Testing for New Physics with Low-Energy Anti-Neutrino Sources: LAMA as a Case Study

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Abstract

Some electroweak models with extended neutral currents, such as those based on the E_6 group, lead to an increase of the $\overline{\nu}-e$ scattering cross section at energies below 100 keV. We propose to search for the heavy Z' boson contribution in an experiment with a high-activity artificial neutrino source and with a large-mass detector. We present the case for the LAMA experiment with a large NaI(Tl) detector located at the Gran Sasso underground laboratory. The neutrino flux is known to within a one percent accuracy, in contrast to the reactor case and one can reach lower neutrino energies. Both features make our proposed experiment more sensitive to extended gauge models, such as the χ model. For a low enough background the sensitivity to the Z_χ boson mass would reach 600 GeV for one year running of the experiment.

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1 Introduction

We have recently revived the idea of using low energy neutrino reactions as sensitive precision tests of the Standard Model (SM) [1] both as probes for non-standard neutrino electromagnetic properties [2, 3] as well as extended gauge structures [4]. The alternative use of reactors such as the MUNU experiment has recently been suggested [5]. Here we discuss in detail the possible advantages of performing measurements at low energy with a very intense anti-neutrino source, such as a ^{147}Pm source proposed in the LAMA experiment [1]. In contrast to ref. [4] where the potentiality of low energy source experiments was discussed from a more general perspective, here we concentrate on the specific case of the LAMA proposal, using the design parameters of the experiment as a case study. In LAMA the neutrino flux should be determined with an accuracy better than one percent. The dimensions of the source will allow to surround it by the detector.

We evaluate the potential that such an isotope source offers in testing the electroweak gauge structure of the SM. For definiteness we consider the sensitivity of this experiment to models that can arise from an underlying E_6 framework [6]. The later have been quite popular since the eighties, especially because they arise in a class of heterotic string compactifications. LEP measurements at the Z peak have achieved very high precision in determining the neutral current coupling constants governing $e^+e^- \to l^+l^-$. This constrains especially the mixing angle between the Z and the Z' bosons. As a result we will focus here on the possible constraint for the mass of the additional gauge boson $M_{Z'}$.

We consider extensions of the Standard Model involving an extra $U(1)$ symmetry at low-energies, coupled to the following hyper-charge [6]

$$Y_\beta = \cos\beta Y_\chi + \sin\beta Y_\psi, \tag{1}$$

while the charge operator is given as $Q = T^3 + Y$. The values of Y_χ and Y_ψ for different particles are well known in the literature and are given in Table 1. Any value of β is allowed, giving us a continuum spectrum of possible models of the weak interaction. The most common choices considered in the literature are $\cos\beta = 1$ (χ model), $\cos\beta = 0$ (ψ model) and $\cos\beta = \frac{\sqrt{3}}{\sqrt{8}}$, $\sin\beta = -\frac{\sqrt{5}}{\sqrt{8}}$ (η model). The masses of the neutral gauge bosons in these

models arise from a 2×2 matrix which may always be written as

$$\begin{pmatrix} M_{Z^0}^2 & \mu^2 \\ \mu^2 & M^2 \end{pmatrix} \tag{2}$$

where $M_{Z^0}^2$ would be the Z-mass in the absence of mixing with the extra gauge boson. The eigenstates following from Eq. (2) are given by

$$\begin{aligned} Z &= cos\theta' Z_0 - sin\theta' Z_0' \\ Z' &= sin\theta' Z_0 + cos\theta' Z_0' \end{aligned} \tag{3}$$

in terms of the weak eigenstate gauge fields Z_0 and Z_0'.

If we restrict ourselves to the case when only doublet and singlet Higgs bosons arising from the fundamental **27**-dimensional representation of the primordial E_6 group are present, then we have the following expression for the mixing parameter [7]

$$\mu^2 = M_{Z_0}^2 sin\theta_W [\frac{1}{3}\sqrt{10}(1 - 2\xi)sin\beta - \sqrt{2/3}cos\beta], \tag{4}$$

depending on the chosen model through the angle β and also through the parameter ξ, defined as $\xi = \frac{v_d^2}{v_u^2 + v_d^2}$, where v_u and v_d are the vacuum expectation values dominantly responsible for the electroweak breaking. Such models were called *constrained superstring models* in ref. [8]. For the χ model we do not have any dependence on the ξ parameter, since in this case $sin\beta = 0$ and therefore any ξ dependence in Eq. (4) is washed out. As a result one obtains a direct relationship between the Z' mixing angle θ' and its mass $M_{Z'}$. This enables us to convert any bound on $M_{Z'}$ into a corresponding one on the Z' mixing angle. The advantage of these models for us is that they allow us to restrict the Z' mixing angle which is not obtained directly by our present method.

2   The Cross Section

In the SM, the differential cross section for $\overline{\nu_e}e \to \overline{\nu_e}e$ scattering is given by,

$$\frac{d\sigma}{dT} = \frac{2m_e G_F^2}{\pi}\{(g_L+1)^2 + g_R^2 - [2(g_L+1)^2 + \frac{m_e}{E_\nu}(g_L+1)g_R]\frac{T}{E_\nu} + (g_L+1)^2(\frac{T}{E_\nu})^2\} \tag{5}$$

where g_L and g_R are the Standard Model model expressions $g_{L,R} = 1/2(g_V \mp g_A)$. Here T is the electron recoil energy and E_ν the neutrino energy.

