GERDA Status Report: Results from Commissioning

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Abstract. In june 2010 GERDA, designed to search for neutrinoless double beta decay of $^{76}$Ge, started the commissioning, with a pilot string of 3 non-enriched Ge detector. One year later 3 $^{enr}$Ge detectors were added, and operated for $\sim$ 4 months. This contribution summarizes the first year of work, the updated evaluation of the setup background, the strategies we implemented to mitigate the most serious background source we faced with, i.e. $^{42}$Ar-$^{42}$K: the $^{42}$Ar activity measured in the final quasi-field free configuration is $0.23 \pm 0.03$ cts/(kg·d) corresponding to 104 Bq/kg; this is assuming an homogeneous and isotropic distribution of the daughter nucleus, $^{42}$K, around the detector array. The background index measured with the $^{enr}$Ge 3-detector array is $0.045 \pm 0.015$ cts/(keV·kg·y).

1. Introduction
GERDA aims to search for $\beta\beta$0$\nu$-decay of $^{76}$Ge; high purity germanium detectors (HPGe), enriched ($\geq 85\%$) in $^{76}$Ge, are operated directly immersed in LAr which acts both as shield against $\gamma$ radiation and as cooling medium. The setup consists of a 64 $m^3$ volume of LAr (5N grade), contained by a double vessel stainless steel cryostat, lined at the inside by a 3 to 12 cm thick layer of OFHC layer. The cryostat is in turn placed at the center of a 650 $m^3$ volume of ultrapure water, equipped with 77 PMTs to veto, by Cerenkov light detection, the residual cosmic muons, and to moderate and eventually capture the fast $n$s. The setup has 2 arms equipped to insert a single 3-detectors string (1SA) and 3 x 3-detectors strings (3SA) respectively. The design energy resolution is $\leq 4$ keV at $Q_{\beta\beta}$=2039 keV, while the background index (BI) at the detector array position is expected to be $10^{-2}$ cts/(keV·kg·y) (dominated by detectors cosmogenic background) and $10^{-3}$ cts/(keV·kg·y) for Phase I and Phase II respectively. The experiment is foreseen to proceed in two phases. In phase I, now ongoing, eight reprocessed enriched p-type HPGe detectors from the past HDM [2] and Igex [3] experiments ($\sim$ 18 kg) are at the center of the setup. If the design Phase I BI ($10^{-2}$ cts/(keV·kg·y)) will be achieved, the GERDA Phase I will scrutinize in one year of data taking the claim of [4], as $\beta\beta$0$\nu$ will produce 7 events at 2039 keV ($\pm 4$ keV), over a background of 1. The duration of Phase I is not yet decided and will depend on the actual BI, the collected statistics and on the Phase II hardware readiness. In Phase II more detectors with a highly improved background rejection power will be added; their total mass will be $> 20$ kg of $^{enr}$Ge, depending on the final mass yield of the production process. If their intrinsic activity will meet the design BI, GERDA will reach a sensitivity on $T_{1/2}^{\beta\beta0\nu}$ of 1.5·10$^{26}$ (90% C.L.), with an exposure of 110 kg·y. When translating the half-life sensitivity limits to effective majorana neutrino mass, one gets 270 meV and 110
meV for Phase I and Phase II respectively, adopting for the nuclear matrix elements, an average value from the recent computations [5, 6, 7, 8].

2. The GERDA Commissioning
GERDA has been commissioned in the year from June 2010 to September 2011. We wanted to test and debug the whole setup, the detectors handling and insertion procedures and, last but not least, to measure the setup background index at the detector array position with the full GERDA shielding, including the Cerenkov \( \mu \) veto. For this, three of six natural HPGe detectors from the Genius Test-Facility (GTF) detectors have been deployed, after having been reprocessed by our industrial partner, Canberra Co. [9], with the same technology adopted for the enriched ones. The operation with the three nat Ge detectors (detectors name and masses: GTF32 (2321 g), GTF45 (2312 g) and GTF112 (2957 g)) started in June 2010 and ended in April 2011 in the 1SA, and was followed by a break of several weeks for the installation of the 3SA. Since the end of June 2011 a first enr Ge detector string (detectors names and masses: RG1 (2110 g), ANG4 (2372 g) and RG2 (2166 g)) has been operated in the 1SA, while the nat Ge detectors string was operated in the 3SA, to debug the latter.

