WBS 3.1 - Trigger

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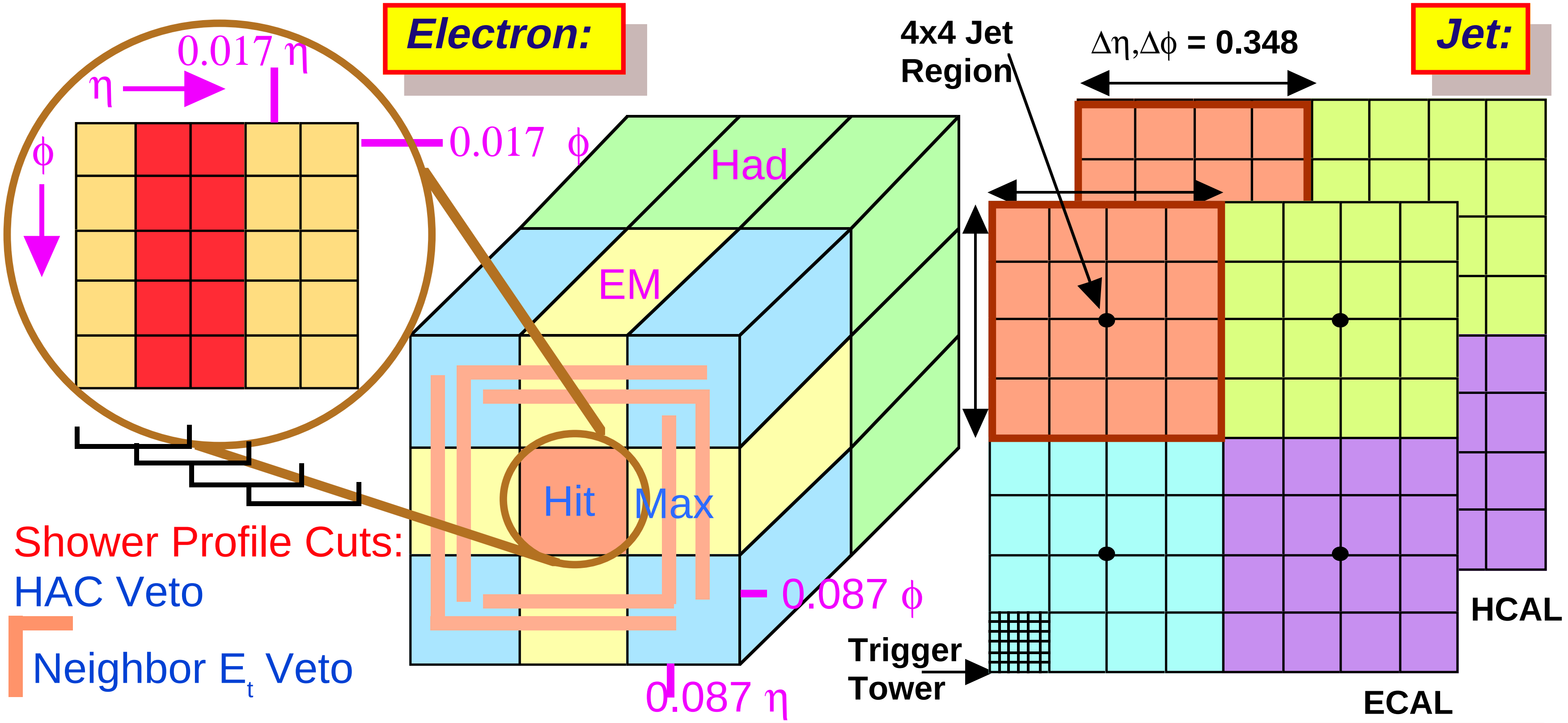
CMS Trigger Project Manager

DOE/NSF Review
May 19, 1998

Outline

- Overview of Calorimeter Trigger
- Overview of Muon Trigger
- Organization
- Cost Estimate
- Scope and Contingency Since Last Review
- WBS, Milestones, and Schedule
- Commitment and Resource Profiles
- Status & Progress
- Committee Concerns and Corrective Actions
- Summary and Conclusions

Calorimeter Triggers



3 x 3 sliding window centered on ECAL/HCAL trigger tower pairs

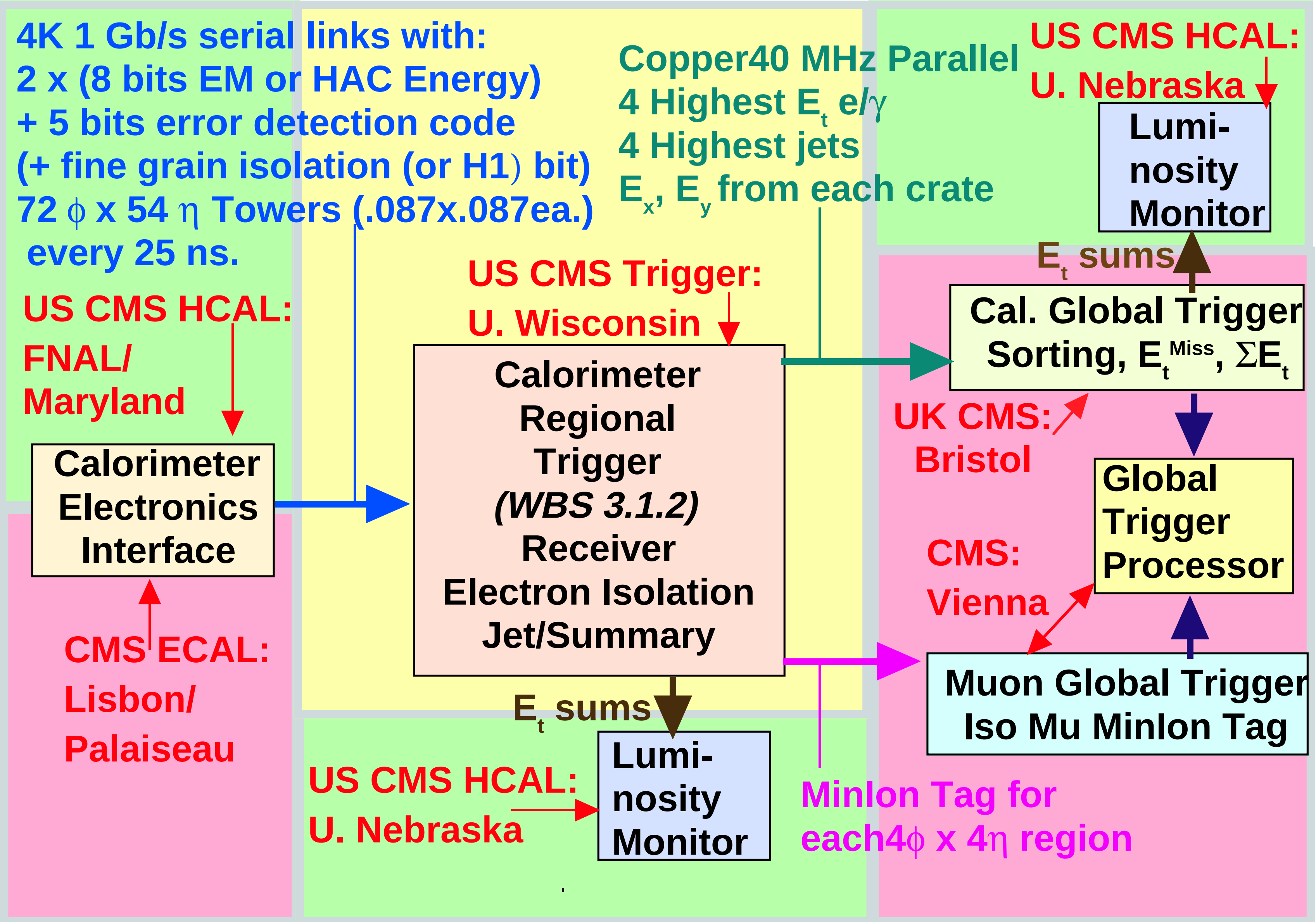
Tower count = 72ϕ x 54η x 2 = 7776

Jet E_t from sum of ECAL& HCAL trigger tower E_t in non-overlapping 4x4 regions (also used for E_x, E_y, E_t, E_t^{Miss})

Use multijet triggers

Jet candidates are sorted to find highest energy jets

Calorimeter Trigger Overview



4K 1 Gb/s serial links with:
2 x (8 bits EM or HAC Energy)
+ 5 bits error detection code
(+ fine grain isolation (or H1) bit)
72 ϕ x 54 η Towers (.087x.087ea.)
every 25 ns.

Copper40 MHz Parallel
4 Highest E_t e/γ
4 Highest jets
E_x, E_y from each crate

US CMS HCAL:
FNAL/
Maryland

Calorimeter Electronics Interface

CMS ECAL:
Lisbon/
Palaiseau

US CMS Trigger:
U. Wisconsin

Calorimeter Regional Trigger
(WBS 3.1.2)
Receiver
Electron Isolation
Jet/Summary

E_t sums

US CMS HCAL:
U. Nebraska

Lumi-nosity Monitor

US CMS HCAL:
U. Nebraska

Lumi-nosity Monitor

E_t sums

Cal. Global Trigger
Sorting, E_t^{Miss}, ΣE_t

UK CMS:
Bristol

Global Trigger Processor

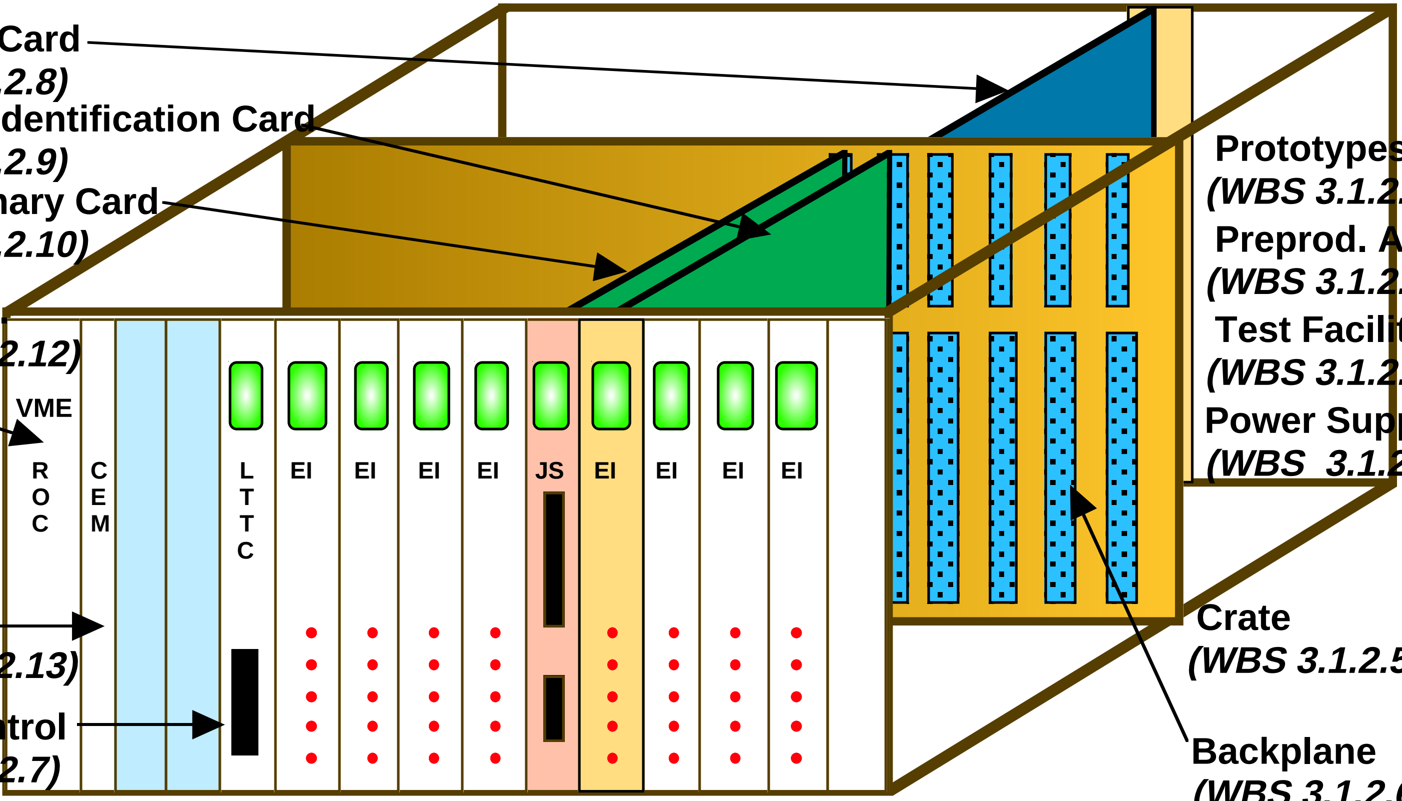
CMS:
Vienna

Muon Global Trigger
Iso Mu MinIon Tag

MinIon Tag for
each4ϕ x 4η region

Regional Calorimeter Crate

(WBS 3.1.2)



