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Rate Dependency Study on Gas Electron Multiplier Gain

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Abstract of bachelor's thesis

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Abstract

In particle physics today, new experiments are constantly being developed. This places high requirements on the detector technology, and especially on the rate capability, which means a detector's ability to cope with high quantities of incoming particles. This study focuses on the effects of high rate on Gas Electron Multiplier (GEM) detectors.

The gain of a GEM detector means how many electrons are collected on the readout inside the detector for each electron that is created in the initial ionization process when a particle enters the gas volume. In 2006 Pieter Everaerts wrote his PhD thesis on triple-GEM detectors, and he found a strange change in the gain of the detector at high fluxes of particles. This study investigates the anomaly in a systematical way in order to find out the reason behind it.

The research was conducted through measurements on a triple-GEM detector in the Gas Detectors Development laboratory at CERN (The European Organization for Nuclear Research). The main measurements were of the gain as a function of the particle flux (rate/area). External causes for the phenomenon such as temperature, pressure, gas flow and issues with the electronics were ruled out during the study.

The systematic measurements show that there is a change in the gain at high particle fluxes. The gain increases at first, and then decreases. The ion backflow of the detector was also investigated in order to know more about the nature of the phenomenon, and the results show that it decreases at first, and then stabilizes as the gain starts to decrease.

The results tell us that this is a real effect that is happening in the GEMs, and it seems to be due to space charge in the GEM holes. When the number of electrons inside a GEM hole per time interval becomes high enough, the gain will increase. As the number of electrons is increasing further, they are creating so much space charge that the hole saturates and starts blocking ions from moving towards the drift cathode and electrons from moving towards the readout anode.

This explanation is just an approximation, and there are other factors influencing the result, such as the diffusion of the electrons. However, it is important to consider these results when developing and using GEM detectors in the future, since there is clearly an effect on the detector gain at high fluxes of particles.

Keywords particle detectors, gaseous detectors, gas electron multiplier, GEM

Contents

1 Introduction

1.1 New challenges in particle detection

The need for an accurate, reliable and versatile detector is an issue that scientists are constantly working on. Being able to detect particles and also determine their position very precisely is crucial for many branches of particle physics, and the technology has made enormous leaps in the last half a century. The main challenges are related to the *spatial resolution*, or how precisely one can detect the position of the incoming particle, and the *rate capability*, or how many particles per second a detector can handle before losing some of the functionality. Another feature with increased requirements is the *acceptance* of a detector, which means how large the coverage of the detector is.

In the Large Hadron Collider (LHC) at the European Organization for Nuclear Research (CERN) the *luminosity*, or the quantity of particles per unit of time, is constantly increased, and the need for detectors with high rate capability is crucial. There is an upgrade plan called the High Luminosity LHC, which would enable values of luminosity up to 10 times larger than the LHC was originally designed for by the year 2020. [1]

The International Linear Collider (ILC) is another enormous project that is under development as a collaboration between CERN and other research facilities. The plan is a 31 km-long linear collider, possibly in northern Japan, that will be able to further investigate the properties of the Higgs particle found at CERN in 2012. [2] In addition to that, there is a new accelerator complex being developed in Germany called the Facility for Antiproton and Ion Research (FAIR). It will be used to study all the elements of the periodic table in great detail, and especially isotopes rich in neutrons. [3] All of these projects and many more will undeniably place extremely high requirements on the detectors industry regarding rate capability and other properties.

1.2 History

Particle detectors can be categorized based on their method of detection, and those that consist of gas-filled chambers and use the ionizing effect of the incoming particles are called *gaseous detectors*. The evolution of the gaseous detectors dates back to 1908, when Hans Geiger and Ernest Rutherford published a new method for particle detection. Geiger invented a device that used this principle to detect alpha particles by accelerating them in a tube with a wire in the middle. This way the alpha particles created avalanches by hitting and ionizing the atoms in the gas. [4]

In 1928, Hans Geiger and Walther Müller introduced the *Geiger-Müller counter*, which was a further development on the technology Geiger and Rutherford had worked on earlier. The device was operated at high voltage differences, which caused avalanche reactions to occur in the whole gas volume. This way, it was not possible to tell how many initial ion pairs had been created, since the amount of charge collected on the wire would always be approximately the same regardless of the energy deposited by the incident particle. The device could consequently only be used as a simple counter, but it had advantages such as the large signal as a result of the high operational voltage, and the low cost. [5, p. 201]

Another invention, which happened earlier in the evolution of gaseous detectors, was the *cloud chamber*. It was invented by C. T. R. Wilson in 1911 (Nobel Prize in Physics 1927), and it was widely used in particle physics until the 1950s. Its principle of operation is having saturated vapor of water or alcohol in a container and visualizing the tracks of the incoming particles as small paths of droplets in the vapor. [6]

After the cloud chamber came the *bubble chamber*, which was invented in 1953 (published in 1955) by Donald Glaser. He received the Nobel Physics prize for his invention in 1960. The bubble chamber is filled with a super-heated liquid that while expanding becomes sensitive to particles and makes their trajectories appear with bubbles. [7] The bubble chamber is, however, unable to identify the energies of incident particles and thus select which events to record, and it became clear that a new type of detector was needed. There was another device in use at the time, the *spark chamber*, which enabled selective imaging but with lesser image quality. It functioned by inducing a spark between the metal plates in the detector whenever a particle with sufficiently high energy entered. It was the first detector to use electronics in the imaging process. [8]

A remarkable breakthrough in the development of particle detectors occurred in 1968, when Georges Charpak published his new invention, the *multiwire proportional chamber*. With its millimeter-precision and ability to measure higher fluxes of particles, it quickly became the first choice of detector, replacing the bubble and spark chambers. [9] Charpak received the Nobel Prize in Physics in 1992 for his invention and the large effect it had on experiments like the ones conducted at CERN [10].

A highly important new feature in the multiwire proportional chamber was the *proportionality.* The aim for this type of system is to have only one electron per initial electron-ion pair amplified, and thus to be able to have a proportionality between the number of initial electrons and the total current collected on the readout. A proportional detector has two separate regions. First there is a drift region, which has a low electric field in order to move the produced electrons towards the readout, but not to create more electron-ion pairs. The second region is the amplification area, which has a high electric field so the avalanche of electrons is created. [5, p. 201]

The multiwire proportional chamber consists of two negatively charged plates with positively charged parallel wires in between them (see Figure 1). When a particle passes through the detector, it hits and ionizes atoms in the gas, and the produced electrons are accelerated towards the anode wires. In the process, when they are very close to the anode wires and the field is extremely high, they collide with more atoms and produce an avalanche of electrons that is collected in the wires and induces a signal. However, the rate capability of the multiwire proportional chamber was low while the high rate requirements grew, and thus new developments became needed.

