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Monte Carlo simulation of the microstrip gas counter

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Abstract

A Monte Carlo simulation was written to describe the Microstrip Gas Counter. The simulation describes ionisation, diffusion and gas amplification. Tuning of the Monte Carlo simulation on data from test beam measurements is discussed in detail. The simulation reproduces the performance of the detector as measured in a beam test for perpendicularly incident particles. It was found that the position resolution in current prototypes is dominated by the sampling error introduced because the anode-to-anode distance is larger than the radius of the electron cloud. This can be overcome by simple geometrical changes, leading to a resolution predicted to be of the order of 20 μm.

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1 Introduction

In 1988, a novel ionisation detector was introduced by A. Oed [1], which was later named the Microstrip Gas Counter (MSGC). It is based on the geometry of a Multiwire Proportional Chamber; to achieve a higher granularity than the MWPC can reach, the MSGC has strips etched on an insulating substrate (glass, foil or ceramic), instead of wires strung in a gas volume. The strips are set to negative and positive high voltage, alternatingly, so a very high electric field exists close to the anodes. This causes gas amplification of all electrons drifting into this region. With the strip structure, one can reach an anode-to-anode distance of 100 μm or even less, making the device extremely powerful for charged particle tracking in a high flux environment.

The geometry of the detector is shown in fig. 1. In most prototypes, the cathodes are around 100 μm wide, the anodes about 10 μm, and the pitch (p) 200 μm. The distance between the strip plane and the drift cathode, L, is a few mm. For tracking highly energetic charged particles, one wants to minimise the amount of crossed material and get the optimum position resolution, so the detector should be positioned such that the particles cross the electrode planes perpendicularly ($\theta \approx 0$). (In fact, the resolution will be still better if the particle has a momentum component parallel to the strip direction.)

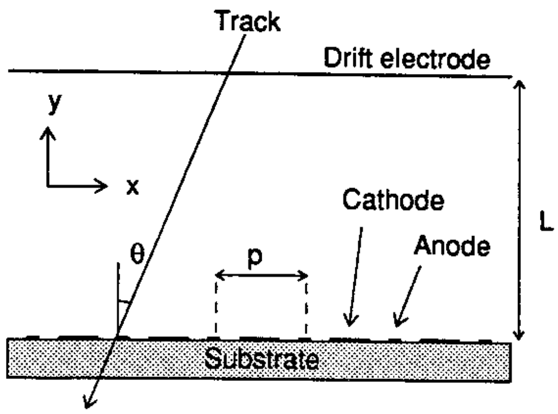

Figure 1: *Geometry of the MSGC.*

Many R&D efforts that started after the Oed paper, proved the MSGC to be very promising for application in high energy physics experiments. Different prototypes showed a good position and energy resolution [2], high rate capability and radiation hardness [3]. Also, a very good homogeneity was achieved over 4"×4" large substrates [4] paving the way towards larger scale applications. Currently, the detector is used in the NA14 experiment [5] and an instrumentation of 16 MSGCs is underway for precision tracking in the SMC experiment [4].

The detector research carried out at NIKHEF was complemented by Monte Carlo studies of the detector behaviour. The Monte Carlo simulation program is presented in section 2 of this paper; it was earlier described in ref. [6]. Section 3 describes the tuning of the simulation, and section 4 gives some predictions on the MSGC position resolution in different geometries.

2 Description of the Monte Carlo simulation

The MSGC is simulated in two dimensions (as in figure 1): the coordinate along the strips is of no relevance as long as the particle moves in the (x, y) plane (unless saturation effects occur in the gas amplification process). A minimum ionising particle traveling through the gas gap causes a number of primary ionisations N_p which is Poisson distributed. Each primary electron (δ-electron) can in turn ionise some more molecules, leading to a total ionisation of N_T electrons, grouped in N_p clusters of electrons.

The clusters are not generated exactly along the track. The δ-electrons are supposed to travel a distance R_p from the ionising track during the secondary ionisation process. R_p, the electron practical range, depends on the initial energy E of the δ-electron, and follows the empirical formula [7]

$$R_p = 0.412E^{1.265-0.0954 lnE} \tag{1}$$

where R_p goes in g/cm^2 and E in MeV. Eq. (1) is valid over three orders of magnitude (E = 10 keV–10 MeV). The use of this equation in the simulation of the MSGC implies an extrapolation in energy down to 1 keV. The δ-electron is emitted randomly in the plane perpendicular to the direction of the incoming relativistic particle [8]. The secondary ionisation is distributed homogeneously along the δ-electron path.

From their starting point, the liberated electrons will drift towards the strip plane, while they undergo a displacement in x because of transverse diffusion. When the electrons reach the quadrupole field (at a height above the strip plane roughly equal to the pitch of the strip pattern) they will be focused towards one of the anodes. This electrostatic focusing makes the probability very low that a drifting electron will diffuse to an adjacent anode. Therefore the diffusion is switched off in this region.

