The Compact Muon Solenoid Experiment
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Performance of the Resistive Plate Chambers in the CMS experiment

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Abstract

Resistive Plate Chambers (RPCs) are used in the Compact Muon Solenoid (CMS) experiment at the Large Hadron Collider (LHC) as a dedicated trigger device. Moreover, they contribute to the muon identification and reconstruction alongside Drift Tubes and Cathode Strip Chambers. The RPC detector performance after more than one year of LHC operation is reported here.

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Performance of the Resistive Plate Chambers in the CMS Experiment

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ABSTRACT: Resistive Plate Chambers (RPCs) are used in the Compact Muon Solenoid (CMS) experiment at the Large Hadron Collider (LHC) as a dedicated trigger device. Moreover, they contribute to the muon identification and reconstruction alongside Drift Tubes and Cathode Strip Chambers. The RPC detector performance after more than one year of LHC operation is reported here.

KEYWORDS: Gaseous detectors; Particle tracking detectors (Gaseous detectors); Resistive-plate chambers.

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Contents

1. Introduction	1
2. CMS Resistive Plate Chambers	2
2.1 Detector	2
2.2 Detector Layout	2
2.3 Readout Strips	2
2.4 Trigger Algorithm	3
3. Detector Performance	3
3.1 Parameters	3
3.2 High Voltage Scan	4
4. Results	5
4.1 Hit Efficiencies	5
4.2 Cluster Size	5
4.3 Noise	5
4.4 Spatial Resolution	6
5. Conclusions	6

1. Introduction

The Compact Muon Solenoid (CMS) [1] is one of two general-purpose experiments at the Large Hadron Collider (LHC) [2] that have been observing $\sqrt{s} = 7\text{ TeV}$ proton-proton collisions for over a year now. Its compact geometry is built around a 6m diameter superconducting solenoid with a 3.8T magnetic field. Outside the solenoid an iron return yoke is interleaved with gas ionisation detectors to trace muons.

Three different gaseous detector technologies are combined to trigger and reconstruct muons [3]. In the barrel region Drift Tube Chambers (DTs) are arranged in coaxial layers to detect muons up to pseudorapidity $|\eta| < 1.2$. The planar endcap regions are equipped with Cathode Strip Chambers (CSCs) ($0.9 < |\eta| < 2.4$) to handle the higher rates and nonuniform magnetic field. Resistive Plate Chambers (RPCs) [4] cover $|\eta| < 1.6$, providing detectors characterised by a time resolution $\lesssim 3\text{ ns}$ and a spatial resolution of the order of 1 cm for both regions, fully adequate for the muon trigger system purposes.

To better understand and optimise the performance of the RPCs within CMS, data of both regular runs and a series of dedicated runs during spring 2011 have been studied. These efforts are described in the following sections. Section 2 starts with an introduction on the implementation and use of the RPCs in CMS. Section 3 then discusses the parameters and techniques used to measure and optimise their performance, leading to the results summarised in Section 4.

Figure 1. Cross-section of a CMS Resistive Plate Chamber. The bottom gap mirrors the top one.

Figure 2. Cross-section of a quadrant of the CMS experiment, showing the muon chambers in the barrel (MB) and endcap (ME) regions. The interaction point is located in the lower left corner, the beam pipe along the z axis.

2. CMS Resistive Plate Chambers

2.1 Detector

CMS uses double-gap Resistive Plate Chambers, with each 2 mm gas gap formed by two parallel bakelite electrodes (bulk resistivity $\rho \sim 10^{10} \Omega \text{cm}$). The gaps are placed one on top of another with common copper readout strips in between (Fig. 1). They are operated in avalanche mode to safeguard the time resolution at high rates ($\sim 1 \text{ kHz cm}^{-2}$), using a three-component gas mixture composed of 95.2 % $\text{C}_2\text{H}_2\text{F}_4$ (R-134a), 4.5 % $i\text{C}_4\text{H}_{10}$ (isobutane) and 0.3 % SF_6 with a 35 %–40 % humidity at 21 °C. Recirculation of the gas mixture in a closed loop with a 10 % fresh mixture injection keeps the cost down, and a set of purifiers limits gas pollution [5, 6]. In addition to a gas chromatograph, a stack of RPCs above ground – exposed to cosmic rays – continuously monitors the recirculated gas mixture before and after the purifiers, as well as the fresh mixture [7].

