Performance of the CMS Regional Calorimeter Trigger

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See also the CMS Level 1 Trigger Home page at

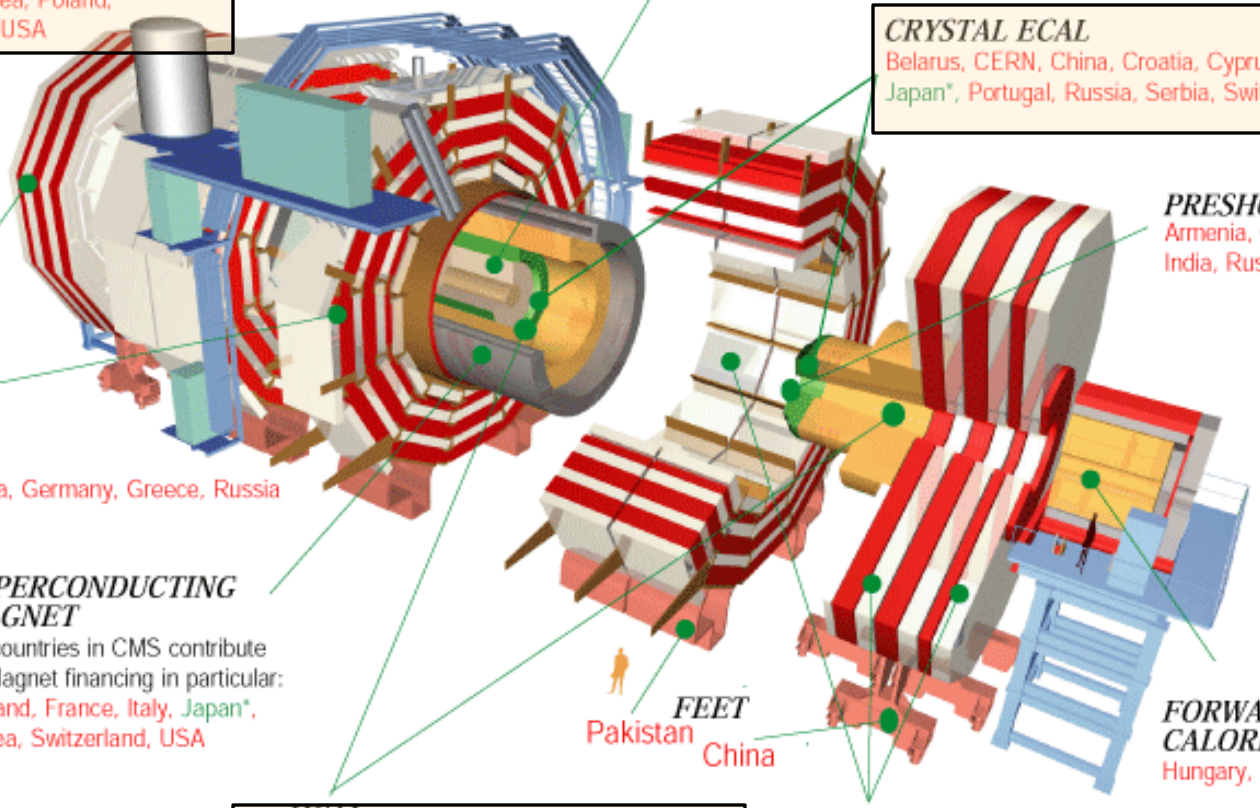
http://cmsdoc.cern.ch/ftp/afscms/TRIDAS/html/level1.html

Outline

- CMS and the Level 1 Trigger
- The Regional Calorimeter Trigger hardware
- Upkeep
- Performance

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

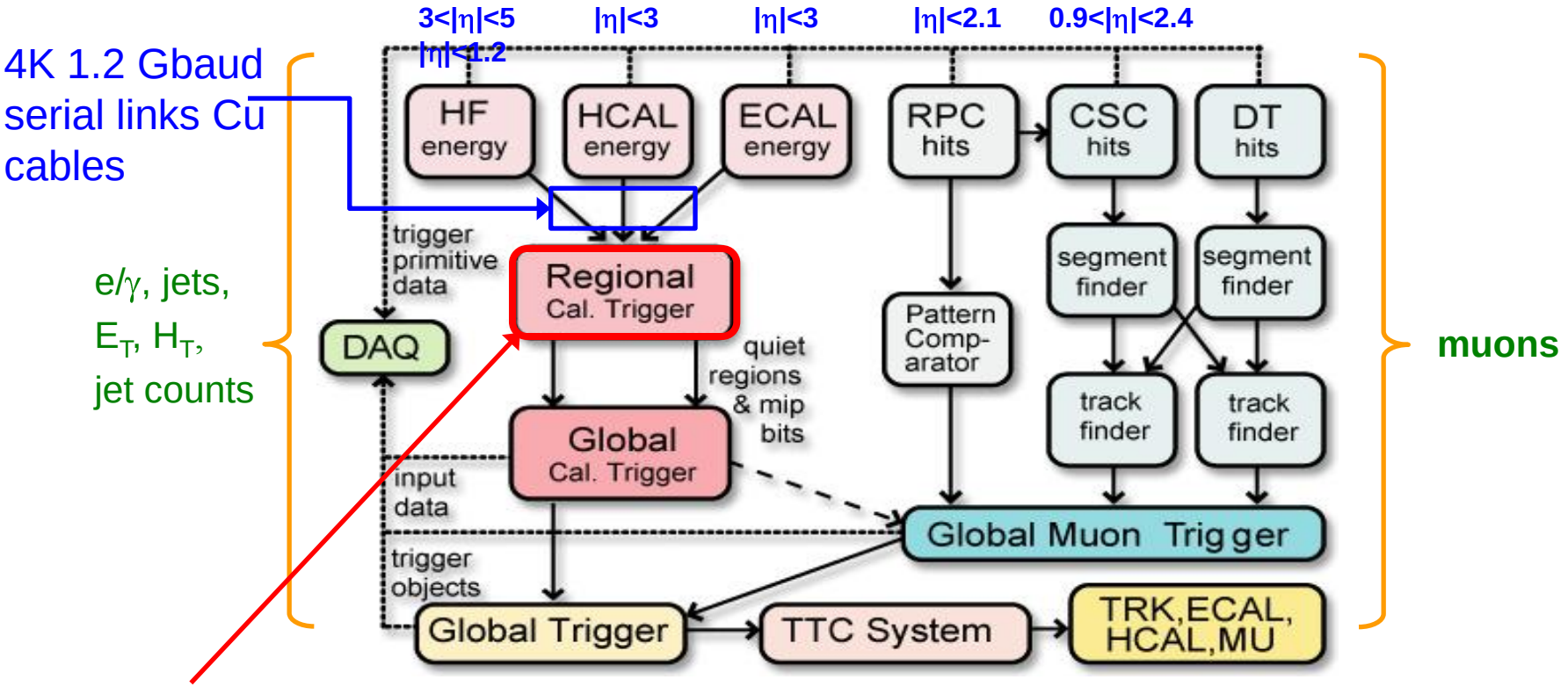
MUON CHAMBERS
Barrel: Austria, Bulgaria, CERN, China, Germany, Hungary, Italy, Spain,
Endcap: Belarus, Bulgaria, China, Colombia, Korea, Pakistan, Russia, USA

