

Pulse shape modeling and discrimination of BEGe detector signals for GERDA Phase II

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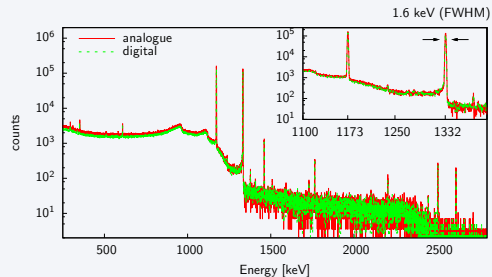
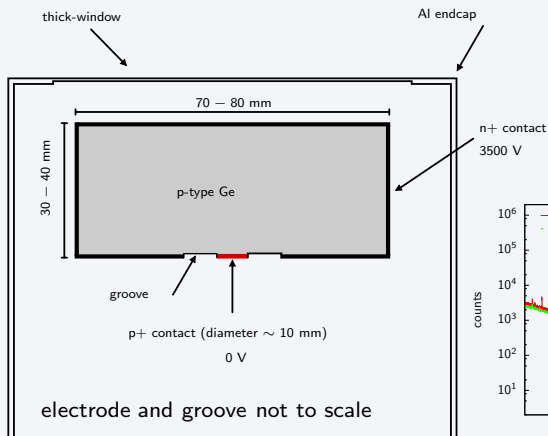


- 1 The BEGe detectors
- 2 The simulation
- 3 BEGe modeling and Pulse Shape Discrimination (PSD) features
- 4 Validation of the Pulse Shape Simulation (PSS)
- 5 Pulse Shape Discrimination performances for external and internal background
- 6 Conclusion

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The BEGe geometry



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The structure of the simulation

I. MC simulation

- > coordinates and energy of the hits

II. Signal formation and development

- <- coordinate of each hit
- > electron and hole trajectories
- > the signal induced on the small-size electrode

III. DAQ simulations

- <- energy and signal for each hit in an event
- <- the preamplifier response
- > each pulse is convolved with the preamplifier response
- > all the pulses of an event are added up
- > the noise is added to the total pulse

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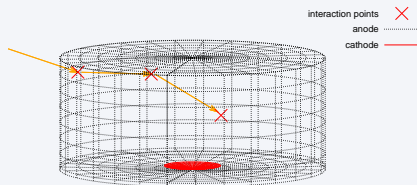
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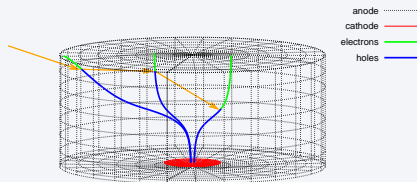
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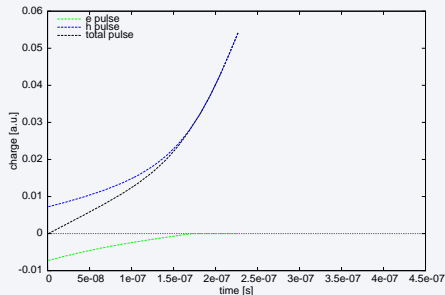
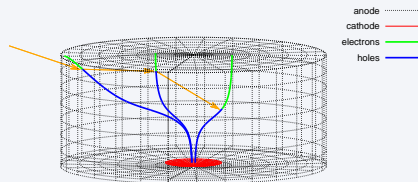
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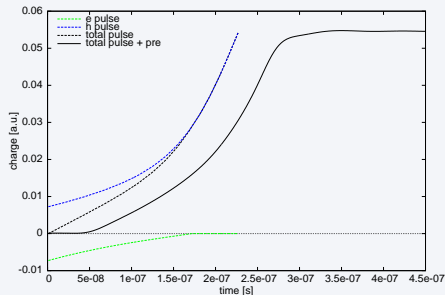
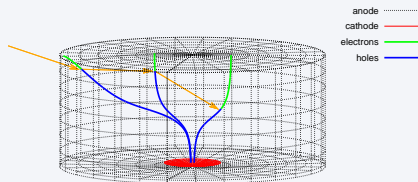
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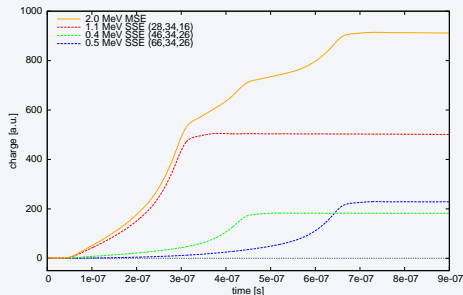
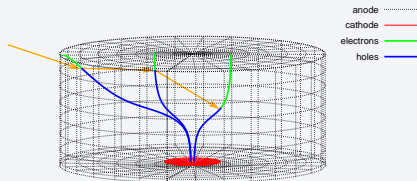
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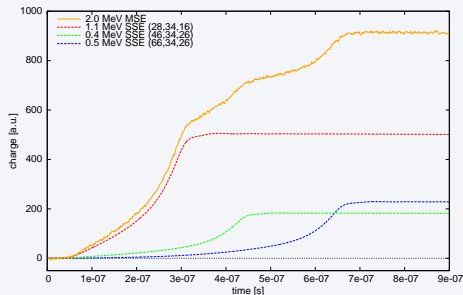
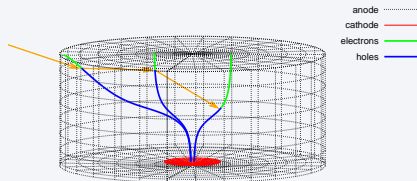
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The simulation design

