

Integration of the CMS Regional Calorimeter Trigger into the Level-1 Trigger



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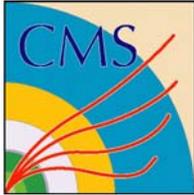
September 26, 2006

The pdf file of this talk is available at:

<http://indico.cern.ch/materialDisplay.py?contribId=54&sessionId=4&materialId=slides&confId=574>

See also the CMS Level 1 Trigger Home page at

<http://cmsdoc.cern.ch/ftp/afscms/TRIDAS/html/level1.html>



CMS Detector



31 Nations, 150 Institutions, 1870 Scientists

TRIGGER & DATA ACQUISITION

Austria, CERN, Finland, France, Greece, Hungary, Italy, Korea, Poland, Portugal, Switzerland, UK, USA

TRACKER

Austria, Belgium, CERN, Finland, France, Germany, Italy, Japan*, Switzerland, UK, USA

CRYSTAL ECAL

Belarus, CERN, China, Croatia, Cyprus, France, Italy, Japan*, Portugal, Russia, Switzerland, UK, USA

PRESHOWER

Armenia, Belarus, CERN, Greece, India, Russia, Taiwan (PC), Uzbekistan

RETURN YOKE

Barrel: Czech Rep., Estonia, Germany, Greece, Russia
Endcap: Japan*, USA

SUPERCONDUCTING MAGNET

All countries in CMS contribute to Magnet financing in particular:
Finland, France, Italy, Japan*, Korea, Switzerland, USA

FEET
Pakistan
China

FORWARD CALORIMETER

Hungary, Iran, Russia, Turkey, USA

HCAL

Barrel: Bulgaria, India, Spain*, USA
Endcap: Belarus, Bulgaria, Russia, Ukraine
HO: India

MUON CHAMBERS

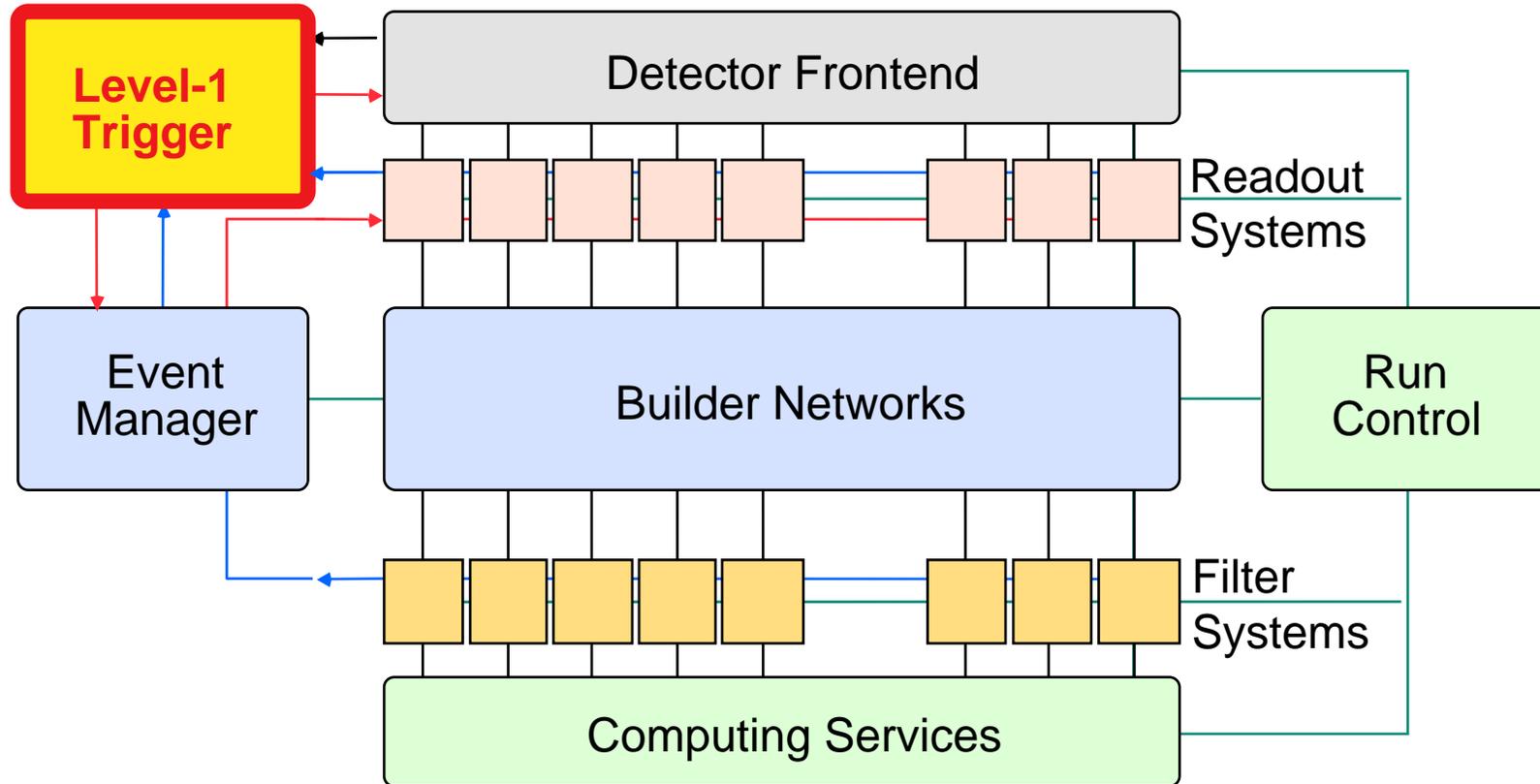
Barrel: Austria, Bulgaria, CERN, China, Germany, Hungary, Italy, Spain,
Endcap: Belarus, Bulgaria, China, Korea, Pakistan, Russia, USA

* Only through industrial contracts

Total weight : 12500 T
Overall diameter : 15.0 m
Overall length : 21.5 m
Magnetic field : 4 Tesla

