Simulating the position sensitivity of the iThemba LABS segmented clover detector

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Abstract. The iThemba LABS detector is made up of four end-closed coaxial, front tapered, electrically segmented n-type germanium crystals, packed closely together in one cryostat The cathode of each crystal is electrically segmented into 8 contacts with depth segmentation at 35 mm. This results in a total of 36 electronic channels of which 32 are associated with the outer contacts and 4 with the inner core contacts of the detector. The position sensitivity of this segmented iThemba LABS HPGe detector is investigated through simulation using the Multi-Geometry Simulation code [1]. This code simulates the electric field, drift velocity, weighting potential and generate the expected pulse shape from an arbitrary gamma-ray interaction's position within the germanium detector volume. Using this code, the pulse shape response at the inner and outer contacts has been generated as a function of the radius, angle and depth of gamma-ray interaction position within the germanium detector volume. Changes in the pulse shapes reflecting changes in the position of the interaction point were observed. This confirms that the detector is sensitive to the exact position of the gamma-ray interaction.

1. Introduction

Germanium detectors have been used for a number of years now for accurate measurements of gamma-rays and helped us extract information about different properties of nuclear states, such as energies, spins, parities, magnetic moments, etc. iThemba LABS has recently purchased a highly segmented gamma-ray detector and aims to fully utilize its position sensitivity capabilities. A detector able to perform gamma-ray tracking will be very valuable as it has the potential for high efficiency due of its size, and high resolving power due to ability to reduce Compton background .For fast moving nuclide such a detector has the ability to greatly reduce Doppler broadening in the gamma-ray peaks because of the substantially reduced opening angle.

In order to evaluate the tracking capabilities of this detector, we will start by determining the position sensitivity of our detector using based on an analysis of the shape of the core and segments pulses.

2. The iThemba LABS segmented clover detector

The iThemba LABS segmented clover detector comprises of four HPGe crystals (with approximately 39% relative efficiency) arranged in a clover-leaf geometry for optimal efficiency purposes. Each crystal is electrically segmented into eight regions on the outer contacts, this adds up to 32 segments for one detector plus four full-volume signals from the inner core contacts as shown in figure 1. The inner contacts provide high resolution measurements of gamma-ray energy deposition for each crystal whilst the outer contacts give information about the location of the gamma-ray interaction inside the detector. The total efficiency of the detector in add-back mode is 220%. Each crystal is 60mm in diameter and 90mm in length before tapering. The depth segmentation is at 35 mm.

