PROCEEDINGS OF SCIENCE

Neutrinoless double beta decay mediated by non-interfering exchange of light and heavy Majorana neutrinos

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We investigate the neutrinoless double beta decay ($0\nu\beta\beta$) process, focusing and commenting on the results reported in [1], in the case where both light and heavy Majorana neutrinos contribute independently without interference, . Our analysis incorporates recent computations of nuclear matrix elements (NME) from different nuclear models. We put bounds on the contributions of light and heavy neutrinos to $0\nu\beta\beta$ decay with current data, and we study the impact of potential signals at $> 3\sigma$ for forthcoming projects such as nEXO, LEGEND, and CUPID.

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1. Introduction

Neutrinoless double beta decay, violating lepton number conservation by two units, is crucial for confirming neutrinos as Majorana particles, regardless of specific decay mechanisms. The primary mechanism under consideration involves the exchange of three known light neutrinos, with the decay's half-life denoted as T_i for a specific isotope $i = (Z, A)$ governed by factors such as the phase-space factor G_i, nuclear matrix element (NME) $M_{\nu,i}$, and the effective Majorana mass for light neutrinos m_ν:

$$(T_i)^{-1} = S_i = G_i \, M_{\nu,i}^2 \, m_\nu^2$$

Alternative decay mechanisms, including both light neutrinos (ν_k) and heavy Majorana neutrinos (N_h) simultaneously, are often possible in scenarios beyond the Standard Model. When these contributions do not interfere, the decay's half-life T_i and signal S_i definitions can incorporate both light and heavy neutrino exchange:

$$(T_i)^{-1} = S_i = G_i \, \left(M_{\nu,i}^2 \, m_\nu^2 + M_{N,i}^2 \, m_N^2 \right)$$

Our objective is to use experimental data from different isotopes to determine the values of m_ν and m_N, provided that the heavy-to-light NME ratios differ for each isotope. If these ratios are similar, distinguishing between the two mechanisms becomes challenging, especially because of the large uncertainties in NME. We analyze prospective $0\nu\beta\beta$ signals observable at $> 3\sigma$ level in ton-scale (Xe, Ge, Mo) projects, and study the effect of nuclear model uncertainties by swapping "true" and "test" sets of NME values [1]. We also present illustrative tests of a particular theoretical model connecting m_ν and m_N.

2. Analysis with different true and test NME sets

The choice of the NME set affects the reconstruction of Majorana mass parameters $(m_\nu, \, m_N)$ based on prospective signals $\bar{S}_i$ and test signals S_i. The best-fit parameters may deviate from the true values, and the resulting χ^2 value, will indicate the goodness of fit.

We focus on a representative scenario involving both light and heavy neutrino exchange, with $(m_\nu, \, m_N) = (15, \, 0.3)$ meV. Combining data from ton-scale experiments and considering 16 pairs of true and test NME sets, we present outcomes in Fig. 1. Each panel corresponds to a pair of (true, test) NME sets, displaying true and reconstructed $(m_\nu^2, \, m_N^2)$ points. The $\chi^2_{\rm min}$ value is provided for each case.

The results reveal various possibilities. Some panels show low $\chi^2_{\rm min}$ values, indicating acceptable fits, but with significant biases in reconstructed mass parameters. Moderate $\chi^2_{\rm min}$ values result in borderline fits, while high $\chi^2_{\rm min}$ values suggest an inadequate fit to the data, raising concerns about the chosen NME set's ability to describe the experimental results.

