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Combining data from high-energy *pp*-reactions and neutrinoless double-beta decay: Limits on the mass of the right-handed boson

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From the recently established lower-limits on the nonobservability of the neutrinoless double-beta decay of ^{76}Ge (GERDA collaboration) and ^{136}Xe (EXO-200 and KamLAND-Zen collaborations), combined with the ATLAS and CMS data, we extract limits for the left–right (LR) mixing angle, ζ, of the $\mathrm{SU}(2)_L \times \mathrm{SU}(2)_R$ electroweak Hamiltonian. For the theoretical analysis, which is a model dependent, we have adopted a minimal extension of the Standard Model (SM) of Electroweak Interactions belonging to the $\mathrm{SU}(2)_L \times \mathrm{SU}(2)_R$ representation. The nuclear-structure input of the analysis consists of a set of matrix elements and phase-space factors, and the experimental lower-limits for the half-lives. The other input are the ATLAS and CMS cross-section measurements of the *pp*-collisions into two-jets and two-leptons, performed at the large hadron collider (LHC). Our analysis yields the limit $\zeta < 10^{-3}$ for $M_R > 3\,\mathrm{TeV}$, by combining the model-dependent limits extracted from the double-beta-decay measurements and those extracted from the results of the CMS and ATLAS measurements.

Keywords: Neutrinoless double-beta-decay; right-handed currents; minimal extension of the standard model; mass of the right-handed bosons.

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1. Introduction

Among the present experimental and theoretical efforts in the field of electroweak interactions, are two interesting extremes in the energy-scale: at the high-energy side of the scale are the measurements of reaction products of proton–proton collisions by different detectors placed at the Large Hadron Collider (LHC),[1] and at low energies there are the experiments dedicated to the measurements of neutrino oscillation parameters,[2,3] and to the observation of the neutrinoless double-beta-decay,[4] which, if detected, may allow for the identification of the neutrino as a Majorana particle. The importance of these lines of research has been stressed by recent Nobel Prices in Physics (2013, 2015), and they share the same goals as both provide unique tests on the assumptions upon which the standard model (SM) and its extensions are based. Beside these approaches, one can mention the intensive experimental activity aimed at the search of several decay channels predicted by the SM and its extensions. Examples of these measurements are the searches for double-Higgs,[5] $\bar{\mathrm{K}}$–K and $\bar{\mathrm{B}}_{\mathrm{d,s}}$–$\mathrm{B}_{\mathrm{d,s}}$ oscillations,[6] the left-right (LR) mixing-angle ζ,[7] etc.[a]

Both types of experiments, the "active" high-energy proton–proton collisions and the "passive" neutrinoless double-beta decay ($0\nu\beta\beta$) measurements, focus on fundamental aspects of modern physics, like lepton-number violation, and LR extensions of the minimal version of the SM.

As pointed out years ago by Keung and Senjanovic,[8] and more recently by Nemevsek *et al.*,[9] limits on the LR symmetry and heavy neutrinos may be established from data taken by some of the experiments performed at the LHC. A more recent analysis of LR extensions of the SM is found in the work of Barry and Rodejohann.[10] The data from the ATLAS,[11] and more recently, the CMS collaboration,[12,13] have refined the exclusion limit for the mass of the right-handed W-boson, M_R, extending previously known values to $M_R > 3$ TeV, provided the mass of the right-handed neutrino is lighter than M_R, and assuming fully symmetric LR couplings.

The $0\nu\beta\beta$ process, which may take place in nuclei if neutrinos are Majorana particles and/or the electroweak interactions contain LR and RR terms,[14,16] give us information about the absolute scale of the neutrino mass, and thus the results which are extracted from the experimental lower-limit of the $0\nu\beta\beta$ half-life in various nuclei are to be compared with other measurements of the same observable, like the electron–neutrino-mass value extracted from the end-point of the tritium beta-decay,[17] or the sum of the neutrino masses determined from cosmological constraints extracted from observed matter-densities in the Universe.[18,19]

The physical scenarios in which the decay can take place have been exhaustively studied in the last decades, and the knowledge about the involved nuclear matrix elements (NME) has improved gradually during the last two decades, as a result of