The neutral current contribution to $\overline{\nu}e \to \overline{\nu}e$ scattering in extended models is given for example in Ref. [8]. The extra contribution due to the Z' to the differential cross section will be, for $\theta' = 0$,

$$
\begin{aligned}
\delta \frac{d\sigma}{dT} = \quad & \gamma \quad \frac{2m_e G_F^2}{\pi}\{2(g_L+1)\delta g_L + 2g_R \delta g_R \\
& -[\quad 4(g_L+1)\delta g_L + \frac{m_e}{E_\nu}((g_L+1)\delta g_R + g_R \delta g_L)]\frac{T}{E_\nu} \\
& +2 \quad (g_L+1)\delta g_L(\frac{T}{E_\nu})^2\}
\end{aligned}
\tag{6}
$$

where

$$
\gamma = \frac{M_Z^2}{M_{Z'}^2}
\tag{7}
$$

and $\delta g_{L,R}$ depend on the model under consideration. For the particular case of the LRSM [9, 10] this corrections are given by

$$
\delta g_L = \frac{s_W^4}{r_W^2}g_L + \frac{s_W^2 c_W^2}{r_W^2}g_R
\tag{8}
$$

$$
\delta g_R = \frac{s_W^4}{r_W^2}g_R + \frac{s_W^2 c_W^2}{r_W^2}g_L
\tag{9}
$$

where $s_W = sin\theta_W$, $c_W = cos\theta_W$ and $r_W^2 = cos2\theta_W$; while for the E_6 models we have, again for $\theta' = 0$,

$$
\delta g_L = 4\rho s_W^2(\frac{3cos\beta}{2\sqrt{24}} + \frac{\sqrt{5}}{\sqrt{8}}\frac{sin\beta}{6})(\frac{3cos\beta}{\sqrt{24}} + \frac{\sqrt{5}}{\sqrt{8}}sin\beta)
\tag{10}
$$

$$
\delta g_R = 4\rho s_W^2(\frac{3cos\beta}{2\sqrt{24}} + \frac{\sqrt{5}}{\sqrt{8}}\frac{sin\beta}{6})(\frac{cos\beta}{\sqrt{24}} - \frac{\sqrt{5}}{\sqrt{8}}sin\beta)
\tag{11}
$$

where, ρ denotes the radiative corrections to the ratio $M_W^2/M_Z^2 cos^2\theta_W \equiv 1$ and β defines the E_6 model, in which we are interested in. All expressions we have shown are for the case of $\theta' = 0$ and in what follows we will always use this assumption.

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We can rewrite Eq. (6) as

$$\delta\frac{d\sigma}{dT} = \gamma\Delta = \gamma\frac{2m_e G_F^2}{\pi}\{D + E\frac{T}{E_\nu}(\frac{T}{E_\nu} - 2) - F\frac{m_e}{E_\nu}\frac{T}{E_\nu}\} \qquad (12)$$

with Δ in obvious notation and

$$D = 2(g_L + 1)\delta g_L + 2g_R\delta g_R \qquad (13)$$
$$E = 2(g_L + 1)\delta g_L \qquad (14)$$
$$F = (g_L + 1)\delta g_R + g_R\delta g_L. \qquad (15)$$

The correction to the $\overline{\nu}_e e$ scattering depends on the model as well as on the energy region. In order to illustrate how these corrections may affect the Standard Model prediction we can define the expression

$$R = \frac{\Delta}{(\frac{d\sigma}{dT})^{SM}} \qquad (16)$$

This ratio depends on the specific model through the angle β and depends also on the electron recoil energy as well as on the neutrino energy.

We have plotted in Fig. (1) the quantity R in Eq. (16) for a class of E_6 models. Different values of E_ν and T are considered, corresponding to the case of a ^{147}Pm source. We can see from the plot that for $\cos\beta \simeq 0.8$ one can have a large deviation from the Standard Model predictions simply by varying E_ν and T. For $\cos\beta \simeq -0.4$ one can see that, irrespective of the kinematical variables of E_ν and T the deviation that can be achieved is very small. For models with $\cos\beta \lesssim -0.4$ we have a negative contribution that would decrease the number of events for some electron energies. This effect is just the opposite of what would be expected in the case of a neutrino magnetic moment and would be a direct signature of extended gauge theories. However the sensitivity is smaller here than for the models for which $\cos\beta \simeq 0.8$.

Altogether, one sees that the χ model is the most sensitive to this scattering. Other popular cases such as the η [‡] and ψ models, often cited in the literature, have a smaller sensitivity. For this reason, from now on we fix on

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[‡]For simplicity of presentation we have chosen to plot this model as corresponding to the values $\cos\beta = -\frac{\sqrt{3}}{\sqrt{8}}$ and $\sin\beta = +\frac{\sqrt{5}}{\sqrt{8}}$. We can do this since, as can be seen from eq. (10) and (11) a simultaneous change in the signs of $\sin\beta$ and $\cos\beta$ does not affect R.

χ model, which is also theoretically appealing as it corresponds to the hypercharge that lies in $SO(10)/SU(5)$. For this case we wish to see for which choices of the kinematical variables of E_ν and T there is greater sensitivity to the new physics.