\[ \begin{array}{c}
\text{Counting rate at the 1525-keV } \gamma \text{ line} \\
\text{Run History}
\end{array} \]

3. The 42 Ar issue
From the very first run with the nat Ge string we had a prominent line at 1525 keV in the energy spectra that was associated to the \( \beta-\gamma \) decay \( ^{42}\text{K} \longrightarrow ^{42}\text{Ca} \) \( (Q_{\beta}=3.52 \text{ MeV}, t_{1/2} = 12.36 \text{ h}, E_{\gamma}: 1525 \text{ keV (BR: 18.1%)}), 1922 \text{ keV (BR: 4%)} \) and 2424 keV (BR: 2%)): \(^{42}\text{Ar} \) is the progenitor, by \( \beta \)-decay, of \(^{42}\text{K} \) \( (Q_{\beta}=600 \text{ keV}, t_{1/2} = 33 \text{ y}) \). The 3.5 MeV \( \beta \)s and the rare 2424 keV \( \gamma \)s can produce background at \( Q_{\beta\beta} \): the first, by entering the detectors in the borehole where the deadlayer is only \( \sim 100 \mu \text{m} \), or by hard bremsstrhalung in materials surrounding the detectors,
Figure 2. Sum energy spectrum of the $^{enr}$Ge detectors deployed in the ISA. The exposure is 0.962 kg·y, the binning is 10 keV. The visible $\gamma$ lines are: 1525 keV and 1922 keV, related to $^{42}$K, 1764 keV (4 cts) from $^{214}$Bi. Only 2 cts are present at 2614 keV $^{208}$Tl line. From this spectrum we evaluate a BI of 0.045$^{+0.015}_{-0.011}$ cts/(keV·kg·y), in the 400 keV energy window 1839 keV - 2239 keV.

the second by Compton scattering. The $^{42}$Ar concentration in LAr is reported in literature only as an upper limit [10, 11]: the best upper limit to $^{42}$Ar concentration is $4.3 \cdot 10^{-21}$ g/g at 90% CL [12], which corresponds to 43 $\mu$Bq/kg leading to 0.094 cts/(kg·d) at the 1525 keV line, assuming an homogeneous and uniform distribution of $^{42}$K around the detectors: as shown in figure 1 the first measured count rates were of $\sim$ 2 cts/(kg·d). It was soon understood that the $^{42}$K, being produced positively charged ($^{42}$K$^+$) by the $^{42}$Ar $\beta$ decay, i) Can be drifted by the electric field dispersed in LAr by the diodes biasing potential ($\vec{E}_{LAr}$), ii) The $^{42}$K homogeneous distribution changes to a new one leading to enrichment of $^{42}$K in the detector surroundings, i.e. to enhancement of the 1525 keV $\gamma$ line intensity. iii) While drifting or when reaching metallic surfaces the $^{42}$K$^+$ can be neutralized ($\tau_{\text{neutr}}$: 20-40 min), and/or decay ($\tau_{\text{decay}}$: 18 h); once neutralized the $^{42}$K can no longer be displaced by the $\vec{E}_{LAr}$ iv) The $^{42}$K $\beta$ decay at the detector surface (mainly in borehole), can produce events at the Q$_{\beta\beta}$. Therefore we surrounded the detectors by a cylindrical 120 $\mu$m thick Cu shroud (MS) to physically separate the LAr bath in two volumes: the smallest $\sim$ (3 l) surrounding the detectors where the $\vec{E}_{LAr}$ is dispersed, and the largest, a potentially infinite $^{42}$K reservoir, outside it where no stray $\vec{E}_{LAr}$ is dispersed. We achieved to reduce the $^{42}$K $\gamma$ line count rate from (1.71 ± 0.09) counts/(kg·day) (average of Runs 1-3) to (0.40 ± 0.05) cts/(kg·d) in (Run 4); the corresponding BI at Q$_{\beta\beta}$ decreased from the initial value of 0.17 cts/(keV·kg·y) down to 0.061$^{+0.013}_{-0.009}$ cts/(keV·kg·y). In the next runs some activity modulation was observed depending on the proximity of the grounded conductors acting as negative electrode, or on the electrostatic field applied between MS and the outer shroud. The subsequent closure of the MS at its top end by a Cu lid, and the shielding of the last portion of the so far unshielded high voltage cables, produced a further reduction of the 1525 keV $\gamma$ line intensity down to 0.23 ± 0.03 cts/(kg·d), and of the BI down to 0.045$^{+0.015}_{-0.011}$ cts/(keV·kg·y). The latter has been evaluated on the $^{enr}$Ge detectors energy spectrum shown in figure 3 (red markers) corresponding to an exposure of 0.962 kg·y (commissioning runs 15-18,22). The origin of the residual background, is at present under study, as no evident $\gamma$ lines are present in the spectrum above Q$_{\beta\beta}$.

