Neutrino Electron Scattering and Electroweak Gauge Structure: Future Tests

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Abstract

Low-energy high-resolution neutrino-electron scattering experiments may play an important role in testing the gauge structure of the electroweak interaction. We propose the use of radioactive neutrino sources (e.g. ^{51}Cr) in underground experiments such as BOREXINO, HELLAZ and LAMA. As an illustration, we display the sensitivity of these detectors in testing the possible existence of extra neutral gauge bosons, both in the framework of E_6 models and of models with left-right symmetry.

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I. INTRODUCTION

Despite the success of the Standard Model (SM) in describing the electroweak interaction, there have been considerable interest in extensions of the gauge structure of the theory. A lot of the theoretical effort has been in models that can arise from an underlying E_6 framework [1] as well as models with left-right symmetry [2,3].

So far accelerator and reactor neutrino experiments have been the main tool used in probing the gauge structure of the electroweak interaction. The first observation of $\nu_e e \to \nu_e e$ scattering at LAMPF [4] resulted in a total of 236 ± 35 events [5]. The value for the total cross section was $(10.0 \pm 1.5 \pm 0.9) \times 10^{-45} cm^2 \times E_\nu(MeV)$ for a neutrino mean energy of 30 MeV. This measurement ruled out constructive interference between neutral and charged currents, in agreement with the Standard Model. Moreover LEP measurements at the Z peak have achieved very high precision in determining the neutral current parameters. As for reactor experiments, electron anti-neutrino fluxes are not accurate enough and have a bad geometrical factor $\frac{\Delta\Omega}{4\pi} = \frac{1}{2}\frac{a^2}{r^2}$, where a is the size of the detector and $r \gg a$ is the distance from reactor. As a result reactors do not allow a precision test of the neutral current weak interaction of the type we will describe here.

The $\nu_e e \to \nu_e e$ scattering process has proved to be an useful tool in studying the ^8B neutrinos coming from the Sun at underground installations. The electron recoil spectrum has been measured in the Kamiokande Cerenkov detector with a threshold energy of 7.5 MeV. Superkamiokande has reached a threshold energy of 6.5 MeV and an energy resolution of about 20 % . Determining the electron recoil spectrum should be also one of the goals to be pursued at the future Sudbury Neutrino Observatory.

In this paper we focus on the possibility of studying $\nu_e e \to \nu_e e$ scattering process from terrestrial neutrino sources with improved statistics. A similar idea has been suggested as a test of non-standard neutrino electro-magnetic properties, such as magnetic moments [6]. In contrast to reactor experiments, a small radioactive isotope source can be surrounded by gas or liquid scintillator detectors with full geometrical coverage. Here we demonstrate that a low-energy high-resolution experiment can play an important role in testing the structure of the neutral current weak interaction. The ingredients for doing such experiments are either already available (e. g. the chromium source has already been used for calibrating the GALLEX and SAGE experiments [7]) or under investigation (NaI detectors have already been used in dark matter searches and the BOREXINO and HELLAZ detectors have been extensively discussed). These detectors should reach good energy resolution and relatively low threshold. Both BOREXINO and HELLAZ are planing to detect neutrinos at energies below 1 MeV [8,9]. The BOREXINO solar neutrino detector should have an energy threshold of 0.250 MeV and an estimated energy resolution of about 12 % at threshold [8], while HELLAZ (Ref [9]) should have an energy threshold of 100 KeV and few % energy resolution. In the case of the LAMA proposal, they are planning to use an ^{147}Pm anti-neutrino source with a one tone NaI detector in the energy region of 2-25 KeV.

We explicitly determine the sensitivity of these radioactive neutrino source experiments as precision probes of the gauge structure of the electroweak interaction and exemplify it in a class of E_6-type models as well as models with left-right symmetry.

II. THE νE SCATTERING CROSS SECTION

We start our discussion of the neutrino electron scattering cross section in a generic electroweak gauge model in which the main contributions to this process arise from the exchange of charged and neutral intermediate vector bosons, i.e. from charged (CC) and neutral currents (NC).

The charged current amplitude for the $\nu_e e \to \nu_e e$ process can be written, after a Fierz transformation as

$$\mathcal{M} = \sqrt{2} G_F \bar{\nu} \gamma^\mu (1-\gamma_5) \nu \bar{e} \gamma_\mu c_L \frac{1-\gamma_5}{2} e. \tag{1}$$

For the specific case of the SM we have $c_L = 1$.

