CMS Jet Trigger Simulation

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Simulation Results

- **Baseline algorithm performance**
- **Comparison with more complex algorithm**

Cal Trig. 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 characterization of energy deposit
- Data presynchronized across all channels, ECAL and HCAL trigger towers with multiple crystals/tower segments

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)
- Total and missing transverse energy (E_t, E_x, E_y)
- Minimum ionization ID and isolation bits for use with muon trigger

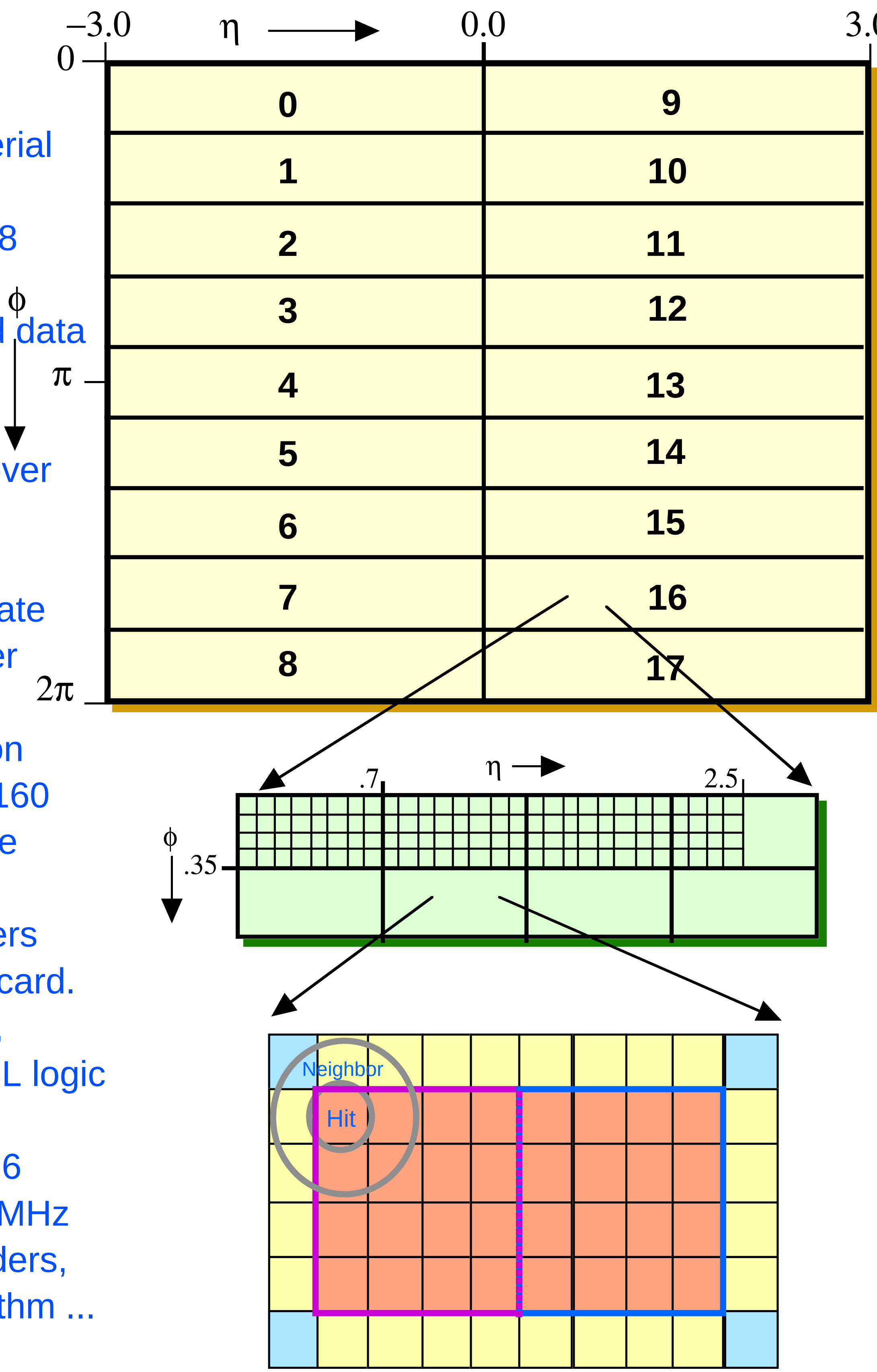
Outut rate

- 75 kHz maximum - half of this for calorimeter trigger
- Simulations should indicate about a factor of 3 safety margin - i.e., ~12.5 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 Trigger Overview



System
- ~4000 Gb/s serial input links
- Received by 18 Crates
- Share reduced data
- Operate synchronously
- Seemlessly cover η–φ plane

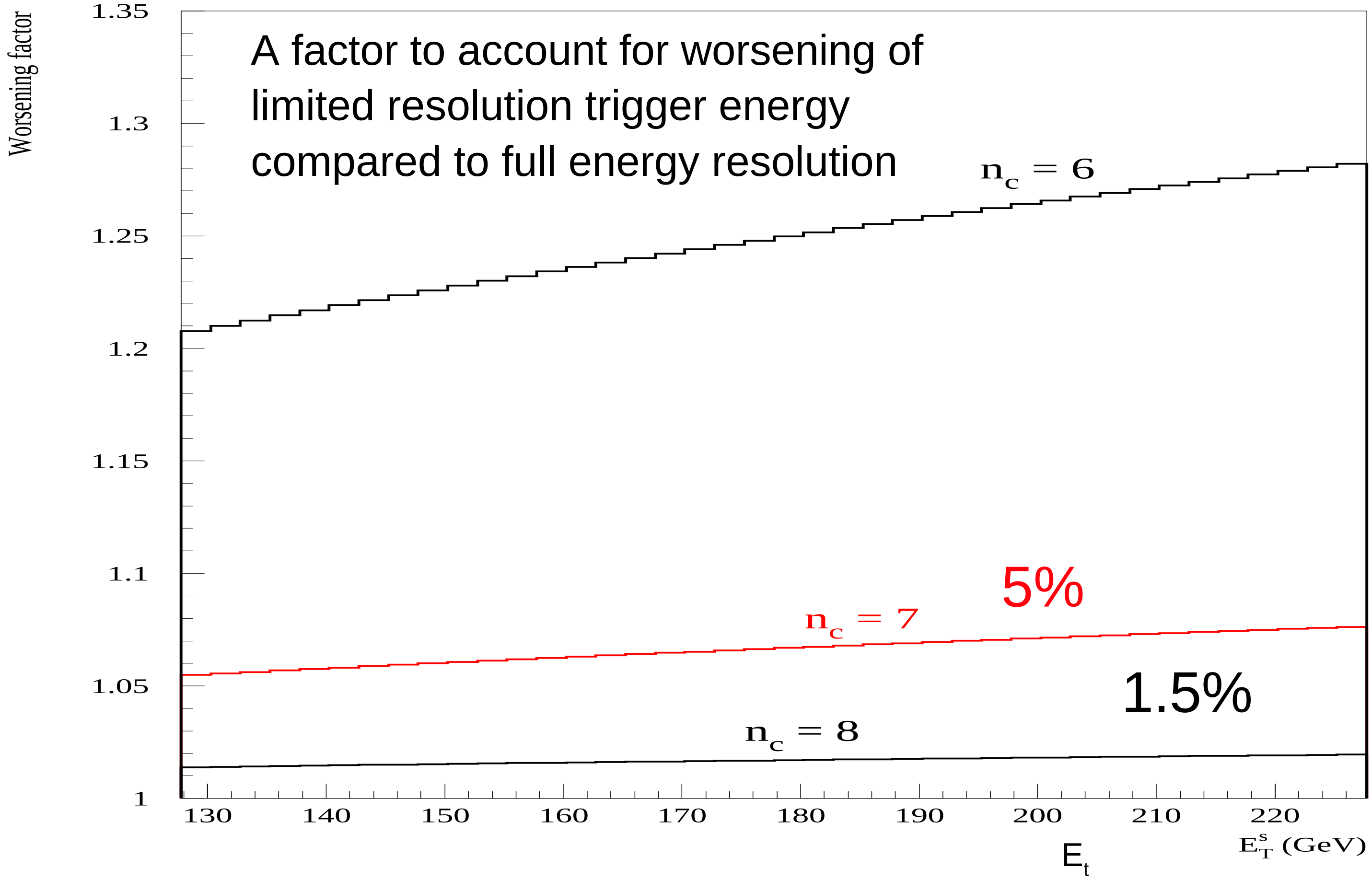
Crate
- 256 inputs / crate
- 18 bits data per trigger tower.
- Data sharing on point-to-point 160 MHz backplane

