Determination of dead layer parameters of semiconductor germanium detectors using machine learning for the LEGEND experiment

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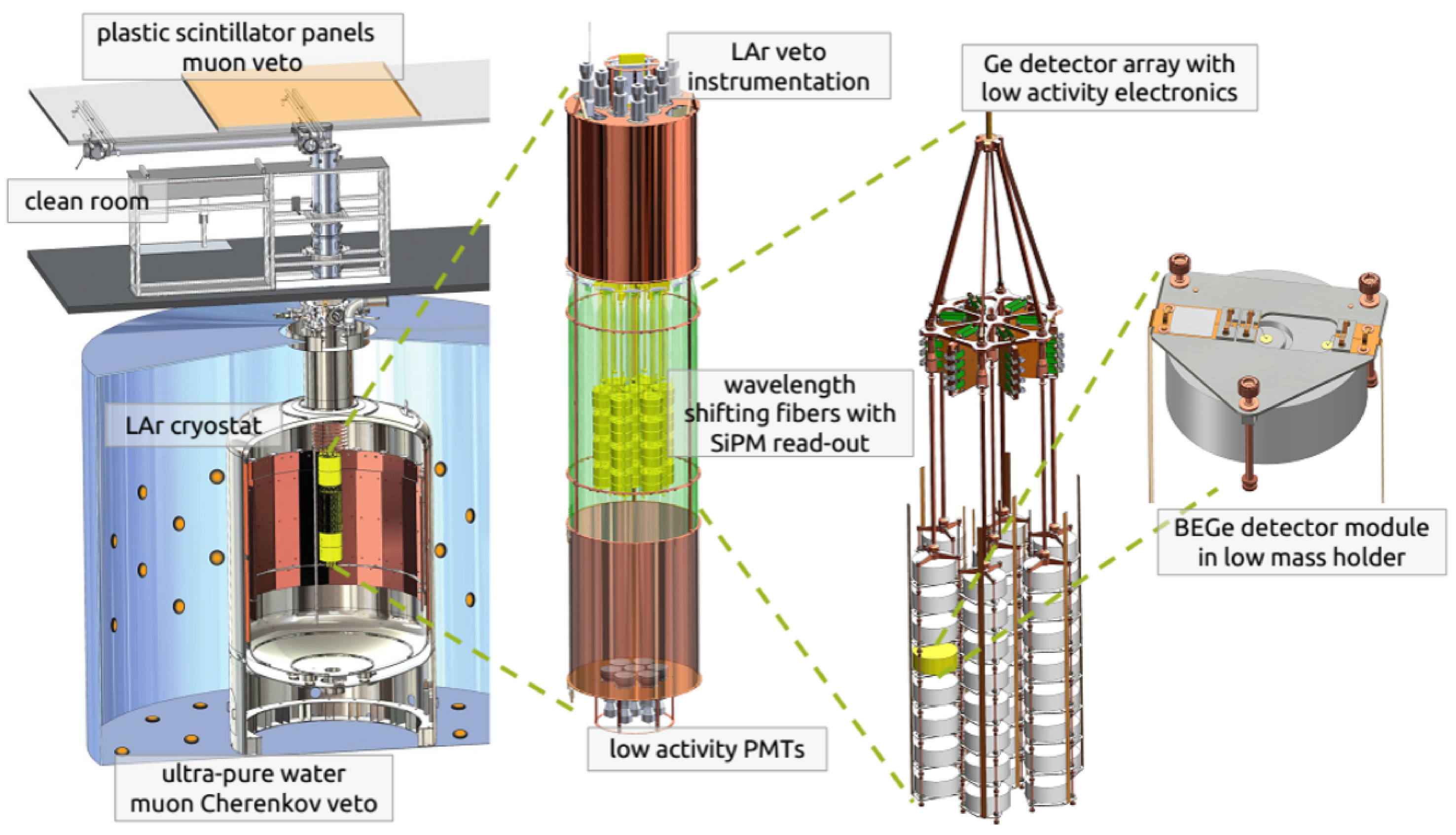
Large Enriched Germanium Experiment for Neutrinoless ββ Decay

Motivation

The search for neutrinoless double beta decay remains today one of the most important areas in particle and nuclear physics. Germanium detectors are an excellent technology for this search because of state-of-the-art energy resolution, but a dead layer in a germanium crystal can reduce the active volume, which can significantly affect both exposure and half-life sensitivity. In this work, we used machine learning methods to study the dead layer in enriched germanium crystals. 1000 sets of events were simulated with various combinations of dead layer parameters. A fully connected neural network was used to determine these parameters from the energy spectra of a gamma calibration source Ba-133.

