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The RPC system for the CMS experiment at the LHC

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Abstract

The CMS detector at the LHC has a redundant muon system. Two independent muon systems are used in the L1 trigger. One of them is based on wire chambers, the other on RPC detectors. Properly combining the answers of the two systems results in a highly efficient L1 trigger with high flexibility from the point of view of rate control. Simulation results show, however, that the RPC system suffers from false triggers caused by coincidence of spurious hits. System improvements, which could avoid oiling the chambers, are possible. RPCs have also proved to be very useful for muon track reconstruction.

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1. Introduction

Resistive Plate Chambers (RPC) [1] will be used as dedicated muon trigger detectors in the CMS experiment at the LHC. The CMS muon trigger [2] also comprises a second system of detectors based on precise wire chambers with multi-layer structure which works independently of the RPC trigger. There are Drift Tubes (DT) in the low pseudo-rapidity (η) region (barrel) and Cathode Strip Chambers (CSC) in the high η region (endcap). Four measuring stations will be installed in the iron return yoke of CMS up to $\eta = 2.4$. The RPC trigger covers both barrel and endcap but only up to $\eta = 2.1$. In the L1 Trigger the final information on the muons found by the two systems is processed by the Global Muon Trigger (GMT).

The muon systems rely on the solenoidal magnetic field in the iron return yoke of the apparatus to estimate the muon transverse momentum (p_t) from the track bending. Four RPC planes are used in the trigger which is based on a pattern recognition algorithm requiring 3 out of 4 coincidences. The DT and CSC triggers perform local reconstruction of track segments in each chamber and require the presence of at least two segments. For High Level Trigger algorithms or

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off-line analysis purposes, muon track reconstruction can be carried out by means of a global fit to the reconstructed hits from all muon detectors.

RPCs have undergone major developments in view of their use at the LHC. A fundamental issue is the use of linseed oil to coat the internal electrode surface. Traditionally RPCs are oiled to reduce the intrinsic noise rate from several tens of $\mathrm{Hz\,cm^{-2}}$ to about $1\ \mathrm{Hz\,cm^{-2}}$. However, aging effects are feared in case of presence of an organic material in detectors that have to work in the LHC environment over several years.

2. The CMS level-1 muon trigger and the RPC system

The Level-1 Trigger (L1) has to reduce the LHC input rate of 40 MHz to no more than 25 kHz. Half of this bandwidth is dedicated to triggers involving at least one muon. Event selection is based on a threshold on the muon p_t (p_t^{cut}).

Complex algorithms are possible in the GMT because both the DT/CSC and the RPC trigger deliver information about p_t, position and quality of detected muon candidates.

Excluding the contribution of punch-through, which has not been studied, the muons found by the trigger systems can be split into three main components according to their source, namely

(1) Prompt muons (from W, Z, γ^*, t, b and c).
(2) Decay muons from π and K.
(3) False triggers created by coincidence of accidental hits: detector noise or low range particles from neutral background.

False triggers are higly improbable for wire chambers due to their multi-layer structure. On the other hand this contribution can be significant for RPC. Contribution (1) and (2) have been studied with data samples produced with PYTHIA 6.1 [3]. Tracking of the particles through the CMS detector has been simulated with the CMSIM 121 program based on GEANT3 [4]. Contribution (3) has been studied by means of events containing only noise and background hits. In all cases the response of the detectors and the trigger algorithms have been fully simulated.

Unless differently specified, the results presented in this paper have been obtained assuming for the RPC detectors uniform efficiency $\varepsilon_{\mathrm{RPC}} = 95\%$, Gaussian time resolution with $\sigma_{\mathrm{RPC}} = 2.7$ ns and average cluster size of about 2 strips (corresponding to the parameter $\mathrm{cs} = 1.5$ of a decreasing exponential distribution). RPC signals are accepted in 20 ns wide gates. Both the RPC spurious hits ($\mathrm{noise_{RPC}}$) and the hits produced by neutral particles have been assumed to be Poisson distributed. The rate of the latter source has been parametrized according to distributions obtained in dedicated simulation studies [5] and is multiplied by the factor *rate_fac*.

