

## Motivation of the CMS Muon System Upgrade with Triple-GEM detectors

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### Abstract

The CMS collaboration considers upgrading the muon detector in the forward region using a technology of Gas Electron Multiplier (GEM) chambers, which are able to handle the extreme particle rates expected in this region along with a high spatial resolution. This allows to improve tracking and triggering capabilities, resulting in a lower trigger threshold along with redundant muon identification. The contribution will review the status of the GEM project at CMS.

**Keywords:** GEM, CMS, Muon detectors, Upgrade

### 1. Introduction

The CMS muon detector system [1], as shown in Figure 1, consists of three types of muon detectors: Drift Tubes (DTs) and Cathode Strip Chambers (CSCs) in the barrel and endcaps respectively, Resistive Plate Chambers (RPCs) in both the barrel and the endcaps. It provide robust, redundant and efficient identification and reconstruction of the muons, in addition to trigger capabilities.

After the ongoing first LHC Long Shutdown (LS1), for  $\eta > 1.6$  the CMS muon identification will rely entirely on the CSC system whose trigger efficiency could degrade as LHC luminosity will increase in the future years. The short lever arm to measure the bending angle in each station affects the muon momentum determination and many low- $p_T$  muons that undergo multiple scattering in the muon system and the iron return yoke are misidentified as high- $p_T$  tracks, leading to a flattening of the muon trigger rate towards high momenta. The presence of additional detector layers in that region could maintain a highly efficient muon trigger with a low  $p_T$  threshold and improve the muon reconstruction

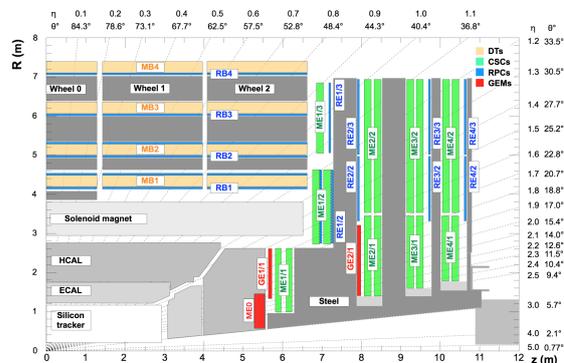


Figure 1: Quadrant of the CMS detector showing the present muon system including RPCs, DTs and CSCs. The proposed locations for the GEM detectors in the inner endcap stations are indicated by the red boxes (ME0, GE1/1, and GE2/1).

by measuring the muon bending angle between CSCs and this new detector.

### 2. The CMS-GEM Project

The CMS GEM Collaboration proposed Gas Electron Multipliers (GEMs) [2] to upgrade the muon system, instrumenting the non-redundant CMS high- $\eta$  region [3]

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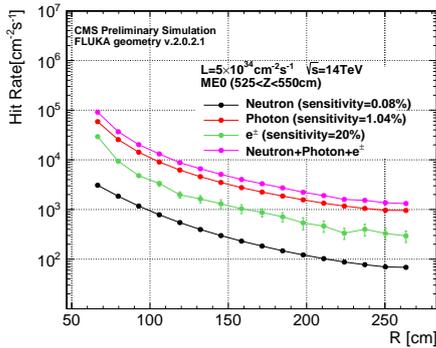


Figure 2: Background rates, normalized to  $5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ , evaluated combining particle fluxes simulated with FLUKA and detector sensitivities (GEANT4 simulation) for ME0 station.

with detectors that could withstand the hostile environment and high luminosity rates at the LHC upgrade.

The first two muon stations will be equipped with GEM detectors denoted GE1/1 and GE2/1 that each contain two high-precision measurement layers. These increase the path length within each station to 28–55 cm, versus 11 – 15 cm provided by the CSC alone.

With pixel tracking extension close to  $|\eta| = 4$  and the replacement of the endcap calorimeters for Phase II, comes the opportunity to extend the muon coverage beyond the present limit of  $|\eta| < 2.4$  with the addition of a small but precise muon detector installed at the back of the more compact calorimeters. This detector, as shown in Figure 1, is denoted ME0. The extended muon coverage should increase the acceptance for all final states with muons, especially multiple-muon states.

### 2.1. The GEM technology

The GEM detector is a thin metal-coated polymer foil perforated with a high density of holes, each hole acting as multiplication region. Triple-GEM detectors, made with three GEM foils in cascade, ensure high gains and safe operation at low voltage. The GEM technology features high spatial resolution ( $\sim 100\mu\text{m}$ ) and a time resolution of  $\sim 4 \text{ ns}$  and is easily able to handle the background hit rates that are expected in this region with detection efficiencies above 98 % [4].

