CMS 101: Trigger

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BROWN

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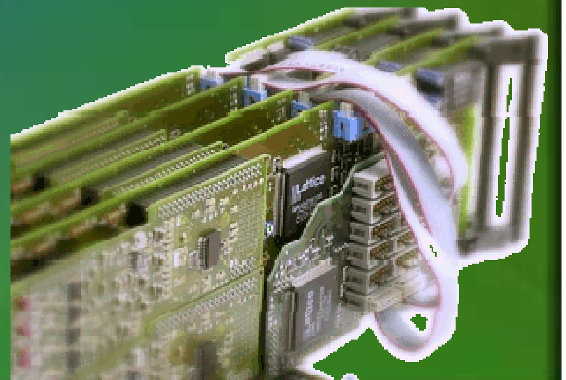
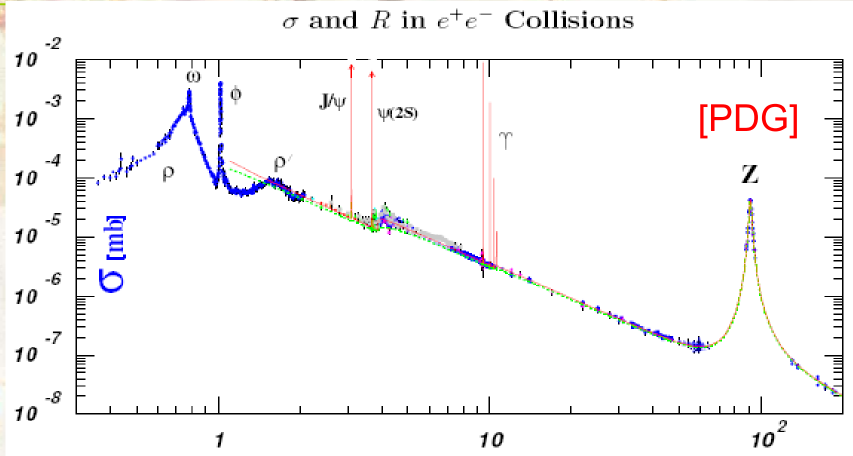
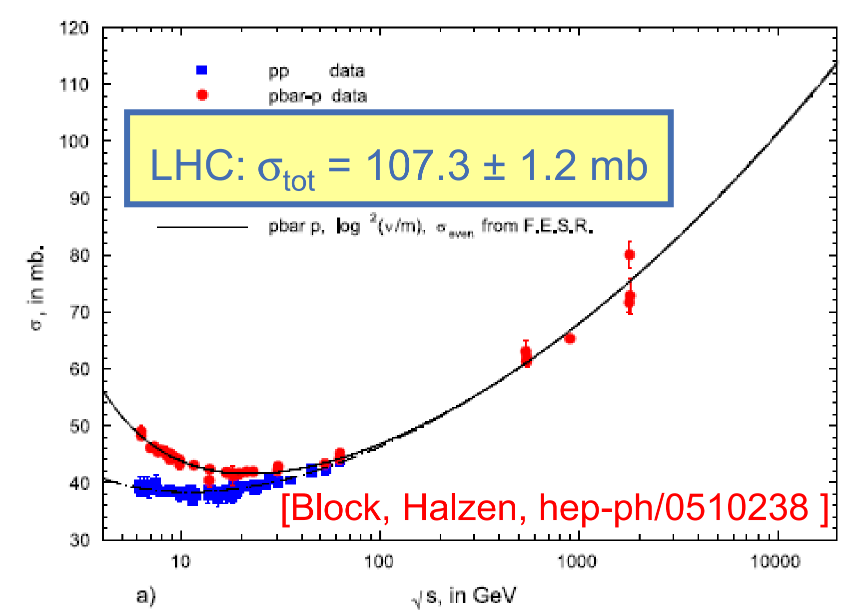
(with many thanks to D.Acosta, S.Dasu, P.Klabbers, and V.O'Dell)



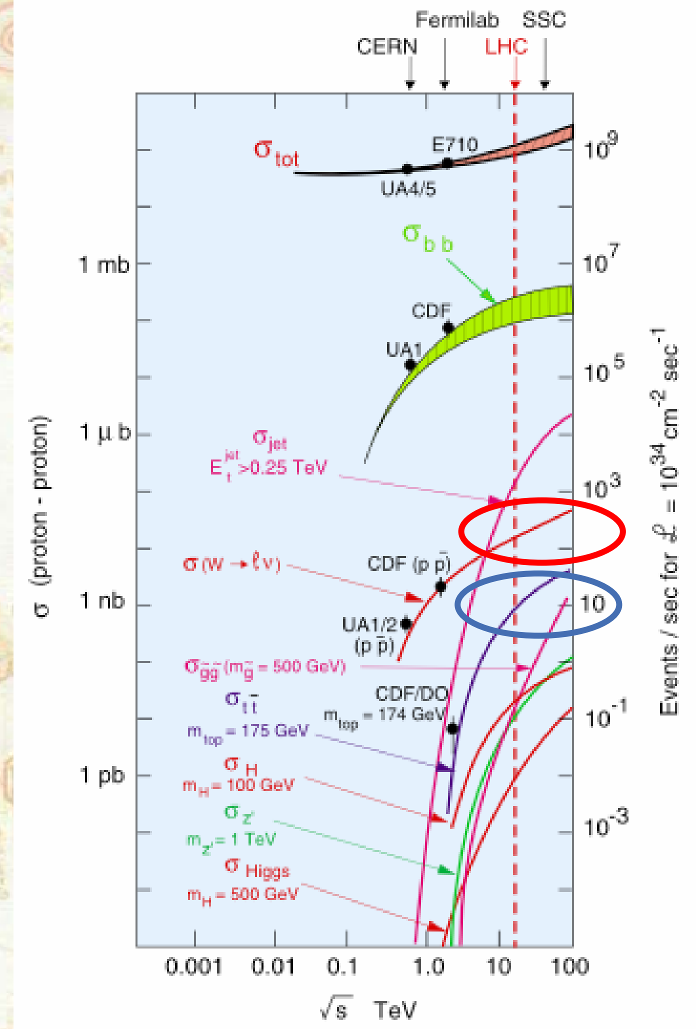
Trigger Strategies

- e^+e^- colliders: low total cross section, low rates
  - Trigger pretty much on everything, perhaps with the exception of very forward processes (low-angle Bhabha)
- Hadron colliders: enormous cross section, unattainable rates
  - Trigger is very selective
  - Only small fraction of collisions is written to tape
  - Additional complications due to pile-up
- LHC:
  - σ_{tot} = 110 mb, σ_{in} ~ 70 mb
  - L = 10^{34} $cm^{-2}s^{-1}$ = 10 $nb^{-1}s^{-1}$
  - Total rate: ~10^9 s^{-1} or ~25/crossing





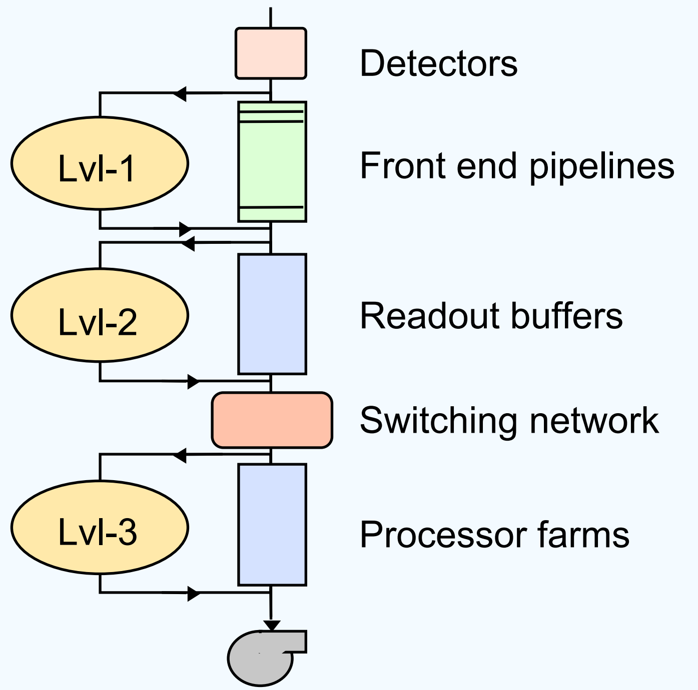
More Trigger Challenges



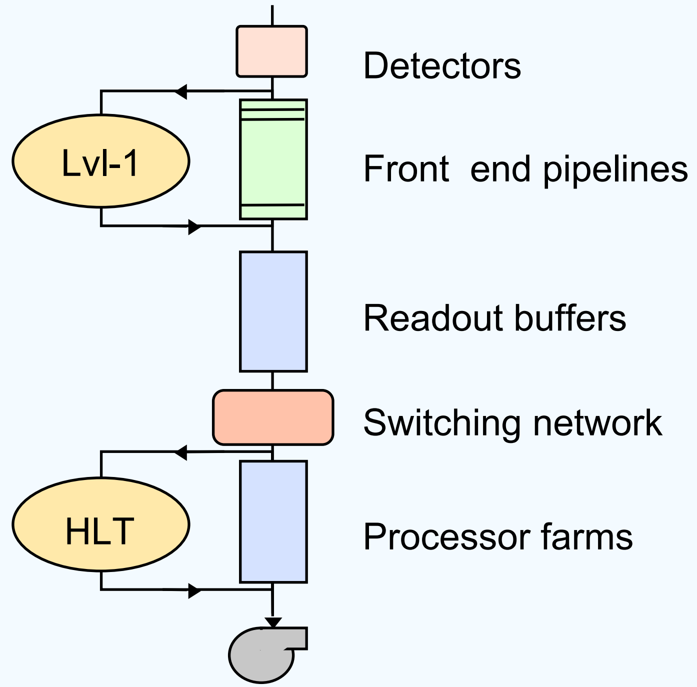
- LHC Physics Demands
  - EWSB in SM (Higgs, W, Z)
    - Lepton/photons E_T ~ 50 GeV
    - High rate (10 Hz of top events!)
  - TeV scale supersymmetry, UED
    - Multiple leptons, jets and LSPs (missing E_T), E_T < 100 GeV
- QCD Background
  - Jet E_T ~ 250 GeV, rate ~ 1 kHz
  - Jet fluctuations ⇒ electron BG
  - Decays of p, k, B ⇒ muon BG
- Technical challenges
  - 40 MHz input ⇒ fast processing
  - 100 Hz output ⇒ physics selection
  - 10^9 events per year ⇒ ≤10^2 higgs events

