Few active mechanisms of the $0\nu\beta\beta$ decay and effective mass of Majorana neutrinos

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It is well known that there exist many mechanisms that may contribute to neutrinoless double beta decay. By exploiting the fact that the associated nuclear matrix elements are target dependent we show that, given definite experimental results on a sufficient number of targets, one can determine or sufficiently constrain all lepton violating parameters including the mass term. As a specific example we show that, assuming the observation of the $0\nu\beta\beta$ decay in three different nuclei, e.g., $G^{76}e$, ^{100}Mo, and ^{130}Te, and just three lepton number violating mechanisms (light- and heavy-neutrino mass mechanisms as well as the *R*-parity breaking supersymmetry mechanism) being active, there are only four different solutions for the lepton violating parameters, provided that they are relatively real. In particular, our analysis shows that the effective neutrino Majorana mass $|m_{\beta\beta}|$ can be almost uniquely extracted by utilizing other existing constraints (cosmological observations and tritium β-decay experiments). We also point out the possibility that the nonobservation of the $0\nu\beta\beta$ decay for some isotopes could be in agreement with a value of $|m_{\beta\beta}|$ in the sub-eV region. We thus suggest that it is important to have at least two different $0\nu\beta\beta$-decay experiments for a given nucleus. We note that obtained results are sensitive to the accuracy of measured half-lives and to uncertainties in calculated nuclear matrix elements.

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I. INTRODUCTION

After the discoveries of oscillations of atmospheric, solar, and terrestrial neutrinos, one has gained a lot of valuable information regarding the mixing matrix and the squared mass differences. The absolute scale of the neutrino mass cannot, however, be determined in such experiments. Our best hope for settling this important issue as well as solving a second challenging problem, i.e., whether the neutrinos are Majorana or Dirac particles, is the observation of neutrinoless double beta decay.

The total lepton number violating neutrinoless double beta decay ($0\nu\beta\beta$ decay)

$$(A, Z) \rightarrow (A, Z + 2) + 2e^- \tag{1}$$

can take place only if the neutrino is a massive Majorana particle [1]. The measurement of the $0\nu\beta\beta$-decay rate could, in principle, determine an absolute scale of neutrino mass, solve the neutrino mass hierarchy problem, and provide information about the Majorana *CP*-violating phases of neutrinos.

The evidence for a $0\nu\beta\beta$ decay of ^{76}Ge has been claimed by some authors of the Heidelberg-Moscow Collaboration at Laboratori Nazionali del Gran Sasso [2] with

$$T^{0\nu}_{1/2}(^{76}\mathrm{Ge}) = 2.23^{+0.44}_{-0.31} \times 10^{25}\ \mathrm{y}. \tag{2}$$

Such a claim has raised some criticism but none of the existing experiments can rule it out [3]. The only certain way to confirm or refute this claim is with additional sensitive experiments [4], in particular, the GERDA experiment [5], which plans to start taking data this year.

There is a general consensus that the $0\nu\beta\beta$ decay has to be observed at different isotopes. Strong limits on the $0\nu\beta\beta$-decay half-life have been achieved in NEMO3 [6] and CUORICINO [7] experiments:

$$T^{0\nu}_{1/2}(^{100}\mathrm{Mo}) \geq 5.8 \times 10^{23}\ \mathrm{y},$$
$$T^{0\nu}_{1/2}(^{130}\mathrm{Te}) \geq 3.0 \times 10^{24}\ \mathrm{y}. \tag{3}$$

After neutrino oscillations established that the neutrinos are massive, nondegenerate, and strongly admixed, naturally most people's attention has focused on the light-neutrino mass mechanism of the $0\nu\beta\beta$ decay.

It is well known, however, that the $0\nu\beta\beta$ decay can be triggered by a plethora of other lepton number violating (LNV) mechanisms. Among these we should mention the exchange of heavy neutrinos, the exchange of supersymmetry (SUSY) superpartners with *R*-parity violating, leptoquarks, right-handed *W* bosons, or Kaluza-Klein excitations, among others, which have been discussed in the literature.

