NEPPSR 2005

Trigger and DAQ Electronics

Part 1 – CMS Trigger/DAQ

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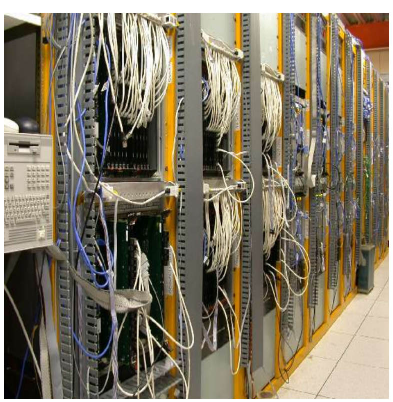
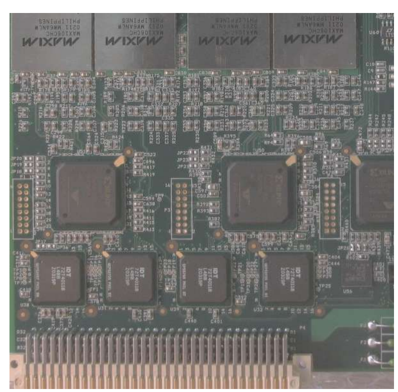
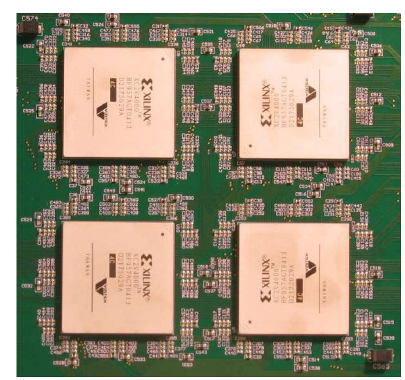
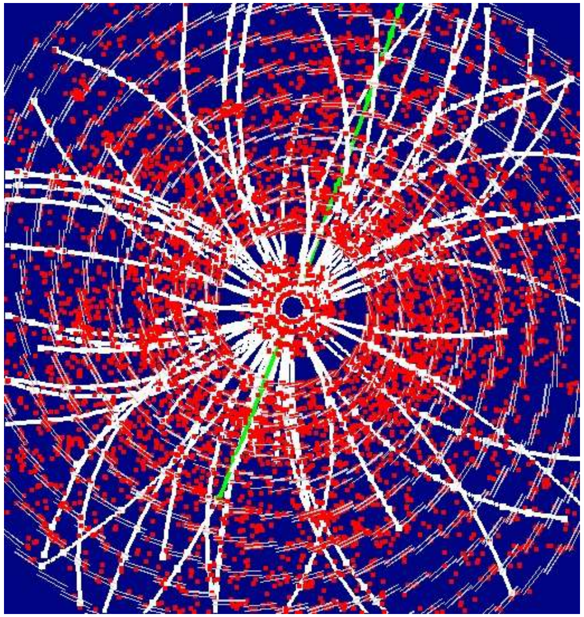






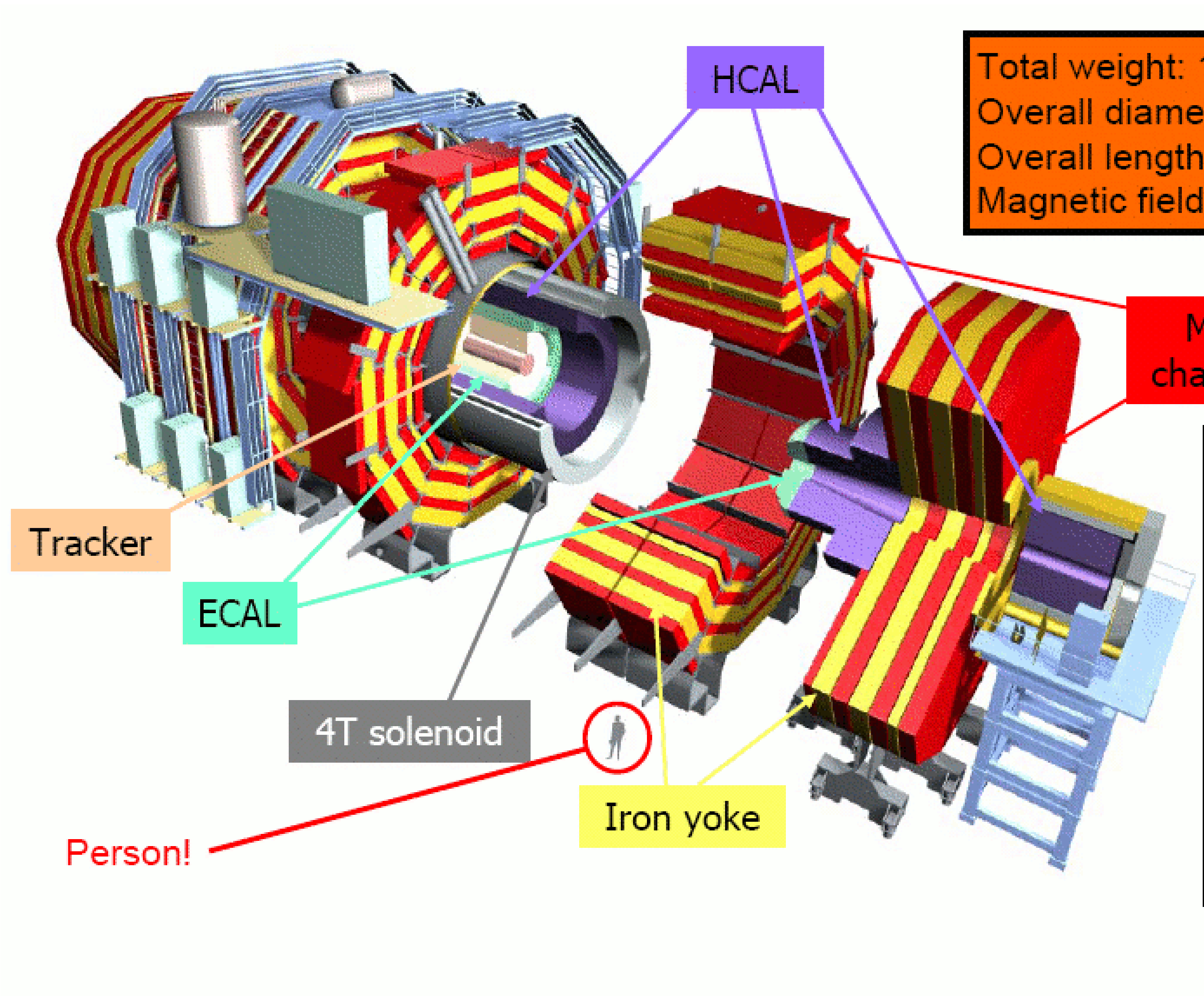
Data Volume- the problem!

- At the LHC design luminousity of $10^{34} cm^{-2} s^{-1}$ there are ~20 pp events every 25ns
  - This is an event rate of 800 MHz
- In CMS (for example), there are 7.5×10^{7} channels
  - The data rate is 800GB/sec
- How do we handle this? With a *trigger* system
  - The “Level 1” trigger -- *hardware*
    - Reduces event rate to 100kHz (1GB/sec)
      Looks for patterns which represent possibly interesting physics events and generating an “accept” for each candidate event
  - The “Level 2” trigger – *software*
    - Processes individual events in CPU farm
    - Reduces the event rate 100Hz (100MB/sec)
      (some detectors have hardware for Level 2 as well)



Let's look more closely at the

Compact Muon Solenoid

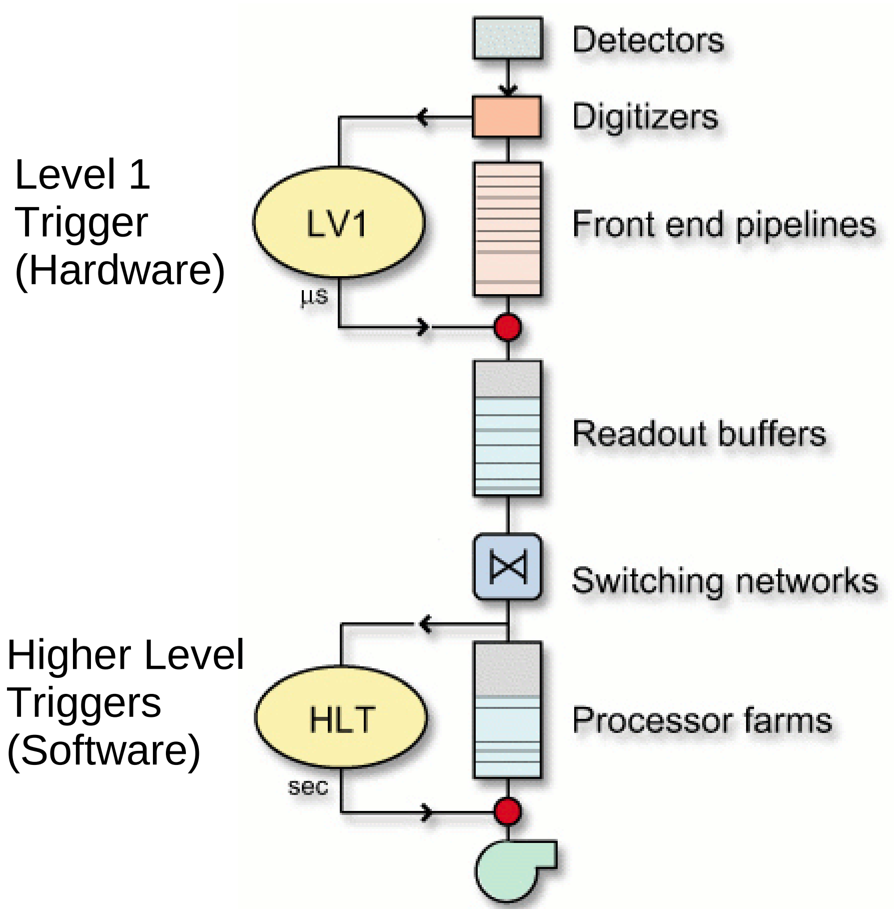


Total weight: 12,500 t
Overall diameter: 15 m
Overall length: 21.6 m
Magnetic field: 4 T

Physics objectives:

- The origin of mass (Higgs boson search)
- Supersymmetry
- Extra Dimensions
- Matter/antimatter asym.
- Quark gluon plasma
- ....

The CMS Trigger/DAQ



Front-end electronics digitizes the charge (energy) present in each detector channel once per clock (25ns)

Pipelines (memories, usually digital) which store data for 3.2us while the level 1 trigger processes the data

When the Level 1 trigger logic accepts an event, data is copied to a readout buffer

Switch network reads event fragments from buffers and sends complete events to CPUs for high-level trigger processing

Finally, at about 100Hz, interesting events are written to permanent storage (disk)

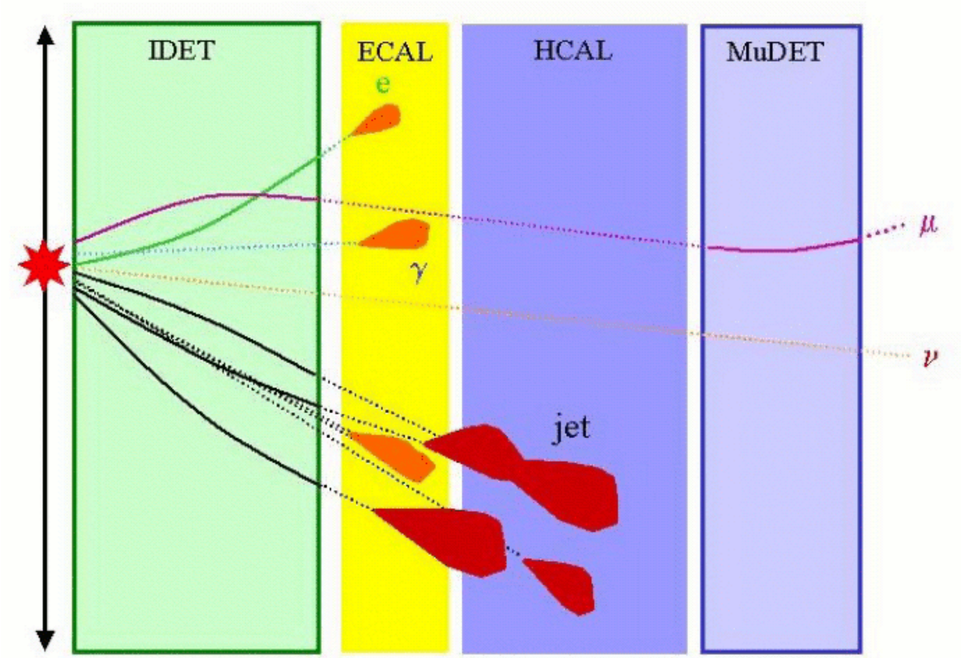
Level 1 Trigger

- Level 1 Trigger identifies:
  - muons (μ)
  - electrons (e)
  - photons (γ)
  - jets
  - isolated hadrons
  - neutrinos (ν), indirectly
    - missing E_T or large total E_T
      (E_T = transverse energy = $E \bullet \sin\theta$)
- Level 1 Trigger uses only ECAL, HCAL and muons (in CMS and ATLAS)

e, γ – isolated cluster in ECAL)

jets – extended cluster in ECAL and HCAL

μ – HCAL tracks (?)

