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ABSTRACT

The small wheel is the innermost component of the muon endcap of the ATLAS experiment at CERN. It is currently being upgraded and replaced by a newer and more efficient model for the higher luminosity runs of the Large Hadron Collider (LHC). New wire chambers for triggering, nicknamed small-strip Thin Gap Chambers (sTGCs), are among the most important elements being enhanced in the New Small Wheel (NSW). The chambers are produced in various institutions worldwide, and then delivered to CERN for wedge assembly and testing. This paper gives a summary of the production chain used for the integration of sTGCs at CERN, with an emphasis on the testing carried out at the Gamma Irradiated Facility (GIF++) and long-term high voltage (HV) testing post-assembly.

I. Introduction

ATLAS is one of the most ambitious physics experiments ever tackled. It is the largest volume detector constructed for a particle collider [1], for the purpose of testing standard model predictions and the study of the smallest of particles. Proton packets, travelling at speeds up to 99.999999% that of light [1], collide at the centre of the ATLAS detector, creating an explosion of fundamental particles that are then researched. ATLAS is a many layered instrument designed to investigate the multitude of particles emerging from the interaction point (IP). The Muon Spectrometer (or muon endcap) is one the major components of the ATLAS

detector [1]. It is constituted of three wheels, as displayed in Figure 1. The small wheel (the innermost wheel of the muon endcap), the big wheel, and the outer wheel are used to detect the position and momenta of passing muons to reconstruct their tracks.

II. The New Small Wheel (NSW)

The LHC needs to enhance its capabilities to allow for a greater number of collisions and systematically increase the proton beams thus enabling members of the physics community to discover more information about the building blocks of the universe. In order to benefit from the LHC's enhanced performance, ATLAS must also upgrade some of its components that are rendered near obsolete at these higher luminosity levels. This is the motivation driving the NSW upgrade.

The old Small Wheel presents many issues within a higher luminosity environment. For example, it is not part of the trigger chain within the muon endcap; the Big Wheel was the primary and only trigger in the system, as such there were many false muon triggers recorded [2]. In a study of the performance of the small wheel in 2012, it was discovered that with the higher luminosity runs of the LHC (and thus higher radiation background), the muon tracking system had a 90% false trigger rate [2]. In fact, low energy particles generated in the system itself between the muon wheels would produce these false triggers by hitting the Big Wheel at an angle similar to the one of real high energy muons (see Figure 2, tracks B and C). The higher luminosity runs would degrade the

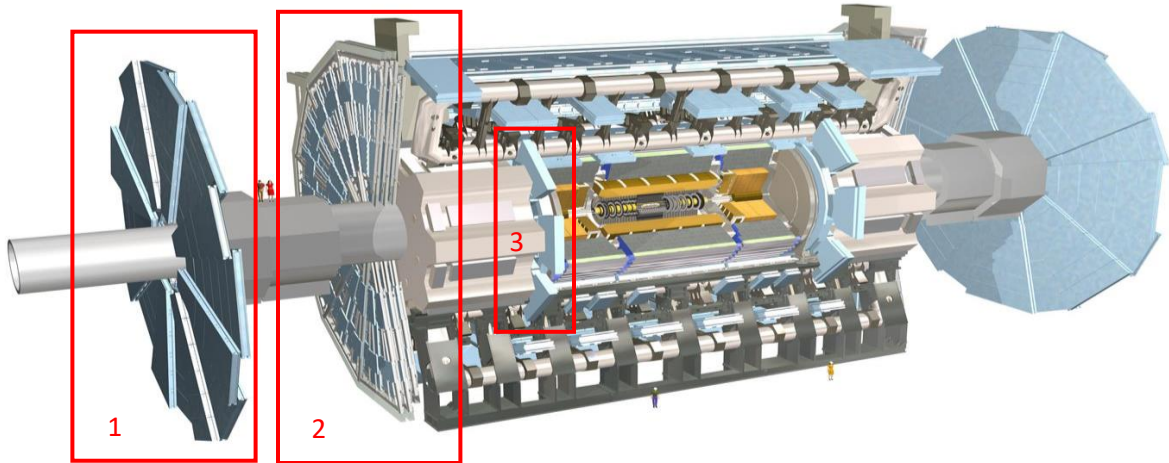


Figure 1. The ATLAS Detector; with the Outer Wheel (1), the Big Wheel (2), and the Small Wheel (3) highlighted [1].

tracking performance of the system in terms of efficiency and in resolution triggering the need for a New Small Wheel (NSW).

