Garfield++ simulation of a TH-GEM based detector for standard mammography beam dosimetry

N. F. SILVA[1]; T. F. SILVA[2]; M. C. CASTRO[1]; H. N. da LUZ[3] and L. V. E. CALDAS[1]

[1] Instituto de Pesquisas Energéticas e Nucleares (IPEN / CNEN - SP)
Av. Professor Lineu Prestes, 2242
05508-000 São Paulo, SP, Brazil.

[2] Instituto de Física da Universidade de São Paulo (IFUSP)
R. do Matão, 1371
05508-090 São Paulo, SP, Brazil.

[3] Institute of Experimental and Applied Physics (IEAP)
Czech Technical University in Prague
Husova 240/5
110 00 Prague 1, Czech Republic

nsilva@ipen.br

Abstract. The TH-GEM based detector is a robust, simple to manufacture, high-gain gaseous electron multiplier. Its operation is based on a standard printed circuit board (PCB) coated on both sides by metallic material, perforated in a millimeter pattern, and immersed in gas. In order to study the feasibility of using TH-GEM type detectors in dosimetric applications for standard mammography beams, a prototype with adequate dimensions and materials was produced. The present work encompasses the calculations of electric fields by the Gmsh and Elmer software packages and the avalanche simulation using Garfield++ library of a TH-GEM detector filled with Ar/CO2 (70:30) mixture at atmospheric pressure.

Keywords. TH-GEM, mammography, dosimetry; Garfield++.

1. Introduction

This work is part of an effort to study the suitability of TH-GEM detectors to dosimetric measures of standard mammography beams. In previous publications [1], the simulation of the detector and its materials regarding acceptance and shielding to spurious signals (scattered radiation) was reported. Here, the first simulation results are reported on the signal generated by the direct calculation of the electron avalanche process. This simulation aims the determination of an optimal voltage configuration of the detector.

For the proper signal formation by the detector aiming for low and medium energy radiation dosimetry, some parameters should be studied. An important parameter is the magnitude of the electric field produced within the orifices. This electric field is responsible for generating the avalanche of ionization, but it presents some limits regarding the gas insulation and production of sparks. Besides that, electric fields in the drift and induction regions are important for the electron transport from the primary ionization location, passing through the amplification, until its collection in the collecting electrode. Generic rules like the electric field between the electrodes is directly proportional to the voltage difference across the detector and inversely proportional to the electrode spacing [2], must be replaced by the detailed simulation of the electric field configuration within the detector for the proper calculation of electron transport and amplification.

In the home-made detector, the drift and induction regions have the same length (~1 cm), and electrodes are located above and below the amplification plate, respectively, to create a uniform field.

The drift field must be chosen to ensure efficient charge transport throughout the system since the primary ionization in the gas occurs in this region. Problems with the collecting efficiency in this region may greatly influence the detector signal generation as it affects the signal prior to the electrons multiplication. Therefore, the difference of potential between the amplification plate and the drift electrode should be strong enough to avoid the ion pair recombination soon after ionization, but not enough to cause secondary ionization (configuring the drift regime).

The gas selection plays an important role in the detector performance since the process of ionization, electron scattering and multiplication occurs accordingly to the gas properties. Different types of gas mixtures may be used. The main criteria for choosing the mixture are: providing stable gain, not being high electron attachment, and having low mean minimum energy of ionization [2]. The most commonly used gases are: Ar/CO_2 in concentrations: 70/30 and 80/20 and Xe/CO_2. The mixture Ar/CO_2 is the most used, due to higher availability of the argon compared to xenon.

TH-GEM based detectors have been studied using Garfield++ as an X-ray fluorescence imaging system [3].

The purpose of this paper is to better understand the operation and charge transport within a TH-GEM detector, aiming to define standards of operation to a home-made prototype. For this, a series of numerical simulations were performed, determining the magnitude of the electric field regarding the signal obtained in the collecting electrode.

2. Materials and Methods

In this work, we used a chain of simulation codes as follows:

- Garfield ++ [4]: A program for calculating the detailed simulations of multiple aspects of charge transport and the avalanche of ionizations in gaseous detectors;
- Elmer [5]: A finite element analysis program that can be used to calculate the electrostatic potential along with the entire space in the detector geometry, and the results can be imported into Garfield ++ for use in simulations;
- Gmsh [6]: A program used to define geometry and the mesh suited for Elmer simulations.