Receiver Card
(WBS 3.1.2.8)

Electron Identification Card
(WBS 3.1.2.9)

Jet Summary Card
(WBS 3.1.2.10)

DAQ Proc.
(WBS 3.1.2.12)

19 X

Monitor
(WBS 3.1.2.13)

Clock/Control
(WBS 3.1.2.7)

Prototypes
(WBS 3.1.2.1)

Preprod. ASICs
(WBS 3.1.2.2)

Test Facilities
(WBS 3.1.2.3)

Power Supplies
(WBS 3.1.2.4)

Crate
(WBS 3.1.2.5)

Backplane
(WBS 3.1.2.6)

Data from calorimeter FE on Cu links @ 1.2 Gbaud

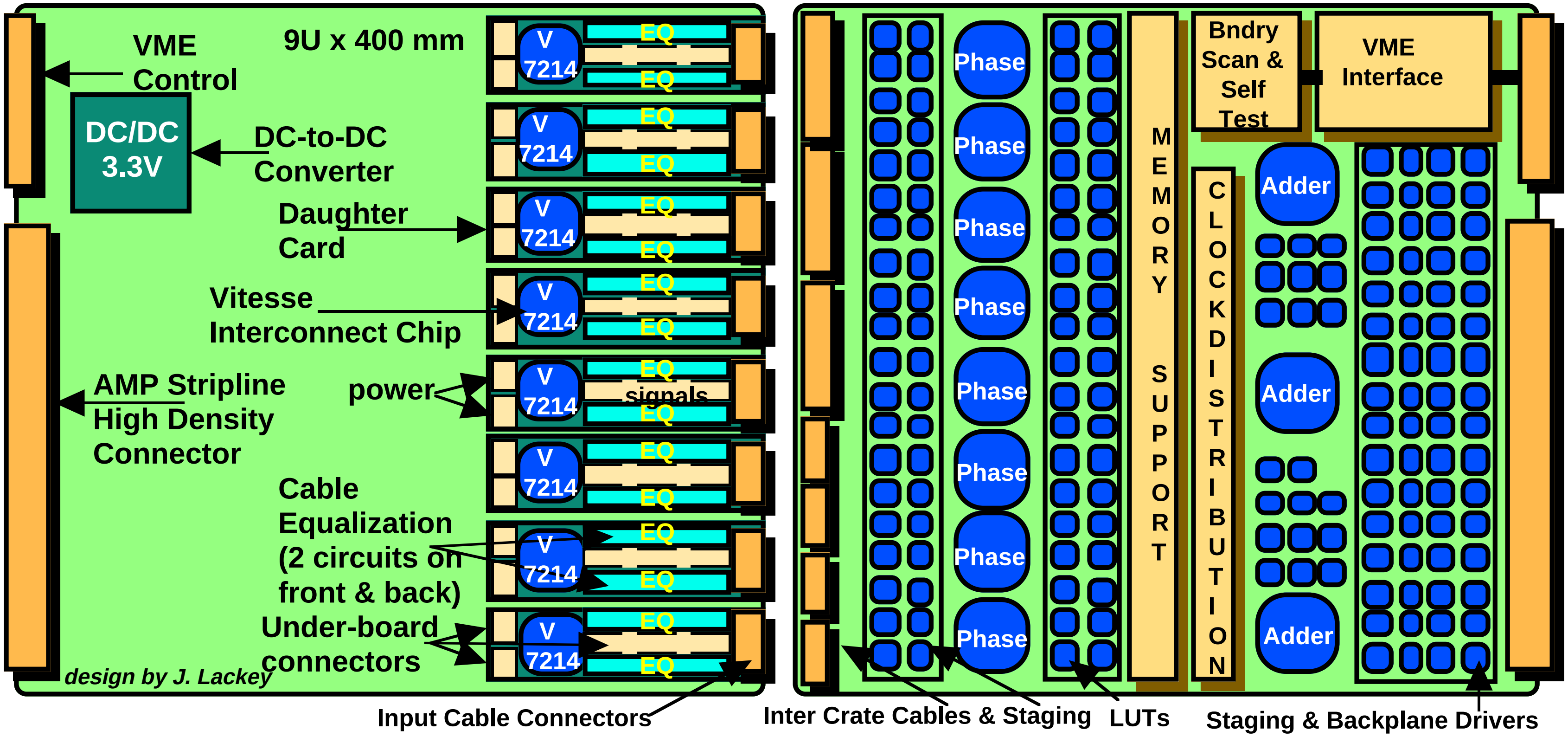
- Into 152 rear-mounted Receiver Cards **(proto. being built)**

160 MHz point to point backplane (proto. built)

- 19 Clock&Control **(proto. built)**, 152 Electron Identification, 19 Jet/Summary, Receiver Cards operate @ 160 MHz

3.1.2.8: Receiver Card

(prototype being built by U. Wisconsin)



Rear:

32 Channels =

4 Ch. x 8 daughter cards

1.2 GBaud copper rcvrs

18 bit (2x9) data + 5 bit error

Vitesse Chip:

Converts Serial to Parallel

Front: Data from Rear @ 120 MHz TTL

Phase ASIC: Deskew,Mux @ 160MHz

Error bit for each 4x4, Test Vectors

Memory LUT @ 160 MHz

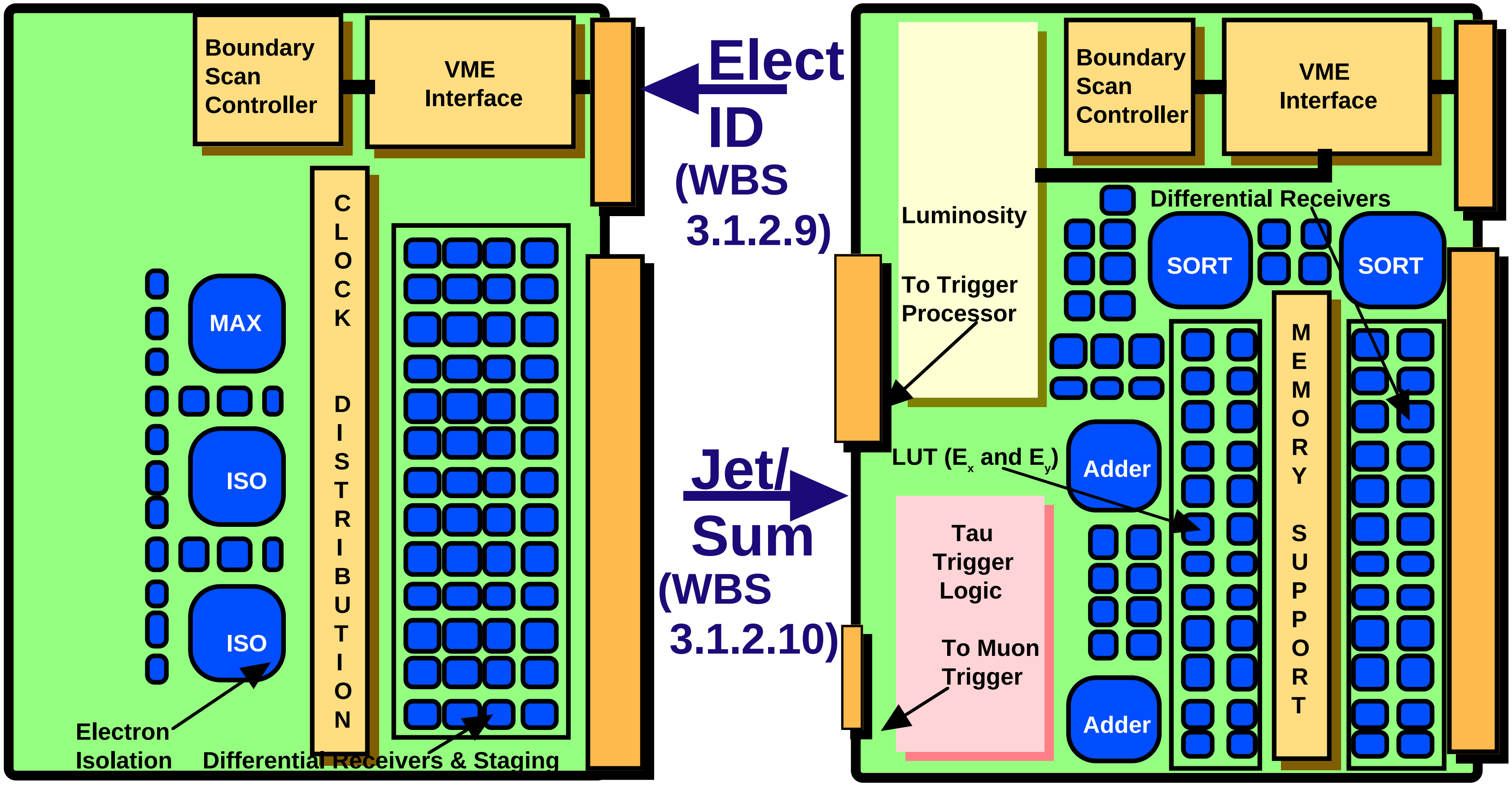
Adder ASIC:

8 inputs @ 160 MHz in 25 ns. (built!)

Differential Output@160 MHz

Electron ID & Jet/Summary Cards

(U. Wisconsin)



Processes 4x8 region @ 160 MHz
Electron isolation on ASIC
Lookup tables for ranking
Takes Max in each 4x4

Summarizes full crate:
Sorts 32 e's,4x4 E_t → top 4 e's, jets
LUTs: E_x & E_y from E_t for 4x4 area
Adder tree for E_t, E_x and E_y sums
Quiet/MinI bits for each 4x4 region

Physics at low luminosity

(Luminosity = 10^{33} cm^{-2} s^{-1})

Trigger Type	Trigger Et Cutoff (GeV)	Rate (kHz)			
		CMSIM		FASTSIM	
		Individual	Incremental	Individual	Incremental
Sum Et	150	1.0	1.0	1.2	1.2
Missing Et	40	2.7	1.7	3.1	2.0
Electron	12	11.4	9.1	5.4	4.4
DiElectron	7	1.2	1.9	0.4	1.0
Single jet	50	1.5	0.3	1.8	0.6
Dijet	30	1.3	0.3	1.7	0.4
Trijet	20	0.8	0.1	1.1	0.1
Quad jet	15	0.6	0.04	0.8	0.1
Jet+Elctrn	15 & 9	11.2	3.4	5.6	2.0
Cumulative Rate		17.8		11.8	

QCD Background

CMSIM and FASTSIM rates are compared for the low luminosity E_t cutoffs.

Electron trigger rate is twice as high in CMSIM results

Process	Efficiency (%)		
	CMS-TN-95/183	FASTSIM	CMSIM
p p → t t → e X	99	97	97
p p → t t → H+ X → t X	99	94	94
p p → b b (hadronize), B → e X	0.2 (But 400Hz)	-	-
SUSY CMS TP Scenario A (M_{LSP} = 45, M_{spart} ~ 300 GeV)	98	-	-
SUSY Neutral Higgs (Range of tan b and M_H values)	45 - 98	30 - 96	39 - 96

Signal efficiency

High efficiency is realized for the benchmark processes involving top decays and SUSY sparticles.

Notes:

A dedicated tau trigger is under study to improve efficiency for the low mass range of SUSY Higgs.

There is also high rate of B signal in level-1 sample.

Physics at high luminosity

Luminosity = 10^{34} cm^{-2} s^{-1}

Trigger Type	Trigger Et Cutoff (GeV)	Rate (kHz)			
		CMSIM		FASTSIM	
		Individual	Incremental	Individual	Incremental
Sum Et	400	0.3	0.3	0.4	0.4
Missing Et	80	1.2	0.9	1.7	1.3
Electron	25	11.4	9.3	4.5	3.9
DiElectron	12	2.1	1.8	1.0	1.0
Single jet	100	1.5	1.0	2.0	1.3
Dijet	60	1.2	0.7	1.9	1.1
Trijet	30	2.3	1.3	3.1	1.8
Quadjet	20	2.6	1.1	3.3	1.4
Jet+Elctrn	50 & 12	1.3	0.3	0.7	0.2
Cumulative Rate		16.7		12.4	

QCD Background

The sum & missing E_t cutoffs chosen to yield 2 kHz rate.

Electron/photon triggers are emphasized, ~8 kHz rate out of total available 15 kHz.

Remaining 5 kHz available for jet triggers.

