74cm × 94cm

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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

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1. Motivation

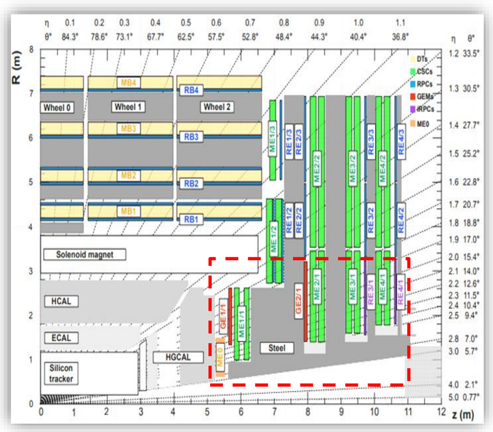


Figure 1. *An $R-z$ cross section of a quadrant of the CMS detector, including the Phase-2 upgrades ($RE3/1, RE4/1, GE1/1, GE2/1, ME0$).*

The high-luminosity LHC (HL-LHC) upgrade is setting now a new challenge for particle detector technologies.

In the CMS muon system gas detectors, the increase in luminosity will produce a particle background ten times higher than under conditions at the LHC.

To cope with the high rate environmental and maintain the actual performance, the new triple-Gas Electron Multiplier detectors will be installed in the innermost region of the forward muon spectrometer of the CMS experiment.

The detailed knowledge of the detector performance in the presence of such a high background is crucial for an optimized design and efficient operation after the HL-LHC upgrade.

For this reason, aging studies and discharge probability studies of CMS triple-GEM detector are in course in several CERN facilities.

2. Gamma Irradiation Facility (GIF++)

The facility consists of an intense $14\ TBq$ (in 2015) ^{137}Cs source emitting $662\ keV$ photons. The GIF++ photons have an energy fairly representative of the energy of HL-LHC photons seen by the muon detectors: $0.1 - 10\ MeV$.

Longevity tests of GEM chambers at the GIF++ zone are ongoing: test involves a full size Triple-GEM detector filled with a gas mixture of Ar/CO_2 $(70/30)$ and running at an effective gas gain of 2×10^4.

With the interaction flux in the detector of the order of $3 \times 10^4\ Hz/cm^2$, the resulting aging acceleration factor is estimated at 30 at the CMS gas gain equal to 2×10^4.

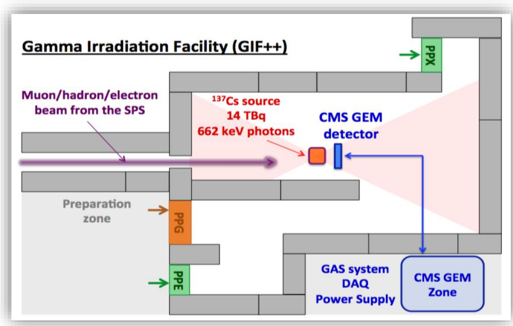


Figure 2. *Schematic view of the GIF++ irradiation facility at CERN used for the triple-GEM aging studies.*

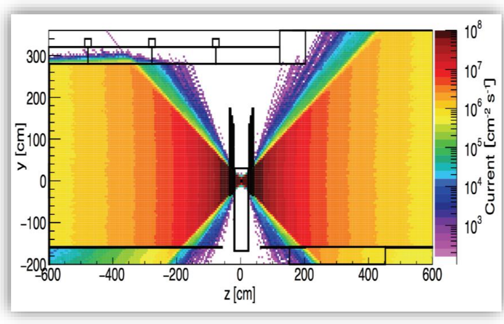


Figure 3. The GIF++ floor plan in the (y, z)-plane, and the photon current map for the open source.

3. GIF++ Installation

The readout system at GIF++ facility consists of two main readout channels:

- Pico-ammeters connected to the GE1/1 detector to monitor the anode current, which reflects the effective gas gain of the detector.
- Complete meteo-station to monitor the environmental fluctuations.

