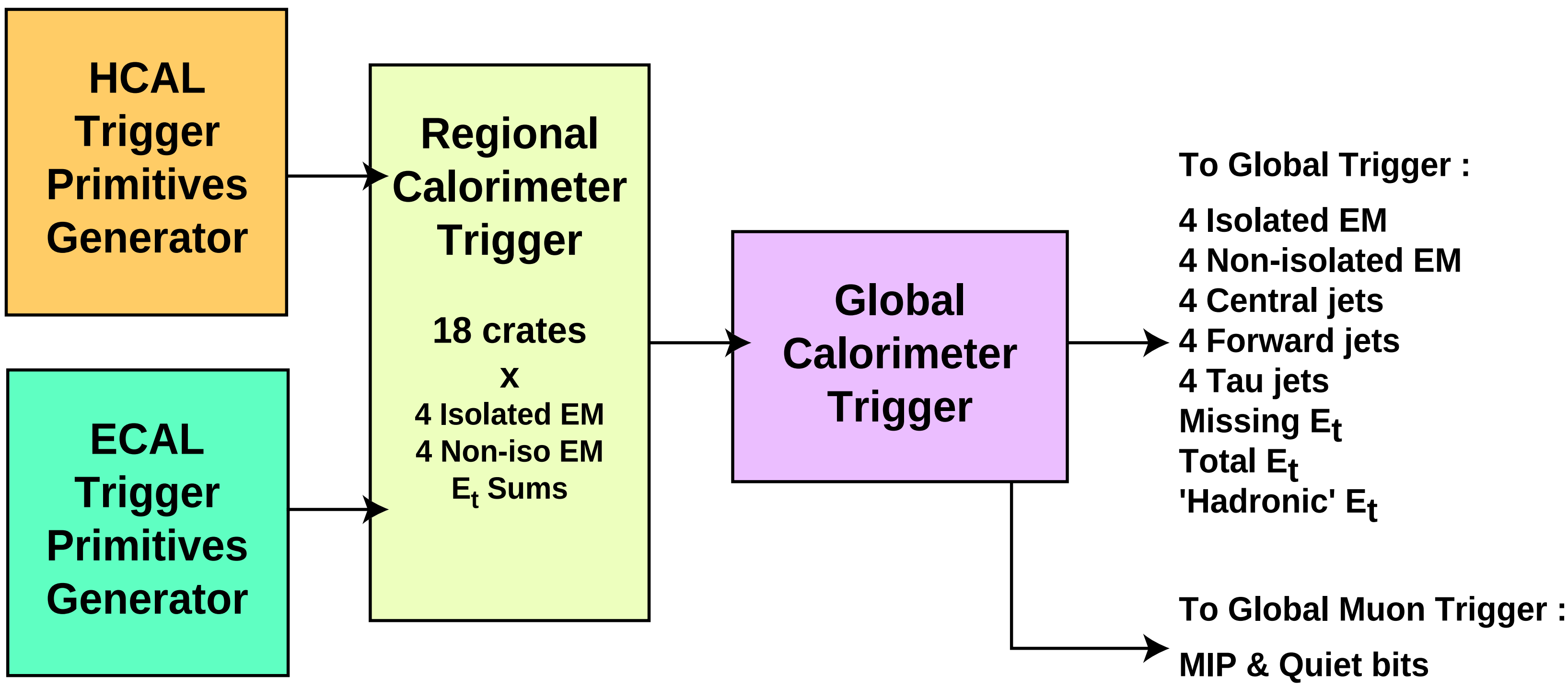
The CMS Level 1 Trigger

Algorithms & Performance

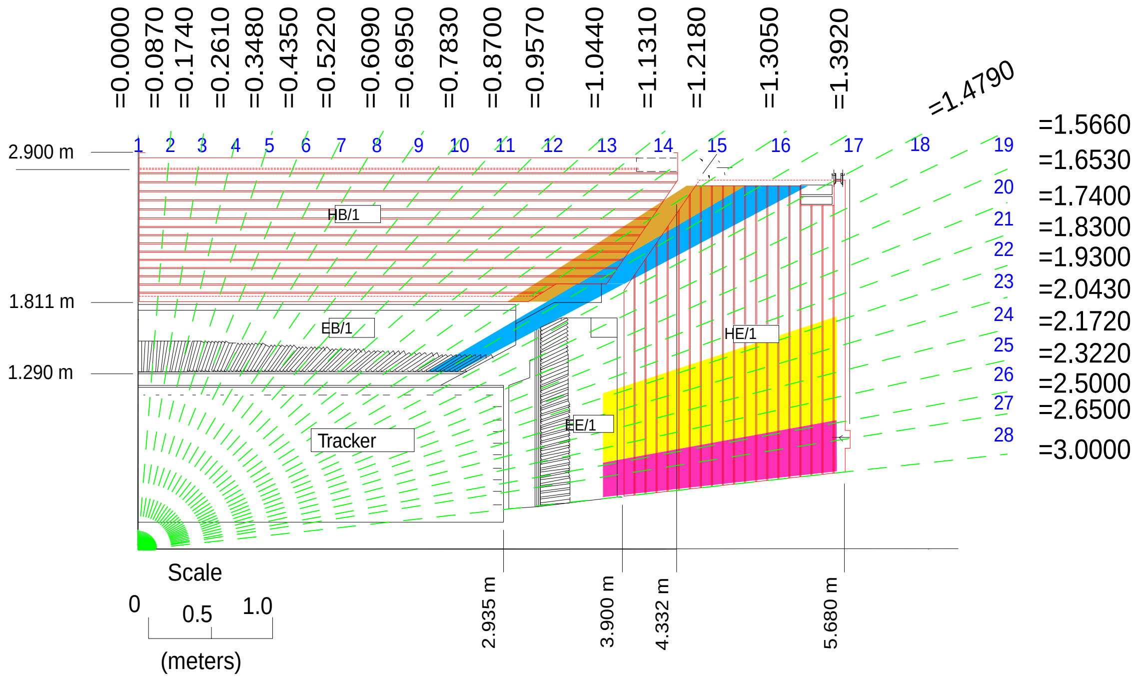
Level-1 Trigger

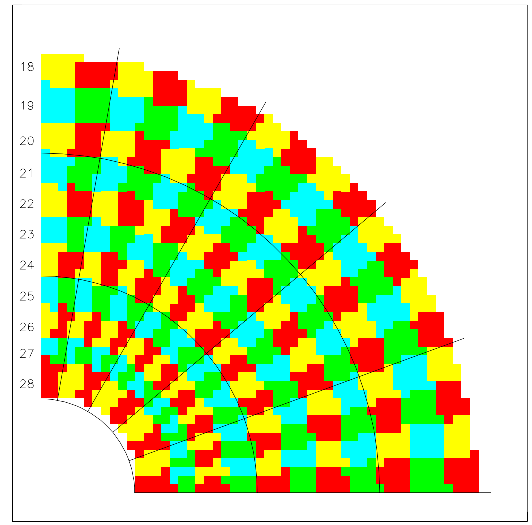
- Some figures...
  - pp interaction rate : 10^9 Hz
  - Crossing rate : 40 MHz
  - L1 accept rate : < 100 kHz
  - L1 latency : < 3 μs
- Sub-detectors :
  - EM calorimeter
  - Hadronic calorimeter
  - Muon chambers
- Calorimeter Trigger
  - E/gamma
  - Jet (inc Tau)
  - Total/Missing E_t
  - Hadronic E_t
- Muon Trigger
  - Muons ...
- Trigger Tables
  - $2x10^{33}$ $cm^{-2}s^{-1}$
  - 10^{34} $cm^{-2}s^{-1}$

L1 Calorimeter Trigger



L1 Trigger Towers

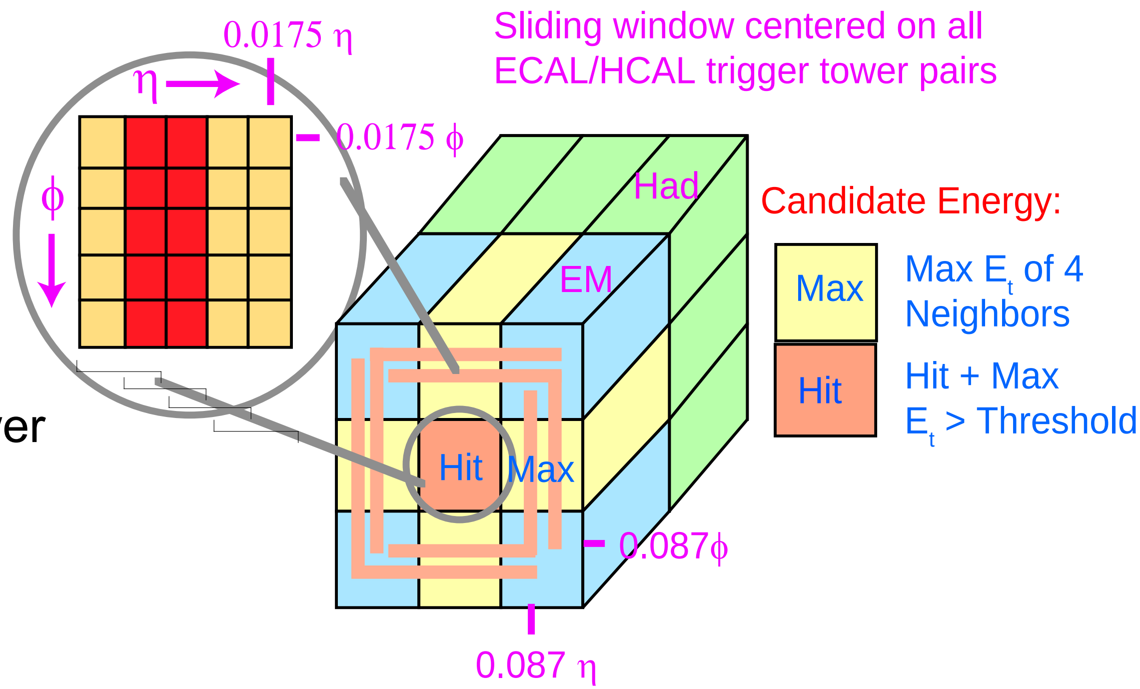




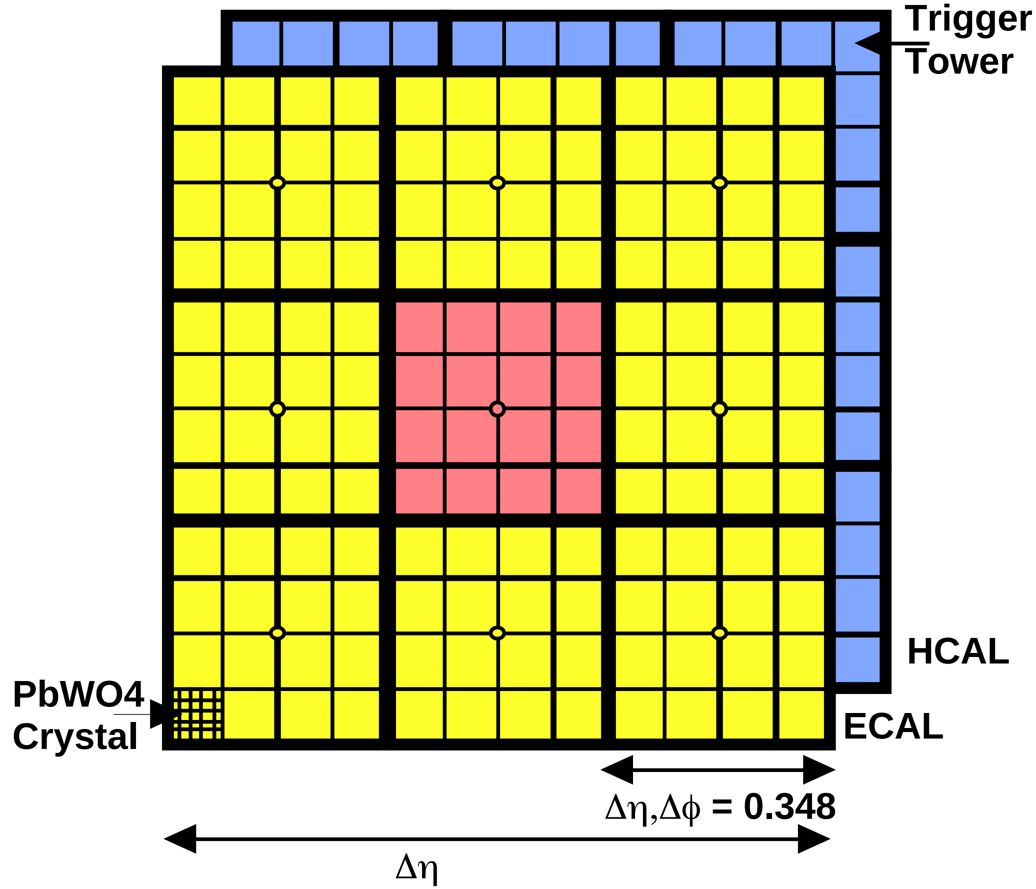
- 1 tower = 5 x 5 crystals
- 28 towers in η, 72 towers in ϕ
- Forward calorimeters have coarser granularity

