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LArGe
R&D for active background suppression in Gerda

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Abstract. LArGe is a Gerda low-background test facility to study novel background suppression methods in a low-background environment, for future application in the Gerda experiment. Similar to Gerda, LArGe operates bare germanium detectors submersed into liquid argon (1 m^3, 1.4 tons), which in addition is instrumented with photomultipliers to detect argon scintillation light. The light is used in anti-coincidence with the germanium detectors to effectively suppress background events that deposit energy in the liquid argon. The background suppression efficiency was studied in combination with a pulse shape discrimination (PSD) technique using a BEGe detector for various sources, which represent characteristic backgrounds to Gerda. Suppression factors of a few times 10^3 have been achieved. First background data of LArGe with a coaxial HPGe detector (without PSD) yield a background index of the order 10^{-2} cts/(keV·kg·y), which is at the level of the Gerda phase I design goal. As a consequence of these results, the development of an active liquid argon veto in Gerda is pursued.

1. Introduction

Gerda is an experiment to search for the neutrinoless double beta ($0\nu\beta\beta$) decay in ^{76}Ge. It has been proposed in 2004 [1], and has recently started data taking at the Laboratori Nazionali del Gran Sasso (Lngs), Italy. Gerda operates high-purity germanium (HPGe) detectors enriched to 86% in ^{76}Ge, which are submersed naked into liquid argon (LAr). The LAr both acts as a high purity shielding against background from gamma radiation, and as a cooling medium for the HPGe detectors. The Ge-crystals are simultaneously used as a source and as a detector for the $0\nu\beta\beta$-decay. The expected signal is caused by the full absorption of the two emitted electrons in the detector, causing a faint peak at $Q_{\beta\beta} = 2039\,\text{keV}$ corresponding to a half life of $> 10^{25}$ years. In order to detect this peak, the region of interest (Roi) must be kept quasi background free, which poses the key challenge to Gerda.

LArGe is the LAr Germanium test facility of Gerda, which was constructed to study novel active background suppression methods in a low-level environment [2]. Similar to Gerda, LArGe operates bare Ge-detectors in 1 m^3 (1.4 tons) of liquid argon, which in addition is instrumented with photomultiplier tubes (PMT). Liquid argon scintillates upon the interaction with ionizing radiation, and produces ∼40,000 XUV photons per MeV deposited energy. Typical background events have excess energy, which is deposited outside the Ge-detectors in the surrounding argon. In contrast, $\beta\beta$-events are single site events confined to the Ge-diode, so that no scintillation light is triggered. Therefore, by detecting scintillation in anti-coincidence to Ge-signals one can actively suppress these background events (LAr veto) [3].

LArGe combines this approach with a pulse shape discrimination (PSD) technique using a BEGe detector: The objective of PSD is to distinguish the *single site events* (SSE) of the $\beta\beta$-decay from *multi site events* (MSE) of common gamma-background with multiple interaction vertices within the Ge-diode. It has been demonstrated that by using the signal-time-structure of a Broad-Energy Ge-detector (BEGe), one can efficiently discriminate SSE from MSE, and thus efficiently suppress background [4]. In LArGe such a BEGe detector was used to study the combined suppression efficiency of LAr veto and PSD.

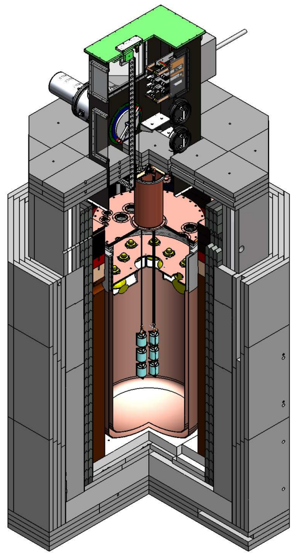

Figure 1. Cutaway view of the LArGe setup. The cryogenic infrastructure, a slow control system, and the DAQ are located adjacent to this setup. For reference: the cryostat (copper color) has an inner diameter of 90 cm and a total height of ∼2 m. Further description is provided in the text.

2. Setup description

Like Gerda, LArGe is located at the Lngs underground lab at 3800 m w.e. The core of the experiment is a vacuum-insulated copper cryostat filled with 1000 l ultra-pure LAr, which is actively cooled by liquid nitrogen (figure 1). The inner wall of the cryostat is lined with VM2000 mirror foil to guide the scintillation light towards nine 8" ETL 9357 PMTs located at the top. Both, mirror foil and the photocathodes, are covered with a 1-4 μm thin layer of wavelengthshifter (TPB in polystyrene), to convert the 128 nm scintillation photons into the sensitive range of the PMTs around 420 nm. Up to nine Ge-detectors on three strings can be inserted into the cryostat through a lock system on top of the assembly. The cryostat is encased by a graded shield of increasing radiopurity: poly-ethylene, steel, lead, and copper.

