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CMS DP -2016/055

The Compact Muon Solenoid Experiment

CMS Performance Note

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31 July 2016

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

CMS Collaboration

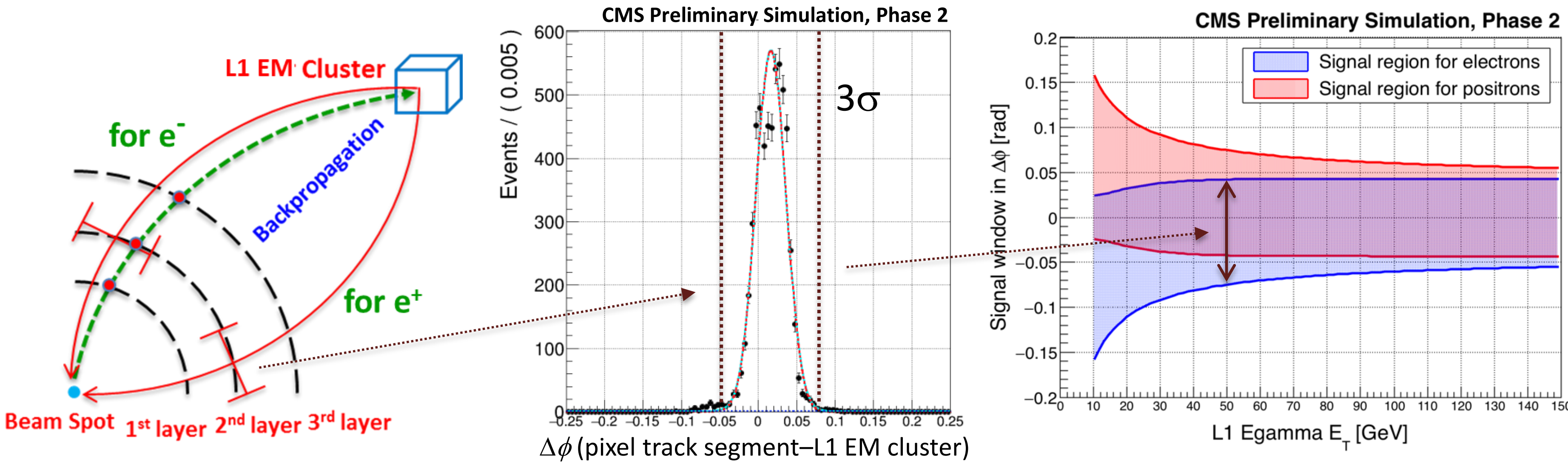
Abstract

We present feasibility studies to investigate the performances and interest of a Level-1 trigger based on pixels. The Level-1 (real-time) pixel based tracking trigger is a novel trigger system that is based on the real-time track reconstruction algorithms able to cope with very high rates and high flux of data in a very harsh environment. The pixel detector has an especially crucial role in precisely identifying the primary vertex of the rare physics events from the large pile-up (PU) of events. The goal of adding the pixel information already at the real-time level of the selection is to help reducing the total level-1 trigger rate while keeping an high selection capability. This is quite an innovative and challenging objective for the experiments upgrade for the High Luminosity LHC (HL-LHC).

