CMS SLHC Trigger

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ATLAS-CMS SLHC Workshop

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Outline:

Calorimeter Triggers

Muon Triggers

Tracking Triggers

& Combinations

This talk is available on:

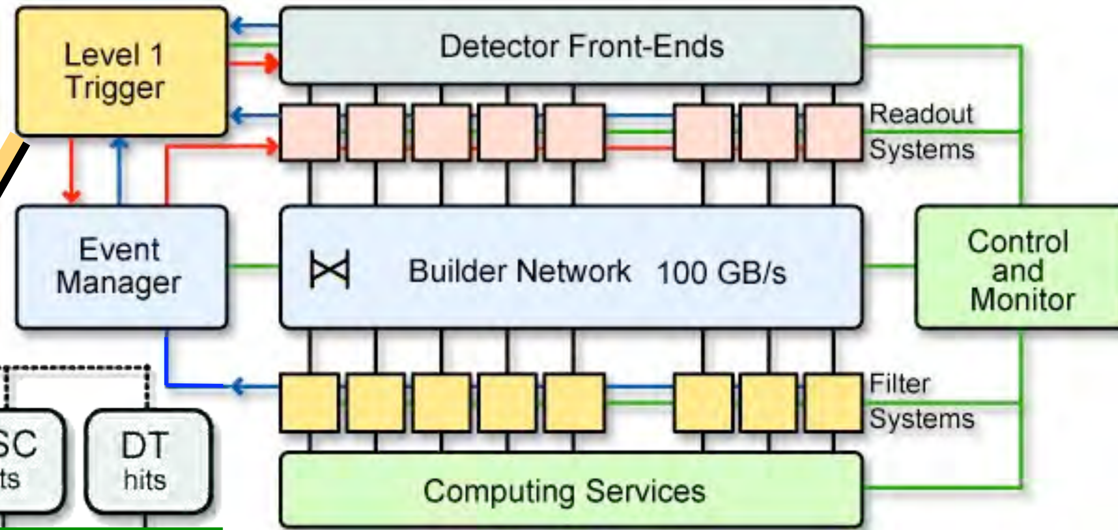
http://cmsdoc.cern.ch/cms/TRIDAS/tr/07/03/smith_trig_slhc_mar07.pdf

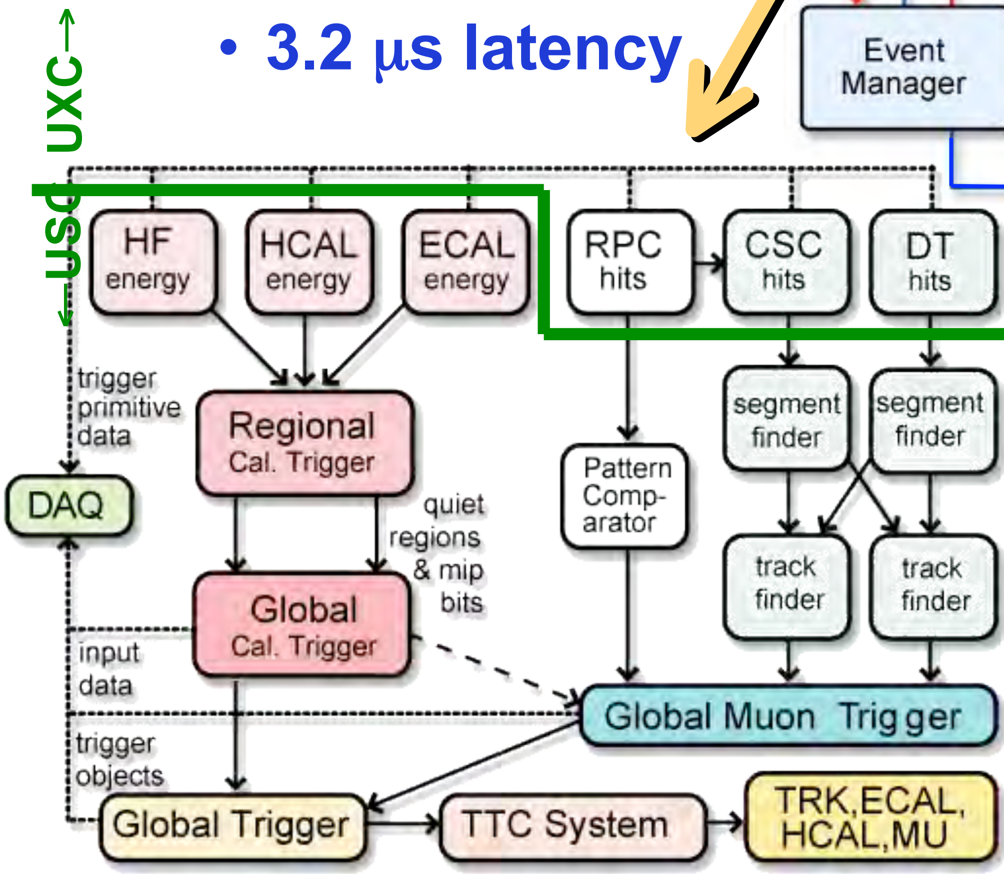
CMS Level-1 Trigger & DAQ

Overall Trigger & DAQ Architecture: 2 Levels:

Level-1 Trigger:

- 25 ns input
- 3.2 μs latency





Interaction rate: 1 GHz

Bunch Crossing rate: 40 MHz

Level 1 Output: 100 kHz (50 initial)

Output to Storage: 100 Hz

Average Event Size: 1 MB

Data production 1 TB/day

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 less inclusive triggers**
  - 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

SLHC Trigger Requirements

High-P_T discovery physics

- Not a big rate problem since high thresholds

Completion of LHC physics program

- Example: precise measurements of Higgs sector
- Require low thresholds on leptons/photons/jets
  - Use more exclusive triggers since final states will be known

Control & Calibration triggers

- W, Z, Top events
- Low threshold but prescaled

SLHC Level-1 Trigger Menu

ATLAS/CMS Studies in hep-ph/0204087:

- inclusive single muon p_T > 30 GeV (rate ~ 25 kHz)
- inclusive isolated e/γ E_T > 55 GeV (rate ~ 20 kHz)
- isolated e/γ pair E_T > 30 GeV (rate ~ 5 kHz)
  - or 2 different thresholds (i.e. 45 & 25 GeV)
- muon pair p_T > 20 GeV (rate ~ few kHz?)
- jet E_T > 150 GeV.AND.E_T(miss) > 80 GeV (rate ~ 1-2 kHz)
- inclusive jet trigger E_T > 350 GeV (rate ~ 1 kHz)
- inclusive E_T(miss) > 150 GeV (rate ~1 kHz);
- multi-jet trigger with thresholds determined by the affordable rate

Trig. Primitives: Calorimeter

HF:Quartz Fiber: Possibly replaced

- **Already fairly robust**
- **Modify logic to provide finer-grain information**
  - Improves forward jet-tagging

HCAL:Scintillator/Brass: Barrel stays but endcap partially replaced

- **Options: Quartz-fiber, PPAC's, si-sensors at highest η part of endcap**
  - SIPMs under consideration to replace HPDs
- **TPG logic already sufficiently performant with full readout tower $\eta \times \phi$ resolution**

ECAL: $PBWO_4$ Crystal: Stays

- **TPG logic already sufficiently performant with 5 $\eta \times$ 5 ϕ towers summed in a single trigger tower (equals HCAL tower size).**
- **Exclude on-detector electronics modifications for now -- difficult:**
  - Regroup crystals to reduce $\Delta\eta$ tower size -- minor improvement
  - Additional fine-grain analysis of individual crystal data -- minor improvement

Conclusions:

- **Front end logic same except where detector changes**

Trigger Primitives: Muons

Drift Tubes (see talk by F. Loddo):

- Can operate at 40 or 20 MHz with no problem (DT only in Barrel)

RPC (see talk by F. Loddo):

- Operate in the low η region with the same FE
- Detector and FE upgrade is needed for $\eta > 1.6$ region
- Trigger Electronics can operate with some modifications
- Some front-end electronics may not be sufficiently radiation tolerant & may need replacement

CSCs (see talk by D. Acosta):

- CSCs in endcaps have demonstrated required radiation tolerance
- Need additional ME4/2 layer recovered (planning for 2009-10)
- Some elements of trigger & DAQ may need replacement to cope with high data rates
- Some front-end electronics may not be sufficiently radiation tolerant & may need replacement

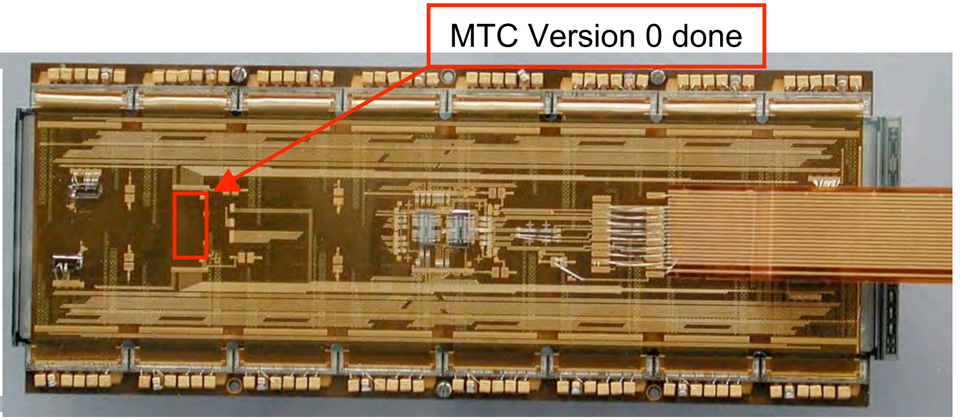
CMS SLHC L-1 Tracking Trigger
Ideas & Implications for L-1

Additional Component at Level-1

- **Actually, CMS could have a rudimentary L-1 Tracking Trigger**
  - Pixel z-vertex in $\Delta\eta \times \Delta\phi$ bins can reject jets from pile-up
    - **Cable not hooked up in final version**
- **SLHC Track Trigger could provide outer stub and inner track**
  - Combine with cal at L-1 to reject π^0 electron candidates
  - Reject jets from other crossings by z-vertex
  - Reduce accidentals and wrong crossings in muon system
  - Provide sharp P_T threshold in muon trigger at high P_T
- **Cal & Muon L-1 output needs granularity & info. to combine w/ tracking trig. Also need to produce hardware to make combinations**

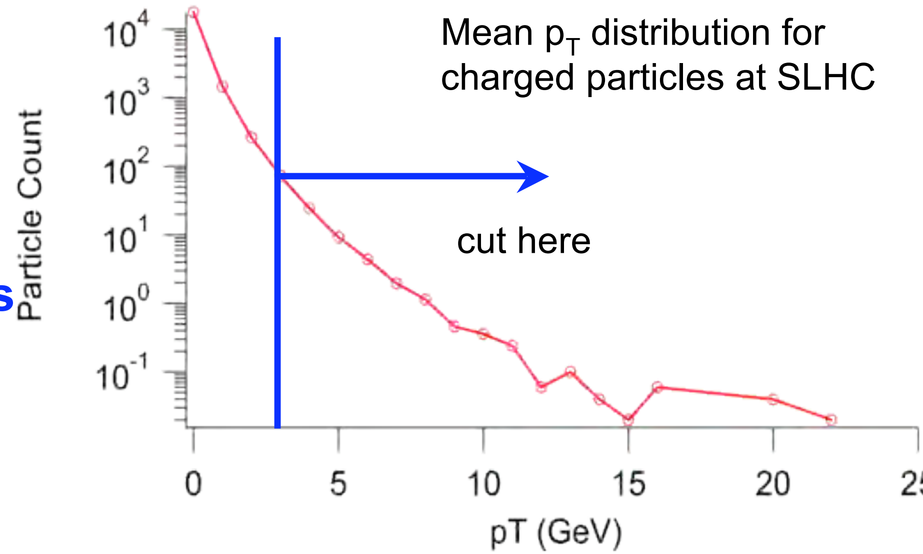
Move some HLT algorithms into L-1 or design new algorithms reflecting tracking trigger capabilities

- Local track clusters from jets used for 1st level trigger signal → jet trigger with σ_z = 6mm!
- Program in Readout Chip track cluster multiplicity for trigger output signal
- Combine in Module Trigger Chip (MTC) 16 trig. signals & decide on module trigger output



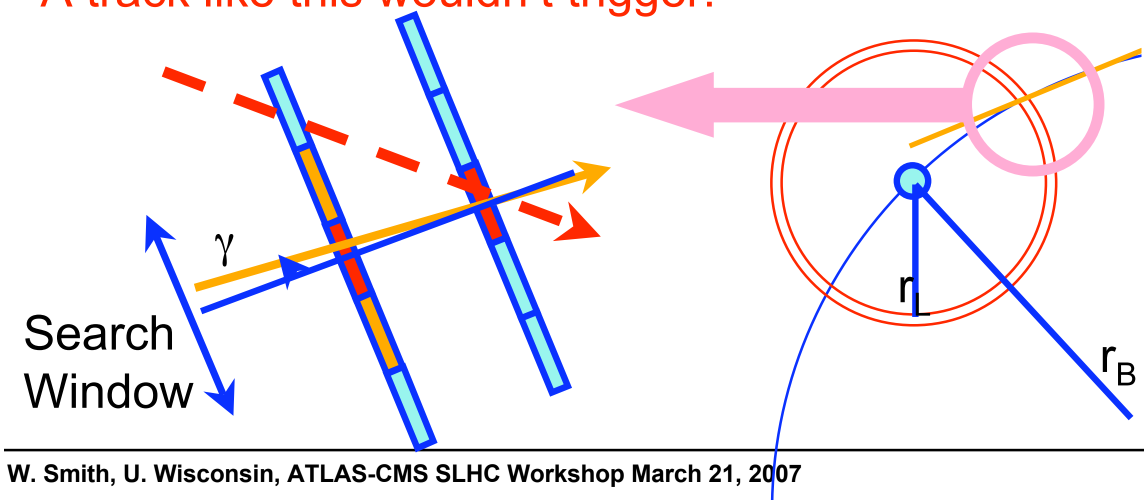
CMS ideas for trigger-capable tracker modules -- very preliminary

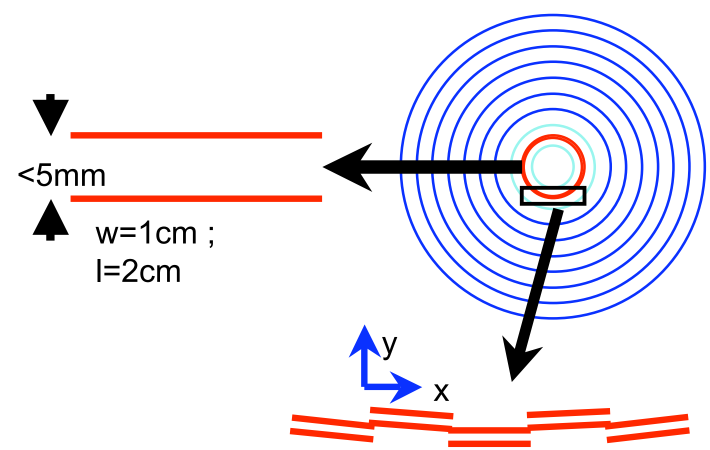
- Use close spaced stacked pixel layers
- Geometrical p_T cut on data (e.g. ~ GeV):
- Angle (γ) of track bisecting sensor layers defines p_T ($\Rightarrow$ window)
- For a stacked system (sepn. ~1mm), this is ~1 pixel
- Use simple coincidence in stacked sensor pair to find tracklets
- More details & implementation next slides



