Journal of Instrumentation

SISSA

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To cite this article: J. Goh *et al* 2019 *JINST* **14** C10020

Published by IOP Publishing for Sissa Medialab
Received: June 29, 2018
Accepted: September 19, 2019
Published: October 15, 2019

14th Workshop on Resistive Plate Chambers and Related Detectors
19–23 February, 2018
Puerto Vallarta, Jalisco state, Mexico

CMS RPC efficiency measurement using the tag-and-probe method

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https://doi.org/10.1088/1748-0221/14/10/C10020

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Abstract: We measure the efficiency of CMS Resistive Plate Chamber (RPC) detectors in proton-proton collisions at the centre-of-mass energy of 13 TeV using the tag-and-probe method. A muon from a Z^0 boson decay is selected as a probe of efficiency measurement, reconstructed using the CMS inner tracker and the rest of CMS muon systems. The overall efficiency of CMS RPC chambers during the 2016–2017 collision runs is measured to be more than 96% for the nominal RPC chambers.

Keywords: Performance of High Energy Physics Detectors; Resistive-plate chambers

Contents

1 Introduction

The CMS experiment has been playing an important role in the recent discoveries of the high energy physics. The muon system allows an efficient and a precise muon reconstruction, with combination of three different technologies: Drift Tubes (DTs) covering the pseudorapidity range up to $|\eta| < 1.2$, Cathode Strip Chambers (CSCs) with $0.9 < |\eta| < 2.4$ and Resistive Plate Chambers (RPCs) up to $|\eta| < 1.9$ as shown in figure 1. Detailed descriptions on the CMS detector design can be found in [1, 2].

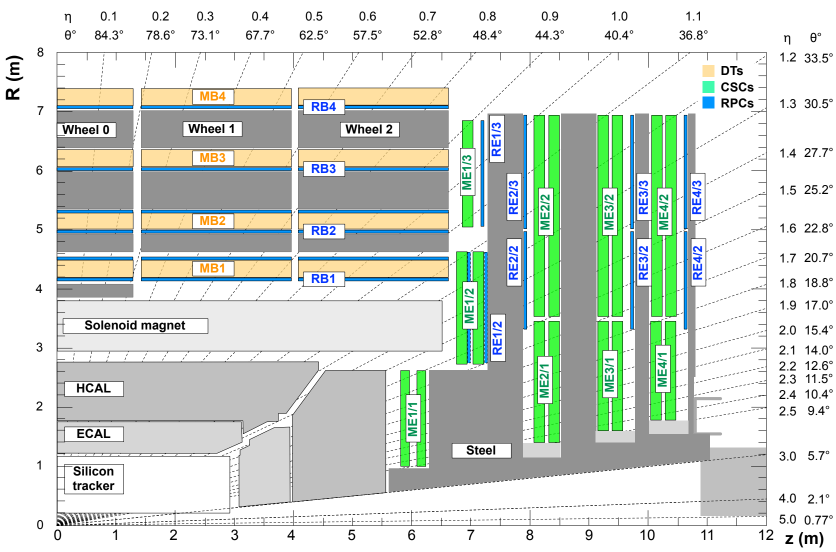

Figure 1. A schematic view of the CMS detector, projected on R-z plane. Muon subsystems are located at the outermost part the CMS detector, DTs are installed in the Barrel region (Yellow), CSCs are in the Endcap region (Green), RPCs are both in the Barrel and Endcap up to $|\eta| < 1.9$ (Blue).

The CMS RPC system is a gas-ionization chamber with a double-gap structure where each *gap* consists of two Bakelite plates separated by 2 mm width. Gaps are filled with a gas mixture of $C_2H_2F_4$ (96.2%), isobutane ($i\text{-}C_4H_{10}$, 3.5%) and SF_6 (0.4%). Chambers are partitioned by *rolls* along the η-direction. Readout strips are located at the region between two gaps parallel to the η-direction with their pitch around 1–2 cm providing good position resolution in ϕ. High voltage of nominal value at 9.6 kV are applied on each gap to operate at the avalanche mode. Charges are induced on readout strips near to the particle passage through the chamber. Because of the fast response of the avalanche mode RPCs, bunch crossing assignment can be improved by providing complementary information to the other muon sub-systems.

