CERN Summer Student Project Report – Simulation of the Micromegas Detector

Summer Student: Sofia Luísa Soares Ferreira Nunes Teixeira

Supervisor: Michele Bianco

Group: PH-ADE-MU PHYSICS DEPARTMENT, ATLAS DETECTOR, MUON SPECTROMETER

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Abstract

My project during the Summer Student Programme at CERN consisted on simulations of the Micromegas (MM) detectors in order to test and characterize them in the presence of contamination by air of the gas mixture. The MM detectors were chosen for the upcoming upgrade of the ATLAS detector. The motivation for this project and the results obtained are here presented. Moreover, the work that should be carried out after this programme as a continuation of this project is also referred. To conclude, final considerations about the project are presented.

I. Introduction

In order to benefit from the expected high-luminosity provided by the LHC, the innermost station of the forward region of the ATLAS Muon Spectrometer has to be upgraded (New Small Wheel (NSW)). The Micromegas (MM) technology has been chosen as the chamber dedicated to precision tracking of the muons.

Micromegas are gaseous detectors. They are parallel plate avalanche chambers consisting of a several millimetre wide drift region and an approximately 100 μm amplification region, separated by thin conductive micromesh (Figure 1). The drift cathode and the readout electrodes are made of copper and the micromesh is usually made of stainless steel. The operating principle (Figure 2) is as follows:

1. Charged particles or photons traversing the drift space ionize the gas releasing electron-ion pairs, depending on the type and energy of the particle;
2. Ionization electrons drift within 100 ns towards the high field amplification region while ions drift towards the cathode;
3. The electrons are multiplied in an avalanche process and released on the anode strips where they are detected;
4. The ions produced in the amplification region are quickly evacuated by the mesh.

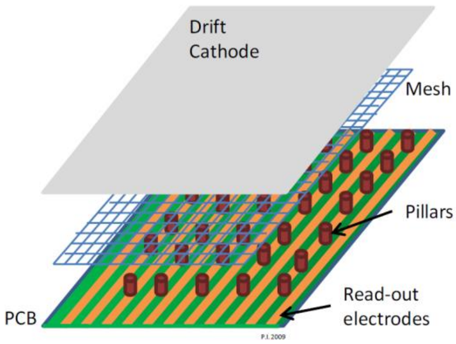

Figure 1 Sketch of the MM layout.

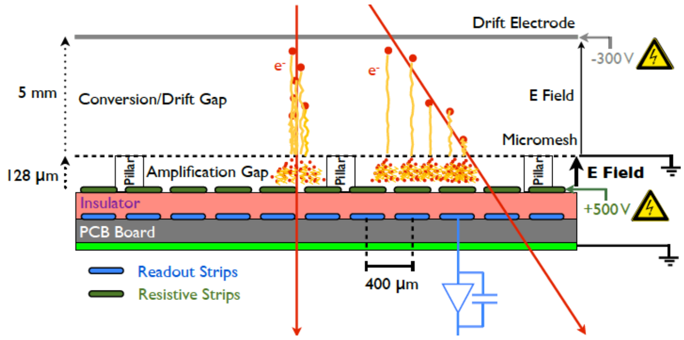

Figure 2 Operating principle, geometric parameters and appplied voltages of the MM.

Having a very thin amplification region, the MM detectors are vulnerable to sparking. For this reason, the MM in ATLAS will have the readout panels covered by 25 μm insulator layer (kapton foil) carrying high-resistivity carbon strips. The gas mixture that will be used on ATLAS is 93% of argon and 7% of carbon dioxide.

Studies for the optimization of the detector performance are ongoing at CERN. Studies in presence of the gas mixture contamination are being carried out as a part of the performance studies. They are being developed in order to know and understand the behaviour of the detector in case of gas leak and gas mixture contamination. Small prototypes (10x10 cm^2) are used to make laboratory tests. In order to compare the results obtained with these small prototypes and to better understand the process, simulations of the MM detector have to be carried out. These simulations were the main goal of my Summer Student Project.

II. Work developed

The simulations of the MM detector were made using the software COMSOL Multiphysics. This software uses finite element methods to solve the PDEs associated with the physics of the problem. It is divided in several models that describe a particular area of physics.

To start with, simulations of the electric field were performed. A simplified version of the MM detector was simulated, containing the drift cathode, the mesh and readout strips. The Electric Currents model was used to perform this simulation. The voltage boundary conditions are represented in Figure 2 and the materials used were already referred. With this, the electric potential and the electric field were obtained.

