THE GERDA EXPERIMENT AT GRAN SASSO*

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The GERDA experiment has been designed to search for neutrinoless double beta decay of ^{76}Ge. Observation of such a process would imply that the neutrino is a Majorana particle, and that the lepton number is not conserved. Establishing the half-life of the decay would also allow to estimate the effective neutrino mass. The installation of the experiment in the Gran Sasso underground laboratory of INFN/Italy has been recently completed. Deployment of the first non-enriched Ge detectors is scheduled for spring 2010.

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1. Introduction

The search for neutrinoless double beta ($0\nu\beta\beta$) decay is the most powerful method to study the fundamental question whether the neutrino is a Dirac or Majorana particle. It allows also to probe the effective neutrino mass down to the meV scale giving additionally some information about the neutrino mass hierarchy. Observation of the process would imply physics form beyond the Standard Model (neutrino is its own ant-particle and the lepton number non-conservation).

One of the isotopes undergoing double beta decay is ^{76}Ge. It is very attractive from the experimental point of view because high-purity germanium detectors (HPGe) can be produced from material enriched in ^{76}Ge (typical enrichment of 86%). HPGe crystals serve simultaneously as a source and as detector medium. Their advantages are the intrinsic radiopurity and excellent spectroscopic performance (energy resolution at the level of $\sim$ 0.2%).

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At the moment the most stringent experimental limits on $0\nu\beta\beta$ decay have been obtained using exactly Ge detectors [1]. One group has additionally reported a claim of evidence [2]. Other experiments searching for $0\nu\beta\beta$ decays with different isotopes could neither confirm nor refute this claim so far [3].

GERDA (GERmanium Detector Array) is a new neutrinoless double beta decay experiment using ^{76}Ge [4]. Its construction has been recently completed at the Laboratori Nazionali del Gran Sasso in Italy. In order to improve the sensitivity, a significant reduction of background compared to previous experiments was required. The main concept for background suppression followed in the project is the operation of bare Ge diodes in a large volume of ultrapure liquid argon (LAr). LAr acts here as a passive[1] shield and cooling medium.

2. The GERDA setup

The design of the GERDA experiment (see Fig. 1) is based on a concept of a multi-layer shield with the purity gradient towards the center, where naked Ge detectors are submersed in a large volume of ultra-pure LAr.

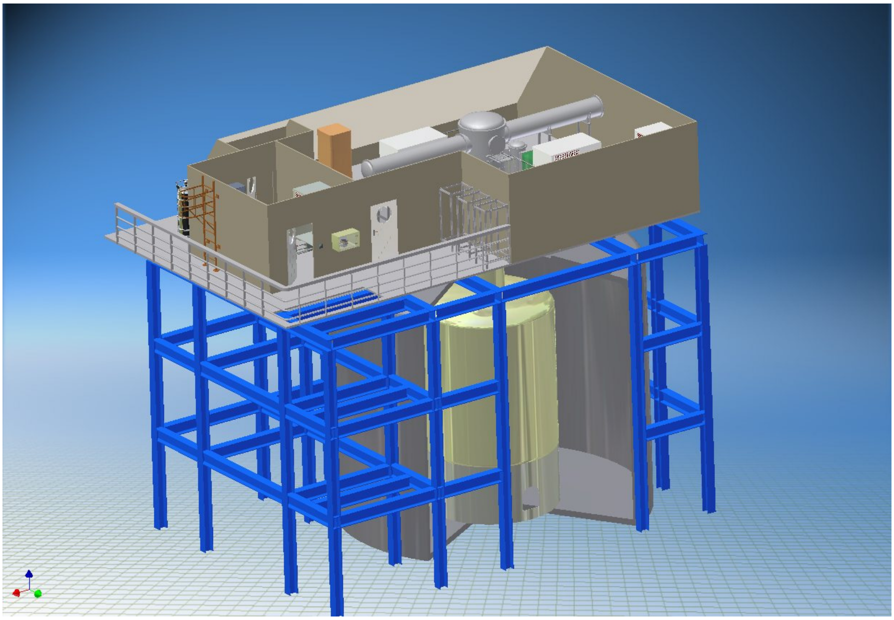

Fig. 1. Overall GERDA experimental setup.