[a] A complete list of these experiments certainly exceeds the limits of a regular paper, these examples are given to illustrate the trend of the text which follows.

the efforts of several groups. Though, the nuclear-structure models used in the calculations are based on different assumptions,[16] a considerable effort was dedicated to compare the results and to establish the validity of the resulting model predictions. We refer the reader to the results reported in the latest MEDEX conference,[20] and to the work of Refs. 21–25 for an extended discussion of this point. The knowledge of the NME which are relevant for the calculation of the $0\nu\beta\beta$ half-life is mandatory to extract the neutrino mass, but the discussion of the results for the NME in each of the models reported in the bibliography will largely exceed the scope of the present work. However, a systematics is emerging gradually, concerning these NME and other quantities of interest, like various decay mechanisms. Then, for the sake of the present study, we shall adopt the results quoted in Ref. 25, to illustrate the main point of our work, which is the complementarity existing between $0\nu\beta\beta$ data and *pp*-reactions at high energies. Once again, we shall insist upon this point, since the aim of the present paper is not to present a review of the existing NME but rather to use them in the context of the extraction of the neutrino mass and the possible determination of other parameters which go beyond the SM, like mixing angles and right-handed components of the currents.

From the experimental side, an intensive search for the signals of the transitions has been conducted.[4] World-class limits for the nonobservation of the $0\nu\beta\beta$ have been established by GERDA,[26] KamLAND-Zen,[27] and EXO-200[28] collaborations.

The intimate connection between the physics which may be probed by LR symmetry restoration in the CMS measurements[12,13] and the $0\nu\beta\beta$[16] has been discussed in Ref. 29. Following the arguments of Ref. 29, the ratio between the amplitudes corresponding to the "new-physics" and the $0\nu\beta\beta$ depends on the scale of the "new-physics", which is of the order of TeV. This estimate is based on theoretical values assigned to the momentum transferred by the neutrino in the $0\nu\beta\beta$ decay and to the mass of the right-handed W-boson mediating the two-leptons-two-jets decay channels of the *pp*-collisions. It has to be taken as a tentative value since it depends on the effective neutrino mass, which is expected to be a fraction of eV, and on the mass M_R, expected to be in the few TeV region. As we are going to show later on, the known $0\nu\beta\beta$ decay limits do agree with this estimate.

In this paper, we shall update the results of Ref. 30, an earlier work which was motivated by the same type of considerations presented later on in Ref. 29, that is the possibility of setting constraints for LR symmetry-restoration from the nuclear $0\nu\beta\beta$ decay. We think that this is justified by the fact that from both sides (neutrinoless double-beta decay data and high-energy data) very important new information has become available recently. Here, we shall use the results of Refs. 26–28 to get limits on the mass of W_R and on the LR mixing angle. In performing the calculations, we have adopted some representative values of the relevant NME.[25,31] Though, the question about definite values of these NME is still open, a consensus has been reached about the basic elements and nuclear structure assumptions which are implicit in their definitions, so that the present set of NME does not seem to be particularly unsuitable for the purpose of the present discussion and/or of minor importance due to the nuclear structure theory which has been applied to calculate them. Naturally, the results which we are going to present here are model dependent, both from the point of view of the nuclear structure assumptions involved in the calculation of the NME, as well as from the weak interaction side, where the interactions are minimally extended with respect to the conventional SM. Then, the main point of our work is to emphasize and make use of the complementarity existing between model-dependent studies of double-beta decay processes and of those of electroweak decays measured in high-energy p–p collisions.

2. Formalism

We now proceed to discuss our method to determine the constraints on the mass of W_R, by looking at the minimal extension of the SM and at the nuclear structure side of the problem.

