CMS endcap RPC performance analysis

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ABSTRACT: The Resistive Plate Chamber (RPC) detector system in LHC-CMS experiment is designed for the trigger purpose. The endcap RPC system has been successfully operated since the commissioning period (2008) to the end of RUN1 (2013). We have developed an analysis tool for endcap RPC performance and validated the efficiency calculation algorithm, focusing on the first endcap station which was assembled and tested by the Peking University group. We cross checked the results obtained with those extracted with alternative methods and we found good agreement in terms of performance parameters [1]. The results showed that the CMS-RPC endcap system fulfilled the performance expected in the Technical Design Report [2].

KEYWORDS: Large detector-systems performance; Performance of High Energy Physics Detectors
1 Introduction

The Compact Muon Solenoid (CMS) [3] is one of the general purpose experiments at Large Hadron Collider (LHC) [4]; the physics motivation is to test and to complete the Standard Model (SM), especially for what concerns the search for the Higgs boson and the exploration of new physics beyond SM. The CMS detector consists of various sub-detector systems [3]. The muon system located outside of the magnetic coil is designed for muon triggering and tracking; it consists of 3 technologies: the Drift Tube in barrel region, the Cathode Strip Chamber (CSC) in endcap region, and Resistive Plate Chamber (RPC) in both regions.

The RPC detector system is designed for trigger purpose and an average detection efficiency of 90% is expected on each muon station. During the production, each RPC chamber was tested extensively using cosmic rays after the assembly, the results agreed well with the expectation [5, 6]. Since year 2008 the endcap RPC system had been installed on CMS yokes and started commissioning, the data collected were analyzed by several algorithms to evaluate the efficiency during the initial operation.

This alternative study tries to set up a more robust algorithm to measure the RPC efficiency also in presence of higher luminosity of LHC.

2 Endcap RPC system

According to the position along the beam pipe, the forward muon system is divided into 2 symmetric endcaps, each of them is further divided into 4 disks. Each disk composed of 2 kinds of muon detectors (CSC and RPC), which form a station. In the mounting of CSC [7], station 1 consists of 3 circular rings, on which chambers are installed with the same radius. Those rings are divided into 36 segments in azimuth $\phi$ by the chambers, on ring 2 the neighbor chambers have slight overlap. Stations 2, 3 and 4 consist of 2 circular chamber rings: the outer ring is divided into 36 segments, while the inner ring is divided into 18 segments.
The endcap RPC system has similar layout [2], which is shown in figure 1. In station 1, the RPC rings are mounted adjacent to the corresponding CSC rings. In station 2 and 3, RPC ring 2 plus ring 3 cover the same area as CSC ring 2. The readout strips inside each RPC chamber are divided into 3 partitions along the radius, those partitions are called “roll” and indicated by letters “A, B, C”. In the following text, we will use the index of station/ring/roll to label the signal from RPC detectors, for example, RE+1/R3/B refers to the signal from RPC in +z endcap station 1, ring 3 and roll B.

CMS-RPC has a double Bakelite gas-gaps structure [8], and operates in avalanche mode [2]. The avalanche production depends on the environmental pressure $P$, the temperature $T$, the gas mixture and the high voltage $HV$. At fixed gas-mixture, the dependence parameter could be summarized as an effective high voltage [8] in eq. (2.1):

$$HV_{\text{eff}} = HV \frac{P_0}{P} \frac{T}{T_0},$$

where $P_0 = 965 \text{mbar}$, $T_0 = 293K$. The dependence on HV is described by a sigmoidal shape as in eq. (2.2), where $HV_{50\%}$ is the effective high voltage when the chamber reaches the half of its maximum efficiency $\epsilon_{\text{max}}$, $S$ is a parameter indicating the steepness of the sigmoid [8, 9]:

$$\epsilon = \frac{\epsilon_{\text{max}}}{1 + e^{-S(HV_{\text{eff}} - HV_{50\%})}}.$$  

### 3 Efficiency analysis algorithm

The RPC efficiency is calculated exploiting of the redundancy of the muon system. CSC segments are used to identify an unbiased sample of muons used to evaluate the RPC performance. As CSC chambers and RPCs are adjacent and cover similar $\phi$ ranges, the segments reconstructed in the CSCs are extrapolated on the RPC surface as shown in figure 2 and RPC hits are searched in a 4 strips wide window around the impact point.

Two improvements are introduced to suppress the fake segments. Firstly, a filter is set up based on the matching between current segment and other segments from neighboring stations. Assume the global direction of current segment and another sampled segment are $(\theta_1, \phi_1)$ and $(\theta_2, \phi_2)$, the directional variance $\Delta R$ is defined as

$$\Delta R = \sqrt{(\theta_1 - \theta_2)^2 + (\phi_1 - \phi_2)^2},$$

[Figure 1. The scheme of the endcap RPC system. The signal division (rolls) in different rings is shown for each station. The $\phi$ coverage of the detectors on each ring keeps the same as the adjacent CSC detectors. The roll indicator is actually wrong and should be inversed.]
where the $\theta$ and $\phi$ are defined in the global coordination in radians. A threshold of value 0.2 on $\Delta R$ is set to discriminate fake muons. Segments from a true trajectory take a coincident direction and has small value of $\Delta R$, while segments from noise will not have a pattern segment in other stations, thus could not pass the filter.

The second improvement is to remove tracks crossing the edges of the RPC roll, which are affected by worst reconstruction quality. Figure 3 describes the principle. The uncertainties in these steps are estimated by corresponding tolerance ranges in $\theta$ and $\phi$, which is called “cone” and produces a projection on RPC surface. Only the events with projection fully inside the RPC sensitive area will be counted, those with part of cone projection outside of the RPC roll are skipped as fake impact events. On the other hand, the RPC rolls overlap with each neighborhood at side edges on most sub-rings. If the cone covers 2 adjacent RPC rolls, both will become candidates in the search of the fired strips.

