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Sensitivity and environmental response of the CMS RPC Gas Gain Monitoring system

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ABSTRACT: Results from the gas gain monitoring (GGM) system for the RPC muon detector in the CMS experiment at the LHC are presented. The system is designed to provide fast and accurate determination of any shift in the working point of the chambers due to gas mixture changes.

KEYWORDS: Gaseous detectors; Timing detectors

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1 Introduction

Resistive Plate Chambers (RPC) detectors are widely used in HEP experiments for muon detection and triggering at high-energy, high-luminosity hadron colliders, in astroparticle physics experiments for the detection of extended air showers, as well as in medical and imaging applications. At the LHC, the muon system of the CMS experiment relies on Drift Tubes (DT), Cathode Strip Chambers (CSC) and RPCs for the muon trigger system, with a total gas volume of about 50 m³. Utmost attention has to be paid to the possible presence of gas contaminants which degrade the chamber performance. The gas gain monitoring (GGM) system monitors the gas quality online and is based on small RPC detectors. The working point — gain and efficiency — is continuously monitored along with environmental parameters, such as temperature, pressure and humidity, which are important for the operation of the muon detector system. Design parameters, construction, prototyping and preliminary commissioning results of the CMS RPC Gas Gain Monitoring (GGM) system have been presented previously [1, 2]. In this paper, results on the response of the GGM detectors to environmental changes are presented.

The CMS RPCs are bakelite-based double-gap RPCs with strip readout (for construction details see [3] and reference therein) operated with a 96.2% C₂H₂F₄ — 3.5% Iso-C₄H₁₀ — 0.3% SF₆ gas mixture humidified at about 40%. The large volume of the CMS RPC system and the cost of the gas make the operation of RPCs in a closed-loop gas system (for a complete description see [4]) mandatory, in which the gas fluxing the gaps is reused after being purified by a set of filters [5].

The operation of the CMS RPC system is strictly correlated to the ratio of the gas components, and to the presence of pollutants that can be produced inside the gaps during discharges (i.e. HF produced by SF₆ or C₂H₂F₄ molecular break-up and further fluorine recombination), accumulated in the closed-loop, or by pollution that can be present in the gas piping system (tubes, valves, filters, bubblers, etc.) and flushed into the gaps by the gas flow. The monitoring of the presence of these contaminants, as well as the gas mixture stability, is therefore mandatory to avoid RPC damage and to ensure their correct functionality.

A monitoring system that detect changes of gas composition and pollution must provide a fast response in order to avoid irreversible damage of the whole system. The GGM system monitors

efficiency and signal charge continuously by means of a cosmic ray telescope based on RPC detectors. In the following we briefly describe the final setup of the GGM system, and the first results obtained during its commissioning at the ISR test area (CERN).

2 The Gas Gain Monitoring system

The GGM system is composed by the same type of RPC used in the CMS detector but of smaller size (2 mm-thick Bakelite gaps, $50 \times 50 \text{ cm}^2$). Twelve gaps are arranged in a stack located in the CMS gas area (SGX5 building) on the surface, close to CMS assembly hall (LHC-P5). The choice to install the system in the surface instead of underground allows one to profit from maximum cosmic muon rates. In order to ensure a fast response to working point shifts with a precision of 1%, 10^4 events are required, corresponding to about 30 minutes exposure time on surface, to be compared with a 100-fold smaller rate underground. The trigger is provided by four out of twelve gaps of the stack, while the remaining eight gaps are used to monitor the working point stability.

The eight gaps are arranged in three sub-system: one sub-system (two gaps) is operated with the fresh CMS mixture. The second sub-system (three gaps) is operated with CMS gas coming from the closed-loop gas system and extracted before the gas purifiers, while the third sub-system (three gaps) is operated with CMS gas extracted from the closed-loop after the gas purifiers. The basic idea is to compare the operation of the three sub-systems and, if some changes are observed, to send a warning to the experiment. In this way, the gas going to and coming from the CMS RPC is compared to the fresh gas. This setup will ensure that pressure, temperature and humidity changes affecting the gaps behavior do cancel out because the three subsystems operate in the same ambient condition.

