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Performances of keystone geometry micro-strip gas chambers

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Abstract

The performances of micro-strip gas chamber detectors with CF_4 counting gas have been tested with a ^{241}Am α source. The behaviour of the gain as a function of gas pressure, the dependence of the energy resolution on gas pressure and anode voltage, and the gain variation along the strip length due to the keystone geometry of the micro-strip pads are reported. An empirical response function to describe such a position dependence of the gain is proposed.

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1. Introduction

One of the most challenging performances required for a detecting system for studies on nuclear reaction mechanisms with heavy ions is the capability to identify the charge (and/or mass) of a large variety of reaction products (from proton to heavy fragments) and to measure their energies. The use of gas detectors in nuclear physics is of great importance to somehow fulfil these requirements on a large dynamical range, i.e. the possibility of selecting the required effective thickness (not often reachable with other detectors) only varying the pressure allows to choose the best compromise between low identification thresholds and large mass range. On the other hand, the recent construction of more complex set-ups determines requests even more stringent on energy thresholds, especially in low- and intermediate-energy heavy ion reactions.

In the last few years, a new possibility arose from the advent of micro-strip gas chambers (MSGCs), initially developed to meet the severe counting rate, high gain and position resolution requirements of high energy physics experiments [1]. The $\Delta E-E$ technique using MSGCs in connection with plastic scintillators [2] or CsI(Tl) crystals [3] was also successfully used for heavy ion identification. The advantages in using micro-strip gas chambers are mainly due, on the one hand , to

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the signal-to-noise ratio for low ionizing particles, which is much higher as compared to ionization chambers, so that even protons and α particles can be easily identified and, on the other hand, to the large dynamical range. These two characteristics allow the simultaneous identification, with only a two-stage telescope, of both light charged particles and heavy ions with low energy thresholds.

In this paper, we characterize the MSGCs used in the GARFIELD apparatus [4] by studying their gain with increasing gas pressure in the 40–100 mbar range, their energy resolution and the gain variation along the strip length. The employed MSGCs have keystone geometry, designed to form a circular crown layer in the GARFIELD apparatus; non-uniformity in the gain of keystone geometry MSGC [5] is not a new problem, but up to now it has not been examined thoroughly. Here, we present the gain trend along the strips and an empirical response function, which is in good agreement with the data. This function, when we deal with the point response of the pad, allows to correct the data for the gain non-uniformity.

2. Experimental

Two types of micro-strip plates, shown in Fig. 1, have been used: one with 2 μm thick chromium strips (purchased from IMT[1]) and the other with 1 μm thick aluminium strips (purchased from SRON[2]), both deposited on a Desag D263 glass substrate. Each plate is divided into an upper part and a lower part. In both parts, the anode strips, 35 mm long and 10 μm wide, are connected—and hence biased—together in two groups (right and left halves), thus providing a total of four anodic signals from each plate. The anode–cathode distance is 50 μm and the width of the cathodes increases gradually from 85 to 190 μm (zones 1 and 2) and from 85 to 140 μm (3 and 4). All the cathode strips are connected together and grounded.

[1] IMT Masken und Teilunger AG, Langacher, CH-8606 Greifensee.

[2] SRON-UTRECHT, Sorbonnelaan 2, 3584 CA, Utrecht.

The experimental set-up is sketched in Fig. 2. The tests were performed in a gas tight chamber with a collimated α source (^{241}Am, $E_\alpha = 5478.7$ keV) positioned on a plane perpendicular to the micro-strip pad so that the α particle tracks were parallel to the strips. A silicon surface barrier detector was placed in front of the source, giving the trigger signal for the data acquisition system; a collimator in front of the silicon detector assured that only the α particles emitted within a 15° angle, equal to the strip divergence, would start the trigger signal. The micro-strip was equipped with a

