Upgrades of the CMS muon system in preparation for HL-LHC

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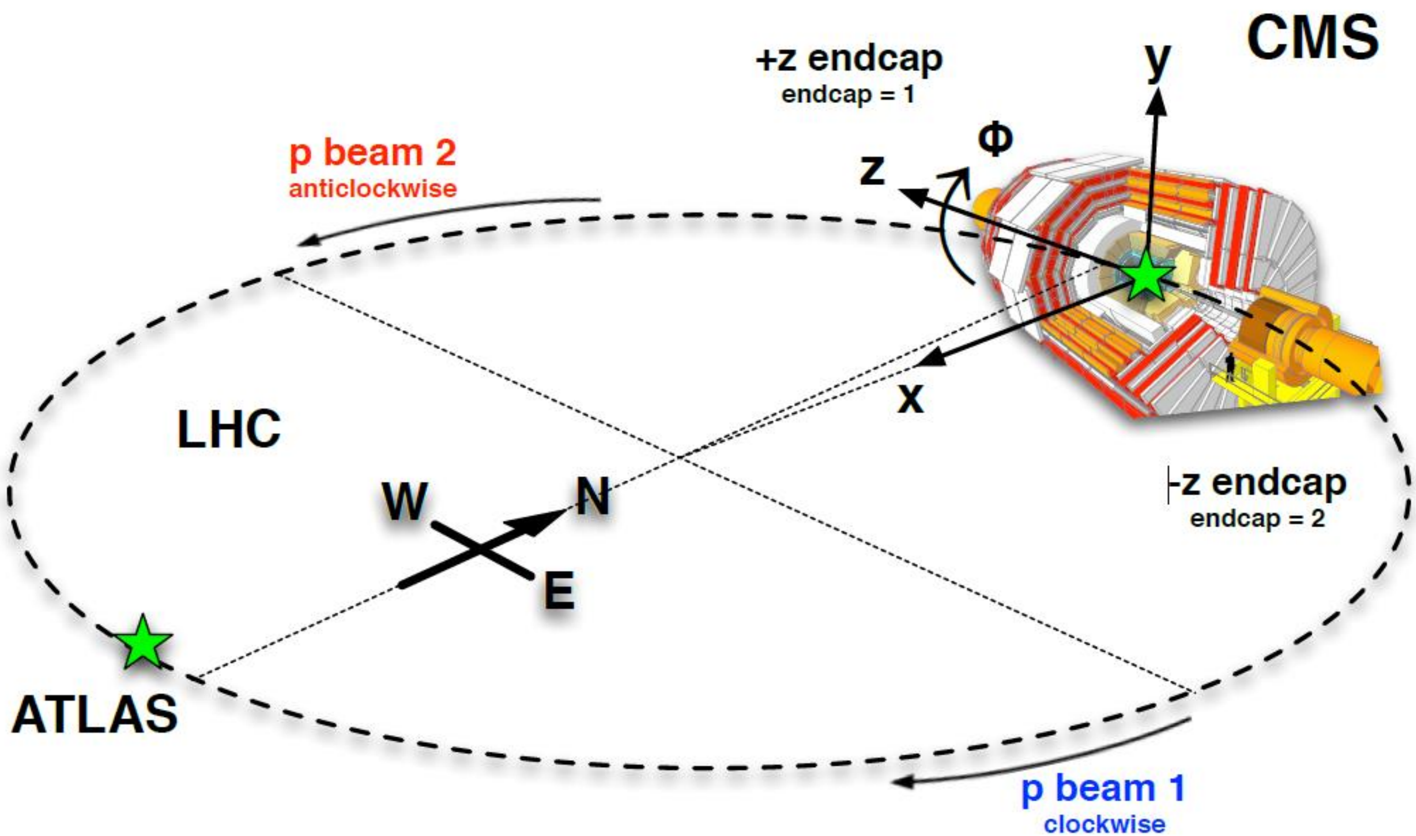
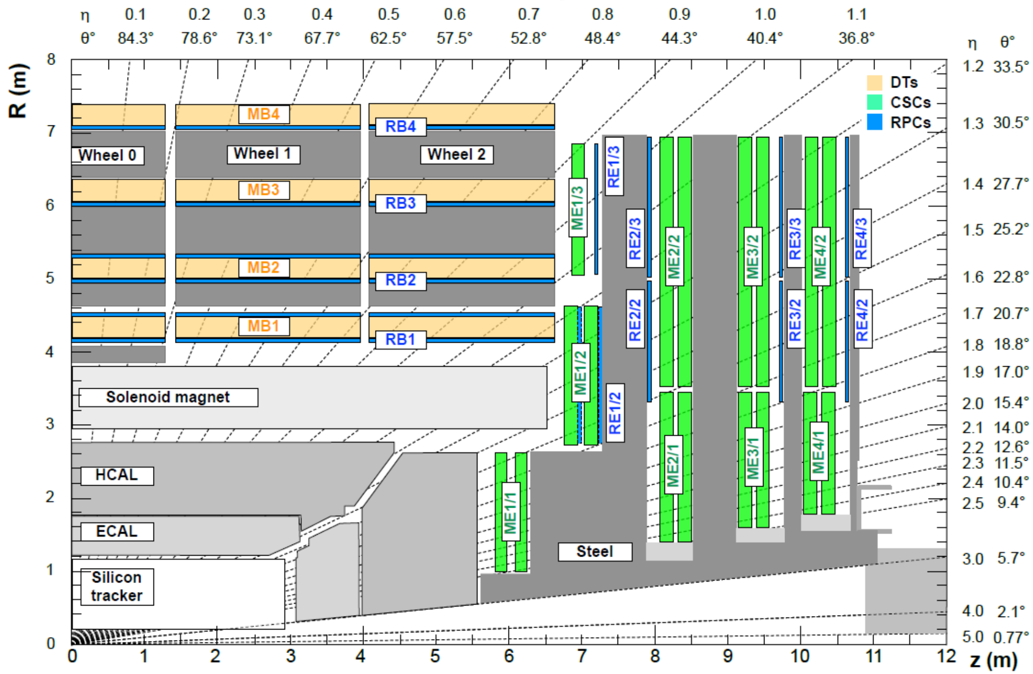
On behalf of the CMS Muon group

