved in our earlier work by taking advantages of neglecting oscillation effects and high neutrino flux [1]. On the other hand, other NSI of neutrino are also possible which are scalar, pseudoscalar and spin-2 tensorial type [3]. Observing of NSI would imply the existence of right-handed neutrinos, therefore, it is an important channel to study new physics BSM. However, there are few studies exist on scalar, pseudoscalar or tensorial type NSI in the literature mainly due to motivation of V-A structure of SM and the assumption of their small contributions to the cross-section. The allowed region in $g_S^{e,e} - g_P^{e,e}$ parameter space and upper limits in $g_S^{e,e} - g_T^{e,e}$ and $g_P^{e,e} - g_T^{e,e}$ parameter spaces at 90% CL for TEXONO and LSND Experiments are displayed in Figure 1 and Figure 2, respectively.

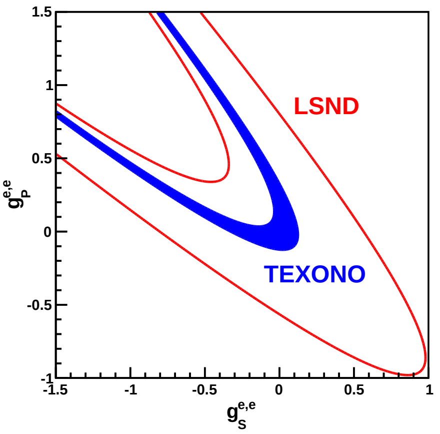

Figure 1. The allowed region in $g_S^{e,e} - g_P^{e,e}$ parameter space at 90% CL for TEXONO and LSND Experiments.

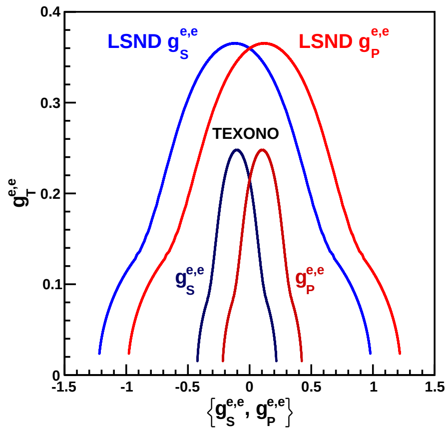

Figure 2. Upper limits in $g_S^{e,e} - g_T^{e,e}$ and $g_P^{e,e} - g_T^{e,e}$ parameter spaces at 90% CL for TEXONO and LSND Experiments.

3. Intermediate Bosons Beyod The Standard Model

3.1. Extra Z' gauge boson

The Z' gauge boson, the new gauge boson, was proposed as a theoretical particle resulting from the expansion of electroweak interactions in particle physics. Its name comes from the SM Z boson. New massive U(1) gauge bosons emerge in grand unified and superstring theories such as SO(10) and E_6, in theories of extra space-time dimensions of the SM gauge bosons. In this study, we will not restrict ourselves to SM gauge bosons. In fact, we will consider a possible new vector boson predicted in many extensions of the SM called the Z' gauge boson, which is a massive, electrically neutral and color-singlet hypothetical particle of spin-1 [4]. The lower limit for the mass of Z' at 95% C.L. for TEXONO experiment is shown in Figure 3.

3.2. Charged Higgs boson

Leptons, quarks and gauge bosons acquire their mass through the Higgs mechanism, while neutrinos still remain massless in the SM. In order to introduce and explain the smallness of neutrino masses without requiring an extra right-handed neutrino, one of the simplest models among other mechanisms is the Higgs triplet model (HTM), through which neutrinos gain their mass. In HTM, apart from the neutral scalar Higgs boson (h^0), there also appear singly charged (H^+) and doubly charged (H^{++}) ones, since Higgs triplets under the standard $SU(2)_L$ gauge group have two units of weak hypercharge [4]. The upper limit of coupling h_{ee} with respect to the mass of CHB M_H at 90% C.L. for low mass values for TEXONO and LSND Experiments are illustrated in Figure 4.

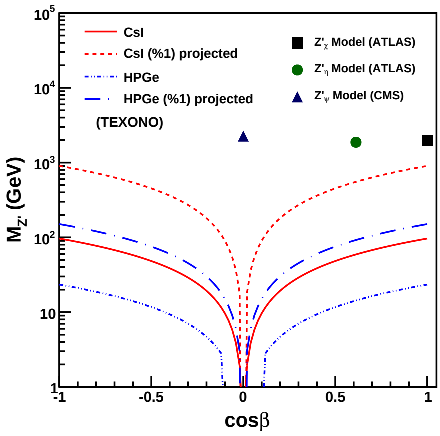

Figure 3. The lower limit for the mass of Z' at 95% C.L. Projected sensitivities by improving the experimental accuracies to % 1 are superimposed.

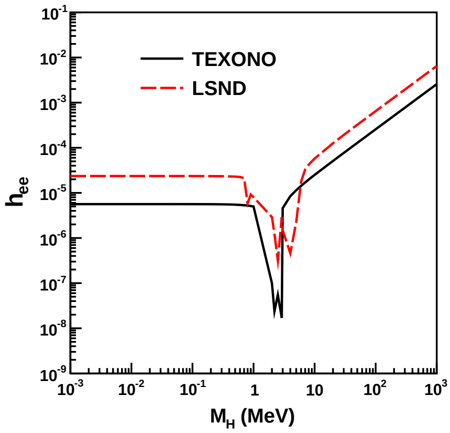

Figure 4. The upper limit of coupling h_{ee} with respect to the mass of CHB M_H at 90% C.L. for low mass values.

