Comparative Aging Studies of GEM Detectors in contaminated Environments

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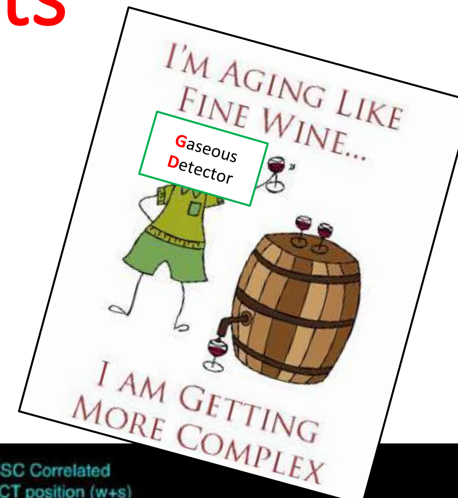
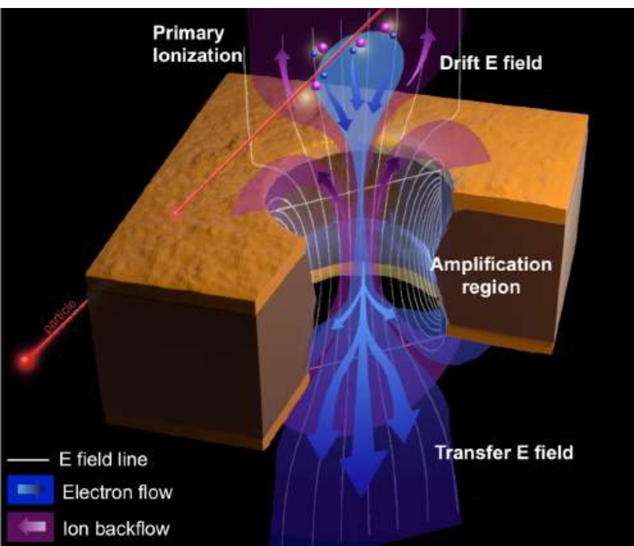
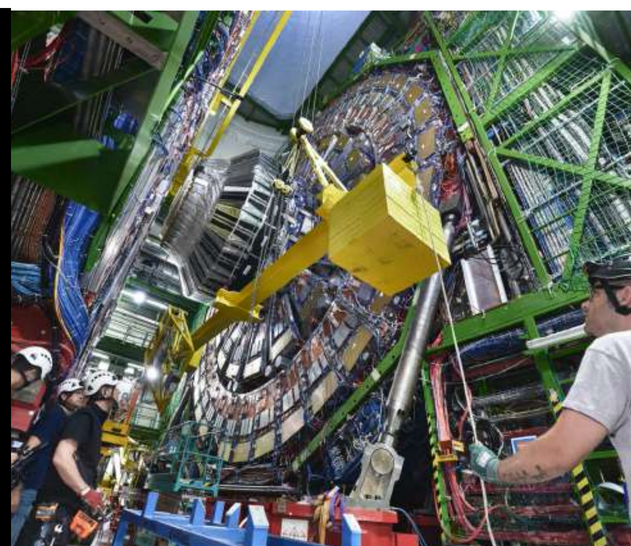
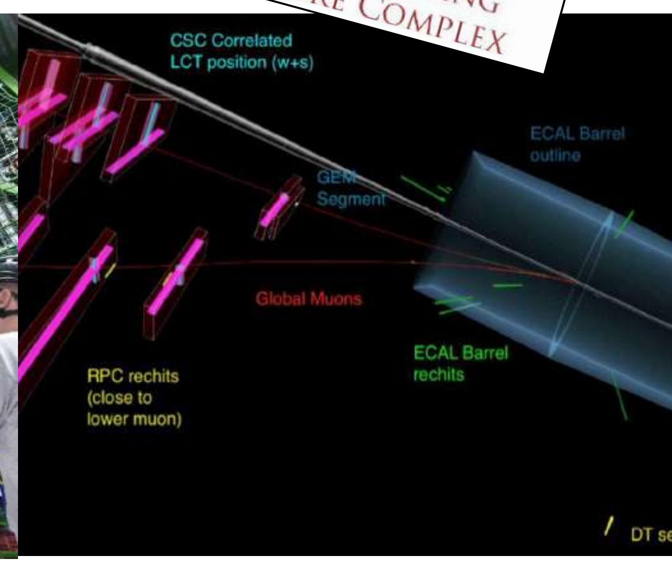






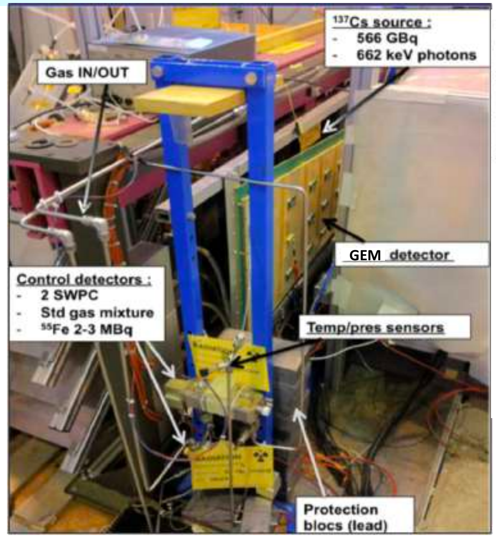


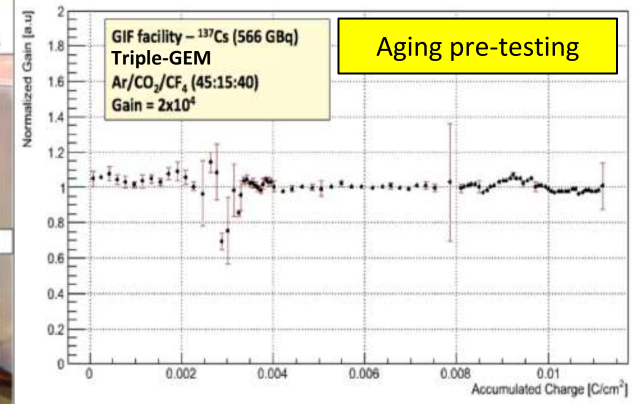
*(now at Gran Sasso Science Institute (GSSI) & INFN LNGS)
**(now at Max Planck Institut für Physik - Werner Heisenberg Institute)

Introduction

Aging pre-testing in 2013-2014:

- Large triple-GEM prototype
- Ar-CO2 (70-30)
- 2 wire chambers for gas purity monitoring (upstream and downstream) with low rate X-ray sources
- ^{137}Cs (662 keV photons)
- Short test period (7 months)



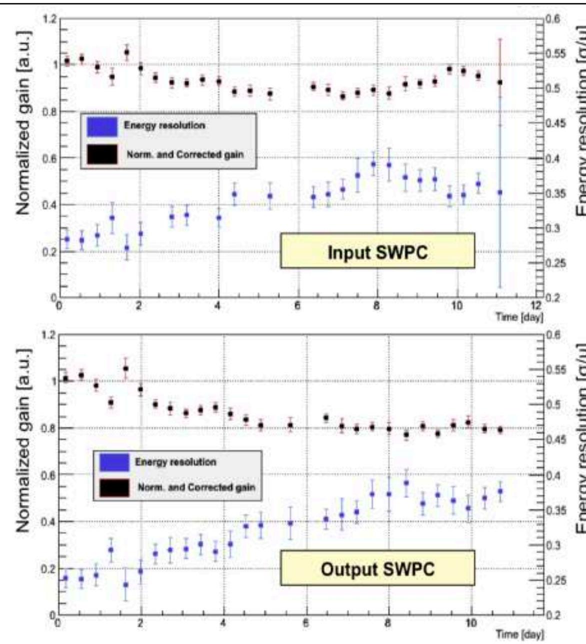


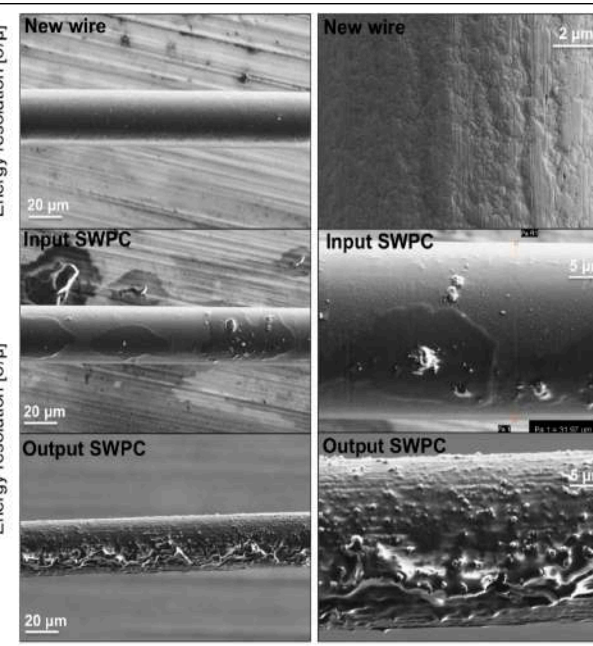
→ No signs of aging in the GEM prototype up to 12 mC/cm^2

