CMS Trigger System

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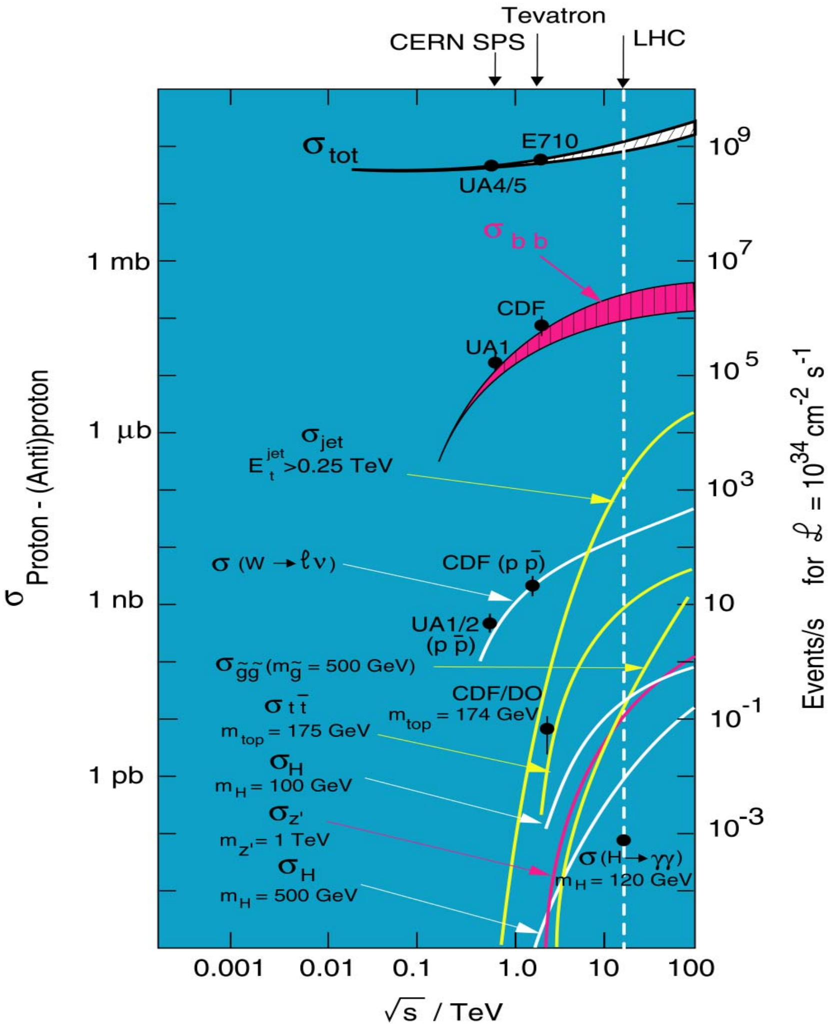
Cross-Sections and Rates

- Formidable task: Trigger Rejection 4.10^5
- Bunch crossing rate 40MHz → permanent storage rate $O(10^2)$Hz

most cross sections 7-9 or more orders smaller than total cross section!



Cross sections for different processes vary by many orders of magnitude

- inelastic: 10^9 Hz
- W -> ln: 100 Hz
- tt: 10 Hz
- Higgs (100 GeV): 0.1 Hz
- Higgs (600 GeV): 0.01 Hz

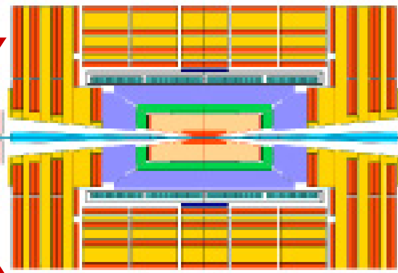
Required selectivity

$1 : 10^{10 - 11}$

↓

Trigger

Principle of Trigger

T ( **)**

Event accepted? → **YES** / **NO**

→ **Successive steps**

Depends on

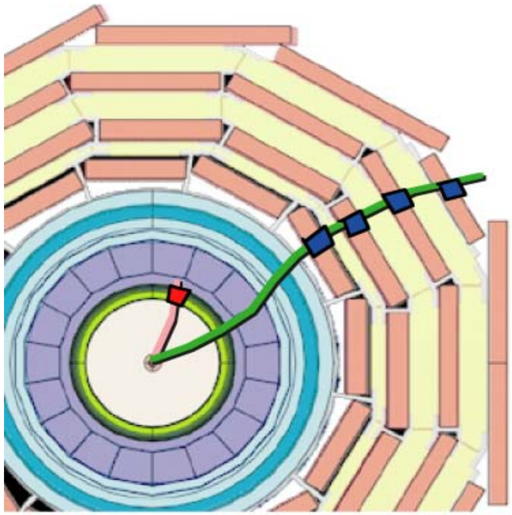
Event type
Properties of the measured trigger objects

Since the detector data are not promptly available and the function is highly complex, T(…) is evaluated by successive approximations.

Trigger objects (candidates): e/g, m, hadronic jets,t-Jets, missing energy, total energy

Trigger conditions: according to physics and technical priorities

Trigger Levels in CMS



Level-1 Trigger

Only calorimeters and muon system involved

Reason: no complex pattern recognition as in tracker required (appr. 1000 tracks at 1034 cm-2s-1 luminosity), lower data volume

Trigger is based on:

Cluster search in the calorimeters

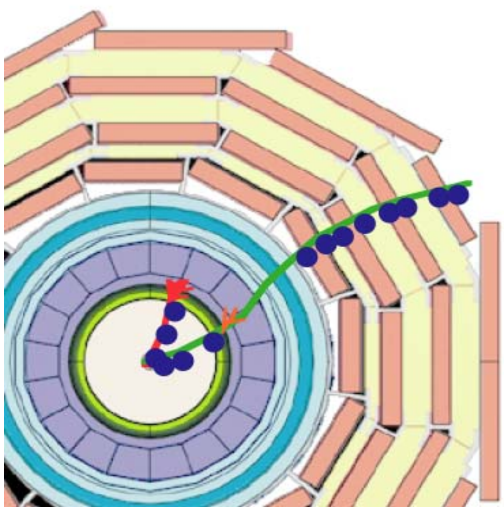
Track search in muon system

Latency: 3.2 μs

Input rate: 40 MHz

Output rate: up to 100 kHz

Custom designed electronics system



High Level Trigger (several steps)

More precise information from calorimeters, muon system, pixel detector and tracker

Threshold, topology, mass, … criteria possible as well as matching with other detectors