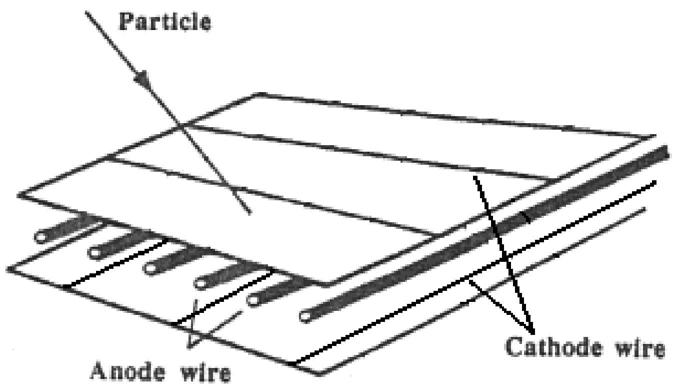

Figure 1: The principle of operation of a multiwire proportional chamber. [10]

In 1988, a new type of micropattern gas detector was introduced: the *microstrip gas chamber.* In this structure, which is shown in Figure 2, thin strips replaced the anode wires. The strips alternated in polarity, so the large potential difference that produced the avalanches was now in between the strips instead of between the wire and the cathode wall of the detector. [11] This made it easier to create the avalanche since the required potential difference was much smaller as a result of the radically decreased distance.

However, the disadvantages of the microstrip gas chamber proved to be fairly problematic; the substrate, which is what the anode and cathode strips are attached to, suffered from charging up and this produced sparks that damaged the strips, which made the detector stop working. It also suffered from discharges due to the creation of high electric fields between the cathode and the anode. The microstrip gas chambers were initially planned for CMS (Compact Muon Solenoid, an experiment of the LHC at CERN), but silicon detectors were chosen instead, because they were determined to be more reliable. [12]

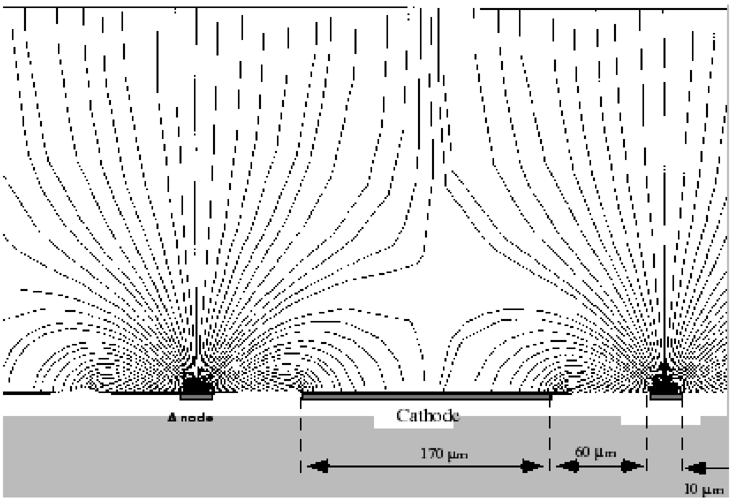

Figure 2: The structure of a microstrip gas chamber.

In order to try to reduce the field between the cathode and the anode, a new design with intermediate amplification was needed. In 1997, Fabio Sauli presented a new method for charge amplification, the *Gas Electron Multiplier* (GEM) (see Figure 3). The structure consisted of a insulating sheet that was covered with a thin conducting layer on both sides and had a matrix of holes in it. The principle of operation was that when a particle enters the gas volume and initial electrons are released, they are drifted towards the GEM hole by a fairly low electric field. The potential difference between the top and bottom of the GEM is distributed over a very small distance (the thickness of the GEM), which makes the field inside the holes extremely strong. Because of this, it is likely that an avalanche reaction occurs inside the GEM hole. [13]

The advantages of the GEM were a higher gain, the high counting rate, the proportionality, which meant the energy deposited in the detector can be measured, and the decoupling of the induction of the signal from the other

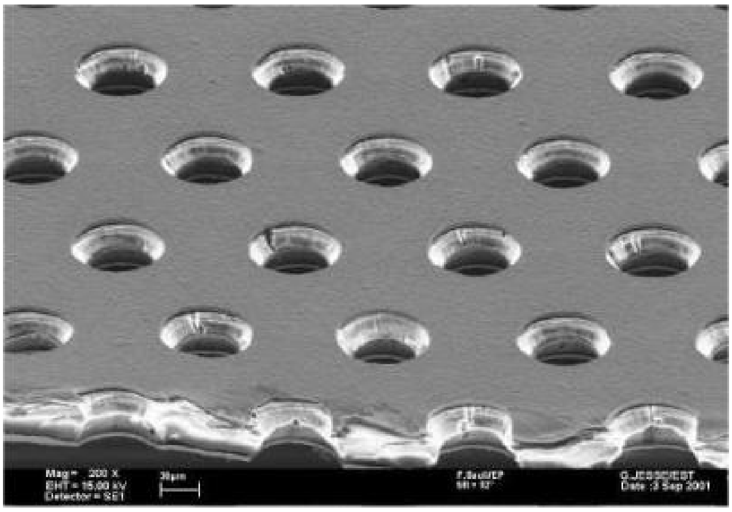

Figure 3: Image of a standard GEM foil, taken with an electron microscope. [14]

stages of the gain, which meant the induction process was purely electron-dominated. It is also possible to create quite large GEMs because the manufacturing of the holes is done by standard printed circuit techniques. At this point in time, microstrip gas chambers were not needed anymore, and GEMs were successfully stacked in order to obtain larger gain in the detector, for example by installing three of them after one another to create a so-called triple-GEM. [13]

At CERN, there are many different detectors in use and under development. GEMs were first used in the COMPASS (COmmon Muon Proton Apparatus for Structure and Spectroscopy) experiment at the Super Proton Synchrotron. COMPASS is an experiment that studied collisions of muons and hadrons against a fixed target. [15]

At the moment GEMs are also used in the TOTEM (TOTal cross section, Elastic scattering and diffraction dissociation Measurement at the LHC) experiment. It is located near the proton beam, next to the CMS (Compact Muon Solenoid) experiment at one of the interaction points of the Large Hadron Collider (LHC). It is used to detect particles that appear in the proton-proton collisions of the LHC. [16] Another significant usage of GEMs has been in the LHCb experiment. A triple-GEM structure has been used in its muon detector since 2009. [17] There is also intensive research and development in progress on installing a triple-GEM detector in the muon system of CMS. A GEM structure is needed for its excellent spatial resolution and rate capability. [18]

1.3 Scope

The rate capability of a GEM is a crucial property to study at the moment, because of the higher luminosity requirements. Pieter Everaerts wrote his PhD thesis in 2006 on the rate capability of a triple GEM detector. He discovered that the performance of the detector starts to change at X-ray fluxes of 10^4 Hz/mm^2 and higher, which can be observed in Figure 4. [19] This Bachelor's thesis will firstly provide a comprehensive introduction to GEM detectors, as well as a section about the gain calibration process. Then measurements at the same rates as Everaerts used will be conducted systematically. The new results will be analyzed and compared with his conclusions.

