# The GERDA Neutrinoless-Double-Beta decay experiment

Béla Majorovits for the GERDA collaboration
*Max-Planck-Institut für Physik, Föhringer Ring 6, 80805 München, Germany*
*email: bela@mppmu.mpg.de*

Neutrinoless double beta ($0\nu\beta\beta$)-decay could be the key to understanding the nature of the neutrino. The GErmanium Detector Array (GERDA) is designed to search for $0\nu\beta\beta$-decay of the isotope $^{76}$Ge. Germanium crystals enriched in $^{76}$Ge, acting as source and detector simultaneously, will be submerged directly into their ultra pure cooling medium that also serves as a radiation shield. This concept will allow for a reduction of the background by up to two orders of magnitudes with respect to earlier experiments.

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## 1. Introduction

Neutrino accompanied double beta-decay is an allowed second order weak process. If the neutrino is a massive Majorana–particle the decay can occur without the emission of a neutrino [1]. The GERmanium Detector Array, GERDA, [2] is designed to search for $0\nu\beta\beta$-decay of $^{76}$Ge. The importance of such a search is emphasized by the fact that the observation of a non-zero neutrino mass from flavor oscillations [3] does not give any information on its absolute value. The neutrino-oscillation observations do allow for two different mass scenarios with a normal or an inverted hierarchy [4]. These can be disentangled by $0\nu\beta\beta$-decay if a sensitivity for the effective Majorana neutrino-mass of 10 $meV$ can be achieved [5].

The most sensitive $0\nu\beta\beta$ experiments are based on High-Purity-Germanium, HPGe,T detector technology. This is due to the combination of a very good energy resolution of the detectors at the $Q_{\beta\beta}$-value of $^{76}$Ge, the very high purity of the detectors (very low intrinsic background) and the high signal detection efficiency of an experiment with detector being equal the source.

Currently the Heidelberg-Moscow (HdMo) and IGEX experiments give lower limits for $0\nu\beta\beta$-decay of $1.9{\cdot}10^{25}y$ and $1.6{\cdot}10^{25}y$, respectively [6,7].

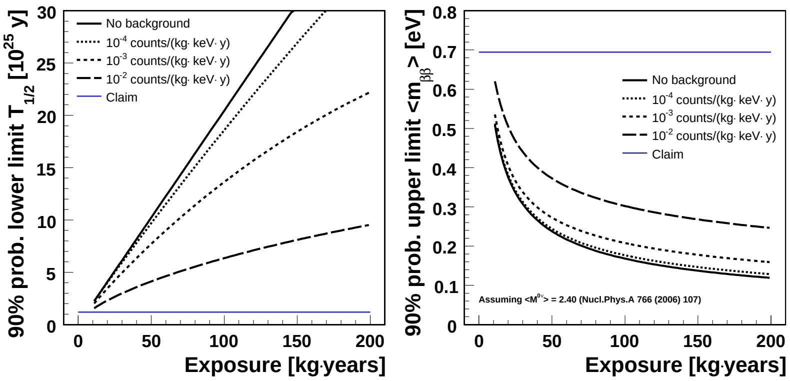

Fig. 1. Left: 90% probability to set lower limit on $T_{1/2}^{0\nu\beta\beta}$ higher than displayed as a function of exposure for different background indices. Right: 90% probability to set upper limit on effective Majorana neutrino mass lower than displayed using matrix elements from [10] as a function of exposure.

These upper limits can be translated into upper limits for the effective Majorana neutrino-mass of 0.35 $keV$-1.2 $keV$ and 0.3 $keV$-1.5 $keV$ for the two experiments, respectively. The large range is due to uncertainties in the matrix-element calculations [8]

A part of the HdMo collaboration claims to have observed a peak at $Q_{\beta\beta}$ with $4.2\sigma$ confidence level which can be attributed to $0\nu\beta\beta$-decay with a half-life of $T_{1/2}^{0\nu\beta\beta}$=$1.29 \cdot 10^{25} y$. [9].

## 2. Sensitivity and the Principles of GERDA

The sensitivity obtainable for double beta experiments with a given exposure and background index is displayed in Fig. 1. The 90 % probability for obtaining lower limits higher than the displayed values as a function of exposure for given background indices are given in the left panel. The right panel shows the upper bounds that can be put on the effective Majorana-neutrino mass using matrix elements from [10] with 90 % probability. The values were calculated using Monte-Carlo ensemble test on the basis of Bayesian statistics [11].

