

Aging Studies on SWPC and Triple GEM Detectors

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1 Introduction

This aging analysis is considering only gaseous particle detectors[3]. Gaseous detectors are based on the electromagnetic(EM) interaction between a travelling particle and the gas it comes into contact with. Usually the atoms of the gas are ionised, producing primary electrons and ions. The electrons drift to the anode(positively charged) surface of the detector and the ions to the cathode(negatively charged) surface. In sufficient electric fields (100kV/cm), secondary ionisation caused by the primary electrons can occur, leading to an avalanche of electrons and amplification of the initial charge. The charge increase can be described by a value called the gas gain, G of the detector[2]:

$$G = \frac{n(x)}{n_0} = e^{\alpha x} = \frac{I_A}{I_0} = \frac{I_A}{n_0 e^- R} \quad (1)$$

where $n(x)$ is the total number of electrons after an avalanche path, n_0 is the number of primary electrons and α is the Townsend coefficient proportional to the probability of emitting an electron. I_A is the anodic current(output current value from the readout board), n_0, e^-, R are the number of primary electrons, the electron charge and the emission rate respectively. The Townsend coefficient is subsequently dictated by:

$$\alpha = \frac{1}{\lambda} \propto \frac{1}{\rho} \propto \frac{T}{P} \quad (2)$$

where λ is the distance an electron can travel before ionising a particle and ρ, T, P are the density, temperature and pressure of the gas respectively. This proves the relationship between the gas gain and the Temperature and Pressure of the gas mixture which will be utilised further into the aging studies.

1.1 SWPC

Single wire proportional chamber is a gas particle detector with internal electron multiplication. The design used in these outgassing studies was created by the CMS GEM group to replace previous designs which were more expensive, fragile and hard to clean[2]. The SWPC structure can be examined in figure 1a. The chamber is similar to a Geiger counter, however with a proportional signal, including an anode made out of a $30\mu\text{m}$ gold plated tungsten wire, and a cylindrical cathode surrounding it. The anode is set at High Voltage (HV), creating a powerful electric field dictated by equation:

$$E(r) = \frac{V_0}{\ln(\frac{b}{a})} \frac{1}{r} \quad (3)$$

where V_0 is the voltage supplied to the cathode, a is the radius of the anode and b of the cathode. The electric field in the SWPC is sufficient to cause secondary ionisation (for this case where 2000V are applied). An ionising particle enters the region between the anode and cathode through 4cm^2 holes, drilled on the chamber as can be seen in Figure 1a and drifts towards the positively charged anode. Close examination under the microscope can provide useful information considering the build up of polymers on the wire surface[1].