The gas, as the media of interaction, is described by the Magboltz program [7], embedded within Garfield++.

In this work, a mixture of Argon and CO_2 in the 70/30 concentration was considered. A voltage of 1 kV was applied between the copper clad of the amplification plate. This was the maximum voltage obtained in the experimental electrical characterization of the amplification plate reported in previous work.

In addition to the particle drift simulation, it is possible to simulate the resulting signal induced on the collecting electrode if the proper weighting potential maps are provided to Garfiled++ as an input [8].

An Intel® Core™ i7-7700 microcomputer was used for the simulation.

3. Results

The first step was to define a detector geometry and creating a mesh of that geometry in the Gmsh software. After that, the Elmer finite element analysis program was used to calculate electrostatic fields using the mesh. During this process, materials were assigned to different parts of geometry, material properties (such as the dielectric constant) and boundary conditions.

The result was a value of the electrostatic potential at each finite element vertex. This list, along with the Elmer mesh format, can be imported into the Garfield++ library. Once imported into Garfield++, this is equivalent to creating all the detector geometry to be used in the charge transport in gas simulation. At this moment of the simulation chain, the boundary conditions are defined for periodicity, which dictates how Garfield++ repeats the field map in spatial coordinates.

The geometric parameters used in the construction of TH-GEM are listed in Table 1.

Table 1: TH-GEM parameters

Value	Description
0.0125 cm	Orifice radius
0.05 cm	Dielectric thickness
0.003 cm	Copper thickness
1 cm	Distance between amplification plate and external electrodes
1 kV	Voltage across de amplification plate
1 kV/cm	Drift field
1 kV/cm	Transfer field

Figure 1 shows the magnitude of the electric field inside a hole of the amplification plate. Figure 2 shows the value of the electric field (V/cm) along an imaginary line passing through the center of a hole (vertical line from top to bottom in Figure1). In Figure 3 the contours of the level curves for the potential obtained with the numerical simulation are shown.

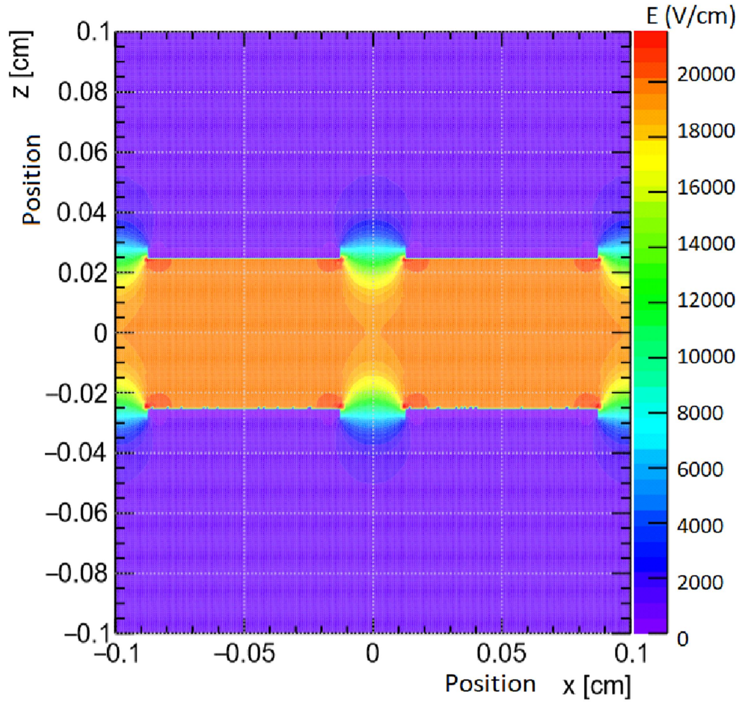

Figure 1: Electric field (V/cm) within a hole of the TH-GEM amplification plate.