-- C. Foudas & J. Jones

A track like this wouldn't trigger:





Tangent-Point Reconstruction

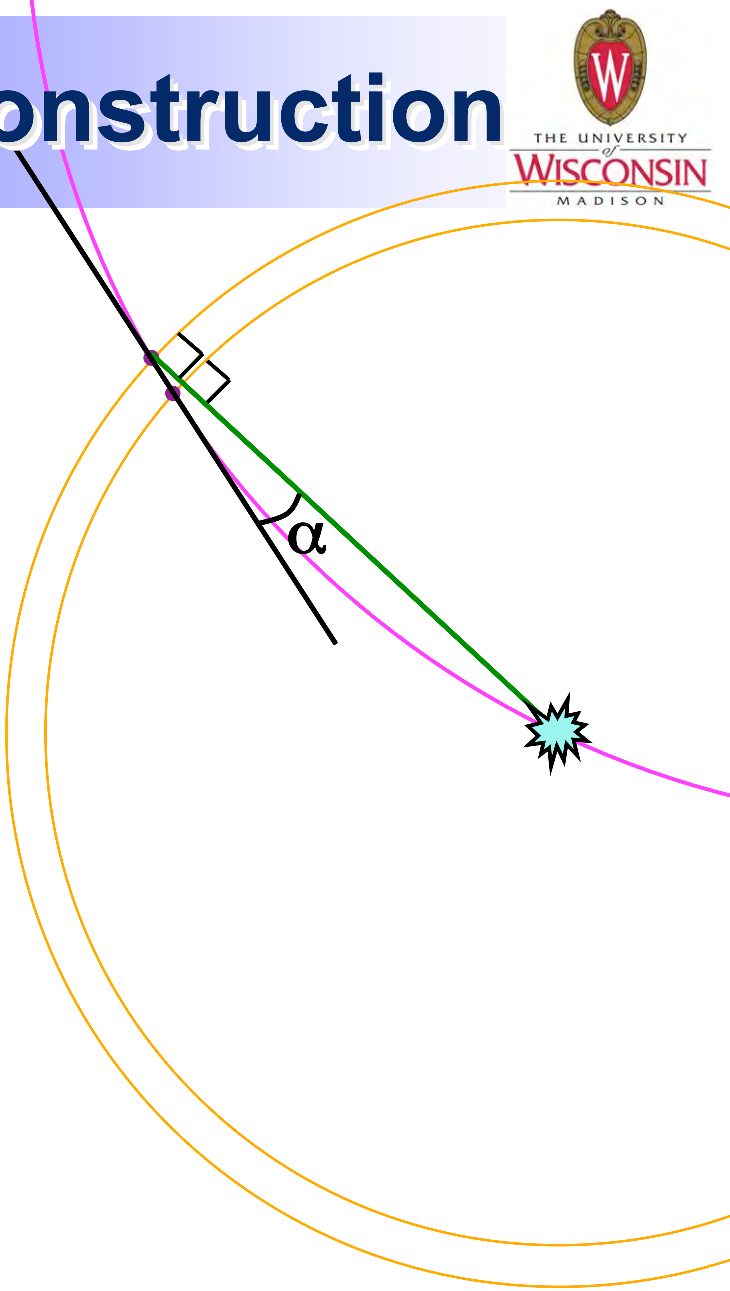
- Assume IP r=0
- Angle α determines p_T of track

Smaller α = greater p_T

- Can find high-p_T tracks by looking for small angular separation of hits in the two layers
- Correlation is fairly ‘pure’ provided separation is small and pixel pitch is small

Matching hits tend to be from the same track

- If sensors are precisely aligned, column number for hit pixels in each layer can be compared
- Finding high-p_T tracks becomes a relatively simple difference analysis