3. Background suppression measurements with various sources

3.1. Characteristic suppression of LAr veto and PSD

The background suppression efficiency was studied for different gamma sources (^{137}Cs, ^{60}Co, ^{226}Ra, ^{228}Th) in different locations (close-by the BEGe or external to the cryostat), which represent characteristic background sources to Gerda. As an example we use the spectrum of internal ^{228}Th (figure 2) 7 cm from the detector: the region around $Q_{\beta\beta}$ (2039 keV) and above is dominated by the Compton spectrum of the 2615 keV gamma line from ^{208}Tl. At lower energies other lines become important. Figure 3 illustrates the fundamental differences of the suppression mechanisms of LAr veto and PSD: the double escape peak (DEP) at 1593 keV is predominantly SSE and as such not rejected by PSD. Conversely, the annihilation gammas that leave the diode have a high probability of beeing absorbed in LAr. Hence, by applying the LAr veto the DEP vanishes (note the color code in the figures). The neighboring peak at 1621 keV is a full energy peak (FEP) from ^{212}Bi. Beeing emitted as a *single* gamma, this line is not vetoed by scintillation. Other gammas are emitted in *cascades* (e.g. 583 keV and 2615 keV) and

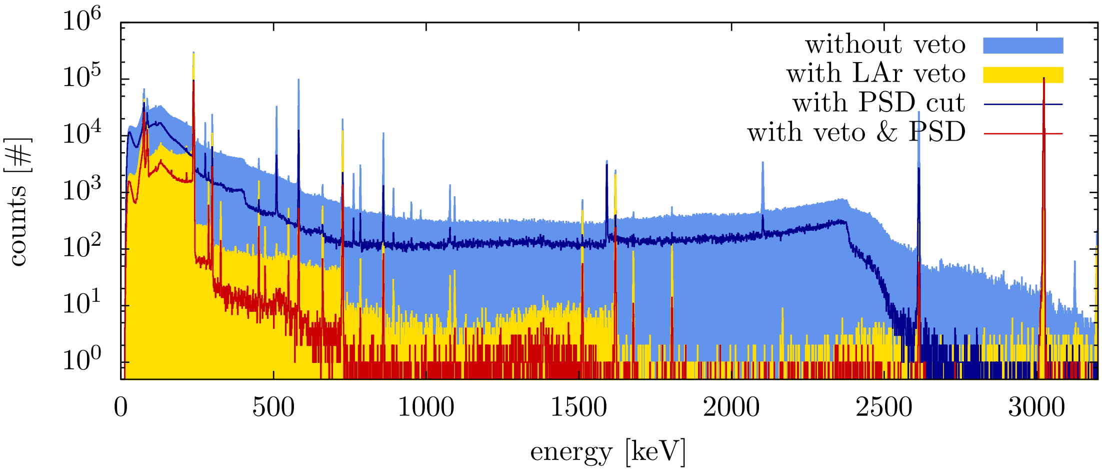

Figure 2. The internal ^{228}Th spectrum. *Single* and *coincident* gamma lines can be distinguished by the different suppression efficiency of the LAr veto. A pulser is set at 3 MeV.

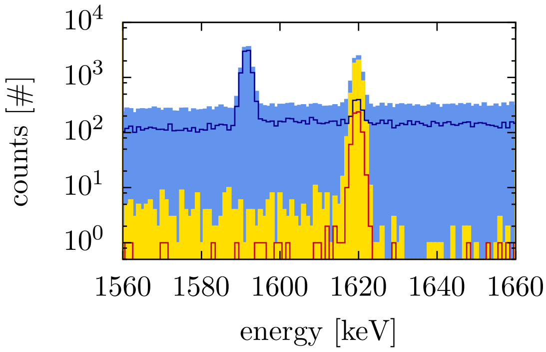

Figure 3. The double escape peak of ^{208}Tl at 1593 keV, and the 1621 keV full energy peak of ^{212}Bi.

