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Exploring generalized neutrino interactions at the COHERENT experiment

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We study the potential to probe *generalized neutrino interactions* (GNI), exotic effective couplings due to new physics interactions beyond the Standard Model, in the coherent-elastic neutrino-nucleus scattering experiments considering the latest COHERENT data. Here we aim to study scalar, vector, and tensor flavored-GNI parameters. We have performed a combined analysis to constrain these exotic couplings for the COHERENT CsI and LAr detector. Finally, contribution arising from the forthcoming reactor-based Scintillating Bubble Chamber detector has also been added to examine these couplings. We have observed that the addition of reactor data strongly constrained electron flavor GNI.

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Introduction: In this work, we aim to investigate the impact of exotic interactions (namely scalar, vector, and tensor interactions) that appear in the form of physics beyond the Standard Model (SM) in the coherent-elastic neutrino-nucleus scattering (CEνNS) experiments [1]. In literature, these exotic interactions are commonly referred to as *generalized neutrino interactions* (GNI). These new interactions modify the SM effective couplings and eventually change the measurements of the SM weak-interaction differential cross-section.

The COHERENT collaboration has published their results using cesium-iodide (CsI) detector in [2, 3], and the measurement of CEνNS process using CENNS-10 liquid argon detector are discussed in [4, 5]. It is very important to study this process because of its ability to probe the SM parameters at low momentum transfer as well as various new physics beyond the SM. The CEνNS process is very well understood in the SM which is induced by the exchange of Z boson [6]. In order to have such scattering, the product of three-momentum transfer ($|\vec{q}|$) and nuclear radius (R) should satisfy ($|\vec{q}|R \ll 1$), which needs neutrino energies below 50 MeV. This is the major challenge that scattering experiments face to observe nuclear recoils with a very small kinetic energy ($\sim$ keV).

Motivated by the latest COHERENT measurements combined analyses of the CsI, and LAr data are made in order to examine GNI parameters. We perform a detailed numerical analysis to constrain and understand these parameters in a model-independent way, which allows one to study various new physics models that can be accepted or rejected in the near future. In addition, we also study the potential of forthcoming reactor-based CEνNS experiment from the Scintillating Bubble Chamber (SBC) Collaboration [7].

CEνNS in presence of GNI: In order to examine the role of GNI at CEνNS process, one needs to find how the differential cross-section changes in presence of GNI. The differential cross-section in presence of GNI at leading order is given by [8]

$$\begin{aligned}\left(\frac{d\sigma}{dE_r}\right)^f &= \frac{G_F^2}{4\pi} M_N N^2 F^2(Q^2)\times \\ &\left[\xi_S^{f\,2}\frac{E_r}{E_r^{\max}} + (\xi_V^f + A_{\rm SM})^2\left(1-\frac{E_r}{E_r^{\max}}-\frac{E_r}{E_\nu}\right) \pm 2\xi_V^f\xi_A^f\frac{E_r}{E_\nu}\right. \\ &\left. + \xi_A^{f\,2}\left(1+\frac{E_r}{E_r^{\max}}-\frac{E_r}{E_\nu}\right) + \xi_T^{f\,2}\left(1-\frac{E_r}{2E_r^{\max}}-\frac{E_r}{E_\nu}\right) \mp R\frac{E_r}{E_\nu} + \mathcal{O}\left(\frac{E_r^2}{E_\nu^2}\right)\right],\end{aligned} \tag{1}$$

where the SM contribution is given by $A_{\rm SM} = 1-(1-4\sin^2\theta_w)Z/N$ and E_r is the recoil energy of the nucleus with $E_r^{\max} = 2E_\nu^2/M_N$, and

$$\begin{aligned}\xi_S^{f\,2} &= \frac{1}{N^2}(C_S^2+D_P^2), \quad \xi_V^f = \frac{1}{N}(C_V-D_A), \\ \xi_A^f &= \frac{1}{N}(C_A-D_V), \quad \xi_T^{f\,2} = \frac{8}{N^2}(C_T^2+D_T^2), \\ R &= \frac{2}{N^2}(C_SC_T - C_PC_T + D_SD_T - D_PD_T).\end{aligned} \tag{2}$$

Here, ξ_X's (for $X = S, V, A, T$) represent scalar (S), vector (V), axial-vector (A), and tensor (T) interactions for a lepton flavor f, respectively, while R being an interference term. To analyze the impact of these GNI terms individually, we do not consider any interference terms in our analysis.

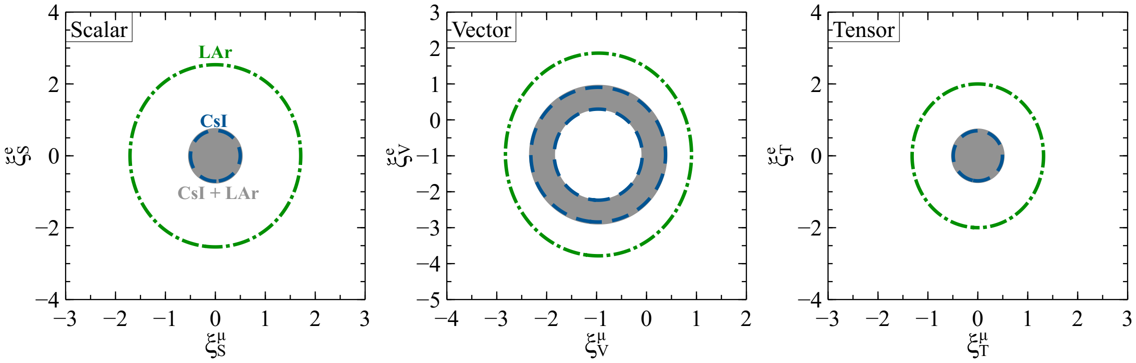

Figure 1: Allowed regions in the $\xi_X^e - \xi_X^\mu$ flavored GNI parameter plane at 90% confidence level. The regions shown by the dashed-blue and dotted-dashed green curves arises from the COHERENT-CsI and LAr measurements, respectively. Their combined limit is described by the gray region.

