Characterisation of the charging up effect in resistive Micromegas detectors

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Abstract. During the last decade, a major improvement in the field of the Micro-Pattern Gaseous Detectors has been reached by adding a layer of resistive strips above the readout strips to reduce drastically the effect of discharges. The resistive strips are separated from the readout strips by a thin layer of insulator. When the detector is operated some gain reduction is observed over the first seconds or minutes after switch-on, stabilising after some time. Is this related to the presence of the insulator or are there other mechanisms at work? We report here the results of a detailed study of this effect and compare resistive-strip and Diamond Like Carbon (DLC) Micromegas detectors. We will present and quantify the main characteristics of this effect, i.e, the relative gain drop and the time to reach a stable regime, as a function of the detector configuration and rate. In addition we studied the influence of the pillars that support the mesh on the behaviour of bulk and non-bulk Micromegas detectors.

1. Introduction

Charging up is a well known effect in gaseous detectors [1] that contain dielectric materials. It is related to the deposition of charges on the dielectric surfaces. Those charges polarise the dielectric and modify the electric field. A typical example of charging up for a resistive-strip Micromegas detector (Fig. 1) exposed to a flux of particles (8 keV Cu X-rays) is shown in Fig. 2 at a relatively low rate of 175 Hz over an area of 1–2 mm^2. It results in a 15% drop of the gain as a function of time, stabilizing after a few minutes.

In order to study the charge-up effect further, two special resistive Micromegas detectors that incorporate four different configurations have been built and tested. One with screen-printed resistive strips[1], the other using a layer of Diamond Like Carbon (DLC) sputtered on the Kapton foil above the readout strips.

The active areas in both detectors have been split into four regions as illustrated in Fig. 3. The goal was to study the charging up for different configurations in the same detector:

- the effect of the exposed insulating material (resistive strips vs DLC)
- the bulk or non-bulk geometry (mesh enclosed in the pillars or pillars below the mesh).

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[1] A carbon-loaded epoxy paste from ESL Electroscience with typical resistivity between 100 kΩ/□ and 1 MΩ/□ was used.
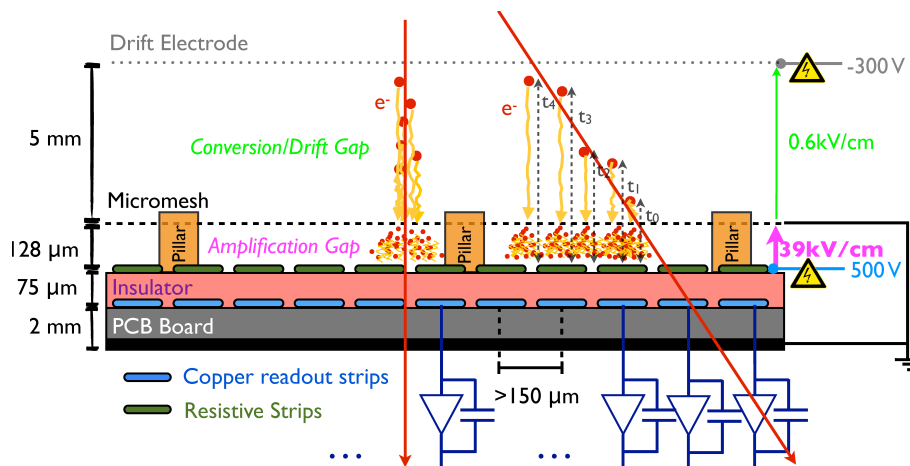
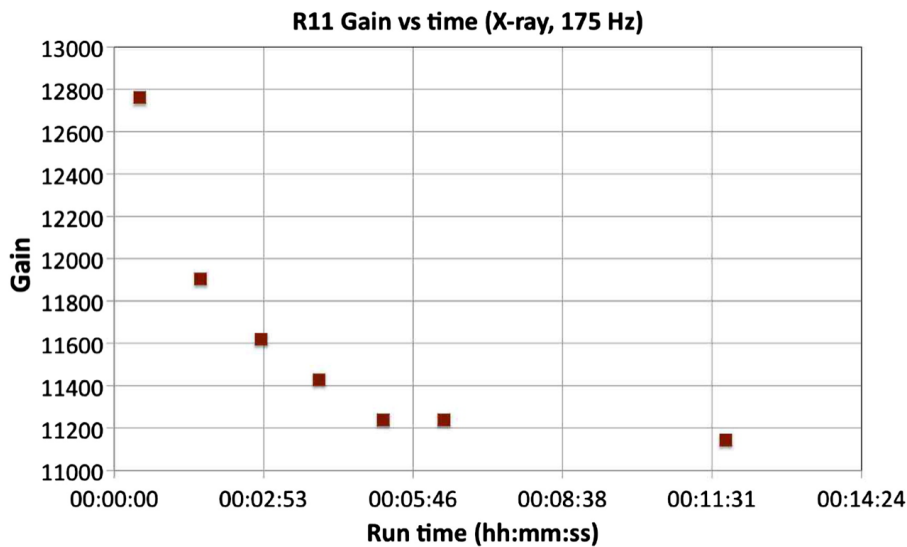**Figure 1.** Resistive Micromegas principle

