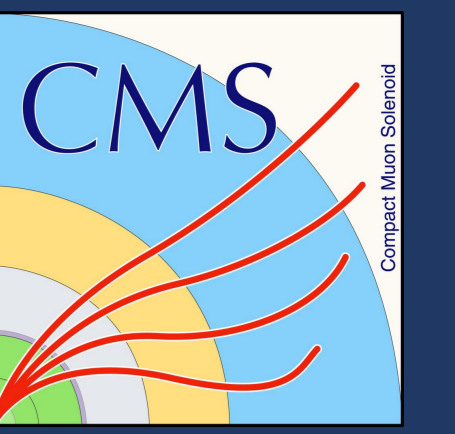# Triggering on electrons, photons, tau leptons, jets and energy sums at HL-LHC with the upgraded CMS Level-1 Trigger

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The High-Luminosity LHC

The upgraded CERN High-Luminosity LHC (HL-LHC) is planned to start in 2029, with:
- instantaneous luminosity up to 7.5×10^{34} cm^{-2}s^{-1}
- center-of-mass energy $\sqrt{s} = 14$ TeV
- simultaneous collisions per bunch crossing (pileup, PU) up to 200

To cope with this harsh environment the CMS detector will be upgraded ("CMS Phase-2 Upgrade")

The upgraded CMS Level-1 Trigger system

The Phase-2 CMS Level-1 (L1) Trigger [1] exploits improved subdetectors, upgraded electronics, and advanced algorithms, with respect to the current system it features:

- Increased maximum total rate of 750 kHz
- Increased total latency, from 3.8 μs to 12.5 μs
- More granular inputs from the detectors
- Tracker & High-Granularity Calorimeter (HGCAL) information
- Advanced machine learning techniques embedded in state-of-the-art FPGA firmware
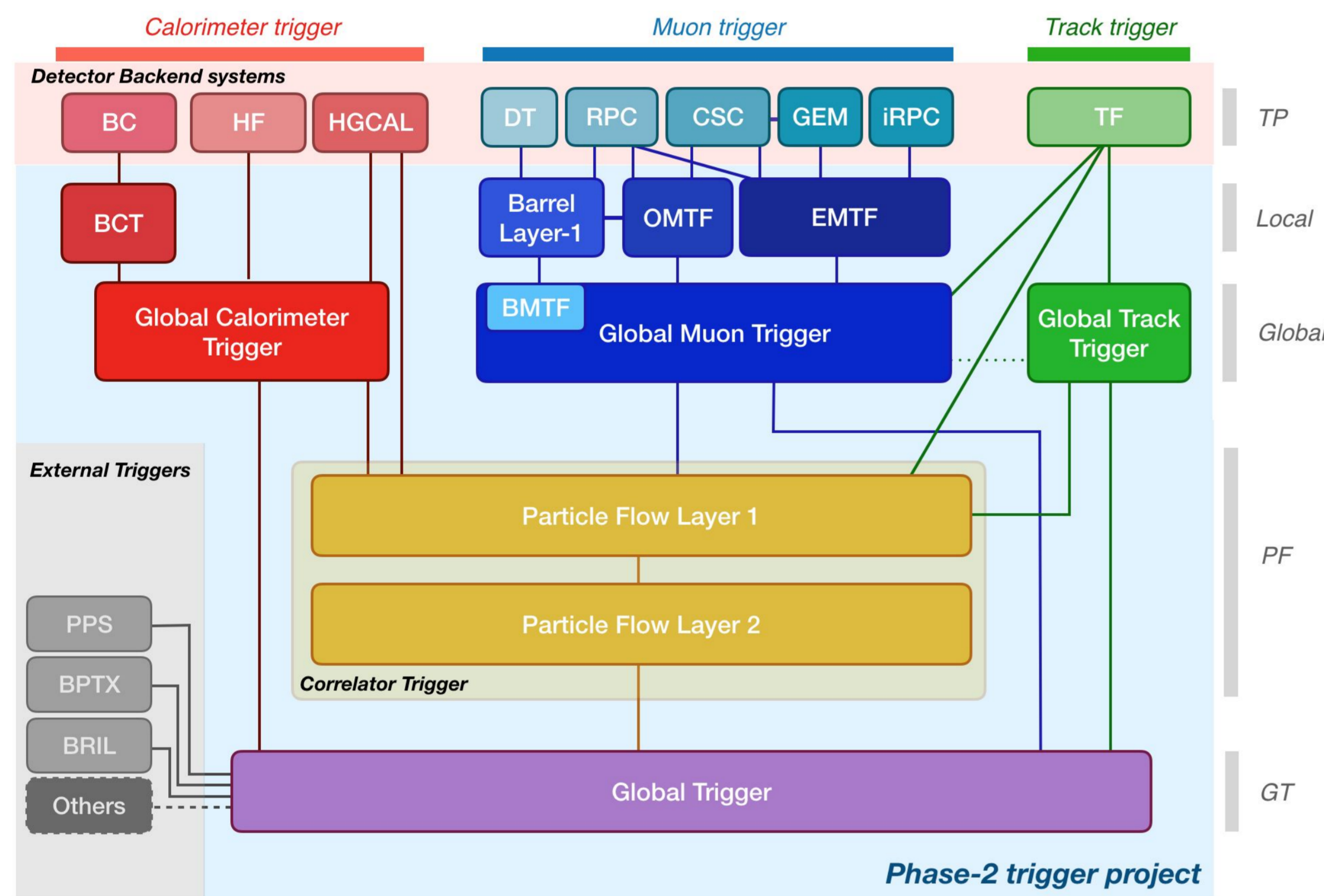
Triggering on electrons & photons

