Pulse Shape Discrimination Studies

of Phase I Ge-detectors

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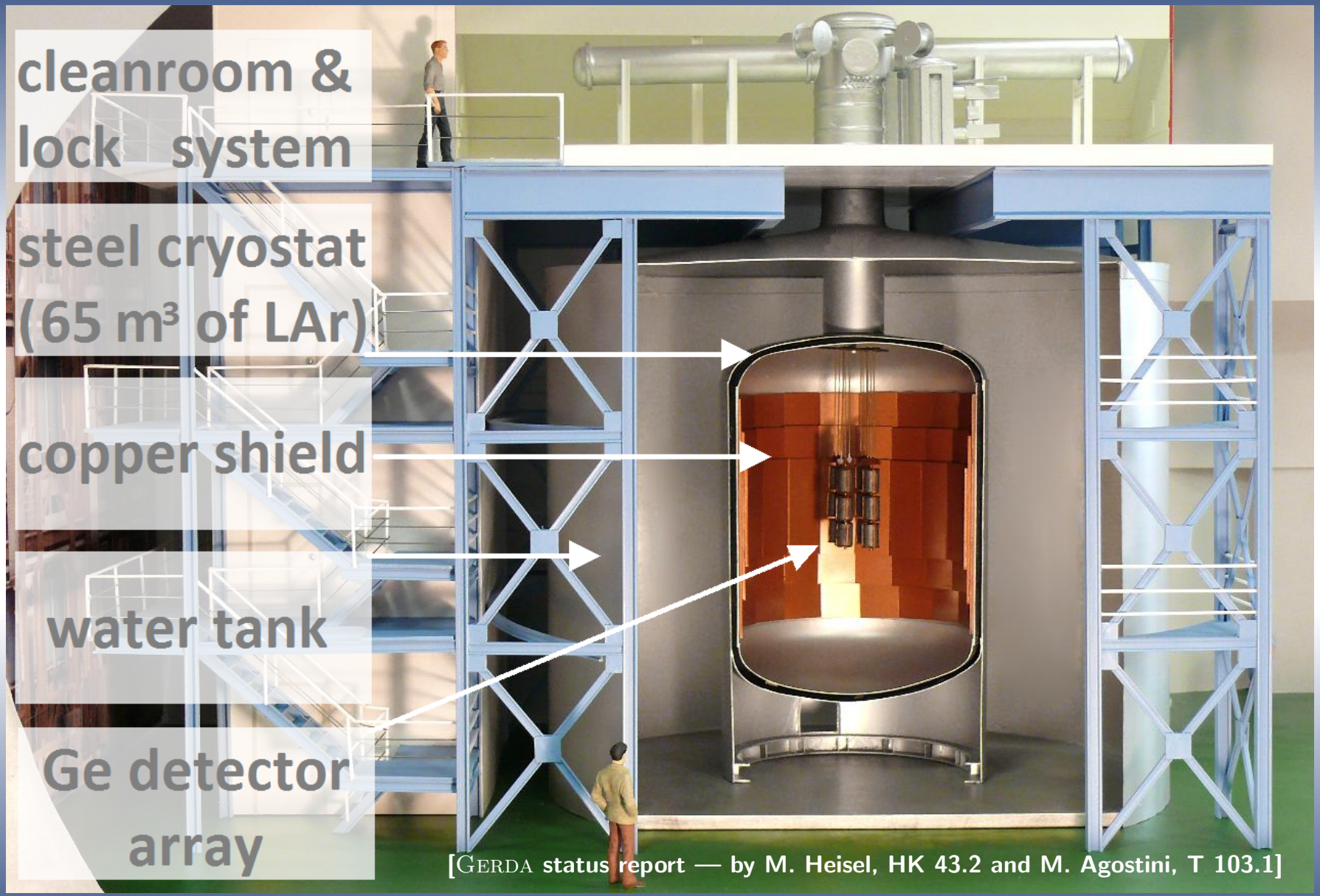
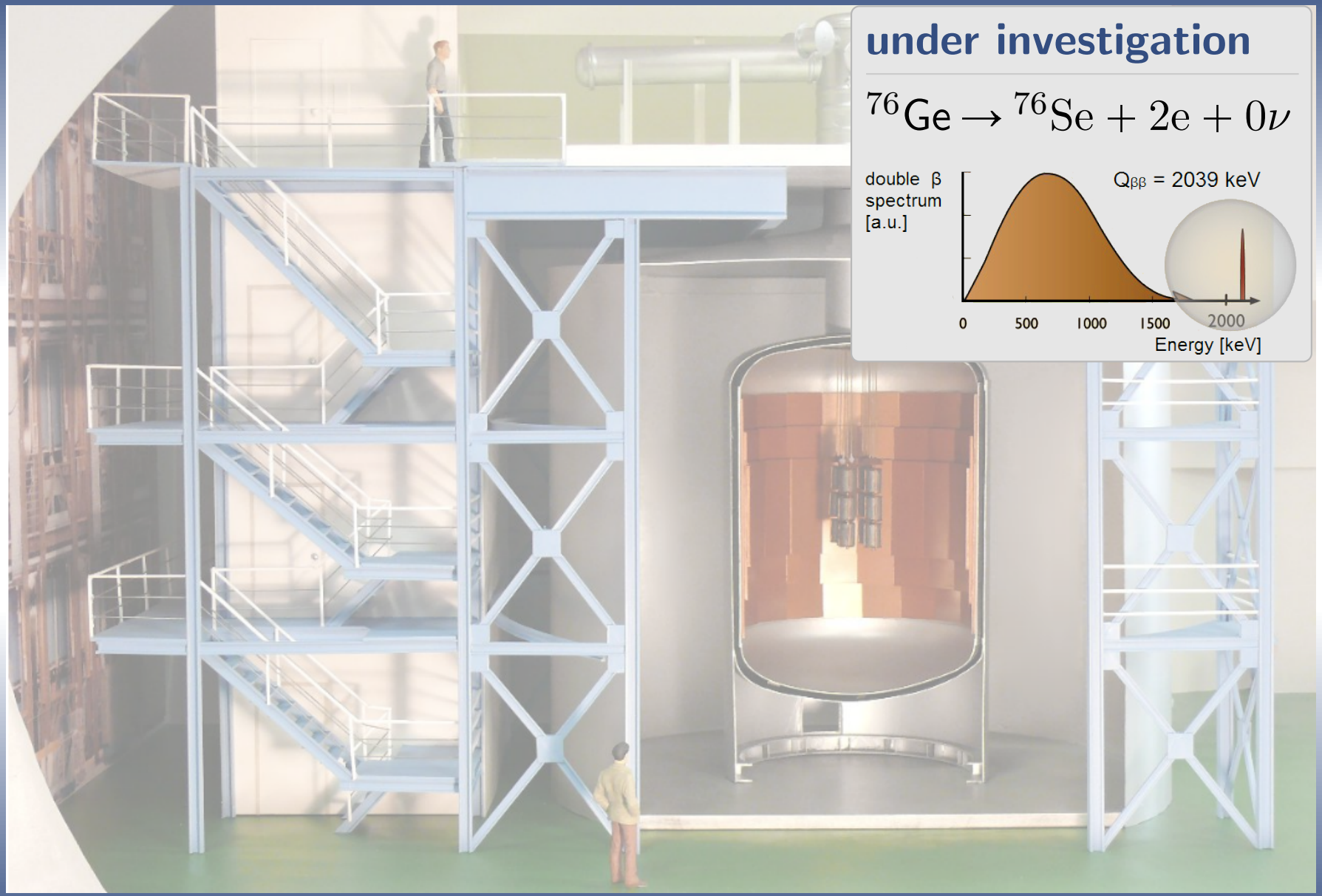
GERDA Experiment



