CMS Trigger Simulation

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Outline:

- **Calorimeter Level-1**
  - Trigger Algorithms
  - Rates and Efficiencies
  - Physics Performance
- **Muon Level-1**
  - Trigger Algorithms
  - Rates and Efficiencies
- **Global Trigger**
  - Physics Performance

CMS/LHC Trigger Physics

Standard model Higgs (high luminosity)

- H (80 GeV) $\rightarrow \gamma\gamma$
- H (120 GeV) $\rightarrow$ Z Z* (4 leptons)
- H (>500 GeV) $\rightarrow$ leptons (+ ν's)
- H (< $2M_w$ Associated t or W or Z) $\rightarrow$ b b (lepton + X)

SUSY Higgs (low luminosity)

- (standard model Higgs like channels)
- h, H, A $\rightarrow \tau\tau$ (lepton + X) or $\rightarrow \mu\mu$
- A $\rightarrow$ Z h ; h $\rightarrow$ bb (lepton + X)
- p p $\rightarrow$ t t X; t $\rightarrow$ H^+ b; $H^+ \rightarrow \tau\nu$; t $\rightarrow$ lepton + X; $\tau \rightarrow$ X

SUSY sparticle searches (low luminosity)

- MSSM sparticle $\rightarrow$ LSP (Missing E_t) + n jets
- MSSM sparticle $\rightarrow$ Same sign dileptons + X

Other new particles

- Z' $\rightarrow$ dileptons
- Leptoquarks: dileptons

Top physics (low luminosity)

- t $\rightarrow$ lepton + X
- t $\rightarrow$ multijets

Bottom physics (low luminosity)

- b $\rightarrow$ lepton + X
- b $\rightarrow \psi k_s$ (leptons + X)

QCD

- Low luminosity 100 GeV jets
- High luminosity 200 GeV jets

fi Trigger candidate requirements:

- High luminosity: lepton/γ (30 GeV), dileptons/$\gamma\gamma$ (15 GeV)
  missing E_t (100 GeV), jets (200 GeV)
- Low luminosity: lepton/γ (15 GeV), dileptons/$\gamma\gamma$ (10 GeV)
  missing E_t (50 GeV), jets (100 GeV)

Calorimeter requirements

Input

- **ECAL trigger towers, 0.087ϕ x 0.087η**
- **Matching HCAL towers**
- **Data every 25ns - including any corrections for time development of calorimeter signal**
  - 8 bit transverse energy
  - 1 bit finegrain charecterization of energy deposit
- **Data presynchronized across all channels, ECAL and HCAL**

Output

- **Top 4 nonisolated electrons/photons (E_t and location)**
- **Top 4 isolated electrons/photons (E_t and location)**
- **Top 4 jets (E_t and location)**
- **Top 4 isolated hadrons (E_t and location)**
- **Total and missing transverse energy (E_t, E_x, E_y)**
- **Minimimum ionization ID and isolation bits for use with muon trigger**

Outut rate

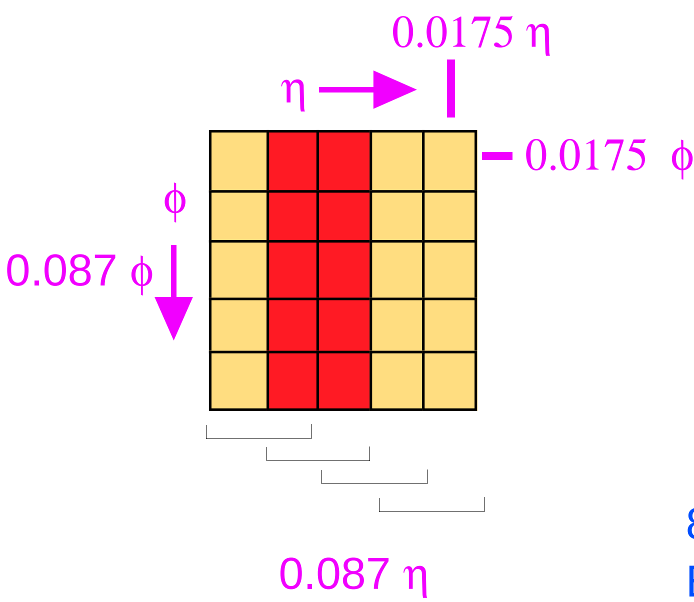
- **50 kHz maximum for calorimeter trigger**
- **Simulations should indicate about a factor of 3 safety margin - i.e., ~15 kHz**

Efficiency

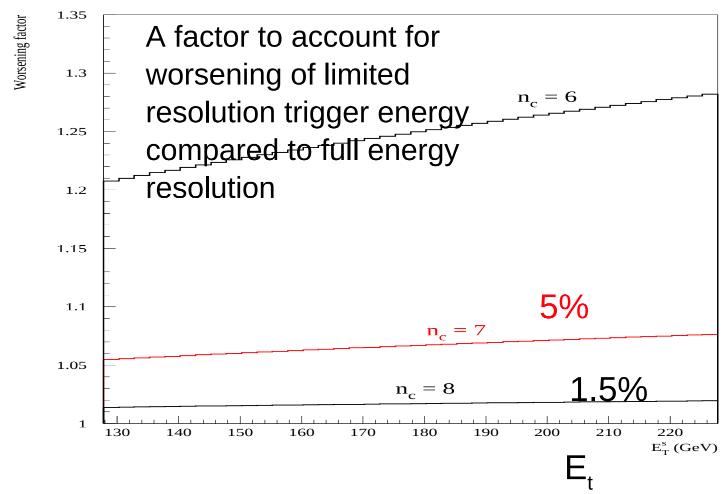
- **Trigger should contribute no more than a few percent inefficiency for any physics channel compared to other offline analysis cuts.**
- **Trigger efficiencies should be measurable**

Cal Regional Trigger Input

ECAL Crystals in Trigger Tower

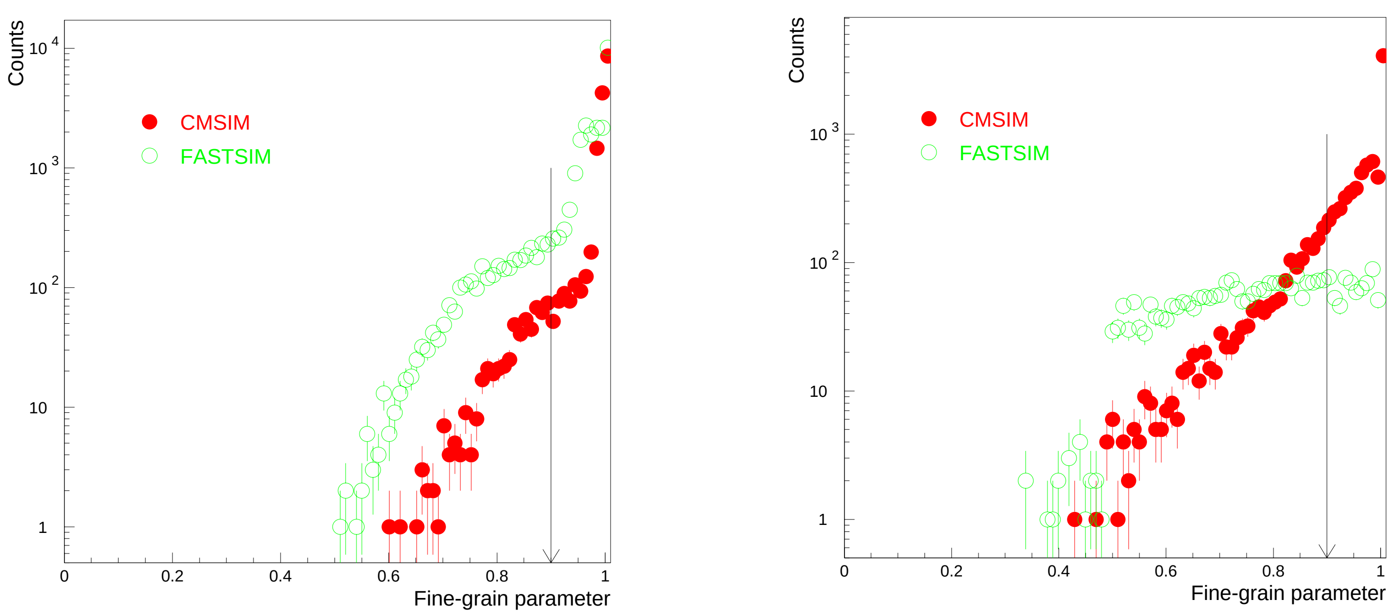


Transverse Energy in Trigger Tower



8 bit transverse energy output from both ECAL and HCAL trigger towers

Shower Profile in Trigger Tower

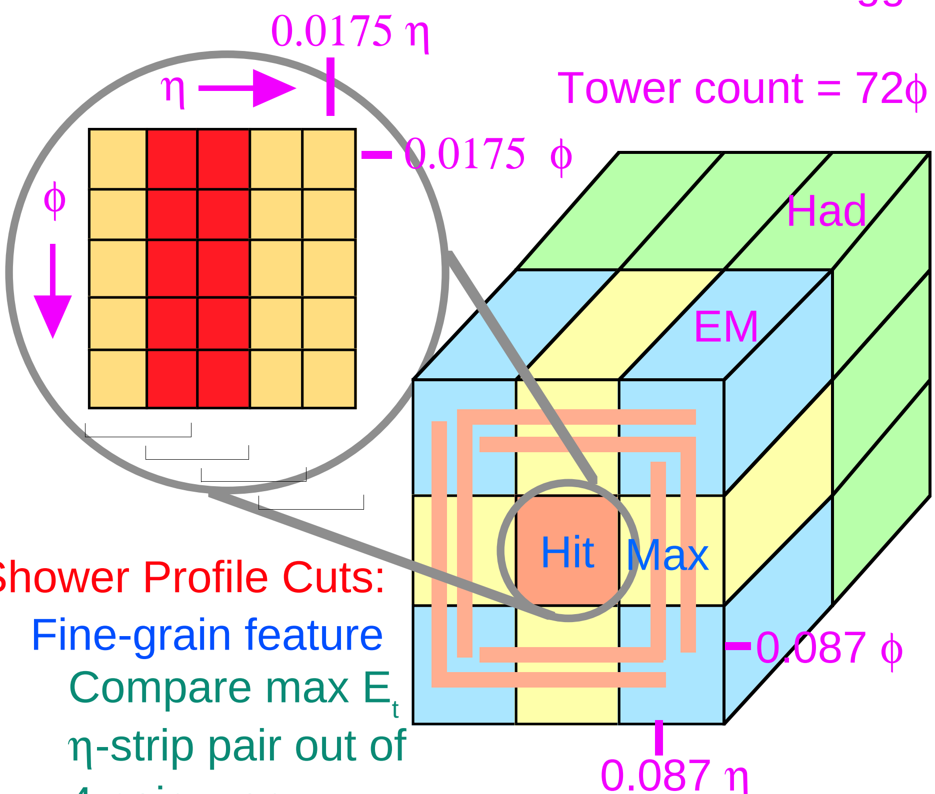


Single bit to indicate electron like shower profile within the trigger tower - Comparison of the maximum strip pair energy sum to the total energy sum in the trigger tower.

