Introduction to the CMS Trigger

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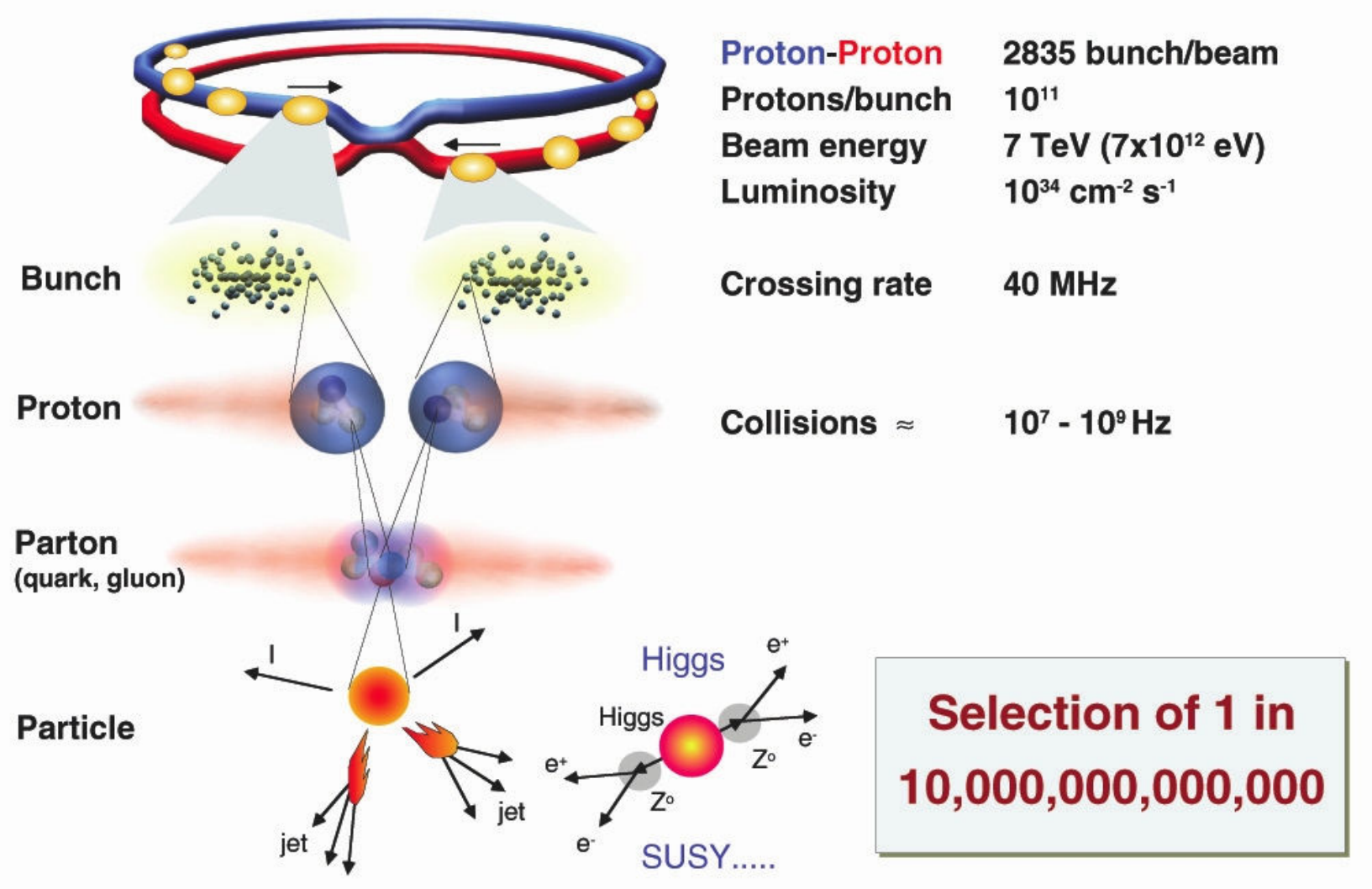
Outline

- Trigger Challenges at the LHC
- CMS Trigger Architecture
  - Level-1 Trigger
  - High Level Trigger
- Trigger Rates and Menus
- HLT Processing Times
- CMS Trigger Group Structure

The Large Hadron Collider



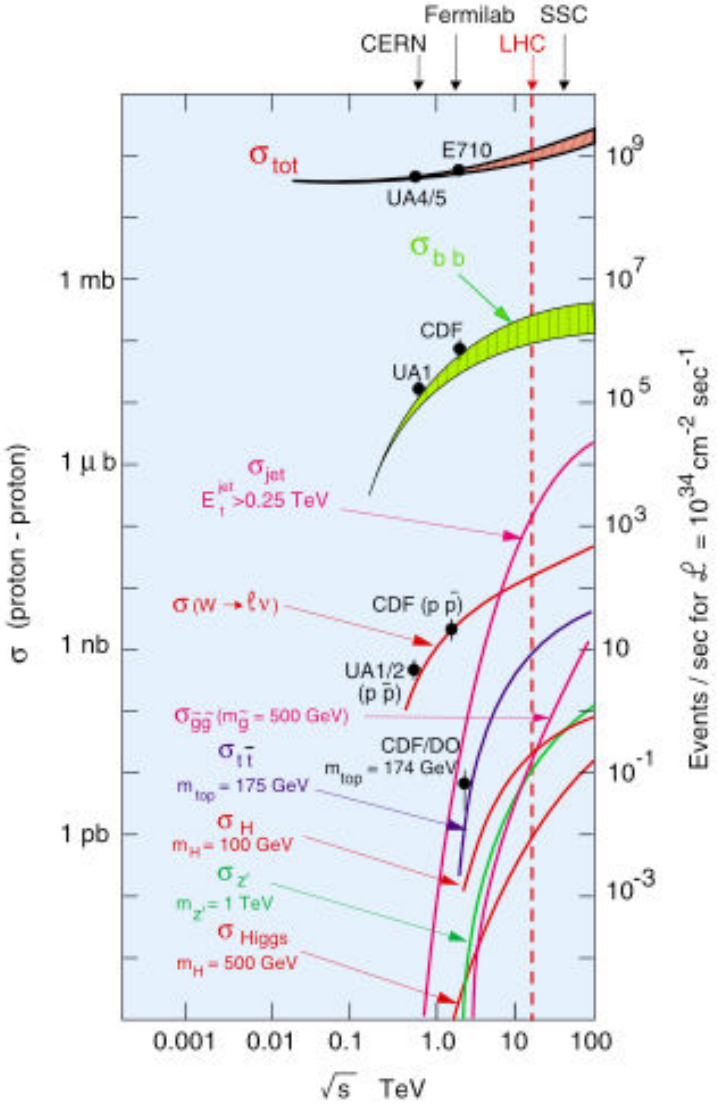
Proton-Proton	2835 bunch/beam
Protons/bunch	10^{11}
Beam energy	7 TeV (7×10^{12} eV)
Luminosity	10^{34} cm^{-2} s^{-1}
Crossing rate	40 MHz
Collisions ≈	10^{7} - 10^{9} Hz

Selection of 1 in 10,000,000,000,000

Tevatron vs LHC

	CDF/DØ	CMS
Inst. Luminosity	10^{32}	10^{34}
Bunch crossing freq.	2.5 MHz (396ns)	40 MHz (25ns)
Pileup	≈2 events	≈20 events
L1 output rate	2-10 kHz	100 kHz
L2 output / HLT input	~500 Hz	–
L3 output rate	50 Hz	100 Hz
Filter Farm	~300 nodes	~1000 nodes

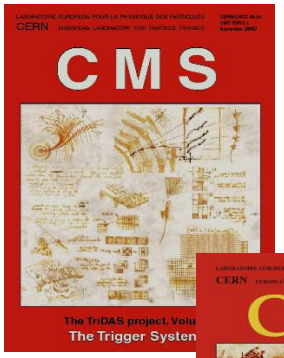
Trigger Challenges at the LHC



- At design L = 10^{34} cm^{-2}s^{-1}
  - Interaction rate: ~1 GHz
  - ~20 pp events per 25 ns crossing
  - 1 kHz W events
  - 10 Hz top events
  - < 10^4 detectable Higgs decays/year
- Event size: ~1 MB (≈75M channels)
  → 1000 TB/sec for 1 GHz input rate
  - ~300 MB/sec affordable
  - Enormous rate reduction necessary!
    - but without losing interesting physics
- Select in stages:
  - Level-1 Triggers
    - 1 GHz to 100 kHz (1/10000 reduction)
  - High Level Triggers
    - 100 kHz to 100 Hz (1/1000 reduction)

References

- Level-1 Trigger Technical Design Report:
  - *CERN/LHCC 2000-038*
- DAQ and High-Level Trigger Technical Design Report:
  - *CERN/LHCC 2002-026*
- Physics Technical Design Report Volume 2 Appendix E:
  - *J. Phys. G: Nucl. Part. Phys.* **34** 995-1579
- CMS High Level Trigger Analysis Note:
  - *AN 2007/009*
- Also a note describing the outcome of the Winter/Spring trigger reviews is being prepared
  - Expected to be available in September



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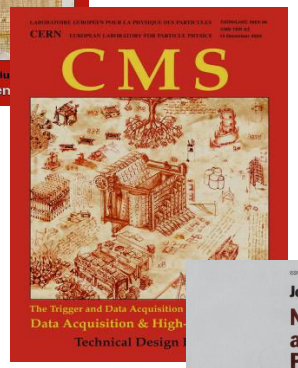

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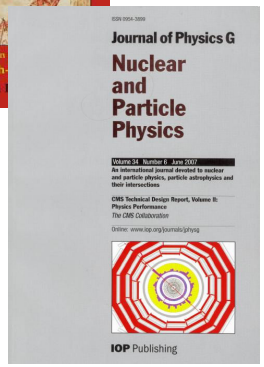