Moreover, one can recover the SM limit by setting $\xi_S, \xi_V, \xi_A, \xi_T = 0$. We point out here that the axial-vector current and interference term R of Eq. (1) are the two term that come with opposite signs in the $\nu(\overline{\nu}) - N$ cross-section. Since in this study we are not analyzing the impact of both these terms, in our numerical analysis we can safely assume equal cross-section for both neutrinos and anti-neutrinos.

Results: In order to constrain the GNI parameters ξ_X^f using the available experimental data from COHERENT, we perform a χ^2 analysis considering different scenarios. A detailed numerical procedure that has been adopted can be found in [9]. Here we discuss the case with two non-zero parameters at a time. We aim to examine the correlation between parameters with the same structure (S, V, T) but with different lepton flavors (e, μ). We show our results at 90% confidence level in Fig. 1. It has been found that the scalar and tensor interactions show similar behavior, however, the tensor interactions are the most constrained by the COHERENT measurements. For vector interactions, a continuous degenerate region has been observed for the COHERENT-CsI and the combined study. In order to break these continuous degenerate solutions, we combine the COHERENT data with the projected measurements of reactor CEνNS experiments. The SBC is a liquid-noble scintillating bubble chamber detector capable of achieving a 100 eV energy threshold and can reduce background very significantly, given its blindness to electron recoils. Currently, the collaboration is building a 10-kg LAr chamber which is planned to be set at 3 m from the 1-MW$_{th}$ TRIGA Mark III research reactor at the National Institute for Nuclear Research (ININ).

As a final step in our GNI analysis in CEνNS experiments, the current COHERENT data has been combined with the upcoming sensitivities of the SBC-CEνNS detector. Since the latter will be sensitive only to the ξ_X^e parameters, it has been decided to perform an analysis by taking two parameters different from zero at a time. In Fig. 2 we have shown the allowed region of this combined analysis at $1, 2$, and 3σ confidence level, respectively. For comparison, we have also presented the allowed parameter space for the combined COHERENT data. We find that the allowed regions are tightly constrained for the electron flavor due to the inclusion of simulated SBC-CEνNS data. The noteworthy result is expected in the vector interactions, where we notice four-fold discrete degeneracies (see blue contours in the middle panel).

Conclusions: We have performed an analysis to study generalized neutrino interactions (GNI)

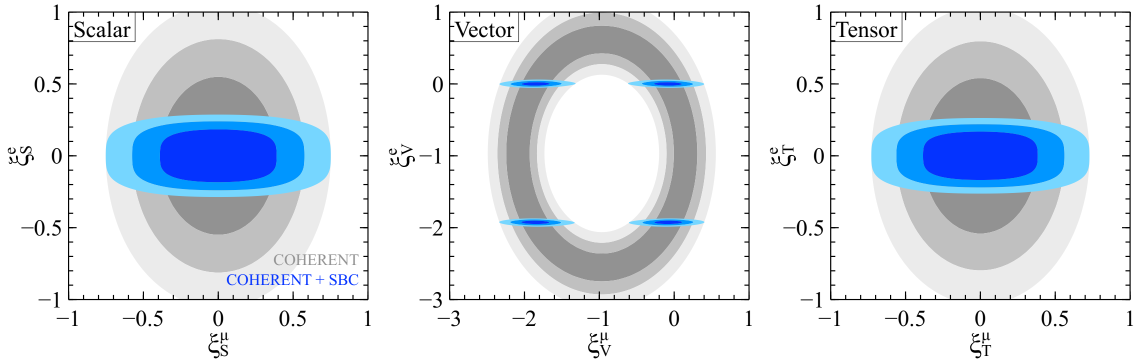

Figure 2: Allowed regions for the scalar, vector and tensor GNI parameters in the $\xi_X^\mu - \xi_X^e$ plane at 1σ, 2σ, and 3σ C.L. The gray-scale regions correspond to the limits obtained from the COHERENT measurements, whereas the blue-scale regions arise from the combination of COHERENT and the expected sensitivities of the SBC-CEνNS detector.

in light of the recent COHERENT-CsI and LAr data. Here we have concentrated on electron and muon flavored GNI. A chi-square analysis has been performed to constrain these GNI parameters. Later, we have also combined the simulated data arising from the planned SBC-CEνNS experiment. We have observed from the combined analysis of COHERENT data that (see Fig. 1 and 2) the allowed parameter space of GNI parameters remain almost the same as in the case of the CsI detector alone. On the other hand, we have found that the addition of SBC-CEνNS data significantly improved our results due to its intense flux, low threshold, and highly-suppressed background.

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