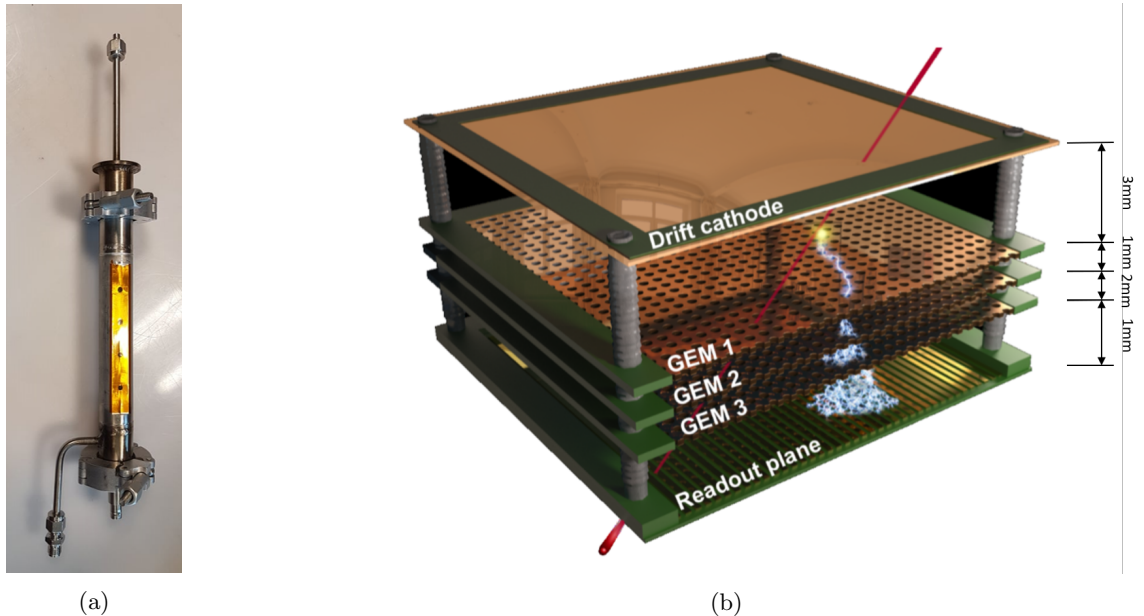


Figure 1: (a) Cylindrical SWPC with holes utilised for irradiation of the detector, kapton tape is used to seal the chamber, (b) Triple GEM configuration[2]. The avalanche occurring from one primary interaction is shown.

1.2 The triple GEM

The triple Gas Electron Multiplier[3] chamber is a micro pattern gaseous detector(MPGD) made through concatenation of 3 kapton foils of $50\mu\text{m}$ with a coating of $5\mu\text{m}$ of copper, an anode(readout board) surface and a cathode(drift) surface as can be seen in Figure 1b. The foils are chemically etched with holes at a density of $5000\text{holes}/\text{cm}^2$. High voltage(HV) is applied between the foils causing the electrons to drift through the etched holes, where the electric field is large enough to cause secondary ionisation and an avalanche. The charge increase defined by a gain, G can reach a value of up to 10^5 . These detectors will be first used in the upgrade of the muon chambers on the CMS detector in correspondence with the High Luminosity upgrade of the LHC[2]. The new GEM detectors will be inserted through projects GE1/1, GE2/1 and ME0 into the pseudorapidity region of the CMS detector on it's end caps ($1.6 < |\eta| < 2.8$). These phase 1 and 2 upgrades aim to enhance redundancy, increase the accuracy of position measurements and subsequently reduce the number of soft muons. The CMS gap configuration is "3/1/2/1", and determines the distance between the GEM foils, as can be seen in Figure 1b.

For the aging experiments the CMS GEM group provided a $10 \times 10\text{cm}^2$ prototype triple GEM[2]. The overall layout is the same, however a single HV channel is used along with a voltage divider to provide the required voltage to the foils. The readout board is made out of 512 strips (256 in each direction) which provide position information, not required in this case. In addition, a Faraday cage is created by wrapping a copper and kapton sheet around the detector and along with an RC filter on the HV line assists in reducing the EM noise. In order for the detector to be irradiated with alpha particles some square holes were cut on top of the drift layer of the detector.

1.3 Aging and Motivation

Aging refers to the deterioration of the performance of a gas based detector by a gain reduction or a decrease of energy resolution[2]. Aging usually occurs due to the formation of radical molecules in the gas chamber. These molecules are formed around the avalanche since the dissociation energy is lower than the ionisation energy of the gas molecules. The radicals are very active and might react with each other to form monomers and subsequently polymers that might deposit on the anode or cathode. Anode aging is characterised by a variation in the electric field leading to a gain and resolution decrease. Cathode aging is well described by the Malter effect[1], where the thin film forming on the cathode doesn't allow for positive ion neutralisation and the positively charged ions along with the charged cathode can cause extraction of electrons from the

surface of the cathode which in turn drift to the anode resulting in dark currents, noise pulses etc.

The Ar/CO_2 mixture along with the GEM technology radically decreases aging effects as studied in various previous experiments[1]. However, pollution that can lead to polymer formation is always present in the detectors, mostly arising from contamination, leakage, residuals and materials in the detector releasing molecules. The GEM could experience a gain decrease through polymer build up around the holes and also be affected by the Malter effect through build up of ions on the rim of the holes of the GEM sheets. In addition, the GEMs used in the CMS upgrade will face high background and interaction rates. Background particles(like neutrons) can have deteriorating effects on the GEM performance since they release a lot of energy in the detector causing discharges and a large amount of radicals. Most aging tests are done through irradiation of the GEM chamber with Xrays(photons) hence are not very representative of the actual effects on the GEM detector.

