Segmented Broad Energy Germanium Detectors

- Motivation
- Germanium Detectors
- Summary

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on behalf of GERDA+GeDet Collaboration

Young Scientist Workshop 2012

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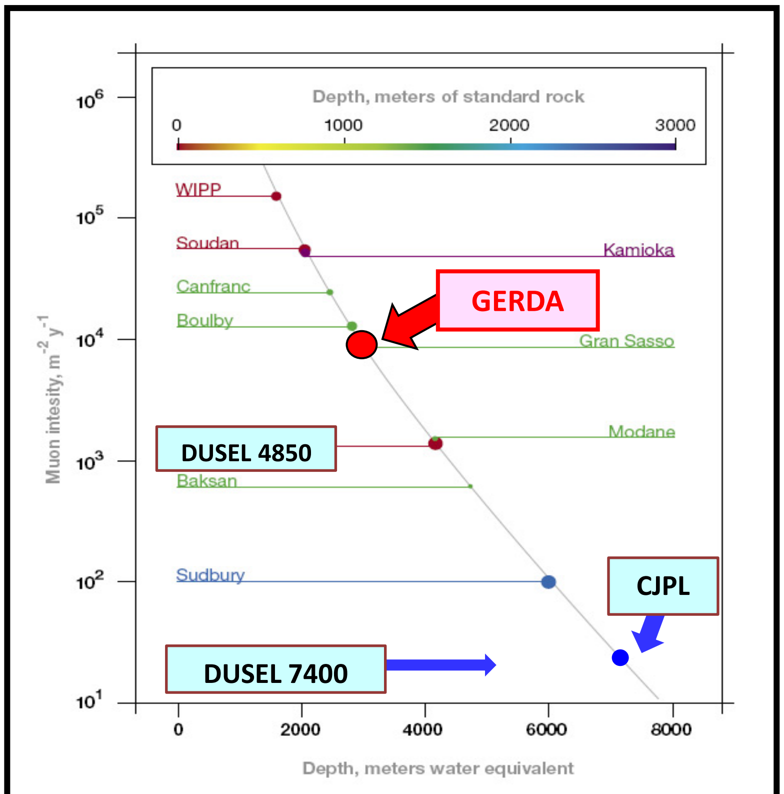
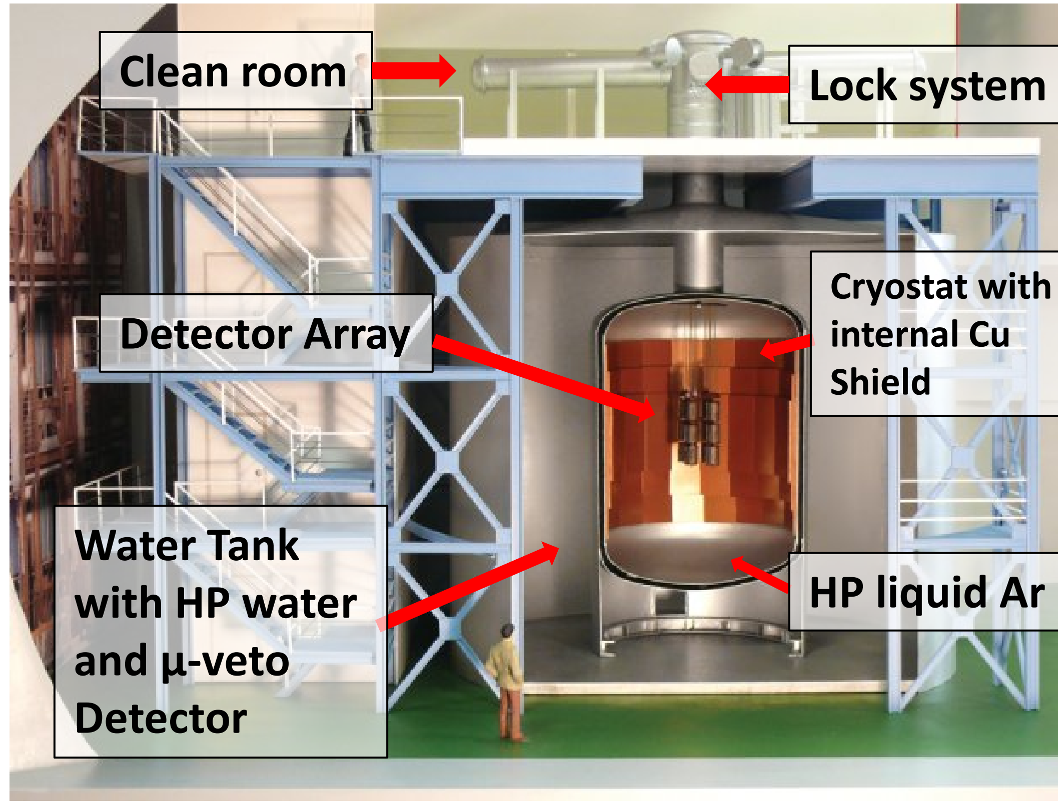
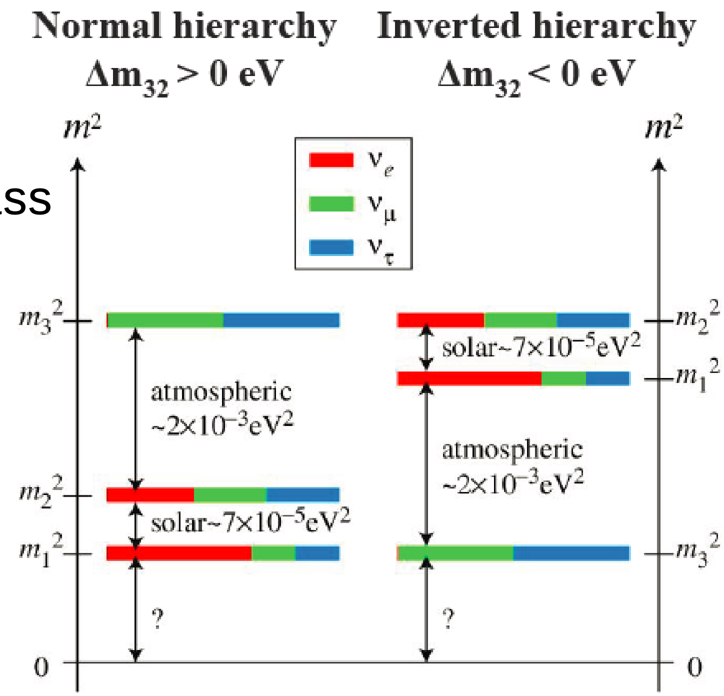
GERmanium Detector Array



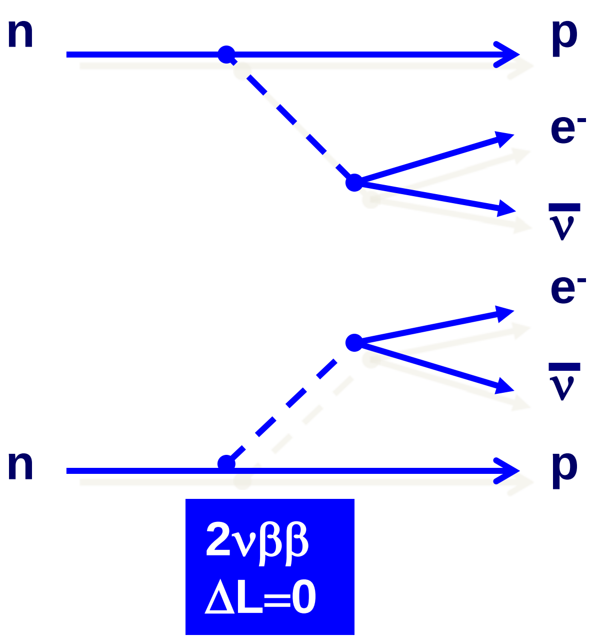


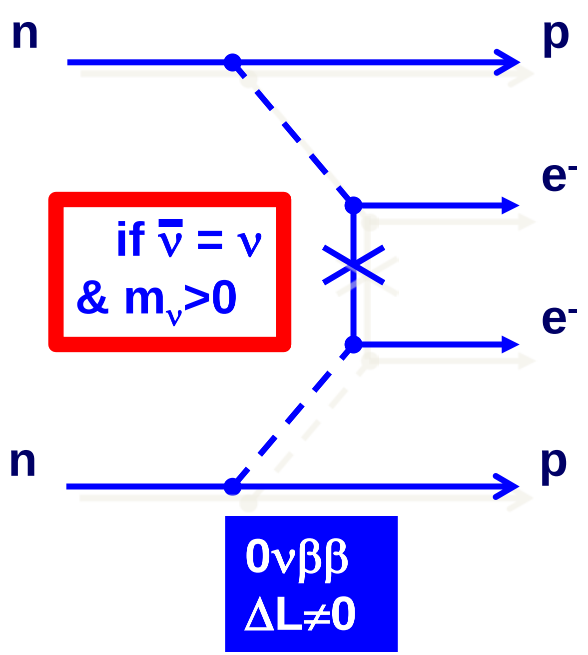
Physics Motivation

- Do we understand neutrinos?
  - ⇨ No! Still many open questions
- We only have information on the squared mass difference between the eigenstates
  - ⇨ Absolute mass scale is still unknown
- We do not know the sign of Δm_{32}
  - ⇨ Mass hierarchy is still unknown
- Are neutrinos their own antiparticle, i.e. Majorana particles?
  - ⇨ Nature of the neutrinos is still unknown



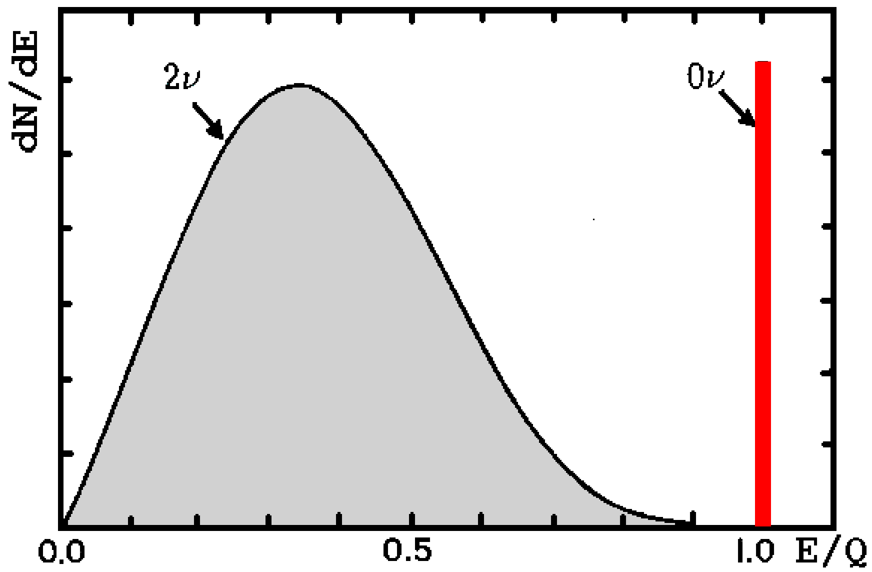
Searching for Neutrinoless Double Beta Decay