For the L1 electrons and photons candidates both Calorimeter and Tracker information [1] are used:

- Calorimeter-only:
  - ➤ Barrel region: x25 more granular
  - ➤ Endcap region: 3D shower shapes from HGCAL and BDT
- Tracker-only
- Calorimeter + Tracks: elliptic [1] or composite [2] identifications
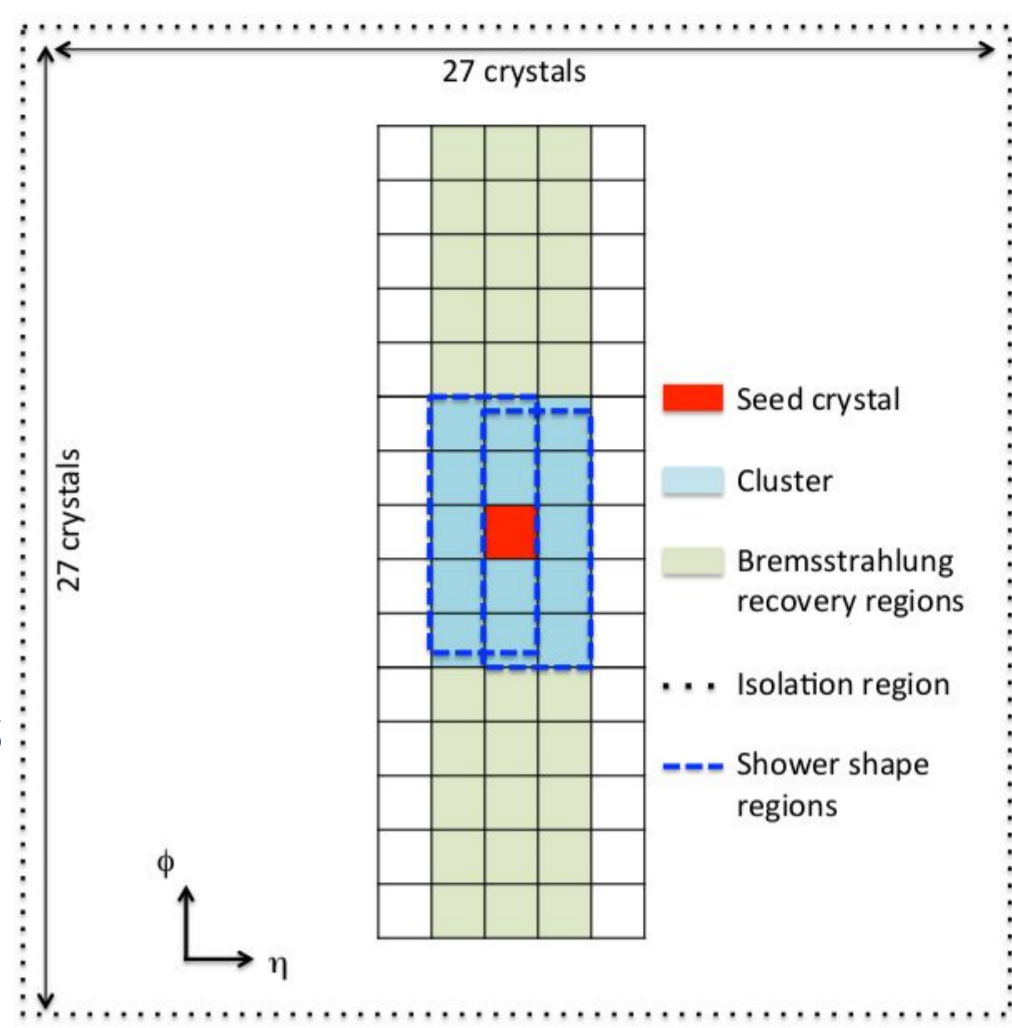
Triggering on jets, energy sums and hadronic taus