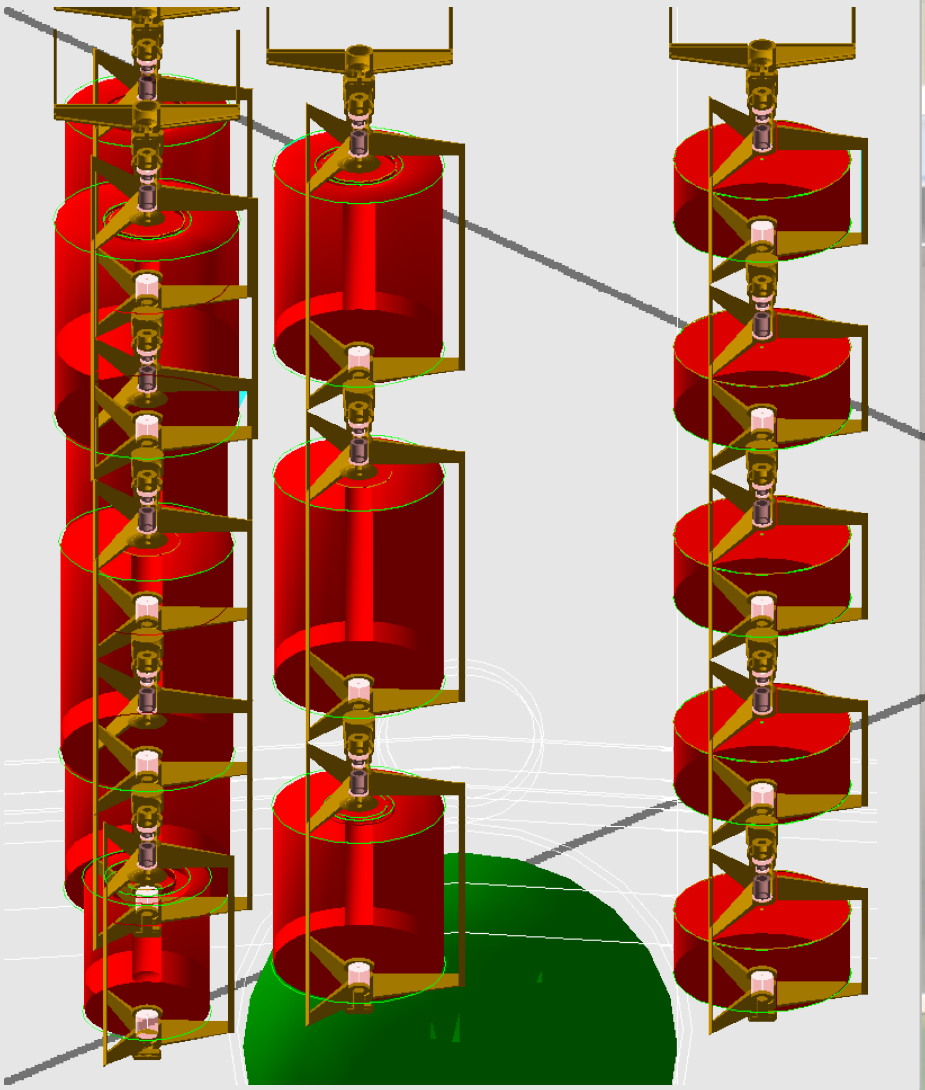
[GERDA status report — by M. Heisel, HK 43.2 and M. Agostini, T 103.1]

GERDA Experiment



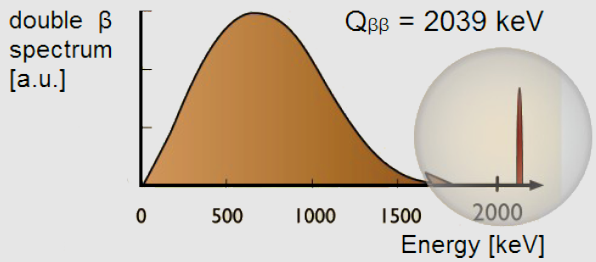
GERDA Experiment

Phase I array setup



under investigation

$$^{76}\mathrm{Ge} \rightarrow {}^{76}\mathrm{Se} + 2\mathrm{e} + 0\nu$$



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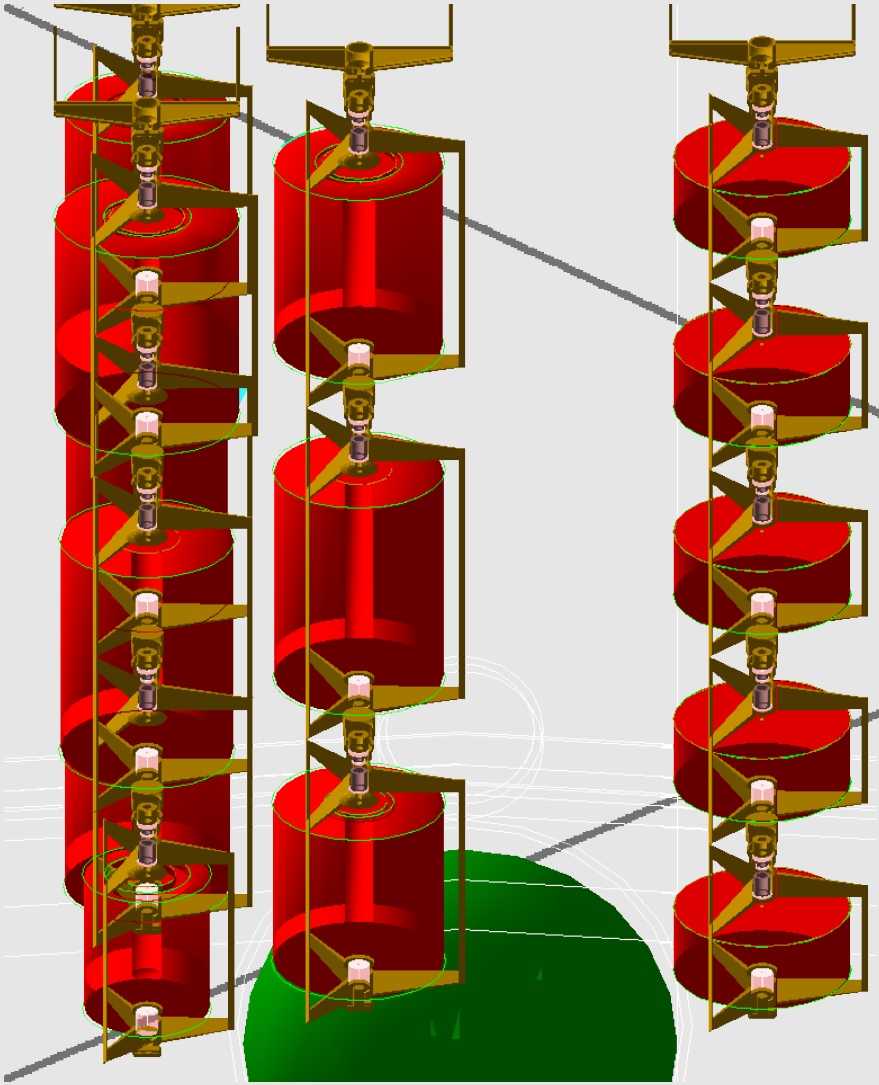

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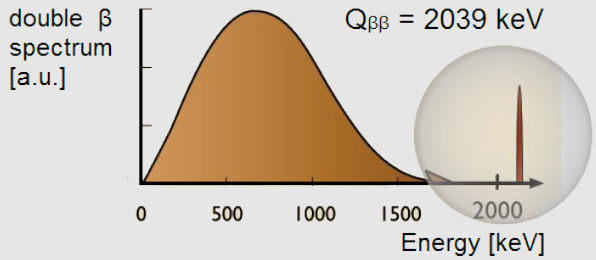


