TOTEM NOTE 06-6
Version 1.0
july-september 2006

Test of the two TOTEM TripleGEM Chambers assembled at G&A Engineering

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Abstract

In this note we report the results of the tests performed at CERN on the two TOTEM TripleGEM chambers assembled by a private company.

1 Introduction

Two TOTEM T2-GEM modules has been assembled by an italian private company [1] and then recently tested at CERN. In this note we describe the various steps of the test. We started with checking the individual components, from the HV distribution board to the discharge studies; then we verified, by using a Cu X-ray tube, that the gain, charge sharing, energy resolution, stability and uniformity of the chamber response were well within the required specifications.
Whenever possible, we followed the procedures described in ref. [2].

2 Preliminary Tests

2.1 Single foil Discharge test

The single foil discharge test of the chamber under study was actually performed at the G&A company during and at the end of the assembly. The test was made with the Keithley Model 237 High Voltage Source-Measure Unit. The result was: $I < 100pA$ for 5 minutes at 550V for every foil. A typical procedure for this test is :

- Flow the chamber for 2/3 hours with nitrogen (2-16 l/h).
- Set the power supply current limit to 50nA.
- Link to ground the non sectored side of the foil and the not tested sectors.
- Increase the HV up to 550V with a rate of nearly 10V/s.
- Record the leakage current and the number of sparks, if any. Note: if a spark occurs, wait some minutes until repeating the ramp-up.

The validation of the single foil is obtained if the:
Leakage current per sector at 550 V and for 5 minutes is lower than 1 nA in dry air, lower than 0.5nA in N_2 and lower than 5nA in $Ar - CO_2$

2.2 The H.V. Distribution Board

We assembled in the Siena lab the H.V. Distribution Chain mounted on the two TripleGEM chambers. The resistors used are shown in Fig.1. We paid attention at the cleaning of the board, but we did not coat or heat it before testing. We have to consider the real value of the resistances used in the H.V. distribution board if we want to compare different chambers performance because the gain has an exponential dependence on the voltages applied to the GEM foils.

2.2.1 H.V. Distribution Chain Characterization

In order to avoid damages to the chambers caused by internal discharges, it's necessary to properly fix the current limit of the power supply (i.e. just 1-2μA above the current needed to bias the detector). For this reason it's better to have a voltage-current characterization of the H.V. Distribution Board. This table could be done with a measurement of the resistors (taking into account also the presence of serial resistance in the H.V. filter if used) or with a direct current measurement for the H.V. distribution board before connecting it to the detector.

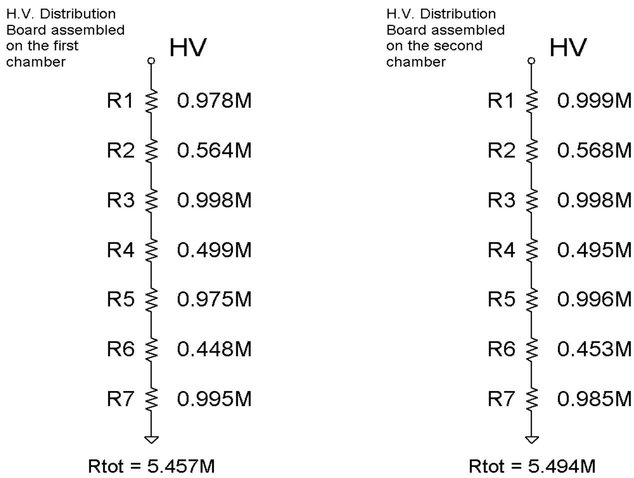

Figure 1: Resistor Chains of the H.V. Distribution Boards mounted respectively on the first and on the second TripleGEM assembled at G&A.

2.3 External/Internal Discharge Studies

2.3.1 Followed procedure and results

We use CO_2 to test the presence of external discharges and an $Ar - CO_2 70/30$ mixture to test the internal ones. Before starting the test, we left the chamber under a flux of 5l/h of CO_2 for nearly 12 hours to clean it and then we applied the voltage. It was carefully raised in steps of 500V to 3kV, then in steps of 200V to 3.6kV and then in steps of 100V. Every time, we did not increase the voltage until the discharges disappeared. We monitored the discharges looking at the output of the preamplifier and the shaper amplifier connected to groups of strips and pads . We saw only external discharges at the beginning for the first chamber , probably because of dust on the H.V. distribution board. The second chamber never showed discharges.

2.3.2 Validation

From the COMPASS validation chart we find:
If after an hour of monitoring discharge does not occurs, the high voltage distribution network is validated. It is quite usual that some discharges occur in the first minutes with high voltage on, due to dust and metal splinters, but their frequency should decrease quickly, since these impurities are burned away.

3 Absolute Gain Calibration

3.1 Measurement Description

After the preliminary test, we studied the absolute gain of the detector using a Cu X-ray Tube. We measured the absolute gain from the formula shown in Eq.1, where:

- I_{tot} = Total current collected by strips and/or pads.
- n = Mean number of electrons produced by the incident particle (for Cu X-Rays we have used 293 as explained in the next section).
- e = Electronic Charge.
- f = Rate of Incident Particle on strips and pads (in this case is the rate of interaction of X-Rays in the gas and it is obtained by a counter unit with as input the discriminated output of the electrodes readout chain).

$$GAIN = \frac{I_{tot}}{n \cdot e \cdot f} \tag{1}$$

Obviously it is possible to consider strips and pads individually or together. To do this we have to insert in the GAIN equation the current and the rate of strips or pads or the sum.

3.1.1 Mean number of electrons produced by the incident particle

One way to obtain n is to consider the two lines K_α and K_β of Copper and the Ar fluorescence yield (nearly the 15%). So, we have to:

- Consider the Ar Fluorescence yield (we used an average energy required to produce one el-ion pair in Ar of 26eV):
  - $n(K_\alpha : 8keV) \sim 0.85 \cdot \frac{8keV}{26eV} + 0.15 \cdot \frac{8keV-2.9keV}{26eV} \sim 290$ K_α Primary Electrons.
  - $n(K_\beta : 8.9keV) \sim 0.85 \cdot \frac{8.9keV}{26eV} + 0.15 \cdot \frac{8.9keV-2.9keV}{26eV} \sim 325$ K_β Primary Electrons.
- Consider the ratio of the two K lines:
  - $\frac{I(K_\beta:8.9keV)}{I(K_\alpha:8keV)} \sim 0.135$
  - $n = (1 - 0.135) \cdot n(K_\alpha) + (0.135) \cdot n(K_\beta) = 0.865 \cdot 290 + 0.135 \cdot 325 \sim 293$

Another way to obtain n is to simulate the interaction between the x-ray emitted from the Cu tube and the gas using HEED and GARFIELD. We simulate the electrons clusters production from the two lines K_α and K_β of Copper, using a ratio $\frac{I(K_\beta,8.9keV)}{I(K_\alpha,8.0keV)} = 0.135$. The result is plotted in Fig.2. From the first plot we found that the mean number of electrons produced by the incident particle is 260 (instead of the expected 293 obtained from the previous calculation). We will use the n value of 293 to use the same value used in other papers. The difference between the calculated and the simulated n may be due to the fact that in the calculation we don't have considered the presence of CO_2. If we do it, we will have a mean energy required to produce one electron-ion pair in the gas of $\sim 28eV$ and not $26eV$ as for Argon alone. With this value we will find with the first calculation a value of ~ 270 that is closest to the simulation result.

