The Compact Muon Solenoid Experiment

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Test beam studies of Gas Electron Multiplier (GEM) detectors for the upgrade of CMS endcap muon system

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Abstract

The High Luminosity LHC (HL-LHC) will provide exceptional high instantaneous and integrated luminosity. The forward region $|\eta| \geq 1.5$ of the CMS detector will face extremely high particle rates in tens of KHz/cm^2 and hence it will affect the momentum resolution and longevity of the muon detectors. To overcome these issues the CMS collaboration has decided to install new large size rate capable Triple Gas Electron Multiplier (GEM) detectors in the forward region of CMS muon system. The first set of Triple GEM detectors will be installed in the GE1/1 region ($1.5 \leq \eta \leq 2.2$) of muon endcap during the LS2 of the LHC and the next one will be installed in the GE2/1 region ($1.6 \leq \eta \leq 2.5$), during the LS3. Towards this goal, full-size CMS Triple GEM prototype chambers have been fabricated and put under the test beam at the CERN SPS test beam facility. The GEM detectors were operated with two gas mixtures Ar/CO_2 (70/30) and $Ar/CO_2/CF_4$ (40/15/45). In 2014 and 2016, good quality data was collected during test beam campaigns. In this talk, the performance of the detectors will be summarised based on their tracking efficiency, time resolution, space resolution, cluster size, etc.

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Test beam studies of Gas Electron Multiplier (GEM) detectors for the upgrade of CMS endcap muon system

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Abstract. The High Luminosity LHC (HL-LHC) will provide exceptional high instantaneous and integrated luminosity. The forward region $|\eta| \geq 1.5$ of the CMS detector will face extremely high particle rates in tens of KHz/cm² and hence it will affect the momentum resolution and longevity of the muon detectors. To overcome these issues the CMS collaboration has decided to install new large size rate capable Triple Gas Electron Multiplier (GEM) detectors in the forward region of CMS muon system. The first set of Triple GEM detectors will be installed in the GE1/1 region ($1.5 \leq \eta \leq 2.2$) of muon endcap during the LS2 of the LHC and the next one will be installed in the GE2/1 region ($1.6 \leq \eta \leq 2.5$), during the LS3. Towards this goal, full-size CMS Triple GEM prototype chambers have been fabricated and put under the test beam at the CERN SPS test beam facility. The GEM detectors were operated with two gas mixtures Ar/CO₂ (70/30) and Ar/CO₂/CF₄ (40/15/45). In 2014, good quality data was collected during test beam campaigns. In this paper, the performance of the detectors will be summarized based on their tracking efficiency, time resolution, etc.

Keywords: CMS, GEM, Gaseous Detector, Test Beam

1 Introduction

CMS[1] is one of the two general-purpose detectors at the CERN, LHC. As the name of detector suggest its Muon identification and reconstruction is important. Currently muon system using three detection technologies: drift tubes, Cathode Strip Chambers (CSCs) and Resistive Plate Chambers (RPCs). The endcap region rely on CSC and RPC for $|\eta| < 1.6$. For higher $\eta > 1.6$, the muon system has limited redundancy and only CSCs are installed. After Long Shutdown (LS2, 2019-2020), when we run at higher luminosity, the particle rate in the forward region is expected to reach several tens of kHz/cm² and the integrated charge will reach several C/cm². So, After LS2, it is not possible to use the RPC in

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region $|\eta| > 1.6$. To overcome this limitations, the CMS-GEM collaboration proposed the Gas Electron Multiplier (GEM)[2] as one of most promising candidate to upgrade the high- η region of the forward muon system. GEM based detectors have demonstrated excellent spatial ($100\mu\text{m}$) and timing resolution ($\sim 5\text{ns}$), and are able to cope with particle rate up to 10 MHz/cm^2 , which make them a promising candidate to complement CSC chambers in high- η region[3]. Therefore, their use in CMS experiment will improve muon momentum resolution for high p_T muon and to provide overall highly efficient muon and trigger tracking capabilities in this region (Fig. 1).

