15/10/19

15th Topical Seminar on Innovative Particle and Radiation Detectors Siena, Italy

Aging Studies on Triple-GEM detectors

for future upgrades of the CMS endcap muon spectrometer at the HL-LHC

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On behalf of CMS Muon Group

Outline

1. Introduction:
    1. CMS GEM-based upgrade for HL-LHC
    2. Aging Processes in gaseous detectors
2. Aging Tests for the GEM projects' validation:
    1. Aging test on CMS-like GEM at GIF++ facility
    2. Aging test on CMS-like GEM with X-ray gun
3. Expand the actual concept of aging study:
    1. Aging test on $10x10cm^2$ GEM in polluted gas environment
    2. Advanced Aging studies present and future

CMS GEM-based upgrade & Aging Processes

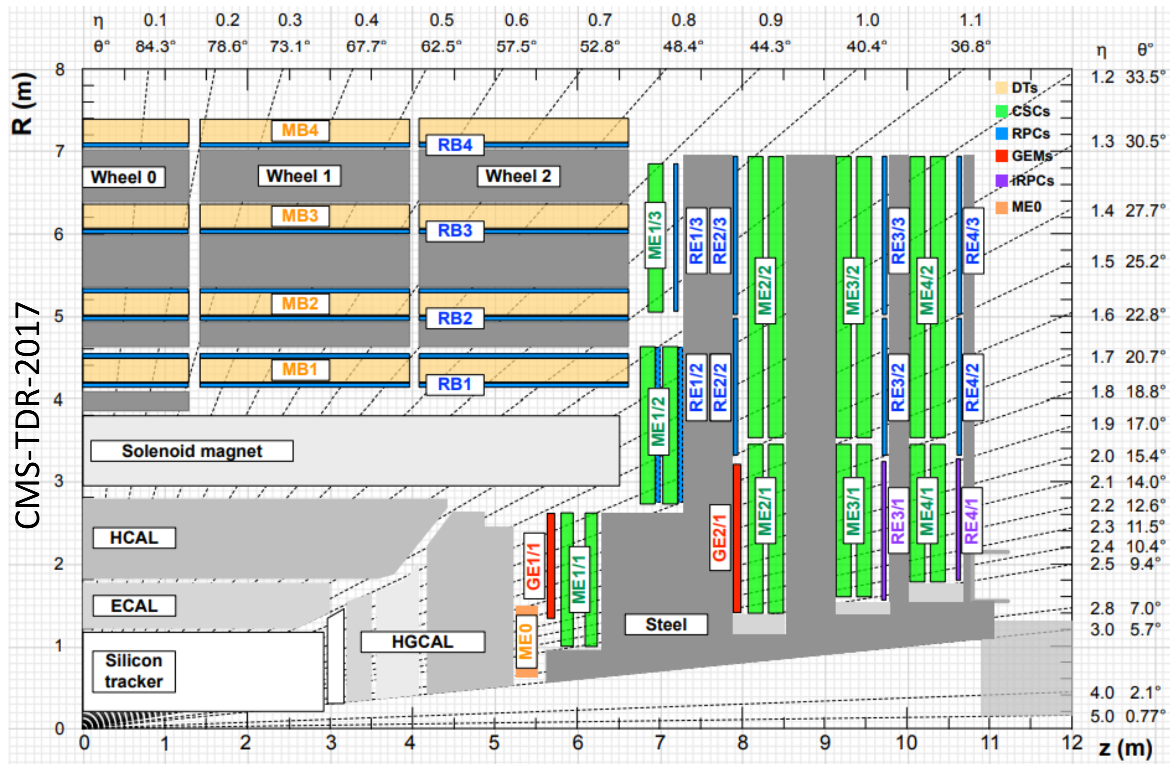
CMS muon upgrade for High-Luminosity LHC

Luminosity

$10^{34} cm^{-2} s^{-1}$

HL-LHC upgrade

$5-7\ \times 10^{34} cm^{-2} s^{-1}$



Higher discovery potential

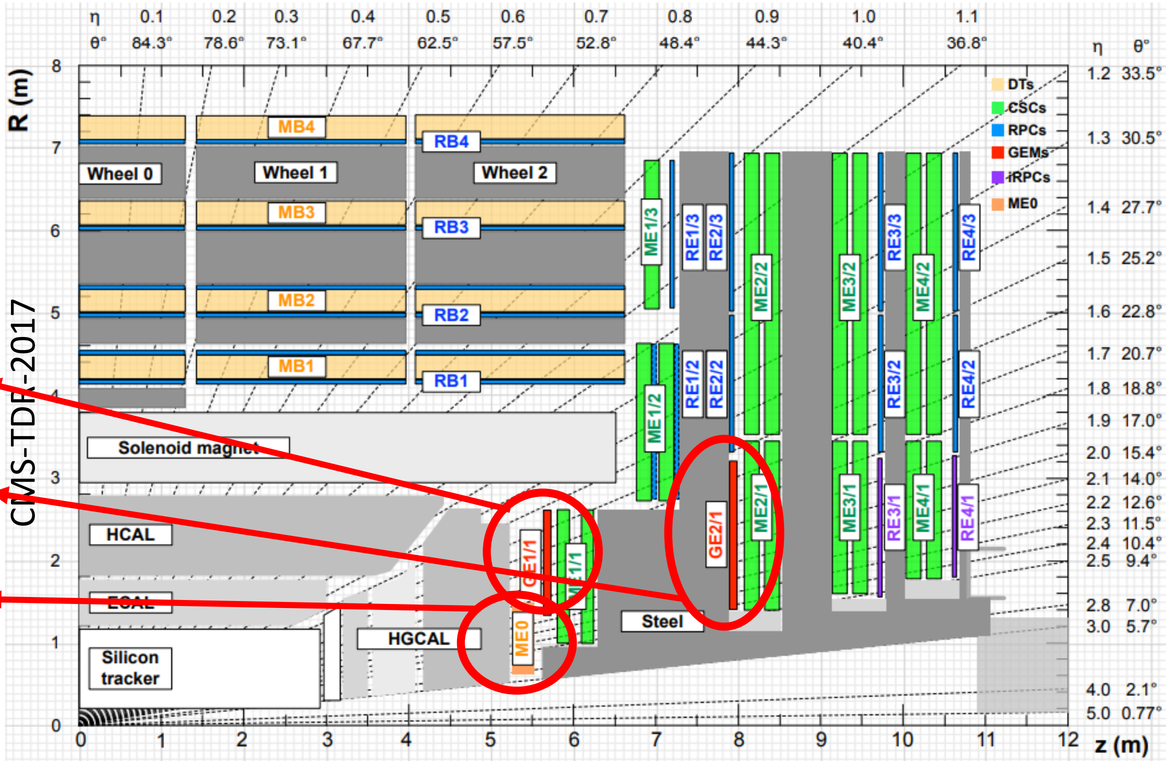
But **Also**

- Higher Event Pile-Up
- Higher background (photons, electrons, neutrons)

CMS muon upgrade for High-Luminosity LHC

New Triple-GEM stations:

	Max Hit Rate (kHz/cm²)	Expected acc. charge in 10 years (mC/cm²)
GE1/1	1.5	6
GE2/1	0.8	3
ME0	50	283



$$\textit{Accumulated Charge} = R_{max} \times n_{pairs}^{tot} \times q_e \times G \times t_{LHC}$$

Primaries released by a MIP

For further information about the GEMs upgrades please refers to Thursday talk by Michele Bianco: 'Upgrade of the CMS Muon Spectrometer in the forward region with the GEM technology'

Aging Processes in Gaseous Detectors

What?

Any degradation of the performance of a gaseous detector: gain drop, non-uniformity, dark current, discharge, etc.

