Installation and Commissioning of the CMS Regional Calorimeter Trigger

P. Klabbers, S. Dasu, T. Gorski, M. Grothe, M. Jaworski, J. Lackey, P. Robl, W.H.Smith

Physics Department, University of Wisconsin, Madison, WI, USA

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The pdf file of this talk is available at:

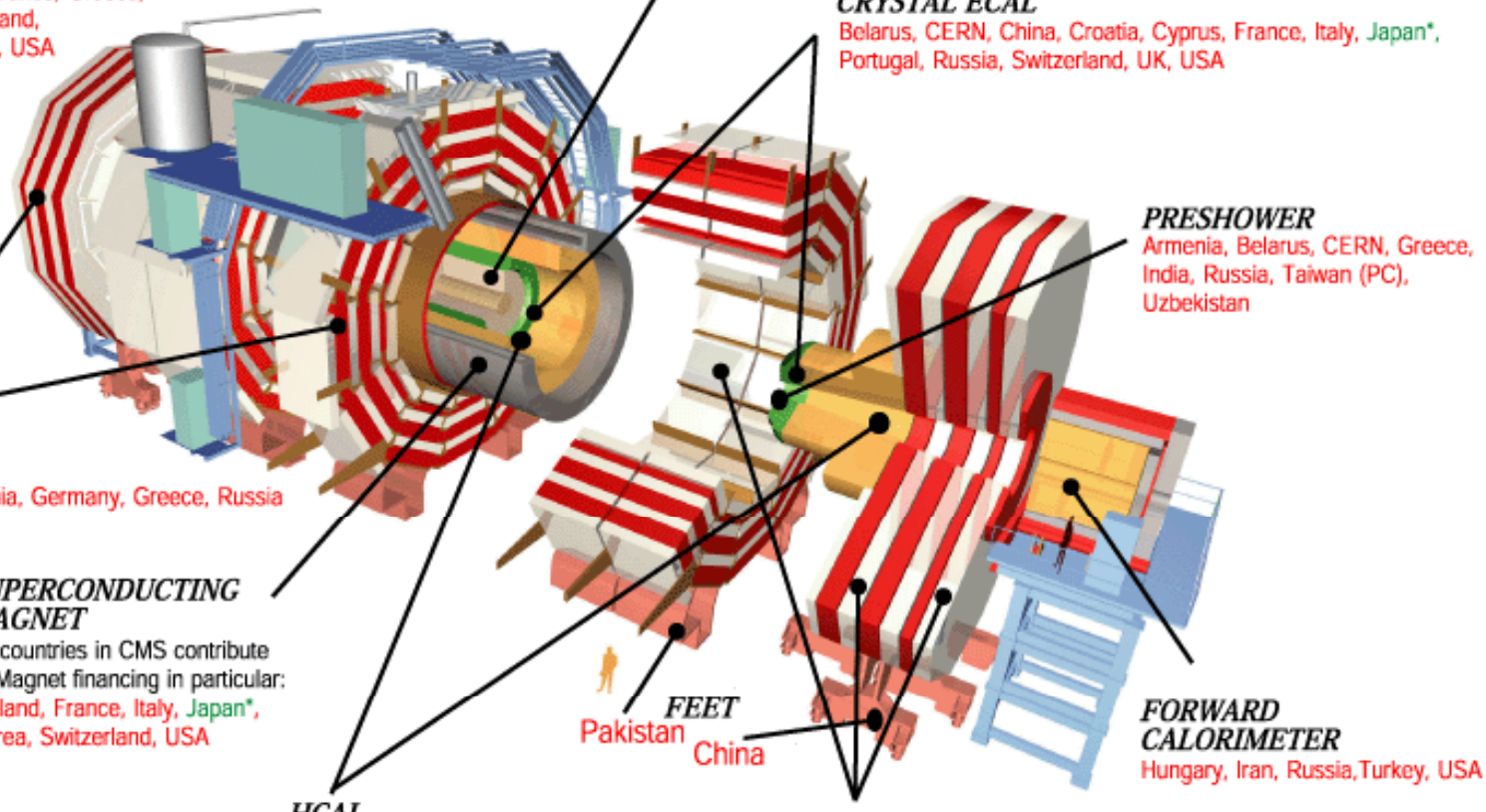
http://indico.cern.ch

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

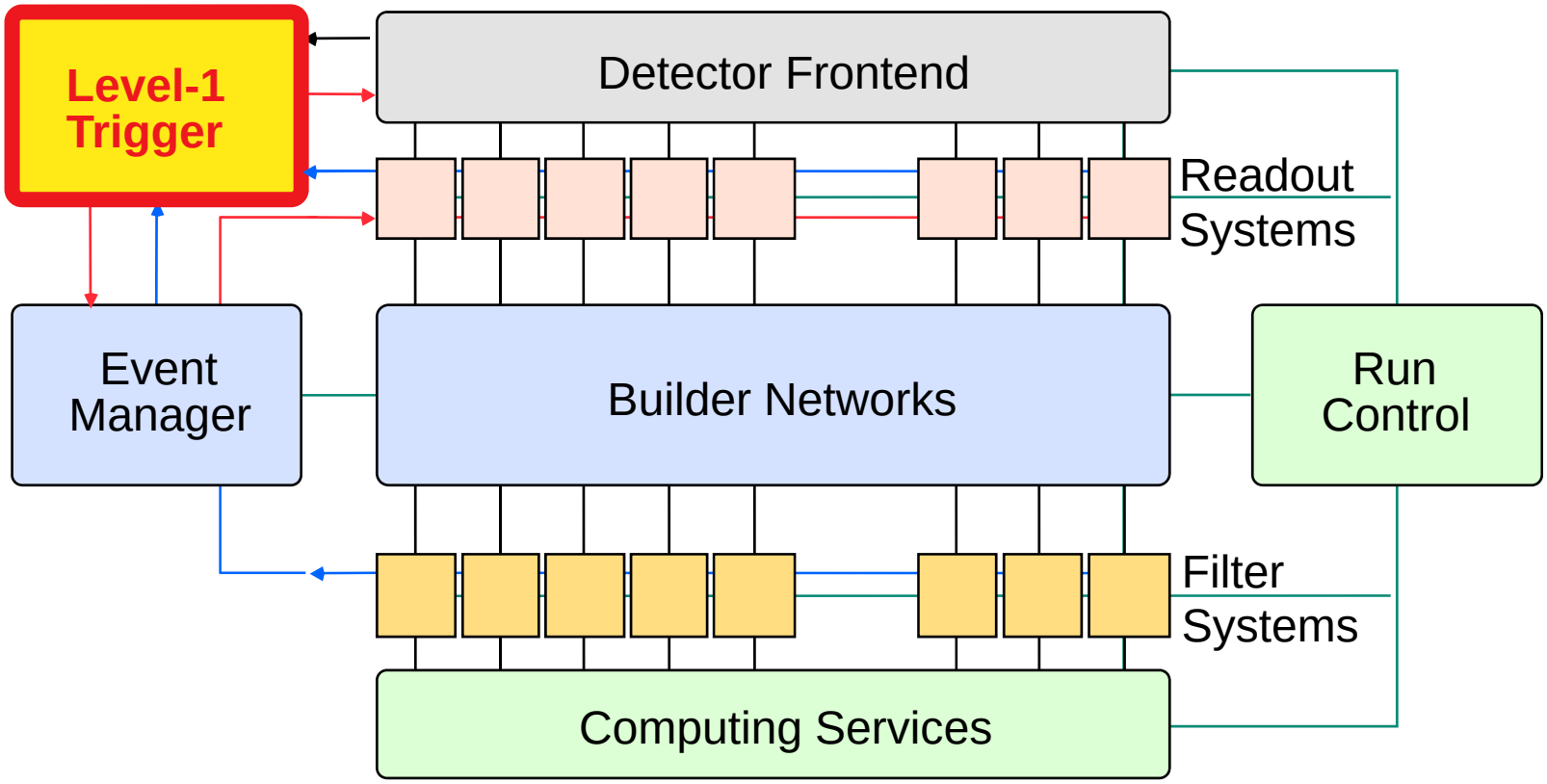
HCAL
Barrel: Bulgaria, India, Spain*, USA
Endcap: Belarus, Bulgaria, Russia, Ukraine
HO: India

