Operation and Monitoring of the CMS Regional Calorimeter Trigger

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The pdf file of this talk is available at:

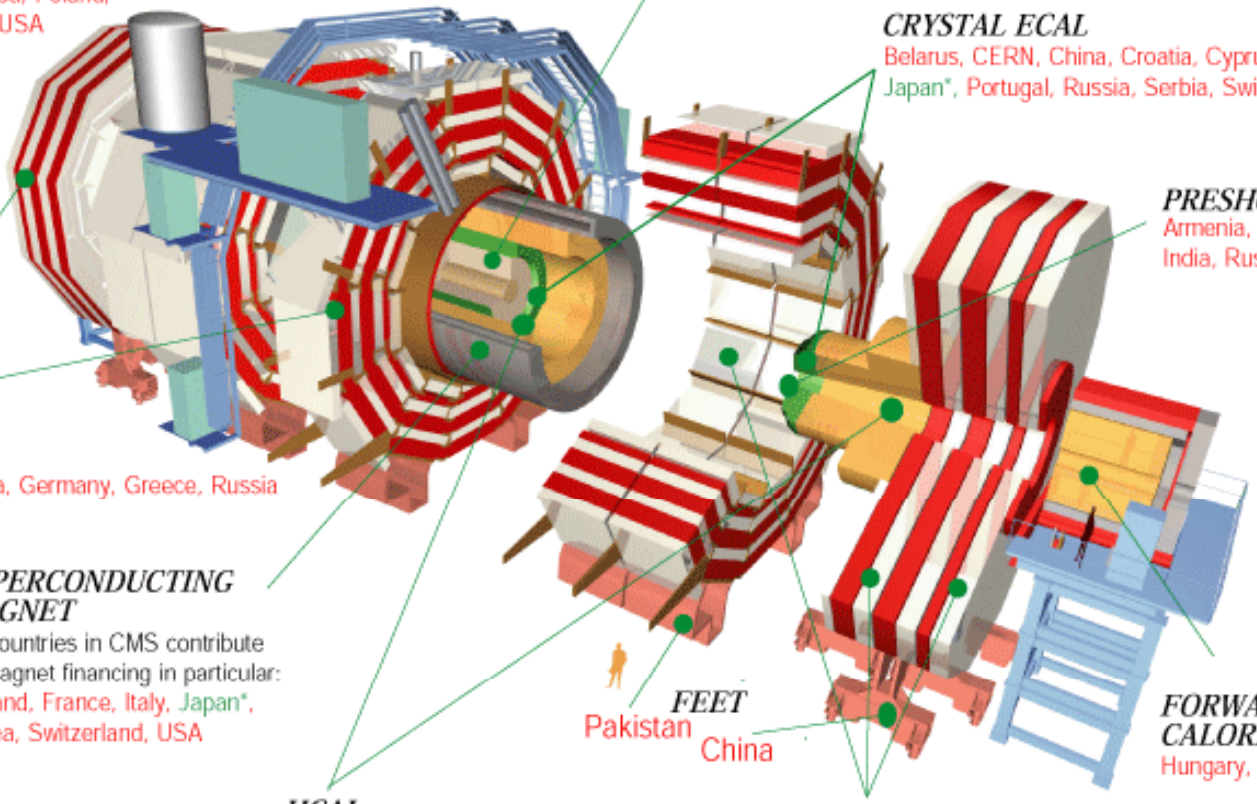
http://indico.cern.ch/contributionDisplay.py?contribId=116&sessionId=9&confId=21985

See also the CMS Level 1 Trigger Home page at

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

CMS Detector

37 Countries, 155 Institutes, 2000 scientists (including about 400 students) October 2006



TRIGGER, DATA ACQUISITION & OFFLINE COMPUTING
Austria, Brazil, CERN, Finland, France, Greece, Hungary, Ireland, Italy, Korea, Poland, Portugal, Switzerland, UK, USA

TRACKER
Austria, Belgium, CERN, Finland, France, Germany, Italy, Japan*, Mexico, New Zealand, Switzerland, UK, USA

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

PRESHOWER
Armenia, CERN, Greece, India, Russia, Taiwan

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

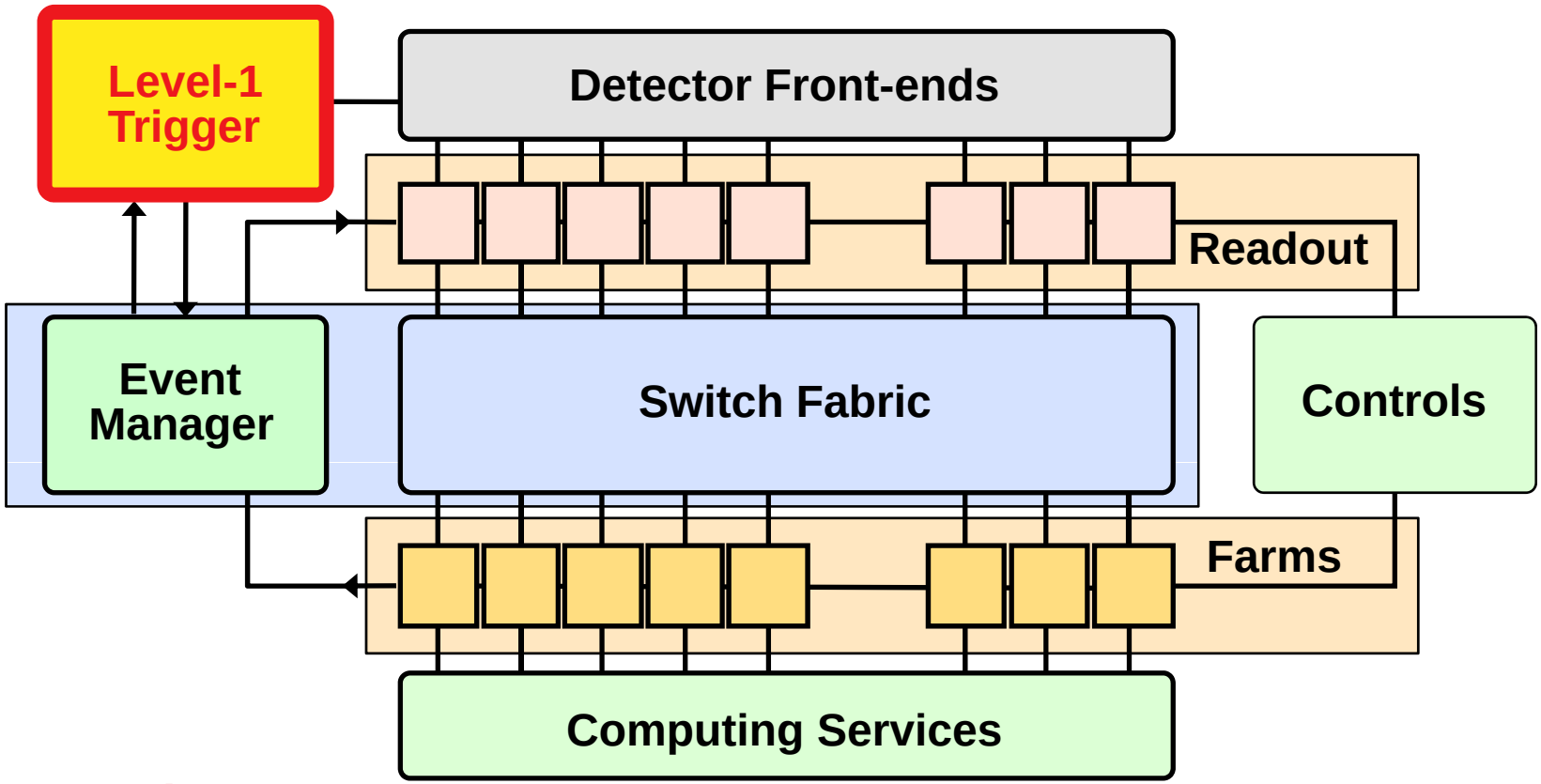
HCAL
Barrel: Bulgaria, India, Spain*, USA
Endcap: Belarus, Bulgaria, Georgia, Russia, Ukraine, Uzbekistan
HO: India

MUON CHAMBERS
Barrel: Austria, Bulgaria, CERN, China, Germany, Hungary, Italy, Spain,
Endcap: Belarus, Bulgaria, China, Colombia, 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**

