CMS L1T Scouting at the HL-LHC

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Slides taken from talks given by E. Meschi, C. Botta, M. Rovere, G. Petrucciani and others

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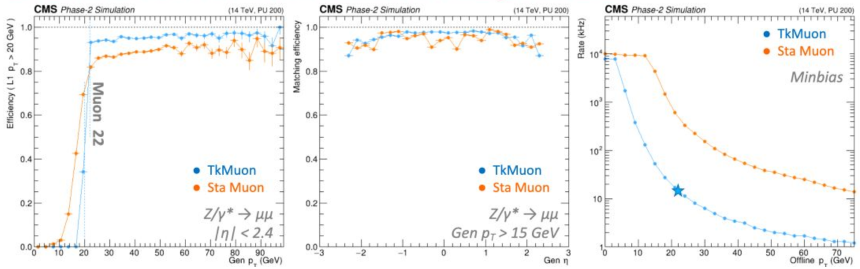
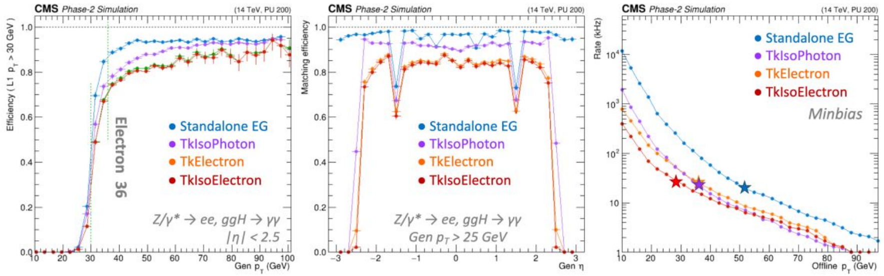
Baseline Physics Acceptance of Phase-2 L1T

- Upgraded sub-detectors provide more information to L1 Trigger (L1T)
  - Tracking (p_T > 2 GeV, $|\eta|$ < 2.4), x 5 η, ϕ granularity from HGCAL, ECAL crystals
  - **Large increase in input data: 60 TB/s (x 30 w.r.t. Phase1)**
- L1T uses cutting-edge technologies and expanded architecture to implement "offline-like" algorithms
  - Correlator Trigger (CTL1 & CTL2), Time Multiplexed Trigger (TMUX), high-speed optical links
  - Track matching, Particle Flow (PF), Pile Up Per Particle Identification (PUPPI)