[1] It is also possible to instrument LAr with PMTs and use it as an active veto shield — see the subsection about LArGe.

The gas ($70\,m^3$) is contained in a vacuum insulated stainless steel cryostat of 4.2 m diameter and a total height (including the neck) of 8.9 m. An inner cylindrical shell of the cryostat is additionally covered by a copper shield (to reduce the background from steel) with a maximum thickness of 6 cm and the total mass of about 20 t. The cryostat is placed in a water tank of 10 m diameter and 9.4 m high. The water buffer serves as a gamma and neutron shield and, instrumented with 66 photomultipliers, as Čerenkov detector for efficient vetoing of cosmic muons. Additional plastic scintillator panels on the top of the detector (with a total surface of about $20\,m^2$) will tag muons which enter the detector.

The cryostat is closed from the top with the lock allowing detector insertion into the liquid argon. The lock is mounted inside a clean-bench, which is successively a part of the clean room sitting on the superstructure.

The Ge detectors will be organized in strings (2–5 detectors) and these later will form an array in the cryostat. Individual strings will be completed in the clean bench and lowered down using a special pulley system installed in the lock.

Single Ge crystals will be mounted in special low-mass ($\sim 80\,g$) holders made out of ultra-pure copper and PTFE. Both materials were screened by gamma ray spectroscopy and only upper limits for U/Th contaminations were found ($\sim 20\ \mu$Bq/kg for copper and $100\,\mu$Bq/kg for PTFE). Monte Carlo simulations have shown that the background from the material of the detector holder fulfills the specification.

3. The GERDA sensitivity

The GERDA experiment will be performed in phases: In phase I 17.5 kg of existing ^{76}Ge (8 diodes) from the previous Heidelberg–Moscow and IGEX experiments will be used (after refurbishment). At the expected background rate of 10^{-2} cts/(kg keV y) at the Q-value of the ^{76}Ge decay (2039 keV) the resulting sensitivity for the half-life of the neutrinoless double beta decay is 2×10^{25} y after a year of exposure. This is sufficient to confirm or refute the existing claim [2]. In the next step (phase II) new diodes will be added to increase the active mass up to 37.5 kg. With a simultaneous background reduction down to 10^{-3} cts/(kg keV y) it will allow to increase the sensitivity to the half-life of the process by one order of magnitude for the total exposure of 100 kg y. In this case it would be also possible to probe the effective neutrino masses (m_{ee}) at the level of 150 meV.

Mentioned background reduction will be achieved by applying special p-type Broad Energy (BEGe) or true-coaxial n-type segmented detectors, minimization of their cosmic ray exposure (during the whole production chain) and sophisticated pulse shape discrimination.

A third phase aiming to probe the inverted neutrino mass hierarchy regime ($m_{ee} \sim 50$ meV) would require about 1 ton of ^{76}Ge target material as well as a further reduction of background. This could be realized only in a word-wide collaboration.

A Bayesian analysis applied to Monte Carlo event samples was used to determine the sensitivity of GERDA. Spectra were simulated for different assumed background rates, $T_{1/2}$ for neutrinoless double beta decay, and exposures, and the probability of observing a given spectrum assuming only background processes was evaluated. The discovery threshold was set at a probability of 0.01%. The analysis assumed a prior probability for background only of 50%, an uncertainty on the background rate of 50%, and a flat probability for the number of signal events up to a maximum corresponding to $T_{1/2} = 5 \times 10^{24}$ years. For the setting of upper limits, experiments were simulated with background events only. The analysis of the resulting spectra assumed that double beta decay processes exist in addition to the background processes, and a 90% upper limit on the possible number of signal events was evaluated.

Fig. 2 shows the expected 90% probability lower limit on the half-life for neutrinoless double beta decay plotted *versus* the exposure under different background conditions. The half-life (most likely value) for the claimed observation for neutrinoless double beta decay of ^{76}Ge [2] is also shown (marked as "Claim").

