Published by Institute of Physics Publishing for SISSA
Received: *September 7, 2005*
Revised: *November 15, 2005*
Accepted: *November 24, 2005*
Published: *December 12, 2005*

Probing new physics with coherent neutrino scattering off nuclei

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Abstract: The possibility off measuring for the first time neutrino-nuclei coherent scattering has been recently discussed by several experimental collaborations. It is shown that such a measurement may be very sensitive to non-standard interactions of neutrinos with quarks and might set better constraints than those coming from future neutrino factory experiments. We also comment on other types of new physics tests, such as extra heavy neutral gauge bosons, where the sensitivity to some models is slightly better than the Tevatron constraint and, therefore, could give complementary bounds.

Keywords: Neutrino Physics, Neutrino Detectors and Telescopes, Beyond Standard Model.

Contents

1. Introduction

Coherent neutrino-nucleus [1] and neutrino-atom [2, 3] scattering have been recognized for many years as interesting processes to probe the standard model (SM). A very attractive feature of such processes is the enhancement of the cross section and perhaps, more intriguingly, the fact that neutrinos can scatter coherently not only on the nucleons inside nucleus but also on the atom itself, including electrons.

The coherent scattering takes place when momentum transfer, q, is small compared with the inverse nucleus or atom size, $qR \leq 1$. For most nuclei the typical inverse sizes are in the range from 25 to 150 MeV. Therefore the condition for full coherence in the neutrino-nuclei scattering is well satisfied for reactor neutrinos and also for solar, supernovae neutrinos and artificial neutrino sources.

Currently, TEXONO collaboration has been considering the possibility of detecting for the first time the coherent neutrino nucleus scattering [4]. They have also pointed out that the detection of this process will be helpful to improve the limits on the neutrino magnetic moment. The NOSTOS collaboration is also attempting to detect this scattering and they have plans to use this reaction for supernovae neutrino detection [5].

In this work we will show that coherent neutrino nuclei scattering is very sensitive to other types of physics beyond the standard model such as non-standard neutrino interactions (NSI) or additional neutral gauge bosons, and may give constraints that are competitive with future neutrino factories. At present, NSI involving neutrinos are allowed to be big [6 – 8]. Moreover, NSI have been studied in the context of solar neutrino data [9, 10] where it has been recently found that a large value of non-universal NSI for the neutrino interaction with the d-type quark is not only allowed but also leads to new solutions to the solar neutrino data [11]. In the atmospheric case, although a two families analysis [12] gives strong constraints, the three family case [13] showed that NSI interactions can be big.

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Coherent neutrino nuclei processes are playing an important role in astrophysical environments like supernovae and neutron stars [14]. Moreover, it was recently discussed that the inclusion of non-standard neutrino interactions may alter supernovae explosion [15].

A new experimental proposal able to test large NSI parameters may forbid new solutions to the solar neutrino data and constraint these parameters that naturally appear in many extensions of the Standard Model. It is therefore of great interest to develop such experiments. We will show in this article that indeed this measurement may put strong constraints to d type NSI. We will also go one step further in this analysis to show that it would be possible to constrain simultaneously u and d type NSI if we consider two different coherent scattering experiments with two different targets such as germanium and silicon.

The paper is organized as follows. In the section 2 we present the coherent neutrino-nuclei cross sections including non-standard interaction contributions. In the section 3 we estimate the expected sensitivity of the proposed experiments and we present possible ways to improve the sensitivity. Discussion and summary are given in the last section 4.

2. Non-standard contributions to neutrino-nucleus coherent scattering

NSI appears in many extensions of the Standard Model. For instance, in $\nu_e d$ scattering we can have additional non-universal and flavor changing contributions to the cross section if we consider models with broken R parity, in which case we can have a ν_τ in the final state due to a squark exchange [16] . Actually, this is just an example, but the violation of the GIM mechanism arises naturally when considering massive neutrinos [17] and NSI appears also in the context of the solar neutrino analysis [18], Supersymmetry [19], models of neutrino mass [20] etc.

In this article we parametrize the NSI contribution by using a typical phenomenological description so that, at the four-fermion approximation (energies $\ll M_Z$) the neutrino NSI with u and d quarks can be described by the effective lagrangian

$$\mathcal{L}_{\nu \text{Hadron}}^{NSI} = -\frac{G_F}{\sqrt{2}} \sum_{\substack{q=u,d \\ \alpha,\beta=e,\mu,\tau}} \left[\bar{\nu}_\alpha \gamma^\mu (1-\gamma^5) \nu_\beta\right] \left(\varepsilon_{\alpha\beta}^{qL} \left[\bar{q}\gamma_\mu (1-\gamma^5) q\right] + \varepsilon_{\alpha\beta}^{qR} \left[\bar{q}\gamma_\mu (1+\gamma^5) q\right] \right), \tag{2.1}$$

