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Resistive Micromegas for the Muon Spectrometer Upgrade of the ATLAS Experiment

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Large size resistive micromegas detectors (MM) will be employed for the first time in high-energy physics experiments for the Muon Spectrometer upgrade of the ATLAS experiment at CERN. The current innermost stations of the muon endcap system, the Small Wheel, will be upgraded in 2019 to retain the good precision tracking and trigger capabilities in the high background environment expected with the upcoming luminosity increase of the LHC. Along with the small-strip Thin Gap Chambers (sTGC) the "New Small Wheel" will be equipped with eight layers of MM detectors arranged in multilayers of two quadruplets, for a total of about 1200 m^2 detection planes. All quadruplets have trapezoidal shapes with surface areas between 2 and 3 m^2. The MM system will provide both trigger and tracking capabilities. In order to achieve a 15% transverse momentum resolution for 1 TeV muons, a challenging mechanical precision is required in the construction for each plane of the assembled modules, with an alignment of the readout elements (the strips) at the level of 30 μm along the precision coordinate and 80 μm perpendicular to the plane. Each MM plane must achieve a spatial resolution better than 100 μm independent of the track incidence angle and operate in an inhomogeneous magnetic field ($B < 0.3$ T), with a rate capability up to 15 kHz/cm^2. In May 2016 the first full size prototype (module-0) has been completed and tested at CERN with high momentum pion beam. The Module-0 construction elements and procedures, and the preliminary results obtained at the test-beam will be presented.

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1. The ATLAS Muon New Small Wheel Upgrade

The New Small Wheel (NSW) [1] is one of the the main upgrades of the ATLAS experiment [2] that will be installed during the Long Shutdown in the years 2019/20 (LS2). It will replace the present Small Wheel in the endcap region of the Muon Spectrometer, presently equipped with detectors that were not designed to exceed LHC original design luminosity. The NSW upgrade is designed to cope with the high background rate that is expected at luminosities between 2 and $7 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$, during LHC Run-3 and for operation at High–Luminosity–LHC, where background rates as high as $\sim$ 15 kHz/cm^2 can be reached in the most forward region.

The main goals of the NSW are to achieve 15% transverse momentum resolution for 1 TeV muons and keep single muon trigger under control. Considering the challenging background conditions and the detector accessibility in the experiment, a multilayer detector, with a high degree of redundancy, is required, with approximately 100 μm spatial resolution per plane in the radial precision (η) coordinate (for the measurement of the transverse momentum), 2-3 mm in the azimuthal direction, and able to provide online segments with a 1 mrad accuracy. Besides this, in order to achieve the ultimate momentum resolution, a challenging mechanical precision is required in the construction for each plane of the assembled modules, with an alignment of the readout elements (the strips) at the level of 30 μm along the precision coordinate and 80 μm perpendicular to the plane.

2. Detector Technologies and the New Small Wheel Layout

The NSW will combine two muon detection technologies. The small strips Thin Gap Chambers (sTGC) [3], and the micromegas (MM) [4]. The sTGC are primarily foreseen as trigger detector, exploiting a good time resolution and online track vector resolution below 1 mrad. The MM, will be employed as primary tracking detectors. They have a good spatial resolution, better than 100 μm, good track separation with fine granularity readout, and will also provide online segments for trigger. Both detectors fulfill both functions (tracking and trigger). In Fig. 1 a sketch of a resistive MM detector layout and its working principle are shown. A MM consists in two gas gaps electrically separated by a metallic mesh: a few mm conversion and drift gap, where charged particles ionize the gas, and a very thin gap (128 μm) for the amplification, where the avalanche of electrons is produced and collected on the resistive strips. The resistive strips serve as protection to minimize the effect of sparks [5] by limiting the spark currents. Signals are induced via capacitive coupling to the readout strips.