On the other hand, the neutral current contribution to the amplitude for the process $\nu_e e \to \nu_e e$ can be given as

$$\mathcal{M} = \sqrt{2} G_F \bar{\nu} \gamma^\mu (1-\gamma_5) \nu \bar{e} \gamma_\mu [g_L \frac{1-\gamma_5}{2} + g_R \frac{1+\gamma_5}{2}] e. \tag{2}$$

In this case the SM prediction is $g_{L,R} = \frac{1}{2}(g_V \pm g_A)$, $g_V = \rho_{\nu e}(-1/2 + 2\kappa \sin^2\theta_W)$ and $g_A = -1/2\rho_{\nu e}$ where the $\rho_{\nu e}$ and the κ parameters describe the radiative corrections for low-energy $\nu_e e \to \nu_e e$ scattering, which have been recently computed by Sirlin [10] and taken into account in our calculations.

The differential cross section for the process $\nu_e e \to \nu_e e$ in terms of the effective amplitudes 1 and 2 is given by

$$\frac{d\sigma}{dT} = \frac{2 m_e G_F^2}{\pi} \{(g_L + c_L)^2 + g_R^2 - [2 g_R^2 + \frac{m_e}{\omega_1}(g_L + c_L) g_R] \frac{T}{\omega_1} + g_R^2 (\frac{T}{\omega_1})^2\} \tag{3}$$

Here, T is the recoil electron energy, and ω_1 is the neutrino energy; therefore $T/\omega_1 < 1$ for any value of ω_1. It is also important to note that we have in this expression the ratio m_e/ω_1. Clearly all terms in this cross section are potentially sensitive to corrections from new physics. However, not all are equally sensitive to these corrections. In particular, the linear m_e/ω_1 term will be important for low energies and negligible for accelerator and reactor neutrino energies. As we will show in section 4, testing for the presence of new physics should become feasible in the next generation of $\nu_e e \to \nu_e e$ experiments with sufficiently low energies and high resolution.

In the case of chiral [11] contributions to the charged currents due to new physics we can consider the value of c_L to be the SM prediction plus some new contribution

$$c_L = 1 + \delta c_L. \tag{4}$$

With this notation the differential cross section for this case can be expressed, at first order in δc_L as

$$\begin{aligned} \frac{d\sigma}{dT} &\simeq \frac{2 m_e G_F^2}{\pi} \{(g_L + 1)^2 + g_R^2 - (2 g_R^2 + \frac{m_e}{\omega_1}(g_L + 1) g_R) \frac{T}{\omega_1} + g_R^2 (\frac{T}{\omega_1})^2\} + \\ &+ \frac{2 m_e G_F^2}{\pi} \{2(g_L + 1) - \frac{m_e}{\omega_1} g_R \frac{T}{\omega_1}\} \delta c_L. \end{aligned} \tag{5}$$

The first term in this equation corresponds exactly to the SM expression while the next one is for the corrections due to new physics. It is easy to see that in this case the effect of the new contributions reduces to a shift in the value of the differential cross section, while the shape is hardly affected, except for a linear correction. In what follows we concentrate in neutral current corrections that can arise in the framework of E_6 models and of models with left-right symmetry.

III. E_6 AND LEFT-RIGHT SYMMETRIC WEAK HAMILTONIAN

In this paper we consider $\nu_e e$ scattering as a test for extensions of the Standard Model. These extensions typically involve an extra $U(1)$ symmetry at low-energies, as in the case of a class of heterotic string inspired E_6 models [1], or an extra left-right symmetric $SU(2)$ [2,3] at low-energies, such as can arise in Grand Unified Theory (GUT) models such as SO(10).

In the case of models with an extra $U(1)$ hyper-charge symmetry may be given an mixture of those associated with $U(1)_\chi$ and $U(1)_\psi$, the symmetries that lie in SO(10)/SU(5) and E_6/SO(10), respectively. In table 1 we show the quantum numbers for Y_χ and Y_ψ for the SM particles.

The corresponding hyper-charge can be then specified by

$$Y_\beta = \cos\beta Y_\chi + \sin\beta Y_\psi, \tag{6}$$

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. Here we focus on the most common choices considered in the literature, namely $\cos\beta = 1$ (χ model), $\cos\beta = 0$ (ψ model) and $\cos\beta = \sqrt{\frac{3}{8}}$, $\sin\beta = -\sqrt{\frac{5}{8}}$ (η model). For definiteness we will also restrict ourselves to the case when only doublet and singlet Higgs bosons are present so that the tree level value of the ρ parameter is one (these models were called *constrained models* in ref. [12]). A more complete analysis over the whole range of β values, as well as the inclusion of the case when there is no restriction on the Higgs sector can be carried out as in Ref. [13]. Moreover one might also consider the case when all the Higgs bosons arise from the fundamental **27**-dimensional representation of the primordial E_6 group (these models were called *constrained superstring models* in ref. [12]). In the latter case one would be able to determine the value of the Z' mixing angle in terms of the masses of Z and Z', thus leading to much stronger constraints.

