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Complementarity of the Two Components of the CMS Muon Trigger System

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Abstract

The general concept of the CMS muon trigger is presented. The advantages of the two component system are discussed with an emphasis on the operational domains where each of the components is necessary. The design is compared with other experiments.

Contents

1 Introduction

The CMS muon trigger system employs two components to provide a sharp p_t cut over a large momentum range and a reliable bunch crossing identification. CMS has been asked by the LHCC referees whether it would be possible to employ a single component muon trigger system by enhancing the performance of one of the existing components and removing the other. This issue was briefly discussed in the Technical Proposal. In this note we wish to expand on this discussion in order to further clarify the reasons for the baseline design of the muon trigger system.

We have grouped the arguments for a two-component muon system into three categories in order of priority:

- cases where each trigger component is necessary,
- safety margins offered by the two-component design,
- additional advantages of this solution.

We wish to point out that while significant progress has been made in the design of the muon trigger system, there is considerable design work remaining. Therefore, this note necessarily must draw on the existing state of the design. In some instances, such as parts of the CSC trigger, this results in conclusions that are somewhat qualitative. We will update these conclusions as the design work progresses. However, we do not expect the details of further design work to seriously influence the basic conclusions presented here.

2 Specific features of the CMS trigger system

The very high luminosity and large particle fluxes expected at LHC impose stringent requirements on the trigger system. The input rate of 10^9 interactions every second must be reduced by a factor of at least 10^7 to 100 Hz, the maximum rate forseen for the data storage system. CMS has chosen to reduce this rate in two steps. The first level (LV1) stores all data for 3 μsec, after which no more than a 100 kHz rate of the stored events is forwarded to the second level (LV2). This must be done for all channels without dead time. The second level is provided by a subset of the on-line processor farm, and passes a fraction of these events for more complete processing by the remainder of the on-line farm.

In this system, the principal bottleneck is the volume of data transmitted from the first level system to the second level system. Uncertainties in rates to be expected at the LHC as well as the CMS detector performance require demonstration that the LV1 trigger can meet its benchmark performance with an output rate considerably below 100 kHz. In addition, some part of the LV1 bandwidth must be devoted to the triggers necessary to understand acceptance. Therefore, we have established a target total LV1 trigger rate of 30 kHz.

We expect one-half of the Level 1 bandwidth to be filled by triggers involving the calorimeter system and the other half to be filled by triggers involving the muon system. However, since we do not anticipate an even division of Level 1 bandwidth among subtriggers, we also plan for flexibility to accommodate variations in rate and performance. For now, as a general rule, we establish the requirement that the sum of all LV1 muon triggers be less than 15 kHz.

The muon trigger must identify the muon, the crossing in which it occurred and apply a p_t cut. We elaborate on these requirements below:

1. Single muon LV1 output rate of a few kHz.
2. Large flexibility.
3. High purity of the sample:
   (a) sharp p_t cut,
   (b) powerful background rejection.
4. Reliable bunch crossing assignment.

Flexibility in setting the p_t cut is necessary in order to allow LV1 to accept the largest number of muon triggers that the LV2 can process. The purity of the sample determines how low the p_t cut can be set. The more background events that accompany the legitimate muon triggers, the higher the overall rate is per good trigger and the higher the p_t cut must be set to reduce the overall rate, thereby reducing the number of legitimate muon triggers. Since the bandwidth from LV1 to LV2 is fixed, there is no possiblity to recover the events cut in LV1 through an increase in this bandwidth. Therefore, there is a premium in the design on producing the highest purity input into LV2.

3 The two-component muon trigger system of CMS

In order to fulfill all of the above requirements we propose to build a system which consists of two components:

1. **Fast**, dedicated trigger detectors – Resistive Plate Chambers (RPC)
2. **Precise** muon chambers – Drift Tubes (DT) in the barrel and Cathode Strip Chambers (CSC) in the endcaps.

The tasks of the two components are different and from a logical point of view they can be treated as two distinct functions.

First:

- recognise a muon,
- identify the bunch crossing,
- estimate the p_t of the muon.

Second:

- confirm the muon identification,
- sharpen the p_t cut.

There is some overlap in function between the two component, which is required for the components to work together. Both should deliver space and time information needed to correlate their answers. Therefore, the muon chambers must have good capability of bunch crossing identification to ensure that the information delivered corresponds to the same event as that of the RPC system. In addition, the p_t estimate by the RPC system is required to support the chamber measurement in ambiguous cases such as those caused by radiating muons and high local backgrounds. The function and interplay of the two components are examined in detail in the next section.

4 Domains of the two trigger subsystems

The CMS muon trigger system depends on two components because each of the individual components is inadequate by itself to fulfill the CMS requirements. In order to illustrate the necessity of both, we examine a number of operational domains where the function of one or the other of the two components is required.

4.1 Low p_t ($<$ 6 GeV)

For the RPC system the lowest possible p_t cut is determined only by the amount of material in the muon path [1, 2]. In the barrel there are two RPC planes in MS1, two in MS2, one in MS3, and one in MS4. At high p_t only one RPC plane per station is used. A coincidence of 3 out of 4 planes is required for a trigger. Probability of such a concidence is shown in Fig. 1 (dashed line) as a function of p_t. Low p_t particles are not able to reach outer stations and therefore only RPCs in MS1 and 2 are used for a low p_t trigger. Again the coincidence of 3 out of 4 planes is required. Probability of this concidence is presented in Fig. 1 as a solid line. It is seen that the lowest possible effective trigger cut is about 3.6 GeV.