LEGEND-200 experiment

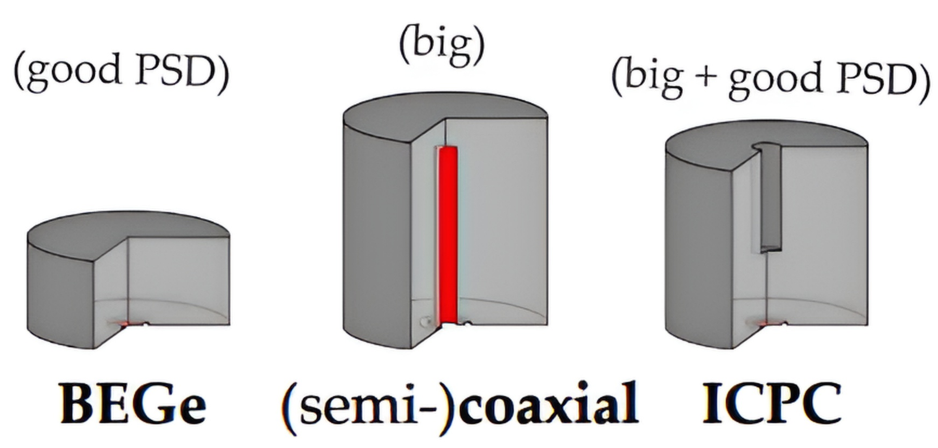
The LEGEND-200 [1] experiment will operate 200 kg of Ge detectors in a bath of LAr in an upgrade of the Gerda [2] infrastructure at LNGS. The LEGEND-200 design combines the best elements of Gerda and the Majorana Demonstrator [3].



Until the next phase of experiment - LEGEND-1000 [4], LEGEND-200 will be one of the leading experiments in the field, reaching a half-life sensitivity of 10^{27} yr after five years of operation.

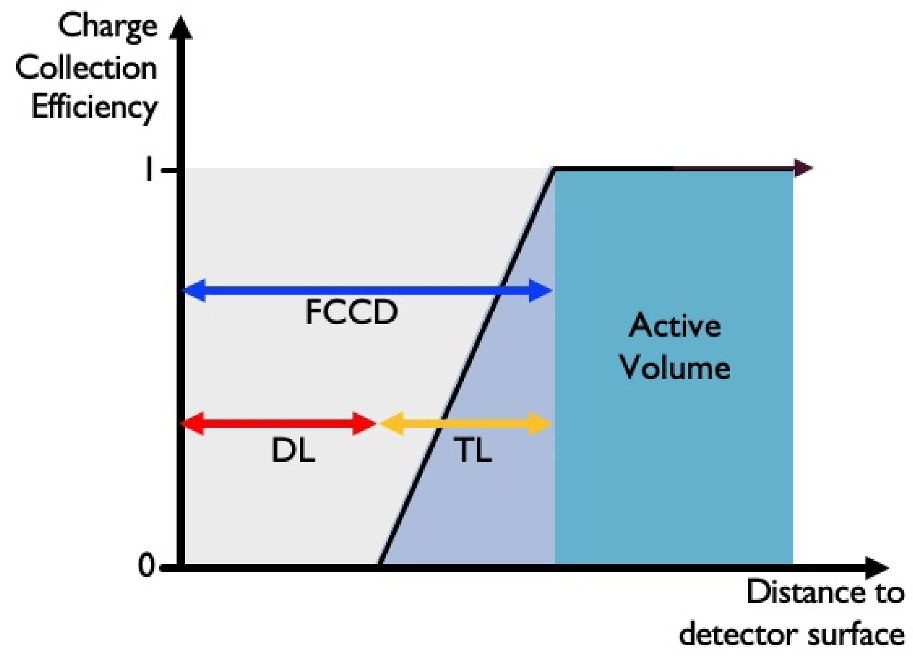
HPGe detectors

Germanium detectors are used in the LEGEND experiment for a number of reasons: Excellent energy resolution - 0.1 % at $Q_{\beta\beta}$ = 2039 keV, practically radio-pure, both a detector element and a source, enrichment at the level > 90% is possible. The innovative Inverted Coaxial Point Contact (ICPC) will be one of the main detector geometries used for LEGEND since they possess a larger mass (> 2 kg) than previous point contact while still preserving good energy resolution.