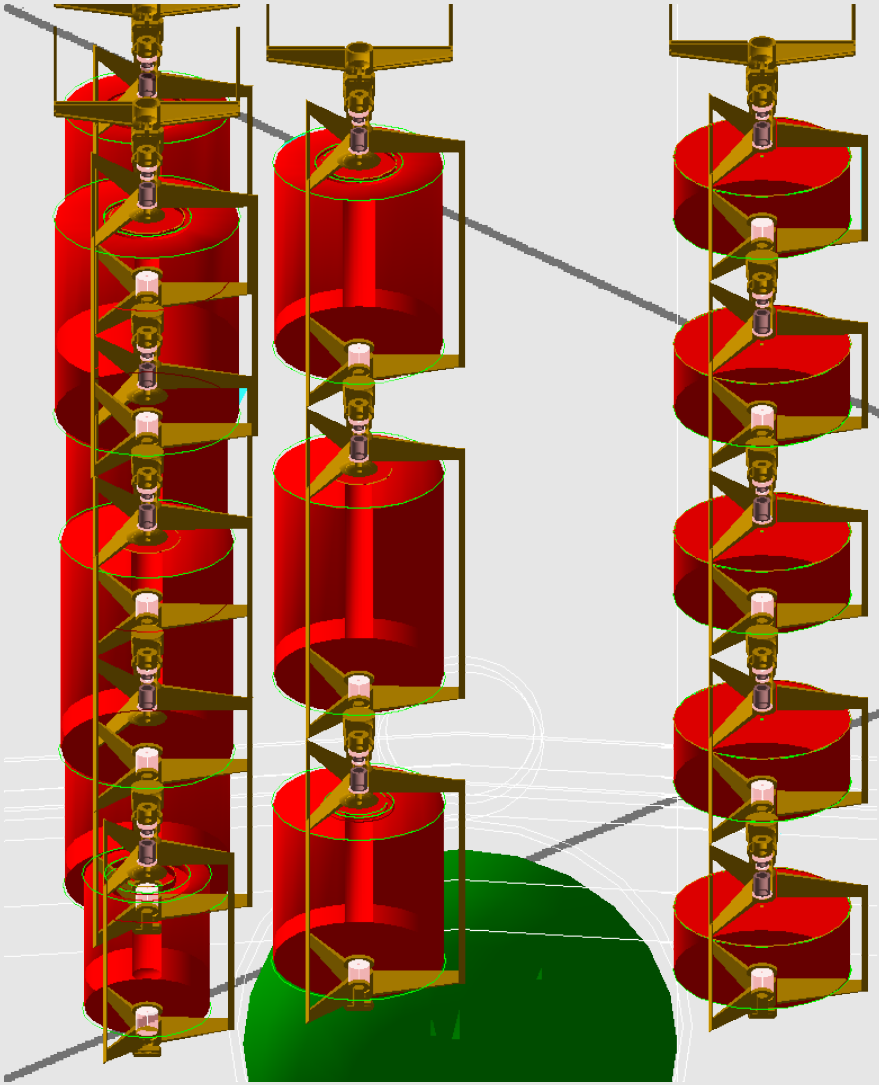
1 string arm

- Broad Energy Germanium (BEGe)

  3.6 kg enriched material

GERDA Experiment

Phase I array setup



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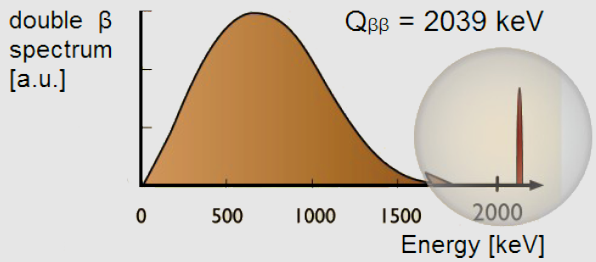


3 string arm

- coaxial High Purity Germanium (HPGe)

  17.7 kg enriched material

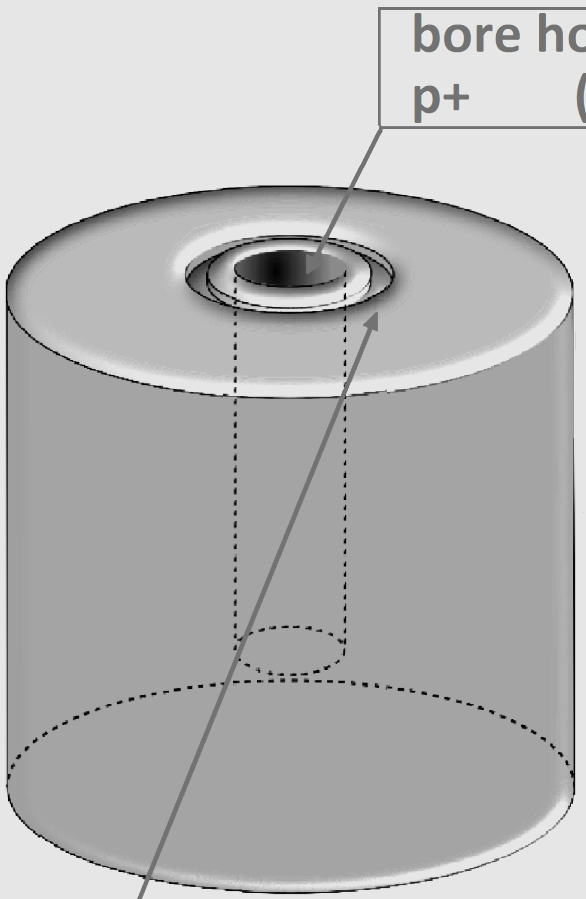
1 string arm

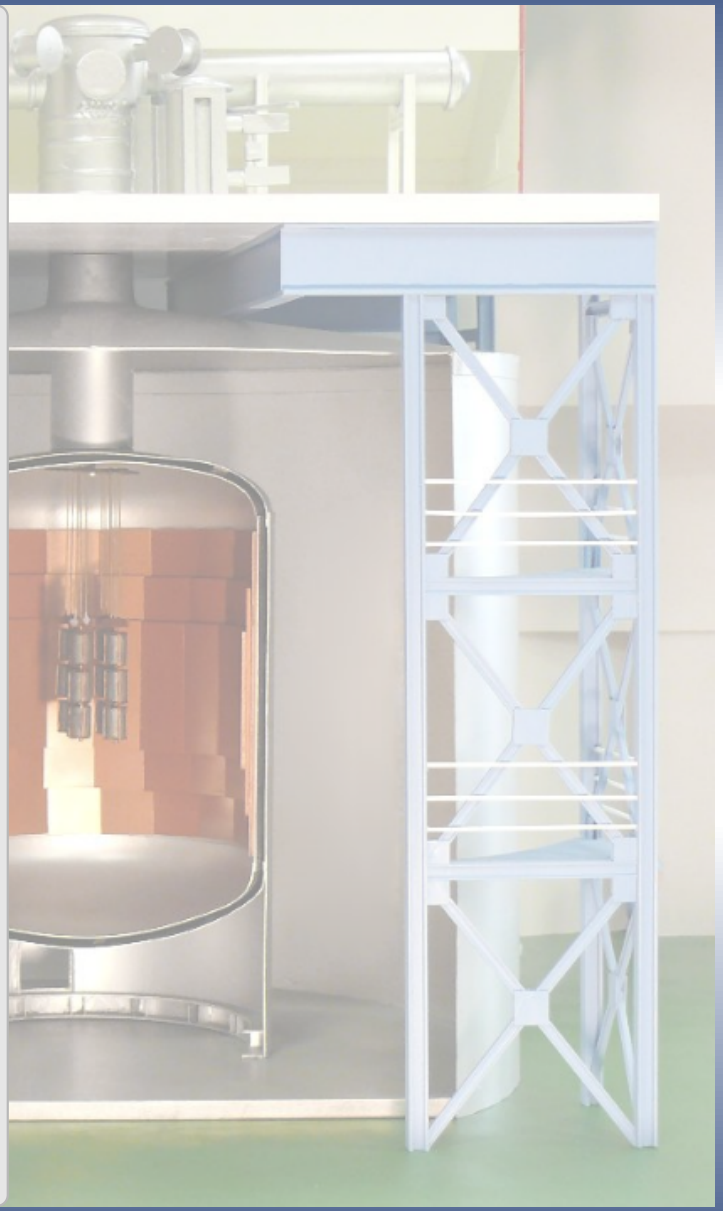
- Broad Energy Germanium (BEGe)