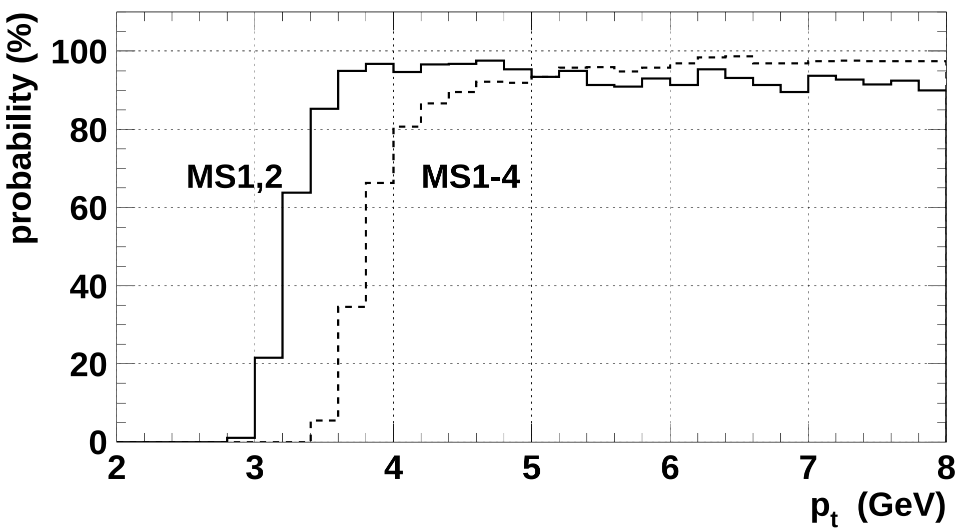

Figure 1: Probability to hit 3 out of 4 RPC planes: MS 1, 1', 2, 2' - solid line, MS 1, 2, 3, 4 - dashed line (geometrical losses included).

The low p_t cut limit of Drift Tubes in principle also can be as low as the muon energy loss limit, but there is an obvious trade off between the angular range to be covered and the complexity of electronics. In the current design the lower limit on the p_t cut comes from the angular range of the meantimers, $\Delta\phi = \pm 45°$. Highly bent tracks with $p_t < 5$ GeV fall outside this range [3]. The efficiency loss due to this effect is shown in Fig. 2.

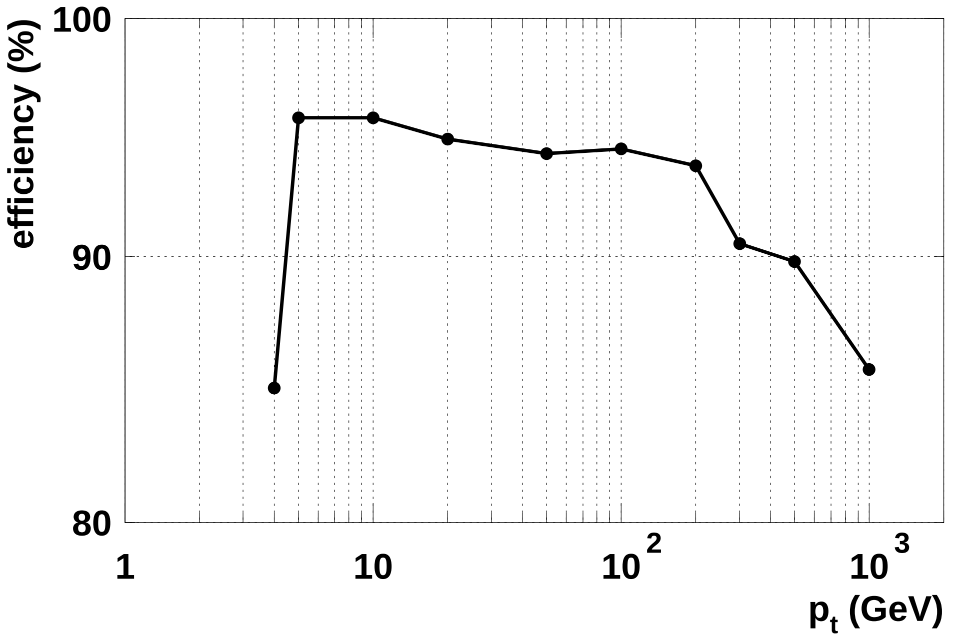

Figure 2: Efficiency of p_t measurement by DT meantimers at MS1 (geometrical losses not included).

The low p_t cut limit of the CSCs is set by the muon energy loss limit. As such it varies with rapidity between 4 and 2.5 GeV since the amount of absorber depends on the muon angle. The logic to identify lower p_t muons employs a larger angular range and complexity of electronics in order to reduce the cut to this value.

In conclusion, the low p_t region in the barrel is only fully covered by the RPCs, which are therefore required for this operational domain. The difference between the p_t reach of RPCs and DTs is small ($\sim$ 1–1.5 GeV) but it is crucial for b-quark and heavy ion physics. For example decreasing the p_t cut from 5 to 4 GeV allows us to collect twice more $\Upsilon \to 2\mu$ events [4] (see Fig. 3).

