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The Compact Muon Solenoid Experiment

Conference Report

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

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The CMS RPC system readiness for LHC Run 3 data taking

Mariana Shopova for the CMS Collaboration

Abstract

During Run-3, the LHC is preparing to deliver instantaneous luminosity in the range from 5 x 10^{34} $cm^{-2}s^{-1}$ to 7.5 x 10^{34} $cm^{-2}s^{-1}$. To ensure stable data taking, providing redundant information for robust muon triggering, reconstruction and identification, the CMS RPC collaboration has used the opportunity given by the LHC long shutdown 2 (LS2), to perform a series of maintenance and preparation activities for the new data taking period. The overall performance of the RPC system after the LS2 commissioning period and the activities in preparation for future data taking will be presented.

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The CMS RPC system readiness for LHC Run-3 data taking

M. Shopova[e], A. Samalan[a], M. Tytgat[a], M. El Sawy[b], G.A. Alves[c], F. Marujo[c], E.A. Coelho[c], E.M. Da Costa[d], H. Nogima[d], A. Santoro[d], S. Fonseca De Souza[d], D. De Jesus Damiao[d], M. Thiel[d], K. Mota Amarilo[d], M. Barroso Ferreira Filho[d], A. Aleksandrov[e], R. Hadjiiska[e], P. Iaydjiev[e], M. Rodozov[e], G. Soultanov[e], A. Dimitrov[f], L. Litov[f], B. Pavlov[f], P. Petkov[f], A. Petrov[f], E. Shumka[f], S.J. Qian[g], H. Kou[h,i], Z.-A. Liu[h,i], J. Zhao[h,i], J. Song[h,i], Q. Hou[h,i], W. Diao[h,i], P. Cao[h,i], C. Avila[j], D. Barbosa[j], A. Cabrera[j], A. Florez[j], J. Fraga[j], J. Reyes[j], Y. Assran[k,l], M.A. Mahmoud[m], Y. Mohammed[m], I. Crotty[m], I. Laktineh[p], G. Grenier[p], M. Gouzevitch[p], L. Mirabito[p], K. Shchablo[p], I. Bagaturia[q], I. Lomidze[q], Z. Tsamalaidze[q], V. Amoozegar[r], B. Boghrati[r,s], M. Ebraimi[r], M. Mohammadi Najafabadi[r], E. Zareian[r], M. Abbrescia[t], G. Iaselli[t], G. Pugliese[t], F. Loddo[t], N. De Filippis[t], R. Aly[t,o], D. Ramos[t], W. Elmetenawee[t], S. Leszki[t], I. Margjeka[t], D. Paesani[t], L. Benussi[u], S. Bianco[u], D. Piccolo[u], S. Meola[u], S. Buontempo[v], F. Carnevali[v], L. Lista[v], P. Paolucci[v], F. Fienga[w], A. Braghieri[x], P. Salvini[x], P. Montagna[y], C. Riccardi[y], P. Vitulo[y], E. Asilar[z], J. Choi[z], T.J. Kim[z], S.Y. Choi[aa], B. Hong[aa], K.S. Lee[aa], H.Y. Oh[aa], J. Goh[ab], I. Yu[ac], C. Uribe Estrada[ad], I. Pedraza[ad], H. Castilla-Valdez[ae], A. Sanchez-Hernandez[ae], R. L. Fernandez[ae], M. Ramirez-Garcia[af], E. Vazquez[af], M. A. Shah[af], N. Zaganidis[af], A. Radi[ag,n], H. Hoorani[ah], S. Muhammad[ah], A. Ahmad[ah], I. Asghar[ah], W.A. Khan[ah], J. Eysermans[ai], F. Torres Da Silva De Araujo[aj], on behalf of the CMS Muon Group