  3.6 kg enriched material

PSD Concept

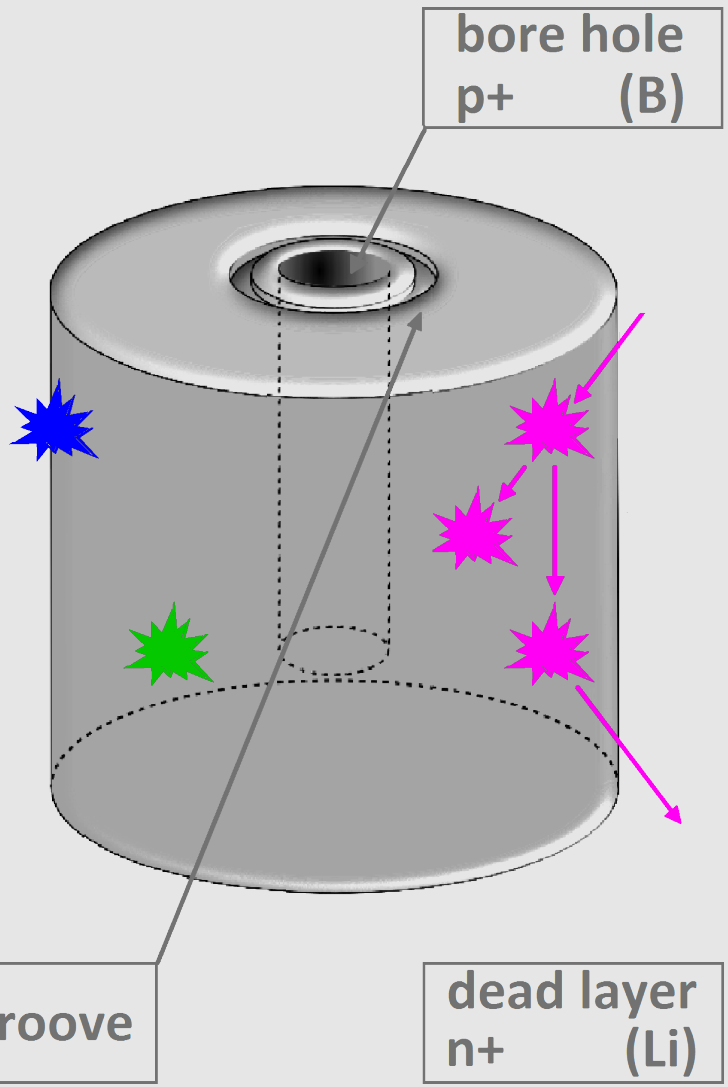
coaxial detector





PSD Concept

coaxial detector

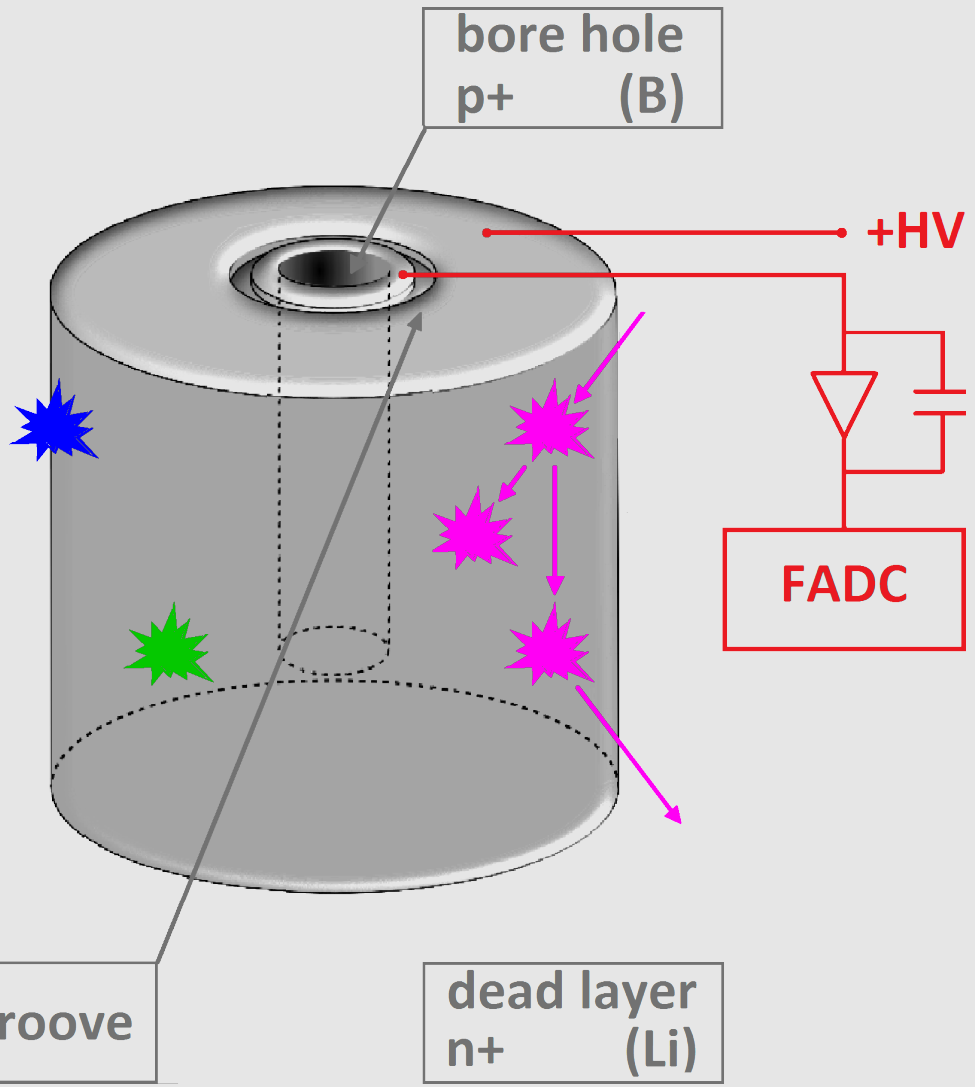


events types

1. single site
   whole energy is deposited locally @ one interaction point
2. multi site
   several energy depositions separated in space
3. surface α and β events

PSD Concept

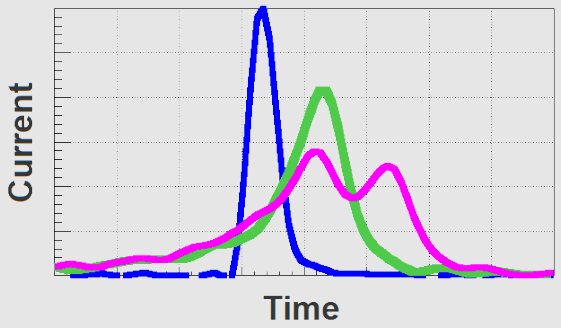
coaxial detector



events types

1. **single site**
   whole energy is deposited
   locally @ one interaction point
2. **multi site**
   several energy depositions
   separated in space
3. **surface** α and β events

→ pulse shape



- fight background @ $Q_{\beta\beta}$

PSD in GERDA so far...

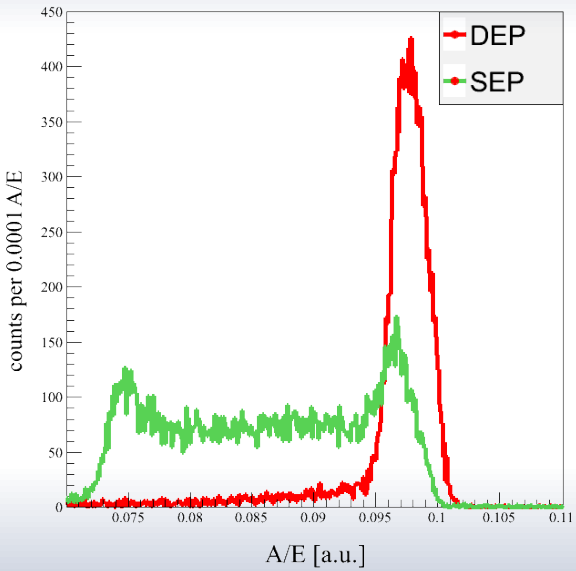
... is based on A/E parameter cut.

[Pulse Shape Discrimination for Broad Energy Germanium Detectors — by H. Liao, HK 7.4]

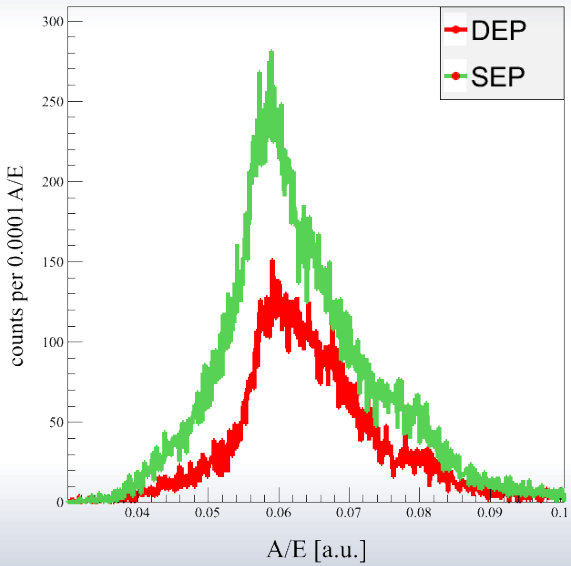
[Application of A/E PSD method to first ^{76}Ge enr BEGe detectors operated in GERDA — by A. Lazzaro, HK 66.6]

[PSA of Enriched BEGe Detectors in Vacuum Cryostat and Liquid Argon — by V. Wagner, T 110.2]

GD32C (BEGe)



ANG5 (HPGe)



- SSE-like events in DEP @ 1.592 MeV and MSE-like events in SEP @ 2.104 MeV (from ^{228}Th calibrations)
- PSD for coaxial detectors needed

problem:

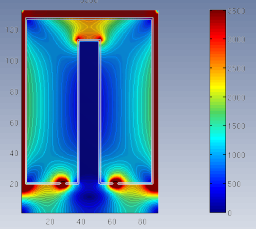
no significant differences in A/E-distribution for coaxial HPGe detectors → cut can not be applied on a large part of the enr germanium!

possible solution:

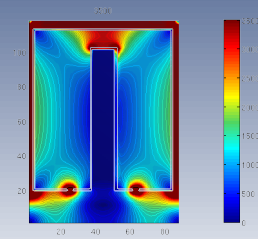
chi^2-distribution of simulated SSE library and measured pulses!

