3 Search for the Neutrinoless Double Beta Decay with GERDA

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(GERDA Collaboration)

GERDA is an experiment to search for the $0\nu\beta\beta$ decay in enriched ^{76}Ge detectors in Hall A of LNGS. The aim of GERDA Phase I and II is to reach a sensitivity of 270 meV and 110 meV for the effective Majorana neutrino mass, 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 (in Phase I) against the external radioactivity. The liquid argon is surrounded by a water shield instrumented with PMTs.

The construction phase of GERDA at LNGS is finished. At the end of 2009, the cryostat was cooled down, filled with liquid argon and, using an active cooling system, a stable temperature of 88 K was reached. The cryostat is thus ready for detector deployment. Several water drainage tests were performed with a partially filled water tank. These tests also provided an opportunity to test the PMTs and read out the veto detector with its final DAQ system. The detector commissioning lock has been installed in the clean room on top of the water tank in March 2010. The lock system will be ready for first detector deployment by the end of April. The first detectors to be deployed will be three non-enriched HPGe detector. These have been mounted in their low-mass holders and tested in liquid argon in the LNGS GERDA test facility. All three are showing excellent energy resolution and stable leakage currents at a few tens of pA, and are thus ready for deployment in the GERDA cryostat. After the planned tests with non-enriched detectors, the deployment of the enriched phase I detectors can start. Concomitantly, the R&D for the phase II detectors is proceeding.

Our group is responsible for the GERDA calibration system as well as for R&D on phase II detectors (in our case, on broad energy germanium detectors). Here we will present some highlights of our contributions to the calibration system during the past year.

Our Monte Carlo efforts were focused on simulating the gamma and neutron induced background from the calibration sources in their parking position for the final Phase I configuration. The geometry of the simulated Phase I detector array with the three calibration sources and their absorbers is shown schematically in Fig. 3.1. For three ^{228}Th calibration sources, with an activity of 20 kBq each, we obtain a conservative background rate of 3×10^{-5} events/kg·yr·keV and 2.4×10^{-5} events/kg·yr·keV in the region of interest for the neutrinoless double beta decay from the gammas and neutrons emitted by these sources, respectively. We have also studied

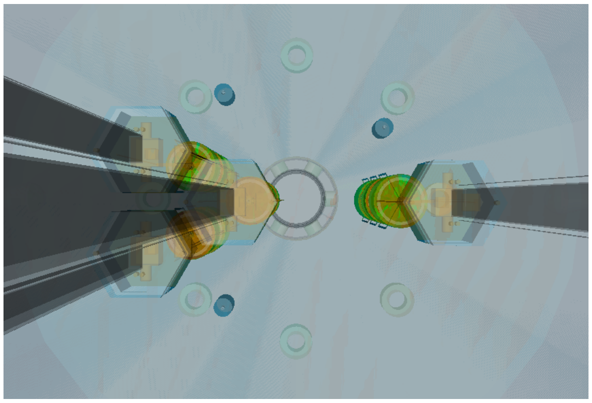

Figure 3.1: Top view of the Phase I detector array (four detector strings a three crystals each) with the three calibration sources along with their tantalum absorbers.

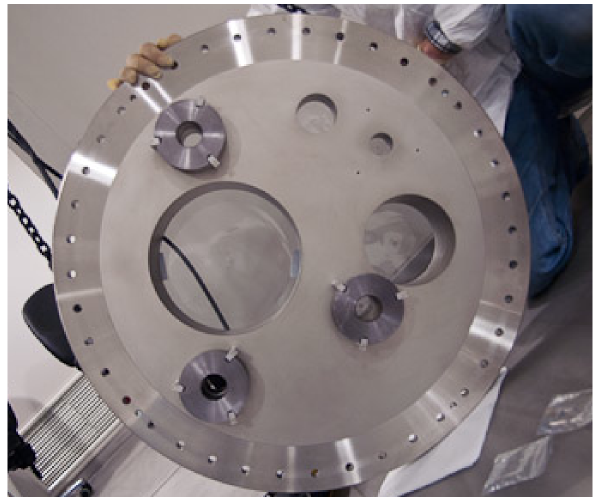

Figure 3.2: Calibration source flange with three tantalum rings mounted. The rings provide additional shielding against the gammas from the ^{228}Th sources in their parking positions.

the background coming from neutron capture in detector and surrounding materials while the sources are in calibration and in parking position. Of all the produced isotopes, only ^{77}Ge is potentially dangerous. It decays with a $T_{1/2}$ = 11.3 h, a Q-value for the β-decay of 2.7 MeV, emitting several gammas with energies up to about 2.35 MeV. The decay of this isotope in the Ge crystals has been simulated, with a rate of 0.045 decays/kg·yr (given the short half-life, the production and the decay rates are in equilibrium). Assuming the measured neutron flux of 9×10^{-4} n/s·kBq and a total activity of 60 kBq, we obtain a background rate of 7.4×10^{-6} events/kg·yr·keV in the signal region.