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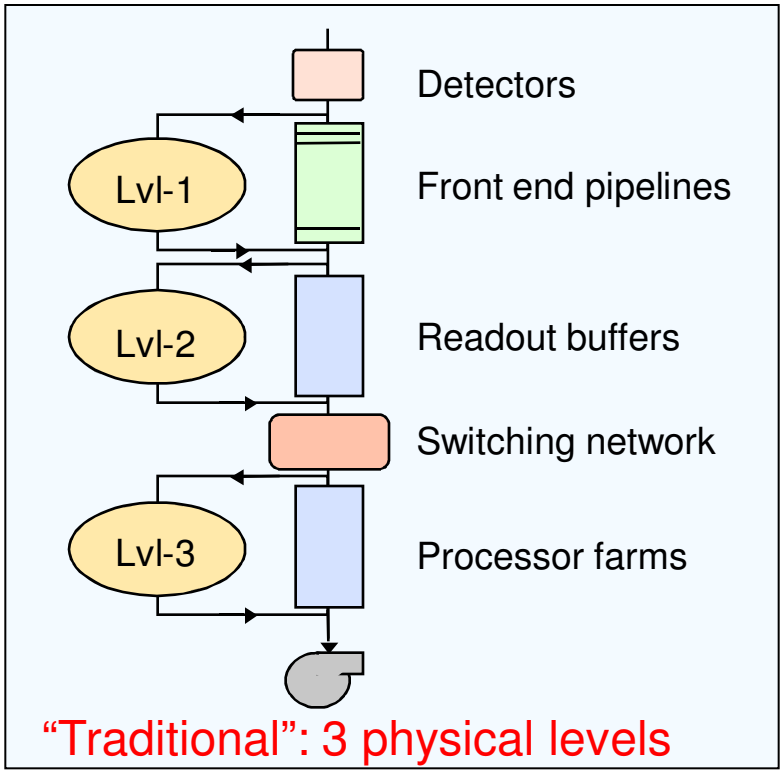
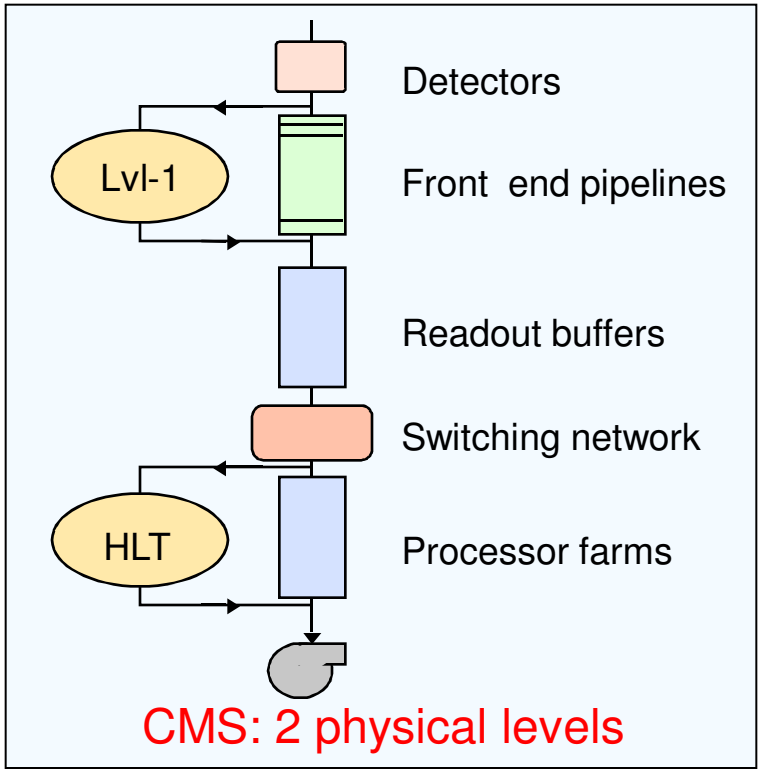
Trigger Architecture

- CMS has a two-tiered system to handle the LHC challenge
  - Level-1 trigger reduces rate from 40 MHz (x^{ing} freq) to 100 kHz (max)
  - High-Level triggers reduce rate from 100 kHz to O(100 Hz)

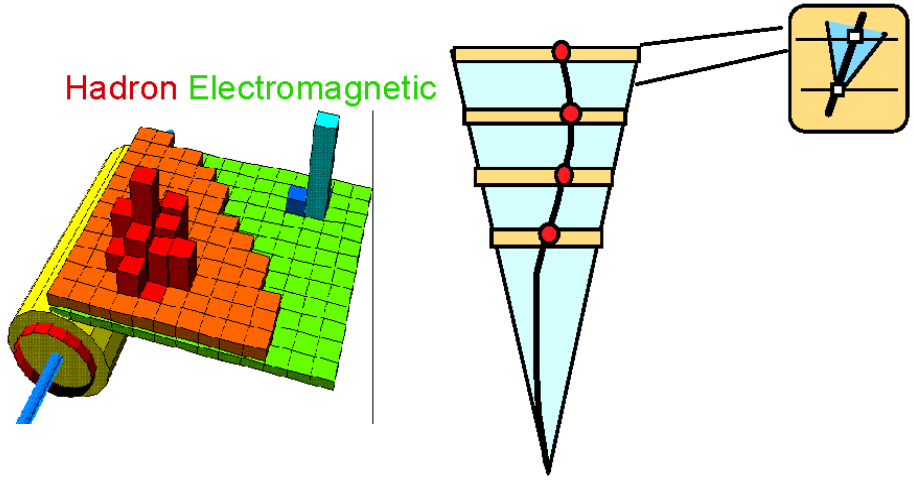




- Progress in networking/switching has justified CMS choice

Level 1: Only Calorimeter & Muon

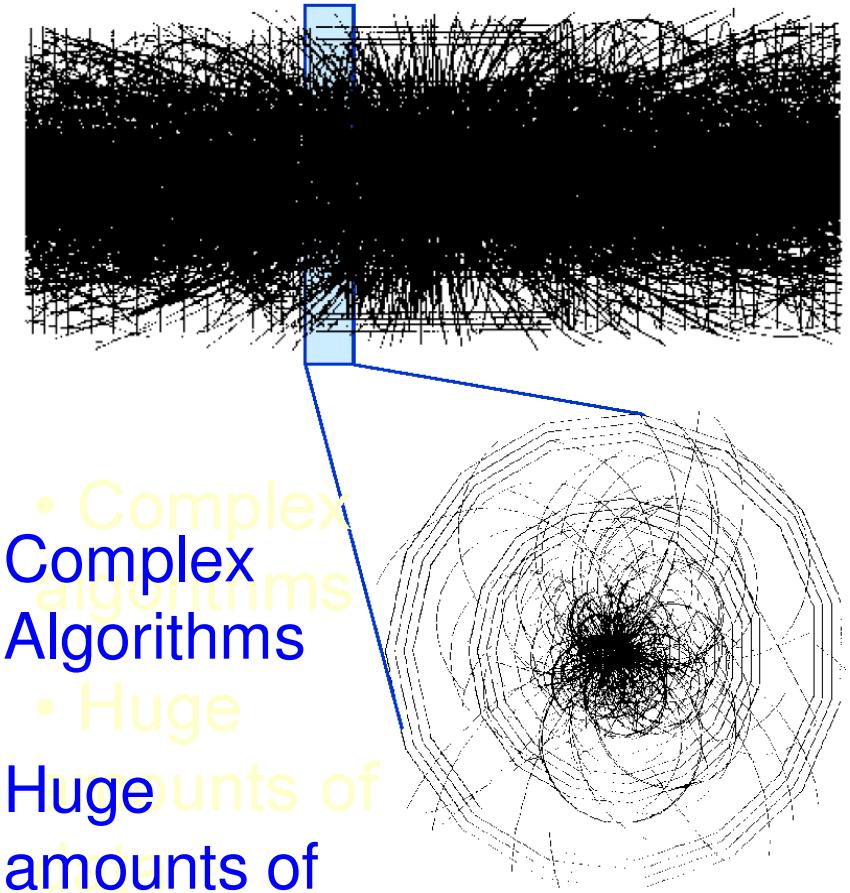
- **Pattern recognition much faster/easier**