* Only through industrial contracts

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

The CMS Level-1 Trigger & Regional Calorimeter Trigger

- Only calorimeter and muon systems participate in CMS L1

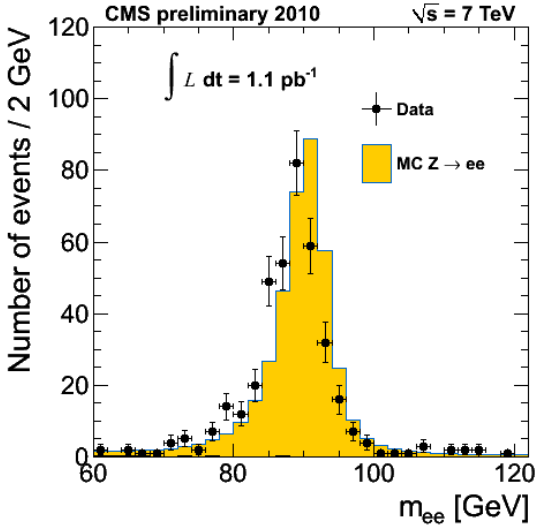


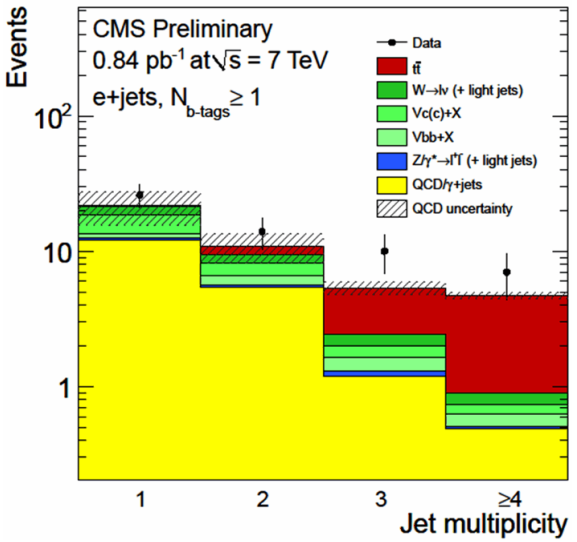
Regional Calorimeter Trigger

- 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

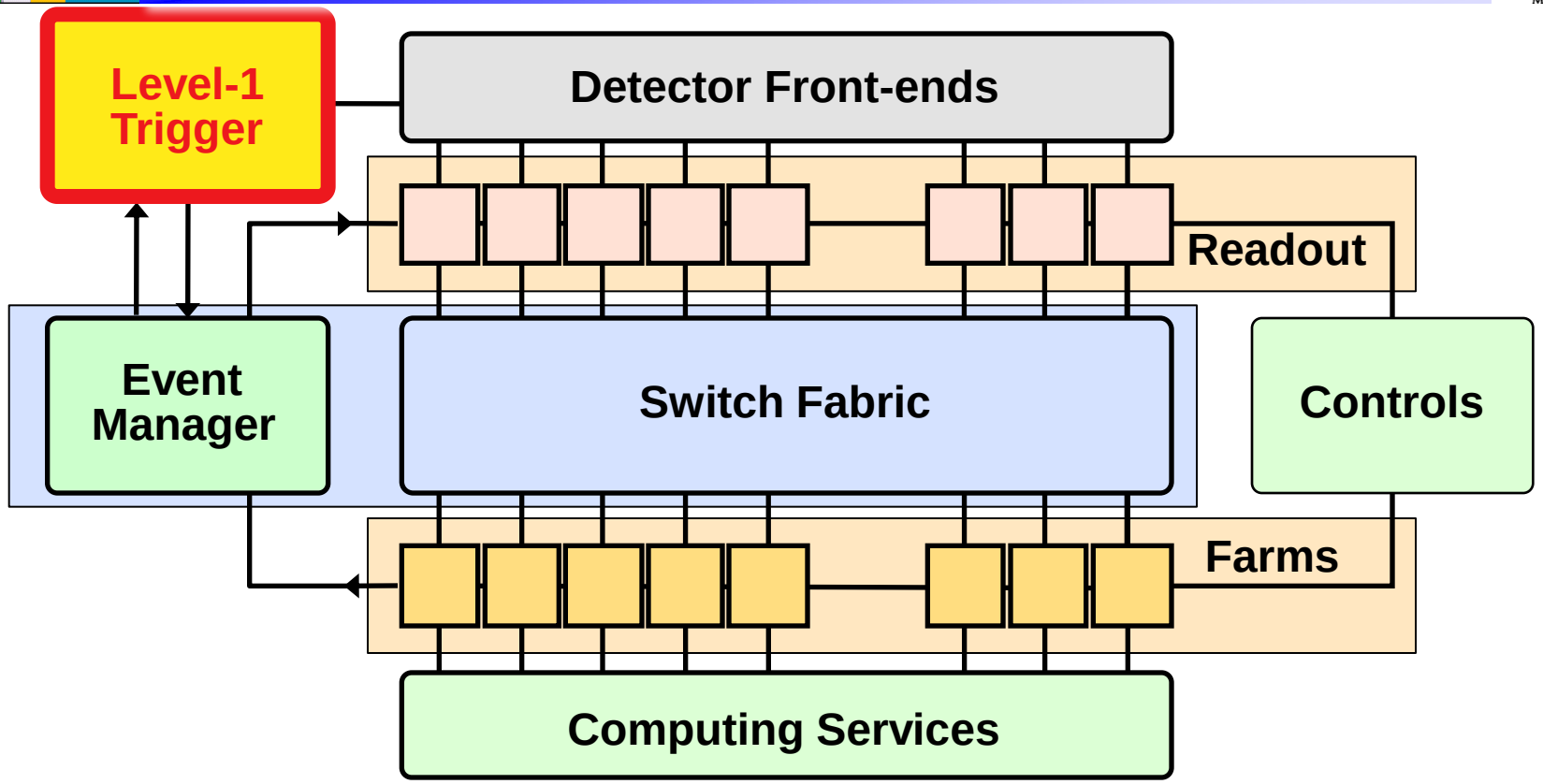
Vital for Physics

- First physics results already available for physics
- Many have already started using triggers from the Level 1 calorimeter trigger



