Radiation hardness and ageing properties of Small Gap plus GEM Chambers

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Abstract

Large size Small Gap plus GEM Chambers were exposed to a low energy hadron beam to characterize their hardness to highly ionizing radiations. During the test, rate and effect of discharges induced by HIPs were studied as a function of the cathode and GEM voltages. We propose an optimization of the voltages to safely operate the detectors at the largest signal to noise ratio.

In a second test, the ageing properties of the chambers were estimated up to a 5 mC/cm integrated charge, induced by an X-ray beam.

We conclude from the two measurements on the reliability and possible improvements of the Small Gap plus GEM Chambers for long term use in a harsh radiative environment.

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1 Configuration of the chambers

As described in references [1–3] the small anode-cathode gap configuration of the MicroStrip Gas Chambers was demonstrated to avoid a substantial charging of the substrate at high particle flux. On the other hand, despite the passivation of the electrode edges, it was observed with small size SGCs that Highly Ionizing Particles can induce discharges in the chambers, limiting the achievable gain [4–6] . To improve the radiation hardness, a Gas Electron Multiplier [7] was introduced in the design of large size detectors (fig. 1).

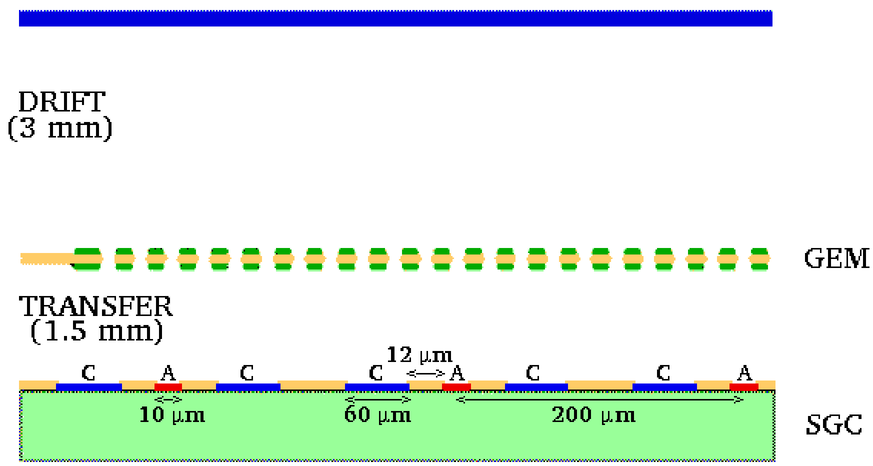

Fig. 1. Geometry of the SGC+GEM chambers.

The substrates [2] were 300 μm thick glasses (Desag D263) with 512 gold plated strips, 14 cm long and 1 μm thick. The passivation was realized with Benzo-Cyclo-Buthene. The strip pattern was wedge shaped as foreseen for the tracker end-cap detectors of the Compact Muon Solenoid experiment at LHC [9]. The pitch of the GEM holes was 200 μm and their diameter was 70 μm, a slightly conservative design with respect to the primary electron's transparency [8]. The drift gap was 3 mm providing a collection time of 50ns and an efficient primary ionization of 36 e^- (with the Ne/DME 40/60 gas mixture). The transfer gap was 1.5 mm, a compromise between mechanical stability and the possibility to maintain the transfer and the drift voltages within practical values. To improve the mechanical stability 4 insulating spacers were glued around the center of the chambers between the upper GEM and the drift plane.

[2] manufactured by Thomson

2 Radiation hardness

The radiation hardness measurement was held at the Paul Scherrer Institut with the experimental set-up described in details in reference [6]. As the data analysis was also performed according to the same procedure presented in this reference, we only remind here the main features of the experimental conditions :

- The 6 kHz/mm^2 beam of 350 MeV pions was used, shown by simulation [10] to produce a 1Hz/cm^2 rate of HIPs with an energy loss of more than 1 MeV in the chambers.

- The gas mixture was composed of 60 % DME and 40 % Neon, found to optimize the gain and the timing properties while reducing the UV rays emission.