2.1. *Minimal extension of the SM*

To start with, we shall write the electroweak Hamiltonian in the minimal LR extension of the SM. In this way, the LR and RR electroweak interactions are added to the LL term and written as the Hamiltonian density.[32]

$$h_W = \frac{G}{\sqrt{2}} \cos\theta_{\mathrm{CKM}} (j_L J_L^\dagger + \kappa j_L J_R^\dagger + \eta j_R J_L^\dagger + \lambda j_R J_R^\dagger) + \mathrm{h.c.}, \tag{1}$$

where $J_{R(L)}$ are nucleon currents, $j_{R(L)}$ are leptonic currents, G is the weak-interaction coupling–constant, and θ_{CKM} is the Cabibbo–Kobayashi–Maskawa angle. Here, for simplicity, we have dropped the Lorentz indices in Eq. (1). The corresponding Lagrangian contains the left- and right-handed bosons W_L and W_R, expressed in terms of the $\mathrm{SU}(2)_L$ and $\mathrm{SU}(2)_R$ gauge bosons W_1 and W_2

$$\begin{aligned} W_L &= W_1 \cos\zeta - W_2 \sin\zeta, \\ W_R &= W_1 \sin\zeta + W_2 \cos\zeta, \end{aligned} \tag{2}$$

where ζ is the mixing angle. While the mass of W_L is known, we shall take the mass of W_R as an unknown quantity without giving any explicit coupling to determine its value.

As said before, we assume a minimal symmetric $\mathrm{SU}(2)_L \times \mathrm{SU}(2)_R$ representation to which the electromagnetic $U(1)$ and the Yukawa couplings to the Higgs boson are added.

This minimal extension of the SM, Eq. (1), belongs to a class of general extensions discussed in the literature.[10] The connection between the present formulation, Eq. (1), and that of other formulations of LR extensions of the SM[14,15] is straightforward. In Eq. (1) we shall take $\kappa = \eta$ and write η and λ in terms of the mixing angle ζ and the ratio between the masses of the left-handed and right-handed bosons.

Then, in the notation of Eq. (A.204) of Ref. 14 one gets

$$\lambda = \frac{\chi + \tan^2\zeta}{1 + \chi\tan^2\zeta},$$
$$\eta = \frac{(1-\chi)\tan\zeta}{1 + \chi\tan^2\zeta}, \tag{3}$$

where $\chi = \frac{M_L^2}{M_R^2}$ is the square of the ratio between the left- and right-handed bosons. The ratio between the RR and LR couplings becomes

$$\frac{\lambda}{\eta} = \frac{\chi + \tan^2\zeta}{(1-\chi)\tan\zeta}. \tag{4}$$

From (4), we can extract the value of χ and write it in terms of the couplings and neutrino mixing parameters. We shall return to this point later on in Sec. 3.

2.2. *Half-life of the* $0\nu\beta\beta$ *decay*

The $0\nu\beta\beta$ decay is a decay mode which depends critically on neutrino properties, like its composition in terms of neutrino mass-eigenstates, mass hierarchies, and the amplitudes of the neutrino mixing-matrix. It also depends on the nuclear structure of the nuclei which may be connected by the decay, reflected on their energy-spectra and electromagnetic properties. The theoretical essentials of the formalism, about the various factors entering the problem, like the calculation of leptonic phase-space factors, the multipole expansion of the transition operators, and the expression of the relevant NME, for the $0\nu\beta\beta$, have been discussed extensively in the literature.[14,16,32] Concerning the theoretical models used to calculate these NME, and their values, since we are interested here in showing the feasibility of the method to extract information about LR and RR couplings, and in order to focus in our problem, we shall refer to the systematics presented in Ref. 25. Therein, the NME for the known double-beta-decay emitters, calculated within the framework of different approximations and/or nuclear structure models are discussed in detail.

For the sake of completeness, we shall briefly comment upon the main issues related to the calculation of the NME relevant for the estimation of $0\nu\beta\beta$ observables. The transitions violate lepton number conservation and they can only take place if the neutrino is a Majorana particle. The expression of the half-life of the decay is obtained by performing a straightforward calculation by folding the lepton and nucleon electroweak currents with the wave functions of the nuclear states involved in the transitions. The leptonic sector of the calculations is folded in by assuming a minimal expression for the electroweak current–current interactions[32] and by adopting also a given mixing for the neutrino mass eigenstates.[14] This procedure leads to the so-called phase-space factors of the decay. The other part of the calculation concerns the matrix elements of the transition operators, which result from the multipole expansion of the nucleon currents, evaluated between the initial and final nuclear states connected by the transitions. These transitions are described as second-order transitions in the electroweak coupling, since the two nucleon vertices are connected by the neutrino propagator, as explained in Refs. 14, 16 and 32. This is the hardest part of the calculation since it requires nuclear model assumptions for the initial, final and intermediate nuclear states, which belong to different nuclei.

