High Level trigger performance in Run-II

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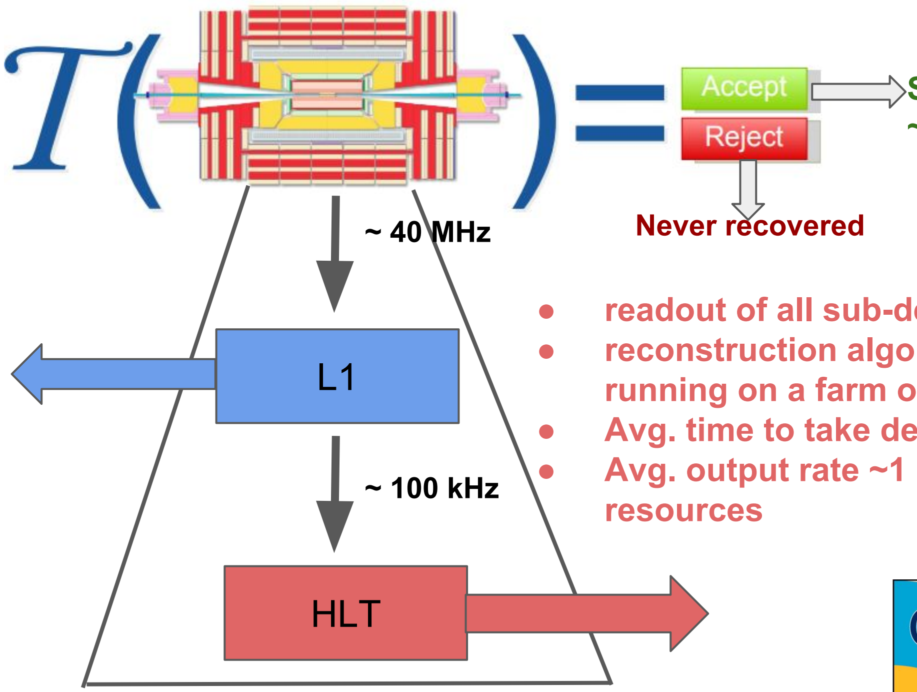
Outline

- Trigger system at CMS and motivation
- HLT Menu overview
- Challenges to design trigger
- HLT Performance
- Summary

Trigger system at CMS

The trigger of an experiment is the system that decides, in real-time, which subset of data is to be readout by the detector and archived for offline analysis.

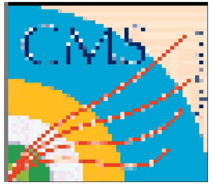
CMS uses two level trigger system



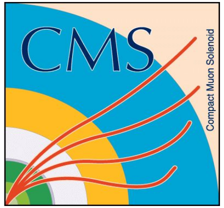
Store events with rate of ~1 kHz to storage system

- **coarse readout of Calorimeter and Muon systems**
- **hardware-based on custom programmable electronics (ASICs and FPGAs)**
- **Should take decision in ~4 μs, constraints from pipeline design**

- **readout of all sub-detectors with full granularity**
- **reconstruction algorithm based on CMSSW, running on a farm of commercial CPUs**
- **Avg. time to take decision ~200 ms**
- **Avg. output rate ~1 kHz, limited by offline resources**