So the day after the $0\nu\beta\beta$ decay is observed and, hopefully, established in a number of nuclei, the main question will be what the dominant mechanism is that triggers the decays.

Possibilities to distinguish at least some of the possible mechanisms include the analysis of angular correlations between the emitted electrons [8], study of the branching ratios of $0\nu\beta\beta$ decays to ground and excited states [9], a comparative study of the $0\nu\beta\beta$ decay and neutrinoless electron capture with emission of a positron ($0\nu EC\beta^+$) [10], and analysis of possible connections with other lepton-flavor violating processes (e.g., $\mu \to e\gamma$) [11].

The main disadvantages of the above approaches are small $0\nu\beta\beta$-decay rates to excited states, suppressed $0\nu EC\beta^+$-decay rates, experimental challenges to observe the produced x rays or Auger electrons, and the fact that most double β-decay experiments of the next generation are not sensitive to electron tracks.

In this paper we shall analyze what happens if several mechanisms are active for the $0\nu\beta\beta$ decay. We will show that all LNV parameters, including the most interesting mass term, can be determined provided that $0\nu\beta\beta$ data from traditional experiments involving a sufficient number of nuclear targets become available.

II. THE COEXISTENCE OF FEW LNV MECHANISMS OF THE $0\nu\beta\beta$ DECAY

The subject of interest is a coexistence of the following LNV mechanisms of the $0\nu\beta\beta$ decay: (i) Light-neutrino mass mechanism. (ii) Heavy-neutrino mass mechanism. Both mechanisms assume only left-hand current weak interactions. (iii) The trilinear R-parity breaking SUSY mechanism generated by gluino exchange. For the sake of simplicity we shall assume that the lepton violating parameters are relatively real as, e.g., is the situation in the case of CP conservation.

The inverse value of the $0\nu\beta\beta$-decay half-life for a given isotope (A, Z) can be written as

$$\frac{1}{T^{0\nu}_{1/2}} = G^{0\nu}(E_0, Z)|\eta_\nu M^{0\nu}_\nu + \eta_N M^{0\nu}_N + \eta_{\not{R}_p} M^{0\nu}_{\not{R}_p}|^2. \quad (4)$$

Here, $\eta_{\nu,N,\not{R}_p}$ and $M^{0\nu}_{\nu,N,\not{R}_p}$ are, respectively, the LNV parameters and the nuclear matrix elements (NMEs), in the order given above. Each of the NMEs depends, in general, quite differently on the nuclear structure of the particular isotopes (A, Z), $(A, Z + 1)$, and $(A, Z + 2)$ under study.

$G^{0\nu}(E_0, Z)$ is the known phase-space factor (E_0 is the energy release), which includes the fourth power of axial-coupling constant $g_A = 1.25$. The $G^{0\nu}(E_0, Z)$ contain the inverse square of the nuclear radius R^{-2}, compensated by the factor R in $M^{0\nu}$. The assumed value of the nuclear radius is $R = r_0 A^{1/3}$ with $r_0 = 1.1$ fm. The phase-space factors are tabulated in Ref. [12].

The lepton number violating mechanisms of interest together with corresponding NMEs are presented briefly below.

A. Light Majorana neutrino exchange mechanism

In the case of the light-neutrino mass mechanism of the $0\nu\beta\beta$ decay we have

$$\eta_\nu = \frac{m_{\beta\beta}}{m_e}. \quad (5)$$

Under the assumption of the mixing of three light massive Majorana neutrinos the effective Majorana neutrino mass $\langle m_{\beta\beta}\rangle$ takes the form

$$m_{\beta\beta} = \sum_i^3 |U_{ei}|^2 \xi_i^{CP} m_i \qquad (\text{all } m_i \geq 0), \quad (6)$$

where U_{ei} is the first row of the neutrino mixing matrix and ξ_i^{CP} are unknown Majorana CP phases. m_i is the light-neutrino mass ($m_i \leq 1$ eV, $i = 1, 2, 3$). In this case only left-handed weak interaction is taken into account.