• Standalone and Track Matched algorithms



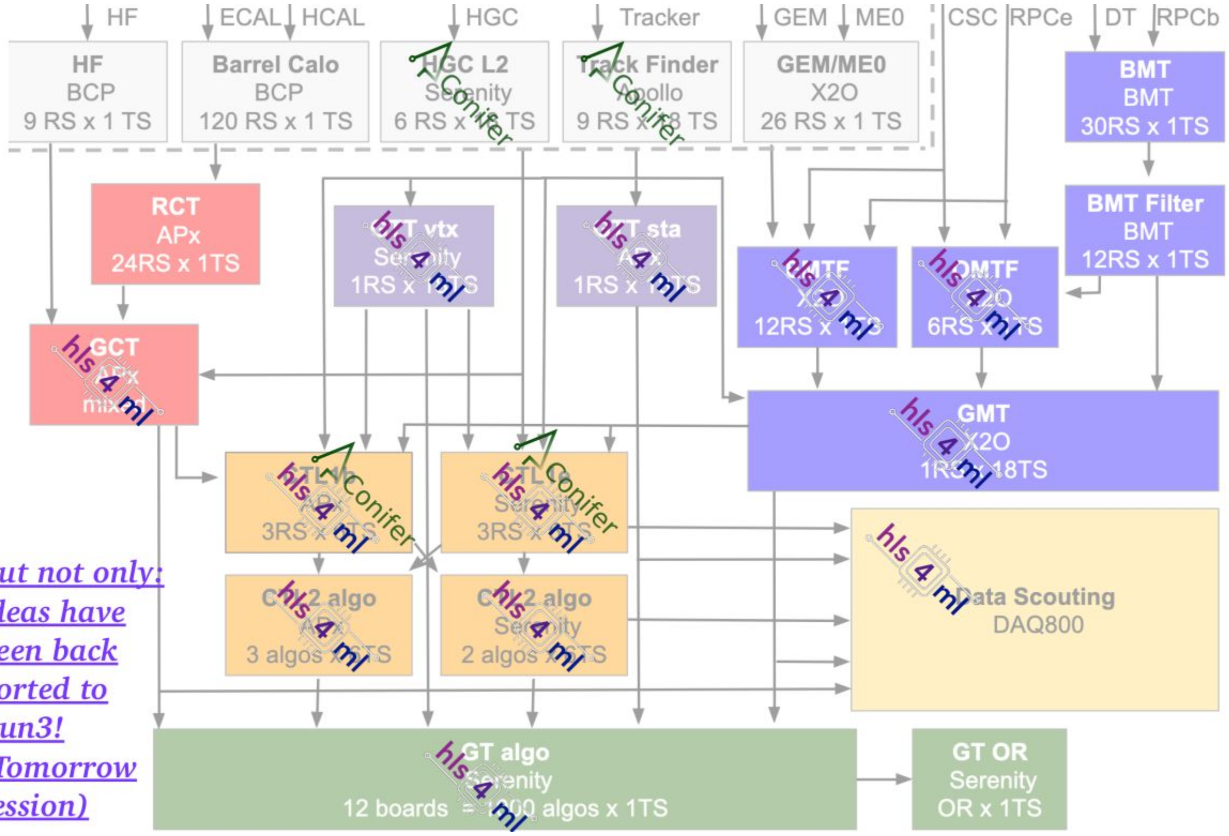
• Tracks used for electron ID, electron & photon isolation



Baseline Physics Acceptance of Phase-2 L1T

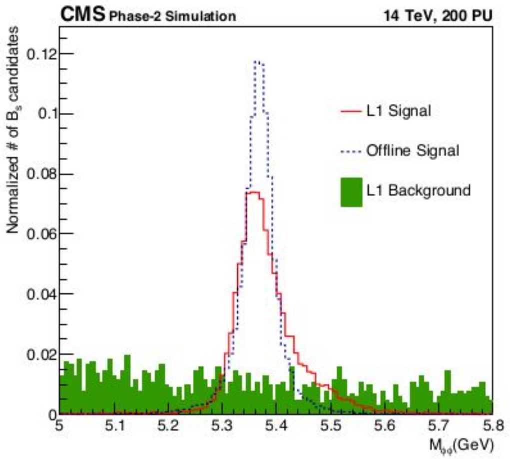
- L1T leverages new tools (hls4ml and Conifer) to synthesize ML models into FPGA firmware and exploit increased FPGA resources
  - 7.5 x more resources than FPGAs used in Phase 1
  - HLS tools compiling simple C++ code to firmware crucial to bring physicists into firmware development: now also available for ML algorithms (hls4ml, conifer)
  - ML (BDT, NN, DNN) used for PU rejection in PF clustering, vertexing and track-to-vertex association, electron identification, hadronic taus identification

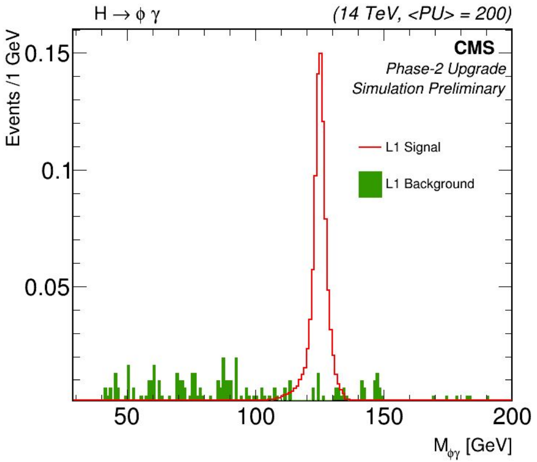
But not only: ideas have been back ported to Run3! (Tomorrow session)