Cards
- 32 trigger towers (E/HCAL) per card.
- Lookup tables, ASICs and ECL logic

ASICs
- Process 8 or 16 towers at 160 MHz
- Implement adders, electron algorithm ...

Cal Regional Trigger Input

Transverse Energy in Trigger Tower



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

Software Tools: Physics Generators, Detector & Trigger Simulation

Generators
- PYTHIA
  - QCD jet events with various ranges of P_T
  - Minbias events
  - Some Higgs/top signal events for electron/photon trigger
- ISAJET
  - ISASUSY events with technical proposal (A) settings

Detector simulation
- CMSIM
  - GEANT based
  - Used essentially as a black box
  - Cuts tuned to be somewhat larger 10 MeV
    - > Speeds up execution
  - Tracker used only as dead material
  - Tracked only within the 4T solenoid
- FASTSIM
  - Home brewed
  - Simplified geometry
    - > Tracker is uniform w/ appropriate r.l.
    - > No holes in calorimeter
      - Except between EB/EE
    - > Gap between calorimeters empty
    - > Pre-TDR geometry (matches CMSIM 111)
  - Parameterized showers
    - > Transverse and longitudinal shapes parameterized using GEANT simulation in bulk PbWO4 and Cu-Scin.
    - > Checked to match published data

Trigger simulation
- Trigger primitives are simply sum of hits
  - No attempt at electronics pulse shaping and filtering effects
- Details of cutoffs and limited resolution scales
- Integer arithmetic matching trigger hardware

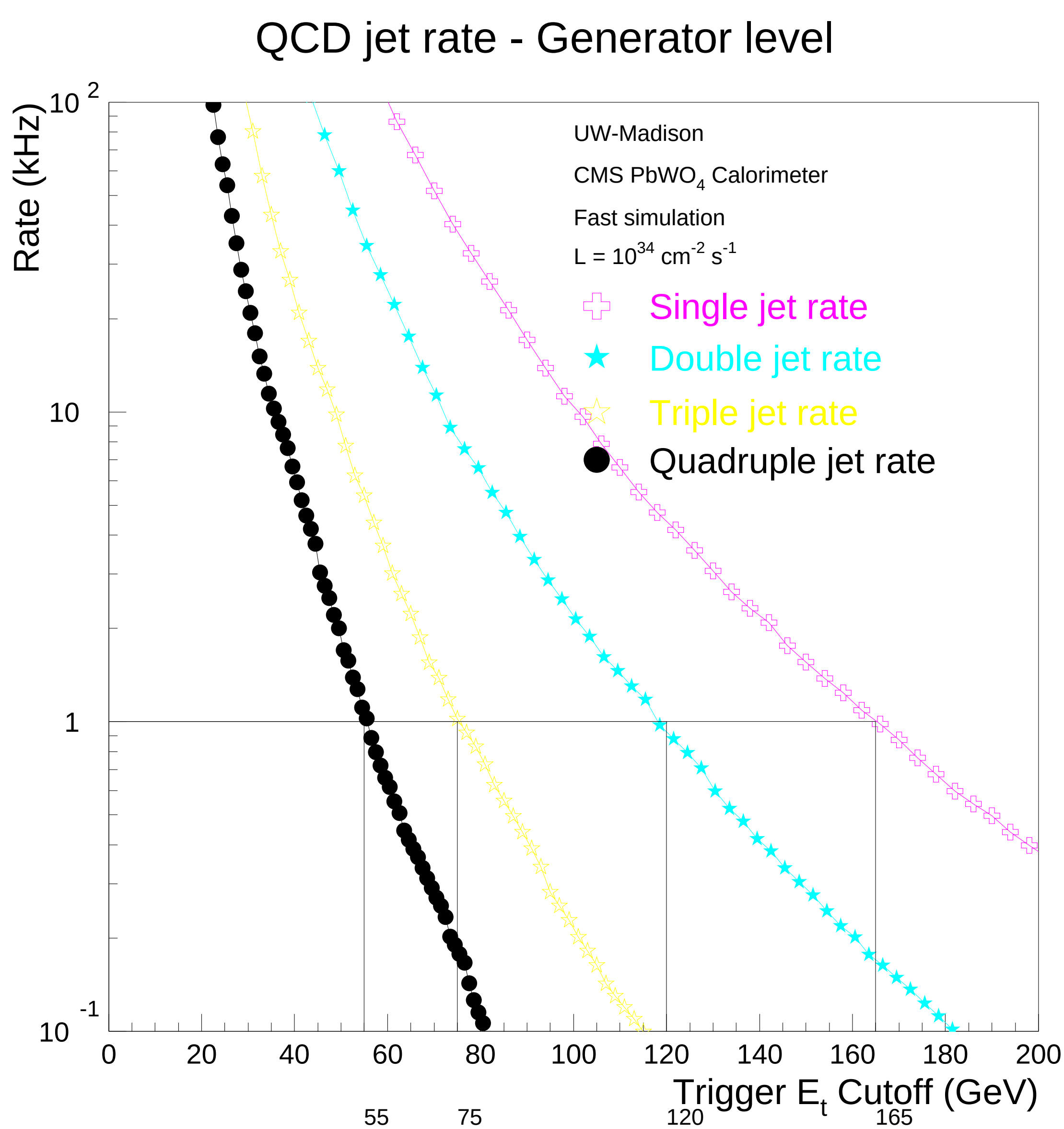
Consistency
- Same events simulated using all programs