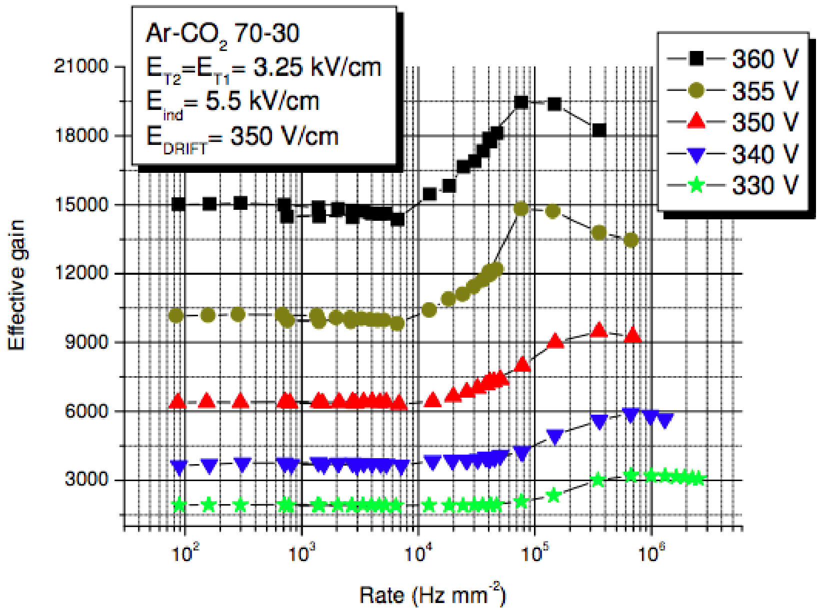

Figure 4: The gain of the detector as a function of the flux. The different colors represent different values of voltage applied to the GEMs. [19]

2 Experimental setup

2.1 GEM: Principle of operation

The GEM consists of a 50 μm thick polyamide film that has a thin layer of copper on each side. A matrix of holes is etched into the film. The copper layers are at different voltages, so there is an electric field inside the GEM holes. In Figure 5 the process is illustrated in detail.

A detector with one GEM consists of a closed chamber filled with gas, a kapton window with a drift cathode, a GEM foil and a readout anode with parallel strips in both vertical and horizontal direction. The drift cathode has a high negative voltage, and the anode is at ground. The detection functions as follows: a particle comes into the gas volume from the window on top. It hits the atoms in the gas and ionizes a number of them (as many as the energy deposit produces). Since the ionization process produces electron-ion pairs, the ions are then slowly drifted up towards the cathode, where they are collected. This collected charge is a quantity called the *ion backflow* or *ion feedback*. The free electrons are drifted down towards the GEM by the drift field. Then they are pulled into the GEM holes. However, some of the electrons are lost because of diffusion in the process, so they end up attached to the top or the bottom of the GEM. The electric field in the GEM holes is extremely strong, so the probability of having multiple collisions is high. Thus, an avalanche of electrons is created. The electrons are transported down towards the anode by the induction field. At the anode the charge of the electrons is collected.

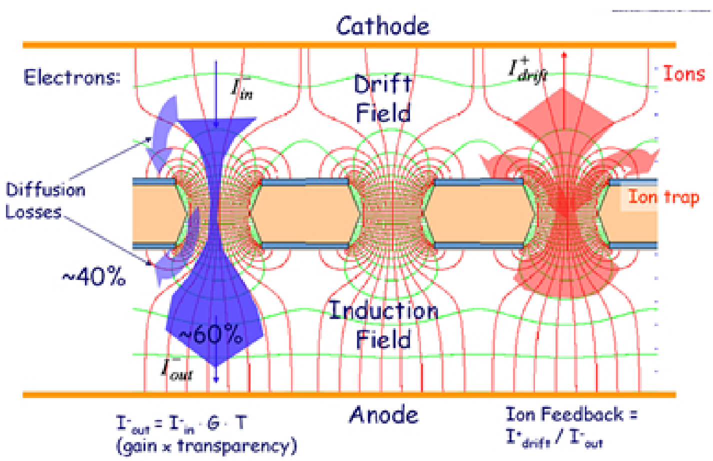

Figure 5: The principle of operation of a single-GEM detector.

In this particular case, a triple-GEM detector was used. Its structure is shown in Figure 6 that also displays the distances between the GEMs, the cathode and the anode. The conductive layers on top and on the bottom of each GEM have negative voltages whose values decrease when moving downwards. These voltage values are chosen to create low electric fields in the drift, transfer and induction regions and extremely high fields in the GEM holes.

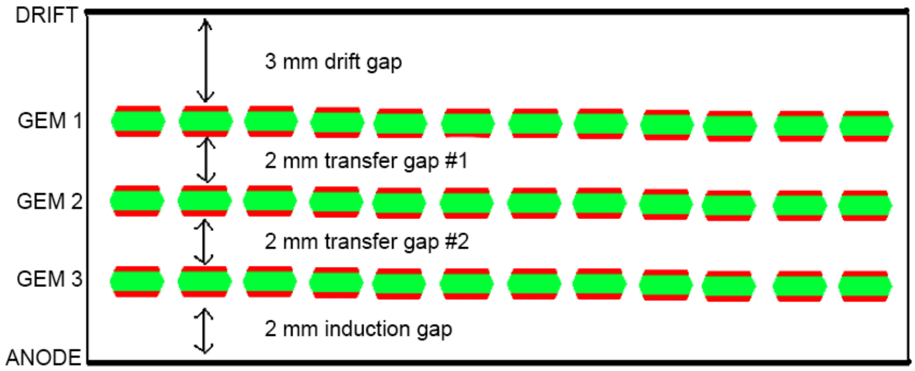

Figure 6: The structure of a triple-GEM detector. Based on the figure by Everaerts [19].

In a detector with three GEMs, the electrons from the first avalanche are transferred to the second GEM, where the avalanche process is repeated, and then the same process occurs again with the third GEM, thus producing a multiplication from the initial electron (see Figure 7). After this, the large number of electrons is transferred to the readout plate by the induction field. When the number of electrons collected is divided by the number of initial electrons created in the drift volume, the result is a coefficient called the *gain* of the detector. The method of measuring the gain is more thoroughly explained in section 2.3.

The sources of high voltage used in these experiments were two CAEN 4CH Programmable HV Power Supplies, one N470 and one N1471H. The high voltage was connected to the drift, and from there a structure of resistors divided the voltage among the GEMs. This created suitable electric fields in the different areas of the detector.

