MICROMEGAS PERFORMANCE BASED IN ARGON-ISOBUTANE AND ARGON-DEMETHYL-ETHER

Hamid Mounir
Mustapha Haddad
Laboratory Spectrometry of Materials and Archaeomaterials (LASMAR), Faculty of Science, Moulay Ismail University, Meknes, Morocco
Seddik Bri
Electrical Engineering Departments, High School of Technology, ESTM, Moulay Ismail University, Meknes, Morocco

Abstract

MICROMEGAS (MICROMEsh GAs Structure) detector which is among the major families of position detectors in High Energy Physics, introduced in the late sixties, detects and localizes energy deposit by charged particles over large areas, is widely used in particle physics. This detector is in a sealed in which mixture gas circulates. This mixture usually based, on a noble gas and a few proportions a "quencher". In this paper, we use ^{55}Fe source that produces X-ray photons of 5.9 keV and a mixture gas on Argon (Ar) with quencher as isobutane (iC_4H_{10}) and dimethyl-Ether. We will present the results of the MATLAB simulations of MICROMEGAS performance taking into account all the processes from the primary ionization, the distribution of charges in the electrodes and the electron avalanche amplification (first Townsend coefficient and amplification gain). All the simulated results obtained indicate that the performances of the detector depend on many parameters. The simulation results are nearly consistent with the data that are published in other references, and provide important information in the MICROMEGAS design, making and operating. Our simulation predicts that further improvements are still possible for give a best spatial and temporal resolution for a MICROMEGAS detector.

Keywords: MICROMAEGAS, Gas mixture, X-ray Source, Primary Ionization, Avalanche phenomenon, MATLAB Program.

Introduction

A lot of effort has been invested in the development of the Micro strip Gas Chamber (MSGC) [1] in order to be used as tracker for the LHC project. This technique allows good localization accuracy and double track resolution. However, it is necessary to operate it with a relatively low gas gain because of the presence of the insulator near the amplification region and because of the fragility of the structure. MICROMEGAS [2] is a high gain gaseous detector, which can stand up alone without a need of an additional preamplification. It combines high accuracy, high rate capability, excellent timing properties and robustness. These results were confirmed by a similar structure having wider amplification gap and thicker metallic grid [3].

In this paper, we will present the simulation results of the parameters characterizing the Micromegas detector as; Townsend coefficient and amplification gain at atmospheric pressure and normal temperature, for gas mixtures: ($Ar-iC_4H_{10}$) and (Ar/DME). These results are compared with measurement results in the literature [4], [5]. The agreement between measurements and calculations has been proved satisfactory. When the simulation program was validated was used to study the influence of various parameters (geometry, gas ...) on the detector's performance. This simulation has been used to optimize detector's performance and understand the detector's response.

Description, Principle and simulation model

In more recent design (1985), MICROMEGAS (Micromesh Gaseous Structure) suggests that new higher performance techniques previously developed. It operates on the principle of multi-wire proportional chamber (MWPC), but with better spatial resolution (≤ 50 microns) and a more rapid formation of the signal.

MICROMEGAS is a gaseous detector strongly asymmetric parallel faces. The basic principle is to decouple the drift region of the amplification gap, either by a grid wires, but by a very fine metal grid (3microns thick). The trick lies in the use this micromesh pierced by a multitude of holes (in less than or equal to 50µm). MICROMEGAS principle is illustrated in figure 1. It consists of a drift gap (3 mm) and a thin amplification gap (100 µm). The properties of the electric field in two gaps have been studied by MC simulation with Garfield [6].The voltage of drift electrode and mesh is HV2 and HV1, respectively, and MICROMIGAS is operated in gas mixture of Argon-isobutane (Ar/C_4H_{10}) and Argon-Dimethyl-Ether (Ar/ DME), at a temperature of 300 K and a pressure of 1 atm. The electric field in the amplification region is very high (≥40 kV/cm), and the one in the conversion region is quite low. Therefore, the ratio between the electric field in the amplification gap and that in the drift gap can be tuned to large values.

