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# Validation of the New Small Wheel MicroMegas sectors for the spectrometer of the ATLAS experiment at CERN

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**Summary.** — The inner forward part of the ATLAS muon spectrometer has been substituted by new detectors able to work with excellent performances at the final design luminosity of $7.5 \times 10^{34}$ cm$^{-2}$ s$^{-1}$ foreseen for the HL-LHC phase. MicroMegas detectors (MM, MICRO MEsh GASeous structure chambers) have been chosen for the New Small Wheel (NSW) muon tracking since they are Micro-Pattern Gaseous Detectors, designed to provide excellent resolution and efficiency, even in a highly irradiated environment. Before being mounted on the mechanical structure, each MM sector is characterized and tested at CERN in terms of high voltage stability and tracking efficiency. Results are presented and some dedicated studies on performances are shown.

## 1. – ATLAS and the NSW

ATLAS [1] is one of the main experiments at the Large Hadron Collider (LHC) [2] and is undergoing the Phase1 upgrade. The old Small Wheels were the innermost muon spectrometer stations in the forward region (End-Cap) covering a pseudorapidity range of $1.3 < |\eta| < 2.7$ and were composed by Cathode Strip Chambers and Monitored Drift Tubes (Thin Gap Chambers for the 2nd coordinate reconstruction). An improvement in the performances was required in the NSW [3] both for the trigger and the track reconstruction in view of the increasing luminosity of the LHC (up to 5–7 $\times 10^{34}$ cm$^{-2}$ s$^{-1}$) to maintain or even improve the performances of the detector. MicroMegas (MM) and small Thin Gap Chambers (sTGCs) were chosen as fast detectors able to perform precision tracking ($\sim$100 $\mu$m per plane) and to cope with the increasing background particle flux as luminosity increases while rejecting fake triggers.

The NSW (fig. 1) has a wheel-like structure and it is composed of 16 sectors: 8 small (SM1 and SM2) and 8 large sectors (LM1 and LM2) whose production is distributed between several industries and institutes. Each sector is a sandwich of 2 sTGC and 2 MM Wedges (*i.e.*, detector quadruplets). Each MM Wedge has 4 detection planes and is formed by 2 detectors one after the other (type 1 and type 2) with 8 PCB in total.

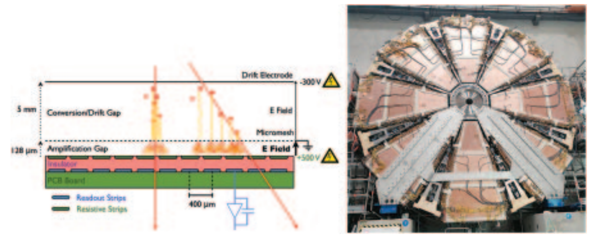


Fig. 1. – Left: working principle of a MM chamber. Right: NSW wheel structure.

## 2. – MicroMegas operating principles

The resistive MM chambers [4] are frontier Micro-Pattern Gas Detectors with a planar geometry as shown in fig. 1 operating in a gas mixture of Ar-$CO_2$ (93%–7%); studies ongoing on a new ternary gas mixture will be presented later. As shown in fig. 1, MM detectors are designed to have a capacitive coupling reading of the signal on copper strips (300 $\mu$m wide and with a pitch of 425–450 $\mu$m); resistive strips are at $\sim$570 V and superimposed to the copper strips to mitigate the intensity of discharges. The detector is really compact, with 5 mm conversion gap between the cathode (at $-300$ V) and the floating mesh (which is grounded and defines the transition between the conversion and amplification gaps). MM have fast ions evacuation ($\sim$100 ns), very good mesh transparency and the amplification gap, between the read out (RO) printed circuit boards (PCBs) and the mesh, is only 128 $\mu$m wide, having an high electric field ($\sim$45 kV/cm) on a surface of $O(\mathrm{m}^2)$.

