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Status report of the Gerda Phase II startup

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Summary. — The GERmanium Detector Array (Gerda) experiment, located at the Laboratori Nazionali del Gran Sasso (LNGS) of INFN, searches for $0\nu\beta\beta$ of ^{76}Ge. Germanium diodes enriched to $\sim 86\ \%$ in the double beta emitter ^{76}Ge ($^{\mathrm{enr}}$Ge) are exposed being both source and detector of $0\nu\beta\beta$ decay. This process is considered a powerful probe to address still open issues in the neutrino sector of the (beyond) Standard Model of particle Physics. Since 2013, at the completion of the first experimental phase (Phase I), the Gerda setup has been upgraded to perform its next step (Phase II). The aim is to reach a sensitivity to the $0\nu\beta\beta$ decay half-life larger than 10^{26} yr in about 3 years of physics data taking, exposing a detector mass of about 35 kg of $^{\mathrm{enr}}$Ge with a background index of about 10^{-3}cts/(keV·kg·yr). One of the main new implementations is the liquid argon (LAr) scintillation light read-out, to veto those events that only partially deposit their energy both in Ge and in the surrounding LAr. In this paper the Gerda Phase II expected goals, the upgraded items and few selected features from the first 2016 physics and calibration runs will be presented. The main Phase I achievements will be also reviewed.

1. – The Gerda experiment

The construction of the Gerda setup was tailored to minimize the several background sources. The germanium detectors are mounted in low mass ultra-pure holders and are directly inserted in 64 m^3 of liquid argon (LAr), acting both as cooling medium and shield against external background radiation. Figure 1 shows the section of the Gerda setup; the argon cryostat is complemented by a water tank with 10 m diameter which further shields from neutron and γ backgrounds. It is instrumented with photomultipliers to veto the cosmic muons by detecting Čerenkov radiation. The muon veto hermeticity is provided by plastic scintillators installed on the top of the structure. A detailed description of the experimental setup is in ref. [1].

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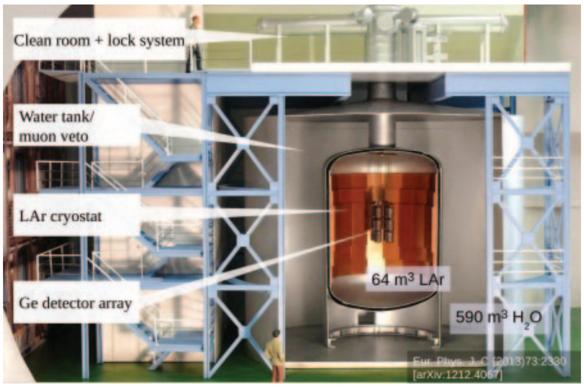

Eur. Phys. J. C (2013)73:2330 [arXiv:1212.4067]

Fig. 1. – Section of the GERDA experiment.

1˙1. *Phase I*. – A first physics data-taking campaign, referred to as Phase I, was carried out from November 2011 to June 2013. In this phase eight p-type semi-coaxial detectors enriched in ^{76}Ge from the Heidelberg-Moscow (HdM) [2] and IGEX [3] experiments and five Broad Energy Germanium (BEGe) detectors were used [4]. Three coaxial detectors with natural isotopic abundance from the previous Genius Test Facility (GTF) project [5, 6] were also installed.

The final Phase I data sets show a flat background in the $Q_{\beta\beta}(= 2039\,\mathrm{keV})$ region and the GERDA background model [7] predicts it comes mainly from Compton events of γ rays of ^{208}Tl and ^{214}Bi decays, degraded α events and β rays from ^{42}K and ^{214}Bi.

To derive the signal strength at $Q_{\beta\beta}$ and a frequentist coverage interval, a profile likelihood fit was performed [8]; the best fit is no signal events above the background and the derived half-life limit on $0\nu\beta\beta$ decay is

$$T^{0\nu}_{1/2} > 2.1 \cdot 10^{25}\mathrm{yr}\ (90\%\ \mathrm{CL}), \tag{1}$$

including the systematic uncertainty.

