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Advanced Aging Study on Triple-GEM

Francesco Fallavollita[3], Davide Fiorina[1,2], Jeremie A. Merlin[3]

on behalf of the CMS Muon Group

[1] Dipartimento di Fisica, Università degli Studi di Pavia
[2] INFN sezione di Pavia
[3] CERN

davide.fiorina@cern.ch

1. Motivation

The high-luminosity LHC (HL-LHC) upgrade is setting now a new challenge for particle detector technologies.

To cope with the foreseen high rate environment and maintain the actual performance, the new Triple-GEM detectors will be installed in the innermost region of the forward muon spectrometer of the CMS experiment.

The detailed knowledge of the detector performance in the presence of such a high background is crucial for an optimized design and efficient operation after the HL-LHC upgrade.

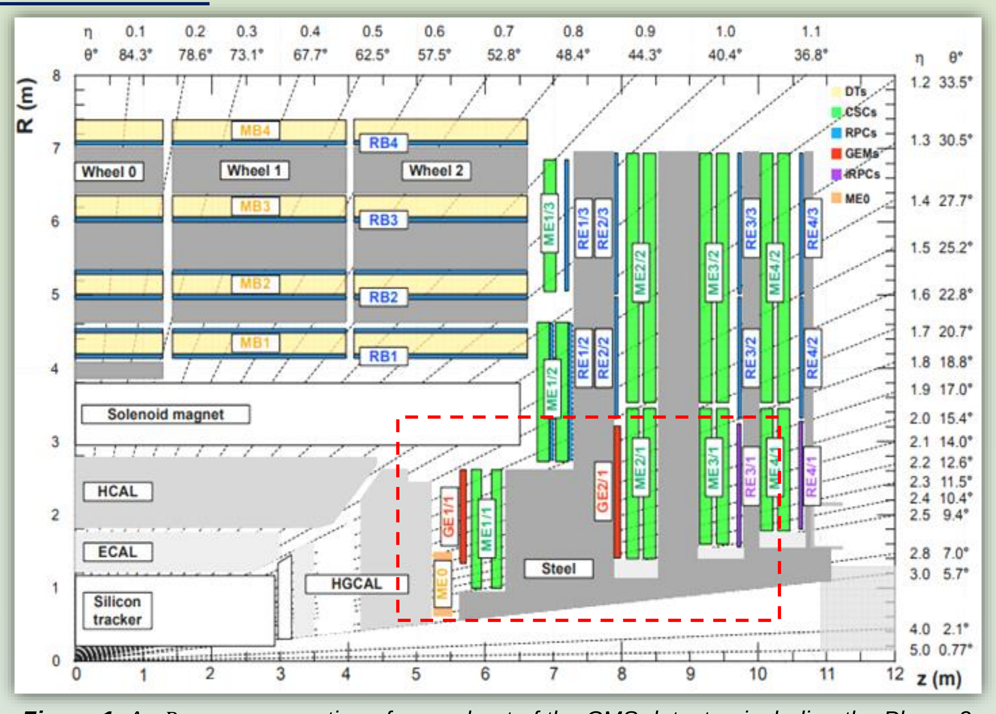


Figure 1. An $R-z$ cross section of a quadrant of the CMS detector, including the Phase-2 upgrades ($RE3/1$, $RE4/1$, $GE1/1$, $GE2/1$, $ME0$).

For this reason, aging tests on full size triple-GEM detector were performed [1]. Nevertheless new type of aging studies have to be invented and performed in order to assure the radiation hardness of GEM detectors in particle environments rich of densely ionizing particles since new, ever studied, longevity issues can emerge in this particular surroundings.
Understanding these issues is a priority for the future GEM-based upgrade and in general for all the future experiments which will employ gaseous detectors in high rate and high ionizing environments.

2. Aging Processes of Gaseous Detectors

Aging is one of the most critical limitations of the use of gaseous detectors in strong radiation environments. It includes all the processes that lead to a significant and permanent degradation of the performances of a gaseous detector: gain drop, non-uniformity, dark current, discharge, etc.