CMS – one of two general purpose detectors at LHC

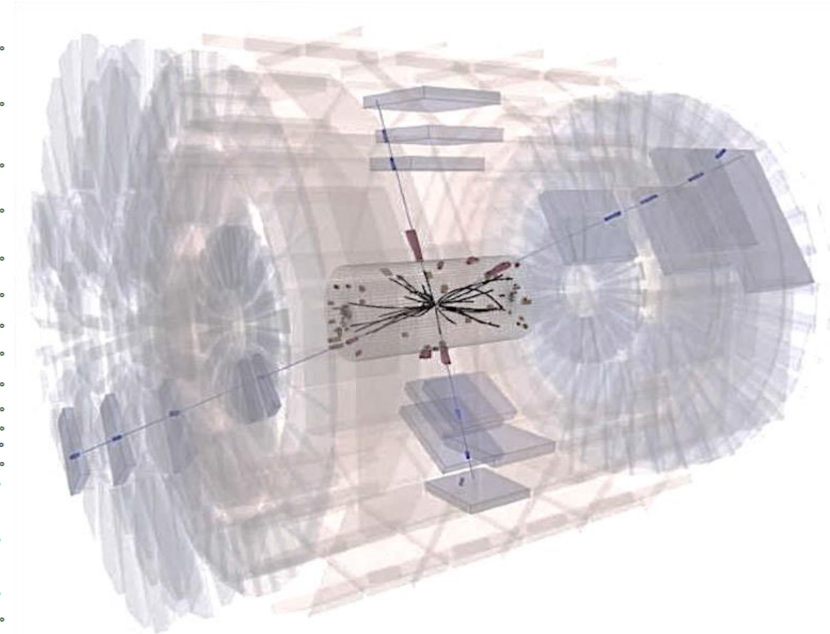


CMS Muon system - 3 types of coordinate detectors

CMS R-z quadrant



4-muon event



1. Drift Tube chambers are used in the Barrel part (DT, yellow, 4μ stations) and cover |η| < 1.2

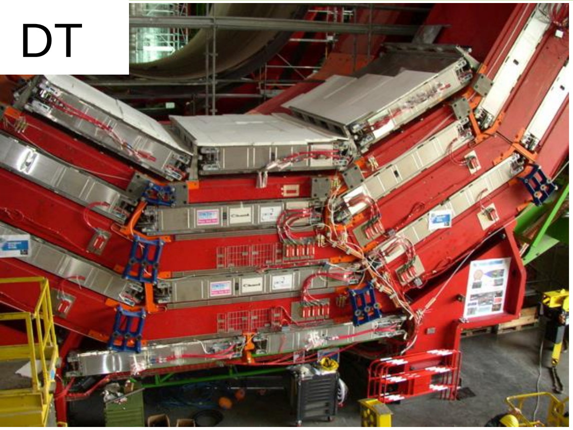
2. Cathode Strip Chambers are used in the Endcap part (CSC, green, 4μ stations) and cover 0.9 < |η| < 2.4

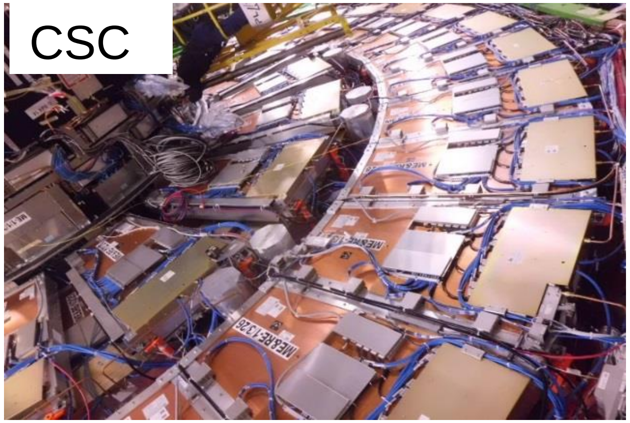
3. Both Barrel and Endcap parts are complemented by a system of Resistive Plate Chambers (RPC) covering the range of |η| < 1.8

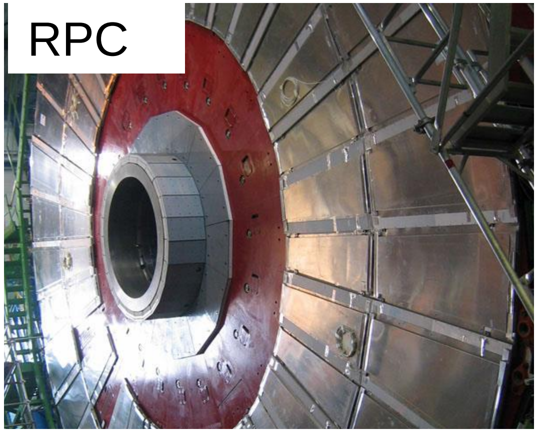
Muon system provides:

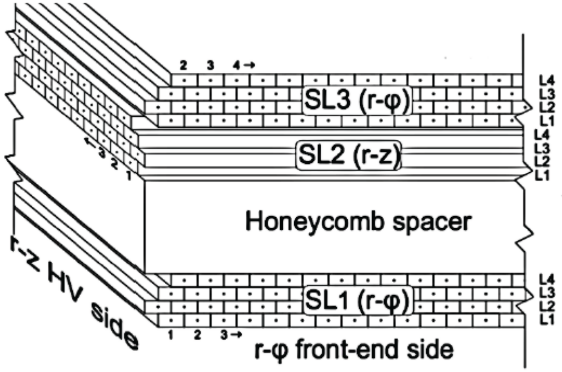
- Muon identification and momentum measurement
- Muon trigger
- Rejection of background and pileup by matching of muon tracks with inner Tracker