The amplitude for neutral $\nu e \to \nu e$ scattering in such models is given by (see for example Ref. [13])

$$\mathcal{M}_{\mathcal{NC}} = \sqrt{2} G_F \bar{\nu} \gamma^\mu (1-\gamma_5) \nu \{ \bar{e} \gamma_\mu [g_L \frac{1-\gamma_5}{2} + g_R \frac{1+\gamma_5}{2}] \} e. \tag{7}$$

with

$$g_{L,R} = 2\rho_{\nu e} [(v_1^{\nu e}(e) \mp a_1^{\nu e}(e))(v_1(\nu) - a_1(\nu)) + \gamma (v_2^{\nu e}(e) \mp a_2^{\nu e}(e))(v_2(\nu) - a_2(\nu))] \tag{8}$$

and

$$\gamma = \frac{M_Z^2}{M_{Z'}^2} \tag{9}$$

and

$$v_1^{\nu e}(e) = (-1/4 + \kappa s_W^2) \mathrm{cos}\phi - s_W \frac{\mathrm{cos}\beta}{\sqrt{6}} \mathrm{sin}\phi \tag{10}$$

$$v_2^{\nu e}(e) = (-1/4 + \kappa s_W^2) \mathrm{sin}\phi + s_W \frac{\mathrm{cos}\beta}{\sqrt{6}} \mathrm{cos}\phi \tag{11}$$

$$a_1^{\nu e}(e) = \mathrm{cos}\phi/4 + s_W (\frac{\mathrm{cos}\beta}{\sqrt{24}} + \sqrt{\frac{5}{8}} \frac{\mathrm{sin}\beta}{3}) \mathrm{sin}\phi \tag{12}$$

$$a_2^{\nu e}(e) = \mathrm{sin}\phi/4 - s_W (\frac{\mathrm{cos}\beta}{\sqrt{24}} + \sqrt{\frac{5}{8}} \frac{\mathrm{sin}\beta}{3}) \mathrm{cos}\phi \tag{13}$$

$$v_1(\nu) = \mathrm{cos}\phi/4 - s_W (\frac{3\mathrm{cos}\beta}{2\sqrt{24}} + \sqrt{\frac{5}{8}} \frac{\mathrm{sin}\beta}{6}) \mathrm{sin}\phi \tag{14}$$

$$v_2(\nu) = \mathrm{sin}\phi/4 + s_W (\frac{3\mathrm{cos}\beta}{2\sqrt{24}} + \sqrt{\frac{5}{8}} \frac{\mathrm{sin}\beta}{6}) \mathrm{cos}\phi \tag{15}$$

$$a_1(\nu) = -\mathrm{cos}\phi/4 + s_W (\frac{3\mathrm{cos}\beta}{2\sqrt{24}} + \sqrt{\frac{5}{8}} \frac{\mathrm{sin}\beta}{6}) \mathrm{sin}\phi \tag{16}$$

$$a_2(\nu) = -\sin\phi/4 - s_W(\frac{3\cos\beta}{2\sqrt{24}} + \sqrt{\frac{5}{8}}\frac{\sin\beta}{6})\cos\phi \tag{17}$$

We now turn to a brief discussion of the effective weak Hamiltonian that arises in models based on the Left-Right Symmetric gauge group

$$G_{LR} \equiv SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}.$$

These models are theoretically attractive since they offer the possibility of incorporating parity violation on the same footing as gauge symmetry breaking, instead of by hand as in the Standard Model [2,3].

The coupling constants for neutral currents in the left-right symmetric model (LRSM) are given by

$$g_{L,R} = A\frac{1}{2}(g_V \pm g_A) + B\frac{1}{2}(g_V \mp g_A) \tag{18}$$

with

$$A = (c_\phi - \frac{s_W^2}{r_W}s_\phi)^2 + \gamma(s_\phi + \frac{s_W^2}{r_W}c_\phi)^2 \tag{19}$$

$$B = \frac{c_W^2}{r_W}[-(c_\phi - \frac{s_W^2}{r_W}s_\phi)s_\phi + \gamma(s_\phi + \frac{s_W^2}{r_W}c_\phi)] \tag{20}$$

where the shorthand notation $s_\phi = \sin\phi$, $c_\phi = \cos\phi$, $r_W = \sqrt{\cos 2\theta_W}$ has been used.

Note that $\nu_e e \to \nu_e e$ scattering is not sensitive to right-handed charged currents because the interference term between the corresponding amplitude and the Standard Model one is suppressed either by the neutrino mass (Dirac case) or by the mixing with the heavy neutrinos (Majorana case, seesaw model). In fact, this is just an example of the general situation that one finds when trying to constrain charged-current parameters via purely leptonic processes (see refs. [14] and [15]).

