Performance of Muon-Based Triggers at the CMS High Level Trigger

Juliette Alimena, Brown University, on behalf of the CMS Collaboration

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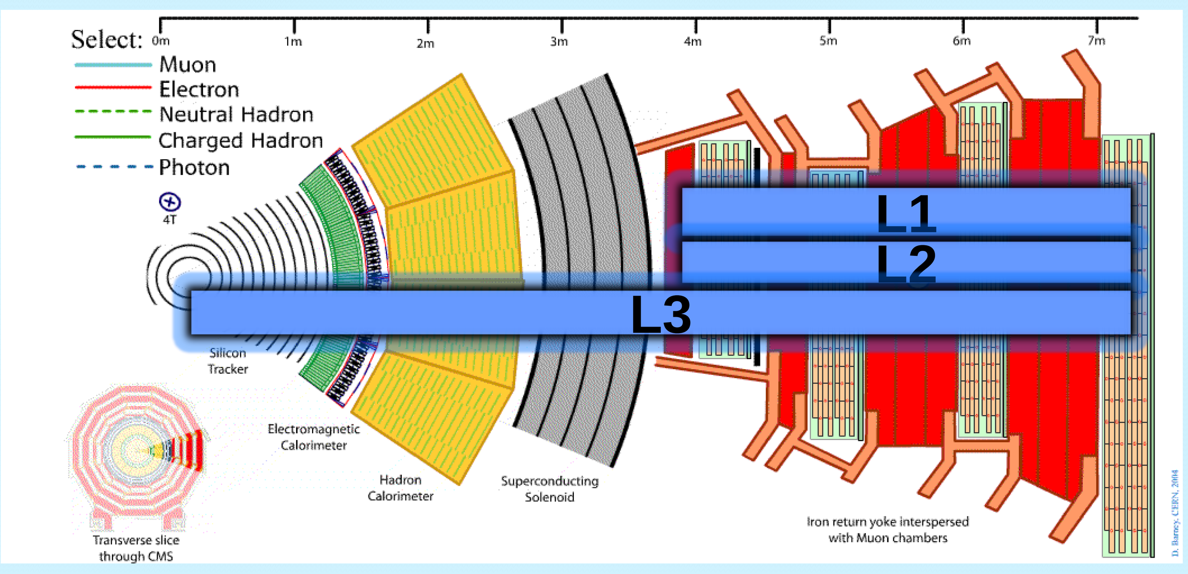
The CMS experiment is designed with a two-level trigger system: the Level 1 (L1) Trigger, implemented on custom-designed electronics, and the High Level Trigger (HLT), a streamlined version of the CMS reconstruction running on a computer farm.

Overview of CMS Muon Trigger

Muon Trigger Stages



Muon triggers require one or more candidates **(Single Muon Triggers)** or two or more candidates **(Double Muon Triggers)** and use isolation, good track quality, good vertex, etc. to select muons

L1: Hardware based, uses muon detectors only

HLT: Software based, uses muon, calorimeter, and tracker detectors

L2: Builds muon tracks in muon system

Steps:

1. Build seed from patterns of DT and CSC segments
2. Start reconstruction of track from seed, using measurements from all muon chambers
3. Filter on L2 muon to reduce rate

L3: Builds full muon tracks from L2 muon tracks and tracker information

Exploits excellent momentum and vertexing resolution of tracker to improve momentum resolution at high p_T

Steps:

1. Build seed for tracker reconstruction, starting from L2 info
2. Reconstruct tracker track
3. Match tracker track and L2 muon

Try different seeding algorithms in the **L3 cascade algorithm** (see below)

Filter on L3 muon to reduce rate

Isolation: Can be measured by searching for tracks and calorimeter deposits in a cone around the L3 muon

