The CMS Global Calorimeter Trigger Test Results and Commissioning

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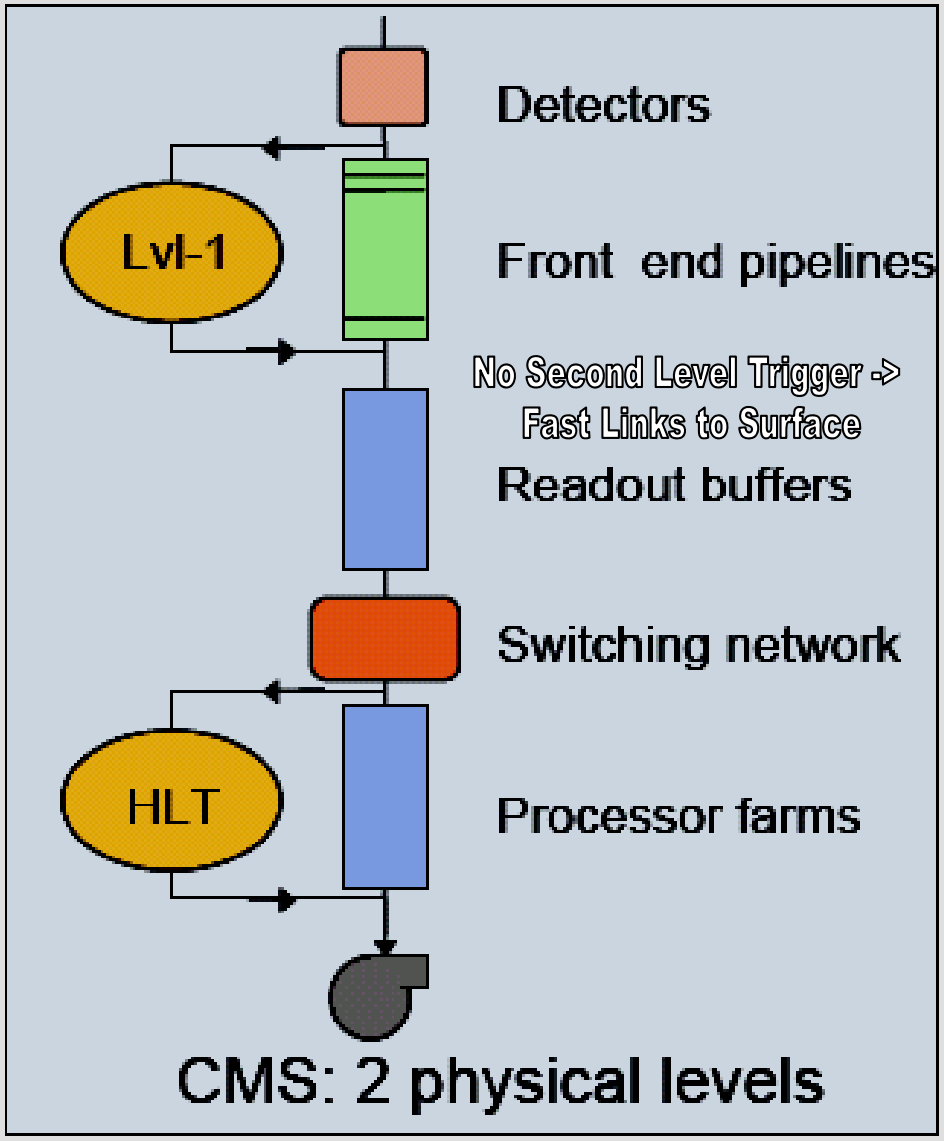
Overview:

- Brief Description of the GCT Design
- The GCT Hardware
- Installation at CMS USC-55
- Pattern Test Results
- Outlook

