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The ATLAS New Small Wheel Simulation and Reconstruction Software and Detector Performance Studies

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After the recent long shutdown of the LHC, the ATLAS detector is now ready to record collision data with several upgrades implemented. The most important and challenging upgrades are those of the ATLAS Muon Spectrometer, where the two forward inner muon stations were replaced by the New Small Wheels (NSW) equipped with two new detector technologies; small strip Thin Gap Chambers (sTGC) and Micromegas (MM). Following the enormous effort for the construction, commissioning and installation of the NSW, the muon software required extensive revisions and new implementations, as well as migration to a new multi-thread approach. The new detectors are now fully integrated into the software. The detector response is simulated and has been compared with real data from cosmic ray test benches and test beams. Nominal geometries, misalignments, and deformations, as well as other possible deviations from the nominal operating conditions resulting from validation studies, have been implemented for a realistic study of final performances. The simulation of both sTGC and MM trigger has been implemented, and the performance has been evaluated in different configurations, with and without background, serving as a crucial input for the optimization of the trigger logic. Full muon reconstruction performance studies are performed and all the software tools, including dedicated data format, are now ready for early data-taking detector commissioning and for physics analyses.

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1. Introduction

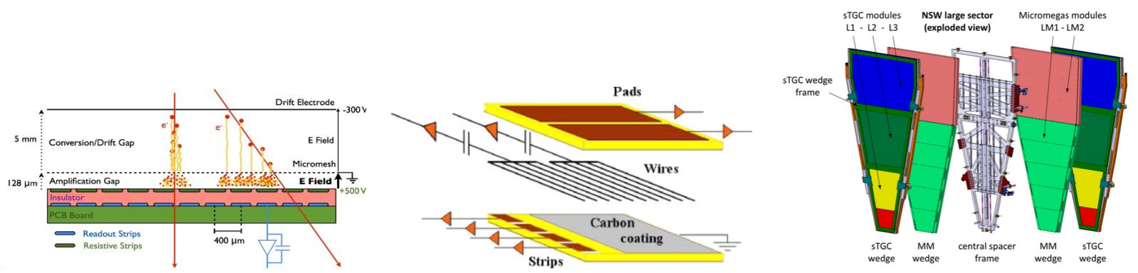
The ATLAS detector [1] at the Large Hadron Collider (LHC) recently underwent the first (Phase-I) of its two scheduled upgrade phases that will allow it to maintain its excellent performance in the foreseen high luminosity of future LHC Runs (up to $7.5 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$). The most challenging project of the Phase-I upgrade program has been the New Small Wheel (NSW) [2], i.e. the replacement of the inner endcaps of the Muon Spectrometer by new detector technologies, MicroMegas (MM) and small strip Thin Gap Chambers (sTGCs). The NSW system is expected to cope with the increasing background particle flux, as the luminosity increases, performing precision tracking and maintaining acceptable trigger rates.

2. NSW Detector Description

Each MM detector layer consists of a 5 mm drift gap and a 120 μm amplification gap filled with a gas mixture of Ar:CO_2:Isobutane (93%:5%:2%), which are separated by a grounded thin metallic mesh, as illustrated in Figure 1(a). The metallic mesh is supported by pillars of insulating material based on the anode readout plane and is transparent to electrons while providing fast evacuation of positive ions. The readout plane consists of resistive strips, with a pitch of 450 μm, capacitively coupled with the copper readout strips below them. The high resistivity (~10 MΩ/cm) of the resistive strips reduces the intensity of sparks that may occur in the amplification gap.

sTGCs are multiwire ionization chambers filled with a gas mixture of CO_2 and n-pentane (55%:45%), operated in quasi-saturated mode at a high voltage of 2.8 kV. Each detector layer is made of two cathodes planes with anode wires in the gap between them (Figure 1(b)). One cathode plane is divided into coarse readout pads, used to define regions-of-interest for fast triggering, while the second is comprised of 3.2 mm pitch strips providing precision track reconstruction. Wires have a 1.5 mm pitch and can provide the second coordinate in the direction transverse to the strips.

Each wheel of the NSW system is divided into 16 sectors. Figure 1(c) illustrates an NSW sector comprised of 16 detector layers; two MM layer quadruplets between two sTGC quadruplets. Both MM and sTGC detector layers were constructed by the collaborating institutes, whereas the final assembly, installation and commissioning of the chambers took place at CERN. Figure 2 shows



(a) (b) (c)

Figure 1: (a) Schematic of the MM layer structure illustrating the readout plane, the gas gaps and the metallic mesh. (b) Schematic of the sTGC layer structure including the strip, wire and trigger-pad planes. (c) Illustration of an NSW sector comprised of two MM layer quadruplets between two sTGC quadruplets.

