The Compact Muon Solenoid Experiment
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Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

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Study of the RPC Level 1 Trigger efficiency of the Compact Muon Solenoid at LHC with cosmic ray data

Alberto Orso Maria Iorio for the CMS Collaboration

Abstract

We report on a study of the Resistive Plate Chambers (RPC) Level 1 Trigger system efficiency in the Barrel of the Compact Muon Solenoid (CMS) detector at the Large Hadron Collider. The method used to study the efficiency exploits the independence of the CMS Drift Tube and RPC trigger systems. Muon tracks in the event are triggered and reconstructed using the Drift Tube subsystem only, and for each of them we search for a compatible RPC L1 trigger object. We discuss in detail the results obtained with cosmic ray data taken in 2008-2009.

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1. Introduction

The Compact Muon Solenoid (CMS) Muon System [1][2] has been designed to provide excellent muon identification, triggering and precise momentum reconstruction over the entire kinematic range foreseen at the Large Hadron Collider (LHC). The Muon System is divided in two regions: the Barrel, that covers the range of pseudorapidity $|\eta| < 1.04$, and the two Endcaps, covering the pseudorapidity range $0.8 < |\eta| < 2.1$. The Barrel and Endcap regions thus overlap in the pseudorapidity range $0.8 < |\eta| < 1.04$. A crucial feature of the Muon System is the redundancy provided by the combination of Drift Tube (DT) and Resistive Plate Chamber (RPC) independent sub-systems in the Barrel region, and Cathode Strip Chambers (CSC) and RPC sub-system in the Endcap region.

CMS has performed dedicated periods of data taking with the magnetic field on during october 2008 and july-august 2009 to collect cosmic ray data (Cosmic Runs at Four Tesla, CRaFT).

An optimized cosmics configuration for RPC L1 trigger was developed for the commissioning of L1 trigger during CRaFT.

We exploited the independence of the DT and RPC systems to develop a method for the measurement of the Barrel RPC L1 trigger efficiency.

We present results obtained on data collected during CRaFT.

2. The Barrel CMS Muon System

The Barrel Muon System[1][2] is composed of 5 Wheels along the direction of the LHC beam axis, referred to as z axis, named W-2, W-1, W0, W+1, W+2 in the direction of positive z .

Defining ϕ as the polar angle with respect to the z axis, each wheel is divided into twelve sectors along ϕ .

Defining r as the radial distance from the z axis, For each sector there are 4 DT stations, from MB1 (the inner one along the direction of increasing r) to MB4 (the outer one). Corresponding to each DT station there is one RPC station, composed by one or two RPC layers, for a total of six concentric RPC layers in the Barrel Muon System.

Defining η as the pseudorapidity, an RPC layer is segmented into two or three η partitions, called rolls.

3. The L1 trigger system for Barrel RPCs

The RPC Level 1 trigger [3] is logically partitioned into sections. L1 trigger objects are searched for independently in each section. Sections in the η view will be referred as *towers*, and for each tower the partitions in the r - ϕ view will be referred as *cones*.

The definition of the η boundaries of towers (see Fig. 1) is based on a set of reference layers.

The RPC trigger logic has 33 towers. In 2009 the RPCs at highest eta were not installed yet, so the coverage of the trigger was $|\eta| < 1.6$ and the towers included in the trigger were 25. A total of 5+5+1 towers is entirely contained in the Barrel.

Figure 1: Trigger eta towers.

On the reference layers, the strips are grouped in non-overlapping sets of 8 adjacent strips called *segments*. Each segment subtends a ϕ angle of 2.5° , for a total of 144 segments (12 segments for each sector). Each cone must contain only one segment of a reference layer.

3.1. The L1 PACT logic

The PAttern Comparator Trigger (PACT) logic collects RPC hits from all stations and searches for spatial and time coincidences independently in each cone. The η and ϕ coordinates of the trigger objects are assigned on the reference station. By comparison with predefined patterns of hits, a P_T value is also assigned to the candidate trigger object.

Trigger candidates are processed by a proper ghost identification and removal logic, and the remaining ones are sorted according to quality criteria.

3.2. Cosmic patterns in PACT

In order to increase the trigger efficiency for cosmic muons, which are not constrained to come from the interaction vertex, a looser pattern definition has been adopted with respect to collision runs. A cosmic pattern is defined as a time coincidence of hits on at least 3 different RPC stations in a cone (3/6 majority). No different patterns as a function of P_T are defined, thus the system does not assign a P_T value to the track in cosmics configuration.

4. The algorithm for efficiency measurement

The redundancy of the RPC and DT L1 trigger systems allows to study a statistically unbiased sample that has not been triggered exclusively by RPCs.

For a precise determination of the position where the cosmic particle hit the reference layer and of the momentum of the track, we use the tracks reconstructed with the Muon System, referred to as StandAlone tracks.

The tracks are matched to a DT trigger object. In this way we reject fakes and define a sample of tracks that have not been triggered exclusively by RPCs.

In order to prevent an eventual bias due to tracks that would not have been reconstructed without RPC hits, we re-run the reconstruction using DT only.

The track-trigger matching is performed in the ϕ coordinate only, which is the most accurate coordinate measured by both DT and RPC trigger systems.