step 0. Create a library of pulses:

- 0.1 divide the detector in cubic cells ($1 \text{ mm} \times 1 \text{ mm} \times 1 \text{ mm}$) and generate a pulse for each cell*
- 0.2 convolve each pulse with the preamplifier response
- 0.3 store all the pulses in a library

step 1. Run the MC simulation (MAGE – GEANT4)

step 2. For each interaction vertex compute the pulse as weighted average of the pulses stored in the library

step 3. For each event compute the total pulse by adding up the pulse of all interaction vertices

step 4. Add the noise

* the simulation of the pulses is performed by using a modified version of the Multi Geometry Simulation (MGS) software developed for the AGATA project. MGS uses the charge carrier mobility models of L. Mihailescu and B. Bruyneel.

Outline

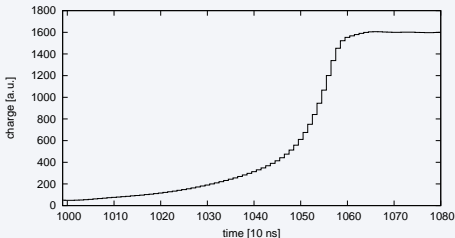
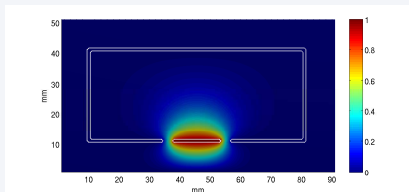
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BEGE Charge-signal development

The charge signal can be derived by using the Shockley-Ramo Theorem:

$$Q(t) = -q\phi_w(\mathbf{r}(t))$$

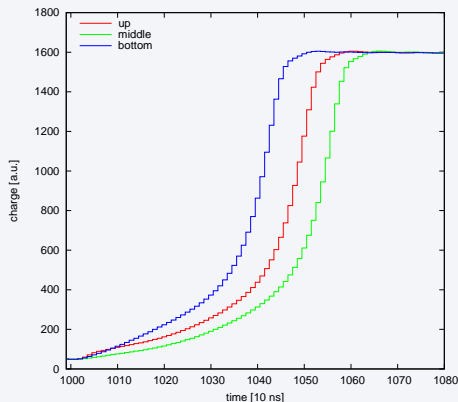
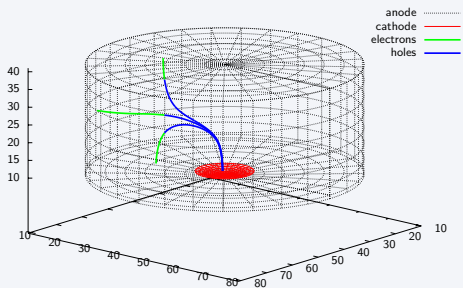
where $\mathbf{r}(t)$ is the position of the charge bunch q at the time t and $\phi_w(\mathbf{r}(t))$ is the weighting potential¹



The signal grows slowly at the beginning when the charges are far from the small-size contact. The fast part of the signal starts when the holes are ~ 1 cm far from the small-size electrode.