GERDA Phase I data show no indication of a peak at $Q_{\beta\beta}$ and the claim for the observation of $0\nu\beta\beta$ [9] decay in ^{76}Ge is not supported.

1˙2. *Upgrade to Phase II*. – The goal of GERDA Phase II is tenfold reduction of the Phase I background; this can only be achieved by an optimized experimental design. After several years of R&D, a version of the broad energy germanium (BEGe) detector [10] from Canberra with a thick entrance window has been selected. The advantages of BEGe detectors are their superior rejection of background by a simple but powerful criteria (based on the ratio A/E between the amplitude of the current pulse A and the total energy E) and their optimal energy resolution due to a very low detector capacitance ($\sim$ pF). In addition an active suppression of background by detecting the LAr scintillation light is introduced.

Figure 2 (left) shows the core of the Phase II GERDA setup: the Ge detector array, whose mass is doubled compared to Phase I, is at the center of a vetoed LAr volume.

The design allows to assemble both the detector array and the surrounding LAr veto system in the open lock under dry nitrogen atmosphere and to lower both systems together into the cryostat.

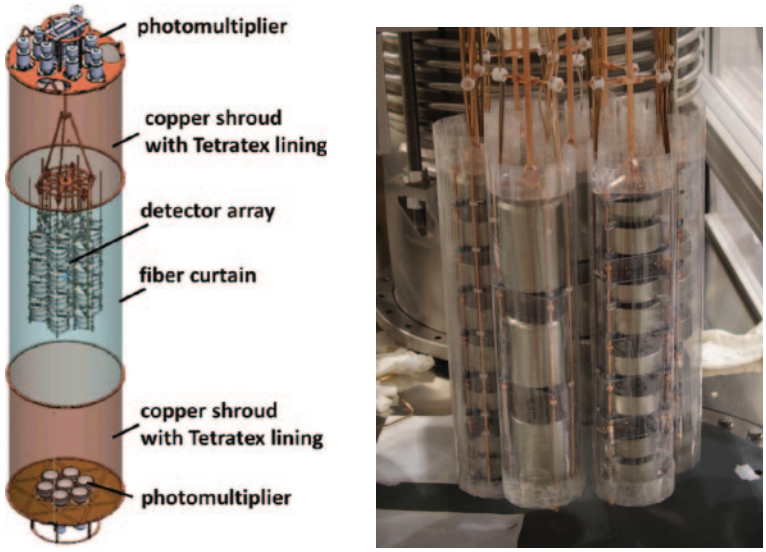

Fig. 2. – Left: Phase II assembly of detector array and LAr veto system as it will be immersed into the cryostat. Right: Full detector array of Gerda Phase II mounted on December 2015.

2. – First result of Phase II data taking

The commissioning of the setup started in 2015 and several runs were performed with different detector configurations.

On December 20th, 2015 the Phase II configuration with all the detectors mounted in the array was achieved and the physics data taking was started.

Figure 2 (right) shows a picture of the full array just before the immersion in LAr: seven $^{\mathrm{enr}}$Ge plus three natural coaxials (both from Phase I) and thirty new $^{\mathrm{enr}}$Ge BEGe detectors for a total of 40 detectors accounting for 35.6 kg of $^{\mathrm{enr}}$Ge and 7.6 kg of $^{\mathrm{nat}}$Ge are organized in seven strings. Each detector string is surronded by a nylon mini-shroud, preventing the ^{42}K ions from being drifted and diffused at the detector surfaces.

After the immersion of the array all 40 detectors are working, most of them are at operational voltage showing a leakage current < 100 pA, 3 BEGes and one coaxial detectors are showing a value of LC $\gtrsim 100$ pA and needed a decrease of the bias voltage. At the end all diodes are above the depletion voltages and the leakage current is stable during the months of operation.

The energy scale is determined by weekly irradiation of the Ge detector array by three ^{228}Th (20–30 kBq) sources. The stability of the setup is monitored comparing the reconstructed peak positions in subsequent calibrations. Excluding few cases, the shift range is between -1 keV and $+1$ keV, showing a Gaussian distribution centered at zero.

