# Detector characterization for the LEGEND-200 experiment

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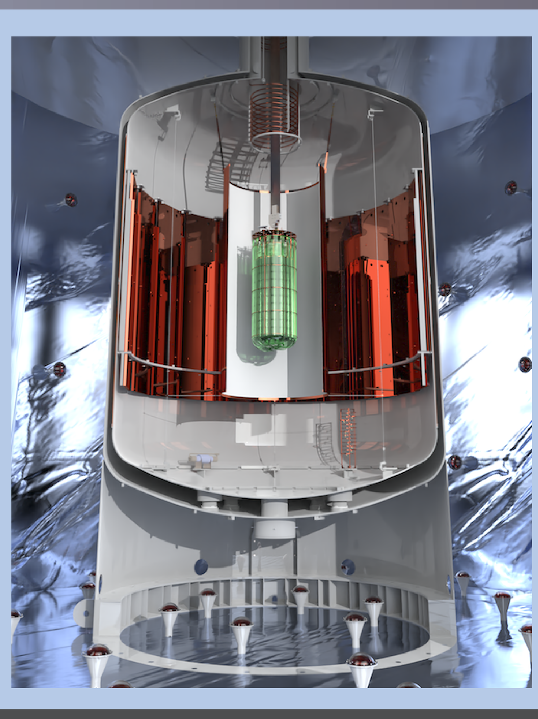
## The LEGEND-200 experiment

The **LEGEND** experiment [1] [2] will search for **$0\nu\beta\beta$ decay in the candidate isotope $^{76}$Ge**. LEGEND is building on the success of the GERDA [3] and the MAJORANA DEMONSTRATOR (MJD) [4] collaborations. The existing GERDA facility at Laboratori Nazionali del Gran Sasso (**LNGS**) is beeing modified to host up to 200 kg of HPGe detectors as a first stage of LEGEND. First physics data is expected later this year, 2022.

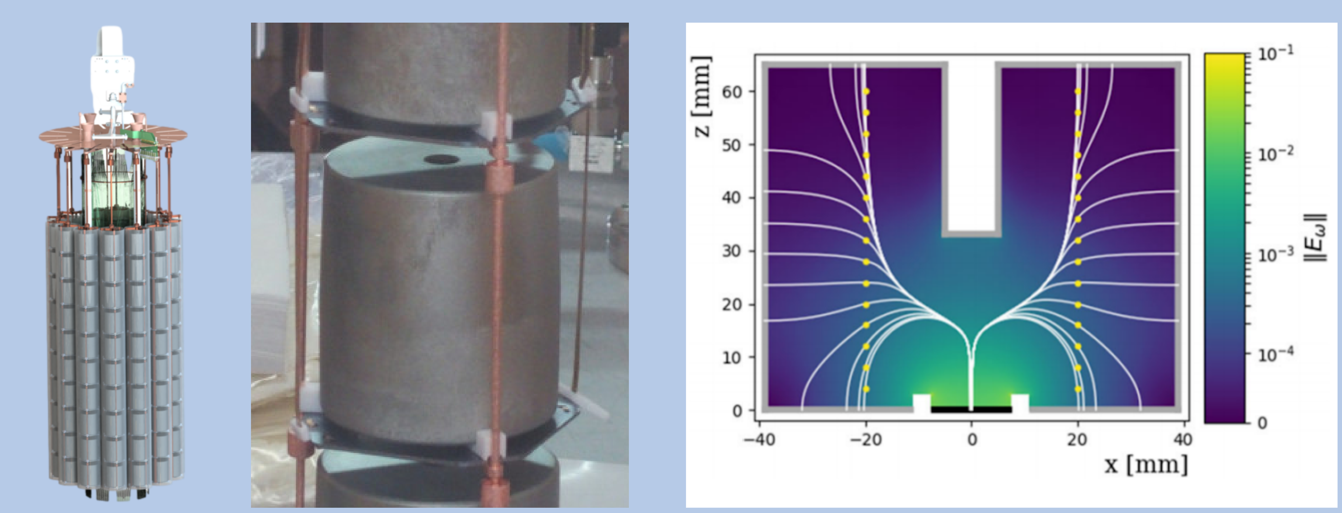


## Why $^{76}$Ge?

The germanium detectors are **suited for $\gamma$ rays measurements** at the energy of MeV scale. They provide a **superior energy resolution** of 0.2% at $Q_{\beta\beta}$ = 2039 keV. The crystal growing procedure results in naturally **low internal radioactivity** and is a **well-established technology**. The source itself acts as a detector as well, yielding **high detection efficiency**.

