CMS High Level Trigger performance in Run2 and new developments for Run3

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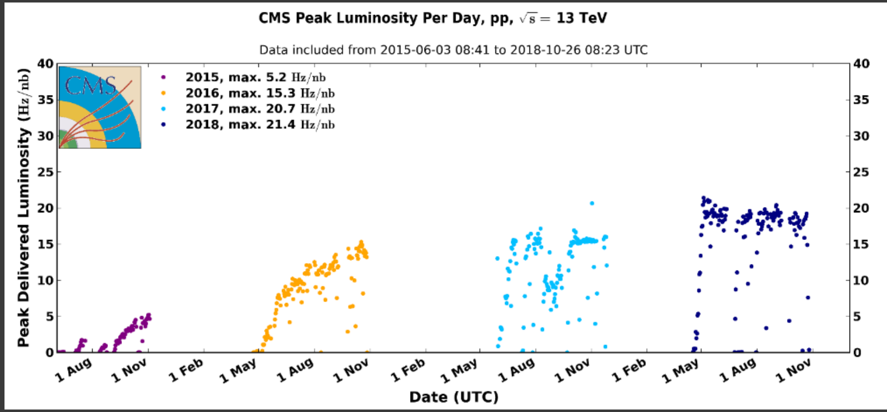
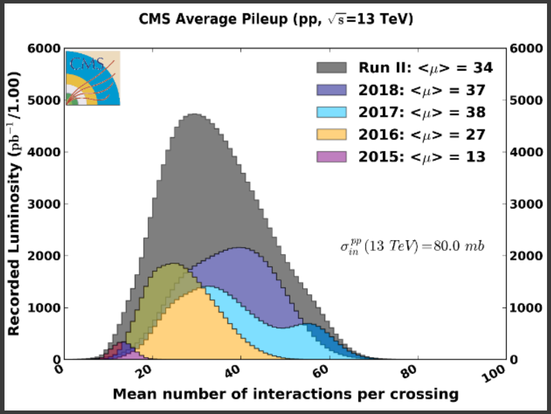
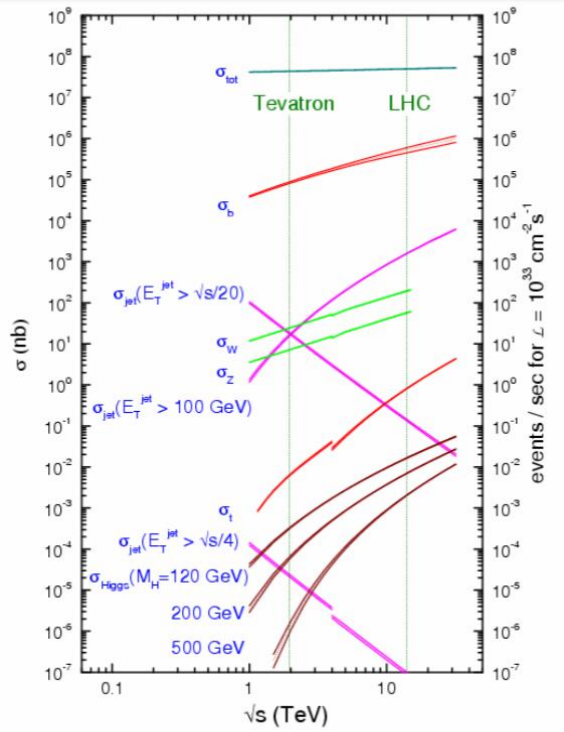
Introduction

The Run2 of LHC provided a 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
- PU and instantaneous luminosity increased during Run2
- conditions similar to the 2018 are expected for Run3



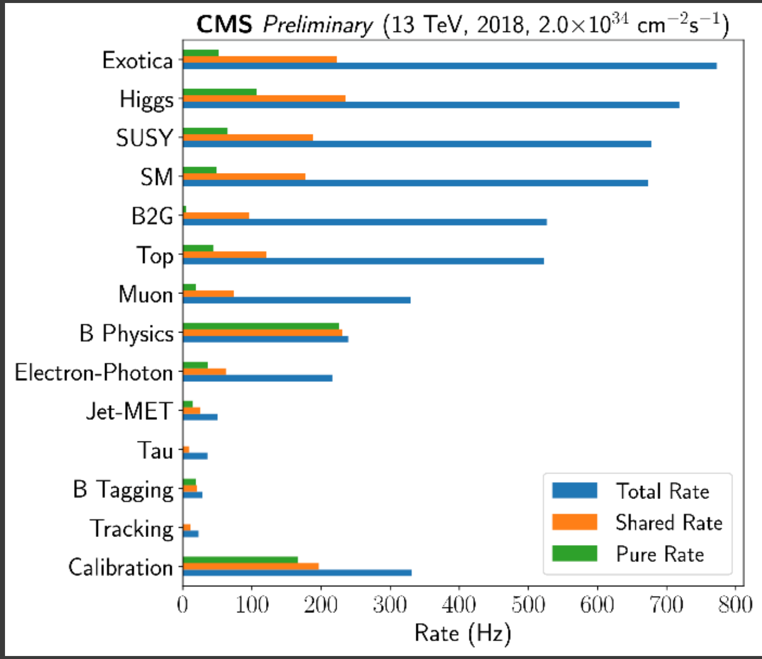




CMS Trigger strategy

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

- the **L1 trigger** hardware [Ecal, Hcal, Muon system]:
  - time constrain ≈ 4 μs
  - rate reduction from 40 MHz to 100 KHz
- the **High Level trigger (HLT)** software [farm of approximately 26K CPU cores] runs a streamlined version of the offline object reconstruction:
  - simplified tracking
  - regional reconstruction
  - **HLT menu is composed by hundreds of paths targeting a broad range of physics signatures within a global rate of 1 kHz**
  - To satisfy the CPU time limitation (26000 cores/100 KHz ≈ 260 ms):
    - faster algorithms run first(calorimeter/muon modules)
    - intermediate filters are applied to run the last part of the paths(slower/more complex modules)only on a limited rate

