Performance of the CMS Regional Calorimeter Trigger

P. Klabbers, M. Bachtis, S. Dasu, J. Efron, R. Fobes

T. Gorski, K. Grogg, M. Grothe, C. Lazaridis,

J. Leonard, A. Savin, W.H. Smith, M. Weinberg

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

TWEPP 2009

September 23, 2009

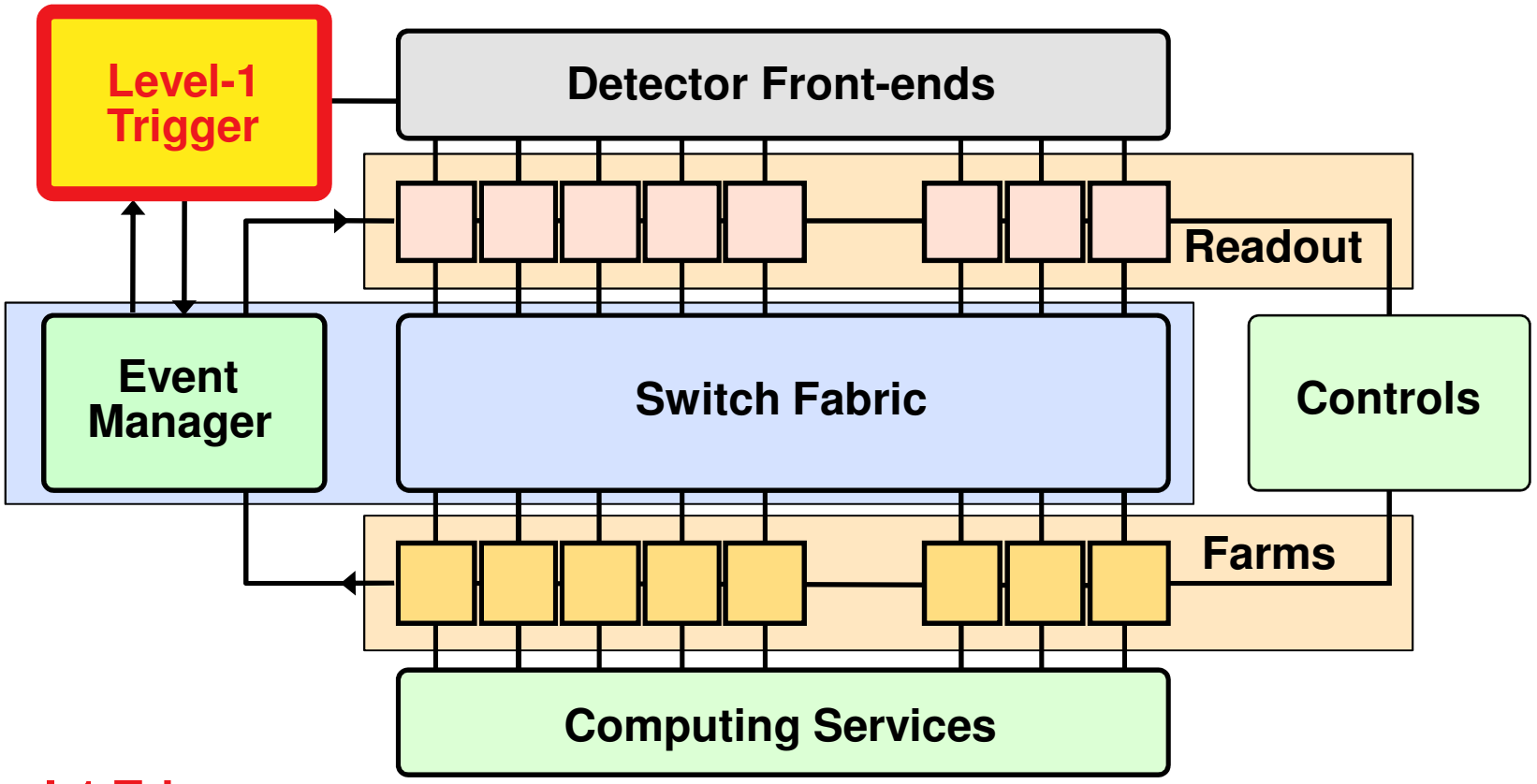
The pdf file of this talk is available at:

http://indico.cern.ch/contributionDisplay.py?contribId=100&sessionId=16&confId=49682

