Physics Studies for the CMS muon system upgrade with triple-GEM detectors

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Physics Studies for the CMS muon system upgrade with triple-GEM detectors

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ABSTRACT: The CMS collaboration considers upgrading the muon forward region with 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 combine tracking and triggering capabilities, resulting in a lower trigger threshold along with improved muon identification and track reconstruction. In the last year the GEM project took a major leap forward by integrating triple-GEM chambers in the official CMS software, allowing physics studies to be carried out. Several benchmark analyses have been studied for the impact of such detector upgrade on the physics performance. In this contribution the status of the CMS upgrade project with the usage of GEM detector will be reviewed, discussing the trigger, the muon reconstruction performance, and the impact on the physics analyses.

KEYWORDS: Gaseous detectors; Micropattern gaseous detectors (MSGC, GEM, THGEM, RETHGEM, MHSP, MICROPIC, MICROMEGAS, InGrid, etc)

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1 Introduction

The CMS muon system [1] is designed to provide robust, redundant and fast identification of the muons traversing the system, in addition to trigger capabilities and momentum measurement. Precision measurements are provided by Drift Tubes (DT) in the barrel, covering acceptances up to $|\eta| < 1.2$, and Cathode Strip Chambers (CSC) in the endcaps covering $1.0 < |\eta| < 2.4$. Resistive Plate Chambers (RPC) cover the region up to $|\eta| < 1.6$. The region $|\eta| > 1.6$ is only instrumented with CSC. One of the main goals during the upgrade phases will be to restore the originally foreseen redundancy in the forward region beyond $\eta > 1.6$ based on modern, high-resolution and fast gas detectors capable of fully exploiting the increased LHC performance [2], and sustaining reliable operation for the next decades.

Such detectors have to satisfy a high rate capability, $O(\mathrm{MHz/cm^2})$, a good time resolution for triggering, and a good spatial resolution, $O(100\mu\mathrm{m})$, for tracking. The current CMS RPC design is not able to sustain the high rates expected during the next phases of LHC. However, there are various solutions in the field of micro-pattern gaseous detectors (MPGDs), the gaseous electron multipliers (GEMs) [3].

2 The CMS GEM project

The baseline of the CMS GEM project is the installation of 36 double-layered triple-GEM chambers in front of the ME1/1 station during LS2, called the GE1/1 system [4]. The chambers will provide full coverage in ϕ and $1.55 < |\eta| < 2.18$ in pseudo-rapidity. The odd-numbered GE1/1 chambers will be slightly larger to maximize coverage in $|\eta|$. The station 2 upgrade (GE2/1) consists of installing two rings of double-layered triple-GEM chambers covering up to $1.6 < |\eta| < 2.45$ during LS3. Each GE2/1 chamber spans about 20 degrees in ϕ. Finally, a muon near-tagger (ME0) with 18 six-layered triple-GEMs, with each chamber providing coverage of 20 degrees in ϕ and

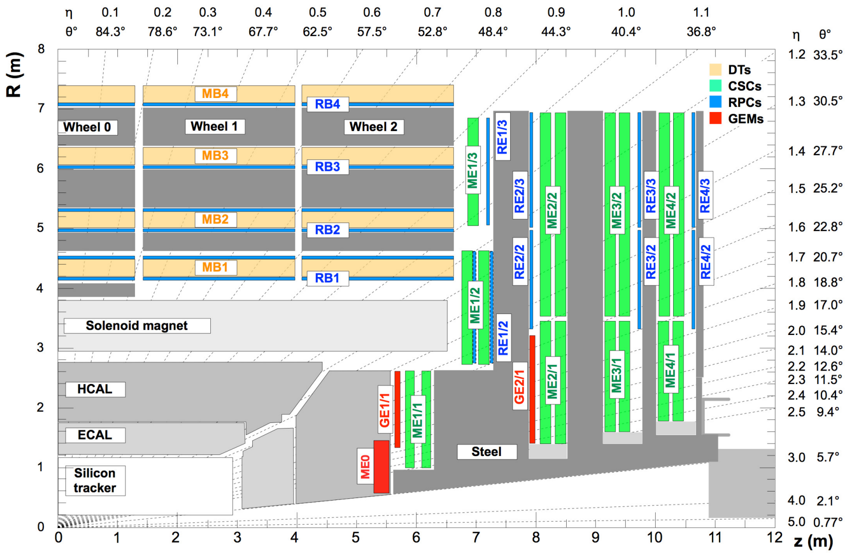

Figure 1. Transverse section of CMS showing the Muon system with DTs, CSCs and RPCs. The proposed GEM stations, GE1/1, GE2/1 and ME0 are given by the red boxes.

