Triggers for HH->bbττ

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On behalf of the ATLAS and CMS collaborations

Double Higgs production at colliders workshop
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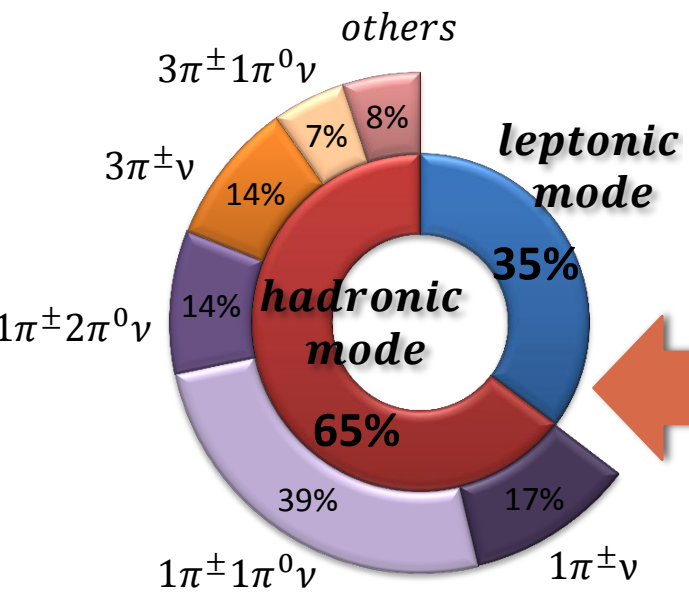
bbττ final states



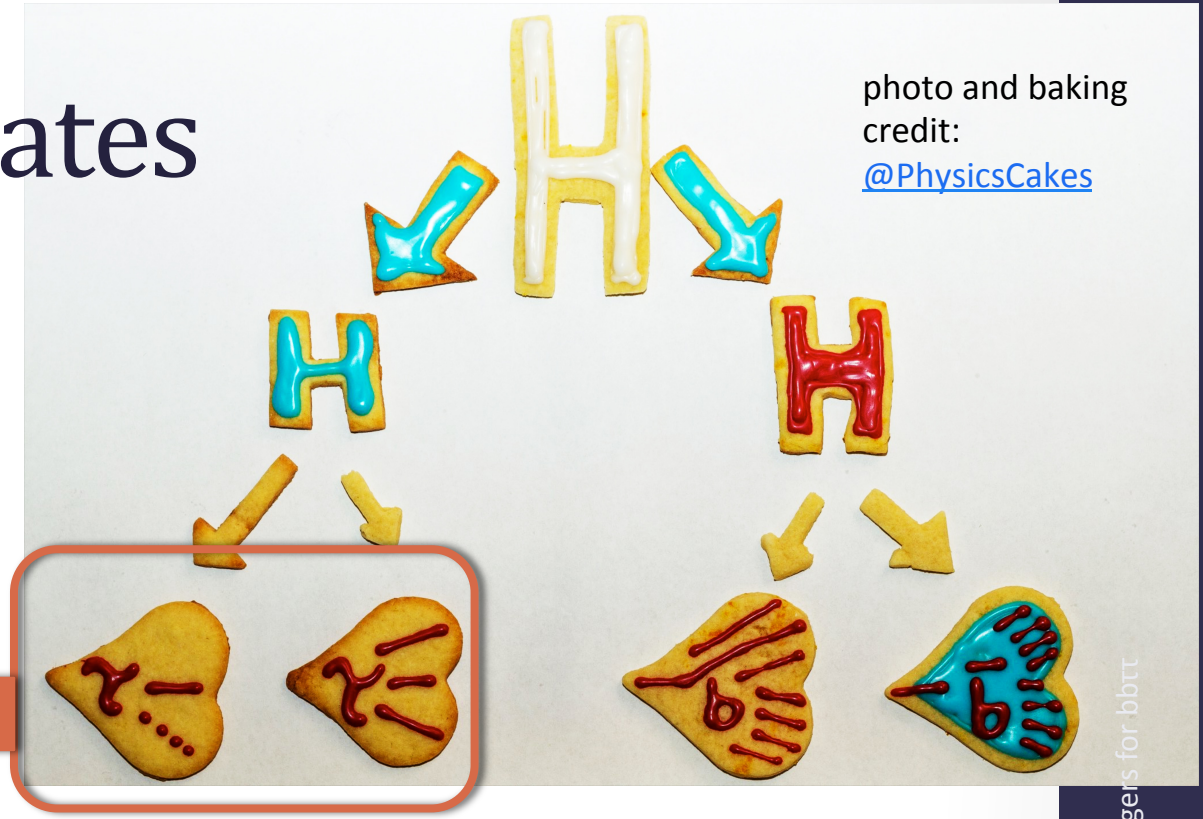


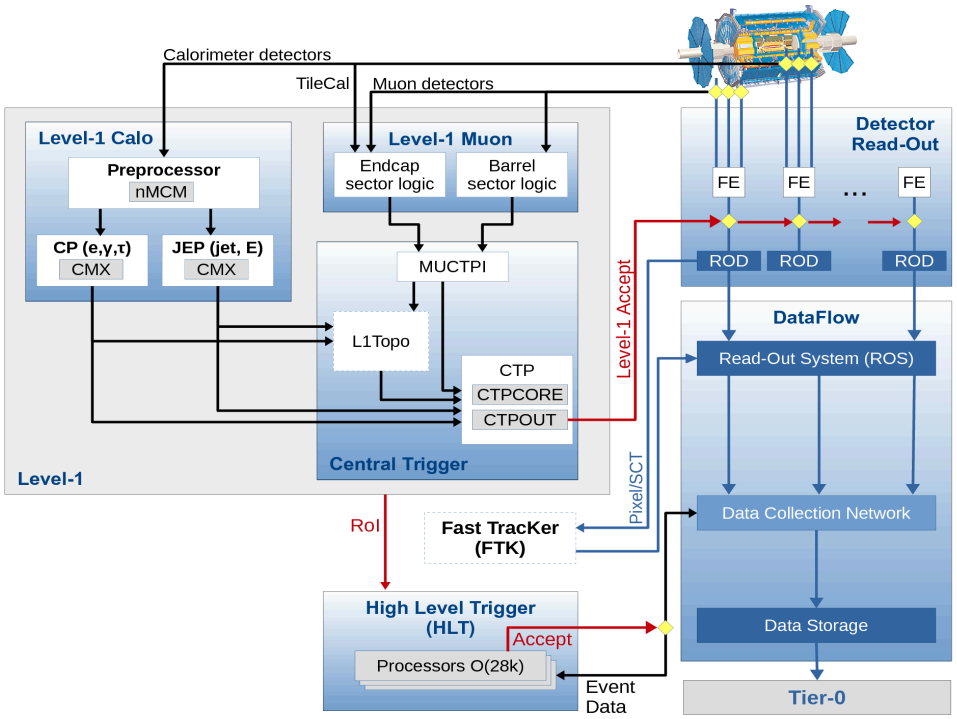
photo and baking credit: [@PhysicsCakes](#)