The main causes behind the detector performance deterioration are chemical processes largely occurring in the hot plasma inside electron multiplication avalanches. Gas molecule fragments produced inside avalanches may form polymers growing on anode wires, cathode surfaces, and anode-cathode insulating elements.

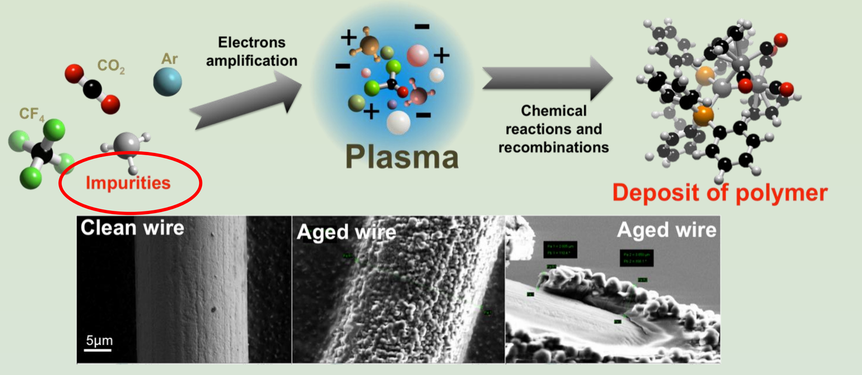


Figure 2. Top: schematic view of the classical aging process. Bottom: SEM photographs of a clean detection wire (left) and aged wires (right) after few weeks of operation in a proportional counter and a dirty environment.

Since the aging phenomena depends on a large number of input parameters and relies on several possible chemical mechanisms, it is not possible to build reliable models or simulation tools that can predict the long-term behavior of gaseous detectors. Most of the contaminants usually comes from the **outgassing** of some materials which tend to release some of their molecules in the gas volume, triggering the polymerization processes and further inducing the performance degradation of the detector.

When an high rate of highly ionizing particles is involved, aging processes could be dramatically worse for the life of the detector. Higher density of deposited energy can lead the formation of different polymers at different speeds thus they can trigger different chemical reactions and change their kinematics.

3. Aging Study State of the art and new ideas

An aging study is usually performed in the framework of a certain experiment for assuring the long term stability of its gaseous detectors during the data acquisition period.
A standard aging study commonly requires a detector in its final version, ready to be mounted into the experiment, to integrate a certain amount of charge similar to the one expected in the lifetime of the experiment; all of that in a clean gas environment.
Usually the detectors are irradiated with photons (X-rays or γ-rays) because of the simplicity to produce and contain them.
In order to perform this test in a reasonable time, the hit rate and/or the detector gain is increased with respect to the one foreseen in the experiment.

These methodologies may not reproduce the exact particle environment in the experiment preventing certain aging processes to happen.

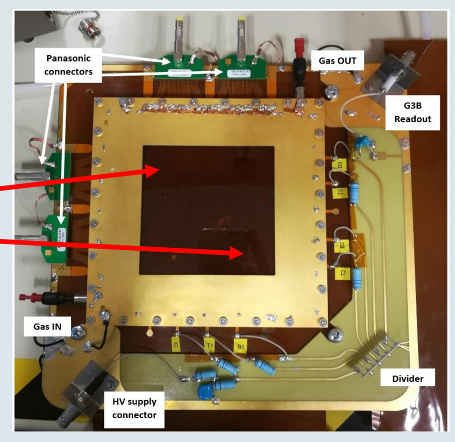
The understanding of the limits of the standard aging tests, if any, will be important for the future experiments and for this reason new ideas which involve new irradiating particles and new accelerating method are needed.

