Physics beyond the standard model with a new reactor experiment

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We discuss the sensitivity to new physics of a measurement of the $\overline{\nu}_e e^- \to \overline{\nu}_e e^-$ cross section at a nuclear reactor, with an accuracy as that foreseen for the MUNU experiment. In particular we consider the anomalous contribution to $\overline{\nu}_e e^-$ scattering arising from extra doublet scalars fields, additional Z bosons, and more exotic particles, such as leptonic photons. [S0556-2821(98)03603-0]

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I. INTRODUCTION

Two experiments have measured the $\overline{\nu}_e e^- \to \overline{\nu}_e e^-$ cross section in the few MeV energy range [1,2]. Both experiments were running close to the core of a nuclear reactor and measured only the kinetic energy of the recoiling electron with plastic or liquid scintillators. The sample of neutrino interactions consists of about 460 [1] and 200 [2] events, respectively. The $\nu_e e^- \to \nu_e e^-$ has been measured at Los Alamos with a fine grained tracking calorimeter exposed to neutrinos from muon decay at rest [3]. The statistics, about 240 events, is comparable to that of the reactor experiment, but the neutrino energy, peaked near 33 MeV, is higher.

MUNU [4], a second generation experiment which will study the $\overline{\nu}_e e^- \to \overline{\nu}_e e^-$ process, is now ready to take data. It will be performed in the basement of a nuclear reactor in Bugey (France) at the distance of 18 m from the core. The filling gas (CF_4 at 5 bar, 18.5 kg) of a $1\,\mathrm{m}^3$ time projection chamber is used as an active target. With respect to previous experiments, two substantial improvements are planned in MUNU: the electron energy and direction will both be determined; about 5000 events will be collected during 2 years of data taking.

In particular the measurement of the electron direction offers an important handle for background measurement and rejection. The physics potential of MUNU for the study of the neutrino magnetic moment and neutrino oscillations has been discussed in [4] and [5]. In this paper we discuss the additional physics items which can be studied with a relatively precise measurement of the $\overline{\nu}_e e^-$ cross section at low energy. In this respect we shall consider the anomalous contribution to $\overline{\nu}_e e^-$ scattering arising from an extra doublet scalar field, the effect of additional Z bosons, and more exotic interactions, due to leptonic photons.

II. THE $\overline{\nu}_E E^-$ SCATTERING CROSS SECTION

In the Born approximation, the standard model cross section for the

$$\overline{\nu}_e e^- \to \overline{\nu}_e e^- \tag{1}$$

scattering is

$$\frac{d\sigma}{dT} = \frac{2G^2 m}{\pi}\left[g_R^2 + g_L^2 \left(1 - \frac{T}{\omega}\right)^2 - g_L g_R \frac{mT}{\omega^2}\right], \tag{2}$$

where

$$g_L = \frac{1}{2} + \sin^2\theta_W,$$

$$g_R = \sin^2\theta_W, \tag{3}$$

G is the Fermi constant, m is the electron mass, ω and T are, respectively, the energy of the incoming neutrino and the kinetic energy of the scattered electron.

We want to study possible deviations of $\overline{\nu}_e e^-$ scattering from the above behavior. We assume that the experiment is collecting 5000 neutrino interactions and 2500 background events in the energy region above 0.5 MeV. We take a 5% systematic error on the cross section measurement, arising from uncertainties on the $\overline{\nu}_e$ spectra (normalization and shape) and detector efficiency, as in [4]. We also assume that the background events have the same energy distribution as in a well shielded high purity germanium detector [6].

For the energy resolution we assume a Gaussian distribution with a full-width-half maximum of 0.1 MeV for a 0.5 MeV electron and with a $\sqrt{T}$ dependence on the electron kinetic energy T. These values, rather typical for gas detectors at high pressure, are similar to the ones foreseen for the MUNU experiment.

For the angular resolution we assume that the scattering angle θ between the neutrino and the electron is reconstructed in the detector with a Gaussian distribution which has the full width half maximum Θ shown in Table I as a function of the electron kinetic energy T.

These values are given by the Moliere theory after a 2 cm range in CF_4 at 5 bar. We shall also discuss the effects of a

TABLE I. Full width half maximum Θ of the angular resolution.

T [MeV]	Θ [degree]
0.5	48
0.75	34
1	27
1.5	19
2	15

50% improvement and of a 50% worsening of this angular resolution. The true resolution of MUNU will probably lie in between these extrema.