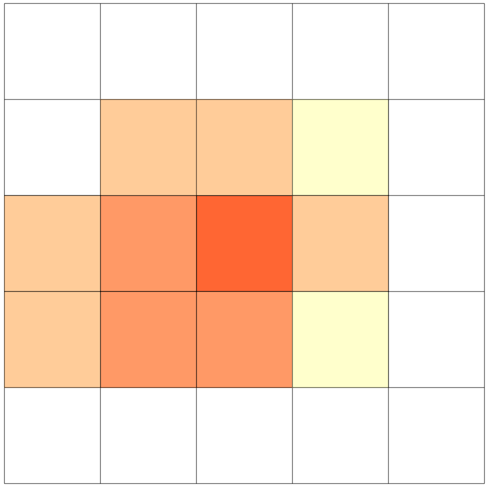


Particle signatures in a typical LHC detector

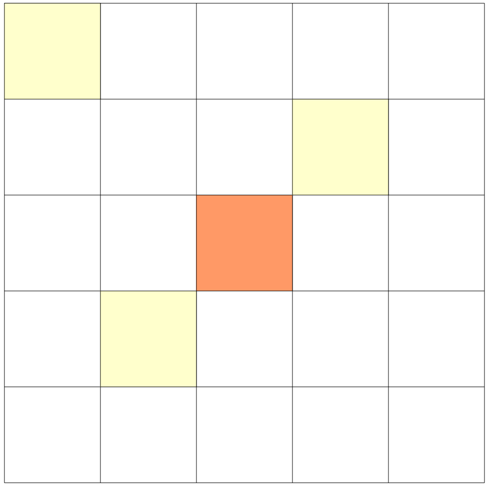
Level 1 Calorimeter Trigger

- *Trigger primitives* are calculated in the readout electronics and sent to the L1 processor.
  - calculate E_T (= E•sin θ) where θ is constant and E is measured
  - sum E_T in trigger regions for jet energy measurement
  - identify isolated clusters (e, γ)

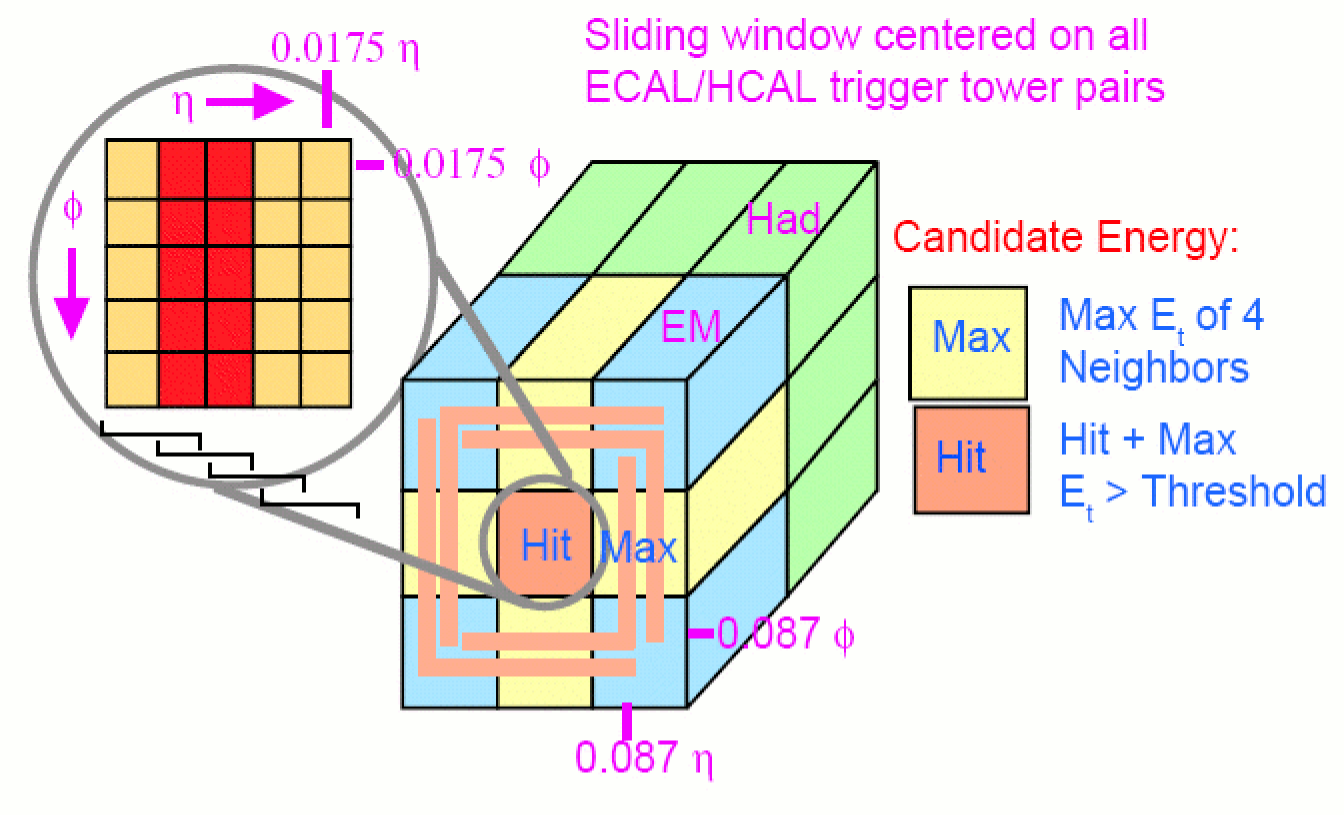
jet signature



e, γ signature



Electron, Photon Triggers



E_T sum of two ECAL towers used to identify e, γ candiates, which are further refined by:

- Isolation (lower limit on energy in neighboring crystals)
- Electromagnetic/Hadronic energy ratio
- Lateral spread of shower in ECAL

Regional Calorimeter Trigger (RCT)

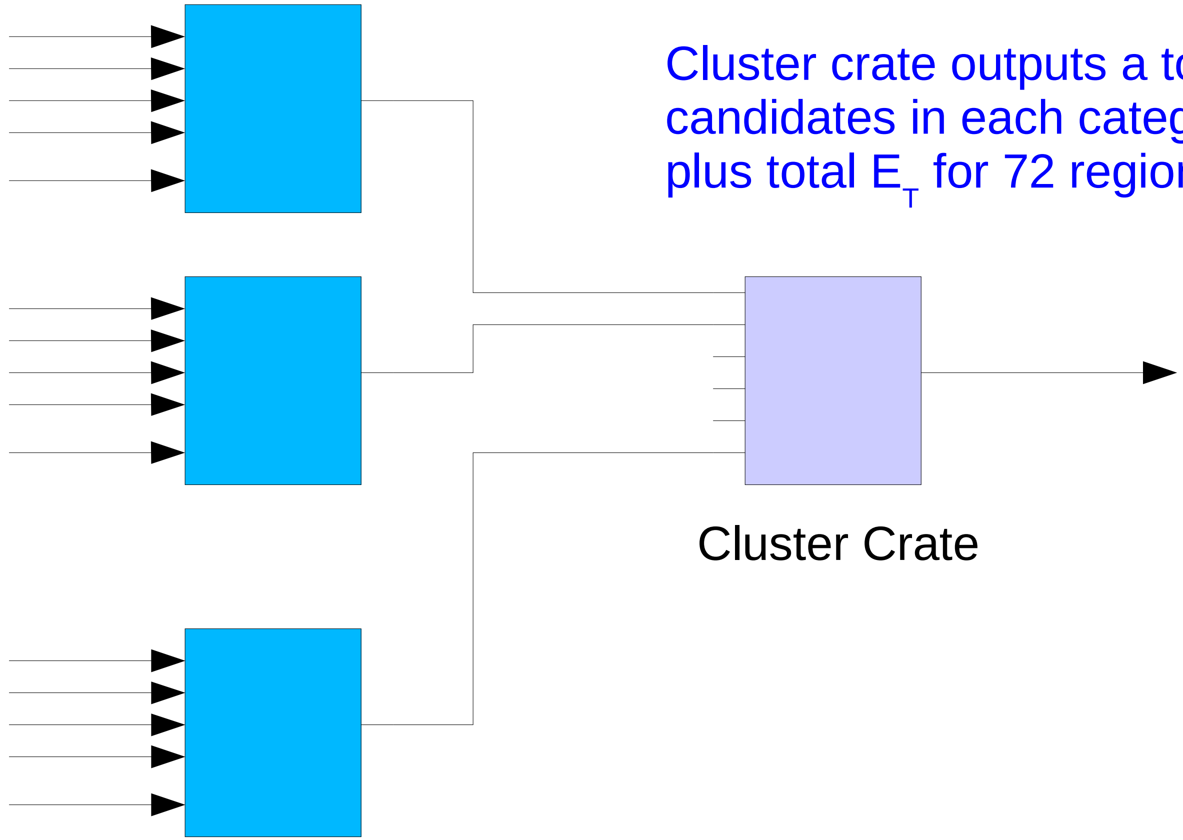
RCT crate outputs 4 top candidates
in each category, with a rank based on E_T:

- isolated and non-isolated e, γ
- central and forward jets
- τ (isolated narrow jets)

Plus total ET for 4x4 tower regions

Trigger Primitives
from HTRs (HCAL)