- Triggers based on the tau decay final state
  - single τ_{had}
  - double τ_{had}
  - single e/μ
  - e/μ + τ_{had}
  - double e or μ
  - e+μ

Neither experiment is considering bjet or MET triggers.
Lower efficiency than lepton and τ_{had} triggers for this final state.
In this talk emphasis on the τ_{had}

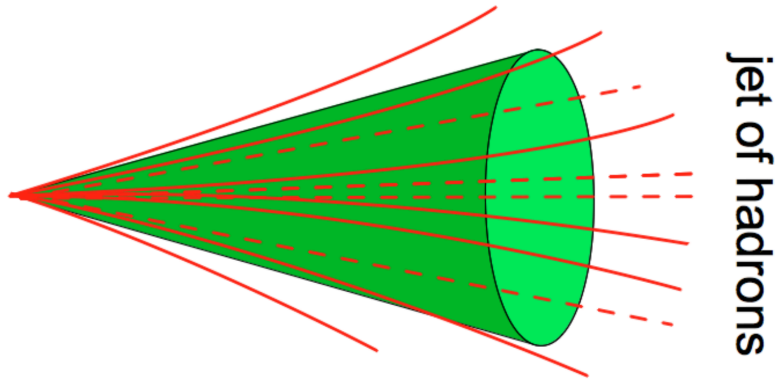
Trigger system ATLAS

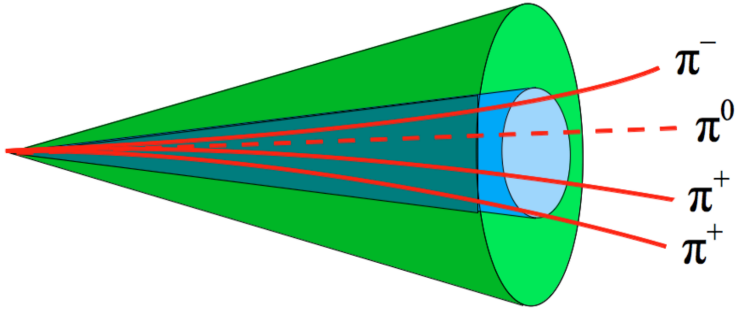
- Two-level trigger architecture.
- Level 1 trigger (L1)
  - 40 MHz → 100 kHz rate reduction
  - Fast electronics find regions of interest using calorimeter and muon data
  - L1Topo: Allows for topological selections between L1 trigger objects (e.g. ΔR) to keep L1 thresholds low
- High level trigger (HLT)
  - Fast offline-like algorithms
  - ~1 kHz output rate achieved



τ_{had} triggers ATLAS

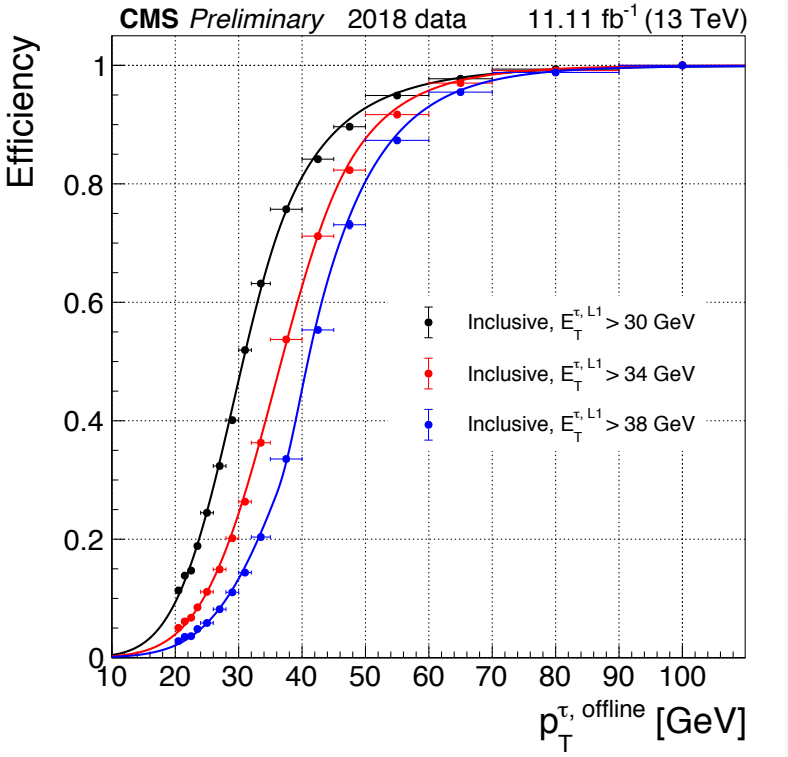
- The τ-jet triggers identify and select events with hadronic decays of the τ leptons
- L1 uses the information about the energy deposits in the electromagnetic and hadronic calorimeter to identify L1 τ_{had}
- The L1 τ_{had} candidate is passed on to the next trigger level
- The HLT uses reconstructed tracks from the the inner detector to distinguish between QCD jets and a τ_{had}