where the parameters $\varepsilon_{\alpha\beta}^{qP}$ ($q = u, d$ and $P = L, R$) describe non-standard neutrino interactions, both for the non-universal (NU) terms, $\varepsilon_{\alpha\alpha}^{qP}$, as well as for the flavor-changing (FC) contributions, $\varepsilon_{\alpha\beta}^{qP}$ ($\alpha \neq \beta$). After adding the SM lagrangian we will get the expression

$$\mathcal{L}_{\nu \text{Hadron}}^{NC} = -\frac{G_F}{\sqrt{2}} \sum_{\substack{q=u,d \\ \alpha,\beta=e,\mu,\tau}} \left[\bar{\nu}_\alpha \gamma^\mu (1-\gamma^5) \nu_\beta\right] \left(f_{\alpha\beta}^{qL} \left[\bar{q}\gamma_\mu (1-\gamma^5) q\right] + f_{\alpha\beta}^{qR} \left[\bar{q}\gamma_\mu (1+\gamma^5) q\right] \right), \tag{2.2}$$

where the NSI parameters have been added to the SM effective coupling constants:

$$f_{\alpha\alpha}^{uL} = \rho_{\nu N}^{NC} \left(\frac{1}{2} - \frac{2}{3} \hat{\kappa}_{\nu N} \hat{s}_Z^2 \right) + \lambda^{uL} + \varepsilon_{\alpha\alpha}^{uL} ,$$
$$f_{\alpha\alpha}^{dL} = \rho_{\nu N}^{NC} \left(-\frac{1}{2} + \frac{1}{3} \hat{\kappa}_{\nu N} \hat{s}_Z^2 \right) + \lambda^{dL} + \varepsilon_{\alpha\alpha}^{dL} ,$$

$$
\begin{aligned}
f_{\alpha\alpha}^{uR} &= \rho_{\nu N}^{NC}\left(-\frac{2}{3}\hat{\kappa}_{\nu N}\hat{s}_Z^2\right) + \lambda^{uR} + \varepsilon_{\alpha\alpha}^{uR}, \\
f_{\alpha\alpha}^{dR} &= \rho_{\nu N}^{NC}\left(\frac{1}{3}\hat{\kappa}_{\nu N}\hat{s}_Z^2\right) + \lambda^{dR} + \varepsilon_{\alpha\alpha}^{dR}
\end{aligned} \tag{2.3}
$$

and

$$
f_{\alpha\beta}^{qP} = \varepsilon_{\alpha\beta}^{qP}, \qquad (\alpha \neq \beta;\ q = u, d;\ P = L, R). \tag{2.4}
$$

Here $\hat{s}_Z^2 = \sin^2\theta_W = 0.23120$, $\rho_{\nu N}^{NC} = 1.0086$, $\hat{\kappa}_{\nu N} = 0.9978$, $\lambda^{uL} = -0.0031$, $\lambda^{dL} = -0.0025$ and $\lambda^{dR} = 2\lambda^{uR} = 7.5 \times 10^{-5}$ are the radiative corrections given by the PDG [28]. In the case of absence of NSI, $\varepsilon_{\alpha\beta}^{qP} = 0$, the lagrangian (2.2) coincides with the SM one.

From the lagrangian in eq. (2.2) we can obtain the neutrino-nucleus differential cross section which is given by

$$
\frac{d\sigma}{dT} = \frac{G_F^2 M}{2\pi}\left\{(G_V + G_A)^2 + (G_V - G_A)^2\left(1 - \frac{T}{E_\nu}\right)^2 - (G_V^2 - G_A^2)\frac{MT}{E_\nu^2}\right\}, \tag{2.5}
$$

where M is the mass of the nucleus, T is the recoil nucleus energy, which varies from 0 to $T_{max} = 2E_\nu^2/(M + 2E_\nu)$, E_ν is the incident neutrino energy and

$$
G_V = \left[\left(g_V^p + 2\varepsilon_{ee}^{uV} + \varepsilon_{ee}^{dV}\right)Z + \left(g_V^n + \varepsilon_{ee}^{uV} + 2\varepsilon_{ee}^{dV}\right)N\right]F_{nucl}^V(Q^2)\,, \tag{2.6}
$$

$$
G_A = \left[\left(g_A^p + 2\varepsilon_{ee}^{uA} + \varepsilon_{ee}^{dA}\right)(Z_+ - Z_-) + \left(g_A^n + \varepsilon_{ee}^{uA} + 2\varepsilon_{ee}^{dA}\right)(N_+ - N_-)\right]F_{\rm nucl}^A(Q^2)\,. \tag{2.7}
$$

Z and N represent the number of protons and neutrons in the nucleus, while $Z_\pm$ ($N_\pm$) stands for the number of protons (neutrons) with spin up and spin down respectively. The vector and axial nuclear form factors, $F_{nucl}^V(Q^2)$ and $F_{nucl}^A(Q^2)$, are usually assumed to be equal and of order of unity in the limit of small energies, $Q^2 \ll M^2$.