3.3. New light spin-1 boson

The exchange of new massive particles can be a possible origin of NSI of neutrinos, manifested as anomalies in the measurable total or differential cross sections. These massive particles, however, can be as light as in the order of a few MeV scale, which is the range of low-energy experiments. The NLS1B is one of the examples of such kinds of particles. A spin-1 particle could also be involved in explaining the NuTeV anomaly. In addition to this, the NLS1B may also explain the muon anomalous magnetic moment value. Moreover, spin-1 bosons can couple to dark matter and the nonbaryonic matter of the Universe in the MeV scale region. They could be responsible for the annihilation that is seen as the unexplained 511 keV gamma emissions anomaly from the galactic bulge. Furthermore, the NLS1B particle, which is lighter than b quarks, would explain the anomalous CP-violation in the mixing of neutral B-mesons [4]. FC NLS1B couplings of ε^L_{ee} vs ε^R_{ee} and FV NLS1B couplings of $\varepsilon^L_{e\mu(\tau)}$ vs $\varepsilon^R_{e\mu(\tau)}$ with various $m_X = 1, 2, 5, 25$ MeV are shown in Figure 5 and Figure 6, respectively.

3.4. Dark Photon

A possible manifestation of an additional light gauge boson A', named as Dark Photon, associated with a group $U(1)_{\rm B-L}$ is studied in neutrino electron scattering experiments. The exclusion plot on the coupling constant $g_{\rm B-L}$ and the dark photon mass $M_{A'}$ is obtained and shown in Fig. 7. It is shown that contributions of interference term between the dark photon and the Standard Model are important. The interference effects are studied and compared with for data sets from TEXONO, GEMMA, BOREXINO, LSND as well as CHARM II experiments. Our results provide more stringent bounds to some regions of parameter space [5]. The 90% C.L. bounds are defined by the GEMMA, BOREXINO, TEXONO-CsI, CHARM II ($\bar{\nu}_\mu$) experiments are displaced in Figure 7.

Acknowledgments

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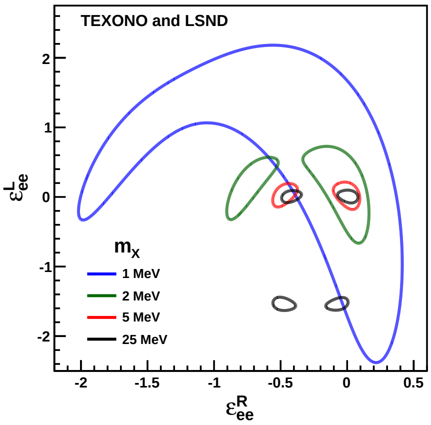

Figure 5. FC NLS1B couplings of ε^L_{ee} vs ε^R_{ee} with various m_X = 1, 2, 5, 25 MeV from outer to inner, respectively.

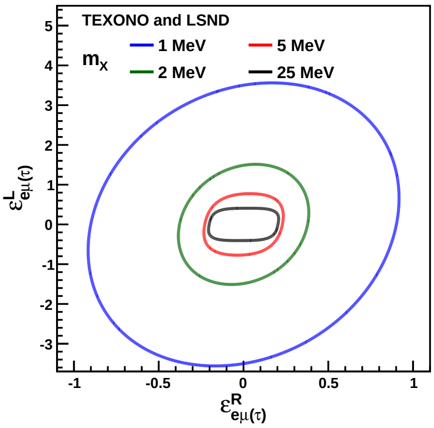

Figure 6. FV NLS1B couplings of $\varepsilon^L_{e\mu(\tau)}$ vs $\varepsilon^R_{e\mu(\tau)}$ with various m_X = 1, 2, 5, 25 MeV from outer to inner, respectively.

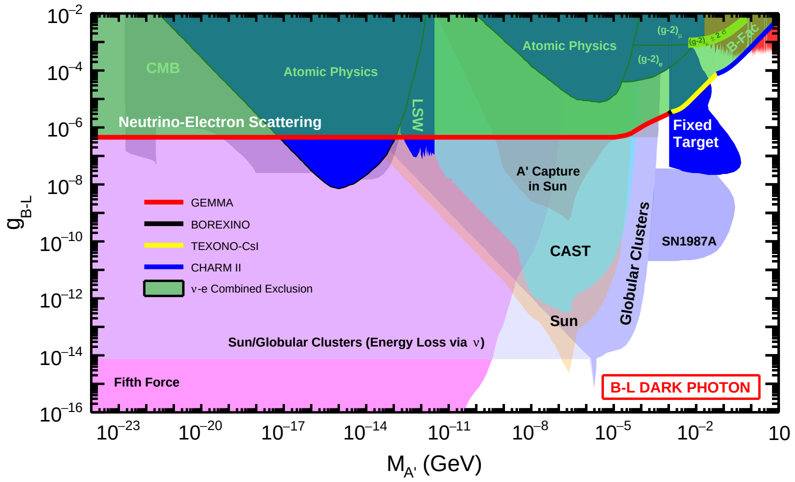

Figure 7. The current global exclusion plot of the bounds on the gauge coupling of the dark photon from different cosmological and astrophysical sources as well as laboratory experiments. The 90% C.L. bounds are defined by the GEMMA, BOREXINO, TEXONO-CsI, CHARM II ($\bar{\nu}_\mu$) experiments, from low to high $M_{A'}$.

References

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