2 Methodology

For this experiment irradiation with both Xrays and alpha particles (Helium nuclei) through sources of ^{109}Cd and ^{241}Am is carried through for a better representation of the aging effects on the detectors. Moreover, accelerated aging is managed by outgassing the chamber with pollutants to simulate the longer outgassing through materials inside the chamber.

2.1 Experimental setup

Both chambers are polluted using a gas system which includes rotameters at the input and output in order to set the volume flow rate to $5l/h$. The system also includes outgassing cylinders which are heated to $50^\circ C$. The pollutants used are adhesives including both Methyl Methacrylate and Methyltrimethoxysilane, whose dissociation create both hydrocarbon and silicon based radicals[2]. They are placed into the outgassing cylinders and heated to increase the pollution rate.

Both detectors are irradiated with alpha particles of 5.6 MeV emitted from ^{241}Am and Xrays of 22.1keV emitted from ^{109}Cd . The GEM is irradiated with both sources at the same time, since its geometry allows for the separation of the signal from the alpha and Xray irradiated regions. However the SWPC only allows for one radiation source input at a time. Here, the readout for the GEM output will be described. However, the SWPC readout, also follows the same procedure but with a single channel output. Pulse height spectra are measured through the setup shown in Figure 3. The signal is firstly preamplified and a discriminator with a threshold value is used to create a trigger signal for the QDC(charge to digital converter). The real signal is delayed and attenuated to follow the trigger signal and be within the range of integration of the QDC. Finally the QDC analyses the signals only when a trigger signal from the dual timer is present so as to capture a channel value proportional to the charge output of the detector. These outputted values can be further processed into a histogram seen in Figure 2. The figure also has a peak at the zero charge position, which is captured through a randomly generated signal from a dual timer in order to act as a reference zero value. The distance between the two peaks is analogous to the gain value and can be used along with the resolution of the peak in question to show aging effects on the detector. Furthermore, anodic current which can be estimated through a manipulation of Equation 1 can be set constant in order to have the same integrated charge when the data acquisition for the GEM is done. Hence the Xray source is attenuated using kapton tape in order to reach the same anodic current to the Alpha source which has a lower rate overall. However, for the SWPC, the Xray source is attenuated to match the rate of the alpha source. The integrated charge was matched by adjusting the running time of both the tests.

2.2 Data Analysis

2.2.1 Spectra processing and integrated charge

Initially, the files containing the spectra information are converted to histogram files through a C++ code ran in ROOT. The histogram files are then fitted with two Gaussian functions, one for the interaction charge and one for the artificial zero, along with a third order polynomial to fit the background noise. An example of a histogram fit can be seen in Figure 2. An output file is then created containing information on the mean, amplitude and standard deviation on all of the spectra. This information is then processed to find

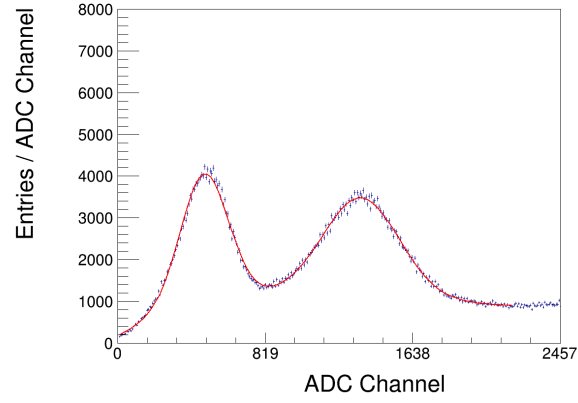


Figure 2: Example of a spectra taken from the SWPC irradiated with Xrays. The first peak from the left is the artificial zero and the peak on the right is from the accumulation of charge.

