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The GERDA experiment at Gran Sasso: Search for neutrinoless double beta decay in germanium 76

A. Garfagnini(*)

Dipartimento di Fisica e Astronomia, Università di Padova e INFN, Sezione di Padova Padova, Italy

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Summary. — The GERmanium Detector Array (GERDA) is a low background experiment at the Laboratori Nazionali del Gran Sasso (LNGS) designed to search for the rare neutrinoless double beta decay ($0\nu\beta\beta$) of ^{76}Ge. In the first phase of the experiment, high purity germanium diodes inherited from the former Heidelberg-Moscow and IGEX experiments are operated "bare" and immersed in liquid argon, with an overall background environment of $2 \cdot 10^{-2}$ cts/(keV kg yr), a factor of ten better than its predecessors. Preliminary measurements on two neutrinos double beta decay ($2\nu\beta\beta$) giving $T^{2\nu}_{1/2} = (1.88 \pm 0.10) \cdot 10^{21}$ yr and a recently published background model are discussed in the paper. Results on $0\nu\beta\beta$ are expected in summer 2013 and, in the absence of a signal, the expected sensitivity is $T^{0\nu}_{1/2} > 1.9 \times 10^{25}$ yr. Phase II of the experiment is scheduled to start at the end of 2013, after an upgrade shutdown, with an additional set of new detectors. Thanks to the new design of the diodes and to the introduction of liquid argon instrumentation techniques, the experiment aims to reduce further the expected background to about $1 \cdot 10^{-3}$ cts/(keV kg yr), and improve the $0\nu\beta\beta$ sensitivity to $T^{0\nu}_{1/2} > 1.35 \cdot 10^{26}$ yr.

PACS 07.85.Fv – X- and γ-ray sources, mirrors, gratings, and detectors.
PACS 29.40.-n – Radiation detectors.
PACS 13.35.Hb – Decays of heavy neutrinos.
PACS 23.40.-s – β decay; double β decay; electron and muon capture.

1. – Introduction

Double beta decay is the simultaneous beta decay of two neutrons in a nucleus. It is a second order weak process, predicted by the Standard Model: $(A, Z) \to (A, Z + 2) + 2e^- + 2\overline{\nu}_e$. The process ($2\nu\beta\beta$) has been experimentally observed in even-even nuclei [1] and can be detected only when the single beta decay is energetically forbidden.

(*) E-mail: alberto.garfagnini@pd.infn.it

Typical half lives are very large and lie between $7 \cdot 10^{18}$ yr and $2 \cdot 10^{24}$ yr [1]. Since neutrinos do not have an electric charge, they could mix with their anti particle and a neutrinoless double beta decay process, $(A, Z) \to (A, Z{+}2){+}2e^-$, could occur ($0\nu\beta\beta$). Its observation implies that the lepton number is violated by two units indicating physics beyond the Standard Model. For a recent review on $0\nu\beta\beta$, see [2]. The GERDA [3] experiment in Europe, and MAJORANA [4] in USA are the current state of the art experiments to search for $0\nu\beta\beta$ in ^{76}Ge using germanium detectors. The process has a clear signature, with a mono-energetic line in the observed energy spectrum at $Q_{\beta\beta} = 2039.061 \pm 0.007$ keV [5], corresponding to the sum of the two electrons energies. Two previous experiments, Heidelberg-Moscow (HdM) and IGEX, have studied double beta decay in germanium and set limits on the $0\nu\beta\beta$ half live: $T^{0\nu}_{1/2} > 1.9 \cdot 10^{25}$ yr [6] and $T^{0\nu}_{1/2} > 1.6 \cdot 10^{25}$ yr [7], respectively. Part of the HdM collaboration claimed evidence for a peak at $Q_{\beta\beta}$ which corresponds to a half live central value of $T^{0\nu}_{1/2} = 1.19 \cdot 10^{25}$ yr [8]. The result was later refined with pulse shape analysis (PSA) techniques giving a half life $T^{0\nu}_{1/2} = 2.23^{+0.44}_{-0.31} \cdot 10^{25}$ yr [9].

