

Testing Left-Right extensions of the standard model of electroweak interactions with double-beta decay and LHC measurements

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Abstract. The minimal extension of the standard model of electroweak interactions allows for massive neutrinos, a massive right-handed boson W_R , and a left-right mixing angle ζ . While an estimate of the light (electron) neutrino can be extracted from the non-observation of the neutrinoless double beta decay, the limits on the mixing angle and the mass of the right-handed (RH) boson may be extracted from a combined analysis of the double beta decay measurements (GERDA, EXO-200 and KamLAND-Zen collaborations) and ATLAS data on the two-jets two-leptons signals following the excitation of a virtual RH boson mediated by a heavy-mass neutrino. In this work we shall compare results of both types of experiments, and show that the estimates are not in tension.

1. Introduction

The theory of the electroweak interactions, in the form of the standard model (SM), assumes massless neutrinos and left-handed couplings [1]. In contrast to this, the observation of neutrino oscillations demonstrates that neutrinos are massive particles [2]. The symmetries of the SM can indeed be extended to accommodate, at least minimally, massive neutrinos and/or left-right (LR) couplings [3, 4, 5, 6]. The experimental search for signals of LR couplings is conducted at LHC [7], where the ATLAS [8] and CMS [9] collaborations have analysed the right-handed boson decay produced in the reactions $p\text{-}p \rightarrow W_R \rightarrow \text{two-jets two-leptons}$, mediated by a heavy-mass neutrino. From these experimental studies a lower mass limit of the order of 3 TeV, for the mass of the right-handed boson, was extracted provided the mass of the heavy neutrino is of the order (or larger than) 500 MeV. The result has significance for the construction of LR models, since it determines the range of allowed values for the mixing between left and right-handed currents [10], since the mass of the left-handed boson is already known. Neutrinoless double beta decay is a unique process which, if detected [11], will provide an answer about the nature of neutrinos (Dirac or Majorana) and their couplings [3]. Recently the GERDA [12], EXO-200 [14] and KamLAND-Zen [13] experiments have produced world-record lower limits of the half-life of the neutrinoless double beta decay of some of the double beta decay emitters (^{76}Ge and ^{136}Xe , respectively). From these values one can extract the corresponding limits for the neutrino mass, the right-handed and the LR couplings. To determine these values one needs



not only the experimental information about the half-life, but also the involved nuclear matrix elements [15, 16]. The complexity of the nuclear structure calculations, due to the relatively large number of parameters entering the calculations, has been a challenging problem since the early calculations performed in the 1960's. After so many years a consensus has been reached about the order of magnitude and individual values of the participant nuclear matrix elements [16, 17], to the extent that we are in conditions to make definite predictions about the half-life of the transitions. In this work we shall discuss about the complementarity of high energy (p-p) and double beta decay data. An earlier version of the work has been published long ago [18], when the information about the high energy sector of the problem was rather limited.

2. Formalism

In this section we shall briefly present the essentials of the formalism which is currently applied to describe double beta decay transitions. It contains three main components, namely:

- Nuclear matrix elements (NME) for neutrinoless double beta decay transitions
- Neutrino mixing matrix and phase space factors from the leptonic sector of the decay
- Left and right symmetries of the electroweak currents

