Performance of the Gas Gain Monitoring system of the CMS RPC muon detector and effective working point fine tuning

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ABSTRACT: The Gas Gain Monitoring (GGM) system of the Resistive Plate Chamber (RPC) muon detector in the Compact Muon Solenoid (CMS) experiment provides fast and accurate determination of the stability in the working point conditions due to gas mixture changes in the closed loop recirculation system. In 2011 the GGM began to operate using a feedback algorithm to control the applied voltage, in order to keep the GGM response insensitive to environmental temperature and atmospheric pressure variations. Recent results are presented on the feedback method used and on alternative algorithms.

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2012 JINST 7 P12004

Contents

1 Introduction

The muon system of the Compact Muon Solenoid [1] (CMS) experiment, at the LHC pp collider of CERN, Geneva (Switzerland), uses three different detector technologies: Drift Tube Chambers (DT), Cathode Strip Chambers (CSC) and Resistive Plate Chambers [2] (RPC). As for any gas-based particle detector, the response of the CMS RPC system is strictly correlated to environmental variables, to the ratio of the gas components, and to the presence of pollutants that can be produced inside the gaps during discharges. The CMS RPCs are bakelite-based double-gap RPCs operated with a 95.2% $C_2H_2F_4$ - 4.5% Iso-C_4H_{10} - 0.3% SF_6 gas mixture with an approximate 40% relative water vapor content. By design, the RPC gas system runs in closed loop [3], with a fresh injected amount of gas limited to only 10%. Therefore, the absence of gas mixture contaminants must be guaranteed by means of suitable filtering and monitoring systems.

The Gas Gain Monitoring (GGM) [4, 5] has been designed to monitor online the working point of the CMS RPC detector [6–8] for changes due to gas mixture differences in the Closed Loop (CL) recirculation system among fresh, before filters and after filters gas mixture. The monitoring is performed by checking the stability of the anodic charges ratios between gas mixtures, in order to cancel out common effects due to environmental parameters (temperature, humidity, atmospheric pressure). The GGM was installed and commissioned in 2010 on the CMS detector and has been taking data since then [9, 10].

Recently a study was performed aimed to provide the system with a high-voltage supply feedback system which allows to compensate for temperature T and atmospheric pressure p variations. With such a feedback algorithm the GGM charge distributions do not depend on p and T, thus allowing one to monitor any gas mixture change common to the three (fresh, before-purifiers, after-purifiers) gas types.

In this paper the status and collected results during 2011 data-taking are presented and discussed along with preliminary results on the T and p feedback algorithm.
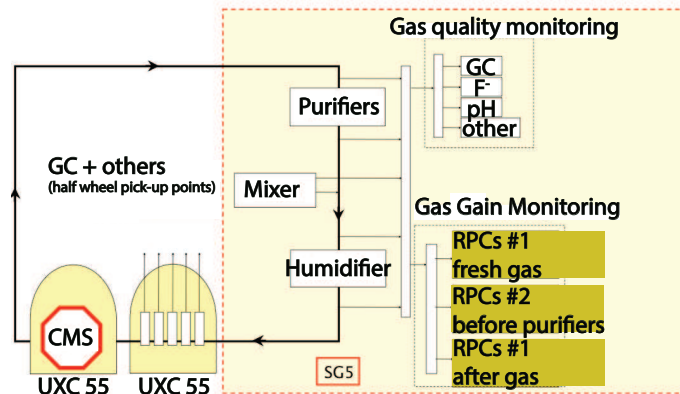
Figure 1. The GGM system integrated into CMS closed loop gas system.

## 2 The Gas Gain Monitoring system setup

The GGM (figure 1) is composed of twelve single-gap bakelite RPC detectors, with 2 mm thickness and (50×50) cm^2 area. The setup is installed, on surface, in the CMS SGX5 building, close to CMS assembly hall, to profit from maximum cosmic muon rates necessary to provide a fast response.

The GGM consists of a cosmic-ray telescope of twelve RPC single gaps arranged in three sub-systems: "Fresh Gas", "Before purifiers" , "After purifiers". The first sub-system (two gaps) is operated with the fresh CMS RPC gas mixture and is used as reference. The second sub-system (three gaps) is operated with gas coming from the CMS RPC closed-loop gas system and extracted before the gas purifiers, while the third sub-system (three gaps) is operated with gas extracted after the gas purifiers. The purpose of GGM is to monitor any deviation of the working point of the CMS RPC detector due to differences among the three gas types. This is accomplished by comparing the signal of cosmic muons in gaps flushed with different gas origin. The GGM system runs continuously in a fully automatic way, each data sample consists in 10^4 events that are collected every 30 minutes and the analysis is completed online providing to RPC operation a prompt working point measurement.

