Characterization of Broad Energy Germanium detector (BEGe) as a Candidate for the GERDA experiment

M. Agostini[1], E. Bellotti[2], C. Cattadori[2], A. D'Andragora[3], A. di Vacri[3], A. Garfagnini[1,4], M. Laubenstein[3], L. Pandola[3], C. Ur[4]

1) Padova University, Italy 2) INFN–Milano Bicocca, Milano, Italy, 3) INFN–LNGS, L'Aquila, Italy, 4) INFN-Padova, Italy

GERmanium Detector Array at LNGS

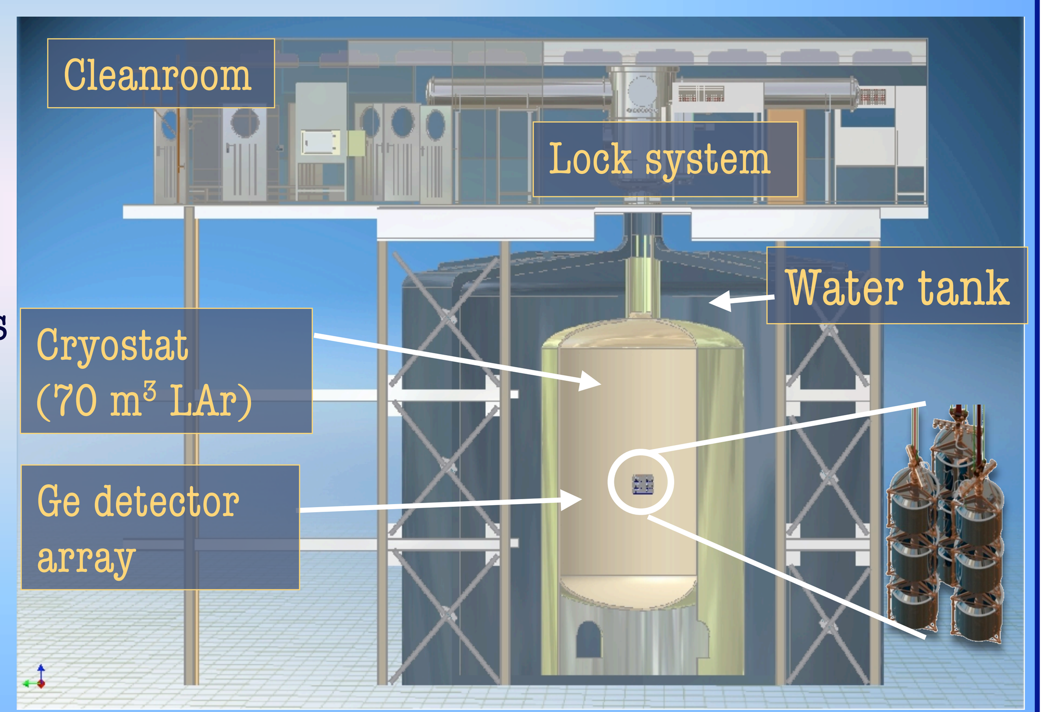
GERDA [1] is designed to search for $0\nu\beta\beta$-decay of ^{76}Ge using high purity germanium detectors (HPGe), enriched in ^{76}Ge, directly immersed in LAr which acts both as shield against γ radiation and as cooling medium. The experiment aims at a background 10^{-3} cts/(kg · y · keV) and energy resolution ≤ 4 keV at $Q_{\beta\beta}$=2039 keV.