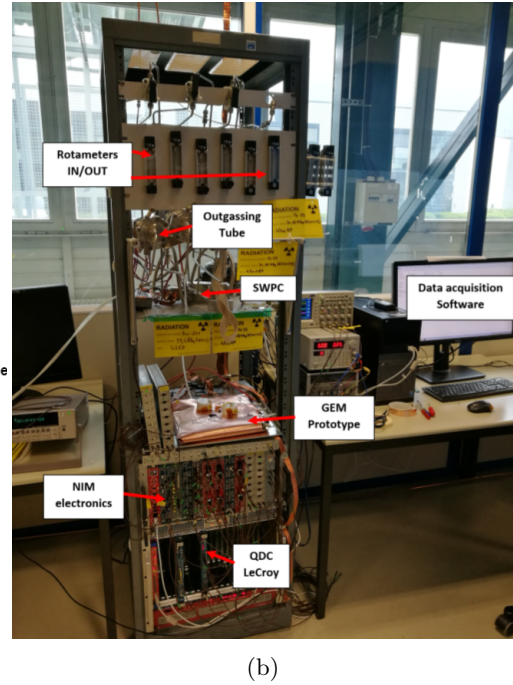
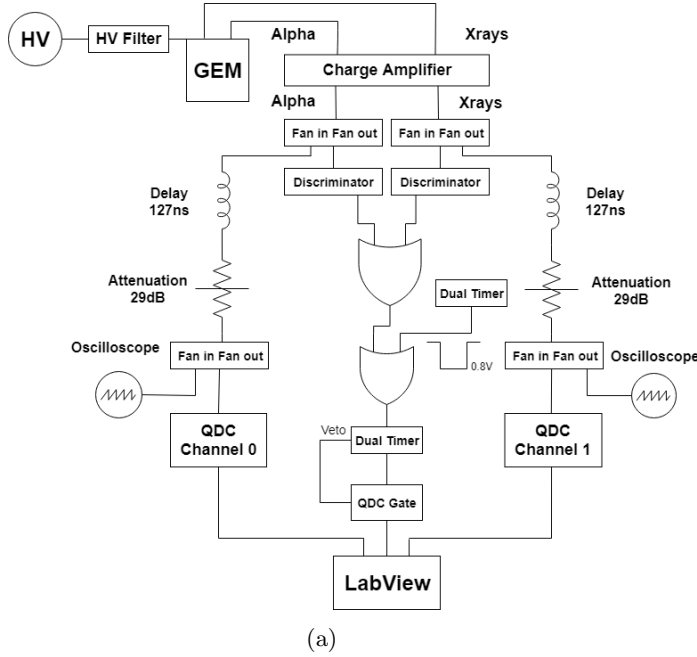


Figure 3: (a) Schematic depicting the setup for the GEM output signal processing, (b) Image showing the whole setup for both the SWPC and the GEM along with the outgassing tubes where the contaminants are inserted.

the distance from peak to peak (analogous to the gain) and the standard deviation (analogous to the energy resolution). Moreover, the file contains ADC values which can be used to estimate the integrated charge.

In order to calculate the integrated charge, the anodic current (I_A) is measured for a time window of 30 minutes for both the SWPC and the GEM. This value is then used along with the time to find the integrated charge for this single spectra ($Q_0 = I_A T$). In the meantime, the QDC produces an ADC value, defined by the following equation[2]:

$$ADC = \sum_i^N x_i y_i \quad (4)$$

where, N is the range of the spectra, and x,y are the respective digitalised values taken by the QDC. This value can then be used to calculate the charge for every spectra (and in turn the integrated charge for all the spectra) using the following analogy:

$$Q_i = Q_0 \frac{ADC_i}{ADC_0} \quad (5)$$

2.2.2 Environmental Correction

It is vital to take into consideration that the gain values are also subject to environmental parameters. The environmental pressure and temperature are captured using an arduino-based weather detector placed outside the gas volume[2]. This is shown in Equation 2 and can be expressed precisely with the following relationship:

$$G_m = G_{corr} \left(\frac{T}{\langle T \rangle} \right)^\alpha \left(\frac{\langle P \rangle}{P} \right)^\beta \quad (6)$$

where, G_{corr}, G_m are the corrected and measured gains respectively, T and P are the temperature and pressure of the environment, $\langle T \rangle, \langle P \rangle$ are their average values and α, β are constants that need to be evaluated experimentally.