To reconstruct the jets and the energy sums [1,3] in the L1 trigger, it is used:
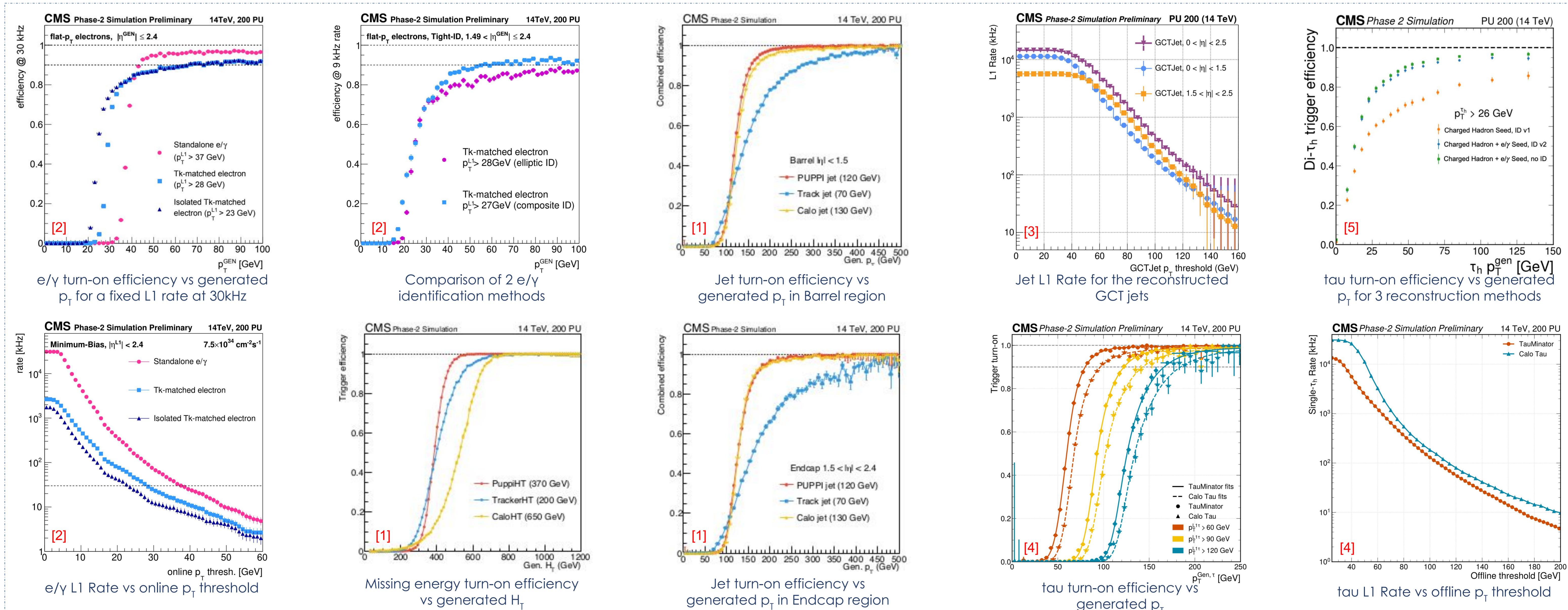- Calorimeter-only
- Tracker-only
- Particle-Flow algorithm: uses PileUp-Per-Particle-Identification (PUPPI) inputs to suppress the PU contribution
