WBS Dictionary/Basis of Estimate

Documentation

US CMS   Endcap Muon

Regional CSC Trigger System

WBS 3.1.1

1. INTRODUCTION

1.1 The CMS Muon Trigger System

The CMS trigger and data acquisition system is designed to operate at the nominal LHC design luminosity of 10^{34} cm^{-2} s^{-1}, where an average of 20 inelastic events occur at the beam crossing frequency of 40 MHz. This 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 that can be archived by the on-line computer farm. CMS has chosen to reduce this rate in two steps. The first level stores all data for approximately 3 µs, after which no more than a 100 kHz rate of the stored events is forwarded to the second level.

During the 3 µs of the level 1 trigger processing time, trigger decisions must be made to discard a large fraction of the data while retaining the small portion coming from interactions of interest. The endcap muon trigger system finds high-momentum muon consistent with coming from the primary interaction region. The identification of high-momentum muons is a crucial element of the CMS detector, allowing identification of Higgs particles, W and Z bosons, etc. In addition, under low luminosity conditions, the muon trigger can identify muons down to the cutoff momentum imposed by range-out in the steel of the magnet flux return, allowing interesting studies of rare B-particle decays.

The baseline CMS muon system currently consists of 4 stations of chambers in the barrel region and 3 stations in the endcap region. In the barrel detector, these are drift chambers, whereas in the endcap detector, they are Cathode Strip Chambers (CSC's). The layout of these systems is shown in profile in Figure 1. Each station of CSC contains overlapping 10 or 20 degree wide chambers, and each chamber contains 6 measurement layers. In each measurement layer, anode wires are read out to measure the non-bend (imprecise) coordinate and radial cathode strips are read out to measure the bend (precision) coordinate. A muon produces a "stub" in each dimension. All of the on-chamber electronics for muon identification, including trigger, is considered and is budgeted as part of the Endcap Muon system. On the other hand, all of the off-chamber trigger electronics which collects muon stubs from the chambers, sends the stub information "upstairs" on optical fibers, and links the muon stubs into a muon track of known momentum and direction is known as the Muon Regional Trigger System (WBS item 3.1.1) portion of the US-CMS Trigger/Data Acquisition (TRIDAS) system, WBS item 3.
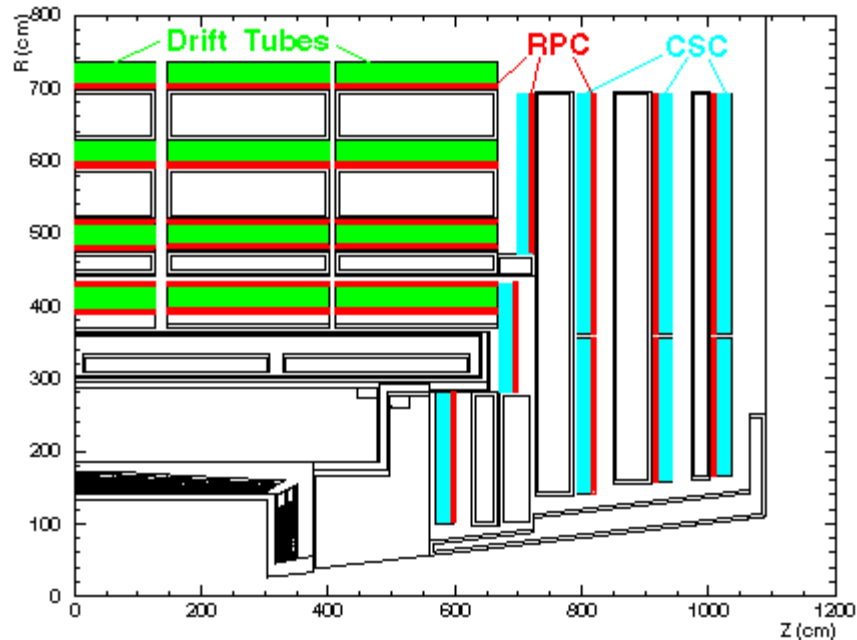
Figure 1.Layout of the CMS Muon Detectors.

1.1.1 Requirements

CMS Endcap Muon trigger system should be capable of selecting events containing muons with high efficiency and good geometric acceptance. At high luminosity, 10^{34} cm^{-2} s^{-1}, the single muon trigger is required to be at least 90% efficient in the pseudo-rapidity range $|\eta|$<2.4 for a threshold of E_t>20 GeV. For the dimuon trigger the threshold should be E_t>10 GeV for each particle in the same η-range. The total muon trigger rate should not exceed appoximately 15 kHz at all luminosities. The trigger E_t cutoffs should be sufficiently low such that full efficiency is realized at the specified physics thresholds while keeping the background rates within the requirements of the data acquisition system. All triggers should also run at prescaled level with lower thresholds. The design of the CSC Muon Trigger is also constrained by the following:

- Background rates in the endcap region of CMS are expected to be large. The background sources are prompt muons, decay in flight muons, accelerator muons, hadron punchthrough, and neutron-induced electrons. The muon trigger electronics is designed to reduce these rates to an acceptable level.

