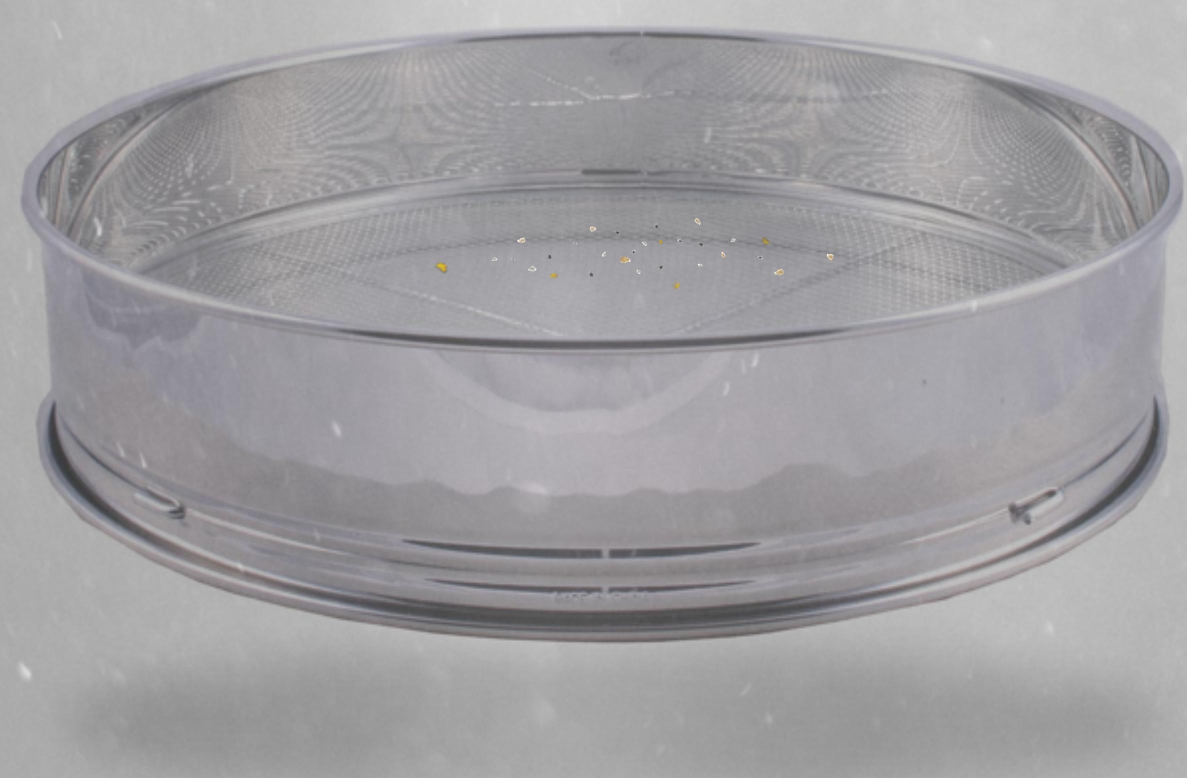
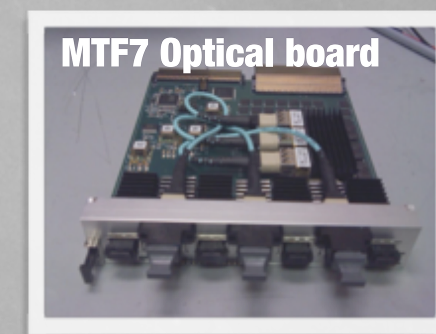
The CMS muon trigger will be completely upgraded using custom designed AMC boards, with more powerful FPGAs and larger memories. The upgraded CMS trigger muon system will implement pattern recognition and MVA (Boosted Decision Tree) regression techniques in the trigger boards for muon pt assignment, drastically reducing the trigger rate and improving the trigger efficiency. The upgraded system design will exploit the redundancy of the CMS muon detectors at a very early stage merging different muon detector information already at L1.