Process	Efficiency (%)		
	CMS-TN-95/183	FASTSIM	CMSIM
H (80 GeV) $\rightarrow \gamma \gamma$	97	92	94
H (120 GeV) $\rightarrow Z Z \rightarrow e e \mu \mu$	76*	76*	74*
H (200 GeV) $\rightarrow Z Z \rightarrow e e j j$	99	96	95
$p p \rightarrow t t \rightarrow e X$	88	82	82
$p p \rightarrow t t \rightarrow H_+ X \rightarrow t X$	82	76	76
SUSY CMS TP Scenario A (M_{LSP} = 45, M_{spart} ~ 300 GeV)	83#	-	-

Signal Efficiency

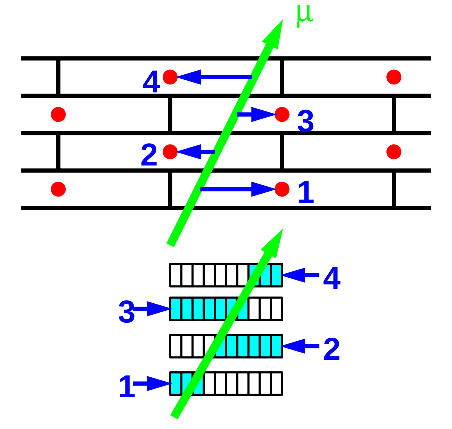
High efficiency for all channels with electrons and photons.

The difficult-to-trigger top decay events have high efficiency, enabling studies of associated Higgs production.

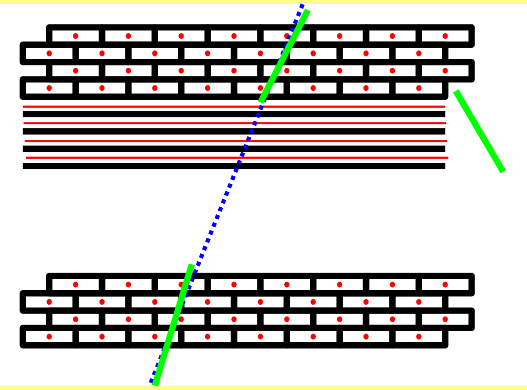
*Inclusion of muon trigger gives full efficiency

Muon Chamber Trigger

Drift Tubes

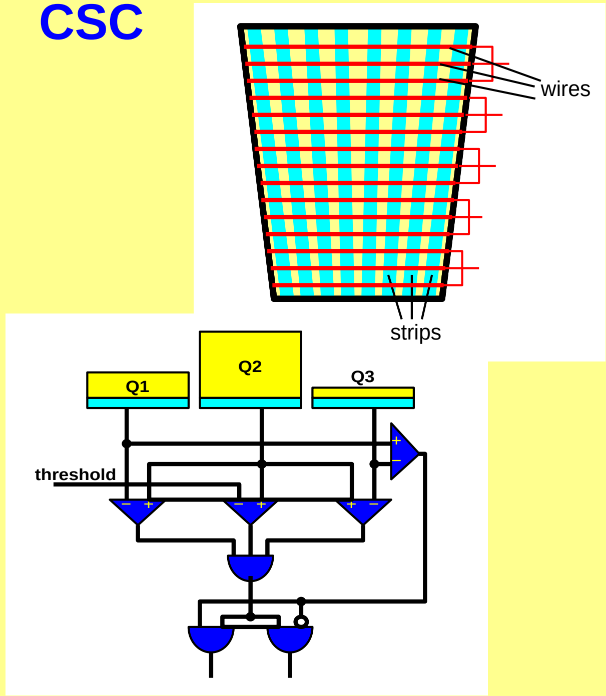


Meantimers recognize tracks and form vector / quartet.

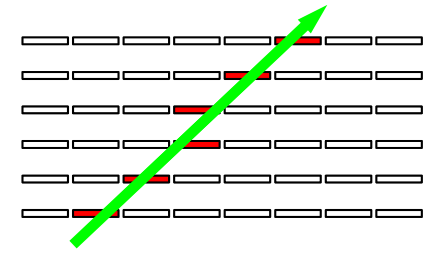


Correlator combines them into one vector / station.

CSC

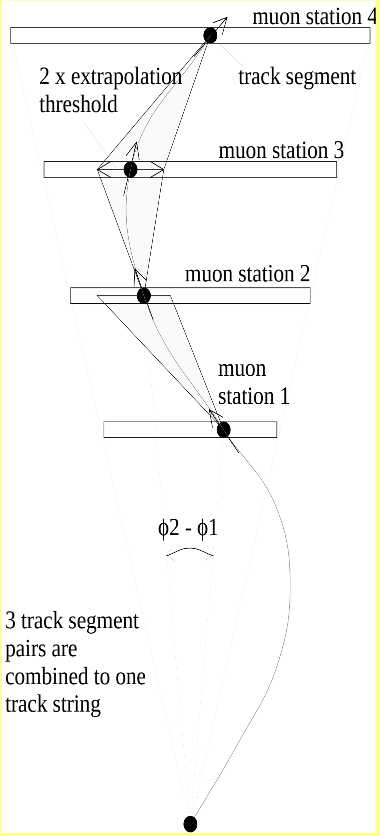


Comparators give 1/2−strip resol.



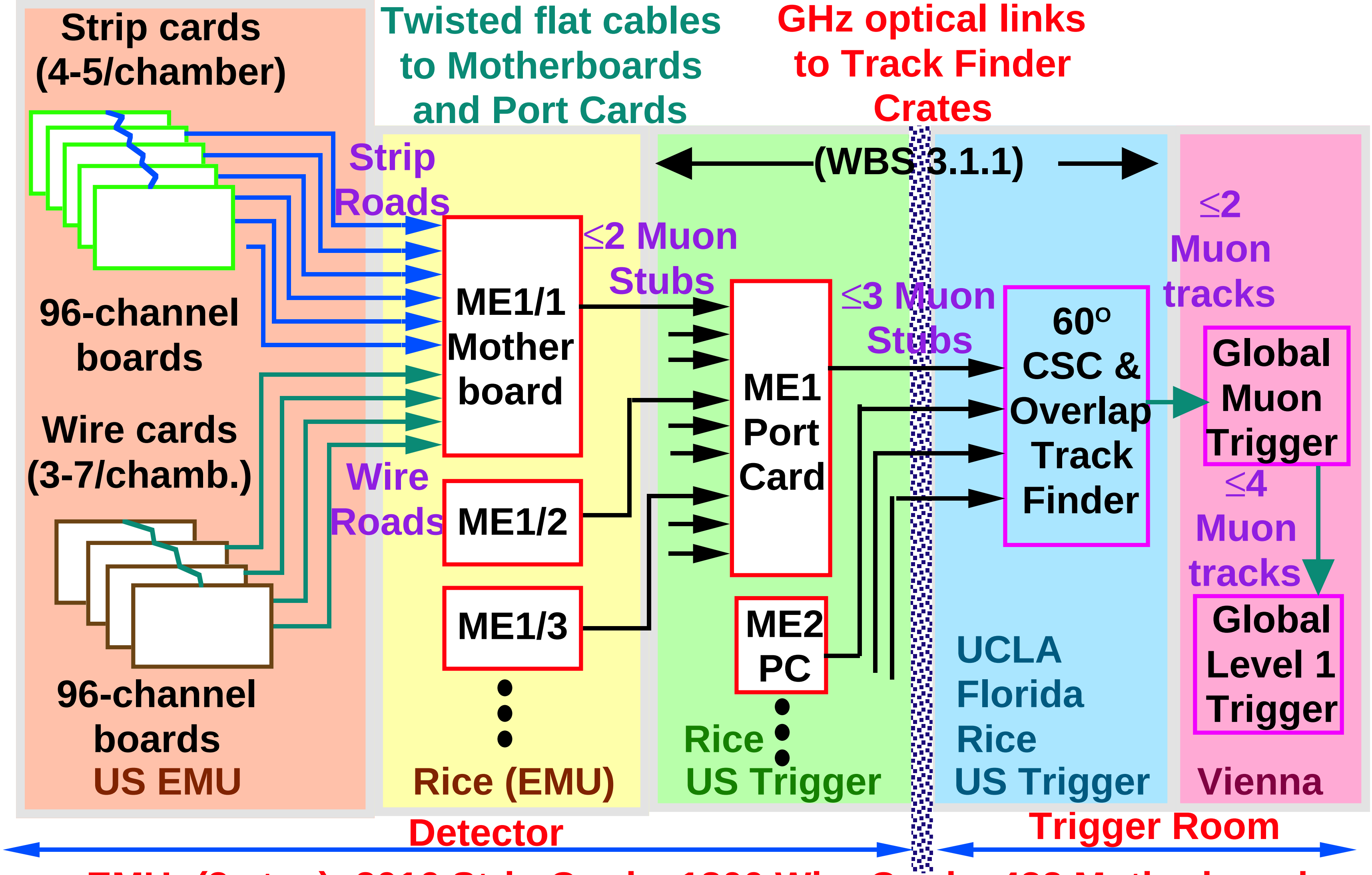
Hit strips of 6 layers form a vector.

Track Finder



- **combines vectors,**
- **forms a track,**
- **assigns p_t value.**

CSC Trigger Layout



Strip cards (4-5/chamber)

Twisted flat cables to Motherboards and Port Cards

GHz optical links to Track Finder Crates

(WBS 3.1.1)

Strip Roads

≤2 Muon Stubs

≤3 Muon Stubs

≤2 Muon tracks

96-channel boards

ME1/1 Mother board

ME1 Port Card

60° CSC & Overlap Track Finder

Global Muon Trigger

≤4 Muon tracks

Wire cards (3-7/chamb.)

Wire Roads

ME1/2

ME1/3

ME2 PC

Global Level 1 Trigger

96-channel boards

US EMU

Rice (EMU)

Rice
US Trigger

UCLA
Florida
Rice
US Trigger

Vienna

Detector

Trigger Room

EMU: (3 stns): 2016 Strip Cards, 1800 Wire Cards, 432 Motherboards

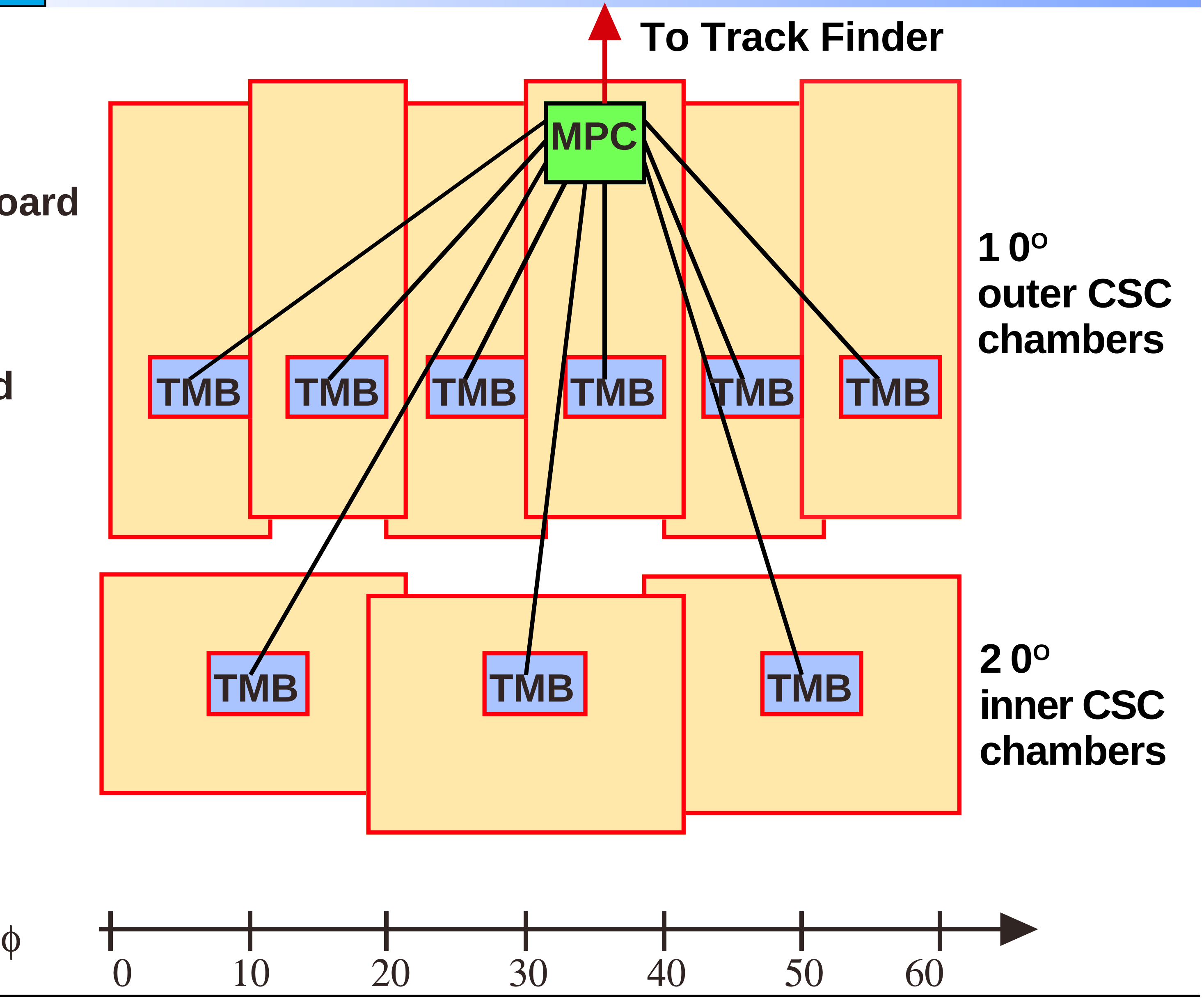
TRIGGER: 48 Port Cards, 336 Data Links, 8 Track Finder Crates

