Gerda

Progress report to the LNGS scientific committee

(Short Write-up)

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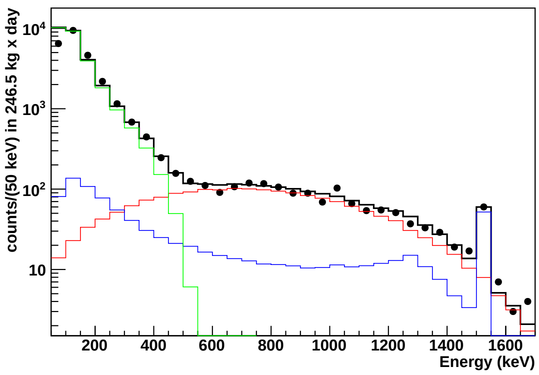
This Gerda report summarizes the progress achieved during the last six months. A *Short Write-up* is linked at:

http://www.mpi-hd.mpg.de/GERDA/reportsLNGS/gerda-lngs-sc-oct11-shwup.pdf.

Previous reports are available at: http://www.mpi-hd.mpg.de/GERDA/reportsLNGS.



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During the last six months, the GERDA collaboration focused on (i) the completion of the commissioning phase using both low-background natural and enriched high-purity germanium detectors, on (ii) the preparation of the deployment of the full enriched Phase I detector array in November, on (iii) the study of the mobility of ^{42}K in LArGe, and on (iv) the preparation of the Phase II detectors and systems. Moreover, the collaboration decided to prepare a design for the liquid argon scintillation readout for active background suppression in GERDA. Currently, the collaboration prepares the deployment of the full set of enriched Phase I detectors to start physics data taking.

Overview of detector configurations during commissioning runs (last six months): The operation with the non-enriched string ended in April and was followed by a break of several weeks for the installation of the 3-string arm. Since the end of June a first enriched detector string has been operated in the 1-string arm. From top to bottom, the detectors are RG1 (2110 g), ANG4 (2372 g) and RG2 (2166 g). The detectors are operated inside a grounded mini-shroud (Cu cylinder, height 480 mm, diameter 104 mm, wall thickness 60 μm, which is closed on both ends with 120 μm thick Cu disks). At the operational voltages, the detectors have negligible leakage current ($\leq$ 50 pA) and the energy resolution ranges around 5.0 keV (FWHM) at 2.6 MeV. The enriched detector string was operated at several vertical positions summarized in Table 1.

In the 3-string arm, the non-enriched detector string previously operated in the 1-string arm, GTF32 (2321 g), GTF45 (2312 g) and GTF112 (2957 g), was deployed with the old mini-shroud (see GSTR-11-003). HV (+3000 V) was applied to the mini-shroud during Run 17. The positions are listed in Table 1. Subsequently, the old mini-shroud was replaced by a new grounded one (diameter 108 mm, wall thickness 60 μm, closed on both ends) and another string containing 2 additional detectors (GTF110 (3046 g) and GTF42 (2467 g)) was added. However GTF42 trips at 700 V. This will be fixed at the next temperature cycle of the 3-string arm.

Main results of commissioning runs: For the first time, three enriched Ge detectors (RG1, ANG4 and RG2) have been deployed in the GERDA set-up. The contribution of the two-neutrino $\beta\beta$ 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 γ-line (1525 keV) (see Fig. 1). The ^{76}Ge half-life for the two-neutrino channel has not been evaluated in detail yet, but it is consistent with the literature values.