Full Charge Collection Depth model

The Full Charge Collection Depth is an important characteristic of the detector, since it completely determines the active volume. In our study, we used a simplified FCCD model:



- Full Charge Collection Depth (FCCD) = DL + TL
- Dead Layer (DL) = region of no charge collection on surface of semiconductor detectors
- Transition Layer (TL) = partial charge collection, here modelled with linear function

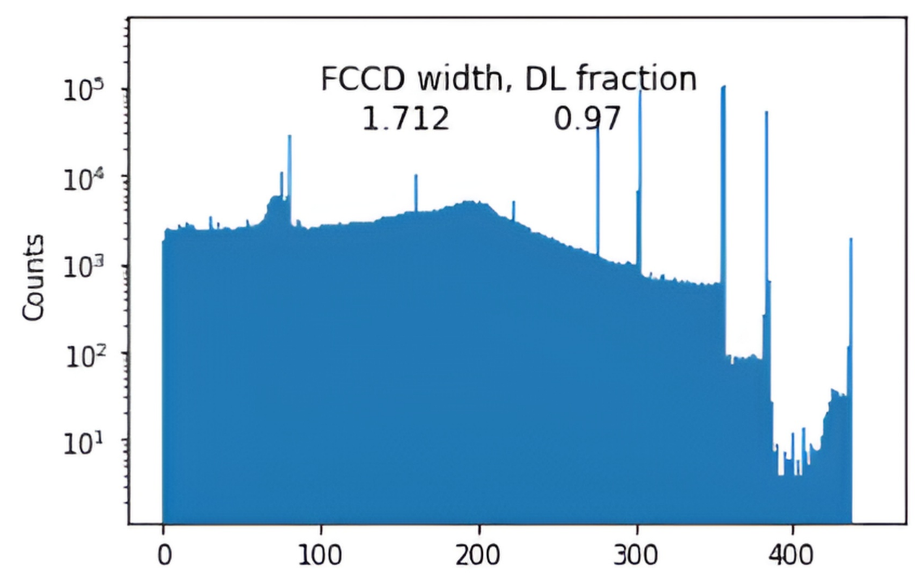
The determination of FCCD is important:

- The $0\nu\beta\beta$ half-life is a function of active mass
- Degraded events could mimic $0\nu\beta\beta$ signature

Procedure

To determine the parameters of the dead layer, it was decided to use neural networks.

Monte Carlo data of ICPC detector exposed to Ba-133 in HADES underground laboratory were prepared with a different set of values for two determined parameters — FCCD and Dead Layer Fraction (DLF), where DLF = DL/FCCD for a linear TL model. Total 1000 files.

