RPC System in the CMS Level-1 Muon Trigger

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RPC2020, Roma

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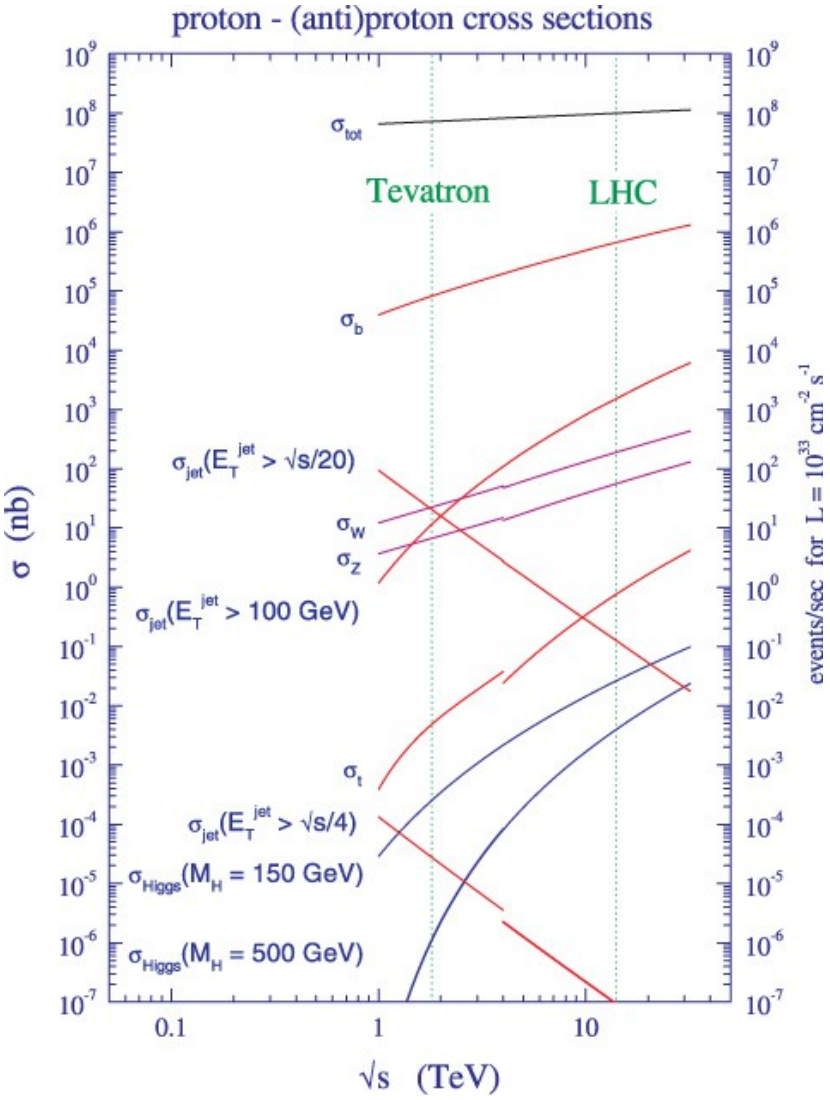
Content

- Why do we need a Muon Trigger?
- How do we design it in CMS?
  - Before (run I)
  - Now (run II and run III)
  - What's next? (HL-LHC)
- How do we use the RPC system?

Introduction

- An important challenge when trying to improve our understanding of elementary particle physics is to be able to study rare processes
  - Rates can be orders of magnitude smaller than the inclusive pp interaction rate (Higgs ~ 10^{10} smaller)
  - Can not afford recording every collision with current technologies (bandwidth, storage and computing power)
- Way out: keep only potentially 'interesting' events



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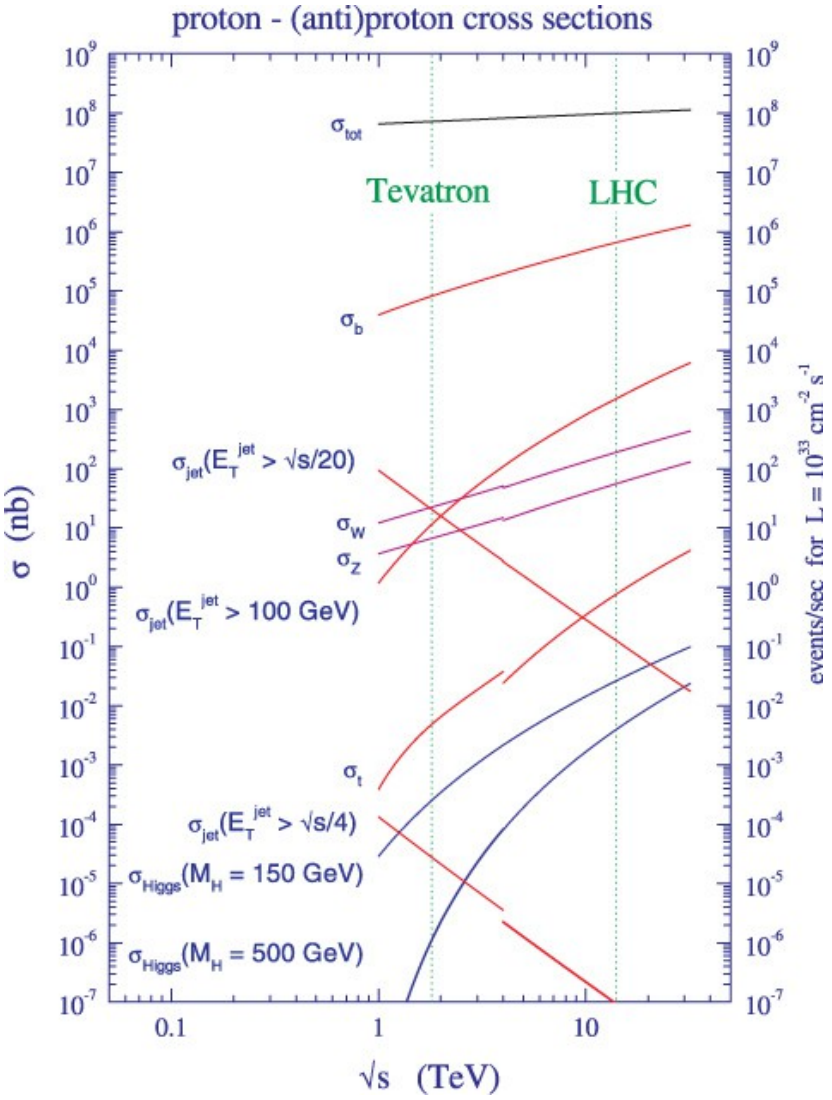

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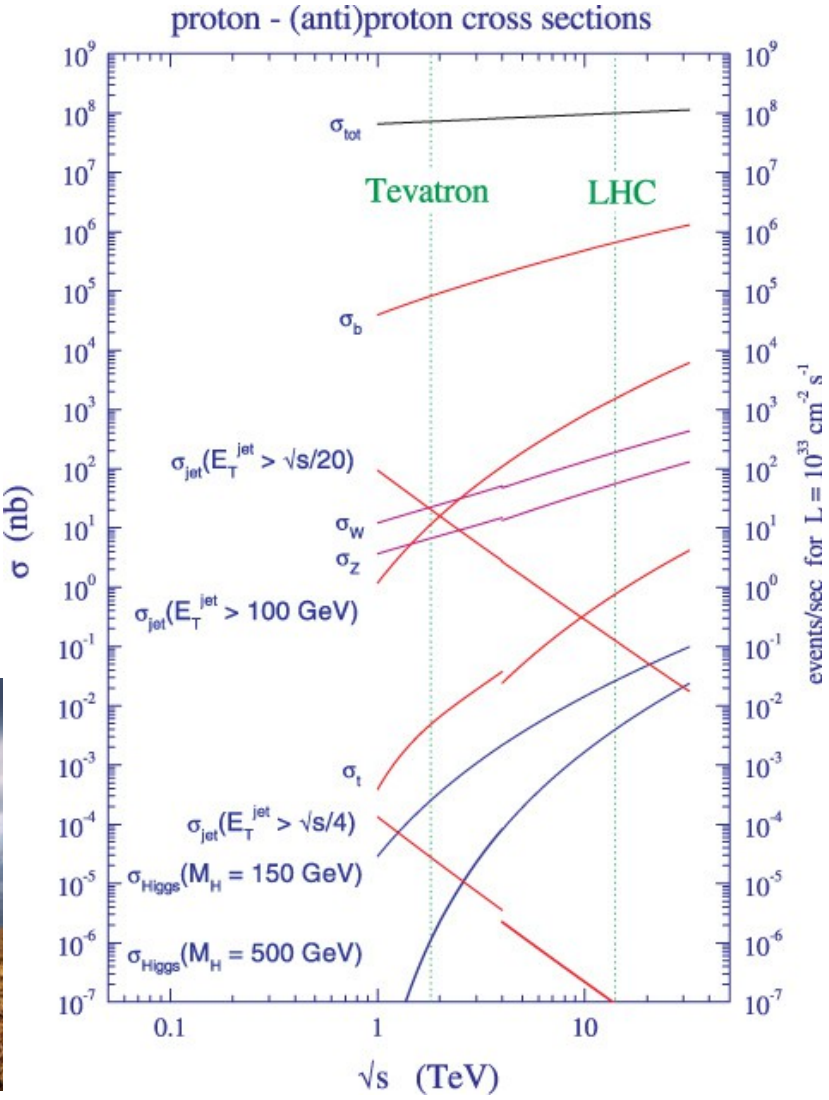
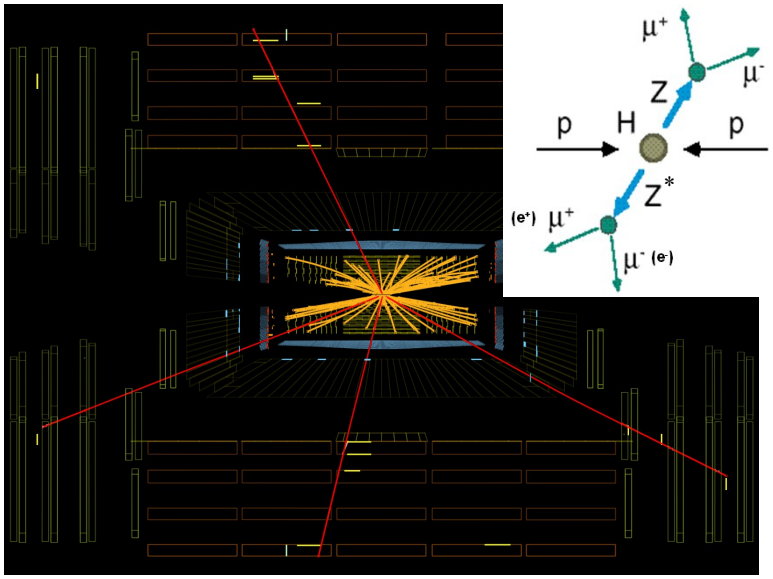
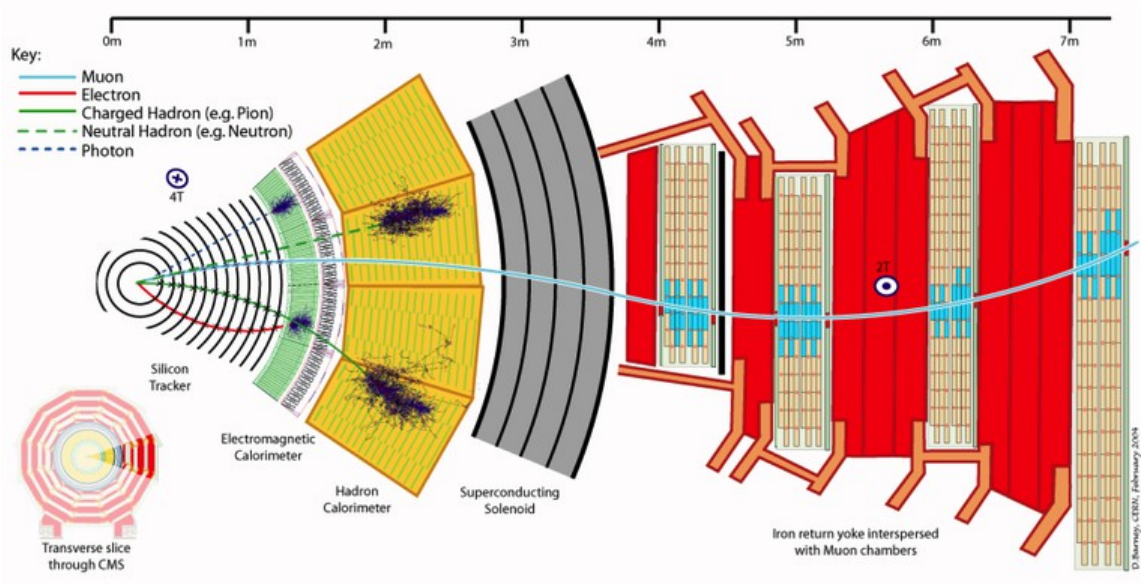
Trigger

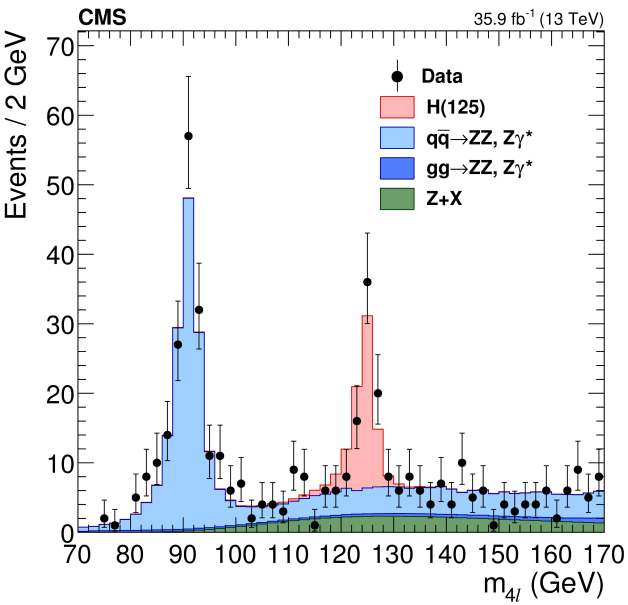


Muons in Trigger

- Many interesting processes involve muons
  - Higgs, SM Physics, BSM (e.g. 2HDM, HSCP), …
- Muons have a clean experimental signature
  - Suitable candidate for triggering purposes!
- About ¾ of data analyses in CMS rely on muon(s)!