The better understanding of background sources was the main focus of the experiment during the last months. Many different issues have been addressed:

- *Is the background for enriched detectors lower than for the GTF detectors?*
  The average background index in the region $Q_{\beta\beta} \pm 200$ keV measured for RG1, ANG4 and RG2 (Runs 15-18, Run 22) is $0.045^{+0.015}_{-0.011}$ cts/(keV·kg·y). This value is somewhat smaller than the rate of $0.061^{+0.013}_{-0.009}$ cts/(keV·kg·y) which has been obtained with the GTF string in the previous phase of the commissioning (Runs 10-12). The integral counting rates in the region $1535 - 3000$ keV, namely above the 1525-keV γ-line

Run	1-string arm		3-string arm		Live time
	Detectors	Position	Detectors	Position	(days)
14	3 enriched	z = +50 cm			7.11
15	3 enriched	z = 0 cm			16.02
16	3 enriched	z = 0 cm	3 GTF	z = +70 cm	8.90
17	3 enriched	z = 0 cm	3 GTF	z = +70 cm	5.96
18	3 enriched	z = 0 cm	3 GTF	z = 0 cm	6.15
19	3 enriched	z = +80 cm			2.17
20	3 enriched	z = +120 cm	4 GTF	z = -40 cm	6.71
21	3 enriched	z = +60 cm	4 GTF	z = -40 cm	13.65
22	3 enriched	z = -25 cm	4 GTF	z = -40 cm	ongoing

Table 1: Description of the GERDA data taking configurations since the installation of the 3-string arm. An enriched detector string is operated in the 1-string arm and up to 4 natural germanium detectors are operated in the 3-string arm. The vertical position of the strings are given relative to the nominal position (z = 0). In Run 17, +3 kV was applied on the Cu cylinder containing the GTF string.

from ^{42}K are (62.7±8.7) counts/(kg·y) and (107±13) counts/(kg·y) for the enriched and GTF strings, respectively. These numbers suggest a reduction of the overall background for the enriched detectors.

- *Is the background for the newly operated 3-string different compared to the 1-string?* With the same GTF detectors used in the past and now operated in the 3-string arm we find a background index of $0.067^{+0.021}_{-0.015}$ cts/(keV·kg·y) (Runs 20-22). This value is consistent with $0.061^{+0.013}_{-0.009}$ cts/(keV·kg·y) measured for the same detectors in the 1-string arm. We are therefore encouraged to operate enriched detectors in the 3-string arm.
  The 3-string crystal array has been placed approximately at the same vertical position which was used for the deployment of the same detectors in the 1-string arm. Nevertheless the two positions differ by more than 20 cm in the cryostat *horizontal* plane. Since the attenuation length in liquid argon of the Compton background at $Q_{\beta\beta}$ from 2.6 MeV γ-rays is about 23 cm, one can conclude that the background which is being observed is not dominated by a possible "hot spot" along the line of sight located at the cylindrical walls of the cryostat.

- *Can the counting rate at the 1525-keV γ-line be further reduced by means of appropriate electric field configurations?*
  Since Run 14 the mini-shrouds have been closed with top lids. Moreover, the HV cables above the lid in the 3-string arm (about 30 cm), which were unshielded, have been shielded since Run 16. There is indication that the top lid plays a role in the reduction of the counting rate at the 1525-keV line, while the effect of the HV cable