Each MM chamber is a quadruplet of 4 gaps formed by 5 stiff panels when coupled: 2 RO panels, based on boards of industrial production, and 3 drift panels composed of cathode PCBs and 4 meshes. Two out of four RO layers have strips inclined $\pm 1.5°$ in order to reconstruct the 2nd coordinate exploiting the stereo concept. Resistive strips are screen printed with equidistant interconnections to have uniform resistance across the PCB, with a design resistivity of $\sim$10 M$\Omega$/cm [5]. This peculiar structure allows the detector to be re-opened for intervention since the mesh is not glued; each PCB is divided into 2 HV sections, having in total 40 and 24 independent HV channels respectively for the type 1 (5 PCBs per layer) and type 2 (3 PCBs per layer) ATLAS MM chambers.

## 3. – MM construction: challenges and solutions

Mechanical requirements were stringent and demanding: 36 $\mu$m of precision in $\eta$ on strips positions over meters was required on strip alignment on each layer and was reached by mechanical supports to the PCB during panel construction together with optical measurements (Rasnik technique [6]) of reference masks etched on the PCB's sides. The technological transfer of RO PCBs production with extremely high quality (pillars shape, resistivity homogeneity, quality of the PCB edges) was one of the most delicate points since, during construction, we faced a serious problem of HV stability, whose solution was affecting different aspects of the production. The main issues and solutions were identified to be: the residual ionic contamination of boards and panels from industrial processing and handling, that was addressed by improving the cleaning procedures, possible effects from mesh mechanical imperfections addressed by implementing mesh polishing, clear correlation of currents with humidity addressed by monitoring the internal humidity and

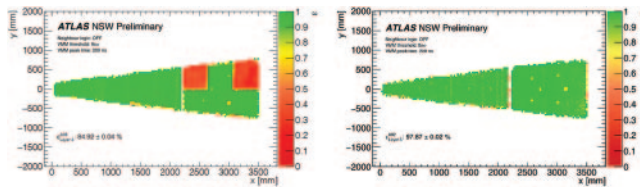


Fig. 2. – Left: tracking efficiency of one layer with 2 bad HV sections. Right: tracking efficiency of one fully working layer.

increasing the gas flux and the low and non uniform resistance of the resistive layer and the strong dependence on the layout (design issue) linked to the non-uniformity of the resistive paste distribution via the screen printing technique, that has been solved with the edge passivation technique [7]. Having this in mind, observing the clear correlation between the minimum resistance and the HV sustained by each section, and mainly with the passivation solution, we managed to address the HV issue. In order to gain the most from all the benefits introduced, a new HV scheme has been proposed, with 3 times more HV channels to cope with weak sections and allowing us to run with only few % of sections not at nominal voltage.

## 4. – MM for the NSW: Double Wedges integration and surface commissioning

Once at CERN, the MM detectors were mechanically assembled in Double Wedges, *i.e.*, 2 detector Wedges and fully tested with cosmics using a self tracking method. Efficiency results are shown in fig. 2 for a layer with 2 HV sections not at nominal HV and a fully working one. For a single layer fully working (electronics and HV) we achieved efficiencies at the level of 98%. Commissioning involved all the validation steps of the sectors installed on the wheel, taking 2 full days after service installation. It involved the preparation of the MM DW for the installation, then cooling, LowVoltage, DAQ, tests on the electronics, gas leak and HV tests. During the wheel A surface commissioning, a relevant problem had to be faced regarding the level of noise on the electronics, which was not affordable at all and led us starting investigating the noise source (fig. 3). After critical months of investigation and studies, the main issues were identified in the grounding quality and in the power distribution, therefore grounding was reinforced with additional braids on the detector bases and RO PCBs, the power distribution was refurbished by adding an output common mode filter and a capacitive filter to cut the common mode noise (2–10 MHz) and the T-sensors power modules grounding was improved. Similar issues were observed by sTGC, with similar solutions.

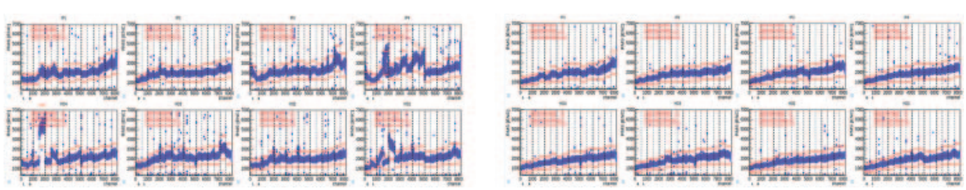

Fig. 3. – Noise level in Equivalent Noise Charge (ENC) of 8 layers (IPX, HOX with X = 1, 2, 3, 4) of a specific MM sector before (left) and after (right) the actions taken on the noise.