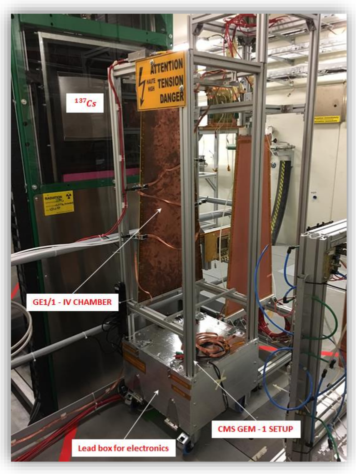


Figure 4. *Pictures of the GIF++ setup showing the GE1/1 detector under irradiation.*

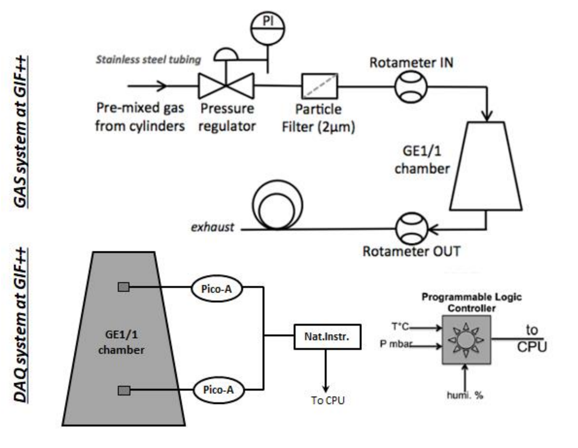
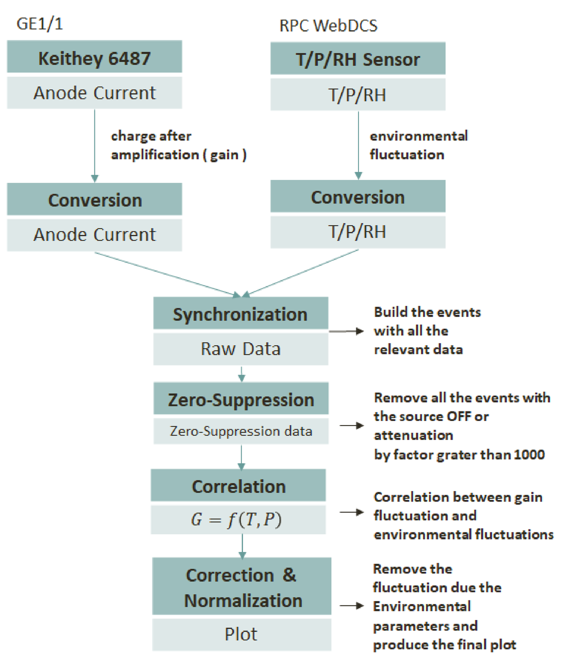


Figure 5. *Schematic view of the gas system and DAQ for the for the classical aging test at GIF++.*

4. Data Analysis Procedure



The response of the detectors can fluctuate not because of aging effects but because of variations of the density of the gas: $\rho \propto P/T$

It is thus essential to remove the environmental effects to isolate the possible aging effects.

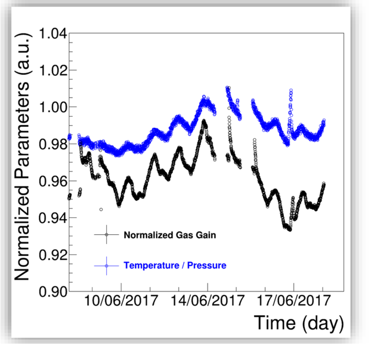


Figure 6. *Left: Schematic representation of the analysis steps. Right: Typical data points taken at GIF++ showing the normalized gain (black) and the ratio temperature over pressure of the gas (blue).*

5. GIF++ Aging Test Results

The classical aging test is currently in course at GIF++ facility with a GE1/1 detector of the 4^{th} generation operating in Ar/CO_2 $(70/30)$.

After 12 months of sustained operation in front of the ^{137}Cs source, the GE1/1 detector accumulated a total charge of $125\ mC/cm^2$.

It represents ten years of GE1/1 operation at the HL-LHC with a safety factor 21, ten years of GE2/1 operation with a safety factor 42, and 44% of the total ME0 operation.