Simple Algorithms

Small amounts of data

- **Compare to tracker info**

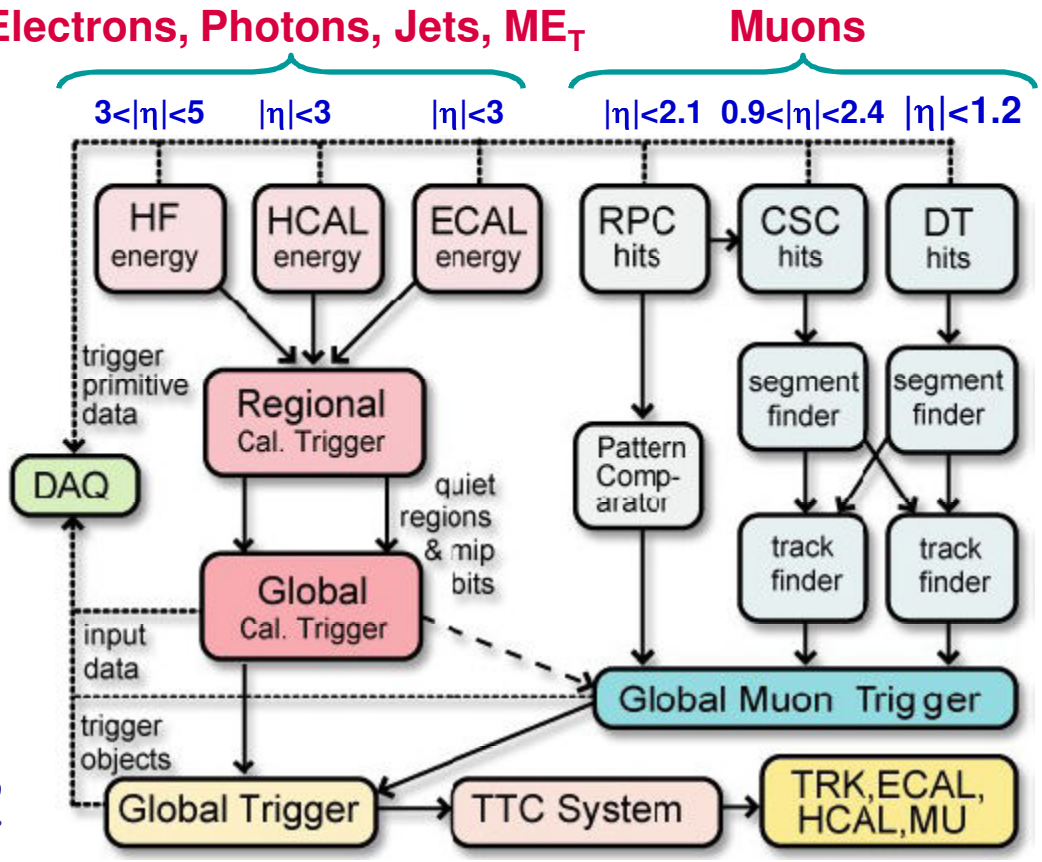


Complex Algorithms

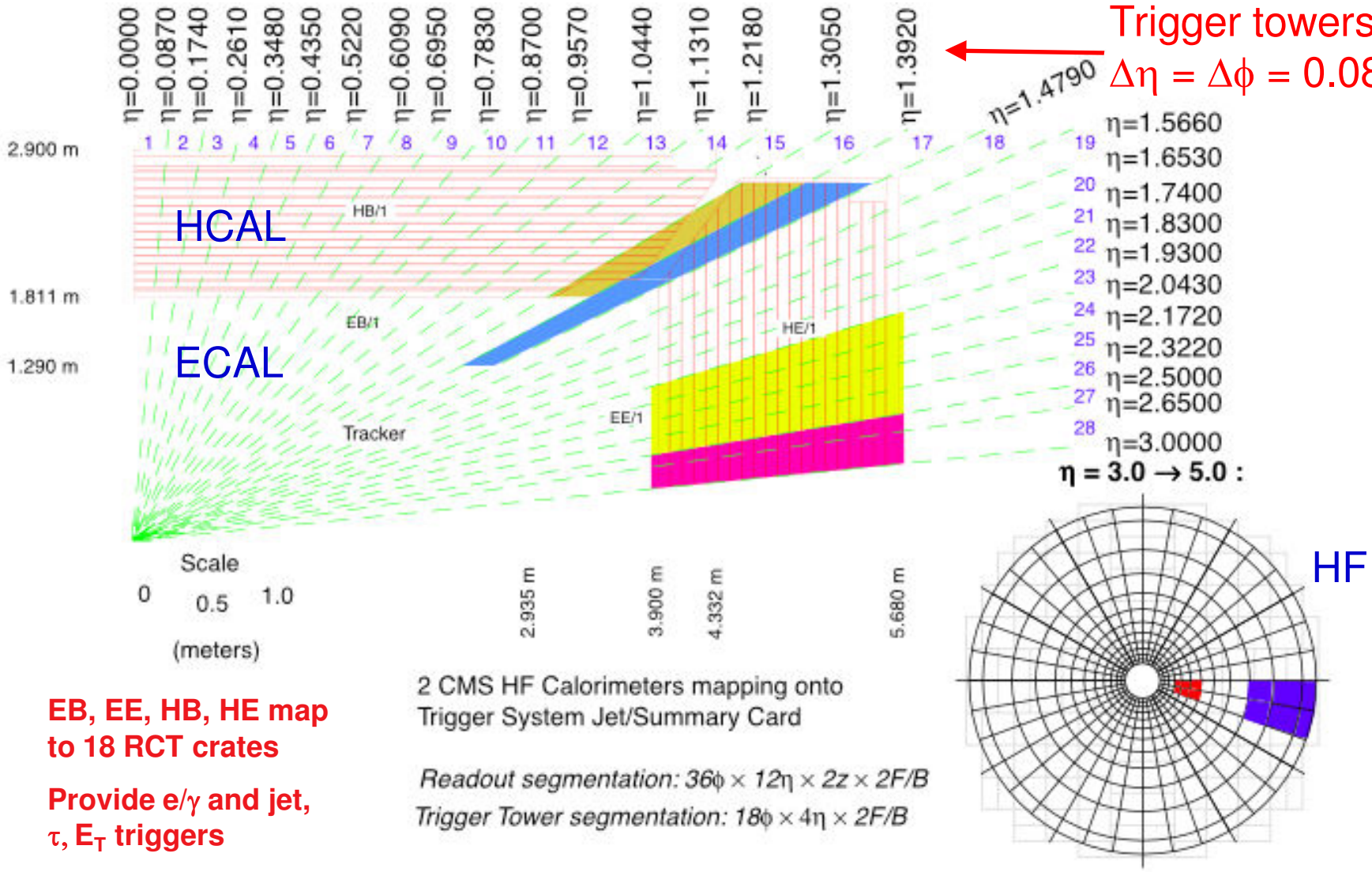
Huge amounts of data

The Level-1 Trigger

- Reduce data rate from 40 MHz to 100 kHz while keeping the interesting physics events
  - Custom electronic boards and chips
- Selects muons, electrons, photons, jets
  - E_T and location in detector
- Also Missing E_T, Total E_T, H_T, and jet counts
- Total decision latency: 3.2 μs



Calorimeter Trigger Geometry



Trigger towers:
$\Delta\eta = \Delta\phi = 0.087$

HF

2 CMS HF Calorimeters mapping onto Trigger System Jet/Summary Card

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

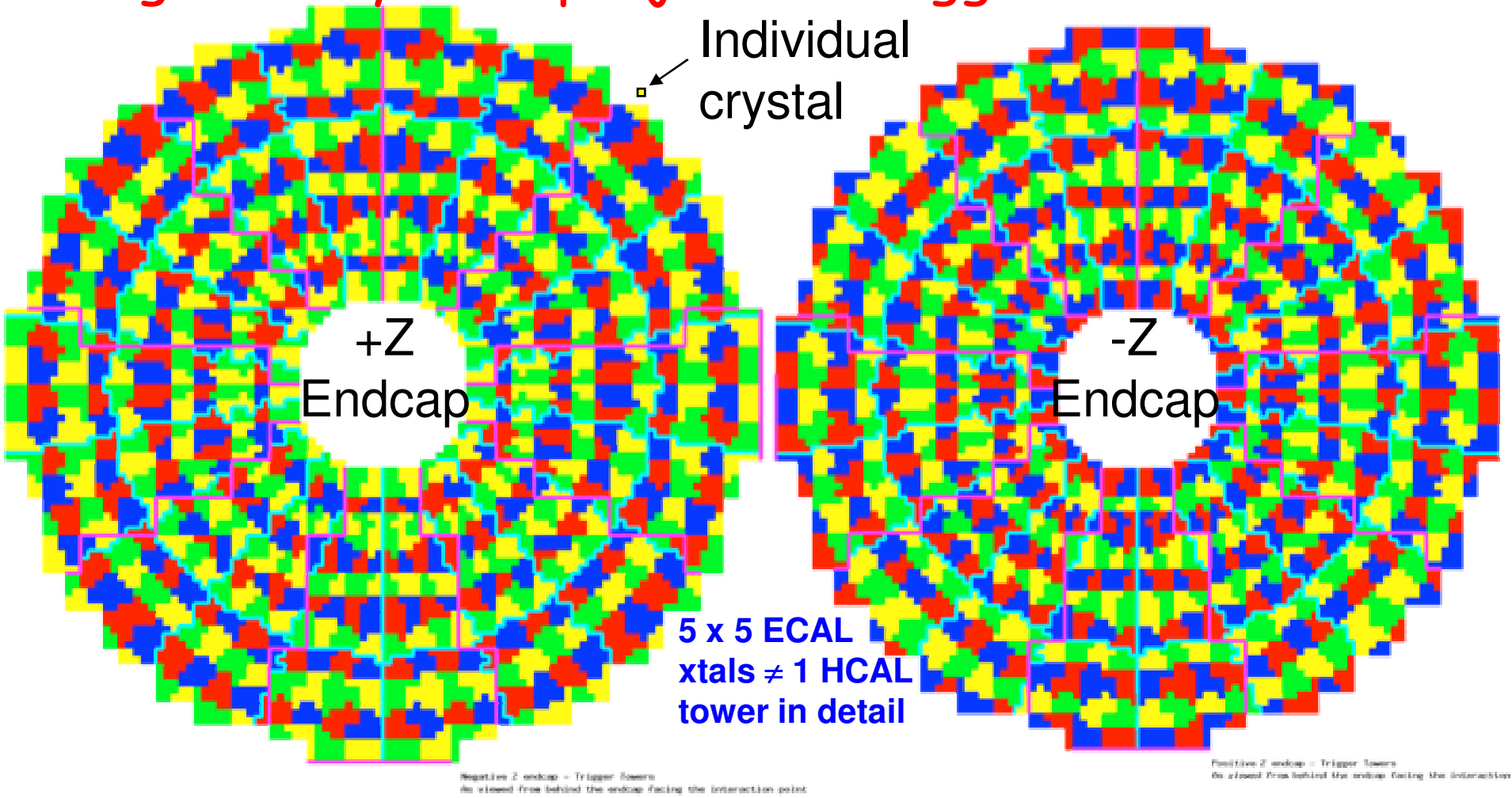
Trigger Tower segmentation: 18ϕ × 4η × 2F/B