The NSW presents several changes that enhance the muon endcap. Firstly, the NSW is now incorporated in the muon endcap's trigger chain. A muon needs to pass through the NSW as well as the Big Wheel to be tracked and confirmed as a legitimate event [2].

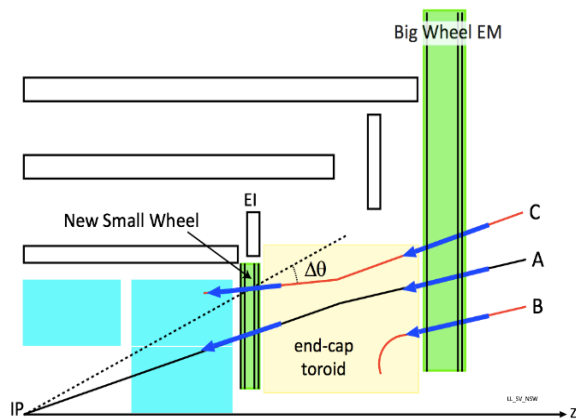


Figure 2. Schematic of new muon endcap trigger chain, with A the track of a legitimate trigger (muon), and B and C being false triggers [2].

As seen in Figure 2, particles generated in the system do not trigger the data acquisition. For instance, track B does not traverse the NSW

thus it is discarded. Track C does not traverse the NSW at the correct angle; thus, it is not perceived as a muon and consequently it is discarded. Only track A triggers the system because it enters at the correct angle. This enhancement reduces the false trigger rate previously observed.

The NSW also improves its tracking resolution and detection system. The NSW is composed of two operating detection systems: the small strip Thin Gap Chambers (sTGC) and the Micro Mesh Gaseous detectors, more commonly known as MicroMegas (MM) [3]. Both detection systems can track and trigger, the MM are primarily used for tracking, while the sTGC are primarily used for triggering [2]. As portrayed in Figure 3, two sTGC wedges envelop two MM wedges, forming a sector. A muon must cross both sTGC wedges for the data to be preserved, otherwise it is discarded. The data collected by the MM is then used for track reconstruction.

There are two different sized sectors that comprise the NSW named small and large sectors (shown in Figure 3). This is to cover the whole area of the wheel as to not miss any passing particle. All together, these detectors have about 2.5 million readout channels [3].

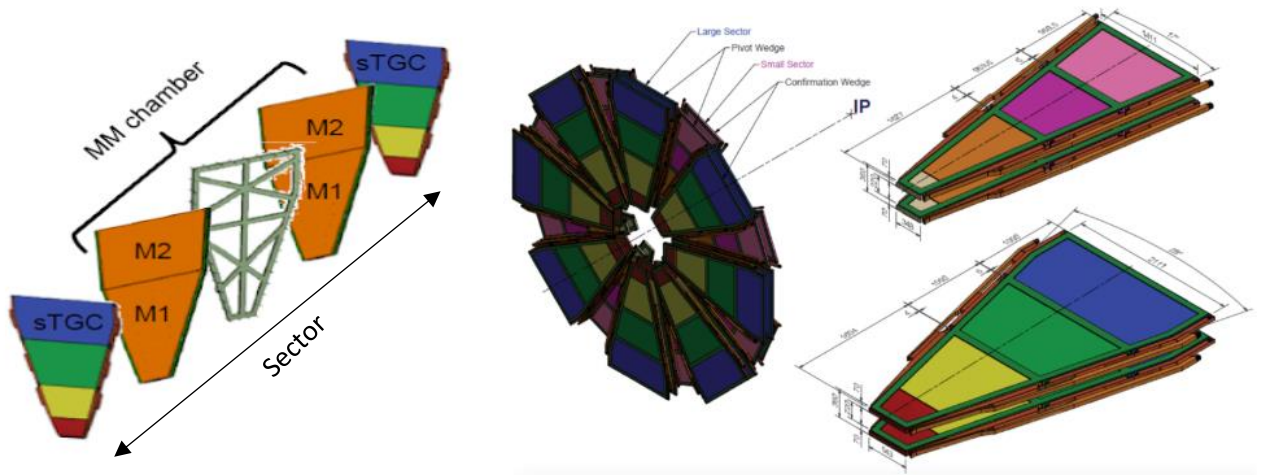


Figure 3. The NSW build and sector composition [2].