In Fig. (2) we have plotted Eq. (16) for the specific case of the χ model for the range of neutrino energies accessible at a ^{147}Pm source. In the plot we show the value of this ratio for different values of the electron recoil energy. For very low electron energies, close to the energy threshold, one has a bigger deviation from Standard Model predictions in the χ model. Indeed, the independent term D in eq. (12) is large and positive, while the other two terms give small negative contributions. The plot shows how the corrections get smaller as the recoil electron energy increases. As we can see from the figure, in order to reach a constraint for $\gamma \lesssim 0.1$, i.e. a Z' mass of about $\gtrsim 300$ GeV or so, we need a resolution of the order of 5 %. From the present global fit of electroweak data the constraint on the Z' mass for the χ model is 330 GeV at 95 % C. L. [11], while from direct searches at the Tevatron the constraint is 595 GeV at 95 % C. L. [12].

In the next sections we will estimate the sensitivity of the LAMA experiment to the χ model Z' boson. This estimate is obtained for the idealised case of anti-neutrino electron scattering from a free electron. In practice in a realistic detector, such as NaI, the electrons are bound and, in some cases it is necessary to take the effect of binding into account, such as for the case of the iodine atom. Recently the corrections to the differential cross section due to the atomic binding energy have been discussed in ref. [13]. They are particularly important for the first level of the I atoms, where the binding energy is $\varepsilon_1 = 32.92$ KeV. These corrections could be taken into account by computing the wave equation for the electron in the Hartree-Fock-Dirac approximation [14]. A useful approximation can be obtained in terms of $q = \varepsilon_i + T$ where T is the recoil electron energy and ε_i denotes the electron binding energy in the I atom [14, 15]. In this case the energy distribution $S_{inel}(q)$ for the bound electron of a given atomic level can be taken as $S_{inel}(q) \simeq S_{free}(q)\theta(q - \varepsilon_i)$ where $S_{free}(q)$ stands for the energy distribution in the free electron case. We estimate an overall uncertainty of about 10 % in our use of the free electron approximation, which would affect the overall statistics (expected number of events in either the Standard Model or its extensions). Note however that they should cancel in the ratio given in eq. 16 and in the corresponding sensitivity plots for the deviations from

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the Standard Model that we have presented.

3   Experimental Prospects

The LAMA experiment
The experiment LAMA [1] has been proposed for neutrino magnetic moment search in the range of $10^{-10} - 10^{-11}$ μ_B. The principle of our proposed experiment is similar to the reactor one. A large neutrino magnetic moment (LMM) would significantly contribute to the neutrino electron scattering process. As an alternative to the reactor idea, we propose the use of an artificial neutrino source (ANS). Our main aim in the experiment is the investigation of low-energy neutrino-electron scattering as a test for a possible deviation from the Standard Model prediction. For definiteness we focus on the possibility of investigating the gauge structure of the electroweak interaction as mentioned above. The use of an ANS has a number of essential advantages with respect to the reactor for the experiments with low-energy neutrinos:

- (a) the effective neutrino flux with the proposed ANS should be at least 10 times higher than in a typical reactor. This could potentially be increased in the future;

- (b) the accuracy of source activity determination should be as high as a few tenths of percent in comparison with 10 % for the reactor case;

- (c) the ANS energy should be low enough, giving the possibility to minimise effect of background from the high-energy part of the neutrino spectrum;

- (d) the experiment should be carried out in a deep underground laboratory, to ensure a low enough background.

All these advantages make the use of an ANS preferable to a reactor for the kind of experiment under consideration.

The isotope for the ANS
The ^{147}Pm isotope has been chosen as an optimal candidate for the ANS both from the point of view of its physical parameters (low enough neutrino energy, absence of gamma-rays, long enough lifetime) as well as the possibility

to produce a large enough activity. The scheme of the ^{147} Pm decay with its basic parameters is presented in Fig 3.

The ^{147} Pm isotope has been produced commercially since 1980 by a Russian Nuclear Plant called "Mayak" by extracting it from used reactor fuel. The other radioactive REE elements admixture in the produced ^{147} Pm is less then 10^{-9} and could be lower, if necessary. A 5 MCi ^{147} Pm source is planned to be used for the first step of the experiment. A source with such an activity can be produced by the plant in 3-4 moths after small improvement in technology. An upgrade in activity up to 15 Mci can be achieved by the plant in a reasonable period of time. The neutrino spectrum of ^{147} Pm is well-known from the experimental measurement of the beta-electron spectrum. It corresponds to an allowed transition and is given in Fig 1 of ref. [16]. We will use in the following the 5 MCi ^{147} Pm source activity, unless mentioned otherwise. It is important to notice that the neutrino flux from the source is expected to be known with high accuracy (0,3%) [16], thus substantially reducing the systematic errors in contrast to the recently suggested [5] reactor neutrino experiment.

Scheme of the experiment

As a target we consider the use of a NaI(Tl) scintillator installed at the Gran Sasso Laboratory for dark matter particles search [17]. The NaI(Tl) detector is an ideal detector for this kind of experiment, as the mass of the detector could be large enough, a threshold of about 2 keV can be achieved [17] and methods of its purification from U, Th and K are well worked out and can be further improved [18]. The mass of detector is about 120 kg and should be scaled up to 1 ton. For our estimate here we will use a 400 kg NaI mass as mentioned in ref. [1]. The source is surrounded by passive shielding of W (20 cm) and Cu (5 cm) from the unavoidable admixture of ^{146} Pm ($\sim 10^{-8}$) with a 750 keV γ line and other possible REE gamma isotopes. After careful measurement of gamma admixtures in the commercial ^{147} Pm samples the possibility to decrease the shielding will also be considered.