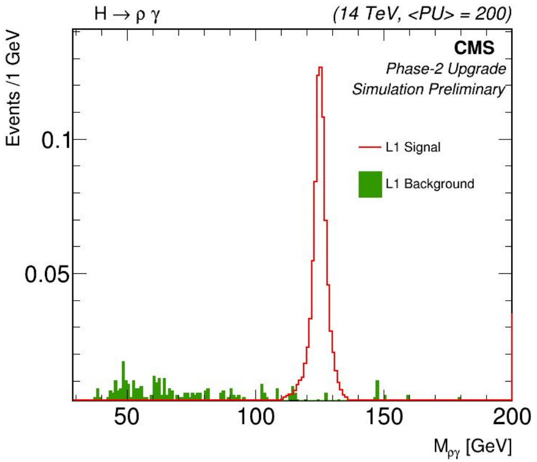


Extended physics acceptance of Phase-2 L1T

- Triggers with soft/correlated μ/tracks
  - Topological triggers being developed in dedicated trigger subsystems (GMT, GTT): $\tau \to 3\mu$, $B_s \to \varphi\varphi \to kkkk$, $B_s \to J/\psi$, $H/Z \to \varphi(kk)\,\gamma$, $H/Z \to \rho(\pi\pi)\,\gamma$, soft unclustered energy patterns (SUEPS), very high multiplicity, spherically-symmetric distributions of soft particles (soft-bombs)