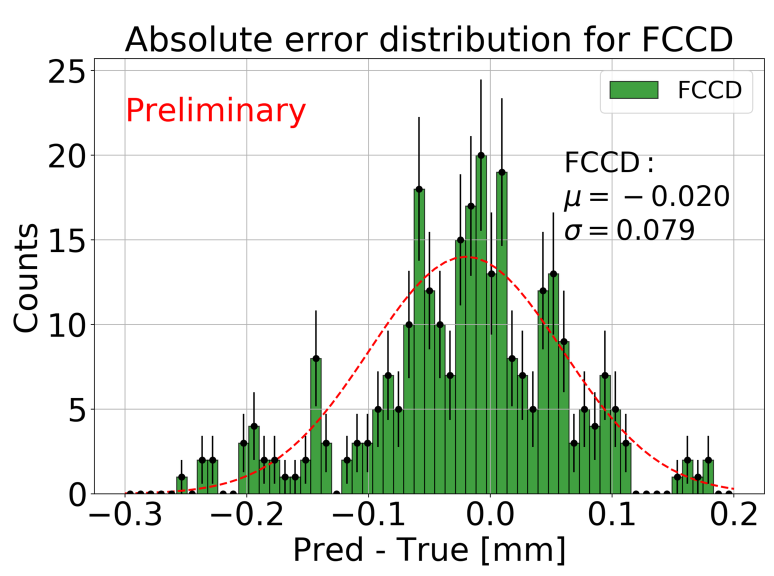


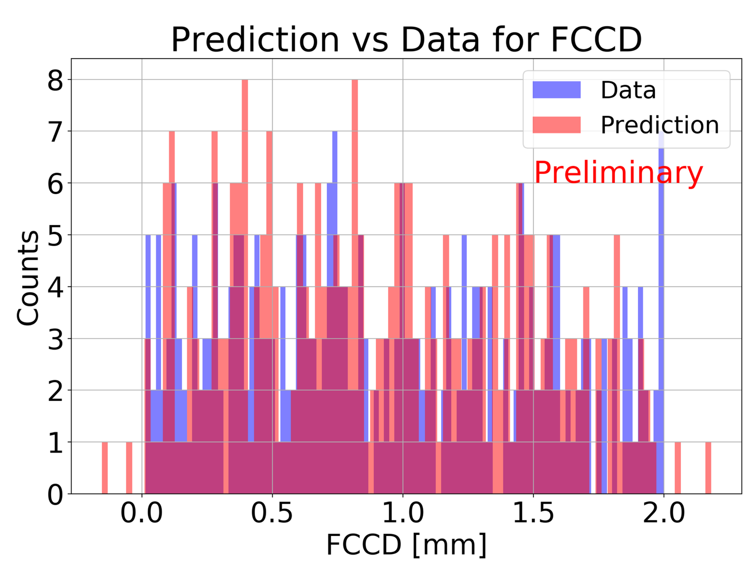
The training was carried out on 700 files. The results of training the neural network were tested on the remaining 300.

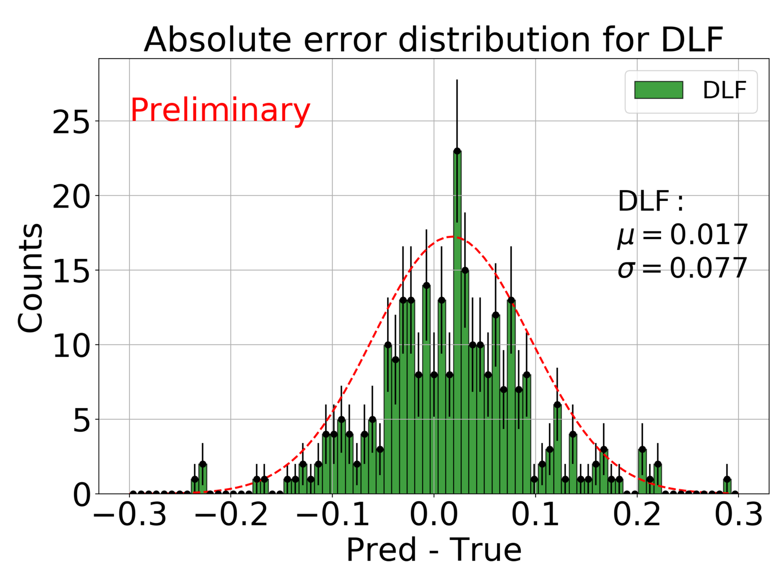
The data represent the energy spectrum of 133Ba in the range of 0 to 450 keV with a bin width of 0.5 keV - an array of 900 values, where each value indicates the number of events that fell into this bin.

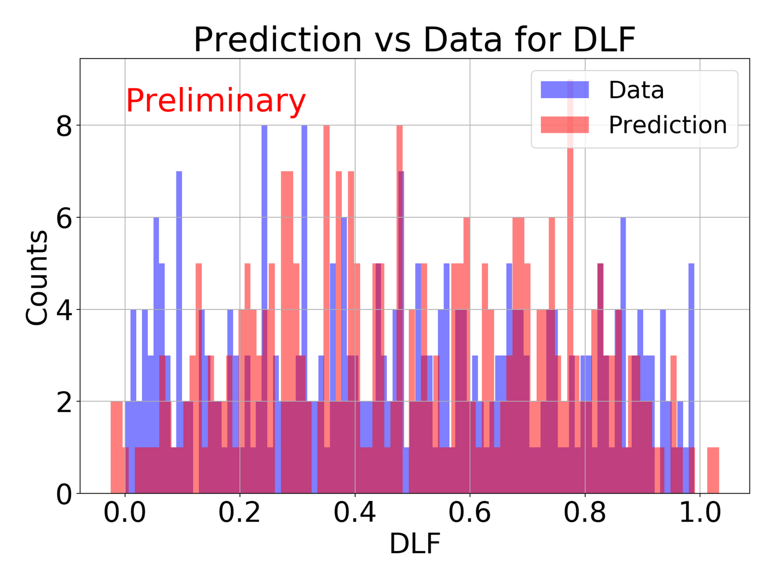
Preliminary results

The resulting plots, in particular plots of absolute parameter determination errors (FCCD and DLF) and distribution plots of predicted parameter values along with true values are presented. With the use of a simplified FCCD model and a fully connected neural network, it was possible to achieve an accuracy of about 0.1 mm in determining FCCD. The next step is to use a more complex neural network and increase accuracy and eventually test the network on real data taken with the HPGe.









References

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