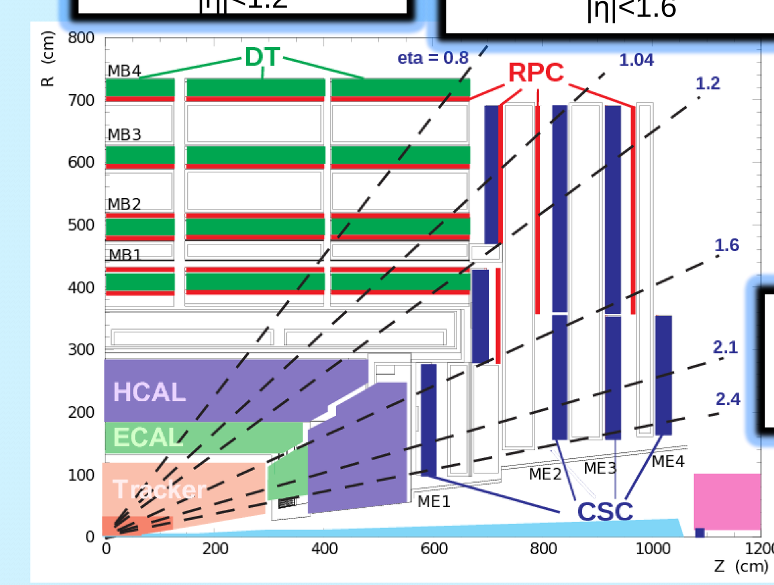
Muon System

All 3 muon subdetectors used in trigger

Drift Tubes (DT) $|\eta|<1.2$

Resistive Plate Chambers (RPC) $|\eta|<1.6$

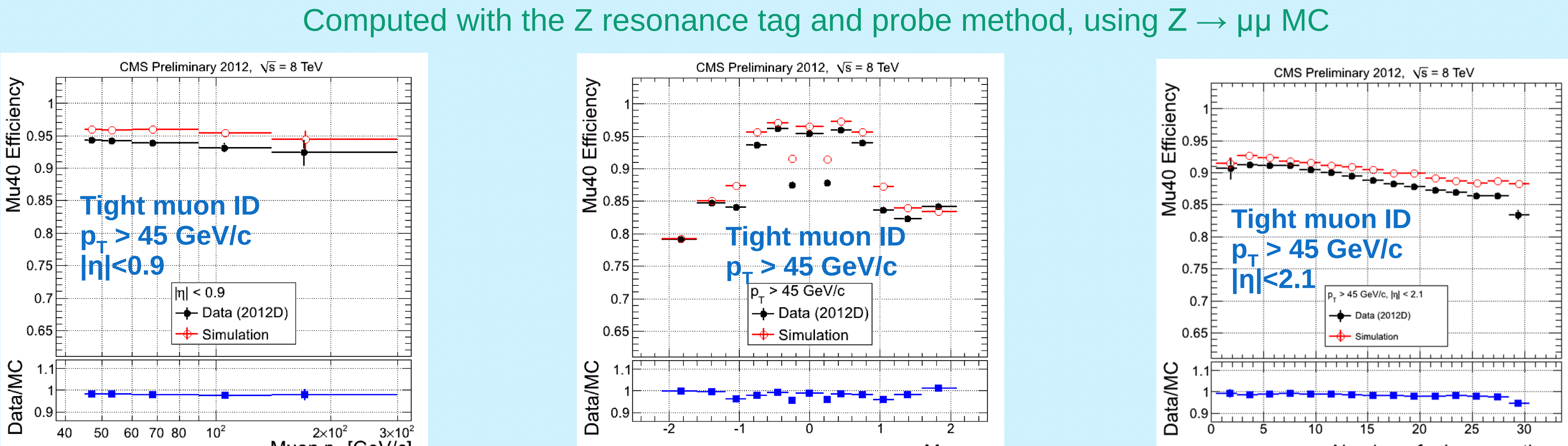
Cathode Strip Chambers (CSC) $0.9<|\eta|<2.4$