A muon is accepted by the GMT regardless of its quality if it is found by both systems, the final p_t is the minimum of the two estimations. Best compromise between contribution to the trigger rate and efficiency gain is the criterium adopted to accept or not unmatched muons of a given quality.

The reconstruction efficiency as a function of η for the GMT, DT, CSC and RPC triggers is shown in Fig. 1. The curves have been obtained with a single muon sample flat distributed in $2.5 < p_t < 100\ \mathrm{GeV}/c$ and $0 < |\eta| < 2.4$. The efficiency for the individual systems is calculated allowing muons of any quality. The GMT efficiency is almost everywhere greater than 90%. Non-perfect geometrical coverage causes the presence of delicate regions in the barrel in correspondence of the cracks between the muon stations and in the so-called overlap region of barrel and endcap ($0.8 < |\eta| < 1.2$).

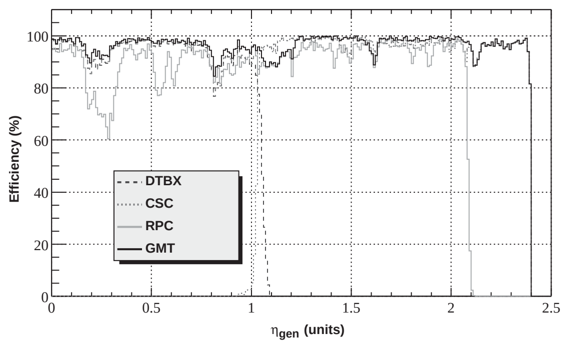

Fig. 1. Reconstruction efficiency as a function of η for the GMT, DT, CSC and RPC triggers.

The single muon trigger rate at the nominal LHC luminosity of 10^{34} cm^{-2} s^{-1} due to contribution (1) and (2) as a function of p_t^{cut} is shown in Fig. 2 together with the generation rate and the trigger rates of the individual systems (all qualities allowed). It is evident the superior performance of the GMT over the individual systems.

If the RPC trigger works alone one is obliged to exclude low quality muons in some parts of the system in order to reduce the output rate. The efficiency of the RPC system at $p_t^{cut} = 20$ GeV$/c$ is shown in Fig. 3 as a function of increasing η regions (towers). The barrel goes up to tower 6, the endcap includes towers 10–16 while towers 7–9 involve chambers from both regions. The plot has been obtained by allowing only 4/4 coincidences in towers 9–12. Various scenarios from the point of view of RPC performance are considered. It is evident that to avoid relevant trigger efficiency losses the detectors must be operated at an efficiency well above 90%. Time resolution appears to be less critical.

The rate of RPC pure false triggers has been calculated for different combinations of noise and background hits rates and cluster size. The results are summarised in Fig. 4, where the trigger

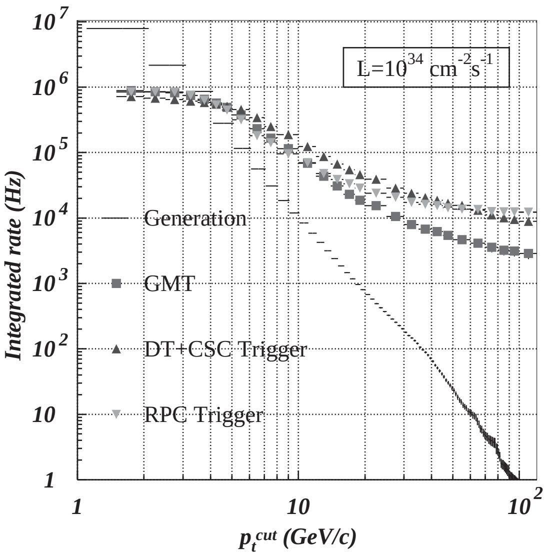

Fig. 2. L1 single muon trigger rate as a function of p_t^{cut} at $L = 10^{34}$ cm^{-2} s^{-1}.