p_T Cuts in a Stacked Tracker – p_T Cut Probabilities

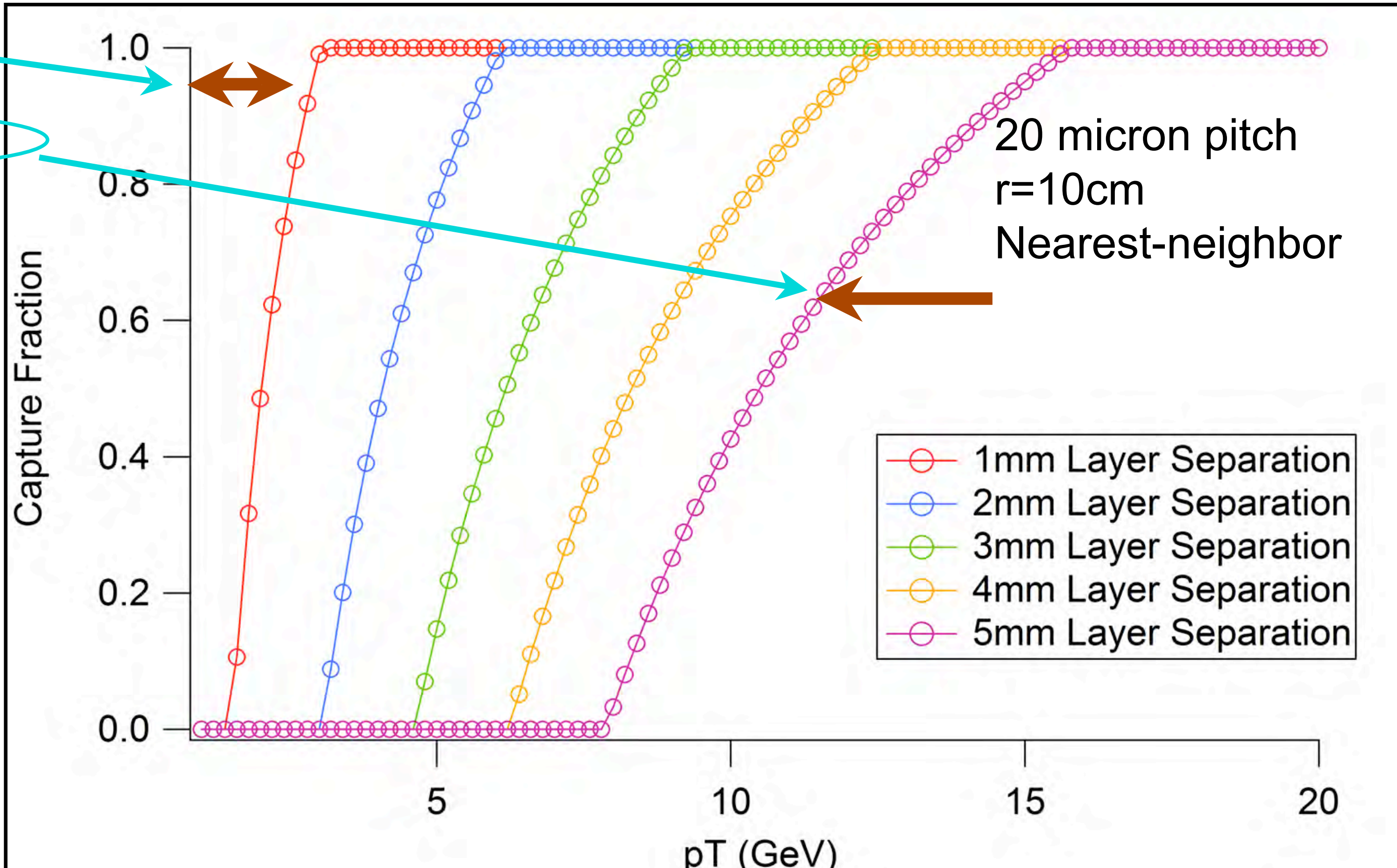
- J. Jones

- **Depends on:**

Layer Sepn. & Radius

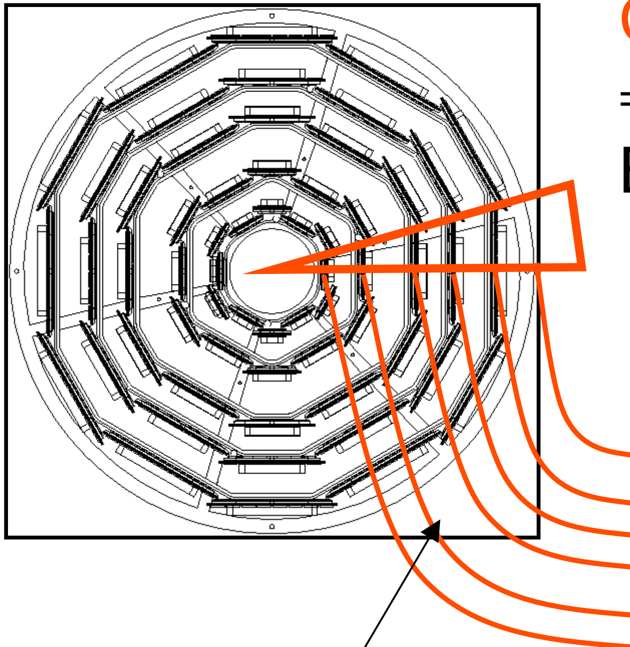
Pixel Size

Search Window



There is an additional 'blurring' caused by charge sharing…

Alternative Tracking Trigger: Associative Memories (from CDF SVX)



Challenge: input Bandwidth
⇒divide the detector in thin ϕ sectors.
Each AM searches in a small $\Delta\phi$

OFF DETECTOR

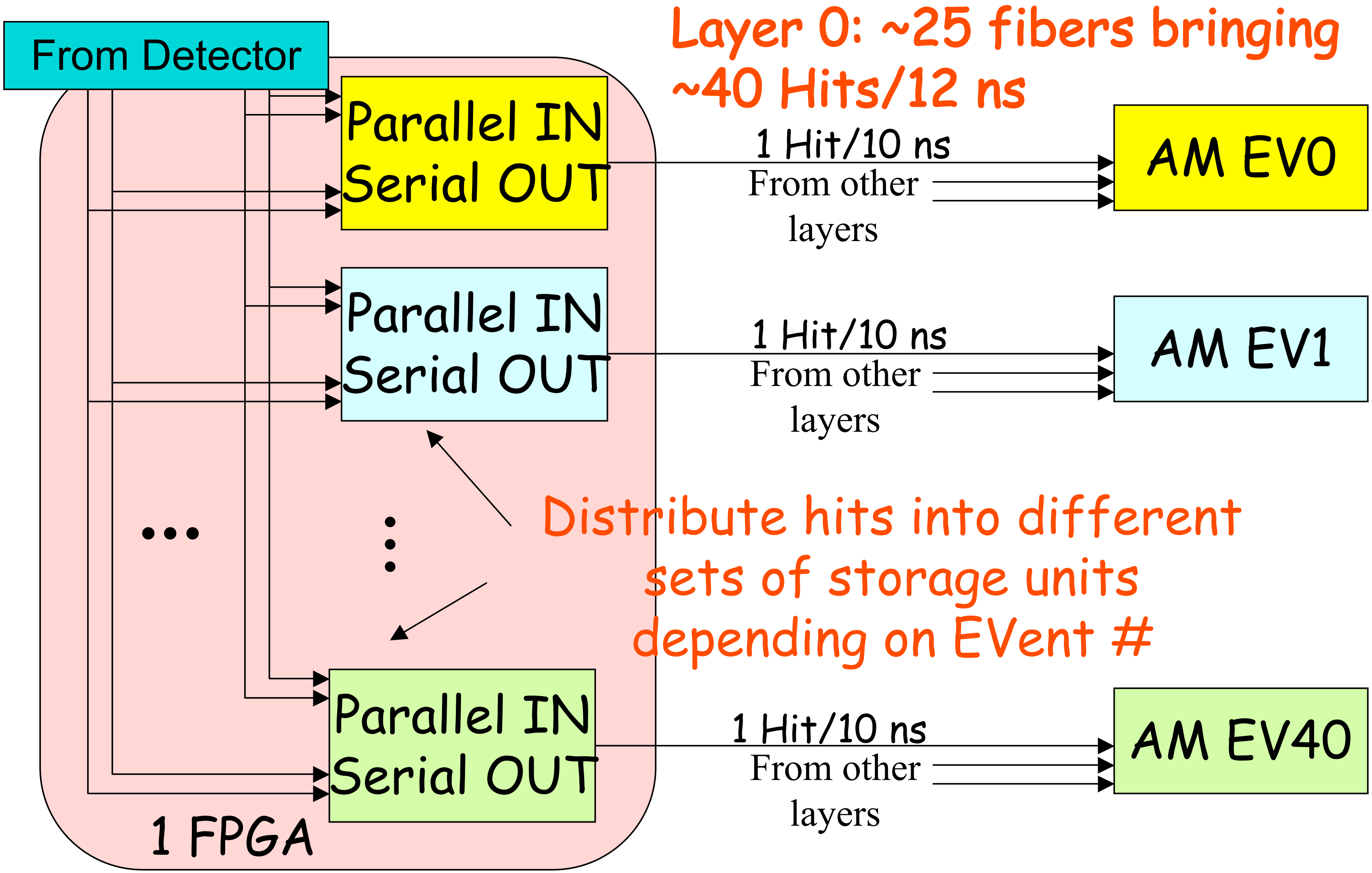
1 AM for each enough-small $\Delta\phi$
Patterns
Hits: position+time stamp
All patterns inside a single chip
N chips for N overlapping events identified by the time stamp

