sTGC Testing for ATLAS' New Small Wheel at McGill University and CERN

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Abstract

ATLAS' muon small wheel must be replaced to improve muon track reconstruction and the forward muon trigger as the LHC tends towards higher collision rates. New multi – wire proportional chambers, small strip thin gap chambers (sTGCs), are being created in five countries for the new small wheel [1]. In Canada, the final stage of STGC production is to test the chambers with cosmic muons at McGill University [2]. The laboratory infrastructure at McGill is almost ready to allow data collection from the sTGCs without an operator present, the final step being to complete a temperature control and monitoring infrastructure for the electronic readout boards of the sTGCs. After the chambers are tested at McGill, they are sent to CERN where they are further tested with muon beam from the Super Proton Synchrotron. Preliminary results on the efficiency of one of the prototype chambers are presented. This report gives an overview of sTGC testing for the muon new small wheel with a focus on work completed by the author as part of the Institute of Particle Physics (Canada) Fellowship and CERN Summer Student Programme from May – August, 2018.

Introduction

Since its inception, the number of collisions and the energy of the proton beams at the Large Hadron Collider (LHC) have continuously increased. By 2026, the goal is to reach a 14 TeV beam with 5 – 7 times the nominal collision rate. ATLAS, one of four particle detectors used to study collisions in the LHC, must be upgraded to continue to provide quality data under these evolving conditions [3]. The phase-1 upgrade of ATLAS is currently being staged for implementation in 2019 [2].

The largest project of the phase-1 upgrade is to replace the muon small wheel. It is one of three wheels that make up the endcap muon detection system in ATLAS (see Figure 1).