See also the CMS Level 1 Trigger Home page at

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

CMS Trigger & DAQ Systems

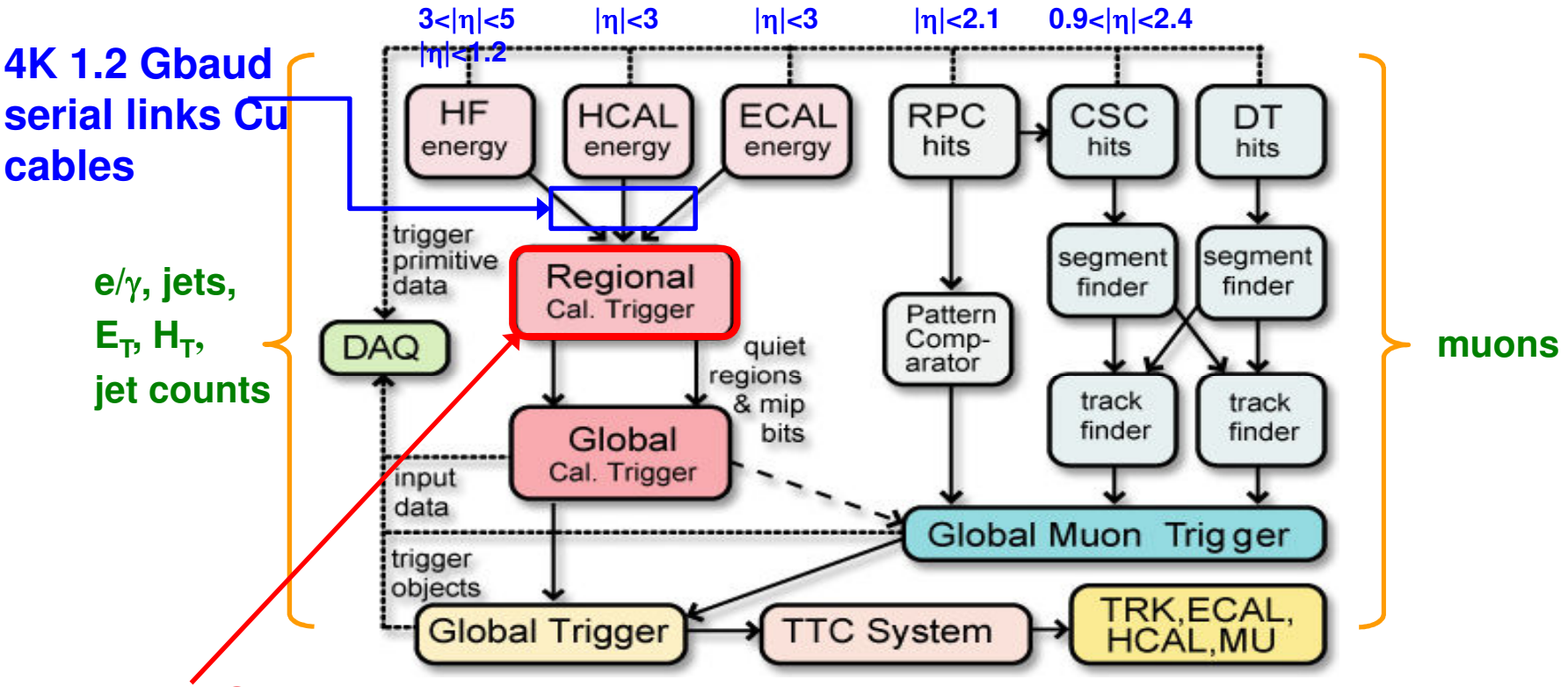


Level-1 Trigger

- 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

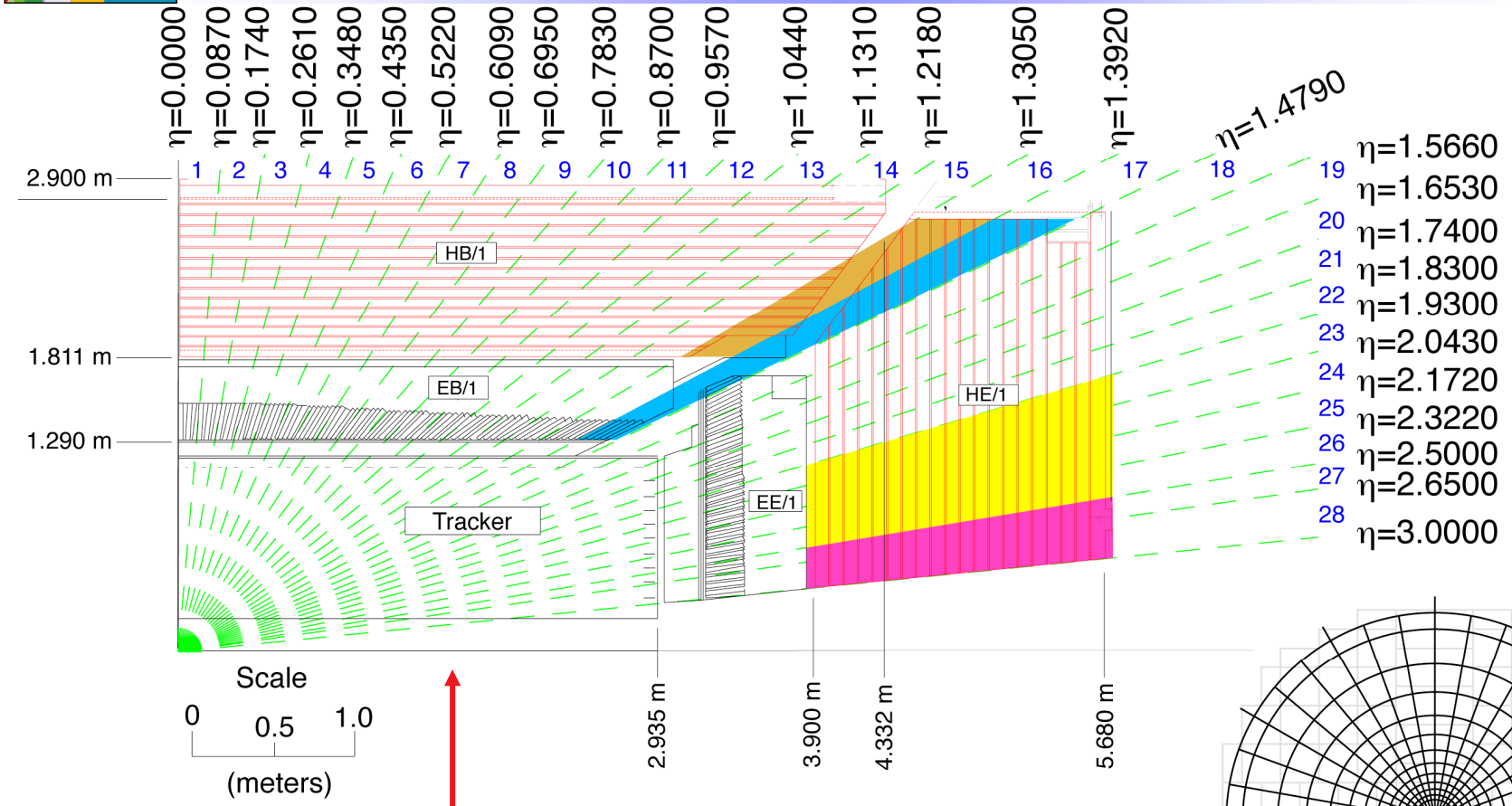
Only calorimeter and muon systems participate in CMS L1



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 (GCT) at 80 MHz on SCSI cables

CMS Calorimeter Geometry



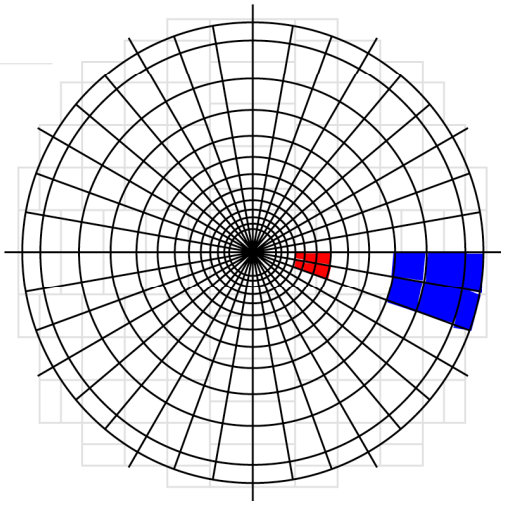
EB, EE, HB, HE map to 18 RCT crates

Provide e/γ and jet, τ, E_T triggers

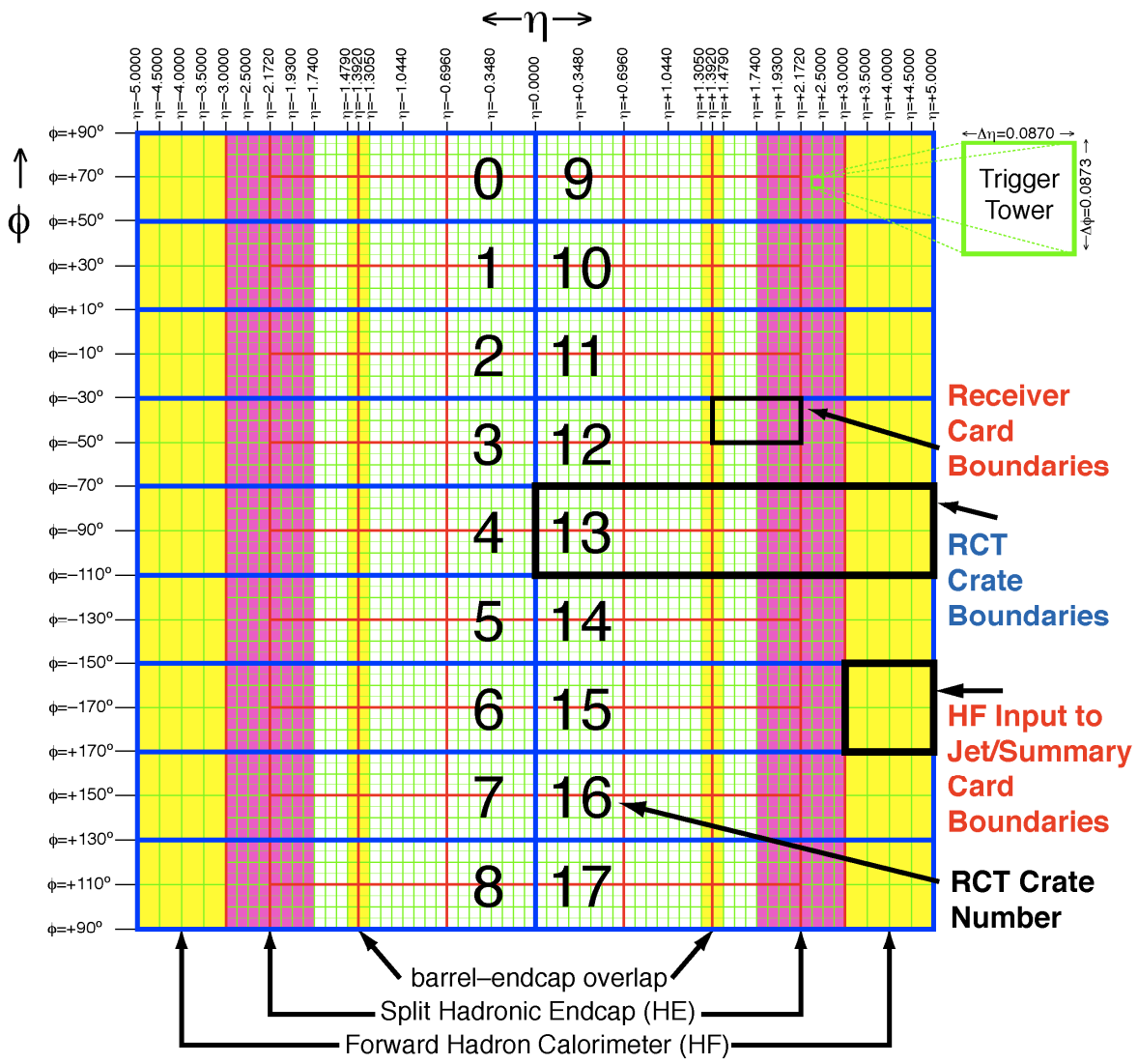
2 CMS HF Calorimeters mapping onto Trigger System HF Crate