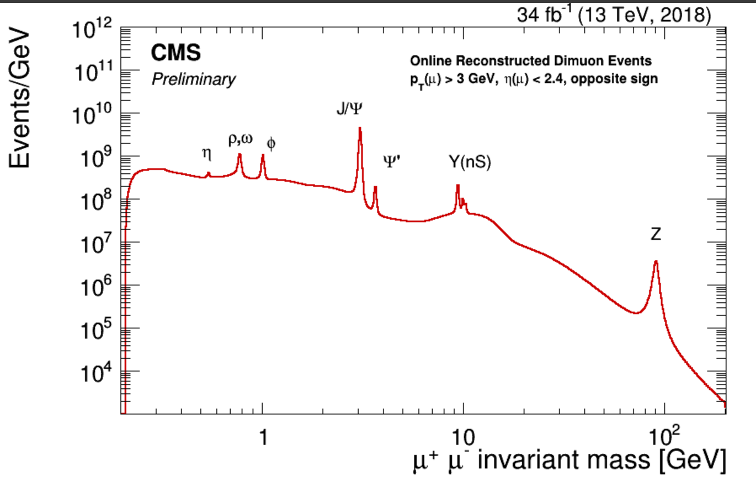


HLT rate

- The average HLT rate limit is about 1 KHz due to the limited CPU used for the offline reconstruction
- data acquisition is able to transfer up to 5-6 kHz
- space on tape allows to record up to 2 KHz

Skipping the offline reconstruction allows to keep higher rate:

- **Data scouting**
  - Only HLT reconstructed objects are saved (up to 1000 times smaller)
  - dimuon scouting triggers to cover low mass range with high rate



- **Data parking**
  - Reconstruction is done when CPU is available as periods of no running, when prompt reconstruction is not done
  - B-physics which needs high rate

HLT Tracking

The ITERATIVE TRACKING algorithm performs subsequent iterations for the overall track-finding

It is seeded by pixel hits, with several updates during the years

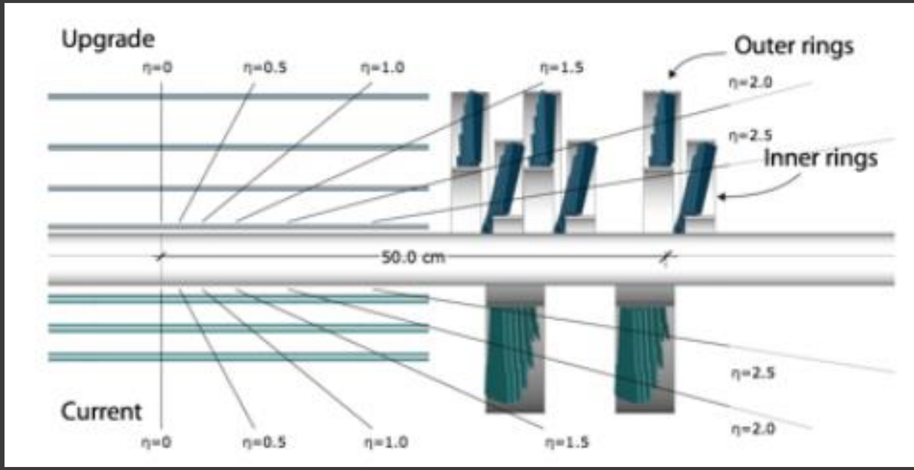
2016:
- 3 iterations seeded by pixel triplets

2017 Phase1 pixel upgrade:
- 3 iterations seeded by pixel quadruplets
  - 10 times smaller fake rate
  - 2 times higher efficiency
  - 5 times faster

- 2 more iterations seeded by triplets and doublets to recover from dead pixel modules

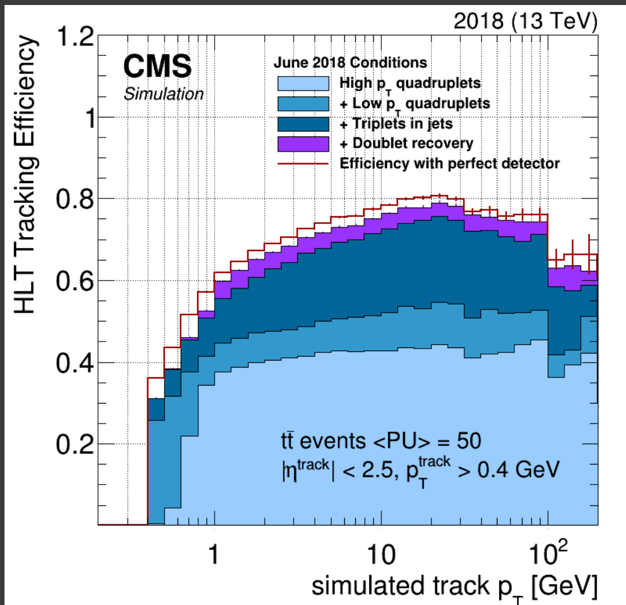
2018 new DCDC converters:
- dynamic mitigation of dead pixel modules