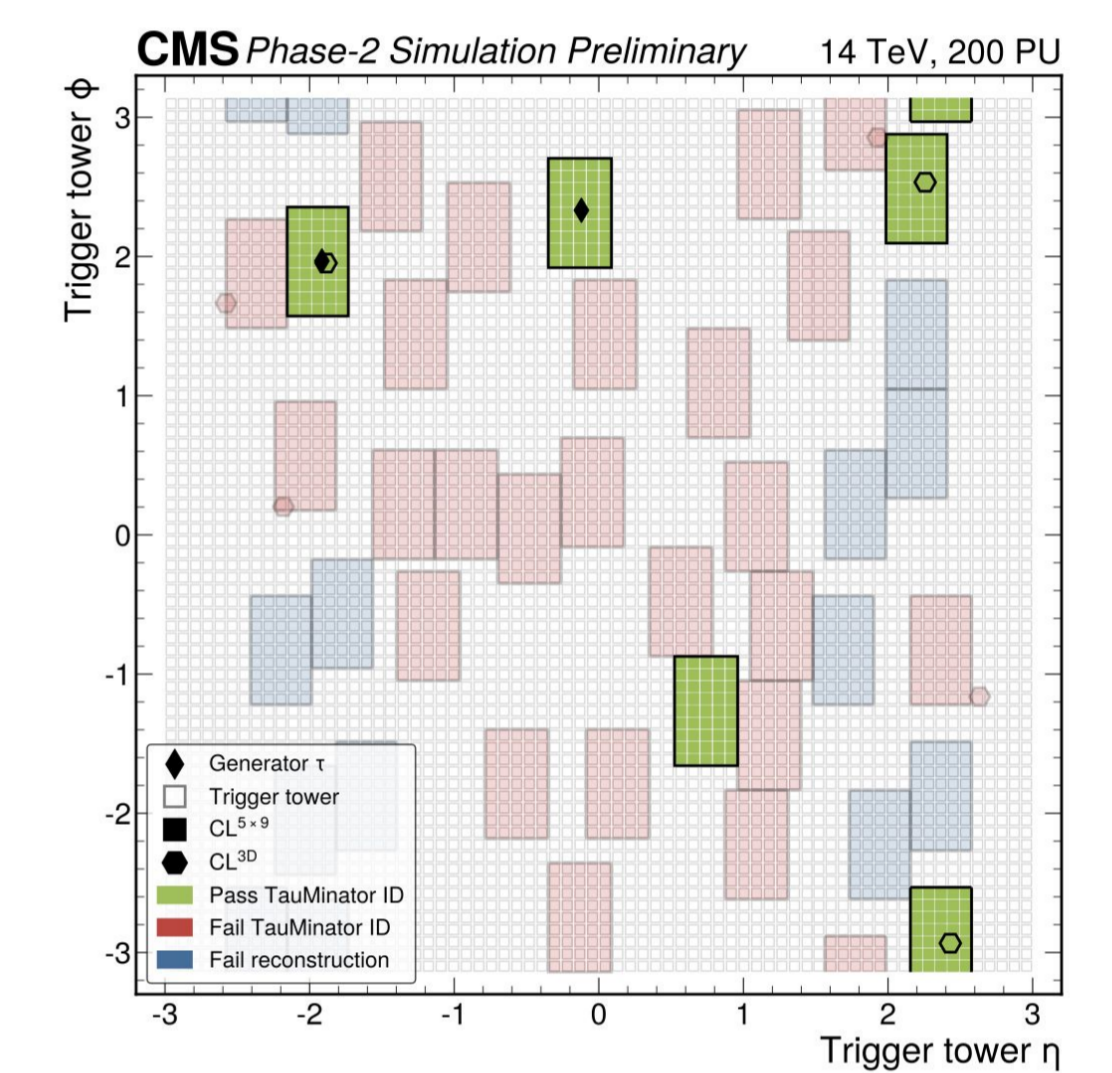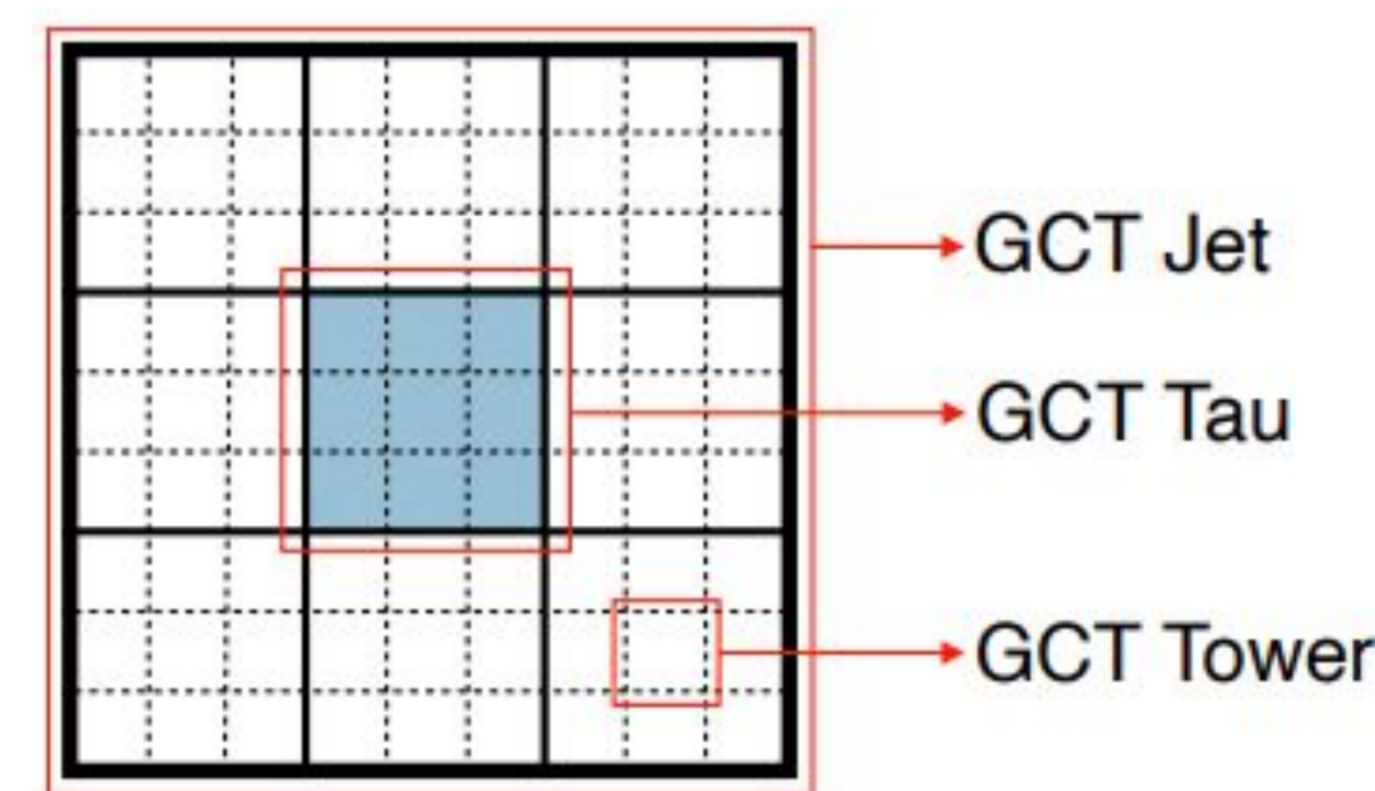
The hadronically decaying taus (τ_h) are reconstructed using three methods:
- Calorimeter-only information (Calo-Tau) [1,3]
- Calorimeter + Neural networks (TauMinator) [4]
- Calorimeter + Tracker (NNPuppi) [1,5]