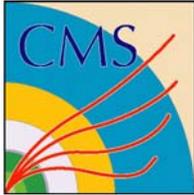


Trigger & DAQ Systems



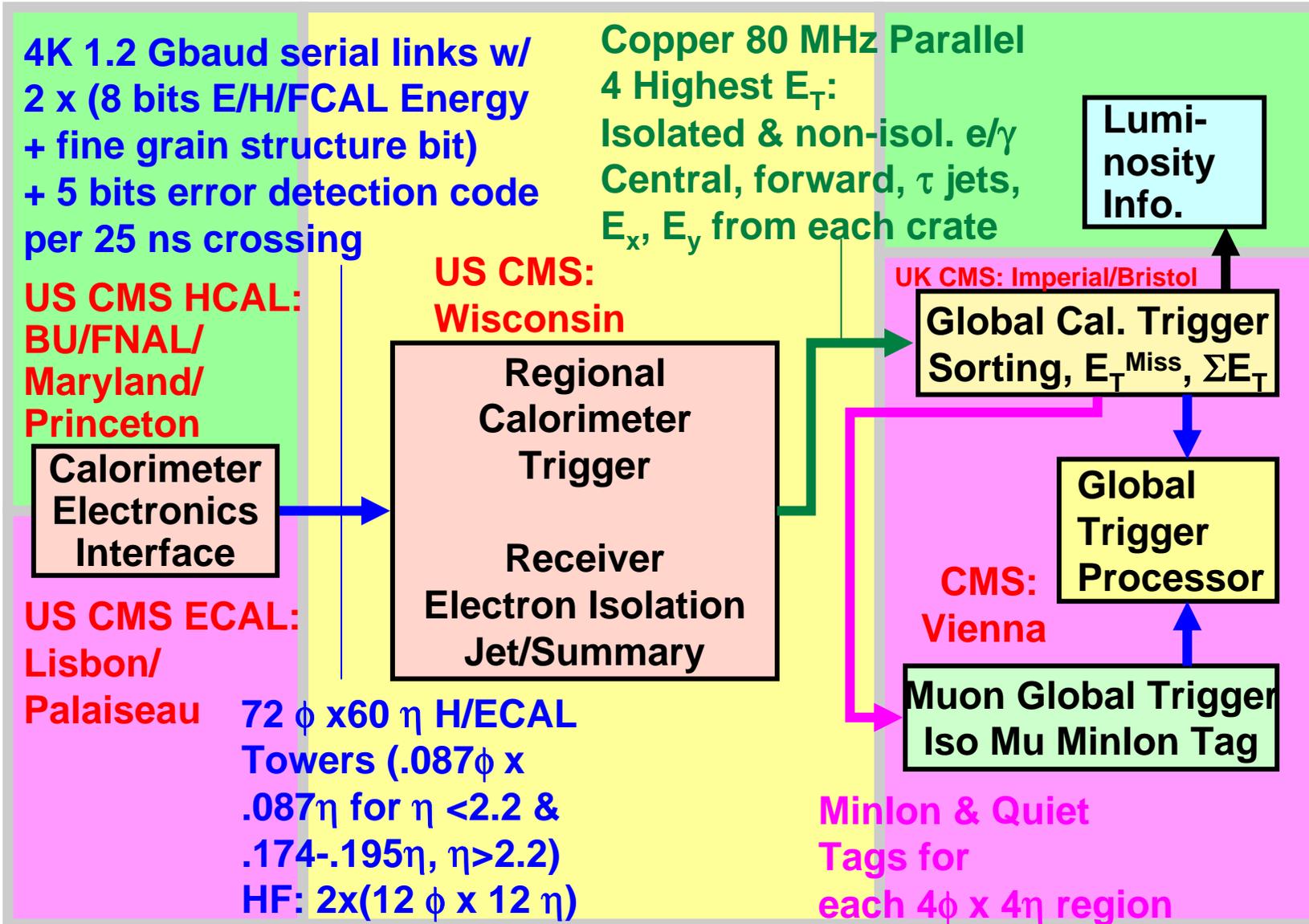
Level-1 Trigger Requirements:

- Input: 10^9 events/sec at 40 MHz at full Luminosity of $10^{34} \text{ cm}^{-2}\text{s}^{-1}$
- Output: 100 kHz (50 kHz for initial running)
- Latency: 3 μsec for collection, decision, propagation



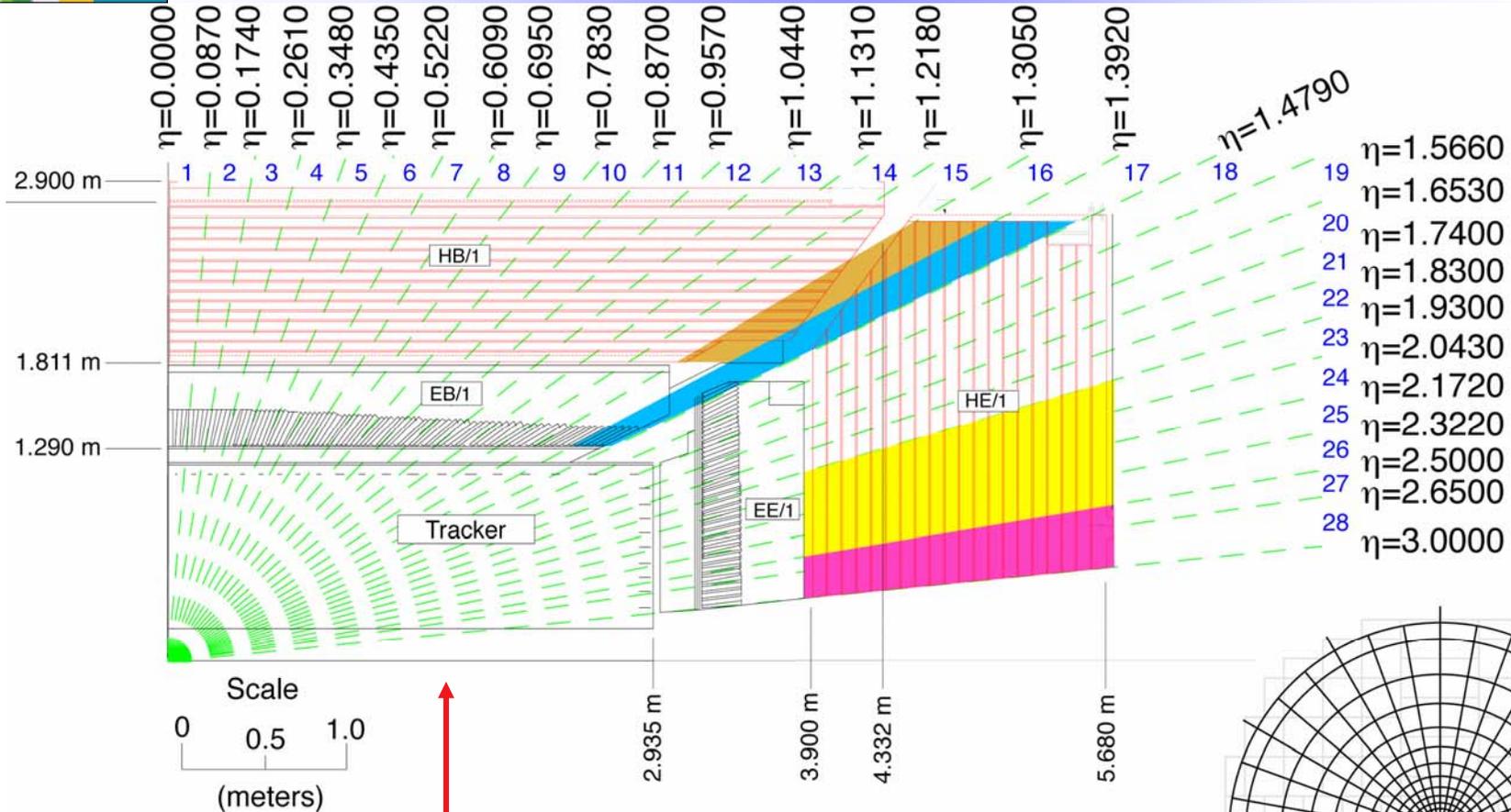
Calorimeter Trig. Overview

(located in underground counting room)