Data links

-- F. Palla, A. Annovi, *et al.*

Event1 AMchip1	Event2 AMchip2	Event3 AMchip3	• • • • •	EventN AMchipN

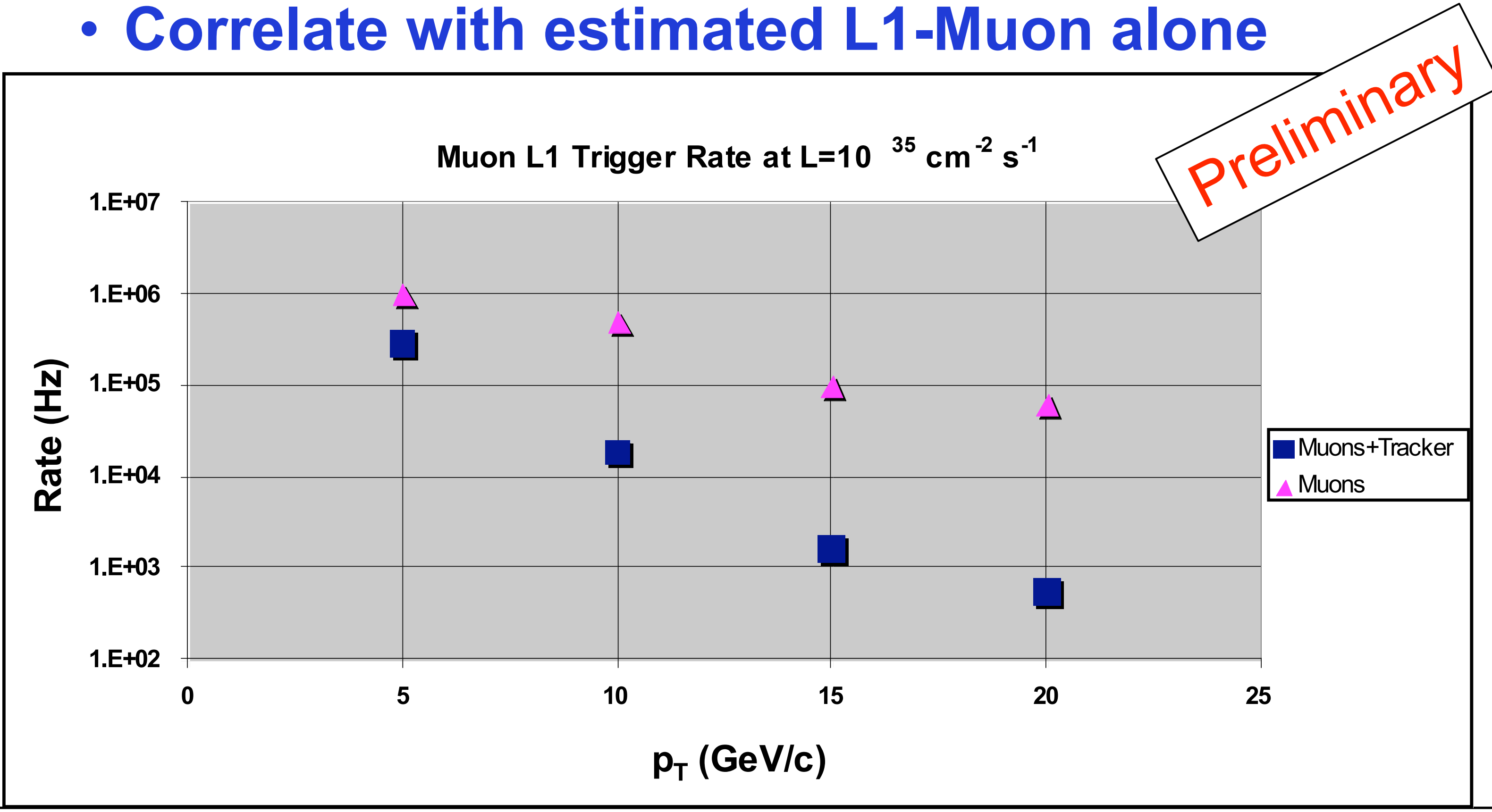
Associative Memories: Conceptual design



Muon Trigger Rate

Estimate of L1 Trigger rate vs. p_T

- Assume very simple Tracker Trigger finding algorithm
  - No isolation required
- Correlate with estimated L1-Muon alone



Use of CMS L1 Tracking Trigger

- D. Acosta

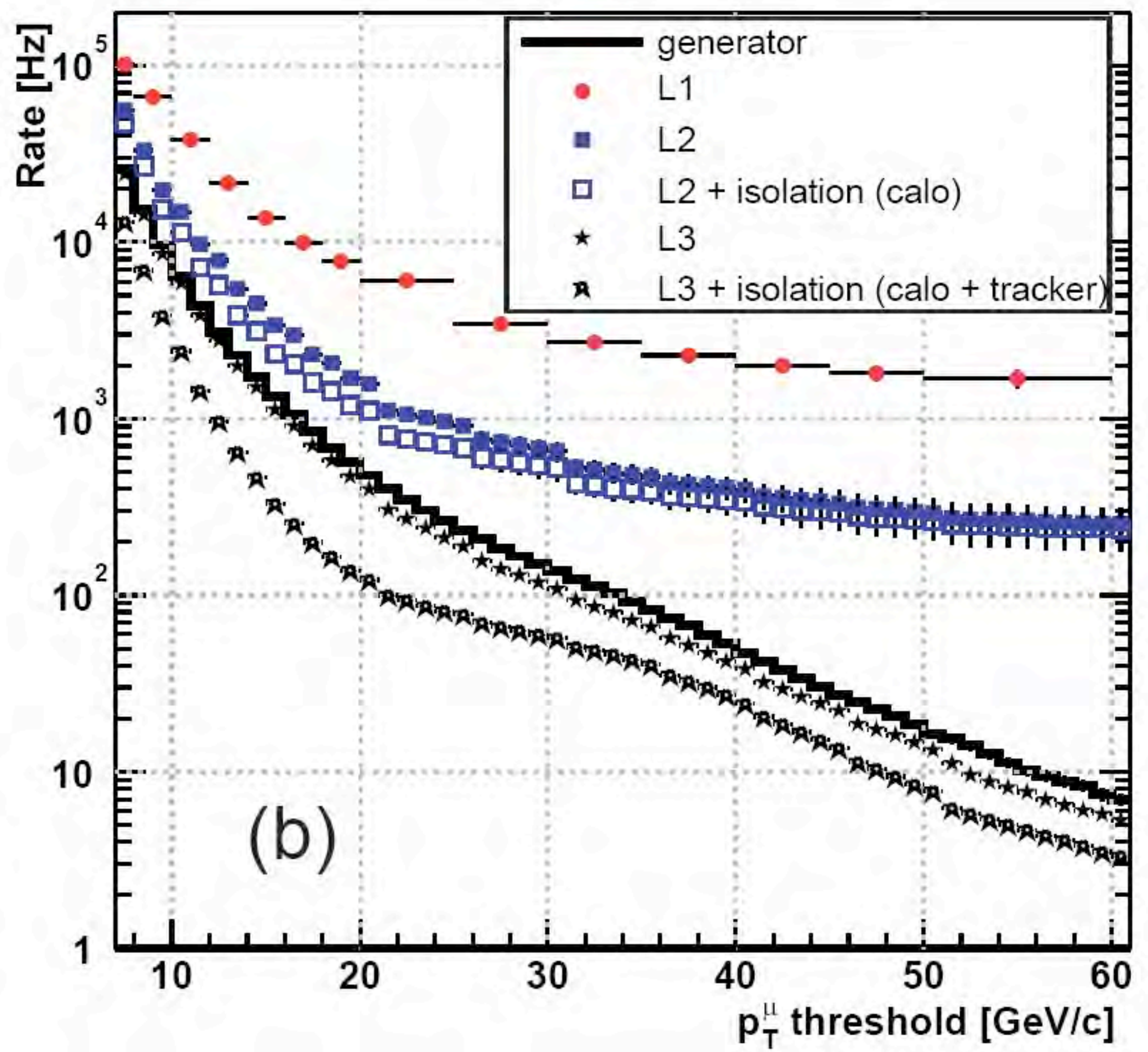
Combine with L1 μ trigger as is now done at HLT:

- **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°**

CMS Muon Rate at $L = 10^{34}$



From CMS DAQ TDR

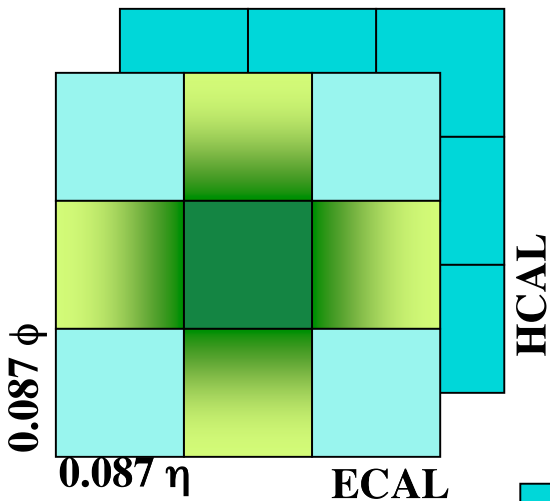
Note limited rejection power (slope) without tracker information

