Aging and outgassing studies for GEM detectors in the LHC high-rate environment

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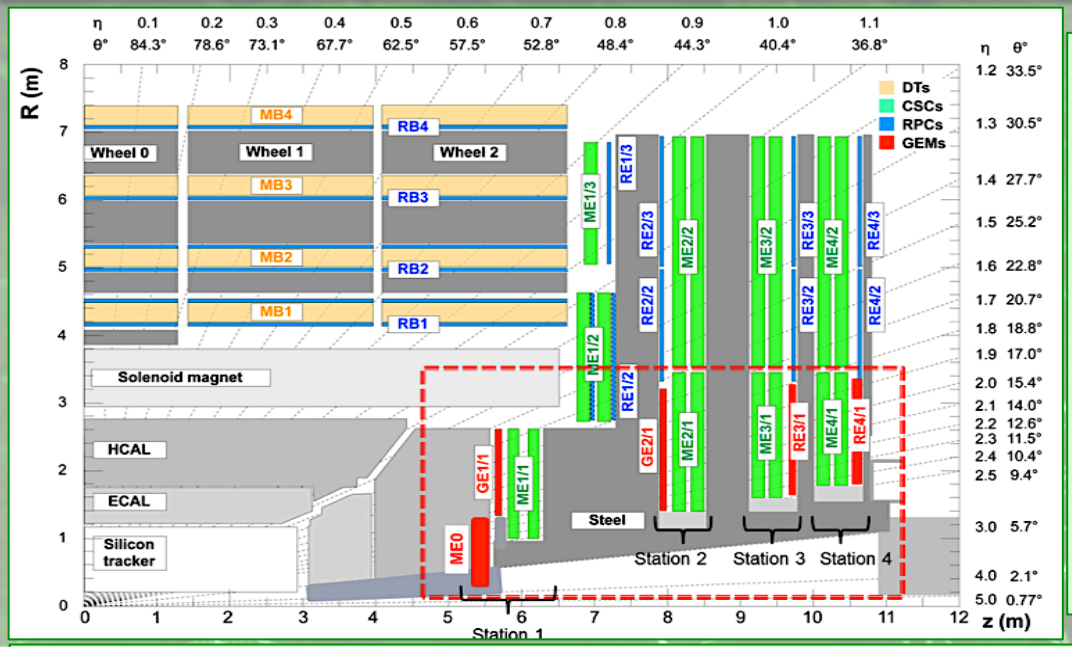
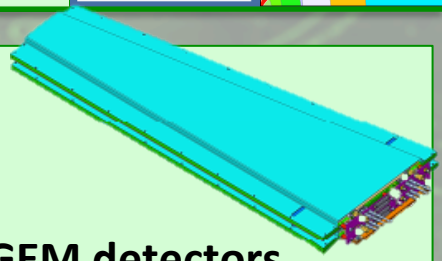
On Behalf of the CMS GEM collaboration*

*** For an overview of the CMS GEM project : Brian Dorney "Upgrade of the CMS muon system with triple-GEM detectors" (Monday afternoon)**

Introduction





CMS GEM Project :

GE1/1

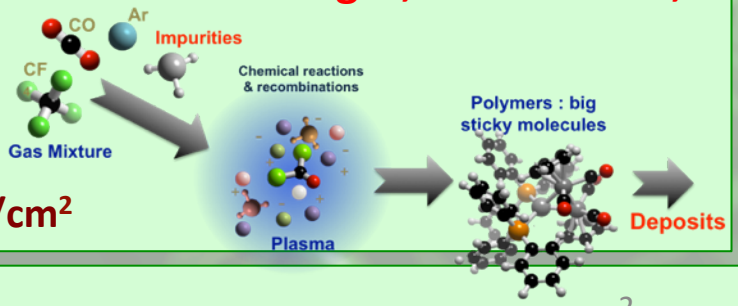
- 144 large triple-GEM detectors
- Eta coverage $1.6 < \eta < 2.2$
- High-rate environment (10^3-10^4 Hz/cm^2)

+ GE2/1 – 72 or 144 detectors - kHz/cm^2
+ ME0 - 216 detectors – MHz/cm^2

Aging issues :

→ *Classical Aging (for gas detectors)*

- production of polymers in the plasmas surrounding the GEM holes
- potential effects : gain losses, non-uniformity, self-sustained discharges, dark current, resolution loss , low rate capability …)



Expected rate @HL-LHC : several kHz/cm^2

Charge 20 years: Rate*Primaries*Gain*Time*e = 100 mC/cm^2

Introduction

Classical aging :

- Many input parameters + Many processes
- Unknown parameters (pollution)
- Strongly depends on the conditions of operation

→ No simulation tools / reliable models for aging predictions

→ Need to measure aging for a given configuration

How to measure longevity of detectors :

→ Measure various properties of the detector at different accumulated charges

→ Monitor gas gain stability during the irradiation

Classical aging :

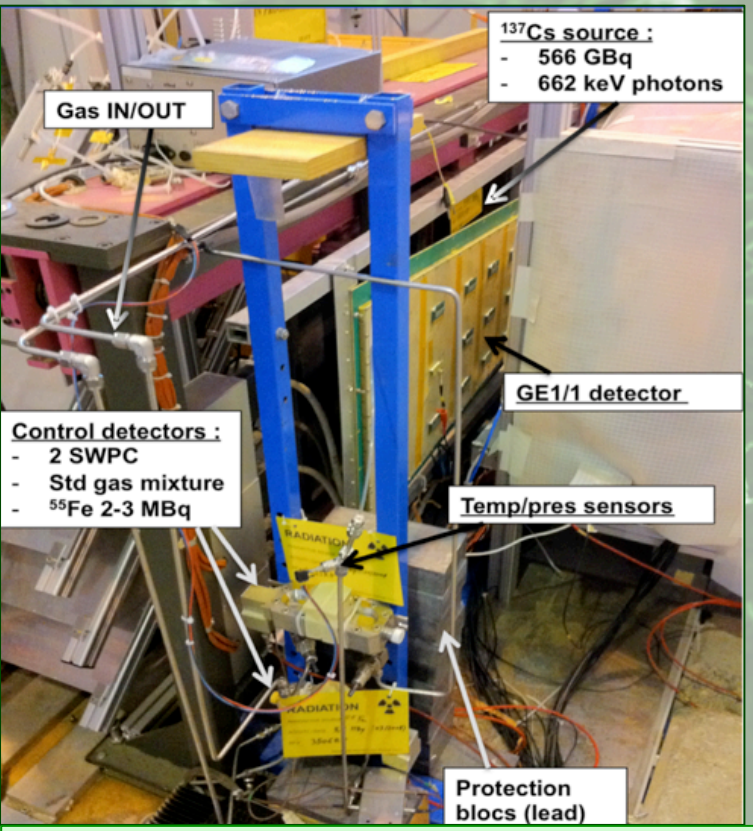
→ Accelerate aging with strong radiation

⚠ High acceleration factors reduce polymer production rate

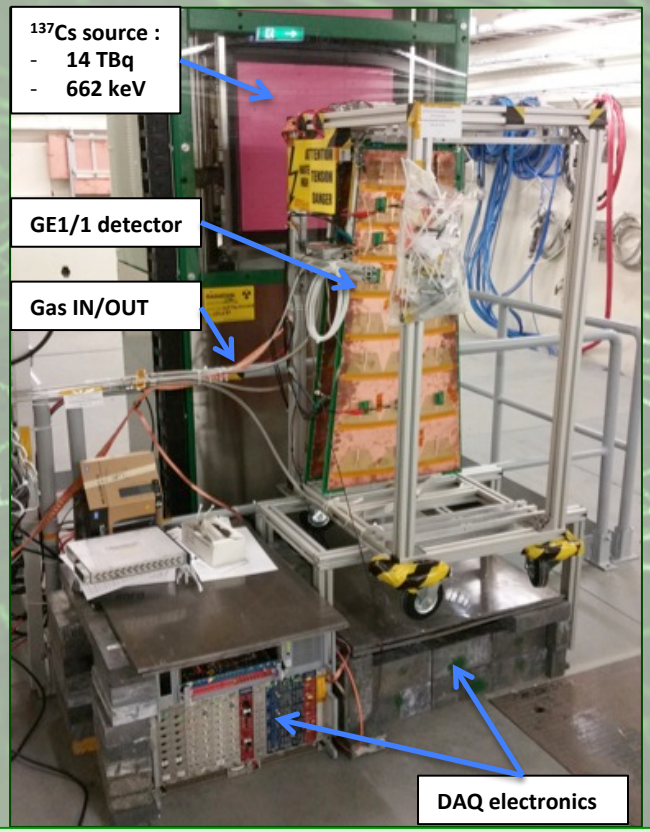
→ Study outgassing of chamber materials to ensure a clean detection volume and prevent aging

Gamma Irradiation Facilities

GIF (CERN / Meyrin)



GIF++ (CERN / Prevessin)



Facilities :

GIF

^{137}Cs – 566 GBq
662 keV photons
Detector : GE1/1-IV (4th generation)
$Ar/CO_2/CF_4$ (45:15:40)
(10^7 γ/cm²@30 cm)

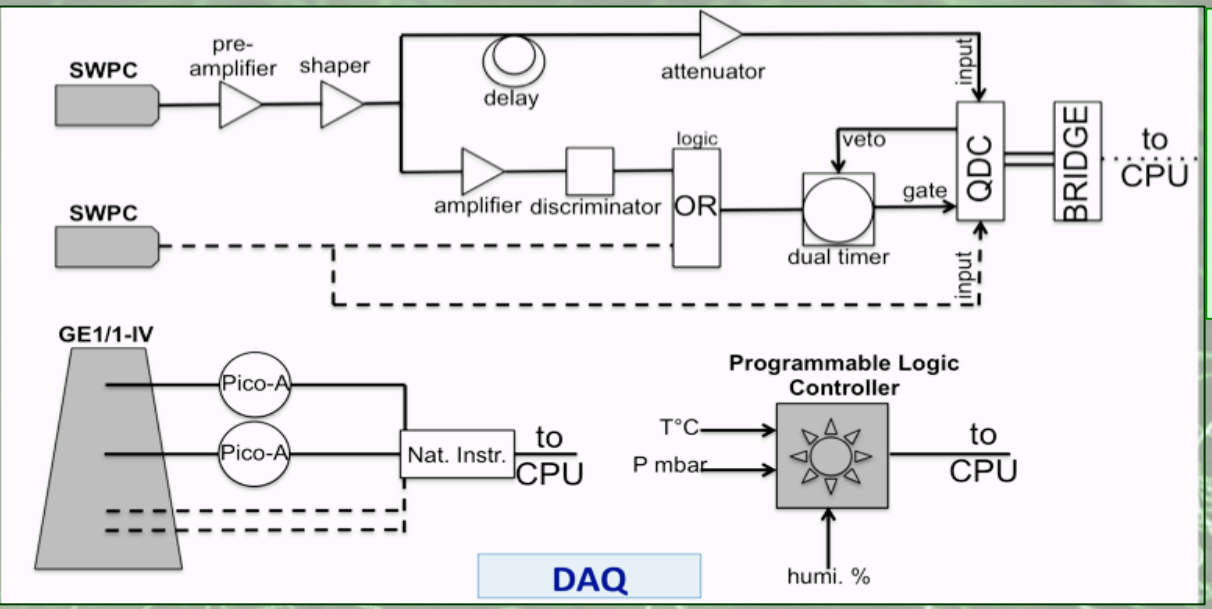
GIF++

^{137}Cs – 14 TBq
662 keV photons
Detector: GE1/1-IV
Ar/CO_2 (70:30)
(10^8 γ/cm²@50 cm)