The performances of the setup are also assessed from the calibration data. The energy spectrum is reconstructed and the energy resolution (in terms of FWHM) of the peaks is evaluated. In Gerda a detector-customized digital filtering method was developed in order to improve the energy resolution [11].

The FWHMs of the 2614.5 keV peak of three calibration runs of Phase II are shown in fig. 3 both for BEGes and coaxials. The reported values are derived applying the

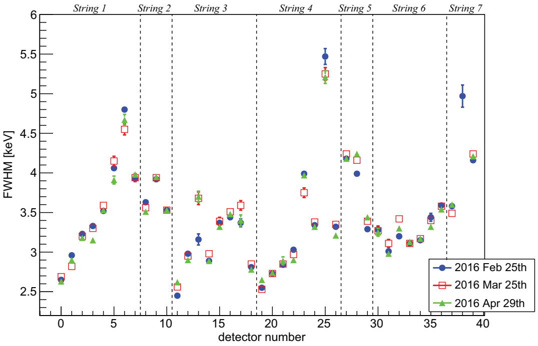

Fig. 3. – FWHM at 2614.5 keV for three calibration runs of Phase II. The horizontal axis follows the detector progressive number and the top legend reports the string number.

optimal filter to each detector. The energy resolutions are in the range from 2.5 keV to about 5.5 keV for the BEGes and from 3.3 keV to 5.0 keV for the coaxials. The FWHM is also substantially stable within 0.2 keV in 5 months of operation.

Figure 3 reveals that the BEGe energy resolution correlates to the detector position in the string: it scales with the distance between detector and readout electronics. The same trend is observed for the resolution of the 1593 keV line A/E distribution; being the double escape peak of the ^{208}Tl 2615 keV γ-line it is a proxy for single site events. This trend is found for all the four BEGe strings and is not completely unexpected, but for its amplitude: the longer the contact, the larger its stray capacitance. Detailed analysis is in progress to model and finally improve the noise.

In fig. 4 the events of the BEGe's data sets are plotted in the plane A/E *vs.* energy; the energy region $Q_{\beta\beta} \pm 25$ keV is blinded for the analysis, while $Q_{\beta\beta} \pm 200$ keV region is not presented in publications at the time of this write up (the green region in the figure). As expected the A/E correlates to a large extent, both with the nature and the position of the particle releasing the energy, hence for BEGes it can be used to discriminate the events at $Q_{\beta\beta}$. For coaxials a Neural Network based study of the pulse profile is implemented instead of the simple A/E ratio.

In the high energy part of fig. 4, alpha events show an high A/E (> 1) consistent with an energy release close to the detector p^+ contact; γ events, mostly visible in the energy region below the hidden data, show a distribution of the A/E with a concentration

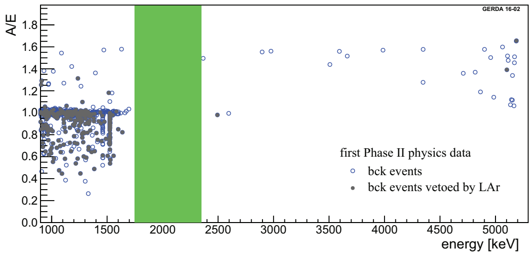

Fig. 4. – A/E ratio for background events in BEGe detectors as a function of the energy.

