Advanced lab course for Bachelor's students

Experiment T8

Gas Electron Multiplier (GEM) Detector Principles

Feb 2022

Prerequisites

Knowledge:

- Gas-filled particle detectors
- $\beta-$decay (see T12 manual)

Hardware:

- please bring a laptop with you, if possible install the software for the PicoScope 5444D. In case of need a service machine with the PicoScope SW can be provided to you
- USB stick to take the data home

Contents

General rules of behavior

Before starting with the experiment on one of the most interesting and fascinating thing in the world, it is usefusl to define the rules that everyone of us has to follow inside and outside the laboratory. **Do not skip this part and do not forget it!**

- Before entering the lab, place the jackets in the dedicated room
- Do not leave food in the wardrobe room. In case you have no place where to leave the not strictly necessary things, ask the supervisors
- Do not touch the radioactive sources with your hands! There are tweezers to move them...
- Always remember your dosimeter that has always to be with you. Attach it to a pocket or wherever you find it comfortable close to your body and do not leave it on the desk or in the bag
- Follow the indication in these instructions so that the apparatus can be preserved intact
- Don't worry about speaking English with the tutors: not a single point will be deduced if you are not confident with the language
- In case you need the tutors for whatever important reason, do not be shy and contact them

And...

... if you believe, like we do, that particle detectors are really cool, come and ask for a thesis in this field: in our institute there are several opportunities!

1 Introduction

The primary purpose of this GEM setup is to provide an opportunity to gain experience with a modern gaseous detector and to study how its operational parameters affect the performance. The aim is to understand how the gain of a GEM detector is dependent on different characteristics of the detector.

The data are recorded with a data acquisition system and should be analyzed with the ROOT analysis package. Inform the tutor if you need help with ROOT.

2 Introduction to Gas Detectors

Micro pattern gas detectors are a recent development with the goal to combine the advantages of gas detectors with a high spatial and temporal resolution. Traditional gas detectors are often based on anode wires for the amplification and read out of the signal. Electrostatic repellant forces limit the distance between neighboring wires and hence the spatial resolution. Micro pattern gas detector technology is finding an increasing use in many different applications, being employed in the detection of highly energetic particles in many different particle physics experiments such as ALICE, CMS and LHCb. Many other applications are developing outside of particle physics.

The basic functionality of gas detectors remains unchanged → see also instructions for T7. When an ionizing particle passes through the gas contained within the active volume of the detector, the energy transferred from the ionization particle to the gas particle causes an electron to be removed from the gas atom. This leaves an electron and an ionized gas atom. When an electric field, of sufficient strength, is present within the gas volume, the electron is accelerated. While drifting, the electron can ionize further gas molecules and generate additional electrons this way. In T7 we discussed the operational modes of gas detectors as a function of the field strength. Here we are in the mode of high amplification, beyond the proportional mode, though not in the continuous discharge phase.

2.1 GEM

GEM stands for gas electron multiplier. The active detector medium is a gas mixture where primary electron-ion pairs are created when a ionizing particle traverses. Unlike traditional gas detectors with an anode wire, the gas amplification (multiplication of electrons) in GEM detectors occurs inside narrow holes in a special foil, hence the name "gas electron multiplier".

The main advantages of GEM detectors with respect to traditional gas detectors is that electron amplification and signal induction take place in different detector regions. This allows for a fast evacuation of the ions and protects the read-out electronics from gas discharge. The fast evacuation of ions allows GEM to reach rate capability of O(MHz/cm^2) overcoming the rate capability of the traditional gaseous detectors by several order of magnitude.

A GEM foil is made by a 50 μm copper-cladded polyimide etched to create holes placed in hexagonal pattern. By applying $\approx 350\ V$ across the GEM foil, an high intensity strength electric field is generate inside the holes with magnitude of about 70 kV/cm. This is sufficient to amplify electrons by a factor of ≈20. Fig. 2.1 shows a profile of the corresponding electric field lines along with a photograph of an individual GEM foil taken with an electron microscope.

In this experiment you are goin to use a $10 \times 10\ cm^2$ triple-GEM detector, in which three GEM foils are used in stack in order to divide the amplification among three stages.

Figure 2.2 shows a graphical representation of how a triple GEM chamber operates. As a ionizing particle (charged massive particle or photon) enters the chamber in the drift region, it ionizes gas particles creating free primary electrons. The drift field created by the potential difference between the drift cathode and the GEM-1 foil accelerates electrons towards GEM-1 A potential difference between the top and bottom of the GEM-1 foil creates the initial avalanche of electrons that will become the electronic signal that is read out from the chamber. A similar phenomena occurs in the transfer regions 1 and 2 as in the drift region as well as between GEM-2 Top /GEM-2 Bottom and GEM-3 Top/ GEM-3 Bottom. This produces the build-up of charge registered by the readout PCB that becomes amplified and is finally readout by the readout electronics. A simulation of the electron avalanche in a triple GEM chamber with the operating conditions also used in this experiment, yields the figure shown in Figure 2.2-bottom.