Figure 2. Charging up effect [1]

The dimensions of the drift gap (5 mm) and the height of the pillars that support the mesh (128 μm) are identical in both detectors. However, the effective amplification gap is typically 10–15 μm smaller in the bulk regions compared to the non-bulk regions in both detectors[2]. The voltage applied to the drift electrode is -300 V and the one applied to the resistive layer (strips or DLC) is 530 V in the bulk region and 540 V in the non-bulk one. The gas mixture used for all tests is Ar/CO_2 (93/7%).

We have used a Cu X-ray generator (producing 8 keV photons) with a 1 mm diameter collimator creating a footprint of $\sim$ 3.6 mm diameter on the detector[3]. The distance between the pillars of 7 mm allows us to shoot between the pillars without having any influence of the pillars in the response of the detector. The X-ray beam can be turned on or off by opening or

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[2] During the fabrication of the bulk the mesh sinks into the pillars while in the non-bulk case the mesh sits on top of the pillars

[3] The footprint is the result of the spread of the X-rays of a bit more than 1 mm convoluted with the 2 mm ionisation trace of the 8 keV electrons.
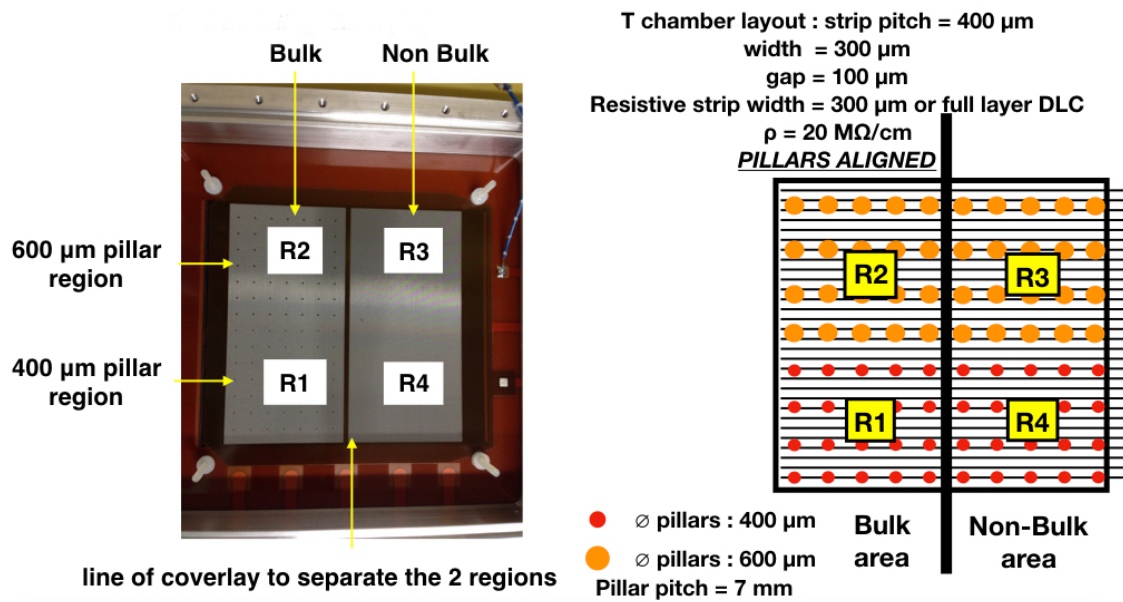
Figure 3. Detector configuration

closing a shutter.

