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ABSTRACT: A new muon reconstruction algorithm is introduced at the CMS experiment. This algorithm reconstructs muons using only the central tracker and the Resistive Plate Chamber (RPC). The aim of this work is to study how a muon reconstructed only with tracker and RPC information would perform compared to the standard muon reconstruction of the CMS detector. The efficiencies to reconstruct and identify a RPC muon with a transverse momentum greater than $20\,\mathrm{GeV}/c$ are measured. The probabilities to misidentify hadrons as muons at low transverse momentum are also reported. These probabilities are compared to the standard muon identification used at CMS.

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

Contents

1 Introduction

The Compact Muon Solenoid (CMS) experiment produced important scientific results with the data taken during 2010–2012 runs at $\sqrt{s} = 7\,\text{TeV}$ and $8\,\text{TeV}$, among them the discovery of the Higgs boson [1]. The CMS muon detectors played a central role on several of these results. The CMS muon detectors consist of Drift Tubes (DT), Cathode Strip Chambers (CSC) and Resistive Plate Chambers (RPC) as shown in the figure 1. A complete description of the CMS detector can be found elsewhere [2]. The DTs and CSCs detect muons in the regions $|\eta| < 1.2$ and $0.9 < |\eta| < 2.4$, respectively. The RPCs are installed in both of barrel and endcap regions up to $|\eta| < 1.6$ as a complementary muon detector.

The DTs and CSCs provide excellent position and time resolution allowing precise muon tracking in the barrel and endcap region of CMS. Thus RPCs are used as dedicated fast trigger detectors, they complement the triggering capabilities of the DTs and CSCs. The RPC contribution to muon reconstruction has been previously studied using the CMS data taken at $\sqrt{s} = 7\,\text{TeV}$ [7].

A new muon object called RPC-muon is proposed. The RPC muon object is reconstructed only with the tracker and RPC hits. Three RPC muon identification criteria are defined, their performance is quantified, such as efficiencies and hadron misidentification probabilities using the CMS data taken in 2012 at $\sqrt{s} = 8\,\text{TeV}$.

2 Muon reconstruction and identification at CMS

Muons produced at the center of the CMS detector can leave hits in three or four stations depending on their pseudo-rapidity. Muons are reconstructed using the hits in the muon detectors and tracks in the silicon inner tracker. Three types of muon reconstruction algorithms are used in CMS. On the muon system, tracking can be done using only track segments reconstructed with DT and CSC hits, these tracks are identified as muons are called *standalone muons*. *Tracker muons* are reconstructed with inner tracks matched to muon segments, the matching is done after extrapolating the inner tracks up to the muon stations. *Global muons* are reconstructed combining inner tracks

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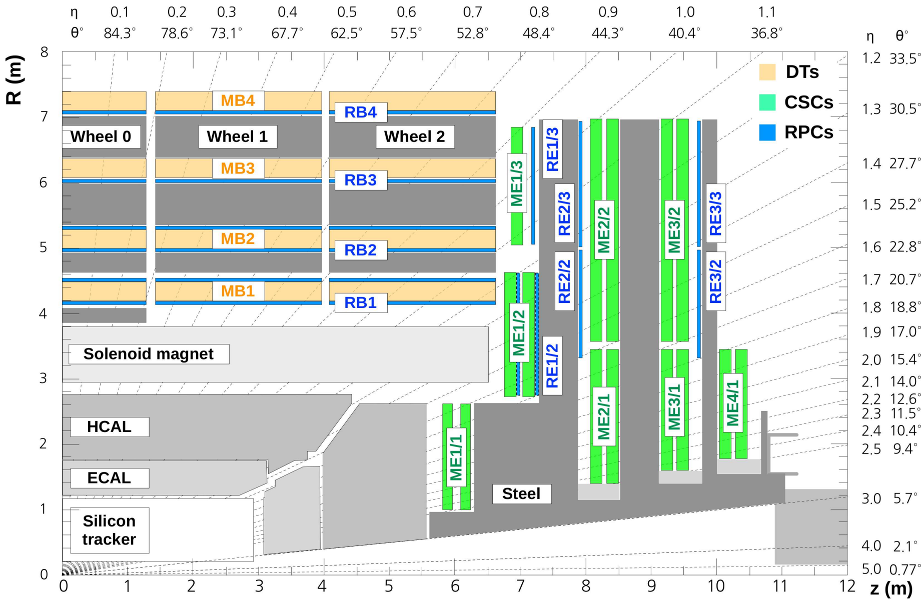

