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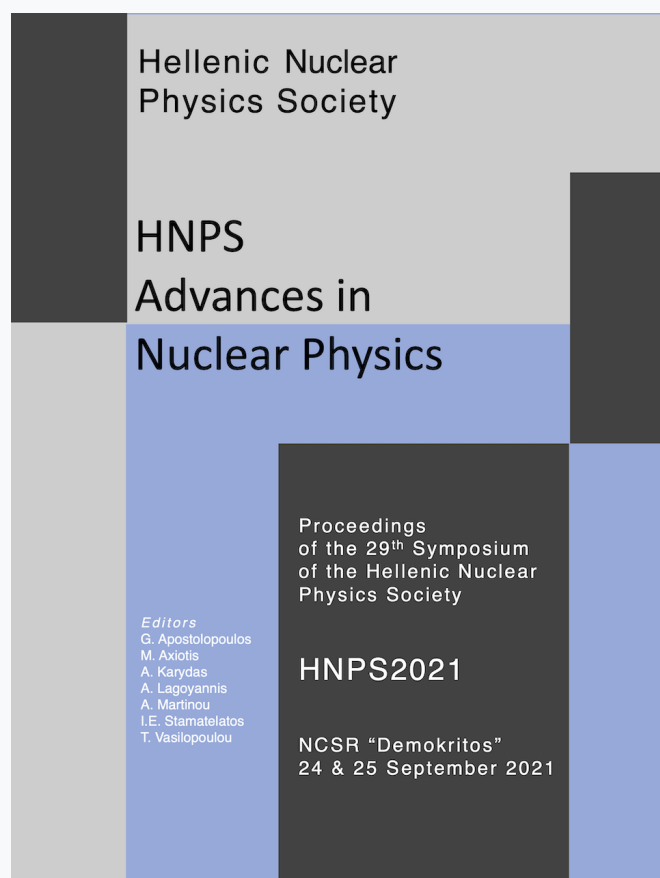
Simulation of a MicroMegas detector for low-energy α-particle tracking using Garfield++

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Βιβλιογραφική αναφορά:

Simulation of a MicroMegas detector for low-energy α-particle tracking using Garfield++

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Abstract   In the present work, the simulated detector was a MicroMegas gaseous one, regularly being used for neutron-induced fission studies at NCSR 'Demokritos'. The initial code tests involved the linear response of the detector with respect to the energy deposition of 5 MeV α-particles. This study was carried out in two distinct steps: First, by collecting simulated data for the deposited charge in the anode electrode for different particle trajectories, as well as, for the same trajectory, but for different gas pressures, ranging between 0.8 and 1.2 atm and then by comparing them with the corresponding results obtained using SRIM2008 regarding the α-particle energy losses inside the detector, with the same set of parameters. Finally, a simulated spectrum of 5 MeV α-particles, having trajectories randomly distributed within the whole detector volume, was obtained using Garfield++ and was compared to an experimental one. The similarities and discrepancies observed are discussed and analyzed.

Keywords   Garfield++, MicroMegas, Monte-Carlo

INTRODUCTION

The main purpose of this work has been the implementation of Garfield++ [1], an object-oriented toolkit for the detailed simulation of particle detectors based on ionization measurements in gases or semiconductors, currently widely used in high-energy physics, for studies tuned according to the needs of nuclear physics applications. The choice of this particular code was based on the following advantageous characteristics: (a) The algorithm performs Monte-Carlo calculations and combines the microscopic approach for the tracking of the produced electrons inside the detector, with the macroscopic and the semiclassical ones for ion tracking and for the calculation of the electron transport parameters respectively, (b) The code offers a variety of options concerning the accurate description of the detector geometry, materials and signal calculation, (c) Garfield++ is compatible with other programs, frequently used in research, such as: SRIM, Geant4, ANSYS, Elmer and COMSOL and (d) Since the toolkit is linked to ROOT [2], there exists an active supporting community, which constantly updates Garfield++ and helps with any kind of occurring issues.