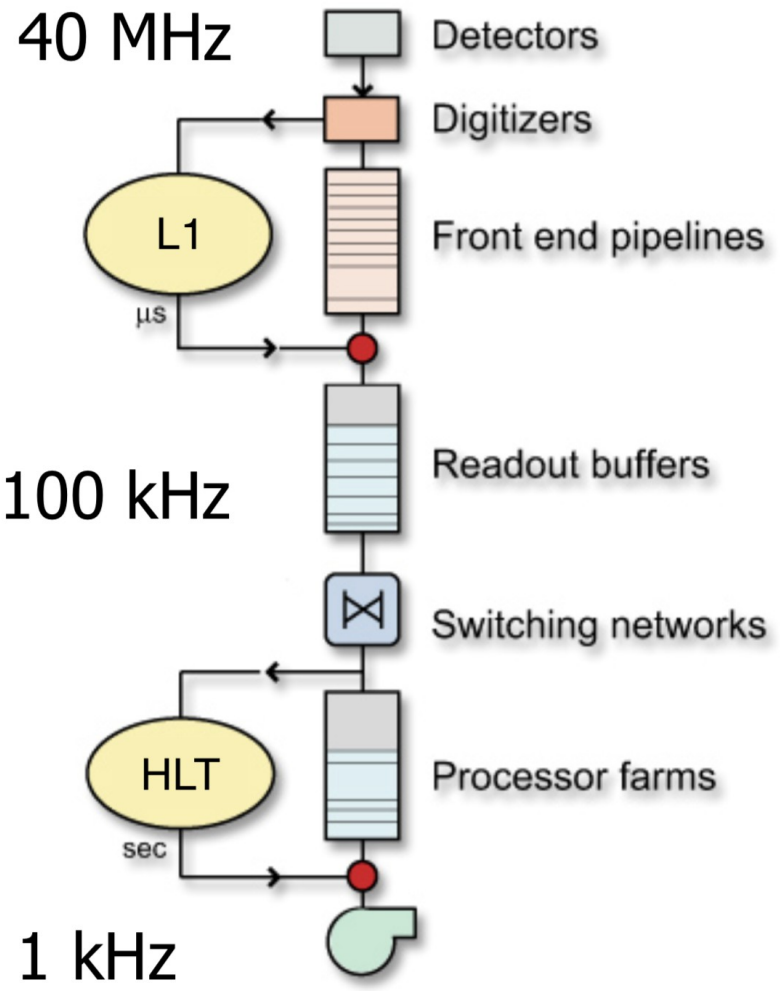


CMS Level-1 Muon Trigger

CMS Trigger

CMS Trigger System is made of two components

- Level 1 Trigger (L1T)
  - Rate reduced by a factor 400
  - Decision taken in 3.6 μs
  - Custom hardware
  - Information from calorimeters and muon detectors
- High Level Trigger (HLT)
  - Rate reduced by a factor 100
  - Decision taken in hundreds of ms
  - Commercial server farm
  - Full detector information



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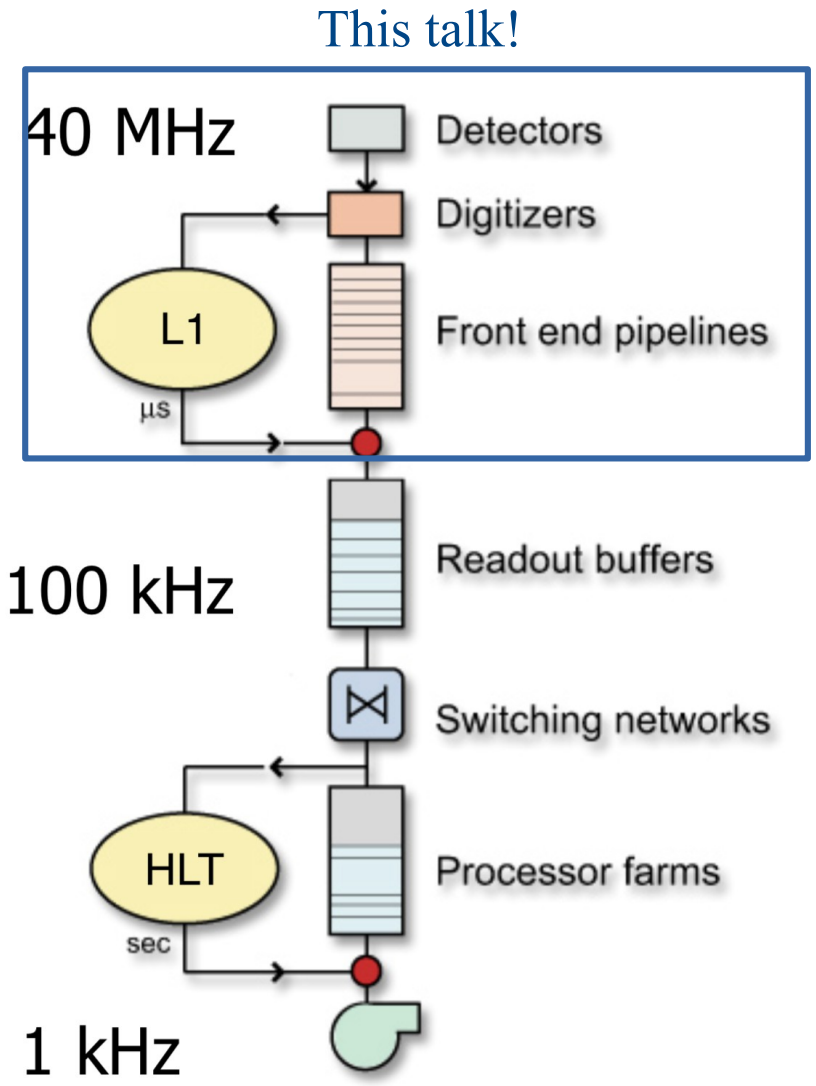
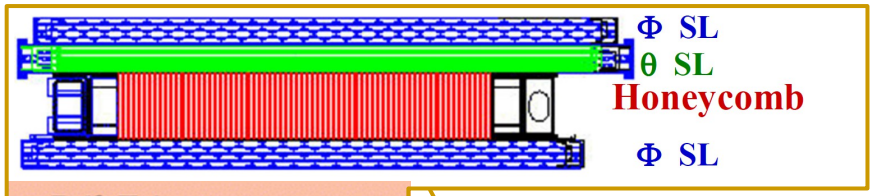
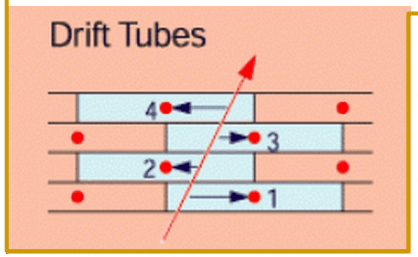
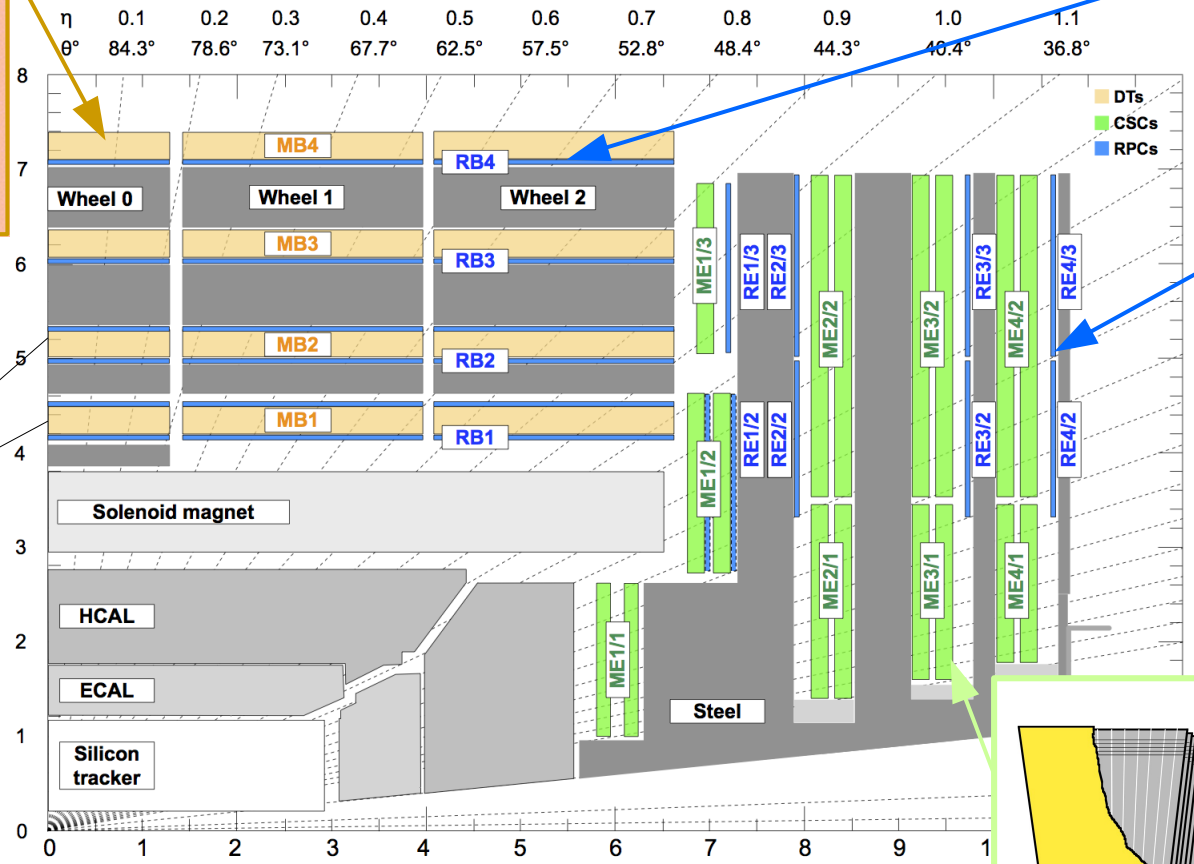
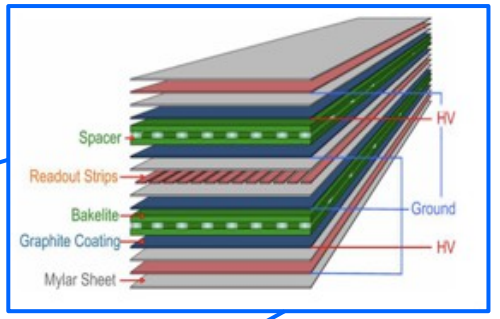


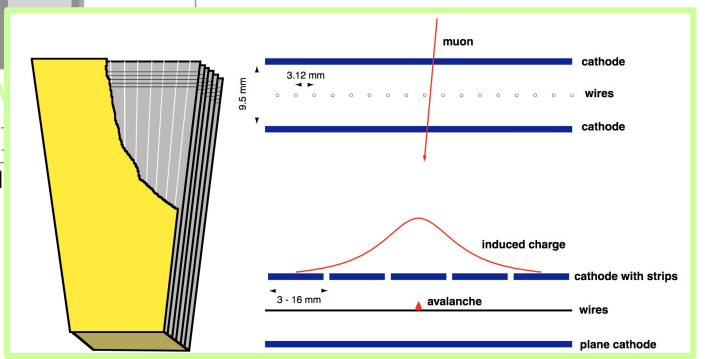
CMS Muon System











Two RPC layers in the first two barrel stations (MB1 and MB2)