Trigger Architecture

- Must reduce 1 GHz of input interactions to 100 Hz
  - Do it in steps/successive approximations: “Trigger Levels”



“Traditional”: 3 physical levels



CMS: 2 physical levels

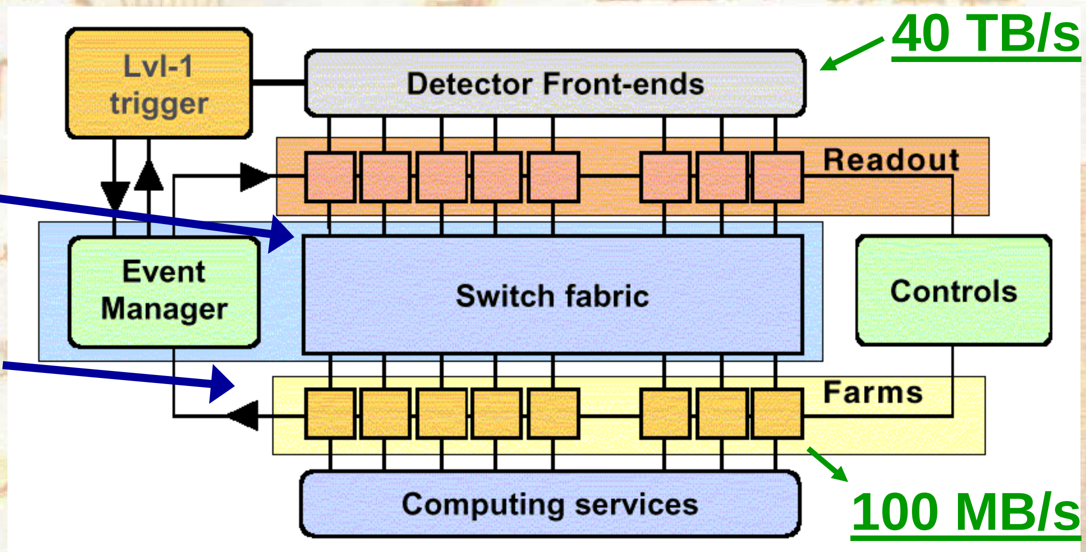
Recent progress in networking/switching has justified CMS choice

CMS Trigger & Data Acquisition

- CMS has a two-tiered system to handle LHC challenge:
  - Level-1 trigger reduces rate from 40 MHz to 100 kHz (max)
    - Custom electronic boards and chips process *calorimeter and muon* data to select *objects*
  - High-Level triggers reduce rate from 100 kHz to O(100 Hz)
    - Filter farm runs online programs to select *physics channels*
    - No custom Level-2 hardware

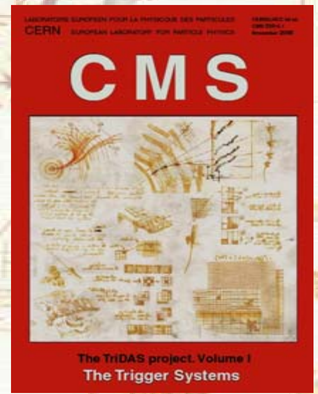
Large switching network (~Tbit/s)

O(1000) node PC cluster



References

- Level-1 Trigger Technical Design Report:
  - CERN/LHCC 2000-038



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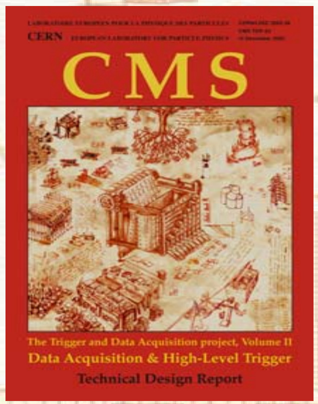
- DAQ and High-Level Trigger Technical Design Report:
  - CERN/LHCC 2002-026

http://cmsdoc.cern.ch/cms/TRIDAS/html/tridas.html



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- Physics Technical Design Report - Volume 1
  - Will have a trigger chapter and is due out this year

Tevatron & LHC: Quick Comparison

	CDF/DØ	CMS
Inst. Luminosity	10^{32}	10^{34}
Bunch crossing freq.	2.5 MHz	40 MHz
Pileup	≈2 events	≈20 events
L1 output rate	2-10 kHz	100 kHz
L2 output / HLT input	~500 Hz	100,000 Hz
L3 output rate	50 Hz	100 Hz
Event size	~0.1 MB	1 MB
Filter Farm	~100 nodes	~1000 nodes

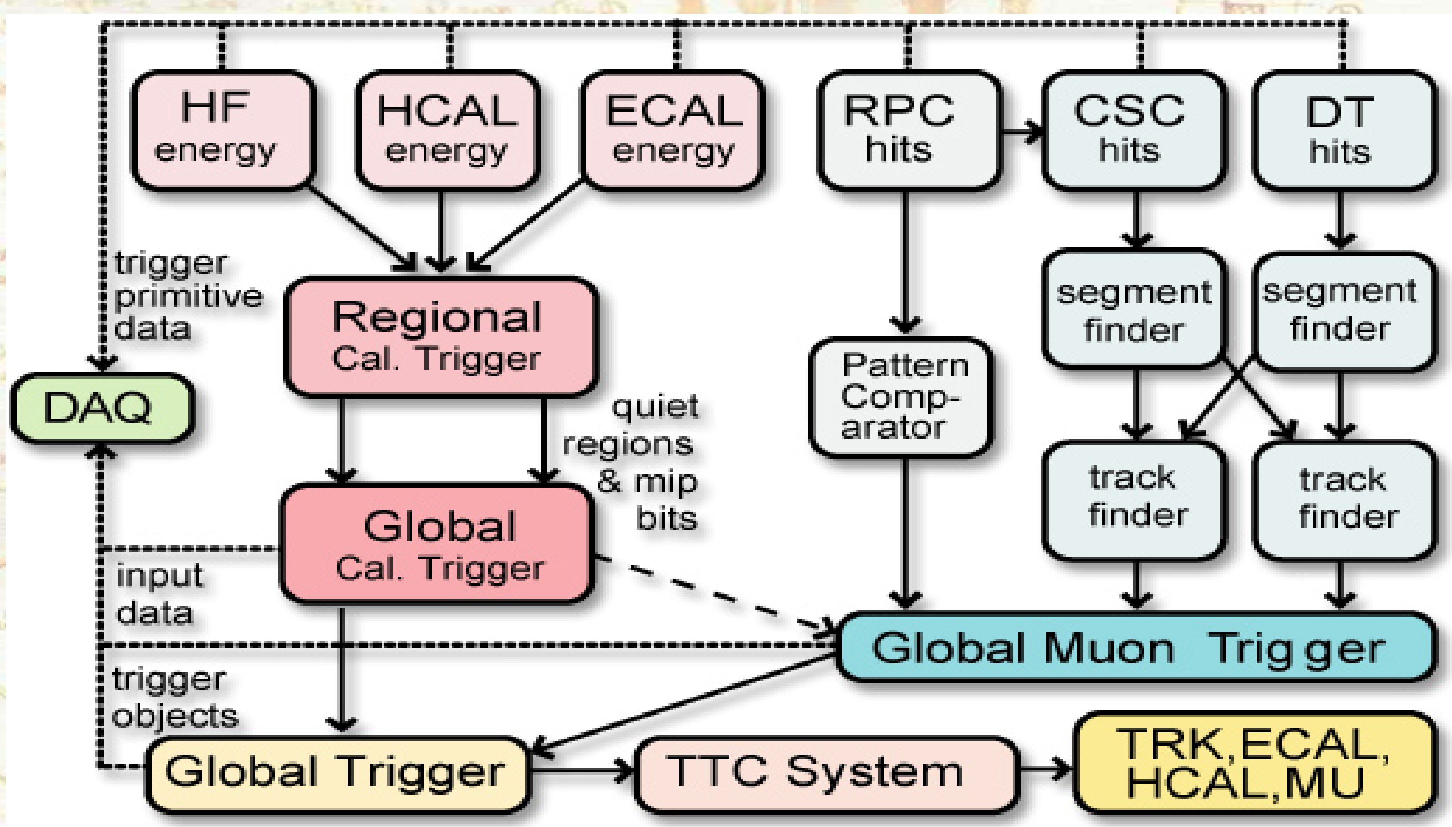
The CMS Level-1 Trigger

- Reduce data rate from 40 MHz to 100 kHz while keeping high-p_T physics
  - Custom electronic hardware, some of which must be radiation hard
  - Algorithms are pipelined at 40 MHz for deadtime-free operation
  - Total decision latency: 3.2 μs
- Only muon and calorimeter systems participate
  - Silicon tracker data is unavailable until the High-Level Trigger
    - Significant handicap compared to the Tevatron experiments
    - Resembles UA1 or DØ in Run I
    - On a positive side, makes L1 trigger logic simpler

