

WBS Dictionary/Cost Estimate Documentation

US CMS Muon Regional 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 $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$, 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 CMS muon system consists of 4 stations of chambers. In the barrel detector, these are drift chambers, whereas in the endcap detector, they are Cathode Strip Chambers (CSC's). 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.

1.1.1 Requirements

CMS Endcap Muon trigger system should be capable of selecting events muons with high efficiency and good geometric acceptance. At high luminosity, $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$, the single muon trigger is required to be at least 90% efficient in the pseudo-rapidity range $|\eta| < 2.4$ for a threshold of $E_t > 20 \text{ GeV}$. For the dimuon trigger the threshold should be $E_t > 10 \text{ GeV}$ for each particle in the same η -range. The total muon trigger rate should not exceed approximately 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 0.9-1.5. 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 $3\mu\text{s}$, 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. There are 2884 Cathode cards and 2268 Anode cards, mounted on 540 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 20 or 40 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 Global Muon and overall Global Level 1 trigger electronics are responsibilities of European groups. A block diagram showing the overall structure of the CSC Muon Trigger system is shown in Figure 1.

The major portions of the off-chamber Muon Trigger contained in WBS 3.1.1 are therefore Port Cards, optical links, and Track Finder crates with their component circuit boards and cables.

A Muon Port Card receives data from all of the Motherboards within a CSC station within a ϕ interval of alternately 20 and 40 degree sectors of the muon system¹, and then sends the data “upstairs” via fast optical links to a CSC Track Finder crate. The MPC are located on the surfaces of the large outer CSC chambers to keep copper cabling distances acceptably short. A depiction of the MPC connections is shown in Figure 2. There are 12 Muon Port Cards per CSC station per endcap, for a total of 96 MPC (12 in ϕ * 4 stations * 2 endcaps). The number of Motherboards connected to a single MPC varies from 3 in the case of 20-degree cards in ME{2,3,4} stations to 10 in the case of 40-degree cards in ME1. It takes 7 Gbaud optical links per MPC to send the information from up to 3 muon stubs to the Track Finder. The reason for having Muon Port Cards rather than connecting optical links directly from chambers to the Track Finder is firstly: 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. Secondly, without the MPC, there would be 150 optical fibers carrying 1 GHz of muon data into a Track Finder crate (vs. the present design of 28 fibers). Together with the data transfer from endcap CSC chambers which are adjacent in ϕ (to handle curving tracks) as well as barrel muon chambers which overlap in η , this is far too much data 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.

The Track Finder system consists of 24 VME crates, each of which handles a 20 or 40 degree slice¹ in ϕ of an endcap. Within each Track Finder crate, 28 optical fiber Gbaud signals are received from MPC connected to the four endcap stations ME{1,2,3,4}. In addition, a very high data rate of signals is fanned out to, and fanned in from those endcap Track Finder crates which are adjacent in ϕ , as well as Barrel Track Finder crates which overlap in η . The reception and

¹ The reason for alternating the ϕ interval is an incongruence between Barrel Muon chambers which subtend 30 degrees, and the smaller CSC chambers, which subtend 20 degrees. Since the Track Finder receives fanned-out signals from adjacent phi chambers in order to handle bending muons at the boundaries, the alternating coverage is OK.

transmission of this data is handled by Sector Receiver cards within the Track Finder crates. The Sector Receiver receives the muon stub data from optical fibers, translates from fiber to copper, and converts from serial to parallel format. The Sector Receiver card contains circuitry to synchronize the incoming data with the local clock, and check for data transmission errors. The optical links come in on the front panel of the Sector Receiver cards, while fan-in and fan-out signals to adjacent Track Finder crates are carried on twisted-pair cables from auxiliary cards connected to the backplanes of the Track Finder crates.

The function of linking muon stubs together into tracks is handled by Sector Processor cards within the Track Finder crates. These cards contain processors which I) create 3D stubs from strip and wire stub projections sent them by the MPC, II) require a coincidence of three to four muon stubs in the rapidity (non-bend) view, III) test for consistency of the bend-angle positions with multiple scattering, and IV) use the sagitta information to determine the track momenta. The part of the processing which takes place in the bend projection has similarities to a portion of a CDF trigger project known as the XFT linker, which finds tracks in the central tracking chamber of the CDF experiment; however, the large amount of multiple scattering between muon stations due to the large amount of steel, means that the patterns which are looked for are can be irregular. Also, the muon stub information has to be handled carefully in order to yield momentum resolution which is good enough to satisfy our constraints.