E_T plus
“isolation bit”
for each channel



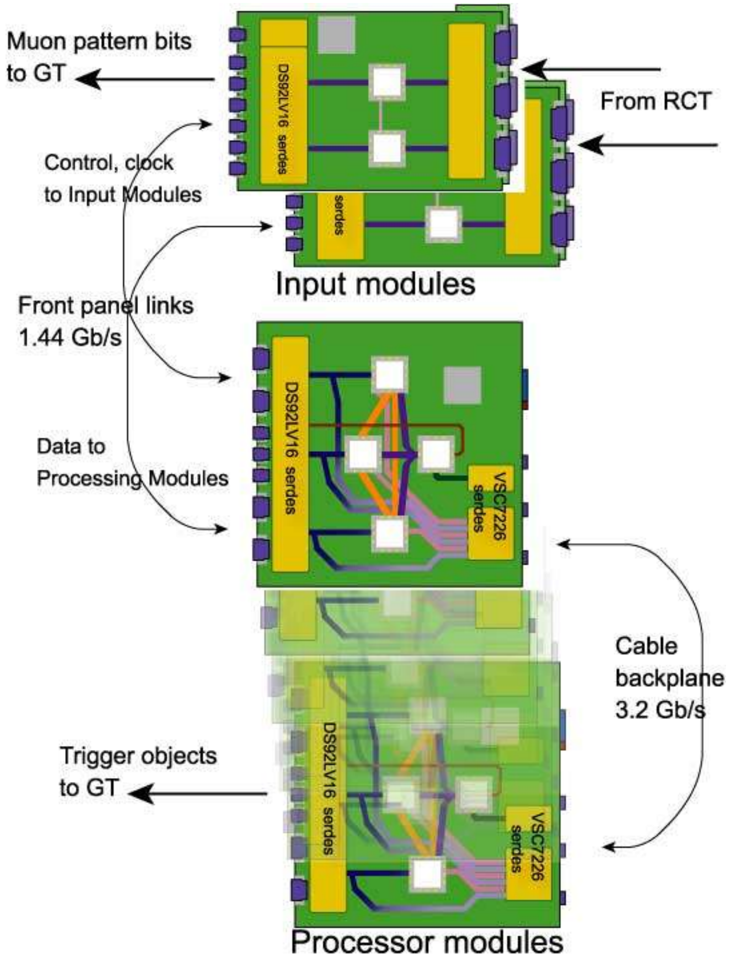
Cluster crate outputs a total of 72
candidates in each category,
plus total E_T for 72 regions

to Global
Calorimeter
Trigger

18 RCT crates for
Barrel and Endcap

Global Calorimeter Trigger

- Final-stage sorting of e/γ, jet and τ jet trigger objects according to rank
- Jet counting for multi-jet events
- Calculation of total and missing transverse energy
- Final Outputs to Global Trigger:
  - Jet Counts 8 x 4 bits
  - Energy Sums
    - 36 regions E_T 36 x 11 bits
    - missing E_T magnitude 13 bits
    - missing E_T ϕ 6 bits



Muon Trigger (Drift Tubes)

Based on pattern matching of hits to identify muon candidates.
Pattern matching logic is located

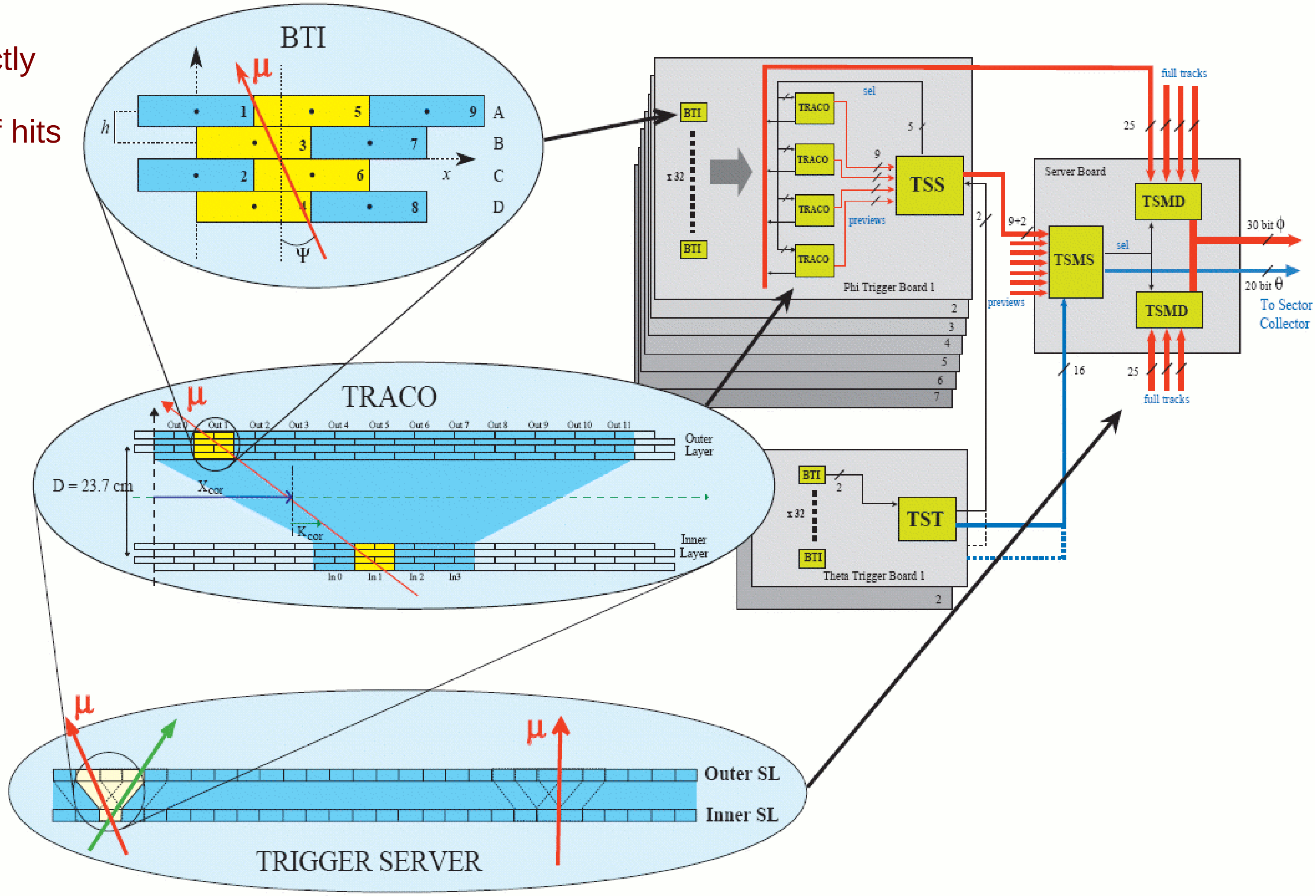
Bunch and Track Identifier

Takes hits directly from detector; finds clusters of hits

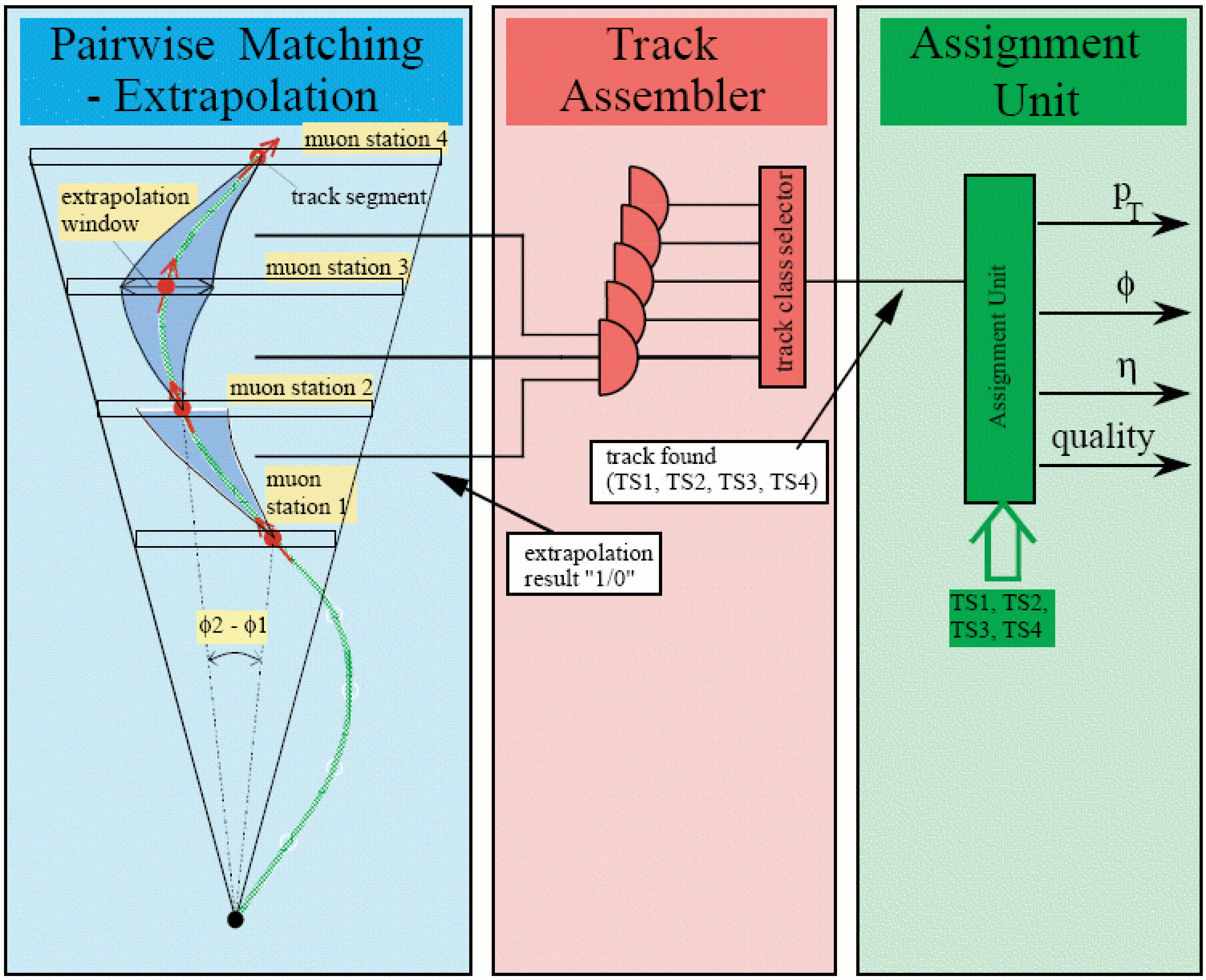
Track Correlator matches hits in two superlayers of drift tubes.

Assigns p and and bending angle to each candidate.

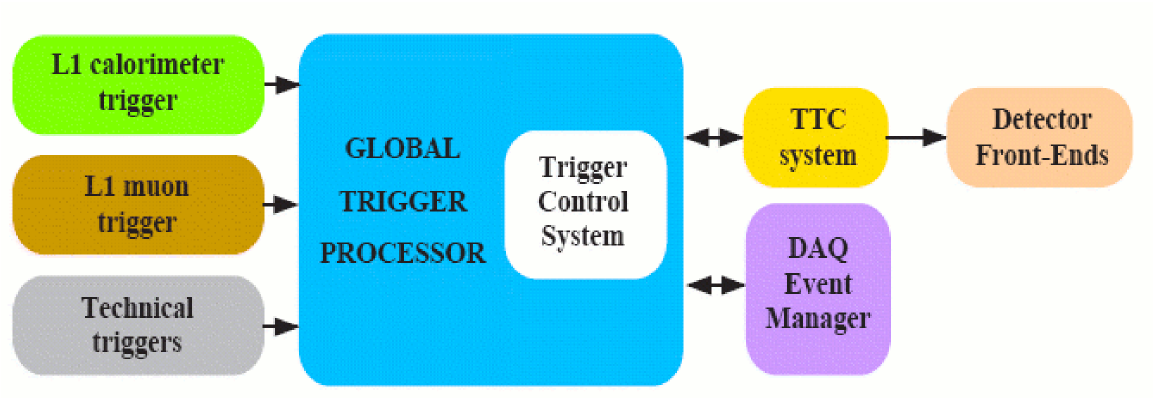
Trigger Server picks and sends candiates with highest ρ_T