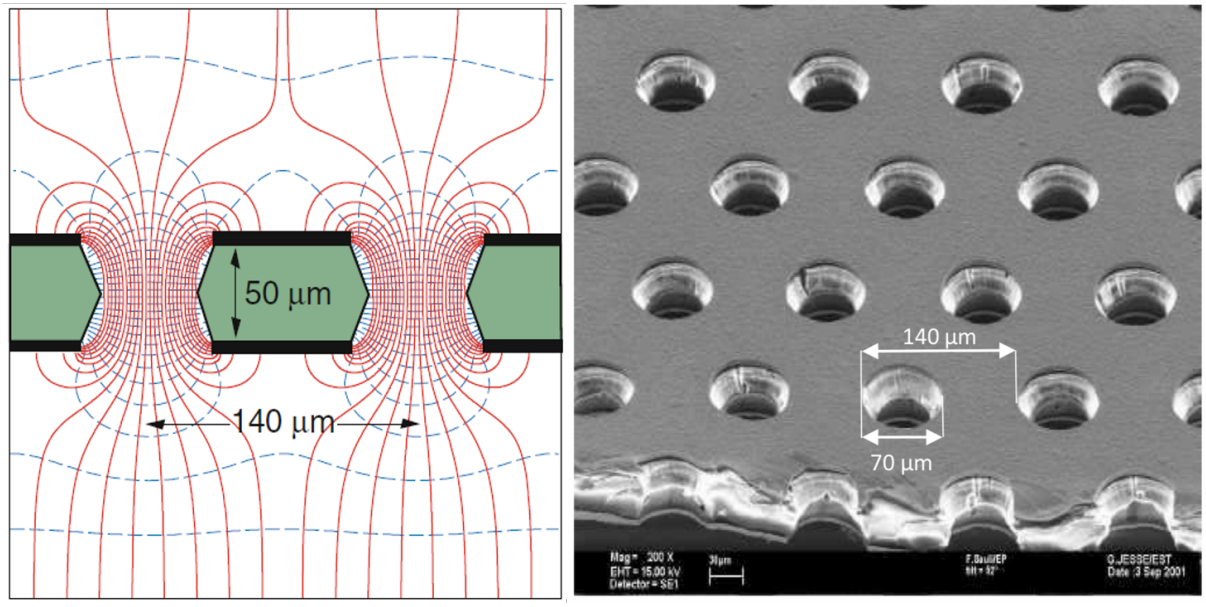

Figure (2.1) Left: Field lines get compressed inside a GEM hole. Right: Photograph of an individual GEM foil taken by an electron microsope.

2.2 Gas mixtures

The arguments for choosing the right gas mixture are independent of the amplification process. The ideal gas mixture will have a high primary ionization, low unwanted background effects, and a gas which is non-flammable and inexpensive. Typically, mixtures of (at least) two gases are selected: (1) a counting gas and (2) a quencher. The counting gas should have a high ionization probability to generate a large number of primary electrons. Nobel gases - such as Ar, Ne, He, Kr, Xe - can provide this with their electron configurations. As an unwanted side effect, these nobel gases may emit UV photons in high amplification scenarios. To absorb these unwanted photons without creating a (fake) signal, a second gas component, called quencher, is added. These are typically gases with several rotational and vibrational degrees to freedom, such as CO_2, CH_4, C_4H_{10}. For demanding environments three or four gas components are mixed. For the application in the lab course a standard gas mixture of counting gas, Ar, and the quench gas, CO_2, are used. The mixing ratio impacts the gas amplification and thus the gain of the chamber.

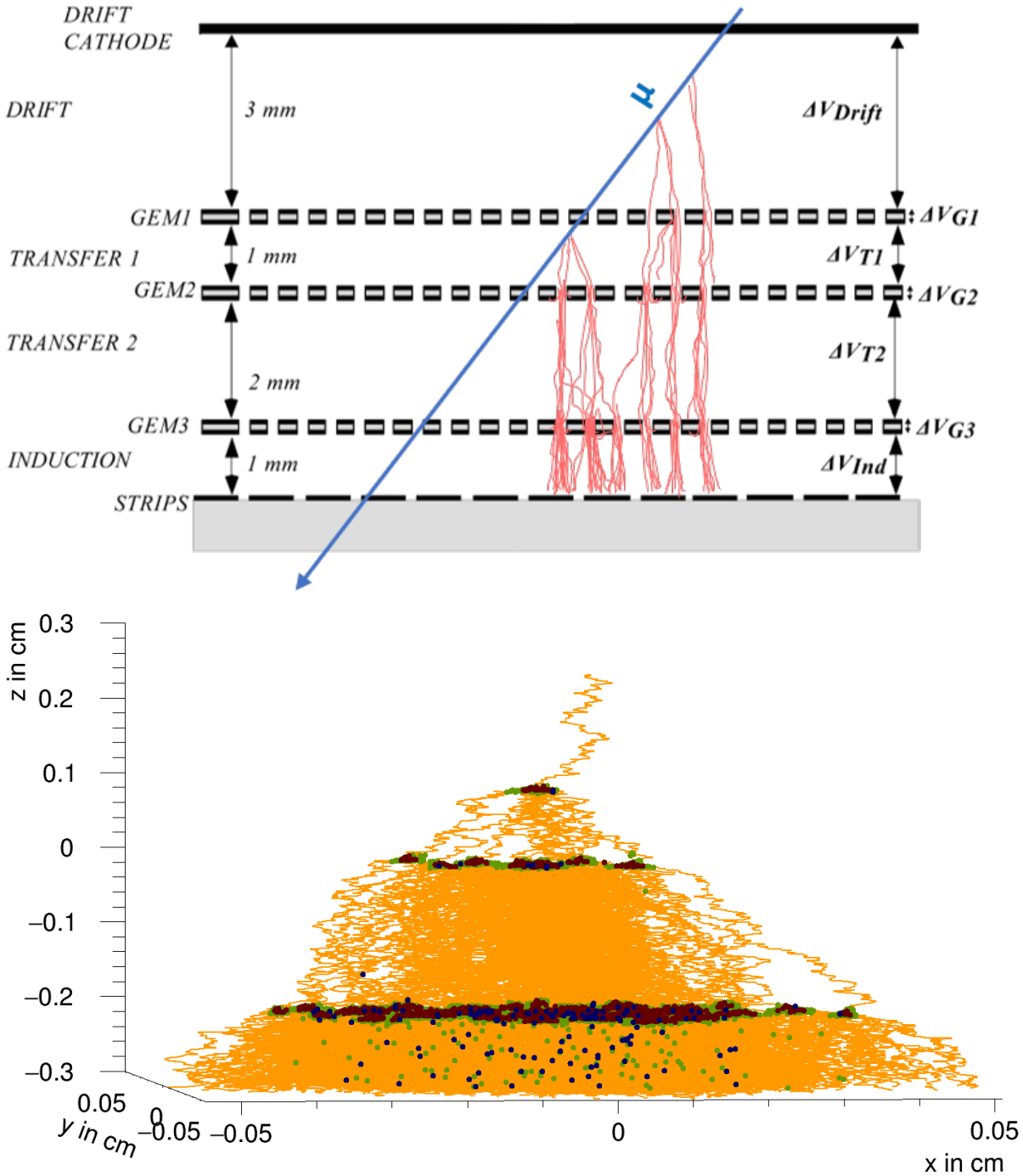

Figure (2.2) Top: Pictorial representation of the amplification stages of a triple GEM chamber. In blue a muon traversing the detector, in red the produced electrons. Bottom: Simulated avalanche from a single primary electron getting amplified in each of the three GEM stages. The color code represents the origin of the electron: green = from excitation, brown = from ionization, blue = electron capture.