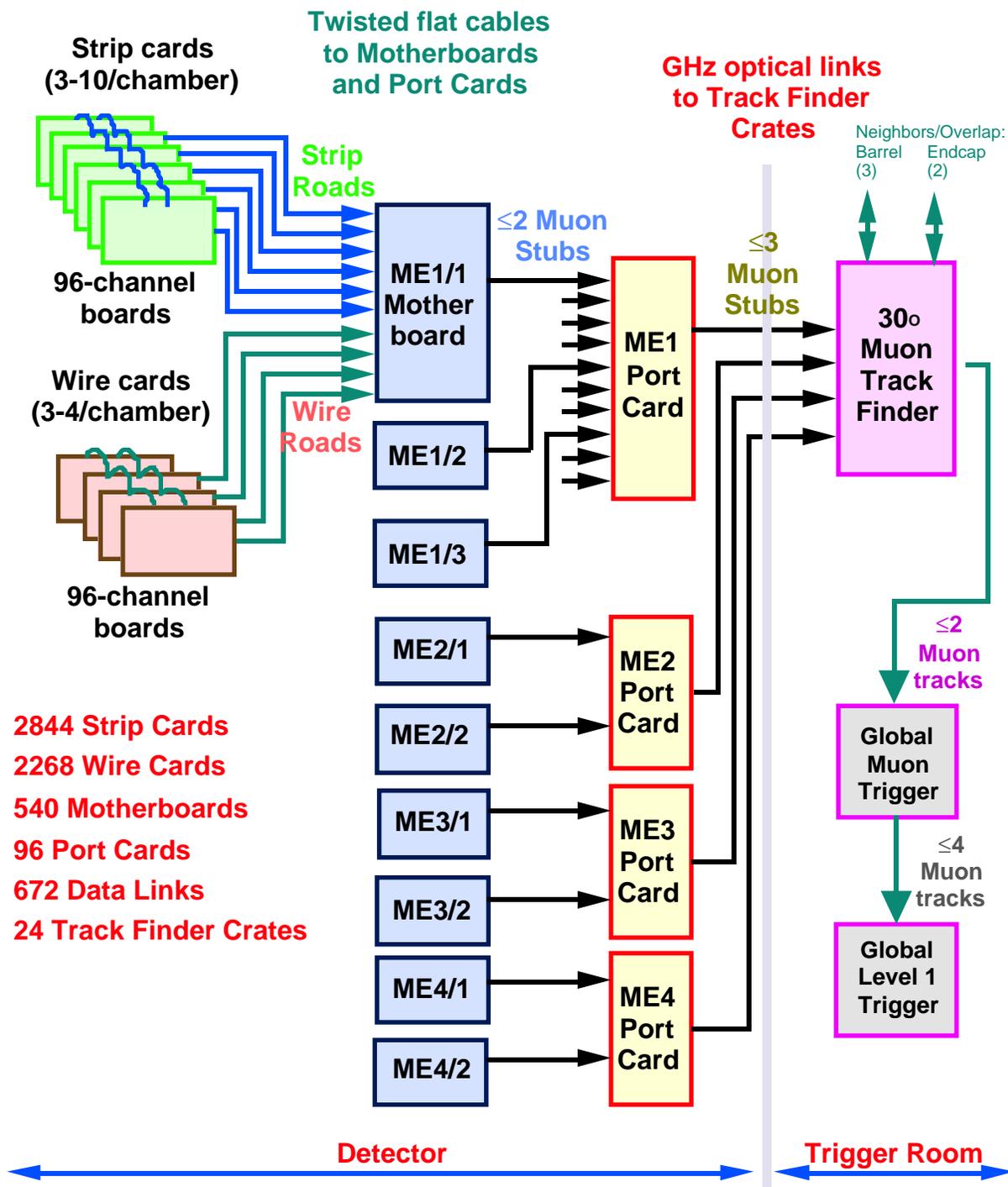


Fig. 1: Architecture of the CSC Muon Trigger System

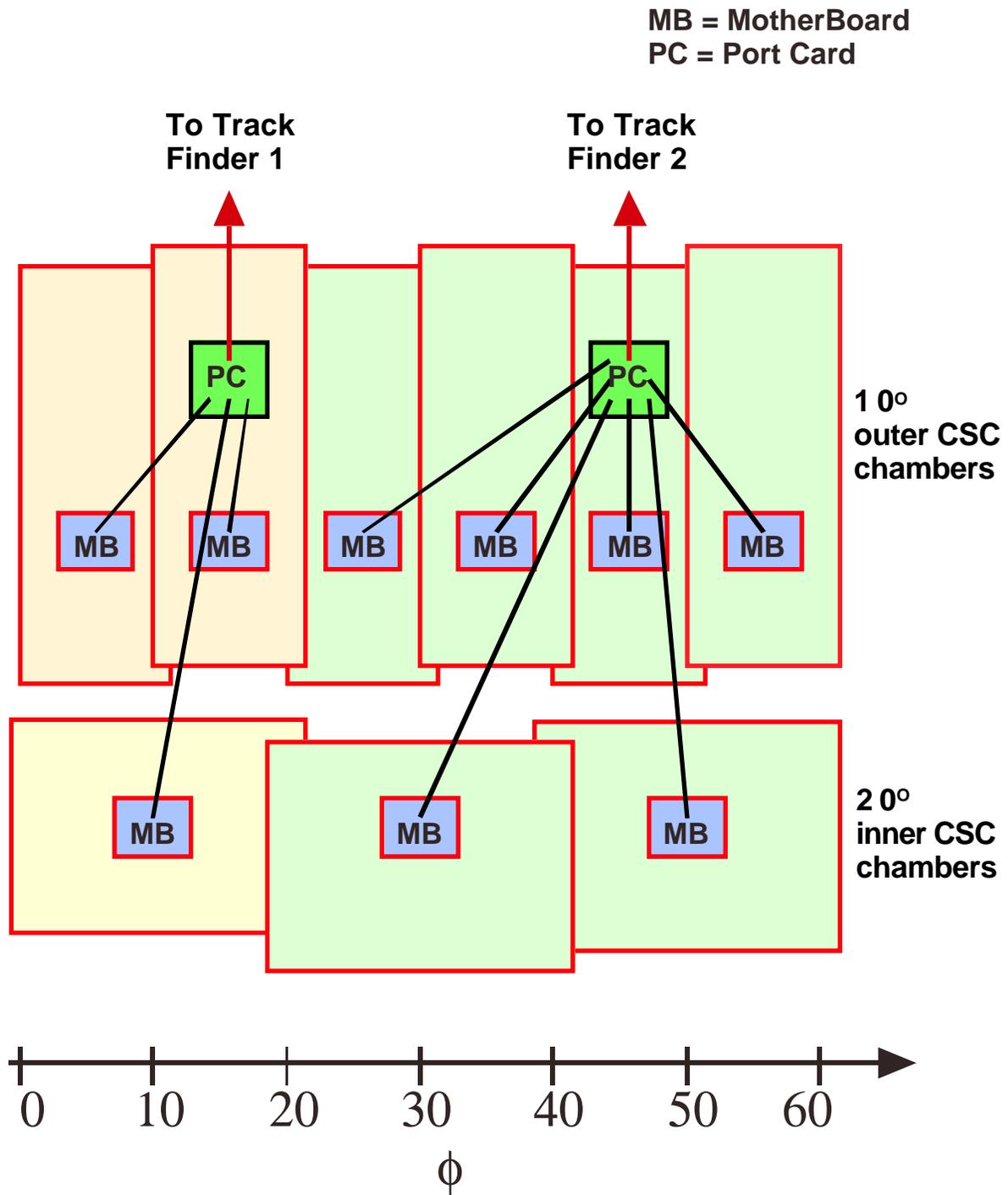


Figure 2. Muon Port Card layout: locations and links to Motherboards on Endcap CSC chambers.

