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Design and construction of Micromegas detectors for the ATLAS Muon Spectrometer Upgrade

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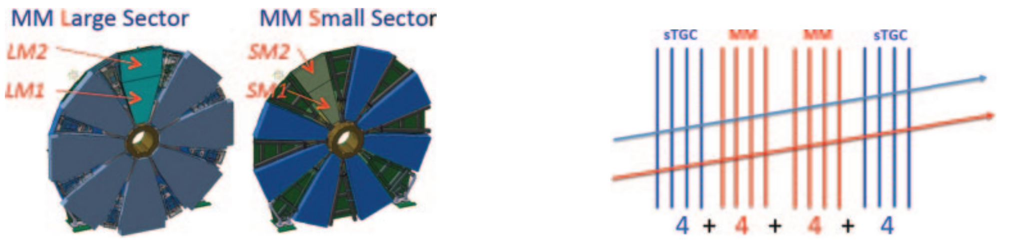
Summary. — Thanks to significant technological improvements, developed during a intensive R&D activity carried out in the last years, large-area Micromegas (MM) will be employed, for the first time, in the High Energy Physics field. Starting from 2019, they will cover a large surface of about $150\,\text{m}^2$ in the forward regions of the Muon Spectrometer. In this paper, the performances of MM chambers and, in particular, the spatial resolution and the efficiency, obtained using data from different test beam campaigns, will be described. Moreover, it will be shown the present status of the Micromegas chambers construction from the Italian INFN groups, focusing, especially, on the construction procedures and the methodologies developed to obtain the challenging required mechanical precision.

1. – The ATLAS Muon Spectrometer Upgrade

Two long shutdowns, LS2 and LS3, are planned for the ATLAS detector, respectively in 2019 (phase-I) and 2024 (phase-II). After LS3, the luminosity will be increased up to $6\text{–}7 \cdot 10^{34}\,\text{cm}^{-2}\,\text{s}^{-1}$ and the number of pile-up events will be ~ 200. Therefore, a very high particle rate in the forward region of the Muon Spectrometer is expected, with a resulting increase of inefficiency with the present detectors. The luminosity increase of the LHC will require an upgrade of the ATLAS detector, in order to keep the present excellent performance in the new running conditions [1]. For this reason, the first muon stations of the high-rapidity region (Small Wheels) will be replaced with the two, so called, New Small Wheels (NSWs), one on each end-cap side of the Spectrometer.

Each NSW will employ Micromegas (MM) and small-strip Thin Gap Chambers (sTGC) detectors, which will allow to reconstruct the muon momentum with a resolution better than 15% at $P_T \sim 1\,\text{TeV}$. Moreover, it will guarantee higher rate capabilities and a better performance for the Level-1 muon trigger.



(a) (b)

Fig. 1. – a) The large and small sectors of the NSW. b) sTGC and MM detector layers in each sector, used for the tracking and triggering in the NSW.

As shown in fig. 1(a) and (b), the NSW will consist of 16 detector planes in two multilayers. Each multilayer comprises four sTGC and four MM detector planes(1). The sTGC are primarily deployed for triggering, given their single bunch crossing identification capability, and secondly for tracking. MM, instead, will provide high precision tracking, but will contribute also in the NWS trigger system. The detectors are arranged in such a way (sTGC MM MM sTGC) as to maximize the distance between the sTGCs of the two multilayers, to improve the online track angular resolution, needed for the L1 trigger.

2. – Micromegas chambers: general aspects and performances

Micromegas (MICRO MEsh GAseous Structure) chambers belong to the family of Micro Pattern Gaseous Detectors (MPGD). As illustrated in fig. 2(a), they consist of a planar electrode (drift cathode), a (Ar : CO_2) gas gap of 5 mm thickness, acting as conversion and drift region, and a thin metallic mesh positioned at 128 μm distance from the readout electrode, creating the amplification region [2]. As shown in fig. 2(b), charged particles, traversing the drift space, ionize the gas. The electrons, liberated by the ionization processes, drift towards the mesh (in some tens of nanoseconds) and in the thin amplification region the electron avalanche takes place (Gain $\sim 10^4$).

Micromegas detectors are characterized by an efficiency greater than 98%. The only dead area of these chambers is due to the pillars, small supports with cylindrical shape, 128 μm high and 300 μm diameter, used to keep the mesh at a defined distance from the board, ensuring, in this way, the parallelism between the mesh and the two chamber planes.

Two methods can be used to reconstruct the track of passing particles: the centroid method, that works very well for perpendicular tracks, and the μTPC method, in which the temporal information is exploited, used mainly for inclined tracks. Combining centroid and μTPC methods, a resolution better than 100 μm can be obtained in the full NSW angular range. A more accurate description of both methods can be found in refs. [1] and [3].