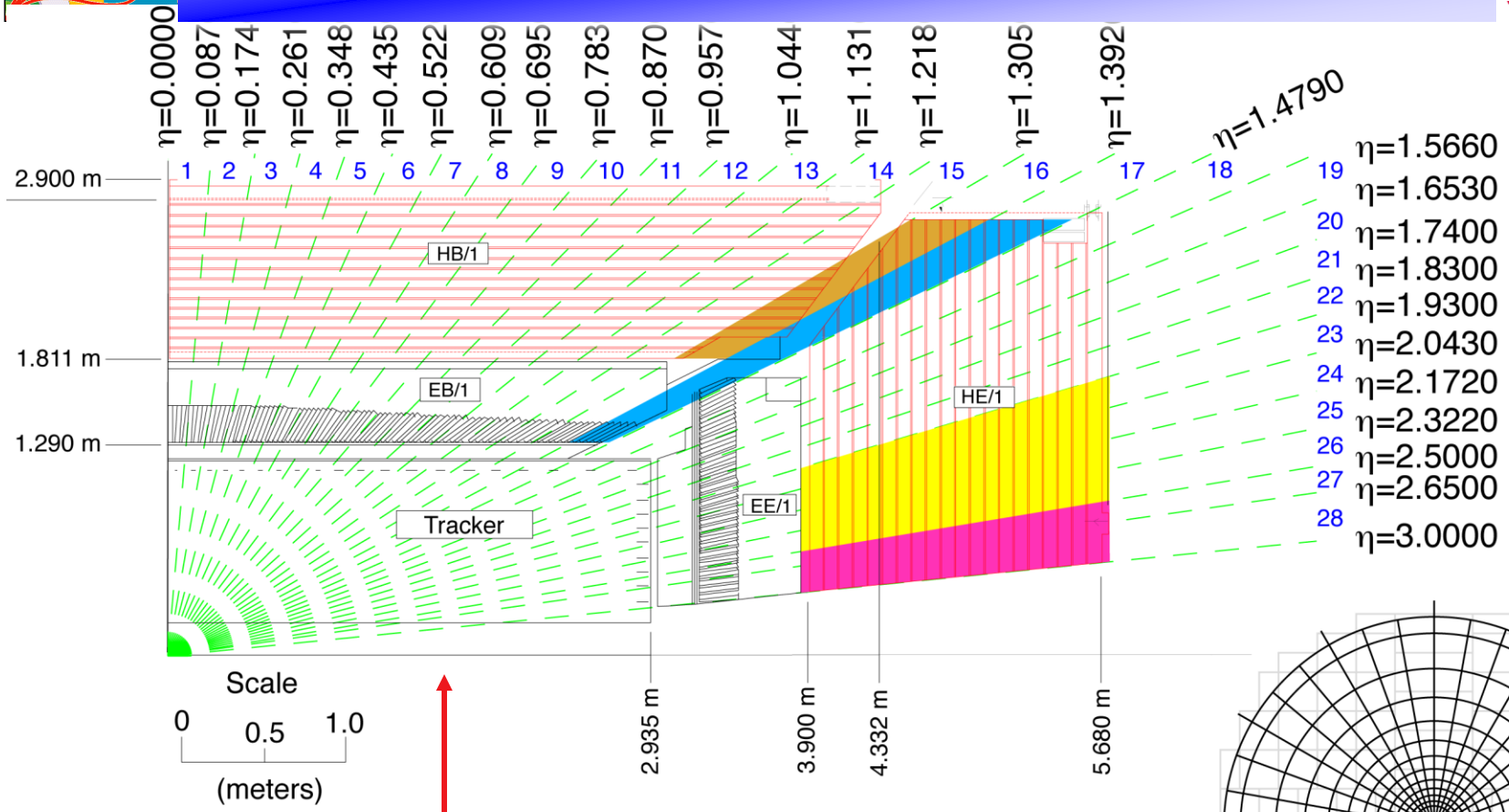


CMS Trigger & DAQ Systems



- 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

CMS Calorimeter Geometry



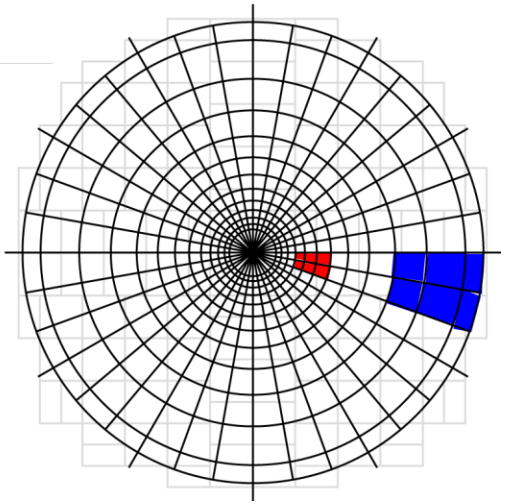
EB, EE, HB, HE map to 18 RCT crates

Provide e/γ and jet, τ, E_T triggers

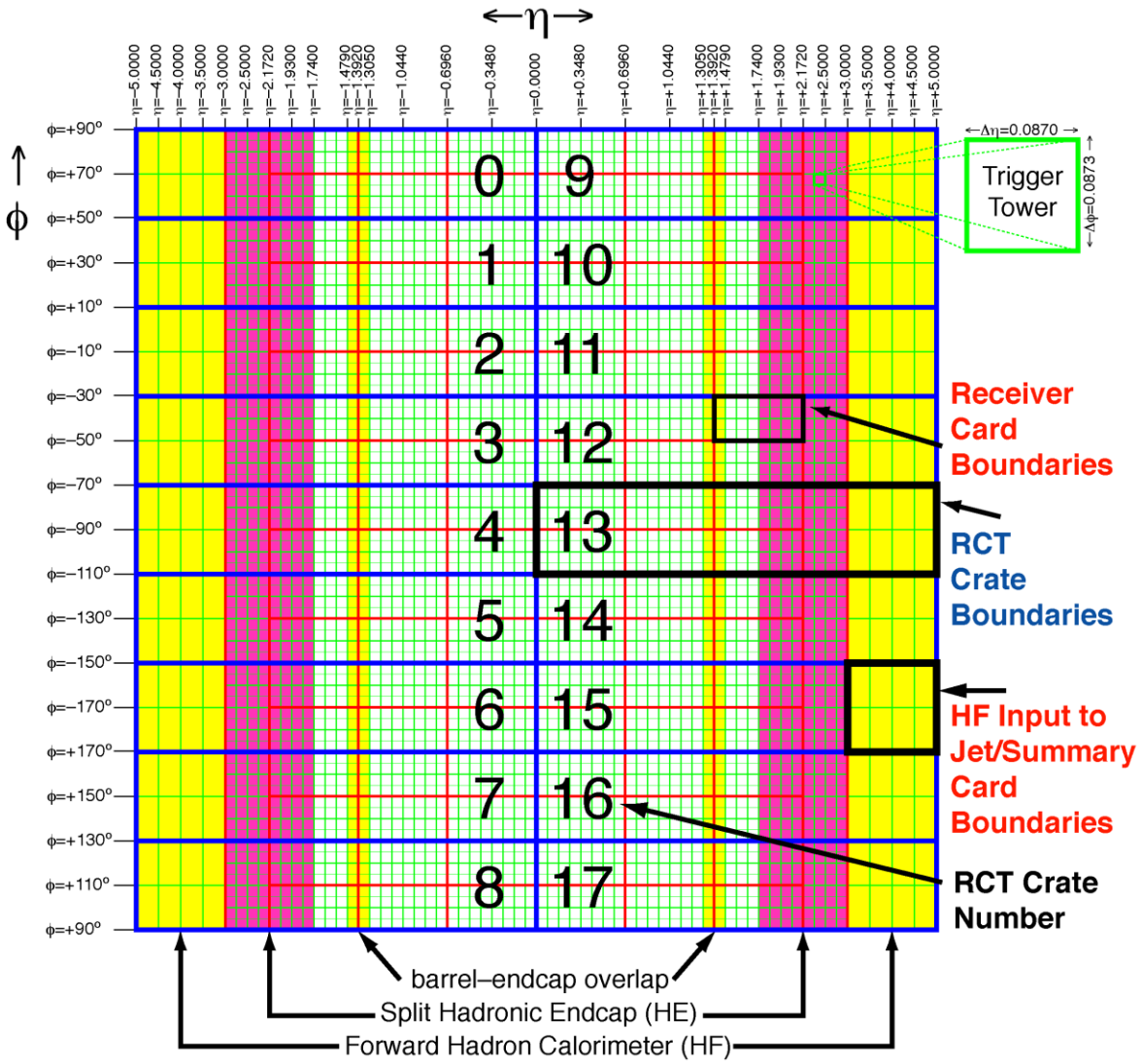
2 CMS HF Calorimeters mapping onto Trigger System HF Crate

