CMS Tracking Trigger

Wesley H. Smith

U. Wisconsin – Madison

CMS Trigger Coordinator

CMS Upgrade Workshop

November 20, 2008

Outline:

Requirements & Luminosity effects

Problems with cal & μ triggers at 10^{35}

Use of a L1 Tracking Trigger

SLHC Trigger Architecture & Latency

SLHC Physics/Trigger Requirements

High-P_T discovery physics

- TeV particle decays to highly boosted lepton or EW boson pairs
- Not a big rate problem with high thresholds for extending reach

Completion of LHC physics program

- Precise measurements of Higgs sector
  - Require low thresholds on leptons/photon
    - Dilepton and Diphotons with L1 thresholds ~25 GeV per lepton
    - But, need a way to avoid multi-object L1 triggers from different proton interactions in the crossing
- SUSY spectroscopy
  - Pair produced and cascade decays with large MET
    - Multiple leptons and jets in final state
    - P_Ts for leptons 25 GeV and jets 50 GeV

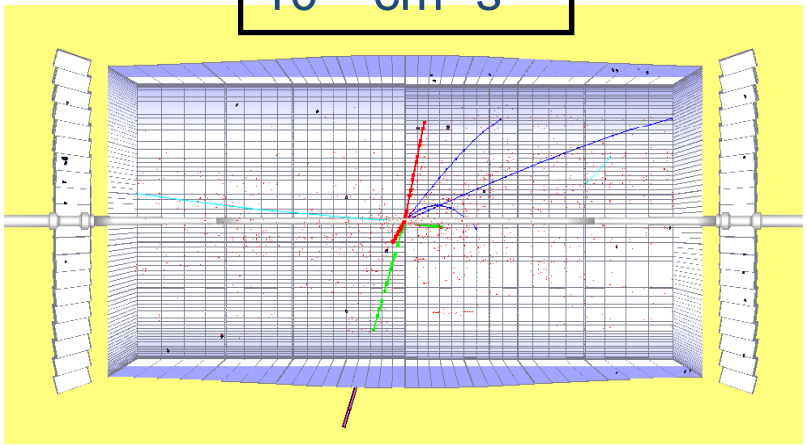
Control & Calibration triggers

- W, Z, Top events (prescaled)
- Large fake rate at low P_Ts

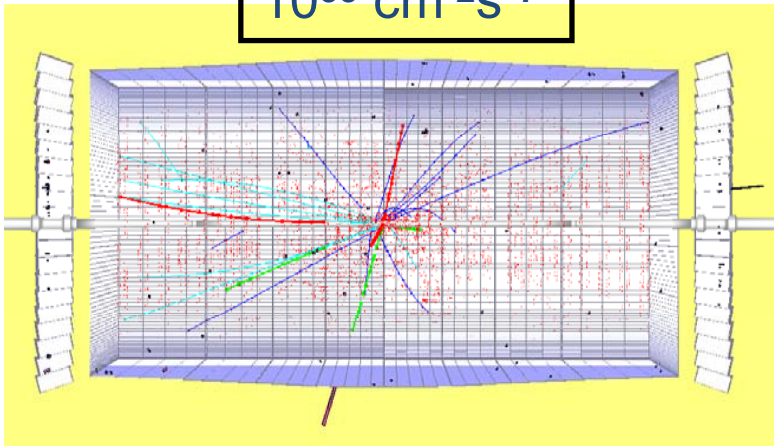
Detector Luminosity Effects

$H \rightarrow ZZ \rightarrow \mu\mu ee$, M_H= 300 GeV for different luminosities in CMS

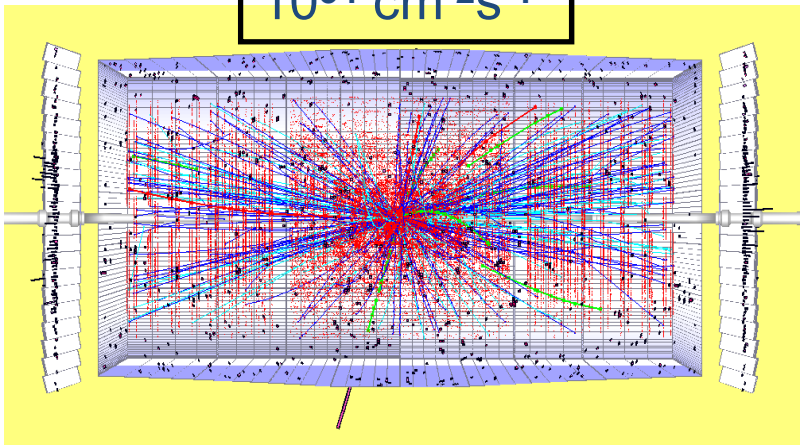
10^{32} cm^{-2}s^{-1}



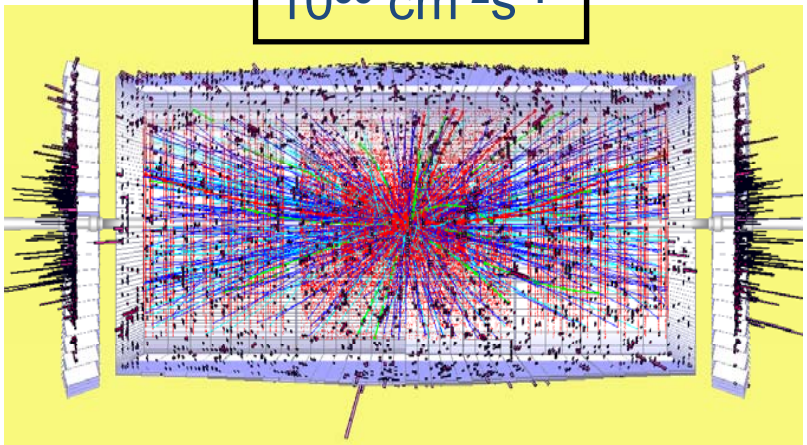
10^{33} cm^{-2}s^{-1}



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



10^{35} cm^{-2}s^{-1}



SLHC Trigger Strategy

Constraints

- Output rate at 100 kHz
- Input rate increases by x2 or x10
- Number of interactions in a crossing goes up by x4 or x20
- Thresholds remain ~same as physics interest does

Final states of interest known for measurements

- Use multiple objects and their correlations at L1
- More sophisticated clustering and isolation to deal with more busy events
- Should suffice for x2 reduction in rate as shown in CMS HLT studies with L2 algorithms

Potential new handles at L1 needed for x10

- Tracking to eliminate e/Γ fakes and muon resolution a la HLT
- Vertexing is useful to ensure that the multiple trigger objects come from the same interaction

SLHC Level-1 Trigger @ 10^{35}

Occupancy

- **Degraded performance of algorithms**
  - Electrons: reduced rejection at fixed efficiency from isolation
  - Muons: increased background rates from accidental coincidences
- **Larger event size to be read out**
  - New Tracker: higher channel count & occupancy → large factor
  - Reduces the max level-1 rate for fixed bandwidth readout.