- The signal was read-out at the anodes strips with PREMUX chips consisting of a multiplexed array of 128 CR-RC amplifiers of 50 ns time constant and of 400 + 40/pF e$^-$ equivalent noise [11]. The constant noise was checked in a measurement without chamber. Then, with the 14cm strips connected, the noise was 970 e^-, showing a 1pF/cm capacitance.

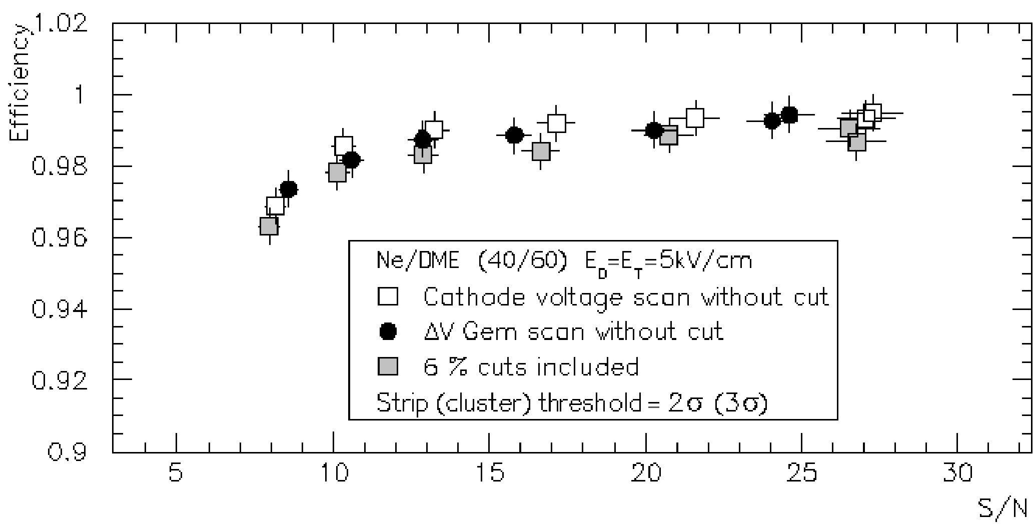

Fig. 2. Detection efficiency of SGC+GEM as a function of the signal to noise ratio.

To avoid hardening effects, as observed at the beginning of a previous HIP test [6], the 8 tested chambers were preliminarily conditioned at their static cathode voltage limit of -500V and at a high GEM voltage of -450V. During this procedure, 6% of anodes underwent short circuits to cathodes, after few discharges were observed. Short circuits were then removed by un-bonding the anodes from their read-out electronics. The subsequent efficiency loss was found to be less than 1%, the signal charge being collected on neighboring anodes when one is disconnected (fig. 2).

At the PSI, the chambers were exposed to the pion beam for 22 days at Vk=ΔV$_{GEM}$=-360V with equal transfer and drift fields of 5kV/cm.The transfer field, defined as the GEM down minus cathode voltage over gap, was chosen to avoid transfer discharges. Then, the drift field was set to an equal value to preserve saturation of the primary electron velocity while maintaining a good transparency of the GEM as it can be seen from the pulse shape shown in fig. 3.

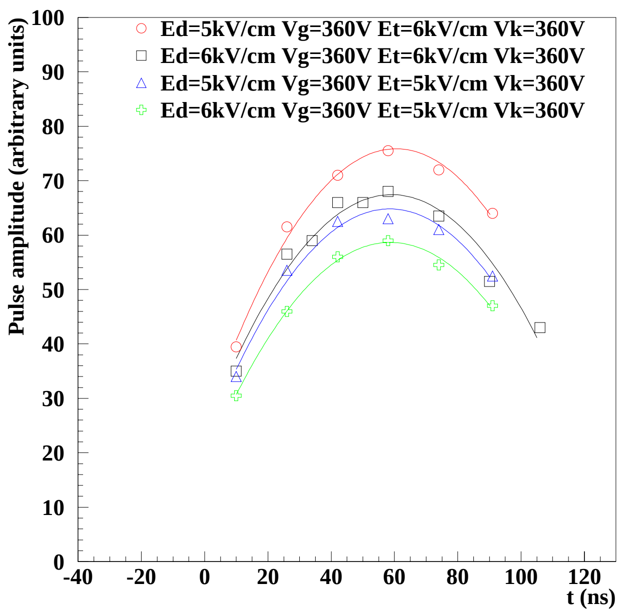

Fig. 3. Mean pulse shapes for various drift and transfer fields (see text for definition of the transfer field).