The main motivation of this work originates from the frequent implementation of the MicroMegas detectors in actinide fission experiments at NCSR 'Demokritos' and CERN by the nuclear physics group of the National Technical University of Athens. This renders the study of both the energy deposition of the α-particles and fission fragments in the detector and the signal characteristics mandatory.

In addition, a main objective of this work is related to the generalization of the use of Garfield++ for the needs of low-energy experimental nuclear physics, since, for the time being, it is mainly popular only for high-energy physics applications. The final goal of this study would naturally be the full reproduction of the obtained experimental results using this code.

Our first task was to test the code on basic functions of the detector. First, we had to prove that

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the detector operates as a proportional counter. This study was carried out in two distinct steps: Initially, we generated 5 MeV α-particles with Garfield++ and we collected simulated data for the deposited charge in the anode electrode for different particle trajectories. Then, for the same set of parameters and trajectories, we obtained the information for the energy loss using SRIM2008 [3]. and we verified the linear correlation between the energy loss and the deposited charge.

In the second step, for a specific trajectory, we obtained simulated data for the deposited charge from Garfield++ for different gas pressures, ranging between 0.8 and 1.2 atm. We did the same using SRIM2008 for the energy loss, for different gas densities, (namely 0.8 to 1.2 ρ_0, where ρ_0 is the initial density of the gas), exploiting the linear relation between the gas pressure and the density. This was repeated for 1000 events for each trajectory and gas pressure. In order to study this problem, a simplified MicroMegas geometry was used, where the cylindrical electrodes were replaced by infinite, lean plates, as shown in Figure 1.
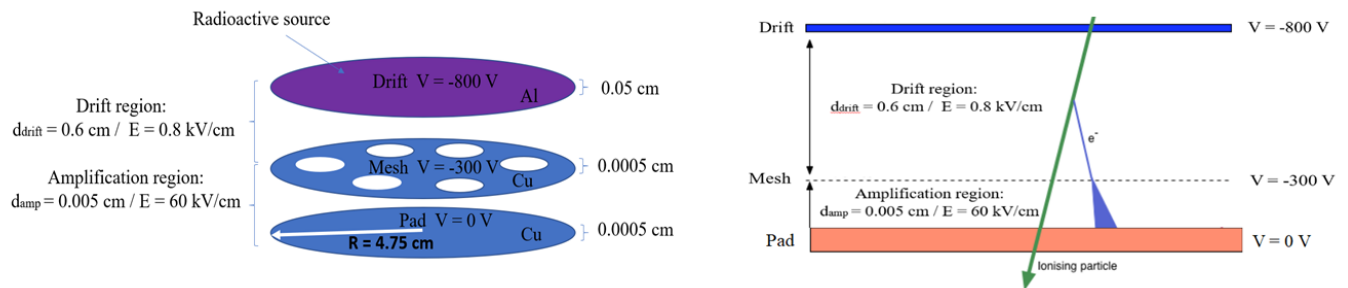

Fig. 1. *Left: The actual detector geometry. Right: The simplified geometry implemented in Garfield++.*

RESULTS AND DISCUSSION

To analyze the obtained results, we created histograms using ROOT. The deposited charge and the energy loss are both following a Gauss distribution around a mean value with an uncertainty, defined by the standard deviation, determined by a Gaussian distribution fitting of the corresponding peaks. These mean values and uncertainties were subsequently plotted for different trajectories in order to study any possible deviations from linearity. In Figure 2 we can see the results for a perpendicular trajectory having a path length of 0.6 cm, while in Figure 3 we can see the final plot corresponding to several different path lengths inside the detector.

