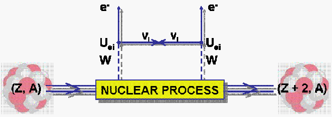
GERDA – a Search for Neutrinoless Double Beta Decay

K. Kröninger - MPI für Physik, München

Neutrinoless double beta decay and the GERDA experiment

Neutrinoless double beta decay (0νββ) is an extremely rare second order weak process which is predicted to occur, if the neutrino is a Majorana particle. The half-life of the process is a function of the neutrino masses, their mixing angles and CP-phases. Today's best limit on the half-life of the 0νββ-process of ^{76}Ge is measured by the Heidelberg-Moscow collaboration with $T_{1/2} > 1.9\cdot10^{25}$ years (90% C.L).



Schematic diagram of neutrinoless double beta decay. The nucleus changes its charge by two units. If the neutrino is a Majorana particle, the two emitted neutrinos can annihilate. Only two electrons remain in the final state.

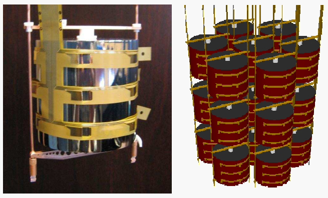
The GERmanium Detector Array, GERDA, is a new experiment that will search for neutrinoless double beta decay of the germanium isotope ^{76}Ge. Its main design feature is to submerge and operate high purity germanium detectors, enriched in ^{76}Ge to a level of 86%, directly in a cryogenic liquid (nitrogen or argon). The latter serves as coolant and shield from external radiation simultaneously. The cryostat is placed inside a buffer of ultra-pure water which serves as additional shielding and will be instrumented as Cherencov detector in order to veto cosmic muons. With this setup a background index of 10^{-3} counts/(kg·keV·y) is expected.

The GERDA experiment will be installed in the Hall A of the Gran Sasso National Laboratory, LNGS, in Italy.

The LNGS is located at the Gran Sasso mountain region about 150 km from Rome. The laboratory is covered by an average of 1,400 m of rock which significantly reduces the flux of cosmic muons.

The detector array and phase II detectors

A phased approach is chosen for GERDA. In phase I germanium detectors from previous experiments will be installed. The detectors for phase II are currently under design. A total mass of 35 kg of germanium for phase II is expected.



Left: Prototype detector with the current cabling scheme. The holder structure is made of copper and Teflon with a total weight of 31 g. The detector mass is 2.1 kg. Right: Detector array as simulated. The detectors are placed hexagonally in strings of 3 detectors each. The read-out electronics will be located above the top crystals.

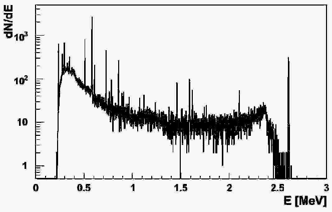
The detectors will be placed in a hexagonal pattern in strings of three detectors each. The read-out electronics will be located above the top crystals.

The current design of the germanium detectors for the phase II forsees a true-coaxial geometry with a crystal size of 8 cm height and 4 (0.5) cm outer (inner) radius. Each crystal will have a mass of approximately 2.1 kg.

The crystals will be segmented and each segment is read out separately. A 6-fold segmentation in the azimuthal angle φ and a 3-fold segmentation in the height *z* is planned.

The suspension system is designed such that a minimum of material is used. For the phase II detectors the holder is made of copper and Teflon with a total weight of 31 g.

A prototype detector is currently being tested. The energy resolution is measured as 2 keV at 1.3 MeV.



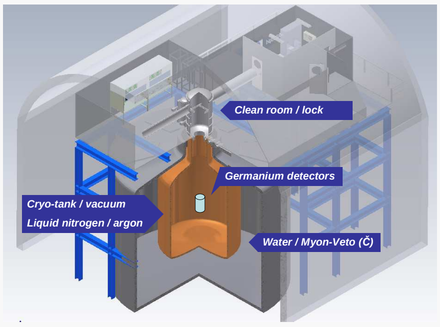
Spectrum of a ^{232}Th source taken with a Phase II prototype detector. The core resolution is measured as 2 keV, the segment resolution is 2-3 keV (at 1.3 MeV).

Detector test stands

Test stands for segmented germanium detectors are under construction at the MPI. Their main purpose is to verify the functioning of bare crystals in liquid nitrogen and the understanding of detector responses.

Test stands for germanium detectors constructed at the MPI.
Left: An unsegmented n-type crystal is mounted on a teflon rod equipped with a preamplifier and PT100 for temperature measurements. The detector is submerged into liquid nitrogen in a specially developed test cryostat.
Right: Segmented and unsegmented p-type crystals can be submerged into liquid nitrogen. The outer aluminum wall serves as Faraday cage. The (warm) readout electronics is positioned on top of the lid.
A third test stand for the GERDA prototype detector is currently being developed.