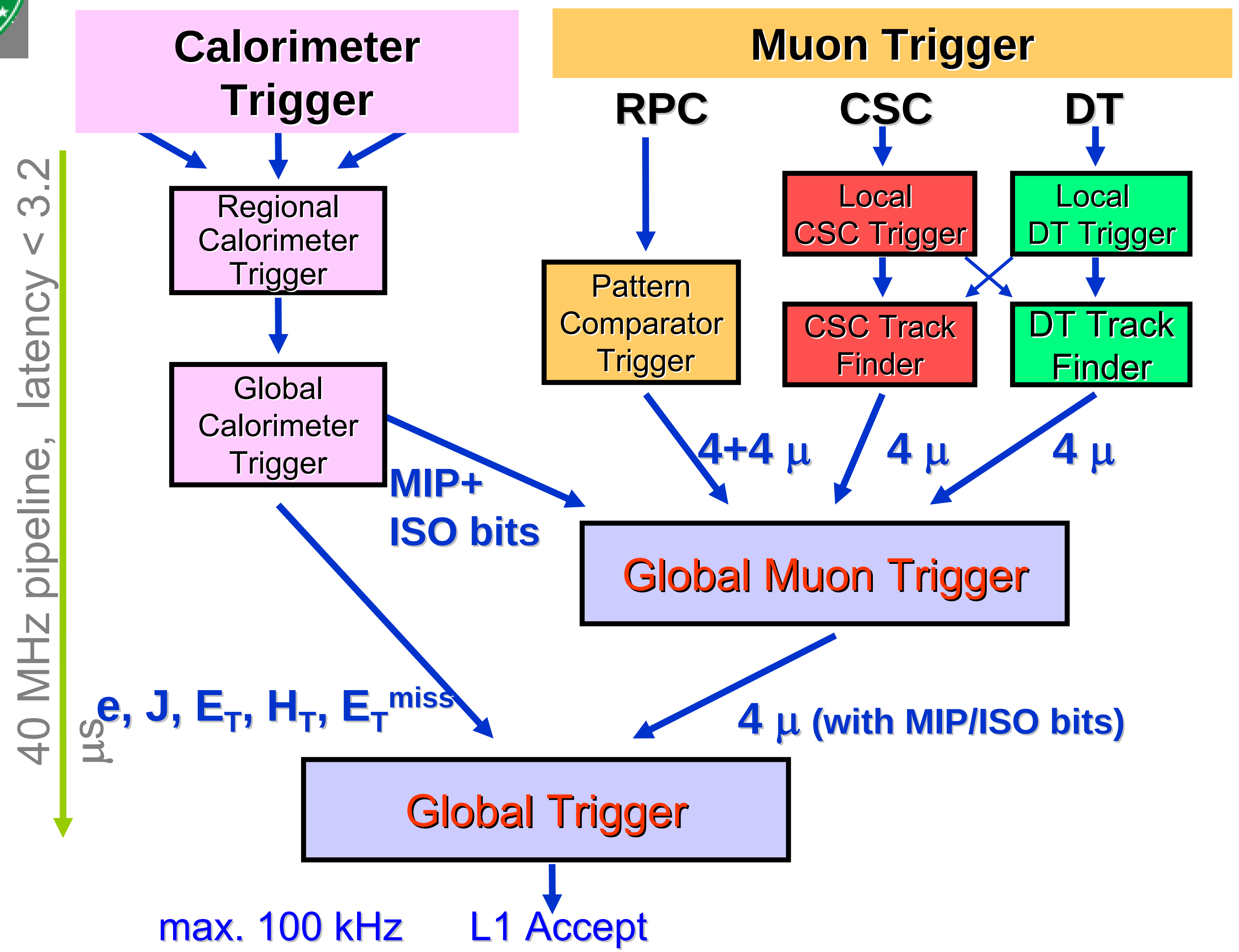
Latency: between 10 ms and 1 s

Input rate: up to 100 kHz

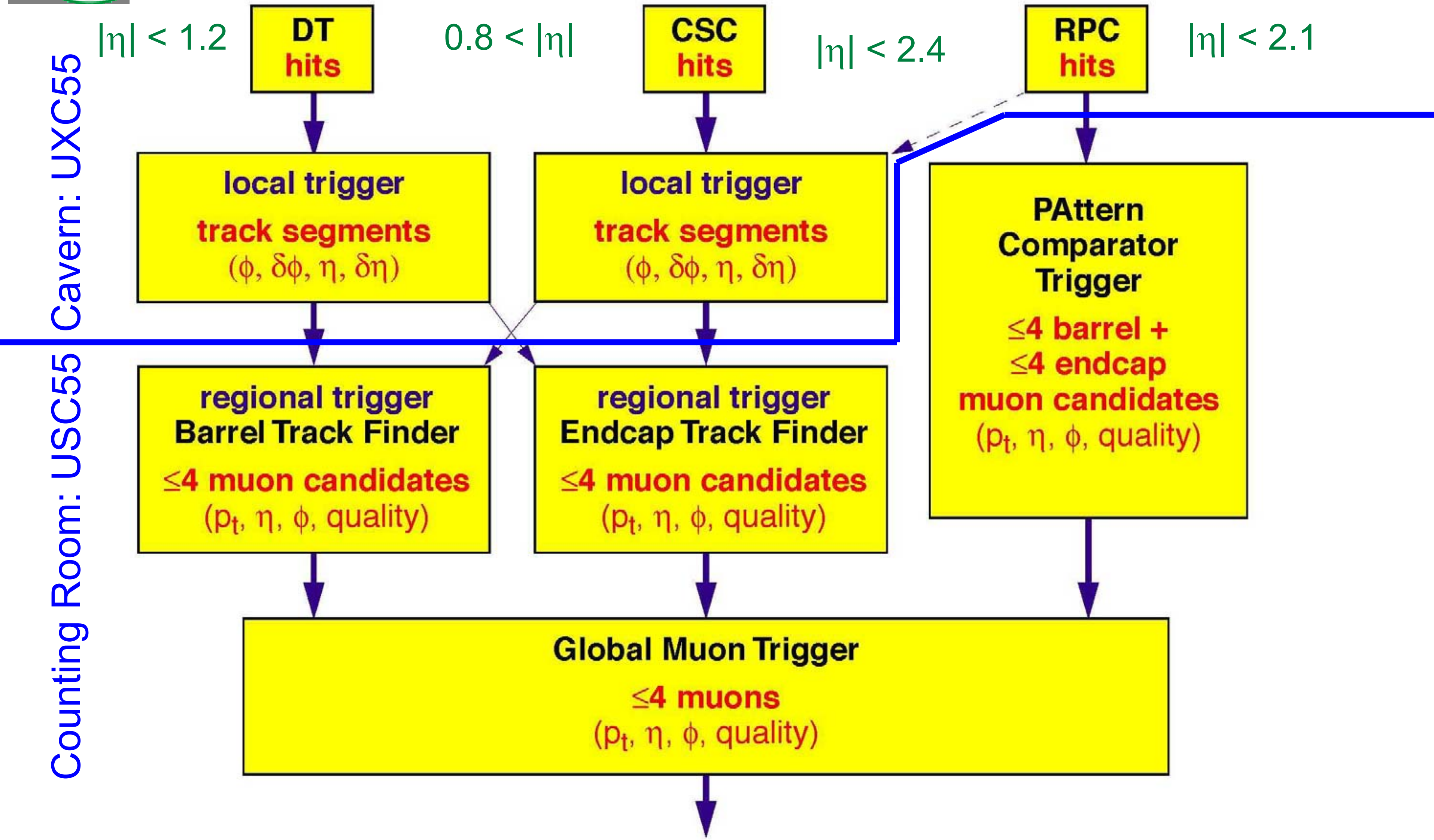
Ouput (data acquisition) rate: approx. 100 Hz