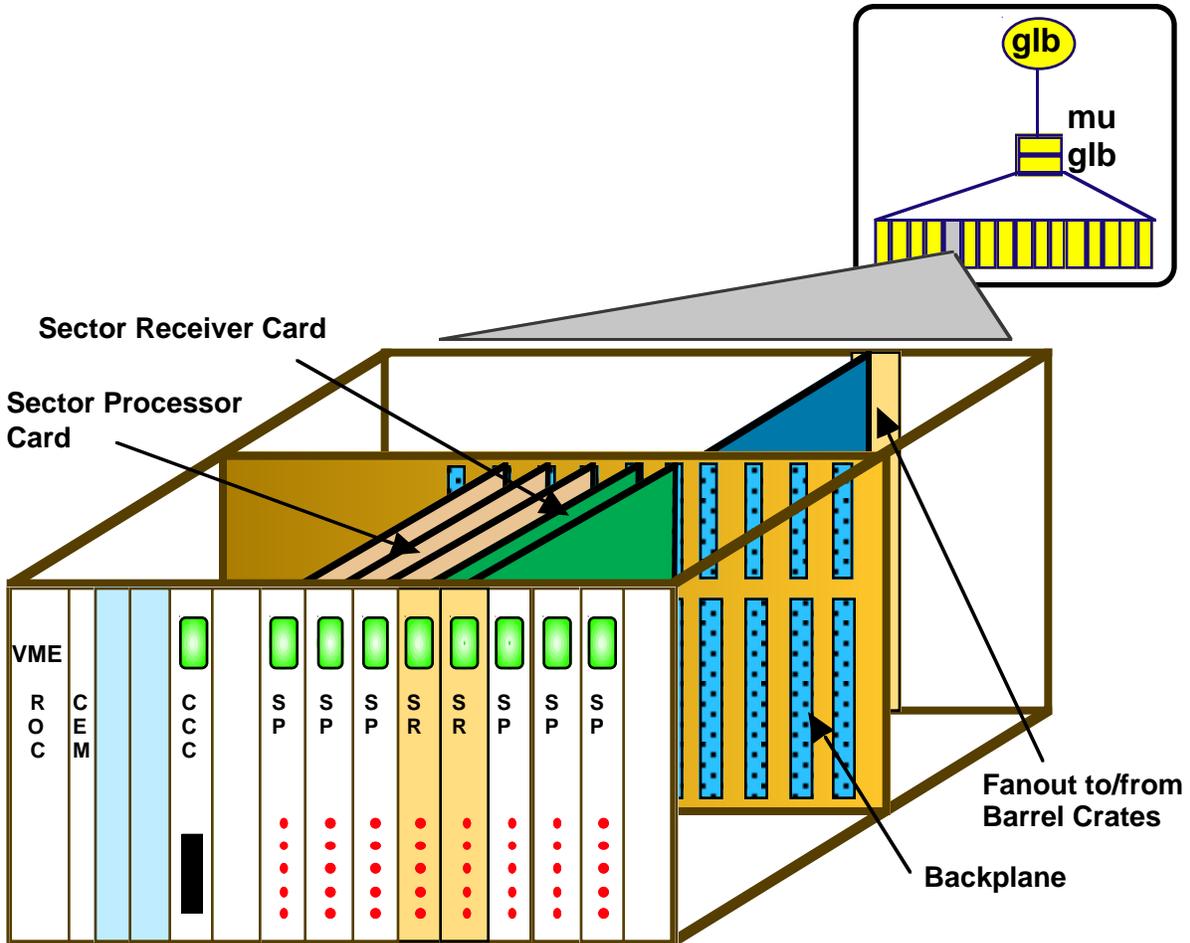


Figure 3. Muon Track Finder: layout of a VME Crate responsible for track finding in a 20 or 40-degree swath of Endcap Muon chambers. The inset at top shows how this crate is part of a system of crates feeding muons to the global level 1 trigger through the global muon trigger .

3. COST

A summary of the cost of the CMS Regional Muon Trigger is contained in Table 1. The unit costs are shown 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	Item	Prj M&S	Prj EDIA	Prj Total	Conting.	%Ct	Total
3.1.1	CSC Muon Trigger	1,037,764	940,000	1,977,764	594,508	30	2,572,272
3.1.1.1	Muon Port Cards (MPC)	311,844	252,500	564,344	165,743	29	730,087
3.1.1.2	Sector Receivers (SR)	204,040	260,000	464,040	142,570	31	606,610
3.1.1.3	Sector Processors (SP)	287,560	260,000	547,560	203,268	37	750,828
3.1.1.4	Clock&Control Cards (CCC)	86,520	82,500	169,020	32,802	19	201,822
3.1.1.5	Crate Monitor Cards	26,000	-	26,000	4,056	16	30,056
3.1.1.6	Muon Backplanes	52,000	45,000	97,000	24,856	26	121,856
3.1.1.7	Muon Crates	15,000	-	15,000	1,980	13	16,980
3.1.1.8	Muon Power Supplies	50,000	-	50,000	6,600	13	56,600
3.1.1.9	Muon Tracker Cables	4,800	-	4,800	634	13	5,434
3.1.1.10	Trigger System Tests	-	40,000	40,000	12,000	30	52,000
3.1.1.11	Trigger Project Management	-	-	-	-		-

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

WBS	Item	Unit Cost	Uts	Prj M&S
3.1.1	CSC Muon Trigger	1,037,764	1	1,037,764
3.1.1.1	Muon Port Cards (MPC)	2,887	108	311,844
3.1.1.2	Sector Receivers (SR)	3,710	55	204,040
3.1.1.3	Sector Processors (SP)	3,465	83	287,560
3.1.1.4	Clock&Control Cards (CCC)	2,983	29	86,520
3.1.1.5	Crate Monitor Cards	1,000	26	26,000
3.1.1.6	Muon Backplanes	2,000	26	52,000
3.1.1.7	Muon Crates	600	25	15,000
3.1.1.8	Muon Power Supplies	2,000	25	50,000
3.1.1.9	Muon Tracker Cables	20	240	4,800
3.1.1.10	Trigger System Tests	-	1	-
3.1.1.11	Trigger Project Management	-	1	-

Table 2. Unit costs for CMS CSC Muon Trigger.