- 2νββ decay:
  (A,Z) → (A,Z+2) +2e$^-$+2ν
  SM allowed & observed

- 0νββ decay: ΔL=2
  (A,Z) → (A,Z+2) +2e$^-$
  if νs Majorana & have mass
  ⇨ **Signature:**
  Sharp peak at Q-value of the decay



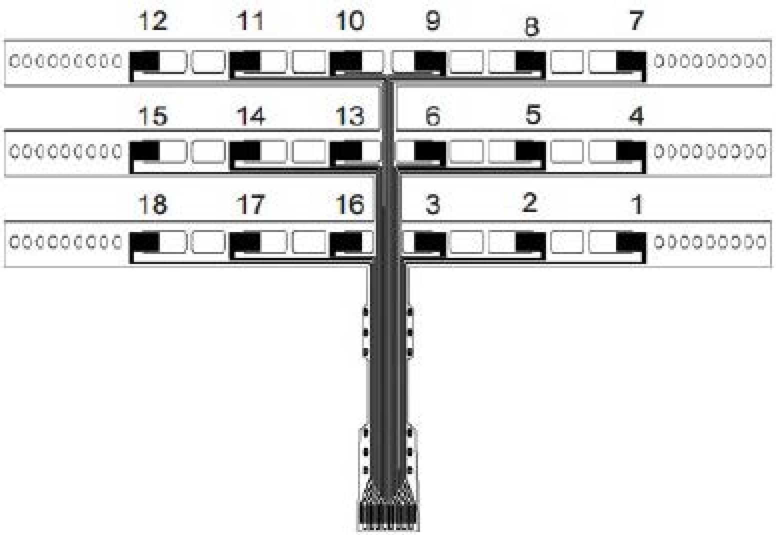
Background & Motivation

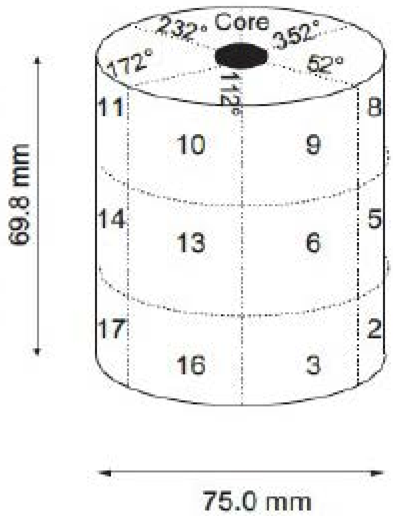
- This peak is *NOT* big enough & there are other backgrounds

- Avoid background:
  - Store enriched material underground
  - Avoid cosmic muons by going deep underground
  - Compact shielding design
  - Minimize material close to detectors
  - ......

Background is unavoidable, you always need to recognize background
⇨ **Build intelligent detectors**
⇨ **topic of the talk today**

Example for Intelligent Design – Segmented Germanium Detectors



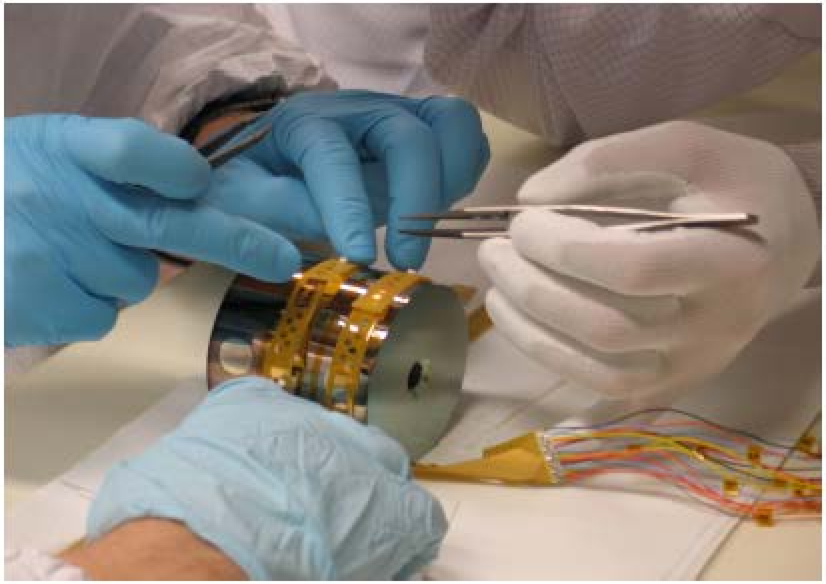


n-type
true coaxial
inner Φ 10mm
outer Φ 75mm
height 69.8mm
1.632kg
Bias 3kV

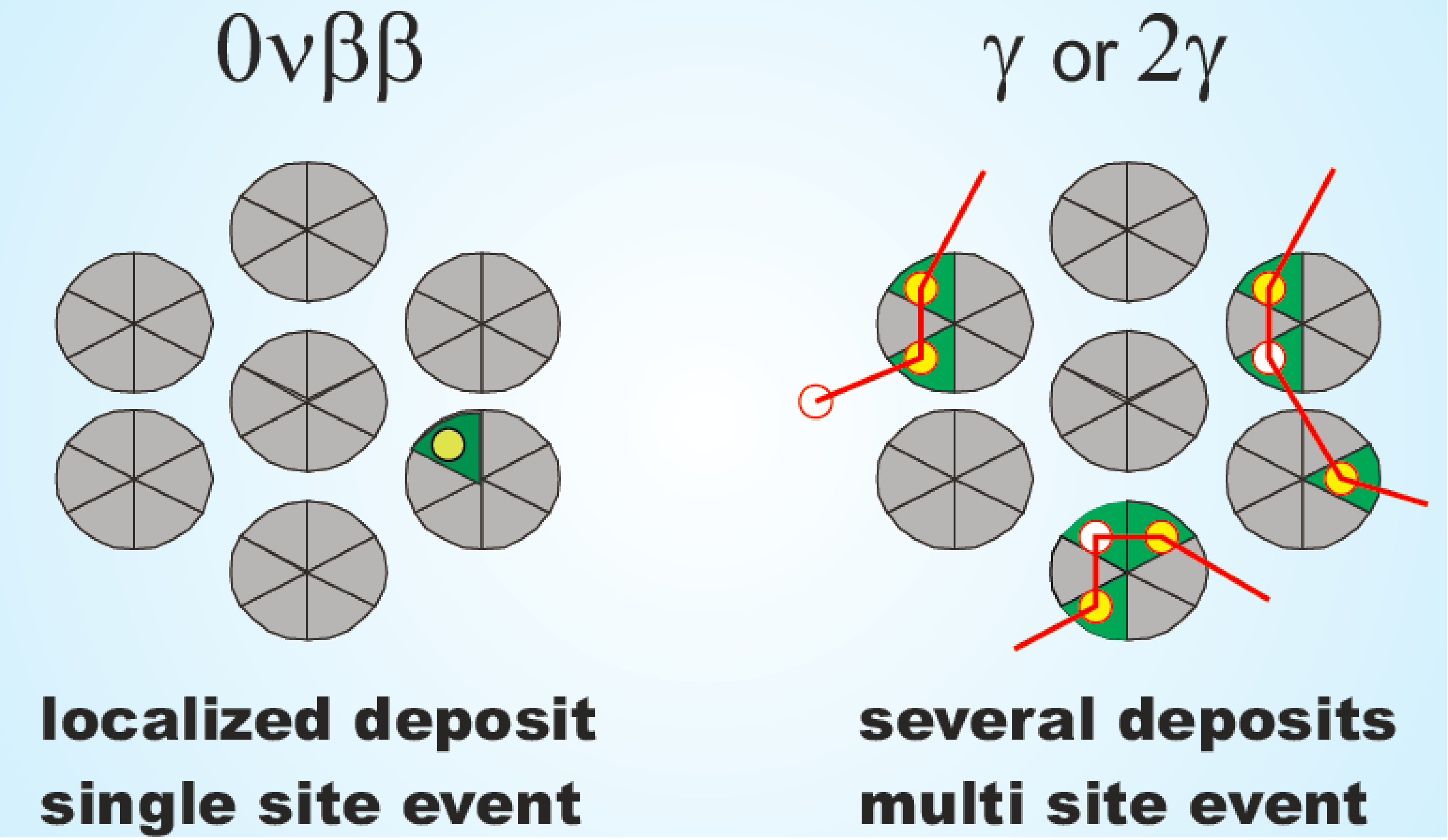
18 segments
3-fold along z
6-fold along Φ