Electron/Photon Algorithm

- All candidates
  - Central tower hit
  - H/E < threshold (5%)
  - FG veto (lateral shower shape)
- Isolation criteria :
  - Neighbours quiet
  - FG & H/E veto on neighbours

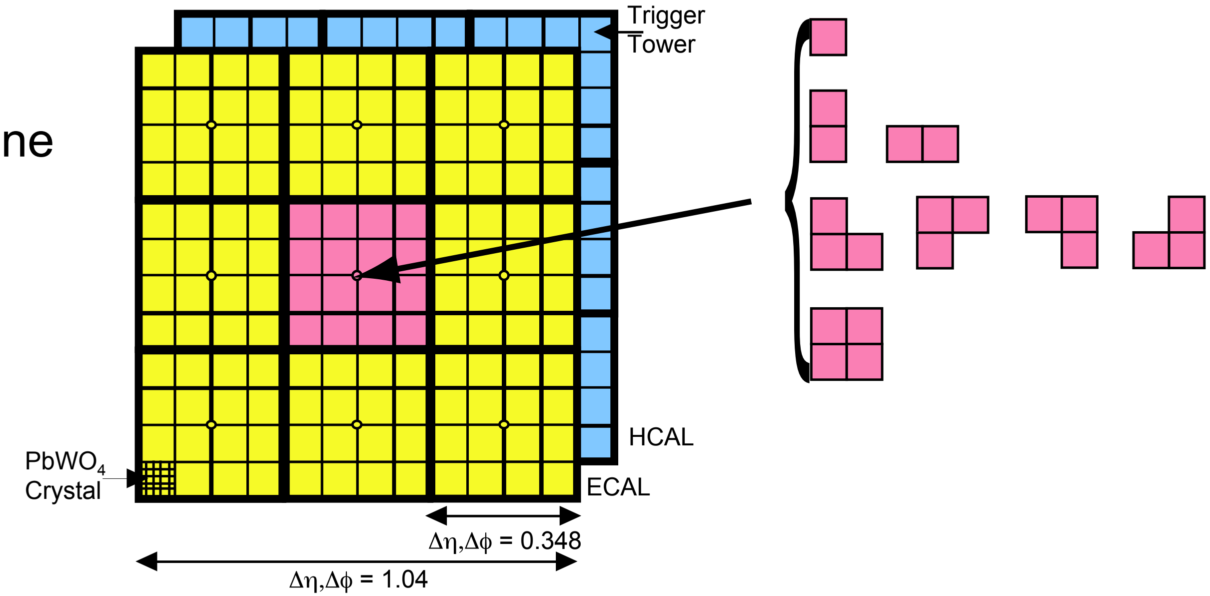


Jet Algorithm

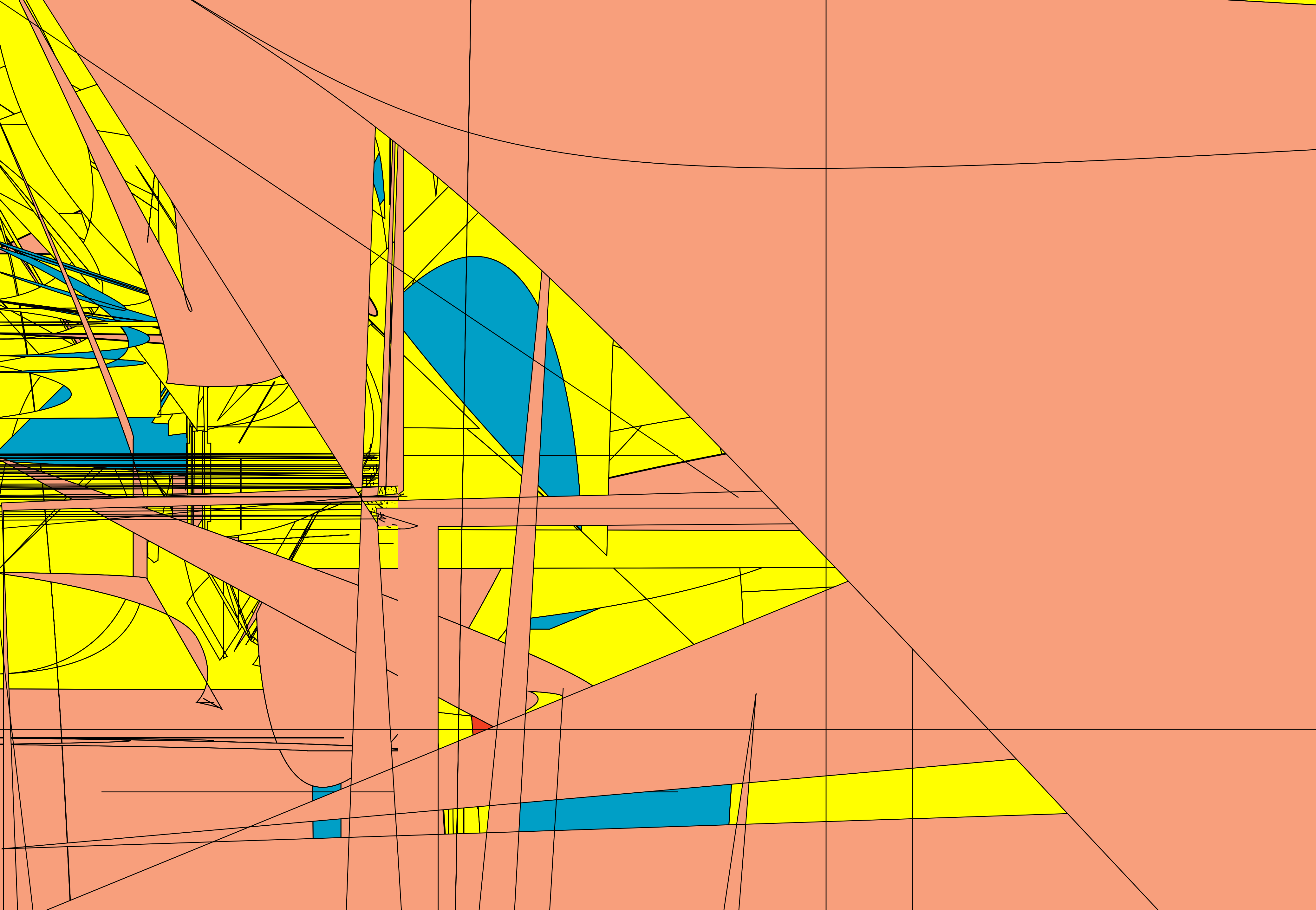


Tau Algorithm

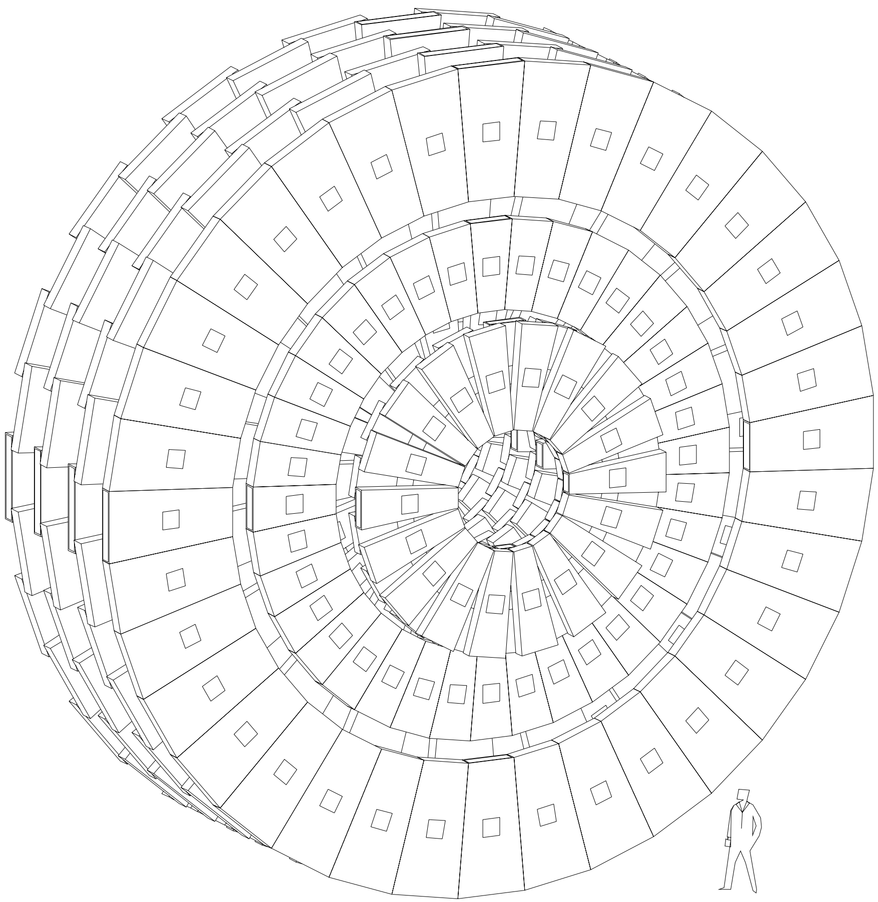
- Improve efficiency for hadronic τ decays
- Regional τ tag
  - hit towers not in one of 8 patterns
- Jet τ tag
  - all 9 regions conform



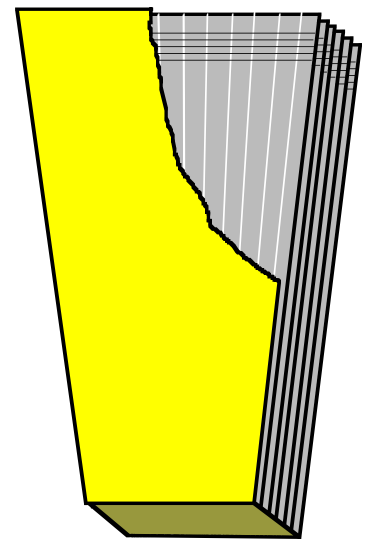
Full details in talk by A. Nikitenko !



