Sensitivity of the LUX-ZEPLIN Experiment to the 0νββ decay of ^{136}Xe

Cláudio Frederico Pascoal da Silva, on behalf of the LUX-ZEPLIN Collaboration
claudio@coimbra.lip.pt, LIP-Coimbra, Universidade de Coimbra

Introduction

Double beta decay (**2νββ**) in ^{136}Xe:

- $^{136}Xe \rightarrow ^{136}Ba + 2e^- + 2\nu$;
- Q-value at ($Q_{\beta\beta}$ = **2457.83** ± 0.37) keV [1];
- $T_{1/2} = 2.165 \pm 0.016^{(stat)} \pm 0.059^{(sys)} \times 10^{21}$ years [2];
- Isotopic abundance of ^{136}Xe in natural xenon: **8.86 %.**

Neutrinoless double beta decay **0νββ**:

- Neutrino is its own anti-particle (**Majorana** particle);
- Lepton number violation (**Δ**L = 2), and B–L violation;
- Observation of a mono-energetic peak at the 2νββ Q-value;
- Sensitivity*:

$$T^{0\nu}_{1/2} \propto \varepsilon a \sqrt{\frac{mt}{B\Delta E}}$$

Efficiency, Isotopic Abundance, Mass, Livetime, Background Rate, Energy Resolution

* *for a flat background, we'll use a 3D PLR.*

The LUX-ZEPLIN (LZ) Detector

LZ is a 7-tonne two-phase (liquid/gas) xenon time projection chamber primarily designed to look for dark matter interactions [3]. It occupies the Davis Campus at the 4850 foot level (4300 m.w.e.) of the Sanford Underground Research Facility (SURF) [4].

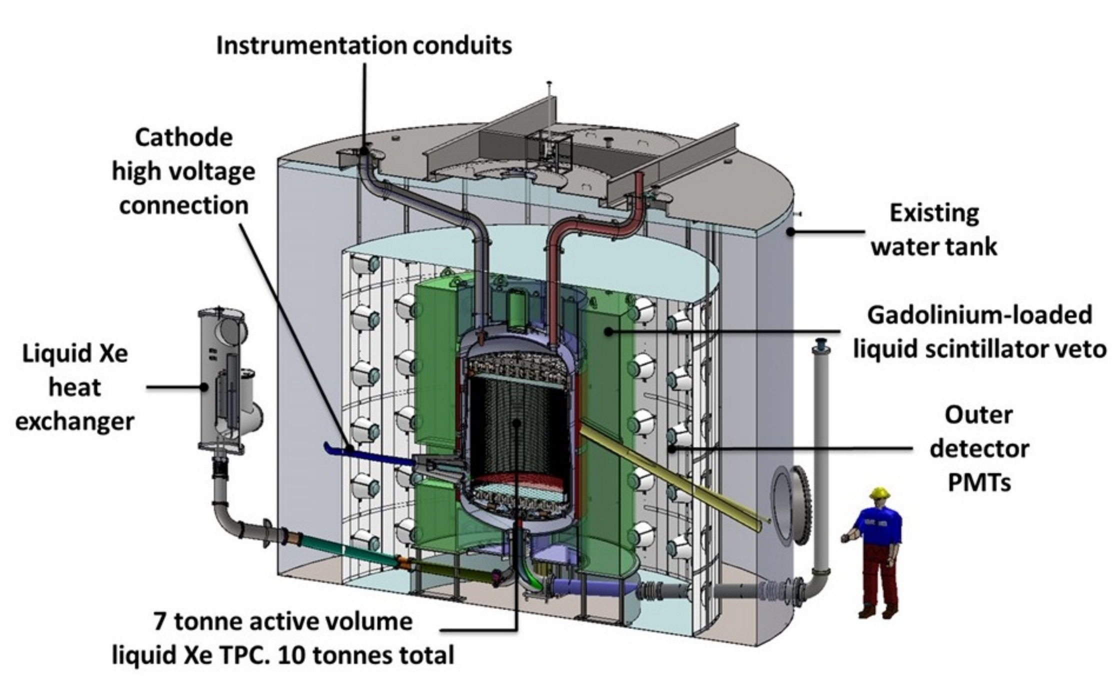


Figure 1: The TPC sits inside a cryostat made from ultra-pure titanium [5]. It is surrounded by i) an active xenon skin located between the TPC and the inner cryostat vessel; ii) an outer detector system consisting of a Gd-doped liquid scintillator in acrylic vessels [6]; iii) both are located within a large water tank. The outer detector is viewed by PMTs to tag energy deposits in the scintillator as well as muons passing through the water tank.