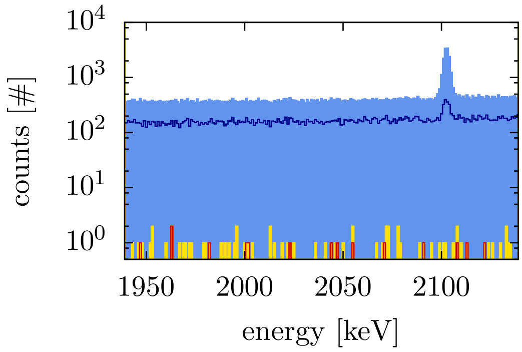

Figure 4. Close-up of the region of interest around $Q_{\beta\beta}$ (2039 keV) for the internal ^{228}Th source.

are therefore vetoed depending on their origin in the setup, whereas PSD is mostly position independend. In general, the particular response of the different suppression methods is a useful tool to understand the origin of different backgrounds on the basis of low counting statistics.

3.2. Background suppression at $Q_{\beta\beta}$

The best background suppression in the region of interest (RoI) around $Q_{\beta\beta}$ (2039 keV) has been achieved for internal ^{228}Th (figure 4): the background is reduced by more than three orders of magnitude. A summary of the measured suppression factors for all sources is given in table 1. Generally external sources are suppressed less by the LAr veto than inner sources, whereas PSD is largely position independent. In addition, the suppression factor depends on whether single or coinident gammas are emitted, and on their excess energy. On average the combined suppression of the LAr veto and PSD is enhanced by a factor (1.8 ± 0.2), compared to the product of the individual suppression factors. This is very beneficial for its application in Gerda.

Table 1. Summary table of suppression factors for different sources in the Roi of $Q_{\beta\beta}$.

source	position	suppression factor LAr veto	suppression factor PSD	suppression factor total
^{60}Co	int	27 ± 1.7	76 ± 8.7	3900 ± 1300
^{226}Ra	ext	3.2 ± 0.2	4.4 ± 0.4	18 ± 3
	int	4.6 ± 0.2	4.1 ± 0.2	45 ± 5
^{228}Th	ext	25 ± 1.2	2.8 ± 0.1	129 ± 15
	int	1180 ± 250	2.4 ± 0.1	5200 ± 1300

4. Background measurement

A background measurement with an exposure of 116 kg·d was carried out with the low-background HPGe-coaxial GTF44 detector (figure 5). Yet, no PSD was available for this detector type, and the LArGe passive shield is incomplete. Nonetheless, the background index achieved by applying the LAr veto is $0.12 - 4.6 \cdot 10^{-2}$ cts/(keV·kg·y) (90% c.l.), which is at the level of the Gerda phase I design goal. An analysis of the residual vetoed spectrum indicates the observation of the $2\nu\beta\beta$-signal . This would be the first measurement of $2\nu\beta\beta$ in a non-enriched germanium detector.

5. Conclusion

The LArGe test facility has demonstrated the great potential of an active liquid argon veto for the suppression of residual background signals which deposit part of their energy in LAr. The combined suppression of LAr veto and PSD is mutually enhanced. Another application for the LAr veto is background diagnostics. As a consequence of these results, the development of an active liquid argon veto in Gerda is pursued.

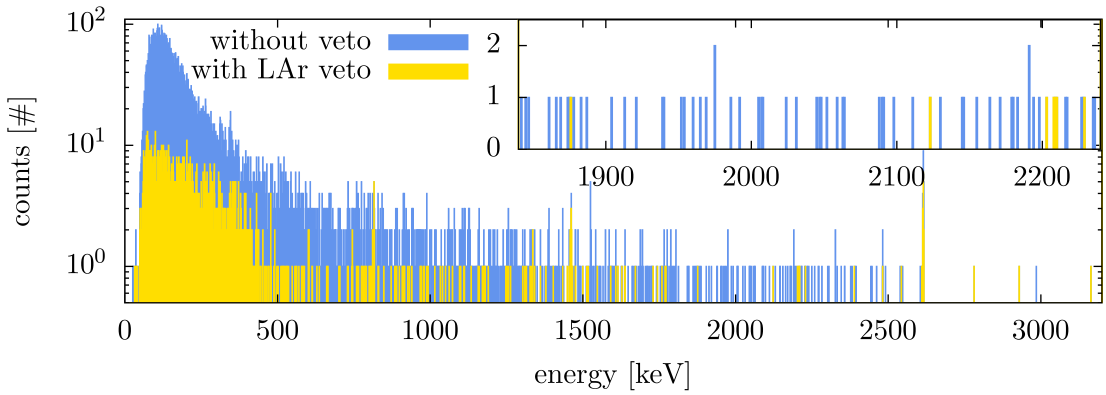

Figure 5. GTF44 background spectrum with a close-up of the region of interest around $Q_{\beta\beta}$.

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