Sensitivity Study of Neutrinoless double beta decay of LEGEND experiment

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1. Introduction

Neutrinos are one of the most abundant elementary particles in the Universe. First hypothesized by Pauli in 1929 to explain beta decay, and successfully used by Fermi to formulate a successful Beta decay theory, we still know so little about the neutrinos. M G Mayer formulated a double beta decay theory for nuclei, which could not undergo single beta decay, but two simultaneous beta decays can make them achieve more stable state. Using Majorana's results that neutrino and anti neutrino yield exactly same beta decay results, Furry showed that there is a possibility for neutrinoless double beta decay as well. Experiments are operational and better sensitive experiments are proposed to search this rare decay to prove the nature of neutrinos and determine precise mass scales and hierarchy of neutrino states.

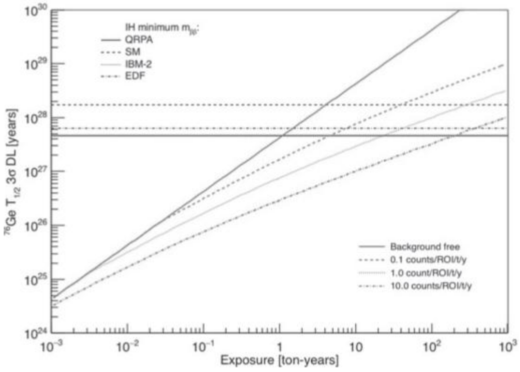

Fig 1: Sensitivity plot of LEGEND for a signal discovery.

We study the sensitivity of the proposed LEGEND experiment about the neutrino mass ordering. This collaboration is the combination of GERDA, Majorana and some other new groups around the globe and Banaras Hindu University is one of them. The LEGEND collaboration aims to increase the sensitivities for ^{76}Ge in the first phase to 10^{27}yr and in the second phase up to 10^{28}yr, both for setting a 90%C.L. half-life limit as well as for "discovery" of $0\nu\beta\beta$ decay defined as a 50% chance for a signal at 3σ significance. Fig. 1 shows the sensitivities of a Ge experiment for discovery as a function of the exposure for different background levels. A signal efficiency of 0.6 is taken into account.

2. Half-life Sensitivity

Neutrinoless double beta decay is a very important theoretical hypothesis. If it is observed, provides an undisputable proof that neutrinos are, in fact, Majorana particle i.e. they have their own anti-particles. Depending on half-lives measured by the experiments, the effective neutrino mass can be obtained. Neutrinoless double beta decay mode is given by,

$$(A, Z) \rightarrow (A, Z+2) + 2e.$$

The decay rate for such reactions is given by,

$$[T_{1/2}^{0\nu}]^{-1} = G^{0\nu} \mid M^{0\nu} \mid^2 \frac{|< m_\nu >|^2}{m_e^2}.$$

The decay rate calculation are not trivial because of the nuclear matrix element ($M^{0\nu}$), and various approximation methods and models like ISM, QRPA, etc are employed to calculate the Nuclear Matrix Element (NME). The phase space factor, $G^{0\nu}$, is calculated [1] to be 2.36×10^{-15} yr^{-1}. Different models predict different NMEs for each element. These calculations, together with effective neutrino mass, $< m_\nu > = 50$ meV, yield range of half-life values for different nuclei as shown in Fig. 2. This range is due to uncertainties in NMEs. The half-life sensitivities of the experiments, though, are restricted by various parameters like background events in the Region of Interest (RoI), detection efficiency, detector energy resolution, etc. The experimental half-life limit can be calculated using Ref [3],

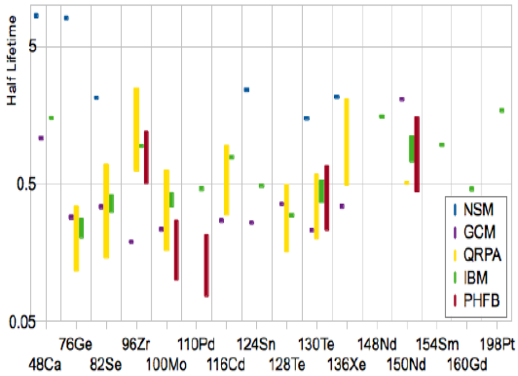

Fig 2: Model dependent half-life of different nuclei [2] shown.

