Geometrical validation of New Small Wheel simulation software

Chilufya Mwewa[2], Valentina Cairo[1], Andrea Dell'Acqua[1], Andrew Hamilton[4], Verena Martinez[3], Sahal Yacoob[2]

CERN[1], University of Cape Town[2], University of Illinois[3], Quest University[4]

E-mail: chilufya.mwewa@cern.ch[2]

Abstract. The Large Hadron Collider (LHC), the largest hadron accelerator ever built, began operations in 2009 at centre-of-mass energies of 0.9 TeV and had reached 8 TeV by the end of 2012. This era was called Run I. After a long shutdown (LS1) of two years (2013-2014), the LHC resumed operations in 2015 (Run II) and has reached a record luminosity of 1.74×10^{34} cm^{-2}s^{-1}, exceeding its design luminosity of 10^{34} cm^{-2}s^{-1}. At the end of Run II (2018), the LHC will undergo another shutdown (LS2) in preparation for even higher luminosity scenarios during Run III. Such high luminosities are anticipated to affect, among other things, the tracking and triggering of muons in the ATLAS detector's muon spectrometer due to high counting rates (mostly from increased cavern background) and fake high transverse momentum tracks. To address this issue, the ATLAS collaboration will replace the innermost stations in the muon spectrometer end caps (Small Wheels) with a set of precision tracking and trigger detectors capable of handling high rates - the New Small Wheels (NSW). The NSW design is proposed to have two types of detector technologies: Small Strip Thin Gap Chambers for triggering and Micro Mesh Gas Structures for precision tracking. The performance of the NSW at these high rates is currently being studied in simulations. A validation study to check how well the simulation software depicts the geometry of the NSW detector planes is presented here.

1. Introduction

The Large Hadron Collider (LHC) is the world's largest particle accelerator with a circumference of about 27 km [1]. It accelerates two like-charge particle beams (either protons or heavy ions such as lead ions) in opposite directions and collides them at four different points once they have reached the desired energies. The interaction points each have a particle detector which captures the outcome of the collisions. These detectors include; ATLAS, A Large Ion Collider Experiment (ALICE), the Compact Muon Solenoid (CMS) and LHC Beauty (LHCb).

The LHC began operations in 2009 and by 2012, it achieved centre-of-mass energies of 8 TeV leading to the discovery of the Higgs boson [2]. During this period, also called Run I, the LHC operated at luminosities of about 0.6×10^{34} cm^{-2}s^{-1} [3]. It is currently in Run II and operating at center-of-mass energies of 13 TeV and luminosities of about 1.74×10^{34} cm^{-2}s^{-1} [4]. By 2021 (Run III), it is expected to operate at centre-of-mass energies of 14 TeV and luminosities $> 2 \times 10^{34}$ cm^{-2}s^{-1} which implies that high particle rates would be encountered by the detector. To prepare for these high rates, the LHC will undergo a shutdown for upgrade between 2019 and 2020. In addition, the detectors will also be upgraded in order to be able to cope with these high rates. Details of the LHC timeline can be found on the LHC high luminosity project

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website [5].

This paper focuses on the upgrade of the ATLAS detector's innermost Muon stations called the Small Wheels (SWs). These stations will be replaced by New Small Wheels (NSWs) during the next shutdown. In particular, the focus of this paper is the validation of the software used to simulate the performance of the NSWs. In Section 2, the general layout of the ATLAS detector and the NSWs is presented. Section 3 highlights the NSW simulation software with Section 3.1 showing the validation procedures used to test NSW simulation software and also some results of these studies. Finally, a summary is given in Section 4.

