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Neutrino-electron scattering and tensor couplings

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Abstract. In this work we study the possibility of new tensorial interactions in neutrino electron scattering. Two new physics schemes are considered, the non standard interactions formalism (NSI) as well as the Unparticle stuff case. Constraints in tensorial couplings are obtained for both cases focusing on the TEXONO collaboration recent results. For the case of tensorial unparticles we find that previous limits are improved, for a given region of parameters, with the analysis of TEXONO data, and for the NSI tensorial parameters, the limit obtained is more restrictive than previous bounds reported in the literature.

1. Introduction

Neutrino physics has been a very exciting topic of research in the last decades. Thanks to a huge amount of experimental evidence of neutrino flavor conversions we now know that neutrinos have mass and their flavors mix [1], therefore the Standard Model must be extended to incorporate this fact.

This challenge has motivated a wide range of phenomenological and theoretical research in order to incorporate the massive nature of neutrinos within structure that contains the Standard Model as a low energy theory, since it has been a extremely successful model with a high power of prediction [2, 3]. In this work we study two new physics schemes from a phenomenological point of view: on the one hand, we have non standard interactions, that are very well stablished in neutrino phenomenology and their parameters can be probed in the experiments designed to do precision measurements of the oscillation parameters, and, on the other hand, the unparticle physics scheme, that is a totally different approach inspired in scale invariant theories and has been more recently proposed.

The formalism of non-standard four-fermion interactions provides an appropriate way of parameterizing different kinds of new physics scenarios, being suitable for different massive neutrino models and having also the advantage of being model independent.

In previous works, non standard interactions have been studied in the neutrino sector, but mostly those operators with $(V - A)$ Lorentz structure have been of interest [4, 5, 6, 7, 8], while

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less attention has been given to non standard interactions with tensor structure. In this work we study this kind of effective interactions in the case of neutrino electron scattering.

Unparticle physics is based in the possible existence of a new kind of fields in nature that unlike those in the Standard Model are scale invariant and do not manifest themselves as particles. This kind of fields were studied first in the Bank and Zaks model [9], and later in 2007 Georgi proposed a scenario where the Bank-Zaks Fields can interact with the Standard Model fields in an ultra violet sector [10, 11].

This proposal has motivated many new phenomenological analyses that involve the presence of unparticle operators, the plethora of analysis in unparticle physics cover a wide range of energy regimes, signals of unparticles can be searched in collider experiments and could be found in the LHC.

Another interesting place to look for evidence of unparticle physics signals is in the modification to the cross sections at low energy. Here we analyze the case of neutrino electron scattering and how possible interactions mediated by unparticles could modify the SM cross section and therefore the neutrino spectrum.

Previous analysis have mostly considered unparticle operators with scalar and vector structure, only a few cases have studied the possibility of tensor unparticle operators. Here we explore the inclusion of an antisymmetric rank 2 unparticle operator and derive the neutrino electron cross section due to the new interaction mediated by unparticles.

The content of this conference proceedings is organized as follows, en section 2 we introduce the statistical tools that are used for the analysis, and also the relevant details of the data analyzed, after that in section 3 and 4 we derive the contribution to the neutrino-electron cross section due to the tensorial NSI and tensorial unparticle respectively. Finally in section 5 we present and discuss the results of both analyses, we also compare our results with previous works in the literature.

2. Statistical analysis and the TEXONO experiment

Since the discovery of electroweak interactions neutrino electron scattering is a topic of high interest in elementary particle physics, given the fact that it is a clean process free from hadronic difficulties in its theoretical calculation, it can be used as a clean probe of the Standard Model and also is very suitable to study many of its extensions. Neutrino electron scattering has been recently measured with improved accuracy by the TEXONO collaboration [12], and since the detector is very close to the reactor neutrino source and therefore neutrino oscillation effects can be avoided, this experimental setup is very appropriate to the study of new physics [13, 14].

The cross section for neutrino electron scattering in the Standard Model is given by

$$\frac{d\sigma(\bar{\nu_e})}{dT} = \frac{2G_F^2 m_e}{\pi}\left[g_R^2 + g_L^2(1-\frac{T}{E_\nu})^2 - g_R g_L \frac{m_e T}{E_\nu^2}\right], \tag{1}$$

where G_F is the fermi constant, m_e is the electron mass, and the coupling constants are given by $g_L = \frac{1}{2} + \sin^2\theta_W$, $g_R = \sin^2\theta_W$.