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

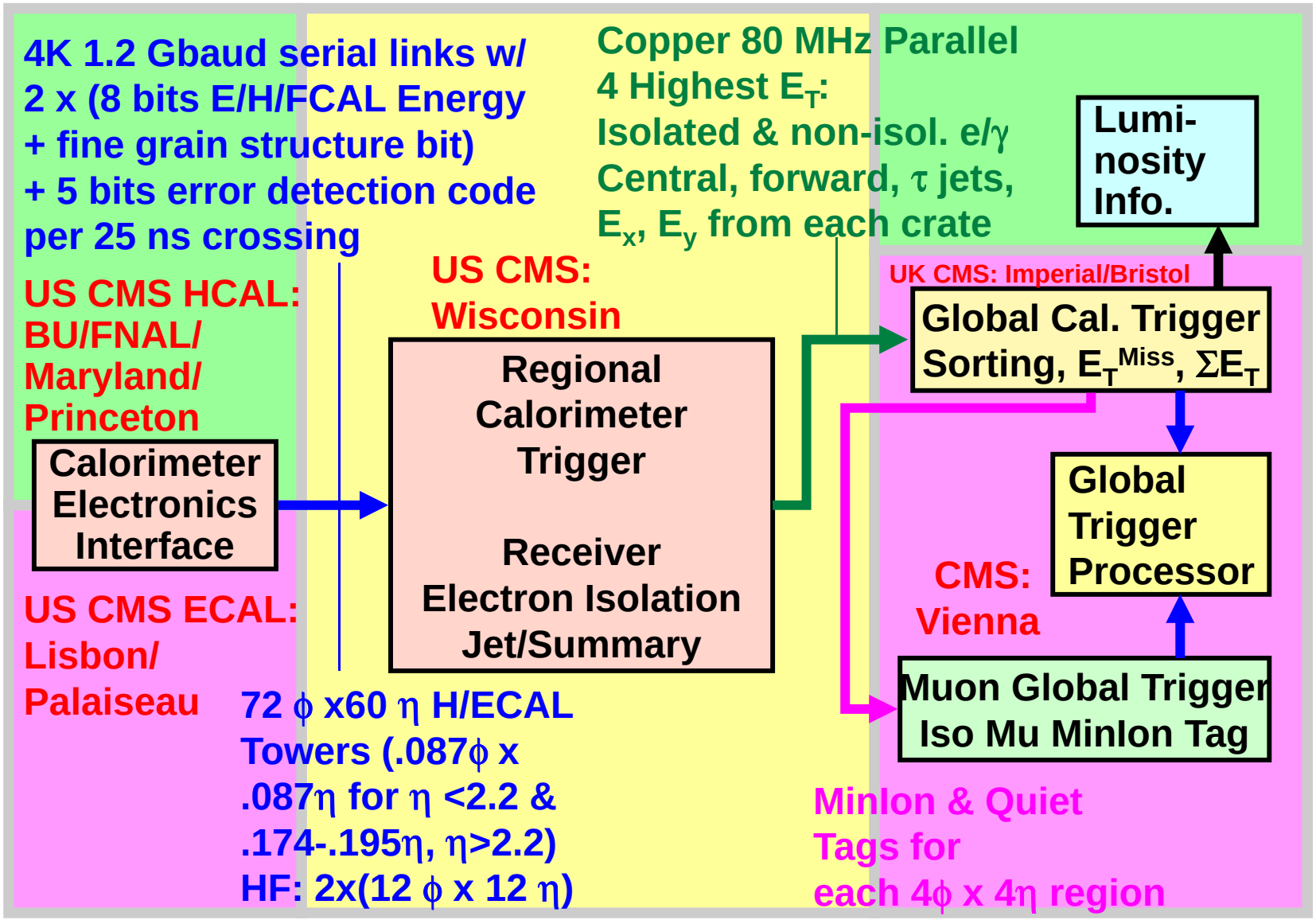


Level-1 Trigger Requirements:

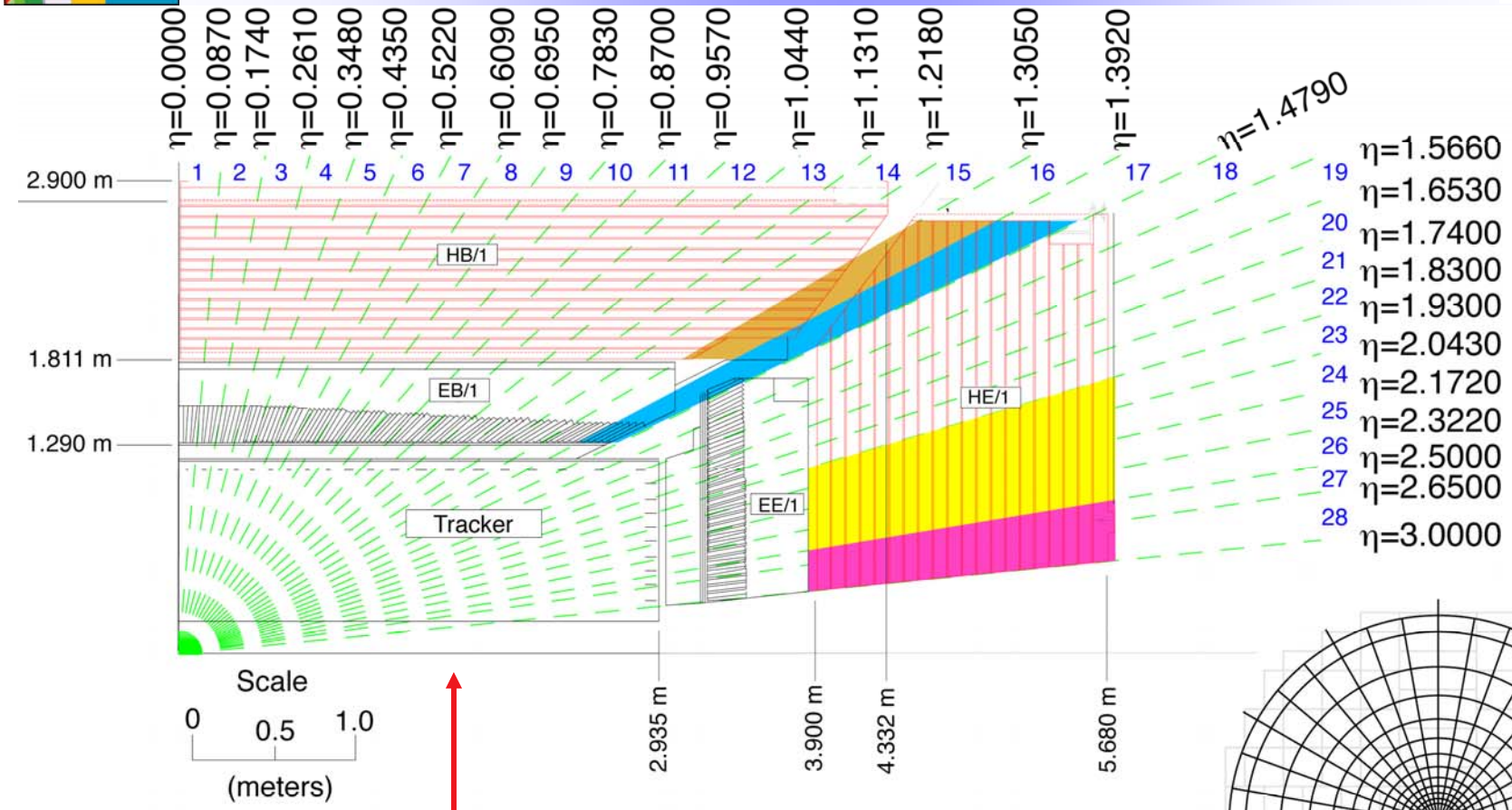
- **Input: 10^9 events/sec at 40 MHz at full Luminosity of 10^{34} $cm^{-2}s^{-1}$**
- **Output: 100 kHz (50 kHz for initial running)**
- **Latency: 3 μsec for collection, decision, propagation**

Calorimeter Trig.Overview

(located in underground counting room)