The data taking of the GERDA experiment has been organized in two phases. During Phase I, the experiment aims to scrutinize the HdM claim, using high purity germanium detectors previously used by the HdM and IGEX collaborations (about 13 kg of active mass), and operating in a environment with a lower background. In case of no confirmation, the limit will be improved by an order of magnitude during the Phase II with the help of an additional set of new detectors (increasing the active mass by about 18 kg) and a higher background suppression thanks to liquid argon instrumentation and enhanced pulse shape discrimination of the new detectors.

In the following sections, after a brief introduction to the experimental setup, the Phase I results will be reviewed: the first measurement on $2\nu\beta\beta$ half life and a detailed study of the GERDA background model. The latter is an important ingredient to exploit the $0\nu\beta\beta$ sensitivity of the experiment.

2. – The GERDA experiment

The GERDA [3] experiment, at the Laboratori Nazionali del Gran Sasso (LNGS) of INFN, operates germanium diodes made of isotopically modified material, enriched to about 88% in ^{76}Ge, without encapsulation in a liquid argon cryogenic bath. The experiment aims to pursue very low backgrounds thanks to ultra-pure shielding against environmental radiation. An artist view of the detector is given in fig. 1. The germanium detectors are suspended in strings into the cryostat. The 64 m^3 of LAr are used both as a coolant and shield. The stainless steel cryostat vessel is covered, from the inside, with copper lining to reduce gamma radiation from the cryostat walls. The vessel is surrounded by a large tank filled with high purity water (590 m^3) which further shields the inner volumes from the experimental hall radiation (absorbing γs and moderating neutrons). Moreover it provides a sensitive medium for the muon system which operates as a Cherenkov muon veto. Further information on design, construction and first operational results of GERDA can be found here [3].

3. – GERDA Phase I results

The first phase of the experiment has started on November 9, 2011 using eight reprocessed coaxial germanium detectors from the HDH and IGEX experiments together with

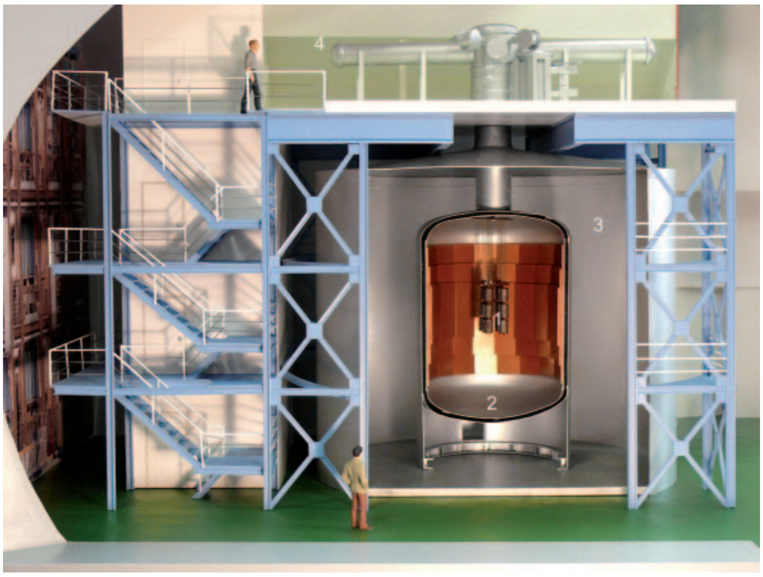

Fig. 1. – Artist view of the GERDA experiment. The following components are labeled in the picture: 1) the germanium array strings (not to scale), 2) the LAr cryostat, 3) the instrumented Water Tank and 4) the Clean Room with the Lock insertion system. From [3].