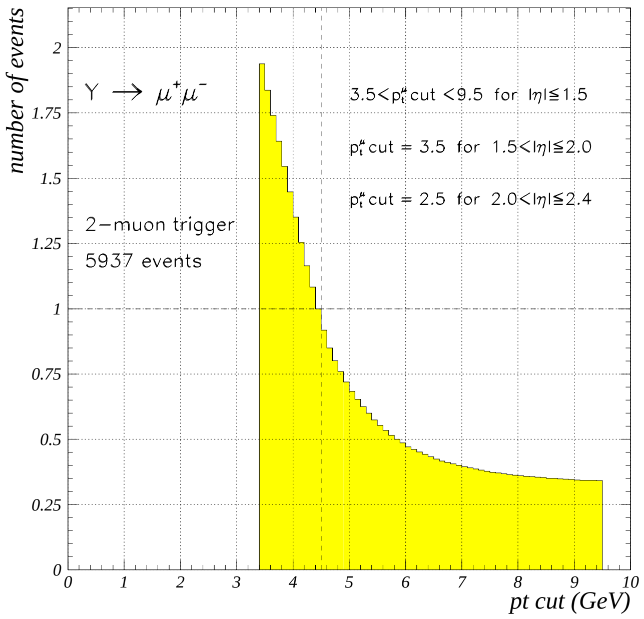

Figure 3: $\Upsilon \to 2\mu$, number of events vs p_t cut.

4.2 Intermediate p_t (20-100 GeV)

The readout granularity of the RPCs limits their momentum resolution above $p_t = 20$ GeV. Therefore, the cut purity (defined as a fraction of triggered muons with p_t truly above p_t cut) degrades from about 60 % below 20 GeV down to 20 % at 100 GeV (see Fig. 4 and Ref. [5]). Result of this is a coresponding increase of trigger rate which can be seen in Fig. 5. Note that the present CMS baseline does not include RPCs for $2.0 < |\eta| < 2.5$, but does leave space for their installation as part of a future upgrade.

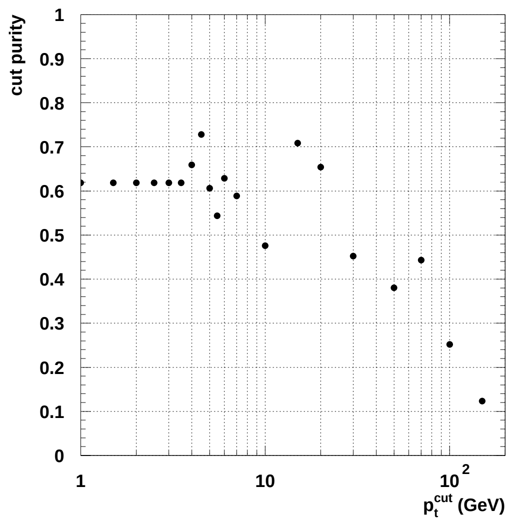

Figure 4: Trigger purity vs p_t cut of the RPC system (preliminary).

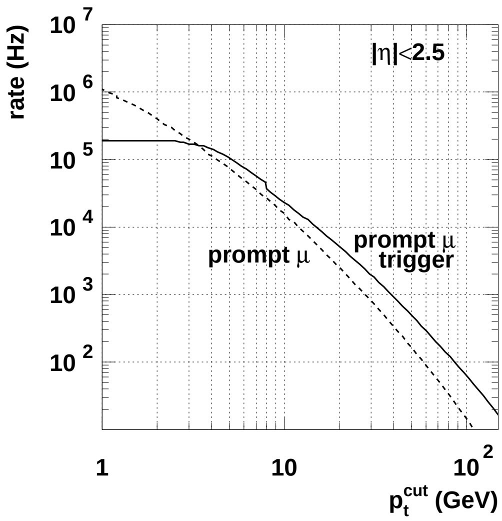

Figure 5: Prompt muon rate (dashed curve) and RPC trigger rate (solid curve).

The detailed simulation of the DT/CSC system is not yet complete. Preliminary results on RPC and DT comparison are shown in Fig. 6. Here the meantimer action was not simulated explicitly and only the ultimate meantimer resolution of 1.25 mm was taken into account. The muon chambers considerably sharpen the momentum cut and therefore, their output rate curve would be close to the dashed curve in Fig. 5, representing the prompt muon rate. This means that sharpening the p_t cut by the DTs/CSCs can reduce the trigger rate in the range of 20-100 GeV by a factor of 2-5 and therefore they are required for the intermediate p_t domain.

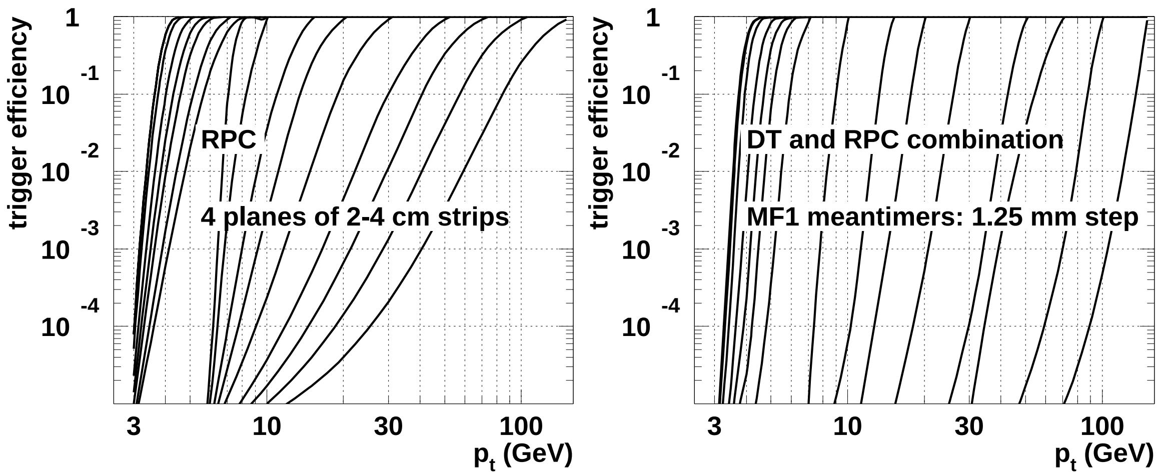

Figure 6: Efficiency of the RPC system alone and sharpened by Drift Tubes. (preliminary)

