Signal modeling of high–purity Ge detectors with a small read–out electrode and application to ^{76}Ge double beta decay search

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Outline

BEGe detector project overview

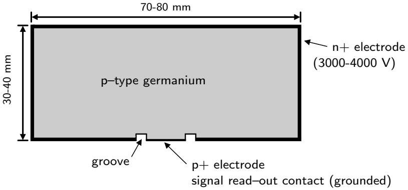
Signal modeling

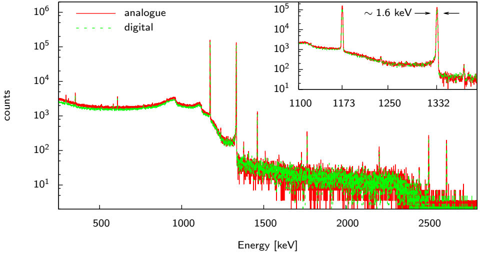
Signal identification and background rejection

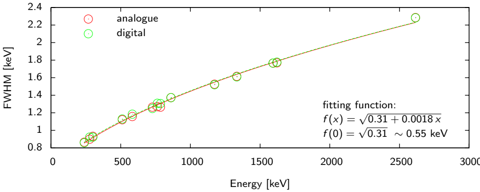
Conclusions

Outline

BEGe geometry and spectroscopic performances







- excellent energy resolution
- low noise
- low energy threshold ($\lesssim$ 10 keV)

BEGe project achievements

- **Good spectroscopic performances for all the detectors studied:**
  - D. Budjáš, *Germanium Detector Studies in the Framework of the GERDA experiment*, Dissertation, University of Heidelberg (2009).
  - M. Agostini et al. arXiv:1012.5200 (2010)
  - G. Pivato, *Experimental characterization of a Broad Energy Ge detector for the GERDA experiment*, Master Thesis, Università di Padova (2010).
- **Enhance capability in identifying the signal and rejecting the background by analyzing the pulse shapes:**
  - D. Budjáš et al. 2009 JINST 4 P10007
  - M. Agostini et al. 2011 JINST 6 P03005
- **No deterioration of the detector performances when operated in LAr:**
  - M. Barnabé Heider et al. 2010 JINST 5 P10007.
- **Tested the full production chain (4 detectors produced and studied):**
  - M. Agostini et al. Nucl. Phys. B, Proc. Suppl.(Neutrino 2010).

According to these results the collaboration has decided to pursue the BEGe detector technology for Phase II.

Outline

Signal formation and development

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

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

$$I(\mathbf{r}(t)) = q_{tot}\ \mathbf{v}(\mathbf{r}(t)) \cdot \mathbf{E}_w(\mathbf{r}(t))$$

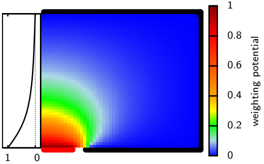
where:

- $\mathbf{r}(t)$ is the position of the charge cluster q at the time t
- $\phi_w(\mathbf{r}(t))$ is the weighting potential
- $\mathbf{E}_w(\mathbf{r}(t))$ is the weighting field

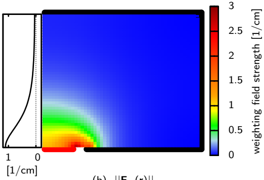
The holes are collected to the small-size contact along the same trajectories

$\Rightarrow$ the final part of the charge signals is independent of starting position

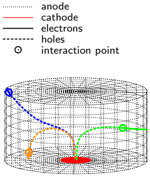
$\Rightarrow$ $I_{max} \propto q_{tot}$

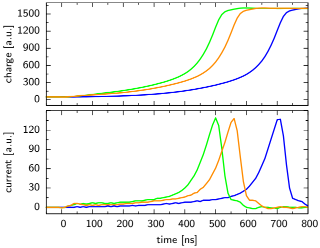


(a) $\phi_w(\mathbf{r})$



(b) $||\mathbf{E}_w(\mathbf{r})||$

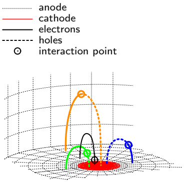


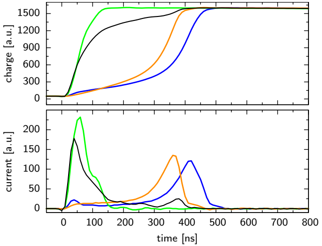


Signal modeling

A distribution ($A := I_{max}$)

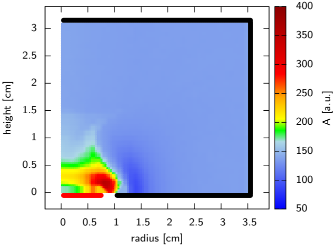
For a given energy deposition, $A := I_{max}$ is constant in the whole detector but close to the small electrode there is an anomalous region where A is is higher:





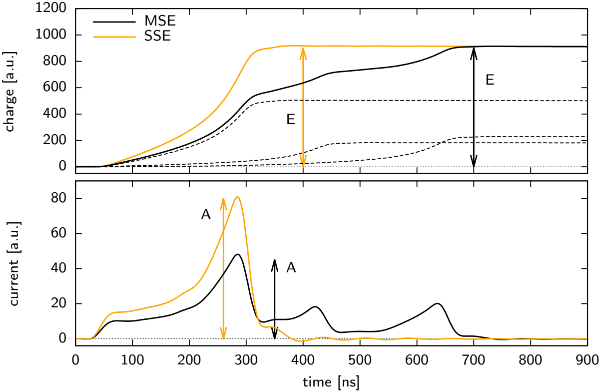
$\Rightarrow$ Both electron and holes signals at the same time

$\Rightarrow$ The volume in which A is not constant is only a few percent of the total active volume



Outline

Pulse Shape Discrimination: A/Energy parameter



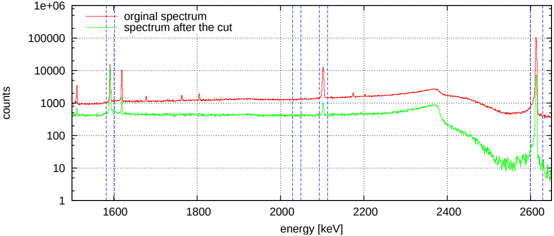
$A_{SSE} \propto q_{tot}$ $E_{SSE} \propto q_{tot}$

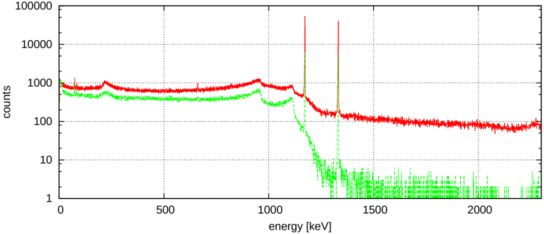
$\Rightarrow (A/E)_{SSE} = k,$ constant

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

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

PSD applied to external sources





Surviving probability after PSD:

experimental ^{228}Th:

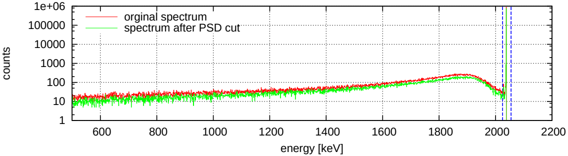
DEP	fixed to 90%
SEP	5%
FEP	7%
$Q_{\beta\beta}$	33%

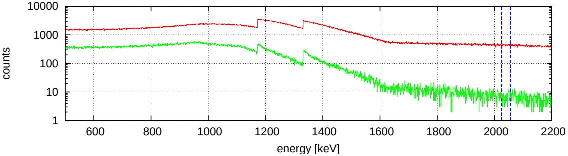
experimental ^{60}Co:

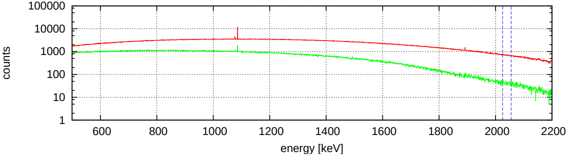
$Q_{\beta\beta}$	1%

Signal identification and background rejection

PSD applied to internal sources







Surviving probability after PSD:

simulated $0\nu\beta\beta$:

$Q_{\beta\beta}$ 86%

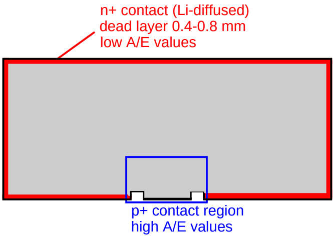
simulated ^{60}Co:

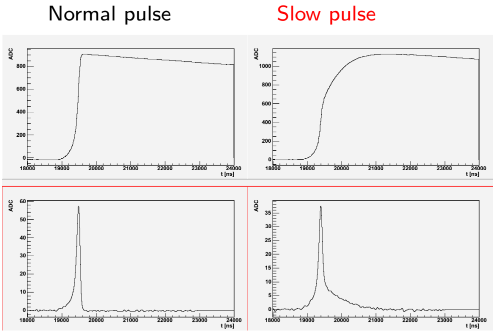
$Q_{\beta\beta}$ 1%

simulated ^{68}Ga (^{68}Ge daughter):

$Q_{\beta\beta}$ 5%

Rejection of surface events





Possible to identify and reject:

- beta events: K-42, Ar-39
- alpha events on the p+ contact

The efficiency in rejecting surface events is still under investigation but the preliminary results are promising.

Outline

Summary

- BEGe detectors have excellent performances for gamma-spectroscopy
- BEGe detectors were successfully operated in LAr (GERDA setup)
- The full production chain of the detector was tested (4 working detectors produced).
- We have achieved a good understanding of the signal formation and development in BEGe detector by developing and validating a simulation of the full detector response
- The PSD capability of BEGe detectors can reduced significantly all the gamma backgrounds expected in GERDA. The estimated surviving probability at the Ge-76 $Q_{\beta\beta}$ are:

$0\nu\beta\beta$	86%
external Th-228	33%
external Co-60	1%
internal Co-60	1%
internal Ga-68	5%

- According to preliminary results, BEGe detector could be able to reject also surface events.