The SM neutral current vector couplings of neutrinos with protons, g_V^p, and with neutrons, g_V^n, are defined as

$$
\begin{aligned}
g_V^p &= \rho_{\nu N}^{NC}\left(\frac{1}{2} - 2\hat{\kappa}_{\nu N}\hat{s}_Z^2\right) + 2\lambda^{uL} + 2\lambda^{uR} + \lambda^{dL} + \lambda^{dR}\,, \\
g_V^n &= -\frac{1}{2}\rho_{\nu N}^{NC} + \lambda^{uL} + \lambda^{uR} + 2\lambda^{dL} + 2\lambda^{dR}\,.
\end{aligned} \tag{2.8}
$$

The axial couplings can be obtained in an analogous way.

In eq. (2.5) we have included explicitly only the non-universal NSI terms; the computation of the cross section for flavor-changing case is straightforward.

From eq. (2.5) we conclude that we can neglect axial contributions in coherent neutrino-nuclei interactions since for most of the nuclei the ratio of axial to vector contributions is expected to be of order of $1/A$.[1] Therefore such types of experiments will be sensitive mainly to vector couplings, $\varepsilon_{\alpha\beta}^{qV} = \varepsilon_{\alpha\beta}^{qL} + \varepsilon_{\alpha\beta}^{qR}$, but not to axial ones, $\varepsilon_{\alpha\beta}^{qA} = \varepsilon_{\alpha\beta}^{qL} - \varepsilon_{\alpha\beta}^{qR}$, which is similar to the case of solar neutrinos.

[1] There are some cases were the axial terms may have some importance, such as in the scattering off hydrogen or nuclei with high spin [2].

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An explicit cancellation of all axial terms will give a better sensitivity to vector couplings. Therefore, we will focus our study on nuclei with even numbers of protons and neutrons with vanishing total spin, and we will assume that the total spins of protons and neutrons, separately, are also zero.

After some algebra and applying the assumptions already discussed, the cross section of electron anti-neutrino coherent scattering off a nucleus in the low energy limit, $T \ll E_\nu$, is given by

$$\frac{d\sigma}{dT}(E_\nu, T) = \frac{G_F^2 M}{\pi}\left(1 - \frac{MT}{2E_\nu^2}\right)\left\{\left[Z(g_V^p + 2\varepsilon_{ee}^{uV} + \varepsilon_{ee}^{dV}) + N(g_V^n + \varepsilon_{ee}^{uV} + 2\varepsilon_{ee}^{dV})\right]^2 + \right.$$
$$\left. + \sum_{\alpha=\mu,\tau}\left[Z(2\varepsilon_{\alpha e}^{uV} + \varepsilon_{\alpha e}^{dV}) + N(\varepsilon_{\alpha e}^{uV} + 2\varepsilon_{\alpha e}^{dV})\right]^2\right\}. \quad (2.9)$$

In the next section we will use this expression to compute the expected number of events for different detectors.

3. Experimental sensitivity to NSI couplings

Experimental detection of coherent neutrino scattering has not yet been achieved. Several possible methods of detecting neutrino-nucleus coherent scattering have been previously discussed using superconducting [21], acoustic [22], cryogenic [23], and gas detectors [24, 5]. Recently, an ultra low energy germanium detector has been proposed by the TEXONO Collaboration [4]. They plan to achieve a sub-keV threshold with a kg-scale detector.

In this section we demonstrate the sensitivity to NSI coming from the coherent neutrino-nuclei scattering. In order to apply our analysis to a concrete case, we will concentrate our discussion on the germanium TEXONO proposal [4]. The detector would be located at the Kuo-Sheng Nuclear Power Station at a distance of 28 m from the reactor core. We asume a typical neutrino flux of 10^{13} s^{-1} cm^{-2}. There are several parametrizations that consider in detail the neutrino spectrum coming from a reactor [25], depending on the fuel composition. In this work we prefer to consider only the main component of the spectrum [26] coming from ^{235}U, since the experiment is not running yet. For energies below 2 MeV there are only theoretical calculations for the antineutrino spectrum that we take from ref. [27].

Besides the TEXONO proposal, we will also discuss the more theoretical case of a silicon detector in order to illustrate the potential of a combined analysis of two different materials.

3.1 The detector

If we neglect for a moment the detector efficiency and resolution, we can estimate the total number of expected events in a detector as

$$N_{\text{events}} = t\phi_0 \frac{M_{\text{detector}}}{M} \int_{E_{\min}}^{E_{\max}} dE_\nu \int_{T_{th}}^{T_{\max}(E_\nu)} dT \lambda(E_\nu) \frac{d\sigma}{dT}(E_\nu, T)\,, \quad (3.1)$$

with t the data taking time period, ϕ_0 the total neutrino flux, M_{detector} the total mass of the detector, $\lambda(E_\nu)$ the normalized neutrino spectrum, $E_{\max}$ the maximum neutrino energy, T_{th} the detector energy threshold. One can see that the minimum required incoming neutrino energy depends on the detector threshold T_{th} and the nucleus mass M through the relation $T_{th}(E_\nu) = 2E_\nu^2/(M + 2E_\nu)$. For instance, for a 400 eV detector's threshold and a ^{76} Ge nucleus, the minimum required incoming neutrino energy is $E_{\min} = 3.8\,\text{MeV}$, which is well satisfied by reactor neutrinos.