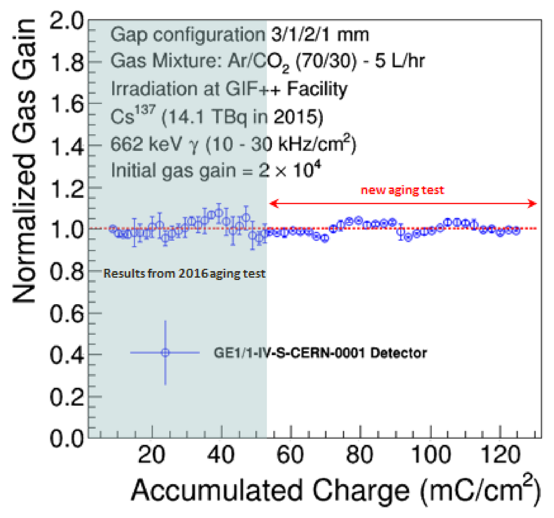


Figure 7. *Results of the GEM aging test showing the normalized effective gain (corrected for pressure and temperature variations) as a function of the accumulated charge.*

The results of the effective gain measurements indicate that the CMS Triple-GEM detector does not suffer from any kind of aging effects or long-term degradation.

6. X-ray Aging Test @ CMS-GEM QA/QC Lab

Another classical aging test, placed at CMS-GEM QA/QC Lab, involves a Triple-GEM detector of the 10^{th} generation flushed with Ar/CO_2 $(70/30)$ and running at an effective gas gain of 2×10^4. We continuously monitor the response of the detector irradiated by a $22\ keV\ X-ray$ source. The entire experiment is designed with the same structure of the one placed in the GIF++.

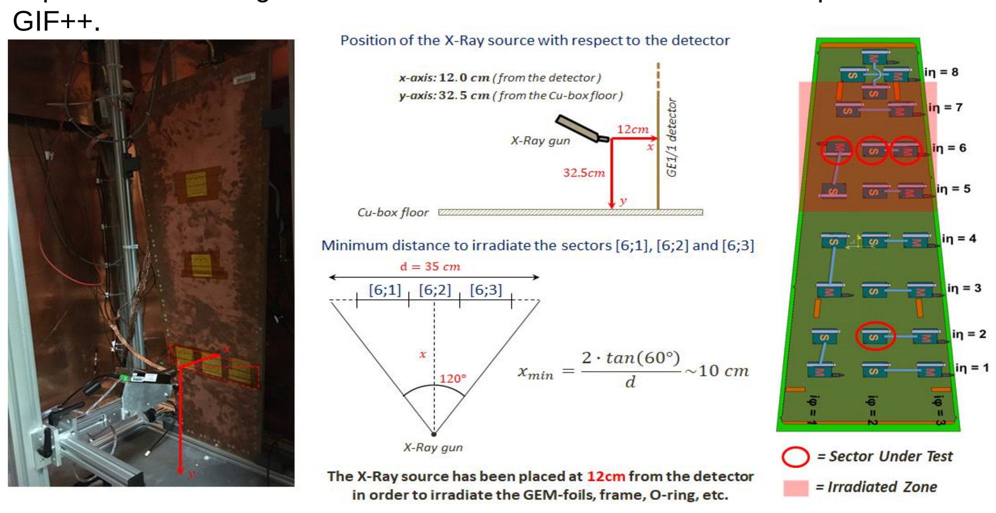
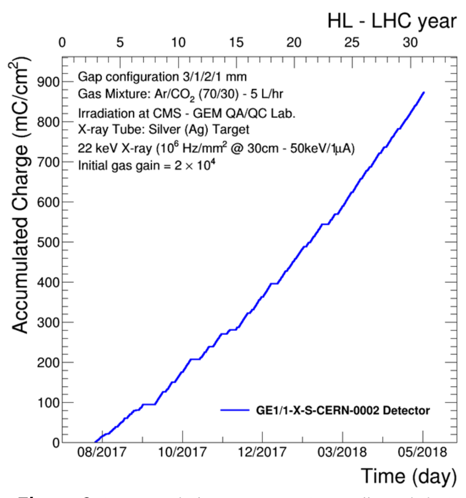


Figure 8. *Left: Pictures of the X-ray setup showing the GE1/1 detector under irradiation. Right: Final configuration for the X-ray aging studies at CMS-GEM QA/QC Laboratory.*

7. Integrated Charge Rate

The overall duty factor since August 2017 is about 83%, i.e. $20hr$ of continuous irradiation per day. About $875mC/cm^2$ have been accumulated until May 2018 in the in hottest R/O sector, thus providing a safety factor about 3.1 with respect to 10 years of HL-LHC operations in the ME0 environmental. The other two irradiated sectors have accumulated $363mC/cm^2$ and $178mC/cm^2$, respectively.