[a]*Ghent University Dept. of Physics and Astronomy Proeftuinstraat 86 B-9000 Ghent Belgium.*
[b]*Universit Libre de Bruxelles Avenue Franklin Roosevelt 50-1050 Bruxelles Belgium.*
[c]*Centro Brasileiro Pesquisas Fisicas R. Dr. Xavier Sigaud 150 - Urca Rio de Janeiro - RJ 22290-180 Brazil.*
[d]*Dep. de Fisica Nuclear e Altas Energias Instituto de Fisica Universidade do Estado do Rio de Janeiro Rua Sao Francisco Xavier 524 BR - Rio de Janeiro 20559-900 RJ Brazil.*
[e]*Bulgarian Academy of Sciences Inst. for Nucl. Res. and Nucl. Energy Tzarigradsko shaussee Boulevard 72 BG-1784 Sofia Bulgaria.*
[f]*Faculty of Physics University of Sofia 5 James Bourchier Boulevard BG-1164 Sofia Bulgaria.*
[g]*School of Physics Peking University Beijing 100871 China.*
[h]*State Key Laboratory of Particle Detection and Electronics Institute of High Energy Physics Chinese Academy of Sciences Beijing 100049 China.*
[i]*University of Chinese Academy of Sciences No.19(A) Yuquan Road Shijingshan District Beijing 100049 China.*
[j]*Universidad de Los Andes Carrera 1 no. 18A - 12 Bogot Colombia*
[k]*Egyptian Network for High Energy Physics Academy of Scientific Research and Technology 101 Kasr El-Einy St. Cairo Egypt.*
[l]*Suez University Elsalam City Suez - Cairo Road Suez 43522 Egypt.*
[m]*Center for High Energy Physics(CHEP-FU) Faculty of Science Fayoum University 63514 El-Fayoum Egypt.*
[n]*Department of Physics Faculty of Science Ain Shams University Cairo Egypt.*
[o]*Physics Department Faculty of Science Helwan University Ain Helwan 11795 Cairo Egypt.*
[p]*Univ Lyon Univ Claude Bernard Lyon 1 CNRS-IN2P3 IP2I Lyon UMR 5822 F-69622 Villeurbanne France.*
[q]*Georgian Technical University 77 Kostava Str. Tbilisi 0175 Georgia.*
[r]*School of Particles and Accelerators Institute for Research in Fundamental Sciences (IPM) P.O. Box 19395-5531 Tehran Iran.*
[s]*School of Engineering Damghan University Damghan 3671641167 Iran.*
[t]*INFN Sezione di Bari Via Orabona 4 IT-70126 Bari Italy.*
[u]*INFN Laboratori Nazionali di Frascati (LNF) Via Enrico Fermi 40 IT-00044 Frascati Italy.*
[v]*INFN Sezione di Napoli Complesso Univ. Monte S. Angelo Via Cintia IT-80126 Napoli Italy.*
[w]*Dipartimento di Ingegneria Elettrica e delle Tecnologie dell'Informazione - Universit Degli Studi di Napoli Federico II IT-80126 Napoli Italy.*
[x]*INFN Sezione di Pavia Via Bassi 6 IT-Pavia Italy.*
[y]*INFN Sezione di Pavia and University of Pavia Via Bassi 6 IT-Pavia Italy.*
[z]*Hanyang University 222 Wangsimni-ro Sageun-dong Seongdong-gu Seoul Republic of Korea.*
[aa]*Korea University Department of Physics 145 Anam-ro Seongbuk-gu Seoul 02841 Republic of Korea.*
[ab]*Kyung Hee University 26 Kyungheedae-ro Dongdaemun-gu Seoul 02447 Republic of Korea.*
[ac]*Sungkyunkwan University 2066 Seobu-ro Jangan-gu Suwon Gyeonggi-do 16419 Republic of Korea.*
[ad]*Benemerita Universidad Autonoma de Puebla Puebla Mexico.*
[ae]*Cinvestav Av. Instituto Politcnico Nacional No. 2508 Colonia San Pedro Zacatenco CP 07360 Ciudad de Mexico D.F. Mexico.*
[af]*Universidad Iberoamericana Mexico City Mexico.*
[ag]*Sultan Qaboos University Al Khoudh Muscat 123 Oman.*
[ah]*National Centre for Physics Quaid-i-Azam University Islamabad Pakistan.*
[ai]*Massachusetts Institute of Technology 77 Massachusetts Ave Cambridge MA 02139 United States.*
[aj]*III. Physikalisches Institut (A) RWTH Aachen University Sommerfeldstrasse D-52056 Aachen Germany.*