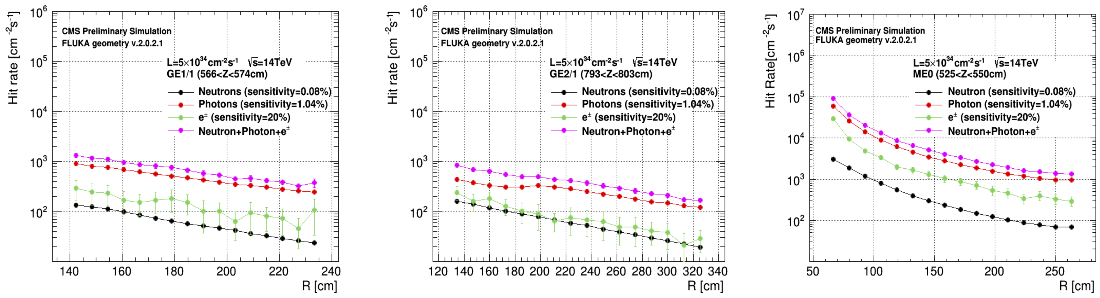

Figure 2. Background rates simulated with FLUKA+GEANT4 for (from left to right) GE1/1, GE2/1 and ME0. Rates expected in each chamber normalized to $5 \times 10^{34}\mathrm{Hz/cm^2}$.

$2.0 < |\eta| < 3$ in pseudo-rapidity, behind the future shortened hadron calorimeter (after LS3). The geometry of both GE2/1 and ME0 is yet to be finalized. The location of the proposed GE1/1, GE2/1 and ME0 in the present CMS Muon system is shown in figure 1.

The detectors will have to sustain a background rate of $O(10^5\mathrm{kHz/cm^2})$, as can be see from the simulation in figure 2, however they are designed to withstand up to $O(\mathrm{MHz/cm^2})$.

3 CMS GEM prototypes

In many years of R&D at CERN, we have made the production of large scale areas ($\sim 0.5\mathrm{m}^2$) cost-effective, enabling the design and testing of CMS-scale prototypes. Six GEM prototypes have been developed since 2009. The first large GEM prototype, GE1/1-I, had all components glued together, had spacers and 8 readout sectors. This number of was increased to 24 in GE1/1-II. GE1/1-III was the first type to make use of the manual stretching technique, that thanks to o-rings and screws on a plastic (FR4) frame attached to the GEM foil allows to adjust the tension accordingly. This technique introduce a new way to stretch the foils and assembly a chamber without spacer and glue,

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reducing assembly time and allowing a fast and easy repair of broken chambers. In addition, the distances of the drift, transfer and induction region were finalized. GE1/1-IV was the first prototype to be fully mechanically constructed and produced at various production sites around the world. The GE1/1-V have an optimized coverage in η and ϕ and have short and long types. The final version GE1/1-VI will have the same features as the V prototype with an optimized coverage in R. The triple-GEMs have shown [5] an excellent spatial and time resolution, $O(100-200\mu\mathrm{m})$ and ~ 5 ns respectively. They have a high efficiency up to 98% and a high rate capability $O(\mathrm{MHz/cm^2})$. In addition, they are radiation hardened and can be operated in a non-flammable gas mixture of $Ar/CO_2/CF_4$ (45/15/40), which makes GEMs ideal material for a triggering-tracking detector.

A slice test will take place during the Year-End Technical Stop of 2016-2017. A small number of fully working GE1/1 chambers will be installed in both endcaps with a total coverage of 40 degrees each. In preparation of the slice test, two sets of dummy chambers were produced (no detector and no electronics inside, same weight and dimensions as a real super chamber). Two trial installations, one in Summer 2013 and one in March 2014 (short and long chambers), have taken place with excellent results.