The gas amplification process is parametrised: each electron will give rise to a signal of N electrons, where N is distributed according to the Curran distribution [9]. This distribution appears when one takes $m=\frac{3}{2}$ in the Polya probability function

$$P_m(x) = \frac{m(mx)^{m-1}}{\Gamma(m)} e^{-mx} \tag{2}$$

The mean of this distribution is 1, the variance m^{-1}, yielding a gain fluctuation RMS of around 0.8 for the Curran distribution. For a complete description of the MSGC, the parameter m should be tuned to experimental data. We have not yet performed dedicated tests to determine the gas gain fluctuations so for the time being we keep $m=\frac{3}{2}$, the canonical value for wire chambers. (Measurements of the MSGC signal when irradiated with an ^{55}Fe source indicate somewhat less variation in the gas gain: the measured energy resolution can be reproduced with $m \approx 2$.)

Electronic noise was described as uncorrelated. All strips have identical performance. There is no magnetic field (Lorentz angle) and the electric field is perfect (no edge effects etc.). And finally, the electrons created in the quadrupole field near the strips are treated in the same way as those liberated in the drift field.

3 Tuning the Monte Carlo to experimental data

The Monte Carlo program was tuned to data collected during a beam test performed in June, 1991 [10]. The experimental setup consisted of 4 MSGCs in a row, with in total 60 channels read out. Most measurements were performed using DME/CO_2 60/40 as a drift gas. The anode pitch was 200 μm. The gas gap L was 2.7 ± 0.1 mm for two detectors, and 2.9 ± 0.1 mm for the other two. Each strip was read out using a preamplifier, shaper and integrating ADC.

The signal was measured in ADC counts, and the average signal of one drifting electron was around 80 ADC counts. The chamber was operated in proportional mode (gas gain around 5000). The noise had a σ of 40 ADC counts. A negative crosstalk of 5% occurred between anodes in the same cathode group. Instead of correcting for this effect in the data, we put it in the simulation, because there was no proper way we could correct the data for events where one of the strip signals caused an ADC overflow.

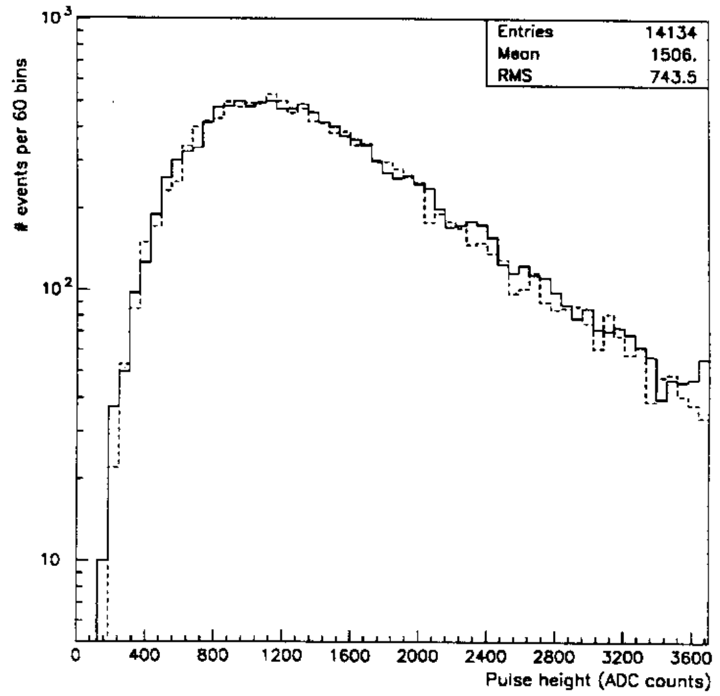

Figure 2: *Measured signal from a minimum ionising particle on one strip (solid line), and the same entity as simulated with the Monte Carlo program (dashed line).*

To simulate the ionisation process, one needs the statistical distribution of the number of electrons in a cluster. For DME this distribution is not known; data for CO_2 are given in [11]. A simple approximation is made for the mixture DME/CO_2 60/40. The probability to find n electrons in a cluster is $w(n)$. According to the Rutherford theory, $w(n)$ goes as $\frac{1}{n^2}$, apart from deviations at small n that depend on the electronic structure of the gas molecules. From experiments it is known that $w(1)$ is around 0.70 for most gases. We set $w(n) \sim \frac{1}{n^2}$ for

$3 \leq n \leq 1000$. $w(1)$ and $w(2)$ were tuned by comparing the Landau distribution of simulation and data.