4.3 High p_t (>200 GeV)

High p_t muons have frequent showers, which can overload the meantimers of the DT system [3]. The CSC trigger does not seem to have this drawback. A significant drop of meantimer efficiency above 200 GeV due to this effect can be seen in Fig. 2. If there is no shower in other stations (which is usually the case) the measurement can still be performed. In the case where showers do not cause the loss of the muon trigger in the meantimers, the DT system provides a much sharper p_t cut than the RPCs. We will use this information when it is available. However, we must have a fully efficient trigger at the highest p_t since this is vital for observing important physics signals.

The RPC logic in the case of any muon above $p_t = 100$ GeV gives the "infinite momentum" answer regardless whether there was a shower or not, since it senses all satisfied patterns and the highest momentum pattern is selected. This is sufficient for trigger purposes. Therefore use of RPCs is required in the high p_t domain.

4.4 Isolated muon trigger

The isolated muon trigger employs a coincidence of a single muon trigger and a "quiet region" of the calorimeter from the calorimeter trigger system. Only RPCs can be used for these triggers for the following reasons. The latency time of the RPC system of 63 bunch crossings (bx) is well matched to the latency of the calorimeter trigger system to produce the "quiet region" sums and is much shorter than either the DT or CSC latency (90 bx). The shorter latency to produce the RPC and calorimeter quiet region results can be used to complete the combination of this information before the results are available from the CSCs or DTs. This allows us to provide this trigger without adding to the overall trigger latency. If the combination of calorimeter information were to be made with the DT or CSC information, this would increase significantly the overall CMS LV1 trigger latency since the DT and CSC systems are in the LV1 trigger critical path. The extra storage of data in all CMS front end electronics implied by such a latency increase would involve a large increase in the cost of the CMS electronics.

Therefore, the ability to implement an isolated muon trigger in LV1 without changing the LV1 latency, requires the use of RPCs, rendering this trigger the domain of the RPC.

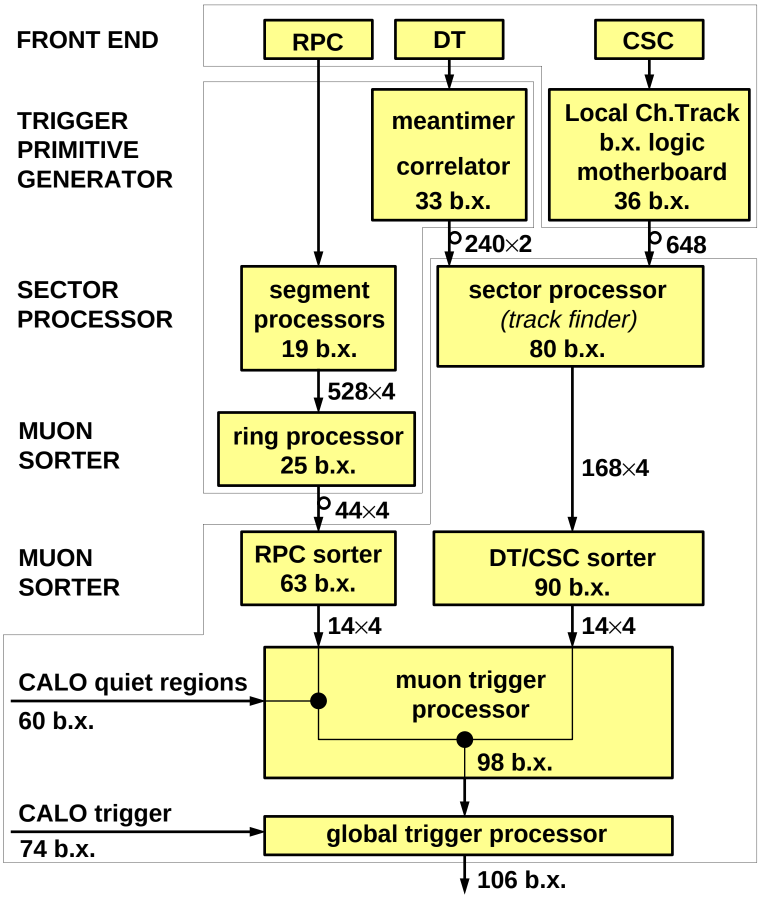

Figure 7: The muon trigger logic and connections with calorimeter and global trigger. Cumulative latency is expresed in bunch crossings (bx).

4.5 Time of flight cut against background

One of the most dangerous backgrounds for muon detectors at pp colliders are real muons not produced at the interaction point, particularly muons coming from the beam tunnel. The experience of many experiments (see Sec. 8) shows the the most effective way to suppress this background is to use a Time Of Flight (TOF) cut. The time resolution of the muon chambers is not good enough to provide such a cut and it is necessary to use dedicated, fast detectors. This is an important argument for the use of RPCs in the CMS muon trigger.