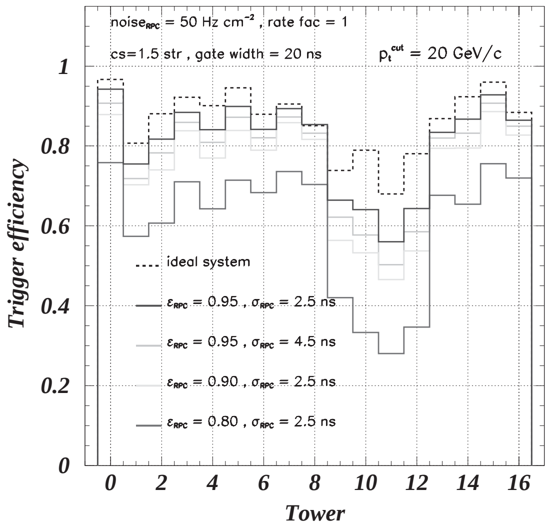

Fig. 3. RPC trigger efficiency versus tower for $p_t^{cut} = 20$ GeV$/c$.

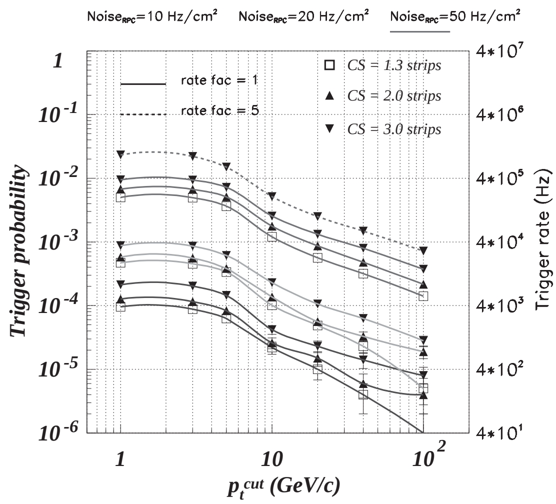

Fig. 4. RPC single muon trigger rates due to coincidences of noise and background hits versus p_t^{cut}.

probability per bunch crossing (the trigger rate can be read on the right y-axis) is reported versus the p_t^{cut}. Only 4/4 coincidences are allowed in towers 9–12. At $p_t^{cut} = 20$ GeV$/c$ the trigger rate is about 40, 4 and 0.4 kHz for noise$_{RPC} = 50$, 20, 10 Hz cm^{-2} respectively, with differences within a factor 2 due to the cluster size. The false trigger

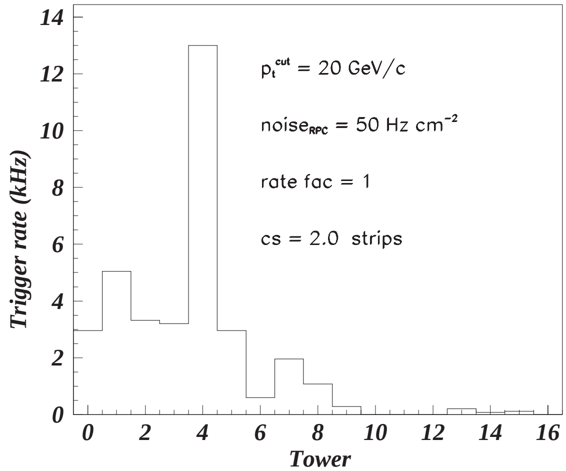

Fig. 5. RPC false trigger rate distribution among towers.

rate for $noise_{RPC} = 50\ \mathrm{Hz\ cm^{-2}}$ and ratefac $= 1$ is largely dominated by the barrel as it can be seen in Fig. 5 which shows the false trigger distribution among the towers. There are two basic reasons for this result. First the large area covered by each single barrel strip. Second, noise levels as high as $50\ \mathrm{Hz\ cm^{-2}}$ are dominant over the neutral hit rate in the barrel while in the endcap they are comparable to it. The endcap starts becoming critical if ratefac is increased.