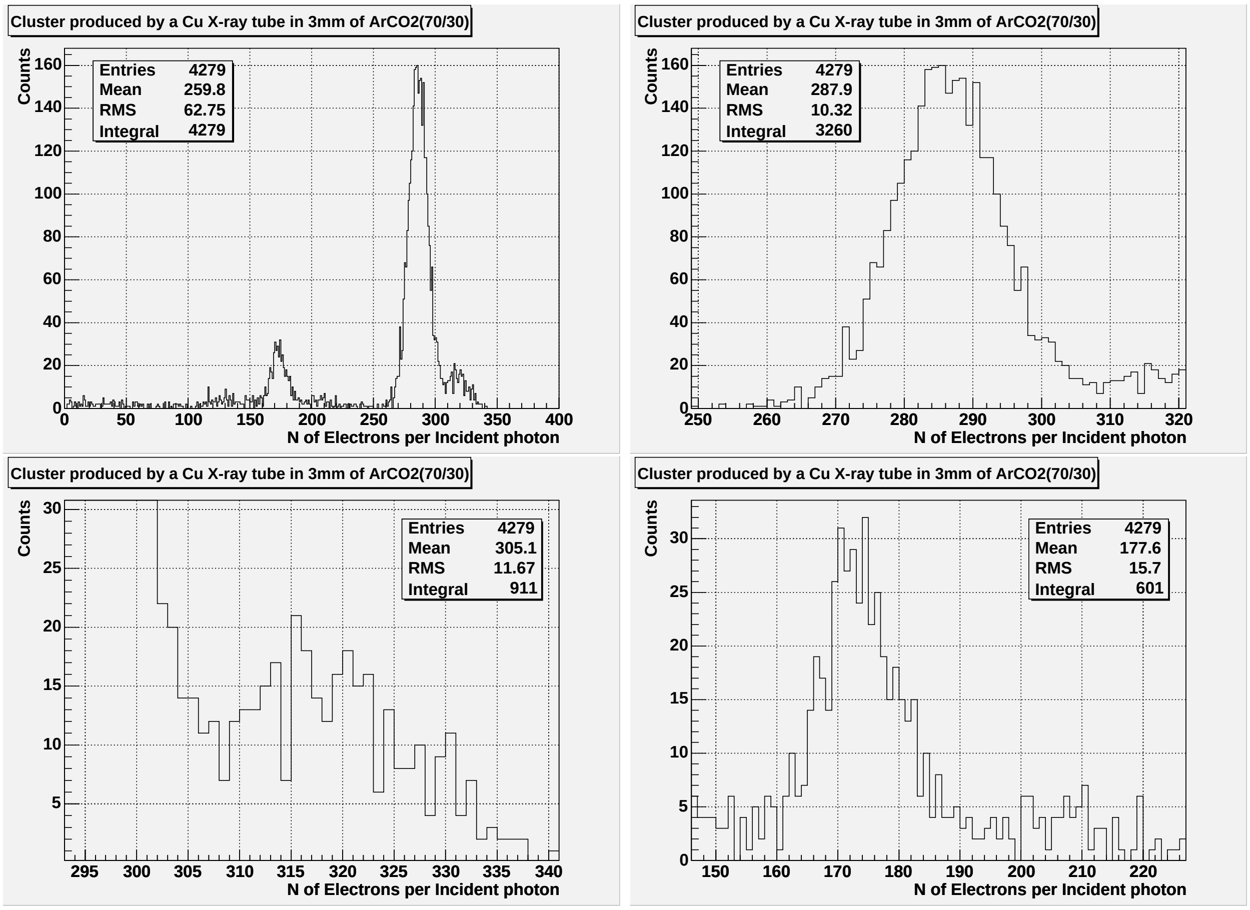

Figure 2: Cu X-Ray cluster production in 3mm of Ar/CO_2 from a Garfield simulation. In the first plot (top-left) we have the total spectrum. In the second (top-right) we zoom in the K_α peak . In the third (bottom-left) we zoom in the K_β peak. In the fourth (bottom-right) we zoom in the Argon escape peak (i.e. when part of the energy of a K_α or a K_β photon escape the chamber as an X-Ray photon of Argon.) In this simulation we have obtained 4279 interaction over 100000 initial photons ($\sim 5\%$).

3.1.2 Current Measurement

We connected together 128 Strips and 120 Pads to measure the total current collected by the electrodes, as shown in Fig.3. These electrodes can be grouped in a different way and each group is connected to a common point in the readout board with a 1M resistor. This point is then linked to ground with another 1M resistor. The measurement of the current was done reading the voltage across the 1M to ground as shown in Fig.3. We have to consider the input 10M impedance of the multimeter to obtain the right current from the voltage readout. With the second chamber we decided to use a bigger number of strips and pads for each group to avoid problems related to edge effects and to be sure of collecting with the Preamp-Amplifier all the electrons produced in the TripleGem per incident photon. This could affect the gain evaluation and the spectrum analysis.

3.1.3 Rate Measurement

The readout system is shown in Fig.4. To measure the interaction rate we used two amplification lines connected to a group of strips and to a group of pads. The signal was read with an ORTEC

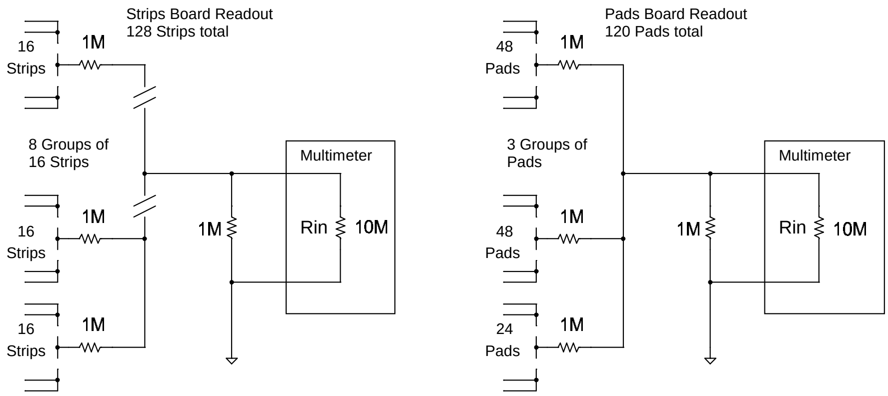

Figure 3: Readout Configuration for the measurement of the current collected from Strips/Pads Group for the test on the second chamber assembled at G&A.

Charge Sensitive Preamplifier (Model 142IH) and with an ORTEC Research Amplifier (Model 450). The signals were sent to a discriminator unit, whose output was sent to a counting unit to measure the rate of interaction. We also saw the signal on the oscilloscope and we acquired it with a LeCroy ADC (Model 2249A) to make the X-Ray spectrum analysis. The gate of the ADC was taken from the delayed (nearly 200ns) output of a Dual Timer unit, that receives the start from the output of a discriminator unit which had the strips signal in input). It's important to check that the two readout lines have similar characteristics (for instance by testing them on the same readout electrode group) in order to make a meaningful comparison between strips and pads. When we