Industral processors and switching network

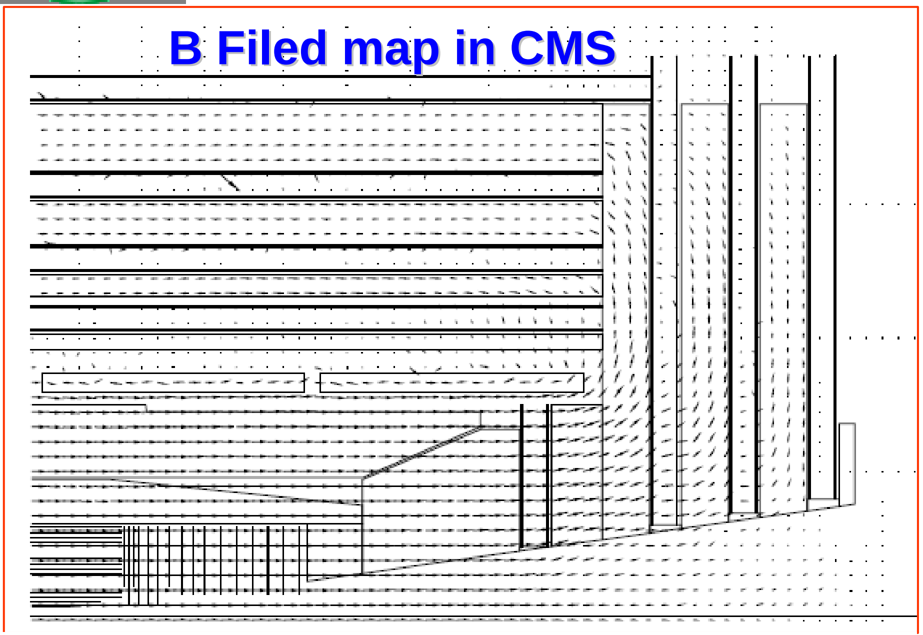
Level-1 Trigger Dataflow

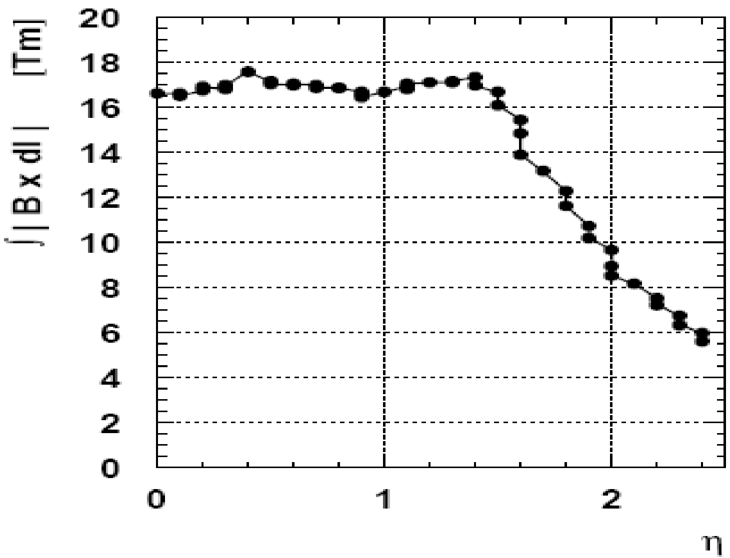


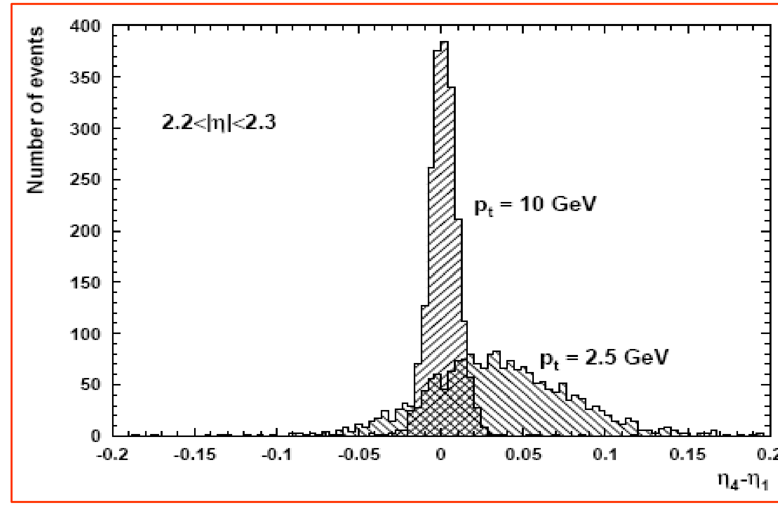
L1 Muon Trigger Overview

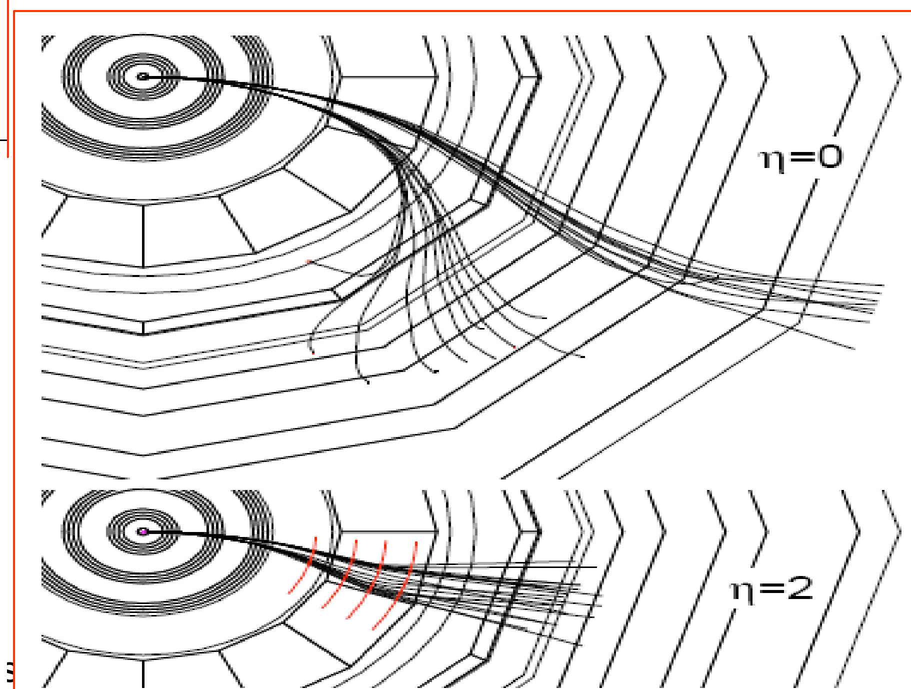


RPC Trigger: Idea



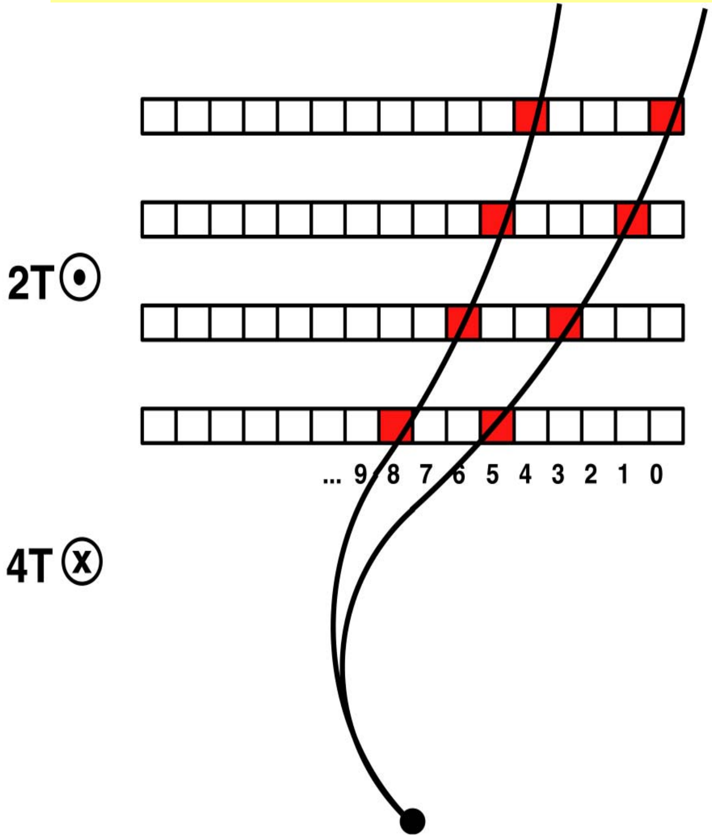




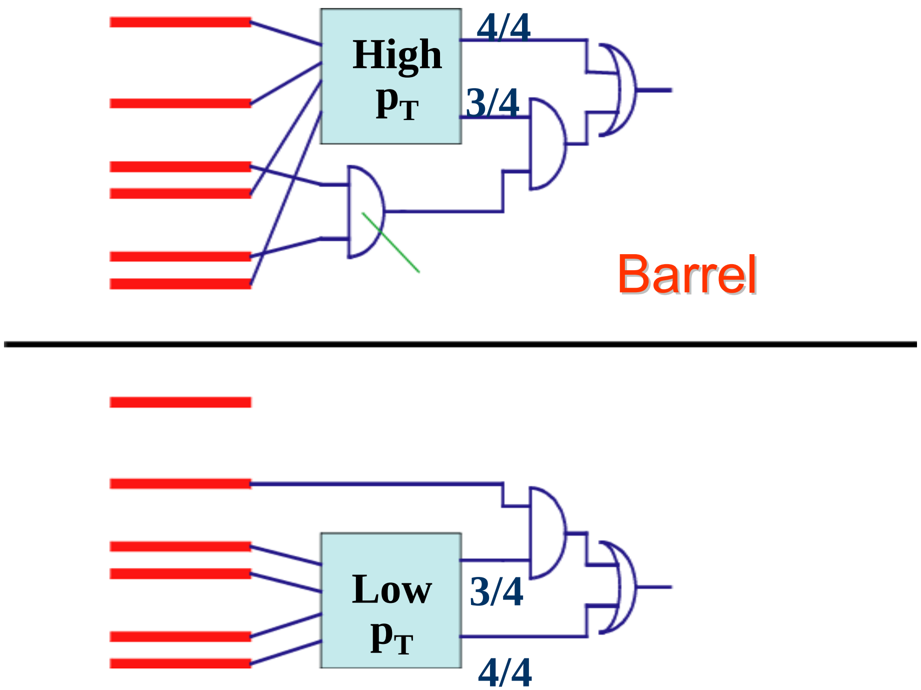


RPC Trigger: Idea

RPC-Trigger is based on strip hits matched to precalculated patterns according to p_T and charge.

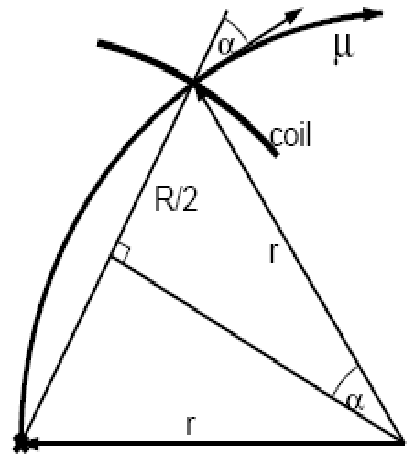


For improved noise reduction algorithm requiring conincidence of at least 4/6 hit planes has been designed. Number of patterns is high. FPGA solution (previously ASICs) seems feasible, but currently expensive. Solutions to reduce number of patterns under study.



RPC Trigger: Role of Strips

- **Track Bending and strip Width**

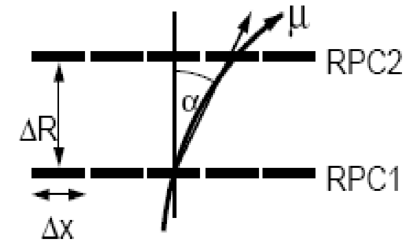


r [m], **B** [T], p_t [GeV]
$r = p_t / 0.3\,B$

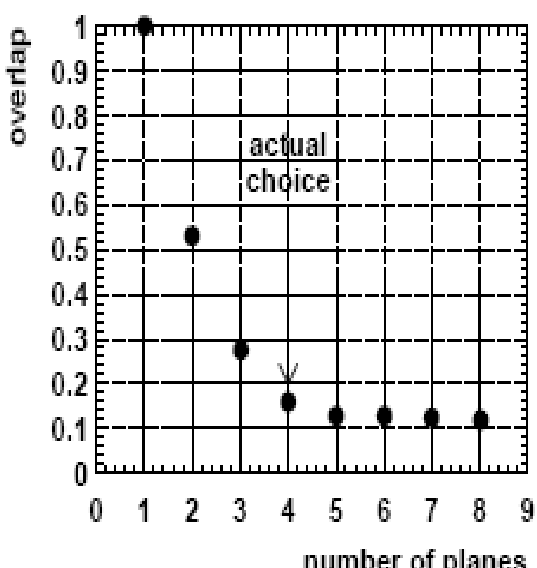
$\sin\alpha = R/2 / r$
$\sin\alpha = 0.3\,BR / 2p_t$

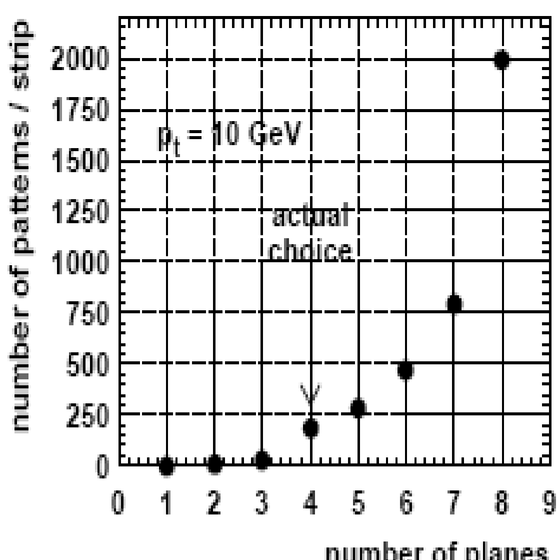
for CMS: B=4T, R=3m
$\alpha \approx 2$ GeV / p_t
$\sigma_{1/p} = \sigma_\alpha / 2$

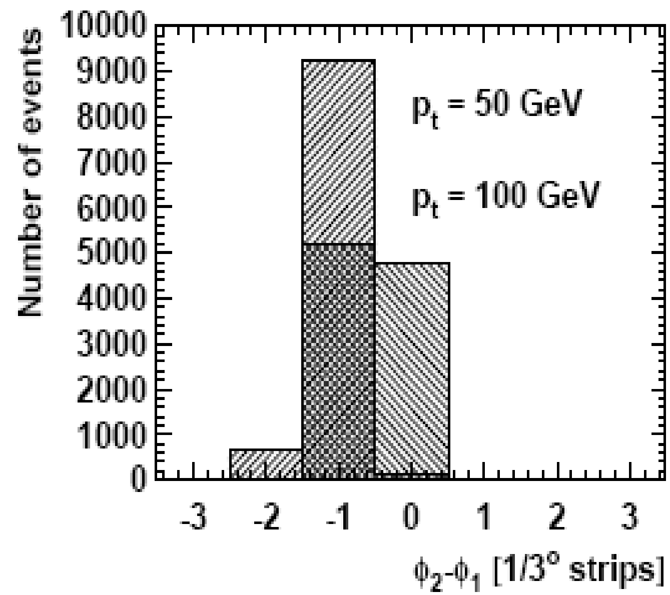
$\sigma_\alpha = \Delta x / \sqrt{2}\Delta R$



For RPCs at MS1 and MS2:
$\Delta x = 2.4$ cm (i.e. $\Delta\varphi = 1/3^\circ$)
$\Delta R = 80$ cm
$\sigma_{1/p} \approx 1 / 100$ GeV