Under these conditions, the gain, monitored with the total power supplies current, was found to be stable at a value of 2800 $\pm$ 300 (fig. 4) and the maximum probability signal to noise ratio on the strip collecting the largest fraction of the signal was 30, well above the value of 12 at the start of the efficiency plateau (fig. 2). Using the read-out noise value of 970e^{-} for calibration, it can be checked that the measured current and the read-out signal are compatible.

In 22 days, 1 short circuit occurred out of 2410 cathode discharges and no GEM discharges were observed. The cathode discharge rate was 2 10^{-8} cm^{-1} s^{-1}, as compared to a 1000 times larger value for chambers without GEMs, tuned to a same total gain [6]. The advantage of the two amplification stages was therefore clearly demonstrated. The short circuit was the only damage observed. It can be extrapolated to a loss of less than 5% of anodes in 500 days of LHC like irradiation, taking into account a loss of 8 strips per short circuit, given the grouping of 8 cathodes on 1 power supply channel.

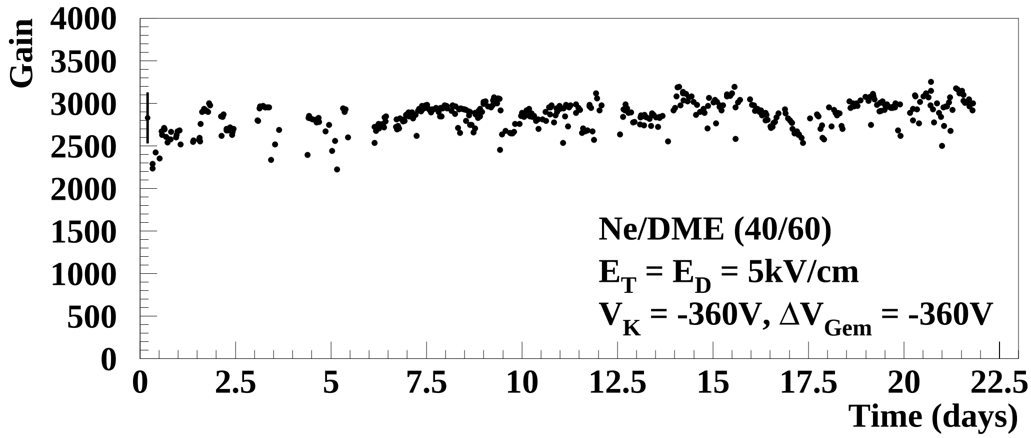

Fig. 4. Stability of the measured gain during the HIP test.

After the long stable running period, 2 voltage scans were performed : one with the cathode voltage, at a fixed ΔV_{GEM}=-360V, and the other with the GEM voltage, at a fixed V_k=-360V. No GEM discharges were observed and the cathode discharge rates were found in both scans to follow an exponential law with the gain, as for the SGCs without GEMs (fig. 5). The advantage with the GEM was again demonstrated by the lower discharge rate, using amplification at this stage rather than at the cathode level. As it can be seen in figure 5, a signal to noise ratio of 50 was reached at V_k=-360V and ΔV_{GEM}=-380V, without increasing the cathode discharge rate as compared to V_k=ΔV_{GEM}=-360V. A cathode voltage lower than 360V, compensated by an equivalent increase on the GEM, leading to a similar gain (fig. 6), should probably be an even better optimization of the operating conditions.

The discharge amplitudes were found to be compatible with the expected strip capacitance of 1pF/cm (fig. 7). During the cathode voltage scan, 6 short circuits occurred out of 3445 discharges, a rate of damage compatible with the one observed in small size chambers (fig. 8). In the small size detectors, the damages were however only anode cuts and their number was found to saturate when the number of integrated sparks reached several thousands. The increase of capacitance with longer strips is an explanation to the difference of discharge effect while the statistics was not sufficient to observe a saturation, if any, in the present measurement.

