Design and performance of the upgraded CMS L1 trigger

Jaana Heikkilä (Helsinki Institute of Physics) on behalf of the CMS collaboration,
133rd LHCC Meeting, February 28 2018, CERN (Geneva)

Introduction - LHC Conditions

During its second run of operation, LHC delivered proton-proton collisions at a centre-of-mass energy of 13 TeV with **a peak instantaneous luminosity larger than $2{\cdot}10^{34}$ cm^{-2}s^{-1}**, more than double the peak luminosity reached during the Run 1 and far larger than the design value. The upgraded CMS Level-1 trigger is designed to improve the performance at high luminosity and large **number of simultaneous inelastic collisions per crossing (pile-up, PU), expected to be 55 on average.**

The Upgraded CMS L1 Trigger

Hardware-based Level-1 Trigger (L1) is the **first part of the current CMS Trigger system**, and its aim is to **reduce the rate of 40 MHz delivered by LHC down to 100 kHz** that is sent to the High Level Trigger (HLT). The expected output rate of HLT is 1 kHz. L1 receives **input from muon systems (DT, RPC, CSC), and from the calorimeters (ECAL, HCAL, HF).** L1 trigger consists of two parts; muon track-finders (MTF) and calorimeter triggers (Calo L1 and L2) which both send data to the global trigger (uGT).

The three main changes with respect to Run 1 are

1. **muon system - achieve more accurate pT assignment**. Combine hits from DT, RPC, and CSC in the Muon Track-Finders (MTFs), and introduce pattern-based (OMTF) and BDT algorithms (EMTF).
2. **calorimeter system - give all algorithms an access to the full trigger tower granularity**. Utilize Field-Programmable Gate Arrays (FPGAs) offering larger computing power and fast optical links.
3. **global trigger - increase selectivity, and offer richer menu.** Receive more candidate objects, and allow at least twice as many algorithms as before. Include the possibility to add dedicated cross-triggers adapted to each physics analysis group, and to implement sophisticated algorithms using invariant mass.

