

## Test of the single state dominance hypothesis for the two-neutrino double beta decay

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**Abstract.** The single state dominance hypothesis for the two-neutrino double-beta decay matrix elements is tested in this work for the double-beta decaying nuclei <sup>100</sup>Mo, <sup>116</sup>Cd, and <sup>128</sup>Te. In addition to this, we analyze the contribution to the double-beta matrix elements from the low-lying intermediate states and from the whole set of intermediate states. We use a proton-neutron QRPA calculation based on a deformed Skyrme Hartree-Fock mean field with pairing correlations, and we compare these results with the half-lives of the double-beta emitters for which we have experimental information.

Neutrinoless double-beta ( $0\nu\beta\beta$ ) decay [1] is a nuclear process, not yet experimentally confirmed, that could provide information on the absolute mass of the neutrino. The dependence of this process on the nuclear structure of the decaying nucleus gives rise to a lack of accuracy in the matrix element and consequently in the neutrino properties that could be extracted from the experiments.

On the other hand, the double-beta decay with the emission of two (anti)neutrinos ( $2\nu\beta\beta$ ) proceeds as a perturbative process in the Standard Model and has already been observed in some nuclei. A successful description of the  $2\nu\beta\beta$  decay mode is a requirement for a reliable calculation of the matrix element corresponding to the  $0\nu\beta\beta$  decay.

An important question in theoretical  $2\nu\beta\beta$  decay studies is whether the contributions of higher-lying intermediate states to the  $2\nu\beta\beta$  decay amplitude play an important role. According to the single-state dominance (SSD) hypothesis [2], when the ground state of the odd-odd intermediate nucleus is  $1^+$ , the double-beta transition through this intermediate state accounts for a large part of the double-beta decay matrix element (DBDME). If SSD hypothesis is confirmed, the half-lives of  $2\nu\beta\beta$  decays could be determined from single  $\beta^-$  and electron capture measurements. The realization of the SSD hypothesis would also lead to a simplification in the theoretical description of the intermediate nucleus, because only the lowest  $1^+$  wave function is to be considered.

In this work we check the validity of the SSD hypothesis by considering only the lowest-energy term in the summation in the cases of <sup>100</sup>Mo, <sup>116</sup>Cd, and <sup>128</sup>Te, which are emitters with  $1^+$  intermediate ground states. Then, we analyze the contributions to the  $2\nu\beta\beta$  nuclear DBDME from terms with increasing excitation energies, with special attention to the low-energy region and to the full set of excited states.

The expressions for DBDME can be found in Refs. [3, 4]. They are computed within a formalism based on a pnQRPA approach with a selfconsistent quasiparticle basis obtained from deformed Skyrme Hartree-Fock mean field with pairing correlations (HF+BCS+QRPA). For each  $(N, Z)$  nucleus, a BCS ground state is obtained from deformed Skyrme (SLy4) HF calculations on a large axially-symmetric harmonic oscillator basis, using phenomenological pairing-gap parameters and solving the BCS equations after each HF iteration. The quadrupole deformation of the nucleus in its ground state is obtained selfconsistently as the shape that minimizes the nuclear energy. The pnQRPA equations are solved using the quasiparticle mean field basis for separable residual spin-isospin interactions in both particle-hole and particle-particle channels [5].