2. ATLAS and the New Small Wheel

ATLAS [6], one of the LHC's general purpose detectors, is a 45 m long and 25 m high particle detector as shown in Figure 1. It is designed in a multilayer fashion with each layer having specialized material suitable for the detection of the diverse debri of particles that emerge from the collisions. These layers include; the inner detector, the electromagnetic and hadronic calorimeters and the muon spectrometer respectively from the interaction point outwards. The inner detector mainly measures the momentum of charged particles. The electromagnetic calorimeters measure energies deposited by particles that interact via the electromagnetic and strong forces respectively. The muon spectrometer measures the momentum of muons. In addition, the inner detector and muon spectrometer are surrounded by a magnetic field of 2T and 4T respectively to aid in the bending of particles and hence the momentum measurement. Every second, the ATLAS detector interacts with particles emerging from approximately 10^9 proton-proton collisions. By 2021, the numbers will have doubled and not all components of the ATLAS detector will be able to work effectively at these extreme conditions. Therefore, in order for ATLAS to benefit from the large statistics arising from these rates and better probe for new physics such as supersymmetry [7], it needs to be upgraded. To this effect, ATLAS will mainly improve the level 1 (L1) trigger system by upgrading the L1 Calo trigger in the calorimeters [8], install a Fast TracKing trigger system (FTK) [9] and replace the small wheels in the muon spectrometer with New Small Wheels (NSWs) [3]. The focus here is on NSWs.

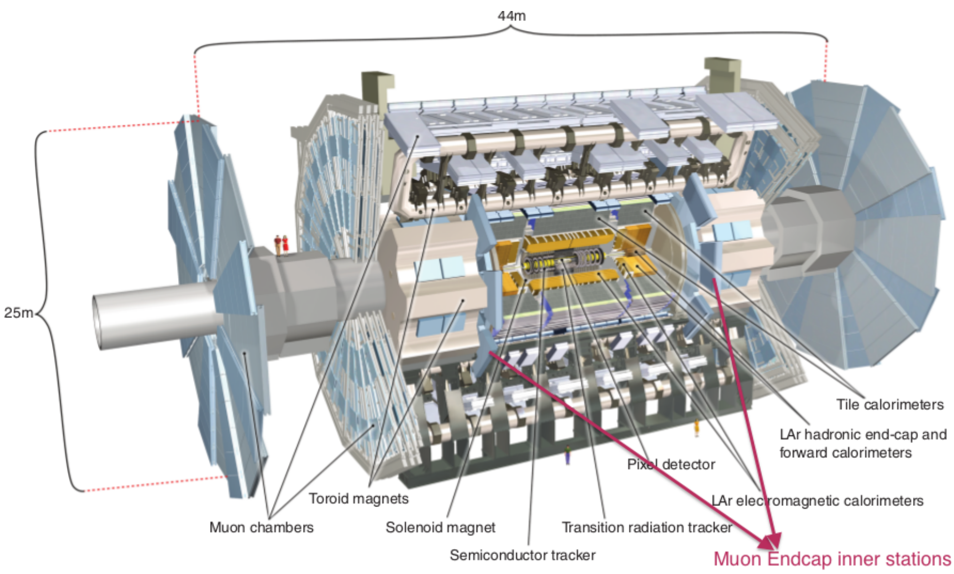

Figure 1. Schematic drawing of the ATLAS detector showing all subdetectors and the positions of the small wheels (Muon endcap inner stations) [6]

At high luminosity, the muon spectrometer is expected to have a reduction in the tracking performance due to a high rate of cavern background. In addition, unacceptable rates of fake high transverse momentum (P_T) L1 muon triggers are also expected [3]. To account for this, the ATLAS collaboration will replace the small wheels in the innermost endcap muon stations with NSWs. The NSWs will be placed at the same location as the small wheels, at Z = $\pm$7 m from the interaction point and cover a pseudorapidity (η) range of 1.3$<|\eta|<$ 2.7. The small

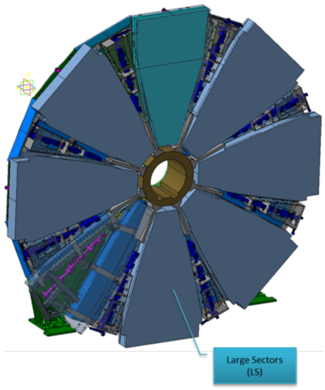

Figure 2. NSW sectors [13]