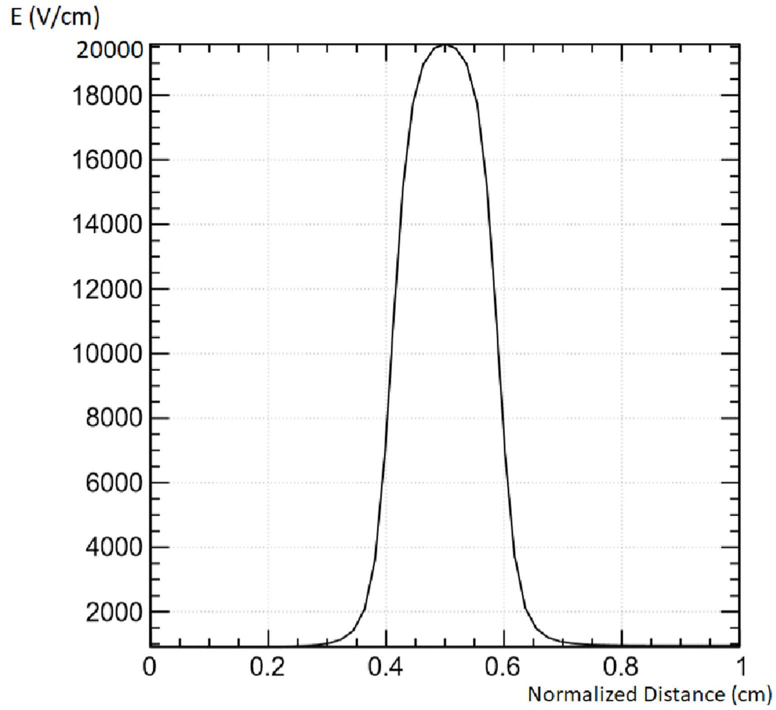

Figure 2: Magnitude of electric field in V/cm, along an imaginary line passing through the center of a hole, over normalized distance.

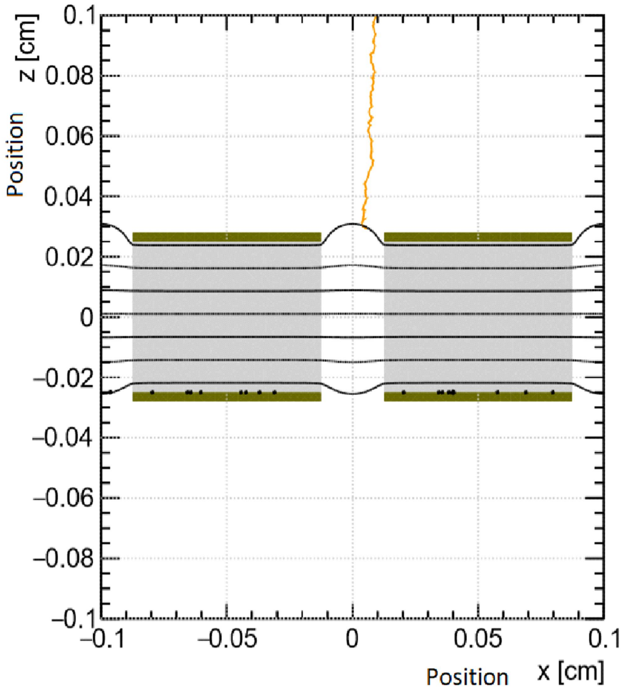

Figure 3: Contours of the potential for a TH-GEM detector, plotted in Garfield++ using a field map created with Gmsh/Elmer software.

Figure 4 shows a typical simulation for the electron traces including the eletron avalanche within the orifices. A single electron was produced in the drift region, guided to the orifice and 4 new electrons were generated.

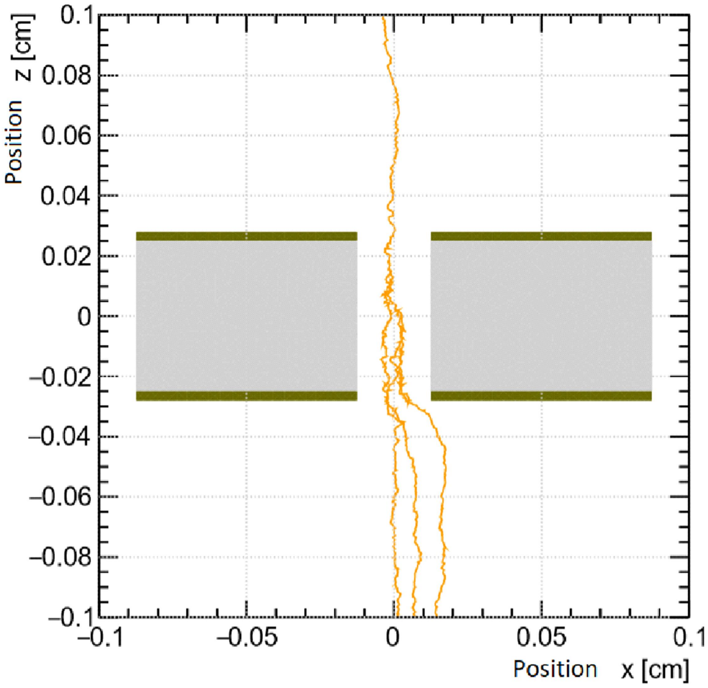

Figure 4: Electron avalanche in a TH-GEM detector simulated with Garfield++. The lower readout electrode is invisible in the rendered geometry, but it is located in the horizontal plane at which the drift lines of all of the electrons escaping the orifice terminate.