For a given exposure the background limits the sensitivity. Therefore the goal is to minimize the background. This can be achieved by using an ultra-pure cryogenic liquid as the cooling medium and as shield against gamma radiation simultaneously [12]. The cryo-tank will be made out of carefully selected stainless steel. Additionally it will contain a low-background copper inlet as a radiation shield against the steel of the cryo-tank. The cryogenic

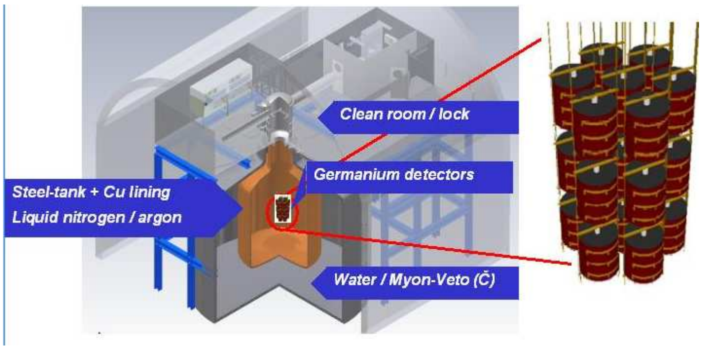

Fig. 2. Schematic view of the GERDA setup. The detector array is sitting in the center of the cryo tank. The cryo tank is surrounded by a water buffer serving as additional shield and as a muon-Čerenkov veto system. The detector array shown on the right is loaded through a lock system from the top of the tank. The lock will be installed in a clean-room

volume is surrounded by a buffer of ultra-pure water acting as an additional gamma and neutron shield. The water buffer is additionally used as a muon-Čerenkov veto. The setup is schematically depicted in Fig. 2.

GERDA will be installed in Hall A of the Gran Sasso underground Laboratory (LNGS), Italy. The experiment is foreseen to proceed in two phases. In the first phase, enriched detectors which were previously operated by the HdMo- and IGEX- collaborations will be redeployed. The aim is to take 15 $kg \cdot y$ of data with a background level of $10^{-2}$ counts/$(kg \cdot y \cdot keV)$ at the $Q_{\beta\beta}$–value of 2039 $keV$. As can be seen in Fig. 1 this will be enough to either confirm or refute the claim from the Heidelberg-Moscow-Experiment. In the second phase custom made detectors will be installed which have a true coaxial geometry and are 18-fold segmented. An exposure of 100 $kg \cdot y$ with a background level of $10^{-3}$ counts/$(kg \cdot y \cdot keV)$ is foreseen. A lower limit on the half-life of $0\nu\beta\beta$-decay of higher than $1.5 \cdot 10^{26}$ $y$ corresponding to an upper limit of 100 $meV$ (using the matrix elements from [10]) can be set with 90 % probability for the case of a null signal (Fig. 1).

## 3. Main Background Sources

To estimate the background expected for Phase II of the GERDA experiment Monte Carlo studies were performed using the GEANT 4 implementation MaGe [13]. The geometries assumed for the detectors are according to the design of the first segmented prototype detector that has been developed and successfully operated [14].

$5{\cdot}10^{-4}$ counts/$(kg\cdot\ keV\cdot\ y)$ are expected from internal contaminations of the detector. The origin of this background is mainly cosmogenic $^{68}$Ge and $^{60}$Co.

This background is reduced by minimizing the exposure of the material to cosmic rays. Since $^{68}$Ge decays with a half-life of $T_{1/2}$=271 $d$ this component will decrease within the life-time of the experiment.

The largest contribution to the background is expected from the detector infrastructure, i.e. detector support cabling and electronics with $2.1{\cdot}10^{-3}$ counts/$(kg\cdot\ keV\cdot\ y)$. This component could already be considerably decreased by reducing the mass of the signal cables around the HPGe-crystal by a factor of four. Further material selection and material minimization are under way.

From the external infrastructure (cryo-tank, water shield, etc.) roughly $4{\cdot}10^{-4}$ counts/$(kg{\cdot}keV{\cdot}y)$ are expected for liquid nitrogen as the cryogenic liquid. Using liquid argon this is reduced to $3{\cdot}10^{-5}$ counts/$(kg{\cdot}keV{\cdot}y)$ being negligible compared to the dominant background sources.

Neutrons and muons are expected to yield roughly $2\ {\cdot}10^{-4}$ counts/$(kg\cdot keV\cdot y)$ the most important contribution being due to the delayed decay of $^{77}$Ge produced by the neutron capture on $^{76}$Ge [15].