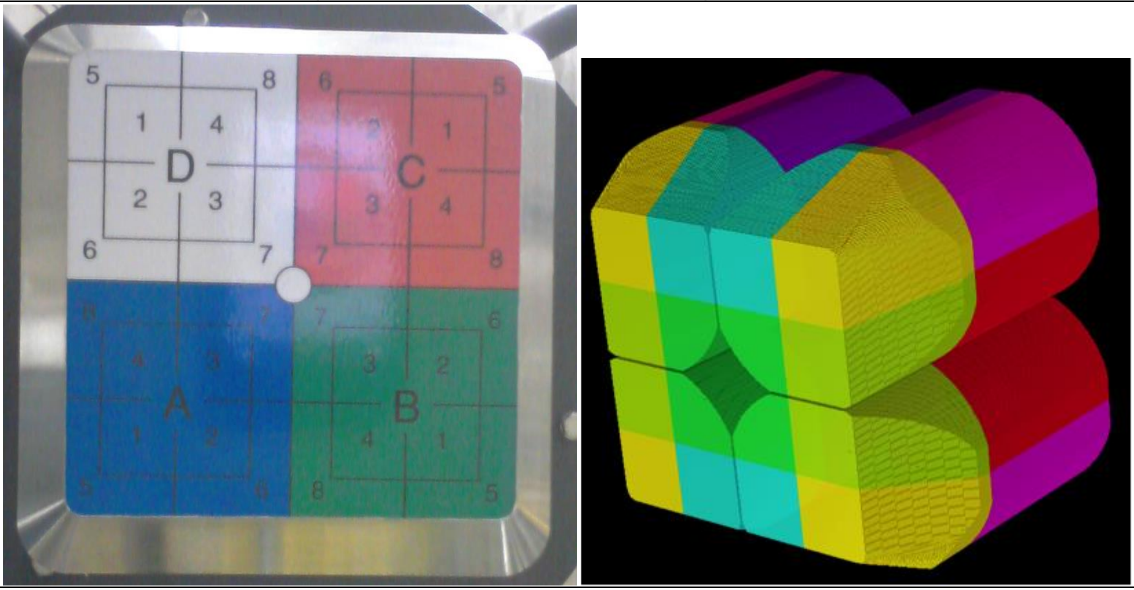


Figure 1: The Ge crystals and segments of the iThemba LABS segmented clover detector with the four front segments labelled as (1, 2, 3, and 4) and the back four segments labelled (5, 6, 7, and 8) [2]. The figure on the right shows the simulated geometry of the detector.

3. Multi Geometry simulation (MGS) code

When an incoming γ-ray interacts within a segmented detector, it generates electron-hole pairs. The deposited energy can then be obtained from the amplitude of the pulse.

As the charge carriers drift, charge is induced in the electrodes and a current is produced. These pulse shapes can be generated using a Multi Geometry Simulation (MGS) code where the electric field is calculated from the Poisson's equation using relaxation methods [3]. For a given interaction inside the detector MGS performs the following routines in order to compute a pulse shape response:

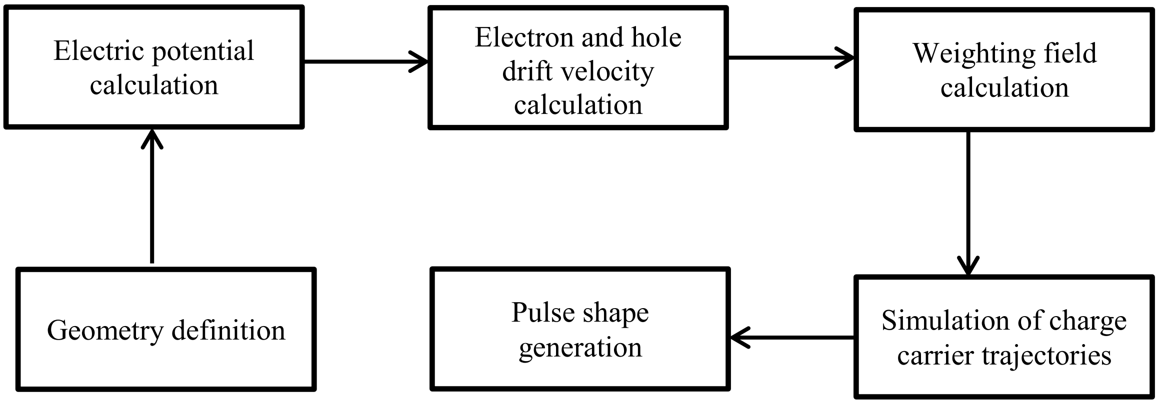
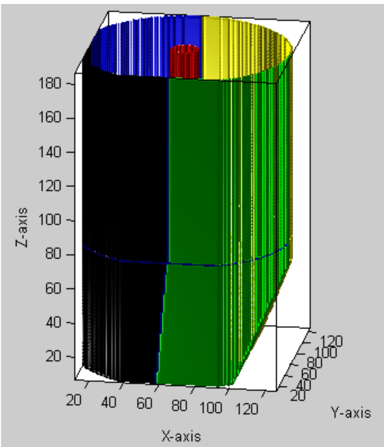
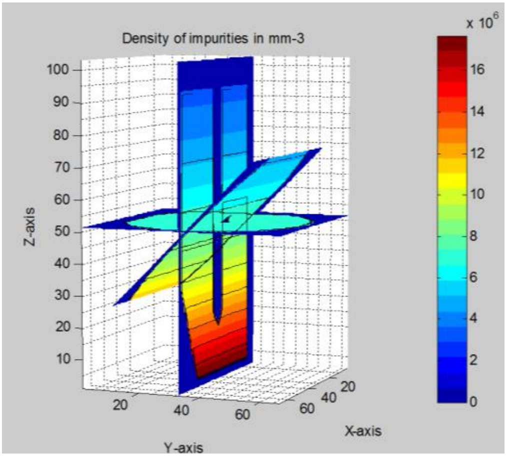