2 Extrapolation algorithms

To measure the efficiency of RPC rolls, we use muons reconstructed without any information of RPCs. Efficiency of a roll is defined as the fraction of number of reconstructed RPC hits from a muon to the total number of successful extrapolations to the RPC rolls along the muon's trajectory. CMS provides various muon reconstruction algorithms such as *StandaloneMuons*, *TrackerMuons* or *GlobalMuons* and its identification criteria [1].

A *segment extrapolation* method [3] was commissioned and have been widely used for the CMS RPC performance measurement from the LHC Run-1. The algorithm is based on the DT and CSC segments, which are reconstructed by combining hits from multiple layers on a station. Position of the muon trajectory on the RPC chamber is estimated by a straight line using the segment position and its direction.

Segments are selected from a Standalone muon, modified not to use any RPC information to reduce background contamination without selection bias. Extrapolation is done only if the trajectory of muon from the reference DT and CSC to the nearest RPC is short enough to be approximated as a straight line. In the 4th station of the Barrel or the 2nd ring of the Endcap, segment extrapolation to the RPCs cannot be performed due to the missing information or too large distance between detectors.

In this paper, we introduce new algorithm based on the TrackerMuons, *track extrapolation* method for the RPC performance measurement. The tracker muons are reconstructed by propagating tracker tracks to find the matched segments in the muon system along its trajectory, considering the magnetic field and geometrical effects. Similarly, the *RPCMuon* [4] is reconstructed with the same algorithm, but requiring RPC hits for the muon identification. The results of extrapolation to RPC rolls are stored in the reconstructed muon object.

We require muons to be reconstructed using the TrackerMuon algorithm which is independent of the RPCs. Since the bending effects are included during the propagation of tracker track of the TrackerMuon, we can safely extrapolate to any RPC chambers. Therefore, the algorithm is robust agains the extrapolation problem which were present in the segment extrapolation method.

3 Efficiency measurement using the tag-and-probe method

The tag-and-probe is a data-driven method to measure the reconstruction, identification and trigger efficiency. Muons with minimal selection bias can be collected by requiring one of the decay products of resonances such as $Z \to \mu^+\mu^-$ or $J/\psi \to \mu^+\mu^-$ modes and using the another decay product. The decay product with the tight selection is named as the *tag* muon and another one as the *probe* muon. We also require the tag muon to be the triggering muon during the data taking to

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be unbiased from the trigger selection. If necessary, contribution from the background event can be removed by subtraction or fitting on the invariant mass distributions.

We use the single muon triggered data, collected during 2017, without any serious hardware problems of the muon detectors and trackers during the data taking. The amount of data used for the efficiency measurement correspond to an integrated luminosity of 42.6fb^{-1}.

The tag muons are required to be the triggering muons with a transverse momentum $p_T >$ 25 GeV and $|\eta| < 2.4$. The selected muons are required to pass the tight muon identification and loose isolation criteria. Probe muons are selected from the TrackerMuons at $p_T > 10$ GeV and $|\eta| < 1.9$ which correspond to the RPC acceptance. The tag-probe pair are required to be within the mass range $70 < M_{\mu\mu} < 110$ GeV. The contribution of the background is expected to be negligible with the selections described previsouly. The invariant mass distribution of the pair of tag-probe is shown in figure 2. Probe muons are mostly populated at $p_T \simeq 50$ GeV which is consistent with the typical p_T range of the muons from Z boson decay.

