CMS Resistive Plate Chamber overview, from the present system to the upgrade phase I

To cite this article: P Paolucci et al 2013 JINST 8 P04005

View the article online for updates and enhancements.

Related content
- Simulation of the CMS Resistive Plate Chambers
  R Hadjiiska, L Litov, B Pavlov et al.
- Uniformity and stability of the CMS RPC detector at the LHC
  S Costantini, K Beernaert, A Cimmino et al.
- Performance of the Resistive Plate Chambers in the CMS experiment
  Filip Thyssen

Recent citations
- Polymide/graphene nanocomposite materials to construct a low resistive RPC
  R. Han et al
- Radiation tests of real-sized prototype RPCs for the Phase-2 Upgrade of the CMS Muon System
  K.S. Lee et al
CMS Resistive Plate Chamber overview, from the present system to the upgrade phase I

P. Paolucci,1 R. Hadjiiska,2 L. Litov,2 B. Pavlov,2 P. Petkov,4 A. Dimitrov,2 K. Beernaert,2 A. Cimmino,2 L. Costantini,2 G. Guillaume,2 J. Lellouch,2 A. Marinov,2 A. Ocampo,2 N. Strobbe,2 F. Thyssen,4 M. Tytgat,2 P. Verwilligen,6 E. Yazgan,2 N. Zaganidis,2 A. Aleksandrov,6 V. Genchev,6 P. Iaydjiiev,6 M. Rodozov,6 M. Shopova,6 G. Sultanov,6 Y. Ban,4 J. Cai,4 Z. Xue,4 Y. Ge,4 Q. Li,4 and Y.-I. Choi

1Atomic Physics Department, Faculty of Physics, University of Sofia, 5, James Bourchier Boulevard, BG-1164 Sofia, Bulgaria
2Department of Physics and Astronomy, Ghent University, Proeftuinstraat 86, BE-9000 Ghent, Belgium
3Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, Tzarigradsko shaussee Boulevard 72, BG-1784 Sofia, Bulgaria
4Department of Technical Physics, Peking University, CN-100 871 Beijing, China
5Universidad de Los Andes, Apartado Aéreo 4976, Carrera 1E, no. 18A 10, CO-Bogota, Colombia
6Academy of Scientific Research and Technology of the Arab Republic of Egypt, 101 Sharia Kasr El-Ain, Cairo, Egypt
7Department of Physics, Panjab University, Chandigarh Mandir 160 014, India
8Universita e INFN, Sezione di Bari, Via Orabona 4, IT-70126 Bari, Italy
9INFN, Laboratori Nazionali di Frascati, PO Box 13, Via Enrico Fermi 40, IT-00044 Frascati, Italy

1Corresponding author.
ABSTRACT: 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.

About 5.6 fb$^{-1}$ (2010–2011) of proton-proton collision data have been used to study the performance of the RPC detector and trigger.

A full high voltage scan of all the RPC chambers has been done at beginning of 2011 data taking to evaluate the working point chamber by chamber and to eventually spot aging effects.

The excellent behaviour of the RPC detector can be summarized with an average detector efficiency of about 97%, an average cluster size of 1.8 and an intrinsic noise rate of 0.1 Hz/cm$^2$. This is a clear fulfillment of all the requirements decided 18 years ago in the CMS TDR document [3].

KEYWORDS: Muon spectrometers; Resistive-plate chambers; Performance of High Energy Physics Detectors; Trigger detectors

ArXiv ePrint: 1209.1941
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.

The first barrel chamber was built in the 2002 at the I.N.F.N. laboratory of Bari. The full production was completed at the end of 2008 with the production of the last endcap chamber at CERN. The full system was commissioned during from 2008 to 2009 with run of cosmic.

The system is taking collision data since the 2010 with excellent results as will be described in the paper. LHC operation will finish in March 2013 to have two years of shut-down (LS1), completely devoted to the CMS upgrade phase I in which the fourth endcap disk will be installed with RPC and CSC detectors.

2 The muon system of the CMS experiment

The CMS muon detector (figure 1) [3] has been designed to fulfill four main requirements: bunch crossing identification, 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 axis 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 \(\eta\) region from 0.9 to 2.4 and
by RPC chambers in the $\eta$ 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, right now, covered only with CSC detectors.