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

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

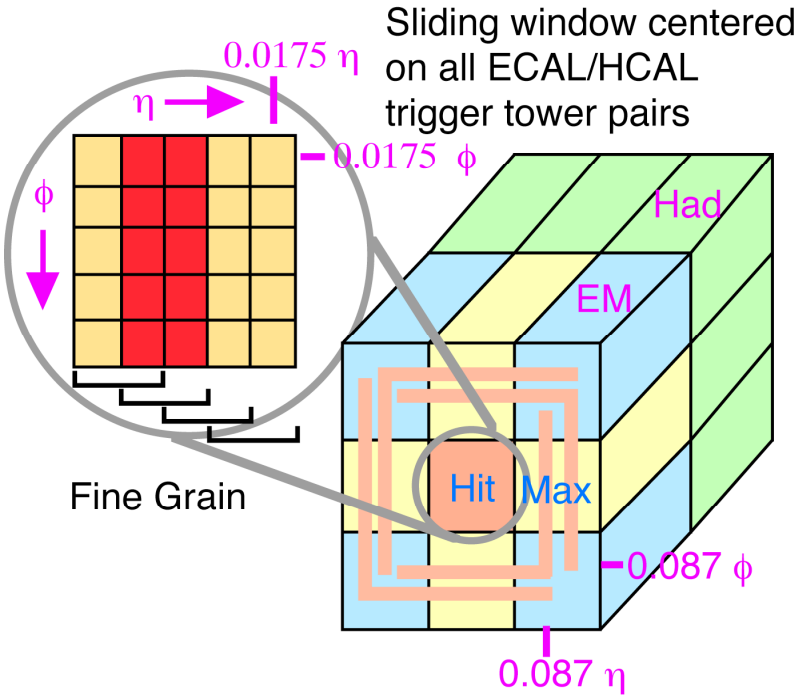


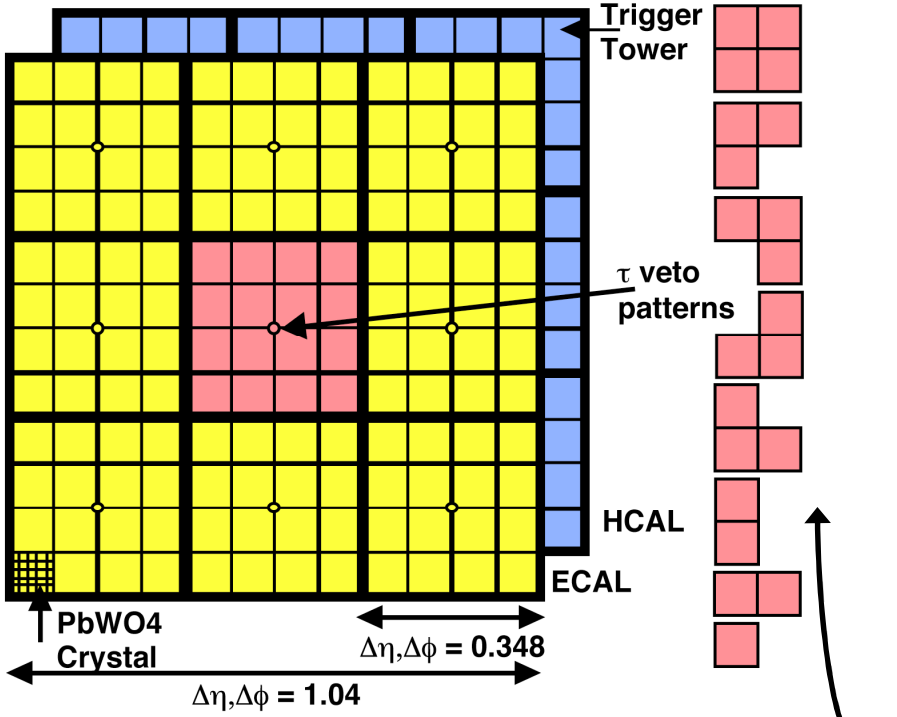
Calorimeter-RCT Mapping



- 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

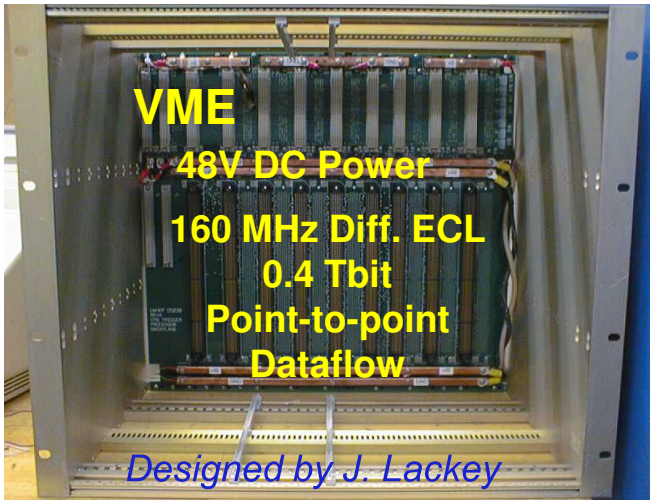
- **12x12 trig. tower ΣE_T sliding in 4x4 steps w/central 4x4 E_T > others**