Evidence of gas contamination:

- Both input and output wire chambers show clear signs of aging after just a few days of irradiation
- Presence of Silicon deposits in the irradiated regions

→ Confirmation that the gas was contaminated even though the GEM detector did not show signs of performance degradation

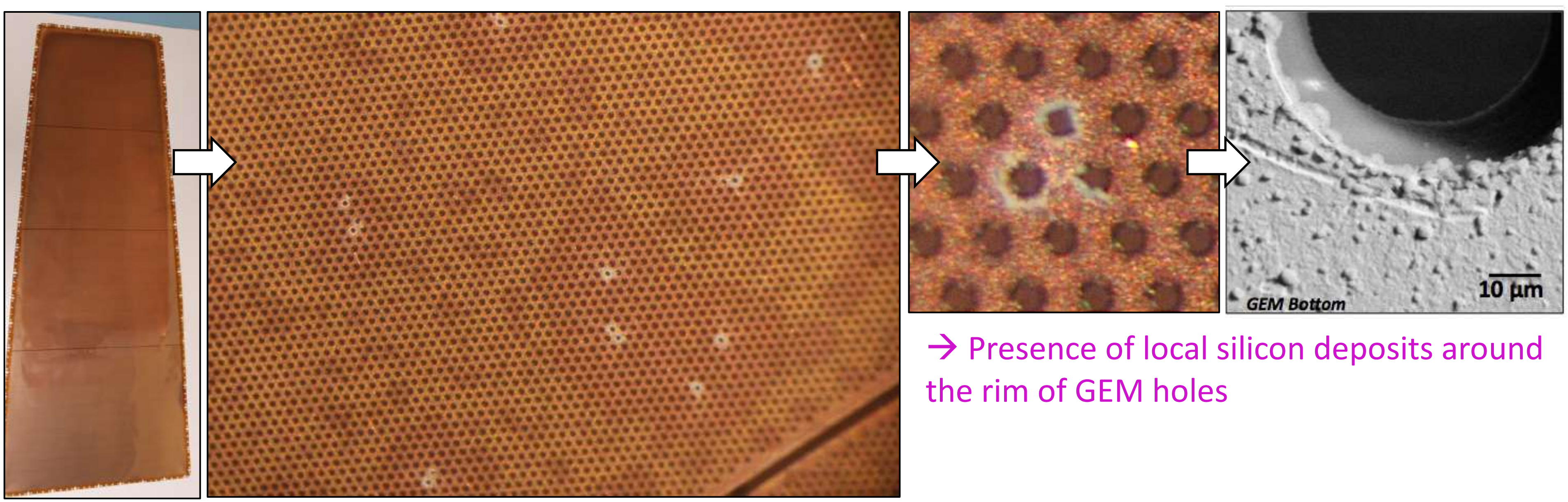




Introduction

Suspicious observations:

- Once the pre-test was done, the final aging test was started after in-depth cleaning of the entire gas tubing, removal of suspicious T sensors in the gas line, and using a later generation of GEM detectors
- The pre-test GEM chamber was opened for inspection:
  - Presence of unidentified "**white dots**" in the irradiated region, typically involving 1-2 holes
  - SEM+EDS (Energy Dispersive Spectroscopy) revealed the presence of silicon deposits
  - Rest of the foil is in perfect state

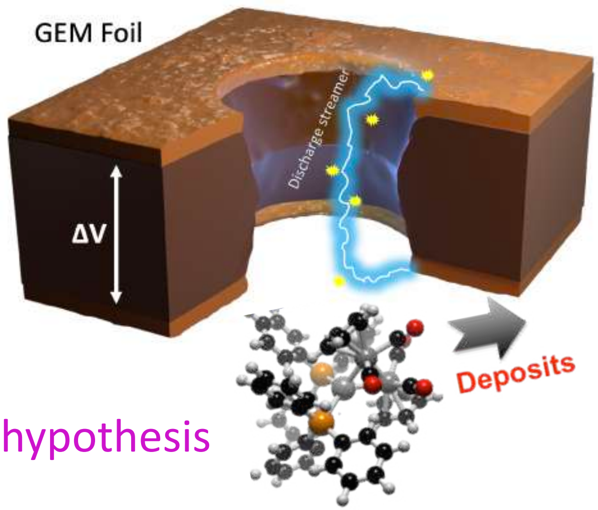


→ Presence of local silicon deposits around the rim of GEM holes

Motivations

Preliminary hypothesis:

- Even in the presence of pollutants in the gas, GEM foils did not suffer polymerization in normal conditions of operation (up to the accumulated charge of this test)
- But polymerization occurred in specific holes subject to discharges:
  - Increased energy involved in the discharge process triggered gas fragmentation and re-combination



→ New tests will be conducted in 2023/2024 to confirm this hypothesis (using simplified single-hole GEM foils)

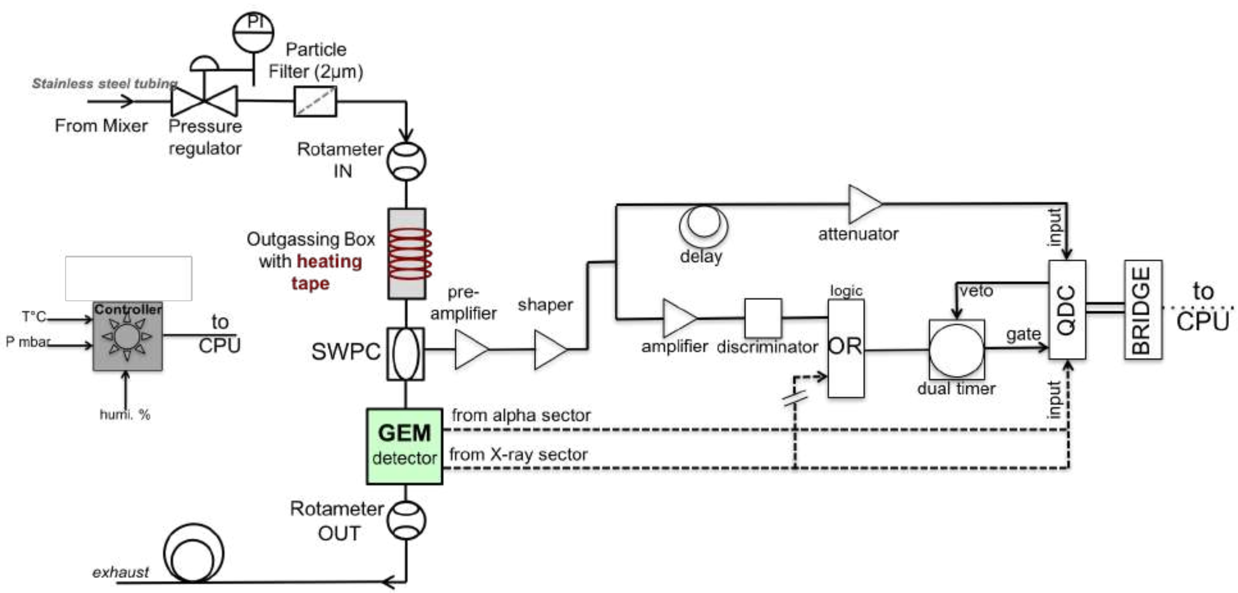
Motivations for new studies:

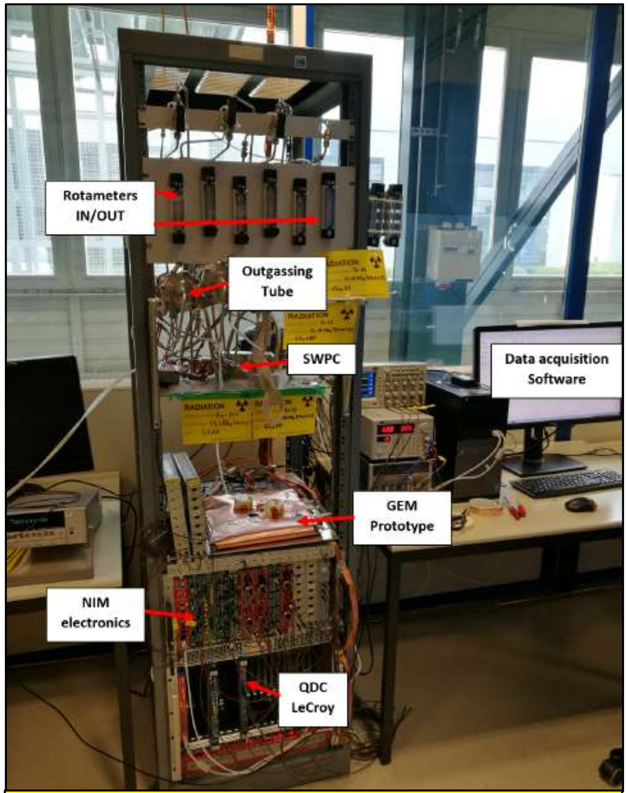
- If the energy at play during in the electron avalanche is a driving factor, the aging rate might then depend on the charge density inside GEM holes
- What is the influence of the primary charge (i.e. particle/interaction type) on the aging rate ?
  - → Proposal to conduct comparative studies with low energy photons vs. Heavy Ionizing Particles (HIP)
  - → Use of heavily contaminated gas to facilitate the observation of aging