III. sTGC

The sTGC wedges are the product of an international collaboration. Each wedge is made of three different sized quadruplets, a trapezoidal structure manufactured in different institutions and then shipped to CERN for wedge assembly (as displayed in Figure 4) [2].

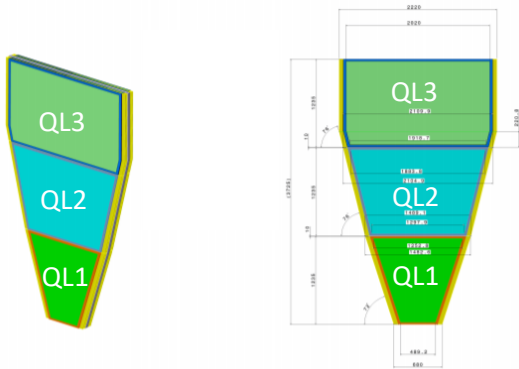


Figure 4. Large Wedge sections: Large Quadruplet 1 (QL1), QL2, and QL3. Similarly, small wedges are made up of QS1, QS2, and QS3 [2].

Each quadruplet is 4 layered gas type detector [2]. One layer is composed of a copper pad and strip enveloping a gas gap 2.8 mm wide, hence the name sTGC. The gaps are flushed with a gas mixture of 55% CO₂ and 45% n-pentane. At the center of the gap, there are high voltage (HV) wires that carry 2.8 kV. A resistive layer of

graphite sprayed onto a layer of FR4 separates the copper from the gas gap [2].

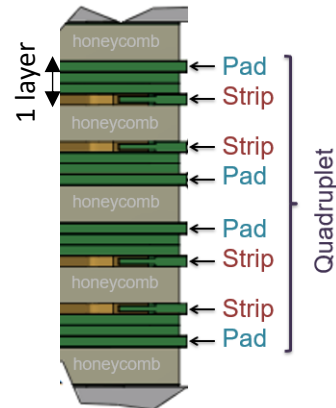


Figure 5. Section view of the internal composition of a quadruplet [4].

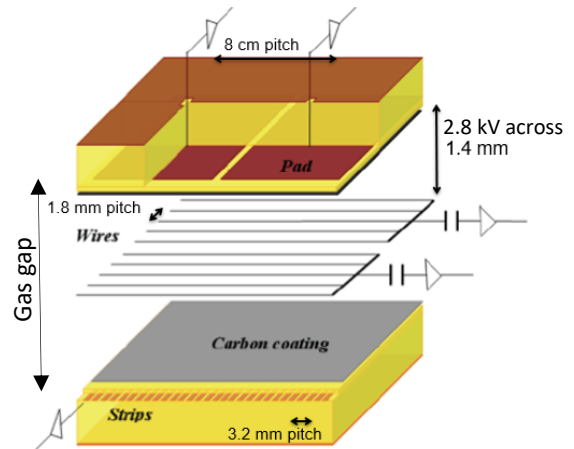


Figure 6. Diagram of the composition of a layer [4].

A passing muon would ionize the gas mixture. An avalanche is created due to the applied high voltage. The electrons created from that ionization drift towards the HV wires, and consequently induce charge in the copper pads and strips. The newly generated currents in the wires, pads, and strips are the signals used by the read-out elements.

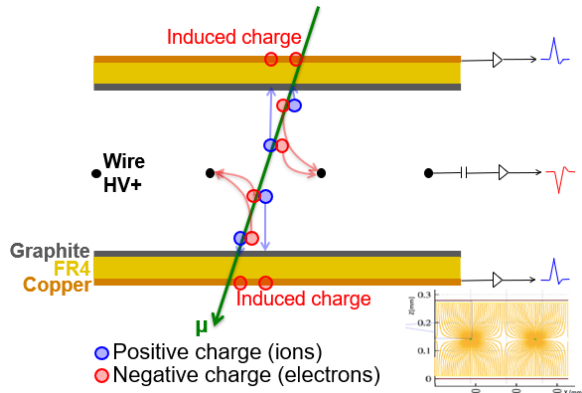


Figure 7. Diagram of the operation of a layer [4].

The signals in the wires and the strips are used for track reconstruction. In Section II, it was mentioned that the sTGC are mainly used for triggering. The signal provided by the pads are used for triggering the region of interest. In fact, there needs to be 3-out-of-4 coincidence: a passing particle needs to induce a signal in the same area of 3 out of the 4 pads in the sTGC wedge for the data to be collected [4]. An event is confirmed when the 3-out-of-4 coincidence occurs in the wedge on the other side of the sector.