GERDA phases and corresponding sensitivities (90% CL):

✓ **Phase I**
– Operation of reprocessed enriched HDM and IGEX detectors (17.9 kg), reprocessed natural Genius-TF detectors (15 kg)
– $T_{1/2} > 3 \cdot 10^{25}$ y, $m_{ee} < 270$ meV [2]

✓ **Phase II**
– New custom made Ge detectors, design has still to be defined between n-type 18-fold segmented detectors and p-type BEGe detectors (20 kg enriched diodes+several natural Ge diodes)
– $T_{1/2} > 1.5 \cdot 10^{26}$ y, $m_{ee} < 110$ meV [2]

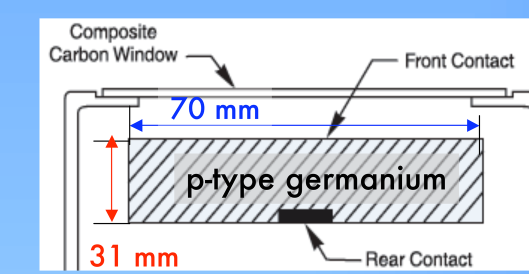
✓ **Possibly Phase III**
– Ton scale array in worldwide collaboration
– $T_{1/2} > 2 \cdot 10^{27}$ y, $m_{ee} < 40$ meV [2]

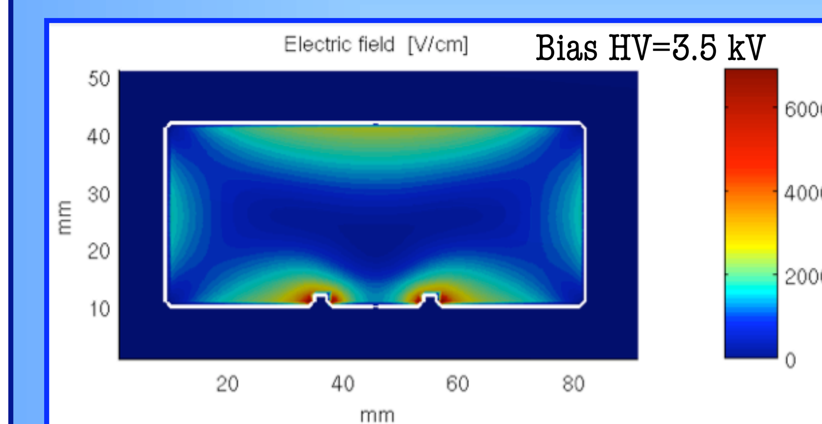


[1] The GERDA Collaboration, Proposal (2004), http://www.mpi-hd.mpg.de/GERDA/proposal.pdf
[2] V.A. Rodin et al., Nucl. Phys. A 766 (2006) 107 and erratum, Nucl. Phys. A 793 (2007) 213

BEGe model

It has been shown in a previous work [3] that a p-type Broad Energy Germanium detector (BEGe) of 80 mm diameter and 30 mm height could be a good candidate for GERDA Phase II, thanks to its enhanced pulse shape discrimination (PSD) capability, allowing to distinguish multi-site events (MSE) from single-ionization (SSE) ones. We have tested another BEGe detector of different geometry, 70 mm diameter and 30 mm height, and developed a full detector model (electric field and pulse generation) to explain the reasons of such a feature. The modelization has been validated with ad-hoc measurements.

