A Novel Segmented Point-Contact BEGe Detector as a Reduced Technical-Risk Alternative to the SIGMA Design

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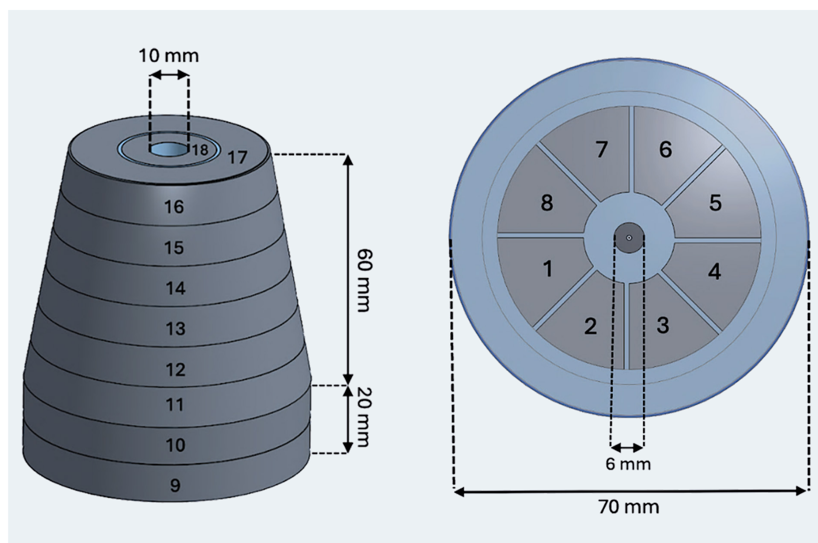
Introduction

- The Segmented Inverted Coaxial Germanium (SIGMA) detector is a large-volume High Purity Germanium (HPGe) detector designed for gamma-ray imaging and tracking.
- This project aims to design novel SIGMA-like geometries to reduce the technical risks associated with the original design and optimise future manufacturing yield while maintaining energy and position resolution.
- Sensitivity maps were produced to assess the initial performance of the novel detector design.

Original SIGMA Design

SIGMA follows a complex segmentation scheme to maximise position sensitivity:

- Two radial segments aid in resolving the radial position.
- Eight azimuthal segments provide angular information.
- Eight longitudinal segments offer depth of gamma ray interaction.
- A P+ point-like contact collects primary charge carriers (holes)



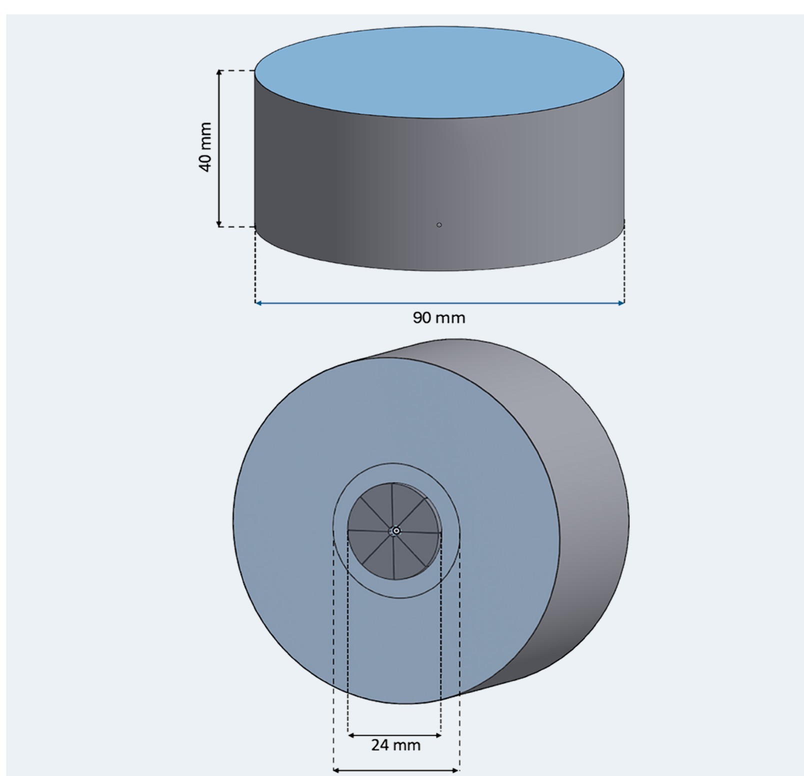
New Proposed Design

In order to minimise technical risk, a new design has been proposed; **a segmented point contact** (SPOT) detector.

