Aging Analysis of Micromegas Detectors for ATLAS New Small Wheel

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Abstract

In preparation for the coming High Luminosity Large Hadron Collider (HL-LHC) upgrade, the New Small Wheel (NSW) will replace the Small Wheel of the ATLAS Muon Spectrometer as part of the 2018 ATLAS Phase-I upgrade. Micromegas (MM) detectors will serve as one component of the NSW. These gaseous micro-mesh detectors will accommodate the higher luminosity and trigger rate of the future HL-LHC.In order to predict performance of MM after several years in the HL-LHC, radiation aging tests were conducted in the Gamma Irradiation Facility (GIF++) using a Cs 137 source. Two small MM prototype "T" chambers were irradiated and studied over the course of several months to accelerate the aging process and characterize chamber behavior. This report outlines a record of the aging process thus far and demonstrates techniques used to describe aging effects, namely measurements of average current, integrated charge, and gain. These will be used in the ongoing aging analysis of the T chambers and in future aging studies of the most recent Micromegas Small Wheel prototype.

1 Introduction

Radioactive aging testing of the Micromegas (MM) detectors was conducted with the aim to study and predict detector performance in preparation for the coming New Small Wheel (NSW) and High Luminosity Large Hadron Collider (HL-LHC) upgrades.

1.1 The NSW and HL-LHC Upgrades

The 2022 High Luminosity Large Hadron Collider (HL-LHC) upgrade will involve a more than doubled luminosity and consequentially much higher trigger rates. As such, the ATLAS experiment must be modified to accommodate higher performance demands. In order to improve trigger performance, the New Small Wheel (NSW) will replace the Small Wheel in the ATLAS Muon Spectrometer as part of the phase-I upgrade in 2018. The two main detection components of the NSW are the Micromegas (MM) and Small strip Thin Gap Chamber (sTGC) detectors.

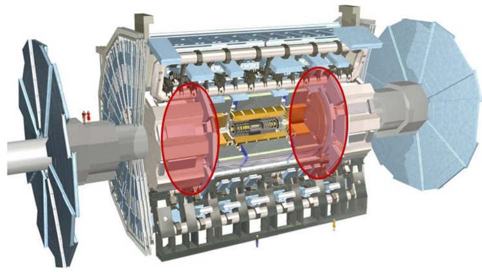


Figure 1: The ATLAS detector. The New Small Wheels will replace the existing Small Wheels, highlighted in red.

1.2 The ATLAS Micromegas (MM) Detectors

Micromegas detectors are gaseous resistive detection chambers designed for precision tracking capabilities. Their operating principle is demonstrated in Figure 2 below. MM detection chambers include a conversion (or drift) gap filled with an argon and carbon dioxide gas mixture, a micromesh, an amplification gap, and resistive and readout strips. Charged particles traverse the drift gap and ionize the gas, releasing electron-ion pairs. Ionization electrons drift towards the amplification gap while ions drift towards the drift electrode.These electrons are multiplied in the amplification gap in an avalanche process before being released on the resistive strips in order to induce a signal in the readout strips. Ions produced in the amplification region are quickly evacuated by the mesh, providing fast evacuation of the positive ions. This makes the MM well suited to operate at very high particle fluxes, such as those expected in the HL-LHC.

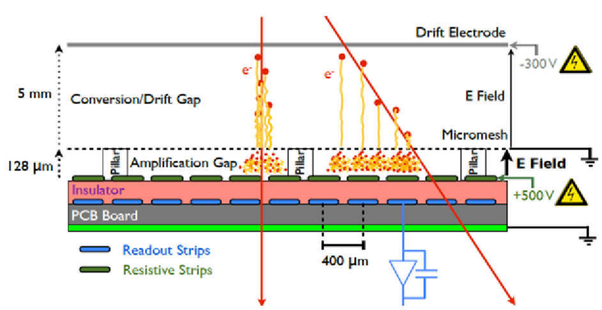
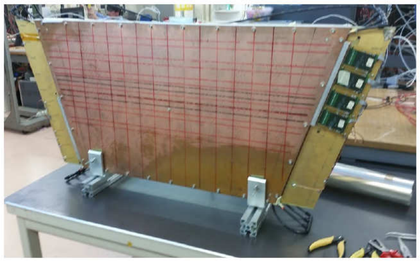
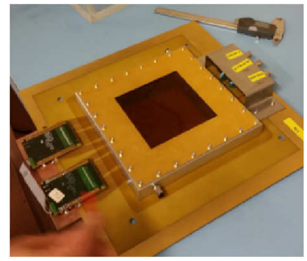


Figure 2: MM Operating principle

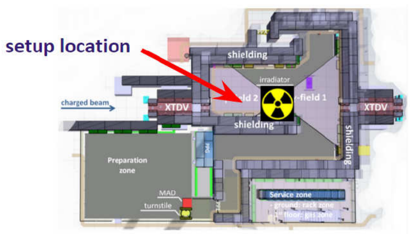


(a) The MMSW prototype.