Generator level jet rate

Rate to tape is 100 Hz. Level-1 output target for jets is about 3 kHz.
What is a reasonable target for jet threshold?
With a "perfect" calorimeter and trigger @ 10^{34}

- **Single jet threshold > 165 GeV**
- **Double jet threshold > 120 GeV**

The detector resolutions and algorithms degrade performance.



Jet trigger algorithm design

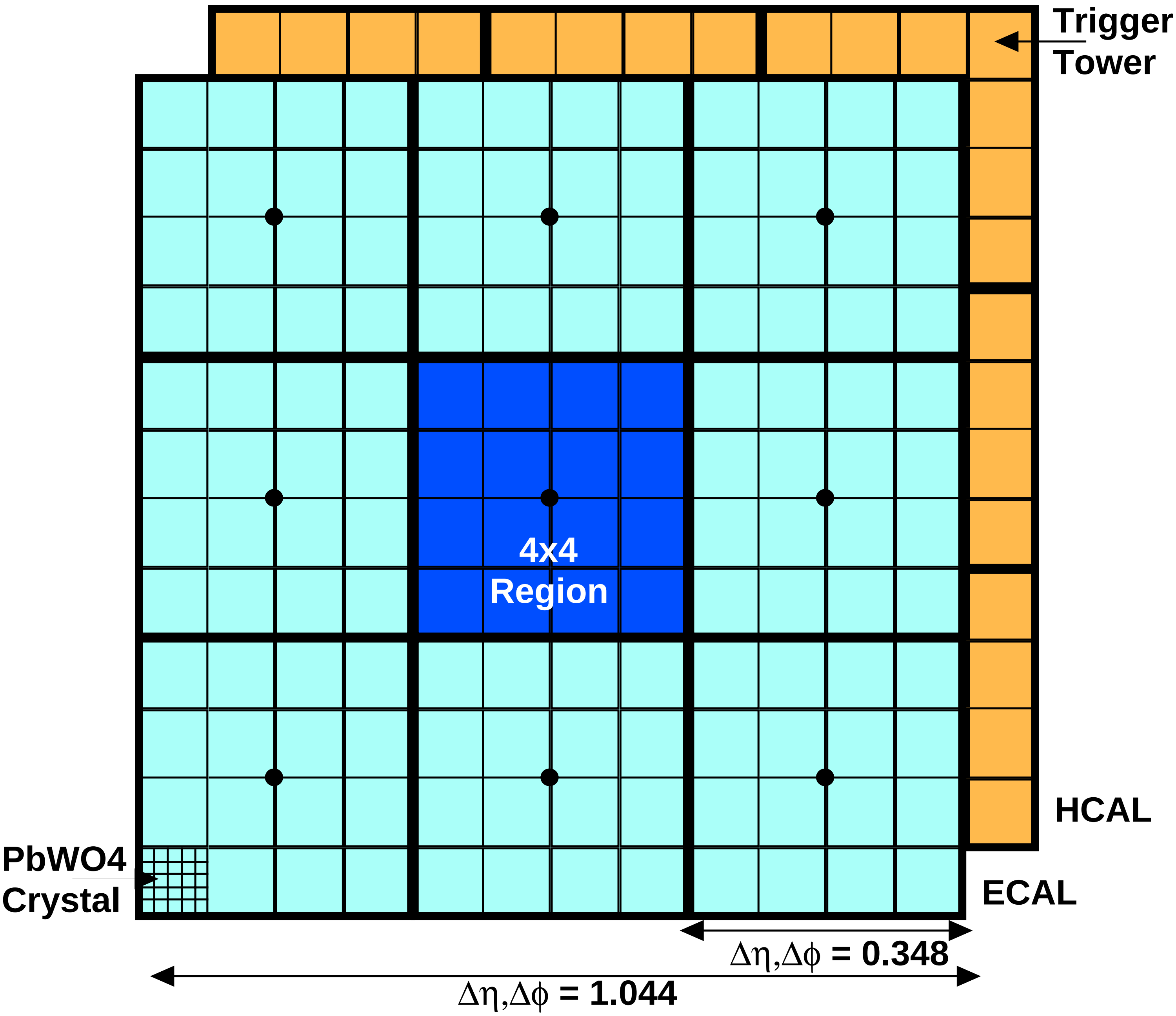
Competing factors

- **Small regions**
  - Some loss in resolution
  - No need for overlapping
  - Some overcounting of jets due to splits
- **Larger regions**
  - Better resolution
  - Overlaps necessary
    - Pruning of spurious multijet candidates needed
  - Care needs to be taken to avoid undercounting jets
  - Larger the region more minimum bias pileup integrated.
    - May have to set higher tower level cutoffs.

Technology

- **Need to sum over fixed shapes - e.g. 4x4, 12x12 towers**
- **Make largest possible sum at the very first card in the system to reduce data transmitted to next card.**
- **Jet overlap processing requires more fancy logic and data sharing between cards.**