Figure 1. Layout of one quadrant of CMS. The figure shows the four DT stations in the barrel (MB1–MB4, yellow), the four CSC stations in the endcap (ME1–ME4, green), and the RPC stations (RB1–RB4 and RE1–RE3).

and standalone muon tracks with full global track fit. In addition, *particle flow* algorithm [3] is applied to reconstruct muons without ambiguity [4].

There are two major muon identification algorithms in CMS, *loose muons* and *tight muons*. Loose muons are particles identified as muons with particle flow algorithm. A muon candidate is discarded from the loose muons if it is reconstructed without inner tracker information. Tight muons are global muons which are also identified with the particle flow algorithm. At least one muon chamber hit must be used in the global track fit with $\chi^2/ndf < 10$. Also, at least two muon segments have to be matched when the inner track is extrapolated to the muon stations. Hits on more than 5 layers of the inner tracker and at least one pixel hit are required. Finally, cuts on the impact parameters in the transverse and longitudinal planes with respect to the primary vertex of the event are required to be $d_{xy} < 0.2$ cm and $d_z < 0.5$ cm [4].

There are additional muon identification criteria based on tracker muons, depending on association of muon hits or segments to tracks. The tracker muon identifications are expected to recover some muons when some chambers are not efficient or missing along their trajectory.

The RPC muons are defined as a subset of the tracker muons. First, tracks reconstructed with the inner tracker are extrapolated to muon stations using the *Kalmann filter* algorithm [6]. A RPC hit is associated with the track, if the extrapolated point is within $\Delta x < 20$ cm and $\Delta x/\sigma x < 4$ from the RPC local x-coordinate. Three different RPC-muon working points are defined corresponding to the number of RPC layers or stations with associated RPC hits. The first working point is called *RPCMuLoose*, it requires at least two RPC layers with associated RPC hits. *RPCMuMedium* working point is defined by requiring the associated RPC layers to be in different stations. For the tightest RPC-muon identification, *RPCMuTight*, at least three RPC layers with associated RPC hits are required.

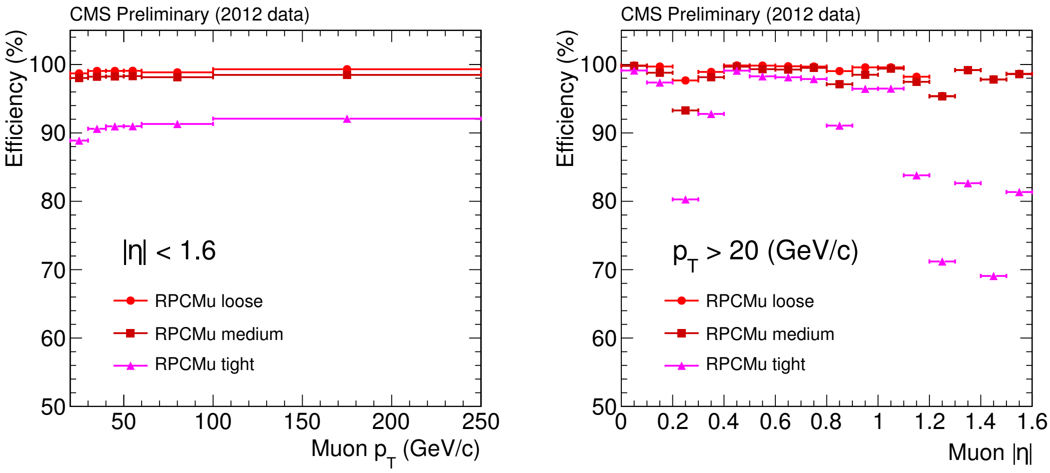

Figure 2. Efficiency of high p_T RPC muon working points for general tracks with basic quality cuts in RPC coverage. Efficiencies are shown as a function of p_T (left) and $|\eta|$ (right).