The gas used in this triple-GEM was 70 % argon and 30 % carbon dioxide. The reason for using a noble gas such as argon is that in those, the avalanche reaction occurs at lower field strength than in more complex molecules. However, a *quencher gas* like carbon dioxide is needed to prevent the gas from

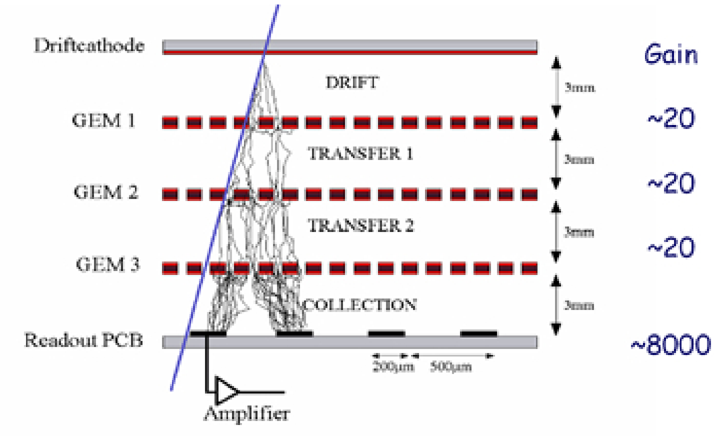

Figure 7: The avalanche process inside a triple-GEM detector.

entering stream mode, which means it generates continuous avalanches. Since carbon dioxide consists of polyatomic molecules, it has a high electron attachment coefficient, which means it is able to absorb excess energy by converting it into vibrations and rotation states. [19]

The gas flow was kept constant throughout each measurement. The value varied between 1 and 5 liters per hour, but was normally at 2-3 l/h.

In this study, both X-ray sources and an X-ray tube were used as radiation sources. The radioactive sources were mainly iron-55 (12 MBq), but also cadmium-109 was used for a few reference measurements. The X-ray tube (Ital Structures, Compact 3K5 X-ray Generator) was used to conduct the high rate measurements, and its target material was copper.

2.2 Energy resolution measurements

The measurements for this study can be separated into two parts: the energy resolution measurements and the gain measurements. The energy resolution is a property of a detector that describes the precision of the measurements of the energy deposited in the detector. The energy resolution of an incoming monoenergetic X-ray source is given as the percentage of the full width at half maximum (FWHM) of the height of the resulting Gaussian peak. In order to measure this, one needs a device that reads each incoming signal and makes a histogram based on the signal amplitude. That device is called a Multi-Channel Analyzer, or MCA (here we used an Amptek Pocket MCA 8000D). It allows us to inspect each individual event that happens in the detector.

In this triple-GEM detector the incoming signal for the MCA was taken from the bottom of the 3rd GEM instead of the anode on the bottom. This was done because the signal for the gain measurements was taken from the bottom, and thus it would be possible to compare these two for reference in case of anomalies in the signal.

As seen in Figure 8, the signal that is induced in the bottom of the 3rd GEM is passed through a pre-amplifier and an amplifier before it is taken to the MCA. From there the MCA sends the information to the software (Amptek dppMCA). The software then produces a histogram that has a Gaussian shape (see Figure 9). From this, we can get the position of the peak, which is proportional to the energy of the incoming radiation.

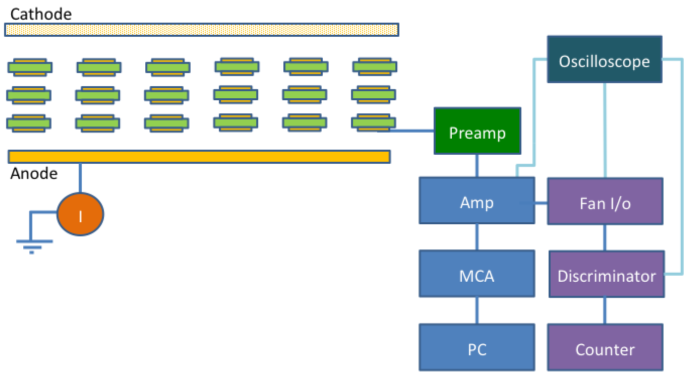

Figure 8: The setup of the measurements with the triple-GEM detector.

In addition to the large peak in Figure 9 (and some noise at the lowest channels), there is a smaller peak around the channel 300 of the MCA, which is roughly half of the energy deposited. This is caused by a phenomenon called the *argon escape*. It is initiated when an X-ray photon with 5.9 keV of energy is emitted from the decay process of iron-55. This photon enters the gas volume and collides with an argon atom. An electron is emitted from the K-shell, which requires 3.2 keV of energy. The produced electron, which has a kinetic energy of 2.7 keV, continues to ionize more atoms. The binding energy will in 85 % of cases be emitted through an Auger electron, which will then also go on and ionize atoms in the gas. However, in 15 % of cases the energy will be emitted in the form of an X-ray photon. This photon has an energy of around 3 keV, which makes it highly likely to escape through the sides of the gas volume. That means that the total charge collected on the readout for these 15 % of cases will be equivalent to 5.9 - 3 = 2.9 keV, in

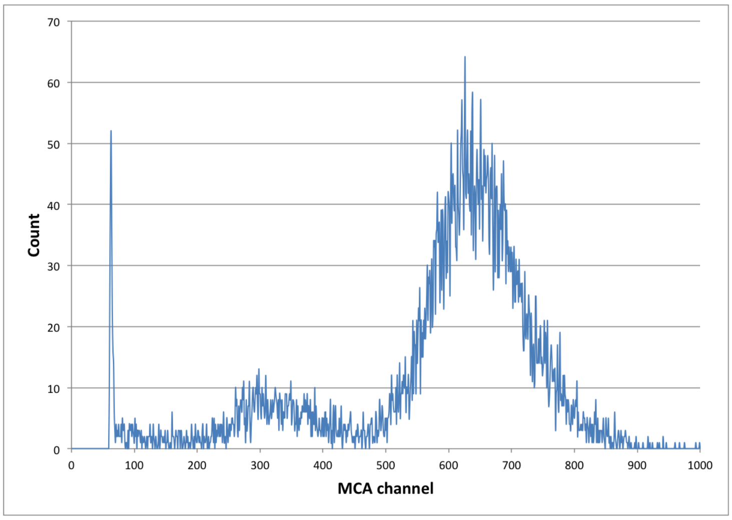

Figure 9: Triple-GEM ^{55}Fe spectrum on Ar/CO_2 (70/30) measured with a MCA.

comparison to the main peak at 5.9 keV. This is why there is a smaller peak at around half the energy of the main peak in the spectrum.