The Kuo Sheng reactor is used as an antineutrino source, it has a power of 2.9 GW and provides an average antineutrino flux of $6.4 \times 10^{12} cm^{-2} s^{-1}$ [15].

In this section we introduce the necessary details for the statistical analysis of the neutrino data collected by the CsI(Tl) scintillator detector.

The TEXONO collaboration also reported recent results in the framework of NSI and in the unparticle physics scheme, where operators of scalar and vectorial structure are analyzed [15], an analysis of the tensor operators is missing, and in this work we introduce the results of such an analysis. We will see that it is possible to obtain strong constraints to the parameters in both physics approaches.

In order to estimate the expected number of antineutrino events detected in an energy bin, we compute the following integral

$$N_i = K \int_{T_i}^{T_{i+1}} \int_{E_\nu} \frac{d\sigma}{dT} \frac{d\phi(\bar{\nu}_e)}{dE_\nu} dE_\nu dT, \tag{2}$$

where the cross section is the one that corresponds to the new physics scheme under study, NSI or unparticle, plus the Standard Model contribution given in equation 1. The factor K accounts for the time exposure and the number of electron targets; $d\phi(\bar{\nu}_e)/dE_\nu$ is the neutrino spectrum which can be parametrized as the exponential of a polynomial of order five as has been recently discussed in the literature [16].

We havealso considered the relative abundances of each radioactive isotope in the nuclear reactor, ^{235}U(98%), ^{238}U(1.5%), and ^{239}Pu(0.4%). The electron recoil energy is divided into ten bins, T_i, running from 3 to 8 MeV.

Once we have computed the theoretically expected events per bin we can compute the χ^2 function as

$$\chi^2 = \sum_{i=1} \left[\frac{N_{expt}(i) - [N_{NSI,U}(i)]}{\Delta_{stat}(i)} \right]^2, \tag{3}$$

where $N_{NSI,U}(i)$, is the calculated event rate in the ith energy data bin for the Tensorial NSI or the unparticle cases, $N_{expt}(i)$ is the observed event rate for the corresponding energy bin given by the experiment, and $\Delta_{stat}(i)$ is the statistical uncertainty of the associated measurement.

3. Limits to Unparticle interactions in neutrino electron scattering

At energies above certain Λ, a hidden sector operator $\mathcal{O}_{UV}$ of dimension d_{UV} could couple to the SM operators $\mathcal{O}_{SM}$ of dimension d_{SM} via the exchange of heavy particles of mass M, in the ultra violet energy regime the interaction Lagrangian is

$$\mathcal{L}_{UV} = \frac{\mathcal{O}_{UV}\mathcal{O}_{SM}}{M^{d_{UV}+d_{SM}-4}}\,. \tag{4}$$

The hidden sector becomes scale invariant at Λ and then the interactions become of the following form

$$\mathcal{L}_{\mathcal{U}} = C_{\mathcal{O}_{\mathcal{U}}} \frac{\Lambda^{d_{UV}-d}}{M^{d_{UV}+d_{SM}-4}}\, \mathcal{O}_{\mathcal{U}}\, \mathcal{O}_{SM}\,, \tag{5}$$

where $\mathcal{O}_{\mathcal{U}}$ is the unparticle operator of scaling dimension d in the low energy limit and $C_{\mathcal{O}_{\mathcal{U}}}$ is a dimensionless coupling constant.

The unparticle sector could appear at low energies in the form of new massless fields coupled very weakly to the SM particles, having important manifestations in neutrino electron scattering.

Scalar and vectorial unparticle interactions have been studied previously in the context of neutrino electron scattering [17, 18, 15]. In what follows we will derive the neutrino electron cross section for the case of tensor unparticle operators.