One can see from eq. (2.9) that, since the number of NSI parameters is big, there are cancellations among them and therefore a degeneracy in their determination, both for non-universal and for flavor changing cases.

Although in many cases it is convenient to reduce the number of parameters (by neglecting the u type NSI, for example), we will demonstrate that it is possible to minimize the degeneracy by choosing particular nuclei. We will introduce in the following a simple criteria to find such detectors.

Let's consider first the case of non-universal NSI parameters, ε_{ee}^{qV}, assuming that flavor changing parameters are negligible, $\varepsilon_{\alpha e}^{qV} = 0$, $\alpha \neq e$. One can easily see that ε_{ee}^{uV} and ε_{ee}^{dV} are related as

$$\varepsilon_{ee}^{uV}(A+Z) + \varepsilon_{ee}^{dV}(A+N) = \text{const}\,. \tag{3.2}$$

The slope of the curve on the plane $(\varepsilon_{ee}^{uV}, \varepsilon_{ee}^{dV})$ is described by the ratio $k = (A+N)/(A+Z)$. It is clear therefore that, in order to constrain both parameters efficiently, two criteria should be taken into account:

- one should choose at least two different nuclei, for which the parameter k is maximally different;
- one should choose nuclei for which the number of expected events is larger.

In contrast to naive expectations the second criteria is non-trivially related with the mass of nucleus, since the maximum recoil energy, $T_{\max}$, also depends on nucleus mass.

These arguments are illustrated in figure 1 where we consider the expected number of events for a one kg detector, after one year of data taking, with either 100 eV or 400 eV threshold. In this figure we show iso-curves of equal number of events depending on the number of protons and neutrons of the nuclei. We show in the same plot some nuclei that have been considered as possible detectors in the literature. Also, as an illustration, lines for $k = 1$ and $k = 1.15$ are shown. From this plot it is easy to see that germanium is actually a good material for this kind of experiments since it lies in a region where the expected number of events is high and the k parameter is big. We can also see that silicon could have a comparable number of events and the smallest possible value $k = 1$. Although at present there is no experimental proposal to use such a material, we will also consider it in our analysis since the theoretical expectations of having complementary information from it are very tempting.

Although in the following sections we will discuss both the case of ^{28}Si ($k = 1$) as well as ^{76}Ge ($k \approx 1.11$) [4], it is also important to note that the computations in figure 1 were done for a fixed detector mass. Therefore, although in our plot the expected number

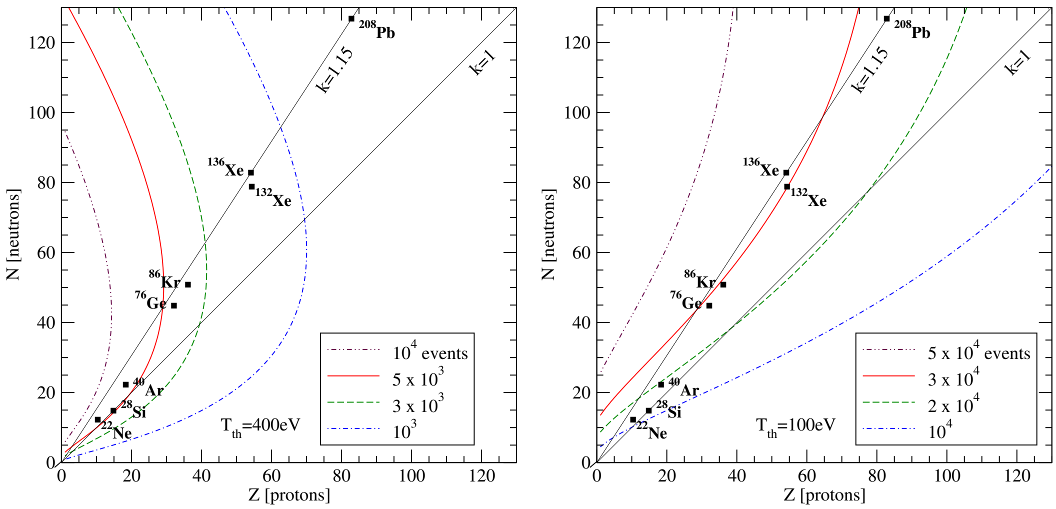

Figure 1: Iso-curves of the expected number of events per kg per year are shown on the plane N *vs.* Z for two values of energy threshold, $T_{th} = 400\,\text{eV}$ (left panel) and $100\,\text{eV}$ (right panel). NSI contribution is neglected. Different elements are pointed. Two solid lines are shown for two values of parameter $k = 1$ and 1.15.

of events for Xenon is lower than for germanium for the energy threshold $T_{th} = 400\,\text{eV}$, this can be compensated by a larger amount of material, as seems to be the case of the corresponding NOSTOS experiment proposal [5].

