"Multi-Physics" Studies of the Micromegas Detector

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Abstract: The "Micromegas" (Micro-MEsh Gaseous Structure) detector is a gaseous particle detector, developed by G. Charpak and I. Giomataris, mainly used in experimental physics and in particular for the detection of ionising particles. Due to its unique characteristics the Micromegas has been selected as one of the two detector technologies that will be used for the upgrade of the Small Wheel of the ATLAS experiment at CERN LHC. The Micromegas will be primarily used as a precision chamber and will also provide triggering information. Here we present studies of the electric field configuration that guides the electrons to the strips through the mesh and its importance to the detector's optimal operation. Furthermore, analysis of the gas propagation inside the chamber for different gas distribution schemes is discussed. All the various studies which have been studied with the COMSOL Multiphysics software, are in a good agreement with the experimental results.

Keywords: micromegas, micromesh, electric field, saggita, gas.

1. Introduction

Micromegas is a gas detector, consists of a two parallel plate regions, the Conversion Region (CR) at 5 mm and the Amplification Region (AR) of the order of 128 μm. Leaving the micromesh grounded and applied opposite voltages on both drift plane and strips a homogeneous electric field is produced in each region. A charged particle passing through the chamber's volume ionizes the gas in the CR, consequently creating an avalanche in AR of charged particles (ion-electron pairs). As a result, the energy that deposited on the strips is affected from the two main operational parameters, the electric field and the gas gain which play an important role on the detector's efficiency. The figure below depicts the Micromegas's operation principle.

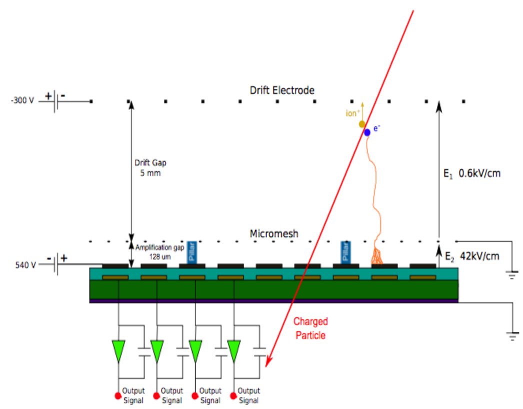

Figure 1. The MM's operation principle.

The correct operation of the detector is directly connected to the electric field and the gas distribution. Firstly, the electric field has been studied based on its shape and its intensity in order to be validated the agreement between the theoretical and experimental results. Finally, the gas distribution has been studied in order to ensure a laminar behavior and the uniformity of the gas in the entire detector's volume.

2. Micromegas Electrostatic Study

2.1 The Electric Field

A homogeneous electric field is produced in both regions via the micromesh. Its shape is of vital importance, because directs the electrons to the strips and evacuates the ions from the AR using the funnel effect, which is directly proportional to the ratio of the electric fields between the two regions**.** The electric field (grey) and the equipotential lines (colored) are shown in the following Figure 2 (in 2D and 3D), accompanied by the electric field intensity at the AR.

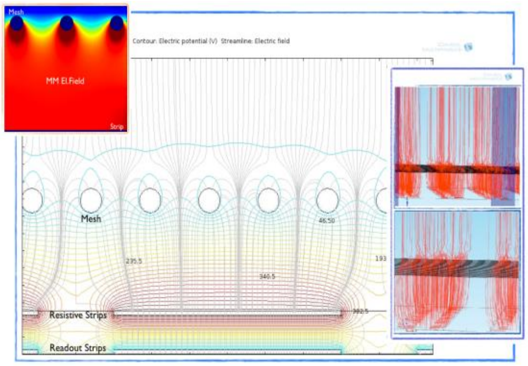

Figure 2. The electric field and potential contour lines of a Micromegas detector (grey and colored, respectively). The middle right plots show the electric field lines in 3 dimensions. On the top left plot the electric field intensity is shown.

Figure 3 shows the increase of the electric field moving from the CR to AR through the micromesh which is in agreement with the expected measured values.