Equation 6 is separated into two functions, one including the pressure terms and one including the temperature terms. The unknown constants($\alpha, \beta, \langle T \rangle, \langle P \rangle$) are evaluated by fitting the expected functions to the data. This is achieved by transforming the equations logarithmically in order to have a linear relationship that can be more easily observed. Examples of the relationship between pressure, temperature and the gain variation for the GEM irradiated with Xrays is presented in Figure 4. The measured gain is then corrected by dividing with the pressure function and the temperature function:

$$f(T) = C_P \left(\frac{T}{\langle T \rangle} \right)^\alpha, f(P) = C_T \left(\frac{\langle P \rangle}{P} \right)^\beta \quad (7)$$

where the constants C_P, C_T arise from the contribution of the other variable and are ignored when correcting for each variable separately. It is important to note that for the gain relationship of the SWPC, less points are considered since the gain drop is significant and the relationship doesn't hold. All the gain values are considered for the GEM gain environmental correction since the gain is not expected to change significantly. Finally, the alpha irradiated gain for the SWPC is not corrected since the spectra are much less (due to the larger anodic current) and the correction would have to be done with a very small amount of spectra and would not have been accurate (< 20).

2.2.3 Resolution

Another measure of aging as mentioned earlier is the energy resolution of the peak (Figure 2). The resolution is governed by the following equation:

$$R(E) = \frac{FWHM}{E} \quad (8)$$

where, FWHM is the full width at half maximum, which relates to the standard deviation of the distribution ($FWHM = 2.355\sigma$) and E is the position of the peak relating to the acquired charge from the detector. The resolution, R increases when the standard deviation is increased. An increase in resolution marks a decrease in measurement accuracy of the detector which results from aging.

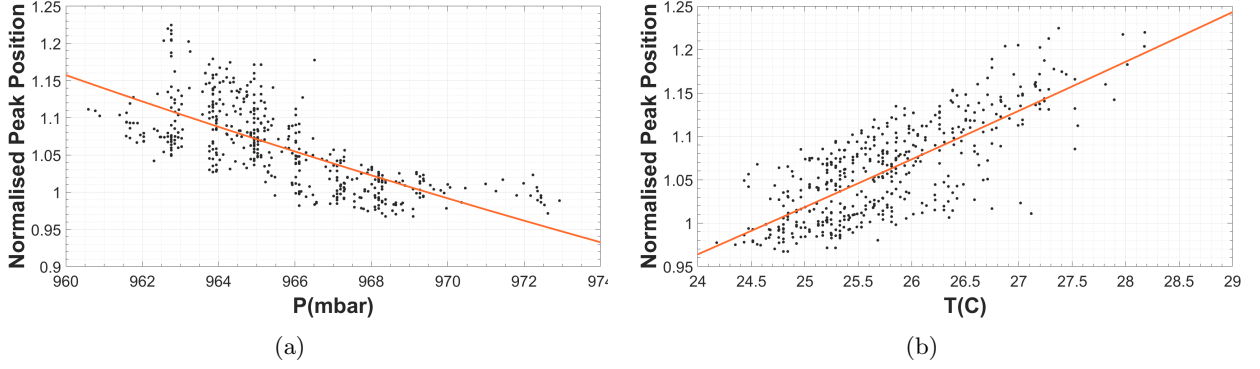


Figure 4: (a) Gain relationship with atmospheric pressure on a linear scale. The fit function is $f(P) = 1.04(\frac{967}{P})^{14.91}$ and the correlation coefficient is $\rho = -0.7$. (b) Gain relationship with temperature on a linear scale. The fit function is $f(T) = 1.07(\frac{T}{26.03})^{1.34}$ and the correlation coefficient is $\rho = 0.8$.