3.2 Non-universal NSI

We start our NSI analysis by assuming only non-universal parameters, and neglecting the flavor changing ones. We will see that in this case, for constraining both u type and d type NSI at a time it is necessary to perform two different experiments. However, if we are interested in constraining only d type NSI a germanium experiment can get a constraint competitive with future neutrino factories.

The expected number of events for germanium and silicon were calculated assuming a detector mass of 1 kg, 1 year of data taking, and two possible experimental threshold energies were considered: $T_{th} = 100\,\text{eV}$ and $T_{th} = 400\,\text{eV}$. To calculate the sensitivity we assumed that both experiments will measure exactly the SM expected number of events and we perform a χ^2 analysis based only on statistical errors.

The results are shown in figure 2 both for the case of a germanium detector (uncolored lines) as well as for the combined analysis of germanium plus silicon. It is possible to see that for the case of one experiment, both u type and d type NSI parameters are strongly correlated while the combination of two experiments can give a simultaneous determination of both parameters at the order of few percent.

In order to compare the experimental reach with other future experiments, note that the expected sensitivity for NSI parameter ε_{ee}^{dV} in neutrino factories, when all other parameters vanish, is approximately 0.006 [8] while the expected sensitivity for the germanium only case for a 400 eV threshold is even better (0.003). We can also note that in the case of considering only one parameter at a time, the sensitivity doesn't improve if we consider the

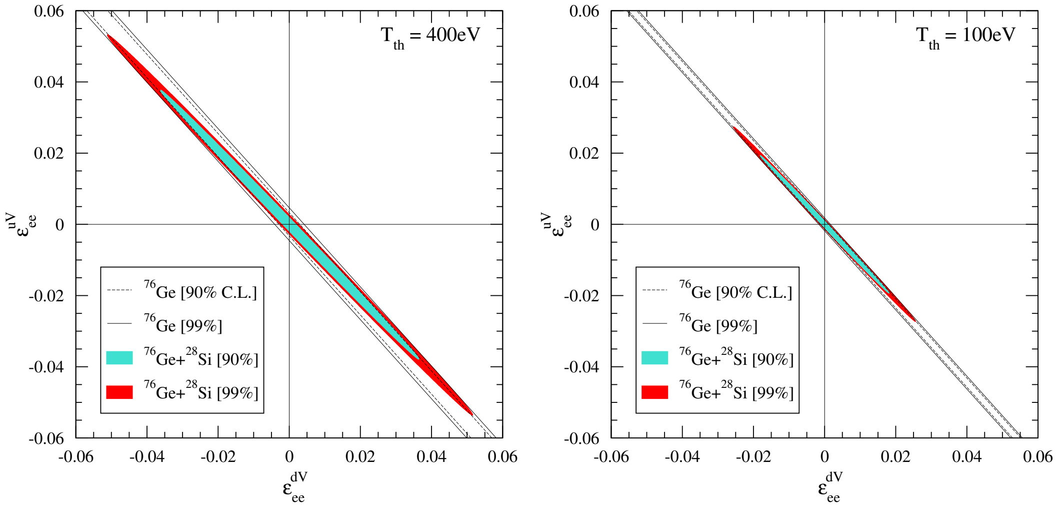

Figure 2: The allowed regions of non-universal NSI parameters ε_{ee}^{uV} and ε_{ee}^{dV} are shown at 90 and 99% C.L. for combined data from two detectors of ^{28}Si and ^{76}Ge (colored regions) and only for ^{76}Ge (solid and dashed lines). It was assumed 1 kg mass and 1 year of data taking for both detectors, only statistical errors are taken into account. The results presented for two values of threshold, $T_{th} = 400\,\text{eV}$ (left) and 100 eV (right panel).

case of a silicon detector. However, such an additional experiment could be very helpful in constraining both ε_{ee}^{dV} and ε_{ee}^{uV} at the same time, especially for the case of 100 eV energy threshold.

3.3 Flavor-changing NSI

Now we consider the case of flavor changing NSI neglecting non-universal terms. For this analysis we also take into account the strong bounds on flavor changing parameters for muon neutrinos, $\varepsilon_{\mu e}^{qV} < 7.7 \times 10^{-4}$, derived from $\mu - e$ conversion on nuclei [8], which motivates us to perform our analysis only for flavor changing NSI parameters that includes tau-neutrinos in the final state, $\varepsilon_{\tau e}^{uV}$ and $\varepsilon_{\tau e}^{dV}$.

The degeneracy problem discussed in the previous section for non-universal interactions is analogous in the flavor changing NSI case and it is described by the same parameter k, defined after eq. (3.2). Because of that we consider the same materials for detectors and we make the same assumptions. We give our results for these parameters in figure 3. In this case the expected sensitivity ($\varepsilon_{\tau e}^{dV} \simeq 0.03$) is again better than that expected for neutrino factories [8] $\varepsilon_{\tau e}^{dV} \simeq 0.06$.