Figure 3 to Figure 5 depict the electric potential. It is verified that the electric potential obeys the boundary conditions imposed. In Figure 5, it is possible to observe the readout strips through the holes of the mesh, although the voltage difference is small when compared to the high voltages applied.

In Figure 6 to Figure 8, the electric field lines are represented. It can be concluded that the electric field in the drift region is approximately uniform and that it goes through the mesh holes converging to the readout strips. The order of magnitude of the electric field in the amplification region is 10^4 V/cm.

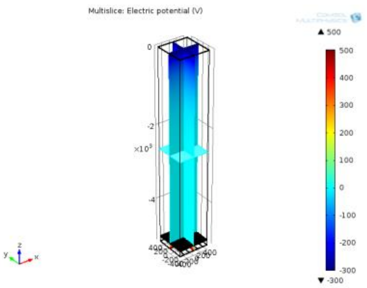

Figure 3 Electric potential of the simplified MM detector.

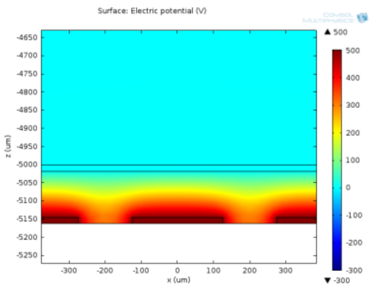

Figure 4 Electric potential of the amplification region and readout strips.

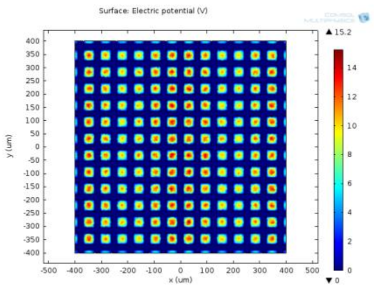

Figure 5 Electric potential of the mesh.

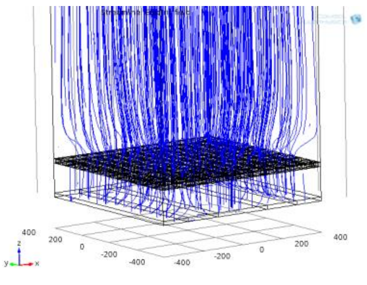

Figure 6 Electric field lines of the simplified MM detector.

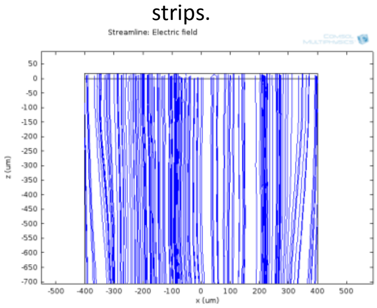

Figure 7 Electric field lines of the drift region.

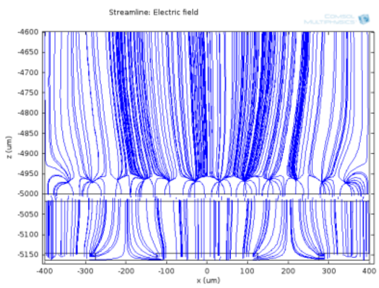

Figure 8 Electric field lines of the amplification region.

More studies concerning the electric field were also carried out, namely a study of the density of mesh holes and a study of a MM detector constituted by readout squares instead of readout strips. These were made in order to be compared with experimental results.

The variation of the electric field as a function of the density of mesh holes was thus obtained. In Figure 9, the dependence of the magnitude of the electric field in the middle of the amplification region on the density is plotted. It is possible to observe that the magnitude of the electric field increases with the density of mesh holes and that it does not depend on the drift voltage.

The geometry of the MM detector with readout squares is represented in Figure 10. It was verified that again the electric field converges to the readout squares. A dependence on the symmetry of the mesh with relation to the readout plane was also observed, being the electric field completely asymmetric when the mesh is asymmetric. This asymmetry was also seen in the experimental results.

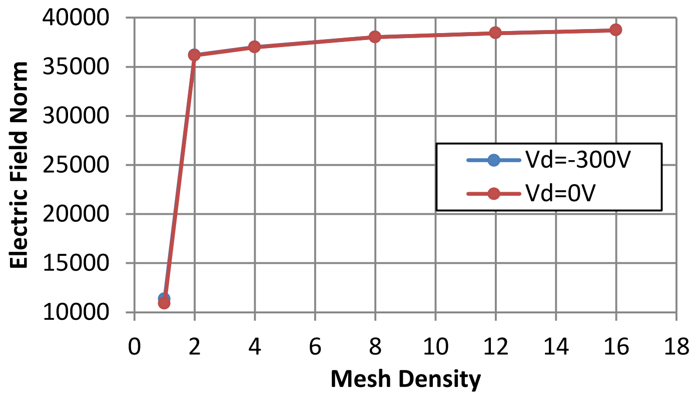

Figure 9 Electric field norm as a function of the mesh density (number of mesh holes in each direction).