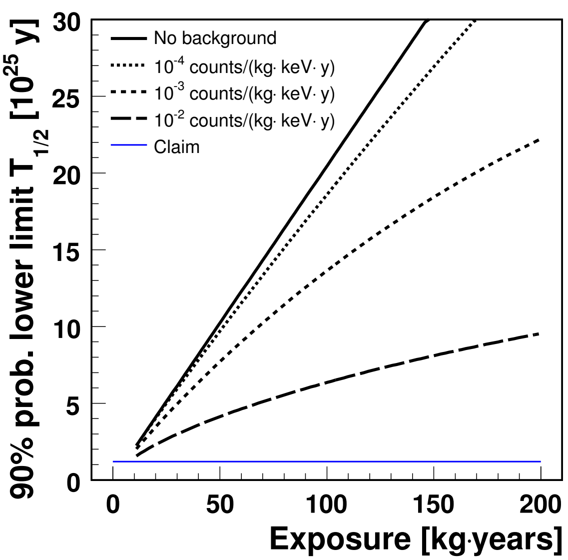

Fig. 2. Neutrinoless double beta decay half-life lower limit as a function of the exposure and background index of the GERDA experiment.

4. Present status of the experiment: selected subprojects

4.1. Cryostat

The cryostat was installed in Hall A of LNGS in 2008. This was followed by the copper shield installation and subsequent radon emanation tests. The last showed a rate almost twice higher than the expected/allowed value. Although it was still within the specification for phase I of the experiment[2], it has been decided to install an additional shroud (in a form of a cylinder made out of a thin Cu foil) in order to protect the detectors against ^{222}Rn moving around by convection in LAr. Filling with LAr was completed in December 2009. Simultaneously with the filling the commissioning of the cryostat's active cooling was carried out. The system works very efficiently and it is exhibiting a practically constant LAr level eliminating virtually the need for LAr refills.

4.2. Water tank

The construction of the water tank started immediately after the installation of the cryostat, and it was completed at the beginning of 2009. In August 2009 the mounting of the VM2000 reflector foil and of the PMTs finished. The tank was sealed and prepared for water drainage tests performed later. At the moment the permanent filling of the water tank is awaiting the approval from the director of the LNGS.

4.3. Clean room and lock systems

Installation of the clean room on the top of the superstructure was finished in Feb. 2009. Recently all the necessary gas and vacuum systems have been completed and successfully tested.

One arm of the commissioning lock (foreseen only for the phase I) has also been delivered to LNGS. It was transferred to the clean room, installed onto the glove box and it is practically ready for use. The second arm needed some modifications and its delivery to Gran Sasso is expected for mid 2010.

The final lock system capable of deploying up to 80 detectors has also been constructed. Its auxiliary installation works will start as soon as the second arm of the commissioning lock system will be dispatched to LNGS.

4.4. Phase I and phase II detectors

Eight detectors of the former IGEX and Heidelberg–Moscow experiments have been refurbished, characterized and are ready for use. The total mass of the available ^{76}Ge is 17.5 kg.

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[2] However, above the specification for the phase II.

Deployment of a mock-up detector (for mechanical/electronic tests) and a single non-enriched detector ("prototype detector") is planned for April/ May 2010. The purpose is to test and debug the spectroscopic performance of the full system. Subsequently three non-enriched detectors will be mounted in one string and deployed. It is planned to operate a three-detector-string for about two months in the GERDA cryostat in order to measure the background of the full detector assembly. Successively it is planned to start the deployment of the enriched detectors.

The development of the phase II detectors has been carried out in parallel with the construction of the phase I of the experiment. 53.3 kg of enriched germanium oxide were procured from the ECP enrichment plant in Russia. Special care was taken to minimize the exposure to cosmic rays during the storage and transportation. This holds also for the future crystal pulling. The whole process of purification and reduction of GeO_2 has been tested using depleted germanium (leftover of the enrichment). Good quality, high yield (up to 90%) and no change in the isotopic composition were demonstrated. At the moment the enriched material is being reduced to metallic germanium at PPM Pure Metals in Langelsheim.

Several test crystals have been already pulled via the Czochralski technique at the Leibniz Institute for Kristallzuechtung (IKZ). Some contaminations (arsenic and phosphorus) were found, however their sources have been identified and can be eliminated.

