Triggering on Particle Types: Calorimeter and Muon Based Triggers

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Many slides stolen from:

Sergio Cittolin, James Linnemann, and Wesley Smith

http://www.hep.wisc.edu/~dasu/public/DasuIEEETrg.pdf

Contents

- Calorimeter Triggers
  - Electrons, Photons, τ-leptons and Jets
  - Global energy triggers
  - Energy clustering algorithms
- Muon Triggers
  - Pattern matching
  - Minimum ionizing signal
- Electrons and Muons
  - Track Matching
- Specific implementation examples
  - e+e- (BaBar)
  - e-p (ZEUS) and Fixed target ()
  - p-pbar (CDF, D0, ATLAS, CMS)
- Technologies: ASICs, FPGAs,...
- Future

We will discuss the triggers by examples that I am familiar with and in the process bring out the general themes.

e^+-e^- B Physics: BaBar, Belle

Purpose of the trigger is to pass most (if not all) collision events

Discriminate against beam-environment collisions

Type	Rate (Hz)
Physics	180
Cosmic	100
Random	20
Beam Background	1000-2000

Hardware trigger (L1) 2 Level Trigger

- Tracks + Energy
- < 2.5 kHz

Software trigger (L3)

- ~ 100 Hz to tape
- Remove background
- Prescale Bhabhas

Event type	Cross section (nb)	Production rate (Hz)
$b\bar{b}$	1.1	3.2
other $q\bar{q}$	3.4	10.2
e^+e^-	~53	159
$\mu^+\mu^-$	1.2	3.5
$\tau^+\tau^-$	0.9	2.8

Table 1: Cross sections and production rates for the principal physics proces at 10.58 GeV for a luminosity of $3 \times 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$. The e^+e^- (Bhabha) cr section refers to events with one or both of the $e^\pm$ inside the EMC detect volume.

BaBar L1 Trigger Overview

Calorimeter Trigger

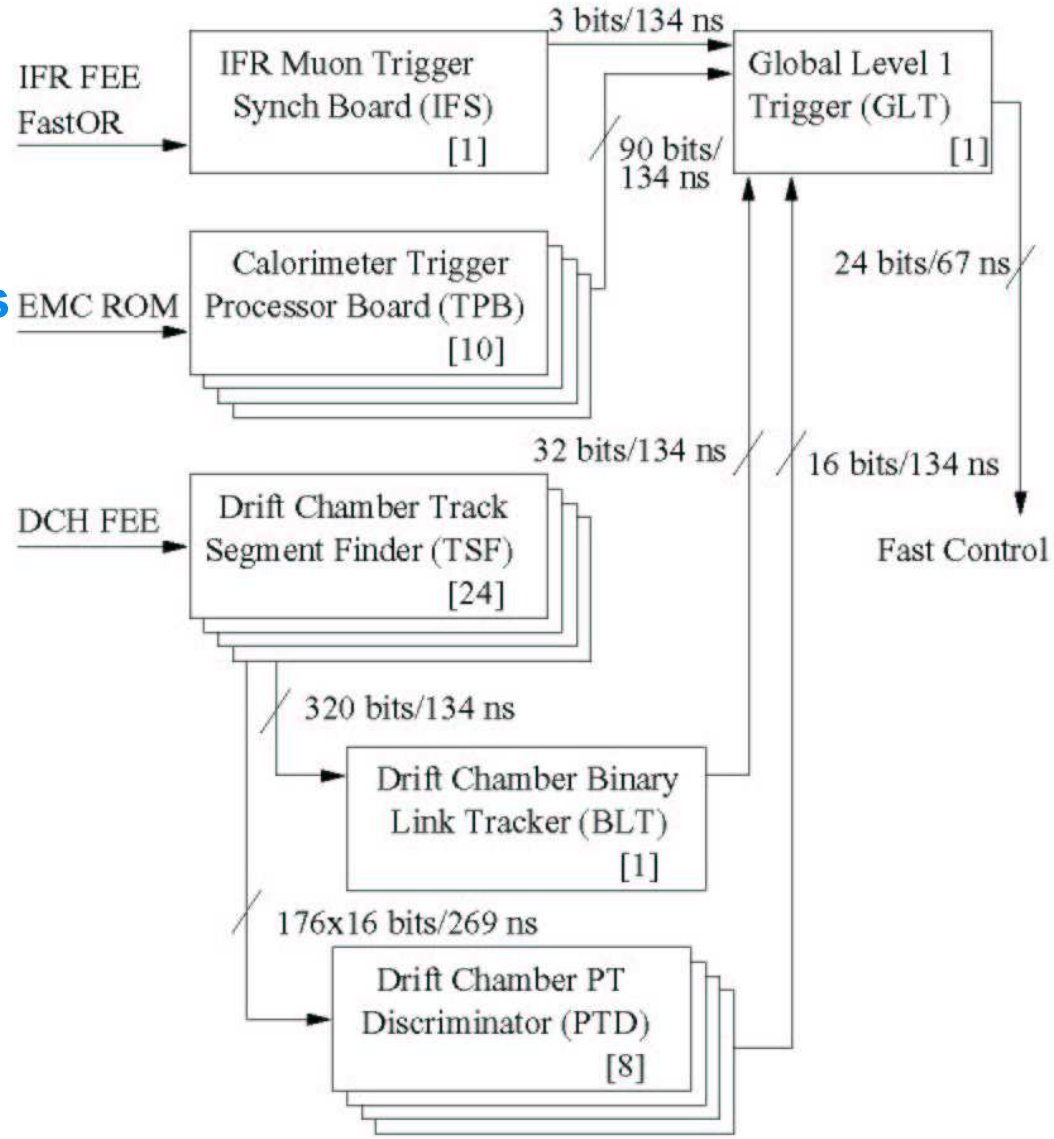
- N-bit pattern of energy deposits in crystals
- Tagged by ϕ angle
- Total ϕ-map from 10 TPBs
- Used in combination with the track trigger

Muon Trigger

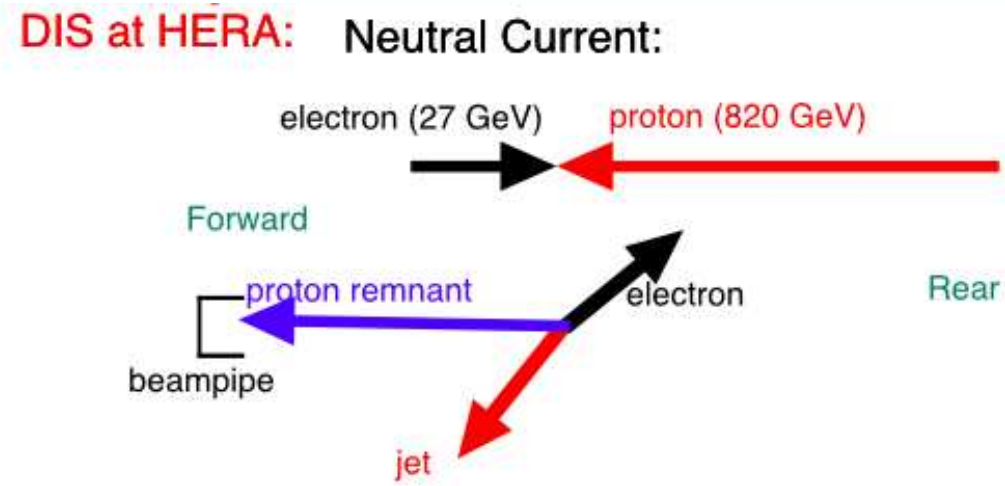
- 3-bit pattern representing hit topology in the muon chambers (RPCs)
- Used for cosmic trigger

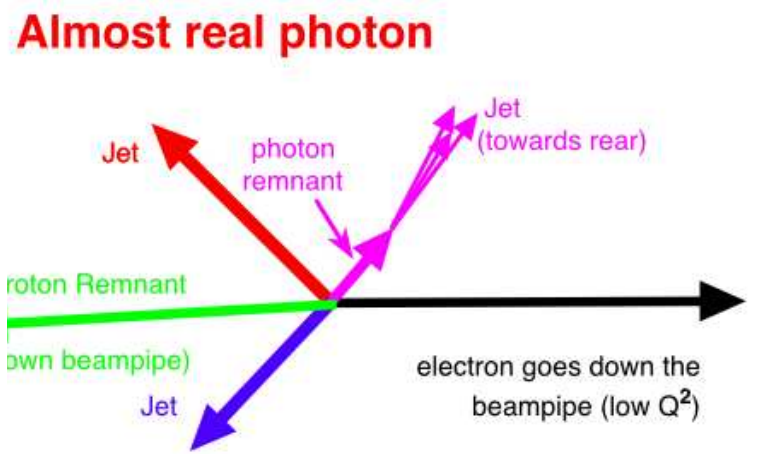
Drift Chamber Trigger

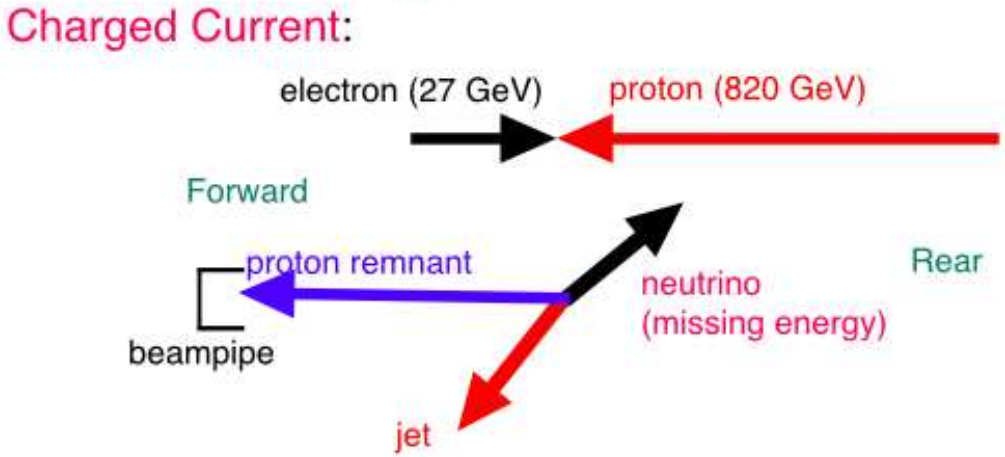
- Track stubs
- P_T discrimination
- Main trigger for BaBar



ZEUS QCD Physics



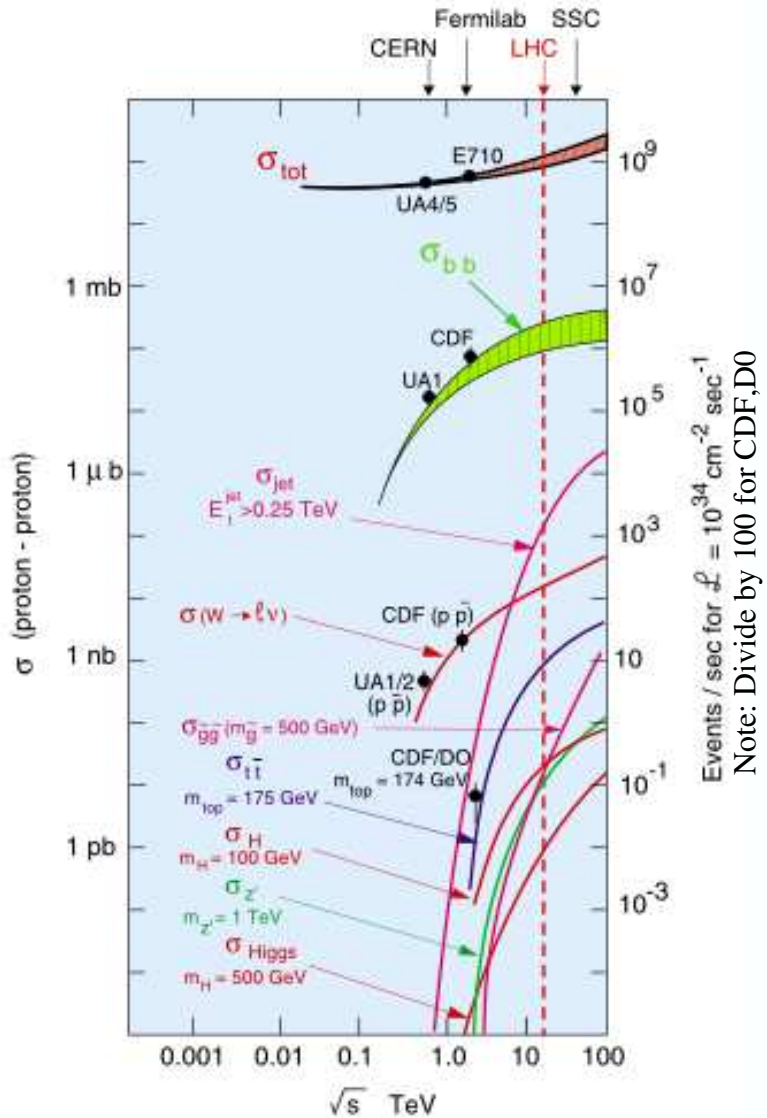




Trigger on

- Electrons
- Jets, Missing E_T
- Total E_T

Hadron Collider Experiments: CDF, D0, ATLAS, CMS



B Physics (10 GeV)

- **2-5 GeV particles**
  - 10 kHz (Tevatron)
    - **Specific Channels, Tracks + Separated vertices**
  - 1 MHz (LHC) - Hopeless for ATLAS, CMS

Physics at EWSB scale (250 GeV)

- **$115 < M_{higgs} < 200$ GeV**
- **Couplings to W (80), Z (91)**
  - Lepton $P_T \sim 40$ GeV
- **TeV scale supersymmetry**
  - Multiple leptons, jets and LSPs (missing P_T), $P_T < 100$ GeV

QCD Background

- **Jet $E_T \sim 250$ GeV**
  Rate = 1 kHz (LHC), 0.01 Hz (Tevatron)
- **Jet fluctuations ⇒ electron BG**
- **Decays of π, k, B ⇒ muon BG**

Technical challenges

- **7,40 MHz input ⇒ fast processing**
- **100 Hz output ⇒ physics selection**

Hadron Collider L1 Trigger Challenge

	CDF,D0	ZEUS	ATLAS,CMS
Bunch crossing (ns)	132 (396)	96	25
Decision latency (μs)	4	5	2,3
Channel count	2000	2000	8000
Rate reduction (kHz)	2525 to 7,50	100 to 0.5	40000 to 100

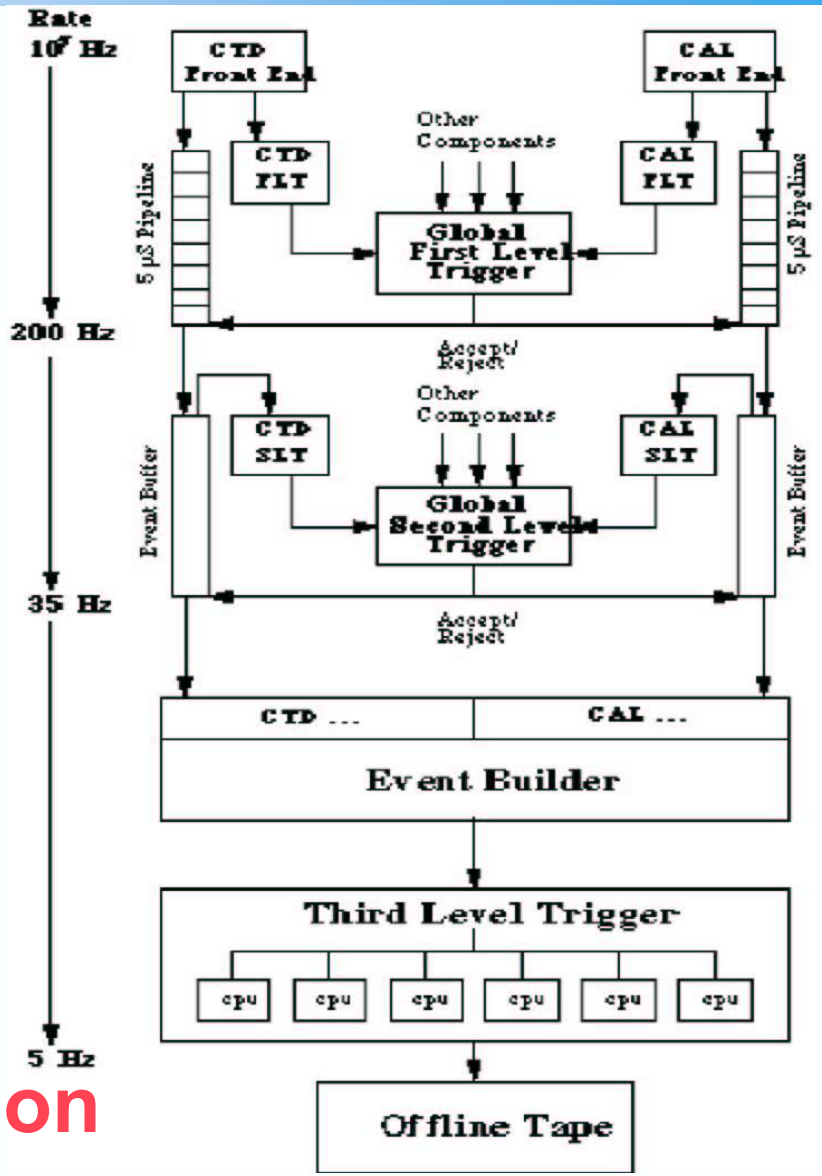
Short timescales
Large channel count
Large rate reduction

→ Faster, high density electronics with fancy algorithms

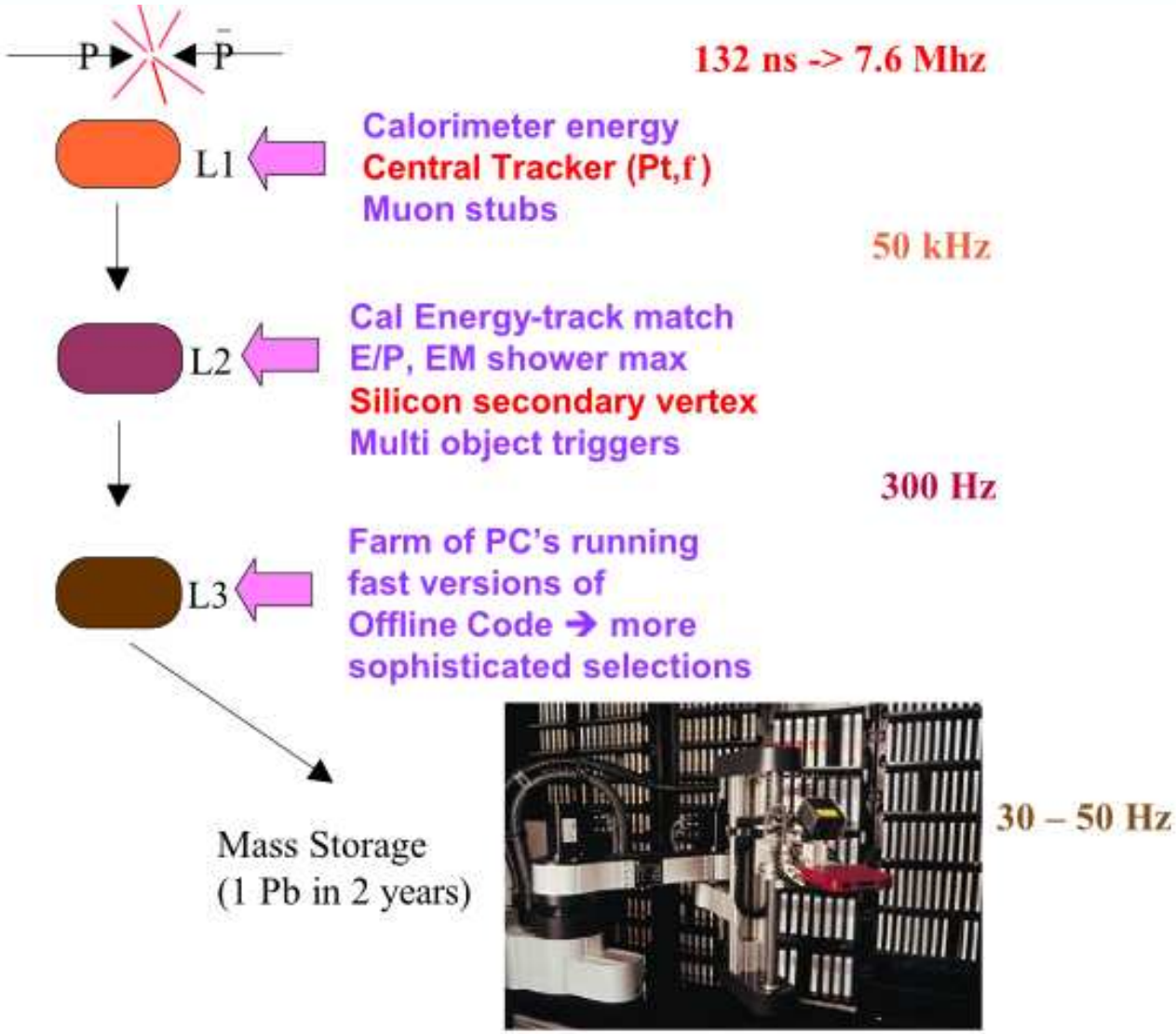
Overview : ZEUS

Pipelined 3 level trigger

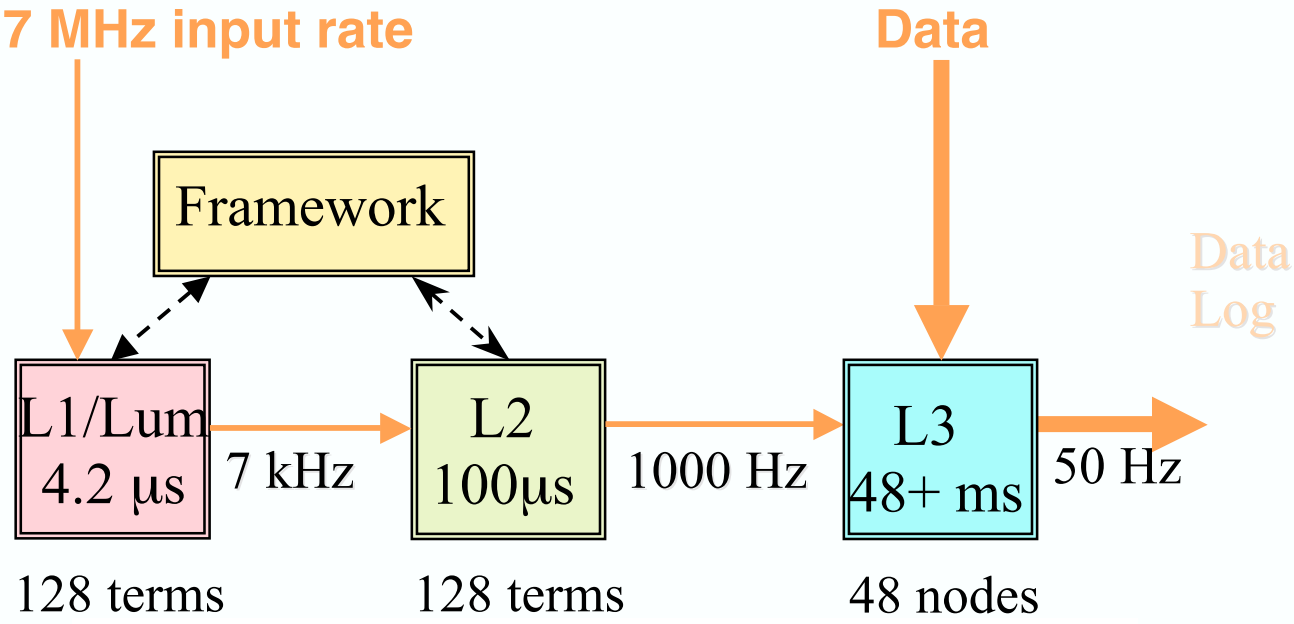
- Level-1 (Electronics)
  - Calorimeter
  - Trackers
- Level-2 (Processors)
  - Calorimeter
  - Trackers
- Level-3 (Software)
  - Event Reconstruction



