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Triggering on electrons, photons, tau leptons, jets and energy sums with the CMS Level-1 Trigger

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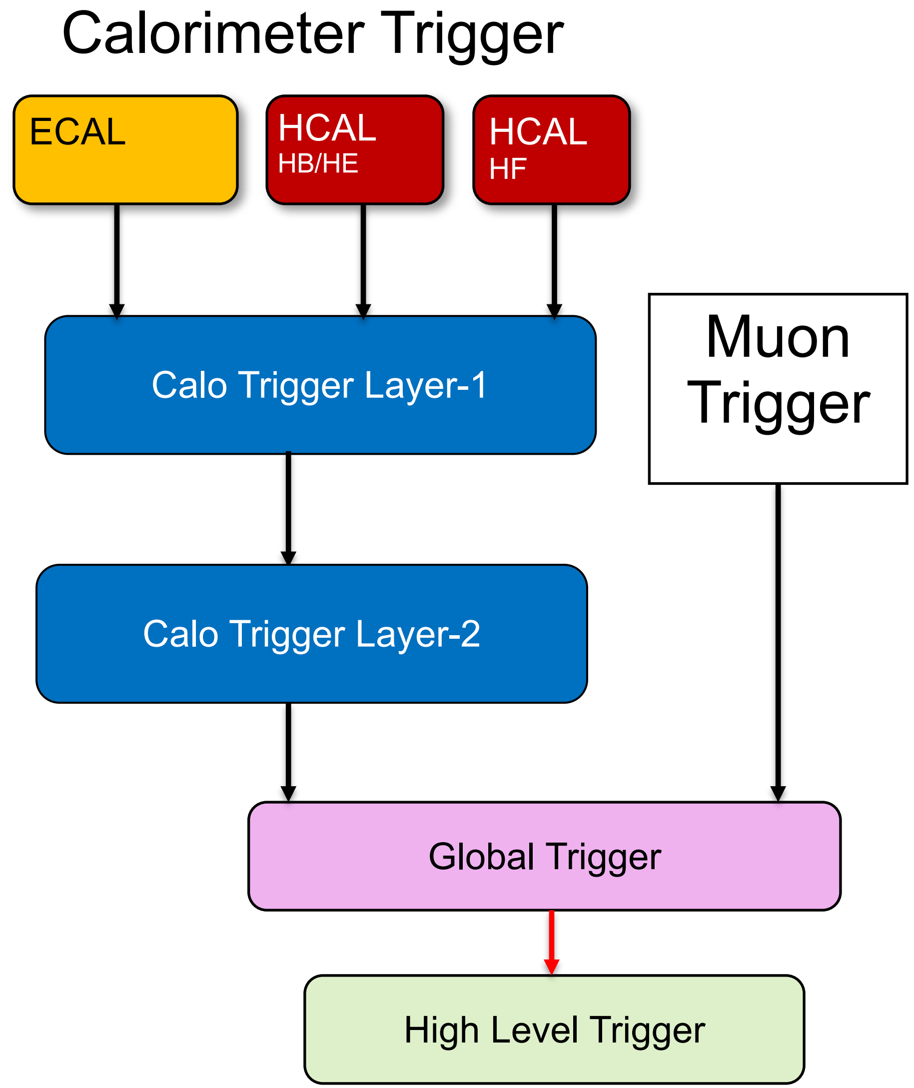
-- On behalf of the CMS Collaboration

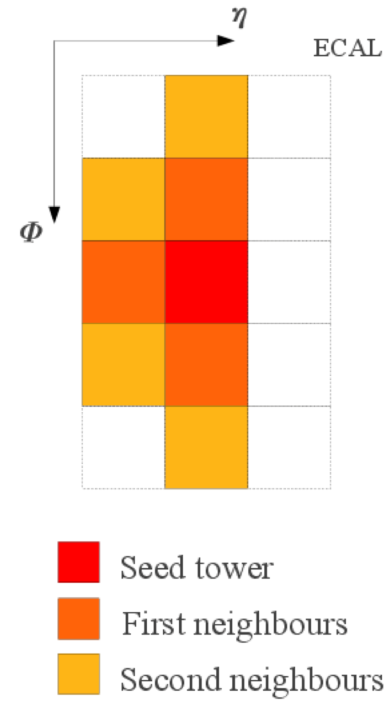
Outline

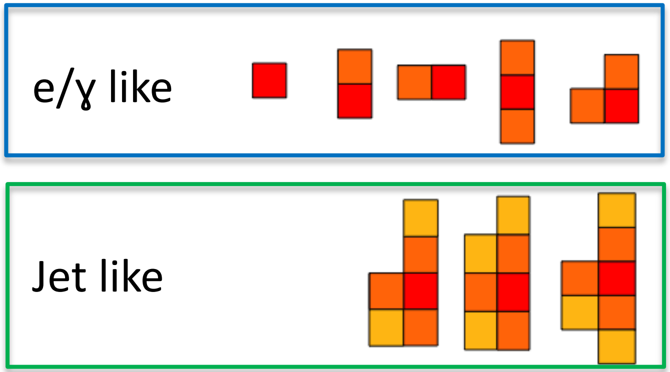
- Trigger Algorithm
  - Electron and photon
  - Hadronic tau
  - Jets
  - Energy sums
- Global Trigger
- Summary



Level-1 e/γ Algorithm

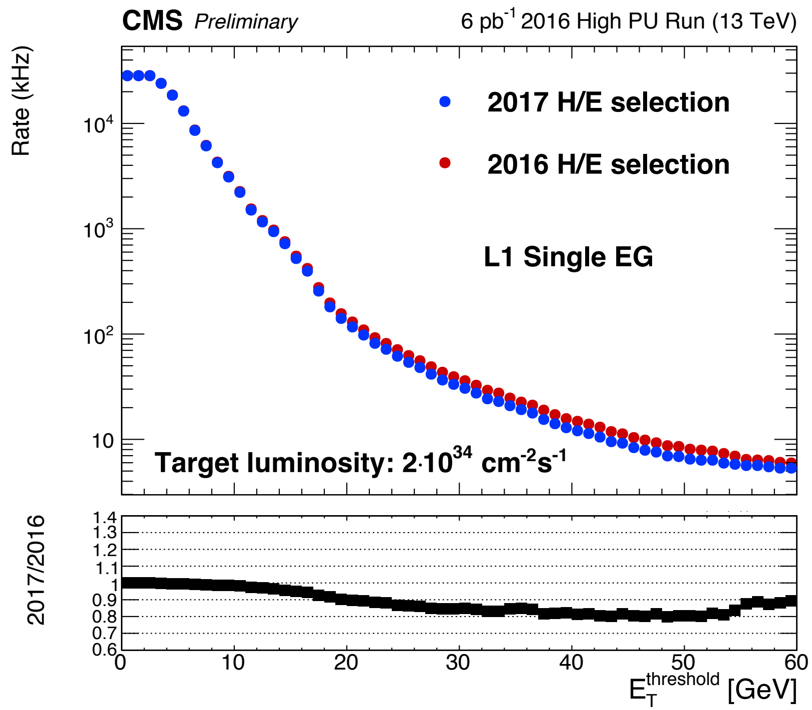
- Dynamic clustering
  - Improved energy containment
  - Minimize effect of pile-up
  - Improved energy resolution
- Cluster shape veto
  - Discriminate using cluster shape and EM energy fraction (H/E) between e/γ and jets
- Calibration
  - e/γ cluster energy calibrated as function of E_T, η and cluster shape



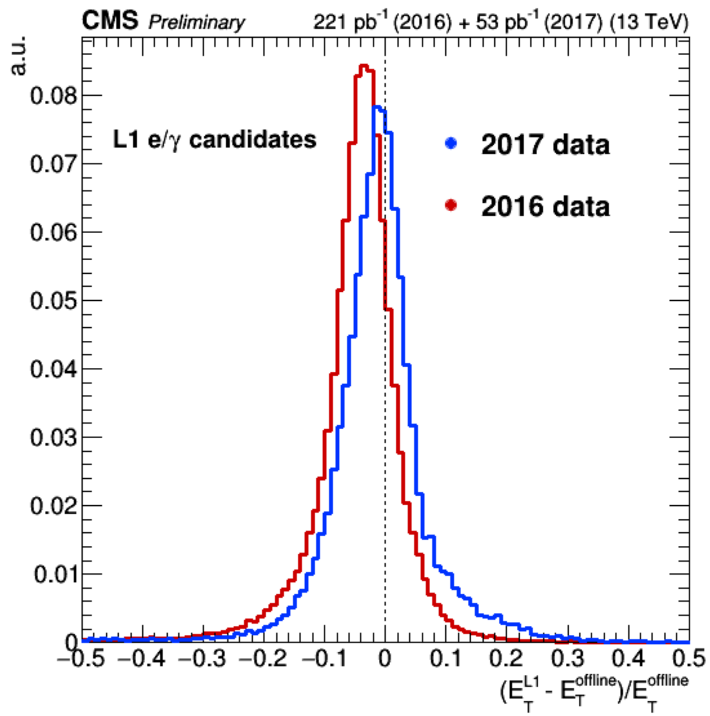


Update from 2016

- 2016: tight H/E applied for seed tower
- 2017: Extended H/E with neighboring towers
  - Applied tight H/E on seed tower
  - No H/E applied for E+H < 5GeV
  - loose H/E threshold applied for E+H > 5 GeV for neighboring towers