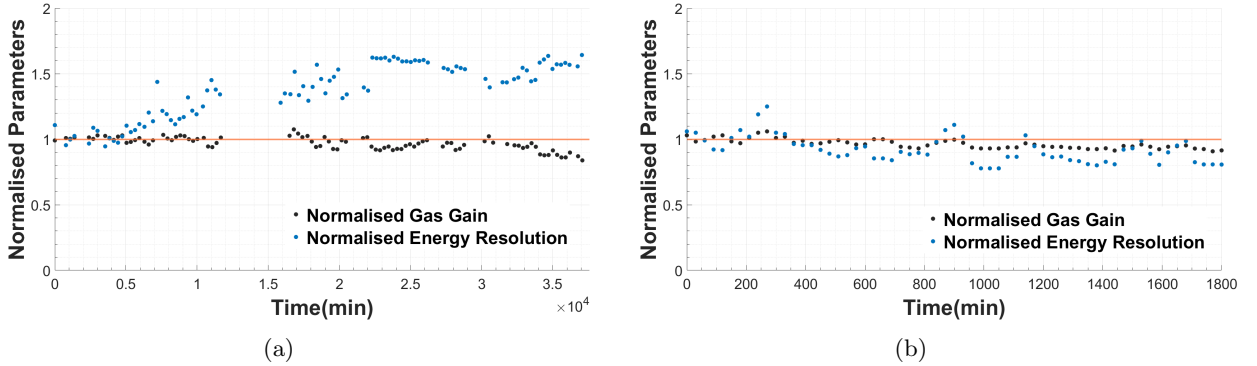


Figure 5: (a) Normalised resolution and gain(peak to peak distance) for the whole of the irradiation time of the SWPC with ^{109}Cd . Averaging every 10 points reduces additional fluxuations. (b) Normalised resolution and gain(peak to peak distance) for the whole of the irradiation time of the SWPC with ^{241}Am . The line at $y = 1$ is used to make the variation in the two quantities clear.

3 Results and Discussion

3.1 SWPC

The SWPC is irradiated with ^{241}Am for 1 day resulting in 49 spectra and an integrated charge of 14mC/cm . Following this run it is also irradiated with ^{109}Cd for 27 days resulting in 1231 spectra and the same integrated charge. The anodic current was 2.5nA for the x-ray source and 52nA for the alpha source. Both sources were calibrated to have the same rate hence more time was required to integrate the same charge for the x-ray source.

The peak to peak distance, analogous to the gain, is normalised to the first gain value and the normalised plots for both the alpha and x-ray sources are presented in Figure 5. Both plots are corrected using the environmental parameters and the gain relationship (Eq. 6). The plots include the change in resolution of the peak, however the resolution is not sensitive to environmental parameters hence environmental corrections are not required. In addition, it is noted that the gap in Figure 5a is a result of the chamber being shut down due to technical issues in the GEM lab. Moreover, the plot for the Xray irradiation shows a degradation of 15% on the gain value and an increase of 60% on the resolution. Figure 5b is showing the gain evolution with alpha particles for the same integrated charge and the degradation is 10%. However, it is noted that the resolution does not increase as expected and this will be examined further in the lab. A considerable amount of degradation is noticed which is mostly attributed to the pollution of the gas mixture and the fact that it is heated to 50°C . The latter is also the reason for a higher aging effect compared to similar studies