As far as the Gaussian distributions are concerned, it can be seen that they are well-formed and quite similar. Moreover, there exists a highly linear behavior between the deposited charge and the energy loss of the α-particles, as expected. The offset parameter, 'a' (as denoted in the graph), was added in the fitting process in order to test the possible deviations from the y=bx behavior and indeed proved to be equal to zero, as expected, within error. The same procedure was carried out for the second step as well. The results corresponding to a pressure of 0.8 atm (for the charge and the energy loss) and the linear fitting for all the different test pressures (namely 0.8, 0.9, 1, 1.1 and 1.2 atm) are shown in Figures 4 and 5 respectively.

As we can see, the Gaussian distributions are again well-formed and quite similar. This time, however, there are certain deviations from the linear fitting. The reason lies in the phenomenological Clausius-Mossotti formula:

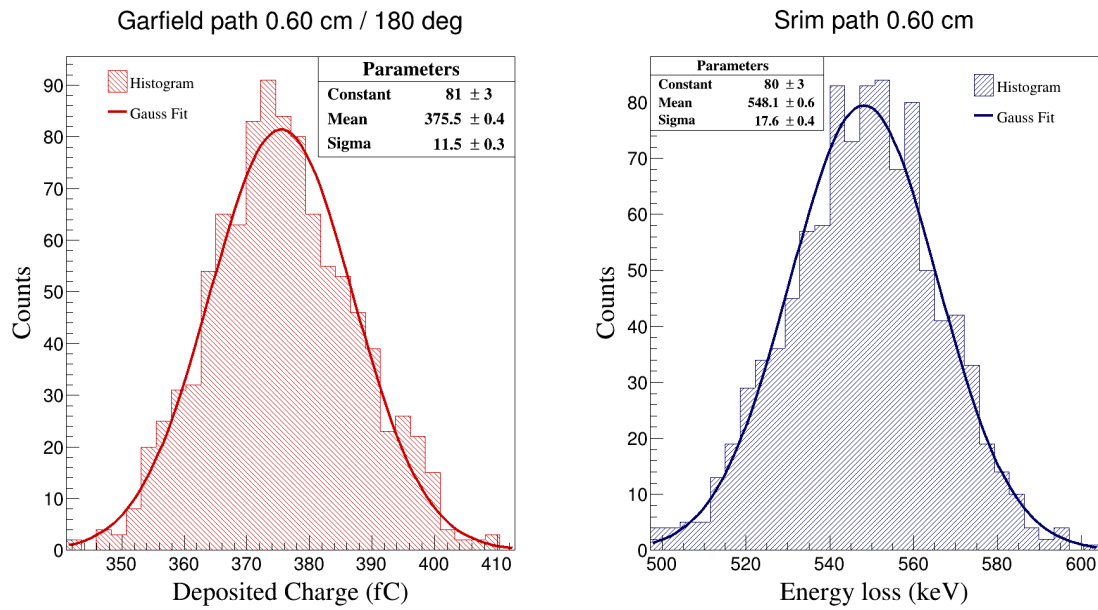$$\frac{\varepsilon_r - 1}{\varepsilon_r - 2} = \frac{N_\alpha}{3\varepsilon_0}$$

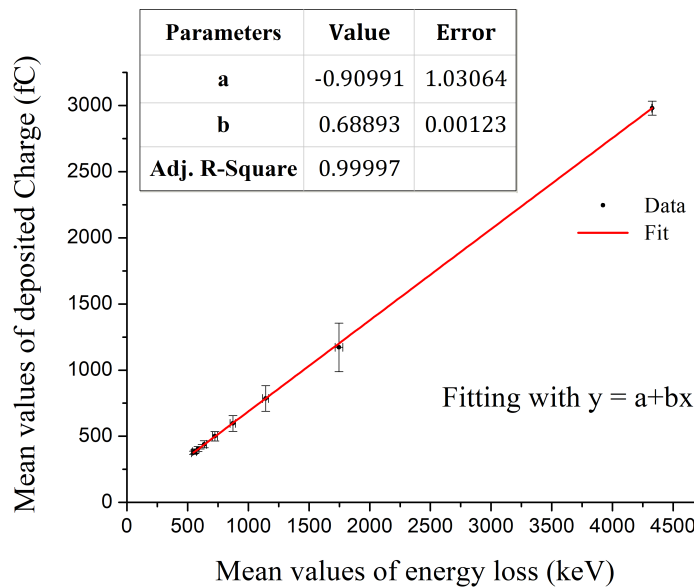**Fig. 2**. *Left: Garfield results. Right: SRIM2008 results.*

