PROCEEDINGS OF SCIENCE

# Reduction of high voltage discharge in GEM detectors for the ME0 station of the CMS forward muon system

**Salwa Mohamed**[a,d,e,*], **Tamer Elkafrawy**[b], **and Jeremie A. Merlin**[c] **on behalf of the CMS Muon Group**

[a] *Academy of Scientific Research and Technology — ENHEP, Cairo, Egypt*
[b] *Florida Institute of Technology, Melbourne, Florida, USA*
[c] *University of Seoul, Seoul, Korea*
[d] *Ain Shams University, Cairo, Egypt*
[e] *Higher Technological Institute, Tenth of Ramadan City, Egypt*
*E-mail:* salwa.mohamed@cern.ch, tamer.elkafrawy@cern.ch, jeremie.alexandre.merlin@cern.ch

The Phase 2 upgrade of the CMS muon spectrometer will include the installation of two new muon stations based on Gas Electron Multiplier (GEM) technology. While the GE1/1 station is already installed and the GE2/1 detectors are under construction, the ME0 station is expected to be inserted in CMS during the Long Shutdown 3 (LS3). The new ME0 system will increase the acceptance for muon detection in the region $2.03 < |\eta| < 2.82$ where there is a high radiation background. When triple-GEM detectors, including ME0, operate at high gain, there are occasional discharges within the transfer gaps that are likely followed by less-common secondary discharges and may cause irreversible damage to the detector. The ME0 detector has the advantage of using double-segmented GEM foils that help lower the probability of high voltage discharges, and in turn, this protects the detector and maintains the high detection efficiency. To optimize the ME0 design, we studied the impact of High Voltage (HV) filter resistors and segment orientation of ME0 GEM foils on discharge propagation probability within the detector.

*The Tenth Annual Conference on Large Hadron Collider Physics - LHCP2022*
*16-20 May 2022*
*Online*

*Speaker





PoS(LHCP2022)265

## 1. Introduction

One of the CERN Large Hadron Collider (LHC) experiments is the Compact Muon Solenoid (CMS), which consists of various particle physics detectors [1]. This will foresee upgrade during the LS3 [2] to fulfill the LHC high luminosity upgrade requirements [3] of increasing the instantaneous luminosity up to $5 \times 10^{34}$ cm$^{-2}$s$^{-1}$. One of the muon detectors which will be installed in the CMS forward muon spectrometer is based on the new triple-GEM detectors. The two new GEM stations, referred to as GE2/1 and ME0, of the CMS endcap muon system will be equipped with the previously installed GE1/1 detectors, shown in red and orange colors in Fig. 1 [2]. The ME0 stack is composed of six modules, arranged as shown in Fig. 2 [4].