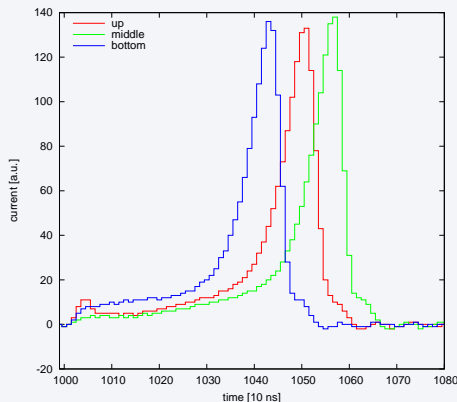
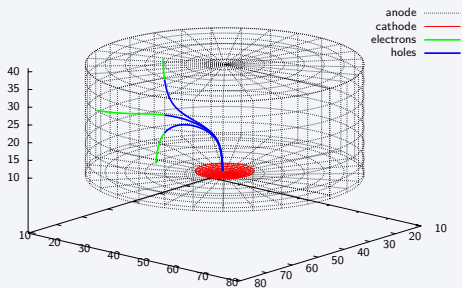
¹The *weighting potential* is defined as the electric potential calculated when the considered electrode is kept at a unit potential, all other electrodes are grounded and all charges inside the device are removed.

Pulse shape dependence of interaction position



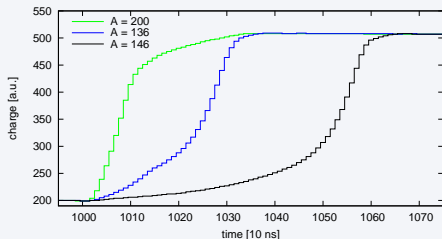
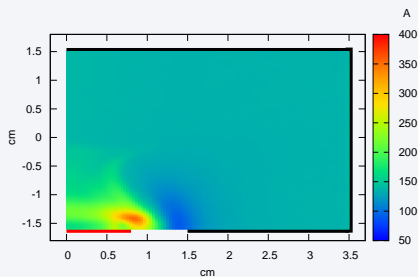
The holes are collected to the small-size contact along the same trajectories
 ⇒ the final part of the charge signals is independent of starting position

Pulse shape dependence of interaction position



The holes are collected to the small-size contact along the same trajectories
 \Rightarrow the final part of the charge signals is independent of starting position

$$Q(t) = -q\phi_w(\mathbf{r}(t)) \Rightarrow I(t) = -\frac{dQ(t)}{dt} = q\frac{d\phi_w(\mathbf{r}(t))}{dt} \Rightarrow I_{max} \propto q$$

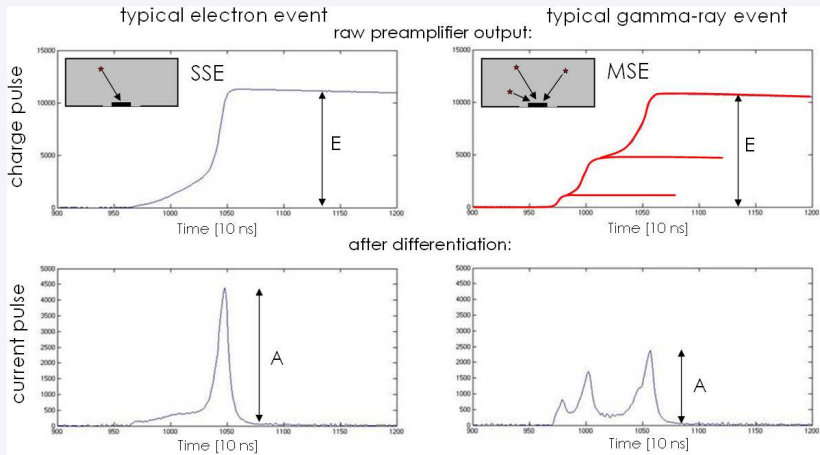
I_{max} distribution

$A := I_{max}$ is constant (for a given energy deposition) in the whole detector volume but close to the small contact:

high A region: electrons and holes move at the same time in the region in which the weighting potential varies sharply. The total pulse is the sum of the two contributions.

low A region: the hole trajectory does not pass through the center of the detector by stays close to the small contact

N.B.: The volume in which the parameter A is not constant is only a few per cent of the total active volume.