Abstract

During Run-3, the LHC is preparing to deliver instantaneous luminosity in the range from 5 x 10^{34} $cm^{-2}s^{-1}$ to 7.5 x 10^{34} $cm^{-2}s^{-1}$. To ensure stable data taking, providing redundant information for robust muon triggering, reconstruction and identification, the CMS RPC collaboration has used the opportunity given by the LHC long shutdown 2 (LS2), to perform a series of maintenance and preparation activities for the new data taking period. The overall performance of the RPC system after the LS2 commissioning period and the activities in preparation for future data taking will be presented.

Keywords: RPC, CMS Experiment, gaseous detectors
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1. Introduction

The Compact Muon Solenoid (CMS) experiment [1] utilizes four different gaseous detector technologies to build its powerful Muon system [2] focused on delivering muon triggering and identification, as well as charge and transverse momentum measurement. Drift tubes (DT) are used in the central barrel region, covering pseudo-rapidity ($|\eta| < 1.2$), cathode strip chambers (CSC) constitute the endcap region ($1.2 < |\eta| < 2.4$), resistive plate chambers (RPC) are used in both regions, covering pseudo-rapidity up to ($|\eta| < 1.9$), and a new type of detector, the gas electron multiplier (GEM), installed in the endcap during LS2, covers the region ($1.5 < |\eta| < 2.2$).

The CMS RPC system is composed in total of 1056 double-gap chambers. Each chamber consists of 2 or 3 double gaps with 2 mm gas gap width each and a copper strip readout plane located between the top and the bottom single gaps [2]. High voltage (HV) is applied to the graphite electrodes, coated on High Pressure Laminate (HPL), called bakelite, with bulk resistivity in the range of 1–6 $\times 10^{10}$ Ωcm.

The RPC are operated in avalanche mode with a 3-gas-component mixture of 95.2% Freon ($C_2H_2F_4$), to enhance the ionization caused by incident particles, 4.5% Isobutane (iC_4H_{10}), used as a quencher gas to reduce the streamer formation and 0.3% SF_6 to clean the signal, controlling the secondary ionization. The barrel region of the CMS RPC system is divided into 5 separate wheels (named W0, W±1 and W±2), while a total number of 4 stations (named RE±1, RE±2, RE±3, RE±4) construct the endcap region [2]. Each barrel wheel is divided into 12 sectors in azimuthal angle ϕ while every endcap station into 36 sectors. The CMS RPC are used mainly as triggering detectors, given their designed and calibrated excellent time resolution of < 2 ns and lower absolute number of adjacent fired strips in a single muon hit, called cluster size, below 3.

In the periods of LHC data taking from 2010 to 2018 (Run-1 and Run-2), the CMS detector recorded ~185 fb^{-1} and the RPC system contributed efficiently with its stable performance during the entire period.

2. CMS RPC Activities in LS2

The CMS experiment had a very intensive upgrade and maintenance program during the 3-years-long LS2 period (2019–2021). The CMS RPC group also used this opportunity to perform a series of activities, to assure solid detector performance able to provide redundant information for robust muon triggering, reconstruction and identification, ensuring stable data taking for Run-3 [3].