Trigger Rates

- **Try to hold max L1 rate at 100 kHz by increasing readout bandwidth**
  - Avoid rebuilding front end electronics/readouts where possible
    - **Limits: <readout time> (< 10 μs) and data size (total now 1 MB)**
  - Use buffers for increased latency for processing, not post-L1A
  - May need to increase L1 rate even with all improvements
    - **Greater burden on DAQ**
- **Implies raising E_T thresholds on electrons, photons, muons, jets and use of multi-object triggers, unless we have new information** (**Tracker at L1**
  - Need to compensate for larger interaction rate & degradation in algorithm performance due to occupancy

Radiation damage -- Increases for part of level-1 trigger located on detector

Rate Problem: Tau Trigger

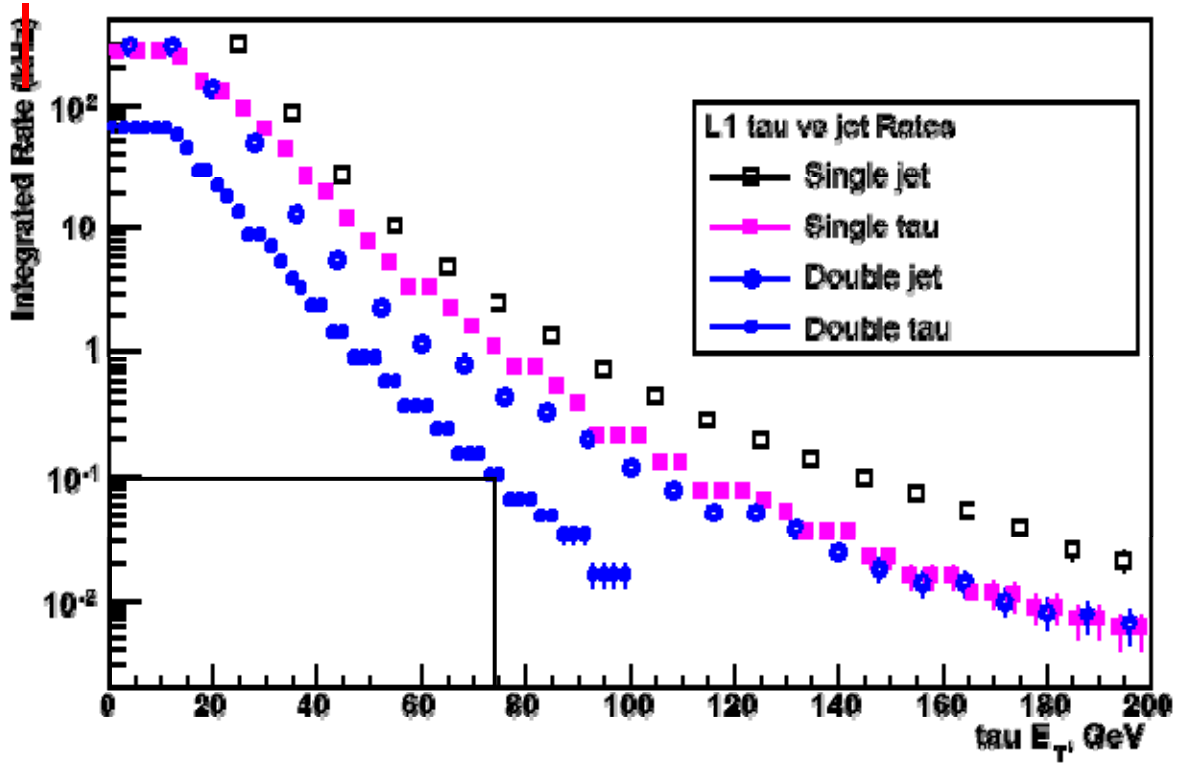
(S. Dasu)

Tau final states (E_T~50 GeV) critical for many SM/MSSM Higgs studies.

The L1T cuts should discriminate against jets, which are produced profusely at ~ 1 MHz at these thresholds.

We already double tau triggers.

MHz



We need to get another x200 (x20) reduction for single (double) tau rate!

But pileup pollution, which is not included here, will render isolation cuts here

Impossible without L1 Tracker Trigger

Over corrected by about x1.5

Tau Triggering in High PU
(A. Safonov)

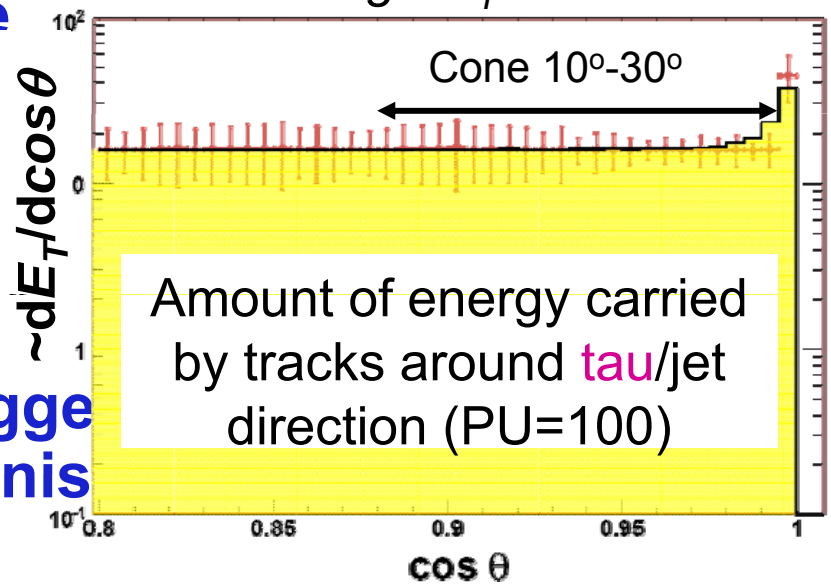
For high PU isolation doesn't work anymore

- **Before we could escape with summing up the surrounding energy as it is small for taus (PU), larger for jets. Now isolation is dominated by (fluctuating) PU**
  - Jet rejection with isolation is gone

What's worse, PU becomes an independent player:

- **"Taus" can come from simple PU fluctuations**
- **Increasing noise thresholds w decrease sensitivity to PU, bu jet rejection will worsen**
- **Performance of even ideal trigge against jets will severely diminis**