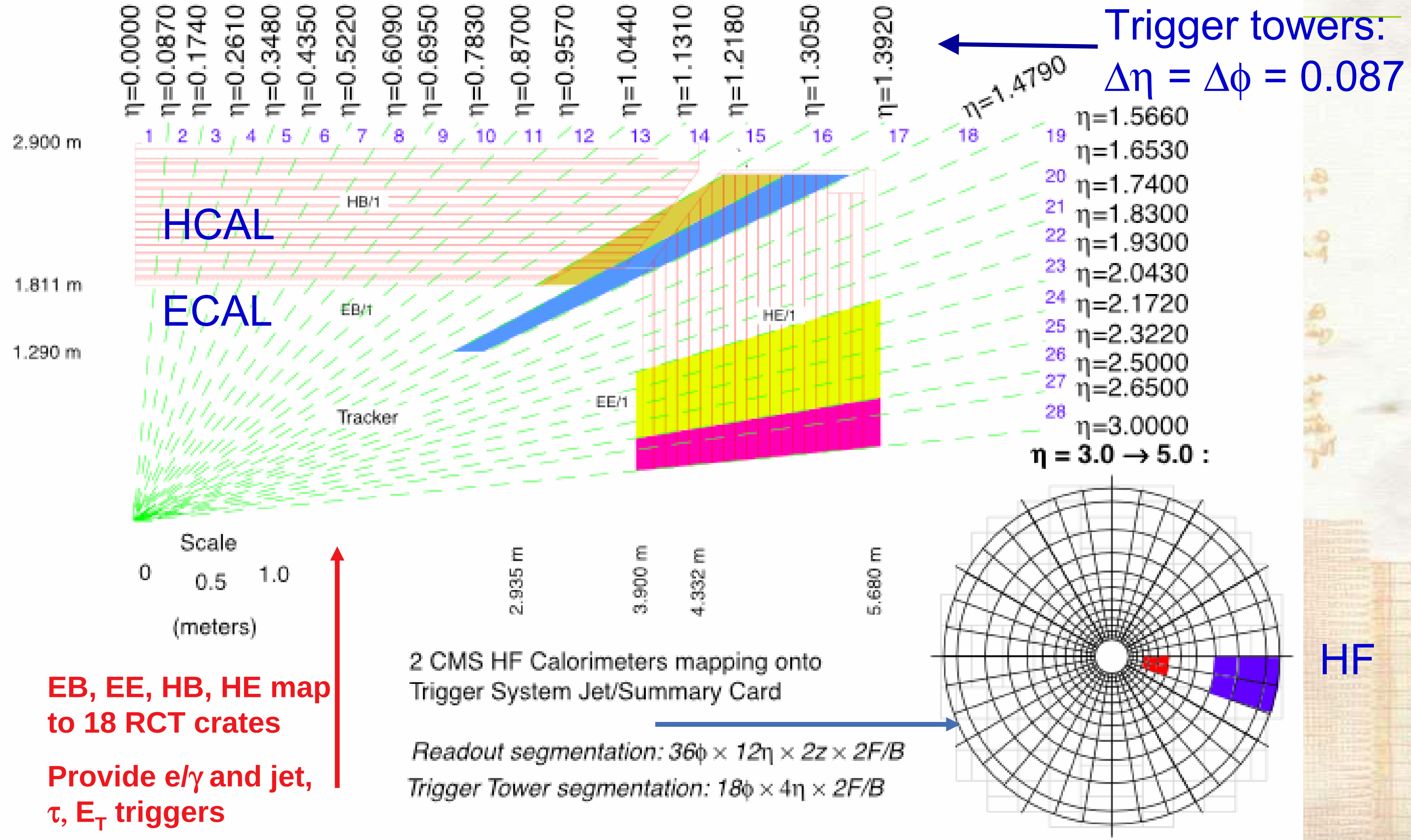
Level-1 Trigger Scheme

Electrons, Photons, Jets, ME_T — **Muons**

$3<|\eta|<5$ $|\eta|<3$ $|\eta|<3$ $|\eta|<2.1$ $0.9<|\eta|<2.4$ $|\eta|<1.2$



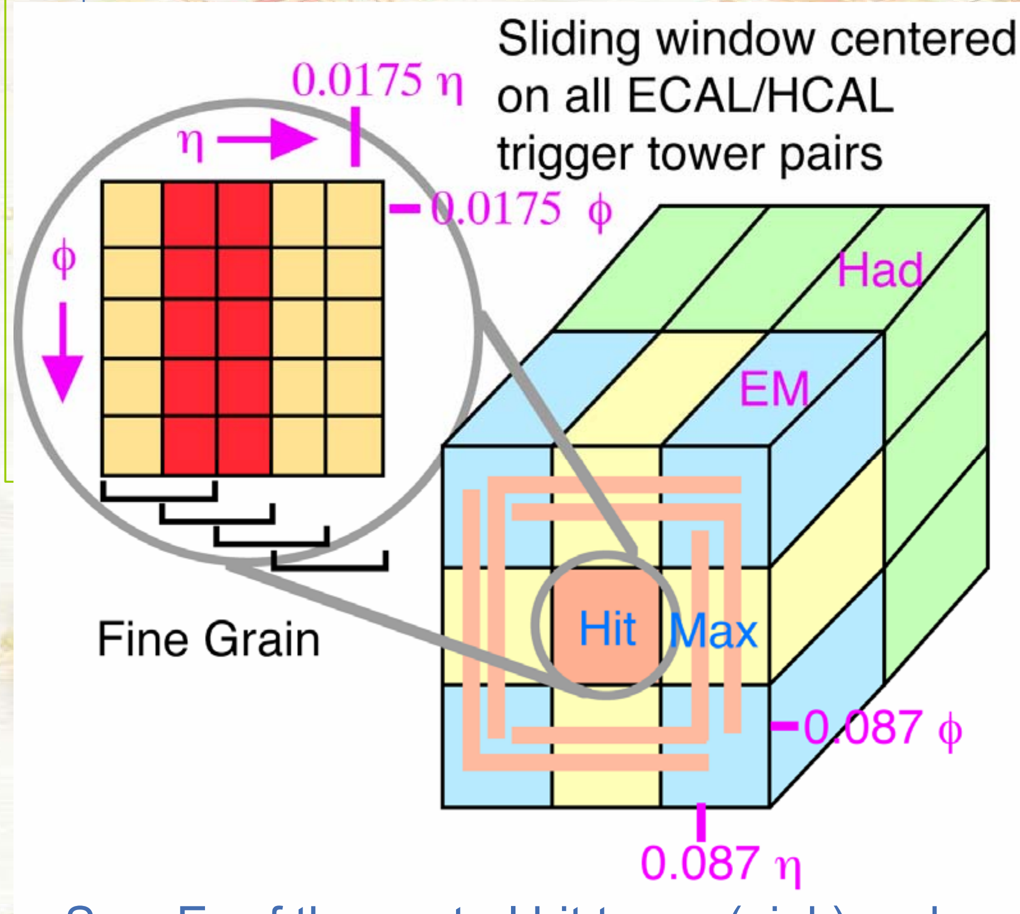
Calorimeter Trigger Geometry



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

Provide e/γ and jet, τ, E_T triggers

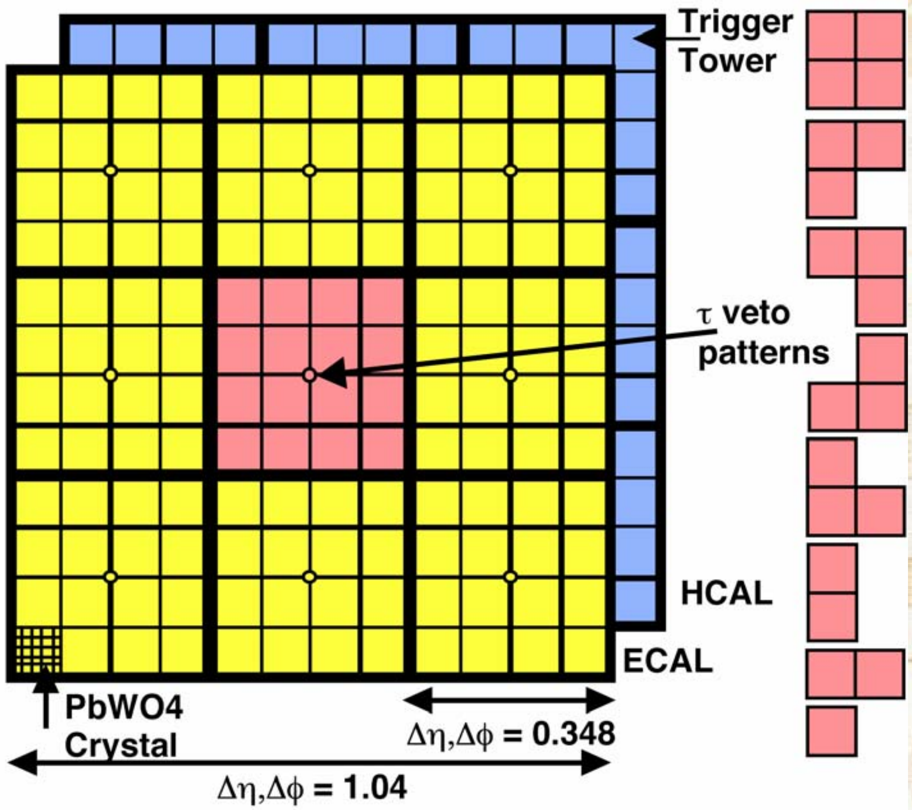
Level-1 EM Calorimeter Trigger



Sum E_T of the central hit tower (pink) and the nearest neigbor w/ the highest E_T (one of the yellow towers)

