New Small Wheels for the ATLAS Muon Spectrometer

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Abstract. The ATLAS collaboration at Large Hadron Collider (LHC) has chosen the Large size multi-gap resistive strips Micromegas (MM) technology along with the small-strip Thin Gap Chambers (sTGC) for the High Luminosity (HL) upgrade of the first muon station in the high-rapidity region, the so called New Small Wheel (NSW) project. The NSW is expected to be installed in the ATLAS underground cavern in the current long shutdown. After the R&D, design and prototyping phase, series production MM and sTGC chambers are being constructed. At CERN, the final validation and integration of the modules in sectors composing the wheel is well advanced. The achievement of the requirements for these detectors revealed to be even more challenging than expected, when scaling from the small prototypes to the large dimensions. In this document the main challenges of the project, the adopted solutions and performance results are presented.

1. Introduction
The HL-LHC aims to achieve instantaneous luminosity of $7.5 \times 10^{34}$ cm$^{-2}$s$^{-1}$. In order to cope with the increased particle rate, the experiments are required to follow a series of upgrades. For the ATLAS experiment the major upgrade of the Muon Spectrometer is given by the New Small

![Image of NSW position and assembly]

Figure 1. Left: The NSW position within the forward region of the ATLAS Muon Spectrometer. Right: The NSW assembly with 7 of 8 Small Sectors in B191 facility.
Wheel project, which will replace the current Small Wheel as the innermost station of the forward detector, covering the the pseudorapidity of \(1.3 < |\eta| < 2.7\) region. The main Muon system upgrade goals are:

- Improve the tracking efficiency in the high rate environment.
- Reduce fake triggers from background hits. Currently, 90% of the forward muon trigger rate is given by fake muons, and this turns out to be intolerable [1].

The NSW (Figure 1) consists of resistive-strip Micromegas detectors and small-strip Thin Gap chambers which both provide tracking and triggering capabilities. Each wheel will be composed by eight large and eight small sectors. Each sector hosts two wedges per detector technology. Each of the 16 sectors will be equipped by the following configuration: sTGC-MM-MM-sTGC. A MM double wedge (DW) is composed by two modules, SM1,2 for the small DWs and LM1,2 for the large DWs. Each module is a quadruplet, thus providing 4 detection layers through the detector thickness, for position measurements in the radial (precision) and in the azimuthal coordinates. This structure allows each sector to provide a total of 16 active layers through the \(z\) coordinates. The sTGC wedge is composed by three modules, QS1,2,3 for the small wedges and QL1,2,3 for the large wedges. This structure allows each sector to provide a total of 16 active layers through the \(z\) coordinates. Thus, the sTGC-MM combination forms a fully redundant detector system for triggering and tracking with both online and offline functions. The NSW MM detectors will cover an active area of 1280 \(m^2\).

1.1. MICRO MEsh GAseous Structure - primarily tracking detector
The MM is a type of parallel plate gaseous detector. Thanks to the metal mesh separating drift and amplification regions, MM is able to track particles with a precision of order 100 \(\mu m/detection\) gap while withstanding a particle rate up to around 20 kHz/cm\(^2\). Free drift electrons arisen from gas ionization, move in the electric field, pass through the mesh and then induce signal on the readout strips through formed avalanches in the amplification region [3].

1.2. Small Strip Thin Gap Chamber - primarily trigger detector
The sTGC is a multiwire chamber, comprising the anode plane, located between two parallel cathode planes. On one side, there are strips that are perpendicular to the wires and on the opposite side, there are pads for triggering. The sTGC system allows to trigger on tracks with an angular resolution of 1mrad) at trigger level. A complete description of the NSW system can be found in ref. [1].