CSC Trigger Port Cards

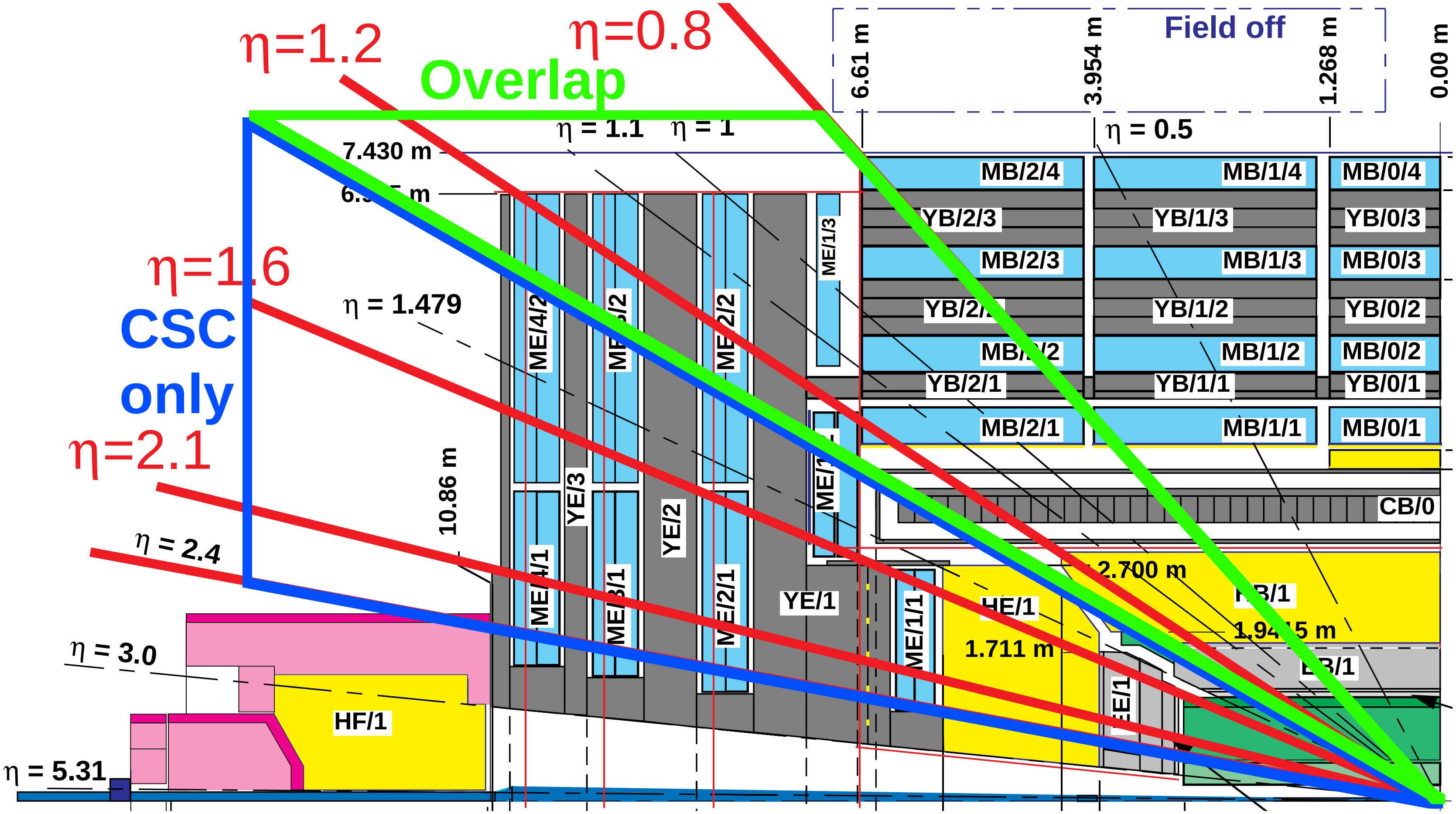
(WBS 3.1.1.1)

TMB =
Trigger
MotherBoard

MPC =
Muon
Port Card



CSC Muon Trigger Geometry



CSC Track-finding:

- **Two Types of Crates:**
  - 4 Overlap Crates
  - 4 CSC-only Crates

Two Sector Processors

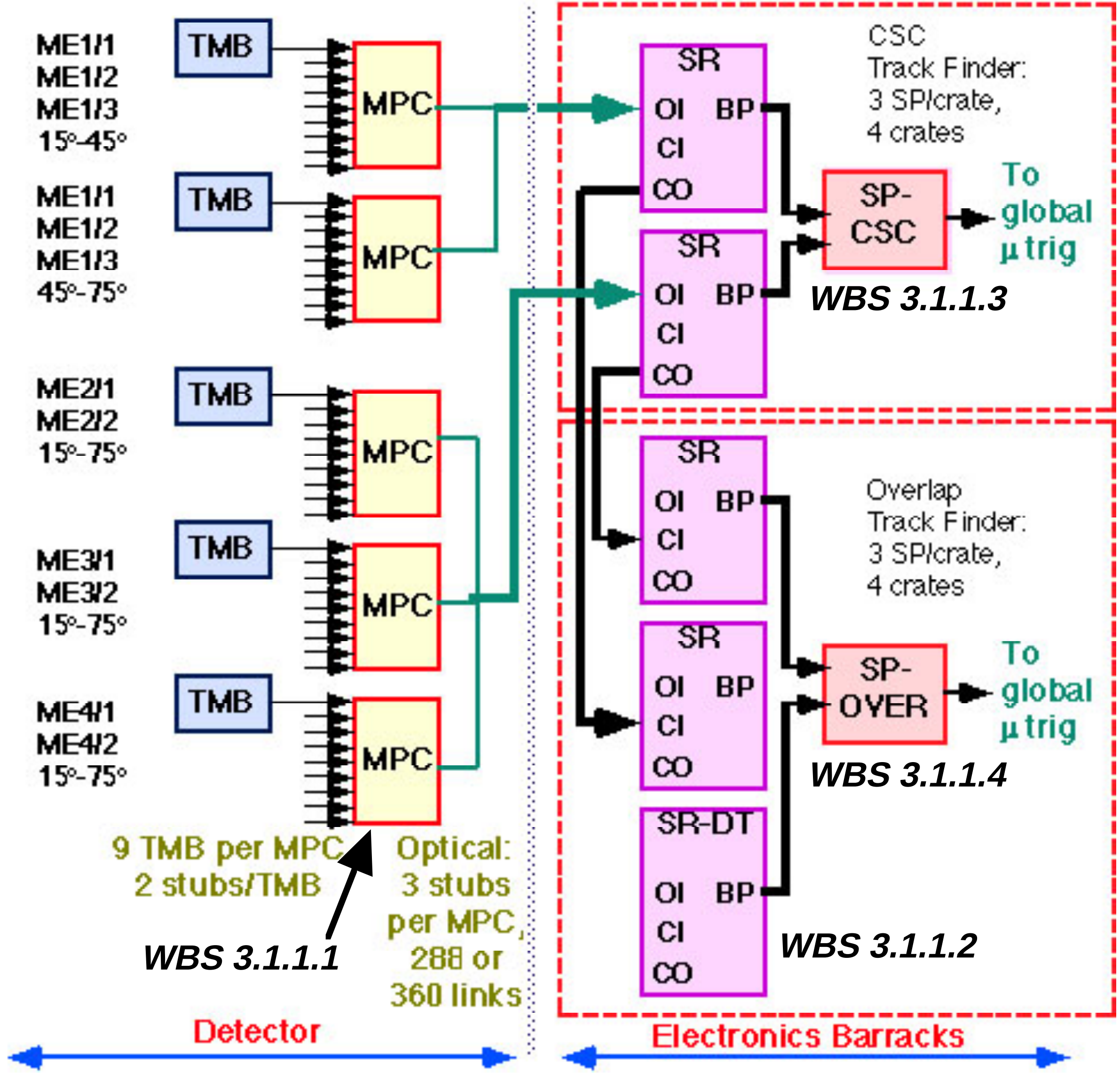
SP-Overlap: **CSC's & Barrel DT's**

SP-CSC: **CSC's only**

One Receiver Card: DT & CSC

CSC & Overlap TF Block Diagram

Diagram of the first 60° Sector (15-75 degrees)



Glossary and Part Count

(counts for 3 vs. 4 stns)

TMB:Trigger Motherbds (432 or 540)

MPC:Muon Port Cards (48 or 60)

SR:Sector Receivers (24)

SR-DT:Drift Tube SR's (12 or 24)

SP: Sector Processor (24 = 2x12)

SP-CSC:CSC SP (12)

SP-Over:Overlap SP (12)

OI: Optical in

CI: Copper in

CO:copper out

BP:backplane

(WBS 3.1.1.7)

Monitor:*3.1.1.6*

Crate Control: *3.1.1.8*

Crates: *3.1.1.9*

Power Supplies: *3.1.1.10*

Cables: *3.1.1.11*

Muon & Cal Trigger Rates

Low & High Luminosity:

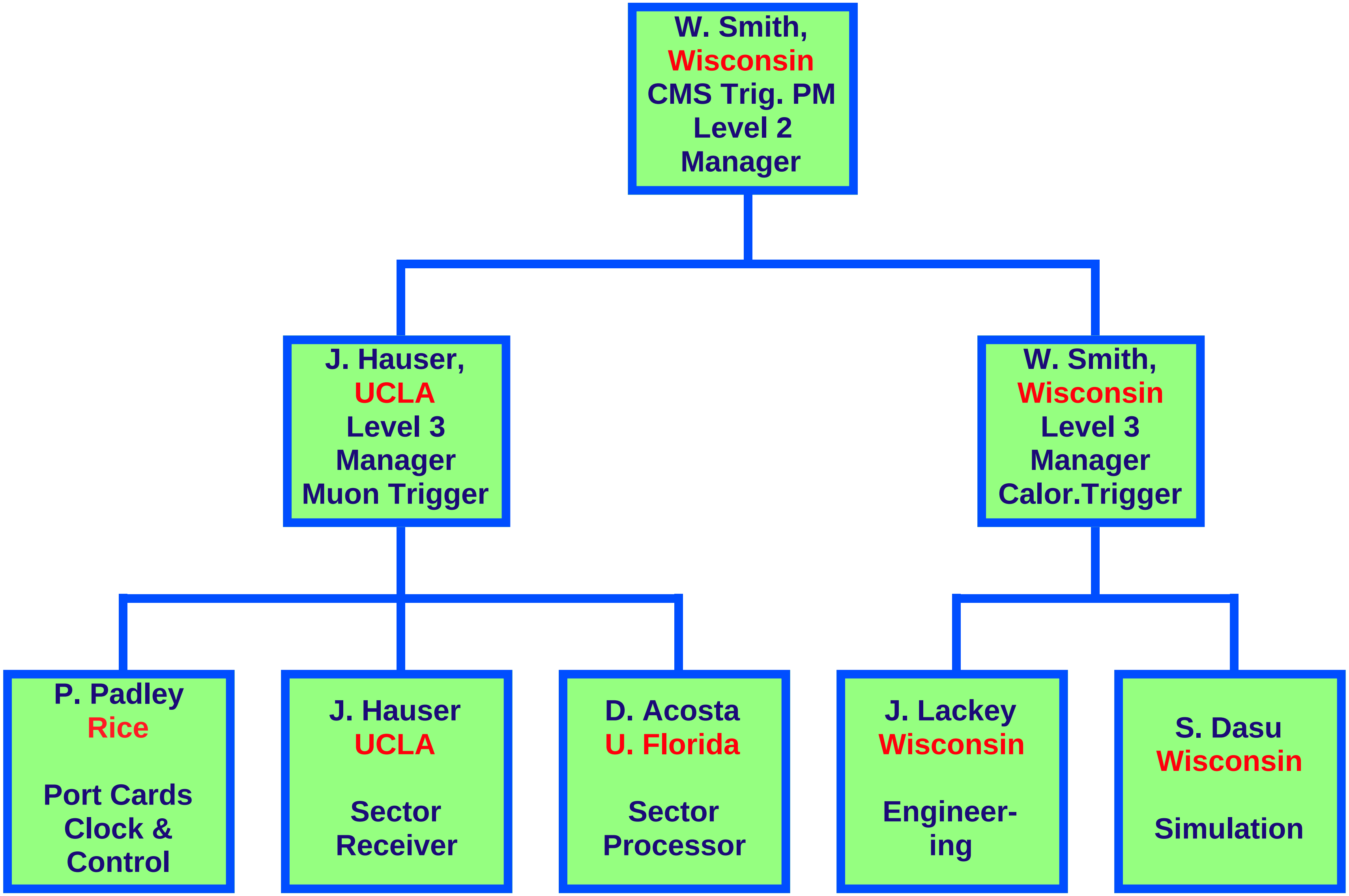
	$L = 10^{33}cm^{-2}s^{-1}$			$L = 10^{34}cm^{-2}s^{-1}$		
trigger type	**threshold [GeV]**	**rate [kHz]**	**cumulative rate [kHz]**	**threshold [GeV]**	**rate [kHz]**	**cumulative rate [kHz]**
μ	**7**	**9.8**	**9.5**	**20**	**7.8**	**7.8**
$\mu\ \mu$	**2-4**	**0.5**	**10.1**	**4**	**1.6**	**9.2**
μ e/γ	**2-4, 6**	**2.5**	**12.2**	**4, 8**	**5.5**	**14.4**
$\mu\ e_b$	**2-4, 5**	**3.5**	**13.4**	—	—	—
μ j	**2-4, 12**	**2.2**	**14.5**	**4, 40**	**0.3**	**14.4**
$\mu\ E_t^{miss}$	**2-4, 40**	**0.8**	**14.7**	**4, 60**	**1.0**	**15.3**
$\mu\ \Sigma E_t$	**2-4, 150**	**0.8**	**14.7**	**4, 250**	**0.2**	**15.3**