Muon Track Fitting



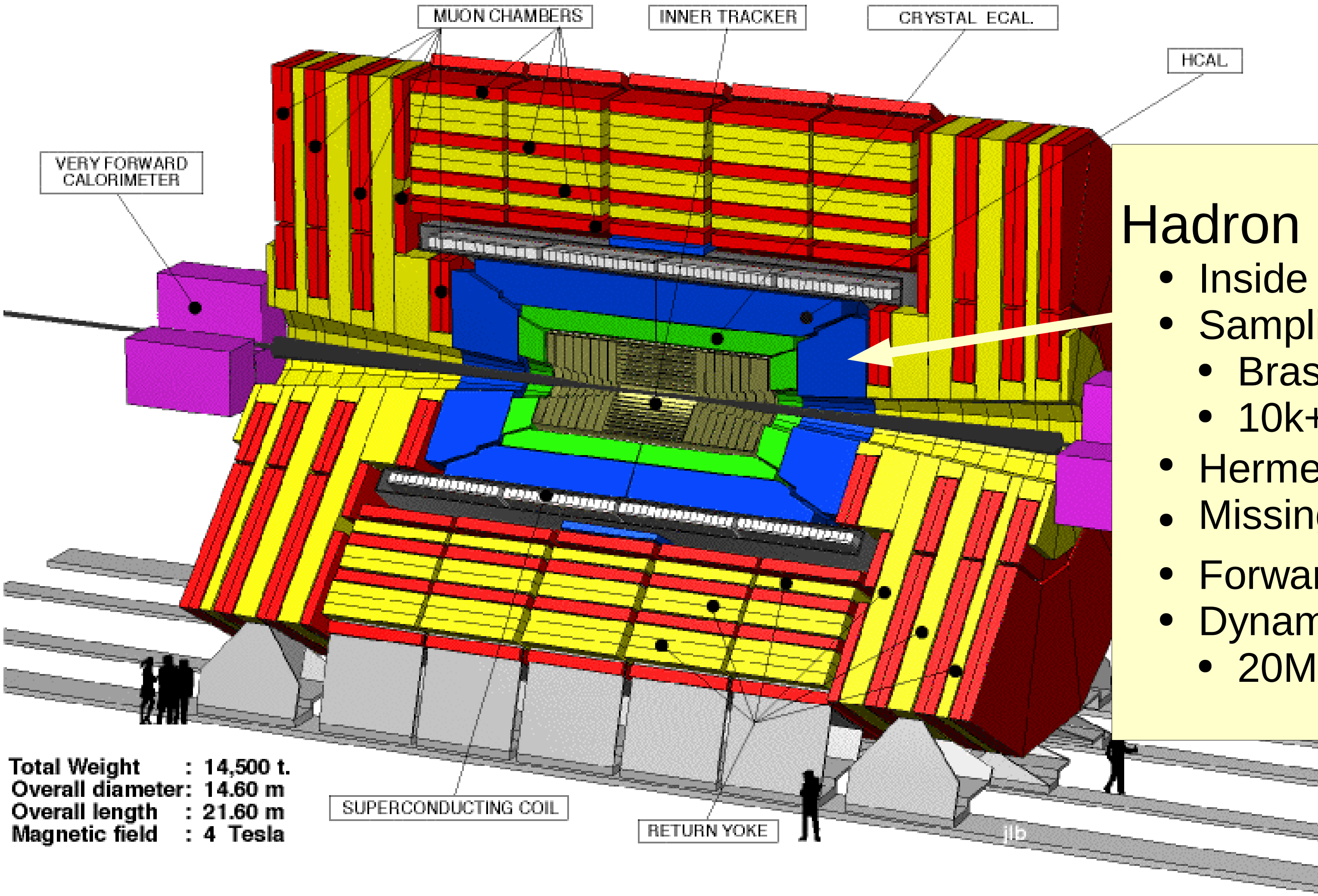
Global Trigger



- Inputs from Calorimeter and Muon Triggers:
  - Best 4 of each, ranked by E_T, ρ, quality:
    - muons; isolated e, γ; non-isolated e, γ central and forward jets; isolated hadrons
  - Total missing E_T, total E_T, count of jets
- Processes up to 128 trigger algorithms in parallel, outputs L1A if any enabled algorithm succeeds

CMS HCAL Readout

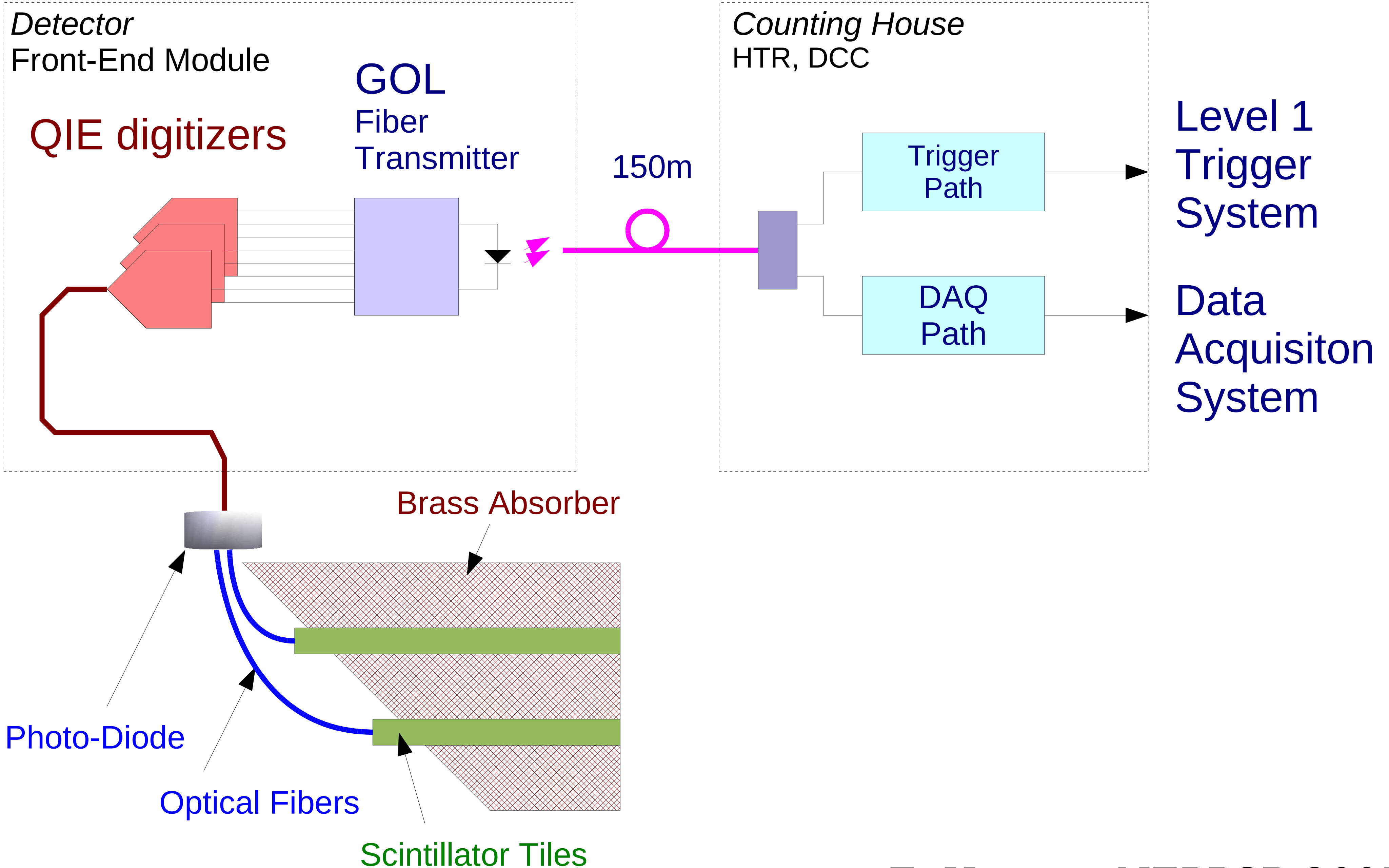
Some Hardware Details



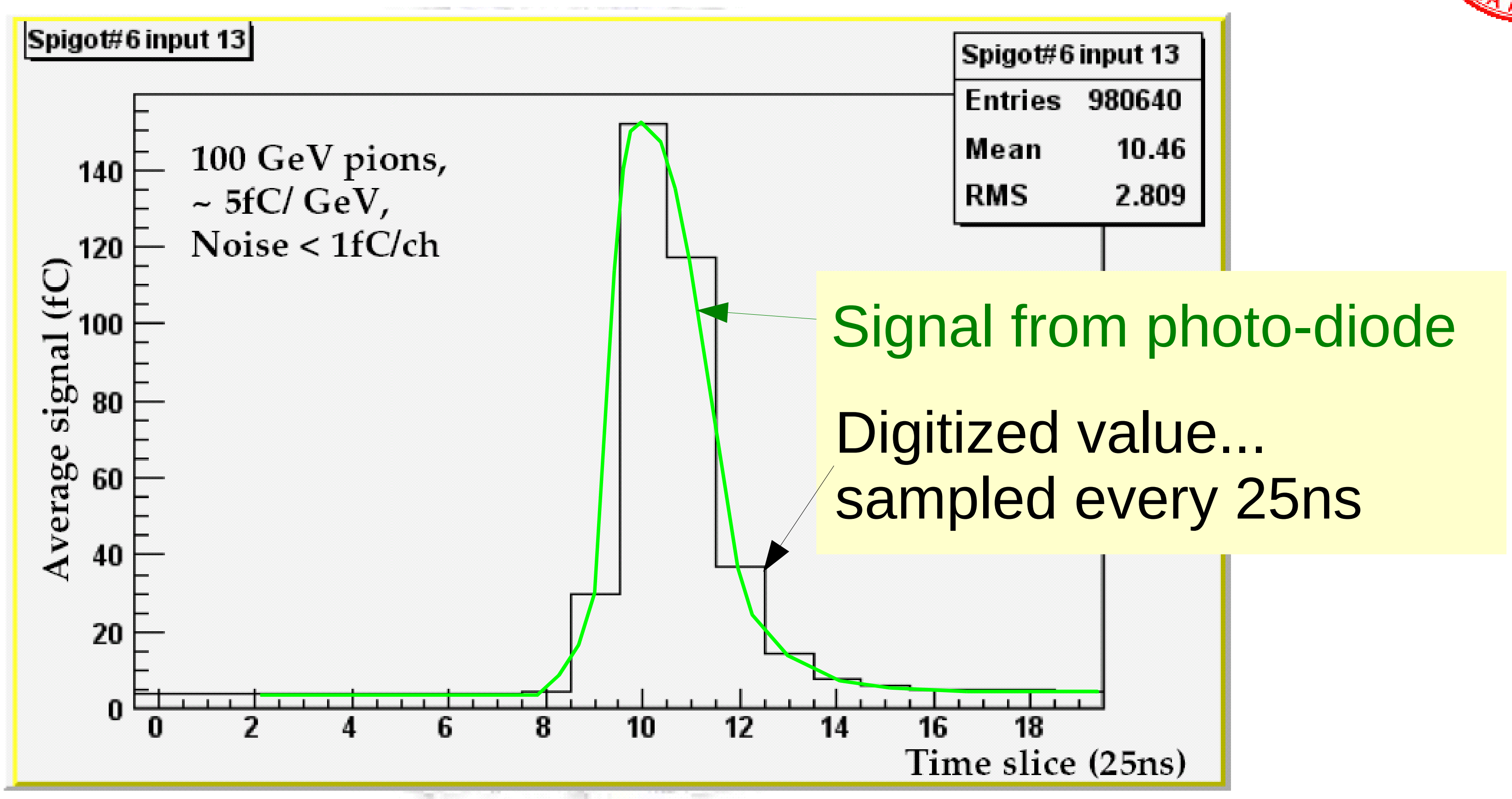
Hadron Calorimeter

- Inside the Magnet
- Sampling Calorimeter
  - Brass absorber
  - 10k+ scintillator tiles
- Hermetic coverage to $|\eta| < 5$
- Missing E_T measurement
- Forward jet tagging
- Dynamic Range
  - 20MeV (muons) to 3 TeV (jet)