2.2 Detector Layout

In the barrel region the muon chambers are organised in four coaxial stations, interleaved with iron return yokes (Fig. 2). The outer two stations each consist of one layer of RPCs and one layer of DTs. The inner two stations contain a layer of DTs sandwiched between two layers of RPCs in order to trigger and reconstruct also low- p_T muons. The endcap region is composed of three iron disks holding a total of 3 RPC planes and 4 CSC planes on each side of the experiment.

2.3 Readout Strips

The geometry of the RPC strips is mainly driven by the need to trigger on the transverse momentum of passing muons. For this reason, each of the 912 RPC chambers contains a plane of strips with a $\Delta\phi \approx 0^\circ 18' 45''$ pitch running along the beam axis in the barrel region and radially in the endcap region. Along the η -direction, each chamber is divided into two to three η -partitions (rolls, Fig. 3), resulting in strip lengths of 57 cm to 125 cm in the barrel and 47 cm to 79 cm in the endcap

Figure 3. Cross-section of a quadrant of the CMS RPC subdetector, showing the RPC strips. For trigger purposes, the RPC subdetector is divided into 25 towers along η , matching the strip lengths in the reference layers (red). Each tower consists of 144 cones along the ϕ coordinate.

Figure 4. The extrapolation algorithm extends the track segment found in a DT or CSC chamber and looks for hits near the extrapolated impact point on the RPC strip plane.

region. On-detector front-end boards with programmable discriminators and pulse shapers convert the signals on the strips to 100ns Low Voltage Differential Signaling (LVDS) pulses.

2.4 Trigger Algorithm

To identify muon candidates for every LHC bunch crossing (BX, 25 ns), the RPC muon trigger uses a pattern comparator algorithm (PAC) implemented on FPGAs [8]. The fired RPC strips in subsequent layers are compared with patterns generated using Monte Carlo simulations of muons passing through the CMS detector. To parallelise the PAC trigger logic, the RPC subdetector is segmented along η and ϕ in so-called cones (Fig. 3), each delivering up to one muon candidate for every BX. Per region up to four candidates are passed on to the CMS Global Muon Trigger and combined with those from the DT and CSC track finders.

When a measurement matches several patterns, the algorithm will favour the one with the highest p_T . For this reason an increase in cluster size (CLS, the number of contiguous strips fired when an ionising particle traverses the RPC) can promote the muon candidate p_T and reduce the overall RPC muon trigger performance.

3. Detector Performance

3.1 Parameters

With the gas-mixture fixed and chambers installed, one of the main controllable parameters of the RPCs is the applied high voltage (HV). The dependence of the avalanche production on the environmental pressure P , the temperature T and the HV can be summarised in an effective high voltage [9, 10]

$$\text{HV}_{\text{eff}} = \text{HV} \times \frac{P_0}{P} \times \frac{T}{T_0} \quad (3.1)$$

Figure 5. Efficiency curve of a typical RPC chamber. The curve is a fit of sigmoid (3.2) to the hit efficiencies measured during the HV scan.

Figure 6. Measured and predicted distributions of the hit efficiency at the calculated working point HV_{WP} for the rolls in the barrel region. Some chambers were switched off during this measurement, contributing to the difference between the observed and expected mean efficiency.

where HV_{eff} is the effective high voltage, and for the results in these proceedings $P_0 = 965$ mbar and $T_0 = 293$ K.

The efficiency ε of an RPC has been found to follow a sigmoidal shape [11]

$$\varepsilon = \frac{\varepsilon_{max}}{1 + e^{S(HV_{eff} - HV_{50\%})}} \quad (3.2)$$

where $HV_{50\%}$ is HV_{eff} for $\varepsilon = \frac{\varepsilon_{max}}{2}$ and S is a parameter indicating the steepness of the sigmoid. An example curve for a typical chamber is shown in Fig. 5. It is clearly important to stay well on the plateau of the efficiency curve despite changes in environmental parameters. Care must be taken however not to increase cluster size, noise and streamer probability needlessly, to avoid poor trigger performance and detector degradation.