CMS Calorimeter Geometry



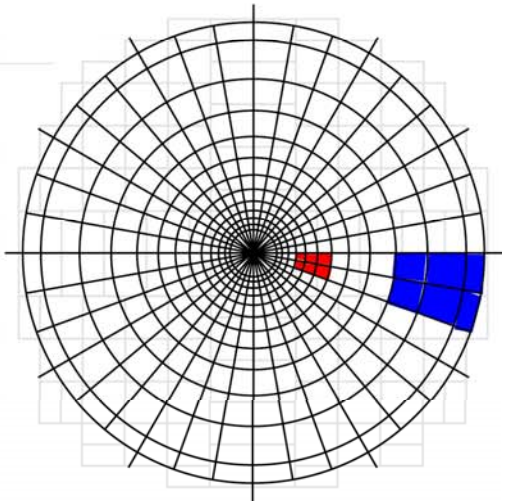
EB, EE, HB, HE map to 18 RCT crates

Provide e/γ and jet, τ, E_T triggers

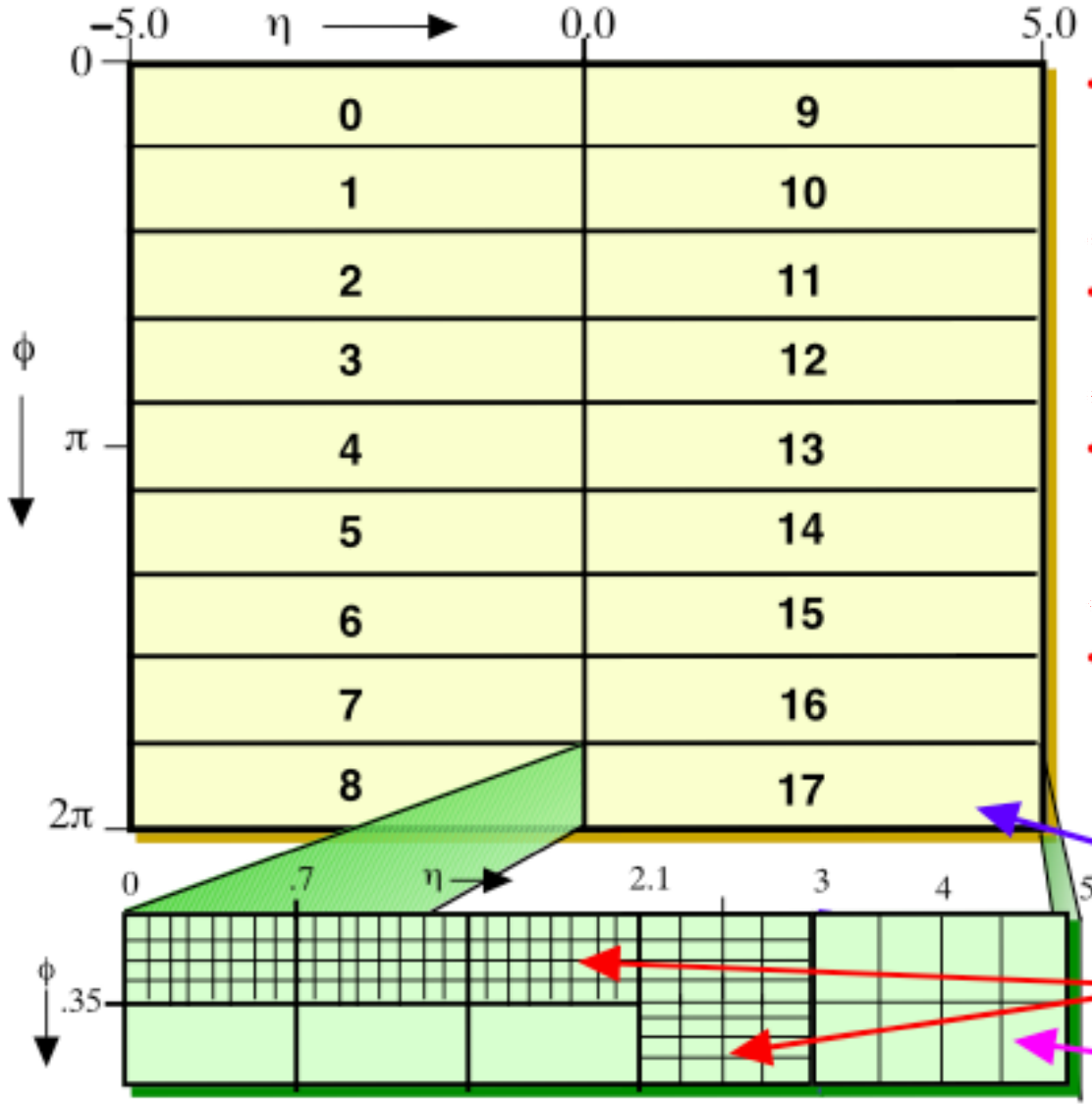
2 CMS HF Calorimeters mapping onto Trigger System HF Crate

Readout segmentation: 36ϕ × 12η × 2z × 2F/B

Trigger Tower segmentation: 18ϕ × 4η × 2F/B



Trigger Mapping



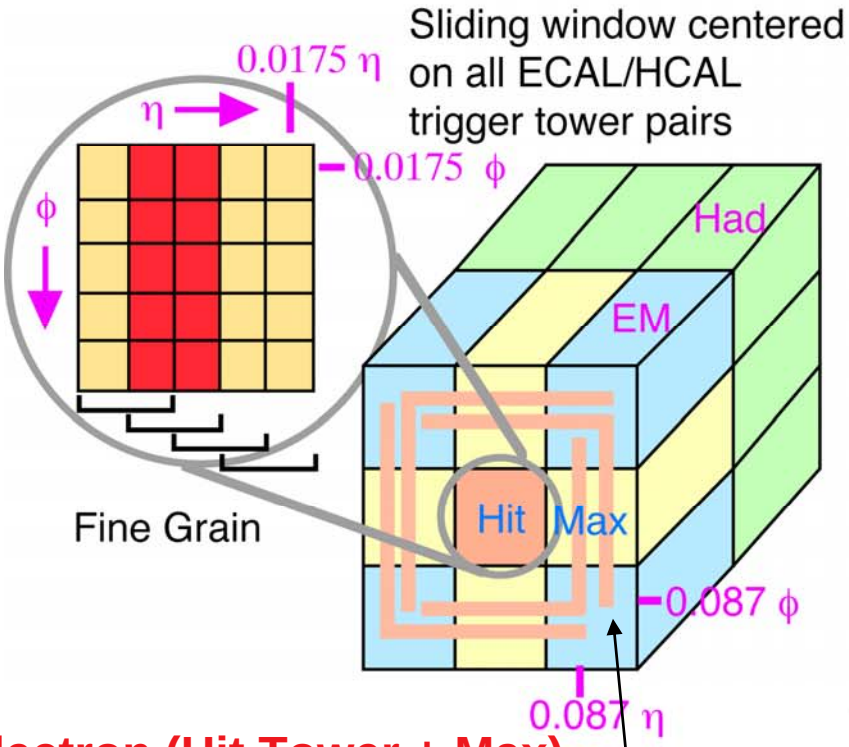
- 18 crates handle all of the CMS calorimeters seamlessly
- Each crate processes a 0.7 ϕ x 5.0 η region.
- Each Receiver/Electron ID card pair typically covers a .35 ϕ x 0.7 η region
- Single Jet/Summary card handles full crate

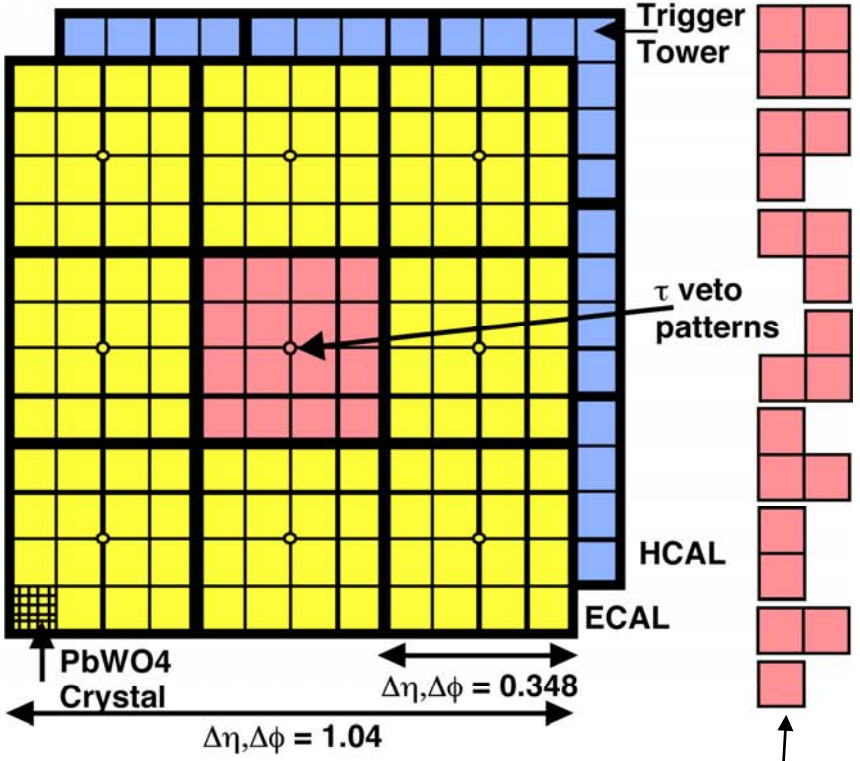
Calorimeter Regional Trigger Crate (18x)

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 < Thr.