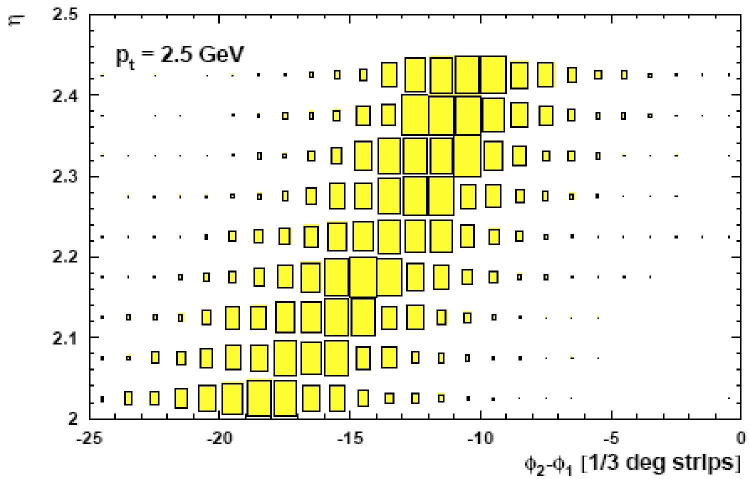


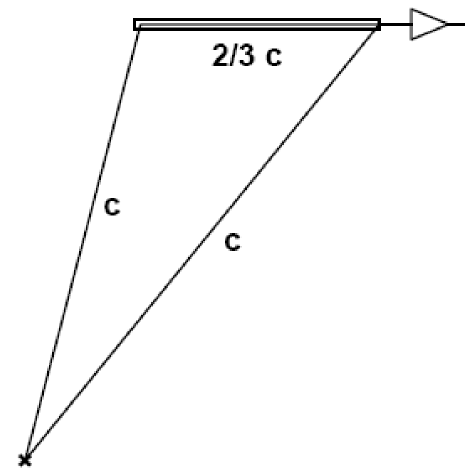




RPC Trigger: Role of Strips

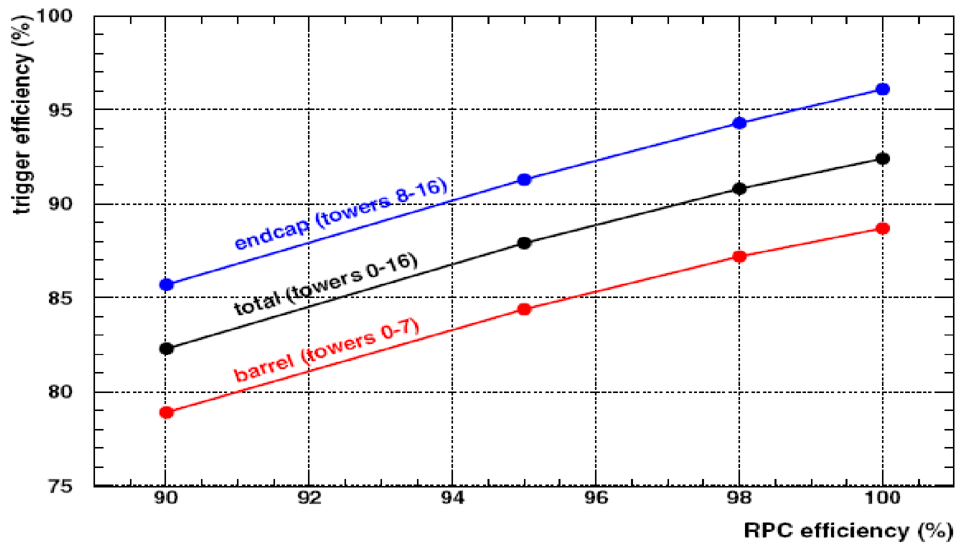
- ❑ **Track Bending and strip Length**





- ❑ **Time of flight and signal propagation**

- ❑ **Random coincidence and background hits**



Level 1 Calorimeter Trigger

Calorimeter Trigger

Regional Calorimeter Trigger

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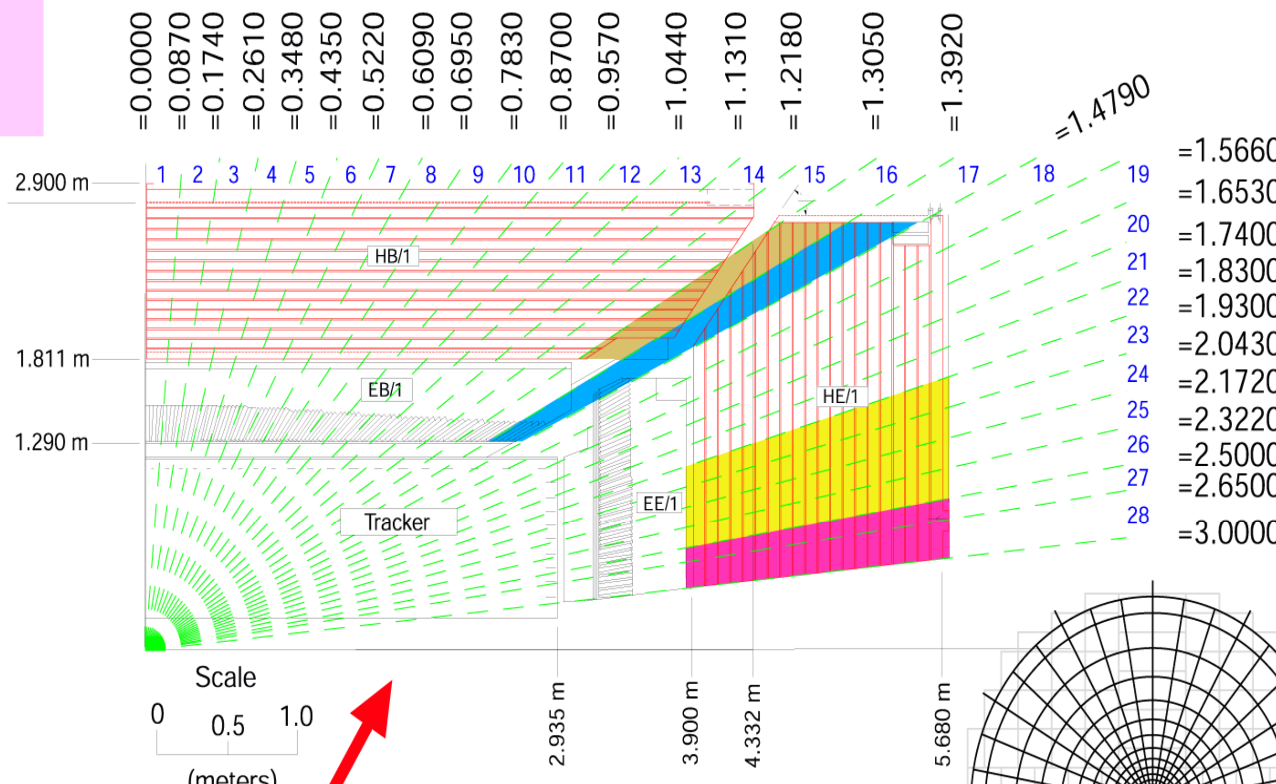
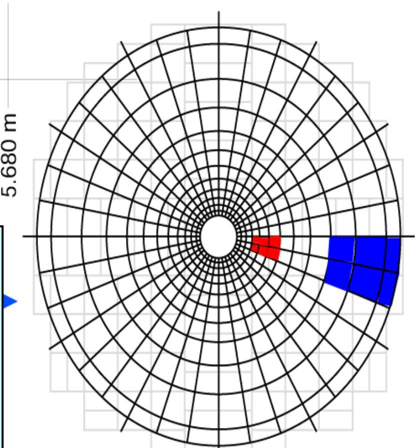
Global Calorimeter Trigger

0.3 η x 0.3 ϕ





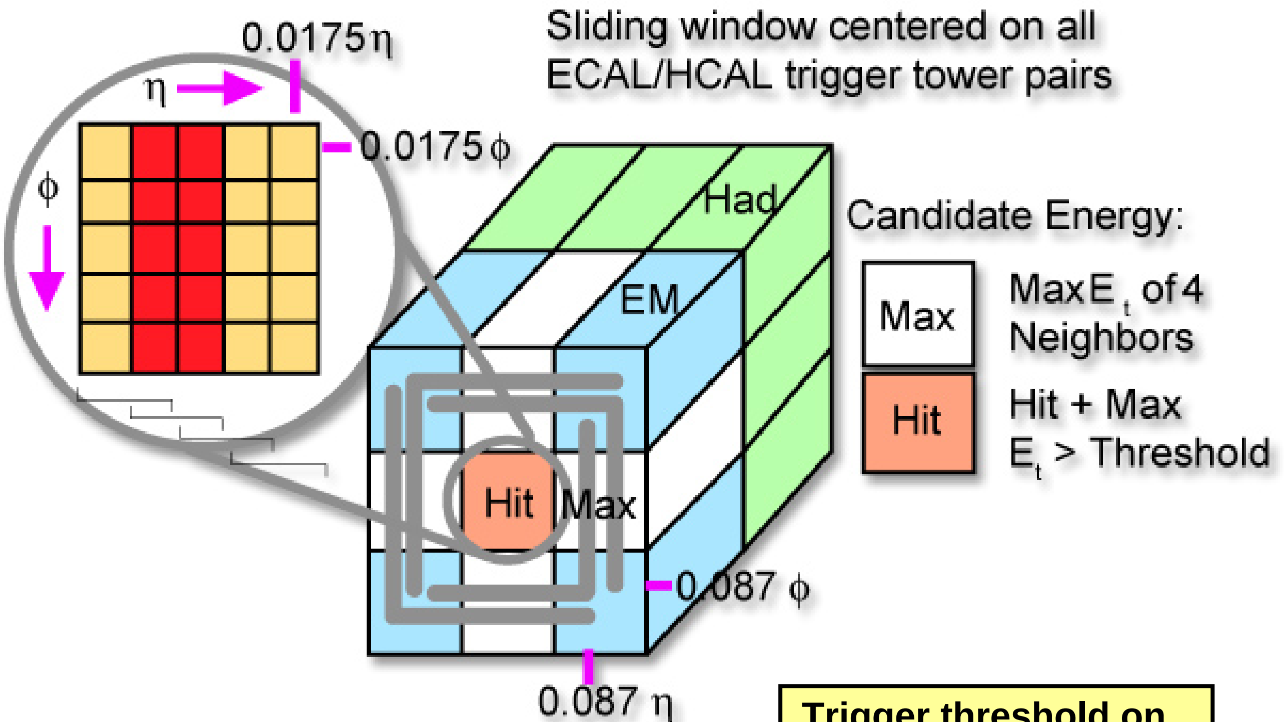
Major Elements

- ❖Trigger Primitive Generator (TPG)
- ❖ Regional Calorimeter Trigger (RCT)
- ❖Global Calorimeter Trigger (GCT)

L1 Electron / Photon Trigger

Issue is rejection of huge jet background

- Electromagnetic trigger based on 3x3 trigger towers
  - Each tower is 5x5 crystals in ECAL (barrel; varies in end-cap)
  - Each tower is single readout tower in HCAL



Trigger threshold on sum of two towers

Non-isolated

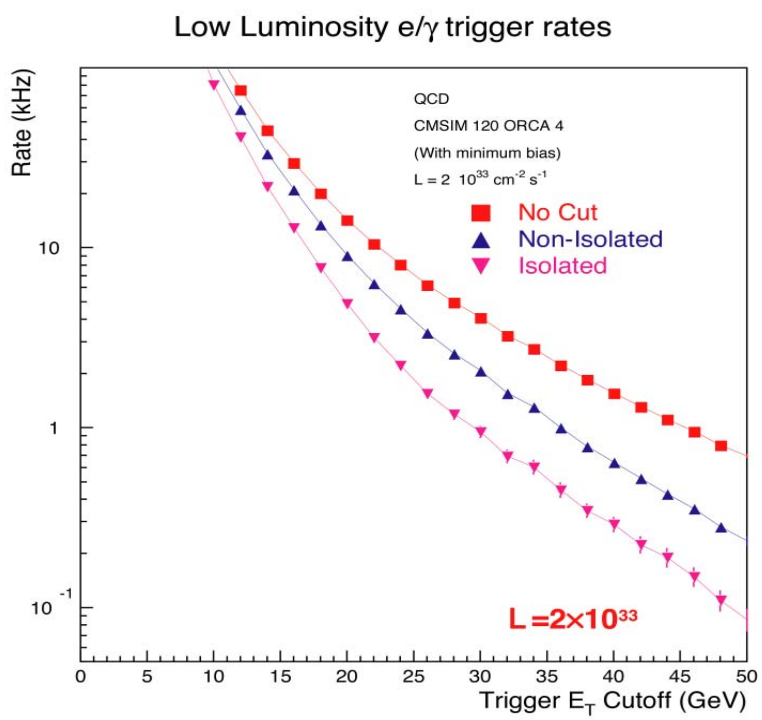
- FG ECAL crystal energy profile
- HCAL to ECAL energy comparison H/E < 5%