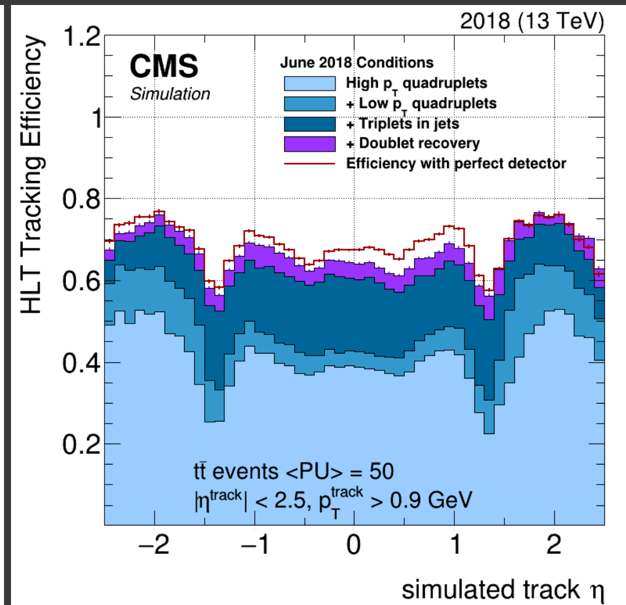
1 more pixel layer in both barrel and endcap

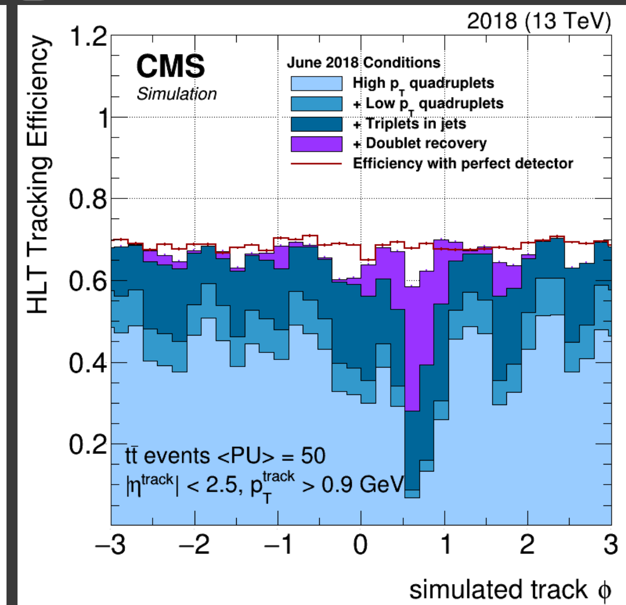


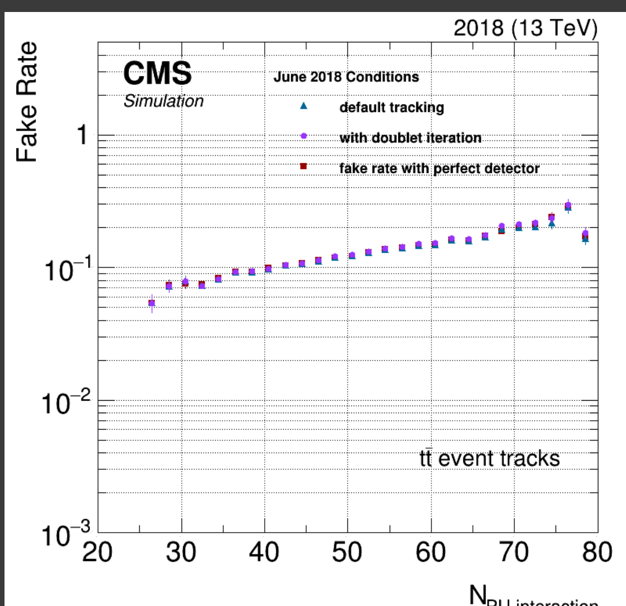
HLT Tracking

CMS-DP-2018-038









Performance measured w.r.t. MC-truth:

- Dynamic doublet-seeded iterations (pT > 1.2 GeV) recover a significant fractions of efficiency
- Recovery happens only for 2 consecutive dead modules and it in not uniform in eta and phi
- Fake rate increases with PU, but is not significantly affected by doublet-seeded iterations

