Non-standard interactions in neutral current ν-N scattering

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Introduction

The Standard Model of particle physics is a theoretical framework that successfully explains a range of interactions. However, it must be extended to explain neutrino oscillations. In the weak sector, the framework commonly known as non-standard interactions (NSI) accounts for potential deviations from the SM predictions. It provides a general effective field theory (EFT) style framework that leads to "new physics" in the neutrino sector. Similar to the SM, the NSI Lagrangian can broadly classified as charge current (CC) NSI and neutral current (NC) NSI, which are new vector interactions between neutrinos and matter fields induced by either a vector or charged-scalar mediator [1]. Recently, Papoulias et al [2] studied the neutral current elastic cross-section within the framework of NSI. We extend the model of Ref. [2] to incorporate the NSI parameters with the well-known electromagnetic form factors such that the Q^2 dependence comes naturally and respects the isospin symmetry.

Formalism and Discussion

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

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

where $N(\equiv p,n)$ stands for the nucleon, and the corresponding four momenta with their masses are given in parenthesis. The effective four-fermion NSI Lagrangian for Eq. (1) is given by

$$\mathcal{L}^{\rm NC}_{\rm NSI} = -2\sqrt{2} G_F \epsilon^{fX}_{\alpha\beta} (\bar{\nu}^\alpha \gamma_\mu P_L \nu^\beta)(\bar{f}\gamma^\mu P_X f)\,, \tag{2}$$

where the projectors $P_{X=L,R} = (1 \mp \gamma_5)/2$. The NC NSI couplings are denoted by $\epsilon^{fX}_{\alpha\beta}$ where $\alpha, \beta = e\,, \mu\,, \tau$ are neutrino flavor indices which can be flavor diagonal $\alpha = \beta$ or flavor changing $\alpha \neq \beta$ and G_F is the Fermi constant. Therefore, the effective Lagrangian encompassing both SM and NSI can be written as:

$$\mathcal{L}^{\rm NC}_{\rm SM+NSI} = -\frac{G_F}{\sqrt{2}} L^{\alpha\beta}_\mu J^\mu_{\alpha\beta}\,. \tag{3}$$

The differential cross-section for the above reaction can be written as:

$$\frac{d\sigma}{dQ^2} = \frac{1}{64\pi M^2 E_\nu^2} \frac{G_F^2}{4} \overline{\sum}\sum |\mathcal{M}|^2\,, \tag{4}$$

and its corresponding scattering amplitude is

$$\mathcal{M} = \frac{G_F}{\sqrt{2}} L^{\alpha\beta}_\mu \langle N; p'|J^\mu_{\alpha\beta}|N;p\rangle\,, \tag{5}$$

where the explicit form of leptonic tensor($L^{\alpha\beta}_\mu$) and hadronic tensor($J^\mu_{\alpha\beta}$) is given by

$$L^{\alpha\beta}_\mu = \bar{\nu}^\alpha \gamma_\mu (1-\gamma_5)\nu^\beta\,, \tag{6}$$

and

$$\langle N; p'|J^\mu_{\alpha\beta}|N;p\rangle = \bar{u}(p')\Gamma^\mu_{\alpha\beta} u(p)\,. \tag{7}$$

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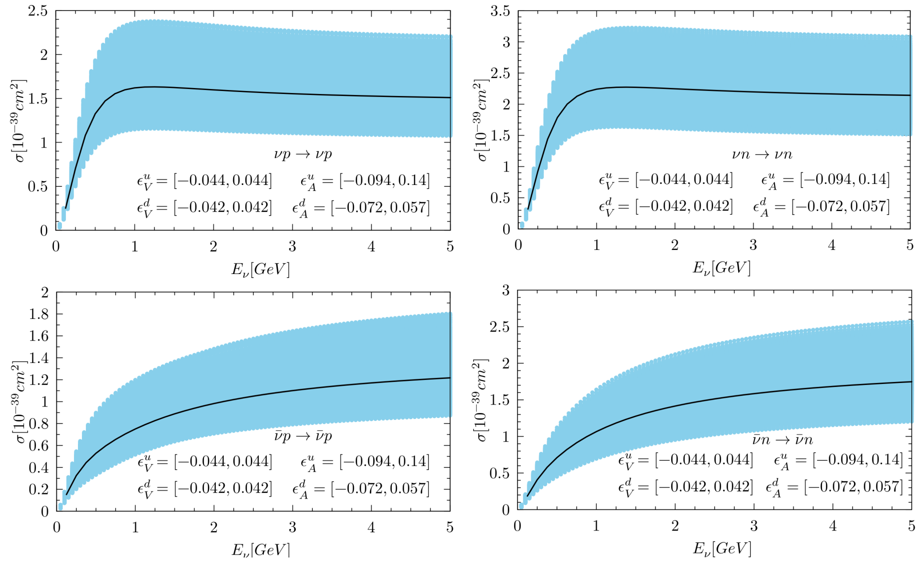

FIG. 1: Total cross section vs incoming neutrino energy(E_ν). Black solid line represents results from the SM. Shaded area represents the variation of quark couplings $\epsilon^{u,d}_{V,A}$ in the range shown in figure.

For the present analysis, we consider only the flavour diagonal cases, i.e. $\alpha = \beta$. We, therefore, drop the flavour indices α and β in the rest of the discussion. This enables us to write the Γ_μ in terms of weak vector($\tilde{F}^N_{1,2}$) and axial-vector form factors($\tilde{F}_A$):

$$\Gamma_\mu = \tilde{F}^N_1(Q^2)\gamma^\mu + i\frac{\tilde{F}^N_2(Q^2)}{2M}\sigma^{\mu\nu}q_\nu - \tilde{F}_A(Q^2)\gamma^\mu\gamma_5\,, \qquad N \equiv n, p\,; \qquad (8)$$

where the explicit form of these form factors in the presence of NSI is parameterized using the electromagnetic vector form factors $F^{p,n}_{12}$ and charged current axial form factor F_A and NSI quark couplings $\epsilon^{u,d}_{V,A}$. One should note that unlike Ref. [2], where Q^2 dependence was taken in an ad-hoc way, the present formalism ensures Q^2 dependence shaped by the known form factors $\tilde{F}^{p,n}_{12}$ and $\tilde{F}_A$. Due to lack of space, the details will be given elsewhere. The allowed ranges of NSI vector and axial couplings are taken from Ref. [3].

The results of the total cross section($\sigma(E_\nu)$) are obtained using Eq. (4) and are shown in Fig. (1). The black solid line represents the results from SM. The blue-shaded region shows the variations due to the presence of NSI couplings. We can see that both ν and $\bar{\nu}$-induced process at $E_\nu = 5$GeV, shows the variation due to NSI around $\sim 30\%$, which shows strong dependence of total cross section over NSI parameters.

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