A level-1 pixel based track trigger for the CMS HL-LHC upgrade

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Outline

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- L1 Pixel Trigger strategies
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Disclaimer: Current baseline options for a L1 Track Trigger are all based on Outer Tracker modules and not the HL-LHC pixel system. This is work in progress on the study of the potential of a L1 Pixel Trigger included in the context of the L1 Trigger for Phase 2 upgrade in CMS at HL-LHC.

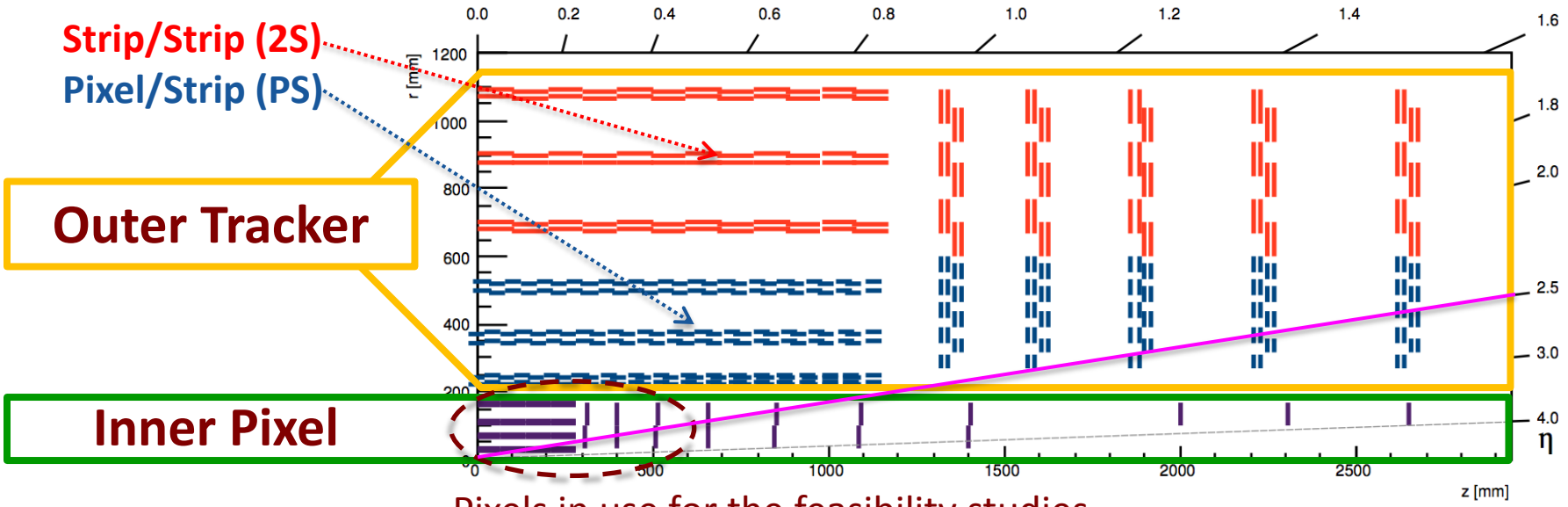
Introduction

- The current Level-1 Trigger at CMS
  - Maximum bandwidth of 100 kHz and latency of 4.5 μsec
  - Electron/Gamma, Tau, Jet based on calorimeters
  - Muon reconstructed by muon chambers
  - No tracking information at Level-1
- The High Luminosity LHC (HL-LHC) conditions are characterized by:
  - Instantaneous luminosity of 5×10^{34} $cm^{-2}s^{-1}$ and 140 average Pile-up (PU) events
  - Large increase in the rates of the physics processes
- The main goal for the L1 trigger of CMS Phase 2 Upgrade:
  - Maintain or even improve the overall physics potential despite the challenging HL-LHC conditions by:
    - Avoiding the increase of the trigger thresholds
    - Refining the selection of physics objects at L1
  - Maximum bandwidth of 750 kHz and latency of 12.4 μsec
- The L1 Track Trigger for Phase 2 Upgrade at HL-LHC: a new L1 key element
  - Self-seeded L1 Track Trigger based on L1 Outer Tracker:
    - Reconstruct "L1 tracks" with $p_T > 2$ GeV.
    - Identify z position along beam pipe within 1mm.
  - Feasibility and performances studies for the L1 Pixel Trigger:
    - How the pixels can further improve some features of the L1 Track Trigger of CMS.