A few remarks are in order here. For a two body final state, as the one we are considering here, the electron scattering angle and energy are related by kinematics. Therefore for a ''perfect'' experiment the capability of measuring both quantities is redundant. However, the above statment assumes a flux of monoenergetic neutrinos, infinite resolution for the neutrino energy and scattering angle, and zero background. In real life the capability to measure both these quantities is extremely useful and is a distinctive feature of the MUNU experiment.

In fact this feature allows for the following.

Background measurement and rejection. Electrons from $\nu_e e^-$ scattering will appear only in the forward direction and therefore signals detected in the backward direction will be used to measure the background even when the reactor is operating [4].

Both measurements are affected by a finite resolution and systematic uncertainities. The two measurements do provide a useful cross check.

Assuming infinite resolution once the electron scattering angle is measured the initial ν_e energy can be reconstructed. Therefore one can study differential quantities (i.e., $d\sigma/dT$) whithout any assumption on the reactor neutrino spectrum which is known only at the few per cent level. In practice this strategy is limited by finite experimental resolution, however, it turns out that this is a valuable source of information.

The capability to reconstruct the initial ν_e energy allows a *direct* measurement of the reactor neutrino spectrum.

A. Radiative corrections

A complete and detailed account of the full [7] set of one loop radiative corrections to $\nu_e e^-$ scattering, as well as a comprehensive set of references, is given in [8]. The same corrections for $\overline{\nu}_e e^-$ scattering are obtained by replacing $g_L(T) \leftrightarrow g_R(T)$ in the formulas given in [8]. In Fig. 1 the impact of the radiative corrections is shown. The typical effect is a correction of about 2.5% mildly dependent on energy and scattering angle. In view of the expected experimental sensitivity this appears an important effect and it is in itself remarkable that a low energy neutrino scattering experiment has some sensitivity to the radiative corrections, at the one sigma level.

A few comments are in order here.

As noticed in [8], the given corrections are unphysically large very close to the e^- energy end point. This is due to

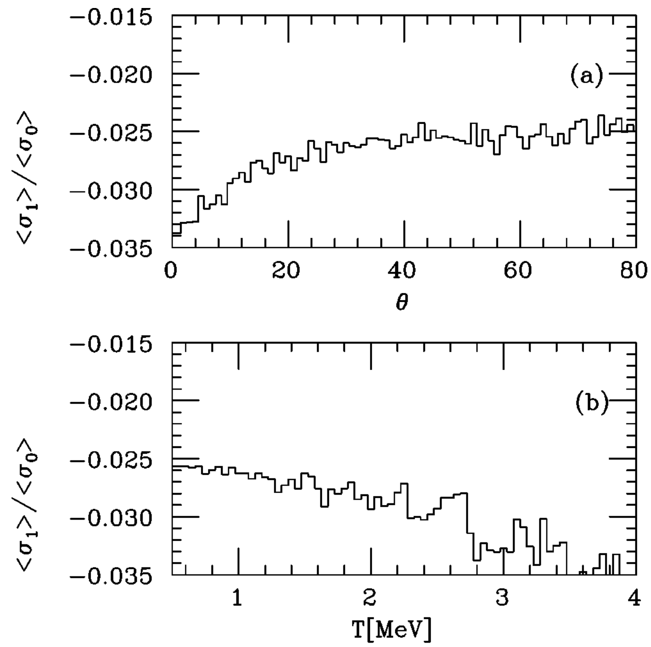

FIG. 1. Fractional contribution of one loop electroweak corrections to $\overline{\nu}_e e^-$ cross section as a function of the scattering angle θ (a) and the e^- recoil energy T (b). $\langle\sigma_{0,1}\rangle$ are the Born and one loop contribution to the $\overline{\nu}_e e^-$ scattering cross section averaged over the reactor neutrino flux and detector energy resolution.

neglecting multiple (real and virtual) soft photon emissions. We have checked that, by substituting the $f_{+,-,+-}$ functions given in [8] with the same functions but bounded to be smaller than 30 in absolute value, the results are unchanged at the per mille level. This strongly suggests that the exact value of $f_{+,-,+-}$, in the energy range[1] where the perturbative expansion does not hold, is unimportant and that higher order corrections are inessential. Notice that this is true even neglecting the experimental e^- energy resolution.

The QED radiative corrections as given in [8] do not account for the exact dependence on the electron mass. A check that this does not affect the final result is therefore important, when analyzing the data, although in the light of the discussion in [8] the effect is expected to be small.

When analyzing experimental data, the corrections due to *detectable* real photons emission have to be included.

In summary one loop electroweak corrections are of the order of a few percent, i.e., of the same size as the experimental accuracy and *have* to be included in the analysis of experimental data. The theoretical error on the $\overline{\nu}_e e^-$ cross section induced by neglecting higher order corrections is below the per mille level and it is therefore completely negligible given the foreseen experimental accuracy.