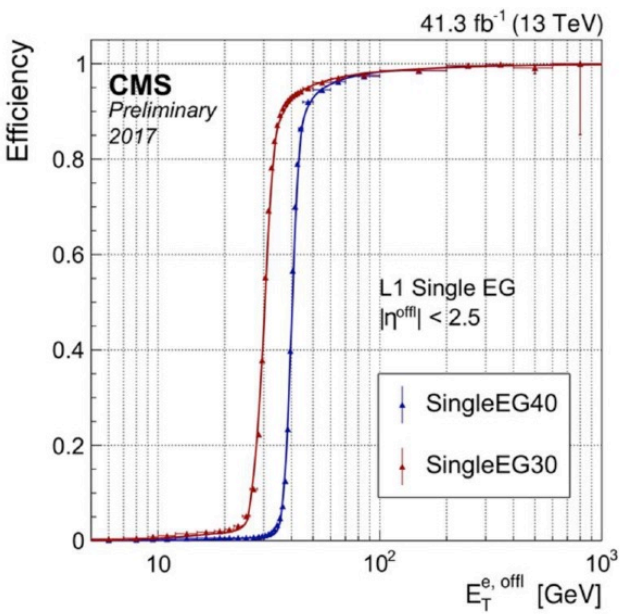


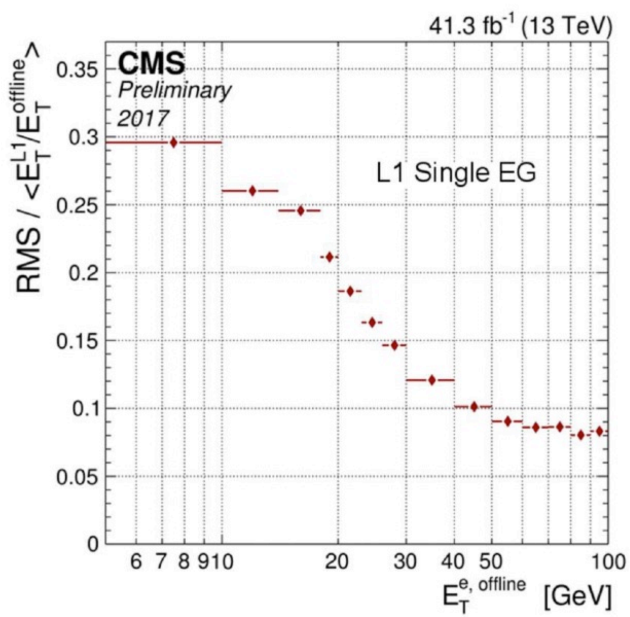
Recalibration of the Calorimeter level-1 trigger objects allowed to mitigate the detector related change in energy response with respect to running conditions in 2016.

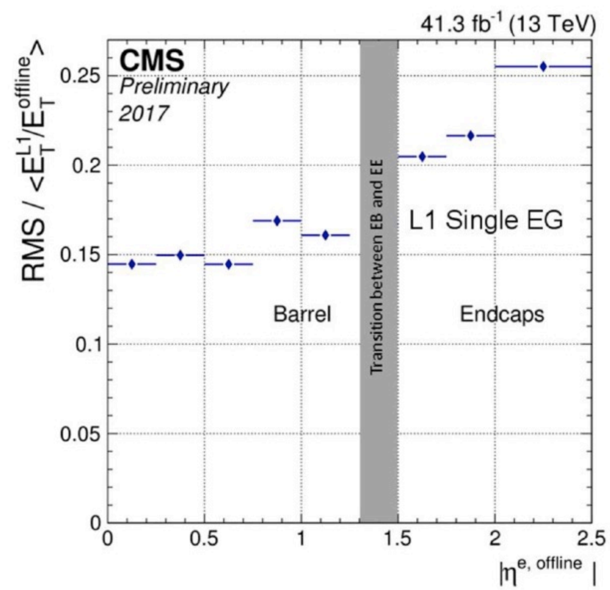


e/γ Performance

- Sharp trigger efficiency curves for an e/γ object as a function of E_T of the offline reconstructed electron, measured with Tag & Probe method on data
- Level-1 e/γ trigger energy resolution with respect to E_T and η of offline reconstructed electron
  - For higher η, the corrections to crystal responses are more consequent due to radiations and ECAL front end electronics has higher noise

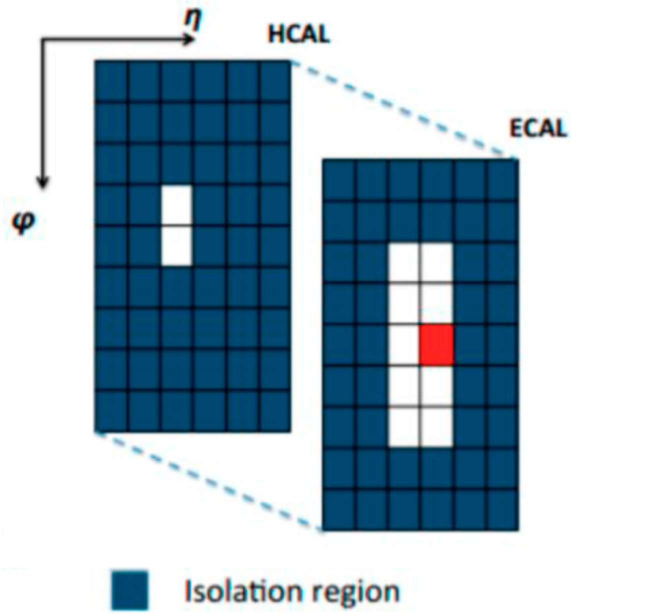


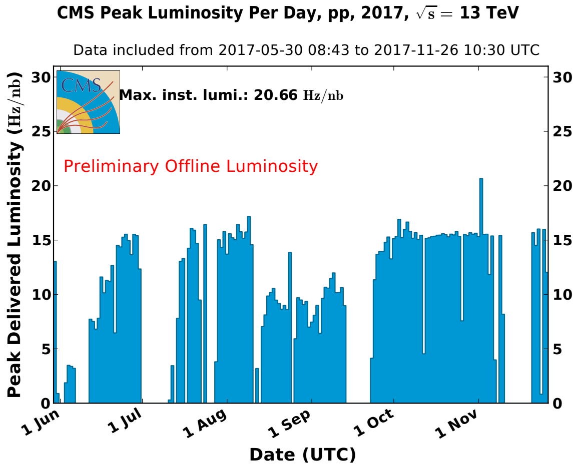


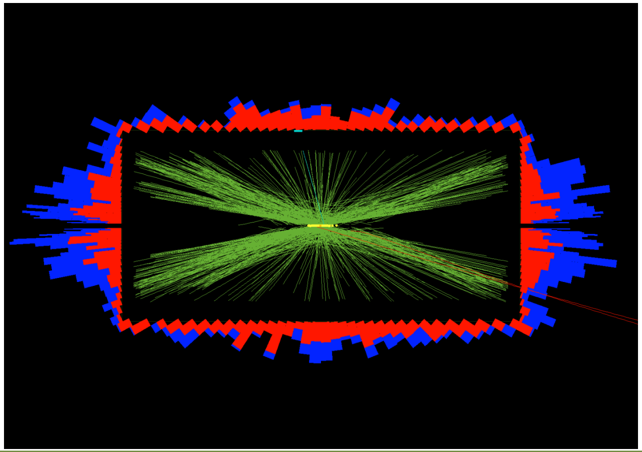


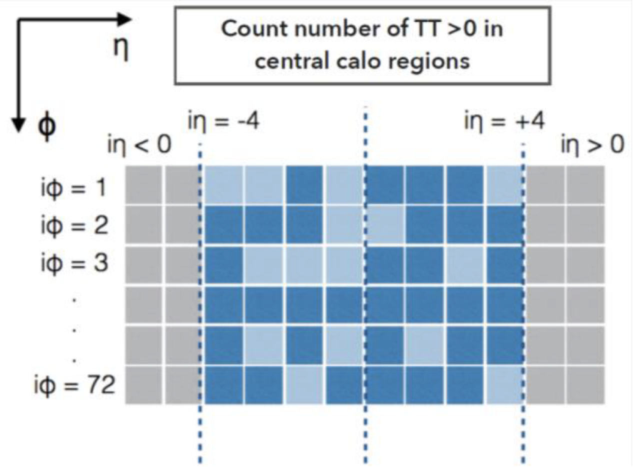
e/ɣ Isolation

- Create isolation annuli (6x9 TT) from ECAL and HCAL around cluster
- Isolation energy requirement parametrized as a function of PU and η
- The number of PU is estimated based on the number of trigger tower (TT) above threshold within the central region of calorimeter towers



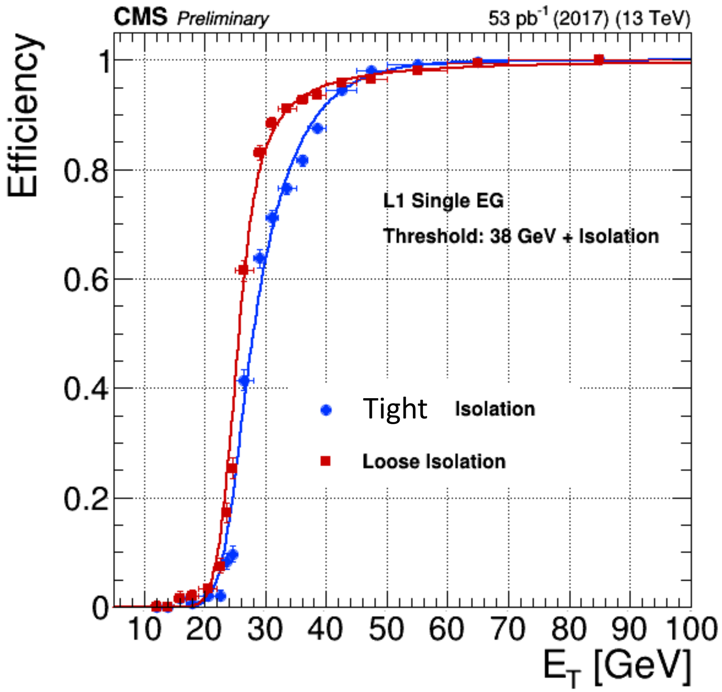


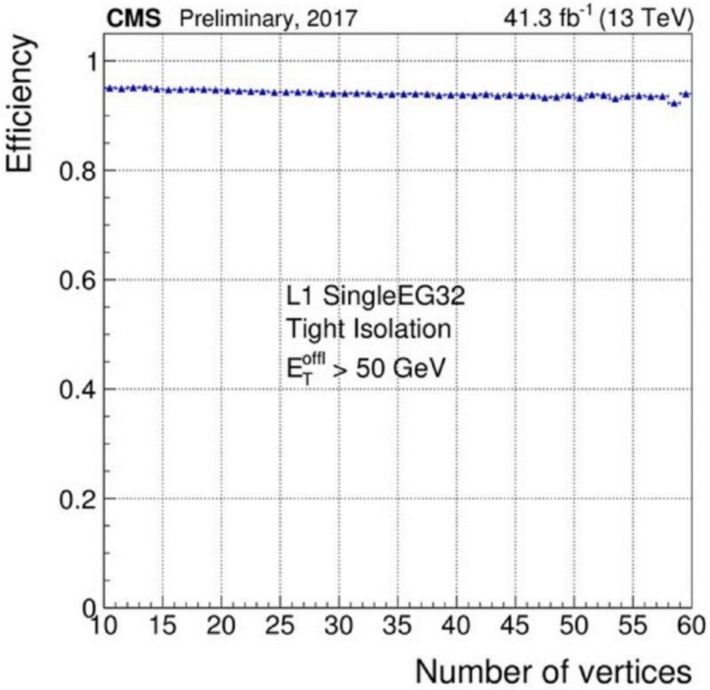




Isolated e/ɣ Performance

- Two Isolation working points (Tight and Loose) are used and correspond to two different relaxation schemes, as a function of E_T
  - Flexible e/ɣ object for single trigger with high threshold or correlated trigger with lower threshold
- Flat trigger efficiency as a function of the number of offline reconstructed vertexes (~ number of PU).