Muon chambers – 3 different technologies



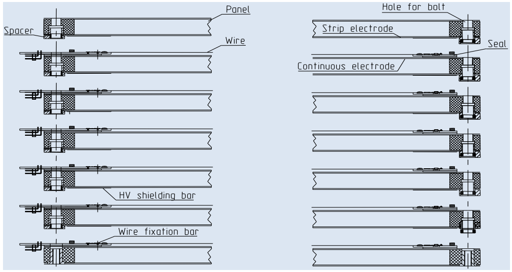


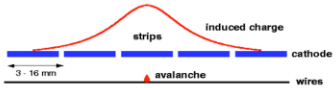




DT chamber consists of 3 super-layers, each composed of 4 layers of drift tube cells

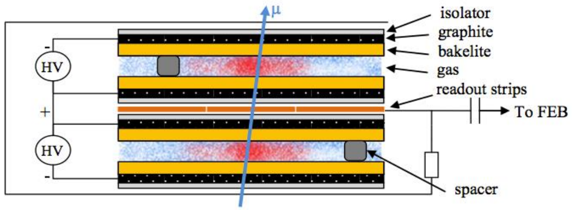
Sensitive area: 18,500 m2
No. of channels: 172K





A CSC consists of 6 layers, and operates as standard multi-wire proportional chamber (MWPC) with cathode readout.

Sensitive area: 6,300 m2
No. of channels: 477K

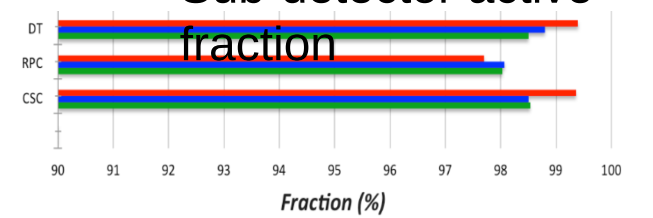


The RPC are double-gap chambers, operated in avalanche mode providing fast and independent trigger signals.

Sensitive area: 4,000 m2
No. of channels: 137K

CMS muon system in Run2 (2016-17)

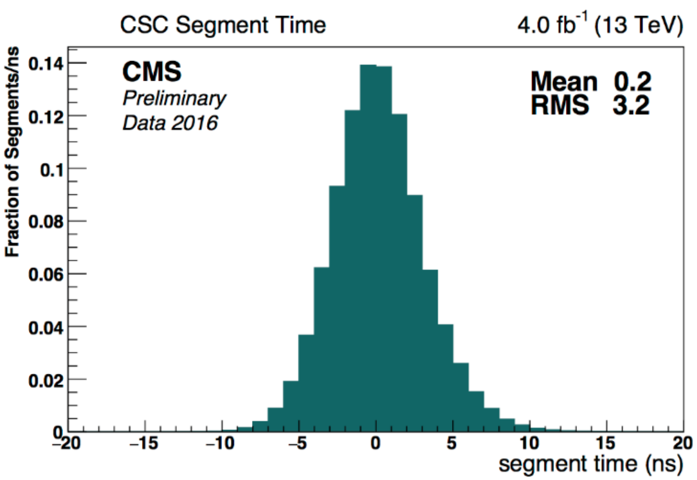
Sub-detector active fraction

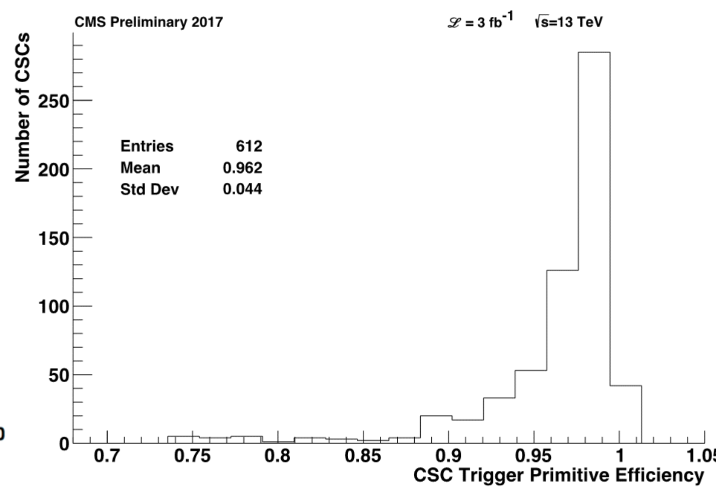


Muon system:
>98% availability

CSC station spatial resolution (μm)
CMS *Preliminary* 2017

Station	Oct 2016 6 fb^{-1}	Jun 2017 4 fb^{-1}
ME1/1a	46	45
ME1/1b	52	52
ME1/2	87	88
ME1/3	105	105
ME2/1	129	132
ME3/1	123	126
ME4/1	123	126
ME2/2	139	141
ME3/2	139	141
ME4/2	143	144