The MICROMEGAS is based on the planar electrodes. The drift electrode is made from 5×5 cm^2 500LPI (lines per inch) steel mesh pasted on an epoxy frame, and the same mesh is used as the amplification electrode. The drift gap is also called conversion gap because the ionization of the gas by incoming radiation occurs mainly in it. The field in the amplification gap catches the free electrons from the drift gap to forcefully accelerate them through the small amplification gap. They, then, acquire enough energy to ionize surrounding gas. The newly ionized electrons gain as well as sufficient energy to ionize the gas again and again, thus forming an avalanche and leading to a measurable electric signal on the anode and on the mesh. Figure 1 and Table 1 show the operating principle and some parameters characterizing MICROMEGAS detector.

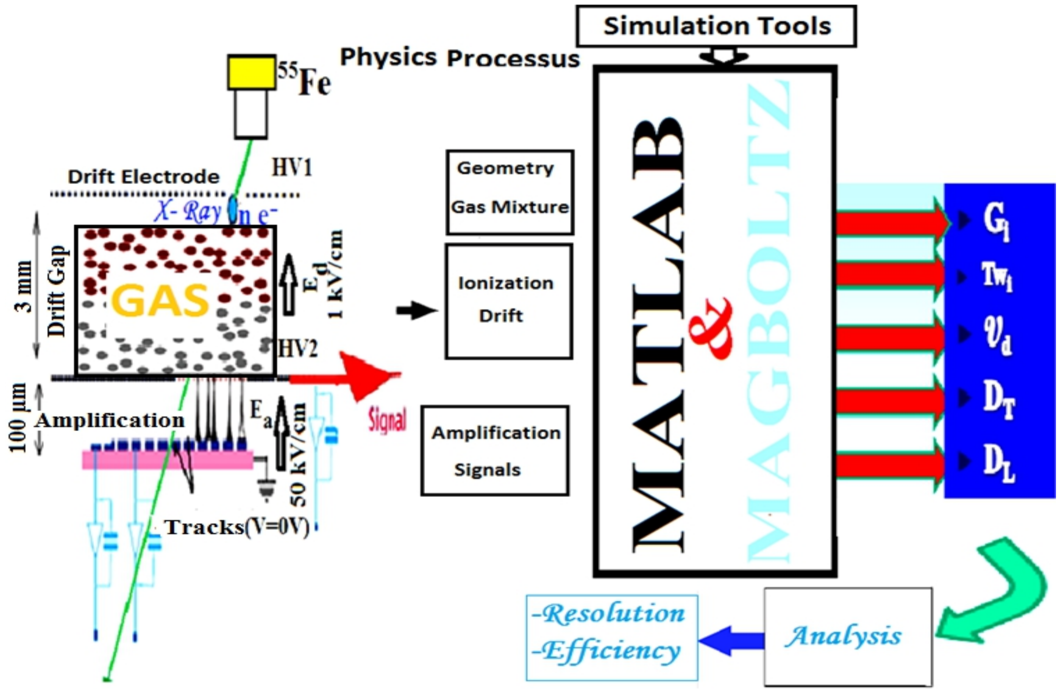

Figure 1*:Description, Principle and Simulation Tools used for MICROMEGAS Detector*

Input Parametrs	**Output Parameters**	**Geometric Parameters**
Drift Field E_d	Drift velocity	Amplification Gap(d)
Magnetic Field B	Longitudinal Diffusion	Drift Gap(h)
Amplification Field E_a	Transverse Diffusion	Track pitch(p_p)
Gas mixture	Amplification Gain	Width of a track(w)
Temperature & Pressure(NTP)	First Towsend Coefficient	Grid pitch(p_g)
Cross Section of gas	Spatial Resolution	
Amplification Coefficient of gas	Temporal Resolution	
Electron mobility	Efficiency	
X -Ray source	Signal	

Table 1*: input and output parameters of MICROMEGAS Detector*

Potential and electric field distribution

The knowledge of the shape of the electric field lines close to the micromesh is a key issue for an optimal operation of the detector and especially for an efficient transfer of electrons to the amplification gap. The electric field is homogeneous in both the conversion and the amplification gap. It exhibits a funnel like shape around the openings of the micro grid: field lines are highly compressed towards the middle of the openings, into a small pathway equal to a few microns in diameter. The compression factor is directly proportional to the ratio of the electric fields between the two gaps.