Molecules dissociate (dissociation potential is 2-5 time lower than their minimum ionization energy)

Creation of Radicals (very chemically active)

Formation of Monomers

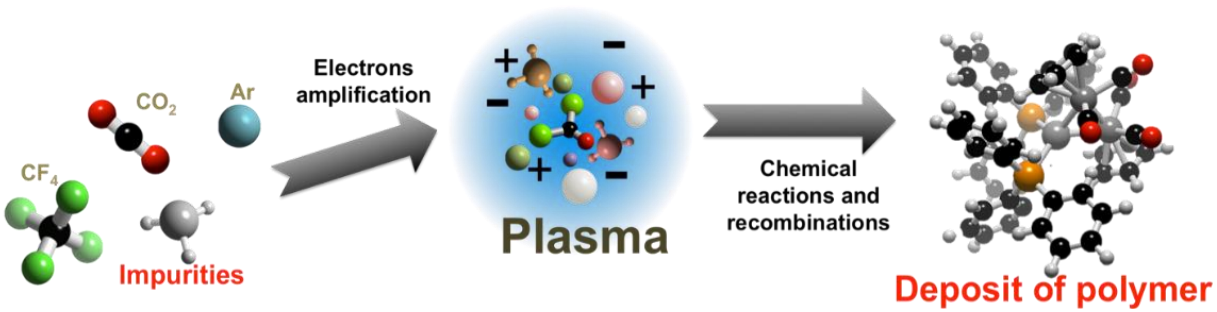
Rearranging into Polymers

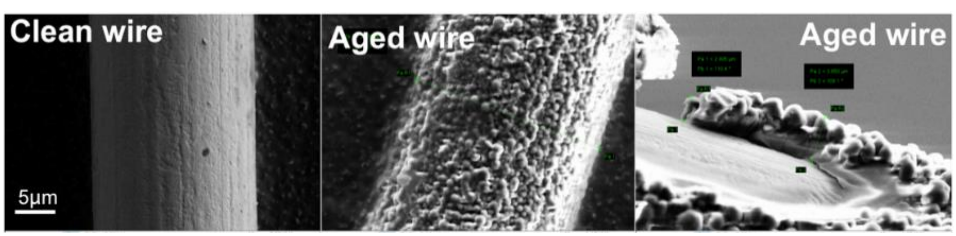
Polymers deposit on sensitive surface

Where does the contamination come from?

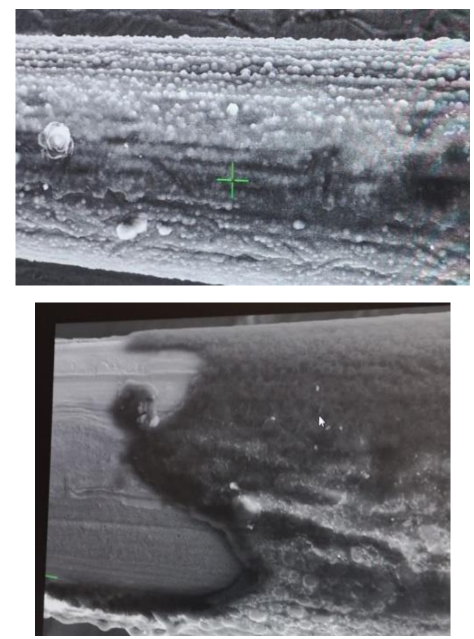
- *Molecules present in gas mixtures (CF4, DME, CH4, etc)*
- *Impurities: tubes contamination, gas leakages, residuals in the gas cylinders, OUTGASSING*

Ar/CO_2 is a clean gas mixture
→ contamination comes from impurities





Aged Wires



Aging test for the GEM projects’ validation

Goals for validation

Irradiate a CMS-like detector until a satisfactory accumulated charge is reached

TARGET:

	Expected accumulated charge in 10 years (mC/cm^2):	With Safety Factor (SF) 3 (mC/cm^2):
GE1/1	6	18
GE2/1	3	9
ME0	283	850

Irradiate (and monitor the performance) at GIF++ facility:

- **Source: 662 keV γ-rays**
- **Hit Rate: 30 kHz/cm^2**

D. Pfeiffer et al., *The radiation field in the Gamma Irradiation Facility GIF++ at CERN*. Nucl. Instrum. Meth. **A 866** (2017). 91-103 arXiv:1611.00299

Irradiate (and monitor the performance) at 904 Lab. At CERN:

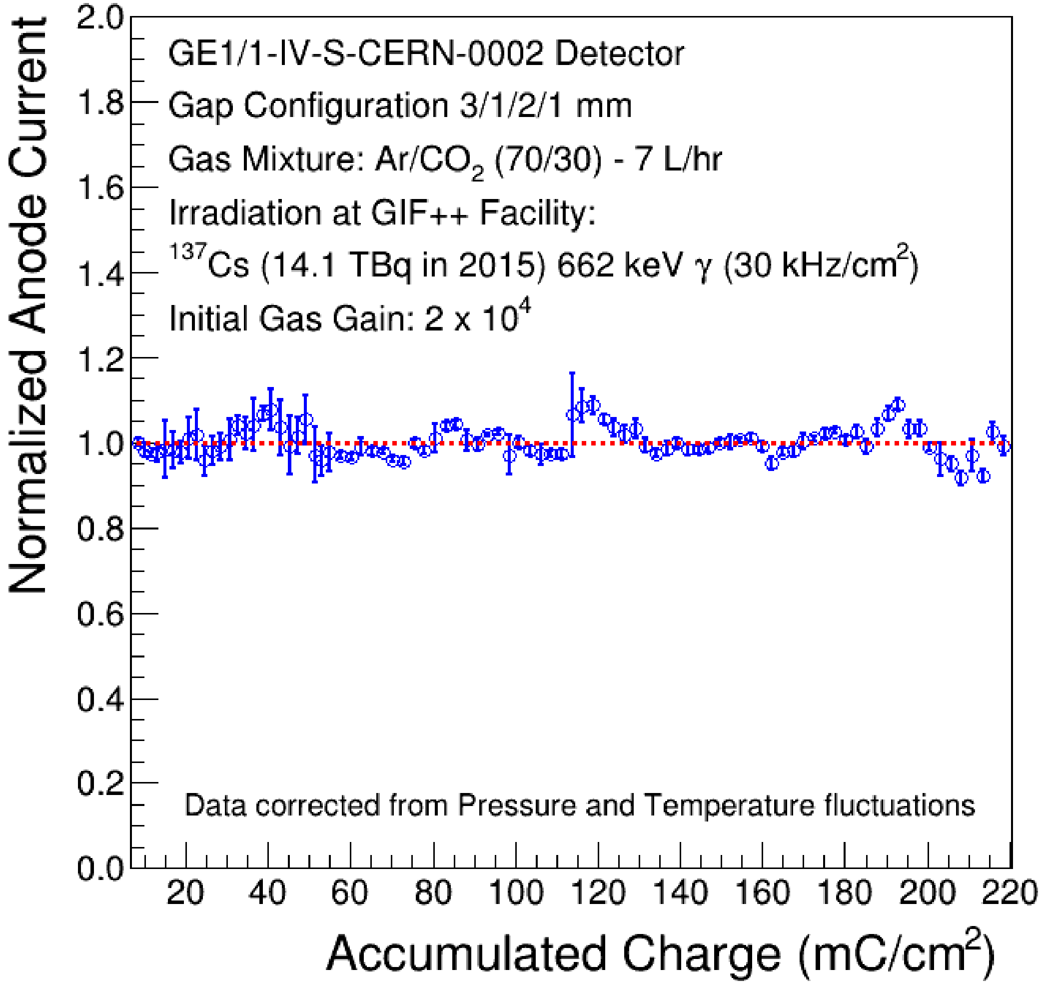
- **Source: 22 keV X-rays**
- **Hit Rate: 1000 kHz/cm^2**

Irradiation at GIF++ facility

(CERN foils)

CERN GEM foils production

Anodic current monitored via Keithley 6487 pico-ammeter



$$Gain = \frac{I_{anod}}{e\, n_0 R}$$

Anodic current follows the Effective gas gain if the Hit Rate & the source type is constant

No Effective Gas Gain loss up to 218 mC/cm²

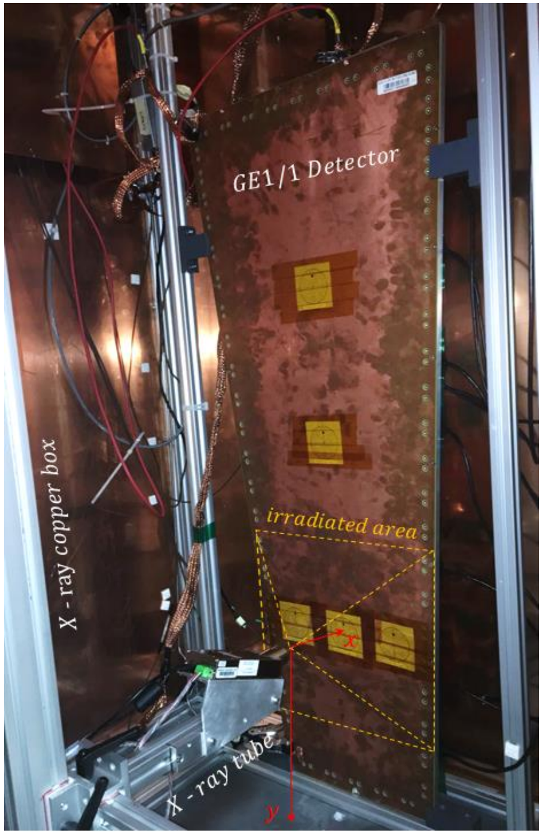
- GE2/1 validated with SF=72.7
- GE1/1 validated with SF=36.3
- ME0 **NOT** validated (SF=0.77)

Fallavollita F, 2018, Triple-Gas Electron Multiplier technology for future upgrades of the CMS experiment: construction and certication of the CMS GE1/1 detector and longevity studies, CERN Ph.D. thesis, CERN-THESIS-2018-349.