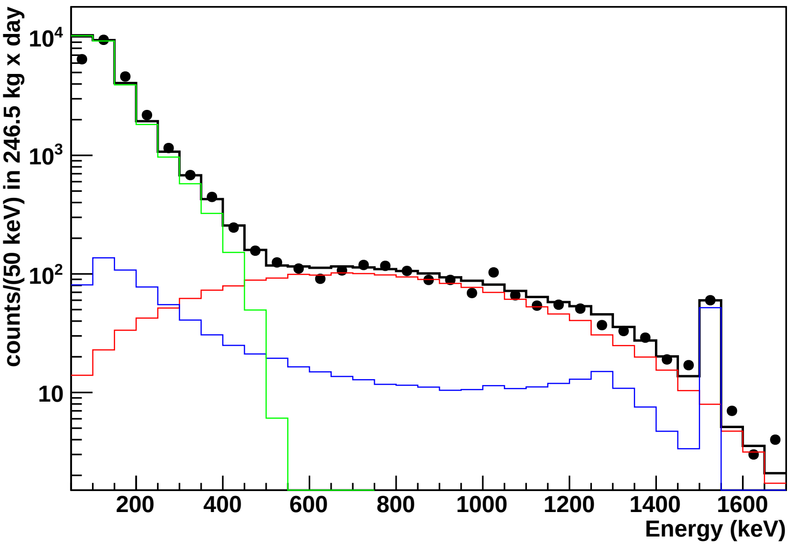

Figure 1: Sum energy spectrum of the ^{enr}Ge detectors deployed in the 1-string arm, in the nominal vertical position (markers). The solid black line is the expected spectrum, obtained as the superposition of ^{39}Ar (green line), $2\nu2\beta$ decay of ^{76}Ge (red line) and ^{42}K (blue line). The ^{39}Ar and $2\nu2\beta$ contributions are absolutely normalized assuming 1.01 Bq/kg of ^{39}Ar in LAr [1] and $T_{1/2} = 1.74 \cdot 10^{21}$ y for ^{76}Ge [2]. The ^{42}K contribution (only the 1525 keV line and the Compton events) is normalized to match the experimental rate at the peak. The lowest energy bin corresponds to the trigger threshold in the current data taking.

shielding is still unclear. This is due to the malfunctioning of the second GTF string in the 3-string arm. The latter seems to act as an attractor of ^{42}K, affecting also the counting rate on the neighbor GTF string.
In one on the runs (Run 17), the mini-shroud surrounding the GTF string was biased at +3000 Volt. According to electric field simulations performed with the software Maxwell, no field line should terminate close to the detectors, thus strongly suppressing any collection effect of positive ^{42}K ions. The rate at the 1525 keV line was reduced on average by 30%, which is much less than initially expected. Thus other effects like ion neutralization or convection must be important for the observed behavior.
A reduction in the line count rate, as measured in LArGe, has not yet been achieved in Gerda. Dedicated studies are therefore carried out in LArGe to develop a design which is applicable also for Gerda.

- *Is the background originating from a localized source above the detectors?*
  Both detector strings (GTF and enriched detectors) have been operated at different vertical positions up to 1.2 m above the nominal one (see Tab. 1). At higher positions, lines from ^{60}Co and ^{208}Tl become clearly visible originating most likely from the heat

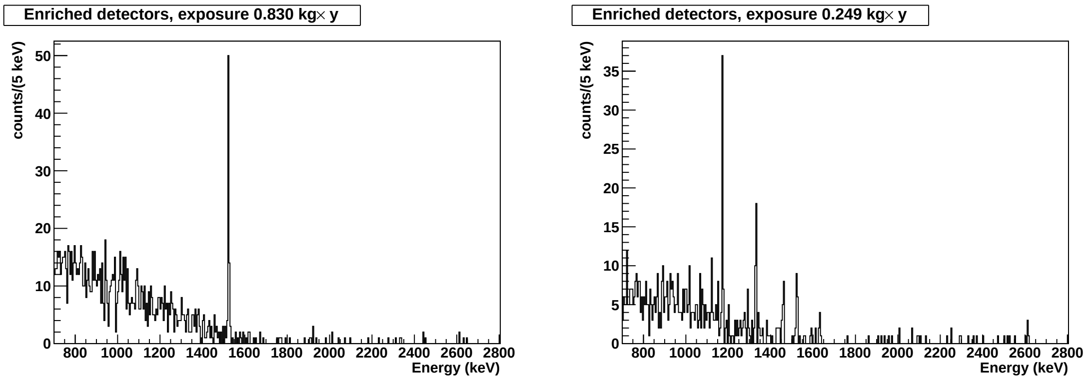

Figure 2: Sum energy spectrum in the region 700-2800 keV taken with the enriched detector string located in the reference vertical position (left) and 60 cm above it (right). Exposures are 0.830 kg·y and 0.249 kg·y, respectively. The spectrum acquired in the higher position shows the two ^{60}Co γ-lines, the 1461 keV ^{40}K line, and as well as the 2614 keV line from ^{208}Tl.

exchanger and its support located in the upper part of the cryostat. For the GTF detector string, the background index in Run 16 is 0.270 ± 0.06 cts/(keV·kg·y): this is a factor of about 4 higher than the value achieved at the lowermost position, which is 110 cm lower. Given the height difference, one would expect however an increase by more than a factor of 100. For the string with enriched detectors a height difference of 60 cm (Runs 15-18 compared to Run 21) should result in a background reduction by a factor of about 14 while we observe about a factor of 3.5 (see Fig. 2). We conclude that the identified ^{208}Tl background contributes to less than 10% to the total observed background.