HCAL Detector and Readout



Signal Digitization



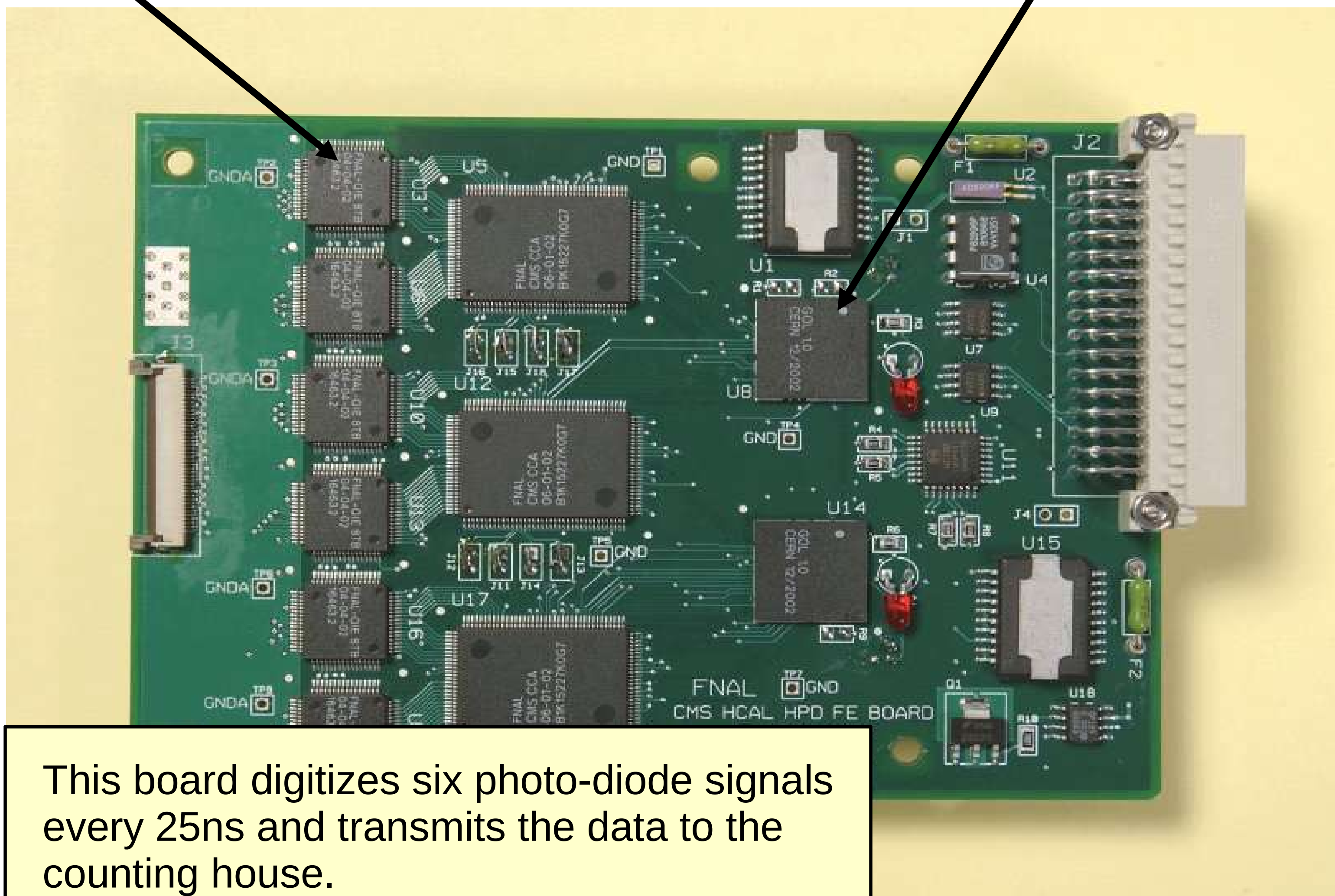
Sampling rate 40MHz = LHC bunch crossing rate

In principle, peak of pulse should always be in the center of a 25ns time bin

HCAL Front-End Module

QIE = Charge (Q) Integrator and Encoder
custom-designed ADC (analog-to-digital converter) chip

GOL =
Gigabit Optical Link

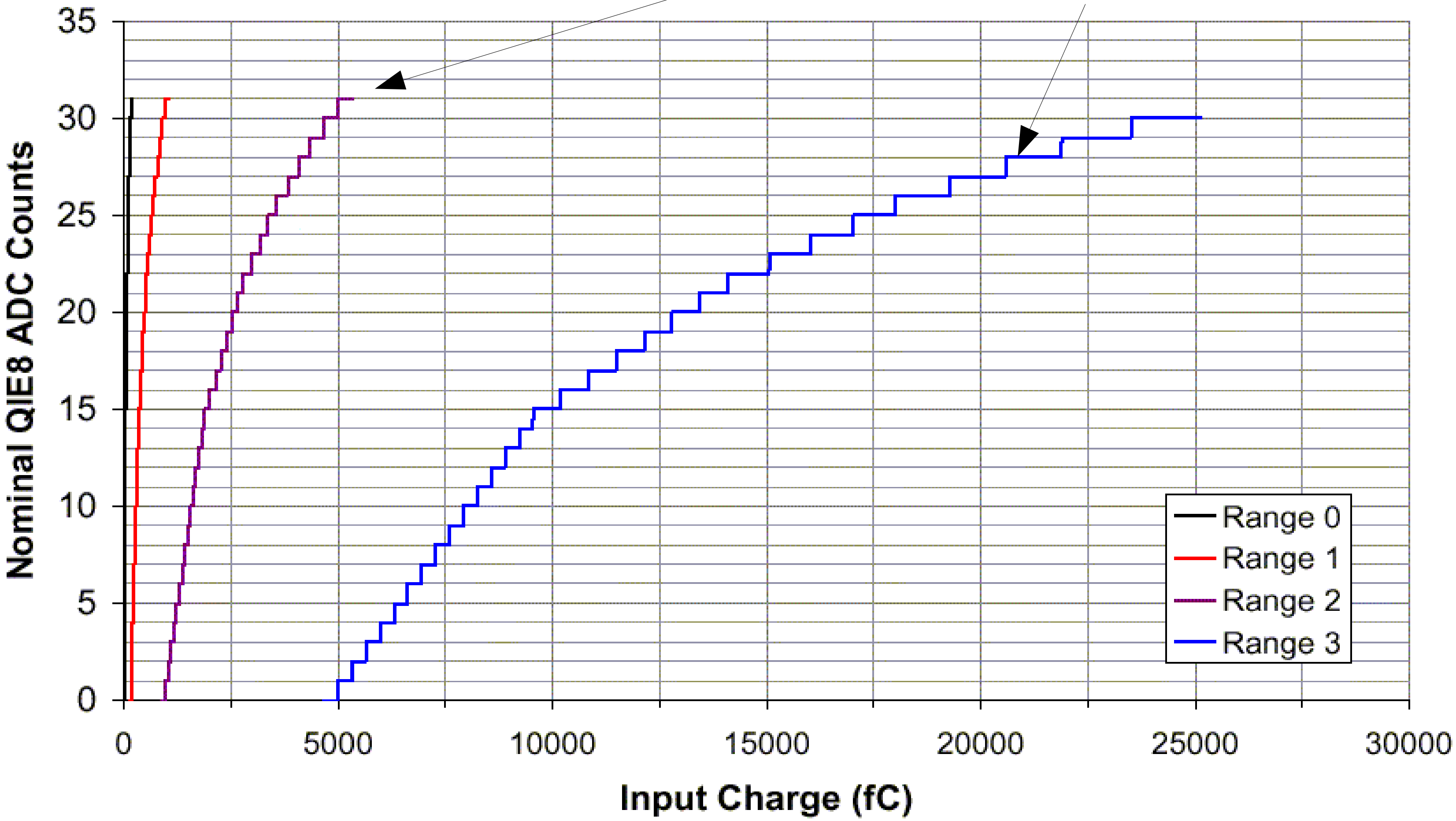


This board digitizes six photo-diode signals every 25ns and transmits the data to the counting house.

Some QIE Details

QIE response is highly non-linear to cover a large dynamic range with a minimum of bits.

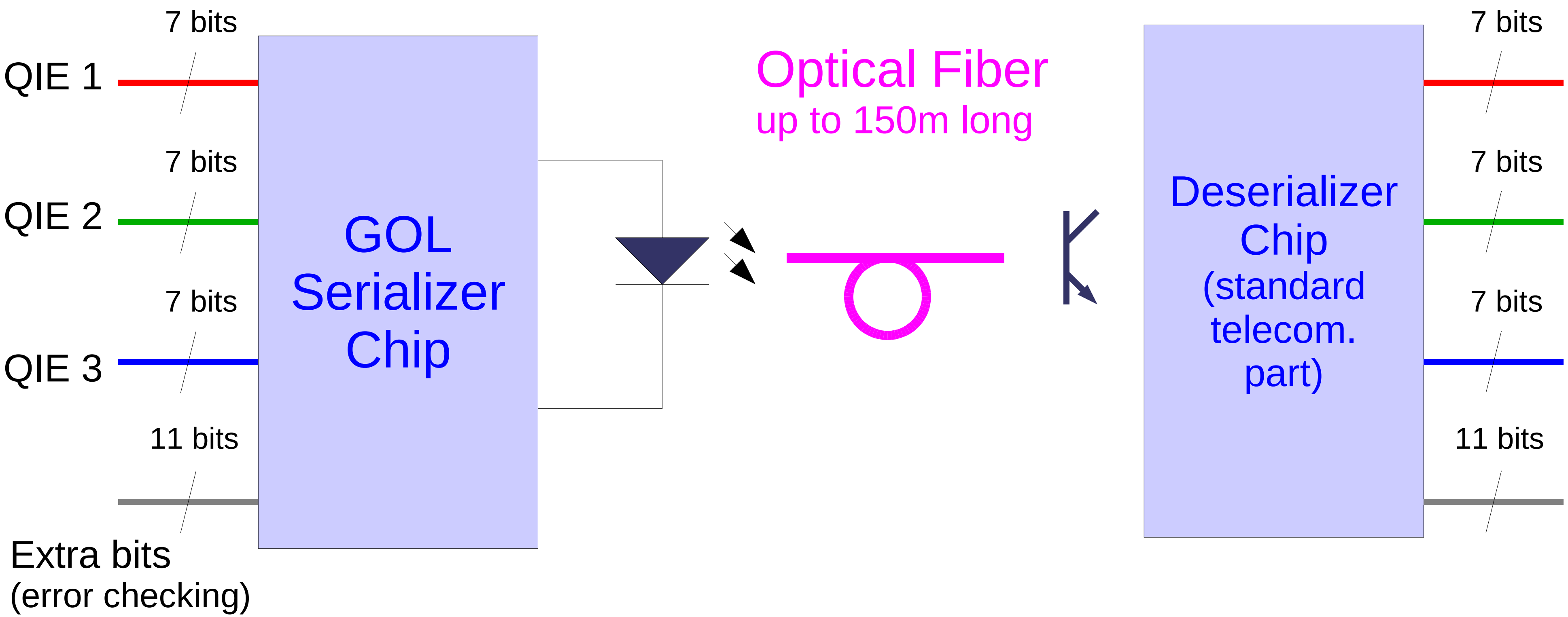
4 ranges, each with 32 steps



QIE Output = 2 range bits + 5 ADC bits = 7 bits total to cover a 10,000:1 dynamic range