Performance plots of the Phase-2 CMS Level-1 Trigger

e/γ turn-on efficiency vs generated p_T for a fixed L1 rate at 30kHz

Comparison of 2 e/γ identification methods

Jet turn-on efficiency vs generated p_T in Barrel region

Jet L1 Rate for the reconstructed GCT jets

tau turn-on efficiency vs generated p_T for 3 reconstruction methods

e/γ L1 Rate vs online p_T threshold

Missing energy turn-on efficiency vs generated H_T

Jet turn-on efficiency vs generated p_T in Endcap region

tau turn-on efficiency vs generated p_T

tau L1 Rate vs offline p_T threshold

Conclusions

- The Phase-2 Level-1 Trigger upgrade proposes solid and flexible solutions to triggering and data acquisition challenges for all objects
- The extensive use of ML technique ensures large improvements in L1 triggering technique, benefitting all envisaged analyses
- Novel trigger strategies are continuously being developed to maintain and extend the physics acceptance of today

References

1. CMS Collaboration, "The Phase-2 Upgrade of the CMS Level-1 Trigger", CERN-LHCC-2020-004, CMS-TDR-021
2. CMS Collaboration, "Electron Reconstruction and Identification in the CMS Phase-2 Level-1 Trigger", CMS-DP-2023-047
3. CMS Collaboration, "Standalone barrel e/γ and calorimeter based jet and tau reconstruction in the Level-1 Phase-2 Calorimeter Trigger", CMS-DP-2024-057
4. CMS Collaboration, "Hadronic Tau Reconstruction in the CMS Phase-2 Level-1 Trigger using NNs with Calorimetric Information", CMS-DP-2023-062
5. CMS Collaboration, "PUPPI Tau reconstruction in the Level 1 trigger with real-time machine learning for the HL-LHC upgrade of the CMS Experiment", CMS-DP-2024-018

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