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CMS NOTE 1999-051

The Compact Muon Solenoid Experiment

CMS Note

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

25 Mai 1999

RADIATION HARDNESS STUDY WITH SMALL GAP CHAMBERS OF 5 AND 9 CM STRIPS

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Abstract

Small Gap Chambers of 5 and 9 cm strips were exposed to a 5 kHz/mm^2 pion beam of 300 MeV in the πM1 area at the PSI. We present the discharge rates and the strip failures measured at different voltages. The results are compared to the LHCC requirements. We extrapolate the expected safety margin and show the improvement that was obtained with two chambers equipped with GEMs.

Summary :

1 Introduction

The Small Gap Chamber design was proposed in 1996 following the successful operation of the Micro-Gap Chamber substrates produced for IPNL at the IBM-Corbeil factory. These detectors allowed, for the first time, to reach a gas gain as large as 6000 with an anode-cathode gap of only 12 μm [1] [2].

While the MGCs were intended to measure two coordinates with a single substrate, involving a complicated fabrication process, the SGCs are 1D detectors with the two layers of passivated MSGCs (fig. 1). They preserve the small gap feature, avoiding the proposed coating of the MSGCs. The passivation of both the cathode and anode edges was introduced from the conception. It appears to be an interesting feature when it was observed that Highly Ionising Particules induce discharges in the usual MSGCs.

The performances of the SGCs with incident Minimum Ionising Particules or X-Rays are reported in reference [1] and [2]. The results of a first test at the Paul Scherrer Institut cyclotron were presented at the Vienna conference in 1998 [3]. Since then, new detectors were produced, at IBM, Thomson, IMEC and REOSC factories. The fabrication process at IBM involves two masks properly aligned, while a single one is used at the other producers. In this case, the passivation is simply obtained by the development of a photoresist polyimide after exposure through the glass and the strip pattern.

The present note summarizes the results obtained in 2 months of experimentation at the PSI where as much as 20 SGC substrates were exposed to the high intensity pion beam.

2 PSI data

The detailed characteristics of the tested substrates are given in table 1. The experimental bench is shown in figure 2. The registered data include the following variables :
- A 2 ms ADC sampling of the detector cathode current (also from time to time of the drift current),
- A measurment of the anode signal using the Premux chips,
- A monitoring of the beam intensity using scintillating counters.

3 Chamber signal to noise ratio

Periodic runs at low intensity were registered to monitor the chamber signal and signal to noise ratio with reconstructed tracks (fig. 3). At high intensity, 50 % of the identified tracks are uncorrelated with the acquisition trigger, which lowers the observed signal to noise ratio. In this case, the short and long term stability of the current shows that the gain is not modified by the incident flux (fig. 4). Moreover, the evolution of the current with the cathode voltage follows the expected exponential law: $e^{-0.022V_K}$ (fig. 5).

3.1 Definition of the nominal voltage for LHC

The nominal voltage for the present SGCs is -3500V on the drift plane and -390V on the cathodes. In these conditions, the ratio of the highest cluster strip maximum probability signal to the channel noise is 15, with a Ne/DME 1/2 gas mixture. This definition of the signal to noise ratio was adopted to allow a direct comparison with the studies of reference [4] and [5], both showing that the pulse processing will reduce this variable by a factor 2. In reference [4] it is shown that for perpendicular tracks a value of 14 will ensure a 98 % efficiency independently of the cluster size, with a bunch crossing pile up of 3 to 4, considered as acceptable for an efficient track reconstruction. With SGCs, the highest strip signal contains 70 % of the cluster (for usual thresholds). A strip signal to noise ratio of 15 is therefore equivalent to a value of 21 in the definition adopted for the CMS tracker Technical Design Report (TDR) (cluster charge divide by the strip noise).

4 Radiation hardness

4.1 Strip failures and spark identification

The radiation hardness of the chambers was estimated from the number of strip failures and from the rate of sparks. The failing strips are identified by a loss of efficiency in the beam profile, correlated with a decrease of noise (fig. 6). The sparks are identified, in the current sampling, as clusters of more than 5 adjacent ADC channels (10 ms duration) above a suitable threshold and with an integrated charge larger than 5 nC (fig. 7(a)). An example of the charge distribution is shown in figure 7(b). Given the grouping of cathodes, the peak value is compatible with an anode-cathode capacitance of 1 pF/cm.

4.2 Strip failures measured at nominal voltage

The IBM and Thomson chambers, set at the nominal voltage (see section 3.1), were exposed to the high intensity beam for 6 to 8 days without strip failures (table 2). According to the active area covered and the limited running time, this measurement is compatible with a strip loss of less than 8 $\%$, for a chamber with 12.5 cm long strips that would be operated 500 days in the high luminosity LHC beam.

4.3 Spark rates and strip failures measured in a voltage scan

The efficiency plateau can be estimated by raising progressively the cathode voltage up to a level of significant sparking. This accelerated procedure provides the spark rates and the corresponding number of strip failures, necessary to extrapolate the strip loss at lower voltages where a direct measurement would be too long.

In figure 8, the measured spark rate, normalized to the length of strip, is shown for each chamber as a function of the cathode voltage. All the measurements are compatible with a factor 10 increase every 10 V. According to this dependence, the rate fluctuations observed for the Thomson chambers are contained within $\pm$ 5V, with a mean value of 4 10^{-8} cm^{-1} s^{-1} at the nominal voltage.

The summary of the integrated number of sparks (N_{sp}) and of strip cuts (N_{cut}) is presented in table 3. In the Thomson chambers, 22 strip failures were observed out of the 12000 first sparks and then 4 were observed out of 25000 sparks in chambers 2 and 3. These results indicate that the failure rate decreases from an initial value of 1 per 500 sparks to an asymptotic value of 1 per 6000 sparks. The first 22 cuts have hardened the chambers.

4.4 Extrapolation of the efficiency plateau according to the LHCC milestone

The LHC Committee milestone specifies that less than 8$\%$ of the strips should be cut in 500 HI days at LHC. From the result of the preceding section a hardening effect of 3.6 $\%$ is expected in a chamber of 512 strips 12.5 cm long. Therefore, the maximum spark rate acceptable to fulfil the LHCC milestone can be expressed as :

$$\mathrm{dN/dtdl} \leq 4.4\% \; / \; (\mathrm{N}_{cut}/\mathrm{N}_{sp}) \; / \; (\mathrm{l}_{strip} \mathrm{~x~} \mathrm{t}_{LHC}) \; (\mathrm{s}^{-1} \; \mathrm{cm}^{-1})$$

Using the asymptotic value $\mathrm{N}_{cut}/\mathrm{N}_{sp}$ = 1/6000, the corresponding spark rate for 12.5 cm strips and 500 HI days at LHC is 5 10^{-7} s^{-1} cm^{-1}. From figure 8 it can be seen that this rate is reached at a voltage of 410 V (strip S/N $\approx$ 23).

A similar analysis with the IBM chambers leads to a maximum voltage of 420 V with a limited statistics of sparks. The REOSC and IMEC chambers exhibit larger spark rates probably correlated to quality of the substrates, as the fabrication process still needs improvements.

4.5 SGC+GEM safety margin

Two IBM SGC's were opened, equipped with a Gas Electron Multiplier (fig. 9) and tested according to the protocol presented above. The transfer gap was 1 mm for 1 of the detectors and 3 mm for the other. To allow a good transparency, the two chambers were operated with an approximately equal drift and transfer field. Since the drift voltage was limited to 3.5 kV for the two chambers, the corresponding field was 7kV/cm for the 1 mm transfer gap and 4.5 kV/cm for the 3 mm transfer gap. The variation of the gain versus the cathode and the GEM voltage is shown in figure 10. An exemple of the signal and signal to noise ratio is plotted in figure 11. The spark rates are compatible with an improvement of the maximum achievable signal by more than a factor 2 (figure 12). During the test, strip signal to noise ratios as large as 60 were reached without cuts.

4.6 Other factors of influence on the spark rates

4.6.1 Beam intensity

The spark rates were measured at different values of the beam intensity. A linear increase was observed, as expected if the effect is related to the beam interactions (fig. 13).