Jet algorithms



Baseline Algorithm

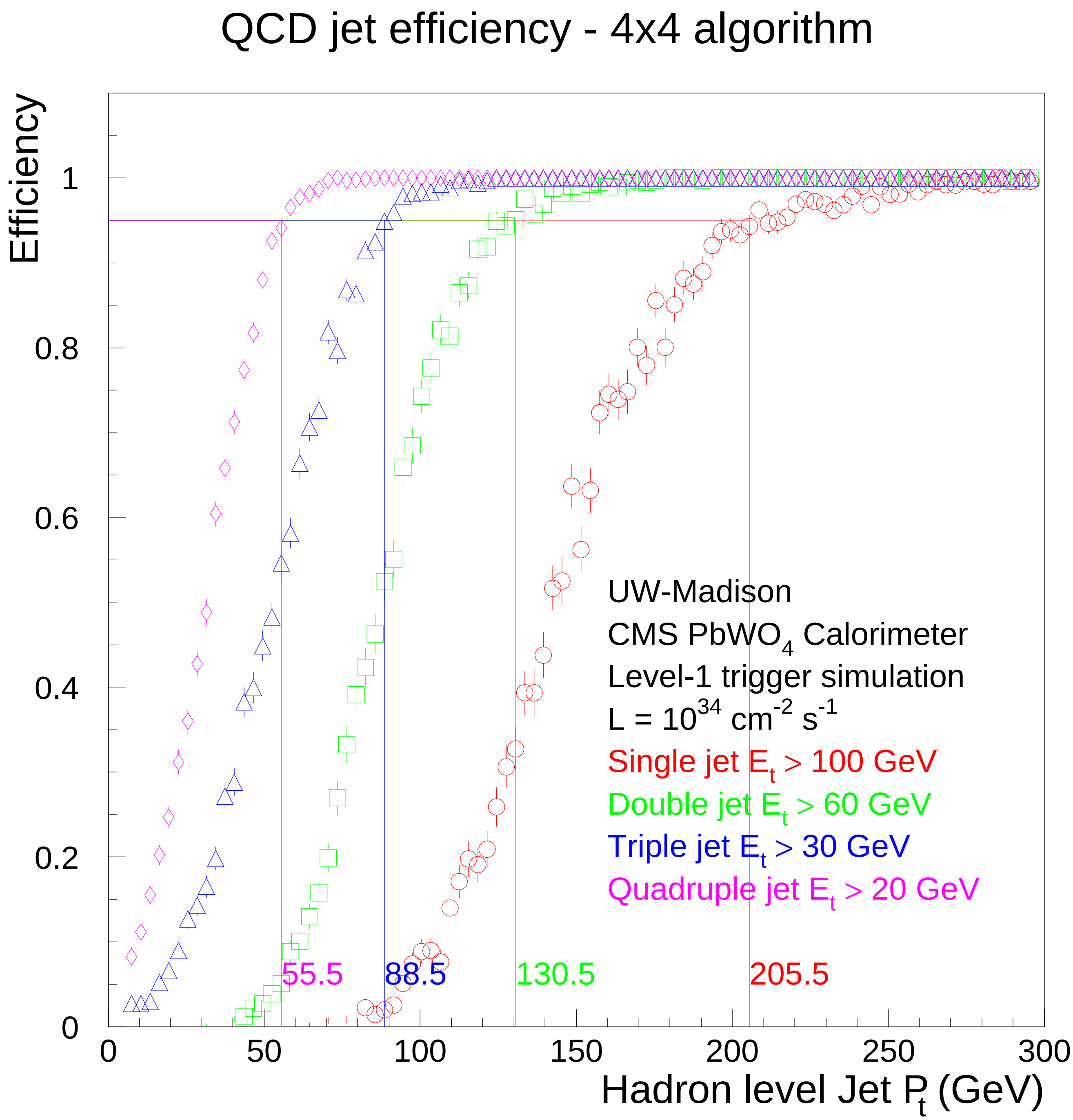
- Jet E_T is given by the sum of ECAL and HCAL trigger tower E_T in a non-overlapping 4x4 region

More Complex Algorithm for evaluation

- Sliding window of 4x4 regions to form 12x12 sums
- Require central 4x4 region to be the maximum

Jet candidates are sorted to find highest energy jets

Baseline jet trigger efficiency

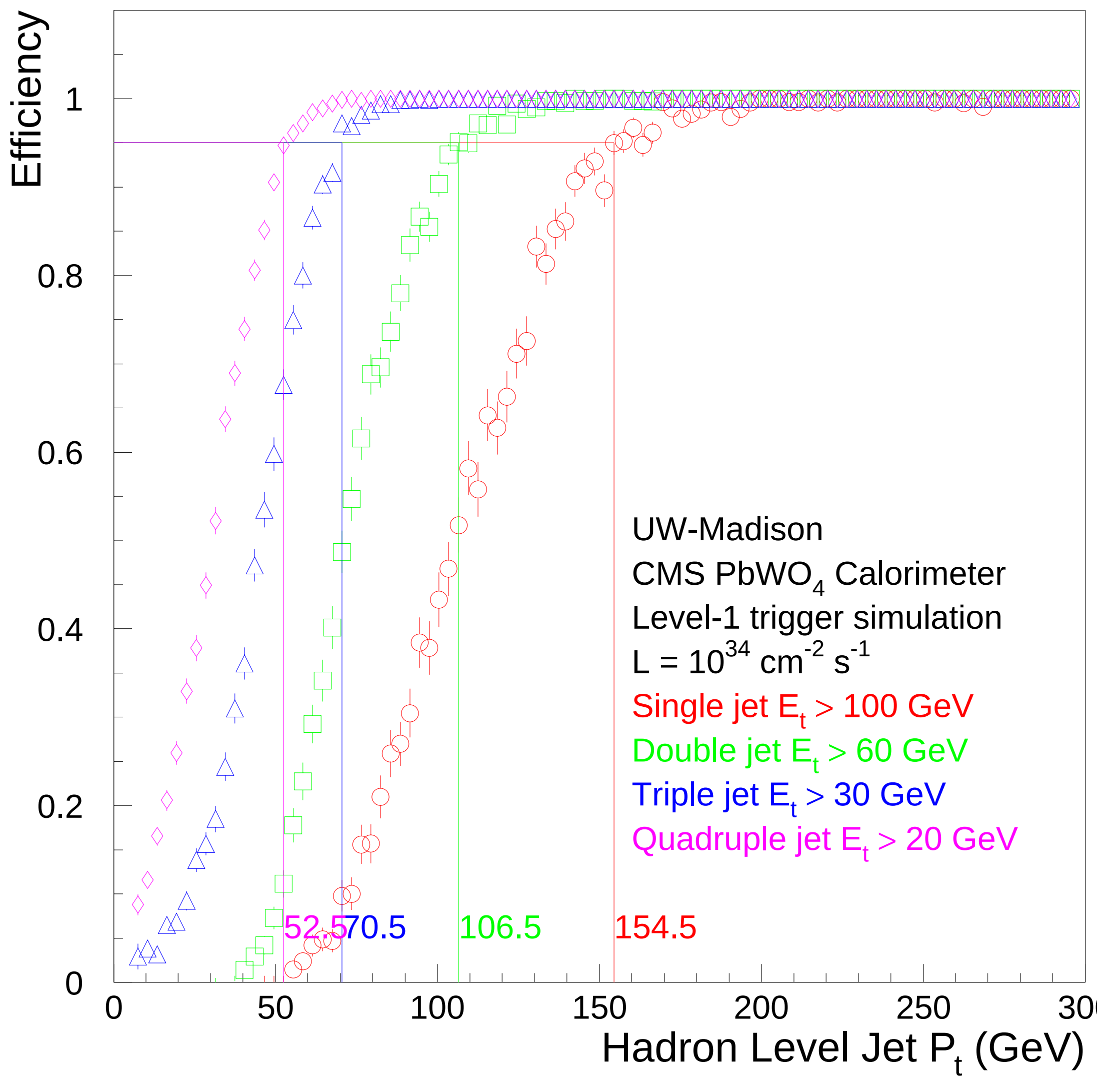


Jet trigger efficiency plotted versus particle level reconstructed jet P_T

Cumulative efficiency for multi-jet triggers plotted versus smallest of the reconstructed jet P_T