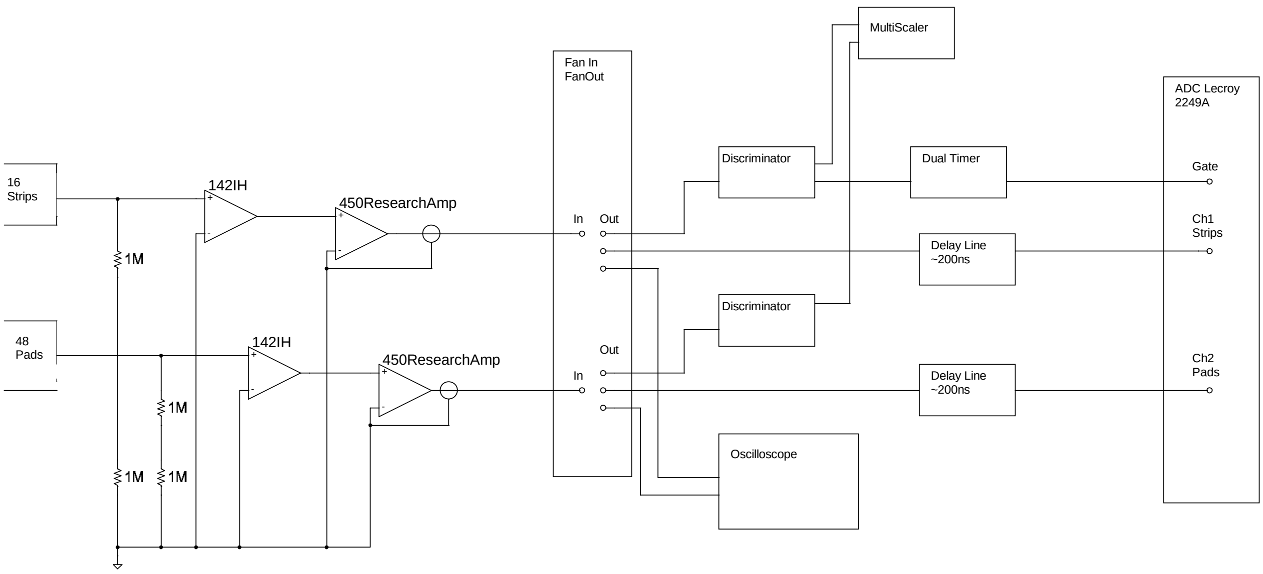

Figure 4: Readout Configuration for the Preamplifier-Amplifier Line

made the measurement of the total current, we had to use a relatively high X-Ray flux. In this way, we have a voltage across the 1M resistors that could be measured with the multimeter. This relatively high interaction rate may lead to a not very accurate measurement of the rate itself, for possible pile up effects in the readout chain. To avoid these problems, the rate measurement was made putting an absorber in front of the X-Ray Gun (a thin Cu foil) and the current measurement by removing it. With the calibration of the absorber efficiency, made at low frequency, we calculated the

”high flux” (without absorber)interaction rate from the rate measurement made with the absorber inserted. The calibration of the Cu-Xray Tube versus the anode current, with and without absorber is shown in Fig.5 . In the same figure we report also the ratio of the rate measured at low fluxes without and with the absorber. This ratio will be used to obtain the rate for Eq.1

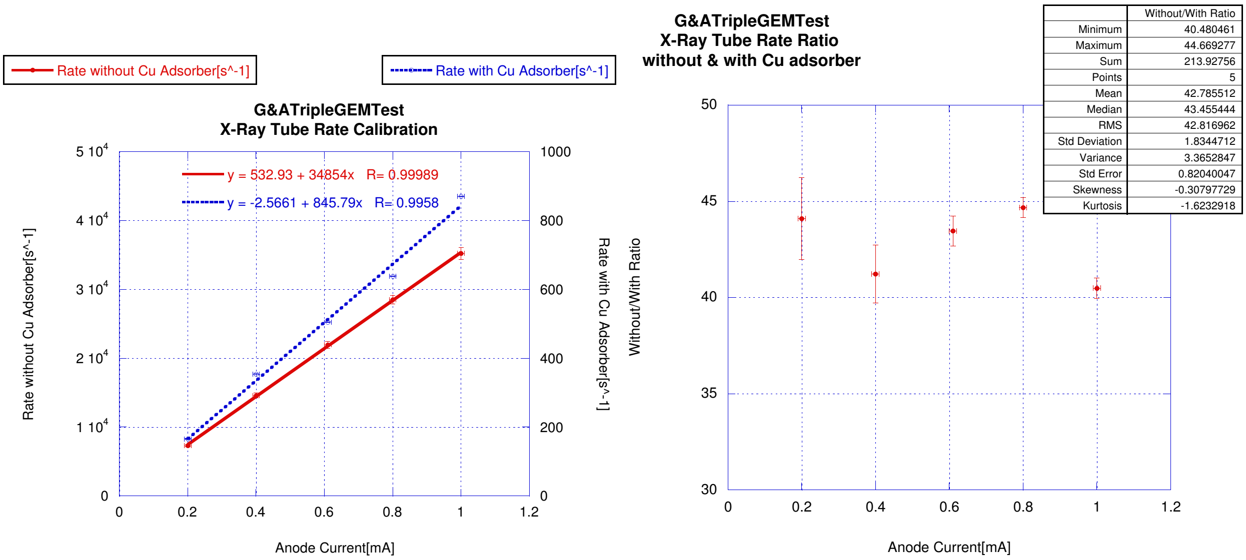

Figure 5: X-Ray absorption rate versus the anode current of the anode Cu Tube (right) and Ratio of the X-Ray absorption rate without and with the Cu Absorber Foil on the X-Ray Collimator, measured at various anode X-Ray tube current(left).

3.2 Measurement Data

Fig.6 shows the Total Gain Calibration Curve of the first Triple GEM assembled at G&A. The values obtained are lower than the medium gain expected but compatible with the acceptable values.

In Fig.7 there is the Gain Calibration Curve made in September on the second Triple GEM assembled by G&A. For this chamber, we decided to use a larger number of strips (16) and pads (48) in the readout groups. We decided to make this change because with a low number of electrodes there could be problems concerning the complete collection of the electrons and with the presence of boundary effects. Using a bigger group the measurements will become more simple and accurate. In the next tests we want to try to use all the 128 strips and all the 120 pads connected to each readout board. Fig.8 shows the comparison between the total GAIN of the first chamber tested in July and of the second one tested in September.

We decided to test again in September the first chamber for the different gains obtained from the second chamber as we have seen in Fig.8. In Fig.9 is shown the comparison of the two chambers made in September and now the gains are nearly the same. A possible explanation could be related to the fact that during the first test:

- we could have investigated a wrong group of electrodes.
- we could have done an error on the evaluation of the frequency. In the second test we selected the right threshold for the discriminator more accurately looking at the spectrums (We fixed the threshold in order to reject the noise and to have the total spectrum of the X-Ray source collected).

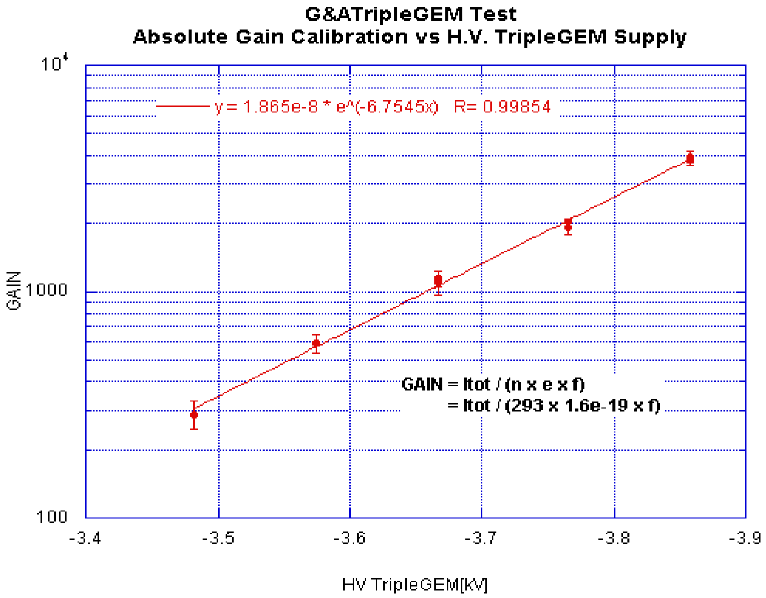

Figure 6: Absolute GAIN versus the TripleGEM H.V. for the first chamber assembled by G&A and tested in July. The GAIN is obtained using Eq.1 i.e. the total GAIN is obtained from the measurement of the current collected from a group of eight strips and eight pads and of the rate of X-Ray absorption. We have used the measurements made on strips for the interaction rate evaluation. The number of electrons produced from the radiation is assumed equal to 293.