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

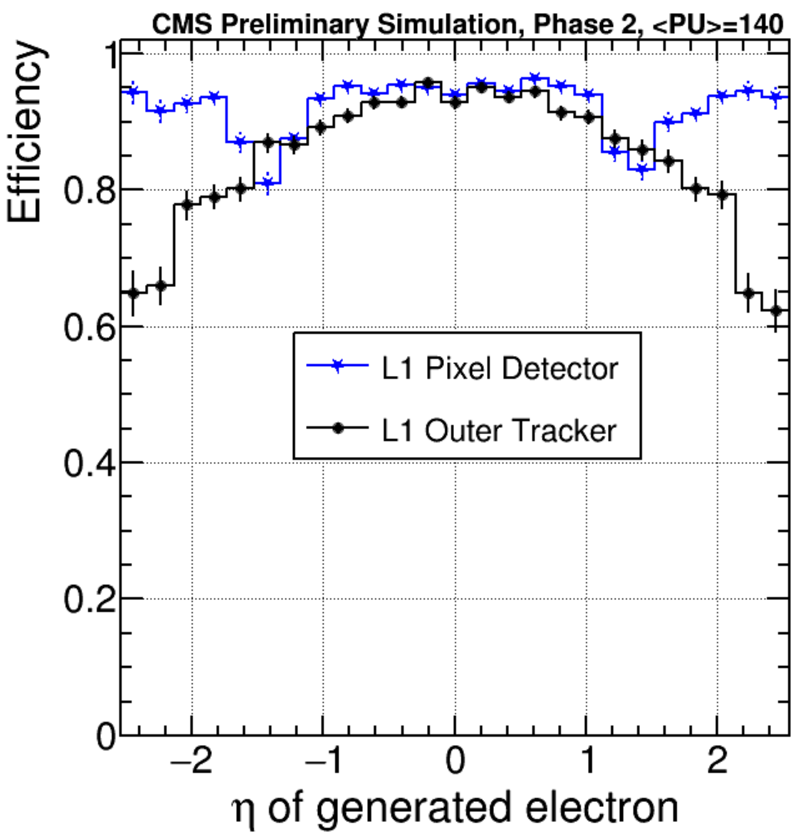
The CMS Collaboration

Electron identification with L1 Pixel Trigger



As an example of the procedure of the pixel track algorithm matching with L1 EM cluster (PiXTRK): $\Delta\phi$ signal window of the PixTRK is designed for electrons (red curve) and positrons (blue curve) respectively. The signal window is obtained by matching between pixel track segment and L1 EM cluster and 3σ boundary of the Gaussian fit is determined as a function of L1 e/γ transverse energy (E_T). The result was based on a single electron gun sample without pileup (JINST 10, C10001 (2015)).

Level-1 Pixel Electron Trigger: Efficiency



Efficiency of L1 Pixel Electron Trigger as a function of the pseudorapidity (η) of the generated electron. The efficiency is measured using a single electron sample with $<E_T>$=35 GeV and <PU>=140.

For each event, the closest ($\Delta R<0.1$) L1 e/γ object to the generated electron is selected.

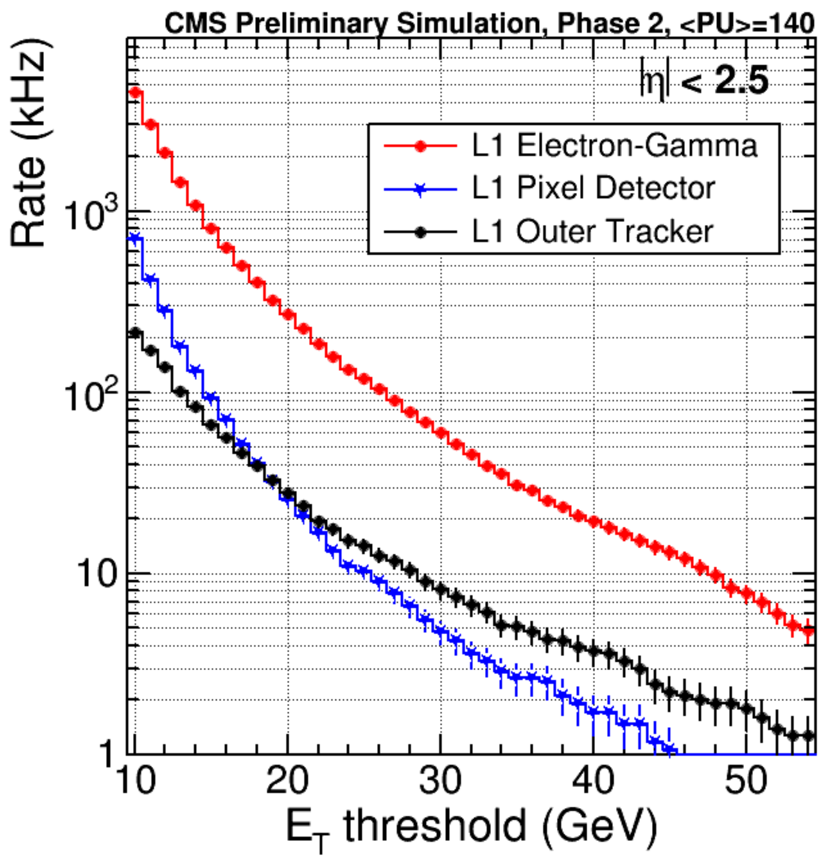
The efficiency is calculated for the L1 e/γ objects: denominator is the number of selected L1 e/γ objects with L1 $E_T>20$ GeV and $|\eta|<2.5$, and numerator is the number of L1 e/γ objects passing the PixTRK algorithm.

The result is compared with the efficiency obtained by an algorithm matching L1 e/γ objects to L1 tracks from the Outer Tracker (*), and applying an isolation requirement with respect to neighboring L1 tracks.

