# 3 Search for the Neutrinoless Double Beta Decay with GERDA

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One of the most interesting questions in particle physics is related to the absolute mass and nature of neutrinos. While we have strong evidence from solar, atmospheric, reactor and accelerator neutrino experiments that neutrinos have a finite mass, these experiments only measure mass differences, $\Delta m^2$=$|m_2^2 - m_1^2|$. Oscillation experiments have established a lower limit for one of the neutrino masses, $\sqrt{\Delta m^2_{atm}}$ $\simeq$0.05 eV, but can not determine the absolute scale of the mass eigenstates. Moreover, the results do not depend on the charge conjugation properties of neutrinos, thus we don't yet know if they are Dirac or Majorana particles. The observation of neutrinoless double beta decay would prove that neutrinos are Majorana particles, that lepton number is violated in Nature and would give us information on the so-called effective Majorana neutrino mass, $m_{ee}$ (1). Current experimental limits on $m_{ee}$ are of the order $m_{ee} \leq 0.3 - 1.0$ eV, with the most stringent upper limits coming from the former Heidelberg-Moscow (2) and IGEX (3) experiments, which searched for the neutrinoless double beta decay with enriched $^{76}$Ge detectors.

GERDA is a new experiment to search for the neutrinoless double beta decay in enriched $^{76}$Ge detectors in Hall A of the Gran Sasso Underground Laboratory (LNGS) in Italy. The aim of GERDA Phase I and II is to reach a sensitivity for the effective Majorana neutrino mass of 270 meV and 110 meV, respectively. This is achieved by operating bare HPGe crystals in a large volume (70 m$^3$) of liquid argon (LAr), which serves as a passive shield against the external radioactivity and is in addition surrounded by a water shield instrumented with light detectors.

## 3.1 Status of the GERDA experiment

GERDA Phase I will operate 17.9 kg of existing enriched $^{76}$Ge detectors, which belonged to the former Heidelberg-Moscow and IGEX collaborations. The double walled, stainless steel cryostat holding the LAr has been delivered at LNGS on March 5, 2008. The water tank (10 m high, and 10 m diameter) will be installed before September 2008, when the installation of the clean room on top of the tank, and of the muon veto will start. Installation of the gas handling system, and of the detector holders will be finalized in April 2009. It is planned to start taking Phase I science data by early summer 2009. However, the phase I enriched Ge detectors will already be operated in the LArGe Facility in the GERDA detector lab at LNGS starting in mid 2008. Apart from providing first tests of these detectors in an ultra-low-background facility, first science data will also be taken. For GERDA Phase I, our group is responsible for the calibration system: calibration sources, collimators, hardware for insertion/parking in the cryostat, Monte Carlo simulations of possible configurations, source strengths and efficiency of pulse shape discrimination.

Figure 3.1 shows the GERDA cryostat shortly after its arrival at LNGS. The cryostat and infrastructure being built for Phase I will also be used in Phase II. An additional 14 enriched HPGe

**Figure 3.1:**
**The GERDA stainless steel cryostat shortly after its arrival at LNGS in March 2008.**

detectors are planned for this second phase. At present, the GERDA collaboration is in the possession of 37.5 kg of enriched Ge material (in the form of $GeO_2$), with an additional 20 kg of enriched material needed. This material will be cleaned by the process of polyzone refinement at PPM Pure Metals in Germany (July-September 2008), after which crystals will be grown at the Institut fuer Kristallzüchtung (IKZ) Berlin (until end of 2009, the period including test runs with natural, and depleted Ge). The actual detectors will be produced at Canberra, France (until about mid 2010). All these steps will occur under close collaboration with the GERDA collaborating Institutions.

Apart from the calibration system and material screening with a new facility run by our group at LNGS (so far operated mainly for XENON), we are building a GERDA detector test facility in our lab at the Physics Institute. The goal is to characterize segmented, natural Ge detectors which will serve to test the entire production process, before the actual enriched detectors will be fabricated.