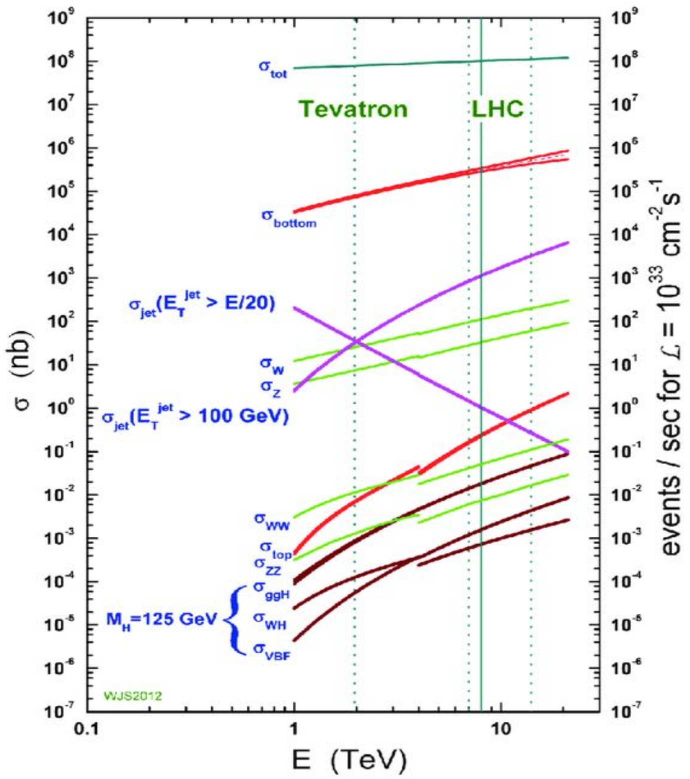


Coarser readout



Full detector readout

Motivation



Interesting physics lies beneath with lower cross section

- LHC achieved peak luminosity upto 2 times higher than designed.
- Interesting physics event rate of the order of few Hz and even less.
- Limited resources (computing and storage): can't reconstruct all the events.

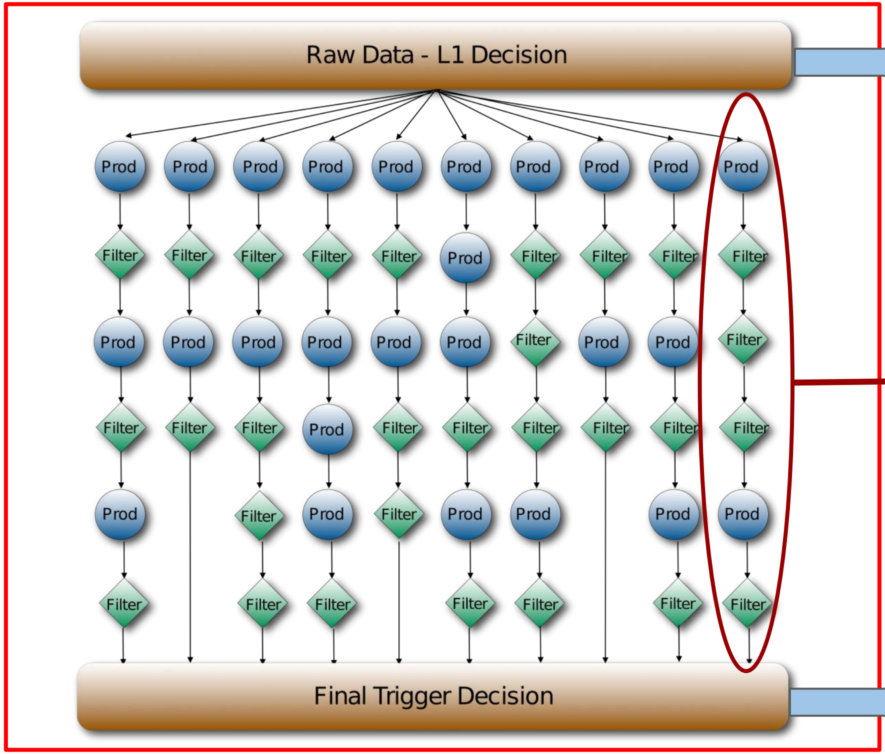
Process	Cross-section (nb) at 14 TeV CM energy	Production rates (Hz) at L = 10^{34} cm^{-2} s^{-1}
Inelastic	10^8	10^9
$b\bar{b}$	5×10^5	5×10^6
$W \rightarrow l\,\nu$	15	150
$Z \rightarrow l\,l$	2	20
$t\,\bar{t}$	1	10
Z' (1 TeV)	0.05	0.5

Keep all the events from interesting physics and reject others

HLT Menu overview

- HLT paths are Sequence of Producer and Filter algorithms.
    - Producer : reconstruction algorithms
    - Filter : reject/accept event

Full HLT Menu : a Collection of multiple Paths, streams etc.