- Electron (Hit Tower + Max)
  - 2-tower ΣE_T > threshold
  - Hit tower *H/E* < *5%*
  - Hit tower 2x5-crystal strips >90-95% of tower E_T in 5x5 (Fine Grain)
- Isolated Electron (3x3 Towers)
  - Quiet neighbors: all towers pass Fine Grain & *H/E*
  - One group of 5 EM corners has E_T < threshold (~1 GeV)

Level-1 Jet Calorimeter Trigger



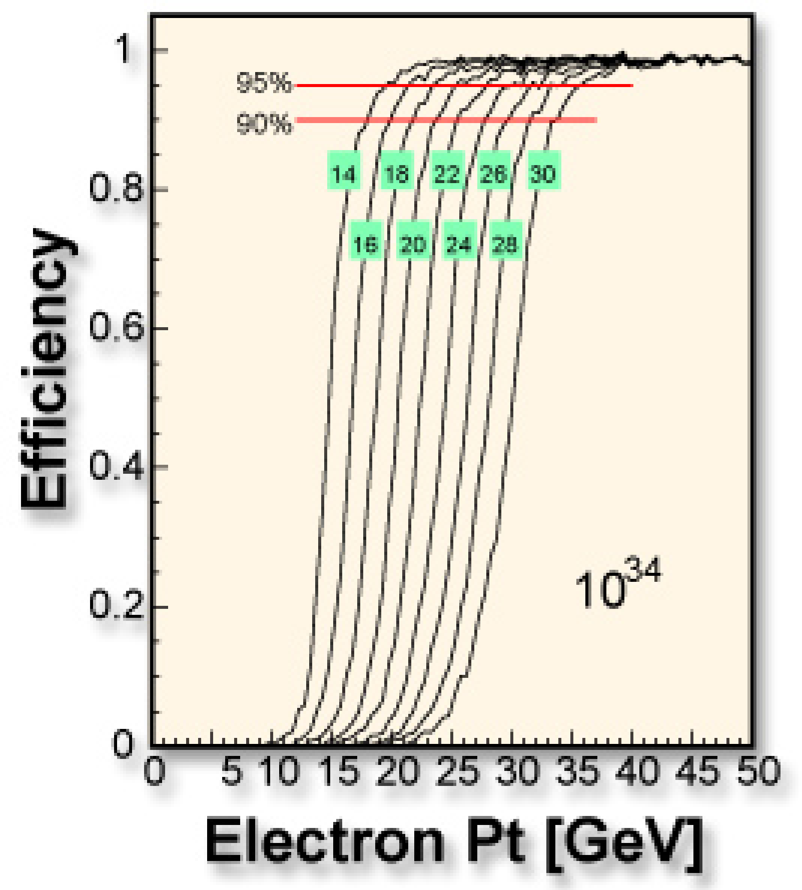
- Jet or τ E_T
  - 12x12 trig. tower ΣE_T sliding in 4x4 steps w/central 4x4 E_T > others
- τ: isolated narrow energy deposits
  - Energy spread outside τ veto pattern sets veto
  - Jet $\equiv$ τ if all 9 4x4 region τ vetoes off

Level-1 Global Calorimeter Trigger

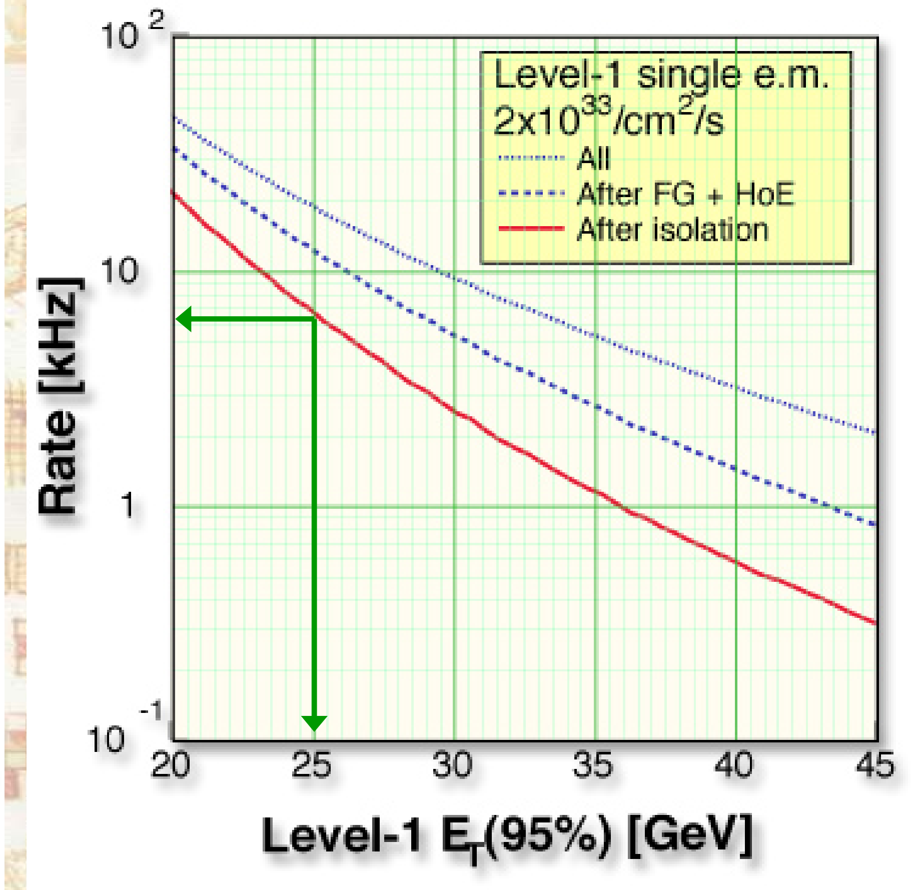
- Implements sliding window jet cluster algorithm
- Sorts electron and jet objects
- Computes energy and missing E_T sums
- Forwards Calorimeter Quiet bits and MIP (minimum-ionizing particle) bits to Global Muon Trigger for each 4x4 tower Calorimeter region.
- Output to Global Trigger (sorted in E_T):
  - E_T and location in detector
    - 4 non-isolated e/γ
    - 4 isolated e/γ
    - 4 central jets
    - 4 forward jets
    - 4 τ objects
  - Total E_T
  - Missing E_T and ϕ angle
  - Jet Counts