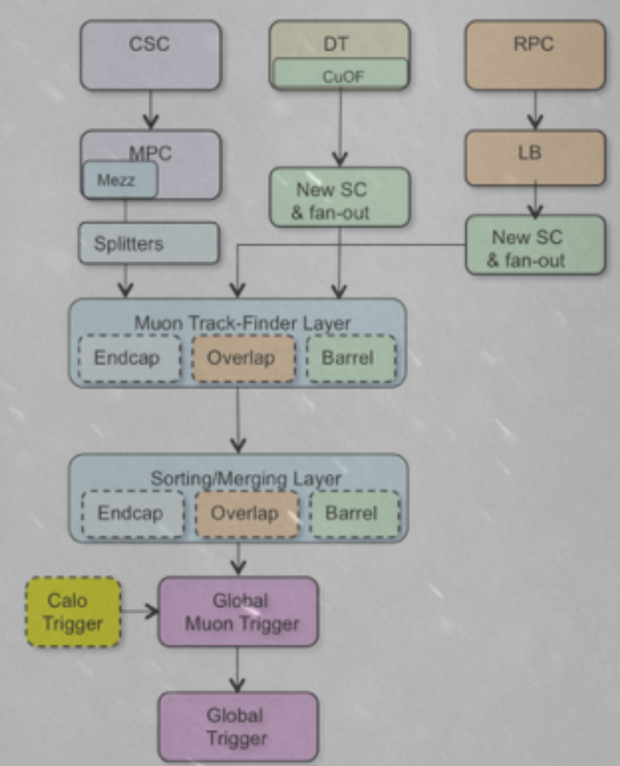
# The new CMS muon trigger

# New physics panning, a new sieve for CMS




**After the Long Shutdown 1 LHC will run at a center of mass energy of 13TeV, providing CMS with proton collisions at an expected rate which is almost double the LHC design goal of 10^34 cm-2s-1, and almost three times the peak luminosity reached during Run1 of 7.7 10^33 cm-2s-1. The higher luminosity and center of mass energy of LHC will raise the Level 1 (L1) muon trigger rate by almost a factor six for a given muon pt threshold. It is therefore necessary to increase the muon transverse momentum threshold to keep the trigger rate under 100 kHz, maximum sustainable rate for the CMS detectors. An increase of the L1 trigger thresholds implies a lowering of the efficiency in detecting signals from new physics and consequently a delay in possible discoveries.**
**It is therefore necessary to upgrade the L1 muon trigger electronic boards and the algorithms that assign the muon pT. The goal is to have algorithms that reduce as much as possible the promotion of low momentum muons to high momentum muons. Low momentum muons come mostly from uninteresting events, while high momentum muons potentially carry information about new physics. Cathode Strips Chambers (CSC), Resistive Place Chambers (RPC), and Derive Tubes (DT) muon hits are used together to create a muon candidate and to measure its momentum. Regional muon candidates are created by three different modules: Endcap Muon Track Finder (EMTF), Overlap Muon Track Finder (OMTF), Barrel Muon Track Finder (BMTF). All candidates are sent to the Global Muon Trigger which eliminated overlap and rank all candidates by quality and momentum.**