CMS Calorimeter Geometry

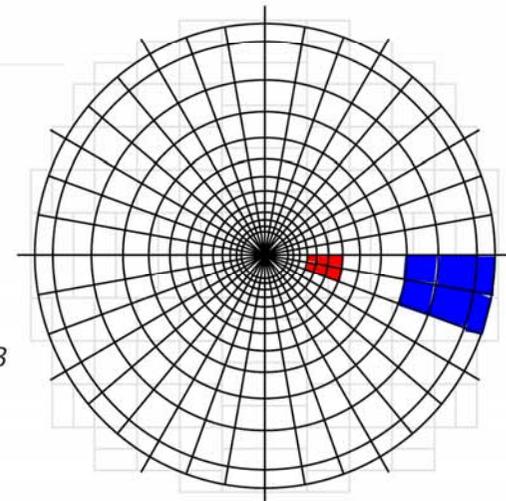


EB, EE, HB, HE map to 18 RCT crates

Provide e/γ and jet, τ , E_T triggers

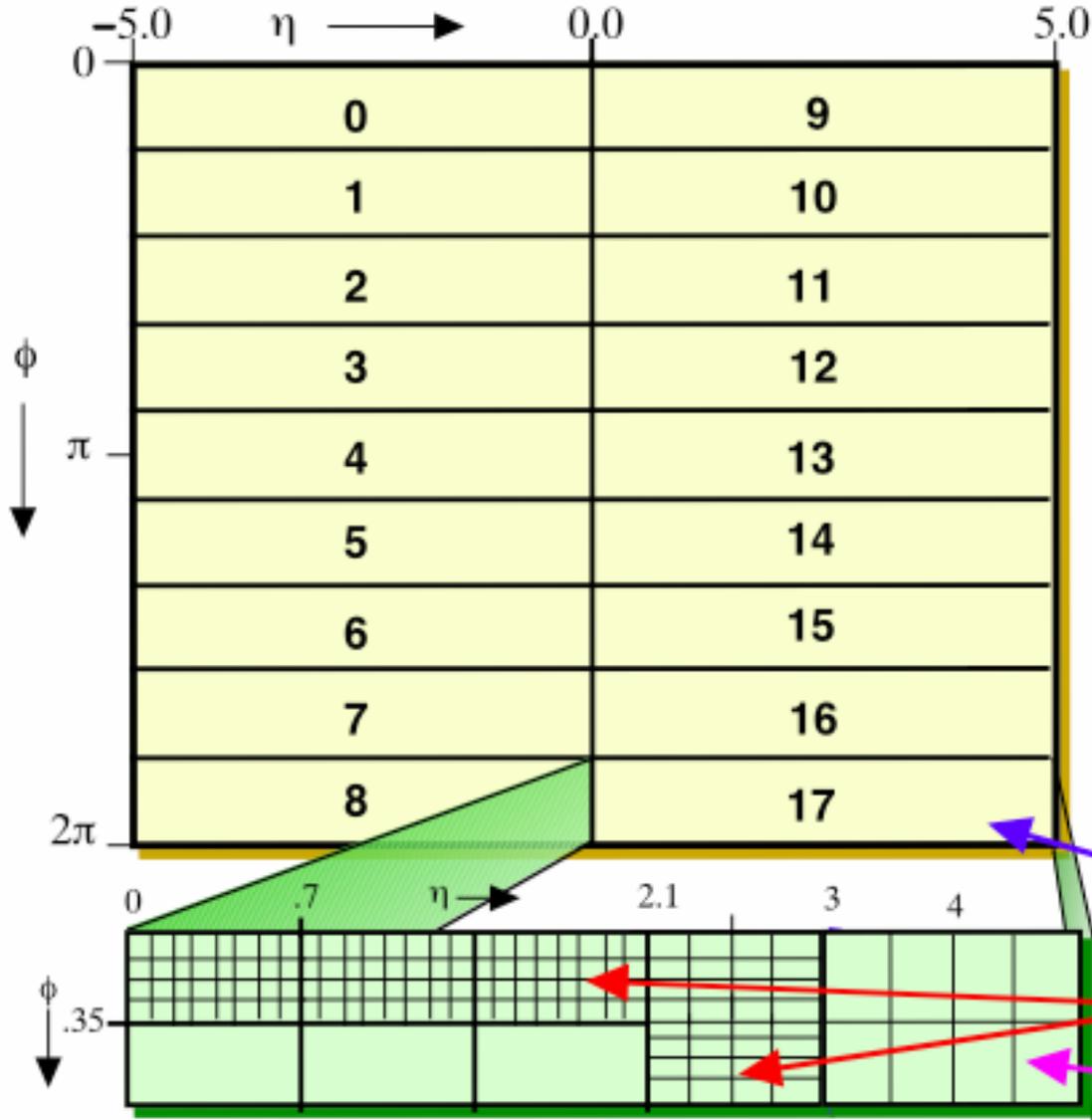
2 CMS HF Calorimeters mapping onto Trigger System HF Crate

Readout segmentation: $36\phi \times 12\eta \times 2z \times 2F/B$
 Trigger Tower segmentation: $18\phi \times 4\eta \times 2F/B$





Trigger Mapping



• 18 crates handle all of the CMS calorimeters seamlessly

• Each crate processes a 0.7 ϕ x 5.0 η region.

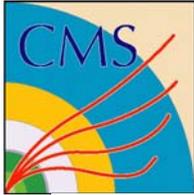
• Each Receiver/Electron ID card pair typically covers a .35 ϕ x 0.7 η region

• Single Jet/Summary card handles full crate

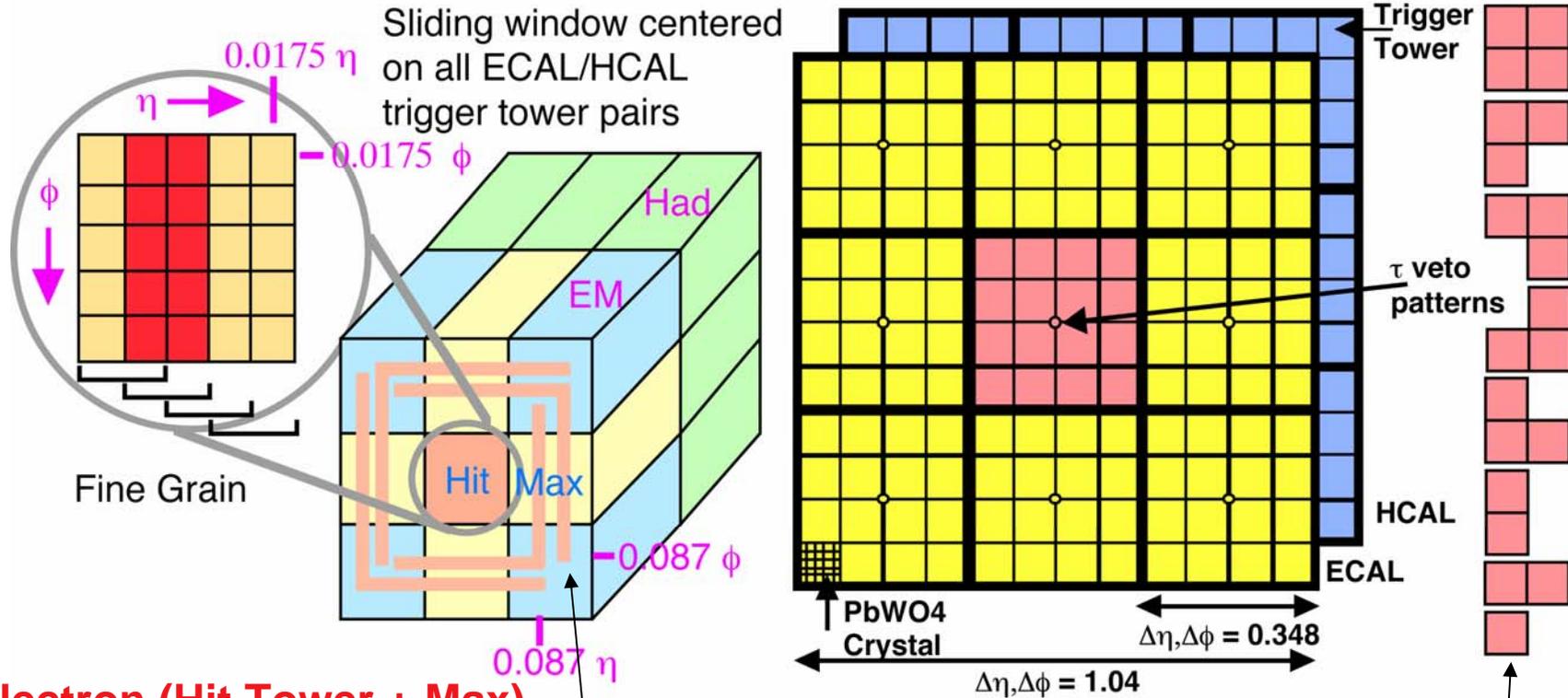
Calorimeter Regional Trigger Crate (18x)

