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Germanium Detector Teststands for the GERDA Experiment

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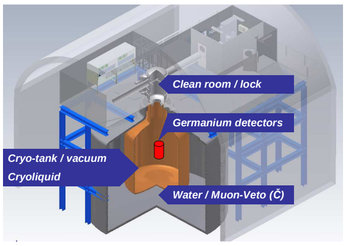
Neutrinoless double beta decay and the GERDA experiment

Neutrinoless double beta decay (0νββ) can occur as an extremely rare second order weak process if neutrinos are Majorana particles. The half-life of the process is a function of the neutrino masses, their mixing angles and CP-phases. An observation of the 0νββ-process would not only reveal the nature of neutrinos but would also give information about the absolute scale of neutrino masses.



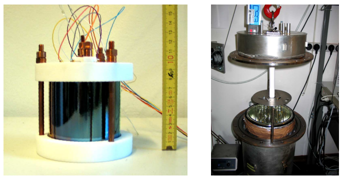
Baseline design of the GERDA experiment.

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 better than 10^{-3} counts/(kg·keV·y) is expected.

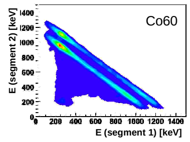
The GERDA experiment will be installed in the Hall A of the INFN Gran Sasso National Laboratory, LNGS, in Italy.

Germanium detectors operated in a cryogenic liquid

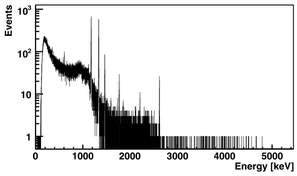
Test stands have been built at the MPI which are used to study the behaviour of bare germanium crystals in liquid nitrogen or argon. Both, p- and n-type diodes were used for these tests. For neither type detoriations of the detector performance was found after ~20 cooling/warming cycles. No difference for liquid nitrogen or argon filling was observed.



Left: A p-type crystal with 6-fold segmentation. The operational voltage of the diode is 2,500 V. All six segments are read-out separately using DC-coupled pre-amplifiers. The core is AC-coupled. Right: ‚Gerdalinchen', a miniature version of the GERDA cryostat. A commercial dewar is surrounded by a steel tank which is used as Faraday cage. A detector can be mounted onto a rod which is connected to the lid. An infrared shield above the detector prevents IR light to reach the diode. The lid with the detector can be lowered into the cryoliquid. Both, liquid nitrogen and argon are possible filling. A system of pre-amplifiers can be mounted on top of the lid.
Calibration sources can be lowered into the dewar through a feedthrough on top of the lid. An energy resolution of approximately 5 keV in the core electrode was achieved for the 1.3 MeV line from the decay of Co-60.



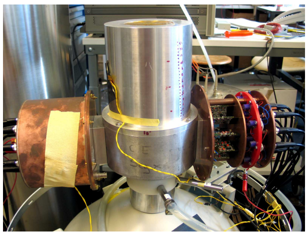
Left: Co-60 spectrum taken with a 6-fold segmented p-type germanium detector submerged into liquid nitrogen. Shown is the energy measured in segment 2 vs. segment 1. A clear correlation for the 1.1 MeV and 1.3 MeV lines can be seen between the segments. This is due to photons which deposit their full energy inside the two segments.



Left: First energy spectrum taken with the n-type detector. A Co-60 source was used. The energy resolution is dominated by electronic noise and was found to be about 5 keV FWHM at 1.3 MeV. Right: The n-type detector is mounted onto a Teflon rod. The FET is operated at cryogenic temperatures whereas the rest of the pre-amplifier electronics is operated at room temperature. The diode is inserted into the cryostat ‚Milchkanne' (far right) which is filled with either nitrogen or argon.
No detoriation of the detector perfomance was observed after ~20 cooling/warming cycles. Both, nitrogen and argon are found suitable as cooling medium.