CMS Trigger & DAQ Systems

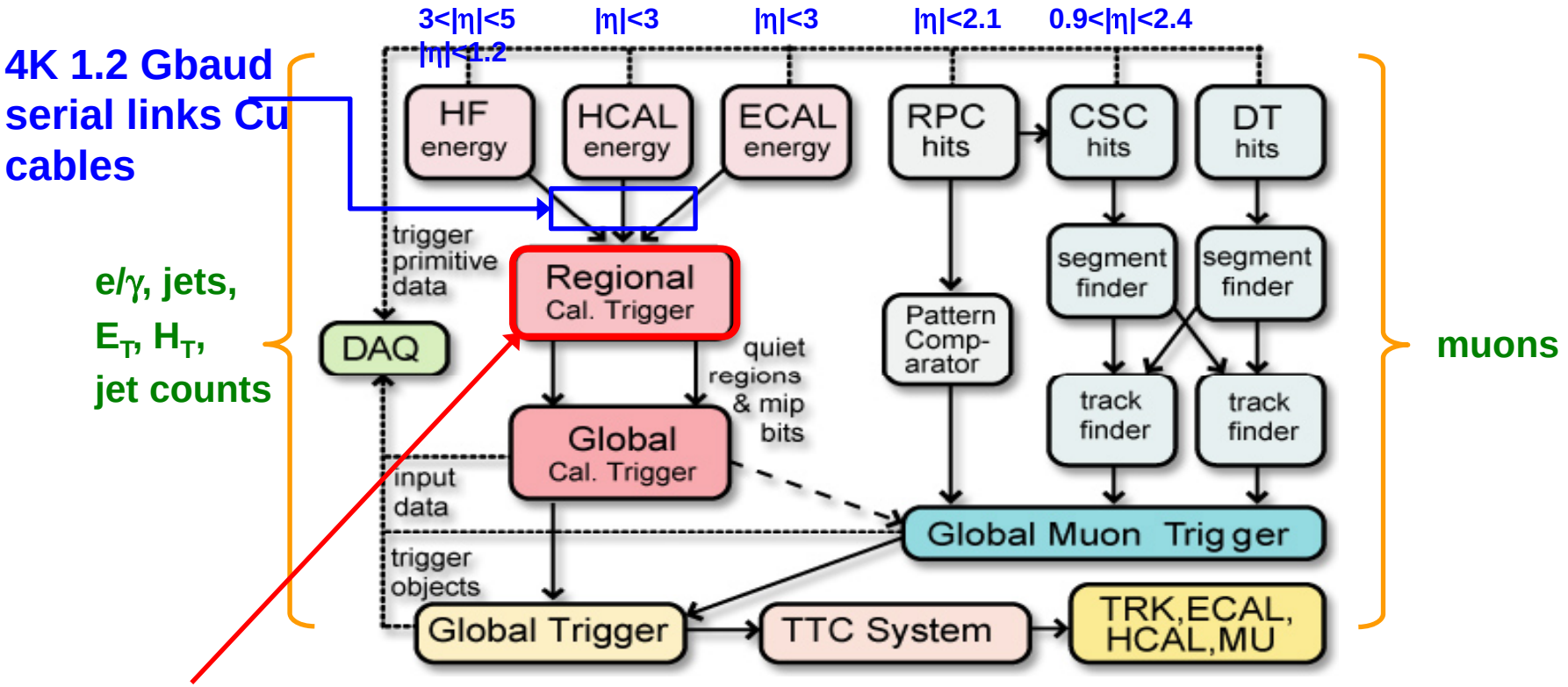


Level-1 Trigger

- LHC beam crossing rate is 40 MHz & at full Luminosity of 10^{34} $cm^{-2}s^{-1}$ → 10^{9} collisions/s
- Reduce to 100 kHz output to High Level Trigger and keep high-P_T physics
- Pipelined at 40 MHz for dead time free operation
- Latency of only 3.2 μsec for collection, decision, propagation

The CMS Level-1 Trigger & Regional Calorimeter Trigger

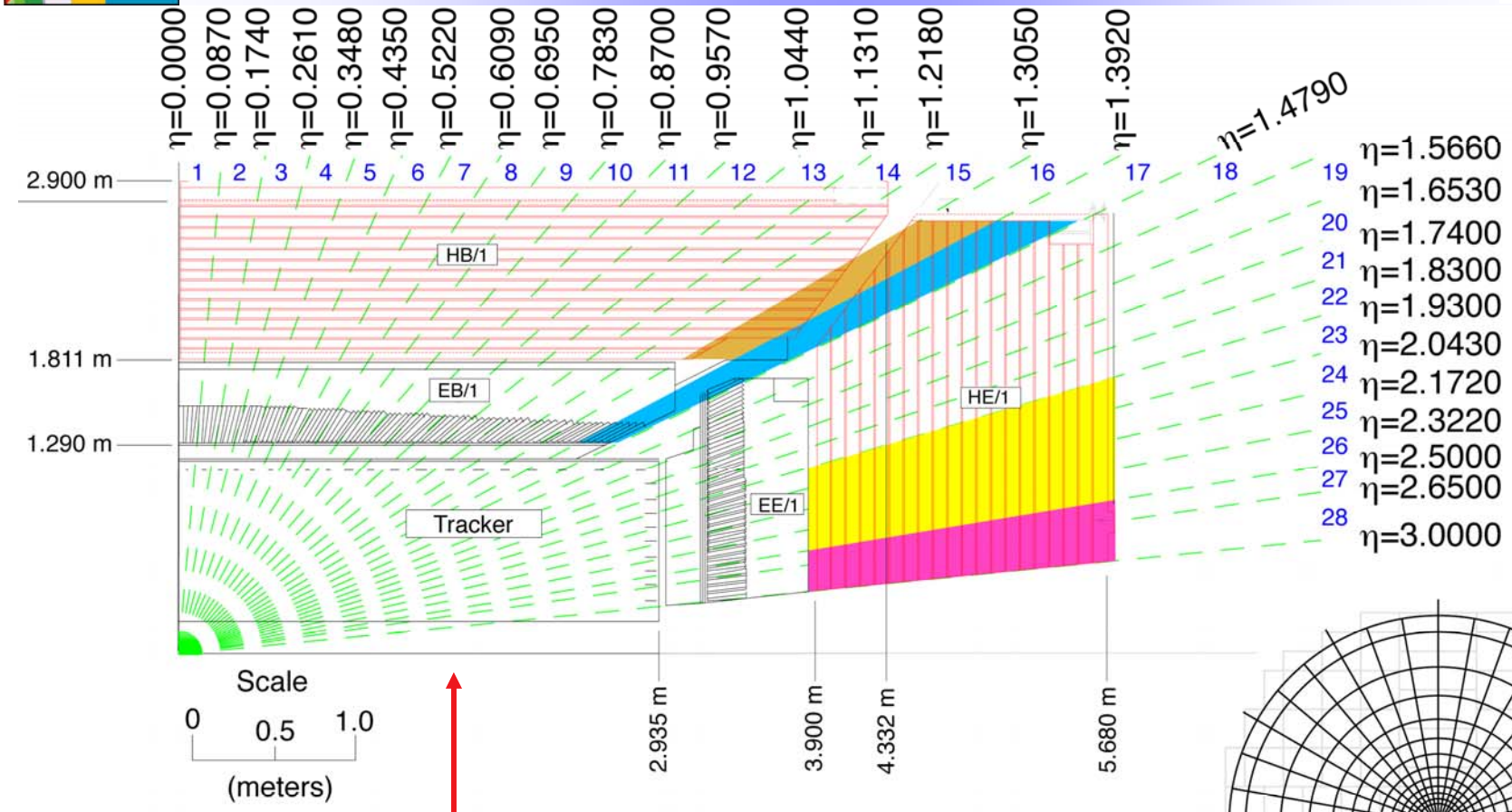
Only calorimeter and muon systems participate in CMS L1



Regional Calorimeter Trigger

- **Receives Trigger Primitives (TPs) from 8000 ECAL/HCAL/HF towers**
- **Finds 28 e/γ candidates, creates 14 central tower sums, 28 quality bits, and forwards 8 HF towers and 8 HF quality bits**
- **All sent to Global Calorimeter Trigger at 80 MHz on SCSI cables**

