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Development of Segmented High-Purity Germanium Detectors

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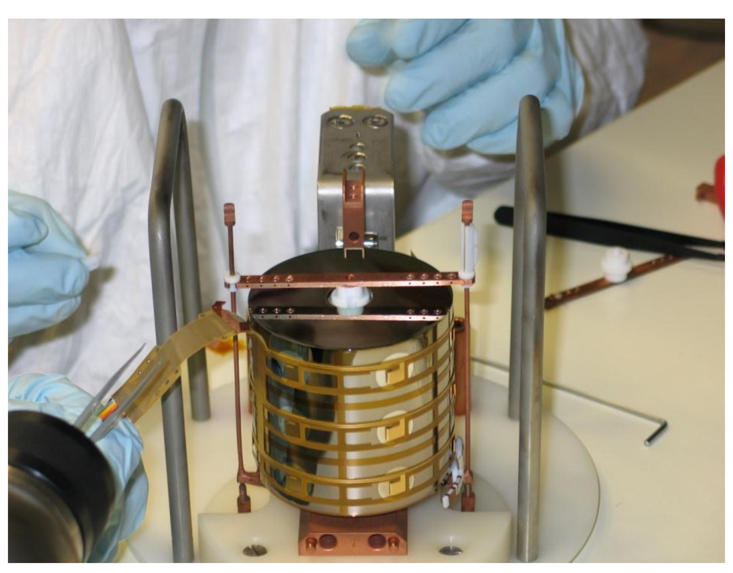
Introduction

Germanium detectors are generally used to detect low levels of γ-radiation. The very good energy resolution of High-Purity Germanium Detectors (HPGeD) allows precision spectroscopy. The analyses of pulse shapes widen their field of applications, especially for low-background experiments, i.e. for searches for neutrinoless double beta-decay ($0\nu\beta\beta$) and dark matter.

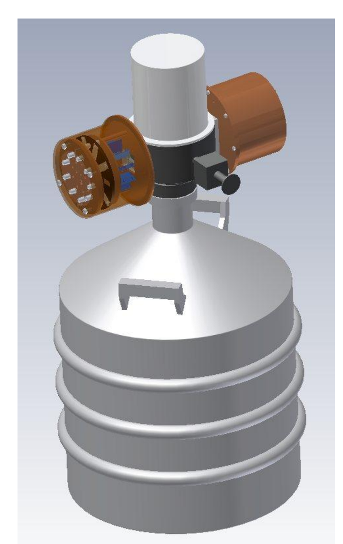
Segmented HPGeDs have been developed for a variety of experiments and applications. The segmentation is used to augment the *excellent energy resolution* with *spatial information* to disentangle event topologies. The successful operation of a Ge-detector requires an overall understanding of the effects that may occur inside, i.e. in the bulk and on the surface. Two studies, one relating to the bulk and one to surface effects are presented here.

Monte Carlo simulations help to understand drift trajectories of the charge carriers and the resulting pulses collected on the electrodes. It is also used to design new detectors in order to develop detectors with improved capabilities for future experiments.

Bulk effects



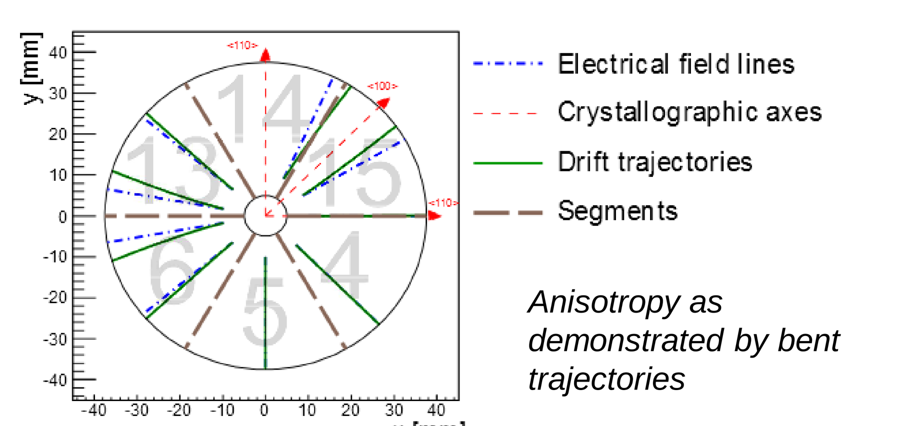
18-fold segmented true-coaxial detector inside a vacuum cryostat