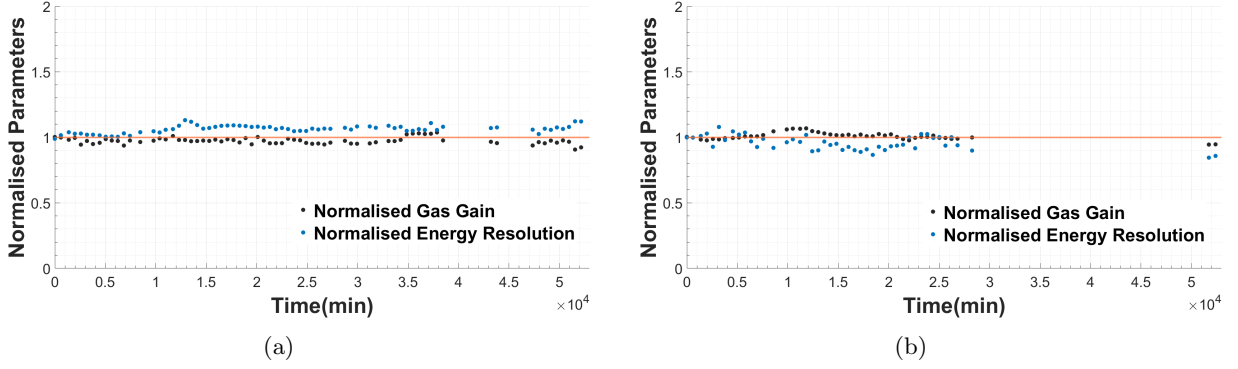


Figure 6: (a) Normalised resolution and gain(peak to peak distance) for the whole of the irradiation time with ^{109}Cd . (b) Normalised resolution and gain(peak to peak distance) for the whole of the irradiation time with ^{241}Am . Both plots show average points of gain, taken every 10 spectra.

where the contaminants were not heated[1]. Radicals are forcibly released by the contaminants and rapid aging is achieved through the outgassing of the chamber.

3.2 GEM

The GEM is also irradiated with the same radioactive sources, however at the same time and on different sectors of it. The amount of spectra is 884 for both the alpha and x-ray sectors. The sources were calibrated as mentioned previously in order to have the same anodic current of 8nA. Hence the total integrated charge on the two regions over the period of 41 days is equal to $60\text{mC}/\text{cm}^2$.

Figure 6 shows the variation in normalised gas gain and resolution during the whole irradiation period of the GEM. The degradation is noticeably lower for both the alpha and x-ray regions. In addition, both plots show a minor 5% decrease in gain. However this decrease is very small and more data is definitely required to ensure that it is not the product of noise fluctuations. This is especially important for the alpha plot in Figure 6b where a large portion of gain values was not captured, even if the detector was still irradiated. This occurred from technical issues with the QDC unit which transfers the spectra information to the computer unit. Moreover, the energy resolution is also relatively constant. The GEM detector will be irradiated for more time, in order to have noticeable aging effects. Previous tests show that even with an accumulated charge $> 100\text{mC}/\text{cm}^2$ and polluted gas, the aging effects are minimal[2].

Moreover, different effects can be seen under the electron microscope through SEM tests. The irradiated wires in the SWPC were sent for a SEM analysis but were not obtained yet(at the time of writing this report). However, pictures of the irradiated wires in previous tests[2] show accumulation of Si-based compounds. The GEM is currently still irradiated with both sources to reach a higher goal and achieve noticeable aging effects before having to analyse the GEM foils under the electron microscope.

Finally, the previous results show the high durability of the GEM detector compared to a different gaseous chamber(SWPC). Moreover, the stated value of $60\text{mC}/\text{cm}^2$ is equivalent to a larger value when the chamber is not polluted. The reasons for its resilience have already been stated[2] and include the fact that the electric field on the anode(readout board) and the cathode(drift) of the GEM is not very high, along with the fact that the GEM consists of three foils, dividing the available region for polymers to be deposited.

4 Conclusion

In conclusion, these aging tests are not used to only prove the resilience of the GEM detectors but also to better understand the aging effects that different particles have on a detector. These aging tests are to be part of a family of aging tests on both these detectors which will examine the variations in gas gain and other aging parameters. Different variable conditions are considered each time. For example this test considered the irradiation of the SWPC with both alpha particles and x-rays with the same irradiation rates and integrated charge. On the contrary, the GEM detector was irradiated both with x-rays and alpha particles and the

sources were calibrated to have the same anodic current but different rates. Varying parameters can be very revealing considering the aging process.

References

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