"snap" contacts
with Kapton cable
and PTFE button

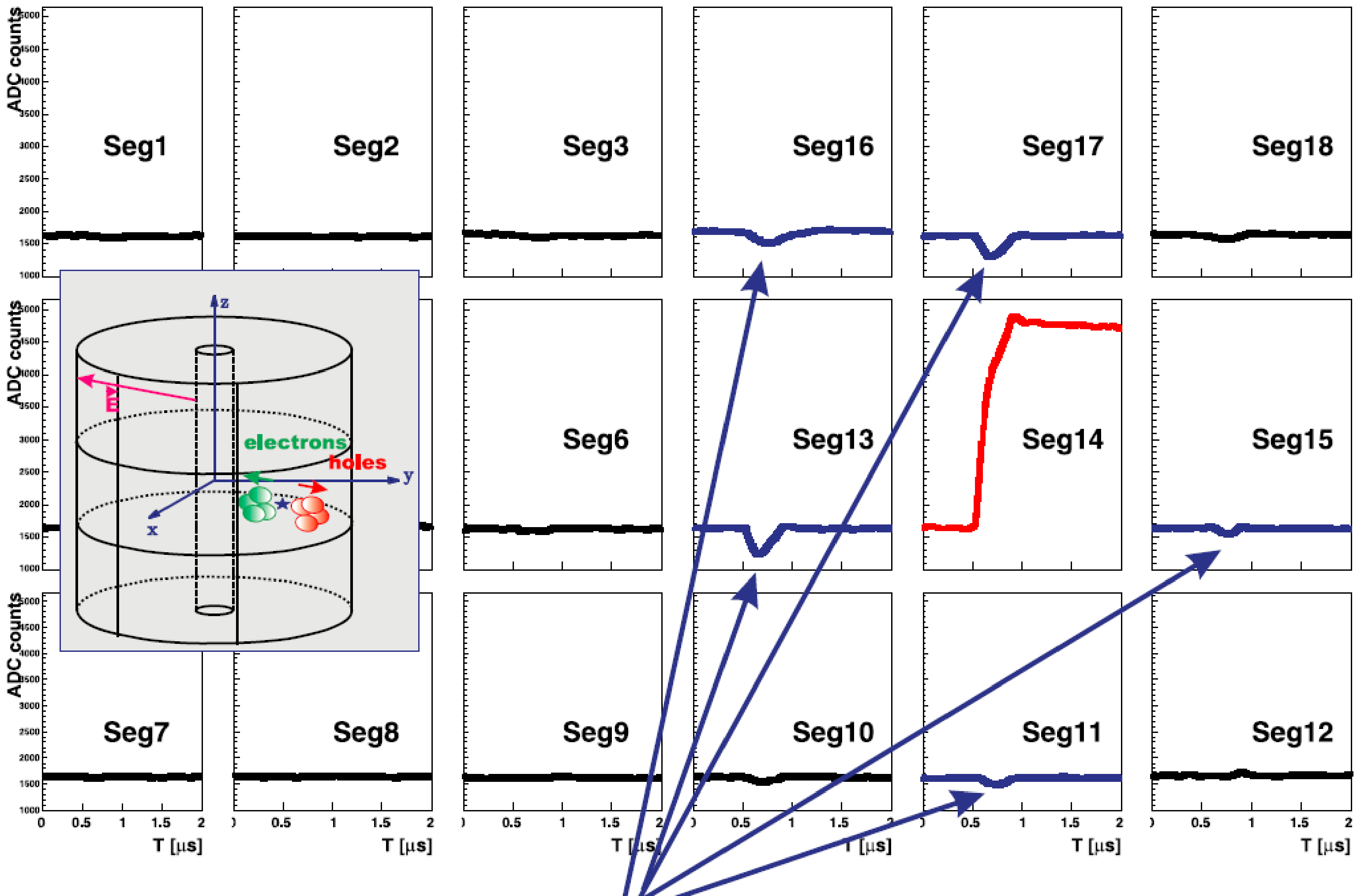
19g Cu,
7g PTFE,
2.5g Kapton
per detector



Signal & Background

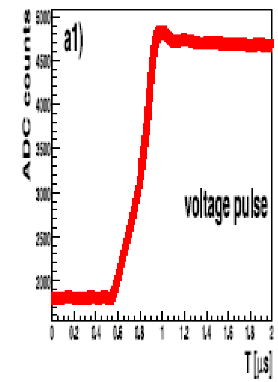


A Real Example



DEP 85

^{208}Tl

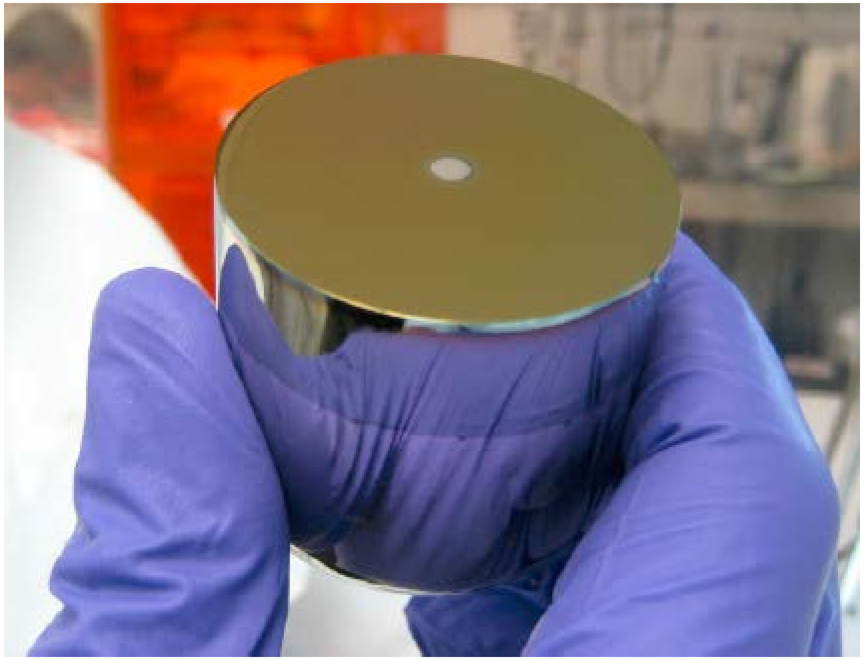


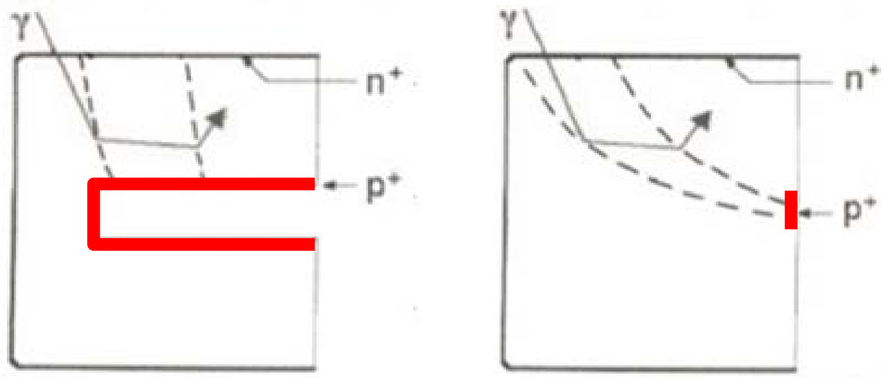
Single Segment and Neighbors

Position reconstruction

Any other good detector design?

Broad Energy Germanium Detector (BEGe)





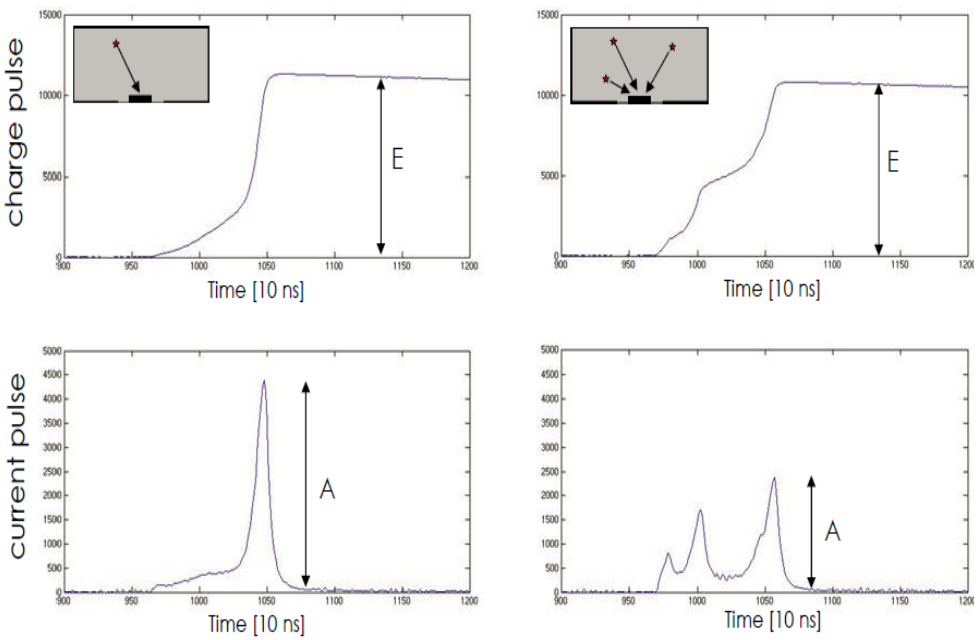
Barbeau, et al. JCAP09 (2007) 009

BEGe Advantages:

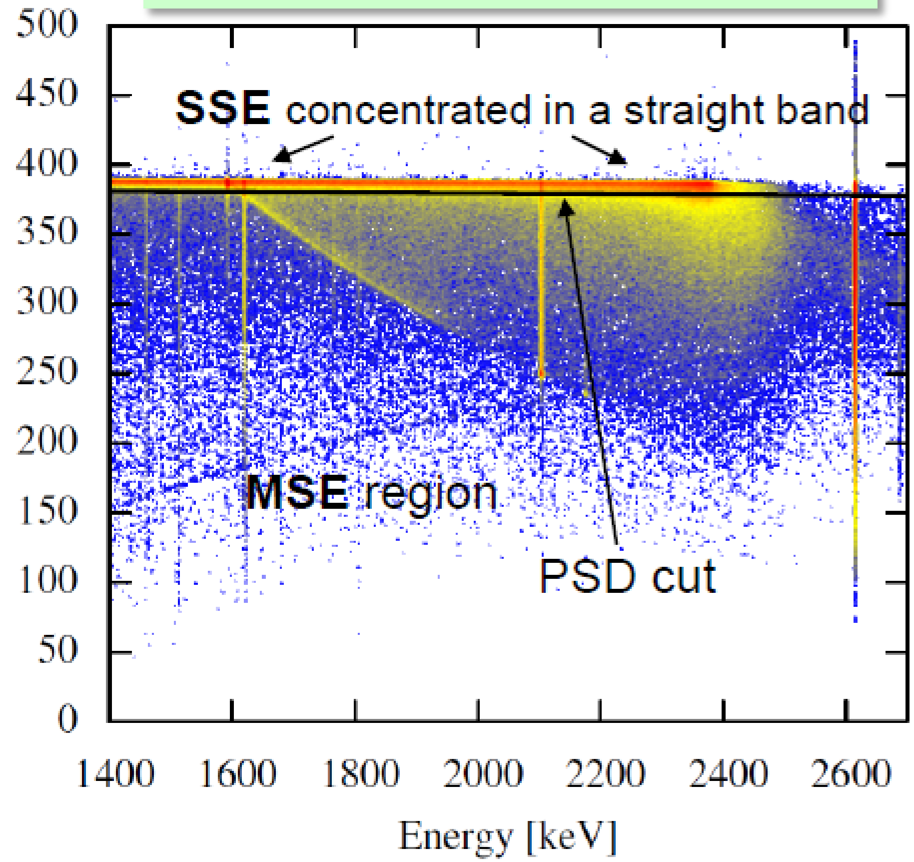
- Smaller p+ electrode ⇨ less capacitance
  ⇨ less noise
- Favorable internal electric field distribution
  ⇨ Powerful PSD capability