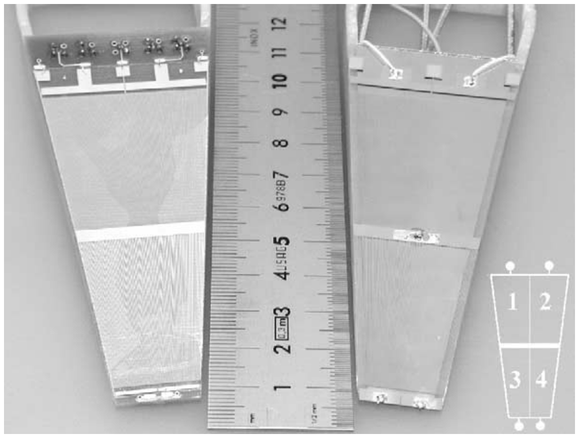

Fig. 1. Picture of the keystone geometry micro-strip pads used for the measurements: on the left an SRON micro-strip, on the right an IMT micro-strip. The dimensions are in centimetres. In the schematic drawing of a micro-strip pad on the bottom right corner of the picture, the labels 1–4 refer to the four distinct zones in which our pads are divided (see text for details), while the white circles represent the positions of the collecting anode electrodes.

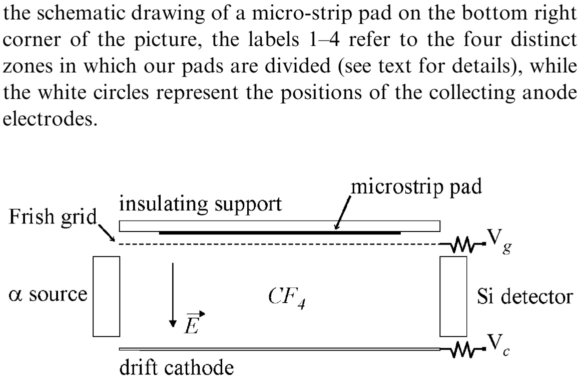

Fig. 2. Schematic overview of the experimental set-up. The distance between the drift cathode and the Frisch grid is 4 cm; the distance between the grid and the micro-strip pad is about 0.4 cm. The strips and the α particle tracks run parallel to the paper.

Frisch grid (95% geometric transparency), and the drift cathode–grid distance was 4 cm, while the grid–micro-strip distance was about 4 mm.

The counting gas used for the tests was CF_4 in the pressure range 40–100 mbar. This gas is frequently used in nuclear physics because of its high stopping power and high electron drift velocity, very useful in timing measurements [6]. The gain values attainable with CF_4 are not very high [7]; however, they are sufficient for the experiments here of interest because of the strong ionization of the expected reaction products. The gas was made to flow continuously (1 std l/min) to avoid contaminations, which could influence the results. The reduced drift electric field was 1 V/cm Torr in order to maximize the electron drift velocity to about 10 cm/μs. Preliminary measurements showed that the highest signals were attained with an electric field, in the multiplication region between the Frisch grid and the micro-strip, equal to three times the drift electric field and with a distance between the grid and the micro-strip of about 4 mm. These parameters, experimentally optimized, were kept constant in all the following measurements. At a gas pressure of 70 mbar this implies a drift cathode bias $V_c = -280$ V and a grid bias $V_g = -60$ V.

A standard nuclear electronic chain acquired the signals.

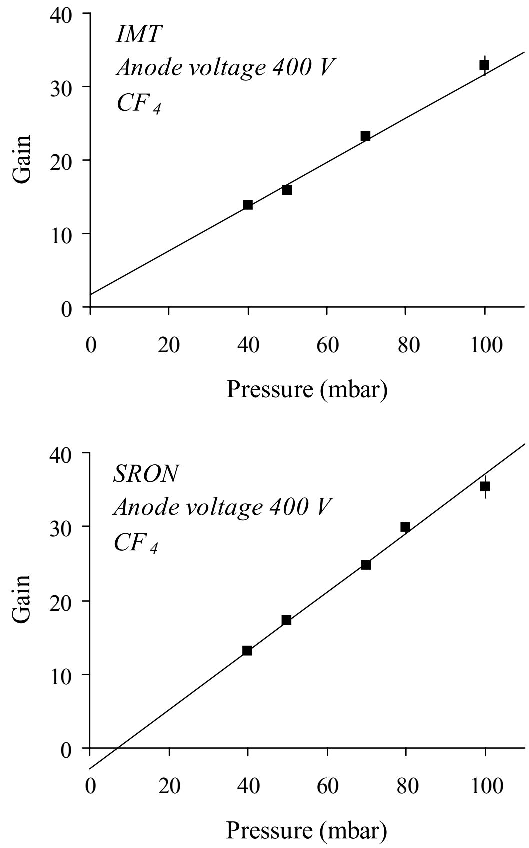

Fig. 3. Gain as a function of CF_4 pressure. The full line is the result of a linear fit to the data, $G = a + b\,P$ with parameters $a = 1.7 \pm 1.0$ and $b = (0.30 \pm 0.02)$ mbar^{-1} for IMT micro-strip and $a = -2.9 \pm 0.9$ and $b = (0.40 \pm 0.02)$ mbar^{-1} for SRON micro-strip.