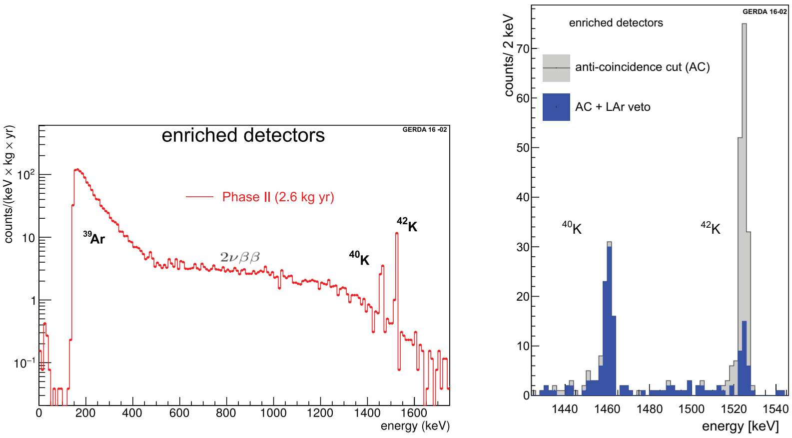

Fig. 5. – Left: GERDA Phase II background spectrum of first 2.6 kg·yr of exposure. Right: Energy region of the γ-lines from ^{40}K and ^{42}K before (in grey) and after (in blue) the LAr veto cut.

around one and a component at low A/E (< 1); this is in agreement with the multi-site fraction of the γ events.

A first Phase II background spectrum cut at 1.7 MeV, normalized to the present exposure of 2.6 kg·yr, is shown in fig. 5 (left). The spectrum shows the expected prominent structures: the low energy region (up to 500 keV) is dominated by the long-lived ^{39}Ar isotope; from 600 to 1400 keV the $2\nu\beta\beta$ spectrum shows up; then the 1461 keV and 1525 keV γ-lines from ^{40}K and ^{42}K, respectively, are visible.

In fig. 5 (right) the two K γ-lines region is zoomed: the anti-coincidence spectrum (grey), with the requirement of energy deposit in only one detector, is superimposed with the spectrum after the LAr veto cut. The ^{42}K peak, generated by the steady ^{42}Ar decay, is highly suppressed by the LAr veto by a factor of ~ 5, while the ^{40}K is not suppressed because it is a single γ-line that releases all the energy in the detectors.

3. – Conclusions

After GERDA Phase I established a new important limit on $0\nu\beta\beta$ decay of ^{76}Ge, the Phase II started in December 2015.

All detectors are working and the performances of the first period of data taking indicate that the physics data taking is progressing smoothly. The main spectral structures have been recognized and the energy and pulse shape analysis methods developed in Phase I have been applied. For BEGes detectors a trend of both energy and PSD resolution is observed and work is ongoing to understand and mitigate it. The achieved LAr veto suppression factor is a factor 5 for the 1525 keV ^{42}K γ-line, the suppression in the blinded region, relevant for $0\nu\beta\beta$, is under evaluation.

The GERDA Phase II physics program is to collect 100 kg·yr of exposure searching for the ^{76}Ge $0\nu\beta\beta$ improving both the half-life and the effective Majorana neutrino mass limits, possibly attaining the top border of the neutrino masses inverted hierarchy region.

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REFERENCES

[1] GERDA COLLABORATION (ACKERMANN K. H. *et al.*), *Eur. Phys. J. C*, **73** (2013) 2330.
[2] GUNTHER M. *et al.*, *Phys. Rev. D*, **55** (1997) 54.
[3] AALSETH C. E. *et al.*, *Nucl. Phys. Proc. Suppl.*, **48** (1996) 223.
[4] GERDA COLLABORATION (AGOSTINI M. *et al.*), *Eur. Phys. J. C*, **75** (2015) 39.
[5] BAUDIS L. *et al.*, *Phys. Rep.*, **307** (1998) 301.
[6] KLAPDOR-KLINGROTHAUS H. V. *et al.*, *Nucl. Instrum. Methods A*, **481** (2002) 149.
[7] GERDA COLLABORATION (AGOSTINI M. *et al.*), *Eur. Phys. J. C*, **74** (2014) 2764.
[8] GERDA COLLABORATION (AGOSTINI M. *et al.*), *Phys. Rev. Lett.*, **111** (2013) 122503.
[9] KLAPDOR-KLINGROTHAUS H. V. *et al.*, *Phys. Lett. B*, **586** (2004) 198.
[10] BUDJÁŠ D. *et al.*, *JINST*, **4** (2009) P10007.
[11] GERDA COLLABORATION (AGOSTINI M. *et al.*), *Eur. Phys. J. C*, **75** (2015) 255.