3 GERDA: Neutrinoless Double Beta Decay in Germanium

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(GERDA Collaboration)

Neutrino oscillations, well established by now, demonstrate that neutrino flavours mix (so lepton flavor is not conserved) and thus that neutrinos have mass. In attempts to explain these observations it is crucial to establish whether neutrinos are Dirac or Majorana particles [1], *i.e.*, whether they exist both as particles and anti-particles or not. The latter option is possible for neutral particles only and even total lepton number would be violated.

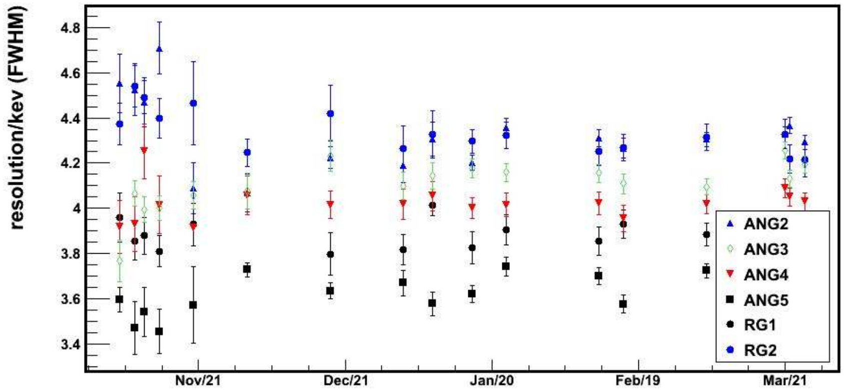
The Majorana nature of neutrinos can be tested by studying the neutrinoless double beta decay ($0\nu2\beta$) which can take place in all isotopes which undergo the allowed double beta decay ($2\nu2\beta$). Neutrinoless beta decay results in the emission of two monoenergetic electrons sharing the Q-value of the reaction. The decay $2\nu2\beta$, at the other hand, results in a continuum energy spectrum. Present lower limits on the $0\nu2\beta$ half lives are of the order 10^{22} years.

GERDA will search for the $0\nu\beta\beta$ decay in ^{76}Ge ($Q =$ 2039.006 $\pm$ 0.050 keV) enriched material which provides at the same time the source and the detector with an energy resolution of $0.1-0.2\%$ FWHM at 2 MeV. The construction and commissioning phase of GERDA, located 1400 m underground at the Gran Sasso National Laboratory (LNGS) in Italy has been completed in late 2011. Bare germanium diodes are operated in a 65 m^3 cryostat filled with liquid argon (LAr) and surrounded by a 3 m water Cherenkov shield. Figure 3.1 gives a schematic view of the experiment.

A physics run with eight existing enriched ^{76}Ge detectors corresponding to 15.2 kg of ^{76}Ge started in November 2011 and is continuing smoothly. With a background level of $0.017^{+0.007}_{-0.003}$ counts/(keV·kg·y) in the region of interest, GERDA has reached its goal of reducing the background by a factor 10 with respect to the previous experiments which will allow us to scrutinize an earlier claim of a signal [2] using a larger total detector mass and a lower background. First results are expected to become available by the end of this year.

Fig. 3.1 – *Mock-up of the GERDA experiment located underground at LNGS. The physics run with all phase I detectors started in November 2011.*

Fig. 3.2 –
Energy resolution (FWHM) at 583 keV as function of time for the GERDA enriched detectors.

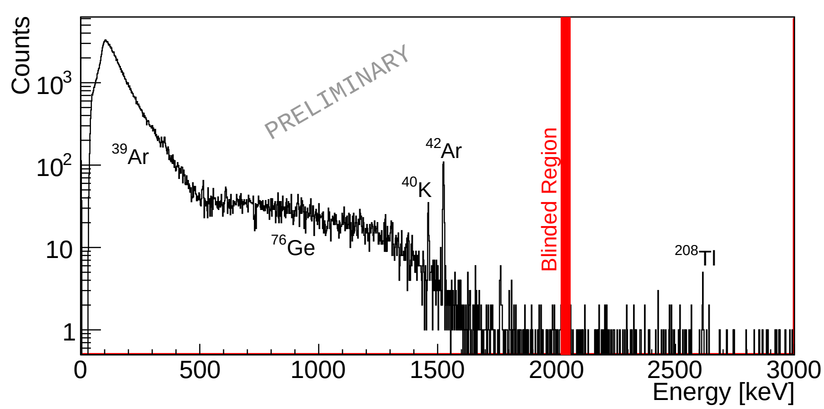


Our group participates actively in the following tasks:

- **Detector calibration**
  A new calibration system was constructed, installed and commissioned during the summer of 2011 and it is working as expected. A fully automatic analysis program for the data calibration was made available to the collaboration. One of the aims of the weekly energy calibrations is to test the stability of the detectors and the electronics chain in time. We developed an online database, in which properties such as energy resolution, calibration function, linearity, etc of all detectors are stored and can be displayed as a function of time. As an example, Fig. 3.2 shows the energy resolution at 583 keV at FWHM for all enriched detectors in the period between December 2011 and May 2012.

- **Energy spectrum analysis**
  We aim to fully characterize the background of the experiment and determine the half life of the $2\nu2\beta$ decay. This is a necessary step towards the $0\nu2\beta$ analysis. We analyze the full energy spectrum (see Fig. 3.3) and compare it with Monte Carlo simulations (MC) of the various potential background sources. A crucial task is the estimation of the active volume of each detector, which is performed by comparing dedicated calibration data to MCs. Since the start of the physics run a 40 keV wide region around the Q-value has been blinded, in order to avoid an unconscious bias. Once all the known background contributions have been identified and quantified, the signal region will be uncovered.

Fig. 3.3 –
Energy spectrum measured by the GERDA detectors in the period November 2011 - April 2012. The $2\nu2\beta$ decay contribution is clearly visible, as well as the beta spectrum induced by ^{39}Ar decays and several gamma peaks. The blinded region is indicated.



- **Detector pulse shape discrimination**
  We are developing a pattern recognition algorithm, based on "Support Vector Machine" (SVM), to distinguish between so-called single site events (SSE) and multi site events (MSE). The two electrons in a double beta decay stop within a short range in the germanium diodes, and thus belong to SSE. On the other hand, a γ-ray depositing the $0\nu2\beta$ energy in a single germanium detector makes several Compton scatters at well separated locations, yielding a MSE. SSE and MSE have only marginally different pulse shapes and are difficult to distinguish in the present coaxial germanium detectors. Our algorithm is in its test phase, where samples of each type, obtained from calibration data are being used. The goal is to decrease the background in the energy region of interest by a factor 2 - 4.

- **New germanium detectors**
  We are active both in the production and the characterization of novel, so-called Broad Energy Germanium detectors (BEGe). About 20 kg of enriched germanium material was supplied to Canberra to grow three first crystals at the end of 2011. The seven BEGe's made out of this batch are currently characterized in the Hades underground laboratory in Mol, Belgium, with the aim of understanding their intrinsic background and pulse shape discrimination performances. They will be inserted in the GERDA cryostat within a few months from now.

- **LAr instrumentation for Phase II**
  A further background reduction can be achieved with the help of the LAr around the diodes. Besides its shielding properties and its use as a coolant for the Ge crystals, LAr is an efficient scintillator. This property will be exploited by installing a light readout system around the argon. The cylindrical side surface will consist of a reflector foil whilst the top and bottom surfaces would be equipped with ultra-low radioactivity photomultiplier tubes. The wavelength of the LAr scintillation light is 128 nm and it has to be shifted to larger values to better match the photomultipliers. The wavelength shifting is usually performed by a tetraphenyl butadiene (TPB) coating on the reflector. Since current coatings are known to be mechanically unstable, and long term stability is crucial for GERDA, we are searching for an alternative. For this purpose, a liquid argon cell was built in our lab in Zurich, it is currently under commissioning. A first set of reflector foil samples was produced and a preselection has been performed using a fluorescence spectrometer at the MPIK in Heidelberg. These foils will be tested in our LAr cell together with the PMT planned for use in GERDA.

[1] E. Majorana,
Il Nuovo Cimento B 14, 171-184 (1937).

[2] H.V. Klapdor-Kleingrothaus *et al.*,
Phys. Lett. B 586, 198-212 (2004).