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Construction of a large-size four plane micromegas detector

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In view of the use of micromegas detectors for the upgrade of the ATLAS muon system, we have constructed a detector quadruplet with an area of 0.5 m^2 per plane serving as prototypes for future ATLAS chambers. It is based on the resistive-strip technology and thus spark tolerant.

We present the detector concept, the experience with the detector construction, and the first evaluation of the detector with cosmic rays. The quadruplet will be installed in ATLAS in fall 2014, to be operated in real-experiment conditions during the LHC Run2.

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1. Introduction

The instantaneous luminosity of the Large Hadron Collider at CERN will be increased up to 5×10^{34} cm^{-2}s^{-1} by undergoing an extensive upgrade program over the coming decade. The Muon System of the ATLAS detector will also be upgraded; the largest upgrade project is the replacement of the first station in the high-rapidity regions with the so-called New Small Wheels (NSWs), to be installed during the LHC long shutdown in 2018/19[1]. The NSWs will include eight layers of micromegas, arranged in two quadruplets, for a total active surface of more than 1200 m^2. It represents the first system with such a large size based on Micro Pattern Gaseous Detectors.

We have constructed a detector quadruplet with an area of 0.5 m^2 per plane serving as prototypes for future ATLAS chambers. It is based on the relevant improvements developed in the past years, in particular: resistive-strip technology[2] providing spark tolerance and mechanically floating mesh (replacing the bulk-micromegas technique). The solution of a mechanicallly floating mesh allows the disassembling of the amplification structure of the micromegas for cleaning or reparation if needed. This is a crucial point for large-size detectors. The electrical configuration is such that the mesh is grounded and high voltage is applied to the resistive strips. This has been proved to give a more stable operation also for resistive bulk-micromegas. The micromesh is ketpt in place by the electrostatic force acting between it and the readout board, when high voltage is applied on the resistive strips, ensuring that the mesh sits on top of the support pillars.

The quadruplet was built in a modular way. It consists of two double-sided readout panels with 128 μm high support pillars and three support (drift) panels equipped with the micromesh and the drift electrode. The distance of the micromesh from the drift-electrode determines the drift (or conversion) gap. The panels are bolted together such that the detector can be opened and cleaned. Each readout panel represent the readout stage of two micromegas layers in back-to-back configuration. Each readout plane comprises 1024 strips with a pitch of 0.4 mm. Two readout planes have strips running in the x-direction (η-strips), the other two are equipped with readout strips inclined by $\pm1.5^\circ$ with respect to the η-strips. The quadruplet thus delivers track coordinates with a resolution of better than 100 μm in y and 1 mm in x. Figure 1 left shows the design of the micromegas quadruplet. The detector will be installed in ATLAS in fall 2014, to be operated in real-experiment conditions during the LHC Run2.

2. Readout printed-circuit board

The readout printed-circuit board (PCB) has a trapezoidal shape with 1024 400 μm readout strips routed to the sides of the PCB. The electrical contact of the strips with the front-end card is done by mean of Zebra[1] elastomeric connectors. This solution avoids connector soldering on the board. The thickness of the PCB is 500 μm and it is copper-clad on the bottom face. A kapton foil 50 μm thick with carbon resistive strips is glued on top of the readout PCB. The resistive strips have the same pitch of the readout strips; they are all interconnected with a defined pattern and have been produced with sputtering technique[3]. The resistivity of the strips is ≈1 MΩ/cm. Each resistive line is divided in two strips at half-lenght, so that each readout strip is faced to two resistive strips. Each half-strip of each side is connected to all the others at the side of the foil, in such a way

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[1] ZEBRA®) connectors from Fujipoly®): http://www.fujipoly.com/usa/products/zebra-elastomeric-connectors/

a single high-voltage line can power half of the resistive foil. After the gluing of the resistive strip foil, the readout plane is completed by the creation, by photolitography, of the support pillars for the mesh. The pillars are small cylinders 128μm high and 300 μm diameter. The pillar distance is 5 mm.