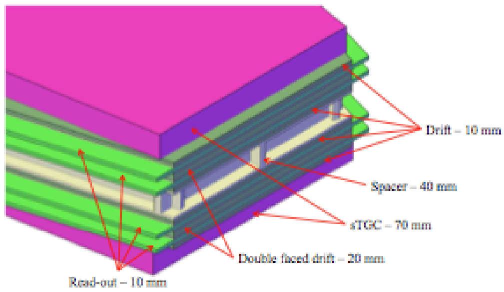

Figure 3. sTGC and micromegas quadruplets [3]

wheels are composed of Thin Gap Chambers (TGCs) for triggering plus Muon Drift Tubes (MDTs) and Cathode Strip Chambers (CSCs) for precision tracking [10]. On the other hand, NSWs will only have two types of detector technologies. These are namely MicroMesh Gaseous detectors (MicroMegas) primarily for precision tracking and small-strip Thin Gap Chambers (sTGCs) primarily for triggering [3]. The NSWs are made up of large and small sectors as shown in Figure 2. Figure 3 shows a zoom-in view on one of these sectors, with two Micromegas quadruplets (in green) sandwiched between two sTGC quadruplets (in pink). Each of these quadruplets is made up of four detection layers and hence there are 16 detection layers per sector. Figures 4 and 5 show schematic drawings of the layout of each of these layers for the sTGCs and micromegas respectively. Figure 4 shows an sTGC layer of two graphite readout electrodes (in form of Printed Circuit Boards (PCBs)) with a gas layer in between them. Each PCB has either pads or strips and inserted in the gas layer is a tungsten wire which is also used for readout. For improved angular resolution, the strips have a much smaller pitch (about 3.2mm) than the TGCs. Pads, on the other hand, aid in the identification of tracks originating from the interaction point and have a much larger pitch of 80mm. In addition, pads also help to define the region of interest to be used when reading out the strips and the wire. The gas is a mixture of CO_2 (55%) and n-pentane (45%) [11]. Figure 5 shows a micromegas layer also with two graphite electrodes (PCBs) and a gas gap. One of the PCBs acts as the cathode (drift electrode) and the other acts as the anode (readout electrode). An amplification mesh is placed at 100 μm from the readout such that the voltage between the drift and the mesh is about 100 V and that between the mesh and the readout is about 45 kV hence providing good tracking resolution at high luminosity conditions.

The production of various parts of the NSWs is currently underway and software has been developed to test their performance in simulation. The next section highlights the features of this software and its validation procedure.

3. NSW simulation software

In general, ATLAS simulation is done in three steps. Firstly, an event generator generates groups of particles or single types of particles. The output of the generator is then passed

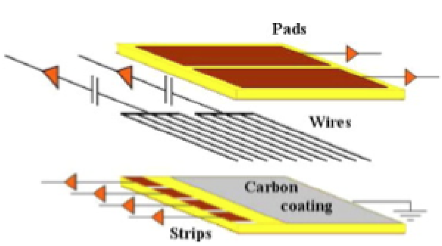

Figure 4. sTGC operation [3]

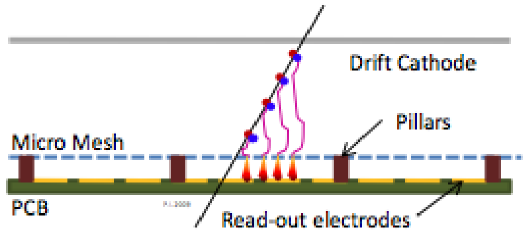

Figure 5. Micromegas operation [3]

to the simulation where the physics interaction of the particles with the detector material is simulated and produces energy deposits called hits. Finally, simulation hits are passed to the digitizer which converts the hits into voltages and current pulses for triggering and reconstruction purposes. The ATLAS simulation software is built in the ATLAS software framework known as Athena and makes use of the GEANT4 simulation packages. More details on the software can be found in reference [12].