Anisotropy effects due to the crystal structure

The drift velocities of *electrons/holes*, $\boldsymbol{v}_{e/h}$, in the electrical field, $\boldsymbol{E}(r)$, is parameterized through the mobility, μ:

$$\boldsymbol{v}_{e/h}(r) = \mu_{e/h} \cdot \boldsymbol{E}(r).$$

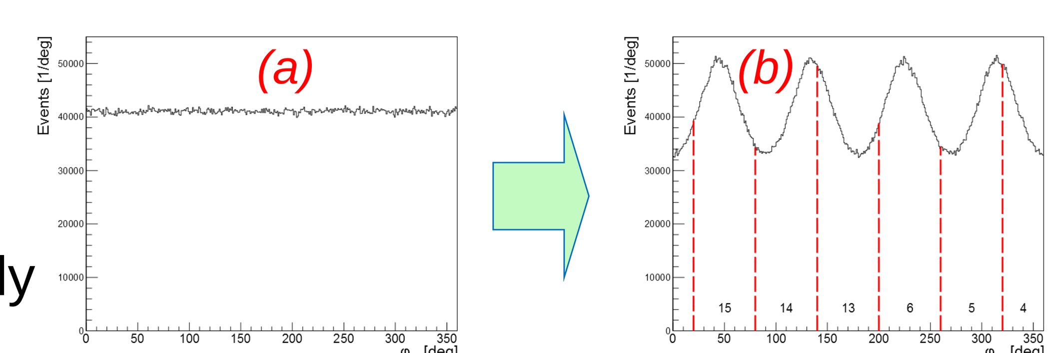


Anisotropy as demonstrated by bent trajectories

Mobility is a ***tensor*** ⇒

$$\boldsymbol{v}_{e/h}(r) \nparallel \boldsymbol{E}(r):$$

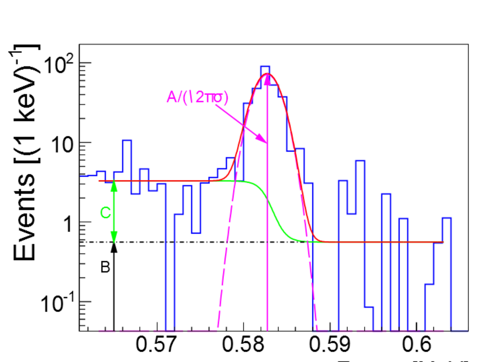
charges do not drift radially



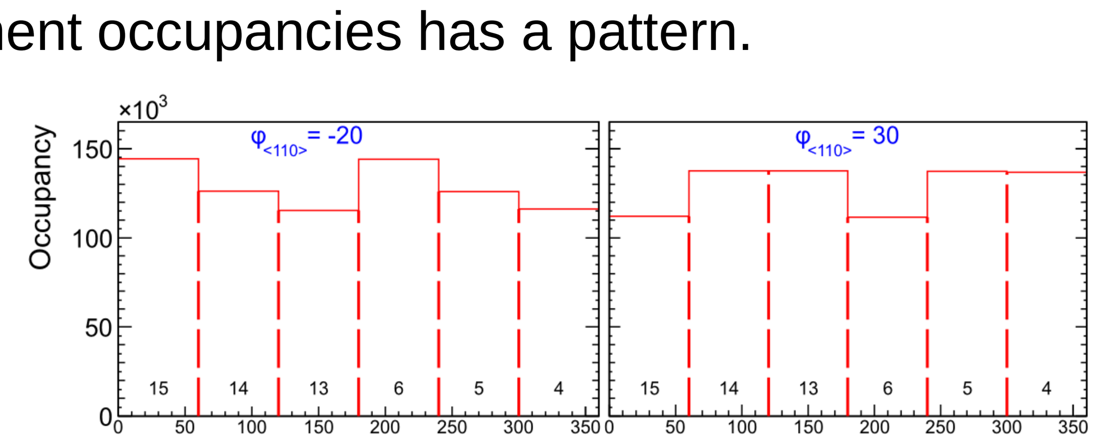
Simulated distribution of (a) the energy deposits inside the detector and the resulting distribution of (b) holes on the outer surface after the drift. Detector segments are shown as dashed lines

Usage of anisotropy for segmented detectors

Distribution of the segment occupancies has a pattern.