The PCB has some precision alignment holes to be used during the panel construction and holes on the perimeter of the active area for allowing for screwing of the panel during the detector assembly. A hole in the center of the panel is used for interconnecting the panels to limit the deformation because of the gas overpressure. The readout strips are routed around this hole in order not to have interrupted lines.

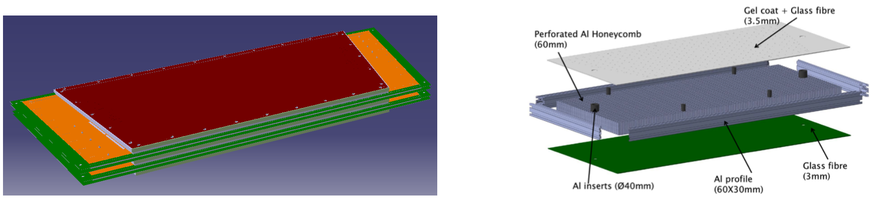

Figure 1: Left: Drawing of the micromegas quadruplet. The two larger planes are the readout panels, sandwiched between two external and a central drift panels. Right: explosed view on the assembly table.

3. Panel construction

Tooling

The panels are constructed with a stiff-back tehnique; to achieve the required precision a dedicated assembly tool has been realized. The tool consists of two stiff assembly vacuum-tables. Each table is made of 60 mm aluminum honeycomb sandwiched between two skins of glass fibre 3 mm thick. One of the skins is covered by a 0.5 mm thick gel-coat layer which is used to realize a flat surface, by using a marble table as reference. The obtained planarity of the surface is $\sim$40 μm; moreover we have observed a temperature dependance of the flatness of the structure.[2] The four sides of the sandwich are closed by aluminum profiles. Holes are drilled in the upper surface of the table and connected to a vacuum system. Figure 1 right shows an explosed view of the assembly table and the map of its planarity.

Panel construction procedure

Each readout panel is composed by two redout PCB skins, described in the previous section, separated by aluminum honeycomb, 11 mm thick and with 9 mm wide cells, and by an aluminum frame all around the panel. The frame is 11 mm thick and 20 mm wide. The readout panels are 20 cm longer than the drift panels (see fig. 1 left) to host the on-detector electronics. The procedure for the panel construction is similar for readout and drift panels (here we refer to the readout panel). It can be summarized in the following seven steps. 1) The upper surface of the readout PCB is prepared to compensate for different heights because of the presence of the resistive foil and pillars in the central part. The $\sim$180 μm difference is compensated by gluing on the naked sides three layers of 60 μm thick adhesive tape, see fig. 2 left. 2) The first PCB skin is placed face down on

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[2] A new vacuum-table made of carbon fiber, offering a smaller temparature expansion coefficient, is currently under construction.

the assembly table. It is positioned by using precise alignment holes (defined in the PCB mask) and peek inserts are positioned on the holes to be used for the chamber assembly (fig. 2 center). 3) The PCB skin is sucked on the assembly table by the vacuum pump, the edges are sealed with adhesive tape. 4) An uniform glue layer is distributed on the PCB surface and the honeycomb and frames are put in position, fig. 2 right. The alignement of the frames is given by holes corresponding to the positions of the peek inserts which fit into the holes. 5) The second PCB skin in placed on the second assembly table and sucked. Glue is distributed on the surface. 6) The two assembly tables are closed to place the second PCB skin on the top side of the panel (fig. 2 right). The alignment of the two PCBs is obtained with the help of reference pins. A precise thickness of the panel is obtained with precise shims between the two stiff-backs, allowing the glue layers to compensate for any honeycomb thickness inhomogeneity. 7) The glue is cured for 24 hours.