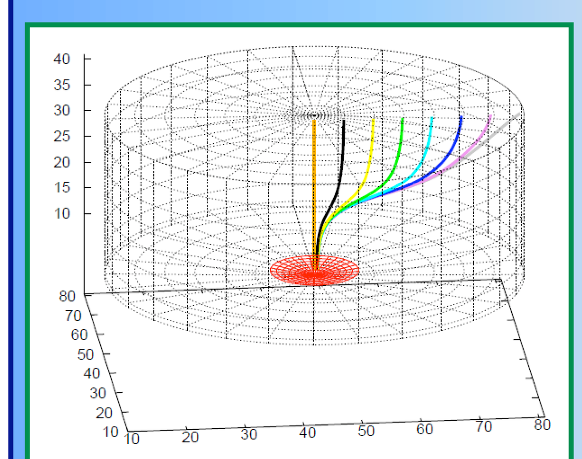


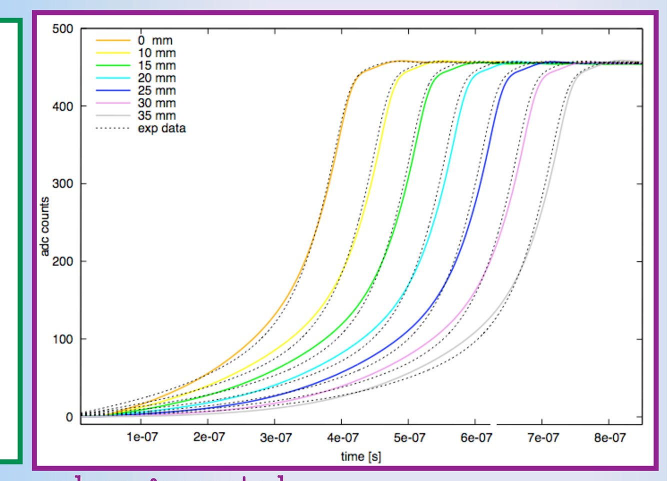


1. The detector E field (E(r)) at the operation voltage (3.5 kV),
2. the charge trajectories and
3. the pulses generated at the readout electrode have been numerically computed by means of the *Multi Geometry Simulation* (MGS) code [4], a detector characterization and pulse shape generation tool.

The PSD capability of the BEGe detector can be explained by:

- pulse "stretching" effect due to large variation of E(r) values along charge trajectory;
- highly different trajectory length for events generated at different radii.


charge trajectories



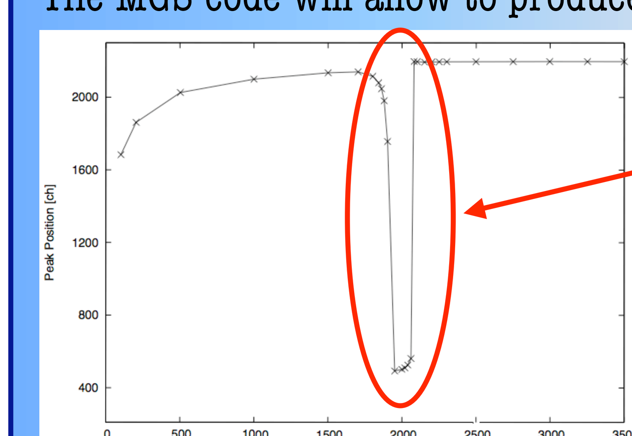
pulses generated

Introduction of the preamplifier transfer function allows the comparisons of generated pulses to the experimental average pulses collected from a radial scan of the top surface of the BEGe with an ^{241}Am source: the model reproduces to a high level the experimental average pulses (dotted lines in the left plot).

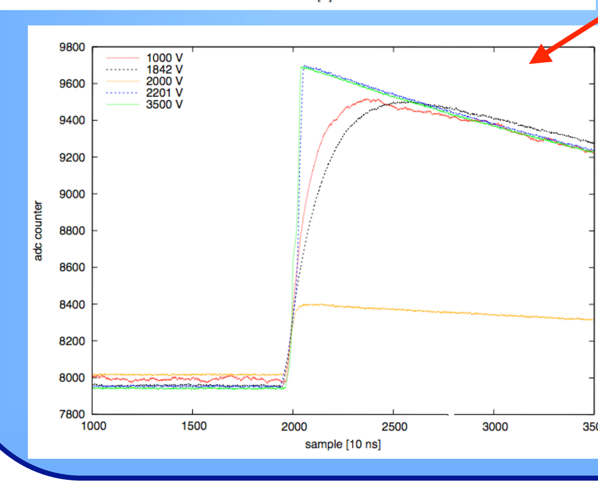
The detector core is a peculiar region where the trajectories are only poorly differentiated, therefore the PSD capability will be much reduced.

The MGS code will allow to produce pulse libraries for BEGe detectors of different sizes.