The monitoring is performed by measuring the charge distributions of each chamber. The eight gaps are operated at different high voltages, fixed for each chamber, in order to monitor the total range of operating modes of the gaps. The operation mode of the RPC changes as a function of the voltage applied. A fraction of the eight gaps will work in pure avalanche mode, while the remaining will be operated in avalanche+streamer mode. Comparison of signal charge distributions and the ratio of the avalanche to streamer components of the ADC provides a monitoring of the stability of working point for changes due to gas mixture variations.

Details on the construction of GGM can be found in [2]. Each chamber of the GGM system consists of a single gap with double sided pad read-out: two copper pads are glued on the two opposite external side of the gap. The signal is read-out by a transformer based circuit A3 (figure 1). The circuit allows to subtract the two signals, which have opposite polarities, and to obtain an output signal with subtraction of the coherent noise, with an improvement by about a factor 4 of the signal to noise ratio. The output signals from circuit A3 are sent to a CAEN V965 ADC (with a 50 fC/channel sensitivity) [6] for charge analysis.

A typical ADC distribution of a GGM gap is shown in figure 2 for two different effective operating voltages, defined as the high voltage set on the HV power supply corrected for the local atmospheric pressure and temperature. Figure 2a), corresponding to $HV_{\text{eff}} = 9.9 \text{ kV}$, shows a clean avalanche peak well separated from the pedestal. Figure 2 b) shows the charge distribution at $HV_{\text{eff}} = 10.7 \text{ kV}$ with two signal regions corresponding to the avalanche and to avalanche+streamer mode.

A3

$R1 = 10 \text{ ohm}$

$C1 = 10 \text{ nF}$

$R2 = 68 \text{ ohm}$

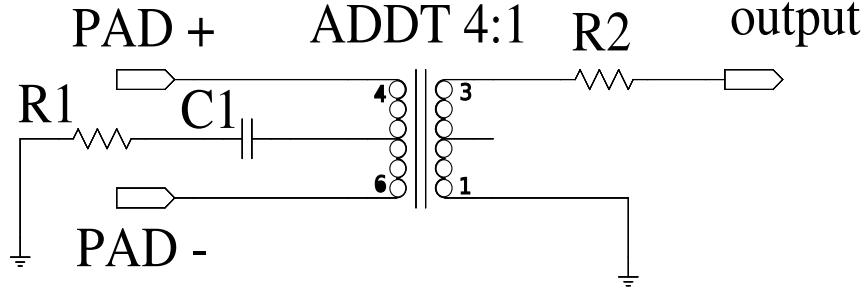


Figure 1. The electric scheme of the read-out circuit providing the algebraic sum of the two pad signal (PAD + and PAD -).