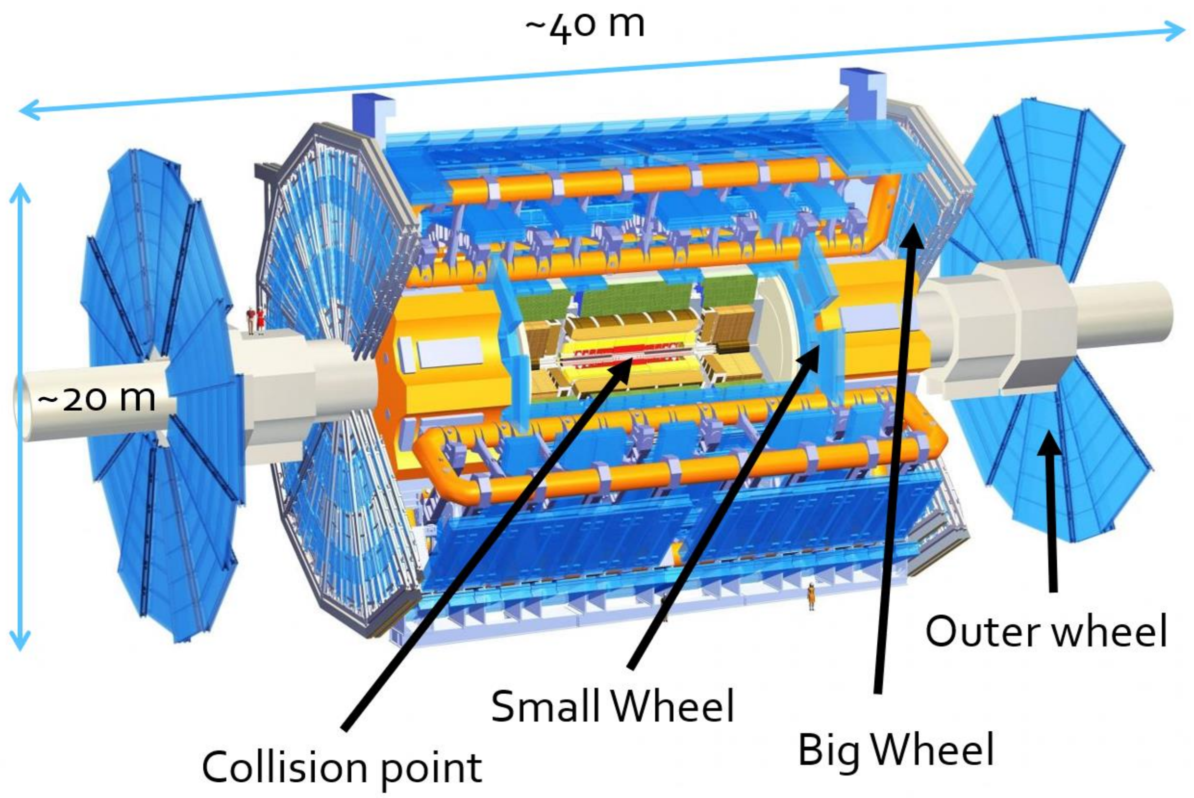

Figure 1: Schematic of ATLAS showing the three wheels of the endcap muon detection system [4]. Each wheel records the position of passing muons and the information is used to reconstruct their tracks. Also, the big wheel's data feeds into ATLAS' level 1 trigger [5], which decides whether to record data from a collision.

The current small wheel needs replacing because the increased number of collisions will reduce its efficiency and position resolution. Moreover, the new trigger system will require that tracks that trigger the big wheel must also correspond to tracks in the small wheel to improve its reliability (currently, the system has a 90 % fake trigger rate) [2].

A schematic of the new small wheel (NSW) is shown in Figure 2. It is formed of two types of detectors, small strip thin gap chambers (sTGCs) and Micromegas. Both detector technologies are capable of triggering and tracking, however, the sTGCs are the primary triggers while the Micromegas are the primary trackers [2].

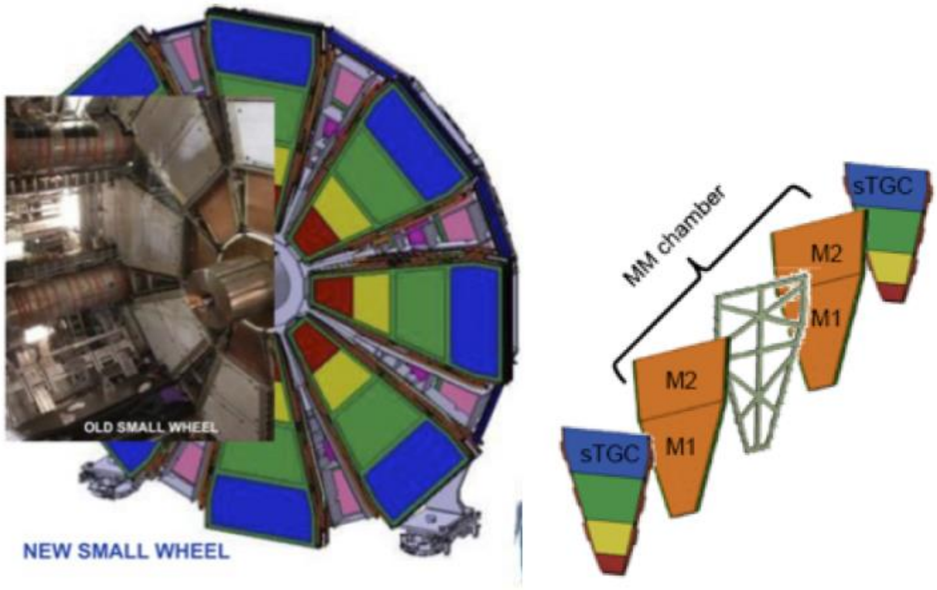

Figure 2: New small wheel structure. The wheel is covered with wedges of detectors. Each wedge is formed of two stacks of four sTGCs and two stacks of four Micromegas [2].