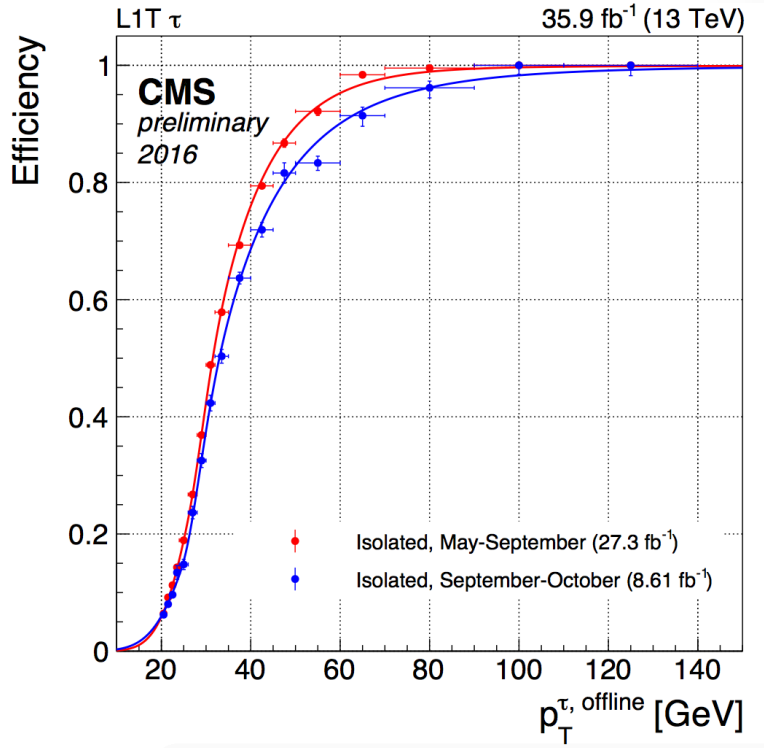
Trigger system CMS

- Level 1 Trigger (L1) - firmware based
  - 40 MHz ->100 kHz
  - L1 receives the information coming from the calorimeters and the muon chambers.
  - A decision is taken based on the presence of energy deposits compatible with physics objects such as photons, electrons, muons, jets or hadronically **decaying tau leptons** (shown on the right)
- software-based High Level Trigger (HLT)
  - reduces the rate to 1kHz
  - a streamlined version of the CMS offline reconstruction software



τ_{had} triggers CMS

- L1 trigger objects use calorimeter information
- Next step consists of a track-based isolation applied on the τ_{had} candidates.
  - Pixel tracks are reconstructed and those coming from the same primary vertex as the τ_{had} candidate are selected.
- Last step uses the particle-flow algorithm to build τ_{had} candidates
  - information from all major subdetectors.

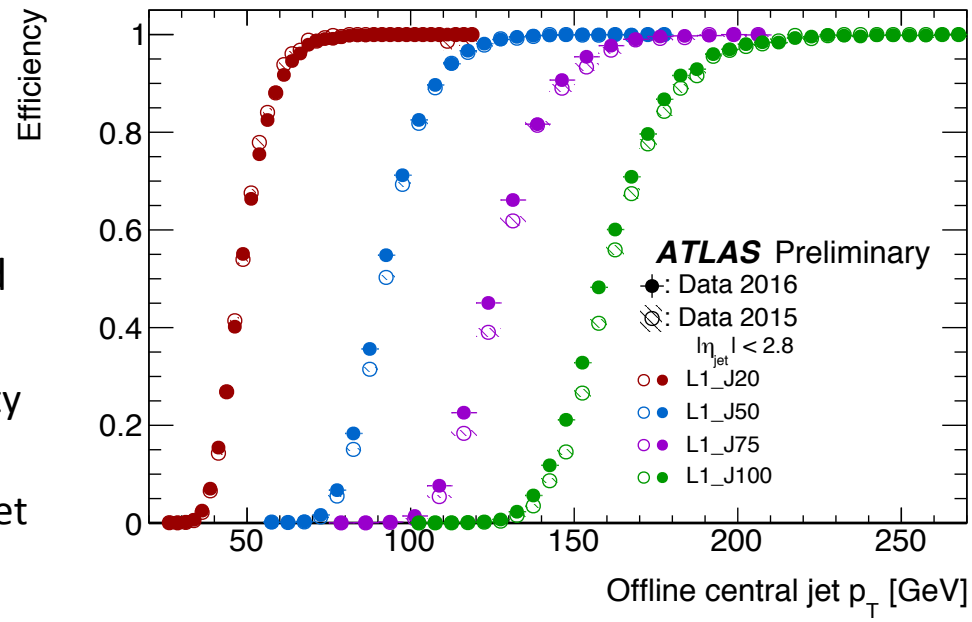


τ_{had} triggers challenges

- Rate driven by L1 due to misidentification of jets (which have a very high rate)
- Only calorimeter information available at L1 identification (jet isolation and shape)
- ATLAS makes requirements on additional jets at L1 to reduce rate further.
- ATLAS uses tracking information provided in the HLT that allow for offline-like reconstruction and identification.
- CMS rely on track-based isolation to reduce the rate
- CMS applies Particle Flow reconstruction

$\tau_{had}\tau_{had}$ ATLAS

- Single τ_{had} trigger : p_T>80 to p_T>160 GeV
  - lowest unprescaled single τ_{had} trigger
  - additional ID criteria
  - threshold depends on run
- Two τ_{had} trigger : p_T>25 GeV and p_T>35 GeV respectively
  - In 2016 instantaneous luminosity increased
  - additional requirement of a L1 jet p_T>25 GeV (L1_J25)
- In both cases τ_{had} candidates satisfy reconstruction criteria
- Only events that don't pass the single τ_{had} trigger are considered for the two τ_{had}trigger
- Leading jet p_T > 80 GeV for triggers requiring L1_J25 in order to stay on plateau