Level-1 Muon Trigger Architecture

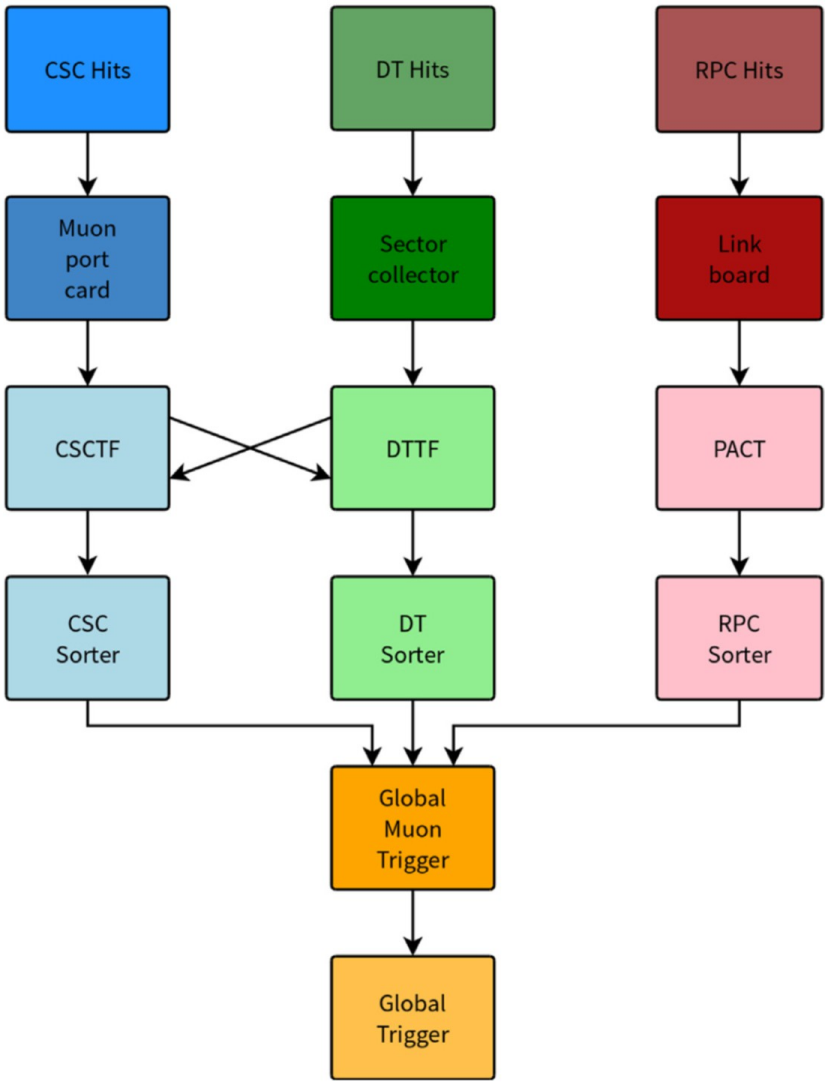
Muon Trigger

- Uses **Trigger Primitives** (TP) from different sub-detectors to identify **tracks associated to muons** and evaluate their transverse momentum

Legacy Trigger architecture used in **Run I** ('Phase-0 Trigger')

- Trigger primitives built in a totally **factorized** way
- Muon Track Finders (MTF) almost completely independent for the three muon sub-systems

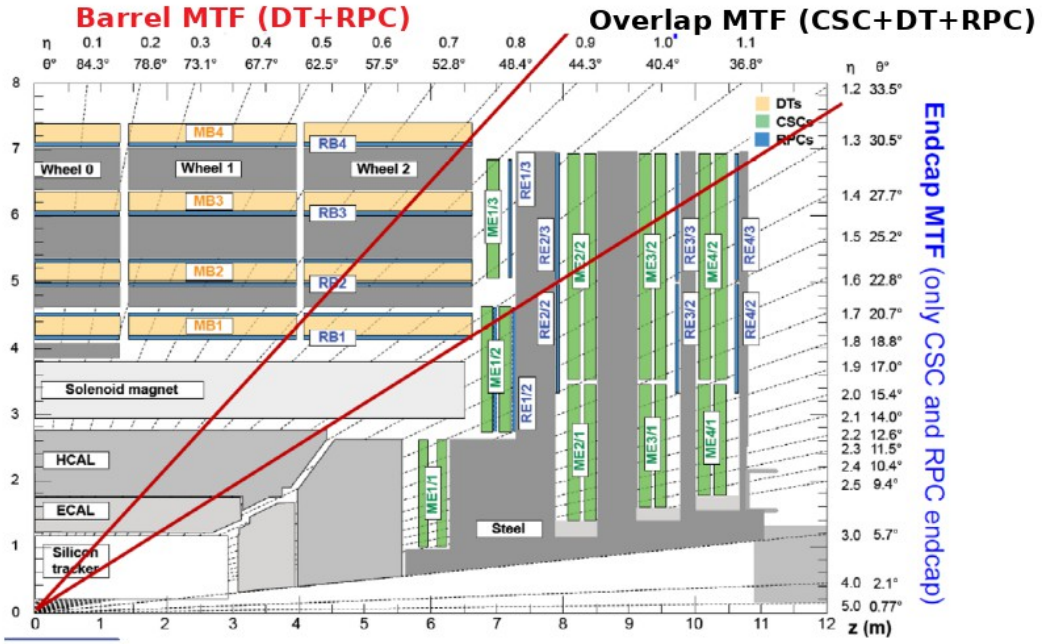
Run I muon trigger architecture



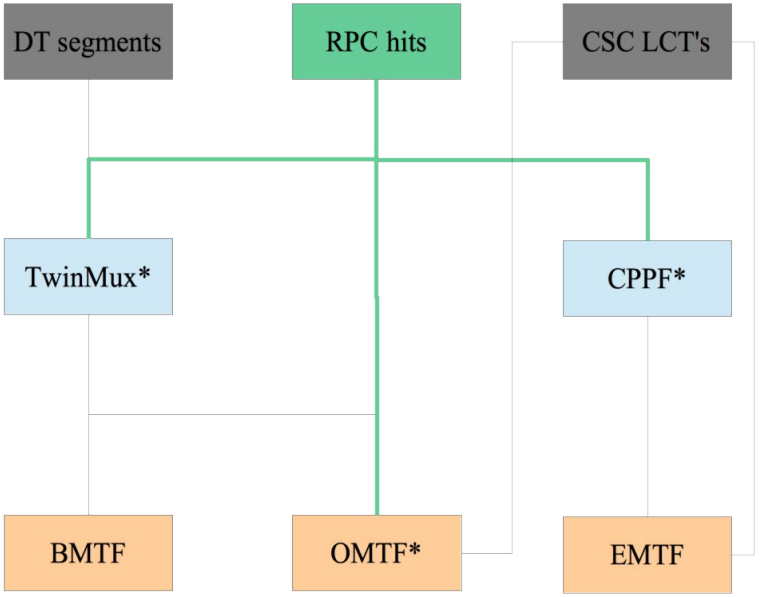
Level-1 Muon Trigger Architecture

Reorganization of the muon trigger architecture from **sub-system** based to **geometry** based for **run II** (current trigger architecture)

- Information from different sub-systems is **available together at earlier stage in the trigger chain**
- Increased redundancy
- Allows to use detectors complementarity at earlier stage to build better trigger primitives



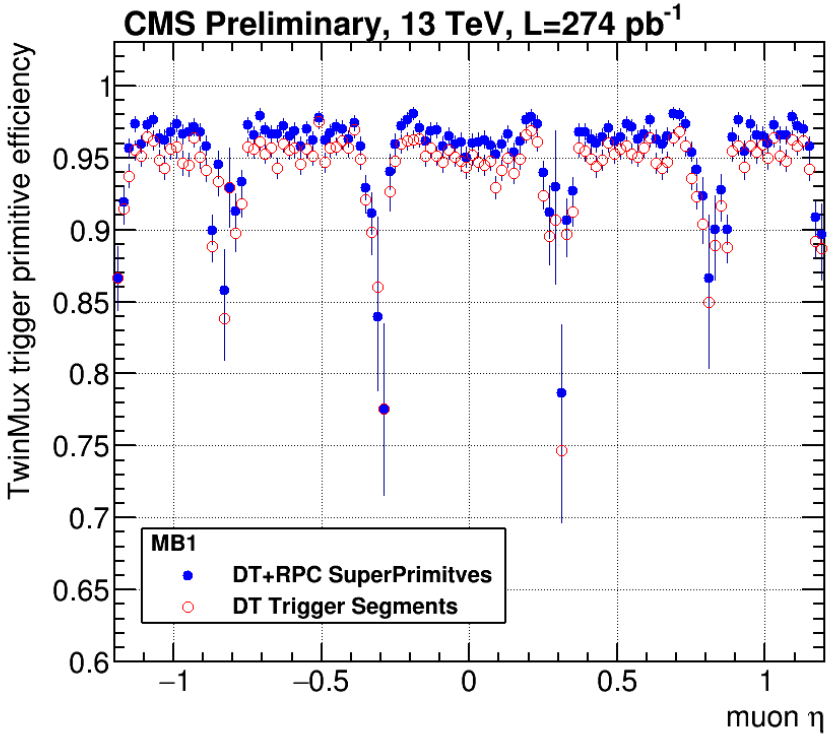
Run II muon trigger architecture

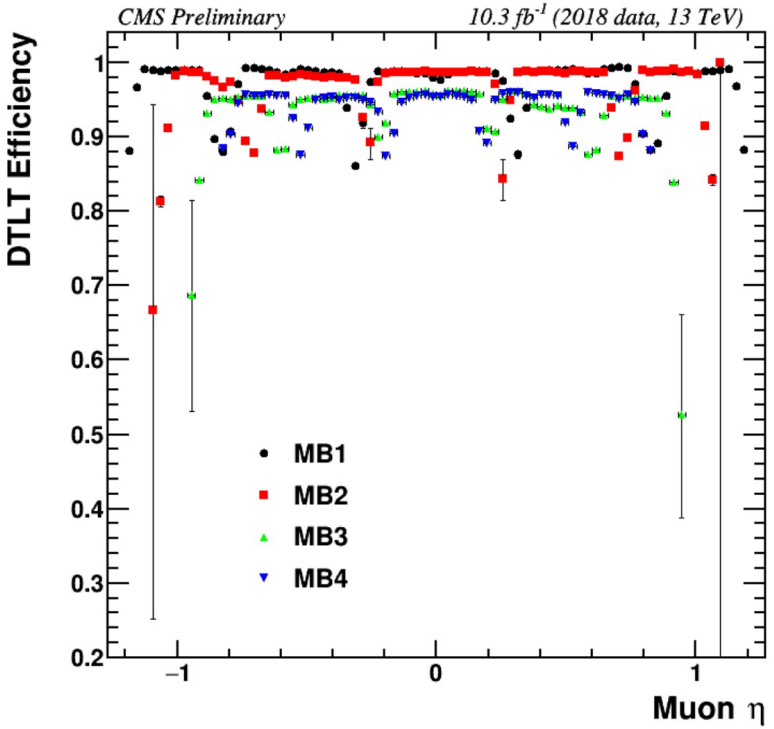


* Module with RPC hit clustering and cluster selection

RPC + DT (run II)

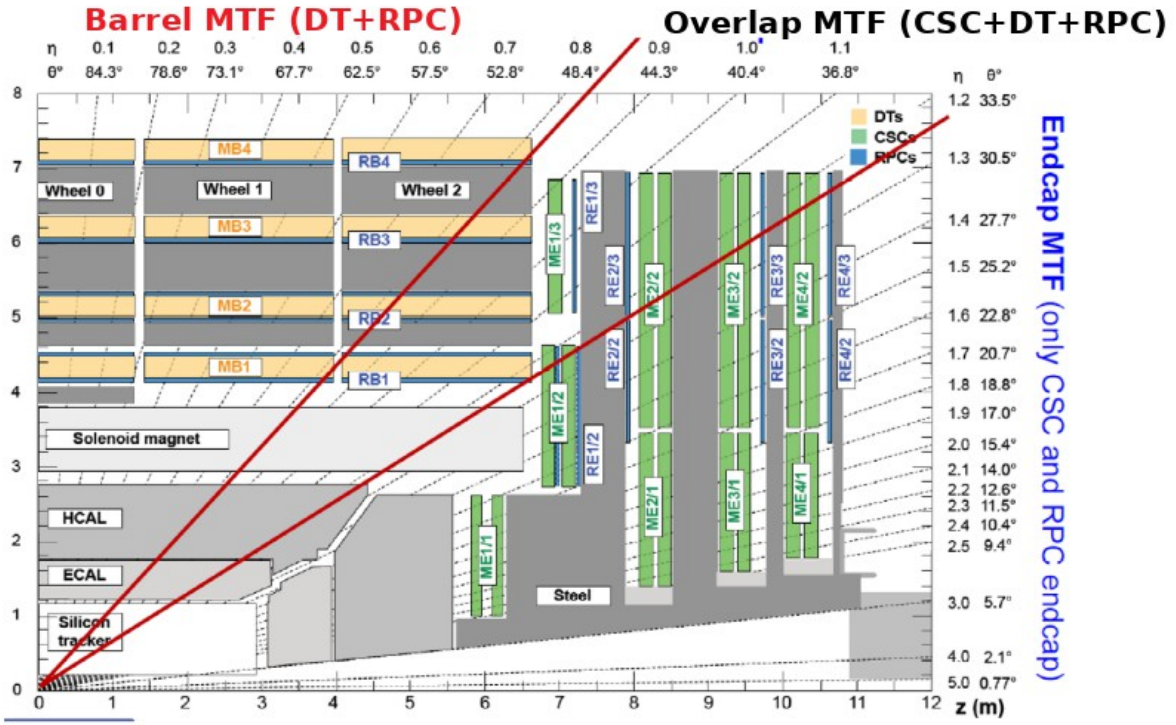
- RPC + DT 'SuperPrimitives'
  - Makes the best out of DT spatial resolution and RPC time resolution (complementarity)
    - RPC is used to assign the bunch-crossing of DT segments's without 8 fired layers
    - TP efficiency increases by 1.4 %
  - In case of DT chamber inefficiency in MB1 and MB2, build RPC-only segment (redundancy)
    - TP efficiency increases by ~4%