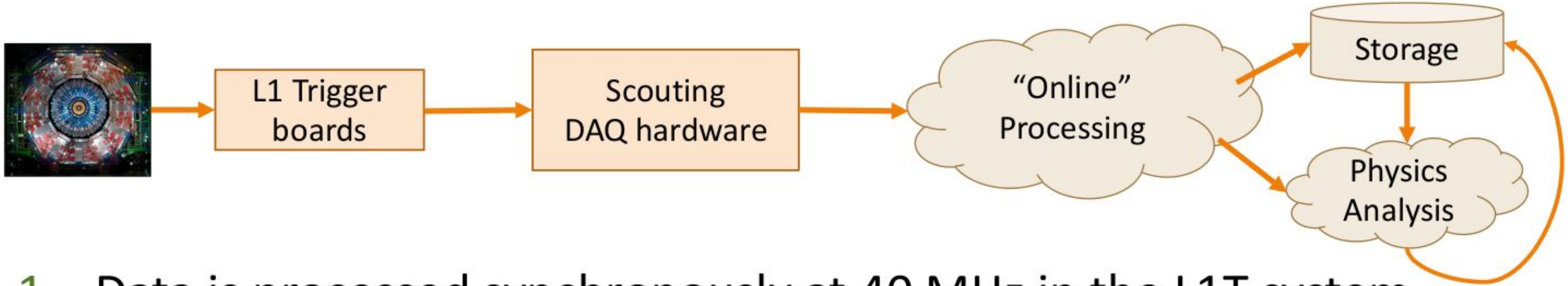




L1T Scouting

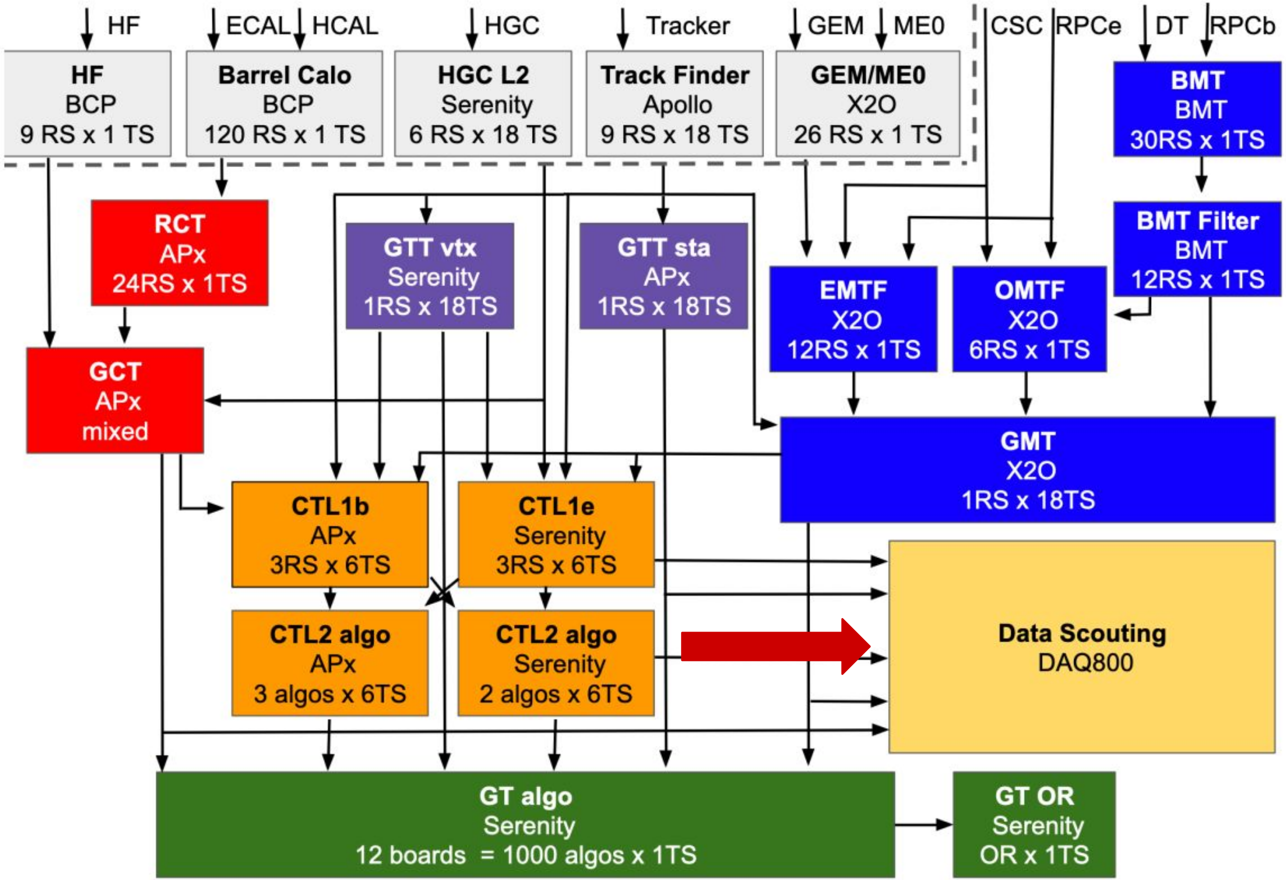
- The Phase-2 L1 trigger will produce - in most cases - physics objects of quality comparable to the present HLT
  - L1 Tracker Tracks, Particle-flow linking, Pile-up per particle identification, etc.
- Acquire L1 Trigger information for all events at 40 MHz
  - look for physics signatures identifiable with just L1 information, i.e less than full detector acceptance and/or resolution
- Study otherwise inaccessible physics signatures that
  - are either too common to fit in the L1 accept budget or with orthogonal requirements to the standard physics triggers e.g. multi-BX signature
  - have no model to drive design of trigger
- “Detector” and L1 diagnostics (e.g. compare GT decision to emulator) with timely and virtually unlimited statistics
- Luminosity measurements