Level-1 Electron Efficiency and Rate

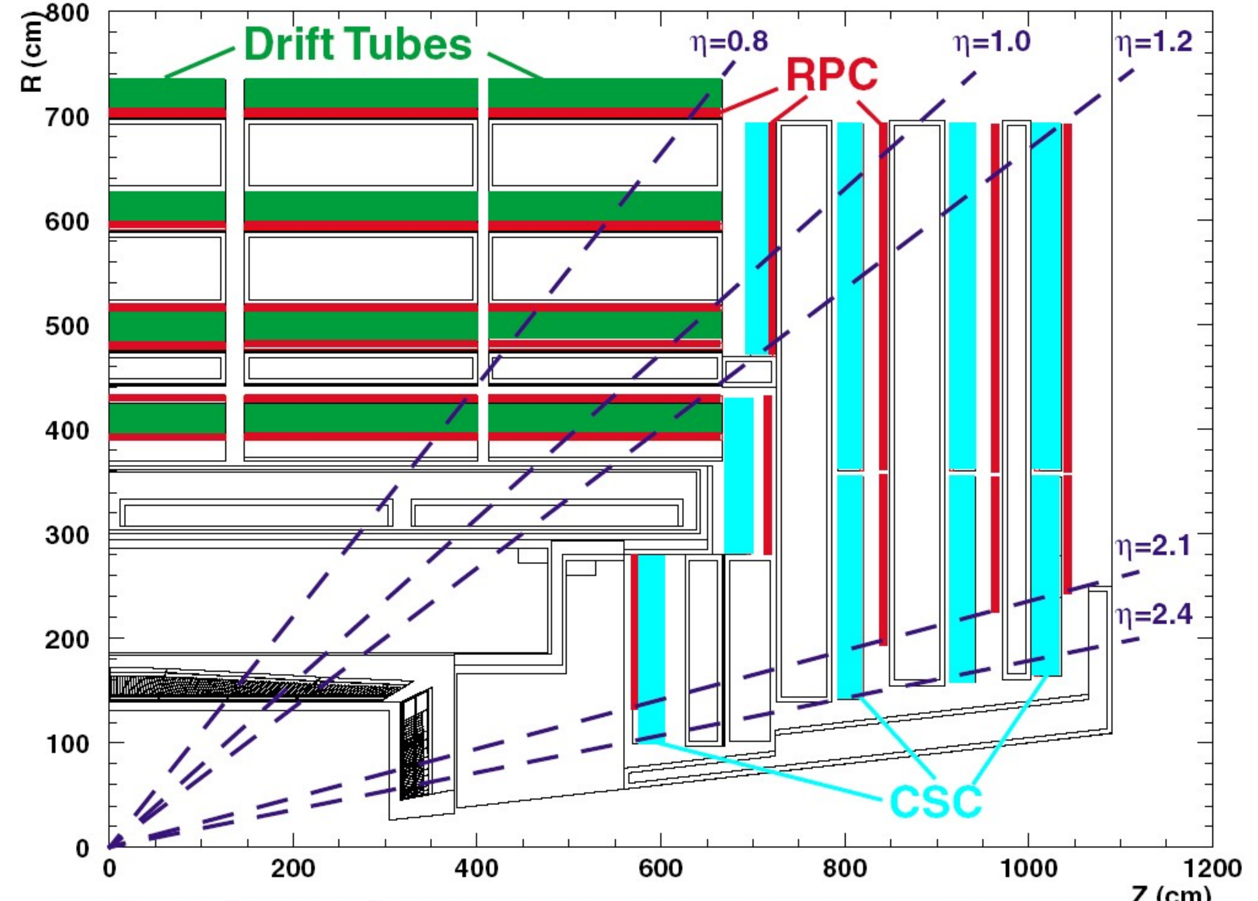
Response to electrons



Rate from QCD background



Muon Trigger Geometry



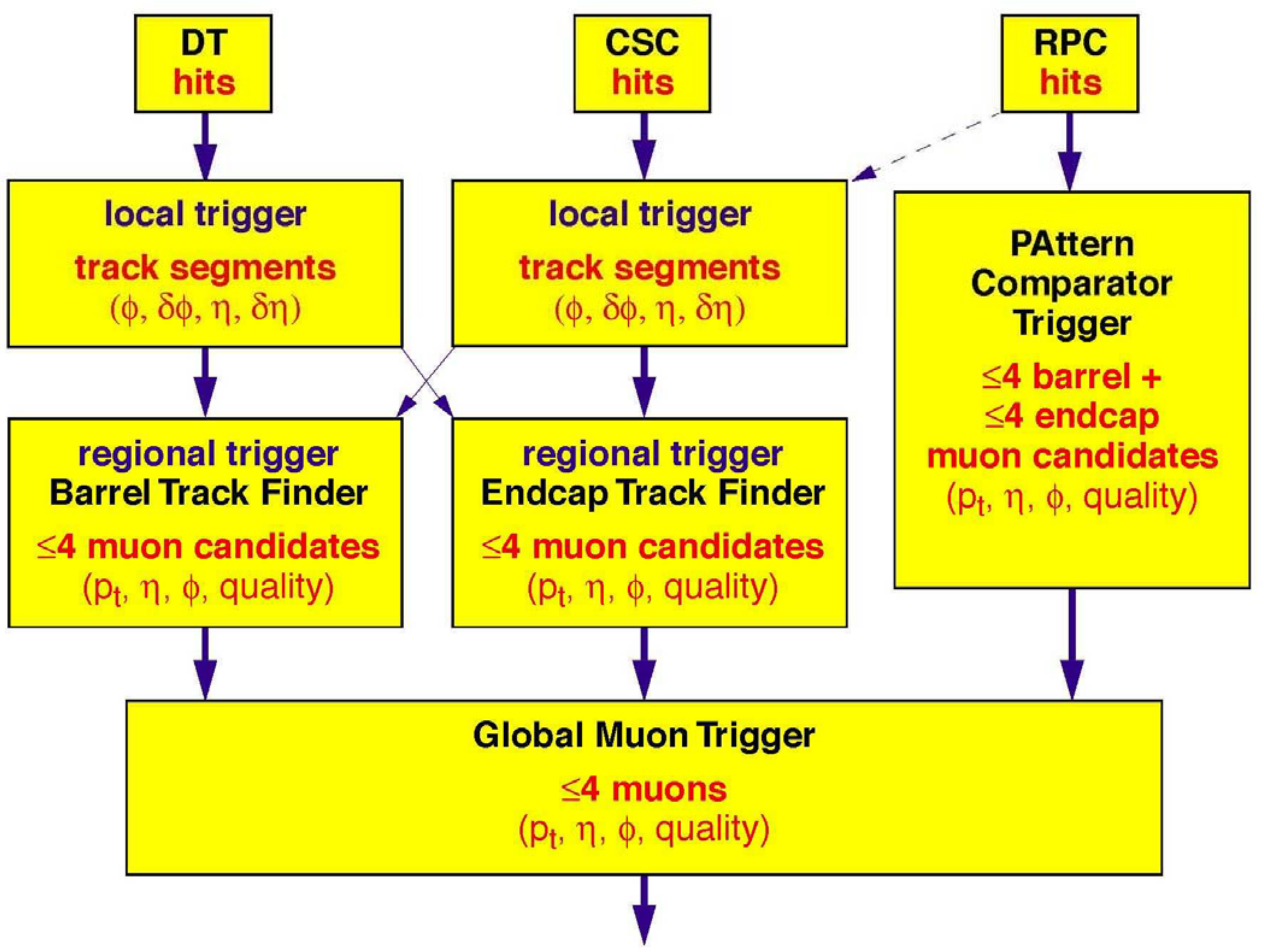
4 Stations in the barrel and each endcap

- RPC: resistive plate chamber system
- CSC: cathode strip chamber system
- DT: drift-tube system

Initial coverage of RPC is staged to $\eta<1.6$

Initial coverage of CSC 1st station is staged to $\eta<2.1$

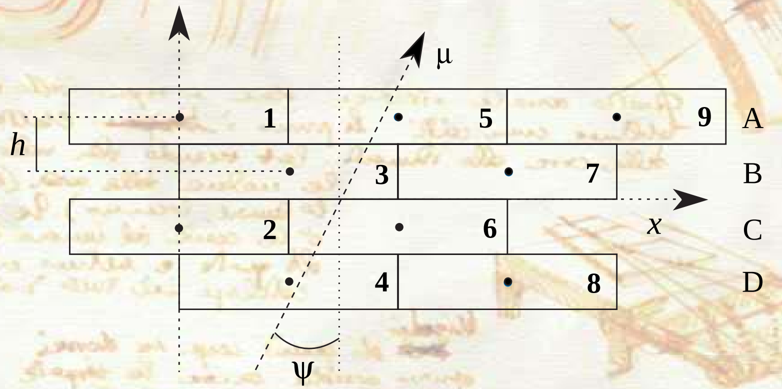
Muon Trigger Overview



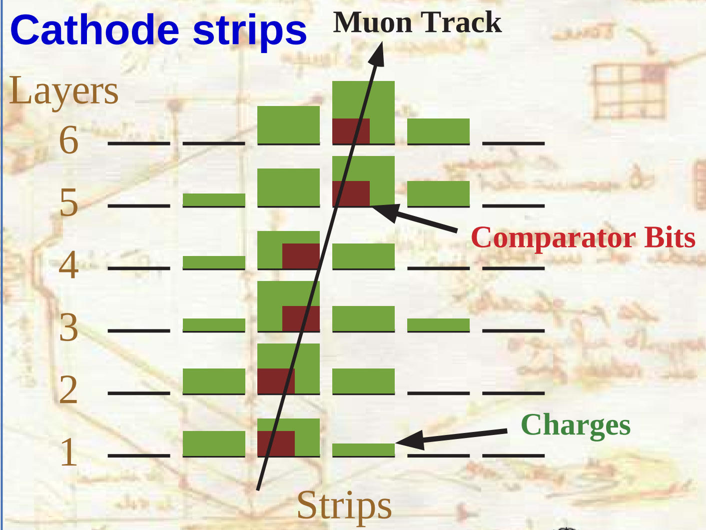
DT and CSC Local Triggers

Both are multi-layer detectors

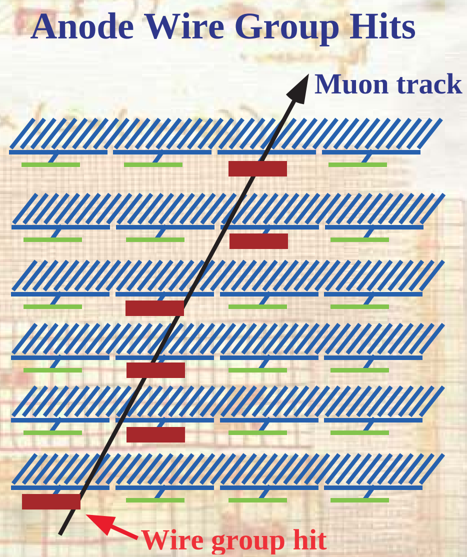
Italy (DT), U.S. (CSC)



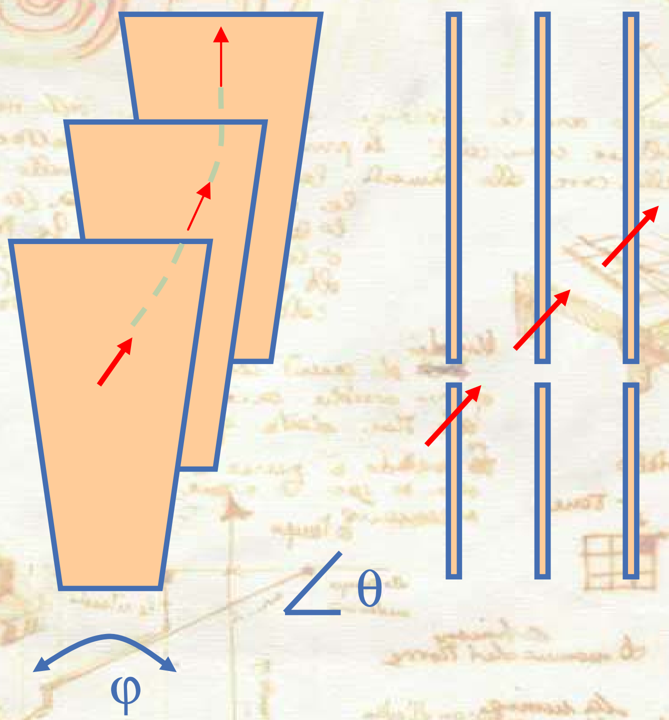
Bunch & Track Identifier (BTI) uses shift registers to search for patterns in drift tubes (ϕ and θ) and to assign correct BX



