Performance of the CMS Muon System in LHC Run-2

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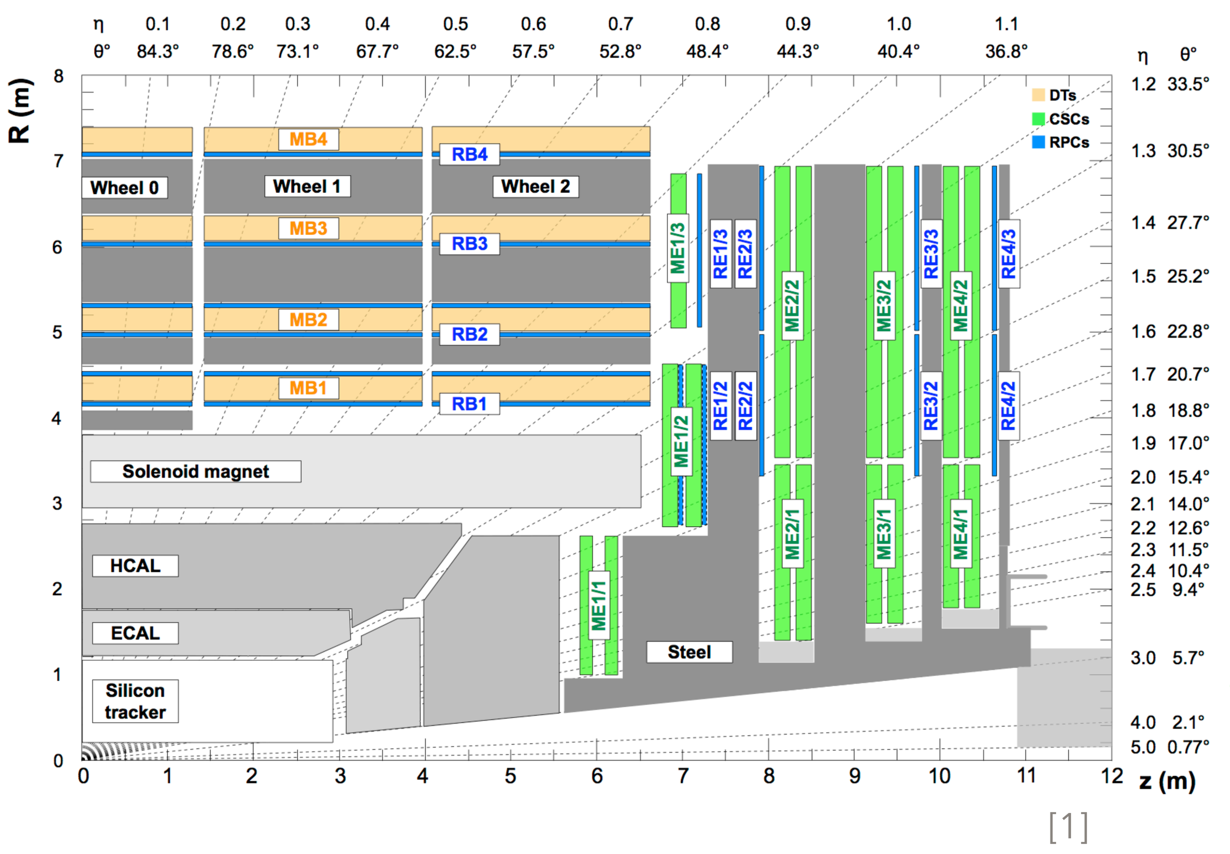
The CMS muon system:



[1]

Drift Tubes (DT) - |η| < 1.2

- Both a tracking and trigger detector
- Basic unit: 4.2 x 1.3 cm^2 cell with ~ constant 54 μm/ns v_{drift}
- 250 chambers - 8 (4) layers per chamber in r-φ (z)
- Segment resolution ~100 μm - Segment time resolution ~2 ns