In conclusion, the numerical variability of NME values across different nuclear models introduces complexity in interpreting future $0\nu\beta\beta$ signals. Reconstruction biases may occur, potentially missing the true parameters, even with seemingly good fits. Conversely, poor fits might signal issues with the chosen NME set. The challenge lies in disentangling the interplay between multi-isotope searches, decay mechanisms, and assumed NME sets, emphasizing the need for more accurate and

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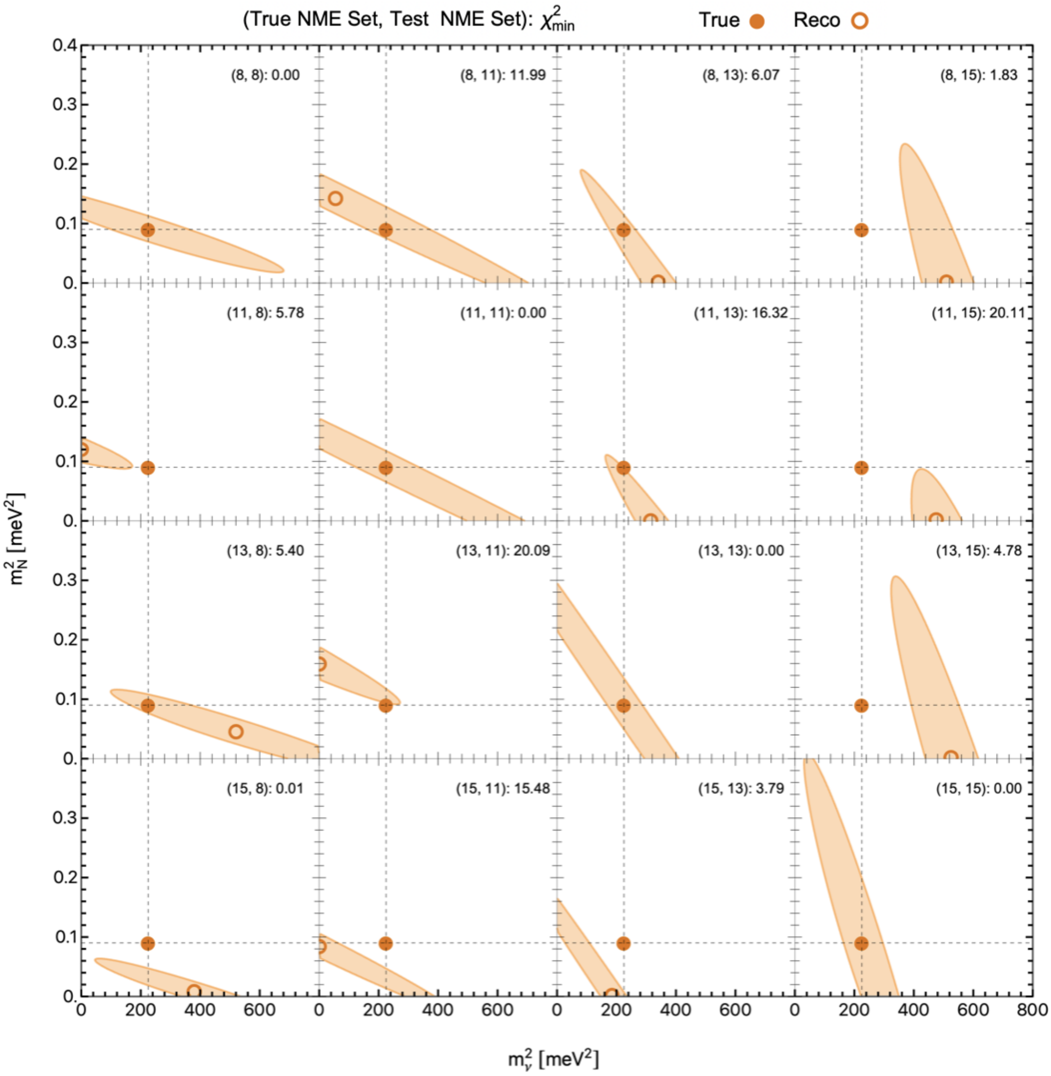

Figure 1: Combined fit to prospective data from nEXO, LEGEND and CUPID, assuming both light and heavy neutrino exchange. Each panel reports a pair of (true, test) NME sets, numbered as in Table I of[1], and followed by the $\chi^2_{\rm min}$ value. The true and reconstructed (m_ν^2, m_N^2) points are marked by solid and hollow circles (coinciding in the diagonal panels); the latter are surrounded by the 2σ allowed region.

converging NME calculations. It is essential to address these challenges for a clearer interpretation of future experimental data in $0\nu\beta\beta$ decay studies.