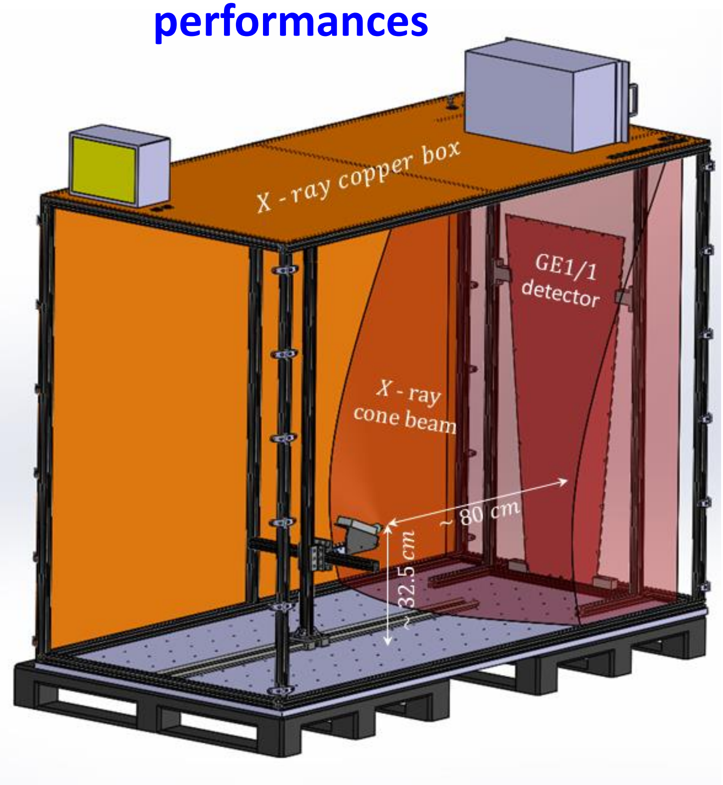
Switching to other irradiation source

To Expand the GIF++ facility limits a chamber was irradiated in our laboratory with an X-ray gun

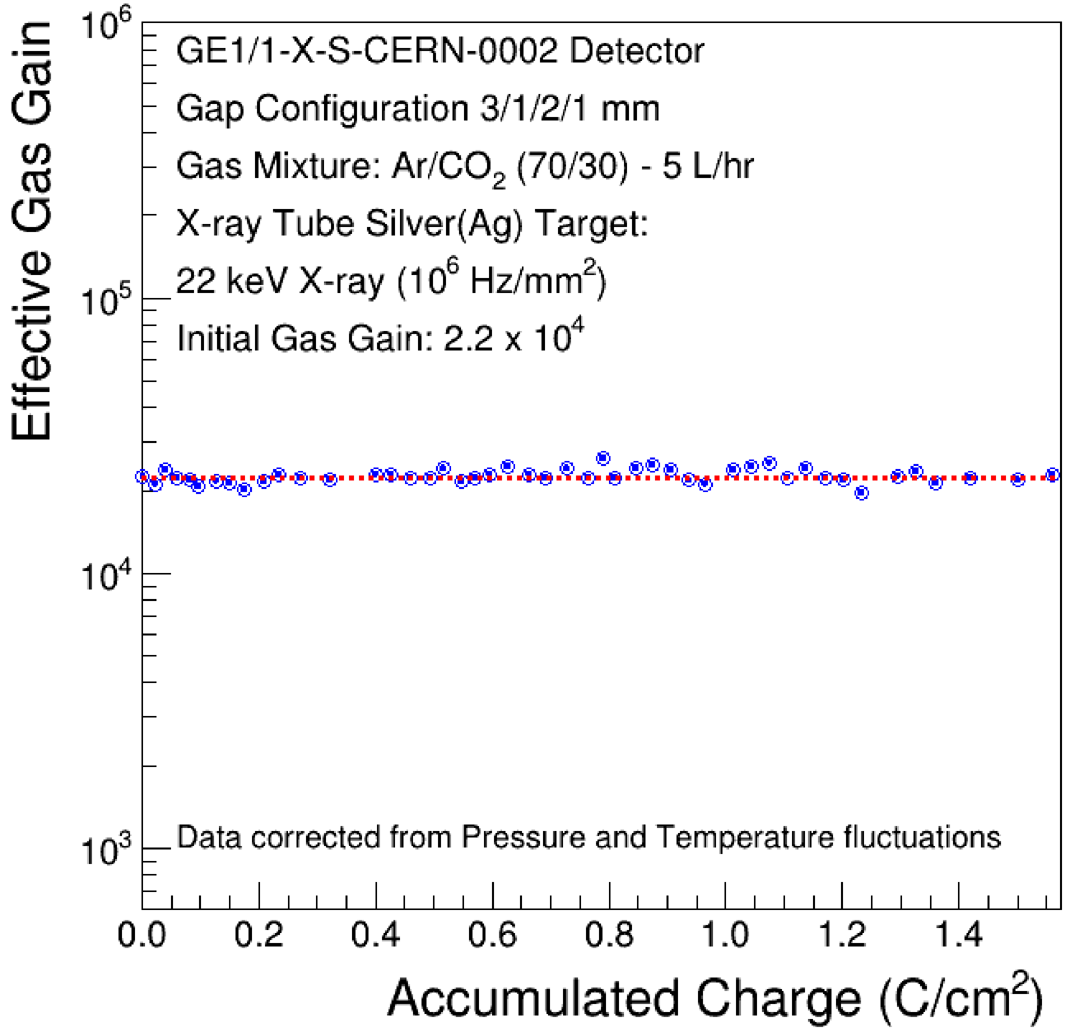
(Acceleration factor is 8 times higher than at GIF++)



Precise measurements of Gas Gain and Energy resolution were made to monitor the detector performances



Effective Gas Gain Evolution



$$Gain = \frac{I_{anod}}{e\, n_0 R}$$

No Effective Gas Gain loss up to 1560 mC/cm²

- **GE2/1 validated with SF=520**
- **GE1/1 validated with SF=260**
- **ME0 validated with SF=5.5**

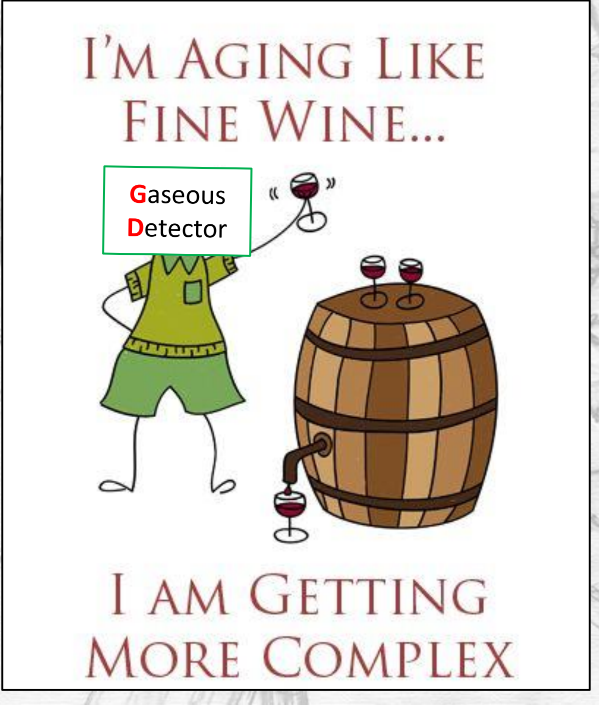
Fallavollita F, 2018, Triple-Gas Electron Multiplier technology for future upgrades of the CMS experiment: construction and certication of the CMS GE1/1 detector and longevity studies, CERN Ph.D. thesis, CERN-THESIS-2018-349.

