# Challenges in the simulations of the iThemba LABS segmented clover detector

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**Abstract**. The Multi Geometry Simulation (MGS) code was employed to simulate the response of the iThemba LABS segmented clover detector for an arbitrary γ-ray interaction within its Ge crystals. The results from these simulations showing that the detector is sensitive to the position of the γ-ray interaction are topic of another paper. Here, the focus is on the challenges experienced during the simulations and on the progress made so far in obtaining realistic pulse shapes with the MGS code. Taking into account all the data, the way forward is outlined.

## 1. Introduction

A large volume n-type HPGe detector dedicated for γ-ray measurements is usually constructed in closed-ended coaxial geometry [1]. In this configuration, one electrode, the $p^+$ contact, is fabricated at the outer surface of the cylindrical crystal and another electrode, the $n^+$ contact, is located at the inner surface of the central hole. These contacts are made through the diffusion of a lithium layer on the inner surface and by boron ion implantation on the outer surface of the detector. The p-n junction of this coaxial detector is located at the outer surface of the detector and when the positive high voltage (reverse biased) is applied to the $n^+$ contact, the depletion region expand from the $p^+$ contact inwards, see figure 1.

When the detector if fully depleted, the potential throughout the coaxial type detector is given by the Poisson equation in cylindrical coordinates,

$$\frac{d^2\Phi}{dr^2} + \frac{1}{r}\frac{d\Phi}{dr} = -\frac{\rho}{\epsilon_0}$$

where ρ is the net charge density, and $\epsilon_0$ is the dielectric constant for the material. This equation can be solved by letting the potential difference equal to the applied voltage. The electric field can be described using,

$$-E(r) = -\frac{\rho}{2\epsilon_0}r + \frac{V + (\rho/4\epsilon_0)(r_2^2 - r_1^2)}{r\ln(r_2/r_1)}$$

where $r_1$ and $r_2$ are the inner and outer radii of the coaxial detector. The depletion region is the sensitive region of the detector. Therefore, when charge carriers are created in this region they will be swept by the applied electric field to their contacts. The depth of the depletion region, $d$, can be calculated using the Poisson equation and the voltage required to deplete the detector, $V_d$, is determined by setting $E(r_1)$=0,

$$V_d = \frac{\rho}{2\epsilon_0}\left[r_1^2 \ln\frac{r_2}{r_1} - \frac{1}{2}(r_2^2 - r_1^2)\right].$$

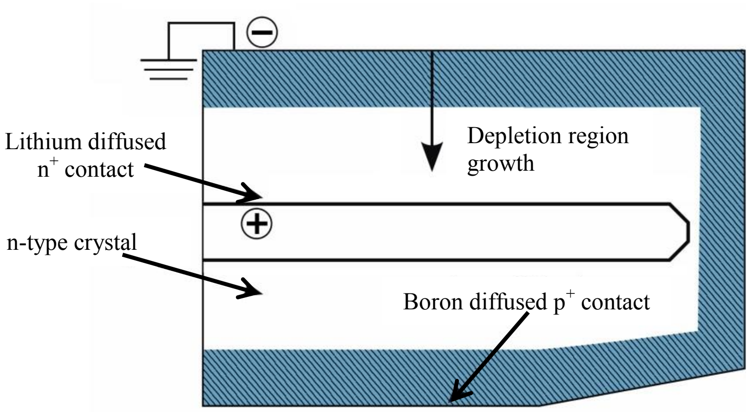


**Figure 1:** Depletion region expand from the p-n junction at the outer electrode when the positive high voltage (reverse biased) is applied to the inner electrode.

## 2. iThemba LABS segmented clover detector

The iThemba LABS segmented clover detector, manufactured by Canberra, France [2], consists of four n-type HPGe crystals. The crystals dimensions are: a diameter of 60 mm (before tapering) and a length of 90 mm. Each crystal is electrically segmented into 8 contacts on the outer surface, 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.

During γ-ray interaction, all segments and inner core contacts produce signals with specific pulse shapes. These pulse shapes carry information about the position (x,y,z) where a γ-ray interacted within the Ge crystal. To make use of this position sensitivity of the detector, a database of simulated pulses for various γ-ray interaction positions is needed.

## 3. Detector simulation

In June 2012, a free access electric field simulation code called Multi Geometry Simulation (MGS) [3] was acquired. It can derive the pulse shape response at the contacts of a segmented HPGe detector. In order for MGS to produce these pulse shapes, it calculates: electric potential surfaces by solving the Poisson equation, electric fields, drift velocities for electrons and holes in the electric field, and lastly weighting potential which is a coupling between the charge carriers and electrodes.