The CSCs provide an additional handle on non interaction point backgrounds due to their accuracy of pointing at the interaction point. Their high angular resolution provides a powerful tool for rejection of such backgrounds.

4.6 Impracticality of channel reduction

At this point a question may arise whether one can build a much simpler RPC system with a reduced number of channels from that outlined in the Technical Proposal. However, this is not possible because the RPC granularity is determined by the requirements on occupancy and rate of random coincidences. With the current design we maintain a hit rate of about 6 kHz/channel (Fig. 8). Reduction of channel counts by enlarging the readout area per channel would increase this rate unacceptably. Table 1 shows some examples.

The rate of random coincidences is 3 orders of magnitude below the signal (Fig. 9), but it increases as the third power of the background flux, resulting in only a factor of 10 safety margin on neutron fluxes (see [6] and [5] for details). This safety factor is the minimum acceptable given the present knowledge of these backgrounds.

Table 1: Examples of n$\rightarrow\gamma\rightarrow$e hit rates.

position		strip size in cm			flux	rate
η	station	width	length	area	Hz/cm^2	Hz/strip
1.6	MF 4	2.3	42	97	50	4800
	MF 1	1.4	27	37	150	5600
2.4	MF 4	1.0	17	17	400	6800
	MF 1	0.6	11	7	1000	6500

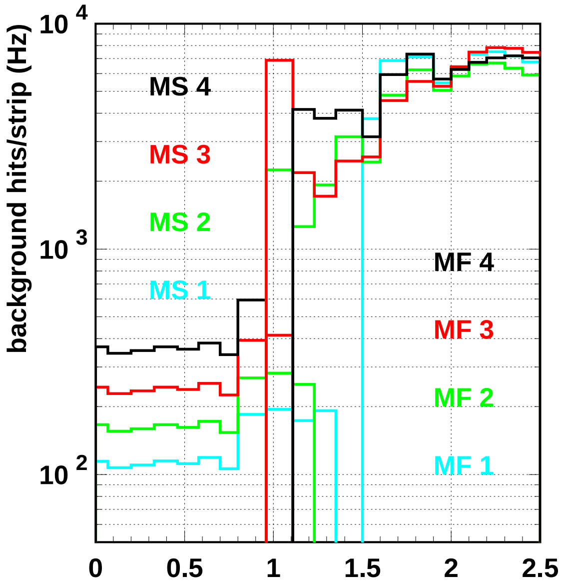

Figure 8: Hit rates in RPCs.

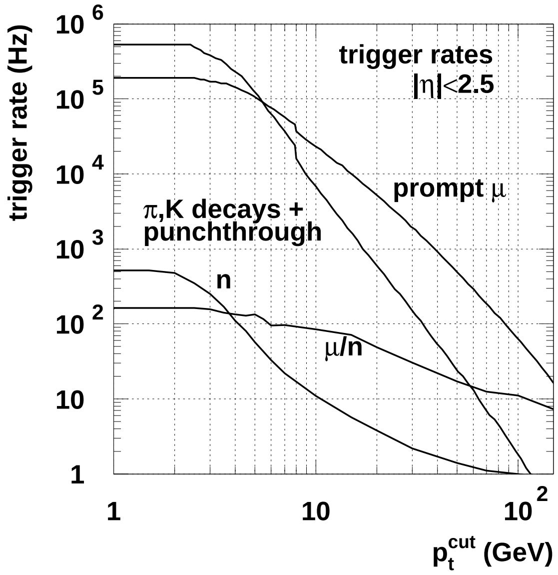

Figure 9: Contributions to trigger rate at $L = 10^{34}$cm^{-2}s^{-1}. Random coincidence of n$\rightarrow\gamma\rightarrow$e hits is indicated by "n". Coincidence of muon and n$\rightarrow\gamma\rightarrow$e is indicated by "$\mu$/n".

4.7 Magnetic field in MS1 and MS2

Between $|\eta| = 1.0$ and 1.3 in MS1 and MS2 the magnetic field is higher than 0.5 T. This may affect linearity of drift time and reduce meantimer efficiency. Therefore the RPC system is needed to ensure efficient trigger in this region.

5 Background rejection and safety margins

It seems to be the experience of all pp experiments in the past that background rates were always underestimated. Therefore it is necessary to consider the safety margins in the system as presently being designed.

5.1 Bunch crossing identification

Both DTs and CSCs have the capability to assign the bunch crossing. However, individual hits come with much greater uncertainty. This is mainly because of the drift time, which is $\sim$400 ns for the DTs and 30-40 ns for the CSCs. Therefore, in order to obtain adequate time resolution, rather sophisticated logic is needed, combining the information from several hits. The DTs use the meantimer technique, as described in [3]. A method currently considered for CSCs is described in the Appendix. The proper functioning of both methods relies on assumptions about the background level. The methods should work with full efficiency if the background rate is as expected, but might fail if it is much higher.

In the case of the RPC, every individual hit comes well within a given bunch crossing window. Therefore the bunch crossing identification is straightforward and more resistant against background. Thus the RPC system offers a larger safety margin on the bunch crossing identification than the DT/CSC system. An correct assignment of the bunch crossing must accompany each muon trigger, otherwise the trigger is lost. Therefore, a failure to determine the bunch crossing is the same as missing the trigger.