- In particular, the rate of prompt muons from collisions which penetrate all muon stations is of order 100 kHz. In order to bring the total trigger rate down to an acceptable level, momentum resolution of 30% or better is crucial.

- The Endcap Muon system overlaps with the Barrel Muon system over the rapidity interval 0.9-1.3. Within that interval, the Barrel Muon system supplies the front-most muon station information. Since the first muon station sees the largest track sagitta, it is most important for good momentum resolution. Therefore, in the overlap region, the Barrel and Endcap muon stub information must be correlated.

- The total latency of the Level 1 trigger is a maximum of 3µs, but much of this time is taken up in cable delays. The processing time which is left includes approximately 400ns for muon stub-finding on the front-end cards, 200ns to collect and correlate anode and cathode signals from front-end cards, 200ns to collect the stub information into 30-degree units and send the

signals onto optical fibers to the Track Finder, 350ns for the Track Finder to link the stubs into tracks and measure the track parameters in 30-degree sectors, and 75ns for the Global Muon Trigger to choose the 4 best muon candidates to send to the Global Level 1 global trigger unit.

2. SYSTEM OVERVIEW

2.1   Design Criteria:

The main design criteria for the system are:

The design is implemented using off the shelf technology where possible.
> ASIC's are used only where fully justified.

The design maximizes flexibility and programmability:
> Digital logic built around memory lookup tables.
> All trigger cutoffs are programmable.

The design is compatible with the Barrel Muon Track Finder, which is built by Vienna.
> Communication between crates uses the same protocol.
> Communication with the Global Muon Trigger presents data in the same format and at the same time.

Boards and crates:
> Designed using realistic power consumption, circuit density and cooling considerations.
> I/O connections, fiber optics, backplane traffic and timing, DAQ and clock and control interfaces can be implemented with present day technology.

Fiber optics and copper cables:
> Designed to minimize the interconnects between crates.
> Gbaud optical fibers carry trigger primitives from detector to the crates in barracks.
> Could be produced with currently available hardware.

Full Trigger system carries sufficient information for diagnostics, efficiency studies, and understanding trigger behavior.

2.2 Baseline design

The on-chamber Cathode and Anode cards which find projections of muon stubs in strip and wire views, respectively, are mounted on the surfaces of the CSC chambers. In the 3-station endcap muon system, there are 2016 cathode strip cards and 1800 anode wire cards, mounted on 432 CSC chambers. There is one on-chamber card per CSC chamber, called the Motherboard, which does the time correlation of the two views and sends the stub information on via copper to a Muon Port Card (MPC). The on-chamber circuitry up to the cables going from Motherboards to Muon Port Cards is considered as part of the Endcap Muon system - from there on, the circuitry is part of the

TRIDAS system. The Muon Port Cards assemble muon trigger data from a 60 degree ϕ swath and pass it on via Gbaud optical links to the Track Finder crates. The Track Finder crates link together the muon stubs into tracks and determine the muon momentum vectors for use in the CMS Global Muon trigger. The drift tube muon trigger, the global muon logic, and the global Level 1 trigger

electronics are responsibilities of European groups. A block diagram showing the overall structure of the CSC muon trigger electronics is shown in Figure 2.

The major portions of the off-chamber muon trigger electronics contained in WBS 3.1.1 are therefore Muon Port Cards (MPC), optical data and clock links, and track finder crates containing Sector Receiver (SR) cards, Sector Processor (SP) cards, Clock and Control Cards (CCC), and ancilliary logic and cabling.
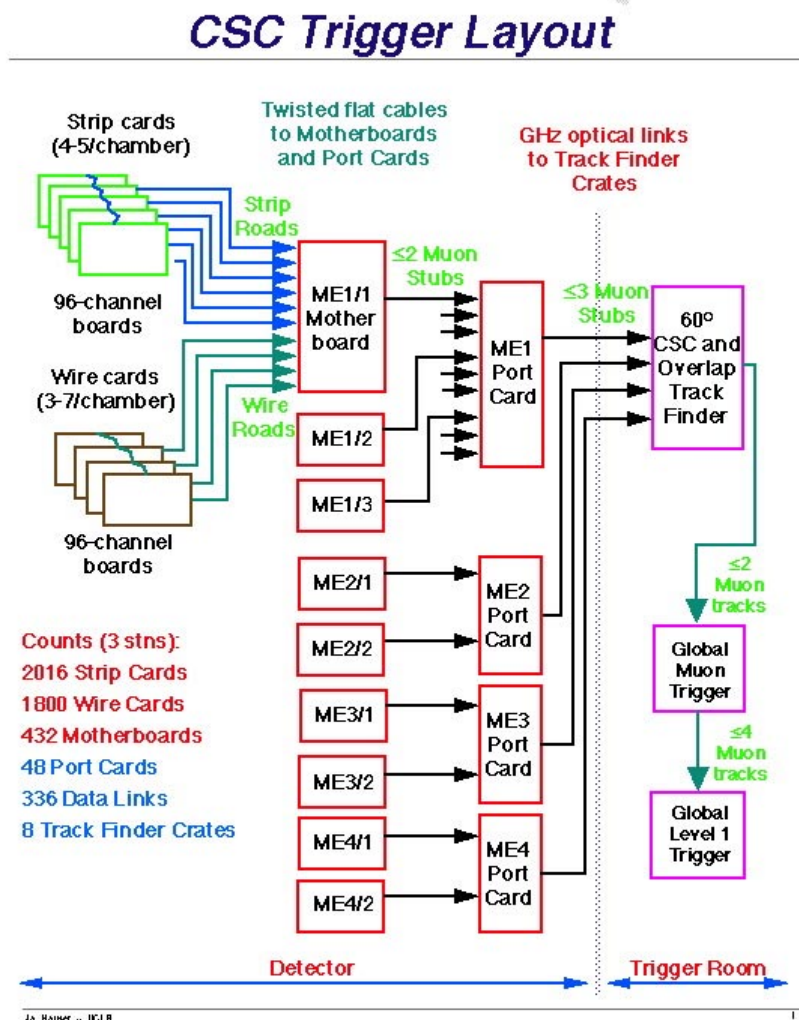