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

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

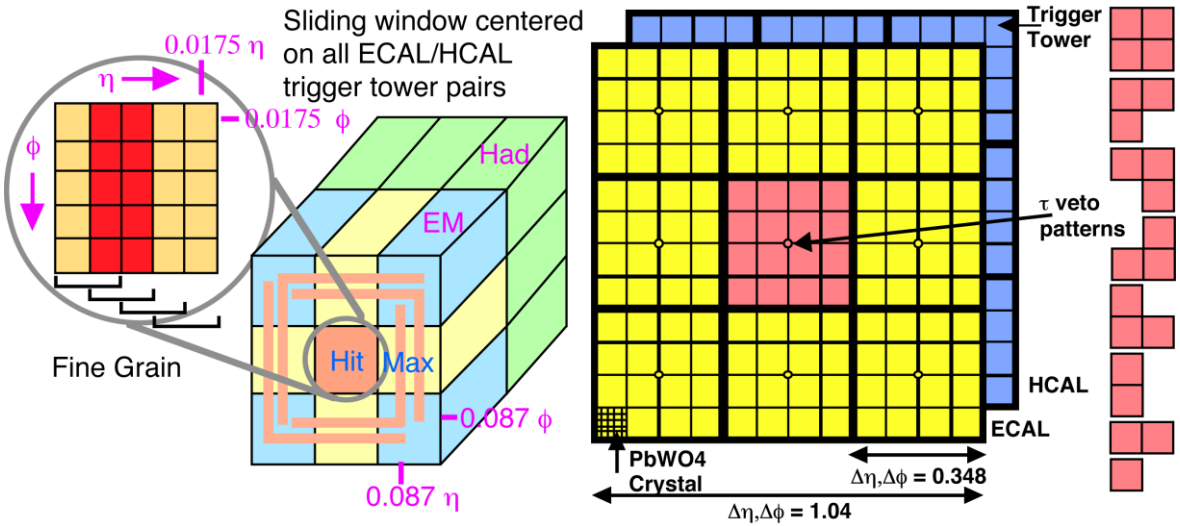


Calorimeter-RCT Mapping



- 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 Trigger Algorithms

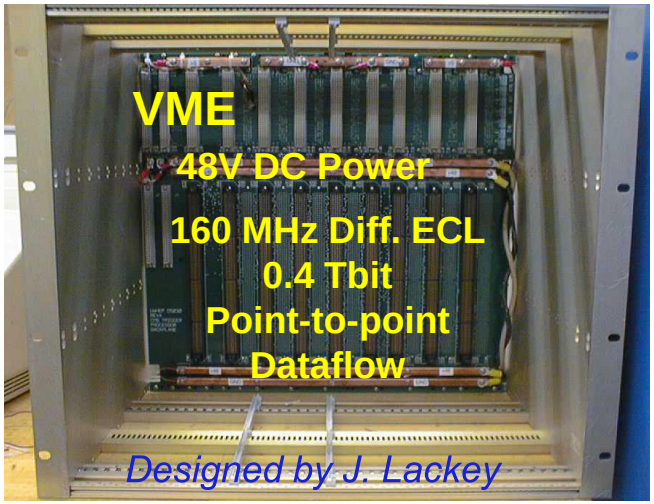


- e/γ Rank = Hit+Max Adjacent Tower
  - Hit: 2 of 5-crystal strips >90% E_T in 5x5 Tower (Fine Grain)
  - Hit: H/E < Small Fraction
    - Not used in first data
- Isolated e/γ (3x3 Tower)
  - Quiet neighbors: all 8 towers pass Fine Grain & H/E
    - Not used in first data
  - One corner of 5 EM towers is E_T < Threshold
    - Current threshold 1.75 GeV

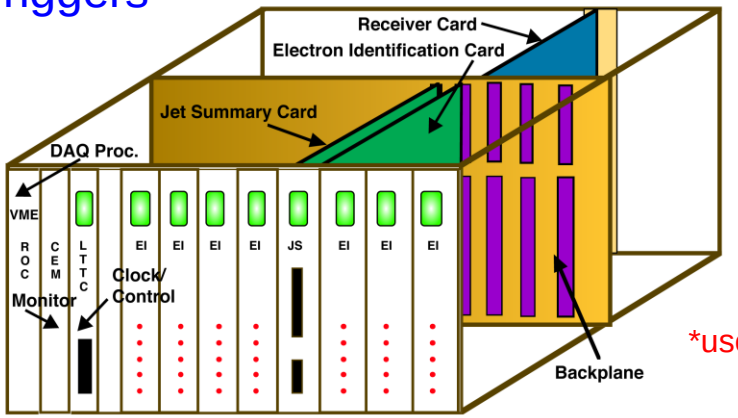
- Jet or t ET
  - 12x12 trig. tower □ ET sliding in 4x4 steps w/central 4x4 ET > others
- τ: isolated narrow energy deposits
  - Energy spread outside τ veto pattern sets veto
    - Current level 4 GeV
  - τ Jet if all 9 4x4 region τ vetoes off

RCT Crates

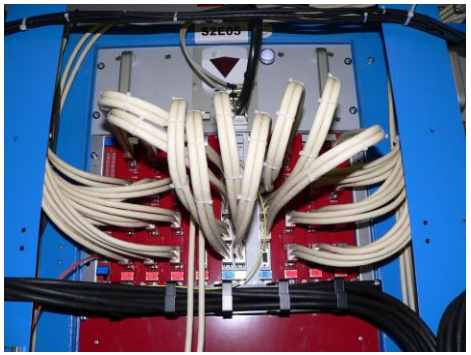
Main RCT Crate



18/26* crates with custom backplane incorporate algorithm: 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.