To study the charge-up effect, we connected the mesh to a Multi Channel Analyser (MCA) after pre-amplification and amplification and observe the variation of the X-ray spectrum. The schematic of the setup is shown in Fig. 4.
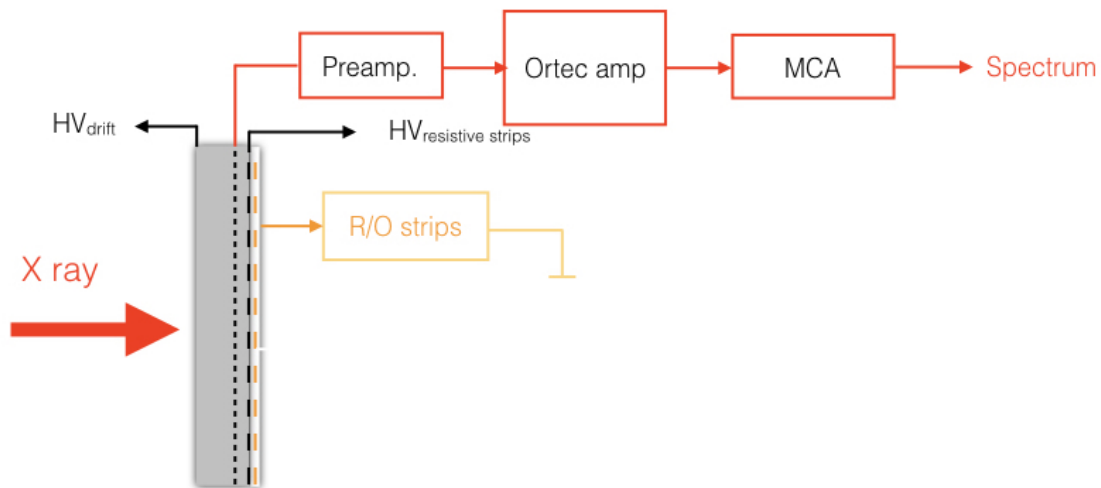

Figure 4. Measurement setup

Figure 5 shows examples of typical X-ray spectra as a function of time and illustrates the parameters chosen to characterise the charging-up:

- the shift of the peak position which is directly related to a gain variation as a function of time
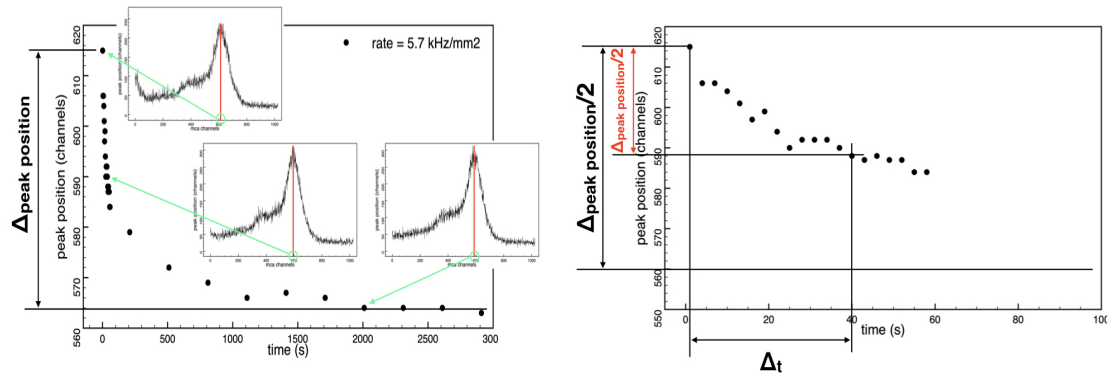- the time to reach half of the peak position drop.