Receiver Cards (x7/crate)

Jet/Summary Card processes HF data (3 < η < 5)



Calorimeter Trig. Algorithms



Electron (Hit Tower + Max)

- 2-tower ΣE_T + Hit tower H/E
- Hit tower 2x5-crystal strips >90% E_T in 5x5 (Fine Grain)

Isolated Electron (3x3 Tower)

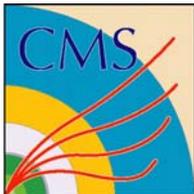
- Quiet neighbors: all towers pass Fine Grain & H/E
- One group of 5 EM $E_T < \text{Thr.}$

Jet or τE_T

- 12x12 trig. tower ΣE_T sliding in 4x4 steps w/central 4x4 $E_T > \text{others}$

τ : isolated narrow energy deposits

- Energy spread outside τ veto pattern sets veto
- Jet $\equiv \tau$ if all 9 4x4 region τ vetoes off



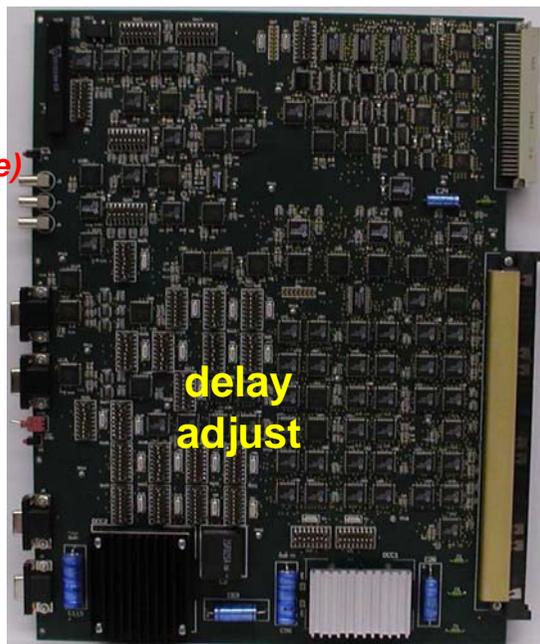
RCT Cards



Clock & Control

(18* - one per crate)

Master
Clock Crate
Input



delay
adjust

Provides 160 MHz and 120 MHz clocks,
reset, BC0 to entire RCT crate

Generated on board or received from Master
Clock Crate fed by CMS Trigger Timing and
Control (TTC) System

Fans out signals and adjusts phase to all
boards

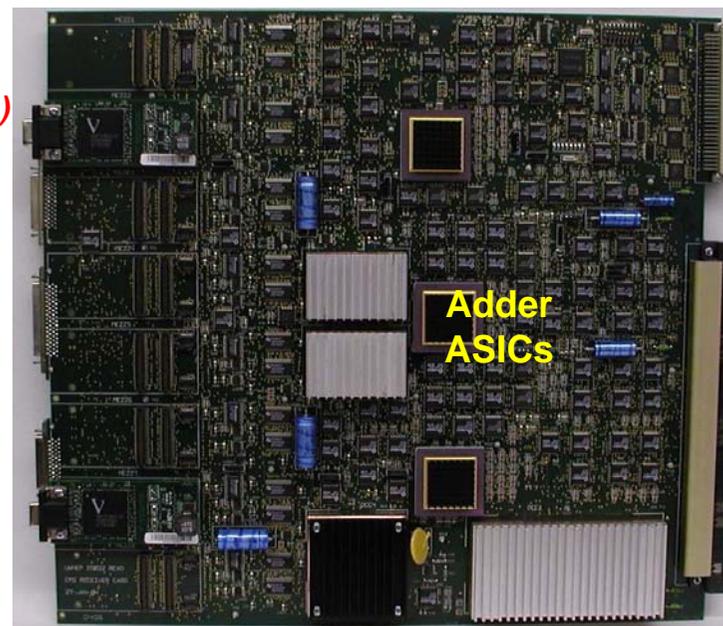
Clock and Reset timing set with delay adjust

Receiver

(126* - 7 per crate)

Data Sharing
on cables for
e/γ algo

Receiver
Mezzanine
Card (RMC)



Adder
ASICs

Receives 8x8 E/HCAL towers on 1.2 GB Cu Links
(Vitesse 7216-1) on RMC's

Phase ASIC: Deskew, Mux at 160MHz and provide
Test Vectors cycle LUTs

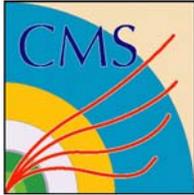
Memory LUT at 160 MHz

Adder ASIC: 8 inputs at 160 MHz in 25 ns.

BSCAN ASIC: Synchronizes shared data & Diff.
Output at 160 MHz to backplane

Reg. Sum E_T s, MIP, τ sent to Jet/Sum. Card

50 Tower E_T s & vetos sent to Electron ID Card



RCT Cards



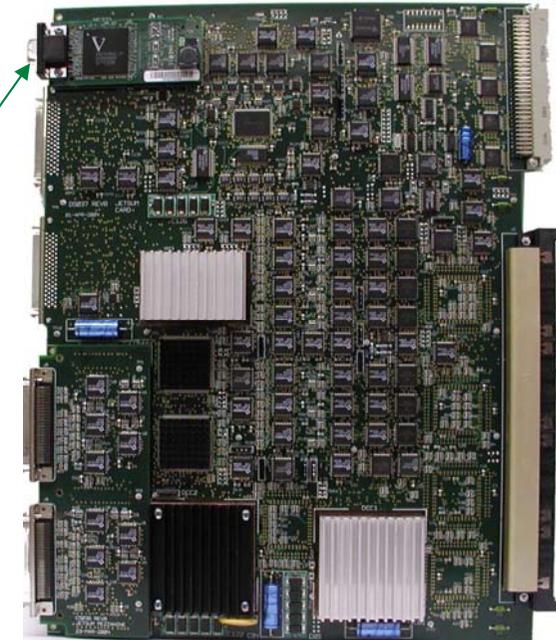
Electron Identification (126* - 7 per crate)



- Processes a 4x8 tower region at 160 MHz
- Uses Sort (disabled) ASIC for BP receive and the EISO ASIC fully implements e/γ algos
- LUT for E_T conversion
- Highest E_T iso and non-iso e/γ per 4x4 region sent to JSC for sorting and top 4 of each type forwarded to Global Calorimeter Trigger
- 7 cards send candidates over backplane to Jet Summary card