3 The Resistive Plate Chamber system

CMS uses double-gap Resistive Plate Chambers, with 2 mm gap formed by two parallel Bakelite electrodes with a bulk resistivity of about $10^{10} \, \Omega \cdot \text{cm}$. 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$_2$H$_2$F$_4$, 4.5% C$_4$H$_{10}$ and 0.3% SF6 with a humidity of 40% at 20–22°C.

All the Bakelite foils and the Barrel gaps have been produced in Italy while the endcap gap in Korea. The same procedure, but with few small differences in spacer dimensions, gluing and drying techniques, have been used in the two gap production sites.

In the barrel region there are 480 chambers equipped with 68136 strips, of width ranging 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$^2$.

Two barrel and four endcap chambers are joined together in order to reduce the number of high voltage channels to the detriment of the possibility to operate every chamber at a different working point.
Data analysis results with 2011 collision data

The 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].

During the 2010 the RPC detector was operated at two different high voltage values: 9550 V (endcap) and 9350 V (barrel), values determined during the construction and commissioning phases with cosmic runs [6–8]. The 200 volts of difference in the barrel and endcap working points, is mostly due to the different spacers used in the gap construction. A detailed study will be done during the production of the gaps in Korea for the endcap upgrade.

The 2010 data allow us to study the overall behavior of the RPC system but not the performance of every single chamber, due to the lower number of muons.

A chamber-by-chamber data analysis was possible in the 2011, when the LHC luminosity reached \(10^{33} \text{cm}^{-2}\text{s}^{-1}\) (figure 2), 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. The high statistics accumulated in the 2011 allow us to measure the chamber efficiency with a resolution of few cm\(^2\) (Chamber Muongraphy) to eventually spot low-efficiency region of every chamber (figure 8).

4.1 Muon event 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 segments 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
Figure 3. The distance between the muon extrapolate impact point on the RPC and the closest RPC hit has been plotted for every chamber type in order to take into account the different strip widths. Residuals have been measured using a Gaussian fit. The results of 3 chamber types of the barrel region are shown here.

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.

4.2 The high voltage calibration results

A high voltage scan was performed during the early 2011 to study in details the behavior of all the chambers. Collision data were recorded at 11 different high voltage points during a series of dedicated runs. Few runs were taken twice to assure the stability of the system during the calibration period.

The efficiency curve as function of the high voltage working point was done using the effective high voltage (HV$_{\text{eff}}$), which is corrected with atmospheric pressure using the following equation:

$$HV_{\text{app}}(p, T) = HV_{\text{eff}}(1 - \alpha + \alpha P/P_0)$$  \hspace{1cm} (4.1)

where $\alpha$ is a parameter less than 1.0 to estimate from the data.

The efficiency curve of every single chamber partition, called roll, has been fitted with a sigmoid function (example is figure 4) to determine the parameters that characterize an RPC chamber: maximum efficiency, HV at 50% of the maximum efficiency, slope and plateau region in which the efficiency is stable.

The working point (HV$_{\text{WP}}$) of the roll has been defined as: HV$_{\text{WP}}$ = HV$_{\text{knee}}$ + 100 V (barrel) or 150 V (endcap), where HV$_{\text{knee}}$ is the HV$_{\text{eff}}$ at 95% of the maximum efficiency.
Figure 4. Detector efficiency as function of the effective high voltage (plateau curve) of one CMS RPC barrel chamber.

Figure 5. Predicted (extrapolated from plateau fit) and observed efficiency distributions of the barrel rolls (chamber partition) measured after the 2011 HV scan calibration. WP correction with Pressure (applied on June 2011) contributed to a more stable efficiency. An average efficiency around 97% has been measured in the second part of the 2011.

The agreement between the efficiency measured in the subsequent collision runs and the efficiency predicted with the fitting procedure, confirmed the effectiveness of the technique (see figure 5).

In the 2012 the HV scan calibration will be done twice, at the beginning and at the end of data taking, to monitor in time the performance of the chambers and to eventually spot any aging effect.
4.3 The detector overall performances

The stability of the RPC system has been monitored looking at the history plots of most important parameters as: current, noise rate (see paragraph 4.4), detector occupancy and efficiency. Most of those parameters have been also monitored roll by roll by the detector experts and by the RPC shifters.