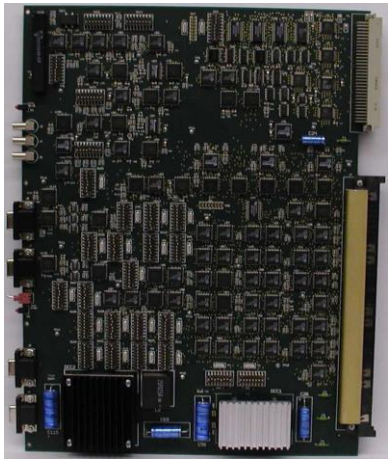
*used/total produced

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



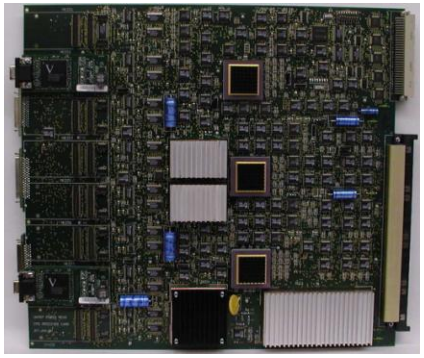
Receiver

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

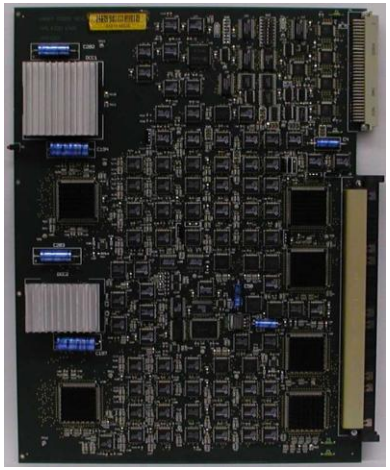
126/157* - 7 per crate

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

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

28 e/g candidates per crate via BP to JSC

- 7x2 Iso & 7x2 Non-Iso



*used/total produced

Jet Summary

18/25* - 1 per crate

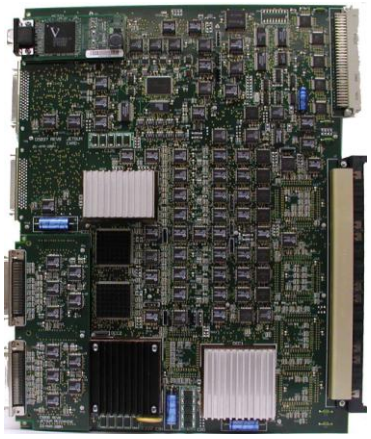
e⁻ γ

- Sort ASICs receive data on BP & find top isolated & non-isolated)

μ

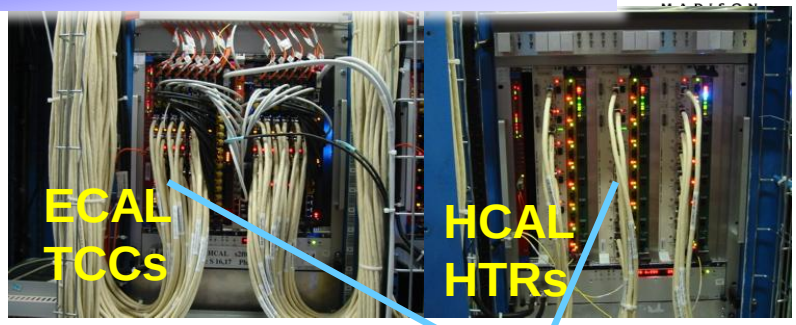
- 14 Quiet Bits by threshold on JS
- 14 MinIon bits from RC

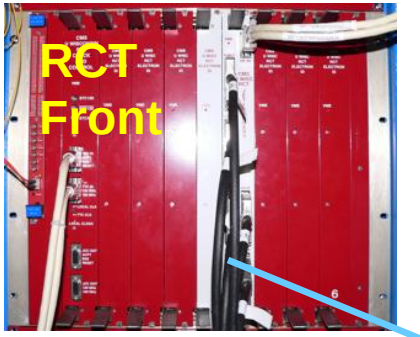
- Forward Calorimeter (HF) RMC & LUTs for HF E_T's
- Regional (4x4 tower) sums to GCT

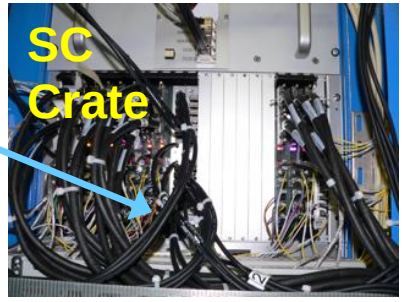


RCT Input and Output

- 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







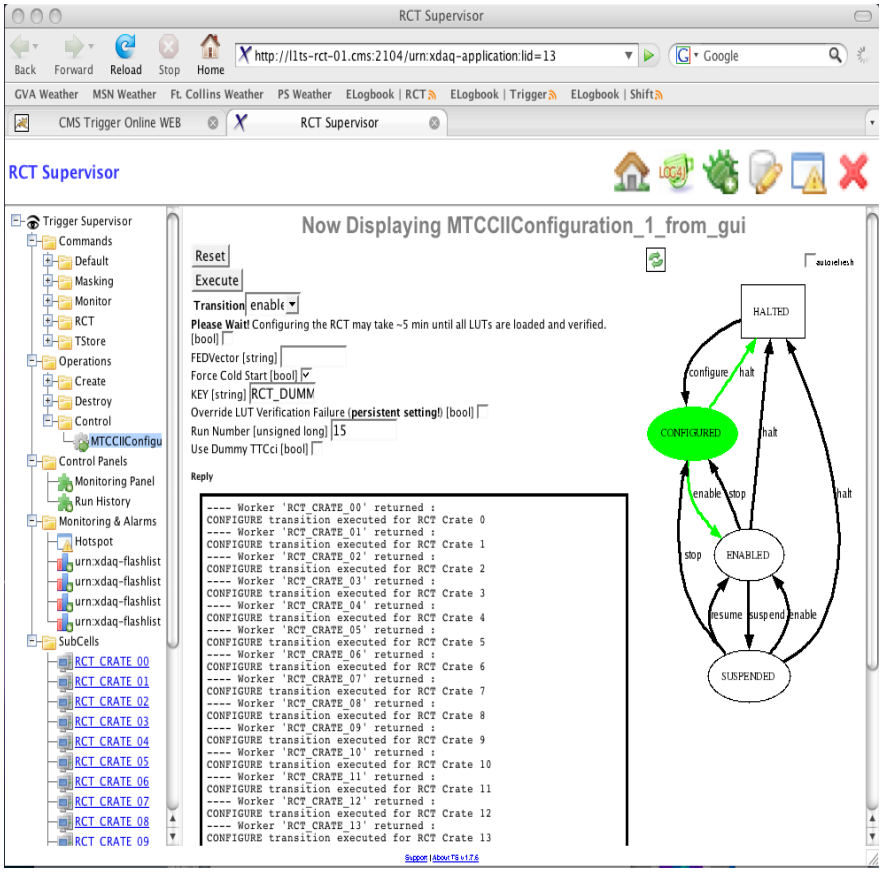
Each RCT Crate to to 3.5 GCT Source Cards (SCs)

- 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)

Trigger Supervisor

- 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 and for configuration including channel masking
    - Accesses CMS front end readouts of ECAL and HCAL to also mask channels
    - Interface for creating new keys
    - Provides feedback after transition