Pulse Shape Discrimination: A/E Energy parameter

$$A_{SSE} \propto q_{tot} \quad E_{SSE} \propto q_{tot}$$

$$\Rightarrow (A/E)_{SSE} = k, \text{ constant}$$

$$A_{MSE} \propto q_{SSE_{max}} \quad E_{MSE} \propto q_{tot}$$

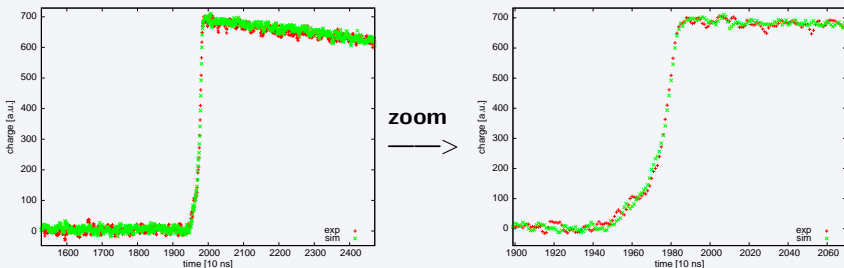
$$\Rightarrow (A/E)_{MSE} < (A/E)_{SSE} = k$$

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PSS validation - pulse shape comparison

- ^{241}Am collimated source \Rightarrow well localized events close to the detector surface;

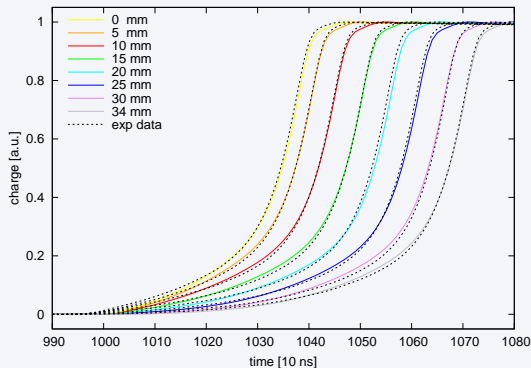
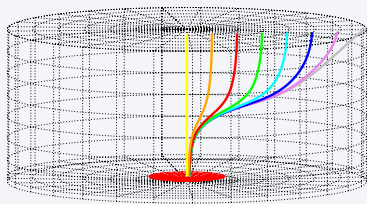


The differences between the simulated and the experimental data are smaller than the noise fluctuations.

Experimental and simulated data of the 70x32 mm BEGe

PSS validation - pulse shape comparison

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- averaging the signals \Rightarrow reduction of noise

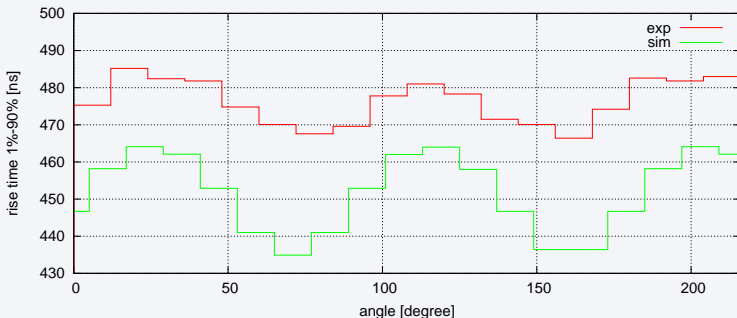


Radial Scanning:

The average pulses are in good agreement for different interaction positions. The small deviation present at the very beginning of the signal is related to the grid width of the pulse library.

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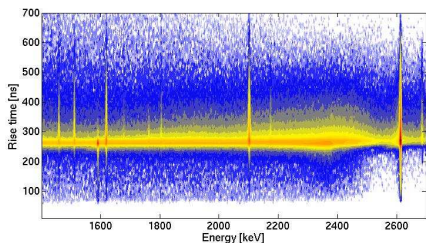
Circular Scanning:

The 1%-90% rise time variations as a function of the angle between the crystallographic axis are qualitatively reproduced by the simulation but the average rise time is slightly shorter ($\sim 20 \text{ ns} = 2 \text{ adc sample}$).