The nuclear matrix element $M^{0\nu}_\nu$ consists of Fermi, Gamow-Teller, and tensor parts as

$$M^{0\nu}_\nu = -\frac{M_{F(\nu)}}{g_A^2} + M_{GT(\nu)} + M_{T(\nu)}. \quad (7)$$

Here, g_A is the axial-vector coupling constant. The Fermi, Gamow-Teller, and tensor operators are defined in the usual way [see Eq. (10) below] with exchange potentials as given elsewhere [13]

B. Heavy Majorana neutrino exchange mechanisms

We assume that the neutrino mass spectrum includes heavy Majorana states N with masses M_k much larger than the energy scale of the $0\nu\beta\beta$ decay: $M_k \gg 1$ GeV. These heavy states can mediate this process as the previous light-neutrino exchange mechanism. The difference is that the neutrino propagators in the present case can be contracted to points, and, therefore, the corresponding effective transition operators are local unlike in the light-neutrino exchange mechanism with long-range internucleon interactions.

The corresponding LNV parameter is given by

$$\eta_N = \sum_{k=4}^6 |U_{ek}|^2 \xi_k^{\prime} \frac{m_p}{M_k}. \quad (8)$$

Here, m_p is the mass of proton. U_{ek} are elements of the neutrino mixing matrix associated with left-handed current interactions. $\xi_k^{\prime}$ are CPviolating phases.

Separating the Fermi (F), Gamow-Teller (GT), and tensor (T) contributions we write down

$$\begin{aligned}\mathcal{M}^{0\nu}_N &= -\frac{M_{F(N)}}{g_A^2} + M_{GT(N)} + M_{T(N)} \\ &= \langle 0_i^+ | \sum_{kl} \tau_k^+ \tau_l^+ [H_F^{(N)}(r_{kl})/g_A^2 + H_{GT}^{(N)}(r_{kl})\sigma_{kl} \\ &\quad - H_T^{(N)}(r_{kl}) S_{kl}] | 0_f^+ \rangle, \end{aligned} \quad (9)$$

where

$$S_{kl} = 3(\vec{\sigma}_k \cdot \hat{\mathbf{r}}_{kl})(\vec{\sigma}_l \cdot \hat{\mathbf{r}}_{kl}) - \sigma_{kl}, \qquad \sigma_{kl} = \vec{\sigma}_k \cdot \vec{\sigma}_l. \quad (10)$$

The radial parts of the exchange potentials can be found elsewhere [12].

C. *R*-parity breaking SUSY mechanism

In the SUSY models with R-parity nonconservation one encounters LNV couplings which may also trigger the $0\nu\beta\beta$ decay. Recall that R parity is a multiplicative quantum number defined by $R = (-1)^{2S+3B+L}$ (S, B, and L are the spin, baryon, and lepton number, respectively). Ordinary particles have $R = +1$ while their superpartners $R = -1$. The LNV couplings emerge in this class of SUSY models from the R-parity breaking part of the superpotential

$$W_{\not R_p}: = \lambda_{ijk} L_i L_j E^c_k + \lambda'_{ijk} L_i Q_j D^c_k + \mu_i L_i H_2, \tag{11}$$

where L and Q stand for lepton and quark $SU(2)_L$ doublet left-handed superfields, respectively, while E^c and D^c for lepton and down quark singlet superfields, respectively. This results in a lepton violating parameter entering the neutrinoless double beta decay: $\eta_{\not R_p}$.

For simplicity we concentrate below on the trilinear λ' couplings and write $\eta_{\not R_p} = \eta_{\lambda'}$. Under reasonable assumptions the gluino exchange dominates [14]. We have

$$\eta_{\lambda'} = \frac{\pi\alpha_s}{6} \frac{\lambda'^2_{211}}{G_F^2 m^4_{\tilde{d}_R}} \frac{m_p}{m_{\tilde{g}}} \left[1 + \left(\frac{m_{\tilde{d}_R}}{m_{\tilde{u}_L}}\right)^2\right]^2. \tag{12}$$

Here, G_F is the Fermi constant; $\alpha_s = g_3^2/(4\pi)$ is the $SU(3)_c$ gauge coupling constant. $m_{\tilde{u}_L}$, $m_{\tilde{d}_R}$, and $m_{\tilde{g}}$ are the masses of the u squark, d squark, and gluino, respectively.