3 Experimental Setup

Figure (3.1) Experimental setup. On the bottom of the cart from left to right: the Desktop PC (black), CAEN HV system (red). On top of the cart can be seen the monitor attached to the copper enclosure with lines for the gas to the GEM chamber.

The setup (see Figure 3.1) consists of the following components:

1. A GEM 10x10 cm^2 detector with three GEM foils.

2. As a particle source ^{55}Fe,^{109}Cd, ^{90}Sr and ^{241}Am can/will be used;
3. CAEN HV SY127 + HV modules as high voltage power supply;
4. Two gas tanks - one containing Ar, as primary counting gas, and the other containing CO_2 for quenching. Two gas flow controllers allow to adjust the Ar-CO_2 mixture;
5. Copper enclosure to shield the radiation;
6. Desktop PC with the necessary software to ramp the HV and control the gas mixture;
7. ORTEC 142PC Preamplifier;
8. PICO Technologies Oscilloscope and Digitizer;
9. Keithley 6485.

3.1 Triple-GEM 10x10 cm^2 Chamber

The GEM 10×10 chamber is, as the name suggests, of dimension 10 cm $\times$ 10 cm cross sectional area. It is depicted in Figure 3.2. The chamber is filled with Ar:CO_2 following the percentages specified by the user. The spacing between the foils follows the sketch in Fig. 2.2-Top. The gaps between the foils are called transfer gaps and they transfer electrons from one GEM foil to the next. The last transfer gap is commonly called induction gap. In fact when the electrons in this region move toward the readout strips (anode), they induce a current on the strips. The signal induction can expressed in terms of the Shockley-Ramo theorem

$$i(t) = -q\ \vec{v} \cdot E_w(\vec{r}) \tag{3.1}$$

where

- i(t) is the current induced by a particle with charge q
- $\vec{v}$ is the velocity of the particle
- $E_w(\vec{r})$ is the so-called weighting field for the electrode

It can be shown that the integral of the induced signal over the induction time equals the total charge presence in the induction gap. Therefore by integrating the current induced signal the total number of electrons that reach the induction gap can be deduced.

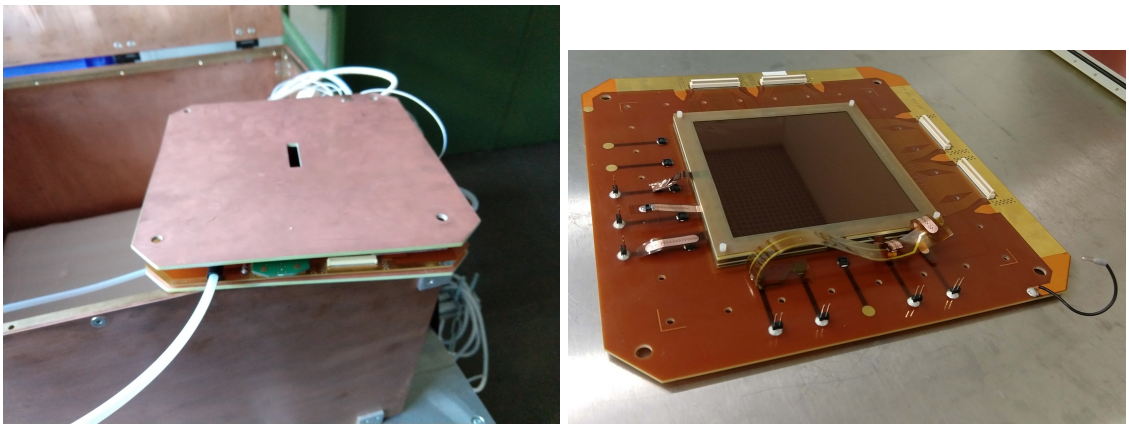

Figure (3.2) Left: GEM Chamber in copper protection with slit cut for particle access to active chamber area. Right: GEM chamber open showing GEM foil connections as well as chamber components.

3.1.1 Triple-GEM Gain

The charge of a single electron is too small to be detected, however by multiplying the electron a detectable charge can be reached. In a triple-GEM detector the electrons multiplication factor is called gain. The

gain of a triple-GEM detector is a measure of many electrons reach the readout plane when one electron is deposited in the detector drift gap.

A direct measurement of the gain of a triple-GEM is possible by exposing the detector to a source of known radiation energy. In this way the number of primary electrons released in the gas volume can be estimated and a measurement of the amplified electrons leads to the calculation of the gas gain:

$$Gain = \frac{N_{RO}}{N_{Dr}} \tag{3.2}$$

where:

- N_{RO} is the number of electrons reaching the readout;
- N_{Dr} is the number of electrons deposited in the drift gap by the incoming radiation.

For a fixed triple-GEM geometry the gain is mainly dependent on the voltage applied to the GEM foils and the gas mixture in use. These two quantities have been optimized over the years, so that now GEM technology can successfully operate in the Compact Muon Solenoid (CMS) experiment at CERN.

In the first part of this experiment you will retrace some of these optimization steps by operating at different voltages and with different gas mixtures.

3.2 Radiation Source(s)

3.2.1 X-Ray sources

The sources with known spectrum used for this experiment are ^{109}Cd and ^{55}Fe. The former has a half-life of 462.6 days and mainly emits 22.1 KeV X-ray photons (83%), while the latter decays by way of electron capture to ^{55}Mn. When the electron is captured, the electrons reorganize themselves to compensate for the reduced charge creating a vacancy in the k orbital. The result is the emission of photons having ≈ 5.9 KeV energy.

The 22.1 KeV photon coming from the ^{109}Cd are absorbed by the copper on the drift cathode of the GEM chamber and re-emitted as 8.34 KeV, while the ≈ 5.9 KeV photons reach the gas volume unchanged.

3.2.2 β sources

^{90}Sr and ^{241}Am are available from T7 experiment and can be used to measure β-decay. The energy of electrons coming from β-decay has a continuous spectrum, therefore the number of released electrons in the drift gap is not fixed. For this reason these sources are not suitable candidates for gain measurement.

The full decay chains can be found in the T7 instructions, but we will describe them briefly here:

Sr-90 decays via β-decay to Y-90 with a half life on the order of 28.9 years giving an electron of energy 550 keV. The chain ends by the Y-90 decaying, again via β decay, to Zr-90 with a half life of order 64.1 hours ejecting electrons of energy 2.28 MeV.