Electron/photon algorithm

Sliding window centered on all ECAL/HCAL trigger tower pairs

Tower count = 72ϕ x 54η x 2 = 7776



Candidate Energy:

Max — Max E_t of 4 Neighbors

Hit — Hit + Max E_t > Threshold

Shower Profile Cuts:

Fine-grain feature

Compare max E_t η-strip pair out of 4 pairs versus total E_t in trigger tower, e.g., require 90% energy in a pair.

HAC Veto

Compare HCAL versus ECAL E_t in Memory Lookup to veto non-EM deposits, e.g., H/E<5% when E is significant.

Isolation Cuts:

Neighbor HAC Veto

HAC Veto passes on all eight neighbors also.

New E_t isolation: Quiet Neighborhood

At least one of four corners has all five quiet towers, i.e, (E_t<1.5 GeV)

Summary:

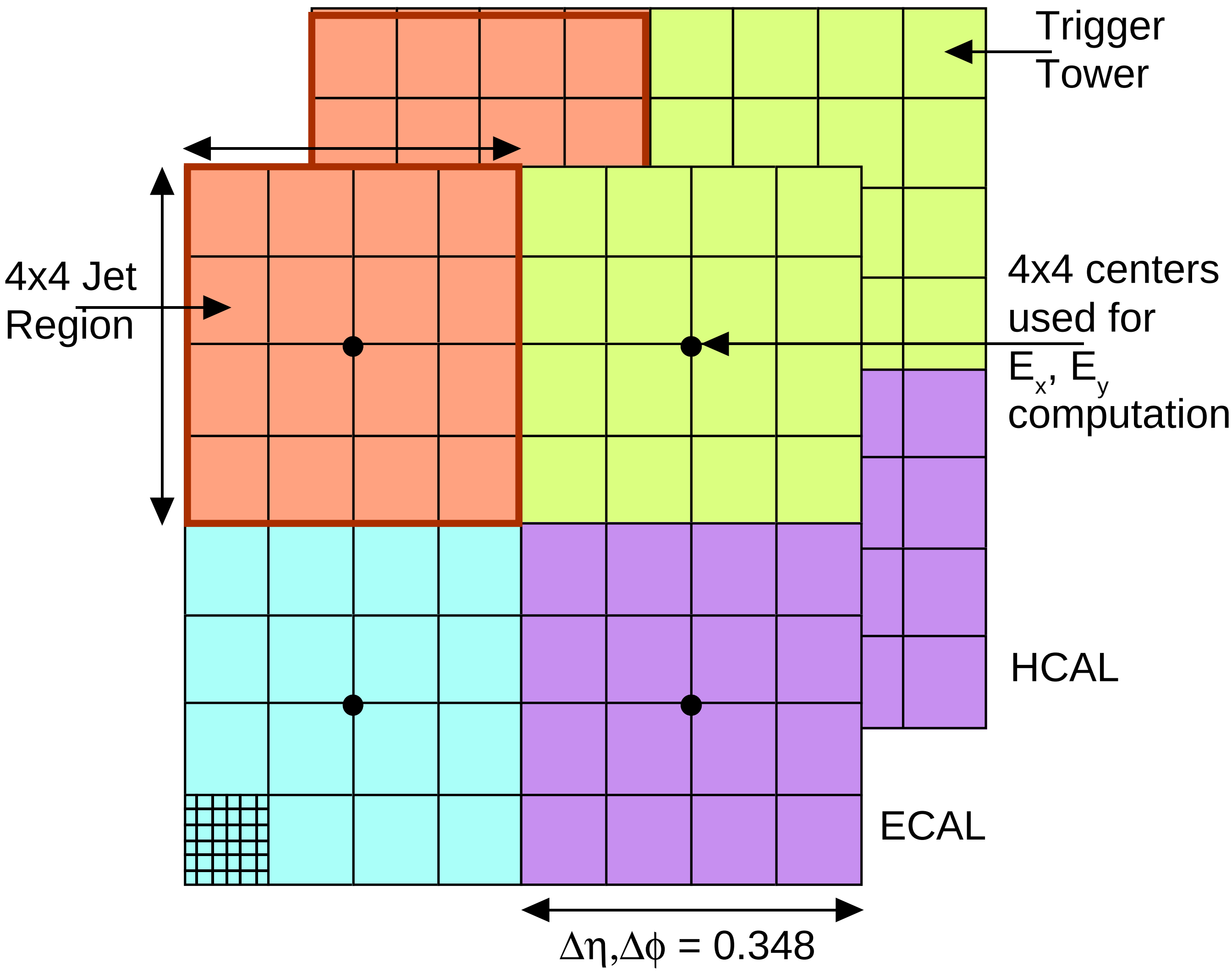
Regional

Pick highest energy candidate in 4x4 trigger tower region.

Global

Sort to find top-4 isolated and non-isolated candidates separately.

Jet, Missing E_t algorithms



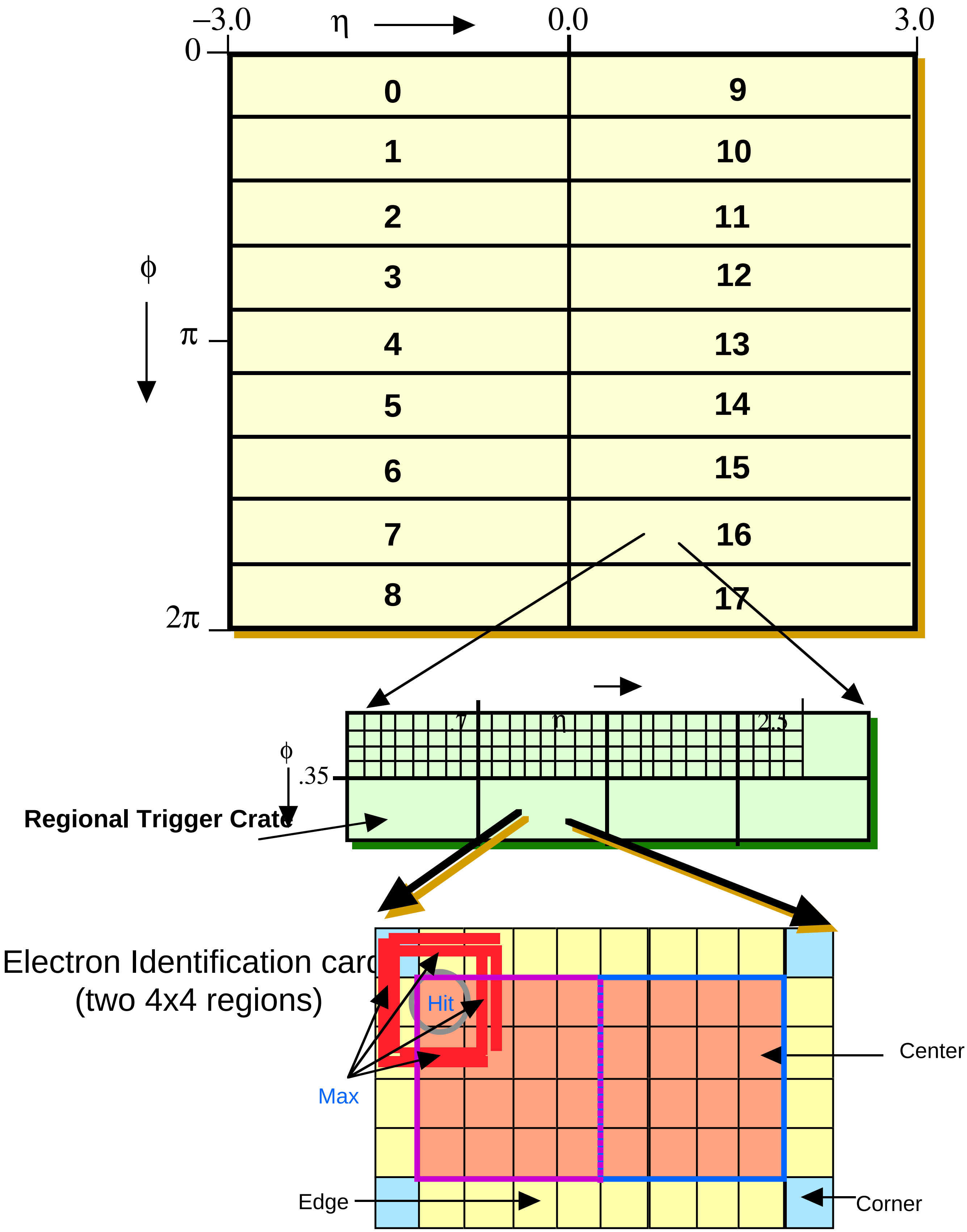
Jet E_t is given by the sum of ECAL and HCAL trigger tower E_t in a non-overlapping 4x4 region

Jet candidates are sorted to find highest energy jets

Jet trigger is caused by core of the physical jet. This allows for jet counting without the problems of dealing with multiple jets overlapping in large ($0.1\eta \times 0.1\phi$) regions

E_x and E_y are obtained by a memory lookup using 4x4 E_t
Signed E_x and E_y sums over the entire calorimeter are made to calculate missing E_t

Trigger/Calorimeter Map



Simulation programs

FSTSIM - Fast simulation of event response

- Simplified CMS geometry, uniform tracking medium, decays of mesons, and parameterized calorimeter showers are implemented.