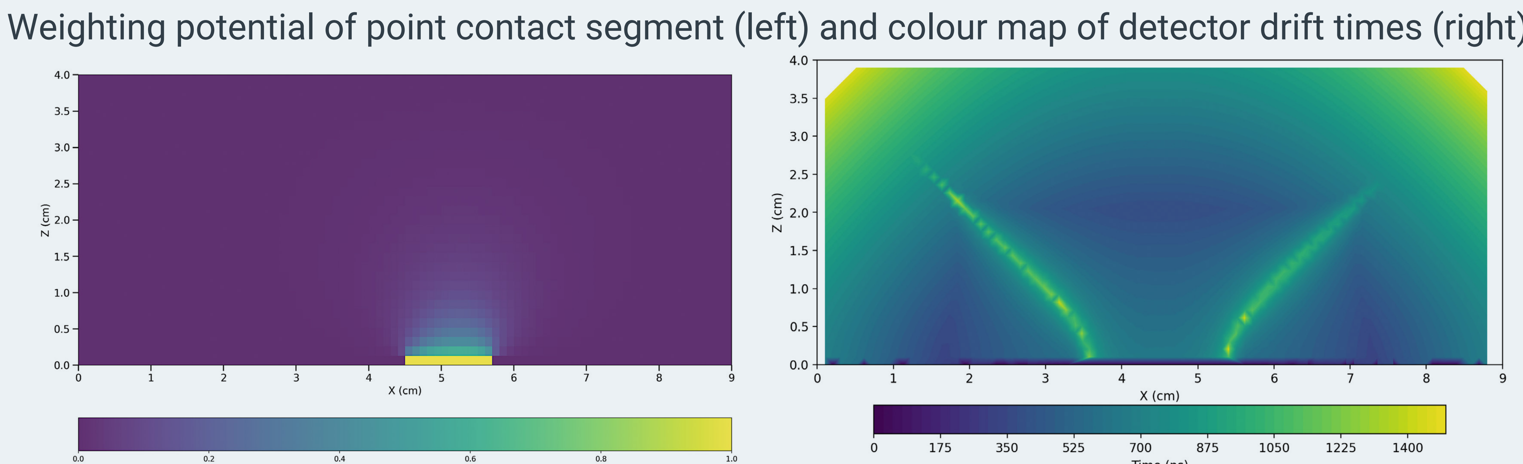
The design follows a Broad Energy Germanium detector (BEGe) convention;

- A segmented P+ point-like contact collects primary charge carriers (holes), providing angular information.
- A n-type contact surrounds the outside of the crystal.

The merging of the azimuthal and point contact segments, makes the **angular information explicit**, reducing uncertainty on interaction position.



Weighting potential of point contact segment (left) and colour map of detector drift times (right).