The same signal that goes to the MCA is also taken to a scaler (in this study: CAEN Quad Scaler and Preset Counter-Timer, model N145) through a fan in/out (LeCroy Linear Fan-in/Fan-out, model 428 F), which changes the polarity, and a discriminator (LeCroy 8 Channel Discriminator, model 620CL), which converts any signal that crosses its threshold into a logical signal, so the scaler can register it. When the total count is divided by the measuring time (usually 10 seconds), the result is the rate. The MCA software also gives a value for the rate. The signal is monitored with an oscilloscope from different stages of the setup in order to have a real-time overview of the process.

2.3 Gain measurements

The gain of a GEM detector is a coefficient that describes how many electrons are collected on the readout for each initial electron that is produced in the drift region. This is calculated using equation (1), where I is the total current collected on the readout, n is the number of primary electrons created per incident X-ray photon, f is the rate of the X-rays (number of incident photons per second) and e is the charge of an electron. The number of primary electrons per photon n is calculated by dividing the energy of a photon with the effective ionization energy of the gas. In the case of the Ar/CO2 70/30 mixture, the effective ionization energy is around 30 eV and when dividing 5.9 keV by that number, the result is $n \approx 200$ initial electrons.

$$G = \frac{I}{nfe} \tag{1}$$

In order to calculate the gain, we only need to measure the current, since everything else is known. The cathode is connected to ground via a picoammeter, which measures the current. The one used for this study was a Keithley 6487 Picoammeter/Voltage Source in combination with LabVIEW software. Since it measures current, it only gives the total amount of charge per second.

Before using a detector for any measurements, one needs to perform a gain calibration. This means measuring the gain for a variety of different high voltages applied on the drift. As long as their relationship stays proportional (gain increases exponentially when voltage is increased), it is possible to use the detector for measurements.

3 Results

In Figure 9 one can see an example of the output of the MCA. Since this is a distribution of all the events in the detector, it tells us the total number of events. We also obtain the energy resolution from this spectrum by dividing the full width at half maximum of the main peak by its peak position channel. In Figure 10 the energy resolution of the detector is plotted against the voltage applied on the drift. The first couple of points are from a range where the peak is not yet completely visible, because the peak is so small that it is still at the same amplitude as the noise. The rest of the points show a fairly constant value.

The electric fields inside the detector have different purposes and hence also different strengths. The purpose of the drift field is to move all of the produced electrons down to the first GEM. If the field is too low, some of the electrons will not be transported all the way, but they will recombine with impurities that exist in the gas. If it is too high, some of the electrons will have so much velocity when they approach the first GEM that they will hit the top of the GEM and get stopped there. Figure 11 shows a scan of the drift field strength. The gain of the detector was kept constant at about

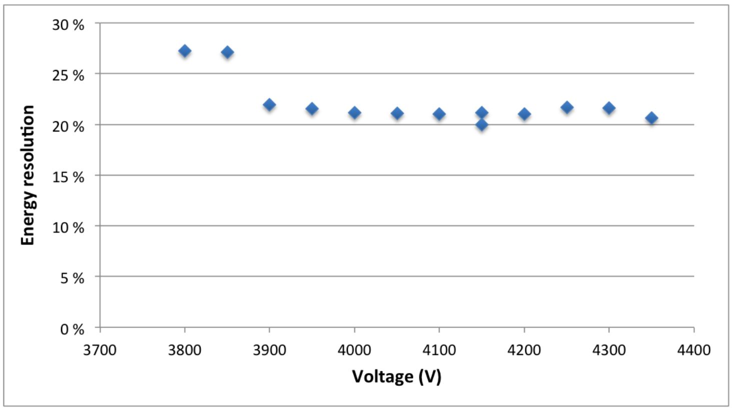

Figure 10: Energy resolution as a function of the input voltage.

9500. In the graph, there is an increase at first, and then a plateau is reached. The range of the measurement does not allow us to see where the plateau ends, but with this measurement we can already determine that close to all electrons seem to be drifted at values between 800 and 1200 V/cm.

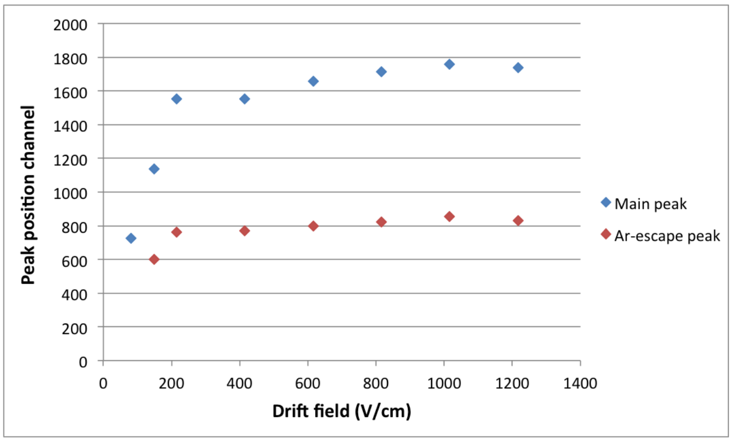

Figure 11: Peak position as a function of the drift field strength.

3.1 Gain calibration

Before taking any other measurements with a detector, a gain calibration must be done in order to know what the gain is at each input voltage and to check that there are no nonlinearities in the performance of the detector. In addition to measuring the current, the peak positions for each voltage are monitored to be able to check that the values also follow the same dependence. The results from the gain calibration for this triple-GEM detector are shown in Figure 12. The dependence is exponential, and the points are laying in a straight line.

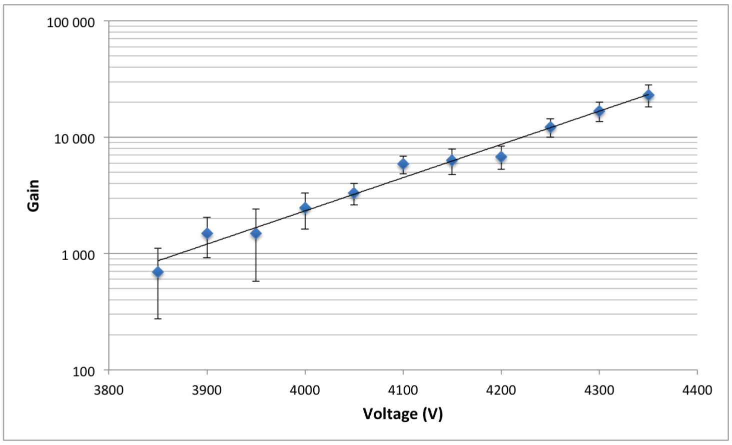

Figure 12: The gain as a function of the input voltage.