Aging experiments :

- Initial study at GIF (7 months) – GE1/1-III (3rd generation) → test the setup / extract aging parameter
- Aging test at GIF (12 months) // Aging test at GIF++ (6 months) – GE1/1-IVs

DAQ & Analysis I



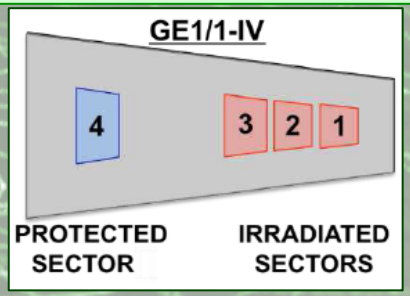
Aging Test DAQ :

→ Spectrum every week

→ Anode Current every 5 min

→ T°, P, RH every 1 min

= 2 millions of points (10 months)



Conditions of operation :

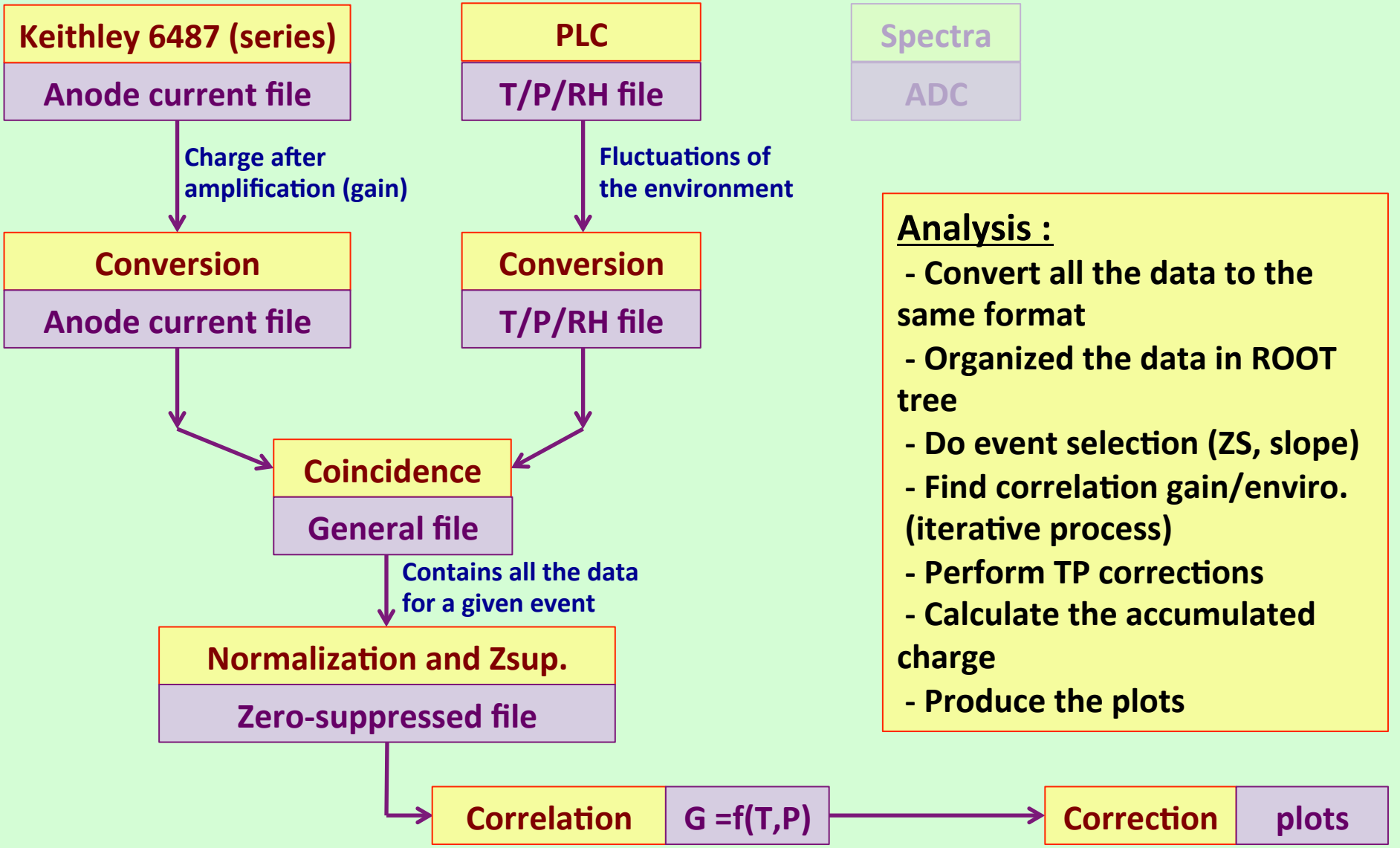
→ Effective gain : 2×10^4

→ Current measured for 128 OR-ed strips using Keithley 6487 pA-meter (Labview interface)

→ Additional spectra measurements : pre-amp + shaper ORTEC → ADC LeCroy (NIM+ VME)

→ Environment monitoring : PLC Siemens S7 (WinCC)

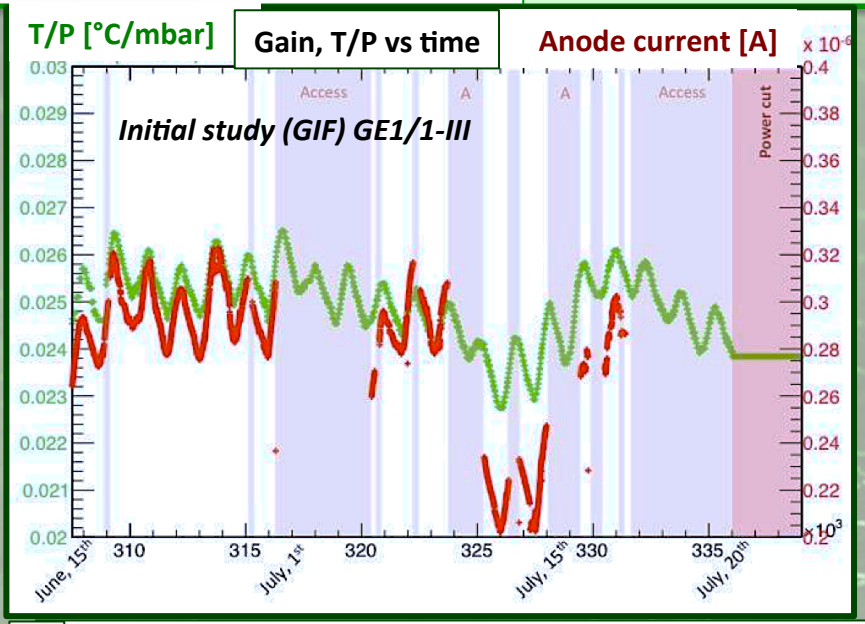
DAQ & Analysis II



Analysis :

- Convert all the data to the same format
- Organized the data in ROOT tree
- Do event selection (ZS, slope)
- Find correlation gain/enviro. (iterative process)
- Perform TP corrections
- Calculate the accumulated charge
- Produce the plots