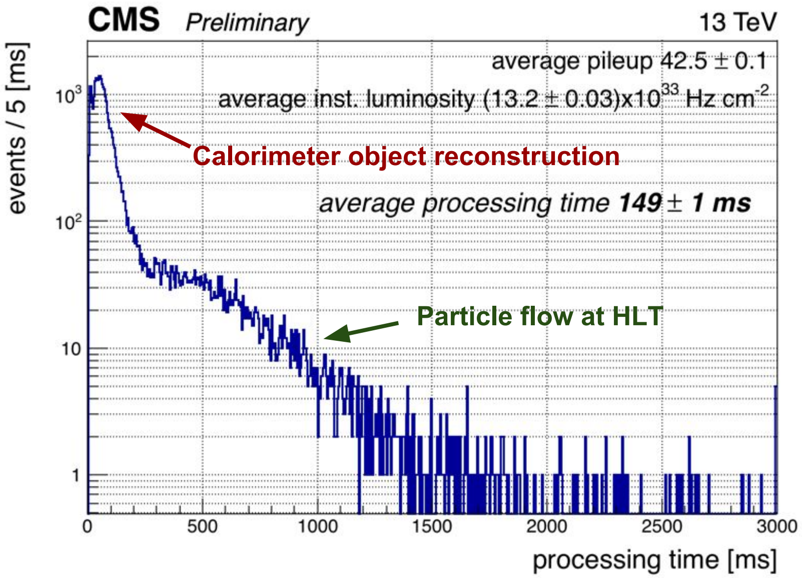
- L1 accepted events
- Input to HLT Paths with rate ~100 kHz

One example HLT path in this example menu.

- Final decision is OR of decision of all paths
- output from HLT Paths with rate ~1 kHz and go to storage

Challenges in designing trigger

- Keep rate in allocated budget due to limited resources at offline.
    - Apply additional filters like mass and DZ or prescaled paths with different prescales depending on inst. luminosity
- High efficiency to store as much as events from interesting physics.
    - Algorithms and calibration used close to offline analysis.
- Take decision quickly to reject uninteresting events.
    - 26k cores to process 100 kHz of L1 accepted rate
    - 26k / 100 kHz ≈ 260 ms per event (≈ 320 ms due to hyper-threading)
    - fast rejection based on reconstructed from calorimeter first
    - Tracking and Particle Flow based event selections at HLT come at end (most time consuming operations)



Tracking at HLT

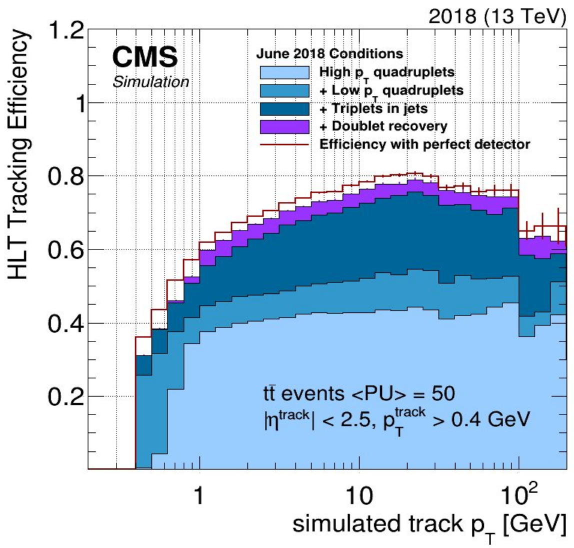
Iterative tracking in successive manner :