- 14 Isolated e/γ
 - 14 Non-Iso e/γ
- } one per 4x4 region

Jet Summary (18* - 7 per crate)



- Forward Calorimeter Input
- Output to Global Calorimeter Trigger

Electron/photon/muon

- Sort ASICs receive data on BP & find top iso. & non-iso.)
- 14 Quiet Bits by threshold on JS
- 14 Minlon bits from RC
- Forward Calorimeter (HF) functionality
 - RMC on board & LUTs for HF E_T's
- Region energies
 - HF and 4x4 tower sums (regions) to GCT for jets, τ, & calculation of global quantities total & missing E_T



Master Clock Crate and Cards

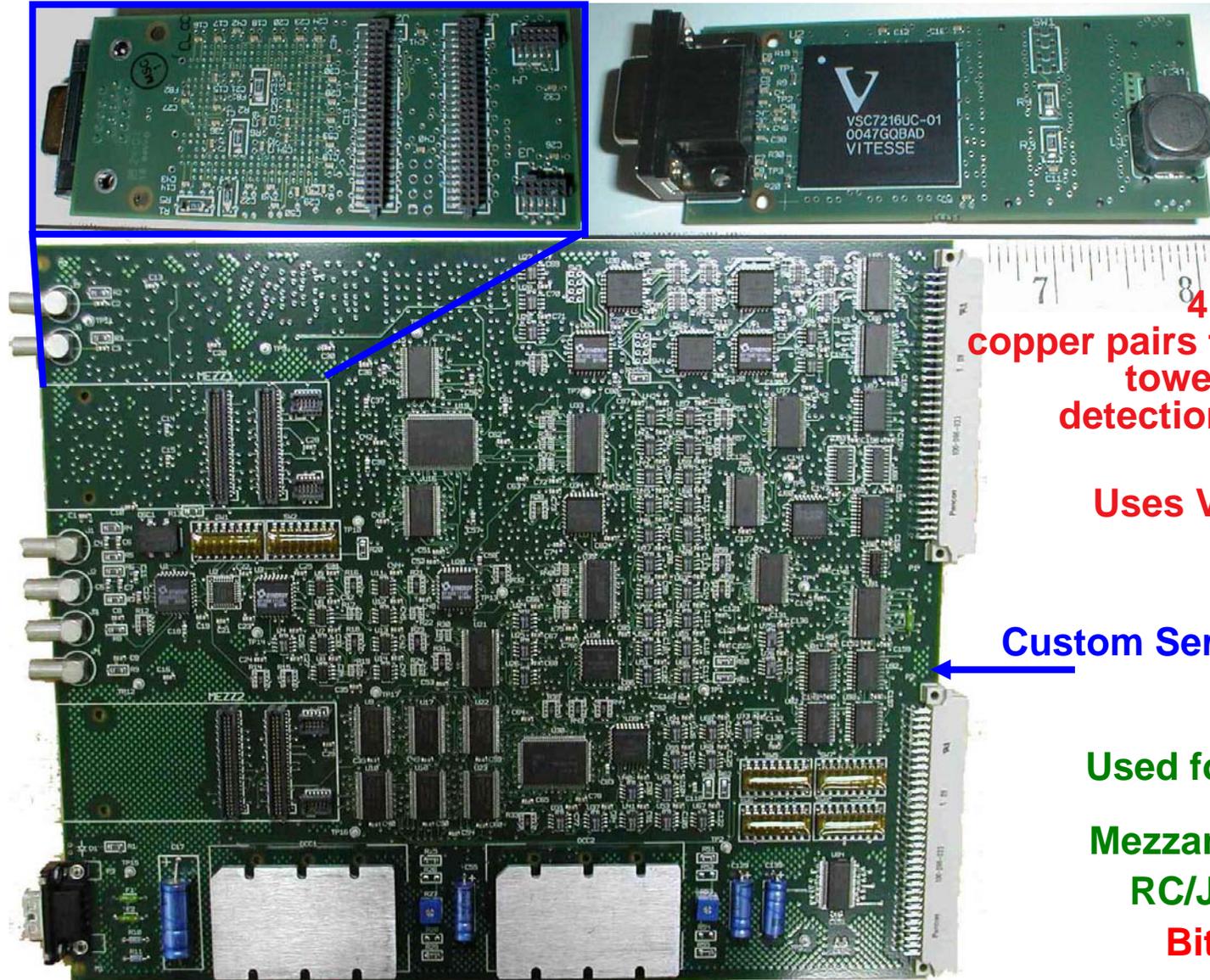


Production underway

- **Creates and fans out 160 MHz and 120 MHz clocks, Reset and Bunch Crossing Zero to RCT Crates' Clock and Control Cards**
 - **Clock Input Card (CIC)**
 - **Input from CMS Trigger Timing and Control system**
 - Provides machine clock, bunch crossing information, and CMS-wide control signals via custom modules
 - **On-board oscillator for standalone testing**
 - **Coarse and fine delay for each signal of up to 25 ns**
 - **Clock Fanout Card Midlevel (CFCM) & Clock Fanout Card To Crates (CFCC)**
 - **Accepts inputs from CIC and fans out to crates**
 - **Fine delay (100E195's) on boards for adjustment of delay to each crate**
- **Signal distribution will be on thirty-six four-pair low-skew cables (Kerpen MegaLine® 8) with VGA type D-Connectors. All cables will be the same length.**