Test Setup Overview

Special aging test setup:

- Standalone setup at CERN previously used for outgassing studies
- 4 identical test lines with: individual gas flow control, outgassing box, monitoring wire chamber
- Common “old style” DAQ chain with NIM (trigger) +VME (ADC)
- Meteo station for T/P monitoring and recording





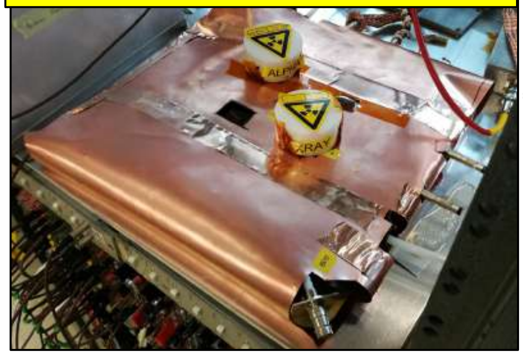
Outgassing/Aging test setup at CERN (CMS GEM Lab)

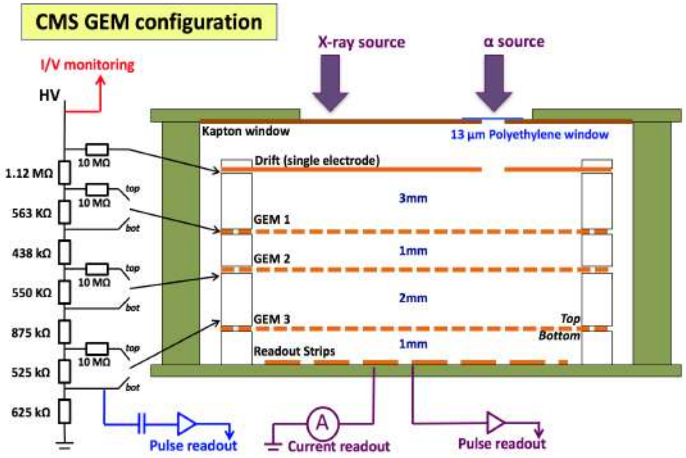
Detector Setup

Triple-GEM:

- 3/1/2/1mm configuration
- Ar-CO2 (70-30%) @ 5L/hr
- Alpha sector (special opening)
  - ^{241}Am: α rate = 600 Hz
  - Primary charge ~ 12k pairs
- X-ray sector
  - ^{55}Fe: γ rate = 900 Hz
  - Primary charge ~ 200 pairs

Triple-GEM

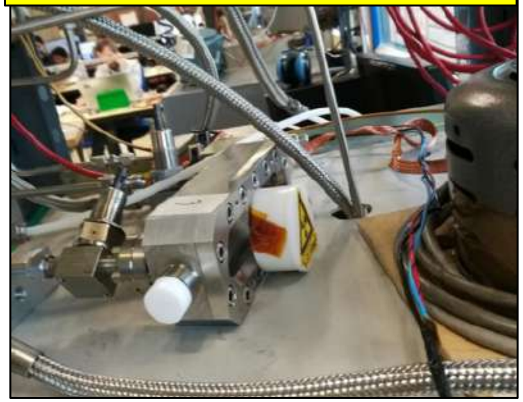


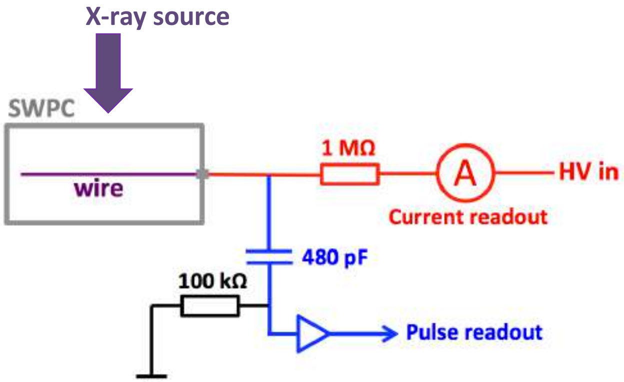


SWPC: (Single Wire Proportional Counter)

- Gold-plated Tungsten wire (diam. 50 µm)
- Ar-CO2 (70-30%) @ 5L/hr
- X-ray irradiation
  - ^{55}Fe: γ rate = 700 Hz
  - Primary charge ~ 200 pairs

SWPC

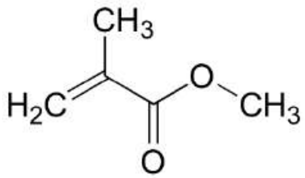




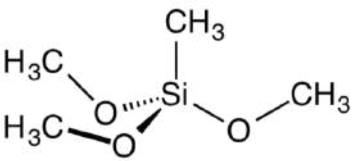
Introducing Pollutants

Outgassing box:

- Use of the outgassing test setup to have any material upstream the detectors under test
- Outgassing box filled with: 10g of 3140 RTV Dow Corning + 10 g of Acrifix 1R 0192 (PCV glue)
- Expected contaminants:



Methyl Methacrylate



Methyl Trimethoxysilane

Polluting sample

Outgassing box

- Heating tape wrapped around the outgassing box to heat up the sample and enhance the outgassing

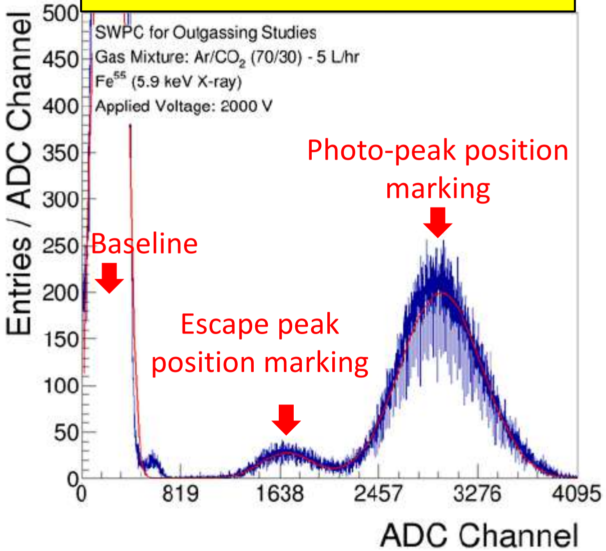
Data Acquisition

Measurement of effective gain variations:

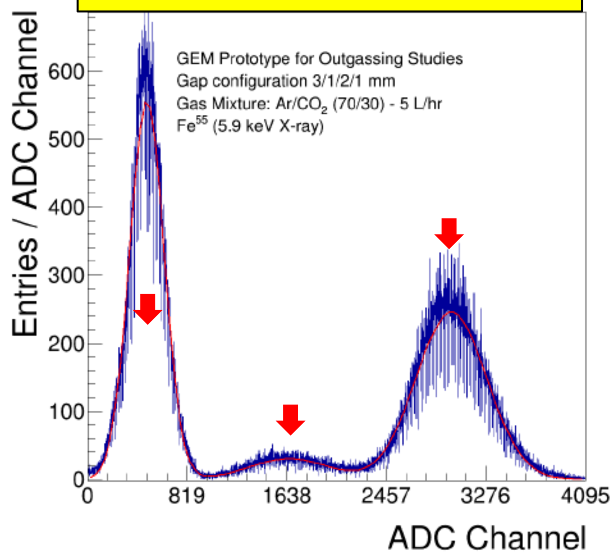
- ADC spectra recorded every 30 min during the long run for both SWPC and the various GEM regions
- Off-line analysis to identify ADC values for: baseline, escape peak and photo peak
- Test duration depends on the source rate and the primary charge (to reach the same accumulated value)
- Polluting material was heated up to 50C during the second half of the irradiation period

→ **Total accumulated charge equ. to 170mC/cm², i.e. > 70 days of continuous irradiation**

