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

Carlos Francisco Erice Cid on behalf of the CMS Collaboration

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The Phase II upgrade: challenges for the HL-LHC

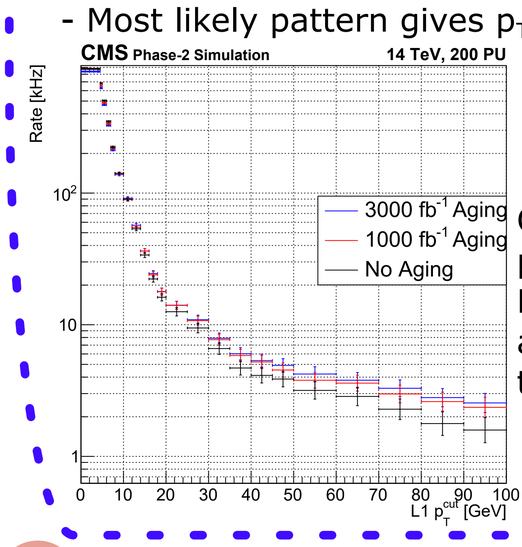
The HL-LHC introduces new challenges into the L1 Muon Trigger of CMS:
- Higher Pileup (PU) scenarios, more detector occupancy, leading to increased complexity of the muon reconstruction process.
- High PU also introduces higher L1 rates, it is not straightforward to keep the pT acceptance range of the Run II L1 muon trigger.
- High radiation environment might result into efficiency losses in the parts of the detector that are most vulnerable to ageing.

The upgraded L1T system will feature:
- Complete overhaul of the readout electronics and DAQ, increasing the accepted L1 rate to 750 kHz at a 12.5 μs latency.
- Upgrade of the L1 system to use commercial FPGA processors.
- L1 Tracks from the silicon tracker will be added to the muon trigger.
- New reconstruction algorithsm that are expected to:
  - Improve the efficiency of the Run II trigger with a controlled rate.
  - Expand the sensitivity of CMS to exotic muon-like physics.
  - Provide a robust response near unaffected by detector degradation.

Three different algorithms for muon track finding (MTF) in the muon chambers updated from their Run II counterparts are presented here.

Overlap Muon Track Finder (OMTF)

Covers the transition region $0.8<|\eta|<1.3$
Combining signals from DT+RPC+CSC
Based on a Bayes classifier discriminant:
- For each subdetector hit measure its ϕ
- Choose a reference hit amongs them.
- Build $\Delta\phi$ with respect to reference hit.
- Compare with several precomputed "patterns" for different p_T values.
- Most likely pattern gives p_T estimation

