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Performance of the High Level Trigger System at CMS in LHC Run-2

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HLT at CMS

The CMS experiment selects proton collision events with a two-level trigger system:

- **L1 trigger** hardware
- **High Level Trigger (HLT)** software

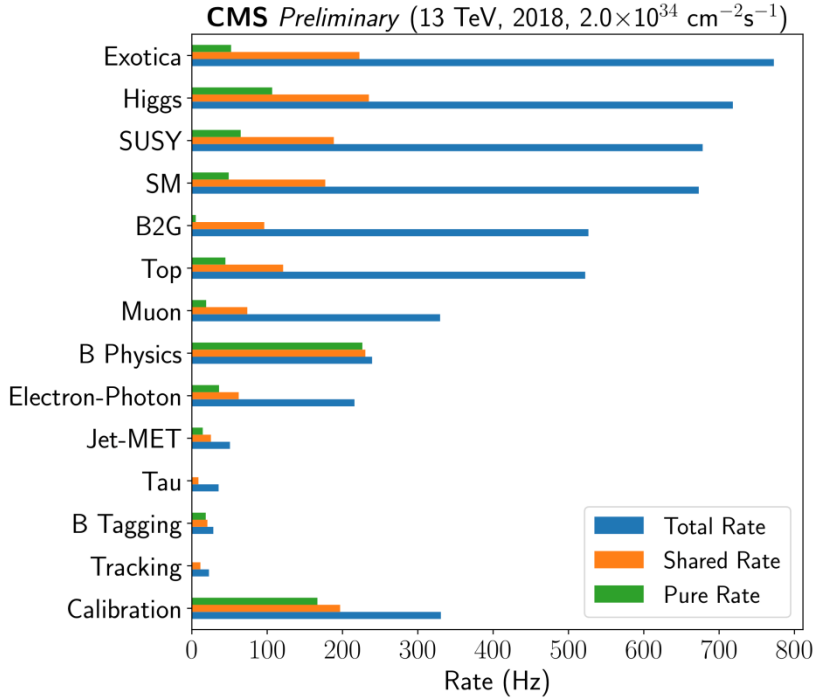
HLT menu with over 400 different paths consist of a sequence of **reconstruction** and **filtering modules** arranged in increasing complexity

LHC Run-2 provided luminosity which allowed to study rare physics events posing a challenge to the online event selection:

- up to 4×10^7 events/s produced at luminosity peak
- HLT rate limited to 10^3 events/s
- pileup and instantaneous luminosity increased

Average HLT rate limit is about **1 KHz** (limited CPU)