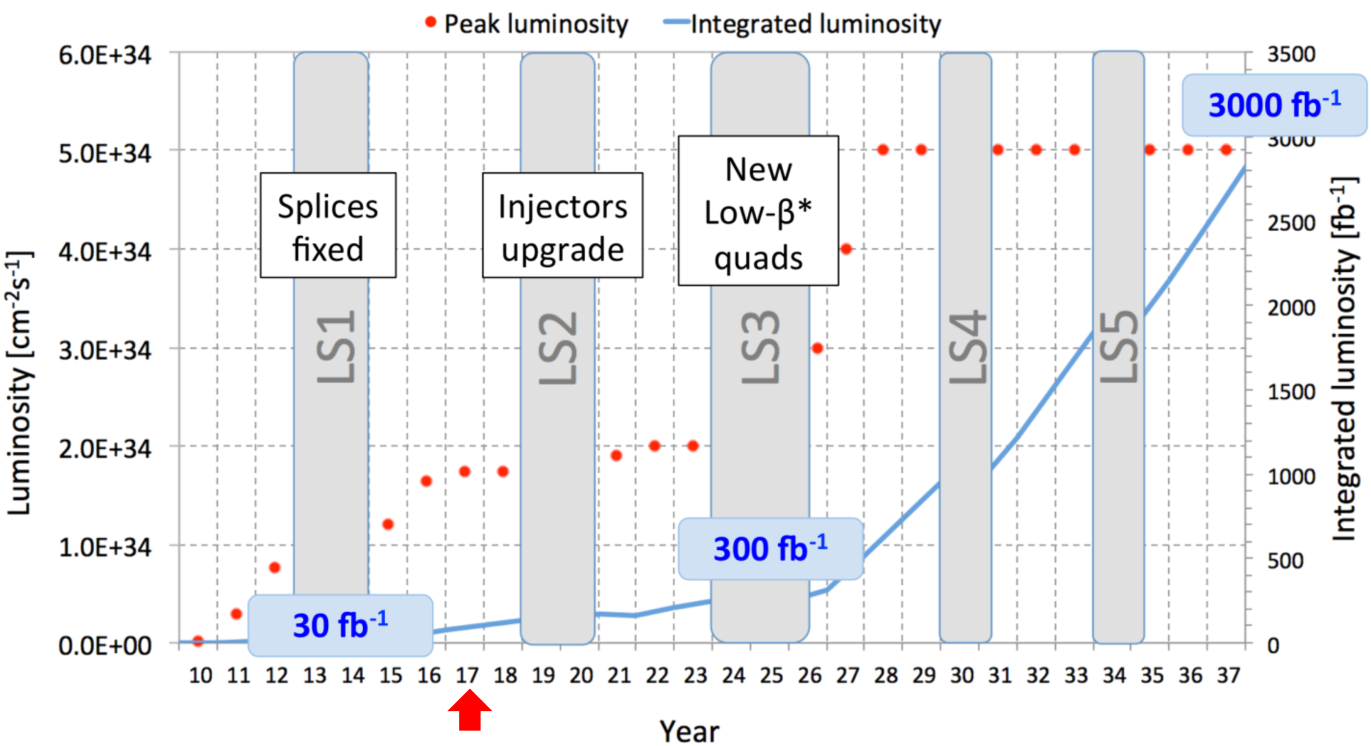




Muon system:

- Fractions of the operating channels >98%
- High Spatial resolution 45÷300μm (DT and CSC)
- Timing resolution ~ 3 ns or better per chamber for all 3 systems
- Local track efficiency ~ 97%

LHC - HL LHC schedule



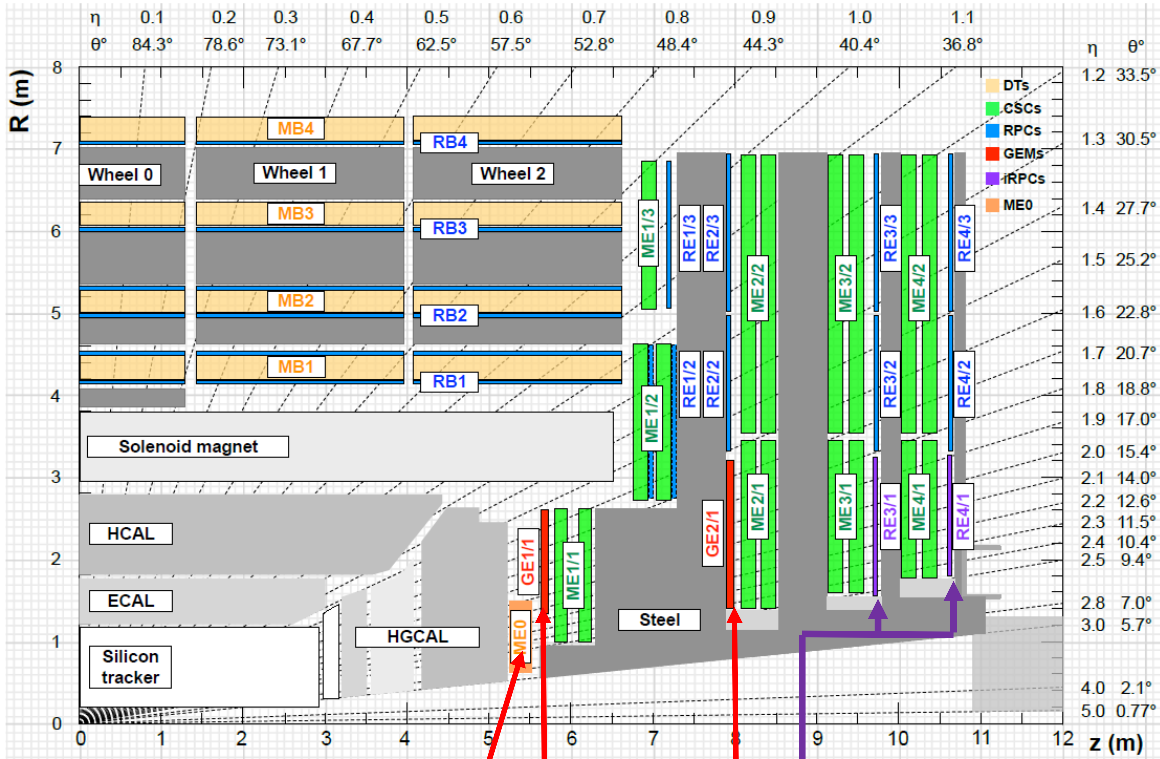
	LHC	HL LHC
Instant. luminosity ($cm^{-2}s^{-1}$)	**10^{34}**	**5×10^{34}**
pileup collisions	**30**	**150**
integrated luminosity (fb^{-1})	**300**	**3000**
CMS L1 trigger rate (KHz)	**100**	**750**
CMS L1 trigger latency (μs)	**3.6**	**12.5**

New HL LHC parameters require detector upgrade in LS2 and LS3

CMS Muon System Upgrade Concept

- Keep the existing muon detectors and DEMONSTRATE the longevity of detectors/electronics for HL-LHC running
- REPLACE some electronics expected to fail HL-LHC requirements (rad. hardness and rate capability)
  - CSC – upgrade of on-chamber and VME cathode and anode r/o electronics for inner ($1.6 < |\eta| < 2.4$) rings to operate with increased data rates at high luminosity and higher L1 trigger latency
  - RPC - new trigger electronics (1.5 ns sampling time, instead of 25 ns)
  - DT – reconfiguration of on-detector electronics readout (mini-crates) architecture
- Add RPC and GEM detectors in the very forward region to improve redundancy on muon ID and L1 triggering

