Level-1 muon triggers algorithms for the CMS upgrade at the HL-LHC

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on behalf of the CMS Collaboration
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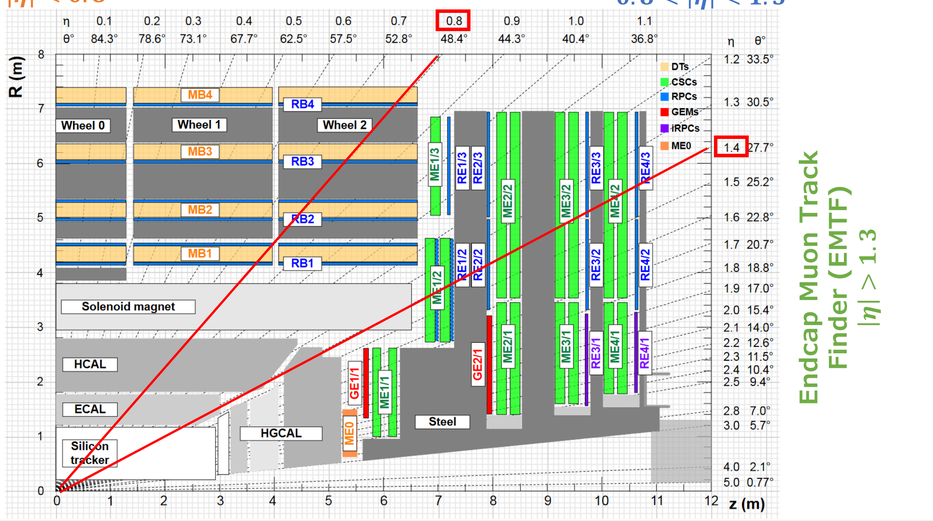
Introduction:

High luminosity LHC (HL-LHC) implies challenging conditions with an increase in pile-up of a factor of 5.

This means:
- Aging of the detectors in high radiation environment must be checked.
- Higher occupancy in the detector yield a complex reconstruction process.
- Level-1 (L1) muon rate will increase: need a precise p_T measurement to keep the rate under control without increase the p_T threshold.

The L1T upgrade will:
- Allow a maximum rate of 750 kHz at a latency of 12.5 μs.
- run on commercial FPGAs processors.
- Include new reconstruction algorithms that will improve the efficiency of Run 2 keeping the rate under control and trigger on exotic signatures as long lived particles.
- Increase η coverage: adding iRPC and GEM subdetectors

The upgrade of the three muon track finder algorithms (MTF) and the global muon trigger is presented

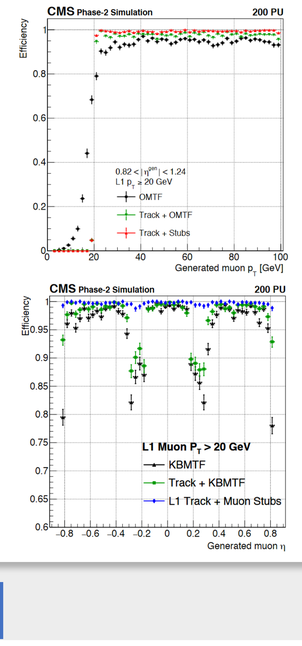


Global Muon Trigger:

Several Options to combine L1 tracks with information from muon chambers:
- **Track + MTF**: geometrical matching of tracker and stand-alone tracks.
- **Track + stub**: matching of tracker + single muon station segment.

Combining information yields to:
- Better muon p_T estimation.
- Smaller rate, allowing L1 seeding with lower p_T.
- Track+stub: reduces "gaps" between DT wheels.

Featuring more sophisticated or topological triggers: muon isolation, $\tau \rightarrow 3\,\mu$, HSCP...

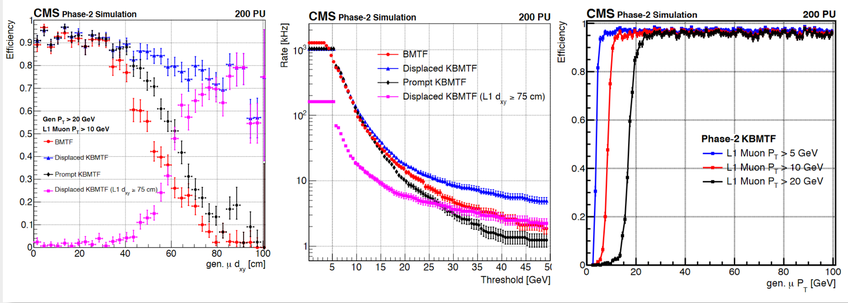


Barrel Muon Track Finder:

DTs + RPCs
Reconstruction based on Kalman Filter:
- Used successfully for Run 2
- Seeding: uttermost muon detector.
- For each hit estimation of: k (curvature), ϕ (position) and ϕ_b (bending).
- Propagate inwards, selecting hit in next station according to compatibility.
- Update parameters and repeat until last DT station.

Store track with out more constrains (Displaced kBMTF)
Sensitivity to long-lived signatures for >60 cm displacements.

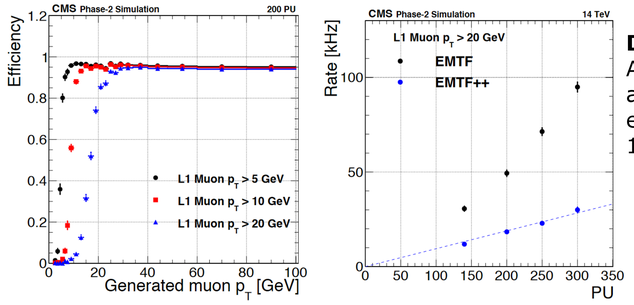
Propagate to CMS center (Prompt kBMTF)
Maintains high Phase-I efficiency with slightly lower rate.



Endcap Muon Track Finder:

RPCs + CSCs + GEMs
Phase-I algorithm rate scales non-linearly with PU → new strategy (EMTF++)
Reconstruction based on Deep Neural Network (DNN):
- Pattern recognition techniques to identify trigger primitives compatible with muon trajectories.
- Angular position (ϕ and θ), bending, time and quality used as input to NN.
- DNN estimates the most likely p_T of the muon.

High efficiency (>95%) for pt > 20 GeV -> significant improvement wrt. Phase-I, also rate increase slower as a function of PU.



Displaced pattern:
Alternative NN achieving >50% efficiency for d_0 30-100 cm.

The CMS Collaboration. *The Phase-2 Upgrade of the CMS Level-1 Trigger*, **CERN-LHCC-2020-004 /CMS-TDR-021**

Overlap Muon Track Finder:

DTs + RPCs + CSCs
Reconstruction based on Bayes Classifier:
- Measure ϕ for each hit and select a reference one.
- Build $\Delta\phi$ with respect to reference hit.
- Compare with precomputed patterns and most likely gives p_T estimation.

Ageing:
Very dependent of the MB1 (innermost DT), expected to be the more affected by ageing.

Efficiency over 95% for $p_T > 20\ GeV$.
Decrease of 5% for the worst-case ageing scenario: non affected thanks to redundancy of the system.