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

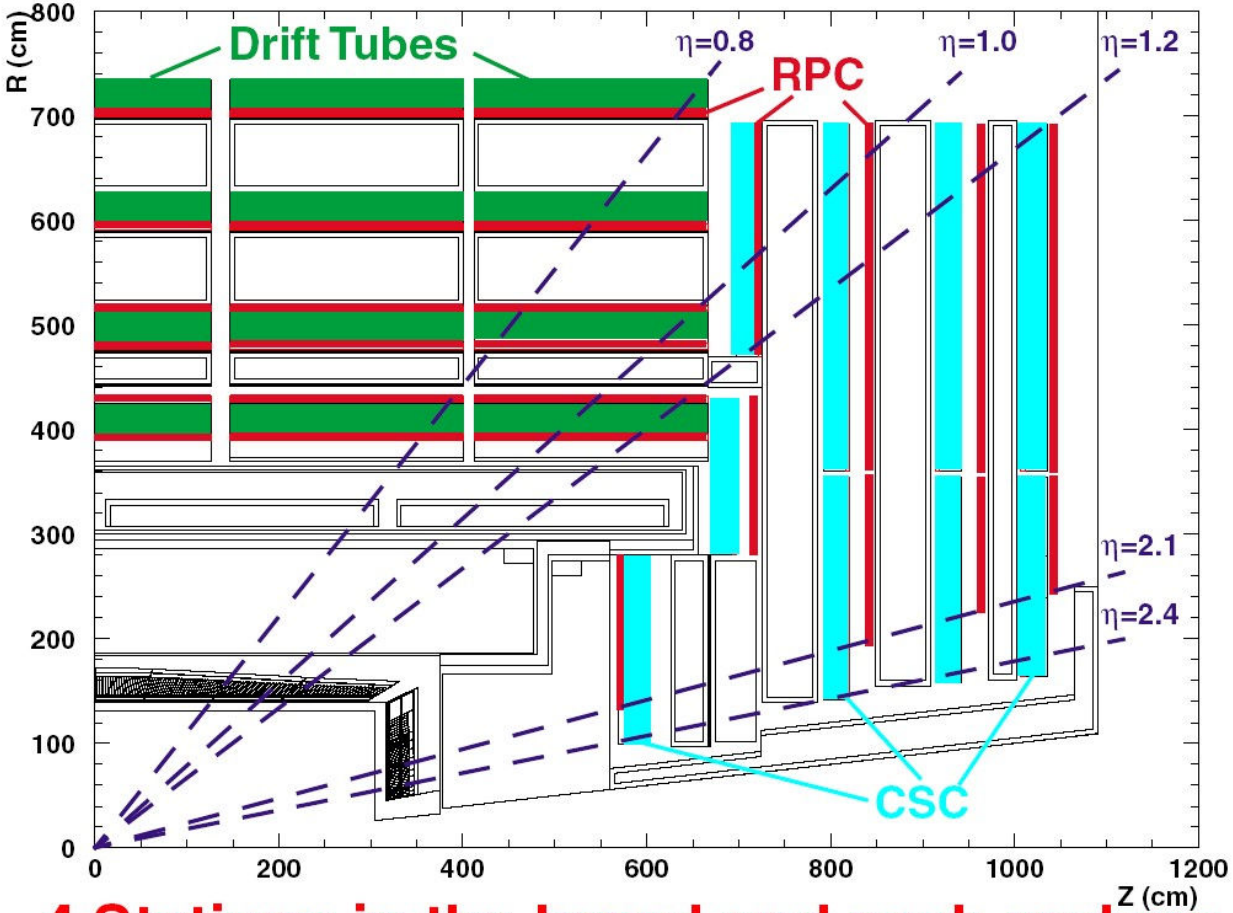
Provide e/γ and jet, τ, E_T triggers

ECAL Endcap Geometry

- Map non-projective x-y trigger crystal geometry onto projective trigger towers:



Muon Trigger Geometry



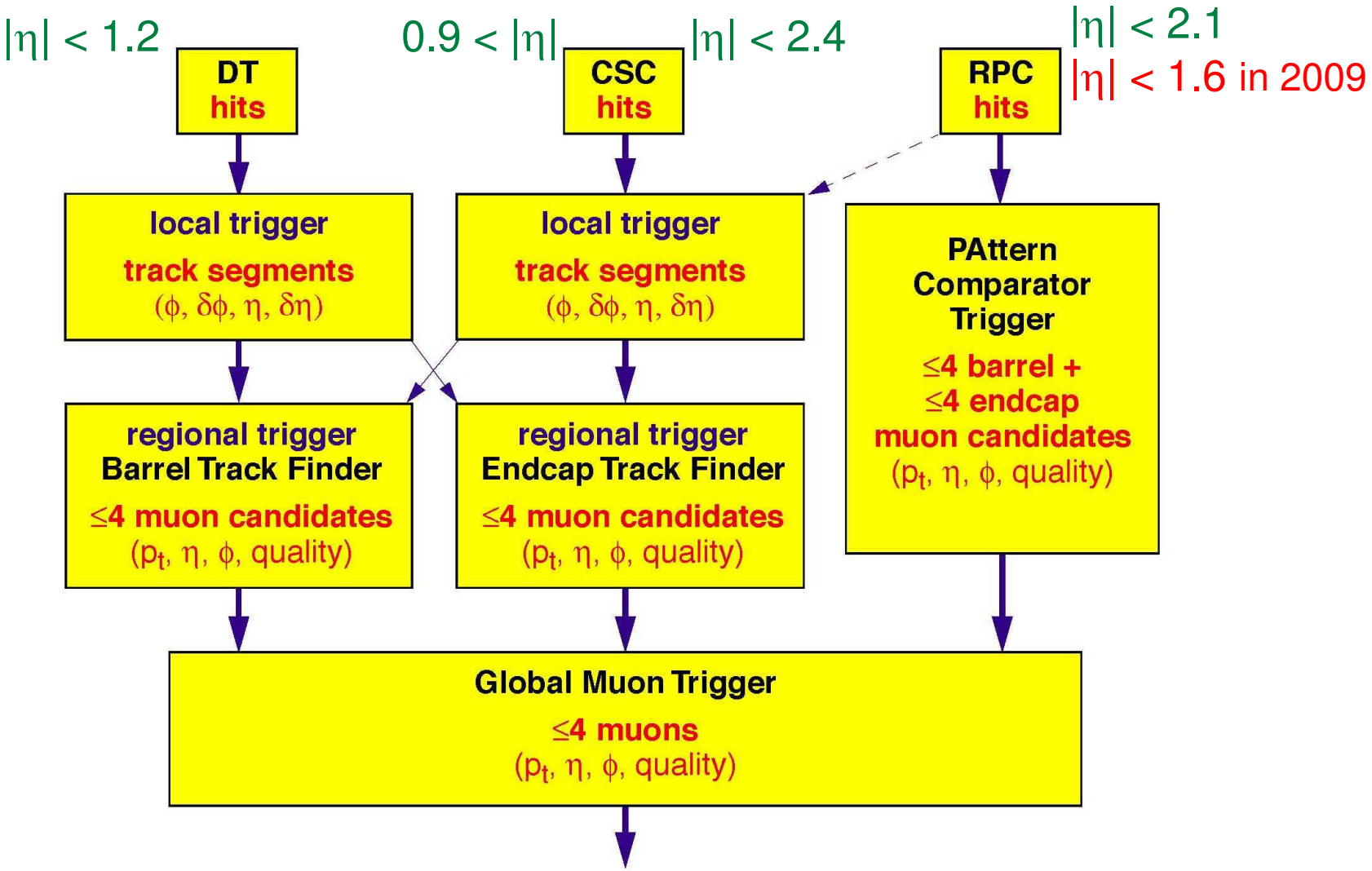
4 Stations in the barrel and each endcap