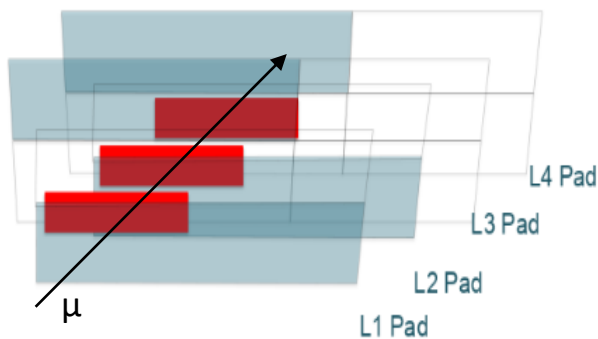


Figure 8. Diagram of the 3-out-of-4 coincidence needed for trigger [4].

IV. Testing and Assembly at CERN

The arrival of the quadruplets at CERN triggers a rigorous chain of testing and assembly:

1. Quadruplet reception tests
2. High radiation testing
3. Pulser test
4. Wedge assembly
5. Electronic noise test
6. Faraday cage installation
7. Faraday cage leak test
8. Long term HV testing
9. X-ray test
10. Electronics installation
11. Sector assembly
12. Mount on NSW frame



Figure 9. Completed assembled wedge [Madhoun, 2019].

The noted testing is designed to ensure the quality of the chambers used. The assembly team tries to repair any possible problem observed during the testing. However, if it is not possible to repair the problem, the testing is then used to document these shortcomings and the performance of the detector chambers. The tests can be separated into two categories: testing the functionality of the detectors and testing the structural integrity.

For testing the functionality of the detectors, there is firstly the high radiation testing, used for checking the chambers' behaviour in a high radiation environment. The pulser test's purpose is to check the electrical connectivity of

the pads, wires, and strips. The electronic noise test's purpose is to make sure that the front-end boards (read-out electronics) are not polluted by too much background noise. The long term HV testing is used for assuring the long-term functional stability of the sTGC wedges.

The reception tests, the Faraday cage leak test (to make sure there are no gas leaks), and the X-ray test (used to measure and record the azimuthal position of the different layers in the wedge) are used to assess the structural integrity of the detectors.

The assembly consists of preparing wedges from the quadruplets, installing the Faraday cage to isolate the system and minimize noise (with the help of Low Pass filters), and finally constructing the sectors to go up on the wheel.



Figure 10. Sector assembly. Left: MM wedge, Right: sTGC wedge [Madhoun, 2019].

V. Reception tests

The purpose of these tests is to assure the structural integrity of the quadruplets when they arrive to CERN. There are three tests performed: a visual test, a high voltage test, and a gas leak test.

a) Visual test

Once the quadruplets are produced, they are shipped to CERN in crates. The transportation is

not always flawless as there could be some rough handling along the way. The first step is to do a visual inspection of the crate. There are shock sensors (20G, 25G) and tilt sensors on the outside and on the inside of the crate.



Figure 11. Opening transport crate [Madhoun, 2019].

Once the sensors are checked, the crate is opened and the sTGC quadruplets are inspected for any external damage. If a problem is observed, such as a broken gas inlet or an exposed cable, it is fixed at the reception site. However, if the problem is more important, such as a punctured or completely damaged chamber, the quadruplet cannot be used.

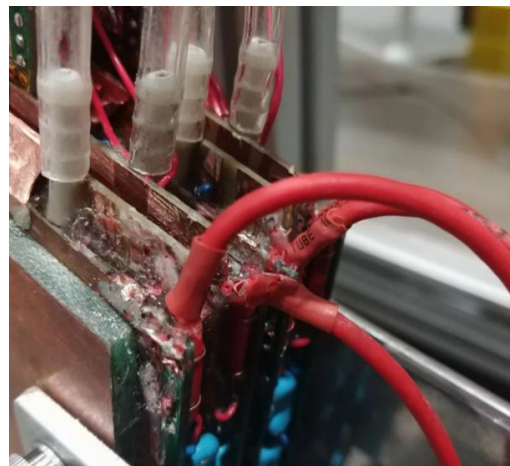


Figure 12. Open/exposed HV cable [Madhoun, 2019].

b) HV test

The next reception test consists of applying 100 V onto the quadruplet. The goal of this test is to make sure that the quadruplet can take the voltage without current being created or observed, as the only current generated in the detector should be that of a passing muon. Once the quadruplets pass this first step, they are flushed with CO₂ and tested with applied voltage up to 2.8 kV. No current should be observed again.