The effective interactions for the tensor unparticle operators have the form in the low enegy regime [19, 20]

$$\frac{-i}{4} \frac{\kappa_T}{\Lambda_{\mathcal{U}}^{d_{\mathcal{U}}}} \bar{f}\, (\gamma_\mu \overleftrightarrow{D}_\nu + \gamma_\nu \overleftrightarrow{D}_\mu)\, \psi_f\, \mathcal{O}_{\mathcal{U}}^{\mu\nu} \text{ and } \frac{\kappa_T}{\Lambda_{\mathcal{U}}^{d_{\mathcal{U}}}} \mathcal{F}_{\mu\alpha}\mathcal{F}_\nu^\alpha\, \mathcal{O}_{\mathcal{U}}{}^{\mu\nu}, \tag{6}$$

where $\mathcal{F}_{\mu\alpha}$ denotes the gauge field strength. The unparticle propagator for the tensorial field is given by

$$[\mathcal{A}_{\mathcal{F}}(P^2)]_{\mu\nu,\rho\sigma} = \frac{\mathcal{A}_d}{2\sin(d\pi)} (-P^2)^{d-2} T_{\mu\nu,\rho\sigma}(P), \tag{7}$$

where

$$\mathcal{A}_d = \frac{16\pi^{5/2}}{(2\pi)^{2d}} \frac{\Gamma(d+1/2)}{\Gamma(d-1)\Gamma(2d)} \tag{8}$$

and the tensor operator $T_{\mu\nu\rho\sigma}$ is given by

$$T_{\mu\nu\rho\sigma} = \frac{1}{2}\left\{\pi_{\mu\rho}\pi_{\nu\sigma} + \pi_{\mu\sigma}\pi_{\nu\rho} - \frac{2}{3}\pi_{\mu\nu}\pi_{\rho\sigma}\right\}, \tag{9}$$

with

$$\pi_{\mu\nu} = -g_{\mu\nu} + \frac{P_\mu P_\nu}{P^2}. \tag{10}$$

If we consider the case of neutrino electron scattering we will arrive to the amplitude

$$M_T = \frac{f(d)}{\Lambda_U^{2d-2}} \left\{\bar{\nu}(k')\sigma^{\mu\nu}\nu(k)\right\} \left(-(P)^2 - i\varepsilon\right)^{d_u-2} T_{\mu\nu\rho\sigma} \left\{e(p')\sigma^{\rho\sigma}e(p)\right\}, \tag{11}$$

where

$$f(d) = \frac{\lambda_{i\nu}^{\alpha\beta}\lambda_{if}}{2\sin(d\pi)} A_d. \tag{12}$$

In what follows we will use the definition for the couplings $\lambda = \sqrt{\lambda_{i\nu}^{\alpha\beta}\lambda_{if}}$ and we will leave the scale $\Lambda = 1$ TeV fixed. From this amplitude, it is possible to obtain the differential cross section for neutrino electron scattering for the tensorial unparticle interactions. The electric part which takes the form:

$$\frac{d\sigma_T}{dT} = \frac{f(d)^2}{\pi\Lambda_U^{4d-4}} 2^{2d-3} m_e^{2d-3} T^{2d-4} \Big[\Big(1 - \frac{T}{2E_\nu}\Big)^2 - \frac{mT}{2E_\nu^2}\Big] \tag{13}$$

and the magnetic contribution to the cross section is given by

$$\frac{d\sigma_T}{dT} = \frac{f(d)^2}{\pi\Lambda_U^{4d-4}} 2^{2d-2} m_e^{2d-3} T^{2d-4} \Big(1 - \frac{T}{2E_\nu}\Big)^2. \tag{14}$$

For the total cross section we add this two contributions plus the one calculated from the Standard Model.

For not only scale but also conformally invariant theories, there is a bound from unitarity constraints in the dimension d [21], in this phenomenological approach we leave free the value of the dimension parameter for a broader range where the case of a theory scale invariant but not conformally invariant is possible.

After performing a χ^2 analysis of the TEXONO data, we have found that, the unparticle tensor interaction, our constraints are more restrictive than previous limits reported for the case when $d > 2.03$. This result is very encouraging and the details of the analysis will be published elsewhere.