Figure 3. A typical setup for an aging study: final detector version irradiated with a photon source (^{137}Cs) [1]

4. Experimental Setup

The main aim of this test is to understand the limits of the standard aging tests and, on the other hand, to learn how particles with different ionization powers can affect the long term stability operation of a Triple-GEMs in the CMS framework. For this reason, the test is performed on a 10x10 cm² GEM prototype with CMS gaps configuration: 3/1/2/1 mm.
Two are the breaking points with respect to the standard aging tests: the use of highly ionizing particles as a irradiation mean and a new method to accelerate the test. The latter is done contaminating the gas mixture in order to simulate years of minor contamination in a clean gas system.

In order to understand the differences between irradiating with photons or with highly ionizing particles, the detector under test was exposed to an **^{241}Am source (5.6 MeV alpha particles)** on one corner and to a **^{55}Fe source (5.9 keV photons)** on the other corner.



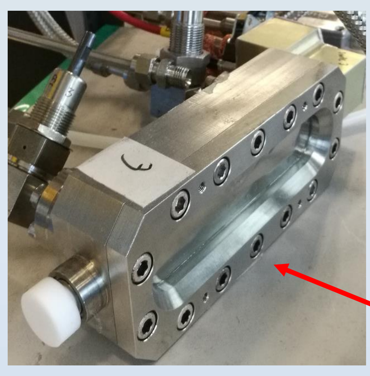


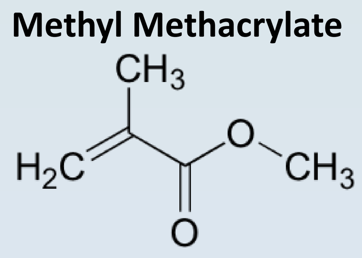
Figure 4(right)-5(left). Figure 4 shows a picture of the GEM detector under test. Figure 5 shows the Wire Chamber used to monitor the polymer formation.

Furthermore, in order to monitor the polymer formation, a detector based on a technology more sensitive to aging - Single Wire Proportional Chamber (SWPC) - is placed along the same gas line irradiated with a **^{55}Fe source**.

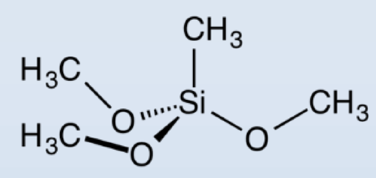
In the context of creating new methods to investigate the aging problem, this test exploit a particular accelerating method; two glues were inserted into a stainless steel cylinder placed in series to the gas flow, these glues release some of their molecules inside the gas volume.

These molecules are hydrocarbons and Si-based; their dissociation during the electron avalanche may create radicals potentially dangerous to the detector.

Methyl Methacrylate



Methyltrimethoxysilane



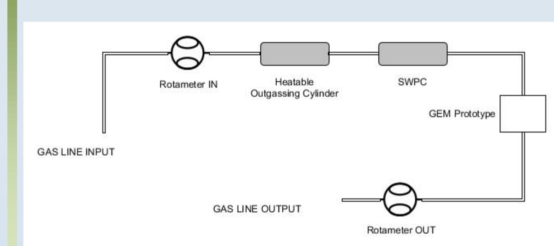


Figure 6. The figure shows the scheme of the gas line: the gas is first contaminated and then is flowed through the SWPC and the GEM detector.

5. Characterization of the GEM detector

A typical GEM detector characterization was performed aimed at verifing the correct operation of the prototype and finding the correct working point.
The detector resulted to be fully operational and the working point was chosen to be 700 μA equivalent to 3623 V applied on the drift plane.

