3 GERDA: Neutrinoless Double Beta Decay in Ge

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(GERDA Collaboration)

When neutrinos propagate over macroscopic distances they can change their flavor eigenstate (so lepton flavor is not conserved), which means that neutrinos have mass. However, some important neutrino properties still remain unknown, such as the absolute mass scale, the full neutrino mixing matrix (including CP-violating phases) and their nature (Dirac versus Majorana). The Majorana nature of neutrinos can be revealed in experiments searching for neutrinoless double beta decay ($0\nu\beta\beta$), in which an atomic nucleus decays by emitting two electrons sharing the Q-value of the process. If the neutrino is a Majorana particle, this transition is allowed in all isotopes that undergo the allowed standard double beta decay ($2\nu\beta\beta$).

GERDA is an experiment searching for the $0\nu\beta\beta$ decay in ^{76}Ge ($Q = 2039.006 \pm 0.050$ keV). The material is enriched in ^{76}Ge, and provides simultaneously the source and detector with an energy resolution of 0.1-0.2 % FWHM at 2 MeV. A novel shielding concept features bare germanium diodes operated in a 65 m^3 cryostat filled with liquid argon and surrounded by a 3 m thick water Cerenkov shield which moderates and captures external and muon-induced neutrons. The argon is used for cooling the diodes and as a passive shield against the residual environmental background [2].

The experiment proceeds in two phases. Phase I uses eleven HPGe detectors, eight enriched in ^{76}Ge and three detectors made of $^{\mathrm{nat}}$Ge, with the total masses of 17.7 kg and 7.6 kg, respectively. The goal at this stage is to improve the current sensitivity levels and scrutinize the results of the Heidelberg-Moscow experiment [1]. Data taking took place between November 2011 and June 2013 at a background level of 10^{-2} counts·keV^{-1}·kg^{-1}·yr^{-1} [3]. A total exposure of 21.6 kg·yr resulted in an experimental limit on the $0\nu\beta\beta$ half life $T^{0\nu}_{1/2} > 2.1\cdot10^{25}$yr [4].

Phase II will use additional enriched broad-energy germanium (BEGe) detectors with enhanced pulse shape discrimination (PSD) performance and aims at a total exposure of 100 kg·yr. The design background is 10^{-3} counts·keV^{-1}·kg^{-1}·yr^{-1} thanks to the instrumentation of the liquid argon with photon detectors allowing to veto background induced by extrinsic radioactive impurities. Data taking will start in summer 2014 and the projected sensitivity after three years of data acquisition is $2\cdot10^{26}$ yr.

[1] H.V. Klapdor-Kleingrothaus *et al.*, Phys. Lett. **B586**, 198 (2004).

[2] M. Agostini *et al.* (GERDA Collaboration), Eur. Phys. J. C73, 2330 (2013).

[3] M. Agostini *et al.* (GERDA Collaboration), Eur. Phys. J. C74, 2764 (2014).

[4] M. Agostini *et al.* (GERDA Collaboration), Phys. Rev. Lett. 111, 122503 (2013).

3.1 Analysis of the Phase I calibration data

Large attention was paid to the energy resolution which directly affects the background level. The calibration of the energy scale and resolution of the individual detectors was performed weekly with the insertion of three ^{228}Th sources in the vicinity of the detectors. The frequent calibration of a dozen detectors requires an automated analysis. After basic quality cuts are applied,

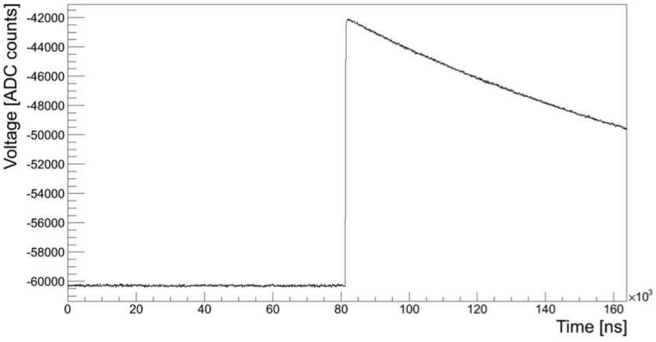

FIG. 3.1 – Original waveform recorded by GERDA.

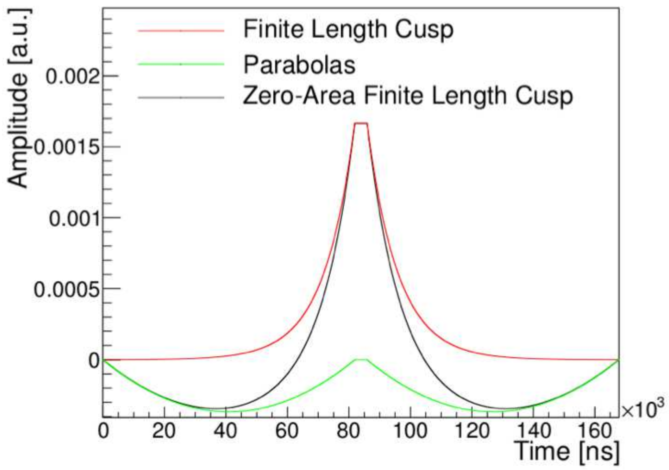

FIG. 3.2 – Finite-length cusp filter matching the 170 μs waveform records. The flat top maximizes the charge integration and the "zero-area" removes low-frequency baseline fluctuations.