The average current is one of the most important parameter of the RPC detector and it is monitored both with and without beam. In figure 6 is shown the average current of the five barrel wheels in a typical 2011 run. The current is clearly correlated to the luminosity and the last part of the history plot, after the vertical line, is the one without the beam.

A fluctuation of the average efficiency of about 2–3% in the barrel region and 4–5% in the endcap region has been measured in the first three months of the 2011 data taking. A detailed analysis showed that these fluctuations were correlated with the atmospheric pressure (P) changes in the cavern (see eq. (4.1)). An automatic correction of the HV working point with P was applied in June 2011 with a default value of $\alpha = 1$. Thanks to the WP correction the fluctuations were reduced to about 1% in the barrel (see figure 7) and 2–3% in the endcap. An additional improvement will be obtained measuring the $\alpha$ parameter from the data. Preliminary results have shown that the best value of $\alpha$ is around 0.8.

In the second part of the 2011, with WP correction applied, the average efficiency was about 96.5% (see figure 7). The inefficiency is mostly due to the spacers (1%–1.5%) (figure 8) and to the necessity to merge 2 (barrel) and 4 (endcap) HV channels to reduce the cost of the HV system.

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 strips fired per event. The cluster
Figure 7. 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 small efficiency reduction showed in the second part of the 2011 is mostly due to few disconnected and single gap mode chambers (HV problems), then recovered in the last part of the year.

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 trigger requirement to keep the cluster size as small as possible (CS < 2). Predicted and observed cluster sizes are shown in figure 9.

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 clearly shown in figure 10. The average background rate, measured in the RPC system, at the luminosity of $3 \times 10^{33}$ 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 CMS trigger design.

5 RPC upgrade phase I

During the long shutdown periods (2013–2014) the CMS Collaboration intends to upgrade several subsystems of its detector. In particular, the instrumentation of the muon system will be extended in both endcaps adding a fourth disk, to ensure efficient muon triggering and reconstruction.
The RPC collaboration is building 144 new chambers in order to cover the fourth endcap disk and upgrading the trigger system to an algorithm based on a 3-out-4 logic (right now is 3-out-3), as designed in the CMS TDR [1].

The 600 gaps needed, will be built in Korea, under the supervision of the CMS Korean Institutes (KCMS) while the chambers will be assembled in three sites: Ghent (Belgium), BARC (India) and CERN (Switzerland).

The installation and commissioning of the system is foreseen in the 2013 and 2014 to be ready for the LHC data taking of the 2015.
6 Conclusion

RPC performances have been well understood and tuned using dedicated collision runs (HV scan) and all the results have shown that the RPC is running in a very stable and reliable way since the 2010, contributing to the muon trigger and reconstruction capabilities necessary for the CMS physics program.

Acknowledgments

We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC machine. We thank the technical and administrative staff at CERN and other CMS institutes, and acknowledge support from BMWF and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, and FAPESP (Brazil); MEYS (Bulgaria); CERN; CAS, MoST, and NSFC (China); COLCIENCIAS (Colombia); MSES (Croatia); RPF (Cyprus); MoER, SF0690030s09 and ERDF (Estonia); Academy of Finland, MEC, and HIP (Finland); CEA and CNRS/IN2P3 (France); BMBF, DFG, and HGF (Germany); GSRT (Greece); OTKA and NKTH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); NRF and WCU (Korea); LAS (Lithuania); CINVESTAV, CONACYT, SEP, and UASLP-FAI (Mexico); MSI (New Zealand); PAEC (Pakistan); MSHE and NSC (Poland); FCT (Portugal); JINR (Armenia, Belarus, Georgia, Ukraine, Uzbekistan); MON, RosAtom, RAS and RFBR (Russia); MSTD (Serbia); SEIDI and CPAN (Spain); Swiss Funding Agencies (Switzerland); NSC (Taipei); ThEPC, IPPST and NECTEC (Thailand); TUBITAK and TAEK (Turkey); NASU (Ukraine); STFC (United Kingdom); DOE and NSF (U.S.A.).
References