DAQ & Analysis III



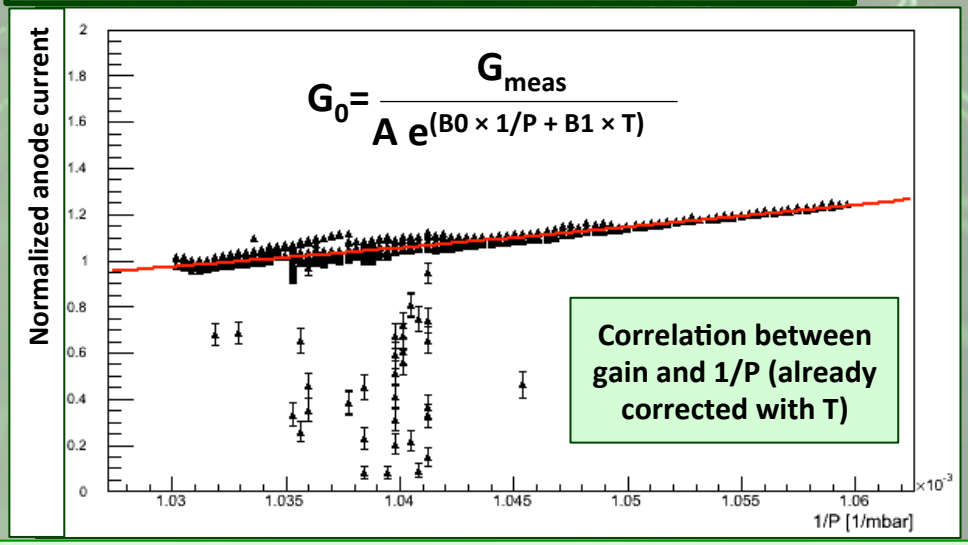
Highlight the correlation between

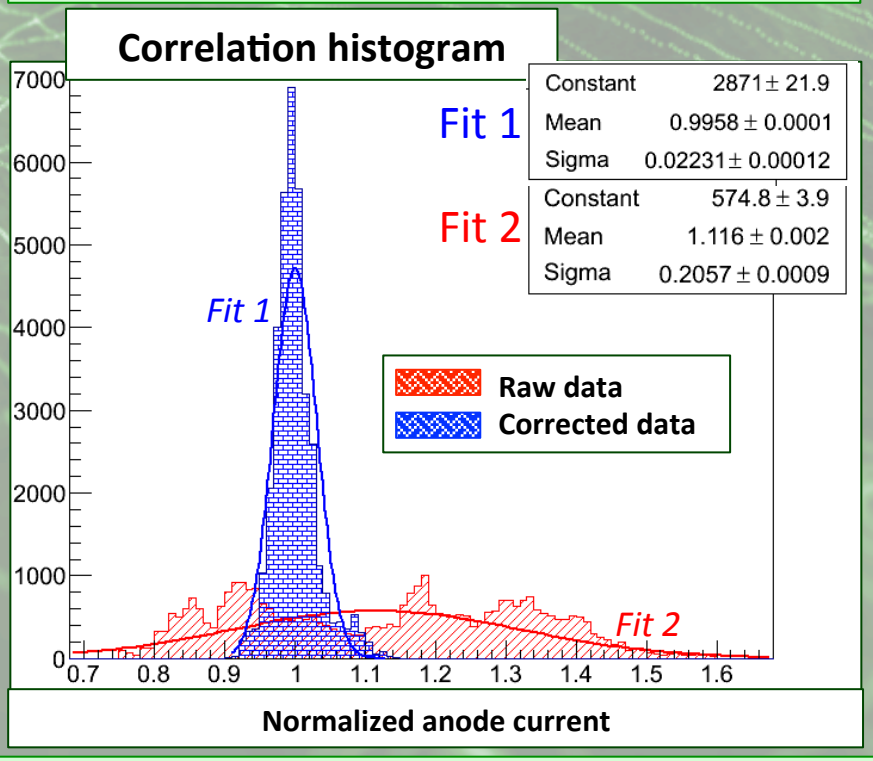
→ **Gain (Townsend coeff.)**

→ **Baseline fluctuations (HV, electronics)**

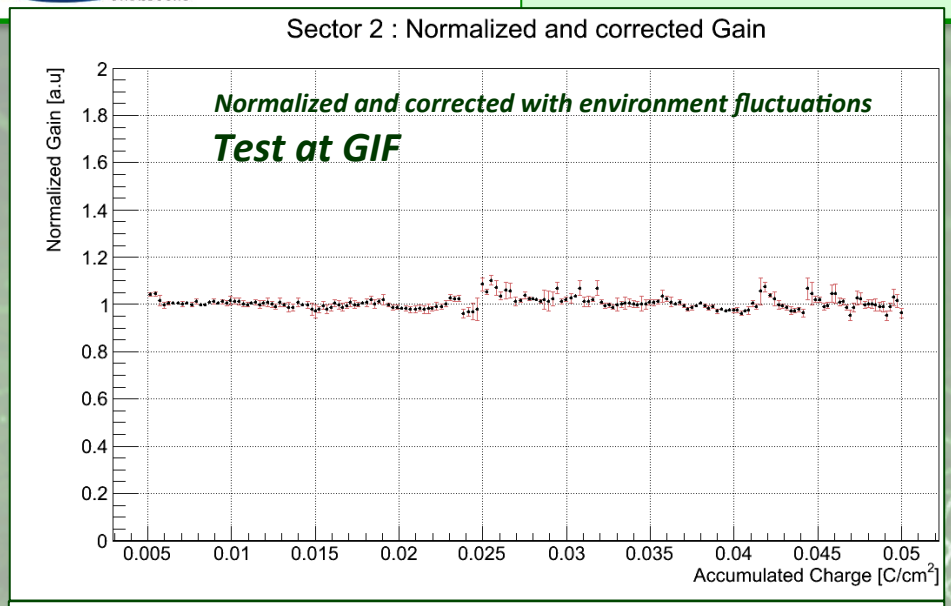
and the environment (T,P)

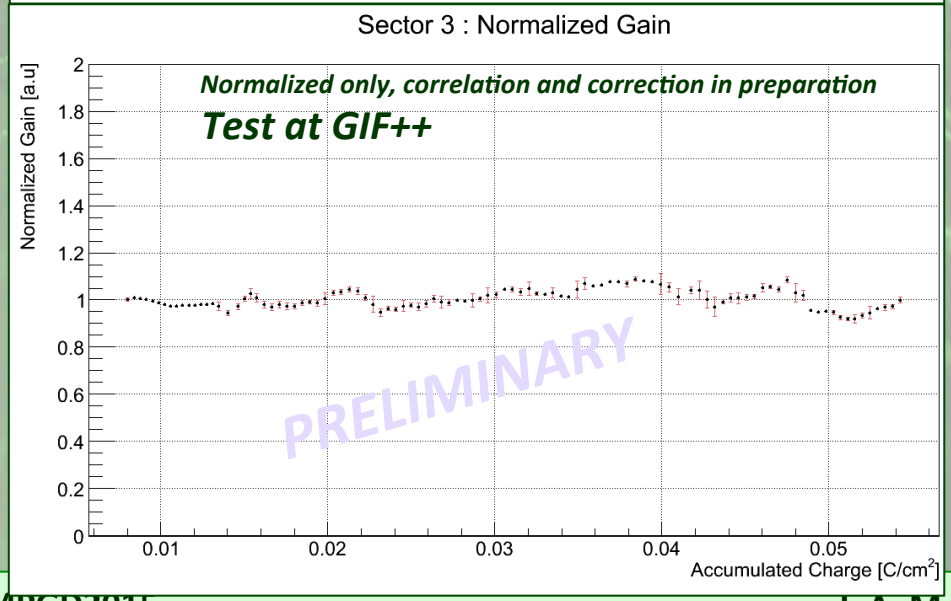
Remove only environment fluctuations





Results





Aging test at GIF :

GE1/1-IV-CERN001 @ gain 2×10^4

$Ar/CO_2/CF_4$ (45:15:40%)

Sector 2 (in front of the source)

12 months of sustained irradiation

Total accumulated charge : 50 mC/cm²

→ 10 CMS years (HL-LHC)

→ No aging effects observed

Aging test at GIF++ :

GE1/1-IV-CERN002 @ gain 2×10^4

Ar/CO_2 (70:30%)

Sector 3 (in front of the source)

6 months of sustained irradiation

Total accumulated charge : 54 mC/cm²

→ 11 CMS years (HL-LHC)

→ No aging effects observed

Observations I

PRELIMINARY

GE1/1-IV after GIF irradiation

- No gain loss
- Normal behaviour in test beam
- Comparable gain uniformity between before & after sustained irradiation
- No loss of GEM tension after 2 years of intense activities (aging test, test beams, calibrations ...)

→ *Oxidation effects on the external HV circuit (sustained operation in air)*

→ *solved with PU coating*

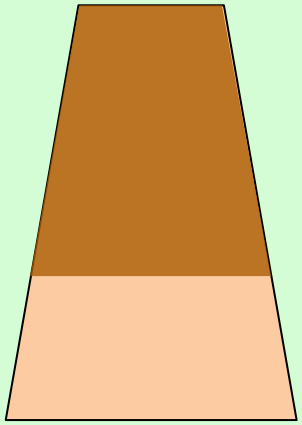
Incident during installation at new facility

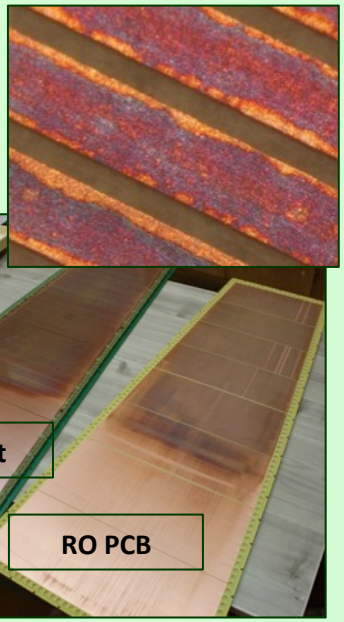
- Wrong gas mixture injected in the detector by external group (not CMSGEM)
- 93% of Ar instead of 70%

→ *Not safe operation region*

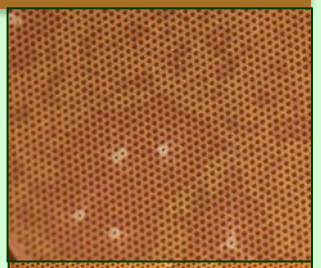
- Detector shows several short-circuits due to destructive discharges