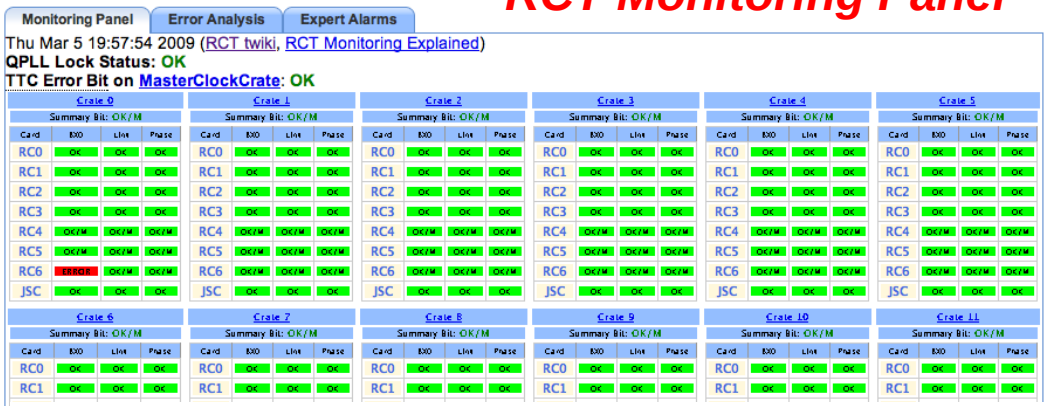
RCT Configuration



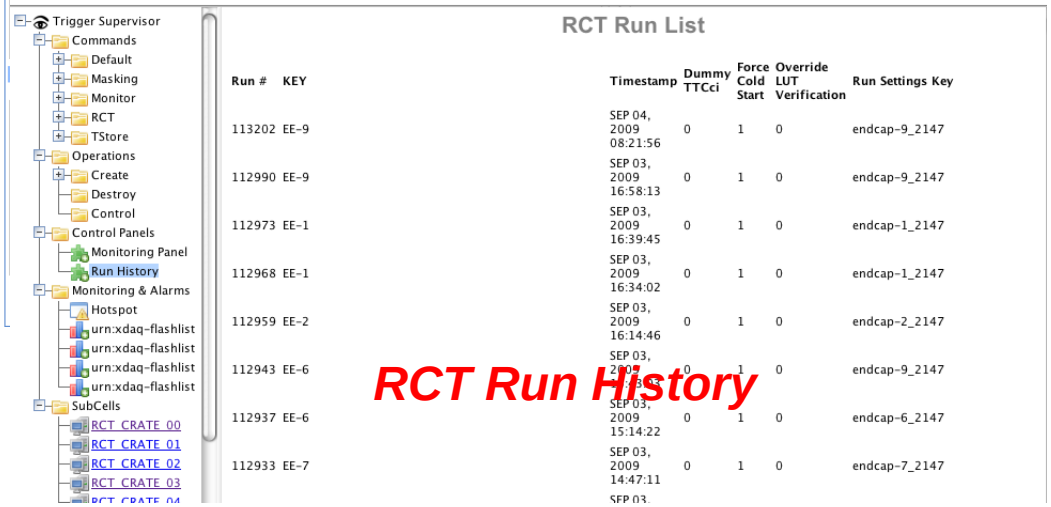
Monitoring

- 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
    - Dynamic and by file
  - 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