CMSIM - Version 111

- CMS standard GEANT based detector simulation
- Detailed geometry for calorimeter, average response for tracker but no preshower.

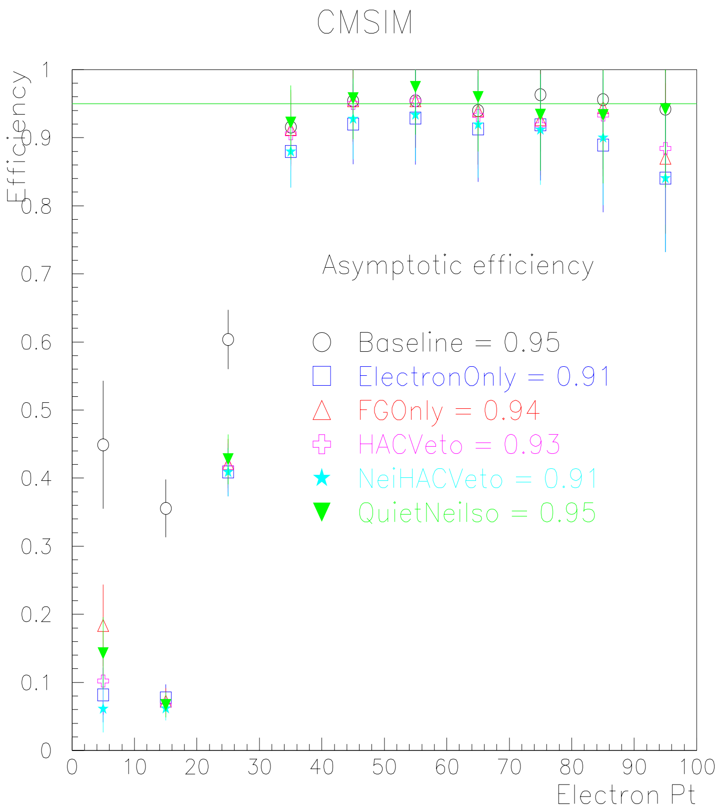
PYTHIA - common for FSTSIM/CMSIM

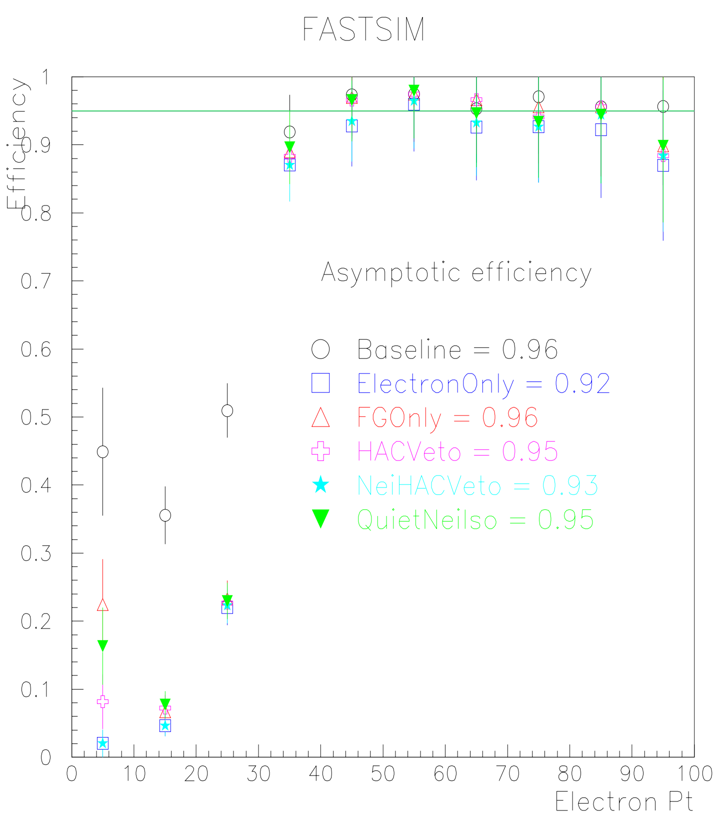
- QCD background events are used for rate studies.
- High P_t signal events, e.g., top, Higgs and SUSY particle decays, are used for efficiency studies.
- Noise hits are superposed with high P_t events.
- Minimum bias included - FSTSIM minbias is added for both CMSIM and FSTSIM high P_t events.

Trigger simulation - common for FSTSIM/CMSIM

- Various digital scales with limited resolution and dynamic range involved in the trigger system are fully implemented.
- Algorithms are performed in integer arithmetic using memory lookup tables when needed.

Electron/photon Efficiency - CMSIM vs FSTSIM



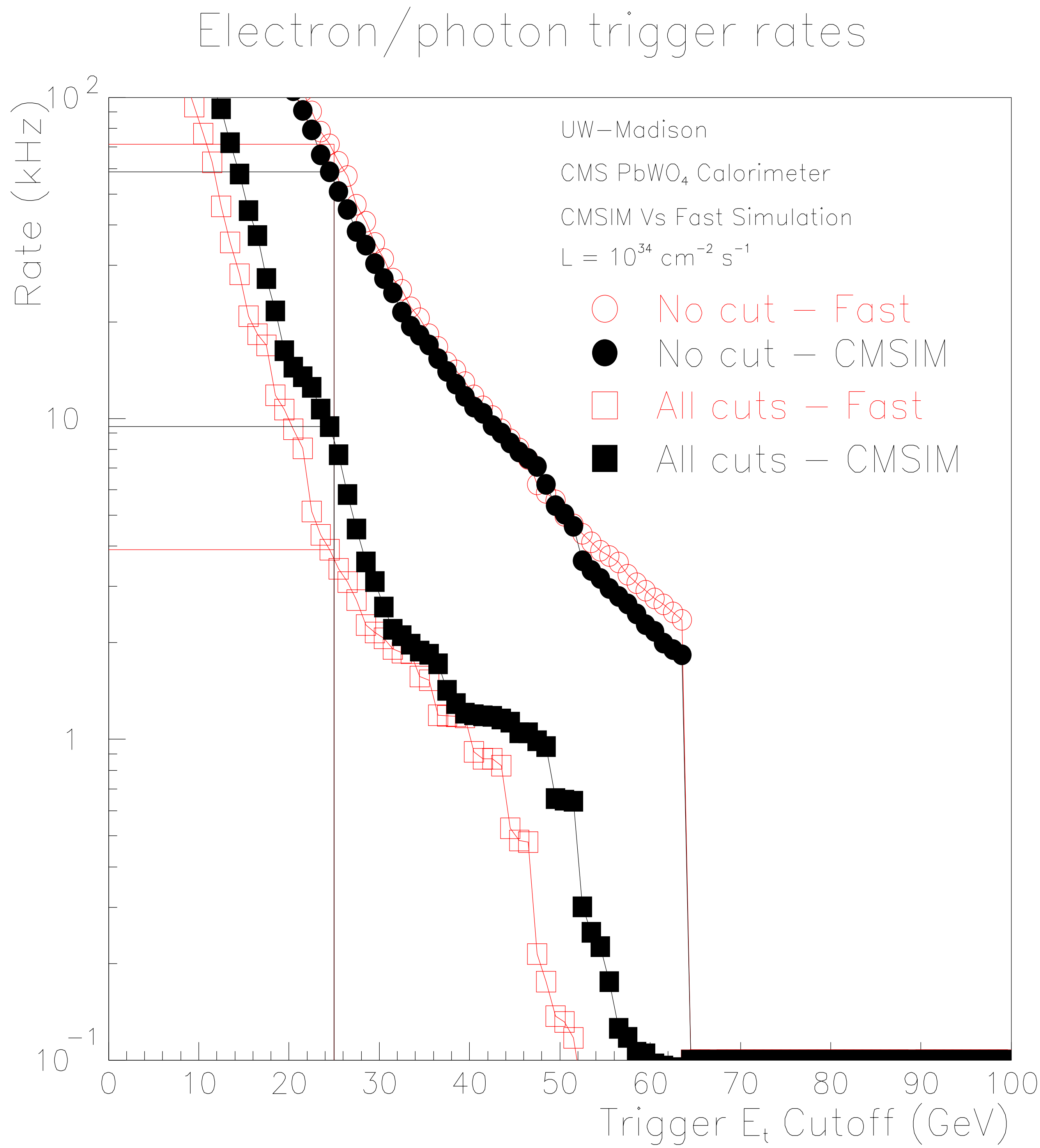


Efficiency for triggering top to electron decay events is plotted versus the P_t of the electron for various cuts.

Identical values for the four cut parameters yield similar efficiencies - custom tuning was not necessary.

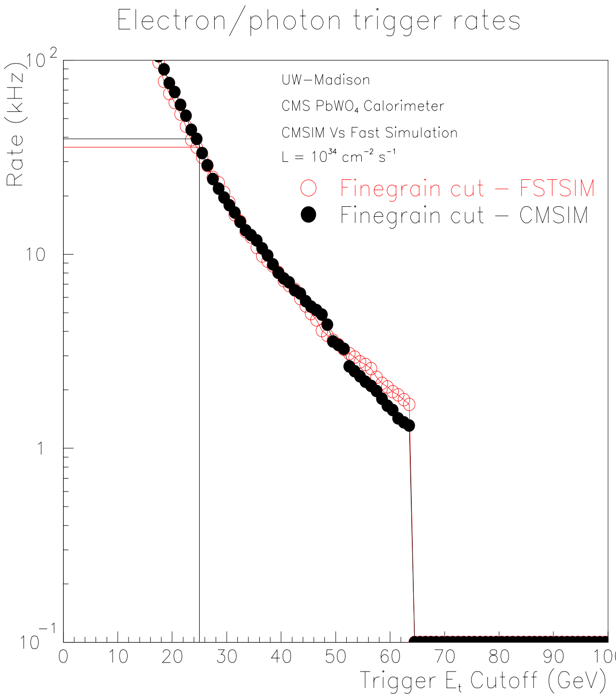
All efficiencies are over 90%.