Muon system upgrade – new detectors in the forward region



6-layer GEM ME0: Extension to cover the far forward region 2.0<|η|<2.8:

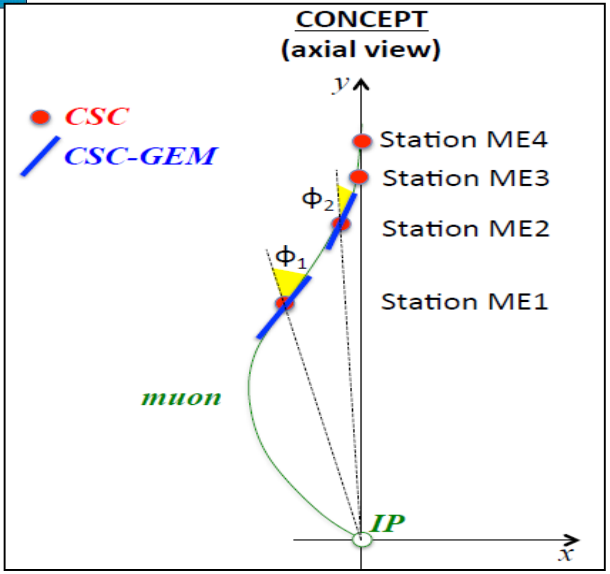
Enhancement of the forward region 1.6<|η|<2.4:

improved RPC (iRPC)

GEM detectors (GE1/1, GE2/1)

CMS GEM detectors - see more details in Martina's report:
"Status and commissioning of the new GEM-based subsystem GE1/1 of the CMS muon system"¶

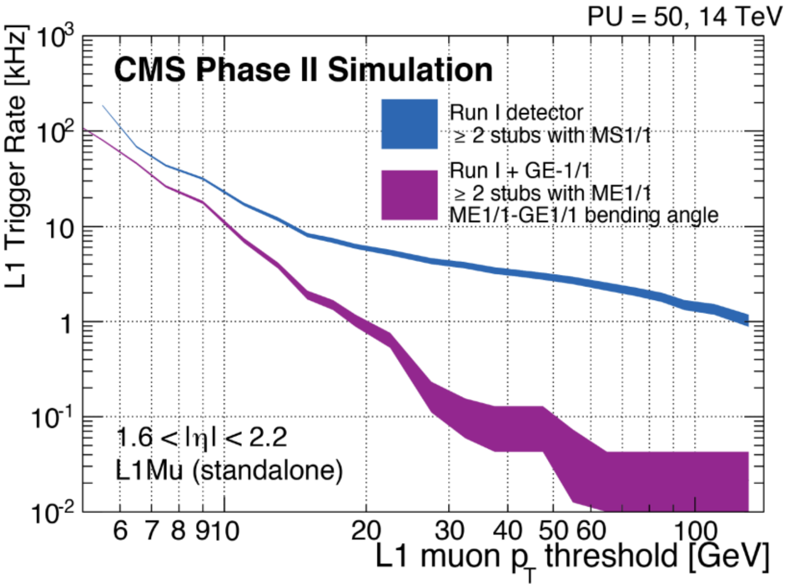
L1 Trigger: p_T measurement and rate

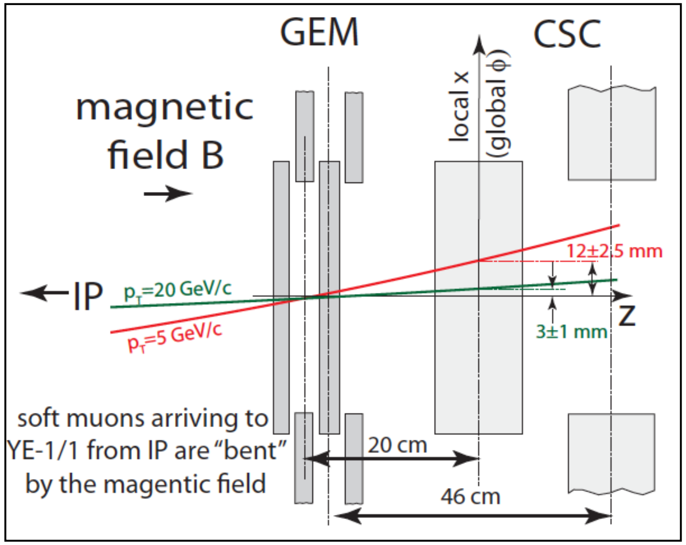


Schematic view of μ trajectory from axial point of view

CSCs alone provide short segments with low-precision info on segment direction

GEM-CSC tandems in ME1 and ME2 stations give accurate measurement of muon "local" direction sensitive to muon p_T



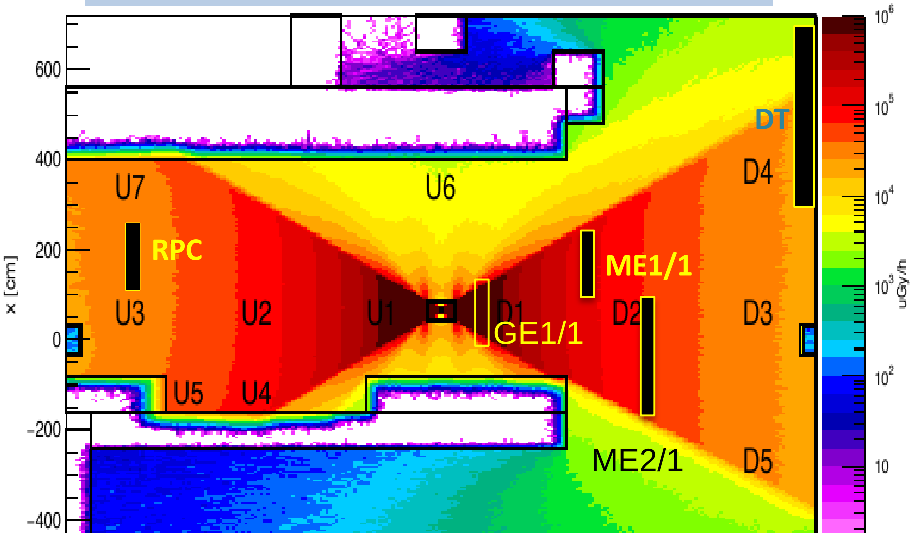


GE1/1-ME1/1 super-stab in YE1 provides direction measurement and allows efficient rejection of the muon backgrounds improving p_T resolution → large L1 trigger rate reduction

