The Micromegas Surface Commissioning For the ATLAS New Small Wheel

Athina Kourkoumeli-Charalampidi\textsuperscript{a}, Dimitrios Fassouliotis\textsuperscript{b}

\textsuperscript{a} INFN Pavia, Italy
\textsuperscript{b} National Kapodistrian University of Athens, Greece

E-mail: athina.kourkoumeli@pv.infn.it

Abstract. In order to cope with the required precision tracking and trigger capabilities from Run III onward in the ATLAS experiment, the innermost layer of the Muon Spectrometer end-cap (Small Wheels) will be upgraded. Each of the two New Small Wheels (NSW) will be equipped with eight layers of MicroMegas (MM) detectors and eight layers of small-strip Thin Gap Chambers (sTGC), both arranged in two quadruplets. MM detectors of large size (up to $3 \text{ m}^2$) will be employed for the first time in HEP experiments. Four different types of MM quadruplet modules (SM1, SM2, LM1, LM2), built by different Institutes, compose the NSW. The modules are then sent to CERN, integrated into double wedges (DW), tested and sent for commissioning on the wheel itself. At the commissioning stage the MM double wedges along with the sTGC wedges are assembled together into sectors which are then installed and tested on the wheel. Each wheel comprises 8 small (made of SM1 and SM2 modules) and 8 large (made of LM1 and LM2 modules) sectors, in order to provide full coverage of the end caps.

The first of the two wheels (NSW-A) has been fully commissioned, installed in ATLAS and the first tests are currently ongoing. The second wheel (NSW-C) is currently under commissioning and is expected to be ready by October this year.

1. Introduction

A substantial part of the Phase-I upgrade of the ATLAS experiment [1] consists of the replacement of the existing Small Wheels in the end-cap region of the Muon Spectrometer with the NSW [2] (figure 1) in order to maintain a high performance of the muon tracking chambers as well as acceptable Level-1 trigger muon fake rates in a high luminosity environment ($\mathcal{L} = 2 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ in Run III and later on $\mathcal{L} = 5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ in Run IV). The NSW will feature two detector technologies, one focusing on the Level-1 trigger function (sTGC) and one primarily used for precision tracking (MM detectors [3]).

The NSW surface commissioning takes place in a large area at CERN where the sector assembly, the sector installation and surveying, the services routing and connections, as well as the sector operational validation are performed. The MM double wedges as well as the sTGC wedges are put together in a sandwich configuration to form a trapezoidal sector. The MM doubles wedges are made of 8 active layers with 8 PCBs per layer for the readout and high voltage (HV) distribution. Each PCB has two HV distribution lines (called HV sections) and 1024 readout strips.
Once the sector is assembled and aligned, it is ready to be installed on the wheel. The tooling used to lift and rotate a sector is shown in figures 2 and 3, where the installation procedure of a sector is shown. When a sector is fully installed, the services can be routed and connected. This includes Cu pipe connections for gas and cooling, fibers for detector readout, high voltage and low voltage (LV) cables and temperature sensor cables. Dedicated detector control systems (DCS) are available to control and monitor the high voltage and the electronics and data acquisition (DAQ) procedures are implemented to fulfill all the commissioning tests.

Several tests at various stages of the services connection and the commissioning phase are necessary to ensure that no damage had occurred during transportation, installation and services routing and that the sector is within the specifications required to successfully run and record data with high performance.

The commissioning phase can be divided into two paths that can be performed in parallel. The first path consists of the gas and high voltage connections and validation. The second path concerns the cooling, the low voltage and the read-out fiber connections, which are certified by continuous monitoring via the DCS systems and performing a variety of signal readout tests.
2. Gas and high voltage
The resistive-strip MM detectors [4], which are used in the NSW, utilize ArCO$_2$ 93:7 gas mixture, while a quenching mixture ArCO$_2$iC$_4$H$_{10}$ 93:5:2 is also being considered and tests are being performed with both gas mixtures at the DW cosmic ray stand and at the gamma irradiation facility (GIF++). The two active volumes on each detector layer, are supplied with -300 V ($E \sim 600$ V/cm) for the cathode (drift region) and +560 V ($E \sim 50$ kV/cm) for the anode (amplification region) for the nominal ArCO$_2$ mixture. For the ArCO$_2$iC$_4$H$_{10}$ mixture the operating voltage is the same for the cathode and +510 V is applied on the anode. At the commissioning stage only the nominal gas mixture has been used.