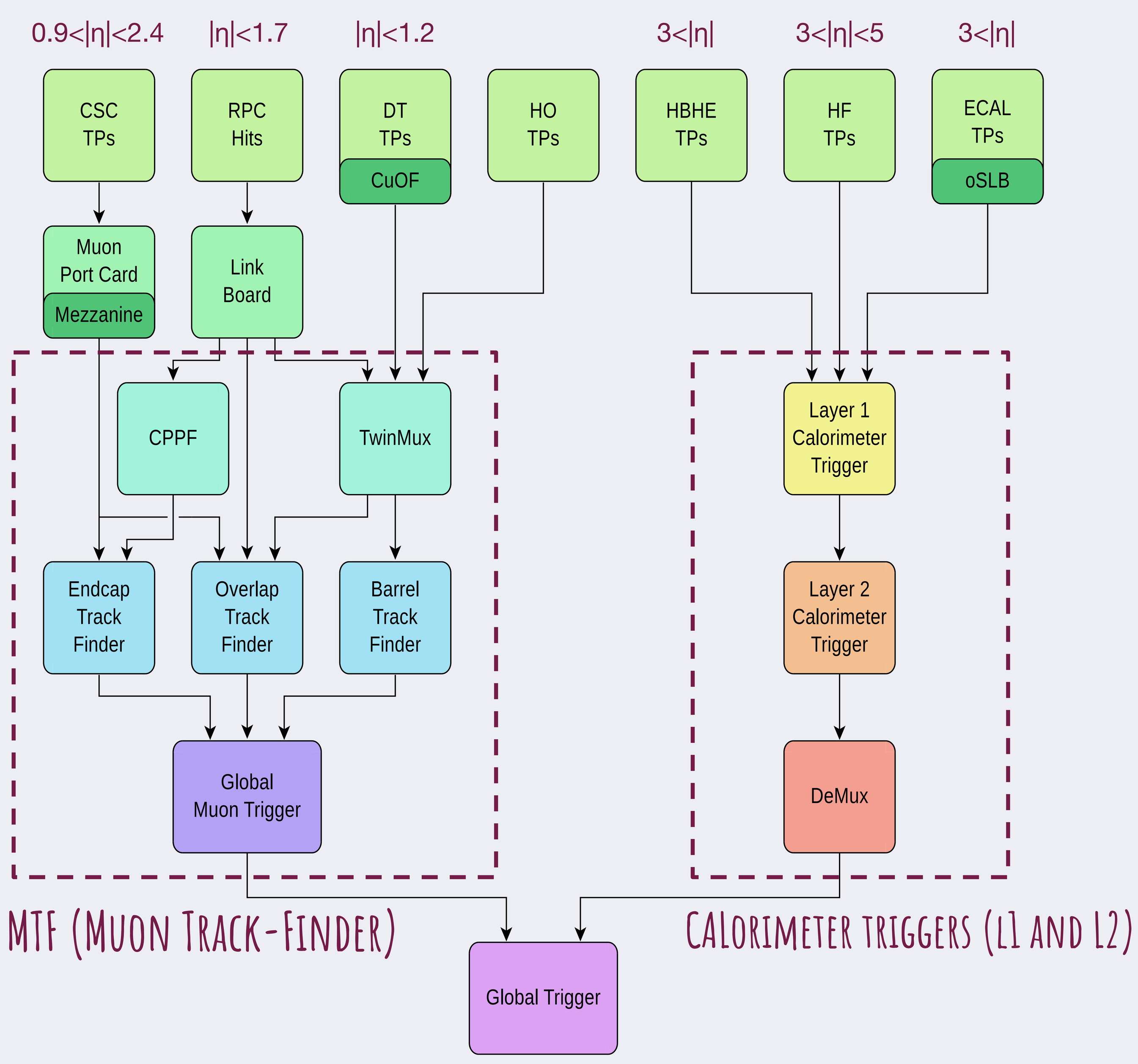

Figure: Full system of the CMS L1 Trigger for 2017. HO trigger primitives are sent to TwinMux but not used for triggering in 2017.

Muons

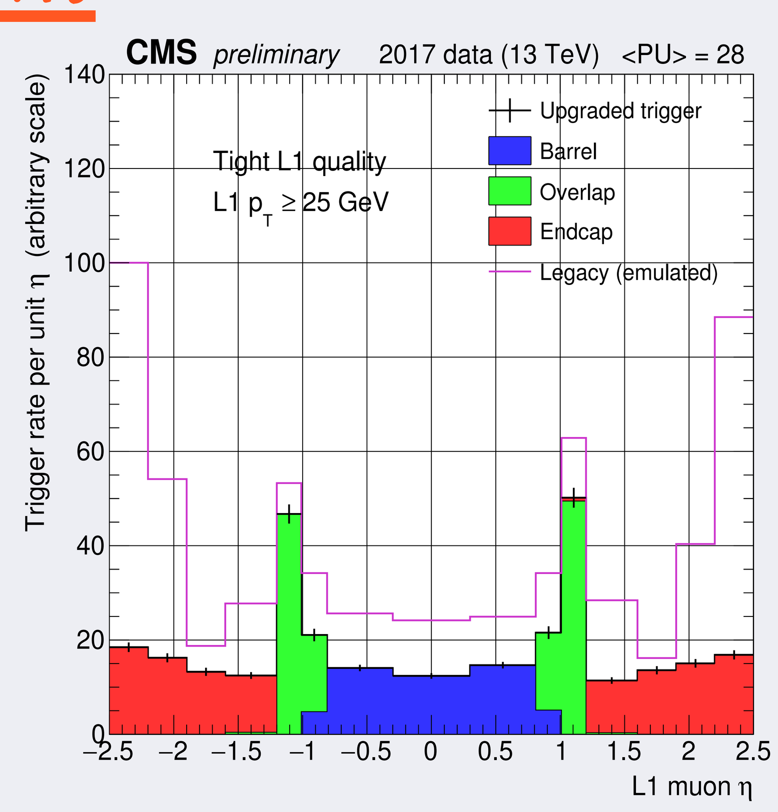

Figure: The distribution of muons per unit η passing a pT threshold of 25 GeV, built by the three track finders (barrel, overlap, and endcap) in the upgraded L1 muon trigger (2017), and compared with the emulated legacy trigger (2015), in arbitrary units. The rate reduction is 50% for a pT threshold of 25 GeV.