The expected number of events

The basic cross section was given in Eq. (5). This cross section has to be integrated over the anti-neutrino energy spectrum from the ANS and averaged over the expected detector energy resolution. What we obtain for the case of interest (^{147} Pm) is shown in Fig. (4). In (a) we show the χ model, while in (b) we give the results for the ψ and LRSM models. As seen here the effect for these models is rather small and we will not include them

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in the following discussion.

The number of $\overline{\nu} - e$ scattering events expected in the Standard Model and in the χ model are shown in Table 2. The results in Table 2 assume a 400 kg detector and a 5 MCi ^{147} Pm source with the geometry presented in Fig. 1 of Ref. [1]. The total number of events is about 10^4, ensuring a statistical accuracy of about 1%. The deviation from the Standard Model prediction induced by an extra neutral gauge boson with mass of about 300 GeV is 4 % or so, and could be detected. As can be seen the deviations are maximal for the lowest energies. It is therefore convenient to present the results for a region up to 30 KeV. In Fig 5 we display the results we obtain when restricting to this optimum region. The plot shows the histogram obtained when we bin the recoil energy variable in 2 KeV bins, the increment due to a 330 GeV neutral gauge boson in the χ model is also shown at the bottom of the figure.

In order to estimate the sensitivity that our proposed experiment to probe the Z' parameters can reach we first consider the idealized case where the background is set to zero. The more realistic case will be discussed later. We perform a hypothetical fit assuming that the experiment will measure the Standard Model prediction and adopt the same treatment as in [4], where the reader can find a more detailed explanation of the analysis. In order to simulate a realistic situation we also ascribe several values for the systematic error per bin (in per cent). The result is summarised in Fig. 6. One can see that, if we consider only the statistical error one can probe at 95 % C. L. a 500 GeV Z' mass in the χ model. This value will decrease as the systematic error increases. In the same Fig. 6 we also show the expectations for the case of a one tone detector. In this case the attainable sensitivity will be 625 GeV if only the statistical error is considered. This value is comparable to the present constraint obtained by the CDF collaboration.

Since the sensitivity to the mixing parameter θ' is rather poor in this kind of experiments any value of θ' in the present allowed region will give the same result. Therefore in our analysis we will assume $\theta' = 0$ for simplicity. This is all the model-independent information we can extract. However, having done that, as we mentioned in the introduction, for the case of *constrained* E_6 models we can translate the sensitivity on $M_{Z'}$ into a corresponding sensitivity on θ' using the model-dependent relationship between the mass of the extra gauge boson $M_{Z'}$ and the mixing angle θ' expected in these theories. Therefore it is possible to infer from Fig. 6 the potential sensitivity on the

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mixing angle for this specific case. This is shown in Fig 7. One can see that the sensitivity will be close to the LEP bound for the general (unconstrained) model case, which applies also to the constrained case.

Background

The above estimates have been made without taking into account the background. The required background level is determined from the condition that statistical fluctuation of the background event number plus standard electroweak model event number should be less than the effect expected. Taking into account our discussion in the previous section we conclude that the background should be less than effect expected in the Standard Model. So the rate of background due to residual radioactive contaminants should be $< 10^{-3}$ /day/kg. It is clear that the background requirements for this measurement are more stringent than e.g. the ones satisfied at present by the NaI(Tl) detectors used in the DAMA installation [19, 20, 21, 18].

The quantitative investigations of ref. [18] on the radiopurity of these detectors and two independent preliminary analyses [22] of the experimental energy spectra, from 2 keV to the MeV energy region, showed that in the relevant 2-20 keV energy region the residual internal standard contaminants (^{238}U,^{232}Th and ^{40}K) should have a counting rate much lower than already measured. This result suggests that most of the background should arise from the external environment and/or potentially from possible internal non-standard contaminants. In fact, up to now low background NaI(Tl) detectors have been developed selecting at certain level the materials to be used in the crystal growing and taking account only the standard contaminants. Up to now only general statements on the handling during preparation in industrial environment have been given. Although this strategy has so-far worked sufficiently well for the old specifications, it was limited by the the fact that the final residual contaminations in the detectors could be somehow different from the expected one (causing also some differences from one detector to another); in fact, e.g.:

1. the uniformity of the contaminants distribution inside the total material used to construct each part of the detectors has not been checked.

2. the materials were activated at sea level to some extent depending on the period they were outside the underground site.

3. the uniformity of the purification effect of the crystallisation process in the whole large mass crystalline bulk, from which more than one detector was cut, has not been checked.

4. the different growing of the large crystalline bulks (needed to build a large number of detectors) could cause different levels of residual contaminants, because of different casual pollution and/or slight differences in the used materials, seeds, cleaning procedures of the crucible, etc.