MM detectors are prone to instabilities such as sparks and high currents that can be created due to impurities or defects in the gas volumes, high humidity levels, ionic contamination etc. For that reason the HV configuration has been upgraded to a higher granularity system where one HV channel is distributed per PCB, which means that for each layer the 16 HV sections are controlled by 8 HV channels.

2.1. Gas leak tests
In order to maintain high efficiency levels, the gas tightness of the MM DW has to be certified after its installation. A portable device based on the flow rate loss method is used for this reason. When the gas tests are concluded, the sector can start being flushed with gas. The chamber is initially flushed with higher rates ($\sim 50$ L/h) in order to allow the relative humidity within the chamber to slowly drop to below 11% before starting to raise the HV levels. Below this level of relative humidity it has been shown that the probability of sparks is greatly reduced and so it is considered safe for operation. It can take a few days for the volume to reach such levels because it greatly depends on the atmospheric conditions. Once the relative humidity is decreased and the volume flushed for days, the flushing rate can be decreased to 10-20 L/h.

2.2. High voltage tests
Once the HV lines are connected to the power supplies through dedicated splitter boxes, which allow an HV channel to feed a PCB and thus two HV sections, connectivity tests are performed and, when the relative humidity levels allow it, the HV can be raised. The HV is initially raised in steps in order to allow for some “conditioning” to occur, which burn any dust residues within the gas volume.

A stable HV behaviour is defined as one that has a mean current below 10 nA and a discharge rate less than 1 spark/min where a spark is defined at a peak in a current above 50 nA. Once the HV reaches the optimal operation values, the sector is left running for at least 24 hours under stable conditions for it to be considered validated. The HV validation of a sector should be concluded in less than a week in order to follow the tight schedules.

As a result of data taken from cosmic runs at the double wedge integration stage at CERN, where runs were taken for various HV values, the level of the HV can be associated with an efficiency. This efficiency of course does not take into account issues with electronics connections and readout, but it gives a good overview of how the HV performs on different parts of the sectors. An average efficiency higher than 85 % is needed for an MM DW to be accepted.

It is important here to note that the time for sector conditioning at the commissioning stage has been very limited due to the strict deadlines imposed by the ATLAS schedule. Such short conditioning in many cases does not allow all the HV sections to reach their full HV potential. Still, the possible efficiency drops can be overcome through the partial overlap of large and small sectors but also through the use of the ArCO$_2$iC$_4$H$_{10}$ mixture where cosmic test results have shown that in these areas the efficiency can increase to above 90%.
3. Cooling and read-out electronics

This part of the commissioning involves checking the cooling connections and tightness as well as the water regulation in order to avoid an increase of temperature on the electronics boards. In parallel to this, the LV connections are performed, both on the detector side and on the power supply side. Then the connectivity is checked through the LV DCS which also allows to power on all the electronics boards. Once the cooling is provided and the electronics are all powered on, the DAQ can start and several sets of data are acquired and analyzed.

3.1. Cooling and temperature sensors

The water flow in the cooling pipes on the wheel is checked before the installation of the sectors, where potential leaks are also fixed, but once a sector is installed and connected, the flow within the detector pipes needs to be verified too. Any abnormalities in the water cooling, such as air trapped in the pipes or connection problems, can be deduced through monitoring the temperature sensors positioned both on the surface of the detector panels and on the detector cooling pipes themselves. The temperature sensors are also monitored through a dedicated DCS.

3.2. Read-out electronics validation

Each sector has 16 low voltage distribution boards (LVDB) which power both the 128 front-end readout boards, known as MMFE8, as well as the 32 data-driver boards, known as LiDDC and ADDC. The readout chain is based on optical link technology as well as differential line signal transmission. The communication between MM detectors and the outside world (USA15 when the wheels are installed) is achieved through optical fibers which should be bundled into multi-fiber termination push-on cables through custom designed patch panels. One of the most delicate jobs therefore is to connect the fibers coming from the detector to the patch panels and test the communication both through signal attenuation measurements, via a wavelength emitter and receiver, and through the DCS. Once the low voltage is connected and fiber connections are checked, the read-out electronics validation is performed.

