Challenges in the simulations of the iThemba LABS segmented clover detector

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Abstract. In June 2012, iThemba LABS acquired a Multi Geometry Simulation (MGS) code [1] from France to simulate the response of the segmented clover detector for an arbitrary gamma-ray interaction within the Ge crystal. With this simulation code, first results on the sensitivity of our iThemba LABS segmented clover detector to the exact position of the gamma-ray interaction were obtained, but this is the topic of another presentation [2]. The challenges experienced during the simulations and the progress made so far in obtaining the realistic pulse shapes with MGS code is presented here. Additional simulations of the iThemba LABS segmented clover detector were performed with another simulation code, the ADL. The resulting pulse shapes are compared with the ones from MGS code and discussed. Taking into account all the presented data, the way forward for obtaining the realistic pulse shapes for the iThemba LABS segmented clover detector will be formulated.

1. Introduction

The n-type HPGe detector dedicated for γ-ray measurements is usually constructed in closed-ended coaxial geometry. In this configuration, one electrode, p^+ contact, is fabricated at the outer surface of the cylindrical crystal and the other electrode, n^+ contact, is located at the inner surface of the central hole. These contacts are made through the diffusion of the lithium layer on the inner surface and boron ion plantation on the outer surface of the detector. The p-n junction of this coaxial detector is located at the outer surface of the detector. When the positive high voltage (reverse biased) is applied to the n+ contact, the depletion region expands from the p+ contact inwards.

2. iThemba LABS segmented clover detector

The iThemba LABS segmented clover detector consists of four n-type HPGe crystals. The crystals dimensions are; diameter of 60 mm (before tapering) and 90 mm length with depth segmentation at 35 mm. Each crystal is electrically segmented into 8 contacts on the outer surface. 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 produces a signal with certain pulse shape. These pulse shapes carry information about the position (x,y,z) of the energy deposition occurred when a γ-ray interacted within the Ge crystal. To make use of this position sensitivity of the detector, we have to create a database of simulated pulse responses for various interaction positions and ensure that the simulated pulse shapes are realistic.

3. Challenges experienced within the simulations

In June 2012, iThemba LABS acquired a Multi Geometry Simulation (MGS) code [1] from France. This was used to simulate the pulse shapes' response on the detector's contacts for an arbitrary γ-ray interaction position [2]. In order for MGS to produce the signals, it calculates the electric potential surfaces by solving the Poisson equation, the electric fields, the drift velocities for electrons and holes in the calculated electric field, and lastly the weighting potential which is the electrostatic coupling between the charge carriers and the electrodes from the point of interaction.

Our first simulation yielded the pulse shapes on all contacts, however, it was observed that the depletion of the region was growing from the inside outwards when the positive high voltage was applied to the n^+ contact, as shown in figure 1(a), and the detector was depleting at a biased voltage higher than the depletion voltage as specified by the manufacturer, figure 1(b).

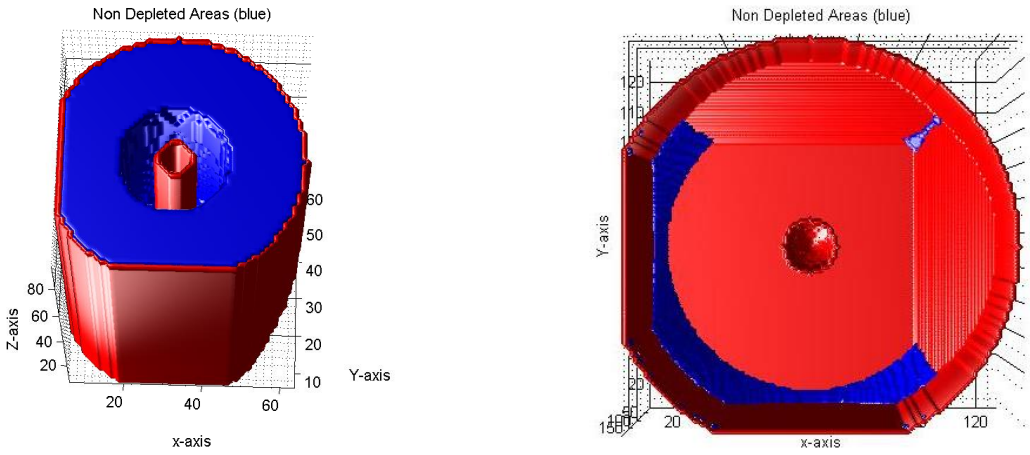

Figure 1. MGS simulations of the depletion region (red) as a function of applied biased voltage. (a) When the biased voltage, 1000V, was applied the depletion region was growing from inside outwards. (b) Some undepleted regions (blue) remained at the front corners of the crystal at a biased voltage of 2250 V, which is higher than the depletion voltage of 2000V, defined by the manufacturer

In addition, it was also important to simulate the geometry and the impurity concentration profile with higher precision to be able to produce the needed realistic pulse shapes for our detector. In our first simulations, the front segments were not exactly matching the shape specified by the manufacturer, see figure 2 (*). In addition the impurity concentration profile was assumed to be linear, see figure 3, while in reality it has more complex dependence from the depth.