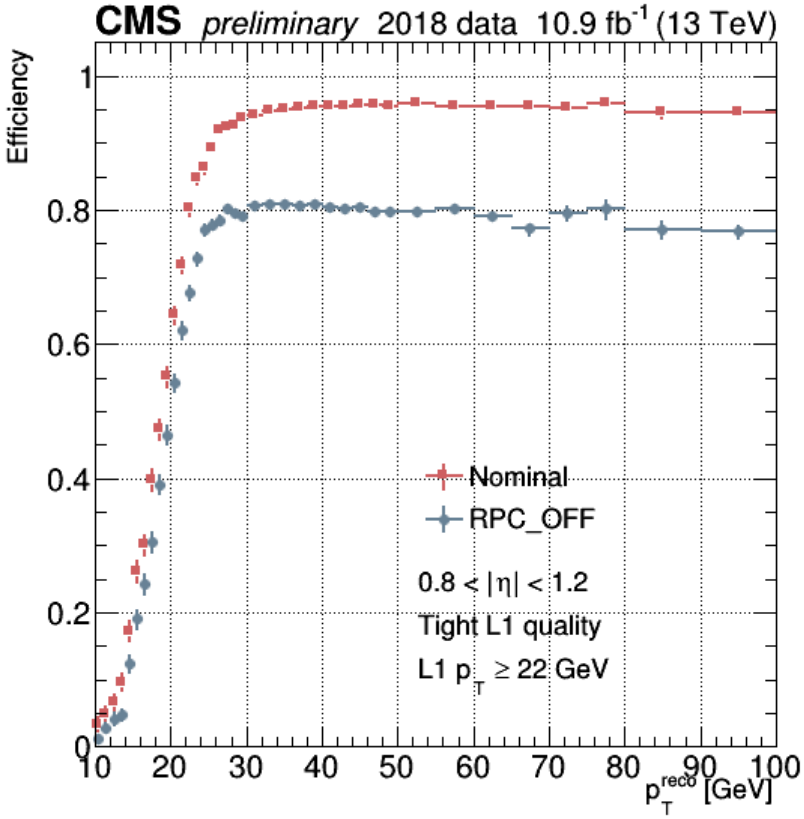




RPC in OMTF (run II)

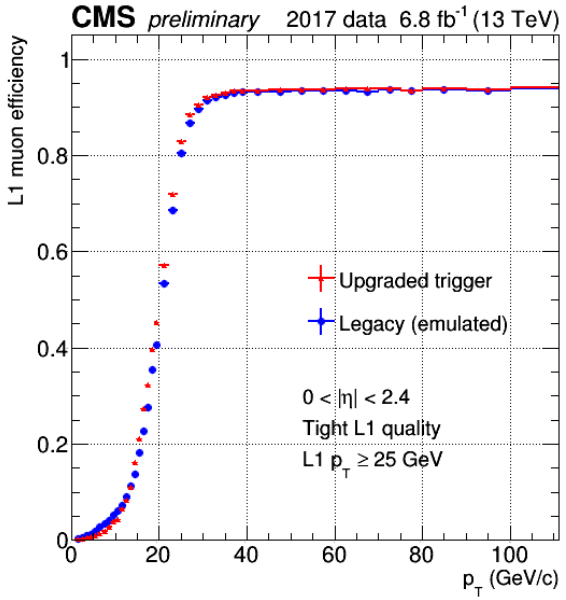
- RPC is a key player in the complicated Overlap region $(0.8 < |\eta| < 1.2)$
  - RPC system is present both in the barrel and the endcap → provides 8 measurements in this region
  - 95(80)% efficient with(without) using the RPC system

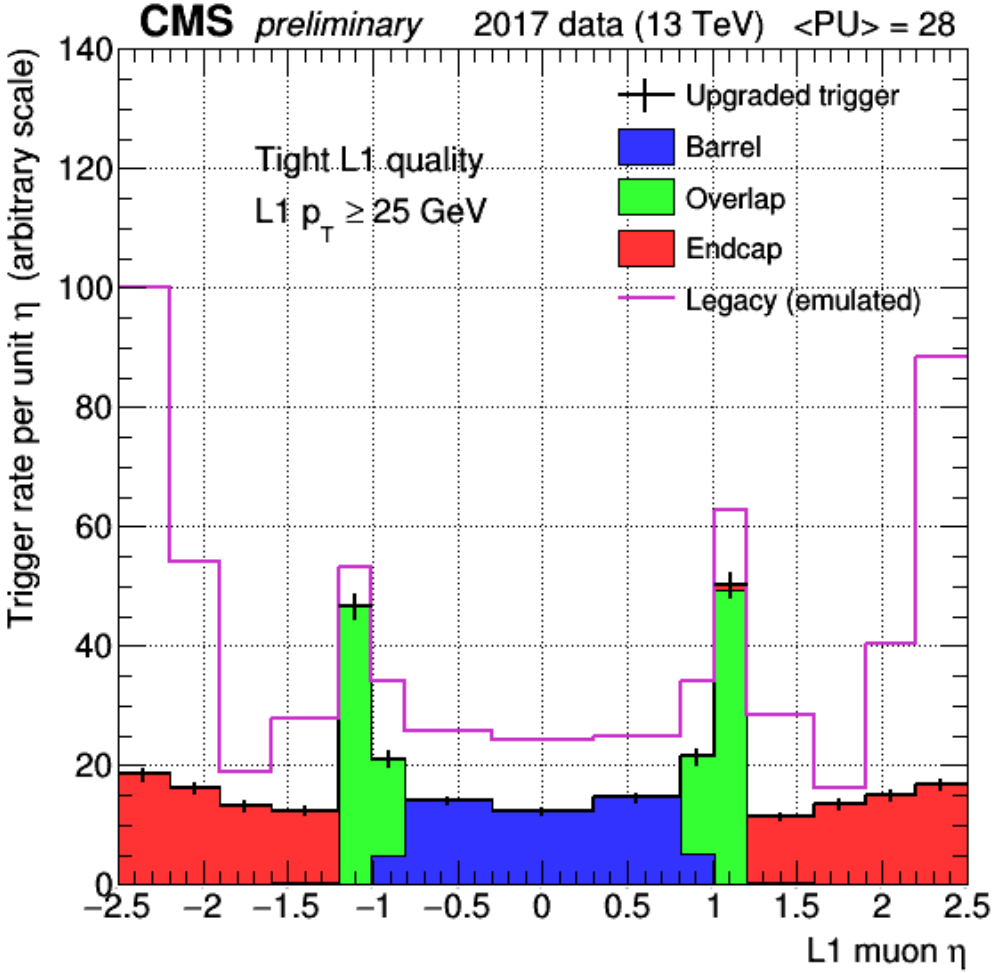




Run II Muon Trigger Performances

- Run II muon trigger has up to factor 5 reduced rate compared to the legacy trigger
  - Keeping same efficiency
  - Due to many factors (merging detector information earlier, usage of more advanced algorithms, …)



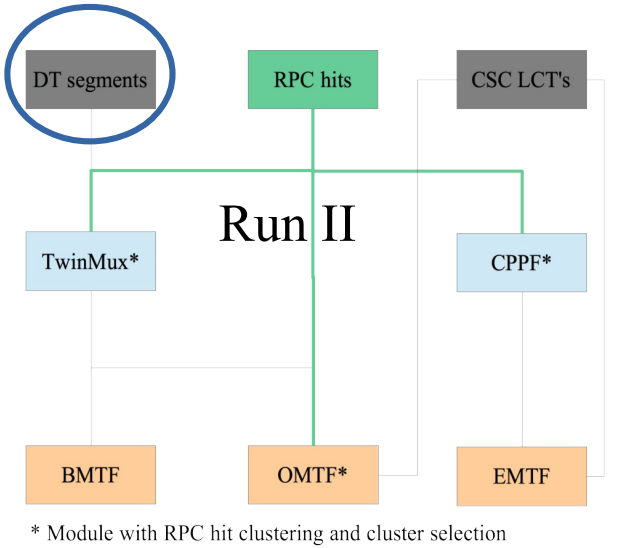


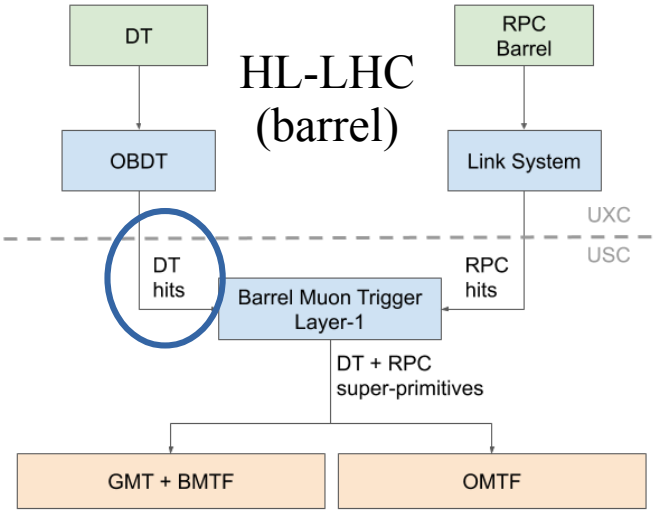
Phase II (HL-LHC) Muon Trigger Upgrade

Phase II Level-1 Trigger

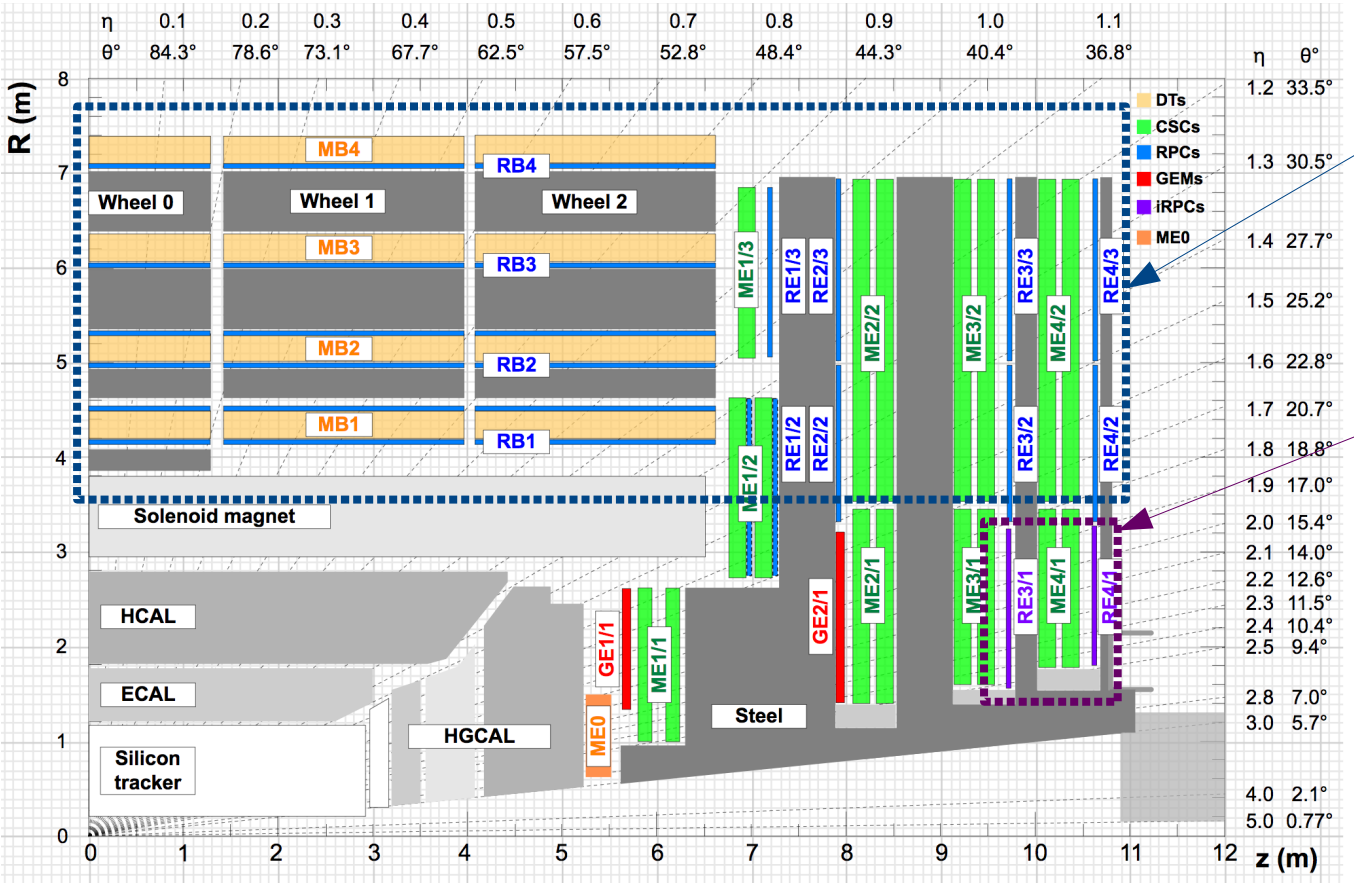
Key aspects of the L1Trigger Upgrade

- 100 → 750 kHz **rate** to HLT
- 3.6 → 12.5 μs **latency**
- Refactored architecture
  - Merging sub-detectors information even earlier (DT and RPC **hits** available in the same boards)
- Increased **bandwidth**
- Availability of tracking information