The layout of the NSW is reported in Fig. 2. Each of the two endcap NSW is segmented in 16 sectors (8 large and 8 small). Each sector is a sandwich of MM and sTGC modules. Each module has 4 detection planes. The first two planes of a MM module have parallel strips for precision η-coordinate measurements. The third and fourth layers (also referred to as "stereo layers") have the strips tilted to +/- 1.5° with respect to the η-strips, for the azimuthal coordinate measurement. There are 4 types of MM modules arranged on the various sectors of the NSW: LM1 (lower radius) and LM2 (larger radius) for the large sectors, and SM1 and SM2 for the small sectors. Each plane of MM is built with 5 (SM1, LM1) or 3 (SM2, LM2) adjacent readout boards. The construction is distributed over several countries: France (LM1), Russia and Greece (LM2), Italy (SM1) and

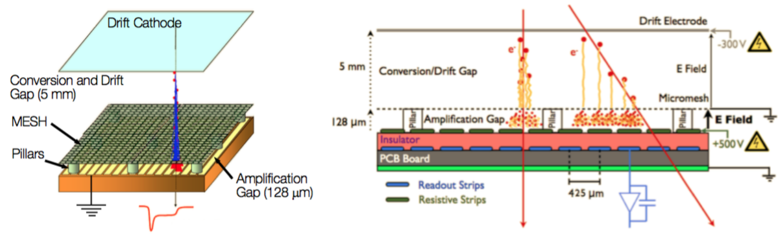

Figure 1: Left: Sketch of the MM detector concept; Right: Principles of operations of a resistive micromegas chamber with reference operational parameters. Dimensions are not to scale.

Germany (SM2). The first module-0 has been recently completed by INFN Italy (SM1). All other modules-0 types are at present under completion. The module-0 for the LM2 type is being built at CERN within a collaboration with the groups of Dubna and Thessaloniki.

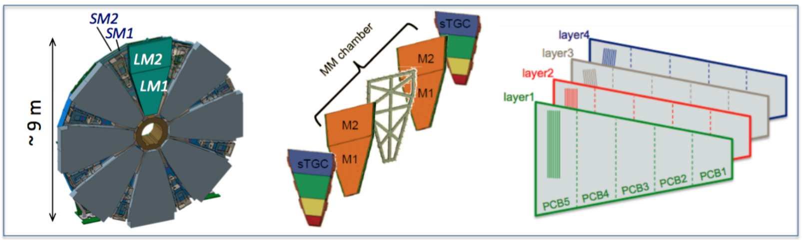

Figure 2: Left: Layout of one of the two NSW; Center: one sector equipped with sTGC and MM wedges; Right: one MM module with eta strips on layers 1 and 2 and stereo strips on layers 3 and 4.

3. Micromegas Components and Construction of the SM1 Modules-0 Prototypes

The basic element of the resistive MM structure is the anode (or readout) board. As illustrated in Fig. 3-left this is produced starting from a 0.5 mm thick FR4 printed circuit board (PCB) with etched copper strips, on which a 50 μm thick Kapton® foil is glued, comprising carbon resistive strips deposited by screen printing. Typical values of the local resistivity are in the range of 10-20 MΩ/cm. Finally, a pattern of 128 μm high pillars with a diameter of 300 μm is created using photolithography. The pillars are required to hold the metallic mesh at the correct distance from the strips, in order to form the amplification gap.

All readout boards have trapezoidal shapes. Depending on the module type and PCB position, the readout board dimensions vary from 40 cm up to 2 meters, with a constant height of about 45 cm. There are 1022 strips per board, with a pitch of 425 (450) μm for small (large) modules. To form the MM quadruplets, the readout boards are assembled on two readout panels.

In Fig. 3 a sketch of the panels composing a MM quadruplet is also shown. It consists of three drift panels, two readout panels and four gas gaps, created by spacer bars around the detector perimeter. The readout boards are disposed in a "back-to-back" configuration on the readout panels. One of them is equipped with eta-strips (parallel to the bases of the trapezoid), while the readout

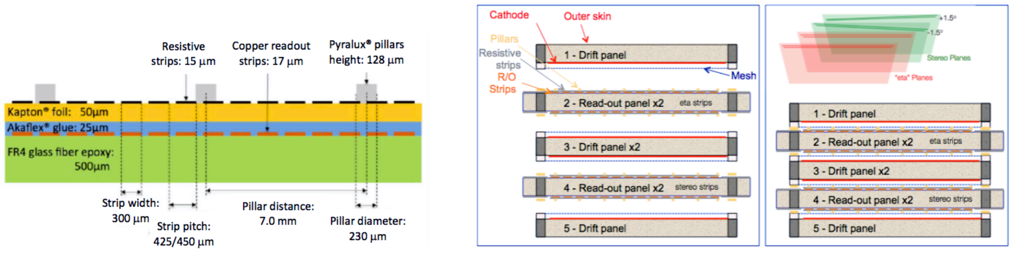

Figure 3: Left: Schematic cross-section through the readout board showing the arrangement and dimensions of the elements of the structure; Center: The five panels before assembly (see description in the text); Right: The assembled quadruplet. In the insert a sketch of the orientation of the eta and stereo strips.

boards with stereo strips are assembled in the second panel. The drift panels integrate the copper cathode plane, the meshes, and the gas distribution system. One central double sided and two external drift panels, sustaining the stainless steel mesh, are coupled to the two readout panels to form the four gas gaps. In each gas gap the mesh separates the drift and amplification gaps, of 5 mm and 128 μm, respectively.