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



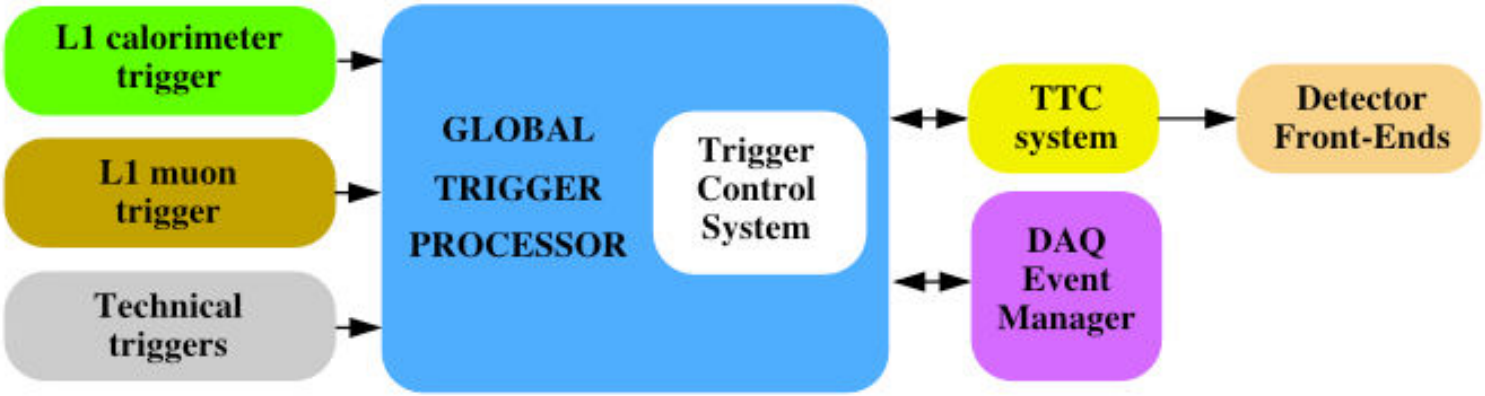
Level-1 Global Trigger

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

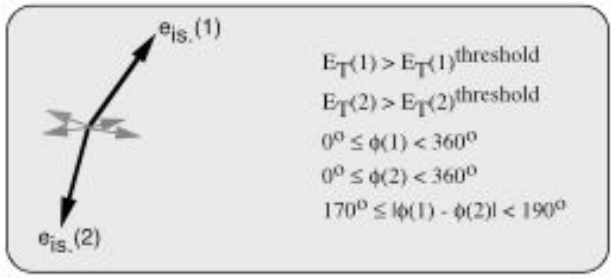
Output

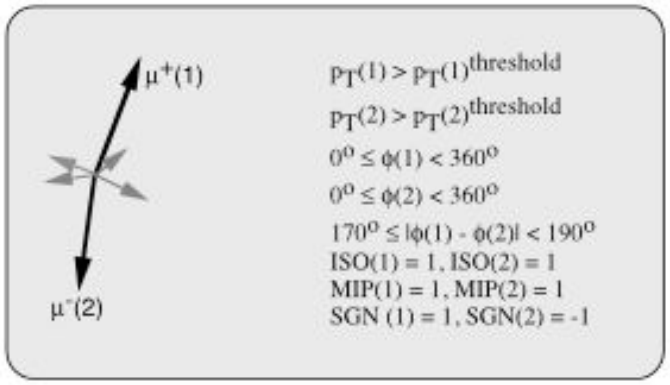
- L1 Accept from combinations & proximity of above



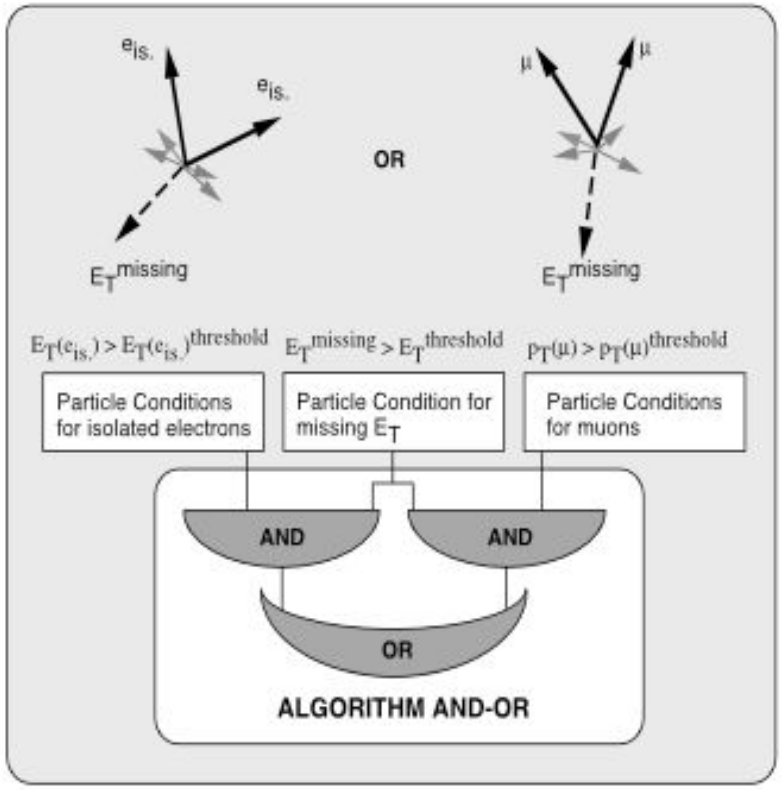
L1 Global Trigger Algorithms

Particle Conditions





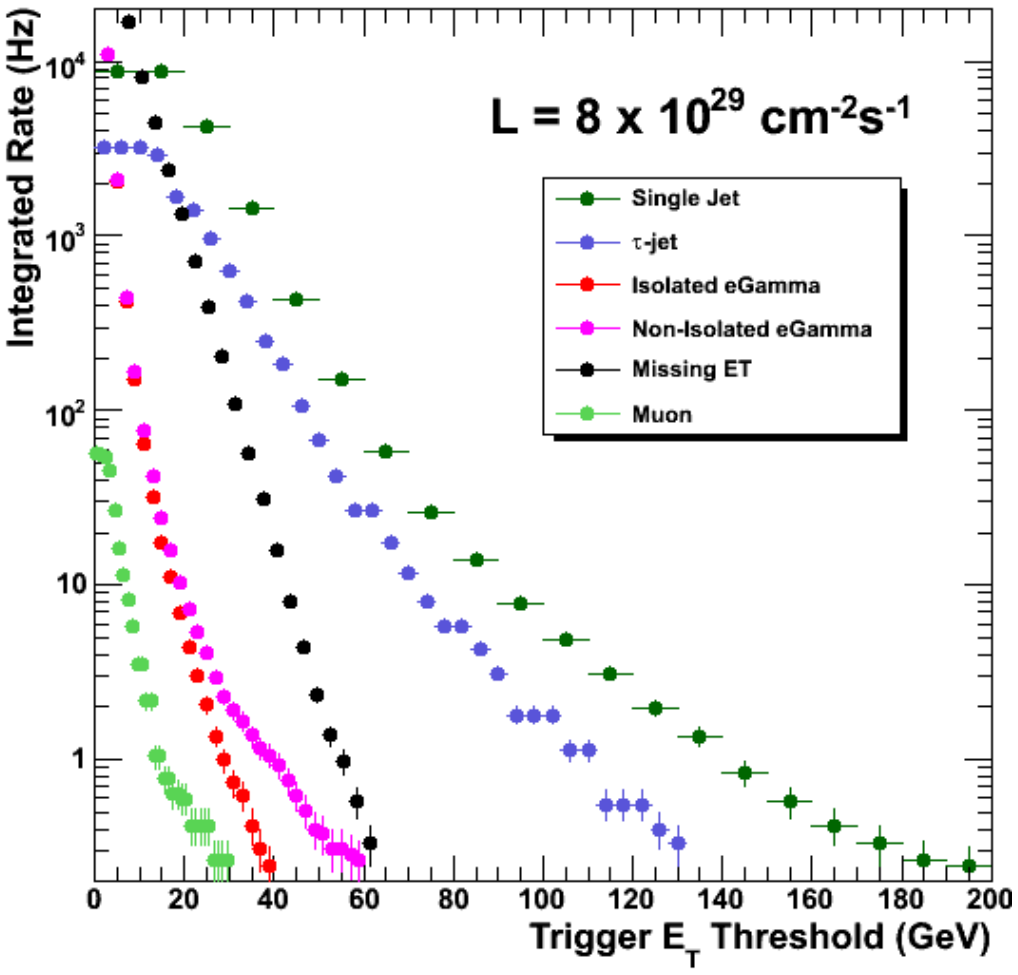
Logical Combinations



128 Level-1 trigger bits. Bits can be set using (up to 128) logical combinations of Level-1 objects.

Thus it is possible to use a single Level-1 bit to seed multiple independent HLT paths.

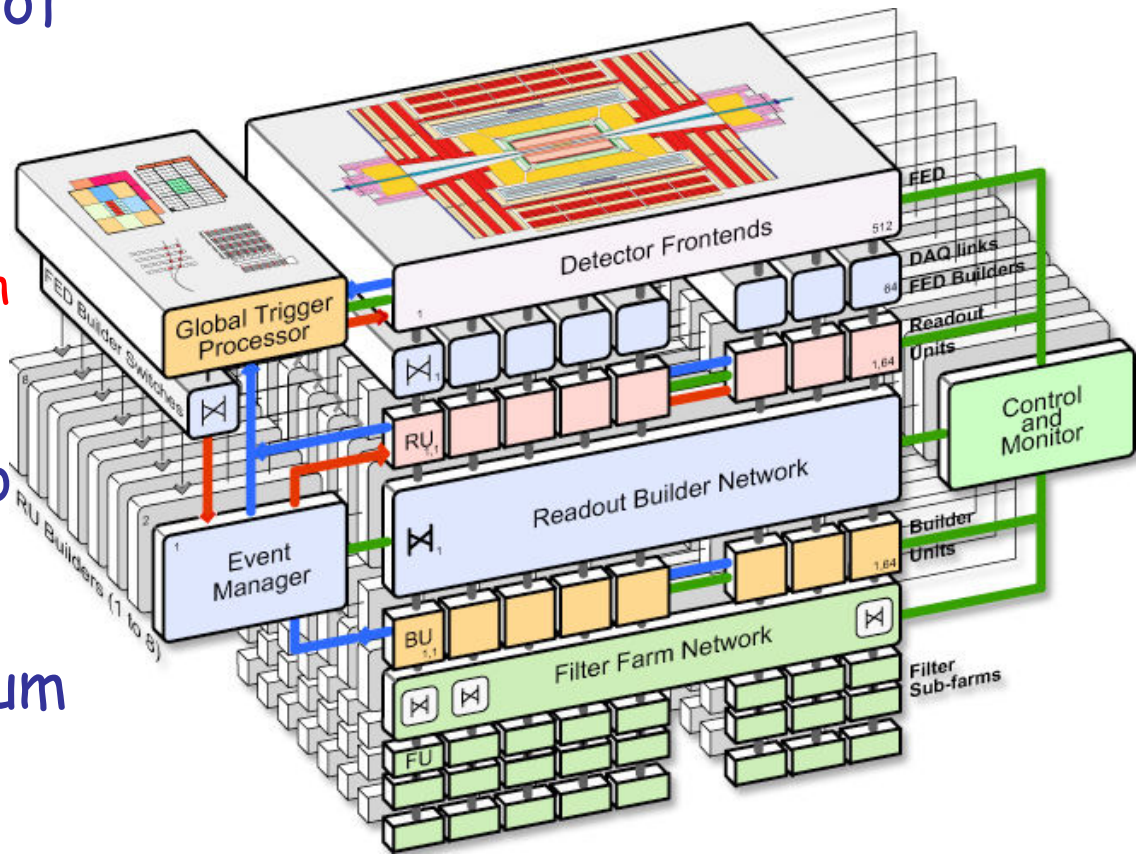
Level-1 Trigger Menu



- Determined by the physics priorities of the experiment
- L1 Menu optimized to fit within the L1 bandwidth
- Allow a safety factor of 3
  - underestimation of input cross sections, poor beam conditions, detector performance, etc.
  - 17 kHz instead of nominal 50 kHz allowed by DAQ
- Realistic menu including double and mixed triggers for specific physics channels
- Two L1 menus currently available
  - L = 8e29 $cm^{-2}s^{-1}$ (day-1 menu)
  - L = 1e31 $cm^{-2}s^{-1}$ (MC studies)