$$T^{0\nu}_{1/2} \geq \frac{4.16\times10^{26}}{n_{\sigma}}\frac{a}{W}\varepsilon\sqrt{\frac{M.t}{b.\Delta E}}.$$

Where M·t is exposure in kg-year, b is background in counts/keV-kg-year, ΔE is the energy resolution of the detector, ε is the efficiency of the detector, W is the atomic mass in gram, *a* is the isotopic abundance and n_σ is the number of standard deviations.

A corresponding limit of neutrino mass, the experiments are sensitive to, is

$$|<m_{\nu}>|^2=[(G)^{0\nu}\,|M^{0\nu}|^2]^{-1}(m_e^2 / T^{0\nu}_{1/2}).$$

3. Results and Discussions

For the projected LEGEND-200 and LEGEND - 1000 experiments, the projected parameters are borrowed from Ref [4]. From recent exposure levels to the proposed exposure of the experiment, the variation in the half-life is obtained.

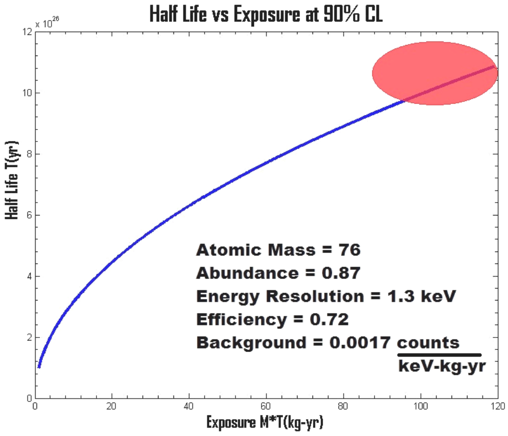

Fig 3: The half-life $T_{1/2}$ (years) vs Exposure, M·t (kr-yr).

If the half-life of decay is within the range of experimental limitation, it may observe the decay. Depending on the obtained half-life, validity of models can be verified. We obtained the expected half-life using QRPA parameters as marked in the region of exposure in the Fig 3. Similarly, including all the models, the predicted half-life is in the range of $5.3 \times 10^{25} – 4.85 \times 10^{26}$ years. If the half-life truly lies in this region, it can be probed by the exposures of about 100 kg-years as can be seen in the graph. The corresponding effective mass value lies around the Inverted hierarchy Spectrum (IS) as projected in Fig 4. Thus, if the neutrino masses are in the Inverted hierarchy, the proposed LEGEND experiment should be able to detect neutrinoless double beta decay events as per the calculations, and settle the questions lingering around neutrinos finally.

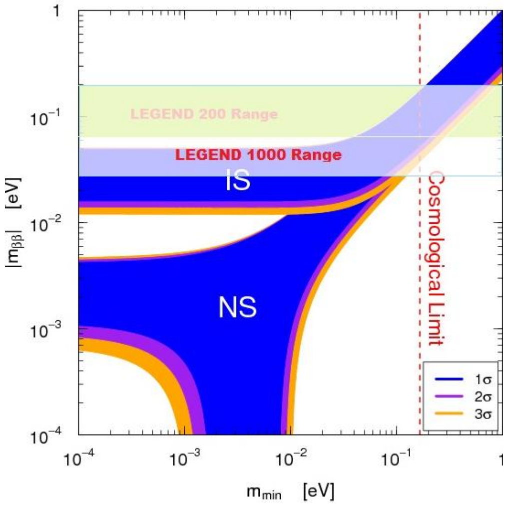

Fig 4: Proposed LEGEND 200 and 1000 experiment's sensitivity for neutrino mass ordering.

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