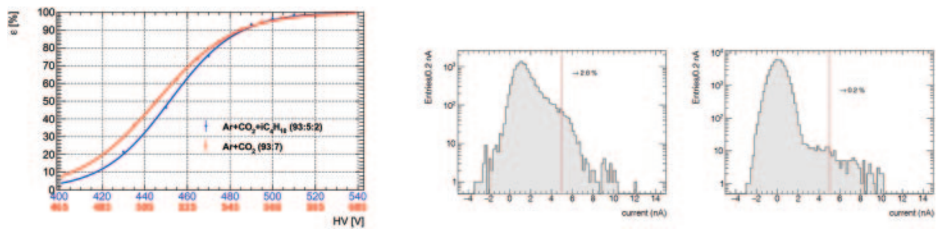


Fig. 4. – (a) Efficiency turn on curve comparing 2 gas mixtures: Ar:$CO_2$ 93:7 and Ar:$CO_2$:i$C_4H_{10}$ 93:5:2. (b) Stability in current in Ar:$CO_2$ 93:7 (left) and Ar:$CO_2$:i$C_4H_{10}$ 93:5:2 (right) gas mixtures.

## 5. – Testing the ternary gas mixture: Ar-CO2-Iso 93-5-2

Isobuthane (i$C_4H_{10}$) is a quencher, therefore it helps in stabilizing the current and dumping the spikes, also allowing to run at significantly lower amplification voltages with equal gain and efficiency, typically $-60$ V on the HV with respect to the binary gas mixture as shown in fig. 4(a). It has been observed that bad HV-sectors behave better while adding Isobutane, improving the sparking picture and allowing for better performances. As shown in fig. 4(b) we can appreciate the stability of the same HV section at nominal voltage in Ar:$CO_2$ 93:7 (570 V) and at 520 V in Ar:$CO_2$:i$C_4H_{10}$ 93:5:2. The improvement in stability, even in the case of a good behaving section, is clear and quantified also by the number of sparks above 5 nA, which, in the case of the ternary gas mixture, are one order of magnitude less. Studies are ongoing at GIF++ at CERN, in parallel with the NSW installation in ATLAS, in order to investigate ageing effects. The first results show that all the problems observed in few HV sections becoming resistive (chambers have been retested with cosmics, re-opened, repaired and re-assembled) were due to weak points independent of the gas mixture. What emerged was anyway fixed by re-opening the chambers, confirming it as a great opportunity.

## 6. – Conclusions

MM chambers will be used for the precision tracking in the NSWs of the ATLAS experiment at LHC starting from Run3. Thanks to the deep knowledge acquired in the past years, we managed to address the main issues affecting the MM detectors (mostly HV issues and noise issues) in time for the installation. Studies with Isobutane enriched gas mixture show promising results in terms of improving the performances of the chambers and we aim to use it right from the start. It has been an incredible work done by the collaboration during such hard times and an impressive achievement that has been possible thanks to the commitment and dedicated effort of hundreds of people.

REFERENCES

[1] ATLAS Collaboration, *JINST*, **3** (2008) S08003.
[2] Evans L. and Bryant P., *JINST*, **3** (2008) S08001.
[3] ATLAS Collaboration, CERN-LHCC-2013-006 (2013).
[4] Giomataris Y., Rebourgeard P., Robert J. and Charpak G., *Nucl. Instrum. Methods A*, **376** (1996) 29.
[5] Alexopoulos T. *et al.*, *Nucl. Instrum. Methods A*, **640** (2011) 110.
[6] Beker M. *et al.*, *JINST*, **14** (2019) P08010.
[7] Alexopoulos T. *et al.*, *Nucl. Instrum. Methods A*, **955** (2020) 162086.