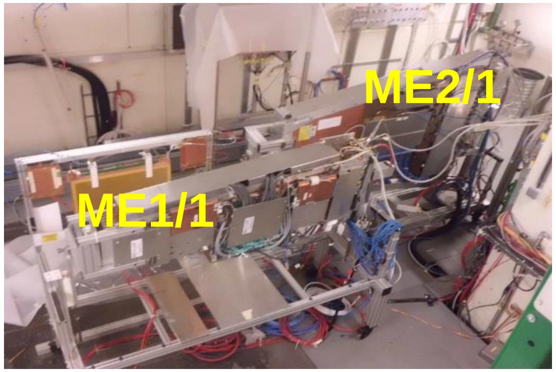
GIF++ detector longevity tests

Ageing tests: full-size DTs, CSCs, RPCs and GEM are exposed to high rates at the CERN Gamma Irradiation Facility (GIF++)

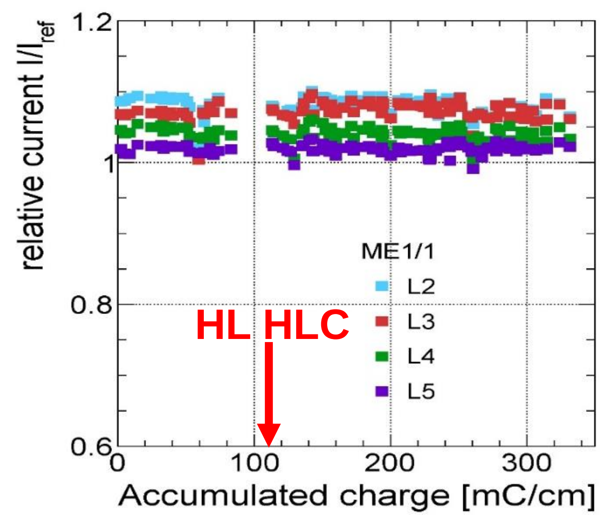
GIF++ irradiation intensity map



- H4 SPS beam line
- 14 TBq Cs^{137} source
  ($E\gamma$ = 662 keV)
- Att, Factor: (1 ÷ 46000)
- Upstream + Downstream
  100m2 irradiation zone



CSC at GIF++



GEM and CSC observed no ageing effects at doses equivalent to 3 HL LHC periods = 3x accumulated charge with $3000fb^{-1}$.

Greenhouse F-gases limitation

New regulations

*In 2014, the European Commission adopted a new regulation limiting the total amount of important **fluorinated greenhouse gases (F-gases)** that can be sold in the EU from 2015 onward and phasing them down in steps to **one-fifth of 2014 sales in 2030***

CSC and RPC: F-gas footprints:

- CSCs use **10% CF_4** (GWP=6500): 274 m3/hr of CO2 equivalent
- RPCs use **95.2% $C_2H_2F_4$** (GWP=2300): 228 m3/hr

and **0.3% SF_6** (GWP=23900): 1440 m3/hr of CO2 equivalent

– F-gases used by CSCs and RPCs prevent aging and ensure reliable operation

but the total release is:

– 1700 m3/hr of CO2 equivalent (yearly, ≈12K cars)

Solutions under study:

– **new eco-friendlier gas options** → RPCs explore operation with new gases **CF_3I, $C_3H_2F_4$** (GWP ≈ 0.4)

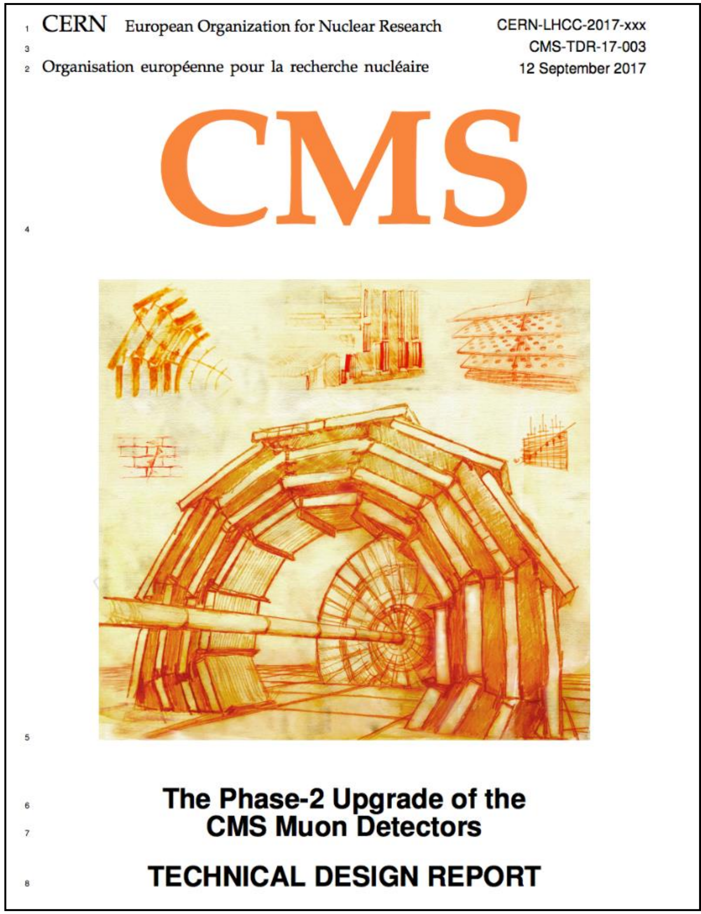
– **F-gas consumption reduction** → CSCs explore operation with **2% CF_4**

– **Other measures being explored:**

- improved recuperation (currently works for CSCs only and ~40% efficient)
- add a commercial abatement system to burn off F-gases on the exhaust into harmless compounds

Summary: CMS Muon System Upgrade main goals

- DEMONSTRATE the longevity of the muon detectors/electronics for HL-LHC running
- REPLACE the electronics expected to fail HL-LHC requirements
- ENHANCE the muon system capability and robustness: additional detectors, GEMs and iRPCs, in the very forward direction
- FIND solution to minimize F- gases release.