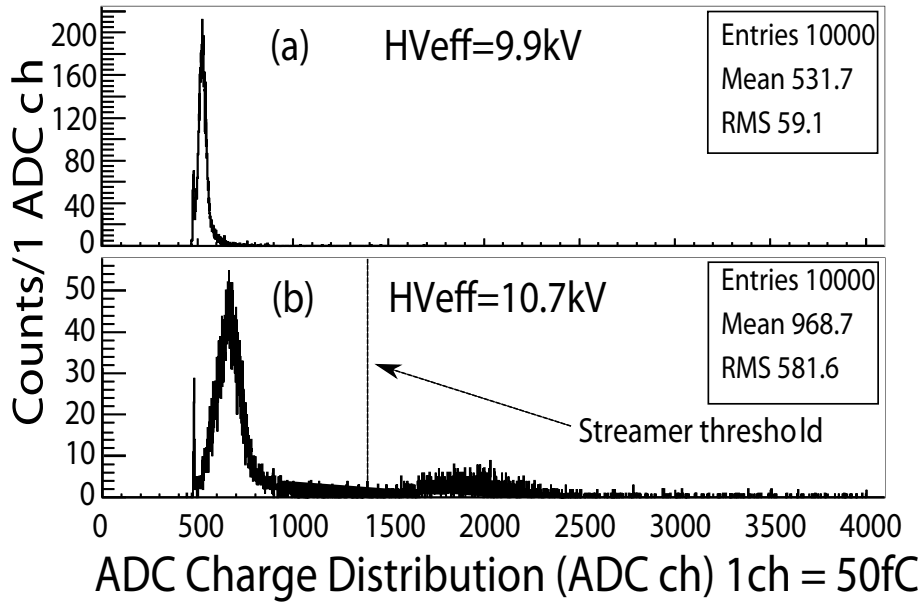


Figure 2. Typical ADC charge distributions of one GGM chamber at two operating voltages. Distribution (a) correspond to $HV_{eff} = 9.9 \text{ kV}$ while distribution (b) to $HV_{eff} = 10.7 \text{ kV}$. In (b) the streamer peak around 1900 ADC channels is clearly visible. The events on the left of the vertical line (1450 ADC channels in this case) are assumed to be pure avalanche events.

Figure 3 shows the GGM single gap efficiency (full dots), and the ratio between the avalanche and the streamer component (open circles), as a function of the effective high voltage. Each point corresponds to a total of 10000 entries in the full ADC spectrum. The efficiency is defined as