Basic equation

The mathematic term of potential is often calculated analytically using conformal transformations or Schwartz- Christoffel transformation [7]. Our work is based on the use of Green functions [8]. The configuration that we want to study is presented in figure below.

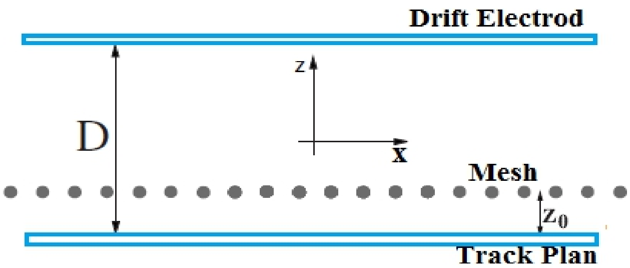

Figure 2*: Configuration for analytic calculation potential*

After all calculus, considering alls processes, we established the following form of Potential:

$$\phi(x,z) = \frac{V}{\pi}\left[arctan\left(cot\left(\frac{z\pi}{2D}\right)tanh\left(\pi\frac{x+{}^{w}/_{2}}{2D}\right)\right) - arctan\left(cot\left(\frac{z\pi}{2D}\right)tanh\left(\pi\frac{x-{}^{w}/_{2}}{2D}\right)\right)\right] \quad (1)$$

The weithing field is deduced from equation (1) using a scalaire form below

$$\begin{cases} \vec{E} = -\vec{\nabla}\phi \\ \vec{\nabla} = \begin{pmatrix} \frac{\partial}{\partial x} \\ \frac{\partial}{\partial z} \end{pmatrix} \end{cases} \quad (2)$$

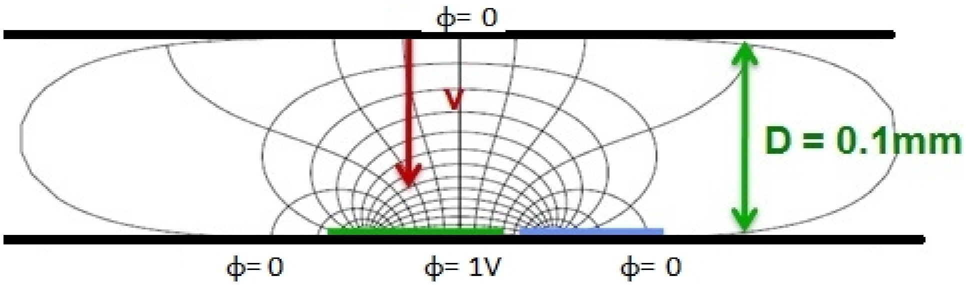

Figure 3*: Weighting Potential by applying 1 volt on a track(V=1 V) and 0 volt on other*

$$E_x = V\frac{1}{2D}\left[\frac{\sin\left(\frac{z\pi}{D}\right)}{\cosh\left(\pi\frac{x-{}^{w}/_{2}}{D}\right)-\cos\left(\frac{z\pi}{D}\right)} - \frac{\sin\left(\frac{z\pi}{D}\right)}{\cosh\left(\pi\frac{x+{}^{w}/_{2}}{D}\right)-\cos\left(\frac{z\pi}{D}\right)}\right] \quad (3)$$

$$E_z = -V\frac{1}{2D}\left[\frac{\sinh\left(\pi\frac{x-{}^{w}/_{2}}{D}\right)}{\cosh\left(\pi\frac{x-{}^{w}/_{2}}{D}\right)-\cos\left(\frac{z\pi}{D}\right)} - \frac{\sin\left(\pi\frac{x+{}^{w}/_{2}}{D}\right)}{\cosh\left(\pi\frac{x+{}^{w}/_{2}}{D}\right)-\cos\left(\frac{z\pi}{D}\right)}\right] \quad (4)$$

The field lines are determined by the equation: $\vec{E}(M)\Lambda\overrightarrow{dM} = \vec{0}$, figure 4 shows the profile of rsolution for this equation.

