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Studies of ageing effects of Small-Strip Thin Gap Chambers for the Muon Spectrometer Upgrade of the ATLAS Experiment

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The instantaneous luminosity of the Large Hadron Collider at CERN will be increased by up to seven times its design value by undergoing an extensive upgrade program over the coming decade. One of the largest upgrades for the ATLAS Muon System is the replacement of the present first station in the forward regions with the so-called New Small Wheels (NSWs), to be installed during the LHC long shutdown in 2019-2020. Small-Strip Thin Gap Chambers (sTGC) detectors are one chosen technology to provide fast trigger and high precision muon tracking under the high luminosity LHC conditions. The basic sTGC structure consists of a grid of gold-plated tungsten wires sandwiched between two resistive cathode planes at a small distance from the wire plane. We study ageing effects of sTGC detectors with a gas mixture of 55% of CO_2 and 45% of n-pentane. A sTGC detector was irradiated with beta-rays from a 10 mCi ^{90}Sr source. Three different gas flow rates were tested. We observed no deterioration on pulse height of the sTGC up to an accumulated charge of 11.8 C/cm. The results of an image and chemical element analysis of the wire are also presented.

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1. Introduction

The Large Hadron Collider (LHC) accelerator complex will be upgraded over the coming decade and is expected to deliver instantaneous luminosities up to seven times its design value to the ATLAS detector [1]. In order to cope with the higher instantaneous luminosities, the ATLAS detector will be upgraded during the second long shut-down in 2019-2020. One of the largest upgrades for the ATLAS Muon System is the replacement of the present muon Small Wheels with the New Small Wheels (NSWs) [2]. Small-Strip Thin Gap Chambers (sTGC) together with Micromegas (MM) [3] are the technologies chosen for the NSWs. The sTGC consists of an array of 50 μm gold-coated tungsten wires, sandwiched between two cathode planes. The wire spacing is 1.8 mm and the cathodes are located at a distance of 1.4 mm from the wire plane. Orthogonal to the wires and on the opposite side of the cathode planes are copper strips with a 3.2 mm pitch and large rectangular pads. The pads will be used for fast triggering purposes while a combination of wires and strips will be used for precision spatial measurements.

The higher instantaneous luminosities expected in the coming decade will require the NSWs to be radiation tolerant. It's therefore important to study, before the installation of the NSW, the performance of sTGC and MM technologies after long-term radiation exposure. The performance of the MM technology has been studied and published in Ref [4]. The studies presented herein aim to assess the performance of the sTGC technology under prolonged radiation exposure, with charge accumulation rates up to 500 times larger than those expected at the LHC.

2. Ageing tests

The main goal of this experiment is to determine whether ageing effects have occurred in sTGC technologies after accumulated radiation doses of 10 C/cm of wire. Ageing effects were studied by irradiating a 10 cm $\times$ 20 cm prototype sTGC with a 10 mCi ^{90}Sr source. The integrated charge collected on the anode wire by each β-particle was used as the main observable quantity. A significant decrease in the integrated charge between the start and end of operation would signify an ageing effect has occurred. The dependency on gas flow rate was studied by irradiating three different areas of the detector for gas flow rates of 10.0, 5.0, and 2.5 cm^3/min.

2.1 Experimental setup at TRIUMF

The experimental setup was located in the TRIUMF Meson Extension Hall[1]. The wires of the sTGC were held at a potential voltage of 3.00 $\pm$ 0.02 kV. The gas mixture was 55% CO_2 and 45% n-pentane, and its flow rate was controlled using a digital flow rate meter. A 1 cm^2 plastic collimator directed β-particles from the ^{90}Sr source and uniformly irradiated 5 wires. A current of $\sim$3.7μA was observed. The output signal was split between a series of logic modules and a delay box. The logic modules discriminated the signal and provided a trigger for an Analog-to-Digital convertor, which integrated the signal from the delay box within a time window of 40 ns.

Environmental conditions, such as the temperature, atmospheric pressure, and humidity were observed to affect the amplitude of the signal pulse. In order to reduce the effects of the humidity,

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the sTGC was enclosed and flushed with dry nitrogen gas. The temperature and atmospheric pressure were continuously monitored during data collection and later used to calibrate the integrated charge to common environmental conditions.

3. Data analysis and results

All observable quantities were averaged over time intervals of one hour. The operating temperature and atmospheric pressure varied respectively in the ranges 21-26 C° and 740-780 Torr during data collection. A positive (negative) linear relationship between the temperature (atmospheric pressure) and integrated charge was observed, and the integrated charge for the entire data set was calibrated to a common operating temperature of 22 C° and an atmospheric pressure of 760 Torr. The integrated charge, current, temperature, and atmospheric pressure, as a function of running time and accumulated charge are shown in Figure 1, for a gas flow rate of 2.5 cm^3/min. No significant decrease in the integrated charge was observed for an accumulated charge of 11.8 C/cm.