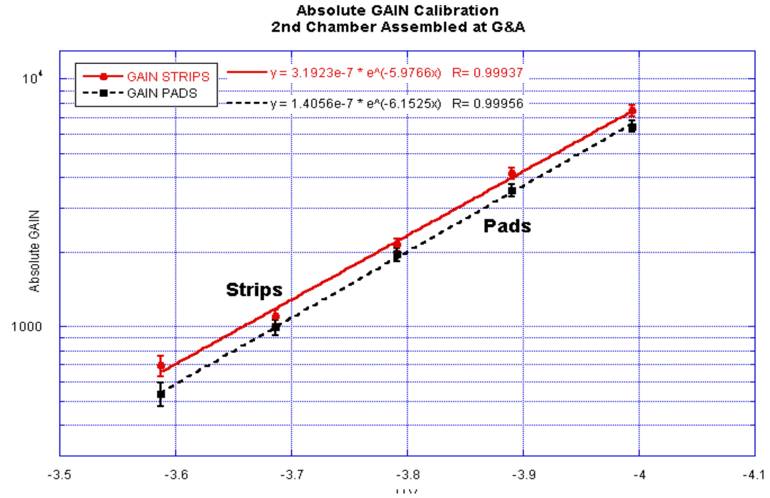

Figure 7: Absolute GAIN of strips and pads versus the TripleGEM H.V. for the second chamber assembled by G&A and tested in September. The GAIN is obtained using Eq.1.

This result underlines the need of a test of reproducibility of the gain measurement to be sure to have all the parameters under control.

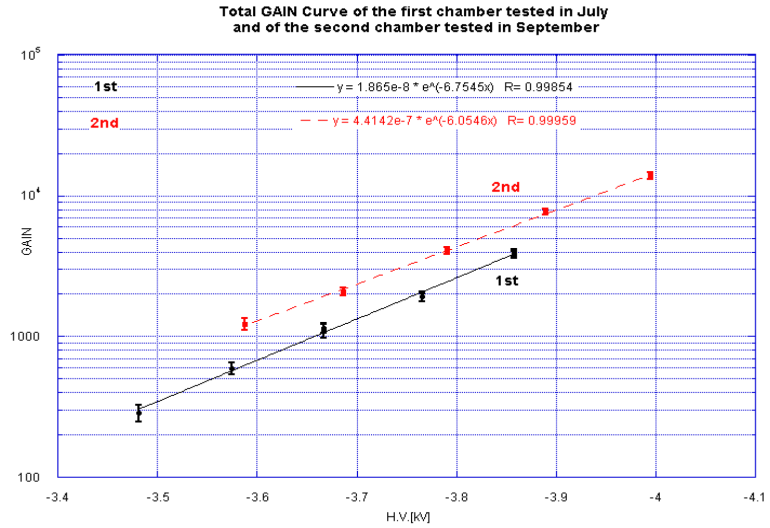

Figure 8: Comparison between the total GAIN Curve of the first chamber tested in July and of the second chamber tested in September.

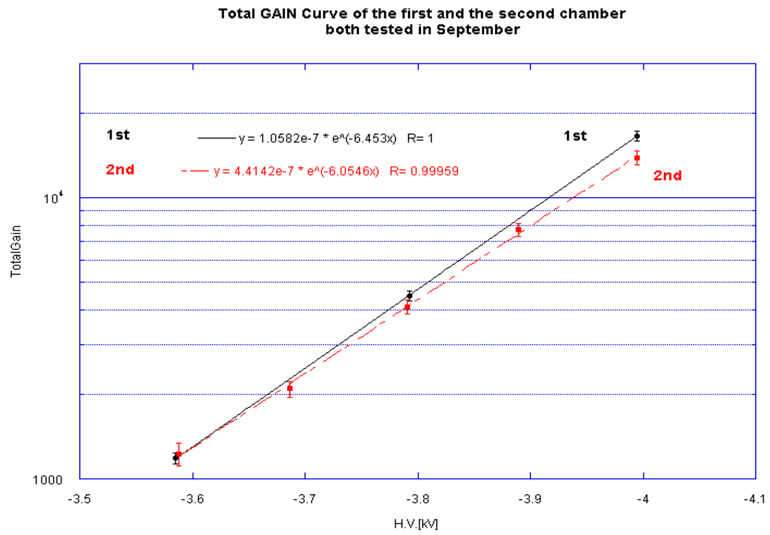

Figure 9: Comparison between the Total GAIN Curve of the first chamber and of the second chamber both tested in September.

4 Charge Sharing

4.1 Measurement Description

In the analysis of the data collected during the test, we paid attention to the charge sharing between strips and pads. This is an important point in relation to the specification of the readout electronics (VFAT in our case). The readout must be able to measure from both the electrodes without saturating or without having a too low signal to be distinguished from the noise. To obtain this we have to find a signal to noise ratio that is good for all the electrodes and that the difference in the intensity, for each electrode, is compatible with the variable settings of the readout electronics. When a particle ionizes the gas, there will be normally involved one or two pads and two or three strips and for this reason the readout plane was designed to have a pad signal about 10% lower than the strips one.

4.2 Measurement Data

In Fig.10 we report the percentage difference between the current collected with strips and with pads. The result is in agreement with the expected value. We had found a bigger variation at -4kV. If we use the fit of the absolute gain curve plotted in Fig.6, we obtain that the ratio in the gain at -4.0kV and -3.9kV is nearly 1.9. If we compare the currents read from strips and pads respectively at -3.9kV and -4.0kV we find that that the strips current is bigger than expected and that the pads current increment is compatible with the other data.

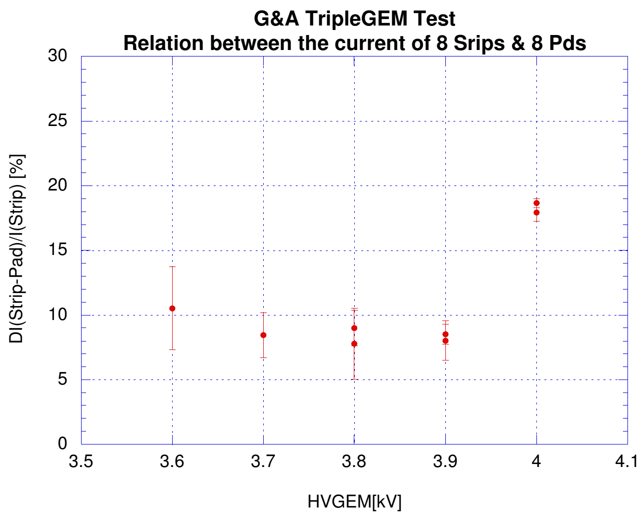

Figure 10: Ratio of the current collected from a group of eight strips and a group of eight pads as a function of the TripleGEM H.V. for the first chamber

In Fig.11 we report the percentage difference between the current collected with strips and with pads for the second chamber tested in September . The result is in agreement with the expected value and with the result obtained from the first chamber. In Fig.12 we have compared the difference[%] of the current collected from strips(128) and pads(120) with the difference[%] of the position of the K_α peak in the strips(16) and pads(48) spectrums and the difference[%] of the GAIN of strips and pads. In Fig.13 we show the charge sharing between strips and pads for the the first chamber tested in July and the second tested in September. The behavior is nearly the same, confirming a pad signal about 10%-15% lower than the strip signal.