Result of the aging campaign

Triple-GEM technology validated for all the CMS GEM projects with a

<u>Safety Factor 5.5 or higher</u>

Expand the actual concept of Aging study



The state of art

STANDARD

- ***Final detector design and materials*** → **This is good!**
- ***Higher Gain and/or Hit rate (compared to the one expected)***
- ***Clean Gas System***
- ***Irradiation with X-rays or γ-rays***

The state of art

STANDARD

- ***Final detector design and materials***
- ***Higher Gain and/or Hit rate (compared to the one expected)***
- ***Clean Gas System***
- ***Irradiation with X-rays or γ-rays***

→ **Well, we need to make some compromises**

The state of art

STANDARD

- ***Final detector design and materials***
- ***Higher Gain and/or Hit rate (compared to the one expected)***
- ***Clean Gas System***
- ***Irradiation with X-rays or γ-rays***

→

- **Real experiment will have clean gas system (of course)**
- **But It will run for much more time than the aging test**
- **The real experiment <u>is more exposed to gas contaminations</u> than Aging tests**

We need to take into account this when designing an aging test

The state of art

STANDARD

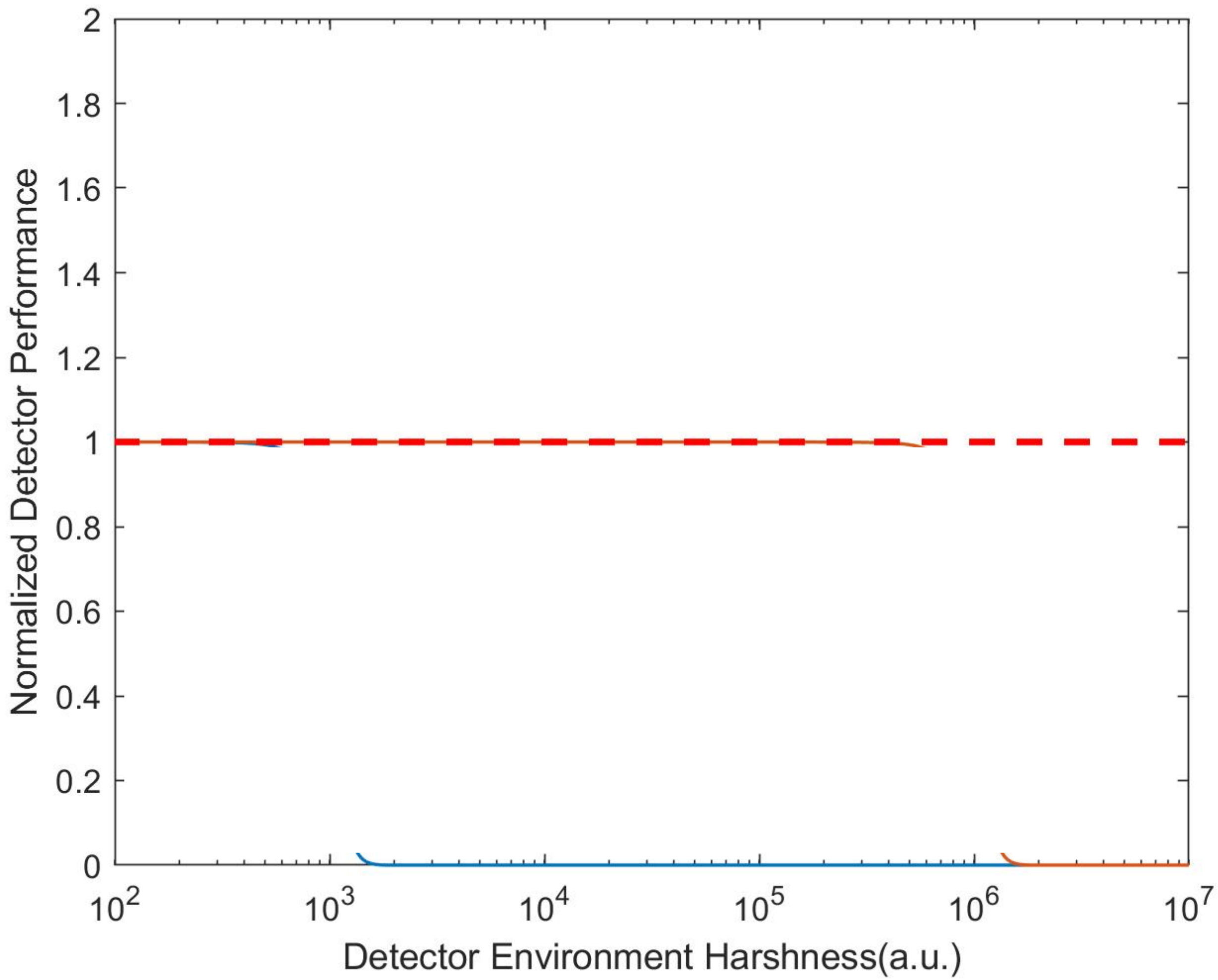
- ***Final detector design and materials***
- ***Higher Gain and/or Hit rate (compared to the one expected)***
- ***Clean Gas System***
- ***Irradiation with X-rays or γ-rays***

It is hard for an experiment to have only photon background

Not good!

Future Perspectives in MPGDs Aging

Parametrizing aging with only accumulated charge doesn't reproduce the real situation



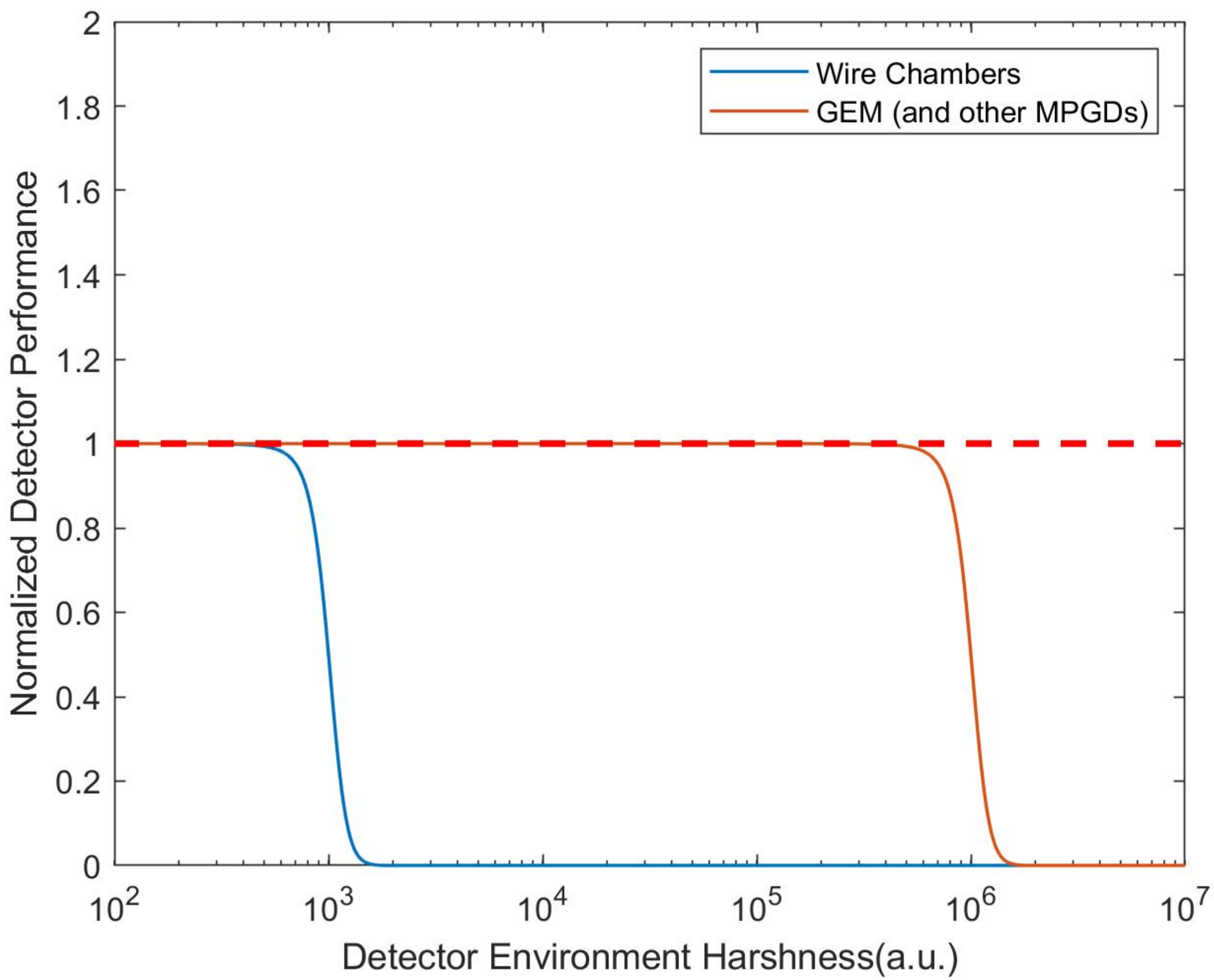
There are too many parameters:

- **Particle type**
- **Gas purity**
- **Cleanliness of the gas system**
- **Irradiation rate (we cannot cope with every rate)**
- **Irradiated surface**
- **…………**

Let's talk about 'Harshness'