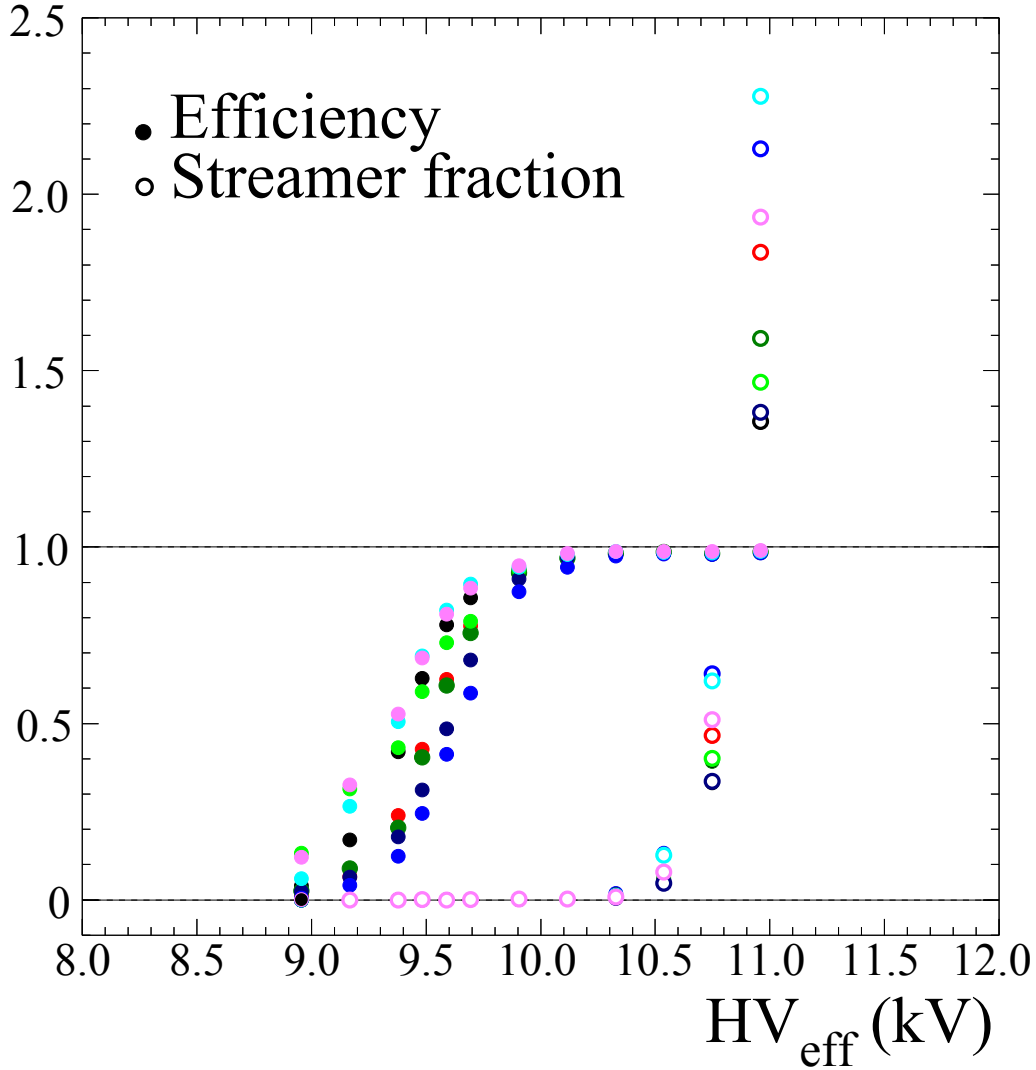


Figure 3. Efficiency plot (full dots) of GGM chambers as a function of HV_{eff} . The efficiency is defined as the ratio between the number of ADC entries above $3\sigma_{\text{ped}}$ and the number of acquired triggers. Open dot plots correspond to the streamer fraction of the chamber signal as a function of HV_{eff} .

the ratio between the number of triggers and the number of events above $3\sigma_{\text{ped}}$, where σ_{ped} is the pedestal width. The avalanche to streamer ratio is defined by counting the number of entries in the avalanche region (below the streamer threshold (figure 2b) and above the pedestal region) and dividing it by the number of streamer events above the streamer threshold. Both efficiency and avalanche plateau are in good agreement with previous results [7].

In order to determine the sensitivity of GGM gaps to working point shifts, the avalanche to streamer transition was studied by two methods, the charge method and the efficiency method. In the charge method, the mean value of the ADC charge distribution in the whole ADC range is studied as a function of HV_{eff} (figure 4). Each point corresponds to 10000 events in the whole ADC spectrum, open squares are the anodic charges of the eight RPC gaps, while the full squares are their averages for each high voltage value. In the plot three working point regions are identified

