Level 1 Muon Triggers for the CMS Experiment at the HL-LHC

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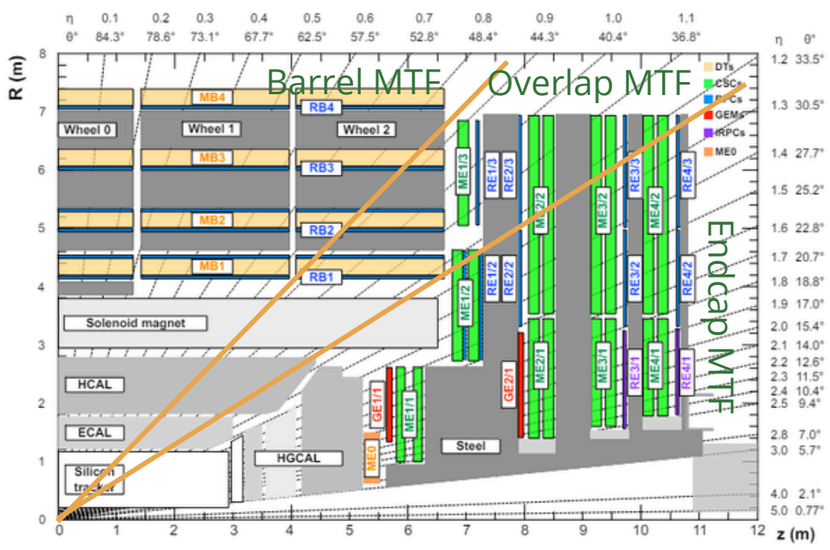
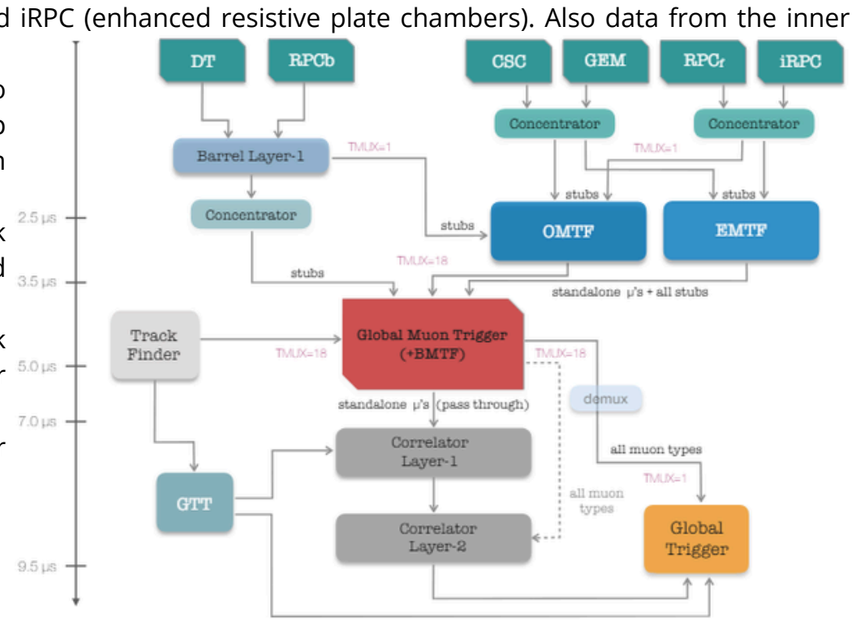
Level-1 muon trigger system for the Phase-2 upgrade



- During the LHC Long shutdown 3 (2026-2028) the CMS detector will be upgraded to profit from the High Luminosity upgrade of the Large Hadron Collider. Increased luminosity will allow for searches of rare phenomena, but also requires improvement of the trigger performance.
- The Phase-2 L1 trigger upgrade is intended to significantly improve the trigger response purity and efficiency. The acceptance rate will be increased to 750 kHz, while the latency budget will grow to 12.5 μs. Increased latency budget will allow to execute offline-like algorithms (particle-flow techniques and machine learning-based algorithms) already at the Level-1 of the trigger.
- Improved electronic boards and new muon sub-detectors will be used to reach the design parameters. New sub-detectors include GEM (gas electron multiplier) and iRPC (enhanced resistive plate chambers). Also data from the inner tracker will be used already at the Level-1.
- The data from the muon detectors is transmitted to three types of Muon Track Finders: Barrel, Endcap and Overlap, each of which accepts data from a different part of the detector.
- The data from the inner tracker is sent to the Track Finder subsystem reconstructing tracks of charged particles.
- Information from Muon Track Finders and Track Finder is combined in the Global Muon Trigger (GMT). The Muon Trigger (GMT) will reconstruct two types of muons: stand alone muons: based on data from muon chambers only, and global muons: tracks from inner tracker correlated with segments in the muon sumsystem.
- Transverse momentum resolution of L1 global muons will be much better than resolution correctly achieved in the L1 Muon trigger.