Local Charged Track (LCT) logic identifies track stubs in CSCs (in ϕ and η) and assigns BX



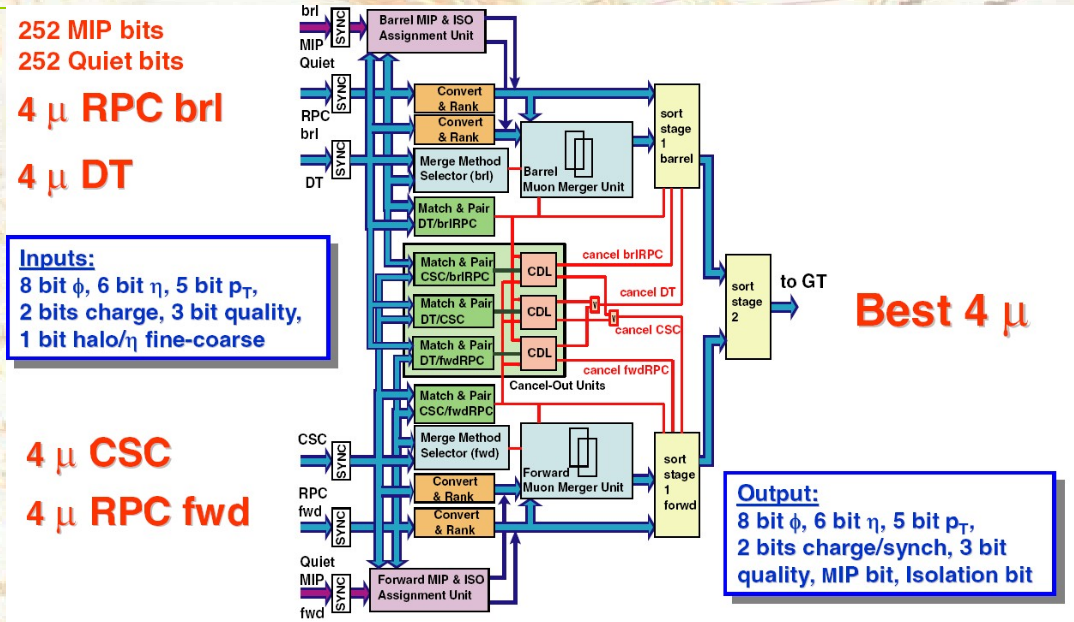
Track-Finding



Austria (DT), Poland (RPC), U.S. (CSC)

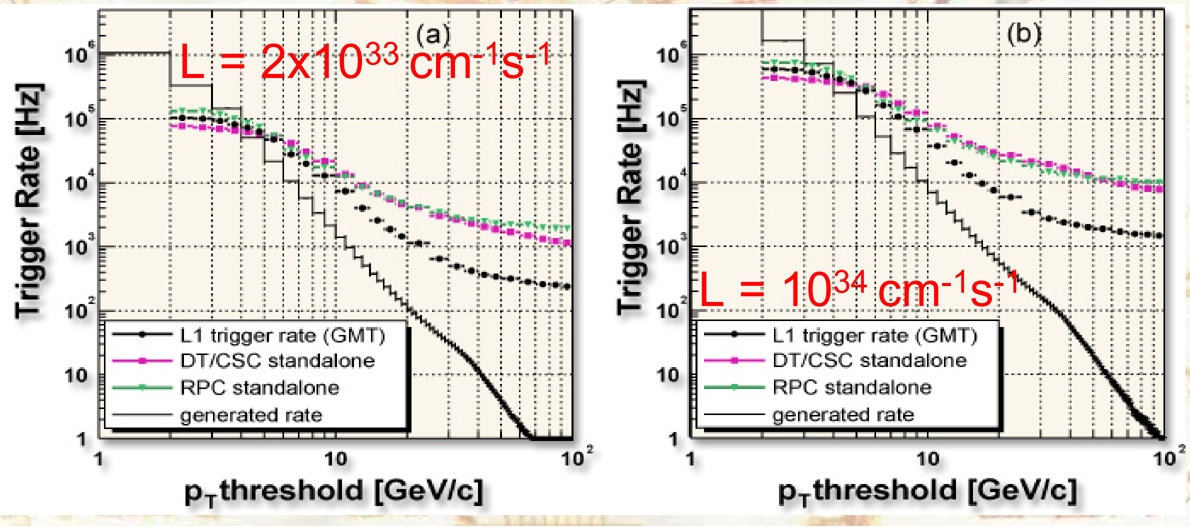
- DT and CSC Track-Finders link local track segments into distinct tracks
- RPC Pattern Comparator Trigger applies coincidence logic along roads in η and ϕ with $\Delta\eta \times \Delta\phi = 0.1 \times 0.005$
- Standalone momentum measurement using B-field in yoke
- Highest quality candidates sent to Global Muon Trigger

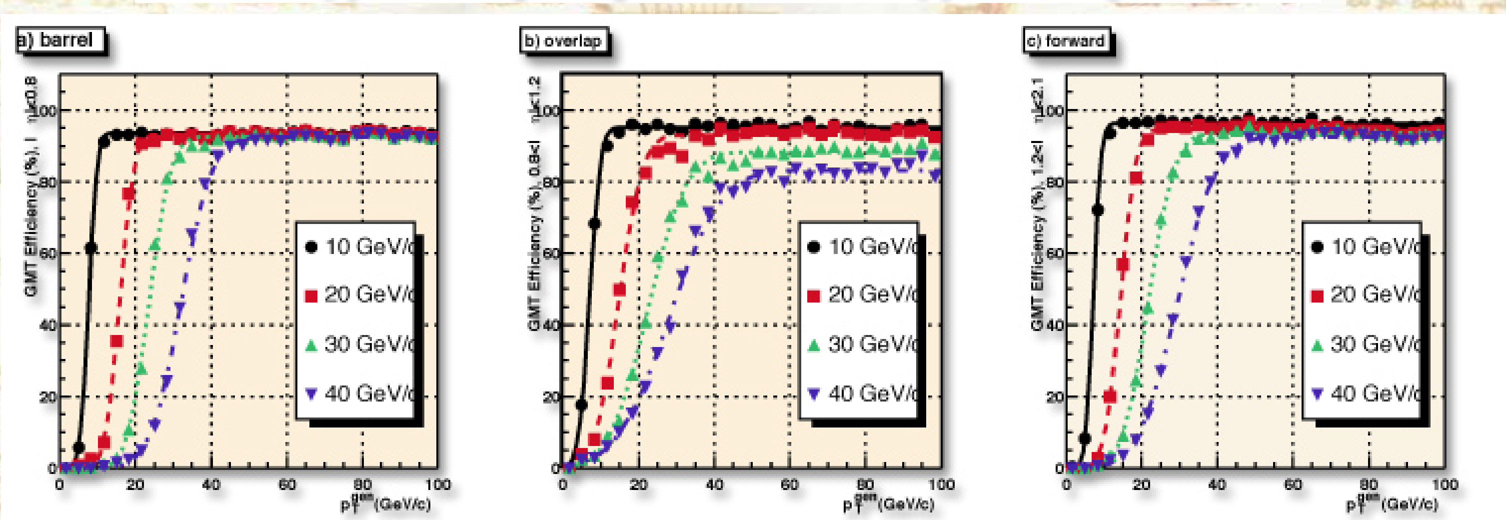
Global Muon Trigger



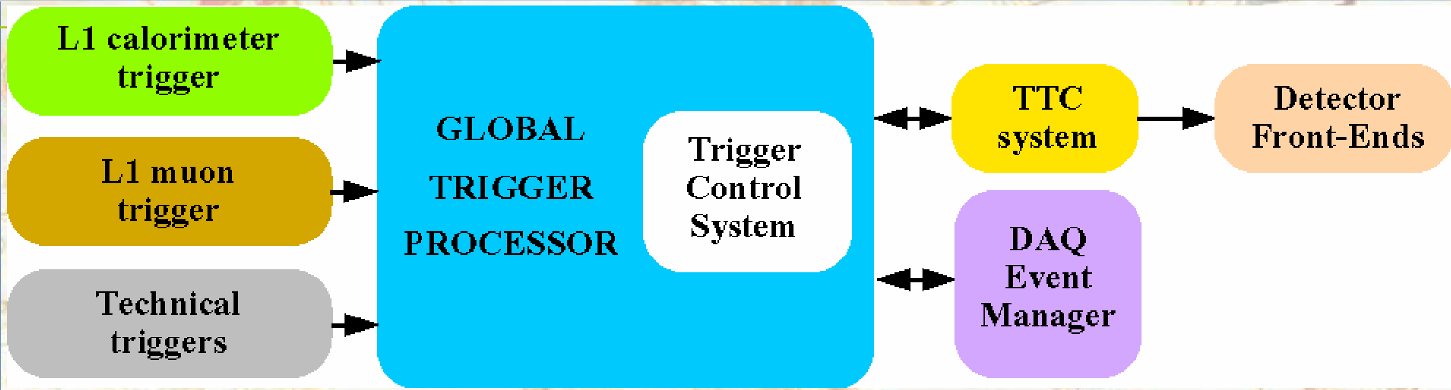
- Combines/matches muons from all 3 systems:
  - Maximize efficiency
  - Minimize rate
  - Cancel duplicates
  - Apply calorimeter isolation or MIP
  - Programmable P_T thresholds from 1 to 140 GeV/c