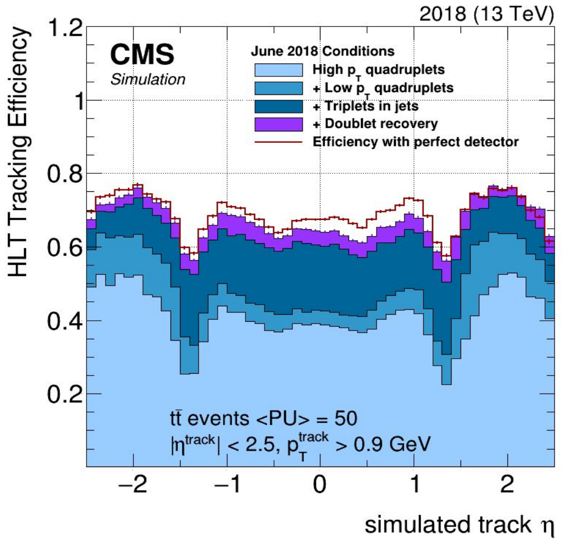
- Iteration 1 : High pT track with 4 pixel hits
- Iteration 2 : Low pT track with 4 pixel hits
- Iteration 3 : at least 3 pixel hits, relaxed hits, restricted with in the vicinity of jet reconstructed in calorimeter or track reconstructed in previous 2 iterations.
- Iteration 4 (from 2018) : additional iteration added with 2 pixel hits allowed in detector region where 2 inactive modules overlap seen from interaction point, allowed only tracks with pT>1.2 GeV (limited CPU time)

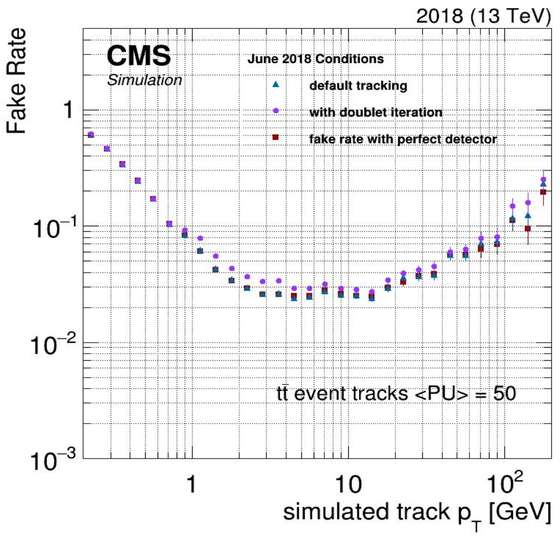
- The tracking efficiency is defined as the fraction of simulated particles from the signal interaction with pT > 0.9 GeV, abs(eta)< 2.5, and longitudinal (transverse) impact parameters < 35(70) cm that are matched to a reconstructed track.

- The fake rate is defined as the fraction of reconstructed tracks that could not be matched to a simulated particle.

- ttbar sample used to check the performance.





