Trigger & DAQ Report

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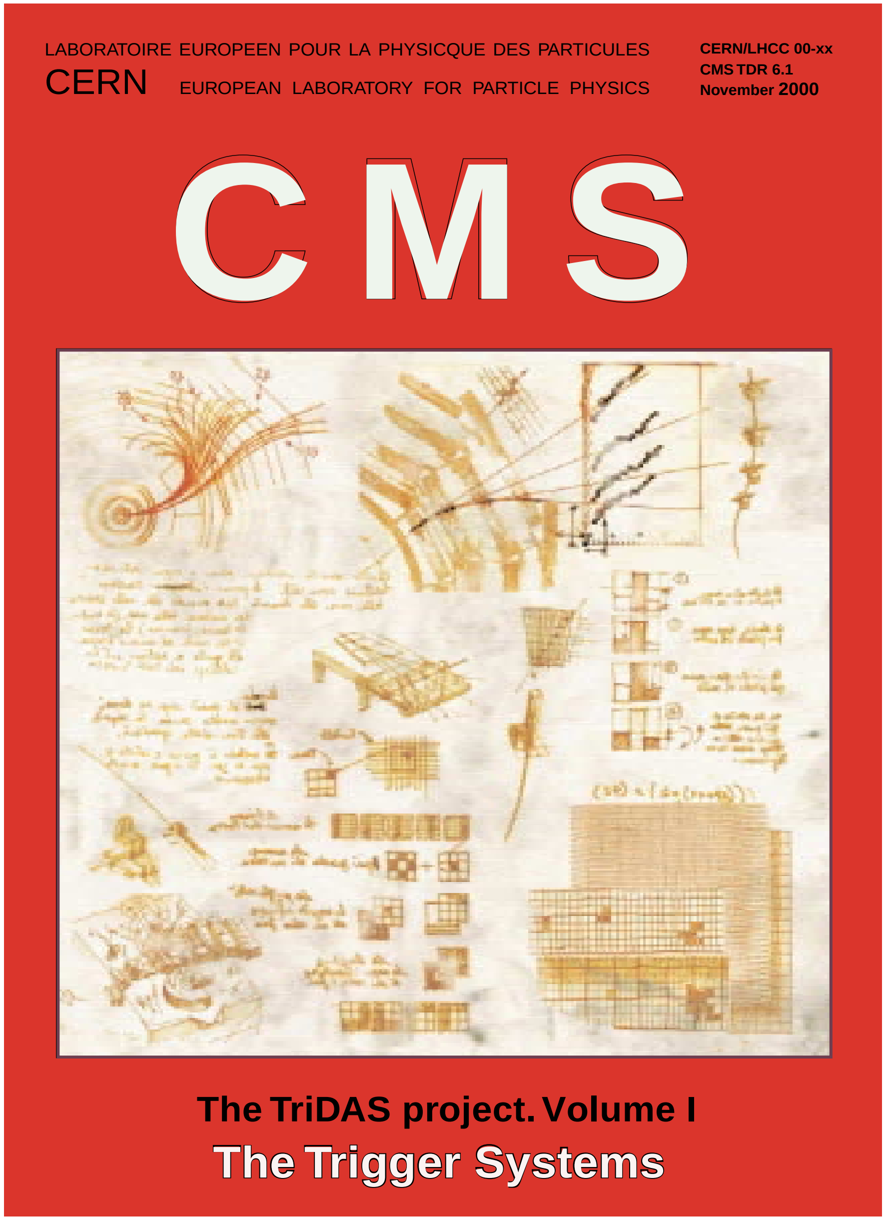
US CMS Collaboration Meeting
May 19, 2001

Outline

- Overview of Calorimeter Trigger
- Calorimeter Trigger Status & Technical Progress
- Overview of Muon Trigger
- Muon Trigger Status & Technical Progress
- Overview of DAQ
- DAQ Status & Technical Progress
- Level-1 Trigger & Physics

CMS Level -1 Trigger TDR



CMS Level 1 Milestone

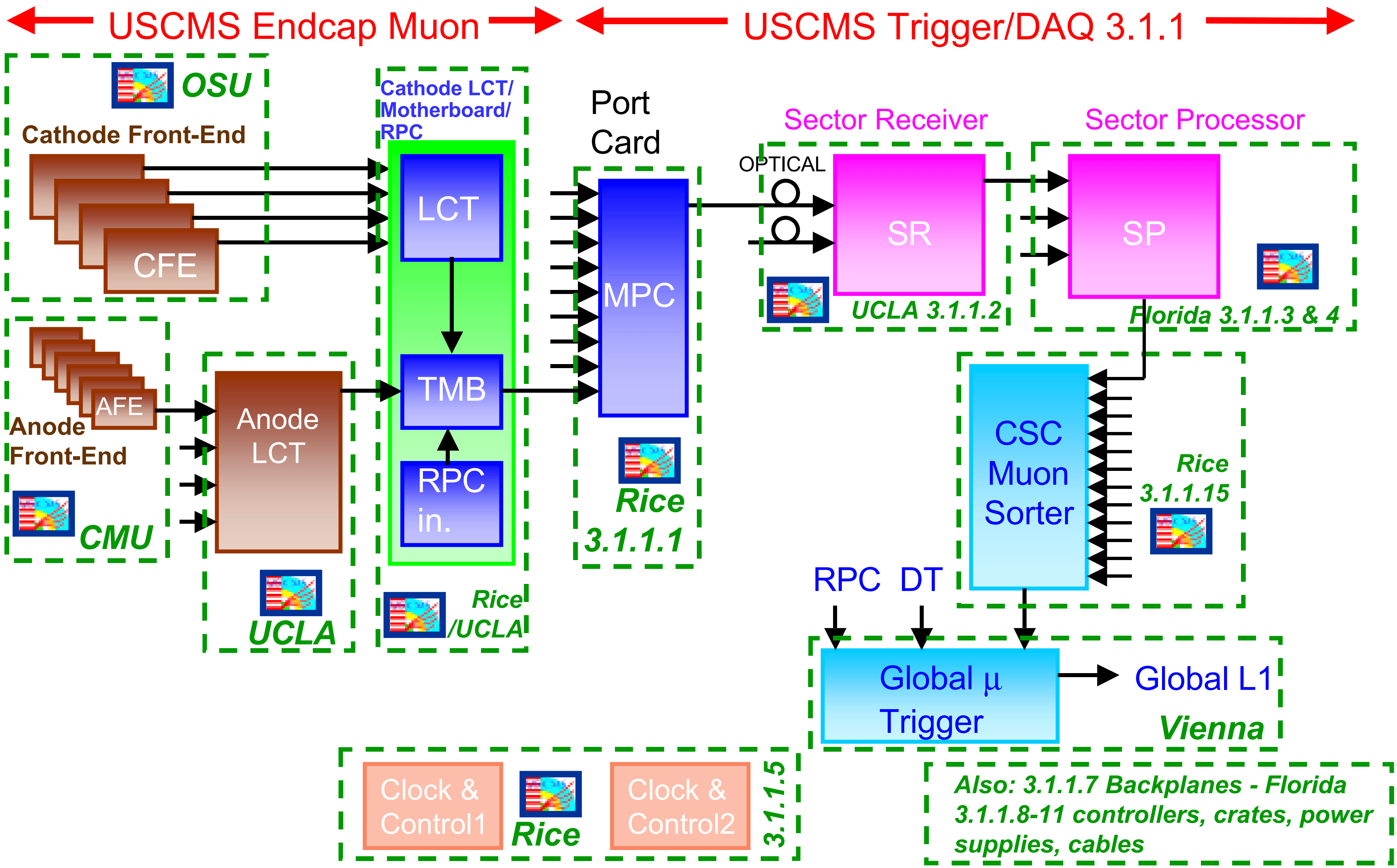
Submitted to LHCC on Nov. 28, 2000: CERN/LHCC 2000 - 38 CMS TDR 6.1

Approved in March, 2001.

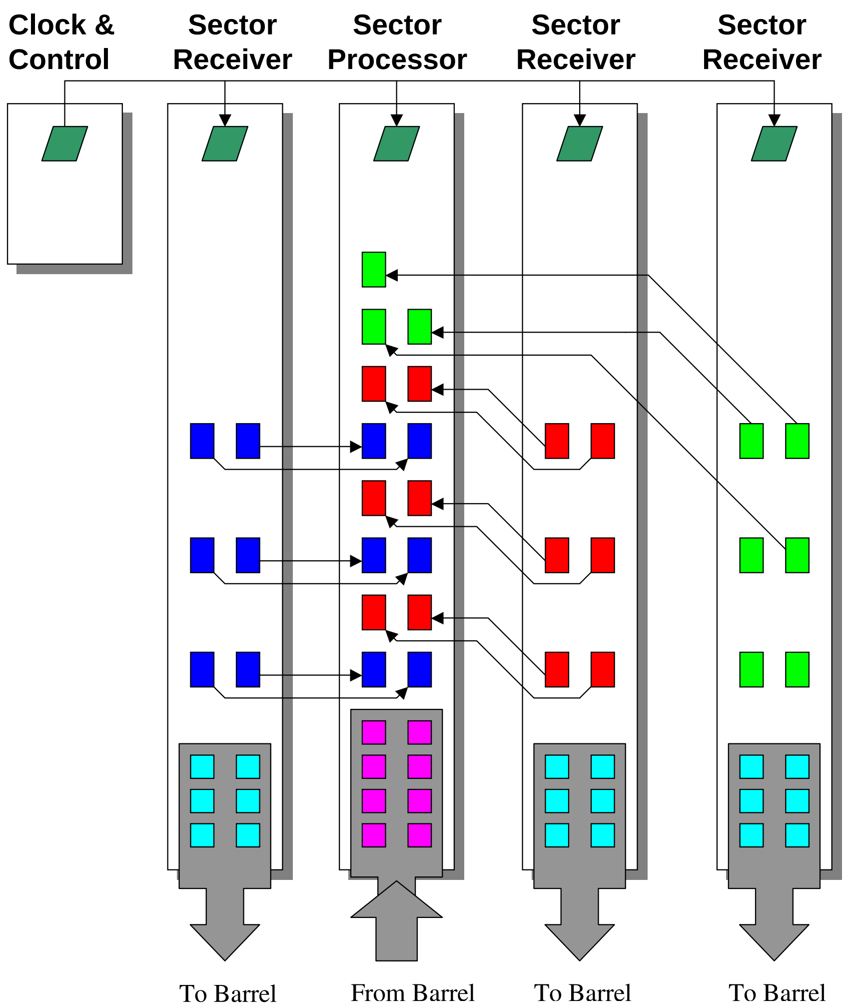
http://cmsdoc.cern.ch/cms/TDR/TRIGGER-public/trigger.html