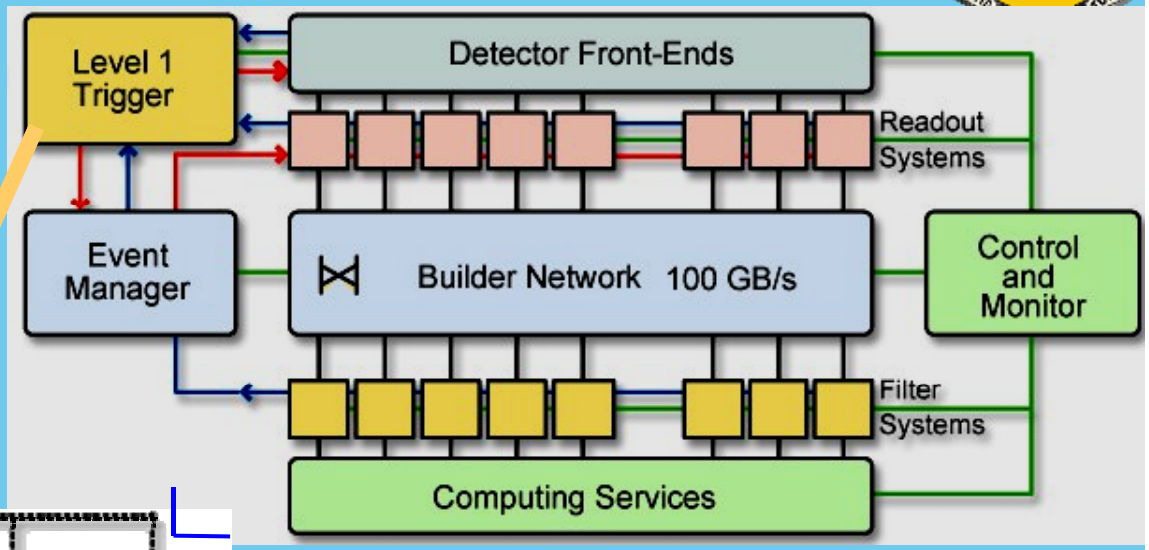
The CMS Trigger System

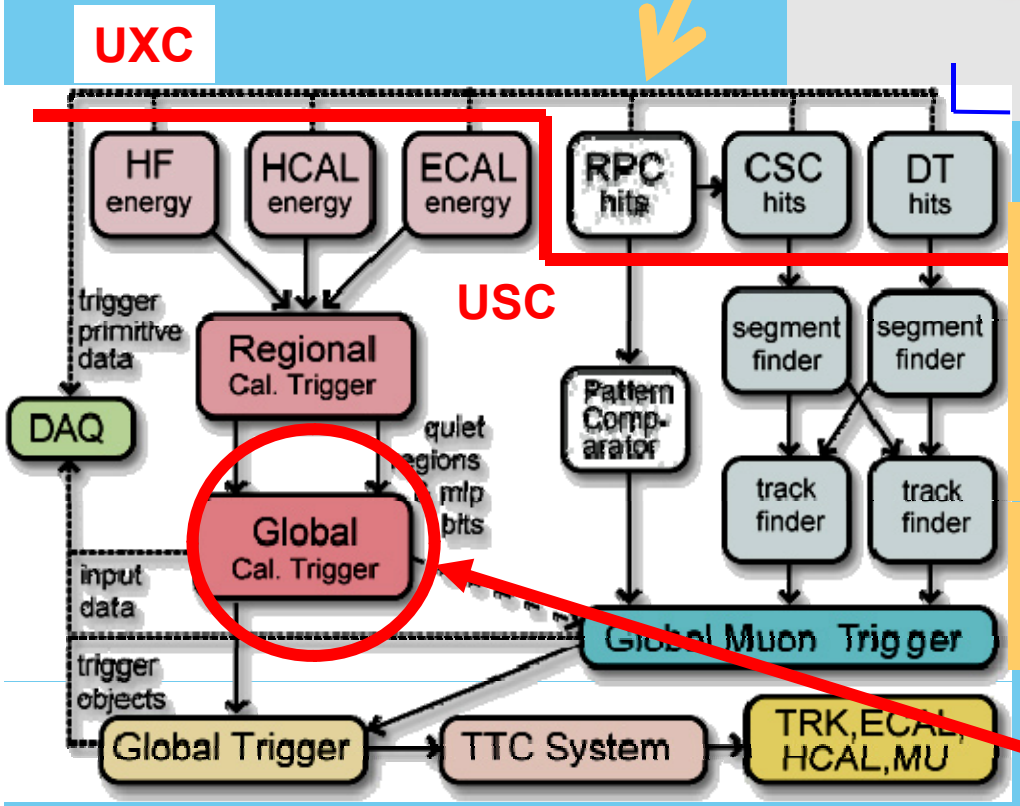


- 40 MHz input
- 100 KHz FLT rate
- 3.2 μsec Latency
- 100 Hz written at the output
- Event Size 1-2 Mbytes
- The requirements on the Level-1 Trigger are demanding.
- Level-1 Trigger: Custom made hardware processor.
- High Level Trigger: PC Farm using reconstruction software and event filters similar to the offline analysis.

CMS Level-1 Trigger & DAQ

The place of L1 Trigger in the CMS TriDAS system



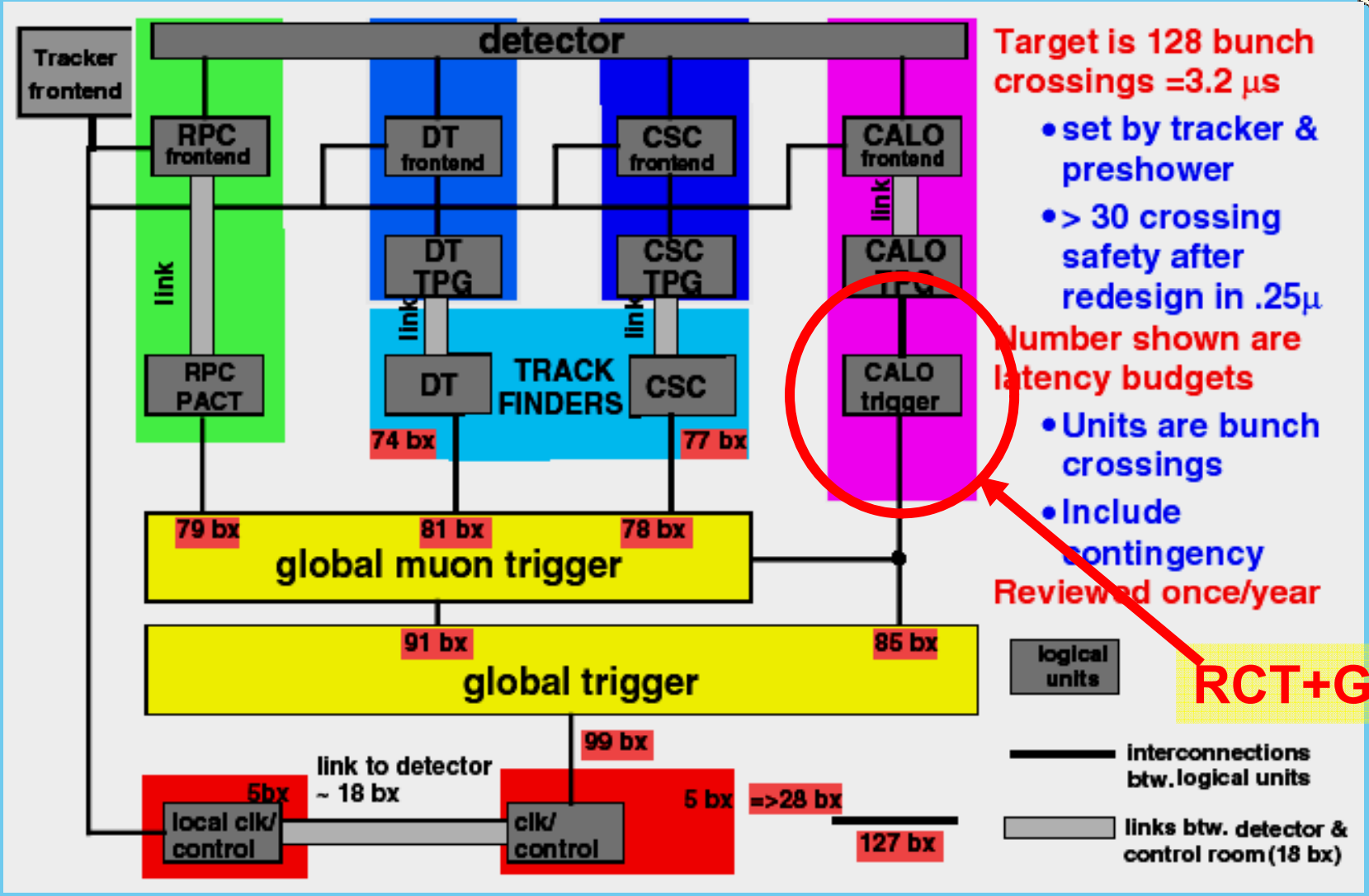


L1 Trigger:

- **Highly distributed**
- **Both on detector and off detector**
- **Large variance in technology**
- **Trigger based on calorimeter and muon systems (no Si-Tracker)**
- **It is reasonably programmable**