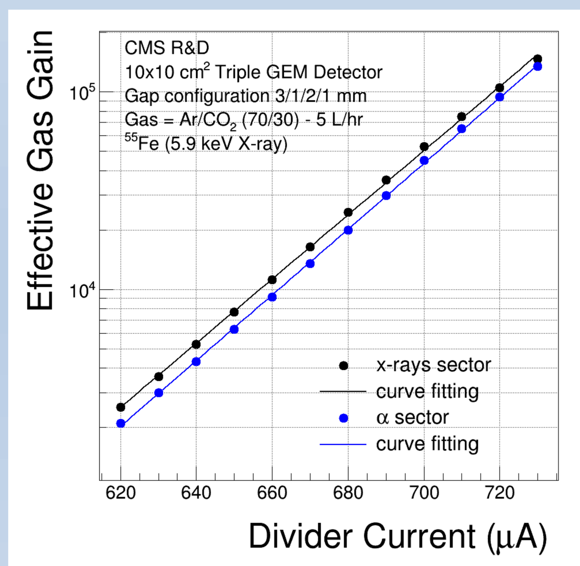


Figure 7. The plot shows the measured values of the Effective Gas Gain of the Triple-GEM detector under test as a function of the Divider Current. Gain differences in the two sectors are due to a hole in the drift plane which distort the electric field.

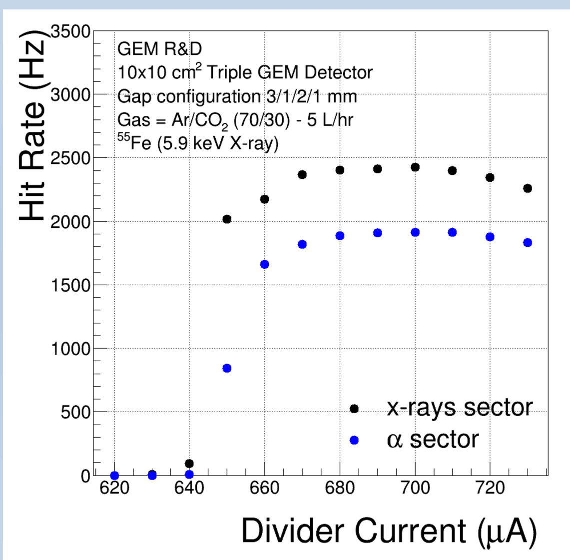


Figure 8. The plot shows the Hit Rate of the Triple-GEM prototype irradiated with a ^{55}Fe source as function of the Divider Current. Rate in the alpha sector is lower because of a hole in the drift plane, resulting in less photon converted into the drift gap.

6. Data Acquisition and Analysis Procedure

Charge spectrum from both the GEM sectors and from the Wire Chambers are acquired, Figure 9 shows some examples. A scheme of the DAQ chain is shown in Figure 10.

Each spectrum contains data obtained in 30 minutes of acquistion. Every spectrum is fitted with 3 gaussian functions in order to find the peaks positions with respect to the Pedestal position. This fundamental quantity is proportional to the gain of the detector, i.e. releated to its performances.

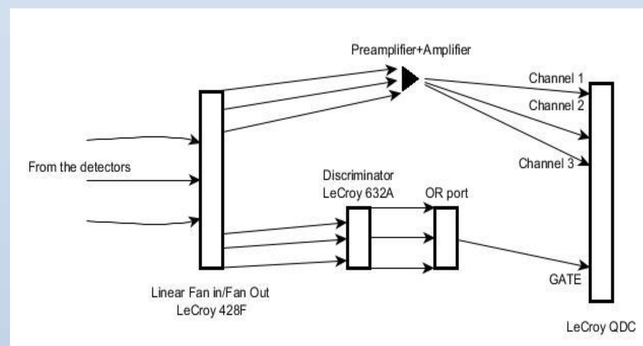


Figure 10. Scheme of the DAQ chain used

Since the gain is influenced by the environmental fluctuations is important to correct each measurement by this effect. The environmental parameters (Temperature and Pressure) are monitored by an Arduino-based meteo station and the peak positions are corrected using a power function [1],[2].