When performing the gain calibration, we also checked the performance at higher gains. As Figure 13 shows, we found that the gain started to saturate at values of around 100 000. The same phenomenon was also observed when measuring the peak positions with the MCA, which is connected to the bottom of the 3rd GEM (see Figure 14), so it is unlikely to be a problem in the electronics. We can also see that the saturation happens at lower voltages for the main peak than for the argon escape peak. This suggests that the phenomenon was due to a high number of electrons entering the GEM hole at the same time, thus canceling out some of the electric field in the holes and decreasing the gain.

3.2 Rate capability

In Figure 15 the gain is presented as a function of the rate. The gain starts at around 5000 and it stays constant even at 10 MHz. Here the radiation was spread all over the detector, so the flux of photons was fairly low. In section 3.3 we study the effects of high flux on the detector gain.

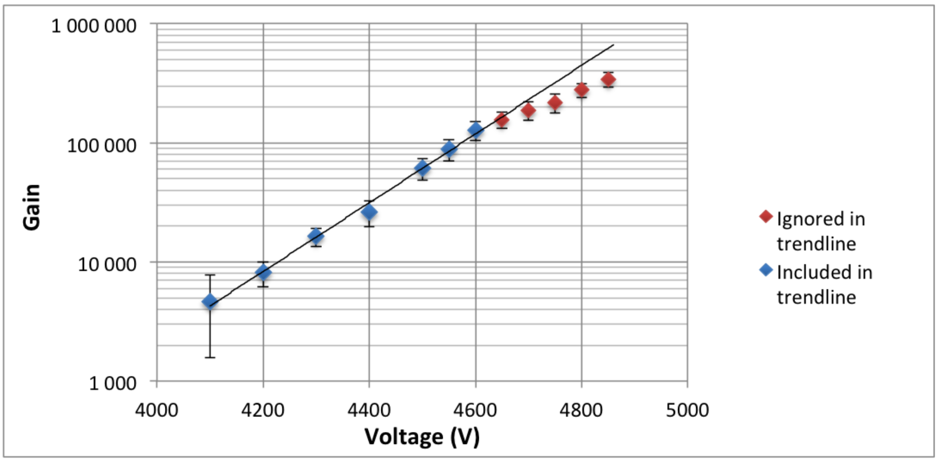

Figure 13: The gain as a function of the voltage. At high gains, there is a saturation in the graph.

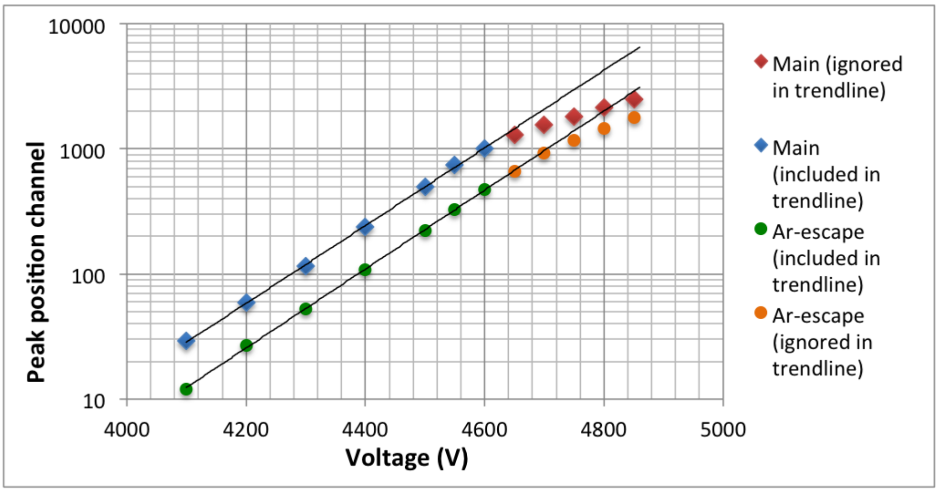

Figure 14: The saturation is also observable in the graph of the peak positions as a function of the voltage.

3.3 Gain dependency on flux

In his doctoral thesis Pieter Everaerts measured the effect of an increasing source rate on the gain of a triple-GEM detector [19]. In this study the measurement was repeated for the same fluxes (rate per area). The two measurements were done with a collimator on the X-ray machine, which enabled determining the size of the radiated area. The results of the first measurement are presented in Figure 16. The figure shows that up to a flux

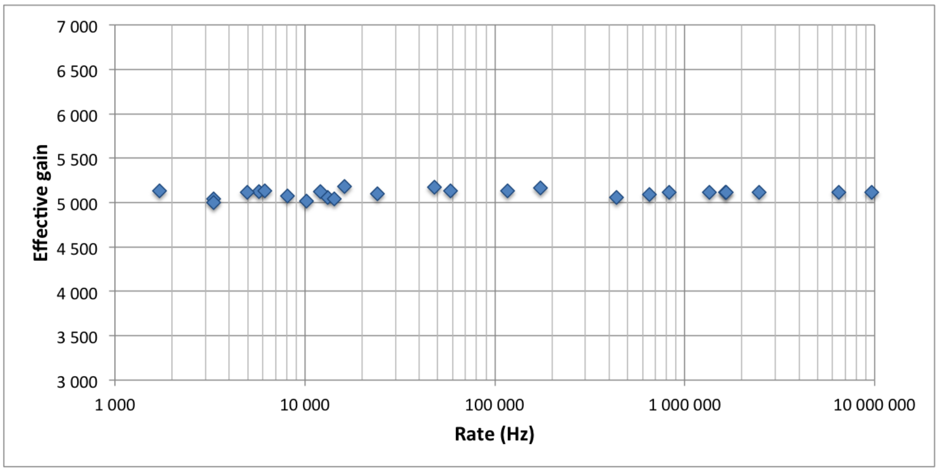

Figure 15: The gain as a function of the rate of X-rays.

of about 20 000 Hz/mm^2, the gain is constant at around 5000, as expected. But after this point, the gain starts to increase quite steeply, until it reaches a flux of about 400 000 Hz/mm^2, when the growth seems to stop. The gain at this point is around 10 000.

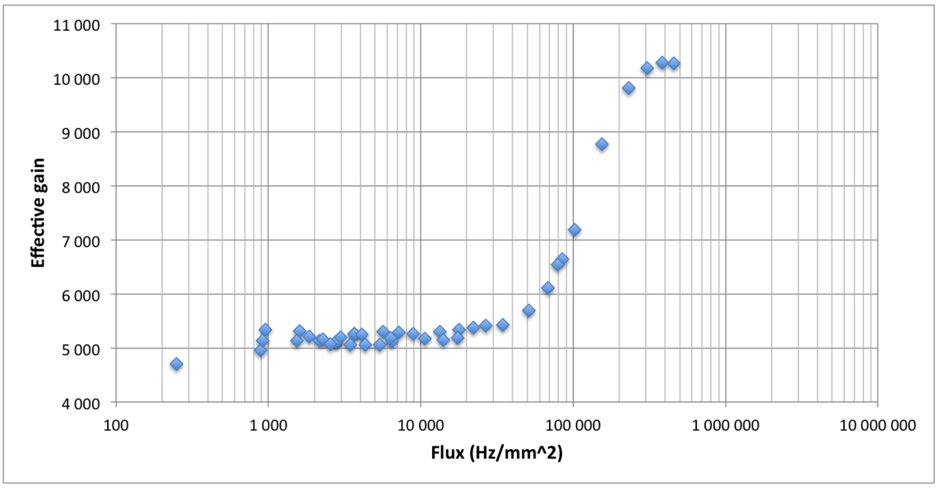

Figure 16: A graph of the gain of the detector as a function of the X-ray flux, with starting gain 5000.