At the hadron level we assume dominance of the pion-exchange mode [14]. We denote the $0\nu\beta\beta$-decay nuclear matrix element $\mathcal{M}^{0\nu}_{\not R_p}$ of Eq. (4) as $\mathcal{M}^{0\nu}_{\lambda'}$ with

$$\mathcal{M}^{0\nu}_{\lambda'} = c_A[\tfrac{4}{3}\alpha^{1\pi}(M_T^{1\pi} - M_{\rm GT}^{1\pi}) + \alpha^{2\pi}(M_T^{2\pi} - M_{\rm GT}^{2\pi})], \tag{13}$$

with $c_A = m_A^2/(m_p m_e)$ ($m_A = 850$ MeV). The structure coefficients of the one-pion $\alpha^{1\pi}$ and two-pion mode $\alpha^{2\pi}$ are [14] $\alpha^{1\pi} = -0.044$ and $\alpha^{2\pi} = 0.20$. The partial NMEs of the R_p SUSY mechanism for the $0\nu\beta\beta$-decay process are

$$\begin{aligned} M_{\rm GT}^{k\pi} &= \langle 0^+_f | \sum_{k\neq l} \tau_k^+ \tau_l^+ H_{\rm GT}^{k\pi}(r_{kl}) \sigma_i \cdot \sigma_j, | 0^+_i \rangle, \\ M_T^{k\pi} &= \langle 0^+_f | \sum_{k\neq l} \tau_k^+ \tau_l^+ H_T^{k\pi}(r_{kl}) S_{kl} | 0^+_i \rangle, \end{aligned} \tag{14}$$

with the radial functions given elsewhere [14]. Under these assumptions the obtained NMEs are given in Table I.

In obtaining the nuclear matrix elements we used the self-consistent renormalized quasiparticle random phase approximation [16] to calculate NMEs $M^{0\nu}_\nu$, $M^{0\nu}_N$, and $M^{0\nu}_{\lambda'}$. The self-consistent renormalized quasiparticle random phase approximation takes into account the Pauli exclusion principle and conserves the mean particle number in the correlated ground state. For $A = 76$ and 100 nuclear systems three different single-particle model spaces are considered (see, e.g., [15]). In the calculation of the $0\nu\beta\beta$-decay NMEs the two-nucleon short-range correlations derived from the same potential as residual interactions, namely, from the CD-Bonn potential [15], are considered. The calculated NMEs and their uncertainties are given in Table I.

TABLE I. Averaged $0\nu\beta\beta$-decay NMEs and their variance σ (in parentheses) calculated with the self-consistent renormalized quasiparticle random phase approximation. The coupled cluster method short-range correlations calculated with the CD-Bonn potential are taken into account [15]. $g_A = 1.25$.

Nucl. trans.	$G^{0\nu}(E_0, Z)$ [y^{-1}]	$M^{0\nu}_\nu$	$M^{0\nu}_N$	$M^{0\nu}_{\lambda'}$
$^{76}\mathrm{Ge} \to {}^{76}\mathrm{Se}$	7.98×10^{-15}	5.24(0.52)	363(44)	525(66)
$^{100}\mathrm{Mo} \to {}^{100}\mathrm{Ru}$	5.73×10^{-14}	4.89(0.22)	392(11)	550(35)
$^{130}\mathrm{Te} \to {}^{130}\mathrm{Xe}$	5.54×10^{-14}	4.53(0.23)	362(23)	511(33)

III. CALCULATION AND DISCUSSION

A. Dominance of a single $0\nu\beta\beta$-decay mechanism

Commonly, it is assumed that a single LNV mechanism is responsible for the $0\nu\beta\beta$ decay. Let suppose it is the light-neutrino mass mechanism ($m_{\beta\beta}$). Then, the $0\nu\beta\beta$-decay half-life T_i ($i = 1, 2, \ldots$) for two and more nuclear systems are related with the equation

$$|m_{\beta\beta}| = \frac{m_e}{|M_i^\nu|\sqrt{T_i G_i}}. \tag{15}$$

Here, G_i is the kinematical factor, while the M_i^ν NME associated with $m_{\beta\beta}$ for the target i.