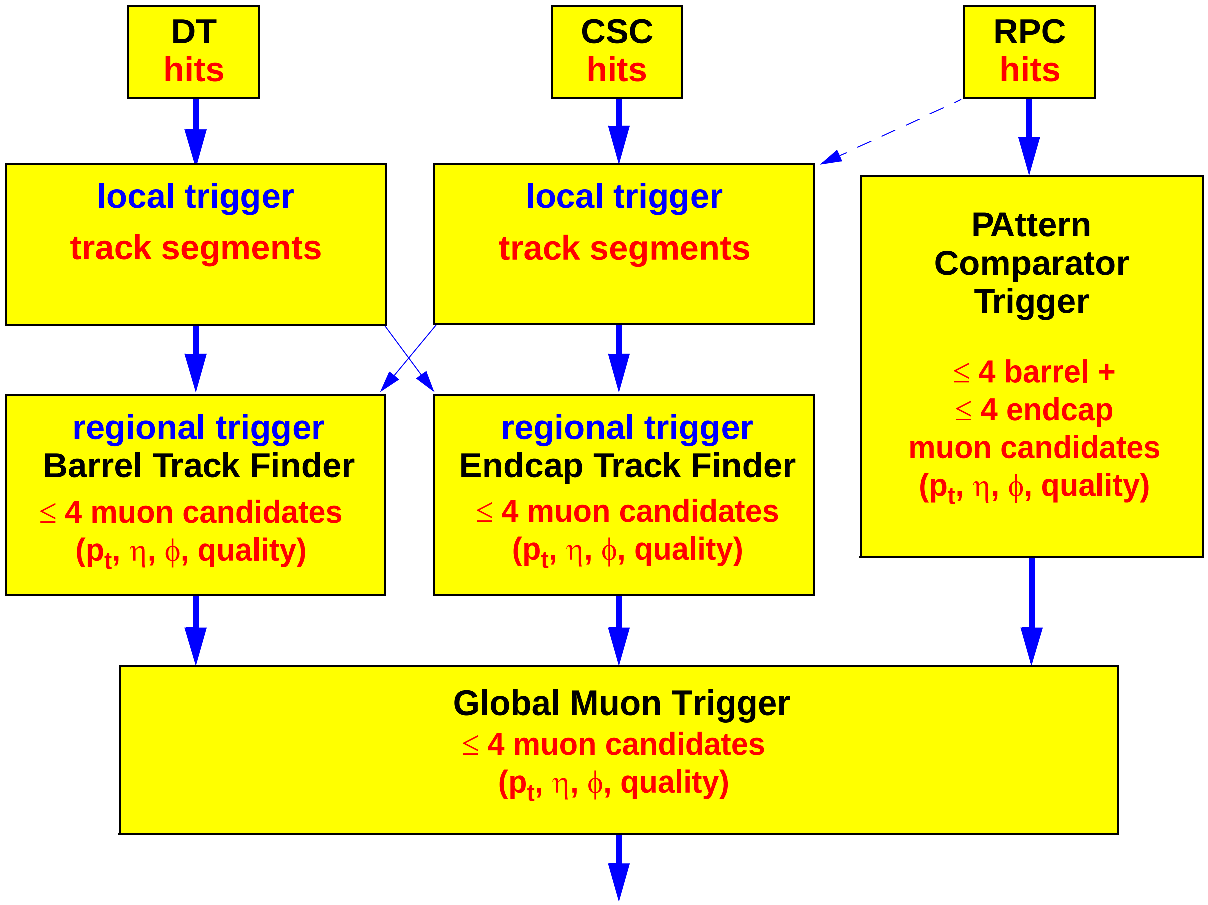
Muon Endcap



- 6 layers radial strips / station
- 6 layers tangential wires / station
- 540 CSCs
- RPCs also used



L1 Muon Trigger

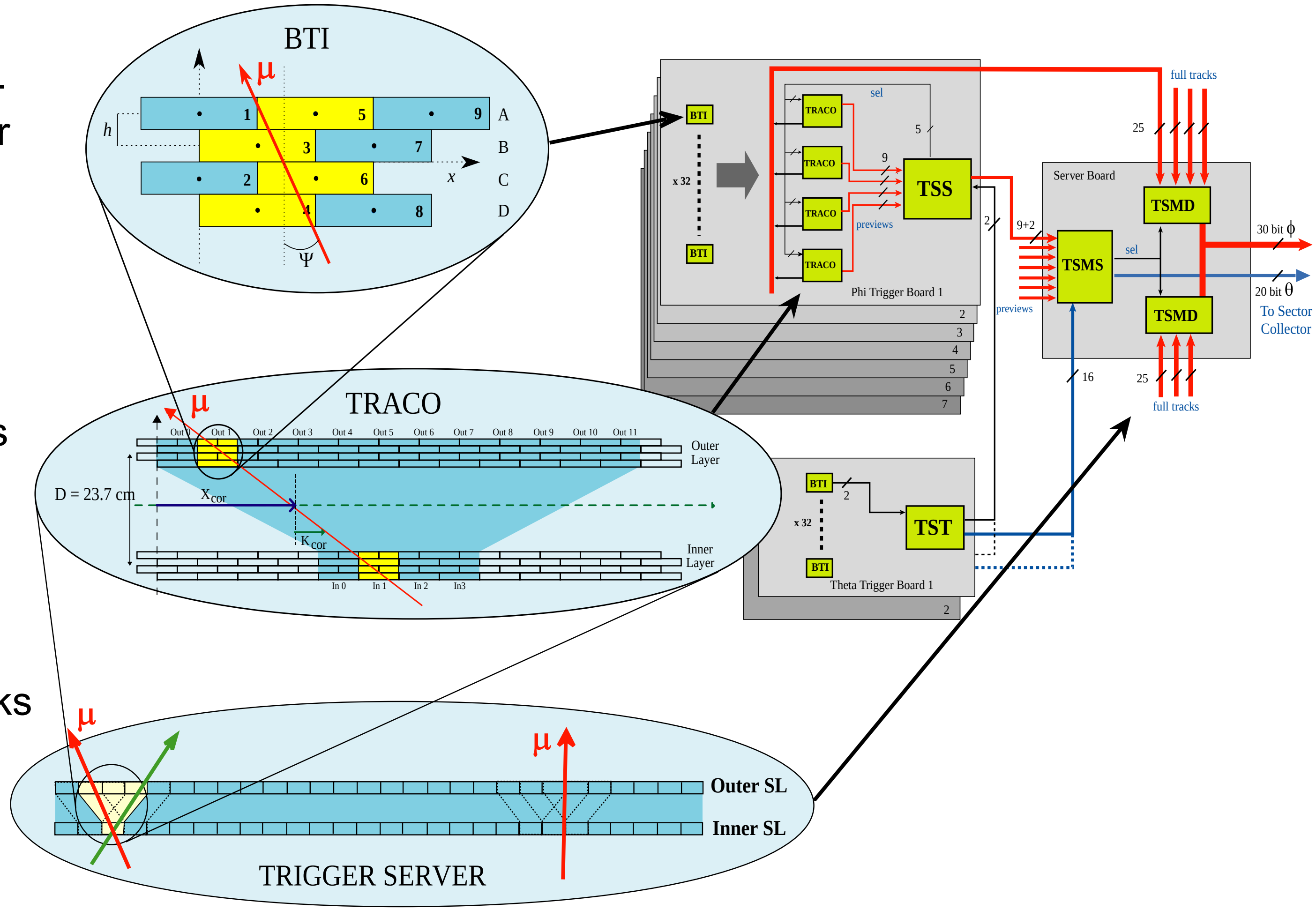


Drift Tube Local Trigger

Bunch & Track ID - for each superlayer ($2 \times \phi$, $1 \times \theta$)

Track Correlator - match ϕ segments

Trigger Server – sort matched tracks (ϕ) and qualify (θ)



Barrel Track Finder

Extrapolate track segments to outer stations (6 pairs)

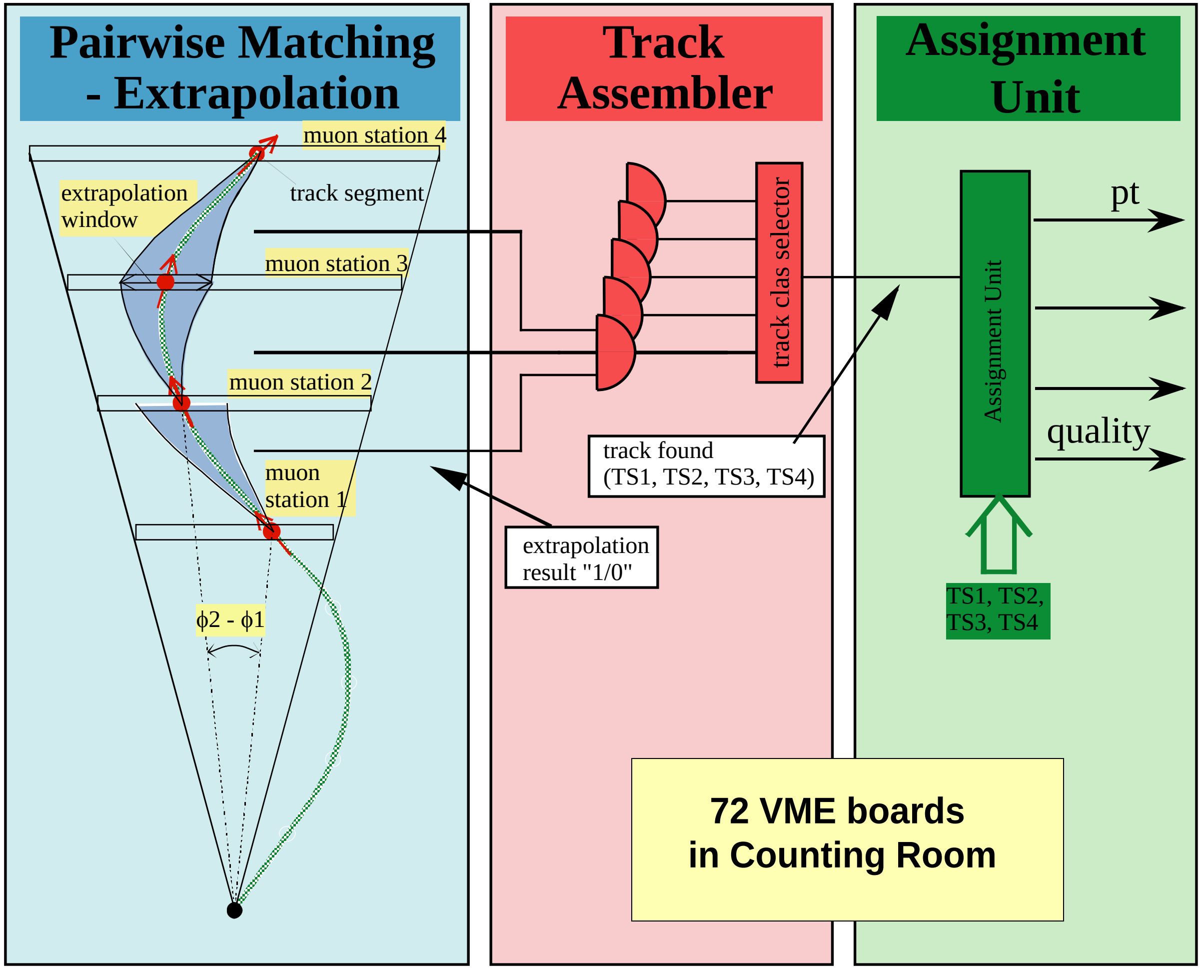
Find all tracks with ≥ 2 segments

Validate tracks by requiring all possible matches e.g.