CMS Calorimeter Geometry



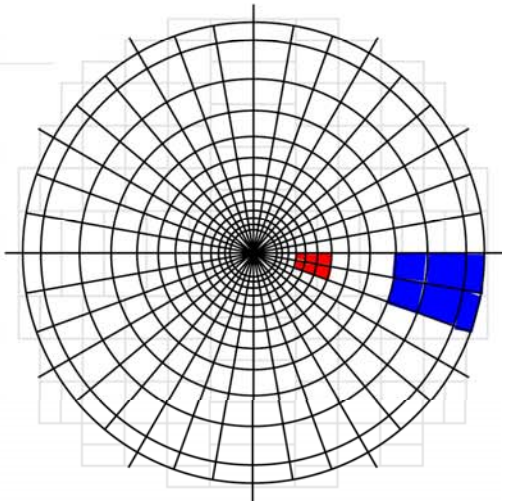
EB, EE, HB, HE map to 18 RCT crates

Provide e/γ and jet, τ, E_T triggers

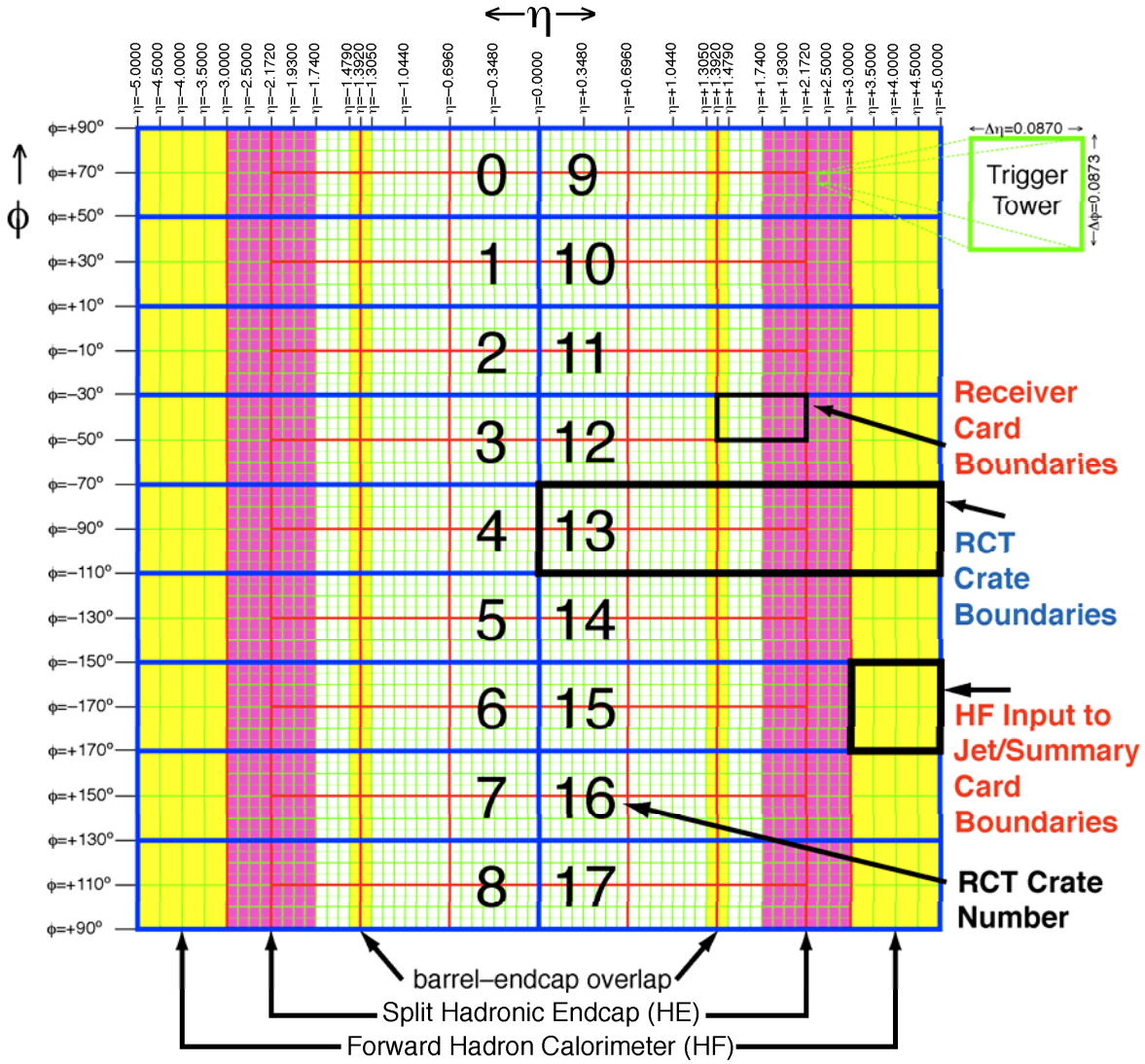
2 CMS HF Calorimeters mapping onto Trigger System HF Crate

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

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

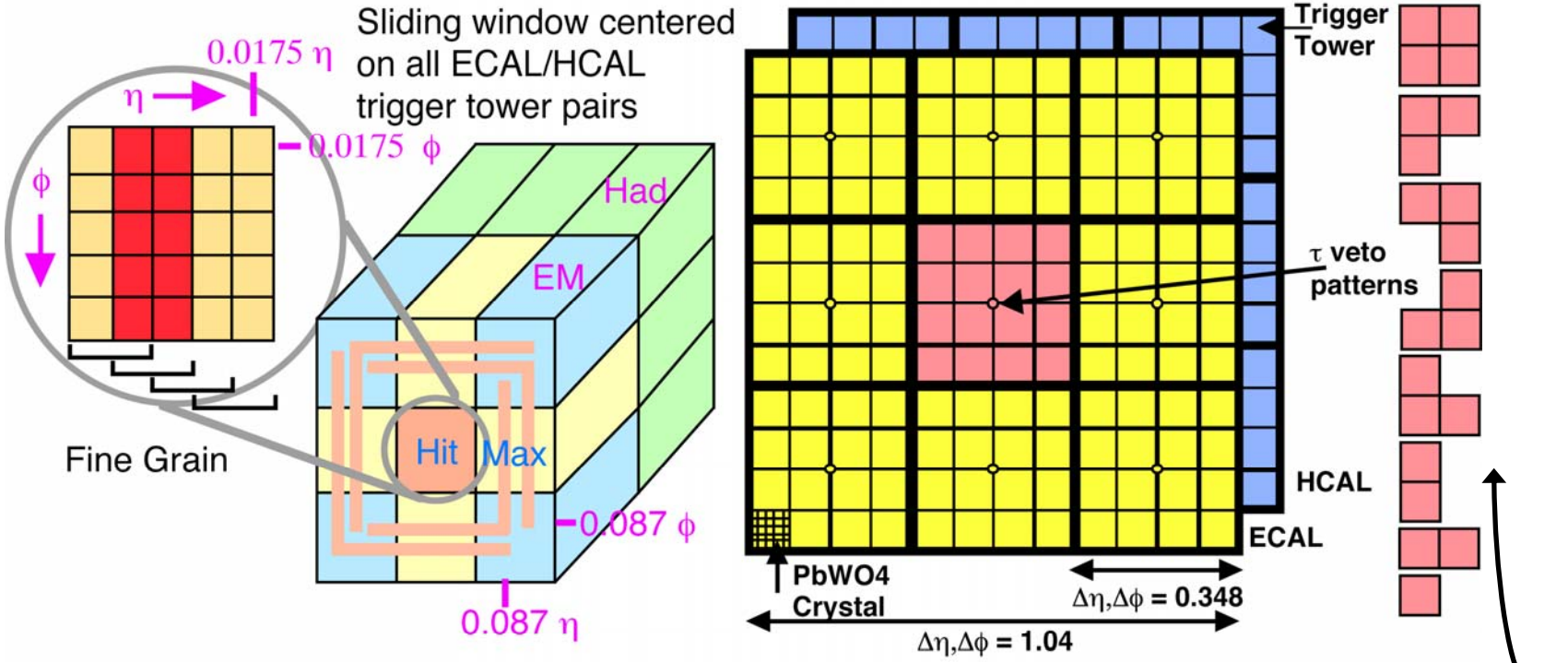


Calorimeter-RCT Mapping



- 18 crates handle the entire CMS calorimeter seamlessly
- Each crate covers a 0.7 ϕ by 5 η region
- Each Receiver - Electron ID Card pair covers a 0.35 ϕ by 0.7 η region (ex. one 0.7 ϕ by 0.5 η)
- Single Jet/Summary card receives HF, finds 8 e/γ, sets Quiet bits and forwards Sums, e/γ, and all bits to GCT

Calorimeter Trig. Algorithms



e/γ Rank = Hit+Max Adjacent Tower

- **Hit: H/E < Small Fraction**
- **Hit: 2 of 5-crystal strips >90% E_T in 5x5 Tower (Fine Grain)**