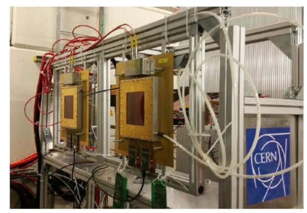


(b) A MM T-Chamber.

Figure 3: Examples of MM Detectors



(a) Layout of GIF++



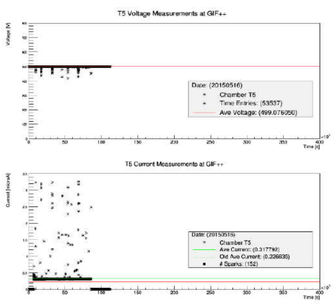
(b) MM T-Chamber Setup

Figure 4: Aging Setup in the GIF++ Facility

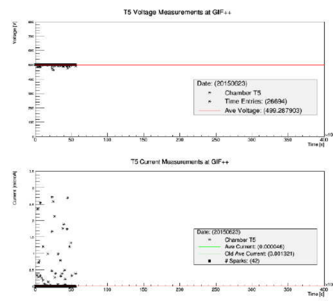
Two MM prototypes are shown in Figure 3.The MMSW (Micromegas Small Wheel) is the most recent prototype designed for use in the NSW. T-Chambers are smaller detectors used for experimentation and testing.

2 Setup for Aging Testing at GIF++

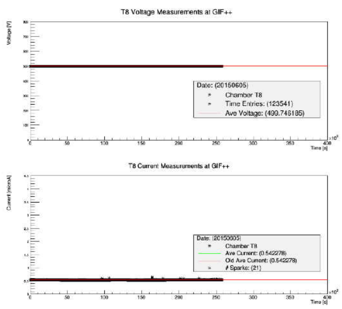
In order to predict how the MM detector will behave after several years in HL-LHC, radiation aging tests were performed on MM prototypes at CERN's Gamma Irradiation Facility (GIF++) in Prvessin. An experimental setup involving two T-Chambers (T5 and T8) was arranged upstream of a 16.65 TBq Cs 137 source, as shown in Figure 4. Detector voltage and current were monitored over a several month period during exposure to the source at different. This experiment was intended to study general performance and current behavior, as well as to investigate features such as gain, integrated charge, detection rate and efficiency, and noise rate prior to and after irradiation. Therefore the experiment served to characterize detector performance and any aging effects.



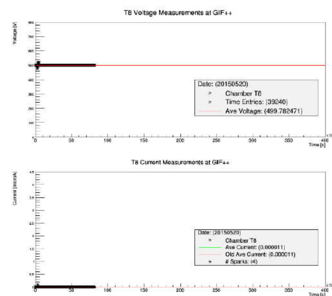
(a) Sparking, source on.



(b) Sparking, source off.



(c) Stable, source on (several days).



(d) Stable, source off.

Figure 5: Examples of Daily Current/Voltage Plots

3 Results and Related Studies

The aging process was monitored and analyzed through studies of average current, integrated charge, gain, and attenuation.

3.1 Monitoring of Current and Voltage Stability

A by-date record of chamber behavior and stability was monitored as shown in Figure 5. Voltage and current values in the T5 and T8 chambers were recorded as a function of time and plotted in order to observe features such as average current and voltage and sparking.Trends in chamber behavior were noted and the average current measurements were used in further studies of average current and integrated charge to characterize any aging effects.

3.2 Record of Average Current over Time

The average current plot in Figure 6 represents a summary of the average currents in both T-Chambers and a timeline of the overall aging process from May until August. Dates where no data was taken are shown in green, and some relevant events are noted, such as chamber rotation and setup. Average current

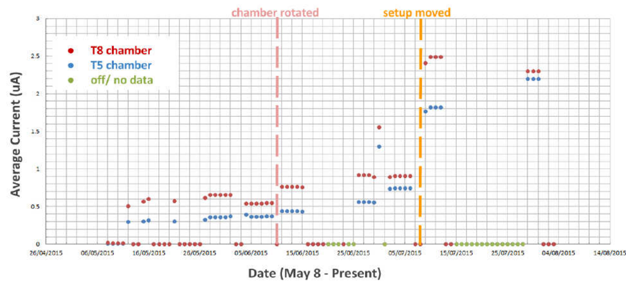


Figure 6: Record of average current in T5 and T8 over time.

measurements were found using an average of points within a range of .25uA of an initial average of all current points above zero. These measurements were used as a general record of data taking and to estimate integrated charge.

