3 GERDA: Neutrinoless Double Beta Decay in Germanium

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in collaboration with:
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(Gerda Collaboration)

During the past decades, neutrino oscillation experiments have established that neutrinos can change their flavor eigentstate while propagating over macroscopic distances. The interpretation of these observations is that neutrinos have mass and that, like in the quark sector, the mass eigenstates are different from the weak eigenstates, i.e. neutrinos mix. The aim of ongoing research is to determine the full mixing matrix of neutrinos, including CP violating phases, to clarify the Dirac or Majorana nature of neutrinos, and to fix their absolute mass scale. The observation of the neutrinoless double beta ($0\nu\beta\beta$) decay would prove that the neutrino is a Majorana fermion and that lepton number is violated. The measurement of its rate would provide information on the effective Majorana neutrino mass.

GERDA is an experiment to search for the $0\nu\beta\beta$ decay in enriched ^{76}Ge detectors (Q-value $Q = (2039.006 \pm 0.050)$ keV), using a novel shielding concept. Bare germanium diodes are operated in a 65 m^3 cryostat filled with liquid argon and surrounded by a 3 m water Cerenkov shield. The aim of GERDA is to scrutinize the claim of a discovery of neutrinoless double beta decay [1] and to reach a sensitivity of 270 meV for the effective Majorana mass. In a second phase, a background index of 10^{-3} events/(keV kg y) shall be reached, which is two orders of magnitude lower than achieved so far. This will allow to probe half-lifes of about $T_{1/2} = 1.4 \times 10^{26}$ y at 90% CL with an exposure of 100 kg·y, and to reach a sensitivity of 110 meV for the effective Majorana mass.

Fig. 3.1 – Mock-up of the GERDA setup situated underground at LNGS. Currently, a string with three natural Ge-detectors is inside the cryostat. Enriched ^{76}Ge detectors are installed this year.

The construction phase of GERDA at the Gran Sasso Underground Laboratory (LNGS) has been completed (see Fig. 3.1) and the commissioning with a first string of three natural Ge detectors started in summer 2010. Data taking with existing enriched ^{76}Ge detectors will start in mid 2011.

Our group is responsible for the full calibration system of the experiment. For energy as well as pulse shape calibration of the enriched Ge detectors, three ^{228}Th sources are to be used. During a calibration run, the sources are lowered by several meters from their parking position on top of the cryostat down to the detectors. Since the sources stay inside the cryostat to prevent radon entering the system, they are placed on tantalum cylinders to properly shield the detectors from their radiation during physics runs. The sources have been custom made by our group, with the assistance of PSI, in order to suppress potential (α, n) reactions in the source materials, which might contribute to the GERDA background.

For the current commissioning phase, a manual calibration system, partly designed and built at UZH, is used. A new, automated system for three sources and with two redundant positioning methods is currently being built in Zurich.

Weekly runs with the sources in position ensure the frequent monitoring of the energy calibration and resolution of the individual germanium diodes which is necessary when combining the data from several diodes over long measuring periods. An iterative automated calibration routine has been developed by us. It uses three alternative energy reconstruction algorithms and is now accepted as standard by the collaboration.

Figure 3.2 shows the variations in the observed position of the single escape peak of the ^{208}Tl line at 2103.5 keV over a period of several months. This energy is close to the $0\nu\beta\beta$ transition energy of (2039.006 ± 0.050) keV [2]. All three diodes currently mounted in the cryostat show excellent stability with deviations from the nominal value below ± 0.5 keV.

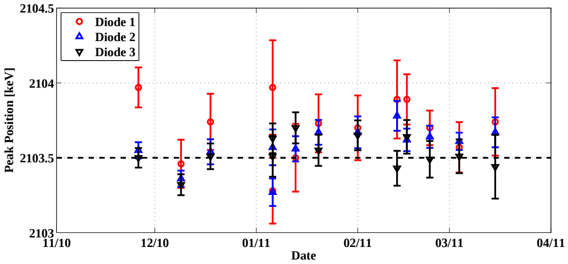

Fig. 3.2 – Long term fluctuations of the energy calibration of three natural Ge detectors currently operated in GERDA using the single-escape peak of the 2614.5 keV ^{208}Tl transition at 2103.5 keV. The observed variations are within 0.5 keV.

A general-purpose MySQL relational database has been developed in order to collect the calibration information and the analysis routine will be part of the GERDA analysis framework.

In summer 2010 the GERDA collaboration has decided to deploy Broad Energy Germanium (BEGe) detectors for the second phase of GERDA. Initial studies had shown that the pulse shape discrimination capabilities of these detectors allow to suppress a high fraction of the expected background in the region of interest for $0\nu\beta\beta$ [3]. To demonstrate that working detectors can be produced from enriched Ge, a full production-chain validation has been performed [4] and five detectors were manufactured. Our group was involved in this process, along with a few other GERDA institutions.

A test campaign with these depleted BEGe detectors is ongoing at LNGS in order to characterize the crystals in terms of their active volume, charge collection and pulse shape discrimination performance. The dead layer of a detector confines its active volume and suppresses external backgrounds. Hence a precise knowledge of the crystal dead layers is essential before they will be operated in GERDA. We are involved in these tests, which scans the detector surface with collimated low-energy γ-rays to determine the dead layer, and use the 1.33 MeV line of ^{60}Co to determine the active volume. The Monte Carlo simulations, required for the data analysis, are currently ongoing at UZH. Our group will be further involved in the production and testing of the enriched BEGe diodes, in collaboration with the other GERDA institutions, and negotiations for the production of 20 kg of enriched Ge detectors have started.

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