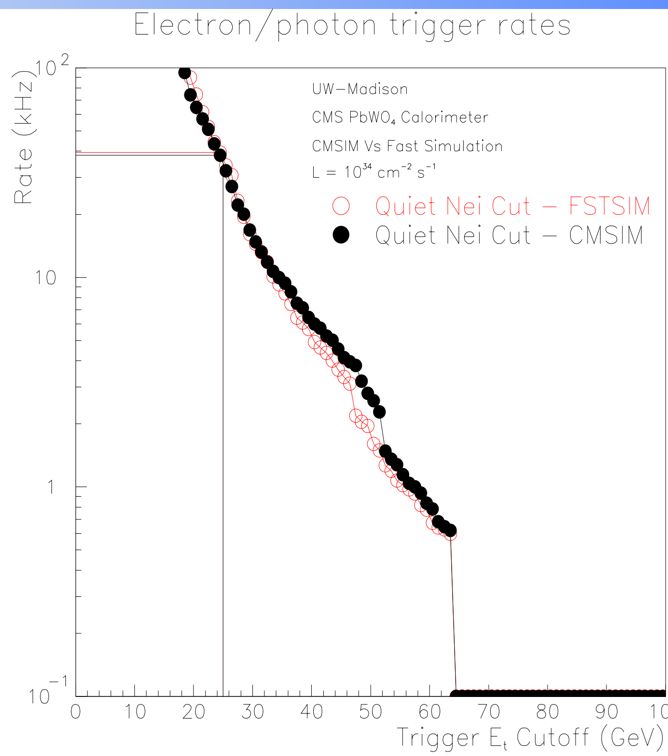
EM Rates - CMSIM vs FSTSIM

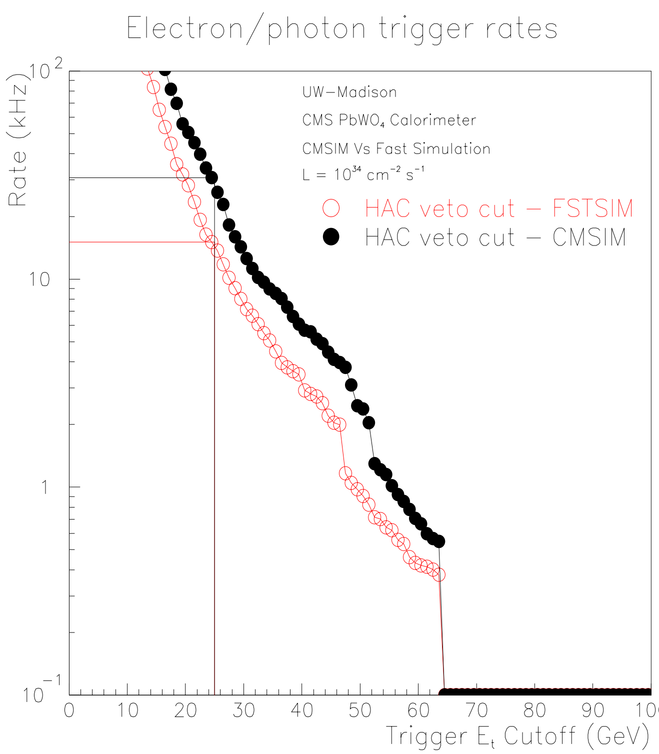


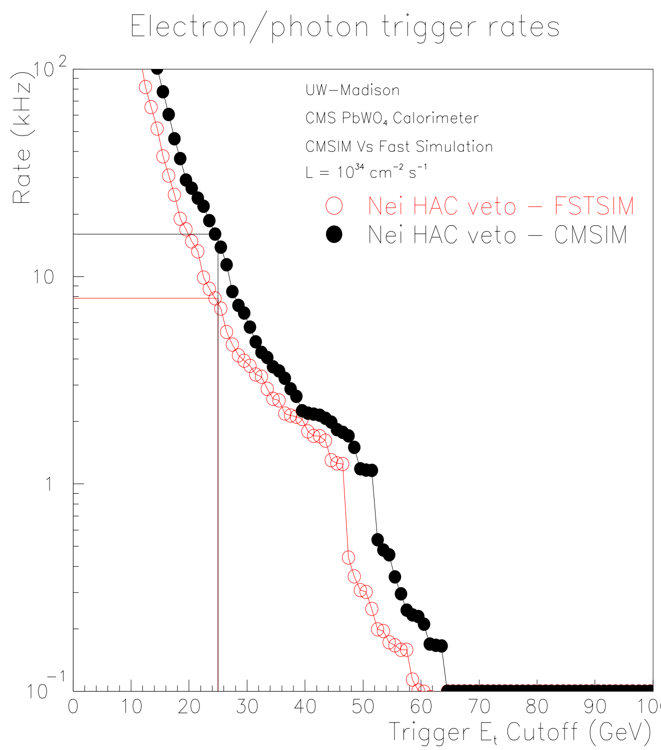
Integrated rate above E_t cut is plotted versus E_t cut.
All four, i.e., finegrain, HAC veto, neighbor HAC veto and quiet neighborhood, cuts are included.
For 25 GeV E_t cut, CMSIM rate is 9 kHz versus to 4 kHz in FASTSIM.

EM Rate Breakdown





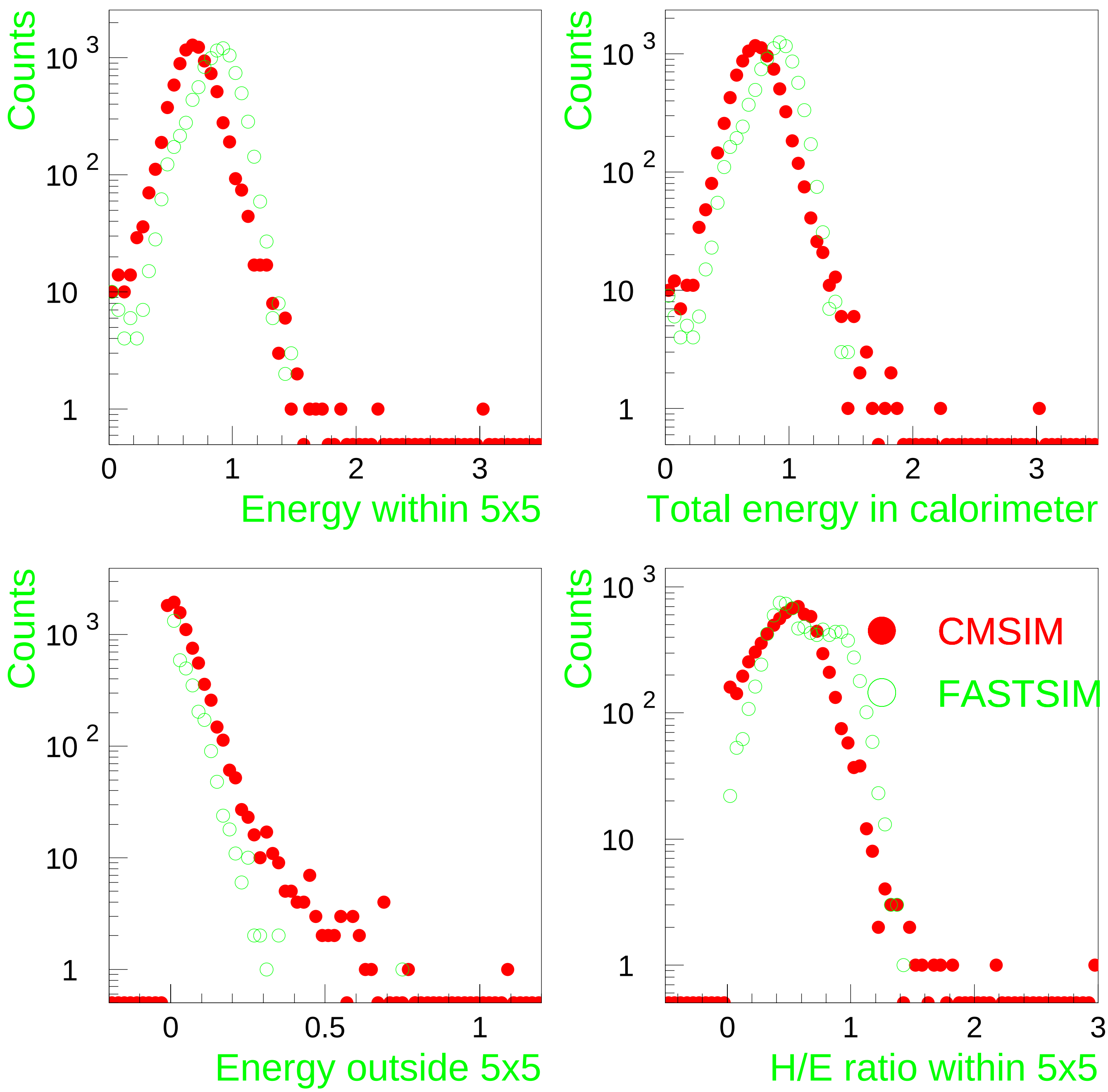




Rates after finegrain and quiet neighborhood cuts match but those after HAC veto and neighbor HAC veto cuts do not.

