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Road for LHC Run III: The ATLAS New Small Wheel and the MicroMegas chambers performances(*)

L. Martinelli([1])([2]) on behalf of the ATLAS Collaboration

([1]) *INFN, Sezione di Roma - Roma, Italy*
([2]) *Dipartimento di Fisica, Sapienza Università di Roma - Roma, Italy*

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Summary. — The two New Small Wheels (NSWs) for the upgrade of the Atlas Muon Spectrometer are now installed in the experiment and ready to collect data in LHC Run III, which started in July 2022. The NSWs are the largest phase-1 upgrade project of ATLAS. Its challenging completion and readiness for data taking is a remarkable achievement of the Collaboration. The two wheels (10 meters in diameter) have replaced the first muon stations in the high-rapidity regions of ATLAS and are equipped with multiple layers of two new detector technologies: the small-strip Thin Gap Chambers (sTGC) and the MicroMegas (MM). The latter are used in such a large scale in HEP experiments for the first time. Each detector technology will cover more than 1200 m^2 of active area. The new system is designed to assure high tracking efficiency with a precision measurement of muon tracks together with a reduction of fake trigger rates in view of the higher background environment of the Hi-Lumi LHC programme. In this presentation, the motivation of the NSWs upgrade and the steps from the commissioning to the data taking together with the first results using the Run III data will be presented, focusing on the MicroMegas performances.

1. – The ATLAS New Small Wheel upgrade

Following the shutdown periods of the Large Hadron Collider (LHC) [1] in 2019-2022 and 2025-2027, there will be a factor 5÷7.5 increase in the instantaneous luminosity compared to the initial design specifications [2]. To ensure that the ATLAS detector [3] can continue functioning effectively in this more challenging high-background environment, significant upgrades are required for certain components of the ATLAS Muon System.

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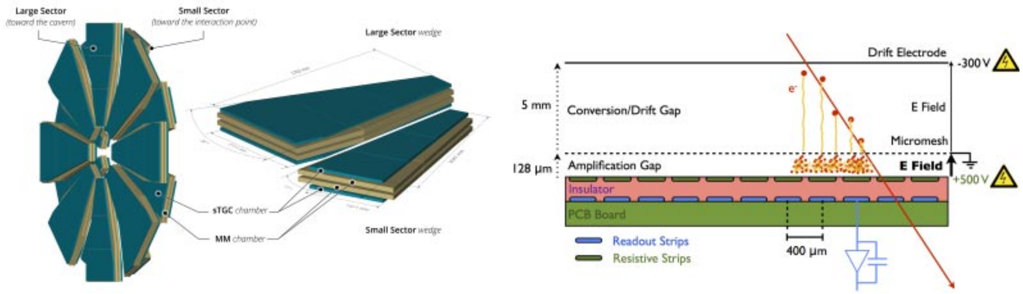

(a) (b)

Fig. 1. – (a) Two NSW sectors, one small and one large, are shown together. The MicroMegas will not be visible (gray chambers), sitting between the two sTGC quadruplets (green chambers). (b) Sketch of the layout and operating principle of a MicroMegas detector [4].

The most extensive upgrade project for the ATLAS Muon System involves the replacement of the current first station in the forward regions with a new set of detectors referred to as the New Small Wheels (NSWs). Two distinct technologies, namely Micro-Mesh Gaseous Structures (abbreviated as MicroMegas or MM) and small-strip Thin Gas Chambers (sTGC), have been selected due to their capability to meet the essential criteria of position accuracy, efficiency, and timing at the expected high-background rates.

The NSWs system [4] is comprised of sixteen detector planes arranged in four multilayers placed in the following order sTGC-MM-MM-sTGC from the innermost to the outermost part of the experiment. Each of the two NSWs consists of eight large and eight small sectors, as shown in fig. 1(a). The total active readout area of all the MicroMegas chambers across both wheels amounts to approximately 1280 m^2. Figure 1(b) provides a schematic representation of the layout and operational principle of a MicroMegas detector, as described in [4].

MicroMegas chambers possess a distinctive design characterised by two highly dissimilar regions. Typical MicroMegas detectors include a planar electrode, a gas gap of 5 mm thickness (drift region), and a fine metallic mesh situated at a distance of 128 μm from the readout electrode (amplification region). In the NSWs region of the ATLAS muon system, where particle rates can reach up to 20 kHz/cm^2, the risk of sparking in MicroMegas detectors becomes a concern. Consequently, a resistive anode MicroMegas was developed, involving the addition of a layer of resistive strips placed on top of a thin insulating layer directly above the readout electrodes. Signals are induced through capacitive coupling with the readout strips, which are no longer directly exposed to the charge generated in the amplification region.

