
CMS Internal Note

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Specification of the Interface between the DT and CSC Level-1 Track-Finders

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Abstract

We propose to fix the boundary between the DT and CSC Level-1 Track-Finders at $\eta = 1.04$. The ramifications of this decision and the details of the electronic interface between the two systems are discussed in this Note. The efficiency and ghost rate of the Track-Finders are also studied near this boundary.

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1 Introduction

A previous agreement [1] describes how the Drift Tube (DT) and Cathode Strip Chamber (CSC) muon systems will be covered by separate Track-Finders [2, 3] in the Level-1 Trigger. Preliminary considerations on how to define a hard boundary between the two systems were given so that multiple triggers do not arise from a single muon. In this Note, we propose to fix¹⁾ the boundary at a pseudo-rapidity (η) of 1.04, and we specify the details of the electronic interface between the two Track-Finders so as to maintain an overall high efficiency in the DT/CSC overlap region and to minimize ghosts. The primary advantage for fixing the η boundary is to simplify the design of the interface between the DT and CSC trigger systems. The disadvantage is a loss of flexibility and some redundancy, which also will be addressed. It is assumed that the latency of the CSC and DT trigger systems will permit a data exchange without adversely affecting the overall Level-1 latency.

The architecture of the DT and CSC Track-Finders is described in the Level-1 Trigger TDR [4]. Relevant to this discussion is the partitioning of the trigger sectors and the number and format of the exchanged trigger primitives. Specifically, the DT Track-Finder divides its coverage into 72 regions (6 divisions, or *wheels*, along z and 12 divisions, or *sectors*, in ϕ). The CSC Track-Finder divides its coverage into 12 regions (6 per endcap) such that a trigger sector is two times larger in azimuth than a DT sector (60° vs. 30°). The boundaries of the CSC sectors, however, align approximately with the DT sectors [5]. The first CSC station (ME1) is further subdivided into two or three subsectors. The baseline had been three 20° subsectors, but a recent decision [6] to stage the readout of ME 1/1a changes the DAQ readout structure such that two 30° subsectors are implemented instead. In either case, only 6 CSC trigger primitives are sent per 60° sector.

2 Motivation for Boundary Choice

The boundary in the coverage between the DT and CSC Track-Finders is proposed to be set at, or near, $\eta = 1.04$. This extends the coverage of the DT Track-Finder approximately to the outer limit in z of the MB 2/2 chambers, and the coverage of the CSC Track-Finder extends approximately to the outer radius of the ME 2/2 chambers. This boundary also corresponds to the separation between the barrel and endcap RPC trigger system. A cross-sectional view of CMS showing the location of the boundary relative to the DT, CSC, and RPC muon systems is shown in Fig. 1. The advantages of defining this boundary are numerous:

1. The interconnections between the Level-1 Track-Finders are cut in half when track segments from ME 2/2 and MB 2/2 are not shared. Only the track segments from ME 1/3 are sent to the DT Track-Finder, and the track segments from MB 2/1 are sent to the CSC Track-Finder. This is motivated by the fact that only very little of the MB 2/2 and ME 2/2 chambers extend past the $\eta = 1.04$ boundary.
2. The mapping of 60° CSC trigger sectors onto 30° DT ones is simplified by not sending ME 2/2 track segments to the DT Track-Finder. Thus, the CSC Track-Finder does not necessarily need to send two copies of the data to two neighboring DT sectors, since the 30° subsectors used in ME 1 match the DT sectors.
3. The Level-1 Track-Finders are allowed to identify all possible categories of tracks from the segments received. The Global Muon Trigger (GMT) recently has been improved to incorporate a ghost cancellation unit [7] to suppress duplicate tracks when a single muon is found by both the DT and CSC systems. Such ghosts can arise because there is some overlap in η in the coverage of the DT and CSC Track-Finders. The ghost cancellation unit also cancels most of the ghosts that can arise occasionally when the RPC trigger logic assigns a muon to the opposite side of the boundary from that found by the DT or CSC trigger. The final level of ghosts that survive after the GMT cancellation logic is expected to be only about 0.4% in the narrow region $0.9 < |\eta| < 1.2$, as discussed in Sec. 4.
4. The azimuthal bend angle ϕ_b does not need to be sent by the CSC trigger to the DT Track-Finder because the latter does not need to perform extrapolations from ME 1/3 to ME 2/2. This further reduces the connections between the Track-Finders.
5. The exchanged bits are reduced enough such that parallel transmission at the 40 MHz beam crossing frequency using the Low Voltage Differential Signaling (LVDS) standard is possible. This removes any latency from data serialization, and alleviates transmission length problems in the underground counting room.
6. The CSC Track-Finder logic is simplified if only $|\eta| > 1.04$ is considered [3], since we can require extrapolations to include a segment in ME 2/2.