Isolated e/γ (3x3 Tower)

- **Quiet neighbors: all 8 towers pass Fine Grain & H/E**
- **One of 4 corners 5 EM E_T < Thr.**

Jet or τ E_T

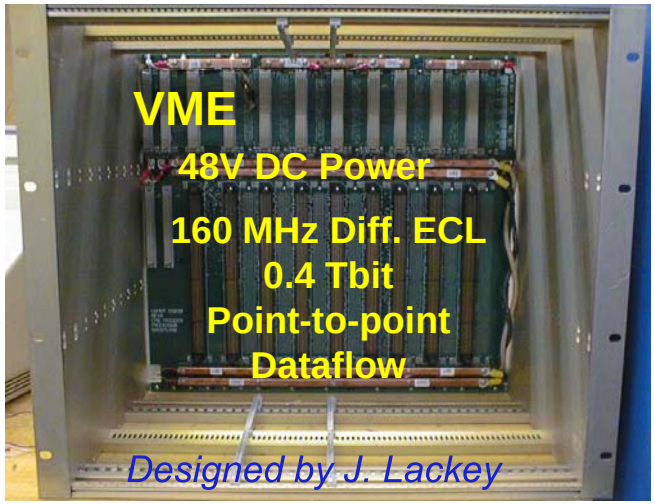
- **12x12 trig. tower ΣE_T sliding in 4x4 steps w/central 4x4 E_T > others**

τ: isolated narrow energy deposits

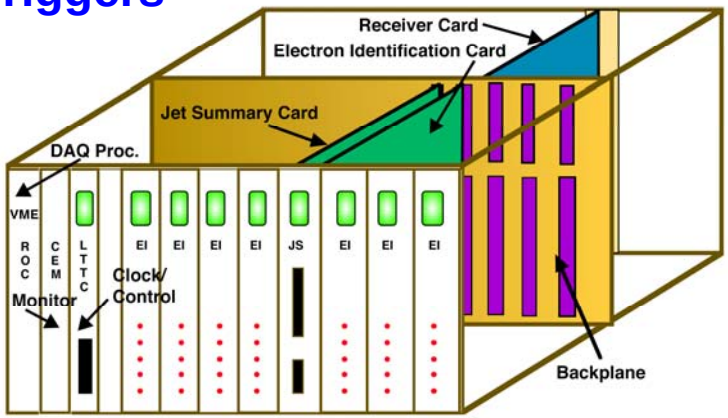
- **Energy spread outside τ veto pattern sets veto**
- **τ Jet if all 9 4x4 region τ vetoes off**

RCT Crates

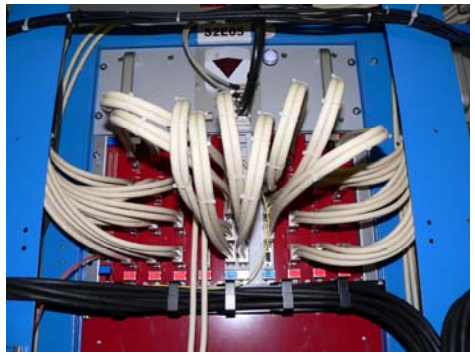
Main RCT Crate



18/26* crates with custom backplane incorporate algos: e/γ, τ & Jet Triggers



Master Clock Crate (MCC)



One crate with 3 custom cards to create and fan-out 160 & 120 MHz clocks, ReSync, and Bunch Crossing Zero to 18 RCT Crates' Clock & Control Cards

- **Clock Input Card (CIC) - 1/5***
  - Source: LHC clock or on-board Oscillator
  - Fine and course delay up to 25 ns
- **Clock Fanout Card to Crates (CFCc) & Clock Fanout Card Midlevel (CFCm) – 2/7* & 7/13* resp.**
  - Fine delay adjust to all crates
- **Signals distributed on 36 4-pair low-skew cables of the same length.**

*used/total produced

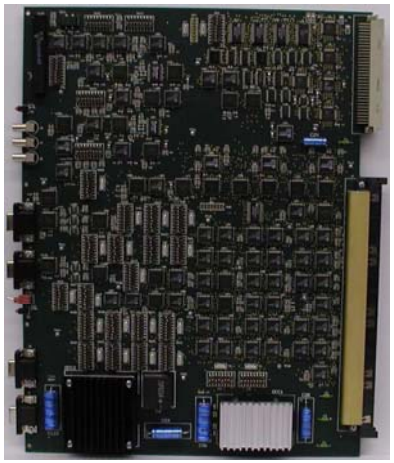
RCT Cards

Clock & Control

18/25* - 1 per crate

Provides 160 MHz & 120 MHz clocks, reset, BC0 to one RCT crate, phase and delay adjustable.

Clock from Master Clock Crate fed by CMS Trigger Timing and Control (TTC) System



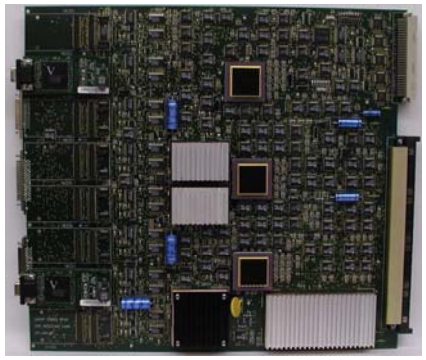
Receiver

126/158* - 7 per crate

Receives 128 E & HCAL towers on 1.2 GB Cu Links (Vitesse 7216-1) on RMC's

Phase, Adder, and Boundary Scan ASICs to realign/deskew data in, regional sums, sync 50 towers for e/g algo

Memory LUT at 160 MHz



Electron ID

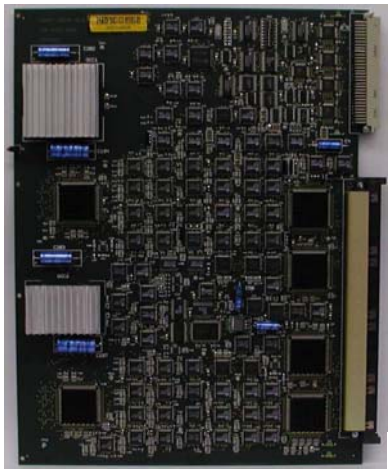
126/157* - 7 per crate

Sort (disabled) ASIC for BP receive and EISO ASIC fully implements e/γ algorithm

Sends highest E_T iso and non-iso e/γ for 2 4x4 regions sent to JSC

28 e/γ candidates per crate via BP to JSC

- 7x2 Iso & 7x2 Non-Iso



Jet Summary

18/25* - 1 per crate

e - γ - μ

- 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) RMC & LUTs for HF E_T's

Regional (4x4 tower) sums to GCT

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 Trigger Primitives (TPs)**

TCC

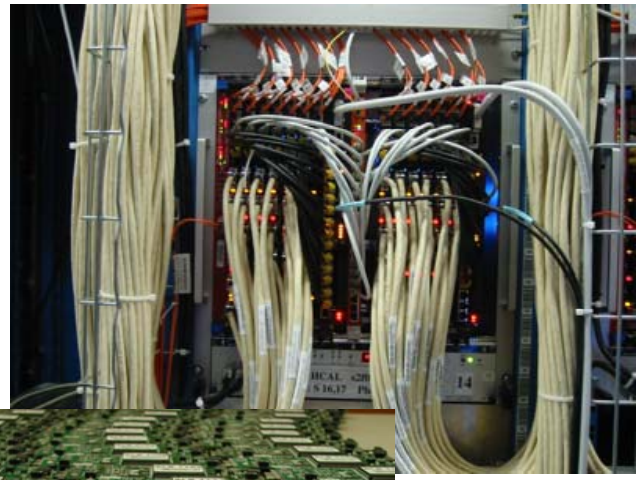
- **Six or nine SLBs send Ps**

Both TCC & HTR Receive front-end data on fibers

Initial tests as early as 2004

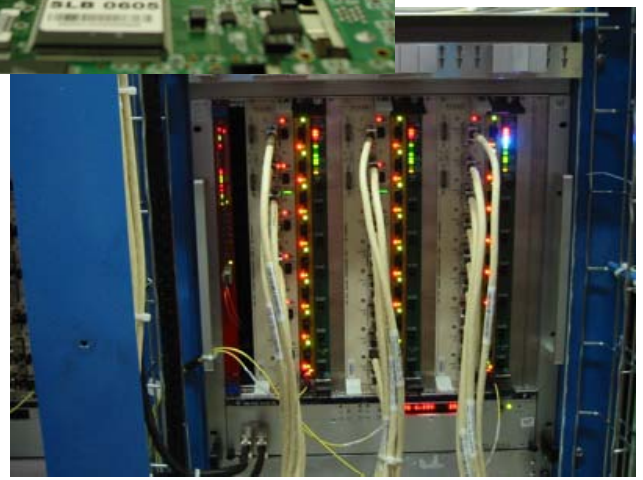
- **Installed and in use on all TP boards**

