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Non-Standard Mechanisms for Neutrinoless Double Beta Decay

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Abstract

Neutrinoless double beta decay is a powerful tool to probe not only for Majorana neutrino masses but for lepton number violating physics in general. We discuss relations between lepton number violation, double beta decay and neutrino mass, provide an overview of the general Lorentz invariant parametrization of the double beta decay rate and highlight a number of different new physics models showing how different mechanisms can trigger double beta decay.

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1. Introduction

The search for neutrinoless double beta decay ($0\nu\beta\beta$) - the simultaneous transformation of two neutrons into two protons, two electrons and nothing else - is the most sensitive tool for probing Majorana neutrino masses. However, while this so-called mass mechanism is certainly the best known example triggering the decay, Majorana neutrino masses are not the only element of beyond Standard Model physics which can induce it. In this proceedings report we present possible other mechanisms of $0\nu\beta\beta$ decay where the lepton number violation (LNV) does not directly originate from Majorana neutrino masses but rather due to LNV masses or couplings of new particles appearing in various possible extensions of the Standard Model. While the same couplings will also induce Majorana neutrino masses, due to the Schechter-Valle black box theorem [1], the $0\nu\beta\beta$ decay half life will not yield direct information about the neutrino mass. We rather consider the $0\nu\beta\beta$ decay rate by expressing the new physics contributions in terms of effective low-energy operators [2, 3].

We here focus on the particle physics aspects. On the nuclear physics side, the uncertainties in nuclear matrix elements are notoriously difficult to estimate and limits derived from $0\nu\beta\beta$ decay are affected. Unfortunately, despite efforts devoted to the improvement of the nuclear calculations, the latest matrix elements in the QRPA approach from the Tübingen group [4] differ from the shell model results in many cases by factors of $\sim (2-3)$. Experimentally, the most stringent bounds on neutrinoless double beta decay are currently from ^{76}Ge [5] and ^{136}Xe [6]. The results presented below are based on [7], using the limits ^{76}Ge

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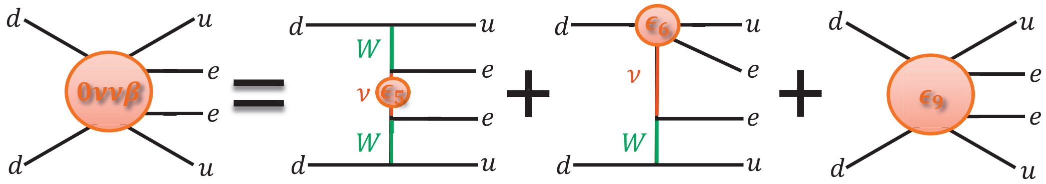

Fig. 1. Schematic overview of different contributions to $0\nu\beta\beta$: Standard mass mechanism, long–range 6-dim operator, short–range 9-dim operator.

of $T_{1/2} \geq 1.9 \times 10^{25}$ y and the recent result $T_{1/2} \geq 1.6 \times 10^{25}$ y for ^{136}Xe. In this report, we provide a brief overview of the possible effective operators (c.f. Figure 1) that can trigger $0\nu\beta\beta$ beta decay and give a summary of the most relevant LNV models. For more details, see the review [7] and references therein.

2. Contributions to Neutrinoless Double Beta Decay

Standard Mass Mechanism. Before discussing other contributions, recall that the mass mechanism of $0\nu\beta\beta$ probes the effective Majorana neutrino mass $\langle m_\nu \rangle = \sum_j U_{ej}^2 m_j \equiv m_{ee}$, where the sum runs over all active light neutrinos. This quantity is equal to the (ee) entry of the Majorana neutrino mass matrix. The $0\nu\beta\beta$ half life in a given isotope is then given by $[T_{1/2}^{0\nu\beta\beta}]^{-1} = |\langle m_\nu \rangle / m_e|^2 G_0 |ME|^2$, where G_0 denotes the nuclear phase space factor and $|ME|$ the nuclear matrix element. The current experimental results lead to a limit $\langle m_\nu \rangle \lesssim 0.5 - 1.0$ eV.

Long–Range Contributions. Long–range contributions to $0\nu\beta\beta$ decay involve two vertices, point-like at the Fermi scale, with the exchange of a light neutrino in between. The general Lagrangian can be written in terms of effective couplings ϵ_β^α [2],

$$\mathcal{L} = \frac{G_F}{\sqrt{2}} \left(j_{V-A}^{\mu} J_{V-A,\mu}^{\dagger} + \sum_{\alpha,\beta} \epsilon_\alpha^\beta j_\beta J_\alpha^\dagger \right), \tag{1}$$

with the hadronic and leptonic currents $J_\alpha^\dagger = \bar{u} O_\alpha d$ and $j_\beta = \bar{e} O_\beta \nu$, respectively. The sum runs over all combinations allowed by Lorentz invariance, except for the standard case $\alpha = \beta = (V - A)$, and all currents have been scaled relative to the strength of the ordinary $(V - A)$ interaction. The operators O_α are defined as

$$O_{V\pm A} = \gamma^\mu (1 \pm \gamma_5), \qquad O_{S\pm P} = (1 \pm \gamma_5), \qquad O_{T_\pm} = \frac{i}{2}[\gamma_\mu, \gamma_\nu](1 \pm \gamma_5). \tag{2}$$

The effective Lagrangian (1) represents the most general low-energy four-fermion charged-current interaction. The interpretation of the effective couplings ϵ_β^α depends on the specific particle physics model. Considering only one ϵ_α^β at a time one can now derive constraints on the effective coupling parameters from a $0\nu\beta\beta$ half life measurement or bound,

$$[T_{1/2}^{0\nu\beta\beta}]^{-1} = |\epsilon_\alpha^\beta|^2 G_{0k} |ME|^2, \tag{3}$$

where G_{0k} denotes the corresponding nuclear phase space factors and $|ME|$ the nuclear matrix elements. For ^{76}Ge and ^{136}Xe, the current limits are shown in Table 1.

Short–Range Contributions. Short–range contributions to $0\nu\beta\beta$ decay involve one vertex, point-like at the Fermi scale. The decay rate results from the following general Lorentz invariant Lagrangian [3]

$$\mathcal{L} = \frac{G_F^2}{2m_p} \left(\epsilon_1 J J j + \epsilon_2 J^{\mu\nu} J_{\mu\nu} j + \epsilon_3 J^\mu J_\mu j + \epsilon_4 J^\mu J_{\mu\nu} j^\nu + \epsilon_5 J^\mu J j_\mu \right), \tag{4}$$