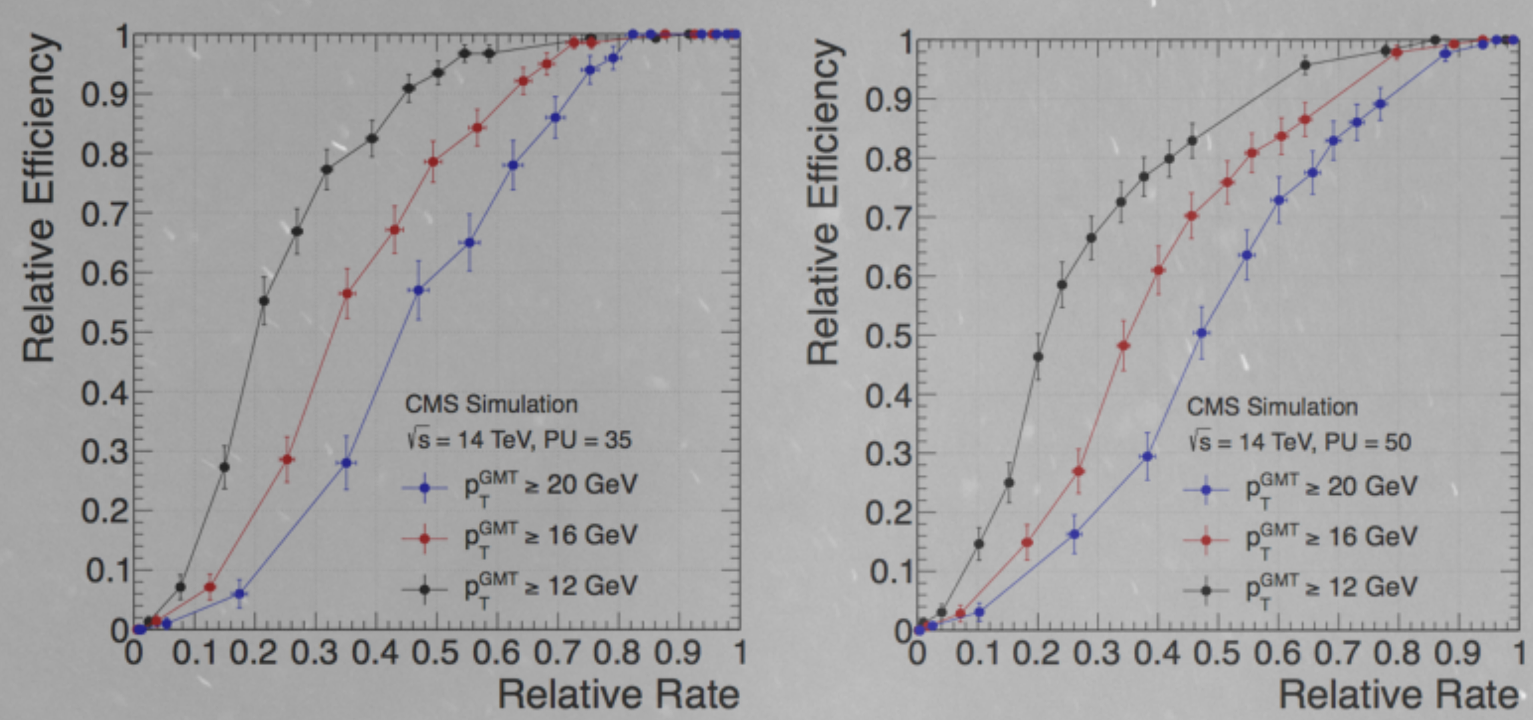



### Physics Performance

New possible physics phenomena will become within reach with the upgrade in energy and intensity of LHC. It is crucial to keep the triggering system at least as efficient as it was for Run1. Physics analyses which will benefit from the muon trigger upgrade are Higgs searches like WH production with H→bb and H→WW with both W decaying leptonically, but also supersymmetry analyses like the direct Stop quarks production search. During Run1 these analyses were using a Single Muon trigger to collect their signal. With the LHC Run2 expected luminosity this trigger will produce 27 kHz, a trigger rate that is unsustainable for the CMS L1 system.