The first simulation of crystal A of the iThemba LABS segmented clover detector yielded the pulse shapes on all its contacts and they looked reasonable. The simulation involved a detailed description of the geometry of the detector, default linear parameterization of the crystal impurities. Most surprisingly, however, it was observed that the simulated depletion region was growing from the inside outwards, which is incorrect for an n-type detector with positive bias applied on the inner core electrode. These results are illustrated on figure 2.

When a positive high voltage of 1000V was applied, the undepleted region (shown in blue) remained large (see figure 2(a)). But even when the biased voltage was increased to 2250V which is higher than the depletion voltage of this crystal as measured by the manufacturer, the simulation yielded some undepleted spots at the corners (see figure 2(b)). To reach complete depletion of the crystal in these simulations a biased voltage higher than 3000V (which is the suggested operational voltage), was needed. The problem was discussed with the MGS code's developer, Mr P. Medina. Nevertheless for a long time it looked as if MGS simply not designed to describe correctly the depletion voltage. While the work on this was in progress, other improvements in the MGS simulations were made.

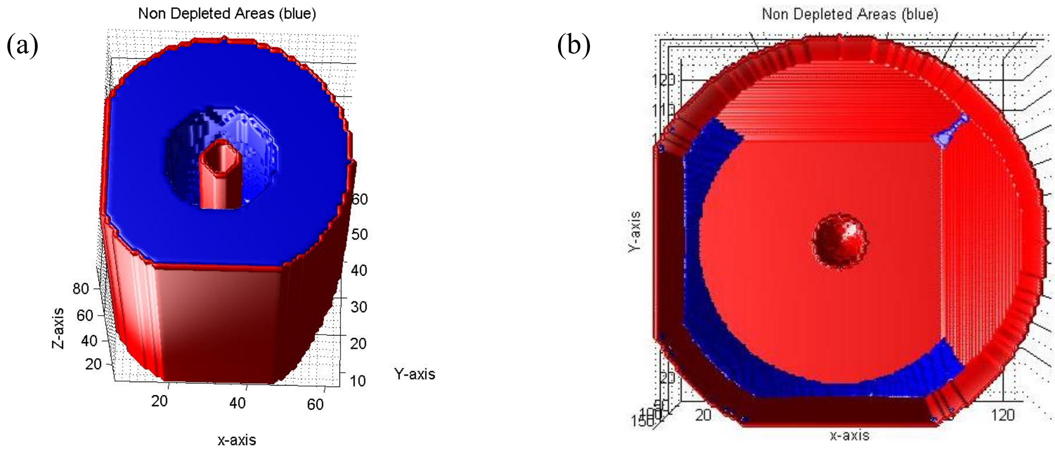


**Figure 2.** MGS simulations of the depletion region for crystal A. (a) At an applied voltage of 1000V. (b) At an applied voltage of 2250V. The depletion voltage, as given by the manufacture, is 2000V.

**Simulation progress**

In the MGS code, the impurity concentration profile of the crystal was assumed to be liner function along the depth of the detector. This was because the manufacturer supplied all detectors with impurity concentration values at front and back of the crystals only.

During a research visit to Canberra Lingosheim in June 2012 there was an opportunity to discuss directly with the manufacturer of the detector some remaining issues. During this visit detailed impurity concentration profiles for the crystals of the iThemba LABS segmented clover detector was obtained. The actual impurity profile for crystal A is shown in figure 3. This profile was then implemented in the MGS code.

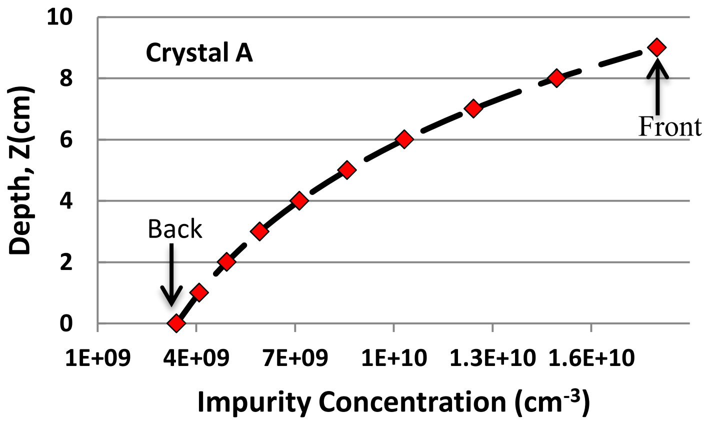


**Figure 3.** An exponential profile of the impurity concentration provided by the manufacturer with higher impurities at the front and lower at the back of the crystal.