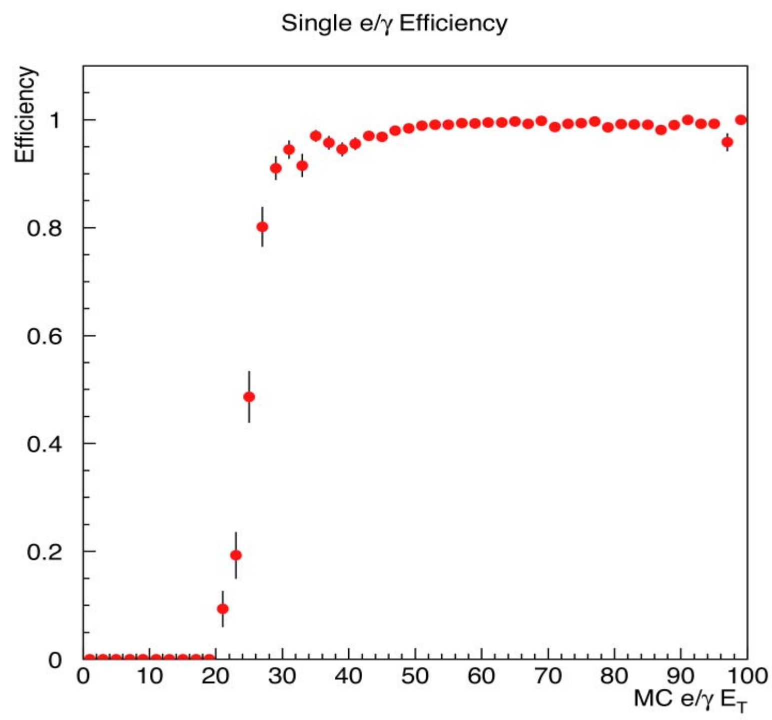
Isolation

- FG+HAC
- At least one quiet corner

Typical Level-1 Rates and Efficiencies

- Single isolated e/γ rate at 25 GeV threshold: 1.9 kHz
- 95% efficiency at 31 GeV





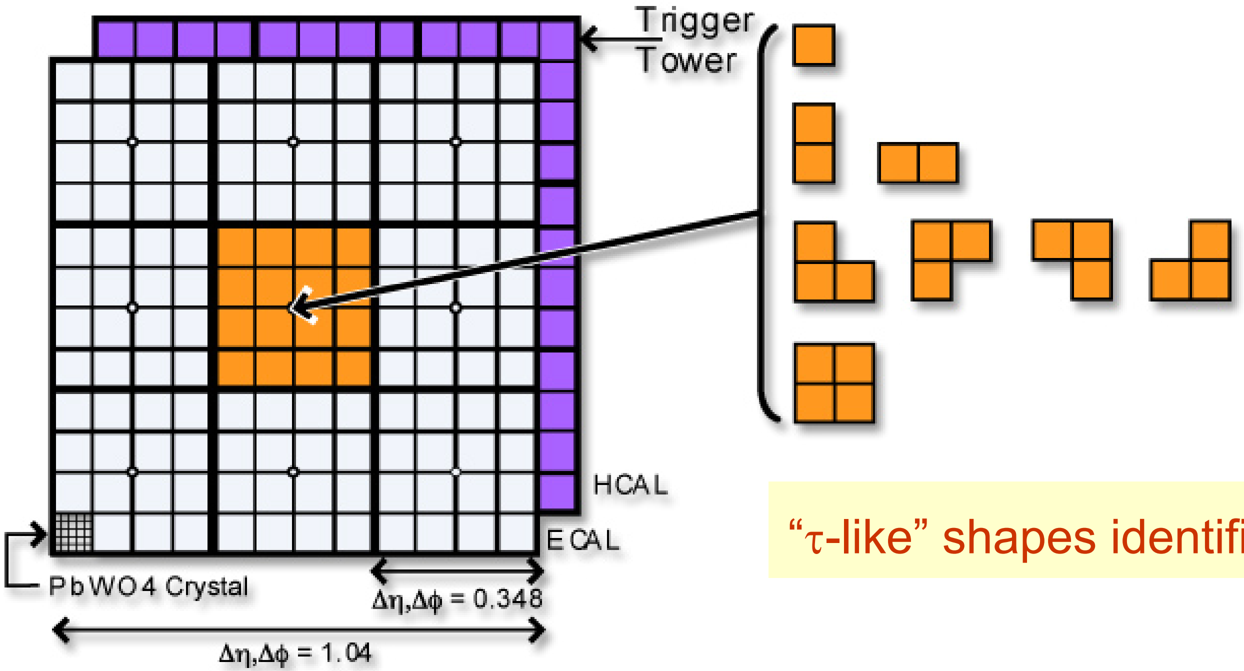
L1 Jet and τ Triggers

Issues are jet energy resolution and tau identification

Sliding window:

- granularity is 4x4 towers = trigger region

- jet E_T summed in 3x3 regions $\Delta\eta,\Delta\phi = 1.04$

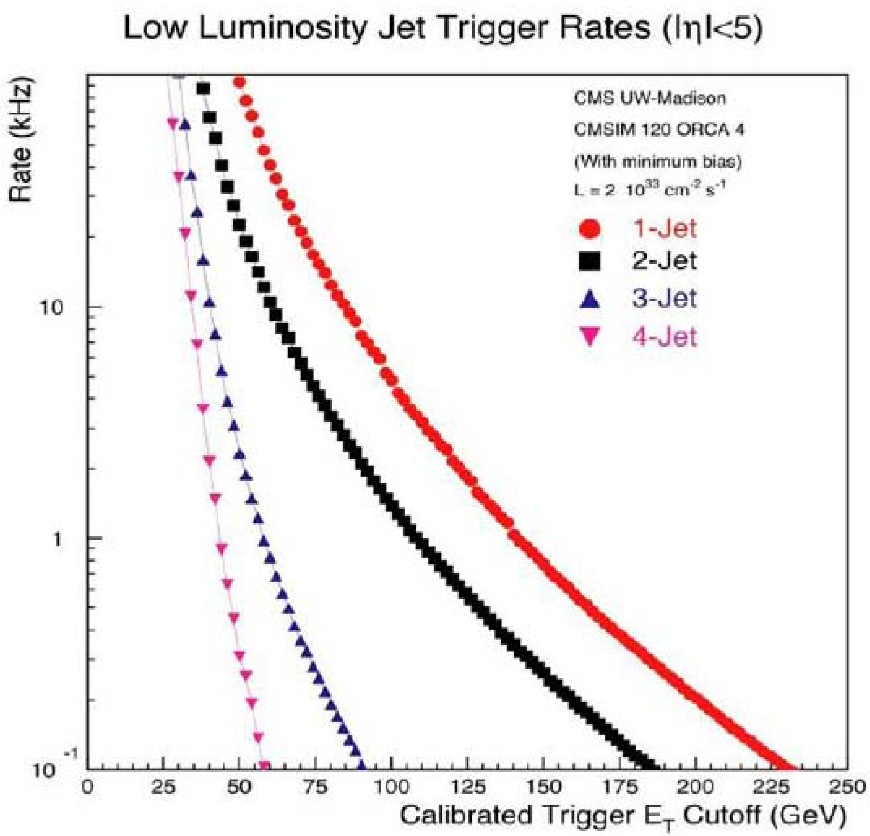


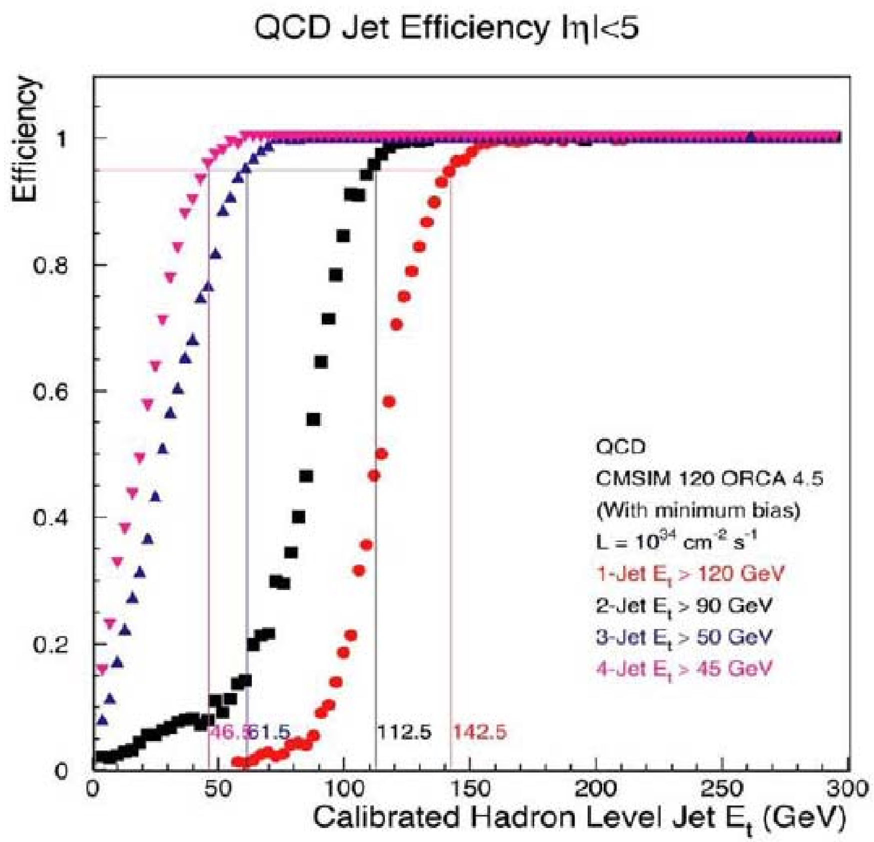
"τ-like" shapes identified for τ trigger

- Single, double, triple and quad thresholds possible
- Possible also to cut on jet multiplicities
- Also E_T^{miss}, ΣE_T and ΣE_T(jets) triggers