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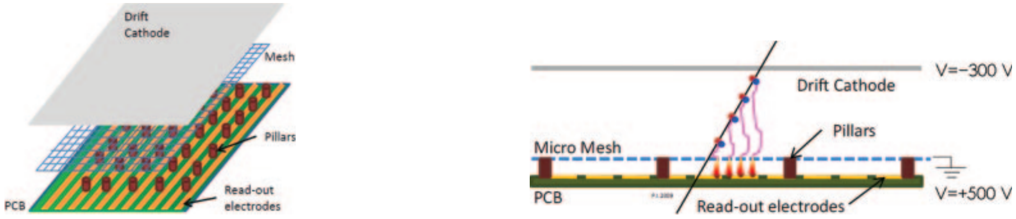
(1) For each MM quadruplet, the first two Read-Out planes have strips running in the x-direction (η-strips) while the other two planes are equipped with strips inclined by ± 1.5 deg with respect the η-strips, for second coordinate measurement.



(a) (b)

Fig. 2. – Layout (a) and operating principle (b) of a Micromegas chamber.

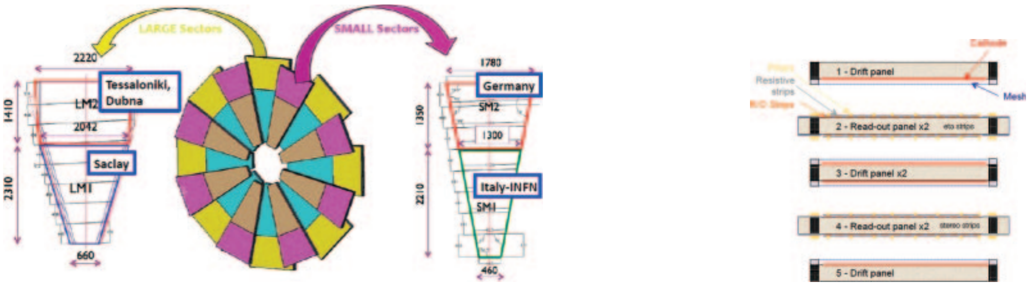
2˙1. *R&D activity.* – The employment of Micromegas chambers in High Energy Physics detectors, such as ATLAS, has been made possible thanks to an intensive R&D activity, started in 2008. First of all, a spark protection system has been developed adding a layer of resistive strips on top of a thin insulator, above the readout electrodes, making MM chambers spark-insensitive [4]. In fact, sparks, between mesh and readout strips, may damage the readout electrodes and lead to large dead times, due to HV drops. In the resistive Micromegas, the charge is collected by resistive strips, capacitively coupled to the read-out strips, which are not anymore directly exposed to the charge created in the amplification region. This configuration offers the possibility to work with higher HV and obtain a greater gain.

The second issue, in which the MM R&D activity focused on, consists in the replacement of the standard *bulk MM* layout, in which the mesh is embedded in the pillars, with the *floating mesh* configuration. In fact, using standard PCB production techniques, it is not possible to realize large surface bulk micromegas, due to the limitation in the dimensions (∼ 60 cm), imposed by the technique of PCB manufacturing [5]. In the floating mesh layout, the mesh is not anymore integrated into the readout PCB, but instead, it is incorporated in the panel containing the cathode plane and simply placed on the pillars, once the chamber is closed. Being the mesh totally decoupled from the Read-Out panel, it is also possible to disassemble the amplification region from the rest of the chamber, for cleaning and reparation, if needed. This configuration however, imposes very challenging mechanical precision.

3. – MM Construction: overview on the Italian production sites

In fig. 3(b) the quadruplet MM layout for the NSW is shown. It consists of 3 drift panels and 2 Read-Out (RO) panels. The RO panels have the electrode strips on each side, while, concerning the drift panels, the two external ones have the mesh on one side only and the central panel has two meshes, one on each side. The assembly of the five panels results in a stack of four gas gaps. In Italy, the manufacturing of NSW SM1 sectors of MM chambers, shown in fig. 1(a), will be shared among different INFN groups. The Italian construction sites will be Roma-1, Roma-3, Pavia and LNF, while the Napoli, Lecce and Cosenza INFN groups will contribute with QA/QC tools and other technical supports to the construction. As shown in fig. 3(a), the SM1 sector has a trapezoidal shape, with a 2210 mm height and 1300 mm (460 mm) long (short) base.