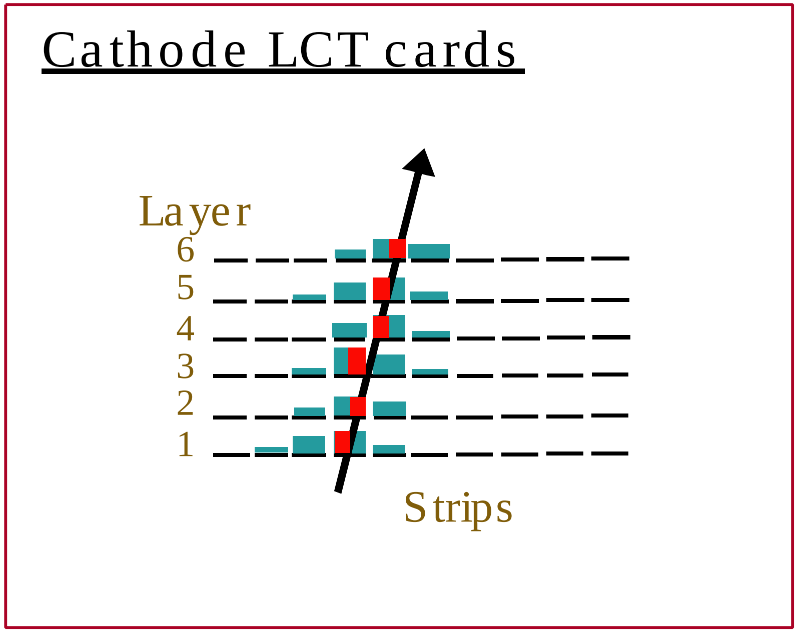
(1-2, 2-3, 1-3)

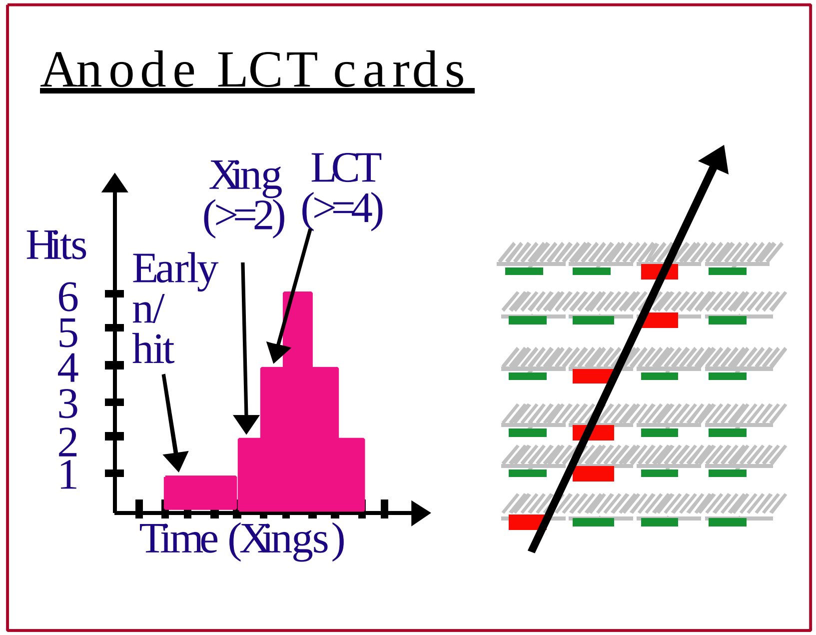
(1-2, 1-3, 1-4, 2-3, 2-4, 4-3)

Assign quality based on # segments



CSC Local Trigger





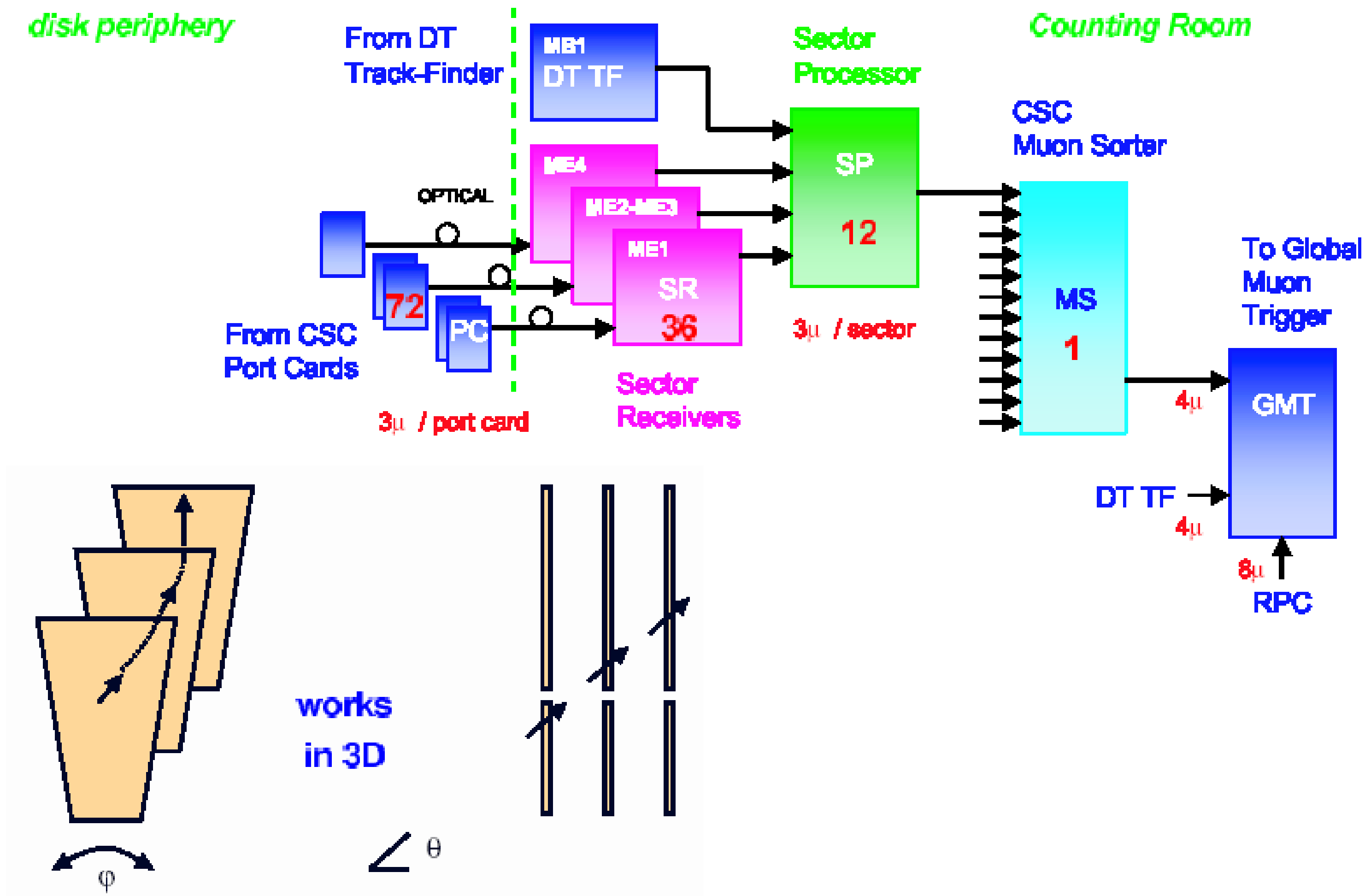
Radial cathode strips measure ϕ coordinate & bending angle

(+ vertex constraint $\rightarrow p_t$)