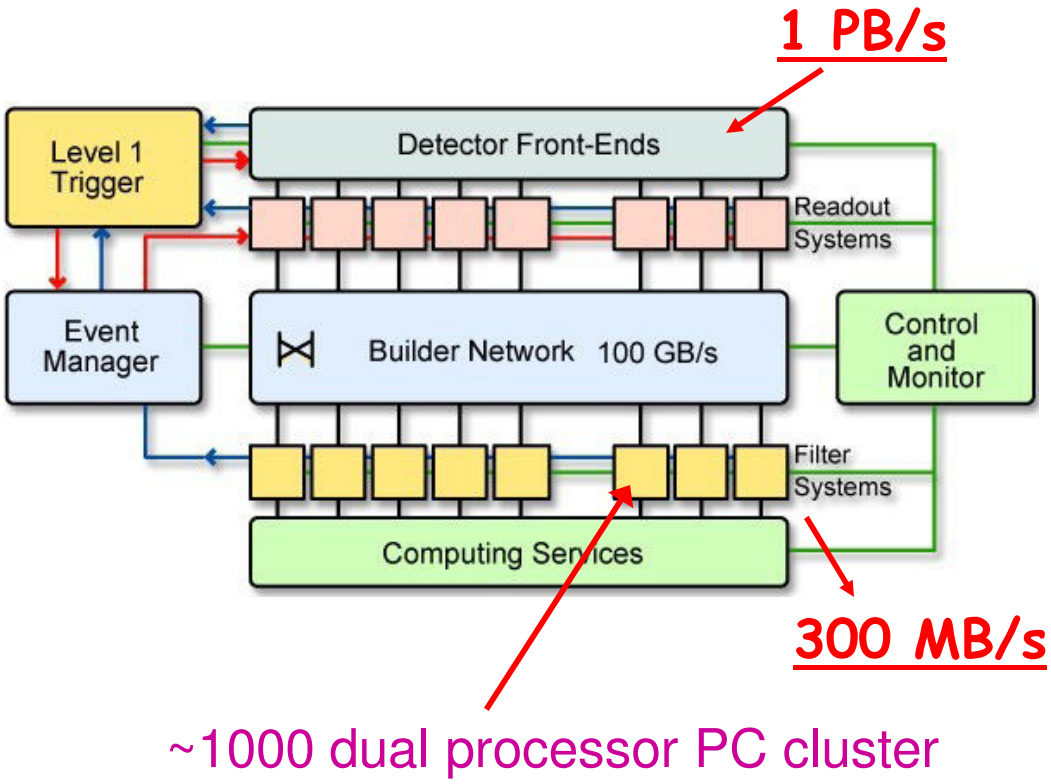
CMS Trigger/DAQ Evolution

- CMS DAQ is a number of functionally identical, parallel, small DAQ systems
  - Build up 512×512 switch from 8 64×64 switches (DAQ slices)
- At startup 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

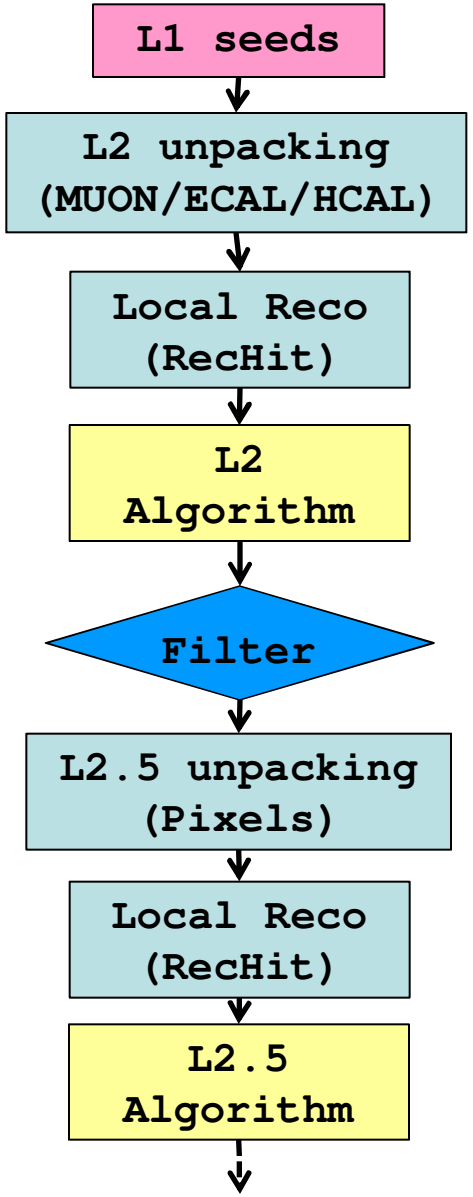


High Level Trigger (HLT)

- High-Level triggers reduce rate from 50 kHz to O(150 Hz)
- HLT does event reconstruction "on demand" seeded by the L1 objects found, using full detector resolution
- Algorithms are essentially offline quality but optimized for fast performance



HLT Algorithm Design



- Each HLT trigger path is a sequence of modules
- Processing of the trigger path stops once a module returns false
- Reconstruction time is significantly improved by doing regional data-unpacking and local reconstruction across HLT
- All algorithms regional
  - Seeded by previous levels (L1, L2, L2.5)

"Local": using one sub-detector only
"Regional": using small (η, φ) region

Trigger Menu for L=8e29 $cm^{-2}s^{-1}$

- Total L1 rate 6 kHz
  - L1 scales optimized for low luminosity
- Muons:
  - L1/L2/L3 muons run unprescaled at p_T=20/9/3 GeV
- Electrons:
  - No isolation requirements at L1
  - Unprescaled at p_T=10 GeV with large pixel-matching window (LW)
- Photons:
  - No isolation requirements at L1
  - Unprescaled at p_T=15 GeV with no isolation requirement
- Jets:
  - No L1/HLT jet corrections, except for 0.7 scale factor in HF
  - Unprescaled at p_T=30 GeV (~60 GeV corr.)
- MinBias:
  - Several algorithms installed based upon HF-tower E_T over threshold, HF E_T ring sums, Ecal E_T, and pixel triplets

Full menu available here: TSG_27_VI_09_8E29

Trigger Rates by Object

- Muon: 33 Hz
- Electron: 30 Hz
- Photon: 9 Hz
- Jet: 36 Hz
- MET & HT: 5 Hz
- B-Tau: 4 Hz
- MinBias: 14 Hz
- Cosmics/Halo: 7 Hz
- Total: 138 Hz

Trigger Menu for L=1e31 $cm^{-2}s^{-1}$

- Total L1 rate 9 kHz

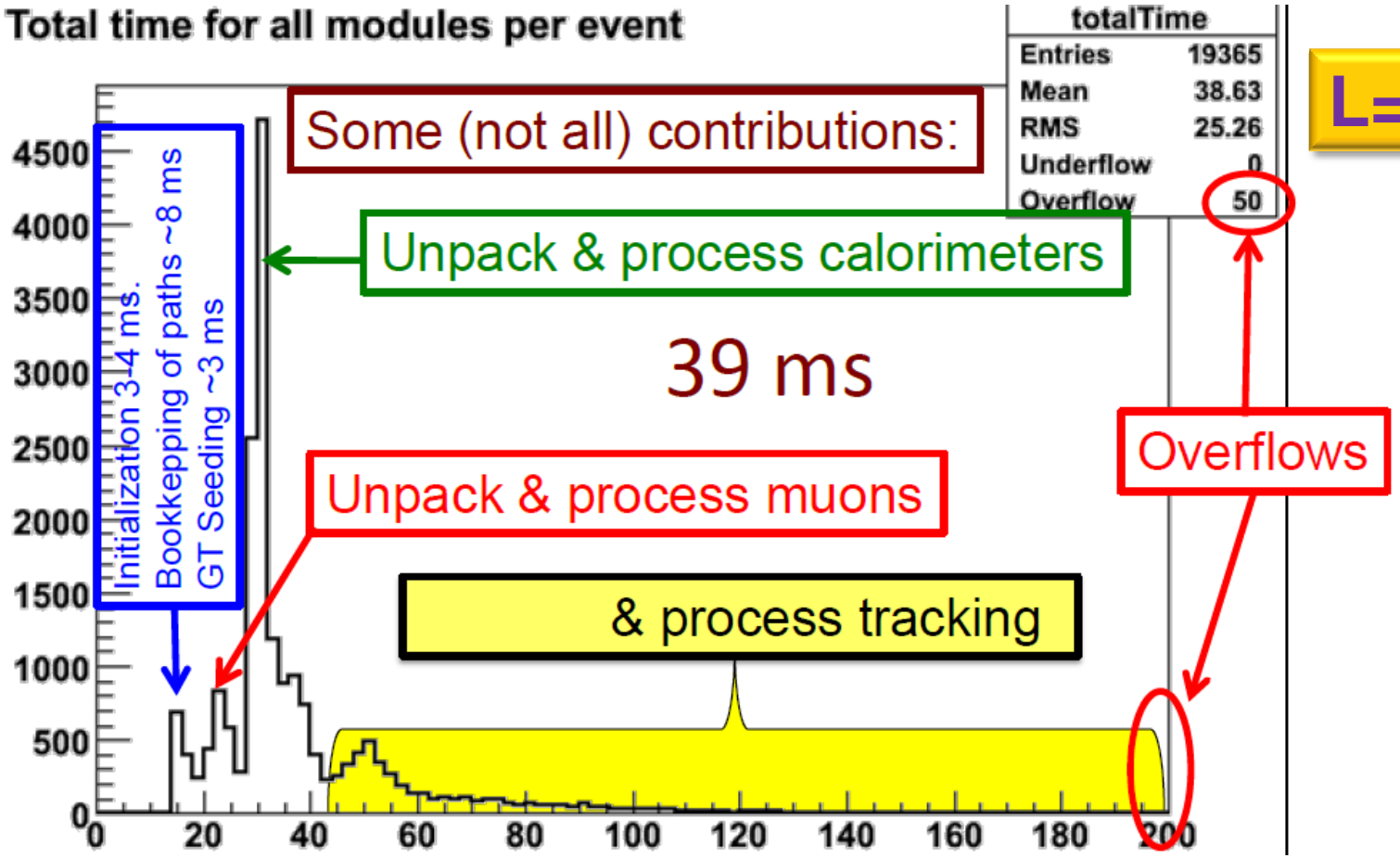
Full menu available here: TSG 27 VI 09 1E31