One of the important RPC LS2 interventions was the extraction of 72 super modules (SM) from the RE4 stations at both endcaps, to allow the CSC electronics refurbishment on ME4/1 chambers. All dismounted RE4 super modules were brought to a dedicated new laboratory with controlled environmental conditions, built on the surface. Once powered back on, RE4 currents were found to be higher than their last Run-2 operational values, which required long recovery conditioning. After staying powered at nominal voltages and with the standard RPC gas mixture flushed for four weeks, the dark currents decreased to their expected values. All necessary reparation and re-validation was done in the laboratory, including replacing all problematic chambers with spare ones, before reinstalling the super modules back into the CMS detector.

An extensive HV and low voltage (LV) maintenance campaign was another key activity performed by the RPC group, aiming to keep the good and stable performance of the system. The goal of the HV maintenance was to identify and fix in the best feasible way all problematic channels and parts of the HV power system. A total number of 65 HV channel repairs were performed and as a result, an increase of ~ 6 % in the RPC system average efficiency, obtained during the system commissioning at the end of 2021 cosmics data with respect to 2018 cosmics data, was observed, as shown in Fig. 1. This improvement in the system performance was achieved due to the recovery of HV lines and the change of detector operation mode from a single-gap to a double-gap one for numerous chambers.

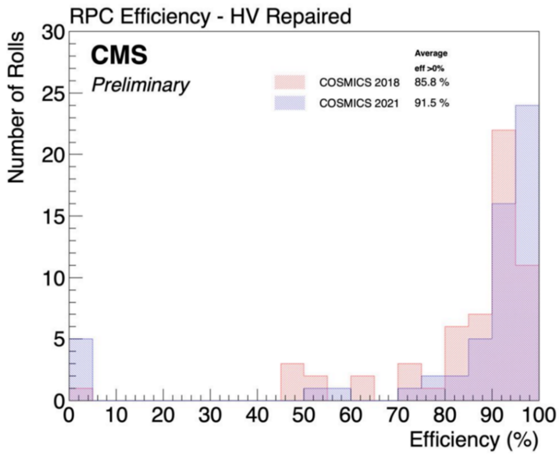


Figure 1: RPC Barrel efficiency comparison between cosmic runs taken in 2018 (Red) and 2021 (Blue).

The LV maintenance aimed at ensuring precise functionality of the LV power boards, flawless operation along the communication buses, as well as proper operation and configuration of the on-detector electronics, including the Front-end Boards (FEBs) and the LV distribution boards (LVDB). The RPC LV campaign resulted in fixing a total number of 12 LV problems.

The RPC gas system consolidation had highest priority among all RPC LS2 activities. As the standard gas mixture is composed mainly of fluorine composed gases (F-gases) with high global warming potential (GWP), the aim of this consolidation campaign was to minimize the environmental impact of the RPC gas system emissions. This was achieved by minimizing the leaks and implementing a newly developed freon recuperation system prototype.

Figure 2 shows the distribution of the gas leak repairs and the number of leaks in all five barrel wheels as of June 2022. A total number of 122 gas leaks due to cracked or broken pipes are

Email address: mariana.vutova@cern.ch (M. Shopova)

identified in the Barrel RPC chambers during the entire 3-years-long LS2 period. Out of those, 43 chambers are successfully repaired and turned back to normal operation mode, including 17 not working during Run-2 chambers. 77 out of the remaining 79 leaking chambers are disconnected from the gas distribution system.

As of June 2022 there is a total number of 108 disconnected chambers in the barrel - 14 non-recoverable leaks, 63 operational leaking chambers and 31 operational non-leaking chambers, sharing gas channels with leaky chambers. The large number of 94 operational disconnected chambers that makes $\sim$ 8.9 % of the RPC system is due to compliance with the CMS gas leak reduction policy of disconnecting of all leaky chambers, even if properly operational.