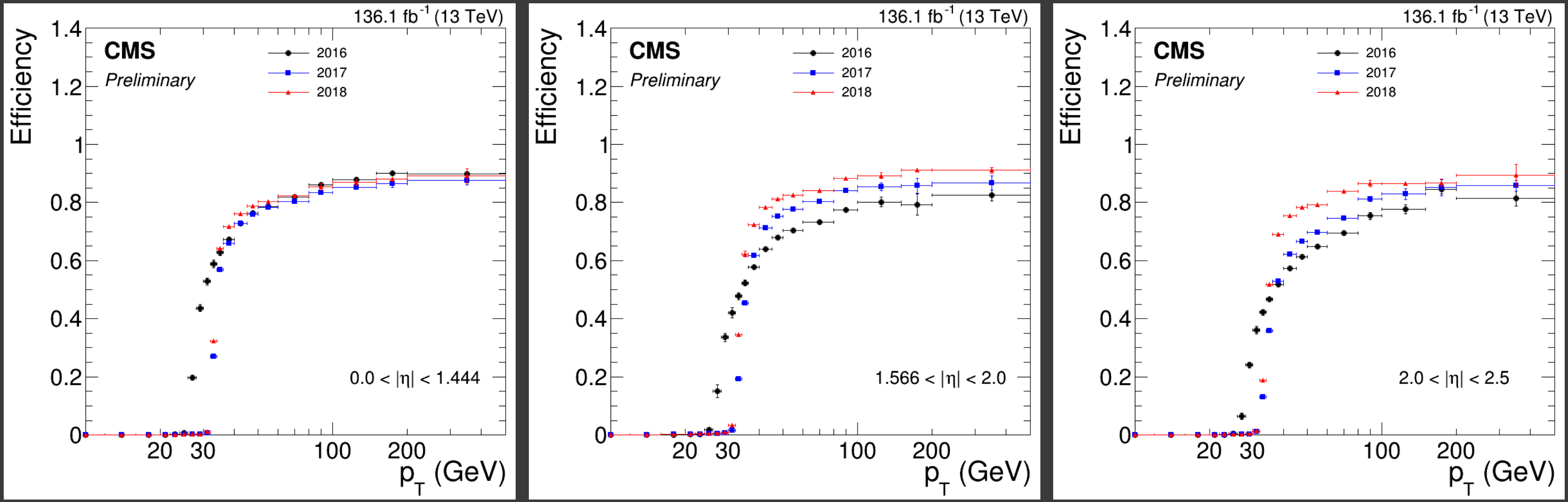
HLT Electrons

CMS-DP-2020-016

The electron reconstruction is seeded by a supercluster(SC) in Ecal matched (in ϕ) to pixel hits:

- in the **2016 SC matched to pixel doublets**
- after the **2017 SC matched to pixel triplets**, or doublets just for trajectories passing through less of 3 active modules
  - significant efficiency gain for minimal increase of rate
- electron tracks are then reconstructed using the same algorithm as offline
- pT threshold and identification criteria have been tuned during the years

Overall L1+HLT Efficiency:



HLT Muons

CMS-DP-2017-056

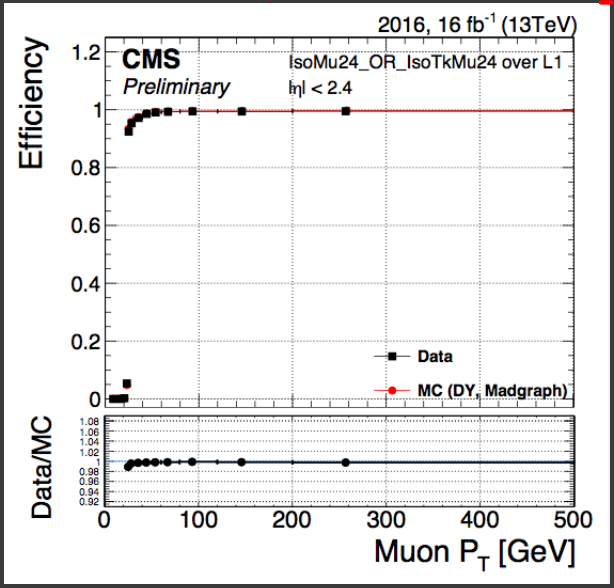
Muons are reconstructed in 2 steps:

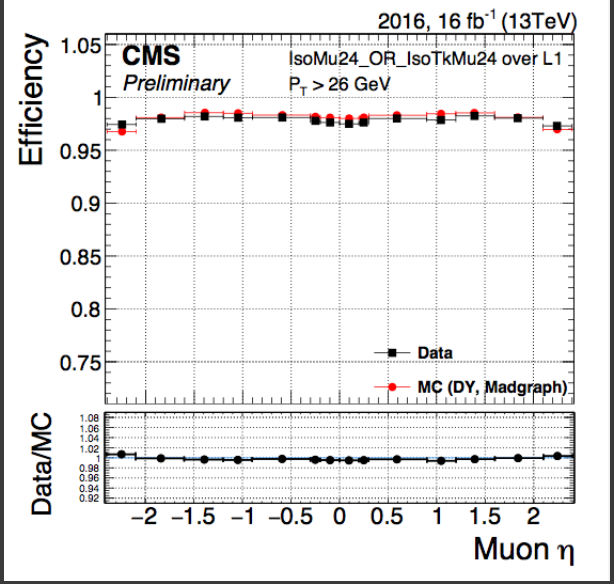
- L2 reconstruction seeded by L1 muons, returns a track built using the muon-system only information
- L3 reconstruction builds tracks in the tracker, combines them to the muon-system information, returns a L3 muon candidate:

2015-16 two separated algorithms used «in OR»:

- CASCADE seeded by L2 muons runs 2 kinds of OutsideIn and 1 InsideOut modules
- TRACKER MUON: seeded by L1 runs the iterative tracking IO module

HLT/L1 Efficiency in 2016 Data and MC





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From 2017:

- ITERATIVE ALGORITHM (to accomodate the new pixel detector) combining the OI, IO from L2 and IO from L1 (only in case of no muon candidates built in the previous steps)

HLT Muons

CMS-DP-2018-034

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- L2 reconstruction seeded by L1 muons, returns a track built using the muon-system only information
- L3 reconstruction builds tracks in the tracker, combines them to the muon-system information, returns a L3 muon candidate:

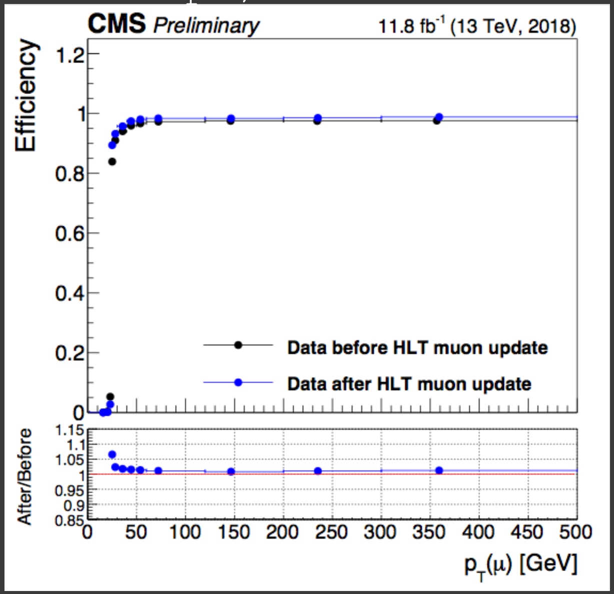
From 2017:

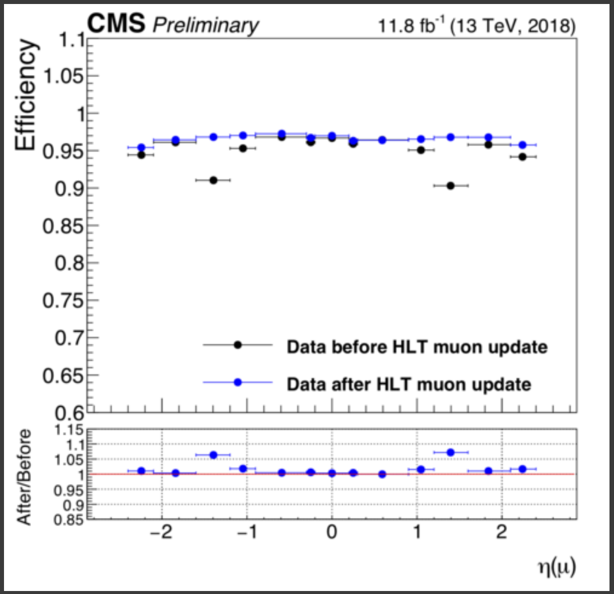
- ITERATIVE ALGORITHM (to accomodate the new pixel detector) combining the OI, IO from L2 and IO from L1 (only in case of no muon candidates built in the previous steps)

2018:

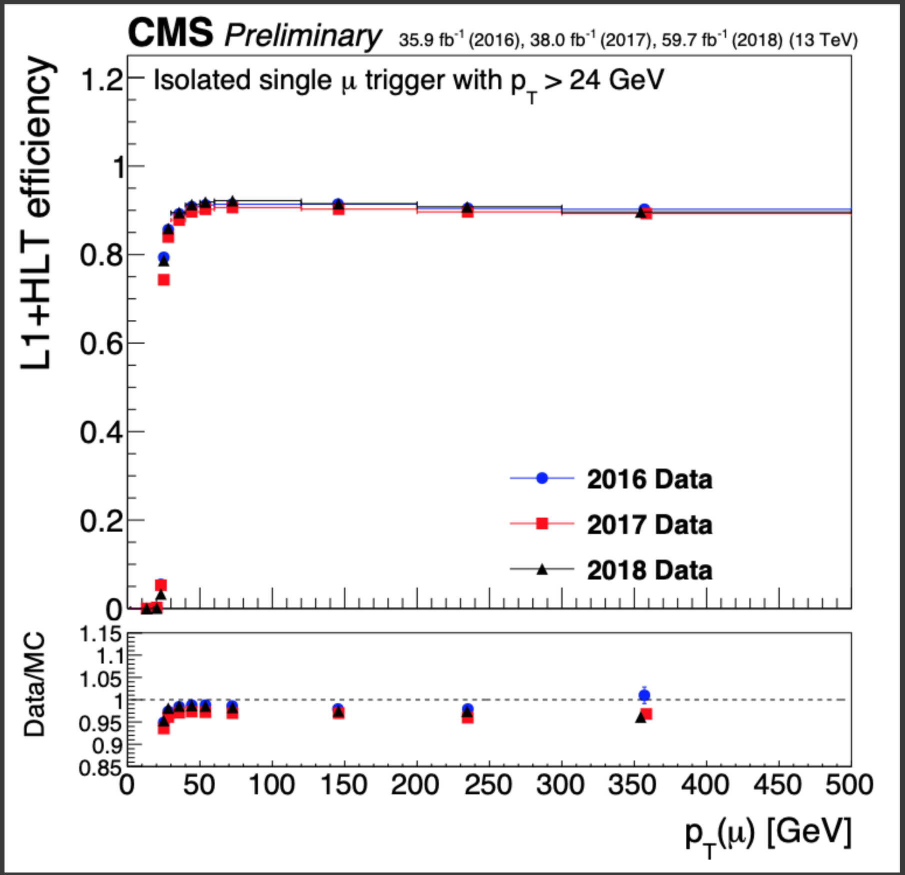
- One more step in the IO to recover from the pixel inefficiency
- IO from L1 always on
- MuonID filter to keep the rate under control