Y-axis: average E_T and RMS



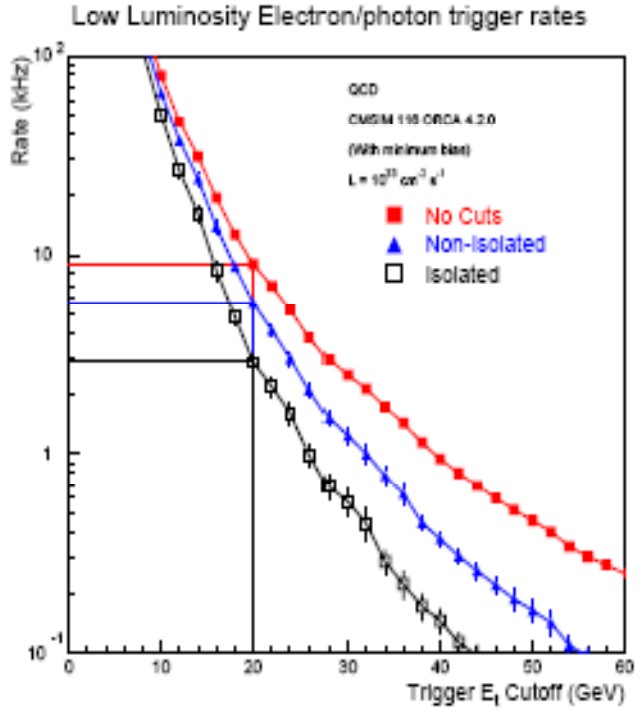
Rate problem: ECAL

-- J. Varela

L1 e/γ trigger: QCD background rates

At LHC low luminosity ($L=10^{33}cm^{-2}s^{-1}$)
~ 1 p-p collision per crossing

	Rates		Prob/collision	
GeV	No cuts (kHz)	H/E+isol (kHz)	No cuts (kHz)	H/E+isol (kHz)
ET>20	10	3	2.5 10-4	7.5 10-5
ET>30	3	0.5	7.5 10-5	1.3 10-5
ET>50	0.5	0.06	1.3 10-5	1.5 10-6



At SLHC ($L=10^{35}cm^{-2}s^{-1}$),
assuming prob/collision x 400 →
(cuts are probably less efficient)

	Rates	
GeV	No cuts (kHz)	H/E+isol (kHz)
ET>20	2000	600
ET>30	600	100
ET>50	100	12

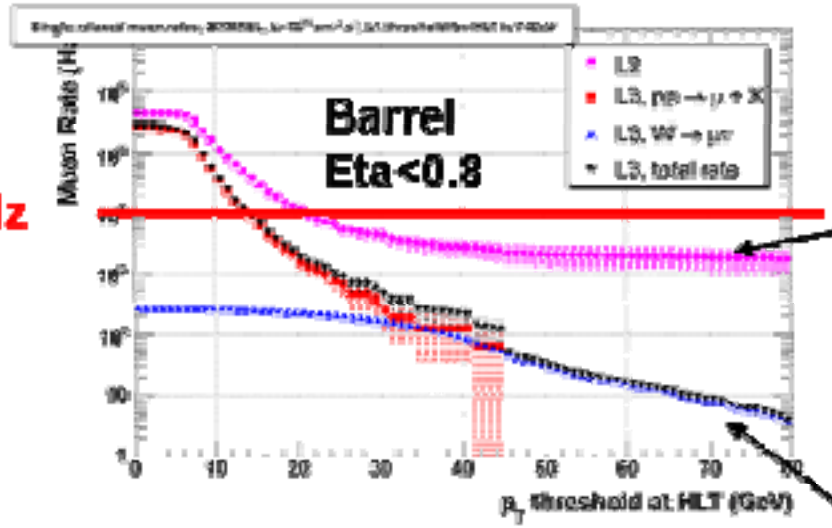
- Per Trigger Tower ($\Delta\eta \times \Delta\phi$ ~0.1 x 0.1), per crossing:
  - ~ 12 γ (γ rate in ECAL ~2.4 MHz/cm^2)
  - $<P_T>$ ~3 GeV
- No empty ECAL towers!

Ultimate limit of L1 μ trigger
(Montanari & Zotto)

From HLT for LHC we know that:

SLHC:
$L=10^{35}cm^{-2}s^{-1}$

10kHz

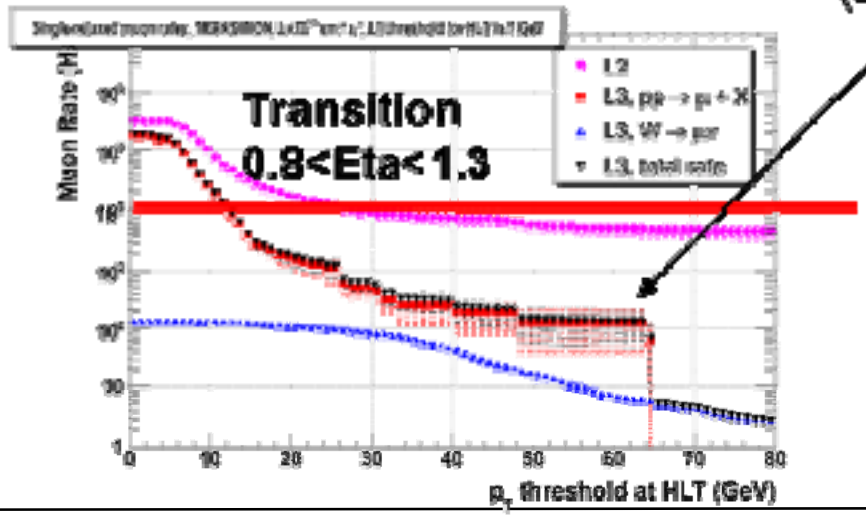


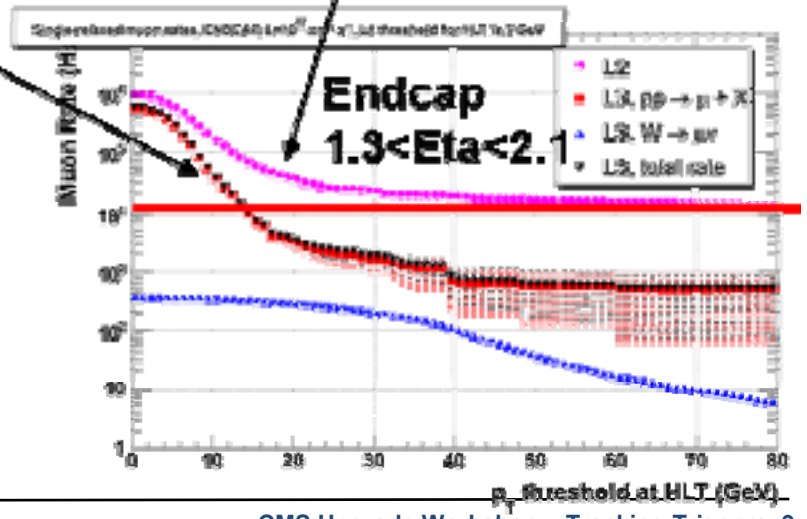
full data reconstruction (DT)
(Level 2)

(Plots: courtesy of J.Alcaraz)