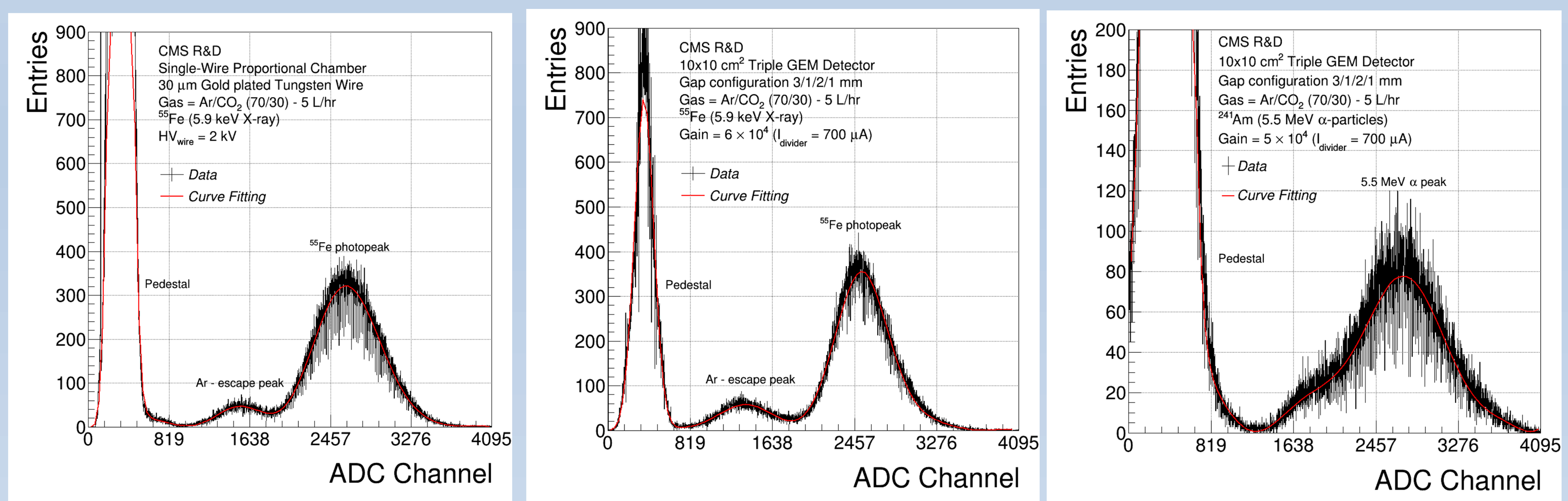
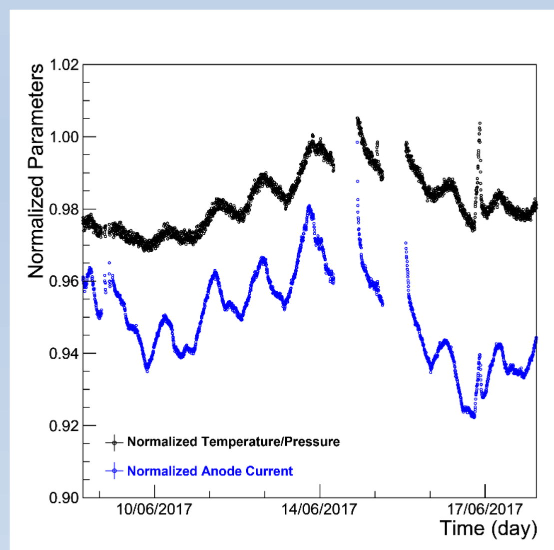


Figure 9. The plots show examples of charge spectra. Left: ^{55}Fe charge spectrum obtained with the Single Wire Proportional Chamber. Middle: ^{55}Fe charge spectrum obtained with the GEM detector. Right: a ^{241}Am charge spectrum obtained with the GEM detector.

Figure 11. Example of correlation between a variable proportional to the gain (in this plot case is the anodic current while in this test case is the peak shift with respect to the pedestal) and the environmental parameters (T/P). The values are normalized to a certain initial value. Plot from [1].



