PROCEEDINGS OF SCIENCE

Characterization of the second generation prototype chamber for ME0 in the endcap muon system for the CMS phase-II upgrade

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The CMS experiment is a general-purpose detector installed in the Large Hadron Collider (LHC) at CERN. During the High Luminosity LHC phase, the luminosity is expected to increase by a factor of 10 compared to the LHC design value. The forward region of the CMS muon system will be equipped with 3 additional triple GEM-based muon stations, where GEM stands for Gas Electron Multiplier. The three stations, in order of distance from the interaction point, are called ME0, GE1/1, and GE2/1. The ME0 station, where ME stands for Muon Endcap, is located just behind the new endcap calorimeter, where the background particle flux can reach up to 150 kHz/cm^2. Recent studies of rate capability and gain drop resulted in a design change in the segmentation of the high voltage (HV) distribution for the GEM foils. The second-generation ME0 prototype has radial segments in contrast to the (approximate) segmentation in pseudorapidity employed for GE1/1 and GE2/1. In this report, we describe the mechanical design of the second-generation prototype, the simulation of the background counting rate in the HV segments, and the measurement of the energy spectrum, the effective gain, and the response uniformity.

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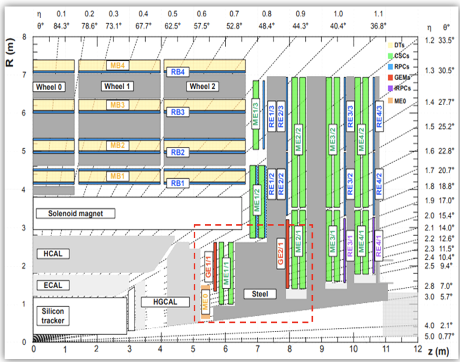
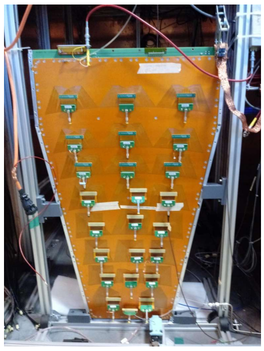


(a)



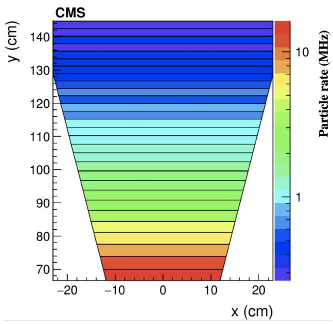
(b)

Figure 1: (a) An R-z cross section of the CMS detector [1], (b) Experimental setup in Building 904 at CERN with an Ag-target X-ray source placed ~ 1m from the backside of ME0 module.

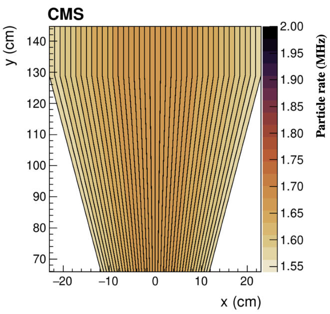
1. Introduction

The High Luminosity LHC expects a 10 times higher luminosity than the LHC design value. The innermost station of the endcap muon system is called ME0. It consists of 36 modules (18/endcap) where each module is composed of six layers of triple-GEM (Gas Electron Multiplier) detectors. The ME0 station extends the muon acceptance, $2.40 < \eta < 2.80$, to the pseudorapidity region as shown in Fig. 1a.

Fig. 2a shows a simulation of the background counting rate in a 1st-generation ME0 detector with high voltage (HV) sectors that are bands parallel to the innermost and outermost edges of the chamber. Each band covers, approximately, a range of η resulting in much higher fluxes in bands closest to the collision axis. The ME0 2nd-generation detector has radial segments, resulting in a uniform rate in all segments that does not exceed 1.5 MHz [2].



(a)



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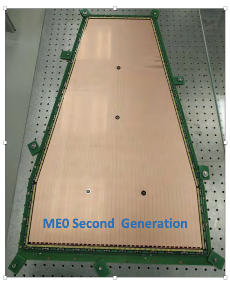


(c)

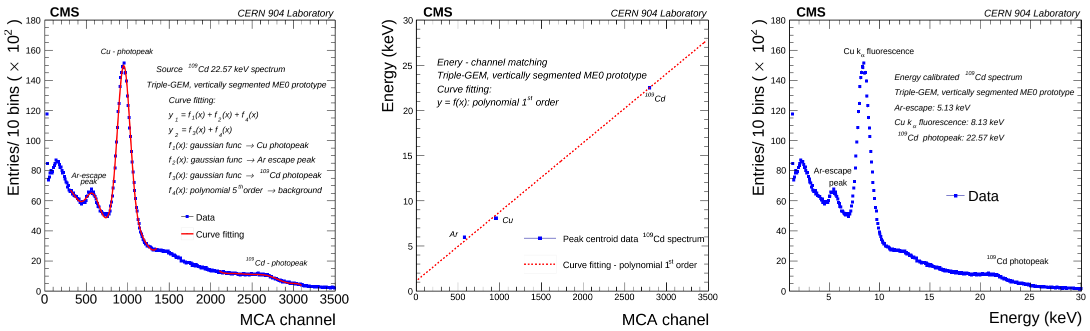
Figure 2: (a) and (b) are the simulation result of background particle rate per sector for 1st- and 2nd-generation ME0s, and (c) is photograph of a 2nd-generation ME0 module.