B. Two active $0\nu\beta\beta$-decay mechanisms

We will now move into the case of two competing $0\nu\beta\beta$-decay mechanisms representing by the LNV parameters $m_{\beta\beta}$ and η; η could be η_N or $\eta_{\lambda'}$. In this case we have four different sets of two linear equations:

$$\begin{aligned} \frac{\pm 1}{\sqrt{T_1 G_1}} &= \frac{m_{\beta\beta}}{m_e} M_1^\nu + \eta M_1^\eta, \\ \frac{\pm 1}{\sqrt{T_2 G_2}} &= \frac{m_{\beta\beta}}{m_e} M_2^\nu + \eta M_2^\eta. \end{aligned} \tag{16}$$

For the absolute value of the LNV parameters we find two different solutions:

$$\begin{aligned} |m_{\beta\beta}| = \Bigg| & \frac{m_e}{M_1^\nu\sqrt{T_1 G_1}} \frac{M_1^\nu M_2^\eta}{(M_1^\nu M_2^\eta - M_2^\nu M_1^\eta)} \\ & \pm \frac{m_e}{M_2^\nu\sqrt{T_2 G_2}} \frac{M_2^\nu M_1^\eta}{(M_1^\nu M_2^\eta - M_2^\nu M_1^\eta)} \Bigg|, \end{aligned} \tag{17}$$

$$|\eta| = \left| \frac{1}{M_1^\eta \sqrt{T_1 G_1}} \frac{M_1^\eta M_2^\nu}{(M_1^\eta M_2^\nu - M_2^\eta M_1^\nu)} \pm \frac{1}{M_2^\eta \sqrt{T_2 G_2}} \frac{M_2^\eta M_1^\nu}{(M_1^\eta M_2^\nu - M_2^\eta M_1^\nu)} \right|. \qquad (18)$$

We note, however, that for $\eta = 0$ Eqs. (17) and (18) are reduced to Eq. (15).

By assuming now $\eta \equiv \eta_N$ the solutions for $|m_{\beta\beta}|$ will be analyzed for $A = 76$ and 130 nuclear systems. An additional assumption is that the $0\nu\beta\beta$-decay half-life of ^{76}Ge has been measured with $T_{1/2}^{0\nu}(^{76}\mathrm{Ge})$ given in (2) (further denoted as T_1). In Fig. 1 the two solutions for $|m_{\beta\beta}|$ are plotted as a function of ξ, where

$$\xi = \frac{|M_1^\nu| \sqrt{T_1 G_1}}{|M_2^\nu| \sqrt{T_2 G_2}}. \qquad (19)$$

The parameter ξ represents the unknown half-life of the $0\nu\beta\beta$ decay of ^{130}Te (denoted as T_2). We note that for $\xi = 1$ the solution for active only the light-neutrino mass mechanism given by Eq. (15) is reproduced and that $\xi = 0$ means nonobservation of the $0\nu\beta\beta$ decay for a considered isotope.

By glancing at Fig. 1 we see that the two solutions for $|m_{\beta\beta}|$ are very sensitive to the accuracy of measured half-lives. For considered experimental errors the allowed values of $|m_{\beta\beta}|$ are described with dashed regions. The first solution [equals sign on the left-hand side of Eq. (16)] can be even equal to zero. The second solution (opposite signs) predicts $m_{\beta\beta} > 1$ eV. Within the considered assumptions the claim of evidence of the $0\nu\beta\beta$ decay of ^{76}Ge [2] is still compatible also with inverted ($m_i < 50$ meV) or normal ($m_i \approx$ few meV) hierarchy of neutrino masses. From Fig. 1 it follows that a small improvement of the current half-life limit for ^{130}Te up to the value 4.1×10^{24} y ($\xi_{\mathrm{Te}} \simeq 1.1$) would exclude these possibilities. Another finding is that the nonobservation of the $0\nu\beta\beta$ decay for ^{130}Te (i.e., $\xi = 0$) cannot rule out the claim for evidence of the $0\nu\beta\beta$ decay of ^{76}Ge. This can only happen if, in a more sensitive Ge experiment like GERDA or Majorana, no $0\nu\beta\beta$-decay signal will be registered.