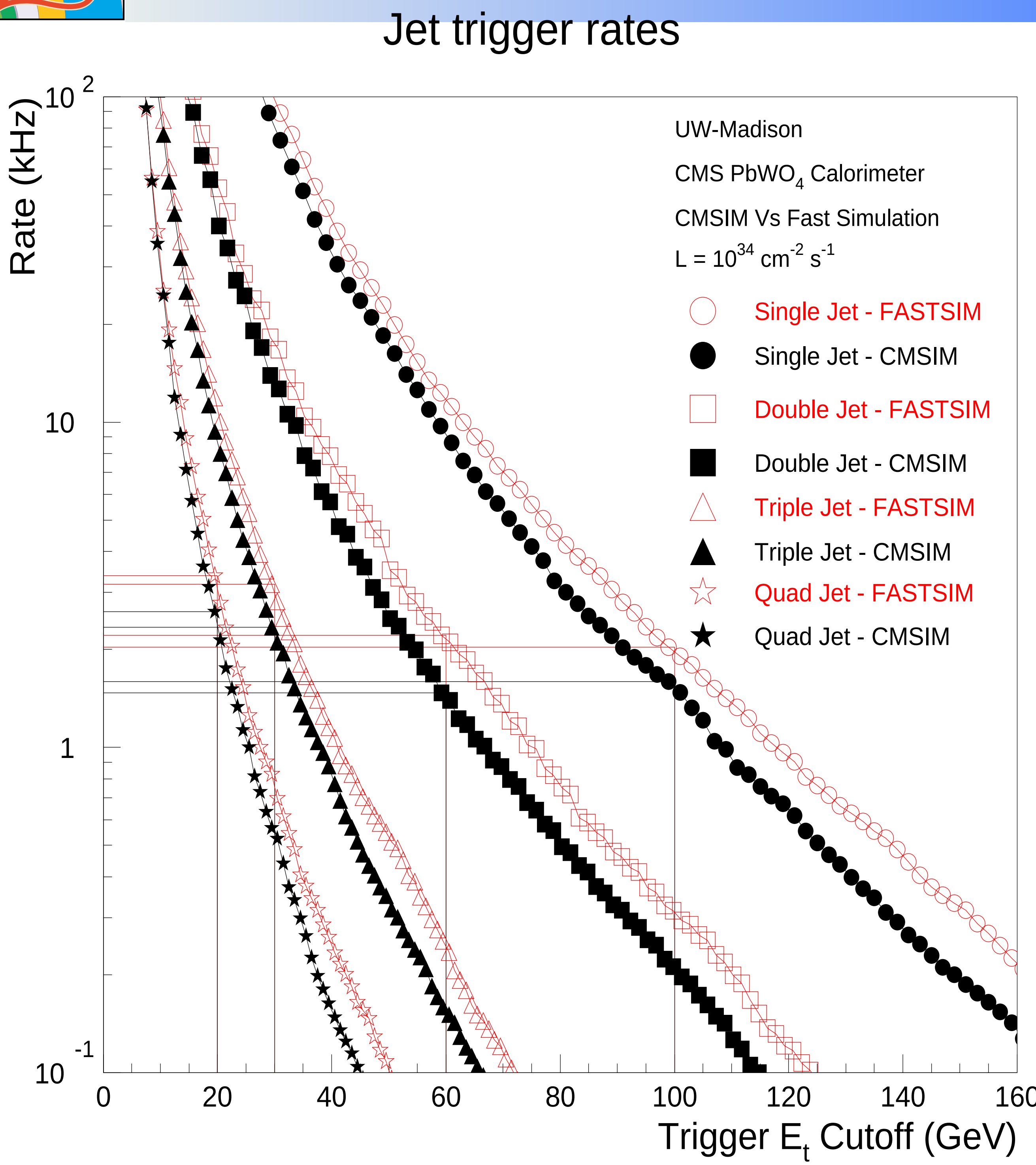
CMSIM vs FASTSIM Differences

Single pion events



Energy loss and transverse spread are higher in CMSIM.
Therefore, longitudinal profile, i.e., H/E ratio is also different.
This leads to the difference in rates. Should examine this further.

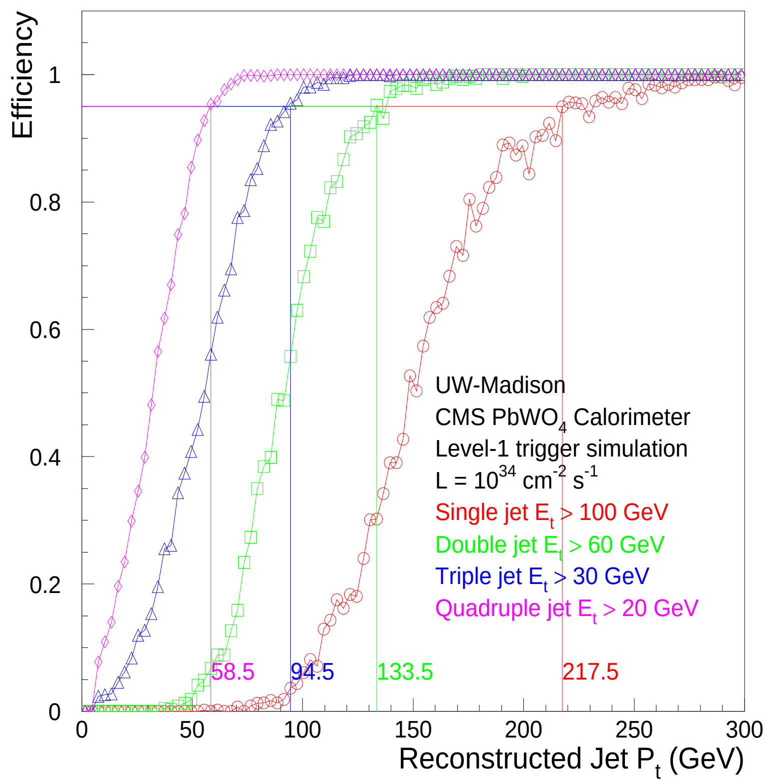
Jet rates - CMSIM vs FSTSIM



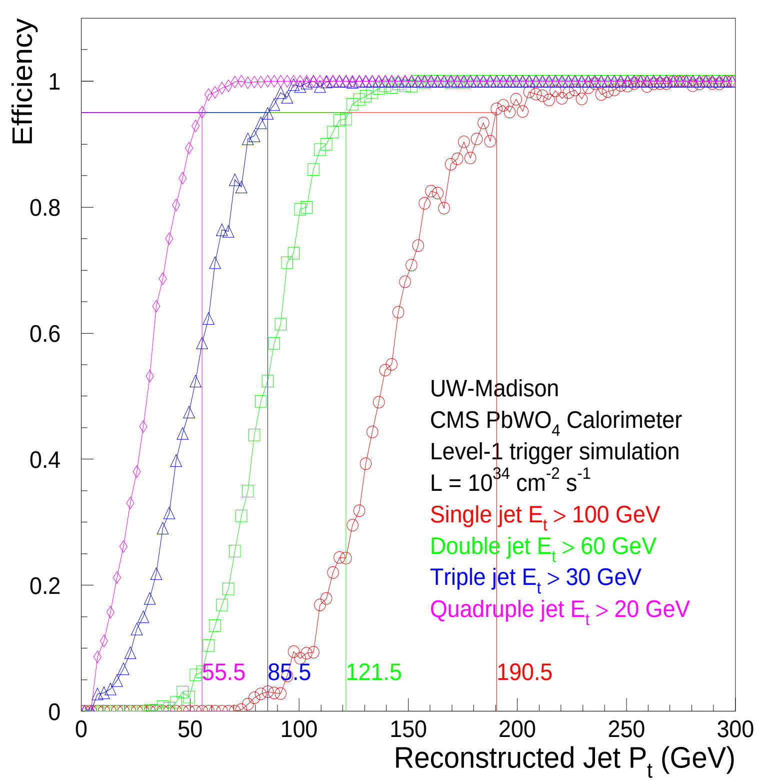
Integrated rates above trigger E_t cutoff are plotted versus the E_t cutoff for single, double, triple and quad jet events.
Rates are in reasonable agreement
More statistics are needed to get the correct spectrum at high E_t.

Jet efficiency - CMSIM vs FASTSIM

QCD jet efficiency - 4x4 algorithm



QCD jet efficiency - 4x4 algorithm



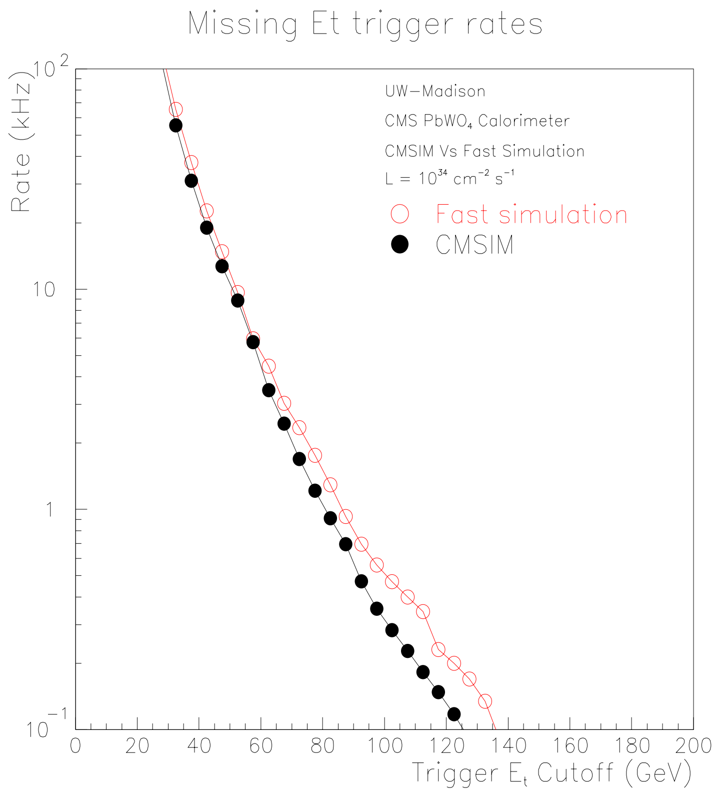
Efficiency for triggering on single, double, triple and quad jet events is plotted versus the reconstructed jet Pt of the lowest energy jet.

N-jet efficiency is cumulative of all jet cuts 1-N.

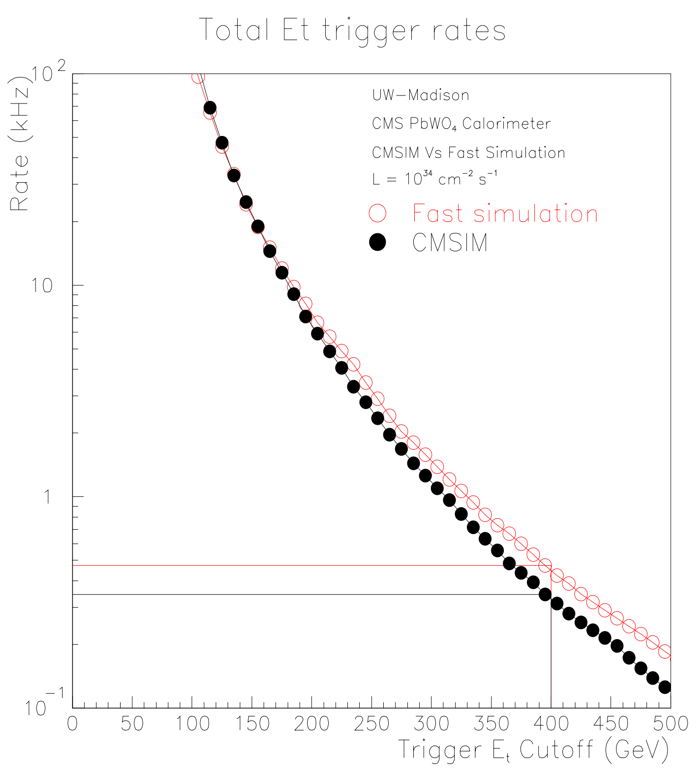
CMSIM efficiency turn-on is somewhat slower than FSTSIM.