The final algorithm was validated with the MC simulation before applying it to the data; the expected performance of 95% efficiency was achieved. Thus the software tool is reliable and ready to be used in real data. Moreover, this new algorithm will be more robust in view of increased pile up scenarios that could introduce a larger number of fake CSC segments not associated to any real muon.
Figure 4. Efficiency for different rolls (1-36) in RE+1/R3/B, measured in pp-collision run 147755 (0.52 \(pb^{-1}\)) with the improved segment extrapolation method. The endcap RPCs were operated at 9500V, rolls 14, 19, 25 and 33 were masked. The error bars are too small to be seen. The efficiency provides a cross check method to the official result and is equivalent for it.

4 Endcap RPC performance from 2010 data

With the previously described software tool, an extensive study of the endcap RPC performance has been carried on using 2010 LHC collision data. Special attention has been given to the first endcap station assembled and tested by Peking University. Similar studies on RPC performance were reported elsewhere [10, 11]. During the 2010 LHC collision period, the endcap RPC system was operated under 3 different HV settings: 9400V, 9500V and 9550V. The threshold of front end electronics was set to 220mV. Rolls affected by known hardware problems are marked in a "black roll" list and excluded by the analysis.

4.1 Efficiency

Figure 4 shows the efficiency in run 147755 with \(HV\) at 9500V, the result shows that most RPC rolls work at efficiency around 95%, some rolls worked under single gap mode are running with lower efficiency and those got masked from the black list are removed.

Presently installed CMS endcap RPC system has totally 432 chambers, efficiency distributions on all the rolls are surveyed, overall the results of the performance agree well with those coming from independent analysis. Figure 5 shows the efficiency distributions on all individual rolls as well as the 2D distribution over the all RE+1/R2/C rolls surface, for the later one all selected runs at \(HV = 9500V\) with large statistics in 2010 data are merged together to assure enough statistics. The regularly distributed low efficiency spots appear clearly on the surface, which correspond to the spacers inside the gas gap structure. This distribution proves the efficiency homogeneity on RPC surface and the accuracy of the segment extrapolation.

Figure 6 shows the efficiency as a function of the run number during 2010B data period. The fluctuations are mainly due to different High Voltage settings and to the impact of environmental parameter variations (temperature and pressure variations).
Figure 5. Efficiency measured in pp-collisions with the conventional segment extrapolation method. Left: Distribution of the efficiency of all endcap RPC rolls measured with Run2010B data. Right: Efficiency of RE+1/R2/C as function of local x and y coordinates of the chamber. For this plot the data is from 17 selected high statistic runs at 9500 V during Run2010B data, the events in all 32 good rolls were overlayed. The regularly distributed low efficiency spots correspond to the spacers inside the gas gap structure.

Figure 6. Average efficiency of the RPC for 27 selected high statistic runs during Run2010B data. The efficiency is affected by high voltage setting, pressure, and temperature, which form a factor in the formula of effective high voltage. For these runs there were 3 high voltage settings: run146644-146804 operated at 9400 V, run146944-147929 operated at mix HVs of 9500 V and 9550 V, while run148002-149291 operated at 9550 V. Fluctuation of pressure and temperature was also recorded. The uncertainty on the total efficiency is smaller than the marker in the plot.

4.2 Spatial resolution

The spatial resolution, surveyed by cluster size and residual distribution, is also crucial for endcap RPC system to provide reliable trigger, and to complete the function of muon tracking. Cluster size is a function of the hit position on the strip and the incident angle of the muon, the last parameter determines how many independent avalanches will be produced in gas-gaps. In our analysis the derived cluster size distribution agrees well with the reported results, and it also presents correlation between incident angle and cluster size, as figure 7 shows. As well as the efficiency analysis, figure 8 shows the fluctuation of average cluster size with respect to the run number, similar behavior as in efficiency case was observed.
The cluster size survey from 2010 data. Left: Cluster size distribution for all RE(1,2,3)/R3/B rolls measured in 2010B data. Right: Correlation between the average cluster size of the endcap and the incident angle of the CSC segment on the RPC surface of RE+1/R3/B, for 17 selected high statistic runs at which the endcap RPCs were operated at mix HVs. The strip pitch at the middle of roll is 3.29 cm. The uncertainty corresponds to the uncertainty on the mean of the cluster size distribution within each bin of the incident angle.

The average cluster size for 27 selected high statistic runs during Run2010B data. The average cluster size is affected by high voltage setting, pressure, and temperature, which form a factor in the formula of effective high voltage. The run conditions are the same with the efficiency scanning. The uncertainty on the average cluster size is smaller than the marker in the plot.

The residual distributions of endcap RPCs from this analysis also agrees well with the reported results, as shown in figure 9.

5 Summary

We developed a software tool to analyze the online RPC performance using CSC track segment information to select and extrapolate muon tracks on the RPC surface. Considering the possible tolerances in CSC segment extrapolation, we optimized the algorithm, validated the software tool by MC simulation, and analyzed the endcap RPC performance using 2010 LHC collision data. The results shows that the CMS endcap RPC operated well as expected under appropriate HV setting, which provides stable and reliable function for physics program. From 2011 and 2012 data similar conclusion could be derived.
Figure 9. Residual distributions: the distance between the RPC fired strip and the impact position extrapolated from CSC muon track, merged from RE(1,2,3)/R3/B in 2010 data.

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