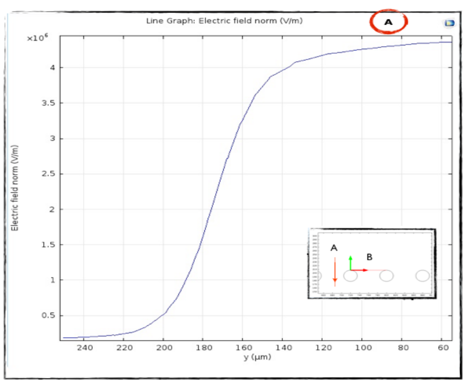

Figure 3. The electric field through the micromesh region, moving downstream to the strips.

2.2 Micro-mesh Sagitta Study

Micromegas as a “capacitor” formed detector, strongly depends on the size of the AR, which could fluctuates locally due to the strong attraction of the electric field. There are pillars which support the mesh. The distance (pitch) between two neighboring pillars is important for the adhesion of the grid on them (the pitch is of the order of 8mm in our simulation). The main goal is to measure this deformation of the mesh due to the electrostatic force, in different mechanical tension values that have been applied during the mesh placement in Micromegas. Figure 4 shows the sagitta ,Z [μm] versus the high voltage [V] in different tension values [N/cm], calculated by the COMSOL Multiphysics software.

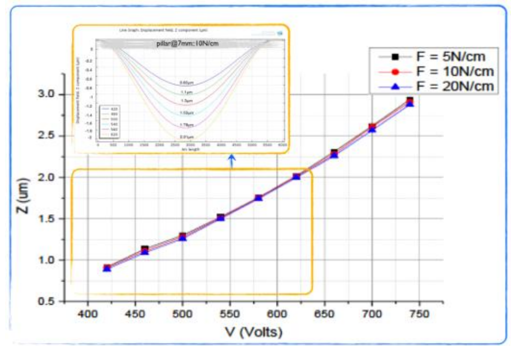

Figure 4. Sagitta versus the high voltage at different mechanical tension values.

3. Micromegas Gas Studies

3.1 Gas distribution configuration

Micromegas uses a new technique for the gas distribution, the so called, Buffer Zones (BZ). These areas are the “vestibule” of the gas distribution inside the detector’s volume. This configuration will ensure firstly, the correct conditions of a laminar behavior and secondly the complete fill of the detector. Moreover, it will guarantee the avoidance of inefficient areas which will cause a decrease in the detection efficiency.

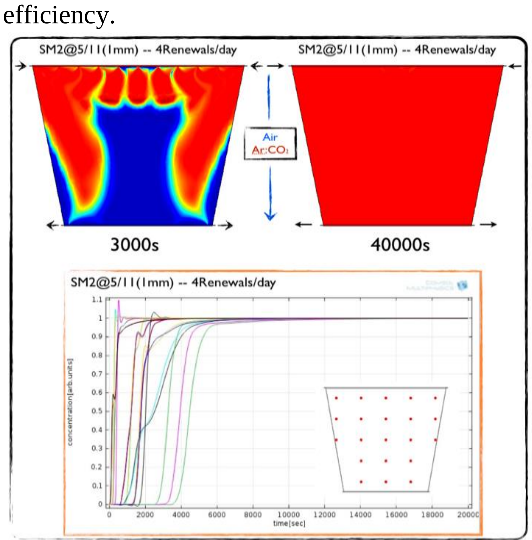

Figure 5. On the top, two instances of the gas propagation through time. The lower plot shows the normalized concentration in each point versus the time.

In order to preserve an optimal operation of the Micromegas, this study is based on some restriction parameters. Namely: a) nominal flow rate at 5L/h on each BZ inlet, b) hole number must be optimized and c) an empirical ratio between the buffer's zone size and the hole diameter (d_{bz}/d_{hole}) which should be close to 10. Figure 5 shows the movement of the gas inside the detector's volume. Red color refers to Ar+7%CO_2 (close to atmospheric pressure) and blue to air (initial condition). The lower plot shows the normalized concentration of the gas mixture in various points inside the chamber versus the time.