τ: isolated narrow energy deposits

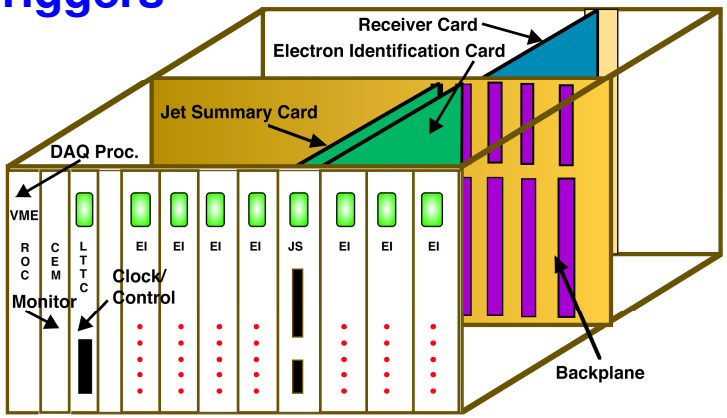
- **Energy spread outside τ veto pattern sets veto**
- **τ Jet if all 9 4x4 region τ vetoes off**

RCT Crates

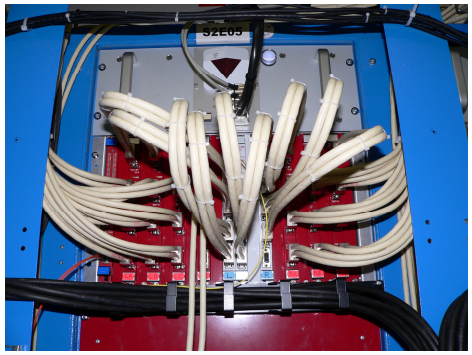
Main RCT Crate



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

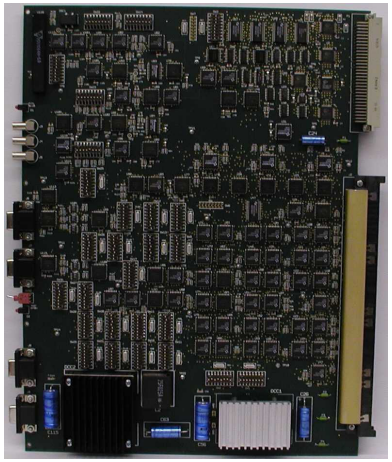
RCT Cards

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



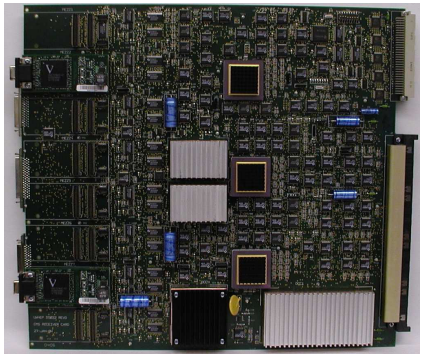
Receiver

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

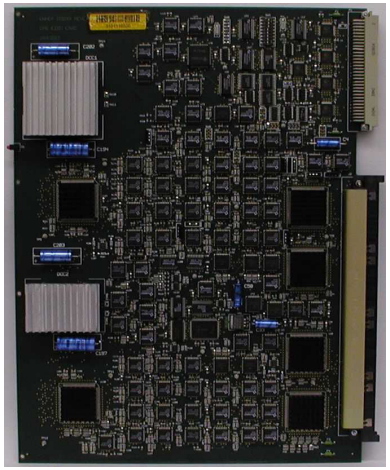
126/157* - 7 per crate

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

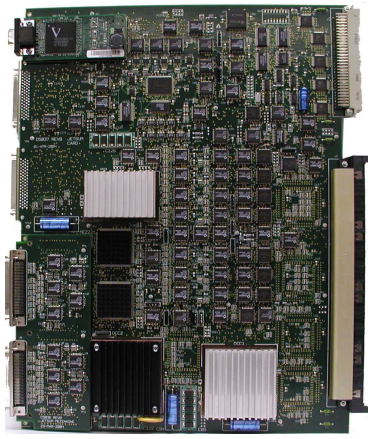
18/25* - 1 per crate

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

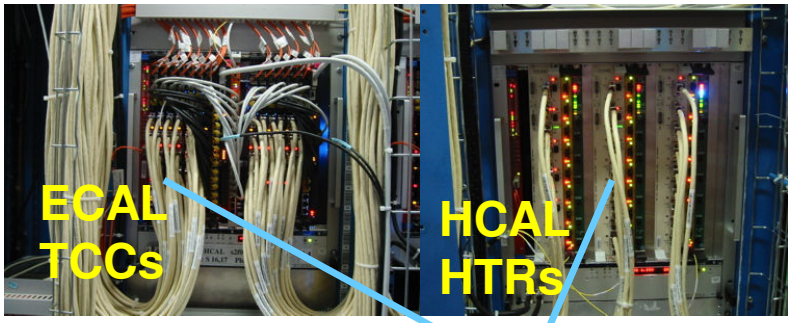


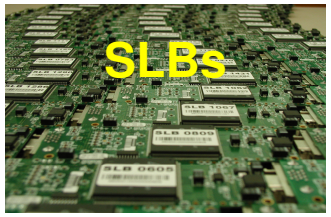
*used/total produced

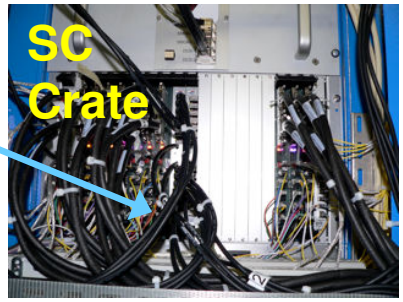
RCT Input and Output

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

- Configurable mezzanine card with 2 FPGAs synchronize data for V2716
- Separate SLB-RCT clock to ensures data in time between subsystems
- HTR: max 6 SLBs send Trigger Primitives (TPs)
- TCC: max 9 SLBs send TPs
- TCC & HTR Receive front-end data on fibers







Each RCT Crate to to 3.5 GCT Source Cards (SCs)

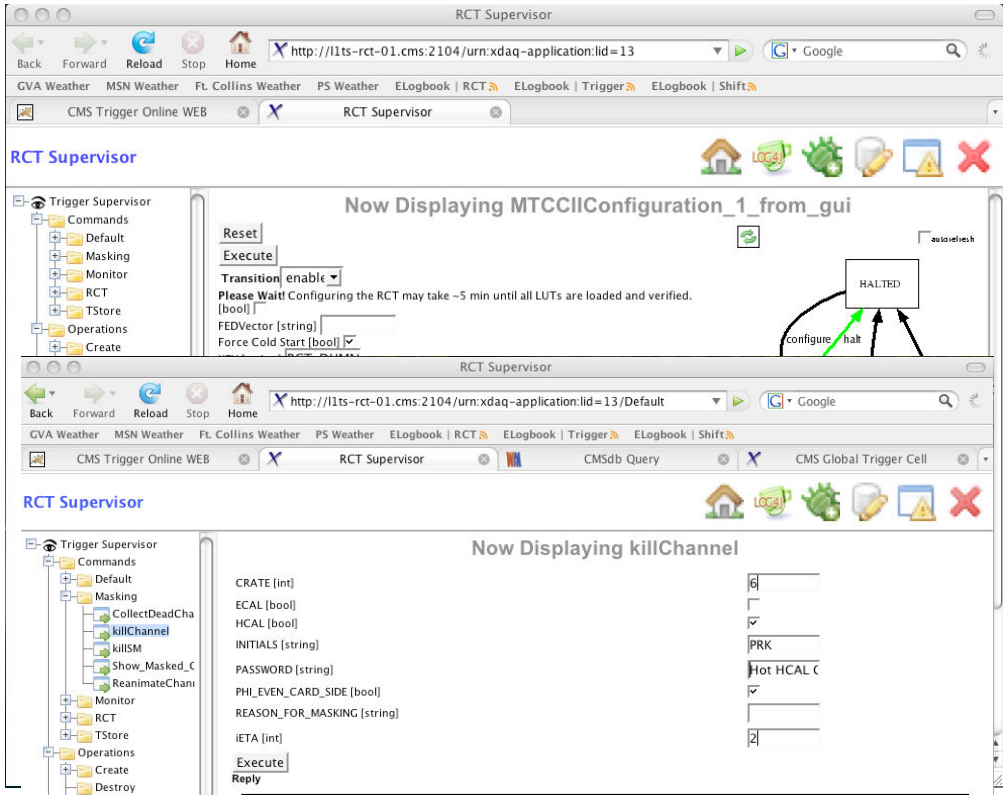
- RCT sends diff. ECL - 6 SCSI cables/crate to SCs
- SC sends data on fibers to main GCT crate
- GCT turns regional sums to jet candidates, sorts jet and e/γ candidates, computes missing E_T, H_T, jet counts and sends to Global Trigger (GT)