Computation of the nuclear wave functions is a very rich field for theoretical approximations but, fortunately, the validity of most of them can be checked experimentally.[33] The systematics presented in Refs. 16 and 25 relies upon a step-by-step evaluation of the nuclear structure components of the problem (like single-particle model spaces, residual two-body nuclear interactions, electromagnetic and particle-transfer properties of the states, etc.) More recently also the renormalization effects on the weak interaction couplings, for single and double-beta decays, has been discussed.[34] Out of the many results available, concerning the NME for the ground-state-to-ground-state $0\nu\beta\beta$ decay transitions, we have adopted the ones calculated within the framework of the proton–neutron quasiparticle random-phase-approximation,[16] since they are not using closure and because they predict reasonably single β-decay and $2\nu\beta\beta$-decay transitions in a large number of cases.[16]

The half-life for the $0\nu\beta\beta$ transition between an initial (A, N, Z) and a final $(A, N-2, Z+2)$ nucleus is calculated by starting from the Hamiltonian density (1) to yield[16,32]

$$\begin{aligned}[T_{1/2}^{(0\nu)}]^{-1} &= C_{mm}^{(0\nu)}\left(\frac{\langle m_\nu\rangle}{m_\mathrm{e}}\right)^2 + C_{m\lambda}^{(0\nu)}\langle\lambda\rangle\left(\frac{\langle m_\nu\rangle}{m_\mathrm{e}}\right)\\ &\quad + C_{m\eta}^{(0\nu)}\langle\eta\rangle\left(\frac{\langle m_\nu\rangle}{m_\mathrm{e}}\right) + C_{\lambda\lambda}^{(0\nu)}\langle\lambda\rangle^2\\ &\quad + C_{\eta\eta}^{(0\nu)}\langle\eta\rangle^2 + C_{\lambda\eta}^{(0\nu)}\langle\eta\rangle\langle\lambda\rangle. \end{aligned} \tag{5}$$

The factors $C_{ij}^{(0\nu)}$ contain the NME[16] and the leptonic phase-space factors.[16,21] The quantities $\langle m_\nu\rangle$, $\langle\lambda\rangle$ and $\langle\eta\rangle$ are the neutrino mass, the RR, and the LR couplings,[30] averaged over the elements of the neutrino mixing matrix.[35] Here, we are going to extract their values numerically.

3. Results and Discussions

We now aim at determining values of the mass of W_R by implementing the following steps of calculation:

- **Step 1.** For a given value of the half-life, $T_{1/2}^{(0\nu)}$, the allowed values of the effective neutrino mass and LR and RR couplings are constrained by the ellipsoid of Eq. (5), constructed with a given set of nuclear-structure factors $C_{ij}^{(0\nu)}$. The semi-axes of the ellipsoid, that is the upper values $\langle m\rangle_{\max}$, $\langle\lambda\rangle_{\max}$, and $\langle\eta\rangle_{\max}$, are extracted by projecting the ellipsoid on each of the planes spanned by a pair of the averaged parameters of Eq. (5). Figures 1 and 2 show the projections on each