It was a challenge to understand how to define the p-n junction of our n-type detector in the code, since in the simulations the n^+ and p^+ contacts are not defined by extra lithium and boron layers but through the electric field.

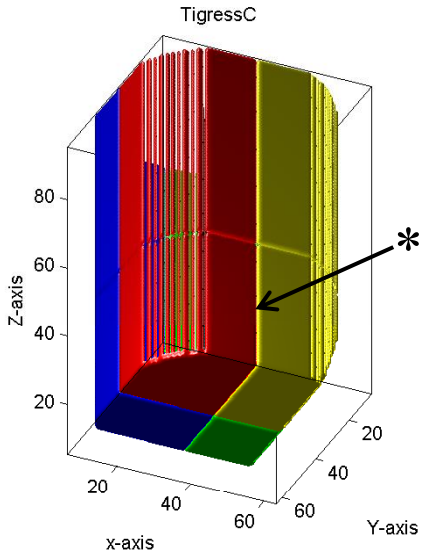

Figure 2. MGS simulation of the crystal geometry with segmentation and tapering.

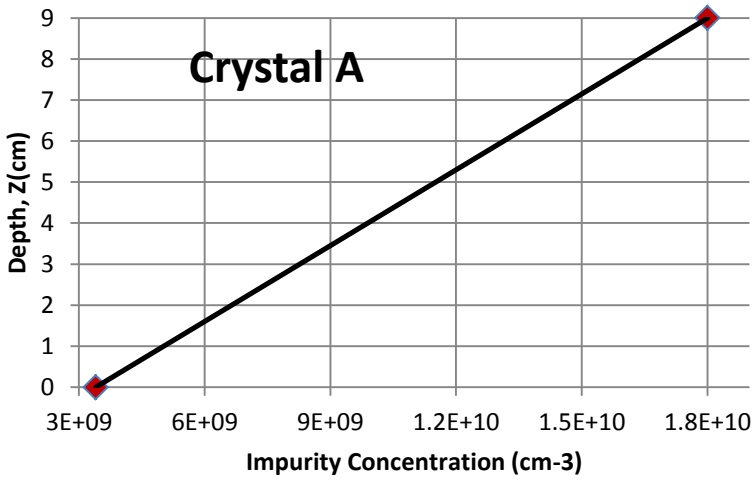

Figure 3. A linear profile of the impurity concentration used in the first MGS simulations.

Simulation progress

Through a continuous collaboration with the developer of the MGS code, several improvements in the simulations were achieved as shown in figure 4 (a)-(c). Most importantly we found how to define the p-n junction and proceed with the simulations. Now we can simulate correctly the depletion of the charge carriers of our n-type detector, and the depletion region is now growing from the outside inwards, see figure 4(a). At voltages below the depletion voltage, an undepleted region is found at the front of the crystal since the impurity concentration is higher at the front and lower at the back, see figure 4(b).

The new MGS simulations showed that the crystal becomes completely depleted at a depletion voltage of 2000V, as defined by the manufacturer, see figure 4(c). Figures 5-7, show the corrections performed on MGS code for the segmentation (*), the newly introduced exponential impurity profile

matching the dependence given by manufacturer, and the simulated impurity concentration, respectively.