The neutrinoless double beta decay is a processes where a nucleus decays by emission of two electrons (or two positrons), and change its charge in (+2) (-2) units. The decay violates lepton number conservation, since the electrons are not accompanied by the corresponding antineutrinos, like in the double beta decay with neutrinos. The two-neutrino mode is allowed by the SM since it takes place *via* two independent single beta decays. The two neutrino double beta decay mode has been measured intensively and its half-life is the longer ever measured in labs, it is of the order of 10^{20} years. It is described as a second order process in the weak interaction Hamiltonian and it is independent of any assumption about the neutrino. The neutrinoless double beta decay mode is much more interesting, since it may take place only if neutrinos are massive and it depends also on the model assumptions about the neutrino. It is a unique source of information about the scale of the mass of the neutrino [16]. It has not been observed and the information about the neutrino may be extracted from the lower limits of the half-life established experimentally. Today, the lower limit for the neutrinoless double beta decay half-life is of the order of 10^{25} years. The minimal electroweak interaction Hamiltonian which may accommodate massive neutrinos, is a current-current interaction where the currents do have left- and right-handed components, and the participant neutrinos are described as superposition of neutrino mass-eigenstates. The inclusion of right-handed currents activates, in the neutrino sector of the currents, three heavy mass mass-eigenstates in addition to the three light neutrino mass-eigenstates. This minimal extension of the model does not include CP violation and the basic factorization obeys the $SU(2) \times SU(2)$ scheme, one for the left-handed currents and the other for the right-handed currents. Each current is then written in terms of a left-handed boson and a right-handed boson depending on the symmetry. Thus, in addition to a mass sector the model lagrangian has left-right and right-right terms. To compute the half-life of the process one has to evaluate the expectation value of the Hamiltonian, between the initial and final states, an a neutrino propagator between each decay vertex [15, 3, 16],

The inverse of the half-life for neutrinoless double beta decay transitions $0\nu\beta\beta$ is written

$$\begin{aligned}
 [T_{1/2}^{(0\nu)}]^{-1} &= C_{mm}^{(0\nu)} \left(\frac{\langle m_\nu \rangle}{m_e} \right)^2 + C_{m\lambda}^{(0\nu)} \langle \lambda \rangle \left(\frac{\langle m_\nu \rangle}{m_e} \right) \\
 &+ C_{m\eta}^{(0\nu)} \langle \eta \rangle \left(\frac{\langle m_\nu \rangle}{m_e} \right) + C_{\lambda\lambda}^{(0\nu)} \langle \lambda \rangle^2 \\
 &+ C_{\eta\eta}^{(0\nu)} \langle \eta \rangle^2 + C_{\lambda\eta}^{(0\nu)} \langle \eta \rangle \langle \lambda \rangle .
 \end{aligned} \tag{1}$$

In the above expression, the factors $C_{a,b}^{(0\nu)}$, where the super-indexes a and b stand for the neutrino mass (m), and RR (λ) and LR (η) couplings [3], are functions of the NME and leptonic phase space factors [15, 16]. The calculation of these coefficients, in the context of different models for the nuclear structure of the participant nuclei, yields results which may vary substantially from model to model, however, it is possible to extract from the different calculations some similarities. In the work of [17] the reader can find a systematics of the NME obtained within the quasiparticle random phase approach (QRPA), which is the set of values we have adopted for the present calculations. The results are quite comparable to those of other models of nuclear structure, where the proton-neutron interactions are explicitly accounted for in relatively large configuration spaces, as it is discussed in the review of [16].

Once the values of the NME are fixed, the expression for the half-life can be viewed as the equation of a surface in three dimensions (each of the three axis being given by each of the three variables, that is the neutrino mass and the RR and LR couplings). The procedure to extract the upper values of each of the variables is rather simple, since to extract them one should perform a diagonalization to find their values in the intrinsic frame, where the half-life becomes a diagonal function of the square of each variable. The results of such a procedure, for the cases of ^{76}Ge and ^{136}Xe , with the matrix elements extracted from the compilation of [17], are shown in Table 1.

In the space of these variables, we have determined the ratios between the RR and LR couplings which are simultaneously consistent with the neutrino mass. All these variables are intrinsic functions of the neutrino mixing parameters, since they are average values taken on the basis of neutrino mass eigenstates [3]. With the values extracted in this manner we have determined allowed values of the right-handed boson, by using the expression [3, 18]

$$\frac{M_L}{M_R} = \sqrt{\frac{(\alpha - \tan \zeta) \tan \zeta}{(1 + \alpha \tan \zeta)}}, \quad (2)$$

where $\alpha = \langle \lambda \rangle / \langle \eta \rangle$, M_L is the mass of the left-handed boson, and ζ is the mixing angle between the massive boson generators of the $SU(2)_L \times SU(2)_R$ minimal extension of the SM.