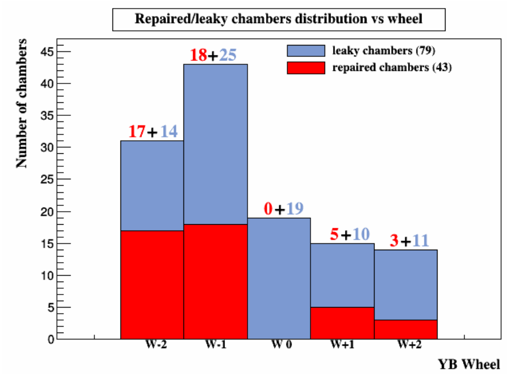


Figure 2: Distribution of leaking and recovered gas channels per wheel - representing the system in June 2022: 122 gas leaks out of which 14 non-recoverable leaks, 63 disconnected operational leaking chambers, 2 leaking chambers still connected and 43 leak repaired cases.

Another major gas system activity was the testing of a freon recuperation prototype connected to the CMS RPC gas system exhaust. CERN EP-DT gas team is finalizing the R&D on the first $C_2H_2F_4$ recuperation system which manifests 80% efficiency. To minimize chamber pressure variations, considered to be a possible source of new leaks, automatic regulation valves on pre-distribution racks in the underground service cavern were installed in November 2021 (for the barrel) and January 2022 (for the endcap). They have been properly operating since then. To restore the gas in the exhaust line and to keep the amount of fresh gas added to the system at a minimum, the RPC group is following the policy to turn off all remaining leaking chambers that were not possible to be repaired, as well as disconnect all conceivably new developed leaks. The recuperation system is expected to be ready and operational by the start of 2023.

3. CMS RPC performance in early Run-3 collisions

In the beginning of Run-3, LHC reached the 13.6 TeV record value of the center-of-mass energy in proton-proton collisions. After finishing successfully its intensive upgrade and maintenance program, the CMS experiment has started the new data taking period with flawless and stable performance, ready to collect good quality data on all possible new phenomena.

The CMS RPC system performance has been closely monitored and a comparison on the main RPC detector working parameters has been carried out, based on 2018 and 2022 proton-proton collisions, to validate how the system operates after all LS2 interventions. Figure 3 shows the RPC overall efficiency distribution in the barrel (a) and the endcap (b) regions. The RPC hit efficiency is obtained using the segment extrapolation method [4], where the RPC efficiency is calculated as the ratio between the number of detected and the number of expected hits. Segments (DT in the barrel and CSC in the endcap) that belong to a standalone muon track with timing corresponding to RPC readout bunch crossing (BX) windows 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 $\pm$ 2 strips from the position extrapolated from the DT or CSC segment.

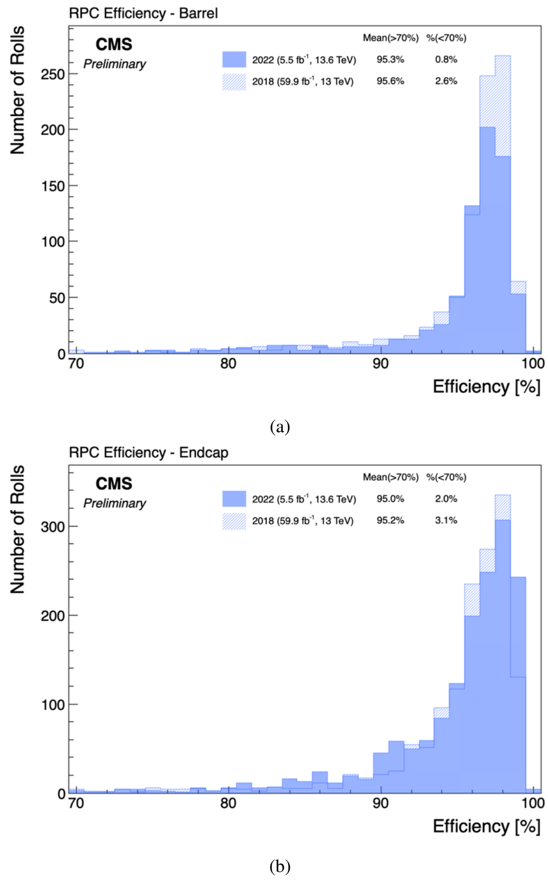
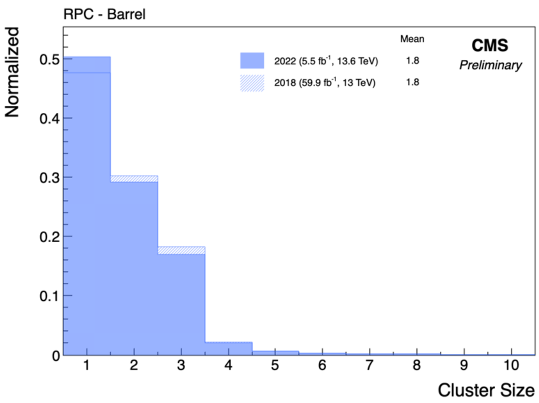