e/γ, central, forward, τ-jets, MET

CMS Trigger and L1 Latency



L1T Latency = 128 Bx or 3.2 μsec

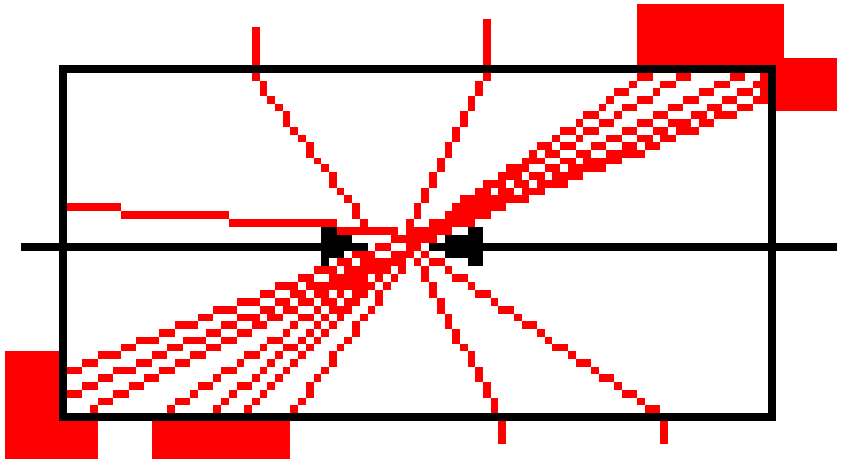
GCT Latency = 24 Bx

The Calorimeter Trigger Task

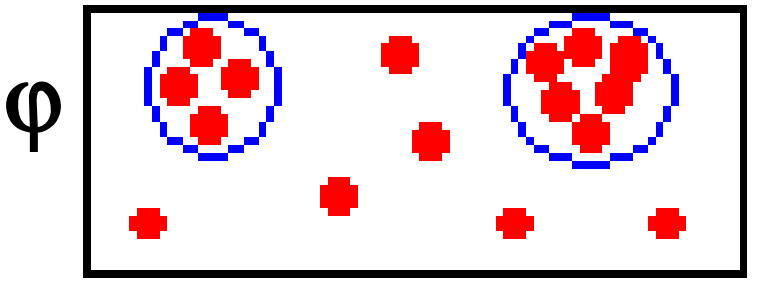
- **Jet Triggers:** Central, Tau and Forward jet finding and sorting.
- **Jet Counters:** Count Jets in 12 different regions of the detector or 12 different thresholds within the detector.
- **Electron/γ triggers:** Select and Sort the e/γ candidates from Regional Calorimeter Trigger.
- **Total Transverse, Total Missing Transverse and Total Jet Transverse Energy** calculation.
- **Muon System:** Receive the Muon data and send them to the Global Muon Trigger.
- **Readout all the RCT and GCT data** for every L1A.

The Current GCT Project started in January 2006 and aimed to deliver the system by summer 2007: First deliver the Electron Trigger with the Jet Trigger to follow shortly after.

Jet Finders: A summary



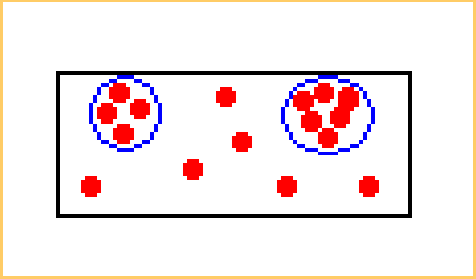
$\eta_{jet}=(-1)\ln(\tan(\theta_{jet}/2))$

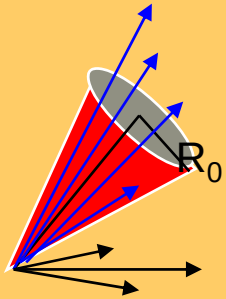


- Particles strike the detectors and deposit their energy in the calorimeters.
- Energy deposits in the calorimeters need to be recombined to reconstruct the transverse energy and direction of the original parton.
- This is done using tools that are called Jet finders.

Cone Jet Finders: Adapted for GCT

- Searches for high transverse energy seeds and a cone in the η-φ space is drawn around each seed.





$$R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$

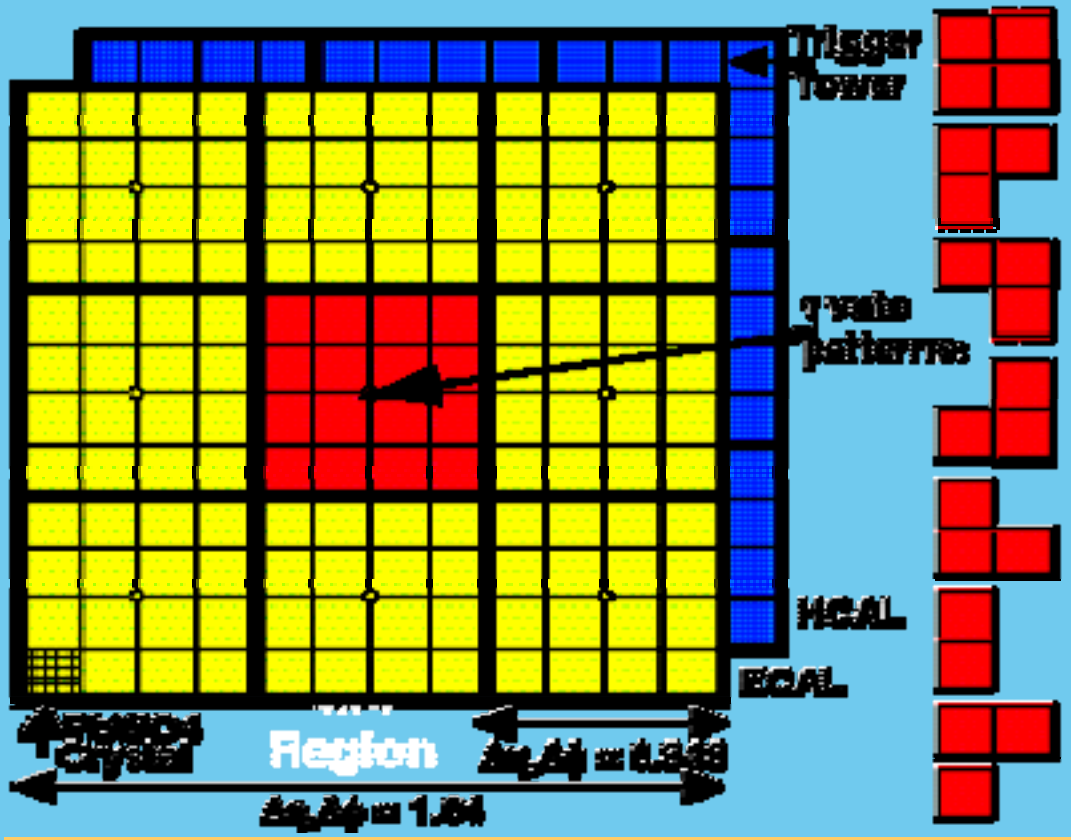
- Energy depositions within a cone are combined and the Et weighted η is calculated:

$$\eta = \frac{1}{E_T} \sum_i E_{Ti} \cdot \eta_i$$

- The new cone is drawn and the process is repeated until the cone transverse energy does not change

$$E_T = \sum_i E_{T,i} \qquad \Phi = \frac{1}{E_T} \sum_i E_{T,i} \cdot \Phi_i$$

GCT Jet Finder



- η, φ of the jet from the centre of the 12x12 tower. (Snowmass Conv. not used)
- Central, forward jets are selected using a prog. η cut.
- All cuts programmable (<1sec).
- Algorithm in principle also programmable but better have a very good reason for doing it (~2months).