+ Tracker
(Level 3)

full data reconstruction (CSC)
(Level 2)

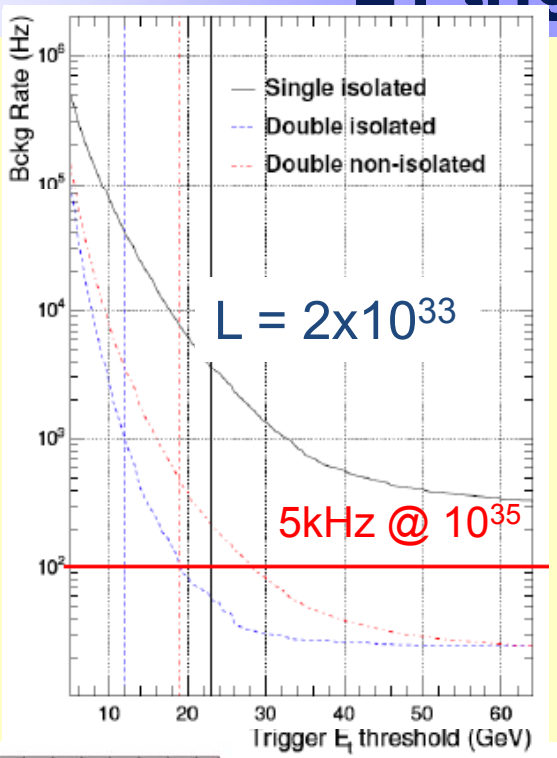


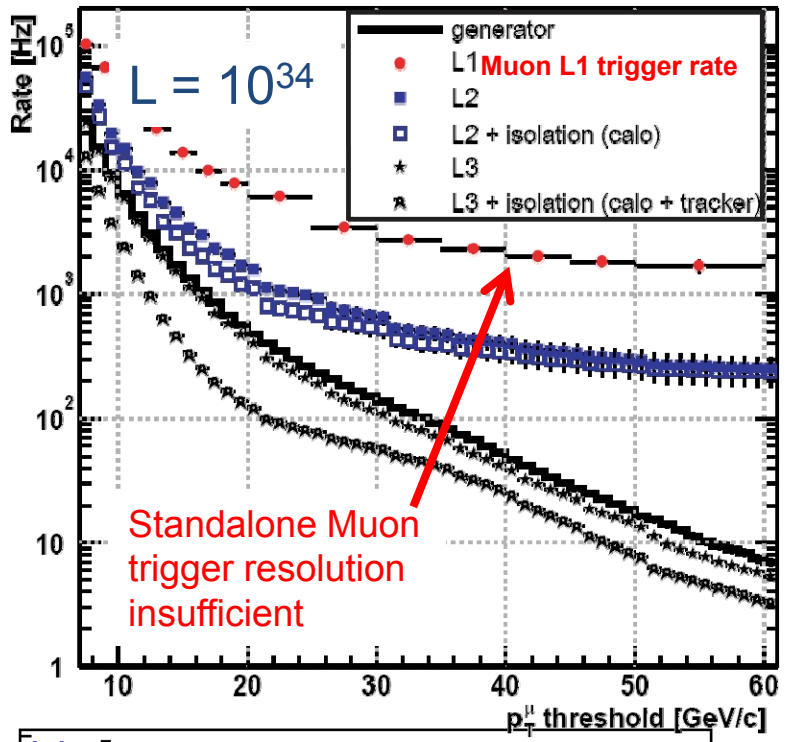


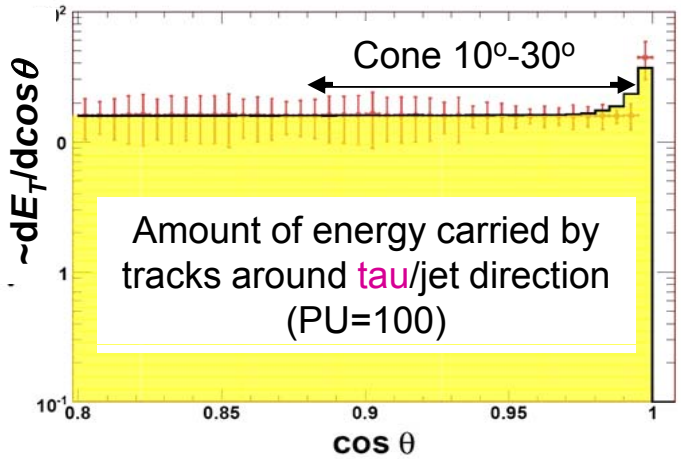
Summary of why Tracking needed for L1 trigger

Single electron trigger rate

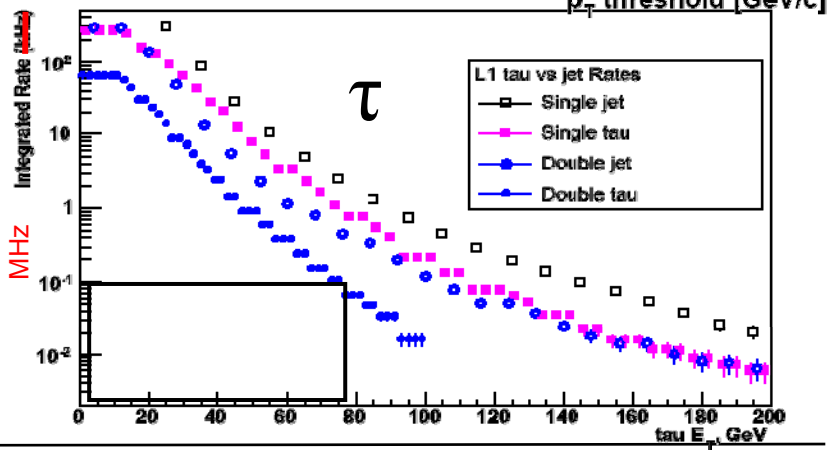
Isolation criteria are insufficient to reduce rate at L = 10^{35} $cm^{-2}.s^{-1}$







We need to get another x200 (x20) reduction for single (double) tau rate!



Use of L1 Tracking Trigger

Combine with L1 τ trigger as is now done at HLT:

- **Attach tracker hits to improve P_T assignment precision from 15% standalone muon measurement to 1.5% with the tracker**
  - Improves sign determination & provides vertex constraints
- **Find pixel tracks within cone around muon track and compute sum P_T as an isolation criterion**
  - Less sensitive to pile-up than calorimetric information *if* primary vertex of hard-scattering can be determined (~100 vertices total at SLHC!)