4. The $\beta\beta$2$\nu$ spectrum

The contribution of the $\beta\beta$2$\nu$ decay of $^{76}$Ge is clearly visible, dominating the counting rate in the energy region between the end-point of $^{39}$Ar (565 keV) and the $^{42}$K $\gamma$-line (1525 keV) (see Fig. 5). The $^{76}$Ge half-life for the two-neutrino channel has not been evaluated yet, but data are consistent with the literature values [14]
Figure 3. Sum energy spectrum of the \( ^{enr}\)Ge detectors deployed in the ISAX, in the nominal vertical position (markers). The solid black line is the expected spectrum, obtained as the superposition of \(^{39}\)Ar (green line), \(\beta\beta 2\nu\) decay of \(^{76}\)Ge (red line) and \(^{42}\)K (blue line). The \(^{39}\)Ar and \(2\nu 2\beta\) contributions are absolutely normalized assuming 1.01 Bq/kg of \(^{39}\)Ar in LAr [13] and \(T_{1/2} = 1.74 \cdot 10^{21}\) y for \(^{76}\)Ge [2]. The \(^{42}\)K contribution is relatively normalized to match the experimental rate at the 1525-keV full-energy peak.

Table 1. Comparison of the normalized intensities of strong \(\gamma\) lines, \(I_{HdM}\), from the Heidelberg-Moscow experiment with the corresponding intensities, \(I_{G}\), observed in GERDA for the \(^{nat}\)Ge and the \(^{enr}\)Ge detectors. The upper limits correspond to the 90\% CL. The original intensity [15] in HdM has been obtained with the exposure of 71.7 kg\(\cdot y\). The GERDA exposure is 1.6 kg\(\cdot y\) and 0.962 kg\(\cdot y\) for the \(^{nat}\)Ge and the \(^{enr}\)Ge detectors respectively. \(R\) denotes the ratio of the \(\gamma\)-lines intensities HdM/(Gerda \(^{nat}\)Ge). In the considered 0.962 kg\(\cdot y\) \(^{enr}\)Ge exposure, most of the lines \(< 1.55\) MeV do not emerge from the \(\beta\beta 2\nu + ^{39}\)Ar + \(^{42}\)Ar background.

| isotope | energy [keV] | \(I_{HdM}\) \((\text{cnts})\) | \(I_{G}^{nat}\) \((\text{cnts})\) | \(R\) HdM/\(Ge^{nat}\) | \(I_{G}^{enr}\) \((\text{cnts})\) |
|---------|-------------|-----------------|-----------------|-----------------|-----------------|
| \(^{40}\)K | 1460.8 | 13010 ± 134 | 287 ± 3 | 14.6 ± 5.8 | 19.7 ± 7.9 |
| \(^{60}\)Co | 1173.2 | 3955 ± 88 | 87 ± 2 | 12.8 ± 5.8 | 6.8 ± 3.1 |
| \(^{137}\)Cs | 1332.3 | 3690 ± 90 | 81 ± 2 | < 7.9 | > 10 |
| \(^{208}\)Tl | 661.6 | 20201 ± 164 | 445 ± 4 | < 2.5 | > 180 |
| \(^{214}\)Bi | 583.1 | 2566 ± 228 | 57 ± 5 | 9.9 ± 5.8 | 5.7 ± 3.4 |
| \(^{228}\)Ac | 2614.5 | 1184 ± 36 | 26 ± 1 | 7.0 +3.8 -2.6 | 3.7 +2.0 -1.4 |
| \(^{214}\)Bi | 609.3 | 7552 ± 96 | 167 ± 2 | 39.8 ± 8.0 | 4.2 ± 0.8 | 8 ± 8 |
| \(^{214}\)Bi | 1120.3 | 1926 ± 86 | 43 ± 2 | 12.2 ± 5.5 | 3.5 ± 1.6 |
| \(^{214}\)Bi | 1764.5 | 2204 ± 51 | 49 ± 1 | 7.0 +3.8 -2.6 | 6.9 +3.8 -2.6 |
| \(^{228}\)Ac | 910.8 | 2135 ± 115 | 47 ± 3 | < 7.7 | > 6 |
| \(^{228}\)Ac | 968.9 | 1259 ± 82 | 28 ± 2 | < 6.4 | > 4.8 |