3.4 Non-universal *vs.* flavor-changing NSI for d-quark

Here we compute the potential of this proposal when both non-universal and flavor changing NSI are considered one at a time, with NSI with d-type quark only, neglecting NSI with u-quark. Besides theoretical motivations, it is also interesting to study this case because, as it has been pointed out in the introduction, for this case is possible to have additional solutions to the solar neutrino problem, if the non-universal NSI contribution is big [11]. As

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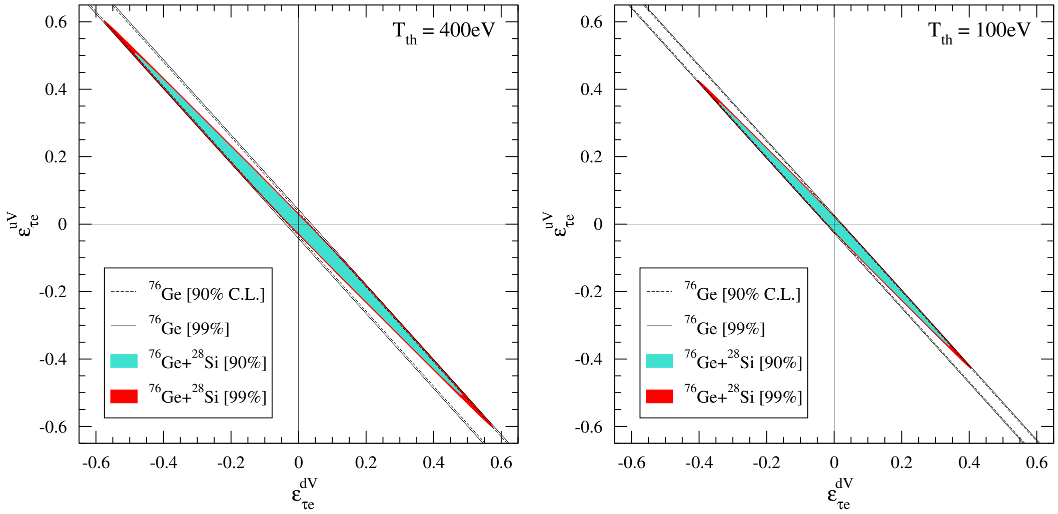

Figure 3: The same as figure 2 but the allowed regions of flavor-changing NSI parameters $\varepsilon_{\tau e}^{uV}$ and $\varepsilon_{\tau e}^{dV}$ are shown.

before we consider only NSI parameters which include tau-neutrinos, since the NSI muon neutrino interaction is strongly constrained.

As one can see from eq. (2.9), in this case we have again a degeneracy in the determination of the parameters ε_{ee}^{dV} and $\varepsilon_{\tau e}^{dV}$. The allowed region on the plane $(\varepsilon_{ee}^{dV}, \varepsilon_{\tau e}^{dV})$ has the form of an elliptic band. The width of the ellipse is twice as big as the height, which is described by the parameter, $a = (Zg_V^p + Ng_V^n)/(Z + 2N)$, the analog of the parameter k used in previous cases.

In the same way as it was discussed in the previous sections, we can use two different elements to break this degeneracy using as a guidance the parameter a. It is straightforward to check that the same materials discussed above are also good for the present case. By doing a similar analysis as in previous subsections we obtained, for the combined detectors case, an allowed region which is simply connected. These results are shown in figure 4 from which it is clear that the combination of the two studied experiments could definitely probe additional solutions to the solar neutrino data.

3.5 Extra heavy neutral gauge boson Z'

As we have discussed above, NSI appears in many extensions of the SM. As an illustration of the coherent neutrino-nuclei scattering we would like to discuss a specific example; we consider in this subsection the particular case of an additional neutral gauge boson Z' that arises from a primordial E_6 gauge symmetry [30]. The new boson Z' affects the neutral current couplings of the SM since these extension usually involve an extra U(1) hypercharge symmetry at low energies that may be given as the mixture of those associated with the symmetries $\mathrm{U}(1)_\chi$ and $\mathrm{U}(1)_\psi$. We show the quantum numbers for the SM particles in table 1.