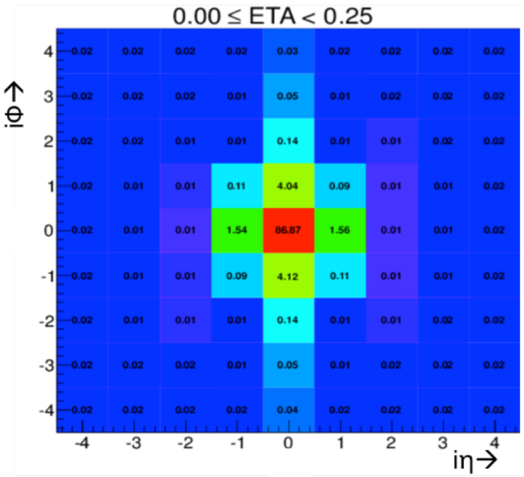


Hadroinc Tau on Calorimeter

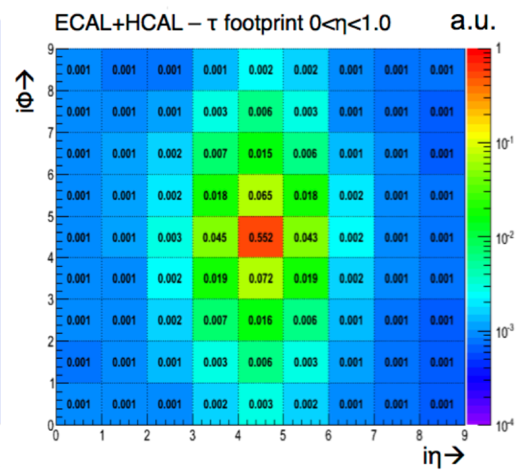
- Different footprints of electron showers and tau energy deposits averaged over a large statistics.

- Different tau decay modes has its individual tau footprint

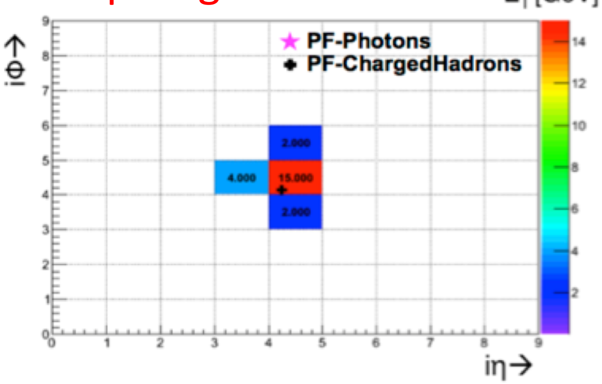
e/γ



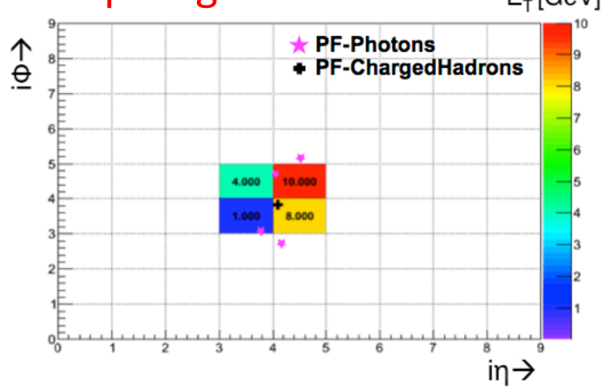
τ



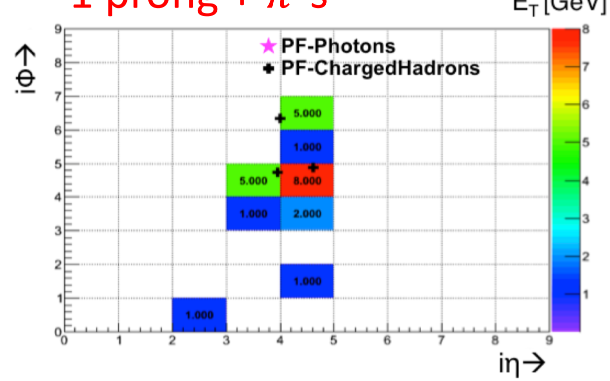
1 prong



3 prong



1 prong + π^0s



Level-1 Tau Algorithm

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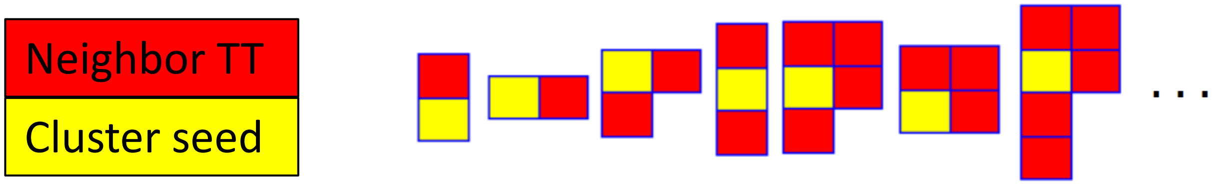
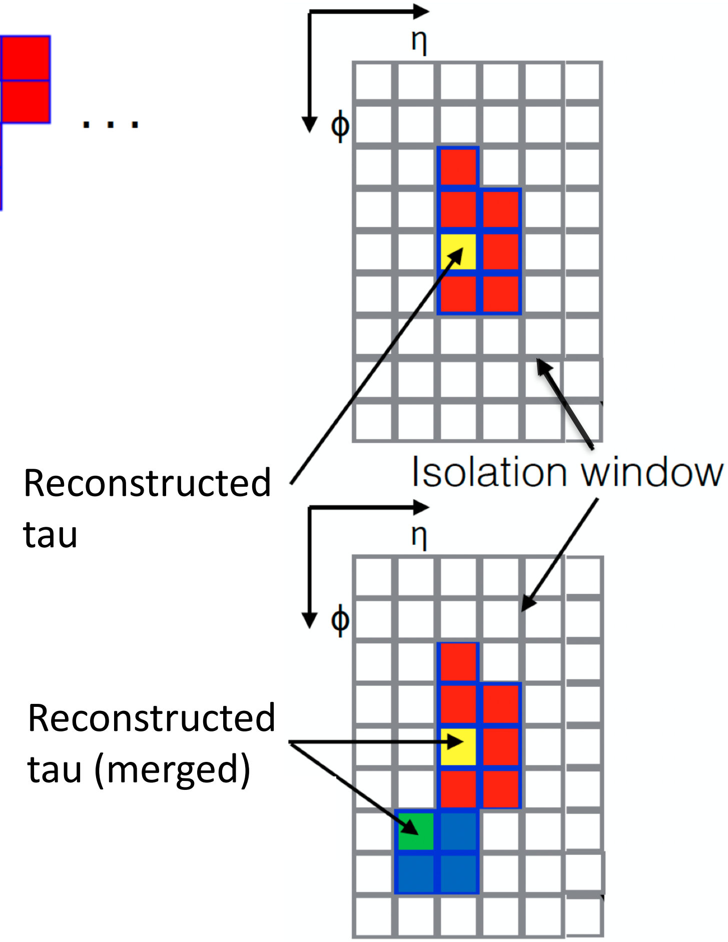
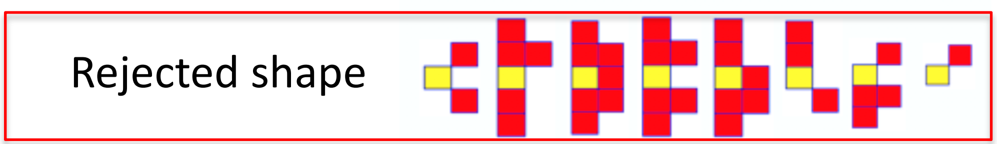


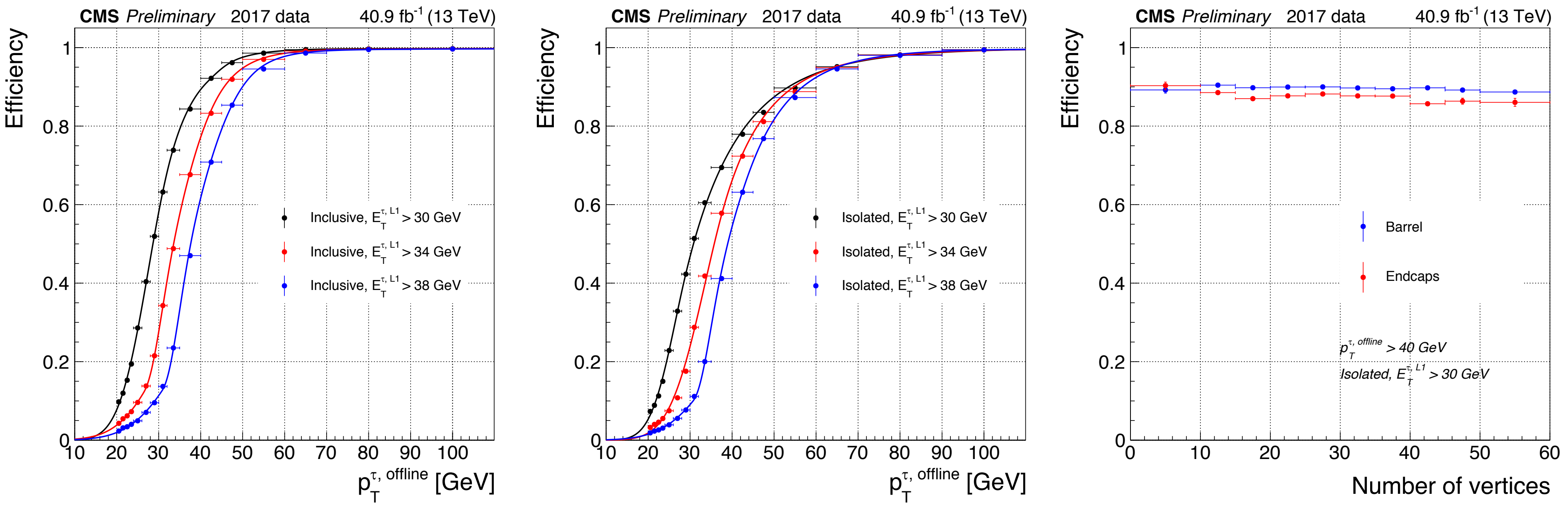
- Similar to e/ɣ, dynamic clustering with tau shapes, forms TT "cluster"
- Two clusters can be merged (based on relative neighbor position) to better reconstruct multi particles hadronic tau decays (~15%)
- Apply shape veto to reject background
- Isolation energy is computed as the energy in a 6x9 window around the cluster seed minus the candidate energy. Compared to threshold as a function of PU, $\eta(\tau)$, $E_T(\tau)$