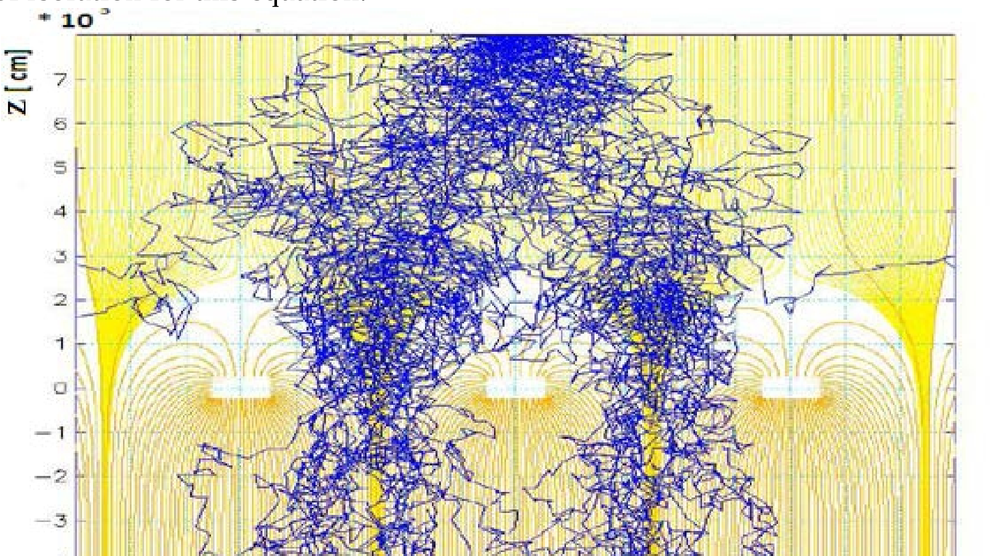

Figure 4*:electric field lines in the vicinity of a micro-grid (500 LPI) with MAXWELL 2D-SV and simulated trajectory of electrons with GARFIELD 7.10*

Study of electron avalanche amplification

When electrons are subjected to an electric field more than ten kilovolts per centimeter, they acquire enough energy to ionize the atoms to gas; new electrons are created and will in turn be accelerated. A process chain snaps and gives rise to an avalanche. It is necessary to add the noble gas mixture forming the basis of a certain proportion of poly atomic gases known as quencher.

The effects of this gas acting on the electron transport, it will also play a role in the development of the avalanche. It also will absorb electromagnetic radiation produced during the avalanche. Numerous levels of excitations, rotations and vibrations will enable it to absorb photons and thus limit the development of the avalanche. This stabilizes the operation of the detector and limits the development of avalanche process leading to a divergent and a hamstring problem. On the other hand, the energy radiated during the collection of ions on the cathode which could cause a new signal will be absorbed by these molecules.

The avalanche phenomenon is characterized by the inverse mean free path for ionization is usually noted α or (T_w). This coefficient is called the first Townsend coefficient (amplification factor). It represents a number of electron-ion pairs produced per unit length of drift. In general α increase with the electric field if this field exceeds a certain threshold. An approximation of the first Townsend coefficient as a function of field strength E is given by several equations proposed to describe this ratio since 1941[9, 10]. ZASTAWNY [11] suggests, to this simple model:

$$\frac{\alpha}{p} = A\exp\left(-B\,\frac{p}{E}\right) \tag{5}$$

Where p is the atmospheric pressure, the coefficients A and B depend on the gas mixture used; these parameters must be adjusted for each gas mixture, considering the cross section of gases used [12] and [13]. Note that these coefficients as a function of electric field and pressure. The gain of a detector can be noted for a length of amplification d as

