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Test of a CMS MSGC tracker prototype in a high-intensity hadron beam

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Abstract

A set of CMS MicroStrip Gas Chambers (MSGC) was exposed to a high-intensity 3 GeV/*c* pion beam at a CERN PS facility for a period of two weeks. The performance of the detectors is reported in terms of stability of efficiency and response to minimum ionising particles as well as to more heavily ionising fragments generated by nuclear interactions. © 1998 Elsevier Science B.V. All rights reserved.

The Compact Muon Solenoid [1] (CMS) experiment at LHC foresees to instrument the outer part of the tracking volume with MSGC detectors. The CMS MSGC tracker group has extensively tested the performance of MSGCs over the last years by using high-momentum particles at rates which are low compared to LHC conditions. Multiple investigations of the MSGCs behaviour under high rates of heavily ionising particles have been made using radioactive sources [2], illuminating limited spots of the detectors. The beam test reported here is the first of a sequence dedicated to investigate the performance of MSGCs and to search for unexpected pathologies using a high-rate pion beam; the pion

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inelastic interactions with the setup material generate a finite rate of heavily ionising fragments, approximating that expected at LHC within a factor of two.

1. Experimental setup

1.1. Detectors

A set of 5 MSGCs were assembled according to the CMS baseline specifications. The substrates were made of DESAG 263 glass 300 μm thick and under-coated by electron conducting films of resistivity 10^{16}, 9×10^{15}, 5×10^{15} Ω/cm^2 (Pestov glass) and 1×10^{15} Ω/cm^2 (diamond-like coating). The gold anode strips were 10 cm long, 0.5 μm thick: anodes and cathodes were, respectively, 7 and 90 μm wide, the pitch was 200 μm. Specialised passivation technology was used in the readout plane [3]: the substrate edges perpendicular to the strips were passivated for 0.6 mm by a polyimide film ("standard passivation"); individual cathode edges along the strips were coated by a 3 μm thick polyimide film, 4 μm wide across the strip ("advanced passivation"). This technique prevents field extraction of electrons from the cathode edges, extending the range of working voltage typically by 100–200 V. All cathodes were connected to high voltage but the first and last, which were grounded to optimise the electric field configuration at the chamber edges [4]. The drift cathode was a 500 μm thick PEEK cover, metalised with gold and separated by a drift gap of 3 mm from the readout plane. Each detector had 512 anode strips, read out individually by PREMUX chips [5] with shaping time close to 50 ns and digitised sequentially by a SIROCCO FADC [6]. The chips differ from the final CMS version only in not being radiation hard and not including the deconvolution logic, used to tag the beam crossing of each hit recorded in the MSGCs. The gas mixture was 28% neon and 72% DME. The standard performance of similar detectors is reported in Ref. [4]. Of the five detectors, one was assembled with the forward CMS tracker layout [1] and read out orthogonally to the other detectors. Two additional Micro Gap Chambers (MGCs) were made available and used during the whole test as a tracking telescope. The choice of the working point was made keeping in mind the working conditions at the future CMS experiment. A signal-to-noise (S/N) ratio[4] of 20 allows for a hit reconstruction efficiency better than 98.5%; the S/N ratio at CMS is expected to be degraded by a factor 2.2 with respect to the beam test value at equal voltage conditions [7]. For this reason, the chambers were operated at S/N values of 44 or larger. The corresponding voltage setting were $V_{\mathrm{Drift}} = 3500$ V and $V_{\mathrm{Cathode}} = 520$ V.

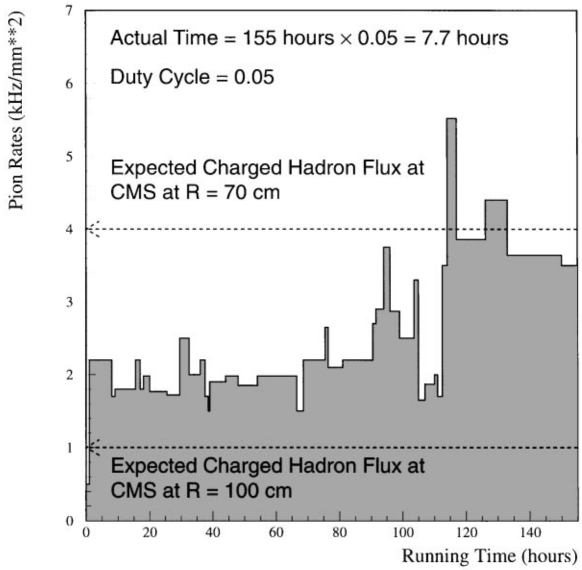

Fig. 1. Average particle rates measured by a 0.5×0.5 cm^2 counter set close to the region of maximum beam intensity as a function of integrated running time.