The GERmanium Detector Array



Materials and radio-purity

The materials which surround the germanium detectors have to be specially selected with respect to their radio-purity so as to minimize possible background contributions from radioactive decays. The radio-purity of the materials is measured down to the µBq/kg level.

Part	Isotope	Activity
Crystal (germanium)	Ge-68	O(3 µBq/kg)
	Co-60	O(0.2 µBq/kg)
Holder (copper)	Co-60	< 10 µBq/kg
	Ra-226	< 16 µBq/kg
	Th-228	< 19 µBq/kg
Holder (Teflon)	Ra-226	< 160 µBq/kg
	Th-228	< 160 µBq/kg
Cabling	Ra-226	2 mBq/kg
	Th-228	2 mBq/kg

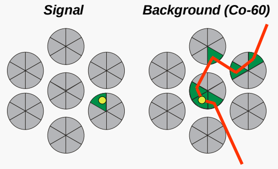
Examples for the radiopurity of materials used in the vicinity of the germanium crystals. The values are used for a Monte Carlo simulation which is performed in order to estimate the background contribution with the GERDA setup (see bottom right box). The activities are measured except for the cables which are estimated.

For further details on material screening see the poster of Dušan Budjáš.

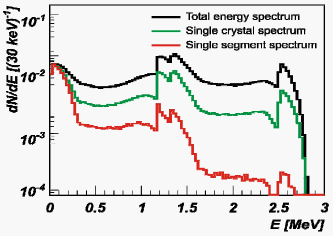
Suppression of background from radioactive decays

The main sources of background are radioactive isotopes with Q-values larger than that of ^{76}Ge, $Q_{\beta\beta}$ = 2.039 MeV. Depending on their position, the energy measured in the detectors is due to α-particles, electrons and/or photons. If only part of the energy is deposited in the detector and the size of the energy deposition is around the Q-value of ^{76}Ge the observed „event" can be misinterpreted as 0νββ.

Background events with photons in the final state can be suppressed by anti-coincidence requirements between segments.



Schematic view of an array of segmented detectors. The location of radioactive decays are indicated by yellow dots, the segments with energy deposist are shown in green. For the signal process (left) only one segment is hit, whereas for background processes (here: the decay of Co-60) (right) the photons scatter multiple times (red lines) and deposit energy in more than one segment.



Energy spectra for Co-60 for different anti-coincidence requirements: no anti-coincidence (black), between crystals (green) and between segments (red). For events with only one segment hit the reduction is larger by an order of magnitude with respect to those with only one crystal hit.

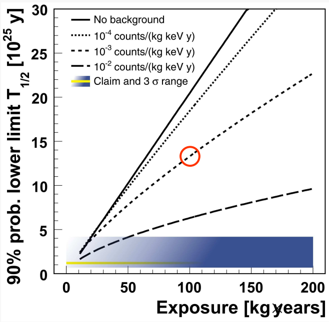
For photons in the energy region around 2 MeV Compton scattering is the dominant process of energy loss. The range of photons is on the order of centimeters and therefore of the size of a crystal segment. The signal process has two electrons in the final state. Their energy is deposited on a scale small compared to the size of a crystal segment. By requiring an anti-coincidence between segments, photon-accompanied background can be suppressed by a factor of 10-50 depending on the decaying isotope.

Background summary and sensitivity

The sensitivity to neutrinoless double beta decay of ^{76}Ge strongly depends on the background index of the experiment. A Monte Carlo study, based on the radio-impurities of the used materials and the muon flux, was performed in order to estimate the total background. With the materials assumed the back-ground index is calculated to be $3.2\cdot10^{-3}$ counts/(kg keV y) and do-minated by radioactive decays from isotopes in the holder structure. Improvements on the material radio-purities and additional analysis techniques using pulse shape infor-mation will help to further decrease the background index.

Part	Background index [10^{-4} counts/kg/keV/y]
Detector	5
Holder (copper)	4
Holder (Teflon)	8
Cabling	6
Electronics	3
Infrastructure	4
Muon, neutron & co.	2
GERDA	**32**

Overview of the background contributions to the spectrum expected in the GERDA experiment using the Monte Carlo package MaGe and the expected level of radioimpurities from the material screening.



Sensitivity of the GERDA experiment using a Bayesian analysis technique. The lower limit for an exposure of 100 kg years and the ensvisioned background index of 10^{-3} counts/(kg keV y) is $T_{1/2}$>$1.35\cdot10^{26}$ years.

Using a Bayesian analysis on Monte Carlo data the 90% probability lower limit which can be set on the half-life, in case no observation is made, is calculated. For the envisioned background index of 10^{-3} counts/(kg keV y) and an exposure of 100 kg years the lower limit on the half-life is $T_{1/2}$>$1.35\cdot10^{26}$ years which corresponds to a limit on the effective neutrino mass of m_{ee}<200 meV/c^2.