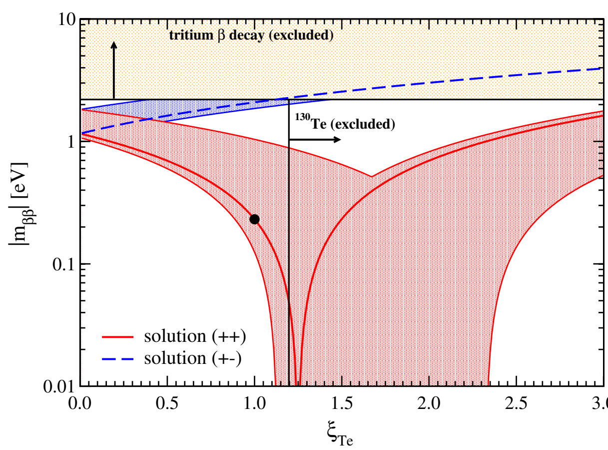

FIG. 1 (color online). The effective Majorana mass of neutrinos in the case of two active mechanisms of the $0\nu\beta\beta$ decay, namely, light- and heavy-neutrino exchange mechanisms, as a function of parameter ξ [see Eq. (19)]. $T_{1/2}^{0\nu}(^{76}\mathrm{Ge}) = 2.23^{+0.44}_{-0.31} \times 10^{25}$ y [2] is assumed. Solutions 1 and 2 were obtained for equal and opposite signs on the left-hand side of Eqs. (16), respectively. The bold point indicates the value of $m_{\beta\beta}$, if the light-neutrino exchange is the only active mechanism. The dashed regions showed the uncertainty of the obtained predictions for $|m_{\beta\beta}|$ if 3σ experimental errors of the measured half-lives are considered. We show also that $|m_{\beta\beta}| > 2.2$ eV is excluded due to Mainz tritium β-decay experiment [17].

C. Three active $0\nu\beta\beta$-decay mechanisms

In the case of three active $0\nu\beta\beta$-decay mechanisms represented by the LNV parameters $m_{\beta\beta}$, η_N, and $\eta_{\lambda'}$ assuming the measurement of the lifetime of the $0\nu\beta\beta$ decay of three isotopes, one obtains a set of three linear equations:

$$\frac{\pm 1}{\sqrt{T_i G_i}} = \frac{m_{\beta\beta}}{m_e} M_i^\nu + \eta_N M_i^\eta + \eta_{\lambda'} M_i^{\lambda'}, \qquad i = 1, 2, 3. \quad (20)$$