4.6.2 Drift field and gas proportions

The gas chamber gain can be increased with the drift voltage up to a regime close to parallel plate chamber operation (fig. 14). Testing this effect, it was found that drift sparks start to occur before any significant improvement of the gain was reached. A further test was performed changing the gas proportion to 50/50 % without success.

5 Conclusions

The sparking behaviour of 5 and 9 cm long SGCs has been tested at the PSI in conditions close to the LHC situation [6]. It was found that the spark rates increase exponentially by a factor 10 every 10 V. For Thomson chambers, the measured rate was 4 10^{-8} s^{-1} cm^{-1} at nominal voltage and the strips were observed to survive 6000 sparks after hardening. The extrapolation of these results to 500 days of operation at high luminosity indicate that these chambers should fulfil the LHCC milestone at a strip signal to noise ratio of 23.

No improvements were obtained when increasing the drift voltage or changing the gas proportions. However, the test of two IBM SGCs equipped with a GEM indicates that a double amplification device can substancially improve the margin. It could be a good solution to compensate, if necessary, a noise increase with longer detectors and full read-out chain, and/or a long term ageing effect.

References

[1] J.F. Clergeau et al., Nucl. Instr. and Meth. A392 (1997) 140

[2] V. Chorowicz et al., Nucl. Instr. and Meth. A401 (1997) 238

[3] V. Chorowicz et al., Nucl. Instr. and Meth. A419 (1998) 464

[4] J.F. Clergeau PhD thesis, LYCEN-T9725

[5] G. Sciacca CMS Note 1999/023

[6] M. Hutinen CMS Note 1997/073

	Substrate (cm)	Strips Length (cm)	Strips Thickness (μm)	Anode-cathode Gap(μm)	Anode width (μm)	Passivation Thickness (μm)	Overlap (μm)
IBM X 3	Si + 12 μ poly.	9	1.2	10	9	2.2 (Poly.)	1
THOMSON X 12	D263 Glass	5	1	10	9	2.5 (BCB)	0.5
IMEC X 1	D263 Glass	9	1	10	9	2.5 (BCB)	0.5
REOSC X 3	D263 Glass	9	1	10	9	2.5 (Poly.)	0.5

Table 1: Substrate characteristics.

	IBM3	IBM1	TTE1	TTE2	TTE3	TTE4	TTE5	TTE6	TTE7
Nb of strips	256	256	2*128	2*128*	2*128	128	2*128	2*128	128
Time (h) at H.I	142	187	160	184	192	135	135	160	135
Ncuts	0	0	0	0	0	0	0	0	0

Table 2: Summary of strip failures at nominal voltage.

	IBM3	IBM1	TTE1	TTE2	TTE3	TTE4	TTE5	TTE6	TTE7	IMEC4	REOSC1	REOSC4	REOSC5
Time (h) at H.I	254	316	316	610	610	254	254	371	254	62	42	25	25
Ncuts total	0	0	2	6	4	2	4	6	2	3	1	4	0
Nsparks total	1055	926	2891	8745	20665	377	1214	2724	539	962	711	2223	1359

Table 3: Summary of strip failures including the voltage scan.

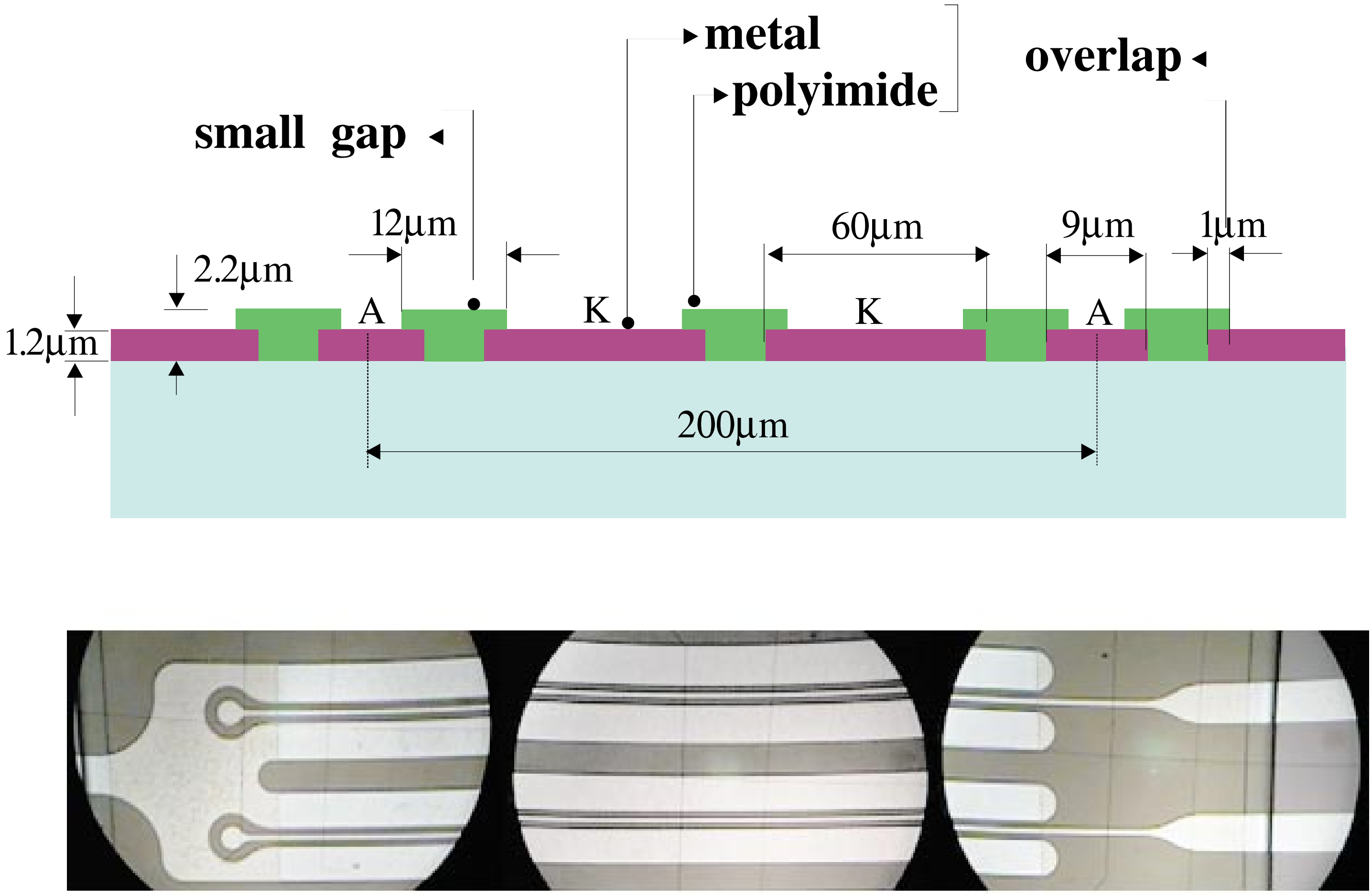

Figure 1: SGC design.