$$G = exp\left(\int_0^d \alpha(x)\,dx\right) \tag{6}$$

In this case of approximation of electric field uniform amplification in the amplification region, α is constant and simply written as

$$G = exp(\alpha . d) \tag{7}$$

Simulation of the First Townsend Coefficients

Using equation (5), and table 2 shown below, we can estimate the first amplification coefficient for different proportions of each gas mixture; the same program remains what we need to change are the values of the coefficients A and B [12, 14]. These parameters are adjusted by experience [15].

Mixture	**Percentage**	**A (cm^{-1})**	**B ($kv.cm^{-1}$)**
Ar-isobutan	6	4700	62.70
	10	4600	69.20
	20	5700	93.90
	30	7200	119.80
Ar-DME	5	2900	39.60
	10	3100	44.40
	15	3500	52.90
	20	3300	53.60
	30	4200	69.10

Table 2*: Townsend coefficient for different mixtures of an amplification gap 100 µm*

Argon-isobutante gas mixture

The amplification coefficient of calculations results Tw_i (first Townsend coefficient, (i = 1 to 4)) for different proportions of Argon-isobutane are shown in figure 5.

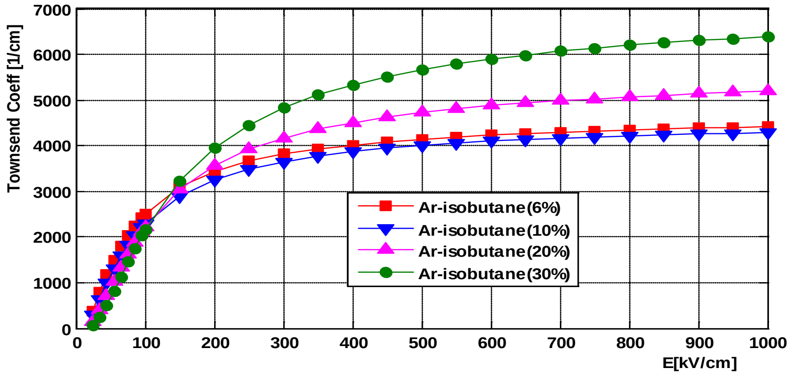

Figure 5*: First Townsend coefficient for Argon-Isobutane as a function ofElectric field*

From figure 5, it seems that a proportion of Argon-Isobutane given, the Townsend coefficient increases with increasing electric field and reaches a saturation value range as the field which is more important.

Argon-dimethyl-Ether Gas mixture

The results of simulation made by gas mixture of Argon-Dimethyl-Ether are shown in figure 6

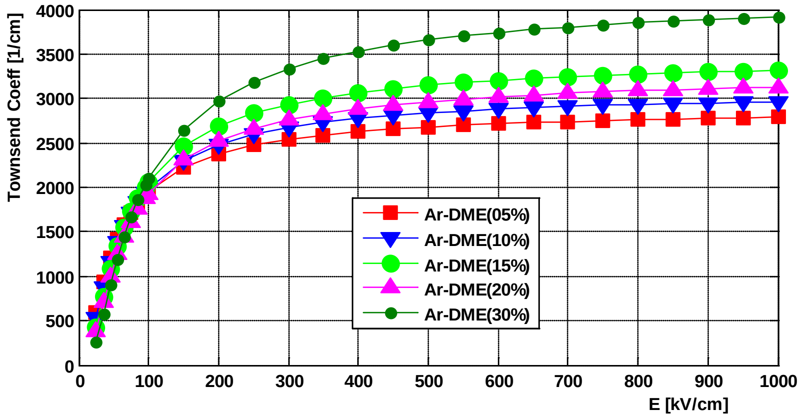

Figure 6: *First Townsend coefficient for different proportions of Argon-Dimethyl-Ether*

The figure 6 shows that the first Townsend coefficient Tw_i (i = 1 to 5) increases with the growth of the electric field and that this coefficient increases with the increase of proportion of Argon-dimethyl-Ether.