## ICPC detectors and characterization campaign

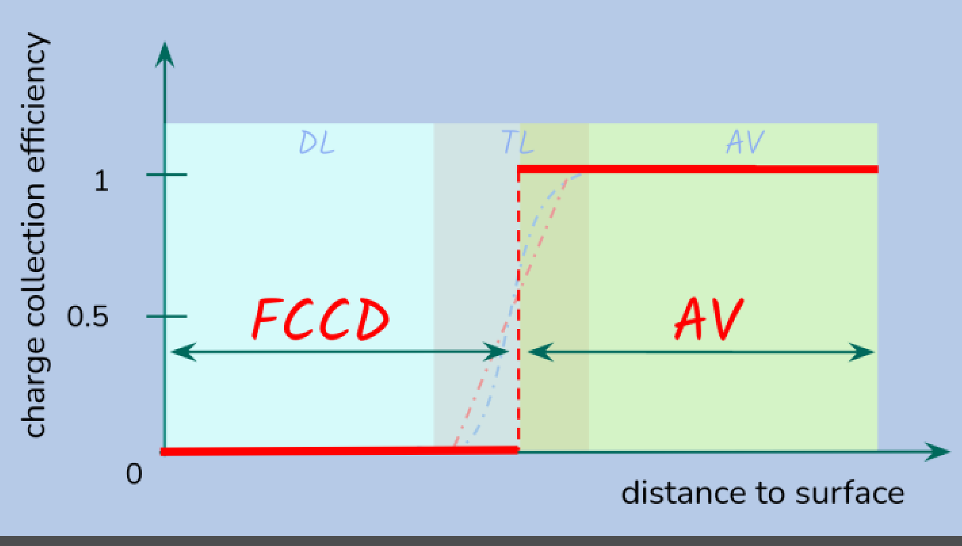
The Inverted-Coaxial Point Contact (**ICPC**) detectors are isotopically enriched to about 92 % in the $0\nu\beta\beta$ candidate $^{76}$Ge. They provide an excellent energy resolution and minimize surface to volume ratio in a configuration that allows for effective Pulse Shape Discrimination (PSD).

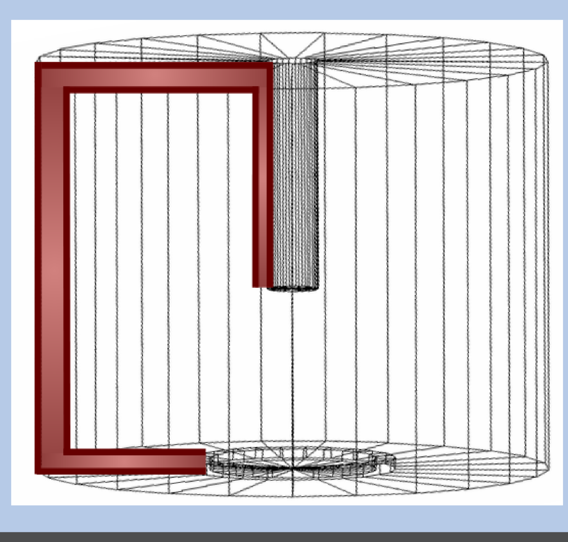



All detectors are being **characterized prior installation** in an extensive characterization campaign performed in **underground sites** to reduce the cosmic activation. Once the **nominal bias voltage** is determined and the **homogeneity of the detector's surface** is scanned, the best achievable **energy resolution** is estimated. The determination of the **PSD performance** and the **active volume** is necessary for a precise **detector efficiency** calculation in LEGEND.

## Detector active volume

The active volume (**AV**) of HPGe detectors differs to their total volume due to the presence of a conductive surface layer where **charges are not fully collected**. The full charge-collection depth (**FCCD**), defined as the depth at which the CCE reaches unity, consists of a dead layer (**DL**) where the CCE is negligible and a transition layer (**TL**) where the charges are partially collected.