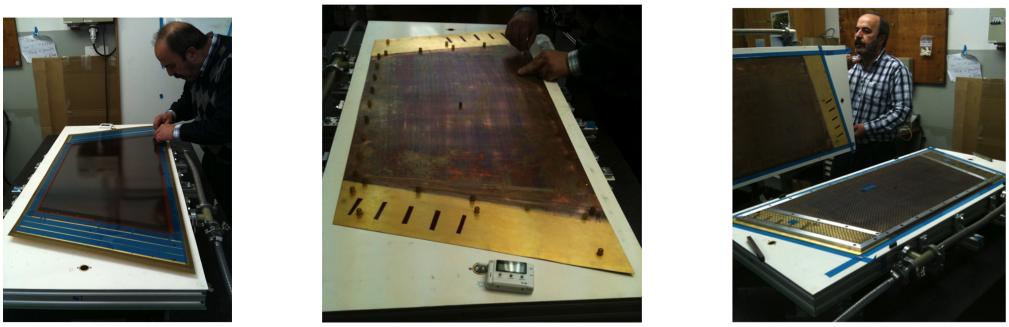

Figure 2: Left: Preparation of the upper side of the readout PCB. Center: Positioning of the peek inserts on the bottom side of the readout PCB. Right: The first PCB skin sucked in the assembly table and equipped with aluminum honeycomb and frames (the double rib of the lateral frames are clearly visible). The second PCB is sucked on the second table.

4. Panel construction results

The quality of the panels is verifyed with several checks. First, a visual inspection is performed to verify the panel integrity and the cleaning (no glue on the external surfaces). Then, two important parameters are measured: the alignment of the strips on the two opposite PCB skins of the readout panels and the panel flatness.

Strip alignment

On the PCB mask the prolongation of two strips every 128 are routed to the side of the panel, these strips can be thus used as reference for the position of the strip pattern. A precisely machined reference pin was inserted in one of the reference holes of the panel. The pin exactly fit in the peek insert inside the panel and its 10 mm head was ensuring a large enough contact surface, see fig. 3 left; the flat surface of the pin is thus parallel to the panel surface. A laser interferometer was used to measure the distance of the reference strips to the center of the reference pin. The same procedure was applied on the second face of the readout panel, the pin was inserted in the same insert but from the opposite side. The acquired data were analyzed by aligning the center positions of the reference pin on the two sides and checking the misalignment of the strips, see fig. 3 center and right. From this analysis we conclude that the strip patterns on the two sides of the readout panel were aligned to better than 20 μm.

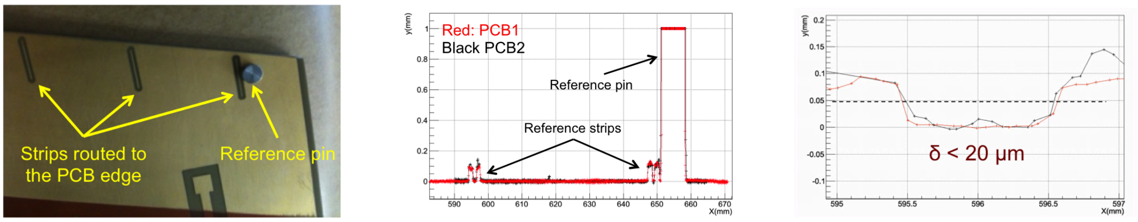

Figure 3: Left: Zoom of one edge of the readout panel showing the reference strips and the precision pin used for measuring the strip alignment. Center: Measurements acquired with the laser tracker. Red and black data points refer to the top (PCB1) and bottom (PCB2) sides of the panel, respectively. The centers of the precision pin in the two measurements have been aligned on the plot with a software procedure, to have a common reference for the two sets of data. Right: Zoom of measurements in the region of two alignment strips. The measurement of the relative alignment of the strip patterns is given by the (mis)alignment of the reference strips. From the plot an upper limit can be set to 20 μm.