RPC Phase II Upgrade

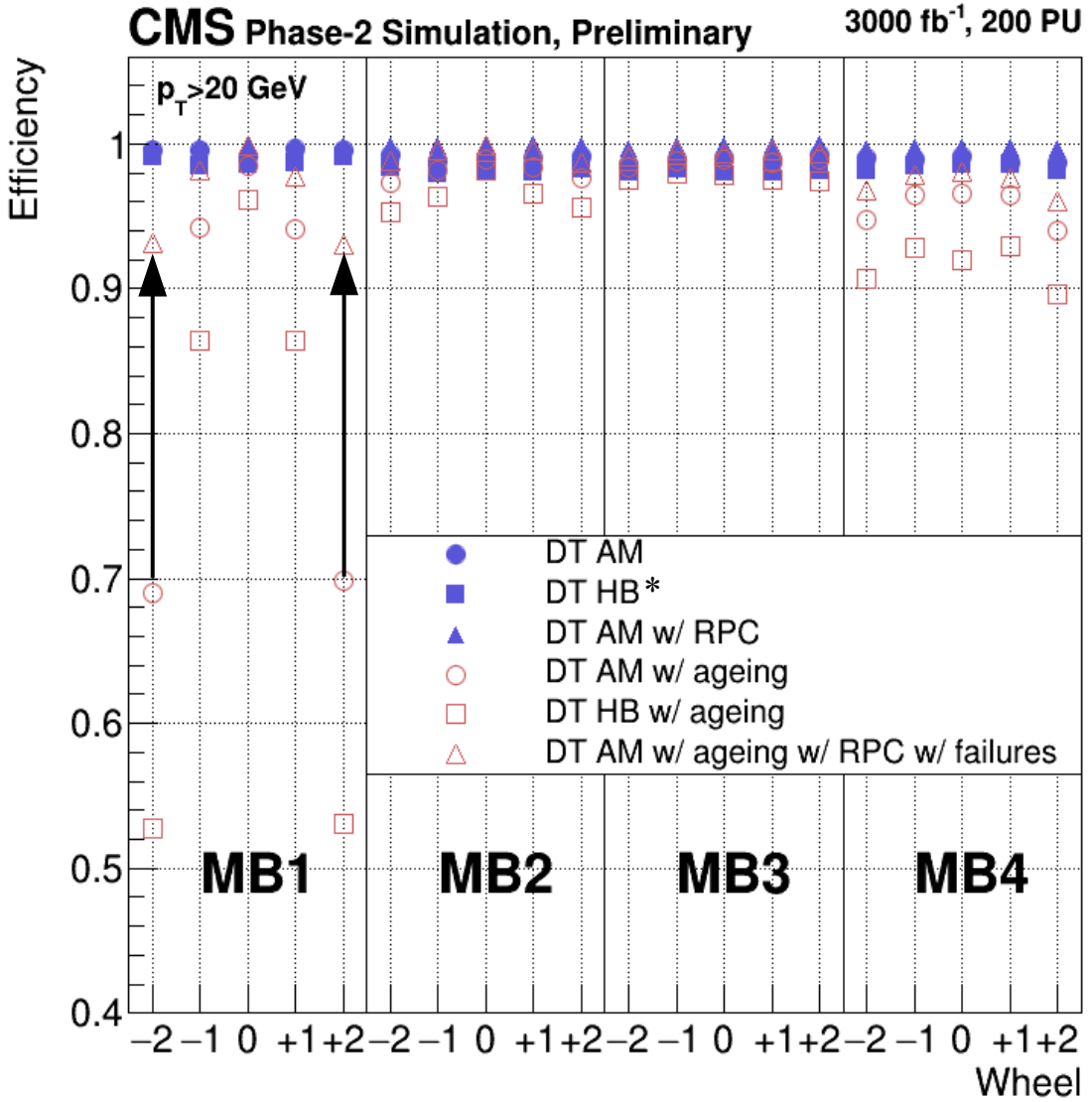


RPC Phase II Upgrade

- Link System
  - Increased readout frequency (every 25 ns → 1.56 ns)
- Improved RPC (iRPC)
  - Extended η coverage with new RE3/1 and 4/1 chambers
  - 2D readout → hit position along the strip (~ 2 cm resolution)
  - Improved intrinsic time resolution (thinner gaps) + modern electronics

Phase II Barrel TP efficiency

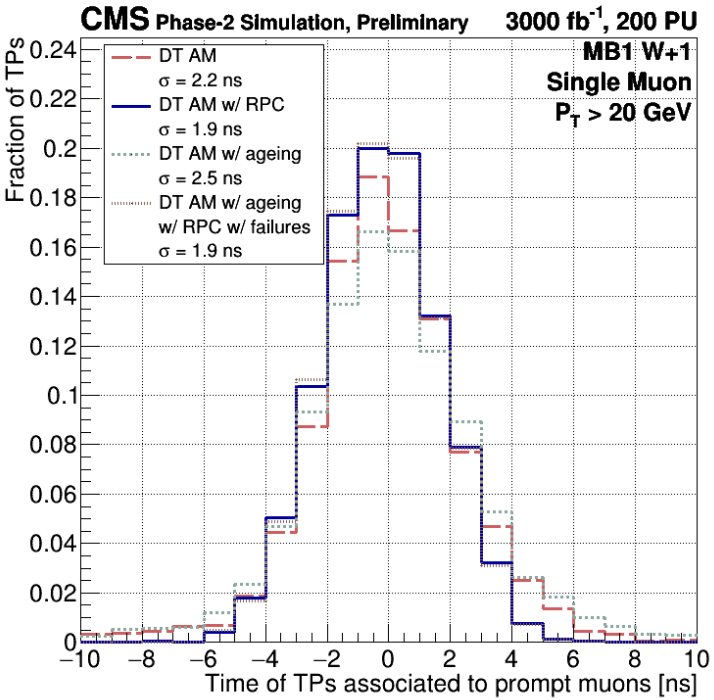
- Barrel Muon TP Efficiency
  - Shown with/without RPC+DT combination, with/without DT ageing and RPC failures
  - DT ageing: efficiency loss due to integrated dose at the end of Phase II
  - RPC failures: switching off chambers (end of Phase II extrapolation of failures based on run I and run II experience)
  - **Even at the end of Phase II, barrel TP efficiency stays within 92-99% with the use of RPC (up to 23% efficiency gain)**

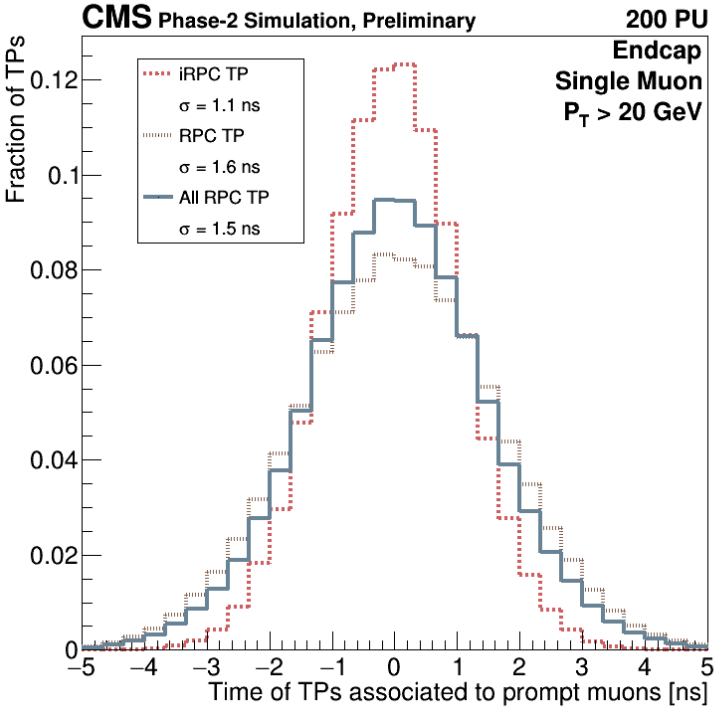


* AM and HB refers to different DT TP algorithms, only AM has RPC included

Phase II Timing Performances

- Time resolution
  - Barrel (left): RPC improves TP time resolution by ~15(30)% without(with) DT aging
  - Endcap (right): RPC is the only muon detector providing timing with more granularity than a bunch-crossing – iRPC simulation does not incorporate last electronic developments

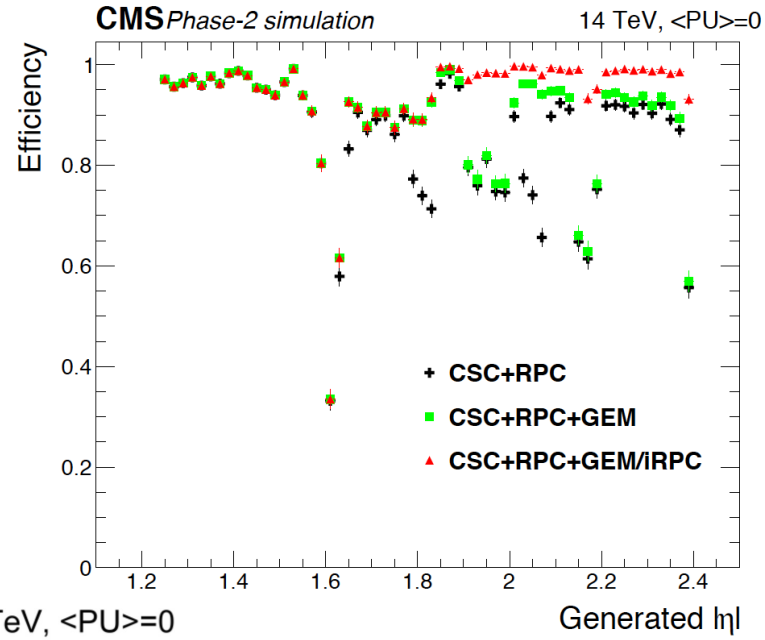


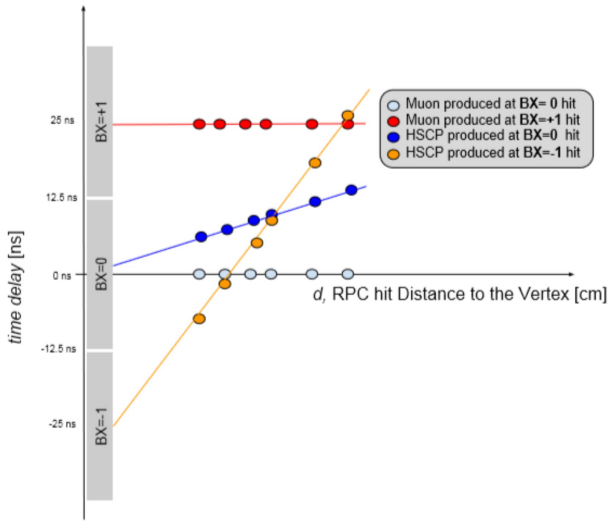


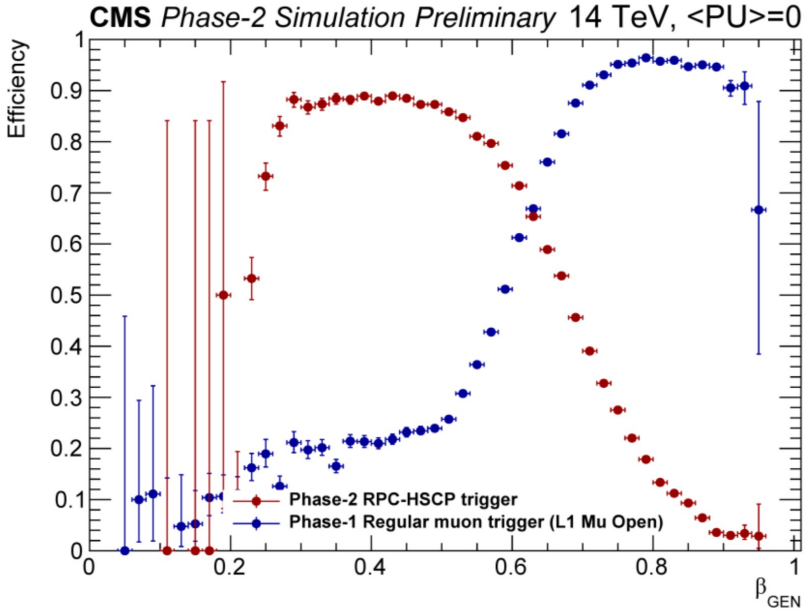
- RPC timing usage in Level-1 Trigger: Reduce out of time pile-up + New trigger path based on time of flight (more details in next slide)

RPC in Phase II MTF's

- iRPC extended |η| coverage importantly increases forward muon efficiency when asking for 4 fired stations
- Heavy Stable Charged Particle (look like muons that move slowly)
  - (i)RPC time information can be used to build a new trigger path based on time of flight