Small Strip Thin Gap Chambers (sTGCs)

An exploded view of part of a single sTGC gap is shown on the left of Figure 3. They are gas ionization chambers filled with a 55 % to 45 % mixture of CO_2 and n – pentane [2], which quenches the photons created as a result of ionization [6]. When a muon passes through the detector, the ionization products send signals through the pad, strip and wire electrodes. The pad signal provides the trigger, and a coarse region of interest for the software to examine the output of the strips and wires. The intersection of the wires and strips that fired indicate the muon’s position as it passed. In the NSW, each sTGC section is composed of a stack of four sTGCs (right image in Figure 3) for better track reconstruction and to ensure that the sTGCs will last for the required lifetime [2].

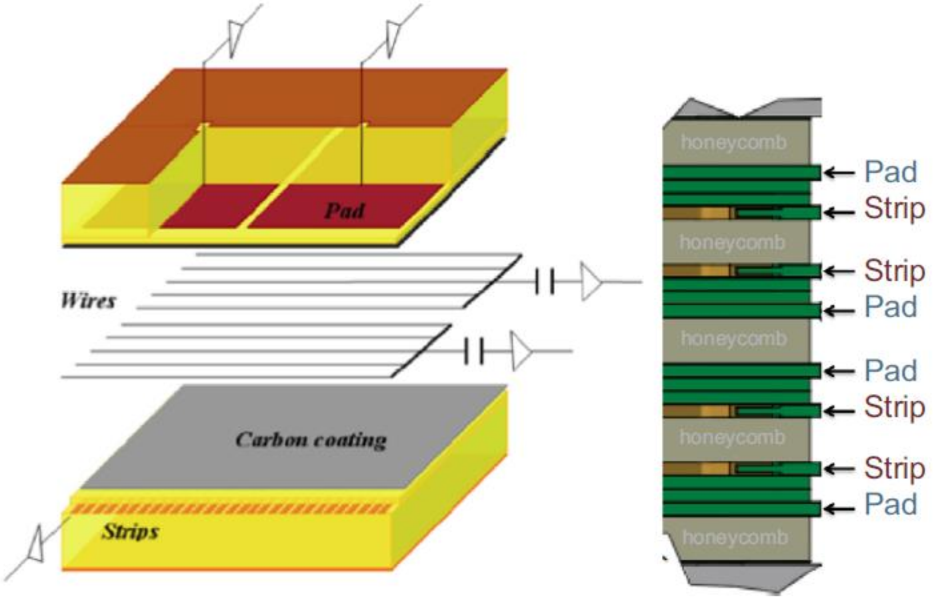

Figure 3: Left – exploded view of a portion of an sTGC chamber. When a muon passes through a chamber, it ionizes the gas inside. The ionization products leave signals on the pad, strip and wire electrodes. The pad signal provides the trigger and the muon's position is reconstructed using the wire and strip signals. Four sTGC chambers are stacked into one quadruplet for installation on the NSW.

sTGCs are being constructed in five countries: Canada, Chile, China, Israel and Russia. In Canada, production begins at TRIUMF in Vancouver, where the raw materials are prepared. The materials are then sent to Carleton University in Ottawa, where the sTGC quadruplets are constructed. Finally, the completed chambers arrive at McGill University for initial testing with cosmic muons.

McGill University's sTGC Laboratory

Cosmic muons come from cosmic rays at a rate of about 1 muon / cm^2 / minute. Scintillators (secondary particle detectors) above and below the sTGC trigger the readout of the sTGC. From this data, the analyst can construct an efficiency map of the chamber and calculate its position resolution [7].

