Performance studies of a micromegas chamber in the ATLAS environment

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ABSTRACT: Five small prototype micromegas detectors were positioned in the ATLAS detector during Large Hadron Collider running at $\sqrt{s} = 7$ and 8TeV. A $9 \times 4.5\, \text{cm}^2$ double drift gap detector was placed in front of the electromagnetic calorimeter and four $9 \times 10\, \text{cm}^2$ detectors on the ATLAS Small Wheel, the first station of the forward muon spectrometer. The one attached to the calorimeter was exposed to interaction rates of about $70\, \text{kHz}/\text{cm}^2$ at $\mathcal{L} = 5 \times 10^{33}\, \text{cm}^{-2}\text{s}^{-1}$ two orders of magnitude higher than the rates in the Small Wheel. We present the results from performance studies carried out using data collected with these detectors and we also compare the currents drawn by the detector installed in front of the electromagnetic calorimeter with the luminosity measurement in ATLAS.

KEYWORDS: Micropattern gaseous detectors (MSGC, GEM, THGEM, RETHGEM, MHSP, MICROPIC, MICROMEGAS, InGrid, etc); Particle tracking detectors (Gaseous detectors)

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1 Introduction

The micromegas technology was developed in the middle of the 1990’s introducing a micropattern gaseous detector with two asymmetric regions [1]. MM standard detectors consist of a planar (drift) electrode, a gas gap of a few millimeters thickness acting as conversion and drift region, and a thin metallic mesh at typically 100−150 µm distance from the readout electrode, creating the amplification region, as shown in figure 1. The HV potentials are chosen such that the electric field in the drift region is a few hundred V/cm, and 40−50 kV/cm in the amplification region achieving gas gain values in the order of $10^4$.

Charged particles traversing the drift space ionize the gas and the electrons liberated by the ionization process drift towards the mesh (tens of nanoseconds). With an electric field in the amplification region 50−100 times stronger than the drift field, the mesh is transparent to more than 95% of the electrons. The electron avalanche takes place in the thin amplification region in less than a nanosecond, resulting in a fast pulse of electrons on the readout strip [2]. The drifting of the electrons along with the avalanche formation in the amplification region for perpendicular and inclined tracks is illustrated in the right schema of figure 1. The ions that are produced in the avalanche process move towards the mesh ~ 100 times slower that the electrons.

Adding a layer of resistive strips on top of a thin insulator directly above the readout electrode, as shown in figure 2, the MM become spark-insensitive. The readout electrode is no longer directly exposed to the charge created in the amplification region. The signals on the readout strips are partly induced signals and partly capacitively coupled to it. By adding this protection some fraction of the signal height is lost but the chamber can be operated at higher gas gain and thus have spark intensities reduced by about three orders of magnitude [3].

The MM technology is quite attractive for High Energy Particle Physics experiments due to its rate capability, excellent performance and simplicity of construction. As a result an R&D activity

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1 An abbreviation for MICRO MEsh GAseous Structure.
was started in 2007, called Muon ATLAS MicroMegas Activity (MAMMA), to explore the potential of the MM technology for its use in LHC detectors. As of May 2013 ATLAS decided to equip the New Small Wheel (NSW) with MM detectors [4], combining triggering and precision tracking functionality in a single device [5].

2 Micromegas detectors in ATLAS

In order to test the micromegas detectors under realistic LHC conditions five small micromegas chambers were installed in the ATLAS detector in February 2012, until the end of the data taking in February 2013 (figure 3). One prototype resistive micromegas detector, with two gas gaps sharing a common drift plane (namely MBT03 and MBT04), with an active area of $9 \times 4.5\,\text{cm}^2$ was installed in the high-rate environment in front of the electromagnetic end-cap calorimeter (LAr), 3.5 m from the interaction point in the $z$ direction, at a radius $r \sim 1\,\text{m}$ (figure 5 left). Four standard $9 \times 10\,\text{cm}^2$ resistive detectors (R13,16,18,19) were installed on the ATLAS Small Wheel (SW), Cathode Strip Chamber (CSC) region, at 1.8 m distance from the beam pipe (figure 5 right).

In the work presented here we measure the hit rate of the different ATLAS regions where the micromegas chambers were installed. We demonstrate also, even with a random trigger, that recorded hits in the adjacent chambers can be correlated indicating real particle tracks. We then study the correlation of the MBT chamber’s current with the luminosity of ATLAS demonstrating the capability of micromegas detector for luminosity measurement.
Figure 3. Sketch of the ATLAS detector. The place where the MBT chamber was installed is indicated with orange arrow while the SW region is also marked on the drawing.