RCT 4 Gbaud Copper Link Cards & Serial Test Card

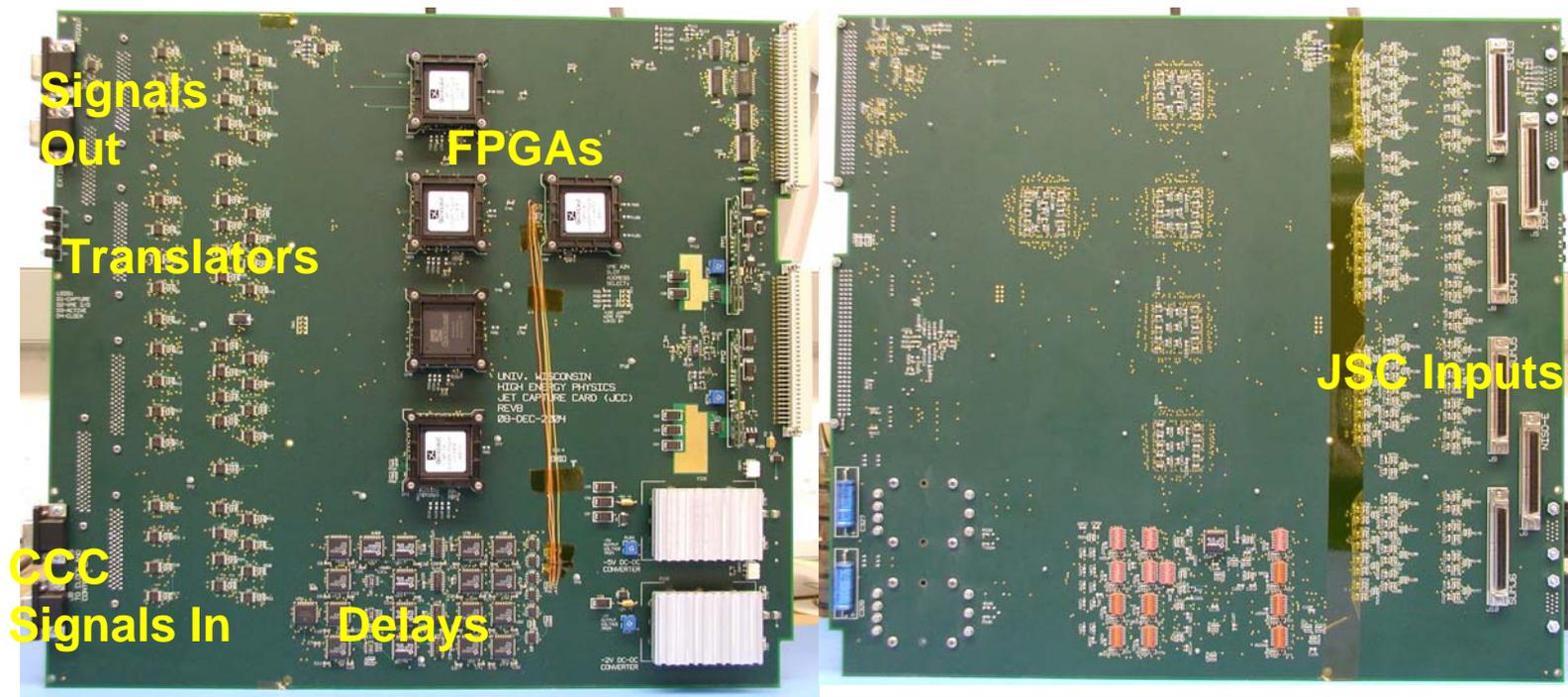


8 Compact Mezzanine Cards for each Receiver Card accept 4 x 20 m 1.2-Gbaud copper pairs transmitting 2 cal. tower energies w/error detection every 25 ns with low cost & power. Uses Vitesse Link Chips (7216-01).

Custom Serial Link Test Card to check links

**Used for integration with ECAL/HCAL, Mezzanine Card Testing, RC/JSC link validation
Bit Error Rate < 10⁻¹⁵**

Test Card: Jet Capture Card



Receives all the data from one RCT crate: 14 Reg. Sums, 8 HF E_T 's, 8 e/γ , and τ and μ bits on 6 SCSI type cables

- Located in spare VME slot of RCT crate
- Clocks, reset, and BC0 from Clock and Control Card on low-skew cable (Kerpen MegLine® 8)
- Triggers out on programmable thresholds
- Different data capture modes
- Used in final validation of RCT crates
- Used in integration tests with HCAL and ECAL Trigger Primitive Generators
- Trigger Output to be used in Magnet Test and Cosmic Challenge Phase II for an HCAL Trigger



Production of RCT Boards

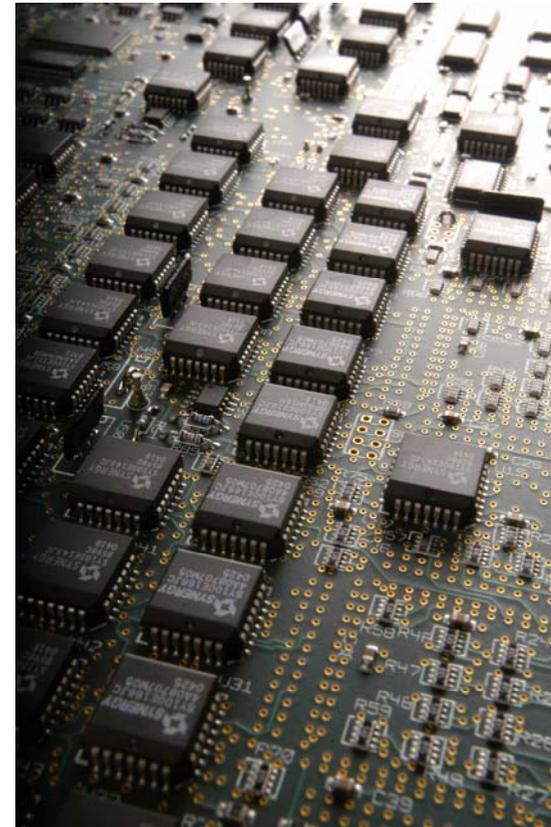


Full production available:

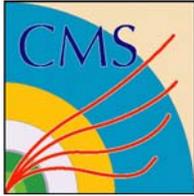
- **Standard RCT Boards**
 - Backplanes and Crates - 28 (BP) & 26 (crates)
 - Clock and Control Cards - 25
 - Receiver Mezzanine Cards - 1420
 - Receiver Cards - 158
 - Electron Identification Cards - 154
 - Jet Summary Cards - 25
- **Test Cards**
 - Serial Test Cards - 20
 - Jet Capture Cards - 10

In production

- **Master Clock Crate and Cards**
 - Clock Input Card in Revision B
 - Cards for Clock Fanout in Design
 - **Clock Fanout Card Midlevel**
 - **Clock Fanout Card to Crates**