Simulation

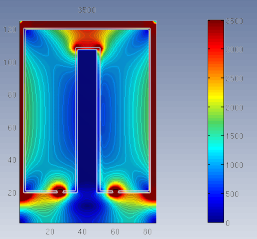
ANG2



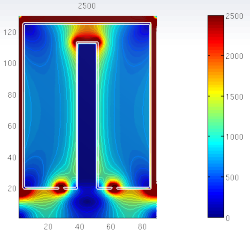
ANG3



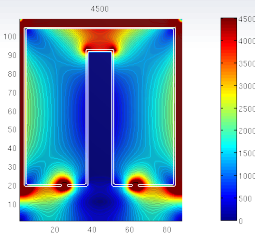
ANG4



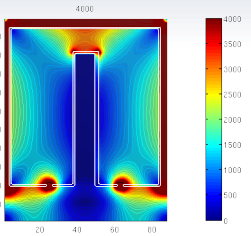
ANG5



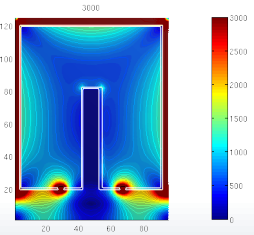
RG1



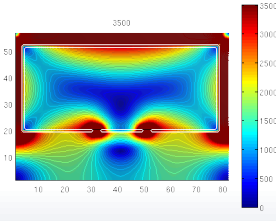
RG2



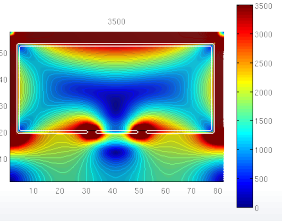
GTF112



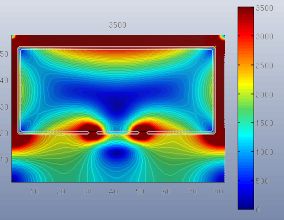
GD32B



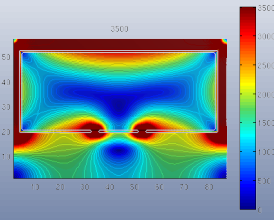
GD32C



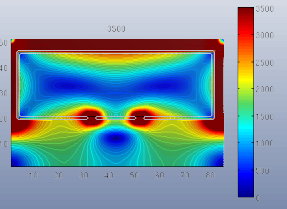
GD32D



GD35B



GD35C



simulated electrical field strength [V/cm] for a vertical section of the Phase I detectors passing through the symmetry axis

ADL 3.0 software of AGATA

[Computational Studies for BEGe Detectors — by M. Salathe, HK 7.3]

- create pulse shape library
- geometries & dimensions of detectors implemented
- impurity concentrations
  → are known for BEGe's
  → determined for HPGe's by using depletion voltage
- MC performed for applied operation voltage
- set of SSE for 1 mm grid
  → question of computing time

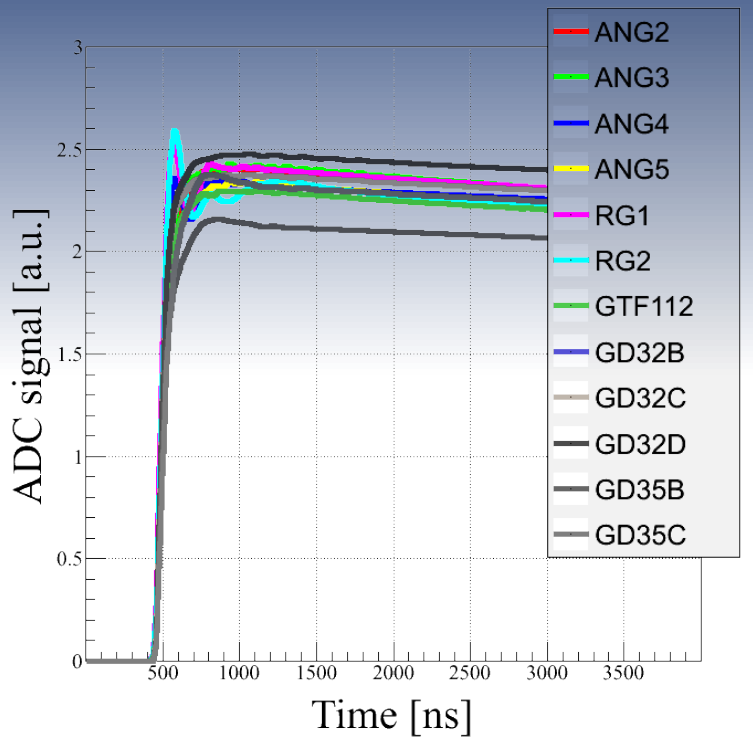
Electronics Response

... MC doesn't consider

exp. electronic setup ...

- measurement of rectangular pulser for GERDA detectors
- fast rise times of $\leqslant 15$ ns

  $\rightarrow$ (input)' $=$ delta function
  $\rightarrow$ (output)' $=$ impulse response
- convolution of simulation $x[n]$ and impulse response $h[n]$ gives realistic pulse shape $y[n]$



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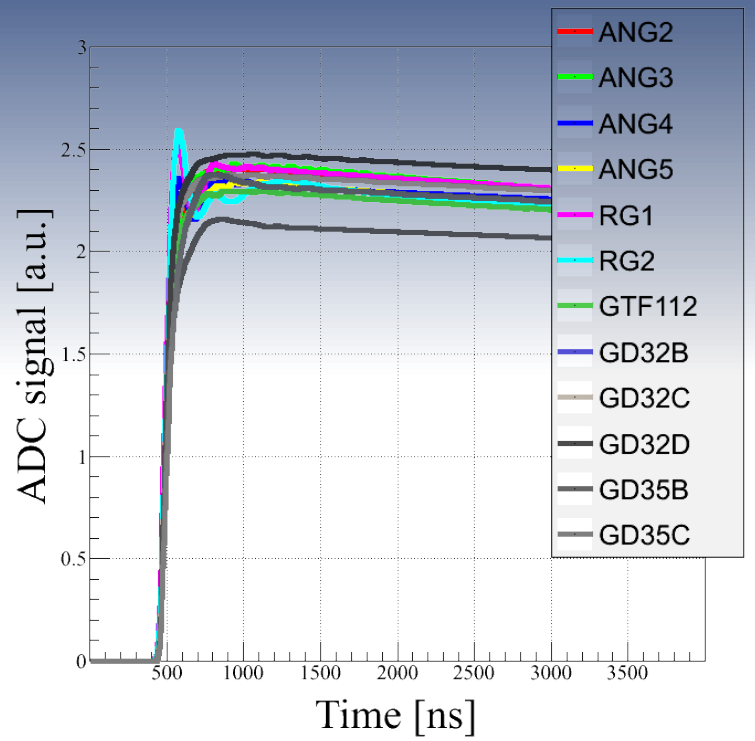
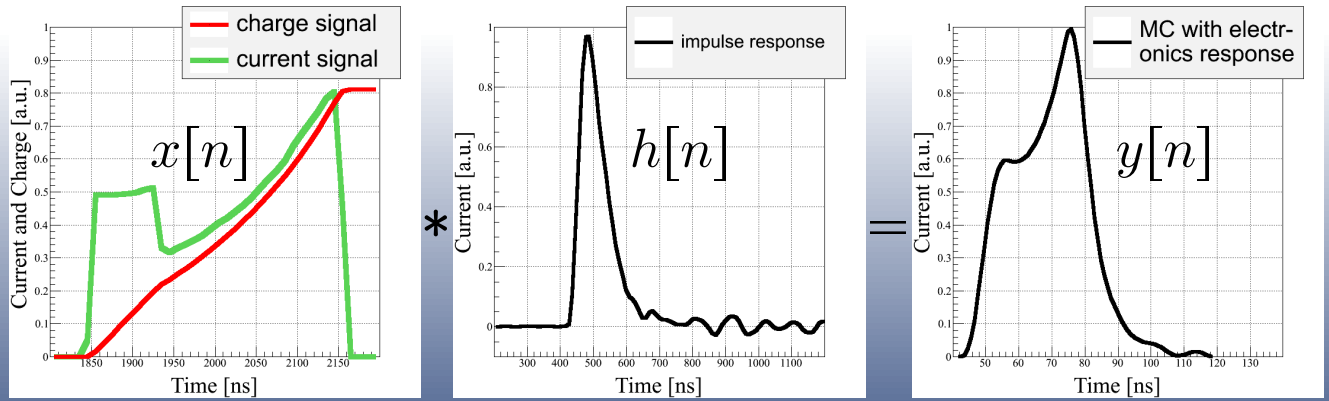