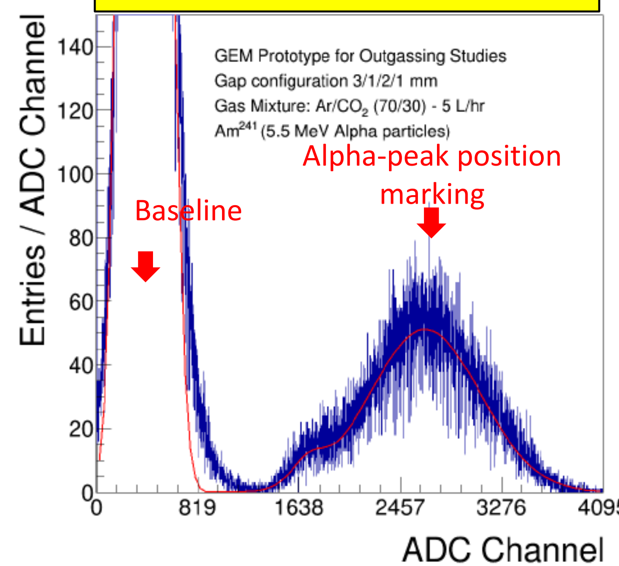
SWPC



GEM X-ray sector



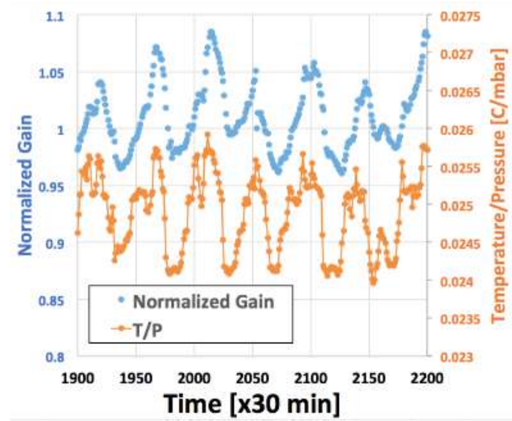
GEM Alpha sector



Data Analysis Overview

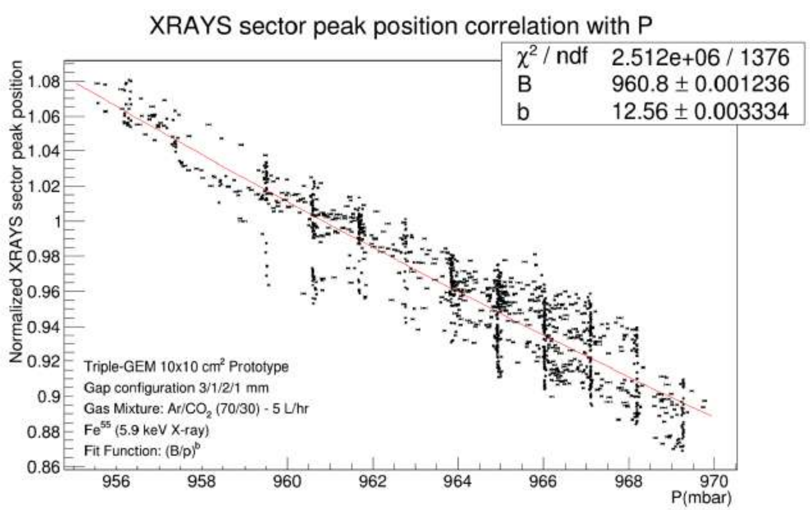
Correlation with the environment:

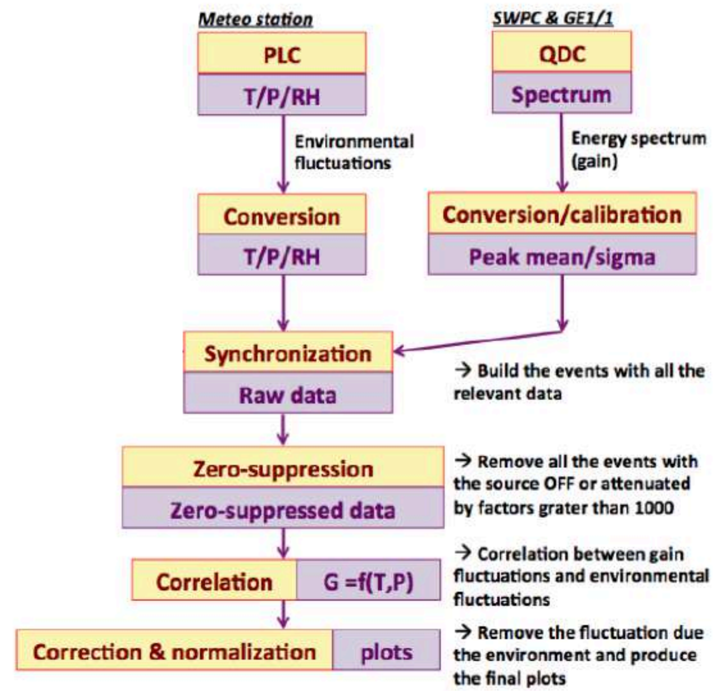
- Usual influence of T and P on the detector gain
- Environment fluctuations are recorded every 5 min during the entire irradiation test
- Data are combine with detector output to make comprehensive events



Analysis workflow:

- Identify the correlation between T/P/Gain
- Apply T/P correction
- Normalize to initial gain values

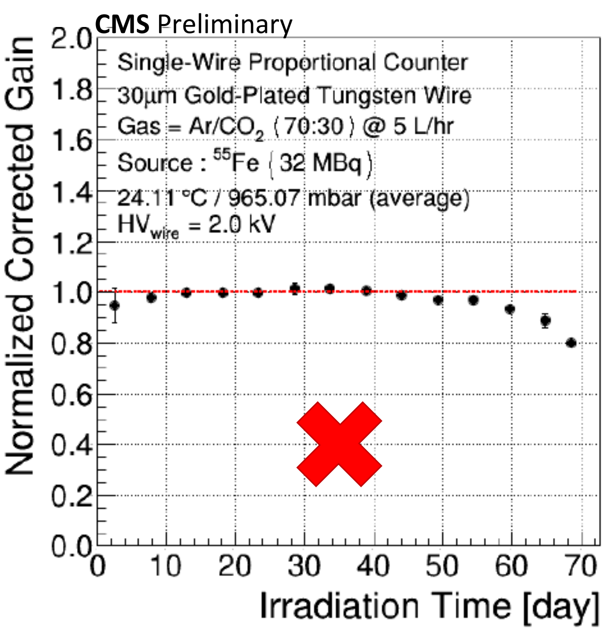




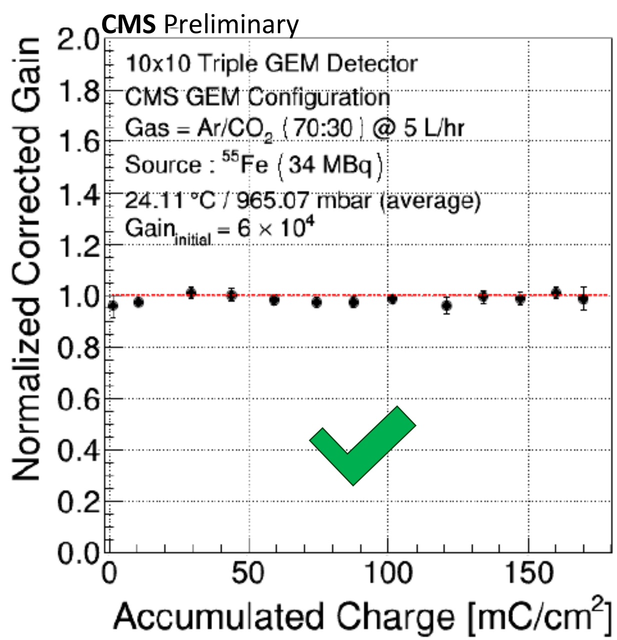
Results Overview

Initial Observations:

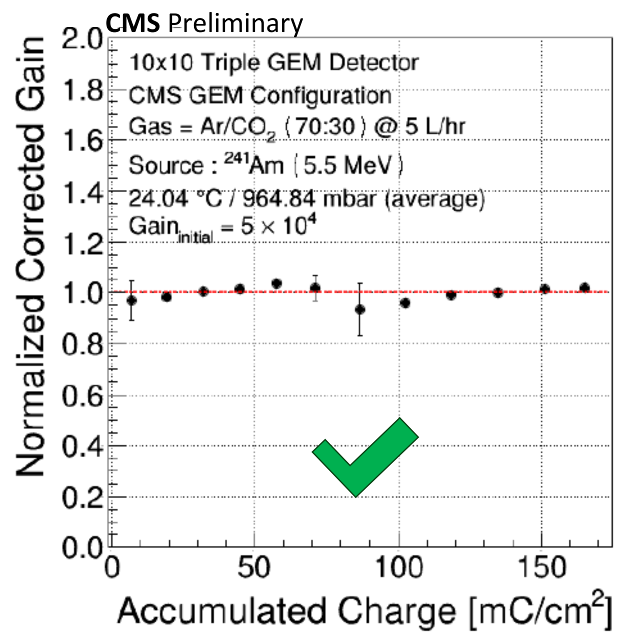
- All detector (all regions) accumulated the equivalent of 170 mC/cm^2 (over a period of 70-90 days)
- Permanent gain drop in the wire chamber
- No change of effective gain in the two GEM regions



