LArGe: Background suppression using liquid argon (LAr) scintillation for $0\nu\beta\beta$ decay search with enriched germanium (Ge) detectors

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Measurements with a bare p-type high purity germanium diode (HPGe) submerged in a 19 kg liquid argon (LAr) scintillation detector at MPIK-Heidelberg are reported. The liquid argon–germanium system (LArGe) is operated as a 4π anti-Compton spectrometer to suppress backgrounds in the HPGe. This R&D is carried out in the framework of the GERDA experiment which searches for $0\nu\beta\beta$ decays with HPGe detectors enriched in ^{76}Ge. The goal of this work is to develop a novel method to discriminate backgrounds in $0\nu\beta\beta$ search which would ultimately allow to investigate the effective neutrino mass free of background events down to the the inverse mass hierarchy scale. Other applications in low-background counting are expected.

1. Introduction

The goal of the Germanium Detector Array (GERDA) [1] is to search for neutrinoless double beta decays of ^{76}Ge. Bare germanium detectors (HPGe), isotopic enriched in germanium ^{76}Ge, will be operated in liquid argon. The cryogenic fluid serves simultaneously as a cooling medium and as a shield against external radiation. R&D is carried out to use the scintillation light of liquid argon to tag and discriminate backgrounds. The concept and the proof of principle were first reported in [2]. The signature for $0\nu\beta\beta$ decay of ^{76}Ge is a point-like energy deposition with $Q_{\beta\beta} = 2.039$ MeV inside a HPGe diode. Background events come mainly from radioactive decays and muon induced interactions. These events deposit typically only a part of their energy inside a HPGe crystal while the residual energy is dissipated in the adjacent shielding material. Detecting the scintillation light of liquid argon would allow to discriminate these events. The work presented here is an R&D project within the framework of the GERDA experiment.

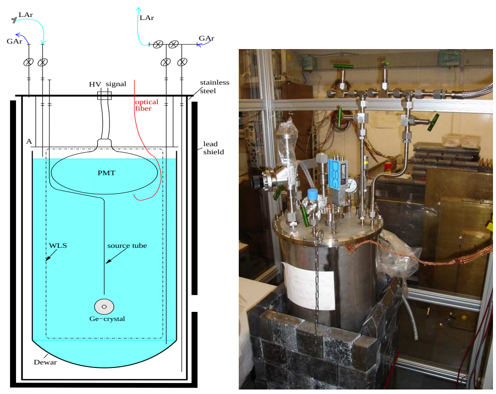

Figure 1. Schematic drawing and photo of the LArGe-MPIK setup.

2. Experimental setup

The experimental setup used for the measurements is displayed in Fig. 1. A bare HPGe crystal (5.1 cm diameter, 3.5 cm height, 0.39 kg) is submerged in a dewar (29 cm diameter, 90 cm height) filled with LAr. A wavelength shifting and reflecting foil defines the active volume of 19 kg liquid argon. The shifted scintillation photons are detected with one 8" ETL 9357 PMT immersed in liquid argon. The dewar system is enclosed in a gas tight stainless steel tank to prevent quenching from oxygen or water traces. Low activity calibration sources can be inserted up to 8 mm from the HPGe crystal via a hermetically closed stainless steel tube. The DAQ is triggered by the HPGe diode. The HPGe and PMT signals are then recorded event-by-event and stored for the off-line analysis on disk. HPGe signals are discarded in the analysis if a simultaneous scintillation signal has been recorded. An analysis threshold at the single photo electron level was applied. A photo electron (pe) yield of about 410 pe/MeV was observed during these measurements. The experimental setup is located in the underground laboratory of the MPIK Heidelberg.

3. Measurements

The measurement were performed from October to December 2005 using various gamma sources (^{137}Cs, ^{60}Co, ^{232}Th, ^{226}Ra), alternated with periods of background measurements. Given the limited space available in this proceedings, we present only the results achieved with the ^{232}Th gamma source. The source consists of a natural thorium metal wire thus containing ^{228}Th and its progeny ^{208}Tl. The measured energy spectrum is displayed in Fig. 2. The line histograms correspond to spectra without background subtraction and the filled histograms after background subtraction. The bottom plot shows a zoom in the region of interest for $0\nu\beta\beta$.

The survival probability P_s is defined as the number of counts in a given energy region after applying the liquid argon anti-coincidence cut divided by the number of counts in the same region in the non-vetoed spectrum. The background spectra have been measured separately and subtracted prior to forming the ratio. For single gamma decays as for example for the 662 keV ^{137}Cs line, the full energy (FE) peak is not suppressed after applying the liquid argon anti-coincidence cut, since no energy deposition occurs in the liquid argon. The measured value for ^{137}Cs is $P_s = 1.00 \pm 0.01$.

An important background source for $0\nu\beta\beta$ is the photons emitted in the decay of ^{208}Tl, a progeny of ^{232}Th. As the ^{208}Tl 2615 keV gammas are typically emitted together with one or more photons, the FE peak is suppressed in case that a second photon deposits energy inside the liquid argon. The measured value for the 2615 keV line is $P_s = 0.22 \pm 0.01$. ^{208}Tl Compton events which deposit an energy close to $Q_{\beta\beta} = 2039$ keV inside the crystal are vetoed with a survival probability of $P_s = 0.058 \pm 0.004$, or in other words, the Compton continuum is suppressed by a factor 17.