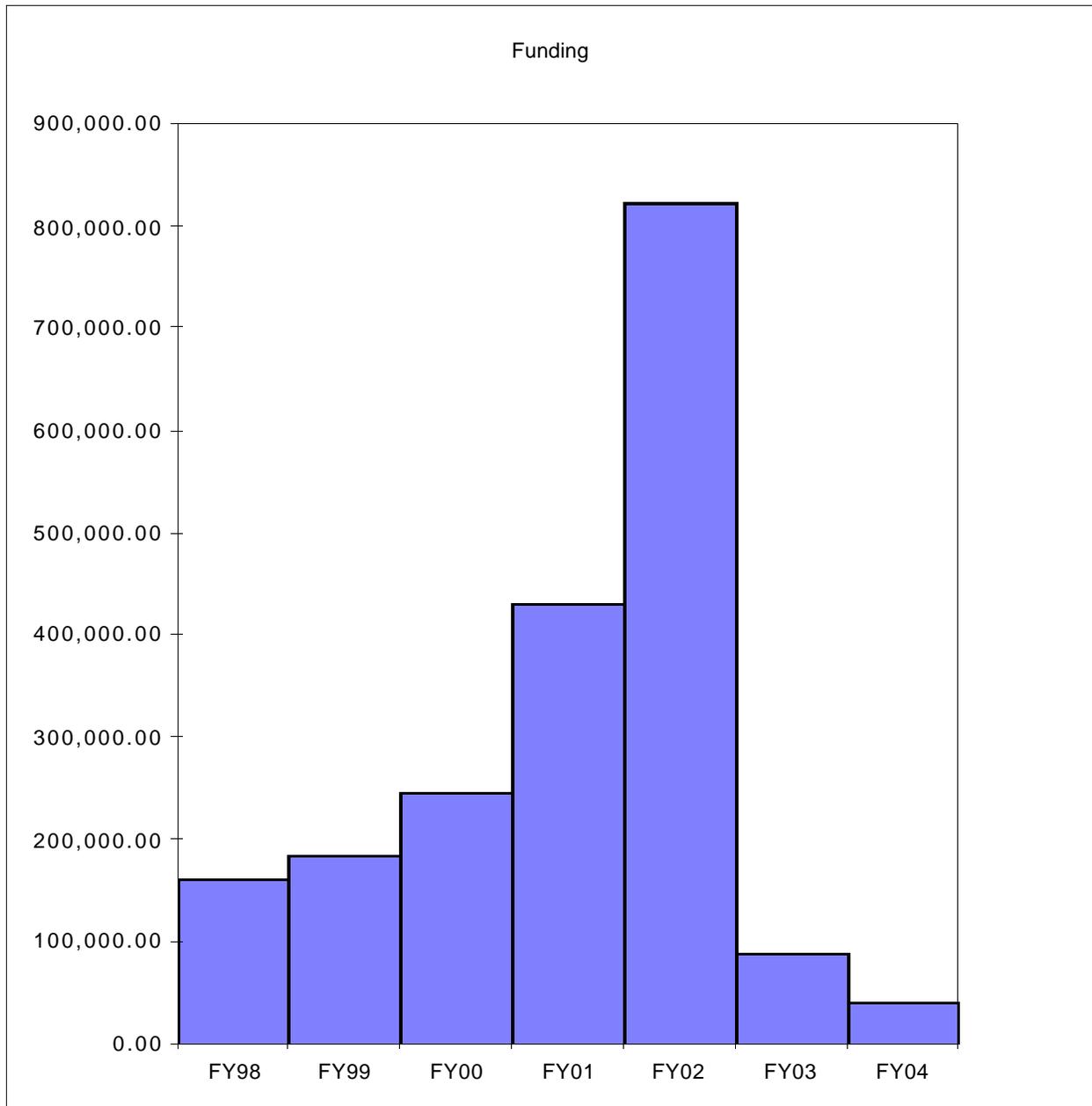


Figure 4. Funding profile for the Regional Muon Trigger Project.

4. SCHEDULE

We foresee the development of the Regional Muon Trigger System in four phases. The prototype design and production phase will continue through 1999. The final design of the various system components will continue until 2002. Production will begin in 2001 and end in 2003. Installation and commissioning will begin in 2003 and continue until 2005. The schedule, at its highest level, is shown in Figure 5 and the schedule milestones are summarized in Figure 6.

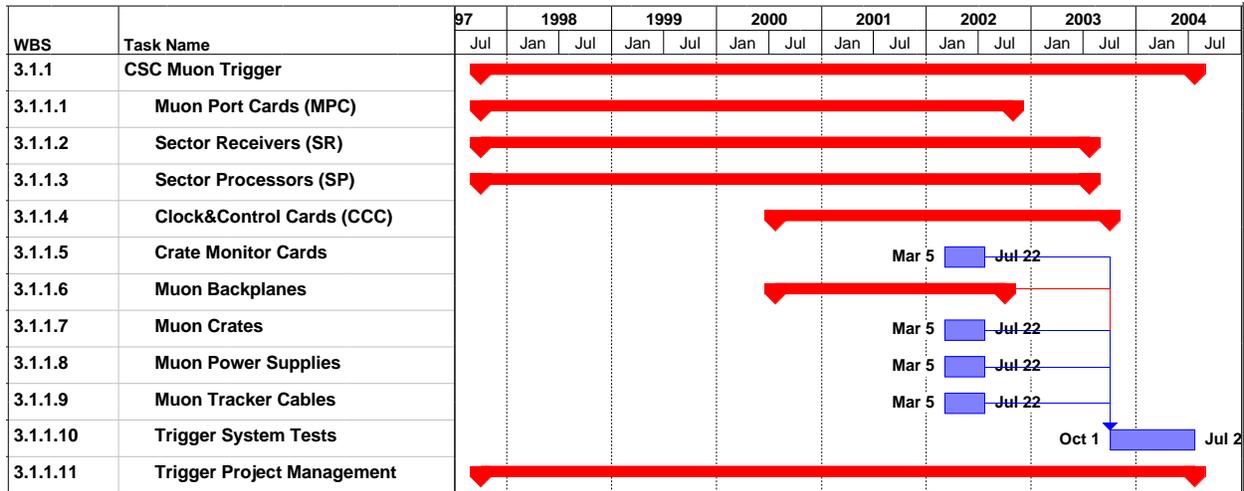


Figure 5. Summary of Muon Trigger Schedule.