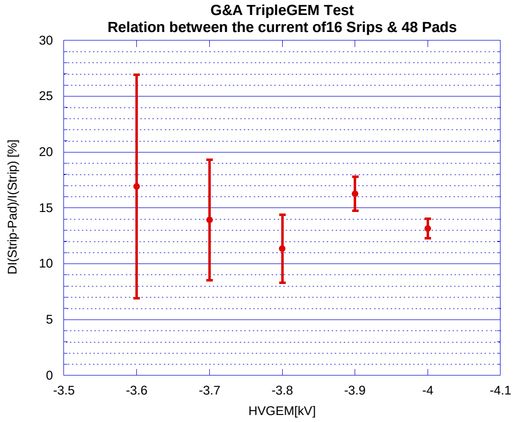

Figure 11: Relation between the current collected from a group of 128 strips and a group of 120 pads at various TripleGEM H.V. values

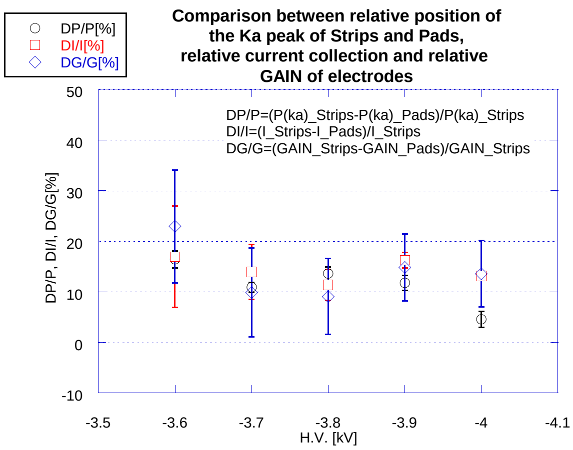

Figure 12: Comparison between relative position of the K_α peak of Strips and Pads, relative current collection and relative GAIN of electrodes

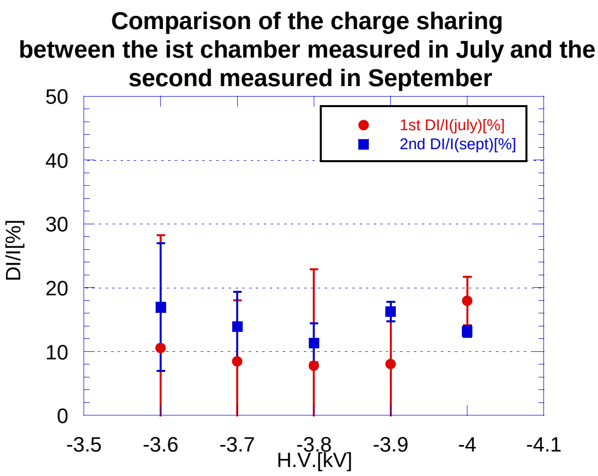

Figure 13: Comparison of the charge sharing between the first chamber measured in July and the second measured in September

5 Energy Resolution Studies

The study of the energy resolution is strictly related to the quality and uniformity of the GEM foils. If the gain is not uniform in the zone irradiated, there will be an anomalous broadening of the peaks of the spectrum.

5.1 Measurement Description

To have a better sensitivity on the energy resolution, the spectrum was acquired by using a Cu foil as an absorber on the collimator output of the X-Ray gun. As we can see in Fig.14, there is a reduction of the bremsstrahlung components and a little increment of the K peaks of Cu, obtained from the conversion of the high energy part of the bremsstrahlung absorbed by the Cu foil.

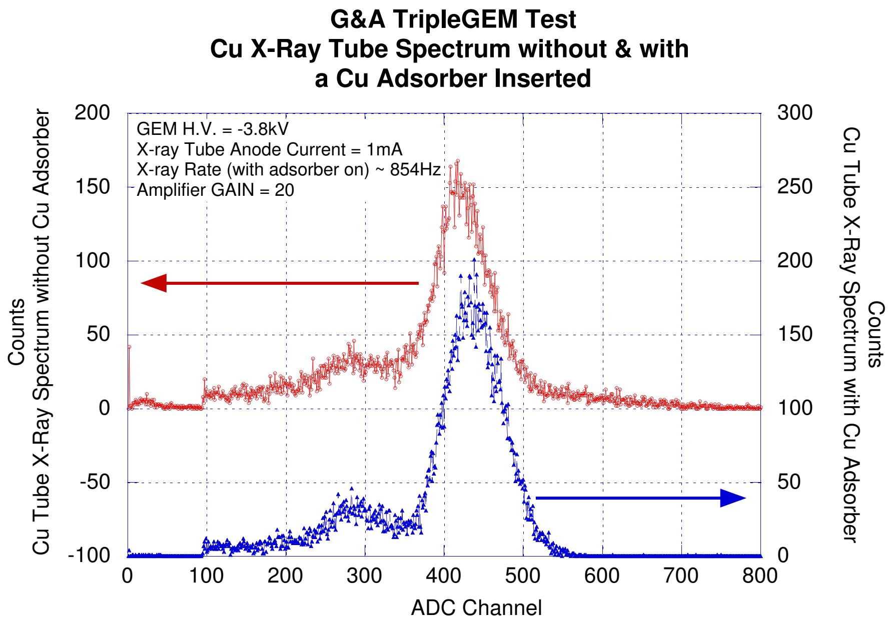

Figure 14: Cu tube X-Ray Spectrum acquired without and with a Cu Absorber Foil on the X-Ray collimator. As we can see, the absorber reduces the bremsstrahlung and increment the Kα (and Kβ) emission of Cu.

5.2 Measurement Data

For the first chamber, the energy spectrums (readout from a group of 8 strips) for four different voltages are reported in Fig.15. Fig.16 shows the energy resolution of the Kα and Kβ peaks taken from the previous plots as a function of the applied HV.

For the second chamber, the energy resolution data are reported in Fig.17. They are taken from the spectrums plotted in Fig.18. We show also the correlation plots between strips and pads to visualize the resolution variation versus the applied H.V. and the gain ratio between Strips and Pads. In Fig.19 we show the two dimensional ones (useful for an immediate gain ratio analysis) and the three dimensional ones (useful for a resolution analysis).

In both chambers the energy resolution is $\sim$ 21% the the H.V. $\geq$-3.7kV.