Each chamber of the GGM has a double side pad read-out, the signal is read-out by a transformer based circuit that allows to algebraically subtract the two signals, which have opposite polarities, and to obtain an output signal with subtraction of the coherent noise and with an improvement by about a factor 4 of the signal to noise ratio [5]. The GGM RPC read-out pads are connected to a VME (VERSABUS Module Eurocard) ADC (Analog to Digital Converter) that is controlled by a semi-automatic DAQ system.

The GGM DAQ starts automatically when all computers boots-up and runs unsupervised thanks to several control scripts. At the end of each 30 minutes data taking run, the DAQ invokes a dedicated post-processor which performs the analysis on the raw files. The post processor produces a Data Summary Tape (DST) file that contains run summary details with the monitored values of each GGM RPC chamber.

All environmental parameters are continuously monitored (room temperature, relative humidity, atmospheric pressure). Temperature, pressure and relative humidity sensors are also installed in the gas line before and after each chamber. The accuracy of the temperature sensor is $\pm1^\circ$C in
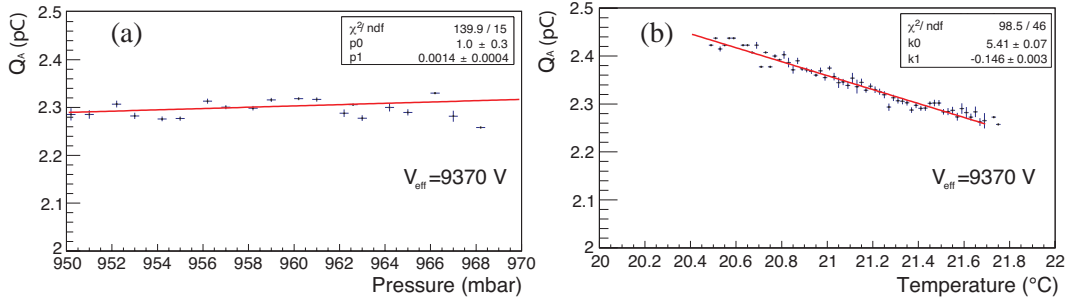
Figure 2. (a) Correlation plot between GGM RPC anodic charge against environmental pressure. (b) Correlation plot between GGM RPC anodic charge against environmental temperature. The meaning of fit parameters p_0, p_1, k_0, k_1 is described in the text.

the range 0–40°C and the resolution is 0.1°C. The relative humidity sensor has an operating range from 2% to 98% with a 0.1% resolution, $\pm 1\%$ absolute accuracy. The barometer operational range is between 700 mbar and 1050 mbar with a 0.1 mbar resolution and a ± 1 mbar accuracy.

3 Feedback algorithm

An HV (High Voltage) feedback function was added in 2011 to compensate for environmental conditions that affect the GGM chambers response. Such an algorithm has constituted a test ground for a possible application of a similar HV feedback to the full CMS RPC system. This solution aims to correct the applied voltage of each chamber maintaining its gain constant against environmental changes that would modify the working point of the chamber. The applied HV (V) is corrected according to the environmental pressure and temperature. The algorithm keeps stable the effective HV (V_{eff}) as in the eq. (3.1) [11]:

$$V_{eff} = V \cdot \frac{p_0 T}{p T_0} \tag{3.1}$$

where p_0=965 mbar and T_0=293 K.

Figure 2(a) shows correlation plots between the anodic charge of one typical chamber against environmental pressure, while figure 2(b) shows the anodic charge against temperature for the same chamber. Both figure 2(a) and figure 2(b) refer to data taken with the chamber operated at the 50% of efficiency, corresponding to an HV=9370 V.

Data points in figure 2(a) and figure 2(b) have been fitted to linear functions:

$$Q_A(p) = p_0 + p_1 p \tag{3.2}$$
$$Q_A(T) = k_0 + k_1 T \tag{3.3}$$

The fit in figure 2(a) returns very poor fit quality and parameters roughly compatible with a constant function. Work is ongoing to study the residual systematics affecting the fit. The quality of fit in figure 2(b) is acceptable and the fit linear function describes adequately the dependence of Q_a with respect to atmospheric temperature. An overcorrection effect is evident. The feedback
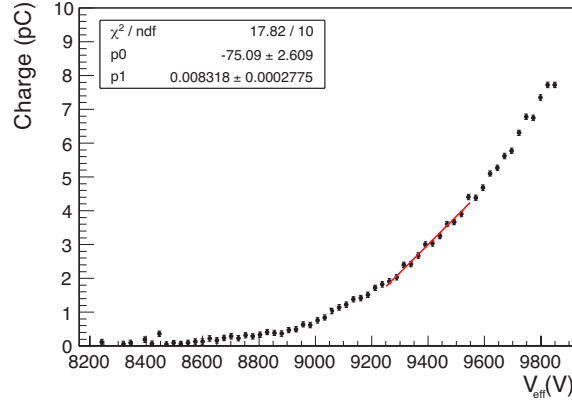
Figure 3. Charge trend as a function of effective voltage one typical GGM chamber.