Courtesy of Jeff Miller, University of Wisconsin, Madison

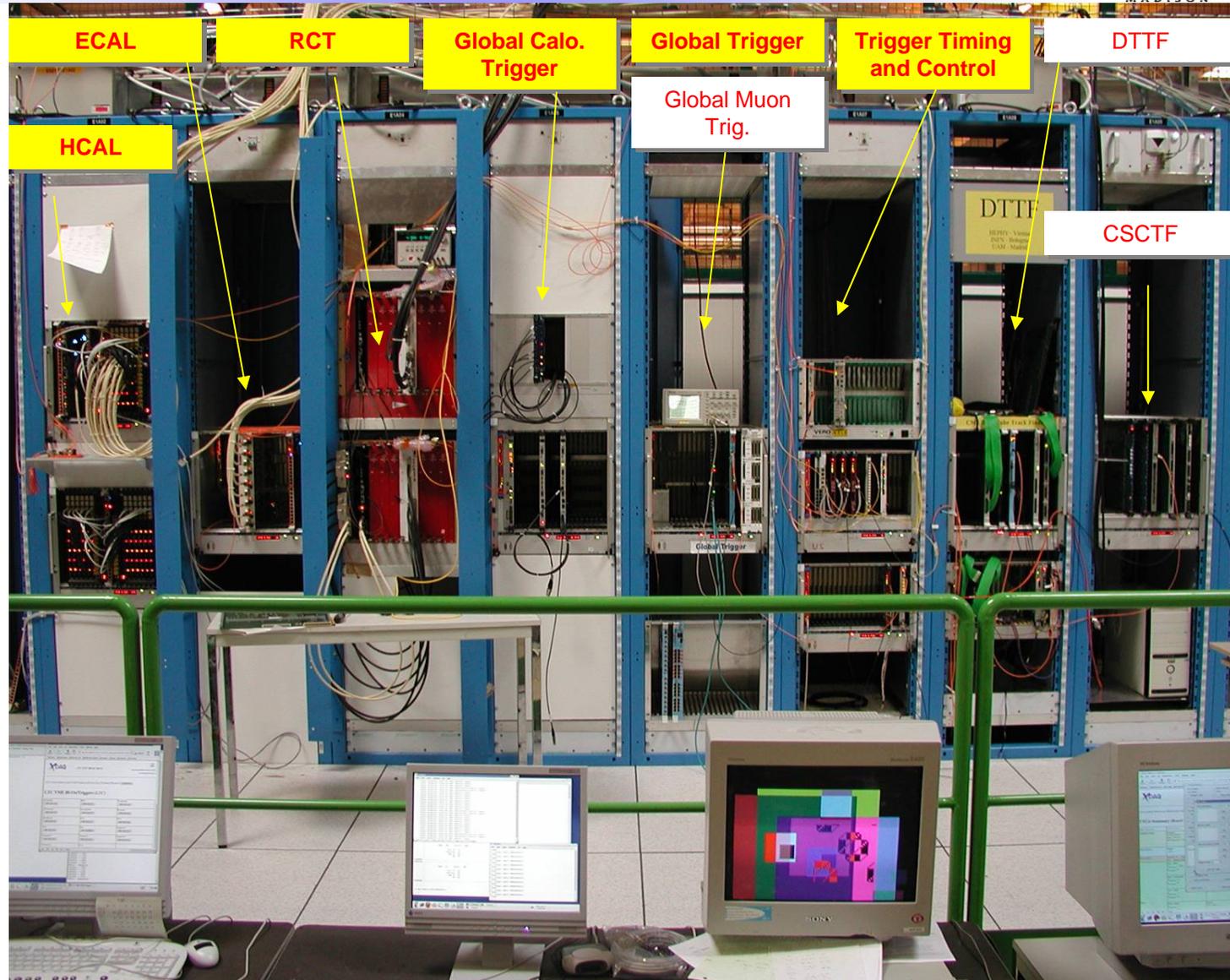


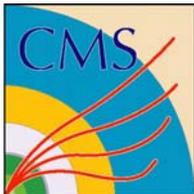
Electronics Integration Center at CERN



Large scale integration tests in central racks using common clocking involving trigger primitives, regional & global processing:

CMS Trigger Timing and Control System used for common clock





ECAL and HCAL Input to RCT



Both HCAL HTR (HCAL Trigger and Readout) and ECAL TCC (Trigger Concentrator Card) use a Serial Link Board (SLB) with the V2716-1 on it

- Configurable mezzanine card
 - Two Altera Cyclone FPGAs synchronize data for V2716 and calculate Hamming Code
- Clocking separate
 - Ensures data in time between subsystems

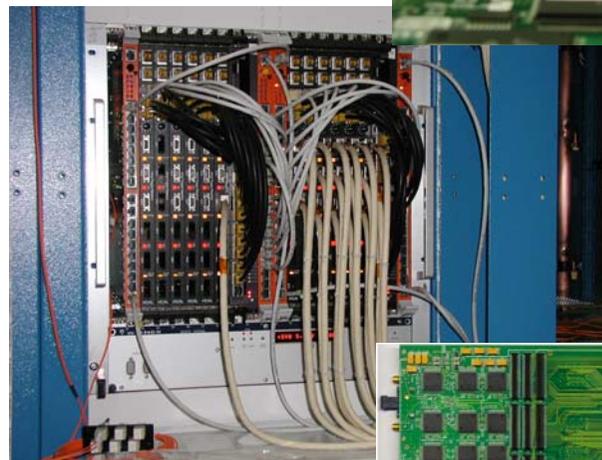
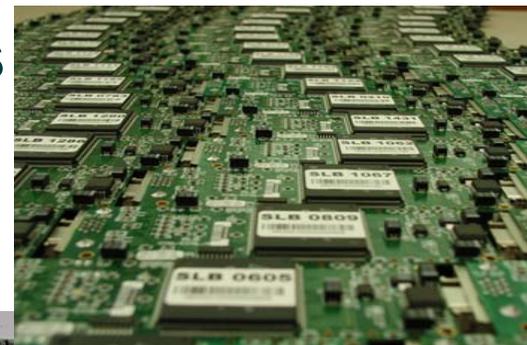
HTR

- Up to six SLBs send Tower Energies
- Receives data from Front-End on fiber

TCC

- Up to nine SLBs send Tower Energies
- Front-end data received on Fiber

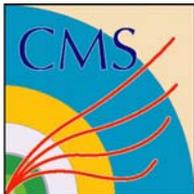
SLBs



HTR

TCC





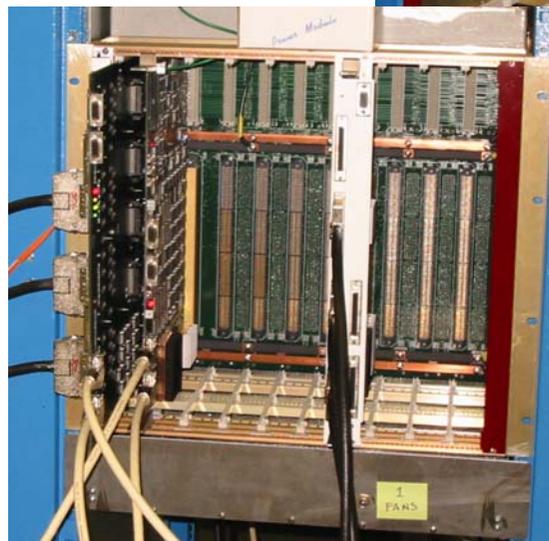
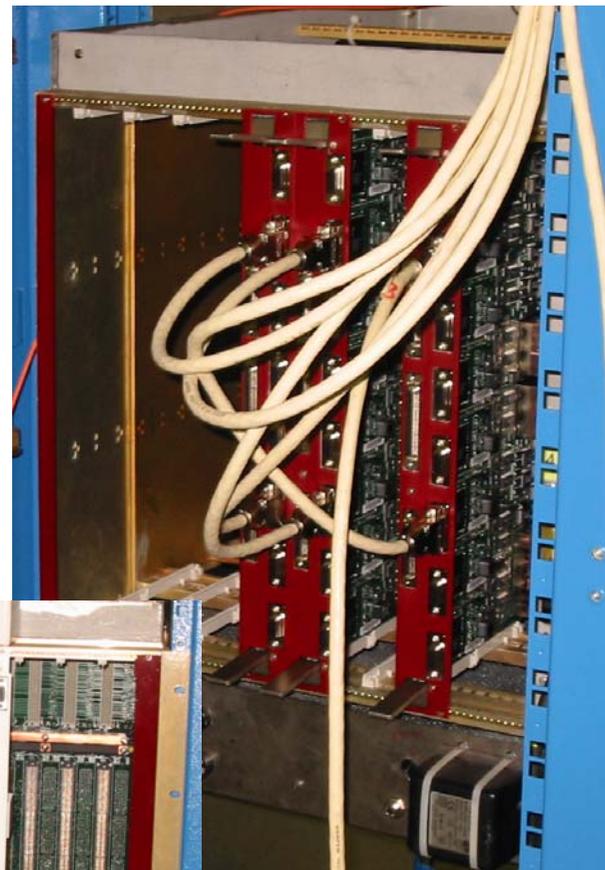
ECAL/HCAL/RCT Integration Tests



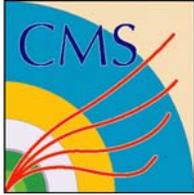
HCAL/ECAL Trigger Primitive Generators (TPGs) to RCT:

- **Common Clocking**
 - TTCvi in HCAL crate
- **HCAL HTR (HCAL Trigger and Readout) to RCT**
 - Used JCC
 - RC created 4x4 Tower sums
 - Verified value and alignment
 - 6 cables used - all in sync
 - Also: latency measurements w/PMT as source of HCAL TPG
- **ECAL TCC (Trigger Concentrator Card) to RCT**
 - Valid link established
 - Simple data sent and Validated with Oscilloscope
 - 2 channels on 20 m cables sent in sync to RCT