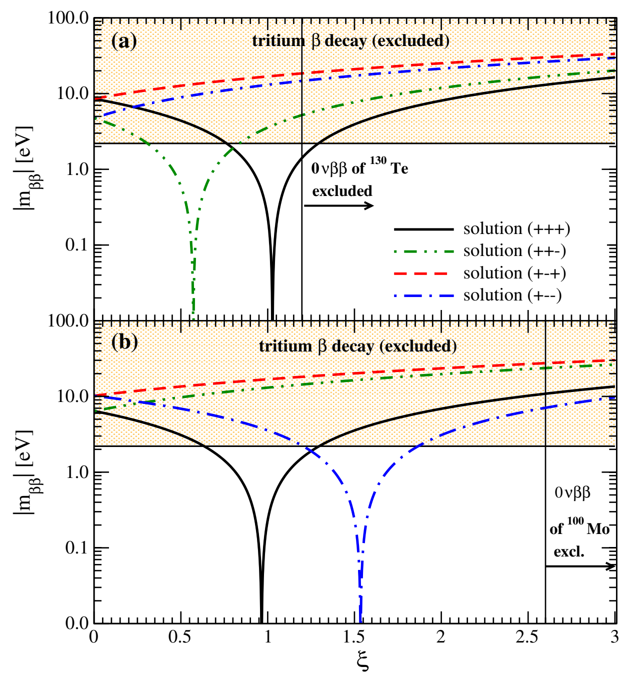

FIG. 2 (color online). The effective Majorana mass of neutrinos in the case of three active mechanisms of the $0\nu\beta\beta$ decay, namely, light- and heavy-neutrino exchange mechanisms and the R-parity breaking SUSY mechanism with gluino exchange, as a function of parameter ξ_{Te}. Nuclear systems with $A = 76$, 100, and 130 are considered. The central value of $T_{1/2}^{0\nu}(^{76}\mathrm{Ge})$ is the same as in Fig. 1. $\xi_{\mathrm{Mo}} = 1.0$ and $\xi_{\mathrm{Te}} = 1.0$ are assumed in the upper (a) and lower (b) panels, respectively. For each solution there are given in brackets signs in front of term $1/\sqrt{TG}$ in Eqs. (20) for ^{76}Ge, ^{100}Mo, and ^{130}Te.

Equations (20) admit a set of four different solutions, which are exhibited in Fig. 2. $A = 76$, 100, and 130 nuclear systems are considered. For $T^{0\nu}_{1/2}(^{76}\mathrm{Ge})$ we assume the same value as in Fig. 1 but the experimental error is not taken into account for this presentation. The upper and lower panels correspond to $\xi_{\mathrm{Mo}} = 1.0$ (current limit) and $\xi_{\mathrm{Te}} = 1.0$, respectively. The upper two solutions are already excluded by the Mainz and Troitsk tritium experiments [17]. In case the claim of evidence of the $0\nu\beta\beta$ decay of ^{76}Ge would be ruled out by other experiments, i.e., for a larger value of $T^{0\nu}_{1/2}(^{76}\mathrm{Ge})$, they would decrease and might be important. The other two solutions are compatible with both normal and inverted mass predictions for $|m_{\beta\beta}|$. Such a possibility could be excluded only for a significant improvement of the current half-life limit for the $0\nu\beta\beta$ decay of ^{100}Mo. We note that especially the upper two solutions for $|m_{\beta\beta}|$ are sensitive even to small uncertainties in calculated NMEs.

IV. CONCLUSIONS

It has been shown that the extraction of the most important neutrino mass contribution, entering neutrinoless double beta decay, can be disentangled from the other mechanisms, if and when the decay rates in a sufficient number of nuclear targets become available. In the present calculation, to simplify the exposition, we restricted ourselves in the special case of no right-handed currents and made the assumption that the LNV parameters are relatively real. To be more specific, in addition to the standard light-neutrino mass mechanism of the $0\nu\beta\beta$ decay, we considered two additional LNV mechanisms, namely, those involving the exchange of heavy neutrinos and R-parity breaking SUSY with gluino exchange. We find that this improved analysis leads to completely different results compared to those of one mechanism at a time. It is now possible that larger values of $|m_{\beta\beta}|$ can be consistent with the data, since the contribution of the other mechanisms could be interfering with it destructively.

We specifically discussed the extracted value of the effective Majorana neutrino mass $m_{\beta\beta}$, assuming the claim of evidence of the $0\nu\beta\beta$ decay of ^{76}Ge [2] as a function of half-life data for the two promising nuclei (^{100}Mo and ^{130}Te). We showed that in an analysis including two and three nuclear systems there are 2 and 4 different possible solutions for $|m_{\beta\beta}|$, respectively. One of the solutions leads to small values of $|m_{\beta\beta}|$, when all mechanisms add up coherently. This is compatible also with inverted ($m_i < 50$ meV) or normal ($m_i \approx$ few meV) hierarchy of neutrino masses. Other solutions, however, allow quite large values of $|m_{\beta\beta}|$, even larger than 1 eV. These can, of course, be excluded by cosmology and tritium β-decay experiments. It may not, however, be possible to exclude these solutions, if the claim of evidence for ^{76}Ge would be ruled out by future experiments, since, then, the values we obtain become smaller than those of the other experiments.

It is thus important that experiments involving as many different targets as possible be pursued. Furthermore, in the presence of interference between the various mechanisms, the availability of reliable nuclear matrix elements becomes more imperative.

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