Micromegas sectors for the ATLAS muon upgrade, towards the installation of the New Small Wheel in 2021

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Abstract: The ATLAS experiment is currently upgrading the first muon station in the high-rapidity region with the construction of new detector structures, named New Small Wheels (NSW), based on large-size multi-gap resistive strip Micromegas (MM) technology and small-strip Thin Gap Chambers (sTGC). The NSW is being installed in the ATLAS underground cavern during the on-going LHC long shutdown 2 to enter operation for run 3. 128 Micromegas quadruplets, each of which provides four measurements of a particle track, are needed to build the two New Small Wheels, covering a total active area of about 1280 m$^2$. The construction of all MM modules, carried out in France, Germany, Italy, Russia and Greece, is completed. Their mechanical integration into sectors, and the installation of on-detector services and electronics for the first NSW is also completed, along with all validation and acceptance tests. The preparation of the second NSW is well advanced. The advanced status of the project, in view of the imminent installation of the two NSW in ATLAS by the 2021 is reported. The integration workflow of Micromegas detectors into sectors is described with focus on cosmic rays results of the final validation tests.

Keywords: Micropattern gaseous detectors (MSGC, GEM, THGEM, RETHGEM, MHSP, MICROPIC, MICROMEGAS, InGrid, etc.); Muon spectrometers; Particle tracking detectors (Gaseous detectors); Performance of High Energy Physics Detectors
The ATLAS New Small Wheel (NSW) upgrade

After the Large Hadron Collider [1] shutdowns in 2019–2022 and 2025–2027, the instantaneous luminosity will be increased by a factor 7.5 with respect to the design value [2]. To still be able to operate in the higher background environment and to maintain its current excellent performance, some parts of the ATLAS detector [3] need important upgrades. The largest upgrade project for the ATLAS muon system is the replacement of the present first station in the forward regions with the so-called New Small Wheels (NSW). Two technologies, Micro-Mesh Gaseous Structures (MicroMegas, MM) and small-strip Thin Gas Chamber (sTGC) can meet the requirements in terms of position resolution, efficiency, and timing at the expected high background rate.

The NSW [4] consist of sixteen planes of detectors arranged in 4 multi-layers each with 4 planes. These are, from the inside to the outside of the experiment, sTGC-MM-MM-sTGC. The sTGCs will be mainly used for the trigger, given their ability to identify products from single bunch crossing while the MicroMegas will be mainly used for tracking. Each of the two New Small Wheels comprises 8 large and 8 small sectors as shown in figure 1 with a total active readout area of all the Micromegas chambers of about 1280 m².

MicroMegas chambers are characterised mainly by their two very asymmetric regions. Standard MicroMegas detectors consist of a planar electrode, a gas gap of a few millimetres thickness acting as conversion and drift region, and a thin metallic mesh at 128 μm distance from the readout electrode, creating the amplification region. Since, in the NSW region of the ATLAS muon system particle rates can reach the order of 15 kHz/cm², the risk of sparking for the MicroMegas can increase. Therefore a resistive anode Micromegas was developed which involves the addition of a layer of resistive strips placed on the top of a thin layer of insulating material directly above the readout electrodes. Signals are induced through capacitive coupling with readout strips, that are no longer directly exposed to the charge produced in the amplification region. The typical internal structure of a MicroMegas is shown in figure 1.
2 MicroMegas validation and testing phase at CERN

Each module built in the construction sites is shipped to CERN to pass to the validation phase. This consists of replicating the high-voltage (HV) and gas leak tests carried out after construction, to verify that they have not degraded with transport. Four different modules of two different sizes are then integrated together to form the so-called double-wedge. This procedure is followed by the alignment between the modules and the installation of all the services. Each double-wedge is equipped with the final electronic boards. To collect the signal directly from the strips, 16 MMFE8 (Front-end Electronics) cards per layer are used. The last step of the validation procedure is the study of the performance of each double-wedge. This is done through a dedicated cosmic ray stand installed at CERN in building 899, close to the integration station. Scintillators are used to trigger events while the double-wedge is placed under them.

