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

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

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

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

**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

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

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

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Muons 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%
New HL LHC parameters require detector upgrade in LS2 and LS3
– 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

Enhancement of the forward region 1.6<|\eta|<2.4:
- improved RPC (iRPC)
- GEM detectors (GE1/1, GE2/1)

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

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”
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 $\text{TBq} \; \text{Cs}^{137}$ source ($E_\gamma = 662 \; \text{keV}$)
- Att, Factor: $(1 \div 46000)$
- Upstream + Downstream 100m2 irradiation zone

GEM and CSC observed no ageing effects at doses equivalent to 3 HL LHC periods = 3x accumulated charge with $3000\text{fb}^{-1}$. 
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% CF₄ (GWP=6500): 274 m³/hr of CO2 equivalent
• RPCs use 95.2% C₂H₂F₄ (GWP=2300): 228 m³/hr and 0.3% SF₆ (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 CF₃I, C₃H₂F₄ (GWP ≈ 0.4)
– F-gas consumption reduction → CSCs explore operation with 2% CF₄
– 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.

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 m$^2$**

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

Overall area: **90 m$^2$**
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 \( \approx -10^\circ \)

Muon systems
- New DT & CSC electronics
- New chambers \( 1.6 < \eta < 2.4 \)
- Muon tagging \( 2.4 < \eta < 3 \)

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 \( \eta \approx 3.8 \)

Beam radiation and luminosity
Common systems and infrastructure
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)

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https://indico.cern.ch/event/517100