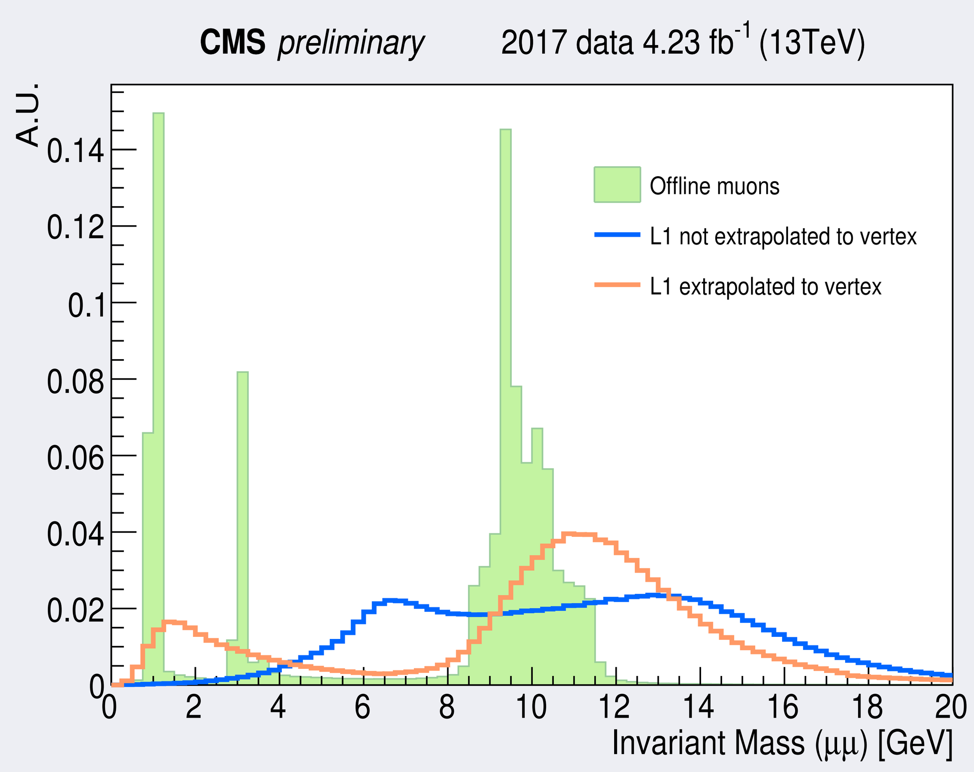

Figure: The invariant mass spectrum of two offline muons (green), compared to the same spectra of two online muons with (orange) and without (blue) L1 track extrapolation to the vertex. The muon track extrapolation to the vertex (added in 2017) improves the L1 dimuon invariant mass resolution. The online spectrum appears shifted compared to the offline spectrum due to p_T offsets designed to make the L1 muon trigger 90% efficient at any given p_T threshold.

E/γ

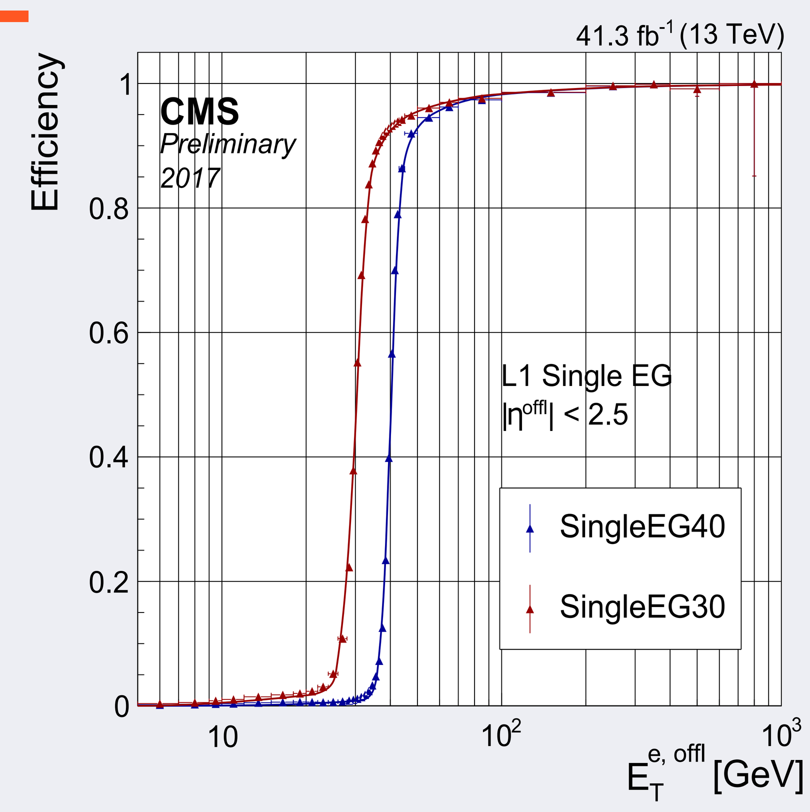

Figure: L1 trigger efficiency curves for an e/γ object as a function of the offline reconstructed supercluster transverse energy E_T of the electron, measured with Tag & Probe on data. A geometrical matching between the electron supercluster and the L1 candidate is applied. The efficiency is drawn for a E_T threshold of 30 GeV (red) and 40 GeV (blue). Offline reconstructed electrons are required to have $|\eta^{offl}| < 2.5$.