threshold = 2-4 GeV means: 4 GeV in the barrel, 2 GeV in the endcaps

muon threshold = transverse momentum threshold
calorimeter threshold = transverse energy threshold

e/γ — electron/photon trigger, e_b — trigger on electron from b-quark decay

U. S. Trigger Organization



W. Smith,
Wisconsin
CMS Trig. PM
Level 2
Manager

J. Hauser,
UCLA
Level 3
Manager
Muon Trigger

W. Smith,
Wisconsin
Level 3
Manager
Calor.Trigger

P. Padley
Rice

Port Cards
Clock &
Control

J. Hauser
UCLA

Sector
Receiver

D. Acosta
U. Florida

Sector
Processor

J. Lackey
Wisconsin

Engineering

S. Dasu
Wisconsin

Simulation

Trigger Project Management

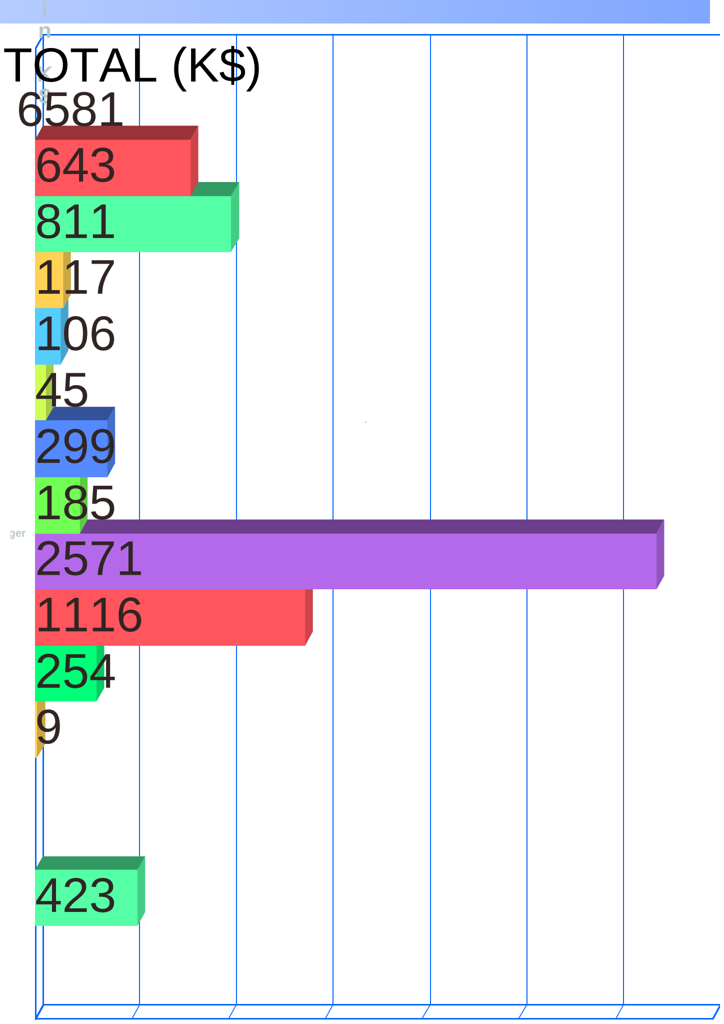
CMS Annual Reviews

- **April: TriDAS Status**
  - Progress, draft R&D plans & expenses for next year
- **November: TriDAS Internal Review**
  - R&D Plans/Progress, Cost & Schedule, Milestones
  - Finalize R&D plans & expenses for next year
  - Internal CMS Review w/CMS referees
- **Internal Electronics Reviews by LHC Electronics Board CMS Reps.**
  - G. Hall (Imperial), G. Stefanini (CERN), W. Smith (Wisc.)
  - Reports to CMS Management Board (next trigger review in Fall '98)

US Reviews/Reporting

- **Monthly Video Conferences:**
  - Florida, Rice, UCLA, Wisconsin, Davis (sim)
    - Review Progress, milestones, simulation activities
- **Integration Meetings:**
  - Calorimeter Trigger: FNAL, Maryland, Wisconsin
  - Muon Trigger: Ohio, Florida, Rice, UCLA, Wisconsin, others.
- **Annual Site Visits:** Florida, Rice, UCLA

Calorimeter Trig. Costs at L4



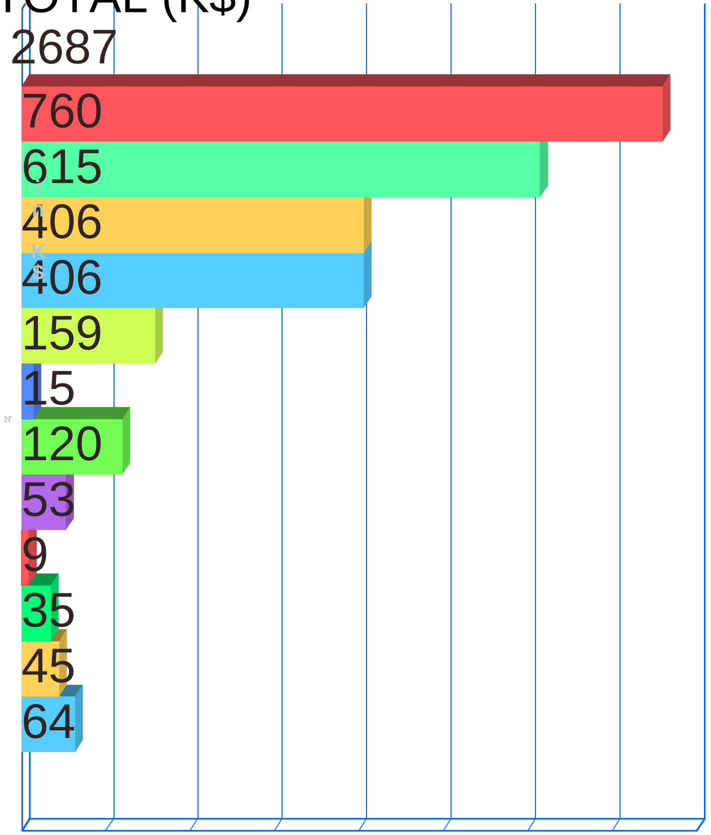
WBS	ITEM	BASE(K$)	Cont(%)	TOTAL (K$)
3.1.2	Cal.Regional Trigger	4,388	50	6581
3.1.2.1	Prototypes	441	46	643
3.1.2.2	Preproduction ASICs	553	47	811
3.1.2.3	Test Facilities	78	50	117
3.1.2.4	Power Supplies	82	30	106
3.1.2.5	Crates	35	30	45
3.1.2.6	Backplane	194	54	299
3.1.2.7	Clock & Control Card	132	40	185
3.1.2.8	Receiver Card	1,670	54	2571
3.1.2.9	Electron ID Card	744	50	1116
3.1.2.10	Jet Summary Card	170	50	254
3.1.2.11	Cables	7	30	9
3.1.2.12	DAQ Processor			
3.1.2.13	Crate Monitor Card			
3.1.2.14	Trigger Tests	282	50	423
3.1.2.15	Project Management			

Changes since last May 1997 Review:

- Contingency analysis performed at lowest level (increased from 39->50%)
- Bottoms-up recosting & new WBS (no substantial *net* cost change)
- Cost profile pushed back 6 months on average

Muon Trigger Costs at L4

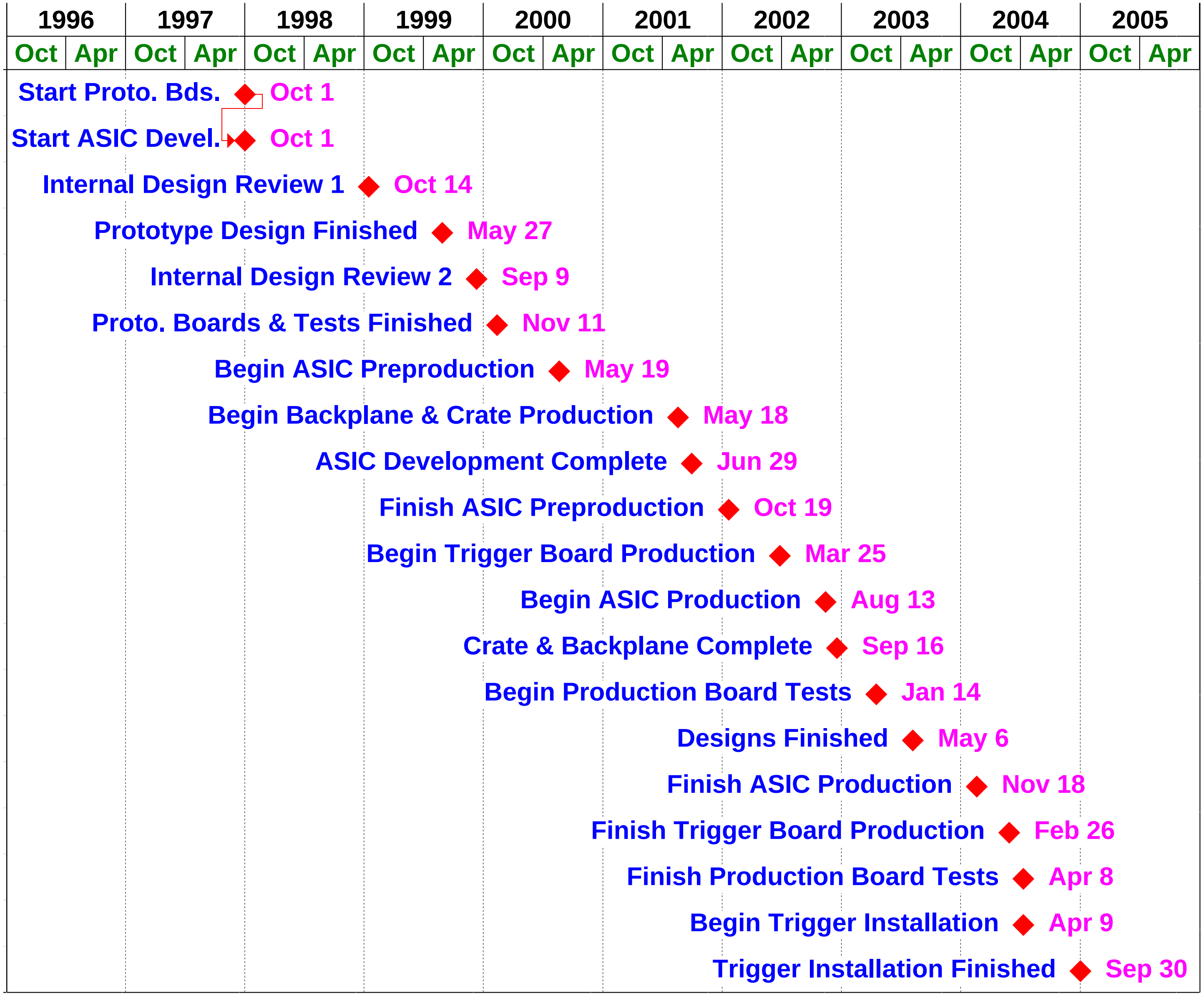
WBS	ITEM	BASE(K$)	Cont(%)	TOTAL (K$)
3.1.1	CSC Muon Trigger	1,749	54	2687
3.1.1.1	Muon Port Cards (MPC)	507	50	760
3.1.1.2	Sector Receivers (SR)	410	50	615
3.1.1.3	CSC Sct. Pr.(SP-CSC)	246	65	406
3.1.1.4	Over. Sct. Pr.(SP-OVR)	246	65	406
3.1.1.5	Clock&Ctrl Cds (CCC)	114	40	159
3.1.1.6	Crate Monitor Cards	10	50	15
3.1.1.7	Muon Backplanes	80	50	120
3.1.1.8	Crate Controllers	35	50	53
3.1.1.9	Muon Crates	6	50	9
3.1.1.10	Muon Power Supplies	23	50	35
3.1.1.11	Additional Cables	30	50	45
3.1.1.12	Trigger System Tests	43	50	64
3.1.1.13	Trigger Proj. Manage.	0		