The result of another measurement, which is presented in Figure 17, shows the same phenomenon. The starting gain in this measurement was 2000 instead of 5000. Here, the gain increases as before, and then it decreases back to the same level (and possibly further down, if the measurement was continued to higher fluxes).

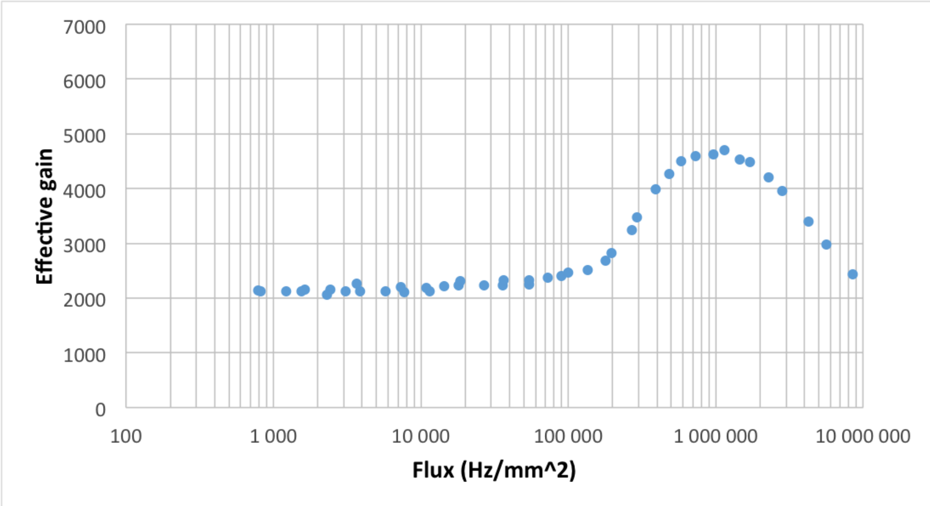

Figure 17: Another measurement of the gain as a function of the X-ray flux, with starting gain 2000.

When the flux increases, the GEMs have more electrons per time interval inside the holes and the gain increases. At a certain point the electrons saturate the holes, and the increase in the gain slows down and stops. The last GEM receives the most electrons, so it will saturate first, and consequently the second and first GEM will follow.

3.4 Ion backflow

When taking measurements at high flux, the ion backflow was also studied. The results for the ion backflow from the same measurement as in Figure 17, as well as the gain, are presented in Figure 18. Here we see a correlation that is negative at first, and then towards the end, both values are decreasing.

When performing these measurements, all possible external causes for this phenomenon were investigated. The temperature and pressure in the surroundings were monitored, as well as the gas flow to the detector. The electronics in the setup were also ruled out as causes for the effect.

The results correspond with the space charge effect that is likely to be the reason for the change in the gain. Regarding the ion backflow, when the electrons are saturating the holes, they are also blocking the ions that are moving upwards.

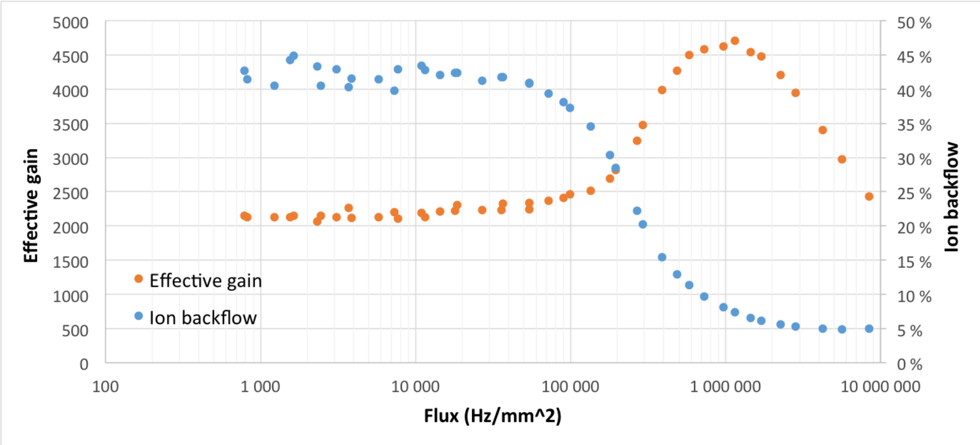

Figure 18: The ion backflow and the gain as a function of the X-ray flux.

4 Conclusions

In this study, it was investigated how the gain of a triple-GEM detector behaves at high fluxes of incoming X-ray photons. The result was that the gain increased at fluxes of 10^5 Hz/mm^2 and started decreasing again at 10^6 Hz/mm^2.

This result could be due to the following: when the flux is still fairly low, the current collected on the anode increases proportionally, and thus the gain remains constant. However, when the flux becomes very high (around 10^5 Hz/mm^2), a large number of electrons is produced and drifted into the GEM holes. At some point, when many electrons enter the hole within a short time interval, the gain eventually starts increasing. But when the number of electrons increases further, the avalanche will start to saturate, which makes the electric field weaker and thus the gain decreases. The effect on the ion backflow also shows this phenomenon. However, this explanation is just an approximation, there are other factors influencing the result, such as the diffusion of the electrons.

This study provides a step forward for the development of GEM detectors, which as a field is constantly under pressure to meet the requirements of the experiments. With the research of new physics at CERN and in other research facilities there are high requirements for, among other things, rate capability. This result is compatible with what Everaerts found in his thesis [19].

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A Sammanfattning på svenska

Inom partikelfysiken utvecklas det konstant nya experiment för att undersöka vad vårt universum består av och hur det har kommit till. I CERN (Europeiska organisationen för kärnforskning) finns den 27 km långa cirkulära partikelacceleratorn Large Hadron Collider (LHC). Den förbättras med jämna mellanrum för att tekniken ska klara av experiment med högre *luminositet*, dvs. mängd partiklar per tidsenhet. Det finns en plan vid namn High Luminosity LHC, som skulle möjliggöra upp till 10 gånger högre luminositet år 2020 än LHC ursprungligen planerades för. Allt detta ställer höga krav på detektorteknologin. En av de viktigaste egenskaperna hos en detektor är *frekvenståligheten*, dvs. förmågan att hantera höga frekvenser av inkommande partiklar, och detta är något som hela tiden behöver förbättras.