Figure 5. Charging up examples explaining the parameters chosen to characterise the effect: (left) high rate behaviour with the shift of the 8 keV X-ray peak versus time; (right) absolute peak position drop as a function of time.

2. Results

2.1. Results for the resistive-strip Micromegas

The curves shown below (Fig. 6) present results that have been obtained by shooting between the pillars to avoid any effect that they could introduce. We have taken measurements in the bulk and non-bulk region for different X-ray rates. The rate varies from several Hz/mm^2 to several kHz/mm^2. As mentioned above, each point represents the peak position at a specific time after the opening of the shutter.
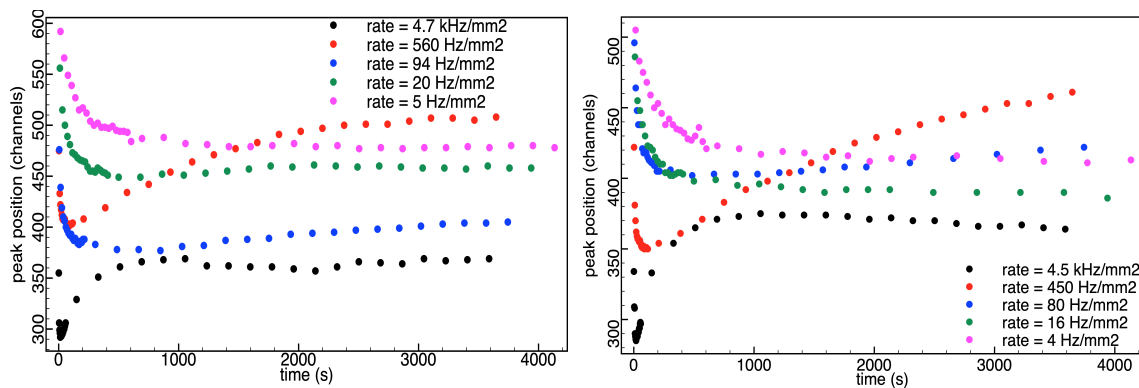

Figure 6. 8 keV X-ray peak position vs time for the bulk and non-bulk regions for different rates.

In both regions we observe the same behaviour of the peak as a function of the time. At low rate (i.e. $\leq$100 Hz/mm^2), first we see a drop of approximately 20% of the peak position over a few hundred seconds followed by a plateau. At higher rate (i.e. several hundreds of Hz/mm^2 to several kHz/mm^2), the first part of the curve also shows a drop of the peak position, followed by a slow rise of the peak reaching values higher than the initial value at the opening of the shutter.

The initial drop of the peak is explained by the fact that when the detector is connected to HV voltage (i.e. 540 V), the resistive strips but also the 100-150 μm thin insulating layer between the strips will take the same potential. At the opening of the shutter, the charges entering into the amplification region see a uniform electric field and move along the field lines.

They will be deposited on the resistive strips but also on the insulating gaps in between the strips. In the first case, they will be almost immediately evacuated to ground but in the other one they will be "trapped" on the insulating layer and decrease its potential to a value much lower than that of the resistive strips. At a certain point an equilibrium will be found and the field lines will be focused onto the resistive strips. This is illustrated in Fig. 7. Concerning the rise of the curve at high rate, we do not have any explanation for the moment, this is something that needs more investigation and measurements.

Another point should be mentioned, even with a 10V higher HV in the non-bulk region (to compensate for the larger amplification gap), the bulk region still has a higher response than the non-bulk one.
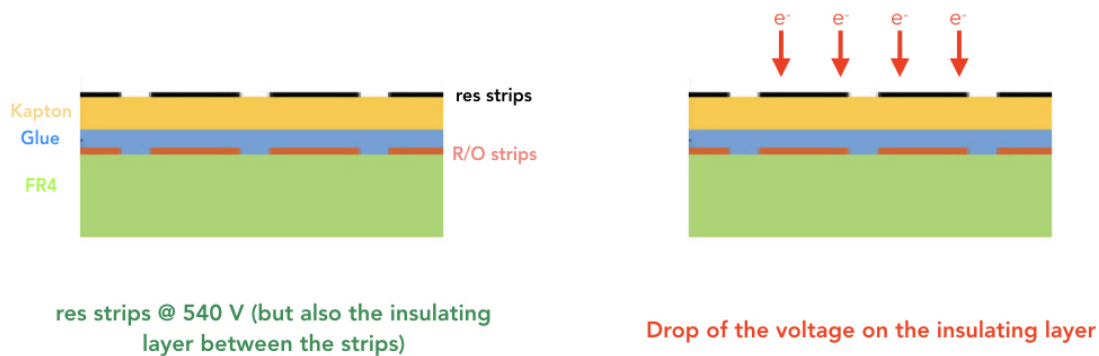