Optical Link

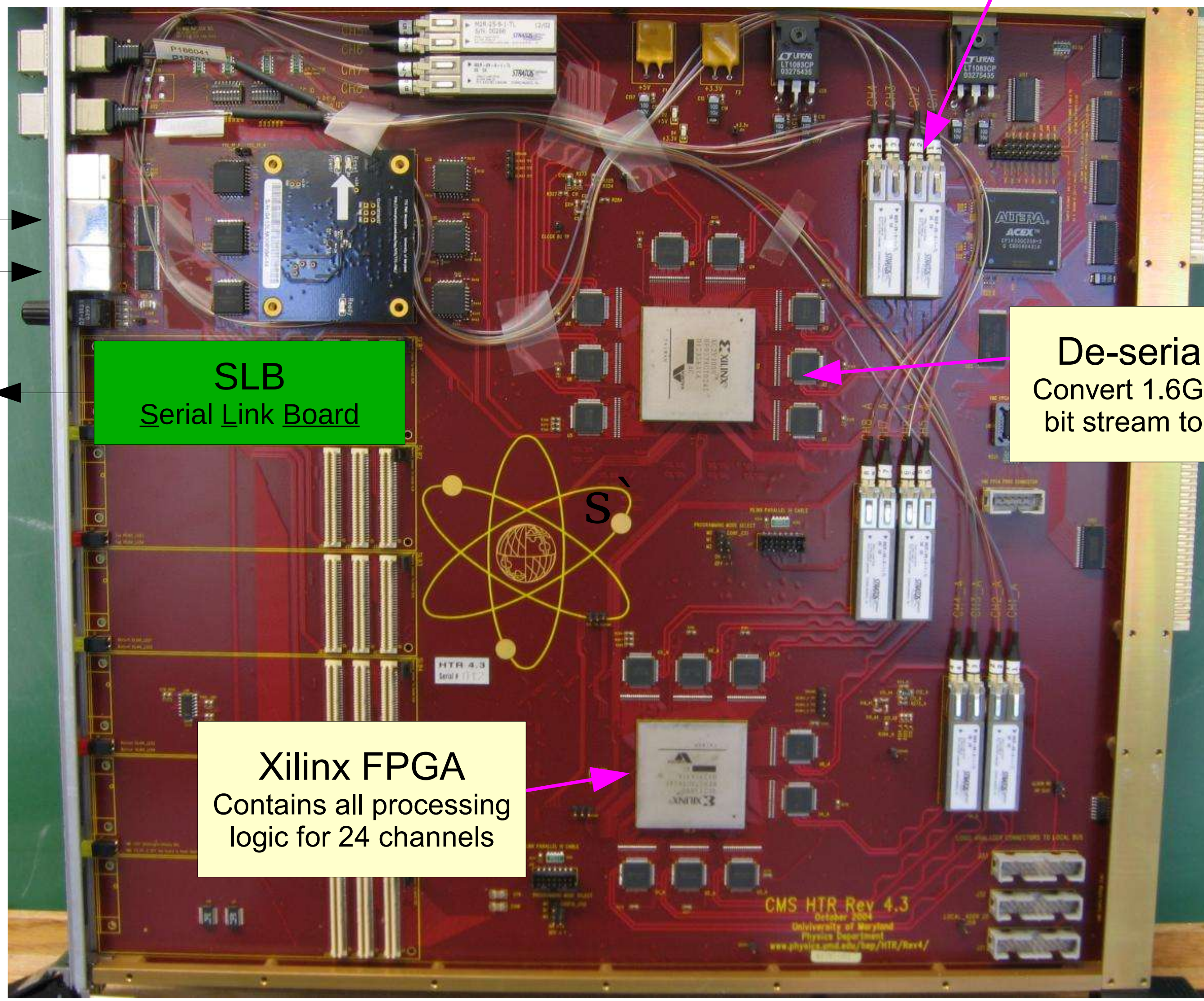
Transmits 32 bits of error-free data at 40MHz to the counting house



GOL transmitter is custom-designed because it must survive a high radiation dose

Counting house electronics is built entirely of standard industrial components

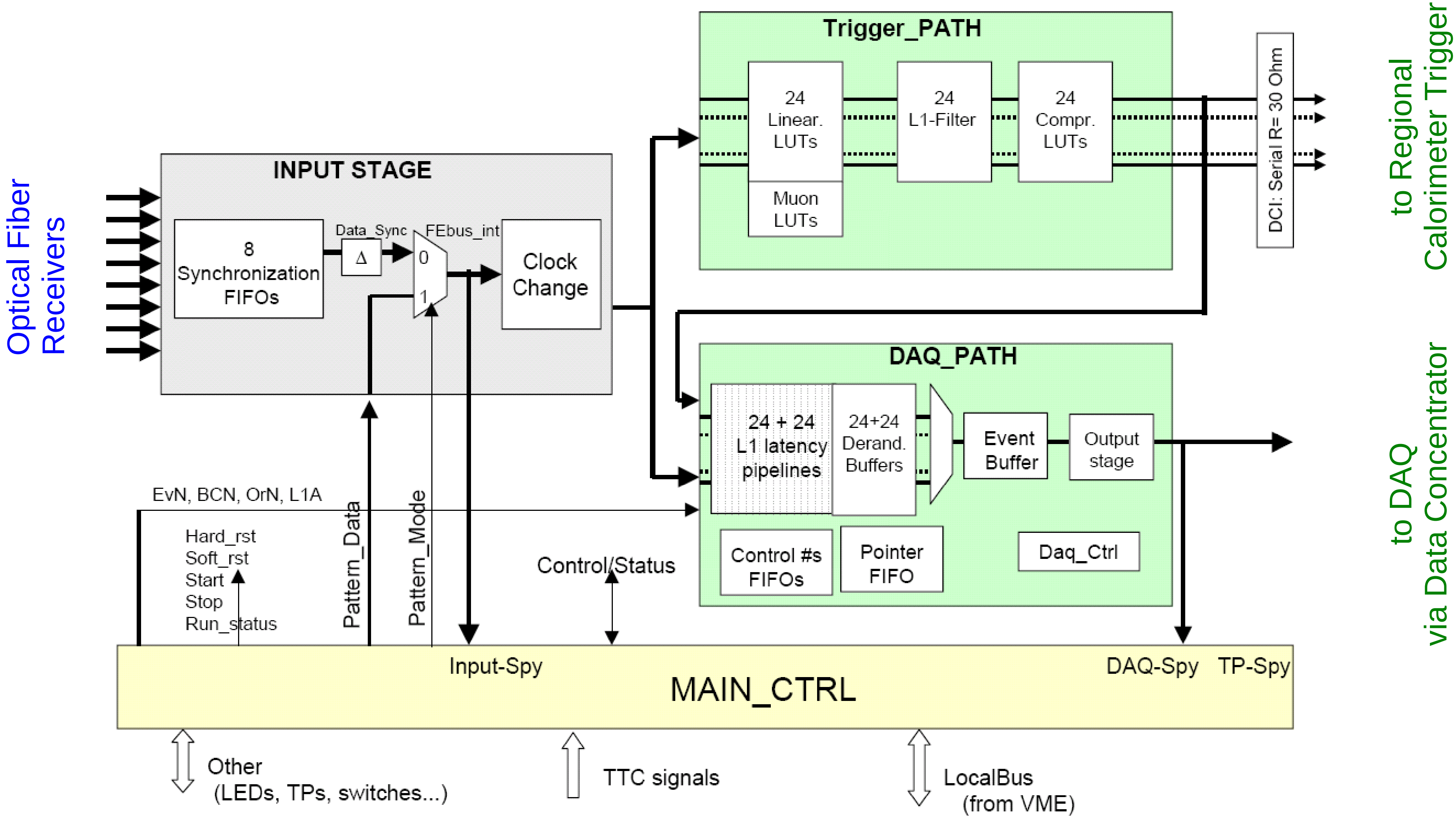
HTR (HCAL Trigger Readout board)



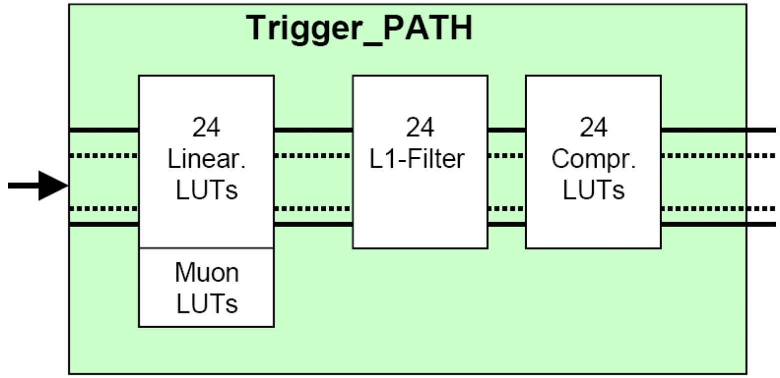
HTR (HCAL Trigger Readout board)

Process 48 HCAL channels (16 optical fibers)

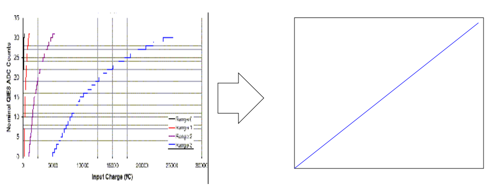
- Generate trigger primitives
- Buffer all data for DAQ



HTR Trigger Path

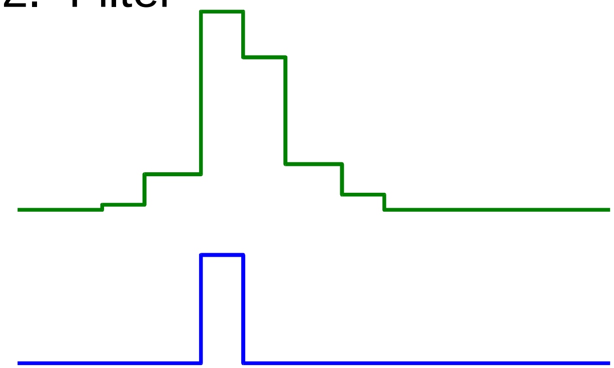


1. Linearize



Convert energy to E_T using a LUT

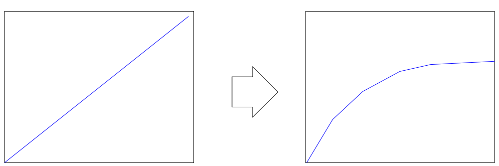
2. Filter



Identify bunch crossing with peak of pulse.

Integrate energy in entire pulse.

3. Compress



Compress E_T using a LUT

(Saves bits in output to central calorimeter trigger.)