¹⁾ The actual boundary is programmable, so some adjustment is possible.

3 Implementation Details

3.1 Interconnections

The CSC Track-Finder can accept and process up to 2 track segments from MB 2/1 per 30° sector (a total of 4 segments per 60° CSC sector); however, when two segments exist, the DT Trigger Servers serialize the data across 2 BX. The CSC Track-Finder group agrees to accept just one segment per BX to reduce the number of connections between the two track-finders. A flag must be sent to denote if a sent segment actually belongs to the previous BX as the second of two segments. The CSC Track-Finder will perform the de-serialization. Note that the validity of the assignment of the correct BX by the DT trigger is a separate issue, and is a concern in the strong fringe field affecting the MB 2/1 chambers. This can be addressed by the “Bunch Crossing Analyzer” logic of the CSC Track-Finder [3].

The CSC Track-Finder will send all track segments from ME 1/3 to the DT Track-Finder along with a flag bit (described below) to denote whether a segment satisfies $|\eta| < 1.04$. However, the DT Track-Finder can accept only 2 principal track segments per 30° sector, not 6 as delivered by the CSC system for a 60° CSC sector in ME1. It can, though, accept additional inputs as neighbors to a given sector, since track segments are expected to be shared across DT sector boundaries. This implies that the DT Track-Finder could not accept any real neighbor connections for this outermost wheel, but simulations indicate that this does not appear to be a problem because of the limited magnetic bending in this region. Specifically, the reduction in the number of tracks found by the DT Track-Finder without neighbor connections in the region $0.8 < |\eta| < 1.2$ is only 0.5%, and essentially all of the lost tracks are recovered by the GMT.

Each Track-Finder shall send the required number of copies of each track segment, distributed on the required number of cables, as required by the architecture of the receiving Track-Finder. Currently, this implies that each Sector Processor from the outermost wheel of the DT Track-Finder sends only one copy of a track segment on a single cable to the CSC Track-Finder, since neighbor connections are not considered in the CSC architecture. Likewise, each Sector Processor of the CSC Track-Finder sends only one copy of the 3 track segments from one of the 30° subsectors in ME1 on a single connection to the appropriate DT Sector Processor, since neighbor connections can be safely ignored for this region of the DT Track-Finder. The 3 track segments from the other 30° subsector are sent on a second connection to the appropriate neighboring DT Sector Processor. If the readout of ME 1/1a is recovered at a future date, requiring that the CSC Track-Finder divide each 60° sector in ME1 into three 20° subsectors, then the CSC Track-Finder group shall be responsible for sending any copies of the track segments required by the DT Track-Finder.

3.2 Data format

The data words exchanged between the DT and CSC Track-Finders are described below and are summarized in Tables 1 and 2. Along with the track segment information, synchronization and clock information are shared as well since the Track-Finders are the first place where the CSC and DT trigger systems are brought together. It will be important to monitor the overall latency of the DT and CSC trigger systems as final production boards are designed, otherwise the data exchange may not be possible within the maximum Level-1 latency.