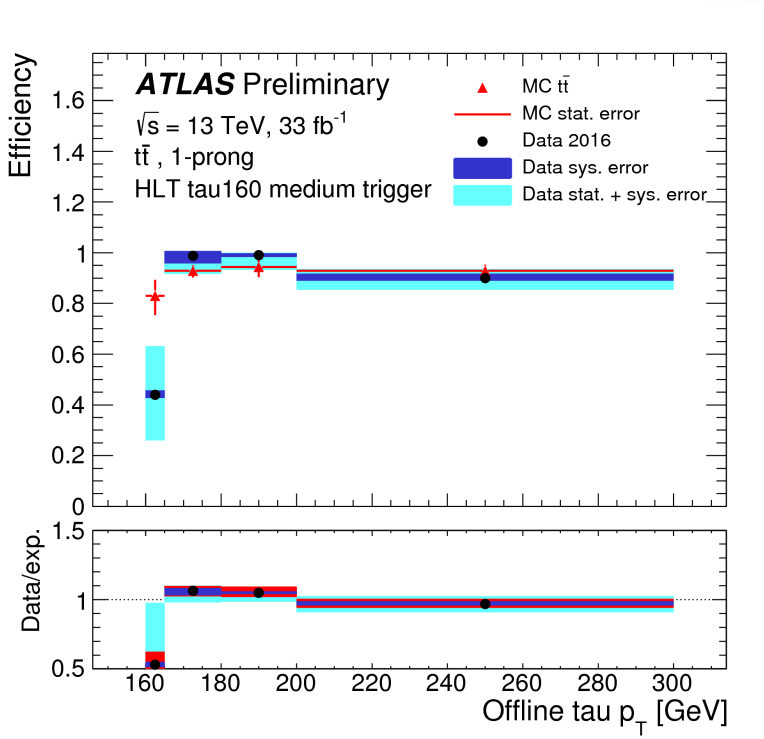


Offline cuts on τ_{had} :
for single τ_{had} trigger +20 GeV on online p_T cut.
for two τ_{had} trigger +5GeV on online cut

$\tau_{had}\tau_{had}$ ATLAS

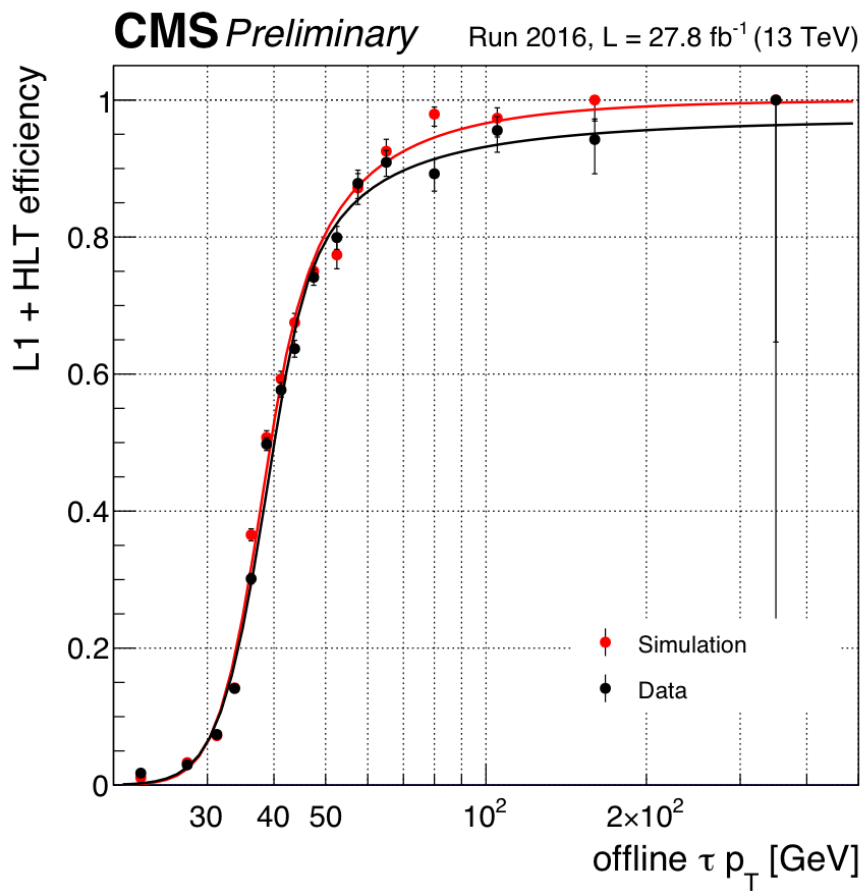
2018 thresholds

- Single τ_{had} p_T>160 GeV
  - lowest unprescaled single τ_{had} trigger already since 2016
- Di-τ_{had} triggers: Previous thresholds can sustain the rate
- Studying several options
  - p_T>80 + p_T>60 GeV
  - p_T> 40 + p_T>35 GeV + L1J25 (requires p_T>80 GeV cut offline on lead jet pT)
  - p_T> 35 + p_T> 25 GeV + 2L1J12 (requires p_T>40-45 GeV cut offline on leading and sub-leading jet pT)



$\tau_{had}\tau_{had}$ CMS

- Di-τ_{had} triggers only used in analysis
- p_T>35 GeV for both τ_{had}
- Apply p_T> 45 GeV offline
- Efficiency of one "leg" of the τ_{had} shown



$\tau_{had}\tau_{had}$ CMS

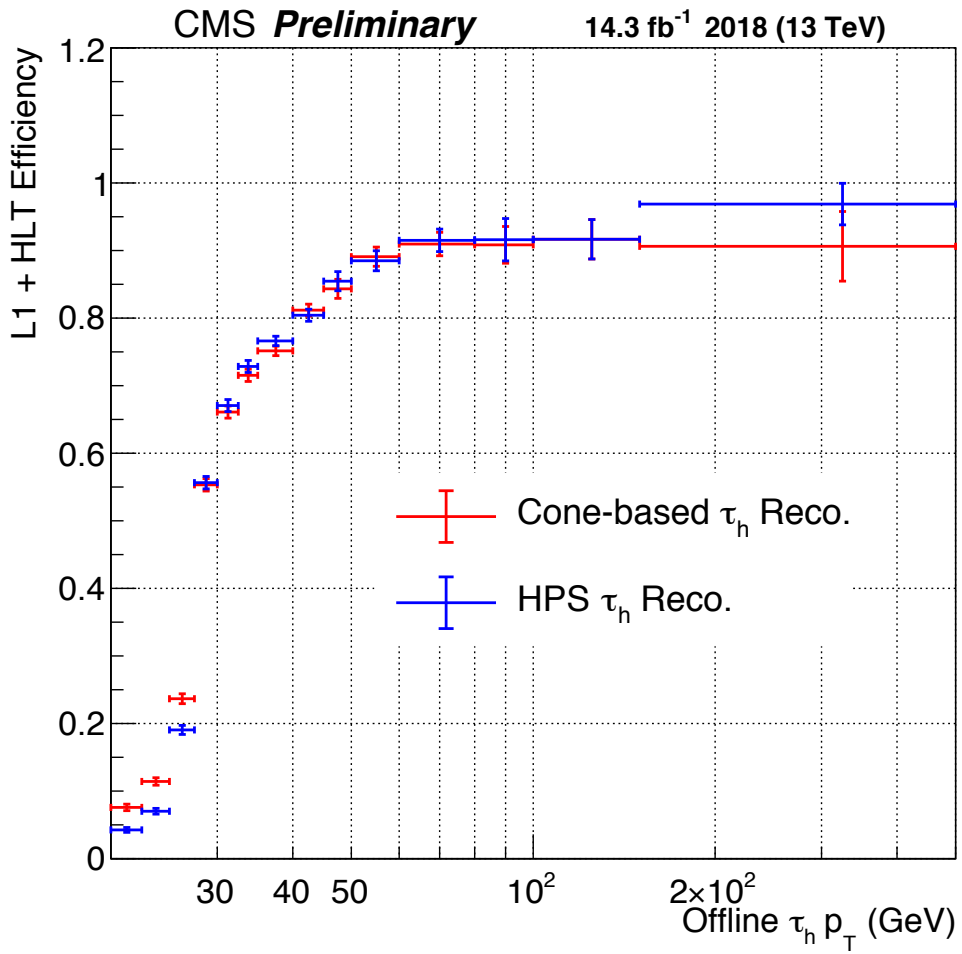
- 2018 thresholds
  - p_T>35 GeV+ isolation for both τ_{had}
  - p_T>40 GeV+looser isolation for both τ_{had}