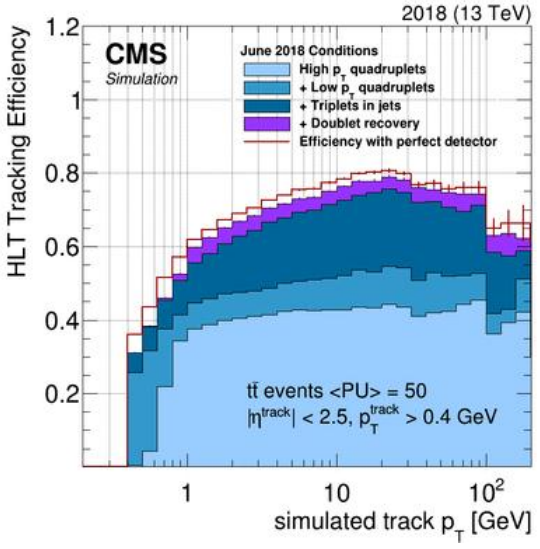
CMS-DP-2018-057

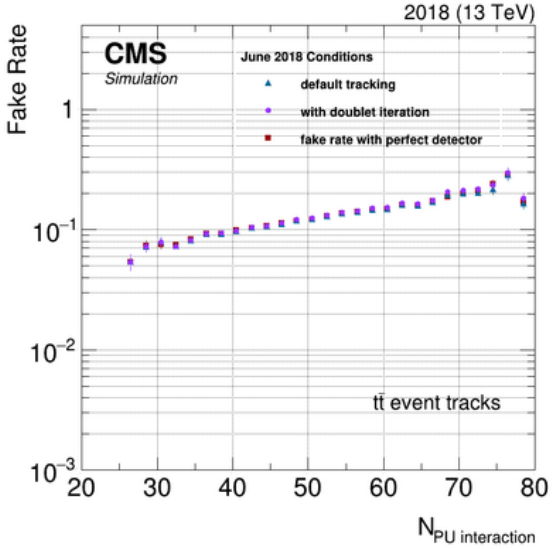


HLT Tracking

CMS DP -2018/038

The iterative tracking algorithm performs subsequent iterations for the overall track-finding.
Seeded by pixel hits, with several updates during the years.
Mitigation with two more iterations to recover the tracks with missing hits since 2017 after phase-1 pixel detector upgrade.
Tracking performance is very close to ideal efficiency after mitigations.
Fake rate increases with pileup.

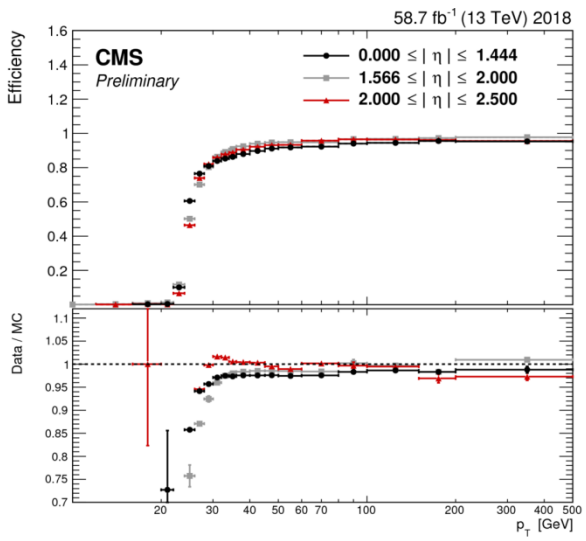




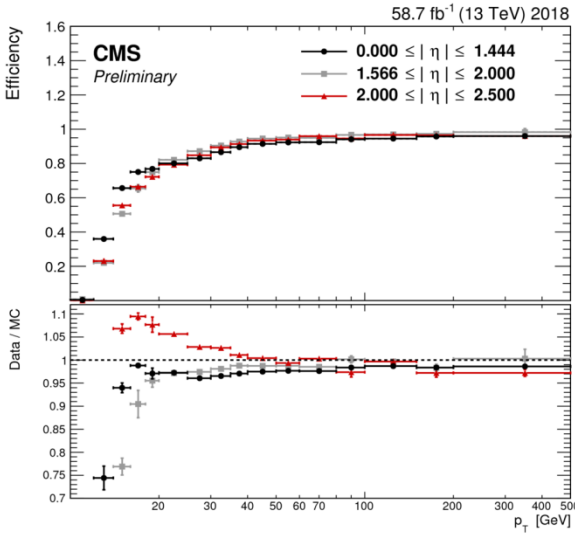
HLT Electrons

CMS DP -2020/016

Electron reconstruction starts with building up superclusters (SC) which are either seeded or unseeded by the L1 triggers and SCs are matched with the pixel tracks.
The pixel matching algorithm was changed from doublets to triplets and retuned in 2017.
Rate is reduced by ≈ 70% with the new pixel detector in 2017.