- A Track-Finder transmits data in the format defined by the receiving Track-Finder [1]. This requires look-up tables on the transmitting Track-Finder.
- Both Track-Finders exchange data in “2’s complement” format
- Azimuth (ϕ): Both track-finders use 12 bits for ϕ , but the range may be slightly different (1 radian for DT and slightly more than 60 degrees for CSC). Moreover, DT Track-Finder sectors are centered at $n \times 30^\circ$, whereas CSC Track-Finder sectors are centered at $45^\circ + n \times 60^\circ$. These differences can be solved, for example, by using look-up tables on the CSC Sector Receiver and on the DT Track-Finder. The CSC sectors will be slightly larger than 60° to accommodate positioning errors of the chambers and the iron disks.
- Pseudorapidity (η): No η information is sent from the DT Track-Finder to the CSC Track-Finder. However, 1-bit of η information will be sent from the CSC Track-Finder to the DT Track-Finder to designate whether a CSC track segment actually belongs to DT trigger region ($|\eta| < 1.04$), since all CSC track segments from the ME 1/3 chambers ($|\eta| < 1.2$) shall be sent to the DT Track-Finder. This allows flexibility in the approach used to maximize the trigger efficiency and yet minimize the ghost tracks found by both Track-Finders, and several schemes are described in Ref. [7] using the GMT cancellation logic.

- Bend angle (ϕ_b): The DT Track-Finder does not need ϕ_b from the CSC system if it is not making extrapolations from ME 1/3 to ME 2/2, which is the case in this proposal. The CSC Track-Finder still requires ϕ_b from the DT system, but only 5 bits are used and the scale may be different than that used by the DT Track-Finder. Only 5 bits will be exchanged between the systems to save bits on the link.
- Quality: Both Track-Finders have a 3-bit quality for each track segment, with somewhat different meanings. An empty, or non-existent, track segment is denoted by having the quality bits reset.
- The CSC and DT Track-Finder groups agree to send the two least-significant bits (LSBs) of the bunch-crossing number (BXN) between every pair of boards that are connected. This can be used to monitor if the two systems drift apart in BXN. Likewise, a bunch crossing zero (BC0) bit is sent also in both directions to facilitate synchronization.
- The relevant clock signal associated with the data sent on a connection between the two Track-Finders shall also be sent. This clock can be used to clock the data into a FIFO on the receiving board.
- A calibration bit will be sent from the DT Track-Finder to the CSC Track-Finder to indicate that the associated data is not valid trigger data.
- No error bits will be sent between the two systems. If an error occurs, the quality bits are set to denote no track segment.

3.3 Transmission Technology and Crate Location

Both Track-Finder groups agree to exchange data between the two systems using LVDS and without any additional serialization that would otherwise increase the latency. Track segments will be sent, therefore, at the 40 MHz beam crossing frequency.

In order to minimize the latency, the Track-Finder crates in the overlap region should be located as close to each other as possible in the underground counting room to keep cable length at a minimum.

4 Impact on L1 Trigger Performance

The consequences of this agreement have been studied by simulation, with the basic results included in the Level-1 Trigger TDR [4]. These studies have been revisited from the results reported in [8] using the newly proposed cancellation logic for the GMT [7], and the updated results are included here. The simulation is based on 100,000 single muon events generated uniformly in the following regions: $-2.5 < \eta < 2.5$, $0^\circ < \phi < 360^\circ$, and $2.5 < p_T < 100$ GeV/c. The events were generated using CMSIM version 118, and the detector digitization, trigger simulation, and analysis were performed using ORCA version 4.5.0.