Baseline jet trigger efficiency II

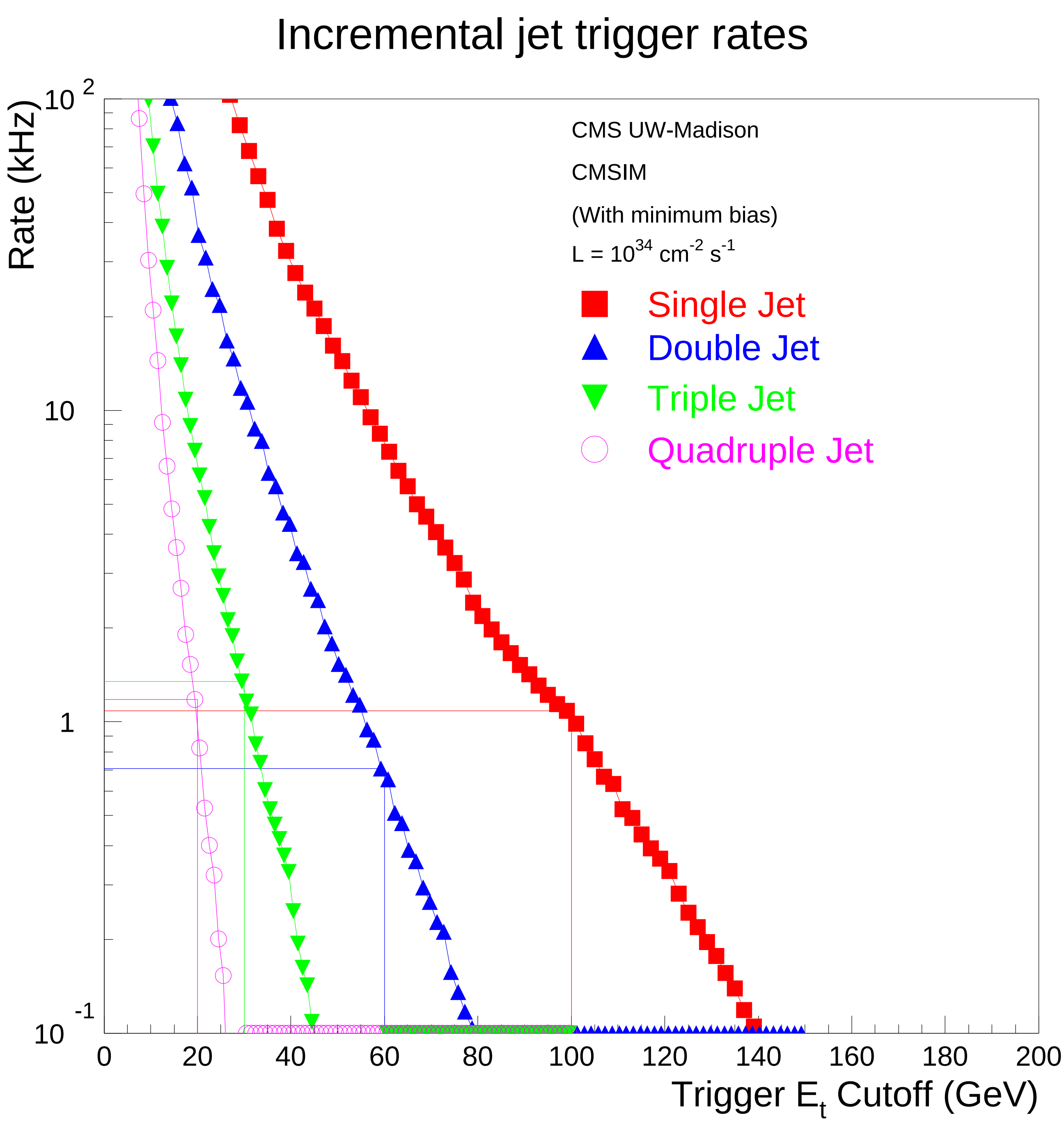
QCD jet efficiency - 4x4 algorithm (all four jet cuts)



Combined jet trigger efficiencies - i.e., if any of the single, double, triple or quadruple region cuts is passed, it is a "jet trigger".

Single jet == Highest jet Pt formed using generated hadron Pt
Double jet == Second highest jet Pt
Triple jet == Third highest jet Pt
Quadruple jet == Fourth highest jet Pt