Figure 7. Scheme of the charging of the insulating material between the strips

Figure 8 shows the relative drop of the X-ray peak position and the dropping time as described in Fig. 5 as a function of the X-ray rate. We observe a relative drop of $\sim$20% slightly decreasing
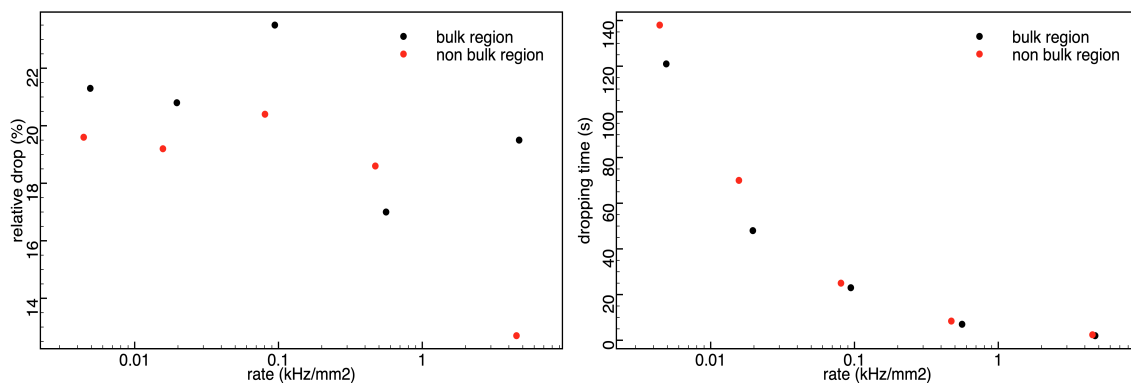

Figure 8. Relative drop (left) and dropping time (right) as a function of the rate

at rates above 500 kHz/mm^2. This decrease may well be artificial since the higher the rate the more difficult it is to record the initial part of the curve and we may underestimate the peak position in the first tens of seconds. The second plot presents the dropping time as a function of the rate. It shows a constant decrease from $\sim$130 s at a rate of a few Hz/mm^2 to $\sim$2 s at a rate of several kHz/mm^2. This is explained by the fact that when the rate increases, the time to deposit the same amount of charge on the insulating space between the strips becomes shorter and so the drop. Bulk and non-bulk regions show the same behaviour as a function of the rate.

2.2. Results for the DLC Micromegas

We have repeated the same series of measurements as described in Section 2.1 with the DLC chamber. Figure 9 shows the behaviour of the X-ray peak as a function of time after the opening of the shutter, again for the bulk and non-bulk areas of the detector.
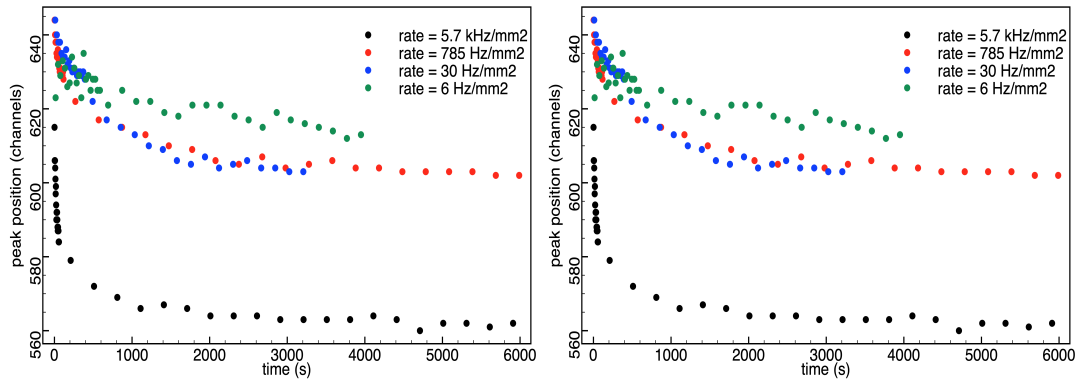

Figure 9. Peak position vs time for different rates for the bulk and non-bulk regions.