5.2 Rejection of single hits

CMS is exposed to high flux of various particles. According to recent estimations [7, 8] the resulting hit rates reaches 800 Hz/cm^2 at the highest $|\eta|$ (Fig. 10). The rate is dominated by single hits originating from neutrons. If this rate is much higher than expected, it can affect the RPC system. This is because the RPC logic requires 3 or 4 hits in different stations. The situation is different in the case of the muon chambers. Their logic requires at least 3 (DT) or 4 (CSC) aligned hits per station. Therefore the chamber triggers are much less sensitive to isolated hits and offer larger safety margins on muon identification.

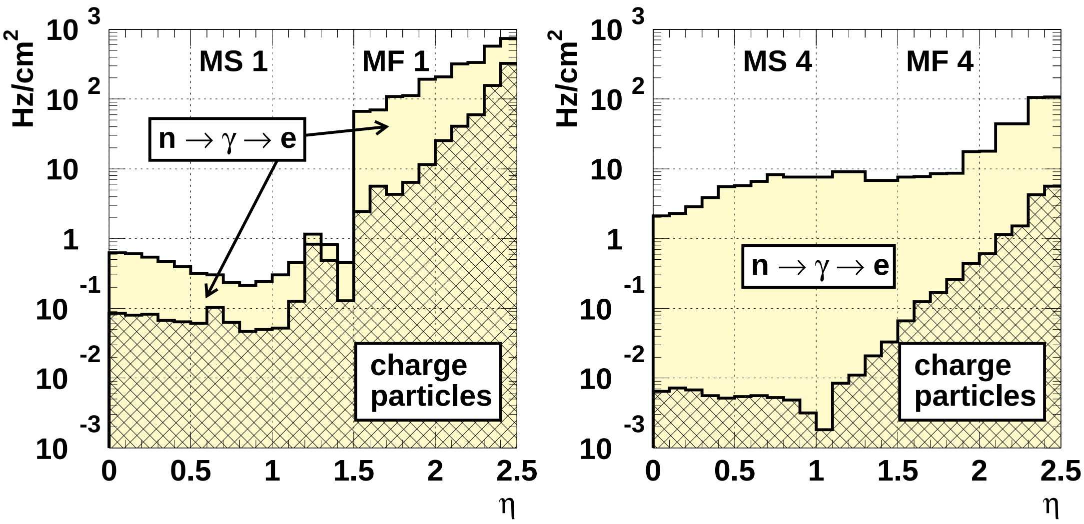

Figure 10: Rates in the muon stations

5.3 Two track separation and ghosts

The muon chambers, both DTs and CSCs, measure two coordinates of a hit independently. If more than one track goes through one chamber there is an ambiguity, which may cause the appearance of "ghost" tracks. This might be dangerous in the forward region where the expected rates are higher and the CSC strips are as long as 1.5-3.5 m, i.e. 0.5-0.9 in η.

This drawback does not exist in the RPC system, because both coordinates are derived from the same signal. Moreover, the RPC strips are 6 times shorter and a few times wider than those of CSC. Thus, from the point of view of the CSC system, the RPC strips can be seen as pads, which helps to resolve multitrack ambiguities.

5.4 Complementarity of the two components

The muon chambers and the dedicated trigger detectors deliver different information about particle tracks. They behave differently in difficult cases and they respond in different ways to various backgrounds. Properly combining the information from both systems results in high efficiency and powerful background rejection. Two extreme cases of such combinations are the logical "OR", which is optimized for efficiency, and the logical "AND", optimized for background rejection. However, neither of these operations results in full use of the complementary functions of the muon trigger components.

Both the muon chambers and the dedicated trigger detectors deliver "quality bits", which may be used in more sophisticated algorithms. These quality bits are different for the different trigger components because they reflect the different information about particle tracks provided by each component. While we retain flexibility in the definition of these bits, we can outline a specific definition here to indicate the type of information used to form these bits. We can define a first quality bit for the RPCs to indicate whether there were 3 or 4 planes in coincidence. For the DTs there is a similar bit indicating whether there were 3 or 4 layers used to make a track in one superlayer. The DTs also deliver a second quality bit indicating whether two ϕ superlayers of one station were succesfully matched. We retain the option in the design to define further quality bits for either the RPC or DT systems. These quality bits are used, along with the p_t information, to set weights in a sorting algorithm to determine the highest rank muon candidates. These weights can also depend on location and component trigger source, giving higher priority to the system which performs better in a given domain of p_t or detector region.

We illustrate the combination logic described above with two examples. If the DT answer is 10 GeV and RPC answer is "infinite", the RPC answer should be taken, because there may have been a very high p_t muon with a shower that spoiled the DT measurement. However, if the DT answer is 30 GeV and RPC answer is 50 GeV, the DT answer should be taken because RPC resolution is limited in this region. However, in each of these two examples, the decision to accept either the RPC or DT answer in place of the other can be modified based on the settings of the quality bits. The setting of these bits can be changed as operating conditions change. For example, when luminosity is low, we worry less about extra background hits and can set the bits and their influence on muon candidates differently from when the luminosity is high.

A major advantage of the two component system is that there is considerable freedom to tune the combination algorithm. It can be adjusted to respond to the actual running conditions such as luminosity, background rates and physics priorities.