HTR



SLBs

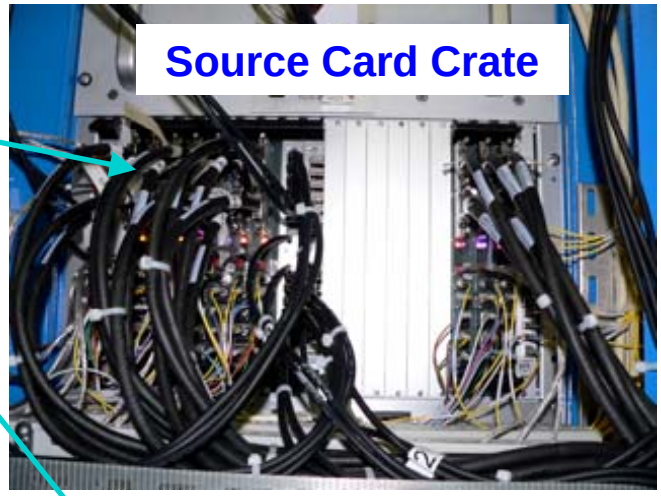
TCC



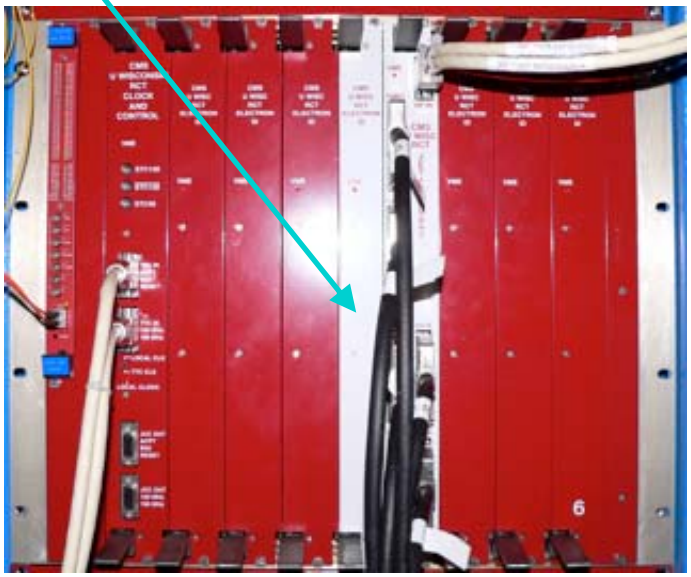
RCT Output to GCT

Each RCT crate is connected to 3.5 GCT Source Cards (SCs)

- **RCT output differential ECL**
  - On 6 SCSI cables per crate
- **63 SCs needed**
  - 2 RCT-GCT cable inputs/SC
  - 45 for Regional Sums
    - **Duplication needed on η=0 for jet algo - one input used**
    - **9 with inputs from 2 different crates**
  - 18 for iso-e/γ and noniso-e/γ candidates, muon bits
- **SC sends data on fibers to main GCT crate**
- **GCT turns regional sums to jet candidates, sorts jet and e/γ candidates, computes missing E_T, H_T, jet counts and sends to Global Trigger (GT)**



RCT Crate Front



RCT Hardware Installation and Commissioning at CMS

One RCT Master Clock and 18 RCT crates tested and cards installed

- **All cabling installed: input HCAL, HF, ECAL, RCT internal data sharing, and output to GCT**

Front of Racks

Full system = 19 Crates

18 HF input

108 Cables to GCT

Crate Rear

56 ECAL/HCAL input cables per crate (Beige)

11 Data sharing connections per crate (Black)

Rear of Racks

Input cabling complete

Total: 1026 SLB-RCT

Operations: Detector Slow Control and Rack Monitoring System

One Custom-built Rack Monitor Card installed in July 2006 per rack:

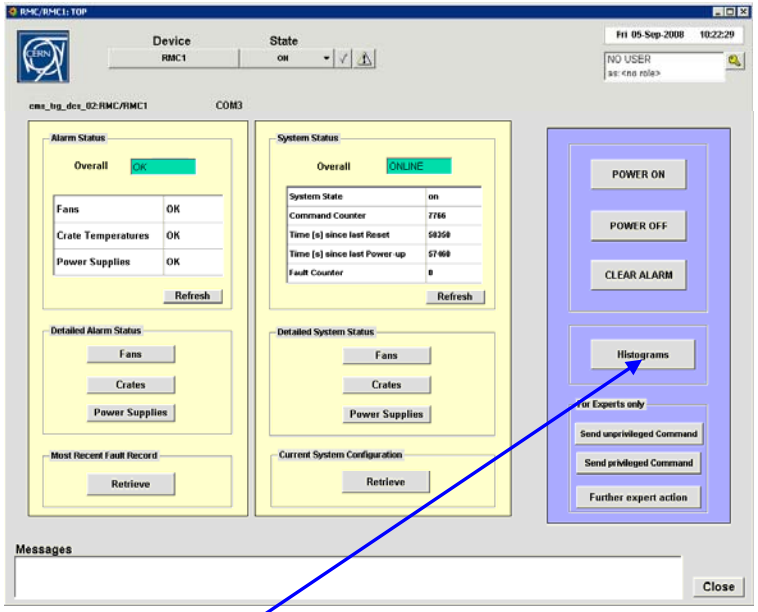
- Monitors power supplies, temperatures, fans
- Configurable - alarm set points, number of fans, power supplies connected…
- Ability to turn on and off system, check for and acknowledge alarms, send notification of…
- Connects to network via a COMTROL serial-to-ethernet port

Slow Control software was developed using PVSS (Prozessvisualisierungs und Steuerungs-System)

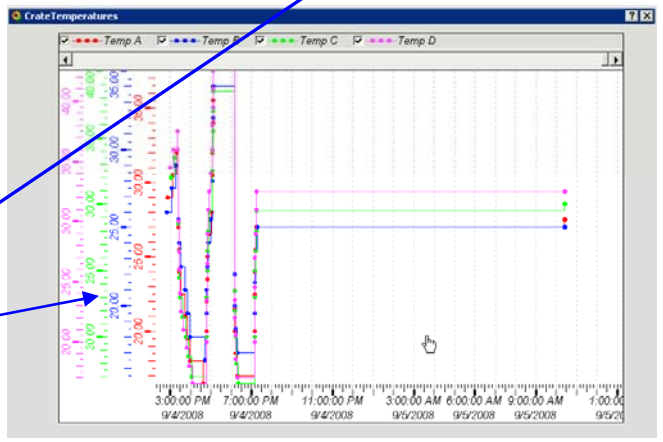
- Fully Implemented in USC55
- Exploits all above functionality
  - Keeps values in database
  - Histograms available