In Fig. 4-left, a photo of one readout panel built for the SM1 module-0 is shown. It consist of a sandwich of a layer with 5 readout boards on one side, and another layer of 5 boards on the second side, glued on a stiffening honeycomb-based structure in the middle, The precision alignment between the assembled readout boards is mechanically reached by precision reference pin-holes. The assembly relies on the stiffback technique, in which the first layer is positioned on the granite table, a second layer on a separate stiffback and then the two parts are assembled and glued together. A very good planarity is reached with this technique. All panels built so far are within the specifications.

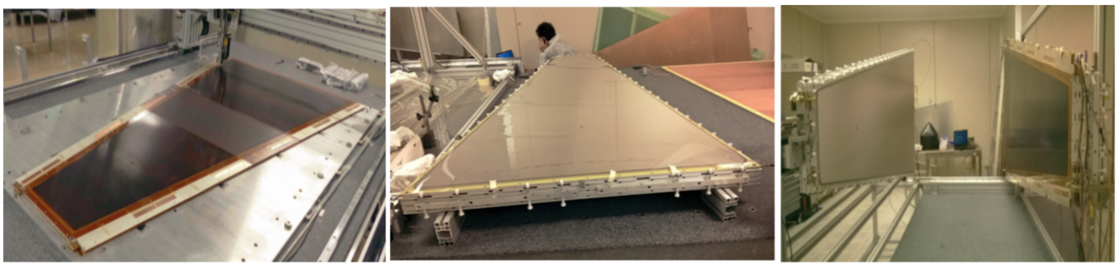

Figure 4: Construction of the SM1 Module-0. Left: the readout panel (INFN-Pavia); Center: the drift panel equipped with the mesh (INFN Roma1 and Roma3 for mesh stretching/gluing); Right: the panels assembly in INFN Frascati.

A similar concept is used to build the drift panels, which must be completed with the gluing of the pre-stretched metallic mesh. In Fig. 4-center, a drift panel equipped with the mesh, for the SM1 Module-0 is shown.

The assembly of all SM1 Module-0 panels to form a quadruplet is carried out in vertical, as shown in Fig. 4-right. The first micromegas Module-0 has been completed in mid-May and shipped to CERN for the Test-Beam in early June. This was a superb achievement of the collaboration, accomplishing one of the most important milestones of the project.

4. Test-Beam Results

In June 2016, the first Module-0 (quadruplet type SM1 built by INFN-Italy) was tested with a 180 GeV pion beam at the SPS H8 Experimental hall at CERN. In Fig. 5 the experimental setup is shown. The beam intensity varied in a range from about 1 kHz up to 0.5 MHz with a spot size of about 1 cm^2. The trigger was formed by a coincidence of three scintillators. The SM1 Module-0 was mounted onto a movable table, with x-y motion perpendicular to the direction of the beam, remotely controlled with a precision of 1 mm. The full setup comprises a set of 5 small-size MM chambers with x-y readout used to reconstruct reference trajectories (Tmm1-5 in the figure). The data acquisition system was based on the Scalable Readout System (SRS) [6] developed by the RD51 Collaboration [7]. The front-end electronics was based on the 128 channels APV25 ASIC [8]. The APV25 will not be employed in the NSW. The front-end ASIC providing the trigger and tracking primitives for both the MM and sTGC will be the VMM [9], currently being produced in its third prototype version. In particular, for the SM1 module, the APV25 front-end card was interfaced to the readout strips by means of a passive adapter board, equipped with zebra connectors. Due to limitations in the available front-end electronics, only the region close to the beam spot was readout (512 strips per layer – see inset in Fig. 5).

The position of the SM1 module with respect to the beam is such that the layers are numbered from 1 to 4, with the strips for layers 1 and 2 parallel to the vertical direction ("eta" strips), and the layers 3 and 4 having the strips rotated by +/-1.5° ("stereo" strips).

