Limits on neutrino non-standard properties from Borexino

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The present experimental world neutrino data provide a robust interpretation in terms of a three active neutrino oscillation scenario (see e.g. [1] for a very recent review). However, there is still room for subleading non–standard neutrino interactions in the interpretation of data. Among other possibilities, a neutrino electromagnetic coupling through an anomalous magnetic dipole moment is an intriguing possibility that has been extensively studied in the past (for a recent review, see e.g. [2]). A non-zero neutrino magnetic moment can give rise to neutrino spin-flavor precession in an external magnetic field, radiative neutrino decay or neutrino-electron anomalous scattering cross-section due to the additional vertex

$$(\Gamma^{\rho}_{\nu-\gamma})_a = -\frac{\mu_a}{2m_e}\bar{\nu}_a\sigma^{\rho\lambda}q_\lambda\nu_a\,. \tag{1}$$

For simplicity, we consider here only flavor conserving interactions, although the extension to flavor changing ones is straightforward. The consequence of this vertex is an additional contribution to the ν_a-e differential cross section as follows

$$\frac{d\sigma^{\mu}_{a}}{dT_e}(E_\nu,T_e) = \frac{\pi\alpha^2_{\text{e.m.}}}{m_e^2}\left(\frac{\mu_a}{\mu_B}\right)^2\left(\frac{1}{T_e}-\frac{1}{E_\nu}\right), \tag{2}$$

where E_ν is the initial laboratory neutrino energy and T_e is the final electron kinetic energy and μ_B is the Bohr magneton.

At moment no evidences have been found for such anomalous vertex. Strong but indirect limits have been fixed by astrophysical and cosmological considerations. However, direct bounds are much weaker. In [3] (where we address the interested reader for further details) we have analyzed the first data relative to about three months of data taking of the Borexino collaboration [4]. In this experiment, solar neutrinos (mainly, those coming from the monoenergetic ^{7}Be source) are detected through ν-e scattering and the recoil electron energy is measured through a scintillation technique. The observed event rate is essentially consistent with the one predicted by the Standard Solar Model. Since the main source observed by Borexino is the monoenergetic 863 keV ^{7}Be line, a precise calibration of the differential $d\sigma/dT_e(E_\nu,T_e)$ cross section is possible through a spectral shape analysis. In particular, a non zero neutrino magnetic moment introduces a term which grows with the inverse of both the energy of the incident neutrino and with that of the recoil electron. For this reason, a low energy experiment (such as Borexino), is in a favorable situation.

Concerning other non–standard interactions, the possibility of a conformal hidden sector, called "unparticle sector", which couples to the various gauge and matter fields of the SM through non-renormalizable interactions has been recently proposed [5]. The unparticle sector is assumed to have a non-trivial infrared fixed point, $\Lambda_{\mathcal{U}}$, below which the sector has a scale invariance and the hidden operators become an effective unparticle operator with non-integral scaling dimension d. Leptons can couple for example with a scalar unparticle sector through the Lagrangian

$$\mathcal{L}_{\mathcal{U}} = \lambda_e\frac{1}{\Lambda_{\mathcal{U}}^{d-1}}\bar{e}\hat{O}_{\mathcal{U}}e + \lambda^a_\nu\frac{1}{\Lambda_{\mathcal{U}}^{d-1}}\bar{\nu}_a\hat{O}_{\mathcal{U}}\nu_a\,, \tag{3}$$

where d is the non-integral scaling mass dimension of the unparticle operator, $\Lambda_{\mathcal{U}}$ is a typical scale of the unparticles physics and it can be assumed $\sim O(\text{TeV})$, $\hat{O}_{\mathcal{U}}$ is the unparticle operator, and the λ's are the coupling constants of the leptons to the unparticle sector (possible flavor changing interactions $\nu_a \to \nu_b$ have been also taken into account). The contribution to the scattering amplitude for elastic $\bar{\nu}_a$-e scattering from the exchange with a scalar unparticle is

$$\frac{d\sigma^{\mathcal{U}}_a}{dT_e}(E_\nu,T_e) = \lambda_a^2\frac{2^{2d-7}\mathcal{F}^2(d)}{\pi E_\nu^2\Lambda_{\mathcal{U}}^{4d-4}}\frac{T_e+2m_e}{(m_eT_e)^{3-2d}}\,, \tag{4}$$

where $\lambda_a \equiv \lambda^a_\nu\cdot\lambda_e$ and

$$\mathcal{F}(d) = \frac{8\pi^{5/2}}{(2\pi)^{2d}\sin(\pi d)}\frac{\Gamma(d+1/2)}{\Gamma(d-1)\Gamma(2d)}\,. \tag{5}$$