Run I Single Muon Triggers Performance

Efficiency of HLT_Mu40 in 2012

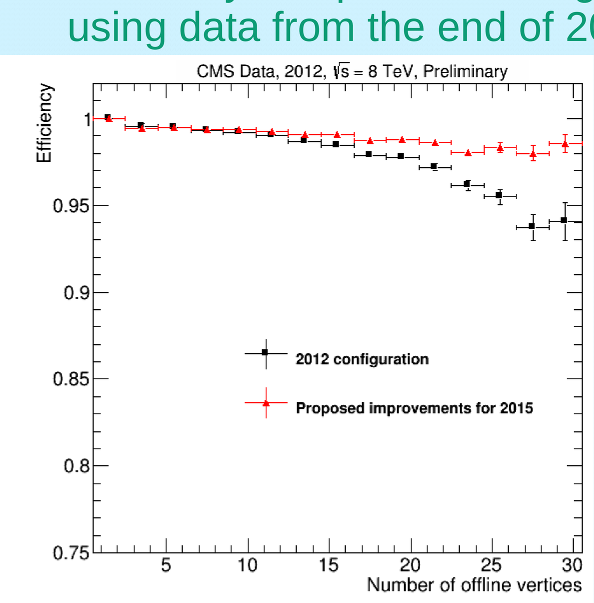
Computed with the Z resonance tag and probe method, using $Z \rightarrow \mu\mu$ MC



Improvements for Run II: Muon Triggers Isolation

Single Muon Isolation

- **Motivation:** Recover efficiency loss at high pileup (PU) and reduce CPU time
  - Done by optimizing PU mitigation and tracking configurations
- Isolation improvements due to:
  - Tracking algorithm improvements
  - PU subtraction algorithm improvements
- Efficiency computed with tag and probe method, using data from the end of 2012



Tight Muon ID [1]
Loose Muon Isolation [1]
p_T > 25 GeV/c
$|\eta|<2.1$
Matched to HLT_Mu24_eta2p1

	Efficiency	Rate Reduction
2012 Configuration	(98.5 ± 0.2)%	(37.8 ± 0.7)% (*)
Proposed improvements for 2015	(99.1 ± 0.2)%	(37.8 ± 0.2)%

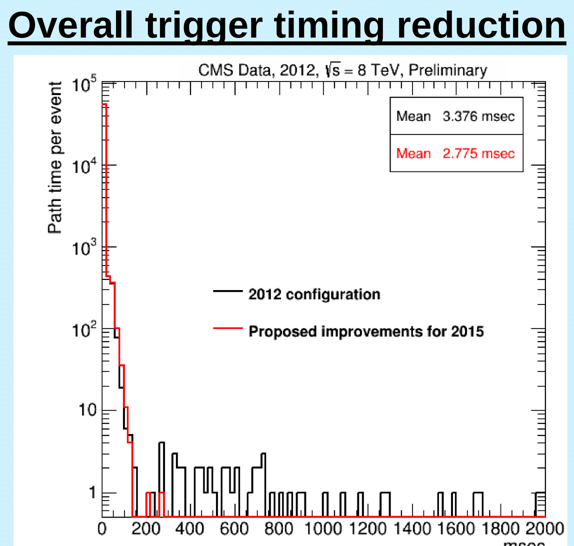
*Statistical errors only

CPU timing of HLT_IsoMu24_eta2p1

<PU>~33

Intel® Xeon® L5420 2.5 GHz processors

Overall trigger timing reduction



HLT_IsoMu24_eta2p1 timing for events firing L1 trigger

Effect of applying isolation:
Mean HLT path time decrease, moving from **2012 configuration** to **proposed improvements for 2015**:
836 ms → 83.9 ms for events passing HLT_Mu24_eta2p1