A dedicated measurement allowed the average gain of the chambers to be estimated at these voltage settings. The anodes of one MSGC were connected to a pico-amperometer and the average charge integrated per spill was normalised to the particle rates measured by a 10×10 cm^2 counter; by using an average primary ionisation of about 40 electrons, a gain of 1700 was estimated.

[4] The S/N ratio is defined here as the ratio of the total cluster charge to the average noise of one strip in the cluster.

1.2. Beam setup

The seven detectors were mounted on a bench at the CERN PS T10 facility and aligned with upstream 5×5 and $10\times10\ \mathrm{cm}^2$ coincidence trigger counters; additional finger counters downstream from the chambers were used for rate measurements.

No dedicated logic was setup to trigger upon inelastic interactions of the pion beam with the chamber material. The probability of interaction was estimated by the ratio of the material thickness to the mean free path for inelastic collisions in the material. Using the π^- cross section on Si,O_2, C and H [8] we estimated an interaction length of 70.5 and 49 cm for the cover and substrate, respectively, amounting to a probability of interaction of about 0.13% per detector. Considering the seven chambers and some material upstream from the first detector, the probability of interaction exceeds 1%. Candidate events with evidence of hard interactions have been found in the data.

2. Data analysis

The 3 GeV/c pion beam was operated at the highest available intensity, and typically two low rate runs per day were recorded to monitor the detector conditions. The beam spill lasted on average 0.3 s every 7.2 s, yielding a duty cycle of 5%.

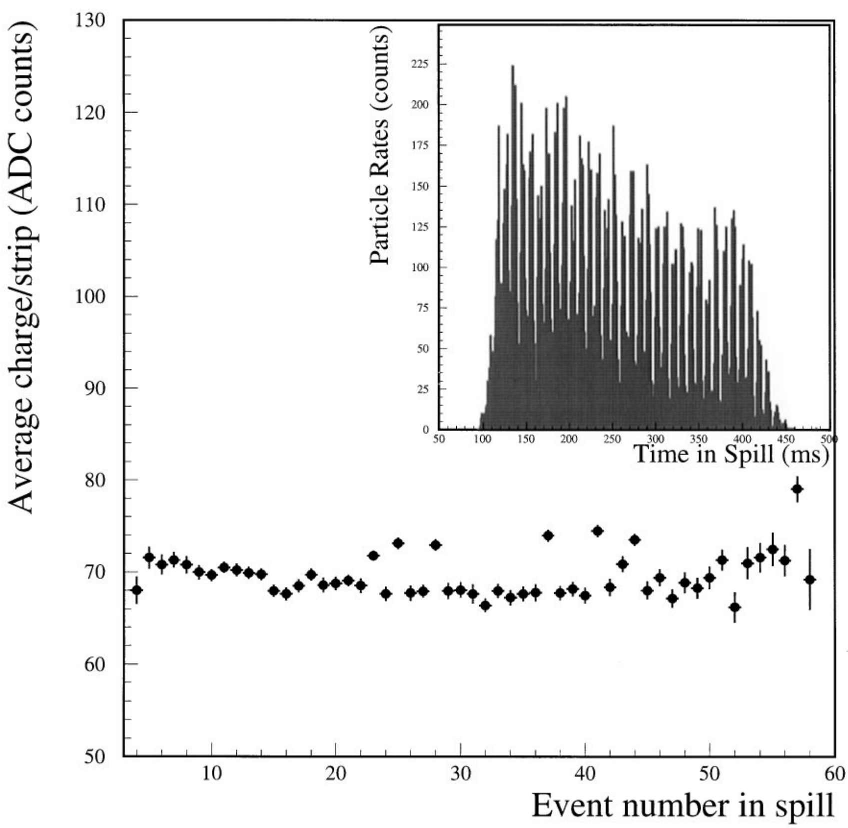

Fig. 2. Most probable value of the total collected charge normalised to the total number of fired strips as a function of the event number in spill. The substrate resistivity is $1\times10^{16}\ \Omega/\mathrm{cm}^2$. The inset shows the instantaneous rates recorded by a $0.5\times0.5\ \mathrm{cm}^2$ counter aligned to the beam profiles maximum (bin = 1 ms) during the same period.