- Muons:
  - L1/L2/L3 muons run unprescaled at p_T=20/11/9 GeV
- Electrons:
  - No isolation requirements at L1
  - Unprescaled at p_T=20 GeV with no isolation & at 15 GeV with loose track isolation
- Photons:
  - No isolation requirements at L1
  - Unprescaled at p_T=25 GeV with no isolation requirement
- Jets:
  - Anticipate L1/HLT jet corrections will be available. Using MC-based corrs. for now
  - 4 jet thresholds. Unprescaled at p_T=110 GeV
- MinBias:
  - Several algorithms installed based upon HF-tower E_T over threshold, HF E_T ring sums, Ecal E_T, and pixel triplets

Trigger Rates by Object

- Muon: 37 Hz
- Electron: 25 Hz
- Photon: 22 Hz
- Jet: 18 Hz
- MET & HT: 9 Hz
- B-Tau: 13 Hz
- X-Triggers: 11 Hz
- MinBias: 8 Hz
- Total: 144 Hz

HLT Processing Times

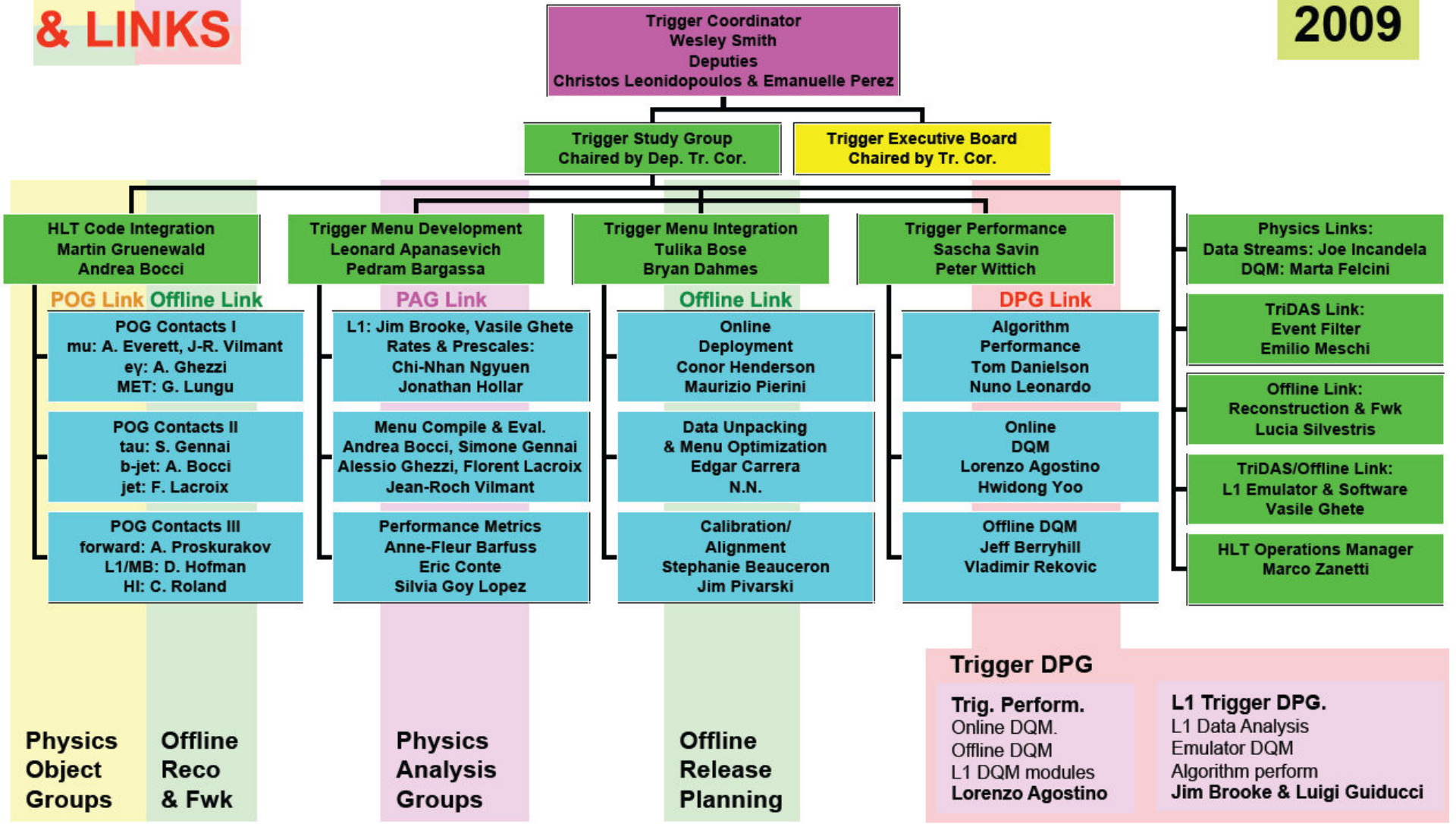


- HLT CPU time budget ~40ms/event
  - Assuming an L1 output rate of 50 kHz and a 2000 CPU Filter Farm
- "Tails" have a significant impact on the average time
  - Will eliminate with time-out mechanism

CMS Trigger Studies Group

& LINKS

2009



Summary

LHC Trigger is Challenging

- A new crossing every 25 ns with ~ 20 events at design luminosity $\rightarrow$ 1 GHz of events input
- All data stored 3 μs then all but 50-100 kHz rejected
  - Rejection of 99.99% of data without losing discovery physics!
- Rate of storage to archive is ~ 150 Hz
  - Rejection of 99.99997% of data without losing discovery physics!!
- Requires extremely fast processing and correlation of local and global information from ECAL, HCAL, DT,CSC and RPC systems
- Distribute & synchronize fast signals over large detector volume
- Remaining event filtering done on a farm of CPUs running offline quality reconstruction algorithms

➢ Now is a great time to get involved in Trigger and DQM activities as we prepare for real data
  - ➢ Understanding the trigger is essential for any physics analysis
  - ➢ Help is needed in many areas
  - ➢ Lots of interesting work remains to be done

Backup Slides

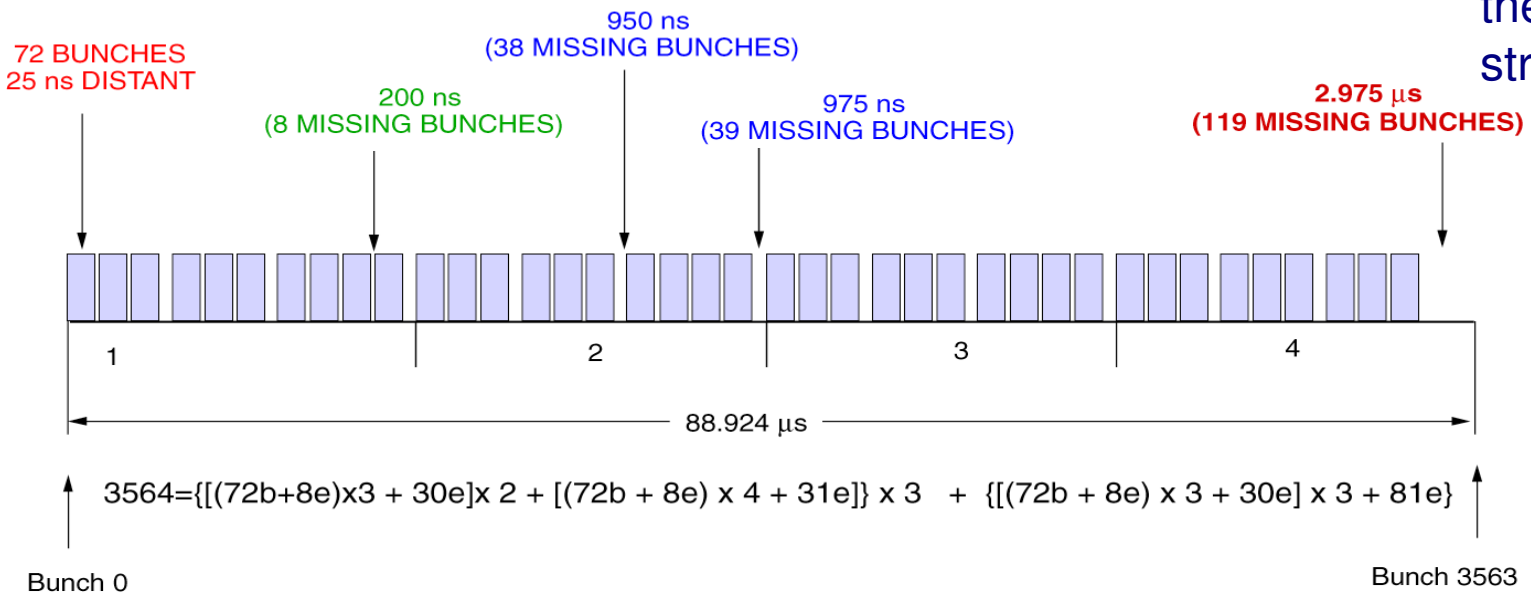
LHC Bunch Structure

Data identification with Bunch Crossing Number (Absolute synchronization)