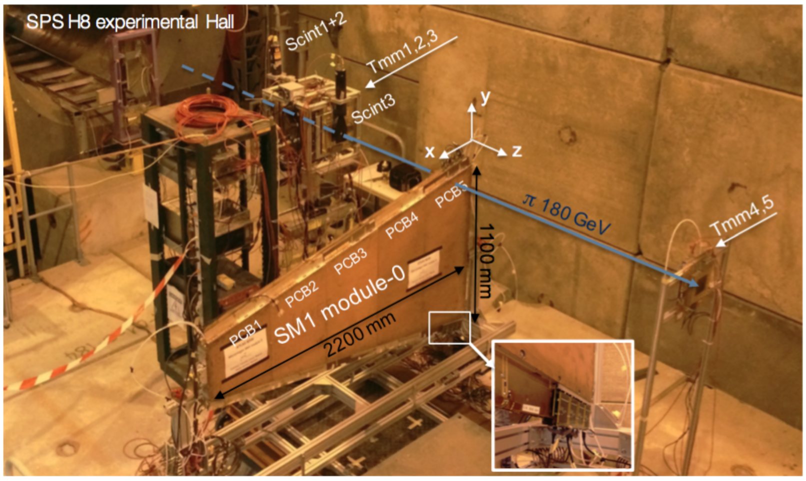

Figure 5: Test-Beam setup. The inset shows the SM1 front-end electronics mounted on the outermost PCB

The chambers were operated with Ar:CO_2 (93:7) gas mixture. Preliminary results on efficiencies and spatial resolutions are reported for perpendicular tracks for the SM1 module operated at 600V/vm electrical field between the cathode and the mesh, and with different values around 45 kV/cm of the amplification voltage between the mesh and the resistive strips. In this case the reconstructed position on each MM layer can be obtained from the charge-weighted positions of the detector hits in the clusters. In Fig. 6-left the efficiency curve of the first layer is shown as a function of the amplification voltage. The efficiency is defined as the ratio of the number of reconstructed clusters on the readout portion of layer-1 and the number of reconstructed tracks from the reference chambers. The turn-on curve is used to establish the optimal working point of the detector. It saturates to full efficiency for amplification voltages $\geq$570 V.

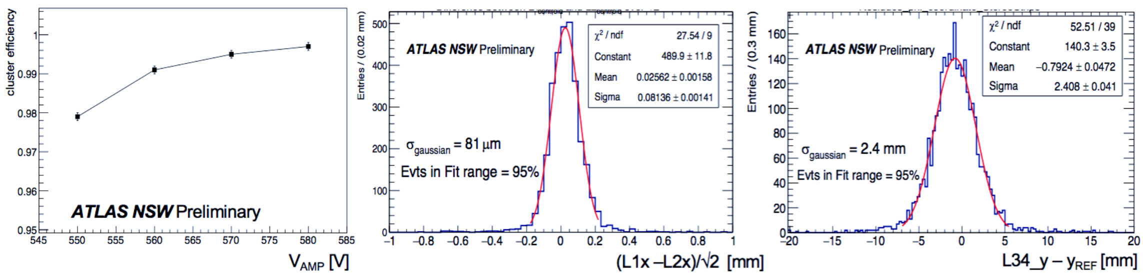

Figure 6: Left: Layer efficiency vs. amplification voltage; Center: Difference of the reconstructed cluster position of the first and second layer of SM1 divided by $\sqrt{2}$; Right: difference of the y-coordinate position, reconstructed with the third and fourth layers of the SM1 chamber and the reference chambers. The spatial resolutions have been measured with $V_{amp} = 570$ V

The spatial resolution for the precision coordinate has been obtained by subtracting the positions reconstructed on layer-1 and layer-2. In Fig. 6-center the distribution of such a difference divided by $\sqrt{2}$ is reported. The width of the distribution is a measurement of the spatial resolution, under the assumption it is the same for the two layers. Its value is 81 μm, well below the required 100 μm, for the precision coordinate.

From the combination of the positions reconstructed on the two stereo layers 3 and 4, the second coordinate position can be measured (vertical in the current setup). The differences with respect to the reference tracks impact points are shown in the right panel of Fig. 6. From the width of the distribution, a resolution of 2.4 mm is measured (assuming a negligible contribution from the reference track error position), which is within expectations.