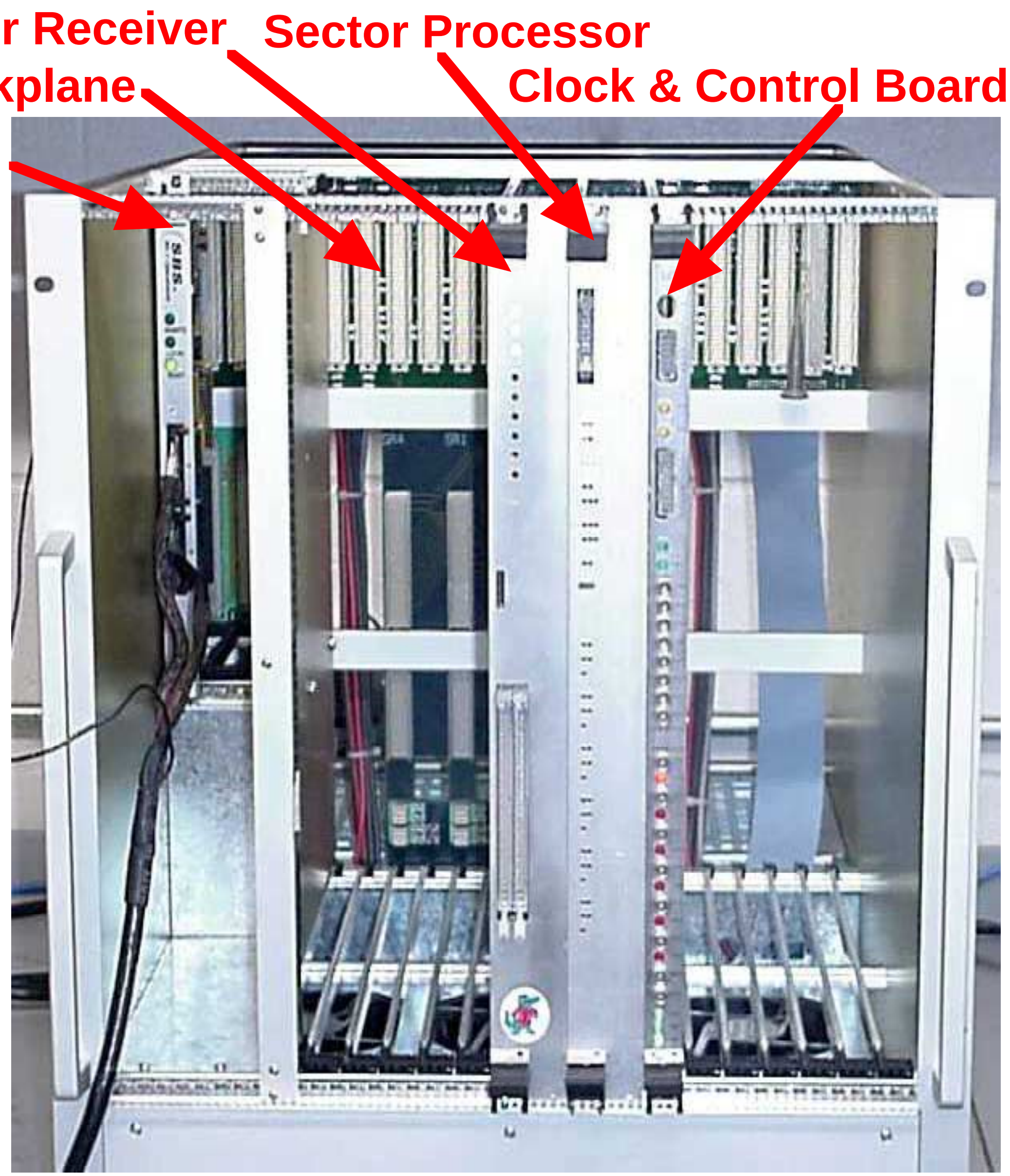
CSC Trigger System

(WBS 3.1.1)

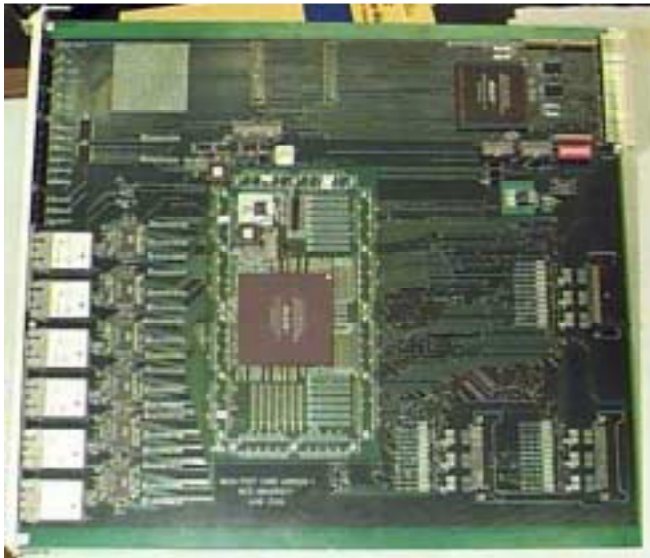


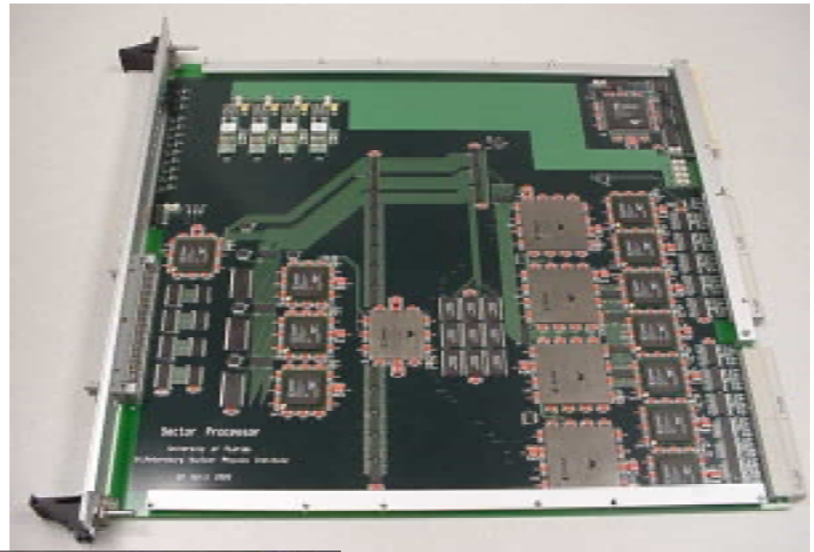
CSC Track Finder Crate





CSC Trigger Protos Tested

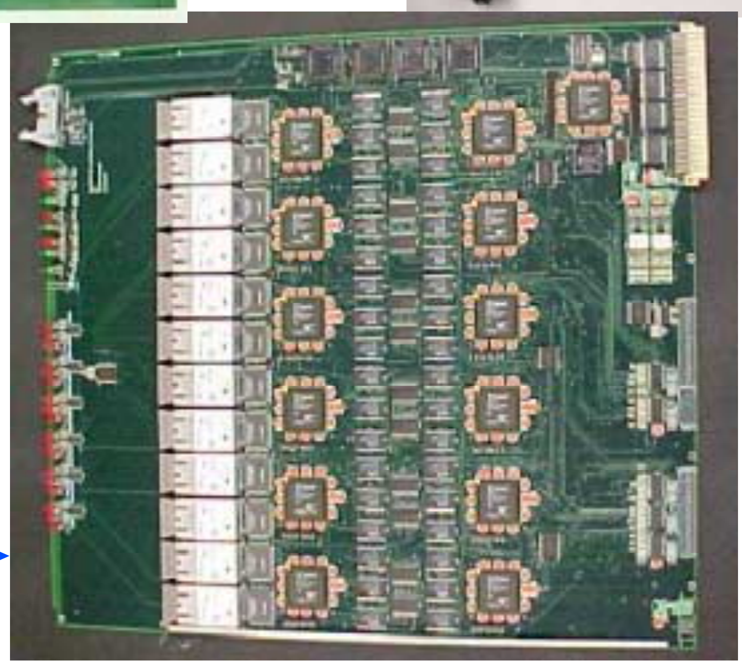




Muon Port Card (Rice)

Sector Processor (U. Florida)

Dataflow verified, incl. optical link



Sector Receiver (UCLA)

All logic tested & agrees with ORCA simulation

CSC Trig.Conclusions & Plans

Conclusions from Test

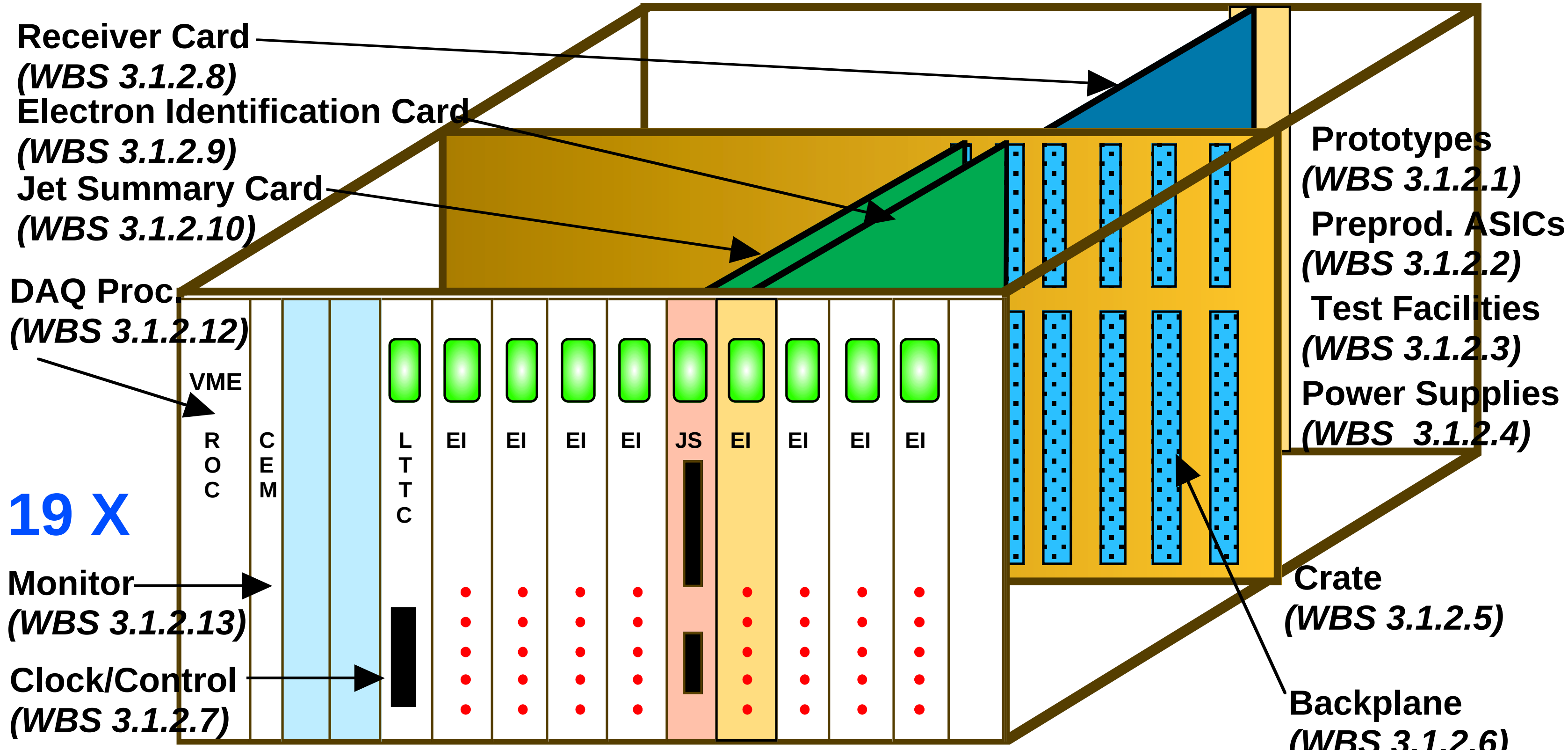
- **Conceptually Sound Design**
- **Need to reduce latency**

Plans for This Year (review at end of May)

