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Neutrinoless double-beta decay search with LEGEND

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Neutrinoless double-beta decay is a nuclear decay, given as $(A, Z) \longrightarrow (A, Z+2) + 2e^-$, with deep consequences in the understanding of our Universe. A strong experimental program is underway to search for this transition with many proposed experiments using different technologies. In this article the LEGEND experiment, which uses ^{76}Ge as the isotope of interest, will be described. We will discuss both the first stage, LEGEND-200, which is in commissioning at the Laboratori Nazionali del Gran Sasso of INFN in Italy, and the future final step, LEGEND-1000.

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[*] Speaker

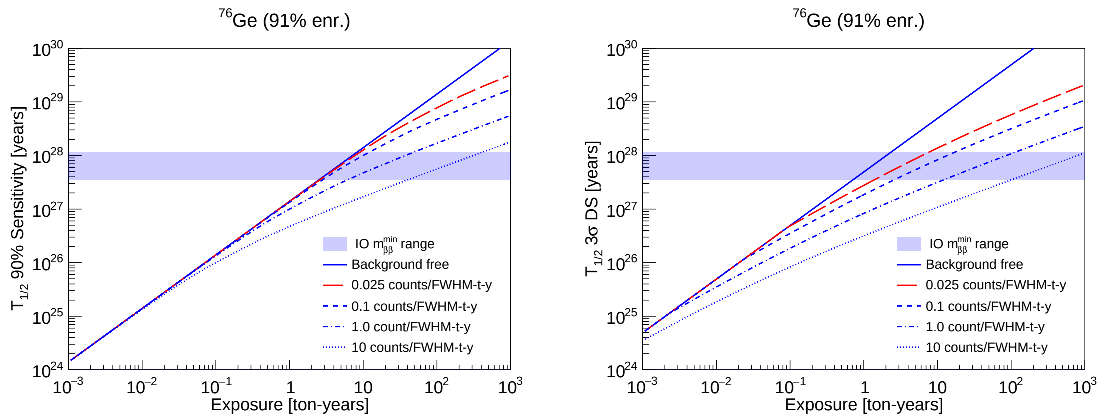

Figure 1: Sensitivity for setting a limit (left) and discovery (right) as a function of the exposure and background. The background rates uses a 2.5 keV FWHM energy resolution around the $Q_{\beta\beta}$ of the reaction. The horizontal band corresponds to the range of half-lives,$T_{1/2}$, necessary to cover the lowest value of $m_{\beta\beta}$ permitted by the inverted order hierarchy. It's clear from these figures, that for a discovery to be made, background reduction is as important as exposure.

1. Introduction

Neutrinoless double-beta ($0\nu\beta\beta$) decay is a process that violates lepton number conservation by two units. Its observation would have other far-reaching consequences. For example, it would prove that neutrinos have a Majorana mass component. An effective Majorana neutrino mass ($m_{\beta\beta}$) can be connected to the decay half-life by using calculations for the nuclear matrix element, assuming the exchange of light Majorana neutrinos. The isotope candidates for such nuclear transition are even-even nuclei in which a single beta decay is energetically forbidden. A particularly promising isotope is ^{76}Ge (with a total energy release of $Q_{\beta\beta}$ = 2039.061± 0.007 keV). Many experiments in the past have used this isotope and in recent years the two experiments GERDA [1] and MAJORANA DEMONSTRATOR [2] obtained competitive half-life limits of 1.8×10^{26} years and 0.8×10^{26} years at 90% C.L., respectively. Building on the successes of and the best technologies developed by GERDA and MAJORANA DEMONSTRATOR, the LEGEND [3] collaboration aims to develop a phased $0\nu\beta\beta$ experimental program. LEGEND-200 is its first phase with the aim of reaching a sensitivity of about 10^{27} yr in terms of both setting a 90% C.L. limit and achieving a 50% chance to make a 3 σ discovery, thanks to a projected background index of 0.6 cts/(FWHM·t·yr) and an exposure of 1 t·yr. The second phase, LEGEND-1000, aims for a sensitivity of beyond 10^{28} yr by operating 1 tonne of enriched germanium detectors for an exposure of more than 10 t·yr at a background index of about 0.025 cts/(FWHM·t·yr). Figure 1 shows the sensitivities for setting limits and for discovery potential for a ^{76}Ge experiment as a function of the exposure for different background indices.

2. The LEGEND-200 phase

The LEGEND-200 [4] phase of the LEGEND project is located at the Laboratori Nazionali del Gran Sasso (LNGS) of INFN in Italy. It reuses the main GERDA infrastructure: cryostat, water tank and clean room. The experiment will use about 200 kg of high-purity germanium (HPGe) detectors made from isotopically enriched material with ^{76}Ge at 86% - 91%. About 70 kg of detectors come from GERDA and MAJORANA DEMONSTRATOR experiments and the remaining detector mass is made of new Inverted Coaxial (IC) detectors [5]. These detectors are deployed naked inside the cryostat, which is filled with liquid argon (LAr). The scintillation light from the argon is collected thanks to a LAr veto made of wavelength shifting fibers that are read out by SiPMs at both ends. The background index of LEGEND-200 will be a factor of 5 lower with respect to the nominal background index of GERDA.This is obtained thanks to materials with improved radiopurity, better front-end electronics, better performances of the LAr veto, and bigger HPGe detectors. The experiment is now in commissioning, the start of the data taking is foreseen for the end of 2022 with about 140 kg of HPGe detectors. During 2023 the detector mass will be increased to 200 kg.

3. The LEGEND-1000 phase

The next phase, LEGEND-1000 [6], will consist of 1000 kg of IC HPGe detectors enriched to more than 90% in ^{76}Ge operated in a liquid argon active shield at an underground laboratory. The baseline design assumes SNOLAB as site, but LNGS is a possible alternative. Its goal is to fully explore the neutrino inverted order hierarchy down to $m_{\beta\beta}$ in the range 9-21 meV, in 10 years of live time, with a sensitivity beyond 10^{28} years. Next year the experiment will start the path towards its approval process in the Critical Design-1 review organized by the DOE.

4. Conclusions

We presented the LEGEND program that will search for $0\nu\beta\beta$ decay with half-lives beyond 10^{28} years in a staged approach. The first stage is LEGEND-200 now in commissioning at LNGS. Its data taking is foreseen for the end of 2022. The final stage, LEGEND-1000, is well under way, with participation in the DOE Critical Design-1 review in the coming year.

References

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