IV. EXPERIMENTAL PROSPECTS

The values of the coupling constants governing $\nu_e e \to \nu_e e$ scattering have been well measured from $e^+e^- \to l^+l^-$ at high energies by the LEP Collaborations. A combined fit from

LEP results at the Z peak gives [16] $g_V = -0.03805 \pm 0.00059$ and $g_A = -0.50098 \pm 0.00033$. These results have given strong constraints on right-handed neutral currents, specially on the mixing of the standard Z boson with other hypothetical neutral gauge bosons, in the framework of global fits of the electroweak data [17,18].

In contrast we focus here on low-energy neutrino-electron scattering experiments. These have been suggested in order to test unusual neutrino electromagnetic properties, such as magnetic moments (see [6]). At present some experimentalists are considering the possibilities of these kind of physics [19,20]. Here we consider their role in testing the gauge structure of the electroweak interaction. Two things are required for this kind of experiment: a strong low-energy electron-neutrino source and a high-precision detector.

The first strong low-energy neutrino sources have been recently prepared for the calibration of the GALLEX and SAGE [7] neutrino experiment. In the GALLEX case this was a ^{51}Cr neutrino source with an activity of 1.67 ± 0.03 MCi. In Table 1 we show the main characteristics of the ^{51}Cr source. Besides the four different neutrino energy lines, there are also 320 KeV photons as well as high energy (above 1 MeV) $\gamma' s$ from impurities. The GALLEX and SAGE collaborations addressed this problem using a tungsten shielding in order to avoid radiological problems. This shielding stopped not only the high energy but also the 320 KeV photons. The size of the source, along with the shielding is close to one meter, therefore we estimate that the neutrino flux just outside the shielding is about $\Phi = 1.8 \times 10^{12} \nu/cm^2 sec$. Other sources have also been proposed for calibration of low energy neutrino detectors [21,22]. For anti-neutrino sources, among different possibilities, the ^{147}Pm source [23] is the one that LAMA proposal is considering for its experiment on neutrino magnetic moment searches. This source has a maximum neutrino energy of 234.7 KeV and it is planned to have an activity of 5-15 MCi. Its half-life is 2.6234 years. The expected size of the source along with the shielding is 70cm. Thus one sees that the preparation of high-quality isotope sources is not a problem, from our point of view the main remaining problem seems to be the design of detectors capable of making precise measurements using these sources.

At the moment no detector is able to measure the $\nu_e e \to \nu_e e$ dispersion at energies below 1 MeV. However, there are several proposals in this direction. Here we will concentrate in BOREXINO, HELLAZ and LAMA. Both BOREXINO and HELLAZ will be sensitive to the required range of electron recoil energy for a ^{51}Cr source (The energy thresholds expected are 250 KeV and 100 KeV, respectively) while LAMA will measure the $\bar{\nu}_e e \to \bar{\nu}_e e$ dispersion for the ^{147}Pm source.

In order to have a good determination of the differential cross section we need to have small errors both in the recoil electron energy and in the differential number of events. Hereafter we will concentrate in the necessary resolution required in the experiments in order to be sensitive to the Z' mass.

The energy resolution of a detector depends on the energy range itself, usually the higher the energy, the better resolution one has. The reason for this is simple, if an electron has more energy then it radiates more photons and then the uncertainties in the photon counting decrease as $1/\sqrt{N_{photons}}$. This is valid for photo-tubes and the same rule applies for other kinds of detectors. A characteristic quantity for the detector resolution is $\Delta = \Delta_\epsilon \sqrt{T/\epsilon}$ with Δ_ϵ being the energy resolution at the fixed energy ϵ. Experimentalists have estimated the resolution they can reach in the three different proposals we are considering here. The corresponding values of Δ_{1MeV} for the three different proposals are shown in Table 3 along with other detector characteristics [8,9,20].

In the case of BOREXINO, bins of 50 KeV are envisaged by the collaboration. The detector will be sensitive to the two main lines of the ^{51}Cr making up 90 % of the neutrino flux; which is equivalent to $\Phi = 1.8 \times 10^{12} \nu/cm^2 sec$, if the source is surrounded by the detector as was the case in the GALLEX calibration experiment [1].

[1] We are assuming that the neutrino source is placed at the centre of the detector; if this is not the case, as in ref. [19], the number of events would be drastically reduced and therefore the statistical error will be too large.

For HELLAZ the energy resolution is of the order of 3 % and the energy threshold is 100 KeV. This detector will consist of six tones of helium ($N_e \simeq 2 \times 10^{30}$). Here we will assume that the bin width will be 10 KeV.