2. – MicroMegas issues and solutions

During the construction and integration phase on the NSWs, several issues on the MicroMegas chambers have been addressed. The high-voltage stability was one of these issues due to the presence of sparks inside the gas gap. Two main causes of this problem were found and solved. The resistive circuit on the readout boards, created using the screen printing technique, displayed a low resistance at the board edges, which fell below the acceptable threshold. Consequently, Araldite passivation has been employed on the

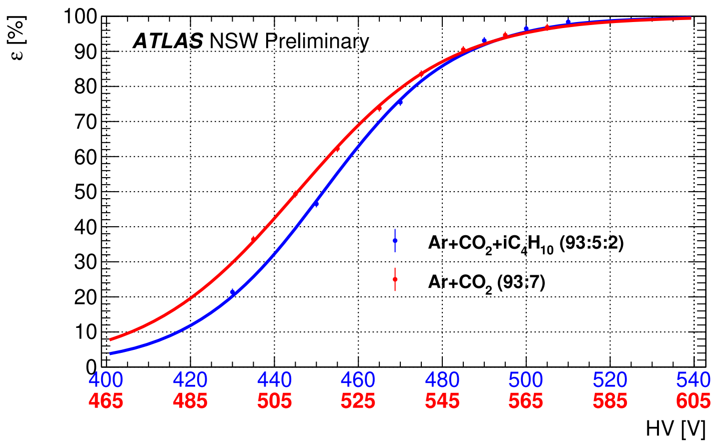

Fig. 2. – MicroMegas single layer efficiency as a function of the amplification voltage for the old gas mixture Ar:CO_2 (93:7%) [red] and the new one Ar:CO_2:iC_4H_{10} (93:5:2%) [blue]. Two different x-axis scales are used in the plot showing a different turn-on curve for the two gas mixtures but the same efficiency plateau. [5].

edges to increase the edge resistance to an acceptable level. In addition, several gas mixtures were tested and the $Ar : CO_2 : iC_4H_{10}$ (93:5:2%) was found to have the same performance in terms of efficiency, as shown in fig. 2, reducing the applied voltage on the readout board and therefore reducing the probability of a spark. While conducting the Wheel Commissioning at CERN, which includes various validation steps for sector installation, a significant challenge was the level of electronic noise. The primary problems were traced back to the quality of grounding and power distribution. Consequently, the grounding was strengthened by introducing additional braids on the detector bases and readout PCBs, and the power distribution was overhauled by incorporating an output common mode filter and a capacitive filter to eliminate common mode noise.

3. – Preliminary performances status of the ATLAS NSWs

Since before the start of Run III (July 2022), the NSWs were included in the ATLAS data acquisition during the LHC special runs with *splashes*([1]) or collisions with reduced centre-of-mass energy (900 GeV). In fig. 3 the first NSWs reconstructed combined muon (track reconstructed using information from the Inner Detector and the Muon Spectrometer) is shown.

Using the first Run III data, the early performances of MM chambers were analysed in terms of cluster charge, cluster size and efficiency as a function of the high-voltage. The NSWs reconstruction efficiency is also studied using the majority of 4 out of 8 MicroMegas layer on-track or 4 out of 8 sTGC layer on-track. The NSWs efficiency map with the described criteria is reported in fig. 4 showing that more than 95% of the muons are correctly reconstructed by the NSWs.

([1]) A single bunch of protons from the LHC that hits a collimator placed in the beamline and generating a large number of particles.