Changes since last May 1997 Review:

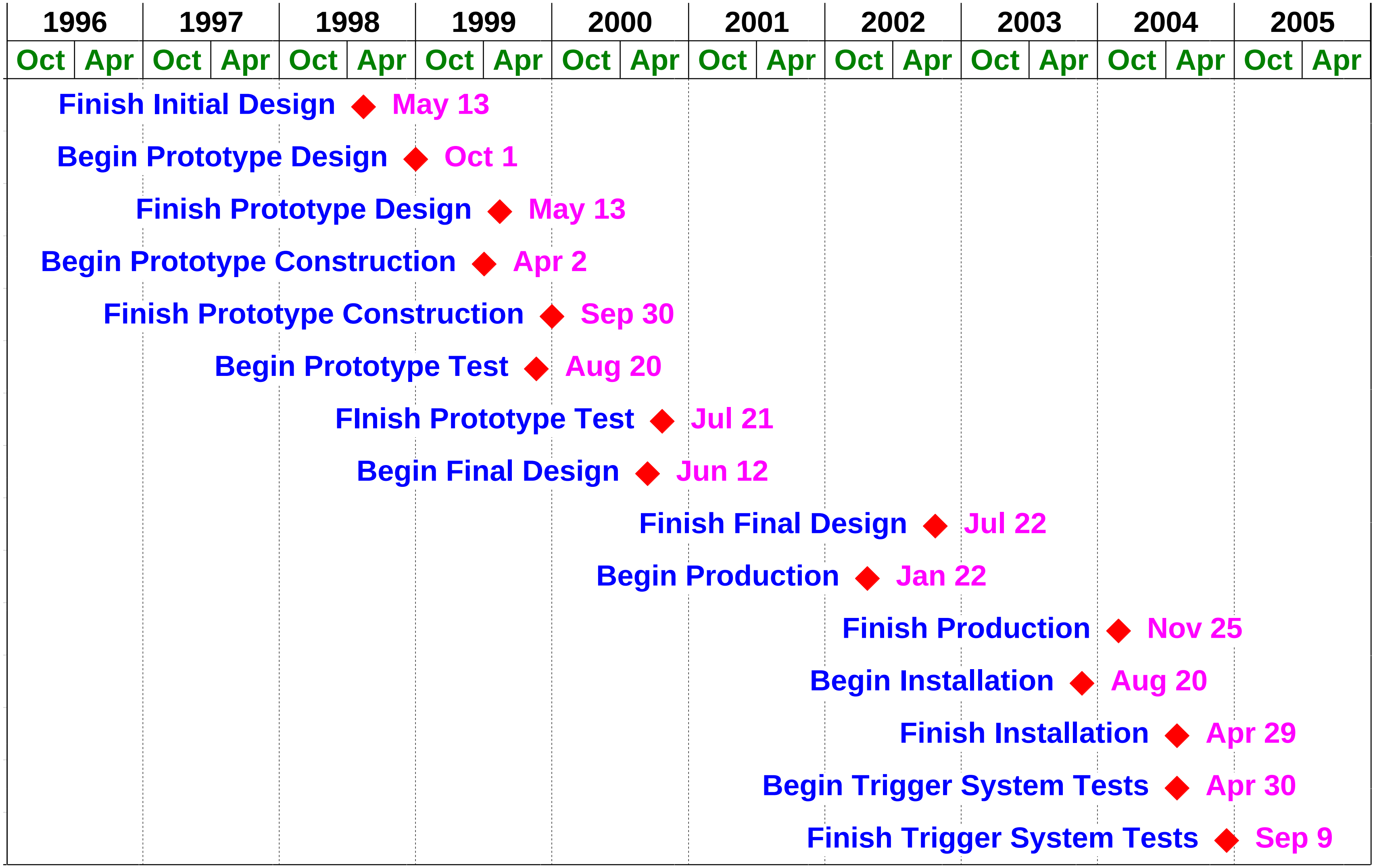
- Contingency analysis performed at lowest level (increased from 39→54%)
- New Architecture & removal of 4th station reduces cost (see next transp.)
- Bottoms-up recosting & new WBS (small cost reduction)
- Cost profile pushed back 6 months on average

Cal. Trig. Schedule & Milestones



Start Proto. Bds.	Oct 1
Start ASIC Devel.	Oct 1
Internal Design Review 1	Oct 14
Prototype Design Finished	May 27
Internal Design Review 2	Sep 9
Proto. Boards & Tests Finished	Nov 11
Begin ASIC Preproduction	May 19
Begin Backplane & Crate Production	May 18
ASIC Development Complete	Jun 29
Finish ASIC Preproduction	Oct 19
Begin Trigger Board Production	Mar 25
Begin ASIC Production	Aug 13
Crate & Backplane Complete	Sep 16
Begin Production Board Tests	Jan 14
Designs Finished	May 6
Finish ASIC Production	Nov 18
Finish Trigger Board Production	Feb 26
Finish Production Board Tests	Apr 8
Begin Trigger Installation	Apr 9
Trigger Installation Finished	Sep 30