Overview : CDF Trigger



Overview : D0 Trigger



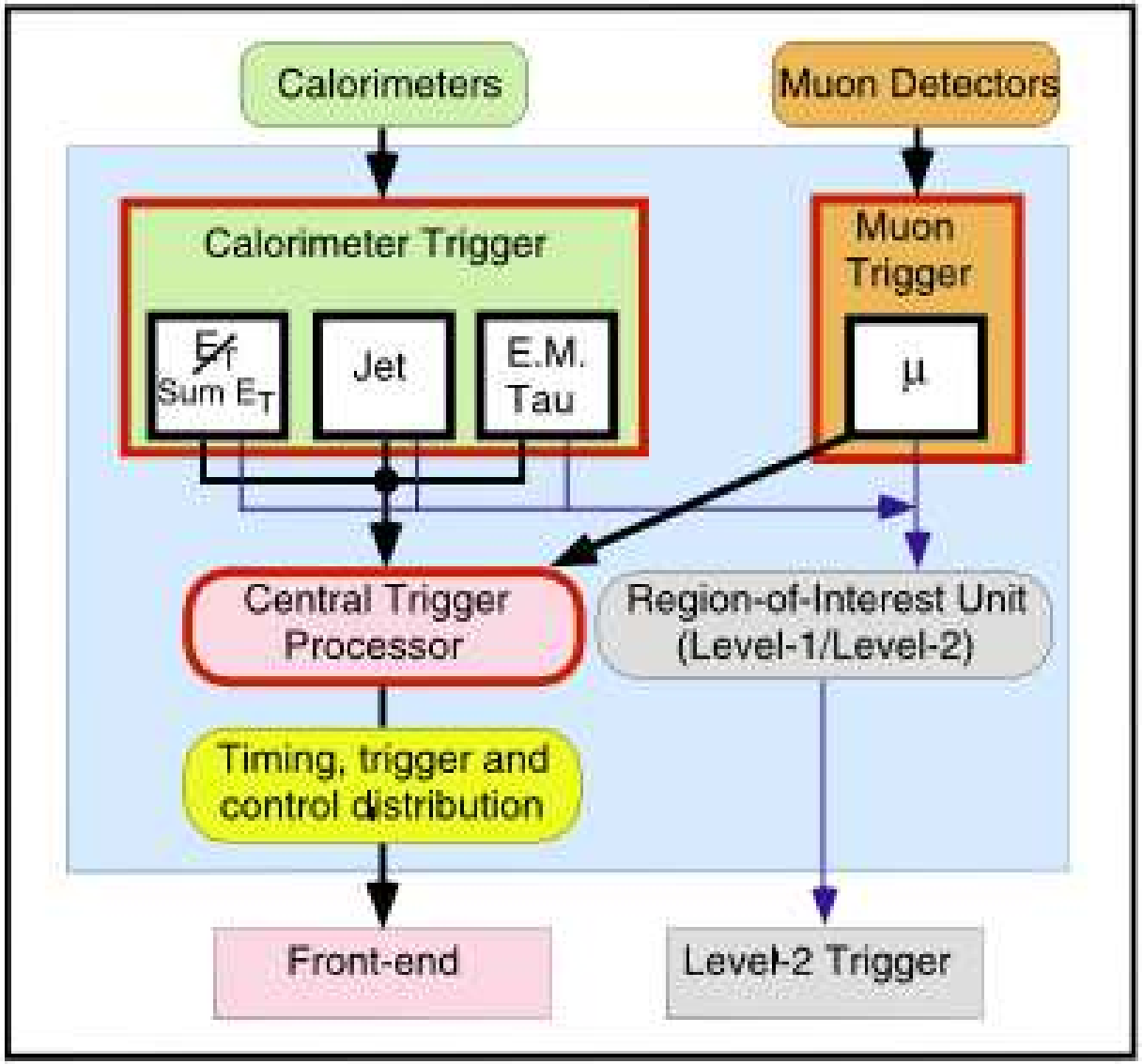
- L1 Trigger uses a pipelined architecture
  - Front End data clocked into a 3.5µs long memory
    - 27 beam crossings
  - L1 trigger has 3.5µs latency to decision
- Trigger decision a two stage process
  - L1 systems send physics bits to the framework every 132ns (7MHz decision rate)
  - Framework ANDs these to give 128 trigger bits
  - If any bits are set → generate a L1 accept

Overview : D0 Framework

- Receive, synch, latch 256 physics input bits
  - Tracker(64), Cal(64), PS(32), Muon(32)Ö
  - Make higher-level (fpga code) combinations
  - And inputs or combinations -> 128 trigger bits
- Implement pre-scaling of high-rate triggers
- Broadcast timing, decisions to Front Ends
- Calculate time and luminosity exposure
  - Scalers per bunch (x159), per trigger bit
- 3 crates, 125 cards
  - 4 variants of base design
    - different connectivity of 16 FPGAís
  - ~20 FPGA code modules; download system in 5 min.
  - Custom backplane for 100MHz timing, distribution
    - Pipelined processing in 2 beam crossings (132ns)
  - Software, firmware to test
    - Connectivity
    - 1-cycle full speed

Overview : ATLAS & CMS Examples

ATLAS

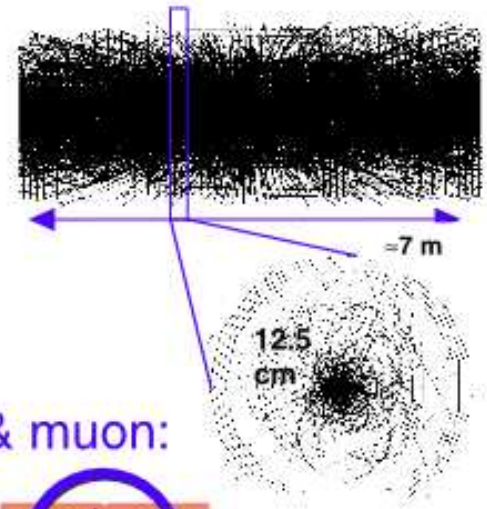


CMS

ATLAS and CMS Strategy

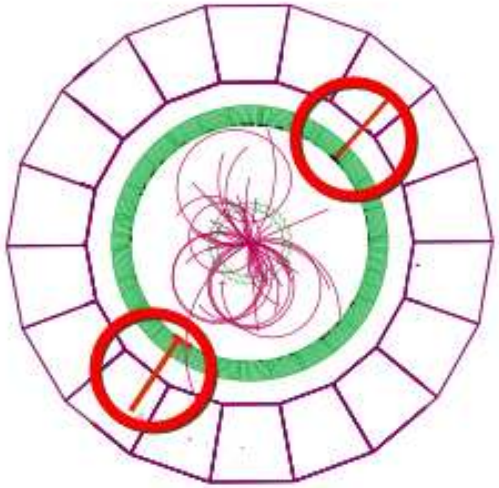
Level-1 : only calorimeters & muons ....

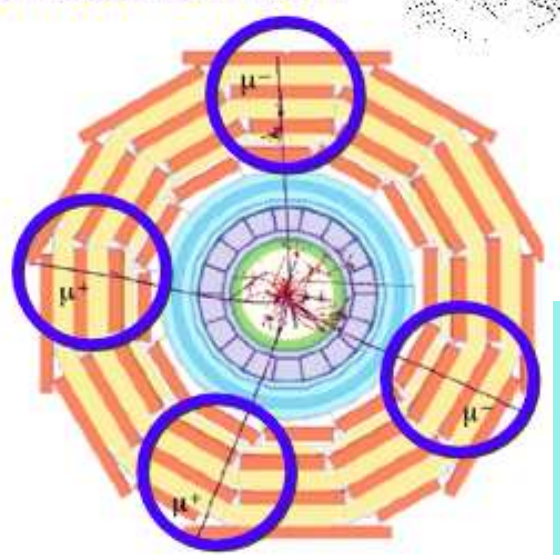
Compare to Central tracking at L = 10^{34}
(50 ns integration, ≈1000 tracks)



Algorithm Complexity
+
huge amount of data

Pattern recognition much easier on calo & muon:





Complexity handled in software on CPUs

Theme

Level-1:

Energy over threshold (BaBar, Belle, CDF, D0)

to object identification (ZEUS, CDF, D0)

to object isolation (ATLAS, CMS)

Level-2:

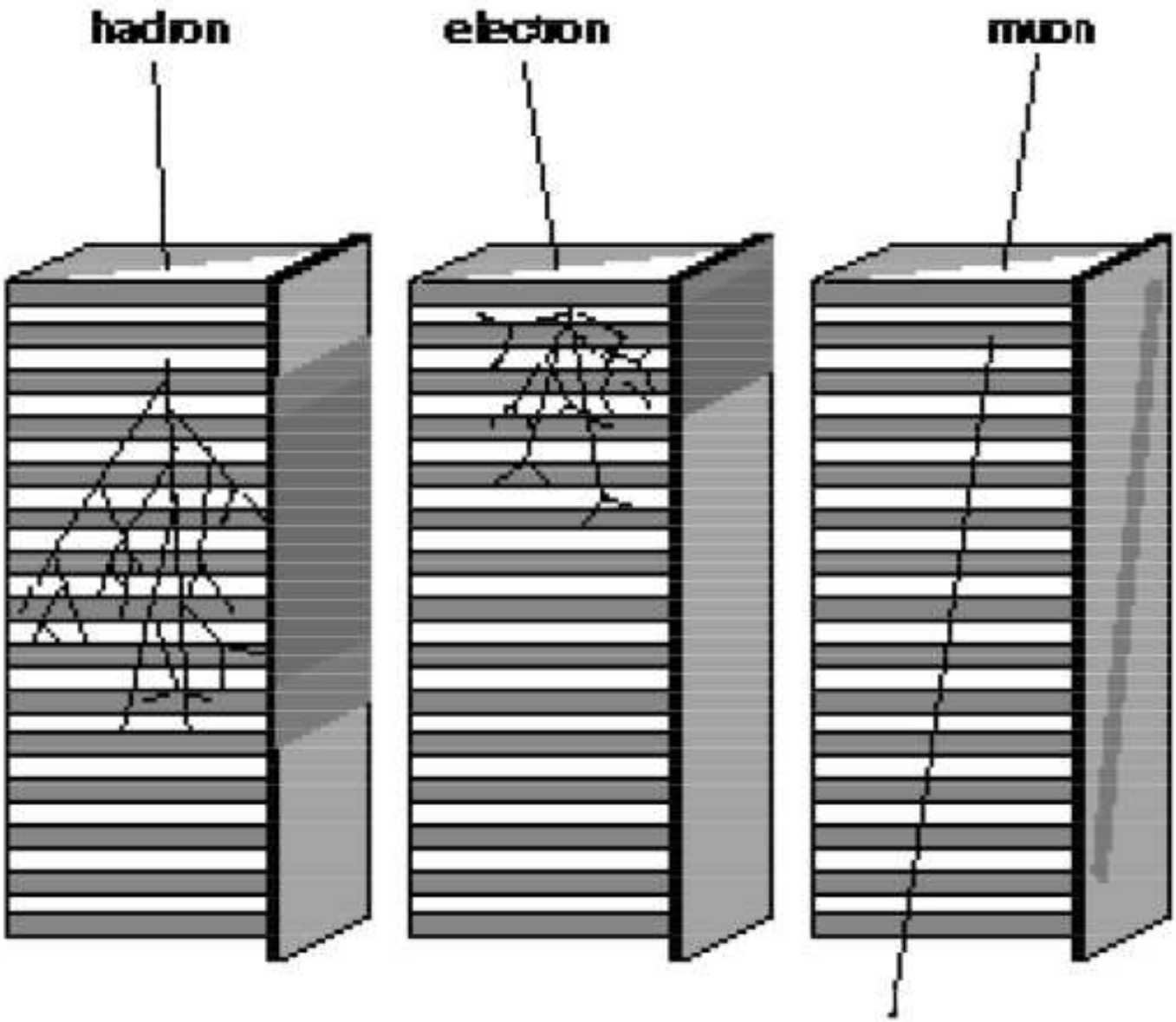
Custom processors (CDF, D0, ZEUS)

to full readout after Level-1 (BaBar, CMS)

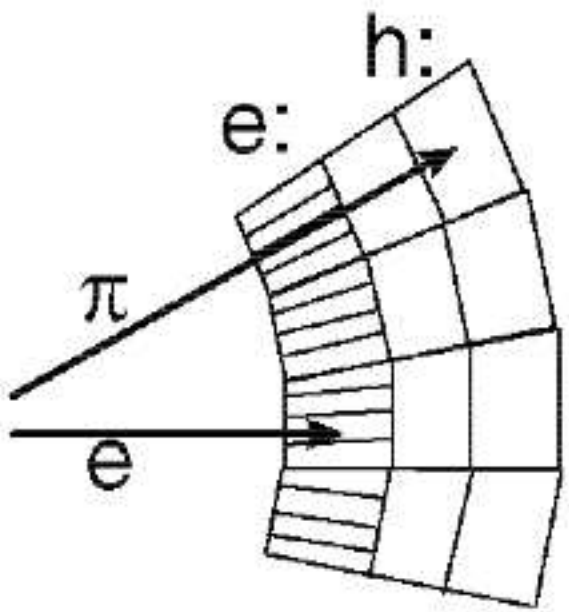
We will talk only about Level-1 Calorimeter and Muon triggers

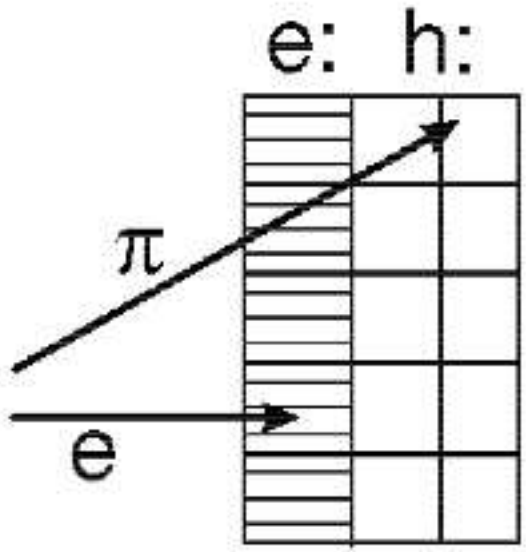
More sophisticated algorithms possible at level-2, separated vertices for B physics, etc. are discussed in other talks.

Interaction of Particles with Matter



Projective Geometry

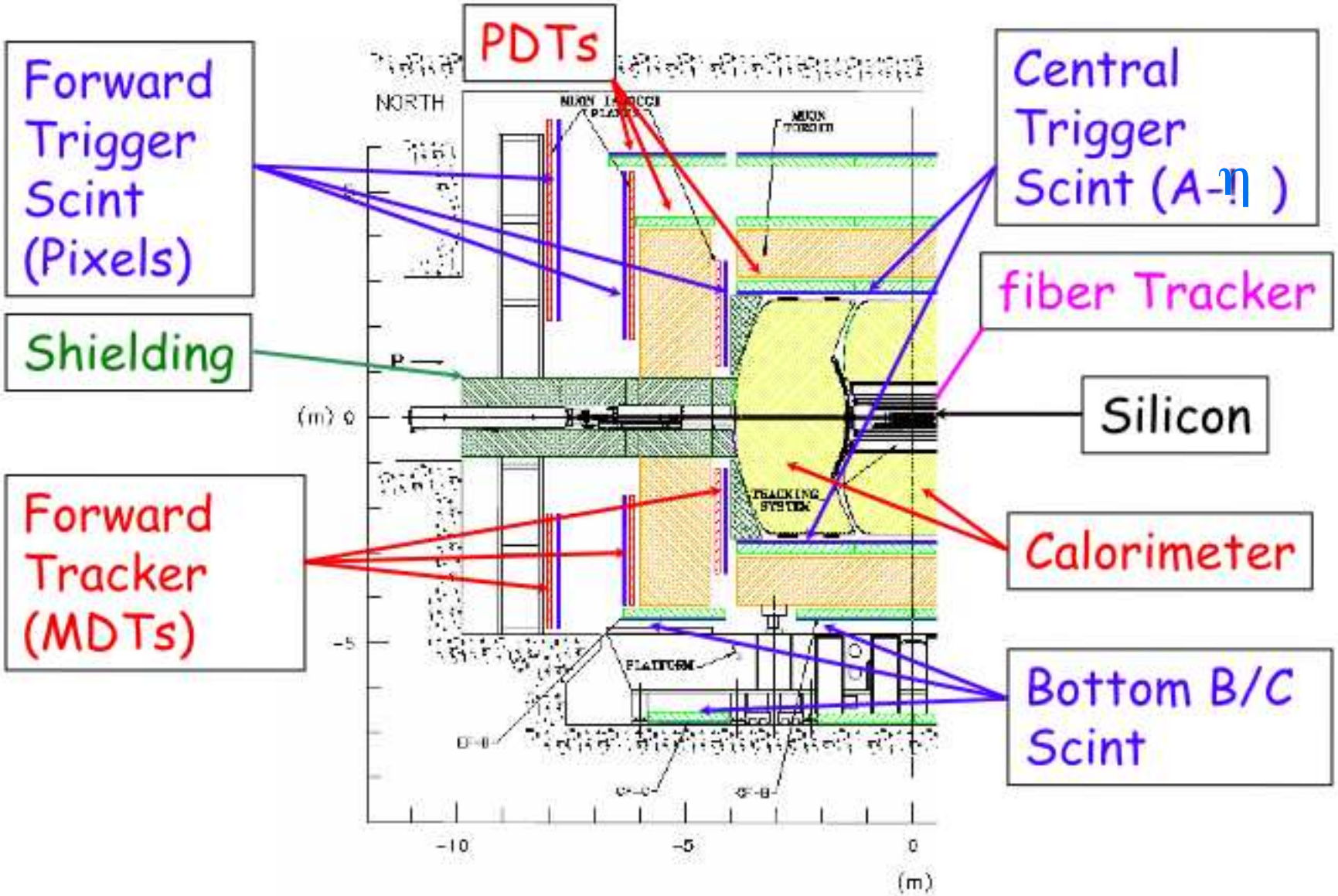




Projective geometry is important

- ZEUS: Used complicated cable mapping and pattern searches to reduce fake rate
- ATLAS, CMS: Calorimeters are built projective
- Mapping with muon system: Important for isolation

D0 Muon System



D0 Calorimeter Trigger

- L1 calorimeter trigger groups calorimeter cells into ìTrigger Towersî
  - 1280 towers in total (40! x 32")
  - Each has an EM and Hadronic energy
- Triggering performed using ìreference setsî
  - Reference set= threshold for each trigger tower
  - 4 EM reference sets (+seed mask for L2)
  - 4 EM+Hadronic reference sets (+L2 seed mask)
- Each reference set has 4 minimum counts
  - Sets a bit if more than N cells above min count
- Pre FPGA: FADC + ECL Summer trees
  - 10 racks!

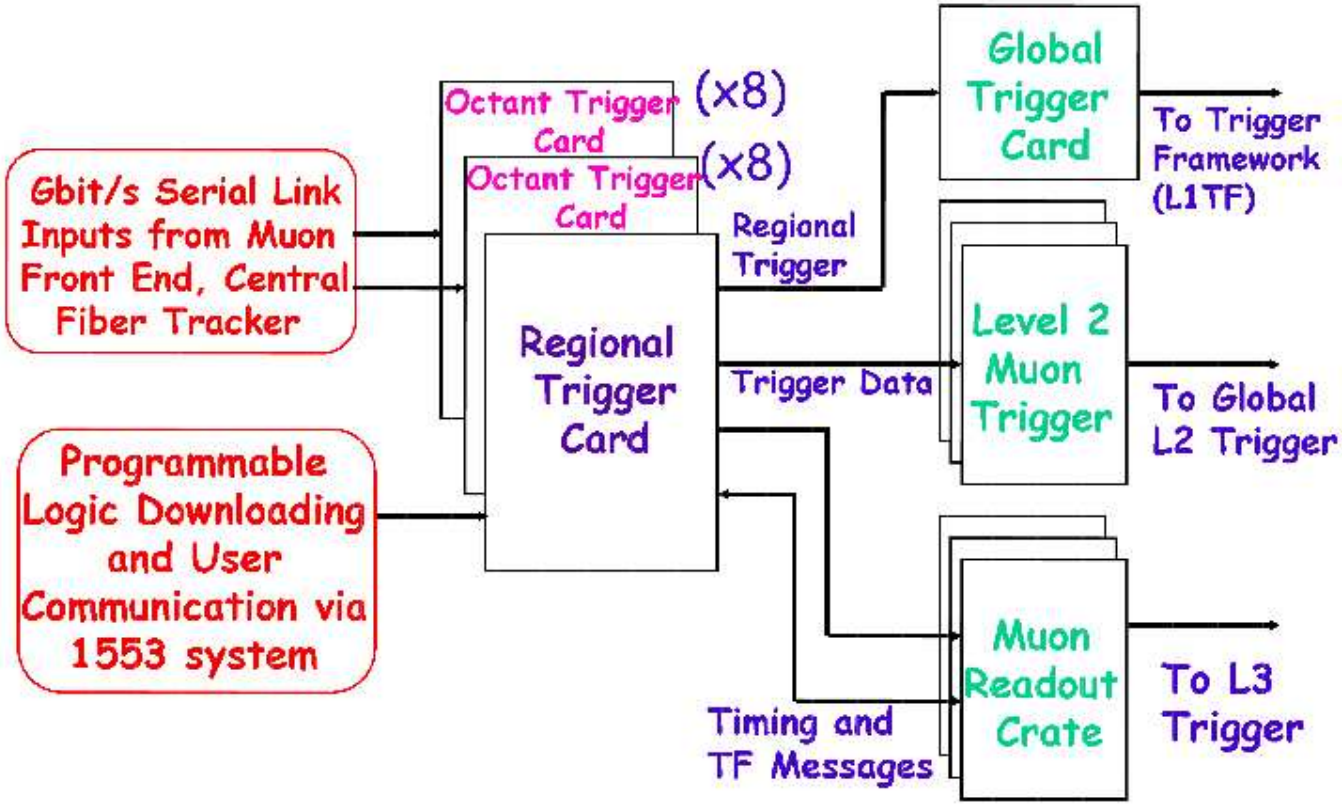
D0 Calorimeter Trigger

- Other triggers possible
  - Total EM and EM+Hadronic energy thresholds
  - Vector summed missing E_T thresholds
- Quadrant triggers on 2 EM and 2 EM+Hadronic reference sets
  - 1 or more towers in a given quadrant
  - 2 or more towers in a given quadrant
- Out of all these possible triggers only 64 wired to the L1 framework

D0 Muon Trigger

- Muon detector divided into 3 regions
  - Central ($|\eta|<1.0$)
  - Forward ($1.0<|\eta|<2.0$) [North and South]
- Each region has three layers (A,B and C)
  - Only the A layer is inside iron toroid
- Each layer consists of drift tubes
  - A has 4 decks, B and C have 3 decks
  - A and C layers also have scintillator
- Trigger creates "centroids" for each layers
  - Centroids combined with scintillator and fiber tracker data to give muons

D0 Muon Trigger



D0 Muon Trigger

- Output to L1 Framework is 32 bits
  - Selected from 256 possible terms at start of run (these terms don't change)
- Terms can select various criteria
  - PT threshold (2,4,7 or 11 GeV/c)
  - η region (|η|<1, |η|<1.5, |η|<2)
  - Quality: Loose or Tight
  - Muon multiplicity

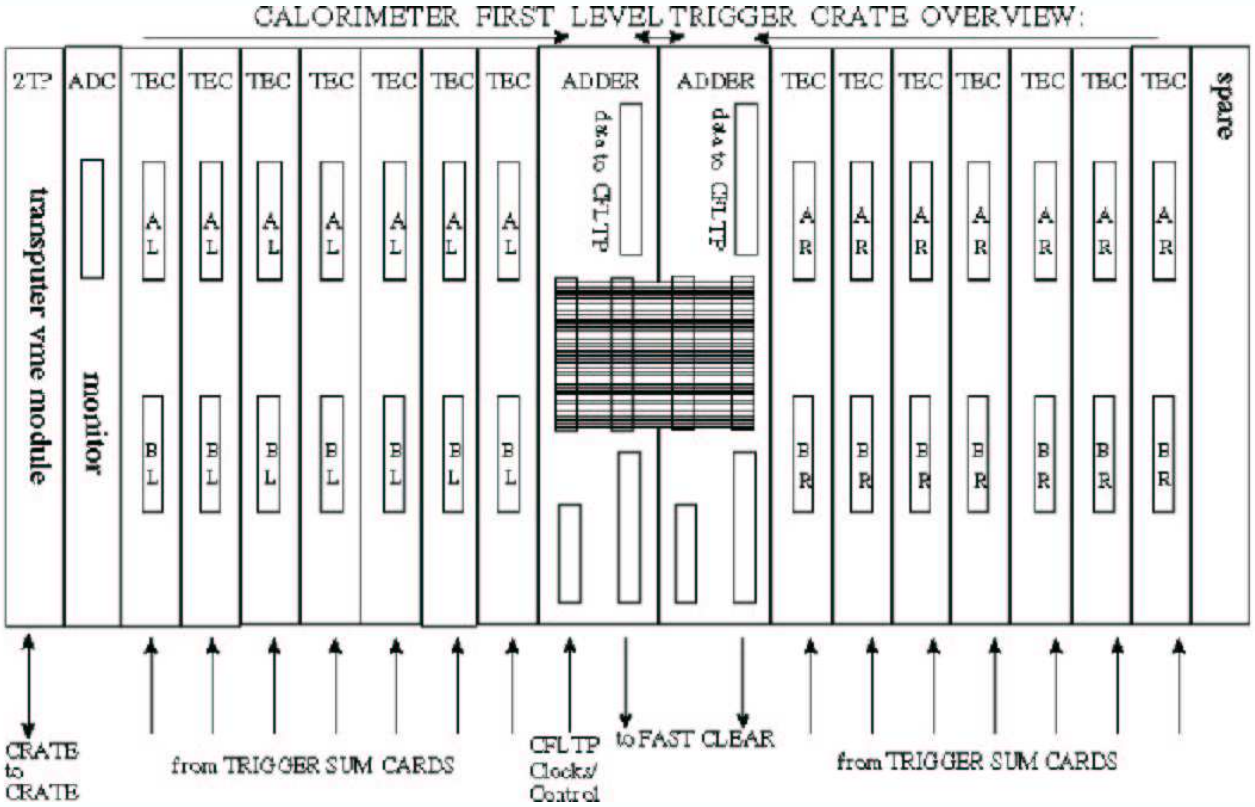
ZEUS Calorimeter Trigger Electronics

- 16 Crates
  - Trigger Encoder Cards, Adder Cards
  - Identify and count objects over threshold
    - Electrons, Jets
  - Energy sums
    - Geometry