Simulation of the Gain

There is a multitude of possible gas mixture. It is possible to use different gas mixtures as a base. We used argon, and different quenchers; we used the DME (Dimethyl-Ether), Isobutane. From these gases, we can compose binary mixtures and varying proportions. Many gas mixtures have been tested, usually binary mixtures by varying the proportion of quencher. For these models, we use a ^{55}Fe source which emits X-ray photons of 5.9 keV. The detector been studied a broad amplification gap of 100 μ m.

Argon-Isobutane mixture

From equations (5) and (7), we get the gain as a function of field E.

$$G = \exp\left(A.\,d\exp\left(-\frac{B}{E}\right)\right) \qquad (8)$$

For this, we consider the distance of the amplification gap of d=100 µm, the field E varies between 30 and 100 kV/cm, A and B are defined in table 2, these parameters depend on gas mixtures. With the equation (8), and table 2, we can optimize the amplification gain for different gas mixtures; it remains the same program that we must change the values of the coefficients A_i and B_i. Figures 7 and 8 shown the estimated gain (a) that is on the left, against that is on the right which is the experimental gain (b) [12, 14].

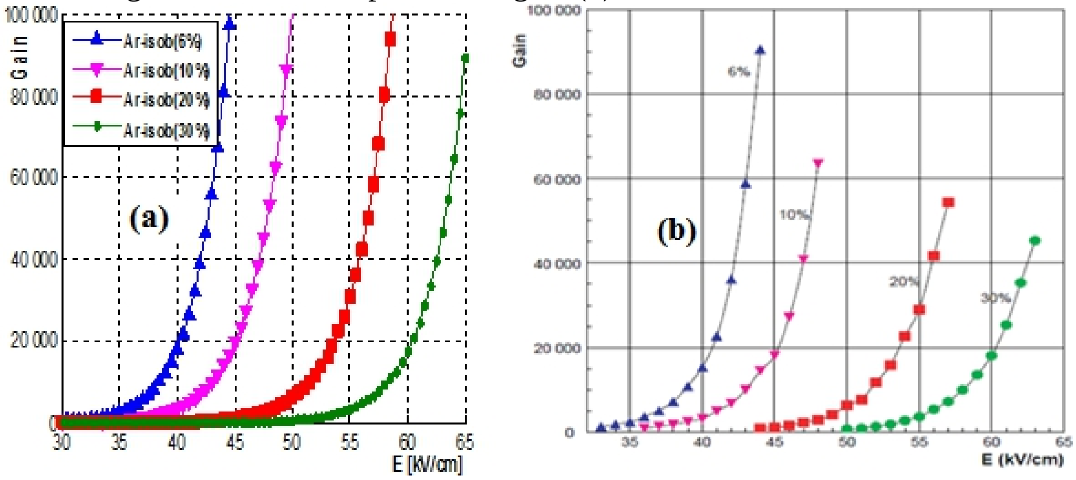

Figure 7*: Comparison between the gain simulated (at) and experimental (b) in the presence of Ar-isobutane mixture for different proportions*

In figure 7, we see that increasing proportion of quencher lowers the gain. We also note that to obtain the same gain, the higher proportion of quencher is more important and the field amplification is important. The maximum gain decreased with the proportion of isobutane in the mixture, breakdowns occurs at lower gains when the proportion increasing of isobutane. Here, we see the effect of the quencher, which tends to limit the development of the avalanche.

Argon-Dimethyl-Ether mixture (Ar/DME)

We will apply the same procedure to simulate the gain of Argon-dimethyl-Ether mixture. The figure 8 represents the results obtained.