Def: convolution summation '*'

$y[i] = \sum_{j=0}^{M-1} h[j]x[i-j]$,

if $x[n]$ is an N point signal running from 0 to $N-1$ and if $h[n]$ is an M point signal running from 0 to $M-1$



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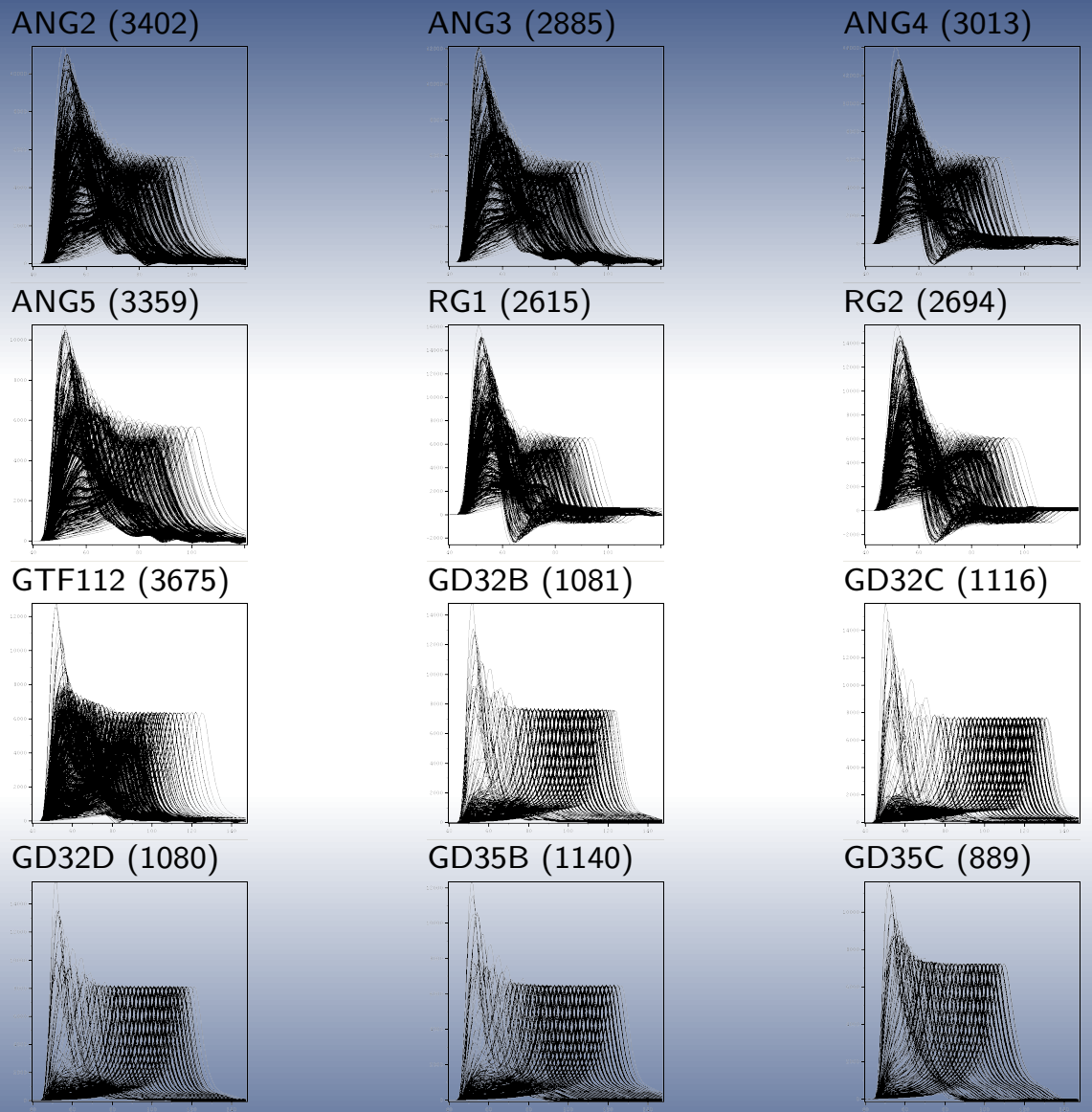


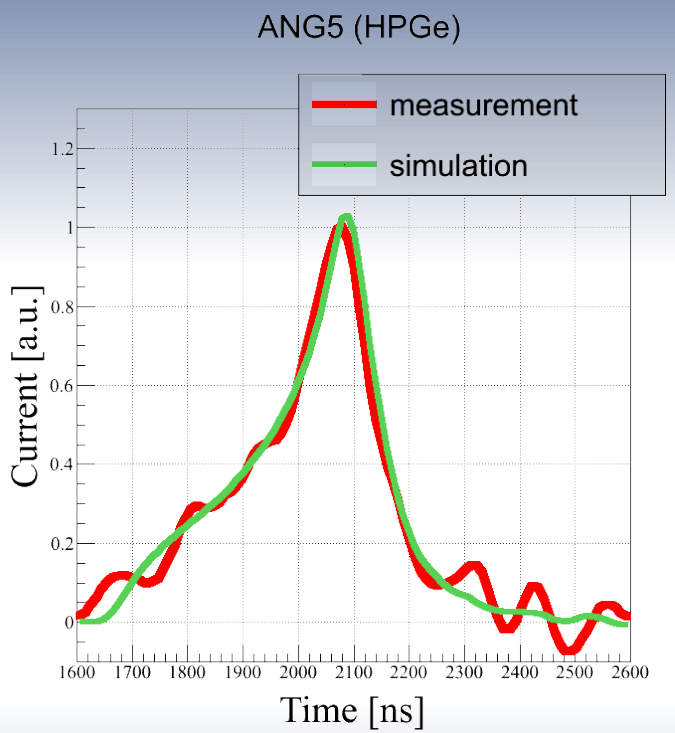
simulated pulse shapes after convolution with impulse response