At this stage minor changes were also made in the geometry of the crystal, to implement the exact shape and the outside segmentation. The current simulated geometry of crystal A is shown in figure 5.

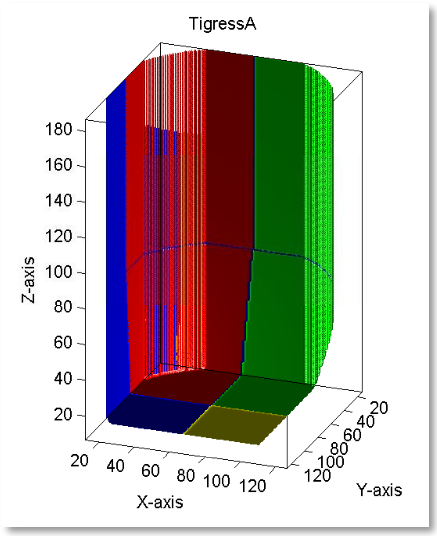


**Figure 5.** MGS simulations of the crystal geometry with front vertical segmentation at an angle as designed by the manufacturer.

Most bothering, however, was the problem with the depletion voltage. It was finally understood, that the code was not able to describe the actual structure of a semiconductor, but the p-n junction of an n-type detector was defined simply through the features of an electric field. That required special definition of the field and net charge density. After then input was corrected, and taking account the other improvements in the simulations, the depletion of the detector was reproduced well. Figure 6 illustrate these results. At the applied biased of 500 V, the depletion region starts growing from outside inwards, see figure 6(a). At the applied biased of 1500 V, a small part of undepleted region remains near the front part of the core electrode see figure 6(b) since the impurity concentration is higher at the front than at the back. Furthermore it was found that crystal A is completely depleted at a voltage of 2000V, see figure 6(c), which matches the depletion voltage given by the manufacture.

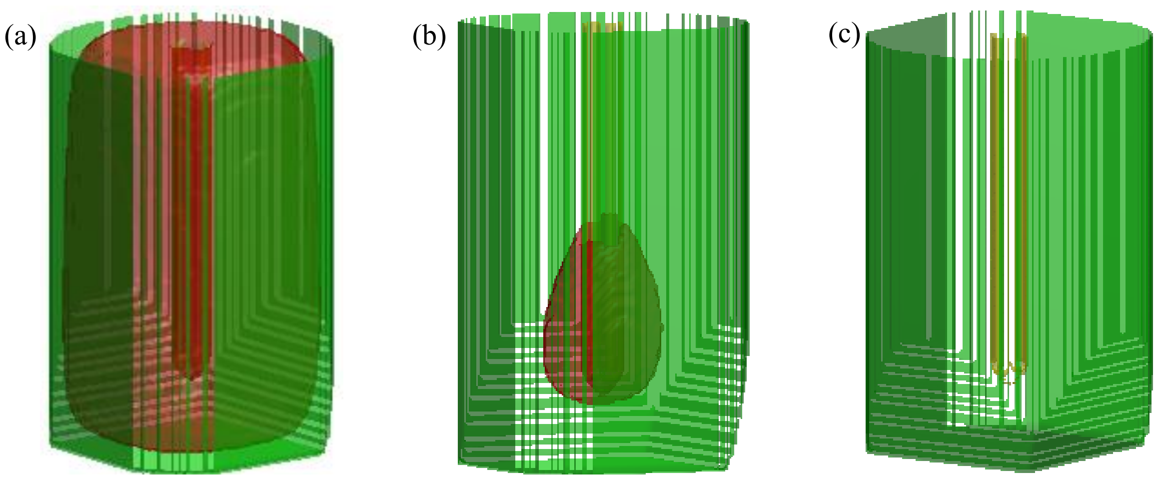


**Figure 6.** MGS simulations of the depletion region as a function of the applied voltage; undepleted region is shown in red. (a) At 500 V, small depletion region near the surface is observed; the depletion is growing from outward inside. (b) At 1500V, undepleted region remains near the front end of the core electrode. (c) A complete depletion of the crystal at a depletion voltage of 2000V.