- **Replace Backplane technology with faster**
  - Channel Link -> GTLP at 80 MHz
  - New prototype backplane tested at Florida
- **New Compact Single Crate Design**
  - Merge all 17 FPGAs of baseline design into one
  - Possible due to new FPGA technology
  - Merge Sector Receiver & Sector Processor Boards
- **New Optical Link Technology**
  - Use new 1.6 Gbit/s links with 80 MHz clock
  - Tested at Rice and Works

Regional Calorimeter Crate

(WBS 3.1.2)



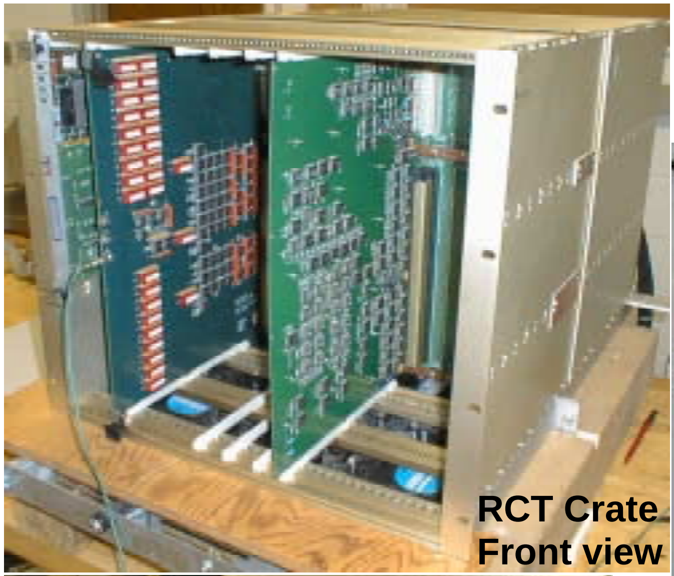
Data from calorimeter FE on Cu links @ 1.2 Gbaud (ptyp. tstd.)

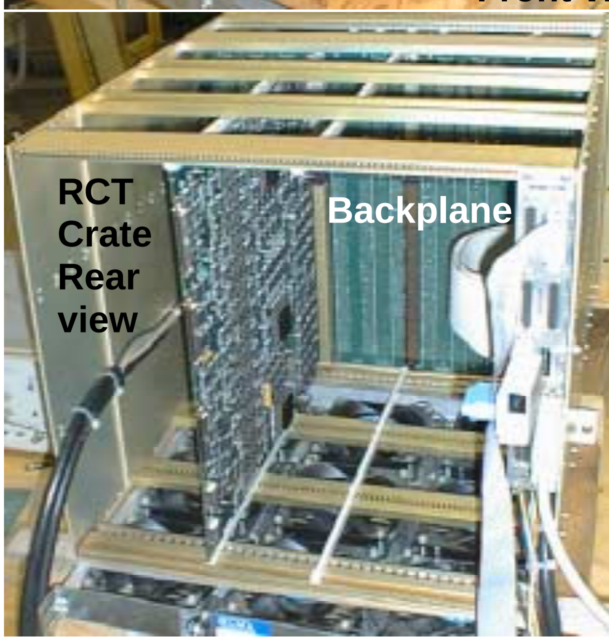
- Into 152 rear-mounted Receiver Cards **(ptyp. tstd. w/ ASICs)**

160 MHz point to point backplane (ptyp. tstd.)

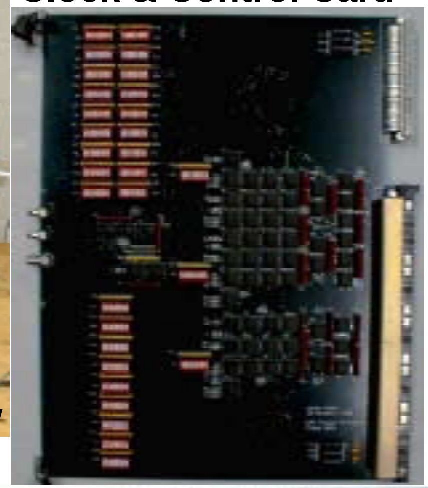
- 19 Clock&Control **(ptyp. tstd.)**, 152 Electron ID **(ptyp. tstd.)**
  19 Jet/Summary, Receiver Cards operate @ 160 MHz

Regional Cal. Trig. Prototypes

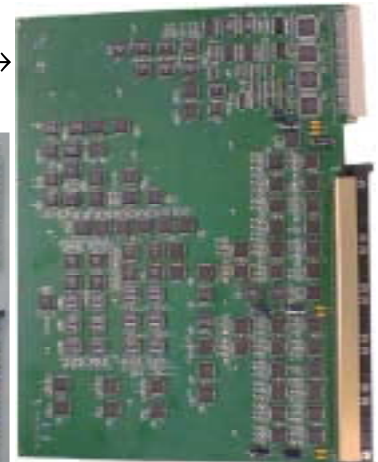




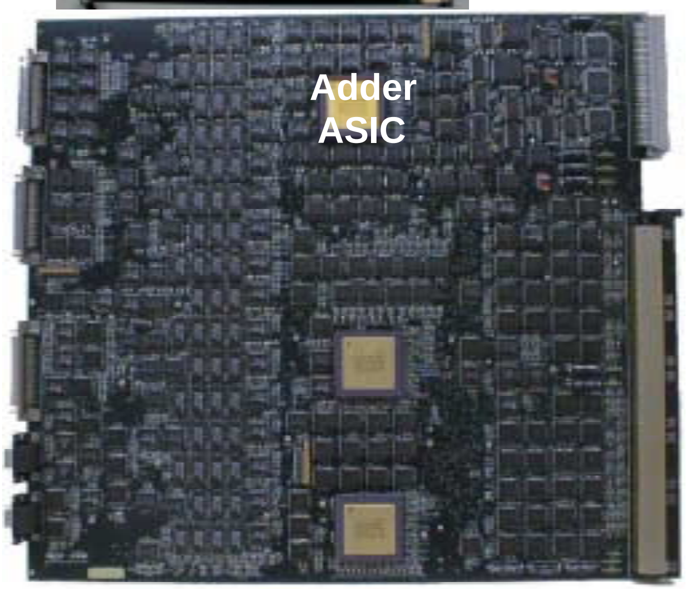
Clock & Control Card



Electron ID Card→



Receiver Card ↓



All Tests Passed

Intercrate sharing checked

Timing checked

Adder ASIC fully qualified for production

Full 160 MHz dataflow verified

VME checked

Calorimeter Trigger Status

Successful Prototyping Program

- Crate, 160 MHz Backplane & Clock Card
- Receiver & Electron Isolation Cards tested
- Adder ASIC tested & production finished
- Links: 4x1Gbit on Cu* ECL x 20 m tested

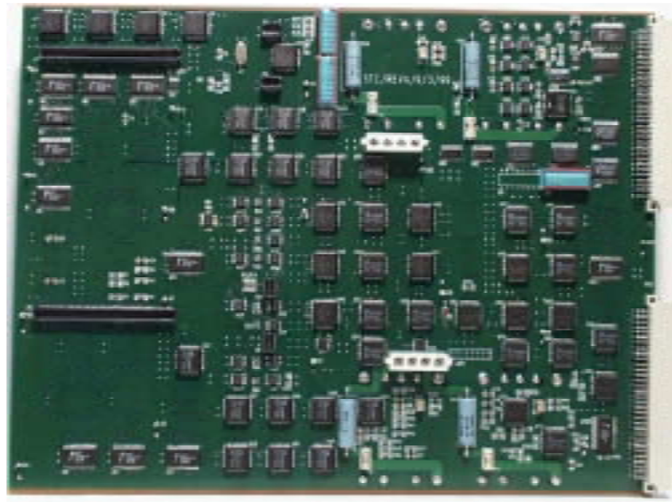
ASIC prototype development finished

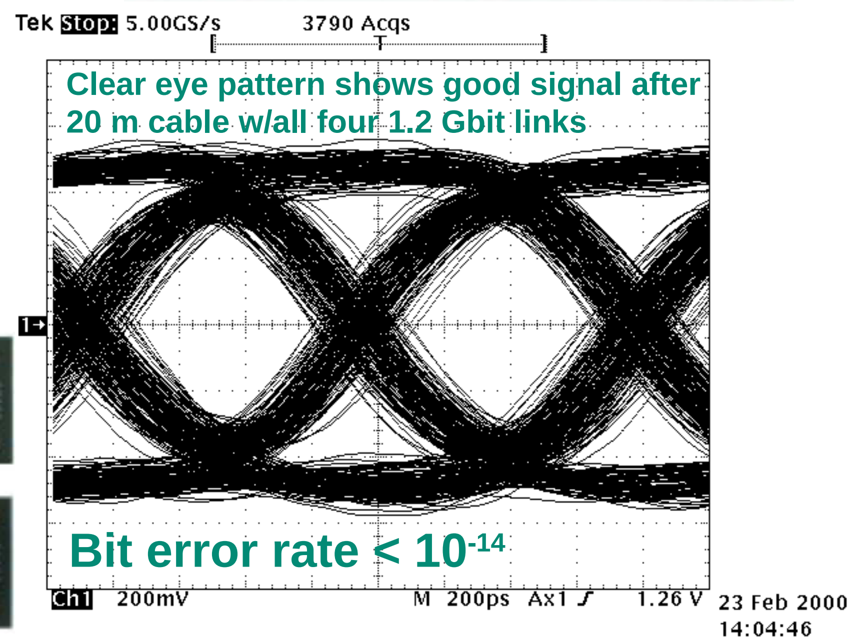
- Phase & Boundary Scan protos delivered
- Isolation & Sort protos manufactured

Testing Program Plans

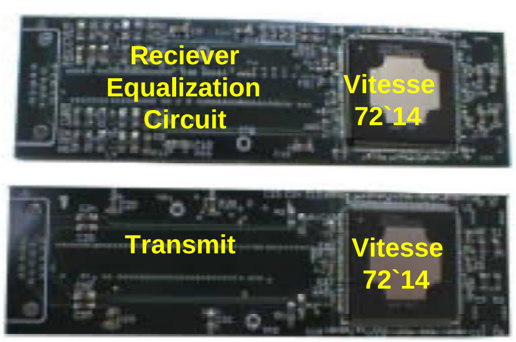
- Next generation Backplane finished
- Next generation Receiver, Elect. Iso.
- Test remaining ASIC prototypes

*Gbit Serial Cu Link Cards & test results:

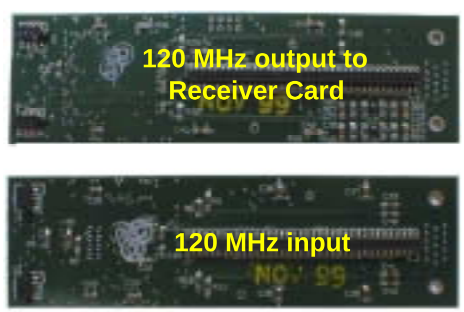




Mezzanine Card (Top view)