^{241}Am decays primarily due to α emission to Np-237 with a half life of roughly 433 years. Np-237 undergoes another decay to Pa-233 by α-decay. The α decays are not, generally, visible to the GEM detector since the gas volume gets shielded by layers of copper and plastic which absorb the αs particles. However, the Pa-233 decays through the β-decay process to U-233 with a half life of roughly 27 days yielding electrons with 570 keV energy. There are many other elements in the decay chain, but the other β-emitters are: Ra-225 going to Ac-225 with half lif 14.9 days and ejecting electrons at an energy of 360 keV, Bi-213 going to Po-213 with half life of 45.6 minutes with electron energy o 1.42 MeV, and Pb-209 going to Bi-209 with a half life of 3.25 hours and electron energy of 640 keV.

Table (3.1) Typical example of triple-GEM voltages for Drift electrode voltage (V_{Drfit}) equals 3230 V.

Electrode Name	Voltage (V)	Multiplication Factor
Drift	3230	1
Gem1Top	2457	0.761
Gem1Bot	2070	0.641
Gem1Top	1769	0.548
Gem2Bot	1391	0.431
Gem3Top	790	0.245
Gem3Bot	429	0.133
Readout (anode)	0	0

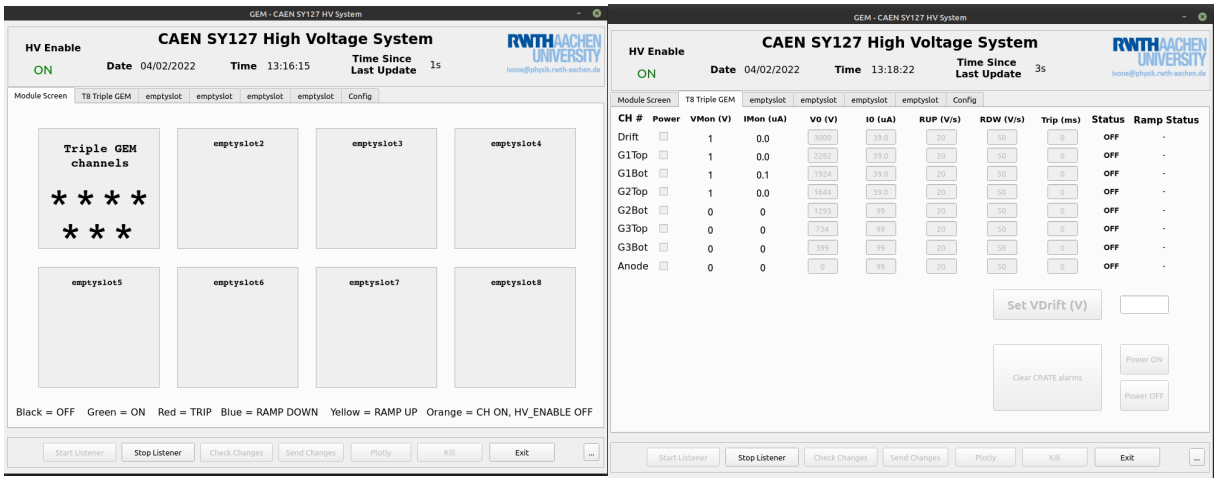

Figure (3.3) Screen shots of the HV interface for the GEM detector. On the left the summary view, on the right the channel specific tab.

3.3 CAEN HV System

As already mentioned the high voltage settings for triple-GEM have been optimized over the years in order to achieve stable and efficient operating conditions. For the sake of simplicity only the drift cathode voltage is set and the voltages for the other stages are determined by a multiplication for a fixed factor.

The CAEN HV system SY127 is used to supply voltages up to 3500 V to the GEM chamber. Your tutors have coded an easy-to-use Graphical User Interface (GUI) in order to communicate with the CAEN HV system SY127, see Fig. 3.3. Two possible modes are available:

1. V_{Drift} mode: setting the voltage of the drift cathode electrode and having the othere electrode voltages automatically set based on Tab. 3.1;
2. Single Electrode mode: allows to change GEM1Top voltage while the other electrodes are unaffected.

The operational HV range depends on the gas mixture in use. As a rule of thumb, the higher the percentage of Ar, the lower the maximum voltage should get.
For Ar/CO_2 (70 : 30) the optimal high voltage range is between 3 kV and 3.40 kV. Below 3 kV the number of produced electrons is too low that the readout electronics cannot separate it from the noise. Above 3.40 kV gas discharges may occur leading to an un-stable detector.

Detailed information on how to operate the HV system will be provided on the experiment day.

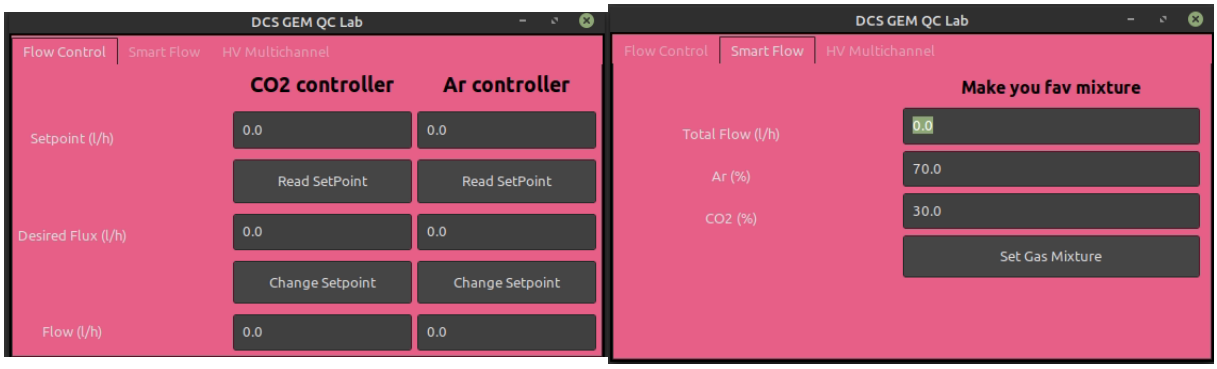

Figure (3.4) The interface to actively change the gas mixture to the GEM chamber. On the left side the panel that allows the monitoring of the gas flows, on the right side the tab to adjust the gas mixture parameters.

