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Outer Tracker

Avalanche and streamer production in Ar/CO_2 mixtures

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Abstract

Avalanche and streamer or Geiger Muller discharges are studied in three mixtures of Ar/CO_2 70/30, 50/50 and 30/70 % as a function of high voltage and source intensity. In the mixtures with 50% and more CO_2 self quenching streamers are observed during irradiation with a Fe55 source at anode wire thickness of 25.4μm.

1 Introduction

In the technical design report of LHCb for the outer tracker [1] it was proposed to use a gas mixture containing Ar, CO_2 and CF_4. CF_4 was added to make the drift time as small as possible. A disadvantage of the CF_4 was that the fluor when freed in the avalanche could etch the wires and even let them break. Because the fluor is electronegative it may bind free electrons and give negative ions diluting the number of primary electrons[2] . These negative ions can exist even during 1 sec. From the ageing tests done by [3] it was concluded to leave out CF_4 and to use a mixture of Ar/CO_2 70/30 %.

Therefore this mixture is studied here in more detail. One has been looking at stability, space charge effects , discharge modes near the breakdown, limits of proportionality and to breakdown of the straws in a small prototype module of 1m length. This module was the first one built with the same parts as the real ones.

When one irradiates a straw with a source, pulse-heights and currents can be recorded. From the pulse-heights one can calculate the gain and one can see the occurrence of other pulse types that denote other discharge types. From the currents as a function of the high voltage one can see space charge effects and different regions of avalanche or streamer production. With Fe55 as a source one can study the behaviour of the escape peak and the main peak.

In this study the pulses are measured with a big dynamical range. Normally current amplifiers or charge amplifiers are used to see the signals of the wires. Current amplifiers and charge amplifiers have a very restricted region of application and strange I-V characteristics. Therefore we choose for the measurement of a voltage over a resistor as current measurement as explained in the next section and to use a voltage amplifier with a big bandwidth and high input impedance.

2 The method

For the measurements straws were used with an inner diameter of 5.00 mm and a pokalon straw of 16mm inner diameter. The straws of 5mm diameter are the standard for the outer tracker of LHCb. The diameter of the anode wire was 25.4 μm. As straws one has used a special short straw of 7 cm length made from a double layer of kapton XC (conducting kapton) and a straw of 50 cm length in a pro-to type module of 1m. This module has all

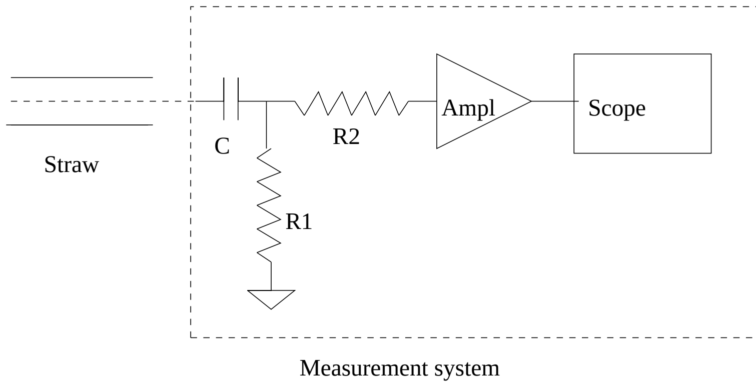

Figure 1: Electronic setup

the characteristics of the real modules but its length is only smaller. In the real modules of the outer tracker the straws are made of three layers . The inner layer was kapton XC, then an isolating layer of kapton and then a thin layer of Al foil.

The pulse-heights were measured with a scope connected to the output of a voltage amplifier of 10 times amplification. This voltage amplifier was connected via a capacitor to the wire. The input of the amplifier was looking at the currents through the wire over a resistance R_1=330 Ω to earth. With the value of R_2 is experimented a lot but finally the value of zero is taken as a good one. A voltage amplifier was used to make the dynamic range as big as possible and to make parasitic capacitances as small as possible. In figure 1 the electronic setup is shown. The amplifier was a AD8010 chip of Analog Devices with an input impedance of 30kΩ.

The oscilloscope (hp54502A of 400 MHz) was connected to the computer to be readout for the sampling of many pulses. For this purpose a USB GPIB interface was used from national instruments. It was checked that the electronics had a rise time of 0.25V/ns on the output. This means that a swing of the current of 0.075 mA/ns on the wire could be seen. In all cases the straws were irradiated with a Fe55 or a Sr90 source. The currents could be measured with a special nano ampere meter measuring the current in the high voltage line. The precision of this meter was 0.1 nA and the dynamic range was 100 nA. For other cases of current measurements a Keithly 485 picoammeter was used to have a bigger dynamical range. But with the Keithly one had to measure the currents between the cathode and earth which was difficult to realize for real modules. The Keithly was only used with the straw of 7 cm length and other little straw detectors.

Ar (%)	CO_2 (%)
70 ± 4	30 ± 2
50 ± 1.6	50 ± 1.6
30 ± 1.8	70 ± 4

Table 1: The gas mixtures and their precisions

The used Ar/CO_2 mixtures 70/30,50/50 and 30/70 % were obtained by mixing them with Brooks mass flow meters. The precision of these meters was 2% full scale. Now in table 1 the numbers are shown. The flow meters were gauged with a soap flow meter on l/h at 20 degrees Celsius and 1 atm air pressure.

3 Results

3.1 Measurements of the current with a source

3.1.1 Ar/CO_2 70/30 %

In figure 2 the current is measured as a function of high voltage with a Fe55 source and a Sr90 source for a real F-module for Ar/CO_2 70/30 % . The Sr data lay nicely on the exponential line but the Fe55 points show above 1.6kV a deviation to lower values. This deviation can be caused by the much bigger primary ionization density in the case of Fe55 leading to a lower gain of the main peak. Above 1.8kV the data-points go sharply upward. In this region one is reaching breakdown . The breakdown voltage is at 1830V. Also the dark currents increase above 1.8kV denoting the prelude of breakdown. The pulses are showing a wild structure meaning that there are produced many centers of avalanches along the wire induced by photons from previous avalanches.

In figure 3 the frequency is measured as a function of the high voltage for a straw irradiated with a Fe55 source. In this figure a plateau is visible extending till 1.8 kV.

To study space charge effects currents are measured at three intensities with a Sr90 source. In figure 4 the currents i_0,$i_1 = i_0/3.4$ and $i_2 = i_0/20$ are plotted. The lower intensity currents are scaled to the i_0 data at currents smaller than 100 nA. i_1 was rescaled between 1.2 and 1.45 kV and i_2 was rescaled between 1.35 and 1.55 kV.It is seen that the i_0 points are going to lower values above 1.65 kV. i_f is the value of the current fitted through the i_2 points. In figure 5 the ratios of $(\frac{i_0}{i_f} - 1).100\%$ are plotted as a function of

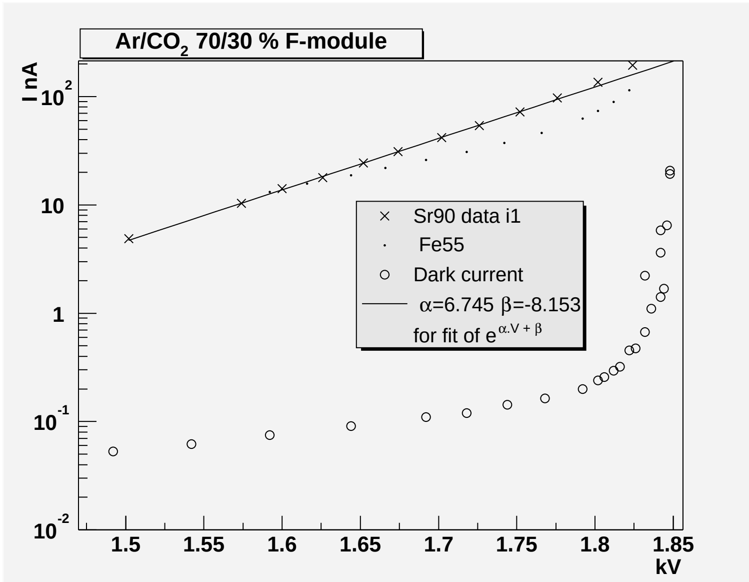

Figure 2: Current as a function of high voltage for Ar/CO_2 70/30 % for a real F-module