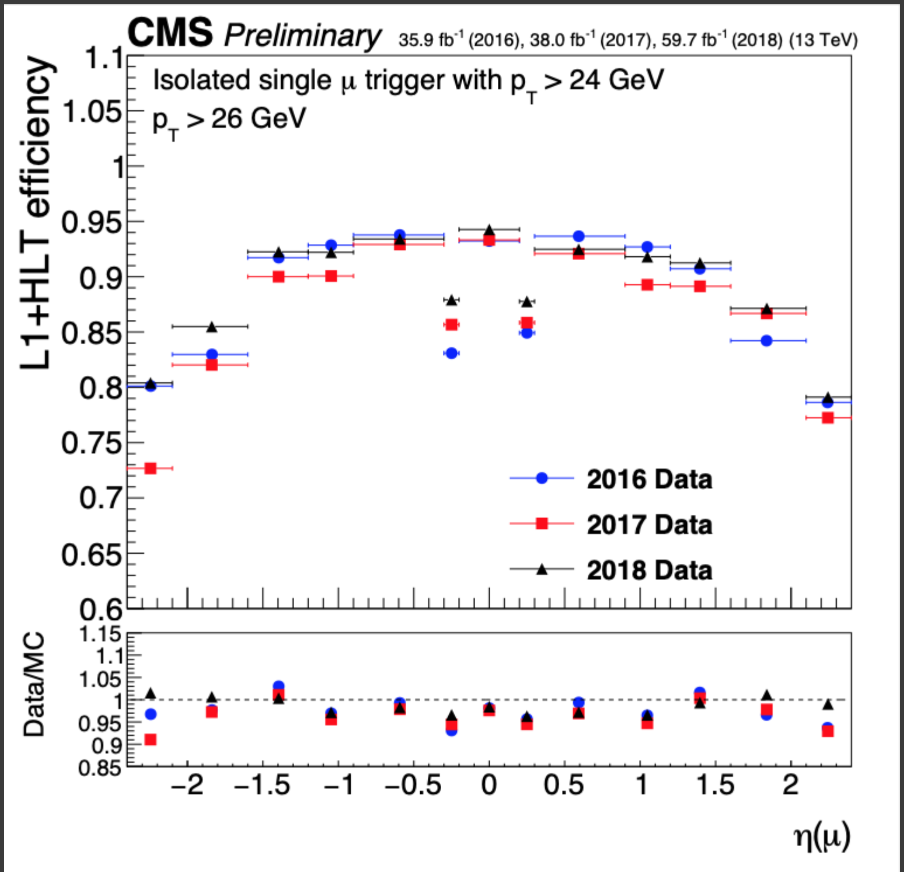
HLT/L1 Efficiency in 2018 Data





HLT Muons





Overall L1+HLT Efficiency:

- genarally stable around the 90% for the entire data taking
- higher in the barrel, mainly due to the L1 performance
- in the 2017 L3 changes offset the improvements done at L1
- in the 2018 the efficiency recovered and exceeded the one of 2016 thanks to the improved L3 and the pixel recovery

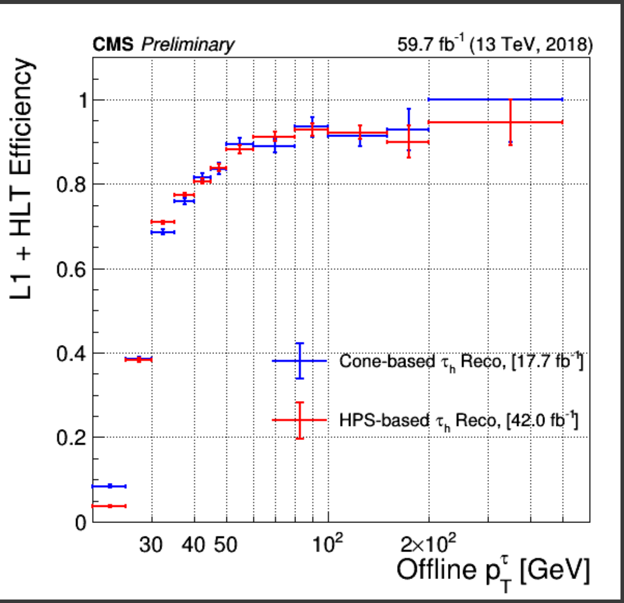
CMS-DP-2019-012

HLT Taus

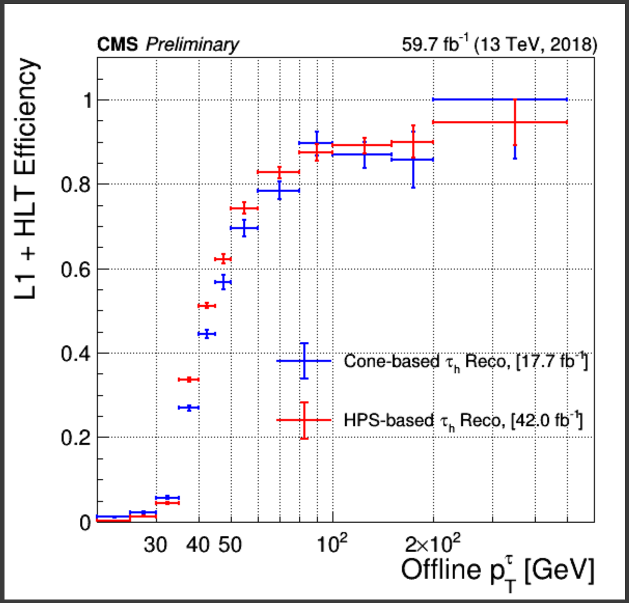
Hadronic taus are reconstructed (L3) using the Particle Flow (PF) algorithm globally ($e\tau_h$ or $\mu\tau_h$ triggers) or regionally around the L1-τ (di-τ_h triggers):

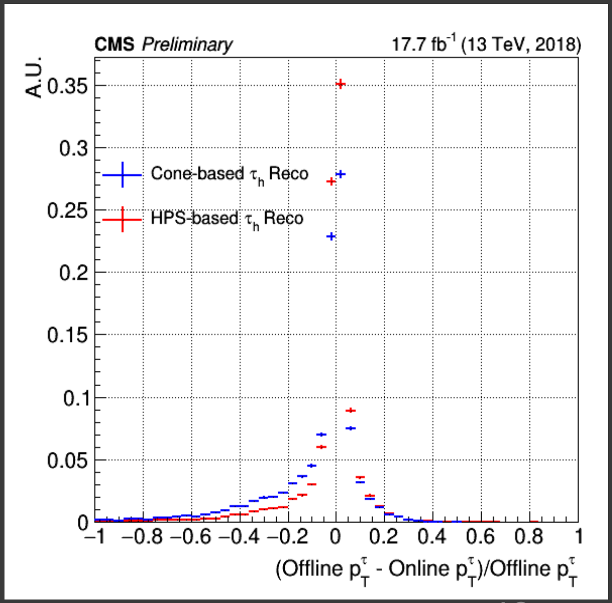
- L2 (calojet based reconstuction) and L2.5 (tracker based isolation) are used as intermediate steps only for di-τ_h triggers
- **L3 was based on the CONE algorithm up to 2018**
- **HADRON PLUS STRIP algorithm deployed during 2018 data-tacking**
  - it allows to separate the 2 legs
  - reduced rate of 10%(20%) for $\mu\tau_h$(di-τ_h) trigger
  - improved momentum resolution