Fig. 3. *Linear fitting for different trajectories.*

which indicates that the relation between the particle density N_a (and so, the gas density and the pressure) and the dielectric constant ε (and so, the electric field E and the deposited charge) is not linear. To confirm this, we fitted the results of the deposited charge for different pressures using the Clausius-Mossotti formula, adding only an extra scaling parameter. The result is shown in Figure 6 and the fit seems to be more satisfactory and explains the deviations from linearity that were observed in Figure 5.

The next step of the analysis was to generate a simulated spectrum of 5 MeV α-particles, having trajectories randomly distributed within the whole detector volume, using Garfield++ and then to compare it qualitatively with an experimental one. In this case the code was modified, so that the α-

particles were emitted from a 4 cm radius source and were being tracked in a cylindrical surface having a radius of 4.75 cm, in accordance to the detector dimensions.
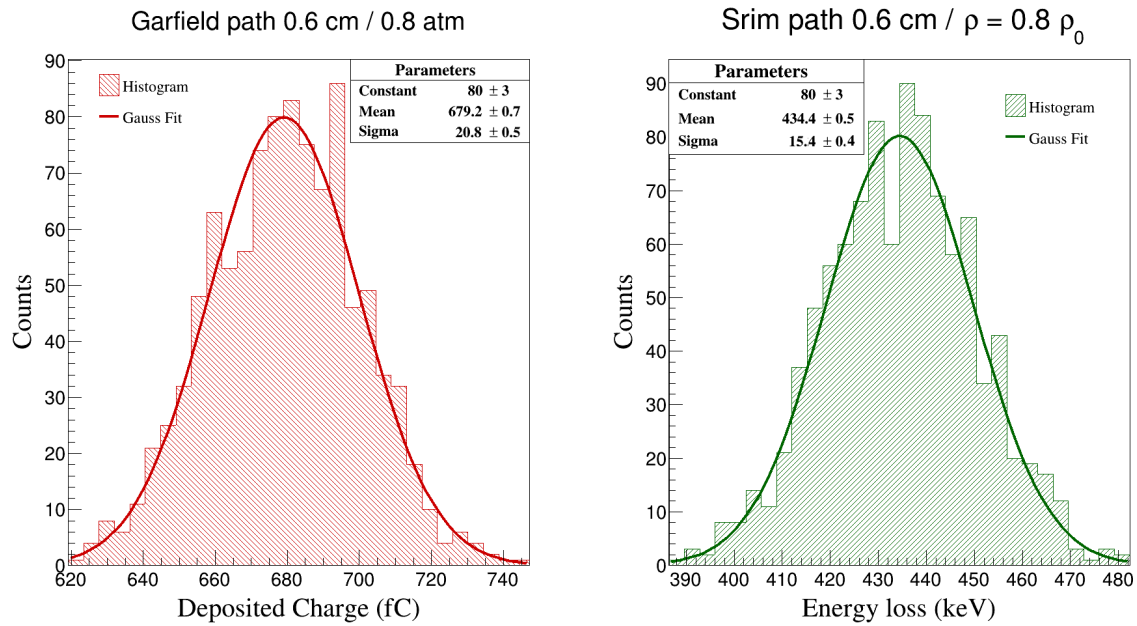