4 Impact on the muon trigger

4.1 GEM-CSC bending angle

The expected increase of the LHC beam instantaneous luminosity from the design luminosity of $10^{34}\mathrm{cm^{-2}s^{-1}}$ up to $5\times10^{34}\mathrm{cm^{-2}s^{-1}}$ in the Phase-II era will have a big impact on the Muon endcap system, in particular the high-η region. Many more soft particles will scatter off elastically in the muon detectors and in particular in the iron return yokes. Low-p_T muons are misinterpreted as high-p_T muons by the CSC Track-Finder, resulting in a flattening of the trigger rate curve at high-p_T. The installation of an additional muon detector (GEM) either can measures the bending angle in station 1, thanks to the "lever arm" between GEM and CSC. It is possible to use the GE1/1-ME1/1 bending angle to achieve a clear separation between soft ($p_T \sim 5\,\mathrm{GeV/c}$) and hard muons ($p_T > 20\,\mathrm{GeV/c}$) as can be see in figure 3.

4.2 Trigger rate

We can exploit the delta phi separation power of the new system GEM+CSC in the L1 trigger. Combining the CSC trigger with the information taken from the GEM, it is possible to obtain a better discrimination power for high momentum and lower the p_T threshold. The GEM-CSC local trigger based on soft stub rejection shows that a rate reduction of a factor 10 can be achieved, see figure 3. Considerably lower fake contributions reduce the trigger rate which allows to lower the trigger threshold. For some physics channels a trigger threshold of about 15 GeV nearly doubles the sensitivity. With the lower rate achieved by the GEM+CSC system, such threshold could be taken into account.

5 Conclusions and outlook

Triple-GEM detectors installation in the CMS high eta region either will allow to improve the muon momentum resolution measuring the bending angle. The detectors will also help to reduce

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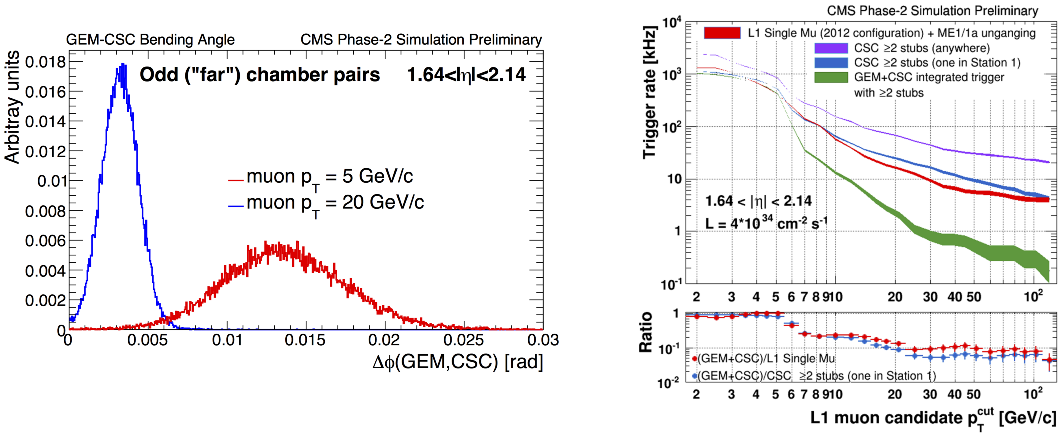

Figure 3. *Left*: GEM-CSC bending angles for soft (5 GeV/c) and hard (20 GeV/c) muons for odd numbered GEM chambers. *Right*: comparison of the trigger rates for the Global Muon Trigger in the 2012 configuration with the CSC Track-Finder track rates for at least 3 stubs (loose), at least 3 stubs with at least one 1 stub from ME1/b (medium), and at least one 3 stubs with at least one 1 stub from ME1/b and a GEM pad (tight). The CSC TF used all patterns. The bottom plot shows the ratio of tight/GMT and tight/medium.

the trigger rate in high luminosity scenarios. Over 5 years of R&D resulted in the validation of performance characteristics, assembly and quality control of triple-GEM detectors for the CMS Muon System upgrade. During the Year-End Technical Stop of 2016-2017, a 40 degrees slices of GEM super chambers will be installed in YE1/1.

Acknowledgments

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