Anode wires perp. to strips - measure η

Also used in trigger for BX ID

Endcap Track Finder

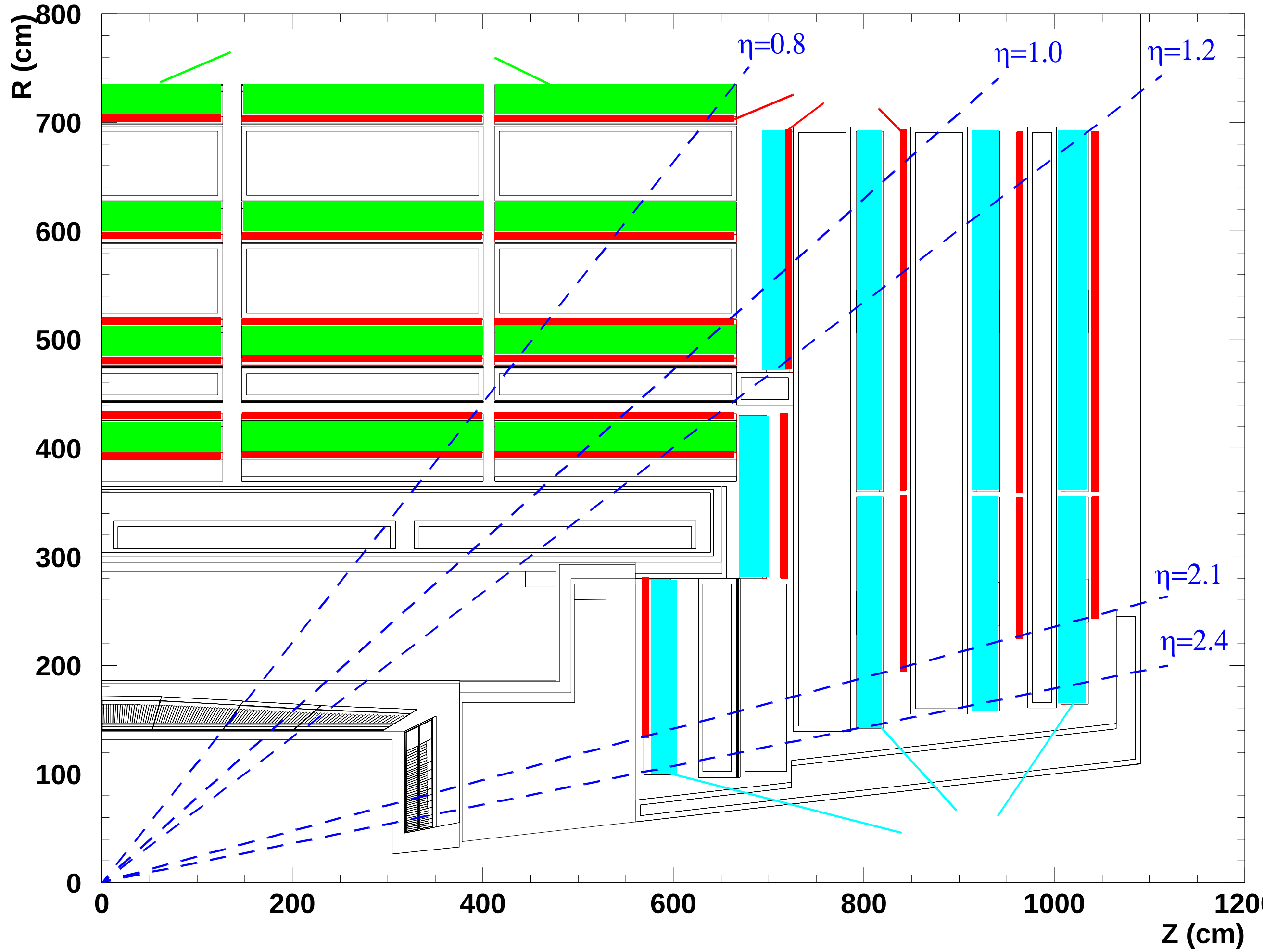


L1 Muon Trigger

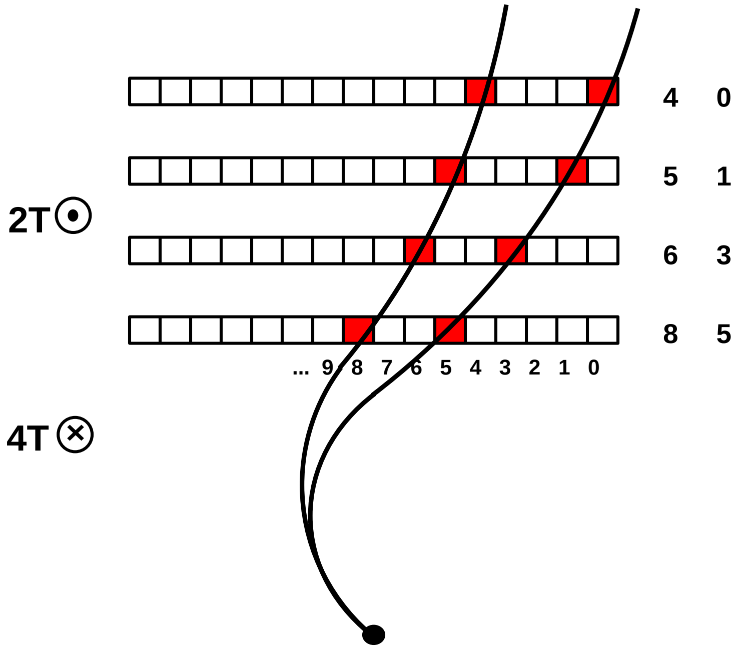
Drift Tubes

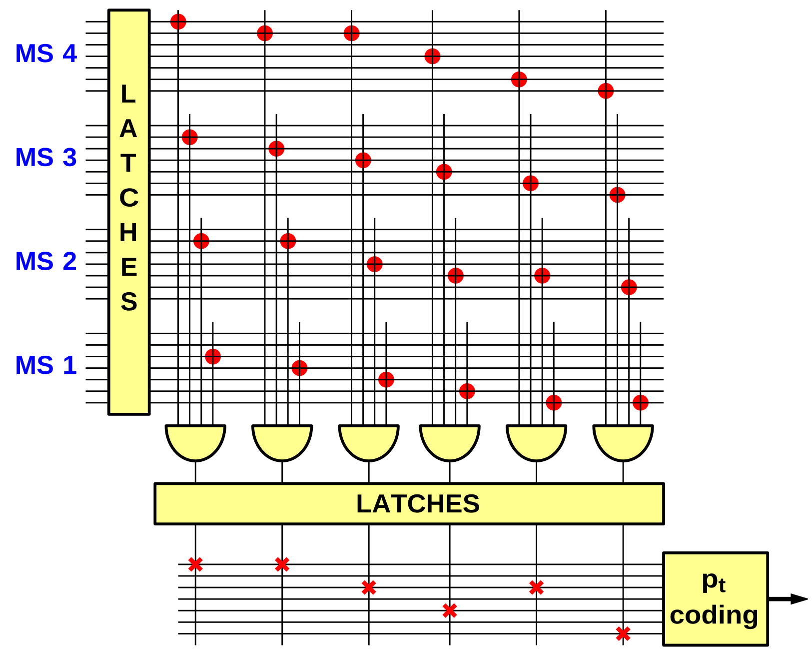
Cathode Strip Chambers

Resistive Plate Chambers



RPC Trigger

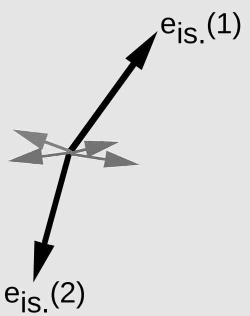




- Algorithm now extended to include all 6 RPC layers
  - Reduces fake rate due to noise...

L1 Global Trigger

- 128 trigger algorithms
- Including cuts on
  - E_t (or p_t)
  - η, ϕ, $\Delta\eta$, $\Delta\phi$
- e.g.
  - 2 back to back electrons



$E_T(1) > E_T(1)^{threshold}$

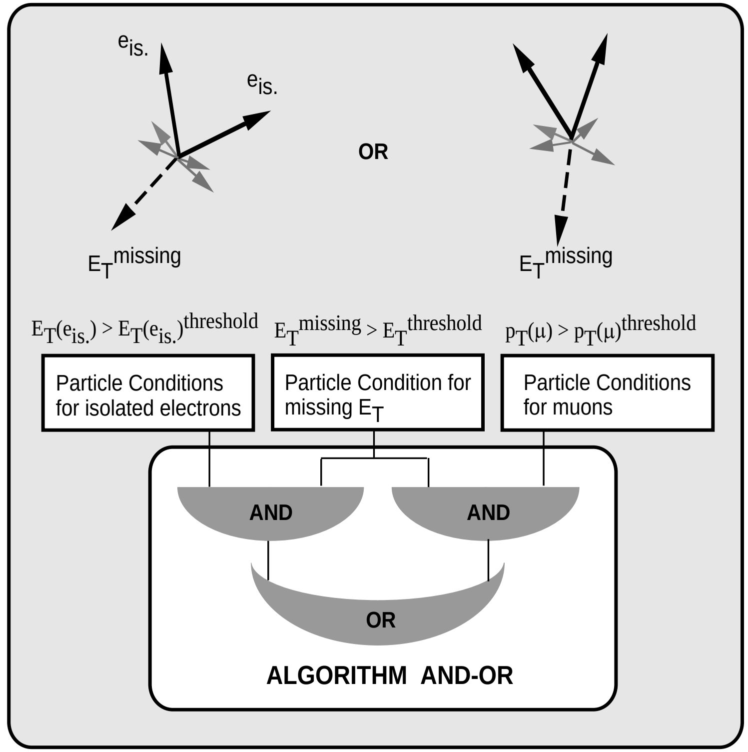
$E_T(2) > E_T(2)^{threshold}$

$0^o < \phi(1) < 360^o$

$0^o < \phi(2) < 360^o$

$170^o < |\phi(1) - \phi(2)| < 190^o$

- e.g.
  - ee + E_t^{miss} OR $\mu\mu$ + E_t^{miss}



Electron / photon

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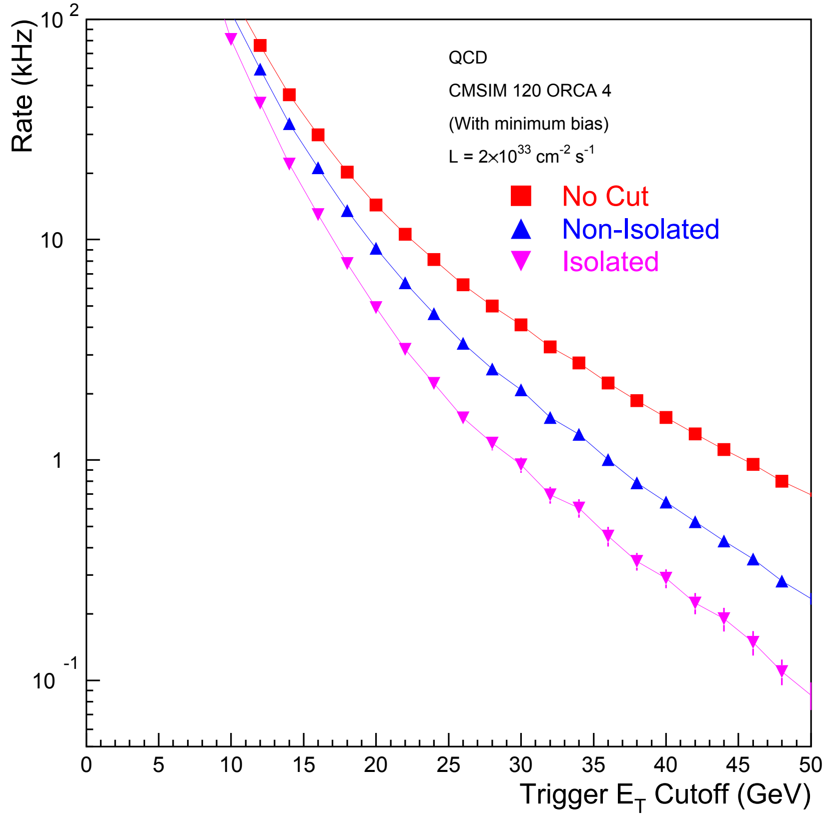
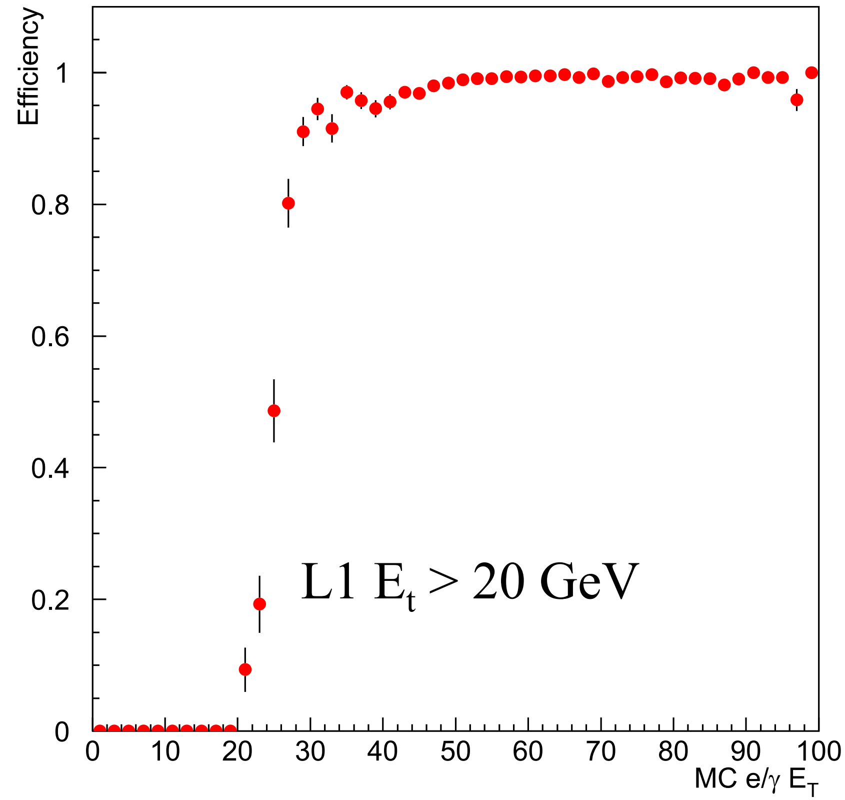
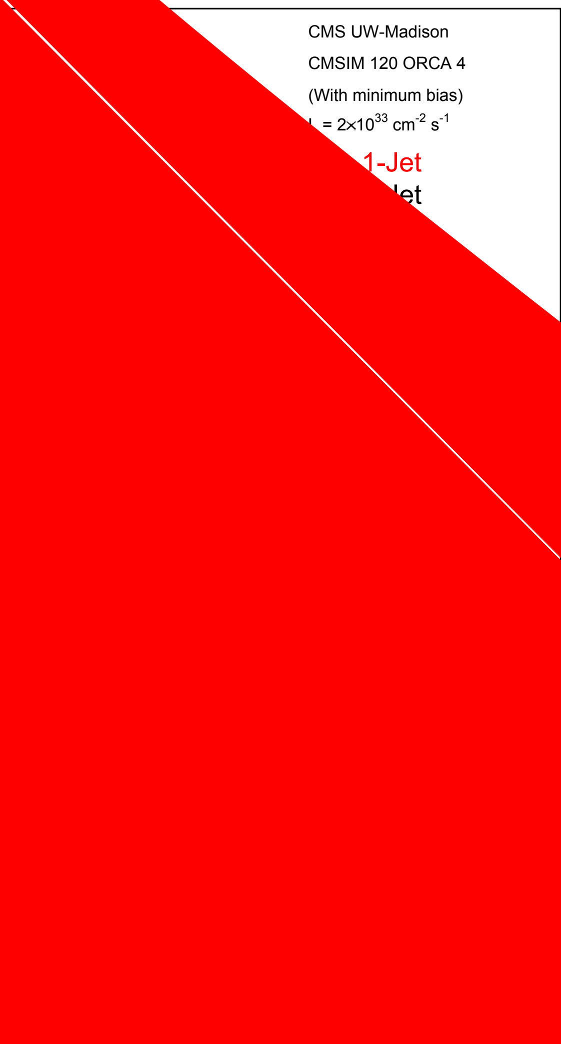
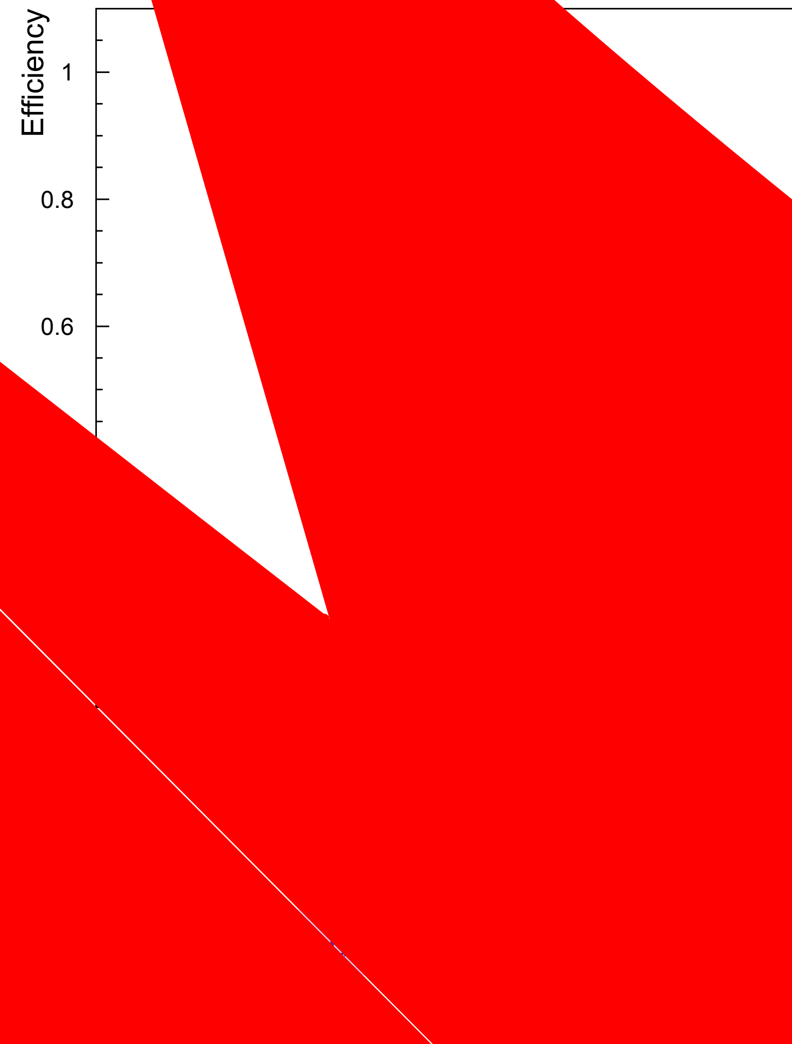