![Figure 4: An example of the RMS of a baseline in ENC for a sector layer. The points in blue refer to the results of the commissioning tests at building 191, while the points in red refer to the DW integration tests at BB5. Copyright 2021 CERN for the benefit of the ATLAS Collaboration. CC-BY-4.0 license.](image-url)
Several types of runs are recorded to characterize each of the 65536 electronic channels for each MM sector. First the baselines are recorded to identify the levels of the electronic noise. Then, thresholds are set for each electronic channel and subsequently random trigger runs are performed using these thresholds to validate them. Pulse runs are used for the calibration of the readout channels and the validation of the trigger path. Finally, the high rate communication electronics which will be used at the HL-LHC are also validated.

Figure 4 shows a typical example of the baselines measurement. The RMS of the baseline in ENC for each VMM (comprising 64 electronic channels) for an entire sector layer is presented. The points in blue refer to the results of the commissioning tests at building 191, while the points in red refer to the DW integration tests at BB5. As expected the RMS of the baselines, which represent the noise levels, grow linearly with the strip length. A very good agreement between the measurement at BB5, where the MM DW is operated alone and the one recorded after the installation on the NSW can be observed. This was not the case at the beginning of the surface commissioning effort. Increased levels of noise were observed at the time and great effort was put by the NSW community to understand and solve this issue. Many improvements were imposed, with the most significant being the addition of specific filters on the LV power supplies and improved grounding on specific areas of the detector electronics.

Figures 5 and 6 show two more examples of the commissioning data taking. Figure 5 shows the thresholds set on the 512 electronic channels of one of the 128 front-end boards. The homogeneity of the threshold values can be observed. Figure 6 shows the results of the connectivity test performed to validate the trigger path on one sector, where excellent response of all the electronic components can be observed.

Using the available infrastructure, the performance of the electronics of three sectors can be tested in parallel for NSW-C.
4. Cosmic tests
The most important part of the commissioning is the sector testing with cosmic rays. However, this is mainly done after the integration of the MM DW at BB5, where the chambers are tested in horizontal position. After the installation on the wheel the chambers lay in vertical position and only a few samples of cosmic ray data were acquired. The trigger can be provided in various modes; with scintillators, with MM auto-triggering, or by using the trigger from the sTGC detectors. Although all the methods are being developed, the one used up to now during the surface commissioning uses a set of scintillators positioned with a special structure in front of the sector. The muon cross section is very low due to the wheel inclination and the access and run time have been very limited due to the strict commissioning schedule, so efficiency measurements have not been achieved, but clear tracks have been observed which demonstrate the functionality of the MM detectors on the wheel. An example can be seen at figure 7.

5. Conclusions
The NSW commissioning of the wheels is a significant part of the project as this is the first time that full sectors are tested and installed on the wheel. The procedure is very complex and through it various issues and weaknesses came to light, which introduced delays on the overall schedule but also led to resolving those weaknesses which otherwise would have appeared in the pit.

The NSW-A has been fully commissioned (figure 8) and is installed in the ATLAS cavern. All the connections have been performed and it is currently being tested. The NSW-C on the other hand will be fully commissioned by the end of September and will be installed in the ATLAS cavern in November when access will be granted.
Figure 8: NSW-A fully commissioned and ready to be transported to the ATLAS cavern. Copyright 2021 CERN for the benefit of the ATLAS Collaboration. CC-BY-4.0 license.

6. Acknowledgements
This work was supported by the European Union and the ESPA 2014-2020 National Fund for Research Infrastructures DeTanet. The authors would like to thank the ATLAS Muon collaboration and all colleagues from the New Small Wheel sTGC and MM communities.

7. References
[1] ATLAS Collaboration, The ATLAS Experiment at the CERN Large Hadron Collider, JINST 3 (2008) S08003.
[2] ATLAS Collaboration, ATLAS New Small Wheel Technical Design Report, CERN-LHCC-2013-006 ATLAS- TDR-020-2013 (2013).
[3] I. Giomataris et al., Micromegas in a bulk, NIM A 560 (2006) 405.
[4] T. Alexopoulos et al., A spark-resistant bulk-Micromegas chamber for high-rate applications, NIM A 640 (2011) 110.