[1]The definition of this energy range is to a large extent arbitrary. What our ''experiment'' demonstrates is that the value of $f_{+,-,+-}$ is unimportant when one loop QED contributions become larger than 5%. In practice this means that, once averaged over antineutrino spectra and energy resolution, one loop radiative corrections contribute at most at the level of 3–4 %. Higher order corrections are of the order of the square of one loop ones namely we expect that they induce an effect of at most a few per mille.

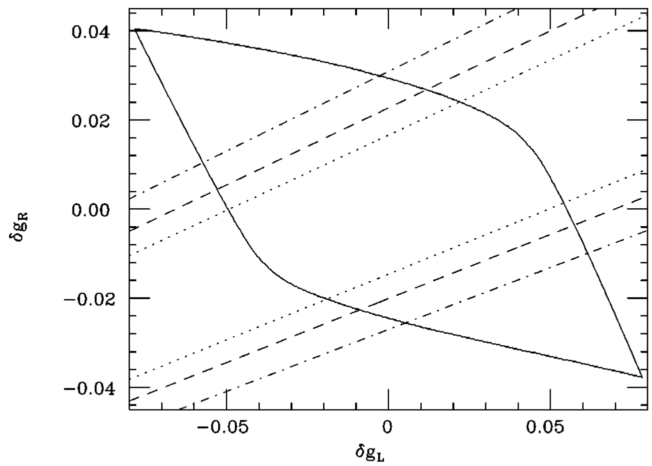

FIG. 2. Expected 90% C.L. exclusion contours in the δg_L, δg_R (shifts, in absolute value, of $g_{L,R}$ with respect to their standard model values) plane. Continuous lines are obtained from the electron recoil spectrum (t_M and t_m variables as defined in the text, Sec. II B). Dashed, dot-dashed, and dotted lines are obtained from the R_θ observable (again as defined in the text, Sec. II B) and assuming angular resolution Θ, 1.5Θ, and 0.5Θ, respectively (see Table I for the definition of the full width half maximum Θ).

In the following we want to discuss the sensitivity of a new reactor experiment, as MUNU, to the effects of physics beyond the standard model. Just for this purpose we can safely neglect one loop electroweak correction. Indeed, let us write the scattering amplitude as $\mathcal{A}=\mathcal{A}_{\rm SM}+\mathcal{A}_{\rm NP}$, SM and NP denoting standard model and new physics contributions, respectively. To assess the sensitivity to new physics effect what matters is the ratio $|\mathcal{A}_{\rm NP}|/|\mathcal{A}_{\rm SM}|$ which will be experimentally detectable. To discuss this issue an estimate of $\mathcal{A}_{\rm SM}$ accurate to few percent is sufficient.

B. Determination of g_L and g_R

In order to discuss the experimental sensitivity to the predictions of the theoretical models, an operative definition of ‘‘sensitivity’’ is needed. For a given model we compute the value of the observables which we are considering. We take the standard model as a reference value and we assume that the relative statistical error is given by the inverse square root of the number of events used to measure the given observable. We then add in quadrature the estimated statistical and systematic errors (including that induced by background counts) to obtain the total error. We say that the experiment is sensitive to the theoretical model if this predicts values that deviate by at least 1.65σ from the reference values.

Once the $\bar{\nu}_e$ spectrum and the experimental resolutions are known, the electron recoil spectra is a function of g_L and g_R (and of the experimental resolution as well) and therefore these two parameters can be determined. Figure 2 represents the sensitivity to δg_L and δg_R shifts with respect to the standard model values, which is achievable with 5000 neutrino interactions and 2500 background events and for the energy and angular resolutions that we have assumed.

The figure has been obtained as follows: for each $(\delta g_L, \delta g_R)$ pair we have determined two values of the recoil kinetic energy $T_{\rm min}$ and $T_{\rm max}$ such that the number of detected events with $T>T_{\rm min}$ or $T<T_{\rm max}$ (for the sake of conciseness from now on we will refer to these observables as t_m and t_M, respectively) maximizes the sensitivity to the g_L and g_R variations.

We checked that a 50% change in the energy resolution does not affect the sensitivity to δg_L and δg_R which is mainly limited by the systematic uncertainties.