Motivation

- Improvement of some features of the L1 Track Trigger:
  - Higher precision of the vertex resolution at L1
  - L1 electron trigger by matching L1 EM calorimeter tower with pixel hits:
    - Helps Improving fake electrons rejection
    - Keeps high efficiency in the high η region
  - L1 b-tagging by combining L1 track with pixel hits:
    - Increases the chances of triggering on very rare physics processes with b-jets in final state at HL-LHC as for example:
      - Higgs pair production
      - Higgs production in association with a top quark pair
- High selection capability for events from low-mass processes
  - Retain good efficiency for Higgs decay products
    - Precision measurement of the Higgs coupling and its properties
  - New physics searches
    - SUSY and Dark Matter
    - Rare decays in B Physics: Bs → ϕϕ → 4 K's
    - Lepton Flavor Violation: τ → 3 μ's
    - Long Lived Charged particles

Simulation framework

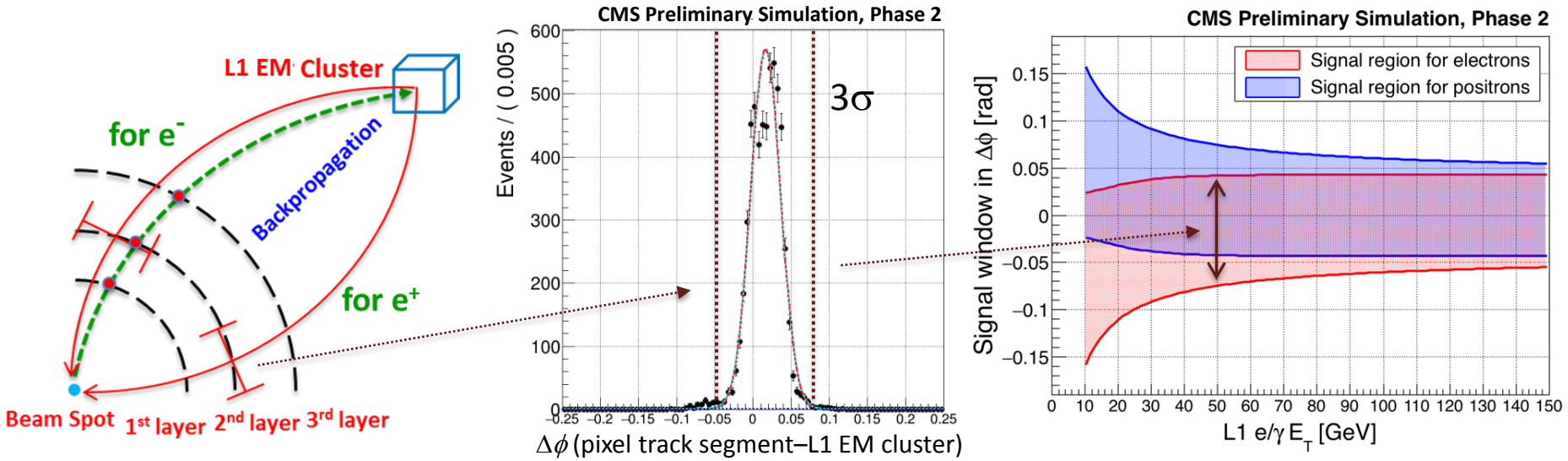


Pixels in use for the feasibility studies

- Feasibility studies: based on the current Phase 2 CMS simulation framework with:
  - The L1 Outer Tracker as based on the flat barrel and endcap geometry design (not final design)
  - The Phase 1 Pixel Detector: 4 barrel layers & 3 disks pixels (i.e. not including the very forward disks)
  - The Phase 1 calorimeters:
    - Tower level EM cluster (not single crystal)
    - L1 jet reconstruction based on coarse calorimeter granularity
  - It provides a first good handle of the detector and trigger performance potentials for Phase 2 although underestimating them.
- New detailed simulation with final Phase 2 features is in preparation in CMS.
  - See Georg Auzinger's talk for Upgrade of the CMS Tracker for the HL-LHC