Aging



No Aging



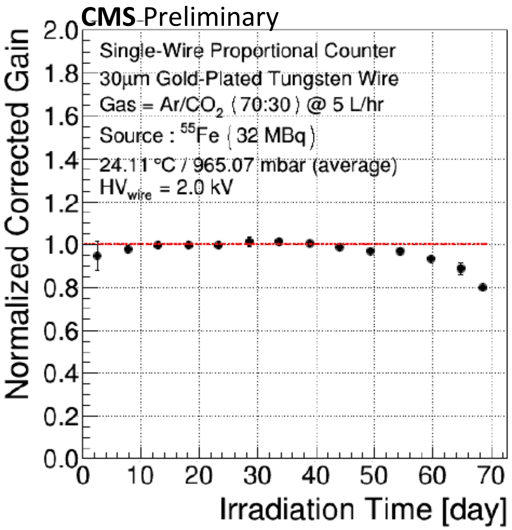
No Aging

SWPC Analysis

Initial Observations:

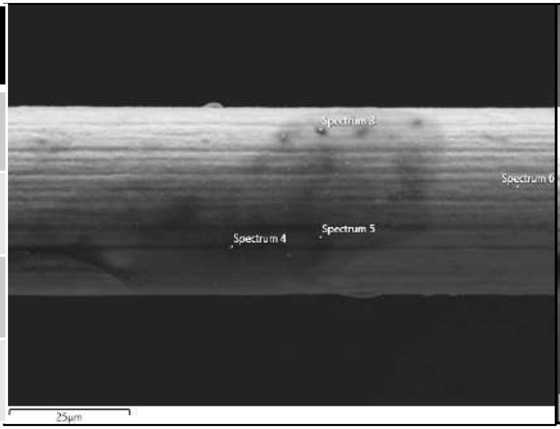
- Clear evidence of gain drop after about 50 days of operation
- Not recovered after flushing gas without HV + neighbor (not irradiation regions) show normal gain values
- SEM confirms the presence of 5-10 µm deposits in the irradiated region
- EDS confirms the presence of Silicon at the level of the deposits

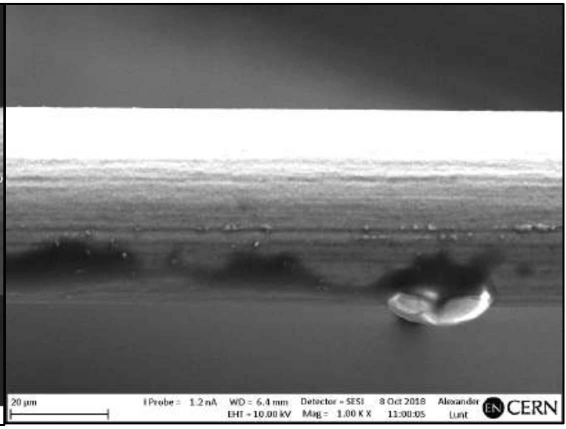
→ Clear confirmation of aging phenomenon triggered by the upstream outgassing material



EDS Analysis:

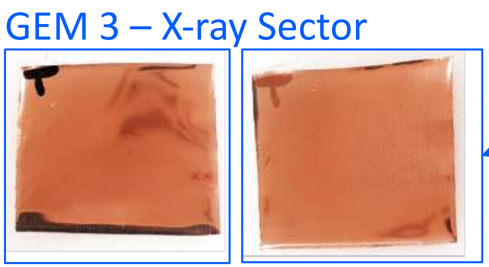
%	Au	C	O	Si	Na	+ traces
Spectrum 3	7.9	67.8	17.7	2.8	1.5	Al, Mg, K, Cl, S, F, Ca
Spectrum 4	9.6	13.2	26.4	27.3	2.2	Al, Mg, K, Cl, S, F, Ca
Spectrum 5	62.4	14.2	10.7	8.3	1.6	Al, Mg, K, Cl, S, F, Ca
Spectrum 6	78.1	4.0	13.0	4.2	0.2	Al, Mg, K, Cl, S, F, Ca

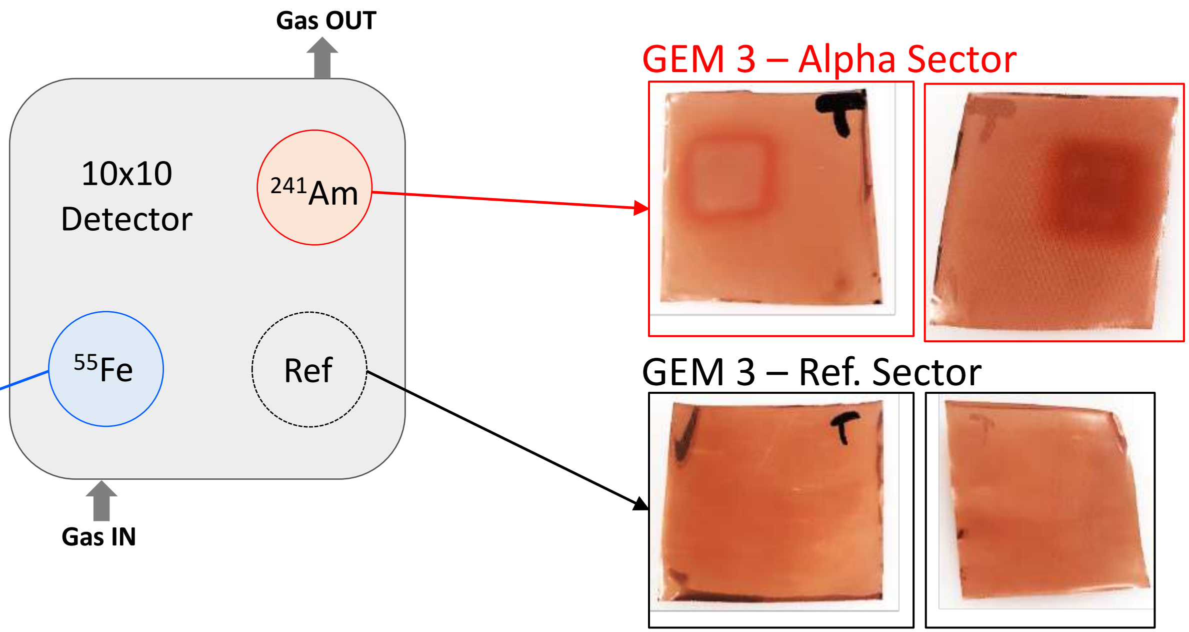




GEM Sample Analysis

Samples collected on GEM3 top and bottom sides for both irradiated sectors and for reference





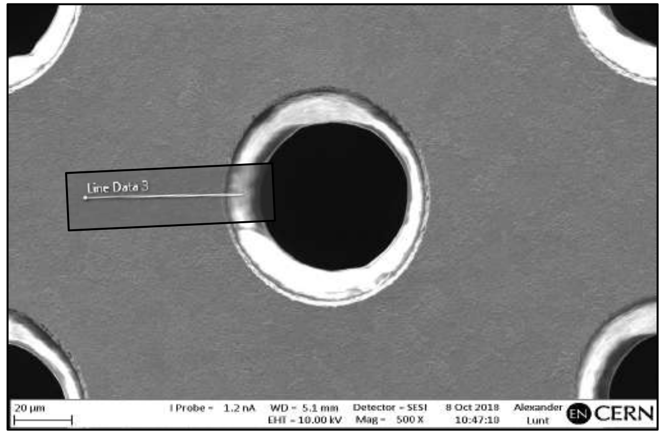
Analysis Plan:

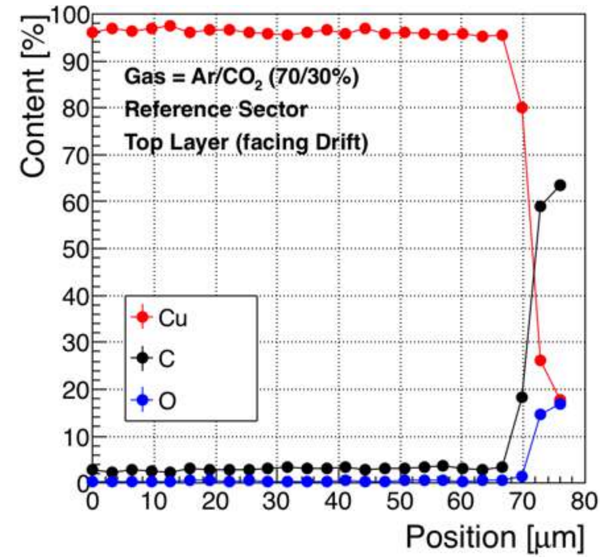
- ❑ Visual Inspection
  - Reference samples and X-ray samples appear clear and shiny
  - Alpha samples show a dark stain with the same shape as the irradiation window
- ❑ SEM imaging of the surfaces with focus on the GEM rim
- ❑ Linear EDS analysis

Reference Sector

Top Side (DRIFT)

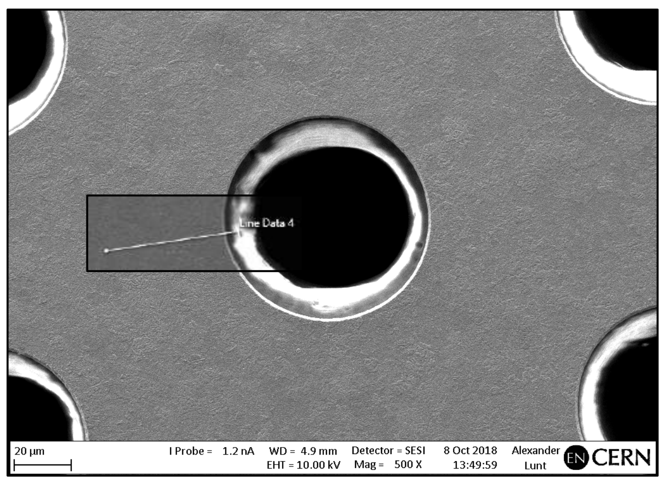
- 25 EDS measurements done along a data line of 75 µm from inter-hole region to hole rim
- Composition of the different elements at the level of %

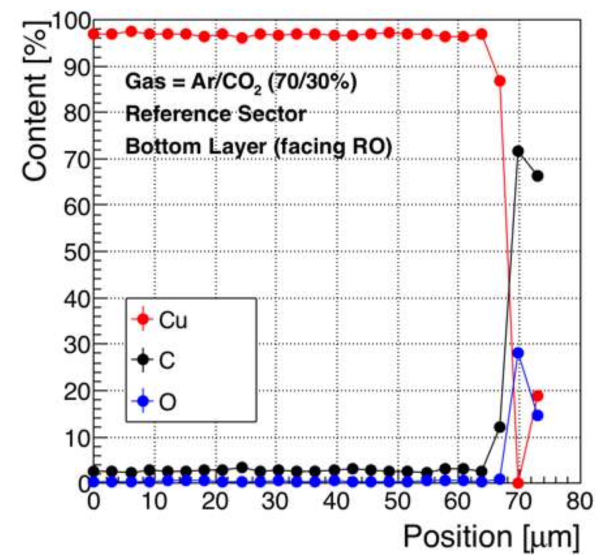




Bottom Side (ReadOut)

- In both cases: clean surface with > 97% copper
- Polyimide region clearly identified along the data line due to the clear increase of C and O compounds
- No other elements

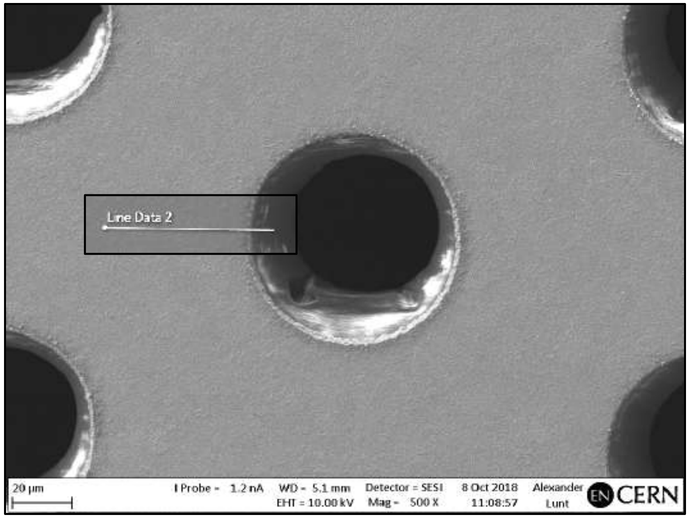


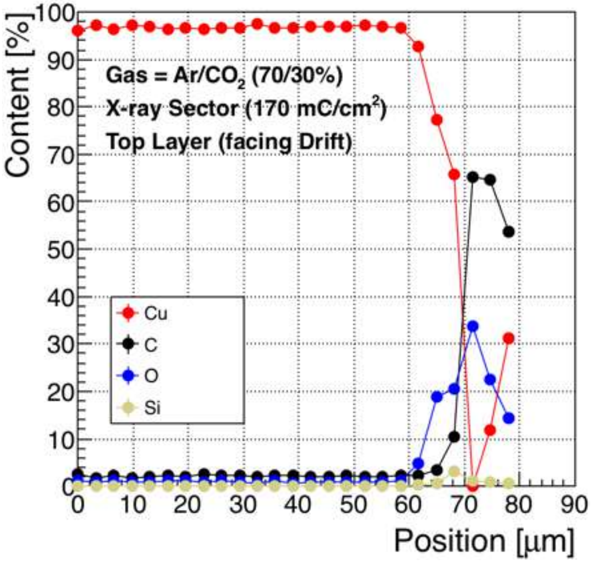


X-ray Irradiated Sector

Top Side (DRIFT)

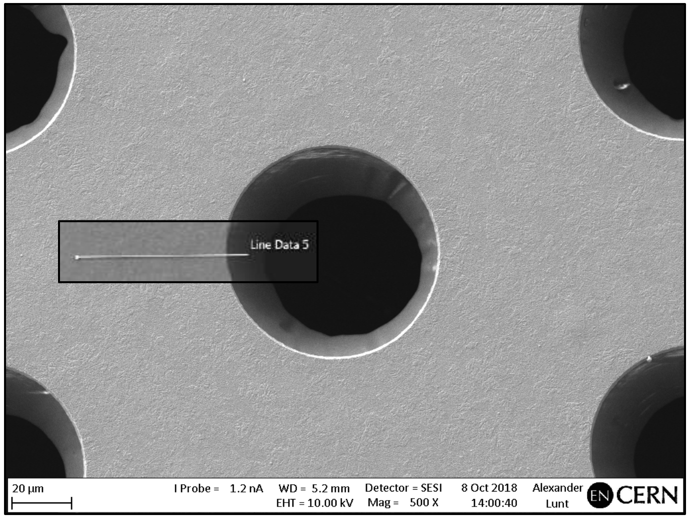
- Presence of slight Silicon deposits (4%) at the very edge of the GEM holes
- The rest of the foil is as clean as the reference sample

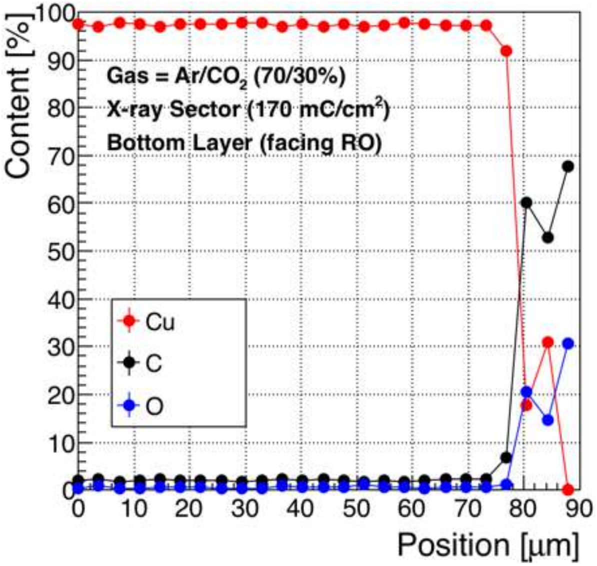




Bottom Side (RO)