Figure 4. Sketch of the MBT double gap and strip configuration.

Chamber characteristics

The MBT is a 4.5 mm drift double-gap chamber, with an amplification gap of 0.128 mm and two-dimensional readout with 500 µm pitch, (400 µm width) of the x strips (in η-direction) and 1.3 mm pitch, (200 µm width) of the y strips which are inclined with respect to the x strips by 30° (figure 4). It is a resistive-strip type micromegas with a resistivity of about 300 MΩ/cm and a resistance of 100 MΩ. For the chamber operation we use a drift high voltage at −300 V (0.67 kV/cm nominal electric drift field) and amplification high voltage applied to the resistive strips of +500 V (39 kV/cm electric amplification field) while the mesh was connected to ground.

The micromegas detectors installed in the SW region are standard 9 × 10 cm² resistive chambers with a 5 mm drift gap and two dimensional readout consisting of x and y strips 250 µm pitch.
The amplification gap is the standard 0.128 mm. The resistive strips are 150 µm wide with a resistivity of 200 MΩ/cm. The R chambers are operated with about the same high voltage configuration as the MBT with a bit higher voltage applied on the resistive strips to achieve the nominal drift electric field.

All chambers were operated with an Ar:CO₂ (93:7) gas mixture and read out, stand-alone, by APV25 [6] hybrid cards through the Scalable Readout System [7]. They were continuously operational except for a few weeks with low luminosity running. The high voltage was kept on the same value independent of the LHC beam conditions (early beam, single bunches, large emittance beam, 25 ns LHC beams, etc). The detector currents were continuously monitored through the CAEN SY1527 high voltage system using the A1821 module with a monitor current resolution of 2 nA [8].

3 Hit rate measurement

The luminous ATLAS experiment is a relatively new environment of operation for the micromegas detector. Therefore it was challenging to measure the recorded hit rate in the two different regions with the installed chambers. For this study we first apply a fiducial time bin cut on our events keeping only strips with measured time between 6 and 15 time bins (each bin width is equal to 25 ns). Since the data were taken using a random trigger this time window ensures that the signal shape is fully recorded, from its rise to its falling tail. The earlier time window (≤ 5 time bins) is mainly dominated by events where the rising edge happens before the start of the charge sampling by the APV25 and therefore is cut out. For times greater than the window’s high edge (≥ 16 time bins) the signal tail is almost totally cut off. In both cases, the charge is not correctly measured and the measured rate would be inaccurate.

We then apply a single clusterization algorithm to form clusters of strips. We allow up to 4 gaps between the strips that belong to the same cluster for the MBT chamber. For the small wheel chambers, due to the smaller strip pitch, we select a maximum gap of 10 strips for our clusterization. We then define the hit rate as the number of clusters counted per square centimeter per second and we present the measurements as a function of the ATLAS luminosity for the different chambers in figure 6.
The hit rate of the small wheel chambers is measured in the order of $40 \text{Hz cm}^{-2} \text{s}^{-1}$ per $\mathcal{L} = 10^{33} \text{cm}^{-2} \text{s}^{-1}$ and almost proportional to the luminosity. This measurement should be compared with the $38 \text{Hz cm}^{-2} \text{s}^{-1}$ per $\mathcal{L} = 10^{33} \text{cm}^{-2} \text{s}^{-1}$ that is the value measured for CSC chambers in the same region. The MBT rate is about $15 \text{kHz cm}^{-2} \text{s}^{-1}$ per $\mathcal{L} = 10^{33} \text{cm}^{-2} \text{s}^{-1}$ and the extremely high hit rates deform the linearity a bit because the two hits are sometimes not separated in the clusterization. The $v$ strips in MBT chambers show relatively low rates due to the wider clusters, due to the $30^\circ$ inclination with respect to the resistive strips, and strips with shorter length in some region.

4 Track identification

Correlated hits between chambers placed one after the other are considered as tracks passing through the chambers. These cases correspond to a 90% fraction of events in MBT chamber, when comparing hits from MBT03 and MBT04 gaps, and about 10% ∼ 20% in SW chambers. The difference of the measurement in the two regions emanates from the distance between the correlated chambers with the two gaps of the MBT having almost zero lever arm compared to the distances between the R chambers. The rest are treated as isolated hits from neutrons or gammas. Figures 7 and 8 illustrate the difference in position and time between two chambers, of the same area in the “real track events”.