Rear of Crate with Cables from HCAL



Front of Crate with JSC and Cables to JCC



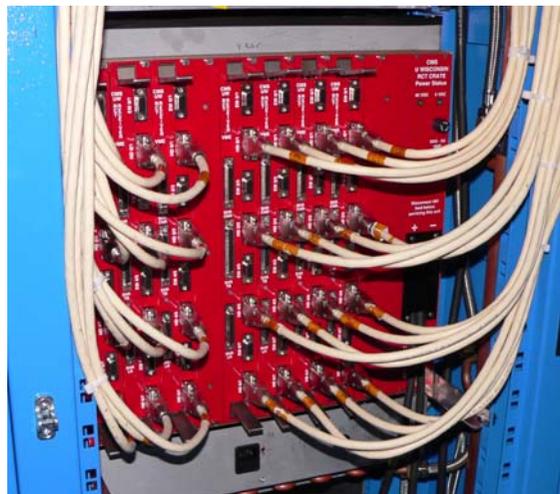
ECAL/HCAL/RCT Integration Tests



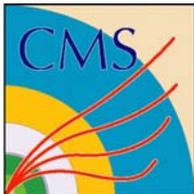
HCAL HTR & ECAL TCC to RCT

- 28 cables to RCT from 9 TCC & 19 HCAL HTR outputs
- Common clocking using CMS TTC system: LTC (Local Trigger Control), 3 TTCci's
- 28 channels in sync - links stable for >10 hours error free running

Front of Racks



Rear of RCT Rack



RCT Integration Tests



RCT to LTC and Global Trigger (GT) for MTCC

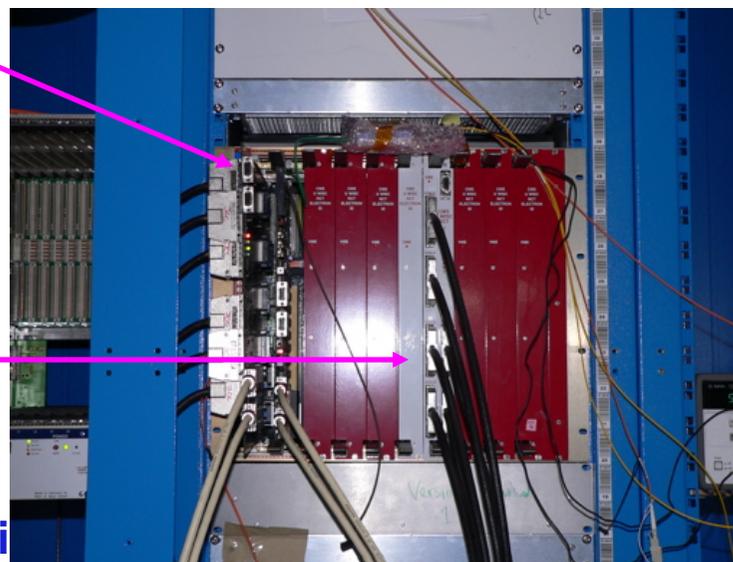
- Send trigger out with RCT Jet Capture Card
 - OR of towers in each half using MIP bit
- Validated connection with LTC/GT
 - GT ANDs top & bottom - reduces rate

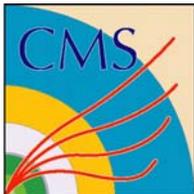
RCT- GCT Source Card

- Two RCT Crates to one GCT Source Card
 - 2 cables with differential ECL data
- Links validated - simultaneous data

ECAL - HCAL Pattern tests - to be done

- Use patterns that mimic those that would give
- RCT can “lookup” incoming data
 - LUTs can be programmed to duplicate incoming data
 - Use trigger emulation to help predict outputs
 - Readout two RCT crates with two JCC's
 - Test of algorithms
 - Test trigger software framework “Trigger Supervisor”





HCAL to RCT for Magnet Test and Cosmic Challenge (MTCC)



CMS barrel rings and endcap disks, parts of the muon system, ECAL, HCAL, and tracker are used to understand the magnetic field and perform a “slice test” of the CMS DAQ system

- **Two Phases: Summer (I) and Autumn (II) 2006**

Use RCT to create a trigger using HCAL MIP bits

- **MIP bit uses upper and lower thresholds and a LUT to avoid the case where shower leakage can incorrectly set it**
- **Installed one full RCT crate and support**
- **Receive 56 HCAL links to all inputs (448 towers)**
 - **Split cabling to create separate paths**
 - **HCAL top to HCAL inputs**
 - **HCAL bottom to ECAL inputs**
- **Send trigger out with JCC**
 - **OR of towers in each half using HCAL MIP bit**
- **Either connect to LTC (TTC) or Global Trigger (GT) and perform an AND of top and bottom HCAL**
 - **LTC: Small logic board before input will perform OR until GT ready**
 - **GT: can perform an AND of top and bottom**
- **Ready for timing in for Phase II**



HCAL to RCT in MTCC

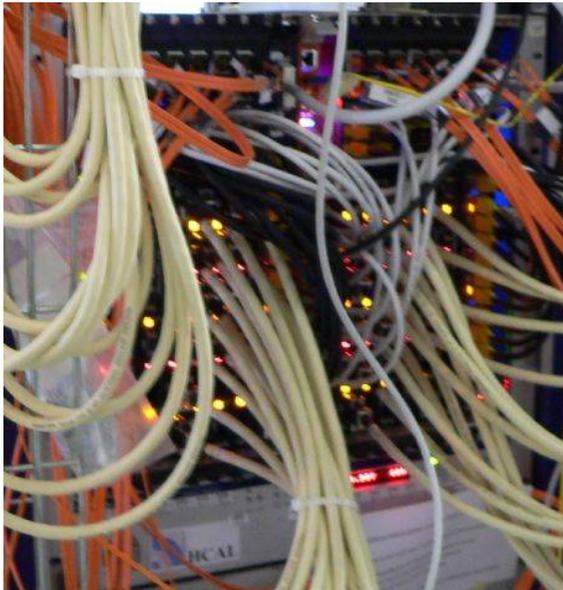


RCT:

- Crate ready and Links Tested
- Cable connections made to HCAL
 - Full modules above and below connected
 - Allows for top-bottom coincidence
 - TTC setup ready

RCT output

HCAL to RCT



RCT input





Commissioning Underground at CMS



Rack Infrastructure Installed

- 10 racks worth of crates, fans, custom rack monitoring, power and associated cabling.
- Card installation and integration starts in October
- Large scale - 1026 links to check



Rack Monitor Card and power chassis





Conclusions



Full production of CMS Regional Calorimeter Trigger boards

- Main RCT board production finished
- Test Boards STC and JCC produced to validate input and output and help with integration tests
- Master Clock Crate and cards in production

Integration in full swing

- Integration performed with HCAL HTR and ECAL TCC in Electronics Integration Facility
 - Alignment verified
 - Common clocking used
 - Long term stability checked
- RCT is part of CMS Magnet Test and Cosmic Challenge Phase II
 - Starts early October
- RCT Installation during October
 - Integration tests to continue underground as infrastructure is available
 - Integration Facility to remain as testing, debugging, and storage area