CERN European Organization for Nuclear Research
Organisation européenne pour la recherche nucléaire
CERN-LHCC-2017-xxx
CMS-TDR-17-003
12 September 2017

CMS

The Phase-2 Upgrade of the CMS Muon Detectors

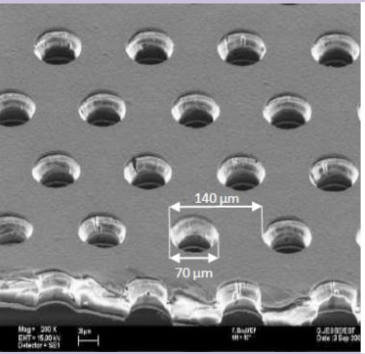
TECHNICAL DESIGN REPORT

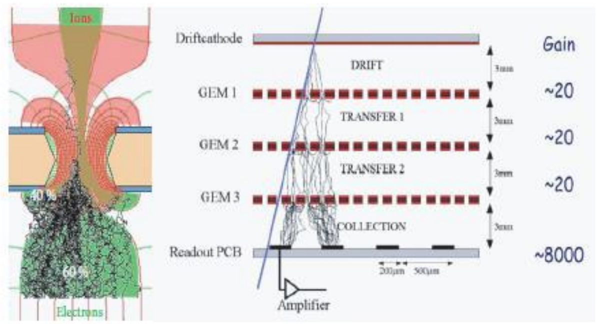
The Phase-2 Muon Upgrade TDR is submitted

Backup

New detectors in the forward region

GEM – gas electron multiplier





Avalanches in strong electric field concentrated in thin holes.

Triplet GEM: **gas gain 10^4**

Operate well in **high rate**

GIF++ Ageing Tests show **excellent longevity**

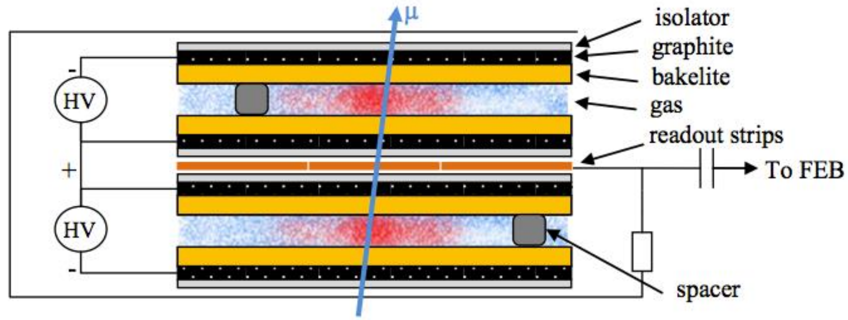
GE1/1, GE2/1 stations: 2 layers of triplet-GEM units

ME0: 6 layers of triplet-GEM units

Overall area (triplet-GEM): **220 m2**

Number of channels: **1.5M**

Improved RPC



Improvements:

- higher rate capability

(Reduced electrode resistivity – 10^{10} Ωcm, smaller gas gain)

- Reduced electrode gas gap thickness
- Low noise FE electronics for high efficiency and low ageing
- two-ended strip readout

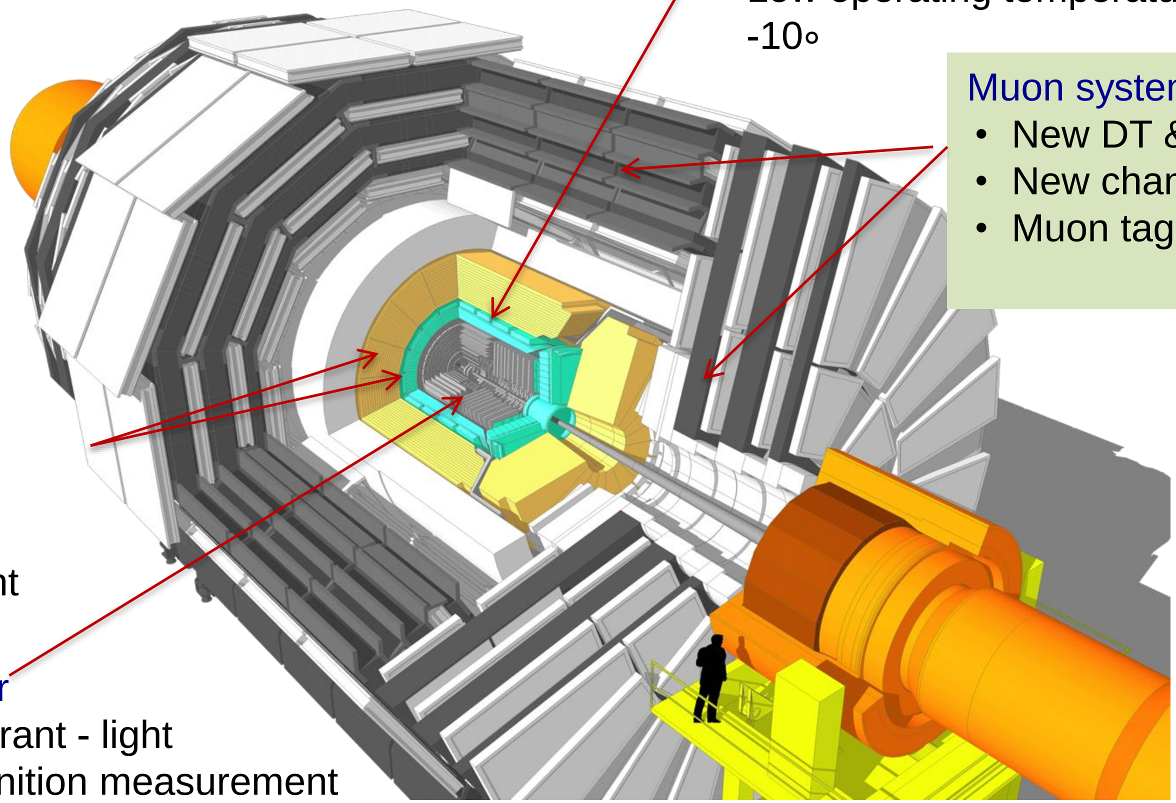
RE3/1 and RE4/1 stations: double-layer RPC units