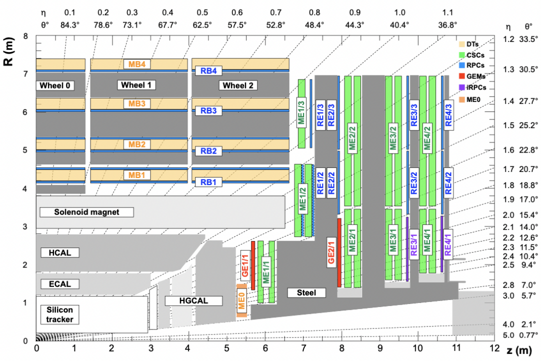


**Figure 1:** A quadrant of the Phase-2 CMS muon spectrometer.

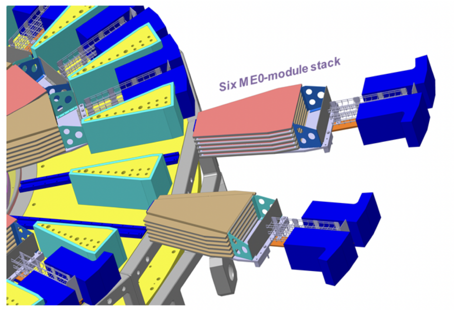


**Figure 2:** Schematic view of the CMS ME0 stack with six triple-GEM.

## 2. Motivation

Based on the experience of the GE1/1 slice test using actual large-size prototypes, the design of the triple-GEM detectors has evolved in order to minimize the probability of triggering propagating discharges while maximizing the internal protection in case such event happens. When operating in normal conditions, triple-GEM detectors may be subject to internal discharges, causing a sudden short circuit between the top and bottom electrodes of GEM foils. In certain cases, and in particular in large-size detectors, discharges within GEM holes can propagate in the gaps between the foils and potentially cause irreversible damages to the detector components or the readout electronics. The GE2/1 design in particular introduces the combination of single-segmented and double-segmented GEM foils to prevent the propagation in the transfer gaps, together with the introduction of a decoupling circuit in front of the electronics to stop the propagation before it can reach the sensitive chips. ME0 detector has a similar design as GE2/1, while its optimization of rate capability needs to be improved. Aspects of improvements could be the segment orientation and optimization of HV filter resistance. Both GE2/1 and ME0 configurations have double segmentation on the first and second-layer GEM foils and single segmentation on the third GEM foil. The GE2/1 layers are horizontally segmented, while ME0 layers are azimuthally segmented. This study aims to investigate the impact of segment orientations and the HV filter resistance on the discharge propagation probability for the second generation of GEM ME0 detector.

## 3. Impact of HV filters on discharge propagation probability in ME0 detector

Transverse segmentation of the ME0 foils was found to cause a drastic reduction and strong non-uniformity in gain, and hence a second generation of ME0 detectors was developed with azimuthal foil segmentation, which was observed to have an effective gain compensation and to minimize the gain drop during the CMS beam time [5]. Also, HV filter helps minimize the voltage drop on the filter resistor during high-flux irradiation. For any change in the design of foil or HV filter, we must re-validate its impact on the discharge propagation probability.

## 4. Experimental setup and measurements

Measurements of the discharge propagation probability in the second generation of GEM ME0 muon detectors were performed at the 904 laboratory at CERN. The measurement setup and its block diagram are shown in Figs. 3 and 4, respectively. Discharge counts were created by injecting alpha particles using the americium source $\mathrm{Am}^{241}$ via a specific hole created during the assembly in the drift layer of the detector. By applying a suitable electric field configuration on the GEM foils, discharges happened at a suitable rate. Discharge and its propagation were counted at several induction fields per HV filter with keeping the transfer-region fields fixed to investigate the impact of both segment orientation and HV filter resistance on the discharge propagation probability.

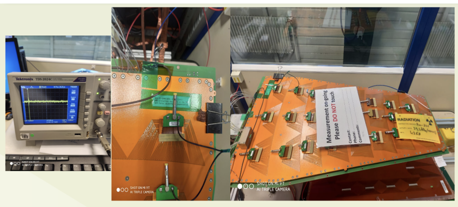

**Figure 3:** Measurement setup at the 904 laboratory.

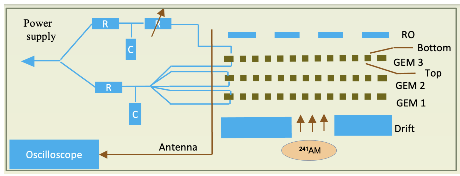


**Figure 4:** Block diagram of the measurement setup at the 904 laboratory.

## 5. Results and discussion

In Fig. 5, results are shown of the first measurement with the redesigned ME0 detector (green curve) using the 100-kΩ HV filter. The discharge propagation probability against the induction electric field is compared for both the GE2/1 detector (black curve) and $10 \times 10$ cm$^2$ prototype (red curve) as shown in the left and middle panels of the figure. The discharge propagation probability against HV filter resistance for the ME0 detector (green curve) is compared to GE2/1 detector as indicated in the right panel of Fig. 5. The green curve in the left and right panels of this figure is produced by fitting the data using the error function up to an induction electric field of 10 kV/cm (left panel) and a resistance of 5 kΩ (right panel) and by extrapolation beyond 10 kV/cm (left panel) and lower than 5 kΩ (right panel). The panels of Fig. 6 are the same as the left panel of Fig. 5 except that they are given for four different values of HV filter resistances (51, 25.5, 10, 5 kΩ). The discharge propagation probabilities in all the tested ME0 configurations are comparable to, and even better than, those for the GE2/1 configuration, which is due to the finer segmentation of the foils except for some re-ignition in the case of 5-kΩ filter. Discharge re-ignition, which is multiple self-triggered discharges, will raise the damage probability of the detector. Therefore, the overall study indicates that the upgrade of the HV filters is suitable from the discharge propagation point of view. None of the options discussed in this report show a significant degradation of the discharge behaviour. Nevertheless, the lowest resistance filter seems to allow for the re-ignitions of the propagated discharges, which remain rare but are proven to be particularly harmful for the readout electronics. This observation is taken into consideration for the final approval of the ME0 design.