This can be explained by the lower energy deposition for the hadrons in the events.

Missing and total E_t Rates



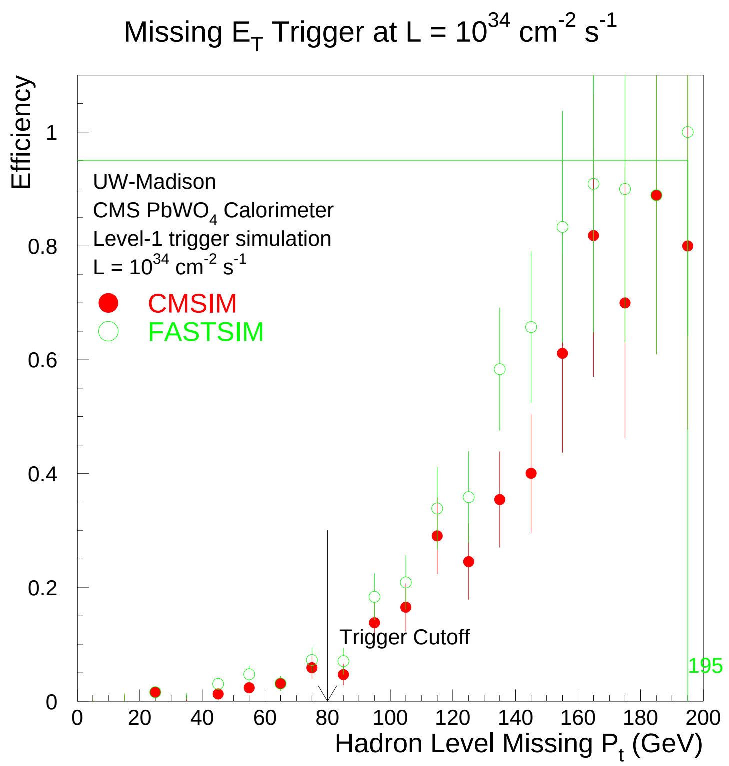
Integrated rates above missing and total E_t trigger cutoffs are plotted versus the missing and total E_t cutoff respectively.



The agreement between CMSIM and FSTSIM is quite good.

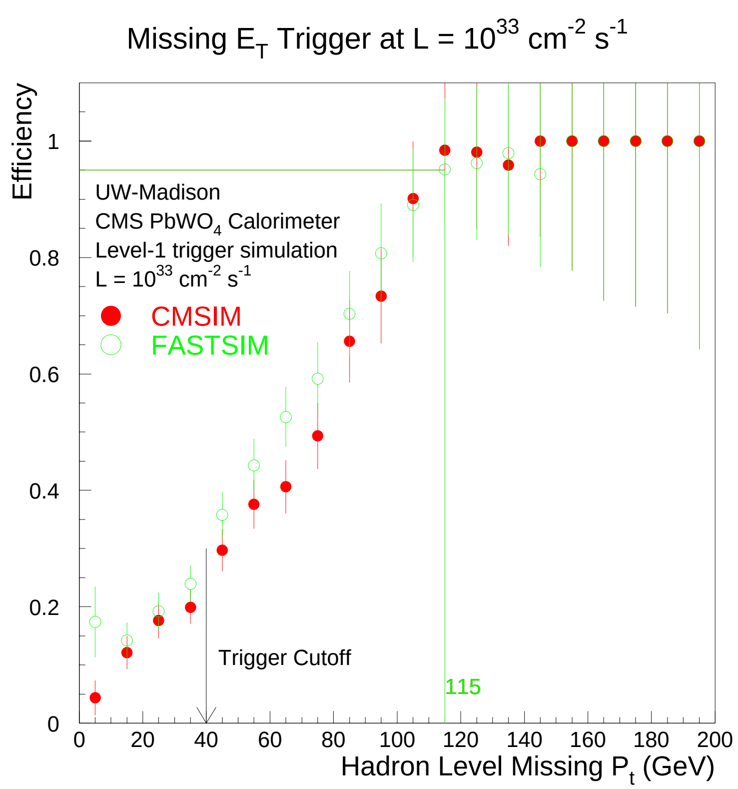
Efficiency studies are underway.

Missing E_t Efficiency



Missing E_T Efficiency is plotted versus the ISAJET hadron level missing P_T for SUSY sparticle production.

Both CMSIM and FASTSIM efficiency turn-on is somewhat slower than desirable.



Trigger factors are responsible for only half the worsening of resolution compared to the ISAJET hadron level values .

However, SUSY events efficiency is supplemented by the total and multijet triggers.

Cal Physics at high lumi

Trigger Type	Trigger Et Cutoff (GeV)	Rate (kHz)			
		CMSIM		FASTSIM	
		Individual	Incremental	Individual	Incremental
Sum Et	400	0.3	0.3	0.4	0.4
Missing Et	80	1.2	0.9	1.7	1.3
Electron	25	11.4	9.3	4.5	3.9
DiElectron	12	2.1	1.8	1.0	1.0
Single jet	100	1.5	1.0	2.0	1.3
Dijet	60	1.2	0.7	1.9	1.1
Trijet	30	2.3	1.3	3.1	1.8
Quadjet	20	2.6	1.1	3.3	1.4
Jet+Elctrn	50 & 12	1.3	0.3	0.7	0.2
Cumulative Rate		16.7		12.4	

Process	Efficiency (%)		
	CMS-TN-95/183	FASTSIM	CMSIM
H (80 GeV) $\rightarrow \gamma\gamma$	97	92	94
H (120 GeV) $\rightarrow ZZ \rightarrow ee\mu\mu$	76*	76*	74*
H (200 GeV) $\rightarrow ZZ \rightarrow eejj$	99	96	95
$pp \rightarrow tt \rightarrow eX$	88	82	82
$pp \rightarrow tt \rightarrow H^{+} X \rightarrow tX$	82	76	76

*Inclusion of muon trigger provides full efficiency

Luminosity = 10^{34} cm^{-2} s^{-1}

QCD Background

The sum and missing E_t cutoffs are chosen to provide a 2 kHz rate. Electron/photon triggers are emphasized, with about 8 kHz rate out of total available 15 kHz. The remaining 5 kHz is available for jet triggers.

Signal Efficiency

High efficiency for all channels with electrons and photons.

The difficult-to-trigger top decay events have high efficiency, enabling studies of associated Higgs production. Unfortunately, no eta cut on trigger particle in new FAST and CMSIM studies!

Cal Physics at low lumi

Trigger Type	Trigger Et Cutoff (GeV)	Rate (kHz)			
		CMSIM		FASTSIM	
		Individual	Incremental	Individual	Incremental
Sum Et	150	1.0	1.0	1.2	1.2
Missing Et	40	2.7	1.7	3.1	2.0
Electron	12	11.4	9.1	5.4	4.4
DiElectron	7	1.2	1.9	0.4	1.0
Single jet	50	1.5	0.3	1.8	0.6
Dijet	30	1.3	0.3	1.7	0.4
Trijet	20	0.8	0.1	1.1	0.1
Quad jet	15	0.6	0.04	0.8	0.1
Jet+Elctrn	15 & 9	11.2	3.4	5.6	2.0
Cumulative Rate		17.8		11.8	

Luminosity = 10^{33} cm^{-2} s^{-1}

QCD Background

CMSIM and FASTSIM rates are compared for the low luminosity E_t cutoffs selected in CMS-TN-95/183

Electron trigger rate is twice as high in CMSIM results

Process	Efficiency (%)		
	CMS-TN-95/183	FASTSIM	CMSIM
p p → t t → e X	99	97	97
p p → t t → H+ X → t X	99	94	94
p p → b b (hadronize), B → e X	0.2 (But 400Hz)	-	-
SUSY CMS TP Scenario A (M_{LSP} = 45, M_{spart} ~ 300 GeV)	98	83	81
SUSY Neutral Higgs (Range of tan b and M_A values)	45 - 98	30 - 96	39 - 96

Signal efficiency

High efficiency is realized for the benchmark processes involving top decays and SUSY sparticles.
A dedicated tau trigger is under study to improve efficiency for low mass range of SUSY Higgs.
There is also high rate of B signal in level-1 sample.

Muon Trigger Requirements

MUON IDENTIFICATION

At least 16 λ of material is present up to $|\eta|=2.4$ with no acceptance losses.

STANDALONE MOMENTUM RESOLUTION

From 8-15% dp_T/p_T at 10 GeV and 20-40% at 1 TeV.

GLOBAL MOMENTUM RESOLUTION

After matching with the Central Tracker:
from 1.0-1.5% at 10 GeV, and from 6-17% at 1 TeV.

Momentum-dependent spatial position matching at 1 TeV less than 1 mm in the bending plane and less than 10 mm in the non-bending plane.

CHARGE ASSIGNMENT

Correct to 99% conf. up to the kinematic limit of 7 TeV.

MUON TRIGGER

The combination of precise muon chambers and fast dedicated trigger detectors provide unambiguous beam crossing identification and trigger on single and multimuon events with well defined p_T thresholds from a few GeV to 100 GeV up to $|\eta|=2.1$.