L1 Pixel Trigger strategy for electron

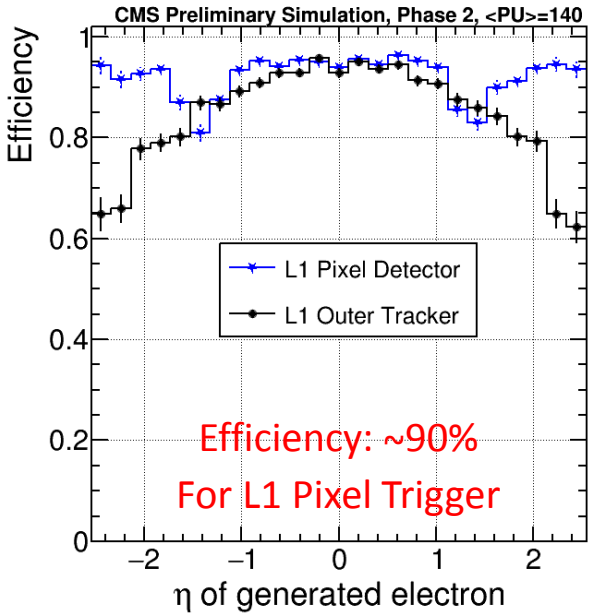
- Electron identification with the L1 Pixel Trigger:
  - Trigger strategy: seed by the L1 EM calorimeter
  - Matching the pixel tracks with the L1 EM cluster in the region of Interest
  - Pixel track matching algorithm developed for both electron and positron in $\Delta\phi$ and $\Delta\eta$ signal windows
    - Defined 3σ signal windows as a function of L1 e/γ transverse energy (E_T) using single electron gun sample.

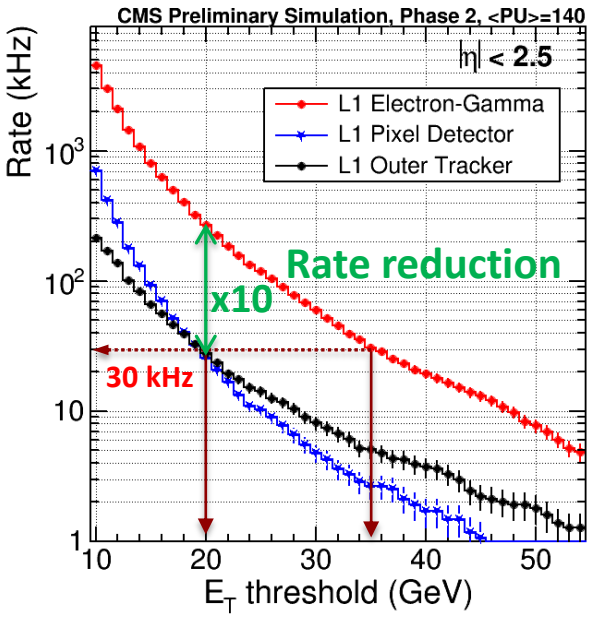


JINST 10, C10001 (2015)