Fully integrated into CMS DCS

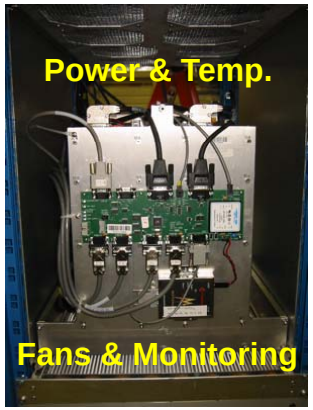
Rack 1 Control Panel



Rack 1 Crate A Temperatures



Rack Monitor Card and power chassis

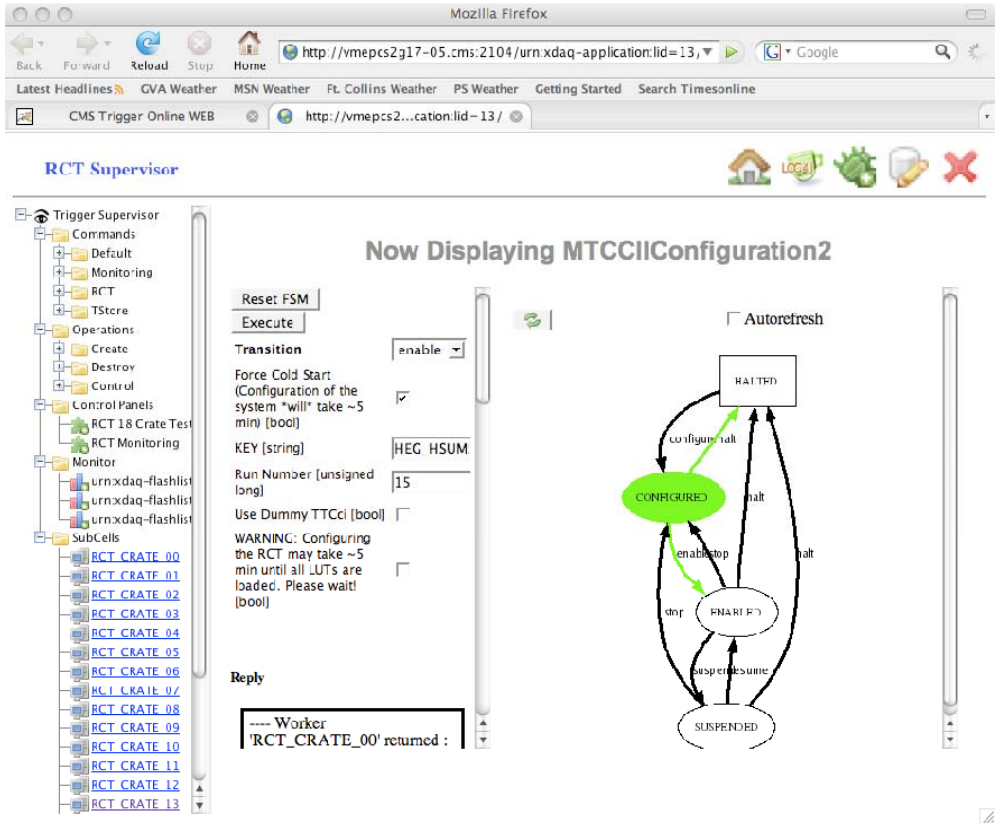


Operations: RCT Trigger Supervisor

CMS Trigger Supervisor

- **An online software framework to configure, test, operate, and monitor the trigger components and manage communications between (sub)systems**
  - Set up as individual subsystem cells and a central cell directing multiple systems at once with SOAP commands
- **RCT Trigger Supervisor handles**
  - System configuration via a pre-defined key for data taking, internal tests, and multi-system interconnection tests
    - **Central configuration of trigger systems by CMS Run Control for data taking and interconnection tests**
    - **User configuration**
    - **Accesses databases for configuration including channel masking**
    - **Provides interface for creating new keys**

RCT Configuration

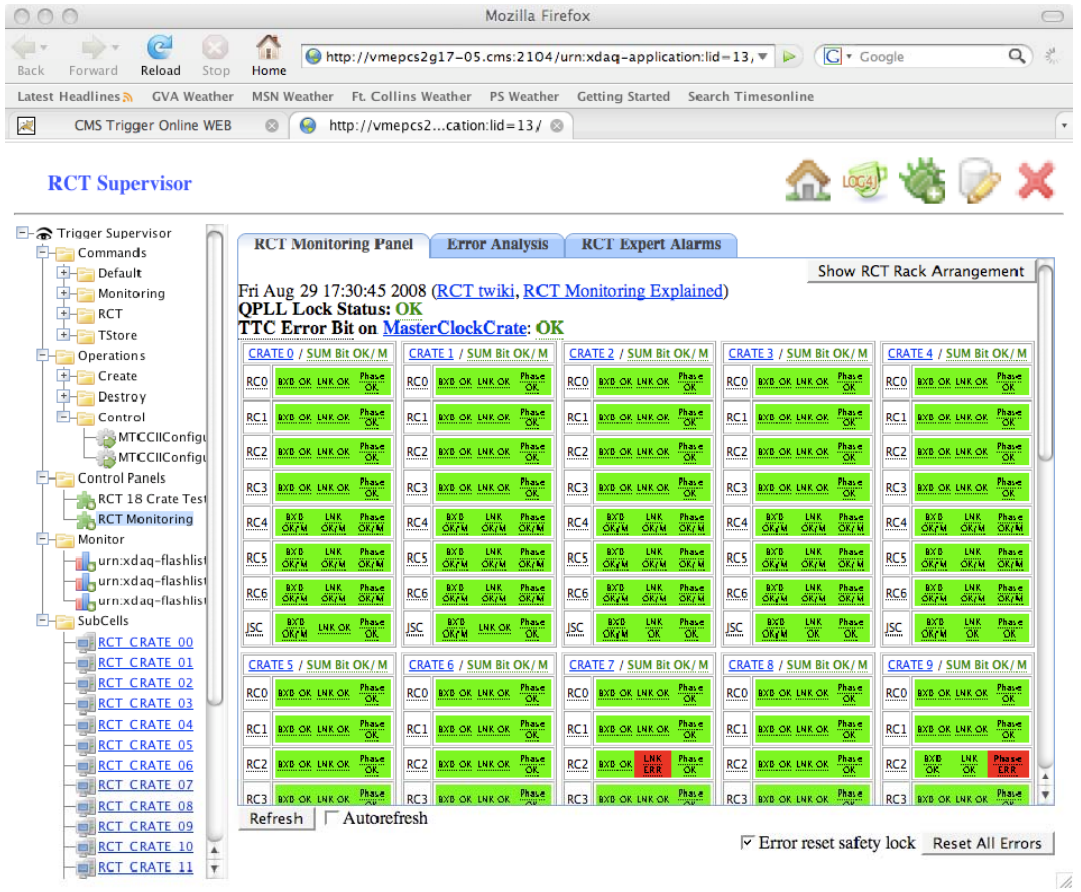


Operations: RCT Trigger Supervisor

RCT Trigger Supervisor also handles Crate monitoring

- RCT hardware registers and errors
- Can mask channels not in use in monitoring panel
  - Using a file or DB
- Will log monitored values in DB
  - Link errors, etc.
- Alert and alarm functionality
  - RCT expert now
  - Development of more central alarm system for TS underway

RCT Monitoring



Operations: RCT Intercrate Testing

Uses the ability of the RCT to cycle the addresses of its input LUTs on the Receiver cards (emulate up to 64 crossings)

- **All 18 RCT crates used and GCT Source Cards capture output**
  - Pattern into emulator to predict output and compare with capture
  - GCT Source Cards are very flexible - multiple capture options including BC0, output patterns, and ReSync
- **First tests were internal, testing timing between RCT crates**
  - Check sharing on every edge, for every tower, timing tolerances
  - Walking zeros & ones, random, ttbar simulated data like
    - **ttbar: Partial output at right**
  - Problems found and fixed
  - Checked RCT-GCT connections
- **Integrate into Trigger Supervisor**
- **Developing tests using patterns injected at TPG level**
  - Tests SLB-RCT link, algos.

```
Test Name: outputTtbar
Test Date: 01/09/08

source card files
/nfshome0/gctdev/TriDAS/trigger/gct/SourceCardController/patt
/nfshome0/gctdev/TriDAS/trigger/gct/SourceCardController/patt

crate 12 card 2 region 0
scrd: Rank 939 mip 1 tau 0 qbit 0 ovfl 0
emul: Rank 1023 mip 0 tau 1 qbit 0 ovfl 1

Summary of errors
        Crate  0                    Crate  1
         rk crd iso rgn ord  TOT     rk crd iso rgn ord  TOT
        --- --- --- --- --- ----    --- --- --- --- --- ----
Card 0
Card 1
Card 2
Card 3
Card 4
Card 5
Card 6



        Crate  4                    Crate  5
         rk crd iso rgn ord  TOT     rk crd iso rgn ord  TOT
        --- --- --- --- --- ----    --- --- --- --- --- ----
Card 0
Card 1  142  16          128  126
Card 2
Card 3   63  16          376   47
Card 4   16                     16
Card 5
Card 6
```

Analysis: RCT Trigger Emulator

Software with the goal of exactly reproducing the L1 Trigger hardware response, including:

- **Use and generate Look-Up Tables (LUTs)**
- **Include Hardware and Firmware registers and any other configuration options**
- **Access same database as TS to get configuration information**
- **It is to be used for hardware validation and monitoring**
  - In use by the calorimeter trigger to predict the response of the full chain to patterns injected at the trigger primitive level
    - **Online and offline Data Quality**
    - **18-Crate test**
    - **Link tests (patterns injected at TP level)**
  - In this way the hardware and the emulator are fully vetted
    - **Bugs are tracked down and fixed in firmware, hardware and software**
- **In reverse: simulation can be used to inject physics patterns into the hardware**
  - Validation of algorithms