3˙1. *Read-out and drift panel.* – The Pavia INFN group will be committed for the coming years in the read-out panel production. This represents one of the most delicate phases of the whole MM chamber construction; in fact, the required mechanical precision



(a) (b)

Fig. 3. – a) Layout of the NSW and production site for each sector. b) Layout of the MM quadruplet.

on large surfaces is a hard challenge for the construction of these detectors. In order to obtain the required momentum resolution, each element of the detector has to be known with an uncertainty better than 30 μm, along the precision coordinate (η-strips), and 80 μm for the coordinate perpendicular to the plane. To achieve the required precision, dedicated assembly tools have been realized and two different techniques will be used to realize RO and drift panels: the *stiff-back*, employed in the Pavia workshop, for the construction of RO panels, and the *vacuum-bag*, developed Roma-1 [6], for drift panels.

Each panel, both RO and drift, is composed by two PCB skins, separated by aluminium honeycomb, 10 mm thick and with 6 mm wide cells, and by an aluminium frame all around the panel. The frame is 10 mm thick and about 30 mm wide. Although two different techniques will be employed by the Pavia and Roma-1 INFN groups for the panel manufacturing, the construction procedure is very similar. The stiff-back technique can be summarized in the following steps [7]:

1) The first PCB skin is placed face down on the assembly table. It is positioned by using precise alignment holes and peek inserts are placed on the holes to be used for the chamber assembly. The PCB skin is then sucked on the assembly table by the vacuum pump and the edges are sealed with adhesive tape.

2) A uniform glue layer is distributed on the PCB surface and the honeycomb and frames are put in position. The alignment of the frames is given by holes corresponding to the positions of the peek inserts which fit into the holes. The glue is distributed also on the surface of the second PCB skin.

3) The second PCB skin is placed on the top side of the panel. 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, allowing the glue layers to compensate for any honeycomb thickness inhomogeneity. Finally, the glue is cured for 24 hours.

3˙2. *Mesh stretching.* – The mesh stretching will be performed by the Roma-3 INFN group, which has already realized a stretching table for real size modules and, also, obtained good results during the first stretching tests. The most recent result showed a high uniformity level of the tension measured point per point on the mesh(²), with a mean value of about 10 N/cm and relative standard deviation smaller than 8%. In this

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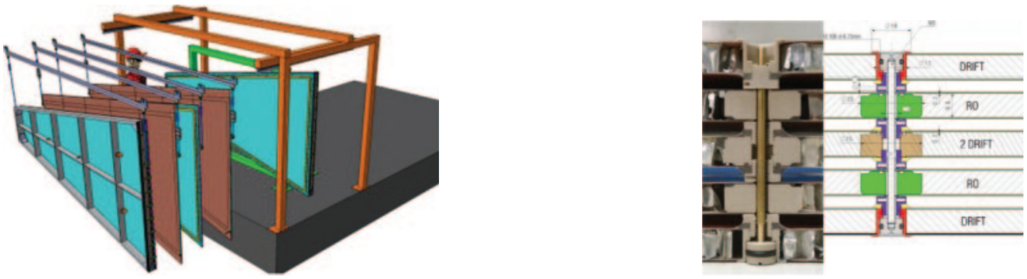
(²) The tensions on the mesh are measured by means of *SEFAR Tensocheck 100*.



(a) (b)

Fig. 4. – Sketch of the procedure of a MM quadruplet assembly. b) Picture and sketch of an interconnection in a MM quadruplet: the screw pass through each panel, as well as each mesh layers.

way, a high level of flatness for the mesh, once mounted on the MM chamber, should be guaranteed. Drift panels are equipped with a drift frame glued and screwed on the perimeter of the panel, on which the mesh, once stretched, will be glued. The frames are 5 mm height to define the conversion gap inside the detector. The mesh will be first stretched, then embedded into a double layer transfer frame and moved to LNF where the assembly will take place in a clean room. Here, it will be glued on the aluminium drift frame and once the mesh is glued, the whole panel is washed, dried and equipped with the o-ring.

3˙3. *Assembly and test.* – The assembly of the five detector panels will be done vertically in a clean room at LNF, as shown in fig. 4(a), in order to reduce possible deformations in the center of the panels, due to their own weight and also to avoid contamination from impurities falling on the panels during the assembly. Each chamber is equipped with reference pins and inserts, that will provide a very high accurate alignment. The full module will be equipped, also, with four interconnections, shown in fig. 4(b), along the central axis, in order to reduce deformations caused by gas overpressure and to guarantee more stiffness to the assembled module. Once each MM quadruplet is completed, it will undergo mechanical and HV tests. Moreover, it will be exposed to cosmic rays at the construction site and, finally, to high irradiation at the *CERN Gamma Irradiation Facility* (*GIF++*), in order to check the quality of the final product and, also, to study the detector performances.

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