Je


CMS UW-Madison
CMSIM 120 ORCA 4
(With minimum bias)
L = 2×10^33 cm^-2 s^-1
1-Jet

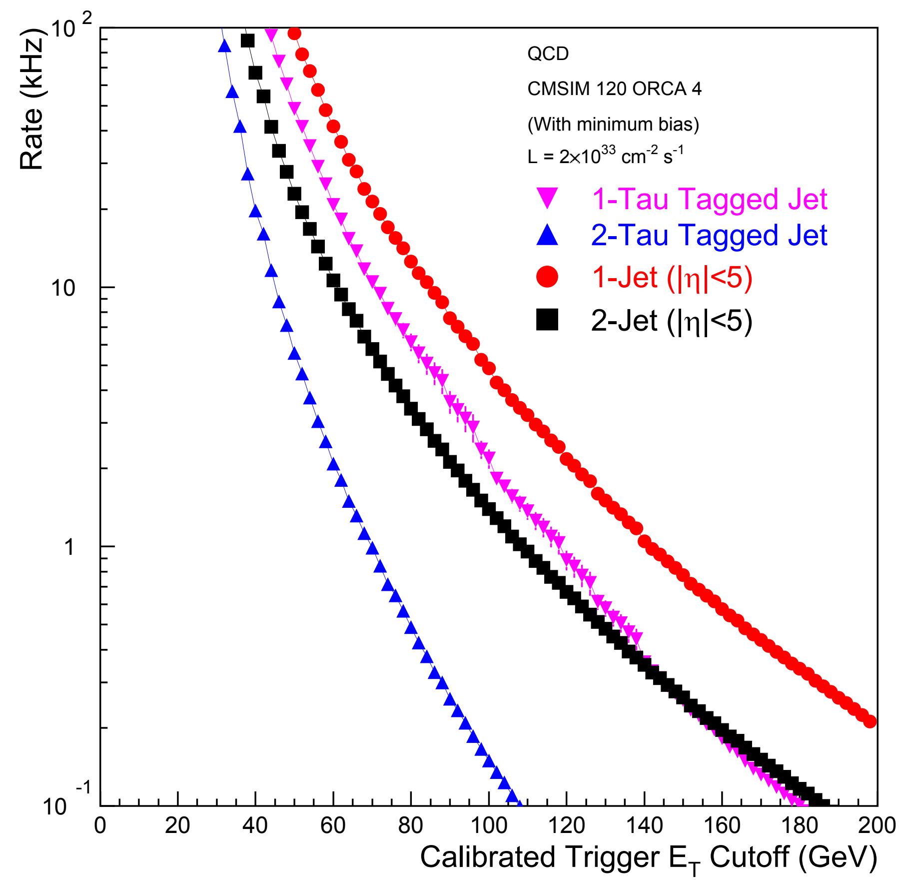

Efficiency
1
0.8
0.6

Tau jets

- Tau algo provides improved τ efficiency at lower E_t
- Full efficiency requires jet trigger as well
- Turn-on curve not really meaningful...

See talk by

A. Nikitenko !



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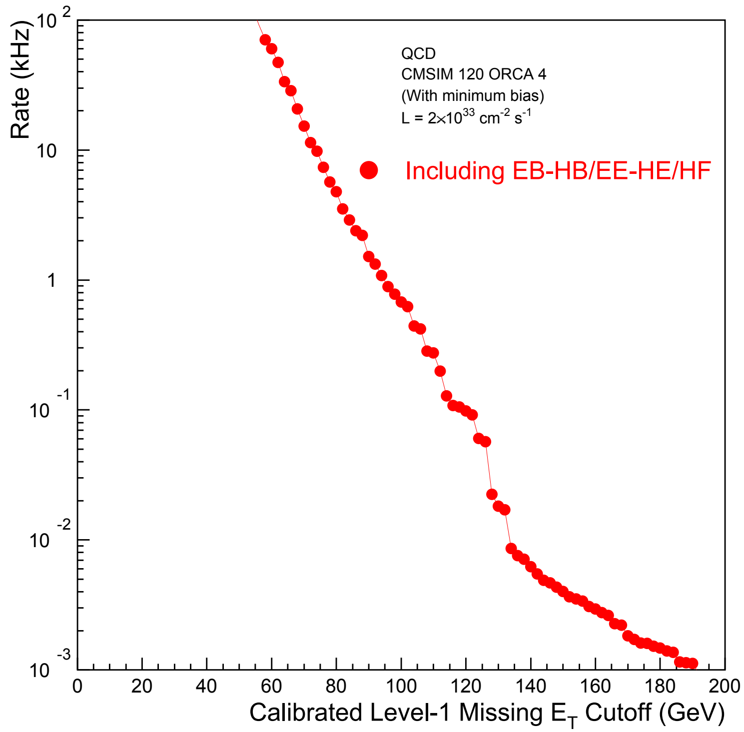
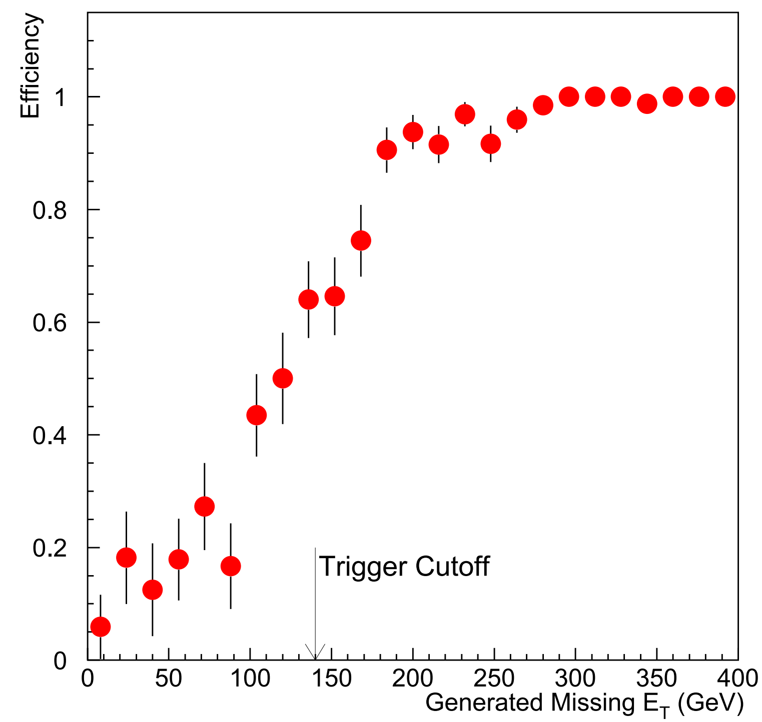
Missing E_t





- Vector sum of L1 towers
- Output to Global Trigger includes azimuthal angle

Total E_t & 'H_t'