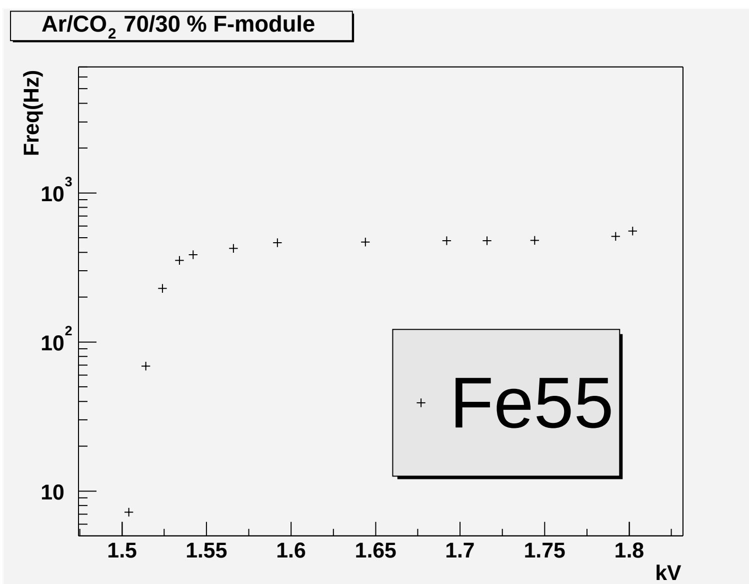

Figure 3: Frequency as a function of high voltage for Ar/CO_2 70/30 % for a straw with a kapton-XC cathode

the current i_f to show the effect of space charge better. The space charge starts to play a substantial role at currents bigger than 1000nA. The straw was irradiated through a slit of 1cm diameter. The region of irradiation on the straw is then bigger than 1cm. The distribution of the irradiated region has the form of a Breit Wigner function with width $\Gamma = 1$cm when the slit has a width of 1cm. This is measured by irradiating a module with a Sr90 source through a slit of 1 cm wide with the slit parallel to the straws. In this case one will see the distribution of currents over the various straws . This distribution is best fitted with a Breit Wigner and not with a Gaussian. If A is the amplitude of the Breit Wigner function, then it holds that $\frac{A}{\Gamma} = \frac{I}{\pi}$. The current density in the region of 1 cm along the straw is then equal to $\frac{0.92I}{\pi}$. In this case the current density at which space charge will build up is 293 nA/cm leading to a 10% diminuation of the gain. So a straw can easily handle a current density up to 100nA/cm as already stated in the TDR and in agreement with previous measurements.

In figure 2 one saw that the current for Fe55 is deviating from the exponential line first downward and then upward when coming near the breakdown region. Now the experiment is redone by irradiating the little straw with two intensities of Fe55, the lower one a factor of 3.4 less. In figure 6 the measurements of this curves are shown for the 7cm straw . Above 1.55 kV the curve of the current bends first downward from the exponential line and then near breakdown goes upward. The curves of the lower and the higher intensity coincide after scaling the lower intensity curve up to the higher with the factor of 3.4. So the deviation downward of the current at 1550V is not due to space charge. In the region where the curve goes below the exponential line , the escape peak (see next section) disappears. If the gain for the 5.9 keV cluster is less than for the 3 keV cluster due to bigger charge density, the difference between them will disappear and the peaks will coincide, see the figure 12. The same measurements are repeated with the pokalon straw of 16mm diameter as is visible in figure 7. Here the escape peak is of good quality till 1.95 kV in Ar/CO_2 70/30 % which scales down to 1.60 kV for a straw of 5 mm diameter. So in the bigger pokalon straw the onset of the disappearance of the escape peak starts at somewhat higher voltages than in the case of a straw of 5 mm.By the bigger drift distance in the pokalon straw the diffusion of the electrons in the gas will dilute the primary charge density more than in the case of a 5mm straw and the influence of the charge density on the gain is less.

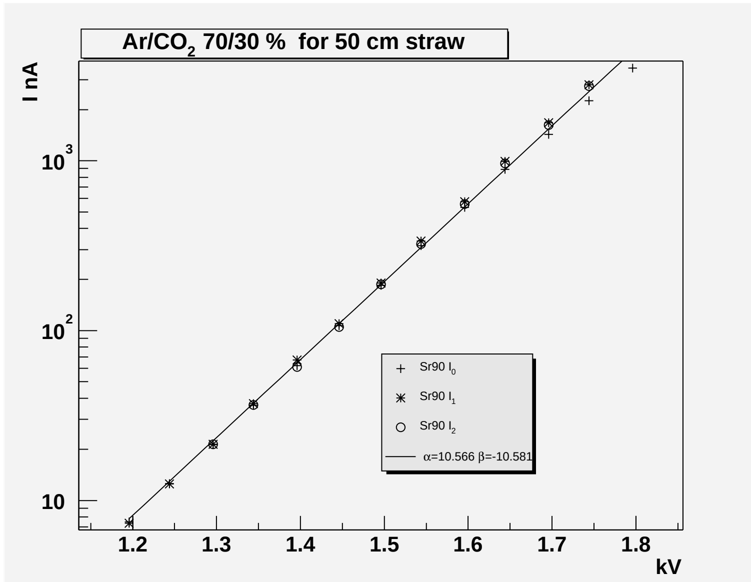

Figure 4: Currents for a Sr source at three different intensities for a 1m straw with kapton-XC cathode

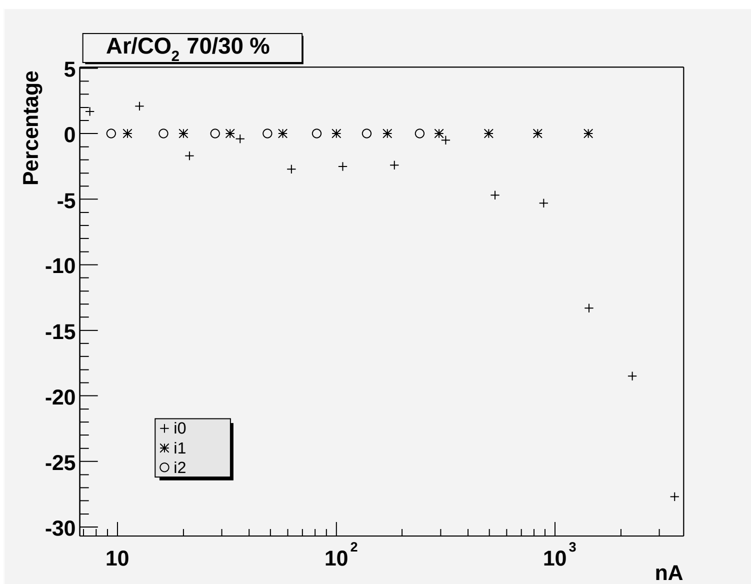

Figure 5: Ratios of currents for a Sr90 source at three different intensities for a 1m straw kapton-XC cathode