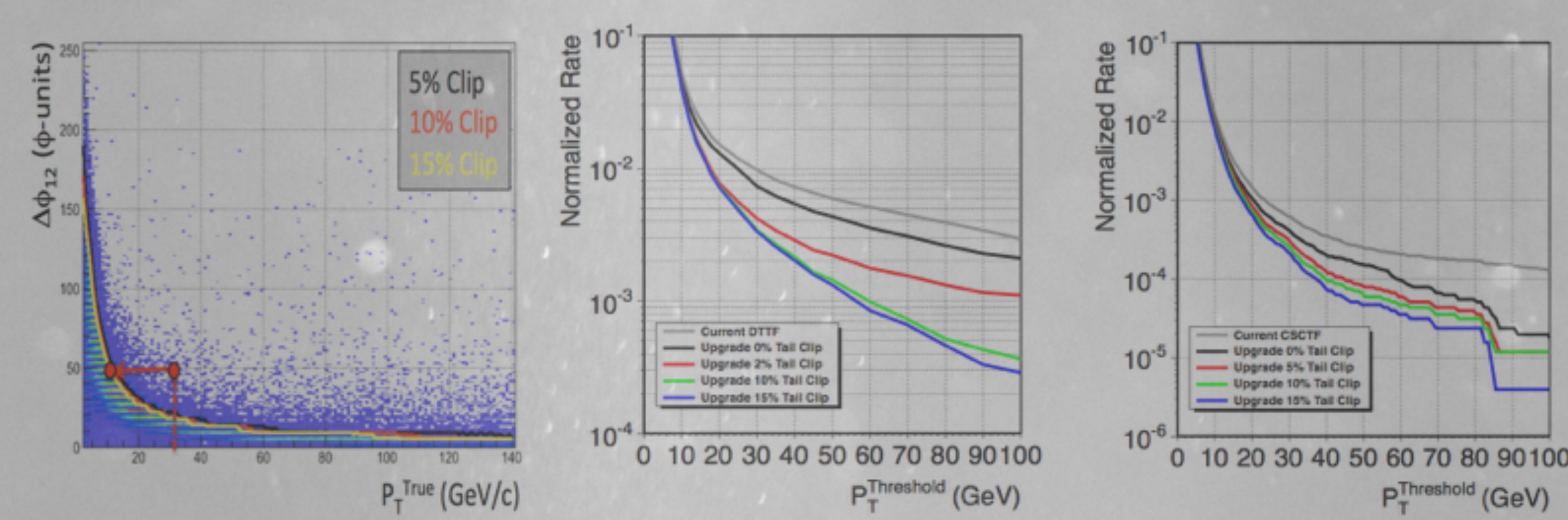
| Level-1 Trigger, 2012 Threshold | 95% Threshold [GeV] | Rate [kHz] $L = 0.4$ $\langle PU \rangle$=15 | Rate [kHz] $L = 1.1$ $\langle PU \rangle$=45 | Rate [kHz] $L = 1.6$ $\langle PU \rangle$=66 | Rate [kHz] $L = 1.1$ (14 TeV) $\langle PU \rangle$=50 |
|---|---|---|---|---|---|
| Single Mu, 14 GeV, $\lvert\eta\rvert < 2.1$ | 19 | 4.1 | 11 | 15 | 27 |

The upgraded system can reduce this rate by a factor for the same muon $p_T$ threshold and keeping the signal efficiency high. In the plots below a W→μν sample is used with the upgrade GMT emulation to show the performance for various possible working points.