5. taking into account that the detectors are built in an industrial environment during several months or more (depending on the number of detectors) one might expect possible (different) casual pollution during the growth, the polishing and the test handling procedures

In particular, regarding the cosmogenic activation we recall that a great variety of long-lived radioactive isotopes are produced by cosmic-ray spallation reactions in the detectors during the time of detector creation. Even at the current stage of low-background experiments, the background from these isotopes (^{54}Mn, ^{57}Co, ^{58}Co, ^{60}Co, ^{65}Zn) is comparable with that arising from other sources. They will represent certainly the main sources of background for the next generation of experiments. The only way to avoid their production inside the detectors is to build them deep underground (see later). We consider this a necessary step in low-background detector development for the next generation experiments.

In order to overcome the above limitations and to develop higher radiopure detectors, suitable in particular to investigate the Z' mass under consideration here, the following approach has been studied:

1. the first step consists in the usual careful selection of all the required materials with the low background Germanium detector deep underground. This ensures the radiopurity of all materials used for building the detectors

2. the second step is totally new. It consists in the selection of all the required materials with a high sensitive mass spectrometer (MS)

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and/or by neutron activation, including measurements of the more important non-standard contaminants (see [18]).

3. subsequent chemical purification of the powders, by using specific additives for every radioactive element. Several purification cycles can be performed. This purification stage has never been utilised before and will ensure an important further purification of the selected powders.

4. growth and assembling of the crystal deep underground in a high quality clean room under control of the proper operating conditions by experimentalists. This will definitively minimise: i) the possible casual pollution with respect to an industrial environment; ii) the activation at sea-level of all the materials. Such program for NaI(Tl) purification and growth has been already developed.

Particular care should be taken to avoid any casual pollution, handling with extreme care the detectors deep underground. Moreover, the detectors should never be exposed to neutron source to avoid their activation and the activation of the surrounding materials. Because the detectors obviously do not measure only internal contaminants, but also the contribution arising from the environment, the shield materials nearest to the detectors should undergo a further complete selection. Moreover, a new generation of low radioactive PMTs is under consideration to reduce their significant background contribution [22]; some preliminary work has already been initiated along these lines.

Furthermore, as regards the background arising from surviving cosmic rays deep underground, since the experiment is planned to be carried out deep underground, the expected muon cosmic-ray intensity is $\lesssim 1/\text{hour}/\text{m}^2$ which is therefore small enough for our background requirements. Moreover it could be further decreased — even by 4-5 orders of magnitude — introducing, if necessary, a suitable anti-coincidence system.

In summary, we conclude that the optimal region for data-taking in our proposed experiment is 2-30 KeV. The statistical accuracy in this case would be only 10 % lower than for the full recoil electron energy range (0-100 keV) but the allowed background level would be 3 times higher.

4 Discussion and Conclusion.

Some Extended Gauge Theories, such as those based on the E_6 group, predict an increase of the anti-neutrino-electron scattering cross section at low energies. For definiteness we concentrate on one of such models, the χ model. We have proposed to look for extra contribution of the heavy Z' boson in $\overline{\nu} - e$ scattering in an experiment (LAMA) with a high-activity artificial neutrino source and with a large-mass NaI(Tl) detector at the Gran Sasso underground laboratory. The neutrino flux is known to within a one percent accuracy, so that even a few percent increase would be detectable. For low enough background the sensitivity to the Z' boson mass would reach 600 GeV for one year running of the experiment.

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Table 1: Quantum numbers of the 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
H_d	$\begin{pmatrix} 1/2 \\ -1/2 \end{pmatrix}$	-2	-2
g^c	0	-2	-2
H_u	$\begin{pmatrix} 1/2 \\ -1/2 \end{pmatrix}$	2	-2
g	0	2	-2
ν^c	0	-5	1
n	0	0	4

Table 2: The expected number of events for the LAMA proposal for the Standard Model and for the χ model for different values of the Z' mass.