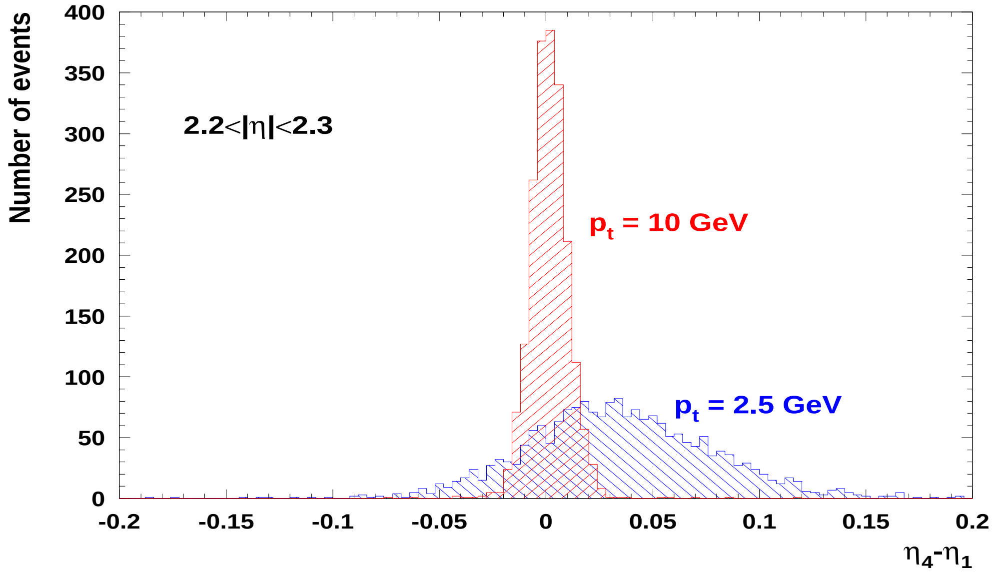
Muon Trigger

Solenoidal fields of CMS bends tracks in Rφ plane.

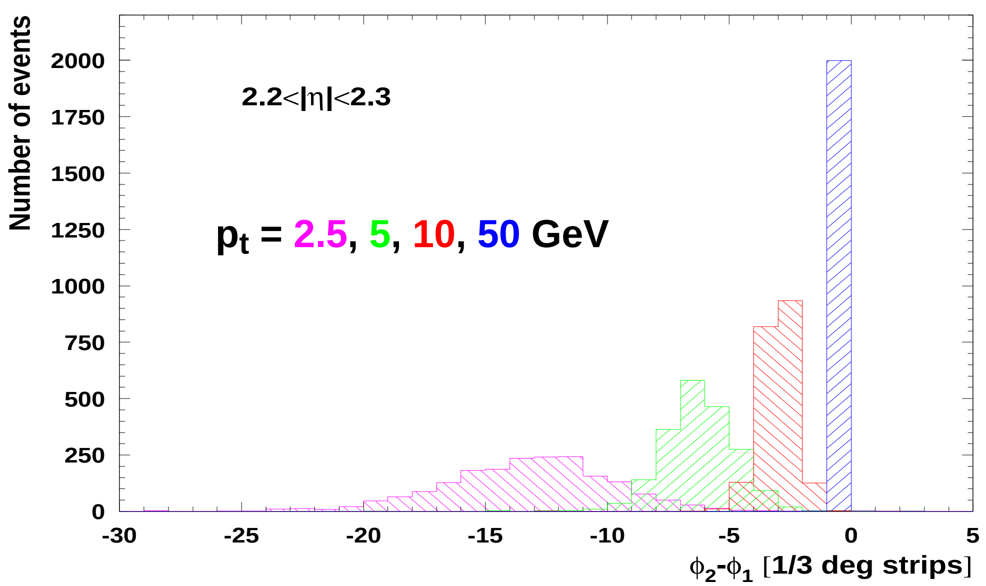
Thus tracks keep almost constant η.

$$\Delta\varphi \propto \int B \times dl \qquad \Delta\eta \approx 0$$

Even for the softest forward tracks Δη<0.15.

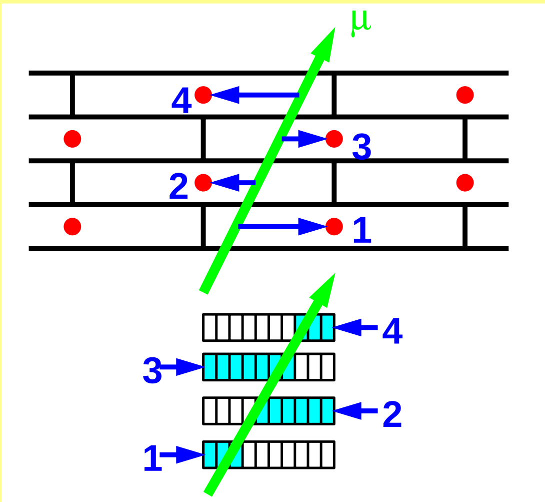


For |η|<2.5 the ∫B×dl is enough to provide a p_t cut.
Strips of Δφ=1/3° are narrow enough.

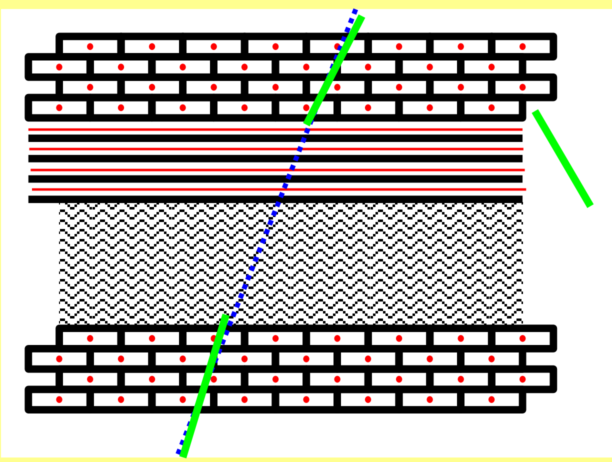


Muon Chamber Trigger Logic

Drift Tubes

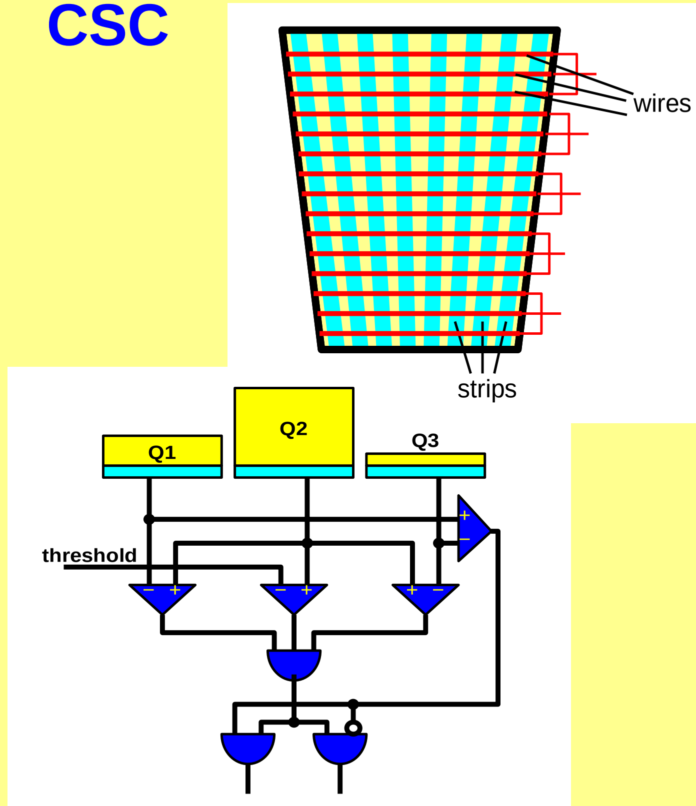


Meantimers recognize tracks and form vector / quartet.

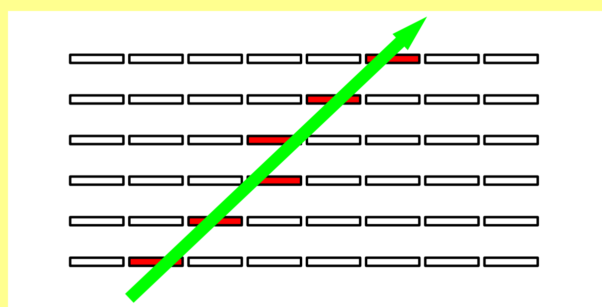


Correlator combines them into one vector / station.

CSC

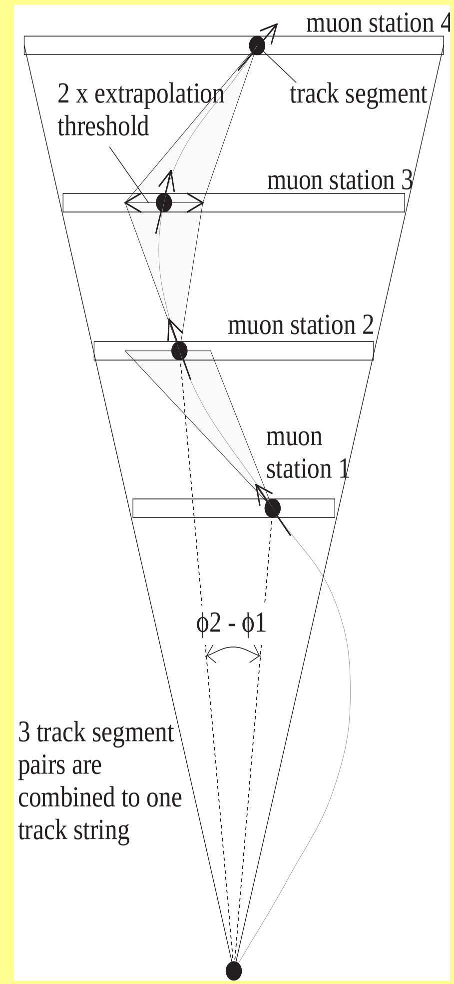


Comparators give 1/2−strip resol.



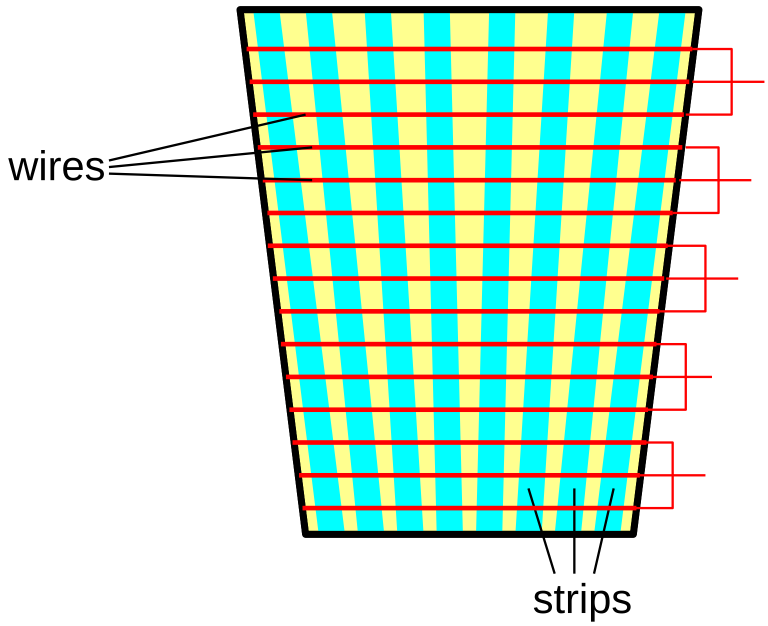
Hit strips of 6 layers form a vector.