- *What is the concentration of ^{42}Ar in liquid argon?*
  For an exposure of 364 kg·d, the count rate at the 1525 keV line for the enriched detectors is 0.193 ± 0.025 counts/(kg·day). This value is lower than our previous estimate of 0.34 ± 0.04 counts/(kg·day) [3].[1] The analysis of the final number for the concentration of ^{42}Ar is ongoing and will depend on the recent studies performed in LArGe.

A single dominant contribution to the background at $Q_{\beta\beta}$ can not be identified. We have a few events at the γ line positions from ^{214}Bi and ^{208}Tl, as well as a few α events at higher energies. We also expect some contribution from ^{42}K, which would be consistent with the observation of a few events above 2614 keV. The next step to a better understanding is the increase of detector mass and to perform a long measurement to become more sensitive to weak lines and the shape of the background spectrum.

[1] As discussed above, the enriched detectors are in a mini-shroud with lids on both side while the previous mini-shroud of the GTF detectors had no lit on top. The HV cables are not shielded in both cases.

Measurement of the ^{42}Ar concentration and ^{42}K mobility with LArGe: Studies on the behavior of ^{42}K ions in LArGe were continued using the GTF44 detector, hermetically encapsulated by a PTFE/Cu/PTFE sandwich. The Cu layer together with the detector holder can be biased independently of the diode in order to attract or repel ^{42}K ions. The goal was to investigate the mobility and neutralization time of ^{42}K ions in LAr for different field configurations with the ultimate goal to develop an ion-sweeper system for Gerda. Measurements were usually carried out with PMTs switched off in order to simplify the electric field configuration.

The 1525 keV line count rate was measured from 0 V (quasi field-free configuration) in steps of 500 V up to -3000 V applied to the encapsulation. The observed peak rate was (0.26 ± 0.08) counts/(kg·day) for the quasi field-free configuration and (4.41 ± 0.51) counts/(kg·day) at -3000 V. Based on the equilibrium peak counting rate, an ionic life-time for the ^{42}K ions of a few tens of minutes was derived assuming a mobility of $6 \cdot 10^{-4}\mathrm{cm}^2/(\mathrm{Vs})$ [4].

In a second set of measurements, the collection of ^{42}K ions was studied after spiking the LAr with about 5 Bq of ^{42}Ar. Given the 40-fold increased counting statistics, transients of the 1525 keV line counting rate, subsequent to sudden changes of the electric field configurations, could also be studied. Moreover, spiked LAr of known activity allows a model-independent measurement of the ^{42}Ar concentration in natural argon. The ^{42}Ar was produced by irradiating two cells filled with gaseous argon with a Li-beam at the Tandem accelerator facility of the MLL at TUM. The overall activity stored in two steel sample containers was about 10 Bq. It was measured by low-background gamma spectroscopy in the TUM underground laboratory. Relative activities of ^{42}Ar in both samples were established with high precision, and no other long-lived isotopes have been identified. For a precise absolute activity determination one of the samples was screened with the high-sensitivity GeMPI gamma ray spectrometer at Lngs. The other one was added to 80 l of LAr used to refill LArGe in August.

We repeated the measurements of the line count rate for different HV settings with spiked LAr. The measurements are still ongoing and the preliminary conclusions are as follows:

- The count rates under the 1525 keV line increased by a factor of about 40 with respect to natural argon (rather constant over the entire range 0 to -3000 V).
- The increase of the ^{42}K line count rate after switching the encapsulation bias voltage from 0 V to -3000 V follows an exponential built-up with $t_{1/2} = (11.4 \pm 1.3)$ hours. This value is incompatible with the previously derived value for the ionic half-life based on equilibrium measurements and literature values for the ion mobility.
- ^{42}K ions attracted by the encapsulation are sticking to the PTFE surface (or alternatively stay close by in case of absence of convection) after switching the bias voltage from -3000 V to 0 V. The count rate reduces with a half-life of (11.1 ± 1.0) hours which is within its uncertainty in agreement with the nuclear half-life of 12.36 hours.