3. Results

We have already mentioned the fact that the main advantage of gas detectors is the possibility of changing the effective thickness (hence the identification thresholds) by varying the gas pressure. Thus, we studied the gain dependence of the micro-strip pad—with fixed anode voltage (400 V)—on the gas pressure, in the range 40–100 mbar. As already pointed out in previous works [7,8], the results, reported in Fig. 3, show that, in this range, the gain increases linearly with the pressure. The gain is calculated here as the ratio between the signals obtained at 400 and 10 V anode bias voltages. We have verified that at 10 V micro-strip anodes only collect electrons created by primary ionization, i.e. without multiplication. Obviously the knowledge of the dependence of the gain on the gas pressure is very important when we have to change pressure for experimental reasons (different pressures are needed, for example, depending on beam energy and on projectile/target mass).

In Figs. 4 and 5, we show the measured energy resolution of the MSGCs. These detectors present an energy resolution better than that of other gas chambers, mainly due to the better anode spatial uniformity and to the reduced volume of the avalanche, which is of the same order of the anode–cathode distance [9]. As we can see in the figure, with the parameters used in the GARFIELD experiment (usually 400 V anode voltage

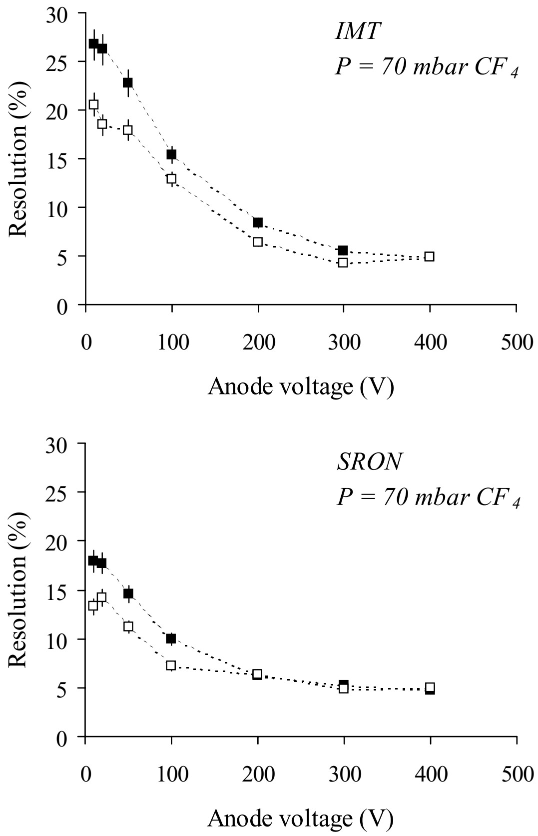

Fig. 4. Energy resolution is shown as a function of the anode voltage for an energy loss of the ^{241}Am α particles in the gas of about 730 keV. Filled squares represent the mean value of large micro-strips, while open squares represent the mean value of small micro-strips. The dashed lines are drawn as a guide to the eye.