DoubleElectron - p_T – Ele23



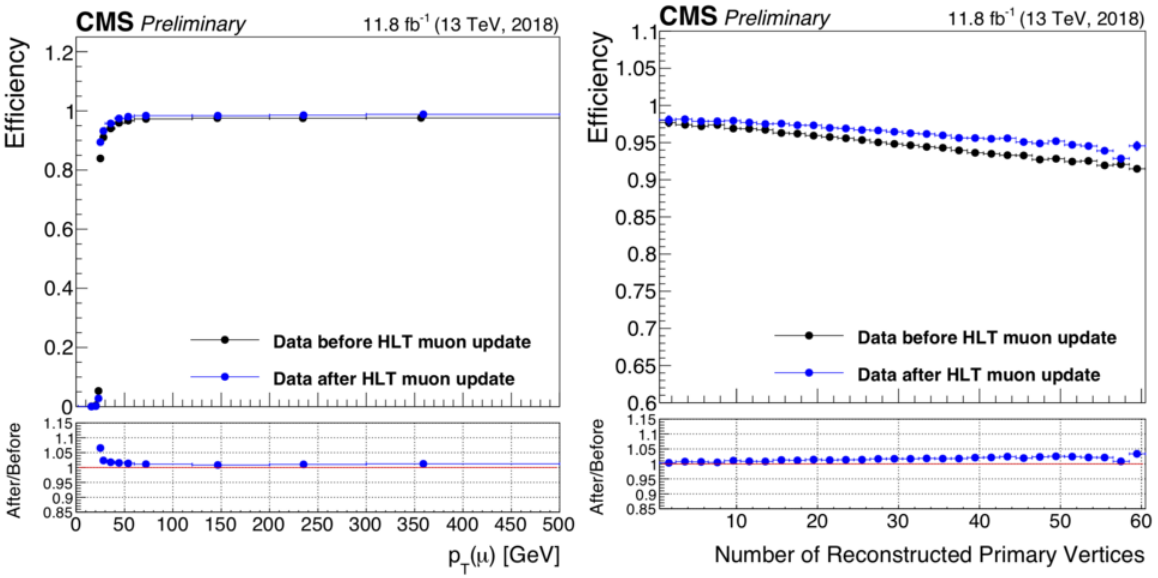
DoubleElectron - p_T - Ele12

HLT Muons

CMS DP -2018/034

Muons at HLT reconstructed exploiting both muon chambers and silicon tracker improving muon p_T resolution.
HLT muon reconstruction updated:
- more seeds for muon track building and one more iterative tracking added to muon tracking algorithm to **improve efficiency**
- a simple identification on HLT muons applied for a **high purity with lower rate**.