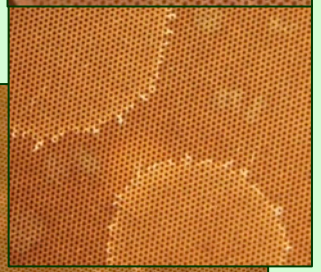
Copper oxidation





White dots/ stains

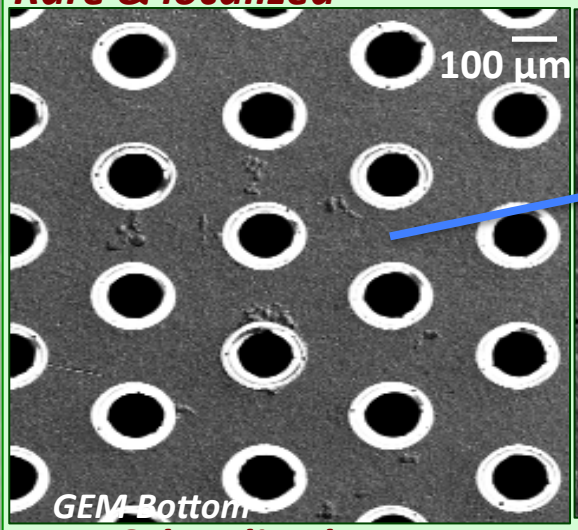


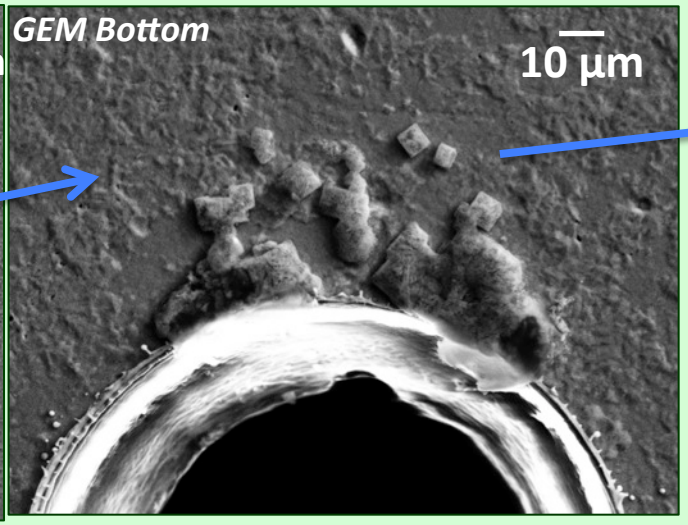


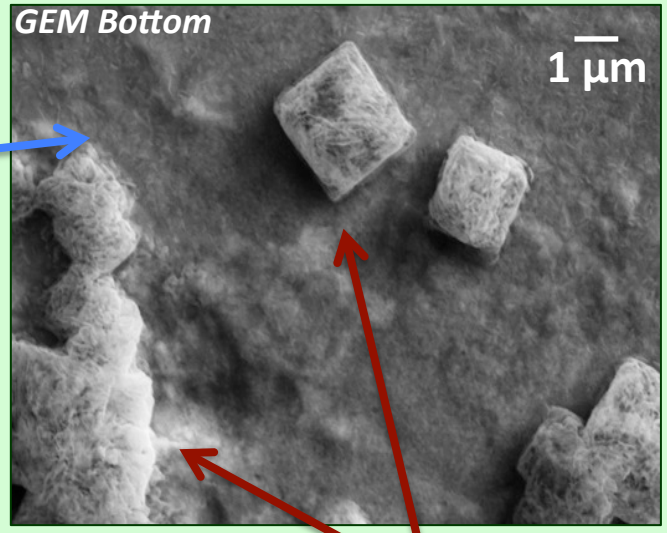
Observations I

PRELIMINARY

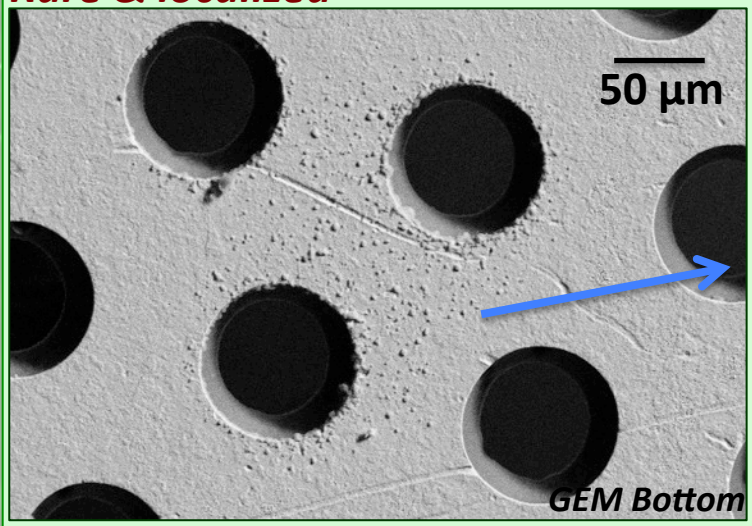
Rare & localized

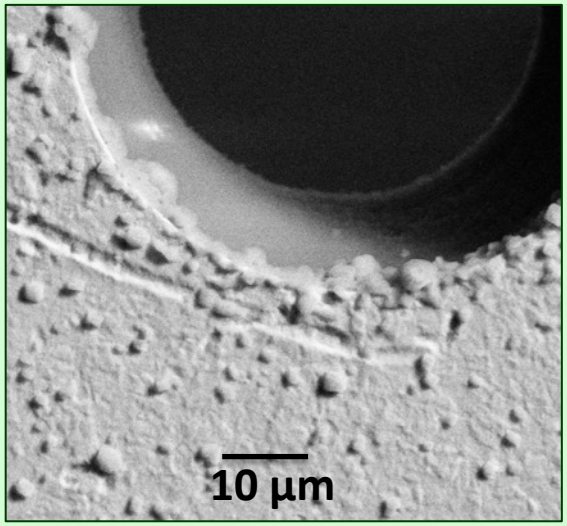






Rare & localized





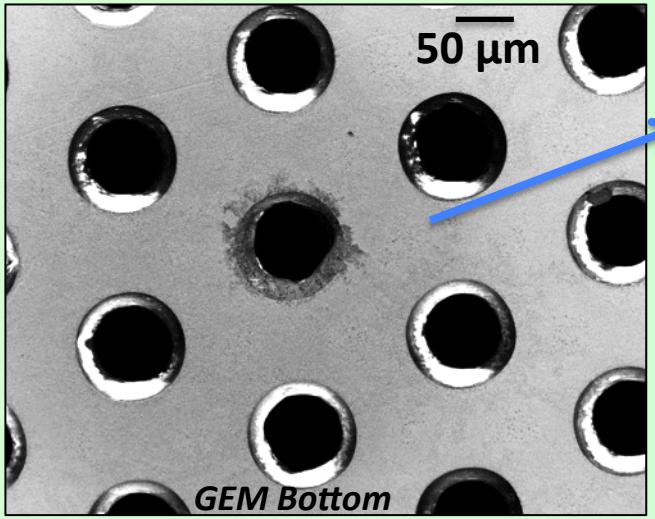
Indications of Si in the deposits

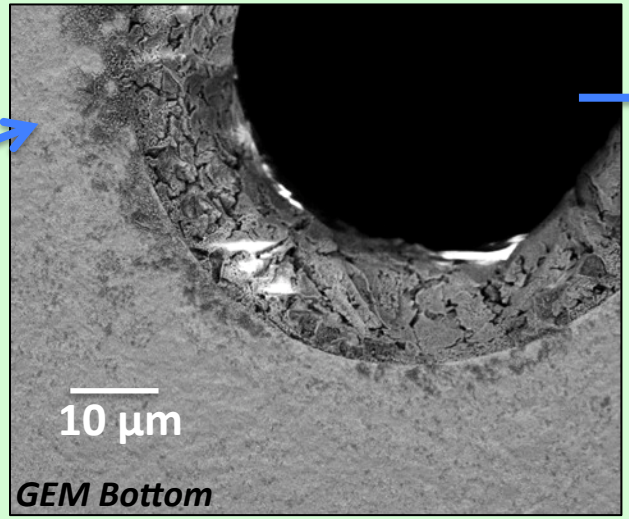
- Small deposits around hole rims
- Deposition growing from hole edge
- Cubic structures / build up

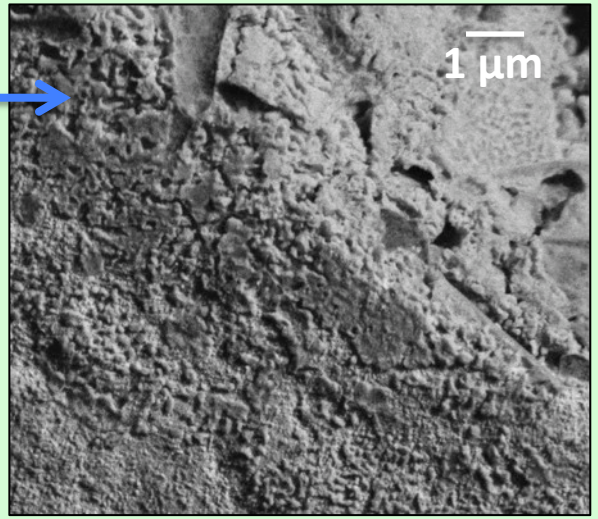
Observations II

PRELIMINARY

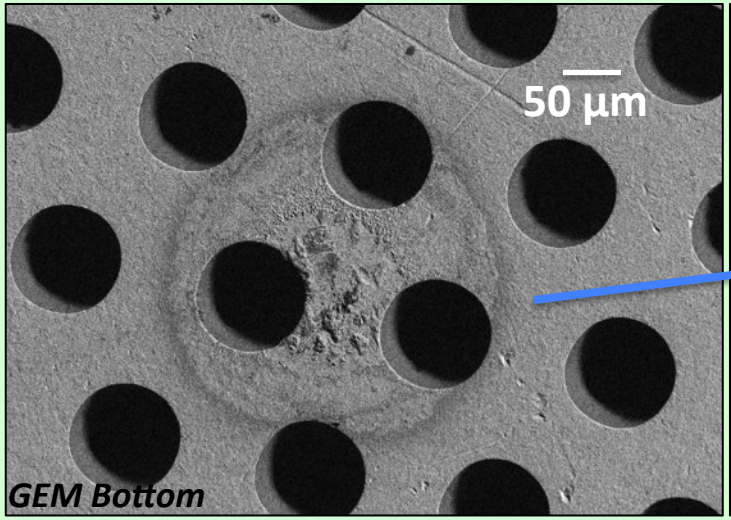
Rare & localized

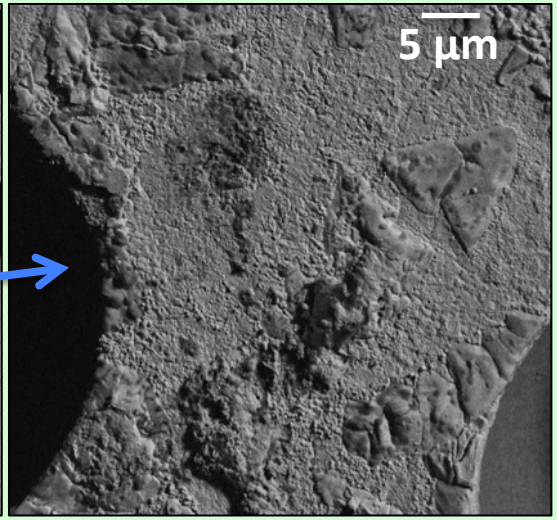






Rare & localized





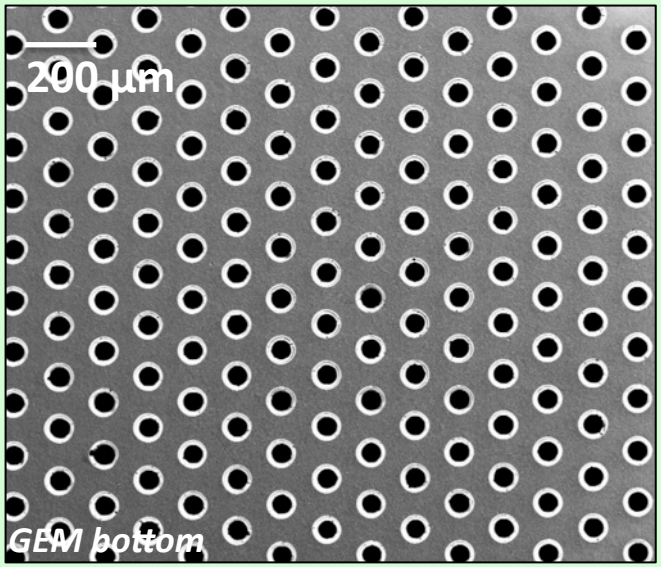
Rare and localized deposits:

- Long-term effect ? (classical aging ?)
- Instantaneous effect ? (discharges during incident)