with the HPS the isolation can be even looser

- Hadron Plus Strips (HPS) τ_{had} reconstruction algorithm
  - used for offline analysis
  - June 2018 τ_{had} trigger paths switched HPS reconstruction
  - The cone-based τ_{had} algorithm uses a signal cone ranging from ΔR = 0.08 to 0.12 which contains all τ decay products

$\tau_{had}\tau_{had}$ CMS

- The HPS τ_{had} :
- Charged hadrons and photons within the signal cone combined
- Combinations ranked based on their consistency with a τ_{had} decay.
- The highest ranked combination is selected as the reconstructed τ_{had} candidate.

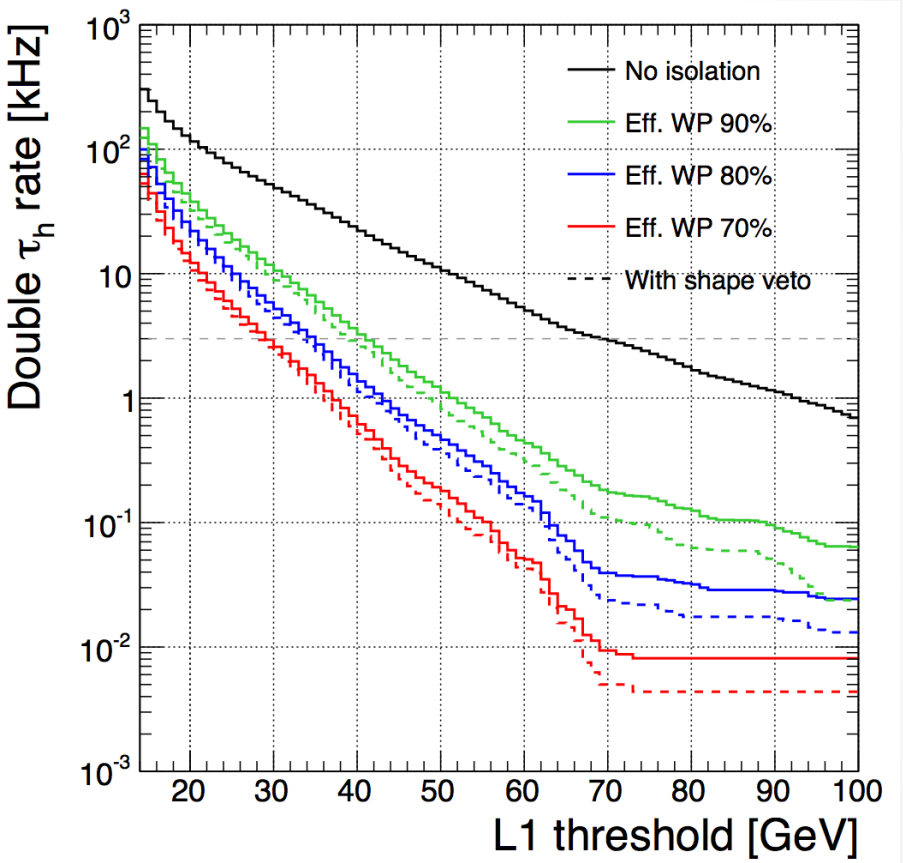


offline cut at 45 GeV

τ_{had} trigger rates

- L1 CMS: ~3 kHz
- HLT two τ_{had} trigger CMS:
  2 x τ_{had} p_T>35 GeV
  rate:50 Hz (59Hz in 2018)

- L1 ATLAS: ~5 kHz
- HLT two τ_{had} trigger ATLAS:
  τ_{had} p_T>35 GeV
  and τ_{had} p_T>35 GeV
  rate: ~ 25 Hz

