PROCEEDINGS OF SCIENCE

RPC project overview, from the present system to the upgrade

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Resistive Plate Chambers have been chosen as dedicated trigger muon detector for the Compact Muon Solenoid experiment [1] at the Large Hadron Collider [2] at CERN. The system consists of about 3000 m^2 of double gap RPC chambers placed in both the barrel and endcap muon regions.

Performance of the RPC detector has been studied by using 40 pb^{-1} (2010) and 5.20 fb^{-1} (2011) of proton-proton collision data. A set of dedicated runs at different high voltage points has been taken in the 2011 to better study the performance of the detector.

The average detector efficiency of 95%, the average cluster size of 1.8, the intrinsic noise rate of 0.1 Hz/cm^2 and a very good agreement between data and Monte Carlo simulation confirm the excellent behaviour of the RPC detector and the fulfilment of all the requirements decided 18 years ago in the CMS TDR document [3]

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1. Introduction

RPC project has been designed, built and commissioned by 8 founder institutions from Bulgaria, China, India, Italy, Korea and Pakistan and 7 institutions from Belgium, CERN, Colombia and Egypt, which joined the project during the years. All the institutions are also involved in the upgrade phase 1 (2013-2014) that consists in the construction of 144 new chambers to be installed on the two external disk of the endcap region.

2. The muon system of the CMS experiment

The CMS muon detector (Fig. 1 left) [3] has 3 functions: muon identification, momentum measurement and triggering. The barrel region ($|\eta| < 1.2$) is equipped with drift tube chambers (DT) and resistive plate chambers (RPC). They are organized in 4 stations, which are a sandwich of one DT and one or two RPC chambers. Muon stations are placed in the magnet return yoke, which is a 13 m long cylinder divided in 5 wheels along his axes direction and each wheel is divided in 12 sectors, housing 4 iron gaps or stations. Endcap is covered by cathode strip chambers (CSC) in the η region from 0.9 to 2.4 and by RPC chambers in the η region from 0.9 to 1.6. Each endcap is divided in 4 disks but only the 3 innermost have been already equipped with CSC and RPC. The fourth disk will be installed during the 2013-2014 CMS upgrade. Each disk is divided in 36 azimuthal sectors with 3 radial rings in each sector. The innermost ring is covered by CSC only.

3. The RPC system

CMS uses double-gap Resistive Plate Chambers, with each 2 mm gap formed by two parallel Bakelite electrodes with a bulk resistivity about of 10^{10} Ωcm. A copper readout plane of strips is placed between the two gaps. They are operated in avalanche mode with a gas mixture composed by 95.2% $C_2H_2F_4$, 4,5% C_4H_{10} and 0.3% SF6 with a humidity of 40% at 20-22 ^{o}C.

In the barrel region there are 480 chambers equipped with 68136 strips, wide from 2.28 to 4.10 cm, and covering an area of 2285 m^2 while in the endcap region there are 432 chambers equipped with 41472 strips, wide from 1.95 to 3.63 cm, and covering an area of 668 m^2.

4. 2011 data analysis results

2010 data (40 pb^{-1}) were used to study the detector and trigger performance and to improve the sophisticated RPC online [5] and offline monitoring tools [6]. RPC detector was operated with two different high voltage values: 9550 V (endcap) and 9350 V (barrel), which were determined during the commissioning phase with cosmic runs [6][7][8]. The statistics taken in the 2010 did not allow us to study the behavior of every single chamber. A chamber-by-chamber study was possible in the 2011 when the LHC luminosity reached 10^{33} $cm^{-2}s^{-1}$ (Fig. 1 right) corresponding to about few millions of high quality muon events per chamber. Detector performance have been studied run by run and all the results have been stored in the CMS database for further analysis and to produce history plots.

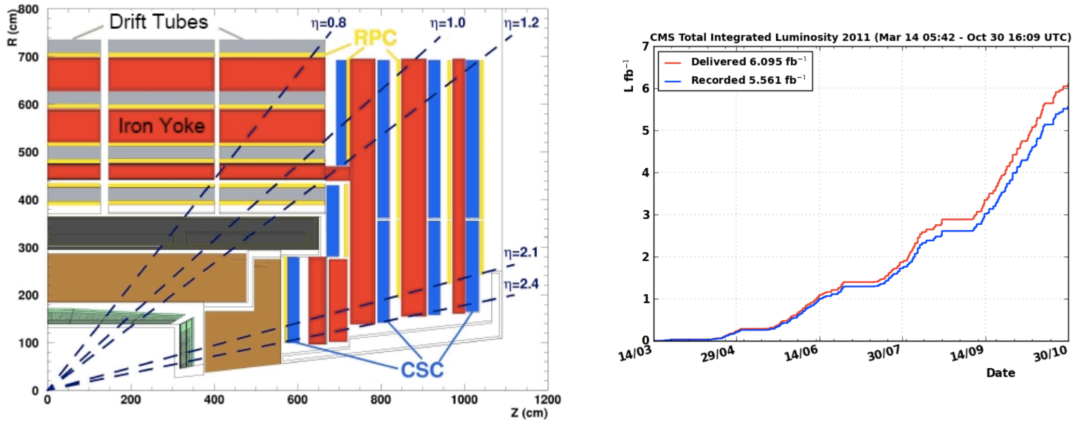

Figure 1: left: schematic longitudinal view of the CMS muon detector. RPC chamber are in yellow. Right: history plot of the total integrated luminosity by CMS in 2011.