Performances of simulated L1 Pixel Trigger: electrons

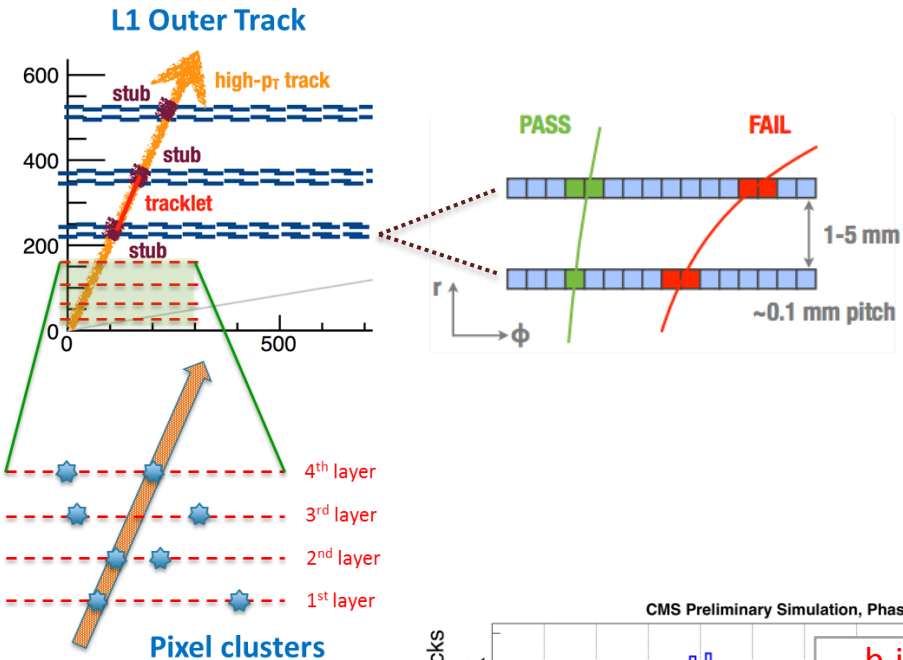
- L1 single e/γ trigger E_T threshold: lowered from 35 GeV to 20 GeV at 30 kHz
  - Overall trigger rate reduced by a factor of ~10 (using either Inner Pixel or Outer Tracker) at 20 GeV E_T threshold.
- Average trigger efficiency: ~90% with the L1 pixels.
  - Similar efficiency with the L1 Pixel Detector as the L1 Outer Tracker in barrel region (|η|<1)
  - Keeping high efficiency by the L1 Pixel Trigger in high η region up to |η|<2.5

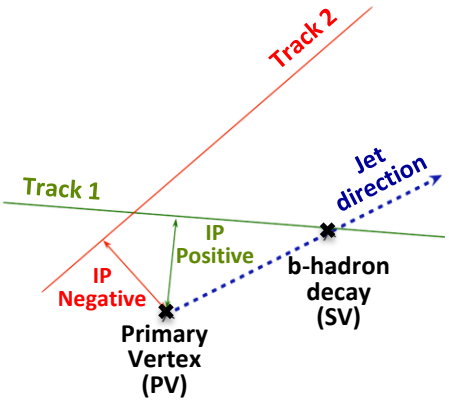


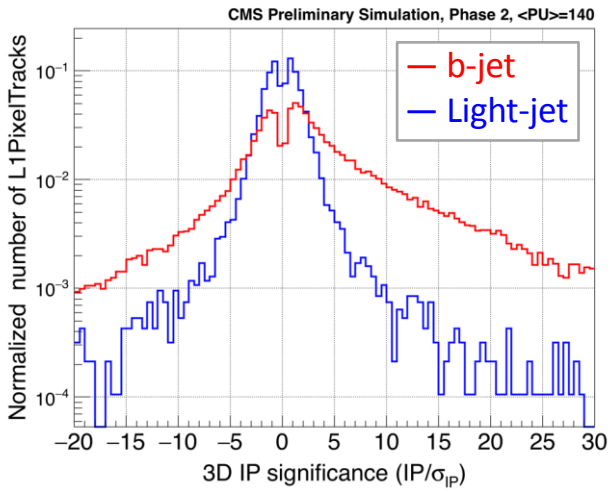


- A factor of 2 better performance estimated with single crystal level EM calorimeter