Jet or τ E_T

- 12x12 trig. tower ΣE_T sliding in 4x4 steps w/central 4x4 E_T > others

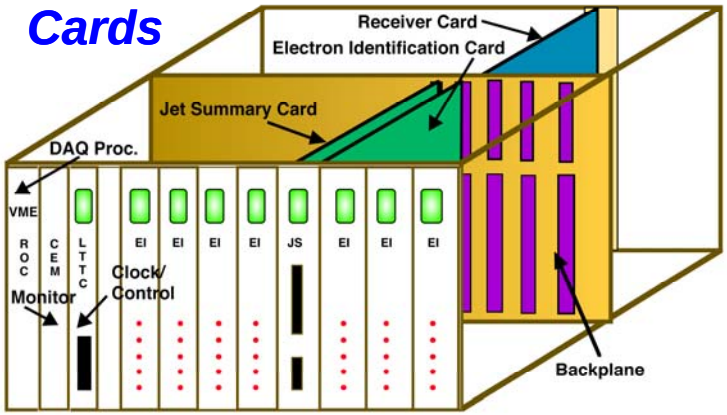
τ: isolated narrow energy deposits

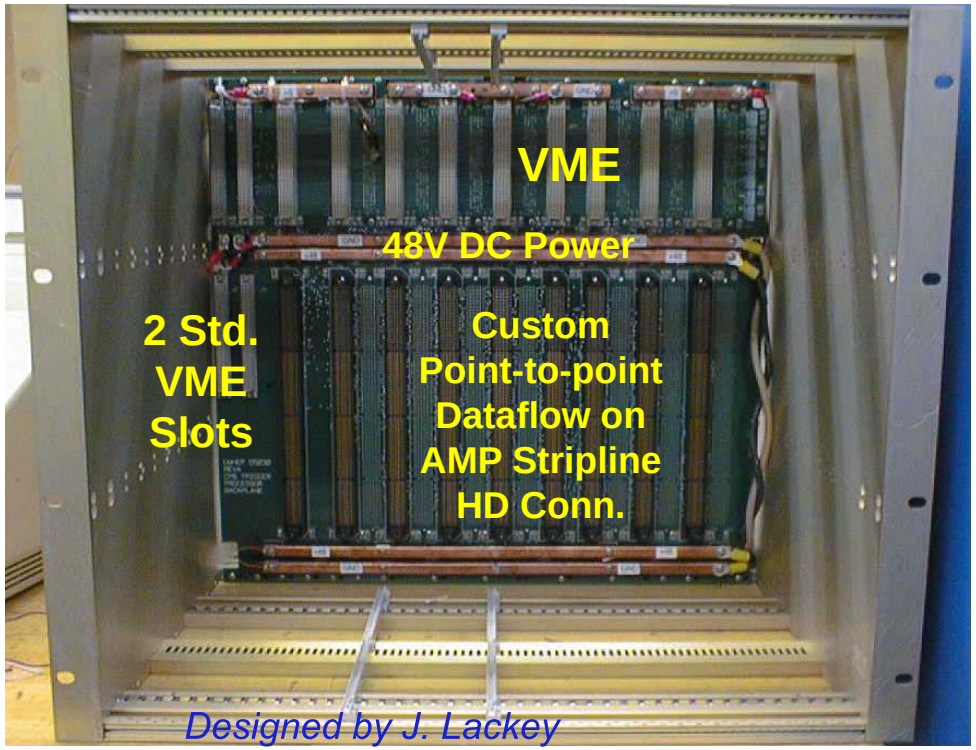
- Energy spread outside τ veto pattern sets veto
- Jet ≡ τ if all 9 4x4 region τ vetoes off

Regional Calorimeter Trigger Crate

Data from calorimeter Trigger Primitive Generators on Cu links at 1.2 Gbaud

- ***Into 126* rear Receiver Cards***





160 MHz point to point backplane, differential ECL with 0.4 Tbit/sec dataflow

- **Designed to incorporate algorithms: Non-Isolated Electron, Tau & Jet Triggers**
- **18* Clock&Control, 126* Electron ID, 18* Jet/Summary Cards**
- **Use 5 Custom Gate-Array 160 MHz GaAs Vitesse Digital ASICs**
  - Phase, Adder, Boundary Scan, Electron Isolation, Sort