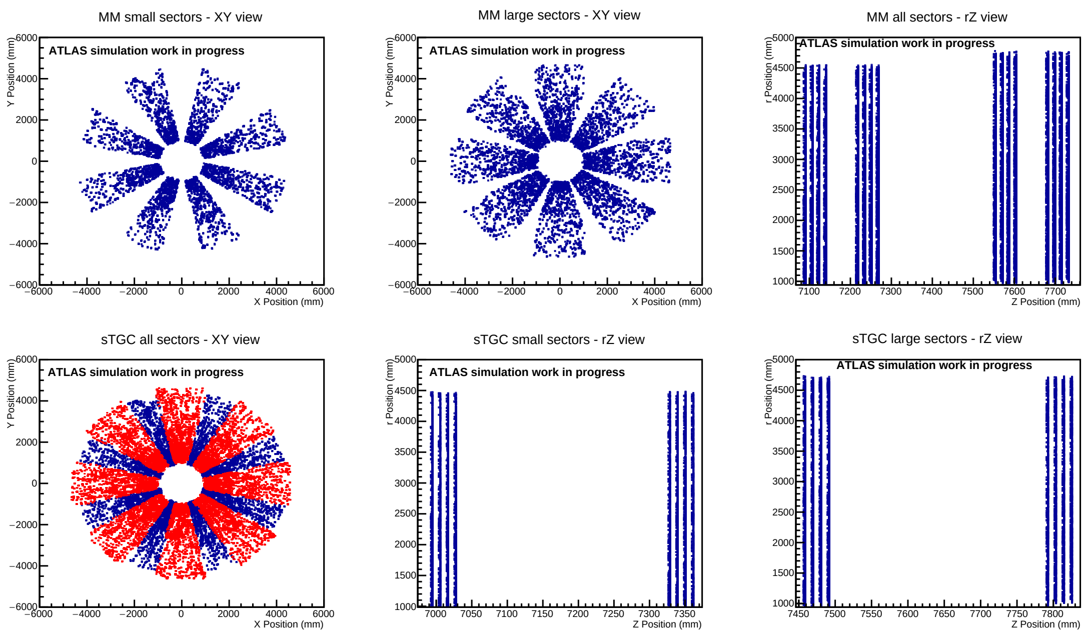

Figure 6. Example of NSW RTT histograms

3.1. Validation

Prior to the assessment of the physics performance in the simulation software, the performance of the software itself has to be validated. ATLAS currently uses two validation procedures which test the software on a nightly basis since the software is constantly evolving. The ATLAS Tests Nightly (ATN) checks for compilation errors and the Run Time Tester (RTT) checks for runtime errors and produces histograms that can be used to check, for example, the geometry of the NSWs. Figure 6 shows an example of the sets of histograms set in the NSW RTT to validate the software during the simulation step. These are shown for the A-side part of the detector (i.e NSW at positive Z). The top row shows some micromegas plots with the first and second column showing transverse view plots of the small and large sectors respectively. The last column shows the longitudinal view of both the small (first two quadruplets) and large (last two quadruplets) sectors. The second row shows sTGC plots with the first column showing the transverse view of both the small (blue) and large (red) sectors. The second and third columns show the longitudinal view of the small and large sectors respectively. These and many other histograms from both the A-side and C-side are assessed for their geometrical positions and dimensions, their hit coverage and so on. Any defects (bugs) found are then fixed accordingly. Note that only the gas gaps (active areas) are seen during the simulation step since that is the only part of the detector from which the particles' energy deposits are sampled. As an illustration