We now consider the additional information provided by the reconstruction of the electron scattering angle θ. In this respect we remark that the angular distribution of recoil electrons is peaked at about 30° and is very small in the very forward region (zero scattering angle). This can be used to discriminate against anomalous signals which, on the contrary, predicts a sizable forward scattering amplitude.[2]

To assess the experimental sensitivity we have selected two bins $\theta_0<\theta<\theta_1$ and $\theta_2<\theta<\theta_3$ (the optimal values depending somehow from the angular resolution) and we have studied the observable defined by the ratio of the events in the two bins, referred to as R_θ in the following. It is important to notice here that this observable is *essentially insensitive to the uncertainties* on the antineutrino spectrum. In fact, we have divided the expected antineutrino spectrum into twenty energy intervals each contributing about 5% each to the total signal. We have then increased or diminished by 9% (3 times the 1σ uncertainty of the spectrum) each of these contributions in order to maximize the variation of the ratio. As a result the variation is always below 1.2% for the best angular resolution which we have considered. This procedure certainly overestimates the theoretical uncertainty and therefore it demonstrates that the observable is free[3] of systematic errors due to the spectrum. The sensitivity of the R_θ observable to g_L, g_R shifts is also shown, as a function of the angular resolution, in Fig. 2 (which also shows the nice cooperation of the two measurements).

As discussed above the main limitation is of statistical nature and therefore by increasing the exposure time and/or the target size the allowed area can be strongly narrowed. Notice that this observable is sensitive only to the ratio g_L/g_R.

The above discussion implicitly includes the measurement of $\sin^2\theta_W$. Because of its relevance, we discuss here, in some detail, the accuracy which can be reached. A shift in $\sin^2\theta_W$ corresponds to correlated shifts $\delta g_L=\delta g_R$. The angular shape method, namely, the R_θ observable, provides a useful constraint; more precisely we estimate a 1σ error of 0.015, 0.022, and 0.03 for the three angular resolutions which we have considered. The best information is provided by the observable t_m using electrons with kinetic energy smaller than 1 MeV. In this case our estimate for the 1σ error is

[2]This is strictly related to the *kinematical zero* noticed in [5] although because of the experimental resolution there is no zero in real life. We should mention here that we have analyzed the impact of the electron recoil angle measurement on both neutrino magnetic moment and neutrino oscillation searches and, once we include a realistic detector resolution in the analysis, our estimate is less optimistic than that given in [5].

[3]With a much larger statistic the statement can become critical, however in this case one can probably define a much more refined sampling and lower the effect

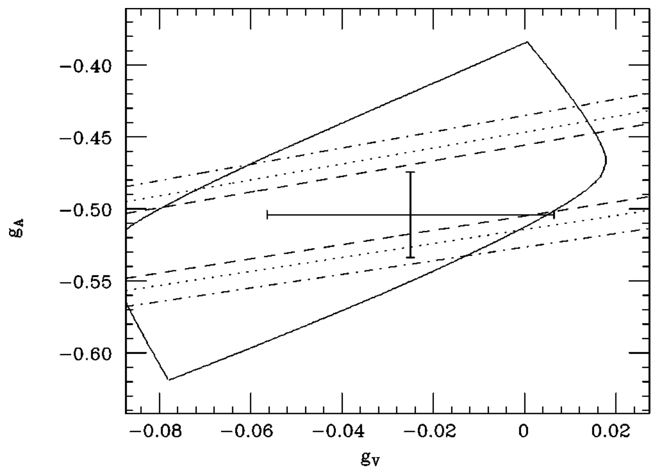

FIG. 3. Expected 90% C.L. exclusion contours in the $\delta g_V, \delta g_A$ plane. The result of the CHARMII Collaboration [9], with 1.65σ error bars, is also shown for comparison. See text for additional comments.

0.014 which should provide the best low energy measurement of $\sin^2\theta_W$.

Finally, notice that, according to the above estimates, we expect an improvement of a factor 5–10 with respect to previous $\overline{\nu_e}(\nu_e)e^-$ elastic scattering measurements thus reaching an accuracy not far from that of $\overline{\nu_\mu}(\nu_\mu)e^-$ "high energy" experiments.

For comparison in Fig. 3 we report the results of the CHARMII [9] experiment together with our estimate for the new reactor experiment. A few words of warning are in order here. To compare g_V, g_A as obtained in $\overline{\nu_e}e^-$ and in $\overline{\nu_\mu}e^-$ we have shifted by -1 the g_L of the reactor experiment.

In the absence of more information we merely report the uncertainty on the quantities $g_V = -0.025 \pm 0.019$, $g_A = -0.503 \pm 0.018$ as given by the CHARMII Collaboration [9]. From CHARMII data one can certainly obtain a standard ellipsis in the g_V, g_A plane.