If current is observed, the source of this problem might be a faulty HV cable or a short created in the system/quadruplet.

c) Gas leak test of the sTGC gas gaps

The purpose of this last test is to verify that the gaps hold the gas and do not present any leaks. Leaks present a huge setback to the system if present. Firstly, the gas mixture used is extremely flammable; a leak becomes a source of explosive danger that can cause permanent damage to the whole NSW. Secondly, the entire operation of the detector is dependant on the gaps being filled with gas – a leak degrades the efficiency of the system.

The test consists of filling the gas gap of each layer with CO₂ up to 4 mbar and then checking that the inside pressure does not drop more than 1 mbar after 5 minutes. If this does occur, the leak is located and attempted to be fixed.

VI. High Radiation Testing

The high radiation testing of the quadruplets is an essential step of assuring the proper functioning of the chambers before wedge assembly. The purpose is to test the stability of the sTGC in a high radiation environment as to recreate the photon background at ATLAS during the runs (estimated around 20 kHz.cm⁻²) [5]. To accomplish this, the test is performed at the Gamma Irradiated Facility (GIF++). A 14 TBq

Cesium¹³⁷ source present at the facility is used for the test [5].



Figure 13. Inside the bunker at GIF++ [5].

After the preliminary reception tests, the quadruplets are transported into GIF++. They are flushed with the CO₂/n-pentane mixture and have 2.8 kV nominal voltage applied onto them. From this point, current and voltage are recorded. After 10 minutes, turn the source on for 30 minutes. Then turn off the source and wait 10 minutes to end the voltage/current measure.

The expected result of this test is to observe no current prior to the source being turned on, then as the quadruplet is being irradiated by high energy photons a constant current should be recorded. The source irradiates with a constant flux. The high energy photons interact with the copper in the chambers, creating a baseline constant current. Once the source is turned off, there should not be any (or very little) current recorded.

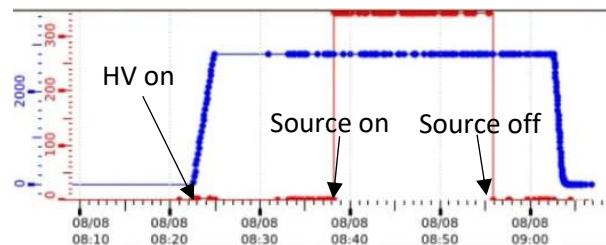


Figure 14. Results of the high radiation test. Blue line - voltage, red line - current [Madhoun, 2019].

During my time at CERN, all the chambers received passed this test.

VII. Long-Term HV Testing

Once the wedges are assembled, they are placed in an isolated room where they are flushed with the CO₂/n-pentane mixture and have 2.8 kV nominal voltage applied onto them for a period of 2 months.



Figure 15. Completed wedges in long-term HV testing [Madhoun, 2019].

The purpose of this test is to examine the long-term stability of the sTGC wedges, and to find any leaks that might develop post assembly. The expected results are very similar to the high radiation test, however there is no radiation source thus there should be no recorded current.

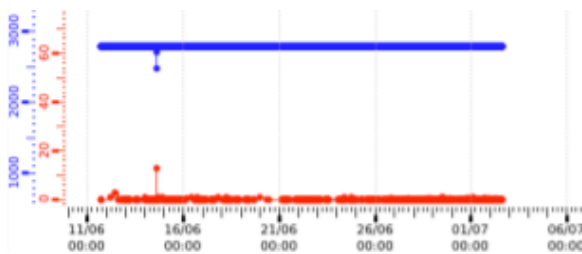


Figure 16. Results of the long-term HV test. Blue line - voltage, red line - current [Madhoun, 2019].

VIII. Conclusion

ATLAS must adapt to the higher luminosity conditions of the future LHC runs. The discussed update to the muon endcap enhances the trigger chain and the resolution of the small wheel. The components that comprise the NSW are currently being produced and assembled.

Though the production and assembly has been successful, there were a few issues faced, such as receiving problematic quadruplets from the construction sites. When these problems are observed, the assembly team at CERN has been successful in rectifying them. During my stay at CERN, 9 small sTGC wedges were assembled and are ready for sector assembly. I have participated in the assembly and testing processes. The 9 completed wedges have all passed the steps described earlier.

References

- 1 "ATLAS Experiment." <https://atlas.cern>
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