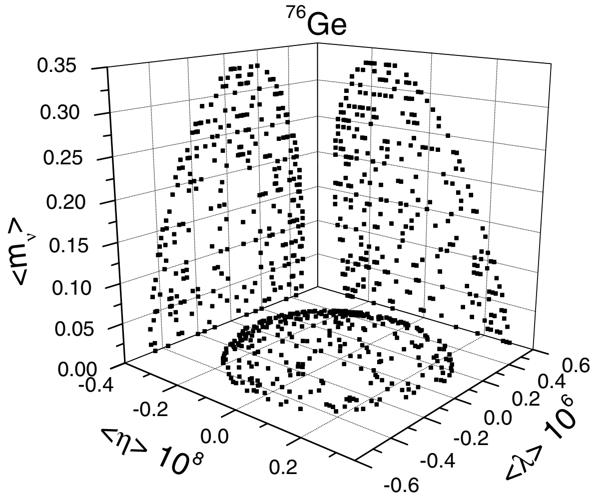

Fig. 1. Projected surfaces limiting the variables $\langle m_\nu \rangle$, $\langle \lambda \rangle$, and $\langle \eta \rangle$, constructed from the measured lower limit for the half-life of ^{76}Ge, as obtained by the GERDA experiment,[26] for positive values of the neutrino mass (which is given in units of eV). The projection on each of the planes gives the limits shown in Table 2.

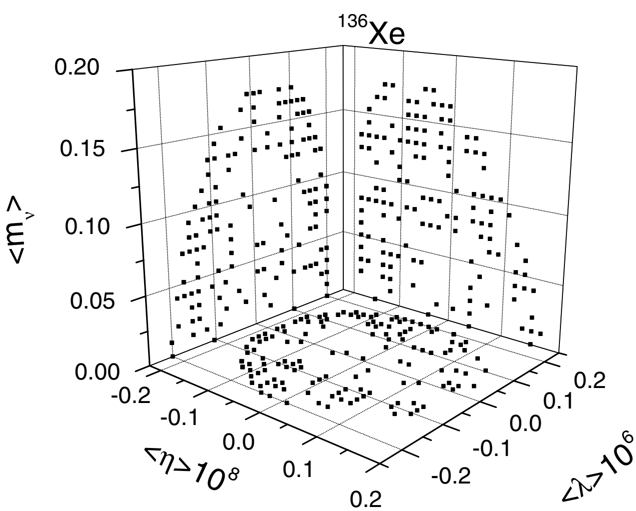

Fig. 2. The same as Fig. 1 for the nucleus ^{136}Xe and for the value of the lower limit of half-life equal to 1.1×10^{25} years.

parametric plane, constructed from the half-life limits obtained by GERDA,[26] KamLAND-Zen[27] and EXO-200,[28] respectively.

- **Step 2.** By keeping the value of the half-life fixed at the experimental lower-limit, we vary the neutrino mass and the mixing angle ζ, and turn on the LR and RR couplings.

- **Step 3.** In the space of all these variables, we search for the regions which are consistent, simultaneously, with the constraints given by the $0\nu\beta\beta$ measurements and p–p cross-section measurements, as explained in the text.

The ratio between the determined values of $\langle\lambda\rangle$ and $\langle\eta\rangle$ will then be proportional to the ratio between the masses of the right- and left-handed bosons, since from Eqs. (3) and (4) one gets

$$\chi = \frac{(\alpha - \tan\zeta)\tan\zeta}{(1+\alpha\tan\zeta)} \tag{6}$$

and since $\chi = \frac{M_L^2}{M_R^2}$, we write

$$\frac{M_L}{M_R} = \sqrt{\frac{(\alpha - \tan\zeta)\tan\zeta}{(1+\alpha\tan\zeta)}}, \tag{7}$$

where $\alpha = \langle\lambda\rangle/\langle\eta\rangle$. In Eq. (7), we have replaced the ratio between λ and η by the ratio between their mean values, taking the electron-entries of the light and heavy neutrino mixing-matrices[14,16]

$$\begin{aligned} \langle\lambda\rangle &= \lambda \frac{g'_V}{g_V} \sum_j U_{ej} V_{ej}, \\ \langle\eta\rangle &= \eta \sum_j U_{ej} V_{ej}. \end{aligned} \tag{8}$$

Although each average value depends on the neutrino mixing parameters, the ratio between them is independent of the modeling of the neutrino sector of the theory. Therefore, the present results are indeed independent of the neutrino mixing parameters, provided the approximation (8) is valid, as we think is the case of the $0\nu\beta\beta$-decay. This approximation would not be valid if μ- and/or τ-neutrinos are explicitly mediating the decay.