VME Crate

Custom P2 & P3 bus

ECL logic runs at 2x, i.e., 20 MHz, on TEC, Adder



ZEUS
Trigger Encoder Card

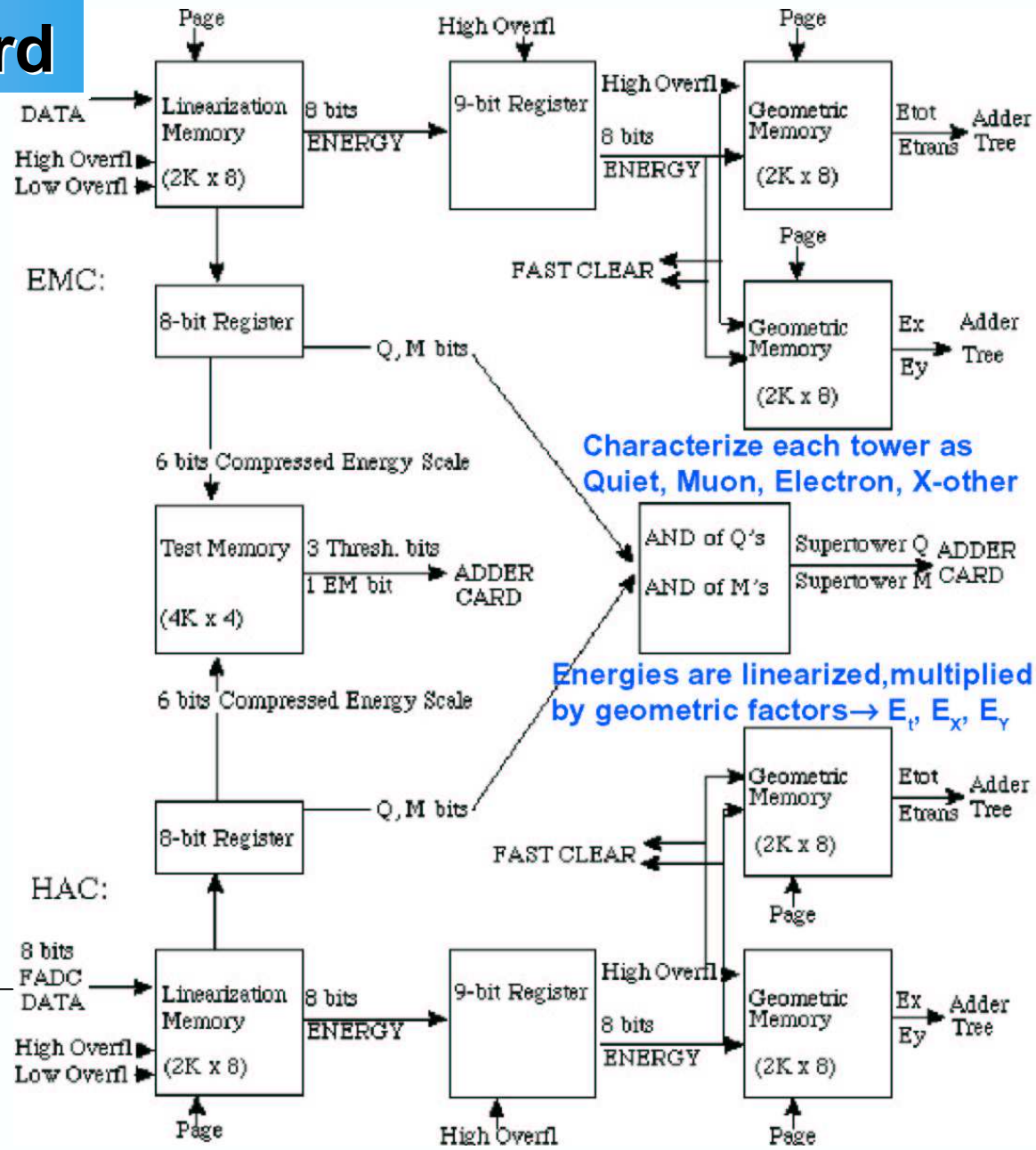
Analog input from calorimeter

- Digitize
- Characterize
- Sum

Flash ADC
EMC, HAC

Bussed backplane for transferring data to Adder Cards

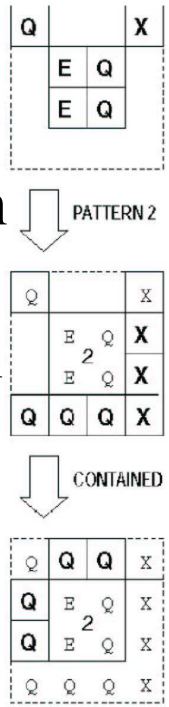
Discrete ECL Logic



ZEUS Adder Card

Object identification using pattern of energy deposition in the calorimeter.

Pattern logic sweeps data across 3 separate tests:

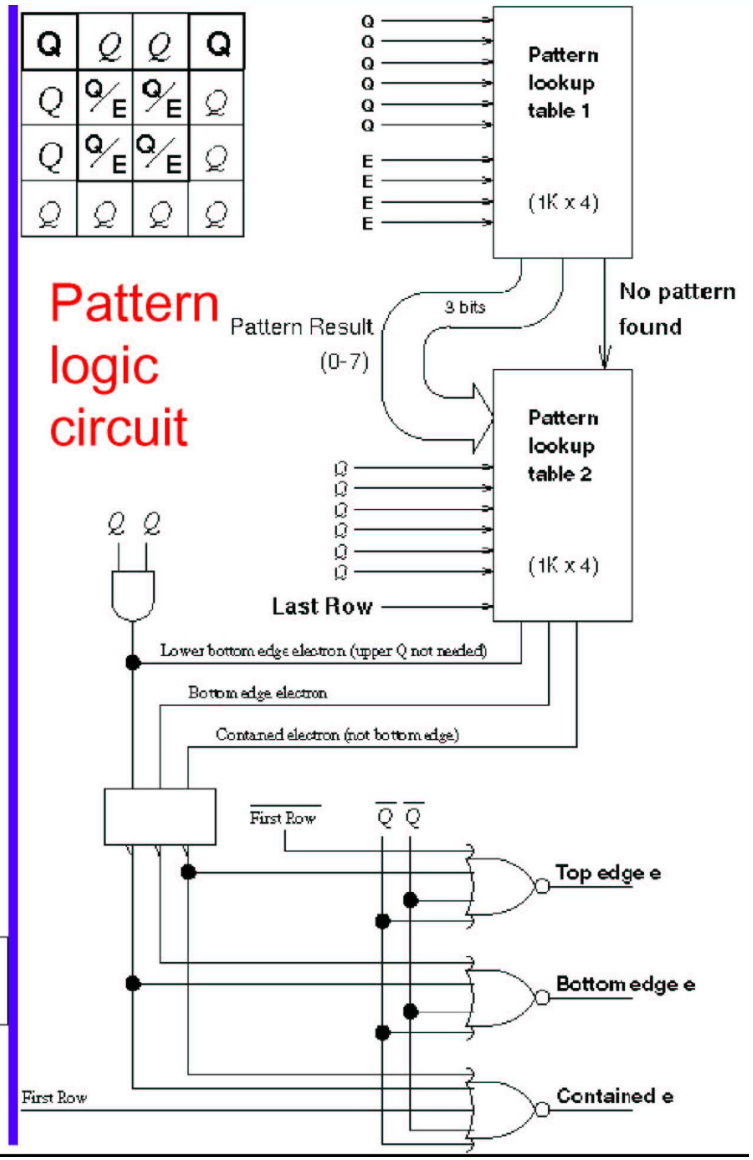


Step 1: Central 2x2 region tested for E, Q, upper corners tested for Q

Step 2: Right and bottom edges tested for Q

Step 3: Top and left edges tested for Q

Key: E = Electron
Q = Quiet tower
X = Don't care



CDF, D0 Level 2

CDF and D0 elected for simple level-1 but more sophisticated level-2 based on processors

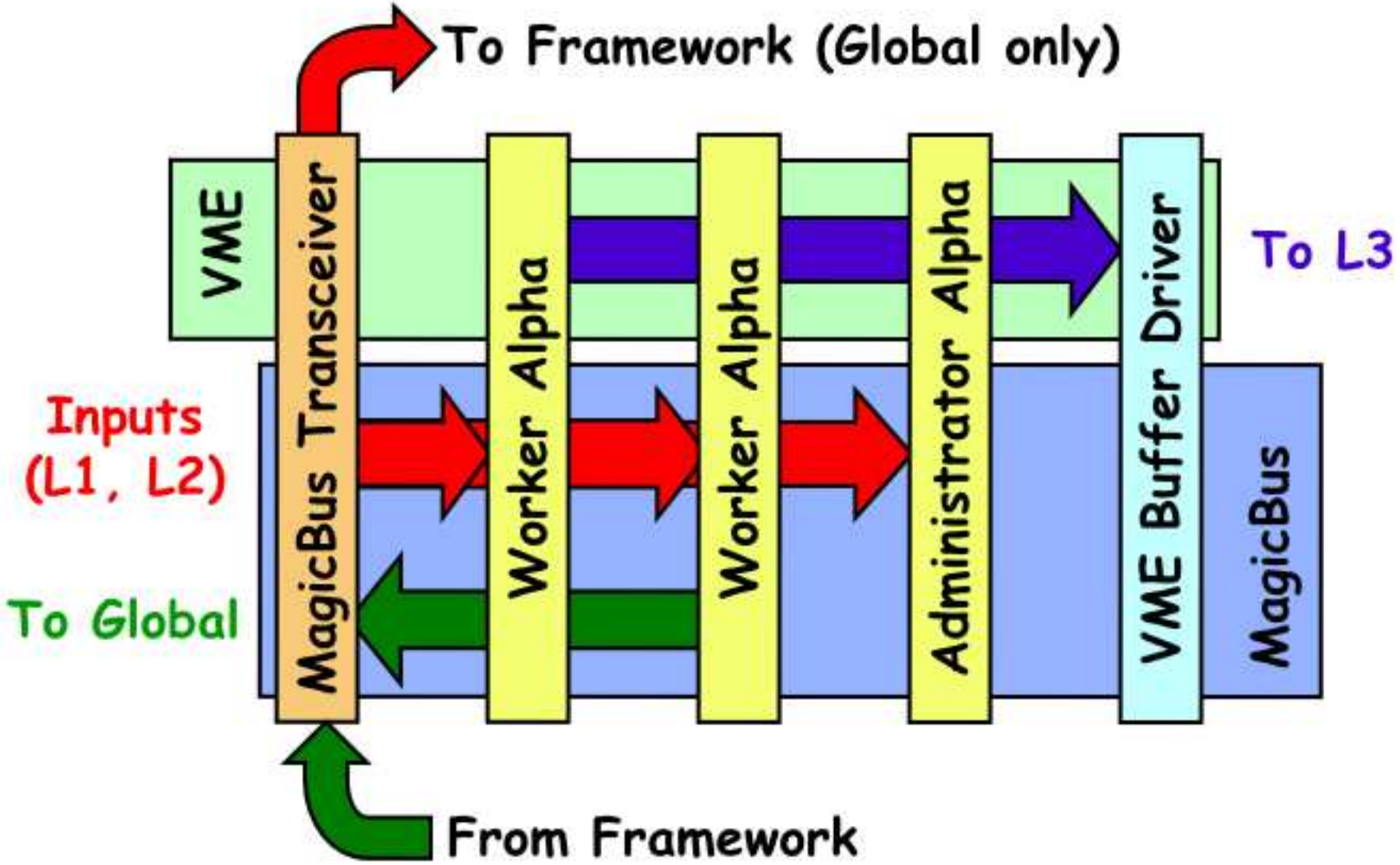
- Rejection goal: 6-10
  - 6-10 KHz in; 1KHz out
    - Flexible combination of data across detectors
- Latency: 16 event buffer for L2 decision time
  - Buffer increments only on L1 Accept: Stochastic pipeline
  - Deadtime generated if buffer fills: ~2 ms
  - Queuing simulations to determine quota
    - 50-150μs/event average processing time
- The level 2 trigger has a two stage design
  - Processors handle sub-detectors
  - Global correlates across the whole detector
- Must respond to events in order received
  - Workstation farm not useful given this constraint
  - Use single, powerful processors: Compaq Alpha

Same processor used by CDF, D0

Level-2 Crate

- Each L2 Crate (pre-processor or global) has:
  - Administrator Alpha Board
  - One (or more) Worker Alpha Boards
  - Input card(s): broadcast data to all Alpha(s)
    - Cypress Hotlinks serial inputs
    - Interface cards to handle other cable types if needed
  - Output card to send data to L3
  - Crate Controller with dual-port memory
- Each crate has two backplanes
  - VME64 for Physics (VIPA)
    - readout, download, monitoring
  - MagicBus (320MB/s, 128bit custom bus)
    - Data broadcasting; low-latency communication

Level-2 Crate



Level-2 Data Bus

- The L2 Jack-of-all-trades!
  - Receives L1 input data and broadcasts it to all the Alphas in the crate
  - Receives output data from pre-processors and sends it to Global
  - Sends 128 L2 trigger bits from Global to the trigger framework
  - Sends commands from the trigger framework to the Administrator Alpha
- Data is sent via MBus
- Control/Setup via VME

Level-2 Software

- Alphas run Linux/Alpha (RedHat 6.2) with a hacked kernel
  - low level interrupt handler
  - Physical memory allocator for DMA
- Code is all written in C++
  - C and Assembly give no appreciable performance boost
  - Restrictions on allowed C++ constructs
    - No dynamic memory, no STL, no RTTI and no exceptions
- All this needed to reach ~50-100μs time budget

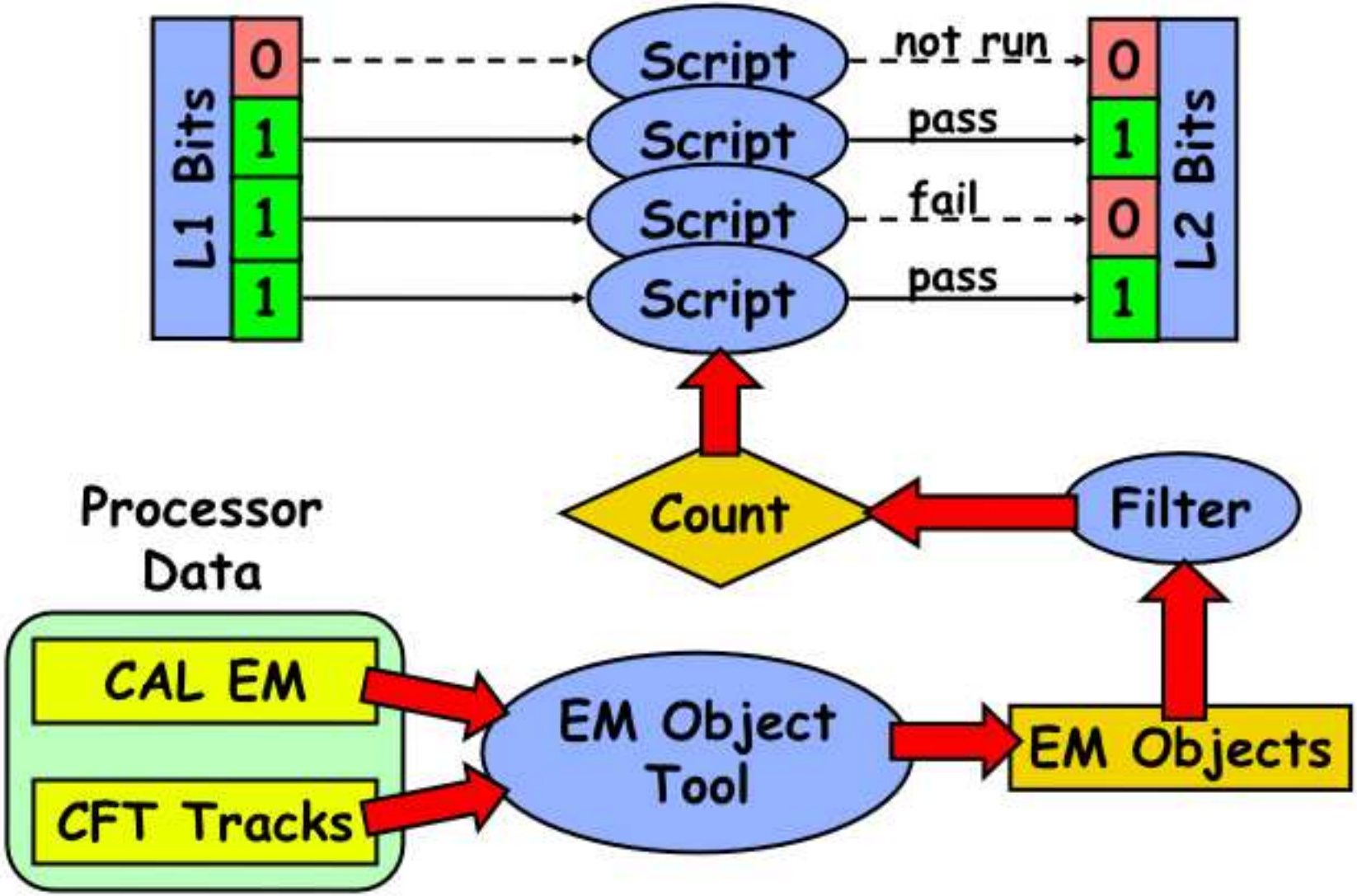
D0 Use of Generic L2 Processors

- Data from one sub-detector in one L2 crate
- Examples: Calorimeter, Tracking, and Pre-shower:
  - Workers in one crate all see same data
  - One worker per algorithm:
    - {Jets, EM, Missing ET}
    - {L1 Tracker list (sort and format),
      L2 Si tracker lists (pt; impact parameter tags) }
      - ñ L2 Silicon Track Trigger: 6 crates feed L2 Tracker crate
    - {Central preshower, forward preshower}
- Muon processors: 2 crates
- Global crate: inputs from other 5 L2 crates
  - Administrator + Worker(s)

D0 L2 Trigger : Calorimeter Objects

- Three workers:
  - Electromagnetic, Jet and Missing E_T
- Input data are
  - Trigger tower energies from L1CAL
    - 1280 X 2 bytes (em, em+tot)
  - EM and Hadronic seed masks (1 bit/tower)
- Performs a clustering algorithm and outputs results to Global
  - EM clusters
  - Jet clusters
  - Missing E_T

D0 Level-2 Electron



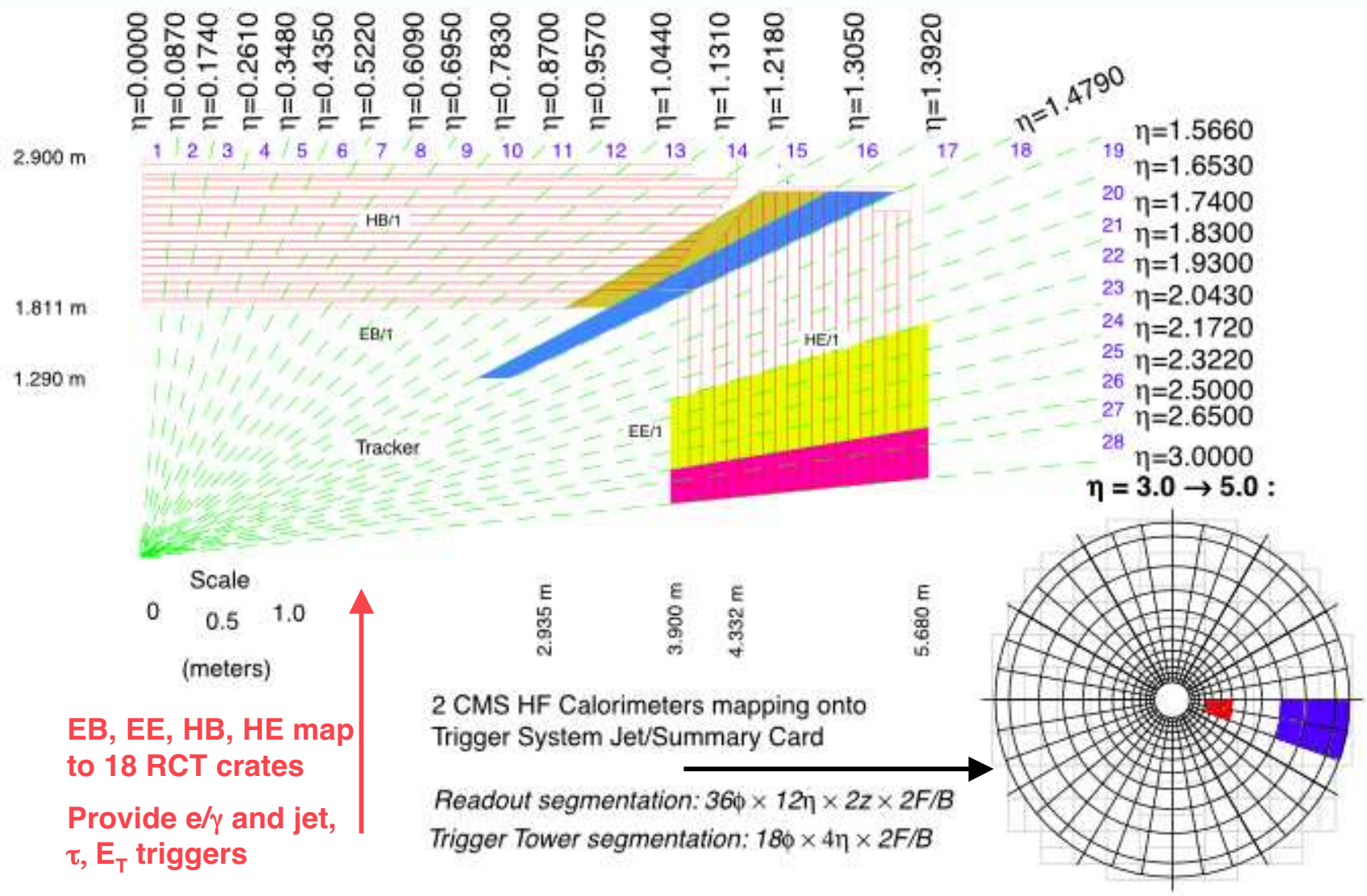
D0 Level-2 Muon

- Sees full muon readout data
  - Scintillator times
  - Drift tube times
- Use Second Level Input Converter (SLIC)
  - 4 DSPís finds track stubs based on times
    - geometrical parallelism: each sees independent region(s)
  - 1 DSP formats, outputs results to Alpha
  - More computing power that Alpha board (each DSP has 1600mips!) but a lot harder to program
    - C with an aggressive compiler
  - Alpha combines stubs into tracks
    - Quality depends on how many layers match

D0 Level-2 Global Trigger

- Global processor assembles pre-processor data into physics objects by ìToolsî
  - Tools exist for EM objects, jets, muons, masses and, eventually, possibly taus
- Output of tools used by ìFiltersî to select objects meeting certain criteria
- Each set L1 bit runs a script
  - Each script runs one or more filters
  - If sufficient objects pass each filter then the script itself passes
  - Passed scripts set their corresponding L2 bit and hence will cause an L2 accept