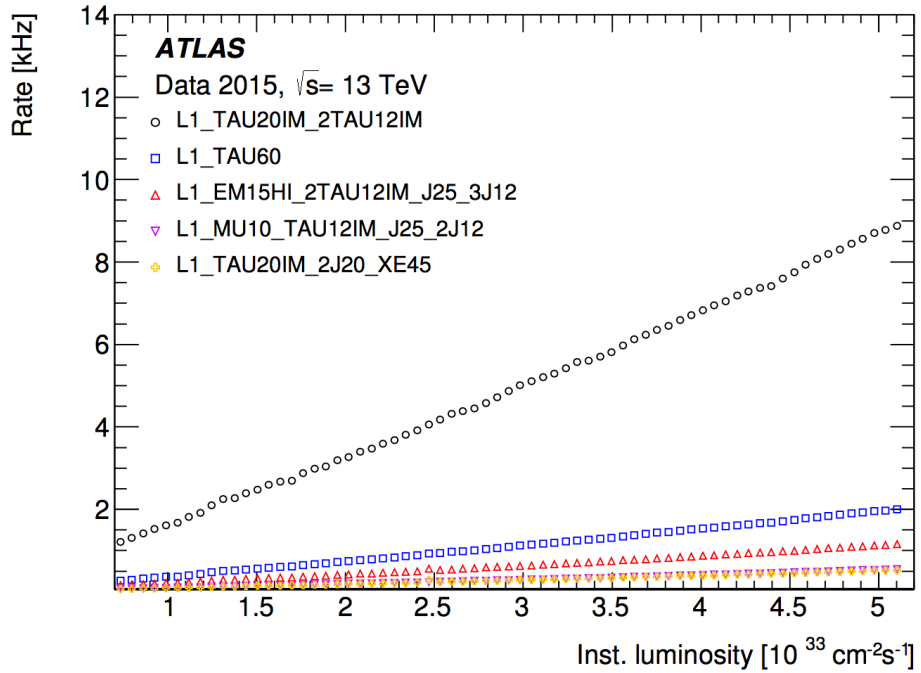


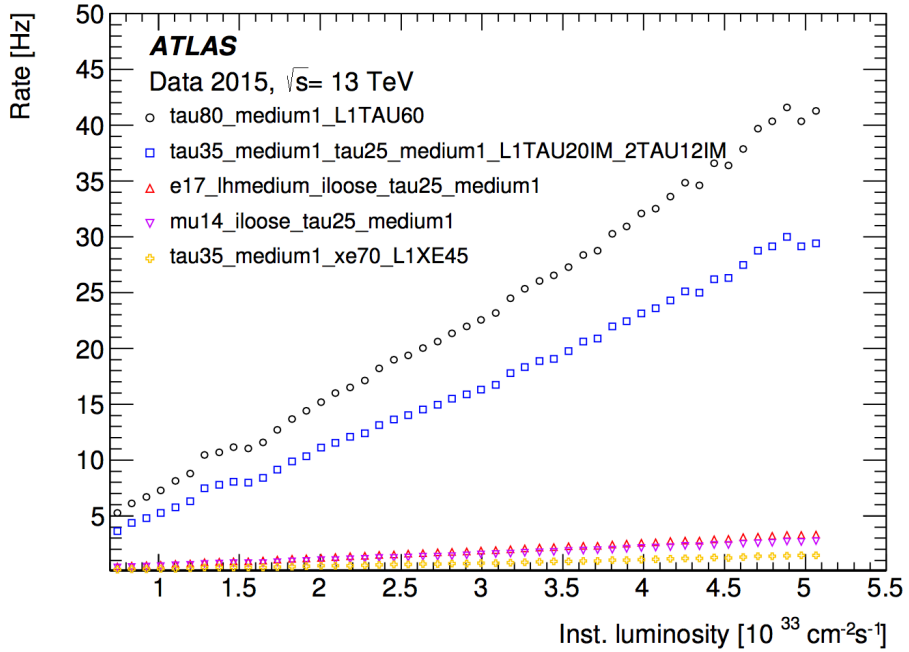
60% working point used offline

τ_{had} trigger rates

- L1 CMS: ~3 kHz
- HLT two τ_{had} trigger CMS:
  2 x τ_{had} p_T>35 GeV
  rate:50 Hz (59Hz in 2018)

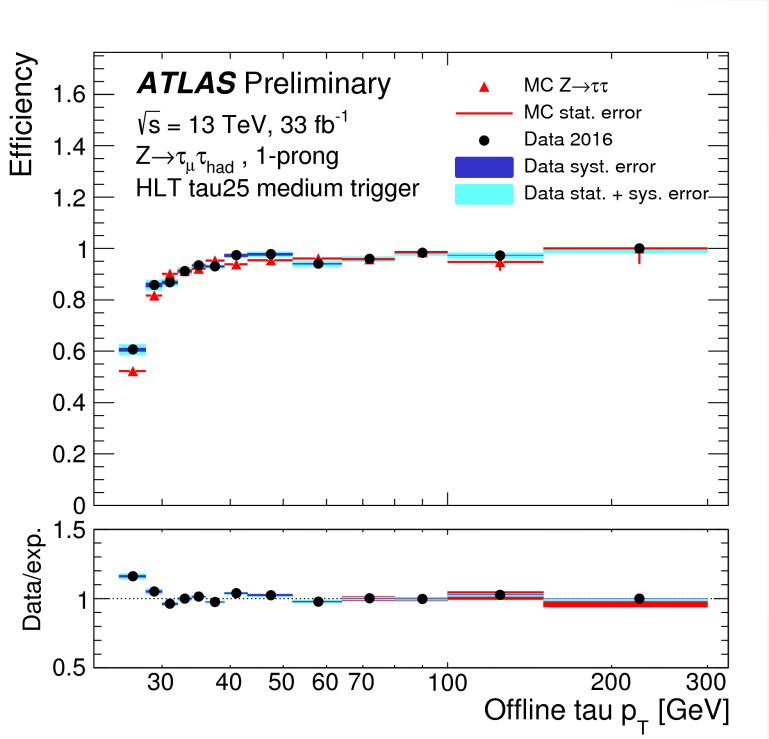
- L1 ATLAS: ~5 kHz
- HLT two τ_{had} trigger ATLAS:
  τ_{had} p_T>35 GeV
  and τ_{had} p_T>25 GeV
  rate: ~ 25 Hz