Future Perspectives in MPGDs Aging

It is very difficult to see aging in a GEM detector

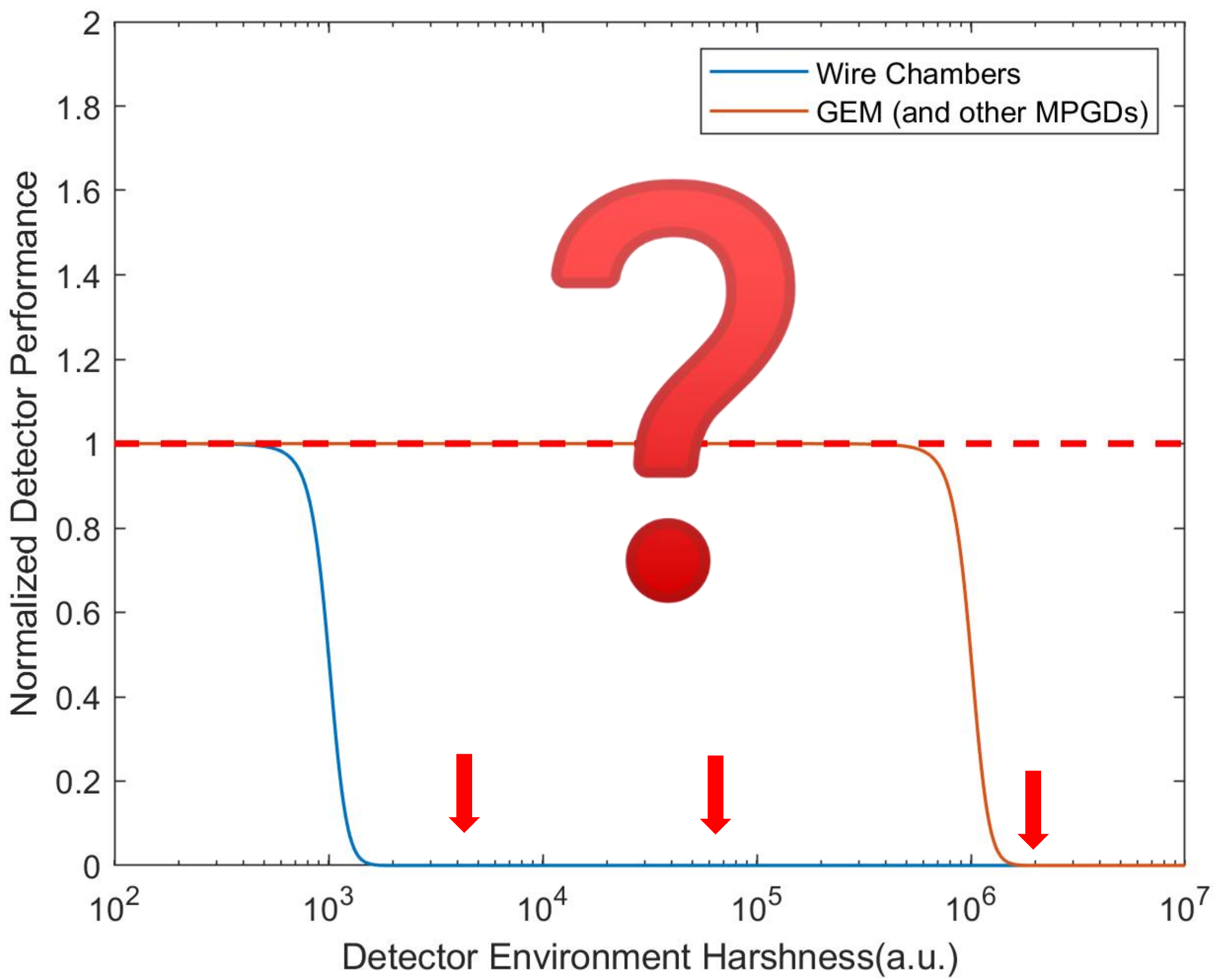


- **Multiplication in 3 step**
- **Anode and cathode far away the multiplication region**

Due to their promising performances (<u>spatial resolution, rate capability…</u>)
GEMs will be used in experimental environment where <u>NO</u> gas detector has ever been used

Future Perspectives in MPGDs Aging

Where is 'ME0 10 years of operation' in this plot?



Will GEMs survive without performance loss?

To answer this we need new aging test with an articially harshened Environment

Expand the standard of the aging study!

New ideas

Using contaminated gas mixtures

- Inserting small ammout of contaminating molecules in the gas volume
- Tuning the gas flow rate and the contaminant concentration
- ...

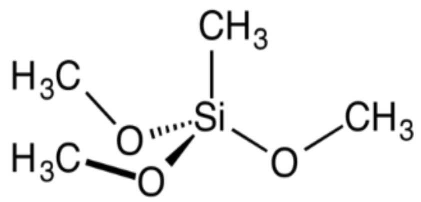
Using particles with high dE/dx

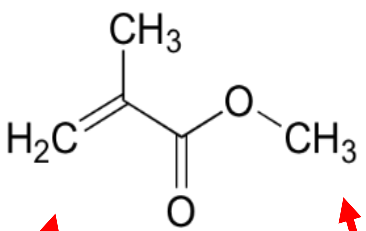
- Tuning the particle Hit rate
- Tuning the anodic current
- Tuning the ionization spatial density
- ...

Measuring different performance-releated quantities

- Spurious count rate
- Efficiency
- Discharge probability
- ...

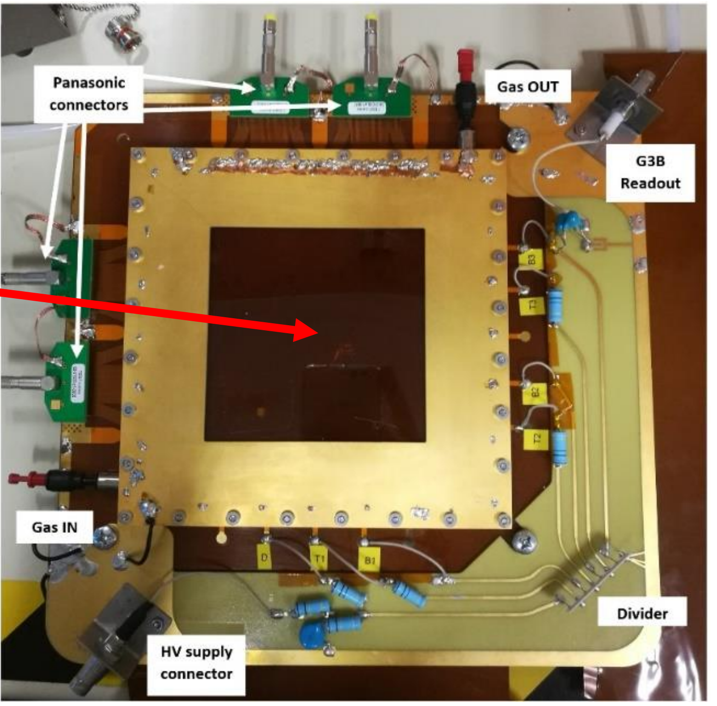
Triple-GEM 10x10 cm^2 Aging test #1





Glue vapors flushed in the gas

^{55}Fe source (X-rays)



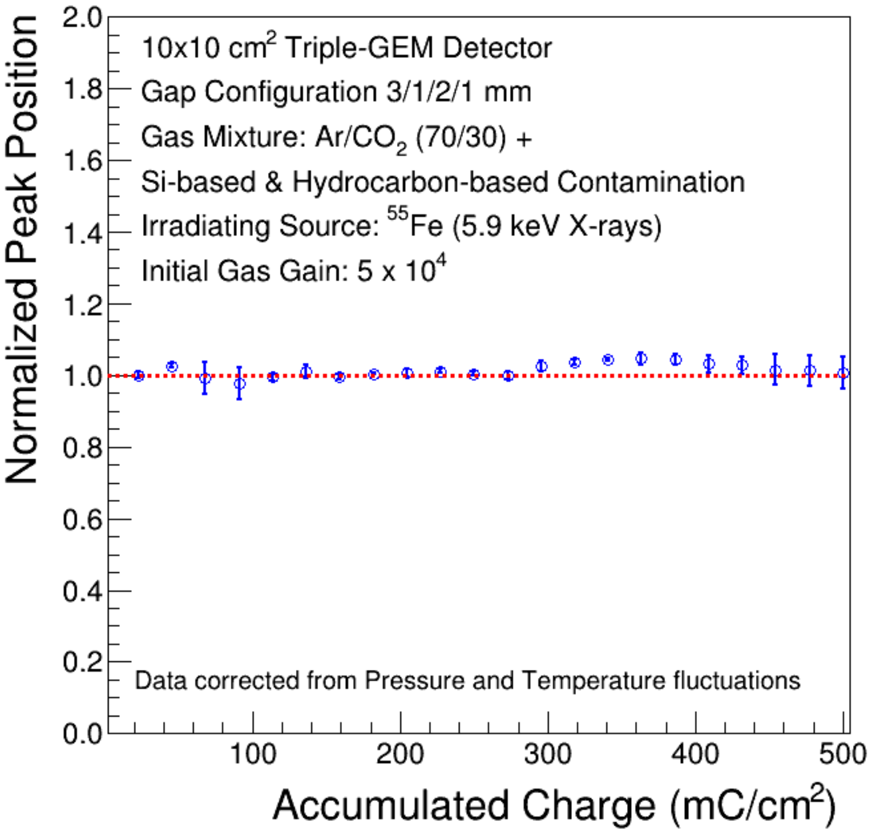
- **Contaminated gas mixture (accelerate the polymers creation)**
  - **Irradiation with ^{55}Fe only (5.9 keV X-rays)**