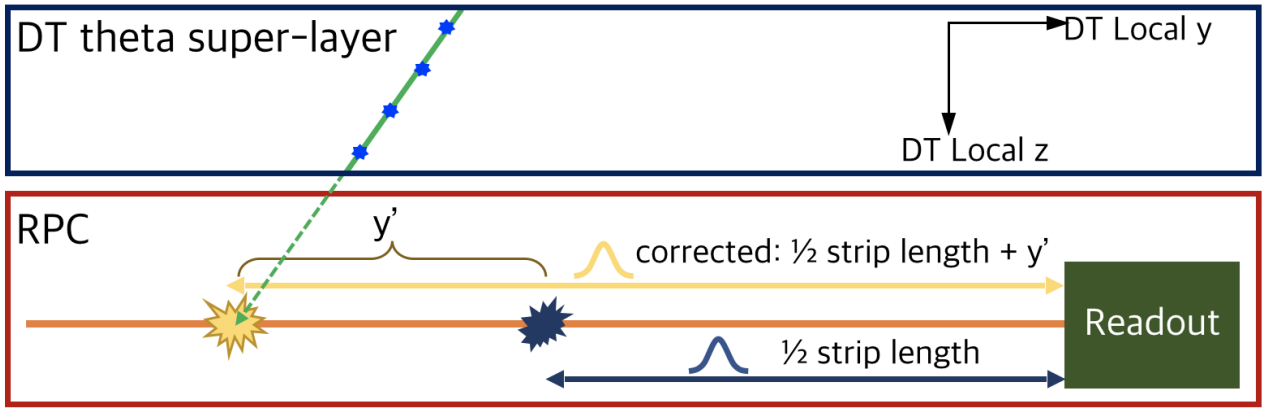


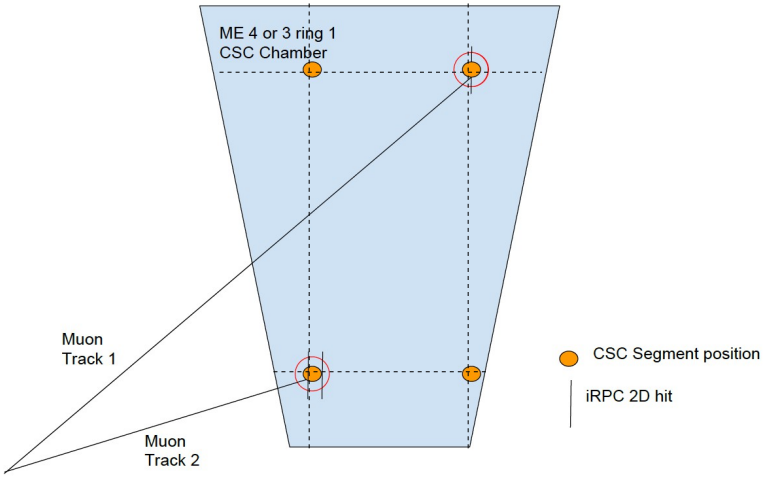




Future plans

- Yet some room for improvement!
  - Reduce CSC TP fake rate with iRPC 2D measurement
    - CSC 'double 1D' measurement leads to ghost hits when two real hits occur in the same chamber
  - Use RPC even earlier in the barrel TP building
    - Instead of acting on DT built segment, use RPC time to build them
  - Use RPC timing to reject out of time hits in other sub-sytems
  - Improve RPC timing: Use DT η measurement to remove smearing coming from unknown signal propagation along the strip





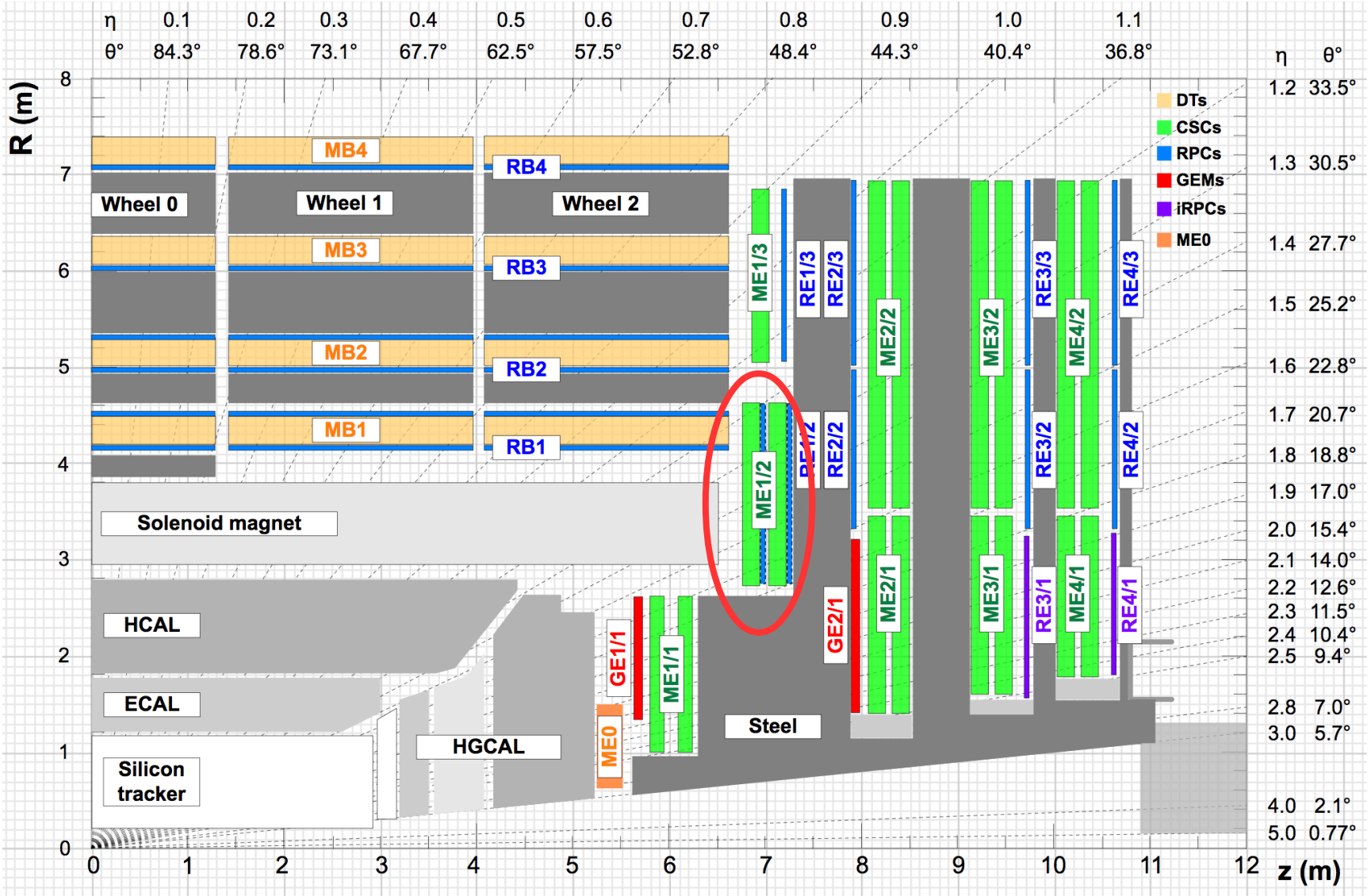
Conclusions

- Level-1 Muon Trigger is crucial for the CMS physics program and significantly relies on the RPC System
  - Exploits the redundancy and complementarity of the different muon sub-systems
    - Merging sub-detector information at earlier stage results in increased performance
- Even with end of Phase II detector ageing/failures the muon trigger primitive efficiency remains well above 90% everywhere
- Phase II Upgrade brings new possibilities for RPC contribution to Level-1 Trigger
  - Increased synergies with other muon sub-systems to build more robust TP
  - Increased trigger efficiency in forward region thanks to iRPC
  - Extended physics program thanks to the improved timing (HSCP)
- Many new ideas will be studied
  - Stay tuned!

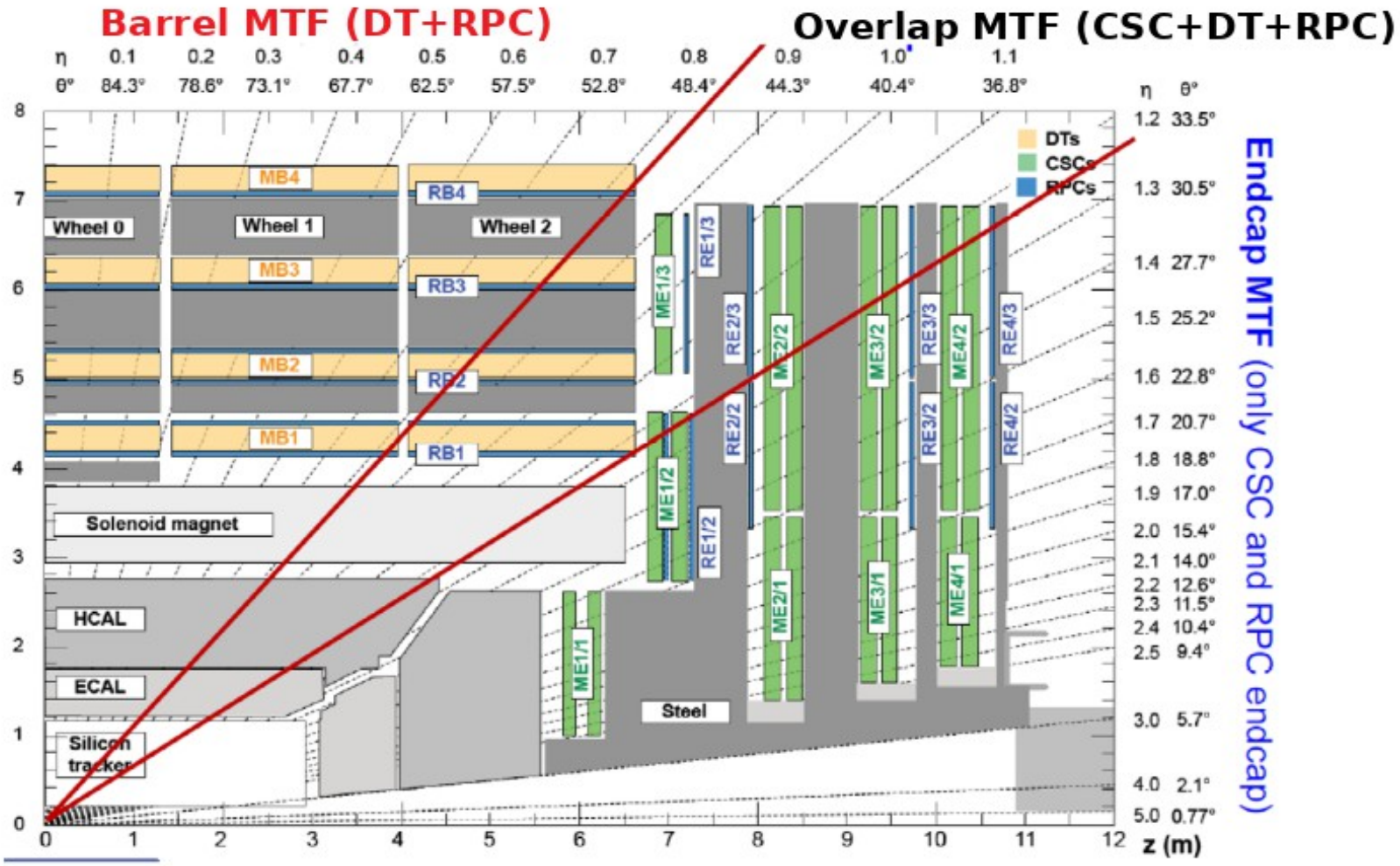
Thank you!

Additional material

Muon System (including upgrade)