A peculiarity

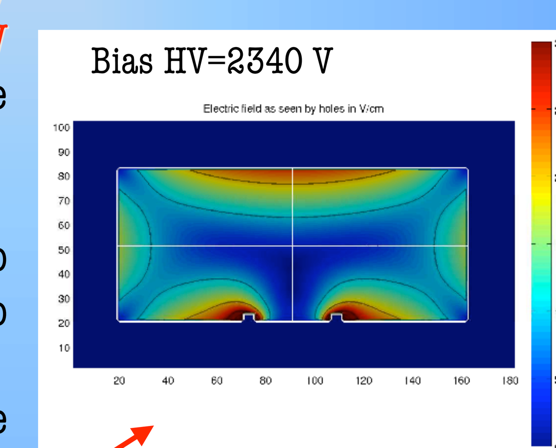


When irradiating with a ^{137}Cs the counting rate curve drops drastically to very low values in the 1.8-2.1 kV range just before reaching the depletion voltage.



The pulse shapes are also considerably different respect to other HV bias values.

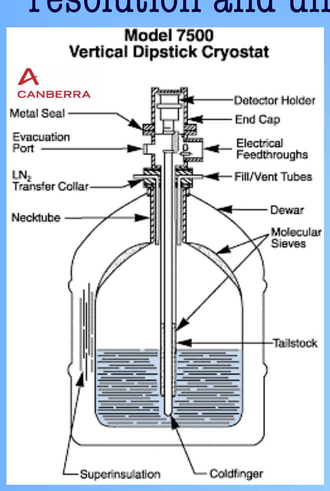
This is most probably due to the electric field configuration inside the detector; the low field region (deep blue in the plot) extends "locking" the collecting electrode.

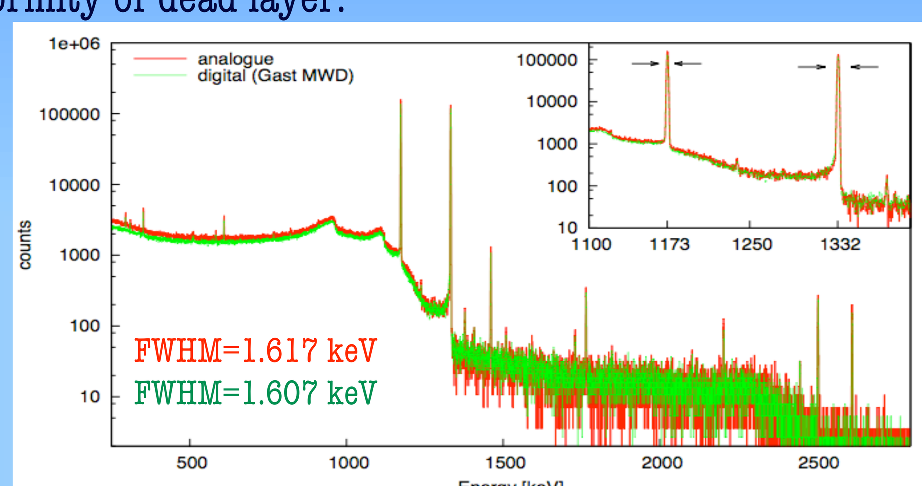


[3] D. Budjás et al., 2009 JINST 4 P10007
[4] P. Medina et al., IMTC2004, Como, Italy

BEGe characterization in a standard configuration

Commercial BEGe from Canberra has been fully characterized in terms of linearity, energy resolution and uniformity of dead layer.