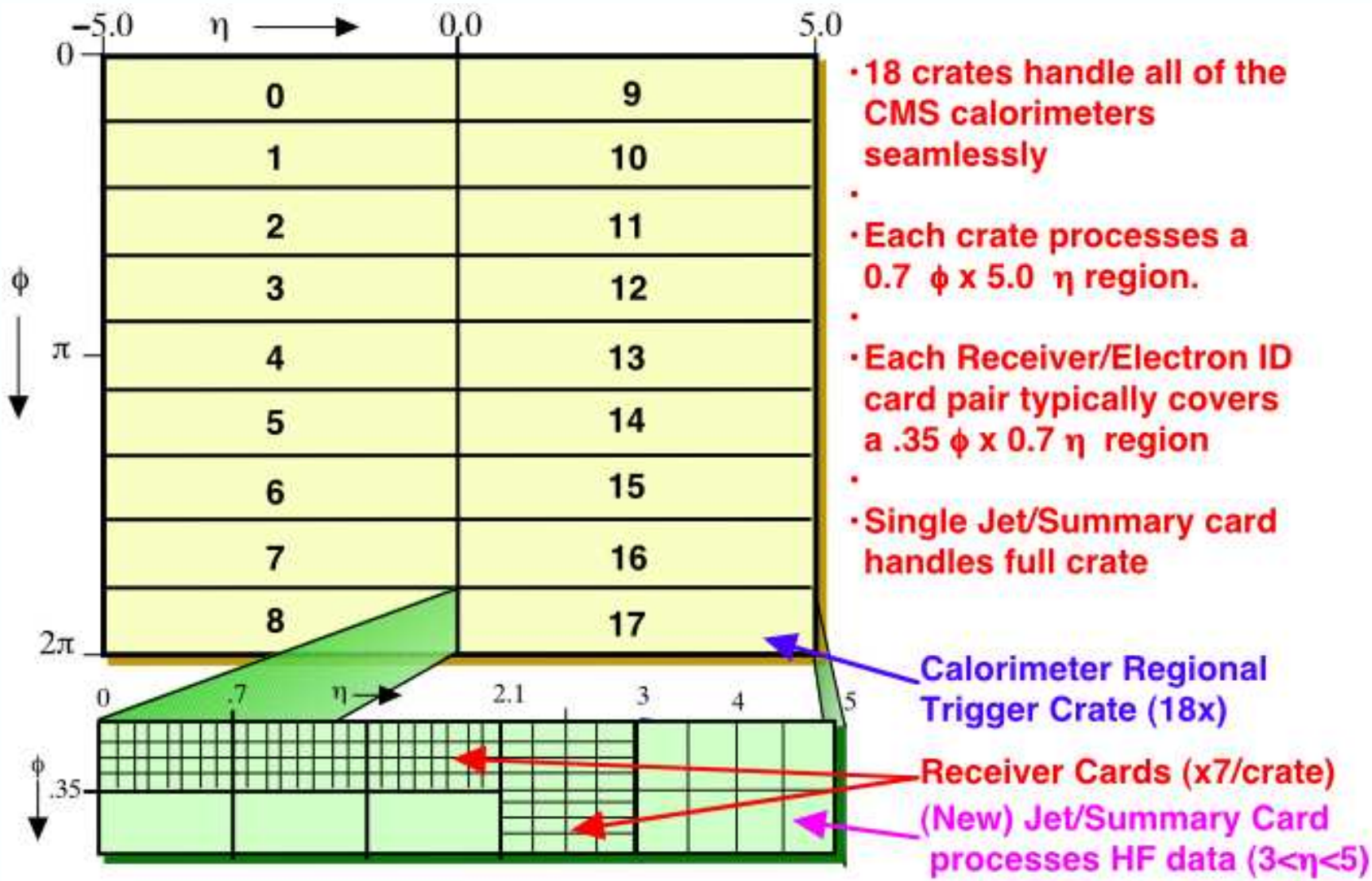
Calorimeter Geometry : CMS Example



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

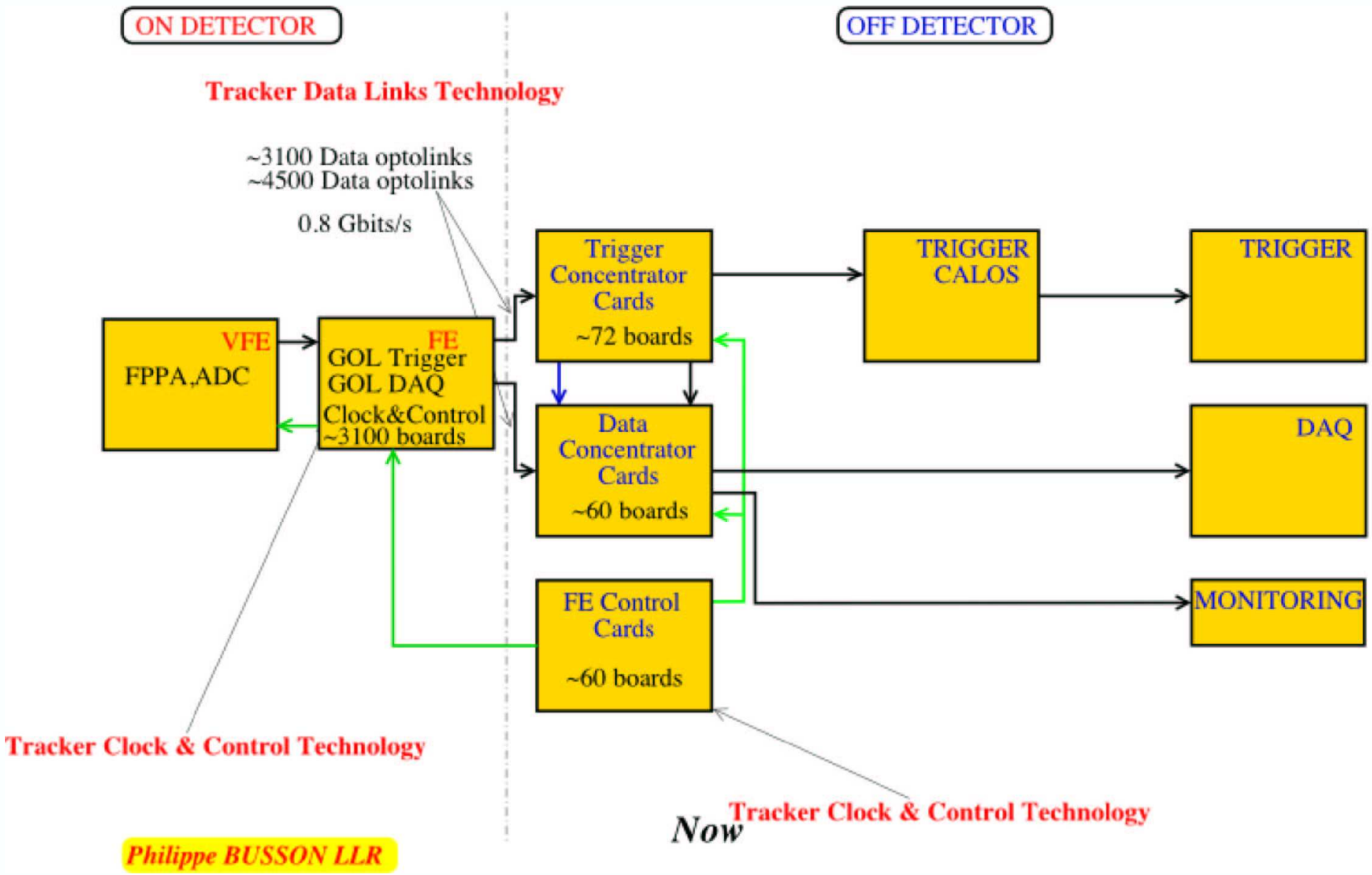
Provide e/γ and jet, τ, E_T triggers

Trigger Mapping: CMS Example



- 18 crates handle all of the CMS calorimeters seamlessly
- Each crate processes a 0.7 ϕ x 5.0 η region.
- Each Receiver/Electron ID card pair typically covers a .35 ϕ x 0.7 η region
- Single Jet/Summary card handles full crate

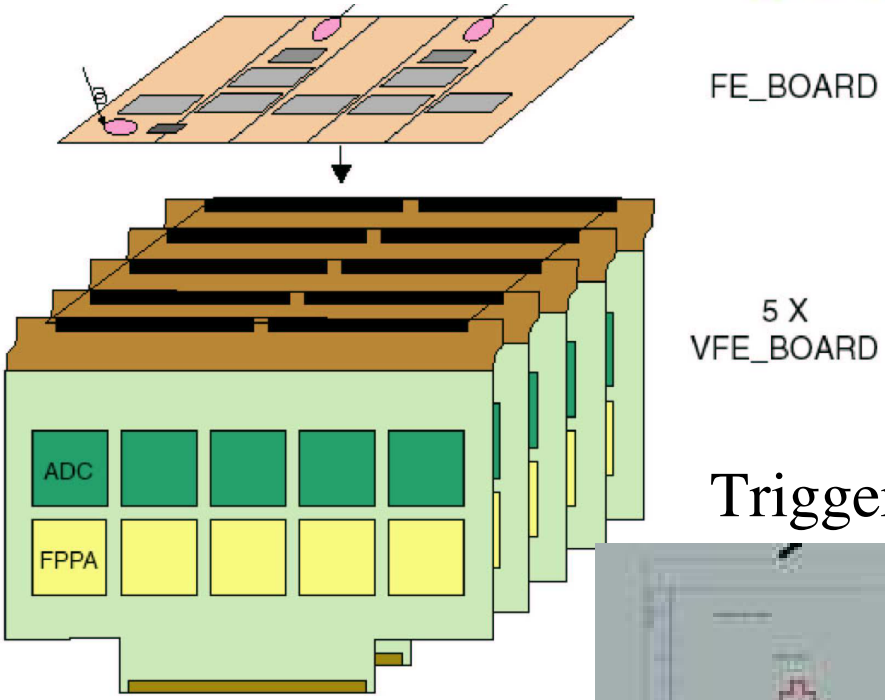
CMS ECAL Front-end Electronics



ECAL Front-end Boards

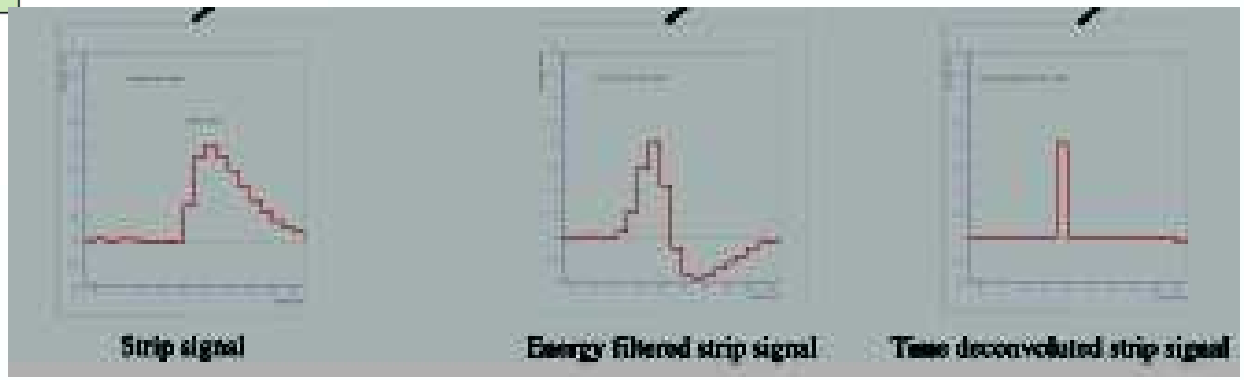
Trigger Primitive Generator

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



Serves one trigger tower
5x5 crystals

Trigger Primitives: BCID, Energy, FG

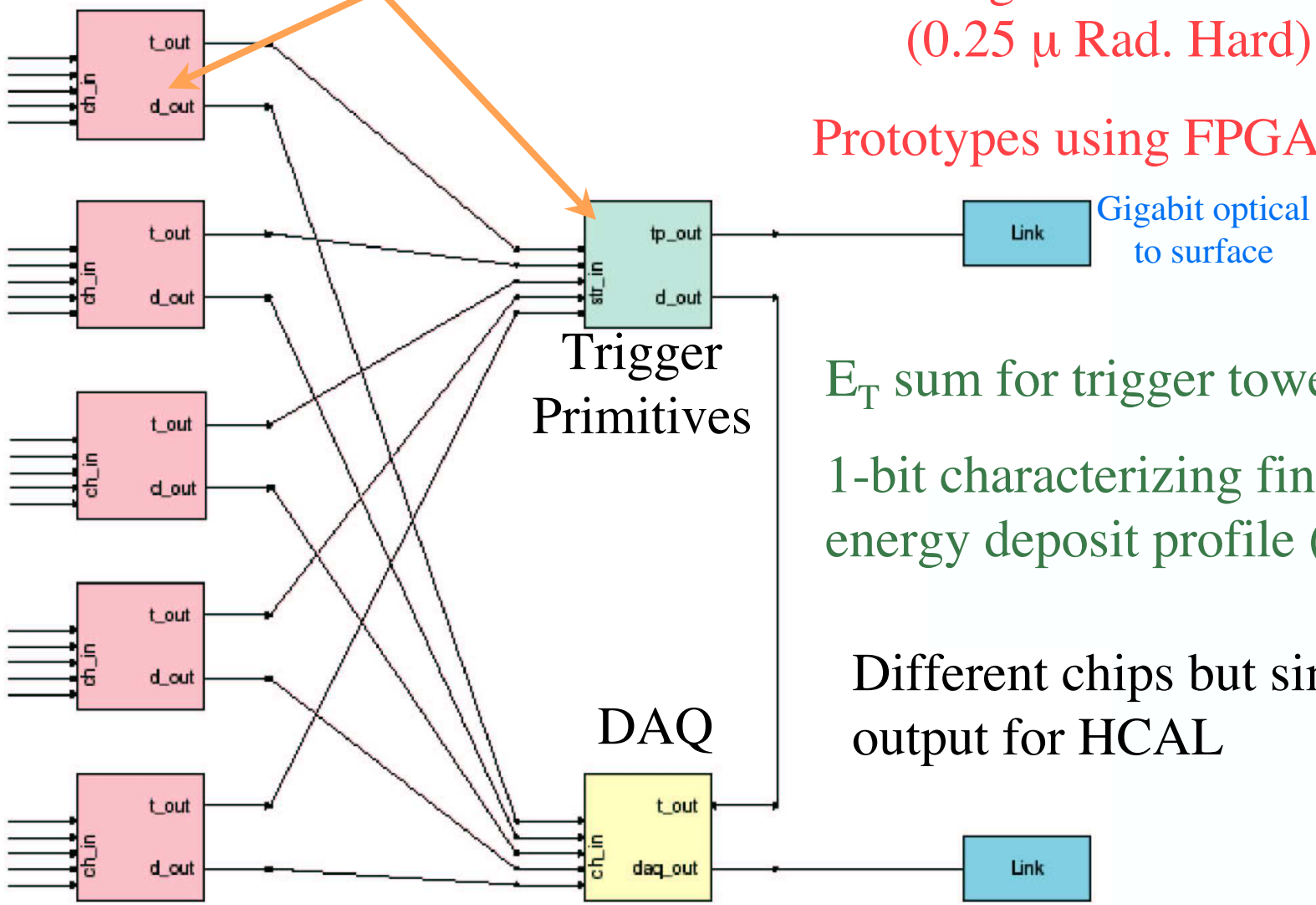


ECAL Frontend ASICs

One ASIC but two personalities

Final Algorithms in ASICs
(0.25 μ Rad. Hard)

Prototypes using FPGAs

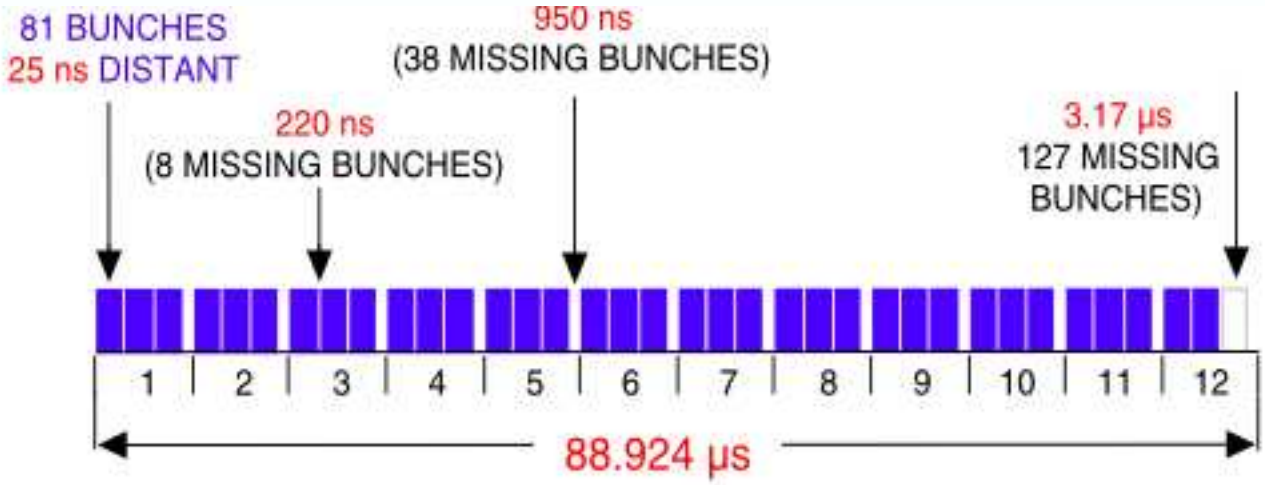


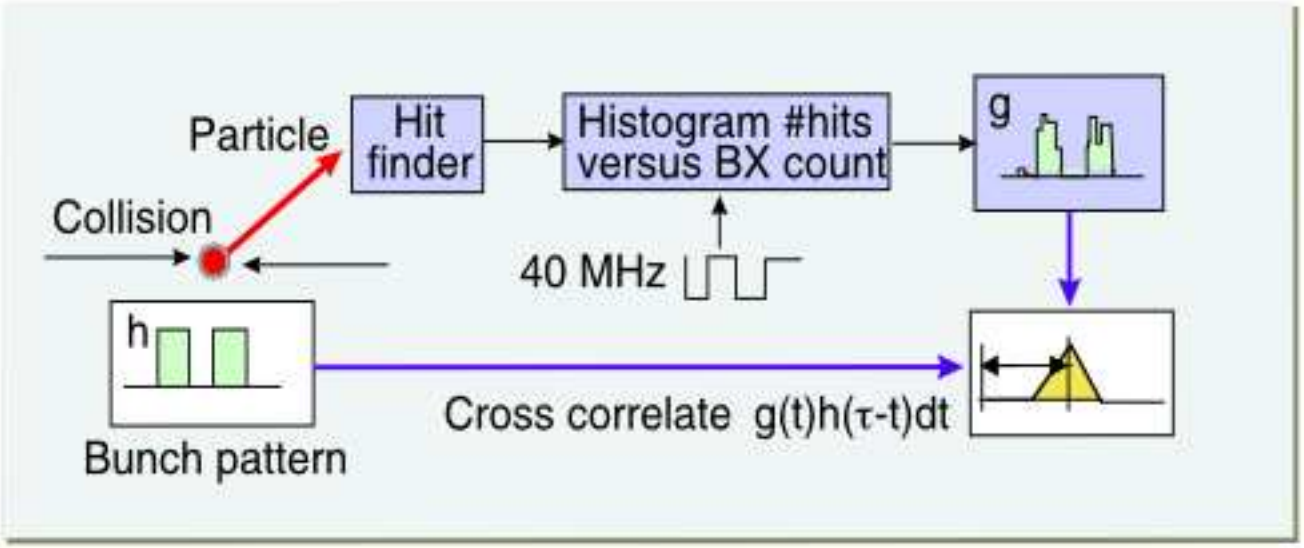
E_T sum for trigger tower

1-bit characterizing fine-grain energy deposit profile (FG)

Different chips but similar output for HCAL

Synchronization





CMS Electron/Photon Algorithm

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

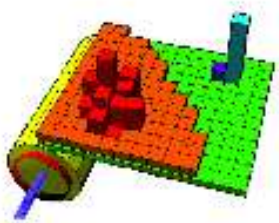
Isolation, Hadronic & EM — < 2 GeV

AND

One of (, , ,) < 1 GeV

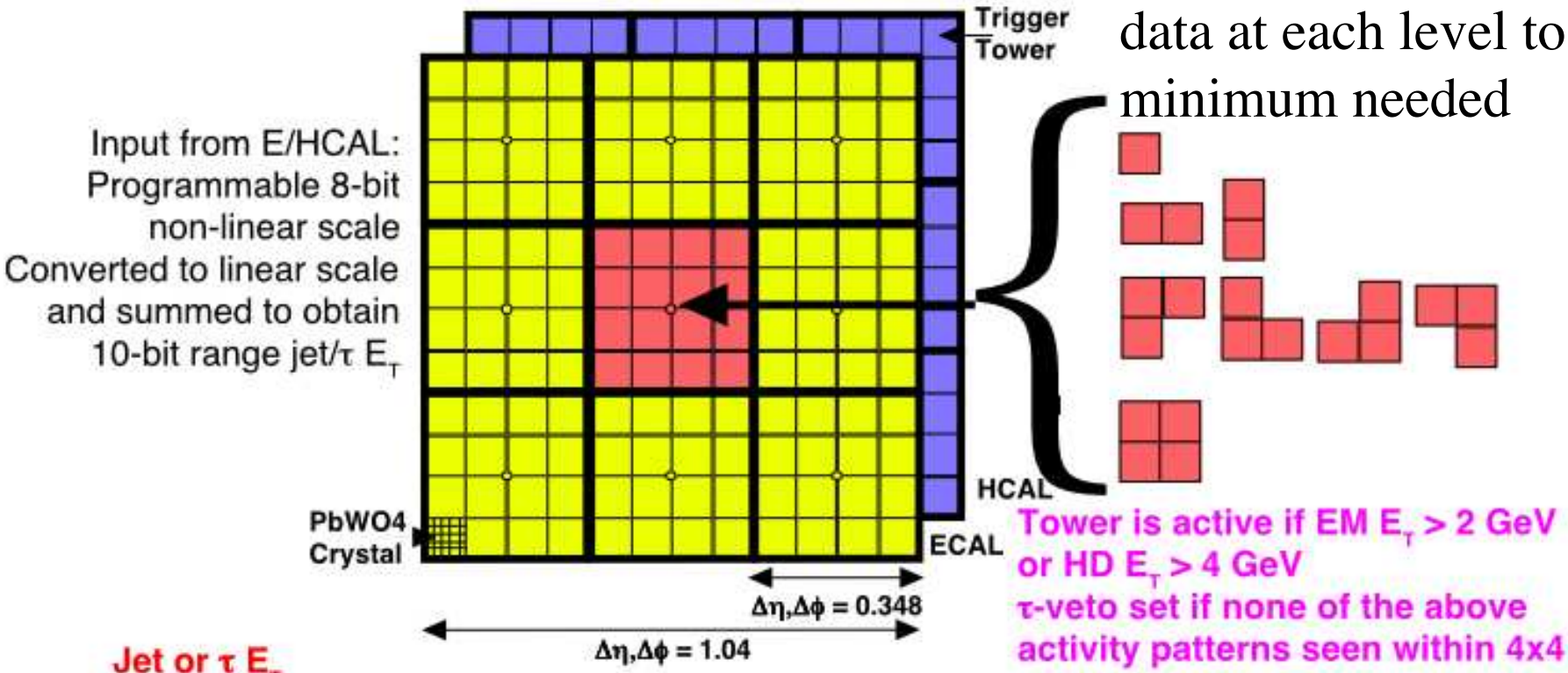
ELECTRON or PHOTON

Limit region of interest to minimum possible



τ / Jet Algorithm

Reduce amount of data at each level to minimum needed



Jet or τ E_T

- 12x12 trigger tower E_T sums in 4x4 region steps with central region > others
- Larger trigger towers in HF but ~ same jet region size, 1.5 η x 1.0 φ

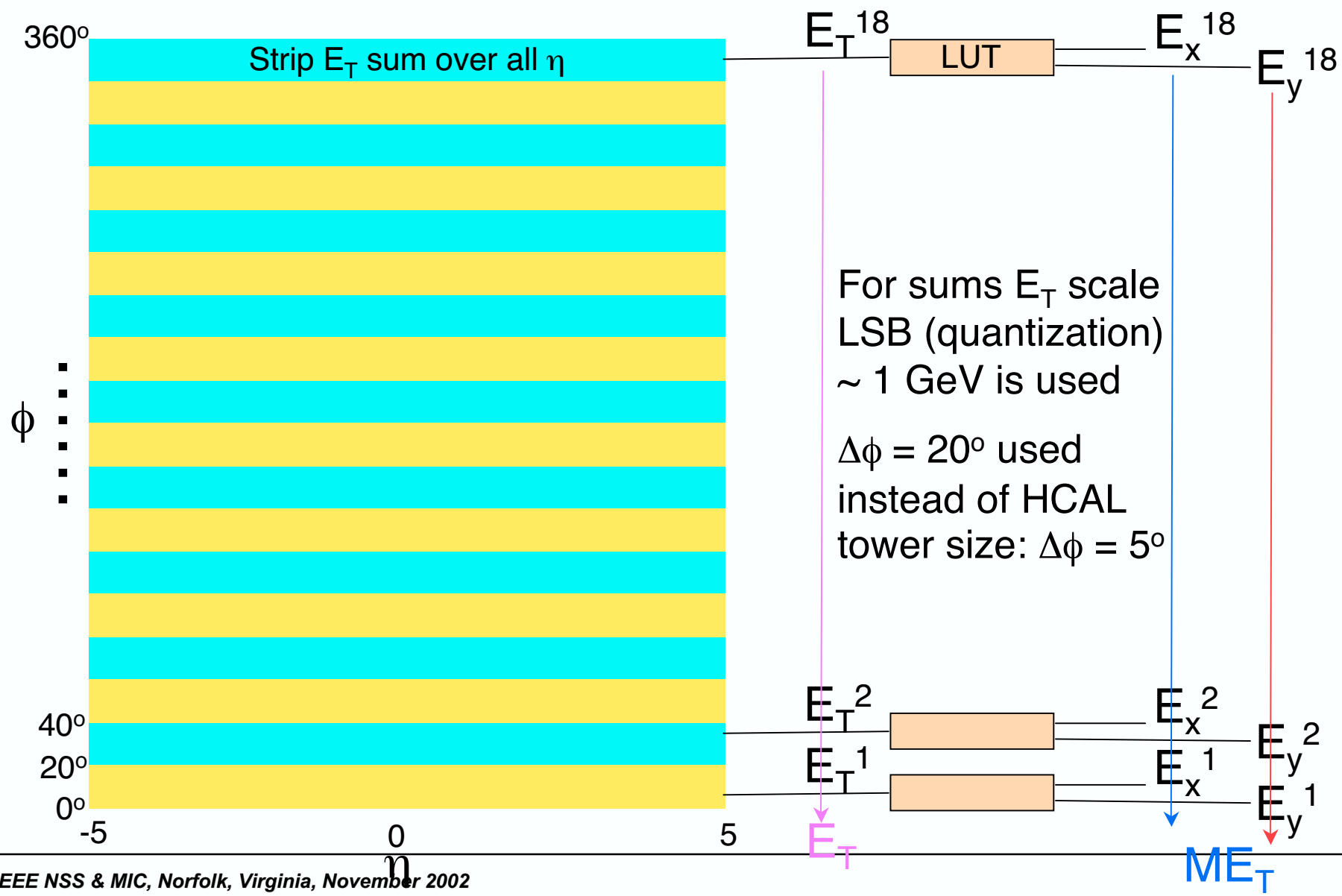
τ algorithm (isolated narrow energy deposits), within -2.5 < η < 2.5