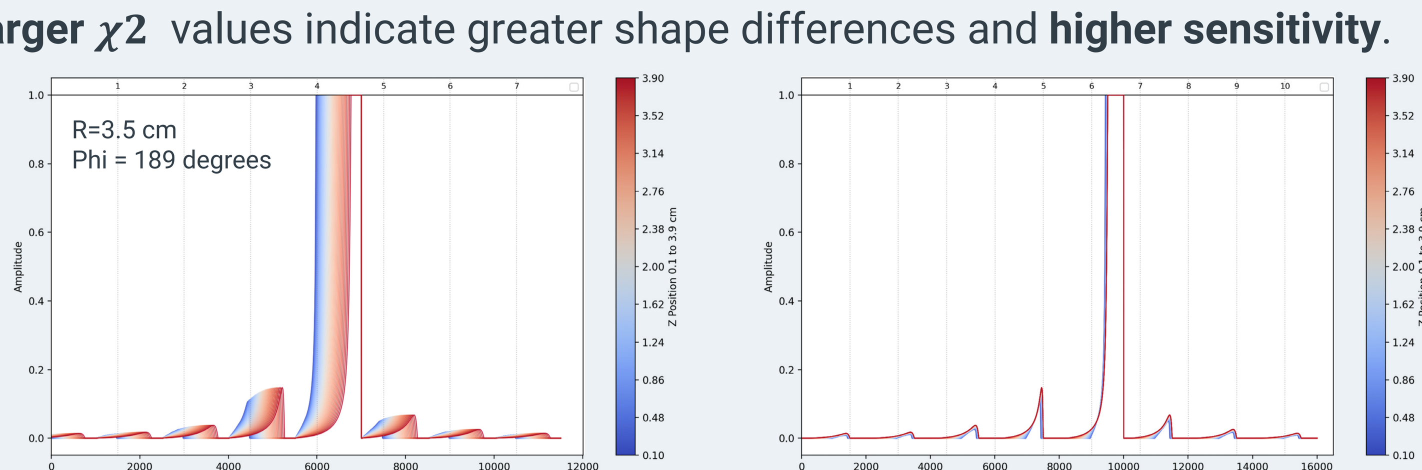
Sensitivity Map Method

Pulses from each interaction are concatenated into a single *Superpulse of length N*. A detector sensitivity map then compares how these Superpulses vary in shape.

$$\chi^2 = \sum_i^N \frac{(x_i-\mu_i)^2}{\sigma_i}$$

- x_i is a point from the test Superpulse
- μ_i from the neighbouring Superpulse
- σ_i is the signal length.

- **Larger** $\chi 2$ values indicate greater shape differences and **higher sensitivity**.

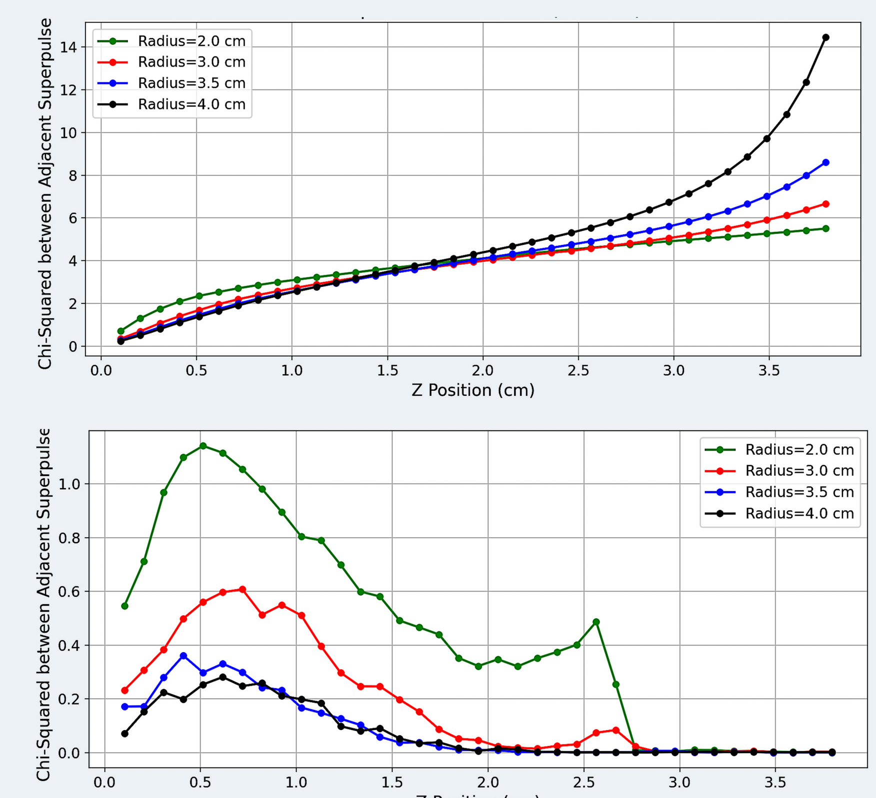


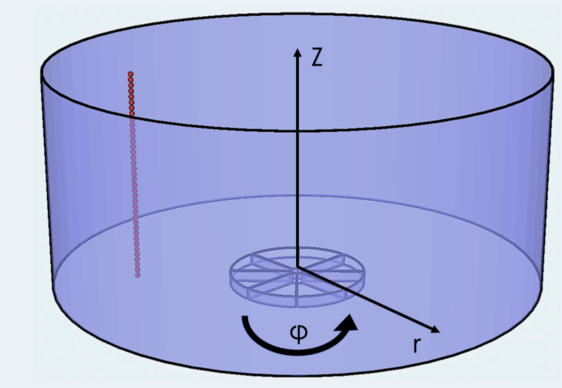
Superpulses through fixed radius and angle with (right plot) and without time alignment (left plot).