Typical Level-1 Jet Rates and Efficiencies

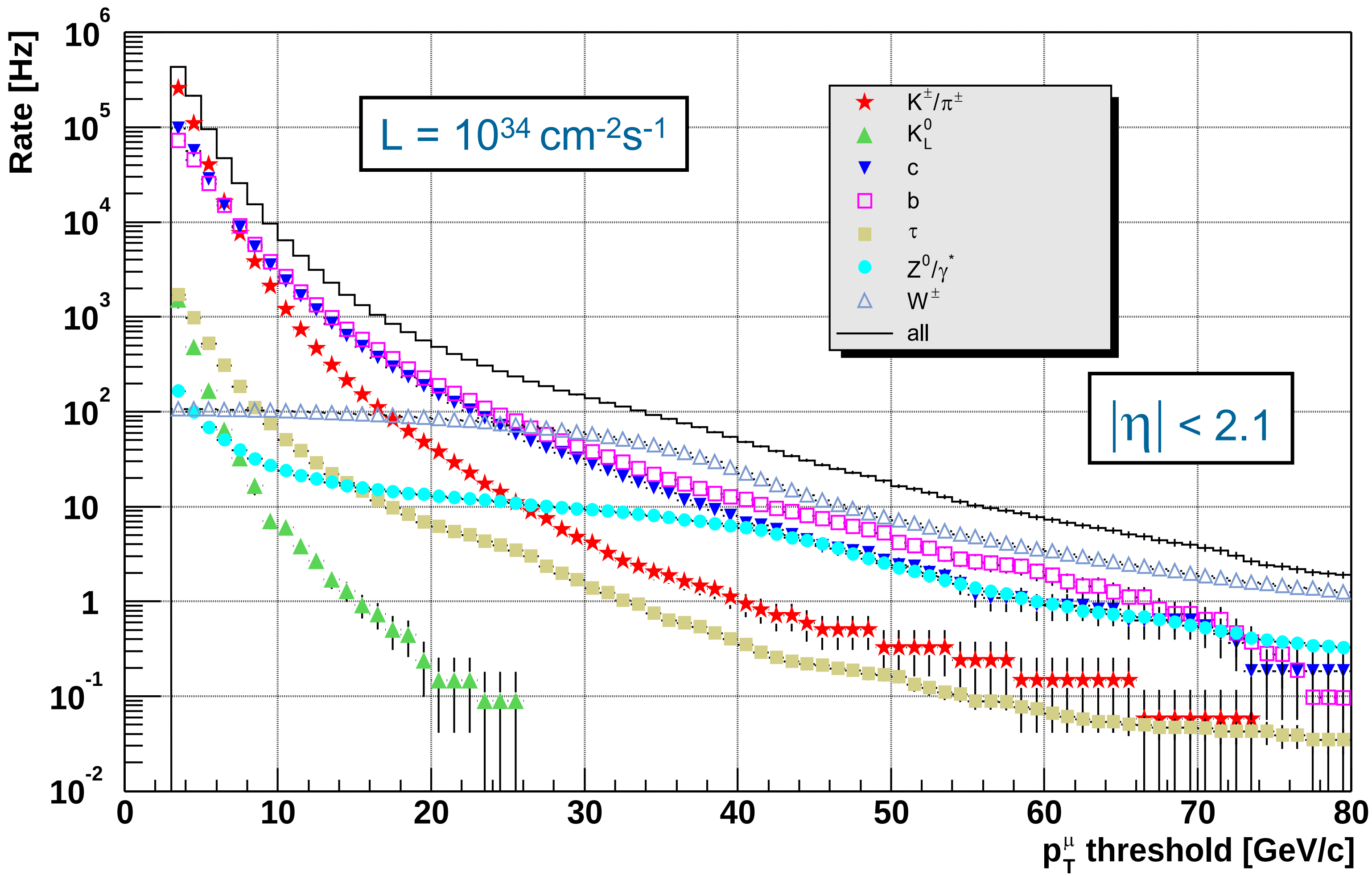
- Single jet rate at 120 GeV threshold: 2.2 kHz, 95% efficiency at 143 GeV
- Dijet rate at 90 GeV: 2.1 kHz 95% efficiency at 113 GeV
- Single t-jet rate at 80 GeV threshold: 6.1 kHz



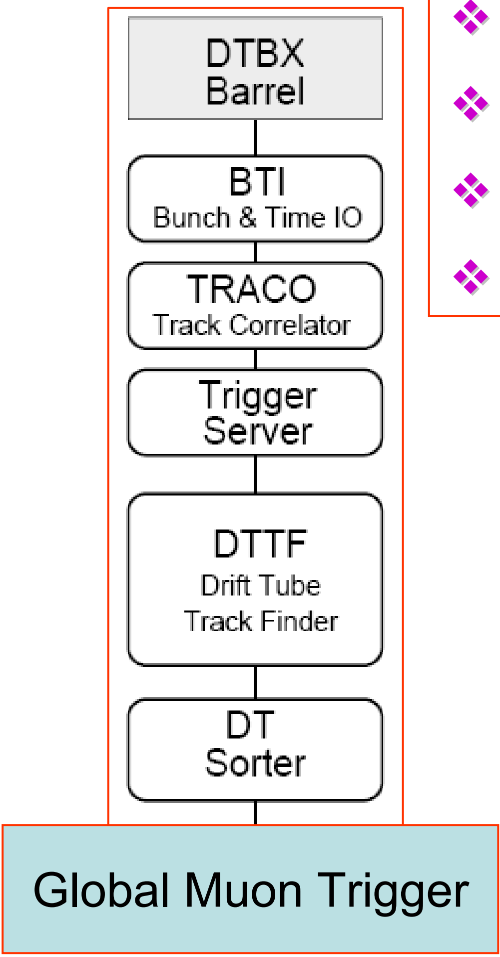


Muons at LHC

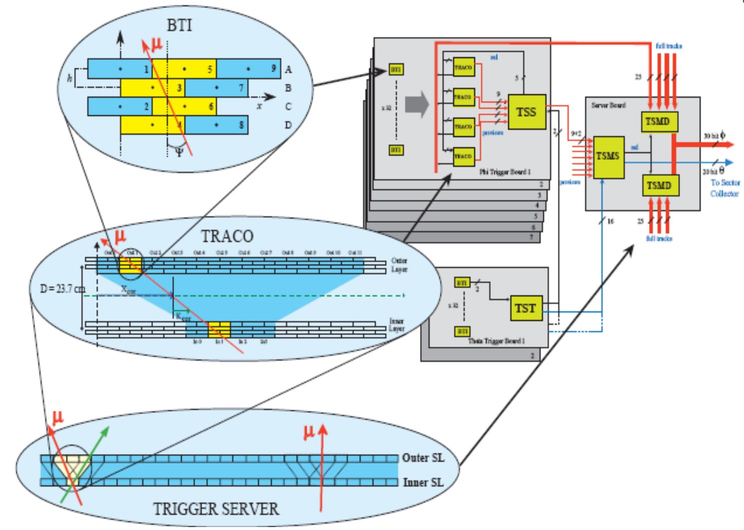
Issue is p_T measurement of real muons

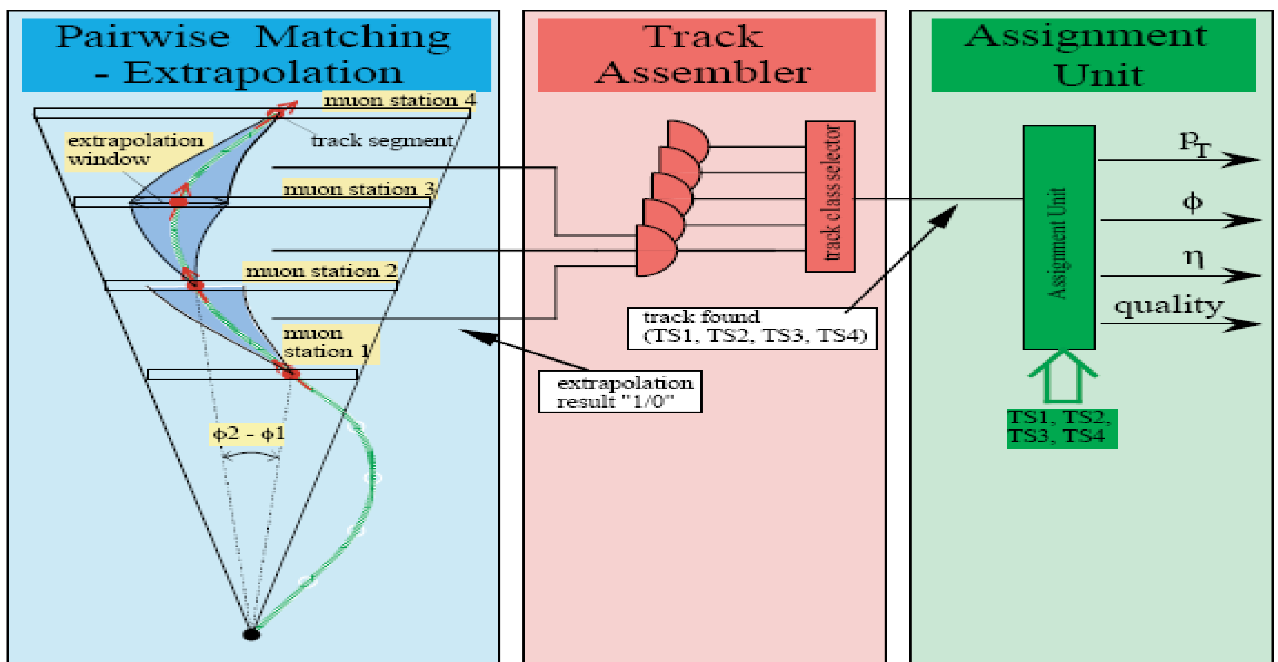


Drift Tube Trigger



- ❖ Bunch and track indentifier
- ❖ Tracker Correlator
- ❖ Trigger Server
- ❖ Drift Tube Track Finder