Muon Trig. Schedule & Milestones



Finish Initial Design ◆ May 13

Begin Prototype Design ◆ Oct 1

Finish Prototype Design ◆ May 13

Begin Prototype Construction ◆ Apr 2

Finish Prototype Construction ◆ Sep 30

Begin Prototype Test ◆ Aug 20

FInish Prototype Test ◆ Jul 21

Begin Final Design ◆ Jun 12

Finish Final Design ◆ Jul 22

Begin Production ◆ Jan 22

Finish Production ◆ Nov 25

Begin Installation ◆ Aug 20

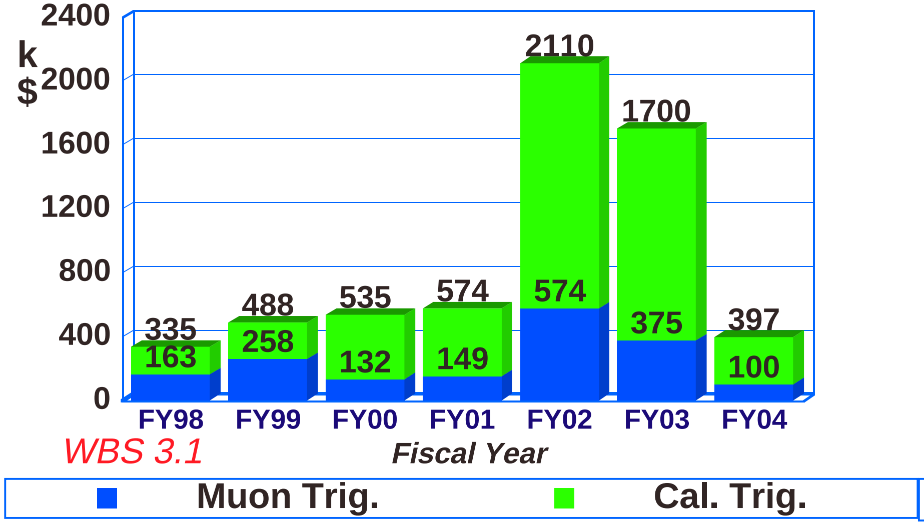
Finish Installation ◆ Apr 29

Begin Trigger System Tests ◆ Apr 30

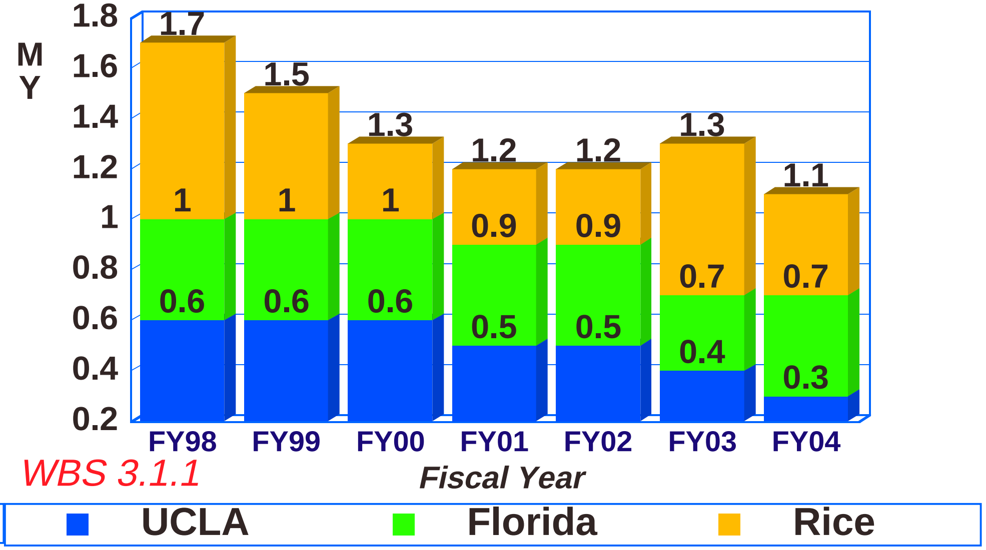
Finish Trigger System Tests ◆ Sep 9

Obligations & Resources

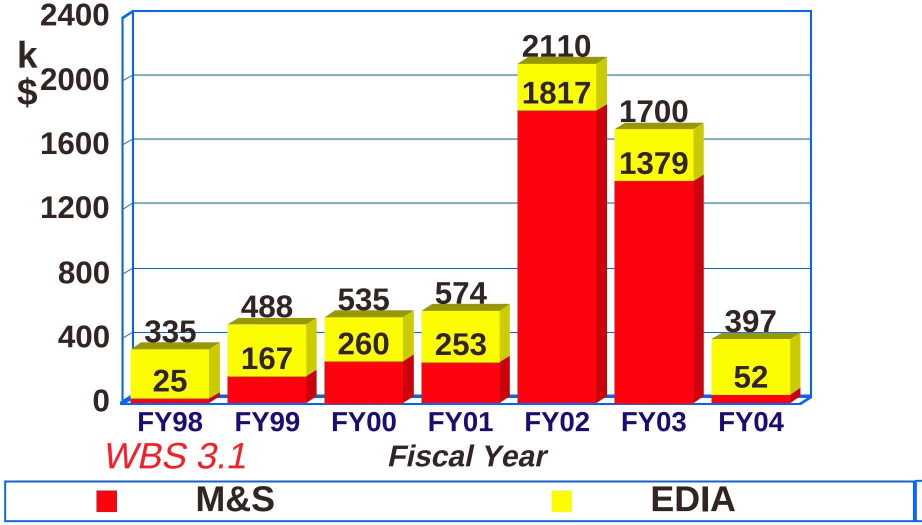
Obligations for Muon & Cal Triggers



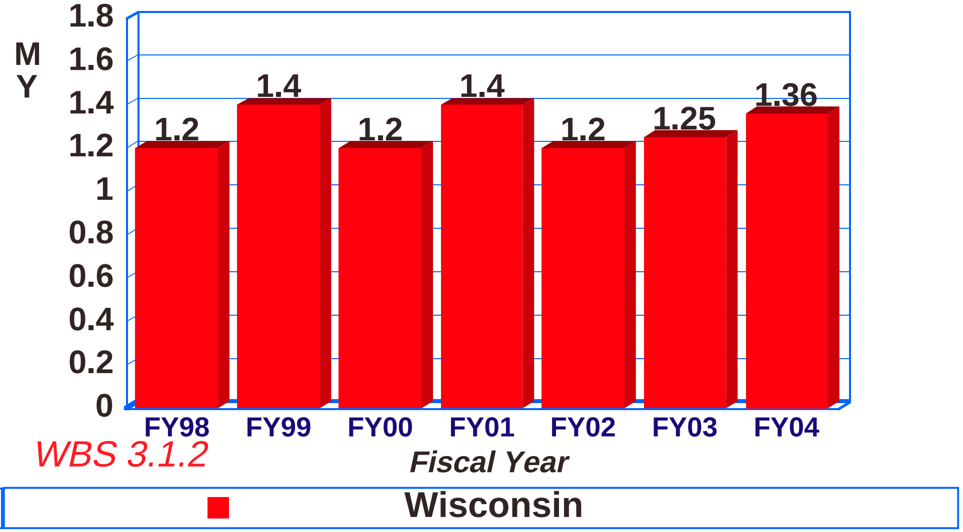
Muon Trigger Peak Engineering



Trigger M&S and EDIA Obligations



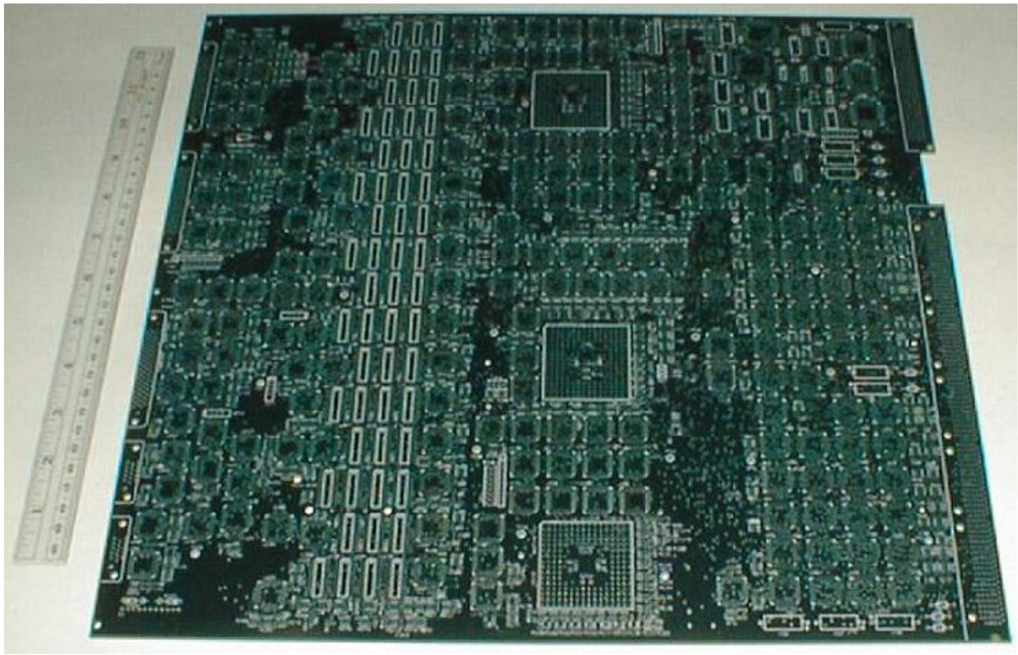
Calorimeter Trigger Peak Engineering



Calorimeter Trigger Status

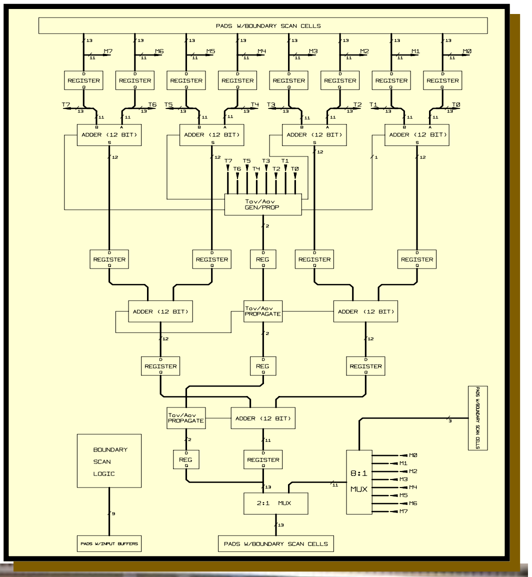
Receiver Card

- Designed for 160 MHz
- Board Constructed



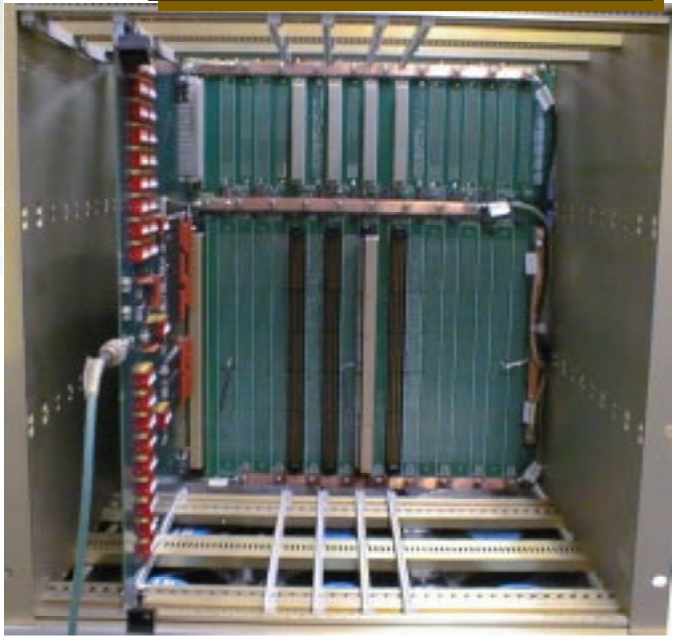
13 x 8 bit Adder ASIC

- tested > 160 MHz



Backplane for VME & trigger data

- Prototype constructed
- Prototype Clock & Control Card built
- Signal performance excellent @ 160 MHz
- Confirmation of design feasibility

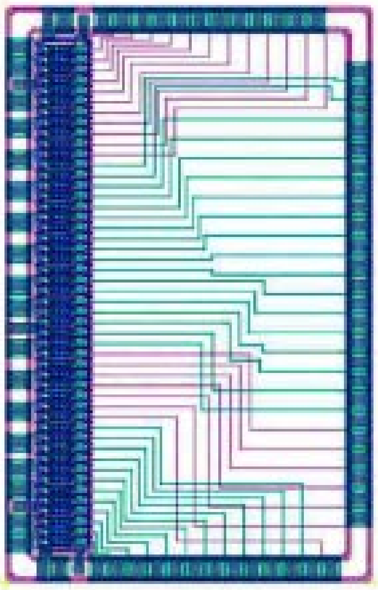


Muon Trigger Status

Operation in Summer '98 test beam

16-ch Comparator ASICs ready

- Excellent performance (1mV offsets)
- Comparator board built, being tested



First Cathode LCT card built

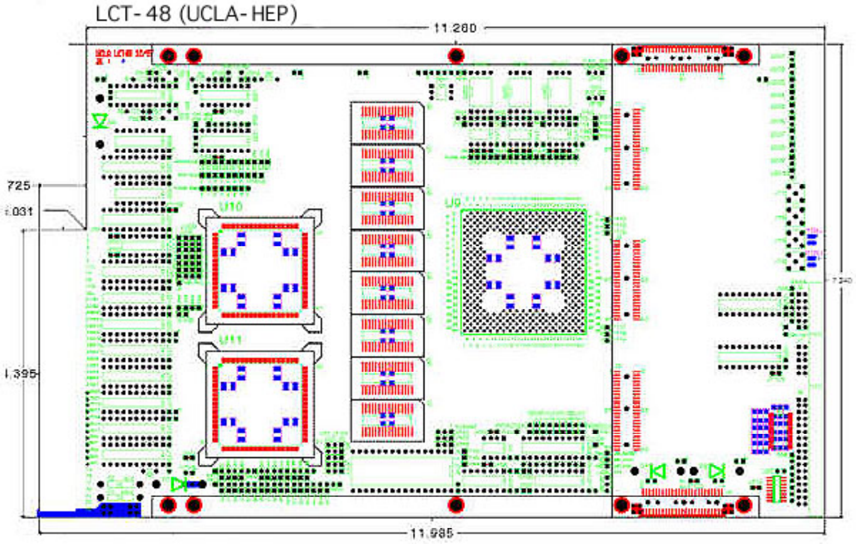
- being debugged

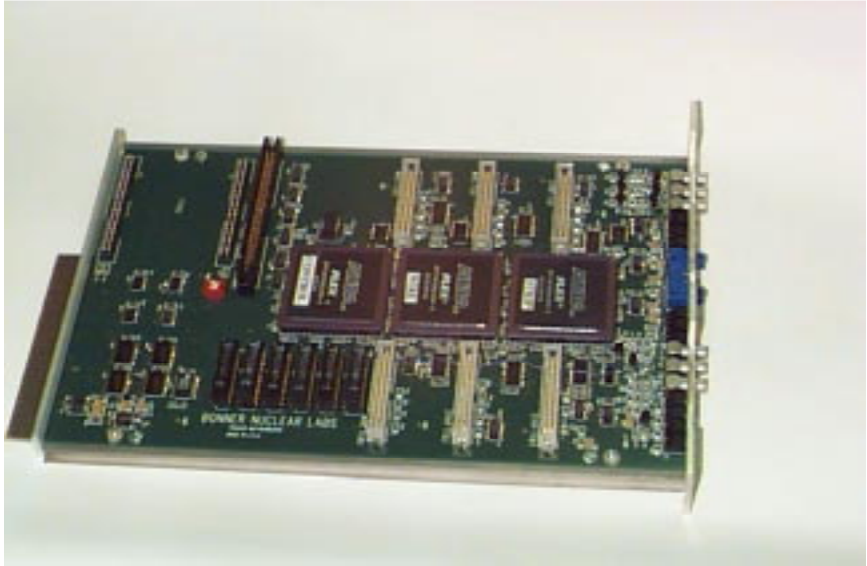
First Anode LCT card built

- being assembled
- software ready

First Trigger Motherboard built

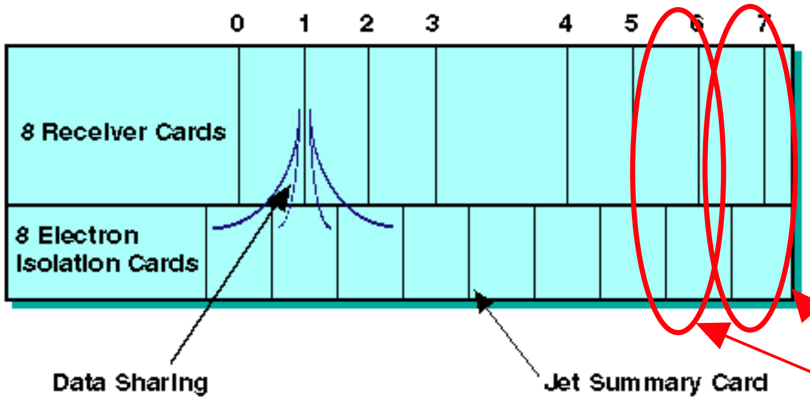
- Ready for test w/LCT card



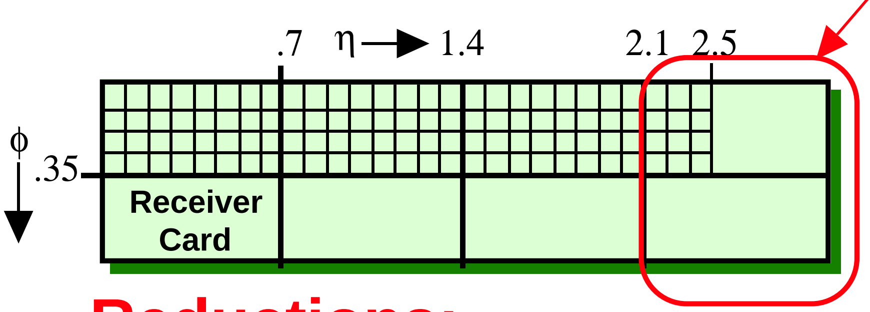


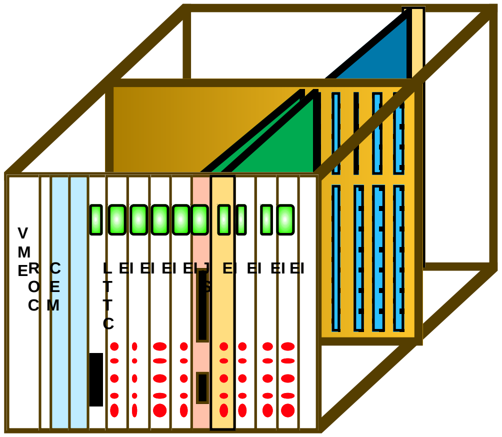
Option: Rescope Cal. Trig.

Crate (Top View)



Trigger Tower Mapping in Crate





Remove 2 outer Receiver & 2 Electron ID Cards that cover η > 2.1

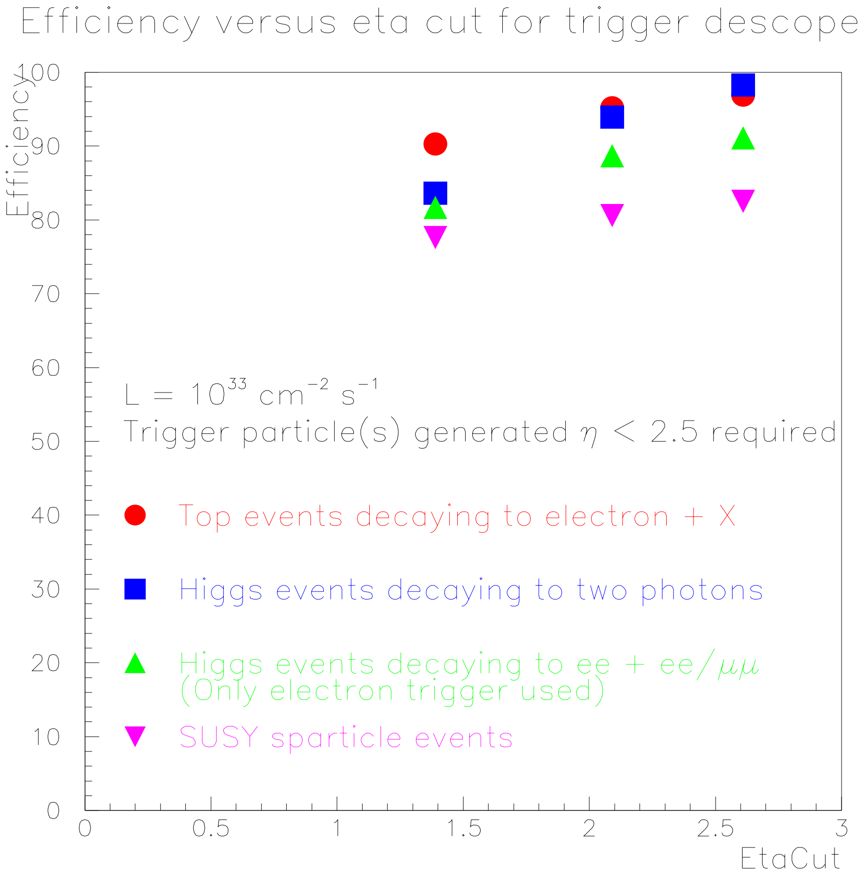
Remove 19th crate that covers very forward cal.