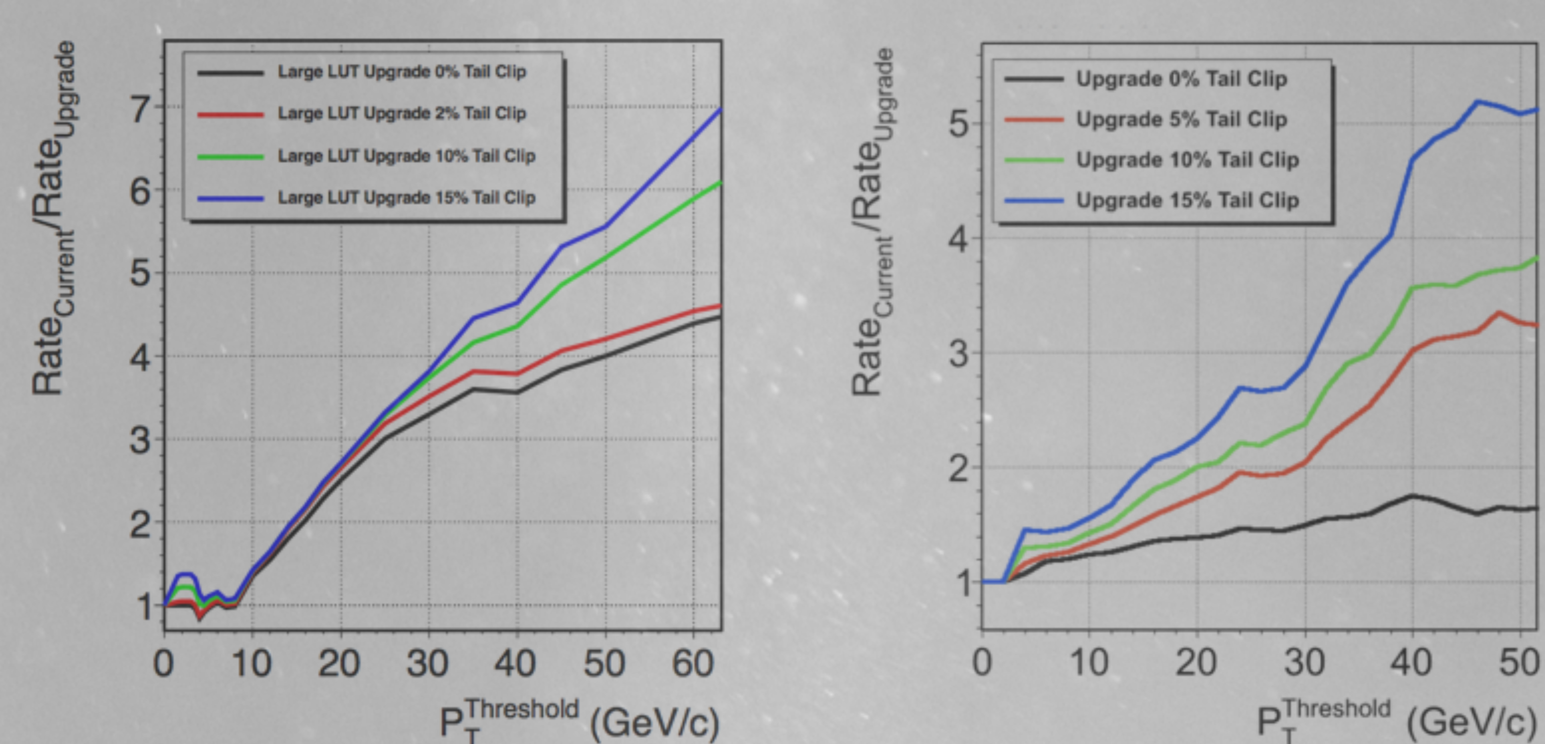

### Tail clipping

A tail clipping method reduces the rate without affecting the signal efficiency. A tail clipping is a post-processing step that allows to route the LUT output back to the main FPGA. For a given tail fraction a boundary curve is computed for every variable and muon candidates that comes out of the LUT with a $p_T$ outside this boundary are demoted to the maximum allowed value. This procedure is repeated for all variables and eventually the minimum $p_T$ found using this procedure will overwrite the $p_T$ from the LUT.




### FPGA with Multi Variate Analysis for pT assignment

A Look Up Table (LUT) is created using a Multi Variate Analysis (a Boosted Decision Tree): it takes as input sensitive information of the muon candidates and it generates a LUT with estimates of the muon momentum using a regression analysis.
The precision on the pT increases compare to the Maximum Likelihood method used for Run1, reducing the muon pT mis-assignment and therefore the muon rate at low pT.




### Barrel Muon Track Finder

The barrel muon track finder is receiving all hits produced by the CMS muon chambers installed in the central region of the detector up to pseudorapidity of 0.8. These include Derive Tubes (DT) and Resistive Place Chambers (RPC). Optical links connect the front end electronics to the track finder boards. The Barrel Track Finder boards are MP7 boards based on Virtex7 FPGA, upgrade that will initially reduce the latency of the barrel track finder, and, in a second stage, allow for more sophisticated algorithms to improve the $p_T$ assignment performance.