A classical aging study but with a contaminated gas mixture

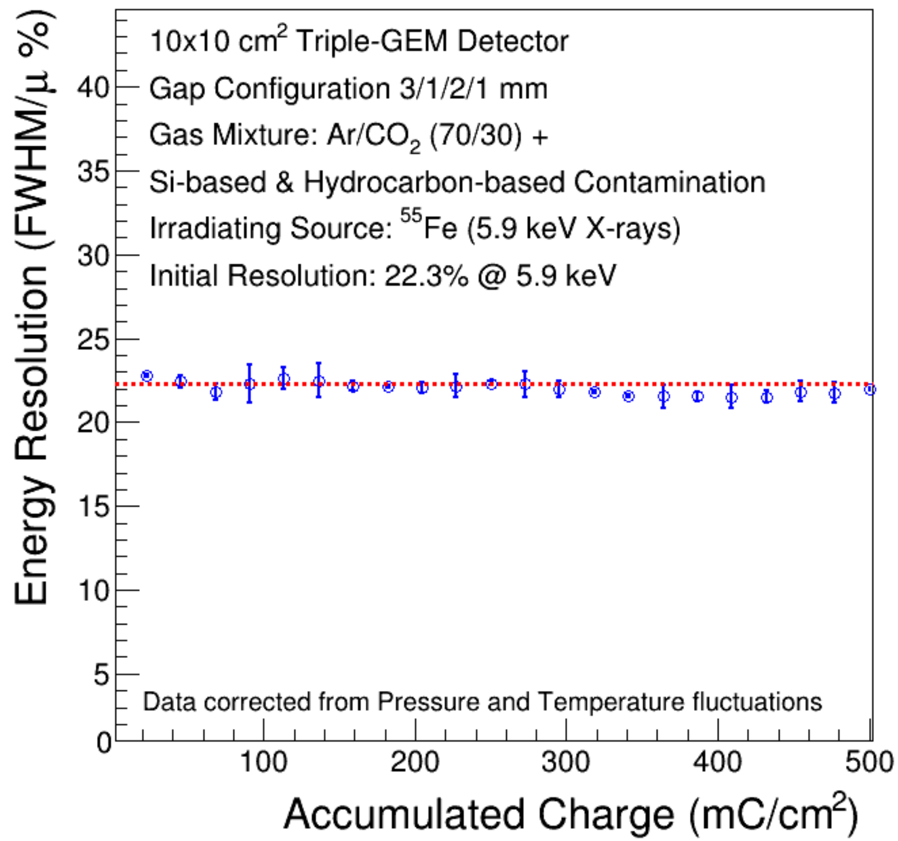
Triple-GEM 10x10 cm^2 Aging test #1

Results

Effective Gas gain monitor



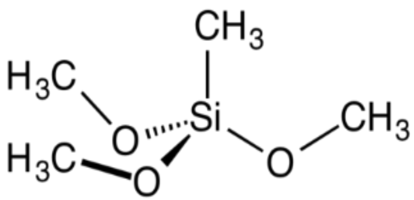
Energy Resolution monitor

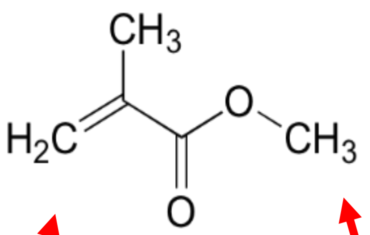


No performance loss up to 500 mC/cm^2

This integrated charge refers to a harsher environment with respect to the traditional aging test!

Triple-GEM 10x10 cm² Aging test #2

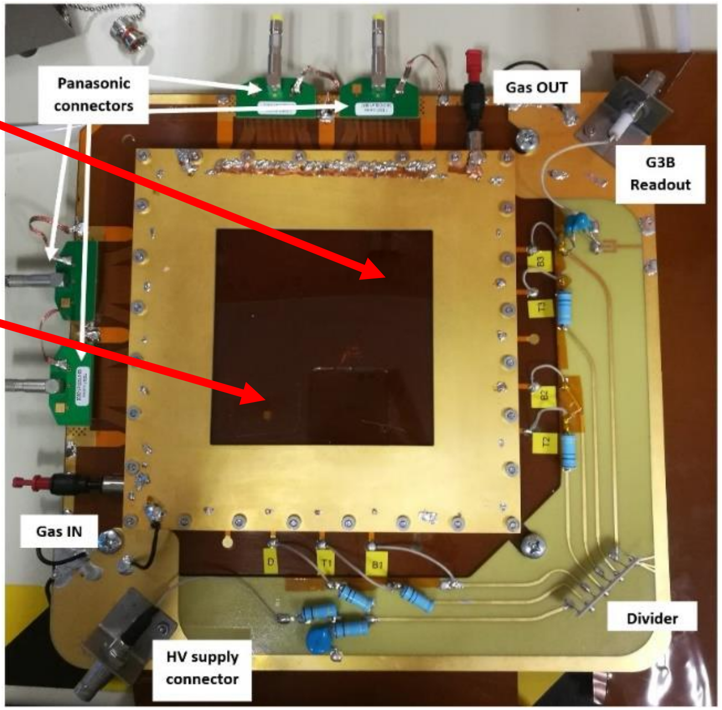




Glue vapors flushed in the gas

^{55}Fe source (X-rays)

^{241}Am source (Alpha Particles)



- Contaminated gas mixture (accelerate the polymers creation)
  - Irradiation with ^{55}Fe (5.9 keV X-rays) ^{241}Am (5.5 MeV α)

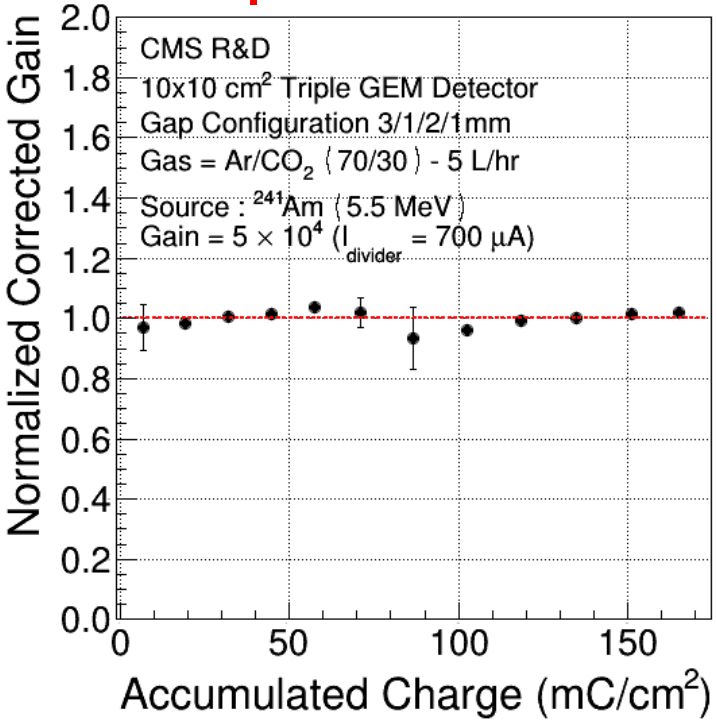
Same Interaction rate in the 2 sectors!!!