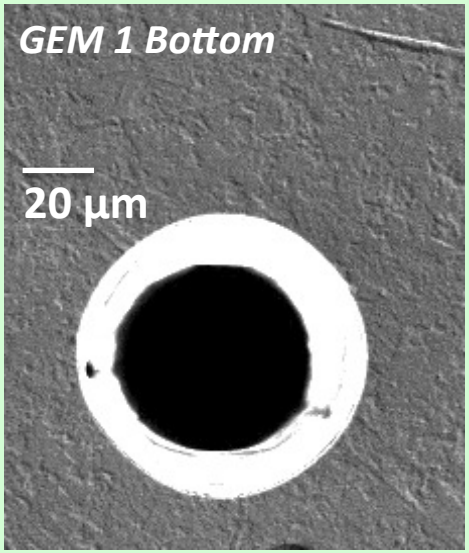
Perfectly clean foil around

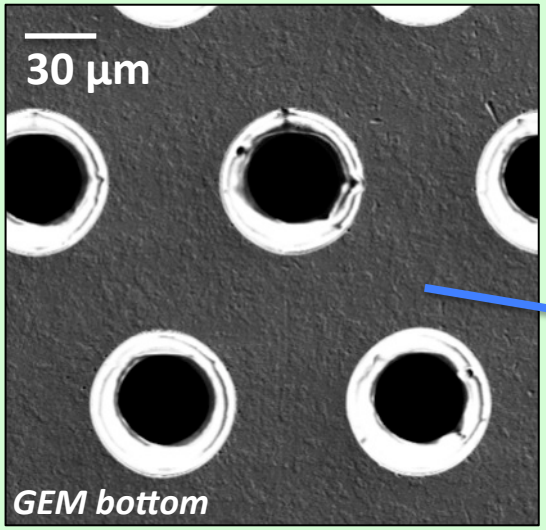
Observations III

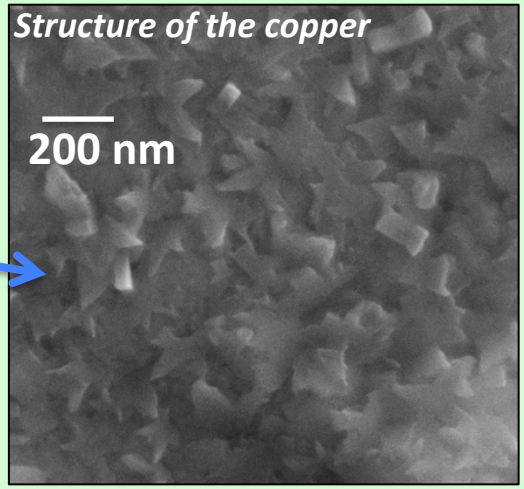
PRELIMINARY

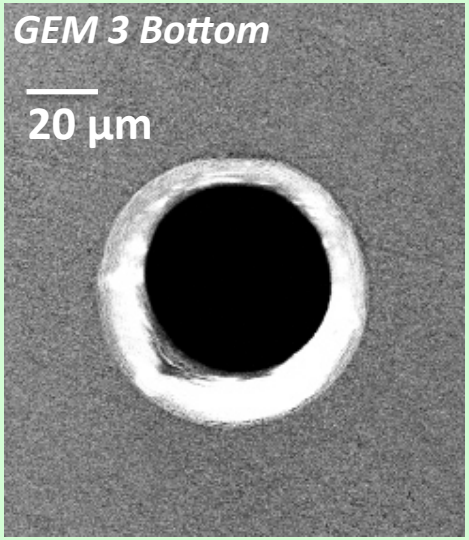


- → **Clean foil** outside the white regions (>99% of the foil)
- → both in irradiated and non irradiated areas
- → No indications of HF-etching
- → **Normal operation of the detector**









Aging study : discussion and plans

Summary & plans :

- 2 tests performed at GIF/GIF++ with GE1/1 generation IV:

- **$Ar/CO_2/CF_4$ (45:15:40%) → no performance loss after equivalent of 10 CMS years (HL-LHC)**

→ ***Opening of the chamber :***

- ***GEM foils essentially clean***

(Standard oxidation of the copper under radiations)

(Small and rare deposits in the irradiated zone – due to sustained operation ? Discharges during the incident ? Effect of outgassing PU CellPack ?)

- **Ar/CO_2 (70:30%) → no performance loss after 11 CMS years (HL-LHC)**

→ ***Test ongoing***

→ ***Charge accumulation up to 100 mC/cm² (20 CMS years)***

- 3rd experiment at CMS GEM laboratory with GE1/1 generation V:

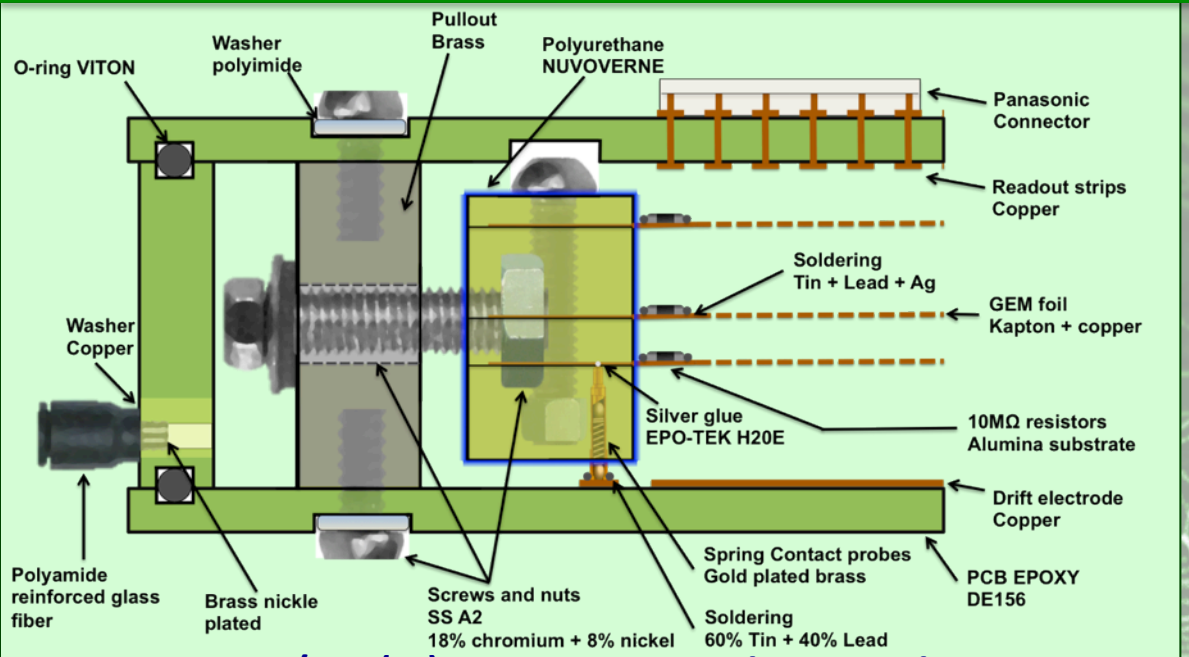
- With different gas mixtures

- Xray source (AMPTEK miniX) with variable power

- Perform local irradiation at different dose rate (i.e. different acceleration of aging)

- First tests foreseen before the end of 2015

Outgassing studies



GE1/1-V (VI) cross-section with materials

Procedure :

→ Calibration of the SWPCs

- Purity check with SWPC
- Insertion of the sample
- 2 weeks at room temperature
- 2 weeks at 50°C

Δ min. 2 months/sample + 2-3 weeks possible cleaning

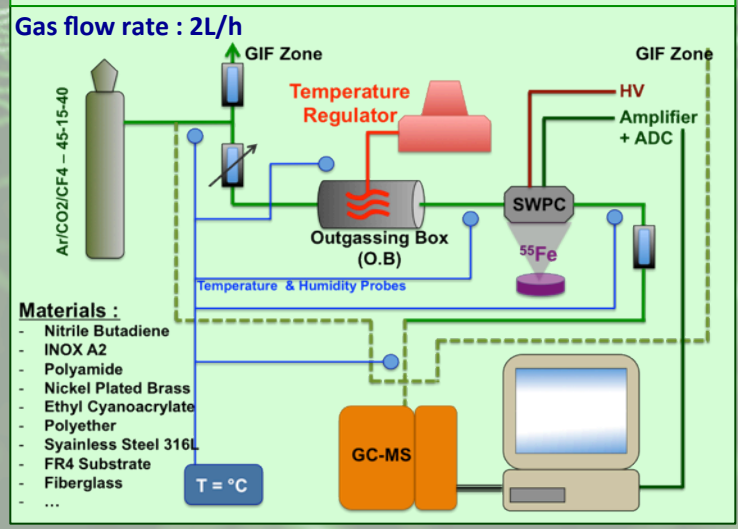
Outgassing test :

Outgassing materials →contamination→ premature aging

→ All materials must be tested

→ Outgassing Box contains samples of materials (about 10x the amount in GE1/1)

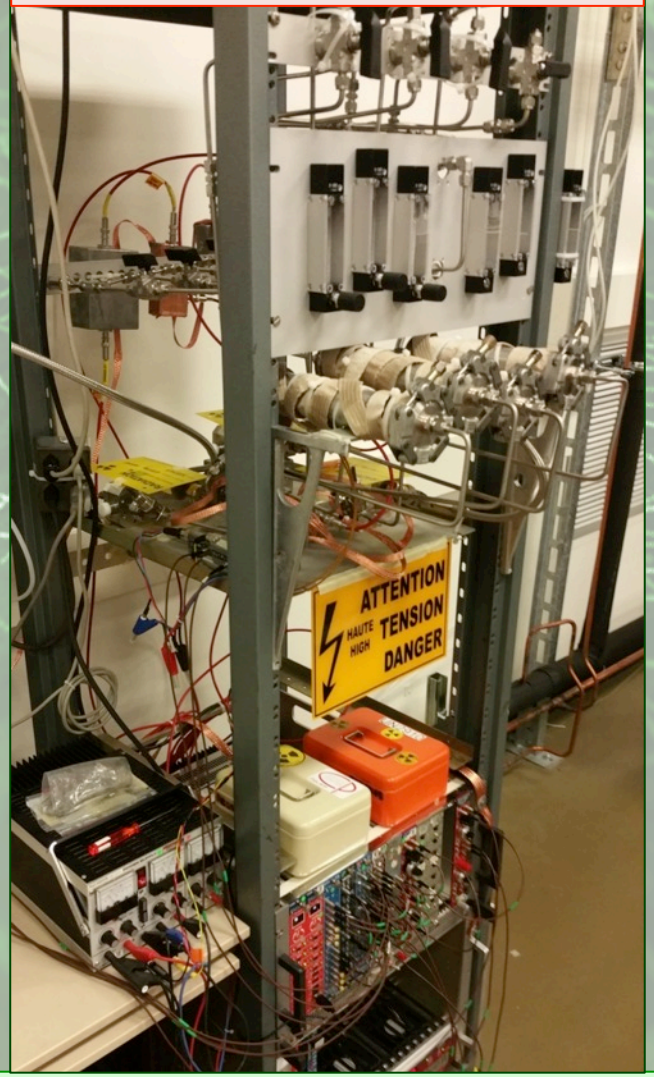
→ Possible pollution is identified with SWPCs



Outgassing setups

GIF (CERN / Meyrin)

TIF (CERN / Meyrin)



Setups :

GIF – 2013

1 outgassing channel
1 SWPC+GEM 10x10
PLC
Gas Chromatograph
→ 3 materials tested

TIF – *Today*

4 outgassing channels
3 SWPCs
PLC
→ 6 materials tested

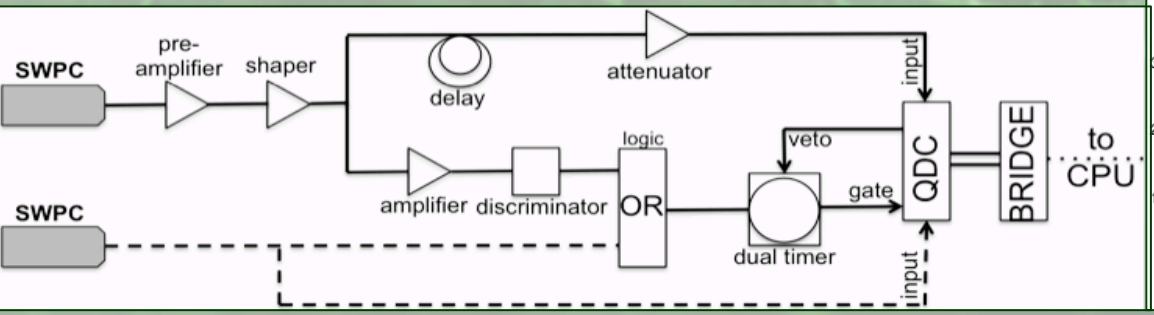
Preparation of the samples
DAQ & Analysis