- Redefine jet as τ jet if none of the nine 4x4 region τ-veto bits are on

Output

- Top 4 τ-jets and top 4 jets in central rapidity, and top 4 jets in forward rapidity

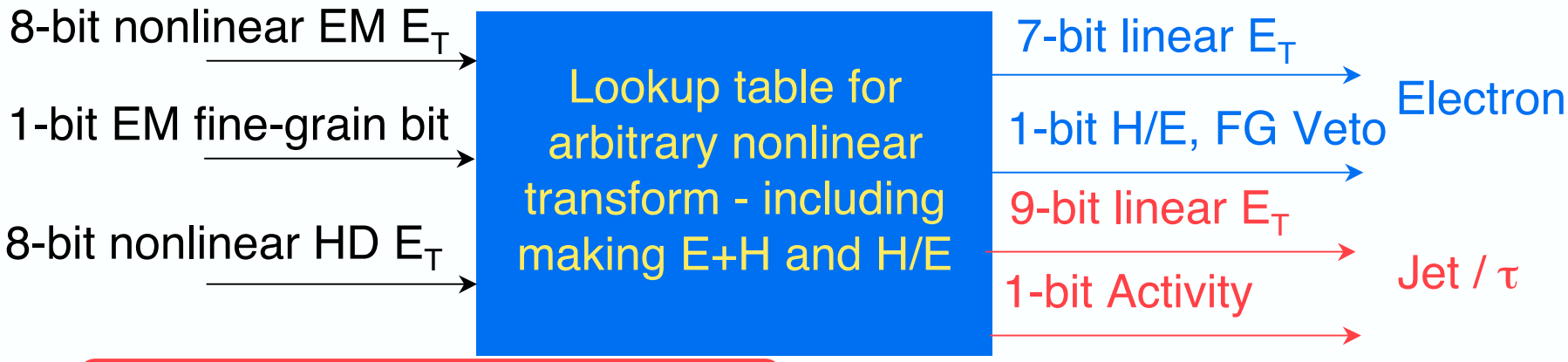
Missing / Total E_T Algorithm



For sums E_T scale LSB (quantization) ~ 1 GeV is used

$\Delta\phi = 20^o$ used instead of HCAL tower size: $\Delta\phi = 5^o$

CMS Tower Level Memory LUT



Fully programmable LUT, Current default values:

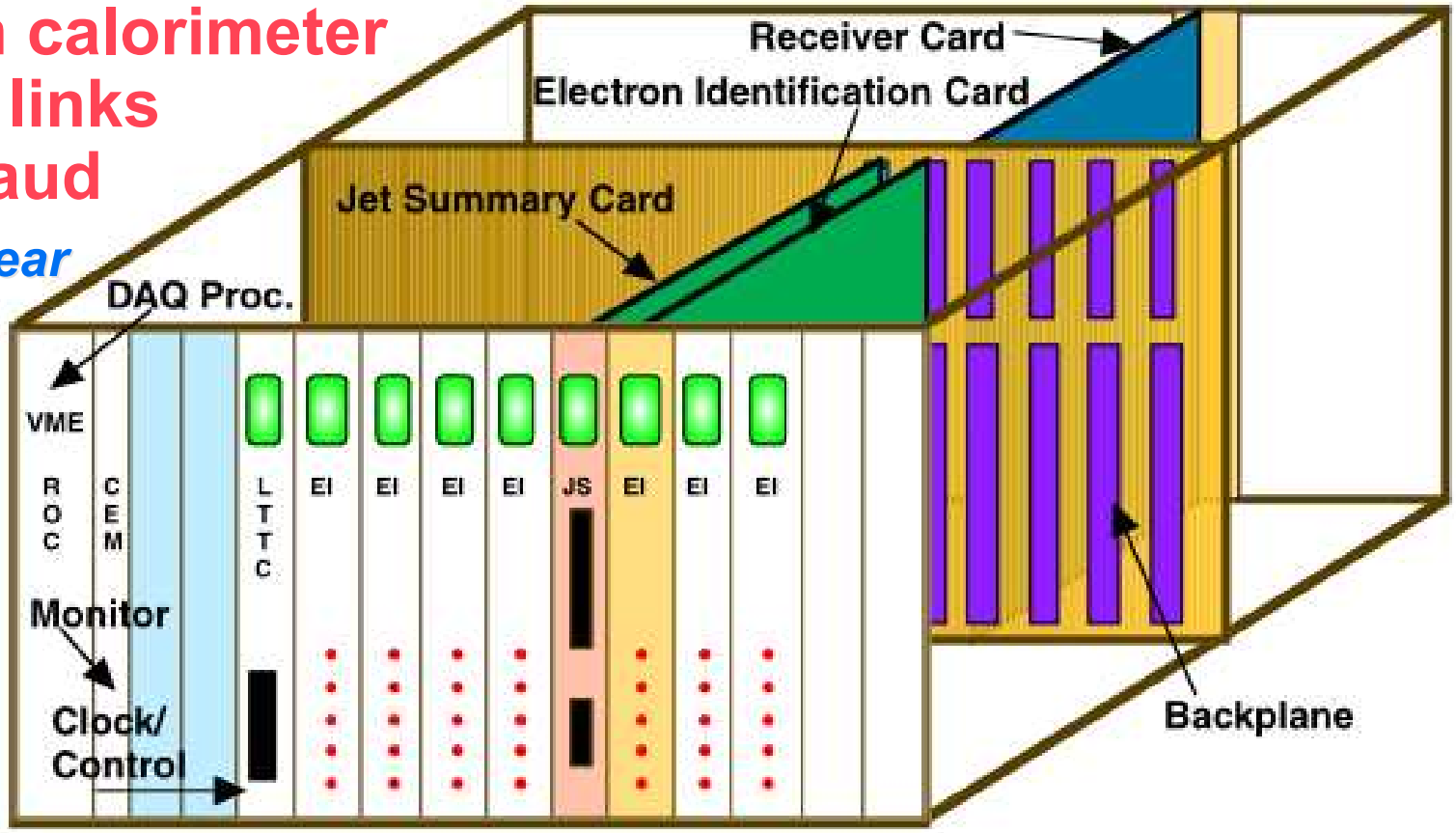
- **Electron scale: 0.5 GeV LSB, E^{max}=63.5 GeV**
- **Veto: OR of fine-grain veto and H / E < 5%**
- **Jet / τ scale (E+H): 1.0 GeV LSB, E^{max}=511 GeV**
  - **Jet energy (12x12 tower sum), E^{max}=1 TeV**
- **Activity level for τ pattern: E > 2 GeV, H > 4 GeV**

CMS Calorimeter Trigger Crate

Data from calorimeter FE on Cu links @ 1.2 Gbaud

- ***Into 126* rear Receiver Cards***
- ***Prototype tested w/ ASICs***

Backplane links fix the algorithm

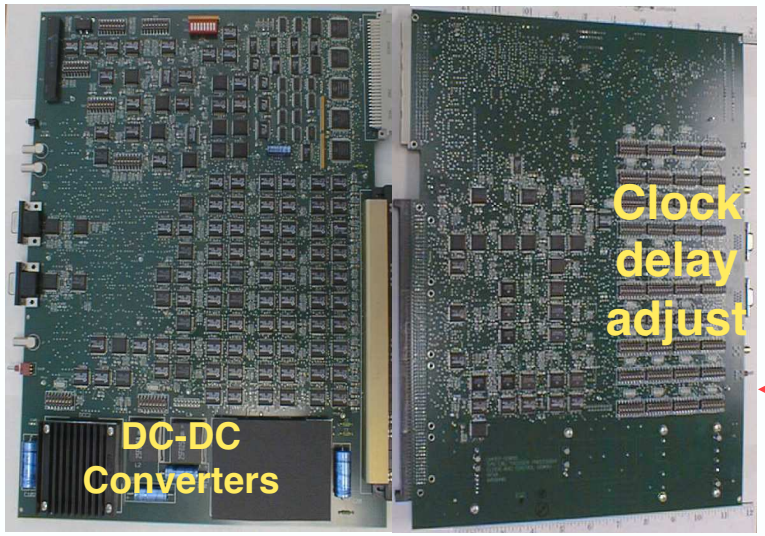


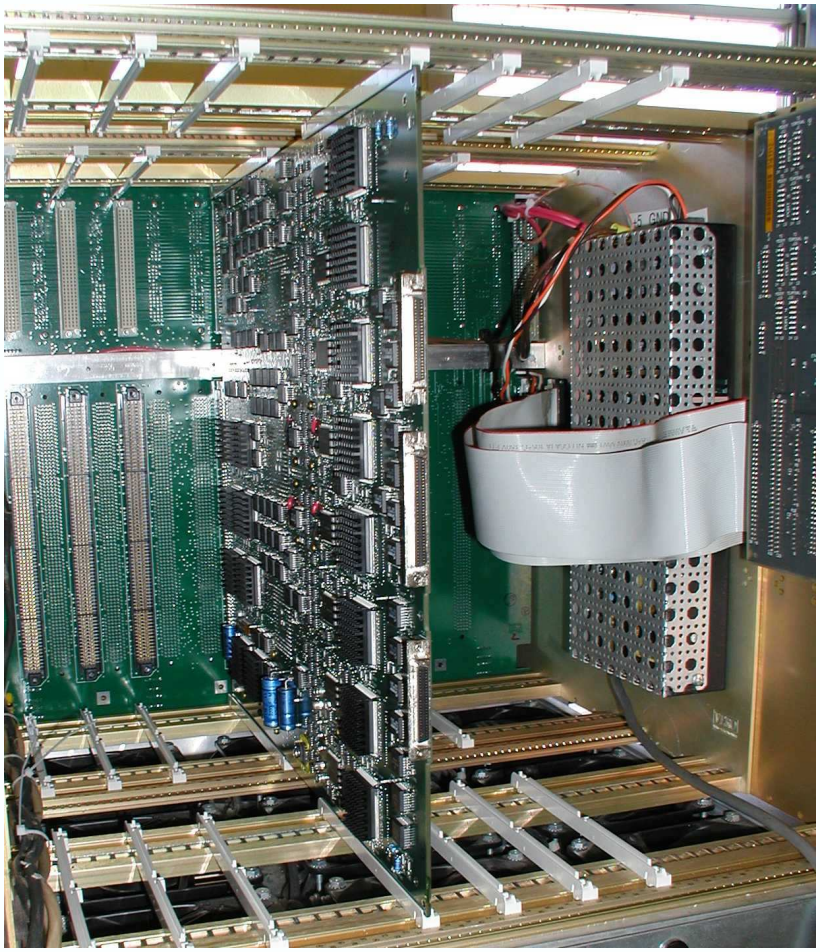
160 MHz point to point backplane (prototype tested)

- **18 Clock&Control (prototype tested), 126 Electron ID (prototype tested), 18 Jet/Summary Cards -- all cards operate @ 160 MHz**
- **Use 5 Custom Gate-Array 160 MHz GaAs Vitesse Digital ASICs**
  - Phase, Adder, Boundary Scan, Electron Isolation, Sort (manufactured)

*Spares not included**

CMS Regional Calorimeter Trigger Prototypes

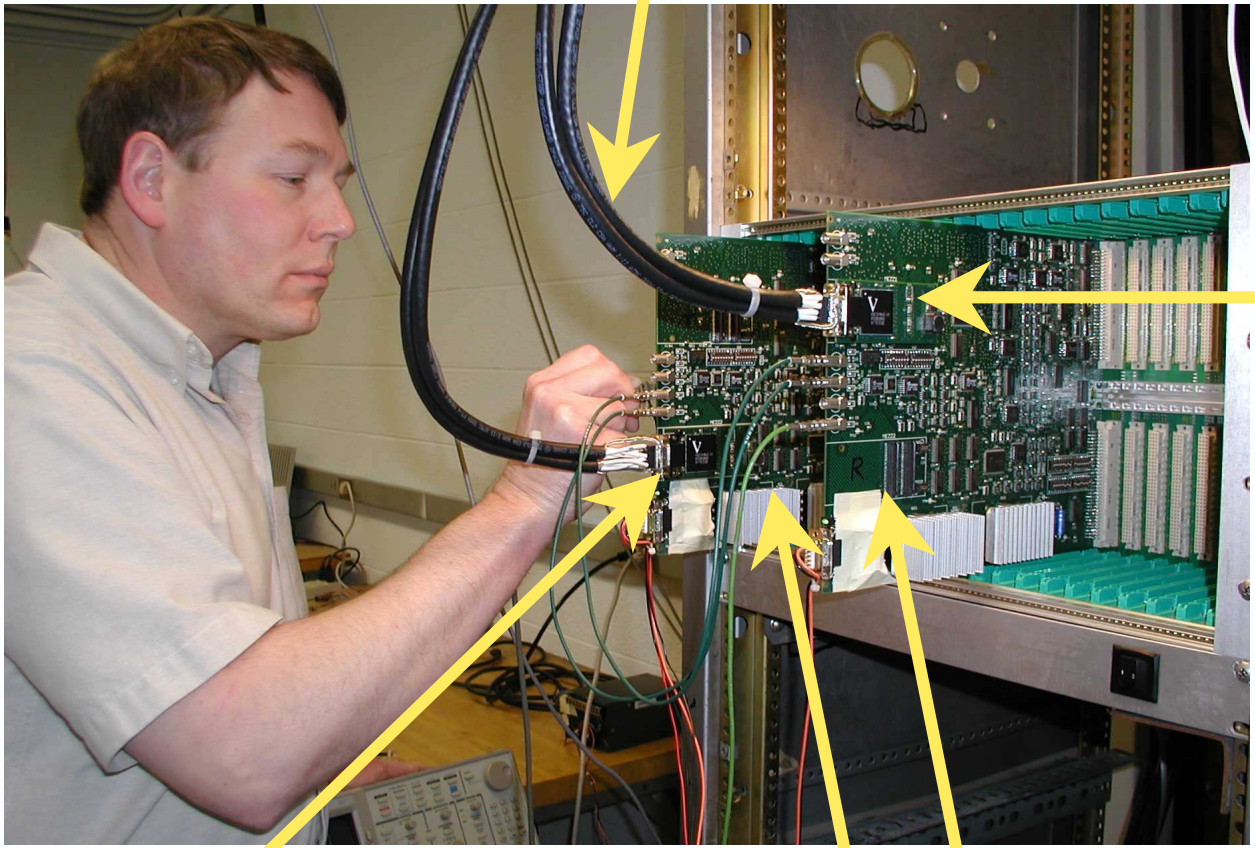




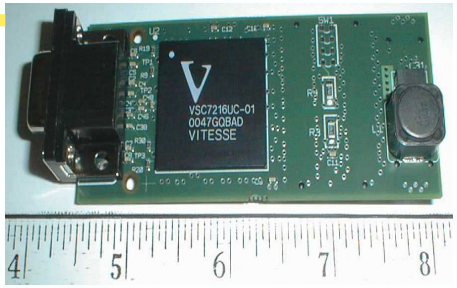
Clock and Control Card
Fans out 160 MHz clock & adjusts phase to all boards

4 x 1.2 GB/s Copper Links

20 m 22 AWG Copper Cable, VGA Connector



Receiver mezzanine card

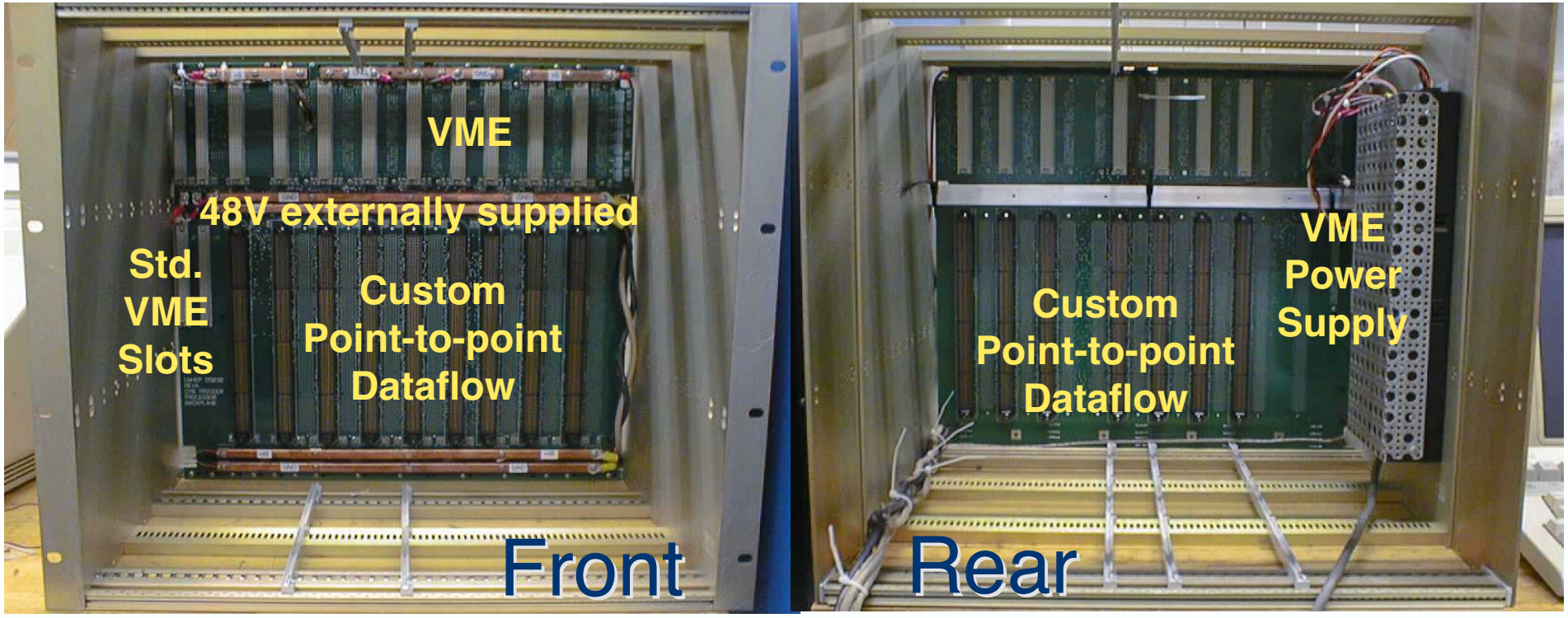


Results:
Bit Error rate < 10^{-15}

Test Transmit mezzanine card

Serial Link Test Cards

Crate & Backplane



160 MHz with 0.4 Tbit/sec dataflow

- Initial tests indicate good signal quality

Designed to incorporate algorithm changes

- New Non-Isolated Electron, Tau & Jet Triggers

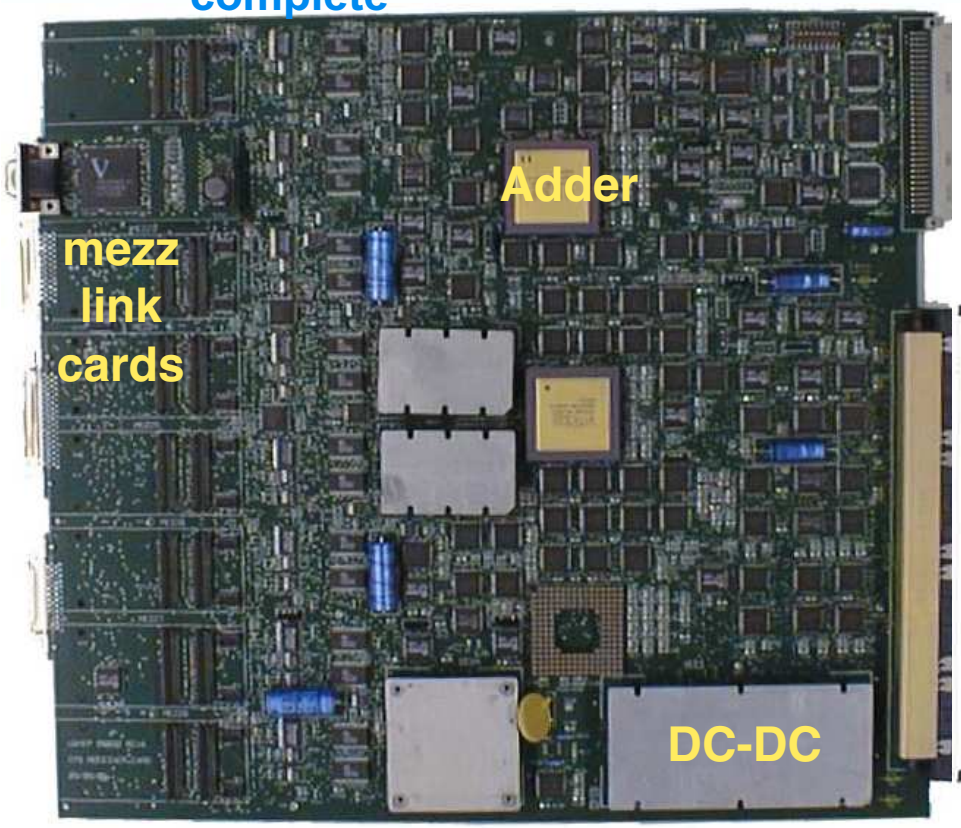
Many data paths checked manually and with JTAG

- Note: we only have one RC and one EIDC for testing
- Plan: one complete fully tested crate for slice test

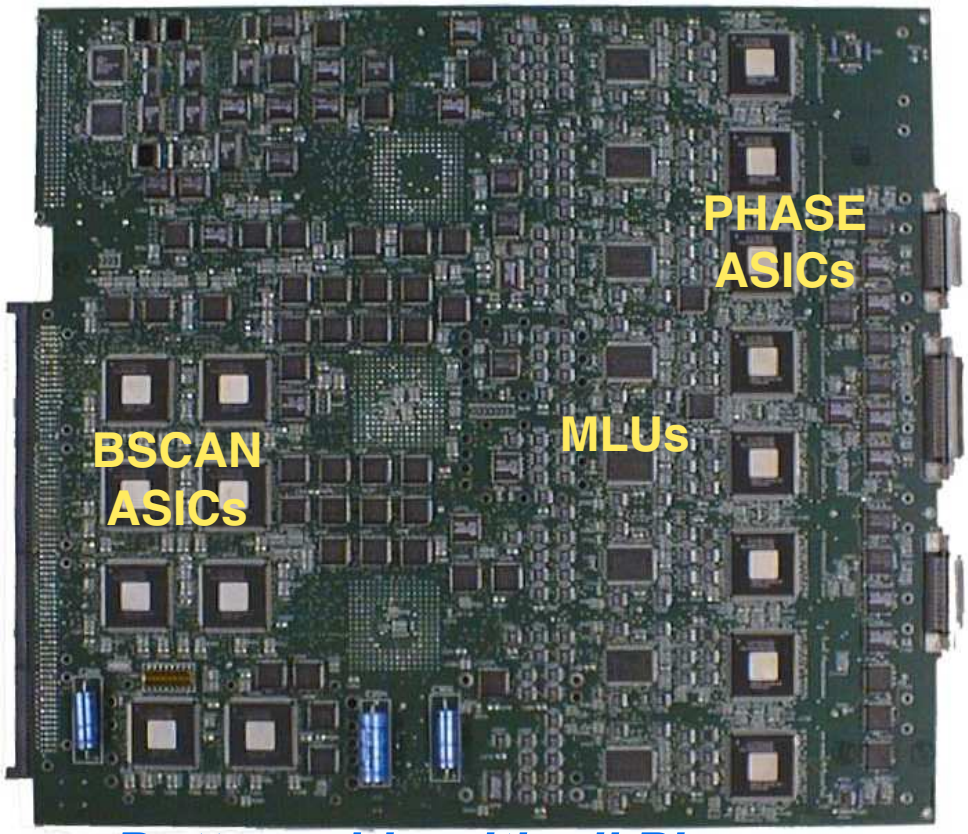
CMS Receiver Card

Full featured final prototype board is in test - ASIC testing successful. Continue to test all data paths - develop software etc. - FY2003 program

- **Phase ASIC validated, BSCAN ASIC validated - all RC ASIC procurement now complete**



