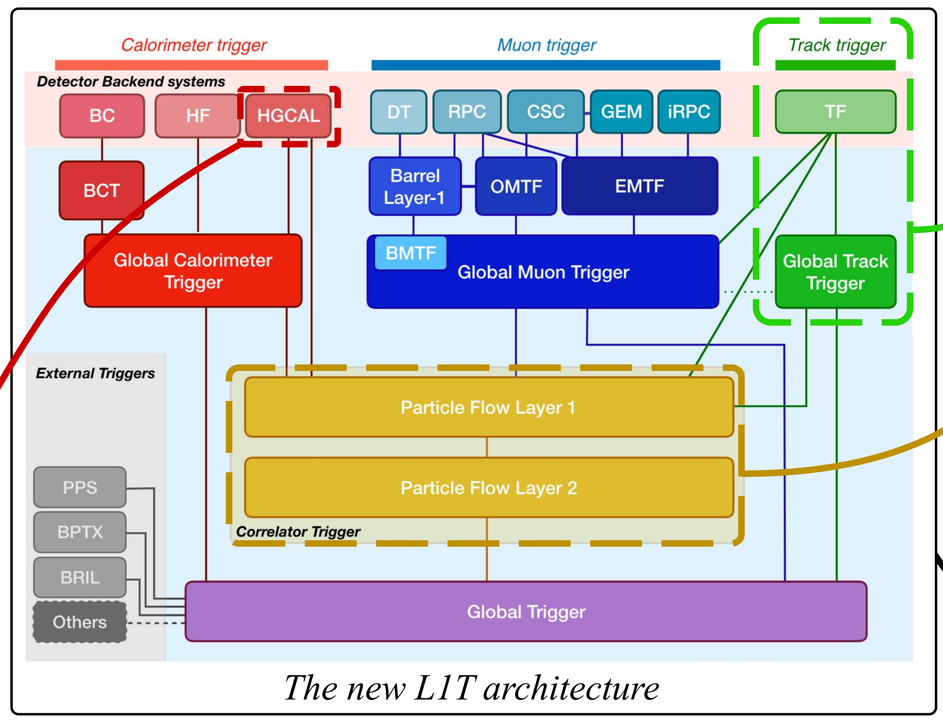
# Triggering on Electrons, Photons, Taus, Jets and Energy Sums at HL-LHC with the Upgraded CMS Level-1 Trigger

**Peter Meiring** (University of Zurich) on behalf of the CMS Collaboration
peter.meiring@cern.ch

## New Trigger Capabilities for HL-LHC

The HL-LHC presents extraordinary physics opportunities by delivering an expected 4000 $fb^{-1}$ of collision data to the experiments. At peak luminosity, 200 proton-proton interactions per bunch-crossing (pile-up, PU) are foreseen. The CMS Level-1 Trigger (L1T), based on custom hardware processors, is redesigned to **maintain and extend the physics acceptance of the existing L1T**, even in the high-luminosity conditions!

The endcap calorimeters will be replaced by the **High Granularity Calorimeter (HGCAL)**. This allows for detailed and rich descriptions of particle showers, that are sent to the L1T and can be used for multivariate object identification.




*The new L1T architecture*

**The Track Trigger** will reconstruct charged particle tracks at the proton-proton collision rate of 40 MHz. Never before could tracks be used by the CMS L1T!

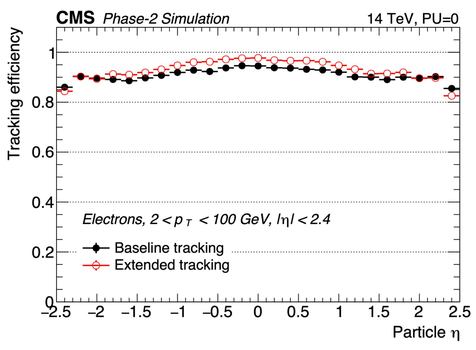
**The Correlator Trigger** performs **track-matching** of Calorimeter and Muon objects to mitigate PU and hosts global event reconstruction techniques, such as **Particle-Flow*** and **PUPPI****.