Figure 2. Block diagram of the CSC Muon Trigger System

A Muon Port Card (MPC) receives data from nine Motherboards within a CSC station. In the first station, this is a φ interval of 30 degrees, while in the other stations this is a φ interval of 60 degrees. The Muon Port Card sends the data "upstairs" via fast optical links to a CSC Track Finder crate. The MPCs are located near the outer periphery of the CSC chambers to keep copper cabling distances acceptably short. A depiction of the MPC connections is shown in Figure 3. There are 12 Muon Port Cards in CSC station ME1 in each endcap, and 6 Muon Port Cards in each of the later stations, for a total of 48 MPC ((12+6+6)*(2 endcaps). It takes 7 Gbaud optical links per MPC to send the information from up to 3 muon stubs to the Track Finder. One reason for having Muon Port Cards rather than connecting optical links directly from chambers to the Track Finder is that the number of MPC is much smaller than the number of chambers, thereby cutting down the

number of optical links required, not only for trigger data transfer, but also for clock distribution. Another reason is that without the MPC, there would be a huge number of optical fibers carrying muon data into a Track Finder crate. The data would be far too much to receive and process within a single VME crate. The front-end electronics is designed to present a priority-ordered set of muon stubs to the Muon Port Cards, where the priority is determined by number of layers hit, a rough measure of momentum (local bending), and consistency with arrival from the primary vertex. Within the MPC, priority encoding circuitry is included to select the best muon stubs in the case that more than three stubs arrive simultaneously. The MPC also handle the function of receiving master clock signals via TTC interface and fanning them out to the front-end CSC chamber electronics.
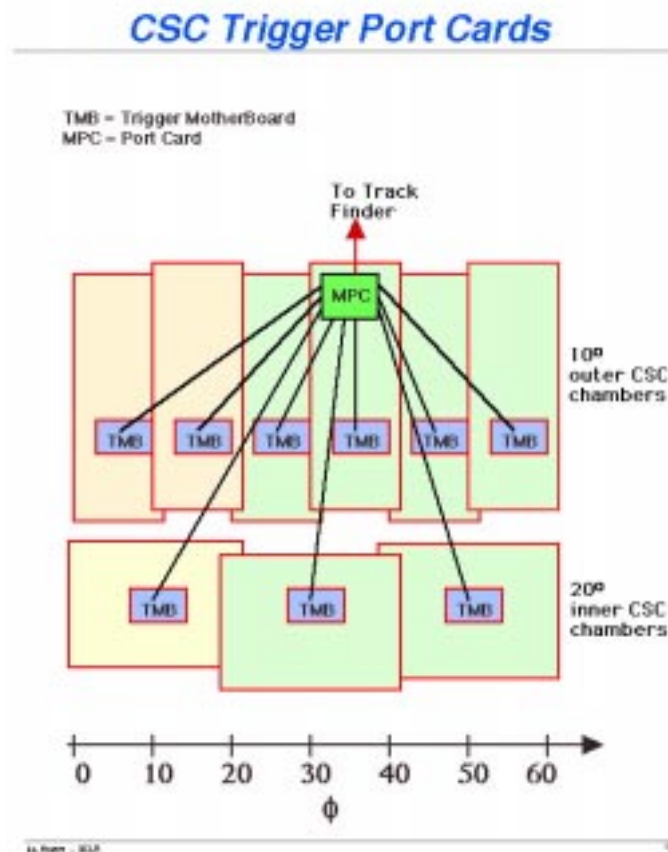

Figure 3. Muon Port Card layout: locations and links to Motherboards on Endcap CSC chambers.