Muon Track Finders

Barrel

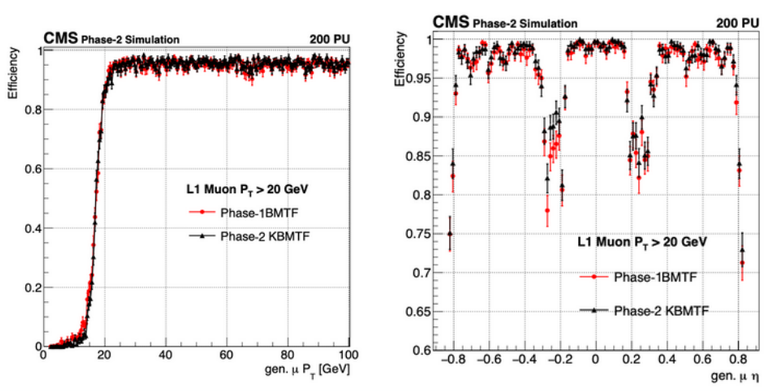
- **Structure and Technology:** Located in the barrel region, the BMTF will utilize Drift Tubes (DT) and Resistive Plate Chambers (RPC) to detect muons. It will consist of two parts: the Barrel Layer-1 and the actual BMTF located on the GMT boards.
- **Algorithms:** A refined version of the Kalman Filter, tailored for the muon trigger, will be used to reconstruct muon tracks with higher momentum precision. The Barrel Layer-1 will combine data from DTs and RPCs to form "super-primitives" which will then be processed by the BMTF to reconstruct muon tracks and momenta.
- **Performance:** Improved resolution will be achieved by providing better stubs from Barrel Layer-1 to BMTF, enabling more accurate and efficient muon reconstruction.

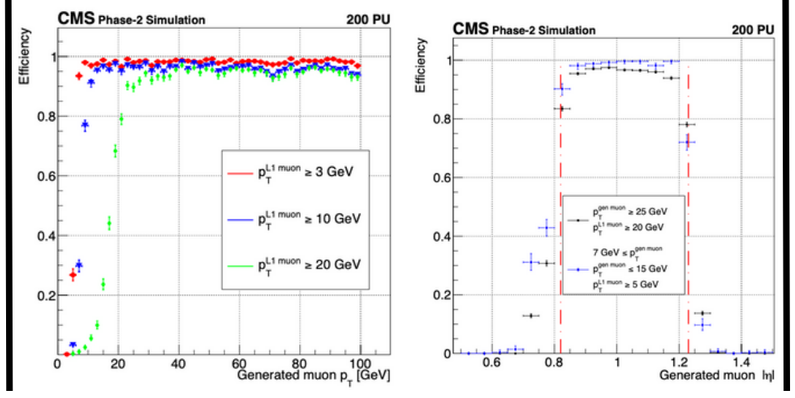
Overlap

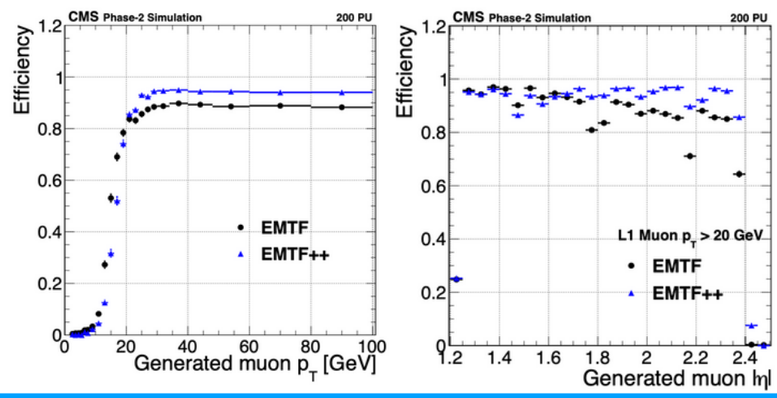
- **Structure and Technology:** Positioned in the overlap region, the OMTF interfaces between the barrel and endcap detectors, utilizing a combination of DT, CSC (Cathode Strip Chambers), and RPC technologies.
- **Algorithms:** It employs a probability-based method, using a naive Bayesian approach to correlate detected hits with muon tracks of various transverse momenta. This method provides a robust way to identify and reconstruct muon tracks amidst the mixed detector technologies present in the overlap region.
- **Performance:** The integration of multiple detector inputs and the strategic use of Bayesian probability by the algorithm ensure reliable muon track identification and reconstruction. Phase-2 OMTF will use a neural network to take into account correlations between measurements, which are neglected in the current Naive Bayes algorithm.

