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Active background suppression with the liquid argon scintillation veto of GERDA Phase II

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Abstract. The observation of neutrinoless double beta decay would allow to shed light onto the particle nature of neutrinos. GERDA is aiming to perform a background-free search for this process using high purity germanium detectors enriched in ^{76}Ge operated in liquid argon. This goal relies on the application of active background suppression techniques. A low background light instrumentation has been installed for Phase II to detect events with coincident energy deposition in the nearby liquid argon. The intended background index of $\sim 10^{-3}$ cts/(keV·ky·yr) has been confirmed.

1. Introduction

GERDA (GERmanium Detector Array) is operating isotopically enriched high purity germanium detectors bare in liquid argon (LAr) to search for the neutrinoless double beta ($0\nu\beta\beta$) decay of ^{76}Ge [1, 2]. The experiment is located at the Laboratori Nazionali del Gran Sasso (LNGS) of INFN in Italy. The mass of enriched detectors in Phase II is 35.6 kg, composed of 7 refurbished coaxial detectors from the former Heidelberg-Moscow [3] and IGEX [4] experiments and 30 custom made broad energy germanium (BEGe) detectors [5]. The detectors are deployed in a cryostat filled with 64 m^3 of LAr acting as coolant and shielding. A signal from $0\nu\beta\beta$ decay would manifest in a monoenergetic peak in the summed electron spectrum at 2039 keV ($Q_{\beta\beta}$). An observation of this process would imply violation of lepton number conservation and could reveal the particle nature of neutrinos being possibly of Majorana type. The sensitivity of this search strongly depends on the number of expected background events in the signal region.

2. Active background suppression in Gerda Phase II

Although having already a low initial background rate due to elaborate material selection and passive shielding, the crucial step towards a background-free search for $0\nu\beta\beta$ in GERDA is achieved by the application of active suppression techniques. The ability to separate signal from background events relies on their distinct topology. The intrinsic decay of ^{76}Ge occurring in the bulk of one germanium diode will lead to a localised energy deposition in this one germanium detector. Events that deposit part of their energy in a detector, but also show a coincident signal in other detectors are removed by an anti-coincidence (AC) cut. It has been shown in [6, 7] that the scintillation properties of LAr can be used to actively suppress background events in germanium detectors operated in LAr. A low background light instrumentation consisting of photomultiplier tubes (PMTs) and wavelength shifting fibers read-out with silicon photomultipliers (SiPMs) [8, 9] has been installed in GERDA, thereby adding the LAr surroundings as active detector volume. Furthermore the germanium detectors - and especially the newer BEGe type detectors - allow to separate events according to their event topology inside a single detector by pulse shape discrimination (PSD) [10].

3. Results from Phase II data taking

Physics data taking with the full Phase II array started in December 2015. The performance for background reduction was studied during integration test runs with a single detector string in May/June 2015. The background event rejection obtained for ^{228}Th and ^{226}Ra calibration sources is summarised in Table 1. The enhanced suppression for ^{228}Th originates from the high probability of observing coincident γs in its decay chain.

Table 1. Suppression obtained in integration tests with different sources. The suppression factor (SF) describes the reduction of events ±100 keV around $Q_{\beta\beta}$ excluding full energy γ lines. The reduced acceptance of the LAr veto cut due to random coincidences is accounted.

	SF of LAr veto	survival prob. PSD	SF of LAr veto + PSD
^{228}Th	85 ± 3	$(45.7 \pm 0.2)\,\%$	300 ± 21
^{226}Ra	5.1 ± 0.2	$(33.6 \pm 0.7)\,\%$	27 ± 2

Figure 1 shows the spectra obtained with BEGe detectors during the first five months of physics data taking released in June 2016. All events ±25 keV around $Q_{\beta\beta}$ did not enter the analysis chain before fixing all cuts in the GERDA blinding approach. The background indices (BI) describing the rate of background events around $Q_{\beta\beta}$ for different levels of the applied cuts are shown in Table 2. All LAr channels are working and have been included in the LAr veto cut. The dead time introduced by the LAr cut originates mainly from random coincidences due to ^{39}Ar decays in the argon and has been determined to be $< 3\%$. This is taken into account in the final GERDA analysis.