Panel flatness

A two-dimensional map of the panel surface was scanned with the laser interferometer. In order to subtract the relative misalignment of the panel with respect to the laser head, the data points were fitted with a plane. The displacements of the points from the fitted plane give the intrinsic shape of the panel, as shown in fig. 4 left for one of the external drift panels. The measurements show an global bending of the panel, in particular in one of the corners; however the overall flatness is below 100 μm rms (fig. 4 right). This result, still encouraging, needs to be improved. The panel flatnes, however, improved after the detector assembly.

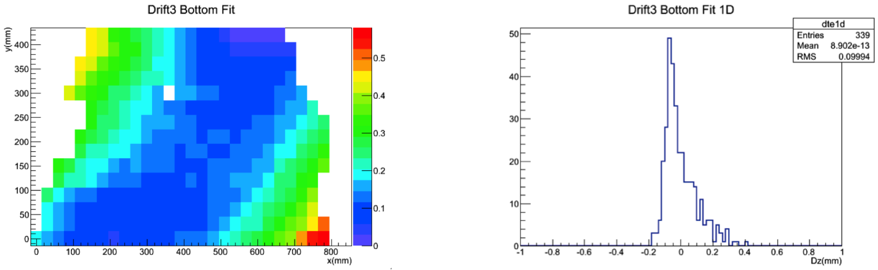

Figure 4: Left: 2-dimensional map of the measured surface of a drift panel, after the fit procedure. Right: Distribution of the differences of each data point with respect to the fitted plane. The rms of the distribution is below 100 μm. The tail is due to the bottom-right corner of the panel.

5. Mesh gluing

The meshes (standard stainless steel woven meshes with 325 lines per inch) are glued on the drift panels. The two external panels have the mesh on one side only; the central panels has two meshes, one on each side. The micromeshes were pre-stretched in industry and glued on a transfer frame. The requested tension was 10 N/cm, but the measured[3]tension varied up to a factor three (from 7 to 20 N/cm) within the same mesh. Even if this parameter is not critical for our application,

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[3] Tensions are measured with an electronic gaude for screen tension (SEFAR Tensocheck 100®).

we aim to a more uniform tensioning for the next detectors. The tension stability was monitored during six months, no relaxation was observed.

The drift panels are equipped with a drift frame glued and screwed (for ground connection) on the perimeter of the panels. The frames are 5 mm height to define the conversion gap inside the detector. Three grooves are machined on the frame: a large one (1.8 mm) to host the o-ring at the moment of the detector assembly and two small ones (250 μm depth) to serve for gluing distribution during the mesh gluing. The frames also have a channel for the gas distribution with holes for gas inlets and outlets, holes for passing through the high-voltage cables and holes to evacuate the water during the washing of the panel (after gluing the mesh). Details of the mesh supporting frame are shown in fig. 5 left. Finally, a central insert is glued on the drift panel in correspondance with the hole where the screw for interconnecting all the panels of the detector will be inserted.

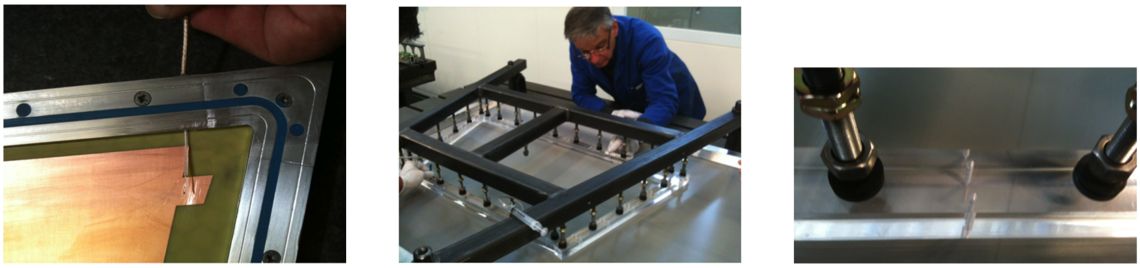

Figure 5: Left: Detail of the mesh supporting frame mounted on the drift panel: the large o-ring groove runs in the center of the frame, at each side two smaller grooves are used for the gluing procedure (see text). The picture also shows the cable for connecting the high voltage to the drift cathode passing underneath the drift frame. Center: The gluing process of the mesh. Right: Particular of the plexiglass frame, showing the channels for the glue injection.