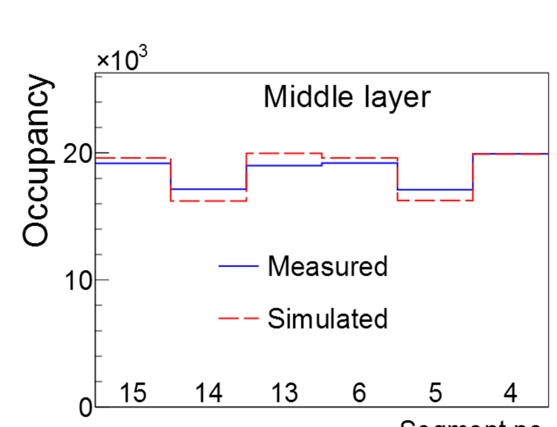


Calculation of occupancy as the number of events under a peak (shown for 0.58 MeV) using the segment spectra



Simulated distributions of occupancy for selected values of the orientation of the <110> axis

The simulated occupancies for different input orientations of the <110> axis are compared to the measured distribution. The axis orientation is determined as the best match of the distributions.



Best match between the simulated and measured occupancy distributions

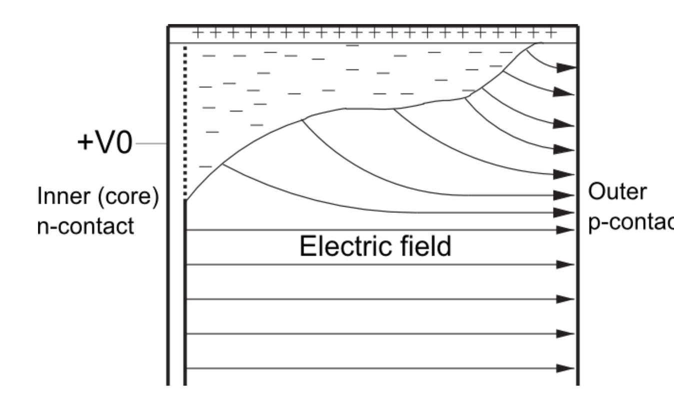
Benefits and advantages compared to the standard scan methods:

- Significantly reduced time needed to perform the axis determination
- Determination inside a complex setup possible

Surface effects

Surface events and inactive layers

Charge carriers drifting close to the detector end-plates may be trapped in a dead layer forming in these regions of the detector ⇒ strange pulses

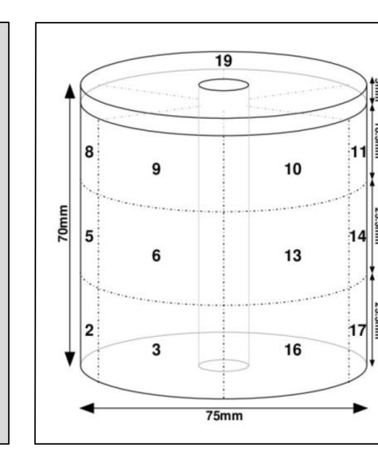


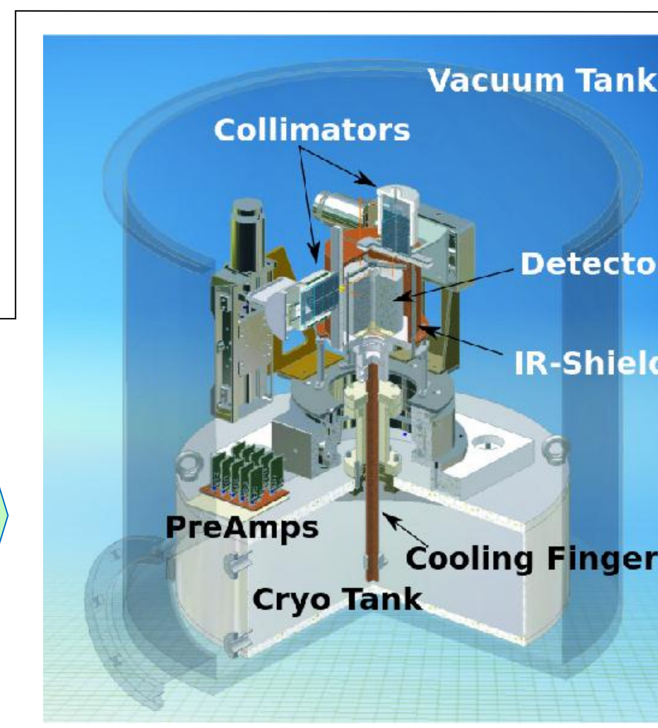
Test stand

GALATEA was designed to study surface events with a special 19-fold detector. Both the source and the detector are in one vacuum volume