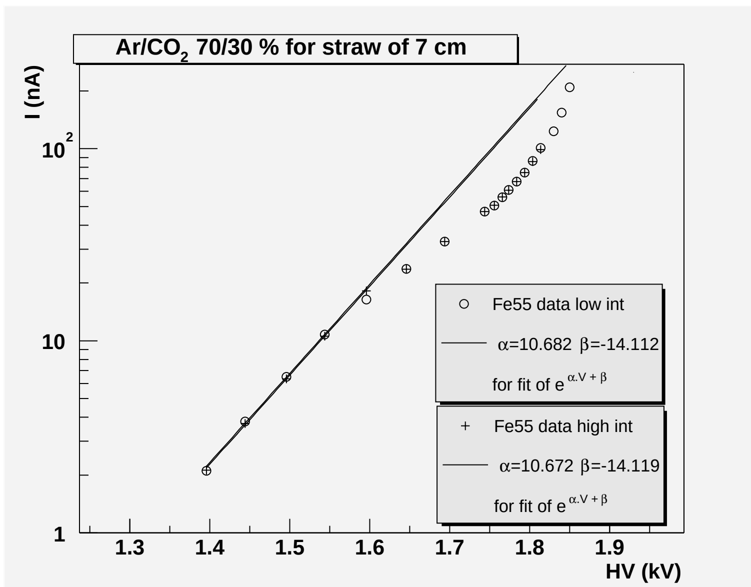

Figure 6: Current as a function of high voltage for the 7cm straw at Ar/CO_2 70/30 % measured for two intensities with a Fe55 source. At voltages above 1.6 kV the low intensity current was a factor of 3.4 less to prevent space charge development , and the values of the low currents were scaled up to the high values to show the effect more clearly

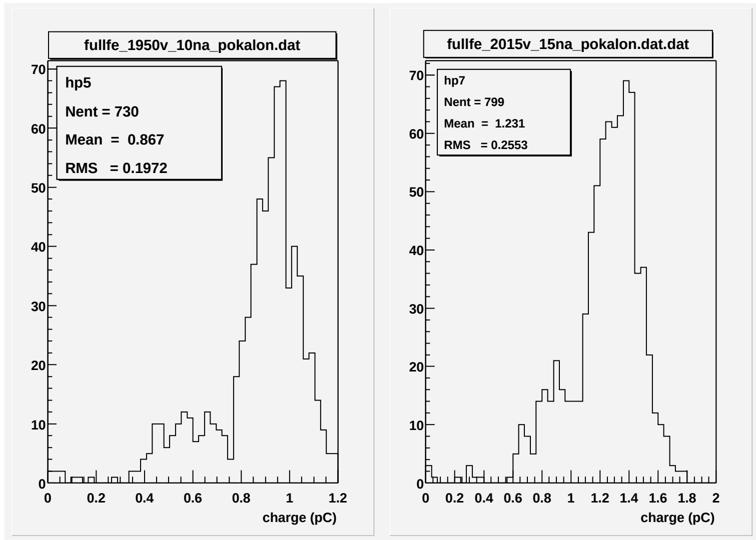

Figure 7: Fe55 current as a function of high voltage for the pokalon straw at Ar/CO_2 70/30 %. At voltages above 1.95 kV one sees that the escape disappears below the main peak.

3.1.2 Ar/CO_2 50/50 % and 30/70 %

In figure 8 a comparison is shown of the currents in Ar/CO_2 at 70/30 %, 50/50 % and at 30/70 %. Therefore the currents at 50/50 % are shifted back with 0.2 kV because the 50/50 mixture has the same gas gain at 0.2kV higher values and in 30/70 % the currents are back shifted by 0.4 kV w.r.t. 70/30%. Now it follows that the proportional parts coincide. The region of non proportionality for the 50/50 mixture is bigger than for the 70/30 mixture. The current dependence is described by an exponential law and can be qualified as a transition region where the proportional and streamer mode coexist. For 30/70 mixture there are three regions visible all three nicely exponential. The lower region with the proportional pulses coincides with the lines for 70/30 and 50/50. The middle region seems to be a transition region from one pulse type to another type of pulse and the third region has the same slope as the proportional region but this region is the region of streamer pulses.

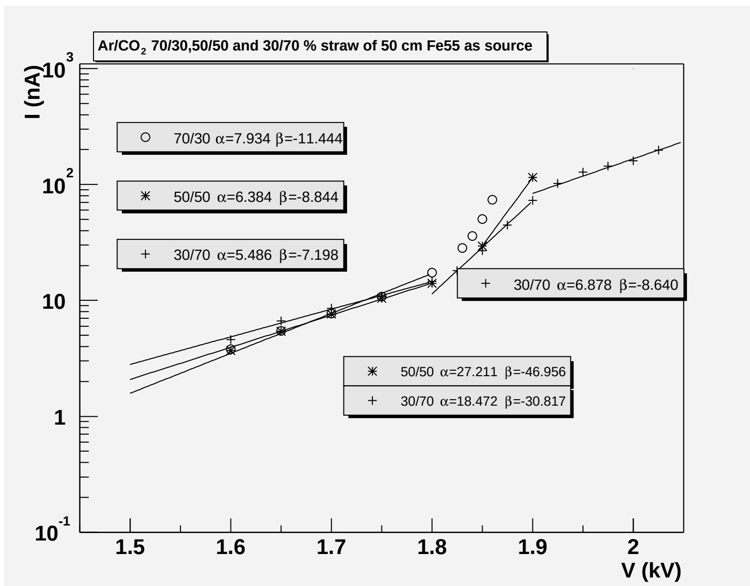

Figure 8: Comparison of currents for a straw of 50 cm length for Ar/CO_2 70/30 % and 50/50 % and 30/70% irradiated by a Fe55 source The lines are parametrized as $I = e^{\alpha V+\beta}$

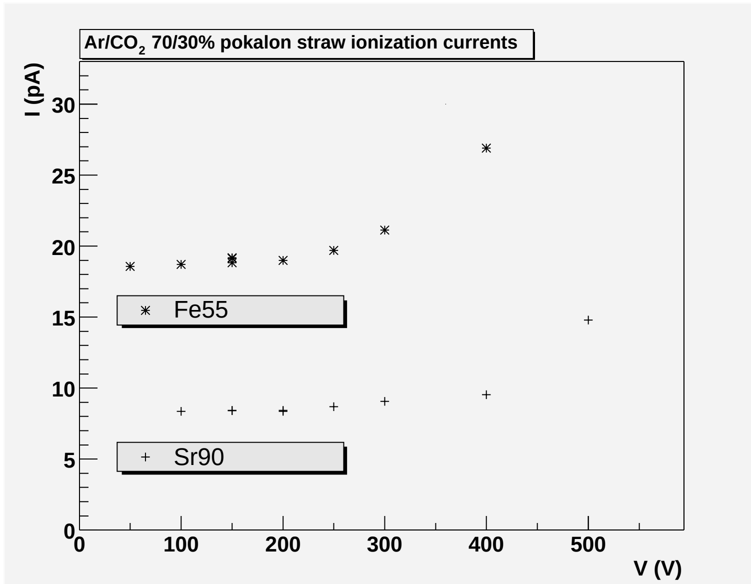

Figure 9: Ionization currents for the pokalon straw

3.2 Measurement of the gas gain in the 70/30 mixture

The gas gain was obtained as the ratio of the current with gain over the ionization current . The measurements were done with a pokalon straw with a diameter of 16 mm and a length of 10 cm. The anode wire was the same as those of the outer tracker. The electric field on the surface of the anode wire will determine the gain. The irradiations were done with Fe55 and Sr90 sources. The ionization currents were $19 \pm 0.1pA$ for the Fe55 source and $8.4 \pm 0.1pA$ for Sr90. These tiny currents were measured with a Keithly 485 picoammeter between the cathode and ground.In figure 9 the I-V plot is shown where a plateau is clearly visible.