The strong correlation is evident in both time and position plots for the two different areas, although the position difference depends on the incoming angle, especially when chambers have a large gap between them, which is the case of the SW chambers. The shift observed in the position difference for the $x$ strips (measuring radius) in SW chambers, in the order of 35 channels, corresponds to the polar angle from the interaction point. The long tails of MBT chambers distributions emanate from combinatorial background due to the high rate, as shown in figure 7.

5 Luminosity measurement

As we have discussed in the introduction, our chambers where connected to a high voltage unit and we were monitoring their instantaneous current using PVSS (see figure 9) with a sensitivity of
Figure 7. Hit correlation for the consecutive gaps of the MBT chamber. Left: hit position difference measured in channel number. Right: hit time difference measured in time bin units (each time bin is 25ns wide).

Figure 8. Hit correlation for the consecutive R chambers. Left: hit position difference measured in channel number. Right: hit time difference measured in time bin units (each time bin is 25ns wide).

2nA. The current drawn by the chambers should be a function of the incoming rate of particles and due to the high resolution of this detector technology a study has been performed trying to correlate the monitored instant current of the chambers with the instantaneous luminosity of the ATLAS experiment [10].

Correlation plots of the luminosity along with the micromegas MBT current, created using data recorded in one day, can be seen in figure 10. In the left plot, the micromegas current is plotted with the red points (measured in µA) and the ATLAS luminosity is plotted with black points as a function of time.

The outlying current points correspond to sparks due to the high rate environment and should be excluded on a more detailed analysis. On the right plot the micromegas current is plotted versus the luminosity. The blue line is a first order polynomial fit performed on the datapoints. The fitted line’s intercept is 6nA and has a slope of 0.55 µA/10^{34} cm^{-2}s^{-1}. The spark points are visible in this plot as well and they do not follow the clear linear relation of the two measured values.

Figure 11 shows the results of this analysis performed in the whole dataset. Performing a fit, we extract an intercept of −6 nA and a slope of 0.56 µA/10^{34} cm^{-2}s^{-1} that is in good agreement with the analysis of one days data shown in figure 10. A linear relation between the current of
Figure 9. An example of micromegas currents as a function of time starting from early May until September 2012. The structure of the LHC fills is clearly visible.

Figure 10. The left plot shows the ATLAS luminosity (left axis, black line) and the MBT current (right axis, red points) as a function of time for a given period. The right plot gives the MBT current versus the ATLAS luminosity for the same period. You can see a good correlation between the current and the luminosity. The blue line is a fit to the data.

the micromegas chamber and the ATLAS luminosity was found (see figure 11) and this allows the micromegas to be used for luminosity measurement along with LUCID and BCM [9].

Using our measurement, we expect micromegas chamber of the size mentioned earlier to draw 0.56 μA at the nominal ATLAS luminosity of $10^{34}$ cm$^{-2}$s$^{-1}$. Using this correlation, together with an integrated LHC luminosity of 15.5 fb$^{-1}$, it is estimated that the total charge accumulated by the MBT chamber during the run adds up to about 1.2 C or 0.03 C/cm$^2$. This figure should be compared to the accumulated charge of 0.005 C/cm$^2$/year that is expected in the micromegas operating at a gas gain of $10^4$ at a rate of 10 kHz/cm$^2$, the highest counting rate expected on the SW. Or in other words, the one year long exposure of the MBT chamber located on the front face of the electromagnetic calorimeter is equivalent to six years of operating the micromegas on the NSW [4] at $\mathcal{L} = 5 \times 10^{34}$ cm$^{-2}$s$^{-1}$. 


Conclusions

We have successfully operated and readout micromegas detectors in a high-rate environment of the ATLAS cavern for a year. Their voltages and current were constantly monitored without any problem even for the ones in front of the electromagnetic end-cap calorimeter ultra high-rate region. From the reconstructed hits that were recorded we were able to measure the hit rate with our chambers which in the case of the MBT was about 70kHz/cm² for a luminosity of $5 \times 10^{33}$ cm$^{-2}$s$^{-1}$, with 90% of the hits being correlated in both gaps.

We have also observed a strong linear correlation between the LHC luminosity and the current drawn by the micromegas detectors. This leads to the conclusion that it could be possible to use the micromegas detectors to monitor the LHC luminosity in the ATLAS cavern with an accuracy that needs to be measured. The measurement also shows that the micromegas chamber show no evidence of ageing effects as there is linear relationship between the current drawn and the ATLAS luminosity even for high luminosity values.

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