$\mu\tau_h$



di-τ_h





CMS-DP-2019-012

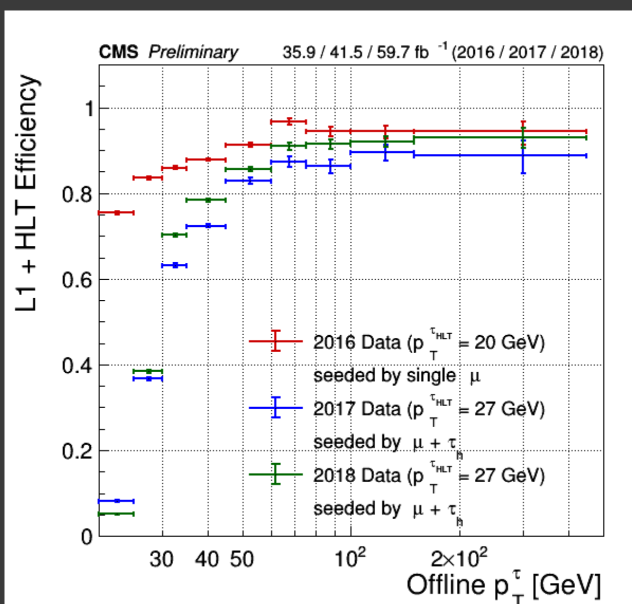
HLT Taus

Performance of the τ_h leg in the $\mu\tau_h$, $e\tau_h$ and di-τ_h triggers:

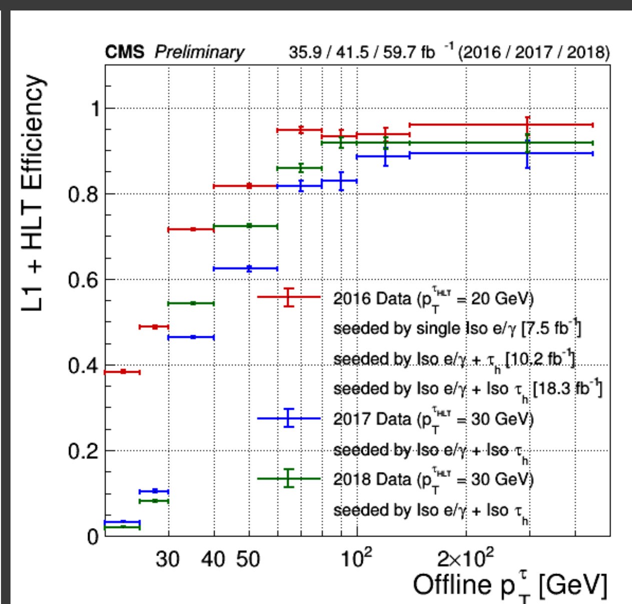
- L1 seeds and HLT filtering criteria have been modified during the years
  - different shape of the efficiency for the $\mu\tau_h$ and $e\tau_h$ triggers in the 2016 w.r.t. 2017 and 2018
  - higher efficiency in 2016 (also due to lower PU)