7. Gain evolution

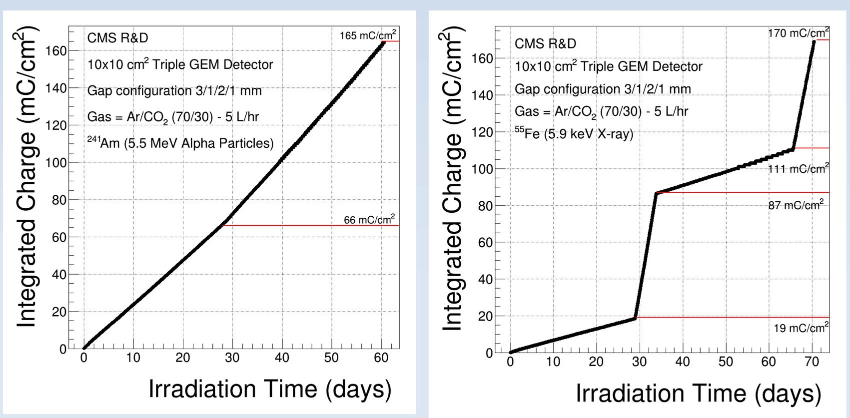


Figure 12. These plots show the collected charge during the acquisition time on the Alpha Sector (left) and the X-ray Sector (right).

After a total integrated charge of 165 mC/cm² on the Alpha Sector and 170 mC/cm² on the X-ray Sector, a 20% gain drop in the SWPC was observed (Figure 13).

The polymer concentration was enough to ruin the performance of a classical technology as wire chamber.

On the other hand the GEM detector revealed to be radiation hard in a contaminated gas volume up to 165 mC/cm² in both the irradiated sectors.

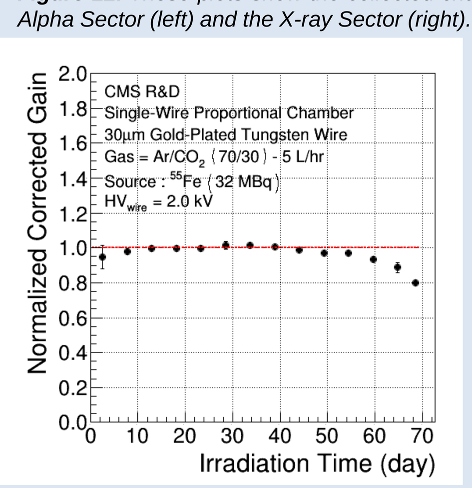


Figure 13. Single Wire Proportional Chamber gain evolution during the test. The chamber lost about 20% of its initial gain.

No aging observed in the Triple-GEM prototype

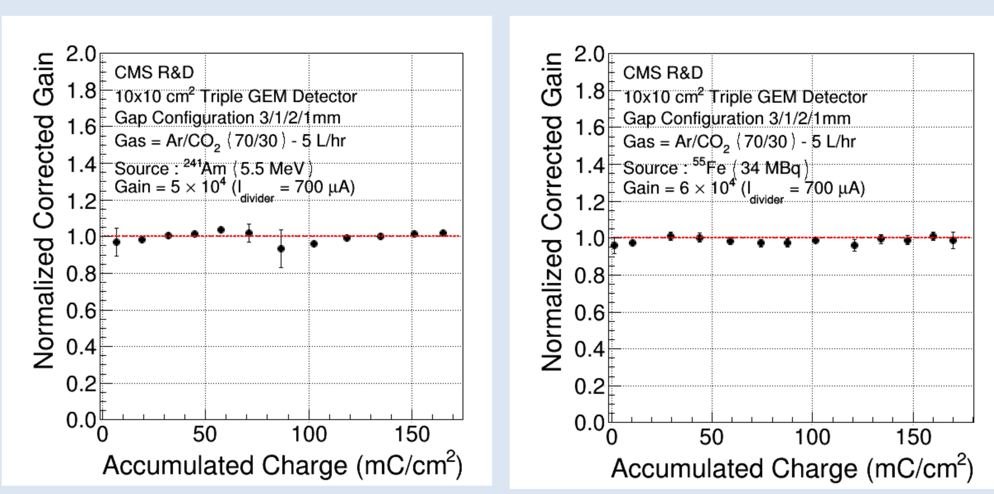


Figure 14. Gain evolution as function of the integrated charge of the Alpha Sector(left) and the X-ray Sector (right). No deviation from the nominal value is observed in both the sectors.