We believe, however, that this comparison is anyhow useful in demonstrating that a new reactor experiment can reach a sensitivity comparable to CHARMII. In summary, the measurements of the energy and angular distribution provide complementary information and the experiment will be sensible to variations of $g_L(g_R)$ as small as 5% (10%)

III. ANOMALOUS CONTRIBUTIONS TO $\overline{\nu}e^-$ SCATTERING

We will explore the effects of new particles/interaction contributing to the process (1) analyzing the present bounds on the coupling constants and particles masses and discussing the possible improvements. We classify the possible operators starting from a renormalizable $SU(3)\times SU(2)_L \times U(1)_Y$ invariant Lagrangian and we derive, whenever appropriate, the effective pointlike four fermions interactions.

A. Extra scalar doublets

Let us first consider the addition to the SM Lagrangian of an extra scalar doublet $\tilde{h}$ coupled to the electron

$$\mathcal{L}_{yuk} = \tilde{y}_e \overline{L_e} e_R \tilde{h}. \tag{4}$$

In the limit of large $m_{\tilde{h}}$, from Eq. (4) we obtain the effective four fermions Lagrangian

$$\mathcal{L}_{a1} = \frac{y_e^2}{m_{\tilde{h}^+}^2} \overline{e_R} \nu_e \overline{\nu_e} e_R + \frac{y_e^2}{m_{\tilde{h}^0}^2} \overline{e_L} e_R \overline{e_R} e_L, \tag{5}$$

where y_e denotes the Yukawa coupling constant of e and ν_e to the scalar doublet $\tilde{h}$.

We will be mostly interested in the term involving neutrinos which, after Fierz reordering, becomes

$$\mathcal{L}'_{a1} = \frac{-y_e^2}{2m_{\tilde{h}^+}^2} \overline{e_R} \gamma_\mu e_R \overline{\nu_e} \gamma_\mu \nu_e. \tag{6}$$

From a practical point of view this amounts to a redefinition of the coefficient g_R in Eq. (2):

$$g_R \to g_R + \frac{y_e^2 \sqrt{2}}{8 m_{\tilde{h}^+}^2 G_F}. \tag{7}$$

The only direct limits on effective interactions (6) come from previous measurements of $\nu_e(\overline{\nu_e})e^-$ cross section which give $\delta g_R < 0.8$ from [3] (reflecting the poor sensitivity of $\nu_e e^-$ experiments to g_R) and $\delta g_R < 0.1$–0.4 from $\overline{\nu_e}e^-$ [1,2] experiments.[4] Limits coming from the nonobservation of the $\tilde{h}^+$ particle can always be evaded by pushing up the value of $m_{\tilde{h}^+}$ and will not be considered here.

An indirect bound can be derived from $e^+e^- \to e^+e^-$ scattering which would receive a contribution from $\tilde{h}^0$ exchange. This bound reads [12] $y_e^2/m_{\tilde{h}^0}^2 \leq 3.0\times 10^{-6}$ at the 95% C.L. Although after SU(2) breaking the $\tilde{h}^{0,+}$ masses become unrelated, a useful insight can be derived from the assumption $m_{\tilde{h}^0} \simeq m_{\tilde{h}^+}$ which would imply $\delta g_R < 0.05$.

So far the analysis has been purely phenomenological, on the grounds of the effective Lagrangian (6) with the only extra requirement that the standard model gauge symmetries are not spoiled. It is of interest to consider the interaction (4) in the framework of some theoretical models. Among these we recall the models for the radiative generation of neutrino masses (i.e., the Zee model [10] and its many variants) and supersymmetric models with R parity breaking [11].

In general, for Zee-like models the above discussed bounds apply with no further constraint. On the other hand for supersymmetry (SUSY) models with R parity breaking some extra constraint can appear because of the supersymmetric nature of the theory. The two natural candidates for $\tilde{h}$ in these models are the muon and tau spartner $\tilde{\tau}$ and $\tilde{\mu}$,

[4]This range has to be understood as purely orientative. No direct limit is quoted in the above papers and the limit is inferred from the quoted cross section and the relative error. We give a range rather than a definite value because we do not know the detection efficiency as a function of the positron energy.