### Endcap Muon Track Finder

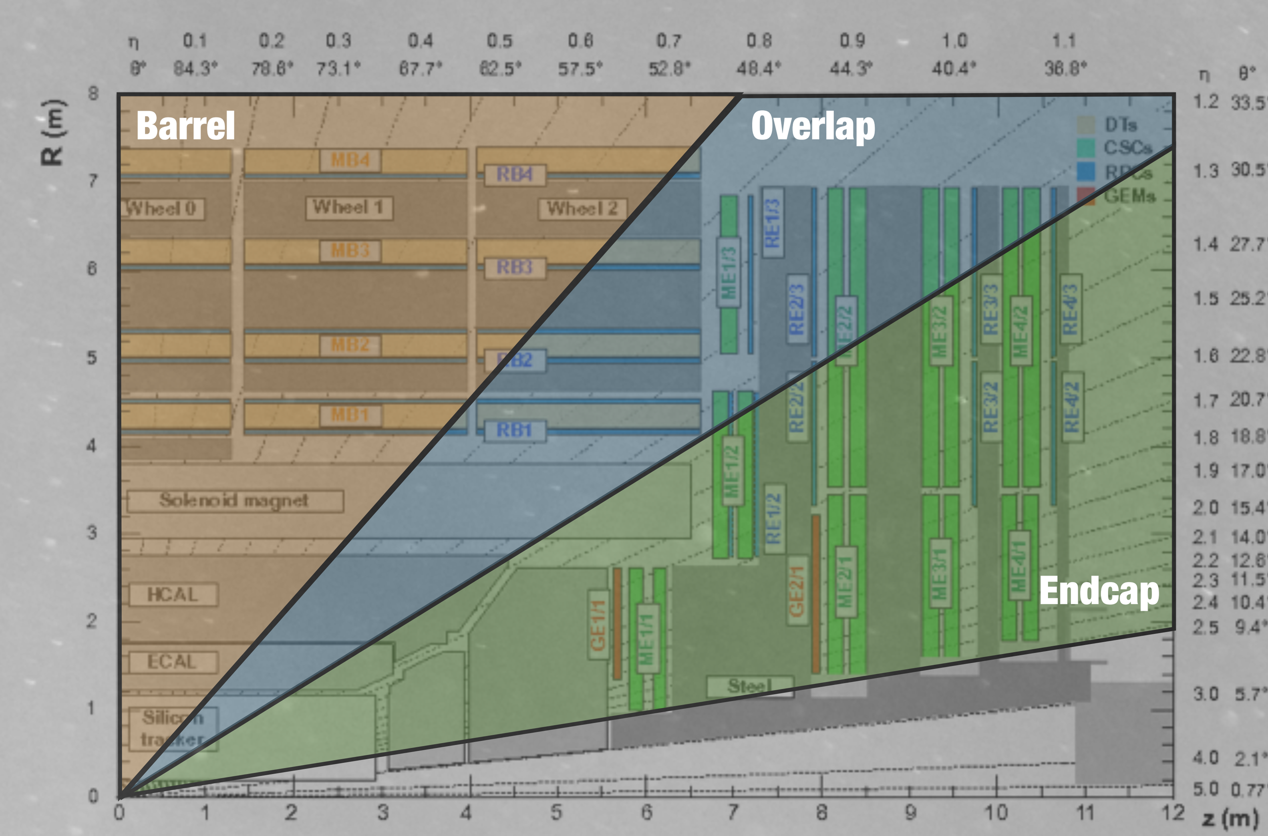
The endcap muon track finder will be triggering events with muons leaving signals in the CMS encdap detectors: the Cathode Strip Chambers (CSC) and the Resist Place Chambers (RPC) of CMS. It will use uTCA boards specifically designed to measure the muon pT with the best precision within the latency allocated by CMS for that purpose (~750ns). It will cover the forward region of CMS, with pseudorapidity between 1.25 and 2.5. Optical signals are sent from the CSC and the RPC to the boards that will use a large memory to load a Look Up Table (LUT) to transform patterns of hits in a $p_T$ measurement. Its design it also allows to accept GEM detector inputs in vision of the installations of this new type of muon chambers.

### Overlap Muon Track Finder

The experience of LHC Run1 showed that the region where the magnetic field is less uniform the muon track finder has special needs. The overlap track finder will take care of this complicated region included between pseudorapidity 0.8 and 1.25. It will use the same board design as the endcap muon track finder (MTF7) but with a customised firmware and algorithm for $p_T$ assignment. The overlap track finder will receive input from all the three different muon detectors installed in CMS and it will combined their information to exploit all the available information in order to reach the best muon $p_T$ assignment.

### Global Muon Trigger

The global muon trigger will receive inputs from the three systems (barrel, overlap, and endcap track finder) and will combine and order all muons that will then be sent to the Global Trigger, the final step of the triggering system of CMS. As the other trigger systems, also the global muon trigger upgraded its copper links to optical links, and it will receive many more candidates than what it did during Run1. It is using CPT7 boards which will allow a better handle of higher number of trigger primitives.




CMS Technical design report for the level-1 trigger upgrade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