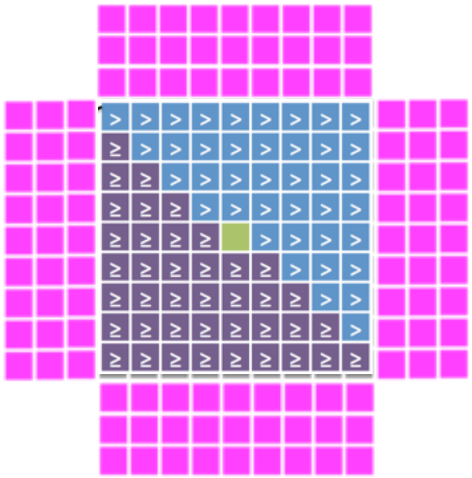
Level-1 Tau Efficiency

- Trigger efficiency measured through tag-and-probe method from $Z \rightarrow \tau_h \tau_\mu$ data
- Isolation is tuned to a given threshold, for double isolated tau trigger, optimized for Physics
  - The increase acceptance has played a major role in the observation of the Higgs $\rightarrow \tau\tau$ in 2017.
- Isolated tau maintain high efficiency across wild range of pileup



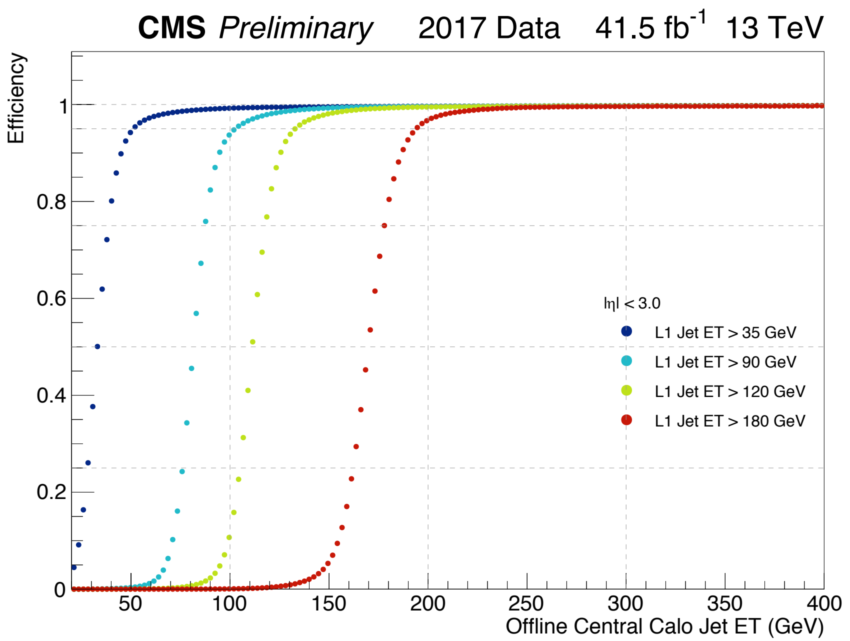
Level-1 Jets Algorithm

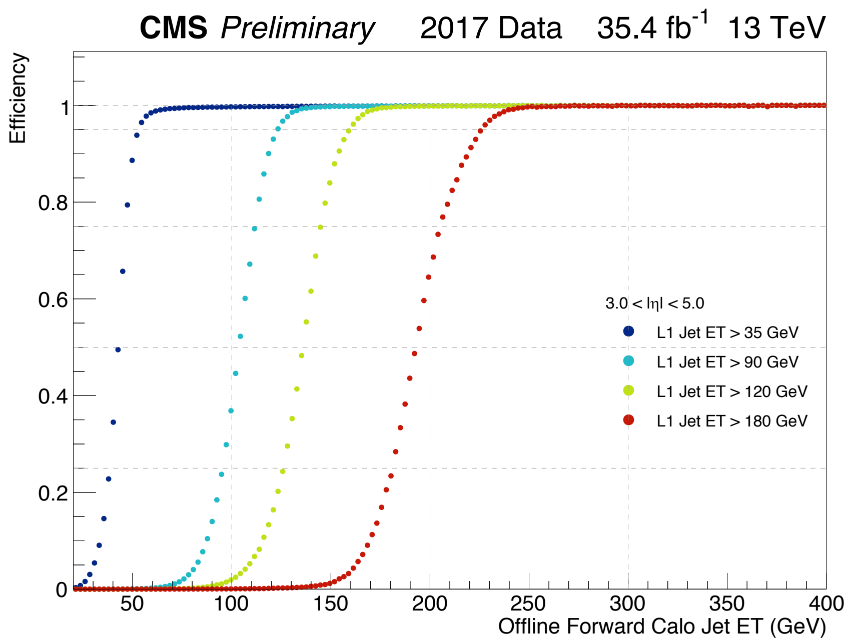
- Sliding window jet algorithm
  - Search for seed energy above threshold
  - Apply mask to avoid double counting
  - Sum 9x9 trigger towers to approximate anti-k_T R=0.4 jet used offline
- Pile-up subtraction
  - Consider four 3x9 areas around jet window
  - Subtract sum of energy in lowest three areas from jet energy
- Calibration
  - Correct jet energies as a function of jet E_T and η



Level-1 Jet Performance

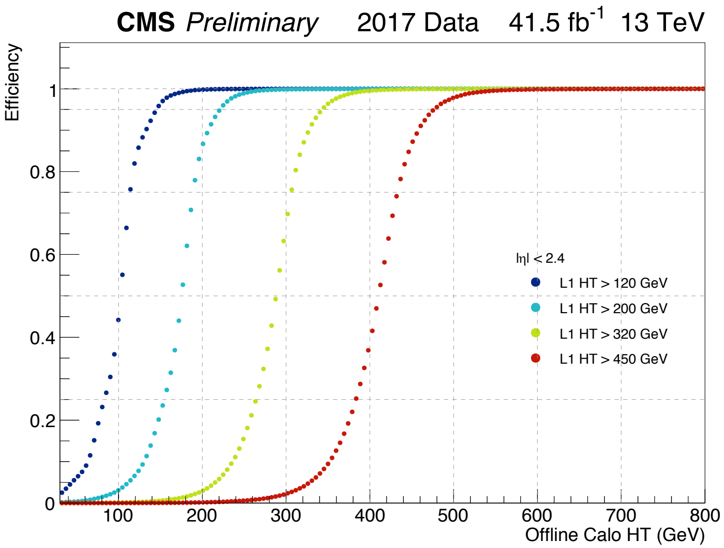
- Match Level-1 jet to offline (anti-k_T R=0.4) jets using $\Delta R <$ 0.25 in single muon data
- Central jets have sharper efficiency turn-on than forward jets
- Data before the HF trigger primitive energy saturation was being correctly set are excluded for the forward jet efficiency

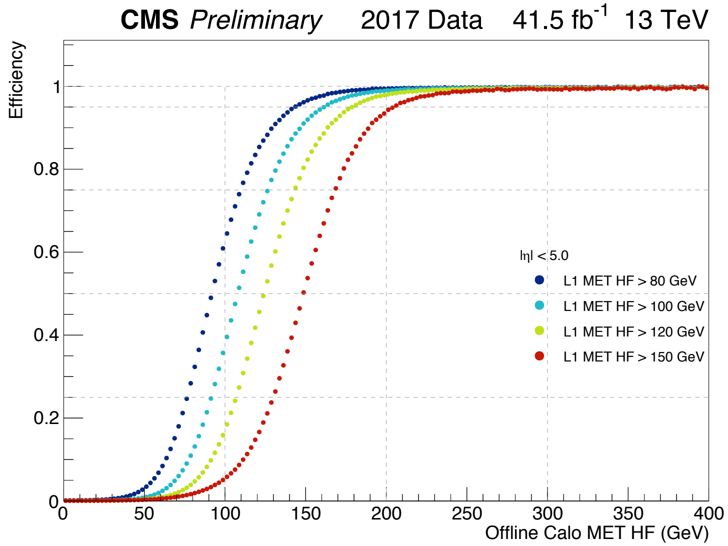


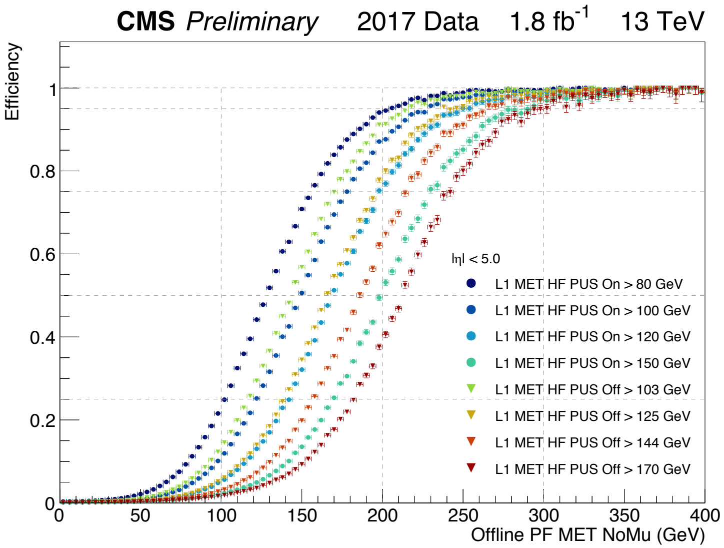


HT and MET

- HT = $\sum E_{Tj}$ for jets with E_T > 30 GeV , $|\eta|$ < 2.4
- MET: the magnitude of the negative vector sum of the transverse momenta of all trigger towers
- MET PUS: apply threshold to towers, as a function of PU and η, to be included in the MET calculation
  - keeping the MET thresholds under hash PU environment