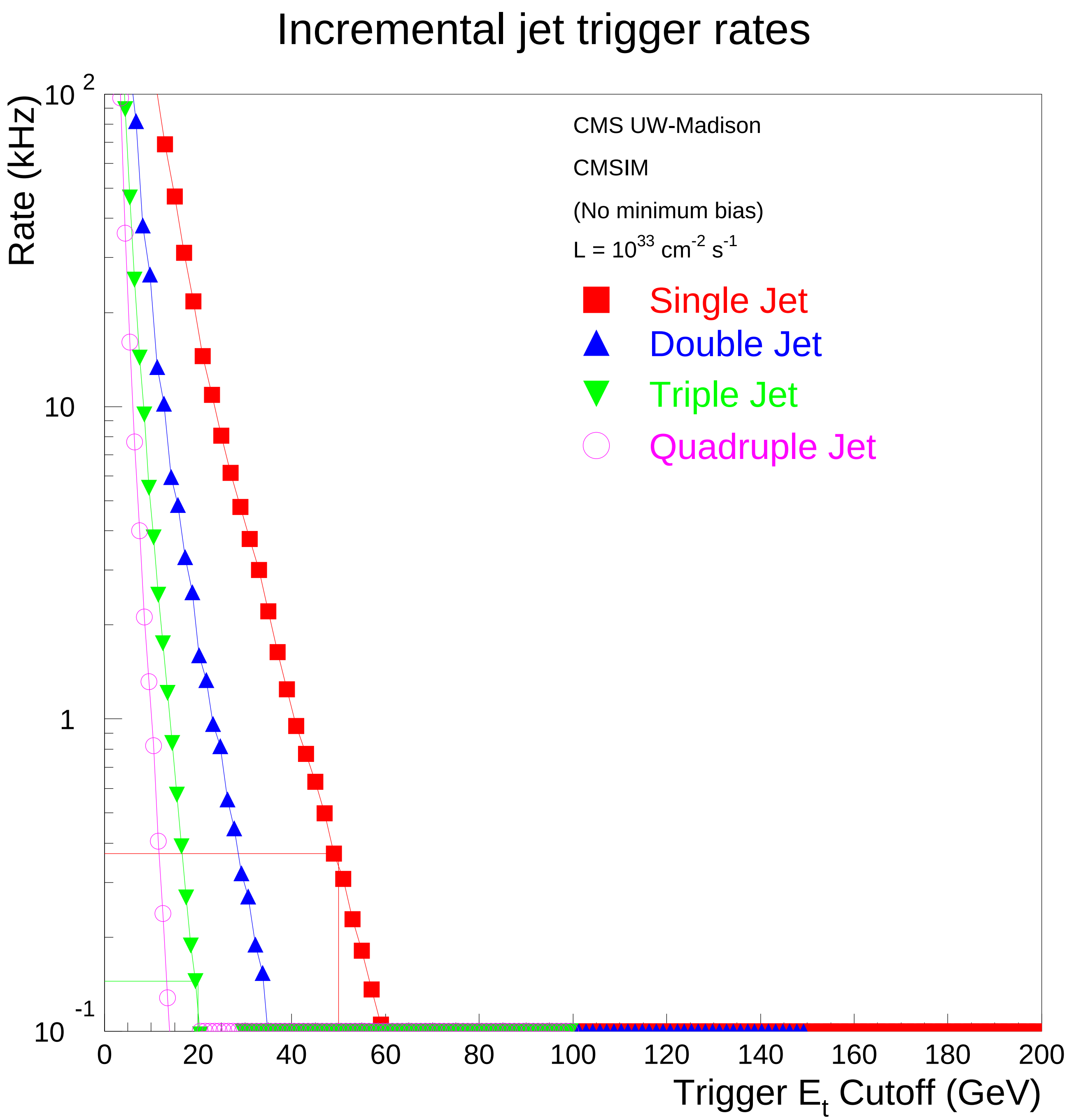
Baseline jet trigger rates



Integrated trigger rate above the trigger E_T cutoff is plotted versus the E_T cutoff.

Multijet rates are incrementally over lower multiplicity triggers.

Jet Rates at Low Luminosity



High Luminosity Rate Table

For a sample set of trigger cuts emphasising e/γ channel

Trigger Type	Trigger E_T Cutoff (GeV)	95% Efficiency Threshold (GeV)	90% Efficiency Threshold (GeV)	Incremental Rate (kHz)
Sum E_T	400			0.3
Missing E_T	80		200	0.9
Electron	27	35	33	5.3
Dielectron	14	22	20	1.3
Single jet	100	155	142	1.0
Dijet	60	106	100	0.7
Trijet	30	70	65	1.3
Quadjet	20	52	49	1.0
Jet + Electron	50 & 14			0.3
Cumulative Rate (kHz)	12.1			

Table 1: E_T cutoffs, 95% and 90% efficiency turn-on thresholds and incremental rate are shown for a variety of triggers at $\mathcal{L} = 10^{34}$ cm^{-2} s^{-1}.

- **The trigger cutoffs are fully programmable.**
  - Can be tuned to yield desired efficiency.
- **The total rate is required to be ~12.5 kHz.**
  - Nominal Level-1 75 kHz rate is shared equally by muon/calorimeter subsystems. Further a safety factor of 3 to account for the limited reliability of rate predictions.

Low Luminosity Rate Table

For a sample set of trigger cuts emphasising e/γ channel

Trigger Type	Trigger E_T Cutoff (GeV)	95% Efficiency Threshold (GeV)	90% Efficiency Threshold (GeV)	Incremental Rate (kHz)
Sum E_T	150			1.0
Missing E_T	50	110	105	0.7
Electron	16	24	20	7.3
Dielectron	8	15	12	3.0
Single jet	50	107	100	0.3
Dijet	35	77	68	0.1
Trijet	20	52	49	0.2
Quadjet	15	40	35	0.04
Jet + Electron	30 & 10			0.2
Cumulative Rate (kHz)	12.8			

Table 2: E_T cutoffs, 95% and 90% efficiency turn-on thresholds and incremental rate are shown for a variety of triggers at $\mathcal{L} = 10^{33}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$.

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Physics Efficiencies High & Low Luminosity

10^{34}

Process	Efficiency (%) Nominal E_T Cutoffs	Efficiency (%) Reduced rate E_T Cutoffs
H (80 GeV) $\rightarrow \gamma\gamma$	93	91
H (120 GeV) $\rightarrow ZZ \rightarrow ee\mu\mu$	76	73
H (200 GeV) $\rightarrow ZZ \rightarrow eejj$	95	95
$pp \rightarrow tt \rightarrow eX$	82	82
$pp \rightarrow tt \rightarrow eH^+X_1 \rightarrow e\tau X_2$	76	76
QCD Background Rate	**16.5 kHz**	**12.5 kHz**