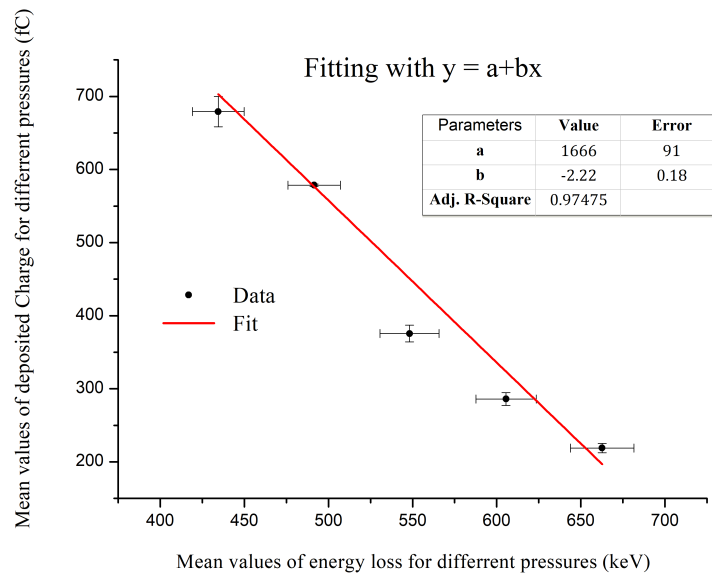**Fig. 4**. *Left: Garfield results. Right: SRIM2008 results.*

Fig. 5. *Linear fitting for the different pressures.*

At the top of Figure 7 we can observe the simulated spectrum and at the bottom, the experimental one, which is a spectrum of ~4.4 MeV α-particles from a ^{235}U thin fission target deposited in the form of uranium oxide on an aluminum backing, which acted as the drift electrode of the MicroMegas detector. The distance between the detector electrodes was ~0.6 cm, while, a 5 MeV α-particle travels a maximum distance of approximately 4 cm in argon, according to SRIM2008. So, due to the compact geometry of the MicroMegas detector, the majority of the trajectories have a relatively small length and, consequently, most of the α-particles lose only a small amount of their kinetic energy inside the

drift region of the detector. This is why we can mark a thick (low-energy) peak in the left side of both spectra. On the other hand, the whole diameter of the electrodes is ~9.5 cm and so, it is also possible for particles having lateral trajectories to lose all of their kinetic energy inside the detector. This is why we can also observe the corresponding right (high-energy) peaks in the spectra, with intermediate energy losses (i.e. trajectory lengths) being also quite .probable and visible in the spectra.
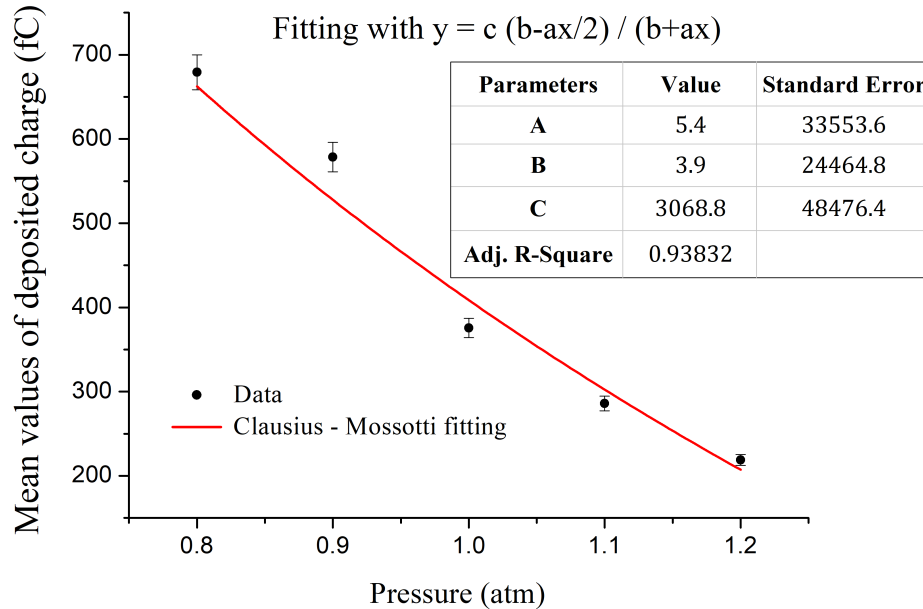