Figure 4 shows the block diagram for the electronics between the stubs sent by Trigger Motherboards (TMB) to the Muon Port Cards (MPC) and the tracks sent by CSC and Overlap Sector Processors to the global muon trigger:
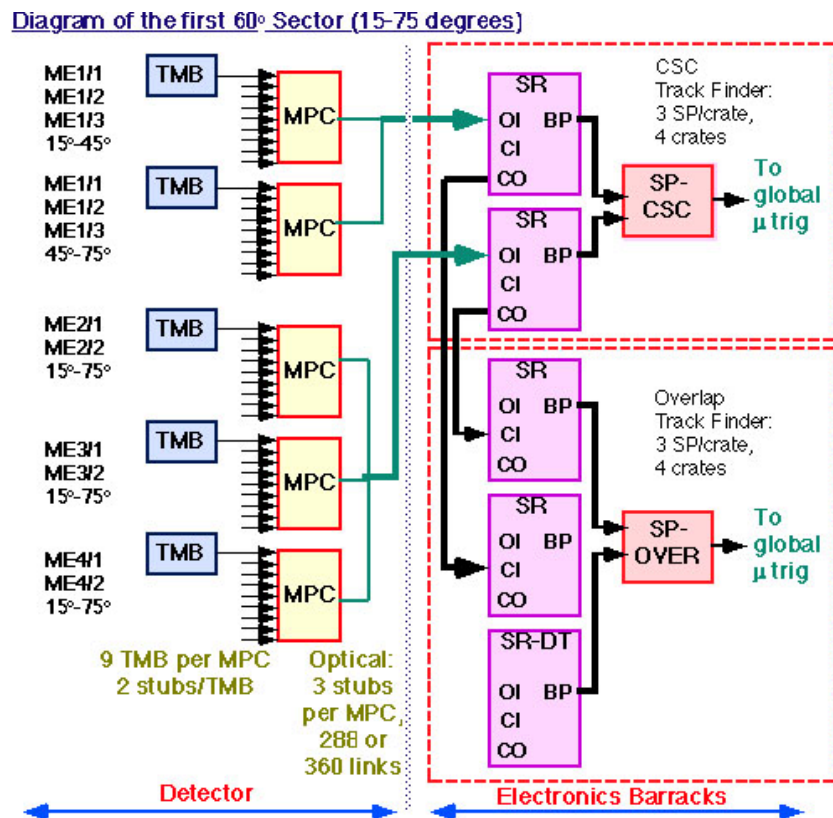
Figure 4. Block diagram of the CSC and Overlap Track Finder system.

The layout of the muon Track Finder contains separate racks for barrel (DT), endcap-only (CSC), and overlap processor regions. Within the barrel system, the Track Finders are organized by wheel. Each VME crate handles 180 degrees in phi of track finding. Signals from the CSC system come to the Track Finder on optical links, and are received in the CSC-only section. A conception of the system, shown below, contains 9 racks, each of which contains 2 VME crates. The CSC-only and overlap Track Finders (U.S. responsibilities) are contained in 4 racks/8 crates.

Connections between sectors in phi need to be made in order to accomodate bending tracks which may travel from one sector to another as they penetrate the several muon stations. This is done in the Barrel DT system, but not in the Endcap CSC system. The justification is that the bending is small in the endcap region for a fixed Pt. Also, the cracks which are created are smallest for the most interesting muons, i.e. having the highest Pt.

There need to be "rapidity" connections between the various muon Track Finder crates because the boundaries are non-projective. In the Barrel DT crates, keyed off of the rapidity of MB4, the outer layer, information from MB1,2,3 flows toward the ends: wheel 0 sends to wheel +-1, and wheels +-1 send to wheels +-2. Wheels +-2 send information to the overlap crates. The CSC-only crates, which receive the information from all CSC stations, send information to the overlap crates. The layout of crates and the data flow between them are shown in figure 5.
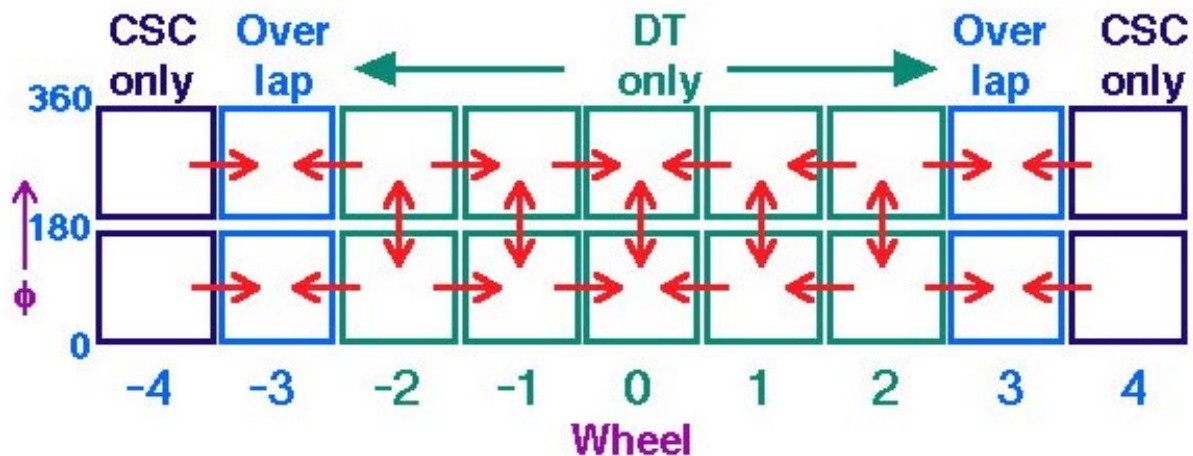
Figure 5. Layout of Track Finder crates and the data flow between them.