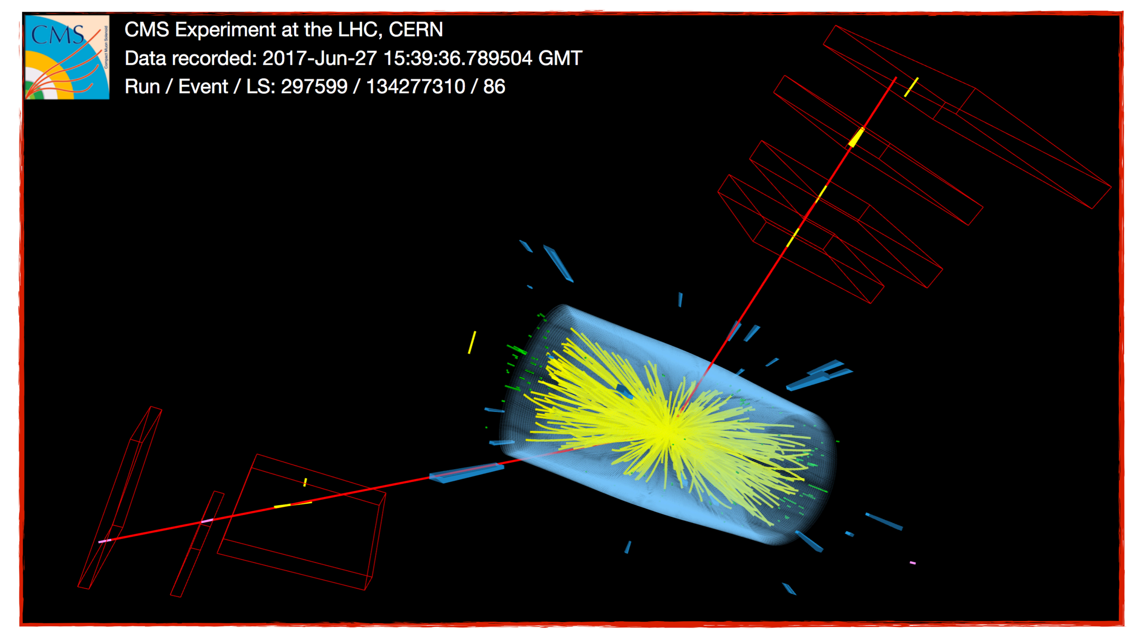
Resistive plate chambers (RPC) - |η| < 1.9

- Mostly used in trigger
- Double gap RPCs operating in avalanche mode
- 480 (576) chambers in barrel (endcap)
- Cluster resolution ~1 cm (r-φ) - Time resolution ~2 ns

Cathode Strip Chambers (CSC) - 0.9 < |η| < 2.4

- Used for tracking and trigger
- MWPC with cathode strip readout
- 540 chambers - 6 layers per chamber
- Segment resolution ~50 to ~150 μm - Segment time resolution ~3 ns

A large-mass event recorded by CMS in 2017 [2]. The invariant mass of the two muons is 2.4 TeV.



Since 2017, a "slice test" of chambers based Gas Electron Multiplier (GEM) detectors is also being operated / commissioned in view of an upgrade happening over the second LHC long shutdown.

Detection and reconstruction efficiency:

From the hits reconstructed within a single DT or CSC chamber, straight-line track "segments" are built using algorithms that differ for the two detectors.

The tag-and-probe method:

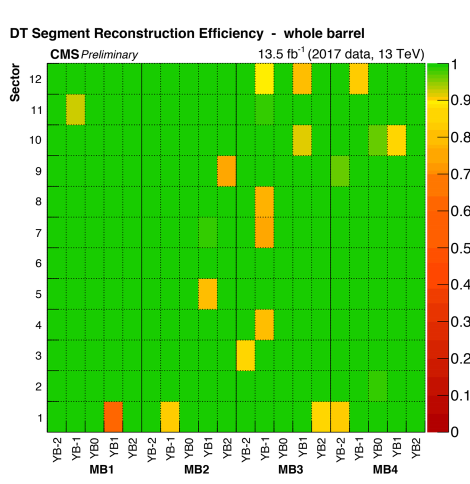
The DT / CSC segment (RPC hit) reconstruction efficiency is measured with a *tag-and-probe* method exploiting opposite-sign muon pairs from Drell-Yan events.

