Charged particle detection performance of gas electron multiplier detector for the upgrade of CMS endcap muon system at the CERN LHC

CMS collaboration

Abstract

The CMS detector is one of two general-purpose detectors at the CERN LHC. LHC will provide exceptional high instantaneous and integrated luminosities after second long shutdown. The forward region $|\eta| \geq 1.5$ of the CMS detector will face extremely high particle rates in 10s of kHz/cm$^2$ and hence it will affect the momentum resolution and longevity of the muon detectors. To overcome these issues, the CMS-GEM collaboration has proposed to install new large size high rate capable triple Gas Electron Multiplier (GEM) detectors in the forward region of CMS muon system. The proposal has been approved recently. The first set of Triple GEM detectors will be installed in the GE1/1 region ($1.6 < |\eta| < 2.2$) of muon endcap during phase-II upgrade of the LHC. 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). There were two extensive data taking campaigns during 2014 during which data was collected with GE1/1 detector. Here, the performance of detector such as efficiency and time resolution is reported.
Charged particle detection performance of gas electron multiplier detector for the upgrade of CMS endcap muon system at the CERN LHC

CMS Collaboration
(cms-dpg-conveners-gem@cern.ch)
Gas electron multiplier (GEM) is a micropatterned gaseous detector.

GE1/1 is a triple-GEM detector, i.e. it contains 3 GEM foils, with gap configuration 3/1/2/1 mm for Drift/Transfer 1 /Transfer 2/Induction gaps, respectively as shown in upper left image.

It is going to support muon system in endcap (1.6 < η < 2.2) region of CMS after long shutdown 2.
Test Beam Setup (½)

Beam Details:
● Beam Type: Muon Beam
● Energy: 120-150 GeV

Experimental Setup Consists of Following Detectors:
● **Three scintillators**: Trigger comes from the coincidence of these scintillators.
● **Three trackers**: Used as track reconstruction. It is a triple-GEM detectors having active area of 10×10 cm², with gap configuration 3/2/2/2 mm and 2D readout.
● **GE1/1**: Full size triple-GEM detector (Trapezoidal shape, 990×220-455mm²) with gap configuration 3/1/2/1 mm having only 1D readout..

Gas Used:
● Ar/CO₂ (70/30) and Ar/CO₂/CF₄ (45/15/40)

Electronics Used:
● **Front-end electronics**: VFAT2 Hybrid
  ○ On detector electronics, with digital readout
● **Back-end electronics**: TURBO
  ○ Off detector electronics, designed for small experiments (test beam) only.

Software:
● Data is taken from TURBO data acquisition software
GE1/1 detector is divided into 8 $\eta$ regions and 3 $\Phi$ region.

We scanned three different readout sectors of the GE1/1 detector $(\eta,\Phi) = \{(1,2),(5,2),(8,2)\}$.

In the figure color shows which sectors of GE1/1's are exposed to beam. Red sectors are taken with gas Ar/CO2/CF4 (45/15/40) while yellow section is taken with gas Ar/CO2 (70/30).
Beam Profile Plot

Typical beam profile for tracker 1, 2 and 3 are shown. Trackers are 10x10 cm$^2$ triple GEMs. This shows beam spot of muon beam. Muon beam is reflected in the 3D plot as the maximum particles hit at center of tracker.
Hit position measured by three trackers and GE1/1 (gap configuration: 3/1/2/1 mm) along x. Here hits in all 4 detectors are comparable and showing that beam is around center of detector.

Hit position measured by three trackers along y. No GE1/1 here since it is with only 1d readout along x. Here hits in all 3 trackers are comparable and showing that beam is approximately at center of detector.
Fiducial Region Selection (½)

*caption in next slide*
Fiducial Region Selection (2/2)

**TOP LEFT:** showing two dimensional profile plot of tracker. This shows number of muons reconstructed by fitting linearly the hits found on the three trackers with a normalised $\chi^2 < 10$.