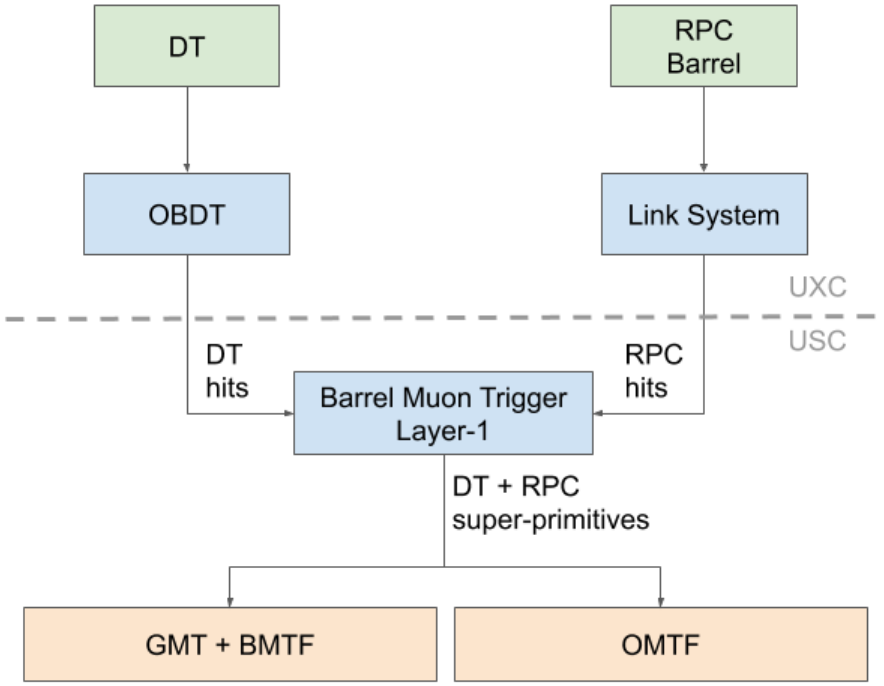


Muon Track Finders



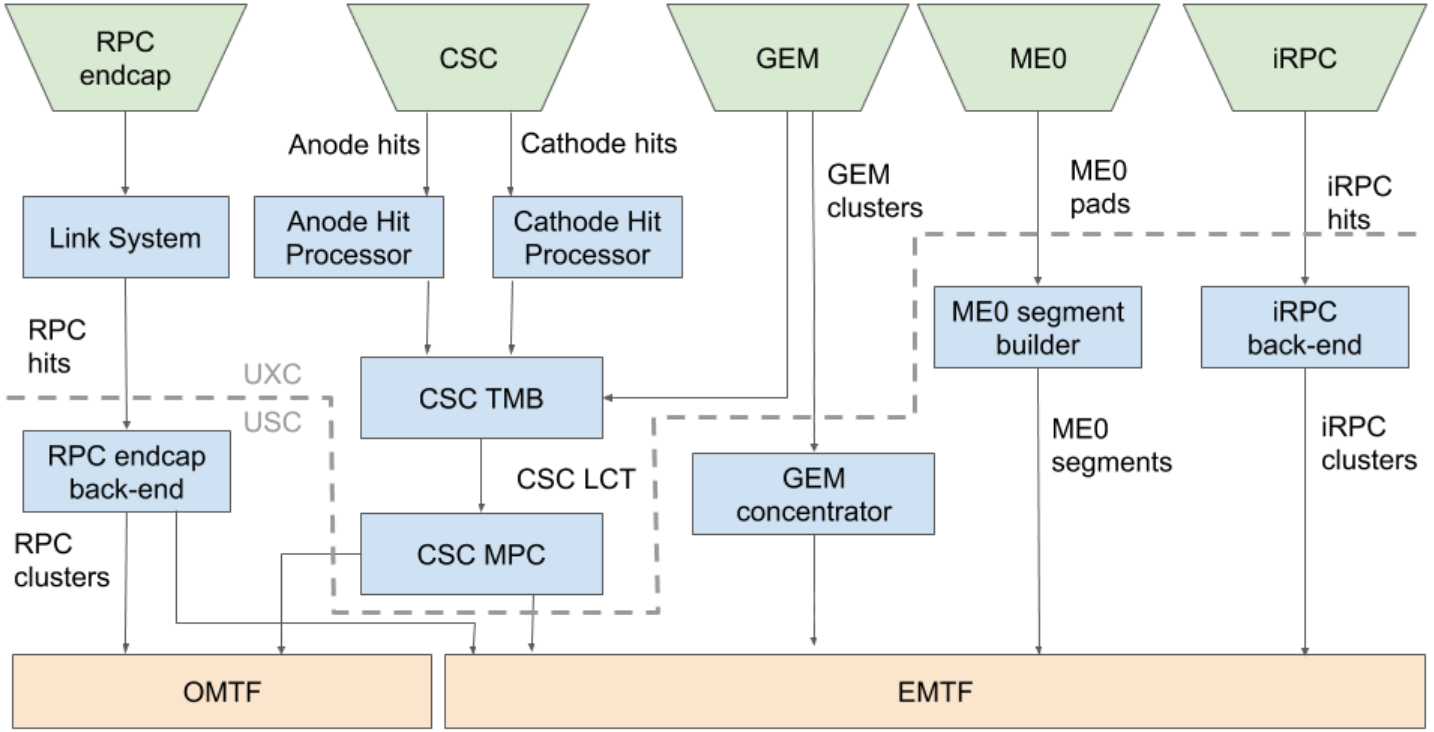
Barrel Architecture

- Barrel muon TP architecture



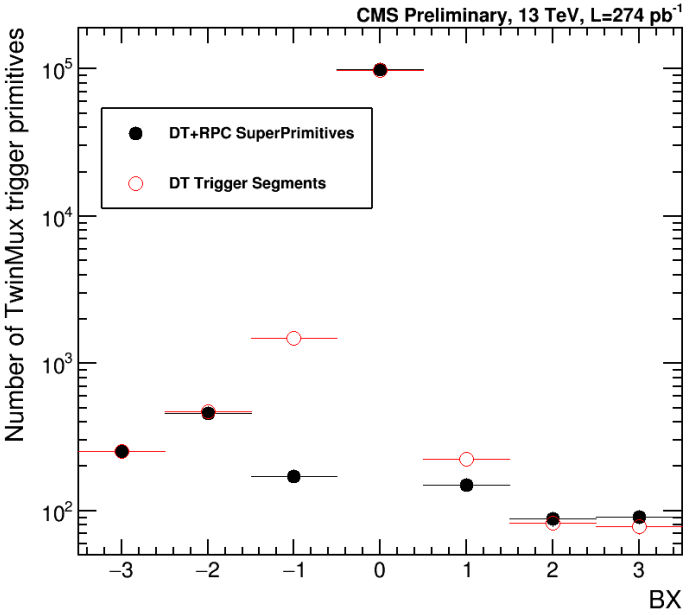
Endcap Architecture

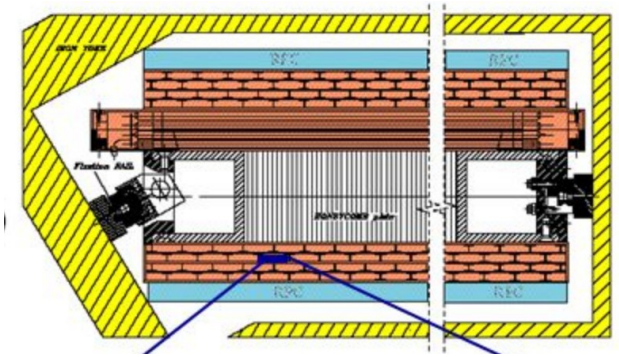
- Endcap muon TP architecture

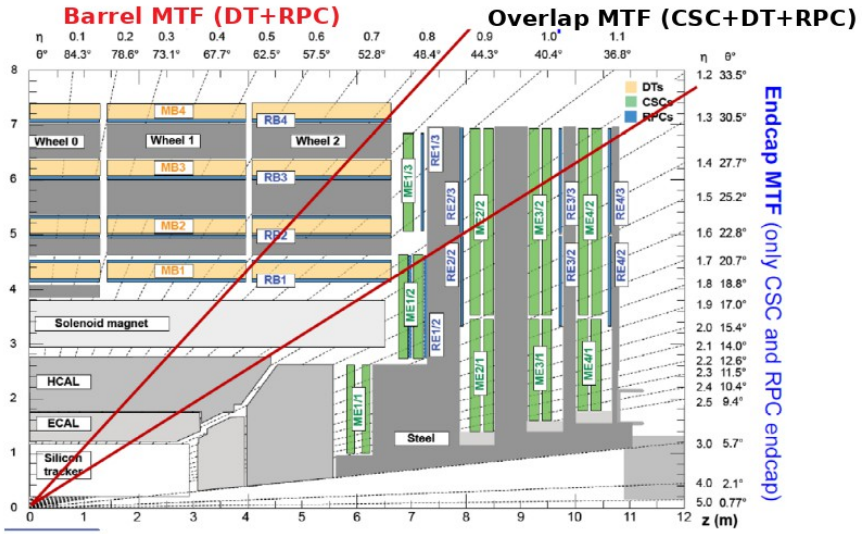


RPC contribution (Phase I)

- RPC contributes to the three Level-1 Muon Track Finders differently
  - BMTF ($|\eta| < 0.83$): assign bunch crossing of low quality DT segments + build RPC only segments in MB1 and MB2 in case of DT segment absence
  - OMTF ($0.83 < |\eta| < 1.24$): the 8 RPC chambers (5 in barrel, 3 in end-cap) are used for position information
  - EMTF ($|\eta| > 1.24$): RPC hits are used in case of CSC segment absence

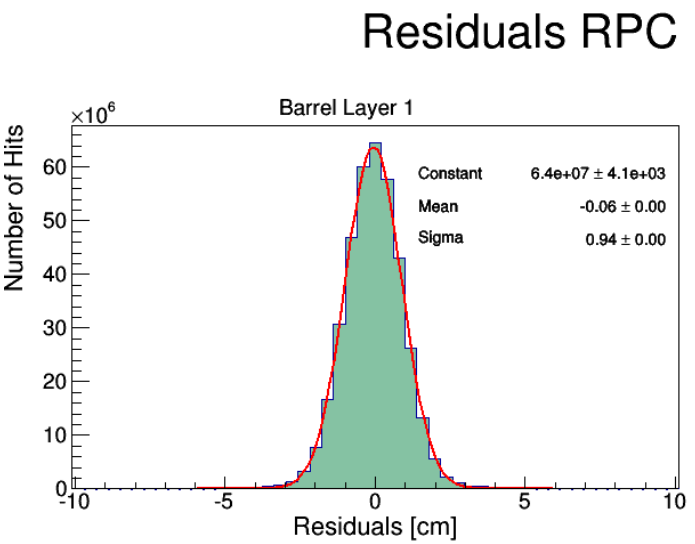


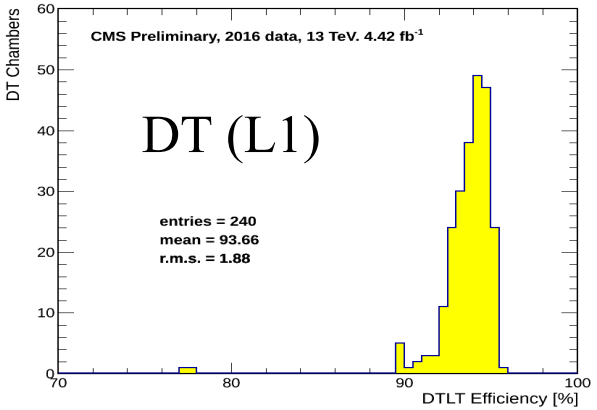


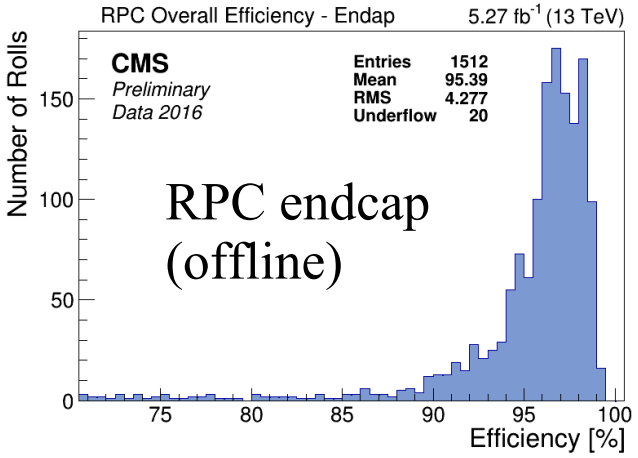


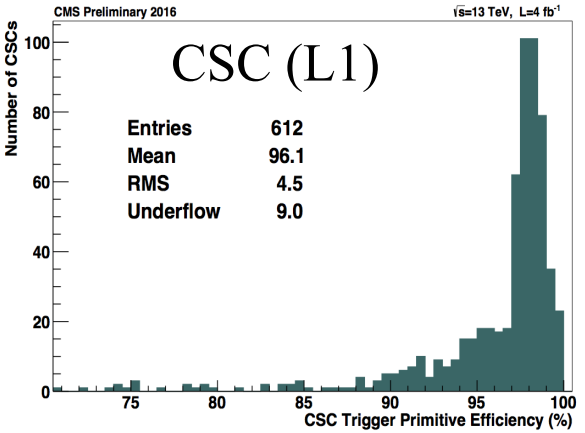
Muon System Performances

- Single hit spatial resolution (φ measurements) – depends on chamber, type of hit, etc
  - DT: Order of **hundreds of µm's**
  - CSC: Order of **hundred of µm**
  - RPC: Order of **cm**
- Timing information available at L1 (run II)
  - **Bunch crossing granularity**
- Efficiency
  - **~93-96%** for all muon detectors at L1