If the background resulting from the detector infrastructure is reduced by a further factor of two, the goal of a total background index of less than $10^{-3}$Counts/$(kg\cdot\ keV\cdot\ y)$ can be reached.

## 4. Phase I and Phase II Status

All IGEX and HdMo detectors are presently underground at LNGS. The first of them have been taken out of their cryostats without any technical problems. The left panel of Fig. 3 shows the dismounting of the first enriched HdMo detector. The detectors are presently being checked for their properties and will then be installed into the phase I suspension. A prototype detector has been operated in liquid argon in the holder at LNGS since beginning of 2006. It has gone through more than twenty cooling and warming up cycles without showing major deterioration.

The enriched material for phase II of the experiment has been procured. 35.5 kg of germanium enriched to 87%-88% in $^{76}$Ge in form of GeO were transported from Krasnoyarsk, Siberia to Munich, Germany in a steel cylinder designed to reduce cosmogenic activation. The powder was unloaded, weighed and inspected (see Fig. 3) and subsequently transported to a 500 $mwe$ underground cite.

The phase II detectors will be 18-fold segmented true coaxial n-type.

Fig. 3. Left: Dismounting of first enriched detector of the HdMo experiment from its copper vacuum-cryostat. Right: Unloading of the 35 $kg$ enriched germanium. The green cylinder was built to shield the material against cosmogenic activation while transport from Siberia to Germany.

The segmentation will help to identify multiple Compton-scatter events in the region of interest. As shown in [16] the Compton background can be identified with high efficiency depending on its source and location.

A prototype detector was produced by Canberra-France. The 18 segments are read out using a novel contacting scheme [14]. The copper contact pads of a Kapton printed circuit board are pressed directly onto the contact areas of the segmented detector. This is shown in the left panel of Fig. 4. The prototype detector was extensively tested in a conventional test cryostat. The energy resolution of all signals and the core were around 3 $keV$ at 1.3 $MeV$. The right panel of Fig. 4 shows a measurement taken with a $^{60}$Co calibration source. The black histogram denotes the full spectrum from the core signal. The red histogram shows the spectrum requiring that only one segment had an energy deposit above a threshold of 20 $keV$. The Compton background discrimination was a factor of 10 for this measurement. The data could be reproduced very well by Monte Carlo simulations [16].

## 5. Conclusions

The Gerda neutrinoless double beta-decay experiment will be installed in the LNGS underground laboratory. For the first phase 15 $kg \cdot y$ data taking with a background index of $10^{-2}$ counts/$(kg \cdot keV \cdot y)$ are planned. This will allow to check the claim of a positive evidence from the HdMo-experiment. The goal of the second phase of the experiment is to collect 100 $kg\ y$ of data with a background index of not more than $10^{-3}$ counts/$(kg \cdot keV \cdot y)$. This

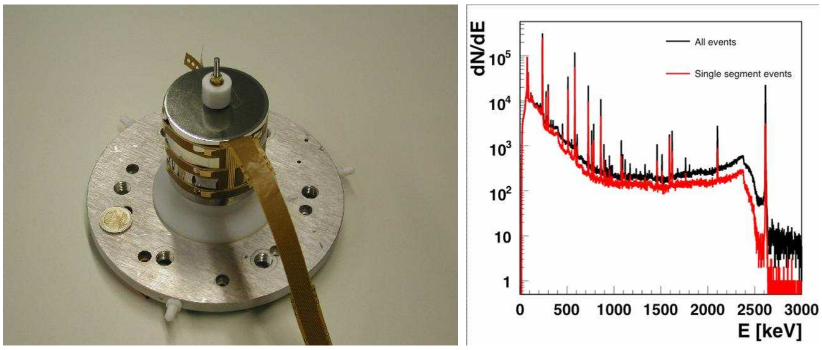

Fig. 4. Left: Germanium crystal with the new contacting scheme. The 18 segments are contacted by pressing the contact pads of Kapton printed circuit boards onto the segment contact area. Right: $^{60}$Co calibration spectrum taken with the first 18-fold segmented true coax n-type HPGe detector. For more details see the text.

will allow to set a lower limit for the $0\nu\beta\beta$ half life of $1.5{\cdot}10^{26}$ $y$ corresponding to an upper limit of the effective Majorana neutrino-mass of 100 $meV$. According to the Monte Carlo calculations this goal can be achieved. The detectors for phase I of the experiment are at the experimental site. The dismounting of the first detectors from the IGEX and the HdMo experiments was successful. A first prototype 18-fold segmented n-type HPGe detector has been produced and checked. Its performance is as expected.

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