Background in the CMS muon detectors: simulation and measure with pp collision data

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IPRD2019:
15th Topical Seminar on
Innovative Particle and Radiation Detectors
14-17 Oct 2019, Siena (Italy)
The CMS Muon Spectrometer

**New Detectors:**
- **GEM:** 72 Chambers $1.6 < |\eta| < 2.8$
- **iRPC:** 18 Chambers $1.8 < |\eta| < 2.4$
- **DT:** 250 Chambers $|\eta| < 1.2$
- **RPC:** 480 Chambers Barrel, 576 Chambers EndCap $|\eta| < 1.9$
- **CSC:** 540 Chambers $0.9 < |\eta| < 2.4$

**Actual System:**

**DT:**
- 250 Chambers
- $|\eta| < 1.2$

**RPC:**
- 480 Chambers Barrel
- 576 Chambers EndCap
- $|\eta| < 1.9$

**CSC:**
- 540 Chambers
- $0.9 < |\eta| < 2.4$

**Diagram Details:**
- The CMS Muon Spectrometer layout with regions labeled.
- DT chambers in the barrel, RPCs in the endcap.
- CSC stations in each endcap, MB1–MB4 and RB1–RB4.
- Chamber numbering by station and ring.

**Figure 6.10:** Scanning Electron Microscope (SEM) picture of a GEM foil (left) and schematic view (right) of the electric field lines (white), electron flow (blue), and ion flow (purple) through a GEM foil.

**Figure 5.10:** Chamber position using the label $R_f n/m$, where $n$ is the station (increasing with $R$) and $m$ is the ring (increasing with $Z$).

**Table 5.3:** Breakdown of the number of components of the new RPC system (chamber, electronics, boards, cables and power supplies).

**Figure 5.16:** Schematic view of a front-end board and on-chamber connection cables.

**Figure 5.17:** Double-gap RPC chambers with gap thicknesses ranging between 1.0 and 2.0 mm.
Background in the Muon Detectors

- The different types of detectors have been chosen to withstand different particle fluxes

- **Main sources of background:**
  - **Punch through hadrons** from the inner detectors and muons from machine background
    - low rate but main concern in segment reconstruction
  - **Neutrons** from showers or from the leaks in the forward shielding
    - large effect on the detector longevity
  - **Photons** produced in de-excitation of nuclei
    - nuclei excitation via capture of low energy neutrons
    - main source of background hits
Background Study

The high rates expected at the HL-LHC are a **challenge** for muon detectors

<table>
<thead>
<tr>
<th></th>
<th>LHC design</th>
<th>HL-LHC design</th>
<th>HL-LHC ultimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>peak luminosity (10^{34} cm^{-2}s^{-1})</td>
<td>1.0</td>
<td>5.0</td>
<td>7.5</td>
</tr>
<tr>
<td>integrated luminosity (fb^{-1})</td>
<td>300</td>
<td>3000</td>
<td>4000</td>
</tr>
<tr>
<td>number of pileup events</td>
<td>~30</td>
<td>~140</td>
<td>~200</td>
</tr>
</tbody>
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- **Main source of concern:**
  - background hits may spoil efficiency of trigger, hit detection and segment reconstruction
  - background hits may spoil the space and time resolutions
  - background segments may affect the muon reconstruction
  - charge accumulation may cause early detector ageing

- **Main study tools:**
  - Measured **hit rates** and **currents** dependence on instantaneous luminosity.
    - Hit rates determined at the lower level in each detector
    - Currents measured by the used HV modules
  - Simulation studies
  - Studies at test facilities (CHARM, GIF++)
Simulation of Background

FLUKA is used to simulate pp primary interactions and particle transport and to estimate the expected fluxes.

Large background levels in the external station due to “neutron cloud” in the experimental cavern.
**RPC and DT Barrel Measurements**

**RPC Station Rates vs Luminosity**

- Linear dependence of Hit Rates vs Instantaneous Luminosity
- Similar rate between the more internal and external station external stations
- Hot points in the DT MB1 chambers in the external wheels linked to the gap in the calorimeters
- Background in MB4 is not $\phi$-symmetric $\Rightarrow$ it affects more the top of the detector.
RPC and CSC EndCap Measurements

- The most exposed chambers are the one more far from the interaction point
- In the Endcap small $\Phi$-asymmetry
- Linear dependence of hit rates and currents on the instantaneous luminosity for every detector in all the range in Run2
Detector Sensitivities