Pulse Shape Discrimination of BEGe

single site event **multi site event**



A/E ⇨ Discrimination parameter



D. Budjáš et al., JINST 4:P10007,2009
M. Agostini et al., JINST 6:P03005, 2011

BEGe V.S. Segmented HPGe

Segmented HPGe

Disadvantages:

- Big Capacity→Noisy
- Short Drift Length → Short rise time
- Segmentation→More material

Advantages:

- More information for event topologies

BEGe

Advantages:

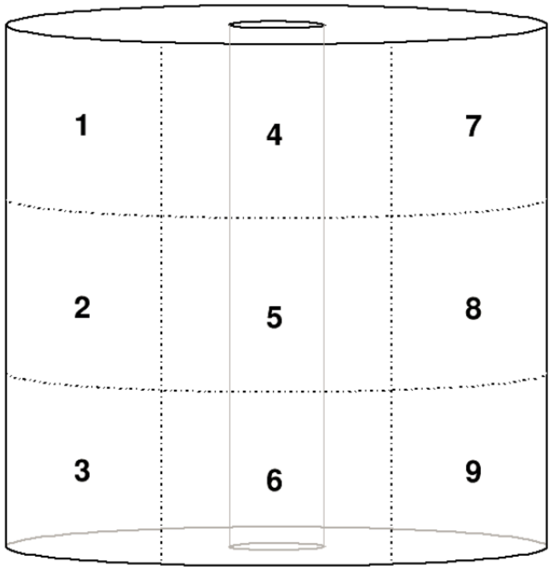
- Low capacity→Low noise
- Low field in bulk→Long Drift
- Powerful MSE discrimination

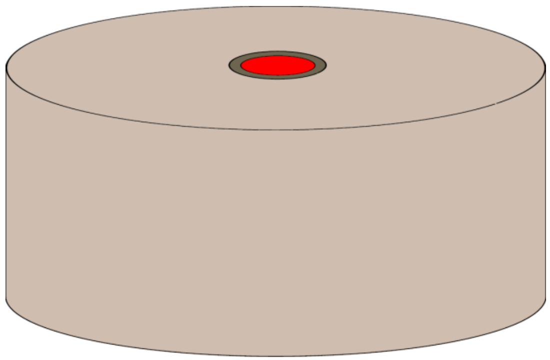
Disadvantages:

- Only 1D hit-separation sensitivity

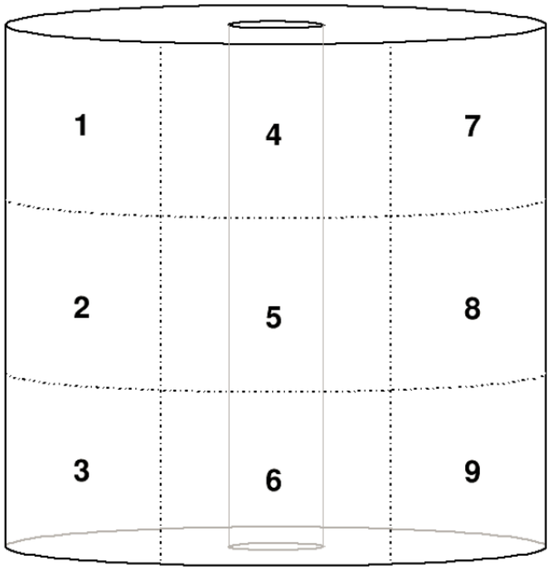
Can we improve current detector geometries?

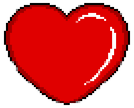
When BEGe meets Segmented HPGe...

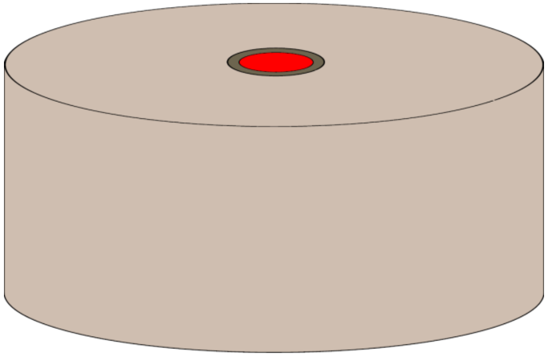


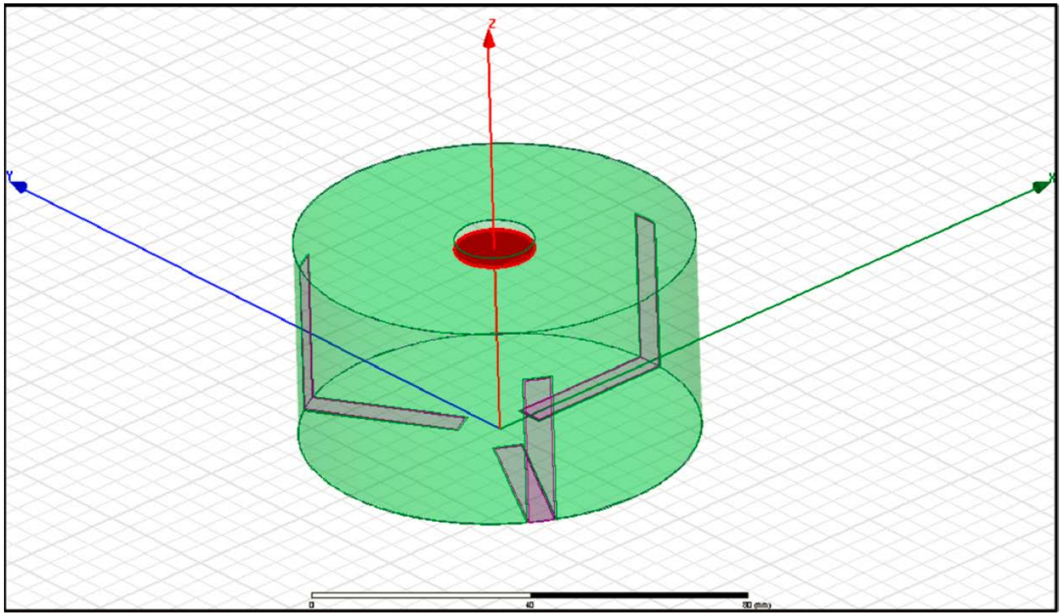


Segmented BEGe

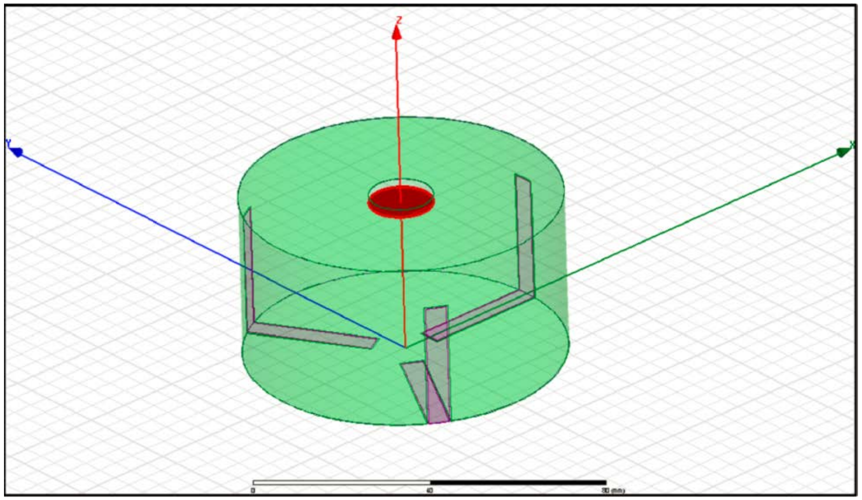








Segmented BEGe



- Break degeneracy in r and ϕ coordinate
- Measure time over threshold (Δt), trigger time(t_0) & Amplitude
- Systematically study charge collection efficiency

Segmented BEGe

How to study ?

⇨ By **pulse shape simulation**.

Why pulse shape simulation?

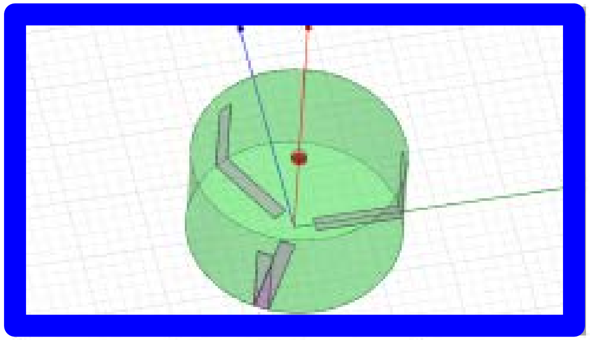
- Help on detector design
- Improve the understanding of Germanium detector
  ex. Impurity distribution
- Estimate efficiency of pulse shape analysis(PSA)
  ex. SSE, MSE
- Tool for real data analysis
  ex. Build PS pool for analysis

Which kind of simulation tools are we using?

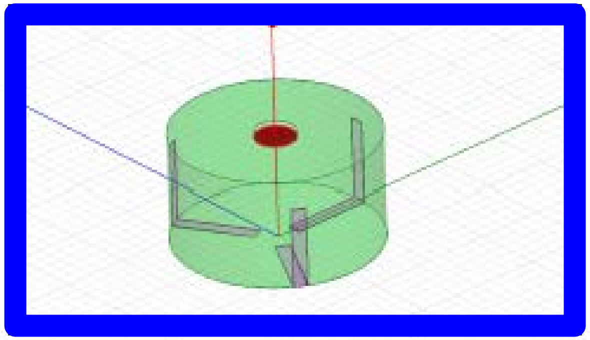
- Electrode design & field calculation are done on Maxwell
- Pulse shape simulations are performed in MaGe.