Under discussion there are still two options for the type of detectors to be used in the phase II of the experiment: n-type 18-fold-segmented- and p-type Broad-Energy Germanium (BEGe) detectors. Segmentation (combined with the pulse shape analysis) will help to identify multiple Compton scattering events as background ones in the region of interest with high efficiency. There are however multiple channels to be read out for each crystal, what complicates the design of the front-end electronics. On the other hand studies of event discrimination with a BEGe detector applying a novel pulse shape method, exploiting the characteristic electrical field distribution inside the detectors, allows to identify efficiently single-site events and to reject multi-site events. The first are typical for neutrinoless double beta decays, and the latter for backgrounds from gamma-ray interactions. Performed measurements show that the novel single-parameter pulse shape discrimination method presented in [5], exploits the special properties of small-electrode detectors. It leads to background rejection factors for ^{76}Ge $0\nu\beta\beta$ decay experiments which favorably compare to those achieved with highly segmented detectors [6]. Unsegmented detectors require also fewer read out channels than segmented detectors. Moreover, the unsegmented BEGe is available as a standard, commercial product. On the other hand, these detectors have the drawback that the crystals are limited in height, constraining the currently achievable mass to about 700 g.

The decision which type of the detectors will be used in the phase II of the GERDA experiment will be taken in the midddle of 2010.

4.5. LArGe

The liquid argon filling of the GERDA low-background test stand LArGe (well shielded 1 m^3 volume, vacuum insulated copper cryostat equipped with an active cooling system), located in the GDL[3], was carried out at the end of 2009. The commissioning of the cryogenic systems was successfully carried out. Applying an active cooling system the argon is sub-cooled to $-187°$C assuring practically no losses. The stability of the gas quality was monitored throughout using a mass spectrometer and by measuring the triplet life time of the argon gas scintillation in response to an internal alpha source. A preliminary analysis of the photo-electron yield corresponds to 100–200 pe/MeV without significant position dependence. It is by a factor 5 to 10 reduced with respect the values measured in the mini-LArGe setup [7]. The light yield is however sufficient to operate the setup in the planned anti-coincidence mode with the Ge crystals. Deployment of the first BEGe detectors in LArGe will follow mounting of the lock system and is scheduled for May 2010. Using the LArGe setup long term stability tests of the BEGe detectors, background measurements and tests of the LAr instrumentation will be performed.

5. Summary

The GERDA experiment is actually moving from the construction to the commissioning phase. All the hardware needed for the first detectors deployment has been already installed in Hall A. The final water filling of the water tank should start very soon and so is the first deployment of the non-enriched tests crystals. Down selection of the phase II detectors will happen in mid 2010.

REFERENCES

[1] M. Gunther *et al., Phys. Rev.* **D55**, 54 (1997); C.E. Aalseth *et al., Phys. Atom. Nucl.* **63**, 1225 (2000).

[2] H.V. Klapdor-Kleingrothaus, A. Dietz, I.V. Krivosheina, O. Chkvorets, *Nucl. Instrum. Methods* **A522**, 371 (2004) [`hep-ph/0403018`].

[3] A. Faessler *et al., Phys. Rev.* **D79**, 053001 (2009).

[4] I. Abt *et al.*, Proposal to the LNGS (2004), `http://www.mpi-hd.mpg.de/gerda/proposal.pdf`

[3] GERDA underground Detector Laboratory.

[5] D. Budjáš *et al., JINST* **4**, P10007 (2009).

[6] I. Abt *et al., Nucl. Instrum. Methods* **A583**, 332 (2007) [nucl-ex/0701005]; *Eur. Phys. J.* **C52**, 19 (2007) [arXiv:0704.3016]; H. Gomez, S. Cebrian, J. Morales, J.A. Villar, *Astropart. Phys.* **28**, 435 (2007) [arXiv:0708.3987]; D.B. Campbell *et al., Nucl. Instrum. Methods* **A587**, 60 (2008).

[7] P. Peiffer *et al., Nucl. Phys. Proc. Suppl.* **B143**, 511 (2005); M. Di Marco *et al., Nucl. Phys. Proc. Suppl.* **B172**, 45 (2007).