Effect of mesh geometry on resistive Micromegas for the ATLAS experiment

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Abstract. The ATLAS Experiment will use resistive Micromegas detectors for the upgrade of the forward Muon System (NSW, for New Small Wheel). With the test of the first production modules, instabilities in the detector operation have been observed, leading to a systematic revision of the selected construction components and working parameters. In particular, the effect of the mesh geometry with respect to the discharge behaviour was studied using a special Micromegas detector designed and built by the ATLAS CERN group in 2014. The detector has a Micromegas structure similar to the one later on adopted by the NSW project; moreover it provides the possibility to easily replace the mesh. The test procedure consisted in measuring current, gain and counting rate from a $^{55}$Fe X-ray source, as a function of the amplification voltage up to the discharge limit. The systematic analysis of the data allowed us to draw conclusions on the stability interval of six different types of mesh, including the one chosen to be used for the NSW, consistent with the expectations. Results suggested that the mesh selected for the NSW (among the few available in the requested big size), was not optimal for operation with a safe plateau at high gain before discharges start to occur. After the present study, cost constraint and available dimension constraints prevented the replacement of the chosen baseline design, which is already available.

1. Introduction
The Micromegas [1] are precision tracking gaseous detectors which base their operation on the charge amplification between the mesh and the anode. The amplification gap is typically 100–150 µm thick with a homogeneous electrical field of 40 – 50 kV/cm. The thinness of this region makes the detector particularly sensitive to discharges, especially in the presence of high particle rates $\sim$15 kHz/cm$^2$. This problem was greatly mitigated in 2011 by introducing a spark protection scheme [2,3]. Micromegas with the spark protection scheme and a plain woven mesh with 71 µm aperture and 30 µm wire diameter [4] were selected as one of the detector technologies which will be installed in the new forward muon stations (NSW) [5] in the upgrade of the ATLAS detector [6] for the operation of the Large Hadron Collider at high luminosity. However, during the production of the first ATLAS Micromegas modules instabilities in the detector operation have been observed, leading to a systematic revision of the selected construction components and working parameters. To study the influence of the geometry of the meshes on the discharge limit, a Micromegas detector, described in the next section, has been built at CERN with a special design that allows for easy replacement of the mesh.
2. Detector Description

The Exchangeable Mesh (ExMe) [4] detector is a resistive-strip Micromegas where the mesh is mounted on an independent support frame that can be easily exchanged as shown in Fig. 1(a). It consists of a readout and a drift panel\(^1\) enclosing the metallic mesh frame. The mesh is pre-stretched on an 4 mm thick iron frame and aligned in the chamber by pins. An EPDM polymer O-ring is sealing the filled gas volume.

The active area of the detector is \(40 \times 50\) cm\(^2\) with 1024 copper readout strips. On top of the readout strips a 50 \(\mu\)m thick Kapton\(^\circledR\) foil carrying the resistive strips is glued. The resistive strips are screen-printed with the same pattern as the readout strips. Both readout and resistive strips have a width of 300 \(\mu\)m and a pitch of 450 \(\mu\)m. The mesh support pillars\(^2\) are circular with a diameter of 300 \(\mu\)m and a height of about 120 \(\mu\)m. The active area is divided into four sections as shown in Fig. 1(b), where the pillars have a different spacing (A = 5 mm, B = 7 mm, C = 8.5 mm, D = 10 mm). For the purpose of these studies only the section with the 7 mm spacing is active in the detector, which is the same spacing used for the ATLAS NSW Micromegas detectors. This section corresponds to an area of about 500 cm\(^2\). The other three sections have been passivated with a 12.5 \(\mu\)m thick Kapton\(^\circledR\) film placed on top of the pillars. Along its perimeter the readout panel carries a 5 mm high FR4 frame defining the gas gap.

![Diagram of the detector setup](image)

Figure 1: (a) Layout of the Exchangeable Mesh (ExMe) Micromegas detector; (b) Photograph of the ExMe readout panel. The magnification shows the central joining region of the four sectors A, B, C and D, corresponding to the four different inter-pillar distances.