### 2.2. Background nature and rates

Background radiation in the muon system arises from low-energy gamma rays and neutrons from p-p collisions, low-momentum primary and secondary muons, punch-through hadrons from the calorimeters.

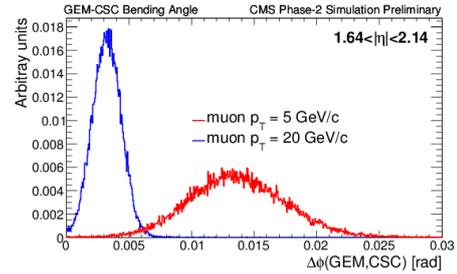


Figure 3: Comparison of GEM-CSC bending angle distributions measured between GE1/1 and ME1/1 stations for muons with low  $p_T$  (5 GeV) and high  $p_T$  (20 GeV) for a lever arm equal to 46 cm.

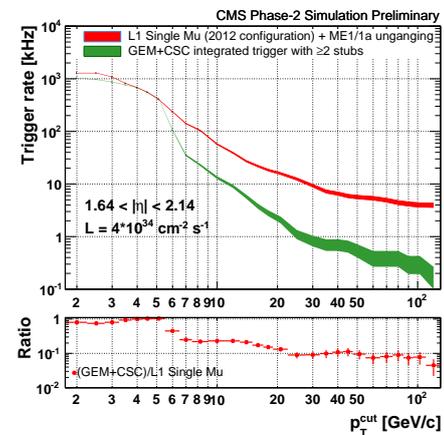


Figure 4: Comparison of the trigger rate for the Global Muon Trigger in the 2012 configuration with reconstructed trigger hits (stubs) in at least 2 CSC stations and the configuration with at least 2 stubs in the CSCs and a GEM signal. The bottom panel shows the ratio of the two configurations.

At the HL-LHC center-of-mass energy of 14 TeV and leveled luminosity of  $5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ , the highest estimated background rate (innermost ME1/1 region) is  $\sim 4.5 \text{ kHz/cm}^2$ , as shown in Figure 2.

## 3. Impact on trigger

The installation of the GEMs is aimed at reduce the trigger rate in the region which currently suffering from the highest background rates and a non-uniform magnetic field. This trigger rate reduction could be possible with the improved momentum resolution deriving from precision measurements of the bending angle performed measuring the lever arm between the existing CSC chambers in stations ME1/1 and the triple GEM detectors in new GE1/1 station. Figure 3 shows the comparison of GEM-CSC bending angle distribution for muons with  $p_T$  equal to 5 GeV and 20 GeV,

for a lever arm equal to 46 cm and demonstrate that the bending angle measurement could be used in the trigger to discriminate high-momentum muons from low-momentum muons.

The better discrimination of high transverse momentum muon candidates could allow, as shown in Figure 4, the trigger rate reduction. Results in the region  $1.6 < |\eta| < 2.1$  obtained with GE1/1-ME1/1 combined informations are compared with the standard CMS configuration used in 2012 (red line) modified to account for the improved ME1/1 detector electronics to be installed in LS1. In the simplified scenarios shown, the tracks satisfy the requirement of having reconstructed trigger hits in at least two stations out of four possible. The plots demonstrate the increased dynamic range foreseen for optimizing the muon trigger due to the addition of the bending angle.

#### 4. Summary and outlook

The CMS GEM collaboration has proposed, for the upgrade of the CMS muon forward system, to install three new stations: the GE1/1 and GE2/1 stations in the  $1.5 < |\eta| < 2.4$  region of the first and second endcap disks respectively will add redundancy to the system and will improve its trigger and tracking capabilities; the ME0 station at the back of the rebuild endcap calorimeter will extend the reach of the muon system to  $|\eta| \sim 3$ .

Many feasibilities and performance studies have been performed and after 5 years of R&D, the design and characterization of the CMS triple-GEM chambers is now close to final. The CMS collaboration approved the installation during the 2016 LHC Year End Technical Stop of a demonstrator system that will allow to gain operational and integration experience. In the presently proposed schedule, the GE1/1 stations would be installed during the second LHC Long Shutdown in 2017-2018, while the installation of the other two stations (GE2/1 and ME0) would be done during the third LHC Long Shutdown scheduled beyond 2022.

#### 5. Acknowledgement

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