- It is not a 'cone' but a square finder
- Jet or τ E_T
  - Jet = (12x12 trig. tower ΣE_T>Cut) AND (central 4x4 E_T > 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

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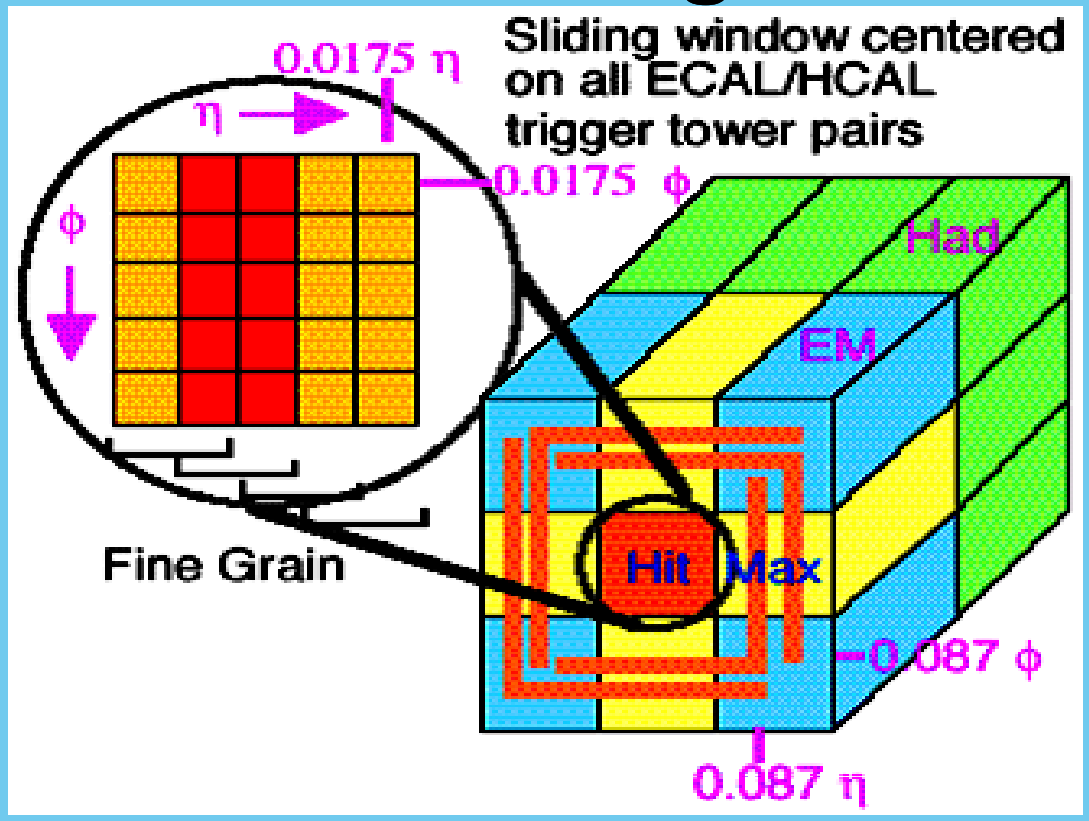
L1T Algorithms: e/γ I



- RCT Finds e/γ
- GCT selects the 4 highest rank candidates → GT
- At GT e/γ = Input to algorithms for L1A

Cuts are programmable. The algorithm is not.

- Electron (Hit Tower + Max)
  - 2-tower ΣET + Hit tower H/E
  - Hit tower 2x5-crystal strips >90% ET in 5x5 (Fine Grain)
- Isolated Electron (3x3 Tower)
  - Quiet neighbors: all towers pass Fine Grain & H/E
  - One group of 5 EM ET < Thr.