Data comes from the Muon Port Cards (MPC) on optical fibers to the CSC-only Track Finder crates. Each MPC sends data representing 60 degrees in phi of one muon station (with the exception of station 1, which sends data in 30-degree sub-sectors). Each muon stub which is transmitted requires 36 (+- a few) data bits. The card which receives these signals is called the Sector Receiver (SR). It is assumed that HP Glink chip set can transmit 21 bits per 25ns bunch interval, of which 5 are used for error detection, thus leaving 16 bits of useful information per BX.

The Sector Receiver card does 2D to 3D muon stub conversion, alignment corrections, and data reformatting. It then sends muon stub data to the Sector Processor (SP) module on the crate backplane. If the Sector Receiver is being used in the CSC-only crate, it must also replicate the data and send it on to the Overlap crate (probably via copper). If the Sector Receiver is being used in the Overlap crate, it must receive its input data over copper. We therefore design a single card having both types of functionality according to the data flow diagram shown in Figure 6. After the data is received by the Sector Receiver cards, it can be reformatted by look-up tables into whatever format is convenient for the Sector Processor track finding. This will generally result in somewhat fewer bits transmitted per muon stub than the 36 bits which are received on the optical fibers.
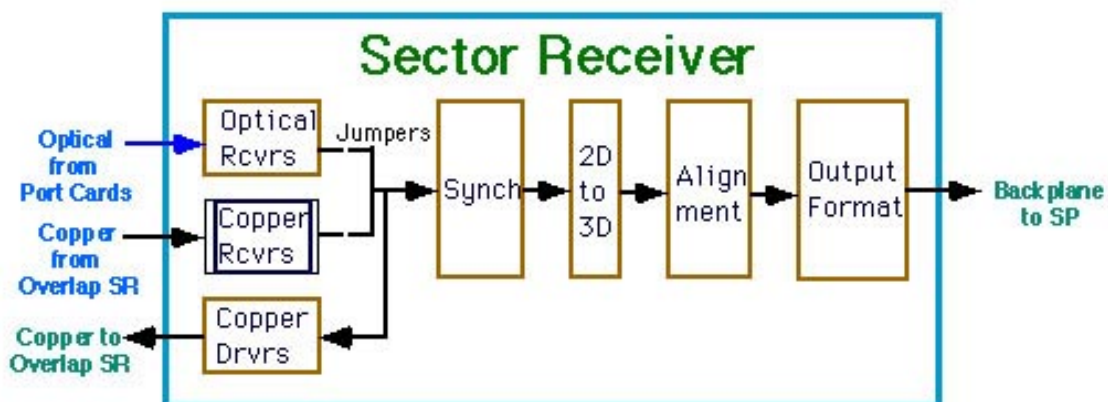

Figure 6. Data flow within the Sector Receiver card.

There are three Sector Processors per crate, each handling 60 degrees in phi. In the baseline design, up to three muon stubs are transmitted from each MPC on six optical fibers. The Sector Receivers are designed to receive 15 optical fibers carrying 270 data bits. Depending on whether we have three or four endcap muon stations, two or three MPCs are connected to each Sector Receiver. The Sector Receiver, which is connected to the two ME1 MPCs in the 60 degree sector, combines the information before transmission to the Sector Processor. Two Sector Receivers send data to each Sector Processor (288 or 384 bits, depending on whether 3 or 4 muon stations are built). One also needs one ground connection per approximately eight signal connections to the backplane. One therefore requires high-density Z-pack (Futurebus+) backplane connectors- these pack 192 pins in 96 mm vertically. (About 350mm are available vertically on a 9U (366mm) height Eurocard.) The worst bottleneck, the SP backplane pin count, with 4-station operation, is shown in Figure 7.

Figure 7. VME backplane pin count (data plus grounds only) in CSC-only Track Finder crate.