Milestones:

- Cooling system (LN)
- Vacuum (10^{-7} mbar)
- Radiation shielding
- Movable source (+collimator)
- Readout electronics



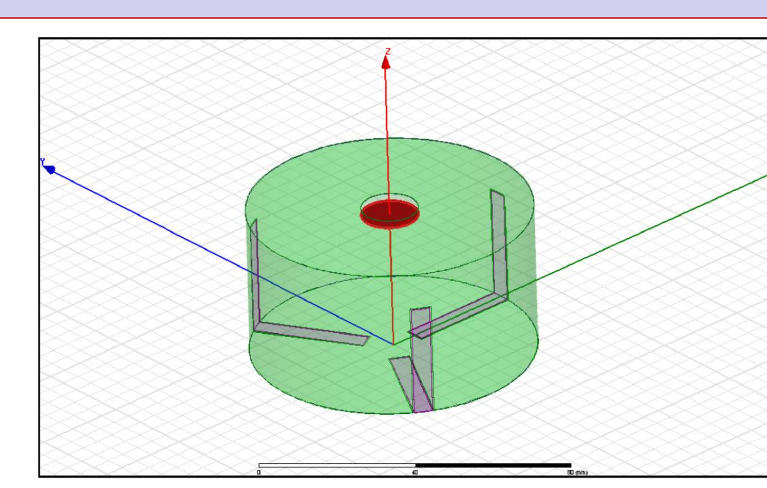


Goals:
Irradiation of the detector with α-, β- and γ-sources inside the vacuum tank → 3D scan

Current status: Commissioning phase

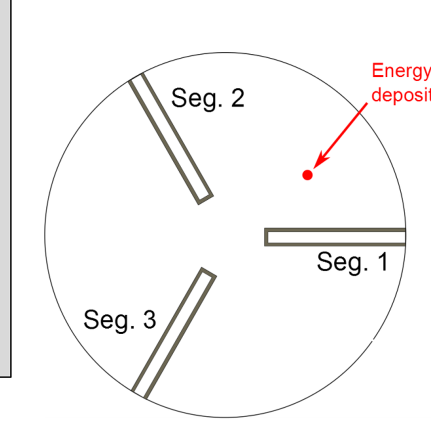
Novel design: segmented BEGe detectors

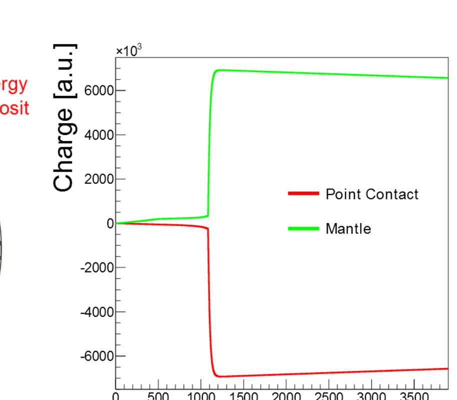
Novel detector design of segmented Broad Energy Germanium detectors (BEGe) for future experiments.
Low capacitance ⇒
✓ low energy threshold
✓ better energy resolution.



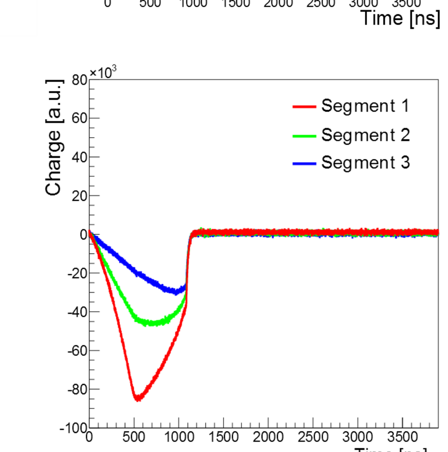
Key features:

- special electric field configuration
- usage of *mirror pulses* induced on contacts which *do not collect charge*





Charge pulses induced on the electrodes for shown position of the energy deposit



Features:

❖ Point contact and mantle for energy and timing information
❖ Segments for event topology reconstruction: position extraction and single-site/multi-site events