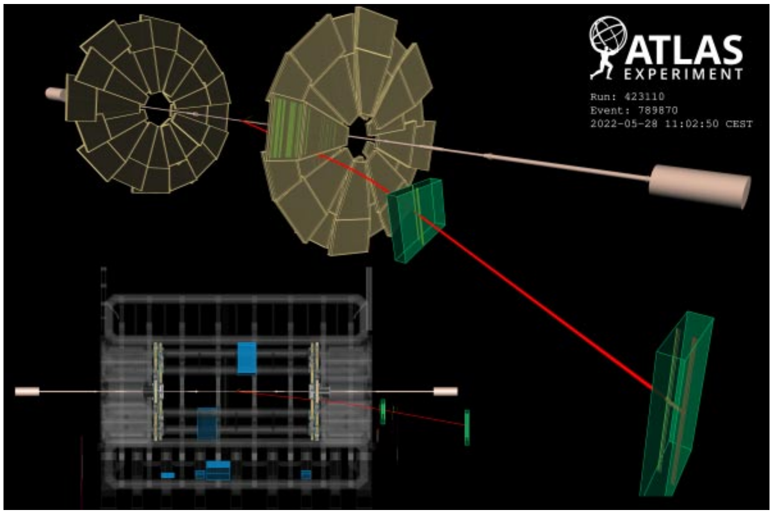

Fig. 3. – Event display of a collision event recorded in ATLAS. The red line shows a muon candidate reconstructed using the NSWs [6].

Position reconstruction for muons remains sub-optimal for both technologies, illustrated in fig. 5. The single-point resolution is adversely affected by residual layer-layer misalignment and the as-built geometry. It is anticipated that a significant enhancement in resolution will be achieved after addressing and rectifying these effects.

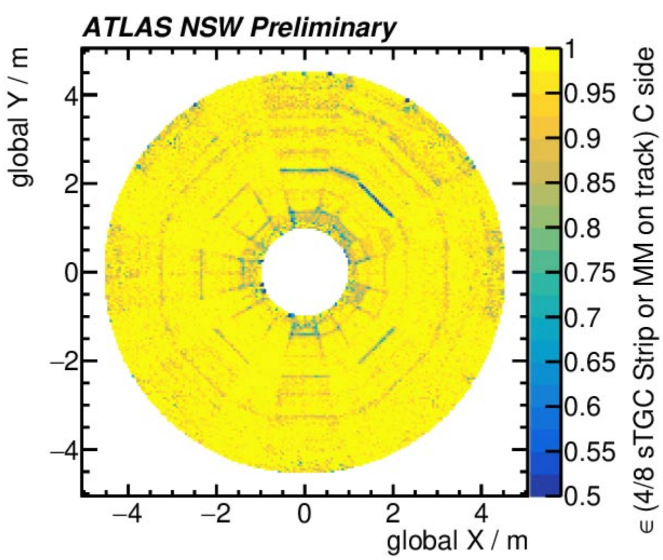

Fig. 4. – Efficiency for having at least four out of eight layers of either MicroMegas or sTGC strips associated to a muon Combined (ID+MS) or Standalone (MS) track with $p_T > 15\ GeV$ passing through the NSWs [7].

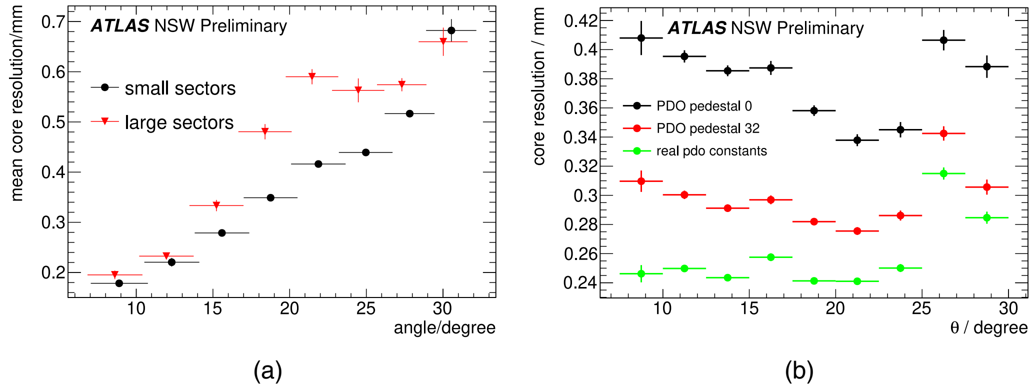

Fig. 5. – (a) MicroMegas position resolution extracted by comparing the cluster position on two neighbouring layers [7]. (b) sTGC resolution for different values of the charge calibration of the readout electronics [7].

4. – Conclusions

The New Small Wheel was one of the largest projects to upgrade the ATLAS experiment at LHC. More than 10 years were needed to complete it, with several issues addressed, including the delays due to COVID. Nevertheless the NSWs are integrated in ATLAS and they are contributing to the muon reconstruction.

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