**BOTTOM LEFT:** Number of muons reconstructed fitting the hits found on the three trackers that are also compatible with the hit detected on GE1/1 within 5mm.

**RIGHT:** GE1/1 detection efficiency: number of reconstructed muons leaving a hit in GE1/1 divided by the total number of reconstructed muons (i.e. ratio of the top left and bottom left plots).
Efficiency Curve (½)

Preliminary

GE1/1

Threshold = 1.2 fC
Beam: Muon
Gap Config: 3/1/2/1 mm
Gas: Ar/CO2 (70/30)
\( \{i_\eta,i_\phi\} = \{5,2\}; \sigma_{\text{eff}} \times 4 \)
Gas: Ar/CO2/CF4 (45/15/40)
\( \{i_\eta,i_\phi\} = \{1,2\}; \sigma_{\text{eff}} \times 4 \)
\( \{i_\eta,i_\phi\} = \{5,2\}; \sigma_{\text{eff}} \times 4 \)
\( \{i_\eta,i_\phi\} = \{8,2\}; \sigma_{\text{eff}} \times 4 \)

*caption in next slide
Detection efficiency of the GE1/1 for two gas mixtures at various \((i_\eta,i_\Phi)\) readout sectors as a function of \(E_{\text{gain}}\) is presented. Where \(E_{\text{gain}}\) is the average electric field in the GEM foil and is given as

\[
E_{\text{gain}} = \frac{I \times R_{\text{avg}}^{GEM \text{ gap}}}{D}
\]

\(I\) is current supplied to high voltage divider, \(R_{\text{avg}}^{GEM \text{ gap}}\) is average of gap resistance and \(D\) is the thickness of GEM foil. The efficiency, \(\epsilon\) is given by

\[
\epsilon = \frac{N_{\text{GE1/1+Trk}}}{N_{\text{Trk}}}
\]

where \(N_{\text{Trk}}\) is the number of events, where a track is reconstructed by fitting the tracker hit positions with linear line, \(y=mx+b\), having normalised \(\chi^2 < 10\), and \(N_{\text{GE1/1+Trk}}\) is the number of events where a GE1/1 hit is found within 5mm from the extrapolated track position.

The filled circle series is taken with Ar/CO2 (70/30) gas mixture at \((i_\eta,i_\Phi) = (5,2)\) while the triangle, square, and open circle series are taken with Ar/CO2/CF4 (45/15/40) at \((i_\eta,i_\Phi) = \{(1,2),(5,2),(8,2)\}\), respectively. At a fixed high voltage operating point the effective gain with the Ar/CO2 mixture is approximately one order of magnitude higher than with Ar/CO2/CF4 mixture. As a result the efficiency distribution shown in the closed circle series, obtained with Ar/CO2, is shifted to lower values of \(E_{\text{gain}}\). \(\sigma_{\text{eff}}\) is the efficiency uncertainty and is scaled by a factor of 4 to enhance the visibility.
Time Resolution Plot (½)

Threshold = 1.2 fC
Beam: Muon
Gap Config: 3/1/2/1 mm
Gas: Ar/CO2 (70/30)
{ \eta, \phi } = (5, 2)
Gas: Ar/CO2/CF4 (45/15/40)
{ \eta, \phi } = (5, 2)
Region of efficiency > 95%

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**Time Resolution vs $E_{\text{drift}}$ for different gas mixtures:** time resolution is extracted fitting the experimental data using a gaussian distribution convoluted with piecewise function which models the LHC's 40MHz clock (in order to remove its impact).

The time resolution with Ar/CO2 (70/30) reaches lower values at lower $E_{\text{drift}}$. However, the gain is one order of magnitude higher w.r.t use of Ar/CO2/CF4 (45/15/40). This means faster timing can be achieved at lower gains with the addition of CF4 reducing the discharge probability and so increasing the detector safety.