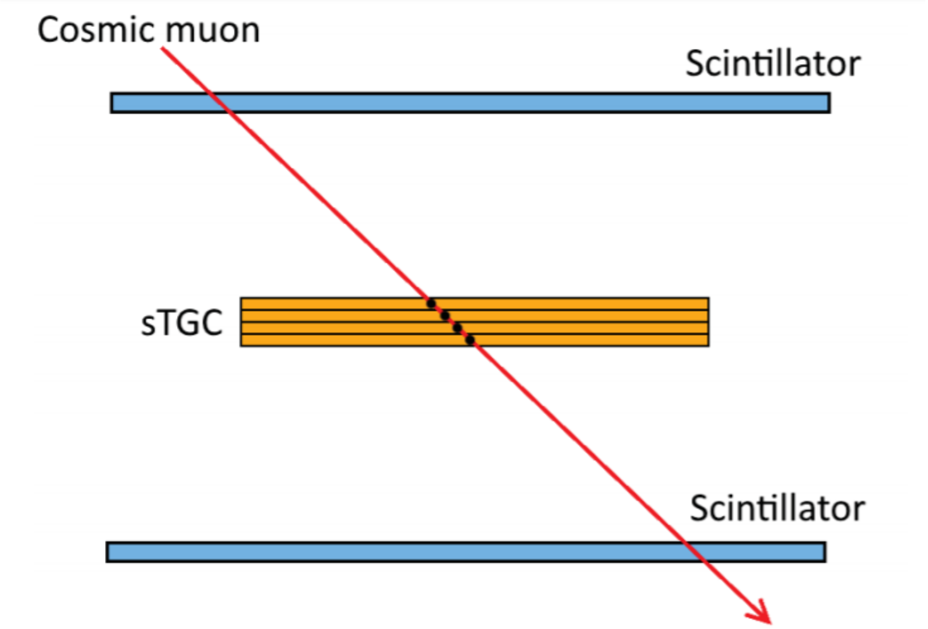

Figure 4: The set up for sTGC testing with cosmic muons. A scintillator above and below the sTGC triggers the sTGC readout whenever a cosmic muon passes [7].

The laboratory infrastructure includes a gas system that controls: the input of gas into the chamber; the concentration ratio of n – pentane and CO_2; and the recovery of n – pentane. A high voltage and low voltage power distribution system is in place to power the sTGC and associated electronics. All systems are controlled by a slow control program created with LabVIEW. The slow control program is used for transitioning the system from dormant to ready to take data. It also processes monitoring data from various sensors in the laboratory and can bring the system into a safe state should a reading go out of bounds. With these safeguards in place, data can be collected without an operator present, which is important since long runs are required to collect enough statistics given the low flux of cosmic muons.

This Summer's Project

At McGill, I helped implement temperature monitoring for the electronics in the sTGC laboratory. At CERN, I helped with sTGC testing and the analysis of the results.

Temperature Monitoring of Electronics

The final step to allow the slow control program to collect data automatically is to implement a temperature monitoring and control system for the electronic readout boards of the sTGC. Pad front end boards (pFEBs) and strip front end boards (sFEBs) readout channels of the pads and strips respectively. While the pFEBs can be operated safely with fans, the sFEBs can still reach over 60˚C with fans, hot enough to damage the boards and cause them to shut off automatically [8].

The temperature monitoring infrastructure is shown in Figure 5. The choice of temperature sensors and readout devices was made before May, 2018 by Kathrin Brunner, but was implemented during May – June, 2018.