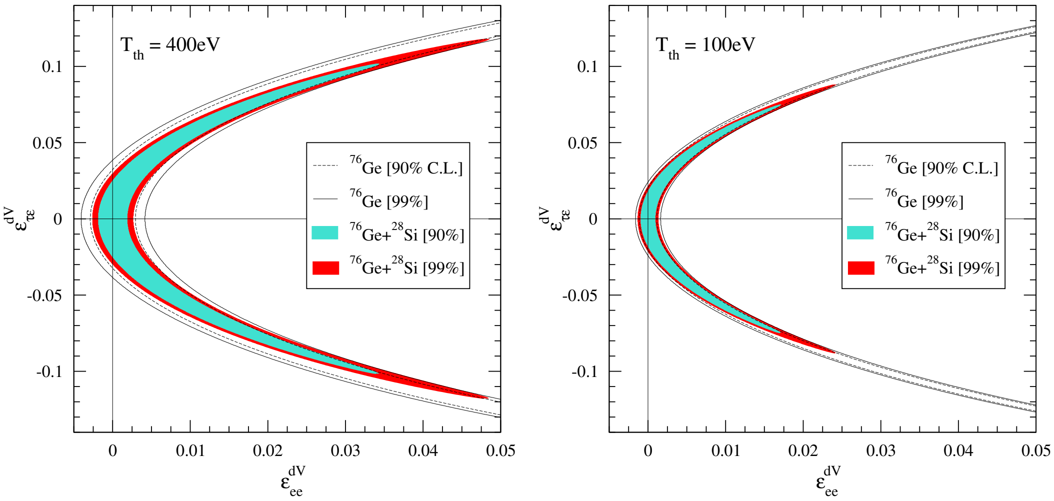

Figure 4: The same as figure 2 but the allowed regions of non-universal *vs.* flavor-changing NSI parameters ε_{ee}^{dV} and $\varepsilon_{\tau e}^{dV}$ for d type quark only are shown.

	T_3	$\sqrt{40}Y_\chi$	$\sqrt{24}Y_\psi$
Q	$\begin{pmatrix} 1/2 \\ -1/2 \end{pmatrix}$	-1	1
u^c	0	-1	1
e^c	0	-1	1
d^c	0	3	1
l	$\begin{pmatrix} 1/2 \\ -1/2 \end{pmatrix}$	3	1

Table 1: Quantum numbers for the light particles in the **27** of E_6.

The corresponding hyper-charge is then specified by

$$Y_\beta = \cos\beta Y_\chi + \sin\beta Y_\psi \,, \tag{3.3}$$

while the charge operator is given as $Q = T^3 + Y$. Any value of β is allowed, giving us a continuum spectrum of possible models of the weak interaction.

At tree level it is possible to write an expression for the effective four-fermion lagrangian describing low-energy neutral current phenomena. We neglect non-standard radiative corrections because its contribution is of order $(\alpha/\pi)(M_Z^2/M_{Z'}^2)$ [31]. The prescription is exactly an NSI type lagrangian such as eq. (2.2) with modified expression for the electroweak coupling constants,

$$\begin{aligned}
\varepsilon_{ee}^{uL} &= -4\gamma \sin^2\theta_W \rho_{\nu N}^{NC} \left(\frac{c_\beta}{\sqrt{24}} - \frac{s_\beta}{3}\sqrt{\frac{5}{8}} \right) \left(\frac{3c_\beta}{2\sqrt{24}} + \frac{s_\beta}{6}\sqrt{\frac{5}{8}} \right) \\
\varepsilon_{ee}^{dL} &= \varepsilon_{ee}^{uL} \\
\varepsilon_{ee}^{uR} &= -\varepsilon_{ee}^{uL}
\end{aligned}$$

	Present Limits	ν Factory	^{76}Ge $_{T_{th}=400\,\mathrm{eV}}$ (^{76}Ge $_{T_{th}=100\,\mathrm{eV}}$)	^{76}Ge+^{28}Si $_{T_{th}=400\,\mathrm{eV}}$ (^{76}Ge+^{28}Si $_{T_{th}=100\,\mathrm{eV}}$)
ε_{ee}^{dV}	$-0.5 < \varepsilon_{ee}^{dV} < 1.2$	$\|\varepsilon_{ee}^{dV}\| < 0.002$	$\|\varepsilon_{ee}^{dV}\| < 0.003$ ($\|\varepsilon_{ee}^{dV}\| < 0.001$)	$\|\varepsilon_{ee}^{dV}\| < 0.002$ ($\|\varepsilon_{ee}^{dV}\| < 0.001$)
$\varepsilon_{\tau e}^{dV}$	$\|\varepsilon_{\tau e}^{dV}\| < 0.78$	$\|\varepsilon_{\tau e}^{dV}\| < 0.06$	$\|\varepsilon_{\tau e}^{dV}\| < 0.032$ ($\|\varepsilon_{\tau e}^{dV}\| < 0.020$)	$\|\varepsilon_{\tau e}^{dV}\| < 0.024$ ($\|\varepsilon_{\tau e}^{dV}\| < 0.017$)
ε_{ee}^{uV}	$-1.0 < \varepsilon_{ee}^{uV} < 0.61$	$\|\varepsilon_{ee}^{uV}\| < 0.002$	$\|\varepsilon_{ee}^{uV}\| < 0.003$ ($\|\varepsilon_{ee}^{uV}\| < 0.001$)	$\|\varepsilon_{ee}^{uV}\| < 0.002$ ($\|\varepsilon_{ee}^{uV}\| < 0.001$)
$\varepsilon_{\tau e}^{uV}$	$\|\varepsilon_{\tau e}^{uV}\| < 0.78$	$\|\varepsilon_{\tau e}^{uV}\| < 0.06$	$\|\varepsilon_{\tau e}^{uV}\| < 0.036$ ($\|\varepsilon_{\tau e}^{uV}\| < 0.023$)	$\|\varepsilon_{\tau e}^{uV}\| < 0.023$ ($\|\varepsilon_{\tau e}^{uV}\| < 0.018$)