$\tau_\mu\tau_{had}$ and $\tau_e\tau_{had}$ ATLAS

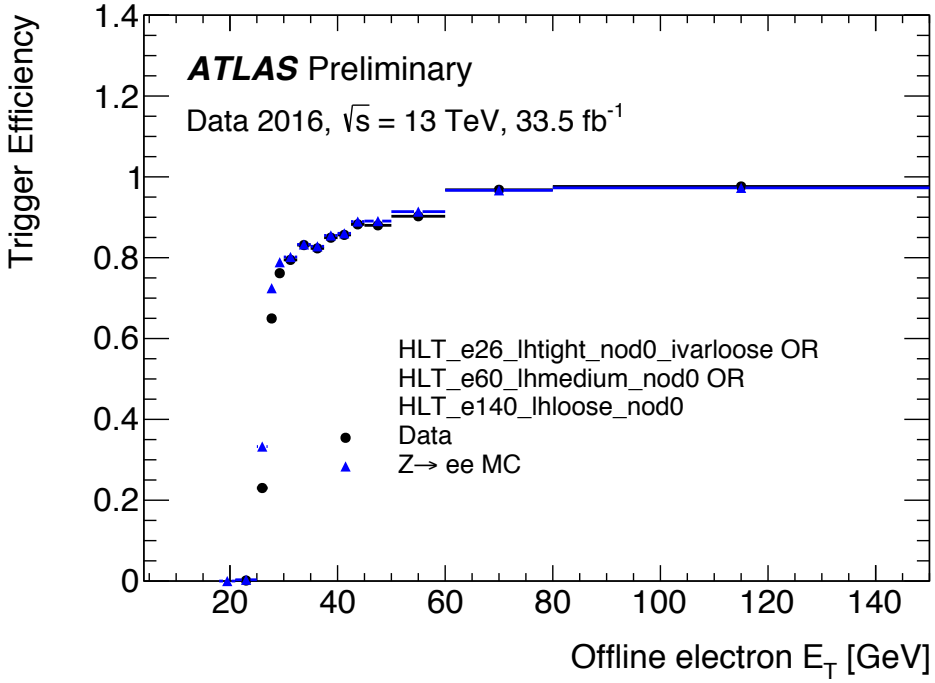
- Single lepton trigger: p_T>24-26 GeV
  - lowest unprescaled single lepton trigger
  - additional reconstruction requirements and isolation requirements
- Lepton+ τ_{had} trigger:
  - mu p_T>14 GeV
  - e p_T>17 GeV
  - τ_{had} p_T>25 GeV
  - additional L1_J25 from 2016 onwards
- The single lepton trigger and and the lepton + τ_{had} trigger are used in mutually exclusive regions, defined by offline p_T selection
- Leading jet p_T > 80 GeV when requiring L1_J25 in order to stay on plateau



Offline cuts on p_T:
for e and μ +1GeV over the online threshold
for τ_{had} +5 GeV over online threshold (30 GeV)

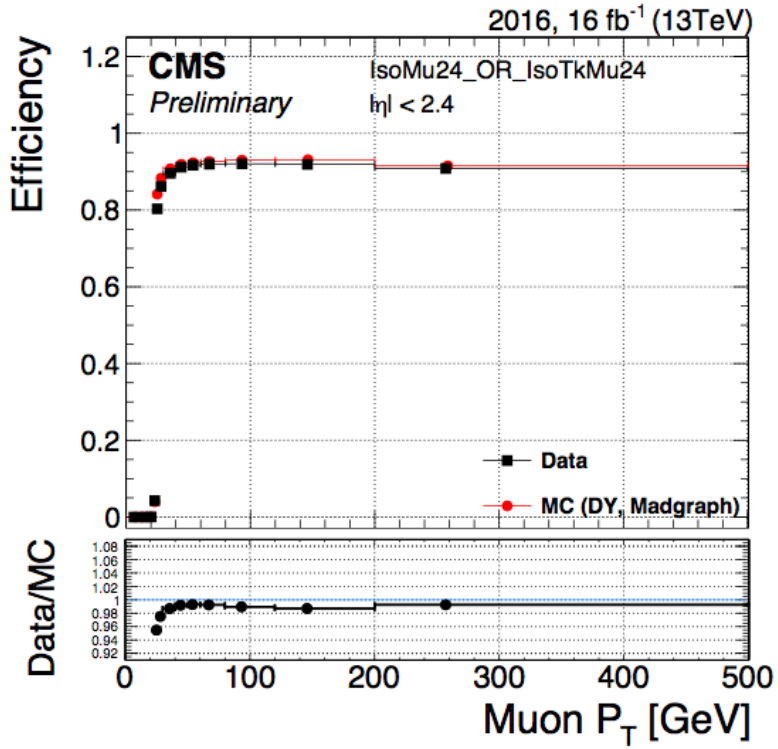
$\tau_\mu\tau_{had}$ and $\tau_e\tau_{had}$ ATLAS

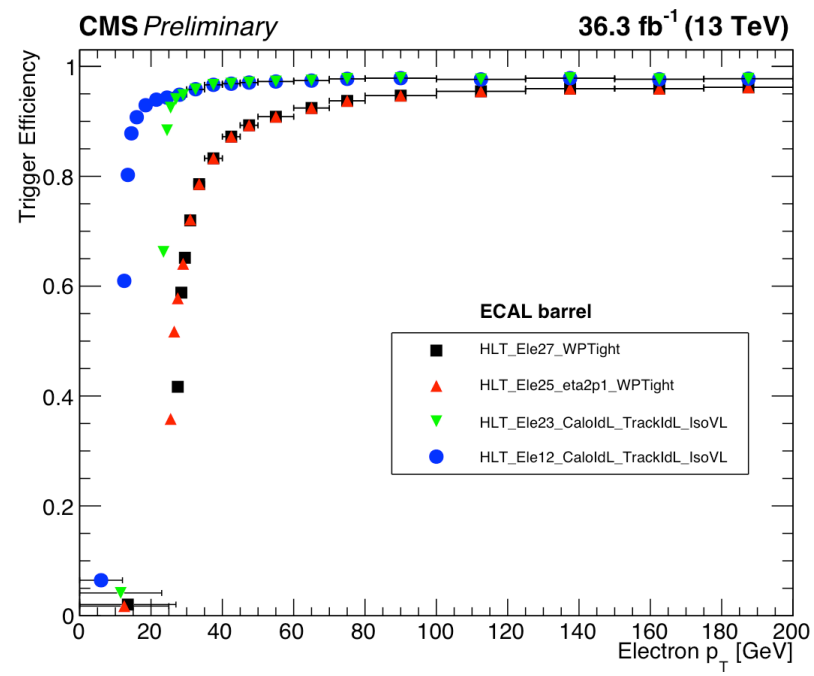
- 2018 thresholds single lepton trigger e and μ p_T>26GeV
  - lowest unprescaled single lepton triggers since 2016
- 2018 thresholds LTT unchanged
  - mu p_T>14 GeV
  - e p_T>17 GeV
  - τ_{had} p_T>25 GeV
- Lepton+ τ_{had} trigger: L1J25 requirement will (?) replaced with 2J12



$\tau_\mu\tau_{had}$ and $\tau_e\tau_{had}$ CMS

- Single lepton trigger
- p_T>21 GeV for μ
- p_T>27 GeV for e
- additional isolation requirements