4. Tensorial neutrino electron NSI

It is a common characteristic of many extensions of the Standard Model to introduce new interactions that can be parametrized with the help of an effective Lagrangian. The most studied case regards with $V - A$ extensions of the Standard Model. It is well known that in this case the effective four fermion Lagrangian takes the form: [22, 23, 24, 25, 26]

$$-\mathcal{L}_{\mathrm{V-A}}^{eff} = \varepsilon_{\alpha\beta}^{fP} 2\sqrt{2} G_F (\bar{\nu}_\alpha \gamma_\rho L \nu_\beta)(\bar{f}\gamma^\rho P f), \tag{15}$$

where f is a first generation SM fermion: e, u or d, and $P = L$ or R are the chiral projectors.

In particular for the neutrino electron scattering the neutrino electron cross section for the $(V - A)$ NSI case is given by

$$\begin{aligned}\frac{d\sigma(E_\nu, T)}{dT} &= \frac{2G_F^2 m_e}{\pi}[(\tilde{g}_L^2 + \sum_{\alpha\neq e} |\epsilon_{\alpha e}^{eL}|^2) \\ &+ (\tilde{g}_R^2 + \sum_{\alpha\neq e} |\epsilon_{\alpha e}^{eR}|^2)\left(1 - \frac{T}{E_\nu}\right)^2 - (\tilde{g}_L\tilde{g}_R + \sum_{\alpha\neq e} |\epsilon_{\alpha e}^{eL}||\epsilon_{\alpha e}^{eR}|)m_e\frac{T}{E_\nu^2}],\end{aligned} \tag{16}$$

with the new effective couplings left and right given by $\tilde{g}_L = g_L + \epsilon_{\alpha\alpha}^{eL}$ and $\tilde{g}_R = g_R + \epsilon_{\alpha\alpha}^{eR}$.

Previous study to this interaction in neutrino electron scattering has been given in different articles [27] and there are some constraints reported in the literature [28].

The Lagrangian describing this type of interaction is given by

$$-\mathcal{L}_{\mathrm{T}}^{eff} = \varepsilon_{\alpha\beta}^{fT} 2\sqrt{2} G_F (\bar{\nu}_\alpha \sigma^{\mu\nu} \nu_\beta)(\bar{f}\sigma_{\mu\nu} f), \tag{17}$$

with $\sigma_{\mu\nu} = \gamma_\mu\gamma_\nu + \gamma_\nu\gamma_\mu$. In this case, for the tensorial contribution the amplitude for the process is given by

$$\mid M \mid^2 = \varepsilon_{\alpha\beta}^{fT\,2} \frac{G_F^2}{2} 128 m_e^2 (4E_\nu^2 + T^2 - (4E_\nu + m_e)T) \tag{18}$$

and therefore the differential NSI neutrino electron cross section takes the form:

$$\frac{d\sigma_T^{NSI}}{dT} = \frac{\mid M \mid^2}{64\pi m_e E_\nu^2} = \varepsilon_{\alpha\beta}^{fT\,2} \frac{4G_F^2 m_e}{\pi}\Big[\Big(1 - \frac{T}{2E_\nu}\Big)^2 - \frac{m_e T}{4E_\nu^2}\Big]. \tag{19}$$

In this case, $\varepsilon_{\alpha\beta}^{fT}$ parametrizes the strength of the tensorial NSI coupling.

The limit obtained for the tensorial non standard parameter on the tensorial coupling gives the bound, at 90 % CL, $g_T \leq 0.20$ which is much better than the previously reported constraint by the LAMPF collaboration [28]. We obtained the value of $\chi^2_{min} = 5.43$ for 9 d.o.f. We have verified explicitly that previous reactor experiments give weaker constraints than those obtained here using the TEXONO data, when we perform the same analysis for the MUNU experiment we find that $g_T \leq 0.25$ at 90 % CL, in an energy range of 0.2 to 2.0 MeV [14].

5. Discussion and summary

The recent experimental results put neutrino physics in a time of precision measurements, where important guidance for physics beyond the Standard Model could be found.

For the unparticle tensor interaction, when $d > 2.03$ we find that our constraints are more restrictive than previous limits reported, for the tensor NSI previous constraints are also improved by this analysis.

As can be seen the results are encouraging and future neutrino electron scattering experiments could give even stronger constraints.

Another possible place to search for this type of interaction in the future could be the coherent neutrino nuclei scattering that is also part of the TEXONO low energy neutrino physics program [29] and other proposals [30, 31, 32].

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