three natural germanium diodes. In July 2012, two of the coaxial detectors with natural isotopic abundance have been replaced by five new enriched Broad Energy Germanium (BEGe) detectors. The latters are a sub-sample of the thirty new BEGe detectors recently constructed by Canberra for the Phase II of the experiment. Figure 2 shows the energy spectra in the range from 100 keV to 7.5 MeV for enriched coaxial (top), enriched BEGe (middle) and natural coaxial (bottom) detectors. The corresponding exposures are $\mathcal{E} = 16.70$ kg yr, $\mathcal{E} = 1.80$ kg yr and $\mathcal{E} = 3.13$ kg yr, for the enriched coaxial, enriched BEGe and natural abundance coaxial, respectively. The low energy part of the plots (up to 565 keV) is dominated by ^{39}Ar β-decay. The upper part of the spectrum (up to 1500 keV) shows an enhanced continuous in the enriched germanium detectors due to $2\nu\beta\beta$ decays. In all spectra γ lines due to ^{40}K and ^{42}K are visible, while the coaxial detectors exhibit γ lines from ^{60}Co, ^{208}Tl, ^{214}Bi, ^{214}Pb, and ^{228}Ac [10]. The higher energy part of the spectra is characterized by α decays with peak-like structures clearly visible in the upper plot at 4.7 MeV, 5.4 MeV and 5.9 MeV; the lines can be attributed to α decays of ^{226}Ra, ^{222}Rn and ^{218}Po on the detector surfaces [10]. As shown in the plot, a region of 40 keV centered on the expected $Q_{\beta\beta}$ value, has been blinded by the GERDA collaboration and excluded from all analysis and background model results presented so far. A background model [10] has been developed and describes the full energy spectrum, from 570 keV to 7.5 MeV, well. The model [10] has been used to predict the background component in the blinded region for the $0\nu\beta\beta$ analysis. The only significant contributions [10] originate from ^{42}K decays in LAr, from ^{214}Bi in the detector holders and from ^{222}Rn and ^{228}Th dissolved in LAr and the detector assembly, respectively. Moreover α surface contamination plays a role. The largest contributions in the $0\nu\beta\beta$ region of interest (ROI) come from all contaminants close to the detectors (mainly holders and readout components). The background index (BI) in the ROI is $(1.75^{+0.26}_{-0.24}) \cdot 10^{-2}$ cts/(keV kg yr) for the coaxial detectors and $(3.6^{+1.3}_{-1.0}) \cdot 10^{-2}$ cts/(keV kg yr) for the enriched BEGes.

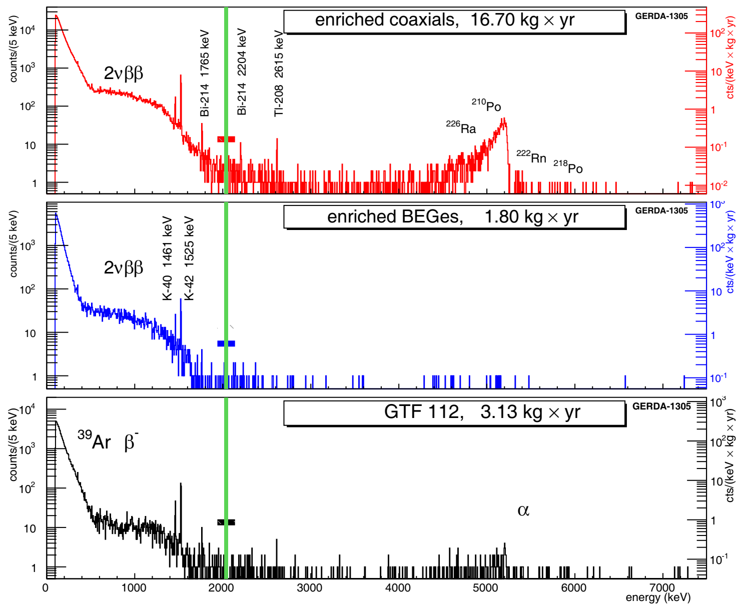

Fig. 2. – GERDA germanium energy spectra. The corresponding type of detectors and exposure is indicated in the plots. The $0\nu\beta\beta$ blinding window (40 keV centered on $Q_{\beta\beta}$) is shown as a green line. Taken from [10].