and coincidence and pile-up events are rejected, gamma-peaks are identified and fitted. We observed that the energy resolution was deteriorated in the presence of low-frequency fluctuations in the baselines of the recorded pre-amplifier waveforms (see Fig. 3.1). A digital shaping filter with enhanced low-frequency rejection has been developed [1]. Cusp filters are known to maximize the noise whitening [2]. The filter was defined on the full region of the recorded waveform and biased to give zero total area for minimal sensitivity to baseline fluctuations. A flat top garantees optimal charge integration. Fig. 3.2 illustrates the procedure. The signal shaping induced by the preamplifier is taken into account by a convolution with the preamplifier's response function; the result is shown in Fig. 3.3. The filter parameters have been tuned for optimal performance for each detector individually.

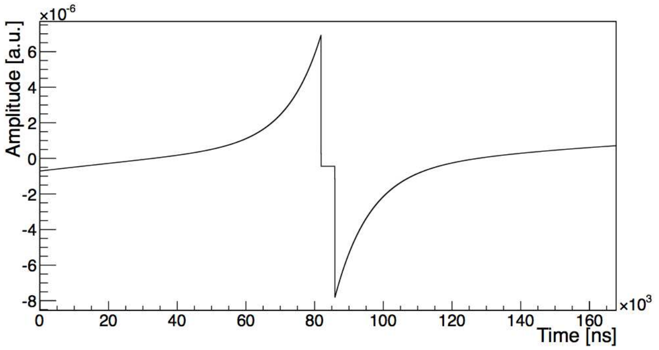

FIG. 3.3 – Filter resulting after convolution with the response function of the charge-integrating pre-amplifier.

All Phase I data were reprocessed with this new filter, leading to an average improvement of 0.3 keV at $Q_{\beta\beta}$ for the calibration data, as shown in Fig. 3.4. The improvement is even better for the background data (~0.5 keV), due to the strong noise reduction property of the cusp filter, which minimizes the peaks broadening in the data merged from different runs. The resolution improvement in the physics reach of GERDA Phase I results in ~5% improvement of the median sensitivity. Thus, the developed cusp filter will be used as a default shaping filter for the Phase II data analysis.

[1] G. Benato, V. D'Andrea *et al.*, *"Performances of germanium detectors by optimized readout and digital filtering techniques in the framework of the GERDA experiment"*, poster presented at the TAUP conference, Asilomar, California USA (September 2013).

[2] M.O. Deigthon, IEEE Trans. Nucl. Sci. 16, 68-75 (1969).

[3] E. Gatti *et al.*, Nucl. Instr. Meth. A 523, 167Ð185 (2004).

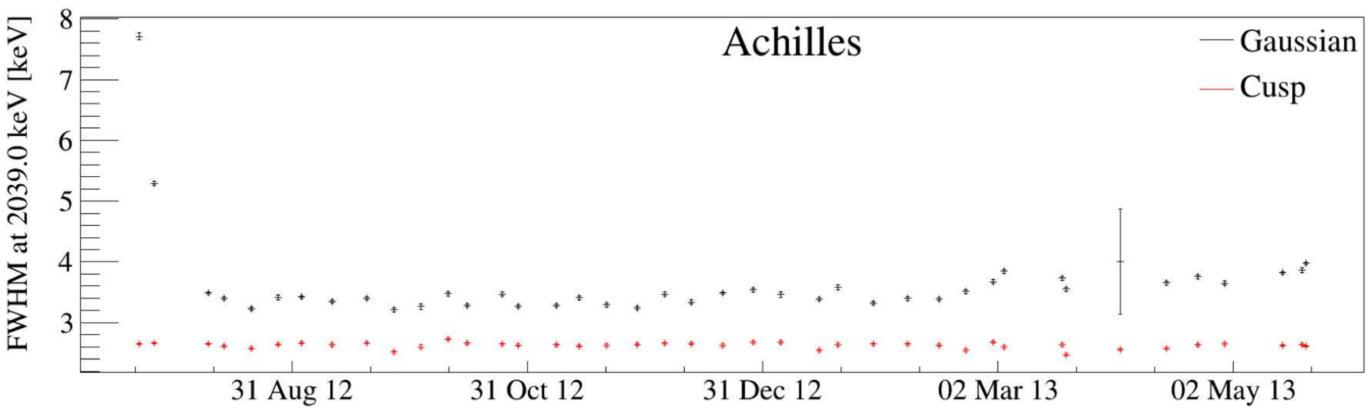

FIG. 3.4 – The energy resolution at $Q_{\beta\beta}$ during the GERDA Phase I data acquisition period for one of the detectors. Note a very significant improvement in resolution (from ~3.5 keV to ~2.8 keV) when moving from Gaussian to cusp filtering.