## 4. Additional simulations

The initial difficulties to simulate the depletion region with the MGS code prompted us to look for alternative software. In June 2013, another free access code called AGATA Detector Library (ADL) [4] was acquired from France. This code is specially developed to simulate pulse shapes for AGATA [5] detectors. The implementation of the geometry of the segmented clover, see figure 7, and the changes in the code making it able to deal with an exponential impurity concentration profile were challenging. Nevertheless, the first preliminary ADL simulations of the iThemba LABS segmented clover detector were completed and are shown in figure 8 (b).

The pulses end when the charge carriers are fully collected. Different end-points of the pulses are easily observed in the MGS simulations, see figure 8(a), while the ADL pulses are artificially extended at a constant value corresponding to the full charge. The comparison of the pulse shapes of the MGS and ADL codes for various γ-ray interaction positions shows very similar results. Fine tuning of the parameters of both codes is in progress. Most importantly the parameterisation of the electron and holes drift velocities in made in a different way in the two codes. Thus it is unclear whether the charge mobility is exactly the same in both codes. Instead to try to adjust drift velocities in the two codes to one another, we plan to measure the experimental pulses, and to make the necessary corrections based on them.

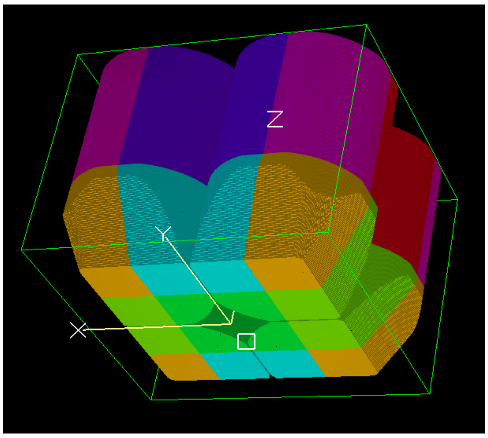


**Figure 7.** ADL simulations of the four iThemba LABS segmented crystals.

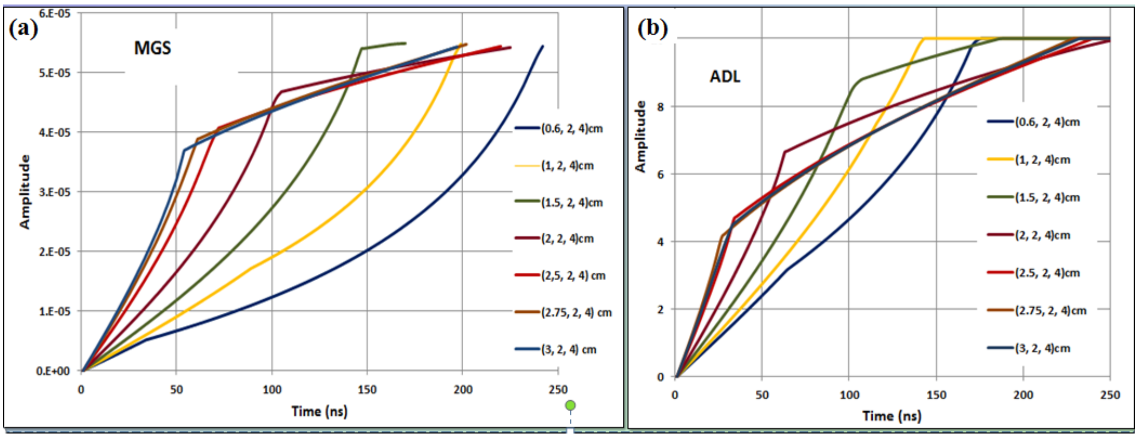


**Figure 8.** The charge pulse shapes on the inner contacts simulated with the MGS (a) and ADL (b) codes for crystal A, and before the preamplifier response function is implemented. The simulations were performed for various interaction positions with different x, but same y and, z.

## 5. Summary

Simulation of the pulses on the 9 electrodes of crystal A of the iThemba LABS segmented clover detector was completed with two software codes, MGS and ADL. The progress so far proved that the task of performing realistic simulations is challenging and requires high precision with numerous details. Next step will be to convolute the simulated charge pulses from the two codes with the response function of the preamplifier and the remaining electronics. Most important will be to compare the simulated pulses with a set of measured ones. For such a measurement precise determination of the positions of the interaction points inside the detector is needed. In addition the electronic cross-talk has to be determined. Preparations for such measurements are in progress.

## 6. References


[1] Knoll G. F., Radiation Detection and Measurements, Chapter 12, Fourth Edition, John Wiley & Sons, 2010.

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[4] ADL, http://www.ikp.uni-koeln.de/research/agata/index.php?show=download

[5] AGATA, official website </http://www-w2k.gsi.de/agata>.