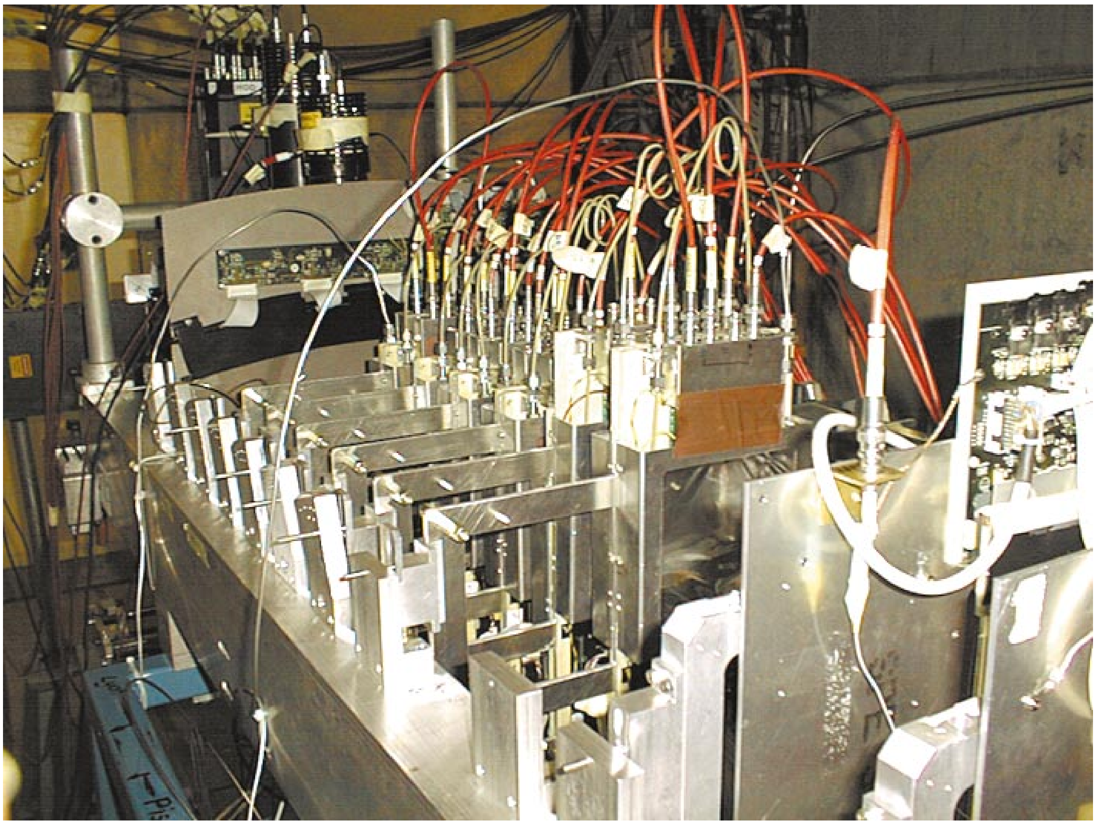

Figure 2: View of the experimental bench at PSI.

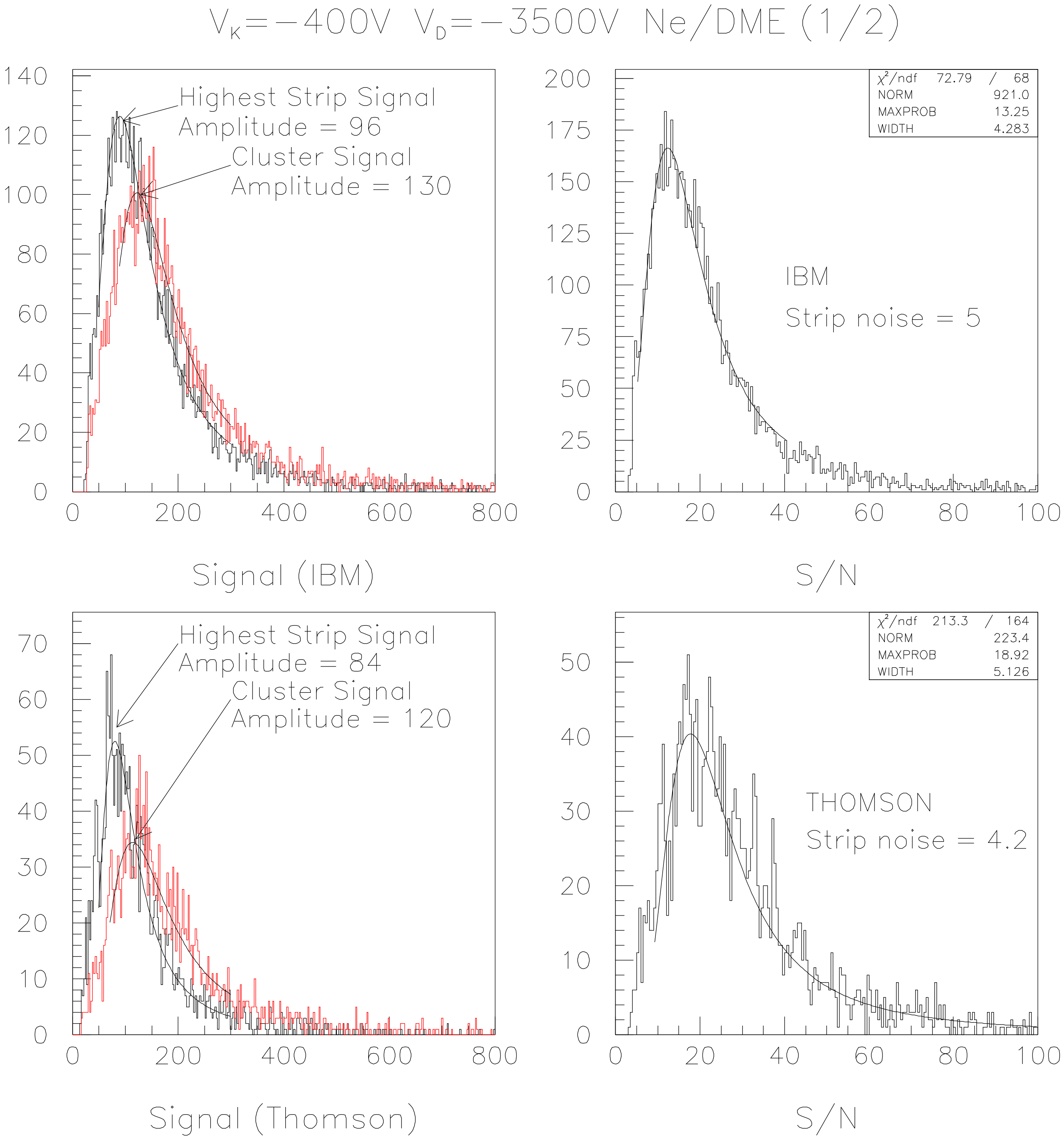

Figure 3: Cluster and highest strip signals and signal to noise ratio for (a) IBM and (b) THOMSON chambers.