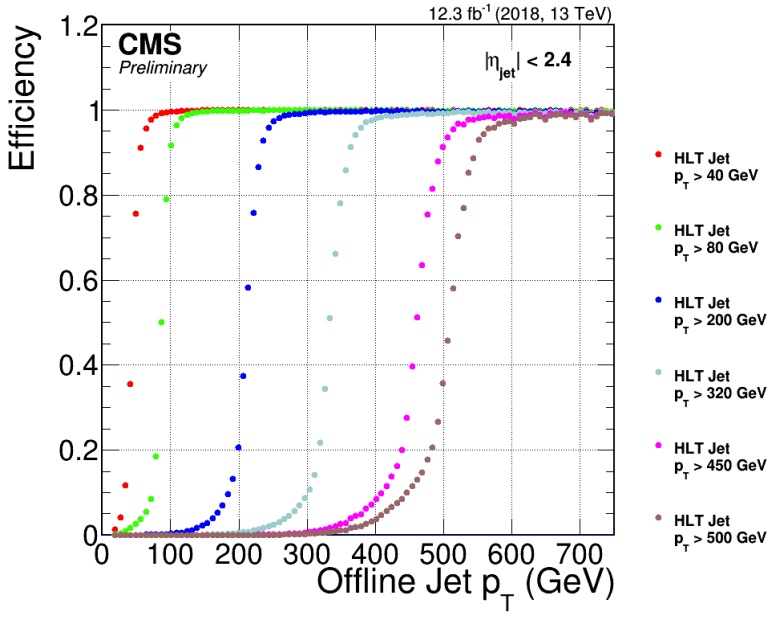
Isolated Single μ Trigger Efficiency



HLT Jets

CMS DP -2018/037

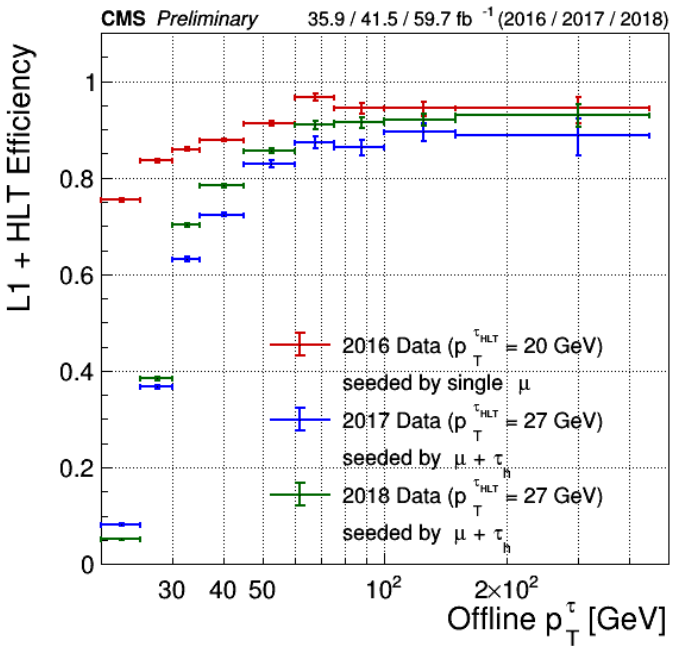
CaloJets built using only calorimeter information used to filter out events at a first step.
PF regional (global) reconstruction to build the final Jets. Tracking used to run simplified version of PF algorithm to improve object reconstruction, especially on jets and MET.
Jet trigger efficiency measured in single muon events, as function of the offline reconstructed jet (anti-k_T, R = 0.4)



HLT Taus

CMS DP -2019/012

Tau reconstruction at HLT was updated to hadron-plus-strip (HPS) algorithm in 2018
The HLT and L1 p_T thresholds and isolation of tau leptons changed during Run 2 data-taking.
HPS algorithm has better p_T resolution and reduces the rate by 10% per tau-leg.
Efficiency is higher in 2016 due to low pileup, lower L1 and HLT thresholds.
Efficiency lower in 2017 because of high pileup and initial problems encountered with the new pixel detector at CMS.

