

STUDY OF THE PERFORMANCE OF RPC SYSTEM
INSTALLED AT THE CMS EXPERIMENT

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Abstract

The CMS (Compact Muon Solenoid) experiment is a general purpose detector, located at the CERN Large Hadron Collider (LHC). It has a muon spectrometer equipped with a redundant system composed of three different detector technologies – Resistive Plate Chambers (RPCs) and Drift Tubes (DTs) in the barrel and RPC and Cathode Strip Chambers (CSCs) in the endcap region. All three are used for muon reconstruction and triggering. The RPC detector system consists of a total of 1056 double-gap chambers, covering the pseudo-rapidity region up to $|\eta| \leq 1.6$. Here we present the Resistive Plate Chambers performance results for the period of 2015 and 2016 with pp collisions at 13 TeV. The stability of the RPC performance is reported in terms of efficiency, cluster size and rate distributions.

Key words: Resistive Plate Chambers, muon spectrometers

1. Introduction. The Compact Muon Solenoid (CMS) [1] is a multipurpose detector operating at the Large Hadron Collider (LHC) at CERN, which has been successfully collecting data since the start of the first physics run period in 2009. It has a redundant and robust muon system [2] which uses three different gaseous detector technologies – Drift Tubes (DTs) in the barrel region, Cathode Strip Chambers (CSCs) in the endcap region and Resistive Plate Chambers (RPCs) both in barrel and endcap regions. The RPC system consists of 1056 detectors which cover an active area of more than 3500 m². The barrel region is cylindrical

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and has 4 stations, which are grouped into 5 wheels around the beam pipe, while the endcap region is planar and has 4 stations called disks. During the first long shutdown (LS1) of the LHC (2013–2014), the CMS muon upgrade collaboration added 144 new double-gap RPC detectors, thus completing the 4 forward stations (RE4s) [3]. Adding these stations increased the overall robustness of the CMS muon spectrometer and improved the trigger efficiency in the endcap region with pseudorapidity in the range $1.2 < |\eta| < 1.6$, shown in Fig. 1.

2. Chamber design and performance. The RPC chambers rely on High Pressure Laminate (HPL) Bakelite gaps with 2 mm gas space between the plates, organized in a double gap design with a copper strip readout panel placed in between [4]. The HPL sheets resistivity is of the order of $2 - 5 * 10^{10} \Omega\text{cm}$. They operate in avalanche mode with a standard gas mixture of 95.2% $\text{C}_2\text{H}_2\text{F}_4$, 4.5% iC_4H_{10} and 0.3% SF_6 .

The barrel region of the RPC system has 480 RPCs, distributed equally among the 5 wheels (W-2, W-1, W0, W+1, W+2). According to the direction of φ (azimuthal angle), each wheel is divided into 12 sectors (S01-S12), where the first sector is aligned to the positive X-axis. Further to the trigger requirements, the chambers are subdivided with respect to pseudorapidity in 2 or 3 partitions, called rolls [2]. This geometry difference is driven by the need to have adjustable trigger on muons with different transverse momentum pT. The endcap region has its 8 disks (4 for the positive side of interaction and 4 for the negative side of interaction), where chambers are trapezoidal, covering 10° of the azimuthal angle and are arranged in two concentric rings. Each chamber is indicated as a segment CH01 through CH36 within a ring. Segment CH01 lays on the positive X-axis direction and the numbering proceeds anti-clockwise in respect to the interaction point. Endcap RPCs are divided in η in 3 rolls.

The readout strips have different geometry depending on which part of the system they are in – the barrel chambers have rectangular shaped strips, while in the endcap chambers their shape is trapezoidal. The pitch of the strips depends on the distance to the beam pipe varying from 1.5 cm for the innermost stations to 4 cm for the outermost stations.

2.1. Efficiency. The RPC efficiency is calculated as the ratio between the number of detected and the number of expected hits. Expected hits are defined using a segment extrapolation method [5, 6]. Standalone muon tracks are reconstructed without taking into account RPC hits in order to avoid biases. Segments (DT in the Barrel and CSC in the endcap) that belong to a standalone muon track are selected and extrapolated to the plane of a given RPC. The detector unit is considered efficient if an RPC reconstructed hit is found within ± 2 strips from the position extrapolated from the DT/CSC segment.