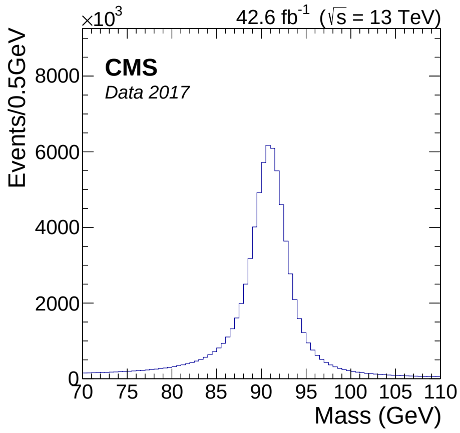

Figure 2. Invariant mass distribution of tag-probe pairs in the efficiency calculation. The distribution shows a peak at 91.2 GeVfrom the Z boson.

Efficiency of a roll is measured as a probability to have a matched RPC hit on the extrapolated point which can be written as:

$$\epsilon_{\text{roll}} = \frac{N_{\text{roll}}^{\text{pass}}}{N_{\text{roll}}^{\text{pass}} + N_{\text{roll}}^{\text{fail}}} \tag{3.1}$$

where $N_{\text{roll}}^{\text{pass}}$ is the number of probe muons with matched RPC hit on the roll, and $N_{\text{roll}}^{\text{fail}}$ is the number of probe muons without matched RPC hit on the roll.

Efficiency distributions of RPC rolls during the 2017 data taking are shown in figure 3. Overall efficiency of RPC rolls in Barrel and Endcap in 2017 is measured to be 96.2% for the rolls above 70% efficiency. There are a few rolls with low efficiencies because of the known hardware problems such as gas leaks from the chambers.

4 Conclusion

Efficiency of the CMS RPC rolls using the 2017 data is measured by a tag-and-probe method with muons from Z boson decay. We applied an extrapolation algorithm using the tracker tracks

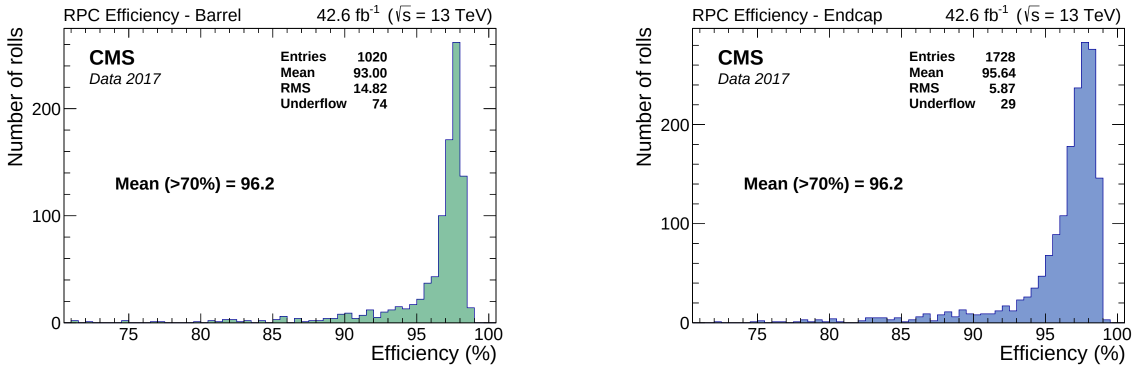

Figure 3. Overall efficiency in the Barrel (left) and Endcap (right) during the 2017 data taking.

considering full geometry and magnetic field of the CMS detector. Acceptance of extrapolation is improved by the new track based algorithm.

RPC efficiency in 2017 is 96.2% with new method for the rolls above 70% efficiency, both in the Barrel and Endcap. There are a few RPC rolls with low efficiency because of known hardware problems.

Acknowledgments

We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC and thank the technical and administrative staffs at CERN and at other CMS institutes for their contributions to the success of the CMS effort. We also would like to give special thanks to the all colleagues of the CMS RPC collaboration for the huge efforts to operate RPC detectors. We gratefully acknowledge the computing centers and personnel of the Worldwide LHC Computing Grid for delivering so effectively the computing infrastructure essential to our analyses. The work in this article is supported by the computing resources of Global Science experimental Data hub Center (GSDC) in Korea Institute of Science and Technology Information (KISTI). This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (grant number NRF-2017R1A6A3A11029637).

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