3.2 Micro-mesh Flow Studies

This study includes the propagation of the gas mixture through the micromesh structure. The aim is to have a uniform distribution in order to avoid "inefficient" areas into the chamber's volume which would reduce its performance. The diagram in Figure 6 shows the concentration of gases in the chamber versus time. The blue curve refers to the gas mixture (Ar+7%CO_2) and the green curve to air, which is initially in the chamber. We observe that the gas mixture fills the volume of the detector with a simultaneous evacuation of the air (1% of the active area).

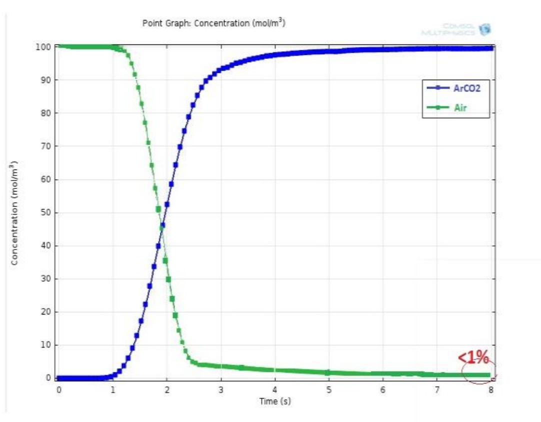

Figure 6. The concentration of gases in the chamber's volume versus time.

The following instances (Fig. 7) show the propagation of the gas through the micromesh. The lower plot shows the distribution of the gas over time in the selected area. After 10 seconds the gas has been spread to the entire area, ensuring the optimal operation of the detector.

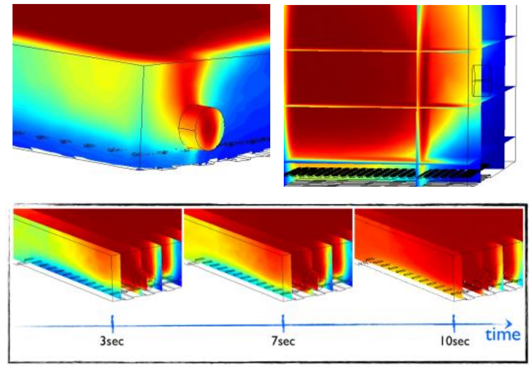

Figure 7. The time evolution of the gas propagation in a small region close to mesh.

4. Micromegas Spatial Resolution

Spatial resolution is one of the most merit parameters of the detector. It illustrates the uncertainty with which the detector can reconstruct an impact point of a passing charged particle. The spatial resolution is directly connected with the absolute gain. Here we validated the importance of the two main operational parameters (electric field & gas gain) on the detector's resolution.

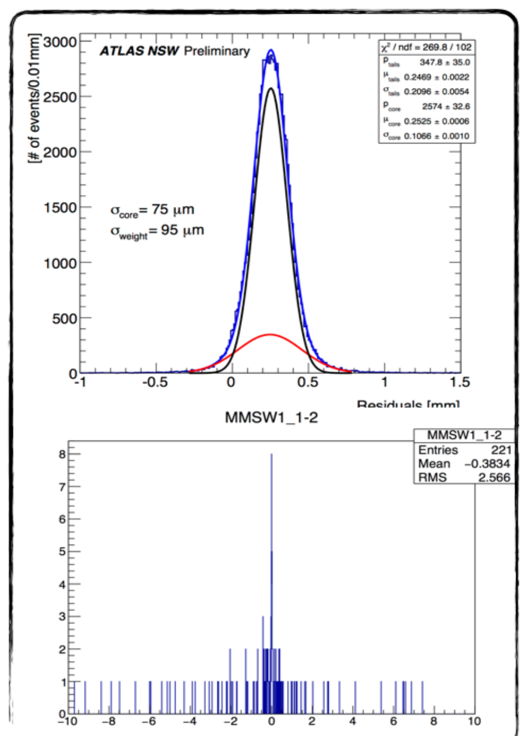

Figure 8. The spatial resolution of a Micromegas chamber without and with gas leak respectively.