Actually, the GEM foil is an electron amplifier. It consists of a thin metal-clad insulating foil with a high density of holes. By applying a suitable voltage between the two sides, electrons released in the upper gas volume drift into the holes, multiply and transfer to the other side where they can be collected or further amplified.

Fig. 1: GEM-CSC bending angles for soft (5 GeV/c) and hard (20 GeV/c) muons for odd numbered GEM chambers.

Fig. 2: Different $(i\eta, i\phi)$ sectors of full size GE1/1 detector prototype.

Fig. 3: Schematic of the test beam set-up.

2 GE1/1 prototype

The GEM prototype for CMS detector is known as GE1/1[3], where the letter “G” indicates the GEM detector, the letter “E” indicates that this is muon end-cap station, the first “1” indicates that it is part of first muon station encountered by particles from interaction point, and the second “1” indicates that it is first ring of muon chamber going outward in radius from the beam line. It is trapezoidal in shape with active area of $990 \times (220-445)\text{mm}^2$. This size is imposed by the geometry of the vacant high- η area in CMS muon endcap. GE1/1 chamber hosts a Triple-GEM detector with a 3/1/2/1 mm (drift/transfer 1/transfer 2/induction) electrode gap configuration. The detector readout board is divided into eight η -partitions with 384 strips each oriented radially along the long side of the detector with a pitch varying from 0.6mm (short side) to 1.2mm (long side). Each partition is subdivided along the ϕ -coordinate into three readout sectors with 128 strips or channels each. During test beam we scanned three different sectors of GE1/1, i.e. $(i\eta, i\phi) = \{(1,2), (5,2), (8,2)\}$. In Fig. 2 red and yellow color shows which sector of GE1/1's are exposed to the beam. Red sectors are taken with gas $\text{Ar}/\text{CO}_2/\text{CF}_4$ (45/15/40) while yellow sector is taken with gas Ar/CO_2 (70/30).

3 Experimental Setup

The GE1/1 detector were tested using $\sim 150\text{GeV}$ Muon beam at the CERN SPS test beam facility during October-December 2014. The test beam set-up is shown in Fig. 3. The set-up consists of three scintillators, three trackers and a GE1/1 prototype. The trackers are triple-GEM detectors with a $10\times 10\text{ cm}^2$ active area. Each tracker has 256 strips in both horizontal (y-coordinate) and vertical (x-coordinate) directions transverse to the beam. Trackers acts as muon telescope which helps us to reconstruct the tracks and reduce backgrounds. The trigger comes from the coincidence of three photo-multiplier tubes with mounted scintillators. The GE1/1 prototype is installed on a movable table for scanning different sectors.

Fig. 4: Efficiency w.r.t. E_{gain} for two different gases and three different $(i\eta, i\phi)$ sectors.

4 Result & Discussion

Efficiency & time resolution is one of most important parameter for the gaseous detectors. Efficiency is defined as the ratio of events reconstructed by tracker+GEM to the number of events reconstructed by tracker alone. Experimentally, the time resolution is the root mean square of the Gaussian distribution of the time taken by particle to reach detector from scintillator. Here, we also used the fast 40MHz (25ns) clock pulse have been used to cope with the LHC bunch crossing. So, the detector time response is modelled as the Gaussian function convoluted with a square wave having pulse length of 25ns to represent discrete sampling. So, to extract the time resolution we fit the experimental data with the convoluted function. Then from fit we extracted the time time resolution of the detector before convolution.

Finally, we were successfully able to get very good efficiency $\approx 98\%$ and time resolution $\approx 7\text{ns}$ in case of both gas mixture Ar/CO₂ (70/30) and Ar/CO₂/CF₄ (45/15/40). In this test beam campaign it was shown that we can operate GEM detectors without using CF₄, while keeping same efficiency and timing resolution as with gas mixture Ar/CO₂/CF₄.

References

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Fig. 5: Time-resolution w.r.t. E_{drift} for two different gases.