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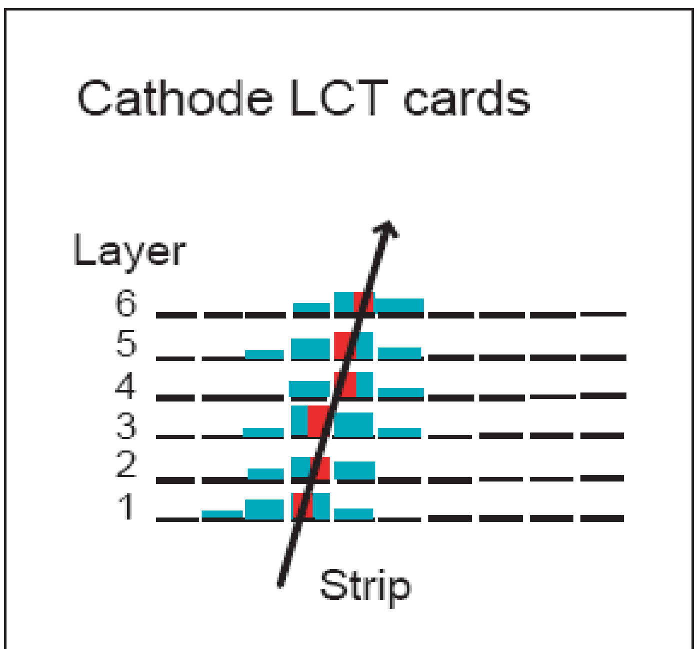
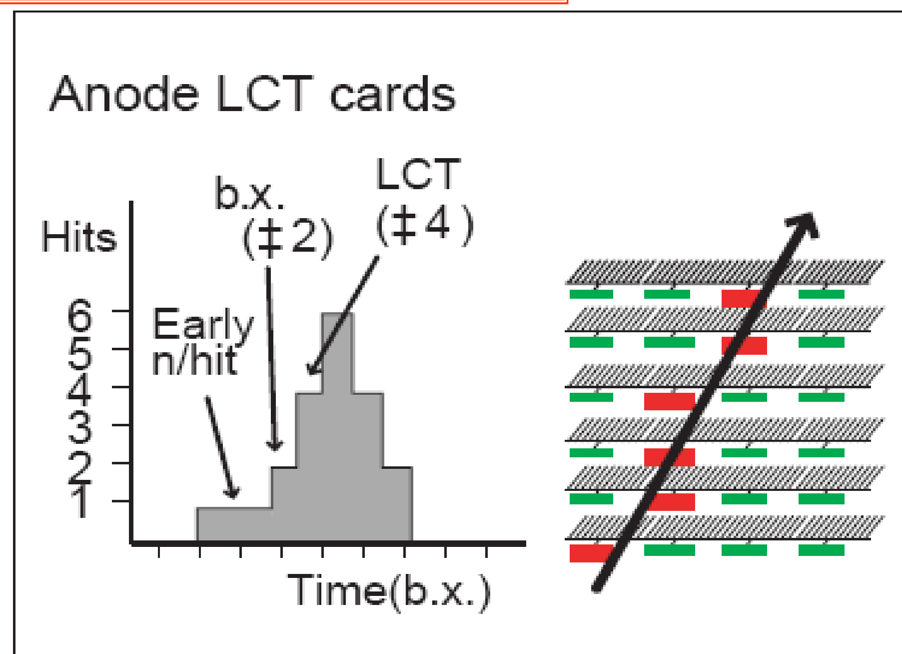
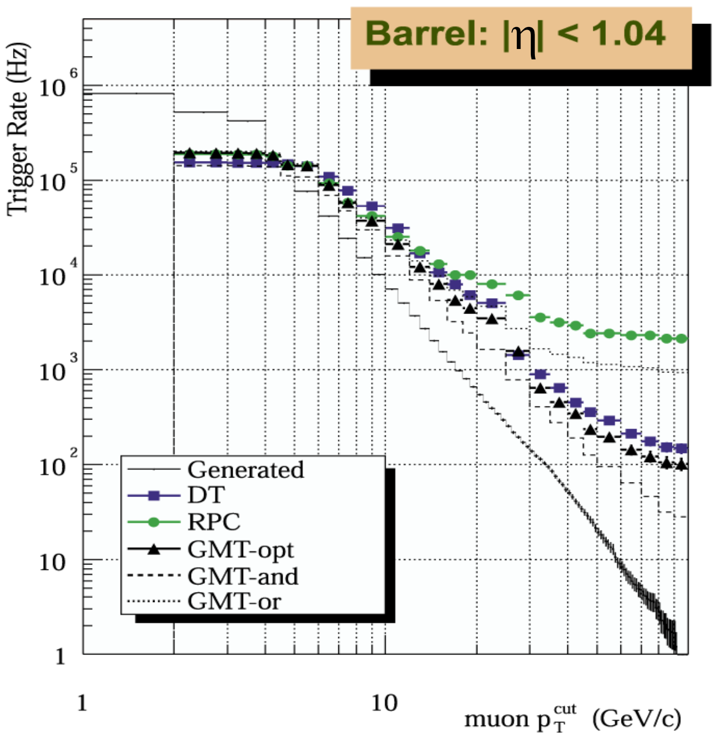
CSC Muon Trigger

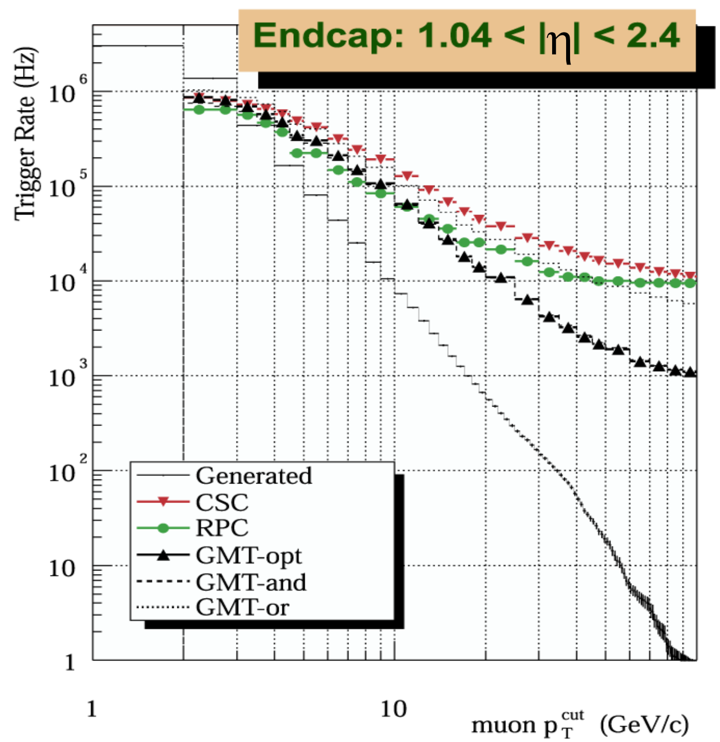
- ❖ CSC Track Finder (TF)
- ❖ CSC Local Charged Tracks (LCT)
- ❖ CSC Anode Trigger Electronics (ATE)
- ❖ CSC Cathode Trigger Electronics (CTE)
- ❖ CSC Track Finder Electronics (TFE
- ❖ CSC Muon Sorter (MS)





Muon Trigger Rates vs. $P_{t\ @}10^{34}$





Curves show individual DT, RPC & CSC & 3 Global Muon Trigger Combinations:

OR, AND, & optimized selection based on track quality & p_t information

Single muon trigger rate is 8.1 kHz for a threshold of 25 GeV (90% efficient)

Dimuon muon trigger rate is 2.8 kHz for thresholds of 8, 5 GeV (90% efficient)

L1 Global Trigger

- Logic combinations of trigger objects sent by the Global Calorimeter Trigger and the Global Muon Trigger

Best 4 isolated electrons/photons	E_T, η, ϕ
Best 4 non-isolated electrons/photons	E_T, η, ϕ
Best 4 jets in forward regions	E_T, η, ϕ
Best 4 jets in central region	E_T, η, ϕ
Best 4 t-Jets	E_T, η, ϕ
Total E_T	ΣE_T
Total E_T of all jets above threshold	H_T
Missing E_T	$E_T^{missing}$, $f(E_T^{missing})$
12 jet multiplicities	N_{jets} (different E_T thresholds and h-regions)
Best 4 muons	p_T, charge, f, h, quality, MIP, isolation

- Thresholds (p_T, E_T, N_{Jets})
- Optional topological and other conditions (geometry, isolation, charge, quality)
- 128 algorithms running in parallel

Level-1 Trigger table (10^{34})

Trigger	Threshold (GeV)	Rate (kHz)	Cumulative Rate (kHz)
Isolated e/g	34	6.5	6.5
Di-e/g	19	3.3	9.4
Isolated muon	20	6.2	15.6
Di-muon	5	1.7	17.3
Single tau-jet	101	5.3	22.6
Di-tau-jet	67	3.6	25.0
1-jet, 3-jet, 4-jet	250, 110, 95	3.0	26.7
Jet*E_T^{miss}	113*70	4.5	30.4
Electron*jet	25*52	1.3	31.7
Muon*jet	15*40	0.8	32.5
Min-bias		1.0	33.5
TOTAL			33.5

High-Level Trigger

- Runs on large CPU farm
- Code as close as possible to offline reconstruction
- Selection must meet CMS physics goals
  - Output rate to permanent storage limited to $O(10^2)$Hz
- Reconstruction on demand
  - Reject as soon as possible
  - Trigger “Levels”:
    - Level-2: use calorimeter and muon detectors
    - Level-2.5: also use tracker pixel detectors
    - Level-3: includes use of full information, including tracker
  - “Regional reconstruction”: e.g. tracks in a given road or region

High Level trigger Goals

- Validate Level-1 decision
- Refine E_T/p_T thresholds
- Refine measurement of position and other parameters
- Reject backgrounds
- Perform first physics selection