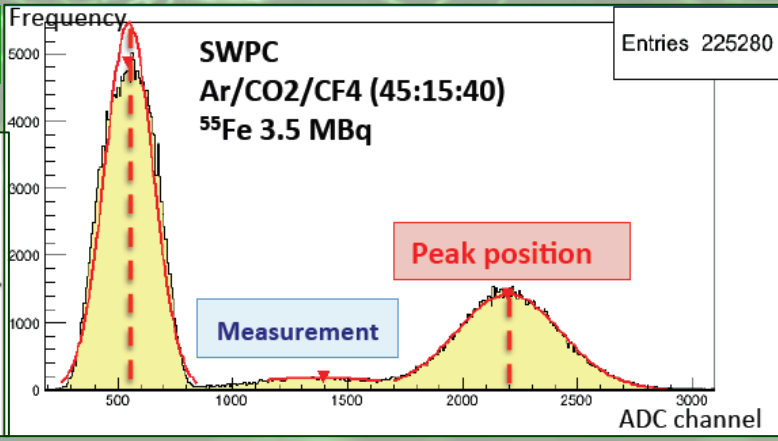
Materials and samples:

- Clean metallic supports
- 10x the amount present in GE1/1s
- Max. surface in contact with gas

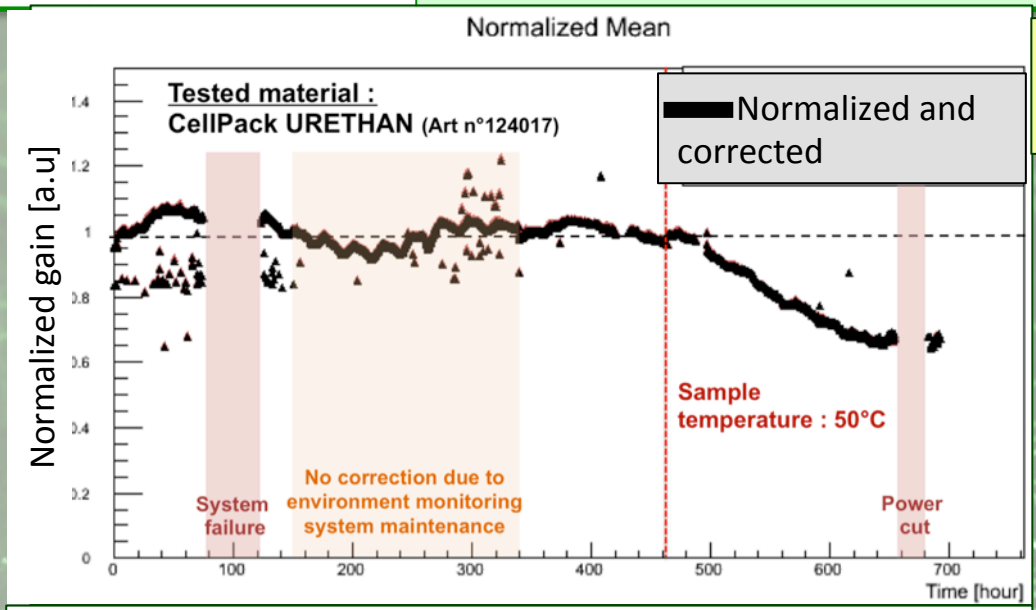
→ *4 weeks of purity check of entire system before inserting samples in the setup*

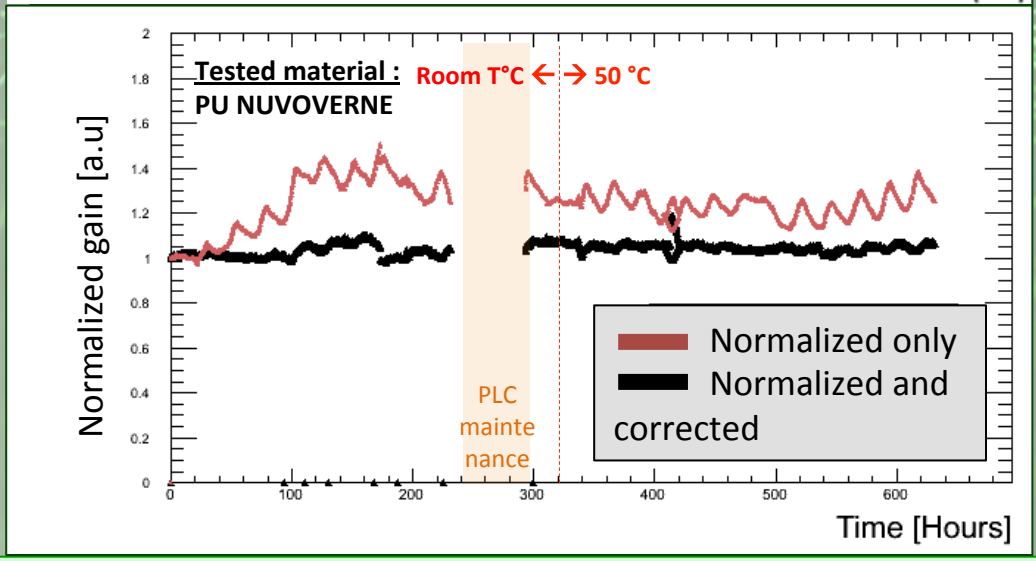
DAQ & Analysis (similar to aging experiments)





Typical results





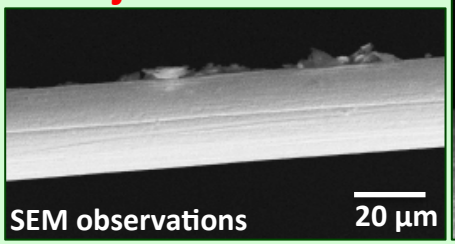
PU used to cover internal frames to prevent dust & leakage current

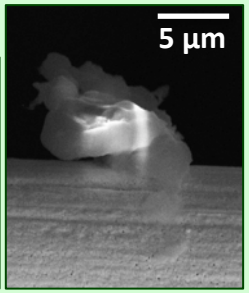
PU CellPack 124017

→ Fast and permanent gain drop

→ Pollution affecting SWPC

→ Rejected material





→ we suspect PU Cellpack as the culprit for deposits observed in GE1/1-IV-CERN001 after GIF test

PU NUVOVERN

→ No gain drop

→ No dark current

→ accepted material

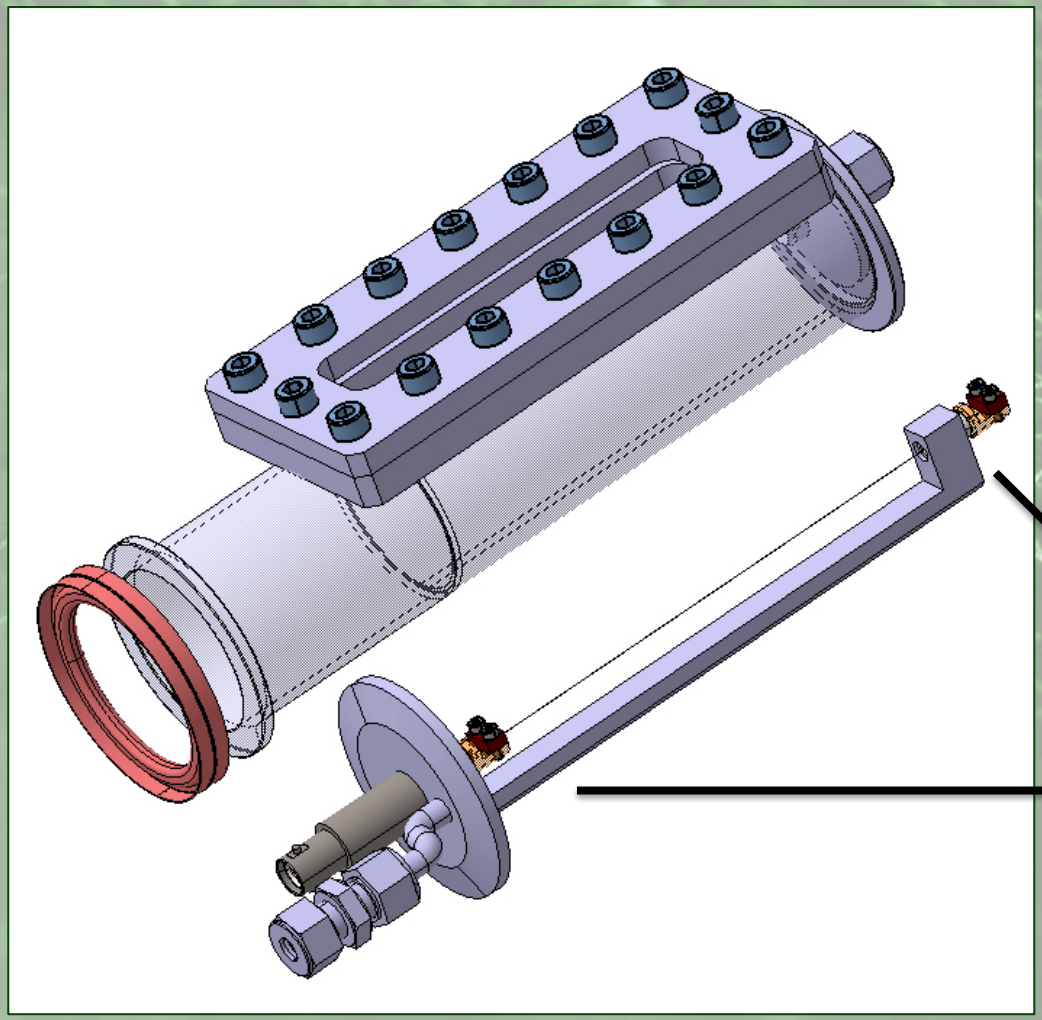
General results

Element	Material	Outgassing test
O-ring	VITON	***OK***
Polyurethane	CellPack 124017	***NOT OK***
Polyurethane	NUVOVERN	***OK***
Silver Glue	MSDS_polytec_EC	***OK***
Soldering mask	Elpemer 2567 (+FR4)	***OK***
Strip cover	Krempel *KDF 0/25/25HT*	***OK***
Washers	Polyamide	*Analysis ongoing*
Used externally on GE1/1	Kapton tape	*Analysis ongoing*
Used externally on GE1/1	Teflon tape	*Analysis ongoing*

Next steps :
Testing different types of grease that can be used to prevent VITON O-ring from drying