- Clean foil with no traces of Silicon deposits, even at the hole rim

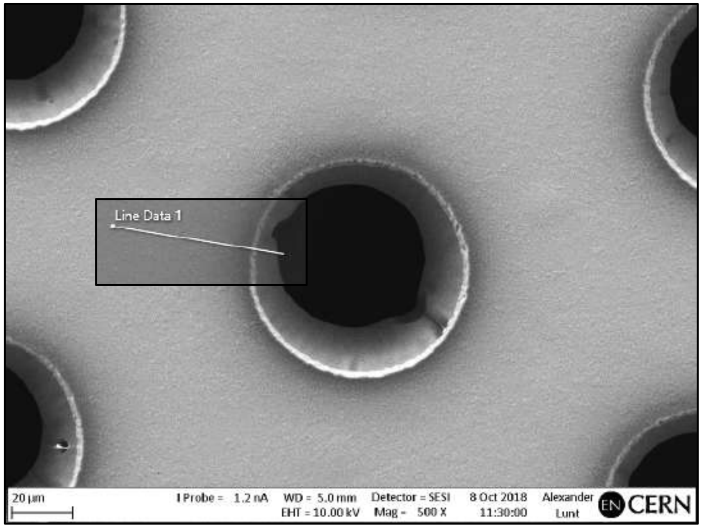


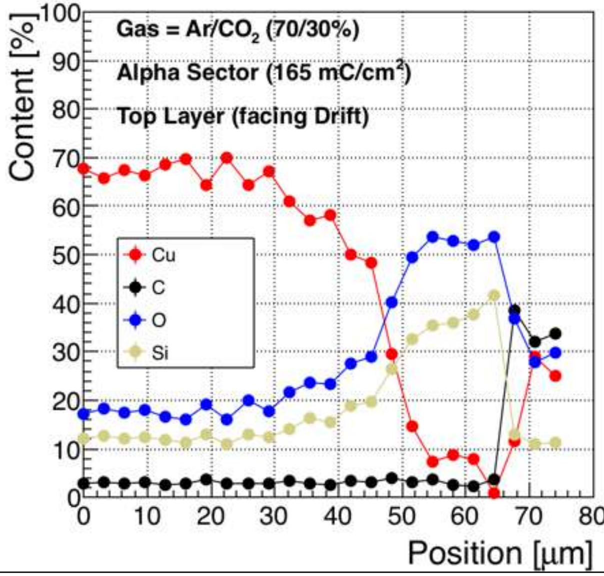


Alpha Irradiated Sector

Top Side (DRIFT)

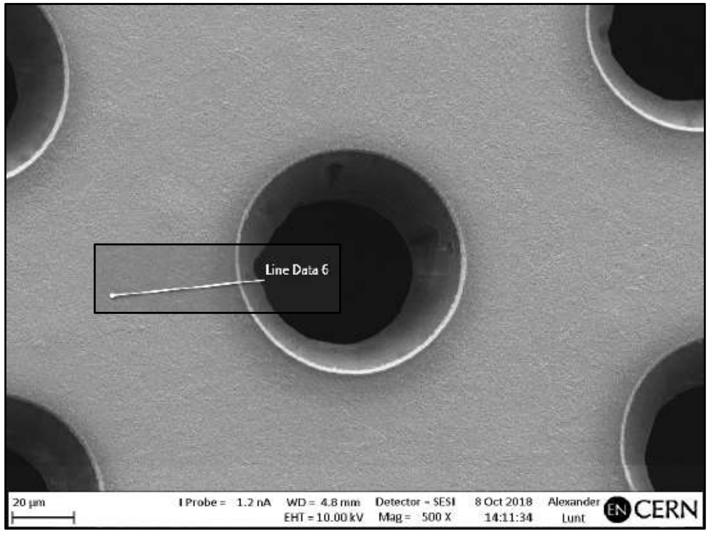
- Presence of slight Silicon deposits on the entire surface (>10%)
- Clear increase of Silicon composition at the rim up to 40%, forming a ring of deposits around the holes

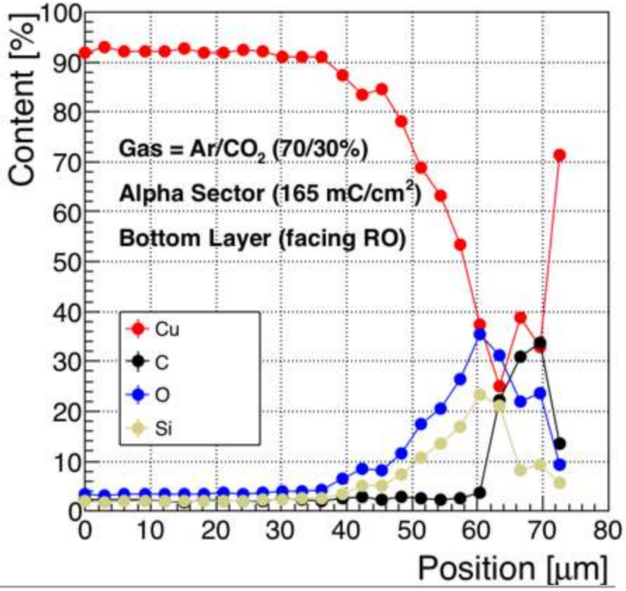




Bottom Side (RO)

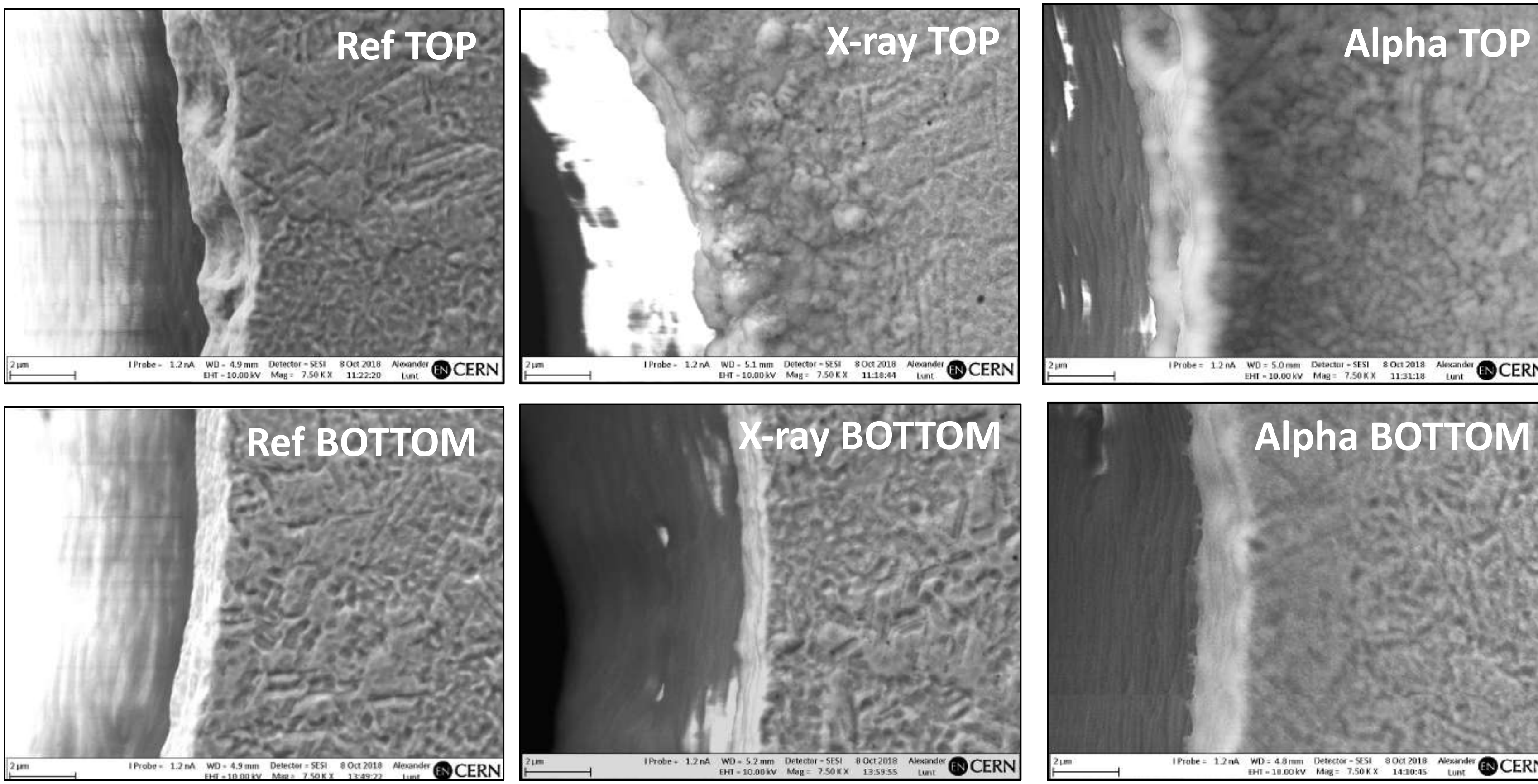
- Lower Silicon content than on the top, but a slight amount on the entire surface (1-3%)
- Clear increase of Silicon composition at the rim, up to 25 %