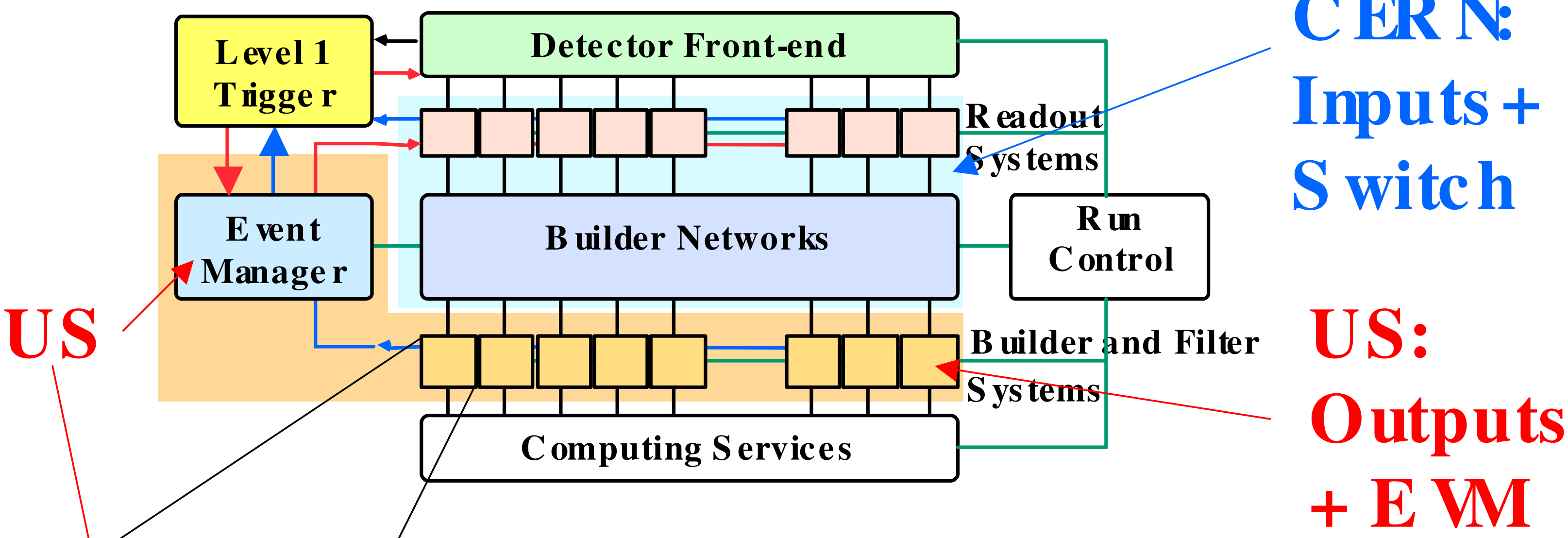


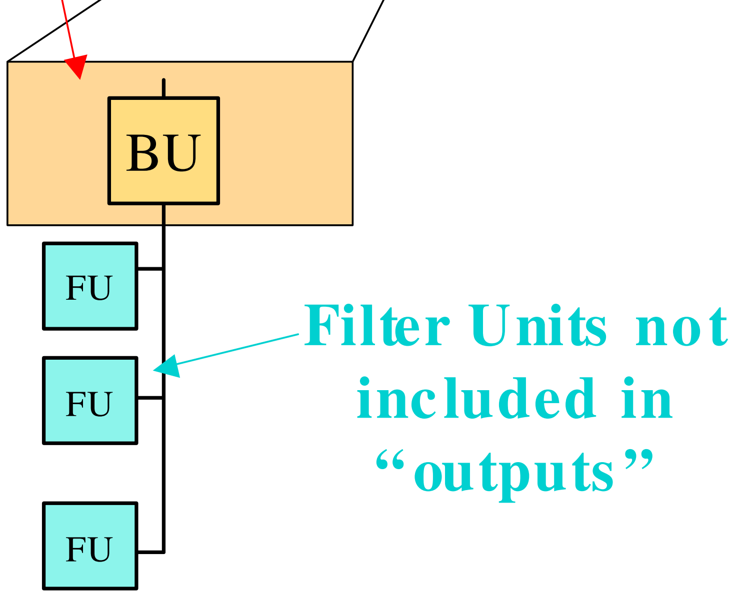
Mezzanine Card (Bottom view)



US CMS DAQ Responsibilities

US: Event Manager + Builder Units





Other responsibilities:

Detector Front-Ends:

detector groups

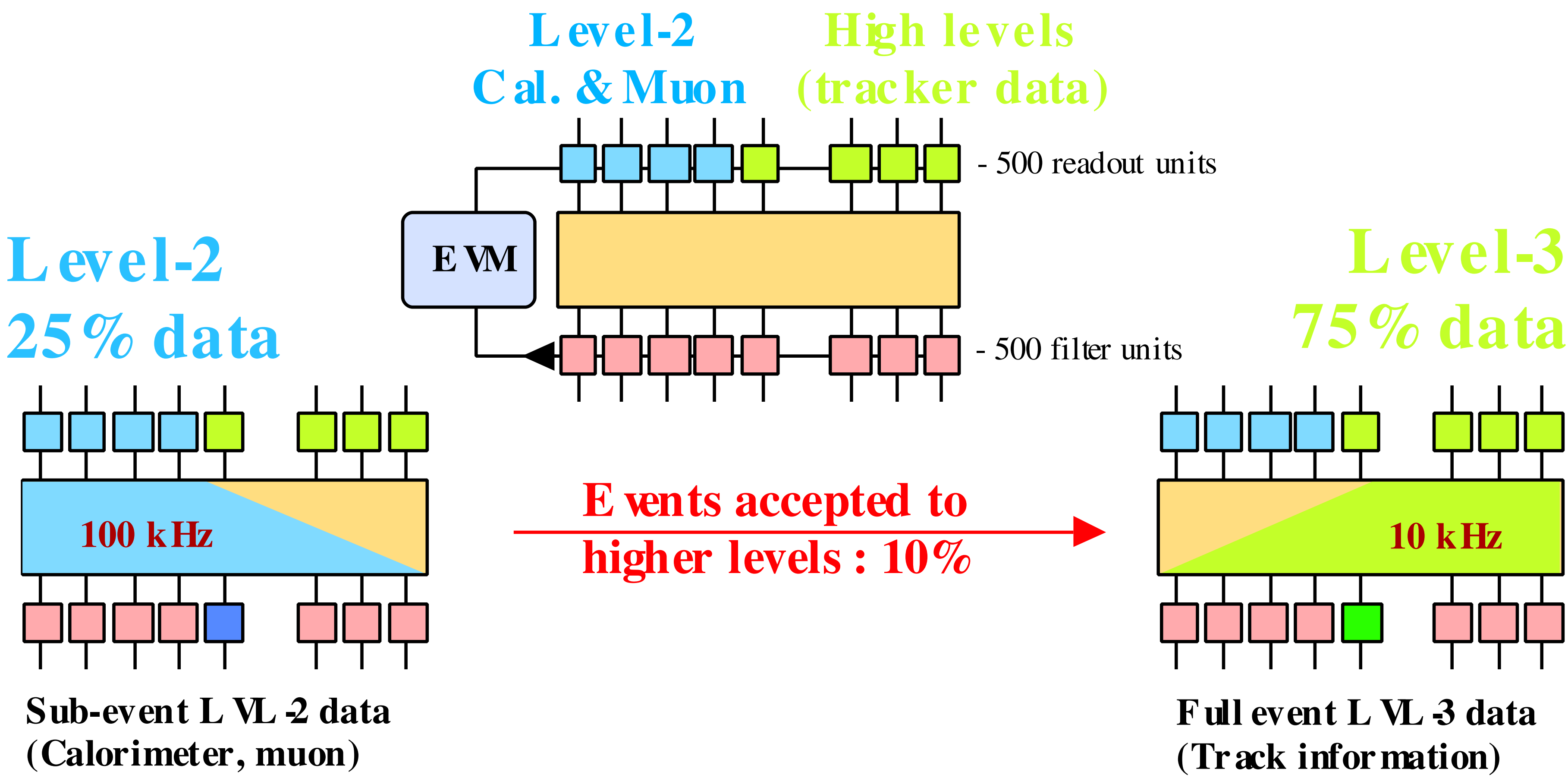
Computing Services:

infrastructure

Major DAQ Development

Multi-step Event Building no longer necessary

- **Validates decision to invest in networking & computing**
  - Today: two alternatives: Myrinet 2000 (2.5 Gb/s links) and/or two Gbit/s Ethernet links/RU



Developments last year

High Level Trigger: included in "PRS"

- Defining "Level-2" as anything doable without tracking information, Level-2 is ~ complete

New LHC schedule ® new date for DAQ TDR

- First beams in early 06, first physics in Aug 06
- Submission date was always set to T_0(LHC)-3.5 yrs.
  - With new schedule, submission goes to end (Nov 30) 2002

Schedule & Milestones:

- Unchanged, especially for the HLT/PRS part(s)
  - What gets delayed is decisions on technologies to use, etc., but not the results of the studies.
  - However, with another year's technology with us, we can expect that most of the data transfer issues are no longer with us, so we just concentrate on

    (a) the algorithm itself and

    (b) the CPU needed

Progress on DAQ

16x16 Event Builder Demonstrator complete:

- Based on Myrinet-2000:
  - Barrel-shifter works at close to 100% (raw) efficiency
- Based on Gbit Ethernet:
  - Looks very promising – especially if 10 Gbit Ethernet in time

Designs for 500x500 switch available

- Simulation results very pomising

Builder Unit prototype:

- Two solutions being looked at:
  - Custom-made board (commercial components)
  - Recycling of units made for Readout into a PC

High Level Trigger:

- “Level-2” equivalent algorithms in place
- Now working on “Level-3” (~ includes tracker information)