In the 4-station muon system, data from muon stations ME1-3 and MB1-3 are sent to the Overlap Track Finder crates. This requires 96 bits (x number of stubs/MPC) from each sector of the CSC system, and 66 bits (x number of stubs/station) from each sector of the Barrel DT system. In any case, this requires use of the high-density Z-pack (Futurebus+) connectors. One needs a special module to receive the barrel signals, which is built by European groups. In the baseline design, up to three muon stubs are transmitted from each MPC on six optical fibers. In this case, two SR modules receive the CSC data as explained above, plus another "SRDT" module (or possibly two) receives the DT signals. This crate starts to get rather full as shown in Figure 8. Again, the high-density Z-pack (Futurebus+) connectors are used to connect to the backplane, and nearly all of the backplane space is used, and a non-standard readout bus will need to be defined.
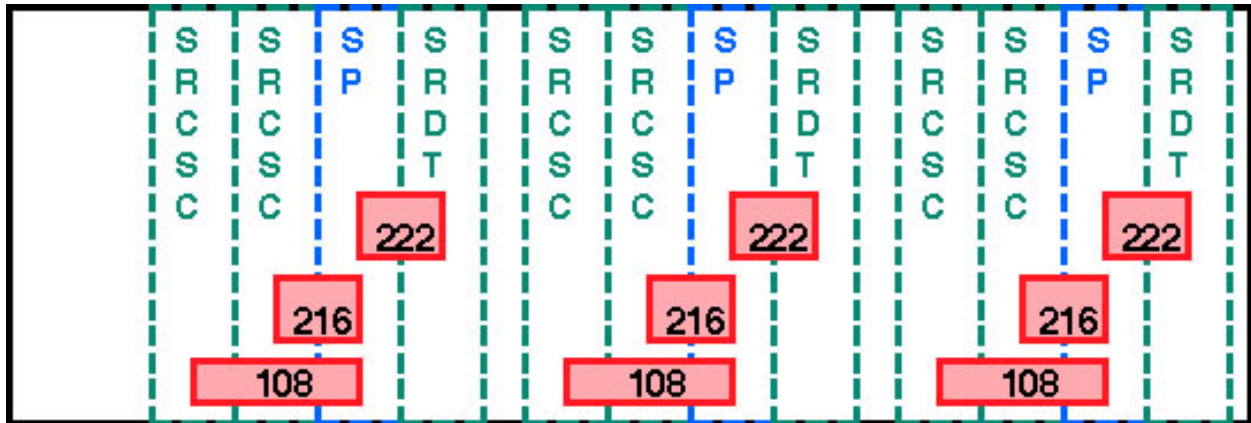
Figure 8. VME backplane pin count (data plus grounds only) in the Overlap Track Finder crate.

3. COST

A summary of the cost of the CMS Endcap Muon Regional CSC Trigger is contained in Table 1. The unit costs are detailed in Table 2. The costing methodology and WBS definitions are explained in the following sections. The funding profile based on the schedule described in section 4 is shown in Figure 4.

WBS Number	Description	EDIA (k$)	M&S (k$)	Base (k$)	Cont (%)	Total (k$)
3.1.1	CSC Muon Trigger	937	812	1,749	54	2,687
3.1.1.1	Muon Port Cards (MPC)	215	292	507	50	760
3.1.1.2	Sector Receivers (SR)	202	208	410	50	615
3.1.1.3	CSC Sector Processors (SP-CSC)	170	76	246	65	406
3.1.1.4	Overlap Sector Processors (SP-OVR)	170	76	246	65	406
3.1.1.5	Clock&Control Cards (CCC)	78	36	114	40	159
3.1.1.6	Crate Monitor Cards		10	10	50	15
3.1.1.7	Muon Backplanes	60	20	80	50	120
3.1.1.8	Crate Controllers		35	35	50	53
3.1.1.9	Muon Crates		6	6	50	9
3.1.1.10	Muon Power Supplies		23	23	50	35
3.1.1.11	Additional Cables		30	30	50	45
3.1.1.12	Trigger System Tests	43		43	50	64
3.1.1.13	Trigger Project Management					

Table 1. Summary of costs of the CMS Endcap Muon Regional CSC Trigger .

WBS	Item	Unit Cost	Uts	M&S
3.1.1	CSC Muon Trigger	812,038	1	812,038
3.1.1.1	Muon Port Cards (MPC)	5,311	55	292,079
3.1.1.2	Sector Receivers (SR)	3,714	56	207,994
3.1.1.3	CSC Sector Proc. (SP-CSC)	5,065	15	75,973
3.1.1.4	Overlap Proc. (SP-OVER)	5,065	15	75,973
3.1.1.5	Clock&Control Cards (CCC)	3,580	10	35,800
3.1.1.6	Crate Monitor Cards	1,000	10	10,000
3.1.1.7	Muon Backplanes	2,000	10	20,000
3.1.1.8	Crate Controllers	3,545	10	35,450
3.1.1.9	Muon Crates	600	10	6,000
3.1.1.10	Muon Power Supplies	2,300	10	23,000
3.1.1.11	Additional Cables	-	-	29,770
3.1.1.12	Trigger System Tests	-	-	-
3.1.1.13	Trigger Project Management	-	-	-

Table 2. Summary of unit costs of CMS Endcap Muon Regional CSC Trigger .

	1998	1999	2000	2001	2002	2003	2004
	October 1998	October 1999	October 2000	October 2001	October 2002	October 2003	October 2004
Cost:	$162,500	$257,996	$131,500	$148,500	$573,576	$375,196	$100,170

Filtered Resources   Cost:

Figure 9. Funding profile for CMS Endcap Muon Regional CSC Trigger Project.

4. SCHEDULE

We foresee the development of the CMS Endcap Muon Regional CSC Trigger System in four phases. The prototype design and production phase will continue until the end of 1999. The final design of the various system components will continue until 2003. Production will begin in 2002 and end in 2004. Installation and commissioning will take place in 2004. The schedule, at its highest level, is shown in Figure 10 and the schedule milestones are summarized in Figure 11.