To do this requires $\eta \times \phi$ information on muons finer than the current $0.05 \times 2.5°$

- **No problem, since both are already available at 0.0125 and 0.015°**

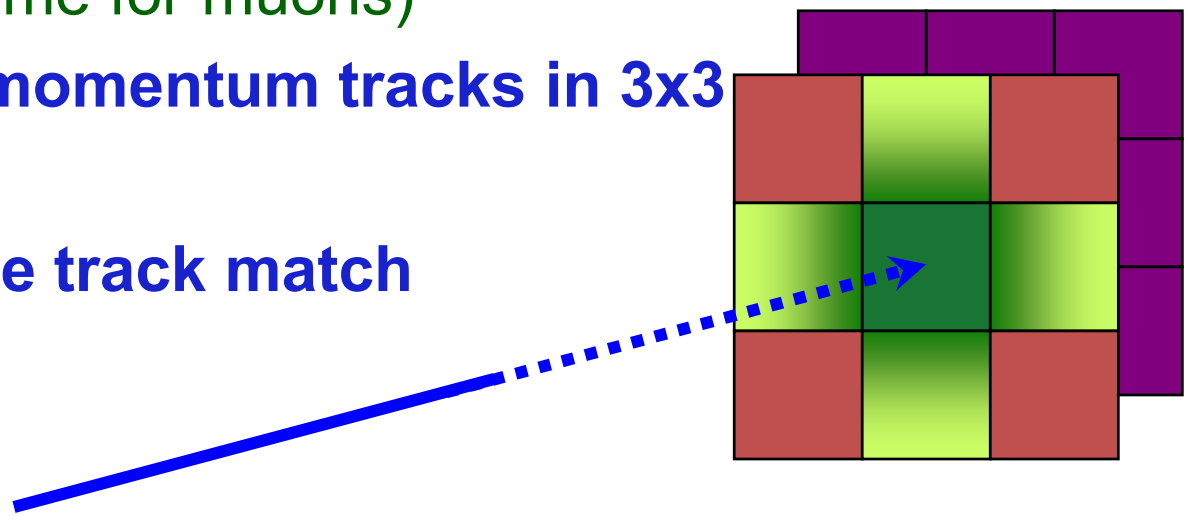
CMS SLHC e / γ / τ object ⇔ track correlation

Use e / γ / τ objects to seed tracker readout

- Track seed granularity 0.087 × 0.087 ⇔ 1 × 1
- Track seed count limited by presorting candidates
  - e.g., Maximum of 32 objects?

Tracker correlation

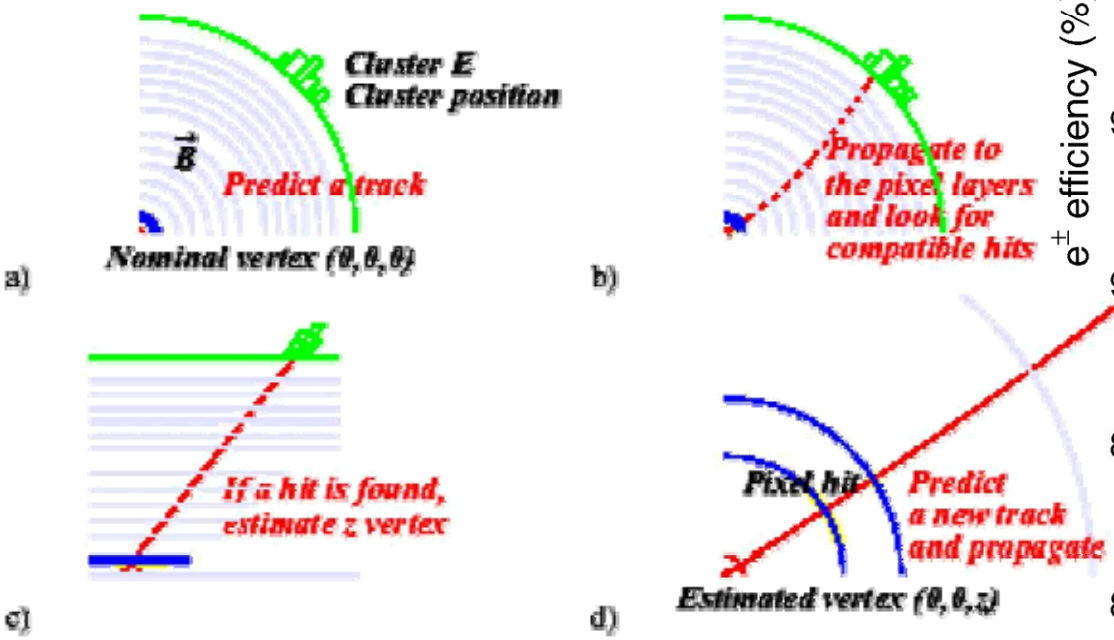
- Single track match in 3x3 with crude P_T (8-bit ~ 1 GeV)
  - Electron (same for muons)
- Veto of high momentum tracks in 3x3
  - Photon
- Single or triple track match
  - Tau