4.1 Muon events selection and spatial resolution

Muon events have been selected, thanks to the redundancy of the muon system, asking for DT or CSC trigger. A linear extrapolation of track segment in DT and CSC chambers was performed toward the closest RPC strip plane, and then matched to any RPC cluster in a range of 8 strips around the extrapolated impact point. This method provides both a measure for the efficiency and for the spatial resolution. Spatial resolution depends on the strip width, the cluster size, and the detector alignment. Measured resolution goes from 0.81 to 1.32 cm in the barrel and from 0.86 to 1.28 cm in the endcap.

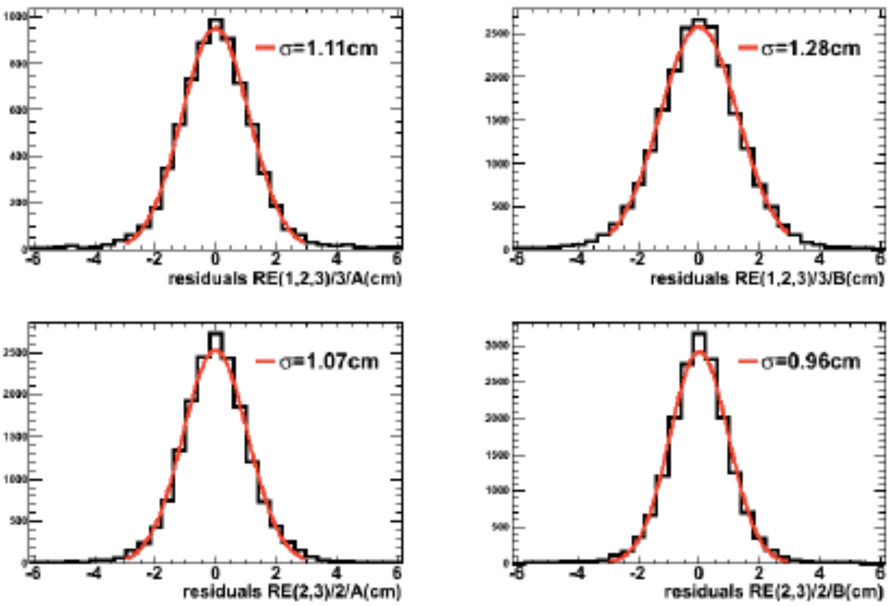

Figure 2: Residual with Gaussian fits for different strips widths (endcap region)

4.2 High voltage calibration results

Efficiency curve as function of the high voltage working point was done using the effective high voltage (HV_{eff}), which is corrected with atmospheric pressure and chamber temperature using the following equation:

$$HV_{eff}(p, T) = HV_{app} \,.\, p_0/p \,.\, T/T_0$$

The efficiency curve of every single chamber partition, called roll, as been fitted with a sigmoid function (Fig. 3) to determine the parameters that characterize an RPC chamber: maximum efficiency, HV at 50% of the maximum efficiency, the slope and the plateau region in which the efficiency is stable.

The working point (HV_{WP}) of the roll has been defined as: $HV_{WP} = HV_{knee} + 100$ V (barrel) or 150 V (endcap), where HV_{knee} is the HV_{eff} for 95% of the maximum efficiency.

The agreement between efficiency measured in the subsequent runs and the predicted one measured using the fitting procedure confirmed the effectiveness of the technique (Fig. 4).

HV scan calibration will be done once per year at the beginning of data taking to monitor in time the performance of the chambers and to eventually spot any aging effect.