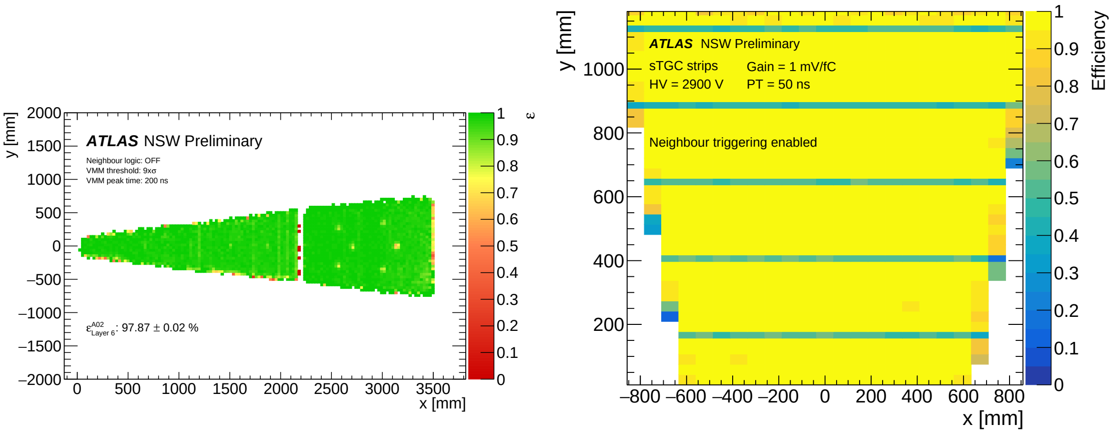


Figure 2: Efficiency map of an MM (left) and an sTGC (right) layer, measured with cosmic rays [3]. In the sTGC layer, the narrow inneficient regions correspond to the wire supports which lie parallel to the strips.

examples of the efficiency maps measured for each MM and sTGC layer using cosmic rays. The final installation of the NSW system in the ATLAS detector was completed in November 2021. Each step of the above procedure was followed by scrutinous quality and performance checks of both detector and electronic components to ensure operation according to specifications.

3. Status of the NSW Software

Along with the finalization of the detector systems, the integration of the NSW into the ATLAS simulation, triggering and event reconstruction chains was also finalized. Nominal NSW geometry parameters are hosted by a dedicated Oracle database, which defines both the representation of the detector volumes in Geant 4 and the geometry of the detector readout channels in the ATLAS experiment software. Based on the geometry description, in the simulation path, particle interaction and propagation within the active volume is digitized into signals as expected from the detector. On the other hand, in the data processing path, individual hits are retrieved from the front-end electronics, decoded and mapped to detector readout channels. In both cases, raw hits are formatted before being fed to hit clusterization algorithms for event reconstruction or high-level triggering.

For the above simulation and data-reconstruction procedures, precise knowledge of the instantaneous detector geometry parameters is critical. Therefore, the geometry parameters are constantly monitored by the NSW alignment system and uploaded to the dedicated *Conditions Database*. The first category of parameters hosted by the Conditions Database describe initial “As-Built” conditions reported by the chamber construction sites, which correspond to the alignment and deformation of individual MM and sTGC readout planes as well as the passivation of MM layer edges. The latter refers to the application of thin layers of araldite along the edges of the MM PCBs to protect from HV instabilities. The passivated width (up to few cm) is different on each side of each PCB, which renders the active area asymmetric. The second category of conditions hosted by the Conditions Database are time-varying chamber rotations and deformations, monitored by the NSW alignment system. Figure 3 demonstrates the displacement, of large MM chambers along the coordinate parallel to the beam-pipe between toroid-off and toroid-on, measured with the NSW alignment

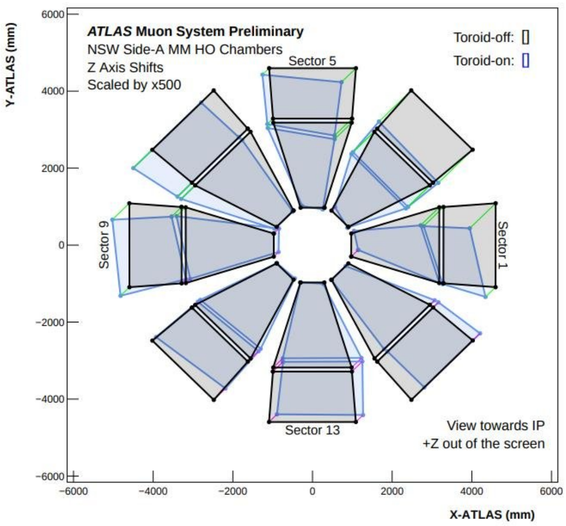


Figure 3: Displacement ∼1 mm of large MM chambers along the z-coordinate (parallel to the beam-pipe) between toroid-off and toroid-on, measured with the NSW alignment system.

system. The uploading mechanism of both As-Built and time-varying conditions as well as their proper retrieval and implementation into the simulation and muon-reconstructions chains has been completed and is presently being validated using real data from the LHC.

4. Conclusion

Both the NSW detector installation and software integration have been completed. MM and sTGC technologies are presently included in ATLAS event generation and event reconstruction, and are ready to contribute to the high-level trigger. Previous tests, before the installation of the NSW on the ATLAS detector, showed that its performance accords to the specifications. Presently the first proton-proton collision data from the LHC are being analyzed as final validation.

References

[1] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, *JINST* **3** (2008) S08003.

[2] ATLAS Collaboration, *New Small Wheel Technical Design Report*, CERN-LHCC-2013-006.

[3] ATLAS Collaboration, *NSW Public Results*, https://twiki.cern.ch/twiki/bin/view/AtlasPublic/NSWPublicResults.

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