Track Finder



- **combines vectors,**
- **forms a track,**
- **assigns p_t value.**

Cathode Strip Chambers



TIME:

OR of 6 planes of wires

first pulse gives t_0 but ≥4 planes out of 6 must be fired

$$t_{drift}^{max} = 40\text{ ns} \quad \Rightarrow \quad \sigma(t_0) < 3\text{ ns}$$

POSITION:

cluster center in every plane of strips

$$\Delta x = 1/2 \text{ strip width}$$

ANGLE:

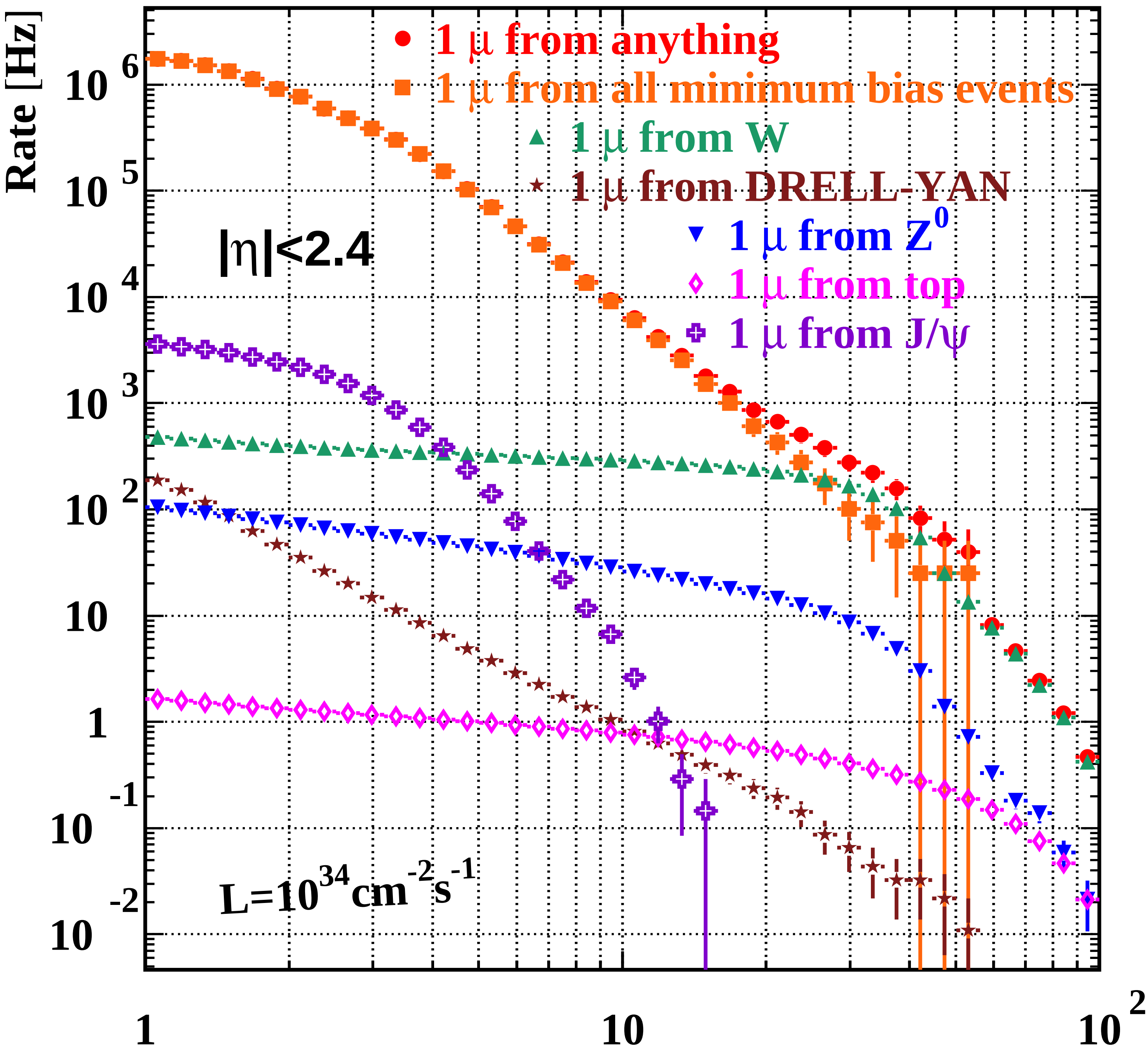
local charged track (LCT) determined by

pattern of fired halfstrips in a gi ven station

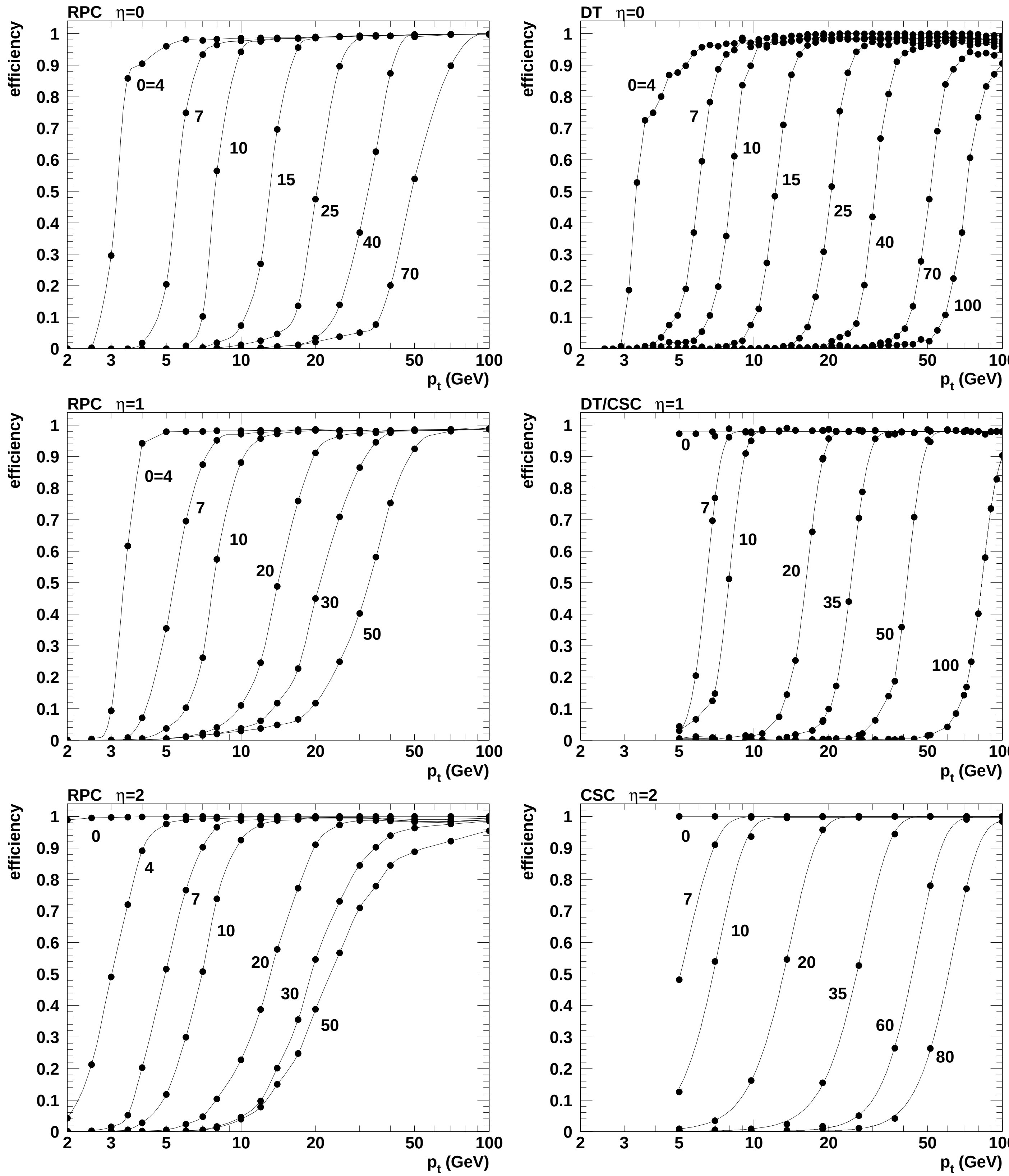
MOMENTUM:

combination of LCT's from all stations

Single Muon Rates



Muon Trigger Efficiency



Cal/Muon Combined Rates

	$L = 10^{33} cm^{-2} s^{-1}$			$L = 10^{34} cm^{-2} s^{-1}$		
trigger type	threshold [GeV]	rate [kHz]	cumulative rate [kHz]	threshold [GeV]	rate [kHz]	cumulative rate [kHz]
μ	7	9.8	9.5	20	7.8	7.8
$\mu\ \mu$	2-4	0.5	10.1	4	1.6	9.2
μ e/γ	2-4, 6	2.5	12.2	4, 8	5.5	14.4
$\mu\ e_b$	2-4, 5	3.5	13.4	—	—	—
μ j	2-4, 12	2.2	14.5	4, 40	0.3	14.4
$\mu\ E_t^{miss}$	2-4, 40	0.8	14.7	4, 60	1.0	15.3
$\mu\ \Sigma E_t$	2-4, 150	0.8	14.7	4, 250	0.2	15.3

threshold = 2-4 GeV means: 4 GeV in the barrel, 2 GeV in the endcaps

muon threshold = transverse momentum threshold
calorimeter threshold = transverse energy threshold

e/γ — electron/photon trigger, e_b — trigger on electron from b-quark decay