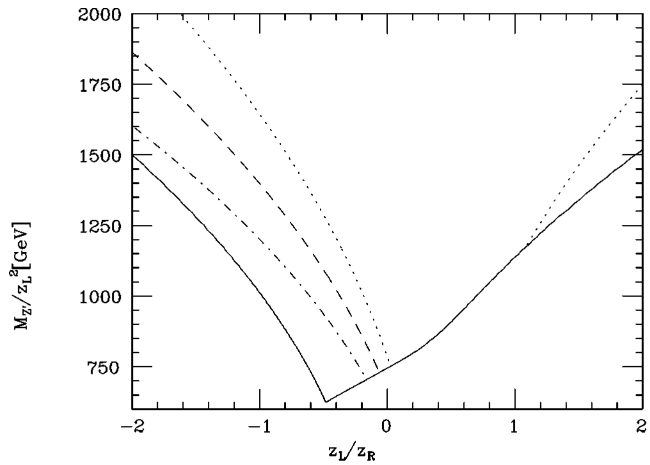

FIG. 4. Expected sensitivity to a new massive neutral gauge boson with mass $M_{Z'}$ and couplings $z_{L,R}$ to left- and right-handed electrons as in Eq. (8). The continuous line is the expected lower bound obtained by considering the electron recoil energy whereas dashed and dot-dashed lines include also the angular information. The notation is the same as in Fig. 2.

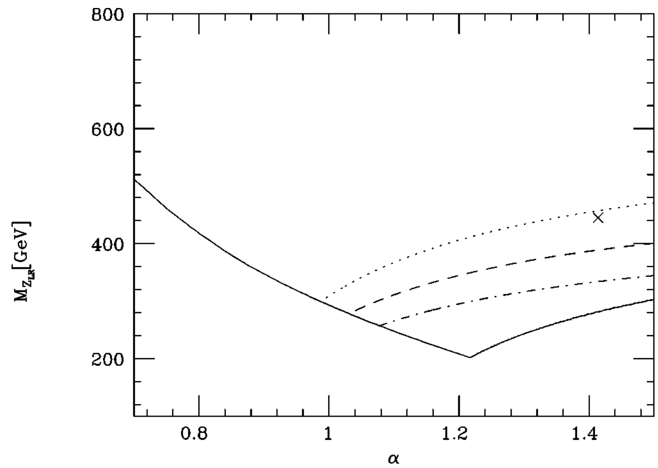

FIG. 5. Expected sensitivity to the left-right symmetric Z' as a function of the parameter α [see Eq. (10)] The notation is the same as in Fig. 4. The cross denotes the CDF lower bound [17] for the value of α corresponding to manifestly left-right symmetric models.

respectively. In this framework bounds on y_e[5] have been discussed in [13]. The bound on $\tilde{\mu}$ comes from the comparison of G_F as determined from μ decay and from semileptonic β decays and it is the tighter one. The looser constraint applies to the $\tilde{\tau}$ couplings for which two very similar bounds can be derived by comparing the ratios for $(\tau\to\nu\bar{\nu}e)/(\tau\to\nu\bar{\nu}\mu)$ and $(\tau\to\nu\bar{\nu}e)/(\mu\to\nu\bar{\nu}e)$ with their standard model values. Both comparisons yield $g_R(m^2_{\tilde{e}_R}/m^2_{\tilde{\tau}_L})<0.012$[6] at the 90% C.L., where $\tilde{e}_R$ is the supersymmetric partner of the right handed electron. If approximate *slepton masses degeneracy* is assumed, $m_{\tilde{e}_R}\simeq m_{\tilde{\tau}_L}$, the above bound can be directly applied to Eq. (4). If this assumption is removed (and this is reasonable for the τ slepton in large $\tan\beta$ [14] models, inspired by SO(10) grand unification, or several grand unified theories (GUT), due to the effect of the top Yukawa coupling around the GUT scale [15]) we are left only with the previously discussed bounds.

Let us summarize the above discussion. The effect of the interaction (4) can be translated into a a shift in g_R, as in Eq. (7), which is constrained by direct limits from $\bar{\nu}_e(\nu_e)e^-$ experiments, $\delta g_R<0.1$–0.4, limits from e^-e^+ scattering, $\delta g_R(m^2_{\tilde{h}^+}/m^2_{\tilde{h}^0})<0.05$, and in the framework of SUSY models with R parity breaking, $\delta g_R(m^2_{\tilde{e}_R}/m^2_{\tilde{\tau}_L})<0.012$.

As can be seen from Fig. 2 the expected sensitivity of a new reactor experiment is $\delta g_R>0.03$ from t_M, t_m observables and $\delta g_R>0.017$, 0.023, 0.032 from the R_θ observable for the three angular resolutions which we have considered.

A final remark is in order: since the interaction (4) is peculiar to $\bar{\nu}_e$ and e^-, i.e., it violates lepton universality, the bounds from $\nu_\mu e^-$ scattering *do not apply*.

[5]In R parity breaking supersymmetric models y_e is conventionally denoted as λ_{121} and λ_{131} for $\tilde{\mu}$ and $\tilde{\tau}$, respectively.