Overall L1+HLT Efficiency

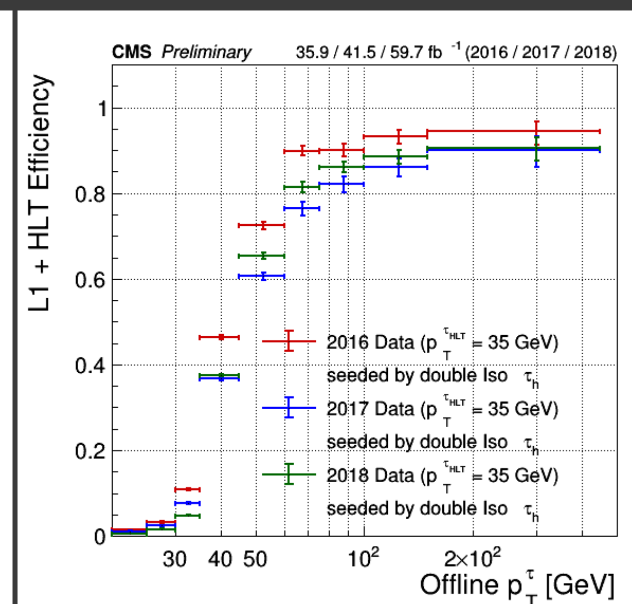
$\mu\tau_h$



$e\tau_h$



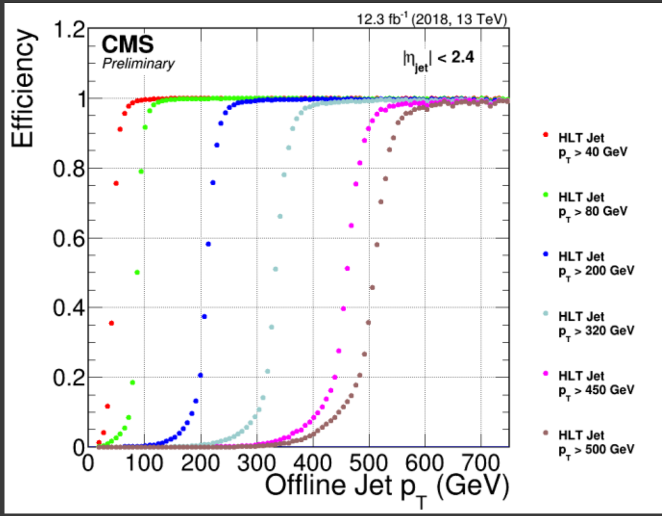
di-τ_h



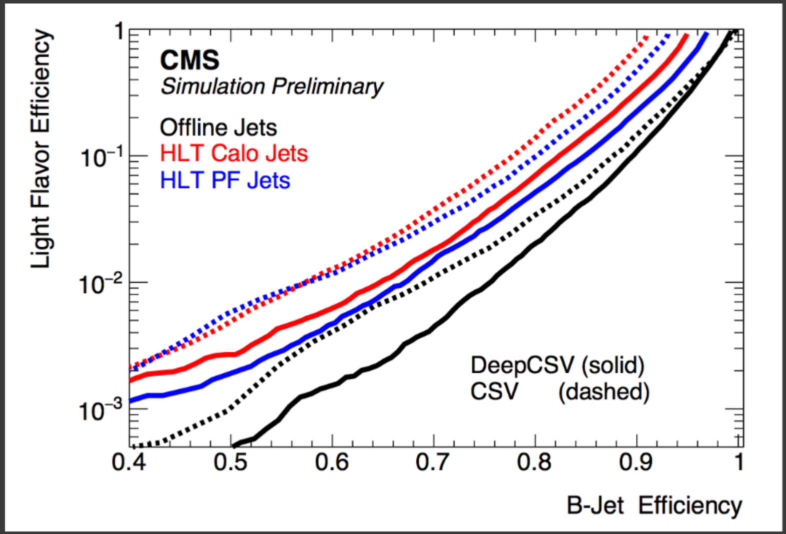
HLT JetMET and b-tagging

Jets and MET are reconstructed in two step:

- caloJets and caloMET built using only calorimeter information are used to filter out events at a first step
- PF regional (global) reconstruction to build the final Jets (MET)
- Main updates during Run2 regarded:
  - calibration for the noise mitigation
  - Jet energy correction
- b-jets are identified at HLT by using the **Combined Secondary Vertex (CSV) algorithm in 2016-17 and the DeepCSV algorithm in 2018**
  - The b-jet tagging is performed in two different ways:
    - using tracking in the PF sequence
    - regional tracking around the leading calorimetric jets (75% of CPU time reduction)



CMS-DP-2018-037



CMS-DP-2019-042

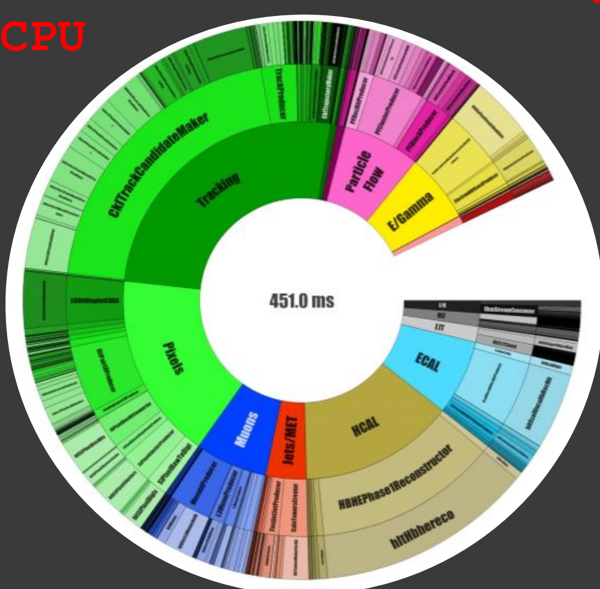
Run3

The Run3 LHC conditions are expected to be similar to those of the 2018

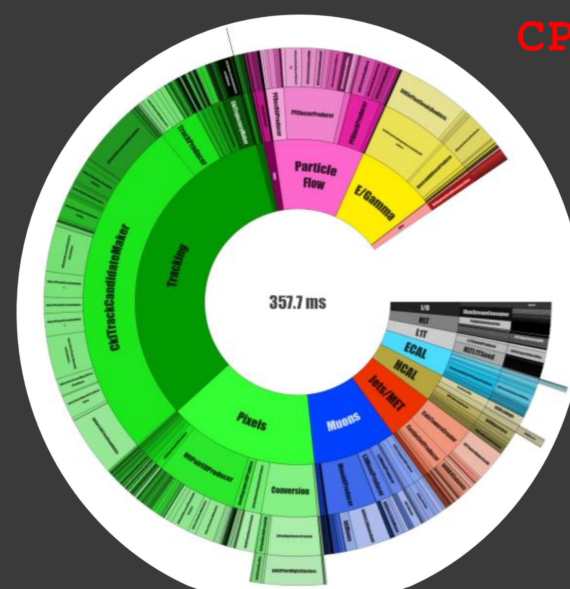
- A lot of efforts are ongoing at the HLT:
  - to profit of updates in local reconstruction (after LS2)
  - aimed to get an heterogenous HLT farm of CPU(80%) and GPU(20%)
    - Pixel local reco, tracks and vertices
    - Hcal local reco
    - Ecal unpacking and local reco
    - CPU time reduced of more than the 20%
    - improved track resolution and efficiency with a big reduction of fake and duplicates rate
    - promising also for PF developments
      - main efforts to increase the rate for scouting

Timing of Run3 HLT menu

CPU



CPU+GPU



Summary

Many developments were performed to improve the HLT object reconstruction during Run2:

- mainly to cope with changes in the LHC and CMS conditions
- HLT performance resulted stable during the full Run2

An ambitious physics program is expected for Run3

Many exotic searches can be accessible using data scouting

- using GPUs to accelerate HLT is critical to enhance it

Back-up

HLT DoubleMu