Global Runs and Data Taking

In order to integrate detectors and get ready for first beam

- **Use cosmic rays and study noise rates**
- **2 days to 1 week periods**
  - Designated periods since Fall 2007
- **Various subsystems participate**
  - RCT took part in most runs with HCAL and/or ECAL providing TPGs
  - GCT e/γ path was commissioned first
    - **RCT LUTs very flexible – forward HCAL or ECAL to e/γ path for triggering**
    - **Each different scenario required different LUT configuration**
    - **Created an individual Trigger Supervisor Key to describe each one**
  - Study data offline to validate algorithms and detect any problems
    - **Use Data Quality Monitoring – Online and Offline**

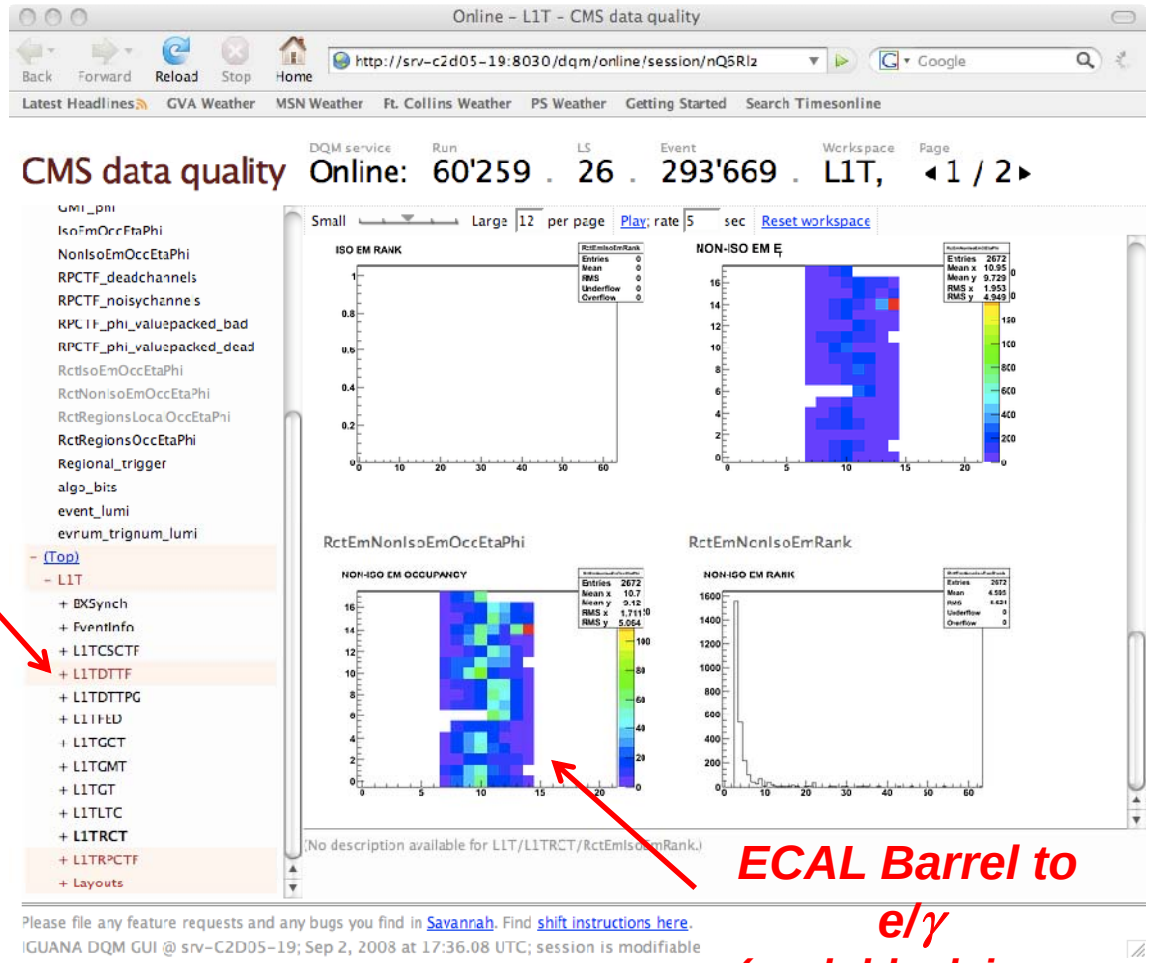
First circulating beam arrived 10.9.2008!

- **Have had additional beam since then, expect first collisions soon…**

RCT Data Quality Monitoring

Online: real time histograms created and filled in the High-Level-Trigger Filter farm during data taking

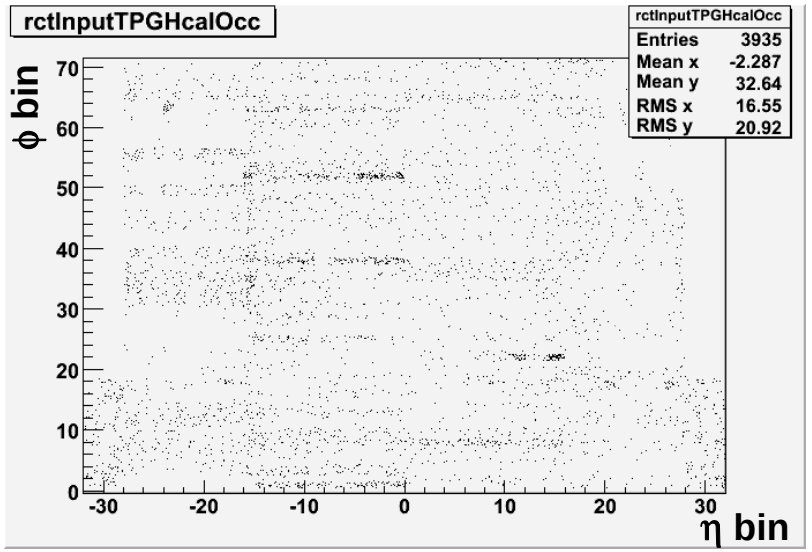
- Also can go back in time to a recent run
- Compare with reference histograms
  - Highlighted if in error
- Real time data validity checks with emulator
- Data delivered at a rate of ~1-10 Hz
- Selected histograms for shift crews

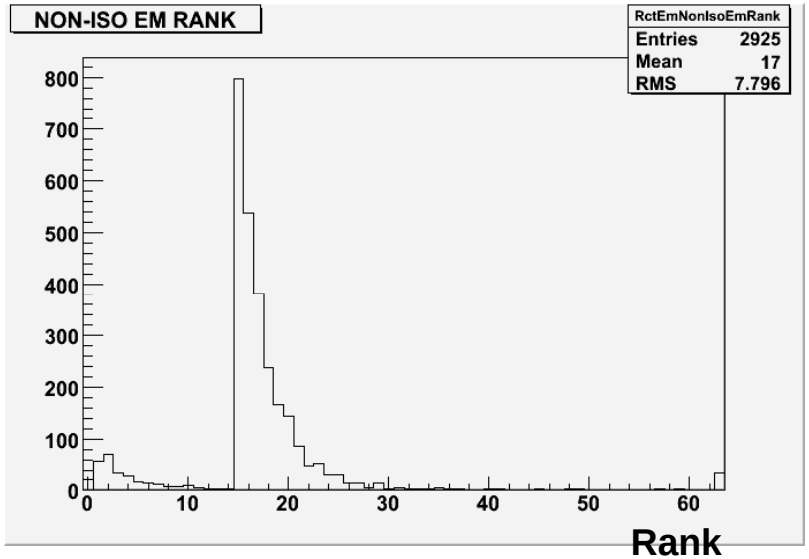


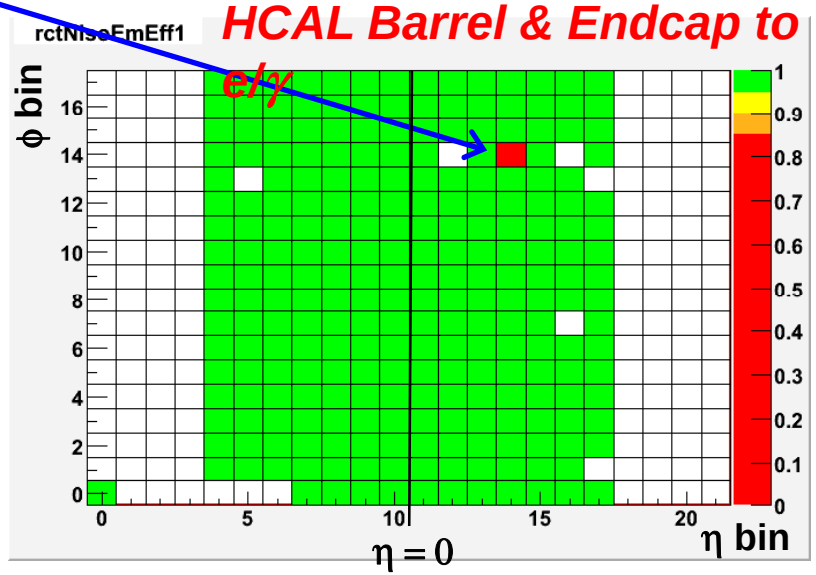
RCT Data Quality Monitoring

Offline – more detailed analysis possible

- Access to a greater number of events than online
- Book more histograms and store an nTuple
- Can be run on CMS online machines for near real-time analysis
- Feed emulator TPGs and get efficiencies, inefficiencies, and overefficiencies
- Valuable debugging tool