3 Efficiency measurement

In this study, the efficiencies of RPC muon identification criteria are reported for muons with $p_T > 20$ GeV$/c$ and $|\eta| < 1.6$. The muons used in the analysis come from the decay of Z^0 bosons mostly. The events used were taken during the 2012 run, they were triggered on single muons, the total integrated luminosity used is 19.6 fb^{-1}. A high purity and unbiased muon sample is guaranteed by requiring a tight muon identification on the leading muon coming from Z^0 boson, this identified muons are labeled *tag muon*. To avoid trigger bias, the *tag* is required to be the triggered muon. The another leg is a *probe* used to measure the efficiency. No identification criteria was required on the probe with the exception of minimum requirements that guaranteed the track quality in the inner tracker where at least 10 valid hits in the inner tracker, and impact parameter cuts with respect to the primary vertex, $d_{xy} < 0.2$ cm and $d_z < 0.5$ cm.

To extract the efficiency from the data, simultaneous binned likelihood fits were performed, the fits were done on the ratio between Z^0 candidates with probes passing the identification criteria, and all of the candidates. Z^0 signal is modeled as a Breit-Wigner function convoluted with a gaussian resolution and a background distribution taken as a 2nd order polynomial.

The efficiency of high p_T RPCMuon is measured to be more than 98% for RPCMuLoose and RPCMuMedium as shown in the figure 2. There are efficiency drops in $|\eta| = 0.2, 0.8$ and $|\eta| > 1$ which reflect the detector layout. Efficiency drops in the barrel correspond to the spaces between wheels. The efficiency drops at high pseudorapidity region are visible for the RPCMuTight due to the fact that there are only 3 RPC layers in the endcaps as shown in the figure 1.

4 Misidentification probability

Some hadrons can be misreconstructed as muons during the identification. For example, a pion or kaon can decay into a muon and neutrinos. The secondary muon hit can be linked with the hadron track and identified as muons (decay-in-flight). Some hadrons can pass through the calorimeters and propagate to the muon detectors (punch-through). If tracks multiplicity is very high, a

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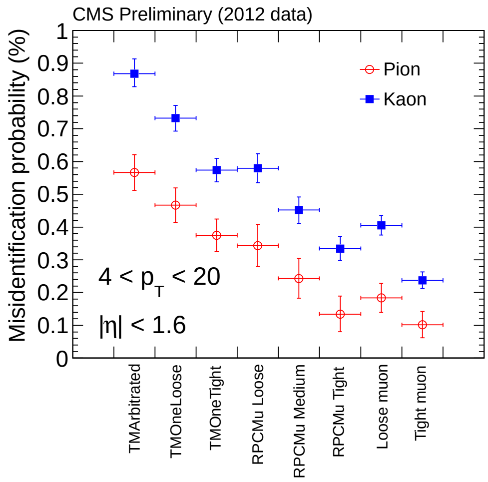

Figure 3. Muon misidentification probability.

pion track can be matched with muon hits by chance (random matching). The misidentification probabilities of hadrons were measured using the well-known decays of resonances. For the pion misidentification probability, the decay of K_s^0 meson into pion pairs was used. In a similar way, ϕ^0 meson were used to study kaon misidentification probability.

The misidentification probability of RPCMuLoose working point is measured to be $0.364 \pm 0.073\%$ for pions and $0.579 \pm 0.045\%$ for kaons which is comparable to the tracker muon identification with one station requirement. The medium working point of RPCMuon identification shows a lower misidentification probability, reaching to $0.261 \pm 0.069\%$ (pion) and $0.452 \pm 0.041\%$ (kaon). Overall misidentification probabilities for the tracker muons, RPCMuons and the standard muon identification in CMS are shown in the figure 3. The misidentification probability of RPCMuMedium is comparable to one for loose muon, which is measured to be $0.171 \pm 0.050\%$ (pion) and $0.405 \pm 0.030\%$ (kaon). RPCMuTight shows best performance among the three RPCMuon identifications where its values are $0.147 \pm 0.063\%$ (pion) and $0.335 \pm 0.036\%$ (kaon). Dependencies of misidentification probabilities to the hadron transverse momentum and pseudorapidities are also presented in the figure 4 and 5.