## References

[1] The LEGEND Collaboration, AIP Proceedings (2017) 1894:020027

[2] The LEGEND Collaboration, arXiv:2107.11462

[3] The GERDA Collaboration, Eur. Phys. J. C (2018) 78:388

[4] The MAJORANA Collaboration, Phys. Rev. Letters (2018) 120:132502

[5] The GERDA Collaboration, Eur. Phys. J. C (2019) 79:978

[6] https://github.com/legend-exp/g4simple

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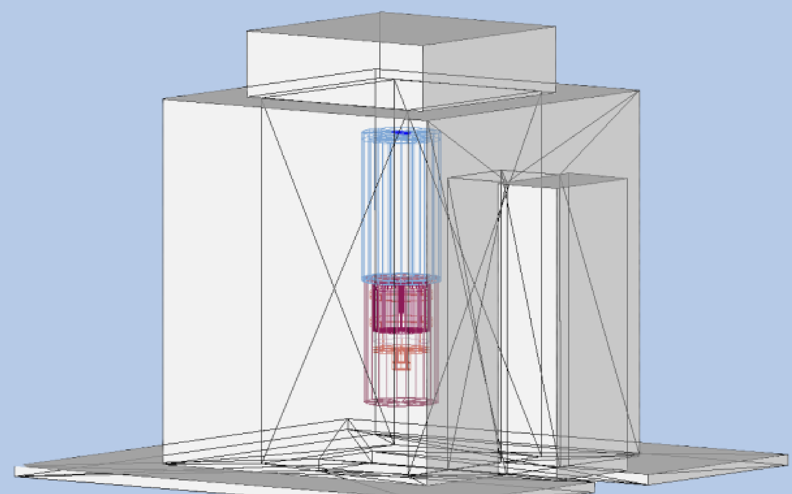
## Analysis procedure

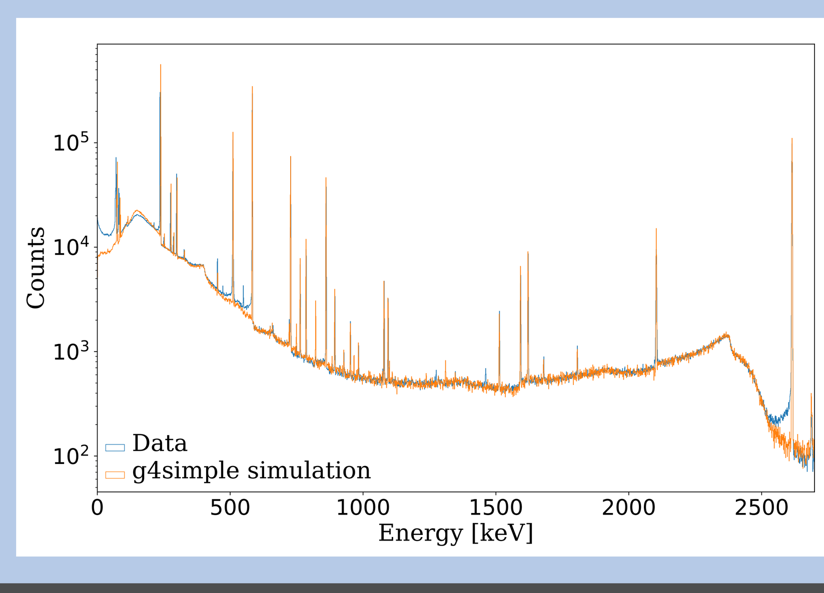
The basic principle behind the AV determination [5] is a **comparison of the energy spectra** of a calibration source measurement with MC simulations of the experimental setup, with **varying FCCD thicknesses**. In this analysis the TL is ignored such that the FCCD and DL are equivalent.

1. Data are taken in an underground laboratory where the detector is irradiated by a radioactive source. The spectrum is calibrated and the energy resolution is measured.
2. Simulations are run in the G4simple software and are post-processed smearing the energy and setting different values for FCCD.
3. The inferred FCCD is the FCCD in the MC spectrum that best describes the measured spectrum. The AV is computed from the inferred FCCD and the dimensions of each detector.

## G4simple simulations

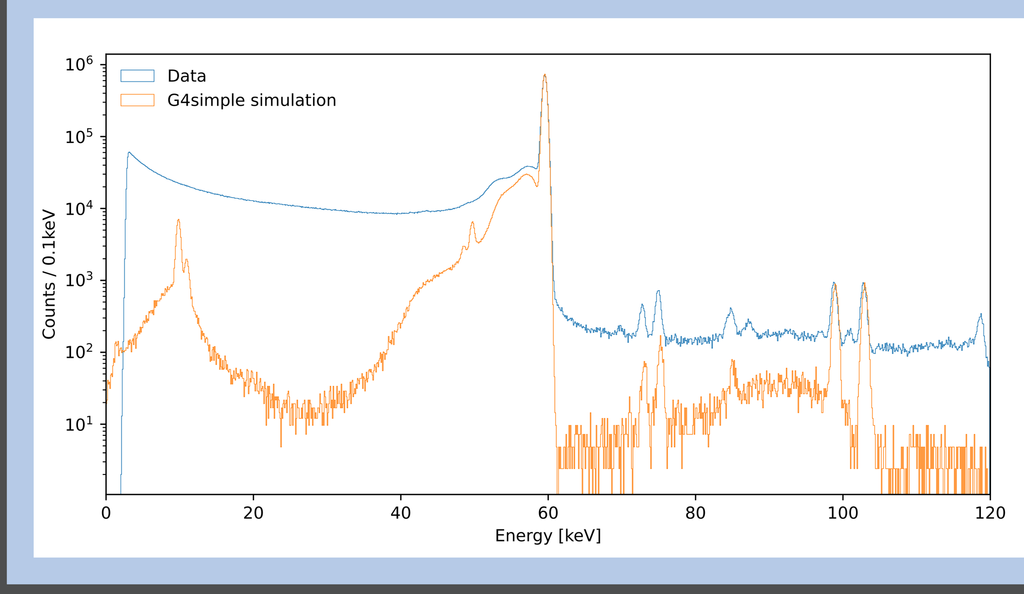
**G4simple** [6] is a simple Geant4 simulation suite developed by the LEGEND collaboration. The simulations are meant to reproduce all the setup components. The figure below shows the lead castle in the **HADES laboratory** (Belgium) with inside the source placed in the source holder, and the detector surrounded by the wrap and the holder installed in a vacuum cryostat. The $^{228}$Th source is required to validate the simulation comparing the resulted energy spectrum with the data.