Table 1 gives the values of the nuclear-structure factors $C_{ij}^{(0\nu)}$ of Eq. (5) for the g.s to g.s decays of ^{76}Ge and ^{136}Xe. The values given in this table are taken from the systematics of Refs. 25 and 31 and they can be considered as reference values, the validity of which has been extensively discussed in the literature.[16,21–25] In Table 2, we list the adopted half-lives, the extracted upper-values of the neutrino mass, LR and RR couplings, and their ratio.

Direct limits on the masses of W_R and heavy Majorana neutrinos have been obtained by the ATLAS[11] and CMS[12] experiments at the LHC. The limits extracted

Table 1. Set of nuclear-structure factors,[31] in units of inverse years, adopted for the calculations. The quantities are expressed in powers of 10 with exponents given in parentheses.

Case	$C_{mm}^{(0\nu)}$	$C_{m\lambda}^{(0\nu)}$	$C_{m\eta}^{(0\nu)}$	$C_{\lambda\lambda}^{(0\nu)}$	$C_{\eta\eta}^{(0\nu)}$	$C_{\lambda\eta}^{(0\nu)}$
^{76}Ge	1.33 (−13)	−6.77 (−14)	2.58 (−11)	1.76 (−13)	4.88 (−9)	−9.54 (−14)
^{136}Xe	9.40 (−13)	−6.02 (−13)	1.49 (−10)	2.18 (−12)	2.92 (−8)	−1.25 (−12)

Table 2. Extracted upper values of the average neutrino mass ($\langle m_\nu \rangle$), and RR ($\langle \lambda \rangle$), LR ($\langle \eta \rangle$) couplings. The values for the couplings are expressed in powers of 10 (indicated in parentheses). The ratio between RR and LR couplings is given in the last column. In the first two columns are indicated the double-beta emitter and the adopted lower limit for the $0\nu\beta\beta$ half-life.

Case	Half-life limit (10^{25} year)	$\langle m_\nu \rangle_{\max}$ (eV)	$\langle \lambda \rangle_{\max}$	$\langle \eta \rangle_{\max}$	$\frac{\langle \lambda \rangle_{\max}}{\langle \eta \rangle_{\max}}$
^{76}Ge	2.5	0.330	0.477 (−6)	0.286 (−8)	1.665 (2)
^{136}Xe	1.1	0.182	0.197 (−6)	0.176 (−8)	1.119 (2)
	1.9	0.138	0.150 (−6)	0.134 (−8)	1.119 (2)

by the ATLAS experiment are based on a luminosity of 2.1 fb^{-1}. The recently reported CMS data[12,13] on the same limits are based on runs with a center-of-mass energy of 8 TeV and an integrated luminosity of 19.7 fb^{-1}.[13] The search was performed in the two-muons-two-jets channel, as well as in the two-electrons-two-jets channels. In the exact LR symmetric model, used for the CMS analysis,[13] excluded regions for M_R go up to 3.0 TeV, and heavy neutrino masses are constrained as functions of the right-handed W-boson mass. However, there are still regions in parameter space which are allowed. They are used for the calculations presented in this paper. In this context, we shall refer to the CMS results for the comparison between the observed and expected limits for the $pp \rightarrow W_R$ production cross-section times the branching ratio for the decay of the right-handed boson into two-muons and two-jets ($W_R \rightarrow \mu\mu jj$), and into two-electrons and two-jets ($W_R \rightarrow eejj$) as said before. From the latest CMS results[12] (see Fig. 5 of Ref. 12) the difference between the observed and expected results for the production cross-section is sensitive to the mass of the right-handed boson, particularly to values of M_R between 2.0 TeV and 3.0 TeV.

Figure 3 shows the results of our calculations, for both double-beta-decay emitters. The lower limits for the half-lives are the ones of Table 2 (for the case of ^{136}Xe, we have taken the smallest of the values listed in the table, that is 1.1×10^{25} years), and the values of the nuclear-structure factors are those of Table 1.

As the NME used in the calculations are the ones given in Table 1, the present analysis adds no additional uncertainty and the confidence level corresponds to the one of the experimental half-life limits. In the calculations, we have enforced the constraints provided by the extracted upper values, of the half-lives, shown in Table 2.