Taus

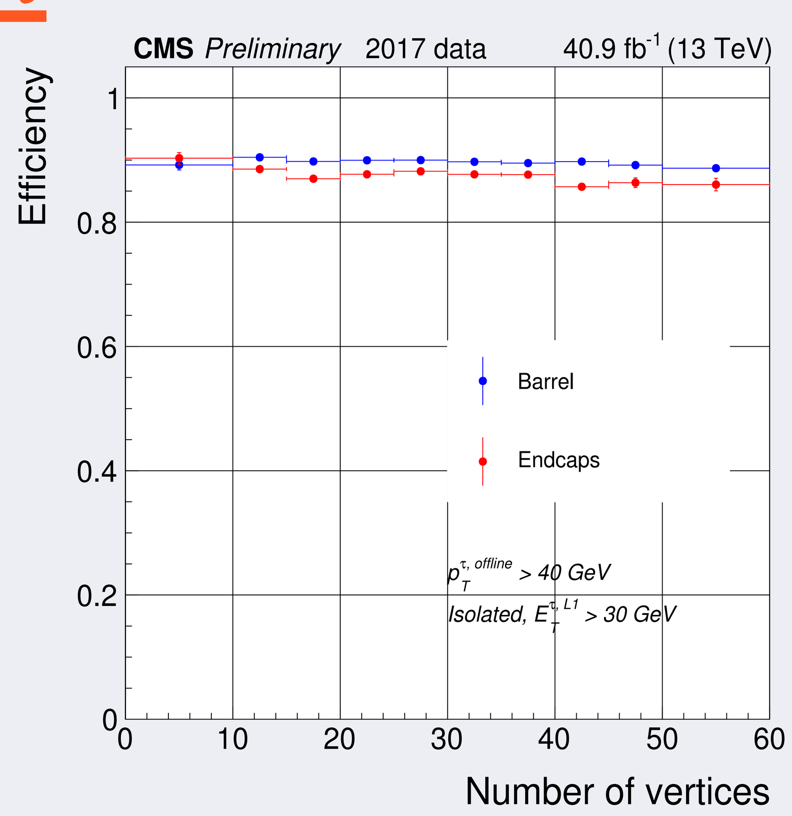

Figure: Integrated Level-1 selection efficiency for isolated τ-seeds with $E_T^{\tau,L1}$ > 30 GeV matched to an offline and well identified τ with $p_T^{\tau,offline}$ > 40 GeV as a function of pileup. The pileup is estimated as the number of reconstructed offline vertices. The efficiency is approximately 90% both in barrel (blue) and endcaps (red) for average PU of 55.