CMS Phase-II upgrades

Trigger/HLT/DAQ
- Track information in hardware event selection
- 750 kHz hardware event selection
- 7.5 kHz events registered

Barrel EM calorimeter
- New electronics
- Low operating temperature ≃ -10◦

Muon systems
- New DT & CSC electronics
- New chambers 1.6 < η < 2.4
- Muon tagging 2.4 < η < 3



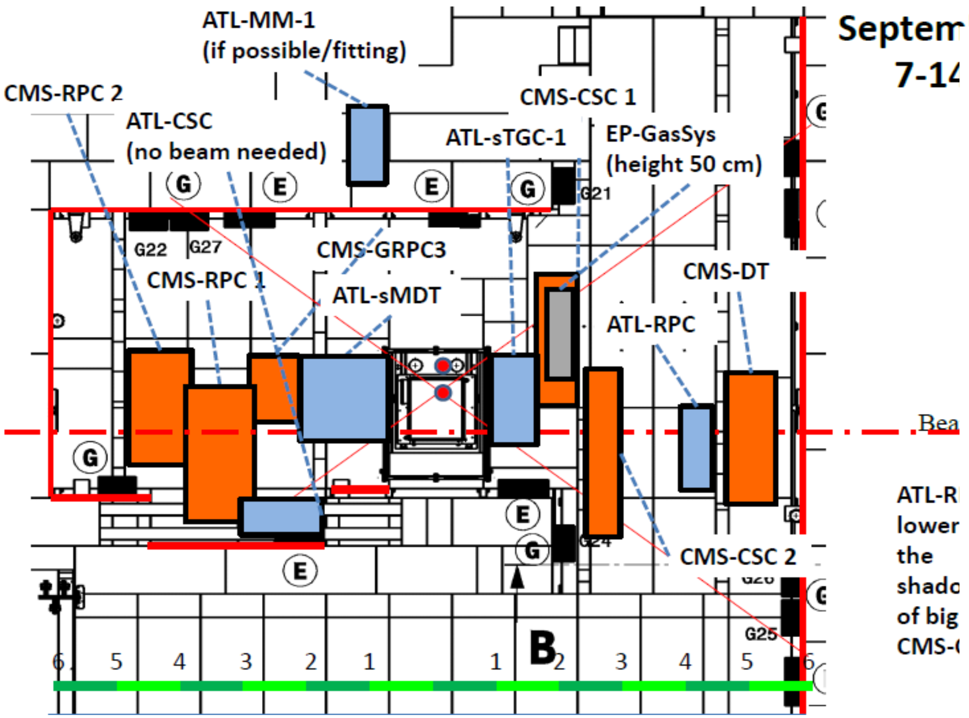
New Endcap Calorimeters
- Rad. Tolerant
- 5D measurement

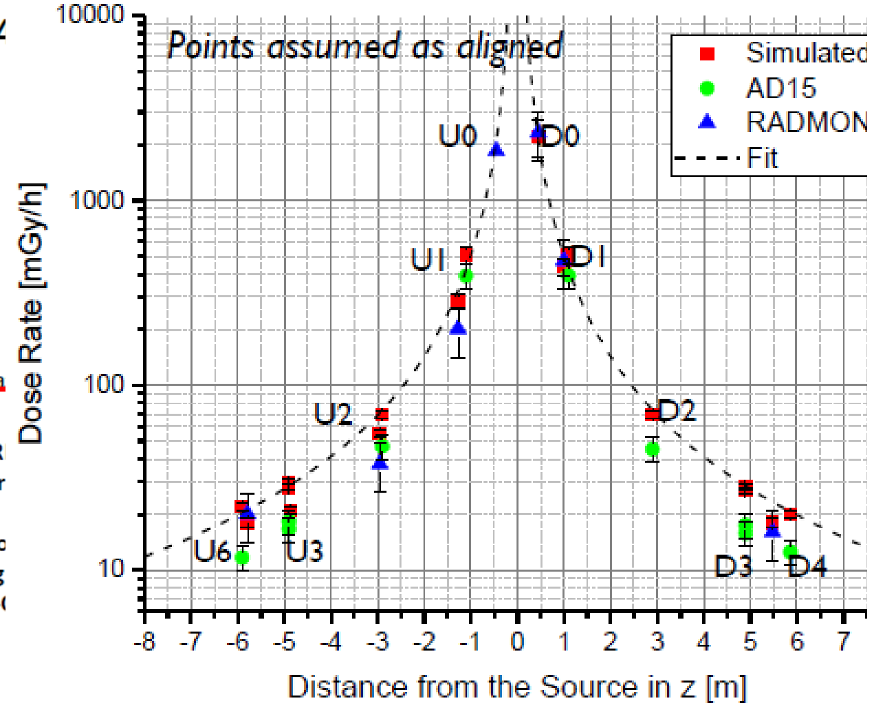
New Tracker
- Rad. Tolerant - light
- High Definition measurement
- 40 MHz selective readout for hardware trigger
- Extended Pixel coverage to η ≃ 3.8

Beam radiation and luminosity

Common systems and infrastructure

Detectors at GIF++





R. Guida. Setups position and schedule for next test beam. https://indico.cern.ch/event/566910/

10 permanent GIF++ users, new requests for longevity tests and RadHardness tests are coming

GIF++ radiation measurements Att. Factor=1 (Dose rate vs distance from the Source)

G. Gorine, GIF++ RADIATION ENVIRONMENT https://indico.cern.ch/event/517100