[6]The bound is stronger than the one given in [13] since experimental measurements have improved so far.

B. Z'

A new Z boson would give an additional neutral current contribution to $\bar{\nu}_e e^-$ scattering. In the following we will neglect Z,Z' mixing since the LEP-I experiments are particularly sensitive to this possibility and therefore the existing bounds are far beyond the sensitivity of a reactor experiment.

The relevant Lagrangian is

$$\mathcal{L}_{Z'}=z_L\bar{L}_e\hat{Z}'L_e+z_R\bar{e}_R\hat{Z}'e_R, \tag{8}$$

where $\hat{Z}'=Z'_\mu\gamma^\mu$. In the large $m_{Z'}$ limit this gives an effective four fermions coupling analogous to that due to the ordinary Z and implies the following shifts in g_L and g_R

$$g_L\to g_L+\frac{\sqrt{2}z_L^2}{4G_F m^2_{Z'}},$$

$$g_R\to g_R+\frac{\sqrt{2}z_L z_R}{4G_F m^2_{Z'}}. \tag{9}$$

The explorable region is shown in Fig. 4. Without any assumptions about the Z' couplings to leptons and quarks the only existing bounds are again from $\nu_e(\bar{\nu}_e)e^-$ and e^+e^- scattering as given in the previous sections.

It is of interest to discuss the sensitivity to a few among the most popular theoretical models predicting a Z' boson. For the left-right [16] Z' the couplings $z_{L,R}$ are

$$z_L=\frac{e}{\cos\theta_W}\frac{1}{\alpha},\quad z_R=\frac{e}{\cos\theta_W}\left(\alpha-\frac{1}{\alpha}\right), \tag{10}$$

where e is the electromagnetic charge, θ_W is the Weinberg angle, and α is a model dependent parameter ($\alpha=\sqrt{2}$ corresponds to manifestly left-right symmetric models). In Fig. 5 the sensitivity to $m_{Z'}$ as a function of α is given. It is comparable to that of the CDF experiment [17] which, however,

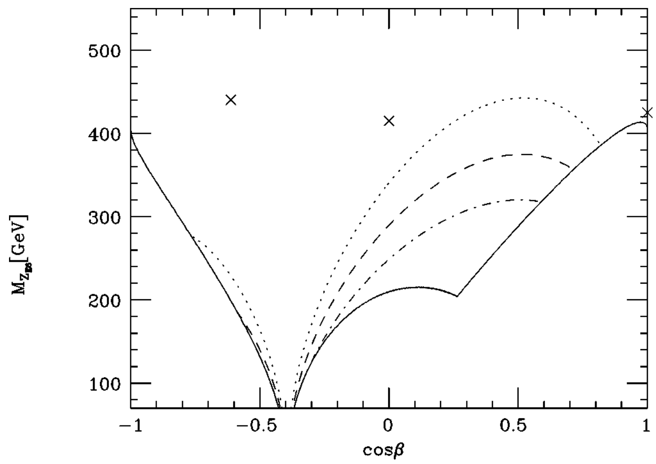

FIG. 6. Expected sensitivity to the $E6Z'$. Same notation as in Fig. 4 and β as in Eq. (11). The cross denotes the CDF lower bound [17] for the value of β corresponding to the so called Z_ψ, Z_η, and Z_ϕ models.

relies on suitable assumptions on the Z' decay modes, i.e., that the Z' decays mainly into known particles.

Another class of interesting models are the extended grand unified theories (GUTs) based on the E_6 gauge group [18] (which arises naturally at the scale M_{GUT}, as a limit of a wide class of phenomenologically interesting superstring theories). In these models the Z' arises as a mixture of two extra U(1) gauge bosons (again neglecting mixing with the standard Z), $Z'=\cos\beta Z_\chi+\sin\beta Z_\psi$, with couplings

$$z_L=\frac{e}{\cos\theta_W}\left(\frac{3}{\sqrt{6}}\cos\beta+\frac{\sqrt{10}}{6}\sin\beta\right),$$

$$z_R=\frac{e}{\cos\theta_W}\left(\frac{1}{\sqrt{6}}\cos\beta-\frac{\sqrt{10}}{6}\sin\beta\right). \tag{11}$$

The sensitivity to $m_{Z'}$ as a function of $\cos\beta$ is presented in Fig. 6; at least for a sizable range of β, it is comparable with existing bounds from CDF [17] and it is free of assumptions about the Z' decay modes.