Progress: BU prototype

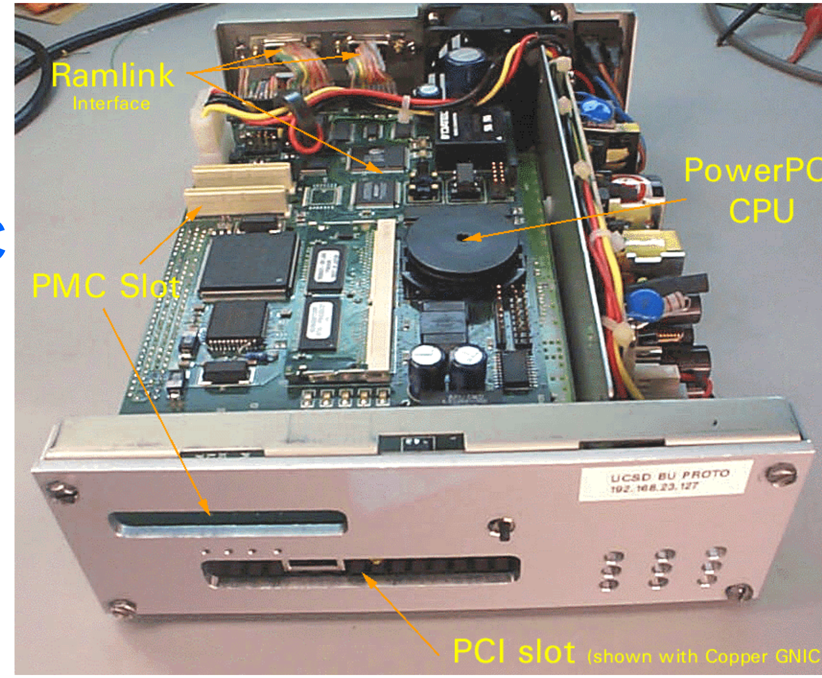
Current device

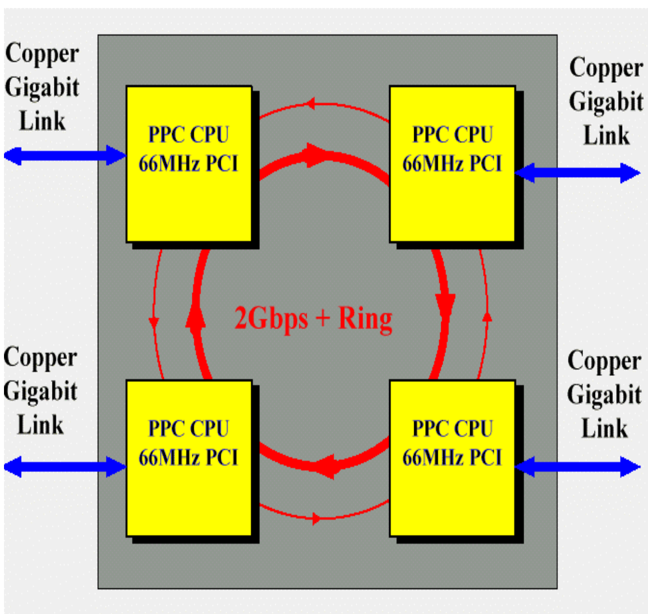
Done at UCSD

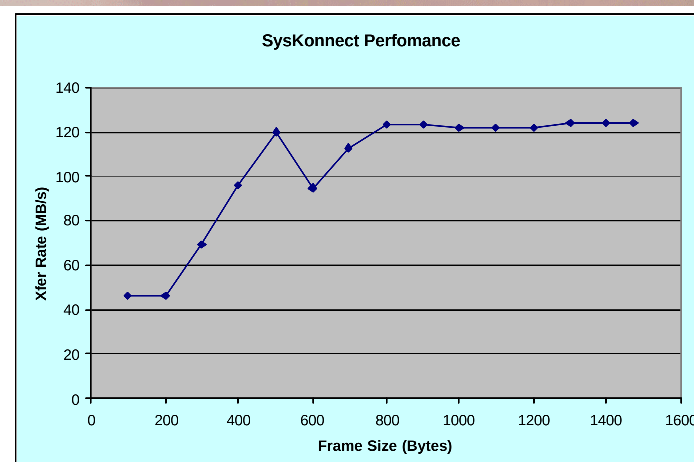
Copper Gbit Ethernet NIC

PowerPC CPU

RAMlink interface







CMS Level-1 Trigger Requirements and Simulation

Capture CMS Physics with high efficiency

- High luminosity targets:
  - lepton/γ (40 GeV)
  - dileptons/γγ (20 GeV)
  - jets w/ missing E_T (100 GeV)
  - 1-4 jets (250-100 GeV)
- Low Luminosity Targets:
  - lepton/γ (25 GeV)
  - dileptons/γγ (15 GeV)
  - jets w/missing E_T (50 GeV)
  - 1-4 jets (150-75 GeV)

Capture CMS Physics with low background rate

- 75 kHz design output x 33% safety factor x 50% into muon & calorimeter triggers = 12 kHz target for simulated rates each
  - Safety factor for unknown physics, detector modelling & DAQ performance
  - Demonstration required using basic trigger capability (not all features)

Full Simulation of Detector, Electronics & Trigger

- ORCA4 -- Object-Oriented Reconstruction for CMS Analysis:
  - Complete Detector GEANT modeling
  - Complete digital hit reconstruction
  - Accurate bit-level integer simulation of trigger function

CSC Trigger Simulation
(Rice, Florida, UCLA)

Studies have been carried out using the object-oriented software framework of CMS

- Geant3 for hit generation
- "ORCA" for detector and trigger simulation

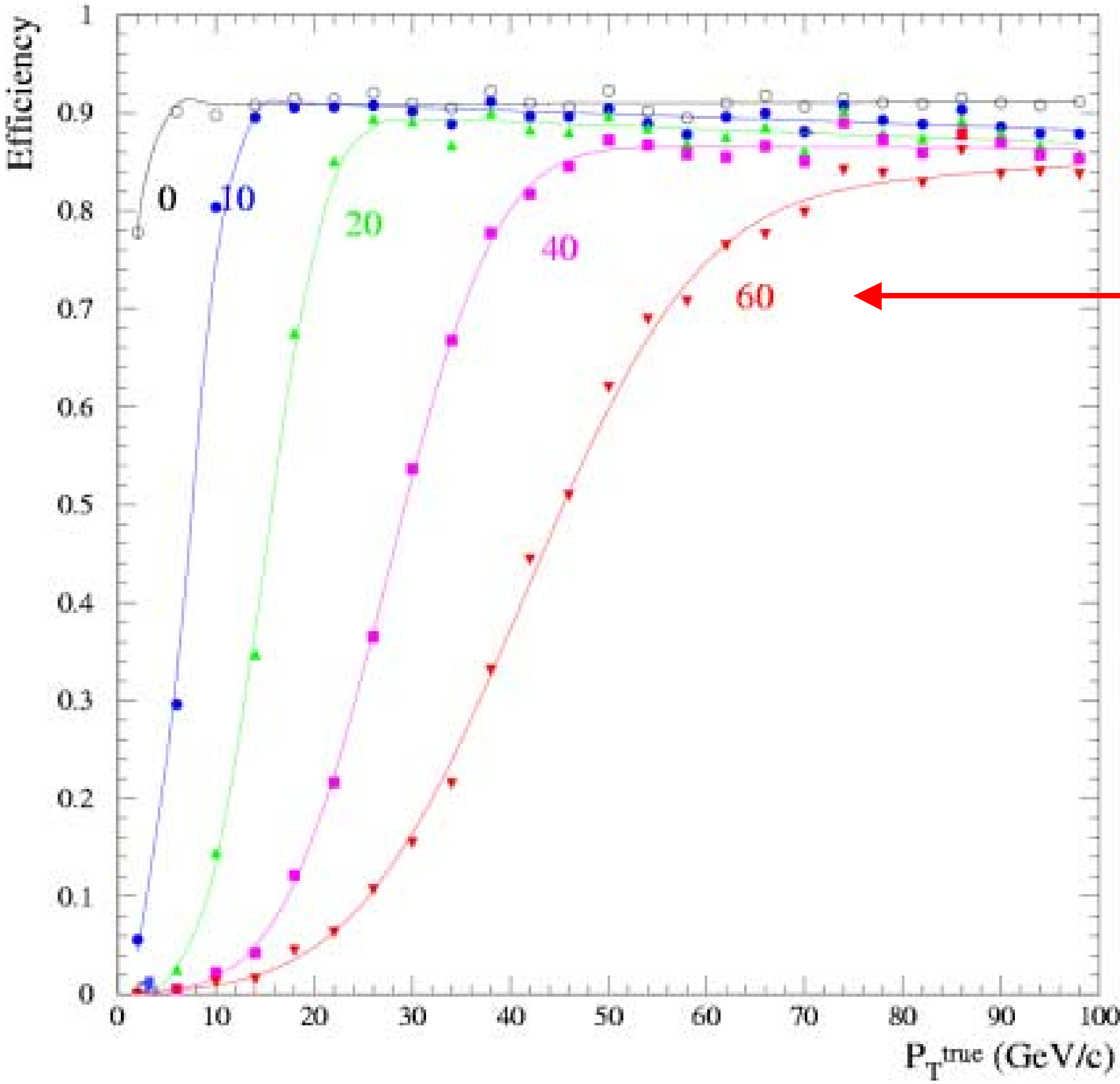
Entire L1 CSC Trigger scheme coded in C++

- Perfect agreement achieved between simulation and hardware for millions of events (MPC, SR, SP)

Trigger rate, efficiency, and P_T resolution studied for $L = 10^{34}$ $cm^{-2}s^{-1}$

- Pile-up includes 17.3 minimum bias collisions per beam crossing and neutron hits from much earlier crossings
- Aim for single muon rate <10 kHz with >90% efficiency

CSC Trigger Efficiency vs. P_T



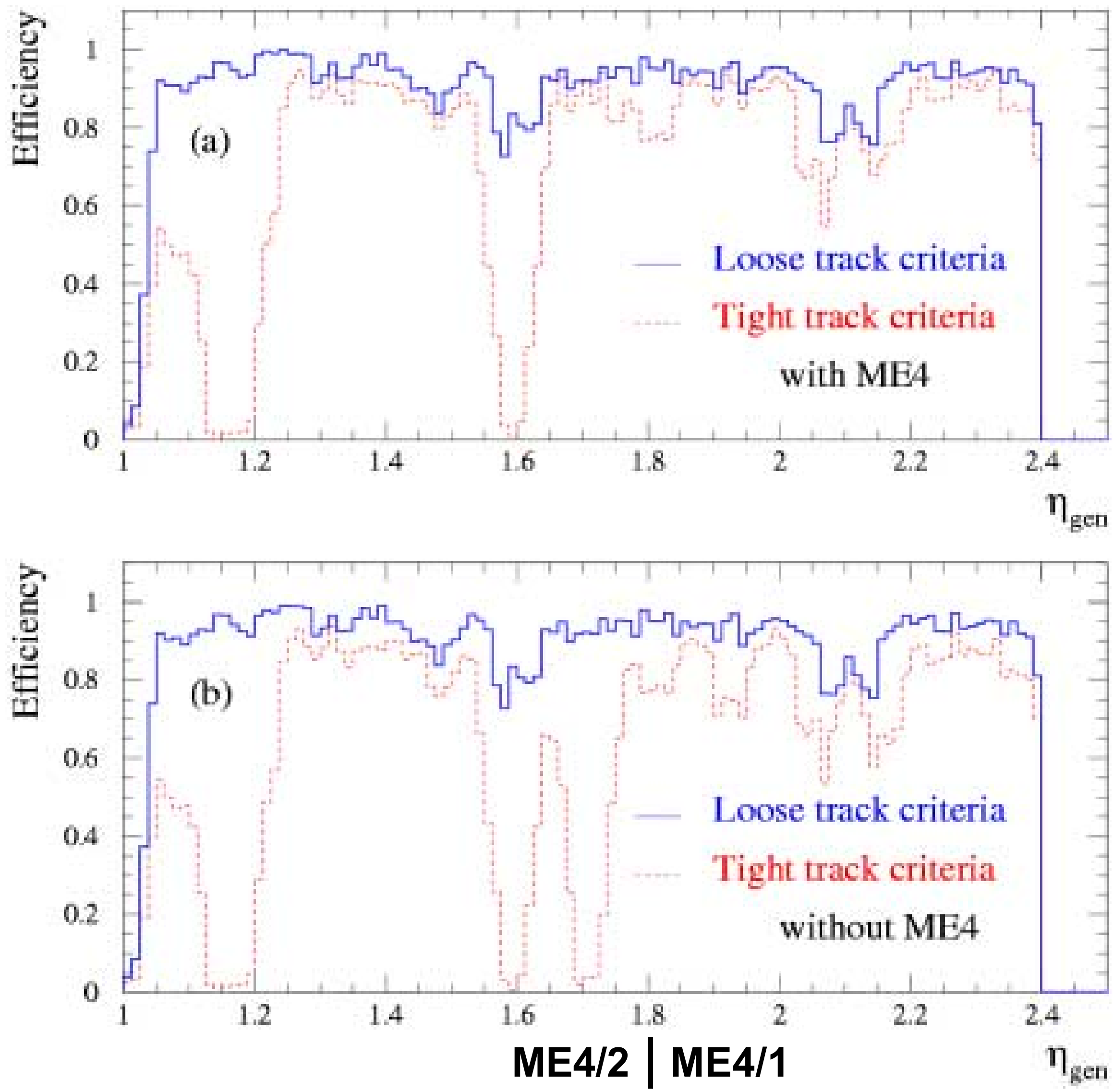
Trigger threshold defined at 90% efficiency