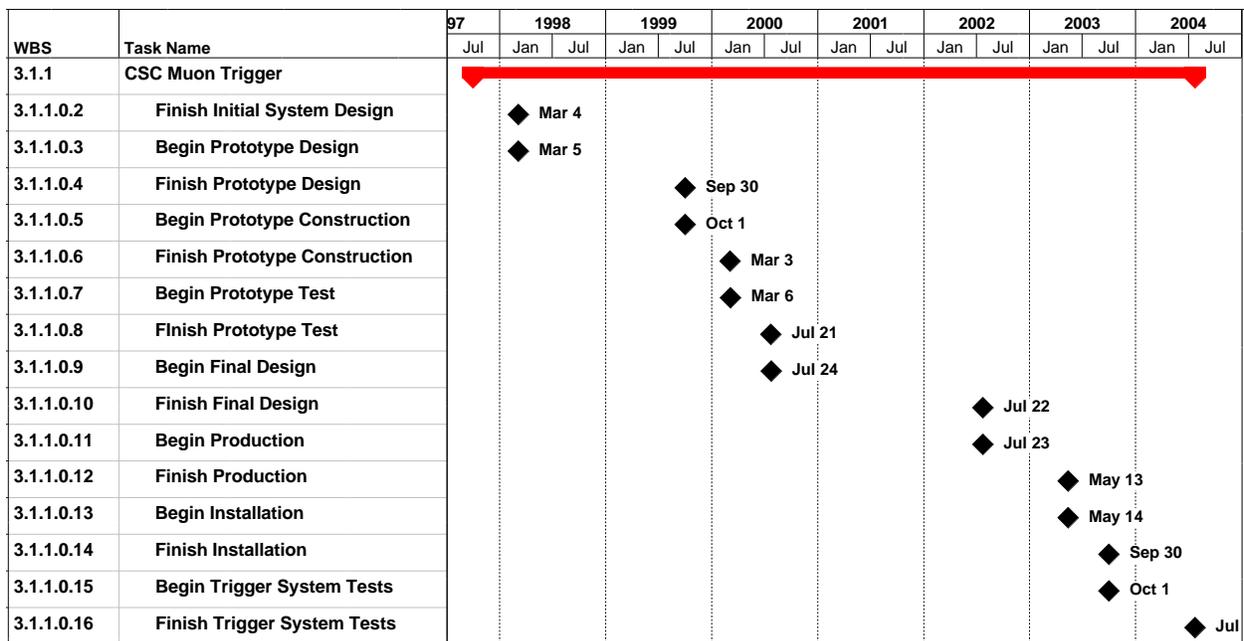


Figure 6. Muon Trigger Major Milestones.

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 trigger interface to DAQ, 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
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 ASIC's, boards, crates, and cables. The numbers of ASIC's, boards, crates, and cables were determined from the design described above.

The EDIA cost for the trigger system was calculated from the EDIA costs already experienced for the design, manufacture and test of prototypes. The M&S and EDIA calculations also used information from an analysis of the Zeus trigger electronics and the XFT project for the CDF upgrade.

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 WBS item. The calculation of contingency was determined from an analysis of the Zeus trigger electronics and the XFT project for the CDF upgrade. 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.

Each item is first assigned a contingency of 20% for M&S and 30% for Labor. This was found to be the appropriate for the most difficult boards in the Zeus trigger system after M&S and Labor costs were increased to take into account the actual experience on Zeus before any contingency was determined. Each item is then assigned a factor based on the degree of difficulty, where 1.0 was assigned to difficult items, 0.8 assigned to average items and 0.6 assigned to easy items. Finally, each item was multiplied by a factor corresponding to its maturity of design, where 1.1 is assigned to items taken from a catalog, 1.2 for items where there is a bid package ready to go out or a quote, 1.3 where the cost is based on an engineering design, and 1.5 where the cost is based on a conceptual design.

7. WBS DICTIONARY AND BASIS OF ESTIMATE

WBS Element: 3.1.1

WBS Element Title: Regional Muon Trigger

WBS Definition:

This WBS element includes all the effort to develop, produce, assemble, install and commission the Regional Muon Trigger.

Basis of Estimate:

This element's costs are generated as the sum of lower-level WBS elements.

WBS Element: 3.1.1.1

WBS Element Title: Muon Port Cards (MPC)

WBS Definition:

This WBS element includes all the effort to develop, produce, assemble, install and commission the Muon Port Card portion of the Regional Muon Trigger. The system contains 96 of these cards plus spares.

Basis of Estimate:

This element's costs are generated as the sum of lower-level WBS elements.

WBS Element: 3.1.1.1.1

WBS Element Title: MPC Design

WBS Definition:

This WBS element represents all of the engineering required to design the Muon Port Cards.

Basis of Estimate:

The design engineering is foreseen to proceed in two stages: an initial period in which the interfaces to Motherboards, Track Processors, and the system clock (TTC) are defined, and a prototype design stage in which these interfaces are realized. The EDIA is based on experience with recent track stub finding prototype development for the CMS muon trigger, and comparable trigger projects in CDF. The logic on the Muon Port Card will be very similar to that on the CSC Trigger Mother Board. This logic for the prototype is being implemented in a standard FPGA.

Therefore, this element is rated to be of average difficulty. The maturity is that of a conceptual design.

WBS Element: 3.1.1.1.2

WBS Element Title: MPC Prototype Construction

WBS Definition:

This WBS element represents the construction of two MPC prototypes which will be bench-tested as well as installed into a working chain of prototype devices.

Basis of Estimate:

The M&S costs are based on current estimates for active components, primarily FPGA and optical link devices, and board costs (M&S). A modest amount of EDIA is included for oversight of the construction of these prototypes. Since the MPC will be built from standard FPGA's and/or ASIC's the difficulty is average. The maturity is that of a conceptual design.

WBS Element: 3.1.1.1.3

WBS Element Title: MPC Prototype Test

WBS Definition:

This WBS element represents engineering required for testing of the MPC prototypes.

Basis of Estimate:

The engineering EDIA is based on experience with prototype testing for front-end CSC muon trigger cards. Since the MPC will be built from standard FPGA's and/or ASIC's the difficulty is average. The maturity is that of a conceptual design.

WBS Element: 3.1.1.1.4

WBS Element Title: MPC ASIC and Board Design

WBS Definition:

This WBS element represents all work required to turn prototype MPC designs into production version devices having optimized cost and reliability.

Basis of Estimate:

The cost estimate is based on experience with recent track stub finding prototype development for the CMS muon trigger, and comparable trigger projects in CDF. Since the MPC will be built from standard FPGA's and/or ASIC's, the difficulty is average. The maturity is that of a conceptual design.

WBS Element: 3.1.1.1.5**WBS Element Title:** MPC Active Components**WBS Definition:**

This WBS element represents the purchase of the active components that are installed on the 96 MPC boards required to operate the CSC Muon trigger, not including spares.