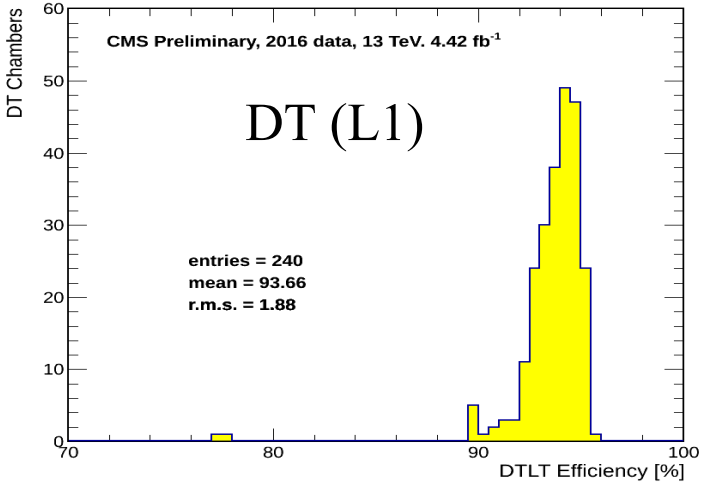


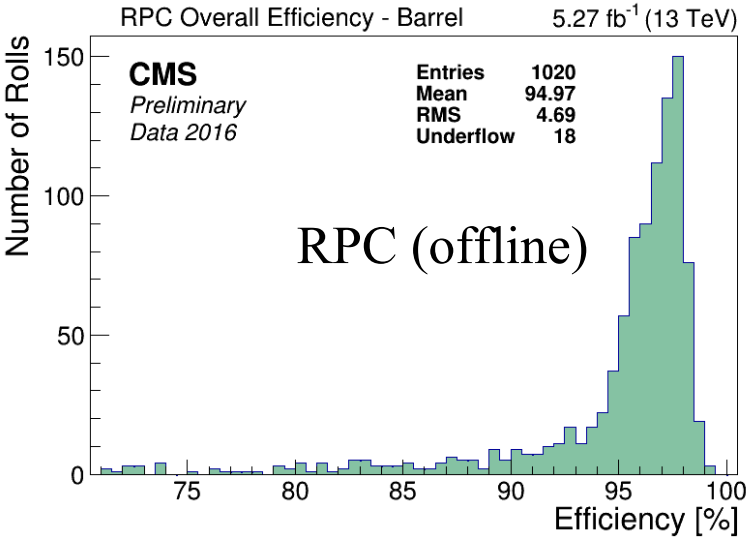


Muon System Performances

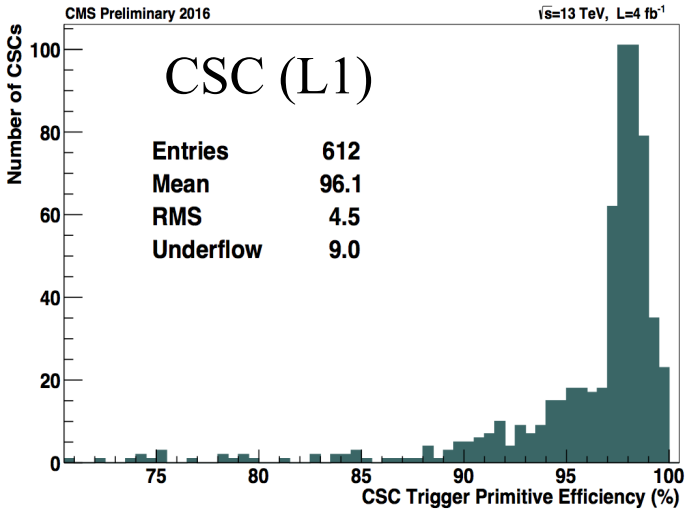
- Efficiency

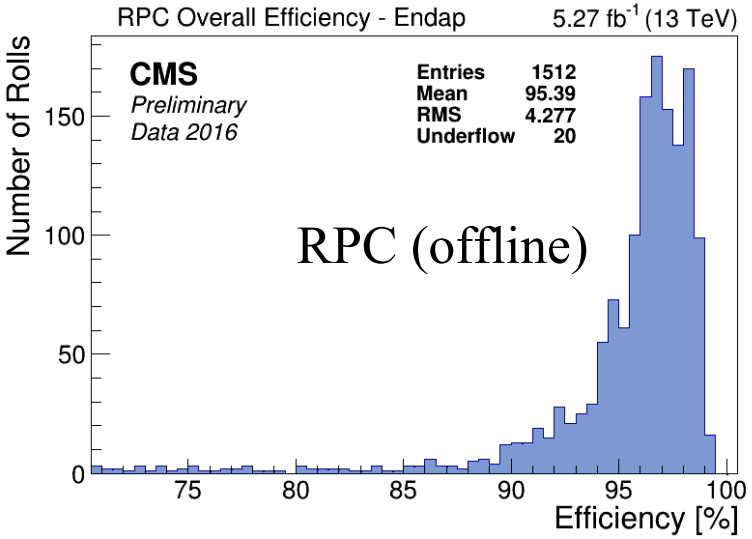
Barrel



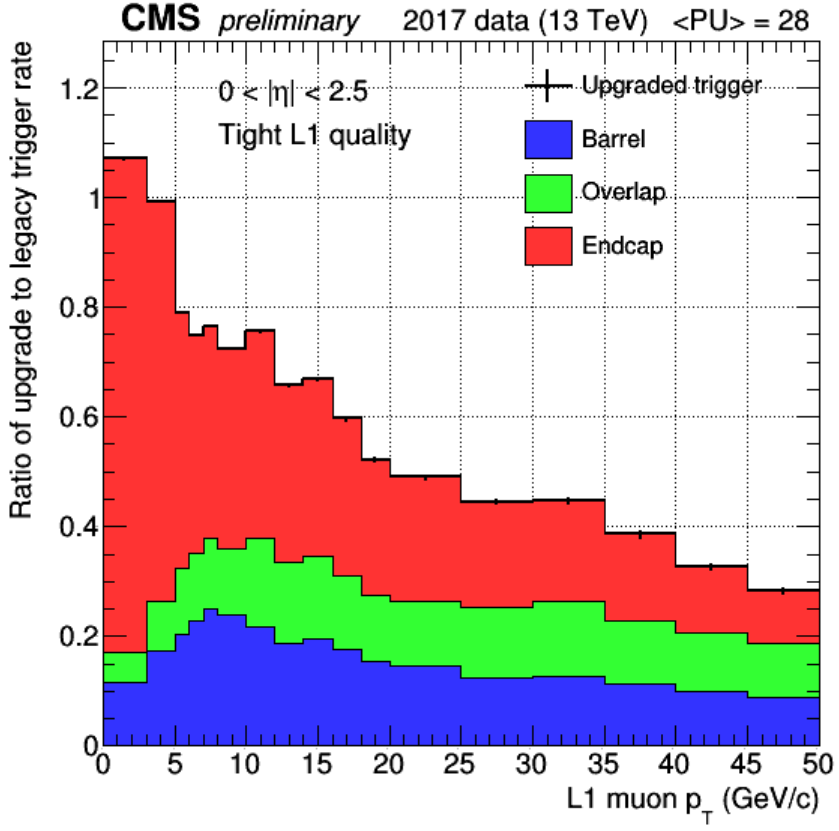


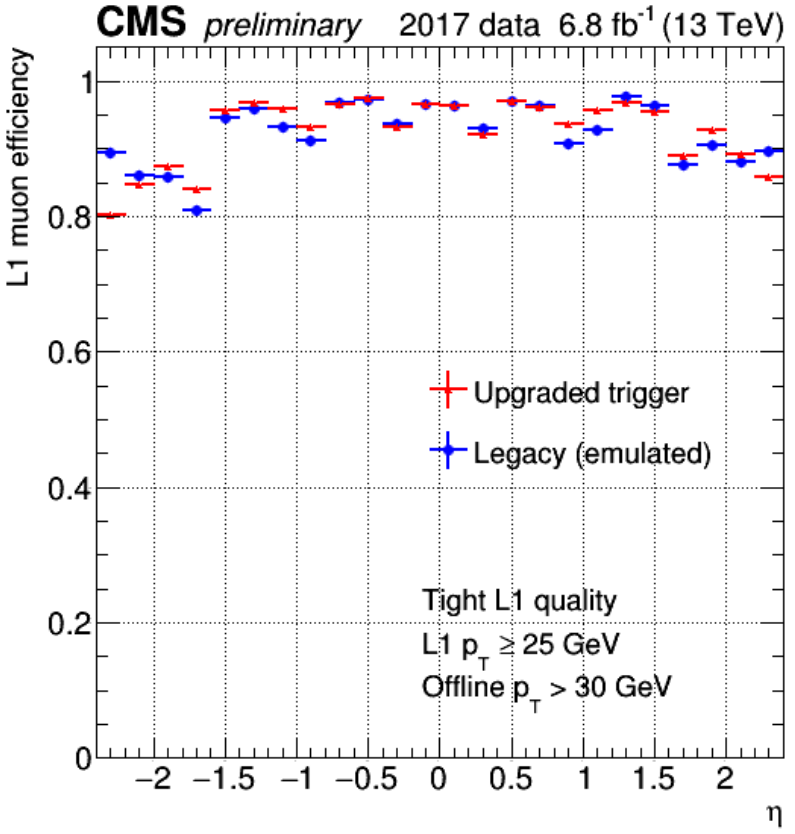
End-cap





Phase I Muon Trigger Performances

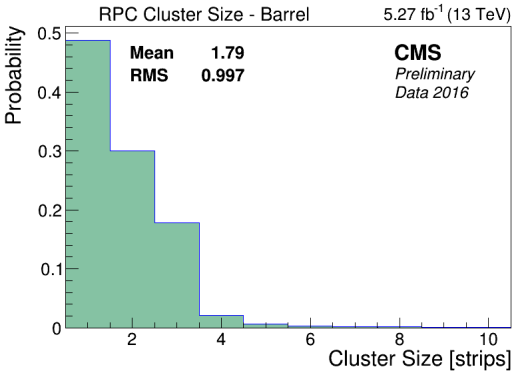


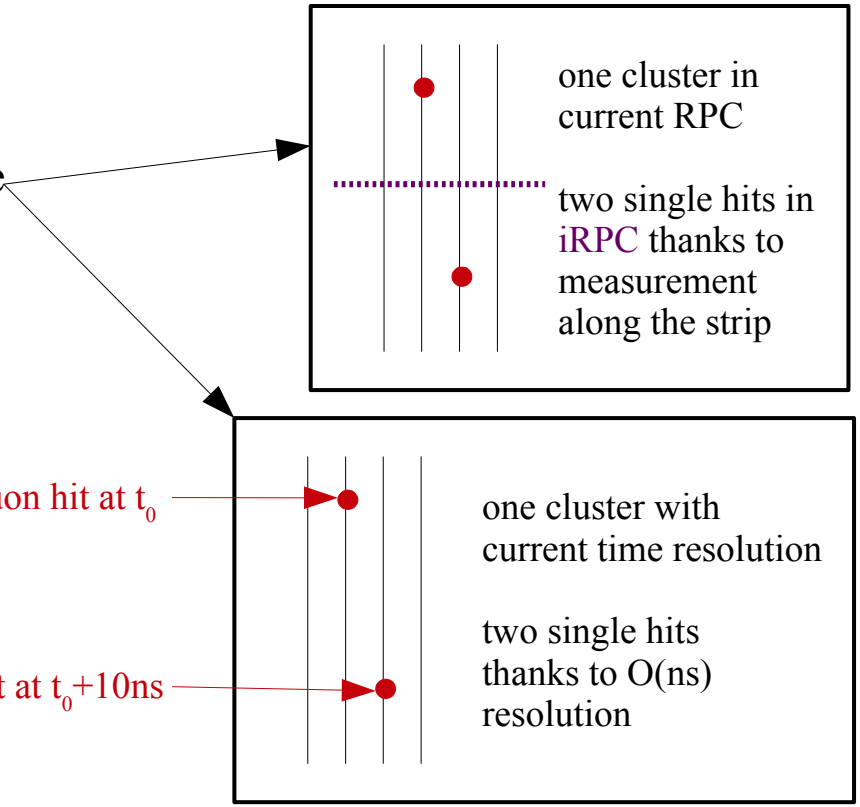


RPC Phase II Trigger Primitives

Impact of the RPC Upgrade on its Trigger Primitives (TP)

- RPC TP are clusters of hits
  - TP position defined as the cluster center
- TP resolution
  - Driven by the strip pitch O(cm) and cluster size
  - Expect improvement both from position along the strip and better timing
- TP purity
  - Prompt muon time arrival is known, background time arrival is uniformly distributed
  - Can expect background reduction thanks to better time resolution

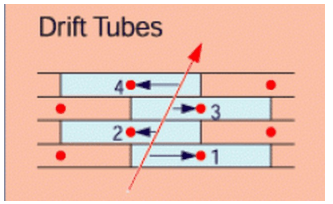


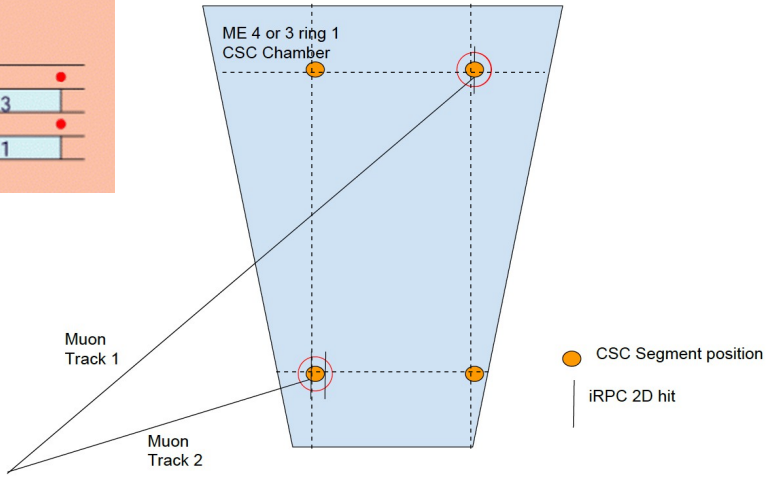


RPC combined to other TP

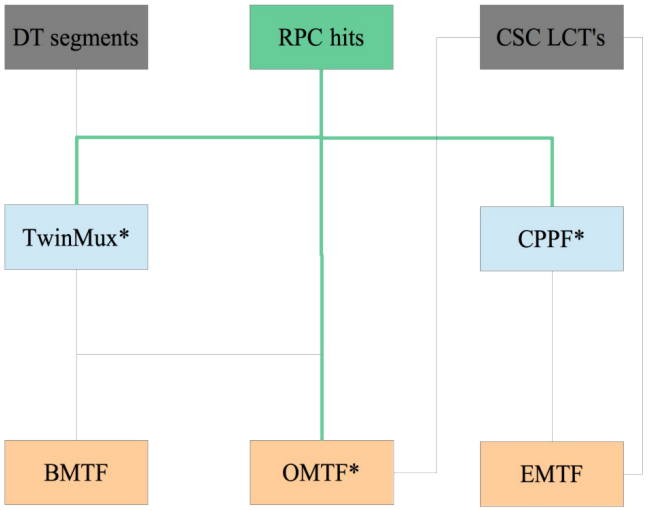
Possibilities offered by a new L1T architecture

- Build DT segments already using RPC information
- Build CSC segment already using RPC information
  - Could resolve ambiguities when two muons cross the same chamber



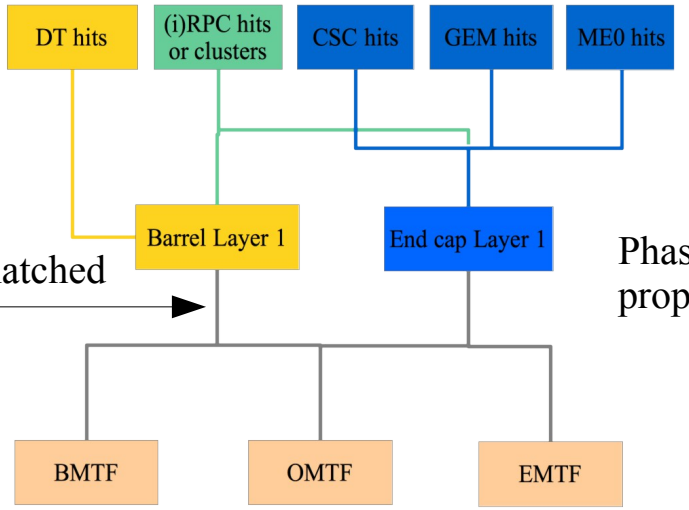


Phase I



* Module with RPC hit clustering and cluster selection

Sends also unmatched RPC clusters



Phase II proposal