JetMET

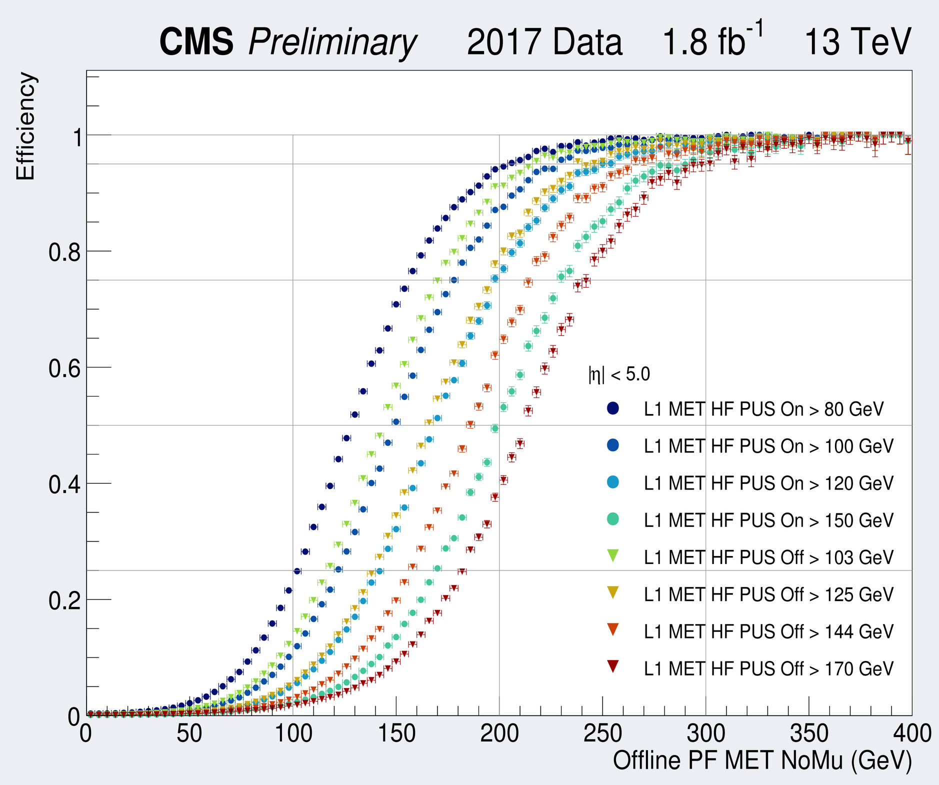

Figure: Efficiency curves for the upgraded Level-1 missing energy trigger using events with a single offline muon as a function of offline PF missing transverse energy (MET) excluding muons. Efficiency curves with and without pileup subtraction applied are compared for trigger thresholds that give the same rate: L1 MET HF PUS on > 80/100/120/150 GeV produce the same rate as L1 MET HF PUS off > 103/125/144/170 GeV, respectively.

VBF

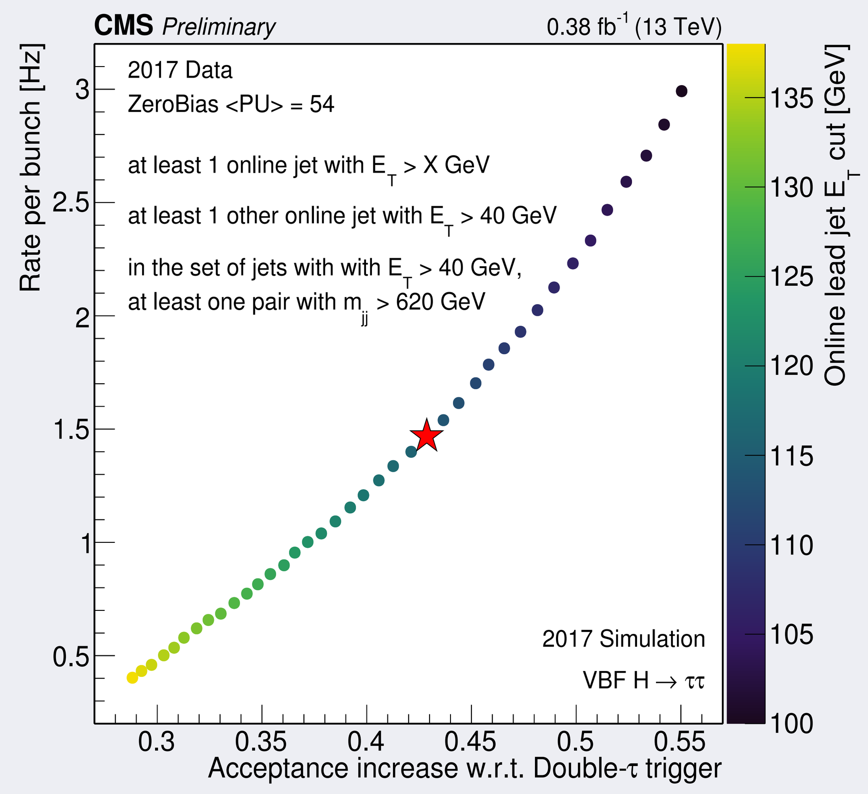

Figure: Total rate (y-axis) from the VBF trigger, estimated in a ZeroBias 2017 sample with <PU> = 54 versus the increase in H→ττ signal events (x-axis, acceptance gains) from the VBF trigger w.r.t. the situation where only the Double-τ trigger is used. The red star on the plot shows the VBF trigger configuration that was used throughout 2017 (X = 115 GeV), providing a ~43% increase in the number of VBH H→ττ expected events.

References:

1. CMS Collaboration, "CMS Technical Design Report for the Level-1 Trigger Upgrade", CERN-LHCC-2013-011, CMS-TDR-12, https://cds.cern.ch/record/1556311.
2. Level-1 Trigger Public Performance Results, and references therein, https://twiki.cern.ch/twiki/bin/view/CMSPublic/L1TriggerDPGResults.

Contact:

jaana.heikkila@cern.ch