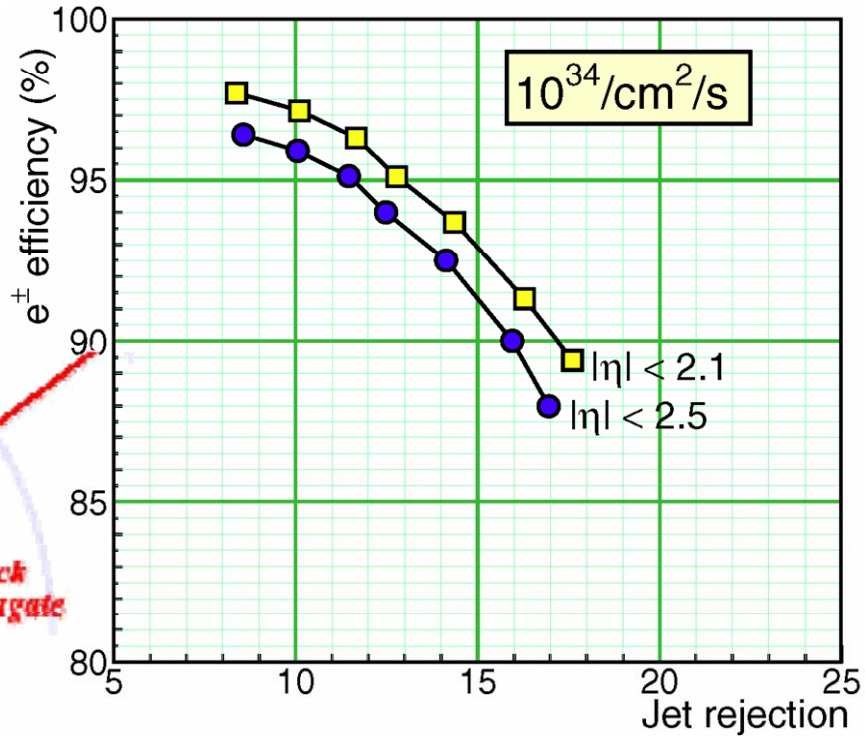


Tracking for electron trigger

Present CMS electron HLT

- C. Foudas & C. See

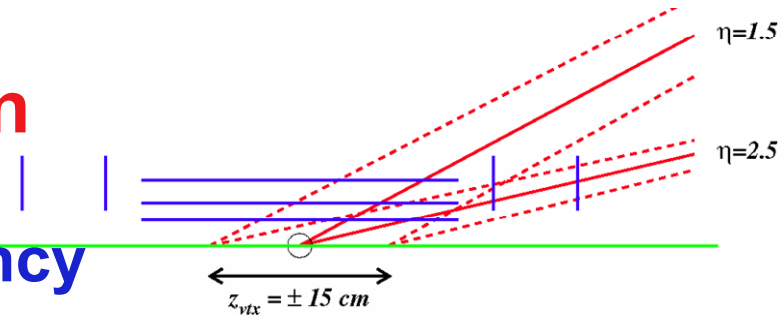




Factor of 10 rate reduction

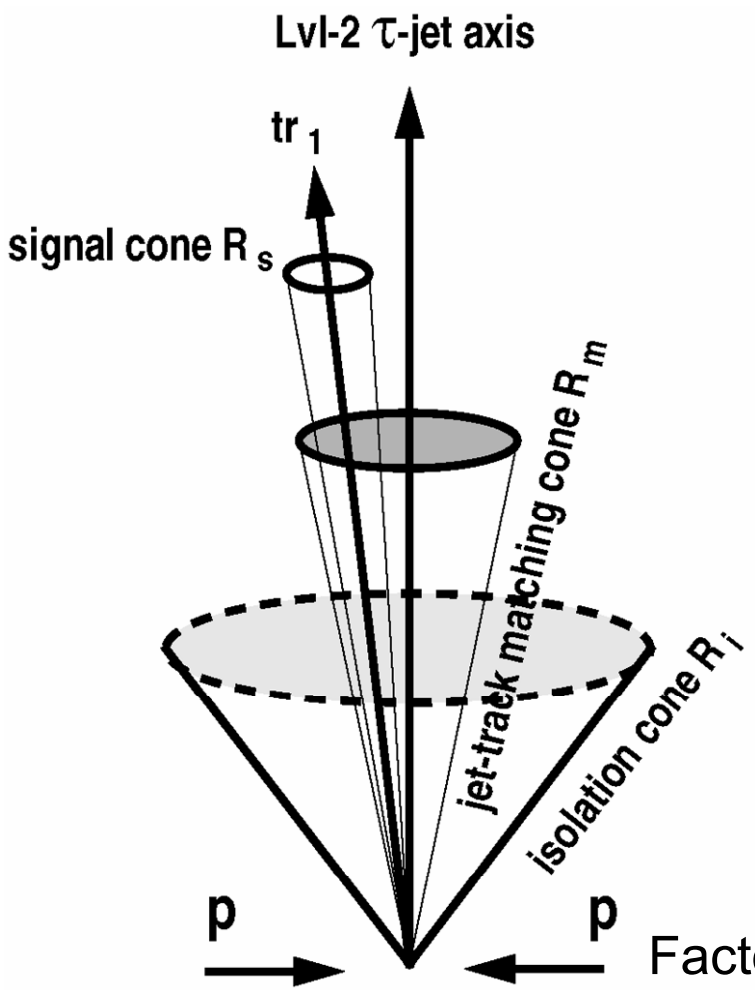
γ: only tracker handle: isolation

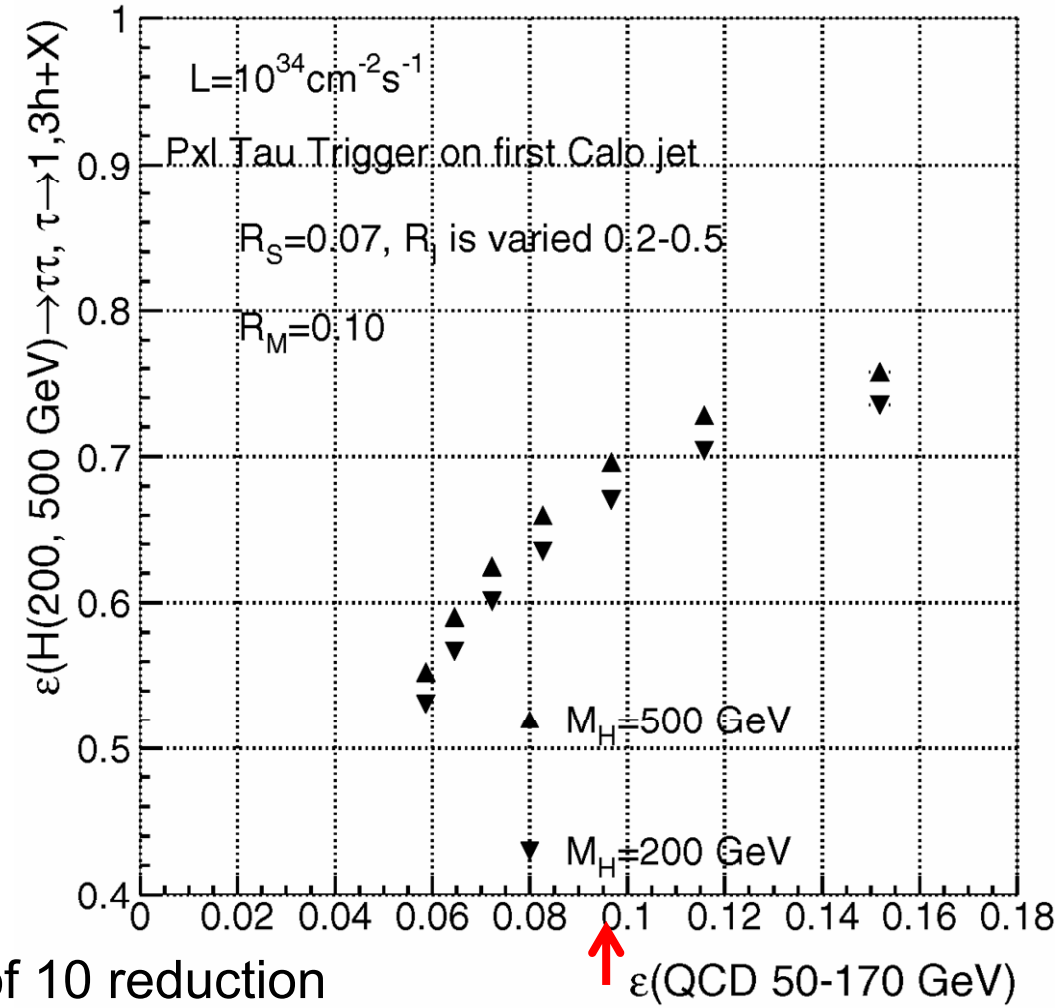
- Need knowledge of vertex location to avoid loss of efficiency



Tracking for τ -jet isolation

τ -lepton trigger: isolation from pixel tracks outside signal cone & inside isolation cone