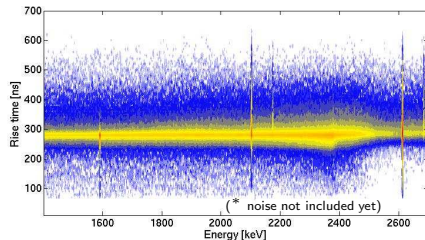
PSS validation - rise time distribution

Rise time 10%-90% distribution for simulated and experimental ^{228}Th spectra:

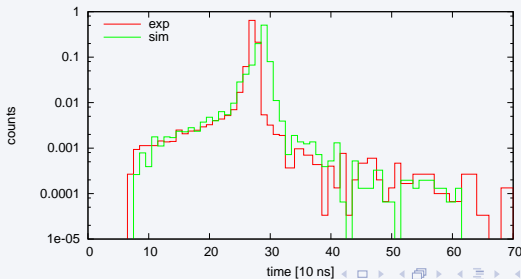
experimental data:



simulated data*:



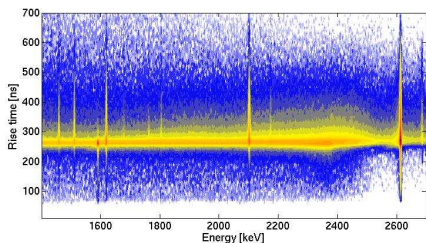
DEP →



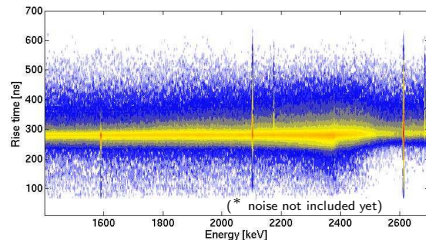
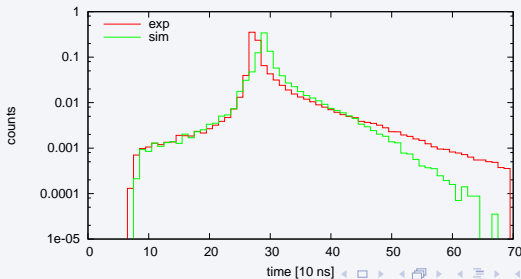
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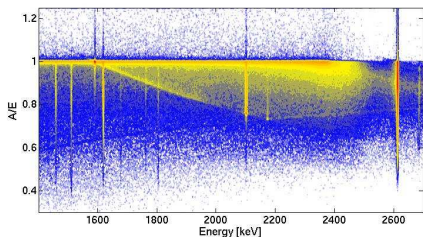
simulated data*:

 $Q_{\beta\beta} \rightarrow$ 

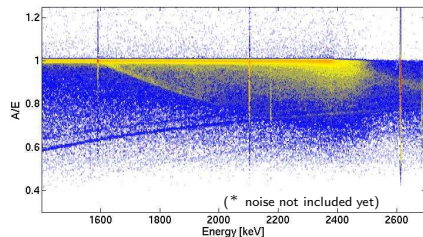
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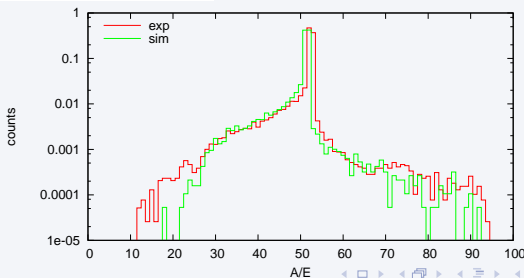
experimental data:



simulated data*:



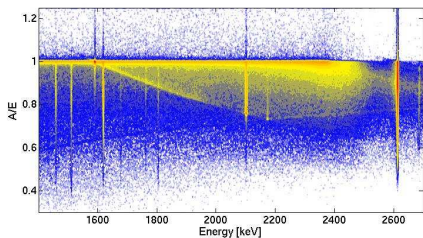
DEP →



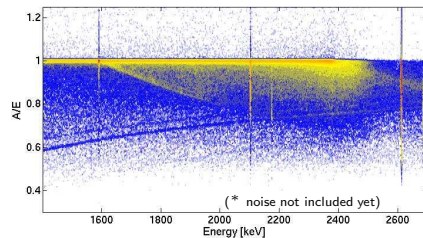
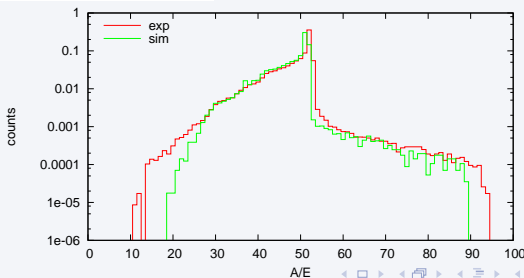
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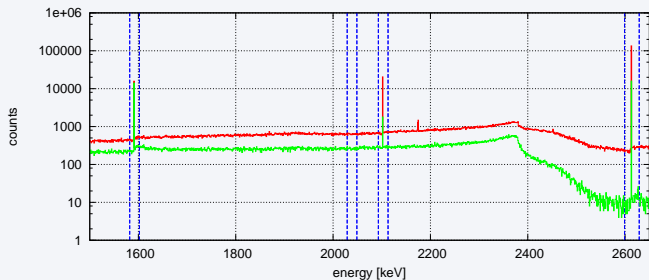
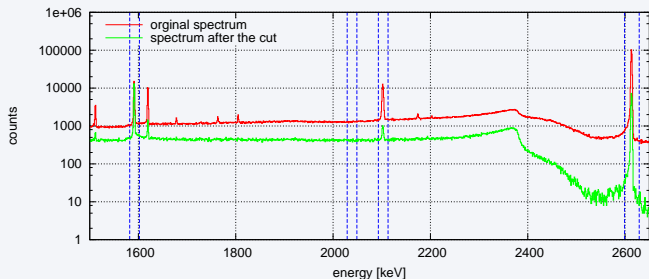


simulated data*:

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PSD applied to simulated and experimental data: ^{228}Th 

Survival probability
after PSD cut for:

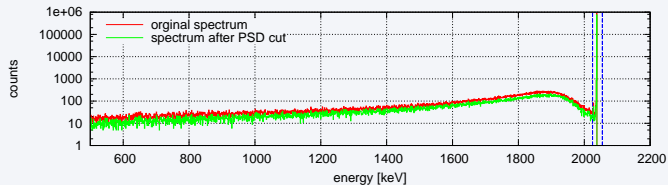
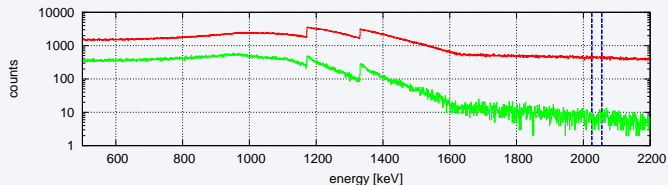
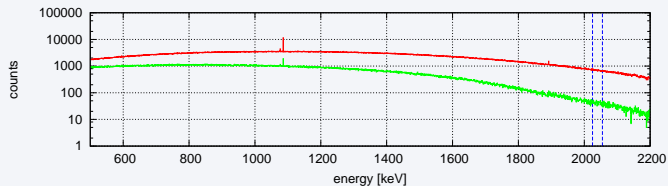
experimental ^{228}Th :

DEP	fixed to 90%
SEP	5%
FEP	7%
$Q_{\beta\beta}$	33%

simulated ^{208}Tl (^{228}Th
daughter):

DEP	fixed to 90%
SEP	7%
FEP	12%
$Q_{\beta\beta}$	41%

PSD of internal background

simulated $0\nu\beta\beta$: $Q_{\beta\beta}$ 86%simulated ^{60}Co : $Q_{\beta\beta}$ 1%simulated ^{68}Ga
(^{68}Ge daughter): $Q_{\beta\beta}$ 6%

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Conclusion

Results:

- The pulse shape simulation gives a detailed understanding of the signal time structure of BEGe detectors. It is noteworthy that the PSS and its systematics do not have an impact on the physics analysis, because the pulse shape discrimination cut is calibrated with experimental data.
- The pulse shape simulation developed shows a quantitative agreement with the experimental data in all the comparisons performed
- For the first time the BEGe PSD rejection performances for internal sources of background were studied and the survival acceptance is $\sim 1\%$ for ^{60}Co and $\sim 6\%$ for ^{68}Ge .