CMS SLHC e/γ/τ object clustering

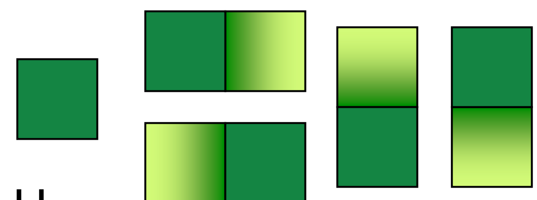
e/γ/τ objects cluster within a tower or two

- Crystal size is approximately Moliere radius
  - Trigger towers in ECAL Barrel contain 5x5 crystals
- 2 and 3 prong τ objects don't leak much beyond a TT
  - But, they deposit in HCAL also

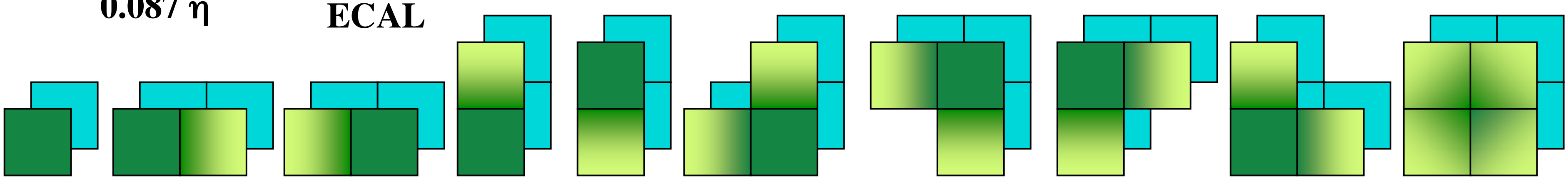
E_T scale: 8-bits



e/γ E_T = 1 x 2 or 2 x 1 sum
e/γ H/E cut for all 9 towers
e/γ isolation patterns:



τ E_T = 3 x 3 sum of E + H
τ isolation patterns include E & H:



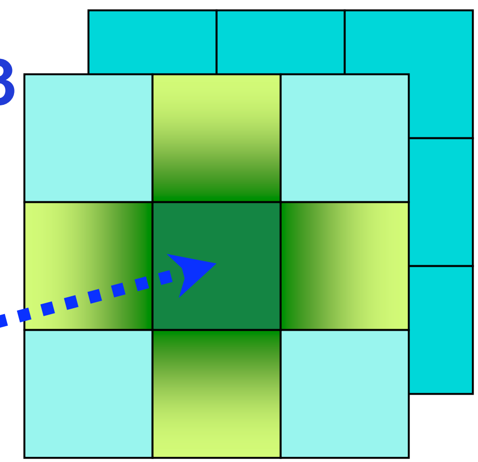
CMS SLHC e / γ / τ object ⇔track correlation

Use e / γ / τ objects to seed tracker readout

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

Tracker correlation

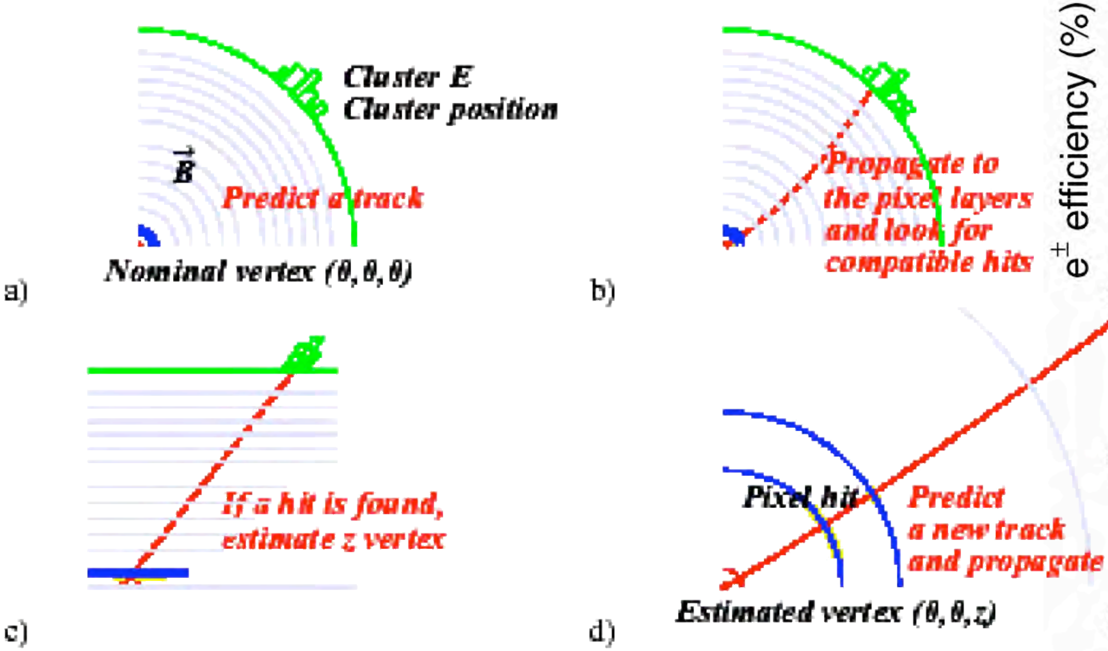
- **Single track match in 3x3 with crude P_T (8-bit ~ 1 GeV)**
  - Electron (same for muons)
- **Veto of high momentum tracks in 3x3**
  - Photon
- **Single or triple track match**
  - Tau