Factor of 10 reduction

L1 Tracking Trigger for CSCs
(D. Acosta)

Combine with L1 μ trigger as is now done at HLT:

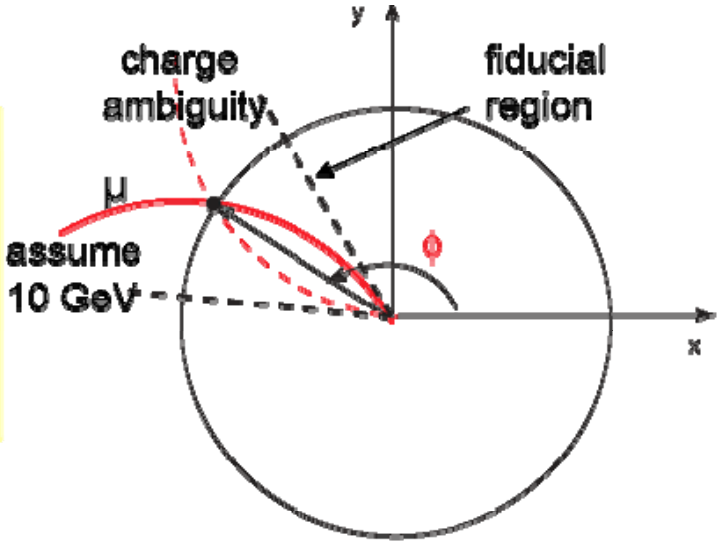
- **Attach tracker hits to improve P_T assignment precision from 15% standalone muon measurement to 1.5% with the tracker**
  - Improves sign determination & provides vertex constraints
- **Find pixel tracks within cone around muon track and compute sum P_T as an isolation criterion**
  - Less sensitive to pile-up than calorimetric information *if* primary vertex of hard-scattering can be determined (~100 vertices total at SLHC!)

To do this requires η-φ information on muons finer than the current 0.05-2.5°

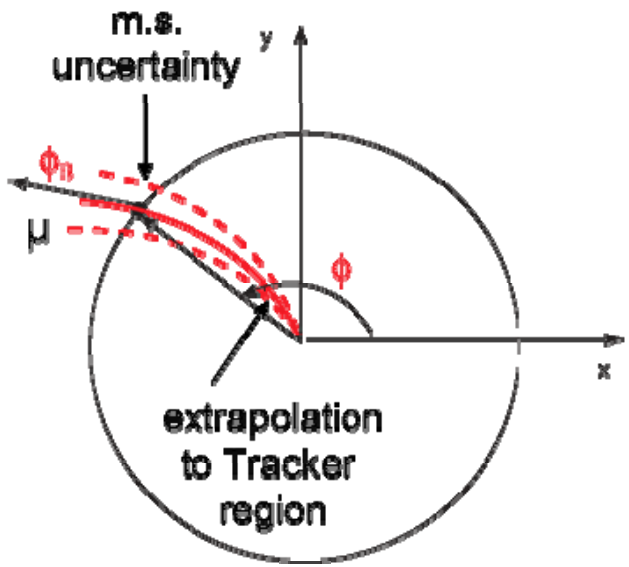
- **No problem, since both are already available at 0.0125 and 0.015°**

L1 Tracking Trigger for DTs
(Montanari & Zotto)

A) Static mapping:
- use only one hit position φ beyond Solenoid
- define fixed maximal regions since no information on p_T is available (use only bending power for p_T>10 GeV
- fast (hardware mapping)



B) Dynamic mapping:
- use hit position φ plus bending angle φ_B which gives a rough estimation of momentum (and charge)
- taking into account the effect of multiple scattering can define regions that are smaller for higher momentum muons
- more sophisticated
- requires one measured hit plus direction
- slower (requires some calculation)



Inner tracker matching to muons
(J. Hauser)

If matching after muon-only track-finding:

- **Pt sharpening by correction based on muon-only track parameters + precision central track stub positions**
- **Can precisely point back to central tracker to identify where to do track-finding:**
  - Calorimeter matching to ~0.03 in delta R, muons even better in principle
  - Isolation cone ~0.2 in delta R, 0.4% of total tracking 4.8 (eta) x 6.283 (phi)
- **Common barrel/endcap electronics solution possible**

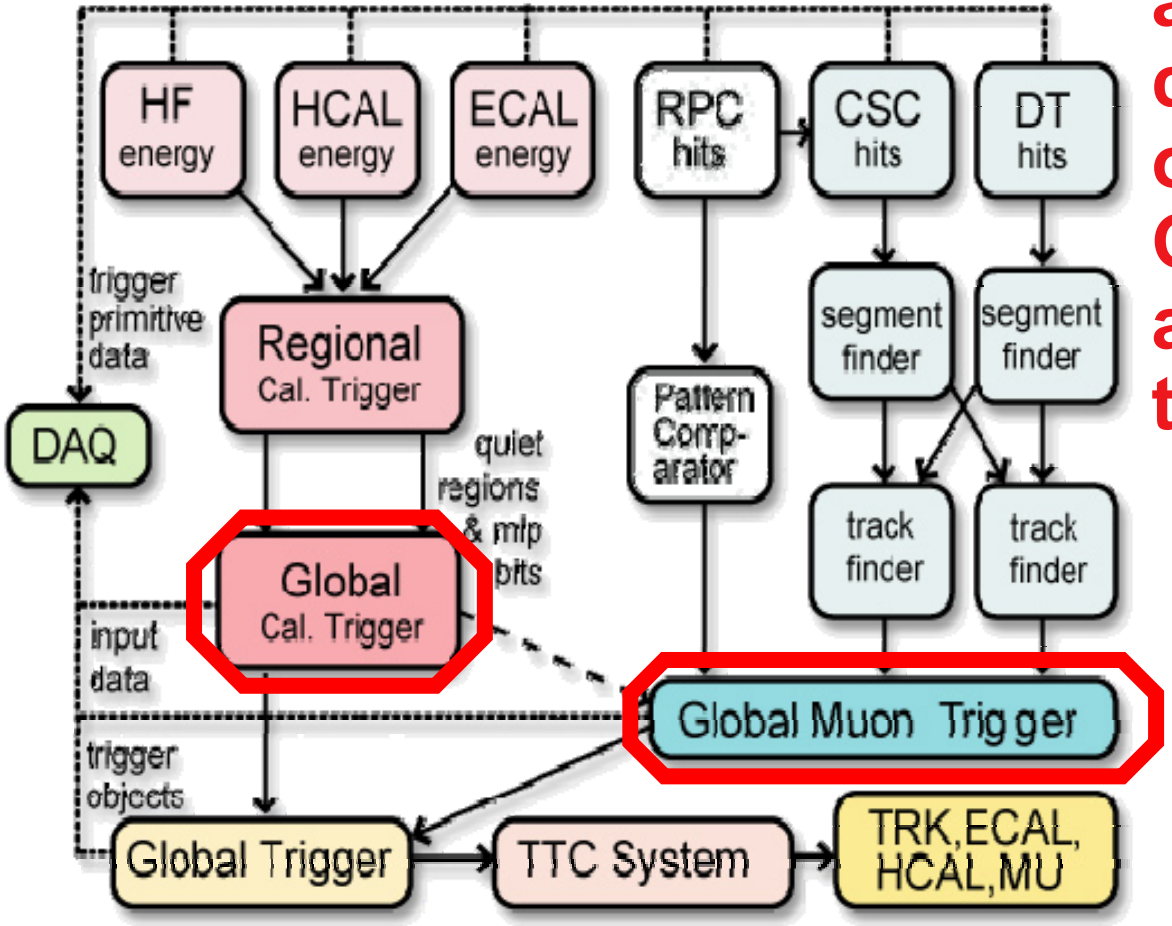
If matching before muon-only track-finding:

- **Probably sharpest resolution: full fit precision central track stub + muon stubs**
- **Save 100-200 ns latency?**
- **Perhaps not a common barrel/endcap electronics solution.**

Phase 1 Addition of Track TPGs

Just a possibility!

Note: Latency remains 3.2 μsec



Combine pixel- based η×ϕ array with arrays of muon & calorimeter trigger objects found in Global calorimeter and Global muon triggers.

- **Only a few bx avail.**
- **Option: combine earlier at muon track-finder sorter or at output of RCT**

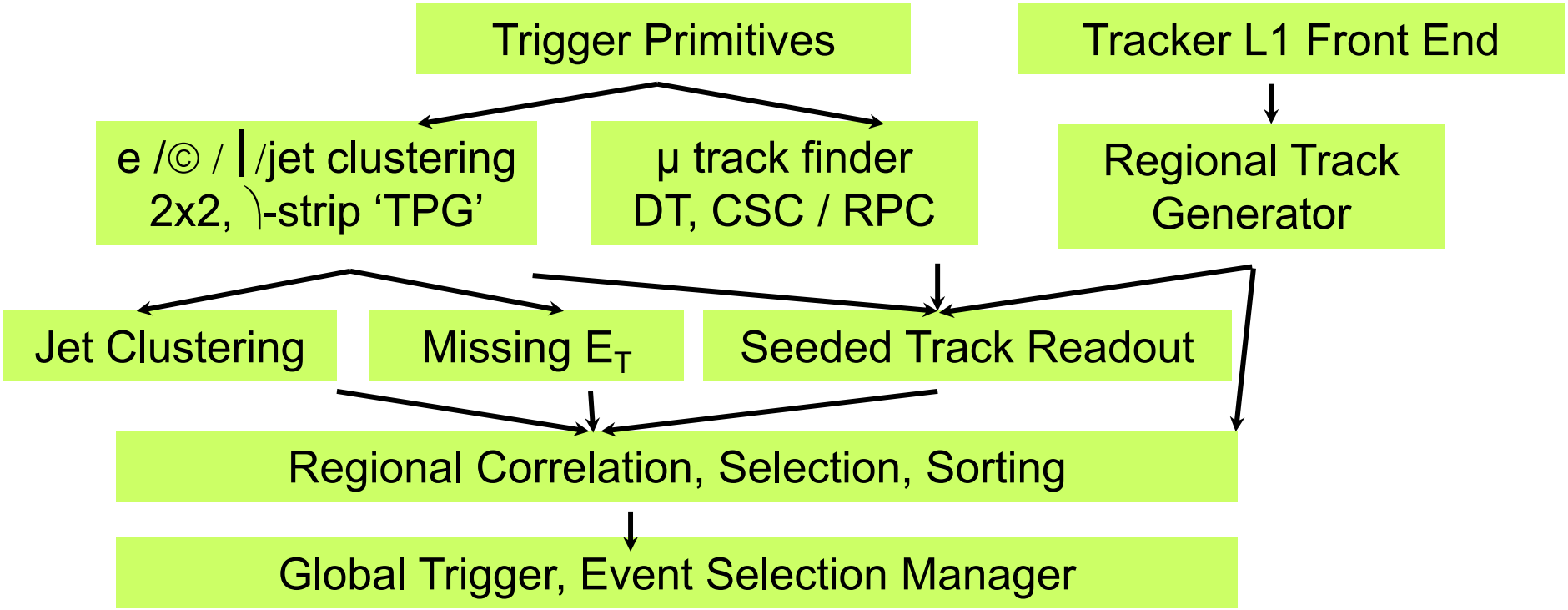
CMS L1 Trigger Stages

Current for LHC:

TPG \ RCT \ GCT \ GT

Proposed for SLHC (with tracking added):

TPG \ Clustering \ Correlator \ Selector



SLHC Trig. Architecture

Phase 1 (?):

- **Correlate η×ϕ×z grid from pixels with calo & muon objects**
- **Correlation comes after or is integrated with GMT, GCT**
  - Or integrated with muon sorters for individual muon detectors?

Phase 2:

- **Combine Level-1 Trigger data between tracking, calorimeter & muon at Regional Level at finer granularity**
  - Option to "seed" tracking trigger data from cal. & μ trig.
- **Transmit physics objects made from tracking, calorimeter & muon regional trigger data to global trigger**
- **Implication: perform some of tracking, isolation & other regional trigger functions in combinations between regional triggers**
  - New "Regional" cross-detector trigger crates
- **Leave present L1+ HLT structure intact (except latency)**
  - No added levels --minimize impact on CMS readout

Phase 2 CMS Level-1 Latency

Present CMS Latency of 3.2 μsec = 128 crossings @ 40MHz

- Limitation from post-L1 buffer size of tracker & preshower
- Assume rebuild of tracking & preshower electronics will store more than this number of samples

Do we need more?

- Not all crossings used for trigger processing (70/128)
  - It's the cables!
- Parts of trigger already using higher frequency

How much more? Justification?

- Combination with tracking logic
- Increased algorithm complexity
- Asynchronous links or FPGA-integrated deserialization require more latency
- Finer result granularity may require more processing time
- ECAL digital pipeline memory is 256 40 MHz samples = 6.4 μsec
  - Propose this as CMS SLHC Level-1 Latency baseline

CMS SLHC Tracking Trigger

L1 Trigger without tracking

- Possible to improve to ultimate performance stand-alone to cope higher than 10^{34} but not out to 10^{35}.
- These improvements involve patterns and granularity more fine than in the present trigger
- These are required in any case for use with a L1 tracking trigger.

L1 trigger with tracking

- Prospects to cope up to 10^{35} look reasonable
- Based on what we know from HLT simulation results
- Moreover, tracking provides a "game-changing" opportunity to keep or reduce the 10^{34} physics thresholds at 10^{35}.

All of this needs validation with simulation