5. Background from other isotopes

Table 1 show the comparison of the major background \(\gamma\)-lines between GERDA and HdM. The original intensity [15] in HdM has been obtained with the exposure of 71.7 kg\(\cdot y\), while the exposure in GERDA is 1.6 kg\(\cdot y\); the GERDA background reduction compared to HdM is a factor \(\sim 5\) for \(^{214}\)Bi, \(^{208}\)Tl and \(^{228}\)Ac, a factor \(\sim 20\), \(> 180\) and \(\sim 7\) for \(^{40}\)K \(^{137}\)Cs and \(^{60}\)Co respectively. Therefore, from the \(^{nat}\)Ge commissioning, in GERDA the expected contribution at \(Q_{\beta\beta}\) of the 2614 keV \(\gamma\) line Compton continuum, is \(2.2 \cdot 10^{-2}\) cts/(keV-kg\(\cdot y\)) ; the preliminar results from the \(^{enr}\)Ge indicate a lower rate.

6. Phase II preparation

The production of new \(^{enr}\)Ge detectors with enhanced pulse shape discrimination (PSD) properties is in advanced stage: they are the BEGe type manufactured by Canberra Co.. We have proved on 8 BEGe detectors, different for dimensions and impurity concentration profile,
i.e. depletion voltage, that the adopted PSD criteria accepting 90% of Single Site Events, rejects 90% of Multi Site, Compton like events [16, 17, 18]. The first batch of enrGe BEGe detectors will be ready in early spring 2012; the full production will follow along 2012. The deployment of Phase II detectors is foreseen to be in 2013, depending both on the Phase I data taking and on the readiness of the HW needed to upgrade the setup. We are at present considering few option (cryogenic PMTs, MPPC coupled to optical fibers or APD UV-sensitive) to implement, in Phase II, the LAr scintillation light readout; this will allow to veto the residual external background events, as $\beta$s or $\gamma$s from $^{42}\text{K}$ or $^{214}\text{Bi}$.

References
[1] GERDA Proposal to LNGS(2004), http://www.mpi-hd.mpg.de/ge76/.
[2] Heidelberg-Moscow Collaboration, M. Günther et al., Phys. Rev. D 55 (1997) 54; C. Dörr and H.V Klapdor-Kleingrothaus, Nucl. Instrum. Meth. A 513 (2003) 596.
[3] C E Aalseth et al., Phys. of Atomic Nuclei 63 (2000) 1225.
[4] H.V Klapdor-Kleingrothaus, Modern Physics Letters A, 21 (2006) 1547.
[5] F. Simkovic et al., Phys.Rev. C, 77 (2008) 045503;
[6] O. Civitarese et al., JoP Conference series 173 (2009) 012012;
[7] J. Menendez et al., Nucl. Phys. A 818 (2009) 139;
[8] J. Barea and F. Iachello, Phys.Rev. C 79 (2009) 044301;
[9] http://wwwcanberra.com.
[10] A.S. Barabash: Proc. Int. Workshop on Techniques and Application of Xenon Detectors, Tokyo 2001, WS (2002) 10.
[11] A.S. Barabash et al., Nucl. Inst. Meth. A385 (1997) 530.
[12] V.D. Ashitkov et al., [arXiv:nucl-ex/0309001].
[13] WArP Collaboration, P. Benetti et al., Nucl. Inst. Meth. A 574 (2007) 83.
[14] H.V Klapdor-Kleingrothaus, Modern Nucl. Instr. Meth. A, 522 (2004) 371.
[15] O. Chkvorets, Ph.D. thesis, 2008, http://www.ub.uni-heidelberg.de/archiv/8572.
[16] D. Budjas Nuclear Instrumentation, Measurement Methods and their Applications Ghent, Belgium, June 6-9, 2011.
[17] C. Cattadori Workshop on Germanium-Based Detectors and Technologies, Berkeley (US), May 18-20, 2010.
[18] D. Budjas et al., J. Instrum. 4 (2009) 10007.