A plexiglass frame has been prepared for the mesh gluing. This frame has the same dimensions as the drift frame with 2 mm diameter holes (channels) which positions correspond to the small grooves in the drift frame (fig. 5 right). The gluing procedure is the following: the panel is placed on an assembly table; the pre-stretched mesh is sit on top of the panel and sandwiched between the drift frame and the plexiglass frame. The plexiglass frame is pressed on the mesh by a metal structure with push-down screws. Once the full structure is in position, glue is injected into the channels of the plexiglass frame and it gets distributed on all the frame surface by capillarity along the small grooves of the frame, fig. 5 center. This procedure allows for a flat gluing surface and good metal contact between the mesh and the drift frame[4]. Particular attension is devoted to the gluing of the mesh on the central insert for the interconnection screw. After 24 hours for glue curing, the gluing structure is removed and the mesh is cut from the original transfer frame. No reduction of the mesh tension was observed at the end of the gluing process. The drift panel is finally completed by removing the part of the mesh which covers the groove for the o-ring (the remaining gluing surface is 8 mm all around the mesh frame). The panel is then washed, dried and equipped with the o-ring.

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[4] Such a contact is important since we use the configuration of micromegas with grounded mesh.

6. Detector assembly

The detector assembly is performed in clean-room. The readout panels need to be carefully cleaned to remove any possible dust from the strip plane, fig. 6 left. The panel stacking is done in steps. The first drift panel is placed on the table with the mesh upward in order to avoid a possible displacement of the o-ring from its groove. The readout panel is then coupled to the first drift panel from the top, by using the assembly screws as guides. The procedure is then repeated for the other panels. The alignment of the two readout panels is achieved with the help of precise pins placed in the inserts of the alignement holes of the PCB. During the assembly process the electrical isolation of the readout plane with respect to the drift plane (ground) is continously checked. Figure 6 right shows the assembled micromegas detector.

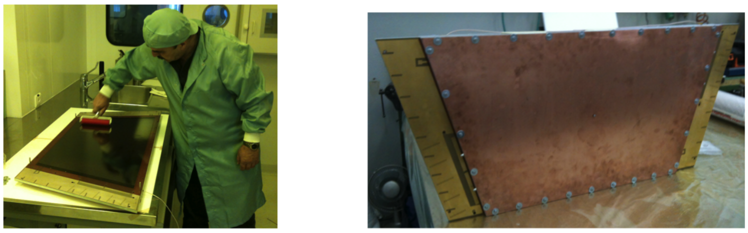

Figure 6: Left: Cleaning procedure of the readout panels. Right: The assembled micromegas detector.

7. Tests

The assembled detector was equipped with APV25 front-end asics, providing analog CR-RC shaped signals sampled at 40 MHz. The APV25 boards were plugged on mezzanine cards inserted on the readout panels, connecting, through Zebra connectors, the readout strips to the Panasonic connectors used by the APV25 boards. This represents the first test of the use of the Zebra connector on a large-size micromegas and a relevant test for the final concept of the front-end boards in the New Small Wheel. Each mezzanine card hosts four APV25 boards, reading out 512 strips; each APV25 card is connected to the ground of the mezzanine card through two Samtec connectors. The same connector type is used for connecting the mezzanine card to the ground of the readout plane.

Preliminary tests were performed at CERN on the ATLAS cosmic ray stand in the RD51 Collaboration laboratory, using two scintillator planes for providing the trigger signal. The gas mixture used was Ar:CO_2 (93:7). The DAQ system was based on the Scalable Readout System with a dedicated software for data taking (MMDAQ).