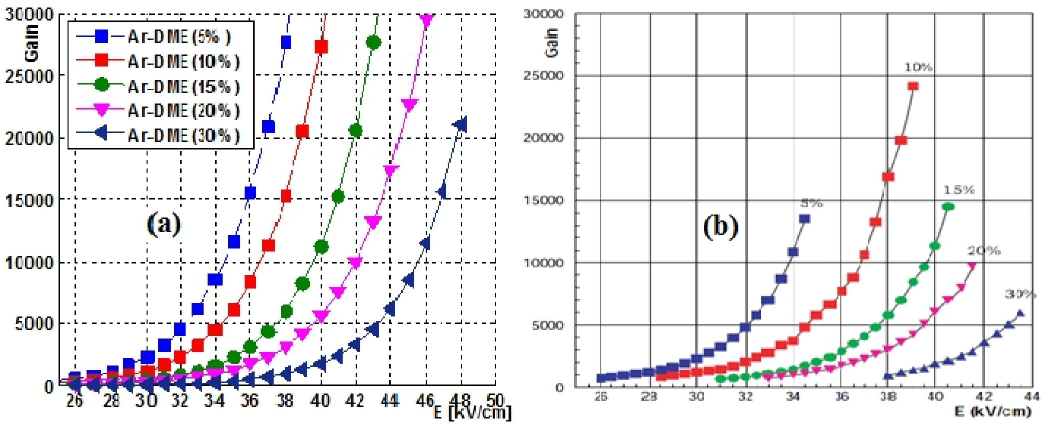

Figure 8: Comparison between the gain simulated (a) and experimental (b) in the presence of Argon-Dimethyl-Ether for different proportions

We see from this figure, the gain decreases by increasing proportions of the quencher, this gain is more akin to the measured gain. The DME is a quencher to reduce further dissemination.

It seems that these results are consistent qualitatively and quantitatively, except for some errors, and table 3 below summarizes some remarkable results:

***Table 7**: Report between simulated (G_S) and measured (G_M) gain*

E [kV/cm]	Simulated Gain (G_S)	Measured Gain (G_M)	% Quencher	Report G_M/G_S (r)	%eff
32	4510	5000	05(DME)	1.100	10
38	15310	17000	10(DME)	1.110	11
40	5658	6000	20 (DME)	1.060	06
42	3310	3500	30 (DME)	1.057	5.7
45	20000	18461	10(isob)	0.920	08
55	30900	28000	20(isob)	0.900	10
55	3480	3200	30 (isob)	0.920	08
58	9190	10000	30 (isob)	1.090	09

The correction factor (eff) that is specified in equation (9) made a good justification for the quality of the program developed using MATLAB software, which gives results comparable to experimentally measured results. This correction factor varies between 5.7% and 11.

$$G_M = eff * G_S \qquad (9)$$

If there is a specific way on the curves representing the calculated and measured gains, we will see that they are similar qualitatively and quantitatively. This is justified by observing and making some outstanding values in view whenever the earnings ratio remains in all cases $r \approx 1$ on the hand, and on the other hand, that the gain is reduced by increasing the proportion of DME which causes the decrease of diffusion coefficients. Therefore, the replacement of isobutane by the DME reduces further the dissemination.

Conclusion

The charge induced by the electrons is much larger for MICOMEGAS that in the case of a multi-wire proportional chamber (MWPC). This property is related to the shape of the electric field. Indeed, in (MWPC), the electric field varies as (1 / r). The majority of electron-ion pairs are produced close to the wires, les electrons travel a short distance before being collected by the anode and the charge induced by the electrons is a very small fraction of the total charge. In the case of MICROMEGAS, the avalanche starts much closer to the cathode due to the uniform electric field in the amplification gap. This property allows MICROMEGAS to obtain faster and more intense signals.

In this part, the simulated results of the MICROMEGAS detector developed are presented. The results indicate that our system with a micro-mesh (500 LPI) can reach rather good operational states. In the summary, the simulation results are nearly consistent with the data that are published in other references.

Our simulation predicts that further improvements are still possible. We expect the use of a 500 LPI would give a best spatial and temporal resolution for MICROMEGAS detector.

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