Basis of Estimate:

The board costs represent the sum of active components, primarily FPGA devices and ASIC's, which are similar to those used on the Muon Trigger Motherboards and Glink optical links being used elsewhere in CMS. We assume 7 Gbaud links are required per MPC. The difficulty is average. The maturity is that of a conceptual design.

WBS Element: 3.1.1.1.6**WBS Element Title:** MPC Boards**WBS Definition:**

This WBS element represents the production of the 96 MPC required to operate the CSC Muon trigger, not including spares. Engineering EDIA is included for management of the production, and technician EDIA is included for inspection and testing.

Basis of Estimate:

The board costs represent the sum of board manufacturing costs, plus cables and connectors. The EDIA is extrapolated from past experience with production of boards for CDF, UA1, KTeV, and other experiments. Since these are standard boards, the difficulty is rated as average. The maturity is that of a conceptual design.

WBS Element: 3.1.1.1.7**WBS Element Title:** MPC Installation**WBS Definition:**

This WBS element represents the engineering required for proper installation and debugging of the MPC cards in the CMS detector.

Basis of Estimate:

The engineering EDIA required is extrapolated from past experience on CDF, KTeV, and other experiments. A considerable fraction of the total effort will be physicist labor paid by the DOE base program. Since the installation will be a standard activity, the difficulty is rated as average. The maturity is that of a conceptual design.

WBS Element: 3.1.1.1.8**WBS Element Title:** MPC Spares**WBS Definition:**

This WBS element represents the spare cards which are required to ensure a proper level of operating reliability.

Basis of Estimate:

The number of spares is determined by using a well-known formula: 10% of the number required for operation, plus two. The spares are costed at the same price as the production units. The difficulty is average, as it is for the majority of the MPC system, and the maturity is that of a conceptual design.

WBS Element: 3.1.1.2**WBS Element Title:** Sector Receivers (SR)**WBS Definition:**

This WBS element represents the design, prototyping, production, assembly, and testing of the Sector Receiver cards within the Track Processor crates.

Basis of Estimate:

There are two Sector Receiver cards within each Track Processor crate required for operation of the Endcap Muon Trigger. Each Sector Receiver card receives data on 14 optical fibers from the Muon Port Cards as well as equivalent data from each of two Sector Receiver cards adjacent in phi, and three equivalent cards within the Barrel Muon Track Processors (to handle rapidity overlap). The cost estimate per board is comparable to the estimated cost per board (\$3220) for the Linker board of the XFT tracker for the CDF upgrade project. The boards use similar board space and part count for FPGA and other active components. The logic and function is relatively straightforward and therefore the difficulty is average. The maturity is that of a conceptual design.

WBS Element: 3.1.1.2.1**WBS Element Title:** SR Design**WBS Definition:**

This WBS element represents all of the engineering required to design the Sector Receiver Cards.

Basis of Estimate:

The design engineering is foreseen to proceed in two stages: an initial period in which the interfaces to MPC's, other SR's, the Sector Processors (SP) and the system clock (TTC) are defined, and a prototype design stage in which these interfaces are realized. The EDIA is based on comparable trigger projects in CDF. This element is rated to be of average difficulty. The maturity is that of a conceptual design.

WBS Element: 3.1.1.2.2**WBS Element Title:** SR Prototype Construction**WBS Definition:**

This WBS element represents the construction of two SR prototypes which will be bench-tested as well as installed into a working chain of prototype devices.

Basis of Estimate:

The M&S costs are based on current estimates for active components, primarily FPGA and optical link devices, and board costs (M&S). A modest amount of EDIA is included for oversight of the construction of these prototypes. Since the SR will be built from standard FPGA's and/or ASIC's the difficulty is average. The maturity is that of a conceptual design.

WBS Element: 3.1.1.2.3**WBS Element Title:** SR Prototype Test**WBS Definition:**

This WBS element represents engineering required for testing of the SR prototypes.

Basis of Estimate:

The cost estimate is based on comparable trigger projects in CDF and Zeus. Since the SR will be built from standard FPGA's and/or ASIC's, the difficulty is average. The maturity is that of a conceptual design.

WBS Element: 3.1.1.2.4**WBS Element Title:** SR ASIC and Board Design**WBS Definition:**

This WBS element represents all work required to turn prototype SR designs into production version devices having optimized cost and reliability.

Basis of Estimate:

The cost estimate is based on comparable trigger projects in CDF and Zeus. Since the SR will be built from standard FPGA's and/or ASIC's, the difficulty is average. The maturity is that of a conceptual design.

WBS Element: 3.1.1.2.5**WBS Element Title:** SR Active Components**WBS Definition:**

This WBS element represents the purchase of the active components that are installed on the SR boards required to operate the CSC Muon trigger, not including spares.

Basis of Estimate:

The board costs represent the sum of active components, primarily FPGA devices and Glink optical links. Since high-speed optical fiber receivers will be taken from other CMS designs, the task difficulty is rated as average. The maturity is that of a conceptual design.

WBS Element: 3.1.1.2.6**WBS Element Title:** SR Boards**WBS Definition:**

This WBS element represents the production of the SR boards required to operate the CSC Muon trigger, not including spares. Engineering EDIA is included for management of the production, and technician EDIA is included for inspection and testing.

Basis of Estimate:

The board costs represent the sum of board manufacturing costs, plus cables and connectors. The EDIA is extrapolated from past experience with production of boards for CDF, UA1, KTeV, Zeus and other experiments. Since these are standard boards, the difficulty is rated as average. The maturity is that of a conceptual design.

WBS Element: 3.1.1.2.7**WBS Element Title:** SR Installation**WBS Definition:**

This WBS element represents the engineering required for proper installation and debugging of the SR Boards in the counting house.

Basis of Estimate:

The engineering EDIA required is extrapolated from past experience on CDF, UA1, KTeV, Zeus and other experiments. A considerable fraction of the total effort will be physicist labor paid by the DOE base program. Since the installation will be a standard activity, the difficulty is rated as average. The maturity is that of a conceptual design.

WBS Element: 3.1.1.2.8**WBS Element Title:** SR Spares**WBS Definition:**

This WBS element represents the spare cards which are required to ensure a proper level of operating reliability.

Basis of Estimate:

The number of spares is determined by using a well-known formula: 10% of the number required for operation, plus two. The spares are costed at the same price as the production units. The difficulty is average, as it is for the majority of the SR system, and the maturity is that of a conceptual design.

WBS Element: 3.1.1.3**WBS Element Title:** Sector Processors (SP)**WBS Definition:**

This WBS element represents the design, prototyping, production, assembly, and testing of the Sector Receiver cards within the Track Processor crates.