The Landau distributions matched best with $w(1) = 0.70$ and $w(2) = 0.20$, which case is shown in figure 2. This figure shows the signal spectrum for the strip with the highest signal. It turns out that the optimum values of $w(1)$ and $w(2)$ are very sensitive to the exact value of L. To establish the actual cluster density distribution we need more accurate information.

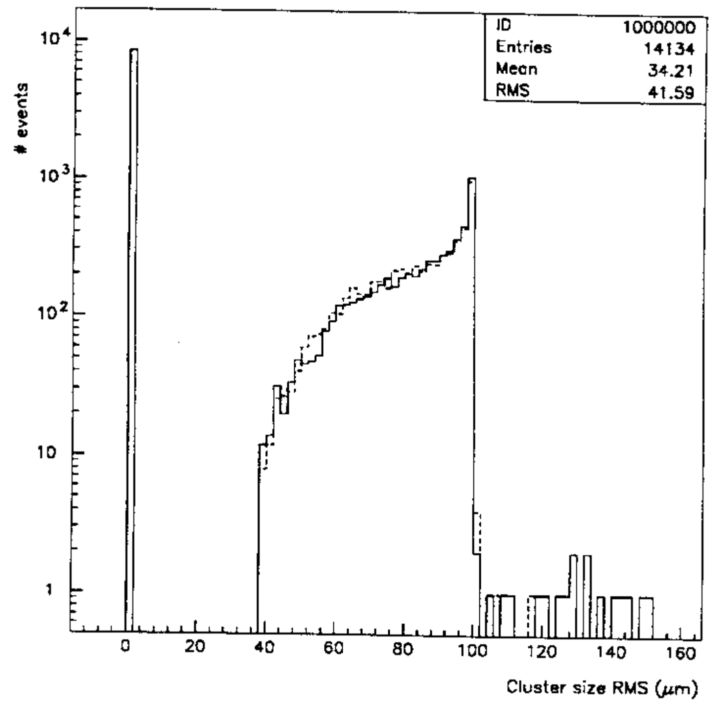

Figure 3: *The RMS of signal clusters arising from a crossing minimum ionising particle, for data (solid histogram) and Monte Carlo (dashed histogram).*

The transverse diffusion of the electrons in the drift region can be tuned by comparing the average number of firing strips, in the data and the Monte Carlo. A more thorough comparison between MC and data can be made by looking at the distribution of the charge cluster RMS in both cases. If only one strip has a signal above threshold, the RMS of the charge distribution is 0 μm. If two adjacent strips fire, the RMS is between 0 and 100 μm, depending on the relative pulse height of the strip signals. If three strips have a signal above threshold, the RMS is between 0 and 200 μm.

The cluster RMS distribution is shown in figure 3 for data and Monte Carlo, after tuning the diffusion constant. We found $\sigma_T = 49 \pm 4$ $\mu m/\sqrt{mm}$. The gap between RMS = 0 and 38 μm is caused by the fact that signals are always between threshold and ADC-overflow. The two histograms compare very well, only the number of events with an RMS > 100 μm is too low in the simulation (the simulation predicts 2 events, there are 17 events in the data with an RMS > 100 μm). These events have a moderate total signal, which leads us to the conclusion that they are not caused by highly energetic δ-electrons. The events can be explained as double-tracks with a distance in x around 250 μm, which are not removed by a cut on separate clusters but do give rise to a wide cluster. The discrepancy is solved if one assumes that 2% of the triggers of the beam test contained inseparable double tracks.

4 Optimisation of the MSGC resolution

One achieves the optimum resolution with the MSGC when the electron cloud spreads out over more than two strips, so the centre of gravity of the cloud can be determined accurately. In the beam test, the clouds spread out over only 1.5 strips on average, so a better position resolution can be achieved by increasing the gas gap or reducing the pitch. The position resolution for varying pitch and gas gap are shown in fig. 4 and fig. 5, respectively. [1]

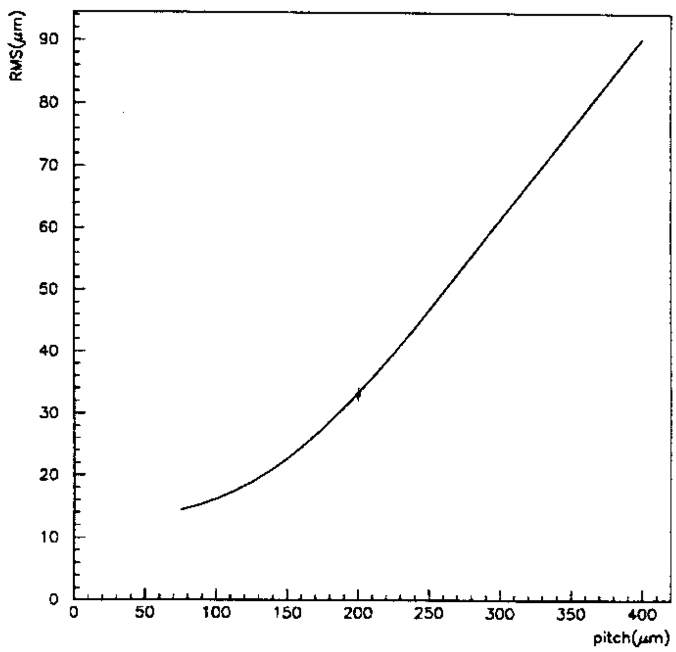

Figure 4: *The position resolution as a function of the pitch for an MSGC with L = 2.8 mm. The point represents the test beam result using the same position resolution algorithm.*