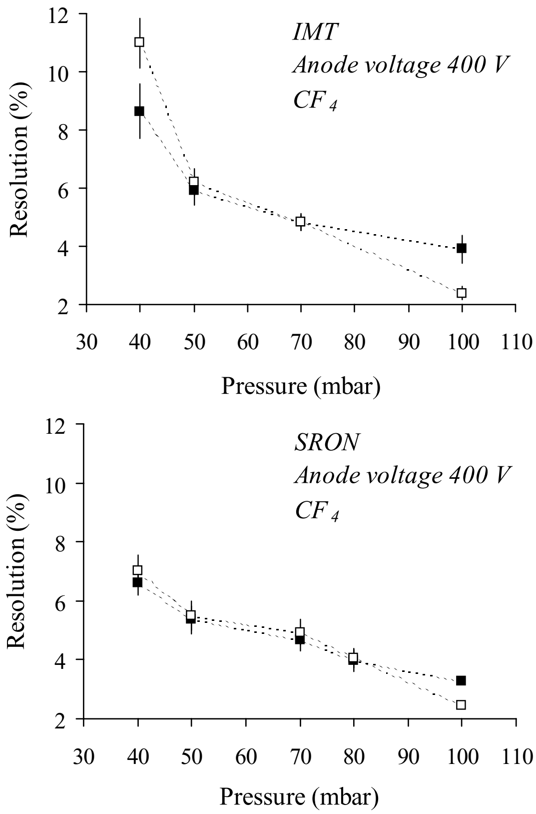

Fig. 5. Energy resolution as a function of CF_4 pressure for the ^{241}Am α particles. Filled squares represent the mean value of large micro-strips, while open squares represent the mean value of small micro-strips. The dashed lines are drawn as a guide to the eye.

and 70 mbar CF_4 pressure, giving an energy loss for 5.48 MeV α particles of about 730 keV along each micro-strip zone length), the intrinsic energy resolution of the detector is about 5% (FWHM). The worsening effect due to the energy straggling of α particles in the gas has been taken into account using the Bohr straggling formula corrected for large fractional energy losses (greater than 10% of the initial energy) [10]. The angular straggling, due to the multiple scattering of α particles in the gas and the acceptance angle of the silicon trigger detector, contributes to less than 1%. The results on straggling are in agreement with the TRIM Monte Carlo calculations [11].

Due to the particular trapezoidal geometry of anodes and cathodes of the pad and prompted by partial results already presented by other authors [5,12], we studied the dependence of the signals of our detector on the collection point of ionization electrons. For this reason, we carried out measurements by ‘‘masking’’ the active area of the micro-strip except for a window of 4 mm length along the strip direction, corresponding to an energy loss, for the 5.48 MeV α particles, of about 90 keV at 70 mbar CF_4 pressure.

Moving the mask along the micro-strip, in each measure we can test the different points of the strip in the four zones. Note that these zones are indeed similar two by two so, in the following, we will call the zones 1 and 2 "large micro-strips" and the zones 3 and 4 "small micro-strips" (see Fig. 1 for reference). In this way, point responses of the micro-strip pads were obtained. The results are shown in Fig. 6.

Note that the gain is not uniform along the strips and that there are different trends for small and large micro-strips. We think that this is due to the interplay of two effects, which contribute differently in small and large micro-strips. As reported in Ref. [12], the gain of an MSGC depends exponentially on the cathode width and in our pad the cathodes have indeed a variable width; this effect contributes in the same way in small and large micro-strips (the difference between the final strip width in small and large micro-strips is negligible). The second contribution is to be ascribed to the finite electrical resistivity of the strips. For this reason, the signal decreases when the electron collection point or the radiation incidence position is far from the signal collection point [13,14]. This effect contributes in a different way in small and large micro-strips, because the former collects the signal, where cathodes are narrower and the latter where cathodes are wider. Obviously, these two effects contribute in the same way in large micro-strips and in the opposite way in small ones, determining the different trends shown in the figure.