New design of a clean SWPC

Design proposal for clean and cheap SWPC

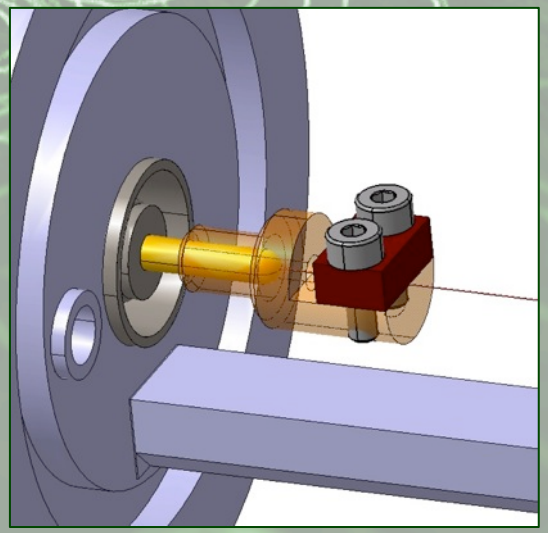


Applications :

- **Extend the outgassing setup**
- **Reliable tool for gas quality monitoring**

Requirements

→ **Clean materials (no glue/soldering)**
→ **Standard materials (low cost)**
→ **Easy replacement of the wire**
→ **Compatible with Fe55 / Cd109 sources**



Summary, Conclusions and plans

- **An extensive study on aging of CMS GEM detectors is ongoing :**
  - The aging preparatory work with GE1/1 proto-III (resistant up to 7mC/cm^2)
  - Aging test at GIF - GE1/1 proto-IV (resistant up to 50mC/cm^2) Ar/CO_2/CF_4
  - Aging test at GIF++ - GE1/1 proto-IV (resistant up to 55mC/cm^2) Ar/CO_2

→ Investigations to identify rare deposits on GEM foils

→ Continue irradiation up to 100 mC/cm^2 (20 CMS years) and further

→ Start fast and controlled aging campaign with Xray source

- **Outgassing studies started in parallel to validate GE1/1 materials :**
  - 6 materials already tested (1 rejected)
  - 3 in the analysis process
  - 3 more materials in preparation

(New design for clean and cheap SWPC for outgassing studies and gas monitoring system)

→ All detector components used in the GE1/1 construction and in contact with the gas are now certified not to outgas

→ Aging results give confidence that GE1/1 will not suffer any gain loss for at least 10 years of operation at HL-LHC

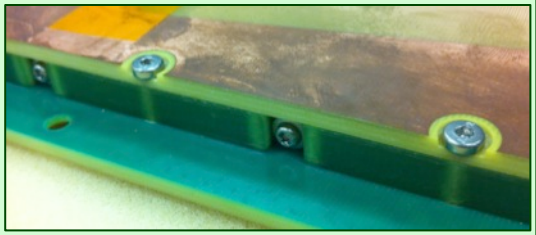
Thank you

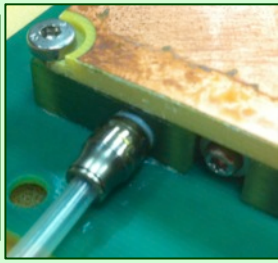
Thank you

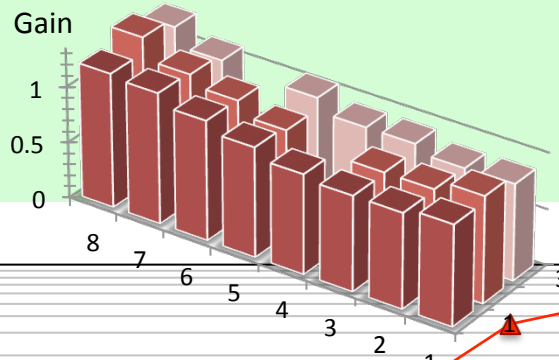
Spare

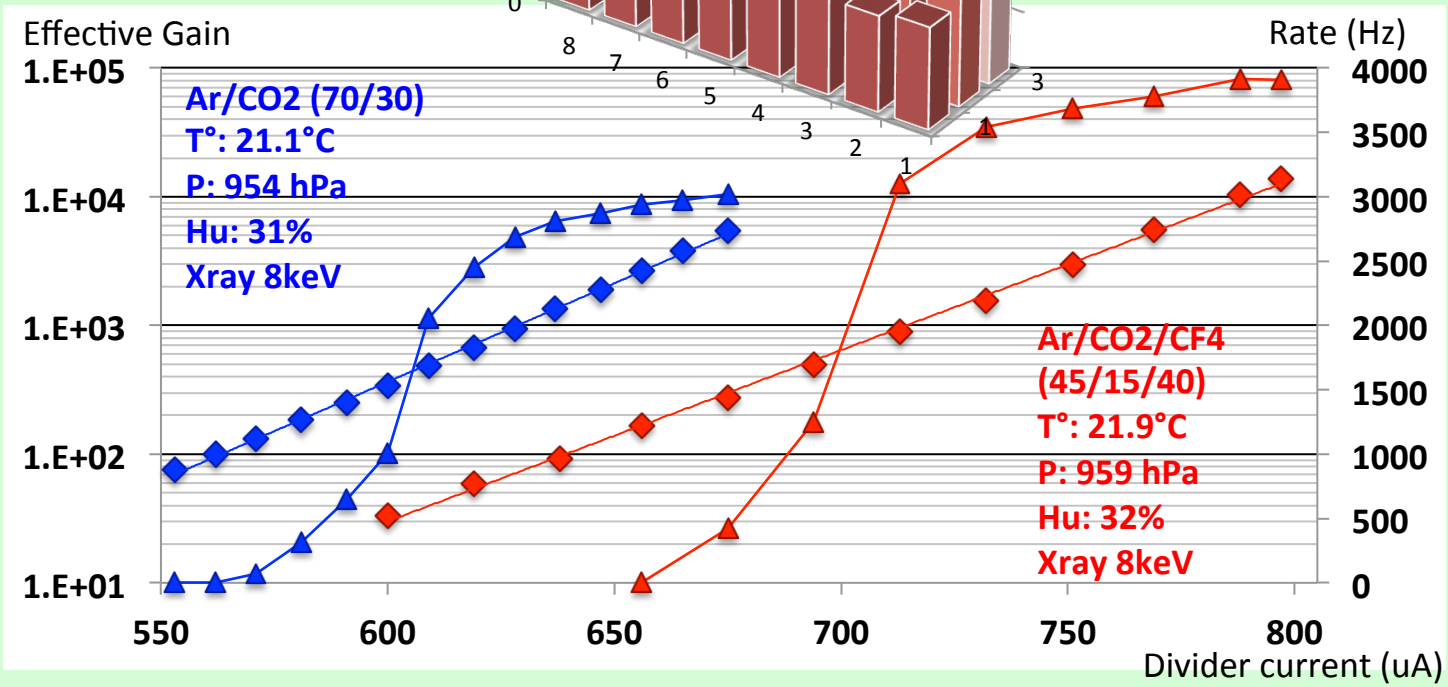
GE1/1- prototype IV:

- **Size : 99x(22-45) cm²**
- **Gap configuration : 3/1/2/1**
- **24 readout sectors (3072 channels)**
- **No Glue/No Spacers**



