Future of the CMS Muon Systems

Upgrades and Aging

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Introduction

- LHC and experiments have been performing incredibly well
  - Record luminosities
    \(1.25 \times 10^{34} \text{ Hz/cm}^2\text{s}\)

- While we have had the last major jump in collision energy, the instantaneous luminosity is expected to increase by at least a factor of 5 in the future
  - HL-LHC expects \(5–7 \times 10^{34} \text{ Hz/cm}^2\)

- Several upgrade projects on the horizon to maintain efficiency to physics processes in those conditions
  - Higher backgrounds (~140 pileup!)

- This talk will focus on the `Phase II’ upgrade projects for the CMS muon systems

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LHC / HL-LHC Plan

[Diagram showing timeline and luminosity milestones]

- **LHC**
  - Run 1
  - Run 2
  - Run 3

- **HL-LHC**
  - Run 4 - 5

- **LS1**
  - Splice consolidation button collimators R2E project
  - Luminosity: \(7 \times 10^{33} \text{ Hz/cm}^2\)

- **LS2**
  - Injector upgrade cryo Point 4 DS collimation P3-P7(11 T dip.) Civil Eng. P1-P5
  - Experiment upgrade phase 1
  - Luminosity: \(1 \times 10^{34}\)

- **LS3**
  - HL-LHC installation
  - Experiment upgrade phase 2
  - Luminosity: \(2 \times 10^{34}\)

- **LS4**
  - Experiment upgrade phase 3
  - Luminosity: \(7.5 \times 10^{34}\)

- **Run Times**
  - Run 1: 2011 - 2012
  - Run 2: 2013 - 2018
  - Run 3: 2019 - 2025
  - Run 4: 2024 - 2026
  - Run 5: 2027 - 2037

- **Integrals**
  - 30 fb\(^{-1}\) (30 fb\(^{-1}\))
  - 150 fb\(^{-1}\) (150 fb\(^{-1}\))
  - 300 fb\(^{-1}\) (300 fb\(^{-1}\))
  - 3000 fb\(^{-1}\) (3000 fb\(^{-1}\))
Three separate technologies currently in use
Three separate technologies currently in use:

- Drift Tubes (DT)
- Resistive Plate Chambers (RPC)
- Cathode Strip Chambers (CSC)
Muons are efficiently taking high-quality data!
Phase II Upgrade Strategy

- Ensure detector longevity
  - Electronics and chamber operation

- Increase redundancy
  - Add layers in \(1.5 < |\eta| < 2.4\), currently CSC coverage only

- Mitigate rate increases
  - Changes to readout electronics
  - New improved detectors for better discrimination of backgrounds
  - Adopt new trigger strategies

- Retain sensitivity to physics processes
  - Maintain reasonable trigger thresholds
  - Add forward coverage to \(|\eta|\) of 2.8
Upgrades of Existing Detectors
CSC Detectors

- Cathode strip chambers used in the endcap sections of CMS
- Current electronics for readout cannot sustain the planned trigger rates and latency
  - Analog pipelines fill up → data loss
- Proposal to replace by digital readout boards for stations MEEx/1
  - $1.6 < |\eta| < 2.4$
  - 108 chambers x 5 boards
  - Improved memory depth
  - Fast optical links

![CSC Detector Image]

![Graph Image]

HL-LHC
DT Detectors

- Detectors expected to operate for the HL-LHC data-taking up to 3000 fb\(^{-1}\)
  - Conservative estimate of 6.3% efficiency loss
  - Can be mitigated further by HV setting changes, e.g.

- Changes to electronics needed to maintain performance
  - Move part of readout chain off-chamber
    - Implemented through fast optical links
  - Improved time resolution from 12.5 ns to 3 ns, factor of 4 reduction in deadtime

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**Failure rates after 10 yrs @ HL-LHC**

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<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifetime of the tubes</td>
<td>1%</td>
</tr>
<tr>
<td>FEB failure rate</td>
<td>2.8%</td>
</tr>
<tr>
<td>HVB failure rate</td>
<td>1.5%</td>
</tr>
<tr>
<td>Lower efficiency due to radiation</td>
<td>1%</td>
</tr>
</tbody>
</table>

**Total chamber efficiency loss** 6.3%

GBT Project Details: [https://cds.cern.ch/record/1235836](https://cds.cern.ch/record/1235836)
New Forward Detectors
Phase II Scenario

- New detectors to be installed
- GEM detectors — GE1/1, GE2/1
- Improved RPC chambers — RE3/1, RE4/1
- Forward muon tagger — ME0

![Diagram showing new detectors and their locations]
GEM Detectors

- Gas electron multiplier detectors new technology for CMS
  - 2 layers of triple-foil GEM chambers to be installed in front of existing CSC-ME1/1 chambers
  - Covers $1.6 < |\eta| < 2.2$

- Signals to be used in conjunction with CSC trigger primitives
  - See slides from J. Ruiz Alvarez for details on DAQ and control systems (4 Aug, 16:15)
GEM Detectors

- Addition of GE1/1 reduces trigger rate by factor of 2-4 or more
  - Bending angle between GE1/1 and CSC-ME1/1 chambers used for discrimination
  - Retain efficiency for physics processes

- GE1/1 scheduled for LS2 and GE2/1 for LS3 or sooner
RPC Detectors

- Resistive plate chambers currently in use in both the barrel and endcap regions of CMS
  - Existing detectors can cope with rates through HL-LHC period
- Addition of rings RE3/1 and RE4/1 restores redundancy in forward region
  - $1.6 < |\eta| < 2.4$
  - Improved chamber design
  - Option considered for timing resolution of $\sim 100$ ps → mitigate rate increases from neutron background
- High rate capability needed!
  - Can perform with particle rates up to $2 \text{ kHz/cm}^2$
ME0 Forward Muon Tagger

- With the new forward calorimetry (HGCAL), space is freed behind for additional instrumentation
  - 6 successive GEM triple-foil chambers
    - Shielding surrounding active elements

- Increases muon coverage and trigger capability
  - Also provides neutron background discrimination

- Efficiency of ~90% for muon identification up to $|\eta| < 2.8$ and $p_T > 5$ GeV
Summary

- Plans for upgrades of the CMS muon systems are well underway!
  - **Improvements** to electronics of existing detectors
  - **New high-rate, rad-hard detectors** in forward regions

- Maintain operation through 10 yr HL-LHC operation with **high efficiency**!
  - More information available in CMS Phase II Technical Proposal [1]
    - Many talks/posters here at ICHEP also!

[1] https://cds.cern.ch/record/2020886
Backup Material

References:

Technical Proposal for the Phase-II Upgrade of the CMS Detector
https://cds.cern.ch/record/2020886

CMS Technical Design Report for the Muon Endcap GEM Upgrade
https://cds.cern.ch/record/2021453
Aging Scenarios

- Assuming some degradation in chamber operation, system loses reconstruction efficiency without upgraded detectors
  - Degradation of CSC, RPC segments/hits included

- With upgrades, ~90% efficiency is maintained due to increased redundancy

- Note: DT aging scenarios not accounted for