Design Evolution

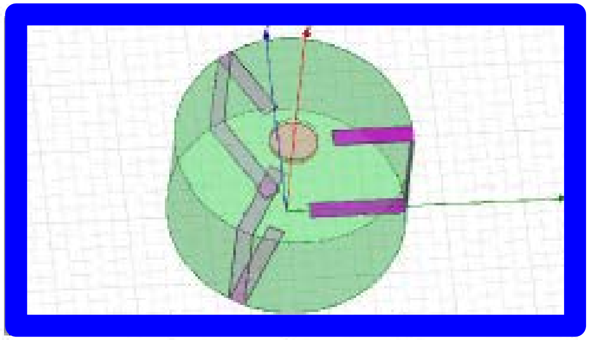
Several Designs are considered



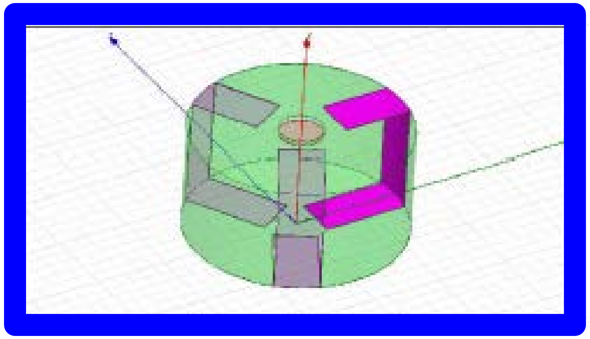
Design 2



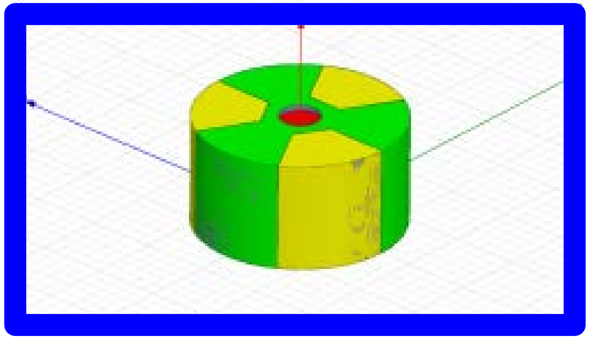
Design 2A



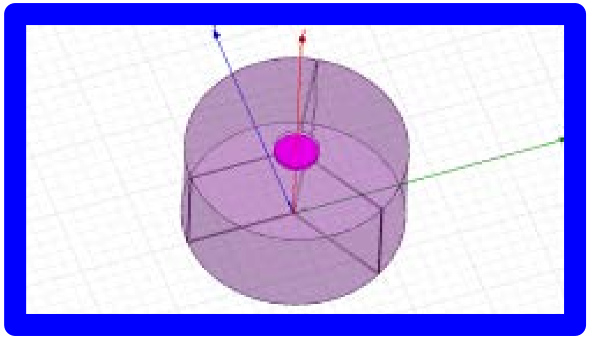
Design 3A



Design 4A

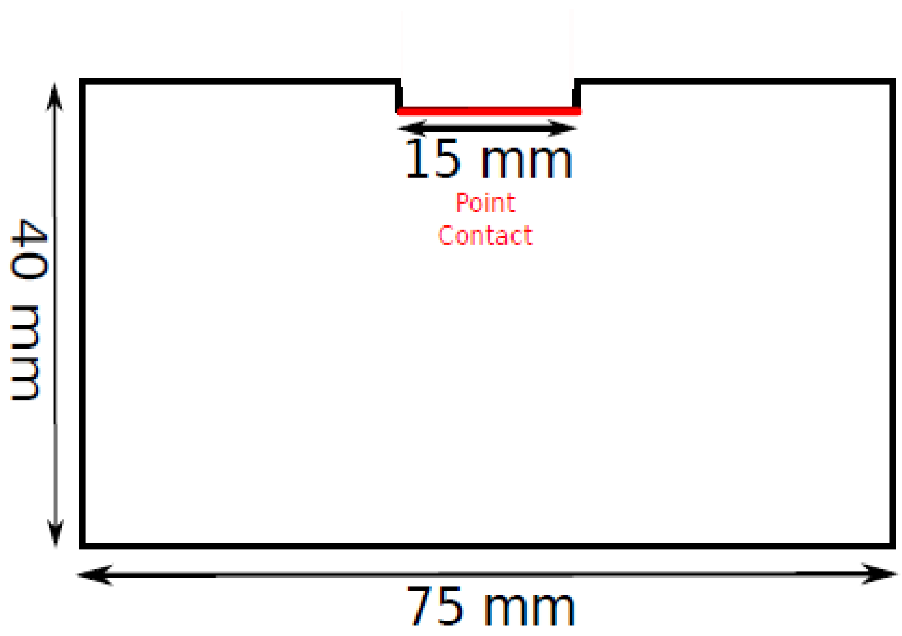


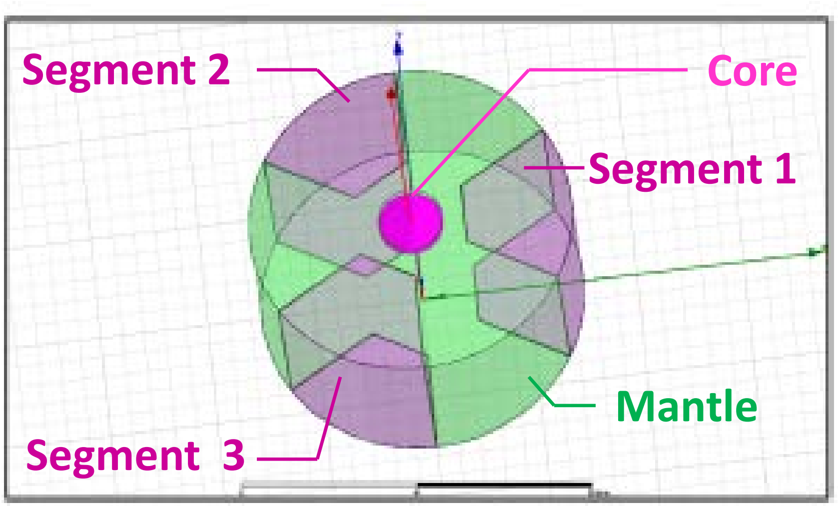
Design 5B



Design 6A

Segmented BEGe Dector – First Prototype

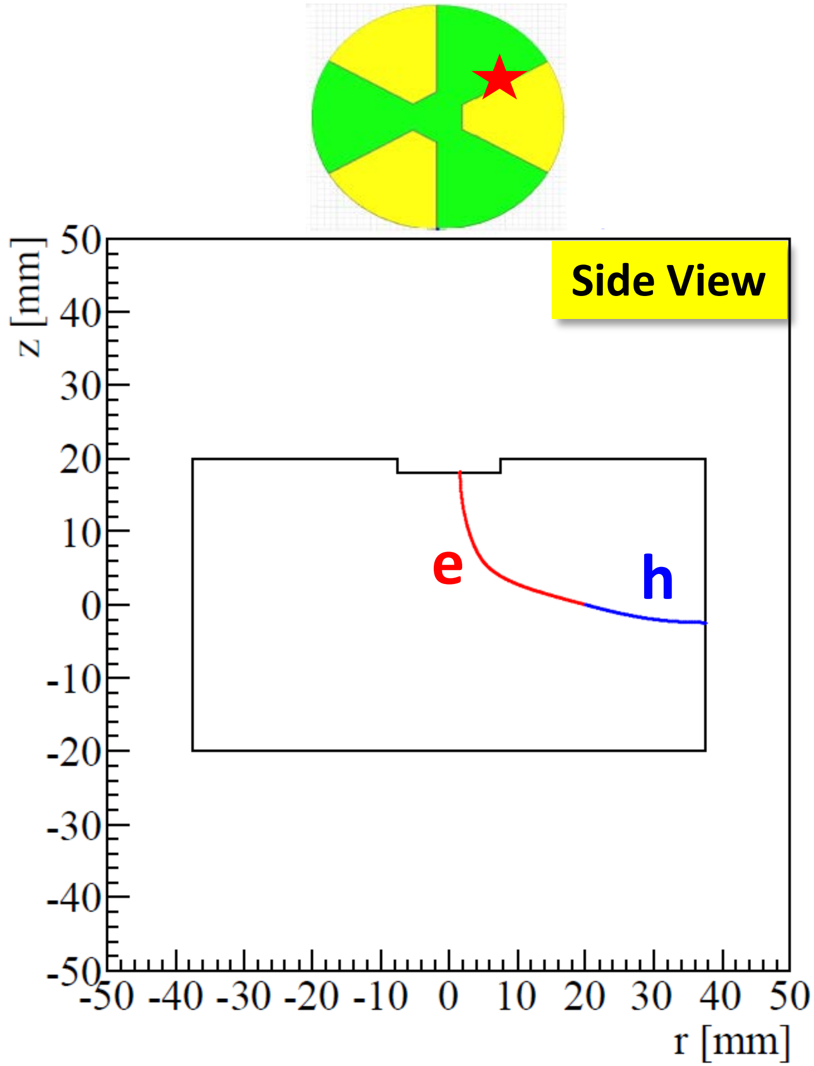


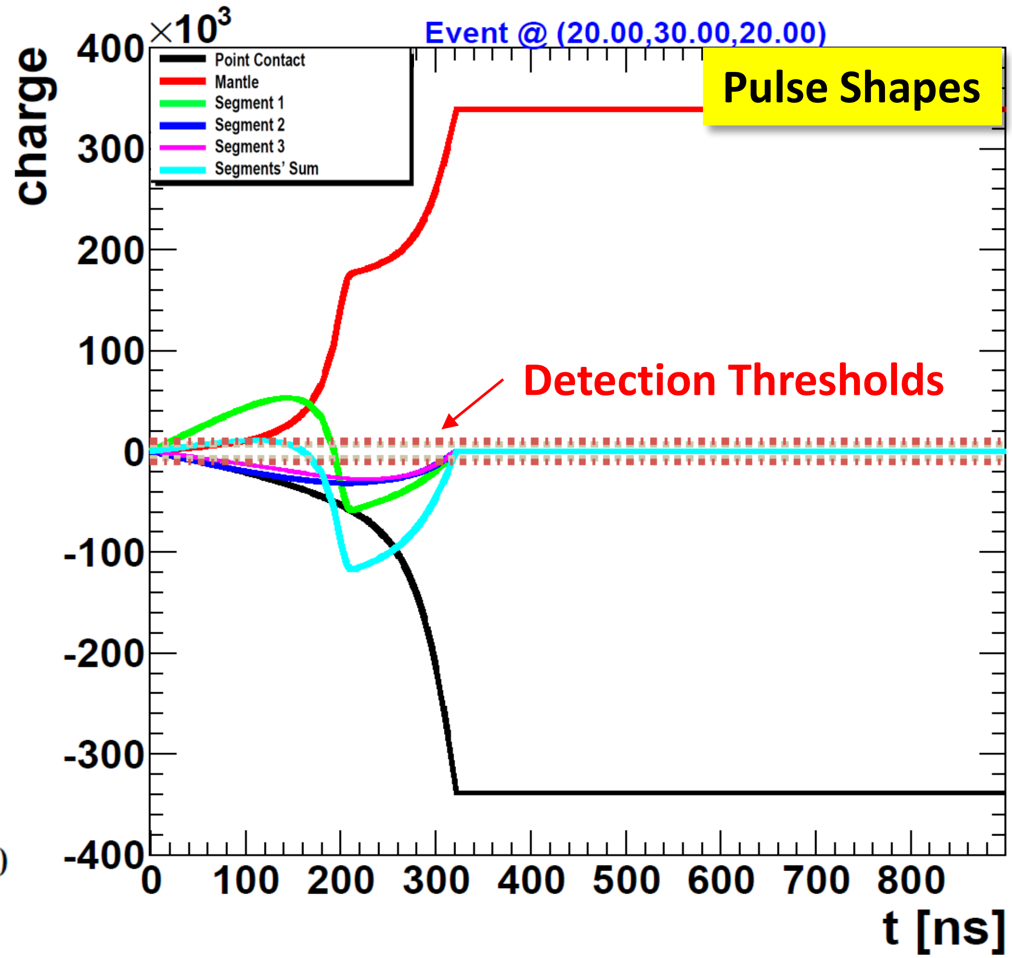


1. Detector dimensions. Height is 40 mm, diameter is 75 mm and point contact diameter is 15 mm.