4. Conclusions

The Phase II design BI of $\mathcal{O}(10^{-3})$ cts/(keV·kg·yr) could be reached thanks to the selection of low-background components close to the detectors and novel active background suppression methods, i.e. LAr scintillation light detection combined with PSD. This will allow a steep

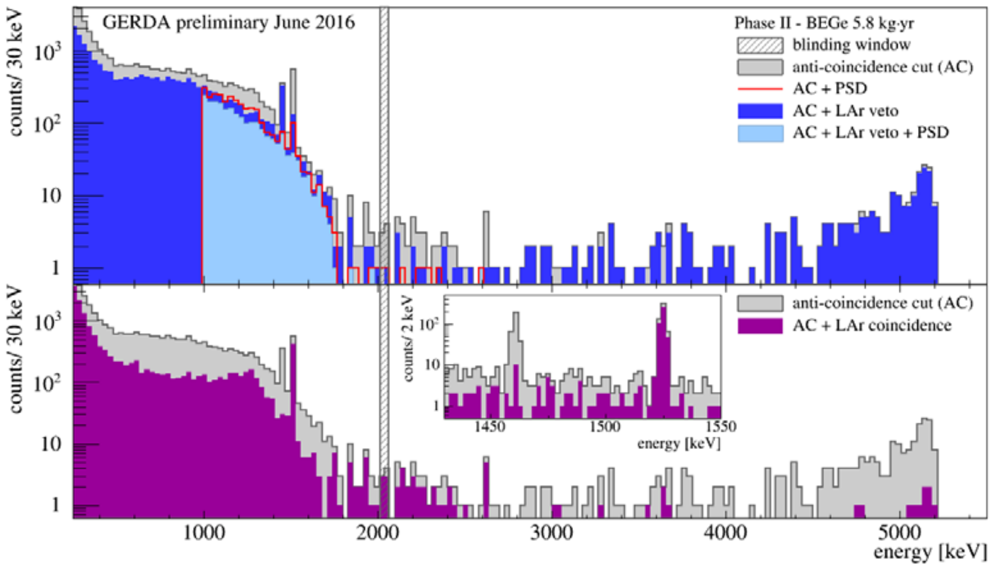

Figure 1. Phase II enriched BEGe spectrum with an exposure of 5.8 kg·yr. The different levels of the applied background reduction cuts are depicted by the differently coloured spectra. The blinding window of ±25 keV around $Q_{\beta\beta}$ is indicated. No event in this region survives the cuts. In the lower pad the spectrum obtained in coincidence with the LAr read-out is shown. The inset shows the two dominant lines of ^{42}K (1525 keV) and ^{40}K (1461 keV). Since the ^{42}K line originates from β decay in the LAr it is mainly seen in coincidence. No coincidences are expected for events in the ^{40}K line due to its electron capture origin. It can be used to determine the acceptance of the LAr veto cut.

Table 2. Background indices of the two Phase II datasets (enriched Coax 5.0 kg·yr, enriched BEGe 5.8 kg·yr) before and after application of background cuts. The background index is determined in a window from 1930 to 2190 keV excluding potential full energy peaks.

	BI $\left[10^{-3} \cdot \frac{\text{cts}}{\text{keV}\cdot\text{kg}\cdot\text{yr}}\right]$	...after LAr veto	...after PSD	...after LAr veto + PSD
enr. Coax	$16.5^{+4.2}_{-3.5}$	$10.4^{+3.5}_{-2.7}$	$6.9^{+2.8}_{-2.2}$	$3.5^{+2.1}_{-1.5}$
enr. BEGe	$15.7^{+3.8}_{-3.1}$	$4.5^{+2.2}_{-1.6}$	$3.7^{+1.9}_{-1.5}$	$0.7^{+1.1}_{-0.5}$

increase in sensitivity over the life-time of GERDA Phase II. Furthermore the instrumentation of the LAr allows for a closer investigation of potential background sources. The ability to register coincident scintillation light signals makes additional information available event by event.

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