The trigger efficiency as a function of η is shown in Figs. 2a–2c for several possibilities on the data exchange, where each figure shows the efficiency for the DT and CSC trigger systems separately and when the two are combined in an “OR”. The scenario when no data is exchanged between the CSC and DT Track-Finders is shown in Fig. 2a, and the overall efficiency in the DT/CSC overlap region $0.9 < |\eta| < 1.2$ is only 76.3%. Figure 2b shows the efficiency when track segments from ME 1/3 and MB 2/1 are exchanged, and the overall efficiency increases to 91.7% in this region. Finally, Fig. 2c shows the efficiency when track segments from ME 1/3, ME 2/2, MB 2/1, and MB 2/2 are exchanged, which increases the overall efficiency slightly more to 92.0%.

It is clear that the sharing of track segments from ME 1/3 and MB 2/1 is necessary to obtain high efficiency in the DT/CSC overlap region, yielding a 15% increase with respect to no sharing. However, it does not appear necessary to share segments from the second set of stations (ME 2/2 and MB 2/2), because the increase in efficiency is only 0.3%, as might be expected from the limited geometrical overlap of those chambers for a boundary at $\eta = 1.04$. It should be noted that in order to achieve a reasonable efficiency in the overlap region, that the CSC Track-Finder must be allowed to report tracks without a segment in the first barrel station (tracks with segments in ME 1/3 and ME 2/2, but not MB 2/1); but this in itself is not sufficient since ME 1/3 only has about 80% coverage in ϕ . Since tracks without a hit in the first station have very poor p_T resolution, their inclusion contributes significantly to the muon trigger rate.

It is assumed that for the data exchange scenarios of Figs. 2b and 2c, that the CSC and DT Track-Finders reconstruct tracks with an overlap of one η bin around the $\eta = 1.04$ boundary (option “(b)” in the figures reported in Ref. [7]). Without dedicated cancellation logic in the Global Muon Trigger, a large rate of ghost di-muons would be reported

when single muons in the DT/CSC overlap region are reconstructed by both the CSC and DT Track-Finders (or between either the CSC or DT and the RPC trigger). The natural place to remove these ghosts is in the GMT, since it receives the information from all 3 muon systems; thus, dedicated cancellation logic has been devised for the GMT[7].

Both the trigger efficiency and di-muon ghost probability as a function of η after the GMT logic are shown in Fig. 3. In the DT/CSC overlap region $0.9 < |\eta| < 1.2$, the overall efficiency is 92.5% and the di-muon ghost rate is 0.42%. The probability of creating a ghost track is independent of the muon p_T , and the ghost is not restricted to low quality. As reported in [7], no other scheme performed at the level of the individual Track-Finders, such as by tuning the η boundary or by adding ghost cancellation logic in the DT Track-Finder, can do as well at reducing the ghost rate while maintaining high trigger efficiency as the GMT cancellation logic.

5 Conclusions

Fixing the boundary between the DT and CSC Track-Finders near $\eta = 1.04$ simplifies much of the engineering issues associated with the interface between these two trigger systems, with negligible degradation of the trigger performance. Details on the implementation of this interface have been specified.

References

- [1] G.M. Dallavalle *et al.*, CMS-IN 1999/015
- [2] G.M. Dallavalle *et al.*, CMS Note 1998/042; A. Kluge and T. Wildschek, CMS Note 1997/091; A. Kluge and T. Wildschek, CMS Note 1997/092; A. Kluge and T. Wildschek, CMS Note 1997/093
- [3] D. Acosta *et al.*, CMS-IN 1999/060
- [4] CMS, The TriDAS Project Technical Design Report, Volume 1, CERN/LHCC 2000-38
- [5] D. Acosta, S.M. Wang, G. Wrochna, CMS-IN 1999/022.
- [6] Management Board/Collaboration Board meeting December 6, 2001
- [7] H. Sakulin, CMS-IN 2002/024
- [8] H. Sakulin, M. Fierro, CMS Note 2001/003

Table 1: Data delivered from the CSC Track-Finder to the DT Track-Finder. Two connections are needed, each of which delivers 3 stubs. Data should be sent at 40 MHz using LVDS.