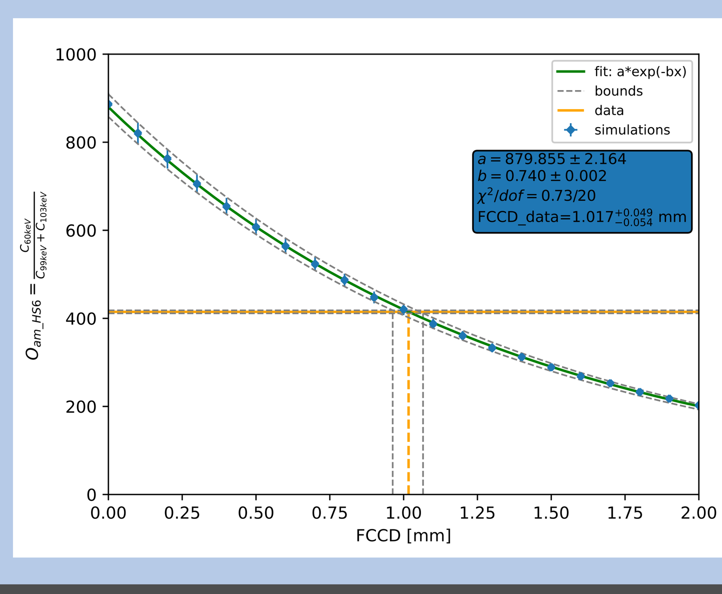





## Observables

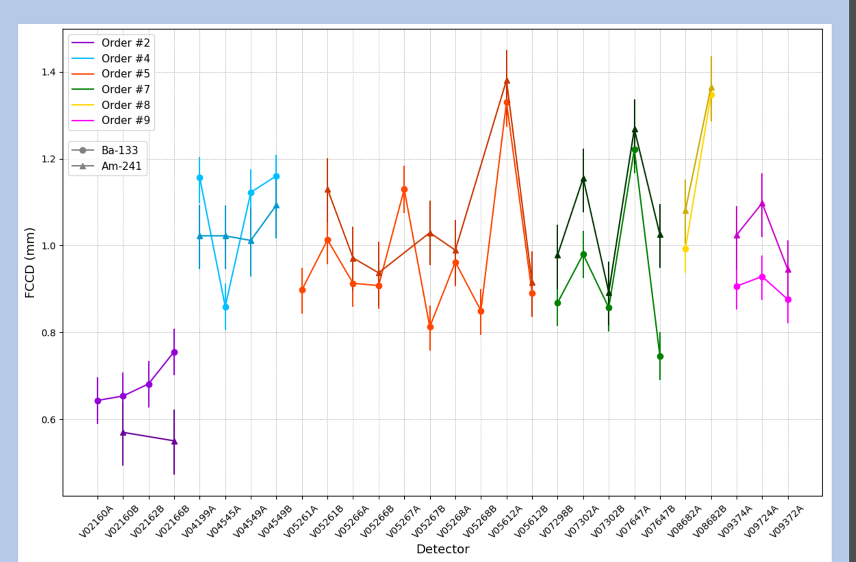
To compare data to post-processed MC simulations, the analysis method uses the **counts ratio** of main peaks as an FCCD sensitive observable. For instance, the observable in $^{241}$Am spectrum is $O_{^{241}Am} = \frac{C_{59.5keV}}{C_{99keV}+C_{103keV}}$.




## Results

The plot shows the FCCD obtained with $^{241}$**Am** and $^{133}$**Ba** sources for all the ICPCs characterized so far in the HADES laboratory. A detailed study of the FCCD at the **bore-hole** and an investigation of the **surface homogeneity** on the top and lateral detector sides are performed to better investigate the FCCD in the specific geometry of ICPCs.



## Conclusion and future work

HPGe detectors must be characterized before being submerged in the LAr cryostat at LNGS. The AV of HPGe detectors is determined by finding the DL thickness. The analysis processed is repeated for all the LEGEND detectors. To better understand the AV, an investigation on the **TL model** is required (next step).