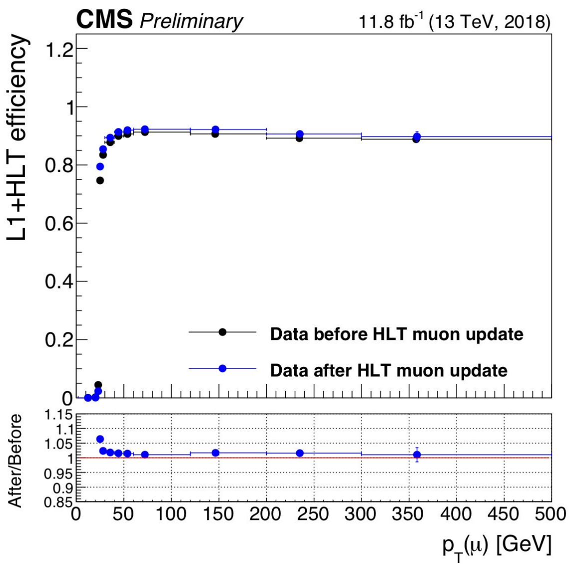


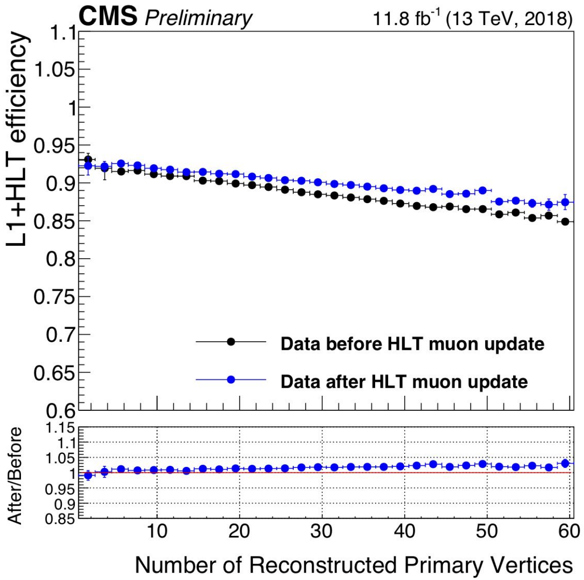
Muon at HLT

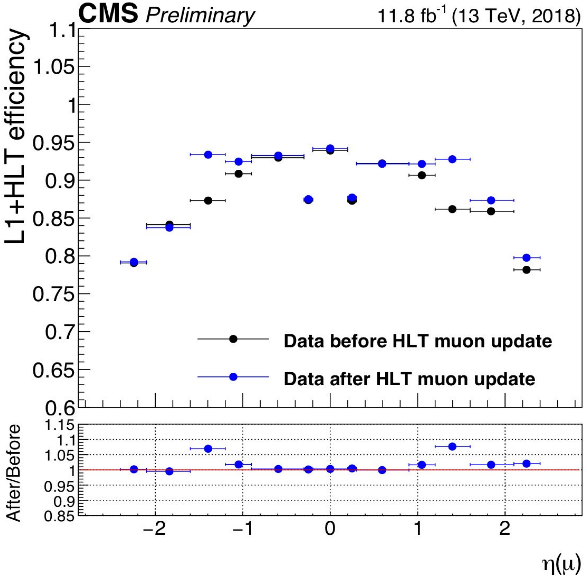
Updated Muon reconstruction at HLT in 2018 :

- Increased in number of seeds to build track of muon.
- One more iteration of tracking.
- Simple ID is applied on HLT muons to keep high purity and low rate.

❖ Performance shown before and after the updates with 2018 data.
❖ Tag and Probe method used on di-muon events.