Efficiency measurements

Once the track is reconstructed using the other double-wedge layers, the efficiencies are measured using the extrapolated track position on the surface of the tested layer. A simple clustering algorithm groups neighbouring strips into clusters which are used to fit the track. The position of the cluster is reconstructed using the centre of gravity method [4]. If a cluster is found within $5\sigma$ from the expected position on the precision coordinate (where $\sigma$ is the RMS of the distribution obtained from the residuals between the layer under analysis and the track) the layer is considered efficient. The nominal gas mixture Ar:CO$_2$ (93:7%) is used with the nominal voltage of 570 V. In figure 2 the efficiency map for a single layer of a double-wedge and the behaviour of the efficiency as a function of the applied HV are shown.

Resolution studies

To be less dependent on the goodness of the track reconstruction and on external factors, such as mis-alignment between layers$^1$ and wedges, it is possible to estimate the resolution of a layer by simply subtracting the reconstructed positions between two layers. In figure 3 (left) the residuals are shown for perpendicular tracks. The resolution is obtained fitting the residuals between two

$^1$In this way, the measurement is only dependent on a roto-translation between the two layers under examination.
layers with a double-Gaussian function to take into account also the tails. The measured core resolution is $109 \pm 2 \, \mu m$, as expected with low-momentum muons [4].

**Figure 2.** (Left) Single layer efficiency map measured with an applied HV of 570 V. (Right) Micromegas single layer efficiency as a function of the amplification voltage [5].

**Figure 3.** (Left) Residuals between two layers of the same double-wedge fitted with a double-Gaussian. $\sigma_{\text{core}}$ corresponds to the width of the narrower Gaussian while $\sigma_{\text{weight}}$ is the weighted average of the two Gaussians [5]. (Right) Micromegas single layer efficiency as a function of the amplification voltage for the nominal gas mixture Ar:CO$_2$ (93:7%) [red] and the alternative one Ar:CO$_2$:iC$_4$H$_{10}$ (93:5:2%) [blue]. Two different x-axis scale are used in the plot showing a different turn-on curves for the two gas mixture but the same efficiency plateau.

**Studies with different gas mixtures**
A dedicated study on an alternative gas mixture is also carried out to eventually improve the HV stability of the detector. Previous results with the detector operated with a mixture Ar:CO$_2$:iC$_4$H$_{10}$ (93:5:2%) have shown that sparks are greatly reduced with this mixture. The efficiency as a function of the amplification voltage is also measured and shown in figure 3 (right).

**3 MicroMegas integration**
Once the double-wedge Micromegas are validated, they are integrated together with the sTGCs to form the sector to be mounted on the NSW. The commissioning of the complete sectors on the wheel consists of repeating the tests already carried out to check HV stability, to check for any new gas leaks and to test the entire final data acquisition chain.
4 Noise studies

Noise levels higher than expected have been observed when the detectors are installed on the wheel, affecting the level of charge threshold that can be applied to the MM electronics. A modification of the grounding scheme together with the addition of Faraday cages on some specific electronics boards have reduced the noise levels. Studies performed at the cosmic stand show that the effect of the strip charge thresholds increase on the single plane efficiency is of few percentage loss up to 40 mV, as shown in figure 4.

![Micromegas single layer efficiency as a function of the average threshold applied to the MMFE8. Typical noise level is up to 30 mV and, considering the electronic gain of 9 mV/fC, this corresponds to about 3.3 fC. The black points are the average values of each bin and the red curve is a 2nd order polynomial fit [5].](image)

5 Conclusions

At the time of writing, both NSWs are installed in the experiment. Performance studies show that the MicroMegas are behaving as expected. Results with the Ar:CO$_2$:iC$_4$H$_{10}$ show a more stable HV behaviour for MM and long term aging study are on-going. Major effort to fix the unexpected high noise levels were invested and the remaining effects have negligible impact on the NSW performance.

References

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