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Performance and Calibration of 2m^2-sized 4-layered Micromegas Detectors for the ATLAS Upgrade

Maximilian Herrmann*, **on behalf of the ATLAS Muon Collaboration**
Ludwig-Maximilians-Universität München, Germany
E-mail: Maximilian.Herrmann@physik.uni-muenchen.de

The increased luminosity of the HL-LHC requires a new, high rate capable, high resolution detector technology for the inner end cap of the muon spectrometer of the ATLAS experiment. For this purpose the Micromegas technology is chosen as precision tracker. The SM2 modules are 2 m^2-sized Micromegas quadruplets and cover about 25% of the active Micromegas area of the New Small Wheels. This large size requires a sophisticated construction to provide a spatial resolution better than 100 µm. The first prototype SM2 module was investigated using 120 GeV pions and muons at SPS/CERN as well as with cosmic muons in a precision facility.

The spatial resolution of the SM2 detector is analyzed using two different methods. A charge weighted position reconstruction, the so-called centroid method, achieves a spatial resolution of about 80 µm for perpendicular particle incident. A drift time evaluation of the strip readout, yields a similar resolution for tracks inclined to the active area of the module.

To investigate and calibrate the full active area of SM2 quadruplets the LMU Cosmic Ray Facility (CRF) is used. Two ATLAS Monitored Drift Tube chambers (MDT) provide precise muon track information in the order of 100 µm. A trigger hodoscope segments the position information in 10 cm bands along the wires of the MDTs. The angular acceptance of the CRF is between -30° and $+30^\circ$ to the zenith angle over an area of about 8 m^2.

We present results for the first prototype SM2 quadruplet with 12288 channels read out fully by 96 APVs connected to six FEC cards. The segmentation of the active area enables a detailed analysis of local detector properties, for example geometrical quality, homogeneity in efficiency, in pulse height and in spatial resolution.

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1. Upgrade of the ATLAS Muon Spectrometer for the HL-LHC

During operation of the high luminosity LHC the inner end cap of the ATLAS muon spectrometer will be exposed to a high flux environment. Therefore these so called small wheels will be replaced with new detector technologies, namely small-strip Thin Gap Chambers (sTGC) and Micromegas.[1] Micromegas are micropattern gaseous detectors for charged particle tracking in high flux environments.[2] A resistive strip anode about 128 μm beneath a grounded micromesh ensures short dead times in case of discharges.[3] For the reconstruction of the intersection point the signal of copper readout strips under the anode strips has to be evaluated (see Figure 1). The Micromegas are constructed as quadruplets with four active layers per module (see Figure 2). In the following results for the first SM2 module prototype Micromegas will be shown. Due to technical limitations the SM2 anode will be built out of three Printed Circuit Boards (PCB) (see Figure 3). This requires a sophisticated construction and a precise alignment. The readout of the strip signals is performed for this study with charge sensitive APV25 ASICs.[5] The detector is operated with a gas mixture of Ar:CO_2 (93:7 vol%).

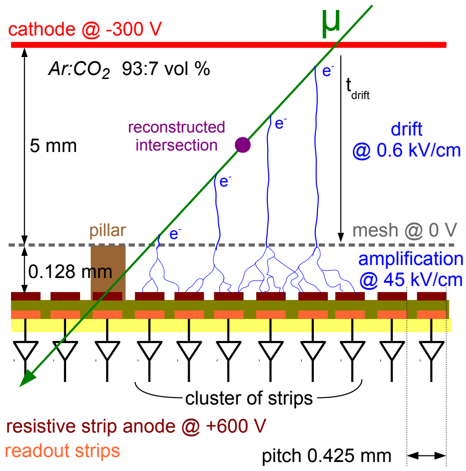


Figure 1: Working Principle of a resistive strip Micromegas detector.

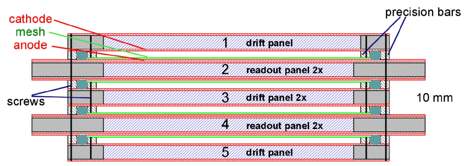
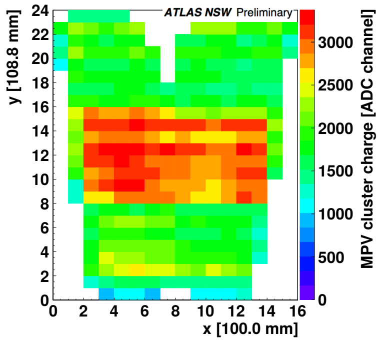


Figure 2: Cut through of a Micromegas Module with four active volumes (between cathode and anode).

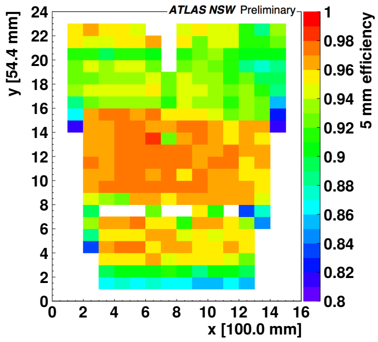
2. Investigation in the Cosmic Ray Facility in Munich