WBS	Task Name	1998		1999		2000		2001		2002		2003		2004	
		Oct	Apr	Oct	Apr	Oct	Apr	Oct	Apr	Oct	Apr	Oct	Apr	Oct	Apr
3.1.1	CSC Muon Trigger														
3.1.1.1	Muon Port Cards (MPC)														Apr 1
3.1.1.2	Sector Receivers (SR)													Oct 7	
3.1.1.3	CSC Sector Processors (SP-CSC)	ar 5													Apr
3.1.1.4	Overlap Sector Processors (SP-OVR)	May 14												Feb 19	
3.1.1.5	Clock&Control Cards (CCC)						Jul 24							Mar 1	
3.1.1.6	Crate Monitor Cards									Jul 23	Dec 9				
3.1.1.7	Muon Backplanes									May 14			Dec 9		
3.1.1.8	Crate Controllers								Nov 19	Apr 22					
3.1.1.9	Muon Crates								Nov 19	Apr 22					
3.1.1.10	Muon Power Supplies								Nov 19	Apr 22					
3.1.1.11	Additional Cables								Nov 19				Mar 4		
3.1.1.12	Trigger System Tests											Apr 30			
3.1.1.13	Trigger Project Management														

Figure 10. Summary of Endcap Muon Regional CSC Trigger Schedule.
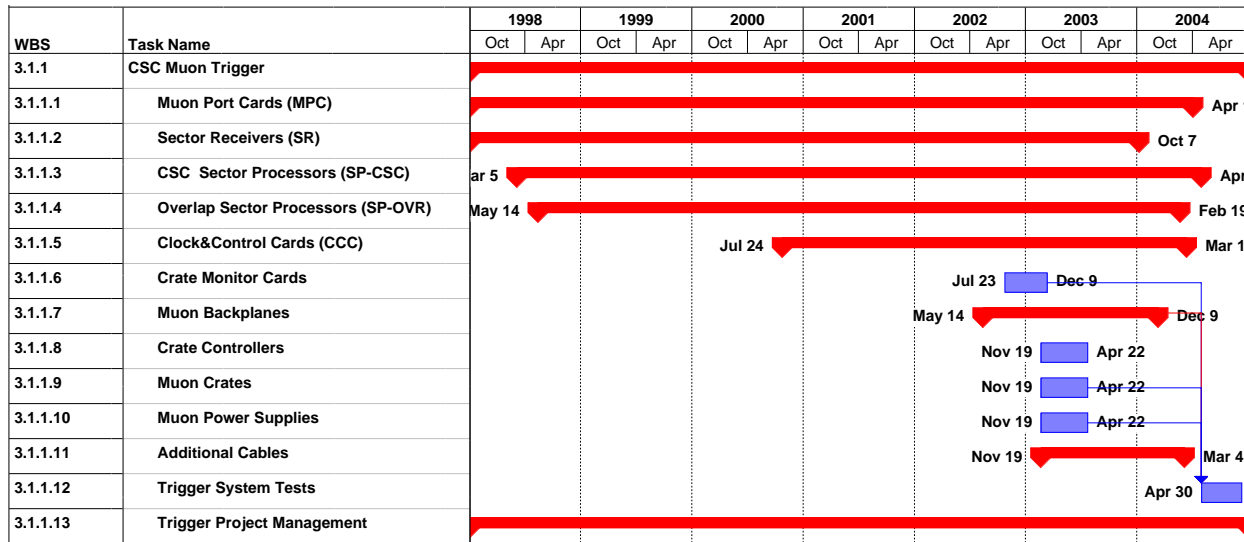
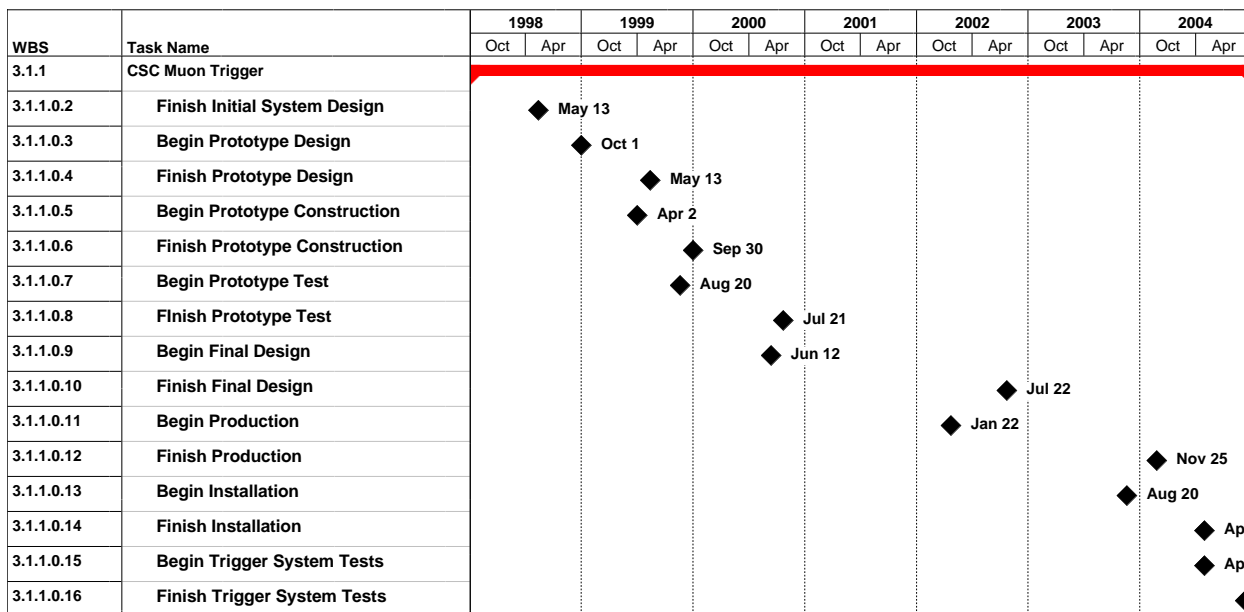| WBS	Task Name	1998		1999		2000		2001		2002		2003		2004	
		Oct	Apr	Oct	Apr	Oct	Apr	Oct	Apr	Oct	Apr	Oct	Apr	Oct	Apr
3.1.1	CSC Muon Trigger														
3.1.1.0.2	Finish Initial System Design		May 13												
3.1.1.0.3	Begin Prototype Design			Oct 1											
3.1.1.0.4	Finish Prototype Design				May 13										
3.1.1.0.5	Begin Prototype Construction			Apr 2											
3.1.1.0.6	Finish Prototype Construction					Sep 30									
3.1.1.0.7	Begin Prototype Test					Aug 20									
3.1.1.0.8	FInish Prototype Test							Jul 21							
3.1.1.0.9	Begin Final Design							Jun 12							
3.1.1.0.10	Finish Final Design										Jul 22				
3.1.1.0.11	Begin Production									Jan 22					
3.1.1.0.12	Finish Production												Nov 25		
3.1.1.0.13	Begin Installation											Aug 20			
3.1.1.0.14	Finish Installation													Apr	
3.1.1.0.15	Begin Trigger System Tests													Apr	
3.1.1.0.16	Finish Trigger System Tests														