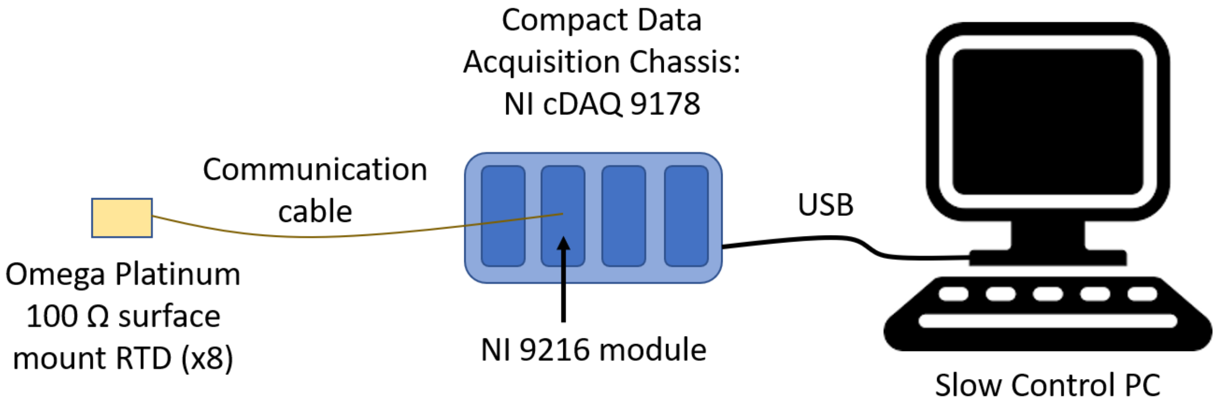

Figure 5: Temperature monitoring infrastructure in McGill University’s sTGC laboratory. Surface mount RTDs were connected to a National Instruments (NI) module made to readout RTDs. This module is attached to the cDAQ, where all sensor data from the laboratory is collected using individual NI modules. All sensor data is bused from the cDAQ to the slow control PC where it is processed and logged.

Ideally, the slow control program should collect, process and display temperature data from the RTDs and cut power to the sFEBS should one become too hot. So far, a standalone LabVIEW program for logging and displaying temperature data was created. The program also gives a warning if one of the temperature sensors records a temperature above 40˚C. This program was used to test the efficiency of various heat sinks at cooling the pFEBs, and can be used to collect sTGC data with an operator present to intervene should the temperature reach a dangerous level. Steps were taken to understand how this temperature monitoring program could be integrated into the slow control system, a task that is currently under way.

Temperature Control of the sFEBs

Heat sinks and fans are required to operate the sFEBs safely [8]. Figure 6 shows that the hottest part of the pFEBs is the analog 1.2 V FEAST, a DC to DC converter. The hottest part of the sFEBs is also the FEAST [8]. The most effective heat sink was chosen by testing which kept the stable operating temperature of the pFEB FEAST lowest. The results are shown in Table 1. Gap pad (brand: Bergquist) is a slightly adhesive, soft, heat conducting pad used to fill the air gaps between the electrical components of the FEAST and provide a flat surface on which to adhere the heat sinks. The RTDs were mounted underneath the FEAST, on a small hole for thermal conduction.

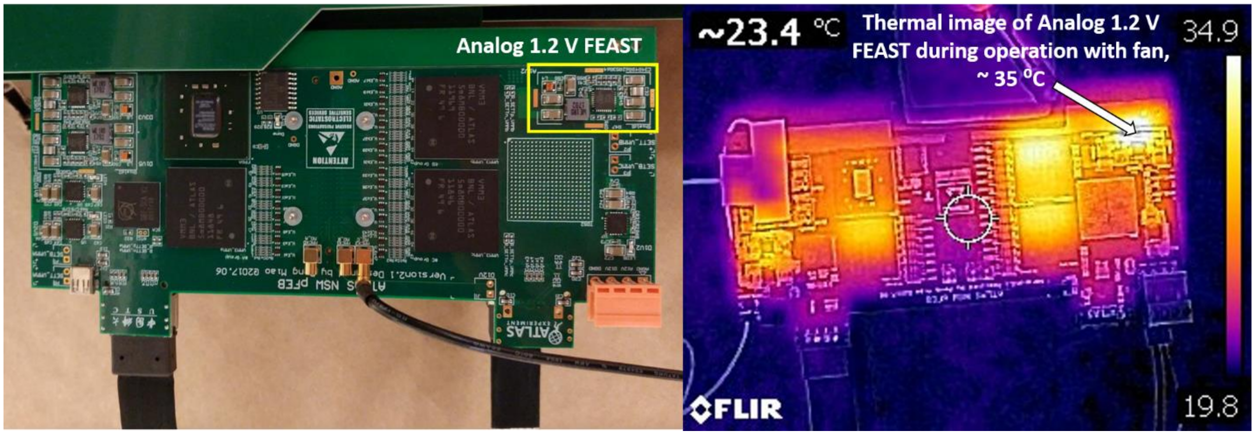

Figure 6: Left – a pFEB with the analog 1.2 V FEAST outlined. Right – an infrared image of the pFEB during operation taken with a FLIR camera. The FEAST reaches 35˚C with fans.