Considering these parameters and a time period of twenty days, we need an estimate of the expected differential number of events both for the Standard Model and for the extended gauge models. We have computed the expectation for the differential number of events both in the Standard Model as well as in extended models by using the expression [22]

$$\langle \frac{dN}{dT} \rangle = \Phi N_e \Delta t \int_{\omega_{min}(T_{trh})}^{\omega_{max}} f(\omega_1) d\omega_1 \int_0^{T_{max}(\omega_1)} R(T,T') \frac{d\sigma}{dT} dT' \tag{21}$$

with

$$R(T,T') = \frac{MeV}{\sqrt{2\pi T'} \Delta_{1MeV}} exp \left(\frac{-(T-T')^2}{2\Delta_{1MeV}^2 T'} \right) \tag{22}$$

In the absence of a direct measurement of the resolution function we use a Gaussian, as advocated in [22].

In the SM case we just need to substitute in the differential cross section 3 the SM expressions for g_L and g_R, while for the extended gauge theories we substitute the expressions given in 8, for the case of E_6 models, or 18 for the LRSM. For the case of a ^{51}Cr source the energy spectrum $f(\omega_1)$ will be given by a sum of delta functions for the different neutrino lines while for the anti-neutrino ^{147}Pm we need to consider the neutrino energy spectrum

$$f(\omega_1) d\omega_1 = \frac{1}{N} \omega_1^2 (W - \omega_1) \sqrt{(W-\omega_1)^2 - m_e^2)} d\omega_1 \tag{23}$$

with N the normalization factor and W equal to m_e plus 234.7 KeV. In this work we assume that the future experiments will measure the Standard Model prediction, and we will make a fit on the extended gauge model parameters by assuming that the measured number of events per bin is given by

$$N_i = \int_{T_i}^{T_{i+1}} \langle \frac{dN}{dT} \rangle^{SM} dT \tag{24}$$

In order to do such a hypothetical fit for the different models under consideration we also need to know the total error per bin σ_i. As we do not know this value we have considered different values of σ_i (in percent) in our analysis. We can only hope, at this point, that they reflect in a realistic way both the statistical and systematic errors. For a preliminary discussion of backgrounds for Borexino see Fig 15 of their proposal [8]. More precise measurements are now underway [24].

As already mentioned, these experiments can not compete in sensitivity with LEP results, therefore is not possible to improve the constraint on the mixing angle with this kind of experiments, but they can play a role in constraining the Z' mass. In our analysis we have fix the mixing angle to be zero and we have fitted for the parameter γ, under the assumptions specified above.

With the expressions given in 8 we can have the theoretical prediction for the E_6 models, in particular for the χ, ψ and η models. From 18 we have the theoretical prediction for the LRSM. With these theoretical predictions and with the different values per bin we can make a fit on each model for different hypothetical σ_i values. The results, at 95 % C. L. are shown in Fig. 1 both for BOREXINO and HELLAZ. In this figure we also show the constraint on γ coming from a global electroweak fit [17]. One can see that the sensitivity is different for different models, the most promising case being the χ model. In this case an error of 5 % in BOREXINO would provide a better sensitivity than that obtained in a *global* fit of the electroweak data [17], while for HELLAZ an error of 8 % would already give a better sensitivity than that of a *global* fit. For the case of η model the situation is much less hopeful. However, one can improve substantially the sensitivity by going to the case of *constrained superstring models*, since in this case the Z' mixing is determined by the Z' mass [12]. In the same figure we also have plotted the result for the HELLAZ experiment in case they can cover the energy range from 100 KeV to 560 KeV instead of the energy range of 100-260KeV. This most optimistic case corresponds to the lower line in each one of the plots in Fig. 1.

One can see that HELLAZ could be more sensitive than BOREXINO in testing new physics if they can control the systematic errors due to their expected better energy resolution (larger number of bins). However it is also important to notice that the expected statistical error in HELLAZ will be bigger than in BOREXINO because of the smaller detector mass. Therefore a good control of the systematic errors is required.

In the BOREXINO case, its huge detector will give a small statistical error, however, the energy resolution is poor, making it necessary to have a good control on the systematic error in order to reach a meaningful sensitivity to the Z' mass, comparable to the present constraint from a global electroweak fit.

We have repeated the same considerations made above for the case of the recent LAMA proposal for the case of a 1 tone detector surrounding a 10 MCi source with 4π geometry and 50 cm radius. Our results are shown in Fig. 2. We have also shown by the black square dot the constraint that one would get in the case when only the statistical error is included for the specific configuration that we have discussed here and one year running. One sees that the prospects for getting a better constraint seem good if they can control systematic errors.

V. DISCUSSION AND CONCLUSIONS

We have illustrated in this paper how the upcoming strong radioactive neutrino sources and new low-energy detector technology are likely to open a new window of opportunity for experimental searches which were originally mainly directed to solar neutrino research. In this work we have considered the case of $\nu_e e \to \nu_e e$ scattering and showed how these techniques could provide a better sensitivity than achieved in present measurements. This would allow stronger tests of the electroweak interaction and, potentially, stronger constraints on extended gauge theories. We have considered three particular detectors that could use isotope sources for studying this process and we have found that there are good prospects for reaching a better sensitivity on the Z' mass than achievable at the moment, if systematic errors can be put under control.