The above plots (Fig. 8) depicts the comparison between the spatial resolutions of a Micromegas detector in two different gas conditions. The plot on the top shows an optimal detector and the plot on the bottom an inefficient detector where a gas leak is in progress, respectively. The comparison of these plots shows the importance of the gas on the statistics. The leak reduces the concentration of the gas mixture in the detector and therefore the number of the collected data. Those are invalid for analysis making the detector inefficient.

5. COMSOL Multi-Physics

In order to achieve our goal, COMSOL multi-physics provides a wide variety of physics interfaces. A combination of those have been used. In this section supplementary information about the simulations are provided.

5.1 Electric Field Study

For the electrostatic study of the Micromegas detector, the "AC/DC Electrostatics (es)" interface has been used accompanied by the governed, continuity equation:

$$\nabla \cdot \boldsymbol{J} = -\frac{\partial \rho}{\partial t}$$

and Maxwell's equations:

$$\nabla \times \mathbf{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$$

$$\nabla \times \mathbf{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$$

$$\nabla \cdot \boldsymbol{D} = 0$$

$$\nabla \cdot \boldsymbol{B} = 0$$

and theirs constitutive relations. In order to create the electric field, high voltage (HV) on the drift panel (-540V, Aluminum) and on the resistive strips (650V, Copper) has been applied, leaving the micromesh (stainless steel) grounded. The gas that has been used is Ar+7%CO_2.

5.2 Mesh Sagitta Study

In order to calculate the deformation of the micromesh the previous study (es) has been taken into account. From the latter, the electric field and the electrostatic force have been calculated and coupled with the "Solid Mechanics" and "Moving Mesh" interfaces (both governed by the respective theoretical models provided by COMSOL Multiphysics). If the determination is very small compared to the gap, the "Moving Mesh" interface would not be required, as the electrostatic force would not vary significantly with the displacement. Different mechanical tensions have been applied on the micromesh in order to stretch it following the industrial procedure. For each mechanical tension, a voltage scan was done (in the range of 540V-760V) in order to measure the deformation of micromesh. The above parameter is governed by the COMSOL's equations.

5.3 Gas Distribution Study

The most complicated part of our simulation, was the gas distribution study (time dependent). To accomplished it two physics interfaces have been coupled, the "Laminar Flow" governed by the analytical "Navier-Stokes" equation:

$$\rho(\boldsymbol{u} \cdot \nabla)\boldsymbol{u} =$$
$$= \nabla \cdot \left[-\rho t + \mu(\nabla \boldsymbol{u} + (\nabla \boldsymbol{u})^T) - \left({}^2/_3\right)\mu(\nabla \cdot \boldsymbol{u})\boldsymbol{I}\right] + \boldsymbol{F}$$
$$\boldsymbol{\nabla} \cdot (\rho \boldsymbol{u}) = 0$$

and the "Transport of Diluted Species" by the following equations:

$$\frac{\partial \boldsymbol{c}}{\partial t} + \boldsymbol{u} \cdot \nabla \mathrm{c} = \nabla \cdot (D\nabla \mathrm{c}) + R$$

solving for the diffusion term:

$$\frac{\partial \boldsymbol{c}}{\partial t} = \nabla \cdot (D\nabla \mathrm{c}) + R$$

In order to measure the concentration of the Ar+7%CO_2 inside the detector, the pressure and the velocity of the gas have been calculated in the first and used by the second interface. The detector was initially filled with air, while from the two BZ's inlets the supply of the gas mixture has been done simultaneously. One crucial point in our simulation was the boundary conditions of the inlet. A step function has been defined in order to overpass the velocity boundary condition issue (two values in the same point, 0 and u_{in}) at the inlet.

6. Conclusions

These studies have offered, with the aid of COMSOL Multiphysics, a series of operations that allows modeling for both the electric field in various applied voltages and the gas BZ's configurations into a Micromegas detector.

Comparisons between the calculated and theoretical results showed a satisfactory agreement.

7. References

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8. Acknowledgements

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