2. n-type detector.
3. Detector bias is 4500 V.
4. Linear Impurity density. $0.7 \times 10^{10} cm^{-3}$ (bottom) and $1.5 \times 10^{10} cm^{-3}$ (top).

Segmented BEGe Dector

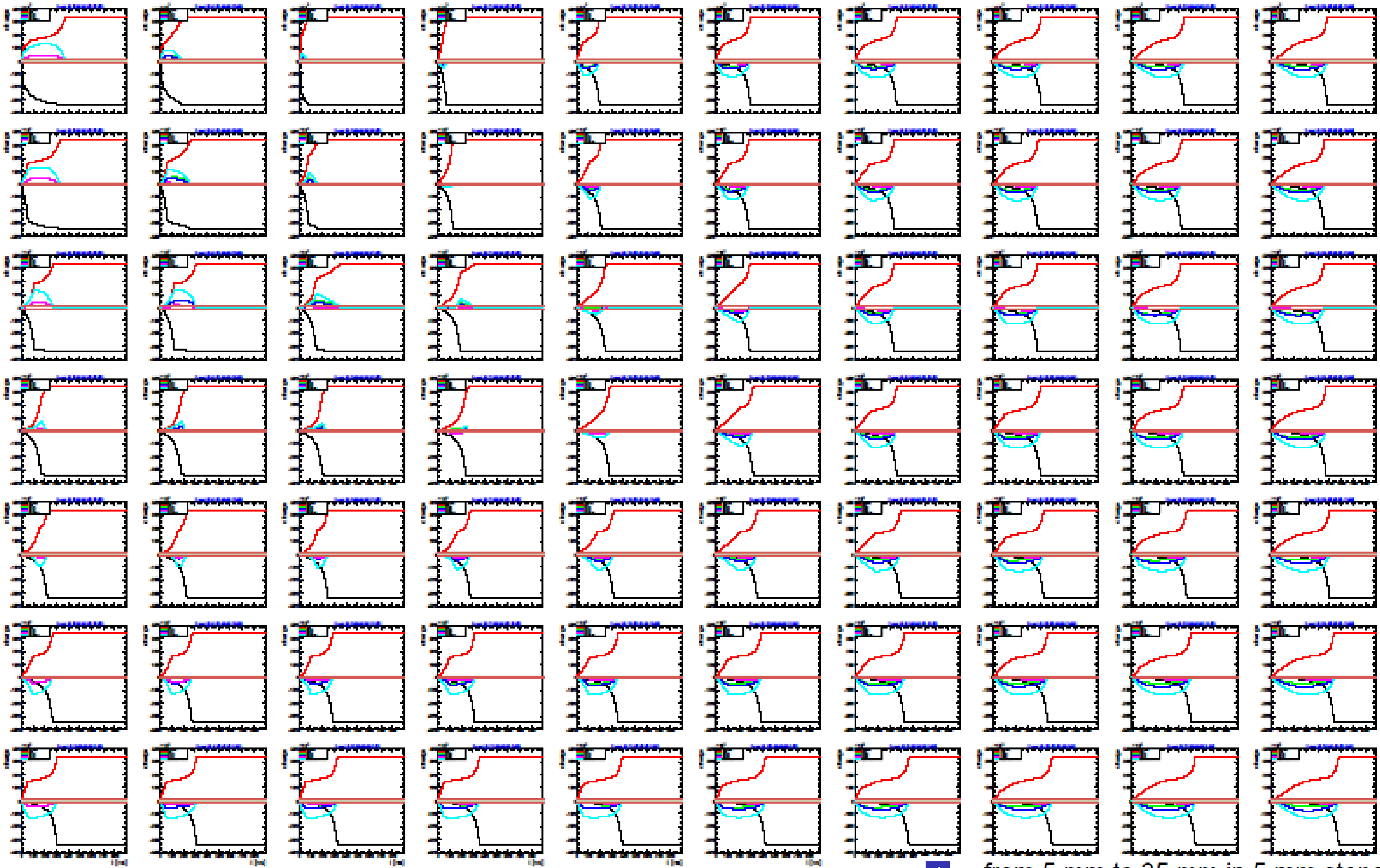
Example: Event located at r=20mm, $\phi=30^0$, z=20mm.





Thorough Scan for All the Detector volume

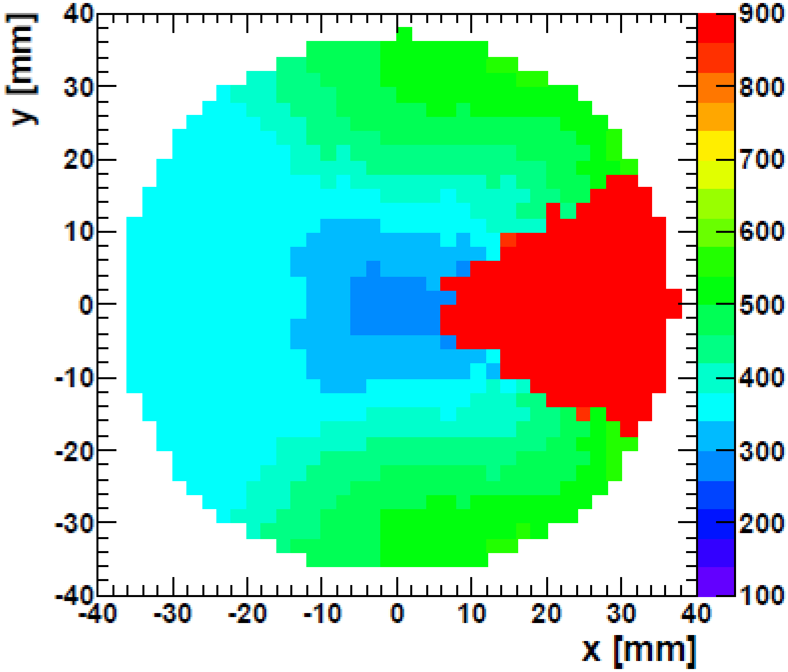
$\phi = 60°$



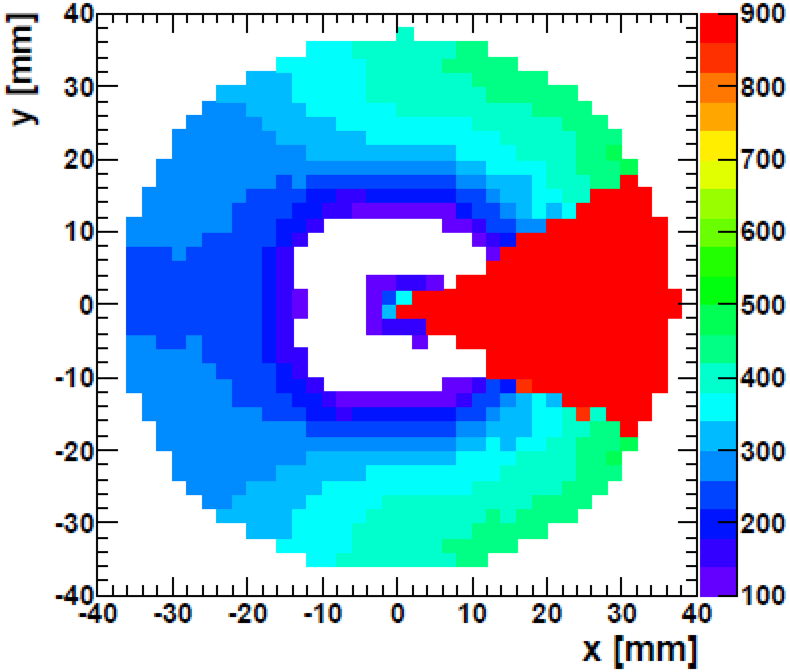
$\uparrow z, \rightarrow r.$

1. z from 5 mm to 35 mm in 5 mm steps.
2. r from 0 mm to 36 mm in 4 mm steps.
3. $\phi = 60°$.