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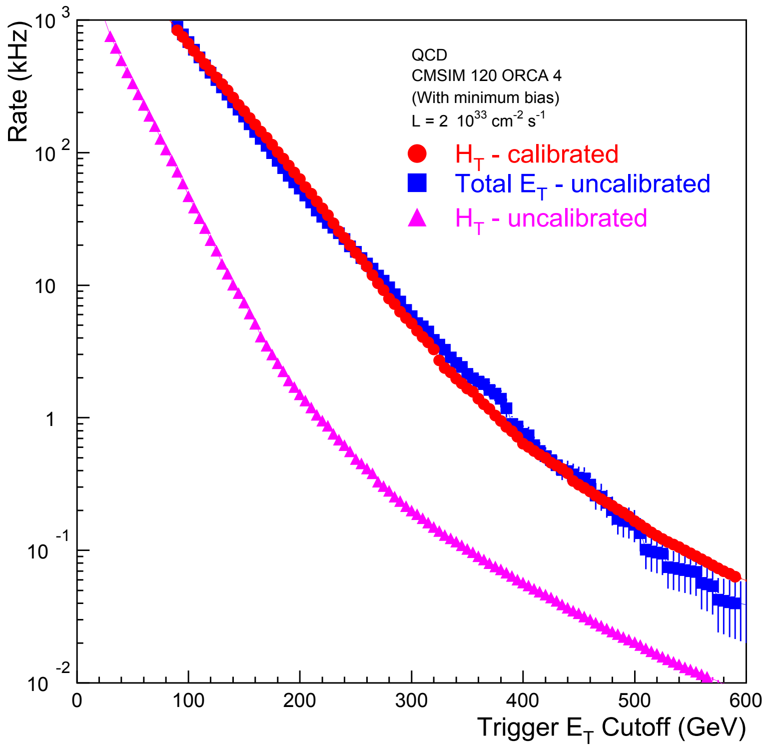
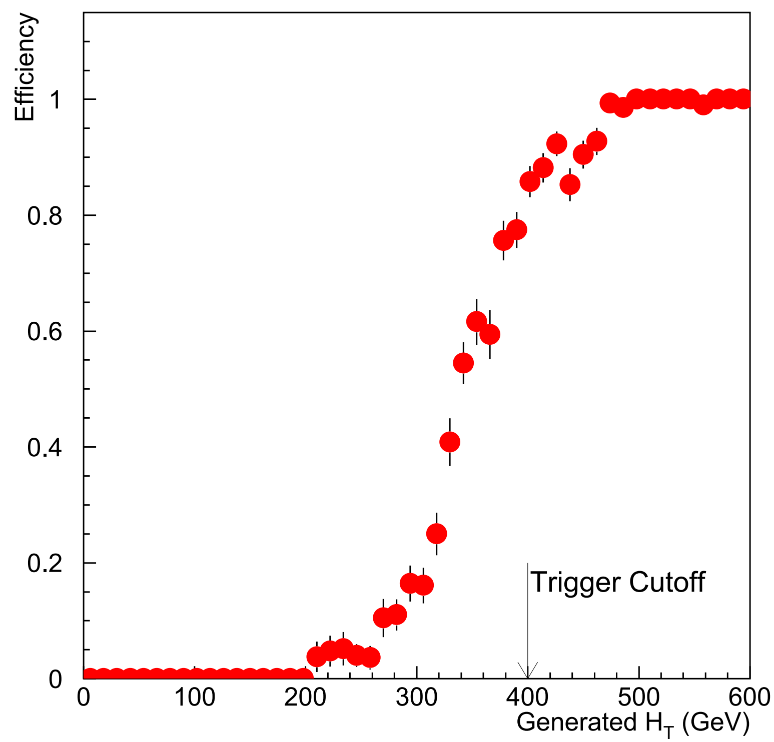
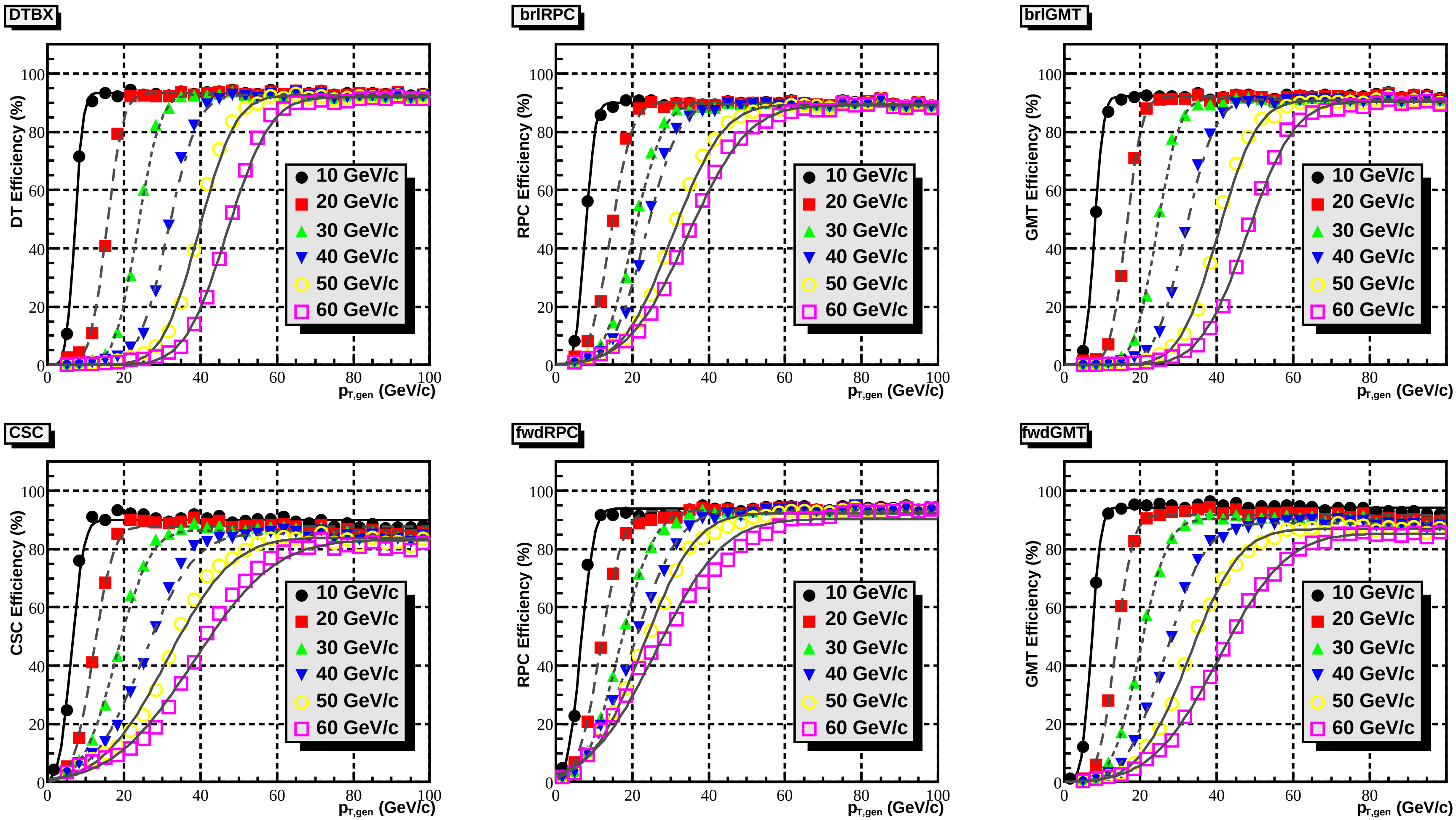




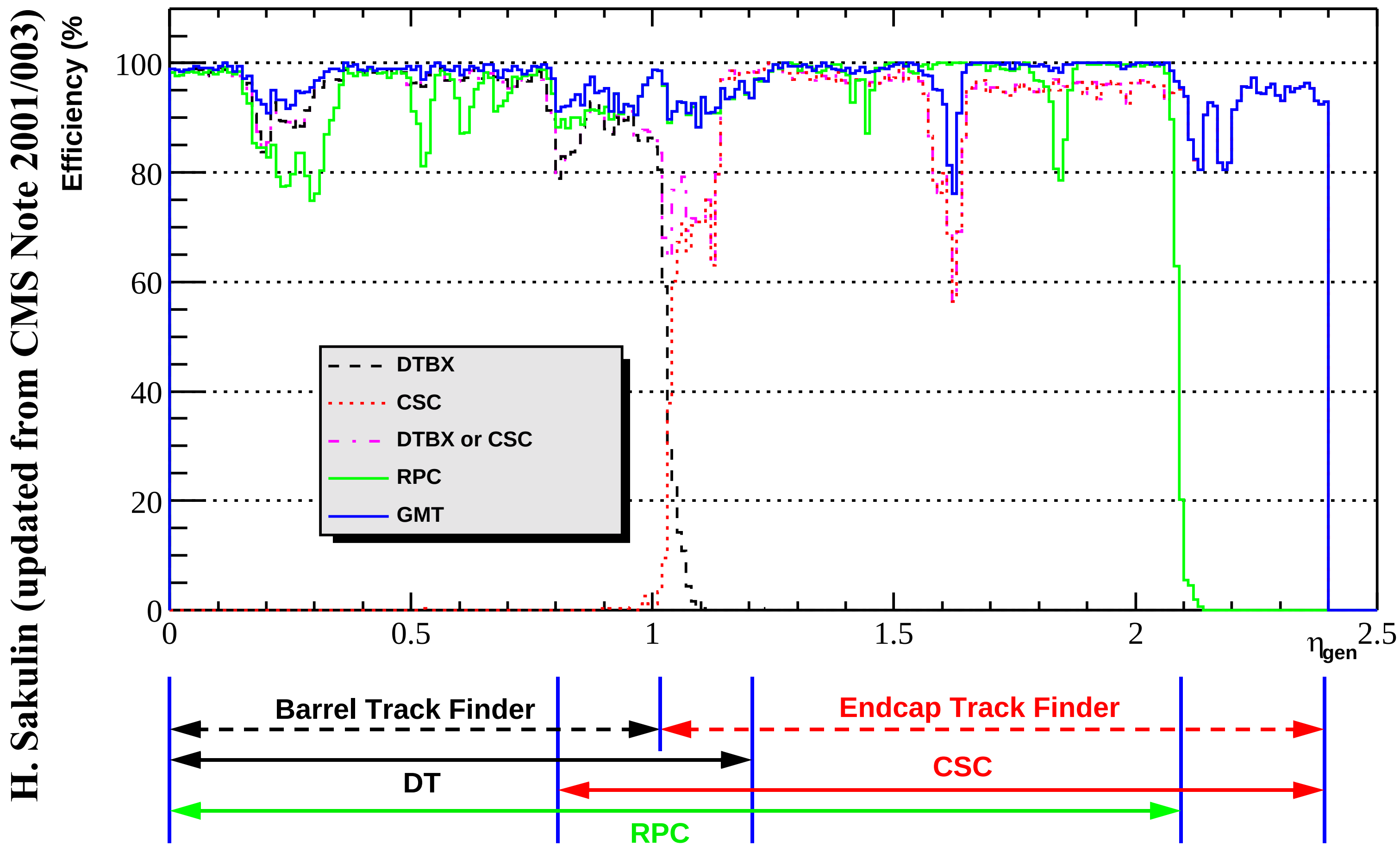
$$H_t = \sum_{jets} E_t^{corrected} \quad \text{for } E_t > \text{threshold (10 GeV default)}$$

Muon Trigger Turn-on



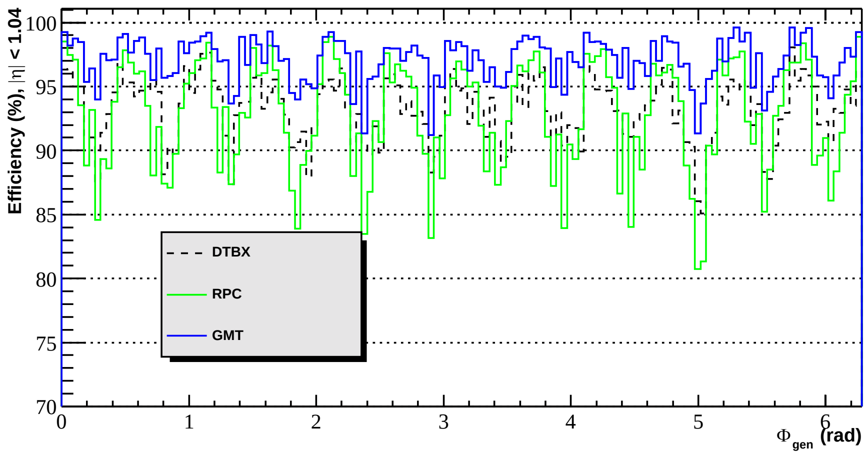
H. Sakulin (updated from CMS Note 2001/003)