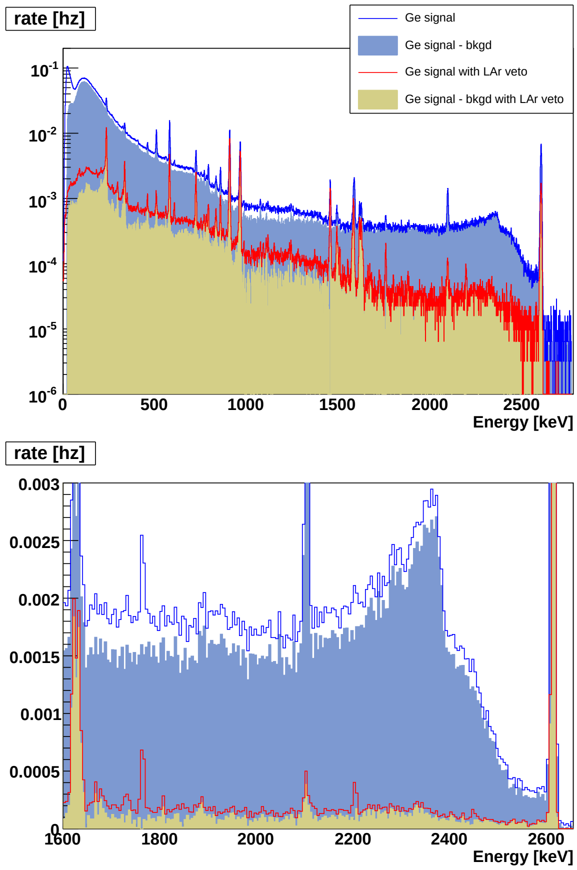

Figure 2. Measured ^{232}Th energy spectrum with (red) and without (blue) LAr anti-coincidence.

4. Simulations

The experimental data are compared with Monte-Carlo simulations using the MaGe Geant4 framework [4] developed jointly by the Majorana and Gerda collaborations. The spectral shape and peak-to-Compton ratio measured with ^{137}Cs, ^{232}Th and ^{226}Ra are well reproduced within typically 5% or better. Fig. 3 shows the simulated ^{232}Th spectrum. The background spectrum (gray) measured without source is added to the MC spectrum describing the source. Note that the ^{232}Th source is not in secular equilibrium, thus the poor agreement at low energies. The survival probability after applying the LAr veto cut at 2039 keV obtained with MaGe MC simulation corresponds to $P_s = 0.025 \pm 0.001$. A possible origin of the lower MC value may be related to the simplified geometrical description of the crystal holder which had small LAr dead volumes not included in the simulation.

5. Conclusion and outlook

The experimental data show that the detection of LAr scintillation photons is a powerful method to suppress backgrounds with negligible loss of $0\nu\beta\beta$ signals. In the setup with an active liquid argon mass of 19 kg we observed a background suppression of the ^{208}Tl Compton continuum at 2039 keV by a factor of 17. The suppression factor is limited by gammas escaping from the small LAr volume. MaGe MC simulations reproduce the energy spectra as well as the suppression factors. An ultra-low background prototype setup is presently under construction at Lngs (Gerda-LArGe). The purpose of the device is to study the novel suppression method at ultra-low backgrounds with an active liquid argon mass of approximately 1 ton. The instrument will be used to study the background of Gerda phase I detector assemblies prior to their operation in Gerda. Applications of the method as an anti-Compton spectrometer for trace analysis is envisioned.

REFERENCES

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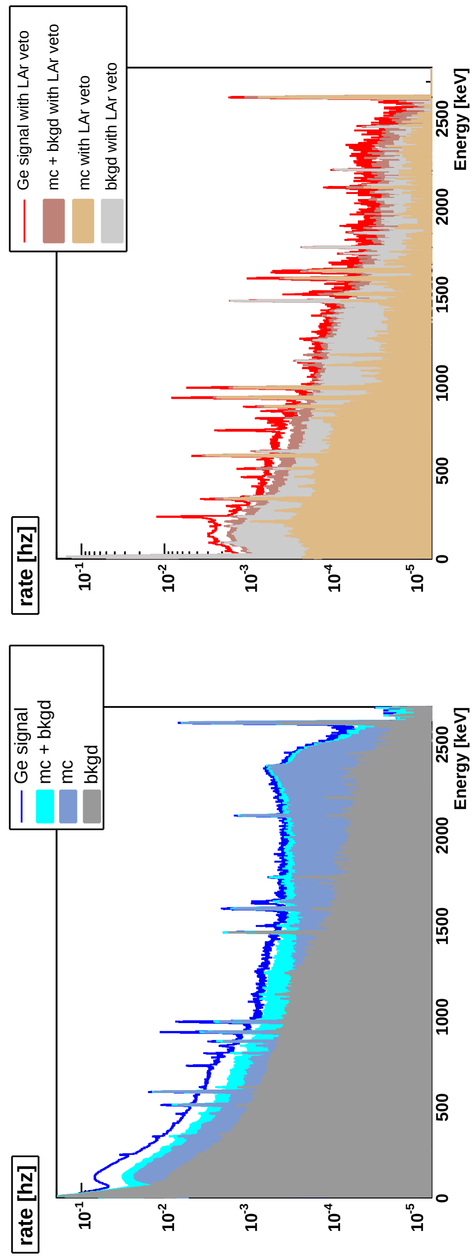

Figure 3. Real data compared to MaGe results: before (left) and after (right) background suppression. The source was not in secular equilibrium thus the poor agreement of MC with data at low energies.