Segment 1 – Time Over Threshold

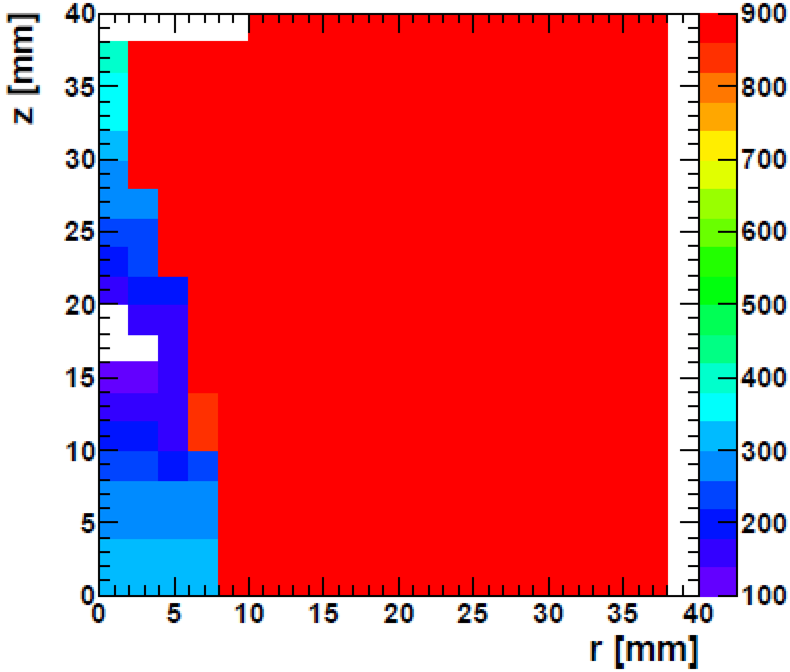


Δt in x-y for z=5mm

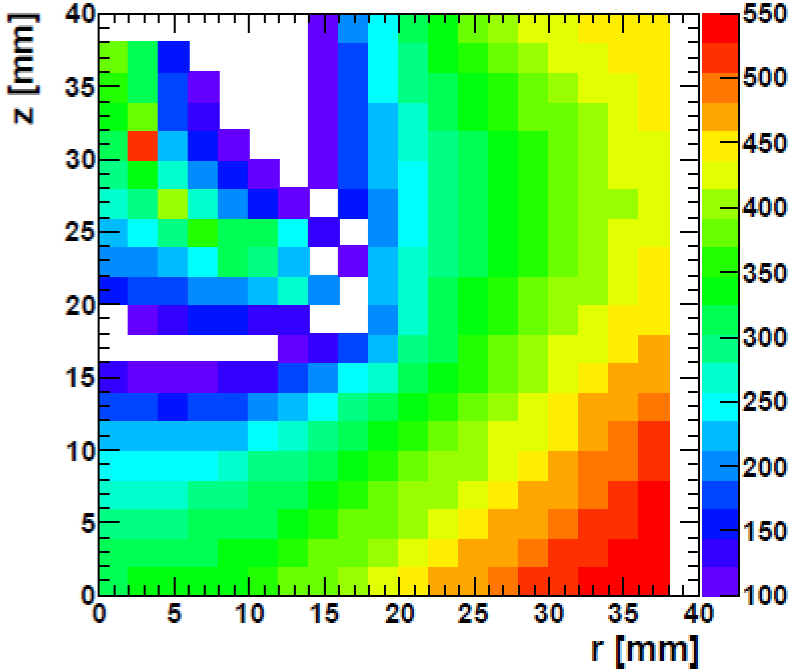


Δt in x-y for z=35mm

Segment 1 - Time Over Threshold



Δt in r-z for $\emptyset = 0^0$



Δt in r-z for $\emptyset = 60^0$

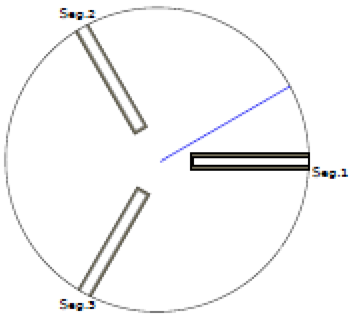
Summary

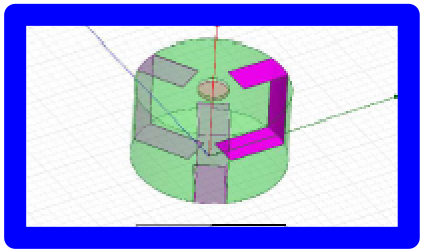
- Designed a novel detector geometry for future germanium detectors
- First prototype has been designed
- Development of PSA tools to study event topologies is on the way

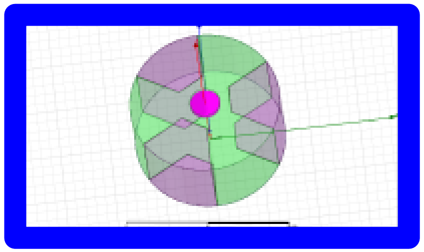
Backup Slides

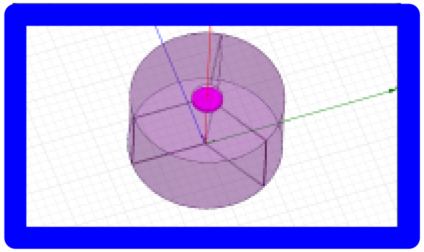
Design 4A vs Design 5A vs Design 6A

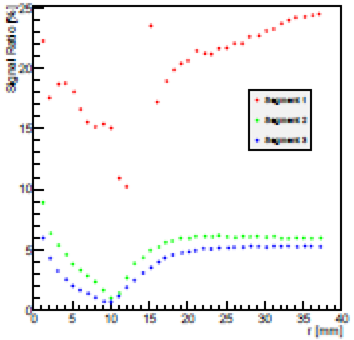
r dependence of the signal induced on the segments at
$\phi = 30°$ and $z = 35$ mm.