Muon rates and efficiencies





Level-1 Global Trigger



Austria

- Receives Trigger Objects:
  - 4 forward and 4 central jet, 4 τ-jets, 4 isolated and 4 non-isolated e/γ, total E_T, ME_T and position information from global calorimeter trigger
  - 4 μ, μ position, sign, and quality information from global muon trigger
- 128 different conditions (thresholds, topological cuts) can be combined to make 128 physics triggers
- Forwards Level-1 accept to DAQ and Trigger Timing and Control (TTC) system for data collection.
- Level-1 decision is transmitted to the Trigger Throttle System, which in turn transmits a Level-1 Accept via the Trigger Timing and Control system to the detector front-end read-out electronics

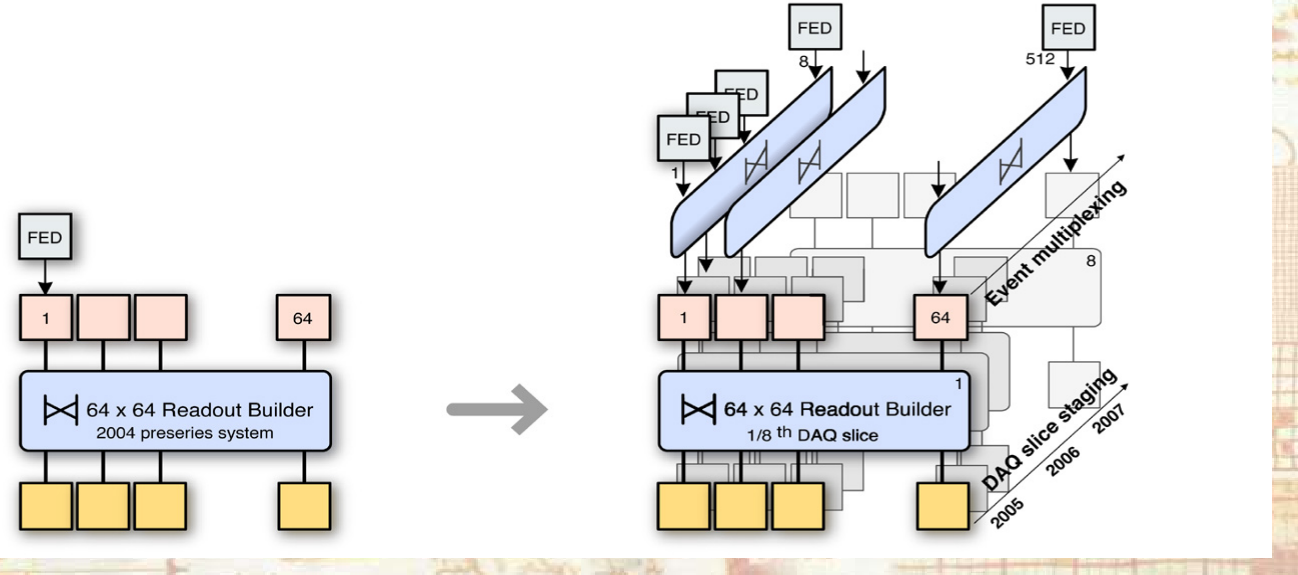
Crude Level-1 Trigger Table

Trigger	Low Luminosity (50 kHz Startup DAQ)			High Luminosity (100 kHz Full DAQ)		
	95% Eff. Thr. (GeV)	Rate (kHz)	Cum. Rate (kHz)	95% Eff. Thr. (GeV)	Rate (kHz)	Cum. Rate (kHz)
e	29	3.3	3.3	34	6.5	6.5
ee	17	1.3	4.3	19	3.3	9.4
μ	14	2.7	7.0	20	6.2	15.6
$\mu\mu$	3	0.9	7.9	5	1.7	17.3
τ	86	2.2	10.1	101	5.3	22.6
$\tau\tau$	59	1.0	10.9	67	3.6	25.0
j,jjj,jjjj	177,86,70	3.0	12.5	250,110,95	3.0	26.7
$j*E_T^{miss}$	88*46	2.3	14.3	113*70	4.5	30.4
e*j	21*45	0.8	15.1	25*52	1.3	31.7
μ*jet	-	-	15.1	15*40	0.8	32.5
Min. bias	-	0.9	16.0	-	1.0	33.5
TOTAL			16.0			33.5

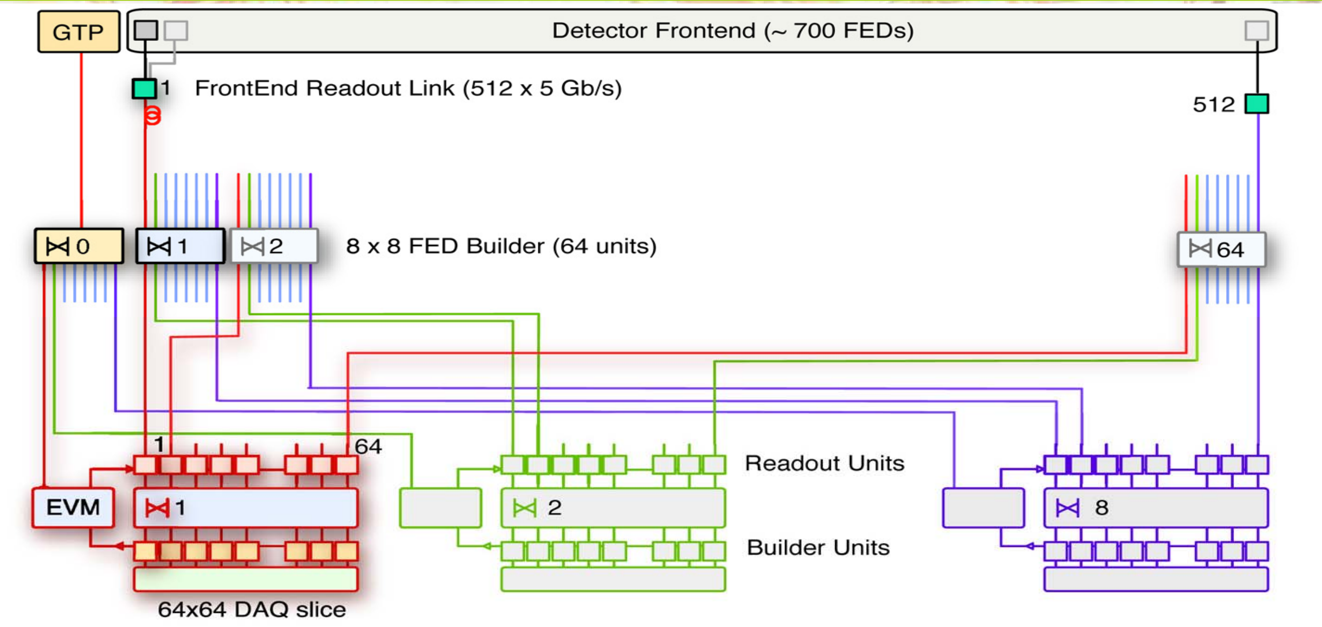
$\times$ 3 safety factor

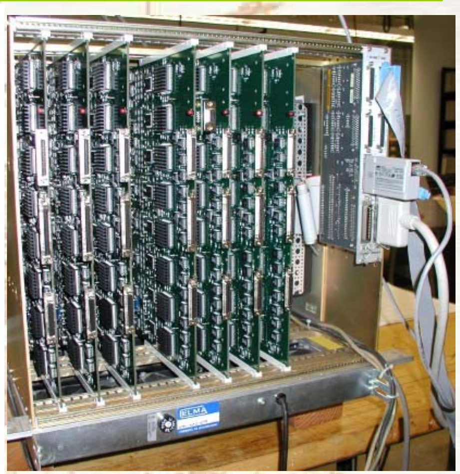
CMS Trigger/DAQ Evolution

- CMS DAQ is a number of functionally identical, parallel, small DAQ systems
  - Build up 512×512 switch from 8 64×64 switches (1/8th DAQ slice)
- Turn-on in 2007 expected to have 4 such slices (US contributes one slice), yielding 50 kHz maximum Level-1 input rate to HLT
  - L1 fully scoped to deliver up to 100 kHz rate, and front-ends able to absorb 100 kHz rate



High Level Triggers





- A Filter Farm with commodity PCs does everything beyond Level-1
- HLT does partial event reconstruction "on demand" using full detector resolution
- Historically: Level-2 uses only calorimeter + muon
  Level-3 uses tracker (90% of data volume)

High-Level Triggers

- Reduces the rate from 100 kHz to O(100 Hz)
  - Final rate will depend on data bandwidth, storage capability, and background rejection capability
  - Deployed as software filters running in an online computer farm (~1000 year 2007 PCs)
  - Software is in principle the same as used offline
- Starts with a data sample already enriched in physics!
  - Level-1 already applied a factor 400 background rejection
- What can be done:
  - Electrons: require high-p_T track match to veto π^0 fakes, recover bremsstrahlung
  - Photons: veto tracks
  - Muons: require high-p_T track match to improve p_T resolution
  - Jets: run standard jet algorithms
  - Tracks: improve measurement of impact parameter, p_T, and charge
  - Quality: Apply isolation criteria to all leptons
  - Event shape: Apply topological and invariant mass cuts