**Technical Proposal for the Phase-II Upgrade of the CMS Detector*

https://cds.cern.ch/record/2020886

Level-1 Pixel Electron Trigger: Rate

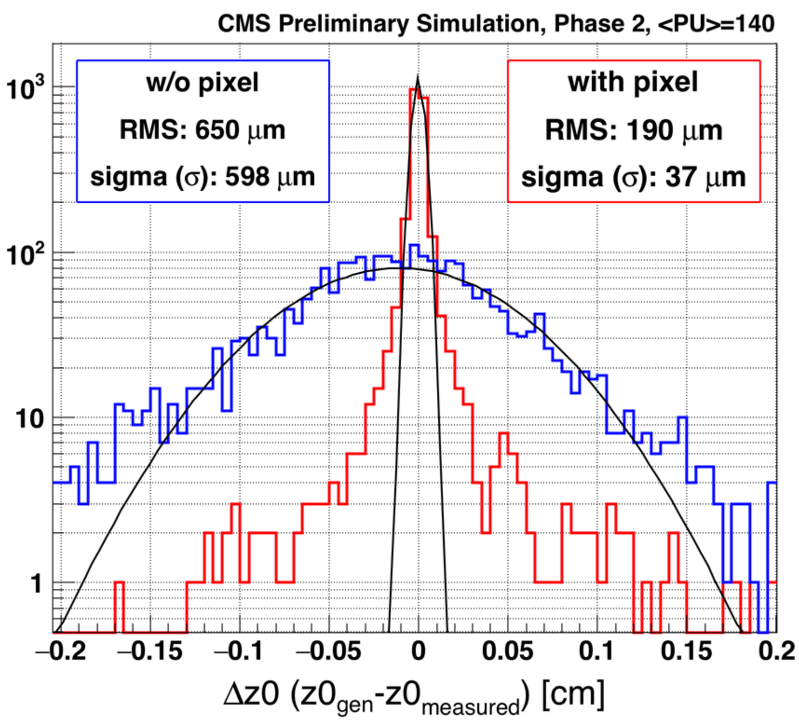


The L1 single e/γ trigger rate as a function of E_T threshold is shown for $|\eta|<2.5$. The rate is computed with a minimum bias sample with <PU>=140.

The red curve shows the L1 single e/γ trigger rate. The blue and black curves show the rates as obtained with the PixTRK algorithm and an algorithm matching to L1 tracks from the Outer Tracker.

At 20 GeV E_T threshold, either L1 Pixel Detector or L1 Outer Tracker can reduce the L1 single e/γ trigger rate by a factor of about 10. For the latter, an isolation requirement with respect to neighboring L1 tracks is made.

Jet vertex resolution using L1PixelTracks in $t\bar{t}$ events



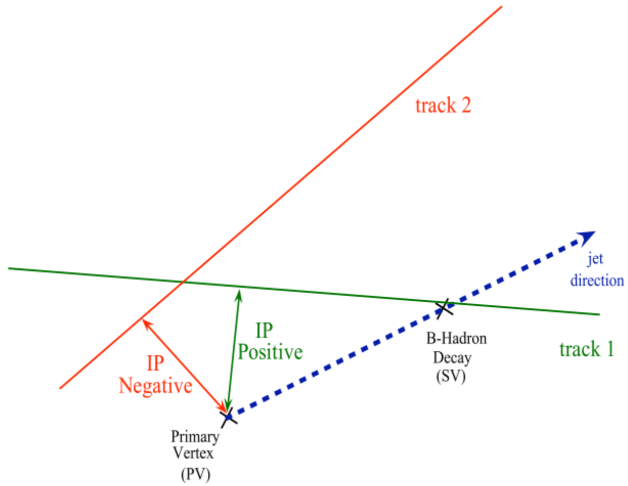
L1 calorimeter jets are matched to L1 tracks from the outer tracker to determine the z position of the jet vertex (*). For these studies, L1 track-matched jets within 2mm of the L1 primary vertex (*) are considered. L1 jets are also matched with gen-level information to select only light-flavour jets.