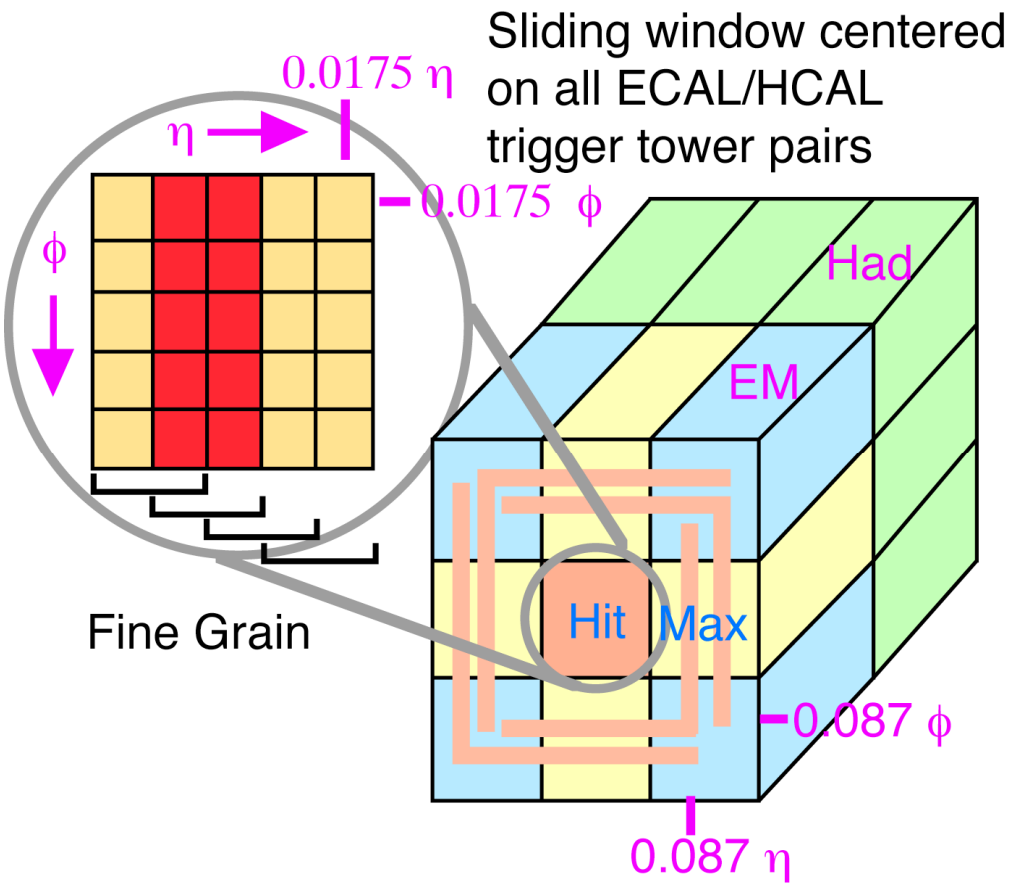
Absolute Synchronization method based on the LHC Bunch Structure

Histograms of the bunch crossing number for physics events show the gaps of the LHC beam structure

LHC bunch structure



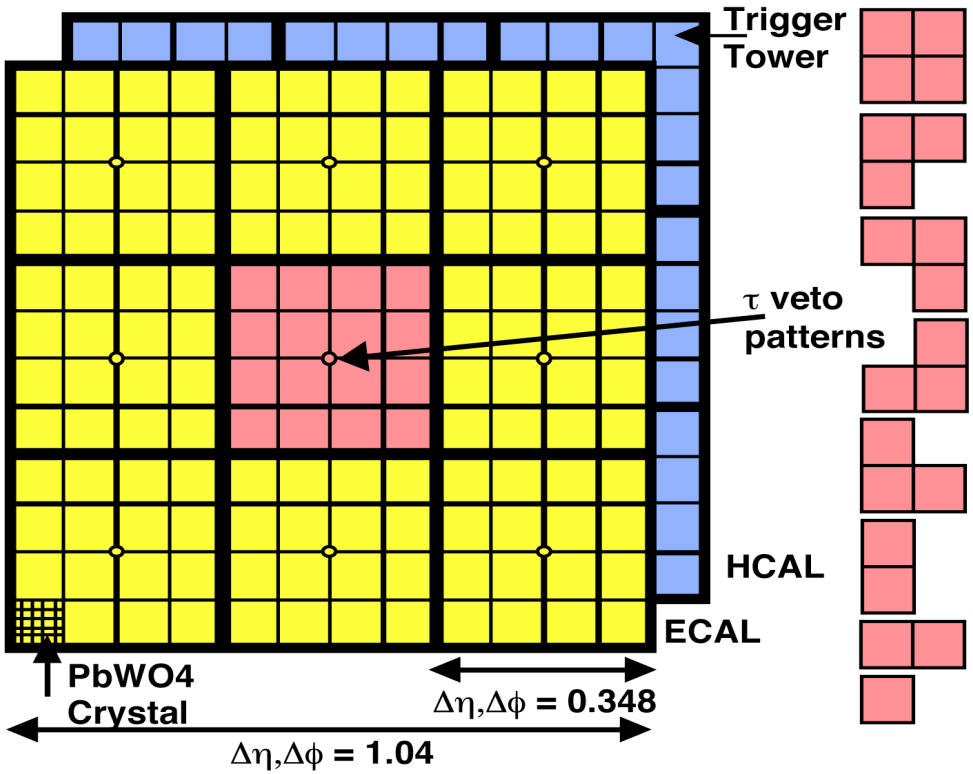
Level-1 EM Calorimeter Trigger



- 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)

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

Level-1 Jet and Tau Trigger



Jet or τ E_T

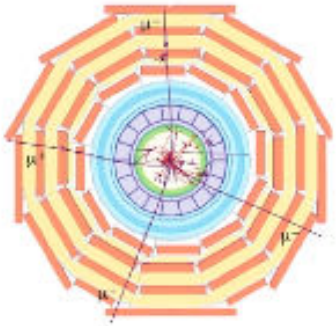
- 12x12 trig. tower ΣE_T sliding in 4x4 steps w/central 4x4 E_T > others

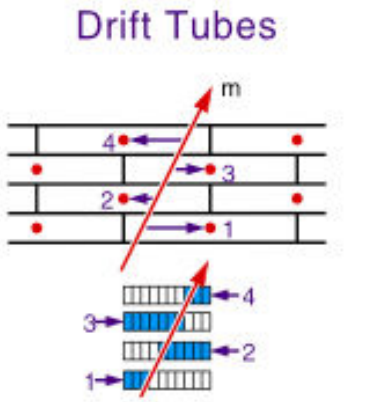
τ: isolated narrow energy deposits

- Energy spread outside τ veto pattern sets veto
- Jet ≡ τ if all 9 4x4 region τ vetoes off

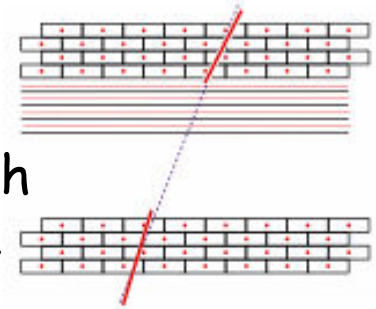
Muon Trigger Track Finders

Drift Tubes (DT)





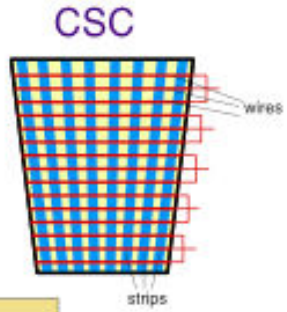
Meantimers recognize tracks and form vector / quartet.

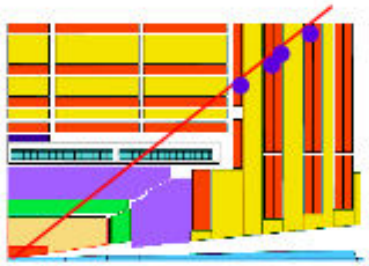


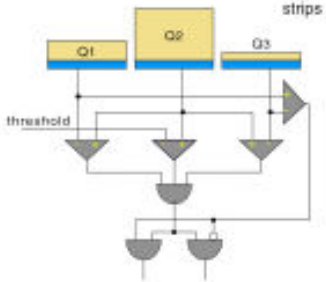
Correlator combines them into one vector / station.

Match DT and CSC tracks with RPC to improve efficiency and quality

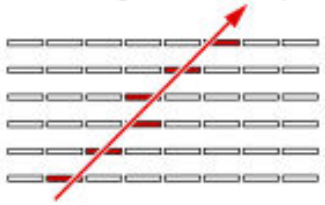
Cathod Strip Chambers (CSC)







Comparators give 1/2-strip resol.



Hit strips of 6 layers form a vector.

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.

HLT Rates (L=1e32 $cm^{-2}s^{-1}$)