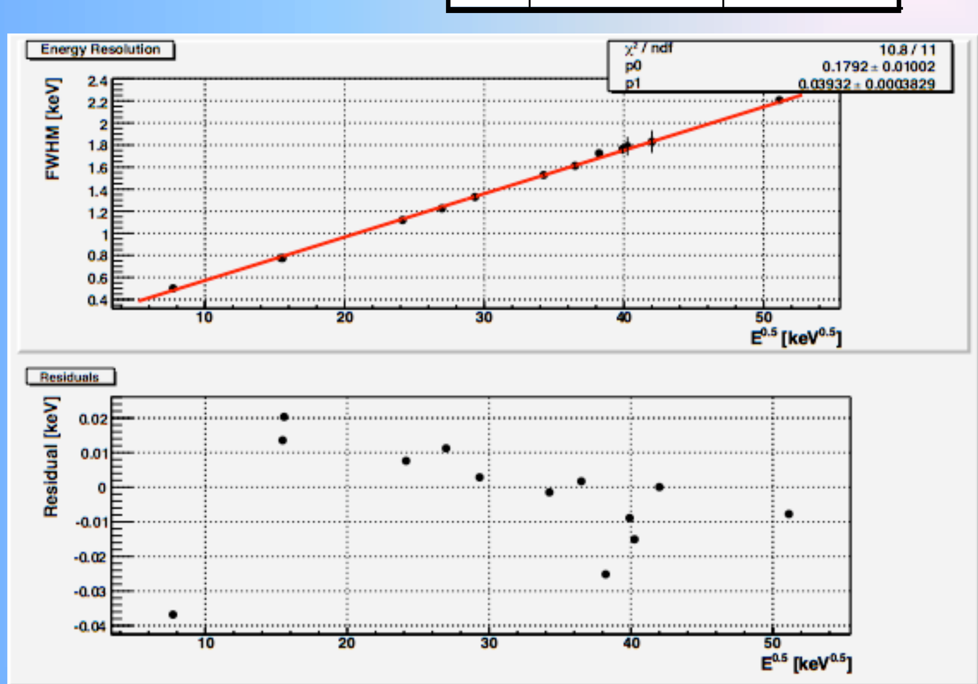




^{60}Co source spectra:
Red → traditional analog electronics (spectroscopy amplifier+ADC)
Green → CAEN N1728B NIM FADC, 4ch, 14 bit resolution, 100 MHz sampling rate.
Energy reconstructed both by Moving Window Deconvolution Gast algorithm and/or by Jordanov algorithm.

Canberra Specifications:

	Energy [keV]	FWHM [keV]
^{57}Co	122.06	0.639
^{60}Co	1332.501	1.752

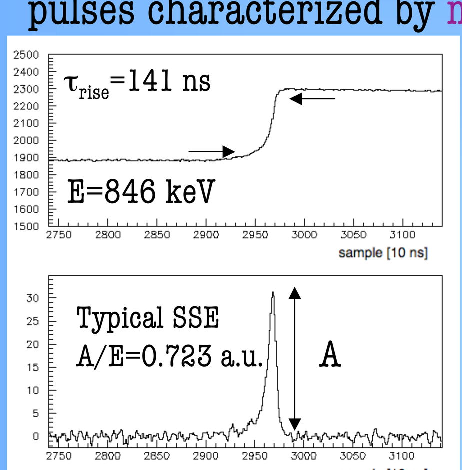


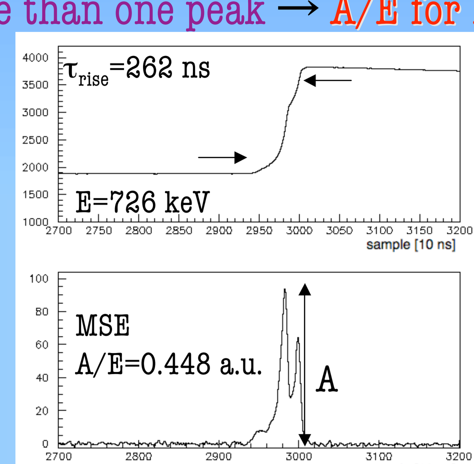
Experimental energy resolution is even better than producer specifications.
For E>50 keV: FWHM ∝ √E with deviations less than 4%
For E<50 keV: FWHM is constant.

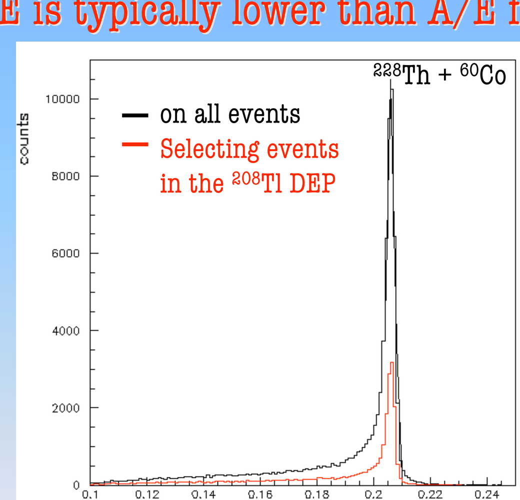
	Energy [keV]	FWHM [keV]
^{241}Am	59.54	0.50 ± 0.01
^{137}Cs	661.657	1.19
^{60}Co	1173.237	1.529 ± 0.011
^{22}Na	1274.53	1.62
^{60}Co	1332.501	1.612 ± 0.022
^{208}Tl	2614.533	2.207 ± 0.021