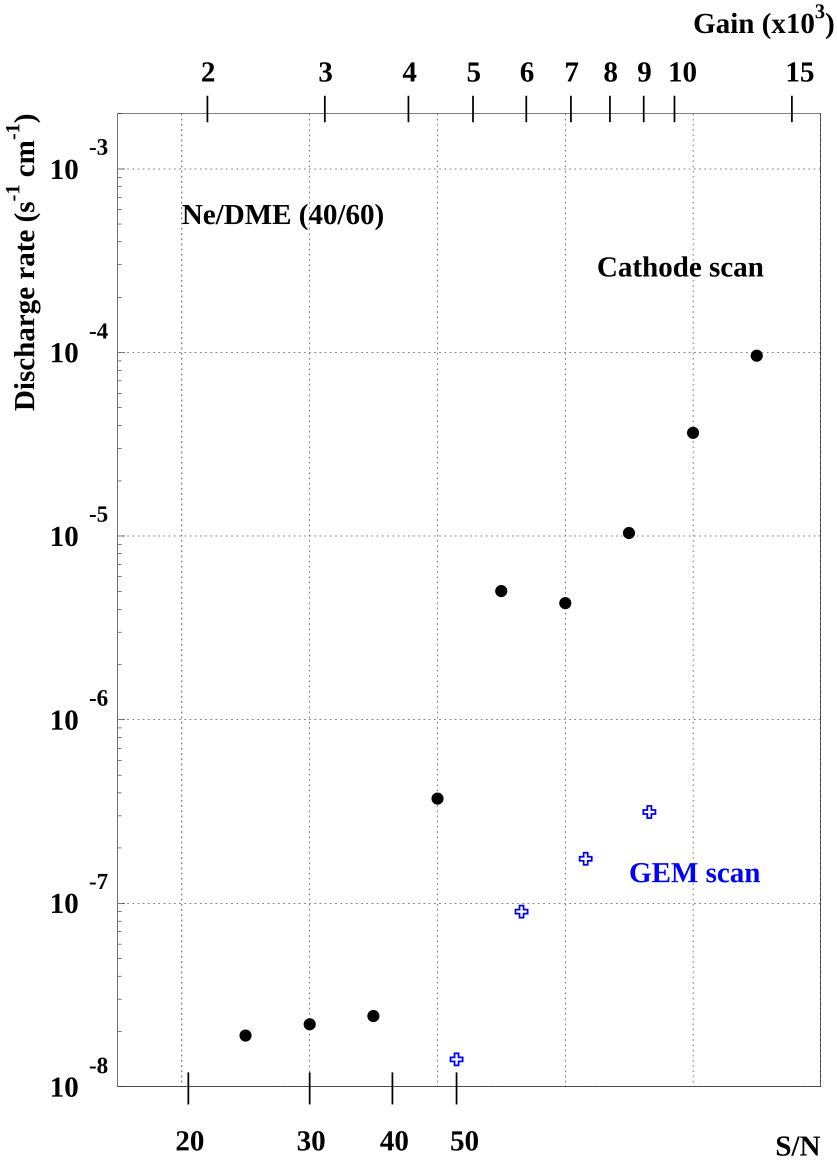

Fig. 5. Discharge rates as a function of gain and signal to noise ratio averaged over all the chambers.

3 Long term ageing

The long term ageing was estimated by the variation of the total current as a function of the integrated charge per centimeter of strip. 4 chambers, 2 with GEMs and 2 without, were exposed for 2 months to an X-ray beam of 6.4 keV. The same NE/DME gas mixture as mentioned above was used and the collimation of the beam was done with 3 different slits of 25 mm^2, 100 mm^2 and 9 cm^2. In all cases, a similar gain loss of 25% was observed after 5 mC/cm of integrated charge, equivalent to a MIP flux of 5kHz/mm^2 during 500 days at a 2800 gain ($\simeq$ LHC conditions).