The results displayed in Fig. 3 point out to values, for the mixing angle, smaller than 10^{-3}, since the values of the mass of W_R must be larger than 3 TeV, as indicated by the CMS analysis.[13] The curves also define, for the mass of the right-handed boson, a lower limit of the order of 0.5 TeV, if the mixing angle ζ is taken to be of the order of 10^{-2}, which is the previously known upper limit for the LR mixing angle determined by the TWIST collaboration.[7]

From Fig. 3, we may extract the correlation between the effective neutrino mass and the mass of the right-handed boson. In fact, for a fixed value of the mixing

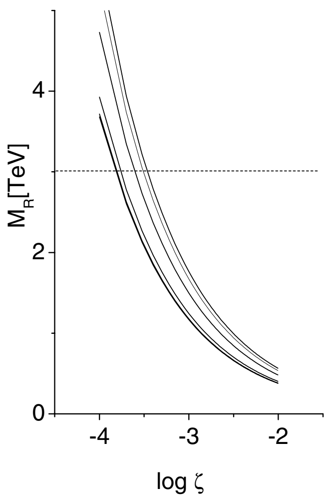

Fig. 3. Mass of the right-handed boson, M_R, in units of TeV, as a function of the log of the mixing angle ζ, and for different values of the average neutrino mass $\langle m_\nu \rangle$, which are compatible with the analysis of the $0\nu\beta\beta$ decays of ^{76}Ge and ^{136}Xe. The curves have been obtained for values of $\langle m_\nu \rangle$ in the range 0.05 eV $\leq \langle m_\nu \rangle \leq$ 0.30 eV. They are read, from bottom to top, starting from the value 0.30 eV and in steps of 0.05 eV. The horizontal dashed-line shows the excluded domain (lower limit) for M_R from LHC experiments. The intersection with the curves gives the upper limit for the mixing angle ζ (see the text).

angle ζ, the value of the mass of the right-handed boson becomes larger for smaller values of $\langle m_\nu \rangle$.

We should stress the fact that the curves of Fig. 3 show the dependence of the mass of the right-handed boson upon the LR mixing angle ζ, for different values of the average neutrino mass $\langle m_\nu \rangle$ which are allowed by the limits determined by the $0\nu\beta\beta$-decay measurements reported by GERDA, KamLAND-Zen and EXO-200. Thus, these results which reflect the properties of the particle-physics degrees of freedom of the processes, may be taken as independent of the nuclei involved in the decays. The difference between the values listed in Table 2, for the extracted limits of the couplings, may then be attributed to the sensitivity of the experiments. The good thing about the results is that the spreading between the upper values of the ratio α between the RR and LR couplings is relatively small, since the value extracted from the germanium experiment is of the order of 30 % larger than the value extracted from the xenon-experiments, much smaller than the difference between the extracted upper values of the neutrino mass.

Our combined analyses of the $0\nu\beta\beta$ and p–p data confine the values of ζ to be at least one order of magnitude smaller than the limit obtained by TWIST.[7]

4. Summary and Conclusions

In summary, we have taken the latest results of the GERDA, EXO-200 and KamLAND-Zen double-beta-decay experiments and extracted from them information about the average neutrino mass and LR and RR couplings. We then discussed these results in combination with the ATLAS and CMS measurements of the decay of the right-handed boson into two-leptons and two-jets. The $0\nu\beta\beta$ analysis was based on the use of nuclear-structure factors which are representative of a broad sample of nuclear-structure calculations. The results of the study indicate a strong complementarity of the high-energy data taken at the LHC reactions and the $0\nu\beta\beta$ decays, in the determination of physical observables linked to the right-handed currents and their couplings.

Our results show that a mass M_R larger than 3 TeV, for the right-handed boson, and a mixing angle ζ smaller than 10^{-3}, are compatible with the measured limits of the $0\nu\beta\beta$ half-life and with the corresponding upper-limit of the average neutrino mass. These values are tied together by the present analysis and the values evolve alongside the progress achieved in the $0\nu\beta\beta$ experiments, in conjunction with the future data gathered by the ATLAS and CMS measurements.

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