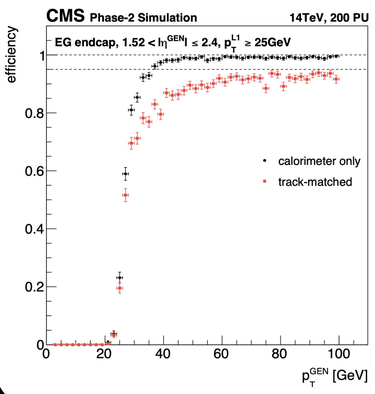
Increased latency (3.8→12.5μs), inter-connectivity and state-of-the-art FPGAs (7.5x more resources) form the basis for advanced trigger algorithms, including also **machine learning techniques**.

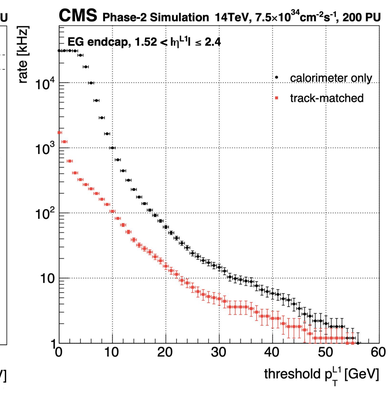
## Electrons & Photons

Barrel e/γ objects are constructed from 3x5 energy clusters, exploiting the **25x higher energy measurement granularity** sent to the L1T by the Electromagnetic Calorimeter, than in the current system.

In the endcap, Boosted Decision Trees (BDT) identify signal clusters using 3D shower shape variables.



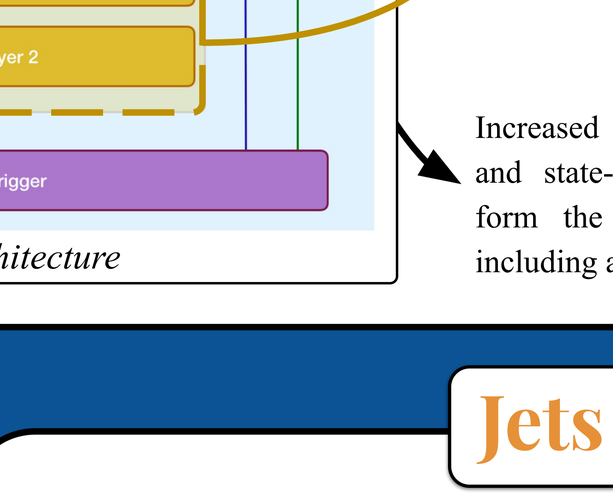



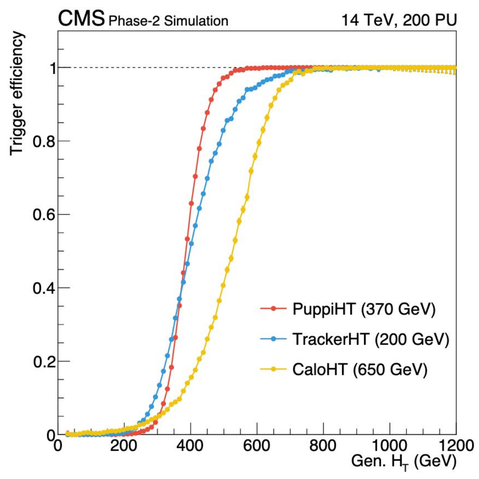

**Track-matching** of Calorimeter objects reduces rates, allowing preservation of current trigger thresholds, even with 200 PU.

Using **tracks that are displaced** (*"extended"*) from the beam spot recovers Bremsstrahlung effects.

## Jets & $H_T$

Jets can be reconstructed from **PUPPI candidates**, binning them in pseudo-trigger towers and clustering in a 9x9 window around a local maximum. This gives similar performance to the AK4 jet reconstruction offline!