formula used (eq. (3.1)) overcorrects the applied HV by decreasing more than necessary the supply voltage. To characterize the overcorrection and determine a more suitable feedback correction function we have used formula in eq. (3.4) from [12]:

$$V_{\text{eff}} = V \cdot \frac{p_0}{p} \cdot \left[1 + \alpha_T \cdot \left(\frac{T}{T_0} - 1 \right) \right] \tag{3.4}$$

In order to determine the α_T parameter we use for each chamber its own gain curve (Q vs V curve). In figure 3 is shown a typical charge vs voltage dependence curve. We fit the data with a linear curve in a interval around the typical operation voltage. The interval is chosen in such a way to take into account the total temperature excursion over one year of operation at SGX5, expected to be about 3°C corresponding to ≈90 V. From figure 2(b) and figure 3 the dependence between voltage and temperature corresponds to 17.5 V/°C. Using the eq. (3.4), from the analysis of our data shown in figure 2(b) we find:

$$\alpha_T = 0.40 \pm 0.05 \tag{3.5}$$

4 Operational experience

In March 2011 an hardware failure occurred to the CMS RPC gas Mass Flow Controller (MFC) leading to a wrong mixture injected into the closed loop. It was concluded that the faulty MFC was delivering about 34% more SF_6 than designed. The content of SF_6 increased from 0.30% to 0.34% affecting the RPC working point. The gain variation was shown by means of a series of HV scans which identified the faulty MFC (figure 4 (top) as example) and confirmed the presence of a wrong gas mixture. The function η adopted to perform the HV efficiency scan fit is described by the eq. (4.1) from [14]:

$$\eta = \frac{\varepsilon_{\text{max}}}{1 + e^{-\lambda(V_{\text{eff}} - V_{50\%})}} \tag{4.1}$$

Figure 4 (bottom) shows the difference (in voltage) at the 50% efficiency between HV scans performed with good and wrong gas mixture. The difference between April (good mixture) - March (wrong mixture) shows about 100 V difference at 50% efficiency.
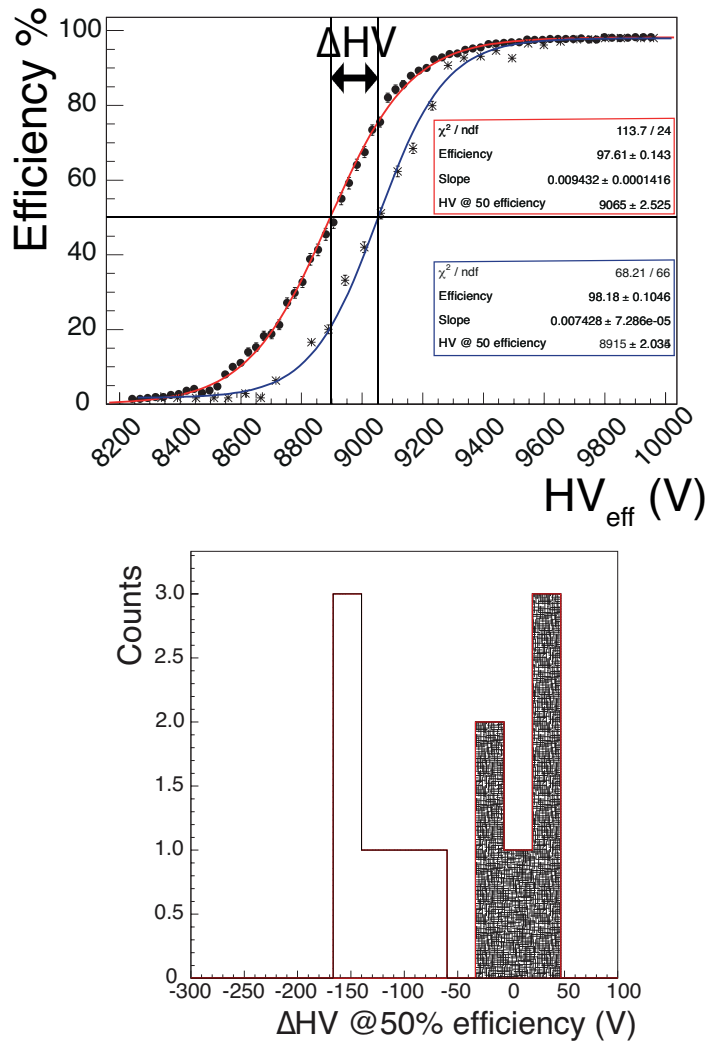
Figure 4. (top) Typical GGM high voltage scan performed during January 2010 (star) and April 2011 (full circle). (bottom) Difference in voltage between the HV scans performed in April 29th 2011 (correct gas mixture) with respect to and March 3th 2011 (empty histogram - wrong gas mixture) and January 10th 2010 (hatched histogram - correct gas mixture).