## 3.2 Monte Carlo simulations

For the Monte Carlo simulations we are using the Geant4 based framework MaGe (4) which was designed for the GERDA (5) and Majorana (6) projects. The scope is to determine which sources will be used, in which configuration, position and strength, and how often. The sources will be employed to determine and monitor the stability of the energy scale and resolution of the detectors with time, as well as to establish and monitor the efficiency of the pulse shape analysis method which will be used to distinguish single-site interactions (as expected from a double beta decay event) from multiple scatters (for instance, multiple Compton scatters, or neutron interactions). Possible sources are for instance $^{60}$Co, $^{228}$Th and $^{133}$Ba. We will design and construct the collimator and the structures which will be used to insert the sources into the LAr cryostat and bring them in suitable positions near the Ge crystals. The structure will be manufactured from ultra-pure materials (high-purity Cu or W, to be decided, and PTFE) and will fit within the current design of the super-insulated stainless steel cryostat.

For a first estimation of the needed source strengths $10^6$ $^{60}$Co events with random angular distribution were generated. Figure 3.2

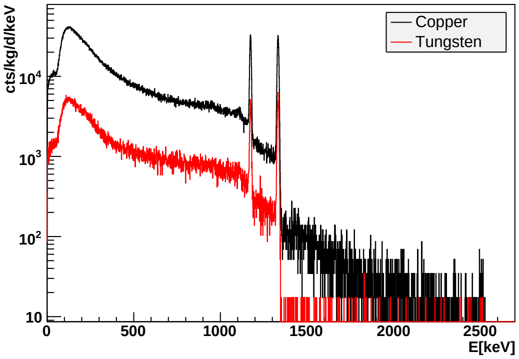

**Figure 3.2: Monte Carlo simulation of $^{60}$Co energy spectra for different collimator materials (Cu and W) in the non-segmented HPGe detectors of GERDA Phase I.**

shows the sum of the full energy spectra in the HPGe detectors. First simulations of the influence of the calibration source in the parking position inside the cryostat show that independent of the collimator material the source (with reasonable activities) produces no significant background. For copper as collimator material, a minimum activity for a $^{60}$Co source of around 20 kBq is required. The Monte Carlo study of other calibration sources is in progress.

## 3.3 GERDA test facility

GERDA Phase II will use new, 18-fold segmented, enriched $^{76}$Ge detectors. Before operating these detectors at LNGS, it is essential to test the performance of non-isotopically-enriched prototype devices. We are building a detector test facility, in which we will first operate a commercial naked Ge-crystal immersed directly in liquid argon. The aim of this first step is to develop the infrastructure for the detector storage in vacuum, to test the cooling and warming-up procedures avoiding any condensation on the detector surfaces, to test low-noise electronics for detector operation and to validate the Monte Carlo simulations of calibration sources. A schematic view of the test facility is shown in Fig. 3.3.

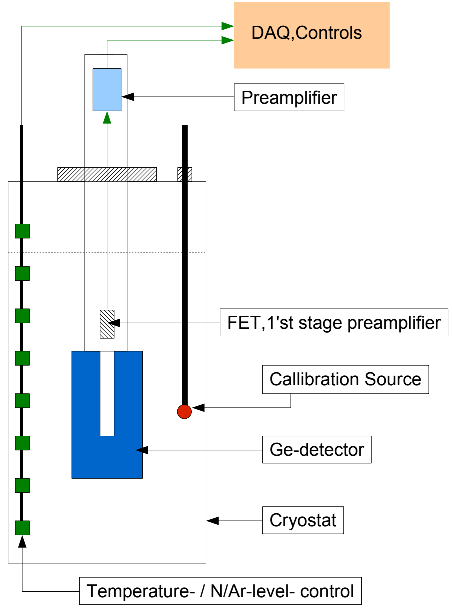

**Figure 3.3: Schematic view of the test facility for the operation of naked Ge-detectors immersed in LAr. In the first phase, a bare, commercial HPGe crystals will be operated in a LAr cryostat.**