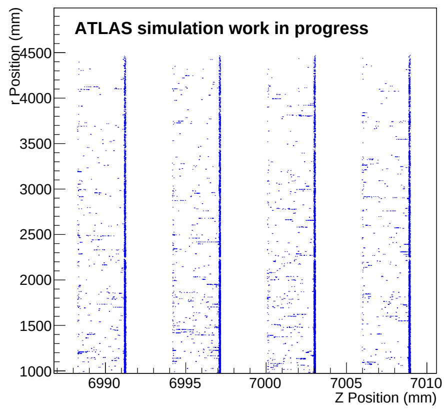

Figure 7. sTGC small confirm quadruplet prior to the fixes

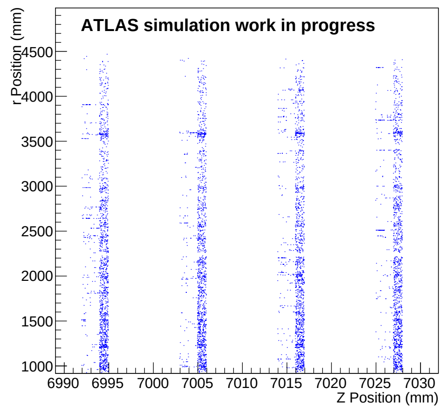

Figure 8. sTGC small confirm quadruplet after the fixes

of the geometry checks and bug fixes done, we zoom into the first quadruplet of the sTGC small sectors as shown in Figure 7. Here, we notice that the center of the quadruplet is at $\approx$ 6998.5 mm. However, the sTGC parameter book (a detailed book of all sTGC parameters) indicates 7010 mm. This is indicative of some mismodelling in the software responsible for building the detector geometry at the simulation step. This software is called the GeoModel and it is the first place we look at for this kind of defect. GeoModel reads parameters from a configuration file which is created directly from a parameter book. It then builds detector volumes and models them in accordance with the engineering specifications of a particular detector. Looking into this software, we found that an sTGC quadruplet was being modelled as having five PCBs (each 2.85 mm wide) and four gas gaps (each 3 mm wide) and arranged (modelled) as shown in Figure 9. However, the engineering drawing shows 8 PCBs (each 1.5mm wide) and four gas gaps (each 2.8 mm wide) as well as some honeycomb material in which these layers are slotted as shown in Figure 10. Therefore, this geometry was re-modelled in the GeoModel software and the center of this quadruplet corrected to 7010 mm as shown in Figure 8. This was also corrected for all sTGC quadruplets and consequently, positions between sTGCs and micromegas were also corrected. Note that this software is constantly evolving and the engineering specifications at the early stages of manufacturing also evolve. Therefore, it is important to regularly check that the software is modelling the NSWs according to the specified engineering model and hence that was the purpose of this study.

Figure 9. Model of an sTGC in GeoModel prior to the fixes

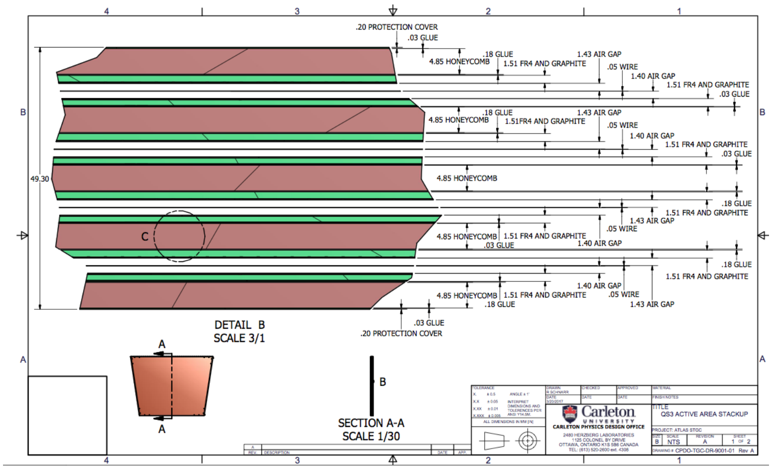

Figure 10. Engineering drawing of an sTGC quadruplet

4. Conclusion

This paper has shown the implementation of validation histograms into the ATLAS RTT for the purpose of validating how well the NSW simulation software depicts the geometry of the NSWs. It has also been illustrated that this type of validation is crucial as both ATLAS software and engineering specifications of the detectors constantly evolve. Therefore, for an efficient validation of the NSW physics performance in the software, the software needs to be validated to ensure that its modelling of the NSWs is accurate. Implementation of digitization validation checks into the RTT is also being done. However, this is beyond the scope of this paper.

References

[1] Evans L and Bryant P 2008 *JINST* **3** S08001
[2] ATLAS Collaboration 2012 *Physics Letters B* **716**
[3] ATLAS Collaboration 2013 *New Small Wheel Technical Design Report* (CERN-LHCC-2013-006)
[4] ATLAS Luminosity Public Results 2017
`https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LuminosityPublicResultsRun2`
[5] LHC high luminosity project website 2017
`project-hl-lhc-industry.web.cern.ch/content/project-schedule`
[6] ATLAS Collaboration 2008 *JINST* **3** S08003
[7] ATLAS Collaboration 2014 *Search for Supersymmetry at the high luminosity LHC with the ATLAS Detector* (ATL-PHYS-PUB-2014-010)
[8] Schwienhorst R 2016 *JINST* **11** C01018
[9] Cavaliere V *et al* 2016 *JINST* **11** C02056
[10] Eldik N 2007 Ph.D. thesis (CERN-THESIS-2007-045)
[11] Perez E 2015 *Small-Strip Thin Gap Chambers for the Muon Spectrometer Upgrade of the ATLAS Experiment* (ATL-MUON-PROC-2015-004)
[12] ATLAS Collaboration 2010 *European Physical Journal C* **70** 3
[13] IRFU website 2017
`http://irfu.cea.fr/en/Phocea/Vie_des_labos/Ast/ast_technique.php?id_ast=2225`