Preliminary results on Pulse shape analysis and MC

Pulse shape analysis is based on the parameter A/E, ratio between the amplitude of the differentiated pulse and the energy: unlike SSE, MSE, mainly due to multiple interactons of γ rays, are a superposition of smaller pulses, resulting in different slopes of the rising edge of the pulse and in differentiated pulses characterized by more than one peak → A/E for MSE is typically lower than A/E for SSE.







The distribution on the parameter A/E shows a peak corresponding to SSE. After fitting the peak, a threshold for pulse shape discrimination is set at:

A/E(threshold)=A/E(mean)-3σ

→ for A/E>A/E(threshold) the population is dominated by SSE.

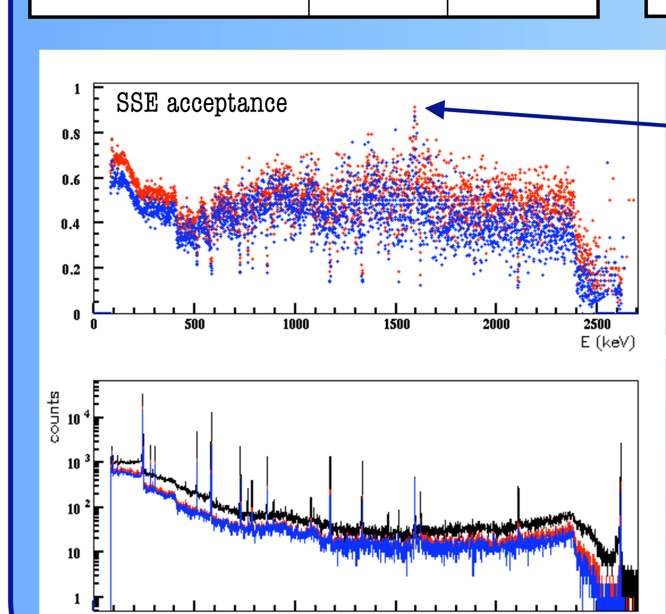
The BEGe PSD capability has been studied on two different populations:

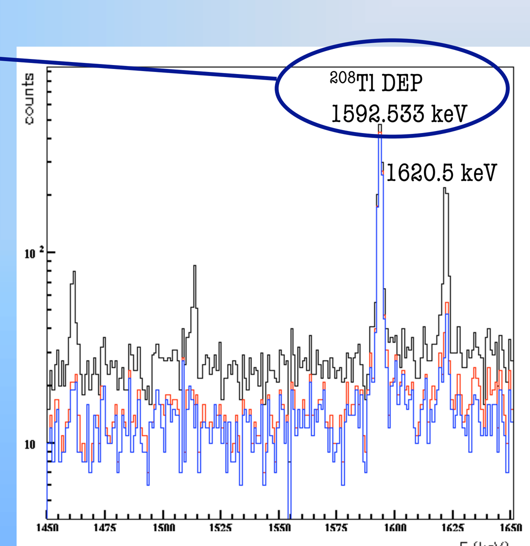
1. BEGe irradiated simultaneously with both a ^{228}Th source (50 kBq) and a ^{60}Co source (low intensity). The Double Escape Peak (1592.5 keV) is a clean SSE sample. The rejection efficiency can be tested using the close γ 1620.8 keV (^{212}Bi) line events that are mainly MSE;
2. BEGe in coincidence with a second HPGe coaxial detector (@ 90°) to select mainly those events in which a ^{60}Co γ undergoes a unique Compton scattering.