So far, we have compared the data set in [4] with the theoretical spectrum in the hypothesis of zero and non zero non–standard coupling (magnetic moment or unparticle interaction). Solar neutrinos undergo "standard" flavor oscillations described by the usual Mikheyev-Smirnov-Wolfenstein effect in the Sun. The functional form of the oscillation probability $P_{ea}(E_\nu)$ have

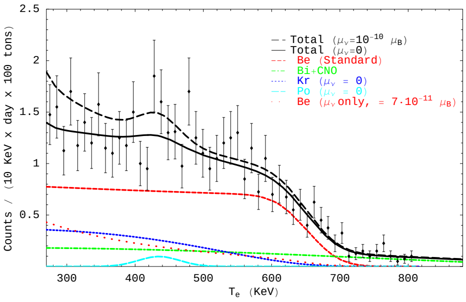

Figure 1. Spectrum of the recoil electron in borexino as function of the kinetic energy T_e with zero and nonzero neutrino magnetic moment in Borexino vs experimental data. Also shown the various contributions due to background.

less importance for our purposes since any change in the probability would reflect only in a very small change of the spectral shape (since it is determined mainly by the ^{7}Be line), while the overall normalization is left free.

Several sources of background due both to the contaminants in the scintillator and from the neutrinos produced by the CNO cycle in the Sun affect the final spectrum. The main contributions to the spectrum come from the CNO+^{210}Bi, ^{85}Kr, and ^{210}Po. Among these, only the first could be slightly affected by the functional form of $P_{ea}(E_\nu)$. We see also that this contribution is almost flat (and thus has a very little dependance from the functional form of $P_{ea}(E_\nu)$), while those from ^{210}Po has a peculiar "bump". The main contribution for the spectral distorsion at low energies (thus mimicking those coming from non–standard interactions) comes from the ^{85}Kr background.

The "best fit" spectrum with standard interactions only is shown in Fig. 1, which is similar to Fig. 6 of [4], with black solid line. For comparison, we also report the number of events per day in the full recoil energy range for each source for 100 Tons of scintillator in our "best fit" case: 49 for the ^{7}Be, 12 for the CNO+^{210}Bi, 18 for the ^{85}Kr, and 1 for the ^{210}Po. In order to show the effect of the magnetic moment, in Fig. 1 in black dashed line we plot also the theoretical spectrum for $\mu_\nu = 10^{-10}\mu_B$ (which is well beyond the 90% limit). From the plot we see that (as expected) the spectrum grows at low energies. We stress that the corresponding upper bound on the neutrino magnetic moment is not dependent on the Standard Solar Model assumed. In fact the ^{7}Be normalization is extracted from the experimental data.

Concerning the limit on the neutrino magnetic moment we have found the 90% C.L. bound

$$\mu_\nu \leq 8.4 \times 10^{-11}\mu_B \,. \tag{6}$$

Although this limit is less competitive than those obtained from reactor experiments like in GEMMA ($\mu_e < 5.8 \times 10^{-11}\mu_B$ at 90% C.L., [6]), we should bear in mind that reactor experiments are short baseline and thus the limits obtained in these experiments are essentially bounds on the μ_e component. Instead, in solar solar neutrinos also a $\nu_{\mu,\tau}$ component is present. For example, also in the worst (and unrealistic) case in which $\mu_{e,\mu} = 0$ and $\sin^2\theta_{12}$, $\cos^2\theta_{23}$ taken at their 2σ minimum allowed values, we obtain a conservative limit on the magnetic moment of the tau neutrino:

$$\mu_\tau \leq 1.9 \times 10^{-10}\mu_B \,, \tag{7}$$

which is three order of magnitude stronger than those quoted by the Particle Data Group ($\mu_\tau < 3900 \times 10^{-10}\mu_B$ [7]).

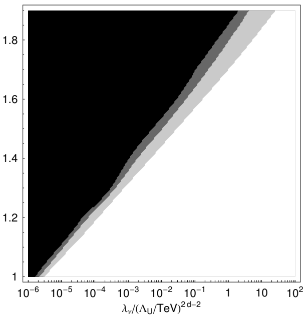

Figure 2. The 90% C.L. allowed zone in the plane (d, λ_ν) (for $\Lambda_{\mathcal{U}} = 1$ TeV) as from Ref. [8] (light gray), with unconstrained ^{7}Be flux (dark gray) and with the ^{7}Be flux fixed by the Standard Solar Model (black).

Concerning limits on unparticle interactions, in Fig. 2 we show the 90% C.L. allowed zone in the plane (d, λ_ν) as from a previous analysis of reactor experiment [8] (light gray) and our analysis with unconstrained (dark gray) and constrained (black) ^{7}Be flux. As in the previous case we obtain direct limits on $\nu_{\mu,\tau}$ neutrino unparticle couplings, while previous bounds applies only to ν_e's. We want however to stress however that this limits strictly apply if *only* scalar and contact unparticle operators are present.

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