6 Additional advantages of two component system

6.1 Crosscalibration

When studying cross sections, asymmetries etc., it is very important to know the trigger efficiency and acceptance. Usually this is done by runing with thresholds much lower than the measurement range. Two component system offers a unique ability to measure these quantities in a more unbiased way.

6.2 Crosscheck

Another advantage of the two component system is the ability to have an instantaneous cross check of the two subsystems. Trigger data from the two components collected by the DAQ can be compared online. This enables the quick discovery of possible problems and gives a possibility of immediate action. Such actions could include such steps as changing the weights of the combination algorithm, as described in Sec. 5.4.

6.3 Offline pattern recognition

Relatively short and wide RPC strips can be also used as pads to support the offline pattern recognition in the muon system. They are 3 times shorter than the DT wires and 6 times shorter than the CSC cathode strips. RPC hits are also much better localized in time. In fact, the current version of muon reconstruction program in the forward makes full use of the RPC information.

7 Summary table

We can summarize the above discussion in form of a table. Superior domains of each subsystem are marked in the following way:

+++ subsystem is crucial for the muon trigger at expected conditions
++ subsystem is needed to provide necessary safety margins
+ subsystem is helpful

For the purpose of this comparison we have artificially divided the RPC system into barrel and forward parts. However, one should remember that this division is not present in the trigger logic. The entire rapidity range in treated a uniform way because 1/3 of the acceptance is in the transition region between the barrel and the endcaps.

	barrel		forward	
	RPC	DT	RPC	CSC
Low p_t (< 6 GeV)	+++		+	+
Intermediate p_t (20-100 GeV)		+++		+++
High p_t (> 200 GeV)	+++	+	+	+
Isolated muon trigger	+++		+++	
TOF cut against background	++		+++	
B field in MS1,2 at $1.0 < \|\eta\| < 1.3$	+++			
Bunch crossing identification	++	+	++	+
Rejection of single hits		++		++
Two track separation and ghosts	++		++	
Complementarity	++	++	++	++
Crosscalibration	+	+	+	+
Crosscheck	+	+	+	+
Offline pattern recognition	+		+	

8 Comparison with other experiments

The two component muon trigger is not an innovation in HEP experiments. To the contrary, it is common practice that fast, dedicated detectors such as scintillation counters or RPCs recognize a muon and precise muon chambers provide a sharp momentum cut. The possible difference in CMS is that often in other experiments, muon chambers are used in the second level processing whereas in CMS the chamber information is used in the LV1 decision. This is well suited to the overall concept of the CMS trigger, which does not have a dedicated hardware LV2.

The most relevant example for comparison is ATLAS, because it is designed for the same conditions. As is the case for CMS, the ATLAS dedicated trigger detectors (RPCs and Thin Gap Chambers) recognize a muon and perform a crude momentum measurement. The momentum cut is then sharpened by the precise muon chambers. The difference is that ATLAS uses the muon chambers at LV2. CMS has chosen to do it at LV1 because of advantages both in cost and in performance. The overall cost of ATLAS trigger/DAQ is higher than that of CMS by 4.4 MCHF. CMS avoids developing and building expensive hardware for LV2 and part of the saved resources (3.4 out of 7.8 MCHF) is invested in a more sophisticated LV1. This allows CMS to run at comparable rates with lower thresholds.

The importance of the lowest possible trigger threshold was persuasively illustrated by Prof. L. Di Lella at the CMS meeting with LHCC referees using the example of the ISR experiments. Raising the thresholds to reduce the high background rate rendered the experiments incapable of discovering the J/ψ.

Other detectors designed for similar conditions to CMS are GEM and SDC. After examining the GEM design, the concept of an RPC-based trigger was rejected in favor of CSCs. There are important differences between CMS and GEM justifying the different choices. First, at the time of the GEM design, RPCs were not able to withstand a rate higher then 100 Hz/cm^2, which was not sufficient performance by far. Today 6 kHz/cm^2 (at 90% efficiency) rates have been achieved. Second, magnetic field in the forward GEM region was much more uniform than in the CMS endcaps. Bending did not depend on rapidity and it was enough to measure only one coordinate, ϕ, to determine p_t. Therefore measurement with long and narrow, radial strips was favorable and the CSCs were natural candidates.

In contrast to GEM, SDC appreciated the usefulness of fast, dedicated detectors and proposed a solution very similar to that of CMS. Dedicated detectors (scintillation counters in this case) determined the bunch crossing and drift tubes provided a p_t cut, both at LV1. RPCs were considered for the fast trigger technology, but were rejected due to concerns about the technology, which have since been addressed.

Even more instructive examples are those of already built experiments. We have already mentioned conclusions from the ISR experiments. Experience with UA1 trigger based only on drift tubes shows clearly how difficult background rejection is, particularly in the forward region.

Similar experience comes from the D0 experiment. In the first phase of the experiment the muon trigger was based only on drift tubes. Then the "D0 upgrade" document reads: "The muon Level 1 trigger is currently the slowest element in the D0 Level 1 trigger. [...] The muon system proposes to add scintillator and other fast trigger elements to surround the detector by the 1993 run. This will unambiguously tag the crossing ...". Another reason for this upgrade was that "the cosmic ray trigger ...becomes too large for the available trigger bandwidth". The scintillators reduced the background rate ~15 times. Another interesting feature of D0 trigger is the "level 1.5", where the muon and calorimeter information is combined.