To time-align Superpulses, a digital leading-edge discriminator (LED) was applied to the hit segment of the Superpulse; this was done to **mimic a real detector triggering system** as alignment at t=0 is unattainable experimentally.

Sensitivity Map SPOT Results

t=0 alignment vs LED 5% alignment



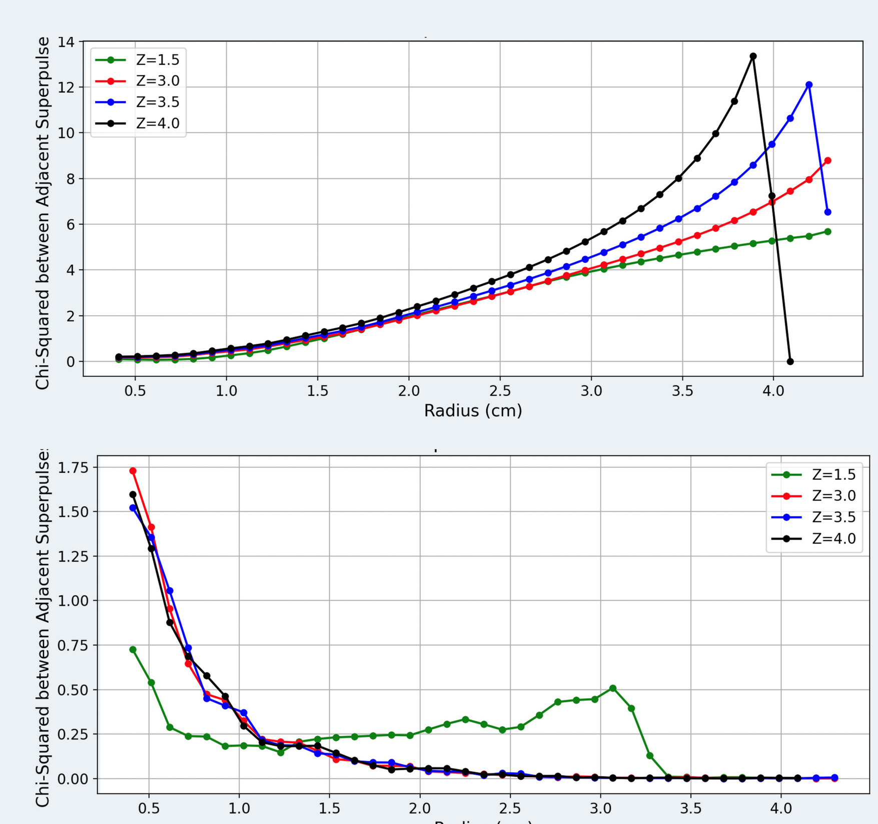


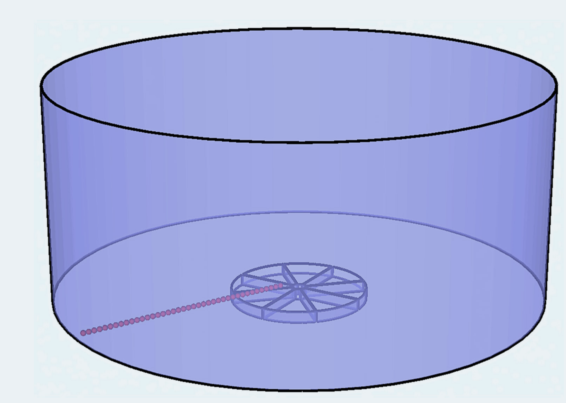
For the non-time aligned map:

- At small values of Z, the sensitivity is approximately linear then rises.
- For all radii, χ^2 increases with Z.