Prototype detector characterization

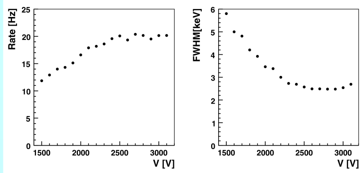
In a second phase of GERDA segmented germanium detectors will be installed. The segmentation scheme foresees a 6-fold segmentation in the azimuthal angle φ and a 3-fold segmentation in the height z. A prototype detector is currently under investigation at the MPI Munich.



A GERDA Phase II prototype detector is currently investigated at the MPI Munich. It is a high purity n-type crystal with a true coaxial geometry and has a mass of approximately 2 kg. The detector is 6-fold segmented in the azimuthal angle φ and 3-fold segmented in the height z. The operational voltage is (+)3000 V.
The core and each segment are read out using charge sensitive PSC 823 pre-amplifiers. The pre-amplified signals are digitized using a data aquisition system based on 5 14-bit ADC PIXIE-4 modules at a rate of 75 MHz. In this configuration the energy resolution of the core is approximately 2.6 keV (at 1 333 keV), the average energy resolution for the segments is 3.3 keV. The threshold of the core and the segments was set to 20 keV.

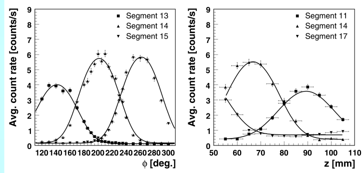
The GERDA Phase II prototype detector under study is a high purity n-type germanium crystal with a true coaxial geometry. It is 70 mm high and has an outer diameter of 75 mm. The inner diameter is 10 mm. It was placed inside a two-walled aluminum cryostat with a total thickness of 6 mm. A copper cooling finger is used as thermal link between the detector and a volume of liquid nitrogen. The operation voltage of the detector is (+)3,000 V.
The detector signals are read-out using charge sensitive PSC-823 pre-amplifiers. The pre-amplified signals are digitized using a data aquisition system based on 5 14-bit ADC PIXIE-4 modules at a rate of 75 MHz. In this configuration the energy resolution of the core is 2.6 keV (at 1.3 MeV), the energy resolution of the segments varies between 2.4 keV and 4.7 keV with an average energy resolution of 3.3 keV.

Bias Voltage



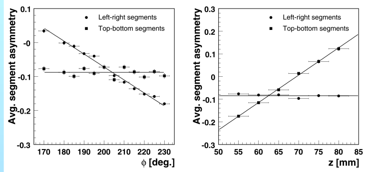
Left: Event rate in the peak of the 1.3 MeV Co-60 line as a function of the applied bias voltage. A stable plateau is reached at 2,500 V when total depletion of the diode is reached. Right: Core energy resolution at 1.3 MeV as a function of the applied bias voltage. Again, a stable (minimal) plateau is reached at 2,500 V. For all further measurements, a bias voltage of 3,000 V was applied.

Segmentation borders



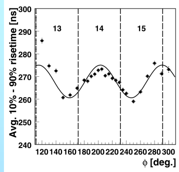
A collimated Eu-152 source was used to measure the segment borders of the detector. The average count rate of the 122 keV line is shown as a function of the angle phi (left) and as a function of the height z. In both cases three segments are clearly visible. The fitted functions are step functions convoluted with Gaussians in order to describe the collimation.

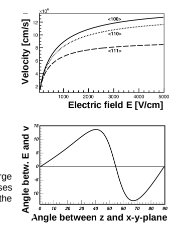
Bias Voltage



If energy is deposited in a segment mirror charges are induced in the neighboring segments. The asymmetry between the left-right and top-bottom segments are shown for a central segment as a function of the angle phi (left) and the height z (right) using the 122 keV line of Eu-152. A clear correlation between the location of energy deposition and the asymmetry is observed.