R/O sector	Integrated Charge	Integrated Charge Rate	Gas Gain Stability	Energy Resolution
$\eta = 6, \varphi = 1$ ($f_{GIF++} \sim 3.1$)	$363.38\ mC/cm^2$	$2.3\ mC/cm^2 \cdot day$	No gain drop observed	$(17.3 \pm 0.1)\%$ Energy Res. Stable
	~ 13 years of ME0 operation @ the HL-LHC			
$\eta = 6, \varphi = 2$ ($f_{GIF++} \sim 8.1$)	$875.05\ mC/cm^2$	$5.6\ mC/cm^2 \cdot day$	No gain drop observed	$(16.8 \pm 0.1)\%$ Energy Res. Stable
	~ 31 years of ME0 operation @ the HL-LHC			
$\eta = 6, \varphi = 3$ ($f_{GIF++} \sim 1.9$)	$178.46\ mC/cm^2$	$1.2\ mC/cm^2 \cdot day$	No gain drop observed	$(16.9 \pm 0.1)\%$ Energy Res. Stable
	~ 63% of the total ME0 operation @ HL-LHC			

Figure 9. Integrated charge versus time collected during the X-ray aging studies. At the time of the finalization of this poster, $875\ mC/cm^2$ have been accumulated in one sector of this chamber and smaller amounts in two other sectors under test.

8. X-ray Aging Studies: Effective Gas Gain

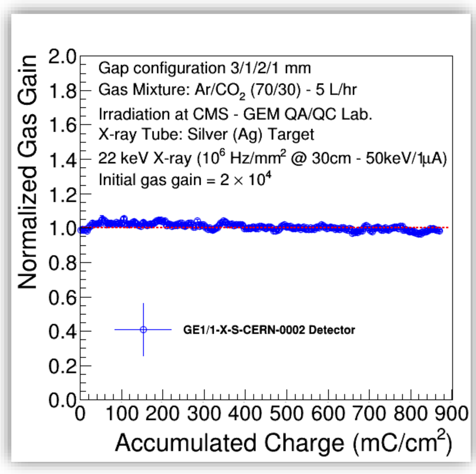


Figure 10. *Normalized effective gain (corrected for pressure and temperature variations) as a function of the accumulated charge.*

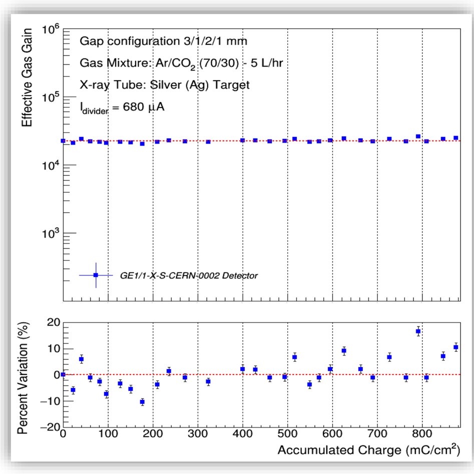


Figure 11. *Weekly QC5 - Effective Gas Gain measurement as a function of the accumulated charge.*

The aging tests currently underway at CMS-GEM QA/QC Lab. demonstrated that the CMS Triple-GEM detector can operate in the CMS - ME0 environment for over 10 HL-LHC years (with safety factor 3) without suffering from gain drop, unstability or any other long-term degradations.

9. X-ray Aging Studies: Energy Resolution

The result of the X-ray Triple-GEM aging test showing the energy resolution as a function of the accumulated charge.

The energy spectrum of the ^{109}Cd source is measured every weeks and the corresponding energy resolution stays stable during the entire test.