Sharper turn-on for better P_T resolution

Require ME1 for good P_T resolution

$1.2 < |\eta| < 2.4$

CSC Trigger Efficiency vs. η

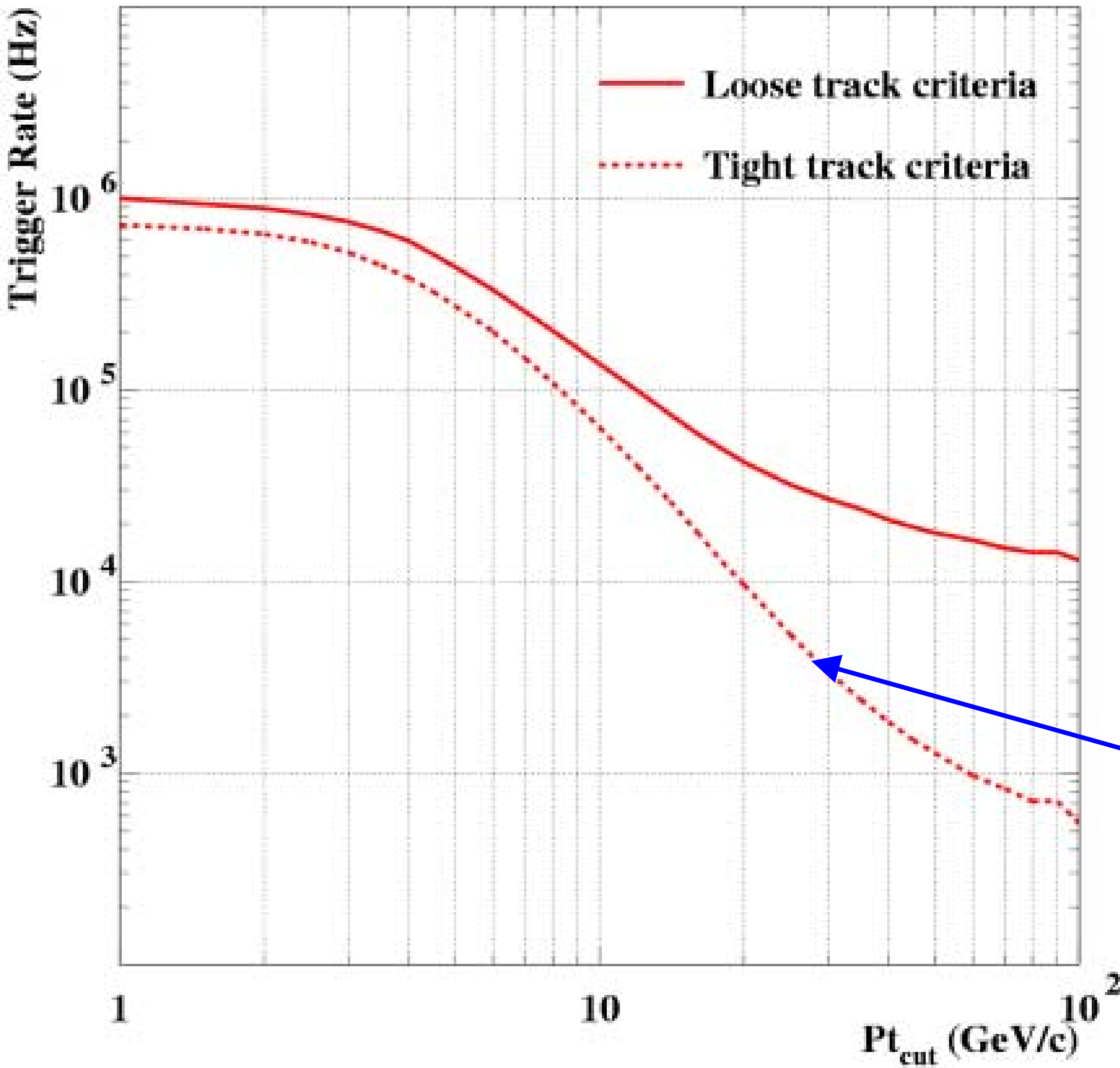


Loose: 2 or more stations including ME1 in endcap, but any two in DT/CSC overlap region
~90% efficiency

Tight: 3 or more stations including ME1 in endcap and MB1 in DT/CSC overlap
~70% efficiency
but better P_T resolution

Significant acceptance loss when 3 stations are required and no ME4

CSC Single Muon Rate

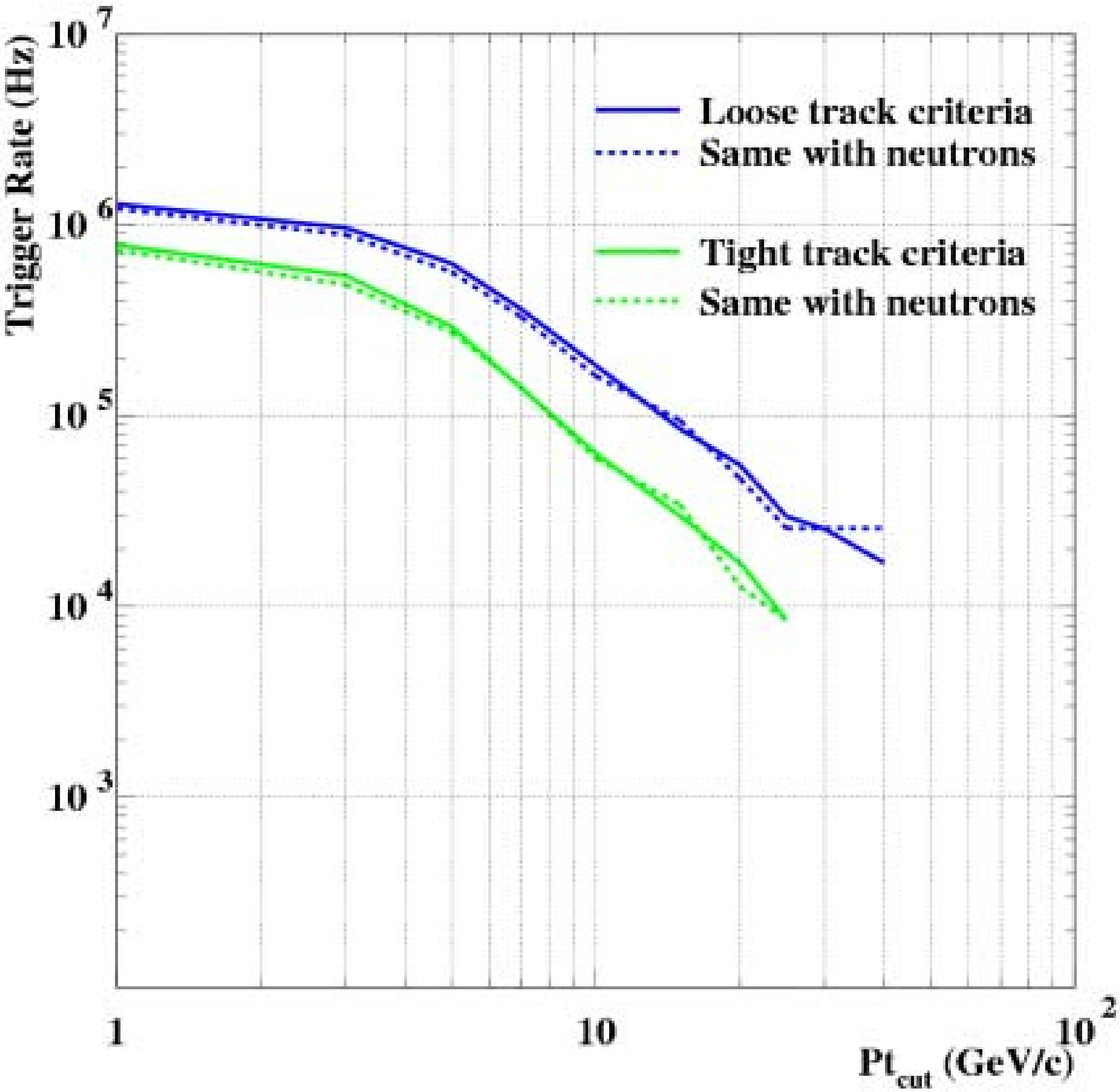


Weighted minimum bias sample used to estimate rate for *L* = 10^{34}

Require "tight" track conditions ($\varepsilon \approx 70\%$) to get acceptable rate from standalone CSC trigger

5 kHz rate for threshold set at 25 GeV

CSC Rate with Neutrons



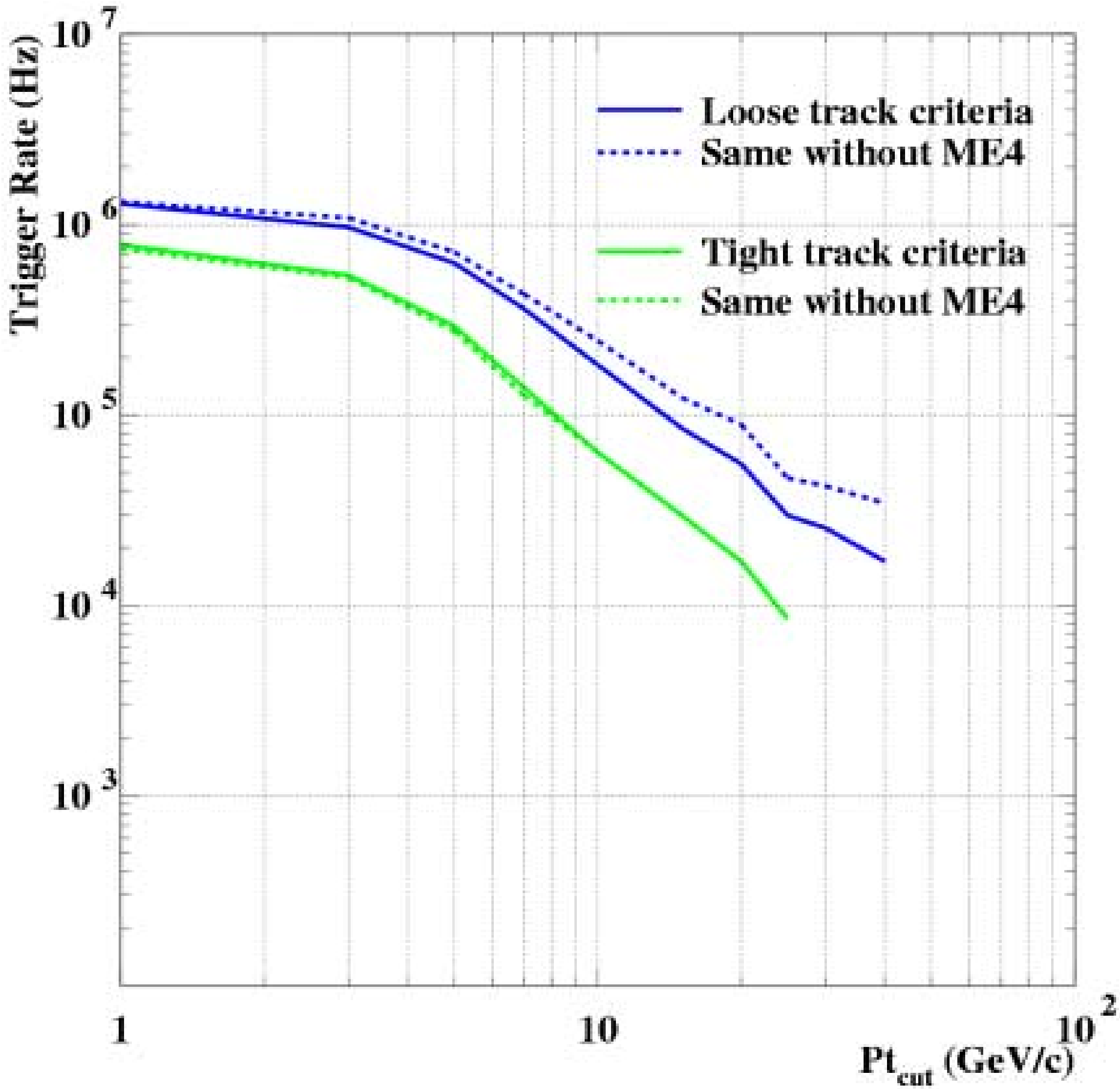
Previous study did not include effect of punch-through or neutron hits

Had used weighted events with muons

But no significant change in rate or efficiency (< 10%) is seen when effects are included

So real muons dominate the trigger rate

CSC Rate without ME4



Trigger rate for "loose" condition increases by ~50% if ME4 is removed because of fewer 3-station tracks
⇒ worse P_T resolution

Trigger rate for "tight" condition stays about the same because 3-station tracks already required

Muon Trigger Conclusions

The previous simulations are the most detailed done to date of the CMS muon trigger

- FE amplifier response/noise is in, neutrons are in, etc.
- Trigger logic mostly validated against current hardware designs (some updates needed)

But we need detailed validation against real data

- Testbeam and cosmic ray data

This requires physicist support!