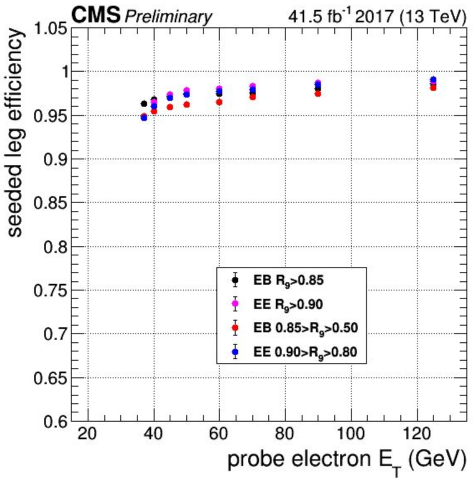


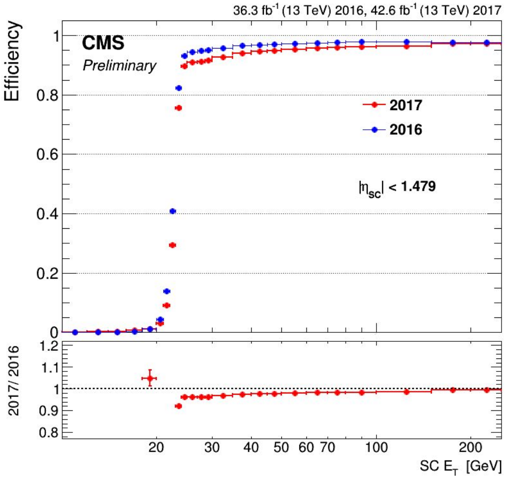
Electrons/Photons at HLT

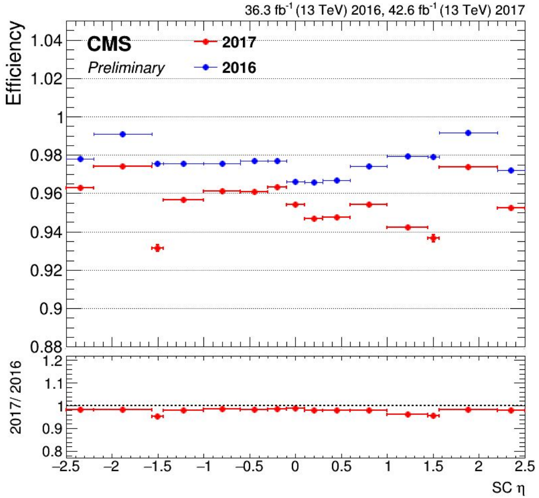
Electrons : with new pixel layer and tuned pixel matching at HLT reduce rate upto 70% with efficiency loss of 1-2%.

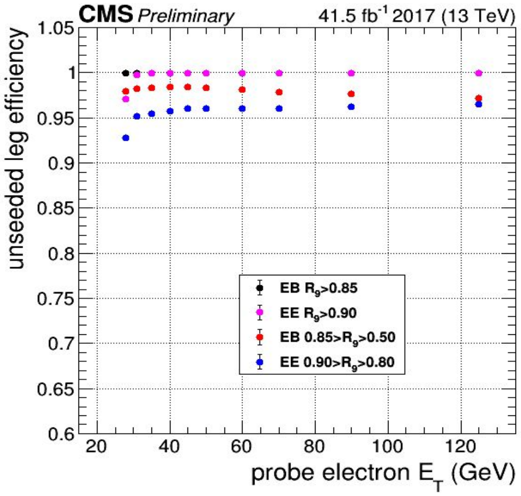
Photon triggers organized in two main parts :

- Seeded : at least one photon matched to a Level-1 electron candidate and with ET > 30 GeV.
- Unseeded : at least 2 photons with ET > 22 GeV, at least one of which survives the “seeded leg” selection
- Tag and probe efficiency computed separately for each part.









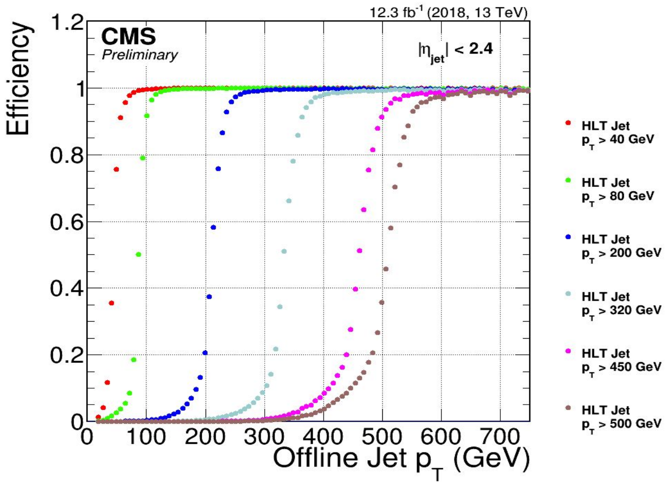
Jet/MET at HLT

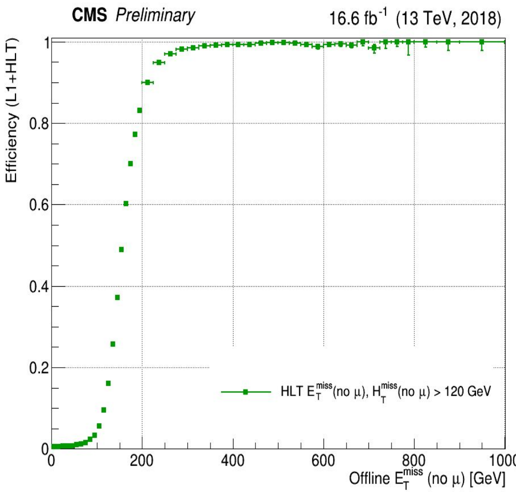
Jet Performance :