L1T Scouting - Conceptual Design

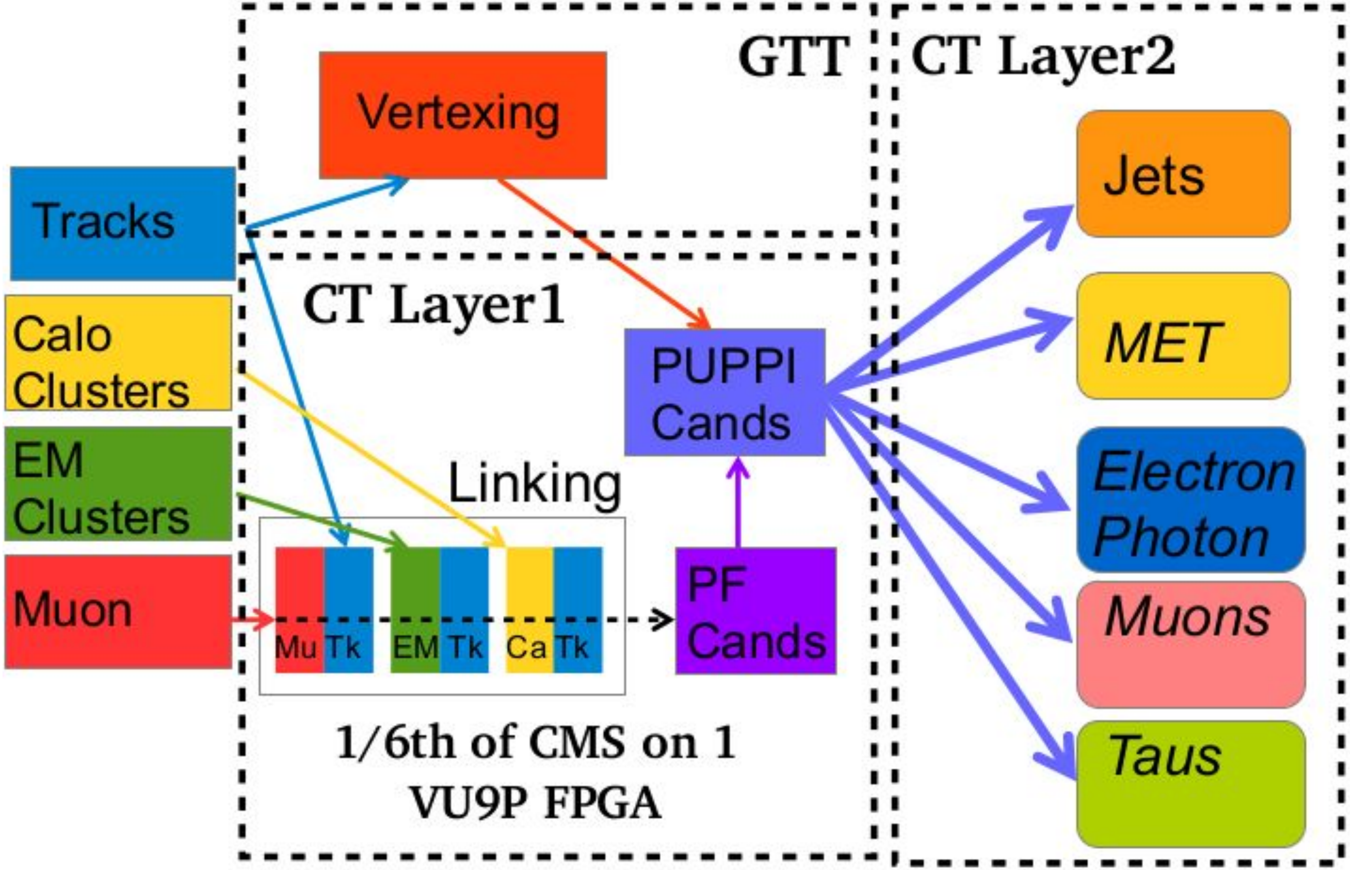


1. Data is processed synchronously at 40 MHz in the L1T system
2. Scouting DAQ hardware receives the data from L1T links, performs zero-suppression & buffering, and sends it to "online" processing
3. "Online" system processes data asynchronously, e.g. doing more zero suppression & compression, and data aggregation
4. Data is stored or analyzed on the fly saving only the analysis output (e.g. signal candidates)

L1T Scouting - Layout



L1T Correlator Trigger



PUPPI drastically mitigates the PU effect and reduces by a factor 10 the PF candidates

L1 Scouting Plans

- Develop ML algorithms to improve the L1T reconstruction (used by standard triggers, and L1 Scouting)
- Develop efficient ways for training & deployment of ML algorithms in L1T
  - updating and redeploying algorithms for changes in detector conditions
- Develop setup for complex trainings of multiple algorithms
  - e.g. simultaneously optimize algorithms for particle ID, object reconstruction, and event selection which are implemented in different subsystems (only limited amount of information is propagated between subsystems)