Definition of chi^2

- measurements are compared with pulse shape library resulting from simulations
- shift in time: center of gravitiy
  amplitude adjustment: energy of pulse
  → avoid computing time consuming fitting procedures
- width of investigated window = when pulse has decreased to $1/25$-th of the maximum amplitude
  → compromise between keeping structure of the signal and not including noise
- calculate difference for each sample i

$$\text{chi}^2 = \sum (\text{data}[i] - \text{simulation}[i])^2$$

- smallest chi^2 out of library is chosen



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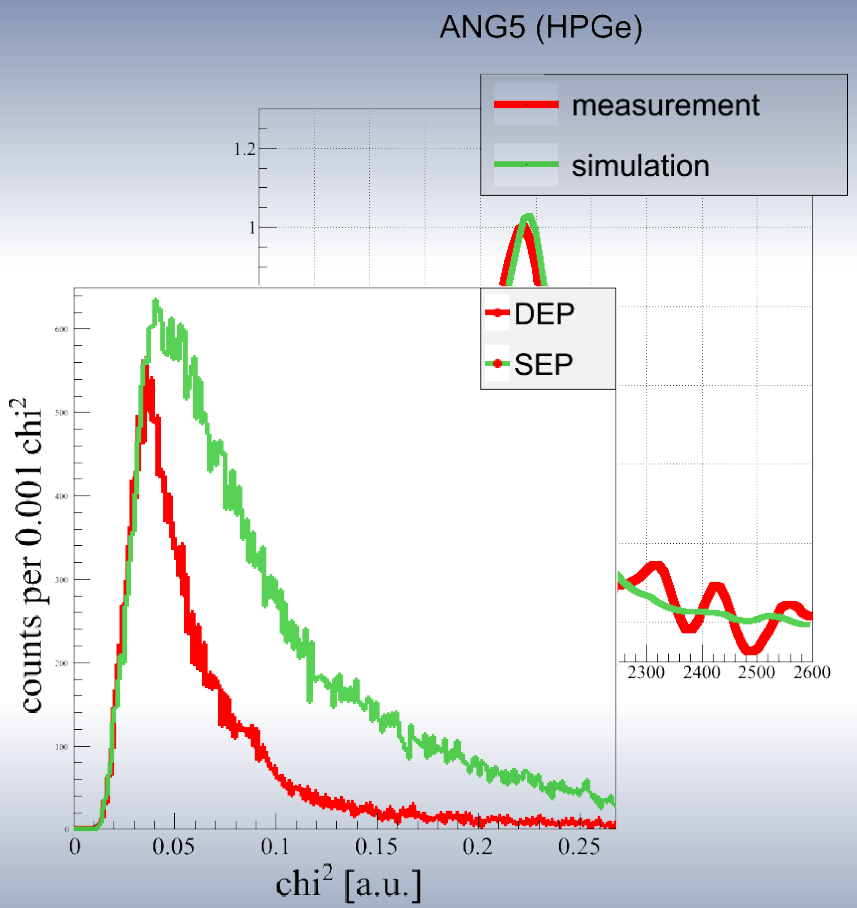
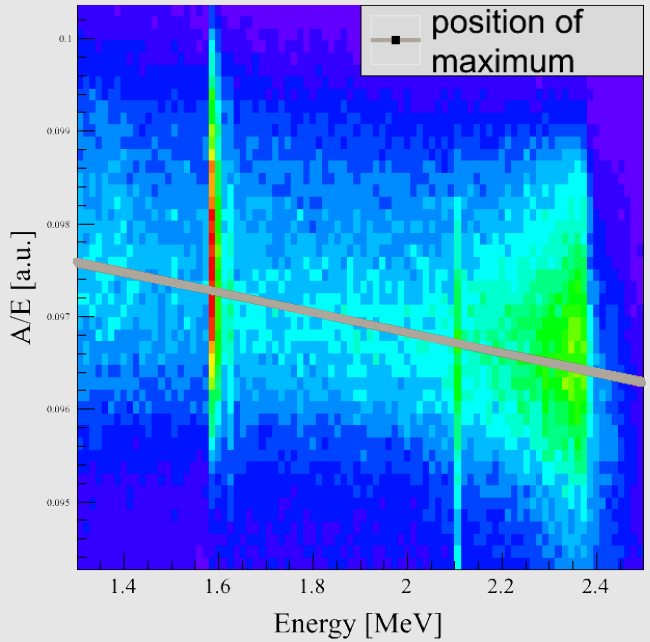


Comparison

A/E

GD32C (BEGe)

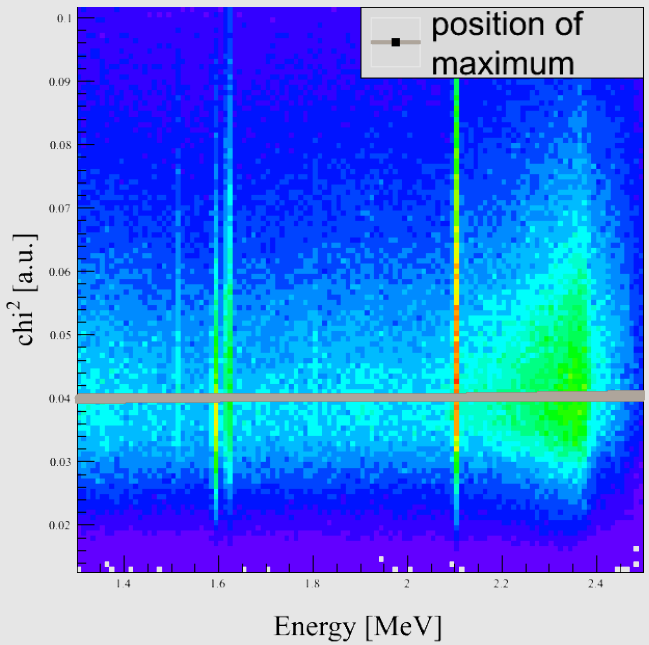


- energy dependency: yes

$\Leftrightarrow$

chi^2

ANG5 (HPGe)



- energy dependency: no or little

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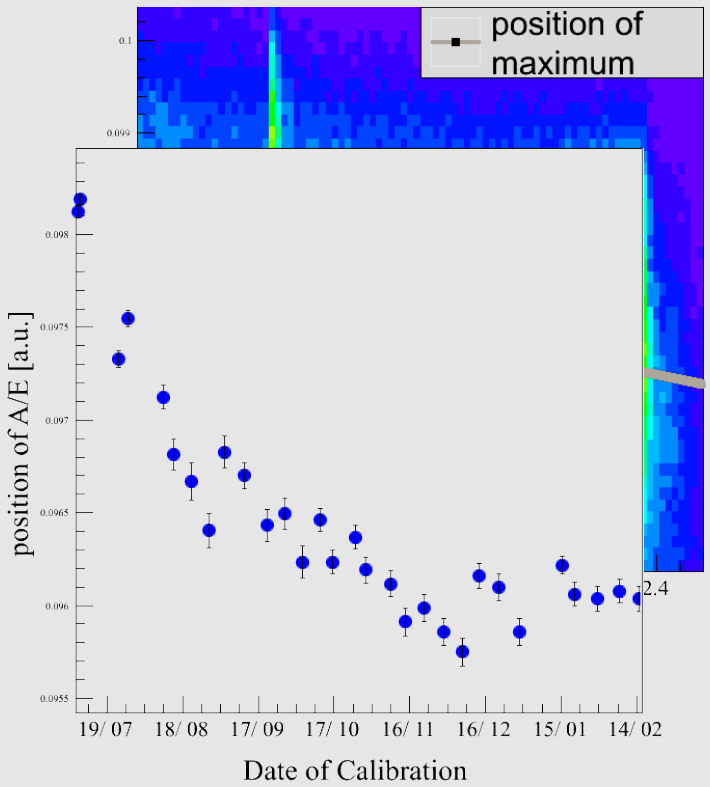
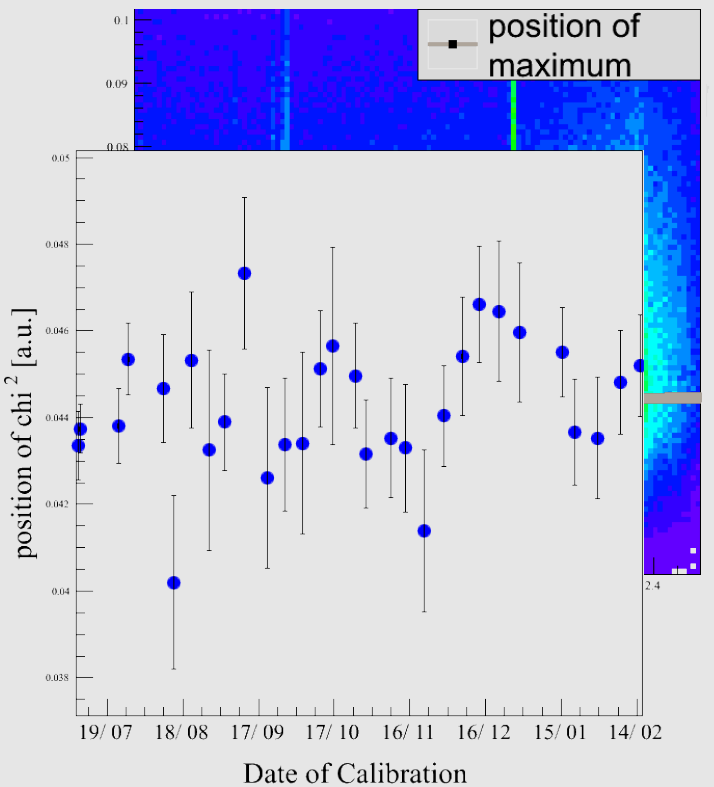