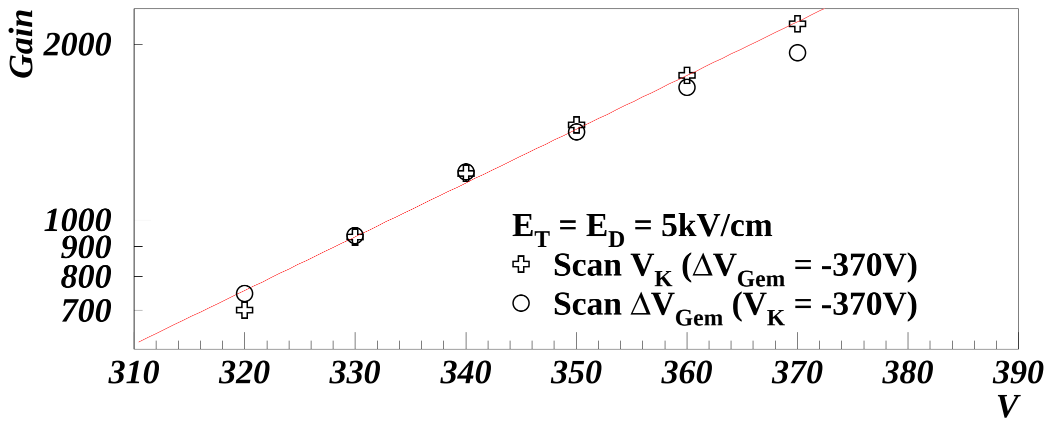

Fig. 6. SGC+GEM gain as a function of cathode and GEM voltages.

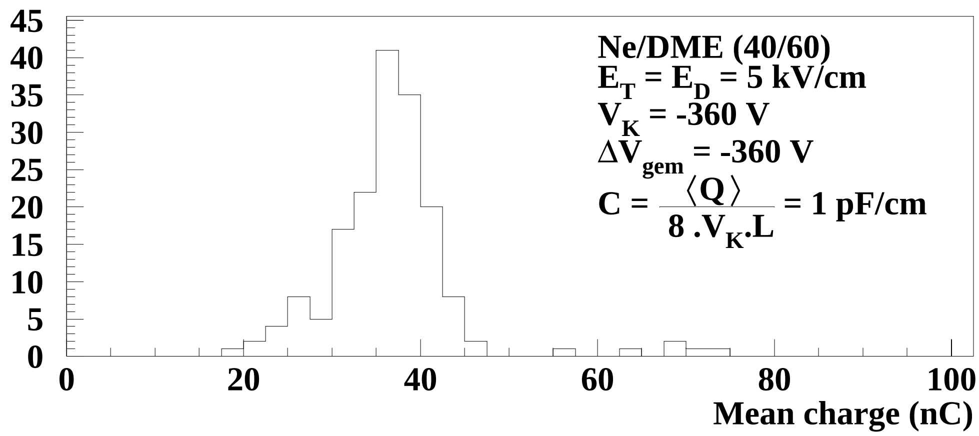

Fig. 7. Charge distribution of discharges.

4 Conclusions

Large size Small Gap chambers equipped with GEMs have been thoroughly characterized for long term use in a harsh HIP environment.

It was found that conditioning the chambers at high cathode and GEM voltages is a useful hardening procedure to avoid short circuits during the beam operation.

Under a high HIP rate, the superiority of the two stage amplification device with a GEM was demonstrated by a significantly reduced discharge rate, show-