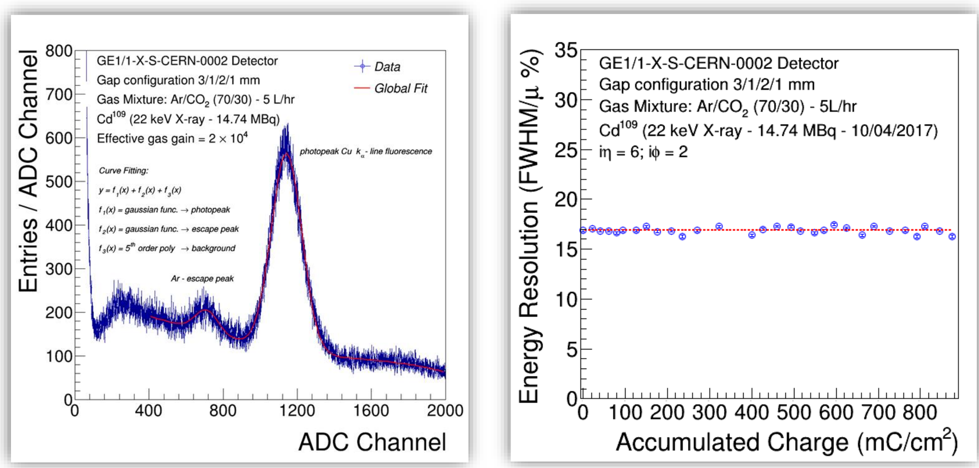
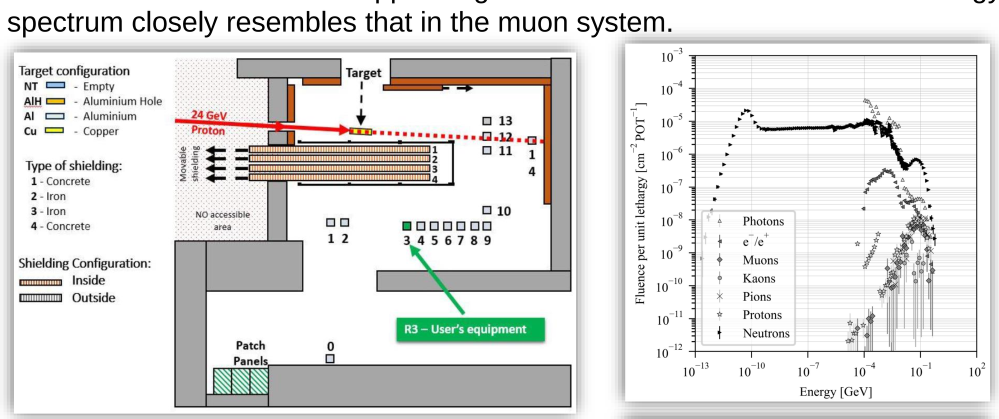


Figure 12. *Typical energy spectrum of the ^{109}Cd source (left) and energy resolution as a function of the accumulated charge (right) of the GE1/1 detector operating in Ar/CO_2 $(70/30)$ at an initial gas gain of 2×10^4.*

10. The CERN High-energy AcceleRator test facility

The CERN High-energy AcceleRator Mixed field (CHARM) facility provides a unique irradiation environment with a mixture of neutrons, photons, electrons/positrons, and charged hadrons.

The mixed composition background is achieved by colliding $24GeV$ protons from the CERN PS with a copper target. One can see that the neutron energy spectrum closely resembles that in the muon system.



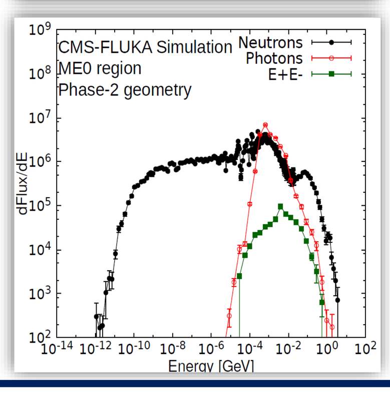


Figure 13. Left: Layout of CHARM configuration with copper target with shielding (CuCIIC). Right: Particles lethargy spectra obtained by Fluka simulation for the CuCIIC configuration in the tested positions R3 (top). Simulated energy spectra for different background particles considering CMS-FLUKA Phase-2 geometry and an instantaneous luminosity of $5 \times 10^{34}\ cm^2 s^{-1}$ for the upgrade ME0 detector (bot).

More recently, the GEM Pavia group has conducted a series of tests in the harsh radiation fields available at the CHARM facility to measure the neutron sensitivity and the discharge probability for the triple-GEM in more realistic conditions.

11. CHARM Installation

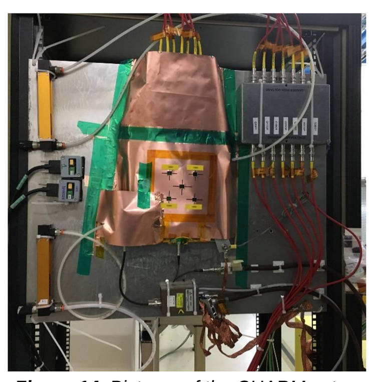


Figure 14. *Pictures of the CHARM setup*

Configuration:

- $10 \times 10\ cm^2$ triple-GEM detector
- $Ar/CO_2 : 70/30\ (5\ L/hr)$
- Initial gas gain 3.5×10^4
- Neutron fluence close to $2.5 \times 10^8/cm^2$ and a dose of about $9.4\ Gy$.