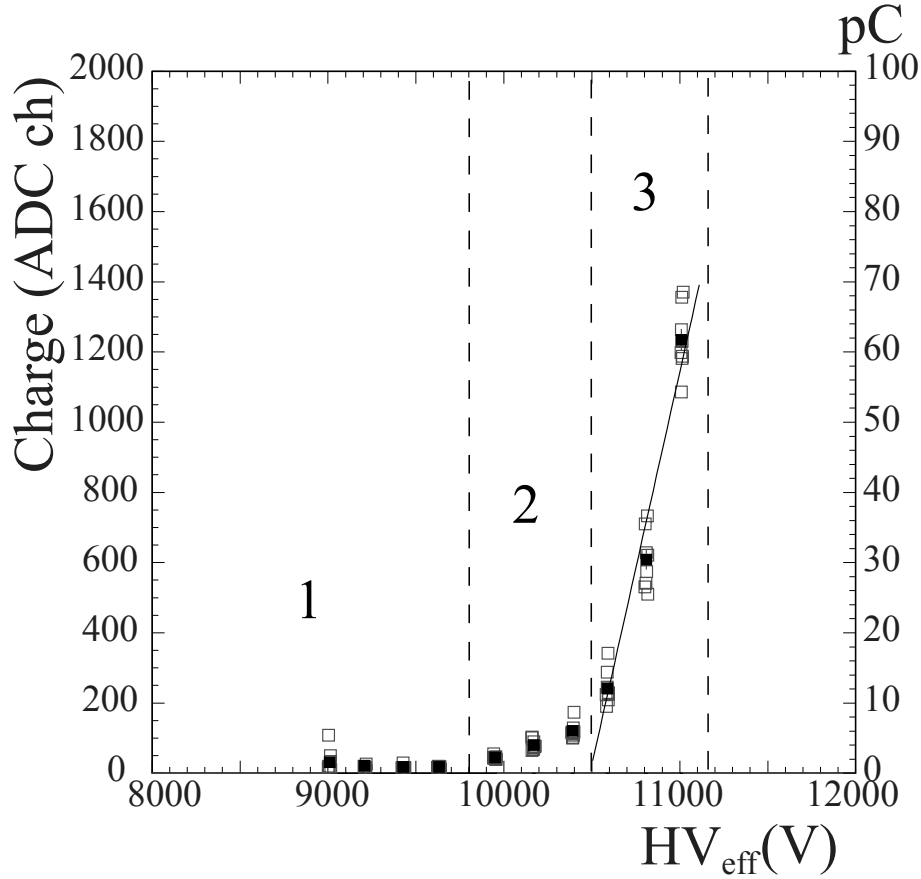


Figure 4. Average avalanche charge of the eight monitor chamber signals as a function of HV_{eff} . The slope is $(2.24 \pm 0.05) \text{ ADC/V}$. Each point corresponds to 10000 triggers.

1. inefficiency ($HV_{\text{eff}} < 9.8 \text{ kV}$);
2. avalanche ($9.8 \text{ kV} < HV_{\text{eff}} < 10.5 \text{ kV}$);
3. avalanche+streamer mode ($HV_{\text{eff}} > 10.5 \text{ kV}$).

The best sensitivity to working point shifts is achieved in the avalanche+streamer region. A best fit of a straight line performed over the data points in the fit region #3 yields a $(2.24 \pm 0.05) \text{ ADC ch/V}$ (or $(112 \pm 2) \text{ fC/V}$) sensitivity.

In the efficiency method, the ADC avalanche event yield is studied as a function of HV_{eff} (figure 5). The avalanche signal increases by increasing the HV applied to the gap, until it reaches a maximum value after which the streamer component starts to increase. A best fit of a straight line performed over the data points in the 9.2 kV–10.2 kV dashed fit region yields a $(13.4 \pm 0.7) \text{ events/V}$ — or $(1.3 \pm 0.1) \% / (10 \text{ V})$ — sensitivity.