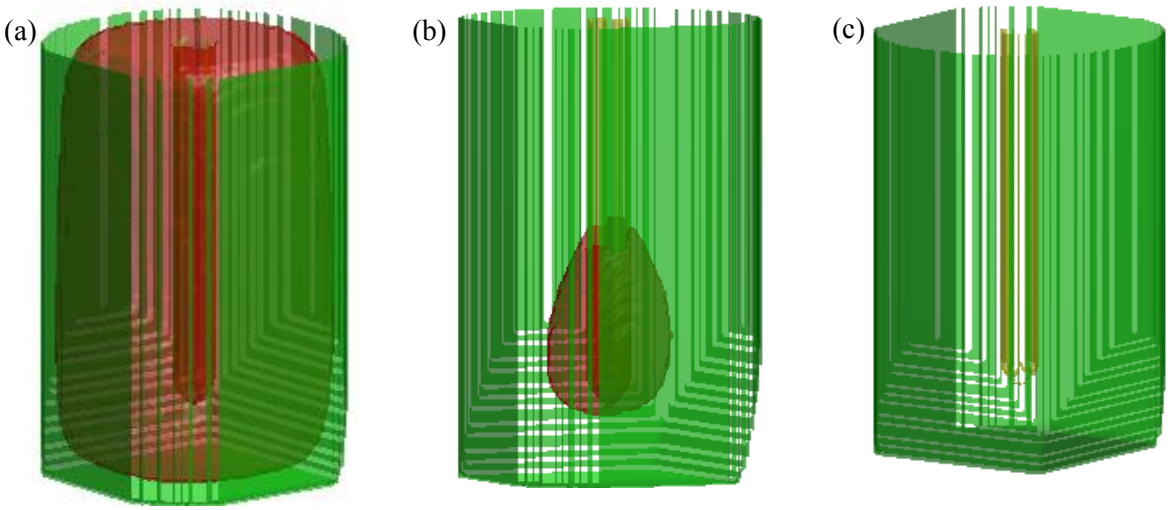

Figure 4. MGS simulations of the depletion region as a function of the applied biased voltage; undepleted region is shown in red. The depletion region is growing from outside inwards (a) when the biased voltage of 500V is applied. (b) At 1500V; undepleted region in the front part of the crystal remains. (c) A complete depletion of the crystal at a depletion voltage of 2000V.

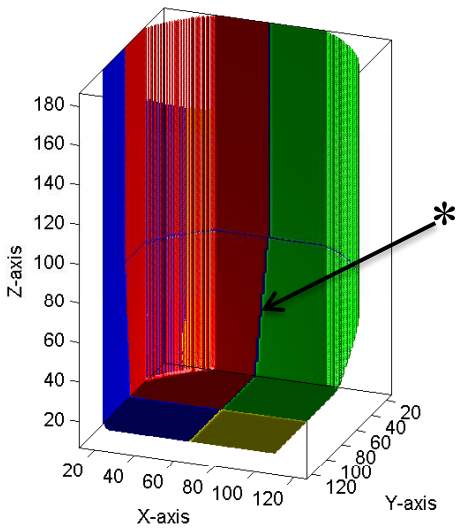

Figure 5. MGS simulations of the crystal geometry with the front segmentation at a small angle (*) as specified by the manufacturer.

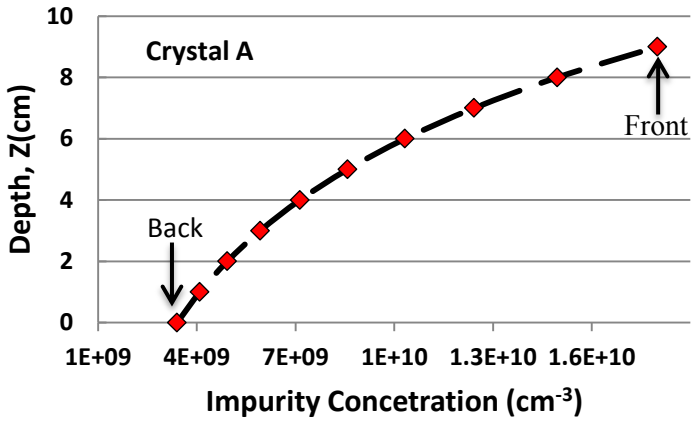

Figure 6. An exponential profile of the impurity concentration provided by the manufacturer with higher impurities at the front and lower at the back.

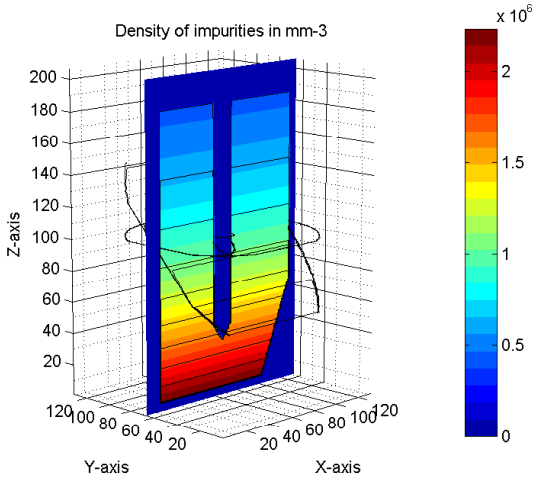

Figure 7. The MGS simulation of the impurity concentrations with the red color inducting a higher concentration and blue indicating the lower concentration of impurities.