Top side with 1 of 8 mezzanine cards & 2 of 3 Adder ASICs

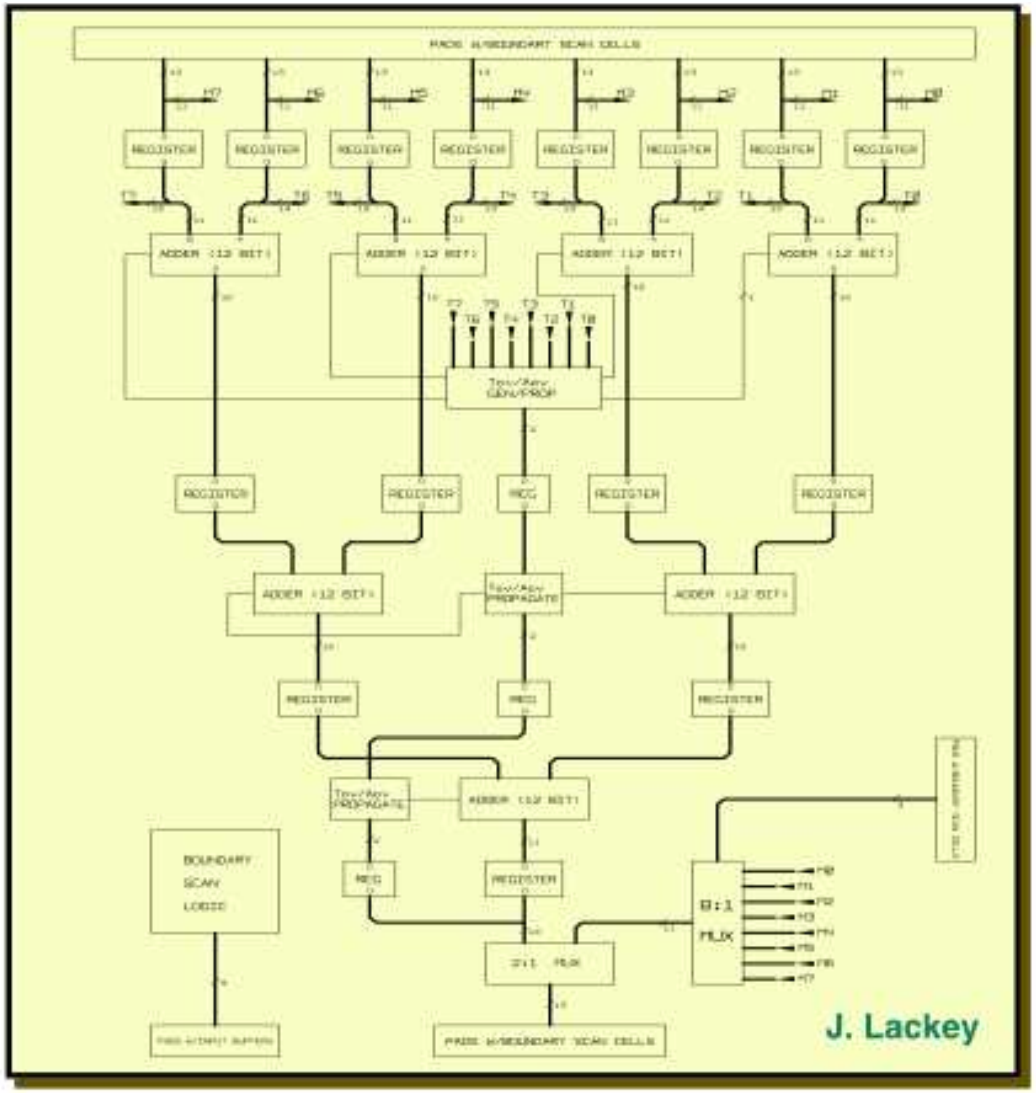


Bottom side with all Phase & Boundary Scan ASICs

CMS RCT : Adder ASIC

Vitesse 0.6μ H-GaAs Process: ECL I/O

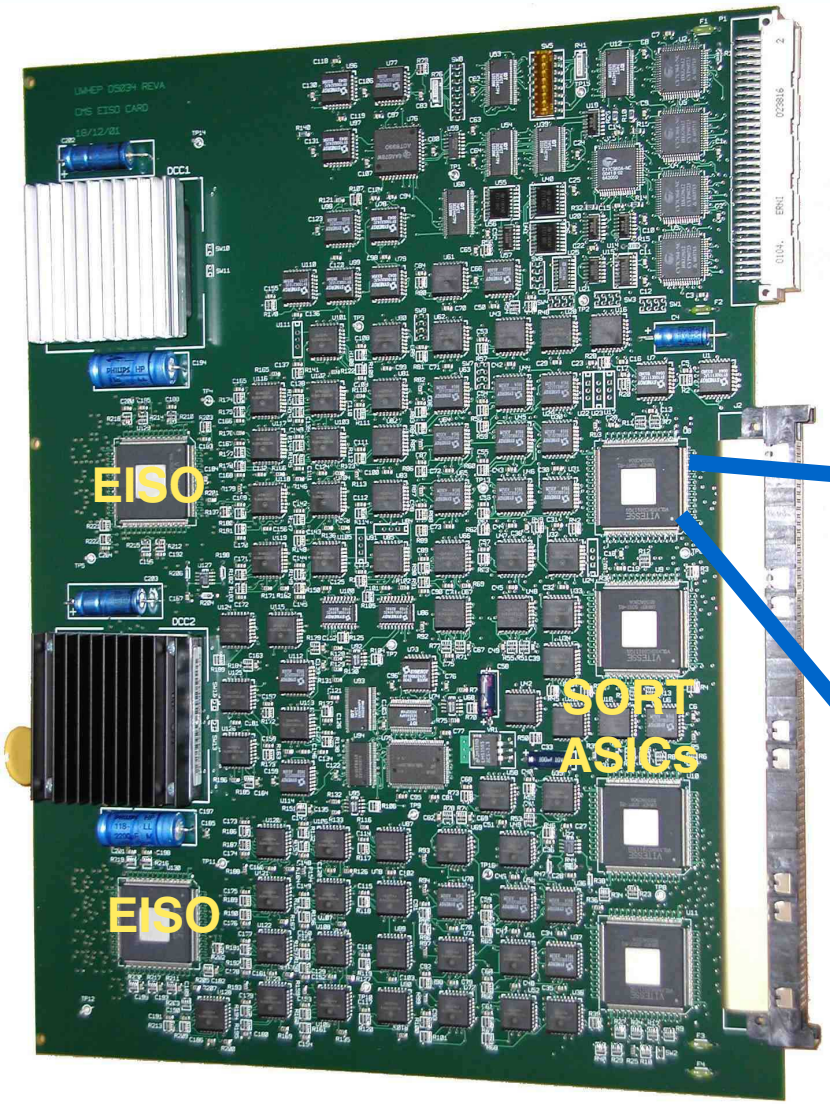
- 13 bits per operand x 8 operands
- Thirteen bit output
- Latency: 25 ns @ 160 MHz
- Full Boundary Scan
- ~11,000 cells
- 4 Watts
- Tested > 200 MHz
- Operated on RC
- Received full order



Key RCT technology

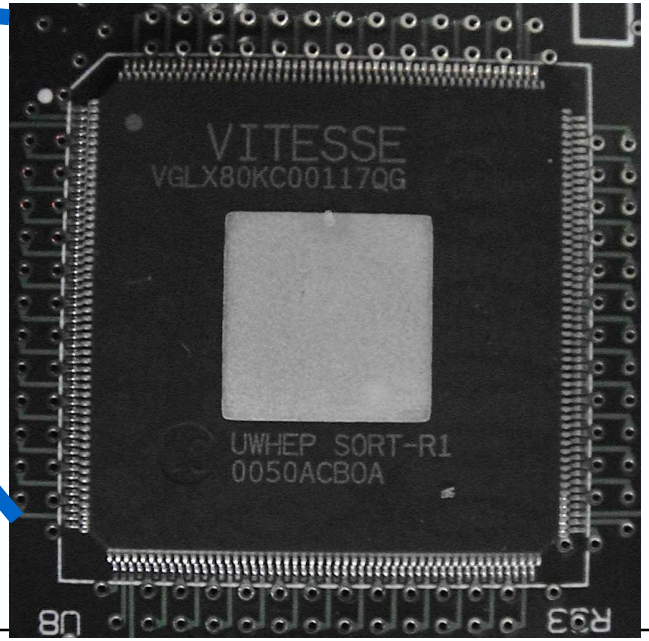
Fast ASICs - compact design

CMS Electron Isolation Card



Full featured final prototype board is finished & under test.

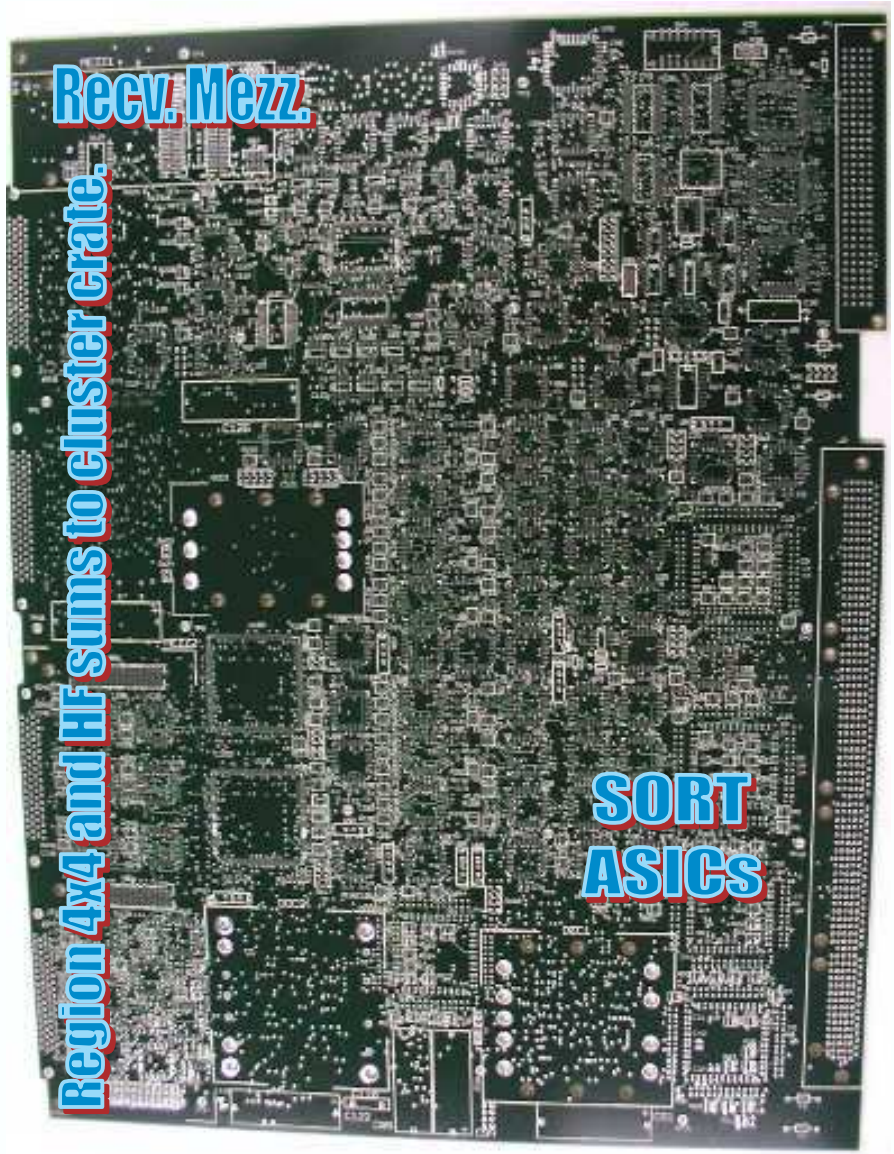
- Electron ID & Sort ASICs tested by Vitesse before delivery
- In house testing fully validated SORT ASIC & mostly validated EISO ASIC - neighbor data requires multiple cards.
- SORT ASIC procurement complete
- Detailed tests of all data paths: FY2003



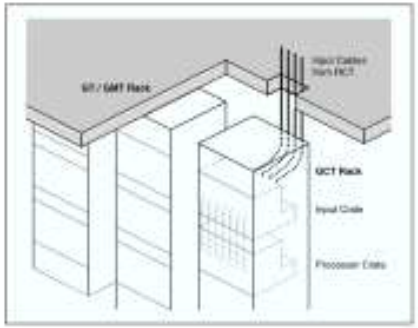
Jet-Summary Card

Being Assembled

- Electron/photon/muon info.
  - SORT ASICs to find top four electron/photons
  - Threshold for muon bits
  - To GCT
- **Region energies**
  - To cluster crate
- **Absorbs HF functionality**
  - Reuses Receiver Mezzanine Card
  - To cluster crate



CMS Global Calorimeter Trigger

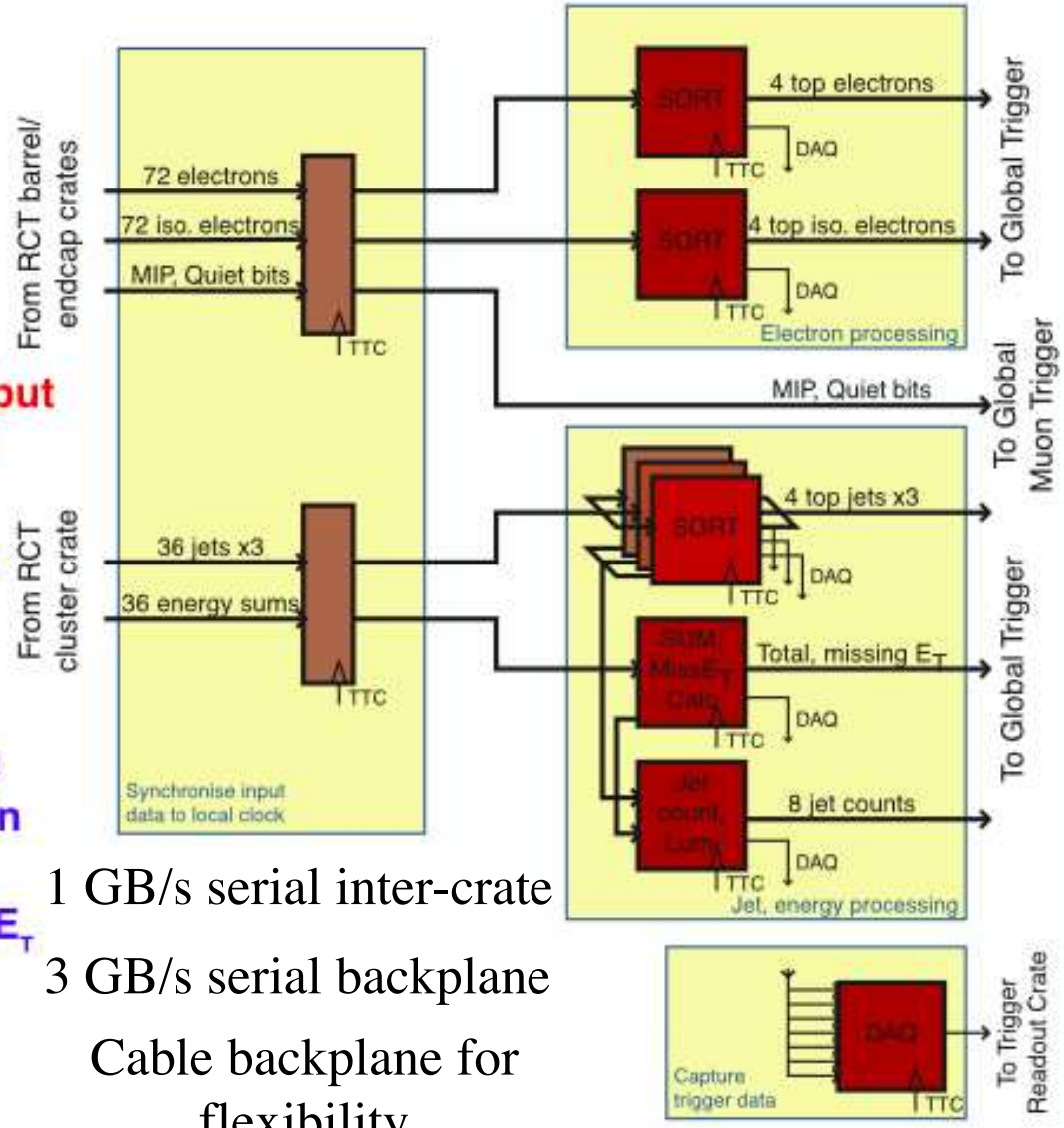


GCT Input Crate - Parallel 80 MHz input

- Receives data from all Regional Calorimeter Trigger crates
- Serializes data and stages them to Processor Module

GCT Processor Crate

- Sorts by E_T isolated and nonisolated electrons, taus, and central and forward jets to obtain top four of each type
- Calculates missing E_T and total E_T
- Makes jet counts and sums for luminosity monitoring



1 GB/s serial inter-crate

3 GB/s serial backplane

Cable backplane for flexibility

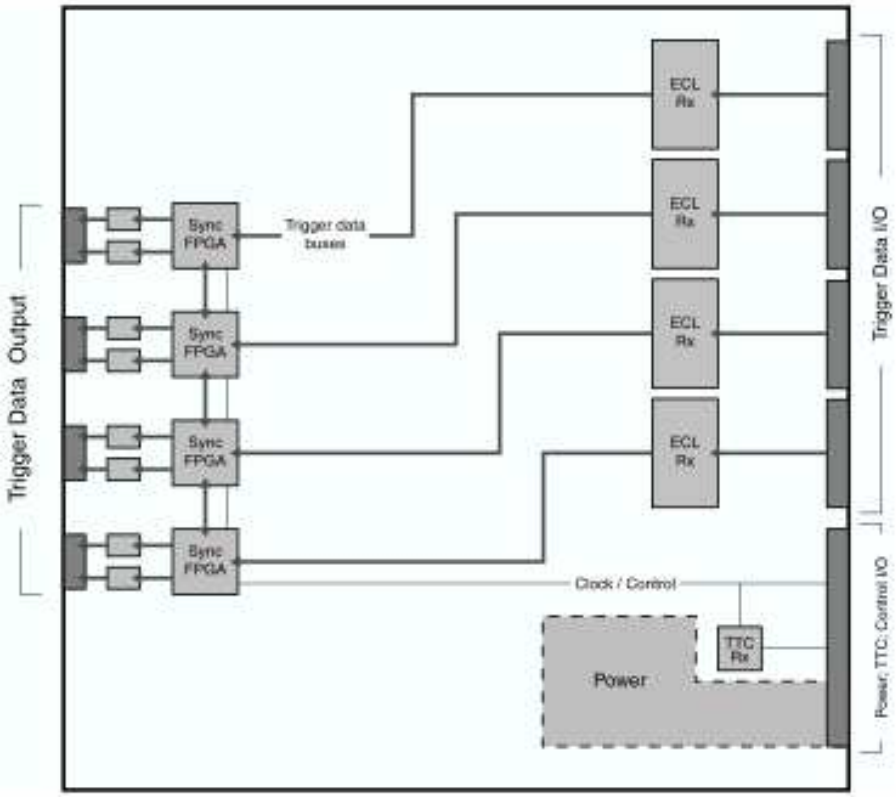
CMS Global Calorimeter Trigger

FPGA-based for maximum flexibility

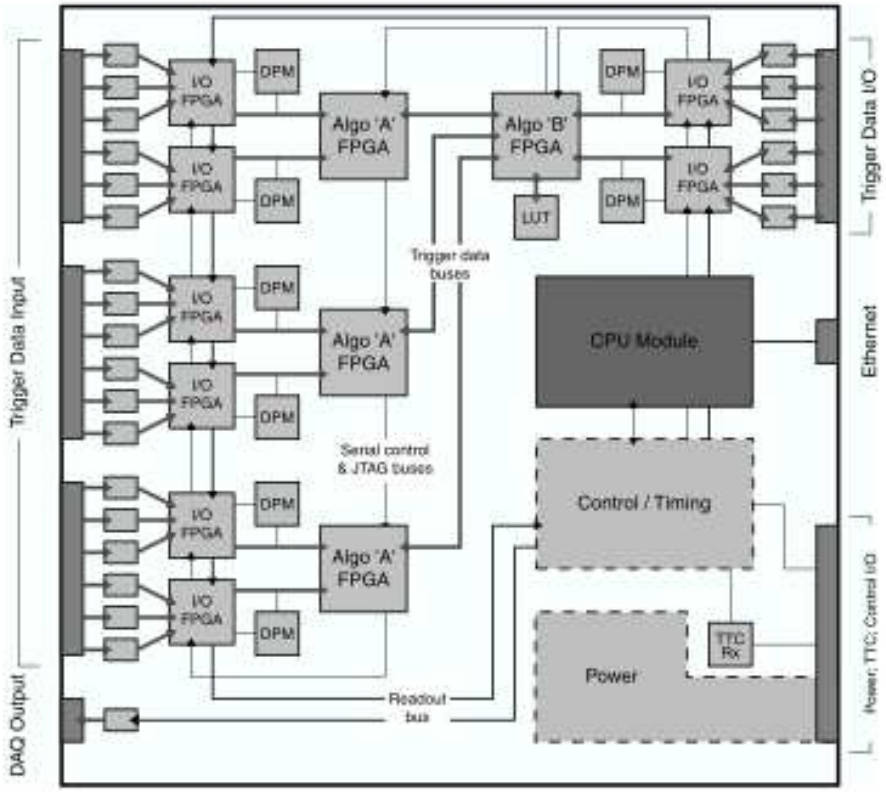
- Input modules in one crate, Processor Modules in the other

Generic: Common CMS, ATLAS

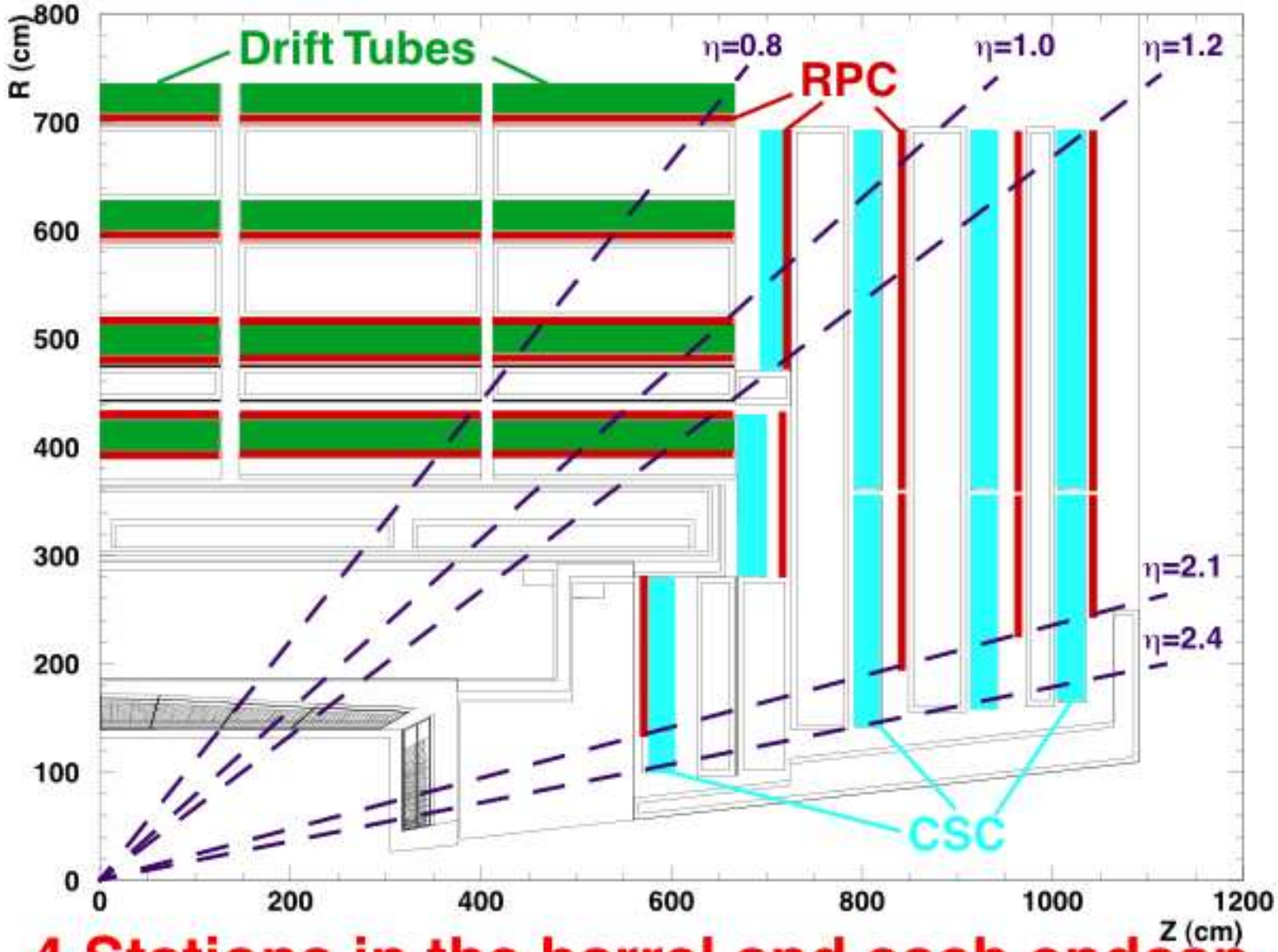
Input Module



Processor Module

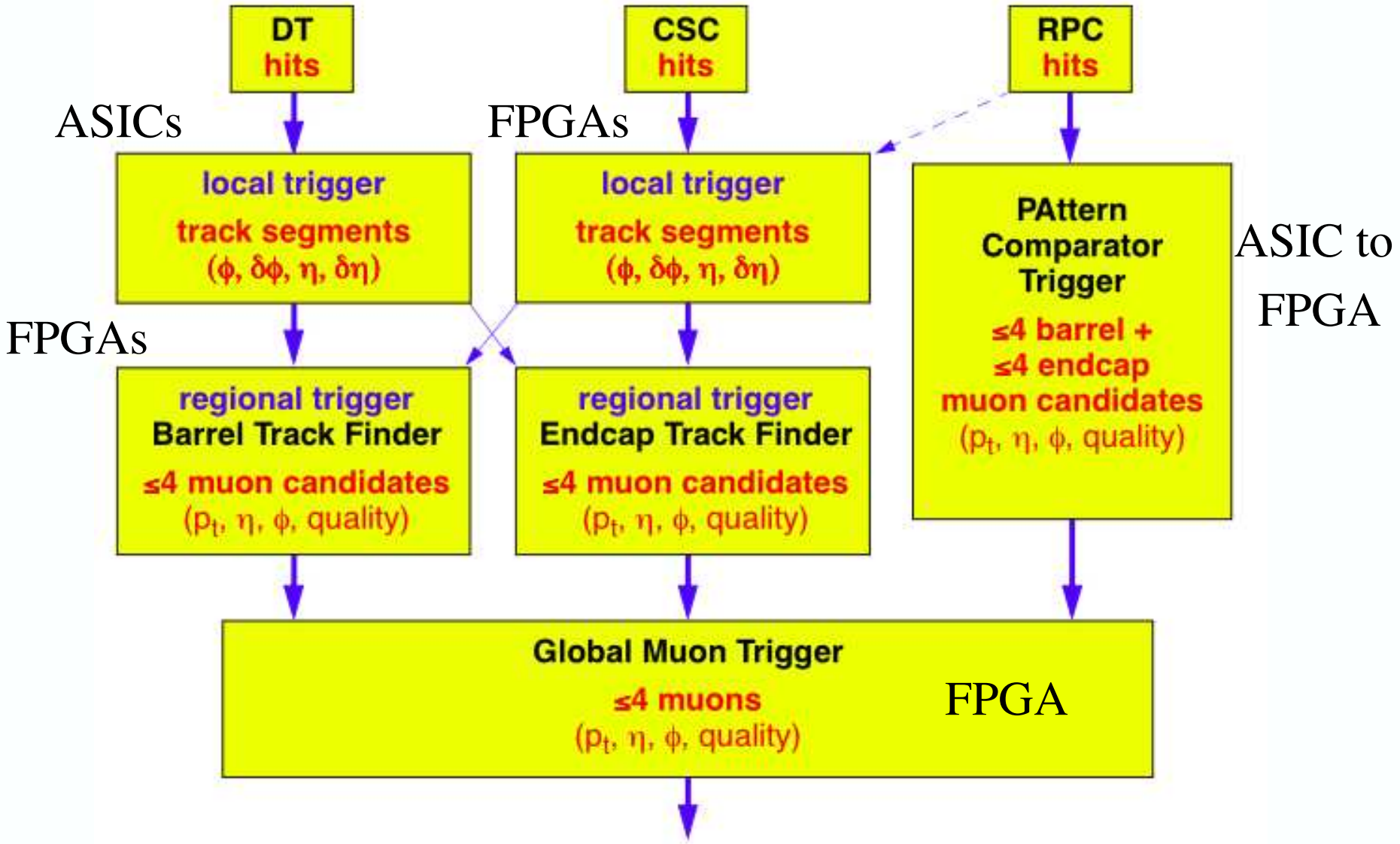


CMS Muon Detectors



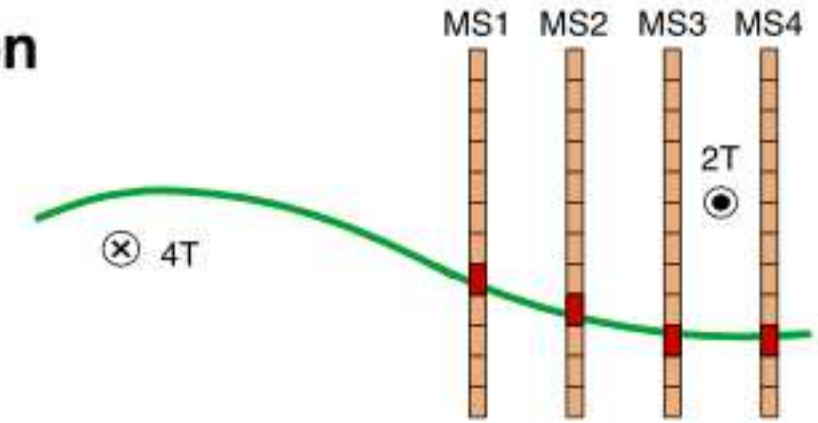
4 Stations in the barrel and each endcap