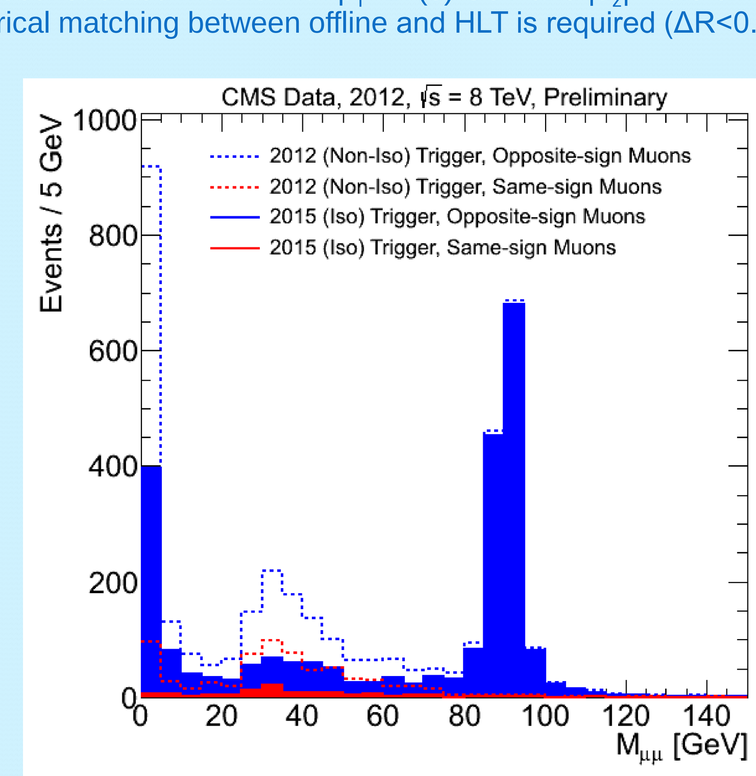
Double Muon Isolation

- **Motivation:** Reduce rate of Double Muon trigger
  - Done by introducing loose tracker isolation
- Isolation including improvements due to:
  - Tracking algorithm improvements
- Rates and efficiencies are computed relative to a non isolated muon HLT trigger, using data from the end of 2012

Original Trigger (to which isolation is applied)	Relative Efficiency (w.r.t. "Loose" muon [2])	Relative Efficiency (w.r.t. "Tight" muon [3])	Relative Rate
HLT_Mu17_Mu8	(99.2 ± 0.2)%	(99.6 ± 0.1)%	(55.7 ± 0.7)% (*)

*Statistical errors only

Offline reconstructed muons with p_T>17(8) GeV and $|d_z|$ < 0.5 cm, geometrical matching between offline and HLT is required (ΔR<0.2)

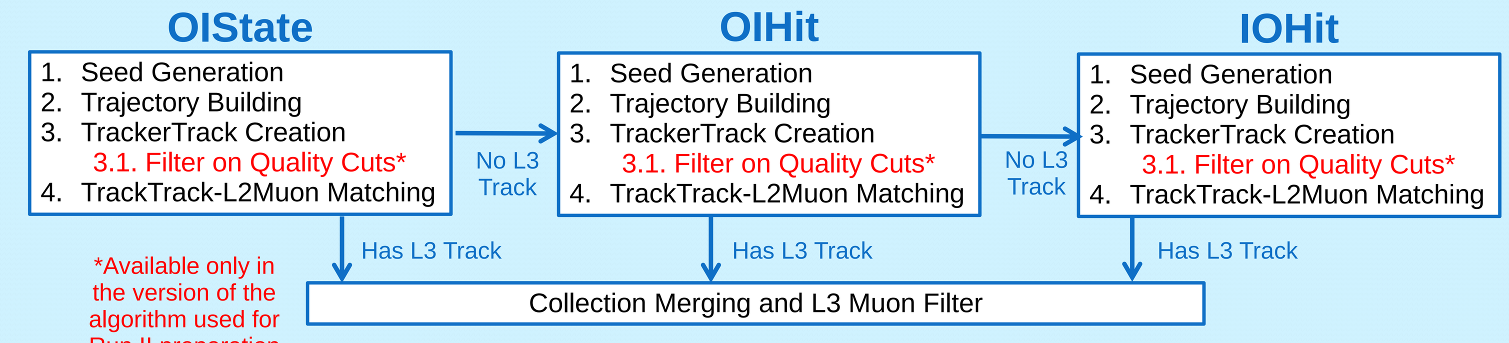


- Invariant mass distribution for muons passing the isolated and non isolated versions of HLT_Mu17_Mu8
- Muons in these distributions:
  1. Genuine muons in the Z boson peak in the opposite-sign sample
  2. Muons from QCD, which dominate the same-sign sample
  3. Muons from J/Psi decay in the low invariant mass bin
- Isolation requirements suppress muons from QCD but keep high efficiency for di-muons from Z boson decays and the non resonant Drell-Yan contribution

Improvements for Run II: L3 Muon Triggers

- **Motivation:** Recover efficiency loss for L3 muon triggers, at high pileup
  - Done by implementing changes in the **L3 cascade algorithm**