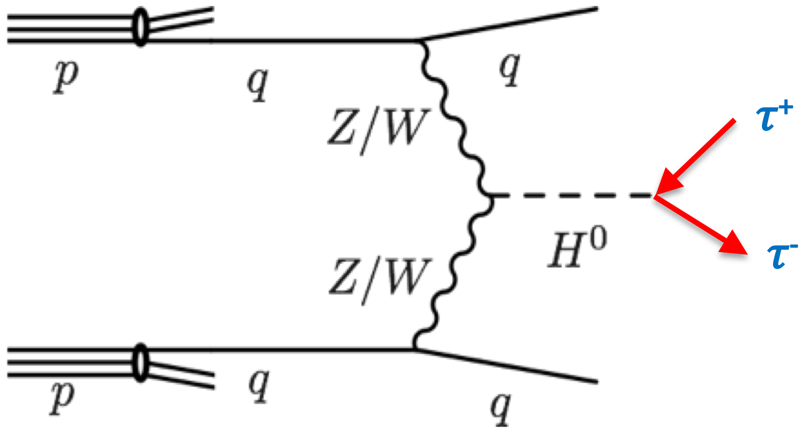




Data Analysis at Level-1

- Global Trigger receives L1 objects and makes algorithmic decision
  - Allows analysis-like algorithm on Level-1 trigger level
  - Invariant mass, W transverse mass from lepton and MET, etc.

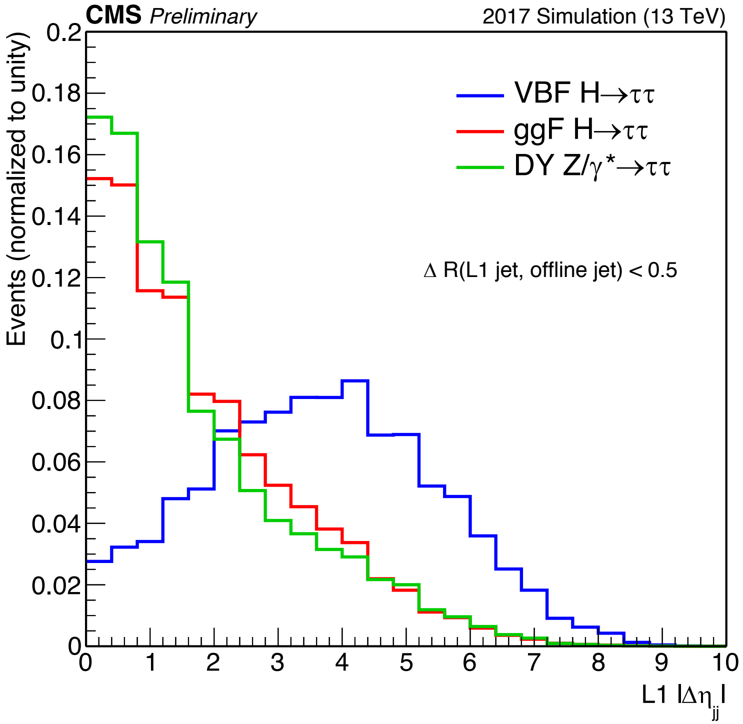
- A Higgs boson can be produced from the fusion of the two vector bosons (VBF)
- The VBF H→$\tau\tau$ is one of the most sensitive categories for the SM H→$\tau\tau$ analysis

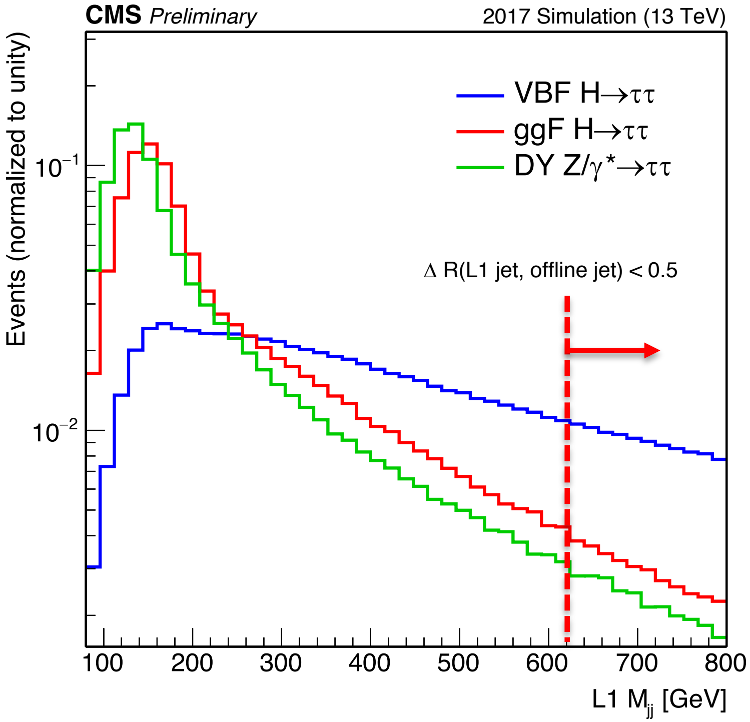


- The Higgs boson decay products are often located in the central of the detector
  - Trigger by DoubleIsoTau trigger, limited by rate budget
- The outgoing quarks producing high-p_T jets in the forward region of the detector

The Vector Boson Fusion Trigger

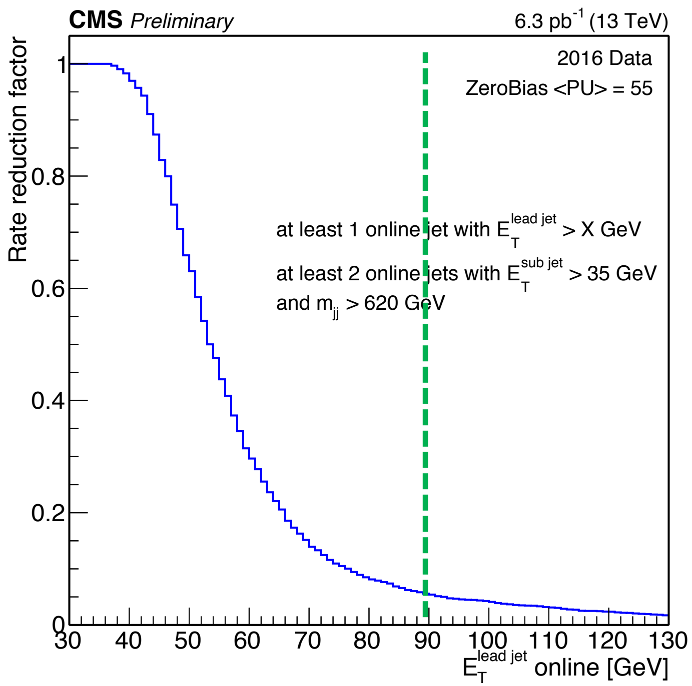
- Comparing distribution from VBF H→$\tau\tau$ signal to SM background and gluon fusion Higgs process
- L1 jets matched to the highest invariant mass pair of offline jets
- The jets produced from VBF process have large η separation and invariant mass

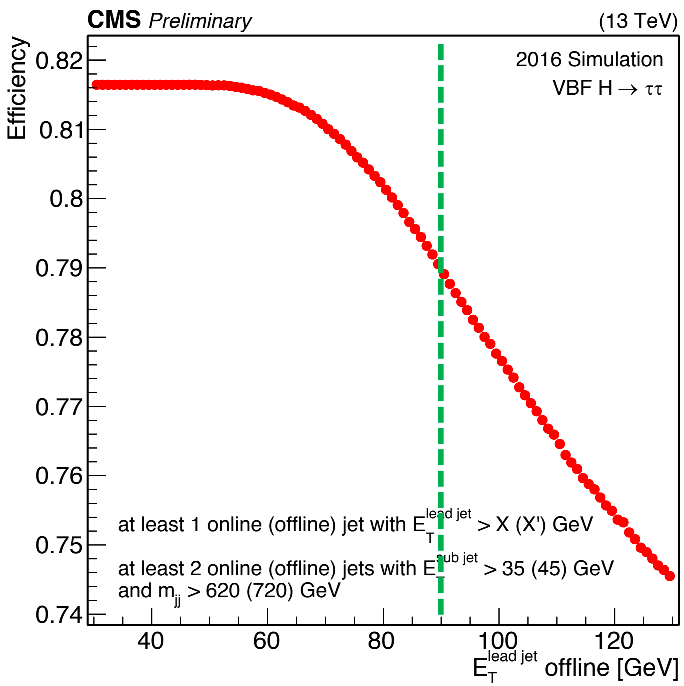




The VBF Trigger Strategy

- At least one jet with E_T > X
- At least two jets with E_T > Y
- In the collection of jets with E_T > Y, at least a pair with m_{jj} > 620GeV