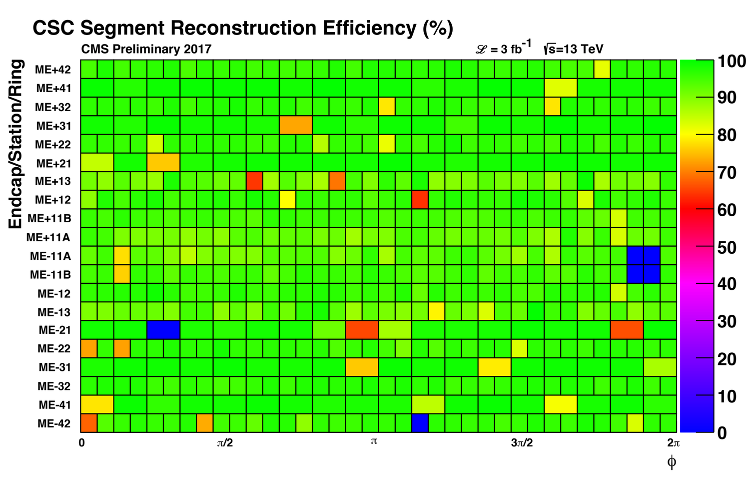
Tags: muons satisfying tight selection criteria that fired single-muon triggers.

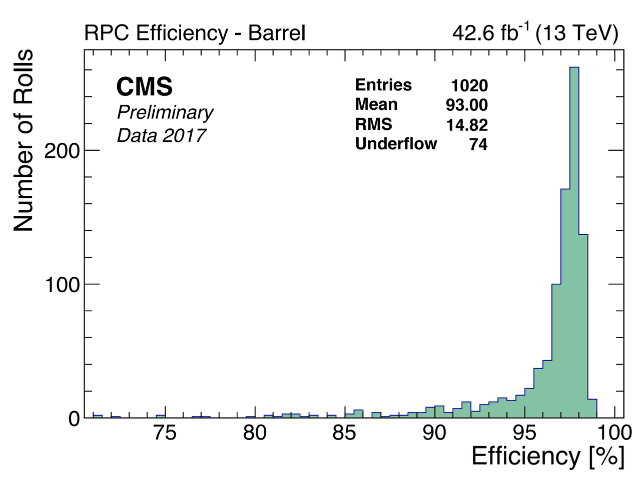
Probes: tracker (or muon) tracks passing a looser identification criteria, tuned to avoid biases.

Probes are propagated to the different chambers looking for the presence of close-by segments (hits).

The efficiency, measured in fiducial regions excluding chamber borders, **is usually >= 95% for all the three subsystems** [3,4,5]. The main exceptions come from chambers with known hardware problems, either sporadic, or that require intervention to be fixed.







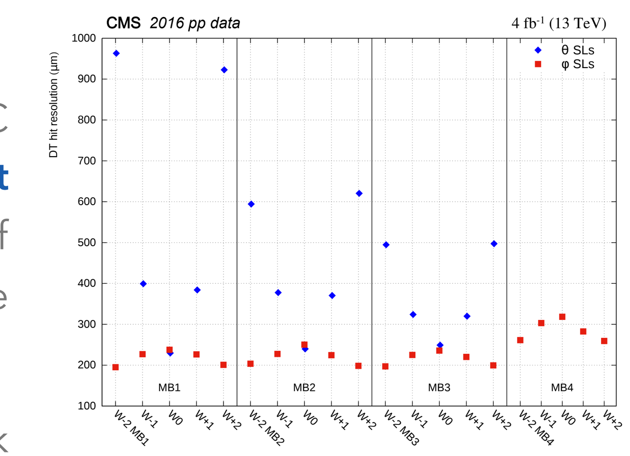
Spatial and time resolution:

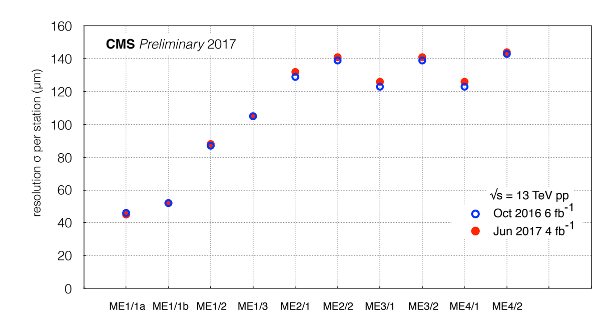
Measurements of the spatial resolution of DT/CSC hits and RPC clusters are computed out of the **width of hit (cluster) - segment residual distributions**. They vary either for different types of chamber or because of the typical position/inclination of the particles crossing a given chamber [1,4].