The gain dependence on the high voltage is displayed in figure 10 . The gain for Sr90 was approximated by $e^{\alpha.V+\beta}$ with $\alpha = 10.48$ and $\beta = -5.33$ in the high voltage region of 1 - 1.65 kV. At 1.7 kV this gain is 7% less than the exponential line and at 1.8 kV 20% less.These deviations are probably due to underestimation of space charge in the thick pokalon counter. For Fe55 the gain goes already down at 1.5 kV mostly due to high ionization density. The photon feedback is less pronounced due to the bigger optical way of the photon to the cathode.

For a straw of 5mm diameter the ionization current is about 10 times

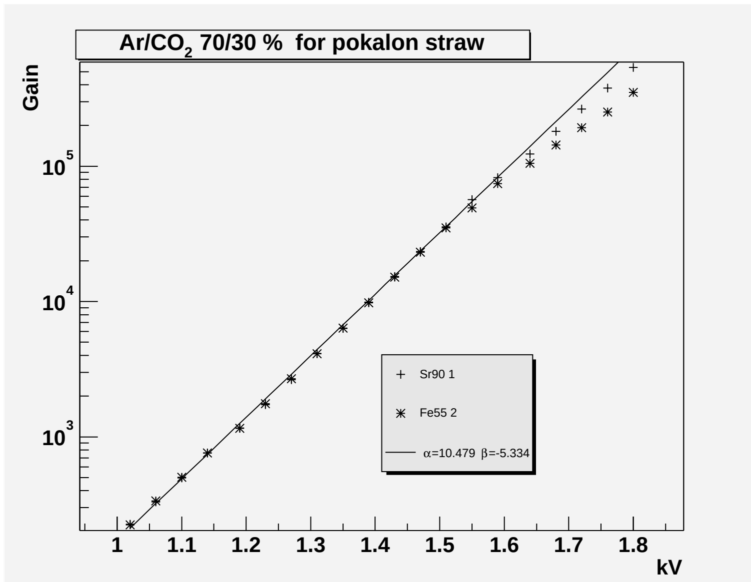

Figure 10: Gain for Sr90 and Fe55 Ar/CO_2 70/30 % measured in the pokalon straw and rescaled to the 5 mm straw

HV (kV)	G	G from [11]
1.45	18500	20300
1.5	31200	36800
1.55	52400	54900
1.6	88200	83600
1.65	150000	118000
1.7	250000	
1.75	420000	

Table 2: The gas gain for Ar/CO_2 70/30 %

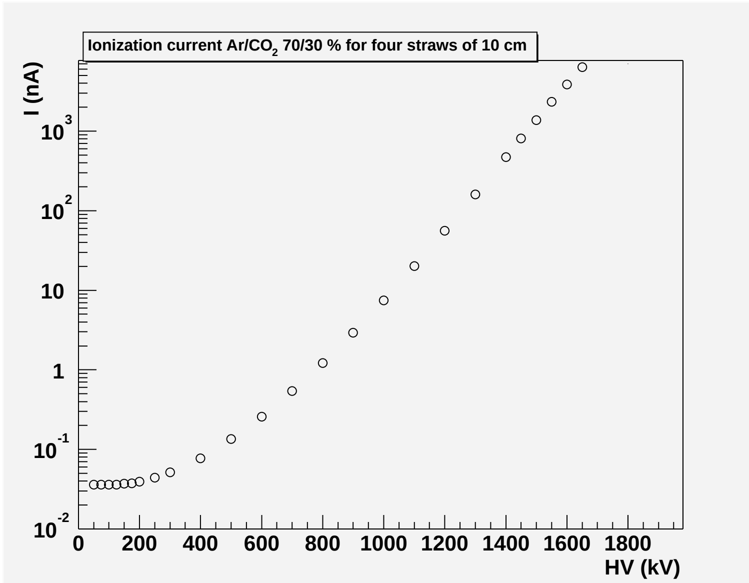

Figure 11: Gain for Sr90 Ar/CO_2 70/30 % measured in four straws of 10 cm length

smaller and could practically not be measured using one straw. Therefore the gas gain was measured with a set of 4 straws with a length of 10 cm. When irradiating these 4 straws with a 2 mCu Sr90 source one gets a ionization current of 36 pA which is hardly measurable with the Keithly picoammeter. These currents are displayed in figure 11.

From this curve the gains can be calculated and are given in table 3. The errors in this table are obtained by measuring the currents 10 times and calculating the average and the root mean square value as error.

4 Results

4.1 Pulse height measurements

4.1.1 Pulse heights for Ar/CO_2 70/30 %

In figure 12 pulse heights are plotted at various HV values from 1550 to 1830V for Ar/CO_2 70/30 % . The highest value is just below breakdown. The lowest value is chosen as the value where the amplifier system works with a good signal to noise ratio. At lower values of the high voltage the signals disappear in the noise. In this figure a nice escape peak is visible at

HV (kV)	G	dG
1.	207	0.3
1.1	559	1.1
1.2	1544	2.6
1.3	4419	8.3
1.4	12999	27
1.45	22358	32
1.5	38141	70
1.55	64605	131
1.6	106685	191
1.65	175700	276

Table 3: The gas gain for Ar/CO_2 70/30 %

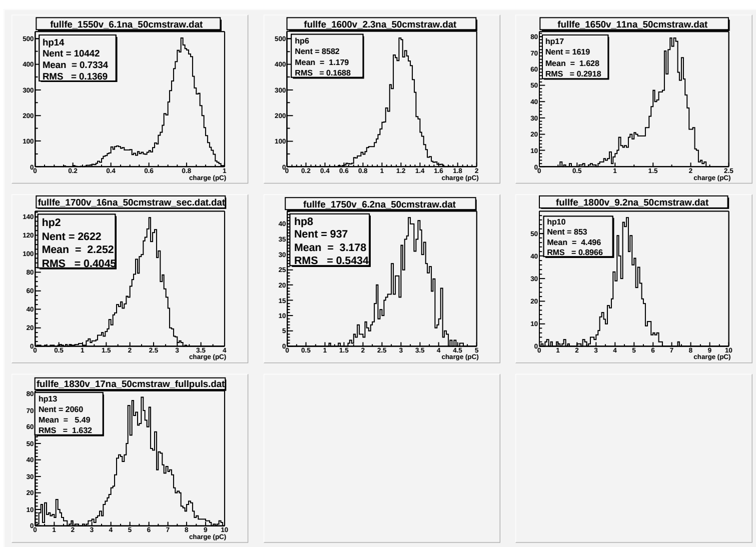

Figure 12: Pulse heights in pC at Ar/CO_2 70/30 % for the 1m straw module

1550V but already at 1600V the escape peak is much less pronounced. At higher values of the high voltage the escape is hardly visible as a shoulder. At the value where the escape disappears the gain of Fe55 drops a bit below the exponential expectation(see figure 6). This phenomenon is also seen when using for example the charge amplifier VV50 borrowed from the university of Heidelberg but in this case one can say that the deterioration of the pulse height distribution is due to amplifier characteristics like saturation of the output. Our setup does not suffer from amplifier characteristics in that sense.

In figure 13 two plots of averaged pulses are shown first normalized to one, then the time at half pulse height is shifted to the same position and then averaged. Now one can see how equal all the Fe55 pulses are. The size of the error bars in the vertical direction is the root mean square value of the pulse height. From this picture one learns that the form of the pulses in the escape peak is the same as the form in the main peak. Around 40 ns one sees a very faint second peak as a shoulder.