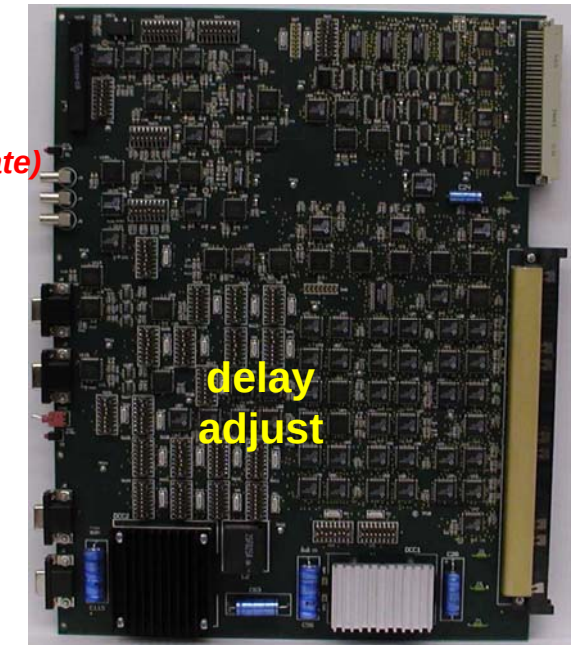
**Spares not included*

RCT Cards

Clock & Control

(18 - one per crate)*

Master Clock Crate Input



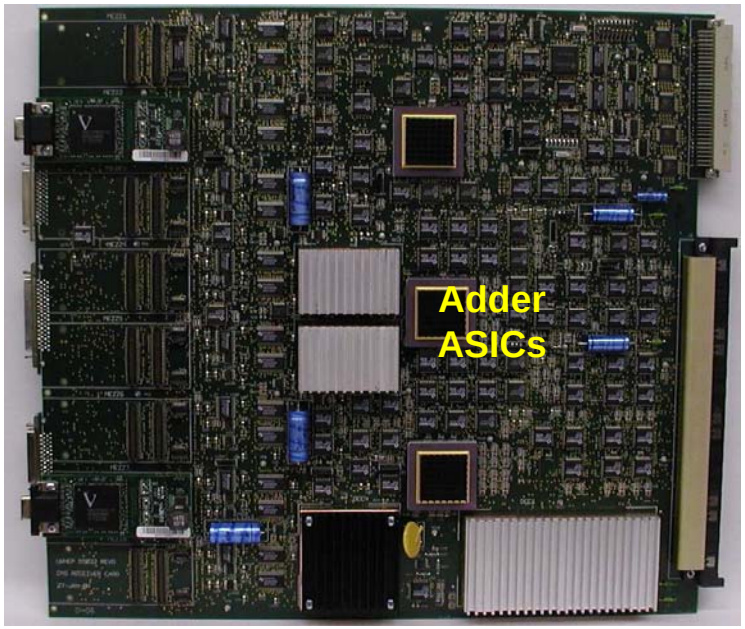
- Provides 160 MHz and 120 MHz clocks, reset, BC0 to entire RCT crate
- Generated on board or received from Master Clock Crate fed by CMS Trigger Timing and Control (TTC) System
- Fans out signals and adjusts phase to all boards
- Clock and Reset timing set with delay adjust

Receiver

(126 - 7 per crate)*

Data Sharing on cables for e/γ algo

Receiver Mezzanine Card (RMC)

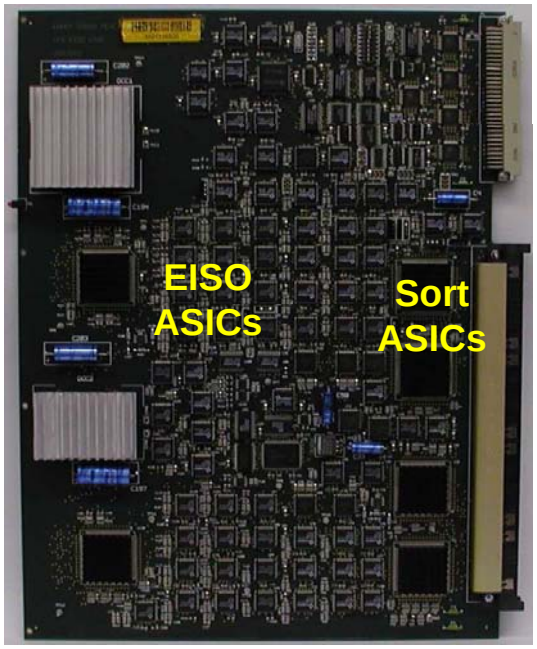


- Receives 8x8 E/HCAL towers on 1.2 GB Cu Links (Vitesse 7216-1) on RMC's
- Phase ASIC: Deskew,Mux at 160MHz and provide Test Vectors cycle LUTs
- Memory LUT at 160 MHz
- Adder ASIC: 8 inputs at 160 MHz in 25 ns.
- BSCAN ASIC: Synchronizes shared data & Diff. Output at 160 MHz to backplane
- Reg. Sum E_Ts, MIP, τ sent to Jet/Sum. Card
- 50 Tower E_Ts & vetos sent to Electron ID Card

*spares not included

RCT Cards

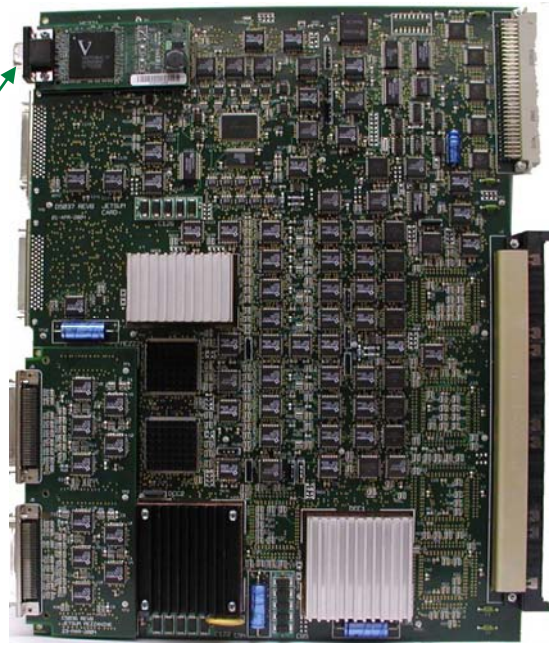
Electron Identification
(126* - 7 per crate)



Jet Summary
(18* - 7 per crate)

Forward Calorimeter Input

Output to Global Calorimeter Trigger



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**

Electron/photon/muon

- Sort ASICs receive data on BP & find top iso. & non-iso.)
- **14 Quiet Bits by threshold on JS**
- **14 MinIon 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

*spares not included

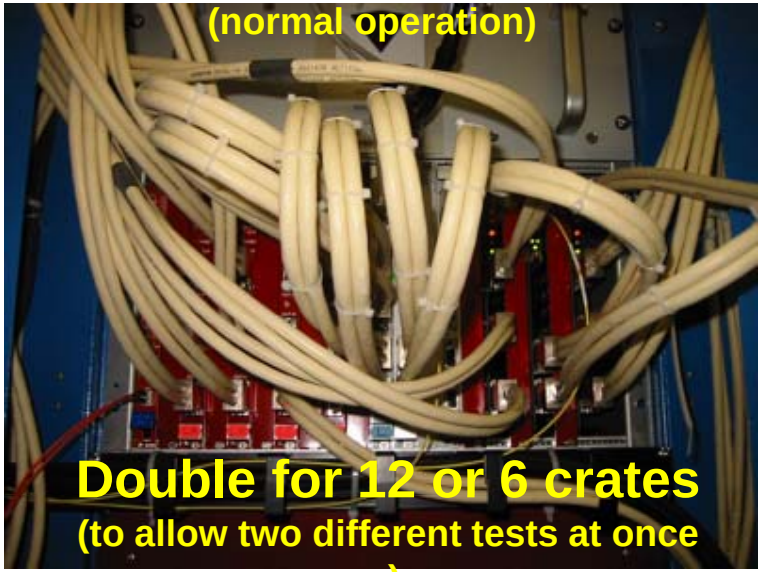
Master Clock Crate and Cards

Produced and installed

- **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 on thirty-six four-pair low-skew cables (Kerpen MegaLine® 8) with VGA type D-Connectors. All cables will be the same length.**