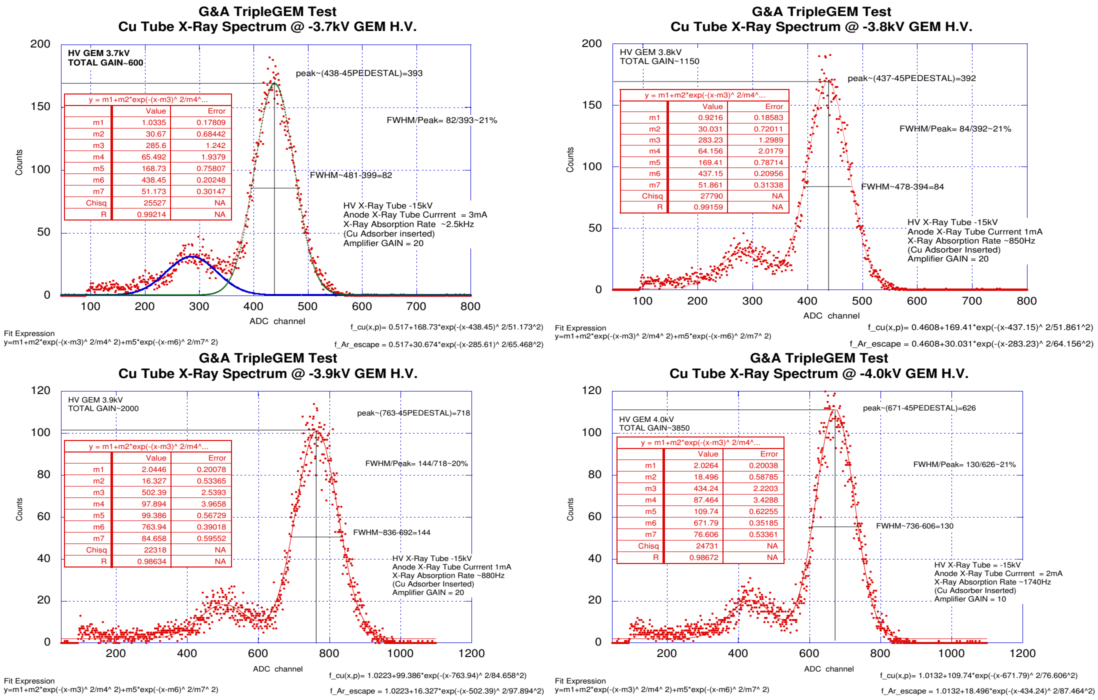

Figure 15: Cu tube X-Ray Strips Spectrum as a function of the TripleGEM H.V. for the first chamber tested in July.

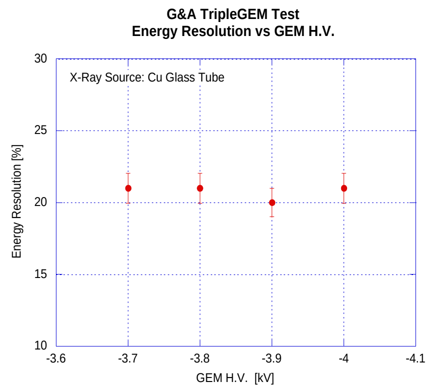

Figure 16: Energy Resolution of the Kα (and Kβ) emission peaks of Cu versus the TripleGEM H.V. values for the first chamber tested in July (strips readout).

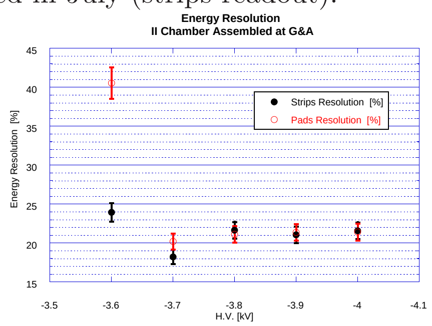

Figure 17: Energy Resolution for strips and pads of the Kα (and Kβ) emission peaks of Cu versus the TripleGEM H.V. values for the second chamber tested in September.

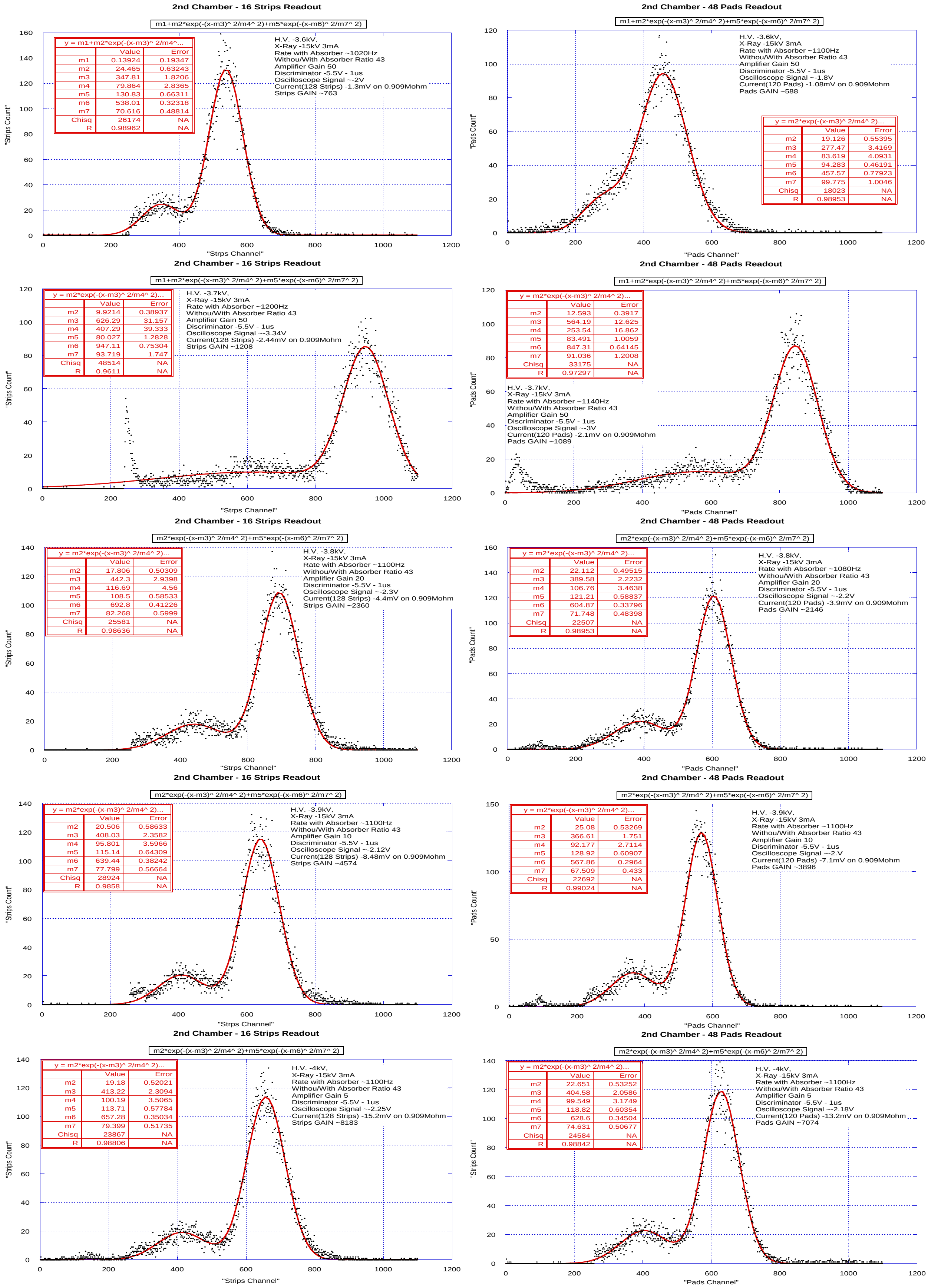

Figure 18: Cu tube X-Ray Strips and Pads Spectrum in function of the TripleGEM H.V.(from -3.6kV to -4kV) for the second chamber tested in September.