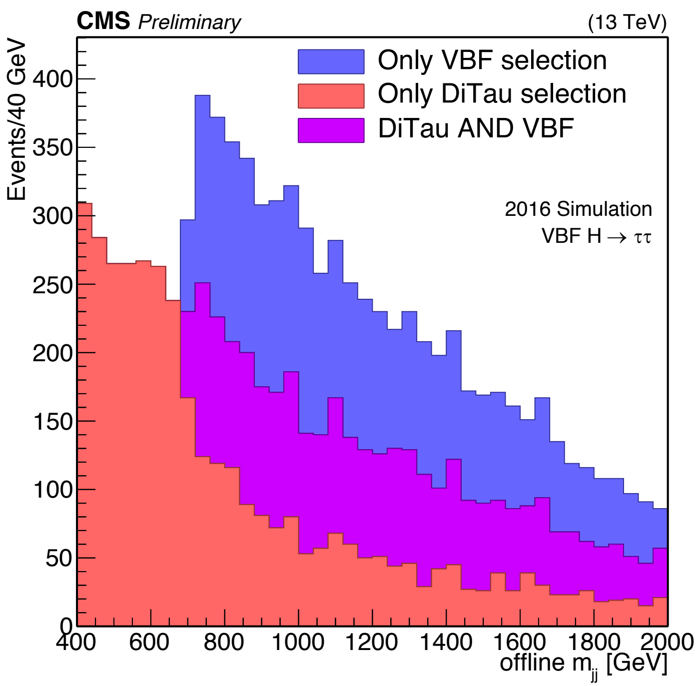


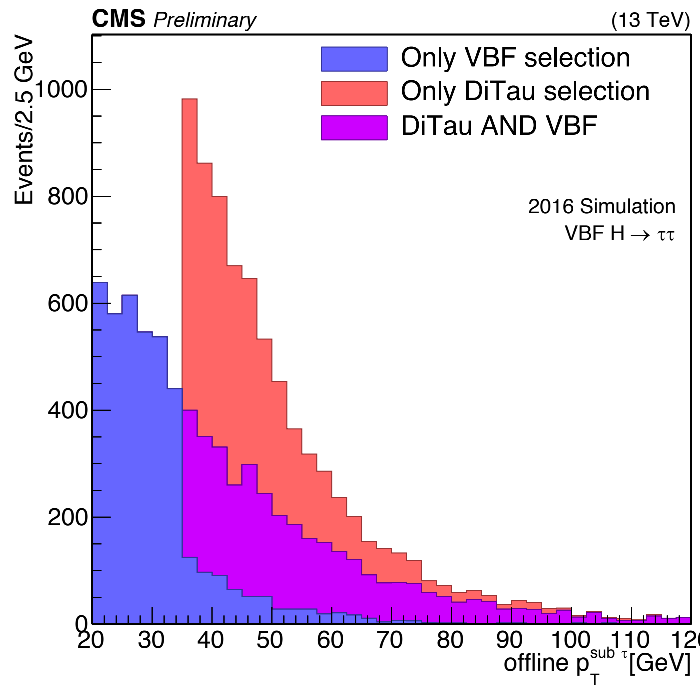


At 90GeV, a ~95% rate reduction for only ~5% efficiency loss is achieved

The VBF H→$\tau\tau$

- A dedicated hadronic $\tau\tau$ algorithm designed for SM H→$\tau\tau$ analysis
- Combined with VBF trigger, ~60% gain in acceptance for an acceptable increase in rate.





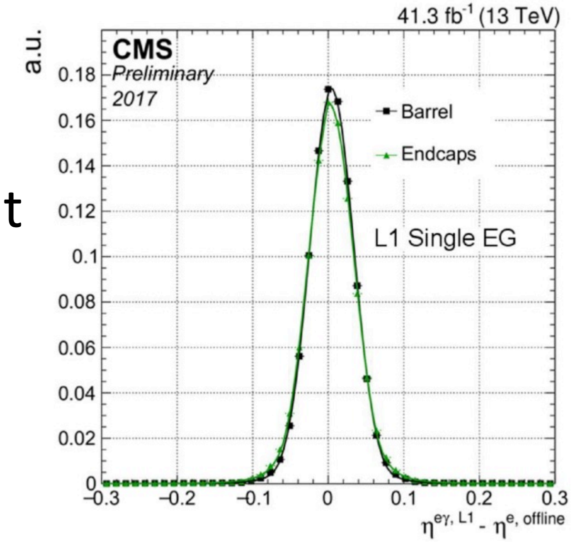
Summary

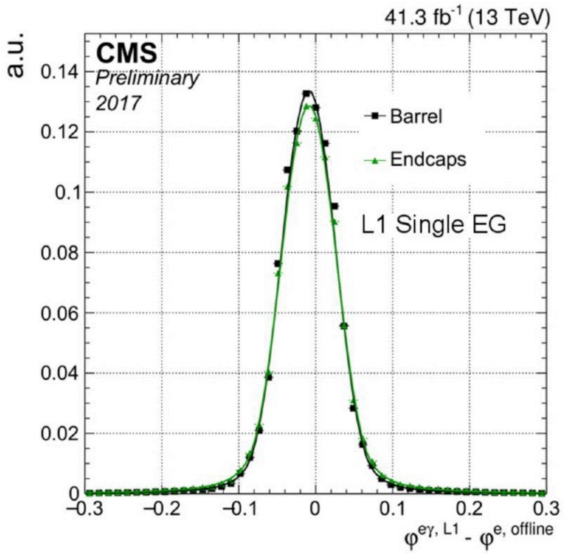
- The CMS Level-1 trigger was fully Stage 2 upgraded in 2016, and has been running successfully since
- LHC provides a challenging environment for CMS level-1 trigger system
  - Increase in instantaneous luminosity, higher pileup and rate
- CMS developed sophisticated algorithms for trigger calorimeter objects
  - Re-optimizing the calibration and working points to adapt fast changing condition from LHC
- Further exploit new functionalities from L1 global trigger, which support new trigger algorithms
  - Bringing analysis-like condition down to CMS Level-1 trigger system

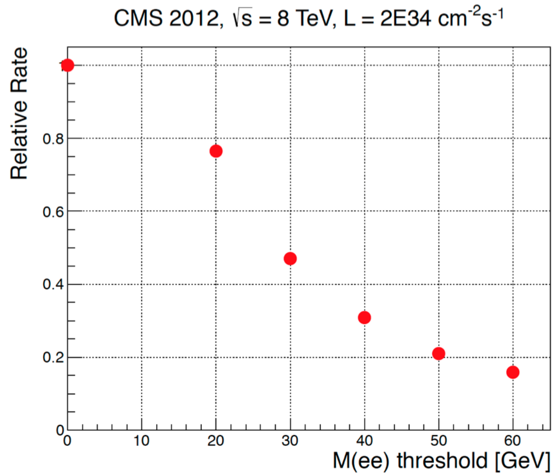
BACKUP

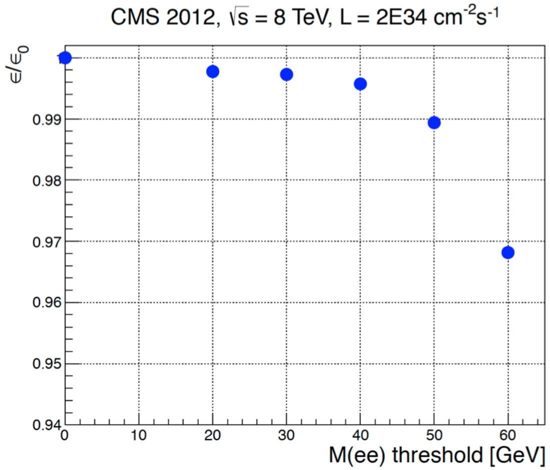
e/ɣ Position

- Energy weighted position
  - Improved position resolution for invariant mass algorithm and correlated triggers







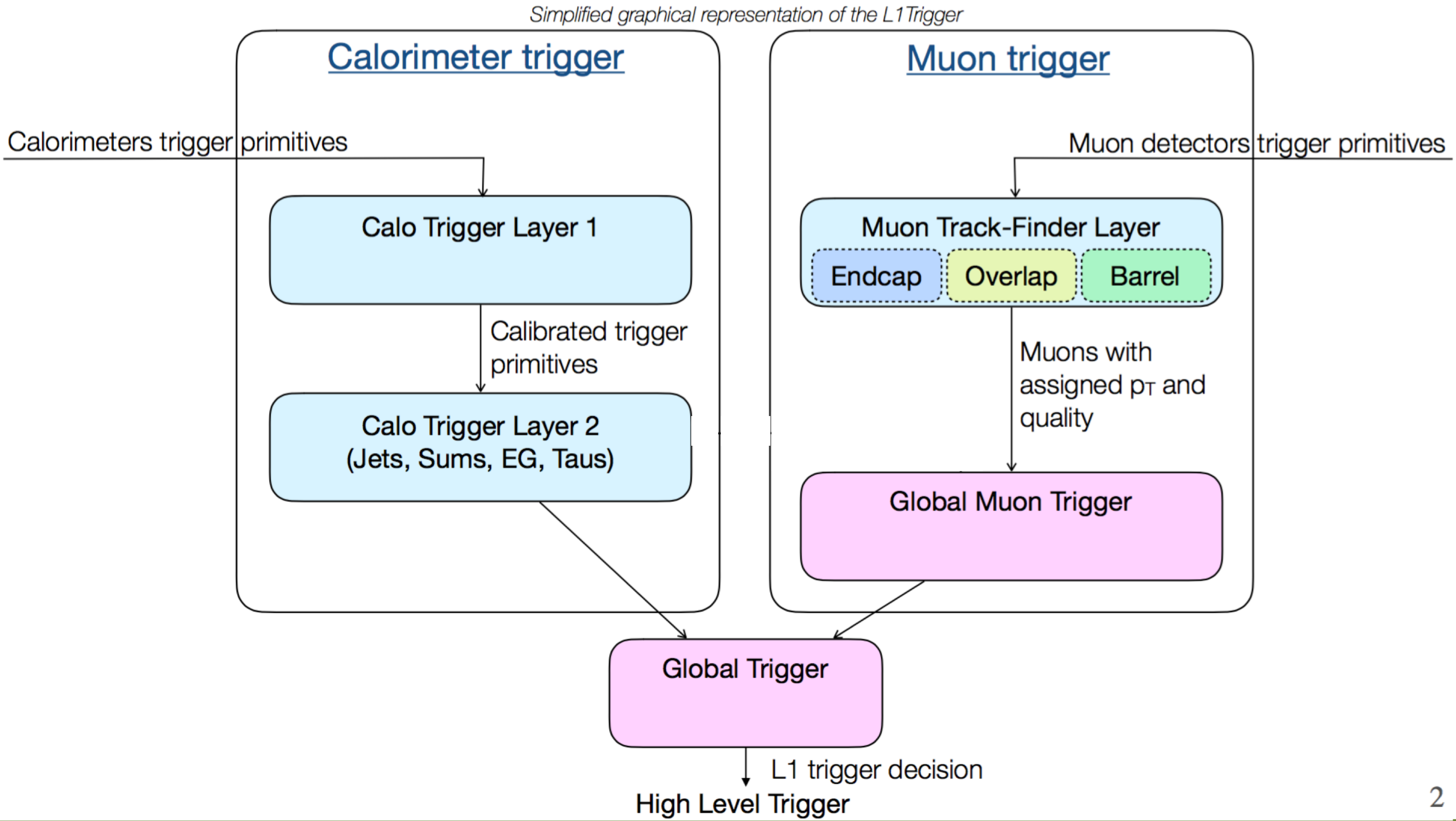


- Relative rate reduction of double EG trigger as a function of M(ee)
- Maintaining similar efficiency for Z→ee events