L1T Algorithms: e/γ II

Trigger Primitive Generator

Fine grain — Flag Max of (, , ,) & Sum ET

Regional Calorimeter Trigger

E_T cut — + Max ( ) > Threshold

AND

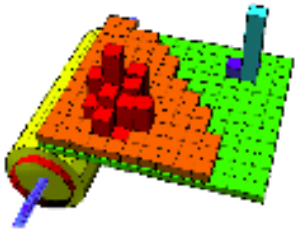
Longitudinal cut (H/E) — / < 0.05

AND

Isolation, Hadronic & EM — < 2 GeV

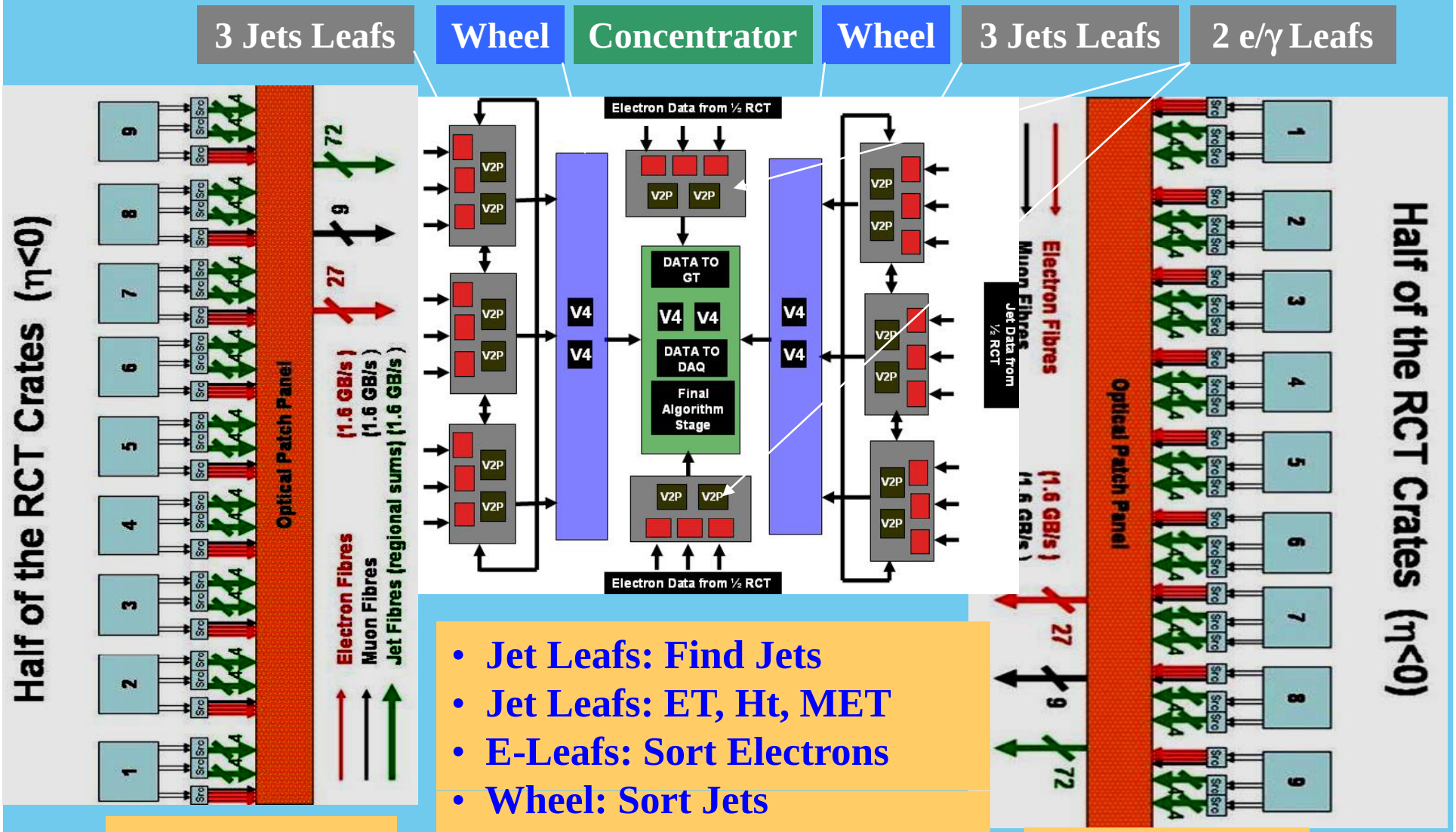
AND

One of (, , ,) < 1 GeV



ELECTRON or PHOTON

The Current GCT Design as of 31.1.06



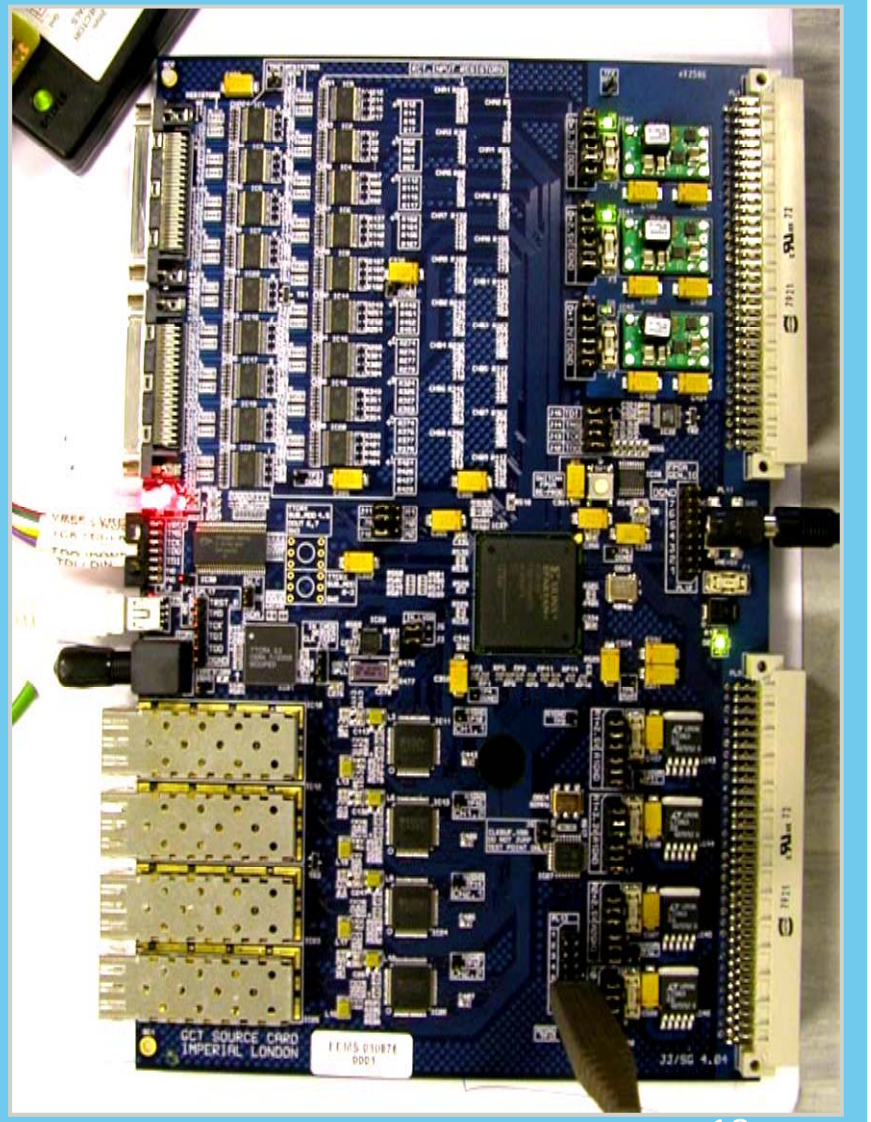
- Jet Leafs: Find Jets
- Jet Leafs: ET, Ht, MET
- E-Leafs: Sort Electrons
- Wheel: Sort Jets
- Concentrator: Final sort.