Level-1 calorimeter trigger only

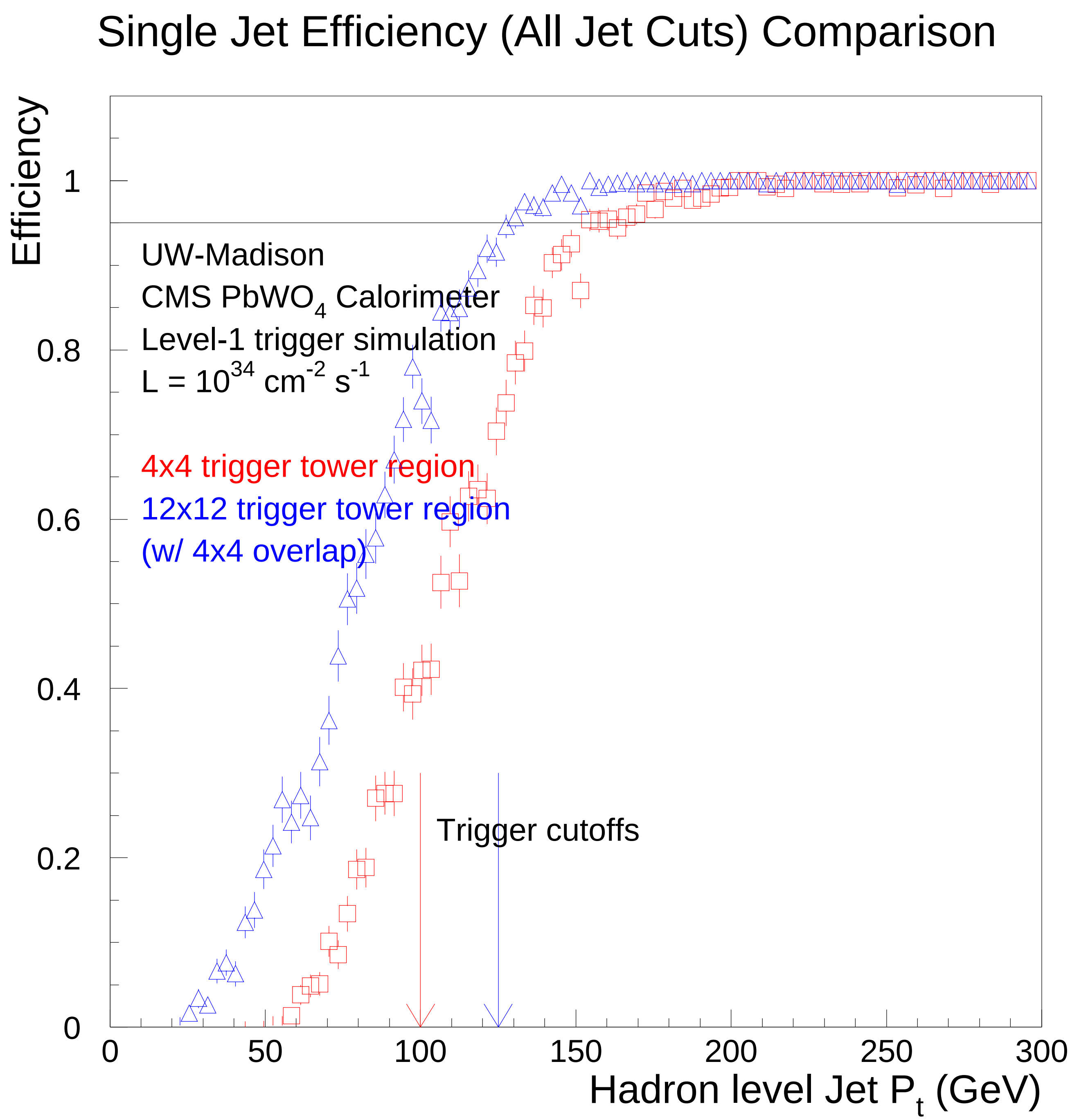
Table 4: Nominal and rate descoped efficiencies are shown for a variety of physics processes relevant at high luminosity.

10^{33}

Process	Efficiency (%) Nominal E_T Cutoffs	Efficiency (%) Reduced rate E_T Cutoffs
$pp \rightarrow tt \rightarrow eX$	98	97
$pp \rightarrow tt \rightarrow eH^+X_1 \rightarrow e\tau X_2$	94	94
SUSY Squark and Gluino production CMS Technical Proposal Scenario A $M_{LSP} = 45$ GeV, $M_{spart} \approx 300$ GeV	82	77
SUSY Neutral Higgs $10 \leq \tan\beta \leq 30$ $100 \leq M_{A,H} \leq 400$ GeV	40 - 96	38 - 96
QCD Background Rate	**16.5 kHz**	**12.5 kHz**

Table 5: Nominal and rate descoped efficiencies are shown for a variety of physics processes relevant at low luminosity.

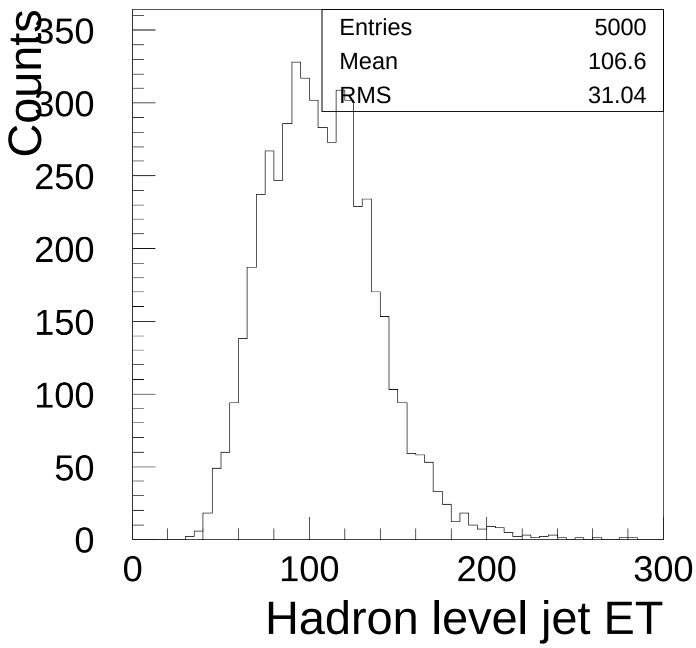
Comparison of jet algorithms I



For the same rate, efficiency for 12x12 algorithm turns on fully at 25 GeV lower P_T than 4x4 algorithm.