3.4 Gas System

The gas system provides constant gas flow to the triple-GEM chamber. The nominal gas mixture corresponds a 70:30 Ar:CO_2 mixture. The Ar and CO_2 flow from their respective containers, reach the flow controllers and get mixed. The obtained gas mixture gets then sent to the chamber. Your tutors have built an easy-to-use Graphical User Interface (GUI) in order to communicate with the flow controllers, adjust the gas flows and the gas mixture, see Fig. 3.4

You will find the gas GUI up and running at your arrival in the lab. Keep the total gas flow to 5 L/h in order to ensure good chamber performance.

Before every gain measurement the gas mixture inside the chamber has to well known and constant over the time.

Fig. 3.5 shows how the gas is distributed inside the chamber. The triple-GEM active volume is connected to the inner chamber volume by a small window on the side. Therefore the gas is not forced to flow inside the active volume which could potentially cause a stagnation of *old gas*. **For every change in the gas mixture it is recommended to flux for 60 minutes at 5 L/h**.

3.5 Copper Enclosure

As the GEM chamber is primarily irradiated with β and X-Ray radiation one needs sufficient shielding between the chamber and the user. Therefore the set-up is installed inside a copper box manufactured with sufficiently thick copper sheets. The GEM chamber and the radioactive sources must always be placed inside this enclosure. It is solid on all six sides with the following exceptions. On the reverse face (face directly opposite from the user) all holes for HV input cables, readout cables, and power for the X-Ray source pass through. Care was taken to only make holes as large as needed for a strain relief for these cables to pass through and fit without allowing any radiation to pass through. The top of the enclosure is designed to be opened on a hinge. This allows the user direct access to the chamber, X-Ray source, and cabling. The enclosure should remain closed as much as possible.

3.6 Readout devices

3.6.1 Picoammeter

The Keithley 6485 is a picoammeter with a resolution of 10 fA. It reads out the induced readout current and show it up on the display. Your tutors prepared a convenient routine to read out the picoammeter measurements and store them in a csv file.

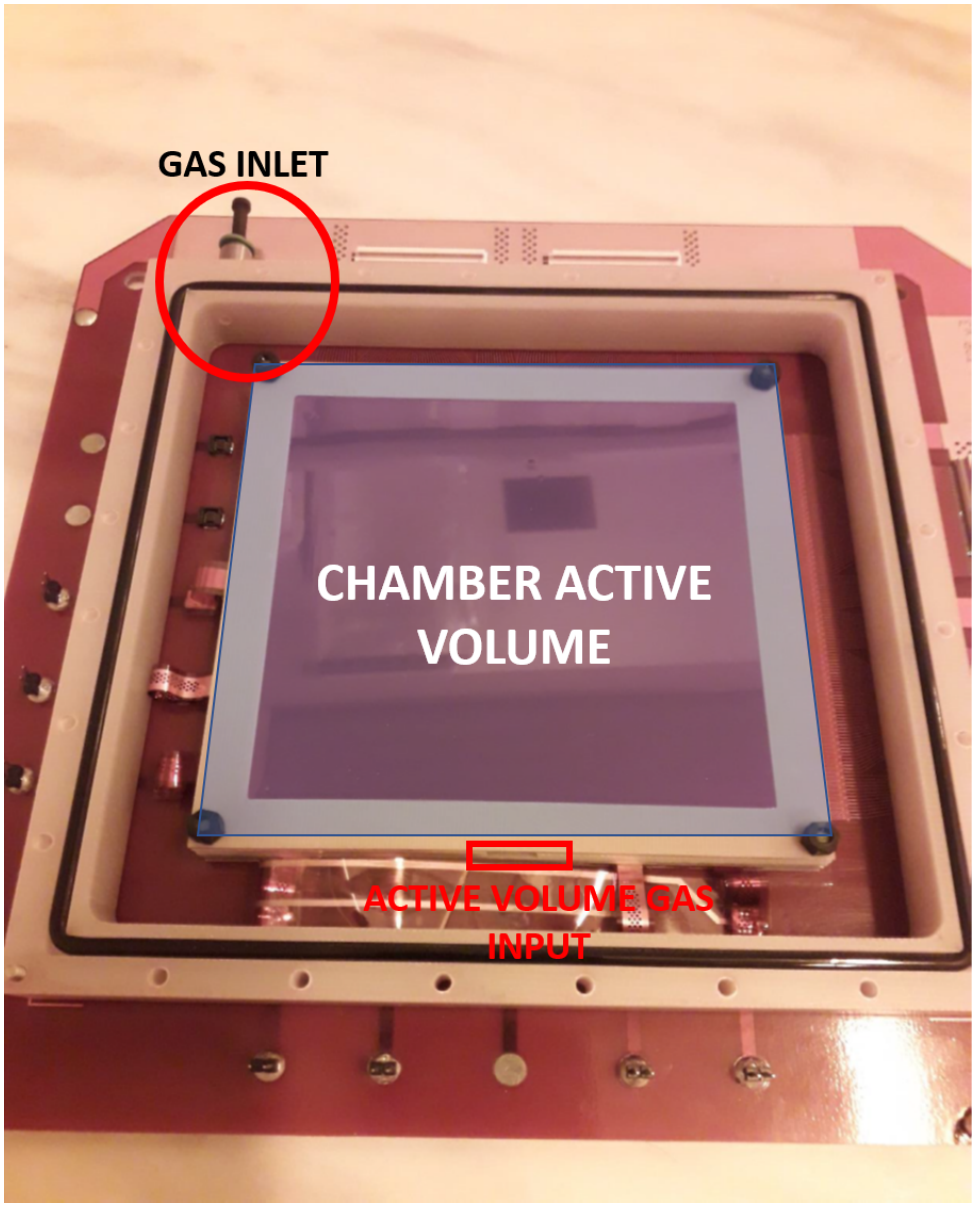

Figure (3.5) Detailed picture of gas distribution inside the triple-GEM. The gas doesn't flow directly into the chamber active volume.

3.6.2 Preamplifier

The ORTEC 142PC is a charge sensitive pre-amplifier. It integrates the current coming from the triple-GEM chamber strips generating as output a voltage-pulse. The pulse max amplitude is proportional to the integrated charge. In more practical terms: the induced current produced by the multiplied electrons is transformed in "stored" in maximum voltage of the signals output by the ORTEC142PC. More produced electrons means bigger output signals.