31 Source Cards

32 Source Cards

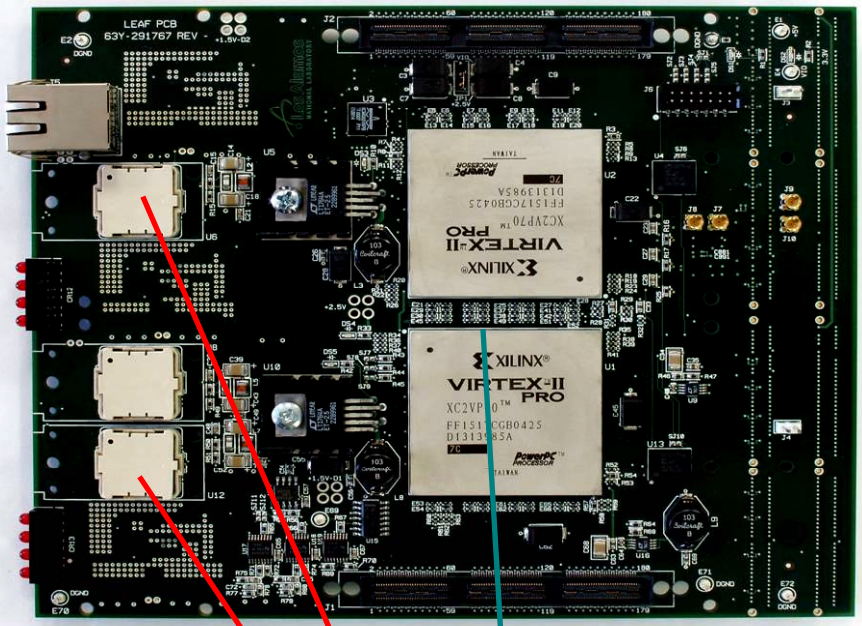
The Source Card

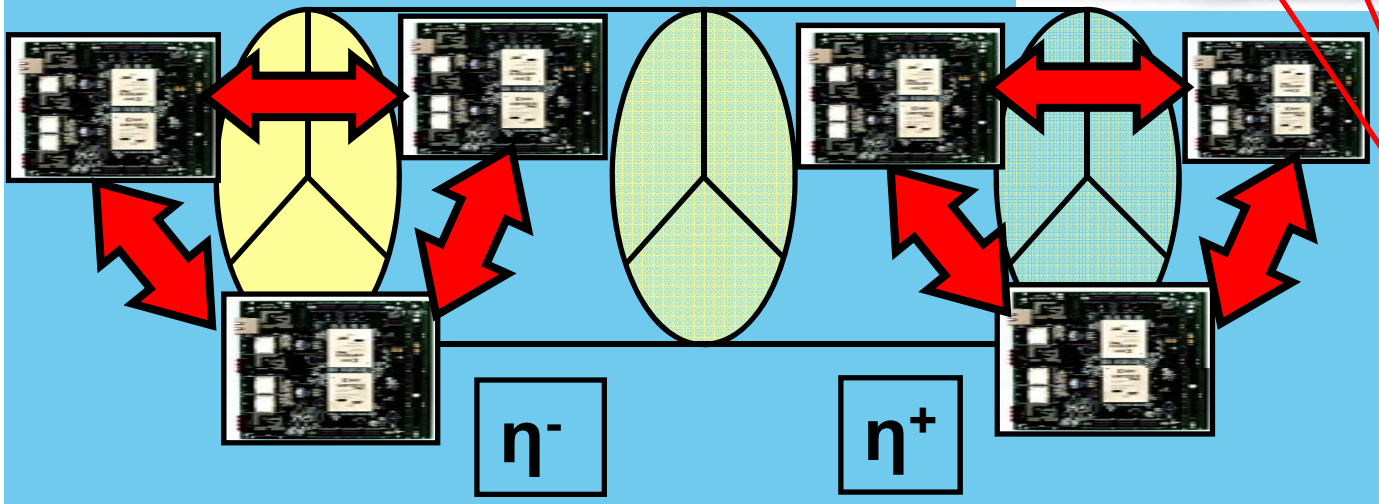
- Converts the 80 MHz ECL RCT Data to Optical.
- Provides an RCT readout for debugging and testing.
- 6U VME Format.
- USB 2.0 Interface for readout.
- 2xVHDCI SCSI RCT Inputs.
- 4xSFP optical outputs.
- Spartan-3 1M FPGA.
- RCT data capture.
- Synchronization test (RCT BX0 vs TTC).
- On board temperature monitor.
- 63 Source Cards are used in GCT.
- 80 Source Cards have been produced.



The Leaf Card

- Two Xilinx Virtex-II Pro P70.
- 32 x 1.125 Gbit/sec Optical Links connect to the MGTs of the 2 FPGAs.
- Each Leaf serves 1/6 of CMS in Jet finding mode and 1/2 in electron sorting mode.
- 16 Leafs have been successfully produced.



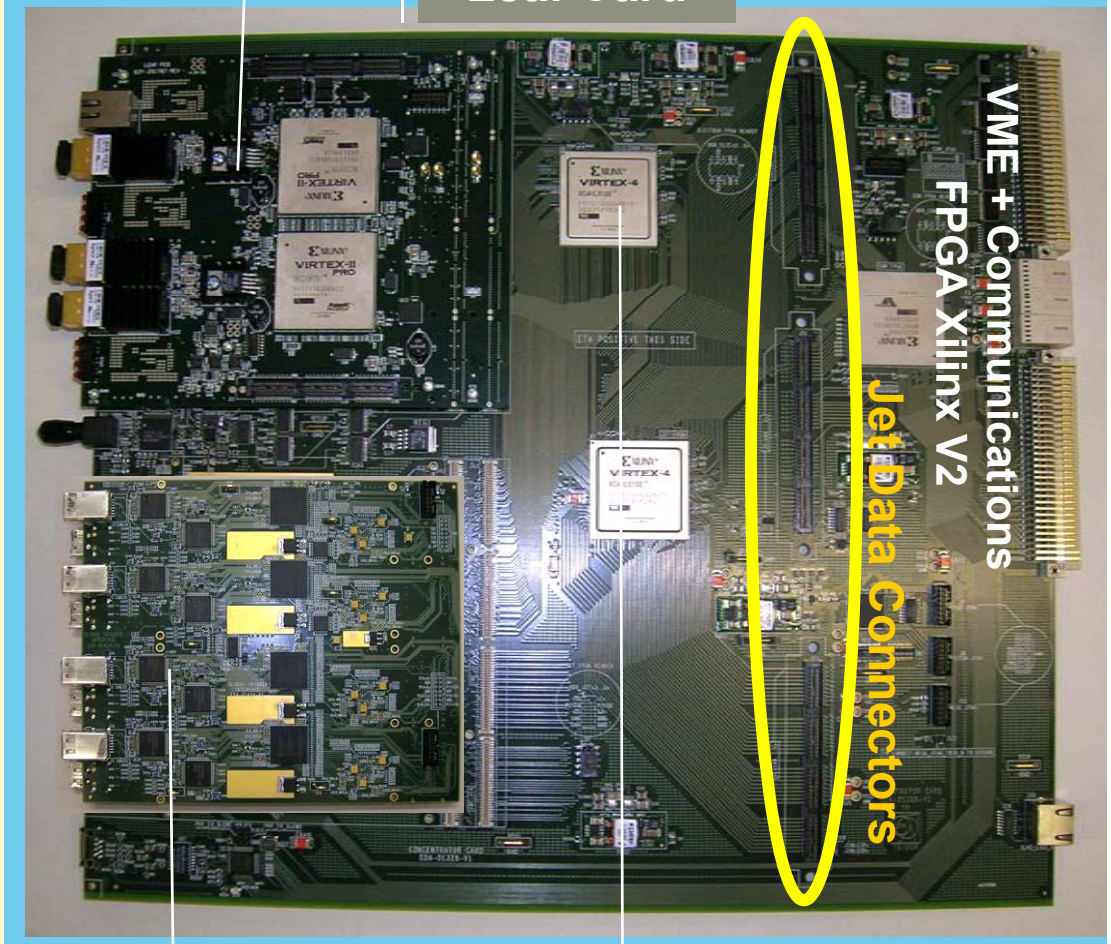


2x Virtex-II Pro-P70

3x12 Channel 1.125 Gbit/s Optical Links

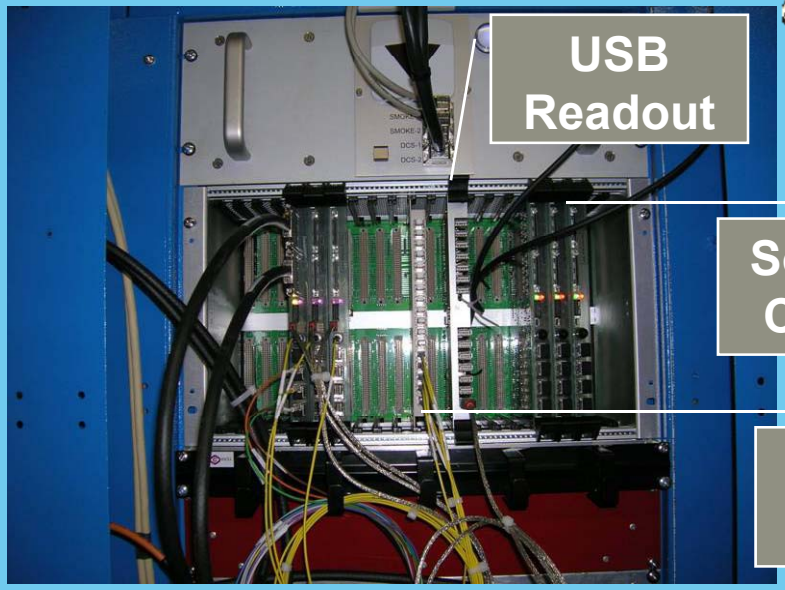
The Concentrator Card

- Collects all Electron and Jet Data and does the final sorting.
- Transmits Algorithm results to GT and Raw input and output data to DAQ.
- 9U 400 mm, VME int. .
- The two Electron Leaf Cards are mounted as mezzanines on both sides.
- The Global Trigger Interface is a 3d mezzanines.
- Energy data (Electrons + Et + MET) are handled by one Virtex-4 FPGA.
- A second Virtex-4 serves all Jet data.