If a high pitch is chosen, the resolution is determined by the anode pitch. Most tracks give a signal on only one strip; only tracks that cross in the middle between two strips will cause signals on two strips so an accurate position determination can be done by the centre-of-gravity method. The straight part of the curve can therefore be approximated by the

[1] The position resolution is calculated as follows. Tracks enter the detector at a random position. With all strip signals above threshold, the centre of gravity is calculated, and related to the actual track position. The resolution was defined as the RMS of the resulting residual distribution. To remove the tails, a cut was set on $\pm$ 100 μm ($\pm$ 200 μm for those geometries where the resolution was larger than 40 μm).

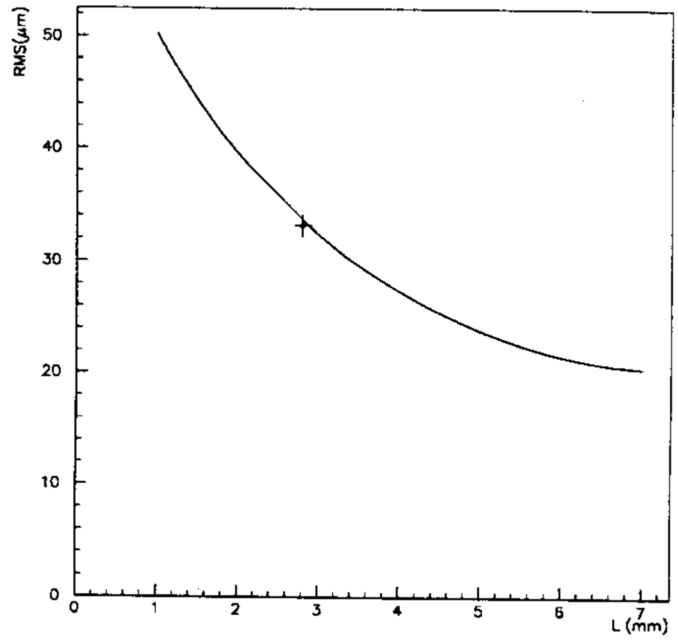

Figure 5: *The position resolution of an MSGC as a function of the gap thickness L with p = 200 μm. The point represents the data using the same position resolution algorithm.*

relation

$$\sigma = \frac{p - 2R}{p} \times \frac{p}{\sqrt{12}} \tag{3}$$

where $p/\sqrt{12}$ is the resolution when there is no transverse diffusion at all, and R is the average radius of the electron cloud after diffusion. The curve shown in the figure yields $R = 50$ μm. This radius can be increased by choosing a gas mixture with a higher diffusion constant, or simply by increasing the gas gap. At very low pitch, the position measurement error is dominated by the gain fluctuations and the transversal diffusion, both giving an error around 10 μm.

Figure 5 shows the effect of varying the gas gap width (thereby varying the electron cloud size and the total signal). For optimal resolution one should aim for a maximal gas gap. In practice this is not by definition optimal: the size of the gas gap determines also the signal duration (given by the electron drift time) and the larger the gas gap is, the worse the resolution becomes for particles that do not enter the detector perpendicularly.

The actual figure for the resolution of an MSGC with very low pitch has a limited meaning because the uncertainty in the tuning becomes important here, especially in the variance of the gas gain. Also, instrumental effects (e.g. alignment) could have a sizable influence for resolutions below 20 μm. However, both figures indicate that the position resolution of 30 μm measured in two beam tests [2, 10] is strongly dependent on the geometry chosen.

5 Conclusions

Starting from the principles of wire chamber operation we succeeded in reproducing the performance of the Microstrip Gas Counter as determined in a beam test. The large number of free parameters in the simulation leaves some room for further optimisation using dedicated measurements. With the current tuning the simulation shows very good agreement with experimental data which makes it a powerful tool in the analysis of test-beam data. The simulation suggests that the position resolution of the MSGC can be pushed below 30 μm by increasing the gas gap or decreasing the pitch w.r.t. the currently used dimensions, because the position resolution in current prototypes is limited by undersampling of the ionisation cloud that creates the signal on the microstrips.

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