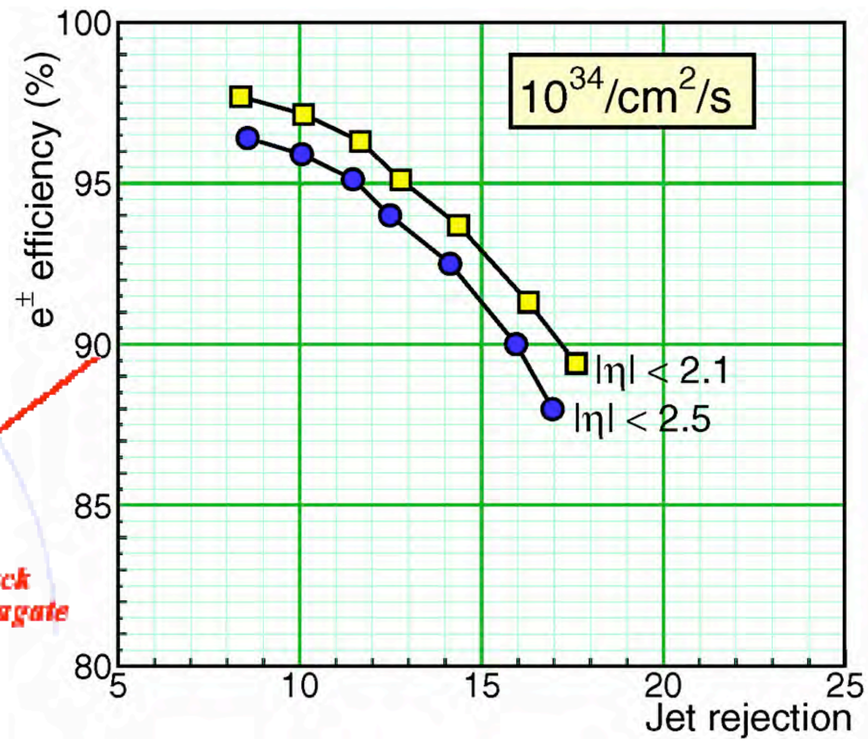


CMS tracking for electron trigger

Present CMS electron HLT

- C. Foudas & C. Seez

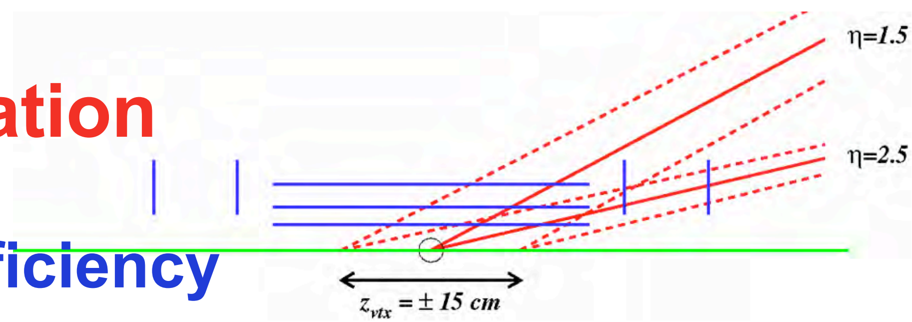




Factor of 10 rate reduction

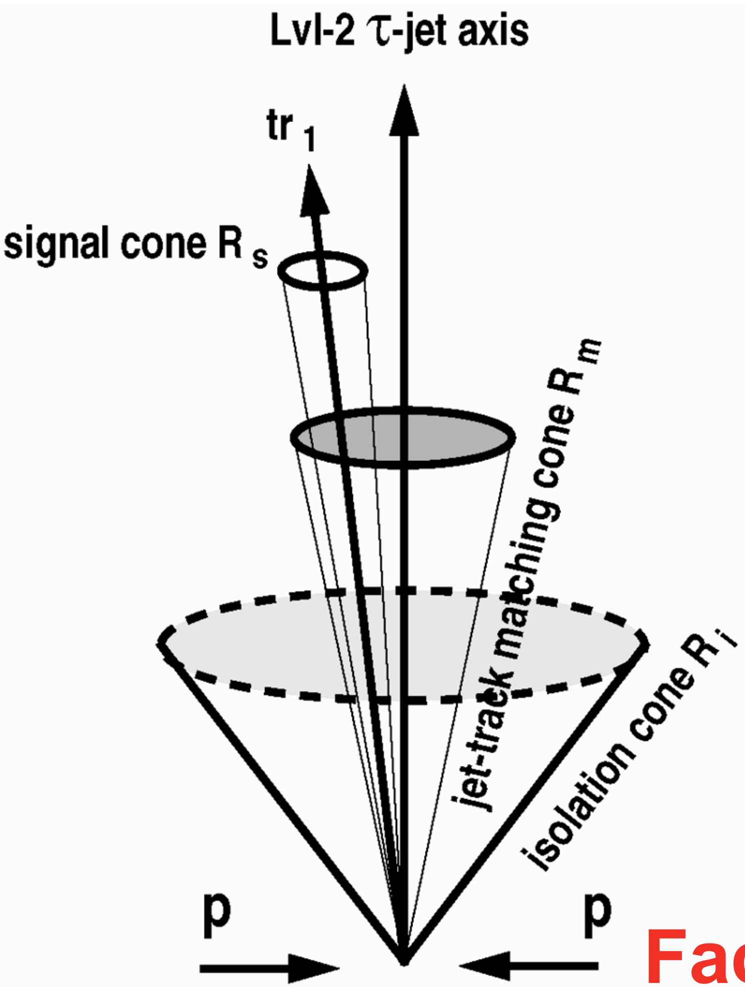
γ: only tracker handle: isolation

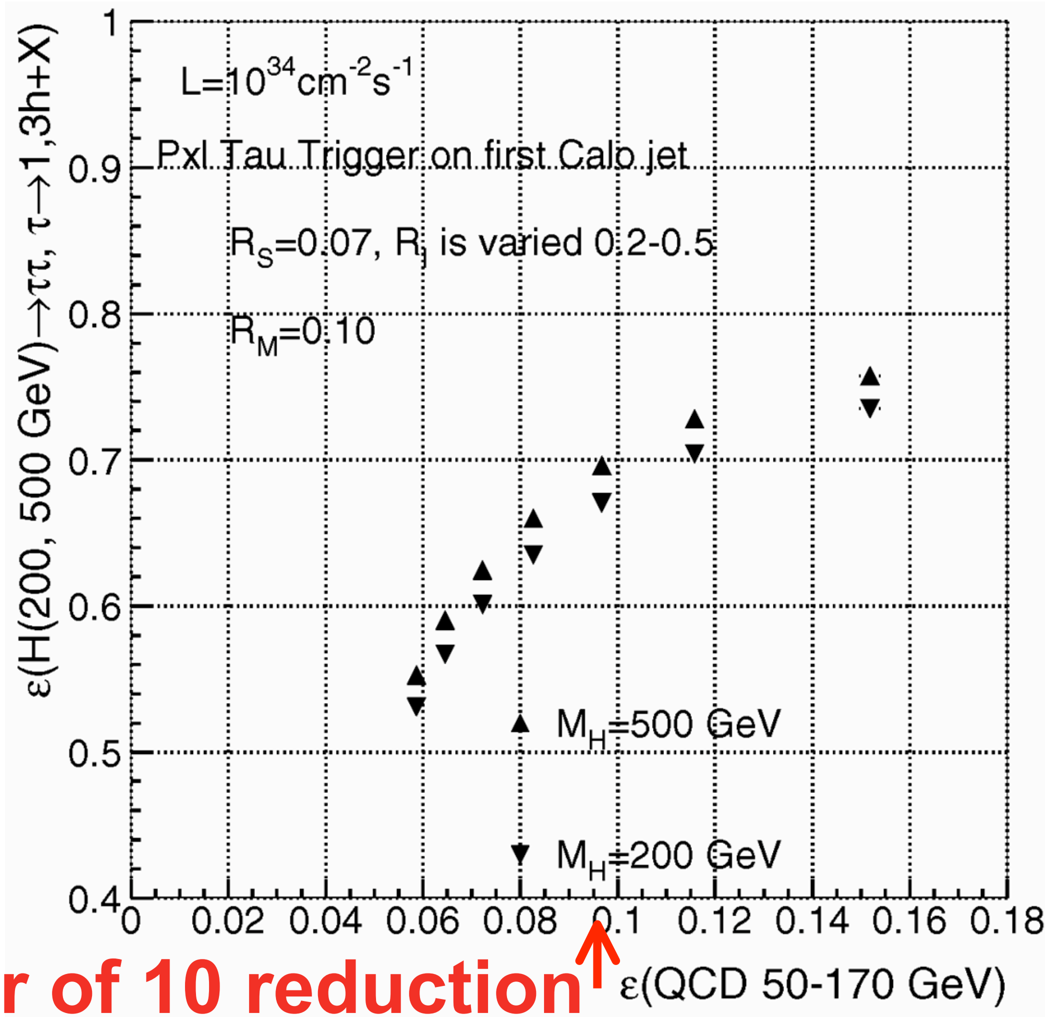
- **Need knowledge of vertex location to avoid loss of efficiency**