L1 Scouting Plans

- Develop autoencoder algorithms for unsupervised anomaly detection in the L1T for Run3 and HL-LHC
- Optimize design of the algorithm - resource consumption and latency - to run it as part of the main L1 Trigger system and in L1T Scouting, both for Run 3 and HL-LHC
- Demonstrate end-to-end physics analysis using unsupervised anomaly detection on Run 3 data
- Develop autoencoders or similar AI algorithms for data compression in L1 Scouting system to allow long-term storage of more scouting data

Summary

- L1 Data scouting is technically feasible
  - 40 MHz data acquisition demonstrated during Run 3
  - Data rate estimates for HL-LHC within capabilities of Phase-2 hardware (of course there's still a lot of R&D to do, but prospects are good)
- Event reconstruction quality at L1 of Phase-2 comparable to present-day HLT/offline, opening the door to many physics analyses

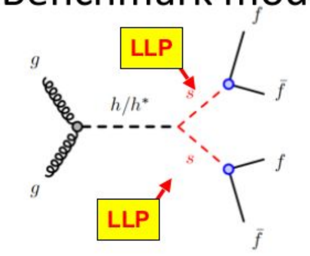
Extended physics acceptance of Phase-2 L1T

Explore new triggering strategies that could not be envisaged or sustained in terms of rate by the Phase-1 system

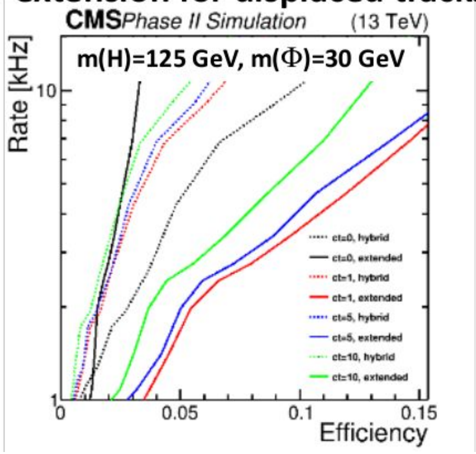
- Triggering on long-lived particles through displaced objects
  - *small displacement*: extended L1 Tracking to retain off-pointing tracks up to $|d_{xy}|$ ~5 cm, $|\eta| < 2.0$. Being used for displaced tracker/PUPPI-jets, displaced vertices, displaced track-matched muons
  - *large displacement*: depth segmentation of HCAL, showers in Muon chambers (already in Run 3), ECAL timing, improved p_T measurements in Muon Track Finders, ML approaches to tag displaced clusters in HGCAL

Extended physics acceptance of Phase-2 L1T

Benchmark model:



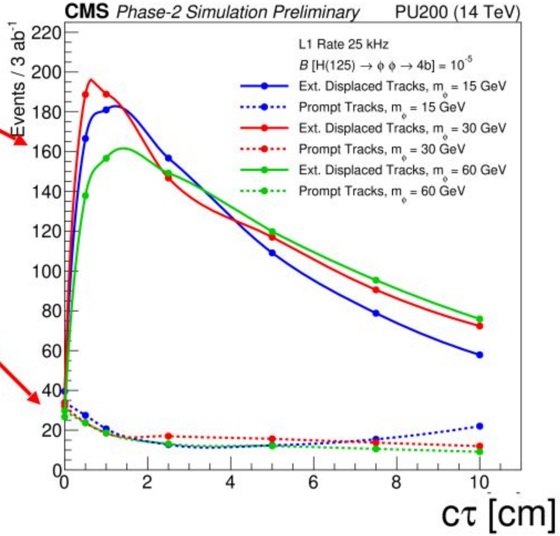
Large improvement in efficiency with extension for displaced tracks:



Enough events for discovery!

Extension for displaced tracks

Baseline track trigger



Extended physics acceptance of Phase-2 L1T

- Jet-tagging
  - Exploiting PUPPI candidates: b-tagging developed in CTL2, expand baseline Menu acceptance towards low mass HH → 4b (q/g tagging also being developed)
- Supervised and Unsupervised ML discriminants
  - Developed using PUPPI candidates in CTL2, or high-level objects in GT: NN/DNN for VBF H → bb, invisible, HH → 4b, HH → bbWW, anomaly detection (already targeting Run 3 implementation)