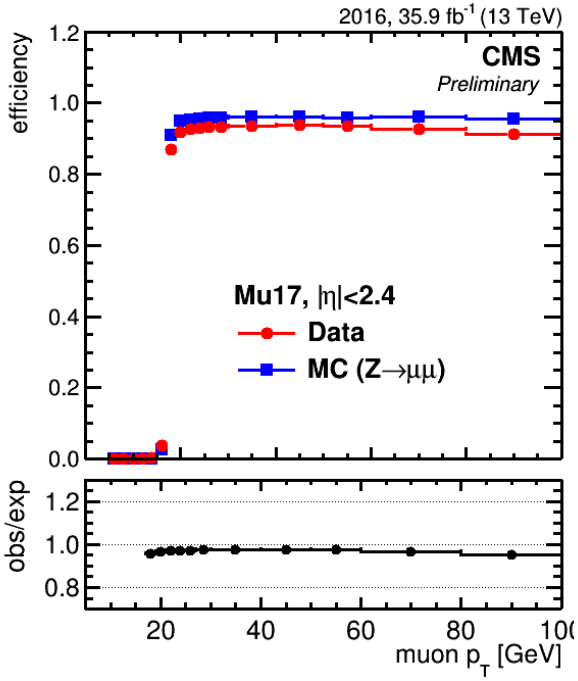


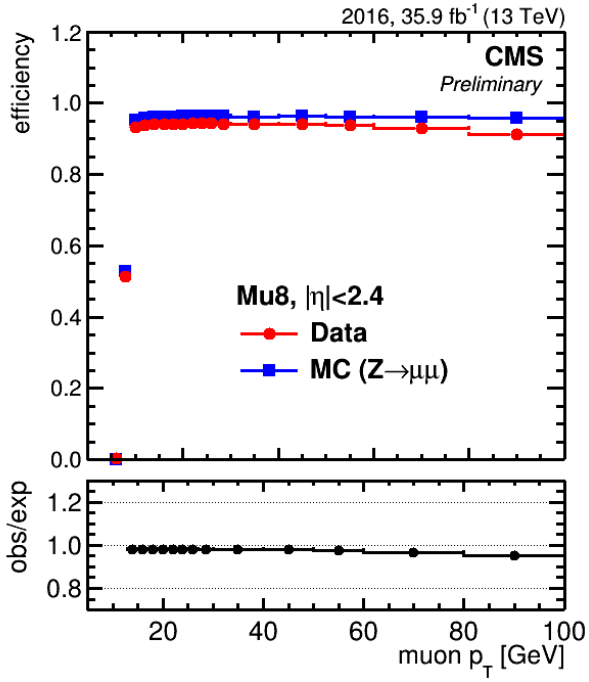
Performance of μ-T_h triggers in Run-2

Physics Trigger / Higgs

CMS DP -2020/029

A same-sign (SS) di-muon HLT for H(125)→aa search in 2HD+1S models at low m_a ($m_a \leq 15$ GeV), with signatures of non-isolated leptons (decay products of light boson overlap). SS requirement reduces QCD contribution, nearly eliminates electroweak and top backgrounds. The charge misID rate using Z →μμ and J/ψ→μμ events measured at 1% level.

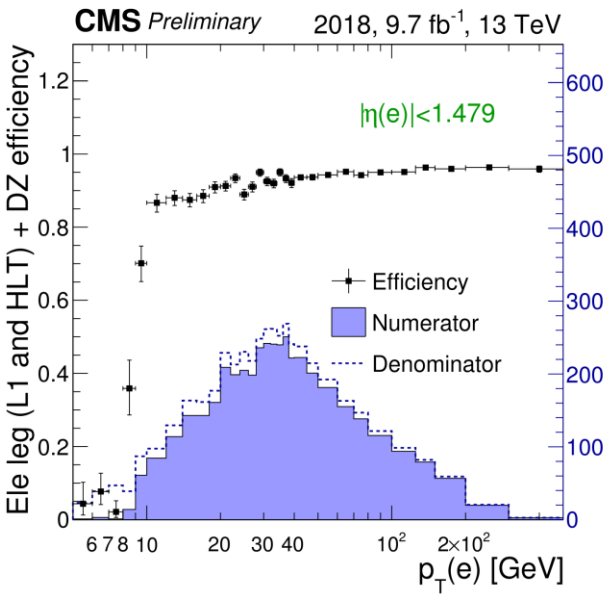


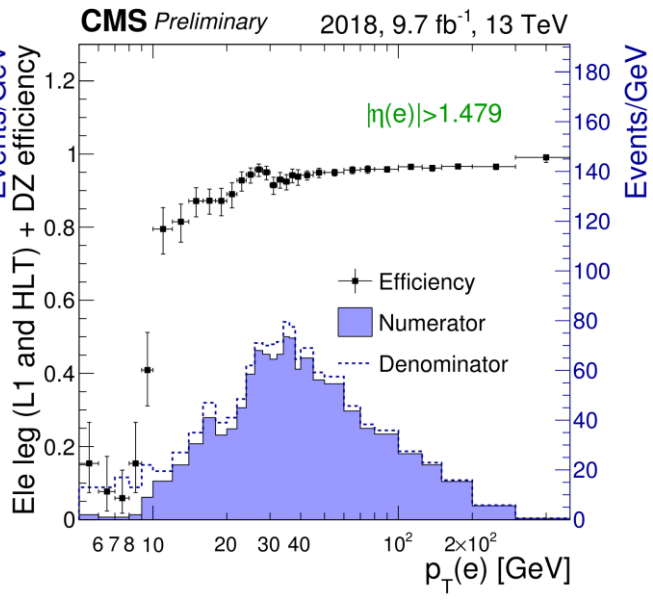


Physics Trigger / SUSY

CMS DP -2018/049

HLT path for SUSY searches with electrons is developed with requirement of two well-identified electrons with $p_T > 8$ GeV, invariant mass > 8 GeV, and a hadronic transverse energy $H_T > 350$ GeV. The efficiency for the electron legs is shown.





Summary

- In LHC Run-2 the peak instantaneous luminosity reached up to 2x10^{34} cm^{-2} s^{-1} posing a challenge to the online event selection. Many developments were performed to improve the HLT object reconstruction during Run-2 mainly to cope with changes in the LHC and CMS conditions with challenges experienced in data-taking.
- The HLT system at CMS performed well and maintained high performance in Run-2.
- In LHC Run-3, there is a plan to use GPUs at HLT to improve the performance with more precise tracking.