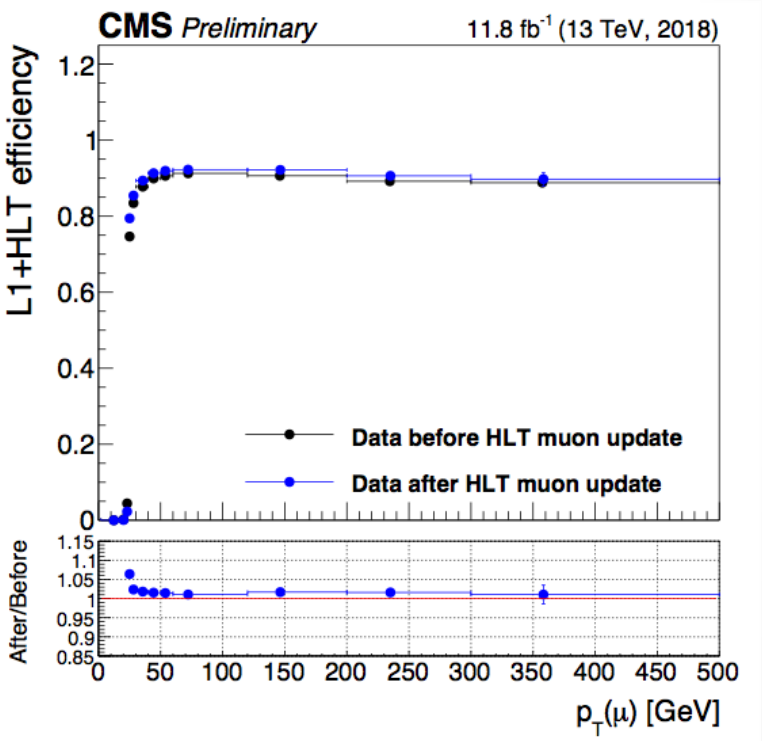




Offline cuts on μ p_T > 23 GeV and e p_T > 27GeV

$\tau_\mu \tau_{had}$ and $\tau_e \tau_{had}$ CMS

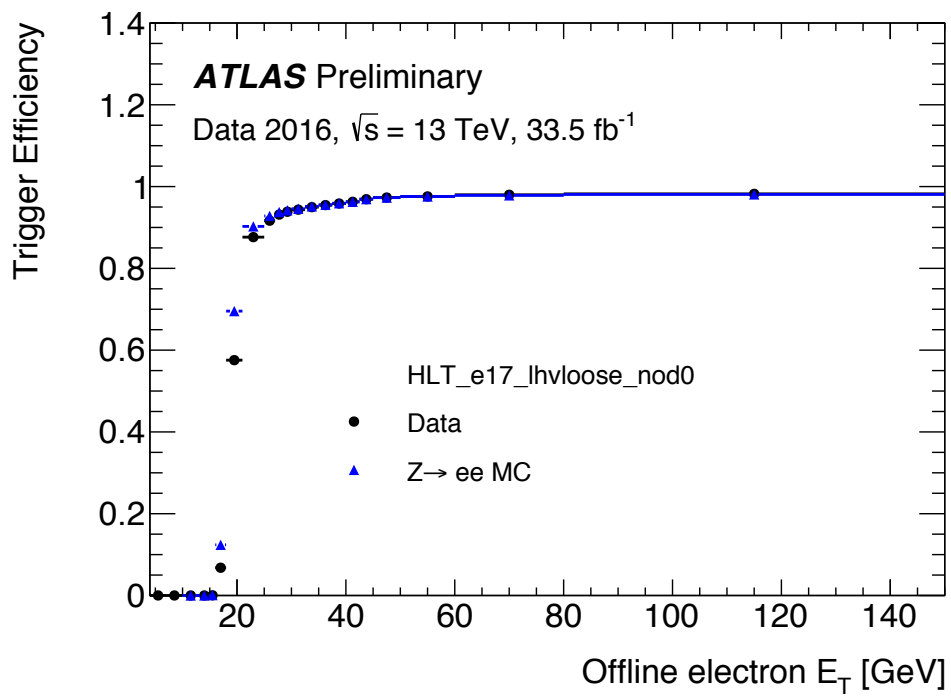
- Single muon trigger 2018 p_T>24 GeV +Isolation and p_T>50 GeV no Isolation
- in May 2018, the muon reconstruction at HLT was updated
  - more seeds for the muon track building ->efficiency
  - more iterative tracking is added to the muon tracking algorithm
  - simple ID on HLT muons
  - improvement in efficiency shown



- HPS for lepton+ τ_{had} triggers
- μ p_T > 20 GeV and τ p_T> 27 GeV
- Might replace single lepton triggers

$\tau_\mu\tau_e$, $\tau_\mu\tau_\mu$ and $\tau_e\tau_e$ ATLAS

- Plan to include this channel for end of run2
- single and di-lepton triggers
- Only events that fail single lepton trigger are considered for the di-lepton triggers (Similarly to $\tau_{had}\tau_{had}$ channel)
- Dilepton triggers
  - 2 x e pt>17GeV
  - e p_T>17 GeV and μ p_T >14 GeV
  - 2 x μ p_T >14 GeV



$\tau_\mu\tau_e$, $\tau_\mu\tau_\mu$ and $\tau_e\tau_e$ CMS

- No plans for this search in CMS (that I know of ☺)
- However other searches with similar final state e.g. HH->WWbb
- Overlaps with bbττ?

- Example triggers:
  - e p_T>23 GeV and e p_T>12 GeV isolation requirements
  - 2 x e p_T>33 GeV and e p_T>12 GeV No isolation requirements

Summary

- Trigger systems and performance very similar in both experiments
- Improvements for 2018 in both channels
  - ATLAS: might not require J25 in tau triggers->80 GeV offline for leading jet
  - CMS: HPS algorithm for τ_{had} and improved muon ID
- Trigger thresholds similar
  - both experiments apply additional criteria in isolation and reconstruction
- HLT rate higher for CMS
- In HH->bb$\tau_{had}\tau_{had}$
  - ATLAS is using single τ_{had} and di-τ_{had} triggers
  - CMS using di-τ_{had}
- In HH->bb$\tau_{lep}\tau_{had}$
  - ATLAS is using single lepton and lepton plus τ_{had} triggers
  - CMS using single lepton triggers
- ATLAS to add HH->bb$\tau_{lep}\tau_{lep}$ channel
  - single and di-lepton triggers
  - di-lepton triggers thresholds 14-17 GeV