From the measurements with Fe55 one can in principle calculate the gain by integrating over the seen pulse. When you calculate then the gain , it is a factor of 2.8 to small compared to what it should really be. When looking to the individual pulses one knows that there is an ion tail that is very long. When one does a fit to the tail of $a + \frac{b}{t}$, one can calculate the contribution of the ion tail to be equal to $b.ln(\frac{t_{ion}}{\Delta t})$ where t_{ion} is the time the ions need to reach the cathode and Δt is the measurement window (for example 200 ns in this case) . In our measurements one found as acceptable values for t_{ion} 10000 to 60000ns. Because of the logarithm it is difficult to determine this value very precise. Extending the window of the scope to higher values of the time , it is very difficult to see the long ion tail. But if one realizes that this ion tail is so long, one can see the effect of it when a few thousand of them add up in case of a high occupancy in the straw.

In figure 15 the development of the signal shape as a function of high voltage is shown. One sees that the shoulder from figure 13 is clearly developing to a second peak and even a third one.The origin of these peaks is clearly understood as caused by a photons of the avalanche hitting the cathode and freeing electrons that again goes to the anode wire. This phenomenon is known as photon feedback.

The appearance of the photon feedback is a sign that one of the self quenching streamer mode conditions is fulfilled, the presence of a cloud of charged particles with high charge density. In this cloud the applied electric field is partly canceled [4], the electrons are cooled and radiative recombination may occur [5] of Ar ions and electrons. But due to the low photon

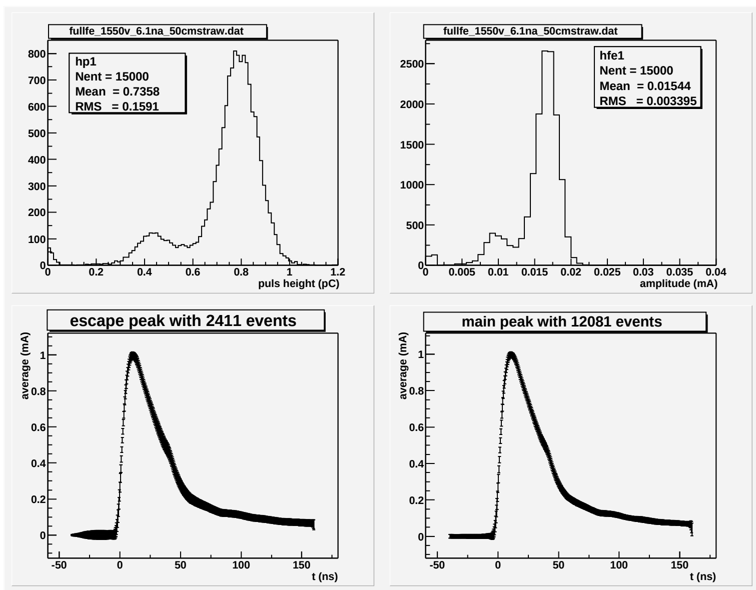

Figure 13: Pulse height distributions for Fe5555 at 1550V in a 50cm straw for Ar/CO_2 70/30 % and the respective averages of the normalized signals in the escape region and the main peak region

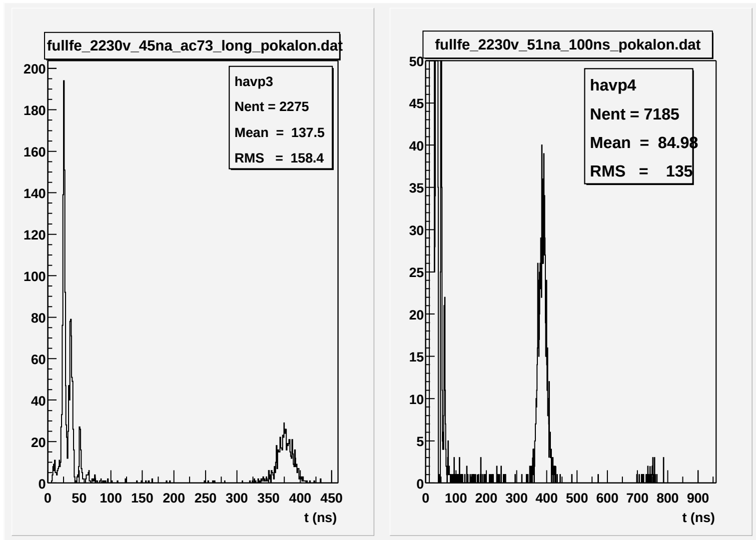

Figure 14: Time distribution of optical feedback signals in a pokalon straw of 16mm diameter for Ar/CO_2 70/30 %

absorption photons can reach the cathode to produce electrons drifting to the anode in 45 ns. A new avalanche is now produced by these electrons somewhere near the original. In Geiger Muller mode it occurs that avalanches propagate along the anode wire. When this happens , the proportional mode is transformed into the Geiger Muller mode. This mode has a range of 40-50 V and changes very fast into breakdown. The occurrence of photon feedback at low values of the high voltage means that CO_2 is a bad quencher as already known for a long time. As a check these measurements are also repeated in a pokalon straw with a diameter of 16mm. Here the second peak occurs at 375ns , equal to the drift time of electrons. As in figure 14 is shown even a small third peak at 750 ns is visible. Photon feedback can be seen very nicely when one switches off the CO_2. After some time more and more equidistant pulses will be seen after the main avalanche.

4.1.2 Pulse heights for Ar/CO_2 50/50 %

In figure 16 one sees the pulse height distributions given as a function of the value of the high voltage from 1900 to 2120V. When going to higher values of the high voltage one sees that the structure of the pulse height distributions is changing. A second peak emerges from the data.

In figure 17 the signals and the pulse height distributions are displayed.

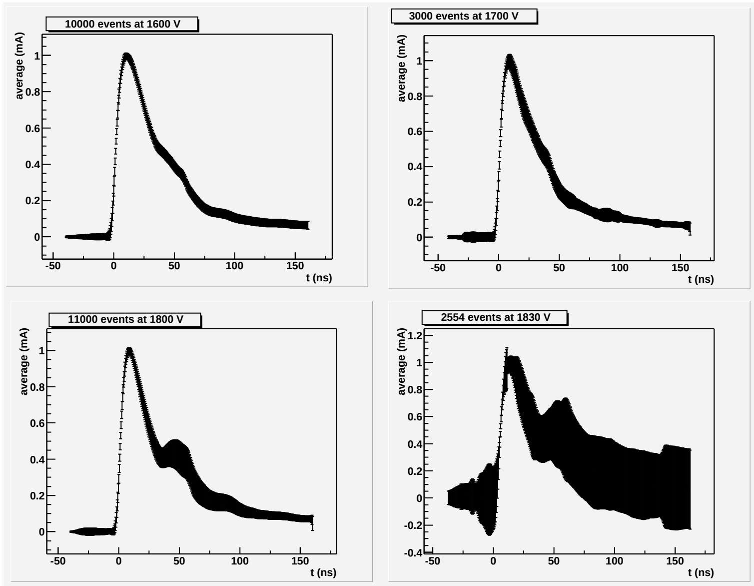

Figure 15: Normalized and averaged signals at various high voltages for Ar/CO_2 70/30 %