Single system for 18 crates

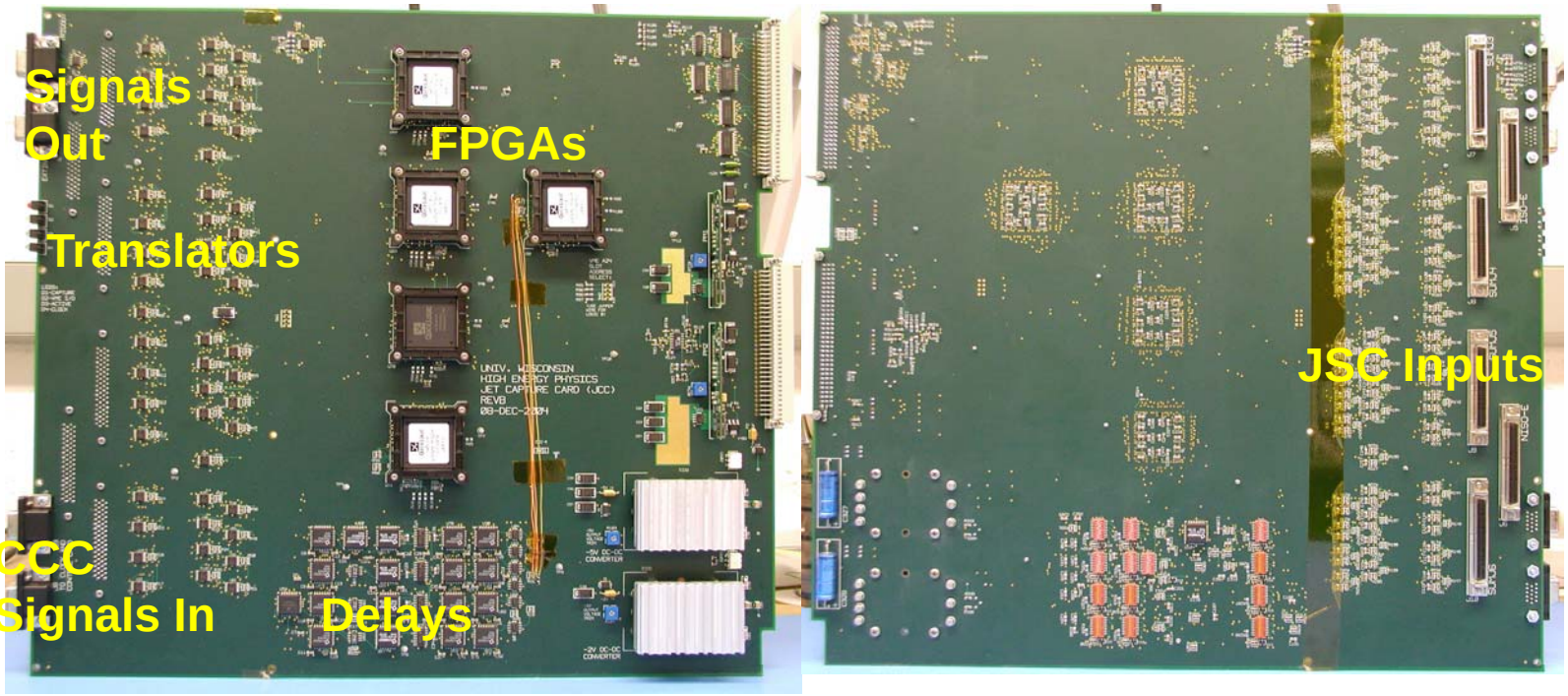
(normal operation)



Double for 12 or 6 crates

(to allow two different tests at once -)

Test Card: Jet Capture Card



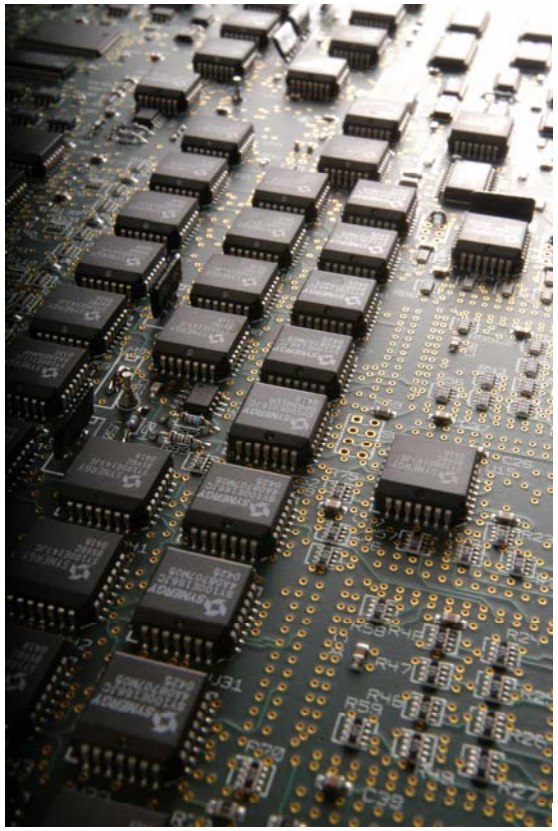
Receives all the data from one RCT crate: 14 Reg. Sums, 8 HF E_T's, 8 e/γ, and τ and μ bits on 6 SCSI type cables

- 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
- **Master Clock Crate and Cards**
  - Clock Input Card - 5
  - Cards for Clock Fanout
    - **Clock Fanout Card Midlevel - 7**
    - **Clock Fanout Card to Crates - 13**



Courtesy of Jeff Miller, University of Wisconsin, Madison

Commissioning Underground at CMS

Rack Infrastructure Installed: 10 racks with 20 crates, 40 fan trays, 10 custom rack monitoring and power chassis and associated cabling.

Front of Racks

Rack Monitor Card and power chassis

Rear of Racks

Commissioning Underground at CMS

Front of Racks

Extra cabling and cards for extensive testing!