The first 5.04 kg yr data, collected before the insertion of the new BEGe detector, have been used to measure the half-life of the $2\nu\beta\beta$ decay of ^{76}Ge [11]. The extracted half-life is $T_{1/2}^{2\nu} = (1.84^{+0.14}_{-0.10}) \cdot 10^{21}$ yr (stat. and syst. errors added in quadrature). As can be seen from fig. 3, the value is higher than previously published measurements. The

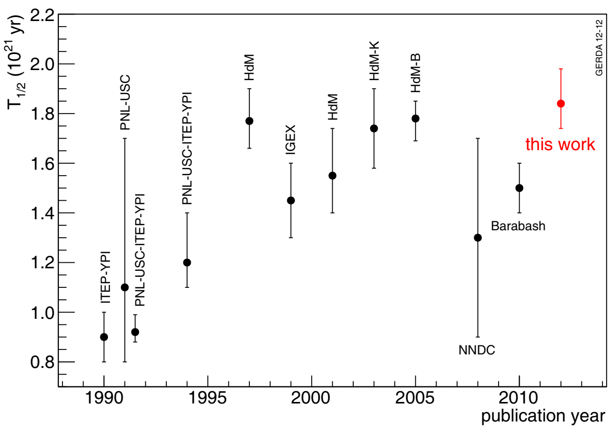

Fig. 3. – Compilations of ^{76}Ge $T_{1/2}^{2\nu}$ results. The plot, taken from [11], includes results over more than 10 years. The GERDA result can be compared to the recent NNDC-recommended value [12] and the global weighted average evaluated by Barabash [13].

systematic longer half life is probably due to higher signal-to-background ratio which are less sensitive to background modeling and subtraction. The total GERDA uncertainty is comparable to the last results of the HdM experiment, in spite of the much smaller exposure (5.04 kg yr *versus* 50.5 kg yr for HdM-B [14] and 41.57 kg yr for HdM-K [15]).

4. – Towards Phase II

The Phase II of the experiment is planned to start at the beginning of 2014. Starting from summer 2013, a shutdown is foreseen to upgrade the experiment infrastructure and install thirty new BEGe diodes. The detectors, which have been recently characterized at the HADES underground laboratory [16], in Belgium will increase the experiment active mass by about 18 kg. Thanks to liquid argon instrumentation and enhanced pulse shape discrimination power of the new BEGe detectors, a background reduction from the current BI of about $2 \cdot 10^{-2}$ cts/(keV kg yr) to $0.1 \cdot 10^{-2}$ cts/(keV kg yr) is expected. With the new configuration, the experiment is supposed to collect an exposure of about 100 kg yr and and improve the $0\nu\beta\beta$ sensitivity to $T^{0\nu}_{1/2} > 1.35 \cdot 10^{26}$ yr.

REFERENCES

[1] Nakamura K. *et al.*, *J. Phys. G*, **37** (2010) 075021.
[2] Schwingenheuer B., *Ann. Phys.*, **525** (2013) 269.
[3] Ackermann K.-H. *et al.*, *Eur. Phys. J. C*, **73** (2013) 2330.
[4] Finnerty P. *et al.*, *The MAJORANA DEMONSTRATOR: Progress towards showing the feasibility of a tonne-scale* ^{76}Ge *neutrinoless double-beta decay experiment, XVIII International Symposium on Particles, Strings and Cosmology, Mexico, June 3-8, 2012*.
[5] Mount B. J., Redshaw M. and Myers E. G., *Phys. Rev. C*, **81** (2010) 032501.
[6] Klapdor-Kleingrothaus H. V. *et al.*, *Eur. Phys. J. A*, **12** (2001) 147.
[7] Aalseth C. E. *et al.*, *Phys. Rev. D*, **65** (2002) 092007.
[8] Klapdor-Kleingrothaus H. V *et al.*, *Phys. Lett. B*, **586** (2004) 198.
[9] Klapdor-Kleingrothaus H. V. and Krivosheina I. V., *Phys. Lett. A*, **21** (2006) 1547.
[10] Agostini M. *et al.*, arXiv:1306.5084.
[11] Agostini M. *et al.*, *J. Phys. G*, **40** (2013) 035110.
[12] Pritychenko B., *Proc. Nuclear Structure 2008, 3-6 June, 2008, East Lansing, MI*; Brookhaven National Laboratory Report BNL-91299-2010 (2010).
[13] Barabash A. S., *Phys. Rev. C*, **81** (2010) 035501.
[14] Bakalyarov A. M. *et al.*, *Phys. Part. Nucl. Lett.*, **2** (2005) 77.
[15] Dörr C. and Klapdor-Kleingrothaus H. V., *Nucl. Instrum. Methods A*, **513** (2003) 596.
[16] Andreotti E. *et al.*, *JINST*, **8** (2013) P06012.