- energy dependency: yes
- time dependency: yes

$\Leftrightarrow$

chi^2



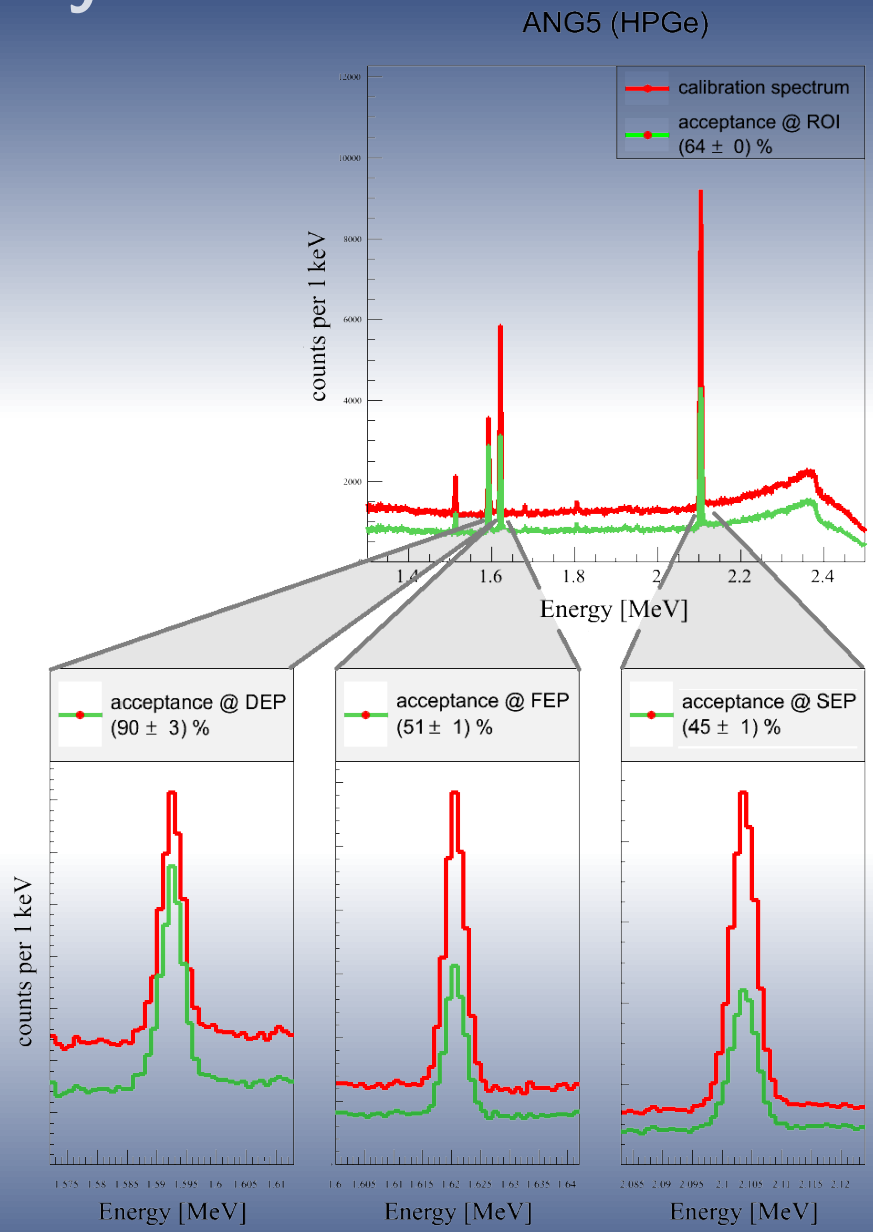
- energy dependency: no or little
- time dependency: no or little

Cut Efficency of chi^2

table of acceptances [%]

detector	calibration		
	FEP ^{212}Bi	SEP ^{228}Th	ROI
ANG2	78 ± 2	71 ± 1	81 ± 1
ANG3	71 ± 2	63 ± 1	77 ± 1
ANG4	53 ± 2	52 ± 1	68 ± 1
ANG5	51 ± 1	45 ± 1	64 ± 1
RG1	61 ± 3	57 ± 1	72 ± 1
RG2	66 ± 2	62 ± 1	75 ± 1
GTF112	54 ± 1	50 ± 1	69 ± 1

- fixed survival fraction of 90% @ DEP
- in future: optimization on $S/\sqrt{B}$
- whole data set of Phase I - so far



Cut Efficency of chi^2

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	FEP ^{212}Bi	SEP ^{228}Th	ROI	ROI
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ANG4	53 ± 2	52 ± 1	68 ± 1	67 ± 27
ANG5	51 ± 1	45 ± 1	64 ± 1	50 ± 18
RG1	61 ± 3	57 ± 1	72 ± 1	78 ± 28
RG2	66 ± 2	62 ± 1	75 ± 1	74 ± 26
GTF112	54 ± 1	50 ± 1	69 ± 1	61 ± 16

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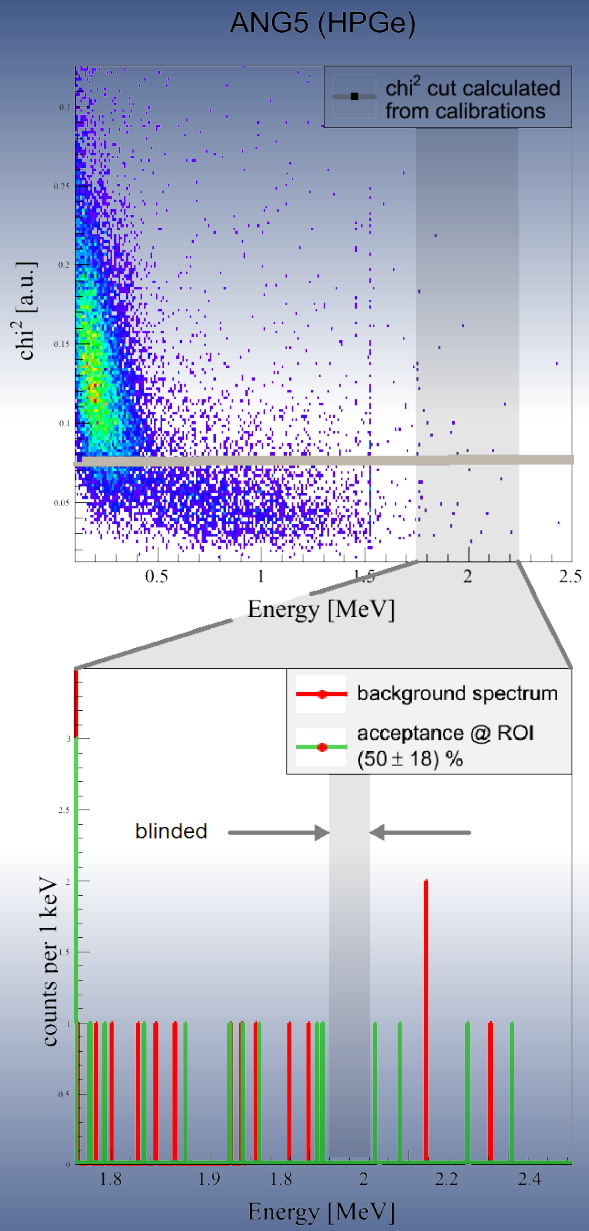

Conclusion

- coaxial detectors offer high operative mass of enriched germanium along with an inferior pulse shape propery (compared to BEGe's)
- composition of Phase I setup: 3.6 kg (BEGe) $\Leftrightarrow$ 17.7 kg (HPGe)
- PSD technique for this detector type helpful to improve understanding of data and sensitivity of Phase I
- ansatz based on simulated pulse shape library of SSE and chi^2 matching was developed and tested on real GERDA calibration / background data
- background suppression efficencies @ ROI around $Q_{\beta\beta}$ seem promising

Outlook

- drawback: not as effective as A/E parameter cut on BEGe detectors, further testing / debugging / improving of chi^2 method
- search for other parameters to characterize signal shape properties, start multi variant analysis with data mining...