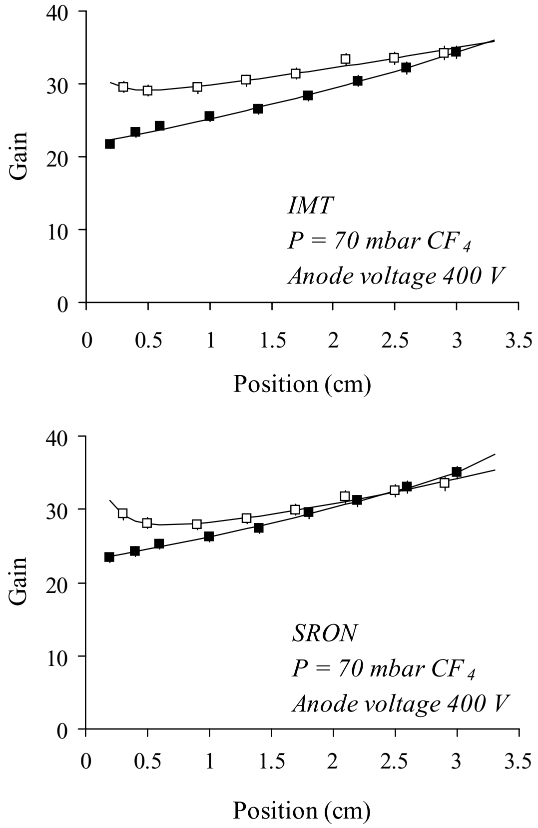

Fig. 6. Gain as a function of ionization electron collection position along the strip length. Filled squares represent the mean value of large micro-strips, while open squares represent the mean value of small micro-strips. The full lines are fits to the data, according to the parameters of the point response function shown in Table 1.

Moreover, we found a function to fit the data on the gain taking into account these two effects; its expression is

$$G(x) = a_1 e^{a_2 x} + \frac{a_3}{l - x}$$

for large micro-strips and

$$G(x) = a_1 e^{a_2 x} + \frac{a_3}{x}$$

for small micro-strips. Here, x represents the position along the strips and varies from 0 to 3.5 cm ($x = 0$ where cathodes are narrower), l is the total strip length (3.5 cm) and a_1, a_2 and a_3 are parameters to be determined by the fit. The results are shown in Table 1. The parameters for the two kinds of micro-strips are quite similar, showing that the actual behaviour of the detectors is mainly due to the geometry rather than the deposited material.

Table 1
Fit parameters of the point response function for the two distinct zones of both types of micro-strip pads and strip material[a]

	a_1	a_2	a_3
IMT micro-strip			
Large	21.6 (0.6)	0.15 (0.03)	0.05 (2.0)
Small	26.9 (2.0)	0.09 (0.03)	0.6 (0.8)
SRON micro-strip			
Large	22.8 (0.6)	0.14 (0.03)	0.3 (2.0)
Small	24.1 (1.8)	0.11 (0.03)	1.3 (0.7)

[a] The absolute errors on the parameters are shown in parentheses.

Table 2
Comparison between the measured total gain (see Fig. 3) and the total gain obtained averaging out the data shown in Fig. 6 for the two distinct zones of both types of micro-strip pads[a]

	Measured gain	Calculated gain
IMT micro-strip		
Large	23.1 (1.4)	27.4 (0.7)
Small	23.1 (1.4)	31.4 (0.8)
SRON micro-strip		
Large	24.8 (1.7)	28.3 (0.7)
Small	24.8 (1.7)	30.2 (0.8)

[a] All the data refer to measurements done with 70 mbar CF_4 pressure. The absolute errors are shown in parentheses.

If we average out the data of the point response function for each micro-strip zone, then we should obtain the experimental gain from the whole micro-strip, as shown in Table 2. The good agreement between the two values makes us confident in being able to correct experimental data for the non-uniformity response.

Note that the dependence of the gain from the position is not in contradiction with the measured good resolution of the detector. In fact, the resolution measurements were carried out with the α particle tracks that are parallel to the strips, while the effects of the position dependence of gain on the resolution of the detector would arise only if the α particle tracks were perpendicular to the strips. In the latter way, the gain would change depending on whether the track is close to or far from the collecting anode, resulting in more spread electric signals from the detector.

4. Conclusions

In this paper, we discuss the performances of MSGC detectors working in CF_4 gas in the range of pressure of 40–100 mbar, conditions suited to the use of MSGCs in heavy ion nuclear physics as the first stage of a telescope, coupled to residue energy detectors. The MSGCs performances seem to be promising. These detectors present a gain varying linearly with the gas pressure in the specified range, thus allowing to easily change the gas pressure whenever necessary.

The good energy resolution (5% at 70 mbar and 400 V biasing voltage for α particle energy loss of about 730 keV) makes MSGCs a good and economic choice to measure, at the same time and in a large dynamic range, both charges and energies of reaction products.

The study of point response of the pads, having constant anode and pitch widths and variable cathode width, shows a change of gain along the strip length. The different point responses for different micro-strip regions could be a problem if we were to use the pad itself as a telescope (small micro-strip as ΔE detector and large micro-strip as residue energy detector). In this case, the residue energy detector signal would also depend on the stopping point of the particle in the gas. The knowledge of the response function of the detector would somehow allow to overcome this limitation if the stopping point can be determined.

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