HTR DAQ Path

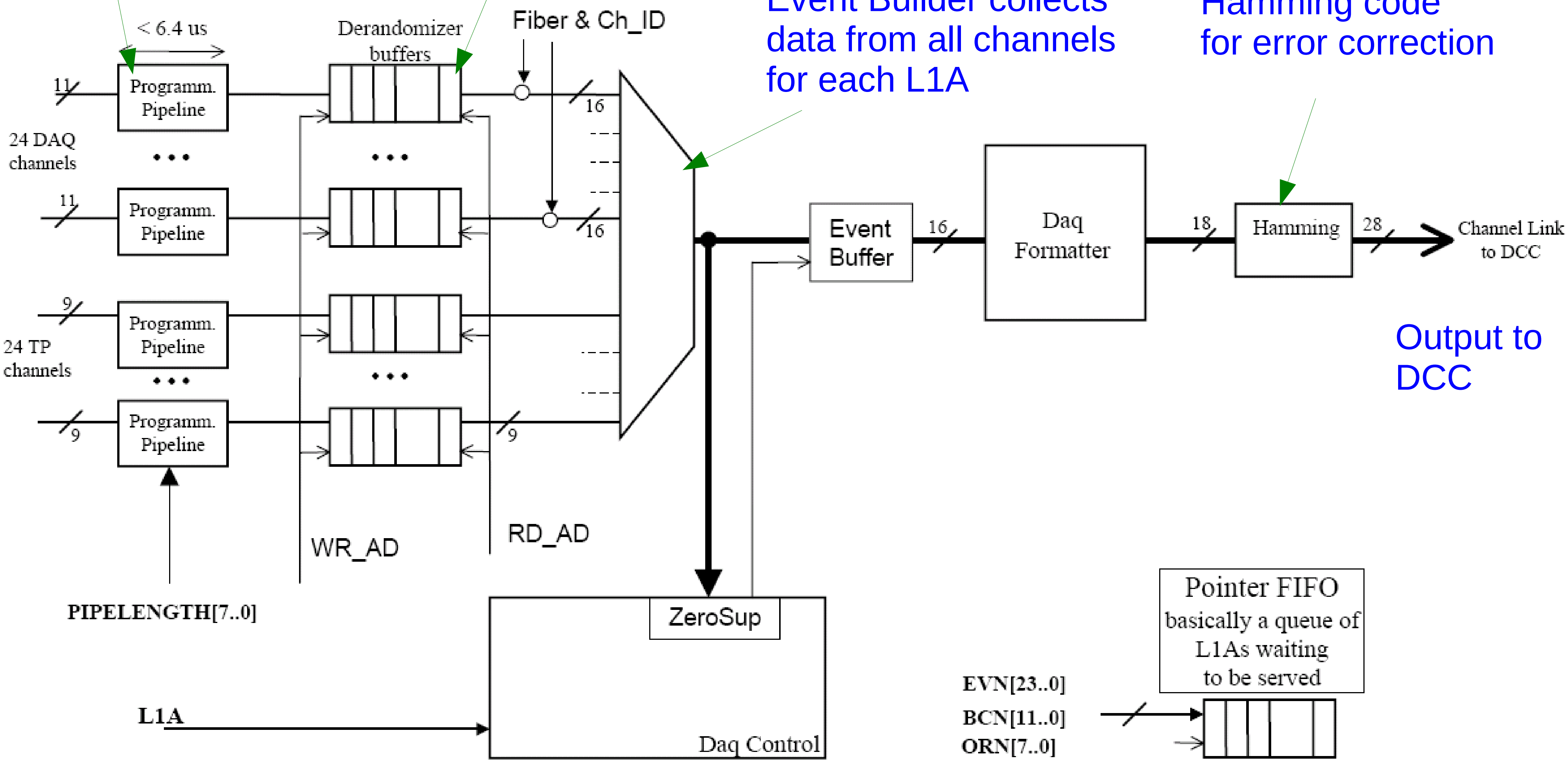
Delay to synchronize all inputs

"Derandomizer" buffer stores data until L1A comes

Event Builder collects data from all channels for each L1A

Hamming code for error correction

Output to DCC

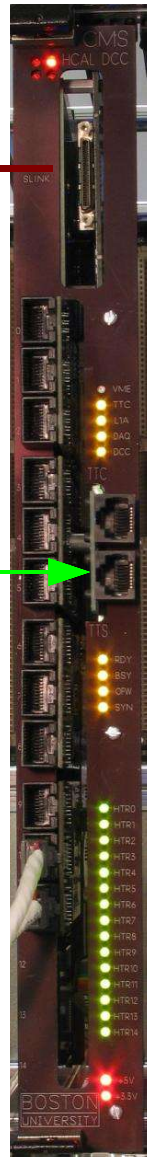


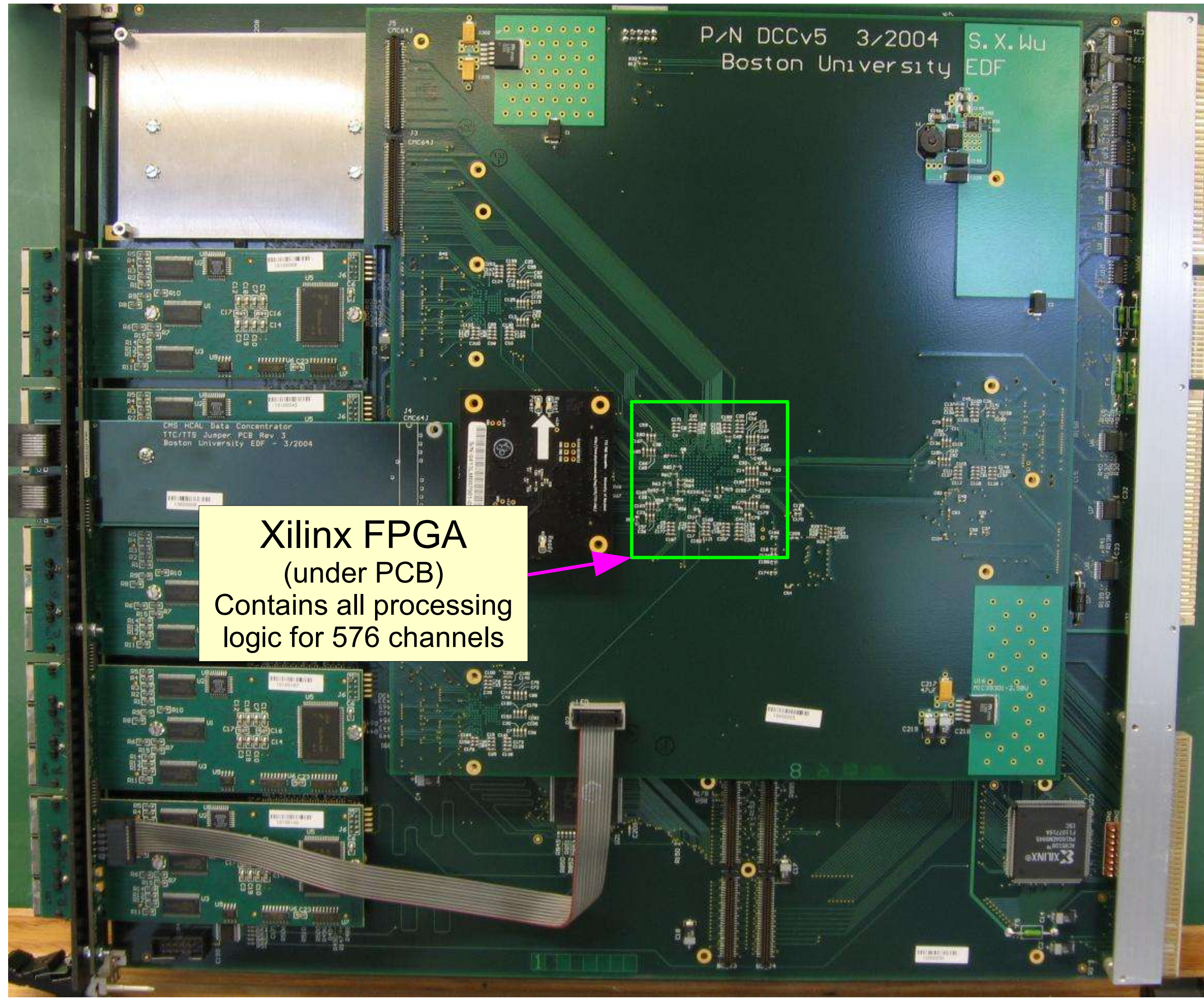
DCC (Data Concentrator Card)

DAQ Output

HTR Inputs
(12 used)

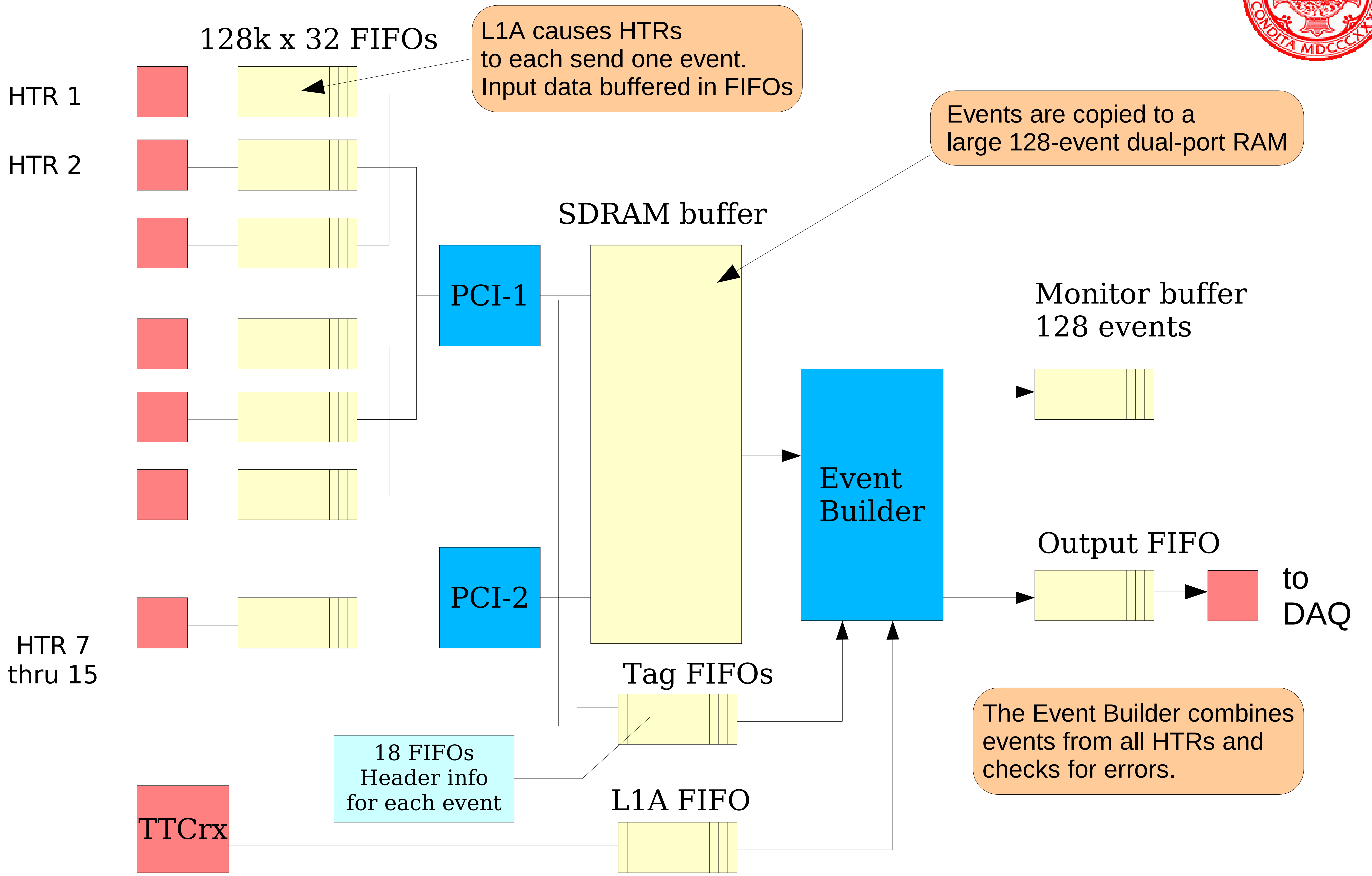
TTC (Trigger, Timing, Control)