- The Sensitivity of the detector is needed to convert simulated fluxes to Hit Rates
  - defined as the probability for a background particle to create a signal:
    \[ S = \frac{N_{\text{signals}}}{N_{\text{incident particles}}} \]
  - computed as a function of the energy of the incident particle for different kinds of particles using GEANT4

\[ \sum \Delta(\frac{df}{dE}) \times \text{norm}(R) = \text{flux} \times \text{norm}(R) \quad \text{flux} @ 1.5 \times 10^{34}\text{cm}^{-2}\text{s}^{-1} \]
• Good agreement between the experimentally obtained results and MC predicted ones!
• Validation on data give confidence on the use of simulation for new detectors
Neutron-induced background in CSC

- Study on the impact of increased hit rates at HL-LHC due to fast (~MeV) and thermal neutrons
  - cause of delayed hits due to $\gamma$ emitted by neutron capture
  - expected hit regime evaluated in simulation
  - delayed hits measured in data using the structure of the LHC bunches
  - results compared to specially modified GEANT4 simulation
  - For all CSCs at various rand z positions, simulation reproduces data to within a factor of 2
HL-LHC Extrapolation

- Linearity of Currents and Hit Rates ➔ extrapolation to HL-LHC conditions from measured data
- Together with simulation clear picture of HL-LHC conditions
  - important for new detector developments
  - evaluation of the intervention on existing detectors
Background and Ageing

- GIF++ used to certify existing and new detectors at the extrapolated HL-LHC conditions
- $^{137}$Cs source, intensity 14 TBq, emitting 662 keV photons, plus a high momentum muon beam (100 GeV)
  - **realistic environment:** neutron-induced photons have an energy in the range 0.1–10 MeV.
  - long period of irradiation to study ageing
  - allows detector performance studies with a high momentum muon beam (100 GeV) in the presence of high radiation

Chambers under test:
- CSCs: 1 ME1/1 and 1 ME2/1
- DTs: 1 MB1, 1 MB2
- GEMs: 1 GE1/1, 1 GE2/1
- RPCs: 1 RE2, 1 RE4, 1 iRPC large prototype
GIF++ results

DT:
- Strong evidence of ageing!

CSC:
- Total integrated charge of 330 (ME1/1) and 340 (ME2/1) mC/cm²
- No noticeable gas gain loss up to $3 \times$ HL-LHC

RPC:
- No noticeable effects of detector degradation up to $\sim 600$ mC/cm²
- Longevity tests also on large size prototype of iRPC
  - main parameters are stable so far
- Tests are ongoing

GEM:
- No ageing observed
Background Mitigation: Forward Shielding

- Leakage in the forward shielding is one of the main sources of background in the experimental cavern.
- Additional shielding has been installed in the Christmas break between 2016 and 2017.
- Obtained a reduction in the currents and hit rates of the most exposed chambers.
- Improvements in the forward shielding are planned during LS2.

Comparison of the 2017 and 2016 hit rates/currents for the RE4/S10 chambers (hottest sector in both positive and negative sides) as a function of the instantaneous luminosity. The effect of the RS-shielding is observed in the reduction of 2017 measured hit rates and currents in RE4/S10 hottest chamber.
Background Mitigation: Barrel Shielding

- Results at GIF++ have shown the risk of **fast ageing** for DT due to depositions on the wires.
- A shielding is being installed in LS2 on the top of the detector to reduce neutron induced charge production.
- **Different prototypes tested in Run2**
  - Final design uses Borated Polyethylene (BPE) to attenuate and absorb neutron radiation plus lead for photons.
  - HV currents halved with **3cm BPE + 7mm of lead** on a single chamber.

![Diagram showing 9 cm BPE + 7mm Lead and 3 cm BPE + 7mm Lead installations.](image-url)
Conclusions

- Extensive program of **measurements on the radiation background** in the CMS Muon system during LHC operations.
- **Simulation**, using FLUKA for flux and dose estimation, and GEANT4 for sensitivity studies, well describes the data.
- Longevity tests being performed at the CERN GIF++ facility show **no evidence of ageing effects** for most of the Muon detectors, **except for the DT**.
- **Improvements on the shielding** are ongoing during LS2 in order to reduce the large background coming from neutrons in the CMS experimental cavern.

- Detailed description of **expected radiation background**.
- Essential an input for
  - future operations
  - new detector design

- Public results at: https://twiki.cern.ch/twiki/bin/view/CMSPublic/MuonDPGResults
- Muon Upgrade TDR: https://cds.cern.ch/record/2283189