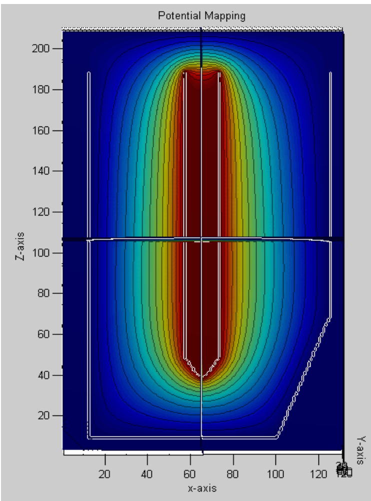
Figure 2: MGS data flow diagram for the simulation of the expected pulse shapes at the contacts of any arbitrary HPGe detector geometry.



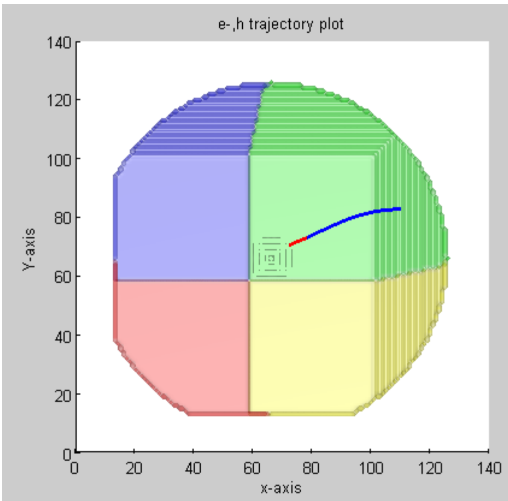
(A)



(B)



(C)



(D)

Figure 3: Simulations of the detector geometry, impurity profile, potential mapping and charge carrier trajectories that have been produced with the MGS code.

4. Results and discussion

The position sensitivity of the iThemba LABS segmented clover detector was investigated by simulating charge collection and induced signals generated on the electrodes of the detector by gamma-ray interactions occurring in different places inside the detector. These signals were analysed and. The interaction was chosen to occur in segment 1 in crystal A. The three parameters that were varied in this investigation were the azimuthal angle within the segment, the radius and the depth.

It was found that when the radius is varied from r = 5 mm to 29 mm, there is a clear differentcein the simulated charge collection pulses on the core electrode. Holes and electrons generate very distinct pulse shapes. At positions closer to the inner electrode the movements of the holes determines the general shape of the charge collection signal as they travel a longer way to be collected at the cathode. As the position is moved towards the outer electrode the total charge collection signal changes its shape as electrons travel larger distance and hence determine the general shape of the pulse as seen in figure 4.