Basis of Estimate:

There are three Sector Processor cards within each Track Processor crate required for operation of the Endcap Muon Trigger. Each Sector Processor card receives muon stub data over the muon backplane and looks for tracks using pattern arrays and combinatorial logic. The cost estimate per board is comparable to the estimated cost per board (\$3220) for the Linker board of the XFT tracker for the CDF upgrade project. The boards use similar board space and part count for FPGA and other active components. The interfaces to the SR boards and the Global Muon trigger, as well as the combinatorics, render this a difficult design.

WBS Element: 3.1.1.3.1**WBS Element Title:** SR Design**WBS Definition:**

This WBS element represents all of the engineering required to design the Sector Processor Cards.

Basis of Estimate:

The design engineering is foreseen to proceed in two stages: an initial period in which the interfaces to other SP's, the Sector Receivers (SR) and the system clock (TTC) are defined, and a prototype design stage in which these interfaces are realized. The EDIA is based on comparable trigger projects in CDF. This element is rated to be difficult. The maturity is that of a conceptual design.

WBS Element: 3.1.1.3.2**WBS Element Title:** SP Prototype Construction**WBS Definition:**

This WBS element represents the construction of two SP prototypes which will be bench-tested as well as installed into a working chain of prototype devices.

Basis of Estimate:

The M&S costs are based on current estimates for active components, primarily FPGA and optical link devices, and board costs (M&S). A modest amount of EDIA is included for oversight of the construction of these prototypes. This element is rated to be difficult. The maturity is that of a conceptual design.

WBS Element: 3.1.1.3.3**WBS Element Title:** SR Prototype Test**WBS Definition:**

This WBS element represents engineering required for testing of the SP prototypes.

Basis of Estimate:

The cost estimate is based on comparable trigger projects in CDF and Zeus. This element is rated to be difficult. The maturity is that of a conceptual design.

WBS Element: 3.1.1.3.4**WBS Element Title:** SP ASIC and Board Design**WBS Definition:**

This WBS element represents all work required to turn prototype SP designs into production version devices having optimized cost and reliability.

Basis of Estimate:

The cost estimate is based on comparable trigger projects in CDF and Zeus. This element is rated to be difficult. The maturity is that of a conceptual design.

WBS Element: 3.1.1.3.5**WBS Element Title:** SP Active Components**WBS Definition:**

This WBS element represents the purchase of the active components that are installed on the SP boards required to operate the CSC Muon trigger, not including spares.

Basis of Estimate:

The board costs represent the sum of active components, primarily FPGA devices and ASIC's. This element is rated to be difficult. The maturity is that of a conceptual design.

WBS Element: 3.1.1.3.6**WBS Element Title:** SP Boards**WBS Definition:**

This WBS element represents the production of the SP boards required to operate the CSC Muon trigger, not including spares. Engineering EDIA is included for management of the production, and technician EDIA is included for inspection and testing.

Basis of Estimate:

The board costs represent the sum of board manufacturing costs, plus connectors. The EDIA is extrapolated from past experience with production of boards for CDF, UA1, KTeV, Zeus and other experiments. This element is rated to be difficult. The maturity is that of a conceptual design.

WBS Element: 3.1.1.3.7**WBS Element Title:** SP Installation**WBS Definition:**

This WBS element represents the engineering required for proper installation and debugging of the SP Boards in the counting house.

Basis of Estimate:

The engineering EDIA required is extrapolated from past experience on CDF, UA1, KTeV, Zeus and other experiments. A considerable fraction of the total effort will be physicist labor paid by the DOE base program. Since the installation will be a standard activity, the difficulty is rated as average. The maturity is that of a conceptual design.

WBS Element: 3.1.1.3.8**WBS Element Title:** SP Spares**WBS Definition:**

This WBS element represents the spare cards which are required to ensure a proper level of operating reliability.

Basis of Estimate:

The number of spares is determined by using a well-known formula: 10% of the number required for operation, plus two. This element is rated to be difficult. The maturity is that of a conceptual design.

WBS Element: 3.1.1.4**WBS Element Title:** Clock & Control Card (CCC)**WBS Definition:**

This WBS element includes all the effort to develop, produce, assemble, install and test the Regional Muon Trigger Clock and Control Card (CCC). This card receives, aligns and logs the clock and control signals and distributes them with adjustable delays along individual lines to each of the cards in the Track Processor trigger crate.

Basis of Estimate:

The M&S and EDIA is based on boards built for the Zeus calorimeter trigger system, and checked against the full-size CMS prototype calorimeter trigger Clock and Control Card already constructed and tested. Since the board will be adapted from the design of the CMS calorimeter trigger Clock and Control Card, the task is rated as easy. Since similar prototype boards already exist, the maturity is that of an engineering design.

WBS Element: 3.1.1.4.1**WBS Element Title:** CCC Board Design**WBS Definition:**

This WBS element represents all of the engineering required to design the CCC Boards.

Basis of Estimate:

The cost is based on comparable trigger projects in CDF and Zeus. It is checked against the full-size CMS prototype calorimeter trigger Clock and Control Card already constructed and tested. This task is rated as easy. The maturity is that of an engineering design.

WBS Element: 3.1.1.4.2**WBS Element Title:** CCC Active Components**WBS Definition:**

This WBS element represents the purchase of the active components that are installed on the CCC boards required to operate the CSC Muon trigger, not including spares.

Basis of Estimate:

The cost is based on comparable trigger projects in CDF and Zeus. It is checked against the full-size CMS prototype calorimeter trigger Clock and Control Card already constructed and tested. This task is rated as easy. The maturity is that of an engineering design.

WBS Element: 3.1.1.4.3**WBS Element Title:** CCC Boards**WBS Definition:**

This WBS element represents the production of the CCC boards required to operate the CSC Muon trigger, not including spares. Engineering EDIA is included for management of the production, and technician EDIA is included for inspection and testing.

Basis of Estimate:

The cost is based on comparable trigger projects in CDF and Zeus. It is checked against the full-size CMS prototype calorimeter trigger Clock and Control Card already constructed and tested. This task is rated as easy. The maturity is that of an engineering design.

WBS Element: 3.1.1.4.4**WBS Element Title:** CCC Installation**WBS Definition:**

This WBS element represents the engineering required for proper installation and debugging of the SR Boards in the counting house.