3.6.3 Picoscope

The pico-scope reads out the ORTEC142PC output signal, digitilize it and stores the maximum amplitude. Fig. 3.6 shows an example of the pico-scope SW. Detailed instruction on how to operate the SW will be provided during the experiment day.

Fig. 3.7 shows a block diagram of the signal chain for the energy resolution measurement (more on this later).

Picoscope legal information

Keep in mind that you are allowed to use pico-scope SW only with Pico products or with data collected using Pico products.

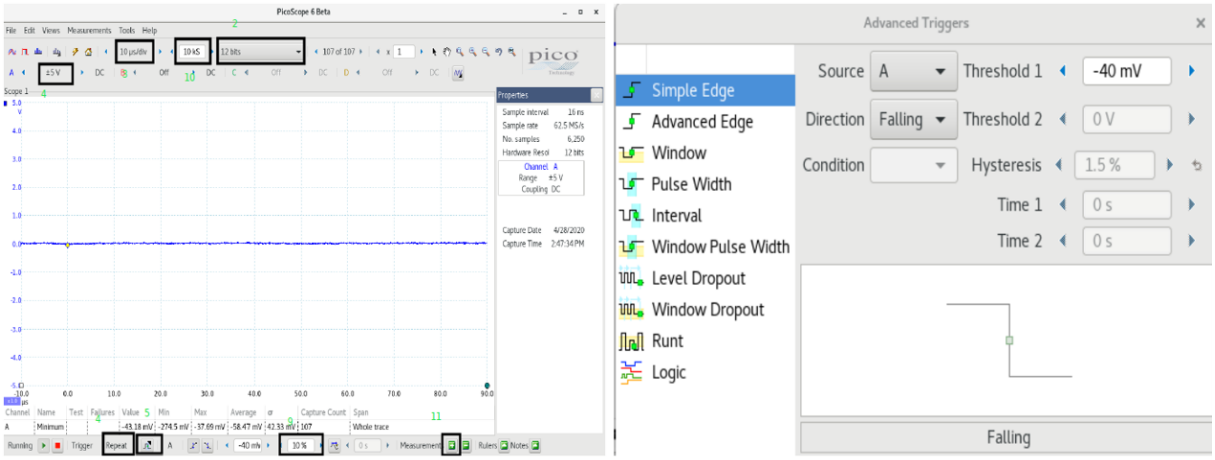

Figure (3.6) The picoscope SW: interface set-up and trigger setup menu.

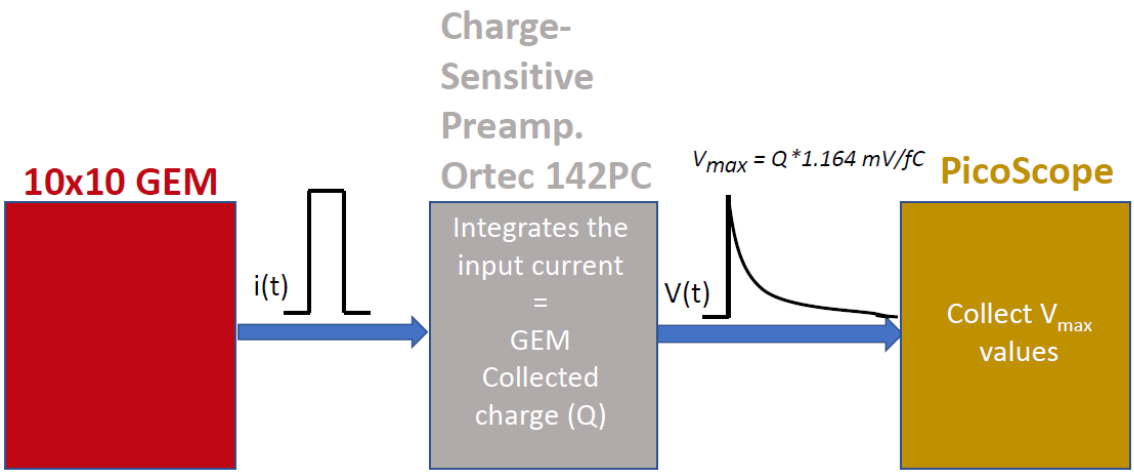

Figure (3.7) Block diagram of the signal processing chain.

4 Execution

The measurements to be performed:

- **Gas Mixture $\mathbf{Ar/CO_2}$** $(70:30)$
  1. Direct gain measurement by varying the overall chamber voltage (Sec. 4.2);
  2. Direct gain measurement by varying the GEM 1 foil voltage (Sec. 4.3);
  3. Energy spectrum distribution of the various sources available;
- **Multiple Gas Mixtures**
  1. Direct gain measurement Ar/CO_2 $(60:40)$;
  2. Direct gain measurement Ar/CO_2 $(80:20)$;
  3. More gas mixtures if time allows;

4.1 Gain Measurement in a nutshell

We start from Eq. 3.2. The evaluation of the number of electrons is not really practical: as you may know electrons are particularly shy particles which prefer to lie in orbitals. Additionally the multiplication process takes in roughly ~ 100 ns. Therefore we choose to measure the rate of electrons over time. In math terms it consists of integrating the numerator and denominator in Eq. 3.2 over 1 second. The number of electrons in the chamber depends on the activity of the radioactive source in use. We reasonably assume the activity to be constant over a 1 second time interval. Thus we can treat the terms N in the integrals as constants.

$$\frac{\text{Output Readout Current}}{\text{Current of Primary Electrons}} = \frac{\int_{t_0}^{t_0+1} N_{RO}\, dt}{\int_{t_0}^{t_0+1} N_{Dr}\, dt} = \frac{N_{RO} \times \int_{t_0}^{t_0+1} dt}{N_{Dr} \times \int_{t_0}^{t_0+1} dt} = \frac{N_{RO}}{N_{Dr}} = Gain \tag{4.1}$$

Eq. 4.1 shows that the gain can be evaluated starting from measurements of the readout current and the current of primary electrons.
The picoammeter can perform a direct measurement of the readout current. The current of primary electrons can be calculated as

rate of emitted X-rays $\times$ number of primary electrons released by the radiation $\times$ electron charge.