Fitting with y = c (b-ax/2) / (b+ax)

Parameters	Value	Standard Error
A	5.4	33553.6
B	3.9	24464.8
C	3068.8	48476.4
Adj. R-Square	0.93832	

Fig. 6. *Fitting with the Clausius-Mossotti formula.*

In the simulated spectrum, the right peak corresponds to a deposited charge of $Q_{dep} = 3316.5 \pm 100\, fC$. According to the result of the first part of the analysis (Figure 3) $Q_{dep} = -0.91 + 0.6889\, E_{loss}$ and so, this generated charge corresponds to a deposited energy of $E_{loss} = 4.89 \pm 0.15\, MeV$. This energy is in accordance with 5 MeV within error, which corresponds to the α-particle energy initially used for all the generated trajectories in Garfield++.

On the other hand, it should also be noted that the right peak of the experimental spectrum is much wider than the simulated one, implying that the inclusion of the full detector geometry in the simulation is necessary, along with an accurate description of the shaping by the electronic units.

CONCLUSIONS & FUTURE PRESPECTIVES

The previous analysis leads to the following conclusions: The similarities between the Gaussian distributions obtained with SRIM and Garfield++ demonstrate that the latter is indeed reliable for detector resolution studies. Also, the highly linear behavior between the deposited charge and the energy loss of α-particles in the experimental environment is quite satisfactory. Finally, the qualitative similarities between the simulated and the experimental spectra are quite encouraging.

Nevertheless, based on the above, there are still several steps that need to be carried out, the most important of which are related to the development of more complicated 3D geometries within Garfield++ and the continuation of the study using fission fragments. Moreover, the creation of a user-friendly interface and the optimization of the code for the purposes of nuclear physics studies will be the subject of a future work.
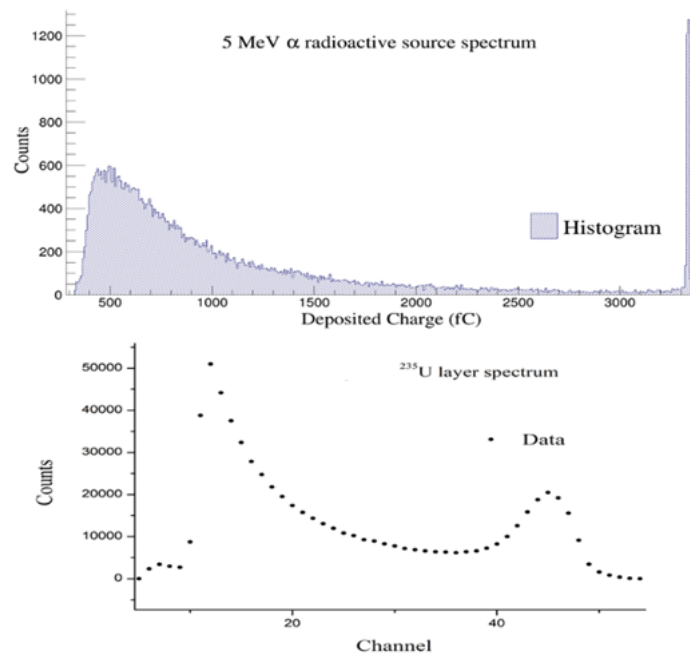
Fig. 7. *Top: Simulated spectrum using Garfiled++. Bottom: Experimental spectrum.*

References

[1] https://garfieldpp.web.cern.ch/garfieldpp/

[2] https://root.cern

[3] J. F. Ziegler, J. P. Biersack, M. D. Ziegler, 'The Stopping and Range of Ions in Matter', Lulu Press Co, Morrisville, NC, 27560 USA, (2015).