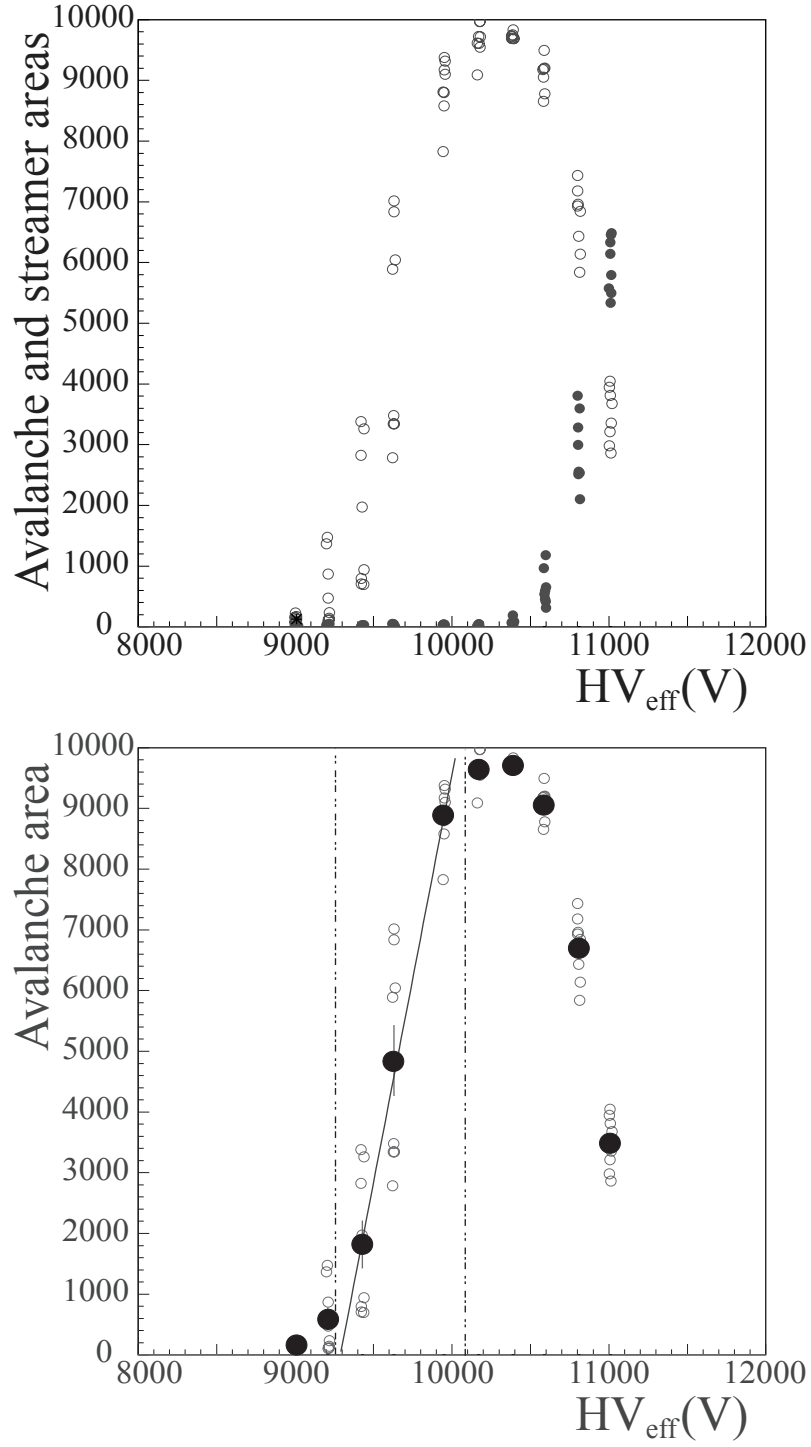


Figure 5. (left) Streamer (empty dots) and avalanche (solid dots) yields as a function of HV_{eff} , for the eight RPC gaps. Each point corresponds to 10000 collected triggers. (right) The solid line is fit to the average of eight gaps (solid dots) in the dashed region, with a (13.4 ± 0.7) events/V slope, corresponding to a $(1.3 \pm 0.1)\%/10\text{V}$ sensitivity.

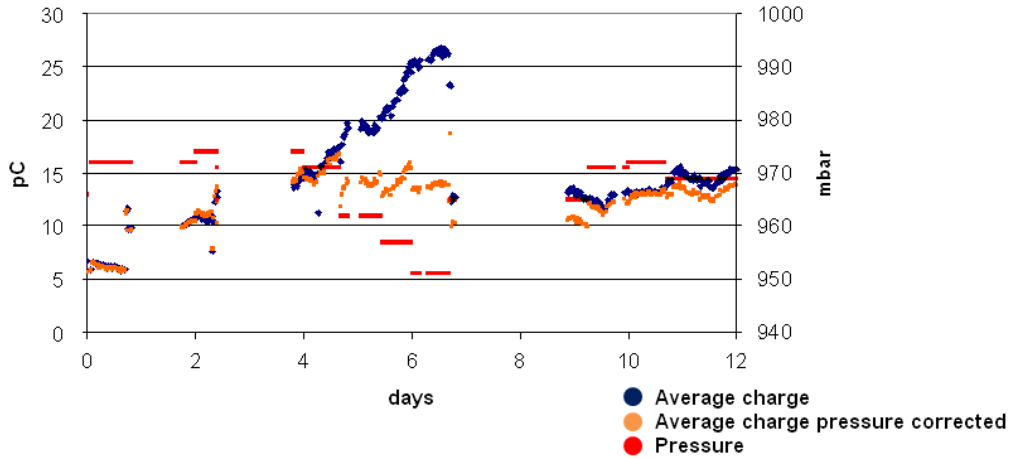


Figure 6. Average charge and pressure-corrected charge.