The GEM foils were powered independently with a multi-channel power supply in order to monitor the current induced on each electrode and to detect possible discharge signals.

A pico-ammeter connected to the readout electrode measured the total charge and the signals induced on the bottom electrode of GEM 3 were used to count the total number of particles crossing the detector and to identify the high-charge signals induced by HIPs. Neutron signals were selected by requiring hits with large charge using an appropriate discriminator threshold: the neutron sensitivity for the triple-GEM was measured to be 7.5×10^{-4}. No trips of the power supply or disruptive events were recorded during the entire test. As a results, we find a preliminary upper limit for the discharge probability of $2.85 \times 10^{-9}/neutron$ at 95% CL.

12. Effects of discharges on the detector operation

Gain calibrations were performed before and after the test in order to identify a possible degradation of the GEM foils in the irradiated areas.

The effective gas gain was not affected by the discharges, nor the energy response of the detector.

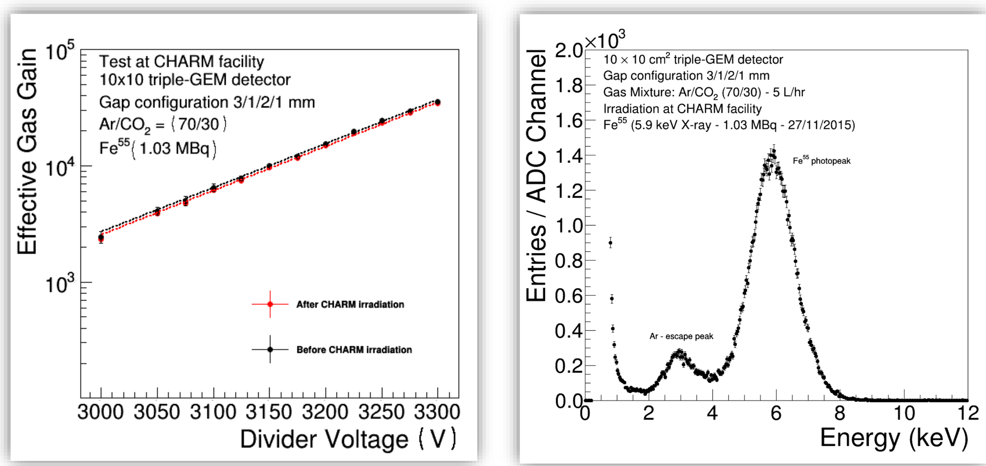


Figure 15. Left: Comparison of the effective gas gain of triple-GEM detectors before and after the intense irradiation with HIPs at CHARM facility. Right: Typical ^{55}Fe energy spectrum collected after the 24 discharges at a gas gain of 2×10^4.

13. Conclusion

The ongoing aging studies at GIF++ facility and in parallel at CMS-GEM QA/QC Lab. aims to identify the possible aging of Triple-GEM detector for CMS experiment and understand the long-term operation in HL-LHC with its future upgrades. The preliminary results presented in this poster indicates that the CMS Triple-GEM detector can sustain the continuous operation in the CMS endcap environment for over 10 years at HL-LHC without suffering from any performance degradation. In addition, due to the complexity of the neutron interactions with the GEM detectors and the dearth of experimental studies on this topic, a dedicated test was done at the CHARM facility to confirm the robustness of the CMS Triple-GEM and evaluate the effect of discharges on the long-term chamber operation.

[1] A. Colaleo et al., *CERN-LHCC-2017-012, CMS-TDR-016*, 12 September 2017.

[2] J. A. Merlin, *Study of long-term sustained operation of gaseous detectors for the high rate environment in CMS*, CERN, May 2016.

[3] A. Infantino, *CERN-ACC-NOTE-2017- 0059, FLUKA Monte Carlo Modelling of the CHARM Facility's Test Area: Update of the Radiation Field Assessment*, 14 November 2017.

[4] https://twiki.cern.ch/twiki/bin/view/MPGD/Phase2BkgFLUKA (CMS-FLUKA simulation for the background condition during Phase-2 for the muon upgrade subsystems).