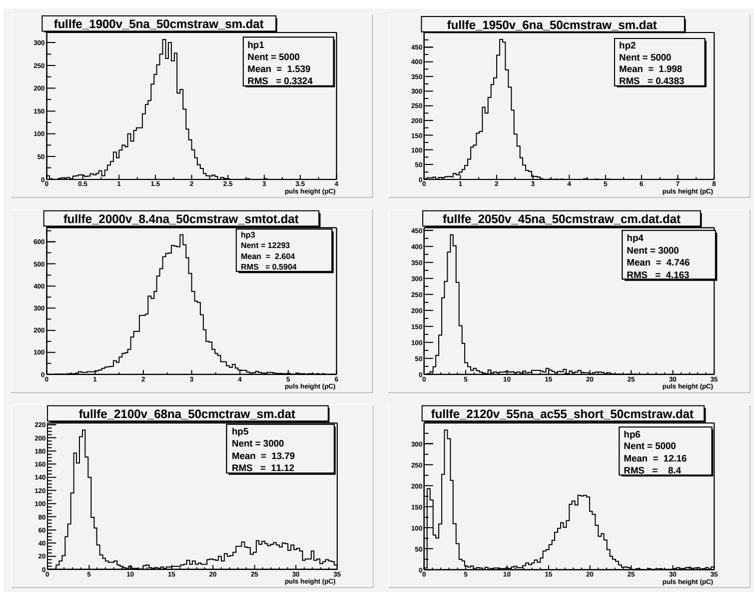

Figure 16: Pulse height distributions for Ar/CO_2 50/50 % at various values of the high voltage

In the pulse height distribution one sees a second peak coming up at high voltages . This peak is not present at lower voltages. When one looks at the signals in both regions, one sees that the pulse shapes in both regions are very different. In the region below 0.1 mA pulse height one sees a typical proportional signal followed by a lot of after pulsing. At values of the pulse height above 0.2 mA one sees a different pulse where the rise time is rather equal and not limited by the amplifier and no after pulsing. Only the tails have a bit of fluctuations.

These pulses have a charge of 10^8 to $1.4.10^8$ electrons so typically corresponding to the size of a self quenching streamer. These numbers are in good agreement with the charge density for the development of a streamer mode [7]. Up till now this mode was only seen at wire thicknesses of 50 μm. From [8] it was shown that this type of pulse appears only for wires with a thickness above 40μm and disappears for thinner wires. In the case of thin wires the avalanche may be rolling around the wire [9] and shielding a substantial fraction of positive ions from each other. This affects the space charge saturation requiring a higher field for space charge to grow farther to make recombination possible. In [10] the transition to streamer mode in 50/50 mixtures was observed in a straw tube of 10mm diameter with an anode wire of 50μm at 2.45 kV. This corresponds to an electric field of 185 kV/cm . In our case the SQS mode was reached for the 50/50 mixture at a voltage of 2.1 kV corresponding to an electric field of 320kV/cm. At thicker wires a smaller electric field does the transition to take place.

When one irradiates the straw with a Sr90 source (see for example figure 20), the second streamer peak will be hardly present. So it happens only if the charge density is high enough as is the case for Fe55 .

4.1.3 Pulse heights for Ar/CO_2 30/70 %

In figure 18 the signal development for Ar/CO_2 30/70 % is displayed for irradiation with a Fe55 source. At low voltages one sees only the proportional signals and at high values one observes the development of a second peak. Also in the case of this second peak the signals are different in form as in the case of ArCO_2 50/50% . The second peak can be identified as the self quenching streamer mode. The signal shapes are shown in figure 19. One sees the same behaviour as at Ar/CO_2 50/50 %. The signals have a charge of $1.4.10^8$ to 2.10^8 electrons typical values for a self quenching streamer. Note the difference between the proportional signals and the sqs signals. When one compares the figures 17 and 19 one sees that the proportional signals are in the case of the 30/70 % mixture more stable, they suffer much

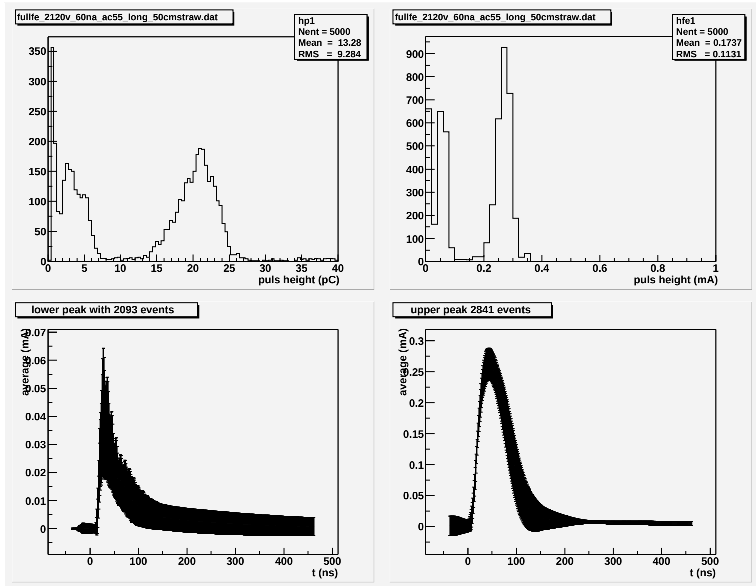

Figure 17: Averaged signals at 2120V for Ar/CO_2 50/50 % and puls height distributions

less from pulses in the tail. When one irradiates with a Sr90 source , the streamer production is much less as displayed in figure 20 meaning that the charge density is mainly too small to make them.

5 Pressure dependence of currents in Ar/CO_2 70/30 %

The little straw of 7 cm long was placed in a pressure tank with a window for irradiation. The pressure was varied between atmospheric pressure and 90 mbar above it. The currents were recorded between the cathode and earth. The pressure in the volume was recorded with a absolute pressure meter with an absolute precision of 0.5 mbar. The value of the pressure was regulated by letting bubbling the gas through a colomn of water or continuously by restricting the out flow of the gas. In figure 21 the dependence of the current as a function of pressure is plotted when irradiated with a Sr90 source. In these measurements the continuous gas flow method was used. The line fitted through the points is parametrized as

$$I = A.p^{-k}$$

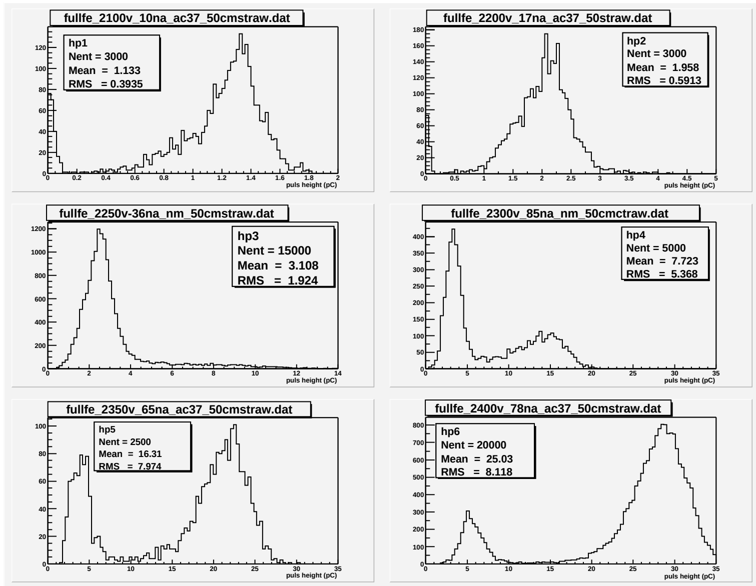

Figure 18: Pulse height distributions as a function of the high voltage for Ar/CO_2 30/70 %