3.3 Estimation of Integrated Charge

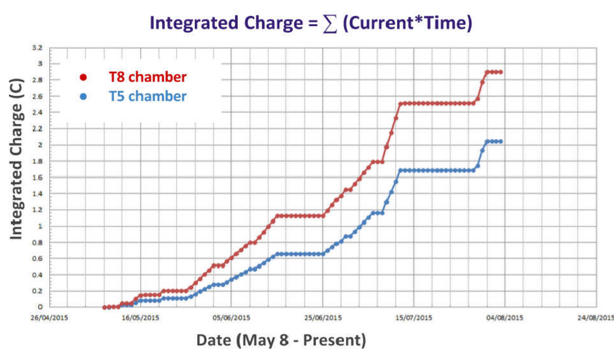
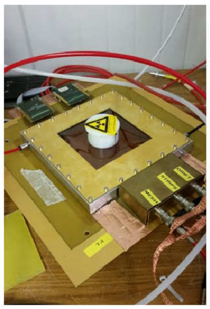
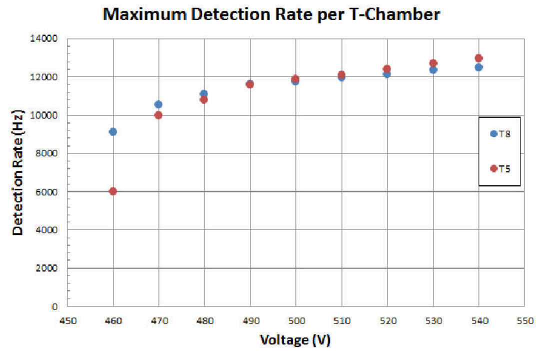


Figure 7: Estimation of integrated charge in T-Chambers over time.

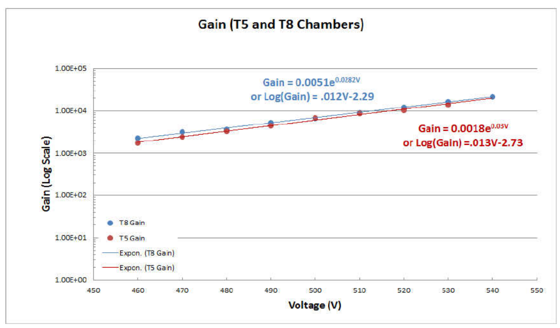
Shown in Figure 7 is an estimation of charge integrated across the T5 and T8 chambers during the aging process. Integrated charge was calculated per chamber using summation of the average current per day (including zero values) multiplied by exposure time. The goal is to accumulate 100C of charge in GIF++, or the equivalent of 10 years exposure in HL-LHC. As of early August, the T-Chambers have integrated about 3C of this total 100C charge. Continued observation of potential aging effects is expected during continued accumulation of charge on the chambers.



(a) Experimental Setup.



(b) Maximum Rate Plateau per Chamber



(c) Expected Gain of T-Chambers vs. Voltage.

Figure 8: Evaluation of T-Chamber Rate and Gain

3.4 Gain Studies

In order to understand rates in GIF++ and look for evidence of radioactive aging a smaller in-lab gain measurement was conducted on the T5 and T8 chambers using an Iron 55 source. Gain of the chambers determined using maximum detection rate can be compared to future gain measurements using GIF++ detection rates. Aging effects may be apparent if damage to the resistive strips causes a decrease in gain (higher detector current causes lower gain in the amplification gap).
A maximum rate of about 13000 Hz was measured in both chambers following a plateau measurement of average trigger rate at increasing voltage. This was used to calculate the gain as follows:

Gain = total current / (e- charge*incoming rate*primary e-s per photon)

An overall gain of about 10^4 was was measured in both chambers and described per voltage. A summary of this experiment is shown in Figure 8.

4 Conclusions and Future Work

Monitoring of chamber behavior and integrated charge will continue in GIF++ according to these methods. This will include further aging of the T-Chambers as well as aging tests on the MMSW prototype in the near future. In addition, there will be an investigation of other variables that may correlate with possible aging effects, such as attenuation, sparking, detection efficiency, temperature, and pressure. There are also plans for updated measurements of integrated charge and gain, particularly following a detection rate determination in GIF++. All of this will be a part of larger preparations for the NSW and HL-LHC upgrades.