Table 2: Constraints on NSI parameters at 90% C.L. taking one parameter at a time in different experiments. Present limits and ν-factory sensitivity are from ref. [8].

$$\varepsilon_{ee}^{dR} = -8\gamma \sin^2\theta_W \rho_{\nu N}^{NC} \left(\frac{3c_\beta}{2\sqrt{24}} + \frac{s_\beta}{6}\sqrt{\frac{5}{8}} \right)^2, \tag{3.4}$$

where $c_\beta = \cos\beta$, $s_\beta = \sin\beta$ and $\gamma = (M_Z/M_{Z'})^2$. Three main models have been extensively studied, namely: the χ model ($\cos\beta = 1$), the ψ model ($\cos\beta = 0$) and the η model ($\cos\beta = \sqrt{3/8}$). In previous articles [29] it has been stressed that low energy neutrino experiments are more sensitive to the χ model than to others E_6 models and therefore we concentrate in this particular case.

We repeat now our analysis for NSI but with the couplings of the χ model that depends on the mass of the extra neutral gauge boson $M_{Z'}$. Considering only the germanium detector case we found a potential sensitivity, at 90 % C. L., of $M_{Z'} > 930\,\mathrm{GeV}$ for a 400 eV threshold and $M_{Z'} > 1420\,\mathrm{GeV}$ for a 100 eV threshold. For the case of a combined germanium plus silicon detector the expectations are even better, with a lower bound of 1160 GeV for a 400 eV threshold and 1640 GeV for the case of a 100 eV threshold at 90 % C.L.

Although the case of an extra neutral gauge boson comming from E_6 models is just one example among many other extensions that can be parametrized by NSI, it is very useful to illustrate the potential of neutrino coherent scattering off nucleus since the sensitivity in this case is quite competitive with the current Tevatron constraints and an improvement will depend on the specific experimental set up.

4. Discussion and summary

We have discussed the physics potential of a coherent neutrino nucleus scattering measurement to test both NSI and extra neutral gauge bosons. We have shown that such experiments could give constrains to NSI that are competitive with those coming from a future neutrino factory. Moreover, if we go one step further and consider two different

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	^{76}Ge+^{28}Si $_{T_{th}=400\,\mathrm{eV}}$	^{76}Ge+^{28}Si $_{T_{th}=100\,\mathrm{eV}}$
ε_{ee}^{dV}	$\lvert\varepsilon_{ee}^{dV}\rvert < 0.036$	$\lvert\varepsilon_{ee}^{dV}\rvert < 0.018$
ε_{ee}^{uV}	$\lvert\varepsilon_{ee}^{uV}\rvert < 0.038$	$\lvert\varepsilon_{ee}^{uV}\rvert < 0.019$
$\varepsilon_{\tau e}^{dV}$	$\lvert\varepsilon_{\tau e}^{dV}\rvert < 0.48$	$\lvert\varepsilon_{\tau e}^{dV}\rvert < 0.34$
$\varepsilon_{\tau e}^{uV}$	$\lvert\varepsilon_{\tau e}^{uV}\rvert < 0.50$	$\lvert\varepsilon_{\tau e}^{uV}\rvert < 0.37$
ε_{ee}^{dV}	$-0.002 < \varepsilon_{ee}^{dV} < 0.034$	$-0.0009 < \varepsilon_{ee}^{dV} < 0.016$
$\varepsilon_{\tau e}^{dV}$	$\lvert\varepsilon_{\tau e}^{dV}\rvert < 0.1$	$\lvert\varepsilon_{\tau e}^{dV}\rvert < 0.074$

Table 3: Constraints on NSI parameters at 90% C.L. taking two parameters at a time.

experiments, we can constrain simultaneously u and d type NSI. We illustrate the physics reach of these experiments in table 2, where we compare the expected NSI sensitivity in the case of a neutrino factory and in the case of either one or two neutrino coherent scattering experiments. In this Table, we have considered the sensitivity to one parameter at a time. In table 3 we consider two different parameters simultaneously for the case of a combined analysis with two neutrino coherent scattering experiments. It is possible to see that these two experiments are very effective in constraining NSI parameters.

In summary we have shown that neutrino coherent scattering off nuclei has a lot of potential to make precision tests of new physics, not only in the case of a non-zero neutrino magnetic moment as had already been discussed, but also to test non-standard neutrino interactions and extra heavy neutral gauge bosons.

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Acknowledgments

We kindly thank for very productive discussions to H.T.K. Wong, M. Fairbairn and D. Julio. This work has been supported by CONACyT, SNI-Mexico. T.I.R. was supported by RFBR grant 04-02-16386-a. T.I.R. thanks Physics Department of CINVESTAV for the hospitality during the visit when this work was done.

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