The number of extrapolated segments depends on the instantaneous luminosity and the amount of data collected. Analyzing smaller data samples requires a special selection procedure. Only events with at least a minimum of 10^2 ex-

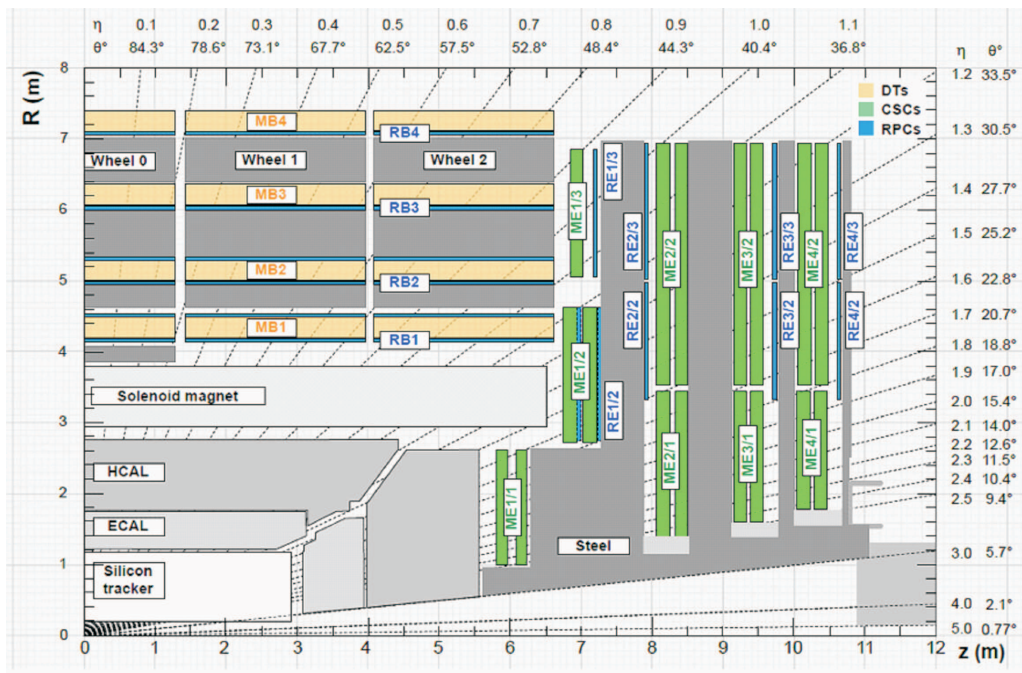


Fig. 1. Longitudinal layout of one quadrant of the CMS detector which shows the enhancement in trigger efficiency with 4th endcap (RE4) in the pseudorapidity region $1.2 < |\eta| < 1.6$

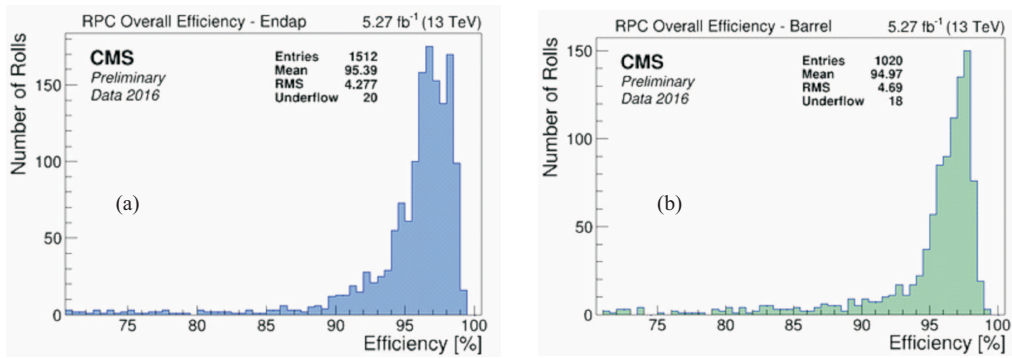


Fig. 2. Overall efficiency for the barrel region (a) and the endcap region (b) estimated for 2016 data taken at 3.8 Tesla