Xilinx FPGA
(under PCB)
Contains all processing logic for 576 channels

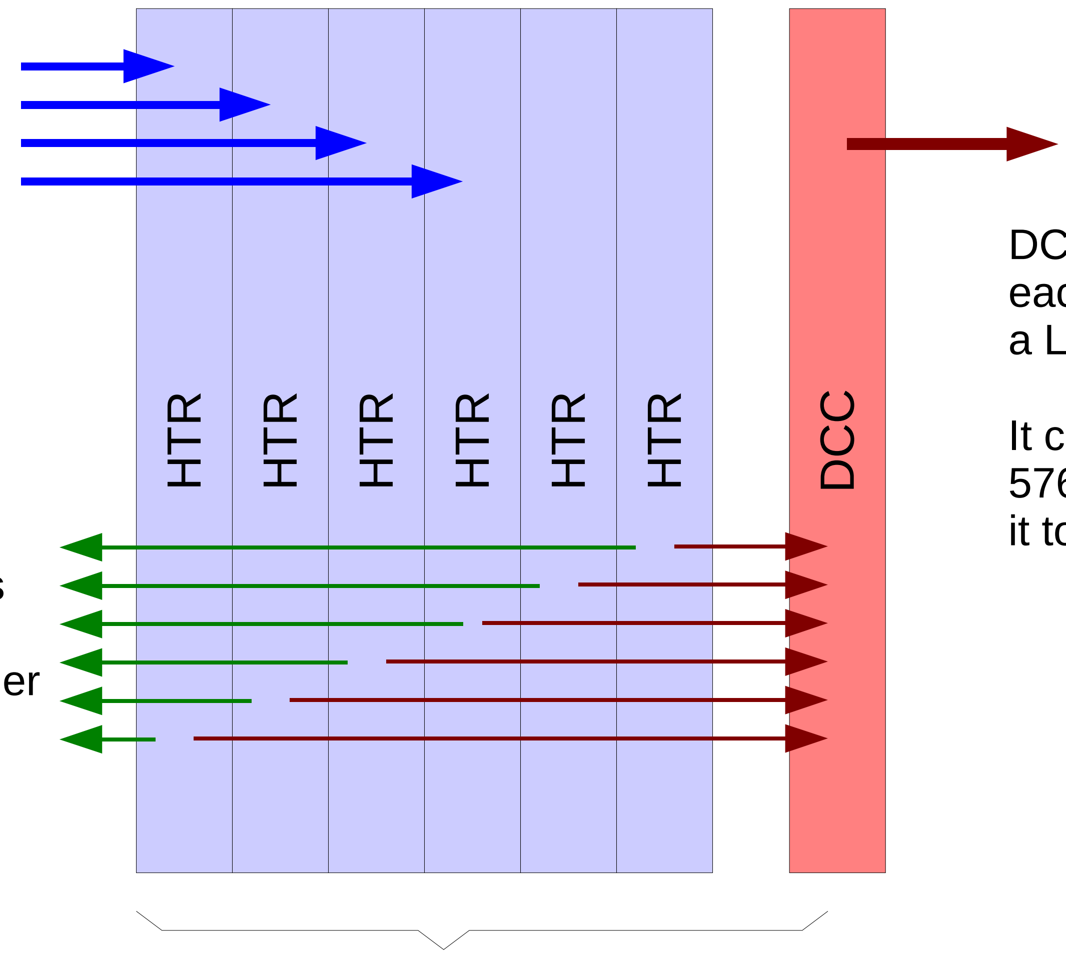
DCC Data Paths



HTR / DCC Crate

16 fibers from
HCAL detector
to each HTR

(3 channels per fiber)



to DAQ

DCC Receives one event from
each HTR in response to
a Level 1 trigger Accept (L1A)

It combines all the data from the
576 HCAL inputs and sends
it to the central CMS DAQ

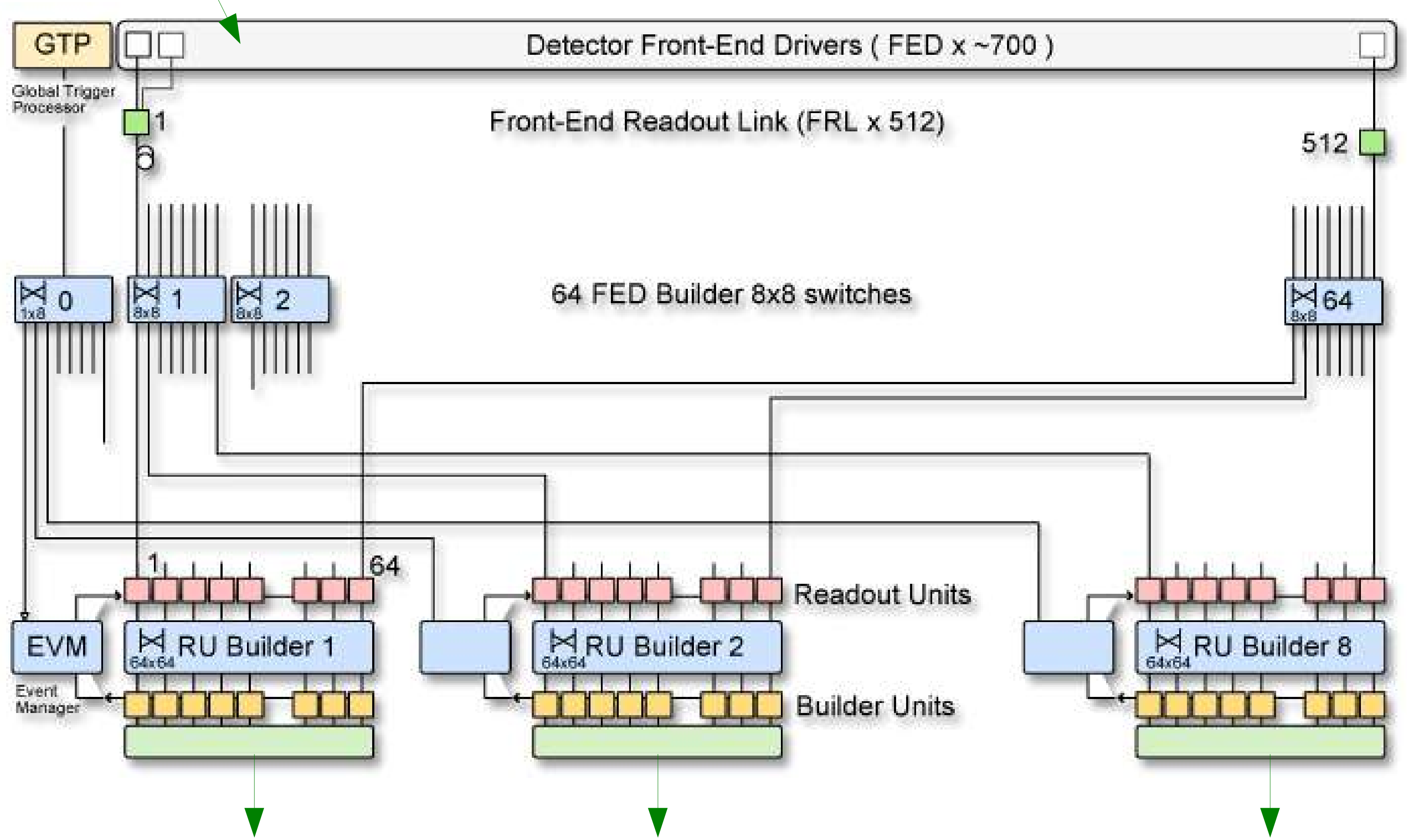
Trigger Primitives
to Regional
Calorimeter Trigger

6 HTRs per DCC
(12 HTR/2 DCC per crate)

CMS Central DAQ

for HCAL:
front-end boards,
HTRs, DCCs

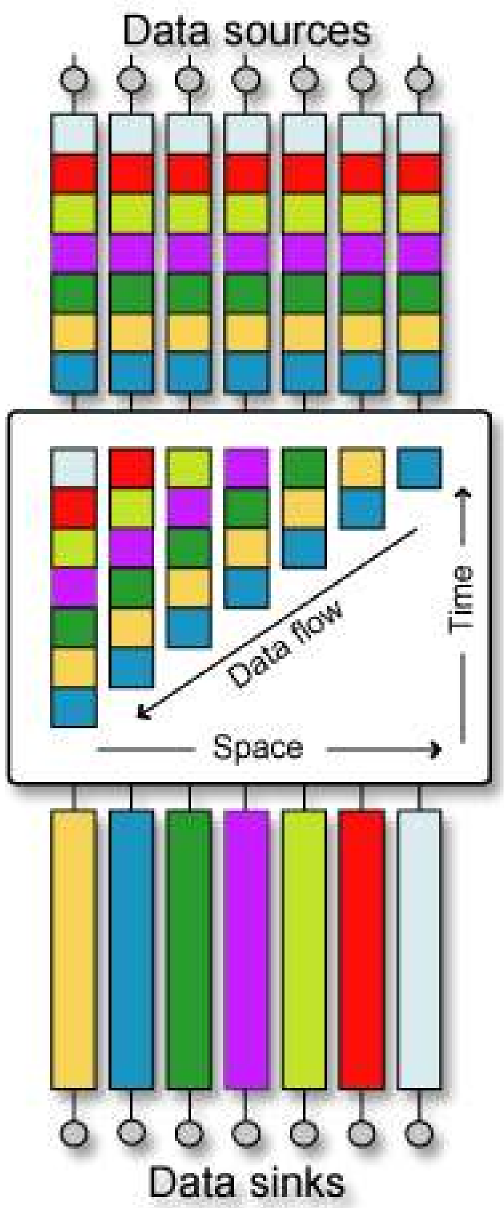
Switches
route data
from each
event to a
single CPU

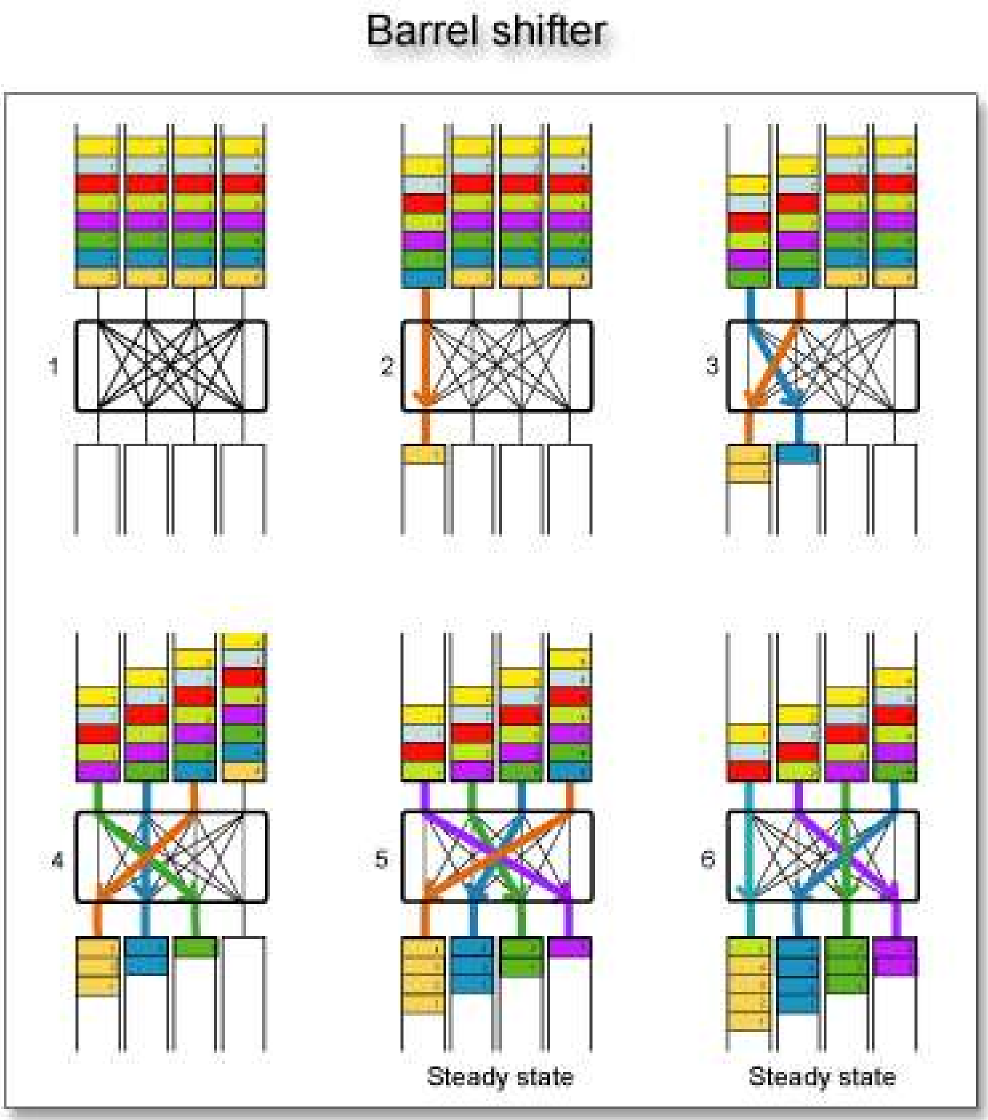


CPU Farm (Higher Level Triggers)

Data Switch

Barrel Shifter data switch routes data from multiple sources to multiple destinations.





CPU Farms

Data is distributed world-wide via the Grid.

CPU farms are located in various countries for analysis.