Data Analysis

Assumptions about the detector performance and selection criteria:

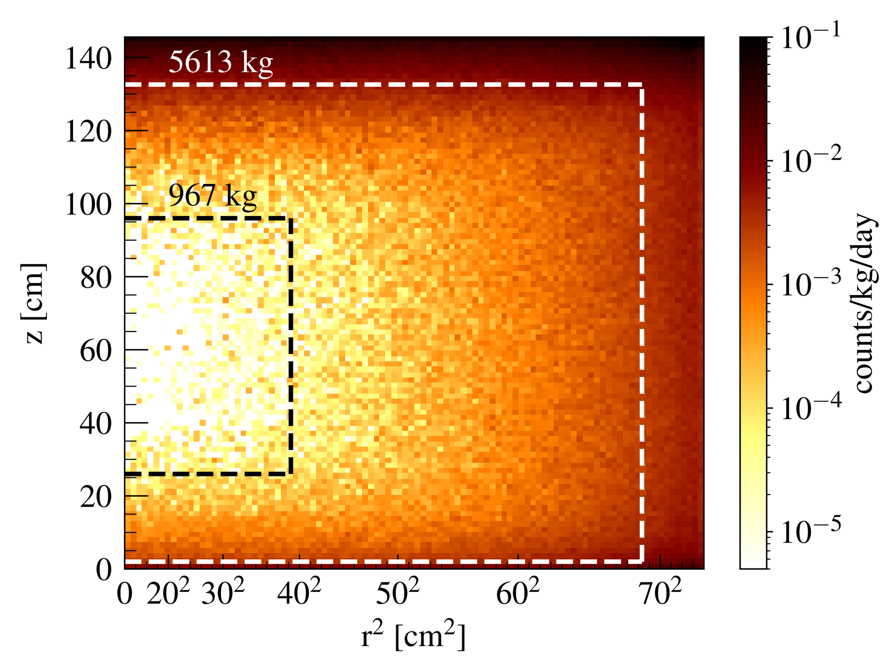
- Livetime for the projections: **1,000 days**;
- Energy resolution (σ) at $Q_{\beta\beta}$: **1%** (24.6 keV) [7];
- Single scatter: minimal vertical vertex separation needed to identify multiple scatter events of **3 mm** [8];
- Any event depositing more than 100 keV within a 1 μs window in the skin and/or outer detector is vetoed;
- Fiducial volume: r<68.8 cm (4 cm from the walls), and 2<z<132.6 cm (2 cm above the cathode and 13 cm below the gate) → 5.6 tonnes of xenon (**497 kg of ^{136}Xe**).

Backgrounds

Extensive Monte Carlo simulations of the backgrounds due to radioactive contamination in detector components and the cavern rock are generated using BACCARAT, a framework based on GEANT4 [9]. The model used in this analysis was constructed using the most recent material assays [10] and detector simulations.

	^{238}U Counts	^{232}Th Counts	Total Counts
Detector components	21.0	2.3	23.3
Rock Cavern Walls	3.2	8.4	11.6
Internal Radon			0.45
Neutron Induced ^{137}Xe			0.28
^{136}Xe 2νββ			<0.01
Solar neutrinos (^{8}B)			0.03
Total	24.2	10.7	35.6

Table: Estimated background counts for a livetime of 1,000 days in the ± 1σ ROI and inner 967 kg mass (see fig 2) where LZ is most sensitive.



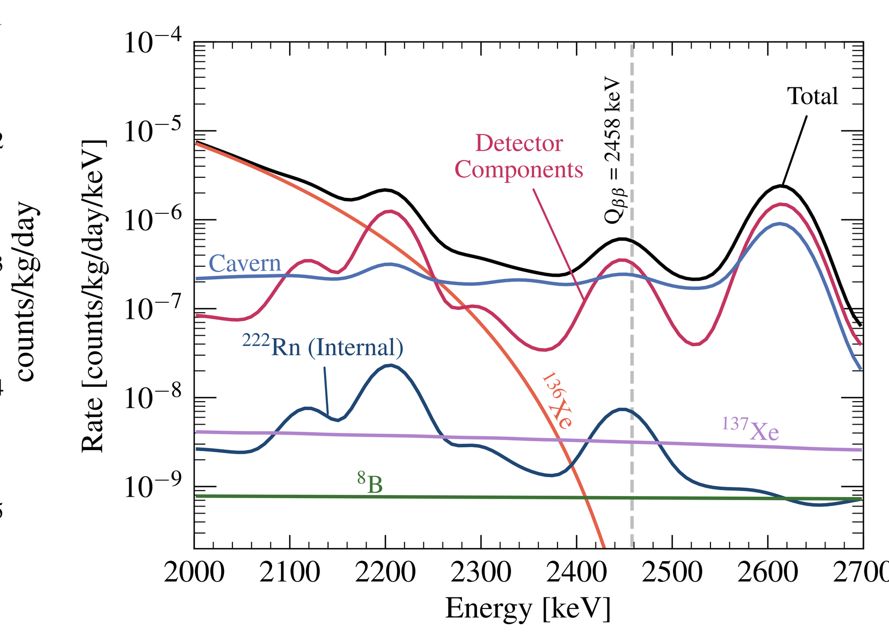


Figure 2 (left): Background event rate in the ± 1σ energy ROI as a function of r^2 and z. The dashed black rectangle represents the inner 967 kg volume, while the larger dashed white rectangle represents the extended fiducial volume used on the profile likelihood analysis. **Figure 3 (right):** Background energy spectrum in the inner 967 kg volume.