Figure 11. Endcap Muon Regional CSC Trigger Major Milestones.

5. US RESPONSIBILITY

The US institutions participating in CMS have undertaken the design and building of the Regional Muon Trigger System. This system begins with the Muon Port Cards which collect data from front-end Motherboards on twisted pair cable, and ends with cables that transmit the results to the global level 1 muon trigger system. Responsibilities for the front-end signals are also a responsibility of US groups but are included as a part of the Endcap Muon system budget (US-CMS WBS item 1). Responsibilities for the fiber optics clock and control transmission system, the Global Muon Trigger, and the Global Level 1 trigger are assigned to non-US CMS groups.

US Institutions participating in the Regional Muon Trigger:

Institute	Contact Person
University of California, Los Angeles	J. Hauser
University of Florida, Gainesville	D. Acosta
Rice University, Houston	P. Padley

6. COSTING METHODOLOGY

6.1 Base Cost

The M&S cost for the trigger system was calculated by determining the cost of FPGA's, parts, boards, crates, and cables. The numbers of FPGA's, parts, boards, crates, and cables were determined from the design described above and in the references. For the Muon Port Cards, there is considerable leverage from the CSC Trigger Motherboard, which has similar logic. For the Muon Port Cards, Sector Receiver Cards and Sector Processor Cards, much of the logic is implemented in standard FPGA's with well-understood costs. The Sector Processor costs ar ealso based upon the Vienna CMS Muon Drift Tube Sector Processor Board, an FPGA-based prototype that has undergone extensive testing. The EDIA for the electronics boards was based on EDIA experience with recent track stub finding prototype development for the CMS muon trigger (UCLA LCT card, XXXX), and comparable trigger projects in CDF (XFT, R. Hughes/B. Winer).

6.2 Contingency

The costs listed in the budget estimate are the base costs of producing each item correctly the first time. There are also explicit costs listed for prototyping where required. The cost contingency is the cost required beyond the base cost to ensure successful completion. The calculation of contingency has been done for each individual WBS item. The determination of contingency was informed by an analysis of the CMS muon trigger prototypes (UCLA LCT card, XXXX), and comparable trigger projects in CDF (XFT, R. Hughes/B. Winer). M&S and Labor costs also took

into account the actual experience on these projects before any contingency was determined. In addition, the prototyping experience on CMS trigger electronics was also used as input.

The calculation of contingency was done for each individual WBS item according to the methodology established by US CMS Project Management. Each item is first assigned a contingency factor composed of the product of maturity of design and a judgment factor. The maturity of design is assigned as 1.5 for a conceptual design, 1.4 for a design which has been partially engineered, 1.3 for a full engineering design, 1.2 where a bid package has gone out, and 1.1 for an item that is ordered from a catalog. The judgment factor is set to 1.0 for most tasks and is increased to 1.1 for the most difficult tasks. The total cost is multiplied by the contingency factor to produce the total cost plus contingency.

The WBS and Basis of Estimate that summarize these costs, the source of the cost estimates, and the justification of the contingency assignment are given in Appendix A.

APPENDIX A:

WBS DICTIONARY AND

BASIS OF ESTIMATE