Reductions:

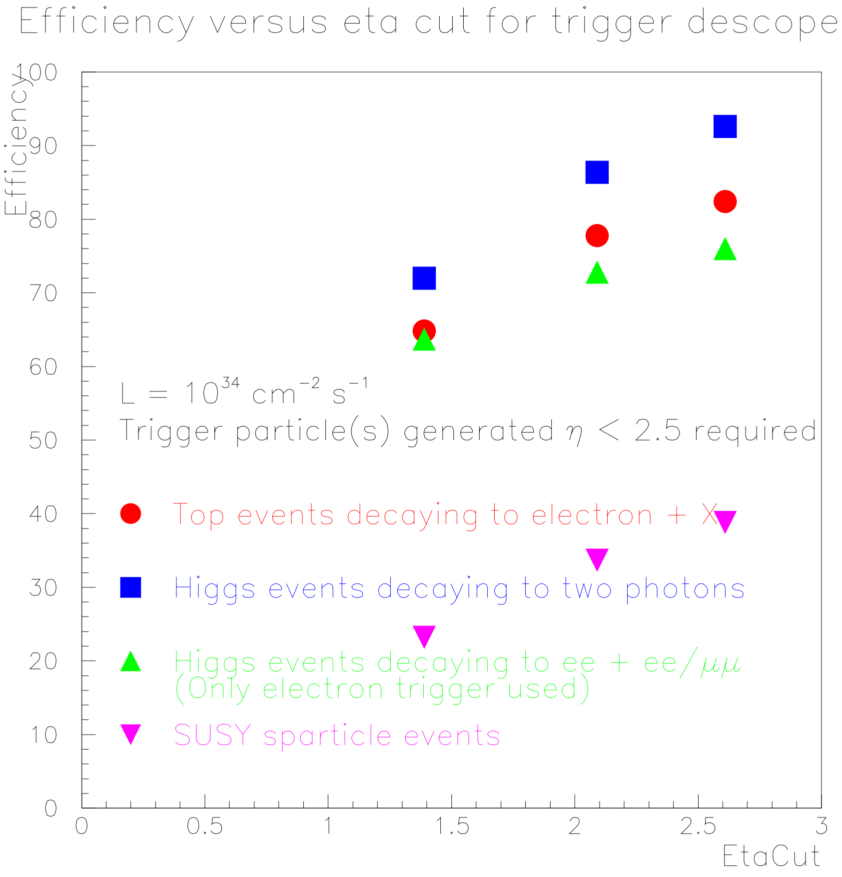
- **Receiver & Electron ID Cards:** 176 to 132
- **Jet Summary Cards & Crates:** 22 to 21
- **Base Cost reduced by 590K**

Impact of Cal. Trig. Rescope

Low Luminosity:

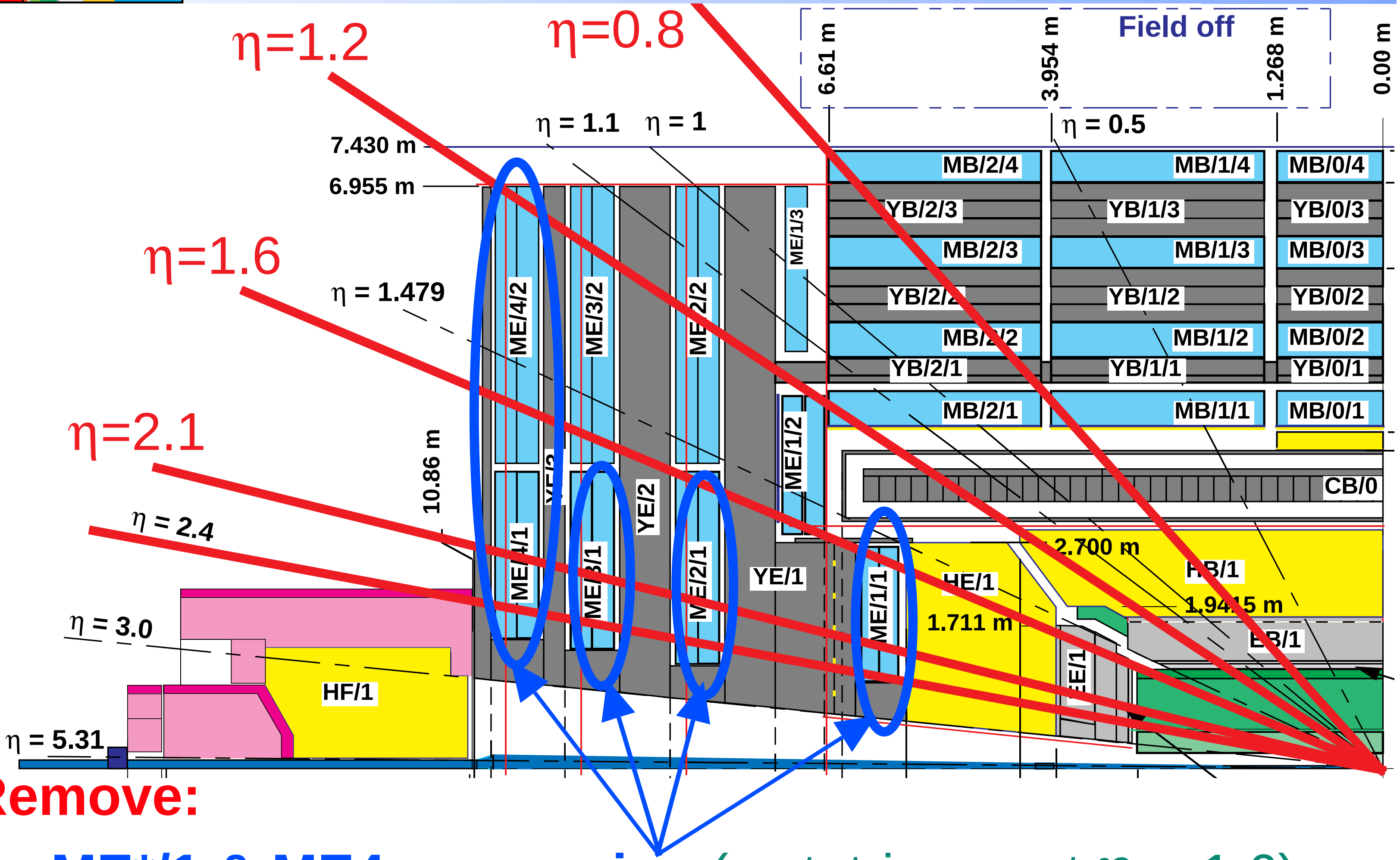


High Luminosity:



CMS Decision: Do not rescope Cal. Trig.

Option: Rescope CSC Trigger

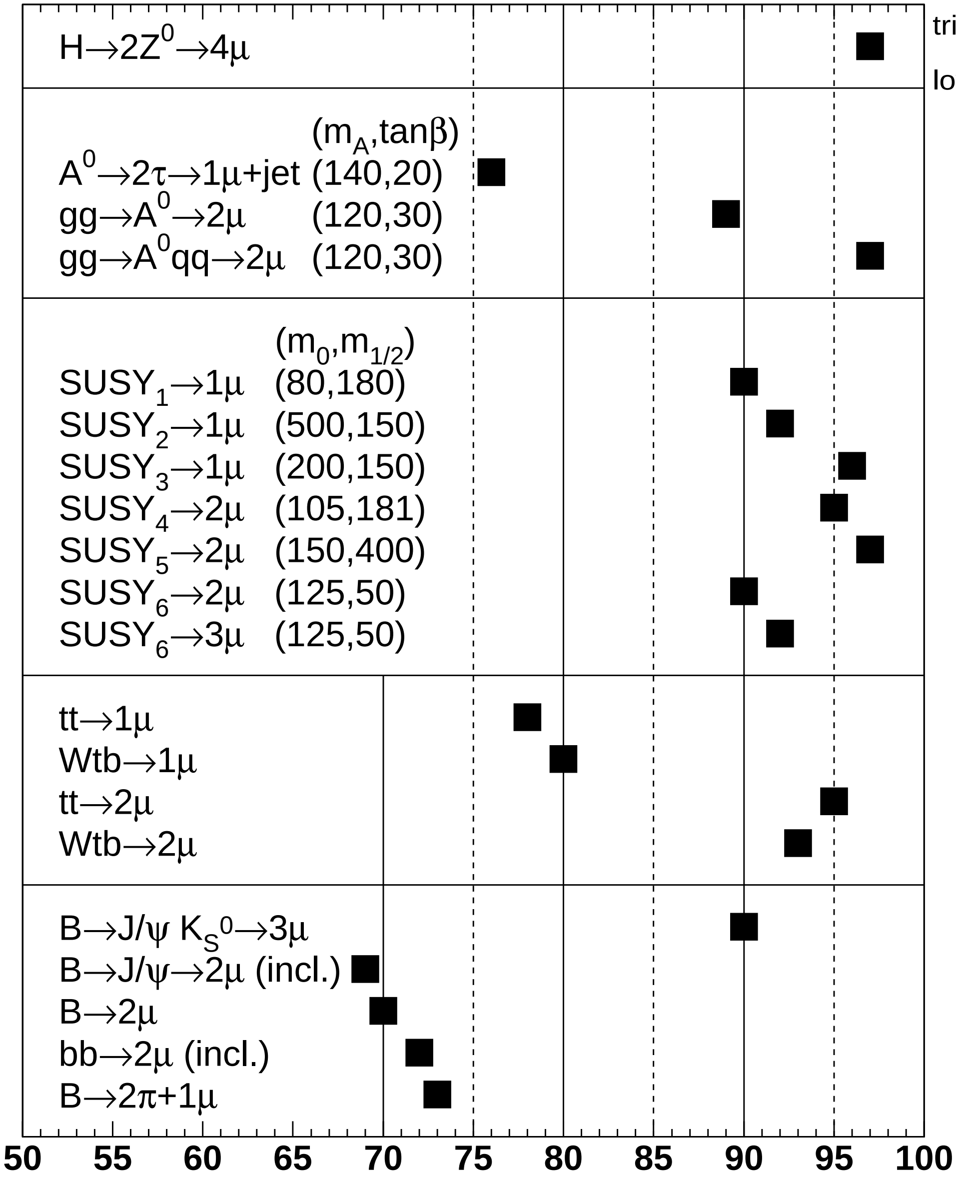


Remove:

- **ME*/1 & ME4 processing** (cut trigger at η > 1.6)
- **5 of 7 Fibers/Port Card** (only 1 stub per 60°)

Base Cost reduced by 404K (incl. new design)

Impact of CSC trig. rescope



trigger acceptance for $|\eta|<1.6$ / acceptance for $|\eta|<2.4$ (%)

low lumi. trigger thresholds - $p_t^{1\mu} = 7$ GeV, $p_t^{2\mu} = 4$ GeV

Ratio of descoped CSC to previous baseline muon trigger efficiency for low luminosity running.

CMS Decision: Do not descope in η but approve other changes:

- **Fourth Station Removed**
  - small loss in efficiency
- **New Architecture**
  - 60° port cards (fewer)
  - keep links/port card
- **New SR/SP design**
  - fewer SR's, SP's
  - fewer Crates

New Base Cost:

- **Reduction by 230K**

Committee Concerns & Corrective Actions

From May 97 Lehman Review:

- **"Base the assignment of contingency and risk on the maturity of the design, and specify it item by item, rather than globally for each subsystem."**
  - This has been done at the lowest level of the WBS and is available in the new MS Project files.
- **"Re-evaluate the Level 1 trigger latency in the context of the details of the evolving system design."**
  - This was done in a detailed TRIDAS review in November 1997 and is scheduled for reevaluation during an additional review planned for Nov. 1998.

These concerns have been addressed

Conclusions - Trigger

- **Trigger algorithms satisfy physics requirements**
  - Active simulation program producing results
- **Hardware design to implement algorithms**
  - Full conceptual design with considerable engineering
  - Extensive prototyping & test program
    - **"Proof of principle" of critical items**
    - **Number of successes already**
- **New Costing**
  - 4th muon station removed & Architecture revision
  - Contingency increased from 30% to 50%
    - **Calculated at the lowest WBS level according to US CMS method**
- **Fully resource loaded schedule**
  - Carefully matched to project & base support
  - Experienced team in place