One observes again a similar behaviour for the bulk and non-bulk regions. After the opening of the shutter, the position of the X-ray peak shifts to lower values. So we still observe a charge-up effect even without any insulating material on the resistive electrode, however, at a much lower level as for the resistive-strip detector. The absolute value of the drop of the peak position seems to be correlated with the rate (i.e. the higher is the rate, the greater is the drop). At very low rate (6-7 Hz/mm^2), the drop is negligible whereas at high rate the drop can reach almost 10%. The relative drop of the X-ray peak and the dropping time as a function of the rate are shown in Fig. 10.
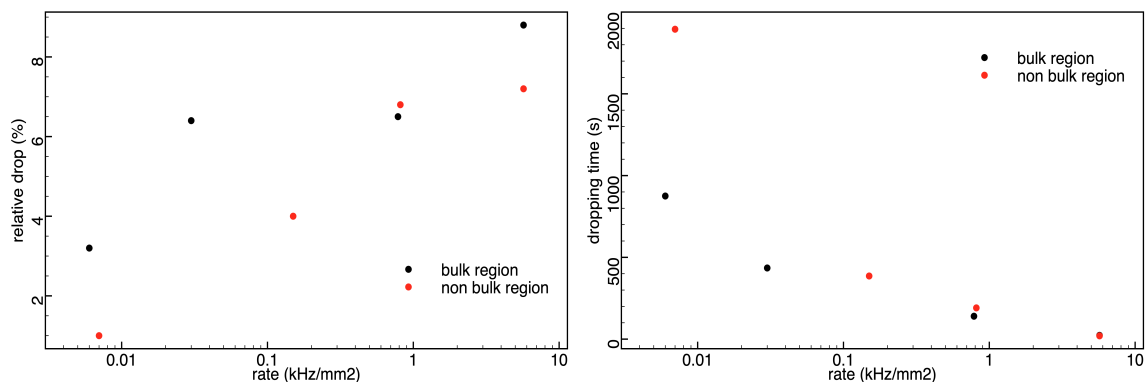

Figure 10. Relative drop of the X-ray peak (left) and dropping time (right) as a function of the rate.

At low rate (≤10 Hz/mm^2) the relative drop of the X-ray peak is 1–3 % and reaches 7–8 % for the highest rate (5.7 kHz/mm^2). The dropping time decreases from 1000–2000 s at the lowest rate to less than 20 s at high rate.

To summarise the difference of behaviour between the two chambers: we observe a lower charge-up effect with the DLC configuration than with the strip one (maximum 8% vs ∼20 %) at equivalent rate. Nevertheless, we still observe a non negligible charging-up effect in the DLC detector. The dropping time is about ten times longer for the DLC chamber than for the strip

one at the same rate. One possible explanation for the charge up effect seen with the DLC could be the non uniformity of the sputtered (and very thin) resistive layer. In fact tiny holes in the DLC layer could trap some electrons thus reducing the effective potential of the resistive layer. Another striking difference between the DLC and strip detectors is the absence in the DLC detector of the slow rise after the initial drop of the X-ray peak that we have observed in the strip detector at high rate.

2.3. Effect of the pillars in the bulk and non-bulk region

In an earlier study [2] we have observed a small increase of the gain when irradiating an area close to a pillar. In order to study this effect further, this time we performed measurements irradiating only an area around a pillar, once in the bulk and once in the non-bulk region[4]. The measurements have been done in the DLC geometry on top of the large pillars (pillar diameter: 600 μm) to observe only the effect of the pillar and to avoid any additional effect that could be related to the insulator between the strips. The measurement was done with a collimator of 1 mm diameter placed directly above a pillar.