We quote also the expected bounds for the standard model Z'_{SM}, i.e., a gauge boson with the same couplings as the Z boson:

$$m_{Z'_{\mathrm{SM}}}\geqslant 430,\ 370,\ 300\ \mathrm{GeV} \tag{12}$$

for the three angular resolutions which we have considered. This has to be compared with the best limit of 505 GeV from the collider Detector at Fermilab (CDF) [17] (which, however, depends on the assumptions about the Z' decay modes).

C. Leptonic photon

The possibility of an extra massless gauge boson (paraphoton) coupled only or mainly to leptons [19], has been considered. Elastic neutrino scattering provides stringent bounds on these exotic interactions.

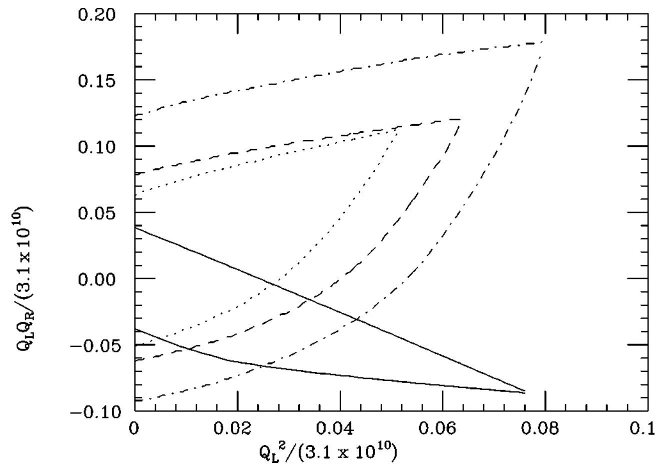

FIG. 7. Expected sensitivity to neutrino-photon (paraphoton) coupling. The continuous line is obtained from the electron recoil spectrum (t_M and t_m as defined in the text, Sec. II B), the region outside the contour will be ''excluded'' at 90% C.L. Dashed, dot-dashed, and dotted lines have the same meaning as in Fig. 2.

For generality, we assume different U(1) charges $Q_{L,R}$ for the $e_{L,R}$ fields[7] and we neglect the issue of anomaly cancellation (which can be achieved by a proper assignment of charges to particles other than ν_e and e^-).

The Lagrangian of relevance to $\nu_e(\overline{\nu_e})e^-$ scattering is

$$\mathcal{L}=Q_L\overline{L}_e\hat{A}_lL_e+Q_R\overline{e}_R\hat{A}_le_R, \tag{13}$$

where A_l denotes the paraphoton field.

Using T dependent g_L and g_R we can still recast the cross section in the form (2) with the shift

$$g_L\to g_L+\frac{Q_L^2}{8m_eT}\frac{\sqrt{2}}{G_F}=g_L+3.1\times10^{10}\frac{Q_L^2}{T(\mathrm{MeV})},$$

$$g_R\to g_R+3.1\times10^{10}\frac{Q_LQ_R}{T(\mathrm{MeV})}.$$

In Fig. 7 we report the estimated sensitivity of a reactor experiment such as MUNU in the Q_L^2, Q_LQ_R plane, it appears that a sensitivity at the level of $\alpha_l=Q_L^2/(4\pi)\sim10^{-13}$ will be achieved.

IV. CONCLUSIONS

In a survey of the physical items which can be studied with a relatively accurate measurement of $\overline{\nu_e}(\nu_e)e^-$ scattering we have considered, particularly, the information from the measurement of the electron scattering angle. We estimate that g_L and g_R will be measured with an accuracy of 5 and 10 %, respectively. This information can be recasted as a sensitivity to signals of new physics.

In particular we considered the following. A new charged scalar boson of mass M coupled to ν_e and e^- with strength

[7]In the original proposal of these exotic gauge bosons only the $Q_L=Q_R$ case is considered, however, there is no compelling reason for this assumption neither theoretical nor phenomenological.

y. Its effects are detectable for

$$\frac{y^2\sqrt{2}}{8M^2G_F}>0.015-0.03. \tag{14}$$

A new neutral massive gauge boson Z'. Using as paradigms E6 grand unification models and left-right symmetric models we estimate a sensitivity up to Z' masses of 400–450 GeV.

Paraphotons. Their effect is detectable even for a coupling strength eleven orders of magnitude below the electromagnetic one.

We thus foresee an important improvement on the sensitivity to these new particles with respect to previous $\overline{\nu}_e(\nu_e)e^-$ experiments. The explorable region in the parameter space significantly overlaps with that of the Tevatron collider; in addition one does not rely on *ad hoc* assumptions about new particles decay modes as in collider experiments.

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