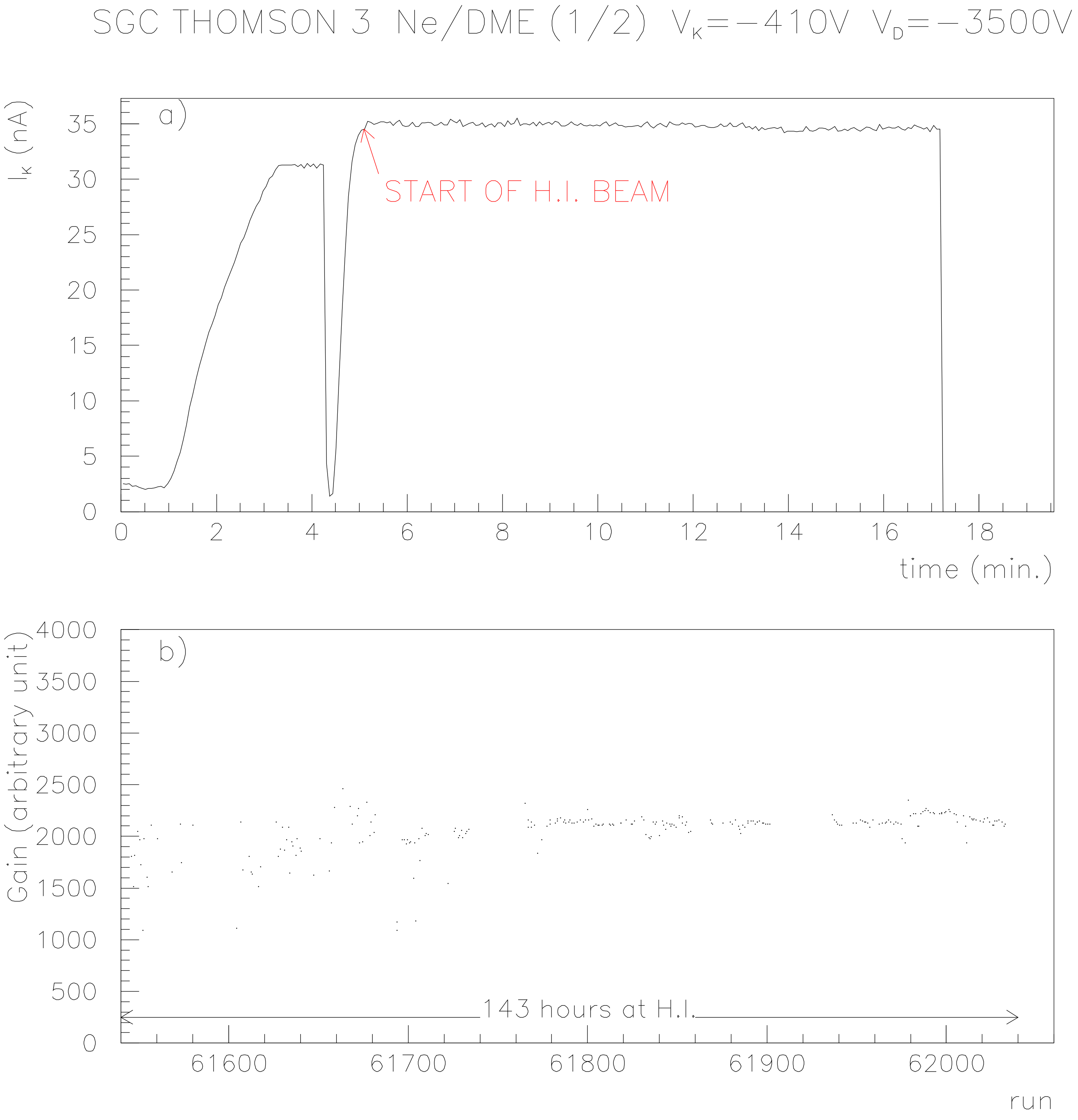

Figure 4: Current versus time at the beginning of a high intensity period (a) and along a H.I. period of 6 days (b).

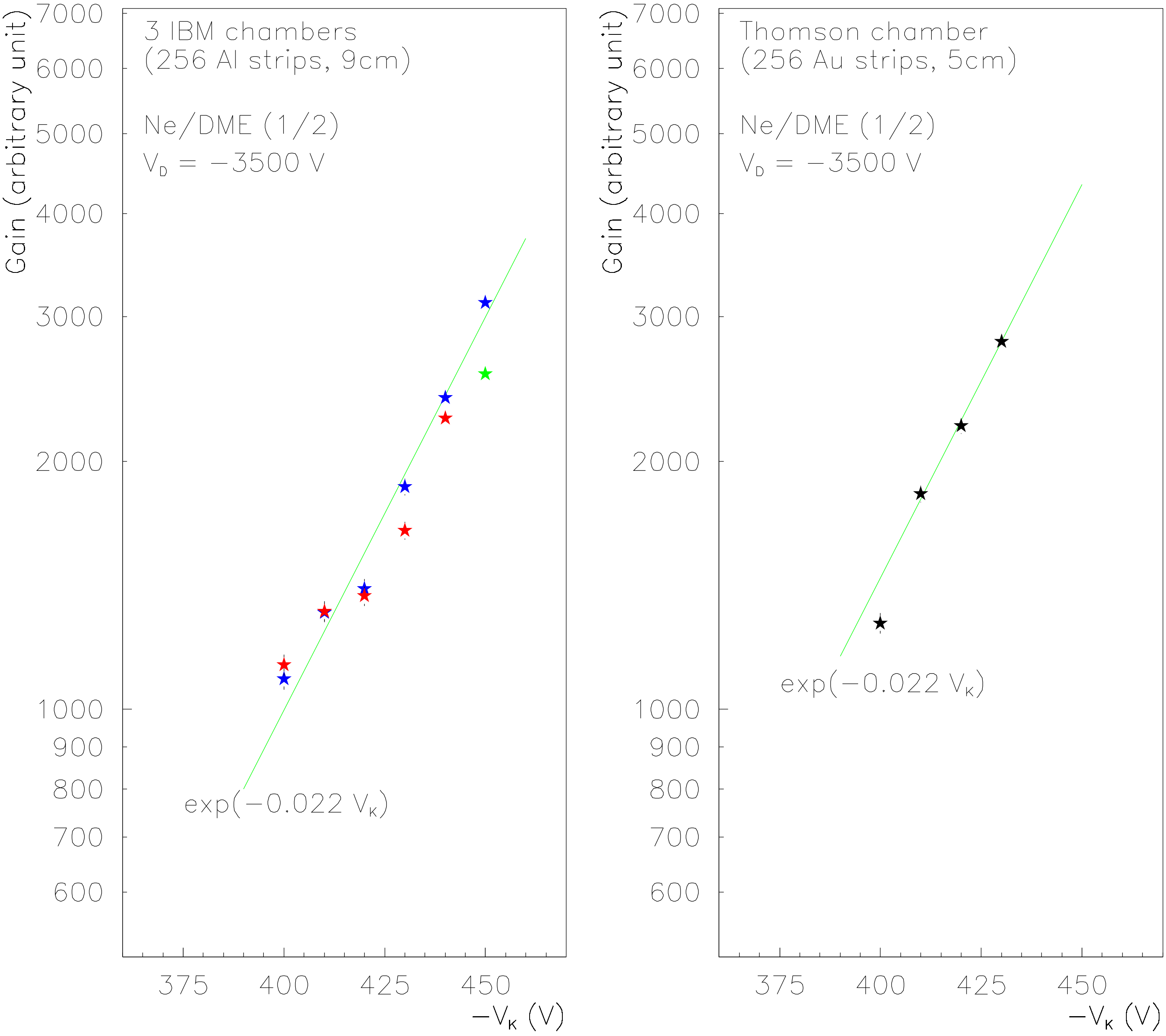

Figure 5: Gain variation with the cathode voltage for IBM and THOMSON chambers.