2. Experimental setup and characterization procedure

The ME0 prototype was assembled and then bench tested at CERN as shown in Fig. 1b. The GEM foils have different protection resistors: 2 MΩ on the drift side of foils, 100 kΩ on readout side of GEM1 and GEM2 foils, and 0 Ω on the readout side of GEM3 foil. The gap configuration between drift board, 3 layers of GEM foils and readout board is 3/1/2/1 mm. The gas composition is Ar/CO_2 (70/30) with refresh a rate of 5 L/hr.

2.1 Energy calibration

The ME0 module is irradiated with a ^{109}Cd source, and the peak positions are measured with a Multi-Channel Analyzer (MCA) as shown in Fig. 3a. The conversion from the MCA channel to corresponding energy is found from a linear fit of known peak energy versus channel count as shown in Fig. 3b. The resulting calibrated energy spectrum is shown in Fig. 3c.



(a) **(b)** **(c)**

Figure 3: Energy calibration procedure of ^{109}Cd spectrum. (a) MCA channel count distribution. Centroids of the three peaks are found using a functional fit. (b) Energy versus MCA channel with linear fit. (c) Calibrated energy spectrum.

2.2 Primary electron yield under irradiation from X-ray and ^{137}Cs sources

The initial number of free electrons, n_{primary}, produced by the ionization of Ar/CO_2 (70/30) in the drift region can be calculated from the calibrated energy spectrum of ^{137}Cs, as shown in Fig. 4a. In Eq. (1), E_{i} is the energy value of the ith MCA channel and Y_{i} is the count in the ith bin. In Eq. (2), 25 and 32 eV are the ionization energies of Ar and CO_2, respectively. The value of n_{primary} is 162 ± 33 for ^{137}Cs, and 356 ± 19 for X-ray source.

$$\langle E \rangle = \frac{\sum Y_{\text{i}} E_{\text{i}}}{\sum E_{\text{i}}} \tag{1}$$

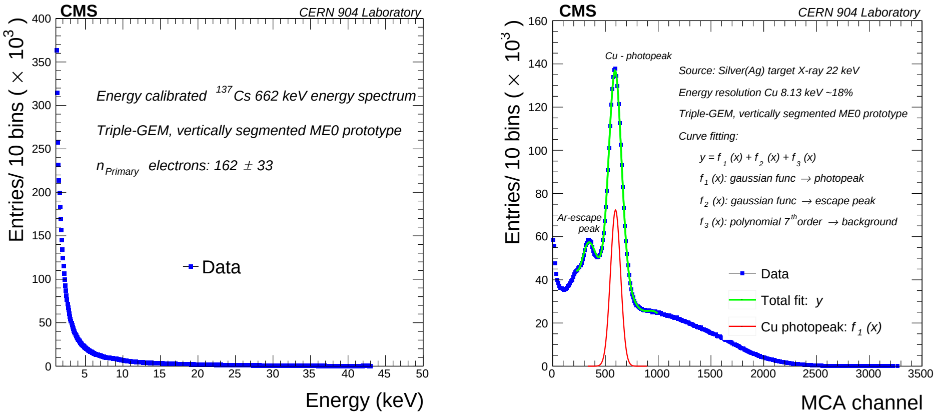
$$n_{primary} = \frac{\langle E \rangle}{0.7 * 25eV + 0.3 * 32eV} \tag{2}$$

2.3 Energy resolution

The energy resolution of the 2nd-generation prototype is measured from the shape of the Cu photo-peak produced under X-ray irradiation, as shown in Fig. 4b. As determined from a fit to the peak shape, the energy resolution is ∼18%, comparable to that of a 1st-generation prototype [3].