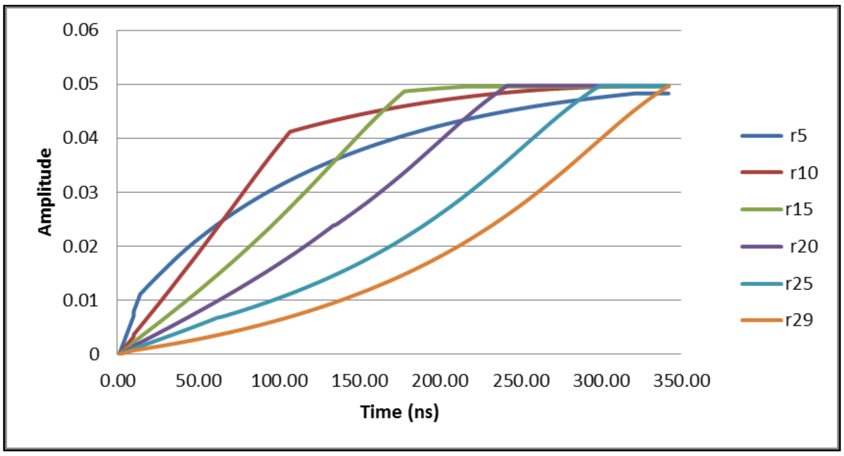


Figure 4: Core signals at different radial positions

Then the interaction position was moved at different angles from 1^0 to 90^0 while keeping the radius and depth the same. No significant difference was observed in the shape of the charge collected pulses at the core electrode, but a noticeable difference is found in the induced pulses from the neighbouring segments . As the interaction position is moved from 1^0 (closer to segment 2) to 90^0 (closer to segment 4) the induced pulse on segment 2 decrease as the pulse on segment 4 increases. The induced signals are very helpful in this case, they are the ones that make it possible to distinguish such interaction points. This is illustrated in figure 5 where the core signals do not show a differencefor interaction points at 35^o and 55^o, but the induced pulses in the neighbouring segments s2 and s4 are different and can be used for the identification of these points.

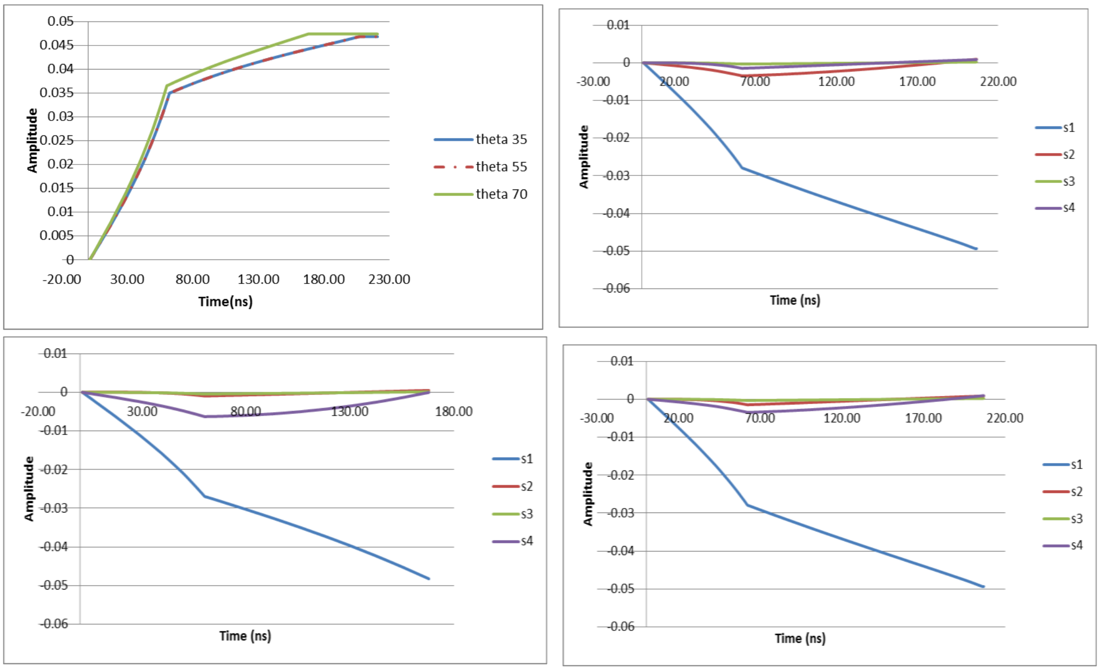


Figure 5: Core and segment signals at the same radial positions, but different azimuthal angles.

Pulse shapes were also analysed for interaction positions at different depths in segment one. The induced pulses were found to differ as the interaction position was varied from a depth of 5 mm (along the z-axis) up to 85 mm. The core pulses show sensitivity from 5 mm to 20 mm as seen in figure 6. The transverse segmentation at 35 mm is then used to differentiate between the induced pulses generated at different depths as seen in figure 7. The back segment however, is large (55mm) and hence makes the detector less position sensitive at depths around 60 mm to 80 mm.