CMS Muon Overview



CMS Muon Trigger Primitives

RPC pattern recognition
- Pattern catalog
- Fast logic

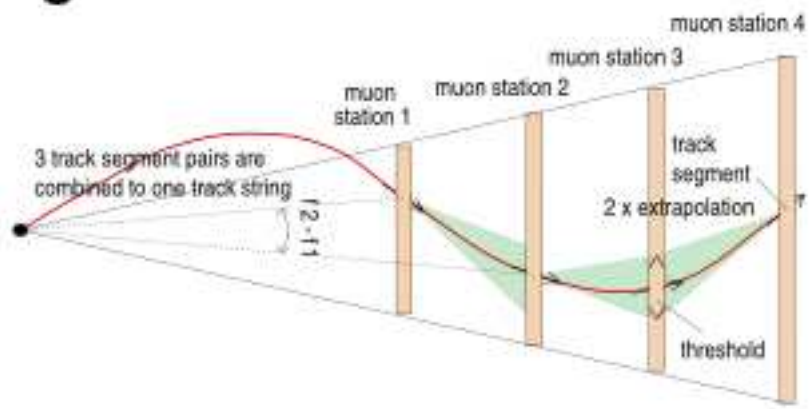


Memory to store patterns

Fast logic for matching

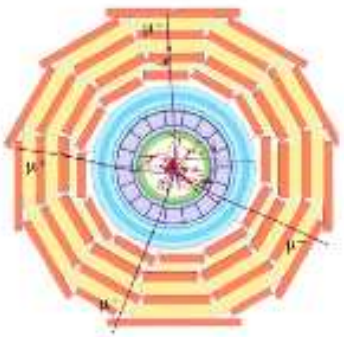
FPGAs are ideal

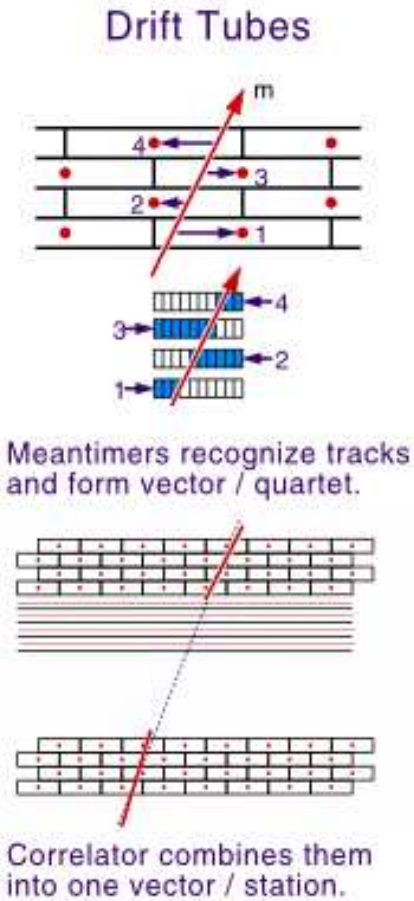
DT and CSC track finding:
- Finds hit/segments
- Combines vectors
- Formats a track
- Assigns p_t value



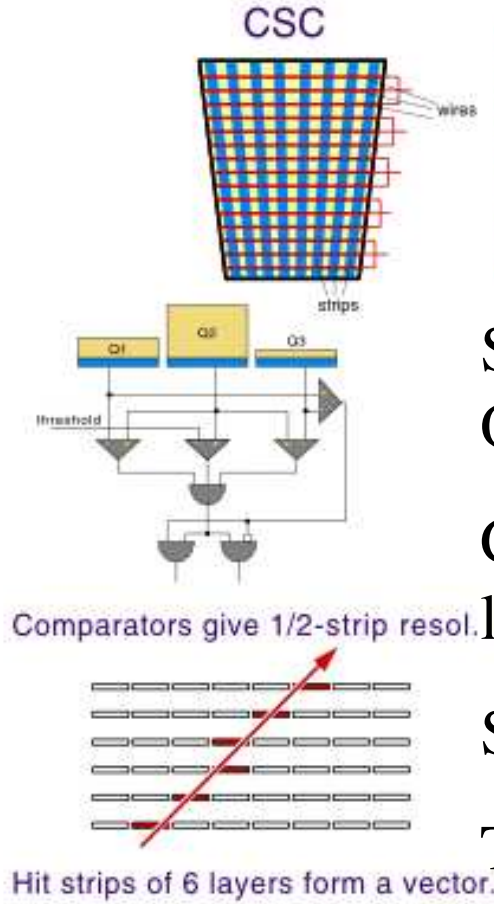
CMS Muon Trigger Track Finder

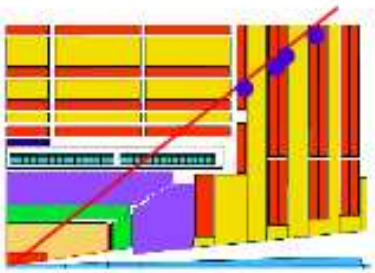
Drift Tubes (DT)





Cathod Strip Chambers (CSC)





Sort based on P_T, Quality - keep loc.

Combine at next level - match

Sort again - Isolate?

Top 4 highest P_T and quality muons with location coord.

Match with RPC

Improve efficiency and quality

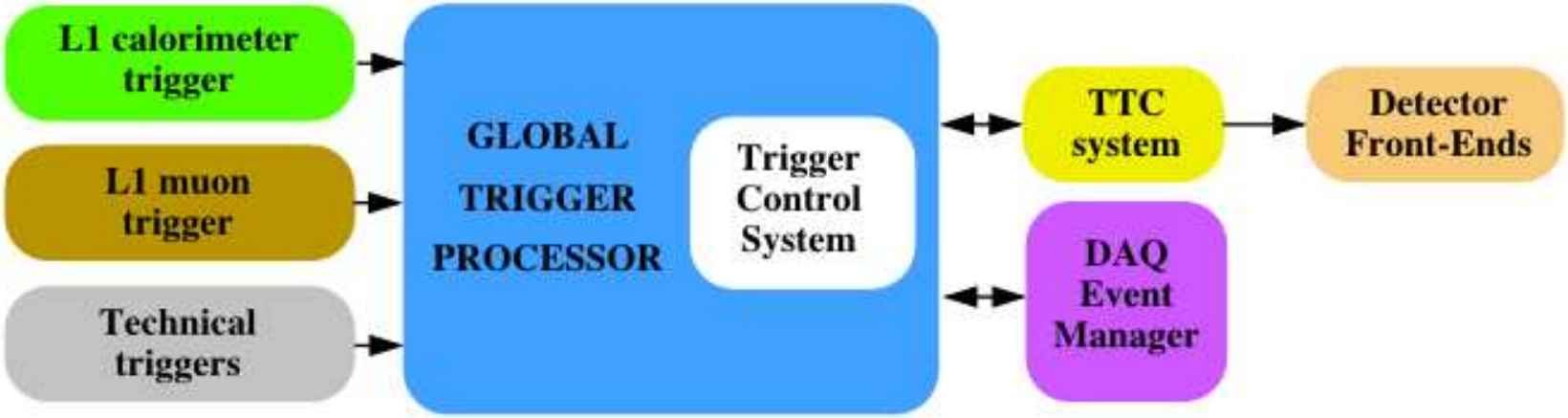
CMS Global Trigger

Input:

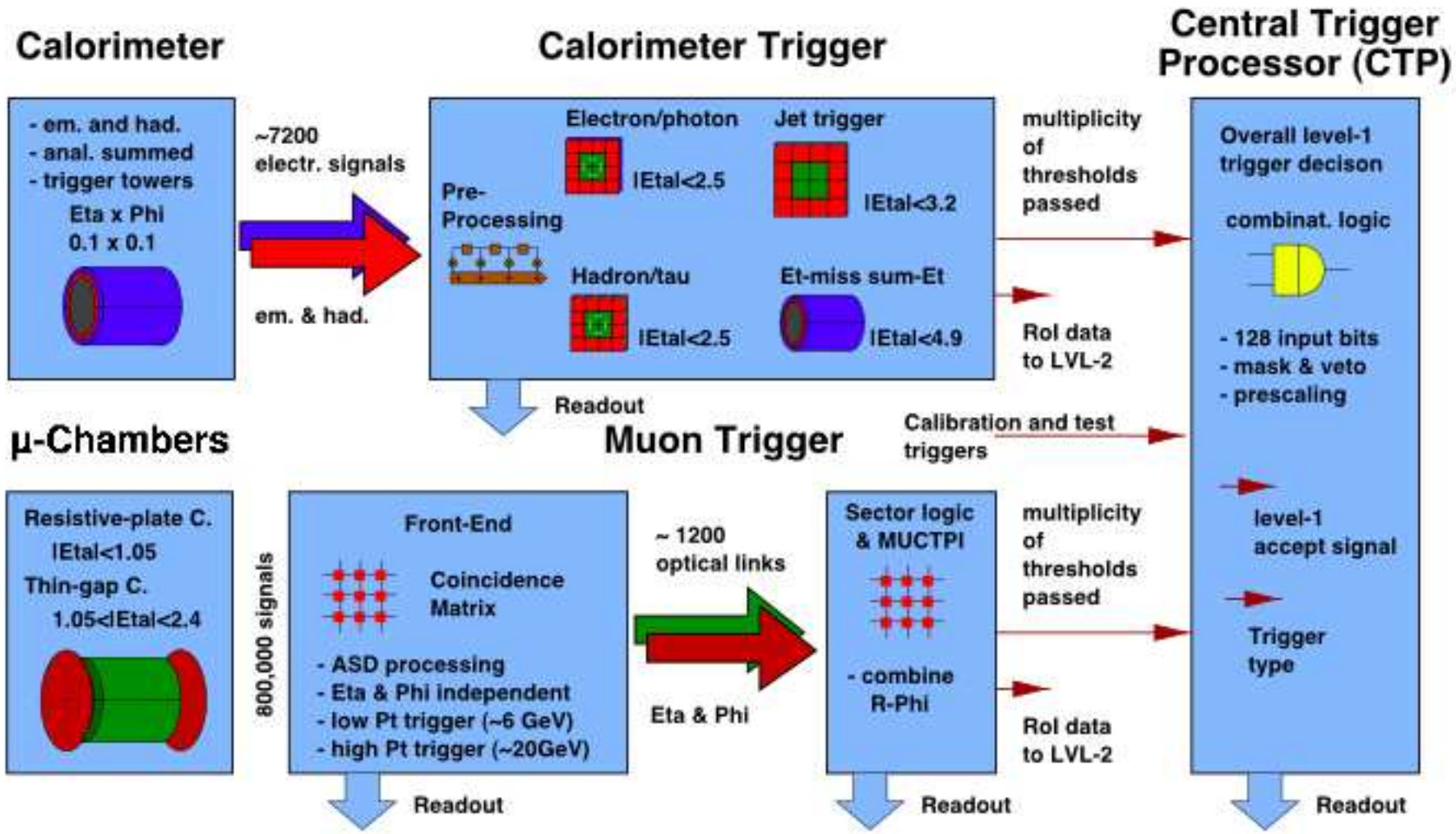
- Jets: 4 Central, 4 Forward, 4 Tau-tagged, & Multiplicities
- Electrons: 4 Isolated, 4 Non-isolated
- 4 Muons (from 8 RPC, 4 DT & 4 CSC w/P_t & quality)
  - All above include location in η and ϕ
- Missing E_T & Total E_T

Output

- L1 Accept from combinations & proximity of above

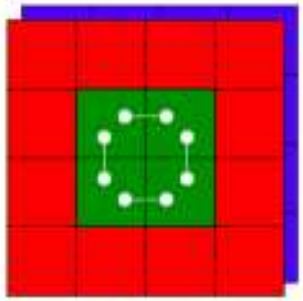


Trigger Flow : ATLAS Example

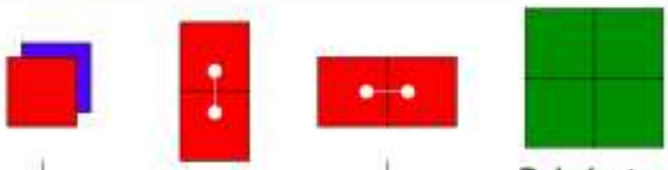


ATLAS Calorimeter Algorithms I

Electron/photon trigger

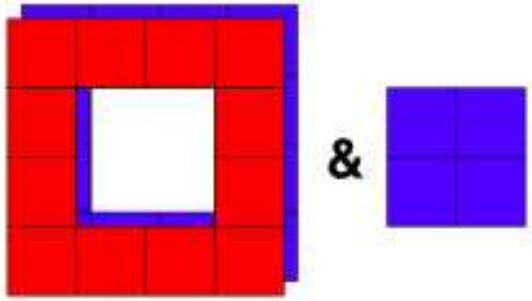


4 x 4 window
0.1 x 0.1 elements
step by 1 element
|Eta|<2.5

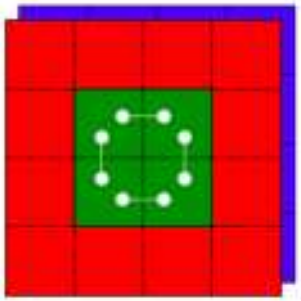


RoI-cluster
Et-measure-cluster
trigger-element, em. and had. separate

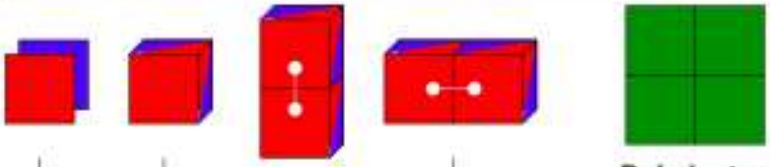
Isolation:



Hadron/tau trigger

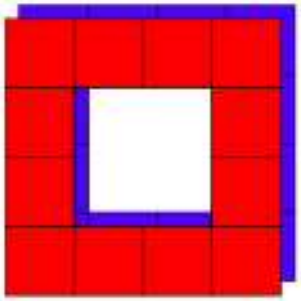


4 x 4 window
0.1 x 0.1 elements
step by 1 element
|Eta|<2.5



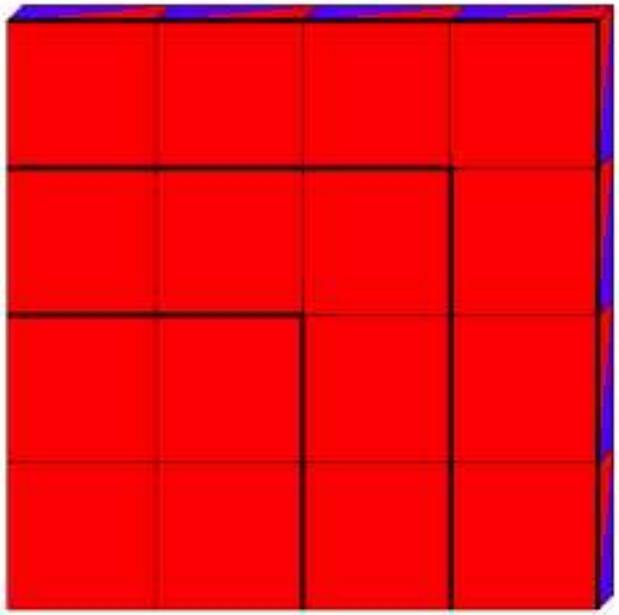
RoI-cluster
Et-measure-cluster
trigger-element, em. and had. summed
trigger-element, em. and had. separate

Isolation:

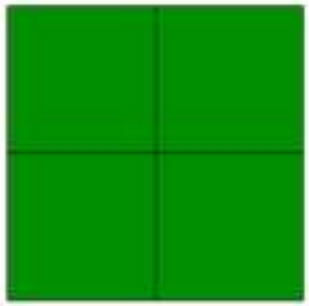


ATLAS Calorimeter Algorithms II

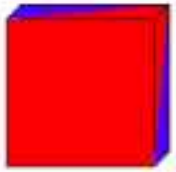
Jet trigger



programmable
4 x 4 or 3 x 3 or
2 x 2 window
0.2 x 0.2 jet-elements
step by 1 jet-element
|Eta| < 3.2

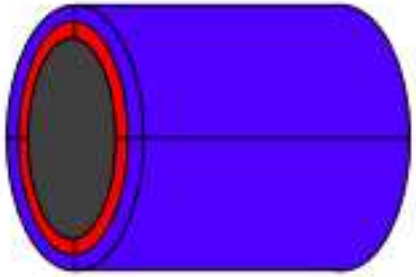


RoI-cluster



Jet-element, em. + had. summed

Et-miss / sum-Et trigger



sum of Et
sum of Ex and Ey
|Eta| < 4.9

Calorimeter Trigger Overview : ATLAS

Trigger Primitives

- Analog sum

Receiver

- Quality cable plant

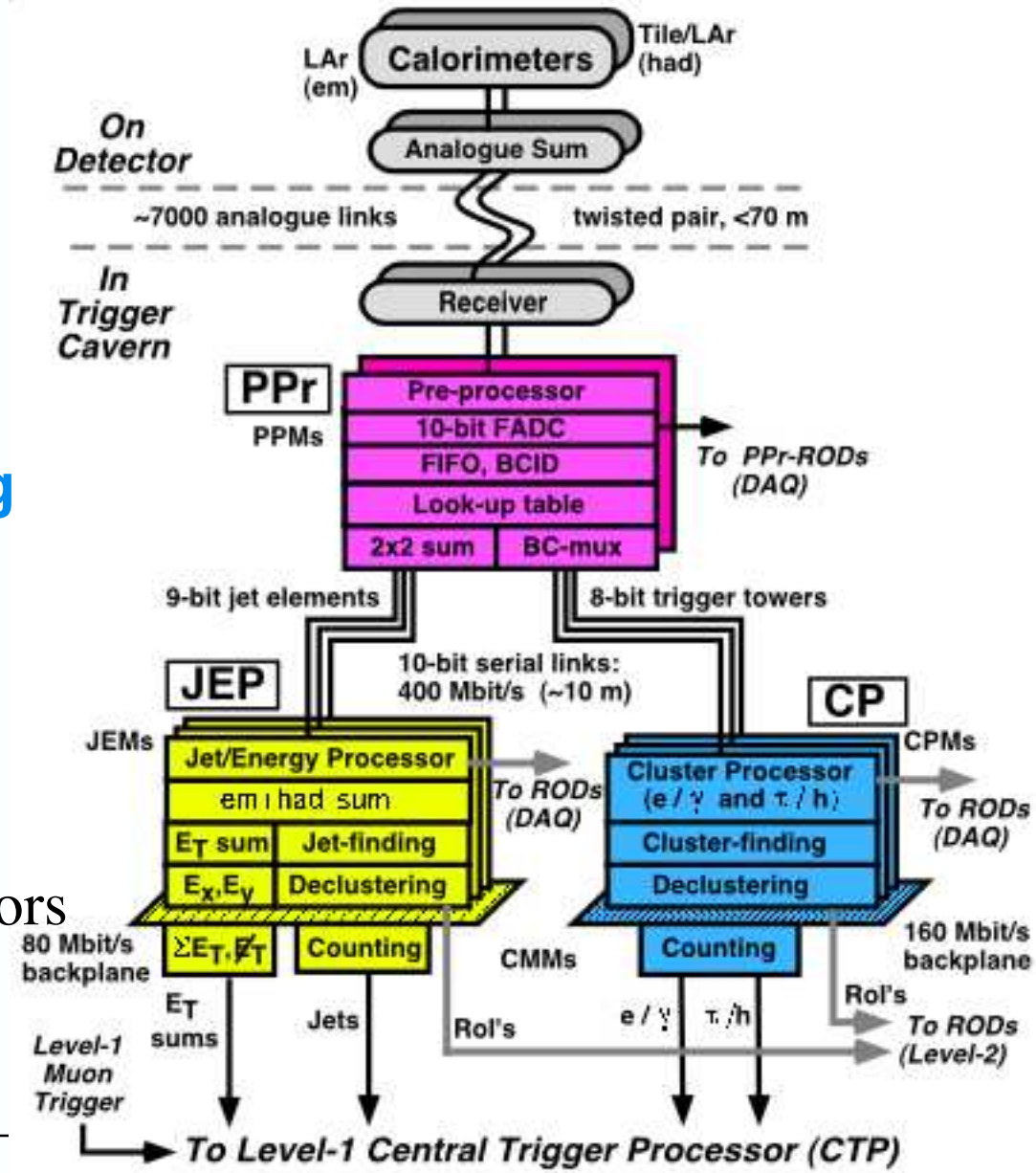
Preprocessor

- ADC, Bunch-crossing
- LUT, sums

Algorithm Implementation

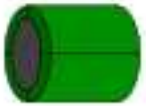
- Jets, ΣE_T, Missing E_T
- e/γ, τ/h

FPGA Based Generic Processors (adopted for CMS GCT)



ATLAS Muon Trigger Detectors

Resistive-plate chambers (RPCs) for Barrel region



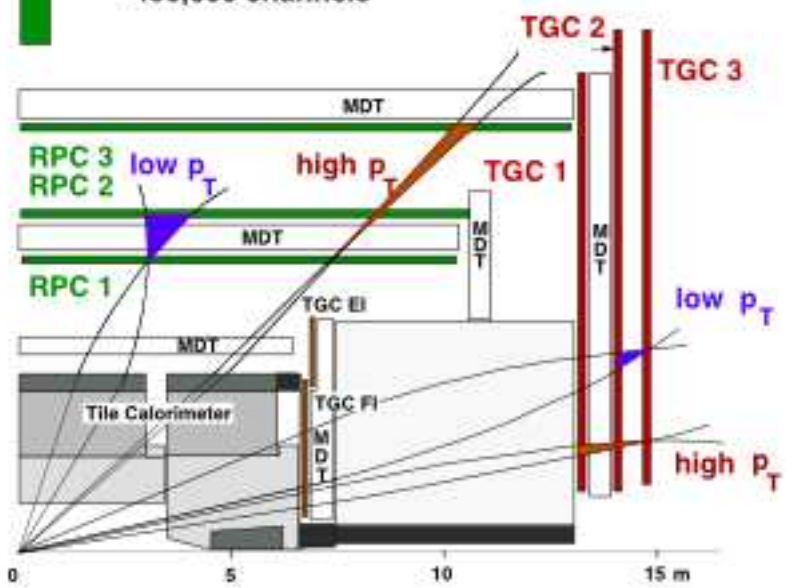
|Eta|<1.05

- Wireless strip detector in Eta & Phi easy to cover large area
- 3 stations
- 430,000 channels