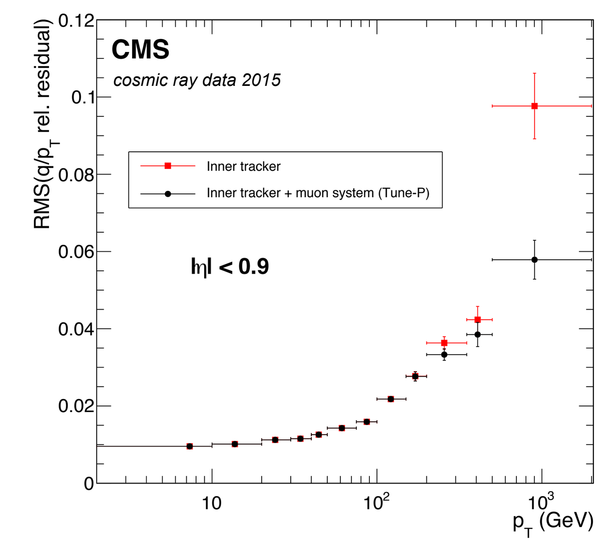
At high momentum, **the combined measurement** of a muon track in the inner tracker and the muon system **improves the estimation of the reconstructed muon p_T** compared to a measurement based solely on the inner tracker [1].

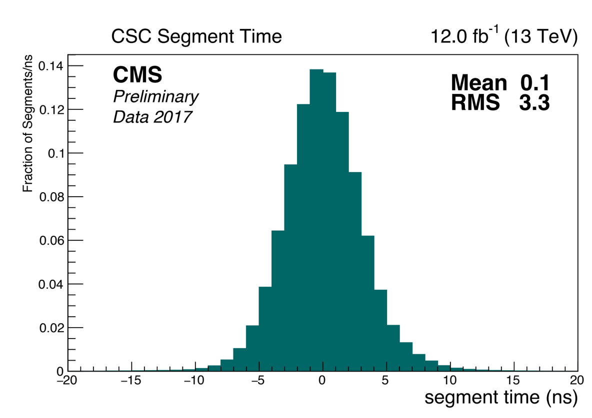
The crossing time of a DT segment is computed by including directly the time as a parameter of the segment fit. For CSC, timing is combination of the timing of both cathode and anode hits [6]. RPC timing is the time of single hits and it is read out with the granularity of the LHC bunch separation (25 ns) [5].

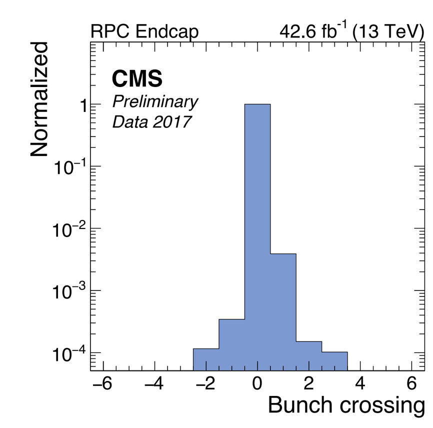
The offline muon time is used in searches for heavy stable charged particles and long-lived particles decaying into muons.