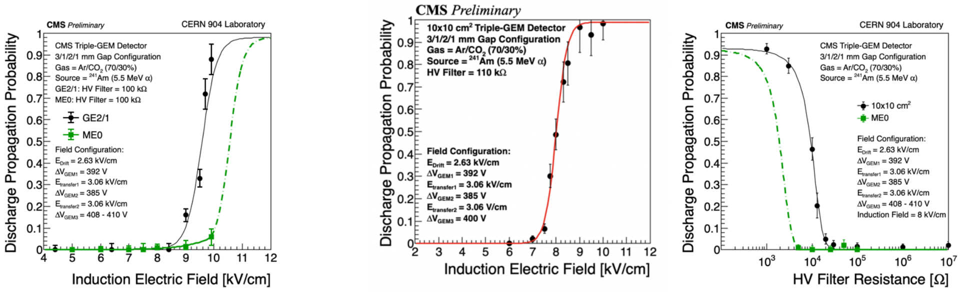


**Figure 5:** Discharge propagation probability versus the induction electric field for GE2/1 (black curve) and ME0 (green curve) detectors (left panel) and $10 \times 10$ cm$^2$ prototype (middle panel). In the right panel is shown discharge propagation probability against the HV filter resistance for applied induction electric fields of 8 kV/cm on ME0 (green curve) detector and $10 \times 10$ cm$^2$ prototype (black curve). The dotted part of the green curve in the right and left panels is an extrapolation over the region where data taking was not possible.

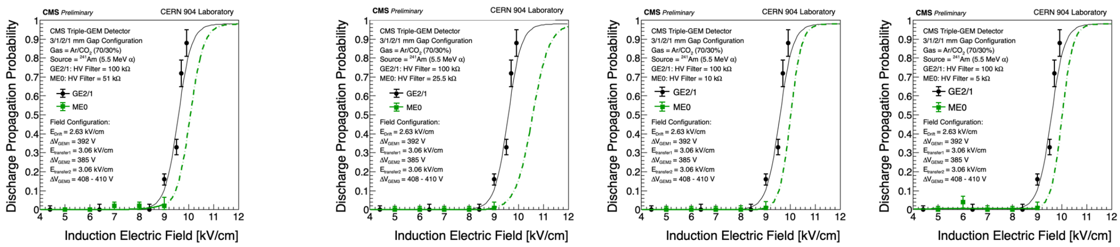


**Figure 6:** Discharge propagation probability versus the induction electric field for the GE2/1 configuration with HV 100-kΩ HV filter and ME0 configuration for different HV filter resistances (51 (far left panel), 25.5 (middle left panel), 10 (middle right panel), 5 (far right panel) kΩ).

## 6. Conclusion

In the scope of ME0 rate capability studies, we measured the impact of the new design of ME0 detector on the discharge propagation probability behavior. Based on our recent measurements using ME0 without electronics installed, we have confirmed that the azimuthal segmentation and lowering the filter resistance from 100 to 5 kΩ do not significantly impact the discharge propagation. In addition, the size of HV segments in ME0 is smaller than that of GE2/1, which makes the ME0 detector more resistant to discharge propagation. The next step will be to perform the same discharge propagation measurements for the GEM ME0 detector with electronics installed to confirm that dissipated discharge energy due to the new configuration will not cause any damage to the electronics.

## References

[1] CMS Collaboration, *The CMS experiment at the CERN LHC*, *JINST*, **3** (S08004) (2008).

[2] G. Mocellin, *GEM detectors for the upgrade of the CMS muon forward system*, *J. Phys.: Conf. Ser.* **1390** (012116) (2019).

[3] F. Fallavollita, *Aging phenomena and discharge probability studies of the triple-GEM detectors for future upgrades of the CMS muon high rate region at the HL-LHC*, *Nucl. Instrum. Methods Phys. Res. A* **936** (0168-9002) (2019).

[4] F. Fallavollita, *Novel triple-GEM mechanical design for the CMS- ME0 detector and its preliminary performance*, *J. Instrum.* **15** (C08002) (2020).

[5] M. Bianco, F. Fallavollita, D. Fiorina, A. Pellecchia, L. F. Ramirez Garcia, N. Rosi, and P. Verwilligen, *Rate capability of large-area triple-GEM detectors and new foil design for the innermost station, ME0, of the CMS endcap muon system*,*CMS-CR-2021-268*, (2021).