For example, for the LAMA proposal, assuming a one tone detector, a Pm activity of 10 Mci and source of 50 cm radius we have determined the number of events per 2 KeV bin which are expected in a year run as a function of the recoil electron energy T in the range 2-25 KeV. The total number of events will be the sum over all bins. This is shown in fig 3. Here we have also computed the Coulomb correction for the anti-neutrino spectrum and found good agreement with the estimates given in Fig. 1 in ref. [23]. Our calculations indicate that Coulomb corrections may have an overall $\lesssim$ 2% effect in the number of events shown in fig. 3, where these corrections have been included. However, they do not affect our results in fig. 2, which are the relevant ones for discriminating against new physics. In this figure we have compared the relative sensitivity of LAMA for neutrino magnetic moment searches [6] and extended gauge model (the χ model, for definiteness) tests. We have fixed, for illustration, a neutrino magnetic moment of $\mu_\nu = 2.5 \times 10^{-12} \mu_B$ and an extended neutral gauge boson mass of $M_{Z'} = 330\ GeV$. In contrast to the case of neutrino magnetic moments (neglecting background) the sensitivity to the extended Z' model becomes competitive a little above 2 keV, and better for almost all values of the recoil energy above this value. Even though the number of events drops, one still has about 4% sensitivity to new gauge boson up to 40 KeV, where one expects one event per day. In other words, for energies in the region $12\ KeV \leq T \leq 25 - 30\ KeV$ this experiment should be sensitive to extensions of the standard model neutral gauge structure, while the sensitivity to magnetic moment becomes gradually lost.

How about improvements? In order to determine what improvements can be achieved we have come back to the recoil energy range from 2-25 KeV for which LAMA is optimum for neutrino magnetic searches. We have studied the sensitivity of the LAMA experiment to a new neutral gauge boson as a function of the *total* error σ that one can reach. We have compared this sensitivity with the corresponding sensitivity to a neutrino magnetic moment and have displayed in fig. 4 one sensitivity against the other.

Although this may seem far future and we do not wish to minimize the experimental challenge posed by our proposal, one can see from this figure that the sensitivity on new gauge boson increases much faster than that on magnetic moment, because the first is linear in σ whereas the second scales as $\sigma^{1/2}$. In summary, we have seen that future detectors will have the possibility of making stringent low-energy tests of the electroweak interaction gauge structure feasible.

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TABLES

TABLE I. Quantum numbers for the light particles in the **27** of E_6.

	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 II. Neutrino Energies and half-life for a ^{51}Cr source.

source	$\tau_{1/2}$	ω_1		T_{max}
^{51}Cr	27 days	0.746 MeV	81 %	0.559 MeV
		0.751 MeV	9 %	0.563 MeV
		0.426 MeV	9 %	0.268 MeV
		0.431 MeV	1 %	0.273 MeV

TABLE III. Characteritics of νe Detectors [8,9,20]

	T_{th} (MeV)	Δ_{1MeV}	N_e
BOREXINO	.250	$\sqrt{1/300}$ MeV	5×10^{31}
HELLAZ	.1	$\sqrt{1/20000}$ MeV	2×10^{30}
LAMA	.002	.026 MeV	3×10^{29}

FIGURES

FIG. 1. Constraints on the the parameter γ of eq. (9) as a function of the total error per bin that could be reached in the BOREXINO (solid line) and HELLAZ experiments (the dotted line is for the energy range from 100-260 KeV while the dashed one is for 100-560 KeV) for four different extended gauge models. The electroweak global fit constraint on γ is also shown for comparison.

FIG. 2. Constraints on the the parameter γ of eq. (9) as a function of the total error per bin that could be reached in the LAMA experiment for four different extended gauge models. The black square dot shows the case when only the statistical error is considered. The electroweak global fit constraint on γ is also shown for comparison.

FIG. 3. Expected number of events in LAMA per electron recoil energy bin for the SM (square), for a neutrino magnetic moment of $\mu_\nu = 2.5 \times 10^{-12} \mu_B$ (star), and for an extended gauge model (χ model) with a Z' mass $M_{Z'} = 330\ GeV$ (circle).

FIG. 4. Comparing the LAMA sensitivity to neutrino magnetic moment vs. Z' mass in the χ model.

Fig 1 O. G. Miranda...