3 Response of GGM to environmental effects

The working point of any RPC detector is affected by environment, most notably by pressure and temperature whose effect is customarily parametrized via linear relationships. An example of correction of the data from GGM using such parametrizations is shown in figure 6, where the average charge distribution (black dots) is plotted across a changeover of gas bottles. Data show a sudden increase in the average charge distribution which may interpreted as a shift of working point due to changes in gas mixture composition. By weighing the average charge with a correction factor linearly depending on atmospheric pressure, however, no significant increase is left in the distribution of corrected average charge (green dots) which may signal an anomalous shift due to gas mixture.

The redundancy in the number of RPC gaps flushed by the same gas mixture allows one to cancel common environmental effects directly, without need of knowing the parametrization law. The cancellation algorithm was studied by means of two-gap ratio of the charge distribution (figure 7). While the charge of two gaps is influenced by the effect of atmospheric pressure, temperature and humidity, their ratio, however, is shown to be stable at the 2% level over a period of several weeks (figure 8).

4 Conclusions

Results from the Gas Gain Monitoring System for the CMS RPC Detector have been reported on. The purpose of GGM is to monitor any shift of the working point of the CMS RPC detector. The system redundancy allows for effectively cancelling out the environmental effects at the 2% level. Preliminary results show sensitivity to working point changes in charge distribution