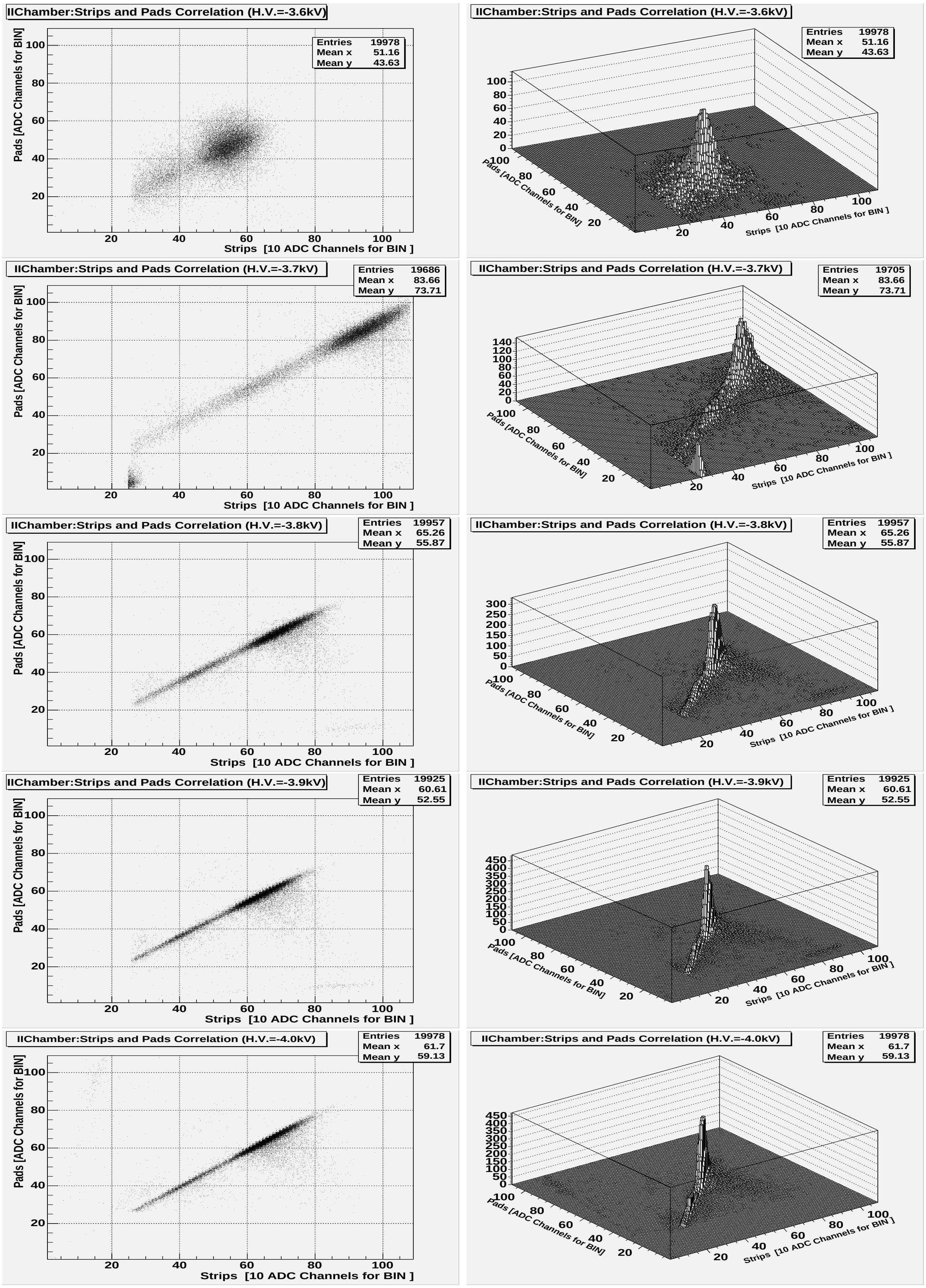

Figure 19: Strips and Pads Correlation for the Cu X-Ray Spectrum in function of the TripleGEM H.V.(from -3.6kV to -4kV) for the second chamber tested in September.

6 Stability Test

6.1 Measurement Description

We have done this test making spectrum acquisitions every 240 seconds. The software that we used saves the position of the Cu K_α peak. For these measurements we recorded 10 ADC Channels for each bin.

6.2 Measurement Data

In Fig.20 we have the peak position versus time and in Fig.21 the overlap of the eighteen spectrums acquired during this test.

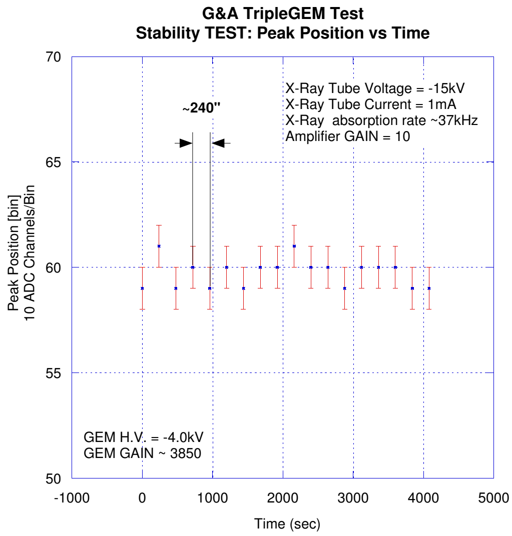

Figure 20: Acquisitions of the Kα (and Kβ) emission peaks of Cu every ∼240sec from a group of eight strips at -4.0kV of TripleGEM H.V.

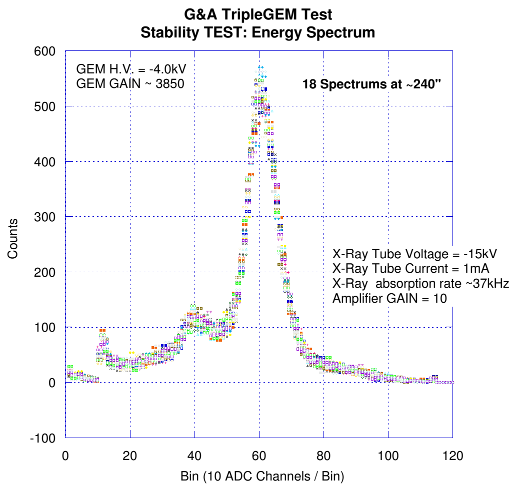

Figure 21: Eighteen Cu-tube X-Ray Spectrums acquired every ∼240sec from a group of eight strips at -4.0kV of TripleGEM H.V.

7 Uniformity Test

The aim of this test is to verify the homogeneity of the response of the chamber. It is important to take into account the presence of sector boundary or spacer that can influence the charging up and the response of the detector. For the definitive test it may be a good choice to place the radiation source in a well defined position in front of the chamber. In this way we can make a more simple correlation of the data obtained from different chambers.

7.1 Measurement Description

To make this measurement we have to change the position of the x-ray gun relative to the chamber. For each position we had to look for the maximum of the signal, for strips as well as for pads. This operation required time and we were not able to complete this test. The measurement that we made were nevertheless useful to understand the operational problems concerned to this test. For example, the use of groups of only eight readout strips and eight readout pads may introduce operative problems for example to be sure to collect all the electrons produced by the interaction.

7.2 Measurement Data

We show in Fig.22 the overlapping of three spectrums obtained from three different groups of eight strips. In the complete test we will have to record, for strips and pads, the gain or the Cu-Spectrum's peak position in function of the position of the interaction zone in the chamber.