- Measurement of muon trajectories in 3 stations
- Two Pt threshold ranges:

Low-Pt:	(6-10 GeV)	3-fold coincidence 3 thresholds
High-Pt:	(8-35 GeV)	3-fold coincidence 3 thresholds

- Signal processing on detector: 800,000 channels

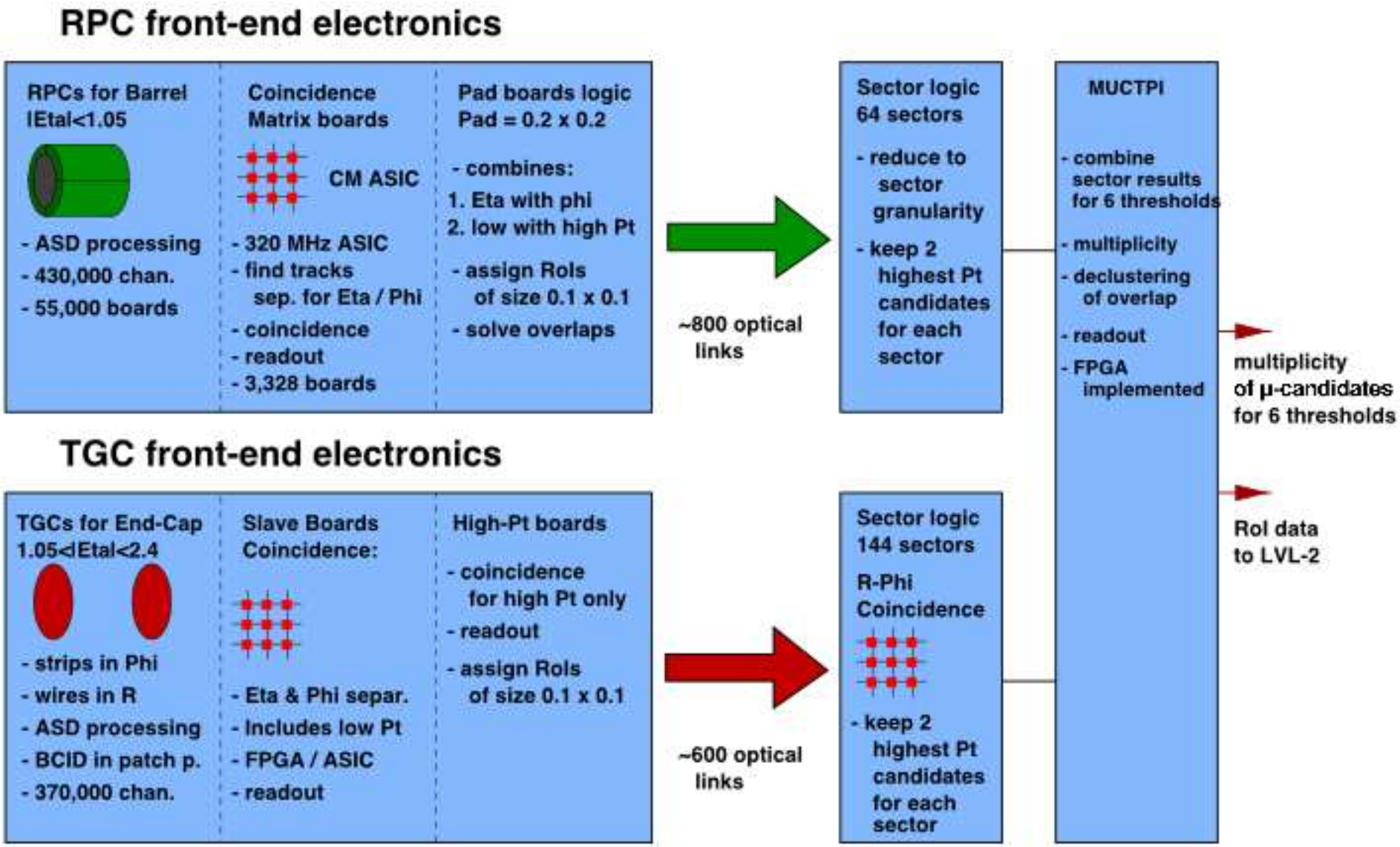


Thin-gap chambers (TGCs) for End-Caps

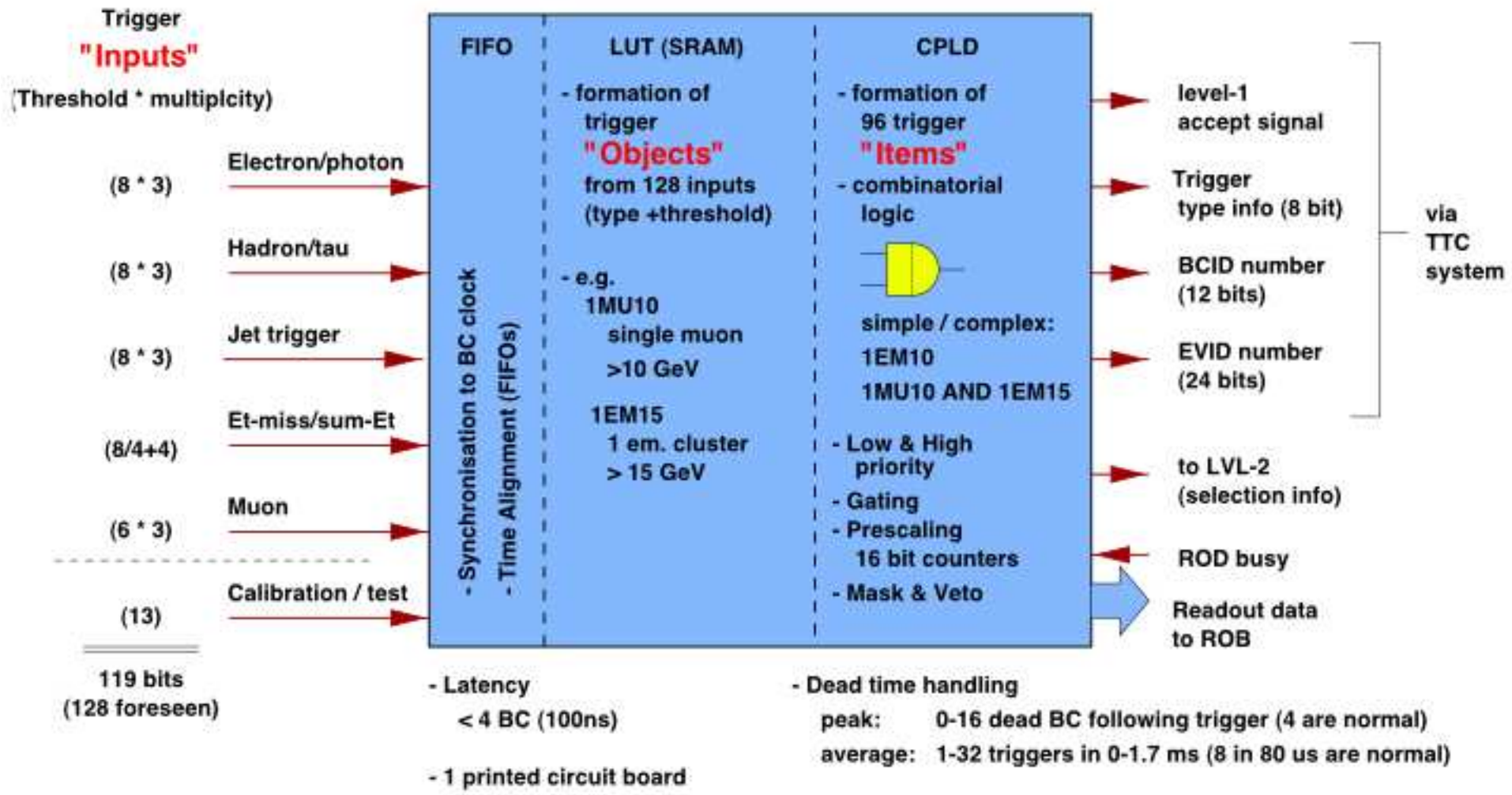
1.05<|Eta|<2.4

- Finer granularity needed
  Chambers outside toroidal field
  Trigger stations close together
- Strips in Phi, wires in R
- 3 stations + EI / FI
- High-rate capability needed for backgrounds in forward region
- 370,000 channels

ATLAS Muon Trigger



ATLAS Trigger Central Processor



CMS Calorimeter Trigger Rates: 2 x 10^{33} cm^{-2} s^{-1}

Mock Trigger Table

Trigger	Threshold (GeV)	95% Eff. (GeV)	Individual Rate (kHz)	Cumulative Rate (kHz)
e	20	27	4.9	4.9
ee	15	19	0.2	5.0
τ	89	~114	3.8	8.6
ττ	75	~100	0.7	8.8
j	130	152	1.5	9.5
jj	115	131	0.8	9.5
jjj	75	77	0.3	9.6
jjjj	55	62	0.2	9.6
e·j	10&100	15&125	0.4	9.8
e·τ	10&75	15&~100	0.8	10.0
Missing E_T	140	200	0.01	10.0
e·ME_T	10&75	15&140	0.4	10.3
j·ME_T	60&90	80&150	0.7	10.6
Total E_T	600	1200	0.04	10.6
H_T	400	470	0.6	10.7
e(NI)	45	51	0.2	10.8
ee(NI)	25	37	0.03	10.8
Total Rate				10.8

Selected Scenario: 5 kHz e/g, 5 kHz τ,jets, 1 kHz combined, rest μ

CMS Calorimeter Physics Efficiency: 2 x 10^{33} cm^{-2} s^{-1}

Scenario:

5 kHz e/γ,

5 kHz τ,jets,

1 kHz comb,

rest μ

No generator level cuts other than requiring trigger objects within calo. (η<5) or tracker (e,γ,τ) acceptance

Channel	Total Efficiency	Trigger Efficiencies by trigger type (individual) cumulative				
W→eν	70	e (70) 70				
t→eX	91	e (82) 82	e·τ (62) 86	τ (55) 89	jjj (24) 90	e·j (54) 91
Z→ee	94	e (93) 93	ee (76) 94			
H(115)→γγ	99	e (99) 99	ee (82) 99			
H(150) →WW →eνX	87	e (78) 78	e·τ (43) 81	τ (34) 83	e·j (39) 85	j (28) 87
H(135)→ττ→ej	84	e (70) 70	e·τ (46) 79	e·j (46) 82	τ (38) 84	j (34) 84
Charged higgs (200 GeV)	98	τ (85) 85	j (77) 96	j·mE_T (60) 98		
H(200)→ττ→jj	81	τ (75) 75	ττ (50) 79	j (24) 81	jj (9) 81	
H(500)→ττ→jj	99	τ (94) 94	ττ (64) 94	j (94) 99	jj (73) 99	
t→jets	53	H_T (39) 39	jjjj (26) 43	jjj (26) 46	jj (21) 47	j (35) 53
mSUGRA	99	j (99) 99				
H(120) → bb	41	jjj (12) 12	j (27) 30	τ (26) 41	jj (16) 41	
Invisible higgs (120 GeV)	44	j·mE_T (39) 39	j (22) 41	τ (13) 44		

Improving L1 Efficiency for qqH

SUSY higgs production in weak boson fusion

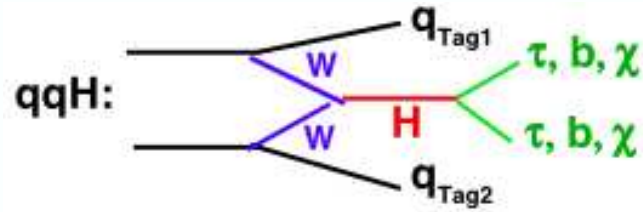
- **Accompanied by jets in the forward direction**

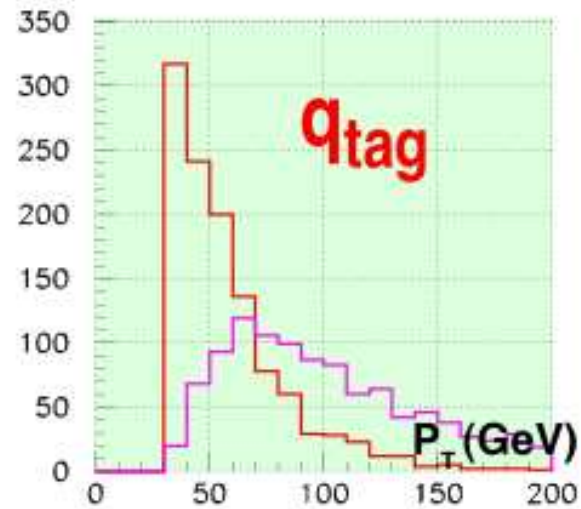
Forward jet characteristics

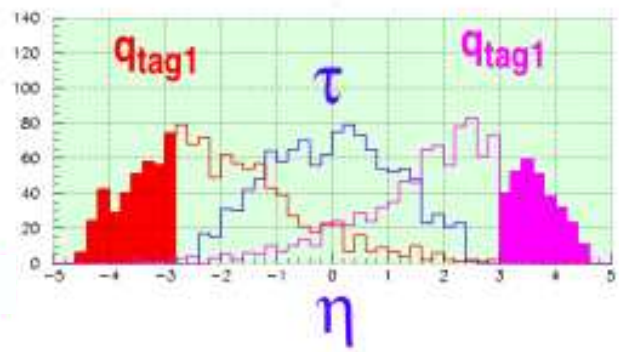
- **Lower jet E_T, but potential beam background**

Strategy at level-1

- **Trigger on higgs decay products**
  - Decays to Z (ee, $\mu\mu$) or photons
    - **Low threshold electron/photon algorithm**
  - Decays to τ
    - **Narrow jet tag - developed better algorithm (2000)**
- **Tag jets with location information**
  - Invisible decays (χ)
    - **Missing E_T trigger by itself is not efficient**
    - **Require two tag jets also**
    - **Require $\Delta\eta$ between the jets**
  - Decays to b jets (dominant but dirty mode)
    - **Four jet trigger including forward tag jets**
    - **Require $\Delta\eta$ between jets**
    - **Exploit that central b jets must be back-to-back**







Global L1 Trigger Algorithms

Particle Conditions

$E_T(1) > E_T(1)^{threshold}$
$E_T(2) > E_T(2)^{threshold}$
$0^o \le \phi(1) < 360^o$
$0^o \le \phi(2) < 360^o$
$170^o \le |\phi(1) - \phi(2)| < 190^o$

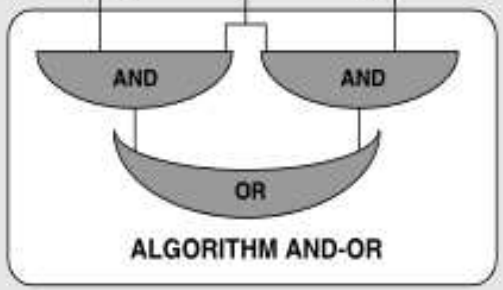
$p_T(1) > p_T(1)^{threshold}$
$p_T(2) > p_T(2)^{threshold}$
$0^o \le \phi(1) < 360^o$
$0^o \le \phi(2) < 360^o$
$170^o \le |\phi(1) - \phi(2)| < 190^o$
ISO(1) = 1, ISO(2) = 1
MIP(1) = 1, MIP(2) = 1
SGN (1) = 1, SGN(2) = -1

Logical Combinations

OR

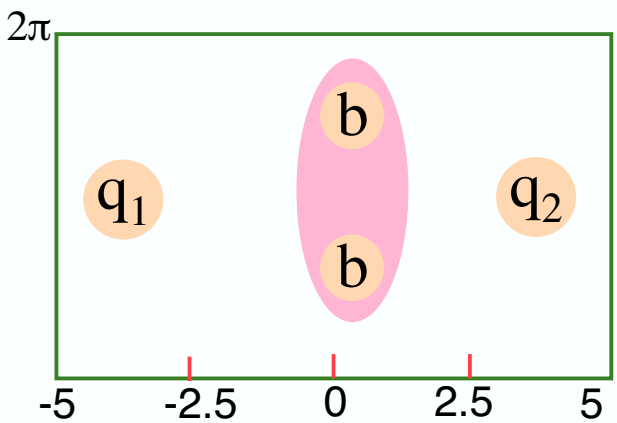
$E_T(e_{is.}) > E_T(e_{is.})^{threshold}$ | $E_T^{missing} > E_T^{threshold}$ | $p_T(\mu) > p_T(\mu)^{threshold}$

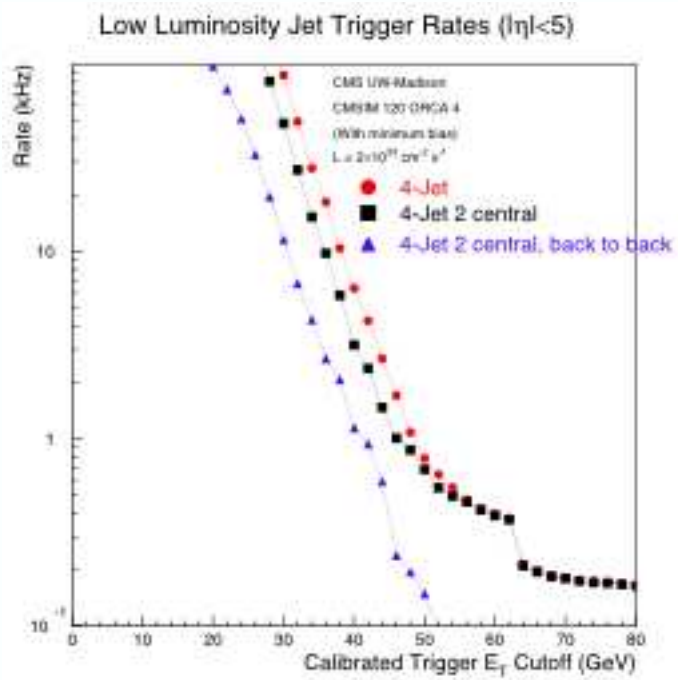
Particle Conditions for isolated electrons | Particle Condition for missing E_T | Particle Conditions for muons



Flexible algorithms implemented in FPGAs
100s of possible algorithms can be reprogrammed
designing physics algorithms

qqH to 2 b-jets + 2 tag jets





Current Level-1 Trigger

- 4 jets anywhere in the detector

Exploit separation of the tag jets in η

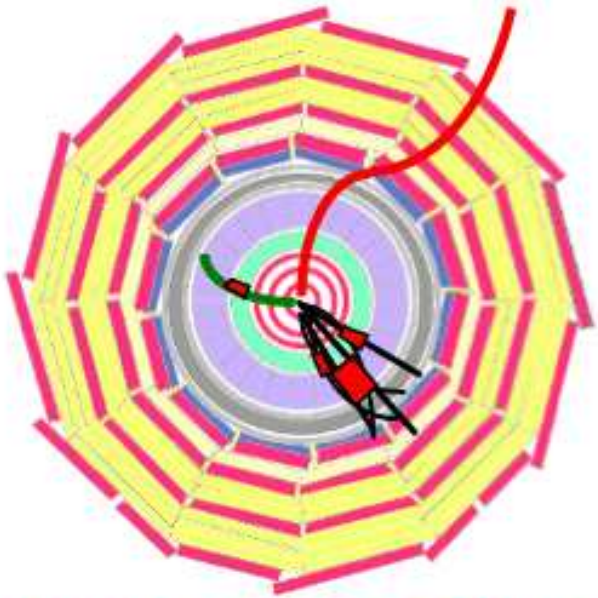
- 4 jets with $\Delta\eta > 3$
- Reduce 1-jet rate to compensate for new rate

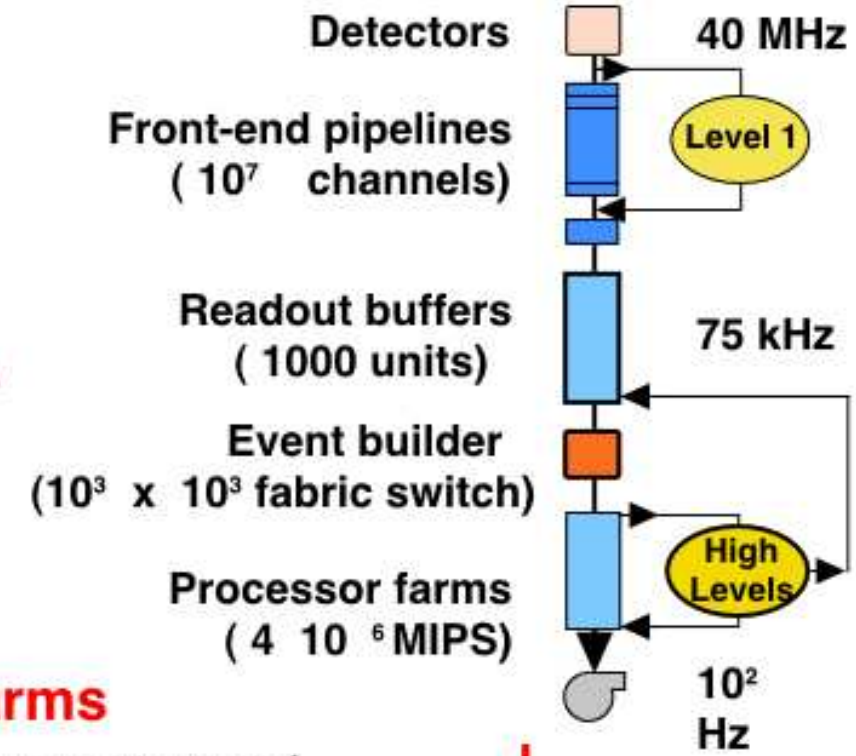
Rate reduction using event topology cuts

- Rapidity gap due to lack of color connection
- Require b-jets to be within the central detector

Algorithm	Efficiency for M_H=110 GeV	Efficiency for M_H=130 GeV
1, 2, 3, 4 jet triggers only	70%	76%
Additional $\Delta\eta$>3 cut	79% (+9%)	82% (+8%)

High Level Trigger Strategy





High level triggers. CPU farms

- Finer granularity precise measurement
- Clean particle signature (π^0-γ, isolation, ...)
- Kinematics. Effective mass cuts and topology
- Track reco and matching, b,τ-jet tagging
- Full event reconstruction and analysis

Successive improvements : background event filtering, physics selection

Evolution of Level-1 Triggers

Input

- Old - separate analog trigger sums + Cu cables
- New - on detector ADCs++ (radiation hard ASICs)
  - trigger primitives formation,
  - giga-bit fiber-optic transport

Backplanes

- Old - VME Bus, FastBus
- New - Point-to-point high speed links,
  serial (1 to 3 GB/s) or parallel (160 MHz)

Inter-crate links

- Old - Parallel differential ECL
- New - Serial 1.2 GB fiber or Cu links

Evolution of Level-1 Triggers

Discrete Logic

D0,CDF

towers over thresholds + sums

ZEUS

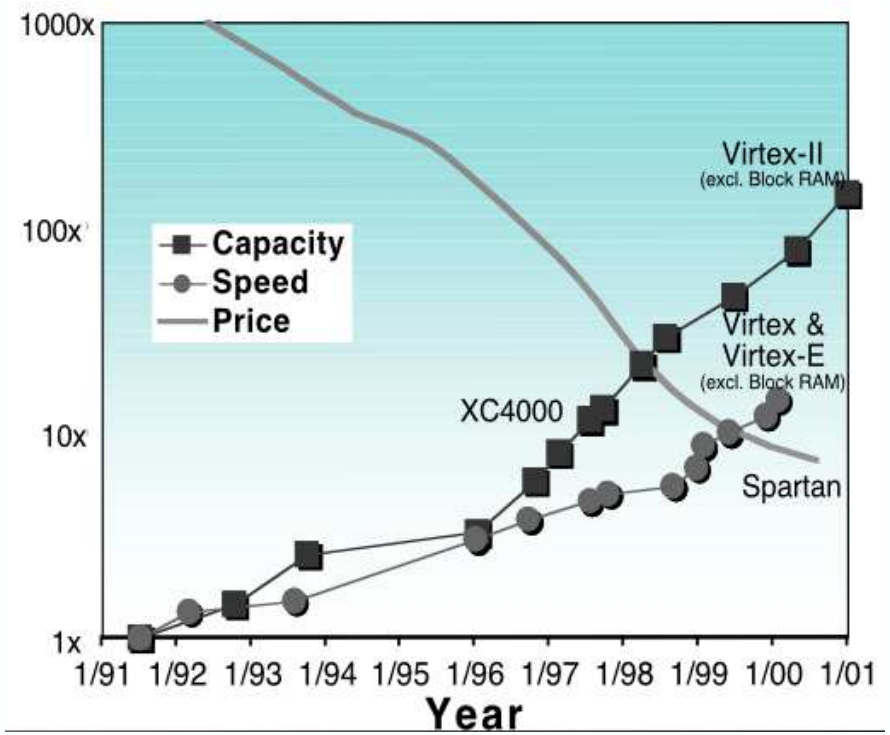
sums + pattern logic for object ID

ASICs

CMS RCT -

object identification
isolation, sorting,
fast adders

FPGAs

Almost everywhere -

Generic processors