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Triple GEM technology has been selected to extend the acceptance of the CMS muon spectrometer to the region $2.4 < |\eta| < 2.8$, the so called ME0 project. The ME0 stations will be formed by stacks (six-layer stations) of triple-GEM chambers, which must operate in a harsh environment with expected background particle fluxes ranging between 3 and 150 kHz/cm^2 on the chamber surface. Both the maximum background rate and the large range in particle rate set a new challenge for particle detector technologies. The rate capability of triple-GEM detectors is limited by voltage drops on the chamber electrodes due to avalanche induced currents flowing through the resistive protection circuits (discharge quenchers). Studies with large-area triple-GEM detectors with moderate fluxes, show drops up to 40% of the nominal detector gas gain. The traditional GEM foils segmentation does not allow for feasible gain compensation acting on the HV settings. To overcome this strong limitation and to cope with the large variation in background flux a novel GEM foil design with electrode segmentation in the radial direction, instead of the ”traditional” transverse segmentation has been introduced. The advantages of the new design include uniform hit rate across different sectors, minimization of gain-loss limiting the need for voltage compensation, and independence of detector gain on background flux shape.Rate capability studies with ME0 chamber prototype by using a high intensity 22 keV X-ray generator will be presented.We prove the possibility to restore the original gain compensating the voltages applied on each GEM electrode, this makes this novel GEM foil layout suitable for the CMS-ME0 application and for all experiments which expose GEM detectors to a high background rate and large rate variation on the detector surface.

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Novel GEM foil layout for high-rate particle environment in the CMS ME0 muon detector

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Abstract

The triple GEM technology has been selected to extend the acceptance of the CMS muon spectrometer to the region $2.4 < |\eta| < 2.8$, the so called ME0 project. The ME0 stations will be formed by stacks (six-layer stations) of triple-GEM chambers, which must operate in a harsh environment with expected background particle fluxes ranging between 3 and $150\,kHz/cm^2$ on the chamber surface. Both the maximum background rate and the large range in particle rate set a new challenge for particle detector technologies. The rate capability of triple-GEM detectors is limited by voltage drops on the chamber electrodes due to avalanche induced currents flowing through the resistive protection circuits.

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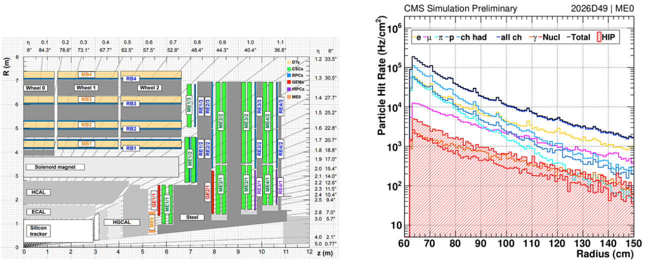

Figure 1: Quadrant of the CMS muon spectrometer (on the left) after the planned upgrade for HL-LHC, including the ME0 station in orange. Expected background particle flux (on the right) as a function of the distance from the beam line.

1. Introduction

To cope with the increased pileup in the High-Luminosity LHC upgrade and to extend the CMS [1] Muon System coverage to the $2.4 < \eta < 2.8$ pseudorapidity region, the triple-GEM technology [2] is approved to instrument a new station, ME0 [3] (Fig. 1).

The ME0 station requirements include a space resolution under $500\,\mu$rad, a time resolution under 10 ns, longevity over an integrated charge of $9\,\mathrm{C/cm^2}$, and a rate capability up to $150\,\mathrm{kHz/cm^2}$ (Fig. 1).

The triple-GEM detector allows a good space (up to $150\,\mu$m) and time resolution ($7-8$ ns). The rate capability has been verified with X-rays up to $100\,\mathrm{MHz/mm^2}$ on irradiated areas of few $\mathrm{mm^2}$ to test the detector response to local effects such as the ion space charge effect, i.e. a distortion of the electric field in the detector gas volume due to the high density of slowly-moving positive charges in the gas [4].

The triple-GEM detectors have three amplification steps, after which the produced charge induces currents on the electrodes that flow in the protection circuits. This phenomenon leads to a voltage drop on the electrodes, which increases with the irradiated area, and could thus lead to a drop in the GEM rate capability. To reduce this effect, a segmentation of the GEM foils has been introduced and each sector has been connected to the power supply through a quenching resistor. The final design chosen for ME0 detectors is endowed with azimuthal segmented GEM foils [5] due to the huge difference of particle flux rate expected in the η partitions, from kHz up to 150 kHz. The rate capability and gain measurements on a $10 \times 10\,\mathrm{cm^2}$ chamber and on the azimuthal segmented ME0 prototype is described in the following sections.

2. Rate capability and gain measurements

The rate capability measurement has been performed on a triple-GEM detector of $10 \times 10\,\mathrm{cm^2}$ area with two silver-target X-ray generators [6] at increasing fluxes to irradiate the detector.

A CAEN A1515 [7] power supply has been used to power the $10 \times 10\,\mathrm{cm^2}$ triple-GEM to a nominal gas gain of 2×10^4 and a Keithley 6487 picoammeter [8], which provides a monitoring of the currents flowing in the seven detector electrodes.