Triple-GEM 10x10 cm² Aging test #2

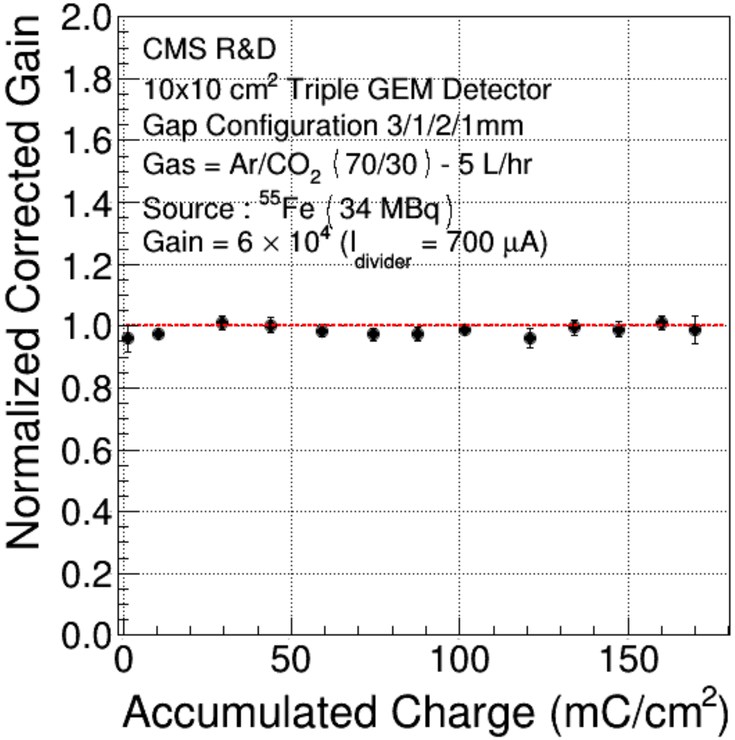
Results

Charge spectrum from the two sectors to monitor the performance

Alpha Sector



Xray Sector



No aging in both the sectors (alpha and X-ray) up to 165 mC/cm² in heavily contaminated gas mixture

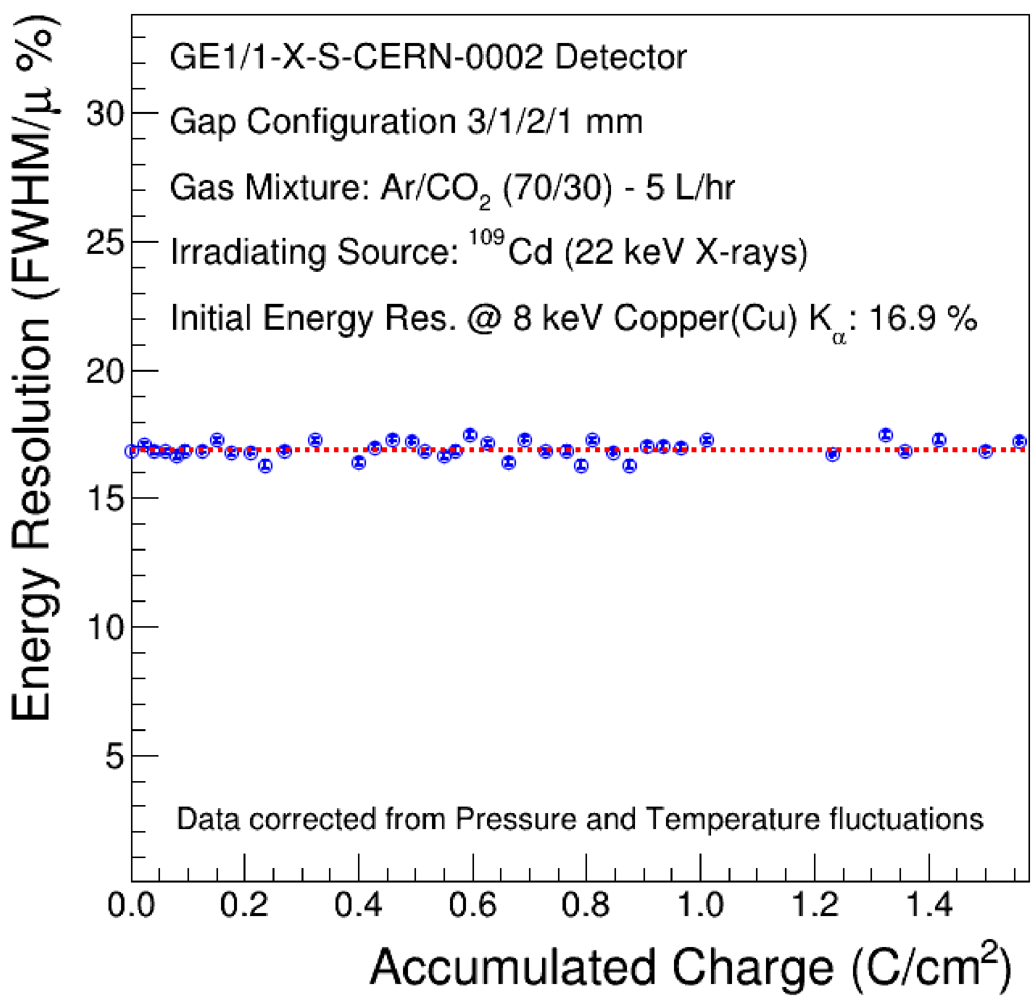
Conclusion

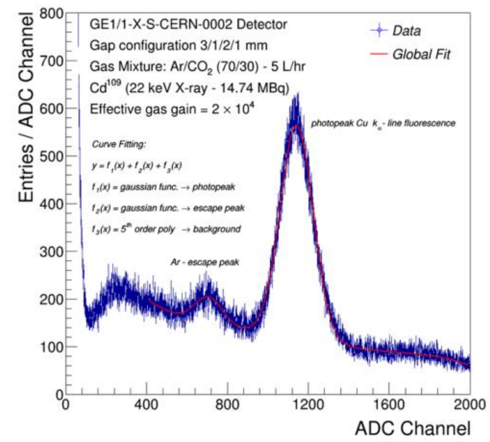
- Standard aging tests validated the GEM technology for all the GEM projects
- New aging tests demonstrated the limits of the Standard aging test, we are trying to find different methods to test detectors.
  - Aging test in contaminated gas mixtures
  - Aging test with HIPs
- It is better to talk about 'harshness' of the detector environment rather than using only the accumulated charge.
  - Still, it is not a well defined concept: it depends on too many variables
- New aging test campaign started to better undestand the effect of the harshening variables (hit rate, primary ionization, gas contamination, current density, gas flow rate...):
  - Wire chambers (possibility to discuss privately about first results)
  - GEM-detector
  - Other technologies (?)

BACKUP

Energy Resolution Evolution

Energy spectrum monitored via MCA





$$R(\%) = \frac{FWHM}{\mu}$$

No Energy Resolution loss up to 1560 mC/cm²

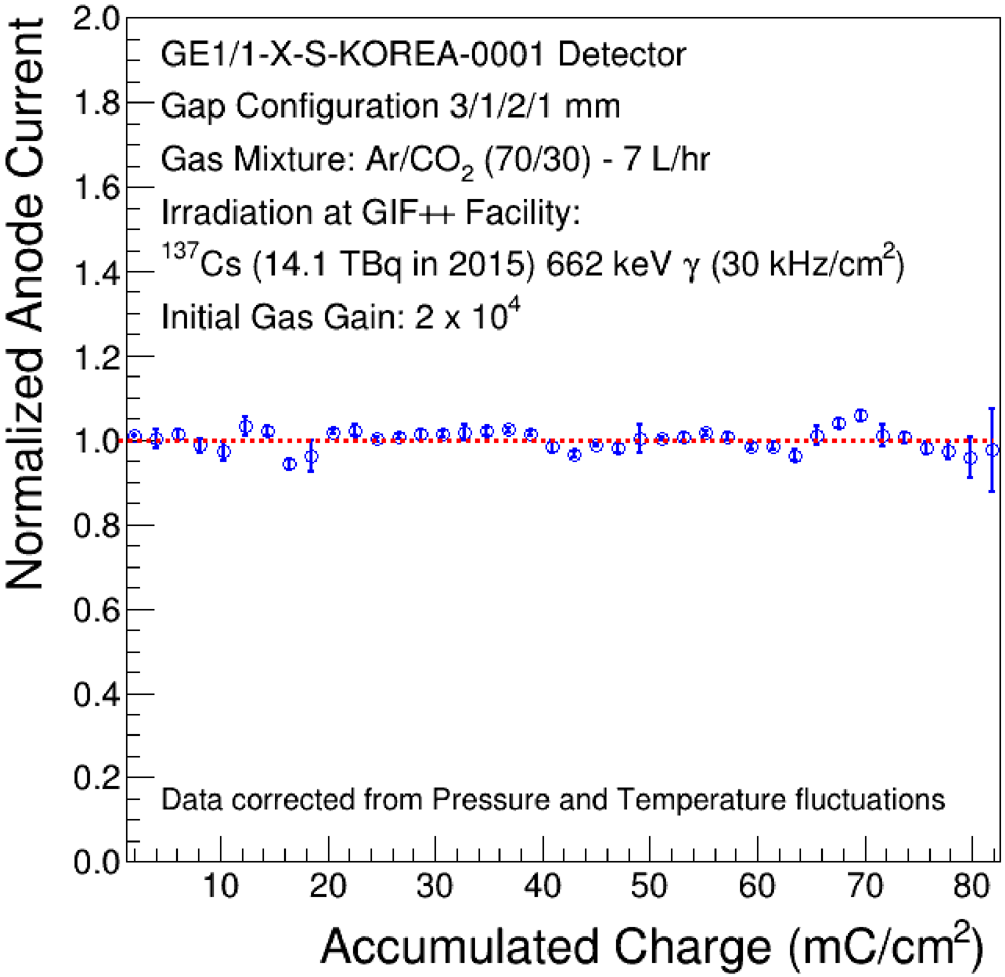
- **GE2/1 validated with SF=520**
- **GE1/1 validated with SF=260**
- **ME0 validated with SF=5.5**