3. RPC system developments

The false trigger problem can be cured if more information is provided to the trigger processors. In the barrel there up to 6 RPC planes available but only 4 at a time are used in the baseline scheme. Coincidence algorithms of 4/6 or 4/5 are therefore possible in this region. The possibility to insert an extra plane has also been considered. In the endcap the problem is less serious but in order to have enough safety margin one must think of ways to improve the system in this region too. The option of inserting an extra plane in the second endcap station has been considered. In this study, the additional planes, either the existing ones or the extra ones, are used to confirm the decision of the baseline processors. Only 3/4 coincidences are required a confirmation. The 4/4 ones are accepted without any further requirement. The confirmation is made if a hit is present in a group of 20 strips on average, therefore higher false trigger rejection can be achieved with a full resolution algorithm. The goal is to find the best compromise between efficiency and false trigger suppression. In order to summarise the results of the optimisation two options for each region have been selected. One option called "loose cuts" was chosen requiring that the efficiency should be at least 80%. The second option called "tight cuts" has been optimised for the rate requesting that the false trigger rate per region for $p_t^{cut} = 25\ \mathrm{Gev}/c$ should not exceed much 1 kHz. These two options, available with the baseline RPC geometry, are compared to options available with extra planes: a fifth plane in the endcap and a seventh plane in the barrel. The results are shown in Fig. 6 [6]. It can be seen that an additional plane in the endcap would significantly improve the performance of the trigger. The gain introduced by the extra barrel layer is much smaller.

Another development study concerning the RPCs for CMS is their use for muon track reconstruction in the L2 trigger, in which only DT and CSC information had been considered so far. The L2 reconstruction efficiency obtained with a single muon sample flat in $2.5 < p_t < 100\ \mathrm{GeV}/c$

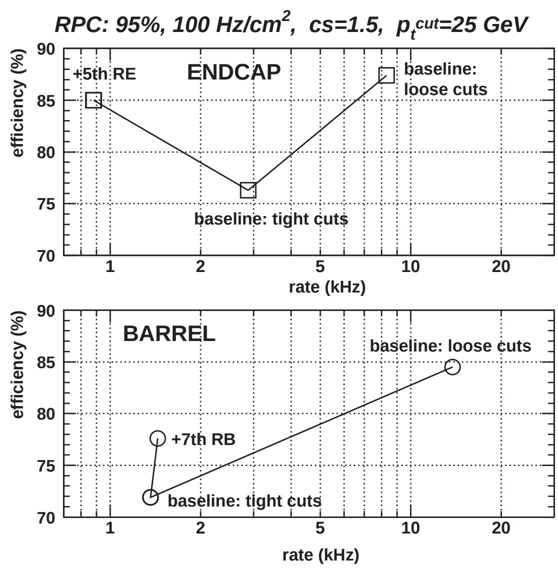

Fig. 6. RPC trigger performance in the barrel and in the endcap for various options.

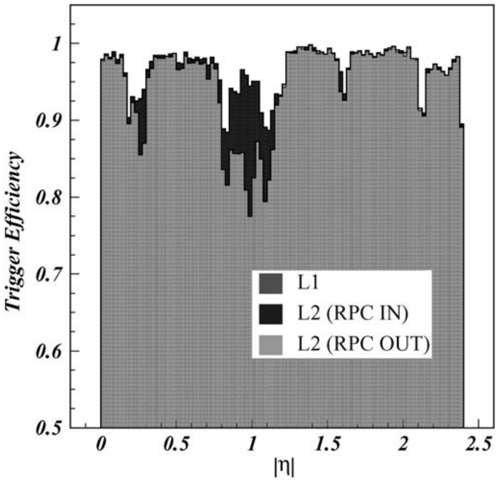

Fig. 7. L1 and L2 muon reconstruction efficiency as a function of η.

is shown in Fig. 7 as a function of η. Two cases are considered: the first is reconstruction at L2 without RPC, the second is reconstruction at L2 with RPC. The L1 trigger efficiency is also shown and refers to the GMT as defined in Section 2. When RPC information is brought in, the L2 efficiency follows closely the L1 one without any efficiency loss. It is evident the improvement achieved in the overlap region when information from all muon detectors is used.

4. Conclusions

Thanks to its redundant structure the CMS L1 trigger performs very efficiently and keeps the output rate within the allowed limits. However, detailed simulation has shown that the RPC trigger with non-oiled chambers will suffer from creation of false triggers due to too high noise levels. Improvements to the system, which could render oiling unnecessary, are possible. In the barrel one should move from a 3/4 algorithm to a 4/5 or 4/6 using full detector resolution. In the endcap, where only 4 planes are available, an extra plane would be very useful. Finally, RPC information has been proved to be fundamental for efficiency completion in muon track reconstruction for the high level trigger.

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