## 3.4 GERDA sensitivity to solar axions

As an ultra low background experiment, GERDA may have the potential to detect other rare events, such from interactions caused by solar axions. Axions are proposed as an extension to the Standard Model of particle physics to explain the absence of charge-parity (CP) symmetry violation in the strong interaction (7). These neutral, very light (mass in the range $10^{-5}$eV to 10 eV) particles interact very weakly with ordinary matter and relic axions from the early Universe could contribute to the dark matter in our galaxy. Axions could also be created near the strong electric field inside the hot plasma core of the Sun. Photons can be converted into axions, then stream freely to Earth where they can be in principle detected. While the primordial axion distribution on Earth is expected to be uniform, the solar axions flux exhibits a preferred direction depending on the relative orientation of an experimental set-up and the Sun, resulting in a modulation of the detection signal.

Figure 3.4 shows the differential flux of solar axions as expected on Earth (8). The mean axion energy is 4.2 keV and the interesting axion search window lies between ~1-8 keV. Responsible for the axion-production in the Sun is the Primakoff effect, which allows a coupling between the axion and the electromagnetic fields with a coupling constant $g_{a\gamma\gamma}$. Following the calculations in (9) a first, conservative sensitivity of GERDA in the coupling constant versus axion mass parameter space was determined. It is shown in Fig. 3.5 along with theoretical predictions and existing direct and indirect constraints. The preliminary limit of $g_{a\gamma\gamma} < 8 \cdot 10^{-10}$GeV$^{-1}$ was calculated for an assumed background of $1 \cdot 10^{-2}$ events/(keV kg year) in the low-energy region, for a total mass of 40 kg Ge and an exposure of 2 years. A more detailed study of the GERDA sensitivity to solar axions including the expected signal modulation, as well as of the background and energy threshold requirements of the detectors is in progress.

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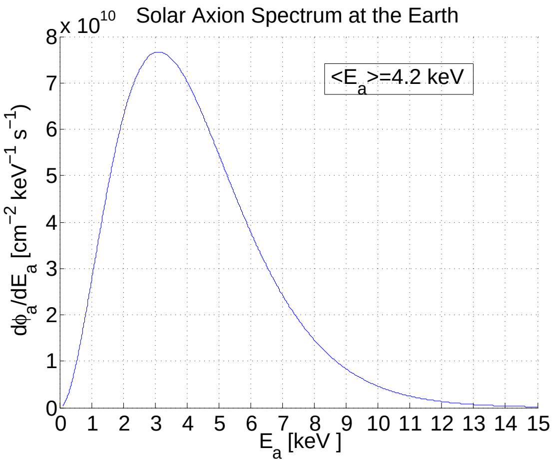

**Figure 3.4: Solar axion flux produced by the Primakoff conversion in the Sun as expected on Earth.**

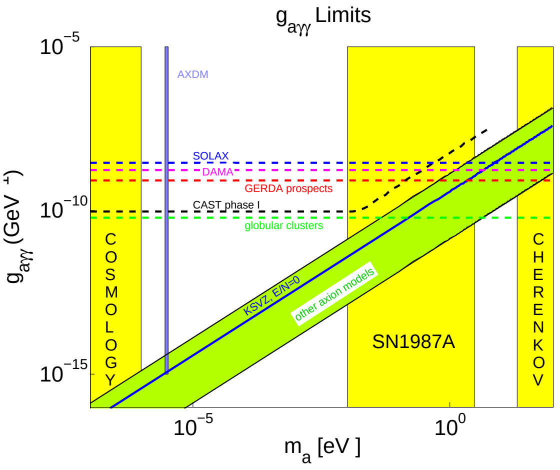

**Figure 3.5: Limits on the coupling constant as predicted by different axion-models (green) in comparison with direct (SOLAX, DAMA, CAST) and indirect (cosmology, SN1987A, globular clusters) bounds and the potential GERDA limit ($g_{a\gamma\gamma} \sim 8 \cdot 10^{-10}$GeV$^{-1}$) with an assumed background of $1{\cdot}10^{-2}$ events/(keV kg year) in the low-energy region, 40 kg of mass and 2 years of exposure.**