Electron recoil Energy	0-20 keV	20-40	40-60	60-80	80-100	Total
St. Model	8472	5207	2899	1359	454	18391
Ext. Model (330 GeV)	8790	5402	3007	1409	470	19078
Difference	318	195	108	50	16	687
Ext. Model (600 GeV)	8570	5267	2931	1374	458	18600
Difference	98	60	32	15	4	209
Ext. Model (700 GeV)	8543	5251	2923	1370	457	18544
Difference	71	44	24	11	3	153
Ext. Model (1000 GeV)	8507	5228	2910	1365	455	18465
Difference	35	21	12	6	1	75
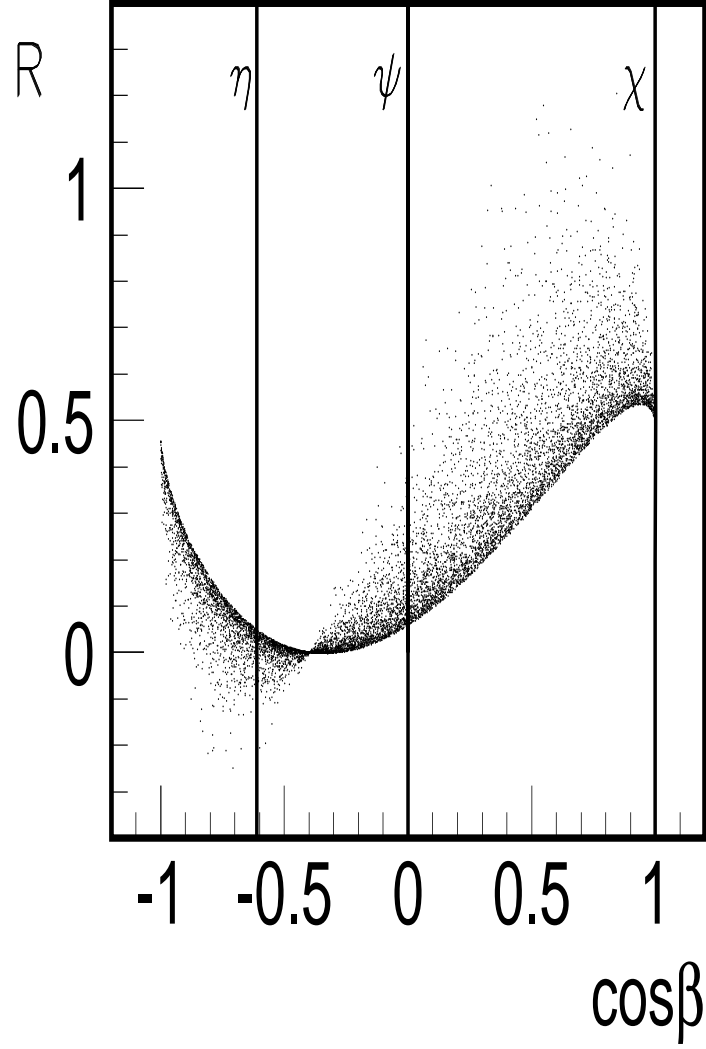
Figure 1: Scatter plot of attainable values for the relative deviation R in eq.16 for different values for the incoming neutrino energy E_ν and the electron recoil energy T. The plot is for different E_6 models. The χ model corresponds to $\cos\beta = 1$. Here we assumed $\theta' = 0$.
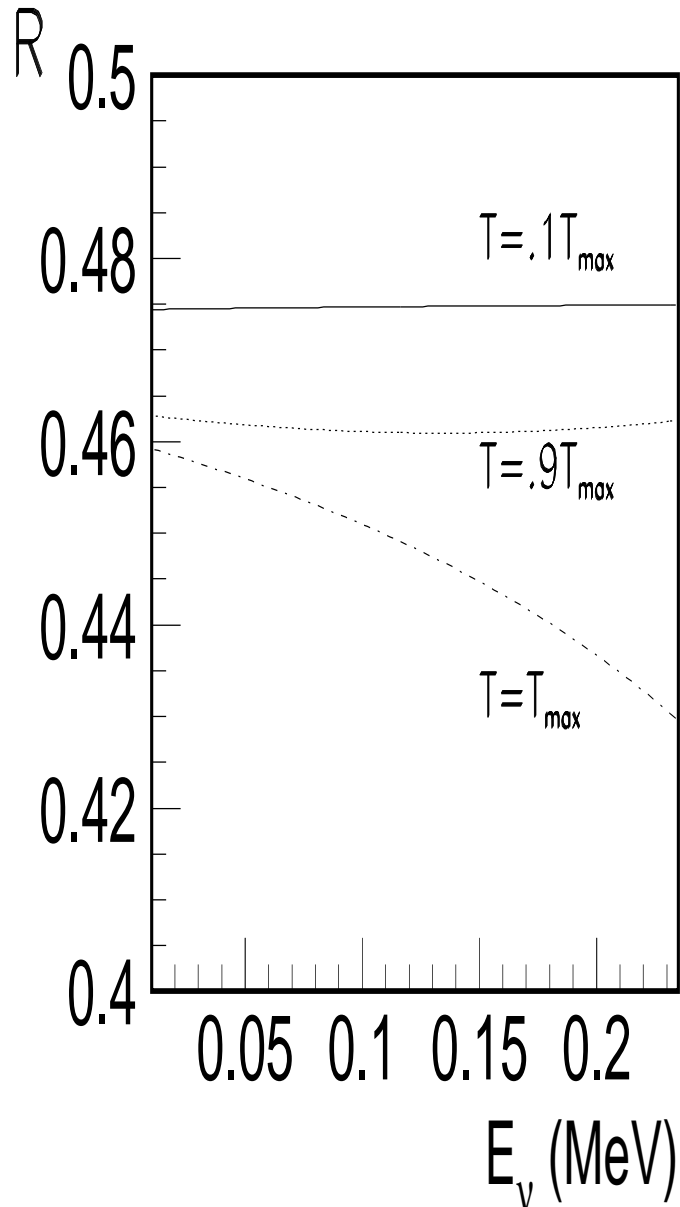
Figure 2: Plot of the ratio given in eq.16 for the χ model as a function of E_ν (in MeV). Different values for the electron recoil energy, T, are shown. Here we assumed $\theta' = 0$.