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
  - Preliminary patterns injected at TPG level
    - Tests SLB-RCT link, algos. and LUTs

```
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

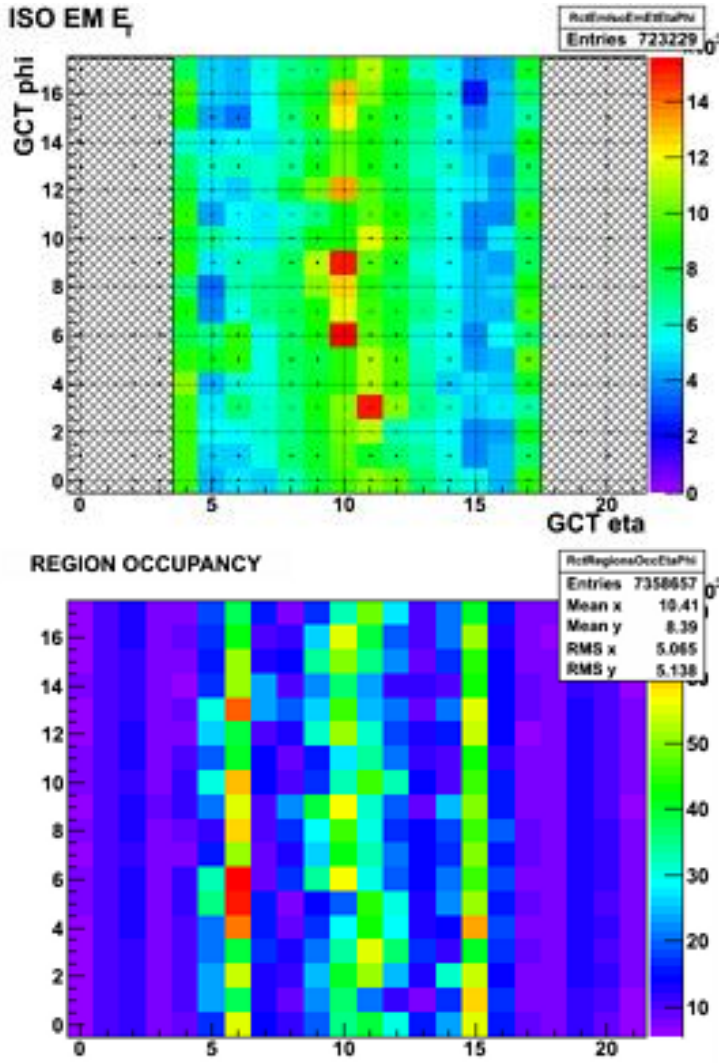
- Software with the goal of exactly reproducing the L1 Trigger hardware response, including:
  - Use and generate Look-Up Tables (LUTs) using information in CMS online database
    - Include hardware and firmware registers and any other configuration options
    - Access same database as TS to get configuration 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

7 Tev Collisions

- Have been running since March
- Early first data was first with significant data in the ECAL Endcap triggers on the $\eta < 0$ side.
  - Corrected early problems with bad links
- Emulator comparisons show that the RCT is performing as expected
  - Maintaining system translated into a working trigger
- Will use early data to calibrate triggers in the Calorimeter chain.
  - Early calibration already in RCT for electron-photon trigger
  - It will improve turn on curves seen following

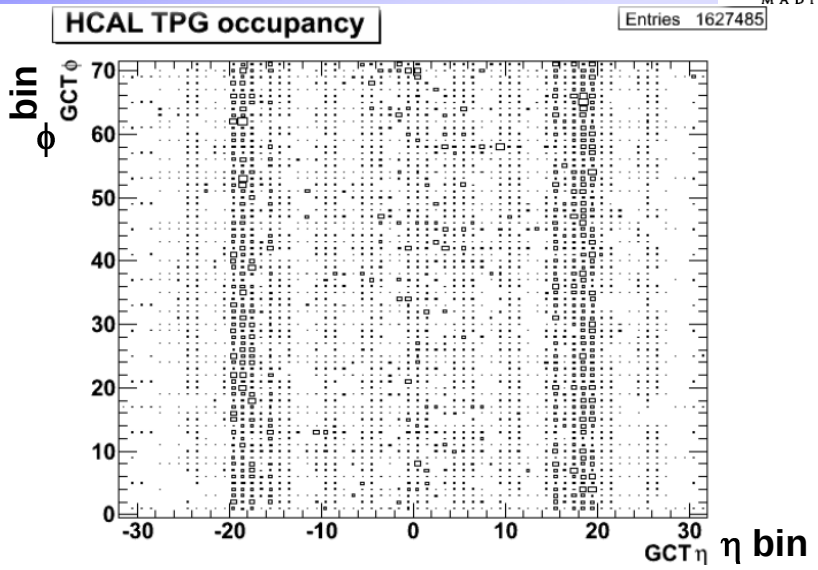
Data Quality Monitoring

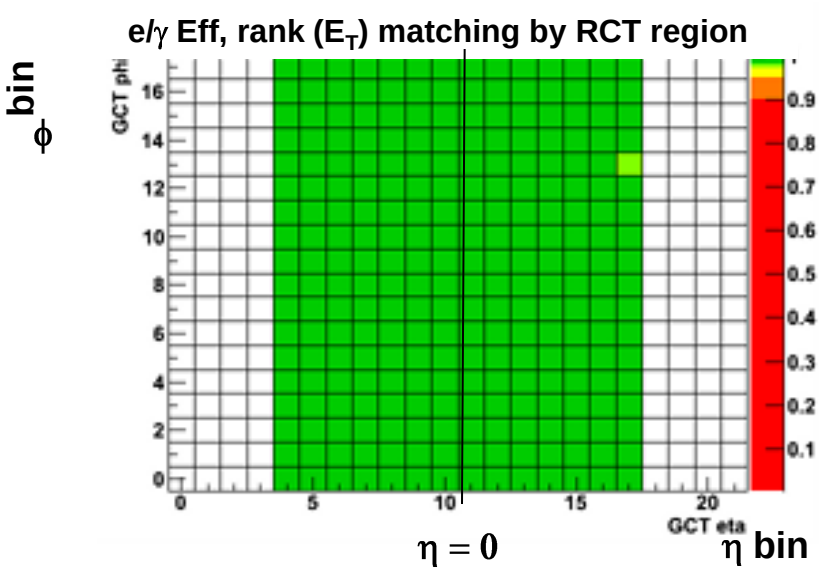
- Online - RCT selected histograms:
  - Problems like a 'Hot' or dead channel
    - Occupancy plots (right) of number of events per region
      - RCT regions distributed
    - Check rank of L1 candidates, etc.
    - Can be compared to a 'reference histogram" – highlighted if in error
  - In addition, 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

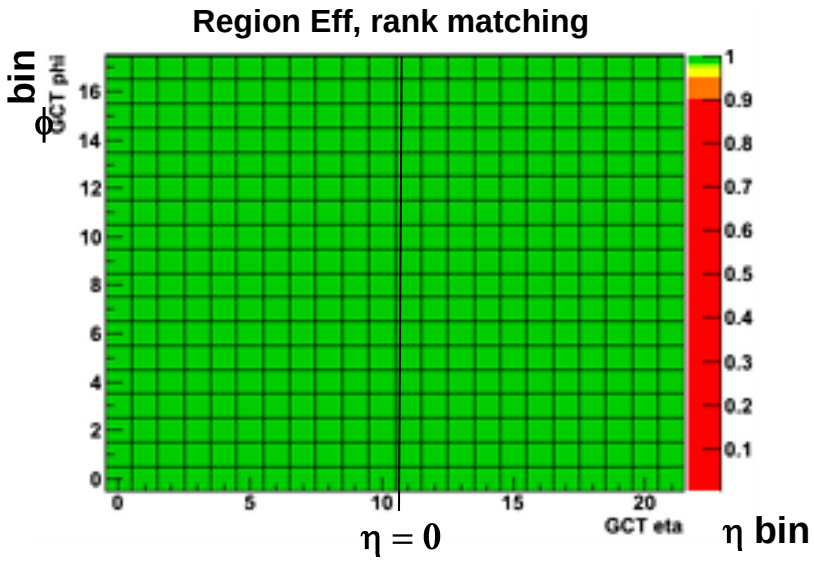


RCT Data Quality Monitoring

- Offline – prompt and more detailed analysis possible
  - Access to a greater number of events than online
  - Emulator uses HCAL and ECAL TPGs to predict results
  - Compared to RCT/GCT data to get eff.
  - Valuable debugging tool
    - Automatic data testing
    - Can reveal intermittent problems
  - Proves that RCT works as expected

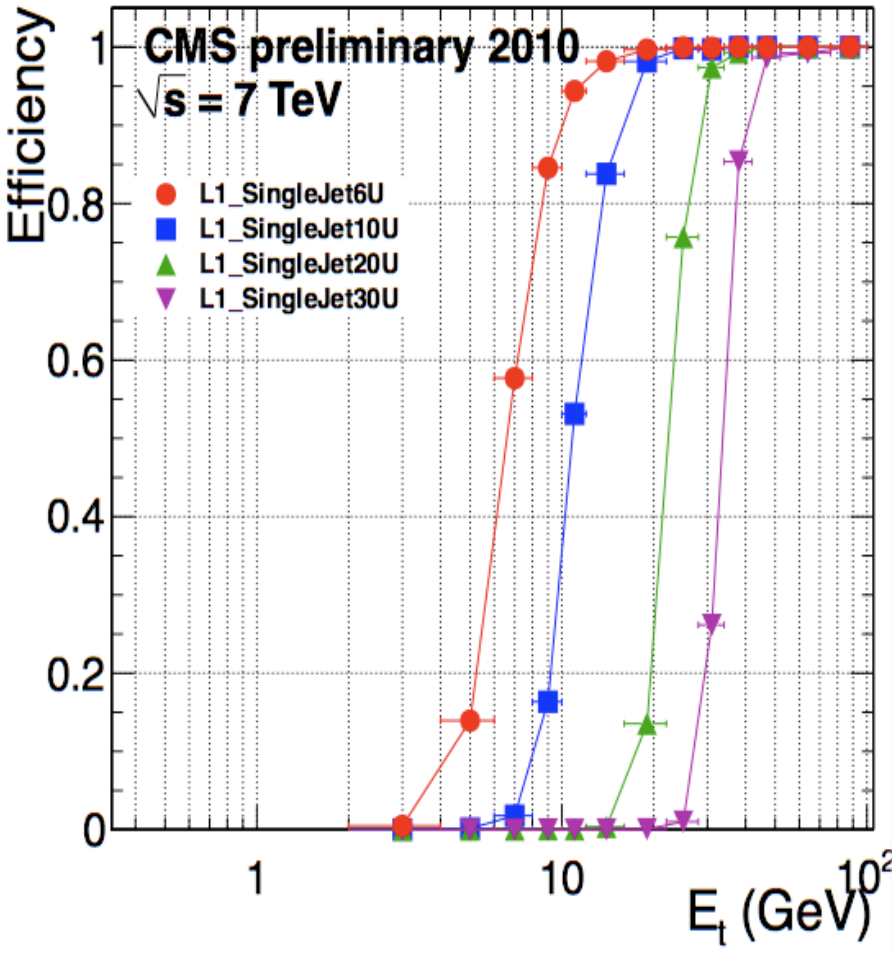






L1 Jet Efficiency

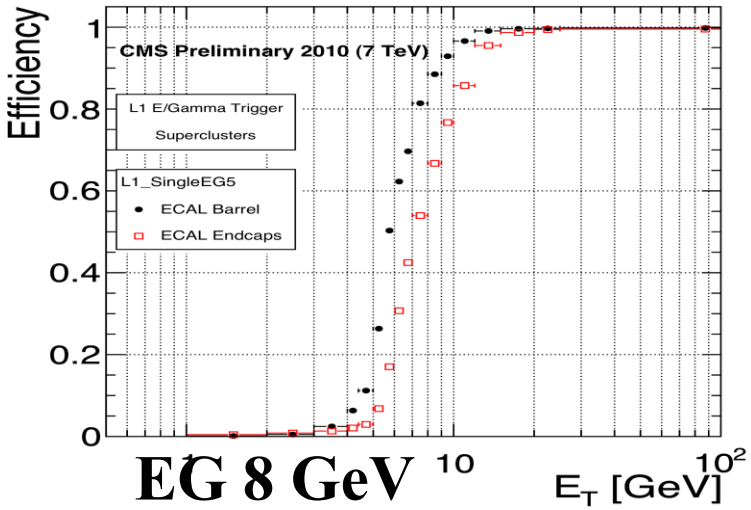
- Events selected on minbias trigger
  - Good vertex/anti-scraping selection
  - Standard filtering/cleaning for noise and anomalous signals
- Offline jet cuts
  - Anti-kt5
  - Loose jet ID
  - $E_t > 10$ GeV
  - $\eta < 2.6$
- Efficiency as function of offline jet E_t