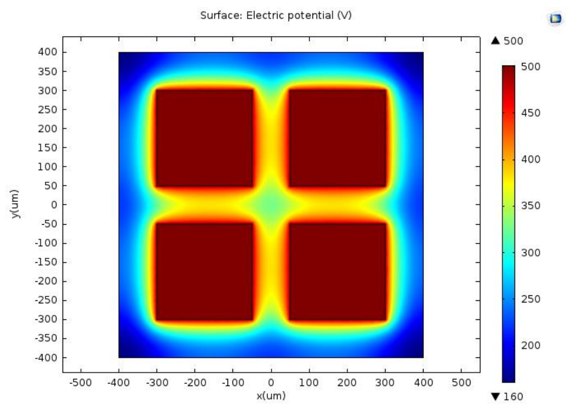

Figure 10 Electric potential on the readout plane, where the readout squares are visible.

Having obtained the electric field and its expected behaviour, the objective was to simulate the interaction of a particle (electron) with the gas mixture. A simulation of this interaction has to include two points:

1. The particle has to follow the electric field lines;
2. All the possible interactions between the particle and the gas mixture have to be considered, such as elastic scattering, excitation of the gas and ionization of the gas (main process for the avalanche to occur).

Various models that exist in COMSOL were considered in order to simulate this interaction, namely Particle Tracing, Drift Diffusion, DC Discharge and Transport of Diluted Species. Some problems occurred because the important points to consider were not being simulated. The main objective is to find the model that best describes the MM detector. The latest conclusions show that the Transport of Diluted Species is the appropriate model. However, more studies using Garfield++ have to be done in order to obtain the coefficients that describe the interactions between the gas and the electrons. With these coefficients, the simulation can be performed using COMSOL.

A part from the simulations, my work also included participation on the group's test beams carried out with the MM for the New Small Wheel at the GIF++ facility located on the North Side of SPS. This work included helping to mount the experimental setup and shifts at the control room throughout the week of the beam test. The final setup installed is represented in Figure 11.

Furthermore, part of the work developed was presented in the Summer Student Session and in the Summer Student Poster session, with the topic "COMSOL simulation of the Micromegas detector".

Figure 11 Experimental setup at the GIF++ facility.

III. Future Work

As stated before, the simulations of the behaviour of the electron are still ongoing. The main goal is to have a working model for this behaviour. The interactions have to be studied using Garfield++ in order to have a model in COMSOl that is able to simulate the MM detector. After having this model, the gain of electrons produced in the avalanche process in a MM has to be calculated and its dependence on the gas mixture obtained. With these results, the comparison with the experimental results carried out by small prototypes (Figure 12) can be made.

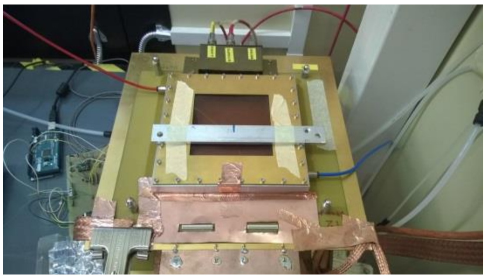

Figure 12 Experimental setup used to perfrom studies of the gas mixture contamination.

Moreover, the studies with the test beam are still being conducted and the results obtained will be analysed.

IV. Final considerations

To sum up, with this summer student project the properties of the MM detector were studied and the reason for this technology to be used in the upgrade of the ATLAS detector was understood. Furthermore, this knowledge was successfully presented to other summer students.

The simulation of the electric field was well accomplished with results that match the ones obtained experimentally. It was verified that the interactions of electrons with the gas mixture is not well simulated only using the COMSOL Multiphysics software. This simulation can only be performed if a full study of the interactions using Garfield++ is done before the actual simulations using COMSOL. With this, the final conclusion is that COMSOL is not the appropriate software to simulate the interactions that occur in MM.

In this project, working in a multi-faceted team was also developed. This experience is of the greatest importance, because how work is conducted in an experience of this magnitude was understood. Moreover, the experimental techniques used and learned are also valuable knowledge important for my future development.