Signal	Bits/stub	Bits/3 stubs	Bits/6 stubs	Description
ϕ	12	36	72	Azimuth coordinate
η	1	3	6	DT/CSC region flag
Quality	3	9	18	stub quality
BXN	–	2	4	2 LSB of BXN
BC0	–	1	2	bunch crossing 0
Clock	–	1	2	clock for data
Total:	16	52	104	

Table 2: Data delivered from the DT Track-Finder to the CSC Track-Finder. Two stubs from one chamber in the same bunch crossing are transmitted on consecutive bunch crossings. Two connections from two different DT Sector Processors are implemented using LVDS at 40 MHz.

Signal	Bits/stub	Bits/2 stubs	Description
ϕ	12	24	Azimuth coordinate
ϕ_b	5	10	ϕ bend angle
Quality	3	6	stub quality
Muon Flag	1	2	2nd muon of previous BX
BXN	2	4	2 LSB of BXN
BC0	1	2	bunch crossing 0
Calib	1	2	data not valid
Clock	1	2	clock for data
Total:	26	52	

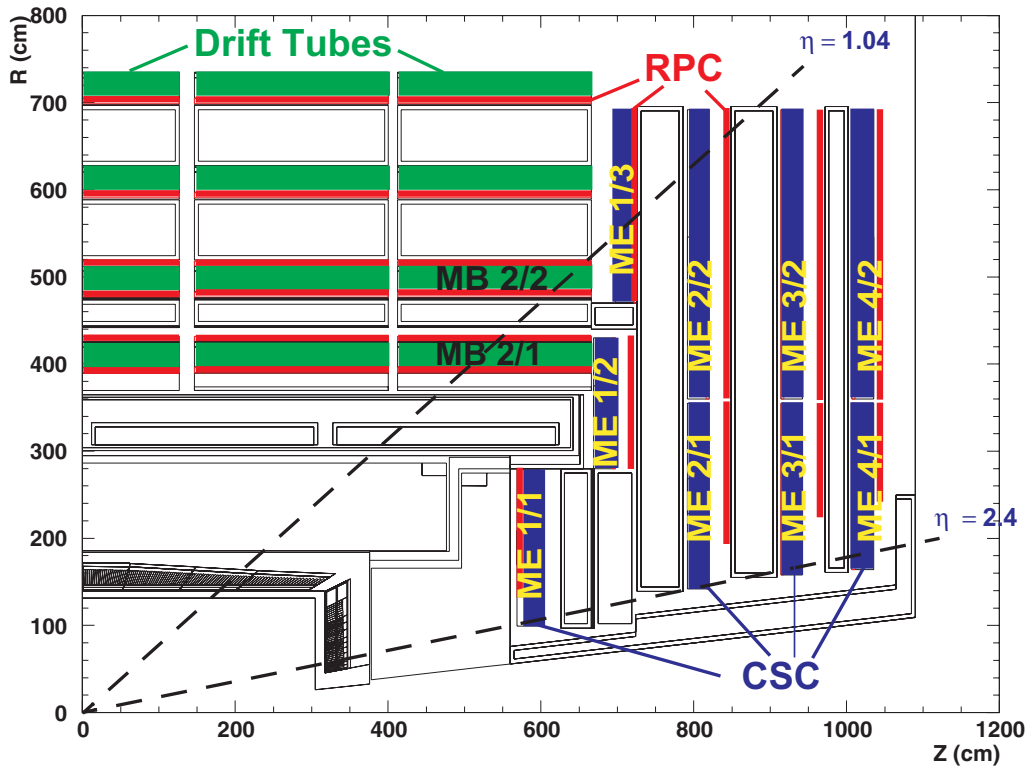


Figure 1: Illustration of the CMS muon system showing the proposed boundary division between the DT and CSC Track-Finders at $\eta = 1.04$.