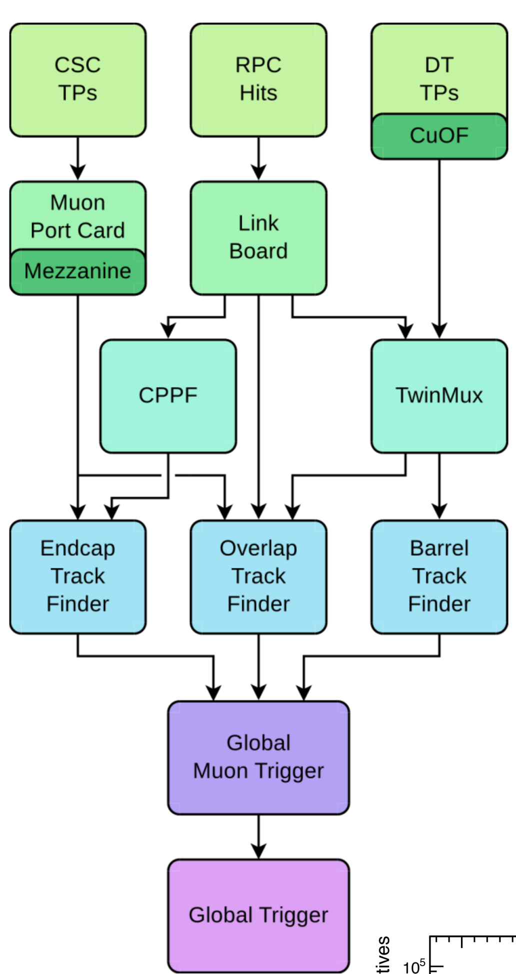






The Level-1 muon trigger:

CMS uses a custom-made electronics Level-1 Trigger (L1T) to select up to 100 kHz of collision events out of a bunch crossing (BX) rate up to 40 MHz. Events selected by the L1T are further processed by a software-based High-Level Trigger (HLT) for a rate reduction down to few 100 Hz.

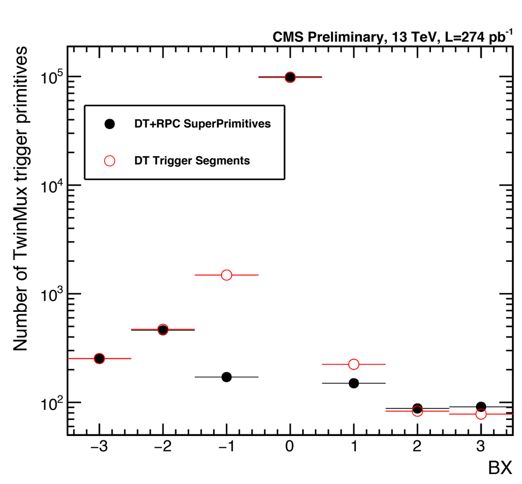


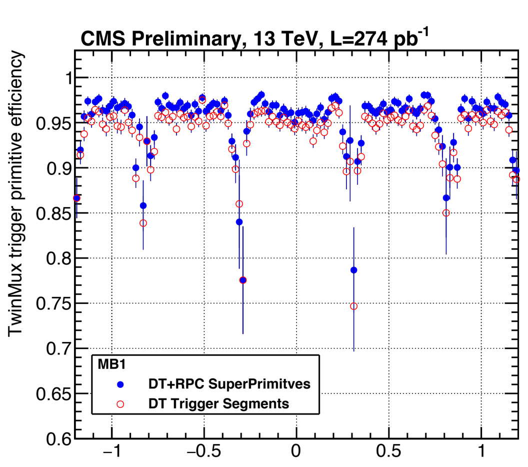
Muon detectors participate both to L1T and HLT. Information from DT and CSC is processed by dedicated electronics to build **trigger-segments**.

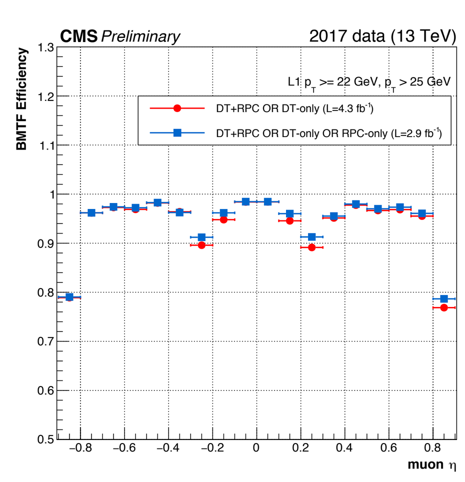
Trigger-segments and clusters of RPC hits are combined by L1 track-finders (TF) into L1 track-candidates. The final sorting of the tracks from the TFs is performed by the Global Muon Trigger.

Trigger-segments and RPC hits provide information on a track **position and direction.** They also **identify the BX** of origin of the incoming particles.

In the muon barrel, DT trigger-segments and RPC clusters are combined by the **TwinMux**. Such combination improves BX identification [7], increases the overall trigger efficiency [7, 8] and reduces typical rates of L1 single muon triggers by a few percent.