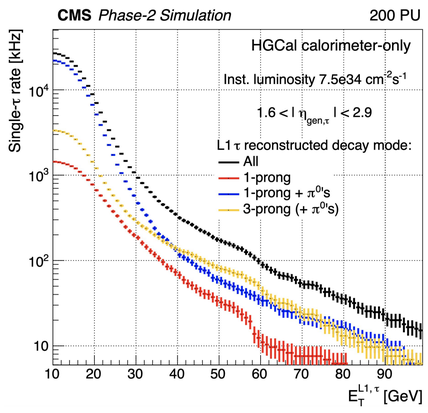



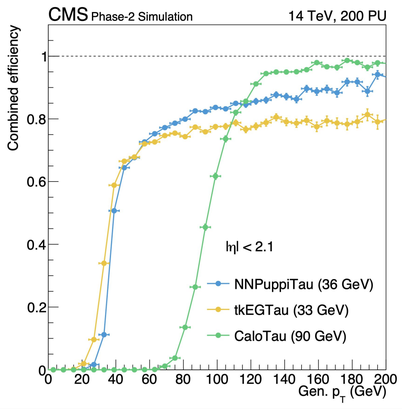

PUPPI-jets will also be used to trigger on $H_T$: the scalar sum of jet $p_T$. The trigger thresholds are significantly lower than with the standard Calorimeter-only approach, that is used today.

## Taus

Hadronically decaying taus ($\tau_h$) can be reconstructed exploiting calorimeter-only information. They are obtained from 7x7 calorimeter towers, using isolation and cluster shape to distinguish $\tau_h$ objects from jets.

Alternatively, in the endcaps, BDTs can be employed to reject HGCAL clusters from PU. The decay mode is then identified using a multiclass Random Forrest.

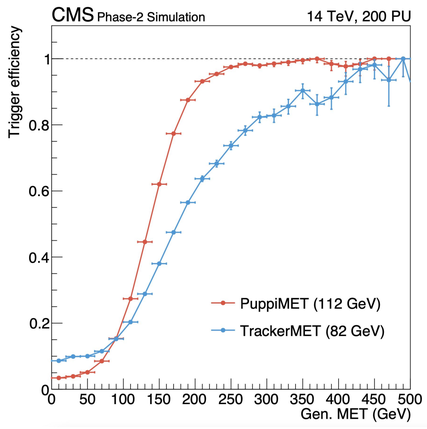


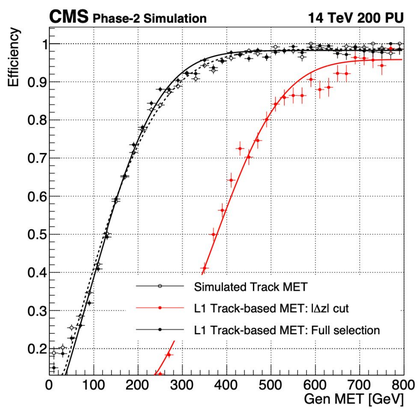




To **drastically lower the trigger thresholds** on $\tau_h$ objects, PUPPI candidates will be used. A neural network was developed to reconstruct $\tau_h$ objects, using properties of the 10 highest $p_T$ PUPPI candidates in the proximity of the highest $p_T$ charged particle seed.

## Missing transverse energy ($E_T^{miss}$)

$E_T^{miss}$ is computed as the negative vector sum of particle transverse momenta. Triggers on $E_T^{miss}$ can sustain thresholds similar to those implemented in the current L1T system, when PUPPI candidates are used for this computation.




Alternatively, the Global Track Trigger computes $E_T^{miss}$ using only tracks. **Track purity requirements** are applied to mitigate contributions from PU or incorrect hit combinations. This significantly reduces the trigger threshold.

*__Particle-Flow (PF)__ is a global event reconstruction algorithm that uses information from all sub-detectors to identify individual particles (PF candidates)

**__PileUp-Per-Particle-Identification (PUPPI)__ is an algorithm that uses a QCD-based ansatz function and vertexing information to reject PF candidates originating from PU

References: [CMS-TDR-021] [CERN-2020-010]

ICHEP 2022, Bologna (Italy)