The Cosmic Ray Facility (CRF) in Munich is well suited for homogeneity studies and calibration of the SM2 modules with cosmic muons.[4] The response behavior of the module can be studied by the charge distribution of strip cluster. For the investigation of the homogeneity over the active area of the modules the cluster charge distribution is considered separately for partitions of about 54.4×100 mm^2. These distributions follow a Landau behavior and are therefore fitted to extract the Most Probable Value (MPV). The central PCB shows significantly higher cluster charges than the other two PCBs (see Figure 4a). This is due to different pillar heights (see Figure 1) of the prototype anode material. The 5 mm efficiency of a partition for a single layer is calculated from the number of single muon tracks going through the active area with a cluster within 5 mm to the track prediction divided by the number of all tracks (see Figure 4b). Due to the higher amplification above the central PCB, even smaller charge depositions of the muons are reconstructed, which increases the efficiency. To investigate the alignment the position of the PCBs with respect to each other is reconstructed. In a single plain this can be achieved by calculating the residual mean as a function of the position perpendicular to the strips. A linear dependence between the two values can be interpreted as a deviation to the nominal pitch between the strips. This can occur due to

Figure 3: Segmented anode PCB design for SM2 Micromegas. The readout strips in the active area (brown) are oriented the same way as the parallel sides of the trapezoid.



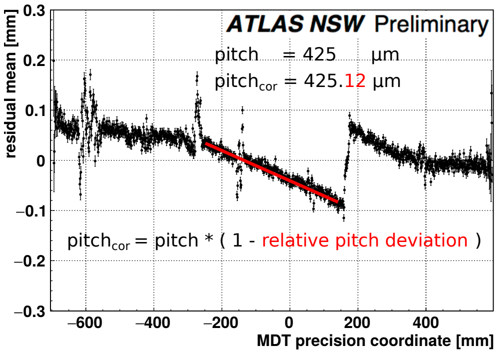
(a) Most Probable Value (MPV) of charge distributions. Partitions missing due to trigger acceptance.



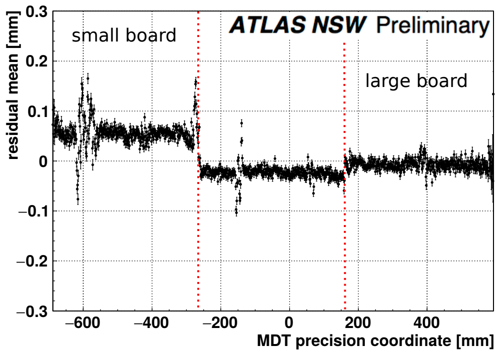
(b) The 5 mm efficiency is increased in the central area due to the higher amplification (seen in the cluster charge in Figure (a)).

Figure 4: Cluster charge (a) and 5 mm efficiency (a) for each partition. The measurement is performed at voltages for amplification of 600 V and drift of -300 V.

deformation of the anode PCBs, which are sensitive to humidity. The red indicated dependence in Figure 5a corresponds to a pitch with 120 nm oversize compared to its nominal value of 425 µm. For the calibration of this effect the deviation of the pitch has to be calculated for each PCB separately. The correction is then applied assuming the center of the respective PCB is fixed. This is motivated by the alignment procedure during construction of the readout panel. After correction the misplacements (see Figure 5b) between the PCBs can be distinguished in the order of 10 µm.



(a)

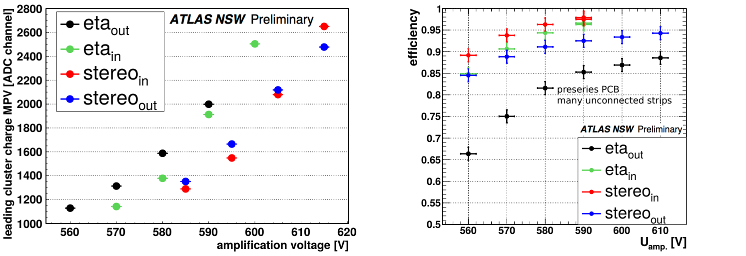


(b)

Figure 5: Residual mean as a function of the position perpendicular to the readout strips before correction (a) and after correction (b) for pitch deviations.

3. Investigation at the H8 Beamline of the SPS

During the beamtime in August 2017 at the H8 beamline of the SPS at CERN, a tracking telescope was used for the investigation of the module with 120 GeV muons. The tracking telescope consisted of four two dimensional micropattern gaseous detectors also equipped with APVs providing a track prediction of 65 µm precision at the position of the SM2 module. The module was investigated by the variation of the amplification voltage. In Figure 6a the MPV of the cluster charge distribution



(a) (b)

Figure 6: The most probable value of the cluster charge distributions (a) and the 5 mm efficiency (b) versus the amplification voltage.

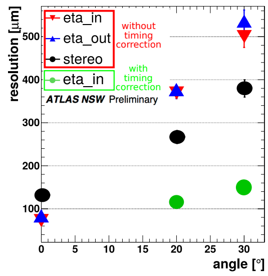


Figure 7: For large angles the usage of the time information of the strip signals improves the resolution significantly.

is plotted as a function of the amplification voltage. All four layers show the expected exponential rise due to the Townsend avalanches in the amplification region. Differences between the layers are due to the varying quality of the anode PCB material. The differences are also prominent in the 5 mm efficiency turn on curve seen in Figure 6b. For the PCB layer eta_{out} the efficiency is spoiled by unconnected strips due to the prototype PCB quality. The other three layers reach the efficiency plateau above 90 % at 580 V. The position resolution of 80 µm is independent of drift and amplification voltage. Due to inhomogeneous ionization along the path of the minimum ionizing particles the resolution of the eta and stereo layer degrades for angles of 20° and 30° without timing correction (see Figure 7). Using the time information of the strip signals and the drift velocity of the electrons to correct the position prediction the resolution improves significantly for inclined tracks (see Figure 7).[6]

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