5 Conclusions

A feedback algorithm was developed and tested on the GGM system of the CMS RPC muon detector. The feedback adjusts the HV supply in order to change the gain and therefore to stabilize the GGM working point against variations in atmospheric pressure and room temperature.

Results show how the feedback function used (eq. (3.1)) provides an adequate correction for pressure but not for temperature. A study of the residual charge-temperature correlation was performed by using a modified feedback function (eq. (3.4)), whose parameter was measured $\alpha_T = 0.40 \pm 0.05$. Our preliminary results are being finalized and will be used to correct (and to be implemented in) the feedback function of the CMS RPC detector.

Finally, the monitoring of the working point of the GGM performed via dedicated HV scans was shown to be a sensitive tool to assess the stability of the gas mixture, as shown for small variations of the SF_6 fraction occurred following a hardware failure of MFC.

References

[1] CMS collaboration, S. Chatrchyan et al., *The CMS experiment at the CERN LHC*, 2008 *JINST* **3** S08004 [INSPIRE].

[2] R. Santonico and R. Cardarelli, *Development of resistive plate counters*, *Nucl. Instrum. Meth.* **187** (1981) 377 [INSPIRE].

[3] M. Bosteels et al., *CMS Gas System Proposal*, CMS Note 1999/018 (1999);
L. Besset, F. Hahn, S. Haider and C. Zinoni, *Experimental tests with a standard closed loop gas circulation system*, CMS Note 2000/040 (2000).

[4] M. Abbrescia et al., *Gas analysis and monitoring systems for the RPC detector of CMS at LHC*, presented by S. Bianco at *IEEE NSS 2006*, San Diego U.S.A. (2006) [physics/0701014] [INSPIRE].

[5] L. Benussi et al., *Sensitivity and environmental response of the CMS RPC gas gain monitoring system*, 2009 *JINST* **4** P08006 [arXiv:0812.1710] [INSPIRE].

[6] L. Benussi et al., *Study of gas purifiers for the CMS RPC detector*, *Nucl. Instrum. Meth.* **A 661** (2012) S241 [arXiv:1012.5511] [INSPIRE].

[7] S. Colafranceschi et al., *Operational experience of the gas gain monitoring system of the CMS RPC muon detectors*, *Nucl. Instrum. Meth.* **A 617** (2010) 146 [INSPIRE].

[8] S. Bianco et al., *Chemical analyses of materials used in the CMS RPC muon detector*, CMS-NOTE-2010-006 (2009).

[9] L. Benussi et al., *The CMS RPC gas gain monitoring system: An Overview and preliminary results*, *Nucl. Instrum. Meth.* **A 602** (2009) 805 [arXiv:0812.1108] [INSPIRE].

[10] L. Benussi et al., *A new approach in modeling the response of RPC detectors*, *Nucl. Instrum. Meth.* **A 661** (2012) S182 [arXiv:1012.5508] [INSPIRE].

[11] M. Abbrescia et al., *Resistive plate chambers performances at cosmic rays fluxes*, *Nucl. Instrum. Meth.* **A 359** (1995) 603 [INSPIRE].

[12] M. Bianco et al., *ATLAS RPC certification with cosmic rays*, *Nucl. Instrum. Meth.* **A 602** (2009) 700 [INSPIRE].

[13] CMS collaboration, S. Costantini, *Calibration of the RPC working voltage in the CMS experiment*, *Proceeding of XI Workshop on Resistive Plate Chambers and Related Detectors (RPC2012)*, Roma Italy (2012).

[14] M. Abbrescia et al., *Cosmic ray tests of double-gap resistive plate chambers for the CMS experiment*, *Nucl. Instrum. Meth.* **A 550** (2005) 116 [INSPIRE].