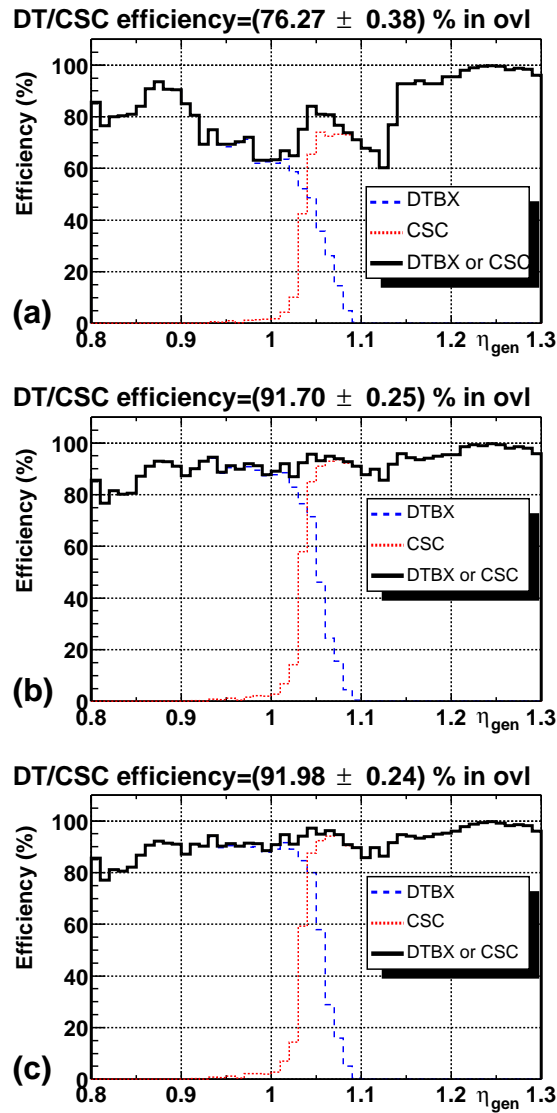


Figure 2: Trigger efficiency for single muons as a function of η for the DT and CSC trigger systems separately as well as from either. The efficiency is presented for several schemes: (a) no sharing of segments from ME 1/3 or MB 2/1 occurs between the Track-Finders, (b) sharing of segments from ME 1/3 and MB 2/1 only occurs, and (c) sharing of segments from ME 1/3, ME 2/2, MB 2/1, and MB 2/2 occurs.

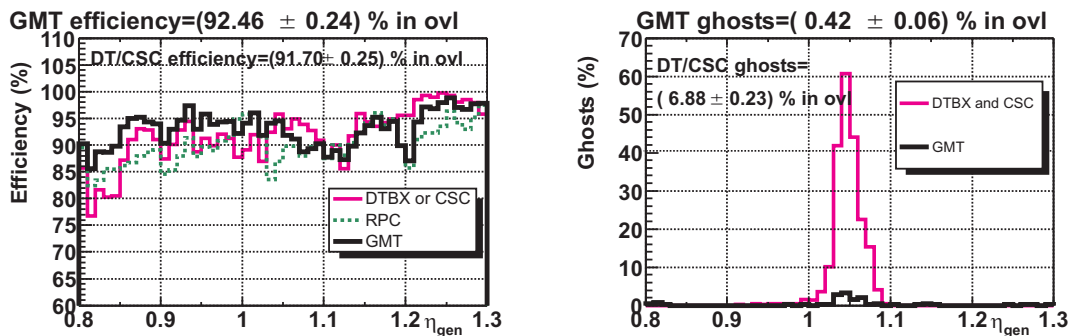


Figure 3: Trigger efficiency for single muons as a function of η (left) and di-muon ghost probability as a function of η (right) after the Global Muon Trigger with ghost cancellation logic. Also shown is the efficiency and ghost probability for the “OR” of the DT and CSC Track-Finders.