- Postdocs, students

It's important to design a highly efficient L1 CSC Trigger

- L2 and L3 algorithms use L1 candidates as seeds.
  If L1 misses the muon, physics may be lost…
- Must have ME1, and re-scoping ME4 helps at high luminosity
- RPC noise/trigger rate may be unacceptably large to help GMT

CMS Level-1 Calorimeter Trigger in ORCA4

ORCA: Object-oriented Reconstruction for CMS Analysis

- **Considerable effort was made to implement CMS Level-1 Regional Calorimeter Trigger systems into OO code**
  - Complete detector and electronics modelling
- **Effort continues to maintain/update existing L1 Calorimeter Trigger code**
  - Level-1 Calorimeter Trigger developed and maintained by UW (Dasu, Chumney, di Lodovico, Mulvihill)
- **Collaboration wide studies of trigger effects and exploration of physics channels**
- **Large database exists of QCD events & physics channels**
  - nearly 600000 QCD events
  - physics channels added regularly
    - **Standard model: $H\to\gamma\gamma$, $H\to bb$, $W\to e\nu$, $Z\to ee$, top quark, $H\to ZZ$**
    - **SUSY higgs: $H\to\tau\tau$, $H^+\to\tau\nu$**
    - **mSUGRA: sparticles**

Level-1 MC Production

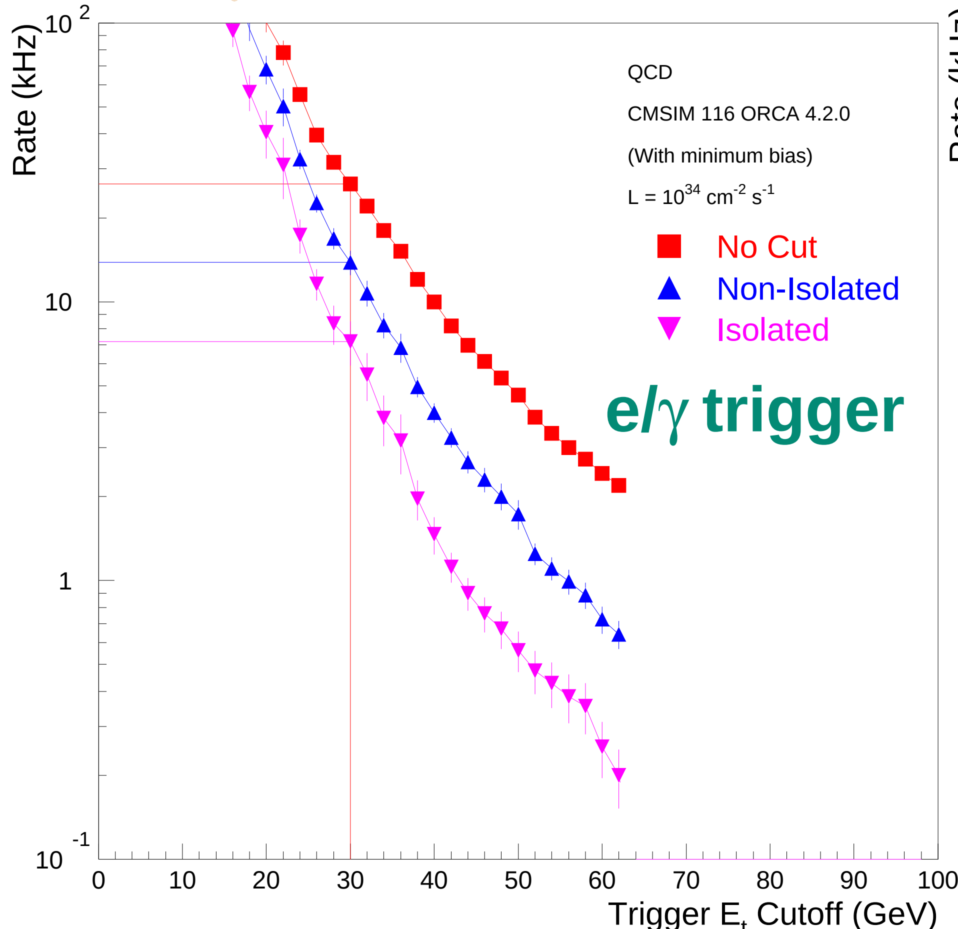
Using UW Condor system

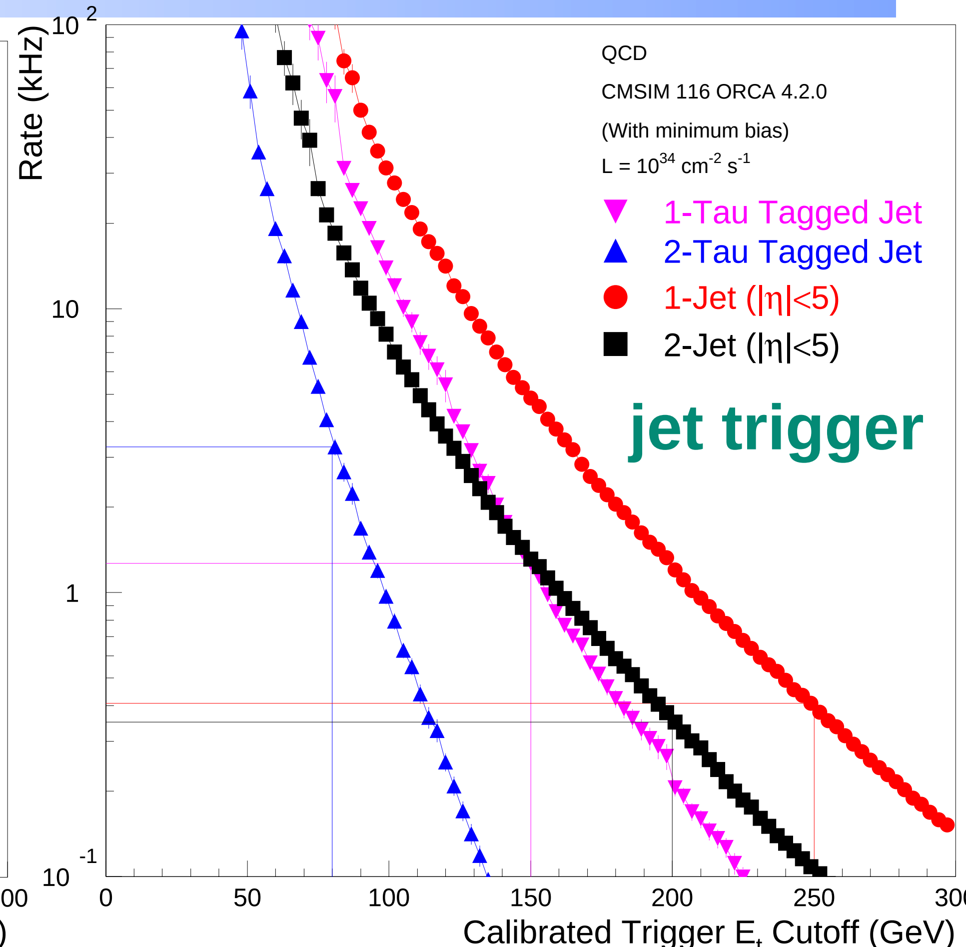
(see http://www.cs.wisc.edu/condor/)

- funded by UW (incl. Rajamani -- C.S. Grad Student)
- S. Rader - system manager, R. Rajamani - production coord.
- submitted from local machine $\rightarrow$ sees local disks
- 1.2 TB RAID for storage
- 20 local CPUs - 5 are Objectivity servers
- Additional 600+ CPUs accessible in Condor pool
- Beginning to assist with Spring 2001 CMS MC Production
- Have created own level-1 datasets (& own minbias):
  - have samples for $t \rightarrow eX$, $Z^0 \rightarrow ee$, $W^{\pm} \rightarrow e\nu$
  - want to add $t \rightarrow$ jets and more...

Actively collaborating with other US production sites, with FNAL as coordinating site.