As explained in Sec. 3.2, ^{109}Cd releases 8.34 KeV photons in the drift gap which then convert into 322 ± 2.8 electrons. The rate of X-rays emitted by the source can be evaluated by measuring the rate of triple-GEM output signals that cross a threshold. At low voltages, a photon in the drift gap it is likely to produce an output signal too small to cross the threshold, thus the measured rate will be lower than the actual rate. As the voltage increases the measured rate asymptotically approaches the rate of X-rays emitted by the source. So the plateau value of the rate measurement is taken as the rate of X-rays emitted by the radiation source. An example can be seen in Fig. 4.1.

4.2 Direct Gain Measurement by Varying the Overall Chamber Voltage

Task: Vary the overall HV of the chamber and measure the triple-GEM gain as a function of HV. Use the CAEN HV system in V_{Drift} mode.

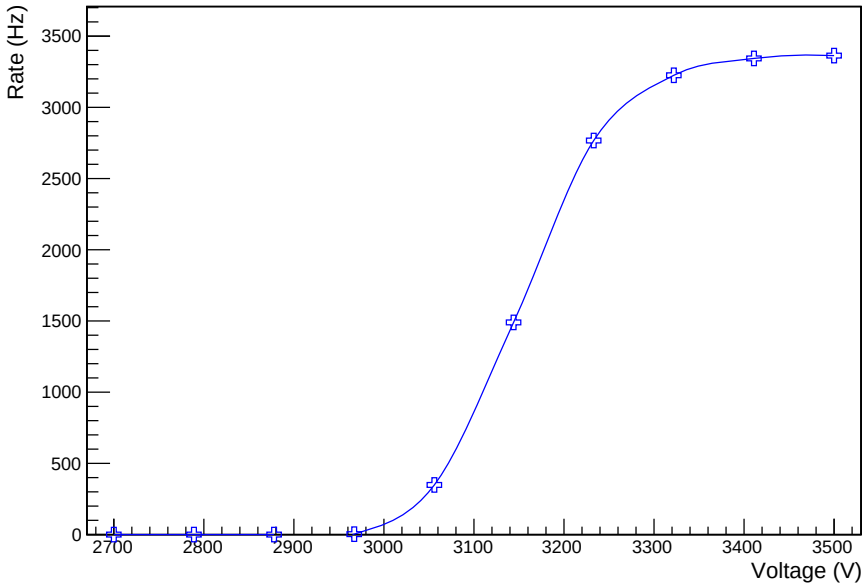

Figure (4.1) Triple-GEM output signal rate against applied voltage, when operating the CAEN HV System in V_{Drift} mode.

This measurement is performed during by CMS GEM collaboration to qualify the GEM chambers prior to installation into CMS. It is one of the most important parameter of a chamber: a very low gain value won't allow the detection of charged particles. You will measure the gain while changing the drift electrode voltage V_{Drift}. Thus, the voltage differences across each individual foils change accordingly as can be seen in Figure 4.2. The numerical values for each HV input can be found by multiplying the V_{Drift} value used by the fractions in Table 3.1.

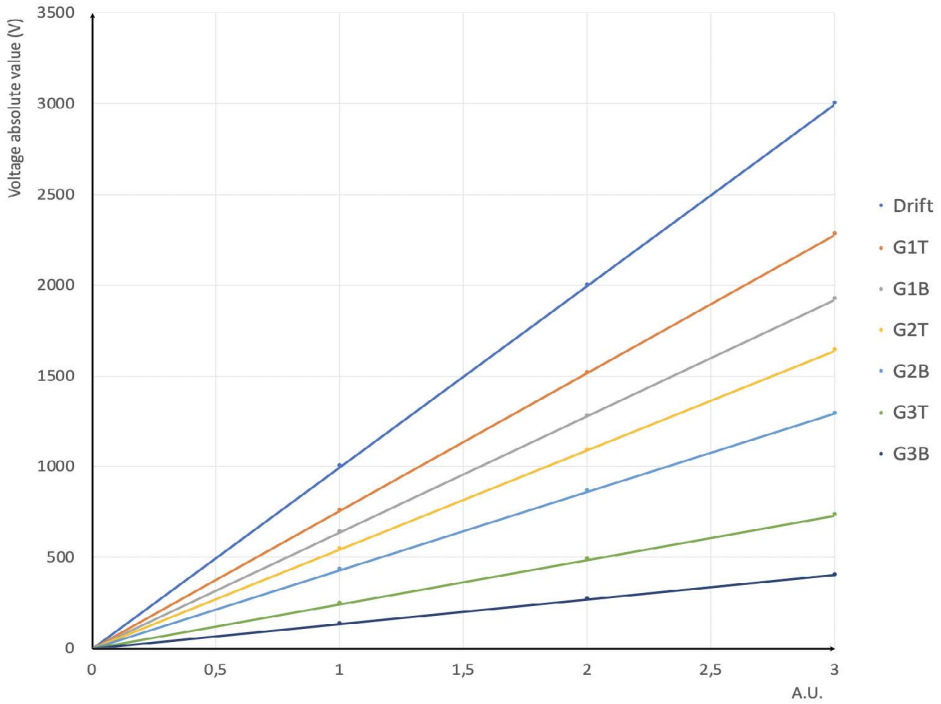

Figure (4.2) Sketch showing the progression of HV when operating the CAEN HV System in V_{Drift} mode

Perform the following steps:

1. Set the gas mixture to Ar/CO_2 (80 : 20);
2. Place the ^{109}Cd source over the GEM chamber opening and make sure the copper box lid is closed;
3. Connect the triple-GEM output signal the Ortec preamplifier, then Ortec time filtering amplifier, then discriminator and finally to the counter;
4. Operate the CAEN HV System in V_{Drift} mode;
5. Measure the number of counts in 1 minute for HV in range $(2900, 3400)$ V. Use at least 7 different HV values;
6. Connect the triple-GEM output signal to the picoammeter;
7. Open a terminal and type **picopicoammeter**. Follow the instructions and measure the output current for at least 7 HV points in the range $(2900, 3400)$.

4.3 Direct Gain Measurement by Varying Single GEM Foil Voltage

Task: Set the overall HV of the chamber at $V_{Drift} = 3400\ V$. Then, by using the CAEN HV system in Layer-by-Layer mode, vary Gem1Top voltage and measure the gain as a function of it. The settings of all other layers remain unchanged.