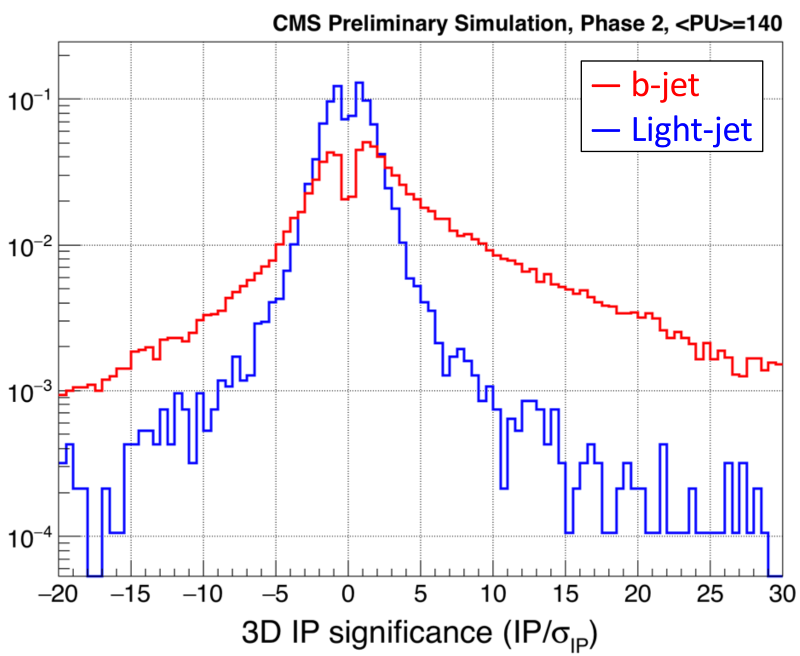
L1PixelTracks are formed by combining L1 tracks with matching pixel clusters and then repeating the linearized track fit. L1PixelTracks with $\Delta R<0.3$ and $\Delta z<2$mm from a L1 track-matched jet are selected. The L1PixelTracks are restricted to $p_T>2$ GeV due to the p_T filtering in the front-end of the L1 Outer Tracker. An updated jet vertex is calculated from the z0 position of the L1PixelTracks weighted by their p_T.

The jet vertex resolution along the beam axis as provided by the L1 Outer Tracker is shown in the blue curve. The red curve shows the jet vertex resolution as determined using L1PixelTracks. The jet vertex resolution is defined by $\Delta z0$ between z0 value of the hard interaction vertex at gen-level and measured z0 provided by the L1 tracks or L1PixelTracks. The jet vertex resolution of 600 μm as provided by the L1 Outer Tracker is improved to 40 μm (Gaussian core) when including the pixels.

**Technical Proposal*

3D Impact Parameter (3D IP) significance





The 3D IP is obtained with the 2D IP in transverse plane and z0 difference between L1 jet and L1PixelTrack as

$$3DIP = \sqrt{(2DIP)^2 + (\Delta z0)^2_{L1jet-L1PixelTrack}}$$

The 3D IP significance is calculated as 3D IP divided by its uncertainty (IP/σ_{IP}) for each L1PixelTrack. A sign of the 3D IP is determined by Δphi between the 2D IP and jet directions in transverse plane; if the $\Delta \mathrm{phi}<\pi/2$, the sign of 3D IP is assigned as a positive otherwise it is negative. The jet direction is computed from L1Pixeltracks associated to the L1 jet.

The 3D IP significance is the main parameter to distinguish the b-jets from the light-flavour jets. The track counting method for b-jet identification requires that at least 1 or 2 L1PixelTrack(s) inside the L1 jet have a minimum value of the 3D IP significance.

The b-jets and light-flavour jets are obtained in the $t\bar{t}$ events by matching the L1jets with gen-level b-hadron or a light quark. A comparison of the 3D IP significance distributions between b-jets and light-flavour jets is shown.

Performance of simulated L1 Pixel Trigger: b-tagging

b-jets identification (b-tagging) efficiency versus light-flavour jet (udsg) efficiency are computed using the track counting method based on requiring a minimum value of 3D IP significance.

$t\bar{t}$ sample with <PU>=140 is used for both b-jet and light-flavor jet cases.

The b-jets/light-flavour jets efficiencies are defined as a number of L1 jets with at least 1 (blue curve) or 2 (red curve) L1PixelTrack(s) which satisfy 3D IP significance above a minimum cut value, divided by the total number of L1 jets matched with gen-level b-hadron within $\Delta R<0.3$ for the b-jets / not matched with b or c-hadron using $\Delta R>0.3$ for light-flavour jets in $t\bar{t}$ events.

A light-flavour jet background efficiency of 10% is obtained for a b-jet signal efficiency of 60-65% for L1 jet $p_T>20$ GeV and $|\eta|<2.5$.