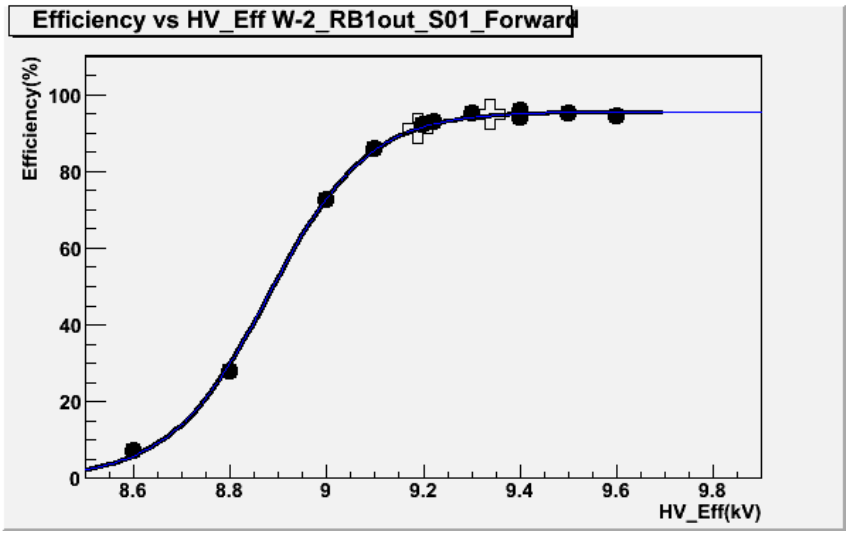

Figure 3: Detector efficiency as function of the effective high voltage (plateau curve) of one CMS RPC chamber.

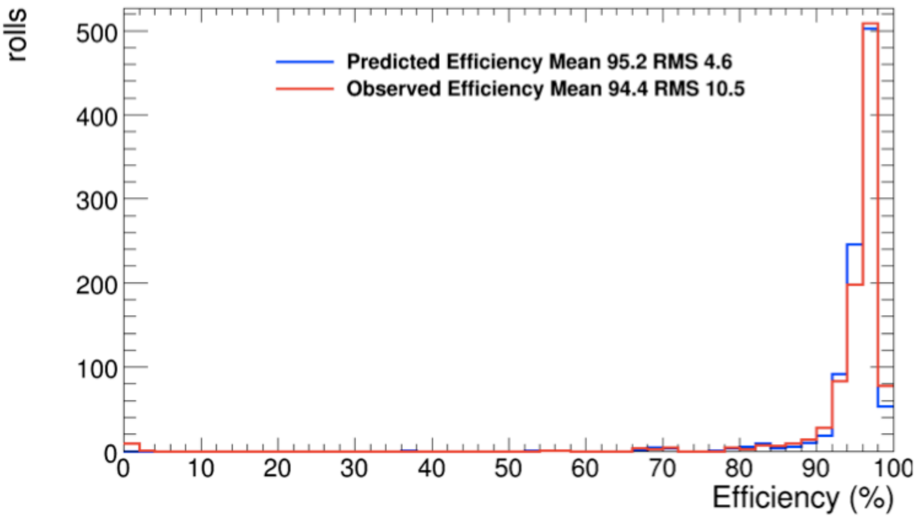

Figure 4: Predicted and observed efficiency distributions of the barrel rolls (chamber partition).

4.3 Detector overall performance

The overall barrel and endcap efficiency (Fig. 5) and the efficiency of every single roll have been monitor in time, run-by-run, to study the stability of the system. A maximum variation of the efficiency of about 3% has been measured in the first three months of data taking, reduced to 1%, in the second part of the 2011, applying an automatic correction of the HV working point with the atmospheric pressure measured in the CMS cavern.

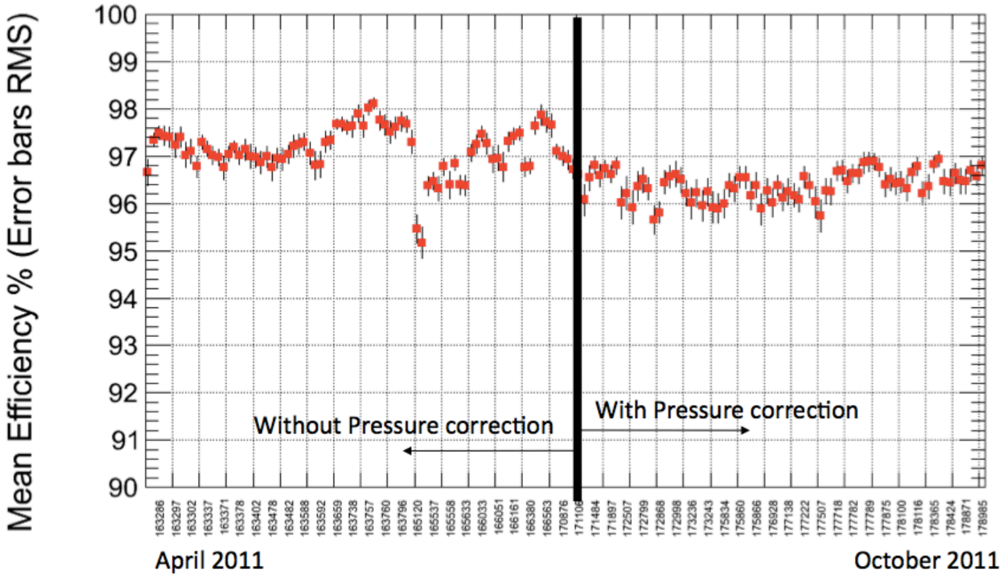

Figure 5: Overall efficiency as function of the run number. Periods with and without automatic correction of the HV working point with atmospheric pressure are shown.