3.2 High Voltage Scan

For the aforementioned reasons a high voltage scan (HV scan) was made during the spring of 2011: collision data was recorded at 11 HV_{eff} settings during a series of dedicated runs to define the optimal operating voltage for each chamber.

The presence of either a DT chamber or a CSC chamber near every RPC makes it possible to predict hits in the RPCs using only track segments reconstructed within the neighbouring CSC or DT chamber. An algorithm extrapolates every segment to the associated RPC strip plane, and then looks for a cluster near the extrapolated impact point (Fig. 4). This method provides both a measure for the hit efficiency ε and, through the residuals, for the spatial resolution. The limited data size and processing time for these elements allow for a small prescaling factor of the monitoring data, limiting the time needed for the 11 HV_{eff} points.

Figure 7. Evolution of the hit efficiency after the HV scan for the barrel region. The average efficiency is found to be $\bar{\epsilon} = 94.9\%$ in the barrel, and $\bar{\epsilon} = 93.8\%$ in the endcap region.

Figure 8. Average cluster size of a typical chamber for different HV_{eff} in the HV scan.

Using this data, sigmoids (3.2) were successfully fitted per roll and a working point HV_{WP} has been defined as

$$HV_{\text{WP}} = HV_{\text{knee}} + \begin{cases} 100 \text{ V} & (\text{barrel}) \\ 150 \text{ V} & (\text{endcap}) \end{cases} \quad (3.3)$$

where HV_{knee} is HV_{eff} for $\epsilon = 0.95 \cdot \epsilon_{\text{max}}$. An averaging procedure was applied for rolls with common HV supply.

4. Results

4.1 Hit Efficiencies

After applying the fits (3.2) to the efficiencies measured in the HV scan, the calculated HV_{WP} were applied to the chambers. In addition to a good χ^2 distribution of the fits, the agreement between efficiencies measured in following runs and efficiencies predicted using the sigmoids (3.2) confirmed the technique (Fig. 6). The system shows a stable efficiency with a remaining 1% fluctuation due to pressure changes (Fig. 7). This as a result of the HV_{eff} dependency around the working point. To suppress also these variations, an automatic online pressure correction for the HV was introduced in the summer of 2011, and is now under evaluation.

4.2 Cluster Size

Given its impact on the PAC trigger algorithm and the resolution, the cluster size has to stay low. A moderate increase was found in the HV_{eff} region around the HV_{WP} (Fig. 8), but the resulting cluster size distribution shows an average below 2 strips (Fig. 9).

4.3 Noise

Still considering the RPC muon trigger, the intrinsic noise of the RPCs should be kept low. By measuring the hit rates during no-collision periods, an intrinsic noise well below 0.5 Hz cm^{-2} was

Figure 9. Measured and predicted cluster size distributions at HV_{wp} .

Figure 10. Gaussian fits to the residual distributions in the innermost and outermost barrel layers. The corresponding strip widths are 2.28 cm and 4.10 cm.

found for most chambers. These rates are negligible for accidental muon triggering, since the RPC muon trigger system needs coincidence of fired strips in three or more planes within a 25 ns window and a limited spatial region.

4.4 Spatial Resolution

Using the extrapolation method mentioned in Section 3, a residual defined as the distance in the RPC plane between the extrapolated impact point and the centre of the RPC cluster can be used as a measure for the spatial resolution (Fig. 4). The standard deviations of Gaussian fits to the distributions of these residuals are then considered as the spatial resolutions (Fig. 10). The values stay below $\frac{\overline{CLS}(w) \times w}{\sqrt{12}}$ for all strip widths w , because the spatial resolution is enhanced by the correlation between the impact point and the cluster size and centre: the probability to find $CLS = 2$ increases when a muon passes near the edge of a strip or between two adjacent strips, resulting in a cluster centre closer to the actual impact point.

5. Conclusions

The performance of the RPCs in the CMS experiment is well understood and tuned using regular and dedicated collision runs. The results show that the RPCs form a stable and reliable sub-detector, contributing to the trigger and reconstruction capabilities for the CMS physics programme.

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