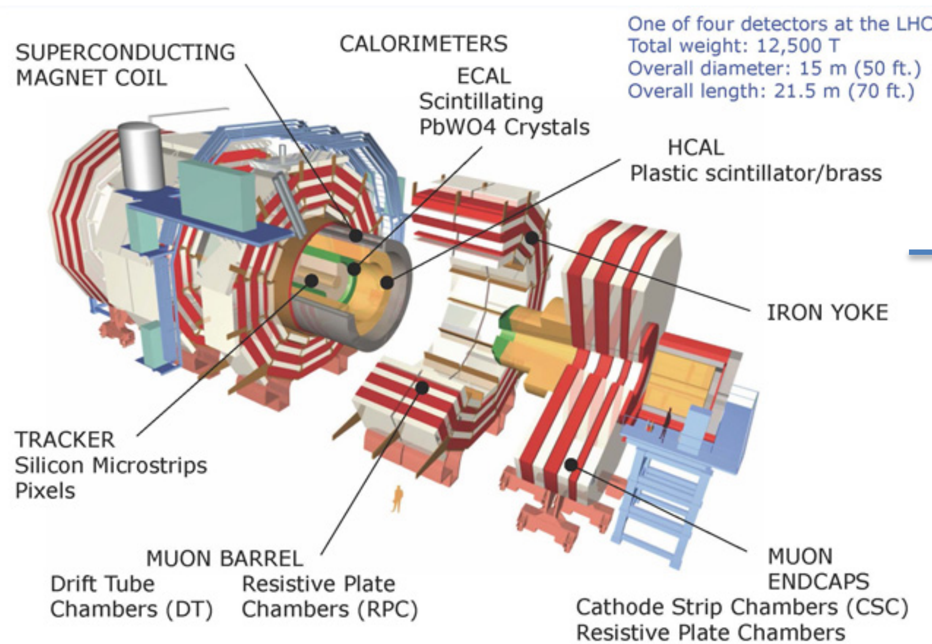
CMS-TDR-012

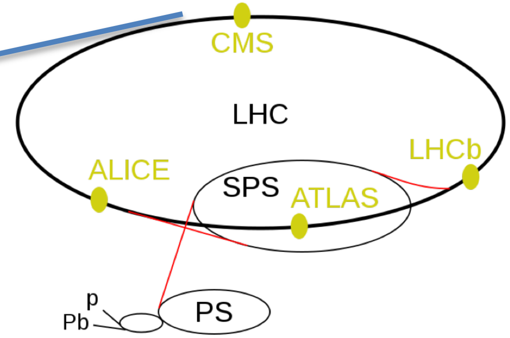
Level-1 Trigger

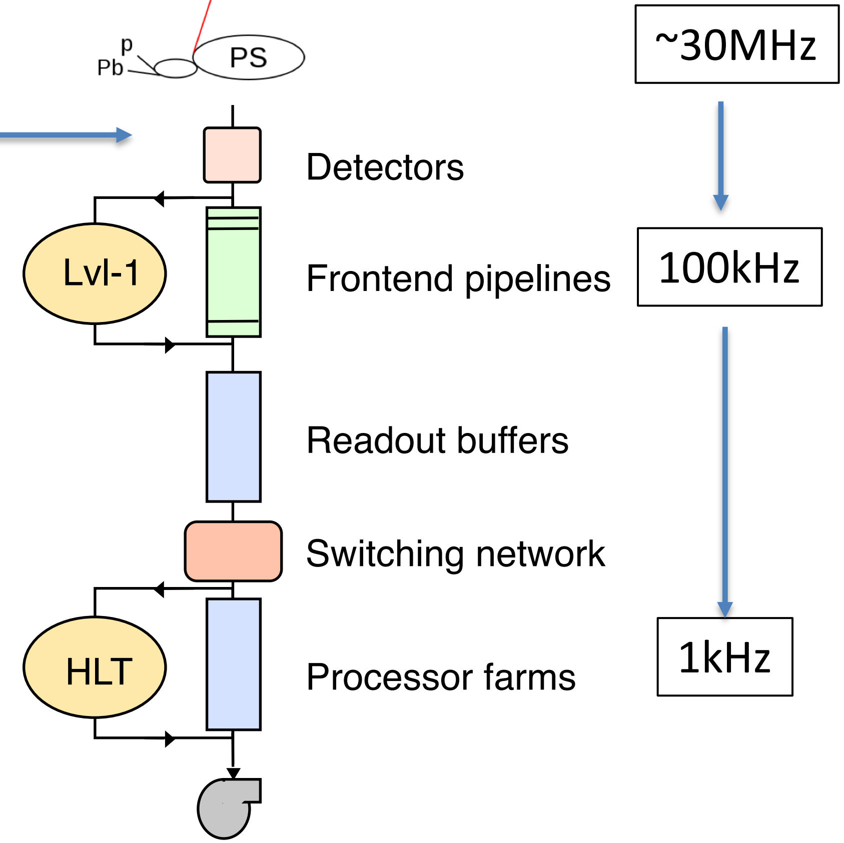
The CMS Level-1 trigger system has been fully Phase 1 upgraded in 2016



CMS Trigger System



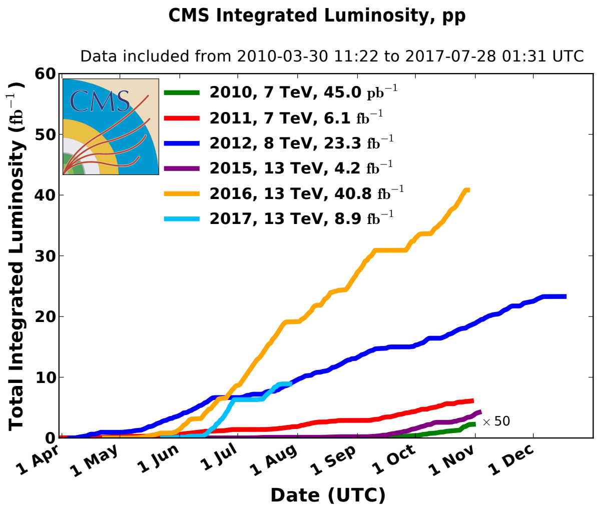




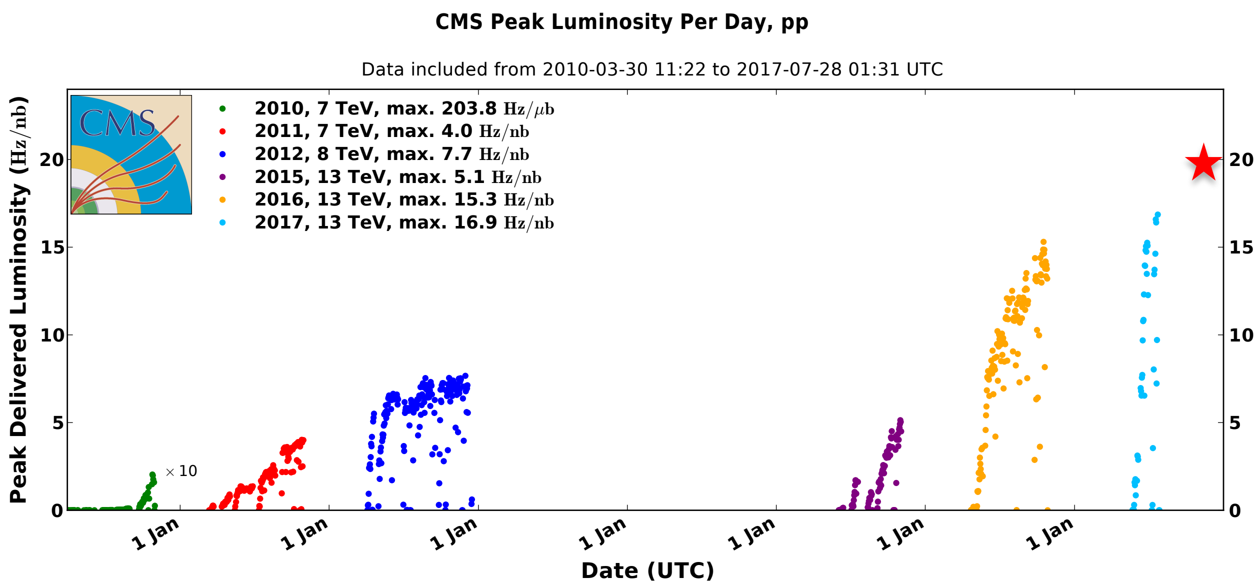
CMS has been designed with a 2-level trigger system

- Level-1 trigger (L1): fast electronics
- High Level Trigger (HLT): processor farm