The efficiency of the RPC muon trigger and the muon P_T assignment are strongly correlated to the detector cluster size, defined as the number of contiguous strip fired per event. The cluster size as function of the HV has been studied during the HV scan and the chamber working point has been chosen taking into account the requirement to keep the cluster size as small as possible. Predicted and observed cluster size are shown in figure. 6.

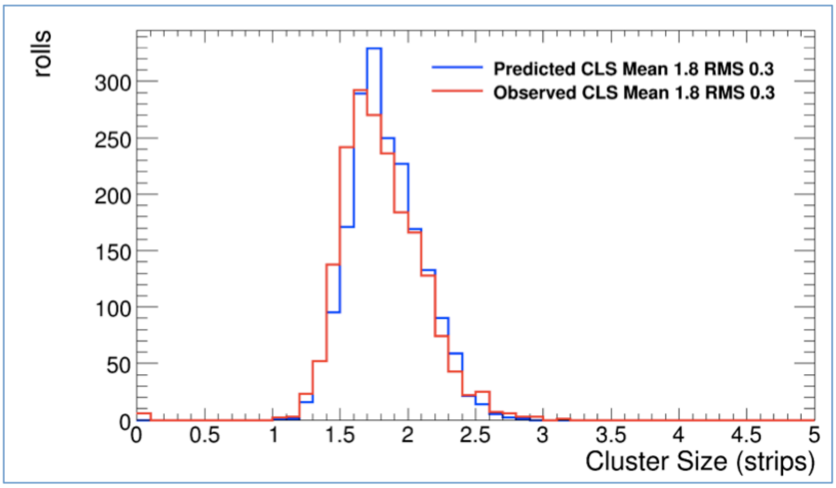

Figure 6: Predicted and observed cluster size distribution per roll.

4.4 Background studies

The strip single rate, defined as the number of hits per second in a single strip, is measured in a fixed time interval of 100 s and stored in a set of database tables. Single rate data have been analyzed to study the radiation background level in the muon detector. The dependence between the background rate and luminosity has been found to be linear as shown in figure 7. The average background rate, measured in the RPC system at luminosity $3 \cdot 10^{33}$ $cm^{-2}s^{-1}$, was 1.7 Hz/cm^2 while the maximum average rate has been measured in the endcap region (innermost ring of disk -2) and was 7 Hz/cm^2. Linear extrapolation to 10^{34} $cm^{-2}s^{-1}$ gives an average background of 6 Hz/cm^2 and a maximum rate of 35-40 Hz/cm^2 that is still well below the limit of 100 Hz/cm^2 used in the trigger design.

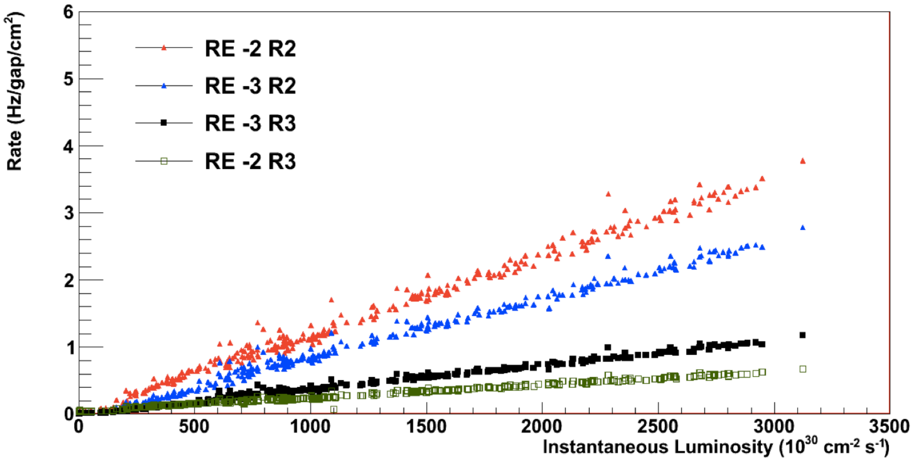

Figure 7: Background rate as function of instantaneous luminosity in the endcap station 2 and 3 of the negative disk 2 and 3.

5. Conclusions

During 2011, different detector parameters, like efficiency, cluster size, intrinsic noise, spatial resolution and background rate have been studied. RPCs performance has been well understood and tuned using dedicated collision runs. The results show that the RPC is running in a very stable and reliable way since the 2008, contributing to the trigger and reconstruction capabilities necessary for the CMS physics program.

References

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