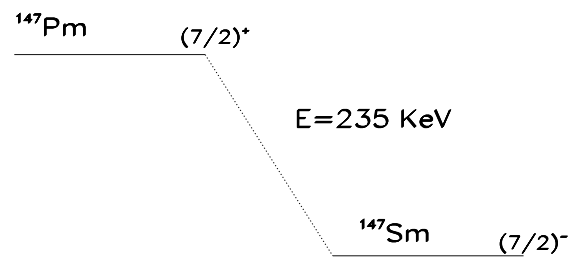
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Figure 3: Level scheme of ^{147}Pm nucleus.
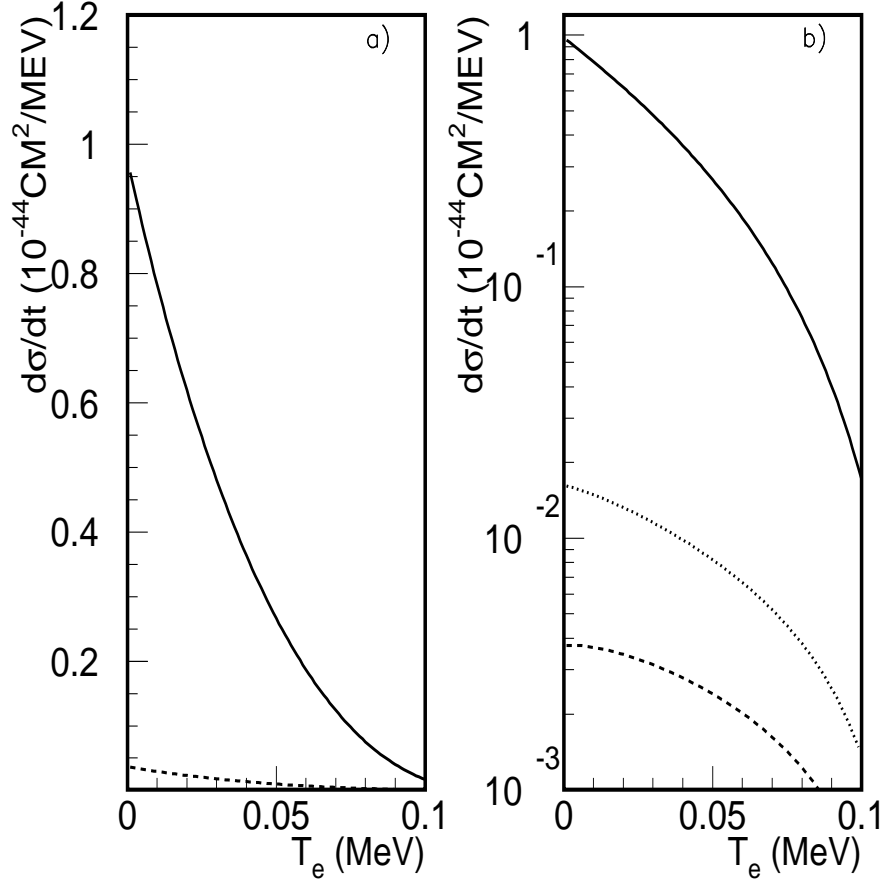
Figure 4: Differential cross section for the $\overline{\nu_e}e$ scattering. In a) we show the Standard Model case (solid line) and the expected increment due to additional positive contribution of an extra 330 GeV gauge boson in the χ model (dashed line). In figure b) we show the Standard Model case (solid line) and the expected increment due to additional positive contribution from an extra 170 GeV gauge boson in the ψ model (dotted line) and from and extra 390 GeV gauge boson in the left-right symmetric model (dashed line). The differential cross section was integrated over the antineutrino energy spectrum and averaged over the energy resolution.