Crude HLT Trigger Table

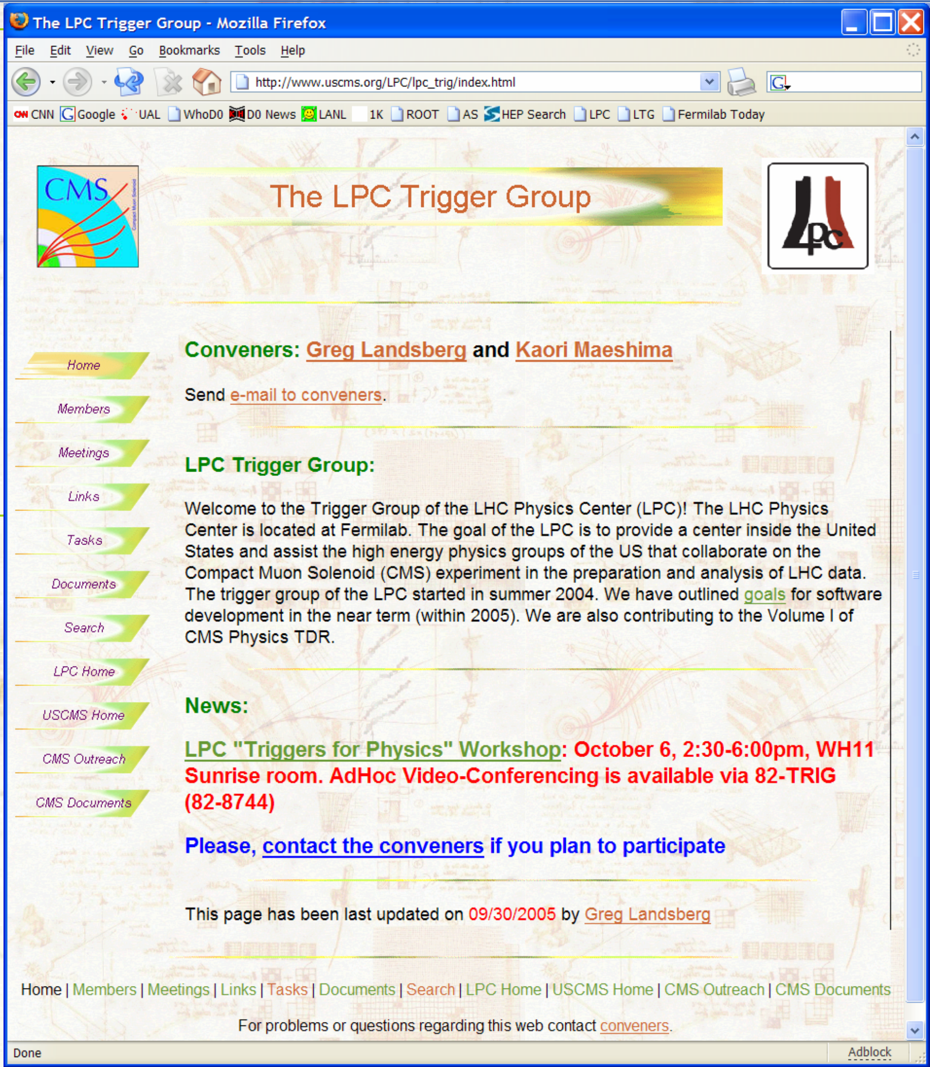
Trigger	Threshold (GeV)	Rate (Hz)	Cumulative Rate (Hz)
Inclusive Electron	29	33	33
Di-electrons	17	1	34
Inclusive Photon	80	4	38
Di-photons	40, 25	5	43
Inclusive Muon	19	25	68
Di-muons	7	4	72
Inclusive τ-jets	83	3	75
Di-τ-jets	59	1	76
1-jet * E_T^{miss}	180 * 123	5	81
1-jet OR 3-jets OR 4-jets	657, 247, 113	9	89
Electron * Jet	19 * 45	2	90
Inclusive b-jets	237	5	95
Calibration etc. (10%)	-	10	105
TOTAL	-	-	105

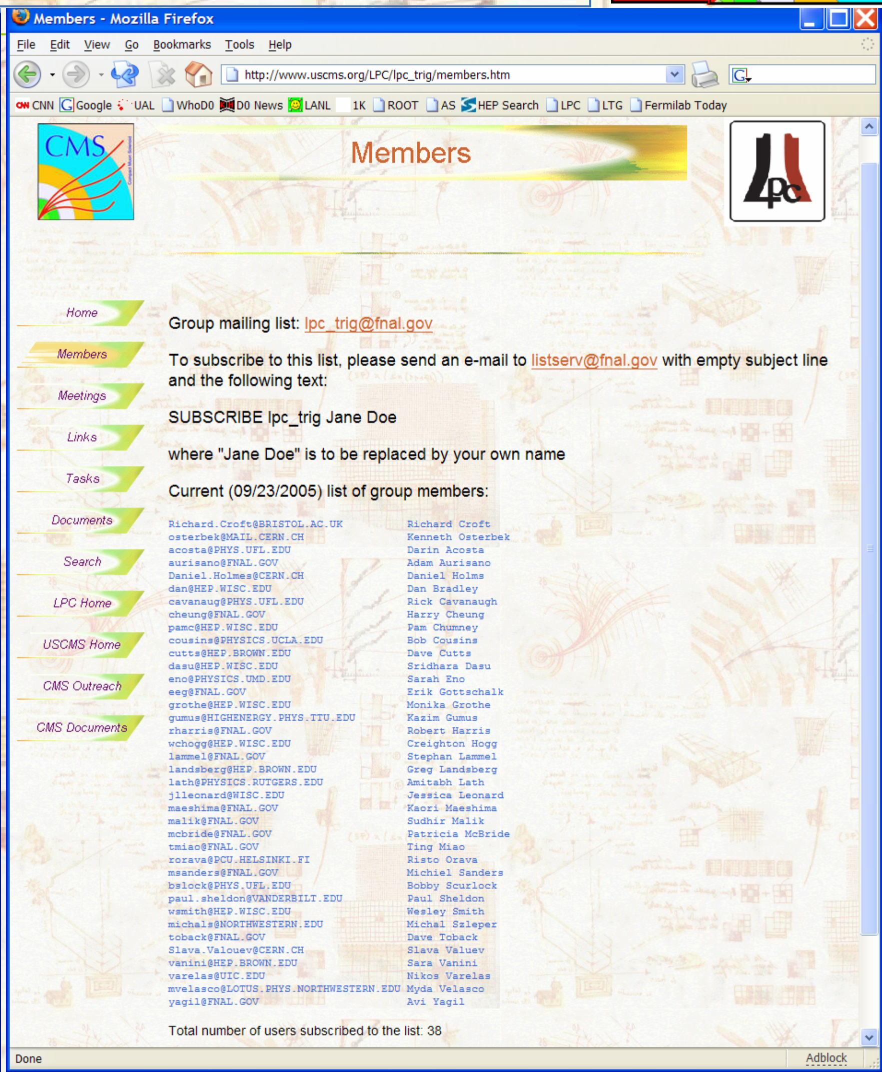
"Low" Luminosity (2×10^{33} cm^{-2} s^{-1})

LPC Trigger Group Logistics

- Conveners:
  - Kaori Maeshima & GL
- LPC Trigger Group Mailing List:
  - lpc_trig@fnal.gov; to subscribe, send an e-mail to listserv@fnal.gov with a single line in the body: SUBSCRIBE lpc_trig Jane Doe ← (replace with your name!)
- LPC Trigger Group Web Site:
  - http://www.uscms.org/LPC/lpc_trig/index.html, linked from the LPC Working Group page
- Trigger Meeting Schedule:
  - Every other Thursday, 2:30-4pm, Sunrise
    - Ad-Hoc video is available via 82-TRIG
    - There is a meeting later TODAY!

LPC Trigger Group Web Site





LPC Trigger Group Mission

- Play a leading role in the development, tuning, monitoring, and commissioning of Level 1 Triggers (LOT), High-Level Triggers (HLT), and related tools for the CMS experiment
- Develop a well-defined and realistic trigger table tailored for high-priority physics topics, commissioning, and calibration of the CMS detector by summer 2007
- Take a leading role in the ongoing effort of setting-up, commissioning, and operation of the CMS Remote Operation Center (ROC) at Fermilab
- All these efforts are pursued with close coordination with other working groups, e.g., OSG (online selection), EVF/DQM (Event filtering/Data Quality Monitoring), Trigger/DAQ, Detector-Sub-Groups, Offline, PRS, etc

Summary

- CMS Trigger system reduces the rate by an overall factor of roughly 10^6 while maintaining good efficiency
- Level-1:
  - First factor of 1000
  - Hadronic τ trigger implemented
  - Sliding window jet triggers
  - Isolated and non-isolated lepton triggers (without central tracking)
  - 128 trigger lines available
- HLT:
  - Second factor of 1000
  - Access to full event information
  - Partial reconstruction based on the calorimeter and muon systems initially (verify and improve Level-1 decision), followed by pixel + tracker information for final rejection
- Lots of flexibility in both Level-1 and HLT; lots of work to do!