The detector was operated at an amplification voltage (applied to the resistive strips, the mesh being grounded) of 610 V and a drift voltage (applied to the drift cathode) of -300 V. One high voltage sector (corresponding to one half of a readout layer) was found in short and couldn't be operated. The detector showed clean signals. Figure 7 shows an example of the APV25 signal (left) and the charge and time measured as function of the strip number for a double-track event (right). Figure 8 shows the hit charge distribution fitted with a Landau function (right), well describing the charge distribution over the full range of linearity of the front-end asic response, and a track

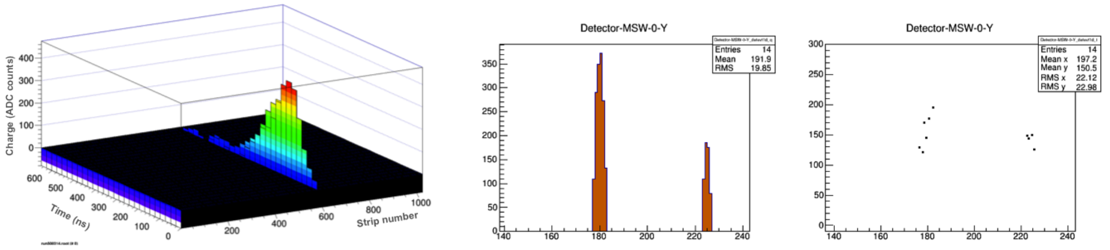

Figure 7: Left: Example of the signal sampled by the APV25 asic. Right: Charge (in ADC counts) and time (in ns) as function of the strip number for a double-track event.

inclined by ~30° with respect to the vertical axis. By measuring the hit time one can use the μTPC method[4] for reconstructing the muon track in the 5 mm wide conversion gap, as demonstrated on small prototypes.

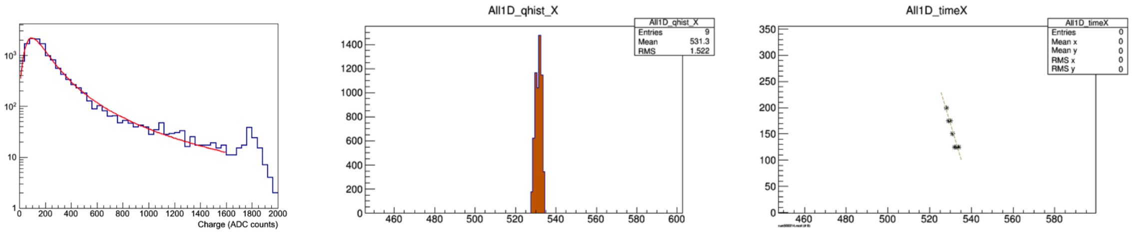

Figure 8: Left: Hit charge distribution fitted with a Landau function. The peak around 1800 ADC counts is due to front-end chip saturation. Right: Charge (in ADC counts) and time (in ns) as function of the strip number for an inclined track.

8. Conclusions and outlook

We have developed the procedure and the tools to build a micromegas quadruplet serving as prototype for the construction for the micromegas for the upgrade of the ATLAS muon spectrometer. The detector is modular. It is composed by two readout and three drift panels, with the mesh mounted on the drift panel. Results of panels construction and detector assembly are satisfying; some critical points (to be improved) have been spotted during the construction procedure. Preliminary test results are encouraging.

The experience shows that reliable construction of large micromegas is possible. This technology is now mature to be industrially produced and to be used in large muon systems. The assembled quadruplet will be installed and integrated in the ATLAS detector to be operated in real conditions during the LHC Run2.

References

[1] CERN-LHCC-2013-006.

[2] Nucl. Instr. and Meth. A640 (2011) 110.

[3] A. Ochi *et. al* Carbon Sputtering Technology for MPGD detectors. Poster presented at TIPP2014

[4] Nucl. Instr. and Meth. A617 (2010) 161.