Endcap

- **Structure and Technology:** The system will operate in the endcap regions of the CMS detector, utilizing CSC, RPC, and the added GEM (Gas Electron Multiplier) and iRPC for the Phase-2 upgrade.
- **Algorithms:** The new EMTF++ algorithm will use a Neural Network based on transverse momentum. It will determine the transverse momentum path through the muon stations using multiple deviation angles (Δϕ, Δθ) and other variables as input. This will increase efficiency compared to the previous EMTF algorithm.
- **Performance:** These technologies will allow efficient pattern recognition in environments where magnetic fields are non-uniform. They will utilize the increased resolution of modern detectors to accurately distinguish muon tracks from background noise.

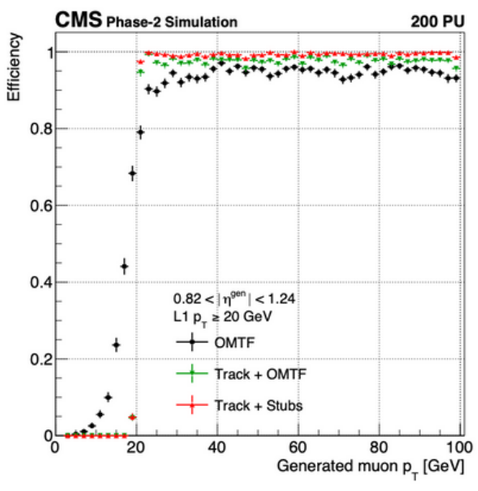


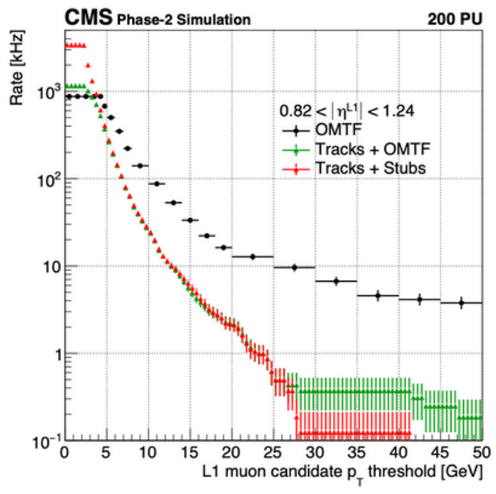




Global Muon Trigger

- The Global Muon Trigger (GMT) in the CMS experiment will play a crucial role in integrating and refining muon track data for the Level-1 (L1) trigger system. The GMT will receive inputs from regional muon track finders. Additionally, the GMT will receive data from newly introduced L1 track finder to better identify and reconstruct muons. In this way, the GMT will reconstruct two types of muons:
  - using only muon chamber data - stand alone muons
  - using data from the inner tracker and from muon chambers - global muons
- **Performance Enhancements:** Improved back-end electronics and detection capabilities with improved muon track detectors will enable the GMT to provide significant precision improvement. This as well as efficient muon track reconstruction will be key to reducing false triggers and improving data quality.





Summary

The CMS upgrade of the muon Level-1 (L1) trigger system, featuring the enhanced Global Muon Trigger (GMT), will bring significant advancements in performance and new capabilities for the High-Luminosity Large Hadron Collider (HL-LHC) era. By integrating advanced computational algorithms and leveraging state-of-the-art detection technologies, the upgraded GMT is designed to effectively manage the challenges posed by increased luminosity and the complex event conditions at the HL-LHC. These enhancements will enable the CMS experiment to probe new physical phenomena more effectively, significantly enriching our understanding of fundamental particles and forces and expanding the experiment's potential to explore novel physics processes involving muons.

Reference: CMS Collaboration, "The Phase-2 Upgrade of the CMS Level-1 Trigger", CERN-LHCC-2020-004, CMS-TDR-021, 10 March 2020

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