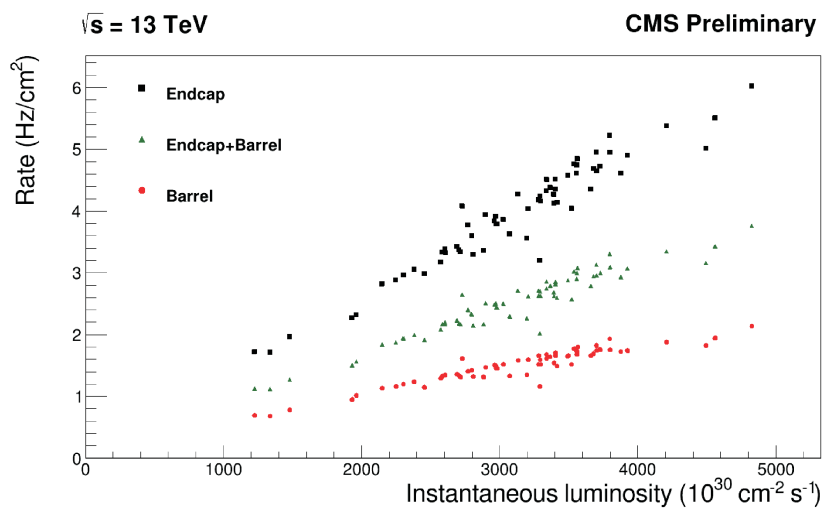


Fig. 3. Average hit rate vs. instantaneous luminosity, with 2015 13TeV pp collisions data

trapolated segments are taken into account. The shown results are statistically significant, as the total number of extrapolated segments in each roll of the RPC system is above 10^5 .

The overall efficiency distribution for both parts of the RPC system is shown in Fig. 2. It is based on the analysis with proton-proton collision data at $\sqrt{s} = 13$ TeV.

The underflow entries in the plots are from rolls with efficiency lower than 70%, caused by the known hardware problems – chambers with gas leak problems in the barrel and low voltage problems in the endcap. These rolls are 1.8% of all barrel rolls and 1.2% of all endcap rolls.

2.2. Cluster size. An important quantity defining the RPC spatial resolution is the cluster size. The RPC cluster size is defined as the number of adjacent strips fired simultaneously. The cluster size depends on the strip pitch and because of this it is higher for the innermost eta partitions and it is smaller for the outermost ones.

The mean value for the RPC system cluster size is < 2 strips which is in good agreement with the designed values and expectations [2].

2.3. Spatial resolution. The segment extrapolation method also allows the estimation of the RPC spatial resolution. Residuals are calculated as the difference between the local x coordinates (transverse view of the RPC detection plane) of the extrapolated point and the centre of the matched RPC reconstructed cluster. The residual distributions are fit to Gaussian distributions and the resulting values for the mean and the standard deviation σ are in agreement with the expectations [2].

2.4. RPC background. The overall performance of the CMS RPC system depends also on the background radiation levels as it gives the main contribution in the measured RPC rate. Figure 3 shows the approximately linear increase of the RPC rates with the increase of the LHC luminosity.

The red dots represent the rate measured in barrel and the black represent the rate measured in endcap. The green markers relate to the overall rate evaluated for the entire RPC system. A higher rate in the endcap is caused mainly by the larger number low transverse momentum p_T muons in the forward (endcap) region with respect to the central (barrel) one. There is also higher background level in this part of the cavern.

3. Conclusions. During the 2015–2016 data taking, the CMS RPC system is operating very well and is stable. The quality of the experimental data taken, as well as the performance of the system is in agreement with expectations and simulations with average efficiency of $\sim 95\%$, average cluster size persistently below 2 and average rate of < 5 Hz/cm².

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