Figure 11 shows the evolution of the 8 keV X-ray spectrum as a function of the time when irradiating a pillar in the bulk region. In order to see the variations of the spectrum more clearly, we have chosen to present the measurement obtained at a low rate (27 Hz/mm^2).
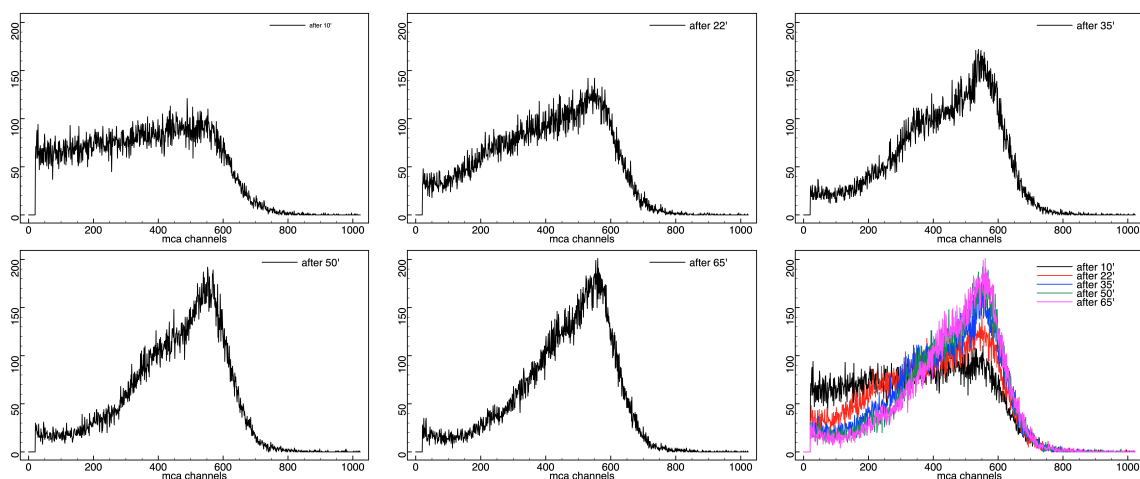

Figure 11. Evolution of the X-ray spectrum as a function of time (after 10, 22, 35, 50 and 65 minutes) in the bulk region; the last plot shows all spectra superimposed.

The spectrum obtained in the first 10 minutes after the opening of the shutter is very broad without any significant peak. When the time increases, the spectrum changes and becomes more and more similar to the spectra taken between the pillars. The last spectrum acquired 65 minutes after the opening of the shutter clearly shows an X-ray peak. The same behaviour is not at all visible in the non-bulk region as presented in Fig. 12.

The explanation of this effect is related to the fact that in the bulk geometry the pillars are protruding into the drift region. In the beginning the pillar surface is at the same potential as the mesh. Therefore, electrons created by the photoelectric effect in the gas will be trapped on it and polarise the pillar surface. The more charges are trapped, the higher will be the negative potential of the top of the pillar, deflecting the field lines. When all the lines are pushed away from the pillar the spectrum obtained will be similar to the one obtained in between pillars.

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[4] In the bulk region the mesh is encapsulated in the pillar material and the pillar extends above the mesh; in the non-bulk region the mesh sits on the pillar, without any insulating material above the mesh.
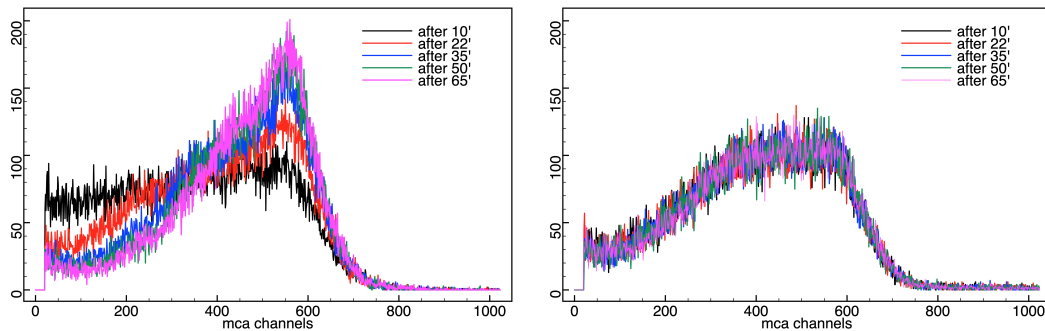
Figure 12. Comparison between the bulk and the non-bulk region