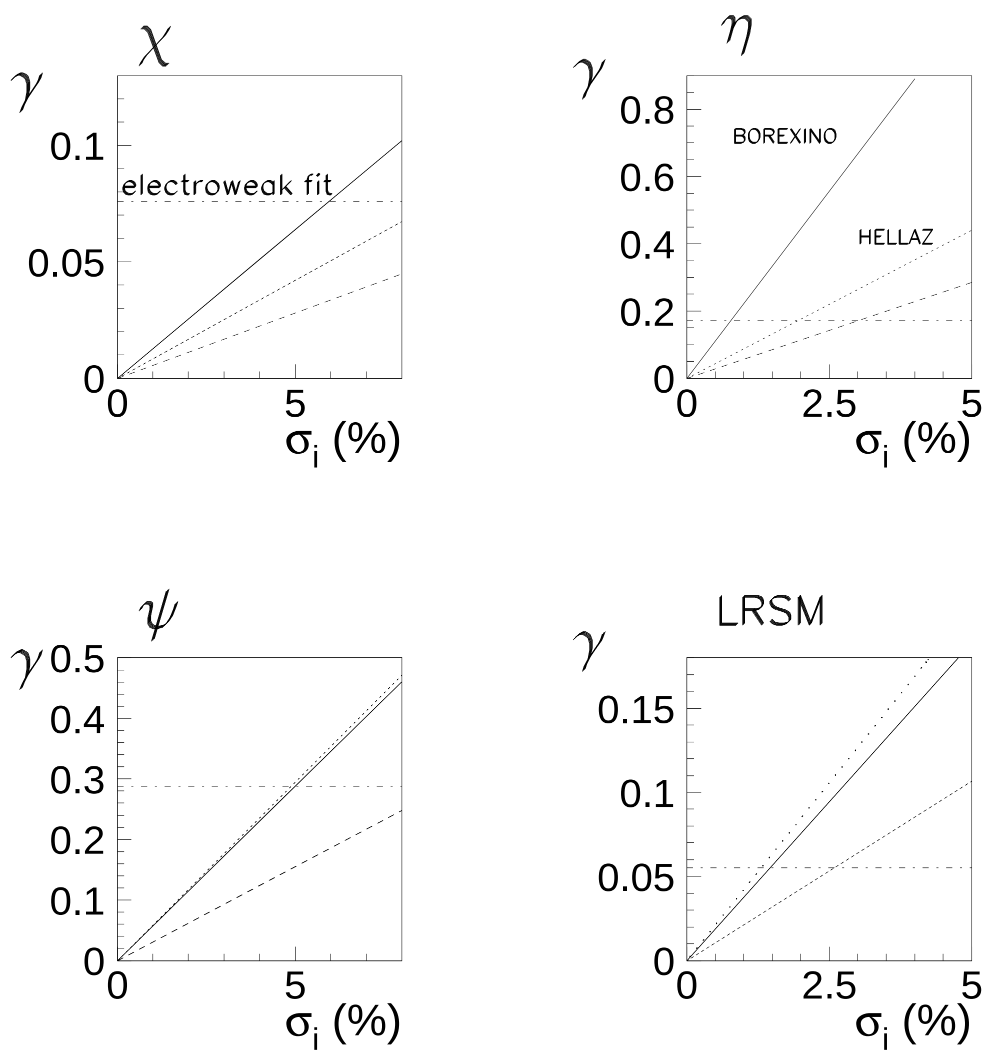

Fig. 2 O. G. Miranda...