RCT Trigger Supervisor Overview

CMS Trigger Supervisor (TS)

- **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 or user configuration**
    - **Accesses DBs for configuration including channel masking**
    - **Interface for creating new keys**
    - **Provides feedback after transition**

RCT Configuration



RCT Masking Tool

RCT Trigger Supervisor Monitoring

RCT Trigger Supervisor does crate monitoring

- RCT hardware registers and errors in simple overview
  - Link errors, etc. in red
- Can mask channels not in use in monitoring panel
  - Using a file or DB
- Time-stamped values in DB
- Alert and alarm functionality

Logs all runs with RCT

- Provides list with key and run settings

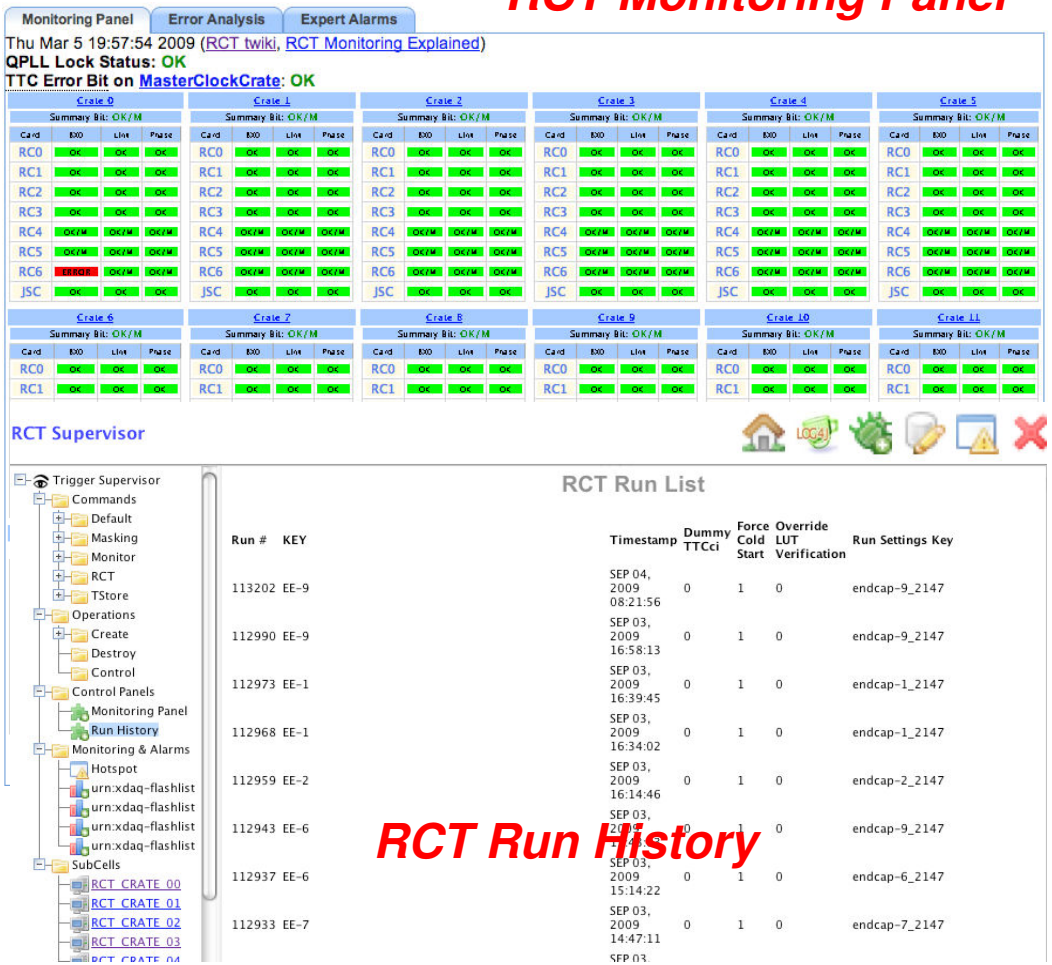
Basic functionality

- Individual crate operations
- Single commands

Will include pattern test management

- Controlled by Central TS
- Multiple sub-system ops

RCT Monitoring Panel



RCT Run History

RCT Intercrate Testing

Uses the ability of the RCT to cycle the addresses of its input LUTs on the Receiver cards (emulates 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
- **Will be integrated into TS**
- **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
```

RCT Trigger Emulator

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

- **Use and generate Look-Up Tables (LUTs) using decompression tables provided by HCAL and ECAL**
- **Include Hardware and Firmware registers and any other configuration options**
- **Access same database as TS to get configuration information**
- **Used for hardware validation and monitoring**
  - In use by the RCT to predict the response of the full system to trigger primitive data and pattern tests
    - **Online and offline Data Quality**
    - **18-Crate test (patterns injected at RCT LUTs)**