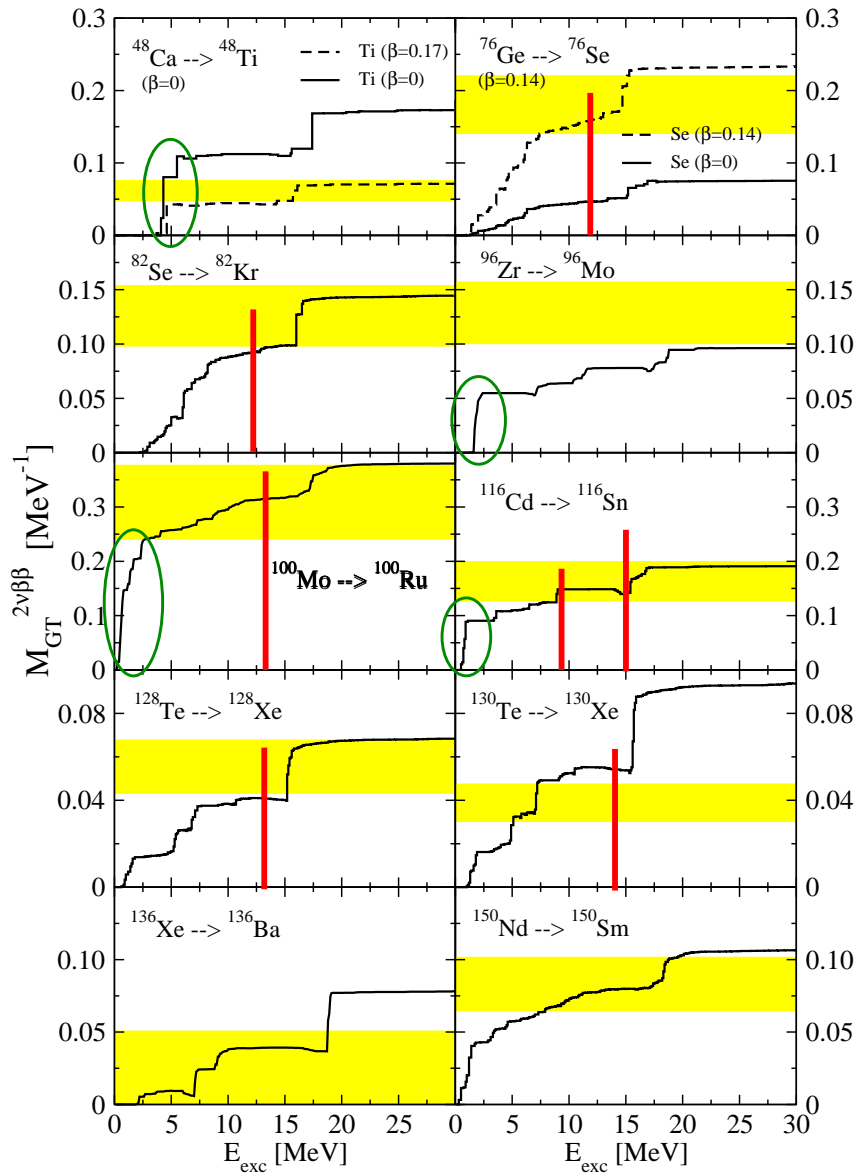
We plot in Fig. 1 the  $2\nu$  DBDME for a set of confirmed double-beta emitters as a function of the excitation energy of the intermediate nucleus taken into account in the calculation. The shadowed area in the plots indicates the experimental range of the  $2\nu$  DBDME, the two limiting horizontal lines being deduced from experimental half-lives [6] using two different values of the constant  $g_A$ , namely  $g_A=1.25$  and  $g_A=1.00$ . The vertical lines indicate the experimental energy positions of the Gamow-Teller giant resonances to show the correlation that we find between them and the sudden increase in the value of the DBDME.

A pure SSD analysis would focus on the first contribution to the DBDME for  $^{100}\text{Mo}$ ,  $^{116}\text{Cd}$  and  $^{128}\text{Te}$ . From Fig. 1 we see that no evidence to support SSD is found in any of these nuclei, since the first transition (the one at the lowest excitation energy) does not account for a remarkable part of the total DBDME value. One has to consider a few MeV of excitation energy (containing the strength of several transitions) to reach a large percentage (around 60%) of the final DBDME value. This increase in the low energy region, which can be referred to as low-lying state dominance (LLSD) hypothesis, is highlighted in the figure by circles, appearing in  $^{48}\text{Ca}$ ,  $^{96}\text{Zr}$ ,  $^{100}\text{Mo}$  and  $^{116}\text{Cd}$ .

Apart from the SSD or LLSD hypotheses, the figure shows the theoretical prediction of the total DBDME, which is the value reached for a large-enough energy range (as the 30 MeV shown in the figure). In many cases the theoretical value lies within the experimental range, and in all of them the order of magnitude is correct. It is worth mentioning that there are two ingredients that strongly influence the computed value of the DBDME. One is the value of the residual interaction coupling constants, especially for the particle-particle channel, which in the calculation shown here has been assigned the value  $\kappa_{pp} = 3/A$  MeV. The other is the different quadrupole deformations of the double-beta partners, whose effect can be seen in the figure in the plots for  $^{48}\text{Ca}$  and  $^{76}\text{Ge}$ . In both cases when the ground states of the double-beta partners have the same deformations (spherical in the case of  $^{48}\text{Ca}$  and  $^{48}\text{Ti}$  and prolate for  $^{76}\text{Ge}$  and  $^{76}\text{Se}$ ), the DBDME is considerably larger than in the case when they have different deformations.

To summarize, we have shown that our deformed Skyrme HF+BCS+QRPA calculations reproduce the experimental  $2\nu\beta\beta$  DBDME when the whole energy range of excitation energy in the intermediate nucleus is considered, with only two exceptions ( $A = 130, 136$ ). We find important contributions to the  $2\nu$  DBDME at relatively high excitation energies in several cases, and consequently dominance of a single or a few low-lying states is not generally found and is at best fulfilled at the 60% level in our theoretical scheme, and only for some nuclei  $^{48}\text{Ca}$ ,  $^{96}\text{Zr}$ ,  $^{100}\text{Mo}$ ,  $^{116}\text{Cd}$ . Other important conclusion of the analysis performed here is the verification of shape dependence of DBDME in  $A = 48$  and  $A = 76$  cases.

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**Figure 1.** DBDME as a function of the intermediate nucleus excitation energy considered in the calculation.

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