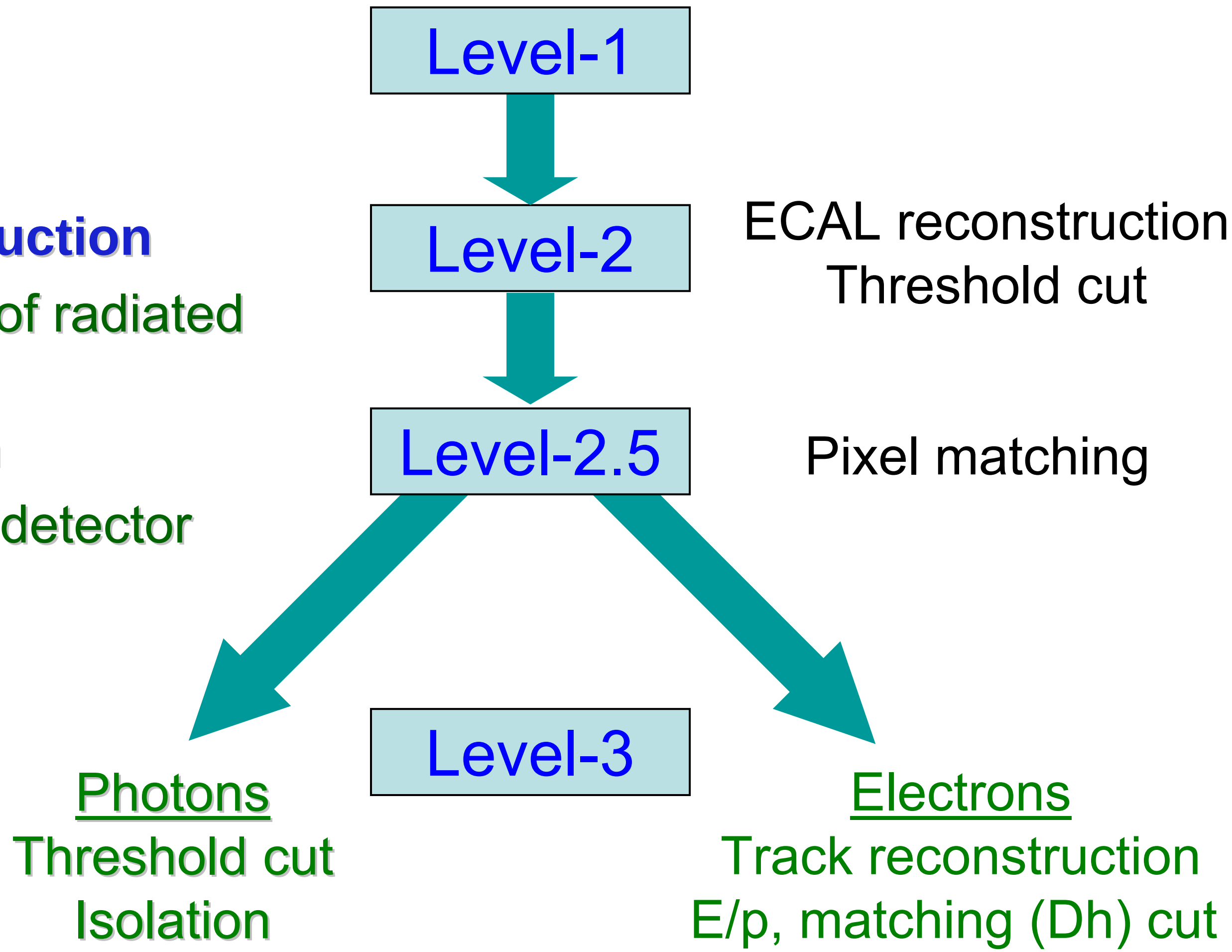
HLT selection: μ, τ, jets and E_T^{miss}

- Muons
  - Successive refinement of momentum measurement; + isolation
    - Level-2: reconstructed in muon system; must have valid extrapolation to collision vertex; + calorimeter isolation
    - Level-3: reconstructed in inner tracker; + tracker isolation
- τ-leptons
  - Level-2: calorimetric reconstruction and isolation
  - Level-3: tracker isolation.
- Jets and E_t^{miss}
  - Jet reconstruction with iterative cone algorithm
  - E_T^{miss} reconstruction (vector sum of towers above threshold).

HLT selection: electrons and photons

- Issue is electron reconstruction and rejection
- Higher E_T threshold on photons

- **Electron reconstruction**
  - key is recovery of radiated energy
- **Electron rejection**
  - key tool is pixel detector



HLT Summary: $2x10^{33}$ $cm^{-2}s^{-1}$

Trigger	Threshold (GeV)	Rate (Hz)	Cuml. rate (Hz)
Inclusive electron	29	33	33
Di-electron	17	1	34
Inclusive photon	80	4	38
Di-photon	40, 25	5	43
Inclusive muon	19	25	68
Di-muon	7	4	72
Inclusive tau-jet	86	3	75
Di-tau-jet	59	1	76
1-jet * E_T^{miss}	180 * 123	5	81
1-jet OR 3-jet OR 4-jet	657, 247, 113	9	89
Electron * jet	19 * 45	2	90
Inclusive b-jet	237	5	95
Calibration etc		10	105
TOTAL			105

HLT performance — signal efficiency

- With previous selection cuts

Channel	Efficiency (for fiducial objects)
H(115 GeV)→gg	77%
H(160 GeV)→WW* →2m	92%
H(150 GeV)→ZZ→4m	98%
A/H(200 GeV)→2t	45%
SUSY (~0.5 TeV sparticles)	~60%
With R_P-violation	~20%
W→en	67% (fid: 60%)
W→mn	69% (fid: 50%)
Top→m X	72%

Summary

The CMS Trigger System is close to become reality after a long period of simulation studies, hardware prototyping and system construction

The CMS trigger design meets the challenging LHC requirements:

- Large rate reduction
- High efficiency for signal events
- Wide inclusive selection (open to the unexpected)
- Huge flexibility allowing future adaptation to the unknown

CMS Trigger system reduces the rate by an overall factor of roughly 106 while maintaining good efficiency

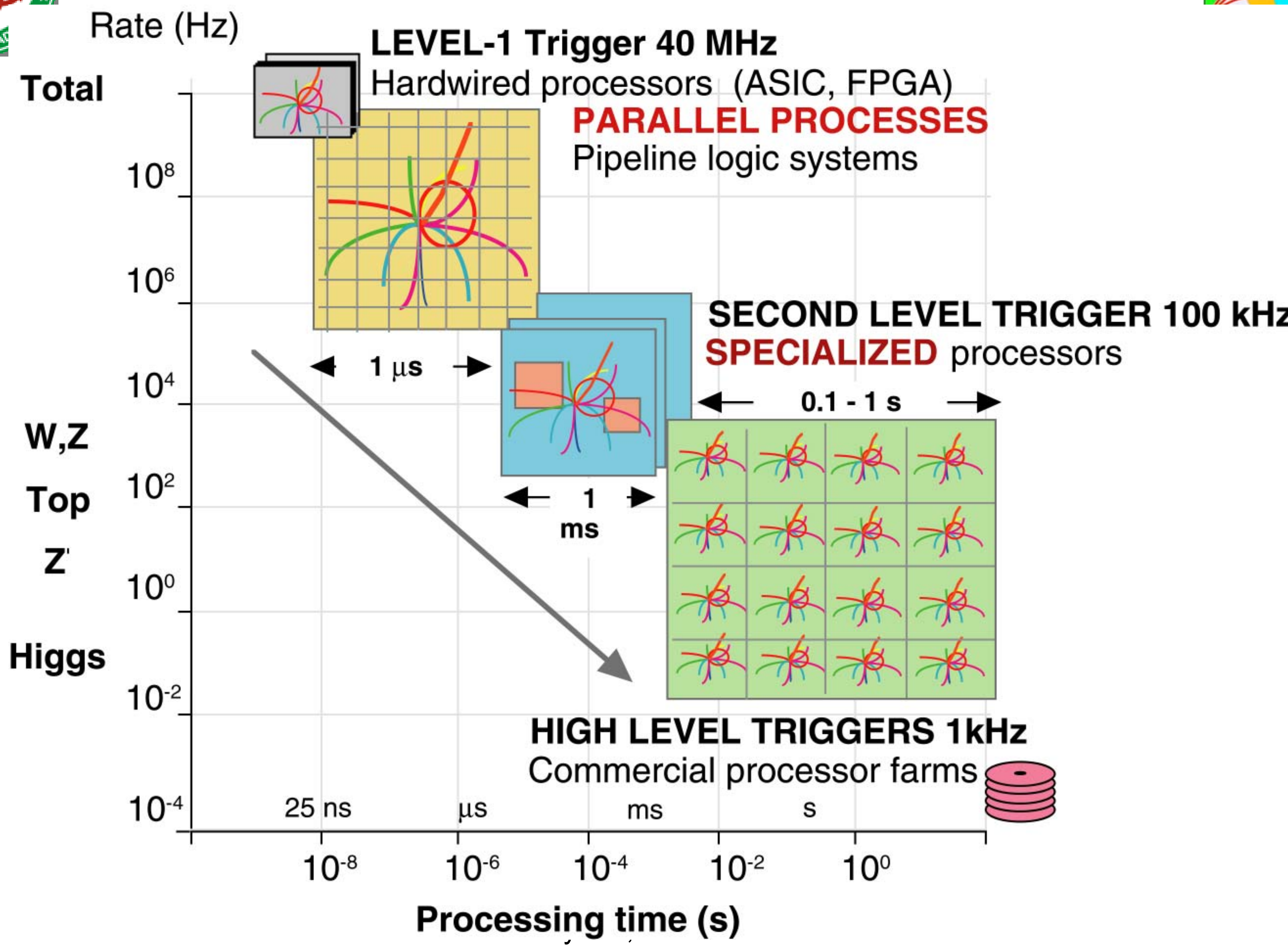
• Level-1:

– 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

Conventional Concept with 3 Steps



Local / Regional Electron / Photon Trigger

Trigger primitive generator (local)

Flag max of 4 combinations ("Fine Grain Bit") & Sum ET

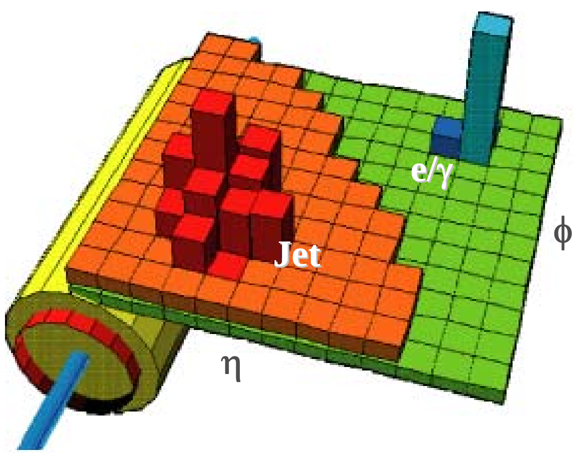
Regional calorimeter trigger

E_T cut — Hit +max of > E_T threshold

Longitundinal cut hadr./electromagn. E_T — / < 0.05

Hadronic and electromagnetic isolation — < 2 GeV

One of — < 1 GeV



Electron / photon

Level-1 Trigger

- Information from Calorimeters and Muon detectors
  - Electron/photon triggers
  - Jet and missing E_T triggers
  - Muon triggers
- Backgrounds are huge
  - Sophisticated trigger algorithms
  - Steep functions of thresholds
- Synchronous and pipelined
  - Bunch crossing time = 25 ns
  - Time needed for decision (+its propagation) ≈ 3 μs
- Highly complex
  - Trigger primitives: ~5000 electronics boards of 7 types
  - Regional/Global: 45 crates, 630 boards, 32 board types
- Large flexibility
  - Large number of electronics programmable parameters
  - Most algorithms implemented in re-programmable FPGAs