År 2006 gjorde Pieter Everaerts sin doktorsavhandling om gas-elektronmultiplikatordetektorer (GEM-detektorer), och i hans resultat fanns en konstig förändring hos en trippel-GEM-detektors förstärkning vid höga frekvenser av inkommande partiklar. Denna upptäckt undersöktes ändå inte grundligt då, så det uppstod ett behov att forska i fenomenet noggrannare. Detta arbete presenterar grunderna i GEM-detektorers uppbyggnad och funktionalitet samt utför en systematisk undersökning i orsakerna till förändringen i förstärkning som upptäcktes av Everaerts 2006.

En gas-elektronmultiplikator, eller en GEM, är en 50 μm tjock polymerhinna som är täckt av ett tunt kopparskikt på båda sidorna. En matris av hål är inetsad i hinnan. En GEM-detektor består av en gasfylld kammare med ett fönster som fungerar som katod, en GEM-hinna i mitten och en anod, som används för utläsning av signalen. Katoden har en hög negativ spänning och anoden är jordad. Övre och nedre sidan av GEM-hinnan har vardera en negativ spänning, och det finns en spänningsskillnad mellan sidorna. Detta gör att det uppstår ett väldigt högt elektriskt fält inne i GEM-hålet och ett svagare fält i resten av gasvolymen. Fälten är lika riktade.

I en GEM-detektor detekteras en partikel på följande sätt: en partikel kommer in i gasvolymen genom katoden, till det så kallade driftområdet. Där joniserar den atomerna som finns i gasen, och skapar elektron-jonpar. Det elektriska fältet drar elektronerna mot GEM-hinnan och in i hålen. Där får elektronerna så mycket energi av det starka elektriska fältet att de i sin tur joniserar flera atomer, och skapar nya elektron-jonpar. Detta fenomen kallas för lavineffekt. Alla dessa elektroner dras sedan vidare till anoden och utläsningssystemet. Jonerna som skapats i processen dras i sin tur uppåt mot katoden, något som kallas för *tillbakaflöde av joner*.

Detektorn som användes för detta arbete var en trippel-GEM-detektor, som i övrigt är likadan som den ovan beskrivna enkel-GEM-detektorn, men har tre GEM-hinnor inuti istället för en. Detta gör att lavineffekten multipliceras, och detektorns signal-brusförhållande förbättras. Gasen som användes i detektorn var 70 % argon och 30 % koldioxid, och gasflödet hölls konstant på ett värde kring 3 l/h. Detektorn testades med röntgenstrålar, både från ett radioaktivt material (^{5}5Fe) och från ett röntgenrör med koppar som anodmaterial.

I denna studie behandlas detektorns förstärkning. Det är en koefficient som beskriver hur många elektroner utläses vid anoden per varje elektron som skapas i driftområdet i början av processen. Man räknar ut den genom att ta strömmen som utläses vid anoden dividerat med strömmen som skapas i driftområdet (frekvensen gånger antal producerade elektroner per foton gånger elementarladdningen).

Innan man kan utföra mätningar med en detektor bör dess förstärkning undersökas. Detta görs genom att mäta förstärkningen som en funktion av spänningen som kopplas till detektorn. Mätningen visar ett exponentiellt beroende, men vid väldigt höga värden för förstärkningen (över 100 000) avtar ökningen. Detta är viktigt att mäta eftersom man då kan välja att göra sina mätningar vid tillräckligt låga förstärkningar så att denna minskning inte påverkar resultaten.

En annan sak som är viktig att mäta är detektorns frekvenstålighet. Detta gjordes genom att börja med en förstärkning på 5000 och en frekvens på 1 kHz, och sedan höja frekvensen stegvis upp till 10 MHz. Förstärkningen hölls hela tiden konstant, så detektorns frekvenstålighet är hög.

För att upprepa Everaerts resultat från 2006 gjordes mätningar av förstärkningen som funktion av flödet (frekvens per tid) av inkommande fotoner. Mätningar gjordes med två olika startvärden för förstärkningen, 2000 och 5000, och båda visade samma resultat: förstärkningen är som förväntat konstant först, men när frekvensen blir runt 100 kHz/mm^2 ökar förstärkningen upp till det dubbla för att sedan sjunka kraftigt. Dessa resultat stämmer överens med de som Everaerts fick i sin avhandling.

Förutom förstärkningen undersöktes även tillbakaflödet av joner. Det beräknas som antalet joner som träffar katoden delat med antalet elektroner som utläses i anoden, och ges som en procentuell andel. Everaerts beaktade inte detta i sin avhandling, men tillbakaflödet av joner ger oss mer information om fenomenets natur. Vid samma punkt där förstärkningen börjar öka sjunker istället tillbakaflödet av joner. När förstärkningen börjar sjunka stabiliseras tillbakaflödet av joner och verkar hållas konstant.

Under mätningarna undersöktes även möjliga externa orsaker till fenomenet, så som växlingar i temperatur, lufttryck och gasflöde samt olika problem med elektroniken, men alla dessa kunde uteslutas. Resultaten tyder på att det verkligen är fråga om en förändring i gas-elektronmultiplikatorns funktionalitet.

Resultaten kan bero på följande: när flödet av fotoner ännu är lågt hålls förstärkningen konstant, som förväntat. När flödet ökar kommer det att vara ett stort antal elektroner inne i GEM-hålen per tidsenhet, och detta ökar förstärkningen. Men när antalet elektroner ökar, kommer den så kallade rumsladdningen i hålet att öka. Detta orsakar en övermättning av hålet, vilket betyder att det blockerar jonerna som försöker röra sig mot katoden och även elektronerna som är på väg mot anoden. På grund av detta börjar tillbakaflödet av joner sjunka direkt, och förstärkningen lite senare. Övermättningen av hålen sker först vid den sista GEM-hinnan, eftersom den tar emot mest elektroner. Punkten då tillbakaflödet av joner slutar sjunka och stabiliseras är eventuellt den punkt då alla tre GEM-hinnor har övermättats och de enda joner som når katoden är från den översta delen av gasvolymen. Denna förklaring är endast en approximation och även andra fenomen, som t.ex. elektronernas diffusion, bör beaktas.

Följande steg gällande detta ämne är att fortsätta med forskningen för att få reda på mera detaljer om fenomenets orsaker. Man bör göra samma mätningar men med olika startvärden för förstärkningen, och även variera andra parametrar såsom de interna spänningarna. Forskningsgruppen i laboratoriet för utveckling av gasfyllda detektorer i CERN har fortsatt undersöka ämnet sedan denna studie utfördes, och de har gjort framsteg i sin forskning.