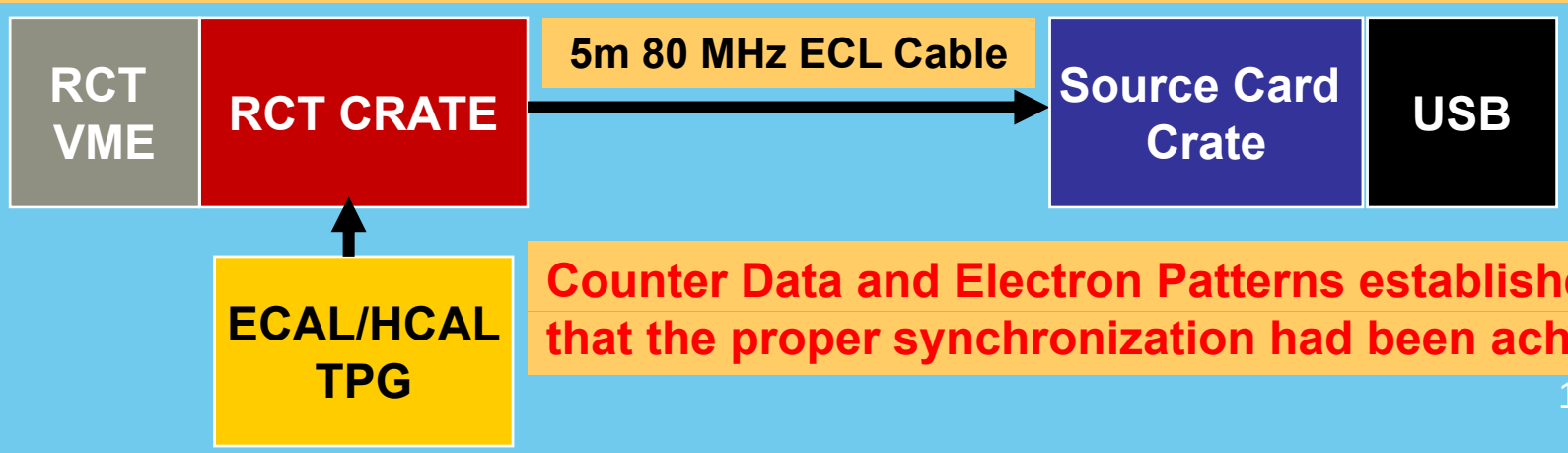
The GCT Electron Trigger

- In March 2007 the Electron Trigger Assembly was installed in the CMS USC-55.
- The Electron Trigger Source Card system consists of 18 Source Cards distributed in 6 x 6U VME crates.
- 54 optical fibres, each 12 meters long, deliver the electron data to the main GCT crate which is located one floor below in USC-55.
- Since Fibres are regrouped and merged to bundles of 12 using a commercial optical Patch Panel.
- The data is received by 2 Leaf Cards mounted on one Concentrator Card in a 9U VME Crate.



TPG+RCT Data Capture by the Source Cards

- The first Month of commissioning activities was dedicated in understanding data captures from the Regional Calorimeter Trigger (RCT) and the ECAL/HCAL TPG.
- Various data patters where loaded into the RCT/TPG buffers and where transmitted via the 80 MHz ECL RCT cables to the Source Cards which read out the data via USB.
- Effort was invested to understand all 'features' of the system and remove all bugs from the software and firmware.
- We have now achieved error free data transmission from RCT to GCT.



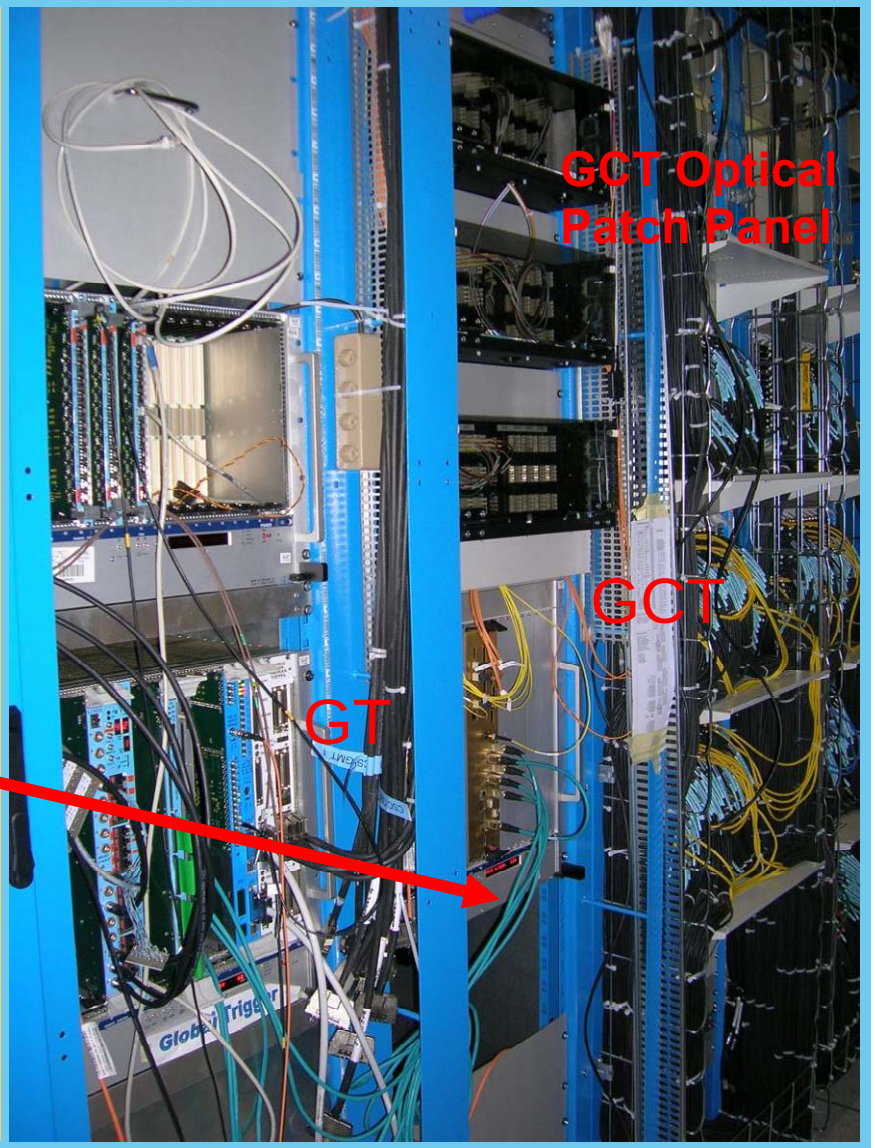
Counter Data and Electron Patterns established that the proper synchronization had been achieved