The results obtained for the electrical signal induced on an electrode in a detector geometry can be seen in Figure 5.

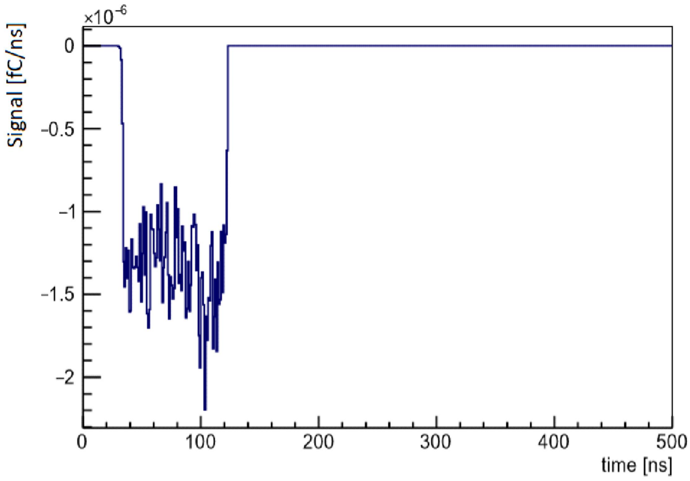

Figura 5: Electron induced signal produced on the lower readout electrode by the avalanche shown in Figure 4, during one avalanche.

4. Conclusions

In this work, the first results are reported by adopting a free software chain for numerical simulation of the physical functionalities of the TH-GEM detector. With this simulation it was possible to determine that the maximum electric field possible to achieve in the produced amplification plate as 20 kV/cm at the center of the orifices. A small amplification factor (one electron produced four new electrons) was observed in the electron avalanche calculation within a hole of the amplification plate. In addition, it was possible to obtain a shape of the electrical signal as response to a single primary ionization obtained at the electrode using the weighting potential maps. Therefore it was possible to establish a simulation routine for the dimensions of the detector in question, making it possible to study the gain and other physical parameters of the TH-GEM based detector to adapt it to the dosimeter function for mammography beams.

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References

[1] SILVA, N. F.; SILVA, T. F.; CASTRO M. C.; NATAL DA LUZ, H. and CALDAS, L.V.E. “Construction of the TH-GEM detector components for metrology of low energy ionizing radiation,” Journal of Physics: Conference Series, v. 975, p. 012043, 2018.

[2] SIPAJ, A. “Simulation, Design and Construction of a Gas Electron Multiplier for Particle Tracking.” PhD Thesis, University of Ontario, Institute of Technology, Oshawa, 2012.

[3] SOUZA, G. G. A. “X-Ray fluorescence imaging system based on Thick-GEM detectors.” Master dissertation, Institute of Physics, University of São Paulo, São Paulo, 2019.

[4] SCHINDLER, H. "Garfield++ simulation of tracking detectors - user guide." https://garfieldpp.web.cern.ch/garfieldpp/, 2017. Access on 08-2019. 4.

[5] RUOKOLAINEN, M.; MALINEN, P.; RABACK, P.; ZWINGER, T.; PURSULA A.; and BYCKLING, M. "Elmer-solver manual." http://www.nic.funet.fi/index/elmer/doc/ElmerSolverManual.pdf, 2018. Access on 08-2019

[6] GEUZAINE, C. and REMACLE J.F. “Gmsh: a three-dimensional finite element mesh generator with built-in pre- and post-processing facilities.” International Journal for Numerical Methods in Engineering, vol. 79, pp. 1309–1331, 2009.

[7] BIAGI, S. F. “Magboltz - transport of electrons in gas mixtures." http://magboltz.web.cern.ch/magboltz/, 1995. Access on 08 - 2019.

[8] SCHINDLER, H. "Garfield++ simulation of tracking detectors - user guide." https://garfieldpp.web.cern.ch/garfieldpp/, 2017. Access on 08-2019. 4.