- Comparing the obtained count rates for the natural and spiked LAr of known activity at different HV biasing of the encapsulation, one can directly estimate the natural abundance of ^{42}Ar. The only assumption is that the spatial distributions of the ^{42}K ions are the same for natural and spiked LAr for a given HV setting. Final numbers are not yet available as the measurements and analysis are still ongoing.

Measurements with positive HV biases are also carried out. One of the next steps is to deploy the same diode as bare detector, however without encapsulation and with the n+ contact grounded and the p+ contact biased with negative high voltage to create a field-free configuration. This is of relevance for an optimal design of the liquid argon instrumentation in Gerda.

Deployment plan of enriched detectors and start of Phase I: It is planned to terminate the ongoing run end of October. Afterwards, all 8 enriched detectors (total mass 17.7 kg) will be deployed in the 3-string arm. As the latter can host 9 detectors, one of the GTF detectors will also be mounted. All detectors will be tested in LAr beforehand. We estimate that 1-2 weeks are required between the removal of the detectors presently in Gerda and the installation of the Phase I detectors. The lowest background index was achieved with the detector strings mounted inside the grounded Cu mini-shroud closed on both ends. Therefore, the enriched detectors will also be mounted in such a shield. The 1-string arm will be free for further detector deployments to test Phase II detectors and electronics.

Status of Phase II preparations: The contract for the production of BEGe detectors from enriched germanium material has been assigned to Canberra industries. The total numbers of detectors will be $\sim$ 25 and the total mass $\sim$ 20 kg. Crystal fabrication will be carried out in Oak Ridge, TN, USA and diode production in Olen, Belgium. In total 35.5 kg of zone refined germanium enriched in the isotope ^{76}Ge to up to 88% will be used. About 13 kg enriched Germanium material will be returned to Gerda, subsequently chemically reprocessed and prepared for a second detector production campaign.

The germanium has been loaded into the transport container and shipped to the port in Bremerhaven on September 29. During transportation by ship (11 days Atlantic transfer plus loading plus lorry drive from and to the port) the enriched germanium will be protected against cosmic radiation by a 70 cm thick steel shield housed in a standard shipping container and a 75 cm layer of water. The container is scheduled to arrive at Oak Ridge on October 14 and crystal production will commence on October 17. The germanium material will be stored underground nearby the germanium production facility. Materials will be above ground only for the manufacturing process. A Gerda representative will monitor all enriched germanium movements at Oak Ridge, ensure that exposure to each individual enriched germanium batch is minimized.

As reported, we developed and tested a front end circuit named GeFRO that could satisfy the mandatory requirements for the Phase II readout. The circuit has been tested with a coaxial detector with 10 m long cables giving excellent results. In the last semester we concentrated onto the search of JFETs and diodes with the proper characteristics deliverable as die to achieve the required low activity ($\sim \mu$Bq/piece). The GeFRO circuit will be tested within this year coupled to a BEGe detector both operated in LAr.

After a detailed internal review of production time schedules and associated risks, it was decided to install a second 3-string arm on the cryostat for Phase II. The design will be similar to the existing one in order to ensure the timely completion of the construction and testing for the start of Phase II.

LAr instrumentation: Based on the successful background suppression achieved with LArGe and the current background counting rate in Gerda, the collaboration decided to prepare a design to instrument the LAr in Gerda. Different options are currently under development: scintillation readout using photomultiplier tubes (PMTs), scintillating and wave length shifting (WLS) fibers coupled to SiPMs, and large-area SiPMs or APDs. The first two systems have been tested in prototype setups and a PMT based design also at length in LArGe. A fiber/SiPM design can be implemented in the current 3-string lock. Its limited sensitive volume can partially be compensated by being sensitive also to the light from outside of the enclosed LAr volume. The PMT design can accommodate a larger volume but the mechanical implementation is more complicated. The large area SiPM/APD design aims at enclosing the detectors with light sensors to readout the light from a small volume without scintillating fibers to impact minimally on the background. The deployment of the LAr instrumentation is planned with the start of Phase II. An earlier deployment is possible, provided that the equipment is available timely and has been tested successfully.