CDF also uses a combination of scintillation counters and drift tubes ay LV1 in the forward region. Again scintillators tag the crossing and drift tubes provide the p_t cut.

At HERA, ZEUS uses two systems of dedicated detectors at LV1. One is a TOF plane of scintillators attached to the forward drift chambers. Another one is a Veto Wall consisting of 3 scintillator planes. It is built on the proton beam side and its main goal is to reject beam halo background. H1, like ZEUS, apart from drift tubes, uses TOF and Veto scintillator systems. In addition it has a third scintillator system for cosmic rays.

We summarise our review of muon trigger systems in the following table:

experiment	H1	ZEUS	CDF	D0	GEM	SDC	ATLAS	CMS
dedicated det. @ LV1	+	+	+	+	−	+	+	+
muon chambers @ LV1	+	+	+	+	+	+	−	+
muon chambers @ LV2	+	+	+	+	+	+	+	+

All of the experiments use muon chambers at LV2. Only ATLAS does not plan to use muon chambers at LV1. Only GEM did not plan to have dedicated trigger detectors. **All experiments currently runing on proton beams chosen the approach similar to CMS, namely to use both kinds of detectors at LV1.**

9 Conclusions

The two component scheme of the muon trigger system fits well into the overall CMS trigger concept. Resources saved by avoiding dedicated hardware for LV2 are partially invested in a more sophisticated LV1, which allows lower trigger thresholds.

The two components of the muon trigger enable effective coverage of full luminosity and momentum range and ensure powerful background rejection. The large flexibility of the entire system provides necessary safety margins. Additional advantages in crosscalibration, crosschecking and offline analysis are also important.

The two component concept is well justified by experience of other experiments. It is employed by **all** experiments currently running on proton beams.

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Appendix: CSC bunch crossing identification

As an existence proof, we describe here a scheme for the CSC trigger to identify the bunch crossing. We start with CSC stations that have six layers. We require hits in at least 4 layers in order to establish a track. Variation of the time of flight, the drift time, and the signal propagation of the CSC is in total about 50 ns. Therefore, we need to establish the coincidence of 4 layers in one station within a 50 ns gate. This scheme depends on two assumptions:

1. On a track with at least 4 hits, the second hit arrives within 25 ns of the first hit.
2. The probability of getting more than one accidental neutron hit within a 50 ns window is negligible.

We use each hit in a CSC layer to produce a 50 ns long pulse. The pulses that are assigned to a road are added together. If a second hit is added to the first, the pulseheight goes over the crossing select threshold and a candidate track in this crossing is stored. However, the existence of a track assigned to this crossing is not established until 2 more additional hits are found in this road within the 50 ns time window established by the earliest hit. If this occurs, the pulsheight exceeds the track verification threshold and the track is confirmed and assigned to the original crossing where the crossing select threshold was passed. Even if the verification (by passage of the 4-hit threshold) happens in the subsequent crossing to the establishment of the candidate track (by passage of the 2-hit threshold), the track is still assigned to the crossing where the candidate was originally found. The scheme is illustrated in Fig. 11.

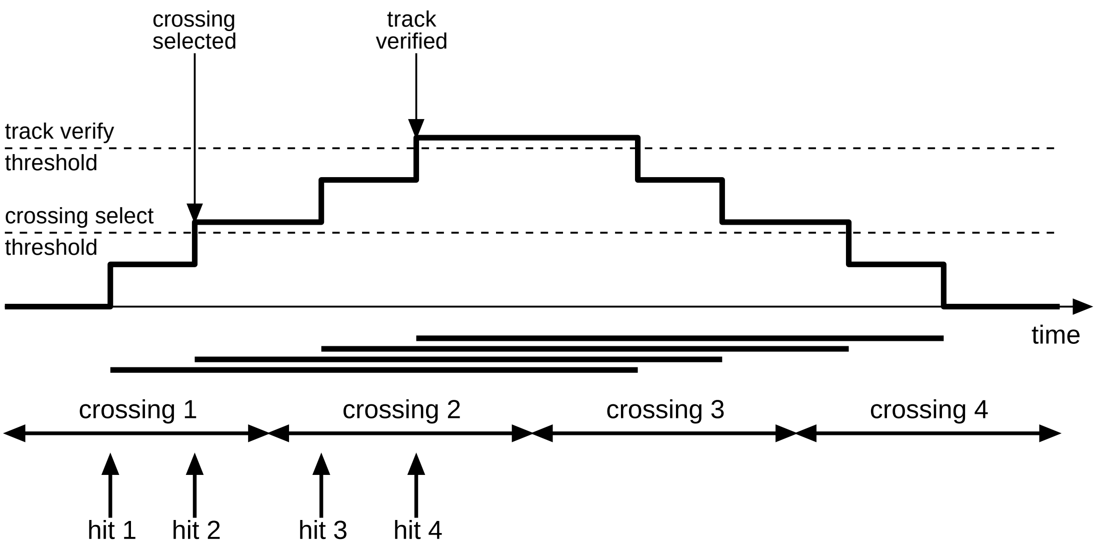

Figure 11: CSC bunch crossing identification.

The addition of a single accidental neutron hit does not cause the wrong crossing to be selected since this would require two accidental neutron hits. The addition of a single accidental neutron hit might cause the verification to happen prematurely, but does not cause a mistake. The Brookhaven test running showed that in a six layer CSC, on a 4 hit track, 99% of the time the first 2 hits were within 25 ns of each other and assigned to the correct crossing.