Challenge from LHC

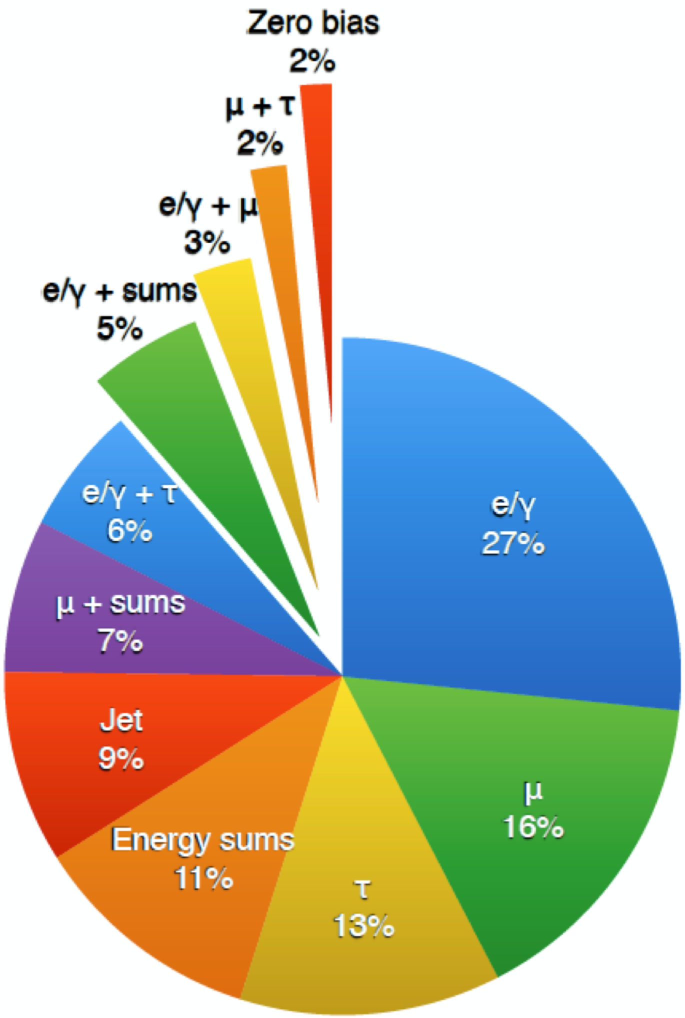


- After LS1, LHC has achieved very high luminosity
  - 2016: $1.5*10^{34}$ $cm^{-2}s^{-1}$ → PU~48
  - 2017: expecting $2*10^{34}$ $cm^{-2}s^{-1}$ → PU~56
- The CMS trigger needs to maintain and improve performance while keeping the rate under control



- 2017 has exceeded 2016 peak luminosity
- Expecting 2017 peak luminosity at 20Hz/nb

The Level-1 Menu

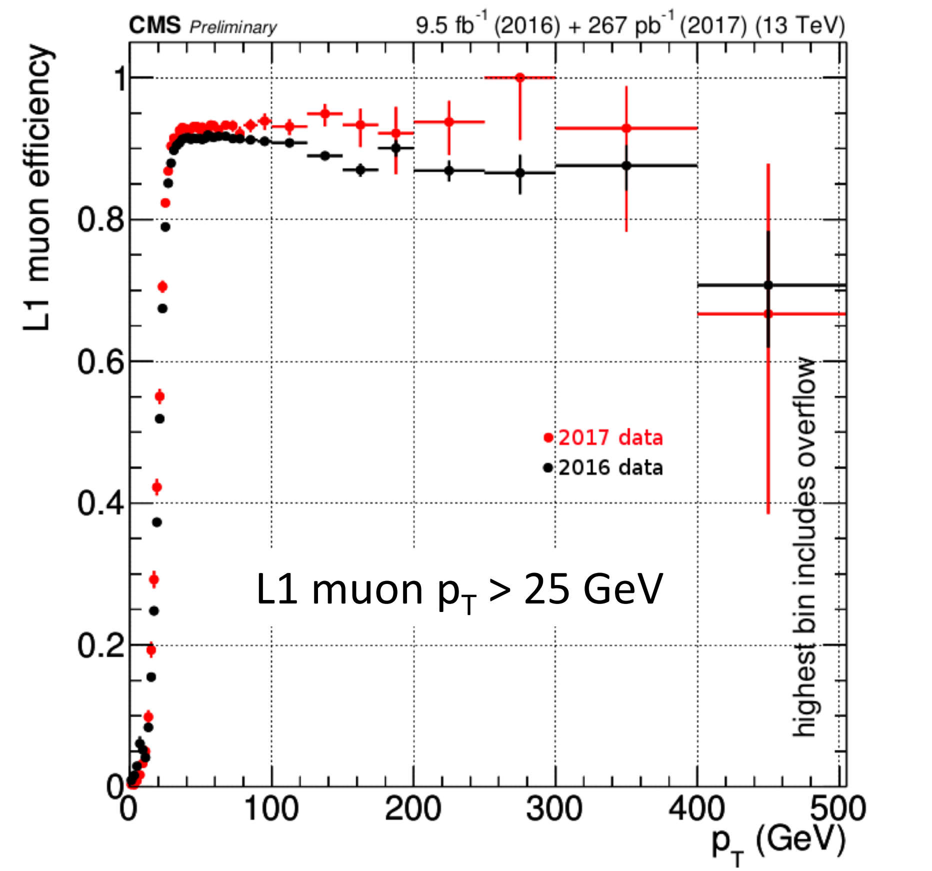


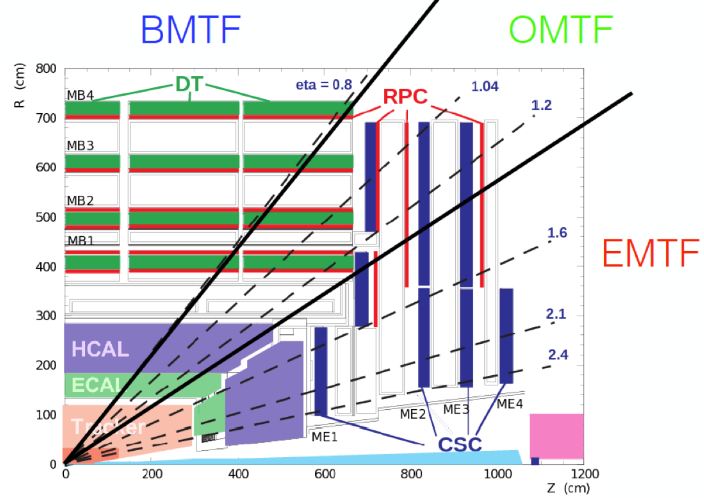
A. Tapper, ICHEP2016

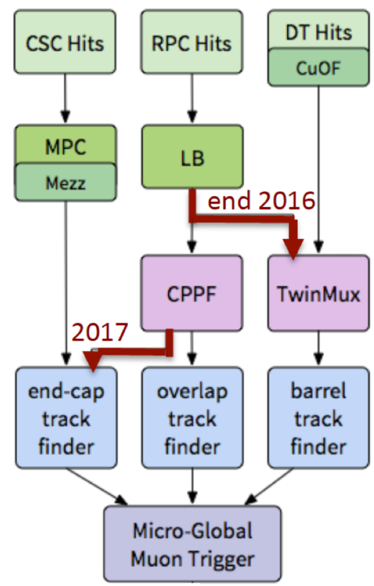
- The bandwidth allocated per trigger object type in 2016 L1Menu for $10^{34}cm^{-2}s^{-1}$ luminosity
- **Note**: fractions are inclusive -> no attempt to correct for overlaps

- Trigger strategy for 2017: data analysis at Level-1 trigger
  - Object matching with offline reconstruction
  - More sophisticated trigger algorithm matching to offline data analysis

L1 Muon in 2017





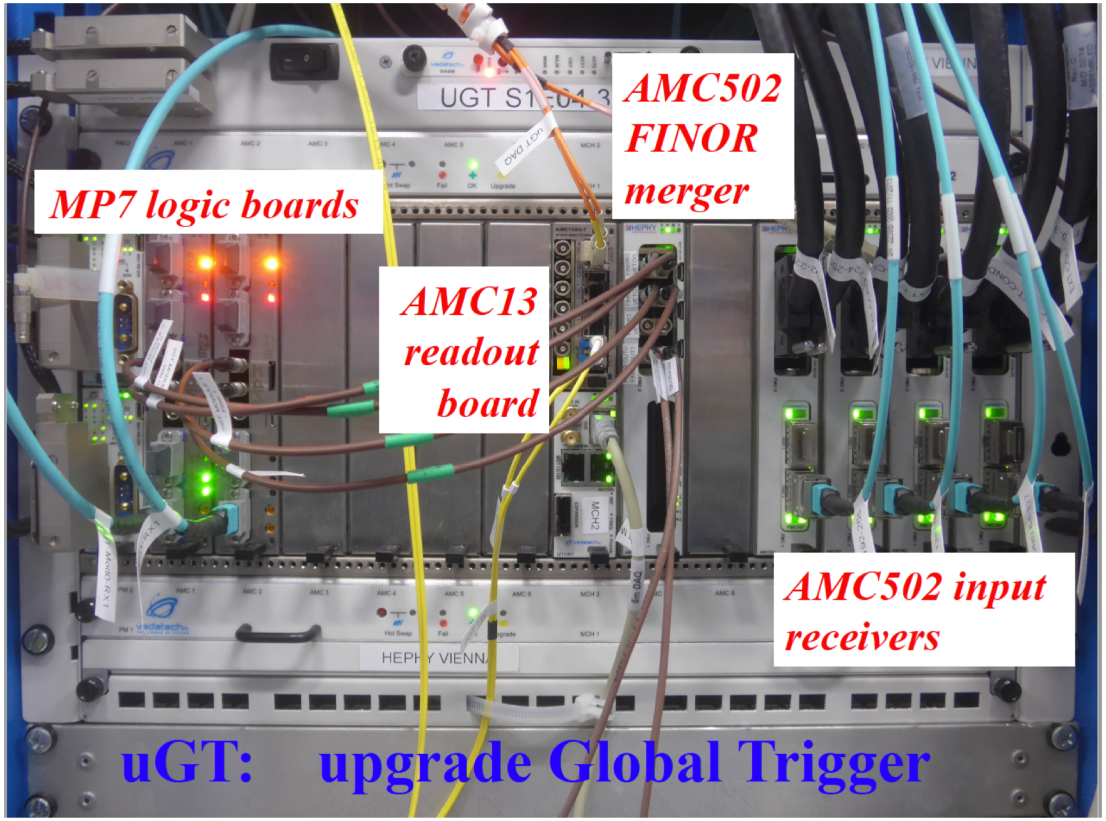


Improved muon efficiency w.r.t 2016:

- RPC added to both barrel and end-cap track finder
- Retuned the muon p_T assignment

Level-1 Global Trigger

- It is implemented in µTCA technology with large FPGAs
- It receives and synchronizes inputs, and issues the L1 trigger decisions
- High flexibility in trigger menu design
- It supports analysis-like conditions, such as invariant mass, transverse mass



$$M_{inv} \approx \sqrt{2p_{T1}p_{T2}[\cosh(\eta_1 - \eta_2) - \cos(\varphi_1 - \varphi_2)]}$$