$$(2.24 \pm 0.05) \text{ADC ch/V}$$

$$(112 \pm 2) \text{fC/V}$$

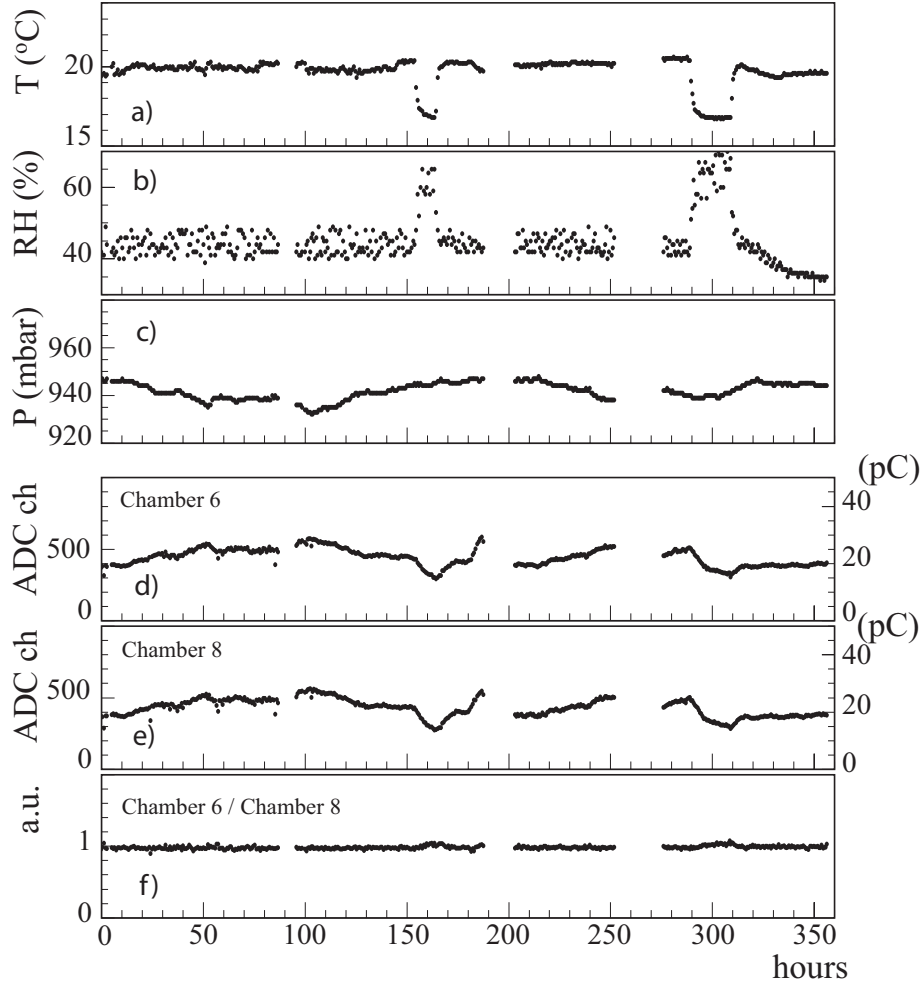


Figure 7. Stability of GGM against environment variation common to all gaps, such as atmospheric pressure (a), temperature (b), umidity (c). The charge of two gaps is heavily influenced by environment (d,e), while their ratio shows a 2% stability over several weeks (f).

and in efficiency

$$(13.4 \pm 0.7) \text{ events/V}$$

$$(1.3 \pm 0.1) \% / (10 \text{ V})$$

The GGM system will be operated with three different gases. Each gas will flush a pair of gaps kept at the same operating voltage. The signal of gaps flushed with same gas will be mutually normalized to cancel out common environmental effects. The normalized output will be then compared with the normalized output of a pair of gaps flushed by a different gas. Our results show how the sensitivity of such a cancellation is adequate to detect 10 V shifts in the working point. The GGM is currently being commissioned in the SGX5 area of the CMS experiment at CERN.

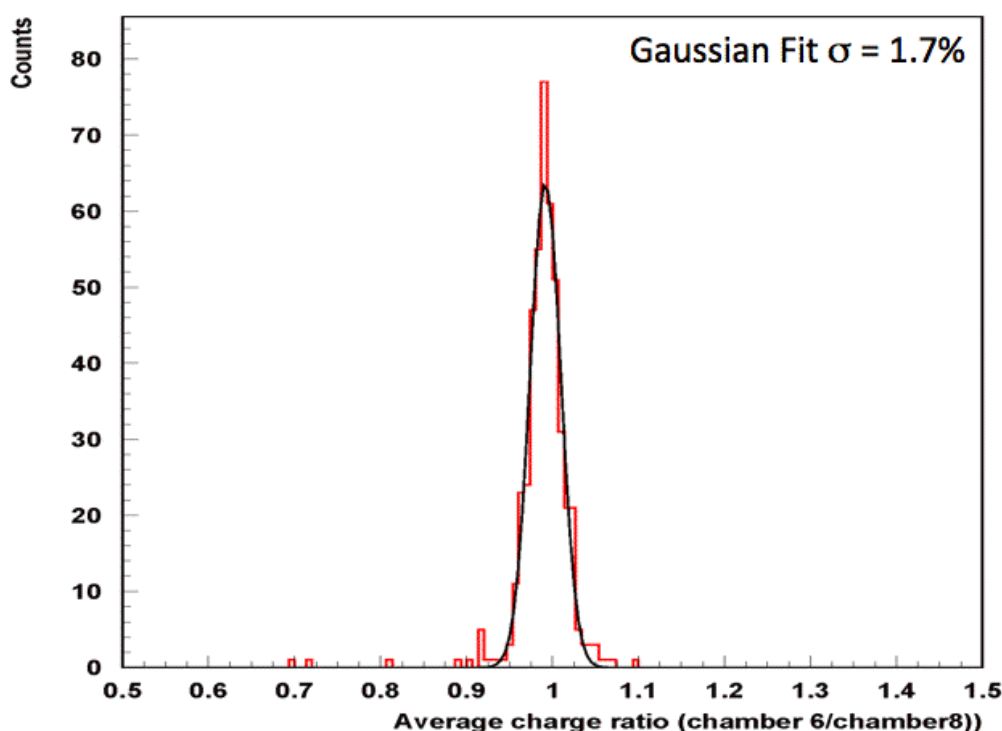


Figure 8. Two-chamber charge ratio. Gaussian fit has a 1.7% rms width.

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