For the time aligned map:

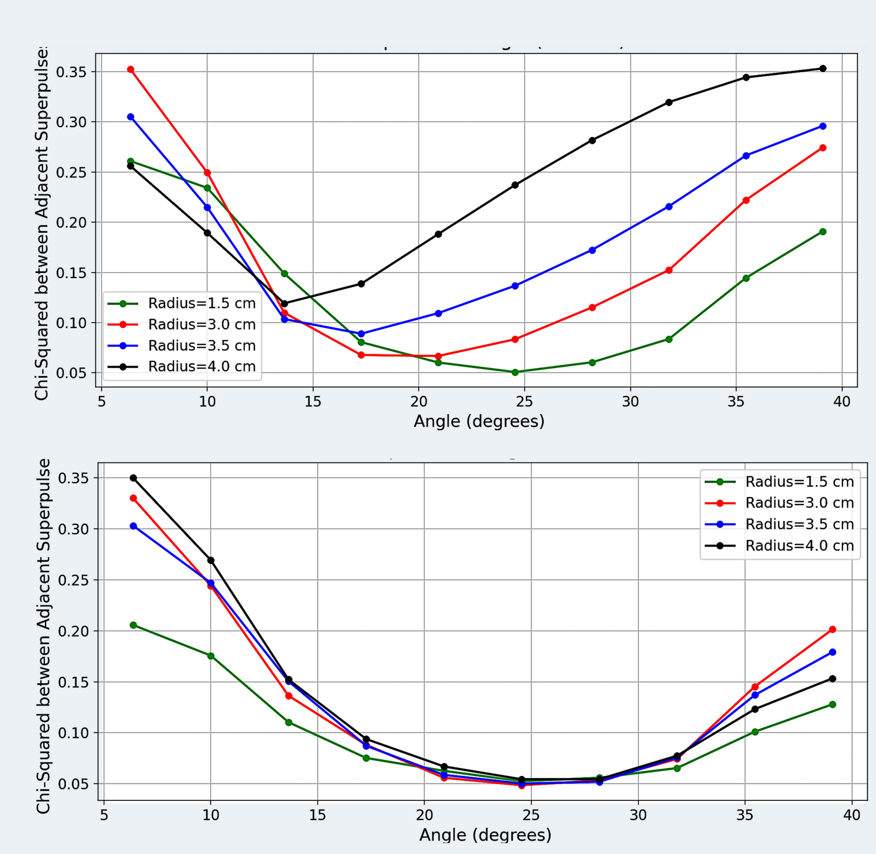
- The χ^2, for all radii, is low initially at small Z. At Z ≈ 0.4–0.8 cm, χ^2 increases then gradually declines. After Z ≈ 2.5–3.0 cm, values drop to near zero.

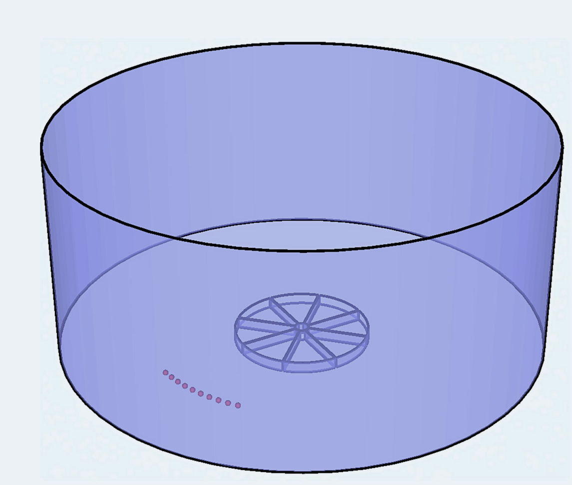




- χ^2 increases with radius for all Z values, starting near zero (~0.5 cm) and rising steadily.
- Larger Z gives greater χ^2 (stronger sensitivity).
- For the time-aligned map, sensitivity starts higher but drops to zero at ~2.5 cm for all Z.

- The difference in the shape of the time aligned and non-time aligned Z and radial maps occurs as the difference in the charge collection signals dominates in these maps.





- Detector sensitivity is lowest at ~15–25° from segment boundaries, showing minimum χ^2 .
- Similar results obtained with and without time alignment as, for this map, it is the transient signals which dominate the difference signal shapes.

Future Work

- Include preamplifier response and electronic noise to simulated Superpulses to more accurately mimic experimental response.
- Perform Pulse Shape Analysis (PSA) using a PSA algorithm to get the achievable position resolution of SPOT in r, phi and Z.
- Enhance the SPOT design by adding an unsegmented guard ring around the point contact to capture events occurring from the back of the crystal and to provide additional height information.

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