CMS tracking for τ-jet isolation

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





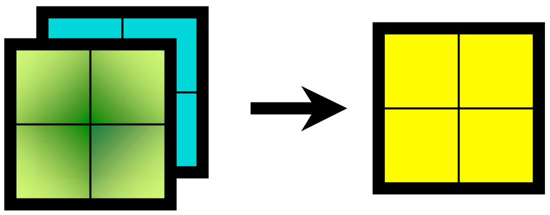
Factor of 10 reduction

CMS SLHC Jet Clustering

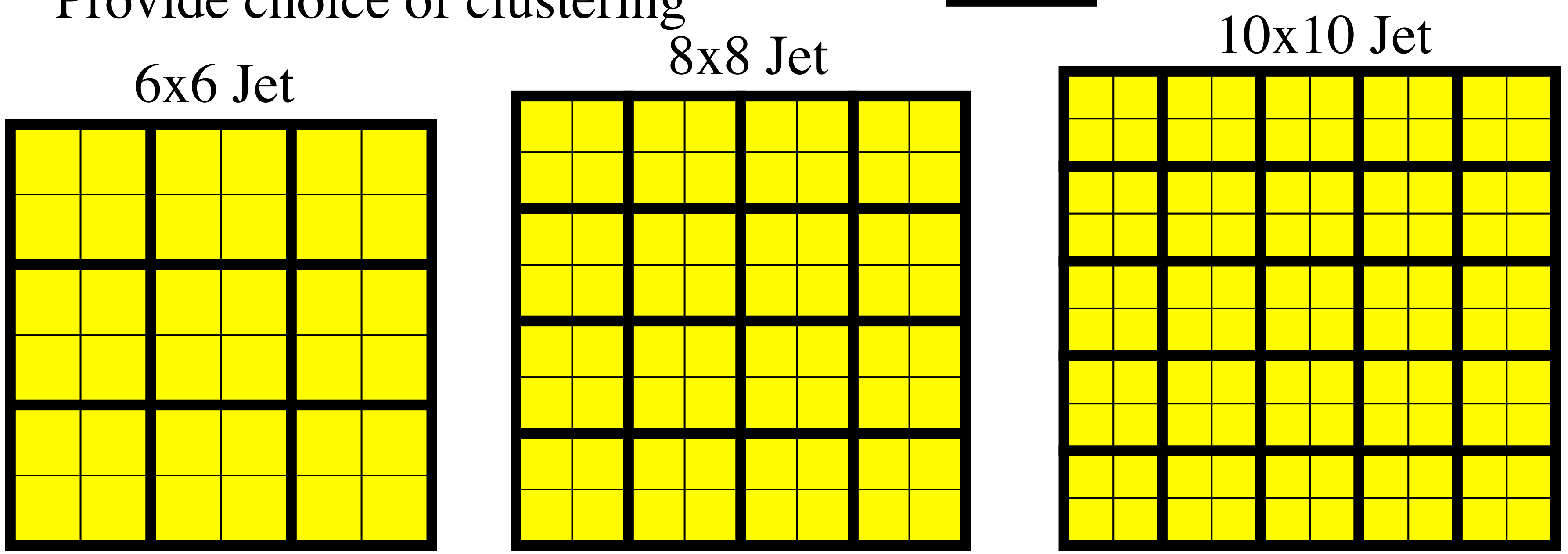
Cluster jets using 2x2 primitives: 6x6, 8x8, 10x10

- Start from seeds of 2x2 E+H (position known to 1x1)
- Slide window at using 2x2 jet primitives
- E_T scale 10-bits, ~1 GeV

Jet Primitive is sum of E_T in E/HCAL



Provide choice of clustering



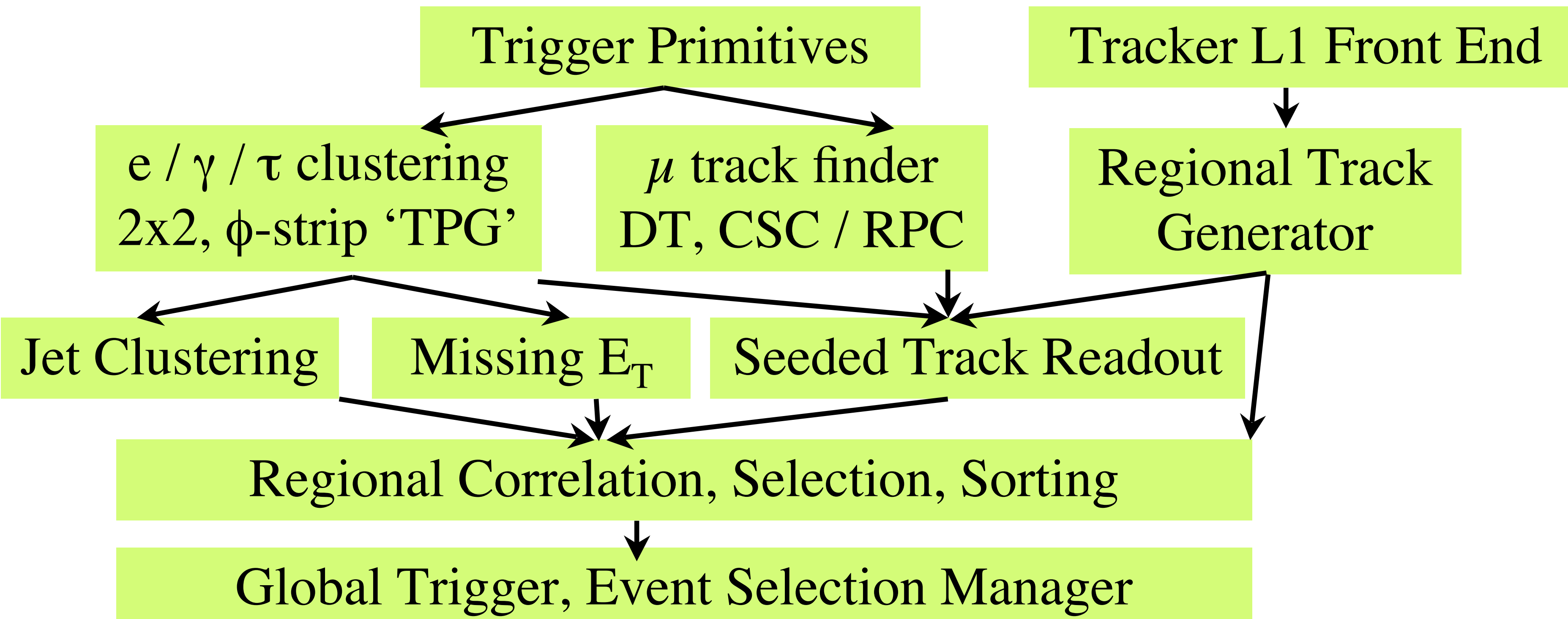
CMS L1 Algorithm Stages

Current for LHC:

TPG ⇒ RCT ⇒ GCT ⇒ GT

Proposed for SLHC (with tracking added):

TPG ⇒ Clustering ⇒ Correlator ⇒ Selector



CMS SLHC Trigger Architecture

LHC:

- Level 1: Regional to Global Component to Global

SLHC Proposal:

- Combine Level-1 Trigger data between tracking, calorimeter & muon at Regional Level at finer granularity
- 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

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 L-1 Trigger Summary

Attempt to restrict upgrade to post-TPG electronics as much as possible where detectors are retained

- **Only change where required -- evolutionary -- some possible pre-SLHC?**
  - Inner pixel layer replacement is just one opportunity.

New Features:

- **Level-1 Tracking Trigger**
  - Inner pixel track & outer tracker stub
  - Reports "crude" P_T & multiplicity in ~ 0.1x 0.1 $\Delta\eta \times \Delta\phi$
- **Regional Muon & Cal Triggers report in ~ 0.1 x 0.1 $\Delta\eta \times \Delta\phi$**
- **Regional Level-1 Tracking correlator**
  - Separate systems for Muon & Cal Triggers
  - Separate crates covering $\Delta\eta \times \Delta\phi$ regions
  - Sits between regional triggers & global trigger
- **Latency of 6.4 μsec**