L1 Pixel Trigger strategy for b-tagging



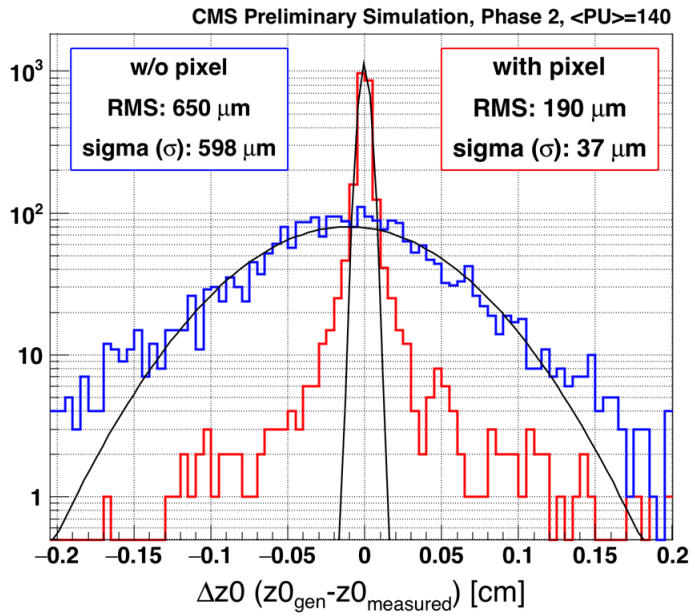




- L1 track from L1 Outer Tracker
  - Tracks filtered for p_T>2 GeV in front-end.
  - 97% tracks are rejected in minimum bias events.
- L1PixelTrack
  - L1 track used as a seed and combined with pixel information.
- Main L1 b-tagging algorithm
  - Employed the track counting method at L1.
  - Based on 3D track impact parameter (3D IP) significance at L1.
  - Required at least 1 or 2 L1PixelTrack(s) inside the L1 jet have a minimum value of the 3D IP significance.
  - Imported HLT b-tagging technique to L1 in a simplified way.

L1 Pixel Trigger studies on jet vertex and b-tagging

- Studies on jet vertex determination and b-jet identification use a MC sample of $t\bar{t}$ events with <PU>=140 for |η|<2.5.
- Main results:
  - Improved jet vertex resolution: 40 μm vs. 600 μm without pixels
  - L1 b-tagging based on the track counting method:
    - (light jet efficiency, b-jet efficiency) ≈ (10%, ~65%)



Concluding remarks

- The feasibility and performance studies of a L1 Pixel Trigger for HL-LHC in CMS are underway.
  - Main goal: explore how it can further improve the L1 Track Trigger.
    - Presented results here: on electrons, jet vertexing and b-tagging.
    - Other studies are addressing: tau's, muons, very forward physics capability.
  - The new CMS simulation in preparation will further refine these studies.
- The potential benefits of a L1 Pixel Trigger shown here are on:
  - Improvement of the jet vertex reconstruction:
    - Resolution along the beam axis ≈ O(40μm) with pixels instead of O(1mm) without pixels
  - Upgrade L1 trigger performance on:
    - Electrons: sizeable L1 trigger rate reduction while keeping high trigger efficiency and low E_T thresholds
    - b-tagging: maximizing a capability to trigger the rare physics process with b-jets at L1.

  ⇒ This impacts a large scope of Physics processes at HL-LHC.
- The integration of such a L1 Pixel Trigger means:
  - Overcoming high technical challenges: L1 bandwidth and L1 latency at HL-LHC
  - Implying developments on: the Frond-End ASIC (RD53), the design of the readout chain and integration in the L1 Trigger architecture for HL-LHC, the real time algorithms and test benchmarking platforms

References

- CMS Detector Performance Summaries
  - A level-1 pixel based track trigger for the CMS HL-LHC upgrade
    - http://cds.cern.ch/record/2203806
- Paper publication (JINST 10, C10001 (2015))
  - Level-1 pixel based tracking trigger algorithm for LHC upgrade
    - http://iopscience.iop.org/article/10.1088/1748-0221/10/10/C10001
- Technical Proposal
  - The Phase-II Upgrade of the CMS Detector
    - http://cds.cern.ch/record/2020886