4. Additional simulations

In June 2013, we acquired a second code ADL [3] from France which is used to simulate pulse shapes for AGATA [4] detectors. The objective is to compare MGS simulation results with another independent software code. However, the running of ADL code is challenging. Nevertheless, first ADL simulations of our detector are already completed as shown in figures 8 and 9 (b). The comparison of the pulse shapes from MGS and from ADL for various positions shows that the rise-times of the charge pulses are different. As seen in figure 6 (a) and (b), MGS pulses are slower than ADL ones. The possible cause could be:

- The crystal lattice orientation angles are different in the two codes.
- The electrons and/or holes drift velocities are calculated differently in the two codes.

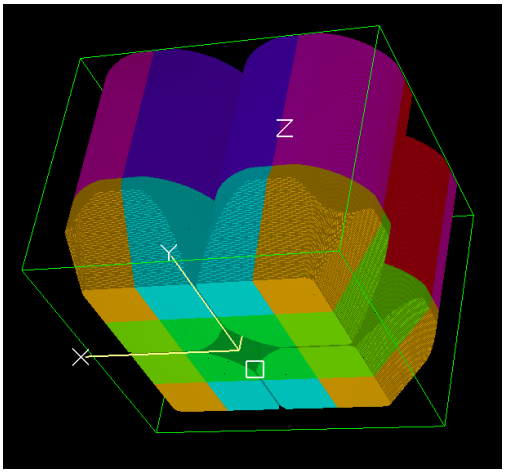

Figure 8. ADL simulations of the four iThemba LABS segmented crystals visualized using SIMION code.

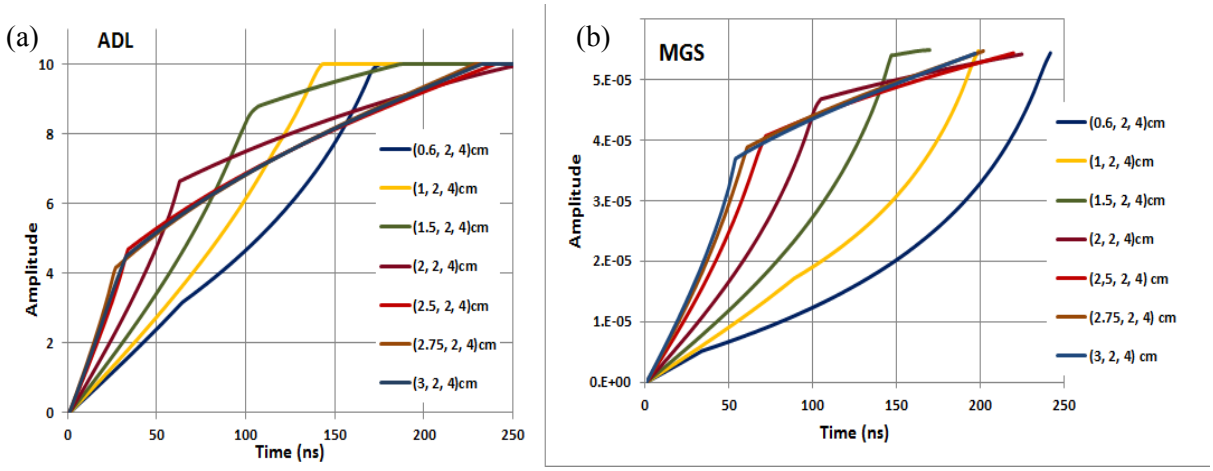

Figure 9. The charge pulse shapes on the inner contacts simulated with the MGS (a) and ADL (b) codes. The simulation was performed for various interaction positions with different x while y, z values are kept constant.

5. Conclusion and future plans

Simulation of realistic pulses is challenging and requires attention to numerous details. The comparison of the MGS simulation results with other simulation codes such as ADL is very beneficial in understanding fine details of the functioning of the detector and the simulation codes. The next step is to expand the ADL simulations and include the convolution of the pulses with the preamplifier response function in order to obtain realistic pulses.

6. References

[1] Medina P, et. al., Proceedings of the 21st IEEE Instrumentation and Measurement Technology (IEEE Cat. No.04CH37510), pages 1828–1832, 2004.

[2] Noncolela S.P, et.al., Simulation of the position sensitivity of the iThemba LABS segmented clover detector, SAIP 2013 oral presentation.

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

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