    - **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

CMS Global Runs and Data Taking

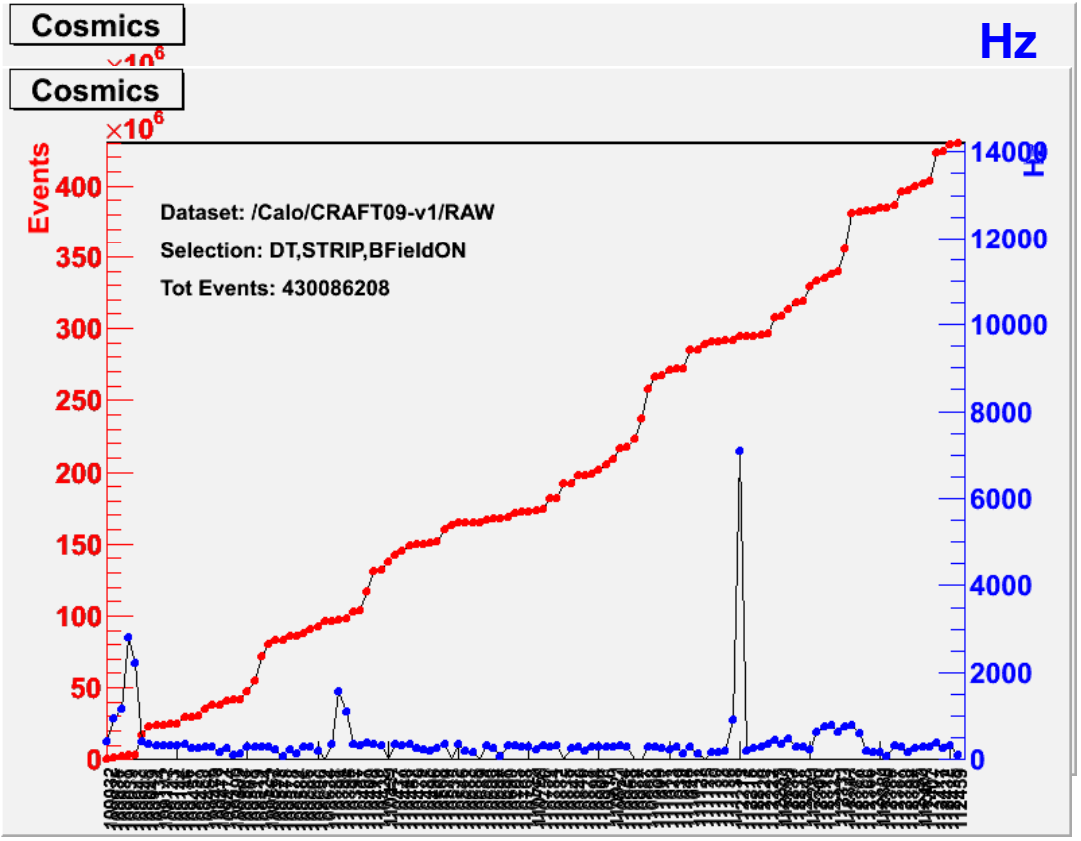
In order to integrate detectors, fix problems, and be ready for data taking when the beam restarts

- **Use cosmic-ray muons, study noise rates, run high-rate random triggers to test DAQ capabilities, etc.**
- **2 days to several weeks at a time**
  - Designated periods since Fall 2007
  - Most recently ~1 month run at 4T – CRAFT 09
- **All subsystems participate**
  - RCT took part with HCAL and ECAL providing TPGs
    - **ECAL E_T with H/E-Fine Grain OR to e/γ path**
    - **HCAL+ECAL E_T to Sums path with activity bit for Tau Veto**
    - **Configurable LUTs allow entire detector or portions to be masked**
      - e.g. hot trigger towers, HF out, etc.
  - RCT studies the data to validate algorithms and detect problems
    - **Use Data Quality Monitoring – Online and Offline**

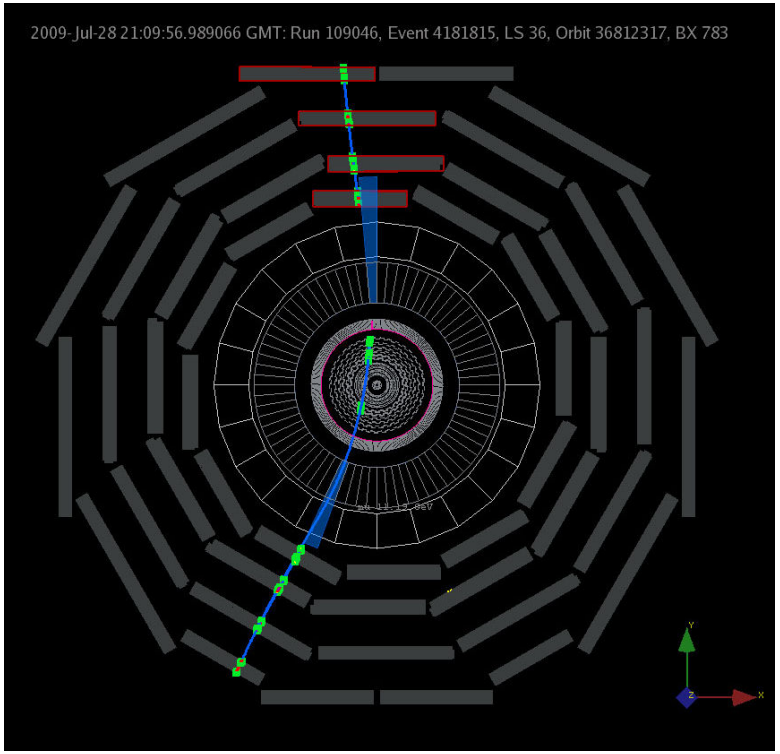
Global Runs and Data Taking

CRAFT09 (Cosmic Run At Four Tesla) in August

- **Goal of 300M muons with full detector reached**
  - Including calo trigger with physics LUTs – lots of valuable data



Muon with calo hits



RCT Data Quality Monitoring

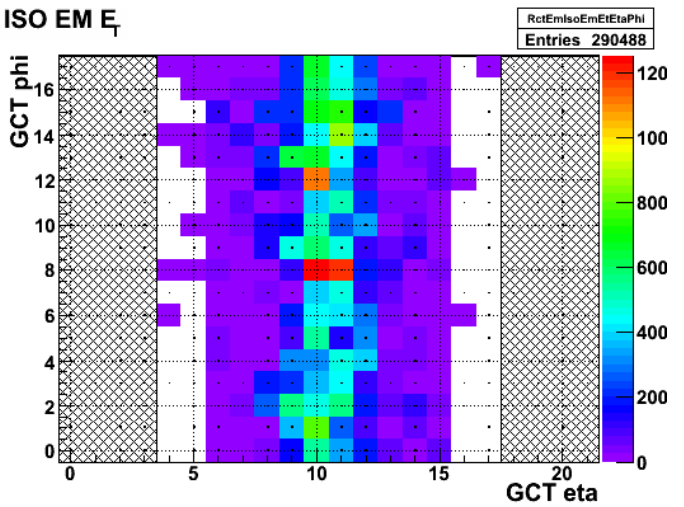
Online: real-time histograms created and filled

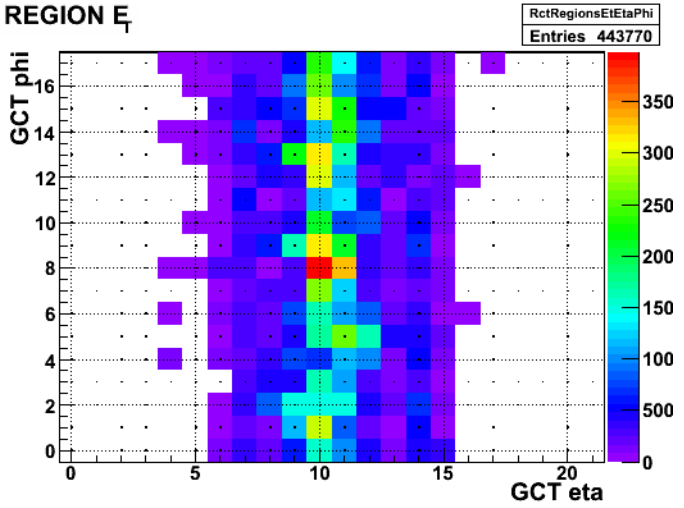
- Older runs available (all cosmic data)
- Data delivered at a rate of ~1-10 Hz
- L1 Trigger Summary Page has selected histos for trigger shifter to check

RCT Data Quality Monitoring

Online - RCT selected histograms help monitor:

- **Problems like a 'Hot' or dead channel**
  - Occupancy plots (right) of number of events per region
    - **RCT regions distributed over η & ϕ**
    - **η=0 between GCT eta 10 & 11**
  - Check rank of L1 candidates, etc.