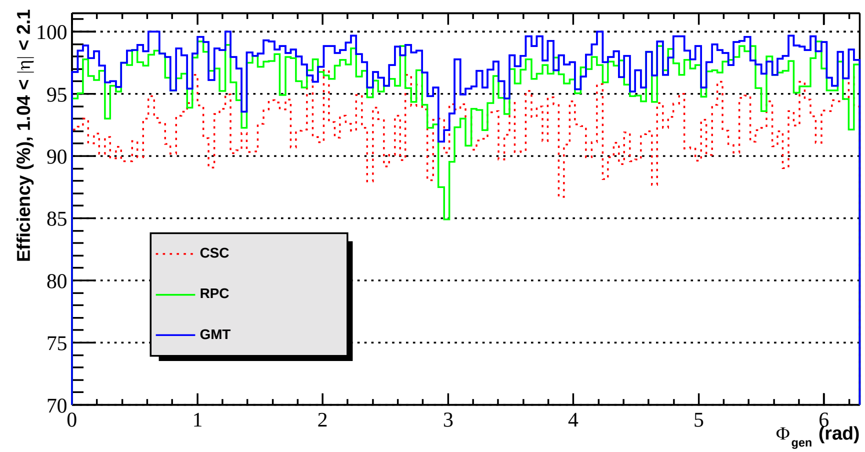
GMT Efficiency

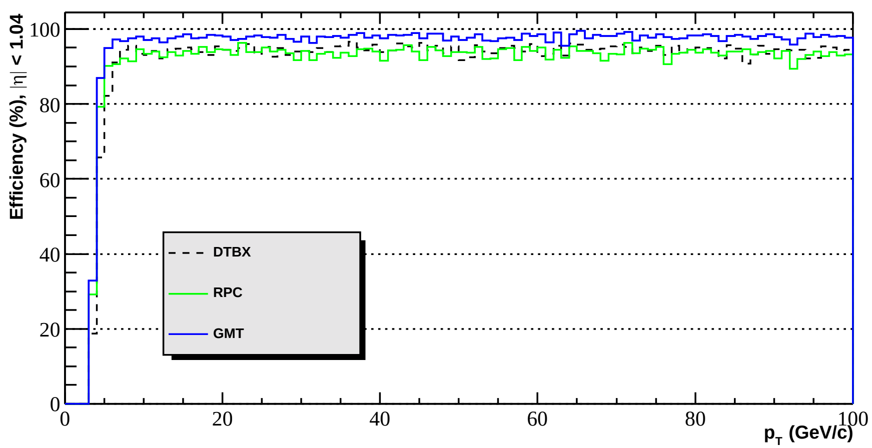


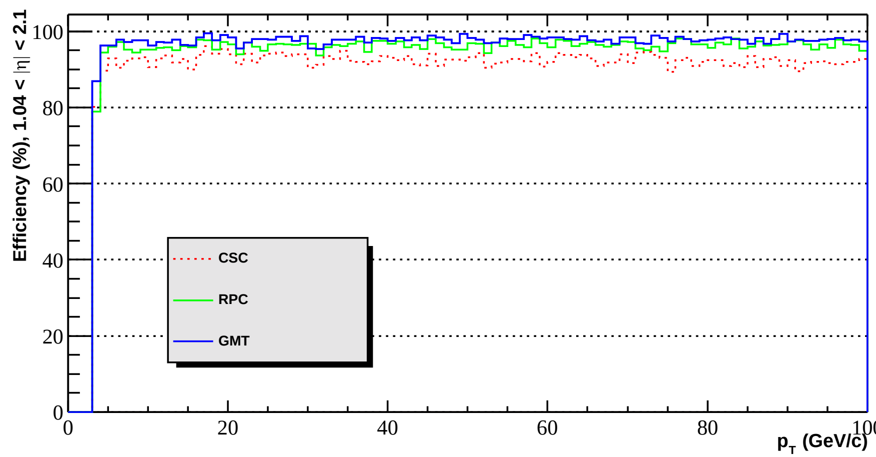
GMT Efficiency

H. Sakulin (updated from CMS Note 2001/003)



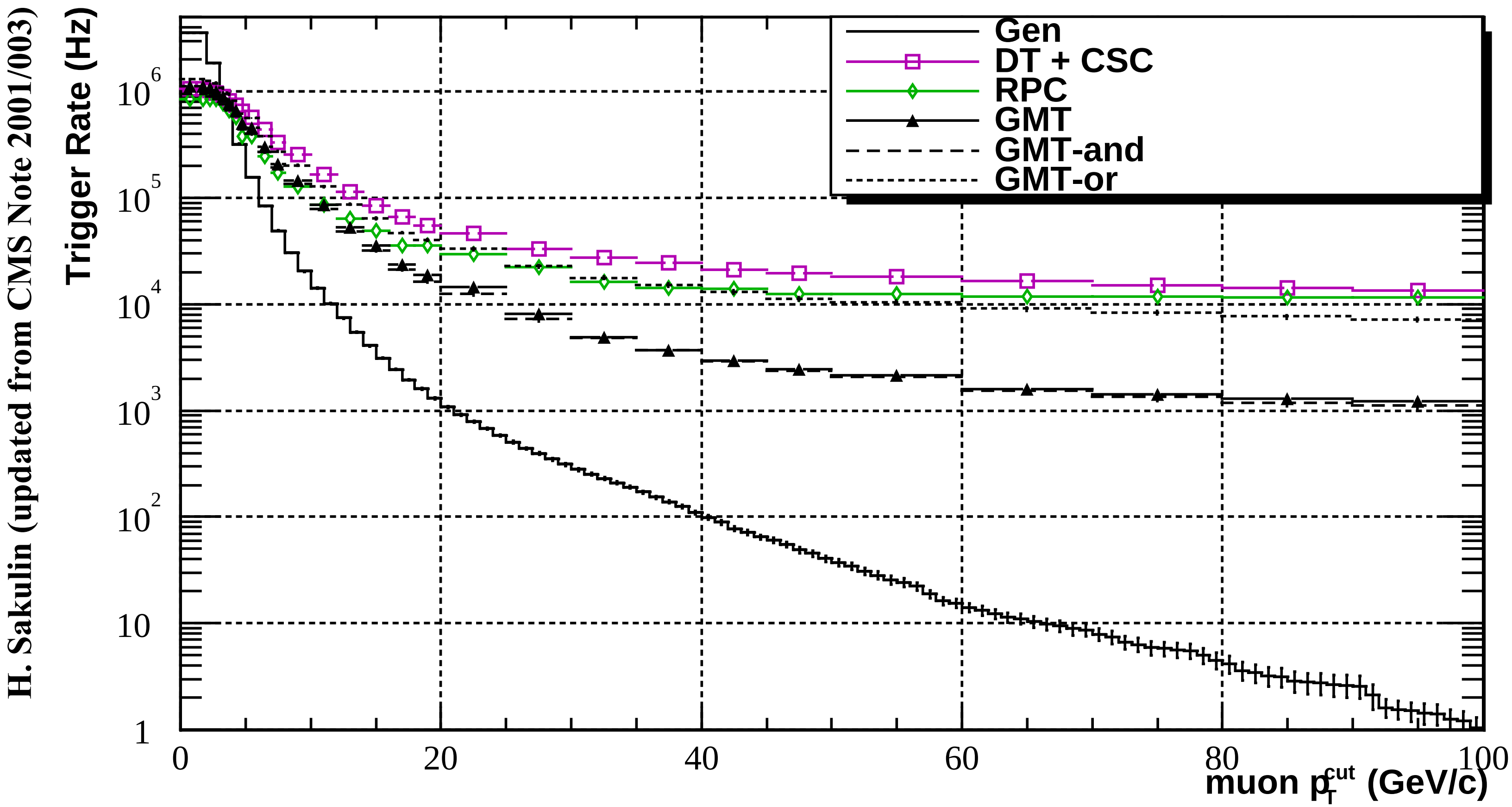






Muon Rate

Rate from whole detector, |η| < 2.4



Calo Triggers

2×10^{33} $cm^{-2}s^{-1}$ luminosity

Trigger	Threshold (GeV)	95% Eff. (GeV)	Ind. Rate (kHz)	Cum. Rate (kHz)
e	21	27	3.9	3.9
ee	15	19	0.2	4.0
τ	85	-	4.9	8.8
$\tau\tau$	75	-	0.7	8.8
j	110	134	3.2	10.4
jj	90	113	2.1	10.6
jjj	60	71	0.8	10.8
jjjj	50	53	0.3	10.9
e · jet	10 & 100	15 & 125	0.4	11.0
e · τ	10 & 75	-	0.8	11.2
E_t^{miss}	140	200	0.01	11.2
e · E_t^{miss}	10 & 75	125 & 140	0.4	11.5
j · E_t^{miss}	60 & 90	80 & 150	0.7	11.7
Total E_t	600	1200	0.04	11.7
H_t	400	470	0.6	11.8
e(NI)	45	51	0.2	11.8
ee(NI)	25	37	0.3	11.8
Total Rate				**11.8**

CMS IN 2002/019 – P. Chumney, S. Dasu, W. Smith

Signal Efficiencies - 2×10^{33}

Channel	Eff. (%)	Trigger efficiencies by type (individual) cumulative				
$W \to e\nu$	69	e (69) 69				
$t \to eX$	92	e (81) 81	$e \cdot \tau$ (62) 85	τ (59) 89	$e \cdot j$ (54) 92	
$Z \to ee$	94	e (93) 93	ee (76) 94			
$H_{115} \to \gamma\gamma$	99	e (99) 99	ee (82) 99			
$H_{150} \to WW \to e\nu X$	86	e (76) 76	$e \cdot \tau$ (43) 80	τ (38) 82	$e \cdot j$ (39) 84	j (39) 86
$H_{135} \to \tau\tau \to ej$	83	e (67) 67	$e \cdot \tau$ (46) 76	$e \cdot j$ (46) 80	τ (41) 84	j (44) 83
$H^{\pm}_{200} \to$	99	τ (86) 86	j (94) 99	$j \cdot mE_t$ (60) 99		
$H_{200} \to \tau\tau \to jj$	87	τ (80) 80	$\tau\tau$ (50) 82	j (54) 87	jj (40) 87	
$H_{500} \to \tau\tau \to jj$	99	τ (94) 94	$\tau\tau$ (64) 94	j (98) 99	jj (89) 99	
$t \to jets$	70	H_t (39) 39	jjjj (34) 48	jjj (47) 57	jj (40) 63	j (50) 70
mSUGRA	99	j (99) 99				
$H_{120} \to bb$	52	jjj (23) 23	j (39) 45	τ (29) 52	jj (29) 52	
$H_{120} \to$ invisible	46	$j \cdot mE_t$ (39) 39	j (30) 43	τ (15) 46		

CMS IN 2002/019 – P. Chumney, S. Dasu, W. Smith

Calo Triggers

10^{34} cm^{-2}s^{-1} luminosity

Trigger	**Threshold (GeV)**	**95% Eff. (GeV)**	**Ind. Rate (kHz)**	**Cum. Rate (kHz)**
e	30	35	7.2	7.2
ee	15	20	0.6	7.5
τ	150		1.3	8.7
$\tau\tau$	80		2.5	10.9
j	250	285	0.4	11.2
jj	200	225	0.4	11.3
jjj	100	125	0.7	11.6
jjjj	80	105	0.2	11.6
e · jet	15 & 150	20 & 165	0.2	11.8
e · τ	15 & 90		1.4	12.2
E_t^{miss}	150		0.005	12.2
e · E_t^{miss}	15 & 100		0.005	12.2
j · E_t^{miss}	80 & 100		0.1	12.3
Total E_t	1000		0.03	12.3
e(NI)	55	60	0.7	12.8
ee(NI)	25	30	0.2	12.9
Total Rate				**12.9**

CMS Note 2000/074 – P. Chumney, S. Dasu, W. Smith

Muon Triggers

10^{34} $cm^{-2}s^{-1}$ luminosity

Trigger	Threshold (GeV)	Indiv. Rate (kHz)	Cumul. Rate (kHz)
μ	25	8.1	8.1
$\mu\mu$	5, 8	2.8	10.4
$\mu \cdot e$	5, 22	1.7	11.9
$\mu \cdot \tau$	5, 70	0.4	12.0
$\mu \cdot j$	5, 80	0.8	12.3
$\mu \cdot$ Total E_t	5, 400	0.6	12.6
$\mu \cdot E_t^{miss}$	5, 60	0.6	12.9
Total Rate			**12.9**

Overlap with pure calorimeter triggers deducted from cumulative rate figures

CMS Note 2000/061 – M. Fierro, A. Jeitler, M. Konecki

Signal Efficiencies - 10^{34}

CMS Note 2000/074 – P. Chumney, S. Dasu, W. Smith

Channel	Total Eff. (%)	Triggers used				
$H_{110} \to \gamma\gamma$	99	e	ee			
$H_{135} \to \tau\tau \to ej$	72	e	τ	j	$e \cdot \tau$	$e \cdot j$
$H_{200} \to \tau\tau \to ej$	74	e	τ	j	$e \cdot \tau$	$e \cdot j$
$H_{200} \to \tau\tau \to jj$	60	τ	$\tau\tau$	j	jj	
$H_{500} \to \tau\tau \to jj$	86	τ	$\tau\tau$	j	jj	
$H_{120} \to$ invisible	56	$j \cdot mE_t$	mE_t	j		

NB. Total efficiency here is calculated with respect to 'offline' cuts on generator level quantities