The measurements of the relative alignment of the strips in different layers was carried out with the beam perpendicular to the module, by performing multiple measurements in a vertical scan. The module was put in position and the deviation from perpendicularity was checked to be smaller than 0.5 mrad (resulting in a bias <25 μm) with an optical survey performed by the CERN EN/ACE measurement survey team[1]. For different impact points of the beam in the vertical direction, the hit positions of the tracks in the different layers are measured with respect to the hit position in layer-1. If the tracks are perpendicular to the chamber, for perfectly aligned layers this difference should be zero as illustrated in the sketch of Fig. 7. The summary plot of the relative differences of each layer with respect to layer-1 is reported in Fig. 7. It shows that all layers are aligned within a maximum deviation of +/- 80 μm. A very good achievement for the first module-0 built, also considering that during the readout panels assembly the final optical tooling that will be used for the series production for the fine control of the boards alignment, was not yet available.

[1] We would like to acknowledge in particular the work of Dirk Mergelkuhl for the measurements

From the plot there are indications of rotation effects (all layers with respect to layer-1) that are currently under investigation.

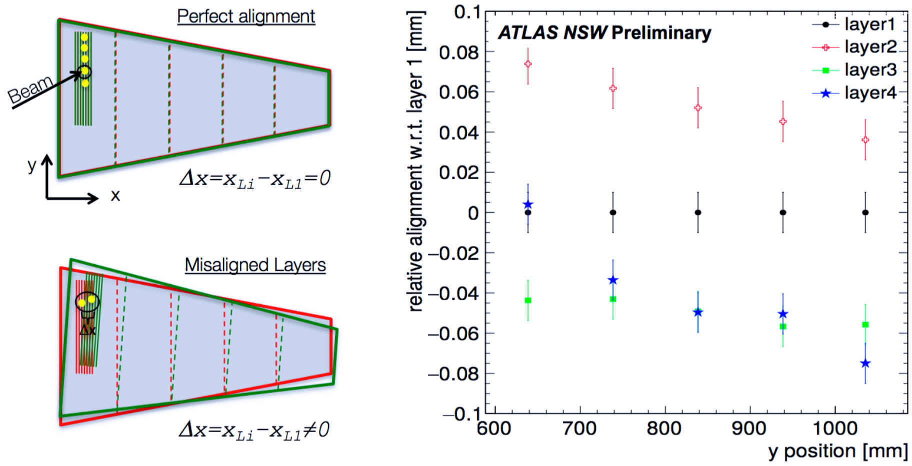

Figure 7: . Left: Illustration of the measurements done to measure the relative alignment of the strips on the different layers; Right: Relative alignment measurements with respect to layer-1 (see text for details).

References

[1] ATLAS Collaboration, *New Small Wheel Technical Design Report*, CERN-LHCC-2013-006.

[2] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, *JINST* **3** (2008) S0800.

[3] A. Abusleme et al., *Performance of a Full-Size Small-Strip Thin Gap Chamber Prototype for the ATLAS New Small Wheel Muon Upgrade*, *Nucl. Instr. Meth.* **A 817** (2016) 85-92.

[4] I. Giomataris et al., *MICROMEGAS: a high-granularity position-sensitive gaseous detector for high particle-flux environments*, *Nucl. Instr. Meth.* **A 376** (1996) 29-35.
J. Wotschack et al., *The development of large-area micromegas detectors for the ATLAS upgrade*, *Mod. Phys. Lett.* **A 28** (2013) 1340020.
M. Iodice, *Micromegas Detectors for the Muon Spectrometer Upgrade of the ATLAS Experiment*, *JINST* **10** (2015) C02026,

[5] T. Alexopoulos et al., *A spark-resistant bulk-Micromegas chamber for high-rate applications*, *Nucl. Instr. Meth.* **A 640** (2011) 110.

[6] S. Martoiu, H. Muller, J. Toledo, *Front-end electronics for the Scalable Readout System of RD51*, *Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC)*, 2011 IEEE.

[7] The RD51 Collaboration, *R&D proposal, Development of MicroPattern Gas Detectors Technologies*, 28 July 2008, CERN-LHCC-2008-011 / LHCC-P-001 14/08/2008.

[8] M.J. French, et al., *Design and Results from the APV25, a deep sub-micron CMOS front-end chip for CMS tracker*, *Nucl. Instr. Meth.* **A 466** (2001) 359.

[9] G. De Geronimo et al., *VMM1 - An ASIC for Micropattern Detectors. Nuclear Science, IEEE Transactions on* **60** (2013) 2314.