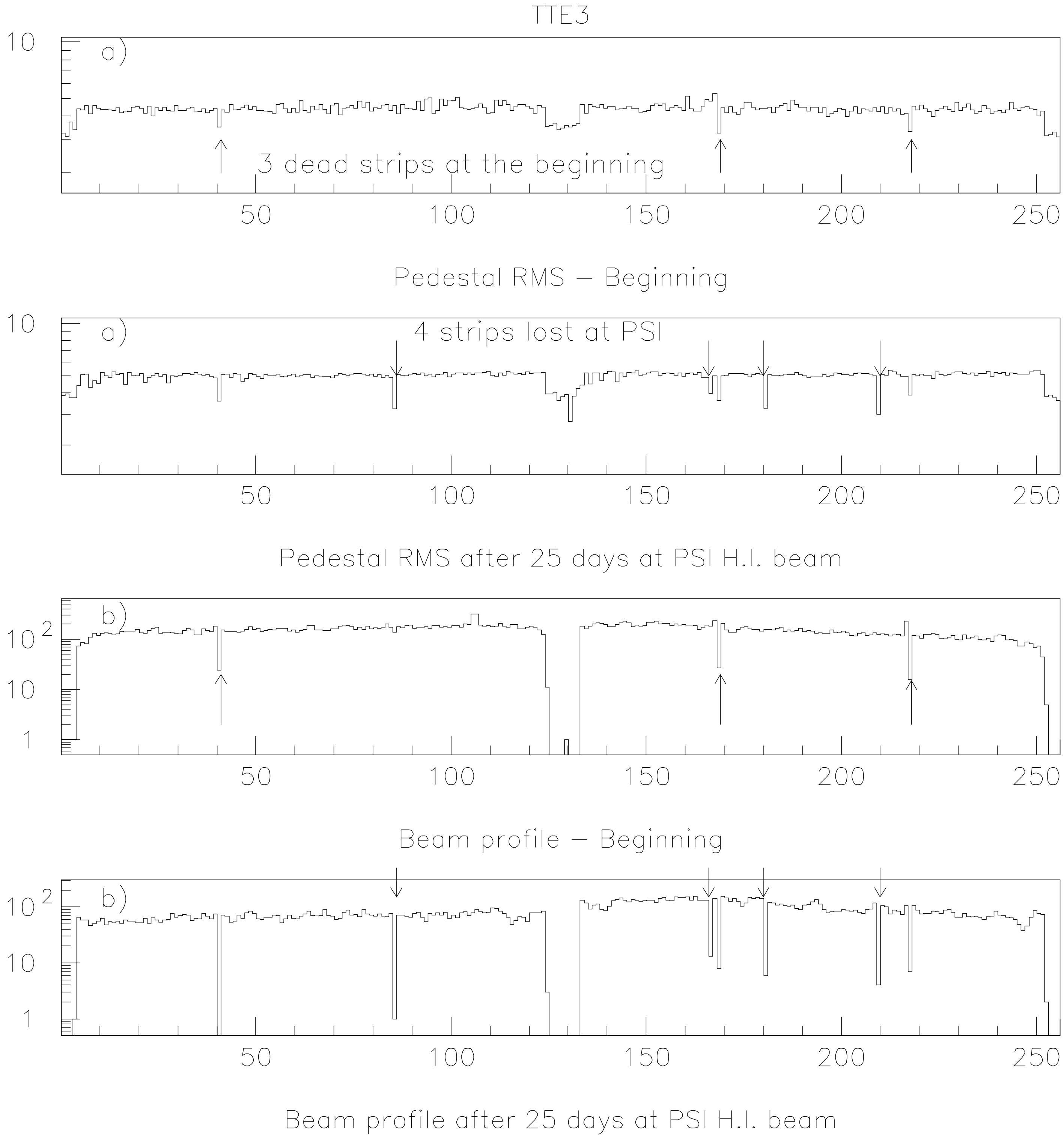

Figure 6: (a) Pedestal rms and (b) beam profiles measured for THOMSON chamber 3 before and after 25 days at high intensity.

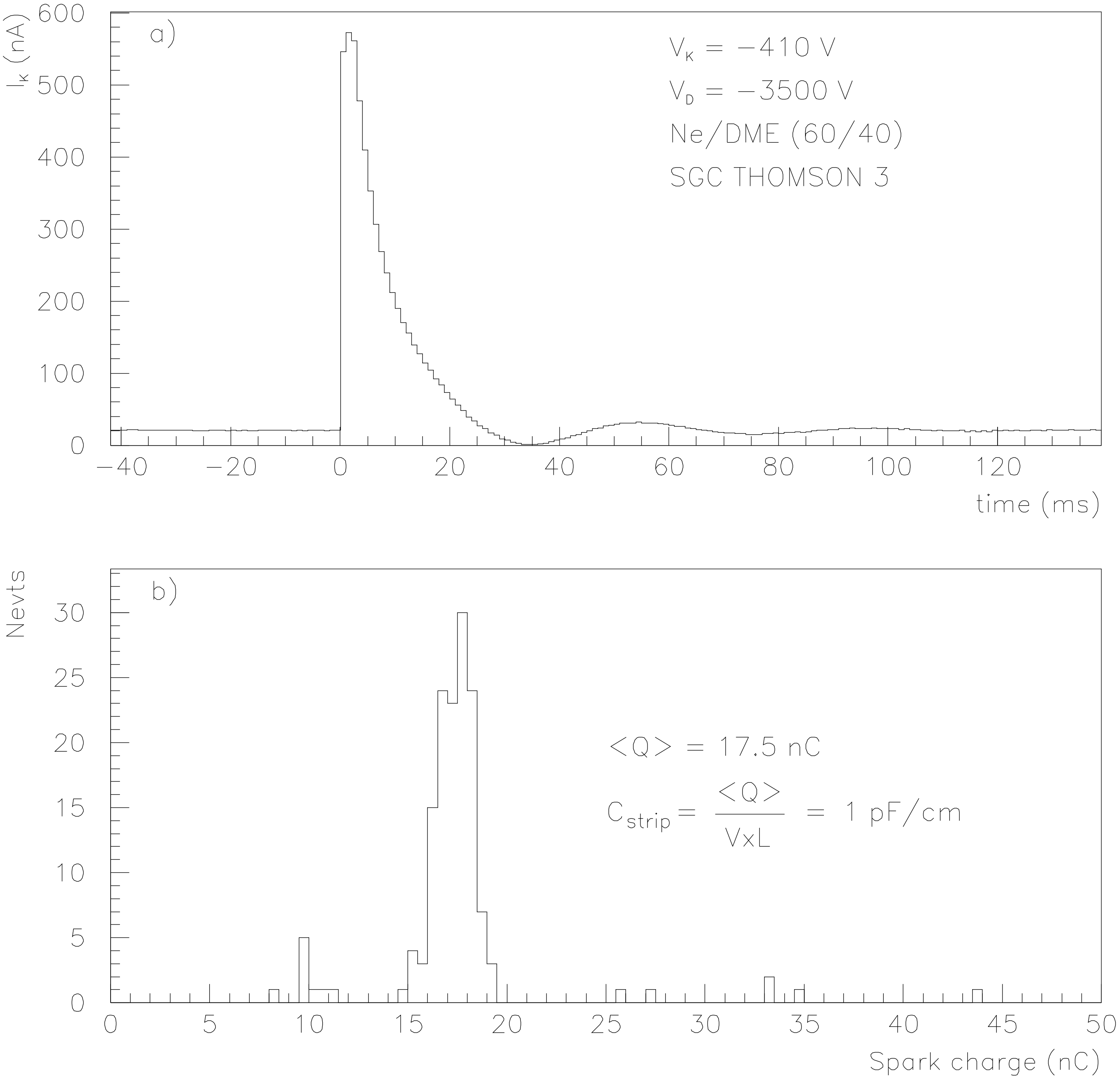

Figure 7: (a) Example of a spark identified in the cathode current monitoring. (b) Typical spark charge distribution.