This explanation has been confirmed by a static simulation using the COMSOL software [3]. This effect can not appear in the non-bulk region because the charges deposited on top of the pillar will be immediately removed by the mesh which is grounded.
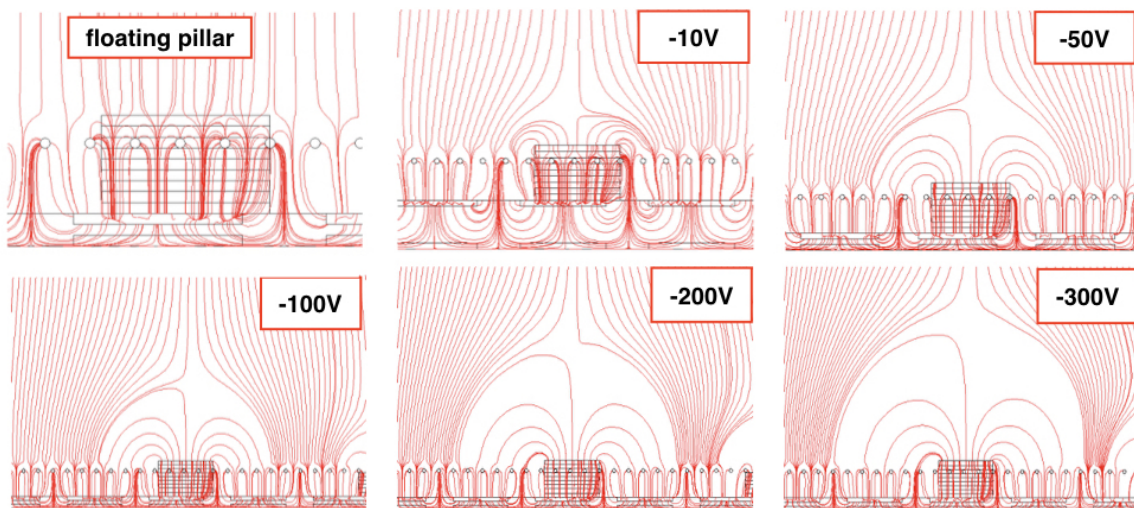

Figure 13. Evolution the field lines with increasing negative potential on the top of the pillar

3. Conclusion

Two different types of resistive Micromegas (with resistive strips and homogeneous DLC resistive layer) have been tested to study the charge-up effect. The charge-up results in a gain drop of typically 20% in the resistive-strip Micromegas detectors over a time ranging from a few seconds to a few minutes depending on the rate of irradiation. The effect can be explained by the charging up of the insulating material located between the resistive strips. Contrary to what we thought, also the DLC detector shows some charge-up, however, at a much reduced level and with a ten times longer time constant. A possible explanation are tiny holes in the very thin resistive DLC layer (to be confirmed). We are also not able to explain why we observe a slow rise of the gain with the strip chamber after the first part of the curve that shows the usual gain drop. The same effect is not present in the DLC detector. Further to this, we have demonstrated that in the bulk area the top of the pillar (above the mesh) is charging up, leading to a deviation of the primary electrons produced above a pillar such that they are not lost. This is not the case in the non-bulk detector. Possible consequences of this in terms of spatial resolution should

be addressed in a forthcoming study. There is still plenty of work to do to explain all observed effects and to understand the physic principles lying behind them.

4. Acknowledgments

References

[1] T. Alexopoulos et al.; *A spark-resistant bulk-micromegas chamber for high-rate applications*, Nucl. Instrum. Meth. A 640 (2011) 110.
[2] O. Sidiropoulou.; *Characterization of the ATLAS-type Micromegas Detectors*, PhD thesis.
[3] COMSOL Multiphysics 5.2a.