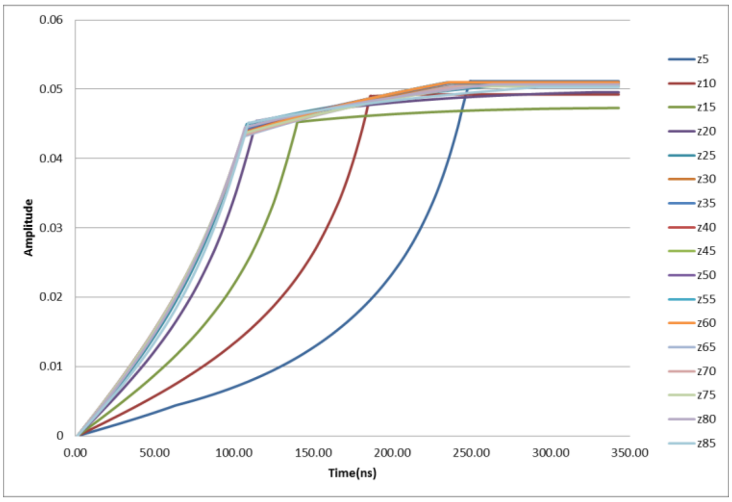
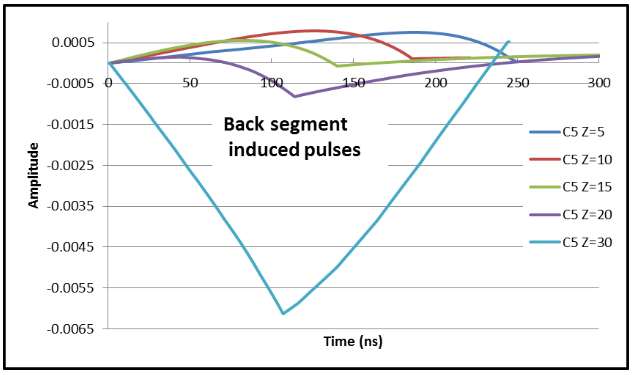


Figure 6: Core signals at different depths



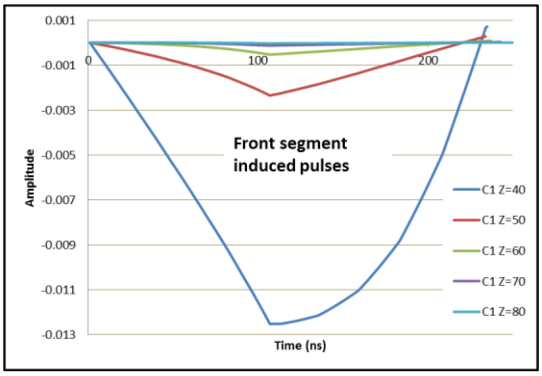


Figure 4.4: Induced segment signals at different depths

5. Conclusion and outlook

The position sensitivity of the segmented iThemba LABS clover detector is being studied with the MGS code. Pulse shapes have been simulated at different positions (for different radii, azimuthal angle and depth) within the detector volume. For interaction points at different radii, the shape of the pulses at the inner contact can be used to resolve the positions. For different azimuthal angles, the induced signal at the neighbouring segments is important in determining the position. At different depths there are positions for which the depth can be determined, but the detector seems to be less sensitive to some parts of the detector especially for interactions at the back of the detector. This is a successful first step towards building a database of simulated pulses, and establishing the position sensitivity of this segmented detector.

The next step is to make more realistic simulations that include the preamplifier response function, other electronic components and crosstalk. After that a data base of simulated pulses will be built and compared to experimental pulses. Simulation of more than one interaction in a segment will then follow.

References

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[2] iThemba LABS clover 6 X 60 X 90 seg32 user's manual, S/N 21
[3] M.R. Dimmock et al., IEEE Trans Nucl.Sci. Vol. 56, NO. 4, Aug 2009