Comparison of jet algorithms II

Jet Energy Resolution



For 10% around mean,

ET difference of

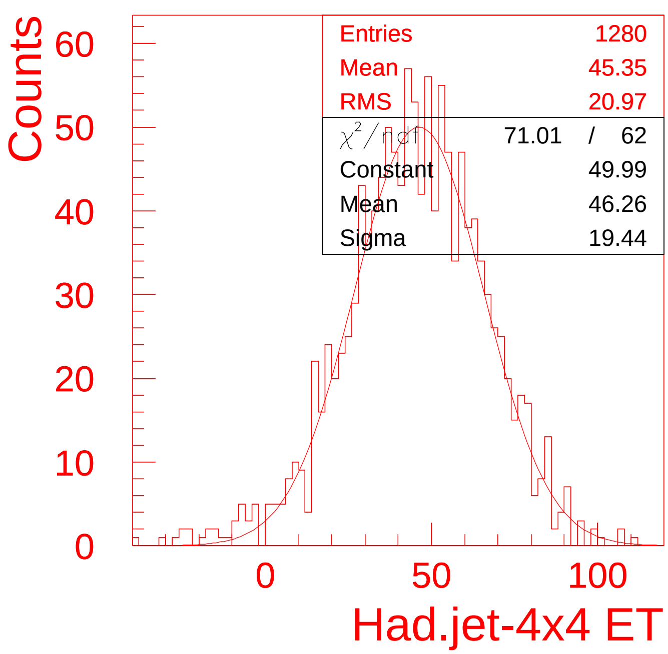
highest hadron level jet and

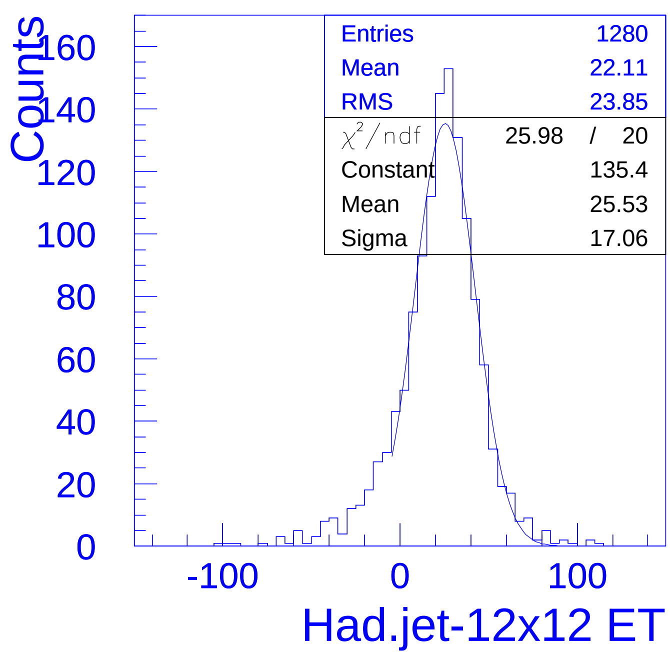
highest non-overlapping 4x4 sum

or highest overlapping 12x12 sum

is histogrammed and fitted

with gaussian

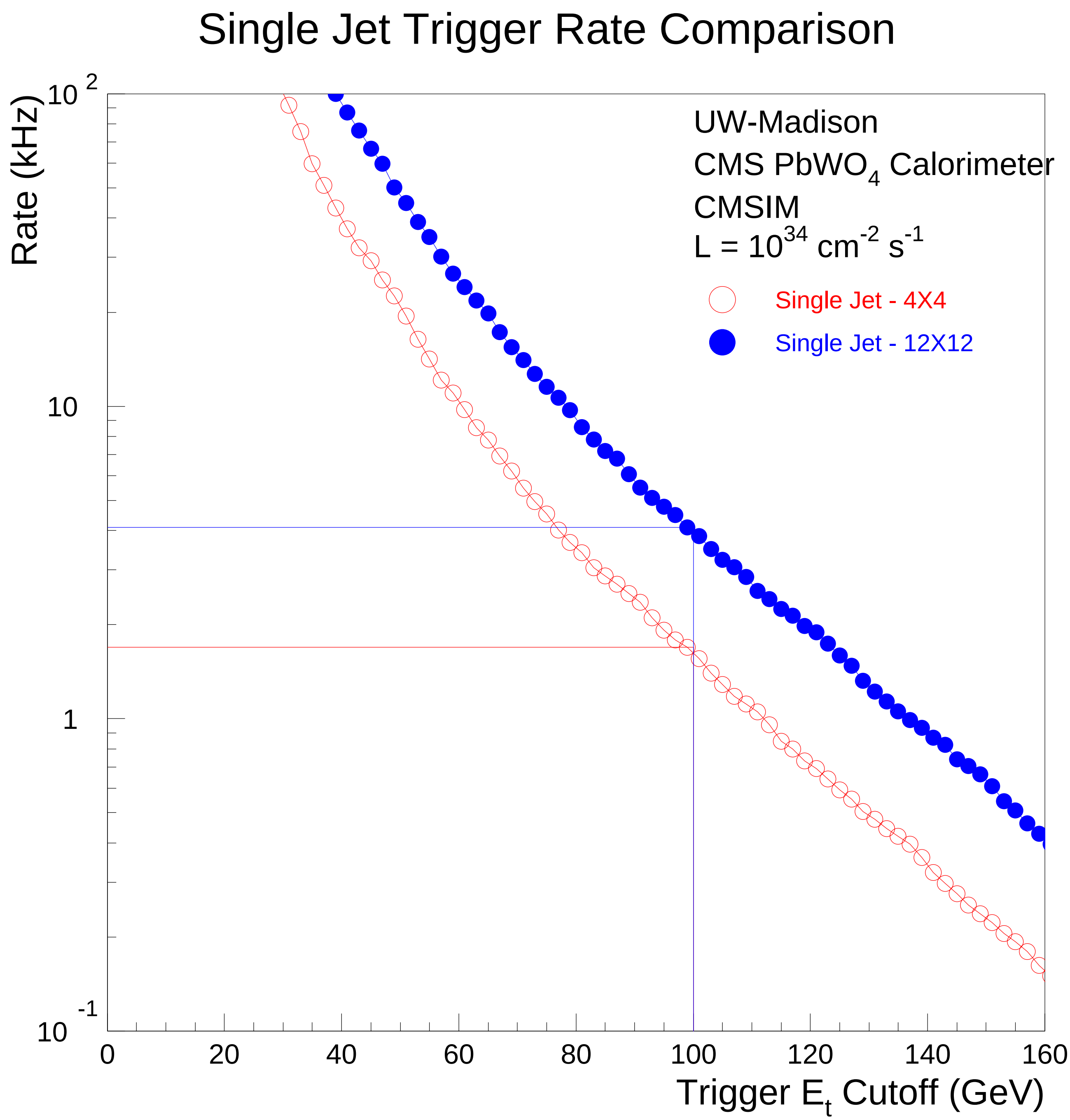




Level-1 jet energies compared to hadron level jets

- Not all energy is collected in the 4x4 jet region
- Improvement in resolution due to 12x12 overlaps

Comparison of jet algorithms III



Lowering 4x4 E_T cutoff by 25 GeV raises rate by 4 kHz
Minimum bias not included - (Next in work plan)

Higher level jet trigger

Task

- ~5kHz rate needs to be brought down to a fraction of 100 Hz

Advantage

- Needs only calorimeter data that can be read out at full 75kHz rate
- Can work with level-1 information as seeds
- Can run offline like algorithm

Result

- Improved resolution - sharp efficiency turn-on
- Accurate jet counting

Consequences of increasing jet trigger input rate

- Bandwidth use scales well - need to bring in only the calorimeter data at higher rate

Our preference

- Use simpler level-1 jet trigger and sharpen the efficiency turn-on in higher level trigger
- Allocate higher bandwidth for jet triggers if the physics demands it

Summary

Baseline CMS jet algorithm uses fixed but small (4x4) non-overlapping trigger tower regions to provide jet trigger

- The efficiency turn-on for combination of single, double, triple and quadruple 4x4 regions above respective E_T cutoffs, is quite acceptable for capturing physics of interest to CMS

Comparison to larger (12x12) overlapping trigger tower region is made

- The efficiency turn-on for this alternative provides full efficiency at about 25 GeV lower P_T

Allocating few kHz more bandwidth to jet triggers will pass same events to higher levels

It is possible to implement full offline style algorithm in the CMS higher level trigger farm.