8. Energy Dispersive X-rays Analysis

In order to understand the different aging processes occurring when irradiating with different particles, an Energy Dispersive X-rays Analysis was performed on the third GEM foil with samples taken from the Alpha Sector, the X-ray Sector and from a non irradiated Sector (as reference)

Figure 17

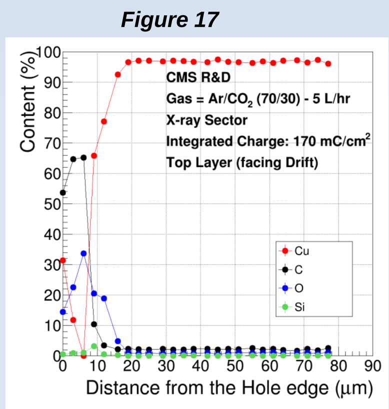
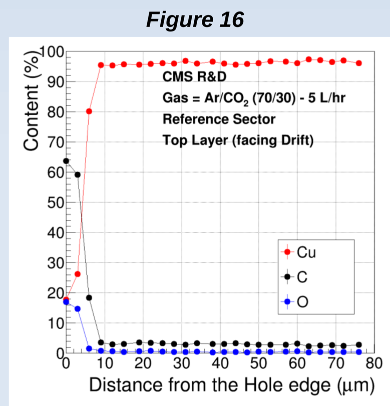


Figure 16



The plots on the left show the percentage concentration of atomic specimens present on the foil surface as a function of the the distance from the hole border. (see Figure 15).

Figure 15

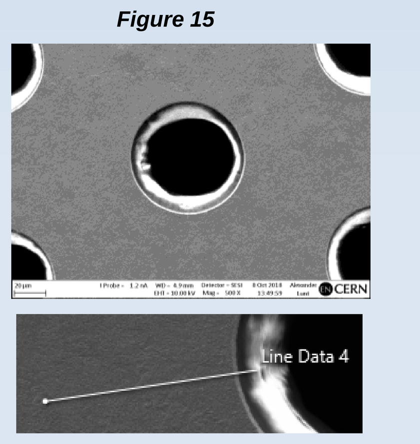


Figure 18

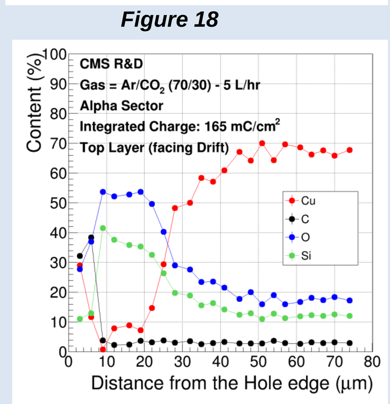


Figure 16 shows no Si deposit on the non-irradiated Sector, as expected. Si traces were found in the X-ray Sector, meaning that the polymers were starting to accumulate (Figure 17). Figure 18 shows a significant presence of Si deposit in the Alpha Sector.

This means that, nevertheless the sectors have collected about the same charge, particles with higher ionization density (alpha particles) create polymers with a considerable higher rate than particles with lower ionization density (X-rays).

[1] F. Fallavollita, Triple-Gas Electron Multiplier technology for future upgrades of the CMS experiment: construction and certification of the CMS GE1/1 detector and longevity studies, CERN, http://cds.cern.ch/record/2658126, January 2018.
[2] J. A. Merlin, Study of long-term sustained operation of gaseous detectors for the high rate environment in CMS, CERN, https://cds.cern.ch/record/2155685, May 2016.