Crate Rear

Crate Front

Rear of Racks

Cards installed and input cabling nearly complete - cabling currently under test.

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 Vitesse V2716-1 link chip 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 (a.k.a. Trigger Primitives or TPs)**
- **Front-end data received on Fiber**

TCC

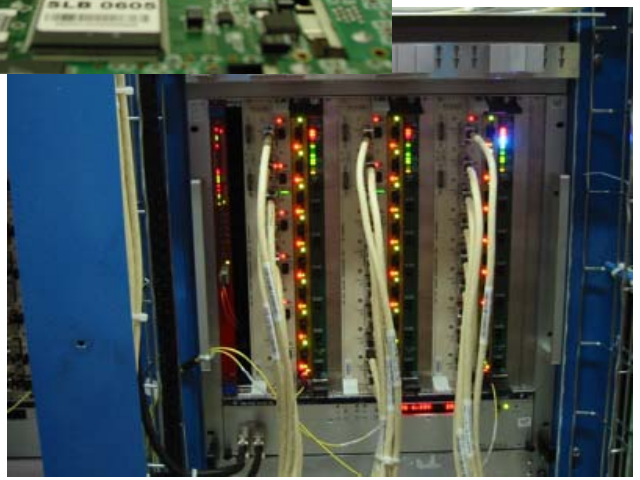
- **Up to nine SLBs send Tower Energies**

Both Receive front-end data on Fiber

HTR

SLBs

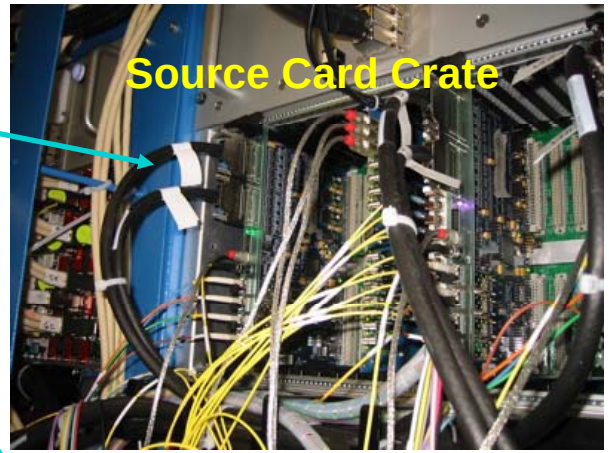
TCC



RCT Output to GCT

Each RCT crate is connected to 3.5 GCT Source Cards

- **RCT output differential ECL**
- **63 cards needed**
  - 2 RCT-GCT cable inputs/card
  - 45 Cards for Regional Sums
    - **Duplication needed by GCT on η=0 boundary for jet algo - only one input used**
    - **One source card has inputs from two different crates**
  - 18 Cards for iso-e/γ and noniso-e/γ candidates, muon bits
- **Source card sends data on optical fiber to GCT crate on lower level of electronics hall**
- **GCT turns regional sums into jet candidates and sorts jet and e/γ candidates and sends to Global Trigger (GT)**



ECAL TCC and HCAL HTR to RCT Pattern Tests

HCAL/ECAL send patterns Trigger Primitives of to RCT:

- **Common Clocking**
  - LHC Clock distribution in place - all systems receive the same clock fanned out from the LHC machine interface
  - Can use Global Trigger or Local Timing and Control board to send orbit signals and other 8-bit global commands to all systems
- **RCT LookUp Tables (LUTs) can be programmed to send data via RCT Sums and/or e/γ path**
- **HCAL HTR (HCAL Trigger and Readout) to RCT**
  - Used JCC to capture data: alignment and value checked
    - **RC receives TPs and creates 4x4 tower sums**
    - **Verified value and alignment at JCC**
    - **Single crossing with all TPs filled and an increment by 5 pattern from HCAL HTR verified as 4x4 sums**
- **ECAL TCC (Trigger Concentrator Card) to RCT**
  - Also used JCC to capture: alignment and value checked
    - **Single crossing with all TPs filled sent to Sums path - result seen as 4x4 sum**
    - **A single tower per bunch crossing sent in incrementing pattern become isolated electrons, as expected**

ECAL/HCAL/RCT/GCT Pattern Tests

HCAL HTR & ECAL TCC to RCT to GCT

- **One RCT crate used**
- **Common clocking used**
- **Verified phase of data arriving**
  - RCT can check phase of 120 MHz data clock with 40 MHz LHC clock and verify alignment of data
- **HCAL HTR and/or ECAL TCC**
  - Sent constant data on one Bunch Crossing
  - Sent increment pattern
- **RCT uses an identity LUT and sends output to GCT Source Card**
- **GCT SC captured data**
- **ECAL TCC data was captured at each step and sent through the GCT SC to the GCT Concentrator Card (just before the Global Trigger)**
  - Checked with L1 Trigger Emulator (Software) predictions
    - **Found bugs in firmware and software**
    - **Repeated tests and verified fixes were correct**

Full Trigger Chain: ECAL/RCT/GCT/GT Pattern Tests

ECAL TCC sends patterns

- Simple one trigger tower (iso-e) increment to RCT
- RCT uses an identity LUT and sends output to GCT Source Card
- GCT SC to GCT concentrator to Global Trigger PSB
- Data captured at all levels and compared to L1 Trigger Emulator prediction
- Data matched software emulator except for a phi index mismatch
- Good hardware/emulator agreement with more complex patterns and RCT e/γ LUT's LSB of 0.5 (same as emulator):
  - Simulated 35 GeV electrons spanning multiple trigger towers in one 4x4 calo tower region and compared to emulator prediction
  - Duplicate the 35 GeV electrons in another RCT crate and check synchronization and compared to emulator
- Next steps
  - Complex patterns to test sort algorithms, isolation in RCT, GCT, and GT
  - Long term pattern verification (available from GT)
  - Expand to larger numbers of RCT crates

GLOBAL CALORIMETER TRIGGER

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**

Installation of RCT completed and commissioning underway

- **10 racks with 18 fully populated crates and two spares crates installed.**
- **Integration**
  - 90% of input data cables
  - MCC clocking in place
  - 30% of output cables connected to GCT source cards - another 30% shortly - remainder in October
- **RCT commissioning and pattern tests ongoing**
  - Checkout of installed cables including mapping and cable quality checks
  - Verification of trigger algorithms and trigger emulator via pattern tests
  - Long term tests
  - Expansion of scope - more crates as systems become available after commissioning