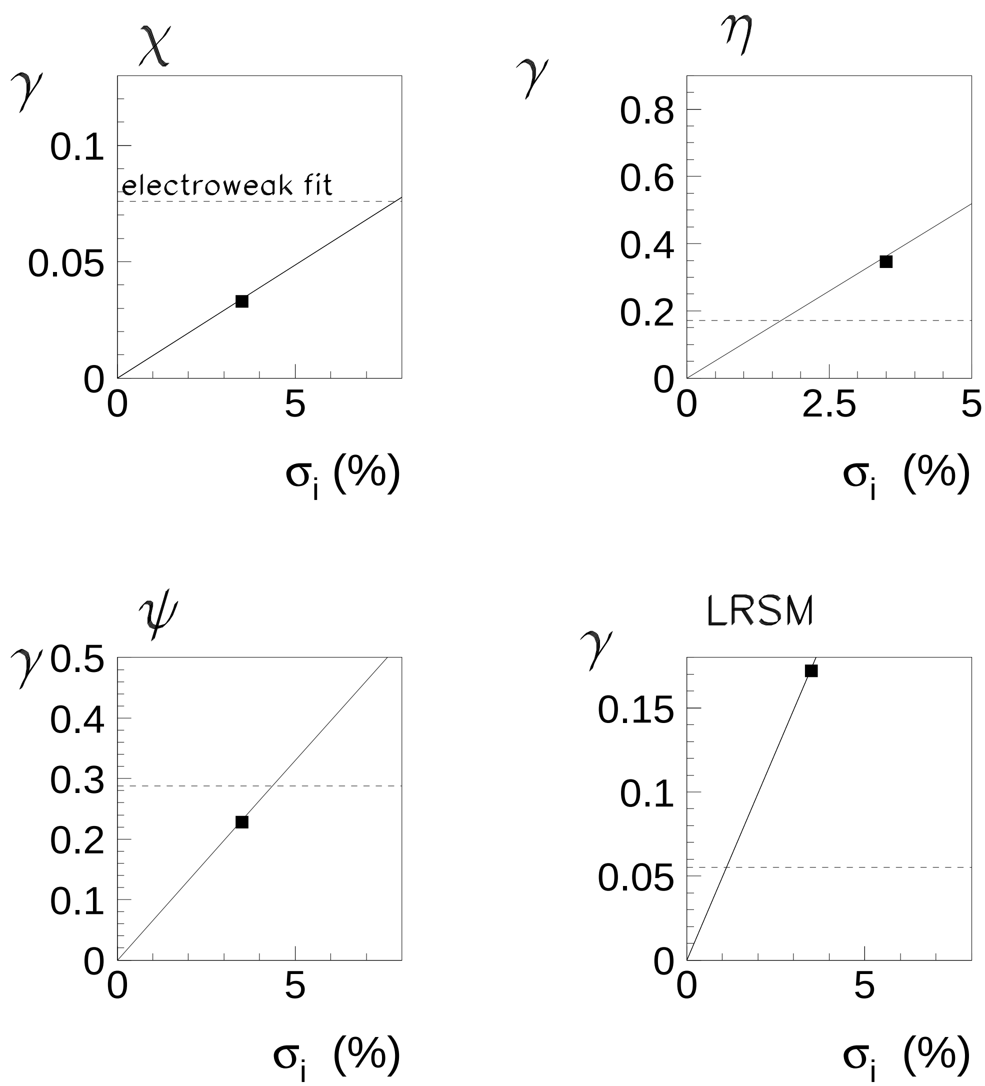

Fig 3 O. G. Miranda...

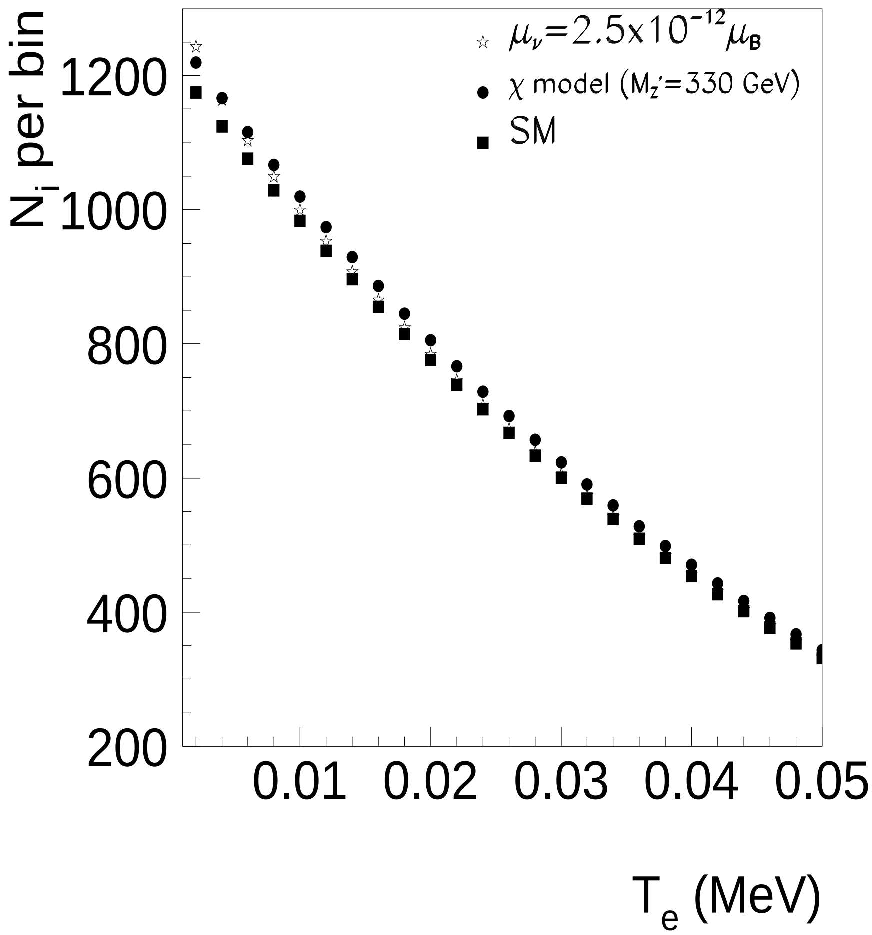

Fig 4 O. G. Miranda...