Basis of Estimate:

The engineering EDIA required is extrapolated from past experience on comparable trigger projects in CDF and Zeus. A considerable fraction of the total effort will be physicist labor paid by the DOE base program. The cost is checked against that required for the full-size CMS prototype calorimeter trigger Clock and Control Card already constructed and tested. This task is rated as easy. The maturity is that of an engineering design.

WBS Element: 3.1.1.4.5**WBS Element Title:** CCC Spares**WBS Definition:**

This WBS element represents the spare cards which are required to ensure a proper level of operating reliability.

Basis of Estimate:

The number of spares is determined by using a well-known formula: 10% of the number required for operation, plus two. This task is rated as easy. The maturity is that of an engineering design.

WBS Element: 3.1.1.5**WBS Element Title:** Crate Monitor Card**WBS Definition:**

This WBS element includes all the effort to develop, produce, assemble, install and test the Regional Muon Trigger Crate Monitor Card. This card receives, checks and logs voltages and temperatures in the Muon Trigger Crates.

Basis of Estimate:

The M&S and EDIA is based on boards used in the Zeus calorimeter trigger system, and in other crate systems. This task is rated as easy. The maturity is that of an engineering design

WBS Element: 3.1.1.6**WBS Element Title:** Muon Backplanes**WBS Definition:**

This WBS element includes all the effort to develop, produce, assemble, install and test Track Processor Trigger Backplanes. The backplane is a monolithic, custom, 9U high printed circuit board with front and back card connectors. The top 3U of the backplane holds 4 row (128 pin) DIN connectors, capable of full 32 bit VME. The first two front slots of the backplane will, however, use three row (96 pin) DIN connectors in the P1 and P2 positions with the standard VME pinout. The bottom 6U of the backplane, in the data processing section of the crate, utilizes a single high speed, controlled impedance, connector for both front and rear insertion at each card position. The design is based around a 340 pin connector, by AMP Inc, to handle the high volume of data transmitted from the Sector Receiver cards to the Sector Processor Cards.

Basis of Estimate:

Both M&S and EDIA costs are based on the full-size prototype backplane already constructed and tested for the CMS calorimeter trigger. The task difficulty is rated as average. The design maturity is that of an engineering design.

WBS Element: 3.1.1.6.1**WBS Element Title:** Muon Backplane Design**WBS Definition:**

This WBS element represents all of the engineering required to design the Muon Trigger Backplanes.

Basis of Estimate:

The EDIA costs are based on the full-size prototype backplane already constructed and tested for the CMS calorimeter trigger. The task difficulty is rated as average. The design maturity is that of an engineering design.

WBS Element: 3.1.1.6.2**WBS Element Title:** Muon Backplane Procure**WBS Definition:**

This WBS element represents all of the M&S required to procure the Muon Trigger Backplanes.

Basis of Estimate:

The M&S costs are based on the full-size prototype backplane already constructed and tested for the CMS calorimeter trigger. The task difficulty is rated as average. The design maturity is that of an engineering design.

WBS Element: 3.1.1.7**WBS Element Title:** Muon Crates**WBS Definition:**

This WBS element includes all the effort to procure, install and test the Track Processor Trigger Crates. The crate is based on standard Eurocard hardware with custom fittings. The height is 9U and the depth approximately 700mm, as determined by the front and rear card insertion. It requires a rack 900mm deep to handle the crate depth with some reserve for cabling, plumbing, and other services. The front section of the crate is designed to accommodate 280mm deep cards, leaving the major portion of the volume for 400mm deep rear mounted cards.

Basis of Estimate:

The cost is based on the full-size prototype CMS calorimeter trigger Crate already constructed and tested. The task is easy. The items will be ordered from a catalog.

WBS Element: 3.1.1.8**WBS Element Title:** Muon Power Supplies**WBS Definition:**

This WBS element includes all the effort to procure, install and test the Muon Trigger Track Processor crate power supplies.

Basis of Estimate:

The cost is based on the power supplies purchased for the prototype Regional Calorimeter Trigger Crate. The task is easy. The items will be ordered from a catalog.

WBS Element: 3.1.1.9**WBS Element Title:** Muon Tracker Cables**WBS Definition:**

This WBS element includes all the effort to procure, install and test the Track Processor Trigger Cables. Each Receiver card sends some of its data off crate at 40 MHz to two neighboring crates. In addition, each Receiver gets data from three Barrel Track Finder crates. The 24 crates are located in pairs in a row of 12 adjacent racks. Crate to crate communication is handled by special cables running between the Receiver cards. The maximum amount of information shared between two Receiver cards in different crates is carried on 204 twisted pair (102 in each direction) at 40 MHz. Special LVDS drivers/receivers may increase this to 140 MHz effective transmission rate per twisted pair.

Basis of Estimate:

The amount of cable is based on the number of interchanged signals and the crate layout in the racks in the electronics barracks. The cost for the cable is based on the cost for halogen free twist and flat differential-pair signal cable that carried signals at the same frequency for the Zeus trigger system. The task is easy. The items will be ordered from a catalog.

WBS Element: 3.1.1.10**WBS Element Title:** Trigger System Tests**WBS Definition:**

This WBS element represents engineering required during installation and debugging in order to successfully commission the Muon Trigger.

Basis of Estimate:

The engineering experiments. EDIA required is extrapolated from past experience on CDF, KTeV, and other A considerable fraction of the total effort will be physicist labor paid by the DOE base program. It is also assumed that prior to the system-wide tests, the prototype versions will have been thoroughly tested in the U.S. together with front-end Endcap Muon motherboards and other trigger boards. The task difficulty is average. The cost is based on a conceptual design.

WBS Element: 3.1.1.11**WBS Element Title:** Trigger Project Management**WBS Definition:**

This WBS element includes all the effort to provide project management of the Muon Trigger project.

Basis of Estimate:

The effort involved is based on the Project Management of the Zeus Calorimeter System and the SDC Trigger System. The required 5% of an FTE engineer is provided by the UCLA base program and therefore there is no cost to the US CMS project.

WBS Element: 3.1.1.11.1**WBS Element Title:** Tracking and Reporting**WBS Definition:**

This WBS element includes all the effort to provide tracking and reporting of the Muon Trigger project.

Basis of Estimate:

The effort involved is based on the tracking and reporting of the Zeus Calorimeter System and the SDC Trigger System. The required 5% of an FTE engineer is provided by the UCLA base program and therefore there is no cost to the US CMS project.