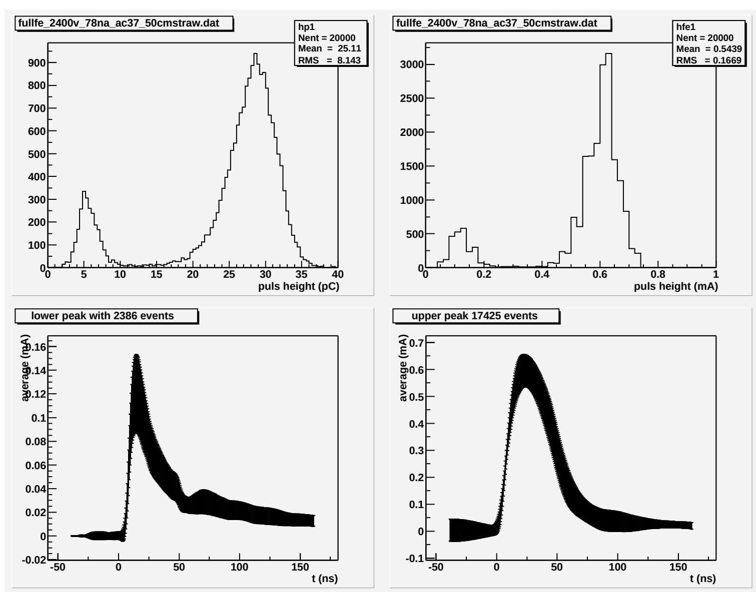

Figure 19: Pulse height distributions and averaged pulse shapes for Ar/CO_2 30/70 % at 2400V with Fe55 irradiation

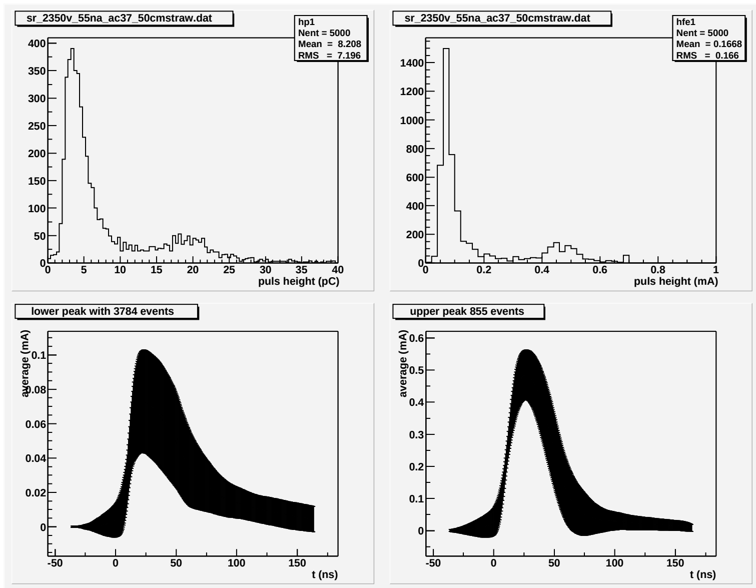

Figure 20: Pulse height distributions and pulse shapes for Ar/CO_2 30/70 % at 2350V with a Sr90 irradiation

where I is the current in nA and p is the pressure in bar. When one looks at the figures one sees actual two lines , one when the pressure is going up and one when the pressure is going down. At pressures just above the atmospheric pressure sometimes the current goes first upward and then downward. This phenomenon can be called hysteresis. This hysteresis seems not to be a consequence of the way one measures the current or the pressure. The current can be systematically wrong due to the delay between the current and the pressure measurement of 4 sec . This gives in the current an systematic error of less than 0.3 nA . The current is measured before and after the pressure measurement and then plotted as an average value of the two. This reduces the chance of this systematics but still one sees the hysteresis mainly in the region just above the atmospheric pressure.

In figure 22 one sees the pressure dependence for a Fe55 source. The pressure is here made with a colomn of water. Therefore there can be pressure jumps in the gas volume because of the irregular bubbling. But in the region where the hysteresis is the biggest, the bubbling is more regular. Here the phenomenon of hysteresis is more pronounced present. In the points of this figure it is tried to correct for it, but it had only a minor effect. As an illustration of what is going on , figure 23 is added. In figure 23 plots

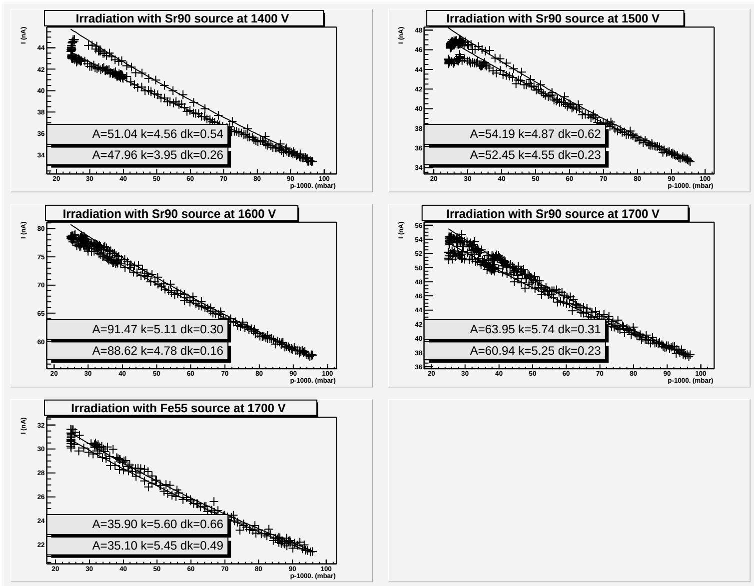

Figure 21: Current as a function of pressure for Ar/CO_2 70/30 % with Sr90 and Fe55 irradiation

are shown of p versus time and current versus time. From this figure one sees that at low pressures it happens regularly that the current goes in the wrong direction . One cannot explain this effect by assuming that it happens because the current is measured not at the same time as the pressure. This is visible when one looks at the raw data and the corrected data.

In figure 24 the dependence of k on high voltage is given for Fe55 and Sr90. It is seen that the dependences of k on the high voltage are completely different for Sr90 and Fe55. The dependence of k for Sr90 on high voltage is according to the predictions of the Diethorn formula in ref [12]. For Fe55 the k goes down when the high voltage goes up.

6 Influence of earthing on the performance of a module

The question was posed what would happen to the current in a straw when the earth connection is interrupted? In this section a little experiment is done to illustrate this. The 1m module was used for this purpose. The module is irradiated with a Fe55 source and the current is measured versus the time.In picture 25 one sees the effect of various actions . When one sees a current

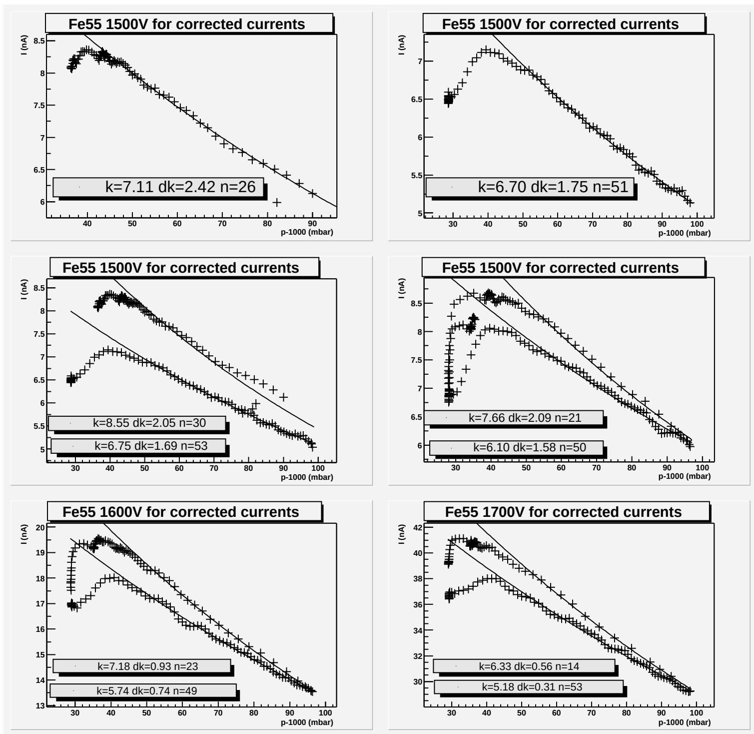

Figure 22: Current as a function of pressure for Ar/CO_2 70/30 % with Fe55 irradiation