3. Test of a particular L-R theoretical model

We also studied a recent see-saw model with LR symmetry [2], that relates light and heavy neutrino masses leading to a bundle of rays in the (m_ν^2, m_N^2) plane. We examine a slice of this parameter space, fixing certain model parameters and comparing the generated values with constraints from current and future ton-scale experiments, using a particular NME set.

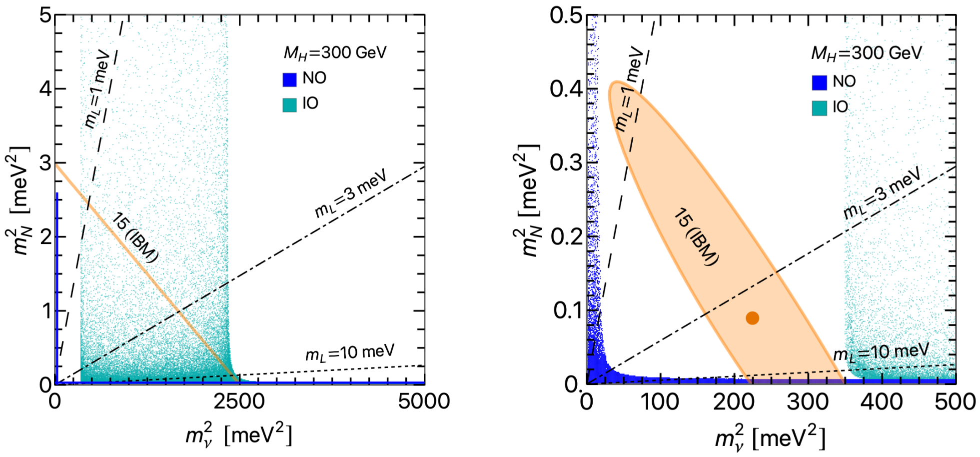

Figure 2: Current constraints (left panel) and future signals (right panel) at fixed NME (IBM set 15) on the model in [2]. The blue and cyan points refer to NO and IO, respectively. A few rays at constant m_L are shown. The value of m_H is set at 300 GeV.

The results, depicted in Fig. 2, show model predictions against current constraints (left panel) and prospective signals (right panel). Points above the orange line in the left panel are disfavored by current data, while the right panel displays the zoomed-in region allowed by future Xe+Ge+Mo data. The illustration demonstrates how $0\nu\beta\beta$ searches can probe heavy neutrino physics in theoretically interesting regions.

4. Conclusions

In this proceeding we report on the results of [1], where we revisited the phenomenology of $0\nu\beta\beta$ decay mediated by non-interfering exchange of light and heavy Majorana neutrinos using current and prospective data from various experiments. We highlighted the significance of NME ratios in determining the degeneracy or non-degeneracy of the mechanisms and derived upper bounds on the effective Majorana mass parameters. We explored various representative cases leading to prospective $> 3\sigma$ signals in ton-scale experiments and showed the allowed regions in the (m_ν^2, m_N^2) parameter space. Our findings provide further motivation to pursue multi-isotope $0\nu\beta\beta$ searches at the ton mass scale and improve the calculations of NME needed for the interpretation of $0\nu\beta\beta$ decay data.

References

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[2] S. Patra, S. T. Petcov, P. Pritimita and P. Sahu, "Neutrinoless double beta decay in a left-right symmetric model with a double seesaw mechanism," Phys. Rev. D **107**, no.7, 075037 (2023) [arXiv:2302.14538 [hep-ph]].