Data Transmissions from the Source Cards to the Concentrator Card

- The Source Cards are equipped with a 2048 event buffer which is used for capturing data from the RCT but also for transmitting data upstream.
- Counter data (incrementing patters fro every bunch crossing were loaded to the Source Cards and were received successfully by the leaf cards. The data were read by the Concentrator Card VME.
- Reliable data transmission was established (tested also via CRC).
- Transmission of data to the CMS DAQ via the Concentrator Card S-LINK64 interface has been tested and has been shown to perform according to specs.

Data Transmissions between GCT and the Global Trigger

- Data transmission between GCT and the Global Trigger was tested in-situ at the USC-55.
- Seven InfiniBand links transmit the GCT data to the Global Trigger (Isolated, Non-Isolated and 5 Jet Cables)
- Data were loaded to the Concentrator output buffers and were transmitted to the Global Trigger
- A BER = 10^{-14} was achieved for Isolated Electrons and 4 Jet cables.
- Detailed testing of the rest of the links is underway



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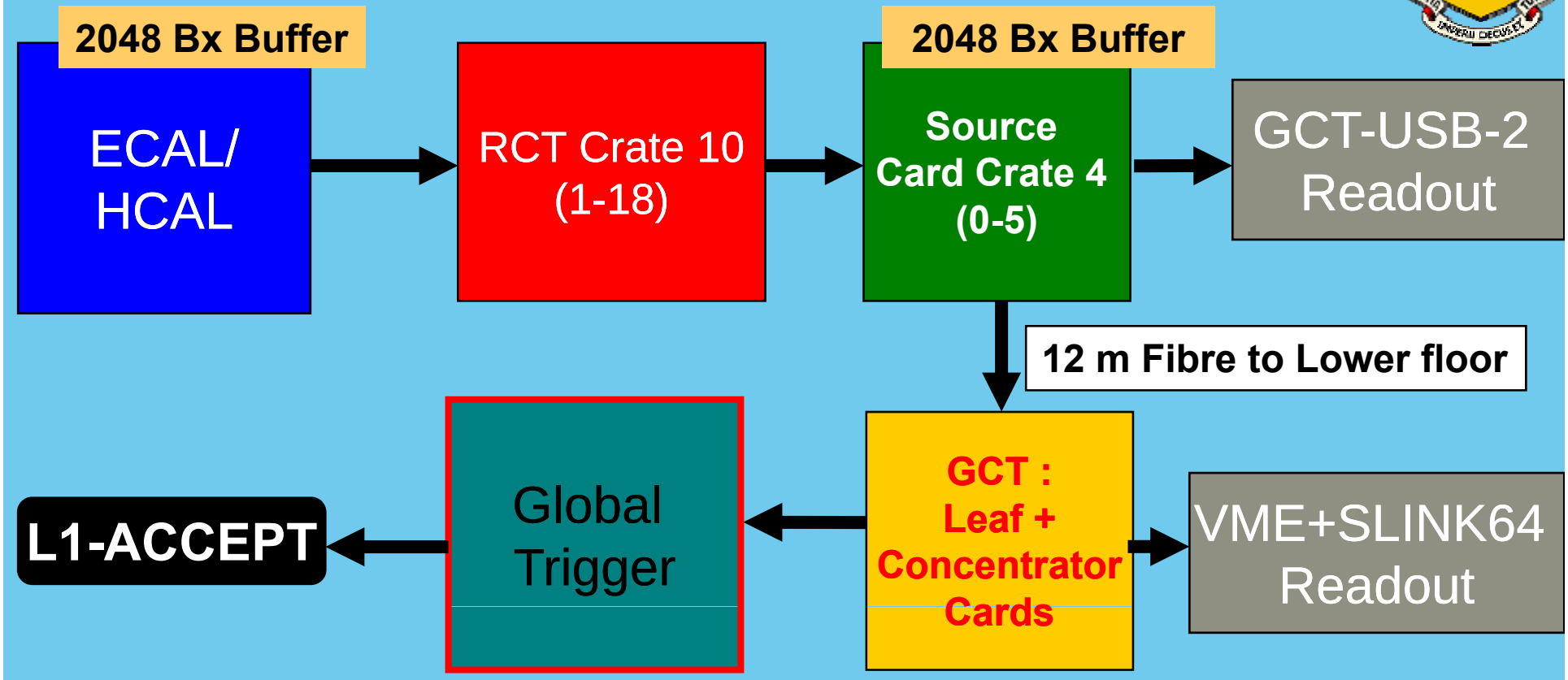
Full Trigger Chain Tests



- Incrementing Data per Bx were transmitted through the full chain correctly.
- Events with just 4 electrons in the final state with empty crossings in between were also transmitted correctly.

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Data Validation with Emulator

- The data files used for the previous full chain counter and the 4-electron event tests can also be processed by the CMS Trigger.
- The Trigger outputs were read both at the GCT and the GT Level and the results were compared with the results of the emulator on an event per event basis.
- As one expects they did not agree in the fist instance due to differences between the firmware uploaded to the FPGAs and the offline emulator software. However, all mistakes have been removed and hardware and emulator agree now.
- With this last test one can say confidently that the CMS Electron/Photon trigger performs now as designed.
- More work is needed to integrate more crates in to the system. However no major problems are foreseen and we expect this to proceed uneventfully.

Status of the Jet Trigger

- All the rest of Source Cards which are required for the Jet Trigger have already been delivered.
- A Prototype Wheel Card which can serve 3 Leaf Cards receiving Jet data from ½ of the CMS calorimeter is currently undergoing detailed tests at the GCT Lab.
- We foresee to install the rest of the GCT Hardware (45 Source Cards, 6 Leaf Cards and 2 Wheel Cards) by the end of November 2007.
- The Jet Assembly will be subjected to the same detailed testing as the Electron Assembly and it is expected that 3-4 will be required until the Jet Trigger is also understood and agrees with the emulator.

Summary and Outlook

- A major part of the CMS Global Calorimeter Trigger has been installed at its final position at USC-55 and has been shown to perform as designed.
- This assembly will provide the Trigger for the first CMS cosmic run planned for November 07.
- It is expected that the Jet Triggers will be installed during the Fall 2007.
- Hence, the CMS Calorimeter Trigger should be complete by the end of 2007.