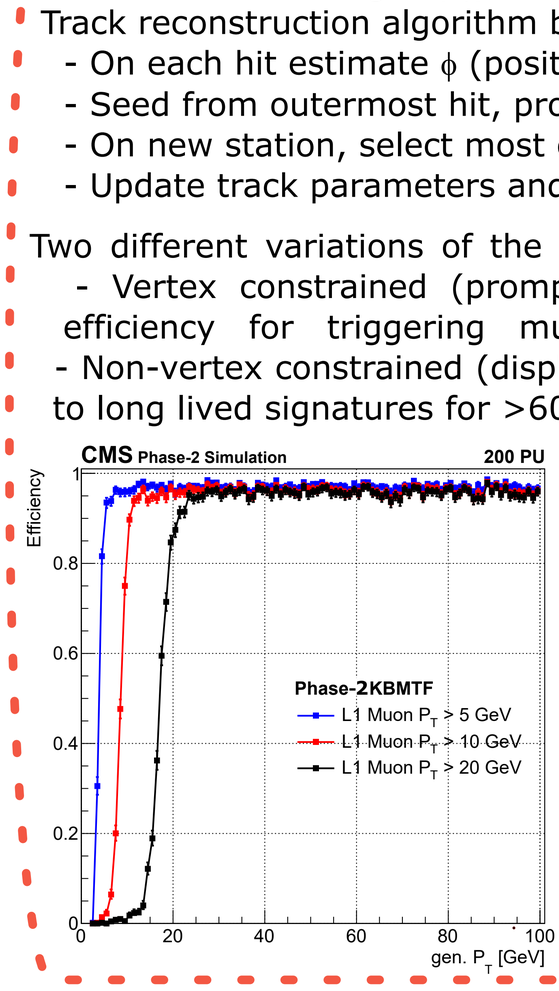


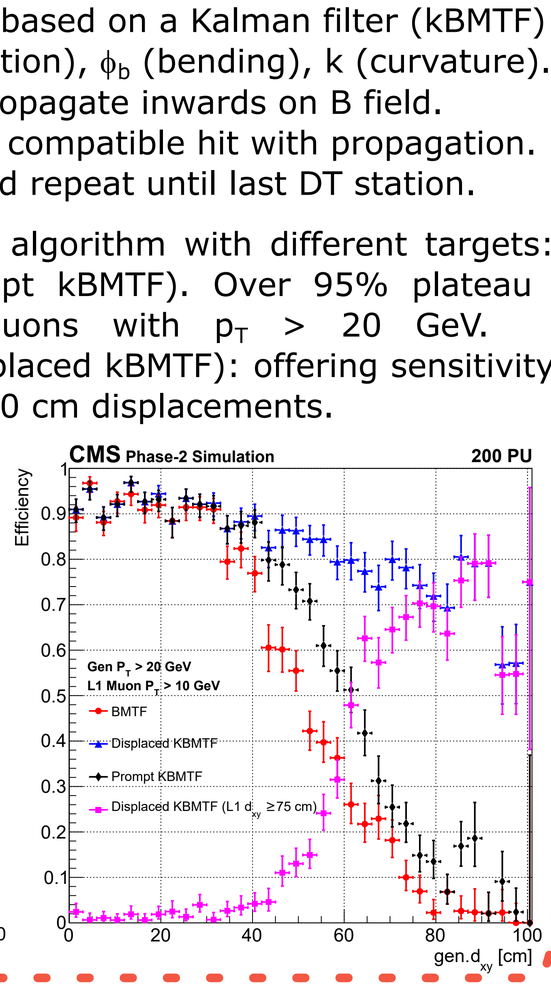
Overall efficiency over 95% for muons with p_T > 20 GeV, with a turn on width of ~5 GeV.
Estimated to be the MTF most affected by ageing effects, due to its dependence on the outermost DT:
- Studied by simulating muon hit losses.
- Performance largely unaffected thanks to detector redundancy.

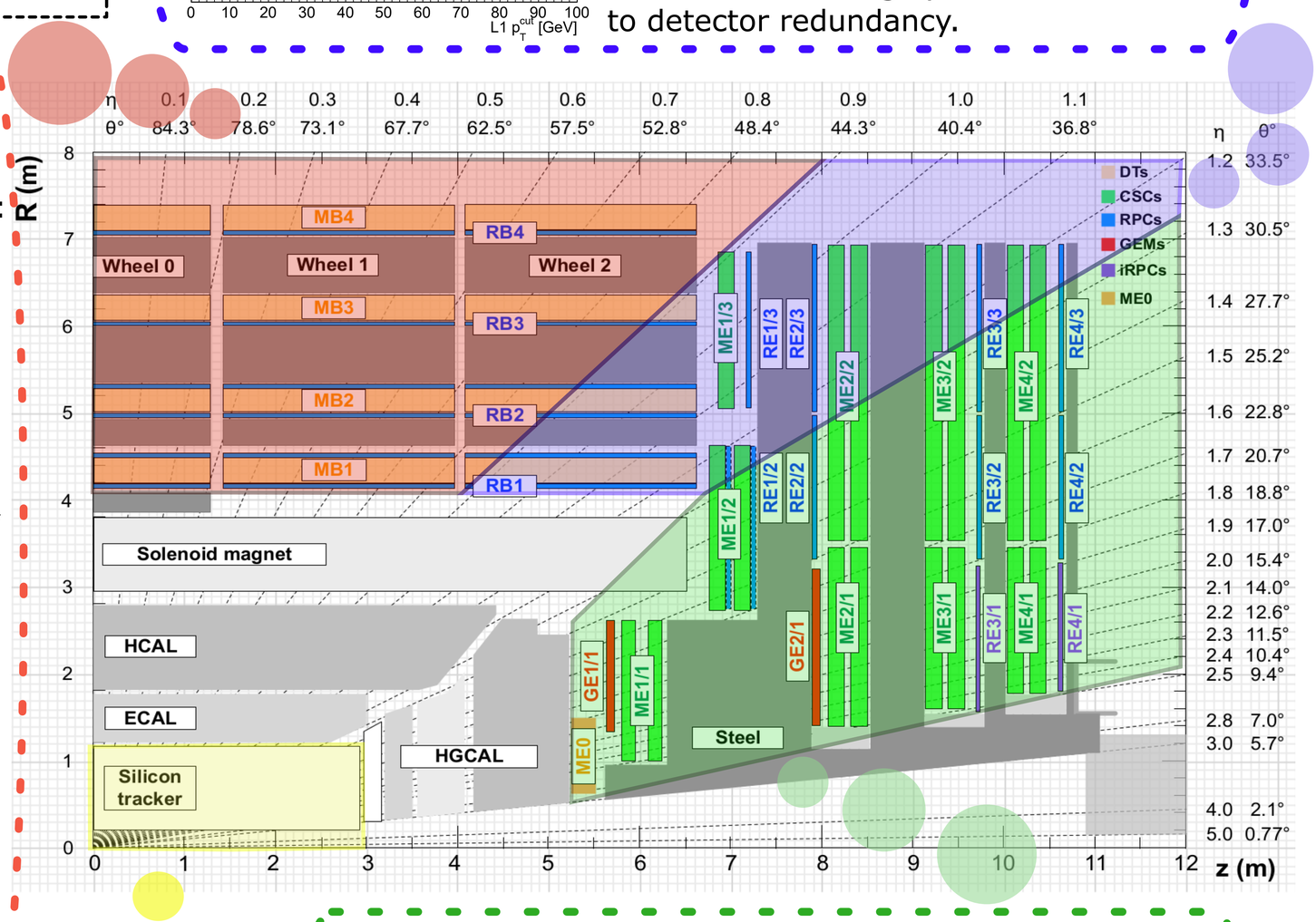
Barrel Muon Track Finder (BMTF)