3. Tested meshes

Six different type of meshes have been tested as listed in Table 1, having different wire diameter, wire aperture (defining geometry is shown in Fig. 2(a)) and construction technique. Among them is the non-calendered 30-71 mesh that is used for the ATLAS NSW Micromegas detectors. Due to the extensive use and manipulation of this specific mesh there were visible defects on its surface; to mitigate them, a polishing procedure was applied with a 2500 grit sandpaper. All the meshes that were tested have a plain weave as shown in Fig. 2(b). The calendered meshes are produced by passing them through precise rollers, resulting in a flattened structure (Fig 3).

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\(^1\) A panel is a sandwich of two FR4 skins and an aluminum honeycomb web with a thickness of 10 mm.

\(^2\) The pillars are produced by thin layers of the Dupont TMDyralux \(^\circledR\) 1025 insulating material.
Table 1: List of tested meshes and prediction from simulation [7].

| Type (d-a μm) | Comment | Prediction from simulation |
|---------------|---------|---------------------------|
|               |         | $E_{\text{max}}$ (kV/cm) | $E_{\text{avg}}$ (kV/cm) | $E_{\text{max}}/E_{\text{avg}}$ |
| 18-45 N       | Non calendered | 112                      | 38.75                  | 2.9                       |
| 18-45 C       | Calendered | 89.2                      | 40.5                   | 2.2                       |
| 28-50 N       | Non calendered | 104                      | 38.25                  | 2.7                       |
| 30-71 P       | Non calendered; Manually polished | 104                      | 37.25                  | 2.8                       |
| 30-71 C       | Calendered | 84                        | 40                     | 2.1                       |
| 30-80 C       | Calendered | 88                        | 39.5                   | 2.2                       |

Figure 2: (a) Defining geometry of a plain weave unit cell; (b) Schematic of the plain weaving pattern; Copyright 2010® ANXINUSA

Figure 3: Microscope photo from a calendered mesh; Copyright 2019® NBC Meshtec Americas Inc.

The electrical fields are primarily determined by the potential difference between the cathode, the mesh and the anode on a Micromegas detector, but those fields are sensitive to small changes in the mesh geometry and position. The mesh geometry creates high intensity field regions near the wires that influence the stability of the detector in comparison to the rest of the amplification gap (average electric field) which defines the working point of the detector. It is thus expected that calendered meshes reduce the maximum electric field and increase the detector gain. The impact of the mesh geometry has been simulated in an independent study [7], confirming the expectation. The maximum and average values of the electric field for the tested meshes from this study are also listed in the Table 1 as predicted by the simulation.
4. Experimental set-up

To study the response of the detector (current, counting rate, gain), 5.9 keV photons from a $^{55}$Fe source have been used. Only part of the X-rays was reaching the detector through a 2 mm diameter hole giving rise to an event rate of $\sim 100 \text{ Hz/cm}^2$. With this rate the current did not appreciably change with the presence of the source; this implied that any abrupt increase of the current, when raising the HV, was mainly due to sparks.

The ExMe detector was operated such that the drift electrode was at negative high voltage (HV) potential, the readout electrode was at positive HV potential and the mesh was at ground potential. The signal from the readout strips was sent to a pre-amplifier (BNL, IO875) that was connected to an ORTEC 672 amplifier. The output of the amplifier was split in two. One output was connected to the Amptek MCA-8000D Multi-Channel Analyser in order to measure the energy of the converted photons; the other output was connected to a scaler to measure their rate. The current between the resistive strips and the ground was monitored through the analogue output of a CAEN N1471 high voltage power supply sent to a Labview program.

The detector was continuously flushed with Ar:CO$_2$ 93:7 at $\sim 5 \text{ l/h}$. For all the measurements with the different meshes the drift voltage was kept at -300 V which corresponds to an electric field of 0.6 kV/cm while the amplification voltage was varied up to the maximum achievable (600-620 V) where sparks appearing up to a frequency below 1 Hz. As discharges at breakdown are also triggered by dust particles, the same (good) level of cleanliness has been assured each time the detector was opened to replace the mesh.