The three tantalum rings for the sources and absorbers in their parking positions were mounted on the inside of the calibration source flange in January 2010. Subsequently, the lowering system for one of the calibration sources including absorber was successfully tested on site. Several lowering cycles down to 10 m ensured that there are no oscillations of the system even with relatively high moving speeds and that no problems occur during the insertion of the absorber into the tantalum ring. An upgrade of the manual lowering system to a motorized one is on its way.

The custom made ^{228}Th source (in collaboration with PSI) has been sent for a precise calibration to IRMM in Geel, along with a new, 25.5 kBq commercial source purchased from Eckert&Ziegler. Two new ^{228}Th custom sources have been produced: one of $\sim$30 kBq source at PSI, and one of $\sim$40 kBq source at Mainz. These sources have been sent for encapsulation to Eckert&Ziegler Braunschweig and will arrive at IRMM for a precise calibration by the end of April 2010. After the calibration procedure, the sources will be sent to LNGS where the neutron fluxes will be measured. To speed up this process, we are acquiring a LiI(Eu) neutron detector, to be installed at LNGS in a few weeks from now. ^{6}Li has a large cross section for neutron capture (940 barns for thermal neutrons), the relevant reaction being n + ^{6}Li $\rightarrow \alpha$ + ^{3}H + 4.8 MeV. The alpha and the tritium are stopped even in a thin layer of a LiI crystal and their full energy is detected. We are studying the optimal moderator thickness and shield configuration via MC simulations based on the Geant4 toolkit.

We have remeasured the n-flux of the first custom source, and in addition we have measured the flux of a commercial source from

Eckert&Ziegler, as well as the background with a ^{3}He counter at LNGS. The detector was inserted in a 6 cm diameter and 6 cm height polyethylene cylinder, which was wrapped in Cd foil and placed in a boron doped paraffin shield.

The neutron rates for the custom and commercial source were measured to be $(2.7\pm0.5)\times10^{-2}$ n/s and $(1.4\pm0.2)\times10^{-1}$ n/s, respectively. Considering that the sources had activities of 15 kBq and 43 kBq, we find a factor of about 1.7 difference in the n-rates. The ^{3}He counter was calibrated with an AmBe neutron source, with a flux of about (10 ± 1) n/s, giving a neutron rate of about 0.72 n/s; hence above numbers assumed an efficiency of about 0.07 for both the AmBe and ^{228}Th sources. A Monte Carlo simulation of the actual geometry and the AmBe n-spectrum, as well as the ThO_2 n-spectrum yielded overall efficiencies of 0.095 and 0.152, respectively. Using these efficiencies, the neutron rate for the custom source goes down to about 0.013 n/s, or, using the activity of 15 kBq, to 9×10^{-4} n/s·kBq. These results will be cross checked by using the LiI(Eu) detector to be installed at LNGS. The relative gamma activities of the two sources have been determined with the Gator HPGe detector, by placing them on a thin stainless steel tube 10 cm above the detector's endcap.

We have cross checked our predictions of the neutron fluxes from the commercial and custom sources, and estimated the systematic uncertainties coming from the $(\alpha$,n) cross sections. We have used the cross sections given in SOURCES, calculated the cross sections using EMPIRE, and also took measured cross sections from the EXFOR database. Since we find that there is quite some variation in the cross sections from these sources, in order to be conservative we have considered the upper and lower envelopes as a function of energy. We thus obtained following intervals for the neutron rates: $(4.5–7.3)\times10^{-4}$ n/s·kBq for a $^{228}ThO_2$ source, $(3.1–7.3)\times10^{-2}$ n/s·kBq for a ^{228}Th source embedded in $NaAlSiO_2$ and $(2.1–4.2)\times10^{-2}$ n/s·kBq for a ^{228}Th source in Al_2O_3. We are also investigating potential contaminations in the custom $^{228}ThO_2$ source and their contributions to the measured neutron flux.

We have started to work on the analysis scheme of the calibration data. The raw calibration data will go through the same analysis pipeline as all other GERDA data. The basic event information (waveforms etc, called Tier-1) will be written out as Majorana-Gerda-Data (MGD) objects. Subsequently, parameters such as energy, pulse rise-time, baseline noise, saturation etc (called Tier-2) will be extracted from the waveforms, using different reconstruction and noise-filtering algorithms. These algorithms, as well as the entire calibration analysis pipeline will be first tested on regular calibration data taken with a commercial ^{228}Th source and a natural HPGe detector in our lab at the Physik Institut. The goal of the calibration analysis pipeline is to calculate the position and energy resolution of the full energy peaks, as well as the number of events under each peak and to look at the stability of the calibration parameters with time. The calibration parameters for each detector and calibration run will be stored as MGD objects, providing a direct interface with the GERDA analysis software. A web interface will also be provided, that will be used for the visual inspection of the individual detector spectra and parameters, and the evolution of these parameters in time.