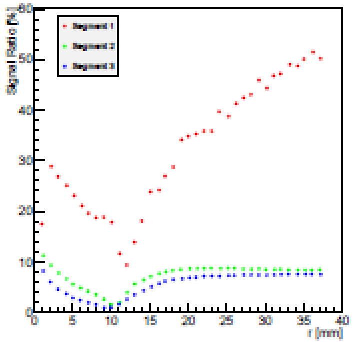


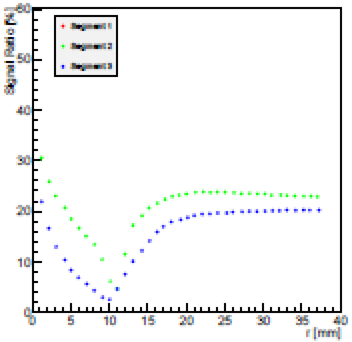




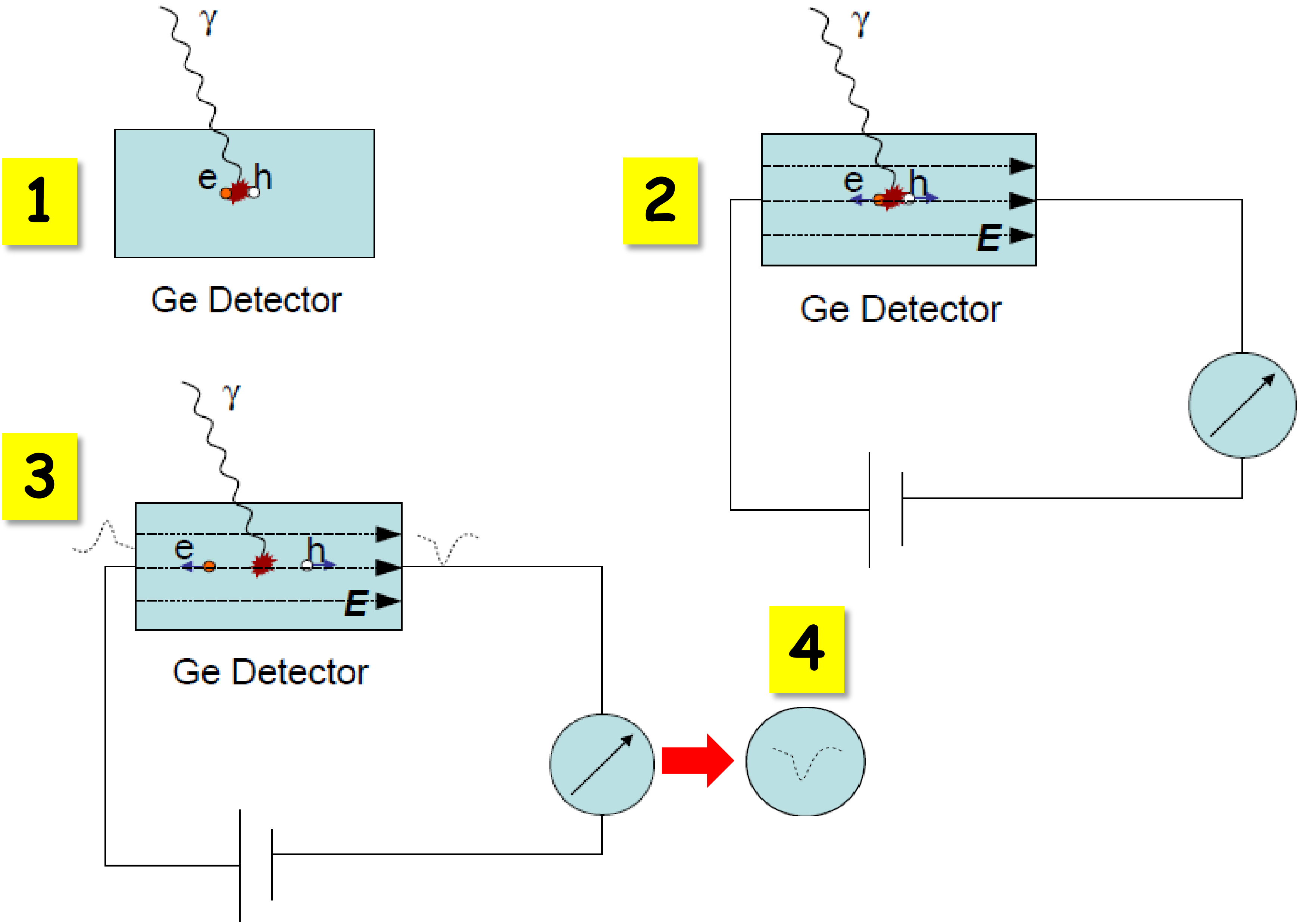




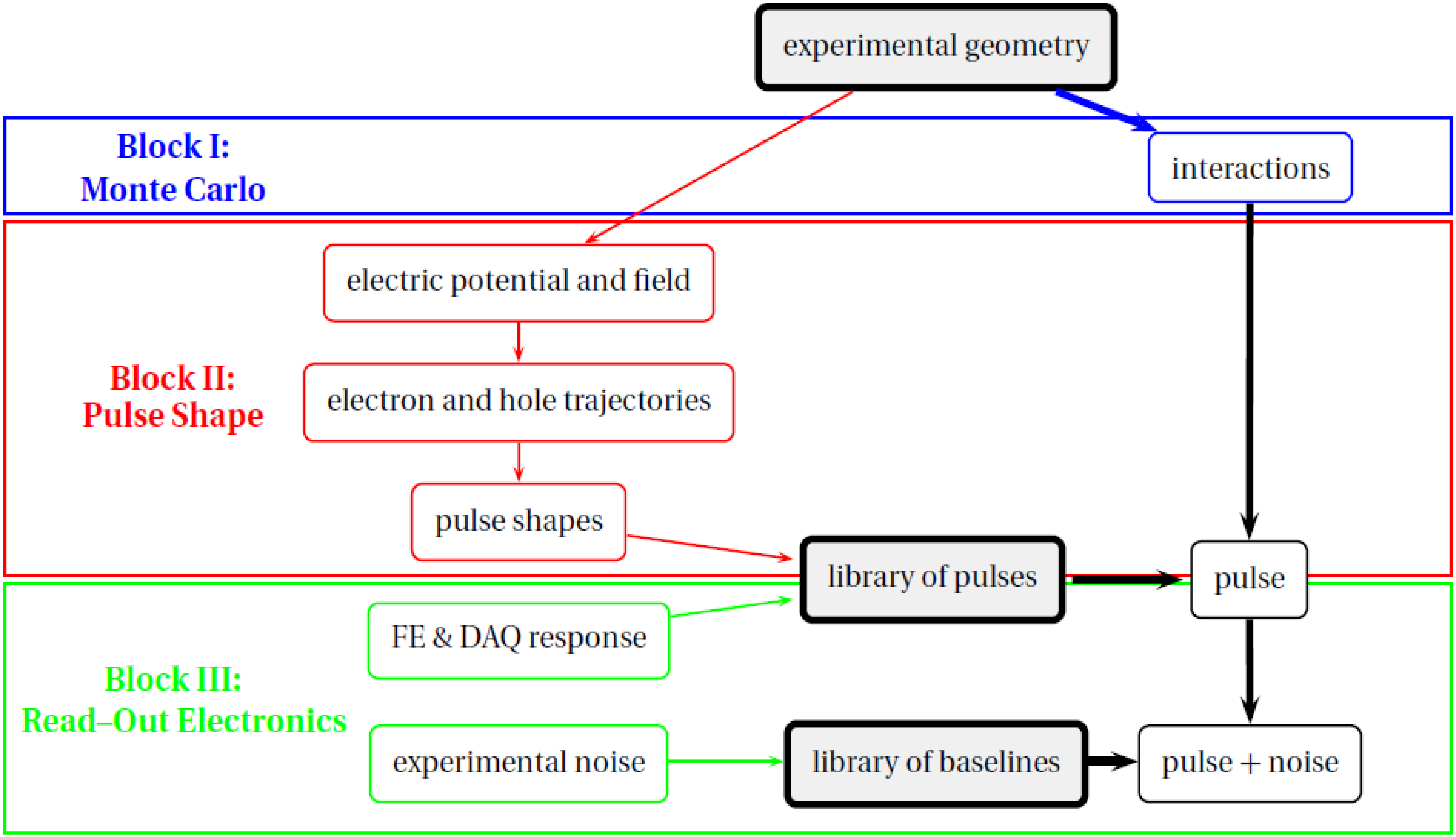




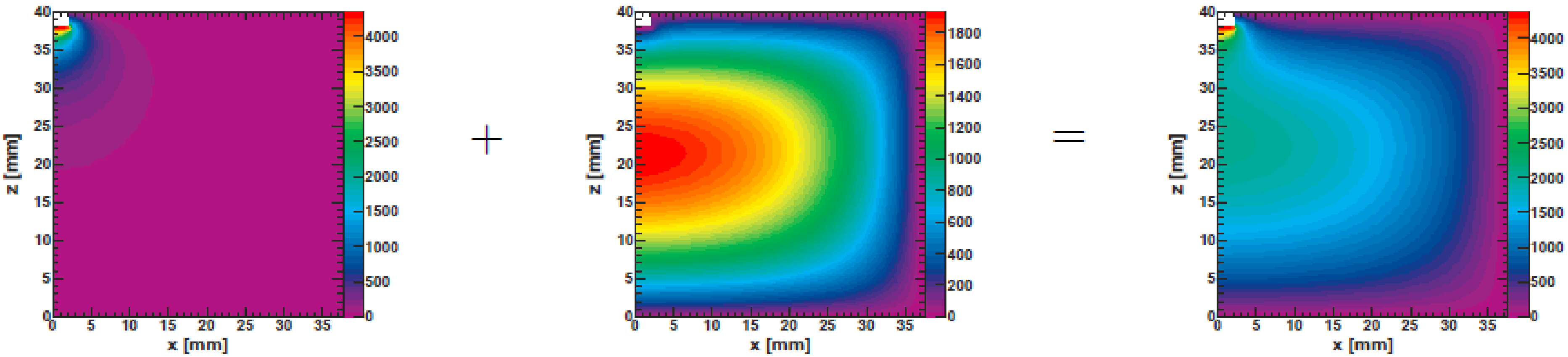
What's Pulse Shape Simulation...



Flow Chart of PSS



Electric Field Simulation

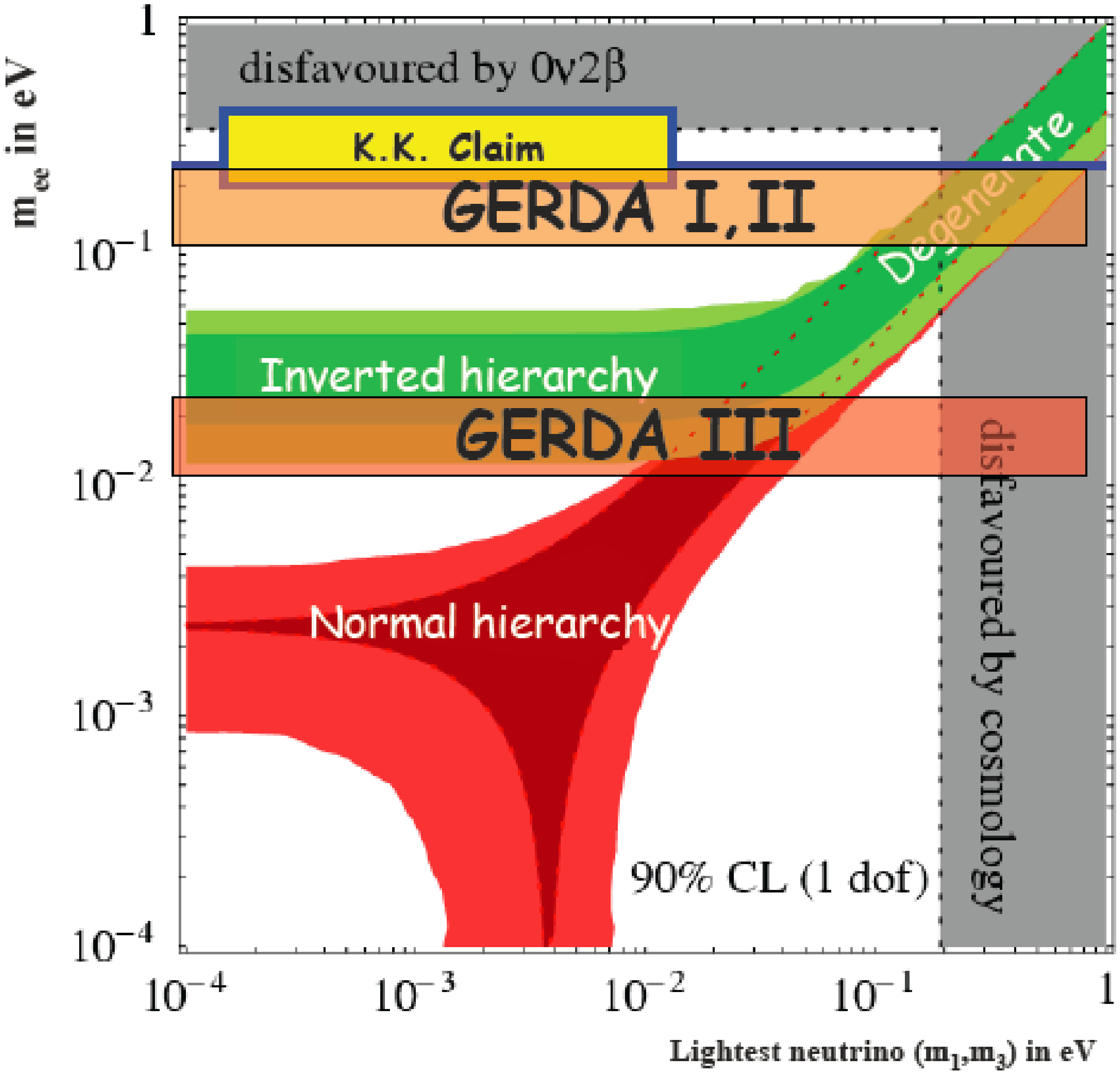


Bias + Impurity = Total

Installation of phase I detectors :

^{228}Th calibration measurement

Detector	Total mass, g	HV_{dep}, V	HV, V	FWHM (2.6 MeV)		LC , pA
				MCA	FADC	
Enriched						
ANG 1	958	3000	4000	3.6	3.8	40
ANG 2	2833	3000	3500	4.4-4.5	4.6	20
ANG 3	2391	3000	3500	4.4-4.6	4.9	<10
ANG 4	2372	2800	3200	4.0-4.5	4.4	<10
ANG 5	2746	1000	2000	4.0	4.2	<10
RG 1	2110	4200	4500	4.4-4.5	4.8	<10
RG 2	2166	3800	4000	4.7-5.0	5.1	<10
RG 3	2087	3300	3300	5.4 (6 μs)	6.1	1360
Non-enriched						
GTF 112	2957	2000	3000	3.7	4.3	<10


disfavoured by 0ν2β
K.K. Claim
GERDA I,II
Degenerate
Inverted hierarchy
GERDA III
Normal hierarchy
disfavoured by cosmology
90% CL (1 dof)
m_{ee} in eV
Lightest neutrino (m_1,m_3) in eV
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1