Crystal axes and pulse rise time

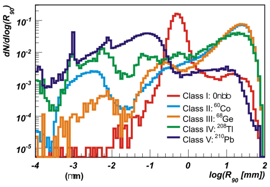




Due to the drift anisotropy of the charge carriers the 10-90% risetime of pulses shows a modulation with respect to the angle phi (top).

Background suppression

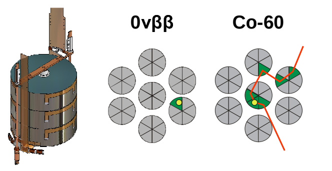
The largest background contribution is expected to come from events with photons in the final state. An identification of those events is therefore crucial for the understanding and suppression of the background.



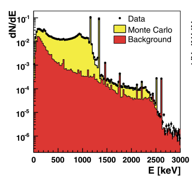
Distribution of the energy spread for different background processes. R_{90} is defined as the radius which contains 90% of the energy within an event. Class II–IV events have photons in the final state and can be distinguished from Class I and V events which have electrons and alpha-particles in the final state, respectively.

Photons in the relevant energy region lead to spatially more extended energy deposition inside the detector than electrons. Segmented detectors can be used to distinguish those two event classes by requiring coincidences between segments.

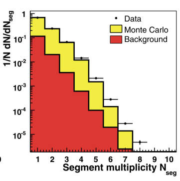
Monte Carlo simulation and Data to Monte Carlo comparison



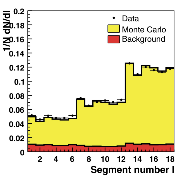
Cross-sectional view onto the GERDA detector array. The signal process has two electrons in the final state which mostly deposit energy in only one segment. In the decay of Co-60 two photons are emitted which scatter and possibly deposit energy in more than one segment. A cut on the segment multiplicity can be used in order to identify events with photons in the final state.



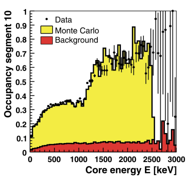
Core energy spectrum taken with a Co-60 source (marker) compared to Monte Carlo (yellow) plus background data (red).



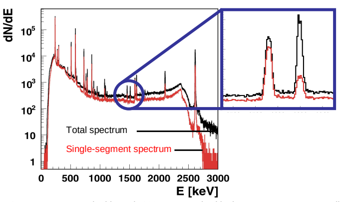
Segment multiplicity for a Co-60 source (marker) compared to Monte Carlo (yellow) plus background data (red).



Segment occupancy for a Co-60 source (marker) compared to Monte Carlo (yellow) plus background data (red).

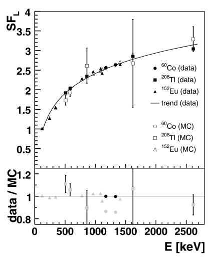


Occupancy of segment 10 as a function of energy for a Co-60 source (marker) compared to Monte Carlo (yellow) plus background data (red).



Spectrum measured with a Th-228 source. The black spectrum represents all events whereas the red spectrum represent events with only one segment hit. The close-up shows two peaks. On the left is the double escape peak of the Tl-208 line, right is a photon line of the Bi-212. Events in the double escape peak deposit energy locally whereas events in the Bi-212 peak deposit energy over a larger volume and therefore stronger suppressed.

A measure for the identification of photon events is the suppression factor. It is defined as the ratio of the number of events in a specific energy region and the number of events in that region which, in addition, have energy deposited in only one segment.
The suppression factor depends on the range of photons and thus on the energy. A measurement with different sources shows that the suppression increases with increasing energy in a region up to 2,600 keV. A Monte Carlo simulation shows and agreement on a level of 10%.



A GEANT4 based Monte Carlo simulation was performed using the MaGe code which is developed by the Majorana and GERDA collaborations. It includes all necessary physics processes and allows for a flexible design of geometries.
After the inclusion of crystal axis and the measured anisotropies of charge carriers the achieved level of agreement was improved and is of the order of 10%.