3.2 Production and characterization of the calibration sources for Phase II

Our group is responsible for the production and characterization of the ^{228}Th calibration sources for the Phase II of the GERDA experiment. The advantages of using ^{228}Th are its relatively long half life (1.9 yr), the presence of a dozen lines in the spectrum and of a double-escape peak at 1592 keV - thus not far from the GERDA region of interest - which is used for tuning the pulse shape discrimination algorithms. The disadvantage is the emission of α-particles by some isotopes of the Th chain, which can induce (α,n) reactions in the materials surrounding the detectors. The produced radiogenic neutrons might then activate the Ge during the calibration measurements.

A reduction of about one order of magnitude in the neutron flux emitted by the sources can be obtained if the ^{228}Th sample is contained in a high-Z material instead of the standard ceramic [1]. Four sources have been produced in December 2013 by depositing $ThCl_4$ solution onto a gold foil, and are now being encapsulated in stainless steel to prevent any loss of radioactive material. The measurement of their activity will be performed in the next months, together with a customized leak test to verify the capsules tightness at cryogenic temperature.

The neutron flux emitted by the sources will be measured with a low-background LiI(Eu) detector operated underground at LNGS (for details see [2]). Calibrations with AmBe neutron source and several measurements with gamma sources were performed in May 2013, which revealed the possible presence of light loss, with a consequent degraded energy resolution. An improvement of the performance was obtained by a more accurate coupling of the LiI(Eu) crystal to the PMT and an additional PTFE sealing (Fig. 3.5), increasing the scintillation light collection efficiency, leading to an improvement of ~30% in the energy resolution of the gamma lines. Since November 2013 the setup is taking background data underground, with an environmental neutron flux of about 0.2 neutrons/day. Results are shown in Fig. 3.6.

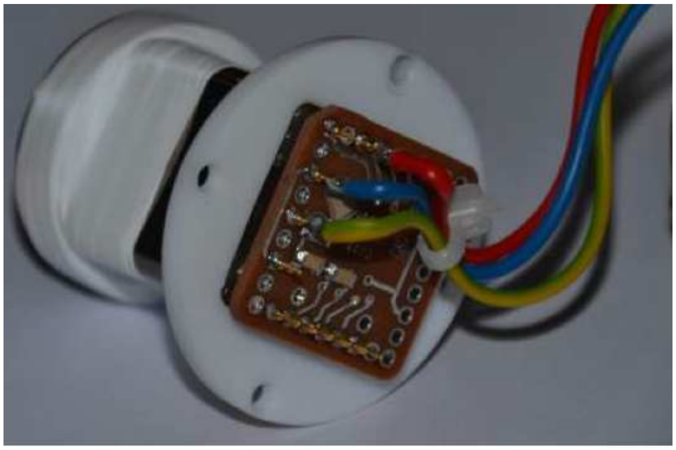

FIG. 3.5 – The LiI(Eu) crystal coupled to a 1-inch Hamamatsu R8520 low-background PMT. The PTFE sealing for light loss reduction is also seen.

[1] W. Maneschg, L. Baudis *et al.*,
Nucl. Instrum. Meth. A680, 161-167, (2012).

[2] M. Tarka, *"Studies of the neutron flux suppression from a γ-ray source and the GERDA calibration system"*,
PhD Thesis, UZH (2012).

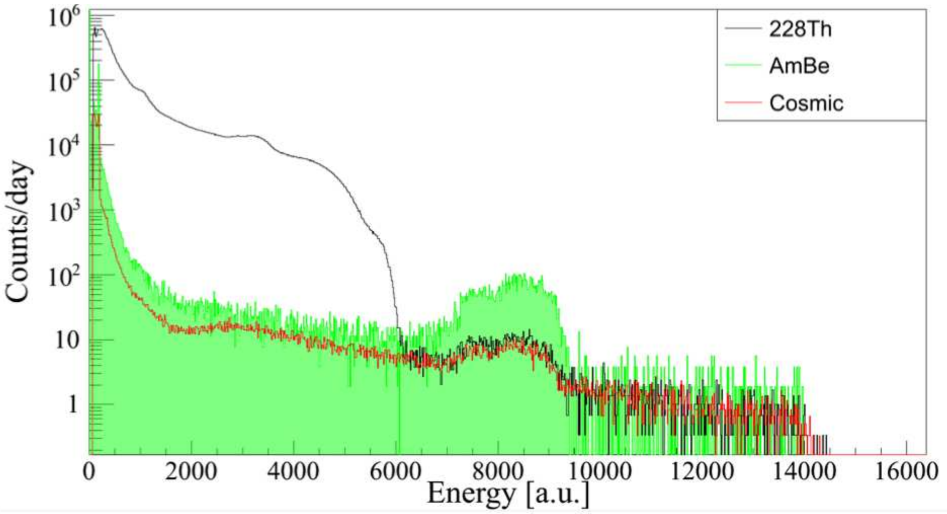

FIG. 3.6 – Spectra acquired with a strong ^{228}Th source, a ^{241}AmBe neutron source, and with cosmic radiation in the external laboratory at LNGS.