Cal. Trig. Rates at 10^{34}

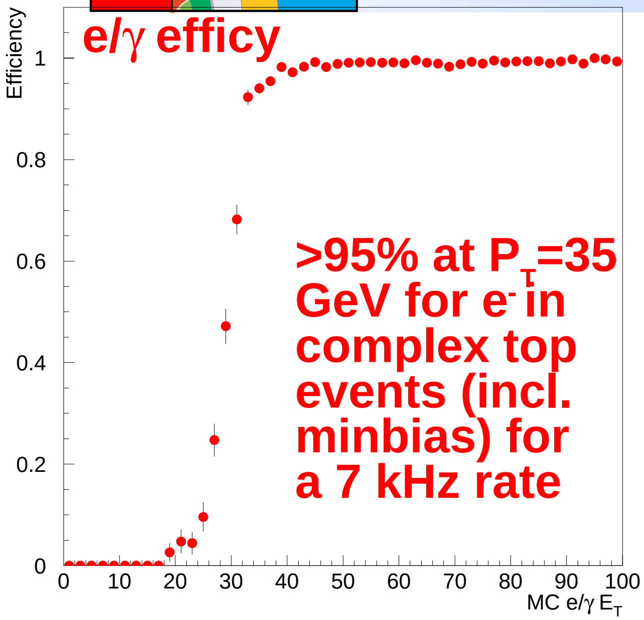


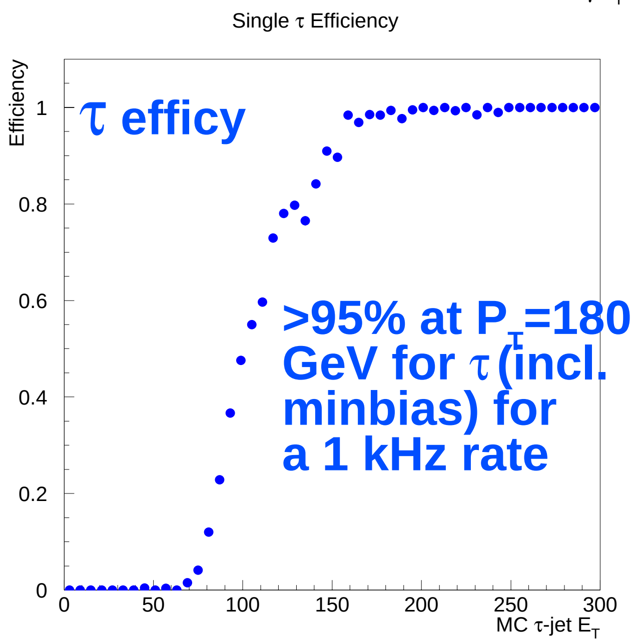


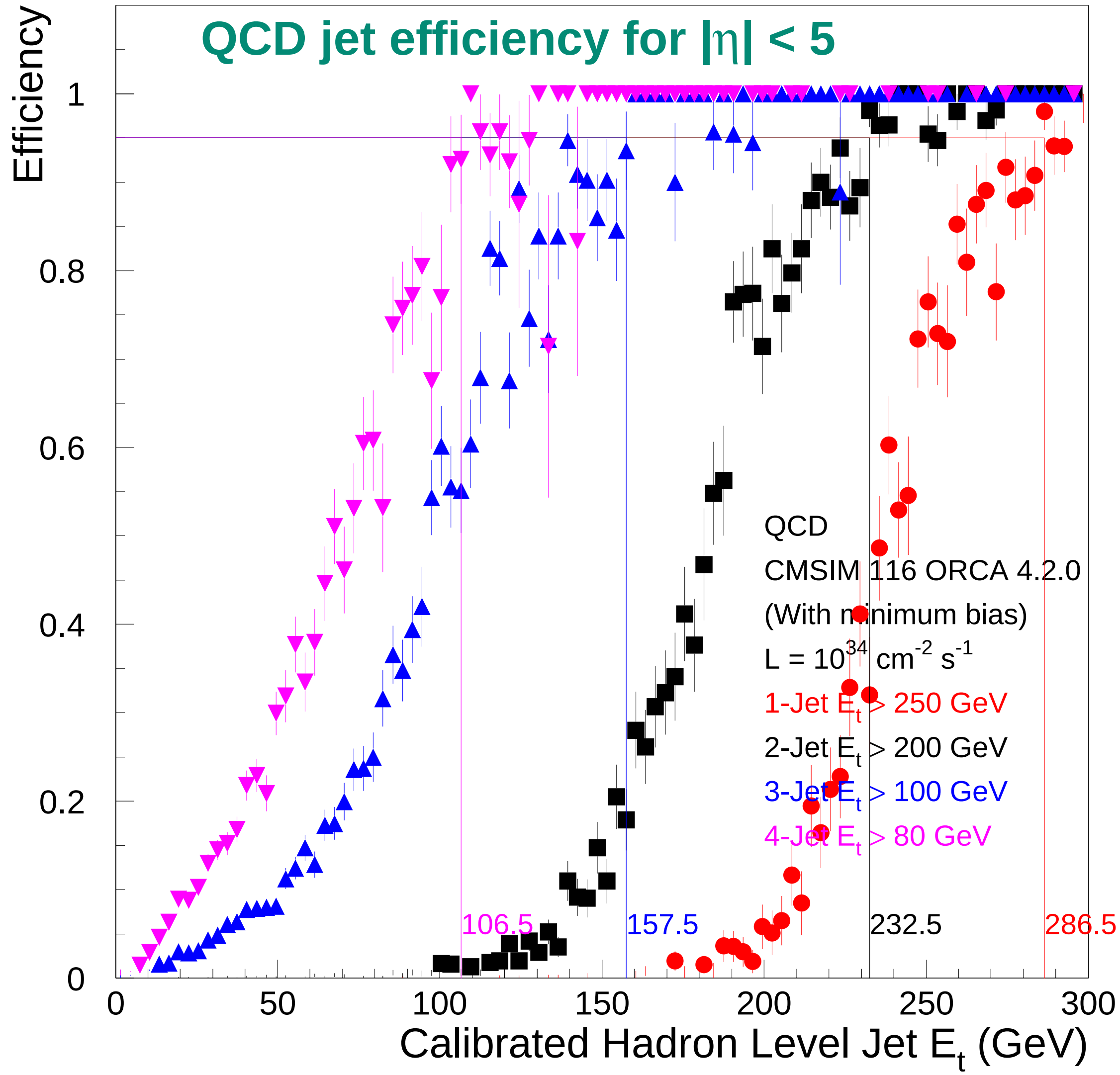
Rates drop sharply with trigger E_T cutoff

- **Provides ability to tune cuts to sustain rates during operation**
- **For electron several cuts are available to optimize efficiency versus rate**
- **For all trigger types there are tunable parameters, e.g., look-up-tables**
- **QCD background rates are within target (~12 kHz for calorimeter triggers).**

Cal. Trigger Efficiency







>95% at P_T=286, 232, 157, 106 GeV for individual 1,2,3,4 jet triggers (incl. minbias) (~0.5 kHz rate each totalling ~2 kHz)

L1 Trigger Thresholds

with ORCA4 simulated rate

	e	ee	τ	ττ	j	jj	jjj	jjjj
Low $\mathcal{L}$	24	18	95	75	150	115	95	75
High $\mathcal{L}$	35	20	180	110	285	225	125	105
	τ+e	j+e	MET	e+MET	j+MET	e(NI)	ee(NI)	ΣET
Low $\mathcal{L}$	80,14	125,14	275	12,175	65,175	NA*	NA*	1000
High $\mathcal{L}$	125,20	165,20	350	18,250	95,250	58	28	1500
	μ	μμ	μe	μτ	μj	μ+ET	μ+MET	Rate:
Low $\mathcal{L}$	10	3	4,12	4,80	4,80	4,600	4,140	25 kHz
High $\mathcal{L}$	25	8,5	5,32	5,140	5,155	5,800	5,200	25 kHz

75 kHz x 33% safety factor = 25 kHz target for simulated rates

Threshold is defined as either 95% (e/γ, τ, j) & 90% (MET, μ) efficiency and is calibrated to uniformly match off-line energy.

*Isolation not used for electron triggers at low luminosity

ET=Total E_T, MET = Missing E_T, NI = Non Isolated

Trigger Physics Efficiencies

for 12 kHz ORCA4 simulated rate

Channel	Low $\mathcal{L}$	High $\mathcal{L}$	Triggers Used
H(200) $\rightarrow$ $\tau\tau$ $\rightarrow$hadrons	93%	60%	e1, τ1, j1, e2, τ2, j2
H(500) $\rightarrow$ $\tau\tau$ $\rightarrow$hadrons	99%	86%	e1, τ1, j1, e2, τ2, j2
H(170) $\rightarrow$ 4 electrons	100%	99%	e1, e2
H(110) $\rightarrow$ 2 photons	99%	98%	e1, e2
H(135) $\rightarrow$ $\tau\tau$ $\rightarrow$e, hadron	96%	72%	e1, e2, τ1, j1
H(200) $\rightarrow$ $\tau\tau$ $\rightarrow$e, hadron	96%	74%	e1, e2, τ1, j1
H(120) $\rightarrow$ Invisible (tag jets)	96%	58%	j1, j2, missing ET
H(120) $\rightarrow$ ZZ*$\rightarrow$ e, e, μ, μ		73%	e1, e2
H(200) $\rightarrow$ ZZ $\rightarrow$ e, e, jets		95%	e1, e2, j1, j2
tt $\rightarrow$ e, X	97%	82%	e1, j1, j2, j3, j4
tt $\rightarrow$ e, H+, X1 $\rightarrow$ e, τ, X2	94%	76%	e1, j1, j2, j3, j4

Note: e at low $\mathcal{L}$ does not require isolation

Post TDR Trigger Efficiencies

Channel	Low $\mathcal{L}$	High $\mathcal{L}$	Triggers Used	Comments
$tt \rightarrow eX^*$		66%	e1	Additional gain from jet trigger
$Z \rightarrow ee$		90%	e1 e2	e1: 77% e2: 72%
$W \rightarrow e\nu$		47%	e1 e2	Neutrino too soft to help trigger
H+ $\rightarrow$ τ + Missing ET + jjj		57%	t1 t2	jet,electron triggers also can contribute
mSUGRA		80%	j1 j2 j3 j4	soft narrow jets in τ trigger, 68% τ only
H(110) $\rightarrow$ bb	83%	40%	j1 j2 j3 j4 t1 t2	High lumi is hard to analyze
H(130) $\rightarrow$ bb	84%	40%	j1 j2 j3 j4 t1 t2	May improve with $\Delta\eta$ cut between two jets

Efficiencies use all triggers except muon triggers

Included in total 12 kHz ORCA4 simulated L1 Calorimeter Trigger rate

FNAL and Wisconsin Simulation

Analysis by P.Chumney and F. di Lodovico

Calorimeter Trigger Tunable Parameters - S. Dasu

Trigger Primitives Level

- **Fine grain bit to indicate energy profile within readout crystals or towers being combined**
  - Presently used to veto e/γ based on energy in the neighboring crystals (programmable cuts available)
  - Presently used to identify MIP signature in HB/HE $|\eta|<2.5$
  - Possible to suppress pile-up in HF (algorithm to be defined)

Trigger Tower Level

- **Separate E_T memory look-up for e/γ and τ/jet/E_T triggers**
  - Use for noise suppression, calibration, optimize trigger scale LSB (default is now 0.5 GeV for e/γ and 1.0 GeV for τ/jet/E_T)
- **H/E veto memory look-up**
  - The cut can be non-linear if desired
- **Active tower definition**
  - E_T cut programmable - adjust for pileup at high luminosity

Cal. Trigger Tunable Parameters II

4x4 trigger tower region level in "jet stream"

- E_T cuts if desired for pileup suppression
- Cut on active tower count to define t bit - can also be used to veto pileup and reduce spurious low E_T jets due to pileup

τ/jet candidate level

- Center region threshold
  - Center region E_T required greater than neighbor region E_T
  - Center region E_T can also be required above programmable threshold, as a function of η, to suppress pileup
- E_T memory look-up for each η region

Global level

- Trigger object E_T, η, ϕ cuts
- $\Delta\eta$, $\Delta\phi$ cuts, Correlations
  - Can require tag jet separation in h for H production in WW fusion - useful for invisible H decay
  - Can lower E_T thresholds by requiring high $\Delta\eta$, $\Delta\phi$ btw. electrons & jets to trigger on Drell-Yan W, Z for ECAL calibration

Calorimeter Trigger Object Data in Global Trigger

Central Isolated & nonisolated e/γ & τ candidates

- Top four highest E_T objects of each type
- Position (η, ϕ in 16 h x 18 f bins, $|\eta_{max}| = 2.5$)

A high E_T electron may appear in both e/γ and τ lists

Jets

A τ candidate is just a tagged jet

- Top four highest E_T objects in $|\eta| < 3$
- Top four highest E_T objects in $3 > |\eta| > 5$ separately
- Position (η, ϕ in 22 η x 18 ϕ bins, $|\eta_{max}| = 5$)
- # jets in several h, f regions above programmable cuts

Summed quantities

- Missing E_T ($|\eta| < 5$) computed from $\Delta\phi = 0.345$ region sums
- Sum E_T in all trigger towers ($|\eta| < 5$)
- Not planned but possible additional GCT algorithms
  - Sum E_T of jets (12 highest objects) requiring E_T > cut
  - Missing E_T from jets (12 highest objects) requiring E_T > cut

US CMS Physics Input

QCD Background Rate

- Target of 12.5 kHz met for muon & calorimeter triggers each (75 kHz/3 for safety split cal & mu)

Physics Efficiencies

- Thresholds selected for high p_T, higgs physics (SM, MSSM)

Opportunity:

- Help define global trigger menu and expand CMS physics reach
  - Keep within allowed bandwidth of 25 kHz for all triggers combined
    - Adjust E_T thresholds
    - Use η,ϕ locations of trigger objects
    - Optimize trigger parameters