Table 1: Temperature of the analog 1.2 V FEAST on a pFEB during operation with various heat sinks. The pFEB was always being cooled with fans. “Operation” was defined as processing test pulses on all channels.

Set up	*Temperature during operation (ºC)*
No heat sinks	37.7 ± 0.2
Gap pad in hole (and change of fans)	32.1 ± 0.5
Aluminum heat sink, gap pad in hole	26.91 ± 0.07
Large copper heat sink, gap pad in hole	25.7 ± 0.7
Small copper heat sink, gap pad in hole	28.8 ± 0.1

Figure 7 shows the gap pad, thermal via and large copper heat sink. Since the gap pad is a better heat conductor than air, filling the hole with gap pad helped to better cool the FEAST, as well as equalize the temperature between the top and bottom of the FEAST. Overall, the large copper heat sink performed best, and so will be used to cool the sFEBs during tests with cosmic muons.

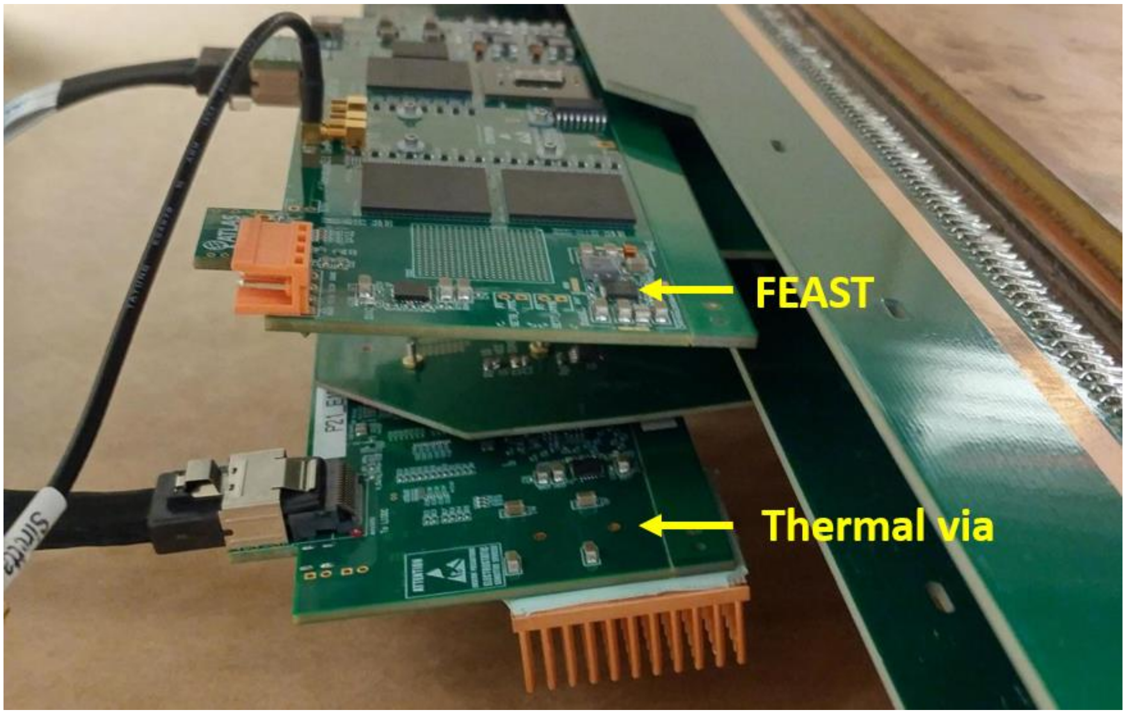

Figure 7: Two pFEBs attached to the quadruplet. The analog 1.2 V FEAST is displayed on the top pFEB. On the bottom, the FEAST is covered by Bergquist gap pad, which is being used to fill the gaps between the board and the large copper heat sink. The gap pad also provides adhesive. The hole below the FEAST is used to help with heat dissipation.