2. Electronics Integration & Validation
The whole NSW structure includes 128 detectors, in total to \(\sim 2.1\) million readout channels. This new generation of readout electronics should be tolerant in the harsh radiation hostile conditions. At the same time the compatibility to the upgraded trigger rates (1 MHz expected rate capability, 400 kHz in the two-stage scheme) should be adjusted. Four different electronic boards are mounted on the MM DW while for the sTGCs three are used. Each MM DW has 16 Level-1 Data Driver Cards (L1DDC), 128 MicroMegas Front-End Boards (MMFE8), 16 Low Voltage Distribution Boards (LVDB), 16 Address in Real Time Data Driver Cards (ADDC). A sTGC wedge has 8 L1DDCs, 4 LVDBs, 12 FE Boards (pad and strip FEBs). The functionality of the MMFE8 board is based on the VMM chip, a custom Application-Specific Integrated Circuit (ASIC), where each channel is connected to the corresponding detector readout strip. The signal of each strip transmitted to the Analog-to-Digital Converters (ADCs). Measurements like the charge and timing are performed [4]. The NSW electronics for the trigger and Data AcQuisition (DAQ) (Figure 2), path of both detectors can be divided into two major categories, the on-detector and the off-detector electronics. The on-detector electronics (detector
area with radiation and magnetic fields) consist of custom made boards mainly using radiation tolerant Application Specific Integrated Circuits (ASICs). The communication between these boards will be established with the use of mini Serial Attached Small Computer System Interface (SCSI) (miniSAS) cables. The off-detector electronics (Front End LInk eXchange (FELIX),

![Diagram](image)

**Figure 2.** New Small Wheel trigger and data acquisition dataflow.

trigger processor, sector logic and services running on commercial server Computers like Read Out Drivers (ROD), Detector Control System (DCS), event monitoring, configuration of boards, trigger monitor and calibration) will be placed outside the cavern in an area without radiation or magnetic fields [2].

After the integration, baselines are taken to validate the performance of the FE board by measuring the VMM noise and by identifying dead/noisy channels. Also pulser runs are carried out to cross check the number of dead channels with those taken from baselines and perform an overview of the electronics. Finally readout and trigger electronics integration, HV and the first DAQ chain validation and measurements on the cosmic ray stand follow.

### 3. High Voltage Validation

Each fully equipped MM double-wedge is tested at the cosmic stand, in order to set the optimal HV settings, to check the full data acquisition chain and measure the efficiency before the final integration into a NSW Sector. HV instabilities that can be attributed to the features of the large-size chambers have been observed in all the first full-size MM prototypes. The choice of a resistive strip anode readout was actually driven by the need of protecting the amplification gaps from discharges, that would naturally arise from various weak points of such a layout possibly related to the mesh, dirt and imperfections. In some cases the resistivity protection proven to be not enough. A long R&D program has been carried out to mitigate this problem and this allowed to improve significantly the HV behaviour of the chambers. The MM HV values of all the 128 HV-sections of a MM DW are defined as follows:

- **Operating gas mixture**: Ar + 7% CO\(_2\). However, studies on alternate gas mixture are ongoing.
- **Operating voltages**: Drift cathode at -300 V, Micro-mesh at ground, Readout at +570 V.
- A moderately unstable HV-section still can be operated at a lower value on a separate HV line (which is referred to as the hospital line). A very unstable HV section is turned off during HV-validation.

The sTGC HV validation is done by keeping the nominal voltage for 1 month with proper gas mixture (nPentane/CO\(_2\) (45%/55%)). For this time term no sparks should be detected and no HV trip.
4. NSW performance validation

After the optimal HV configuration, a sequence of tests follows, i.e. noise levels, data taking chain, track reconstruction and efficiency measurements. The latter is performed with the use of external scintillators for trigger purposes. The MM setup consists of 2 pairs of scintillators providing a 120 Hz trigger covering partially the detectors along $\phi$ coordinate. Some of the studies mentioned before are shown in Figures 3-4.

![Figure 3. Mean MM cluster charge as a function of the the incident angle $\theta$ taken from the track reconstruction using the other layers of the double-wedge (see the plots here).](image1)

![Figure 4. Micromegas efficiency as a function of amplification voltage (HV) for chambers tested with cosmic muons (see the plots here).](image2)

5. Conclusion

The two NSWs are expected to be finalized and installed in ATLAS in the LS2. This schedule is very challenging. Among the main challenges we quote the following: 1) New electronics system: Separate sTGC & MM new readout architecture, several different frontend/backend electronics that have to provide precise segments in the trigger and precision hits for muon reconstruction. The reduction of noise levels (noise rate, spark rate) is a main electronic challenge. 2) New TDAQ: Up-to-date using FELIX and Software ROD. System is still in developing mode. Focusing on data format and running functionalities. It needs initialization, recovery, integration with ATLAS system. 3) HV Configuration: Achievement of stability of HV/layer is a challenge for every sector.

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