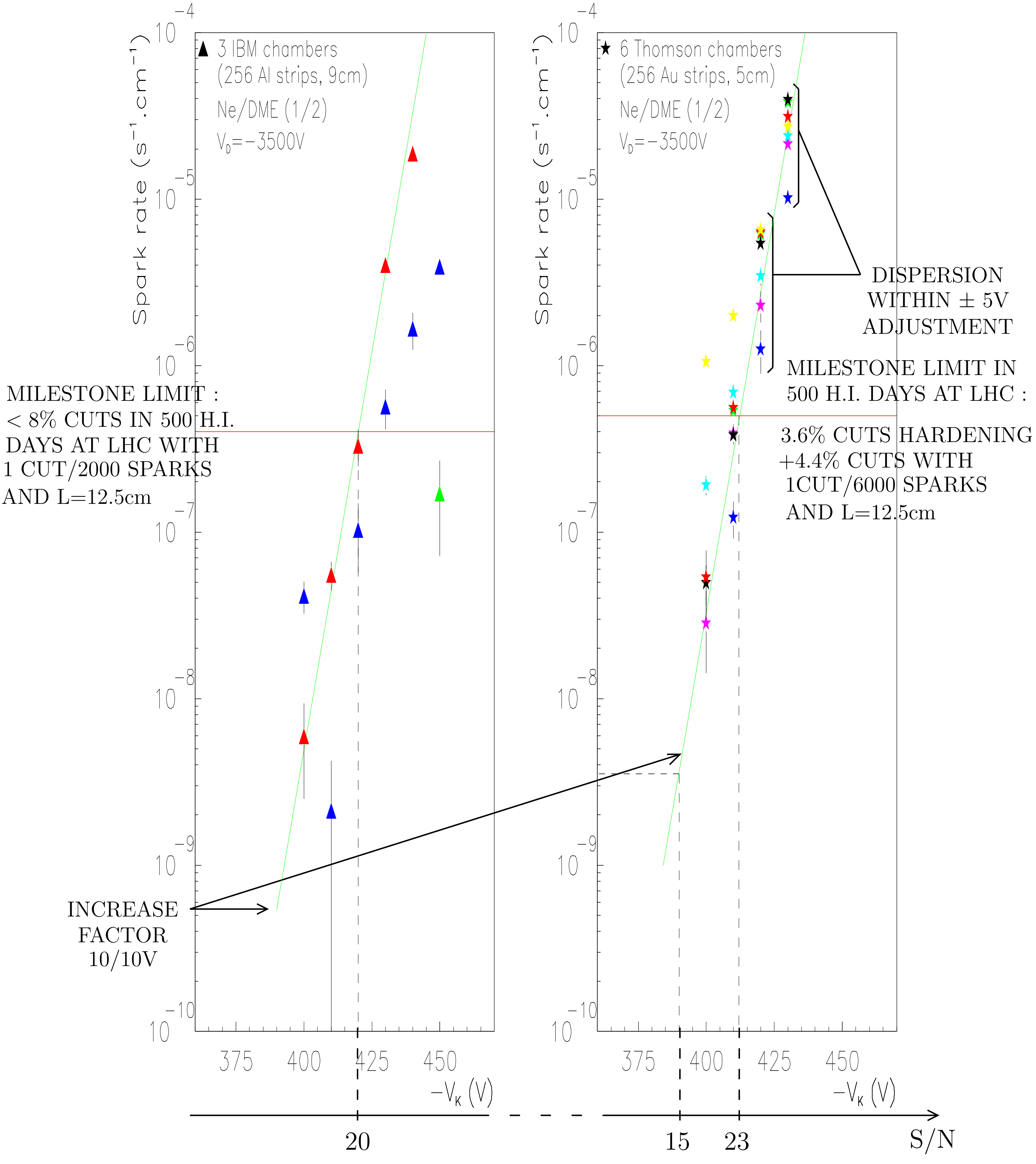

Figure 8: Spark rates as a function of the cathode voltage (strip S/N, as defined in text).

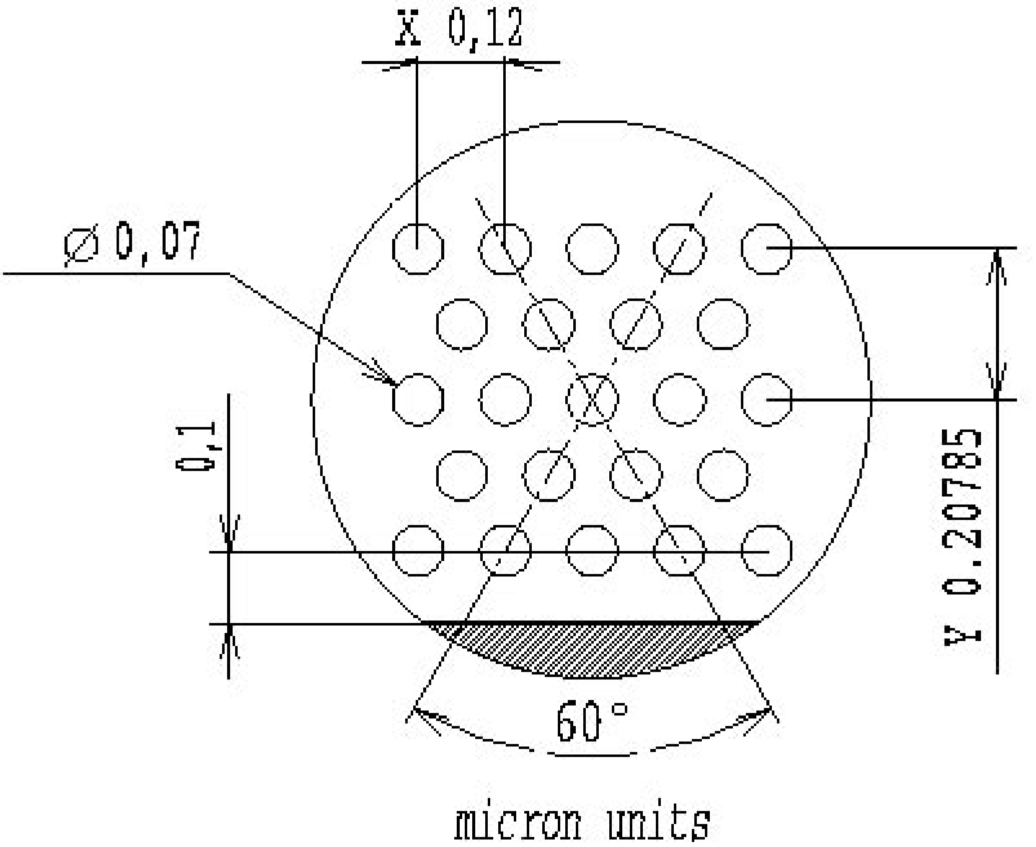

Figure 9: Gem design.

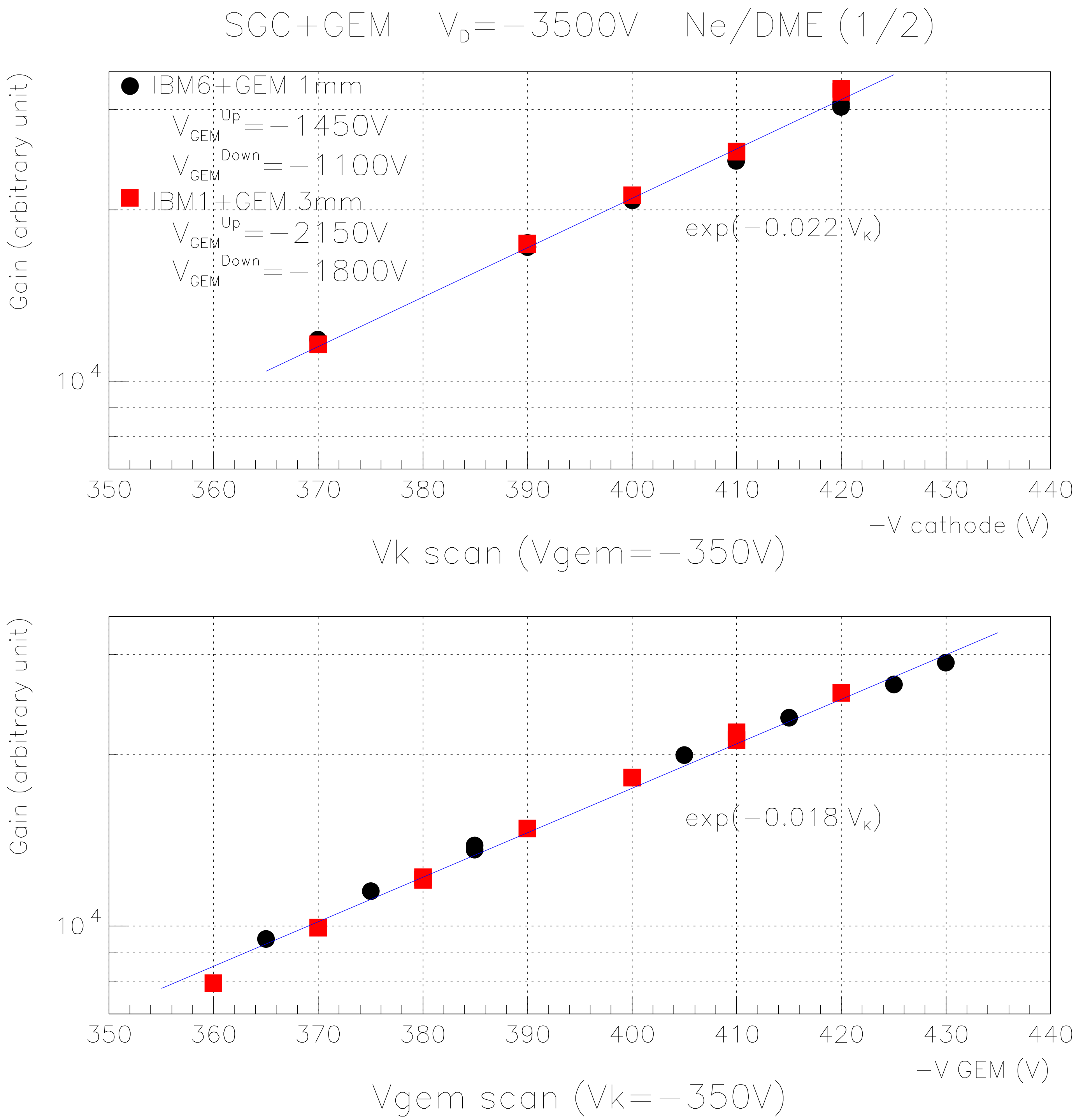

Figure 10: Gain versus cathode voltage and GEM voltage.