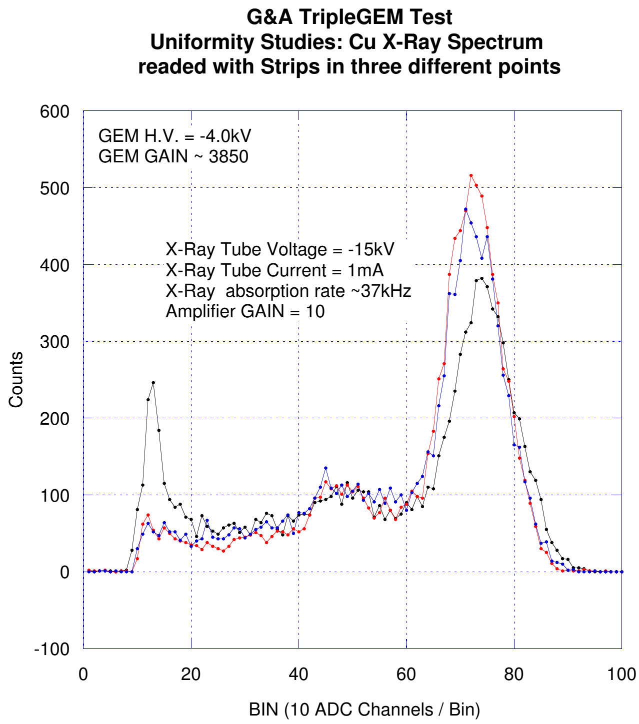

Figure 22: Cu-tube X-Ray Spectrums acquired on three different point over the chamber from groups of eight strips at -4.0kV of TripleGEM H.V.

8 Charging-Up Studies

When a chamber is irradiated after a long period of no incident radiation, we should see a variation of the gain for the charging up of the dielectric zones of the foils (hole, sector boundary, spacer). The time development of this gain variation should be faster for the charging-up of the inner part of the holes than for example for the sector boundary one and it could range from some tenth of seconds to some tenth of minutes.

8.1 Measurement Description

To make this measurement we need to be very fast in the acquisition of the spectrum (some seconds for example) and we need to be able to center the X-Ray gun over the readout group of pads and strips without irradiating them before. This is a problem if we have to look for the maximum signal. If we have instead a mapping of the position irradiated and of the relative electrodes or if we can repeat the measurement after a period of no incident radiation, without moving X-ray Gun and detector position, this measurement can be done easily.

8.2 Measurement data

In Fig.23 we plot the variation in time of the K_α peak. The time between two acquisitions is nearly 90 sec. The zone was not irradiated before, but the time between each acquisition and the time spent for centering the beam respect to the electrodes was too long (some minutes). So it makes little sense to look for a charging up effect. In Fig.24 we show the spectrums acquired during the measurement. The two lines are the first (the red one) and the last spectrum acquired. As we expected, there are no evidences of charging effects.

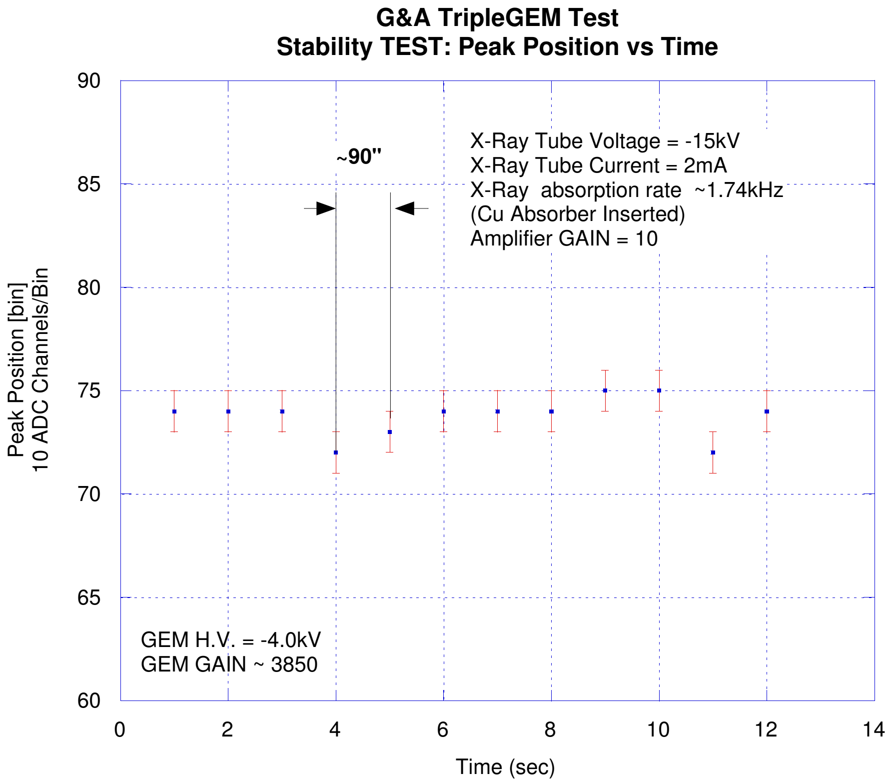

Figure 23: Acquisitions of the Kα (and Kβ) emission peaks of Cu every ~90sec from a group of eight strips at -4.0kV of TripleGEM H.V., in a position not irradiated before

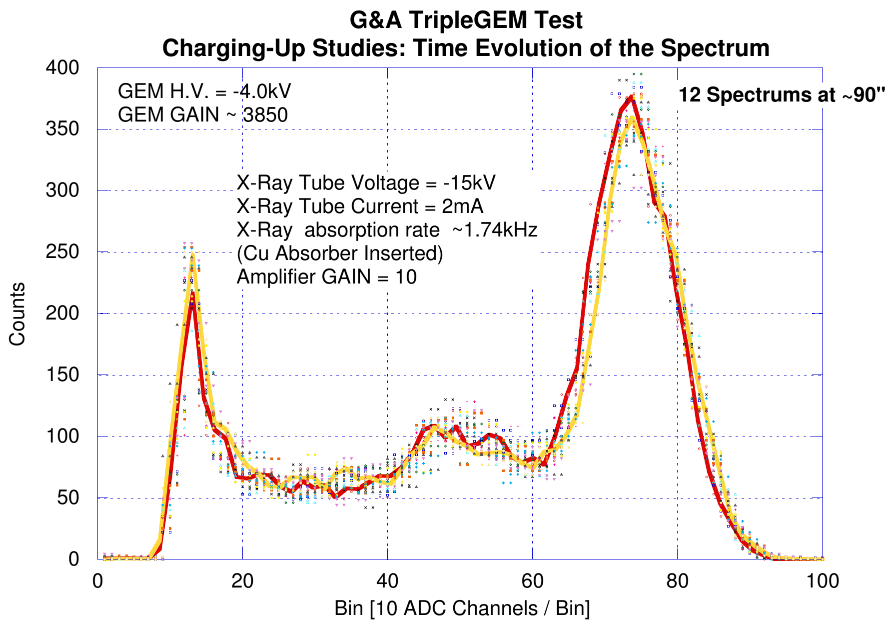

Figure 24: Twelve Cu-tube X-Ray Spectrums acquired every ~90sec from a group of eight strips at -4.0kV of TripleGEM H.V., in a position not irradiated before

References

[1] *G&A* Engineering, Carsoli (Aquila) - Italy, www.gaengineering.com .

[2] 'Testing procedure for the COMPASS triple-GEM detectors', Internal Note, April 2001.