  - Leading offline jet matched to a L1 jet
  - with dR < 0.5



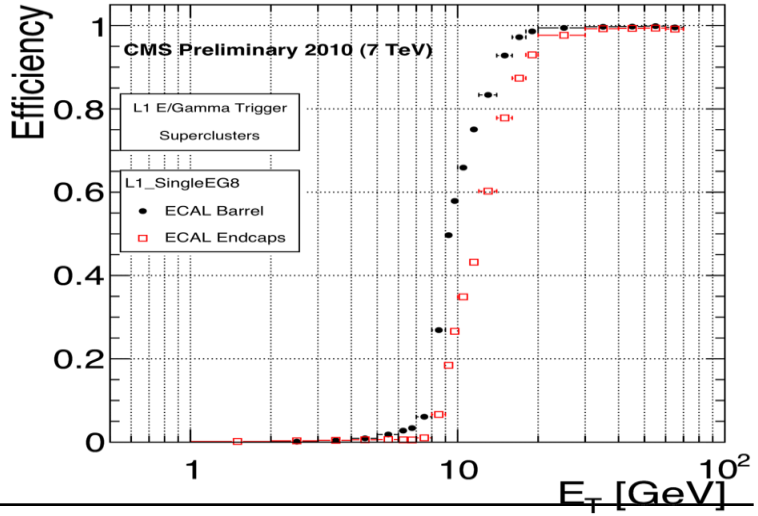
L1 EG efficiency for Superclusters

- Sample of ECAL Activity HLT triggers (seeded by L1 ZeroBias)
  - Anomalous ECAL signals removed using standard cuts
- EG trigger efficiency for finding a L1 candidate, given an ECAL supercluster
  - All superclusters included
  - L1 threshold of 5 GeV (top), 8 GeV (bottom)
- Two η ranges shown
  - Barrel and endcaps

EG 5 GeV



EG 8 GeV

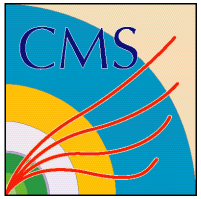


RCT Performance

- Continuous data-taking since before collisions
  - Rare 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
  - Rare errors in emulator comparisons
    - Errors due to hardware problems which have been promptly been fixed
- Overall very stable operation ensured by diligence of RCT crew

Summary

- CMS RCT operating throughout 2010
  - 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 collisions
    - RCT triggers used in public results
    - Usefulness of RCT DQM and emulator proven
      - Online and offline analysis to study RCT
      - Found problems early
    - RCT flexible
      - RCT masks sections or entire sub-detectors
      - Trigger Supervisor can dynamically mask parts of calorimeter not contained in a run
      - Ensured RCT had copious data to analyze!
      - Can be used to calibrate triggers
    - RCT performance solid



Backup Slides

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)

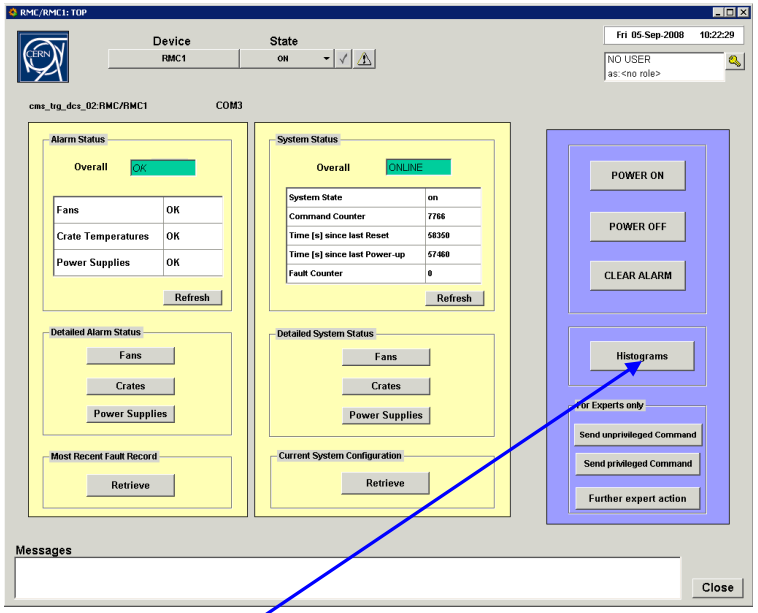
Rear of Racks

- Input cabling complete
- Total: 1026 SLB-RCT

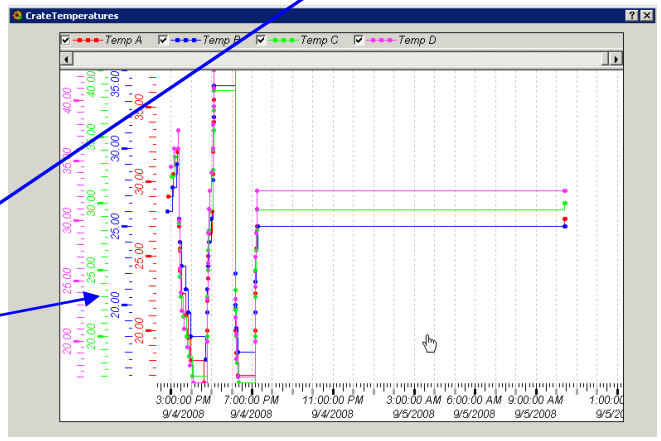
Operations: Detector Slow Control and Rack Monitoring System

- 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

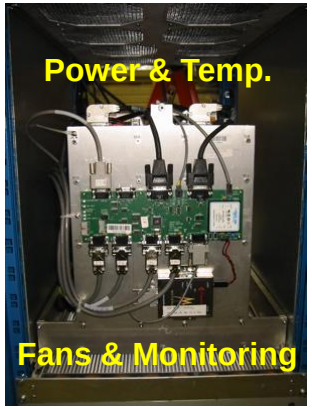
Rack 1 Control Panel



Rack 1 Crate A Temperatures



Rack Monitor Card and power chassis



L1 resolution for Superclusters (E_T > 5 GeV)

- Sample of ECAL Activity HLT triggers (seeded by L1 ZeroBias)
  - Anomalous ECAL signals removed using standard cuts
- Resolution of L1 candidates with respect to superclusters
  - Superclusters with ET > 5 GeV
  - Barrel (top), Endcaps (endcaps) shown separately
- Note
  - L1 EG algorithm = 2 tower sum
  - Supercluster is generally spread over many towers, especially in endcaps

Resolution = E_T(L1) – E_T(Super~~Cluster~~)
E_T(SuperCluster)