  - Can be compared to a 'reference histogram" – highlighted if in error
- **In addition, real time data validity checks with emulator – L1TEMU**
  - Updated functionality
  - Histograms also highlighted
  - Level of errors reported per trigger subsystem on front page of DQM
- **Detailed histograms for each trigger subsystem's experts**
  - Accessed from L1T or L1TEMU summary page

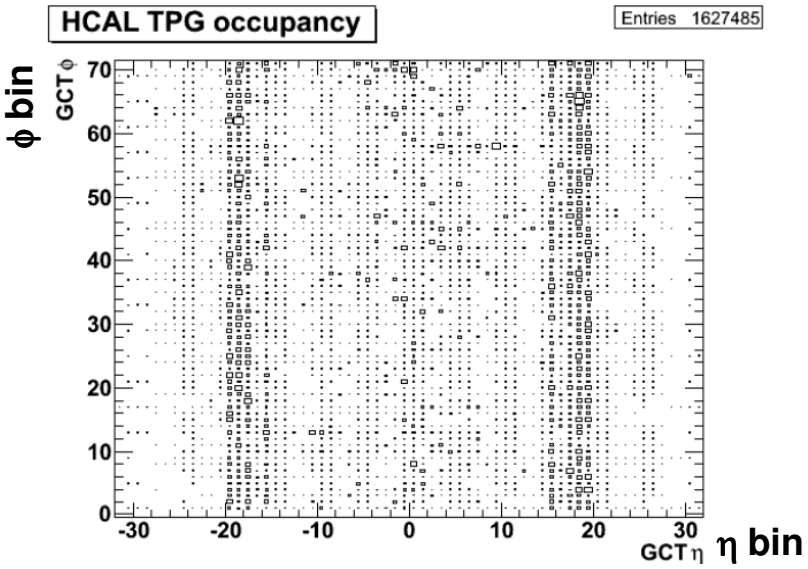




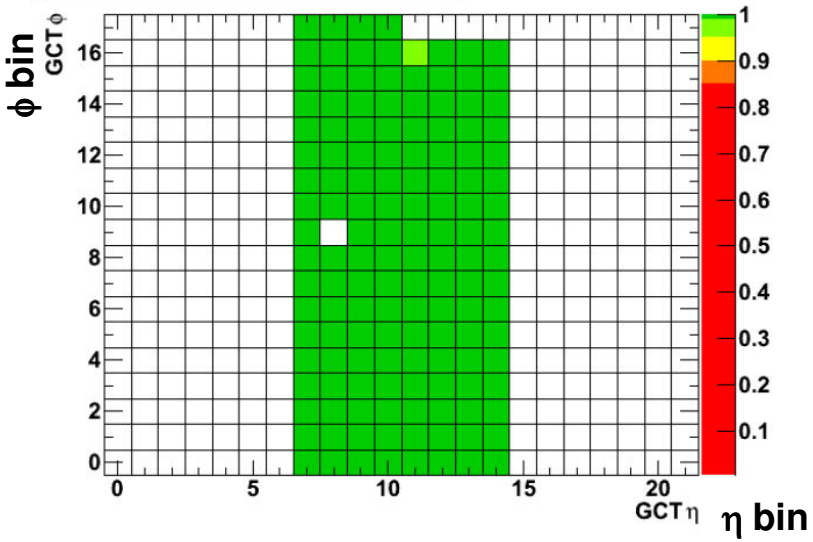
RCT Data Quality Monitoring

Offline – prompt and more detailed analysis possible

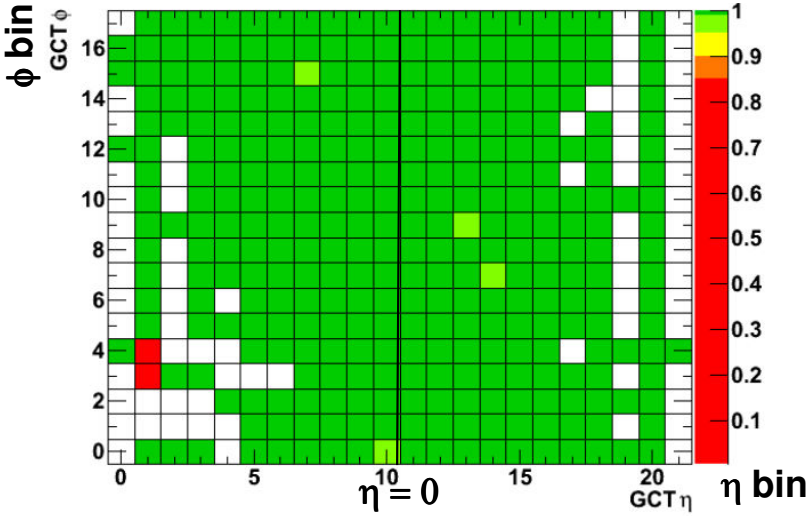
- Access to a greater number of events than online
- Book more histos (e.g. indiv. channels)
- Emulator uses HCAL and ECAL TPGs to predict results
- Compared to RCT/GCT data to get eff.
- Valuable debugging tool
  - Efficiencies reveal intermittent problems – Dark green is 100% efficient



e/γ Eff, rank (E_T) matching by RCT region



Region Eff, rank matching



RCT Performance

During CRAFT09 – 24/7 running

- **Repeated configuration of the RCT at run start**
  - No configuration errors due to hardware problems
    - **18 crates with >20x2^{17} locations in LUTs**
    - **Rare computer crashes/hardware driver problems excluded**
  - Rare software-related configuration errors
    - **New versions of software packages address this**
- **Monitoring of RCT performance**
    - **DQM online and offline evaluated daily**
    - **Caught problems early**
- **Efficiencies show near-perfect hardware performance**
  - Minor hardware issues repaired in time for restart of running and beam
    - **Very few fixes during CRAFT running possible**
- **Overall very stable operation ensured by diligence of RCT crew**

Finally

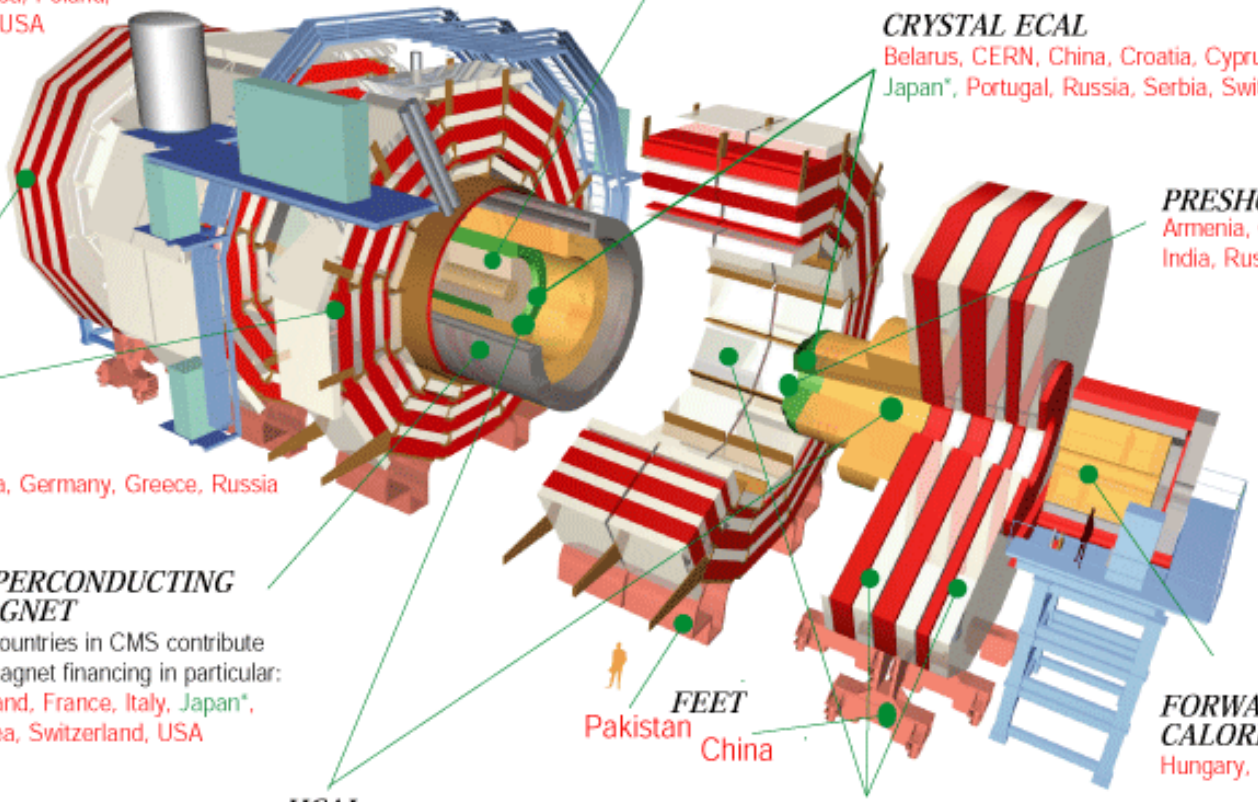
CMS RCT operating throughout 2009