0νββ Sensitivity Projection

The upper limit on $T_{1/2}$ is calculated using the profile likelihood ratio (PLR) method, utilising the asymptotic one-sided profile likelihood test statistic. For this, the signal and background models are combined in a unbinned likelihood function:

$$L(\mu_s, \{\mu_b\}) = \left[\mu_s P_s(E) + \sum_{i=1}^{n_b} \mu_b^i P_b^i(E, r^2, z)\right] \prod_{j=1}^{n_b} g(a_b^j, \sigma_b^j)$$

Number of signal events; Number of background events for the i-th source; Gaussian constrain term; Expected background rates and respective uncertainties

The sensitivity is defined as the median 90% confidence level (CL) upper limit on the number of signal events that would be obtained from a repeated set of background-only experiments.

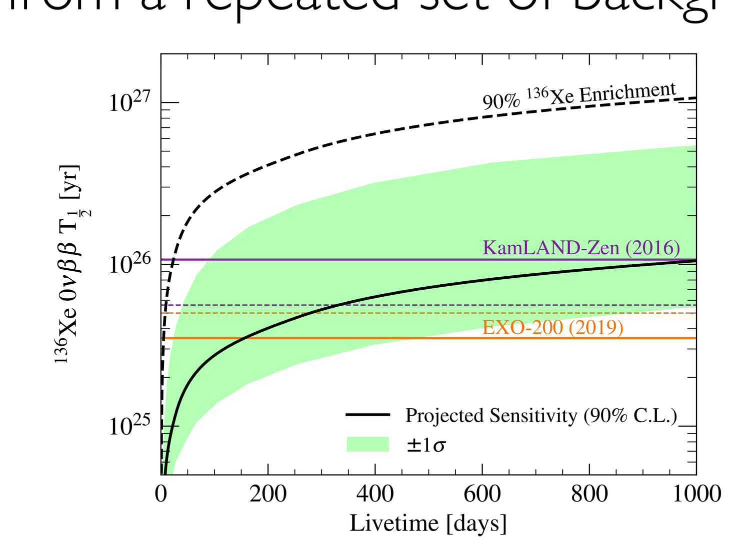


Figure 4: Projected 0νββ sensitivity as a function of detector livetime and.

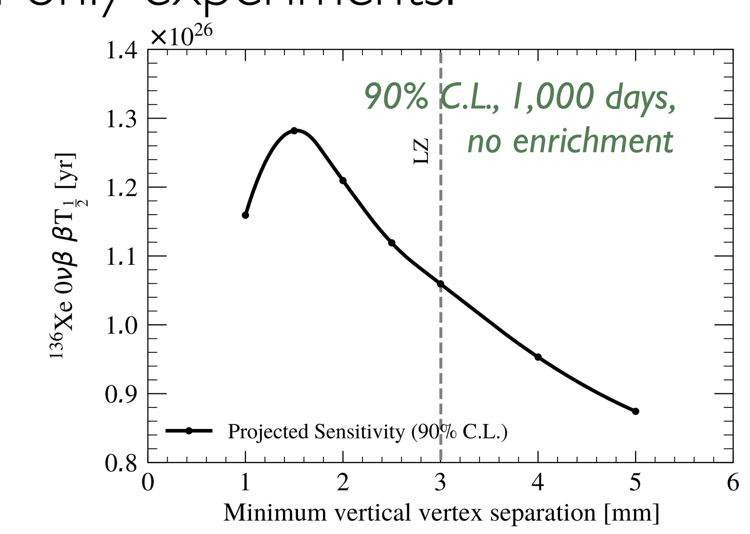


Figure 5: Sensitivity for various assumed minimum separable vertex distances in depth.

For the expected LZ WIMP-search run:

^{136}Xe 0νββ $T_{1/2}$ < 1.06 ×10^{26} years *(90% C.L., 1,000 days, no enrichment)*

A dedicated post WIMP search run with with ^{136}Xe enriched xenon:

^{136}Xe 0νββ $T_{1/2}$ < 1.06 ×10^{27} years *(90% C.L., 1,000 days, 90% ^{136}Xe enrichment)*

Full details in https://arxiv.org/abs/1912.04248 *(Accepted in PRC)*

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