The beam profiles seen by the detectors are well fitted by Gaussian functions of parameters $\sigma_v = 2.4$ cm and $\sigma_h = 2.5$ cm, respectively, in the vertical and horizontal readout directions; the 250 central strips of each detector were then illuminated at the maximum intensity during a period of 155 h. A $5 \times 5\ \mathrm{cm}^2$ scintillator was well centred with the 70% beam containment area; nevertheless, the scaler showed dead time limitation at high beam rates. For this reason we report the rates recorded

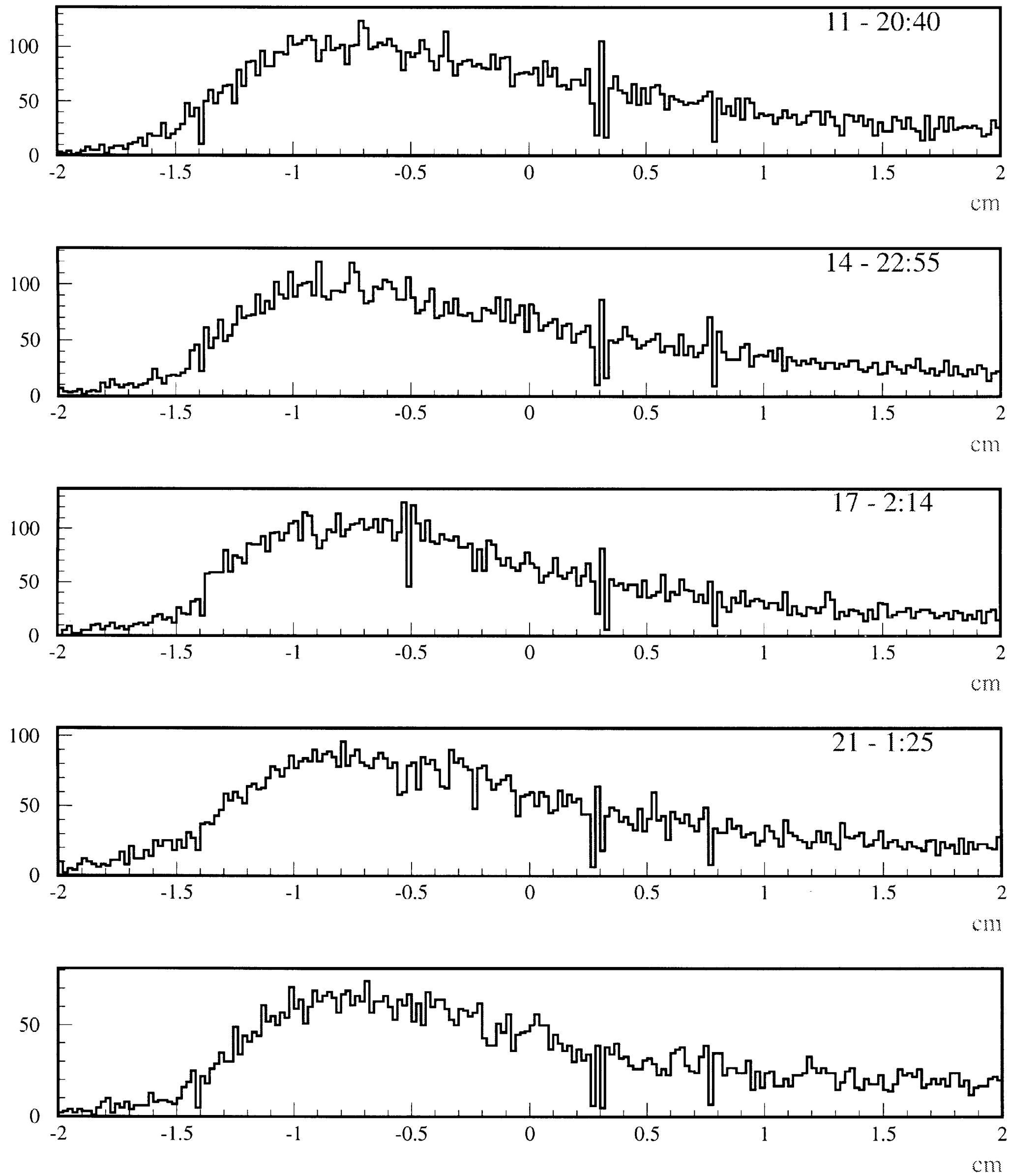

Fig. 3. Beam profile seen by a MSGC detector from the beginning (first plot) to the end (last plot) of the test. No dead or inefficient strip could be detected.

by a $0.5 \times 0.5\ cm^2$ finger counter a few millimetres off the Gaussian peak (Fig. 1). The ratio R of the rates recorded by the small and large scintillator counters varies with the collimator setting and is not well determined from the data available; indicative figures are $R = 3$–4 for the first 100 h and $R = 1$–1.3 for the following 55 h. The measurement of rates should be considered accurate within a factor 2. Within these limitations, the rates reported in Fig. 1 still allow for a reliable comparison with expected LHC conditions, shown in the same plot; the T10 test amounts to about 7.7 h of continuous beam at an integrated rate comparable or larger than the one expected at LHC at a radial distance of 100 cm. It should be noticed from the inset in Fig. 2, that represents the beam spill structure of a typical high-intensity run, that the instantaneous rates can be higher by more than a factor 2 with respect to the average rates reported: for this run the average spill rate is 100 particles/ms to be compared with the actual fluctuations reported in the plot.