- **Tools necessary for operation in place**
  - RCT Trigger Supervisor to configure, monitor, and test the RCT
    - **Integrated with Central Trigger Supervisor, controlled by CMS Run Control during daily data taking**
  - DQM running stably
- **Plenty of data taking in 2009**
  - Usefulness of RCT DQM and emulator proven
    - **Online and offline analysis to study RCT**
    - **Found problems early**
  - RCT flexible
    - **Not dependent on including complete calorimeter in run**
    - **RCT could mask sections or entire sub-detectors**
    - **Trigger Supervisor configuration keys set up for a variety of scenarios**
    - **Ensured RCT had copious data to analyze!**
  - RCT performance solid
- **RCT is ready for colliding beams!**

Backup Slides

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

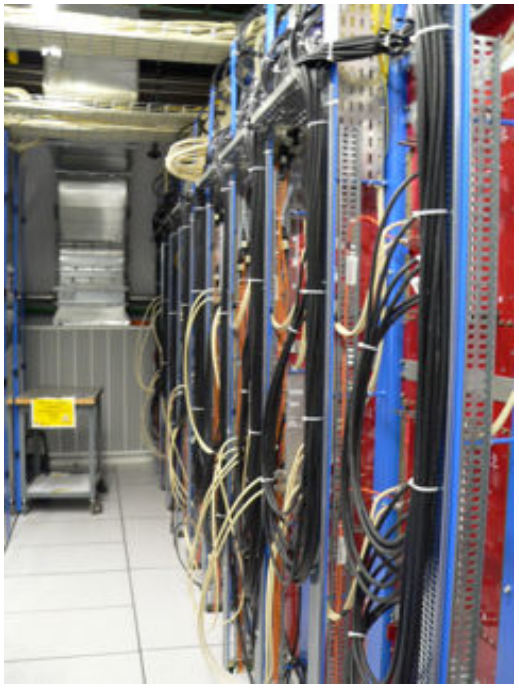
Total weight	**:**	**12500 T**
Overall diameter	**:**	**15.0 m**
Overall length	**:**	**21.5 m**
Magnetic field	**:**	**4 Tesla**

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

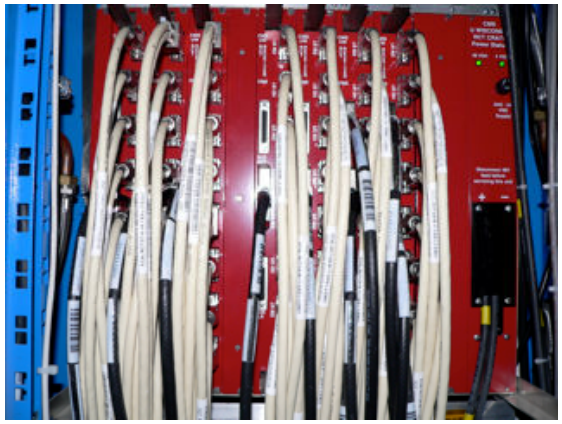


Full system = 19 Crates

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:

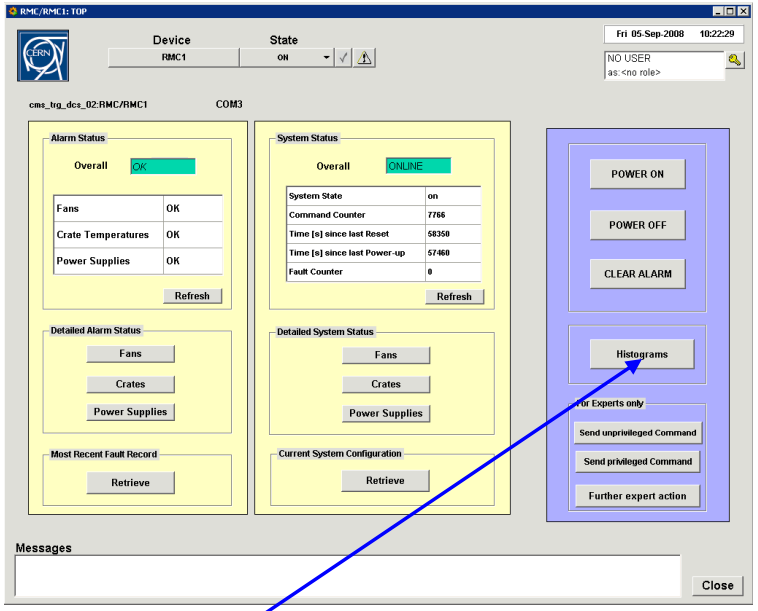
- Monitors power supplies, temperatures, fans
- Configurable - alarm set points, number of fans, power supplies connected…
- Ability to turn on and off system, check for and acknowledge alarms, send notification of…
- Connects to network via a COMTROL serial-to-ethernet port

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

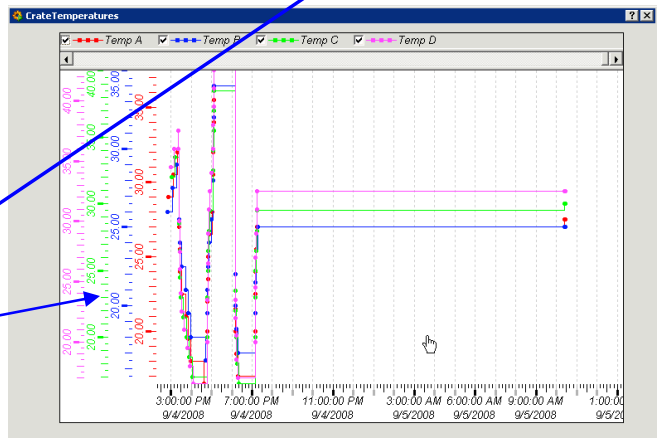
- Fully Implemented in USC55
- Exploits all above functionality
  - Keeps values in database
  - Histograms available

Fully integrated into CMS DCS

Rack 1 Control Panel



Rack 1 Crate A Temperatures



Rack Monitor Card and power chassis