5 Conclusions

The muon reconstruction with RPC hits was implemented as one of the standard algorithms of the CMS experiment. Efficiencies of RPC tracker muon reconstruction algorithms were measured using the Tag-and-probe technique in the region of transverse momentum above 4 GeV$/c$ and pseudorapidity $|\eta| < 1.6$ using muons from the decay of Z^0 bosons. The efficiencies of loose and medium working points of RPC tracker muon algorithms were measured to be greater than 98%. The misidentification probabilities from hadrons were measured using the decay of K_s^0 and ϕ^0 mesons. The $\pi^\pm \to \mu^\pm$ misidentification probability at the loose working point is $0.364 \pm 0.073\%$ and the equivalent number for $K^\pm \to \mu^\pm$ is $0.579 \pm 0.045\%$ which is comparable to the standard identification criteria.

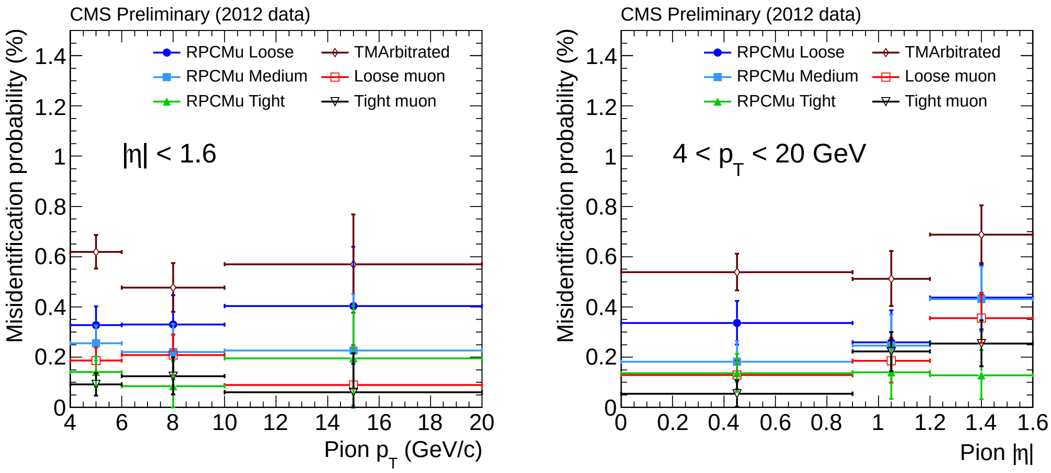

Figure 4. Muon misidentification probability from pions in transverse momentum and $|\eta|$.

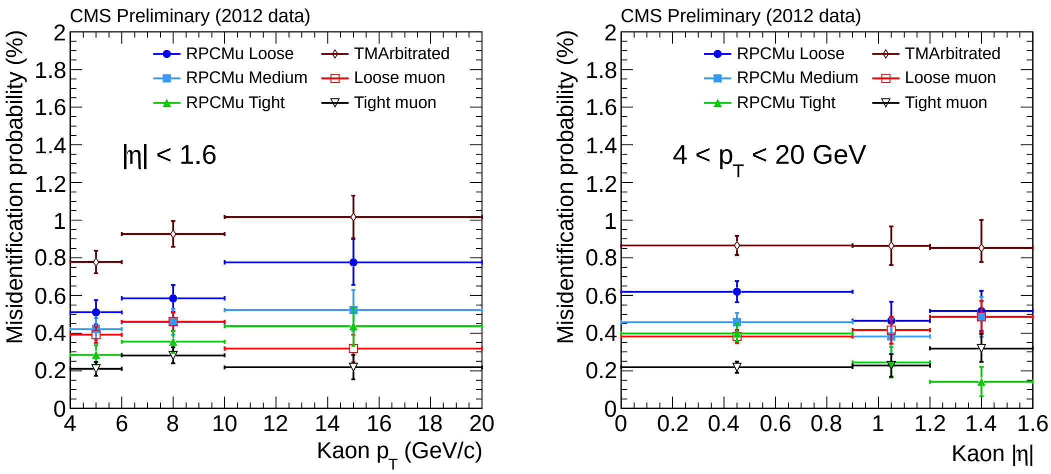

Figure 5. Muon misidentification probability from kaons in transverse momentum and $|\eta|$.

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