In addition, the environmental parameters (temperature, pressure and relative humidity) were measured at the gas outlet though the MSR145 sensor. All measurements were performed at a constant overpressure of $\sim 5 \text{ mbars}$ at a relative humidity of $\sim 3\%$.

5. Detector Performance with different meshes under irradiation

Figure 4 shows the detector response as a function of the amplification voltage at a fixed drift field of 0.6 kV/cm for the different tested meshes. The same gas gain of $10^4$ is reached at lower amplification voltages for the meshes having a smaller aperture as expected. We see also that there is no essential difference in the gain between the meshes having a wire diameter of 28 $\mu$m and 30 $\mu$m (for the 28-50 N, 30-80 C, 30-71 C). It is notable that the 30-80 and 30-71 meshes are both calendered and we have seen that calendering increases the gain. However, the 30-71 P shows a different behavior which is probably caused by local defects in the wire surface.

![Figure 4: Detector response as a function of the amplification voltage at a fixed drift field of 0.6 kV/cm for the different tested meshes. The insert shows an example of the photon energy spectrum of the $^{55}$Fe source.](image-url)
The signal rate as a function of the $^{55}$Fe 5.9 keV peak position is shown in Fig. 5. We see that larger aperture between the mesh wires give rise to discharges at lower gain. However, less clear is the behavior for the meshes having a wire diameter of 30 µm. Nevertheless calendered meshes can reach higher gain than non-calendered meshes before discharges start to occur.

![Figure 5: Signal rate as a function of the $^{55}$Fe 5.9 keV peak position for the different tested meshes.](image)

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![Figure 6: Average current as a function of the $^{55}$Fe 5.9 keV peak position.](image)

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Figure 6 shows the average current as a function of the $^{55}$Fe 5.9 keV peak position. In principle, the current induced by the $^{55}$Fe source should increase as the gain increase or as the peak position moves towards higher values. Due to the very low rate of the source, the increase of the current is so low that it is hidden in the measured current. Thus any deviation from flatness indicates

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3 Here the current was averaged over the period at constant voltage by removing the points during transient.
the onset of spikes\textsuperscript{4}/rise of discharges as shown in Fig. 7. We see that the average current and the number of spikes increase earlier for meshes having a larger aperture between the wires. However the tested meshes with the same wire diameter but different aperture (30-71 & 30-80) show the opposite effect. This can be explained by the fact that even if the 30-71 was polished the final quality was lower when compared to the others. The presence of local defects explains the poorer performance of this specific mesh. From all the tested meshes the 18-45 calendered is found to be the best one.

Figure 7: Spike rate as a function of the $^{55}$Fe 5.9 keV peak position, for the different tested meshes.

6. Conclusions
With the first production modules of the ATLAS NSW Micromegas detectors, instabilities in the detector operation have been observed, leading to a systematic revision of the selected construction components and working parameters. The impact of the mesh geometry on the high voltage stability of the resistive-strips Micromegas detectors has been studied comparing meshes with different wire diameter, wire aperture and construction technique. The results show a clear dependence on the stability of the detectors depending on the geometry of the mesh and are summarizing as follows:

- Smaller aperture between the mesh wires show a higher stability, probably due to a more uniform amplification electric field.
- Thinner wires produce less inhomogeneity in the gap, allowing a higher gain.
- Calendering of the meshes helps to improve the uniformity of the electric field.

From these studies, it is clear that the 30-71 non-calendered mesh used in ATLAS NSW Micromegas detectors is not the optimal one. Among the tested meshes the best one is demonstrated to be the 18-45 calendered mesh; it is the standard mesh used in all the bulk Micromegas detectors. However, cost constraint prevented the replacement of the mesh already chosen and available in large size. Nevertheless, a manual polishing with a 2500 grit sandpaper is used for all the NSW meshes which in any case helps to reduce local defects in the regions where the wires are crossing.

\textsuperscript{4} A spike is arbitrarily defined as the current exceeding 10 nA.
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