In the fiber/SiPM solution, a cylindrical array of narrow spaced fibers absorbs and re-emits the 128 nm XUV scintillation light. The array is designed to fit into the 3-string locks and is coupled to SiPMs. Critical is the intrinsic radiopurity of fibers and SiPMs. The Munich based company Ketek sells us SiPMs in die. We designed a low weight copper holder that serves as electric contact and mechanical support for the SiPM. The bonding and the optical coupling of the 3mm $\times$ 3mm SiPM to a bundle of nine 1mm $\times$ 1mm fibers was tested with success.

The necessary amount of WLS fibers was delivered by Saint Gobain. Screening will be done during the next months. At least parts of the proposed setup should be ready and tested in LAr within a few months. In parallel MC studies are carried out to estimate the veto efficiency and the background caused by the fibers. Taking into account the light detected from the outside of the cylinder, ^{228}Th decays close to the crystals and in the fibers are suppressed by more than a factor of 100. For distant sources the factor is more than 10 assuming a realistic threshold.

For the PMT option, five 8" (R5912-02 MOD) and ten 3" (R11065-10) low-background PMTs have been ordered at Hamamatsu. Some arrived and all will be available by the end of the year. Several designs are under consideration which would allow to implement already for phase I an active LAr veto system without emptying the cryostat. The various scenarios include (i) an assembly of four 8" and nine 3" PMTs which inspect from bottom and top a sensitive volume of about 0.6 m^3, (ii) a somewhat smaller yet easier installable system in which the LAr volume (0.4 m diameter, 2-3 m height) is inspected only from the top by nine 3" PMTs, and (iii) a system in which the PMT(s) would be deployed through the single string lock and the Ge diodes through the 3-string lock. In options (i) and (ii) the sensitive volume would be defined by a thin-walled copper cylinder covered with VM2000 reflecting foil and a wave length shifter like TPB. Monte Carlo calculations for assessing the efficiency of the various designs are in progress.

The third option uses Si devices like large area APDs (1 cm^2) and large area SiPM (1 cm^2) to directly readout the LAr scintillation light without WLS. These devices would be mounted close to the Ge diodes (unlike the radioactive PMTs). They could veto energy depositions in volumes shadowed by the detectors themself or inside a mini-shroud. MC studies to define the needed coverage are in a very early phase. SiPM tiles will be provided in die by IRRST Trento and by Hamamatsu, however not as die but mounted on a custom substrate. Hamamatsu provides also the chosen large area APD: S8664-1010 (to be used with WLS) and S8664-1010VUV SPL. The latter is a novel devices that thanks to a special treatment of the surface is sensitive to UV light (nominal QE of 50% at 128 nm). We expect two samples for testing. All the selected devices will be deployed in a comparative experimental test, together with reference PMTs, to demonstrate the veto efficiency.

Outlook: The GERDA commissioning phase is currently being completed. The estimated background index at $Q_{\beta\beta}$ is significant lower than in previous experiments, however still above the Phase I goal. A single dominant contribution to the background could not be identified. More counting statistics is required to identify weak lines and the shape of the background spectrum. The collaboration thus decided to proceed with the deployment of the full array of enriched Phase I detectors and to commence with the physics data taking. Preparation of Phase II has made major progress and first crystal slices for enriched BEGe detector production could be available by January 2012. According to the schedule of Canberra Industries, 20 kg of Phase II BEGe detectors shall be available within eleven months after start of production on October, 17, 2011, thus allowing a timely start of Phase II. Design work for the instrumentation of LAr in GERDA is pursued with high priority. We are confident that the background can be reduced substantially with the superior pulse shape discrimination of BEGe detectors together with the LAr scintillation veto.

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