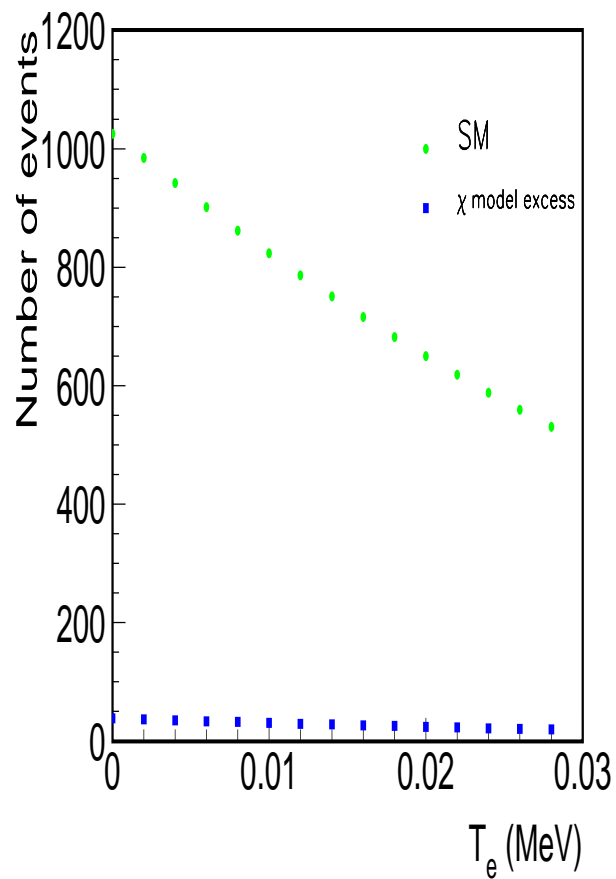
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Figure 5: Expected number of events per bin (2 KeV width) in the standard model and in the χ model for the parameters discussed in the text.
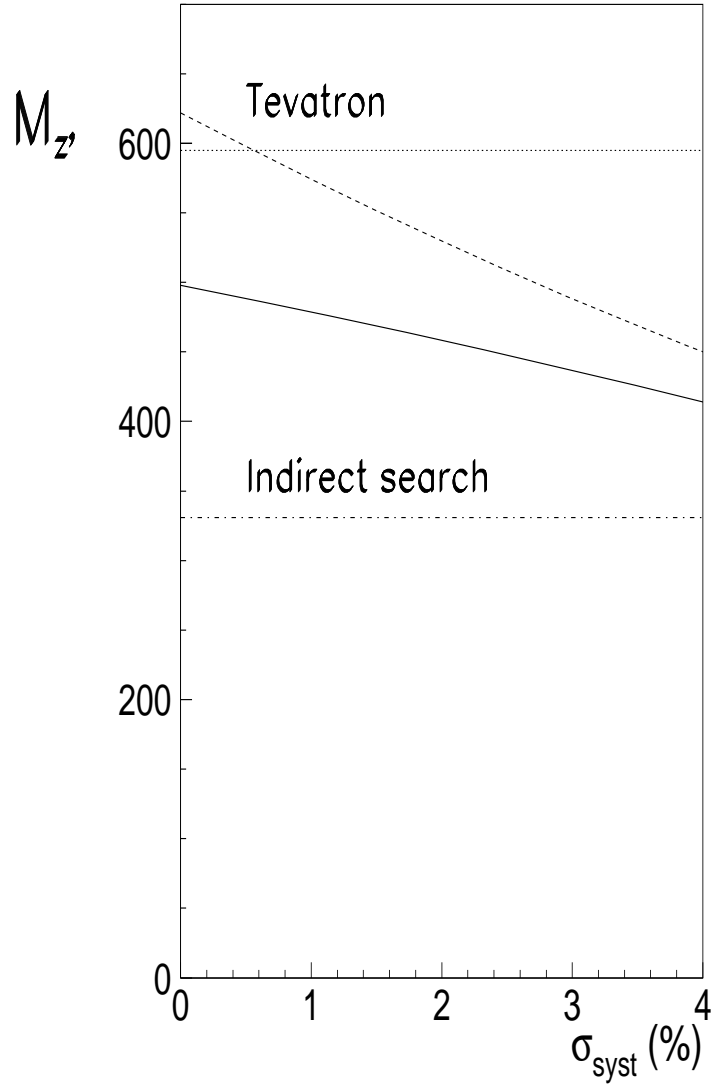
Figure 6: Attainable sensitivity to the mass of an extra gauge boson at 95 %
C. L. in the χ model for the LAMA proposal as a function of the systematic
error per bin. The results consider the cases of a detector of 400 kg (solid
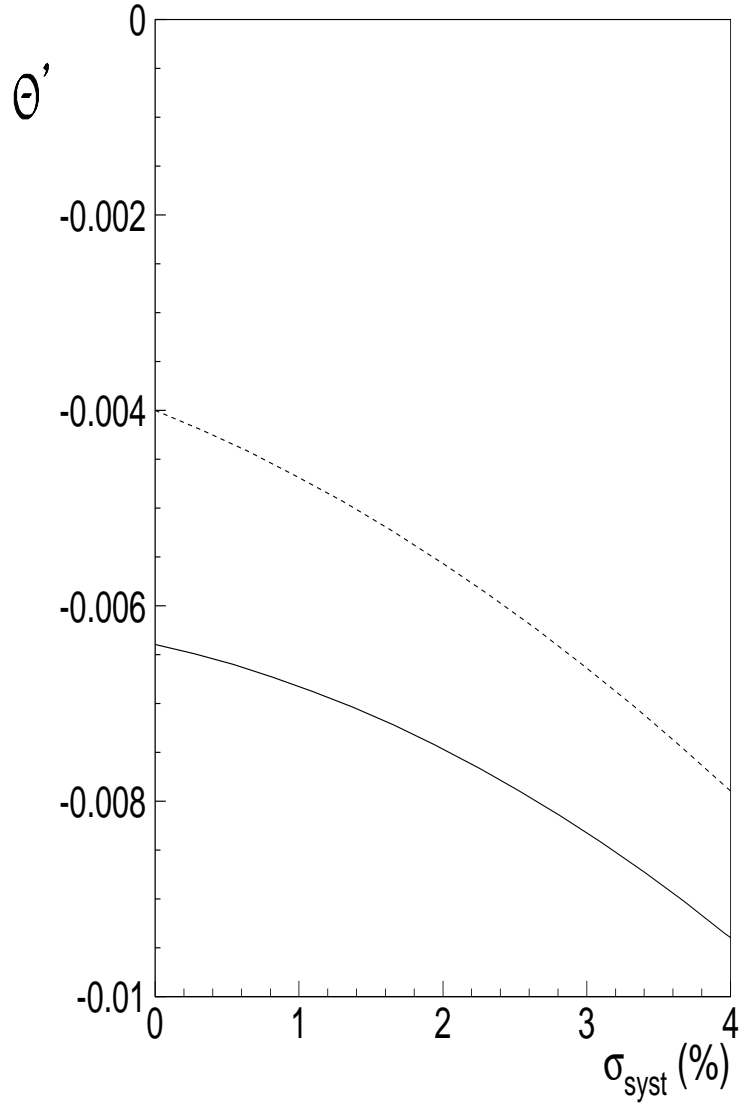line) as well as 1 tone (dashed line).

Figure 7: Attainable sensitivity to the mixing angle of an extra gauge boson in the constrained χ model for the LAMA proposal as a function of the systematic error per bin. The results consider the cases of a detector of 400 kg (solid line) as well as 1 tone (dashed line).