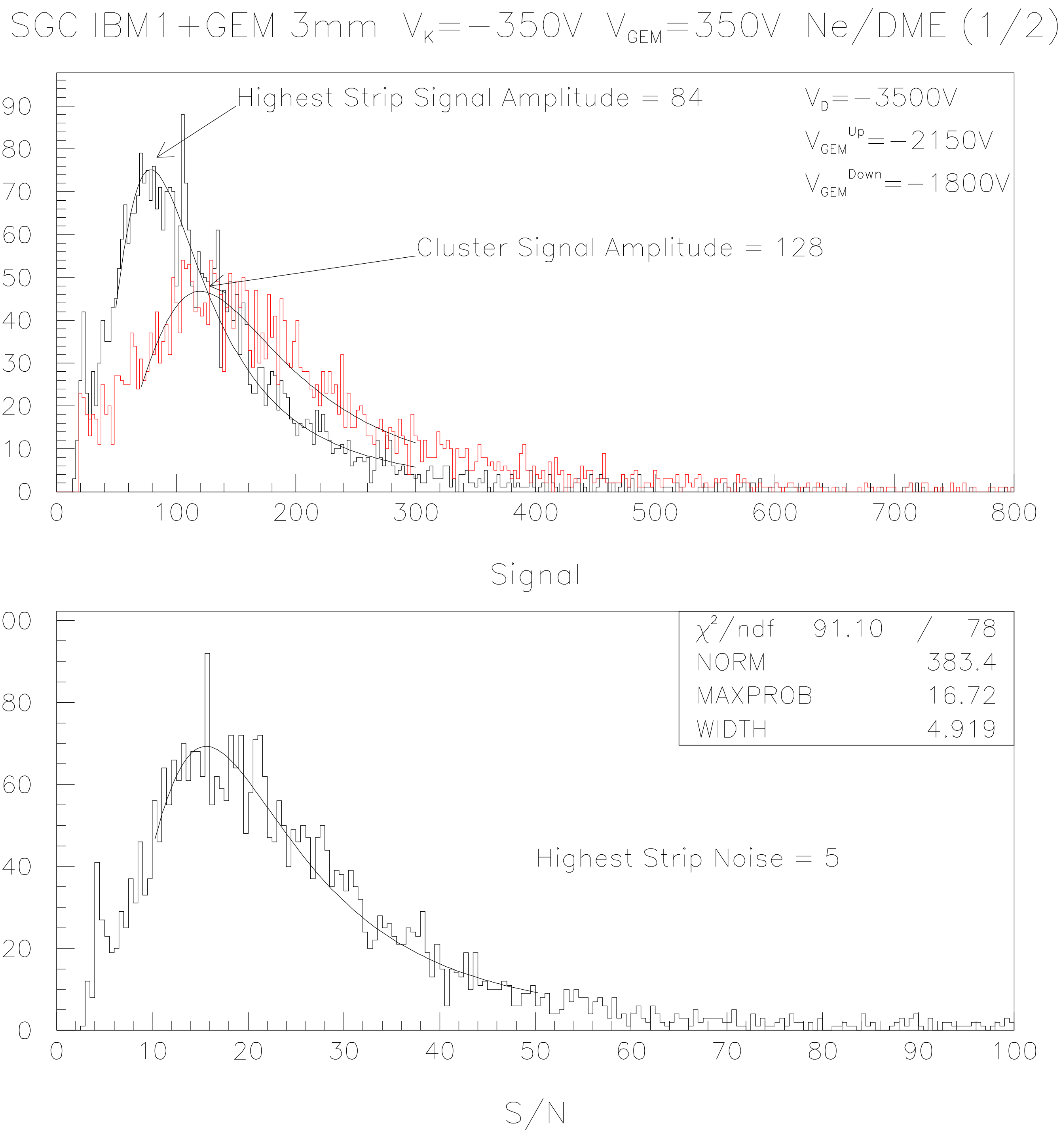

Figure 11: Signal and strip signal to noise ratio (see text) of a SGC+GEM.

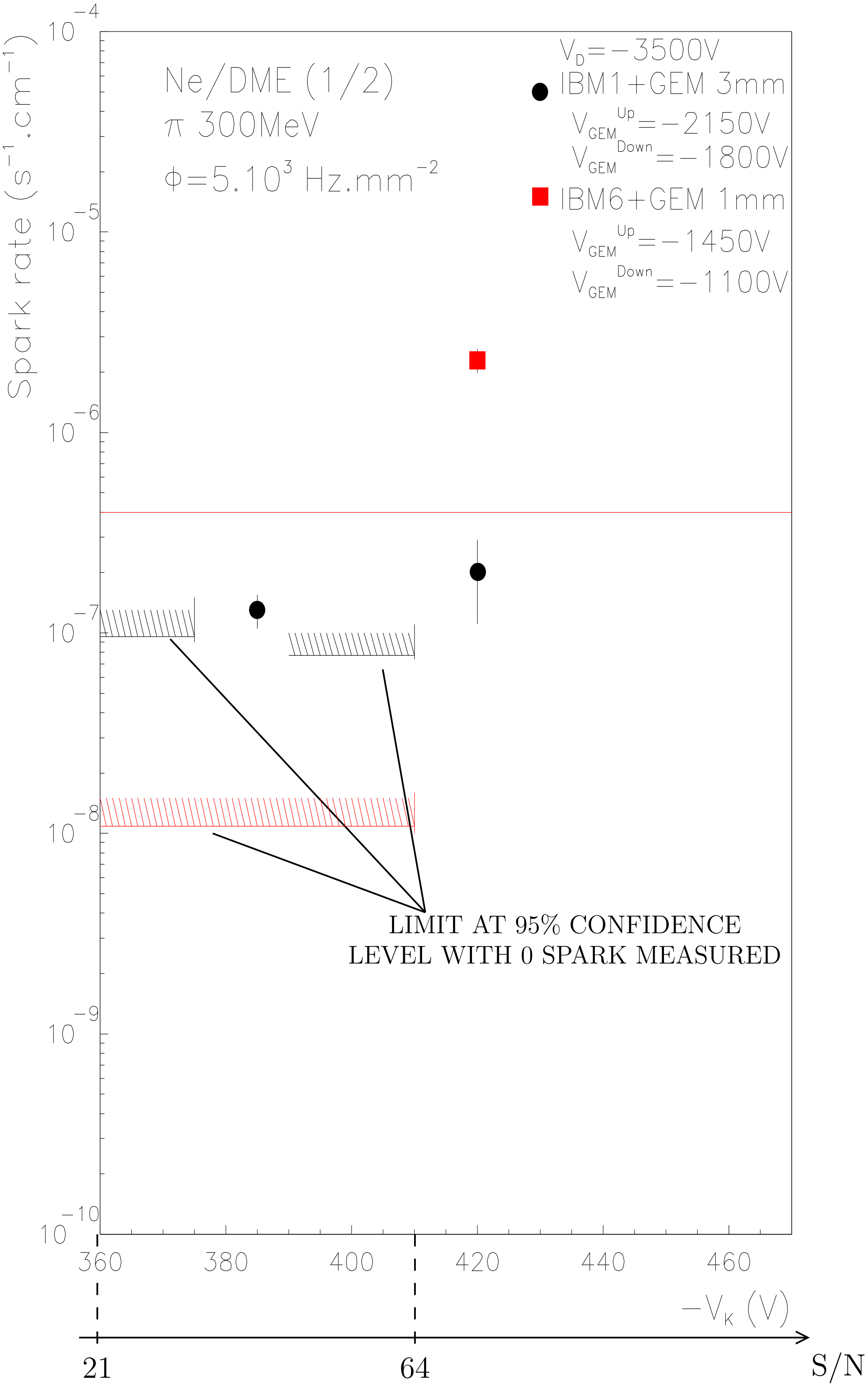

Figure 12: Spark rates of 2 SGC+GEM (S/N as defined in text).