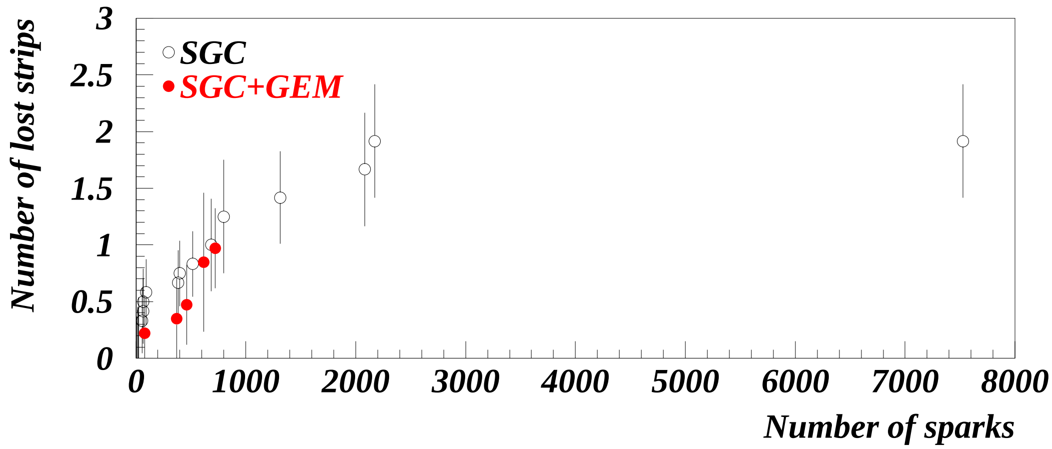

Fig. 8. Number of lost strips as a function of the number of sparks normalized to the number of chambers.

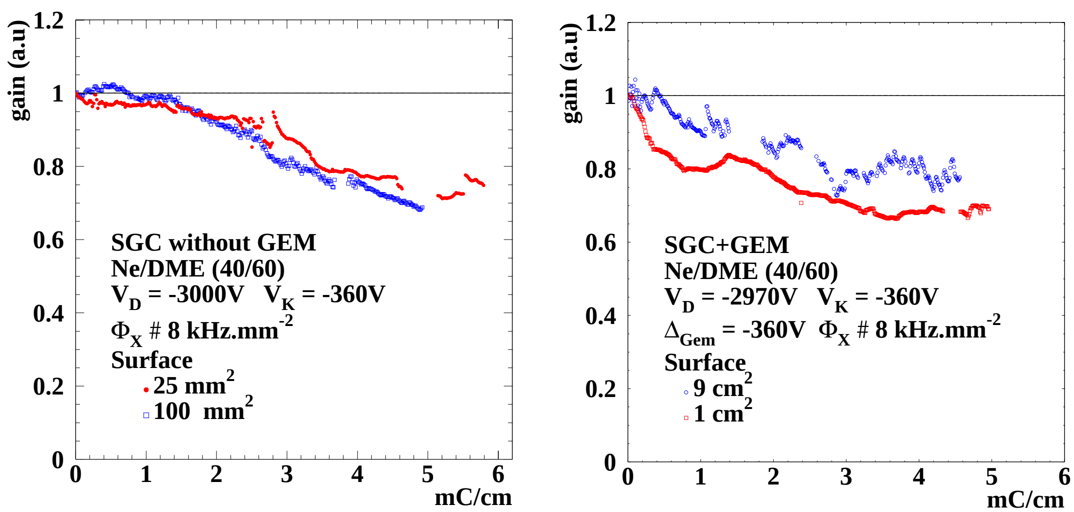

Fig. 9. Gain loss as a function of integrated charge. The data were not corrected for temperature and pressure variations.

ing that this phenomenon depends on the cathode voltage rather than on the total charge collected.

It was shown that a signal to noise ratio of 50 can be reached for a long term application without significant degradation of the detection efficiency. The voltage scans, performed on both cathodes and GEMs, indicate that a decrease of the cathode voltage compensated by an equivalent increase on the GEM could provide a better optimization of the discharge rate versus the signal to noise ratio.

The large value of the signal to noise ratio that was reached, as compared to a value of 12 at the start of the efficiency plateau, allows to consider shorter final shaping times, as obtained for instance with the pulse processing discussed in [12].

The chamber ageing was found to be limited to 25% per 5mC/cm of integrated charge, which will not affect the detection efficiency at the allowed gain.

Finally, although the major parameter of the discharge rate is probably the chamber substrate print quality, it was observed that the drawback of the small gap chambers as compared to the standard microstrip chambers lies in the strip capacitance increase from 0.5 pF/cm to 1 pF/cm due to the smaller anode-cathode gap. It significantly increases the noise with the present read-out electronics and it is also a very sensitive parameter of the discharges effect, leading to short circuits rather than cuts as observed with the 14cm strips detectors. A final optimization of the microstrip chamber anode-cathode gap should take into account the balance between this effect and the possible charging of the substrate at high flux.

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