Covers the barrel region $|\eta|< 0.8$, with input from DT + RPC.
Track reconstruction algorithm based on a Kalman filter (kBMTF):
- On each hit estimate ϕ (position), ϕ_b (bending), k (curvature).
- Seed from outermost hit, propagate inwards on B field.
- On new station, select most compatible hit with propagation.
- Update track parameters and repeat until last DT station.

Two different variations of the algorithm with different targets:
- Vertex constrained (prompt kBMTF). Over 95% plateau efficiency for triggering muons with p_T > 20 GeV.
- Non-vertex constrained (displaced kBMTF): offering sensitivity to long lived signatures for >60 cm displacements.



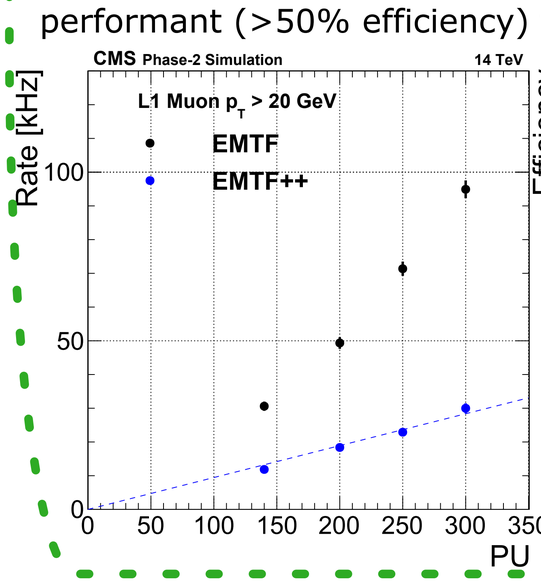


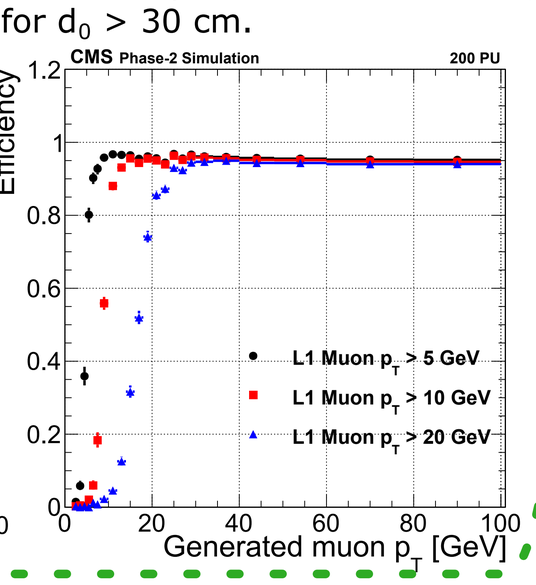


Endcap Muon Track Finder (EMTF)