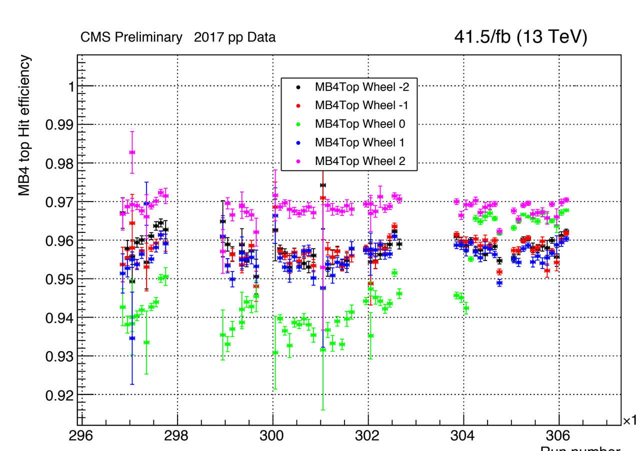
Longevity and optimisation of operational conditions:

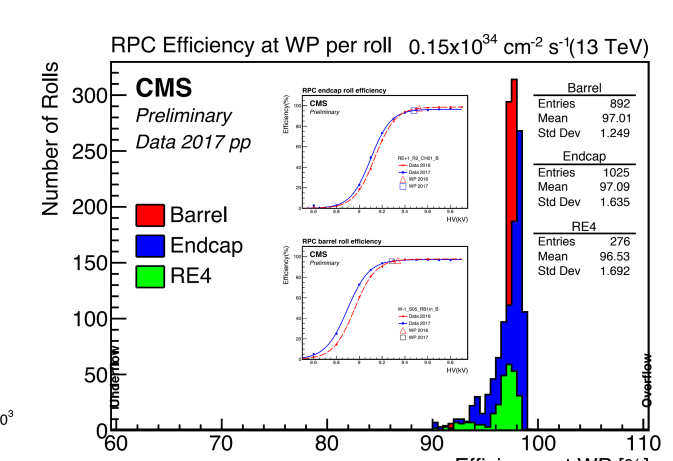
The **performance** of gaseous detector **deteriorates above given values of total integrated charge** released in the gas volume. The existing muon chambers will not be replaced during the CMS Phase-2 upgrade. Therefore, the **operational conditions** of the detectors **are tuned to maximise chamber longevity**.

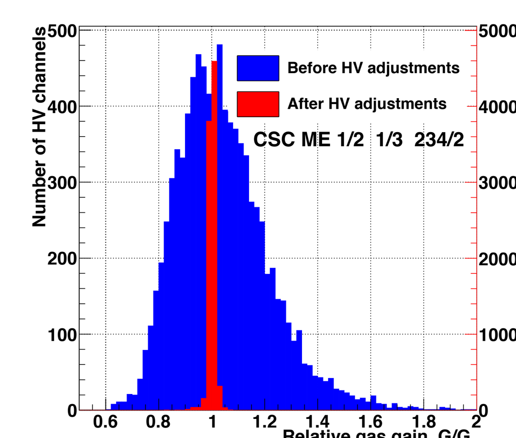
In 2017, the **DT chambers with highest background were operated at HV values reduced by 50 V** compared to the others. This caused a decrease of hit efficiency up to 3%. To cope with it, **the front-end (FE) thresholds** of the most affected chambers **were reduced from 30 to 20 mV**. The noise increase was deemed acceptable, hence, in 2018, all DT chambers are operated with lower FE thresholds, and more of them are operated at reduced HV values.

In 2016, **CSC HVs**, previously all set to a single value, **were adjusted to target a uniform gas gain** response [9]. Furthermore, a **reduction of the HV settings,** targeting working points with lower gain, but with chambers still operating at plateau efficiency, is planned for 2018.

HV scans campaigns are regularly performed to tune the working points of RPC chambers. HV working points are defined for each barrel (endcap) chamber as the ones 100 (120) V above the 95% efficiency point [5].







References:

[1] Performance of the CMS muon detector and muon reconstruction with proton-proton collisions at $\sqrt{s}$ = 13 TeV (https://arxiv.org/abs/1804.04528) [2] CMS-PHO-EVENTS-2017-005
[3] CMS DP-2018/016 [4] CMS DP-2017/038 [5] CMS DP-2018/001 [6] CMS DP-2017/050 [7] CMS DP-2016/074 [8] CMS DP-2018/007 [9] CMS-TDR-016