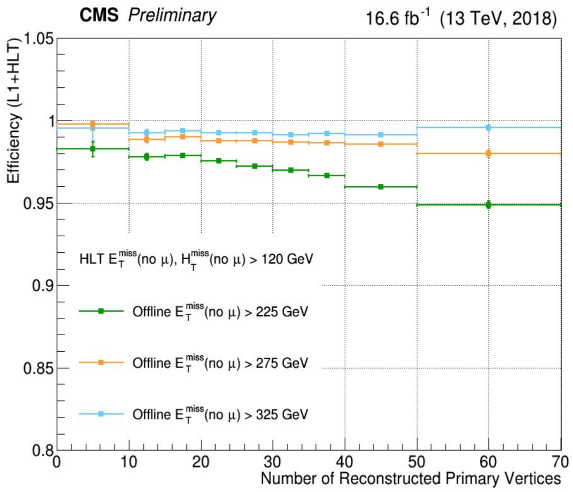
- Efficiency measured on single muon events wrt offline reconstructed Jet (Anti-KT, R = 0.4).
- Offline and Online Jets reconstructed using PF algorithm.
- Re-run HLT to produce online jets to match them with offline jets.

MET Performance :

- Efficiency computed wrt offline E_T^{miss} with no μ
- PF algorithm used to reconstruct MET offline and at HLT
- Slow turn on due to L1 resolution and PU







Hadronic Taus (τ_h) at HLT

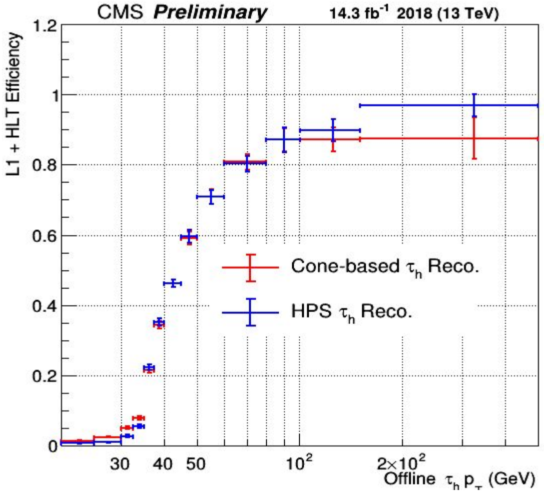
2015-2017 :

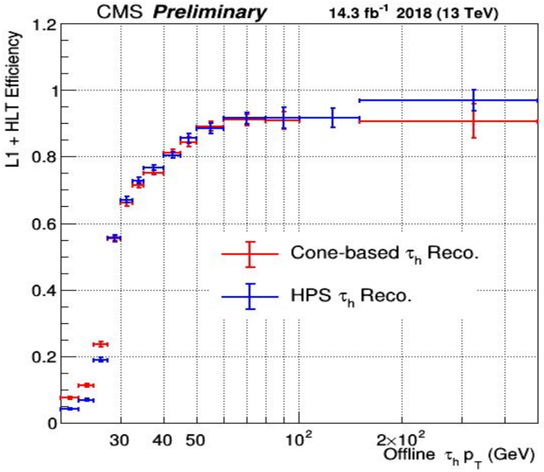
- Cone-based algorithm for hadronically decaying tau reconstruction at HLT.
- Charged hadrons, photons, and neutral hadrons within the cone ranging from $\Delta R = 0.08$ to 0.12 for τ_h reconstruction.

2018 :

- Hadron Plus Strips (HPS) algorithm for hadronically decaying tau reconstruction at HLT.
- HPS algorithm reconstructs various decay modes of hadronically decaying tau.
- Combine charged hadrons and photons within the signal cone and ranked based on their consistency with a genuine τ_h decay
- highest ranked combination is selected as the reconstructed τ_h candidate.

  Advantage :
  - Gain in efficiency with reduction in rates up to 20%.
  - Same algorithm also used in offline hadronic tau reconstruction.





Summary

- Overall good performance of High level trigger of the CMS in LHC Run-II.
- Tracking at HLT improved with the addition of pixel layer.
- New algorithms and selections are incorporated at HLT that help to keep threshold not too high with respect to Run-I of the LHC to keep rate in budget allowed.
- More public results at : https://twiki.cern.ch/twiki/bin/view/CMSPublic/HighLevelTriggerRunIIResults