The hit rate has been estimated through anode current measurements with increasing flux of the X-ray sources (Fig. 2). The saturation of the measured anode current is due to gain drop at high particle flux. The curve was fitted with the parametric function

$$i_{anode}(P_{X-ray}) = \frac{AP_{X-ray} + B}{1 + k(AP_{X-ray} + B)}, \qquad (1)$$

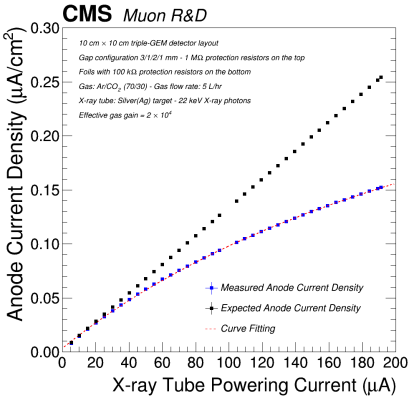

Figure 2: The anode current density of the $10 \times 10\, cm^2$ detector was measured in Ar/CO2 (70/30) at gas gain of 2×10^4. The blue dots are the measured anode current density, while black dots are the extrapolated anode current density.

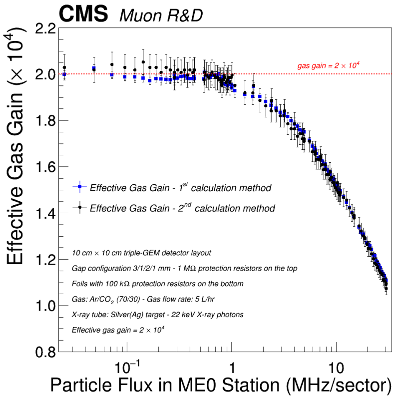

Figure 3: Comparison of the effective gas gain as a function of the expected hit rate on the whole electrode area: blue dots show the gain measured under irradiation(first method) while black dots shows the gain when only resistive voltage drops are expected(second method).

where P_{X-ray} is the current powering the X-ray source and k is a parameter quantifying the non-linearity of the curve, and then linearized ($k = 0$) to obtain the anode current in absence of gain drop. Finally, the rate was calculated from the gain equation

$$R = \frac{i_{linearized}}{q_e n_p g_{nominal}}, \tag{2}$$

where q_e is the electron charge, n_p the average number of primary electrons formed in the chamber from the X-ray photons and $g_{nominal}$ the effective gain.

The gas gain measurement has been performed at different particle rates after the rate estimation by two independent measurements. The first 'direct' method, returns the gain through the measurement of the anode current

$$g_{eff} = \frac{i_{anode}}{q_e n_p R}. \tag{3}$$

The second method returns the gas gain by two steps. The first step is measuring the effective voltage V_{eff} on the $i-th$ electrode as follows:

$$V^{(i)}_{eff} = V^{(i)}_{set} - I^{(i)}_{mon} R^{(i)}_{protection}, \tag{4}$$

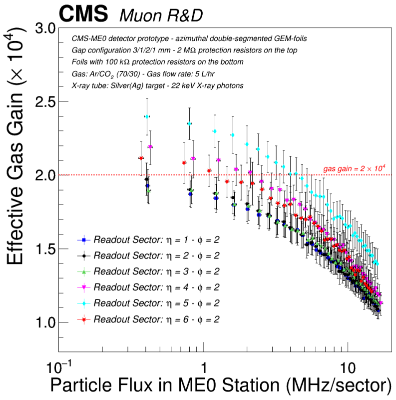

Figure 4: Measured effective gas gain as a function of the expected hit rate per unit area in different η-regions. The measurement was performed on a real-size ME0 detector prototype operated with $Ar/CO_2(70/30)$ at nominal gas gain of 2×10^4.

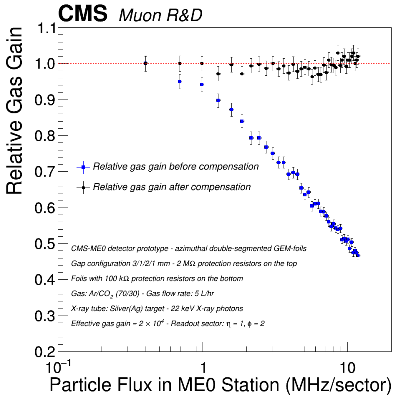

Figure 5: Effective gain of a triple-GEM chamber operated at increasing values of the nominal gain as a function of the background particle rate per sector. The top axis shows the nominal gain at which the detector is operated to achieve full gain compensation.

where $I^{(i)}_{mon}$ is the current measured by the CAEN board on the $i-th$ electrode at high flux when the voltage is fixed at V_{set} and $R^{(i)}_{protection}$ is the protection resistors on the $i-th$ electrode.The second step is obtaining the gas gain at low flux by powering each electrode at the same V_{eff}. This method is only sensitive to the voltage drop due to the 'Ohmic' effect. The results obtained with the two methods are compatible with each other (Fig.3) highlighting the gain drop is mainly due to voltage drop. The same measurements have been performed on the azimuthal segmented ME0 prototype irradiating different η-partitions (Fig.4), and the same drop effect was seen.

3. Conclusion

The first tests on the ME0 prototype have been presented with a focus on the rate capability of each sector. The main challenge for this station is the gain compensation with a high particle rate, that leads to the final design proposed for the GEM foils segmentation. This approach allows a uniform particle rate on each sector and is reducing the voltage drop global effect.

The future tests will focus on a complete detector irradiation for gas gain uniformity studies and for gain compensation strategy. The proposed solution for the gain compensation has been tested with a single sector irradiation (Fig. 5), where the voltage for each electrode has been compensated by adding the voltage drop measured through $I_{mon}^{(i)}$ current.

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