Figure 3: RPC overall efficiency distribution comparison for the barrel (a) and the endcap (b), obtained using 2018 and 2022 proton-proton collisions data.

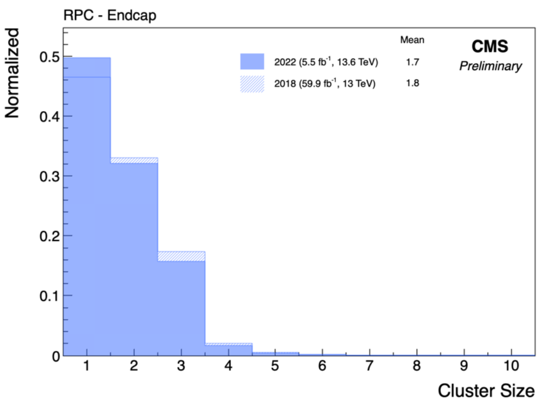
To estimate the performance of the RPC system configuration during the data taking both in 2018 and 2022, all RPC chambers with known hardware problems or switched off due to the CMS gas leak reduction policy are excluded. The underflow entries are coming from detector units with efficiency lower than 70%, caused by known hardware problems, e.g. chambers working in single gap operation mode. The numbers given on the plots show the average efficiency for the well performing, as well as the fraction of the problematic RPC detector units. The

RPC efficiency measured in 2018 and 2022 is comparable (∼ 95 %) and in agreement with the expectations. The pronounced decrease of the fraction of detector units operating at lower efficiency demonstrates the success of the HV, LV and gas repairs during the long maintenance period in LS2.

Another important RPC working parameter is depicted in Fig. 4. Here the 2018 and 2022 proton–proton collision data is used to show the comparison of the cluster size distribution of RPC hits associated with muons in the barrel (a) and the endcap (b). The RPC mean cluster size measured in 2018 and 2022 is below 2, which is comparable and in agreement with the expectations.



(a)



(b)

Figure 4: Cluster size distribution of RPC hits associated with muons in the barrel (a) and the endcap (b), based on data taken during 2018 and 2022 proton-proton collisions.

4. Conclusion

The CMS RPC system kept stable performance during the entire Run-1 and Run-2 data taking (∼185 fb^{-1}). To ensure the optimal operation during Run-3, the RPC group used the LS2 period to undergo a massive maintenance campaign to repair gas leaks, HV and LV issues. Additional effort was made to minimize the environmental impact of the RPC gas system by disconnecting all remaining leaking chambers from the gas distribution and performing intensive tests on validating the design and performance of the new $C_2H_2F_4$ recuperation system. 2022 data show stable performance of the RPC system with average efficiency of ∼ 95% and average cluster size below 2. Results obtained from the early Run-3 data analysis confirm the success and importance of all activities performed during LS2 to bring the RPC system to optimal and smooth operation.

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