Non-Standard Interactions in Neutral Current

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Introduction

Despite its vast success, there are still phenomena that Standard Model(SM) fails to explain [1]. For example, in neutrino experiments, new physics beyond the SM may appear in the form of unknown couplings, typically termed non-standard neutrino interactions (NSIs). NSI provides a general Effective Field Theory(EFT) style framework to explain such a process. In weak interactions, while the components of a specific model may vary, they commonly categorize as Charge Current (CC) NSI and Neutral Current(NC) NSI.

In weak sector, NSI has been studied by many authors in the past. However, most of the studies were centered around neutrino oscillation, their masses, and neutrino electromagnetic properties; the effects of NSI in $\nu - N$ interactions are still unexplored. Recently, Papoulias et al. [2] studied the cross-section within the framework of NSI. In this work, we extend the model of Ref. [2] to explore the effects of NSI in polarisation observables.

Formalism

The NC induced $\nu(\bar{\nu})$-elastic scattering can be put as:

$$\overset{(-)}{\nu}(k,0) + N(p,M) \rightarrow \overset{(-)}{\nu}(k',0) + N'(p',M), \quad (1)$$

where, the four momenta with their masses are given in parenthesis. The cross-section for the above reaction can be written as:

$$\sigma = \frac{G_F^2}{2}\int_{Q^2_{min}}^{Q^2_{max}} \frac{1}{64\pi M^2 E_\nu^2} \times \frac{\mathcal{N}}{2} dQ^2$$
$$\mathcal{N} = \mathcal{L}^{\mu\nu}\mathcal{J}_{\mu\nu}$$
$$= \mathcal{L}^{\mu\nu}\,\mathbf{Tr}\left[\mathrm{j}_\mu(\not{p}+\mathrm{M})\tilde{\mathrm{j}}_\nu(\not{p}'+\mathrm{M})\right] \quad (2)$$

where Q^2 is the four momentum square $[-(k-k')^2]$ with $(\mathcal{L}_{\mu\nu})$ as the leptonic tensor and the hadronic current j^μ is parameterised using the vector $(F_{1,2}^{p,n})$ and axial-vector $(F_A^{p,n})$ form factors. The explicit form of these form factors in presence of NSI [2] is given as:

$$F_{1,2}^{p,n}(Q^2) = \pm\frac{1}{2}[F_{1,2}^p(Q^2) - F_{1,2}^n(Q^2)]$$
$$- 2\sin^2\theta_w F_{1,2}^{p,n}(Q^2) \pm \epsilon^{p,n}(Q^2)$$
$$F_A^{p,n}(Q^2) = \pm\frac{1}{2}g_A\left(1+\frac{Q^2}{M_A^2}\right)^{-2} \quad (3)$$

where upper(lower) sign is for $p(n)$ target, and $\theta_w \sim 28.7^\circ$ is Weinberg angle. In vector form factor we include an extra term $\epsilon^{p,n}(Q^2)$ due to presence of NSI. For $p(n)$, they are written in terms of NSI neutrino quark couplings for u and d as:

$$\epsilon^p(Q^2) = (2\epsilon^u_{\mu e} + \epsilon^d_{\mu e})\left(1+\frac{Q^2}{M_V^2}\right)^{-2}$$
$$\epsilon^n(Q^2) = (\epsilon^u_{\mu e} + 2\epsilon^d_{\mu e})\left(1+\frac{Q^2}{M_V^2}\right)^{-2} \quad (4)$$

The coupling $(\epsilon^{u,d}_{\mu e})$, determines the strength of NSI. For the present work we chose $\epsilon^u_{\mu e} = \epsilon^d_{\mu e}$ in the range $[-0.05, 0.05]$ following the works of Ref. [2].

We extend the study in the polarisation sector, to see the effects of NSI due to spin asymmetry. The polarisation observable are constructed using the four-vector ζ^τ defined as [3, 4]:

$$\zeta^\tau = \frac{1}{\mathcal{N}}\mathcal{L}^{\alpha\beta}Tr[\gamma^\tau\gamma_5\Lambda(p')\Gamma_\alpha\Lambda(p)\tilde{\Gamma}_\beta\Lambda(p')].$$

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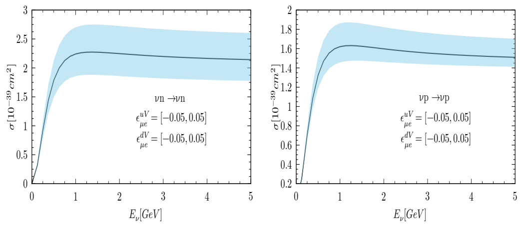

FIG. 1: Cross section(σ) vs neutrino energy E_ν. Shaded area represents the variation of quark couplings $\epsilon^{u,d}_{\mu e}$ in the range $[-0.05, 0.05]$. Solid line represents results from SM.

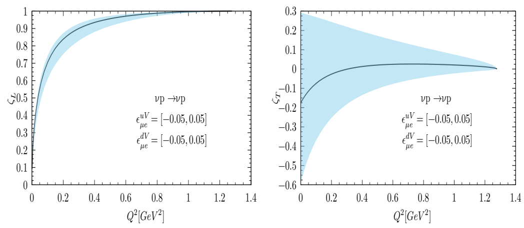

FIG. 2: Q^2 distribution of $\zeta_{L,T}$ for $\nu p \to \nu p$ reaction. Notations as in Fig. 1.

The plane of polarisation are chosen such that, in the rest frame of $\vec{\zeta}$, the longitudinal(transverse) components $\zeta_L(\zeta_T)$ may be expressed as:

$$\vec{\zeta} = \zeta_L \hat{p}' + \zeta_p \hat{e}_p;$$
$$\hat{e}_p = \hat{p}' \times \frac{(\vec{p}' \times \vec{k})}{|\vec{p}' \times \vec{k}|)} \quad (5)$$

while the explicit expressions for $\zeta_L(Q^2)$ and $\zeta_p(Q^2)$ are given in Ref. [4] in terms of the form factors $F_{1,2}$ and F_A for CC interactions.

Results and Discussion

We obtained the total cross section for NC process as given in 1, using Eq. 2. The results are in agreement with Ref. [2]. The other channels (not shown here) also follows the similar trend. In Fig. 1, for n-target the variation due to NSI is $\sim 20\%$, the other shows a slightly mild variation at $E_\nu \sim 5GeV$. However, the effects get cancelled in polarisation observable (not shown) when we integrate over Q^2. Surprisingly, the Q^2–variation shows strong dependence over NSI parameters, see eg. Figs 2 and 3. In Fig. 2, we show the Q^2 dependence of longitudinal (ζ_L) and transverse (ζ_T) polarisation at $E_\nu = 1$GeV, where the ζ_L shows a mild effect, ζ_T shows a strong effect due to NSI specially at low Q^2. On the other hand, in the anti-neutrino sector, mid Q^2 region seems to be more sensitive to NSI parameters.

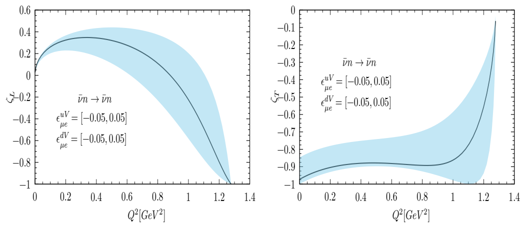

FIG. 3: Q^2 distribution of $\zeta_{L,T}$ for $\bar{\nu} n \to \bar{\nu} n$ reaction. Notations as in Fig. 1.

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