This measurement allows to study the impact of GEM1 ΔV on the overall chamber amplification. In this scan, only the field inside GEM1 holes is varied. All the remaining fields inside the GEM chamber are kept constant. A visual understanding of the difference with respect to the previous measurement can be provided by comparing Fig. 4.2 with Fig. 4.3.

Perform the following steps:

1. Don't move the ^{109}Cd source from the previous position, you can use the previous rate measurement;
2. Operate the CAEN HV System in Layer-by-Layer mode;
3. Open a terminal and type **picopicoammeter**. Follow the instructions and measure the output current for at least 7 HV points in the range $(2576, 2596)$ V.

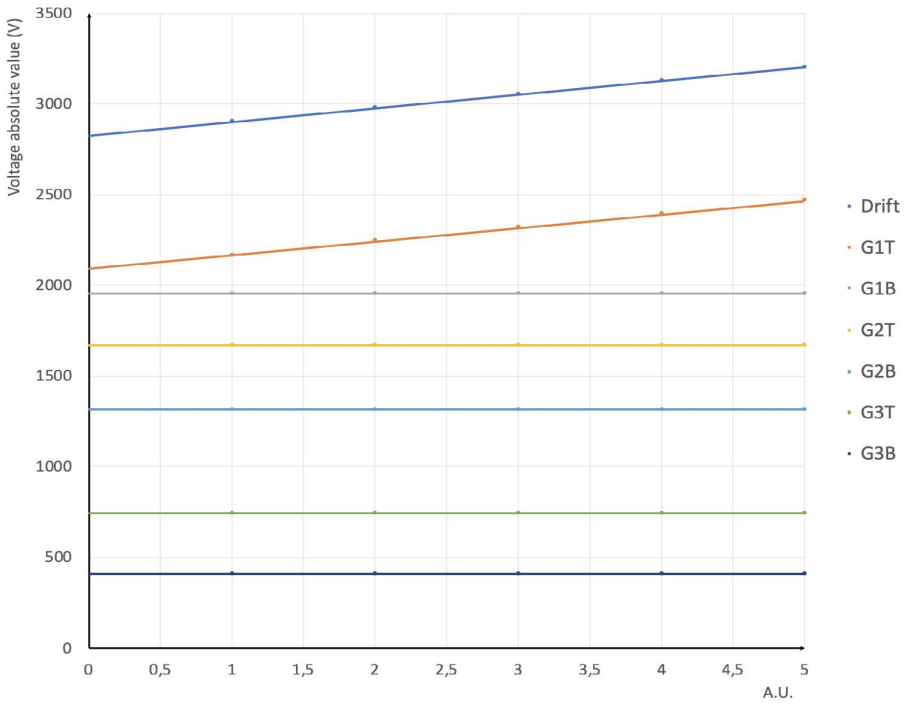

Figure (4.3) Sketch showing the relative progression of voltage when, by operating the CAEN HV System in Layer-by-Layer mode, only Gem1Top voltage is changed.

4.4 Energy Spectrum Of Various Sources

Task: use the GEM detector to study the energy spectrum of the following elements using the pico-scope:

- ^{109}Cd
- ^{90}Sr
- ^{55}Fe
- Cosmic ray muons (if time allows)
- ^{241}Am (if time allows)

Connect the signal output from the Triple-GEM to the pre-amplifier, the amplifier and finally in the pico-scope. As discussed in the previous sections, the max amplitude of the signal fed into the pico-scope is proportional to the number of electrons in the induction gap. Therefore, for a given high voltage value, the max amplitude depends on the energy released in the drift gap.

Perform the following steps:

1. Set the overall HV of the chamber to 3.4 kV by using the CAEN HV system in V_{Drift} mode;
2. Place the radioactive source on the chamber;
3. Set up the picoscope;
4. Size the number of signals to be collected based on the statistics needed and the available time.

4.5 Gain as a Function of the Gas Mixture

Task: study the impact of the gas mixture by changing the mixture of Ar:CO_2.

Repeat the steps done in Sec. 4.2 for each gas mixture. Each time a new gas mixture is selected, let the chamber flux for 60 minutes at 5 L/h (see Sec. 3.4). Use the gas mixtures

- Ar/CO_2 (60 : 40);
- Ar/CO_2 (80 : 20);
- If time allows, Ar/CO_2 (65 : 35) and Ar/CO_2 (75 : 25).

5 Analysis report

5.1 Intro

Quick physics recap:

- Each avalanche comes from an X-Ray photon that release $N = 322 \pm 2.8$ primary electrons in the GEM drift gap;
- These electrons are amplified by the triple-GEM based on a factor called Gain;
- The amplified charge cloud reaches the induction gap where it induces a current.

$$Gain = \frac{\text{OutputCurrent}}{\text{N} \times e \times Rate} \tag{5.1}$$

where e is the electron charge. Use this equation to evaluate the gain in the different scenarios.

5.2 Gain Analysis

The gain has been measured in 2 main HV variation modes:

1. By changing the ΔV of all the GEM layers at the same time for different mixtures
2. By changing the ΔV in GEM1 and keeping all other ΔV constant.

5.2.1 Steps

1. Plot Gain (w/ error) vs HV value and fit them with an exponential curve. Repeat for all datasets taken in V_{Drift} mode;
2. Repeat separately for the dataset taken in layer-by-layer mode;

5.2.2 Questions

1. How does the gas mixture affect the gain?
2. How does the overall high voltage affect the gain?
3. How does the ΔV across GEM1 affect the gain?

5.3 Spectra Analysis

You have measured the max amplitude of the integrated signals produced by a triple-GEM detector when exposed to different radiation sources. The max amplitude of the pre-amplifier output depends on N. Indeed, different sources give a different number of primary electrons based on their energy. You have potentially used ^{55}Fe, ^{109}Cd, ^{90}Sr, ^{241}Am and cosmic rays as radiation sources.

5.3.1 Steps

1. Plot the distribution of Max Voltage for all the used sources;
2. Fit (when possible) the peak of the distribution with a gaussian distribution;
3. By using the known energy of ^{55}Fe main peak, find the calibration factor from Max Voltage to radiation energy;
4. Plot the same distributions of point 1. in terms of energy.

5.3.2 Questions

1. What are the differences between the sources?
2. How many peaks can you find for the ^{55}Fe? Do they match with its spectrum in literature? *Hint: Argon escape peak??*
3. How many peaks can you find for the ^{109}Cd?
4. How can you explain them based on physics you know?