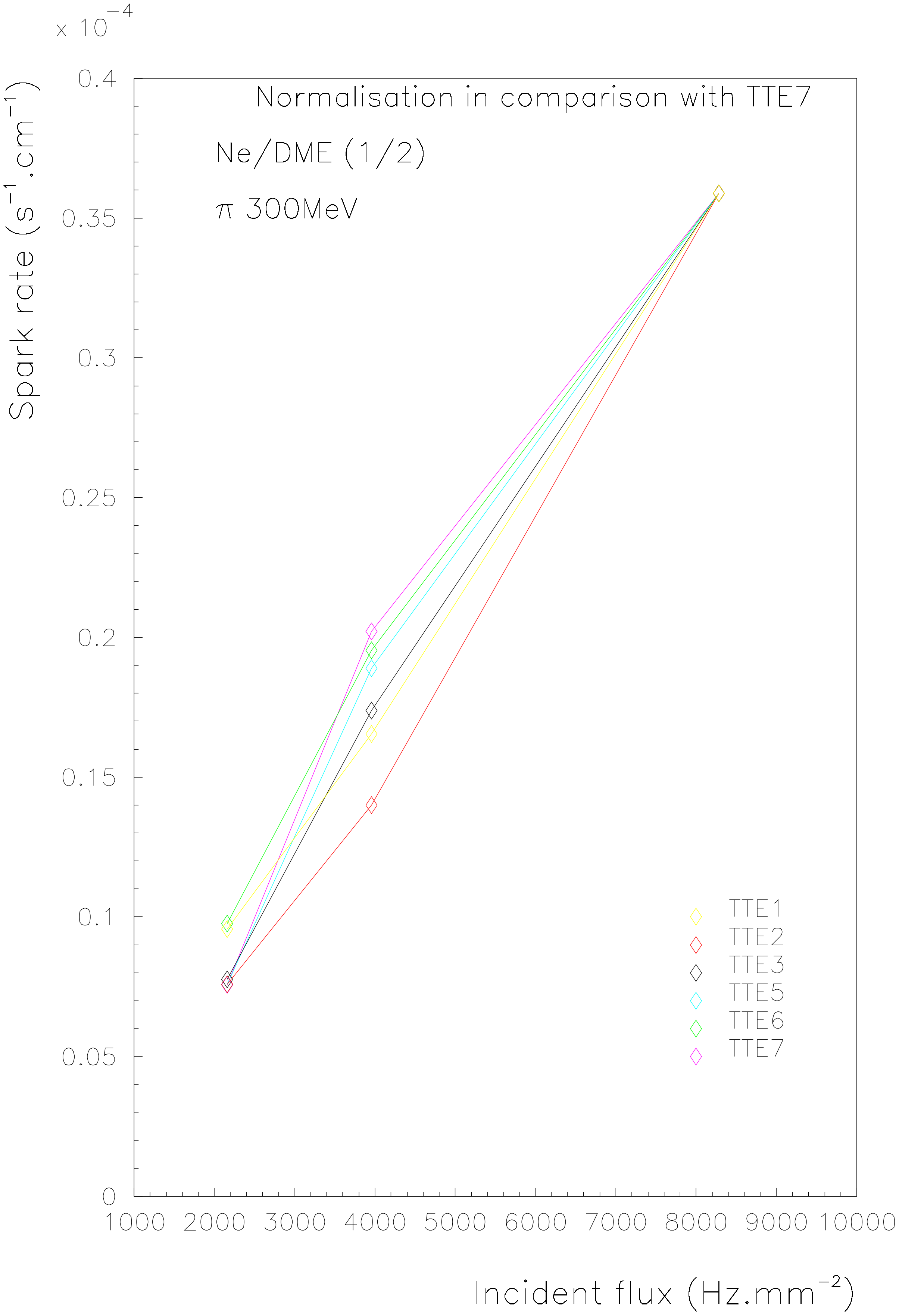

Figure 13: Spark rates versus beam intensity

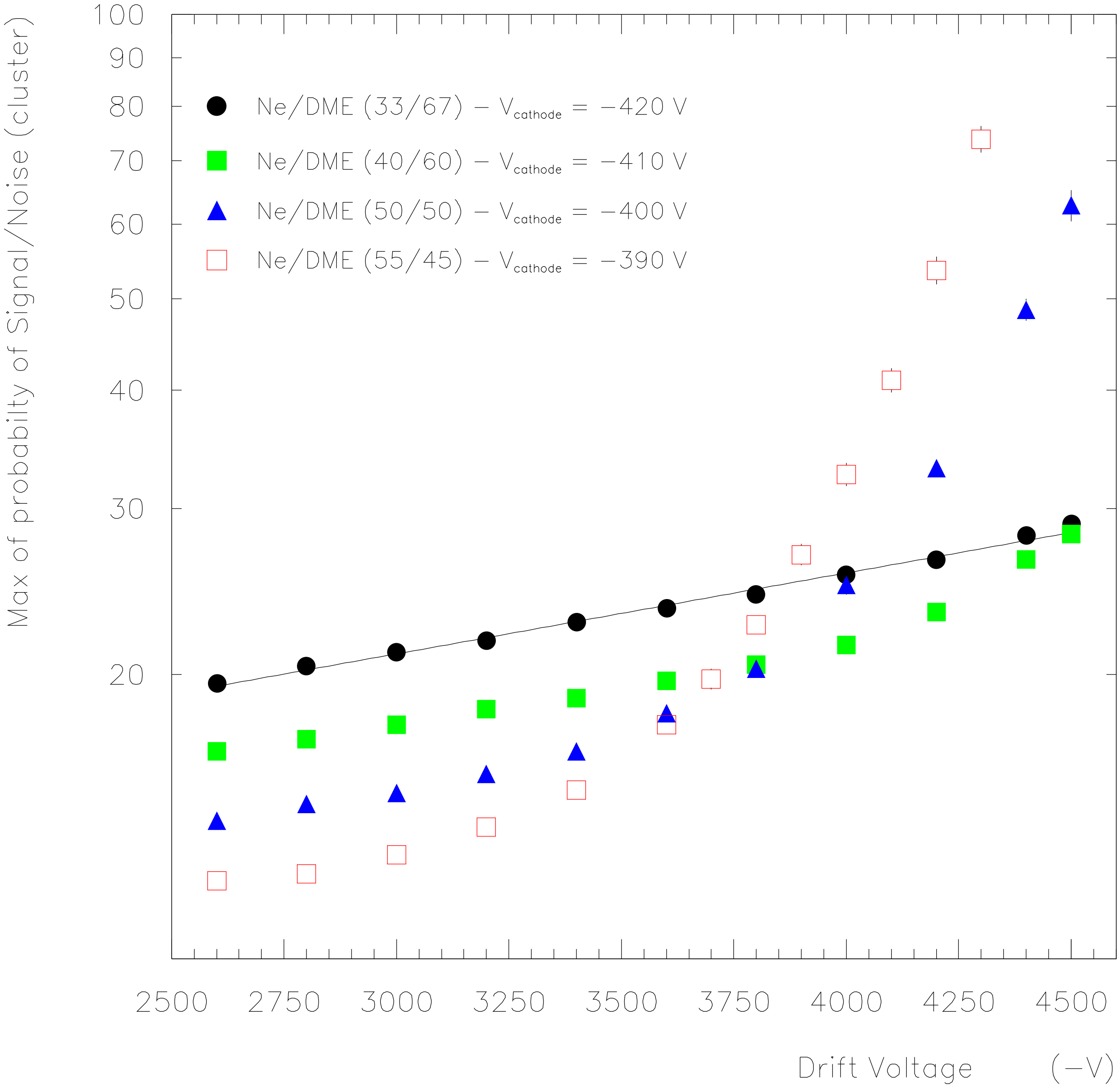

Figure 14: Relative gain versus drift voltage for different gas mixtures.