Transient effects of charging up of the substrate have been investigated. We have selected the highest luminosity runs and studied the behaviour of the collected charge as a function of the event number within the spill: the most probable value of the sum of the charge in all detected clusters normalised to the total number of strips fired is reported in Fig. 2. An accumulation of positive charge on the substrate or on the polyimide strip passivation would cause a shielding of the electric field and consequently, the collected charge should decrease as a function of rate (time). The analysis reported excludes such an effect on a substrate of resistivity $1 \times 10^{16}\ \Omega/cm^2$.

The cathode voltage of two chambers were ramped up several time during the test, to a maximum of 600 V and at different beam intensity conditions. During about 8% of the total beam time, one MSGC chamber was operated at a cathode voltage between 540 and 570 V, at a typical rate of $4\ kHz/mm^2$. No deviation from the expected exponential behaviour was measured [9].

The detector conditions were monitored periodically to check for the onset of a possible streamer regime, leading eventually to destructive sparks between anodes and cathodes. A streamer mode could be induced by extremely large energy depositions caused by heavily ionising particles, e.g. slow fragments from nuclear interactions, and in general, by a very large instantaneous rate. Destructive sparks involve an amount of energy sufficient to melt the gold strips locally, causing a shortening of the strip active length, and thereby producing irreversible damage in the chambers. Different approaches were used to check the MSGCs condition at the end of the test; we report in Fig. 3 the beam profile recorded by one of the detectors at the beginning (1st plot) and end (5th plot) of the run;

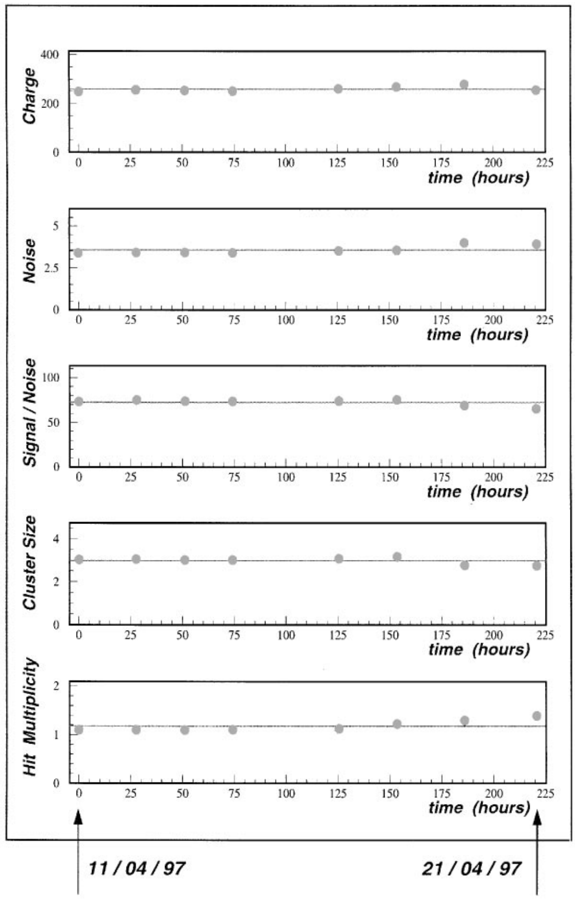

Fig. 4. Stability study for a MSGC chamber. All variables are plotted for the 225 h of running time; the data were recorded in low-intensity runs.

intermediate stages are shown in the other three plots. The plot binning is equal to the strip pitch and a dead or shortened strip would be detected as an inefficiency. No damage has been detected in the MSGCs [9]. A visual inspection of the strips through the glass substrate has confirmed the offline analysis.

The performance of the detectors were analysed for the whole data taking period and a summary of the study is reported in Fig. 4 for a specific chamber [9]. The collected charge, the noise level as well the other variables reported were extremely stable over a period of 225 h.

3. Conclusions

A set of CMS MSGC chambers were tested in a high rate mip beam, containing about 1% of heavily ionising particles. The integrated rate amounts to more than 7 LHC equivalent hours at a radius of 100 cm from the beam pipe to be compared with the CMS MSGC tracking detector ranging within $R \approx 70$ cm and $R \approx 115$ cm. The data show no indication of charging-up of the substrate under the effect of a strong gradient of particle rates. No spark-induced damage has been etected in any of the chambers, inspected by offline analysis and by subsequent visual inspections. The onset of discharges has been investigated to some extent also by raising the chamber gain to values up to 4 times larger than the standard setting expected at CMS conditions. The performance of all detectors has proven to be extremely stable over the whole test period.

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