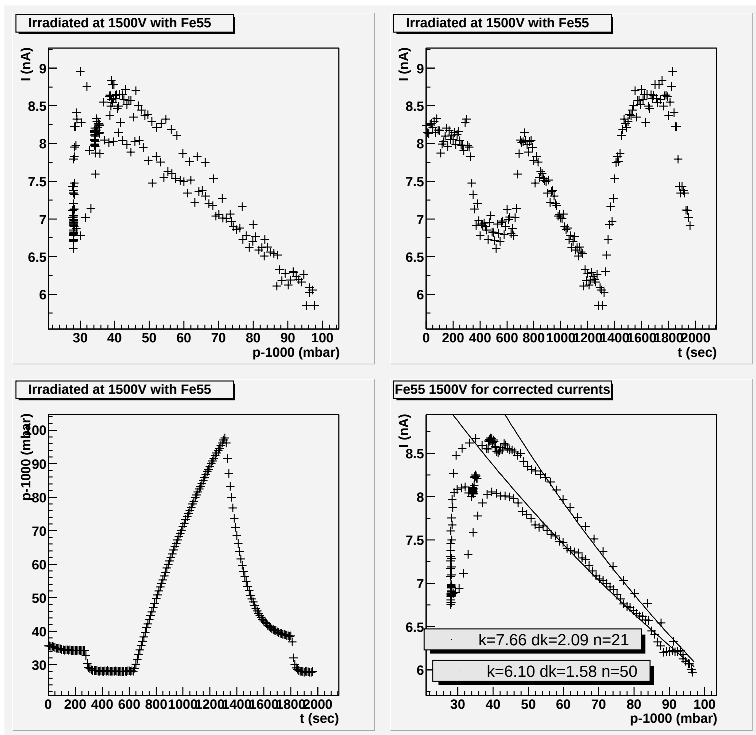

Figure 23: Current as a function of pressure and time for Ar/CO_2 70/30 % with Fe55 irradiation at 1500V to show the problem of the measurement

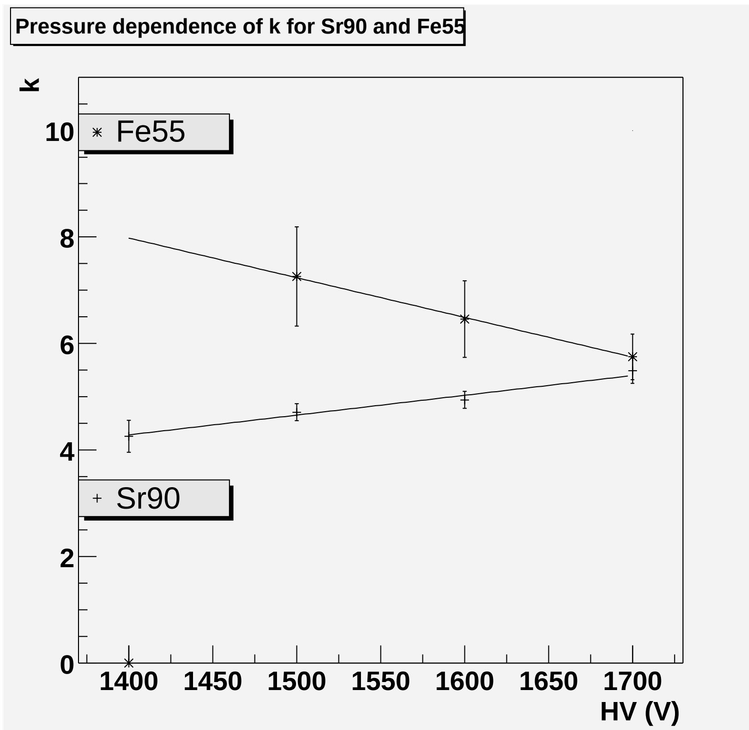

Figure 24: k as a function of high voltage for Ar/CO_2 70/30 % with Fe55 and Sr90 irradiation

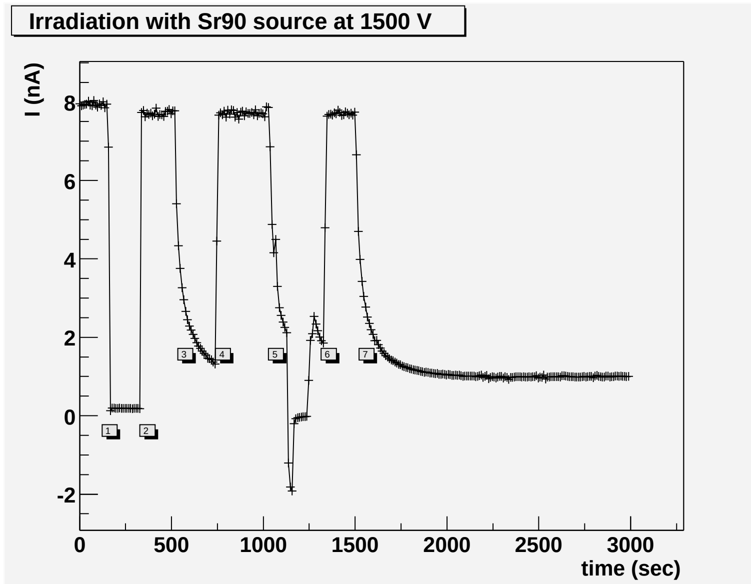

Figure 25: The current as a function of time for Ar/CO_2 70/30 % at 1500V with a Sr90 irradiation. The numbers refer in the text to the the different actions done on the grounding

high voltage is on and the source is on.

1. *In this point the current drops to zero because the source was removed.*
2. *The source was put back on the straw.*
3. *The ground connection was interrupted.*
4. *The ground connection was again restored.*
5. *The ground was interrupted and the high voltage was switched off, one sees the current changing direction.*
6. *Then the ground was restored and the high voltage was switched on.*
7. *Finally the ground was interrupted for a longer time*

From this one concludes that interrupting the ground does stop all currents and causes no harm to the straw or module whatever conditions there are.

7 Conclusions

1. The old straw type (double kapton-XC) and the new straw type (kapton-XC,kapton,Al) behave identical.

2. If cathode is not grounded , there are no currents visible.

3. Only for Fe55 irradiation the gas mixture of Ar/CO_2 70/30% shows optical feedback pulses meaning that the CO_2 is a bad quencher. The other mixtures show also photon feedback but the more CO_2 the less feedback. An advice would be to admixture another polyatomic gas for example a few pro cent of CH_4 or CF_4.

4. The escape peak deteriorates at higher voltages because the gain of the main peak goes down.

5. In the case of 50% or more CO_2 sqs mechanism turns on when irradiated with Fe55 but not with Sr90 at higher voltages. This effect typically depends on the charge density in the primary clusters. This is not seen in the mixture with 30% CO_2.

6. When measuring the gain with an Fe55 source, at higher voltages the gain may be underestimated by the high primary ionization density. This effect is a bit dependent on the geometry of the detector.

7. The hysteresis of the perssure dependence is regarded by the authors of this note as very suspicious. More experiments should be done to find out what is the exact cause of this phenomenon.

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