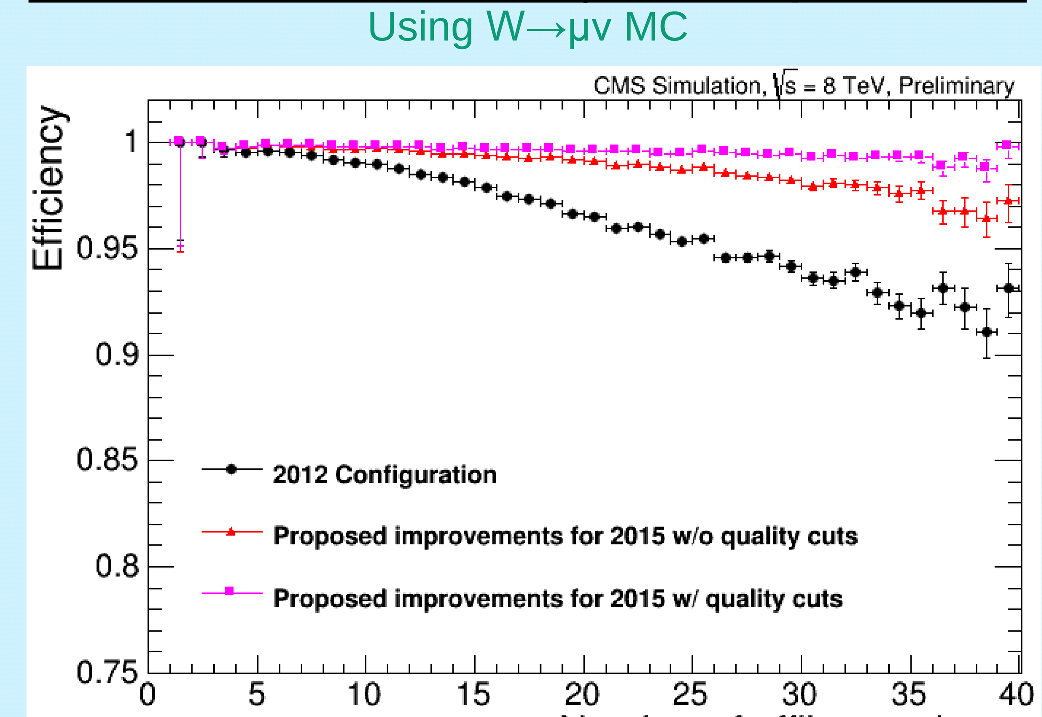
L3 Cascade Algorithm



- A sequence of three algorithms is tried in "cascade" from the fastest to the most CPU consuming one and exits as soon as a L3 track is found
  - OIState: seeds to reconstruct tracker tracks are built on the basis of L2 muons propagated to tracker layers
  - OIHit: seeds are built on the basis of L2 muons propagated to tracker including also information from one tracker hit
  - IOHit: L2 muons are used to build regions where to look for hits but seeds are built using pixel/tracker hit information
- **Cascade algorithm improvements:**
  - Default version: exit as soon as L3 track was built
  - Idea: a step of the cascade can build a track failing final cuts, but next ones might do better
  - Update: filter on quality cuts at each step of the cascade

Efficiency for the L3 step
Before and after cascade algorithm improvements

Using $W \rightarrow \mu\nu$ MC



Denominator: Number of generated muons matched with a L2 track passing HLT trigger quality cuts
Numerator: Number of generated muons as above that also match a L3 track passing the final L3 Muon filter quality cuts and whose tracker track component has >75% shared hits

- Rate increase moving from **2012 configuration** to **proposed improvements for 2015 with quality cuts**:
  - 4.3% for HLT_IsoMu24
  - 6.8% for HLT_Mu40
  - Expected rate to increase with efficiency
  - Rate increase is acceptable

References

[1] **CMS DP-2013/009** (Tight Muon ID definition; Loose Muon Isolation corresponds to the <0.2 relative isolation working point)
[2] **EPJ C 73 (2013) 2677** ("Tight" muon definition used to study the isolated double muon triggers)
[3] **PRD 89 (2014) 092007** ("Loose" muon definition used to study the isolated double muon triggers)