The matching requirement is $|\Delta\phi_{t-DT}| < 30^\circ$, where $\Delta\phi_{t-DT}$ is the difference between the ϕ of the track at the reference layer and the ϕ of the DT trigger. If a match with a DT trigger is found, a RPC trigger that matches the track is looked for. Figure 2 shows the overall $\Delta\phi_{SA-RPC}$ as measured using both cosmic patterns and collision patterns (the latter one obtained by running the trigger emulator).

The second peak at $\Delta\phi_{SA-RPC} \approx -0.06$ for the residuals distribution of cosmic patterns is due to the fact that the cosmic pattern configuration cannot identify the P_T of the track.

In case of two candidates with the same quality then the one with the smaller ϕ is selected. The plot shows that this feature is only relevant for cosmic ray patterns.

Figure 2: Distribution of the difference $\Delta\phi_{SA-RPC}$ between the ϕ of the StandAlone track measured at the reference station and the ϕ of the RPC trigger (CRaFT08, Run 66783).

Given the number of tracks matched to a DT Trigger object N_{match}^{DT} , under the assumption that RPC and DT triggers are uncorrelated the RPC trigger efficiency ϵ_{L1}^{RPC} is given by the fraction of tracks in the sample that are matched also to an RPC

trigger object:

$$\epsilon_{L1}^{RPC} = N_{match}^{RPC\&DT} / N_{match}^{DT} . \quad (1)$$

We select tracks pointing to the $p-p$ interaction region by requiring that the track passes through a cylinder centered in the interaction point, with the height parallel to the z axis $h = 260$ cm and a radius $r = 90$ cm (definition of TrackerPointing skim). In addition, the tracks are required to have:

- Transverse momentum P_T of the track evaluated at the track's innermost point $> 5\text{GeV}/c$
- Number of hits in the DT chambers used to reconstruct the track $N_{hits} > 20$;
- χ^2 of the fit performed to evaluate the track parameters < 20 .

The P_T cut removes tracks which are bending in the transverse plane due to the magnetic field. The last two cuts ensure good quality of the DT reconstruction.

5. Efficiency on cosmic ray data

Figure 3 shows the trigger efficiency in bins of $z - \phi$ of the track extrapolated to the reference layer in the top ($0^\circ < \phi < 180^\circ$) part of the CMS Barrel.

Figure 3: RPC trigger efficiency in CRaFT09 as a function of $zeta$ and ϕ for tracks in the top part of the Barrel detector ($0^\circ < \phi < 180^\circ$). The $zeta$ and ϕ coordinates are extrapolated to the reference layer. The wheels (sectors) corresponding to different $zeta$ - ϕ regions are labelled on the left (top) part of the plot.

The efficiency of the trigger drops in the regions of separation between two adjacent sectors or wheels.

The gaps in the regions $-200 < z < -220$ cm, $45 < \phi < 75^\circ$ and $180 < z < 200$ cm, $75 < \phi < 105^\circ$ are due to the presence of the cooling chimneys of the CMS magnet.

The cosmic particles distribution disfavours vertical sectors (sectors 1 and 7), which are less populated.

Some regions of the plot are not populated because certain sectors of the detector were off during the particular data taking period.

However the loose trigger matching condition of 30° when the RPC/DT trigger object is found in an adjacent sector can give a contribution in those regions.

We use the momentum of the reconstructed track in the Muon System to define the efficiency vs P_T of the incoming cosmic particle.

We also introduce geometrical cuts in order to select only cosmic tracks in the central regions of the rolls and sectors. Indeed, in the border regions DT and RPC triggers are affected by common inefficiencies due to geometry, which introduces correlations between the two systems.

The fiducial cuts choice along ϕ is : $|\phi - \phi_{center}| < 5^\circ$, where ϕ_{center} is the value of ϕ at the center of each barrel sector. The fiducial cuts choice along z is : $|z| < 100$ or $200 < |z| < 300$ or $450 < |z| < 550$ cm.

The trigger efficiency vs. the P_T of the tracks is shown in Fig. 4.

Figure 4: P_T for cosmic tracks in the fiducial region defined by Table ?? . The efficiency plateau is reached at around $P_T > 50$ GeV/c at a value $\epsilon_{09} = 98.01 \pm 0.08\%$.

6. Conclusions

A method to measure the L1 RPC trigger efficiency has been developed. It exploits as efficiency probes cosmic ray tracks matched to a DT trigger. It can be used to measure the trigger efficiency also for channels where there are not two back-to-back muons (W channels, top channels, etc.). The method has been applied to determine Barrel RPC trigger efficiencies with cosmic data from 2008 and 2009 and is ready to be applied on collision data.

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- [2] The CMS experiment at the CERN LHC, JINST 3, S08004
- [3] The Trigger and Data Acquisition Project, Volume I, the Level-1 Trigger TDR

- [4] Performance Study of the CMS Barrel Resistive Plate Chambers with Cosmic Rays, CMS Collaboration 2010 JINST 5 T03017
- [5] Performance of the CMS Level-1 Trigger during Commissioning with Cosmic Ray Muons, CMS Collaboration 2010 JINST 5 T03002