Testing the sTGC Quadruplets at CERN

Once the quadruplets have been tested with cosmic muons in their various countries of origin, they are sent to CERN. The beam from the Super Proton Synchrotron (SPS), one of the pre – accelerators to the LHC, is used to provide a more localized source of muons with a higher rate with which to test the chambers.

From June 24th – July 2nd, the prototype sTGC wedge was tested. In the same way as with cosmic muons, each time a scintillator placed between the beam source and the wedge sensed a muon, the output of the sTGC pad being hit was saved. In each saved file, the trace of a muon should have been present near $t = 0$. A code to smooth the signal peaks and identify them was written to calculate the efficiency of the chamber. For some runs, a cobalt 60 source was present, providing photons that may have busied the electronics and made them less efficient to muons. Also, layer 2 of the quadruplet used pFEBs that had an electronic component called the pi – network. The pi – network was supposed to reduce deadtime, the time the system is insensitive to muons because it is busy processing a previous pulse. Saturated signals are known to have longer deadtimes, so the pi – network grounds some of the charge deposited by the ionization products with the hope of improving the deadtime. There was a risk the pi - network would reduce the efficiency of the chamber by cutting some signals down to the level of noise, preventing the peak from being detected. The effect of the pi – network and the cobalt – 60 source on the efficiency of the chamber is shown in Table 2.

Table 2: Efficiency of the sTGC prototype wedge under different conditions.

Quadruplet layer	*Threshold (mV)*	*Pi – network*	*Source*	*Percent Efficiency (%)*
3	260	No	No	98.86
2	220	Yes	No	97.60
3	260	No	Yes	98.32
2	220	Yes	Yes	97.45

The threshold is the voltage level a signal must surpass to be considered a muon trace by the analysis code, chosen to be the mean of the baseline noise plus five standard deviations. Since the pi – network attenuated the signal, a lower threshold was used for pFEBs with it. The source had seemingly no effect on the efficiency, while the pi network dropped the efficiency by about 1 %. However, this difference could also be intrinsic to the quadruplet layer. Moreover, more sets of pads on more chambers must be studied to reach a conclusion as to whether the pi – network is a positive addition to the electronics. Efficiency and deadtime analysis of the pi – network is ongoing, with these preliminary results showing that overall it has little to no effect on the chamber efficiency.

First Production Quadruplet Tests

The first production quadruplet arrived to CERN on August 8th. It was first tested with muon beam from August 10th – August 14th. On August 15th, it was craned into CERN's gamma irradiation facility, GIF++. In GIF++, the chamber will continue to be tested with muon beam, but this time in the presence of a 13.5 TBq gamma point source. The radiation background in GIF++ is comparable to the conditions the chamber will face in ATLAS. Gamma radiation leaves some signals in the chamber, which could busy it as real muons pass, reducing its efficiency. The performance of the chamber in these conditions will be assessed to ensure it can deliver quality data in ATLAS. The analysis of the data from both beam tests is ongoing.

Conclusion

The phase-1 upgrade is part of a greater plan to allow ATLAS to provide quality data for years to come as the LHC pushes the frontiers of physics with more collisions. Specifically, ATLAS' NSW will improve its muon track reconstruction and ability to trigger on muons. Replacing the NSW is an international, multi – stage process, with five countries creating sTGCs alone. Taking

Canada as an example, three major teams are required to produce sTGCs, one of which is based at McGill University where the first tests of the chamber with cosmic muons are performed. At McGill, the laboratory infrastructure is still being improved to make the testing process as efficient as possible. This summer, the hardware to monitor sFEB temperature during tests was installed, and a LabVIEW program written to display the temperatures. Also, tests revealed that copper heat sinks with Bergquist gap pad were the best heat sinks. Once sent to CERN, the chambers are tested in conditions more like those in ATLAS, with a higher rate of muons from SPS beams and in a gamma background comparable to ATLAS provided by GIF++. The results of such tests are still preliminary but indicate that the chambers will work efficiently in ATLAS. More importantly, scientists working on the sTGCs are building expertise that will be invaluable as they move from testing to installation on the ATLAS new small wheel.

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