3. Results

With the elements introduced in the previous section we are in conditions to calculate the mass of the right-handed boson and the limits on the mixing angle ζ by the combined analysis of ATLAS [8] and CMS[9] results and those of GERDA[12], EXO-200[14] and KamLAND-Zen[13]. We have extracted the couplings of the RR and LR sectors of the minimal extended electroweak

Table 1. Extracted upper values of the average neutrino mass and the RR and LR couplings

Case	Half-life limit (10^{25} yr)	$\langle m_\nu \rangle_{\max}$ (eV)	$\langle \lambda \rangle_{\max}$	$\langle \eta \rangle_{\max}$
^{76}Ge	2.5	0.325	$0.431(10^{-6})$	$0.286(10^{-8})$
^{136}Xe	1.1	0.182	$0.197(10^{-6})$	$0.176(10^{-8})$

lagrangian. In order to determine exclusion regions in the parametric space we have taken, for our analysis, the data acquired in the measurement of two jets+two leptons final states in pp collisions performed at the LHC facility[7] by ATLAS [8] and CMS [9]. The data reported by CMS correspond to collisions with center of mass energies of 8 TeV and integrated luminosity of 19.7 fb^{-1} [9], while the limits determined by ATLAS [8] correspond to a luminosity of 2.1 fb^{-1} . From these results a lower limit for the mass of the right-handed boson, of 3 TeV, was

established. We then proceeded to extract the same information, from the reported lower limits for the half-life of two double beta decay emitters, germanium and xenon, as measured by GERDA[12] and EXO-200[14] and KamLAND-Zen[13], respectively. In order to extract these values we have used a set of NME whose validity, as representative of the state of the art results in microscopic nuclear structure calculations, has been well established [17].

Figure 1 shows the intersection between the extracted values, for the mixing angle ζ and the right-handed boson mass M_R from the $0\nu\beta\beta$ half-life lower limits, and the regions excluded by TWIST [10] $\zeta > 10^{-2}$, and the region excluded by the CMS [9] data: $M_R < 3$ TeV. The curves constructed from the neutrinoless double beta decay half-life lower limits display the results for allowed values of the average neutrino mass, as explained before. The detail of the calculations and the corresponding discussion are presented in [19].

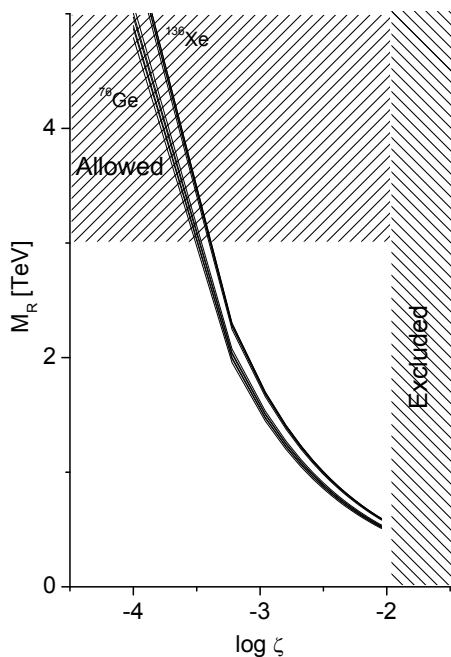


Figure 1. Allowed and excluded regions for the mass of the right-handed boson M_R and mixing angle ζ , extracted from the CMS [9] and ATLAS [8] data. The curves labelled ^{76}Ge and ^{136}Xe show the results extracted from the $0\nu\beta\beta$ half-life limits determined by GERDA [12], EXO-200 [14] and KamLAND-Zen [13] measurements, respectively

4. Conclusions

By the comparison between the limits determined by the experiments performed at CERN and the data obtained by the neutrinoless double beta decay experiments, we conclude that both type of experiments are complementary, since they explore the same physics. The results of our calculations show that the neutrinoless double beta decay relevant factors, like the average neutrino mass and couplings, are consistent with the limits determined by the experiments performed with the LHC facility, for channels where the decay of the right-handed boson in two jets and two leptons could be inferred from the data.

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6. References

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