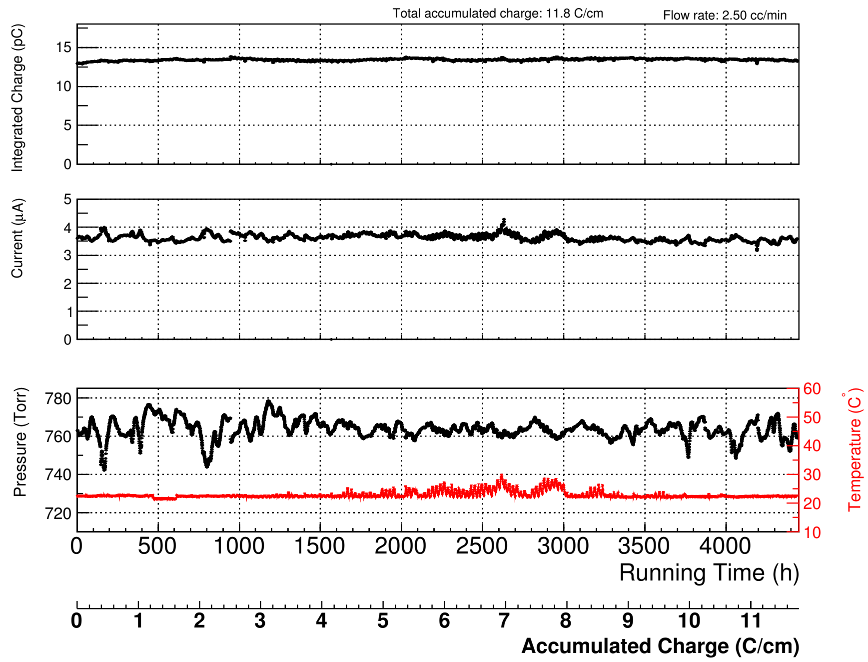
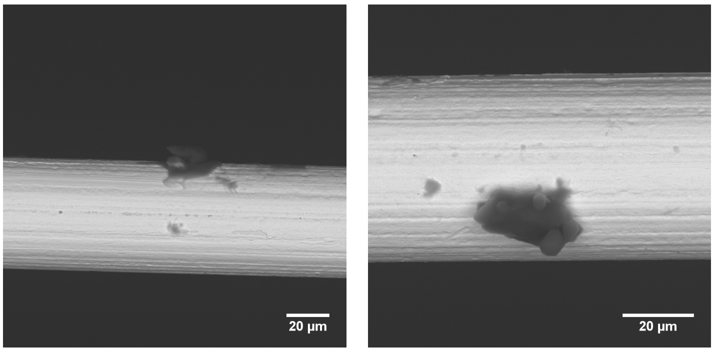


Figure 1: The integrated charge, current, temperature, and atmospheric pressure as a function of running time and accumulated charge for the sTGC ageing studies are shown. The gas flow rate was 2.5 cm^3/min.

In order to quantify the change in the integrated charge between the start and end of data collection, the first and last 100 hours were fit with a constant function. The accuracy of the high voltage power supply was the dominant systematic uncertainty affecting the integrated charge. An uncertainty of $\pm$0.82 pC on the integrated charge was found by varying the high voltage around its nominal operating value. The statistical uncertainty from the fit was negligible. The fitted values for the 2.5 cm^3/min flow rate were 13.06 $\pm$ 0.82 pC and 13.34 $\pm$ 0.82 pC, for the 5.0 cm^3/min flow rate were 13.90 $\pm$ 0.82 pC and 13.68 $\pm$ 0.82 pC, and for the 10.0 cm^3/min flow rate were

12.52 ± 0.82 pC and 12.61 ± 0.82 pC, for the first and last 100 hours of data collection, respectively. Since no significant drop in the integrated charge was found for any of the flow rates, we conclude that no ageing effects have been observed up to a total accumulated charge of 11.8 C/cm.

An image and elemental analysis of the wires was performed using a Scanning Electron Microscope at the Simon Fraser University 4D labs[2]. Elements associated to the breakdown of the gas molecules, such as carbon and oxygen, were observed sparingly distributed on the wires. Close up images of the deposits adhered to the wires can be seen in Figure 2.



(a) (b)

Figure 2: Images of molecules enriched in carbon and oxygen found on the irradiated wires.

4. Conclusions

The signal characteristics of a prototype sTGC were studied after prolonged radiation exposure. Flow rates of 10.0, 5.0, and 2.5 cm^3/min were investigated. The integrated charge was the main observable and found to be stable up to an accumulated charge of 11.8 C/cm, corresponding to approximately 200 years of operation at the High Luminosity LHC [5]. We conclude that the sTGC technology will perform well throughout Run-III and at the High Luminosity LHC.

References

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