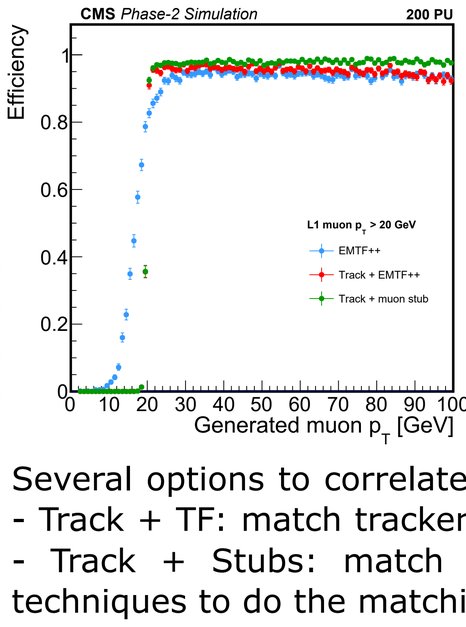
Covers the endcap region $|\eta|> 1.3$, input from CSC+RPC+GEM.
Run II algorithm rate scaling non-linearly with PU.
New strategy (EMTF++) based on neural networks (NN):
- Identify sets of local CSC+RPC+GEM consistent segments, using pattern recognition techniques.
- Combine information from angular position, time, bending, and quality into a neural network algorithm.
- NN provides p_T estimation based on these inputs.

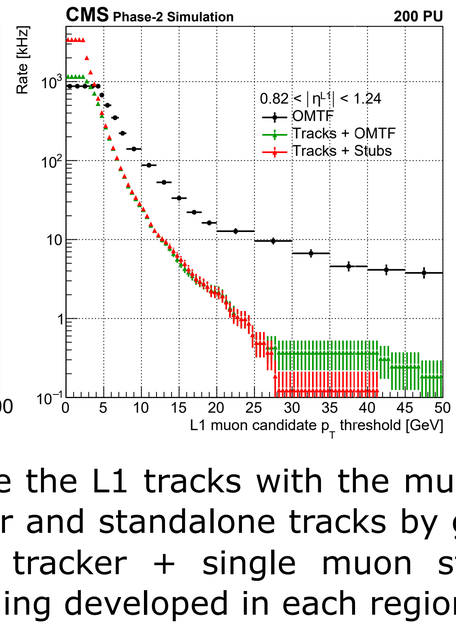
Quite stable results, reducing the rate vs Pile Up significantly.
High efficiency (>95%) for triggering p_T>20 GeV muons.
Alternative network also trained for displaced reconstruction, performant (>50% efficiency) for d_0 > 30 cm.

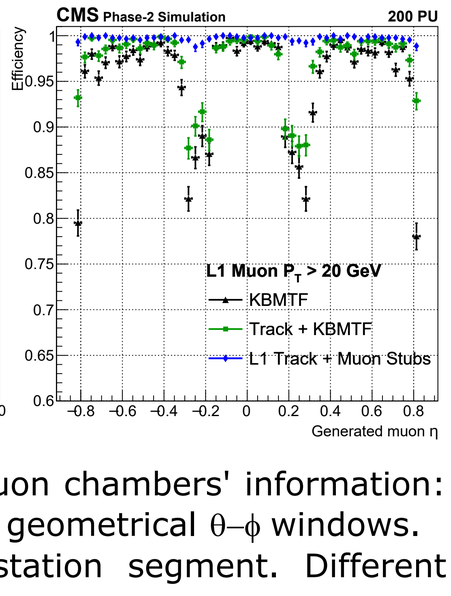




Going global: Benefits of a track trigger







Several options to correlate the L1 tracks with the muon chambers' information:
- Track + TF: match tracker and standalone tracks by geometrical θ–ϕ windows.
- Track + Stubs: match tracker + single muon station segment. Different techniques to do the matching developed in each region.

Benefits are quite clear with respect to all three considered track finders:
- Significant improvement in the lepton p_T estimation.
- As a consequence, the rate is reduced, allowing L1 seeds with lower p_T.
- Track+Stubs "closes gaps" where TFs are inefficient (i.e. between DT wheels).

[0] CMS Collaboration, "The Phase-2 Upgrade of the CMS Level-1 Trigger", CERN-LHCC-2020-004/CMS-TDR-021 (https://cds.cern.ch/record/2283189)