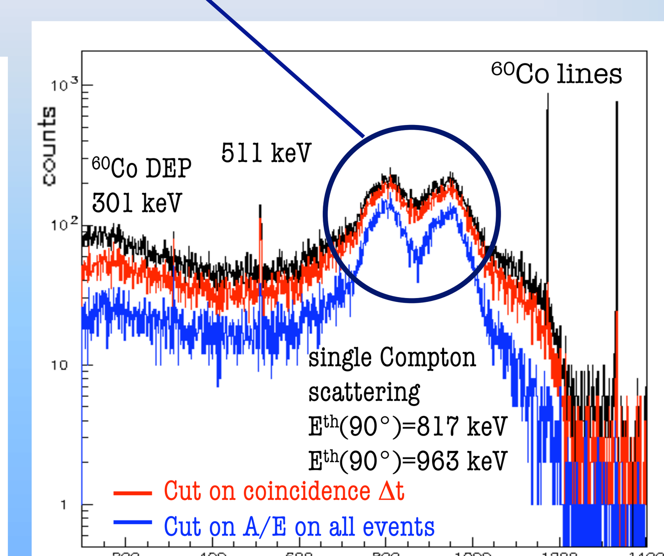
SSE acceptance= Counts after cuts on (A/E)/total counts

Acceptance (^{228}Th+^{60}Co)	DEP	1620 keV
A/E on all events	98%	18 %
A/E on DEP	94%	13%

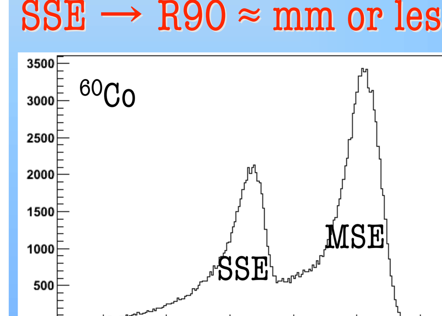
Acceptance (^{60}Co)	200-600 keV	656-1077 keV	1162-1346 keV	DEP	511 keV
for coincidence	49%	61%	26%	94%	21%
for single mode	53%	54%	29%	---	---

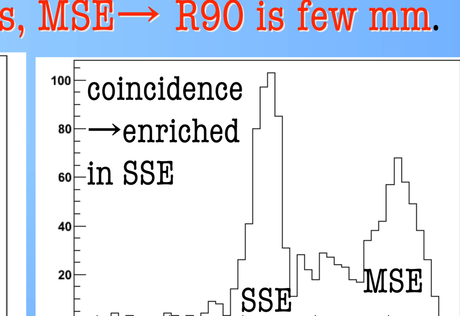






An intense MC activity has been carried out for quantitative definition of MSE and SSE.
The adopted parameter is R90: radius within 90% of the energy is released.
SSE → R90 ≈ mm or less, MSE→ R90 is few mm.





Conclusions and perspectives

- A 70 mm diameter BEGe detector from Canberra has been characterized:
  – energy resolution: FWHM = 1.6 keV @ ^{60}Co both with analog and digital electronics;
  –linearity: linear within a few 10^{-4} (this issue will be further investigated);
  –depletion voltage: already depleted at 2.3 kV (nominal value is 3 kV);
  –estimation on the dead layer: 0.8 mm uniformly on the top and 0.7 mm on the lateral surface in agreement with the Canberra specification.
- A full numerical model of the BEGe for the numerical calculation of the electric field, of the charge trajectories and of the pulses induced at the readout electrode, based on the MGS software, has been developed. It has been validated with ad-hoc measurements. It will allow to improve the pulse shape analysis.
- Preliminary results on the pulse shape analysis based on the cut on the parameter A/E are:
  - >94% SSE acceptance @ DEP
  - >87% MSE rejection @ 1620 keV γ line

  These results are compatible within a few percent with the ones obtained in the previous work with a 80 mm diameter BEGe.
- Next steps will be:
  - characterization of specially produced BEGe from depleted Ge in the ^{76}Ge isotope;
  - test of one or more standard BEGe naked in LAr;
  - Full simulation of the events from the primary interactions to the final pulses.