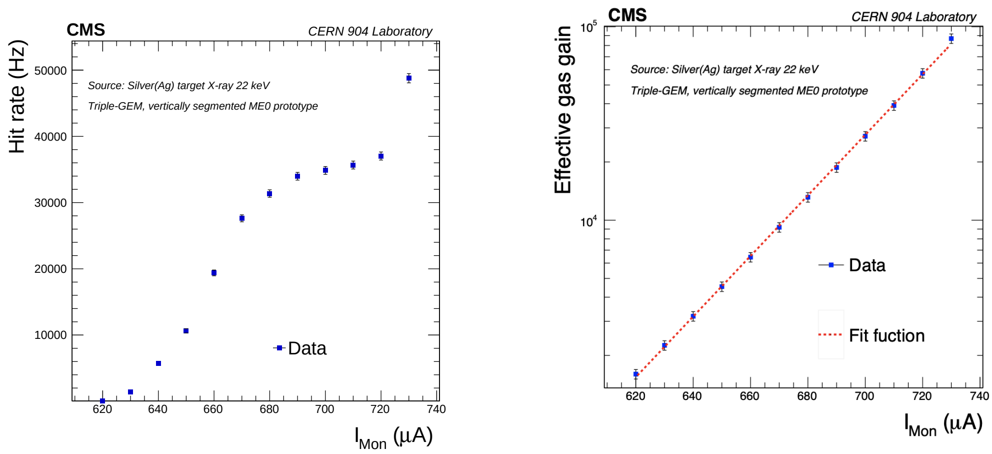
2.4 Rate and effective gas gain

Effective gain at a given temperature (T) and pressure (p) is determined from Eq.(3) where $I_{Readout}$ is the collected current measured with a pico-ammeter, $Rate$ is the number of particle counts per time, and e^- is the electron charge. Measurements are made for 24 sectors of the ME0



(a) (b)

Figure 4: (a) Calibrated energy spectrum of ^{137}Cs. (b) Energy resolution measurement using Cu photo-peak of X-ray spectrum.



(a) (b)

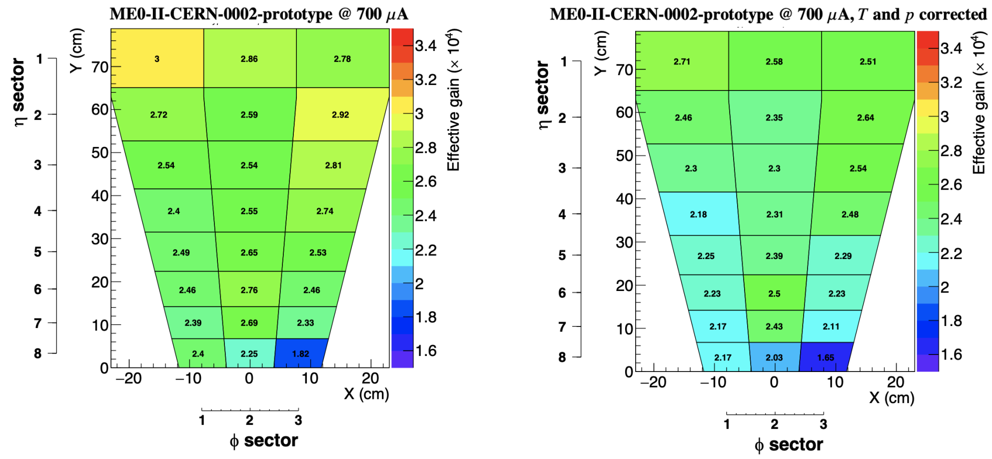
Figure 5: (a) Hit rates as a function of the currents (I_{Mon}) on high voltage divider circuit. (b) Gas gain versus current is fit with an exponential function.

prototype under irradiation from an Ag-target X-ray source. Different values of HV bias are utilized in the range 3625-3084 V. The measurements of readout rate versus current in the HV divider circuit are shown in Fig. 5a. The corresponding Gain versus current is shown in Fig. 5b.

$$Gain(T,p) = \frac{I_{\mathrm{Readout}}}{Rate \times n_{primary} \times e^{-}} \tag{3}$$

3. Gain uniformity and T, p tune

The gains measured for the 24 sectors, at a divider current of 700 μA, are displayed on the geometrical layout of the sectors in Fig. 6a. The same measurements but extrapolated to the annual average temperature (T_0) and the pressure (p_0) in the CMS experimental cavern are shown in Fig. 6b.



(a) **(b)**

Figure 6: (a) Bench test $Gain(T, p)$ at HV divider current of 700 μA mapped on to the ME0 HV segment-layout. (b) $Gain(T_0, p_0)$, by extrapolation to the conditions in the CMS cavern.

4. Conclusion

The 2nd-generation of the CMS inner-most endcap muon station ME0, a triple Gas Electron Multiplier based muon station, utilizes radial high voltage segments to equalize the counting rate in all segments. A prototype detector has been irradiated with radioactive and X-ray sources to measure the energy resolution of ~18%, the gain of ~ 2×10^4 (at 700 μA divider current), and the gain uniformity of < 10%. This performance meets the requirements for successful operation at the High Luminosity LHC.

Acknowledgments

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