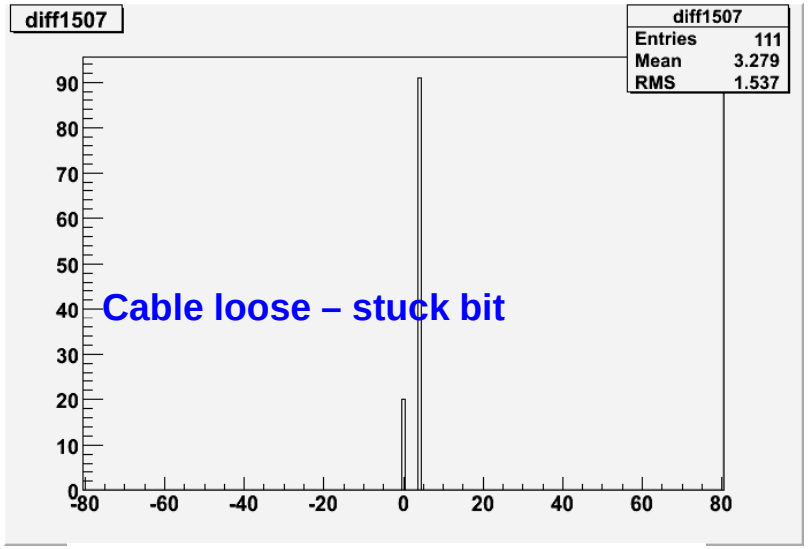


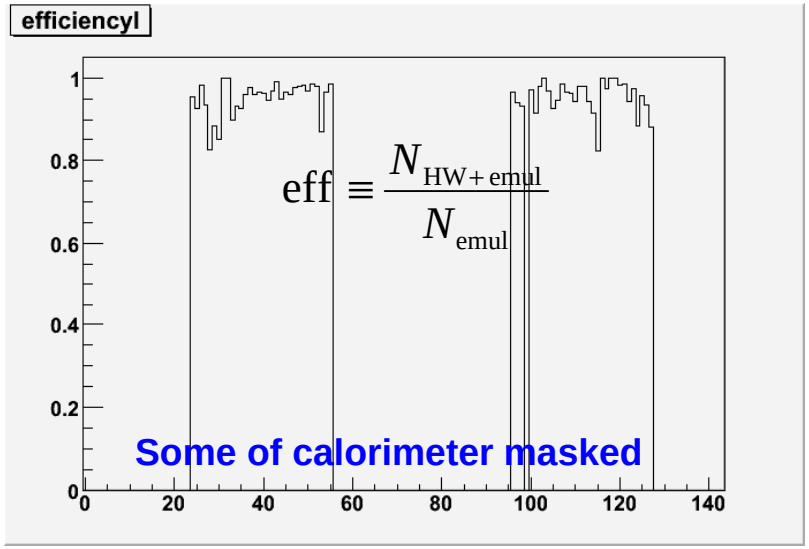


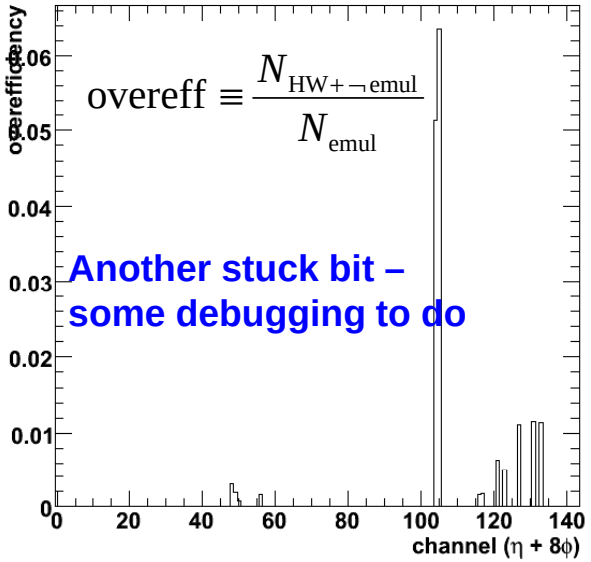
RCT Data Quality Monitoring

Offline – more detailed analysis

- Very valuable during early runs with special conditions
- Can retrieve a single tower or region
  - Energy difference to see problems at the bit level
- Compare in 1D to see subtle differences
- Use emulator to find extra and missing candidates (overefficiency an inefficiency)





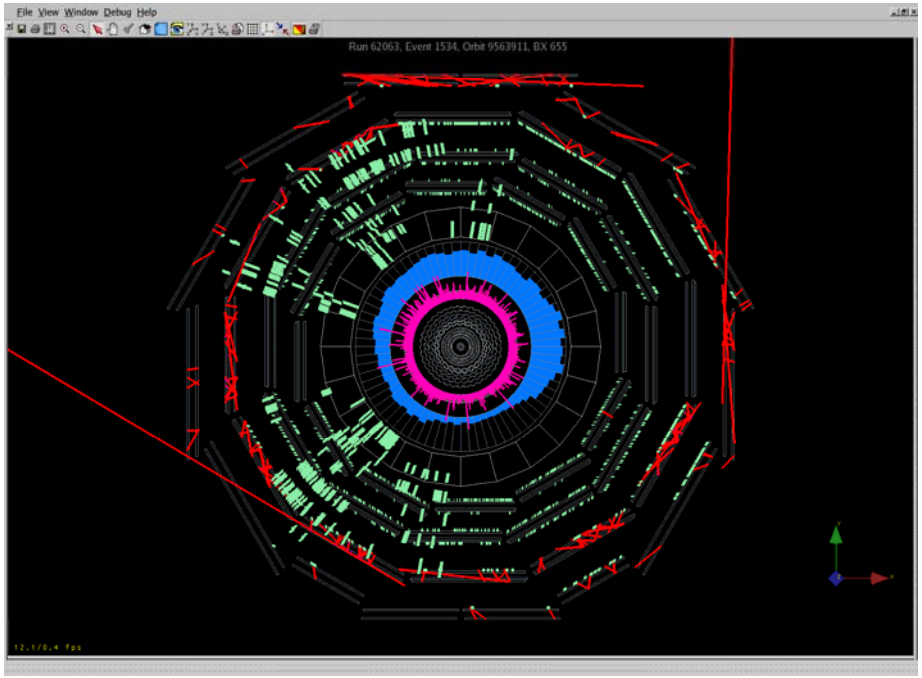


Recently

CMS Closed 6 Sep 2008

First beam 10 Sep 2008 at ~9:30!

HF in foreground



Calorimeters in pink & blue

Finally

CMS Regional Calorimeter Trigger boards produced and installed

- **Successful commissioning and integration**
  - 19 crates and all boards installed
- **Tools necessary for operation in place**
  - RCT DCS integrated with central CMS DCS
    - **Alerts/alarms go to central control as well as to RCT personnel**
  - RCT Trigger Supervisor to configure, monitor, and test the RCT
    - **Integrated with Central Trigger Supervisor, controlled by CMS Run Control during daily data taking**
- **Starting real data taking**
  - RCT DQM and emulator
    - **Online and offline analysis to study RCT**
    - **Found problems early using cosmic ray and noise runs**
  - RCT flexible
    - **GCT had e/γ trigger ready first**
    - **RCT could send either HCAL or ECAL TPGs down e/γ path**
    - **Trigger Supervisor Keys set up for a large range of scenarios as we commissioned**
  - Calorimeter trigger on for first beam.
- **RCT is ready and anxious for colliding beams!**