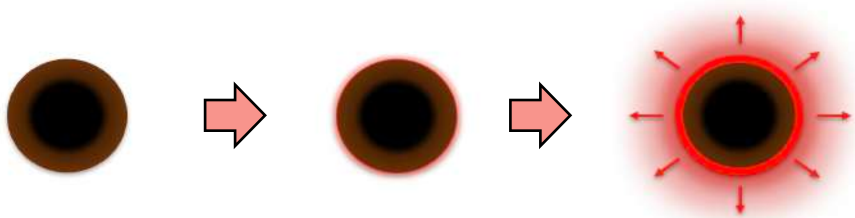


GEM Rim Analysis

Edge Analysis:



- Silicon deposits grow from the GEM rims and spread over the entire foil surface
- Larger effect on top side
- Beginning of depositing process with X-rays
- Clearly establish deposits with Alphas



Conclusions

- Several aging tests were performed in parallel (within the same gas volume)
  - Comparison between X-ray irradiation and HIP (alphas)
  - Heavily contaminated Ar/CO2 gas with outgassing silicon glues (not realistic but helps to speed up the aging process)
  - Both tests performed at similar particle rate (600 to 900 Hz) to reach the same accumulated charge 170 mC/cm^2

- Clear difference in the aging rate between the two sources
  - Beginning of silicon deposits on the top side of the X-ray sector
  - Well established silicon deposits on both sides of the Alpha sector

  → Clear evidence of the influence of the ionization power on the detector longevity

Next steps/open questions:

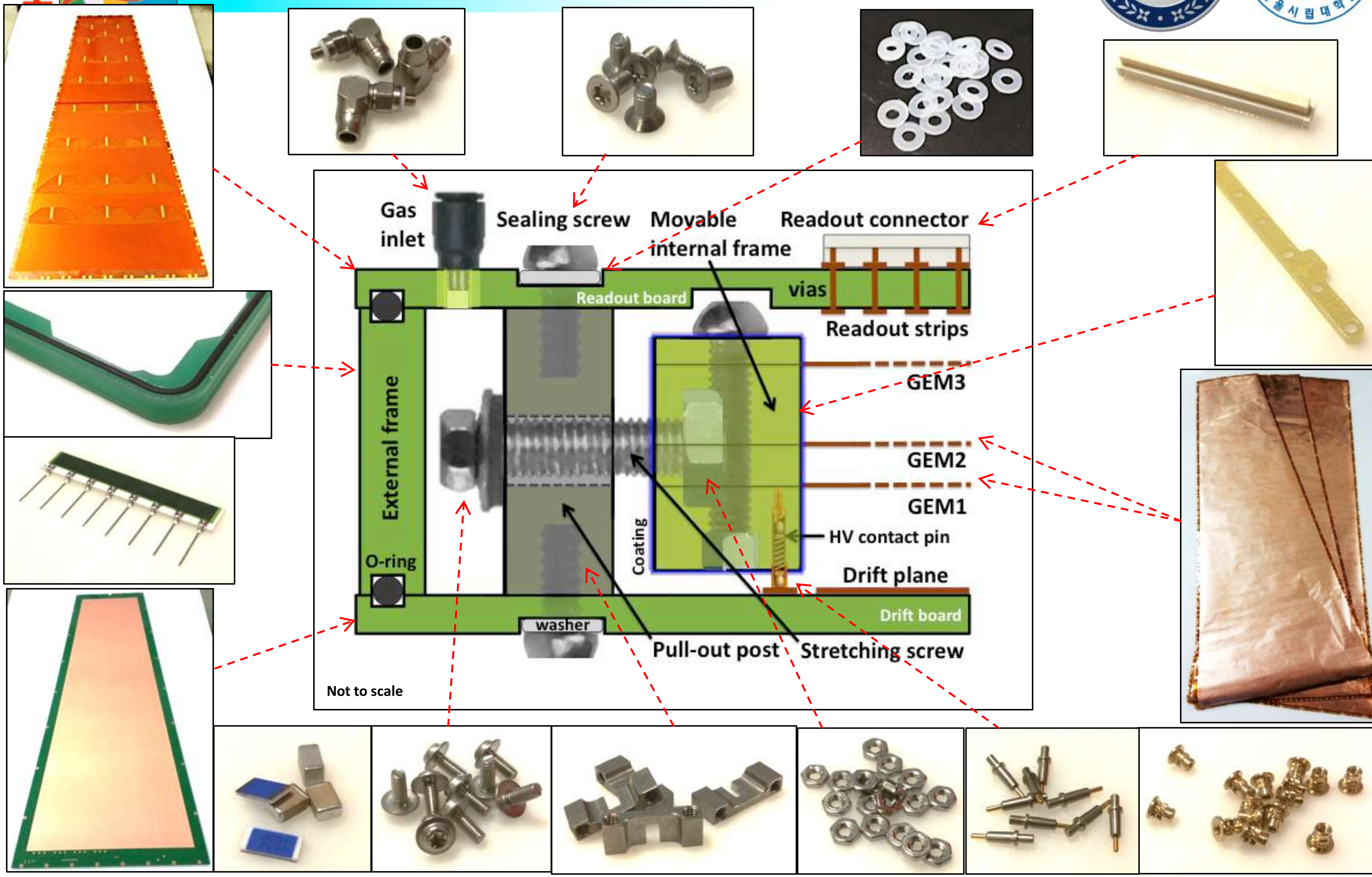
→ Impact on how we design aging studies for future applications ?

→ How to ensure realistic representation of the background in the target applications when designing aging tests?

→ What facilities can be used for long-term HIP irradiation with full size (large) detectors ?

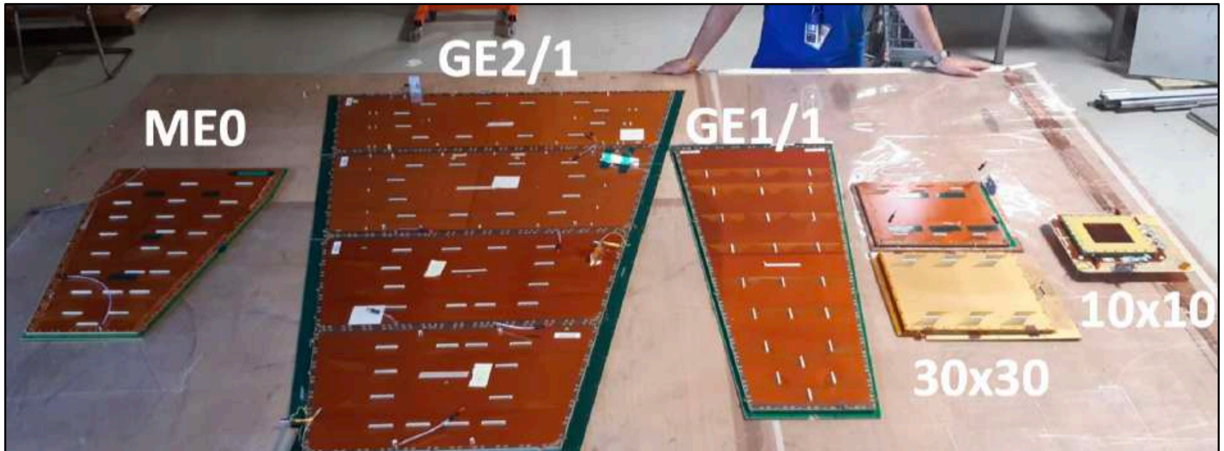
Thank you

Detector Components

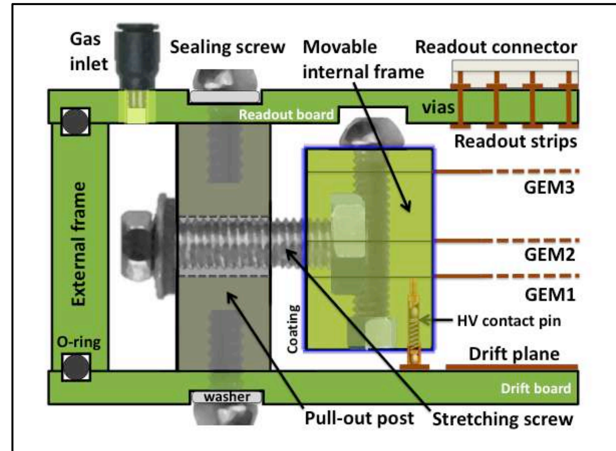


Detector Concept

Basic structure similar to GE1/1 and GE2/1



CMS GEM Detectors (from prototypes to final designs)



Self-stretching mechanism

Strong experience with triple-GEM detector construction

- Assembly and QC procedures developed during the R&D phase and optimized for the various GEM projects
- Expertise and documentation in place for many years
- Continuous R&D within the GEM group to increase the understanding of the detector operation/longevity and tackle new issues (and train new generations of detector experts)