Irradiation at GIF++ facility

(KOREA foils)

KOREA GEM foils production

Anodic current monitored via Keithley 6487 pico-ammeter



$$Gain = \frac{I_{anod}}{e\, n_0 R}$$

Anodic current follows the Effective gas gain if the Hit Rate & the source type is constant

No Effective Gas Gain loss up to 82 mC/cm²

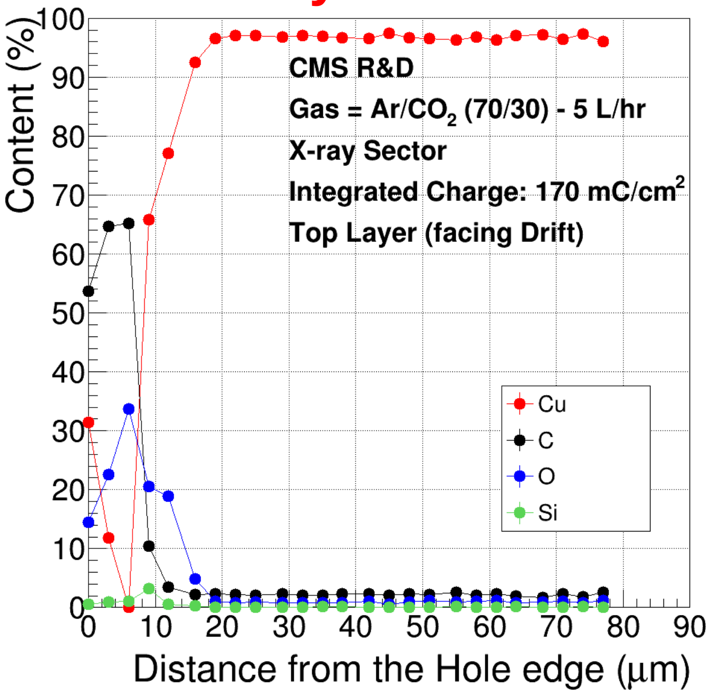
- **GE2/1 validated with SF=27.3**
- **GE1/1 validated with SF=13.7**
- **ME0 NOT validated (SF=0.29)**

Triple-GEM 10x10 cm^2 Aging test #2

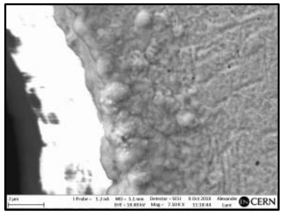
EDX Analysis of GEM foils

Third GEM foil composition analysis from both the sectors

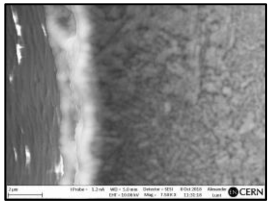
Xrays Sector



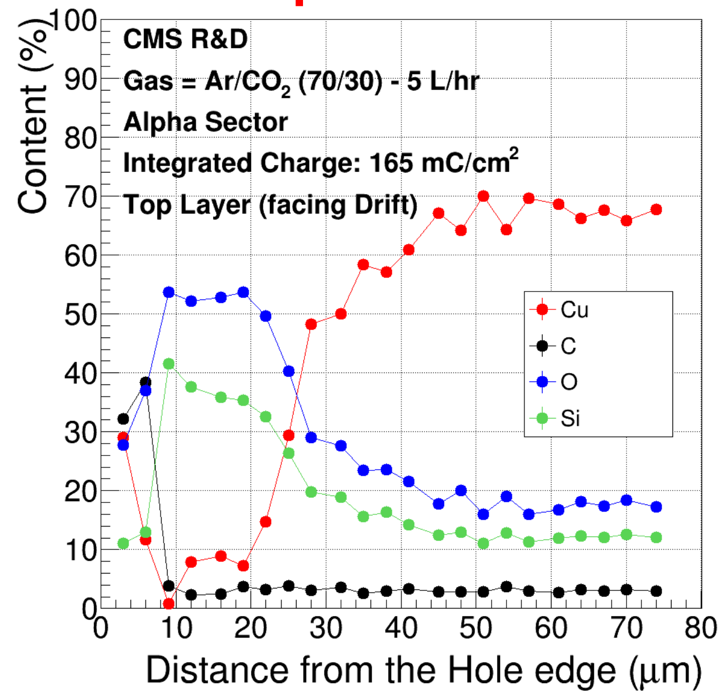
Xrays Sector



Alpha Sector



Alpha Sector

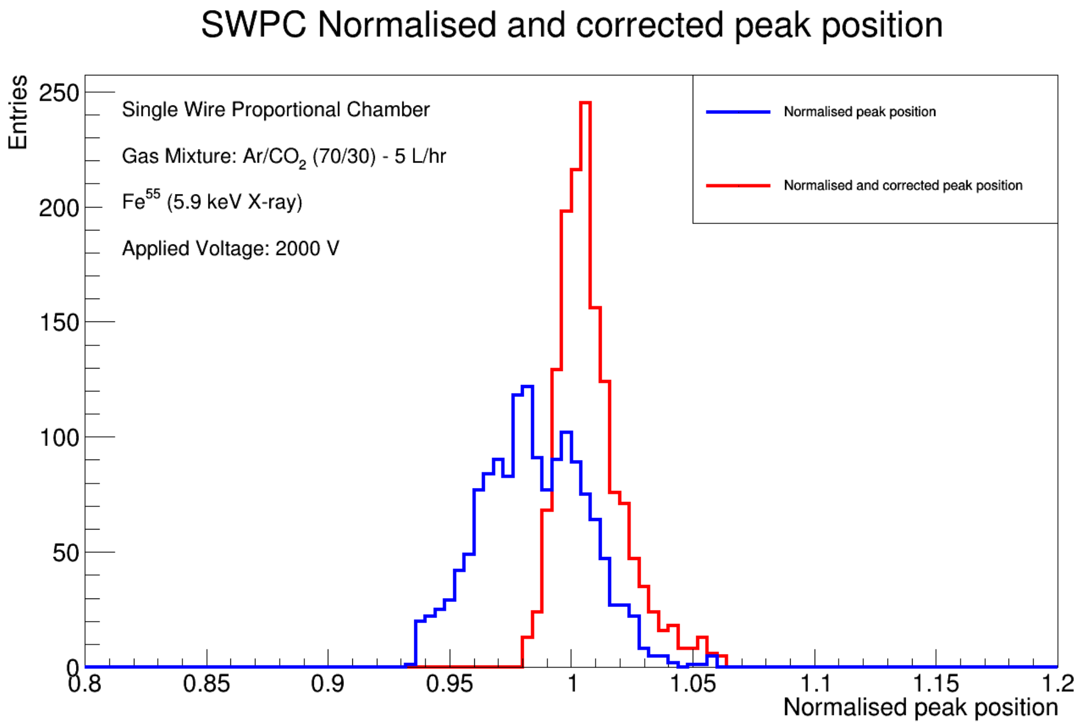


Nevertheless the same integrated charge, the alpha irradiated foil contains way more silicon deposits

Environmental Correction

Fitting with a power law

$$G_{meas.} = G_{real.} \cdot (A \cdot T)^a \times (B/P)^b$$



Acceleration factors

Expected Charge accumulation rate in ME0

$$R_C = \frac{283\,\frac{mC}{cm^2}}{3650\ days} \approx 0.08\,\frac{\frac{mC}{cm^2}}{day}$$

Charge accumulation rate during GIF++ irradiation

$$R_C \approx 0.4\,\frac{\frac{mC}{cm^2}}{day}$$

5x ME0

Charge accumulation rate during X-ray gun irradiation

$$R_C \approx 3.2\,\frac{\frac{mC}{cm^2}}{day}$$

30x ME0

8x GIF++

Typical DAQ scheme