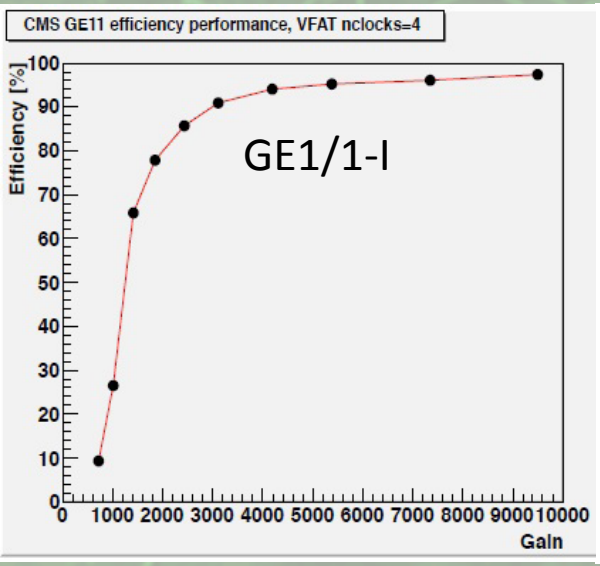


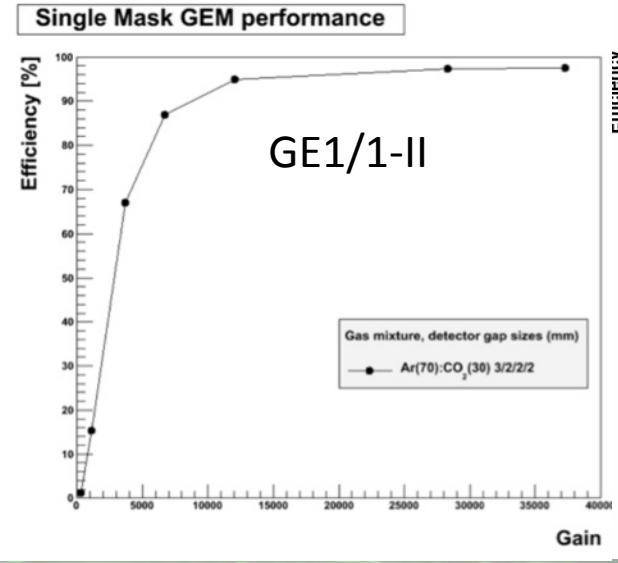


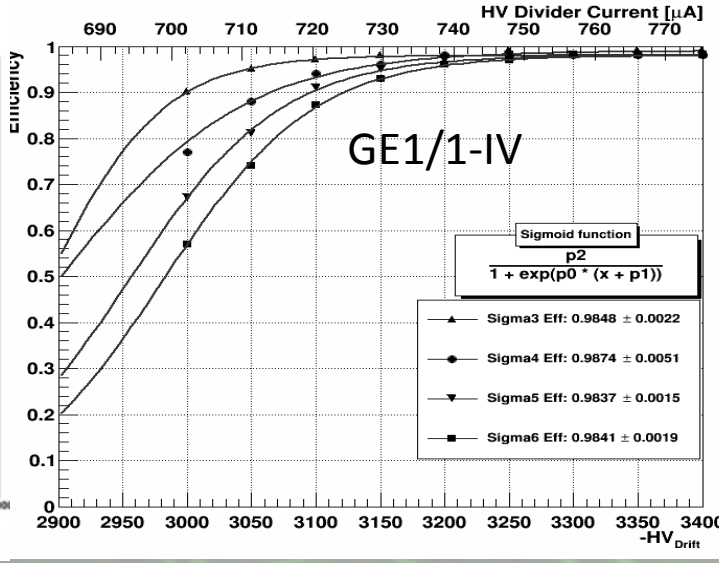


CMS GEM Test Beam summary

Efficiency





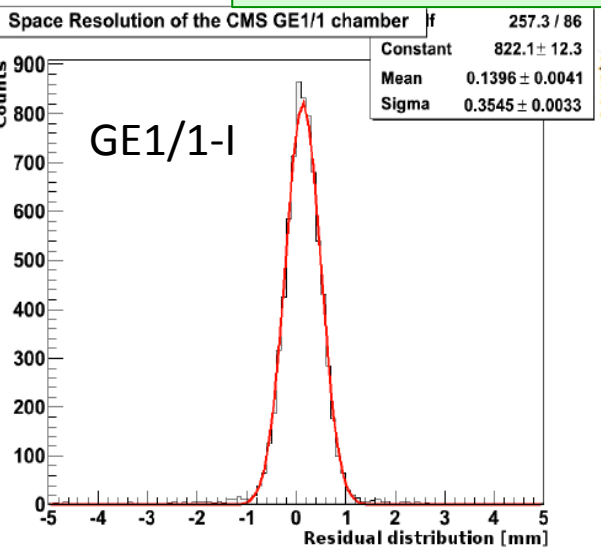


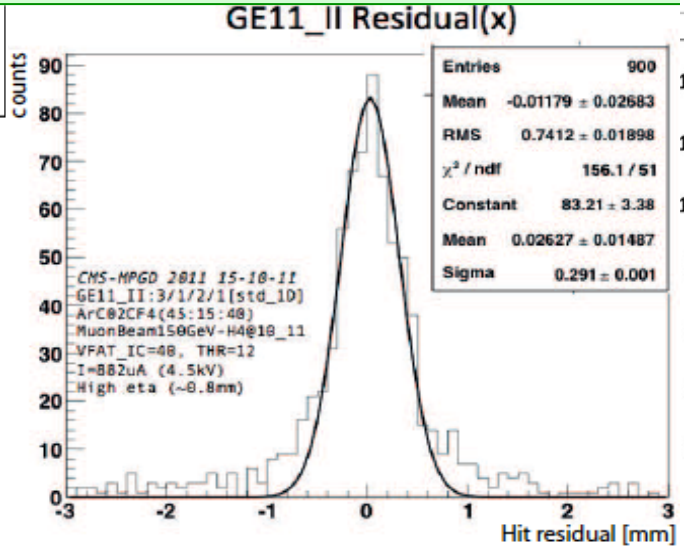
Efficiency fully compatible with standard double-mask GEM detectors

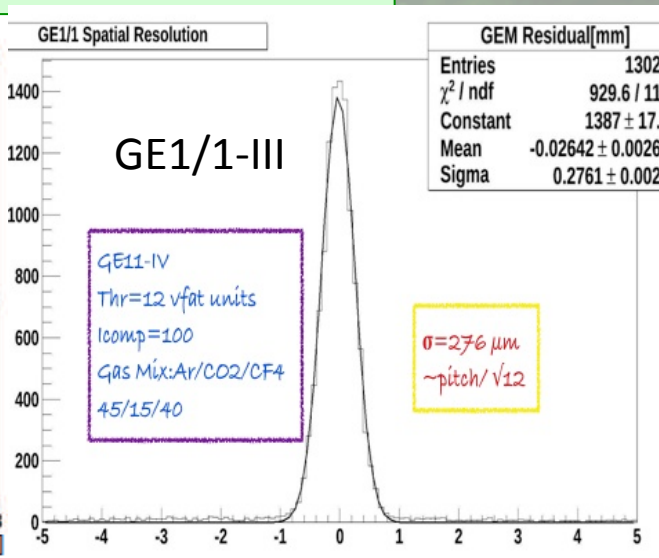
Eff > 97% for Ar/CO2 (70/30) and Ar/CO2/CF4 (45/15/40)

CMS GEM Test Beam summary

Residuals

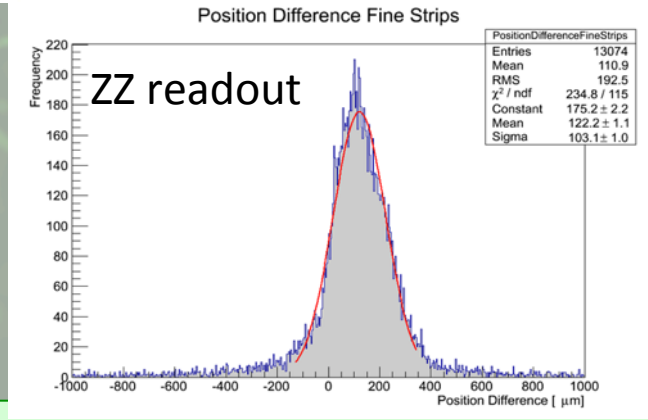






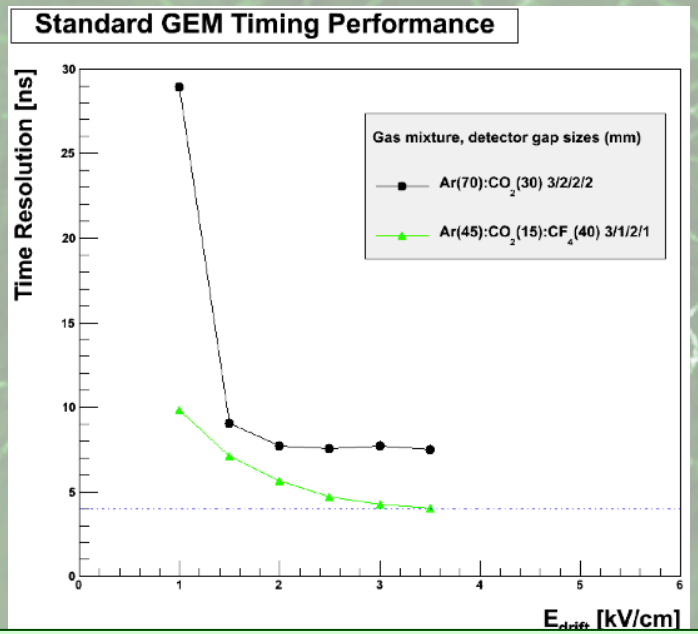
GE1/1 residuals fully compatible with expected values (depending on the readout pitch)

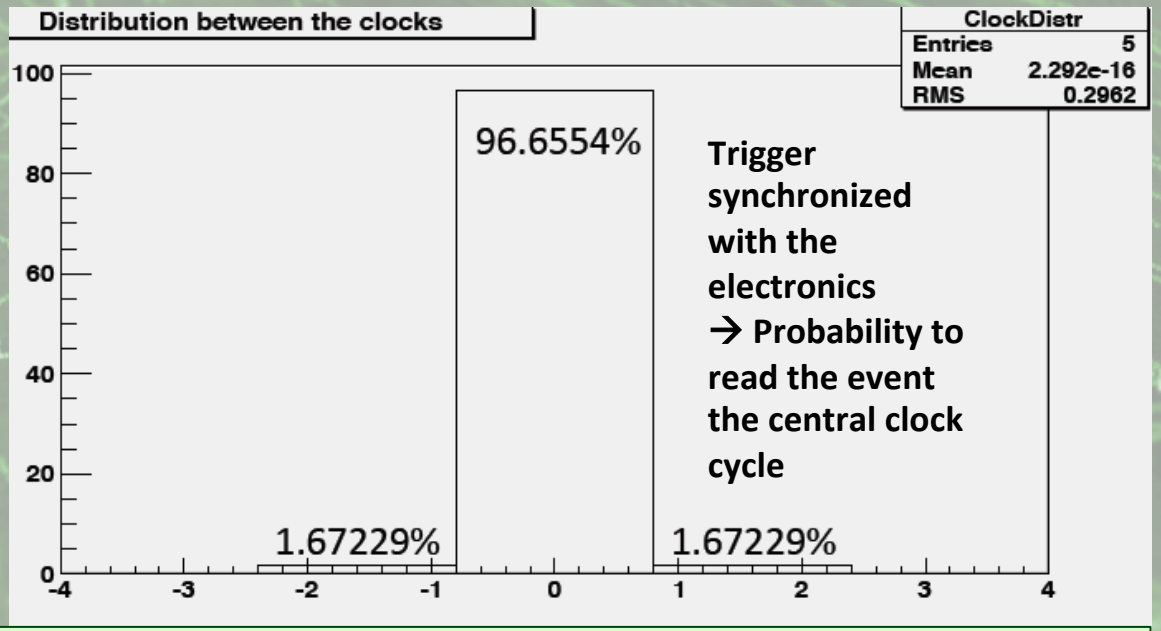
→ Detectors show residuals < 100 um with ZigZag readout board



CMS GEM Test Beam summary

Time resolution



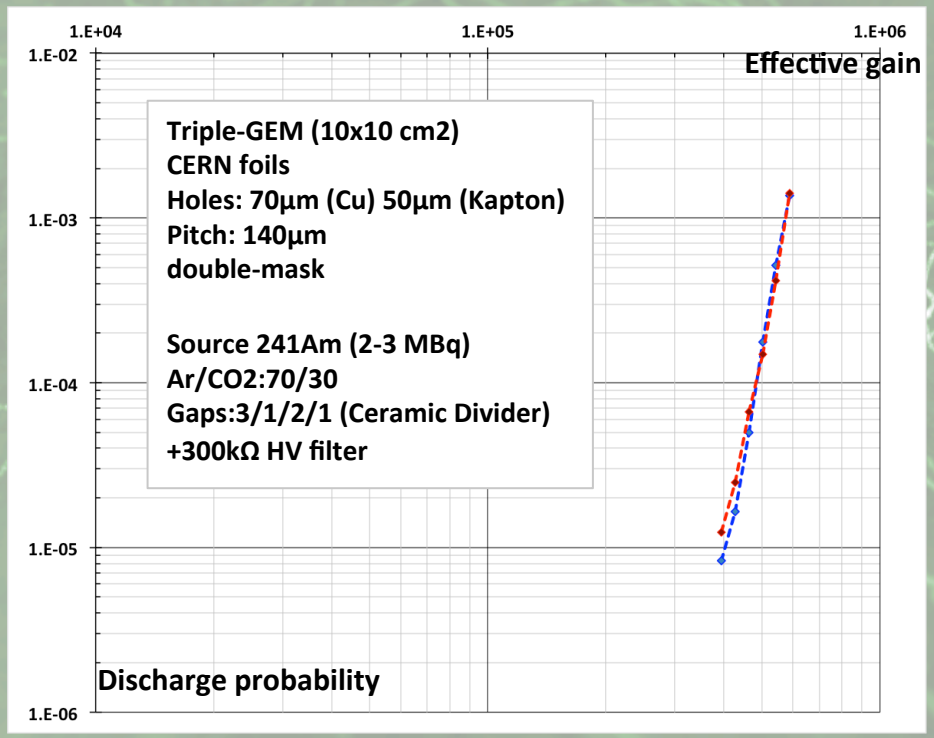


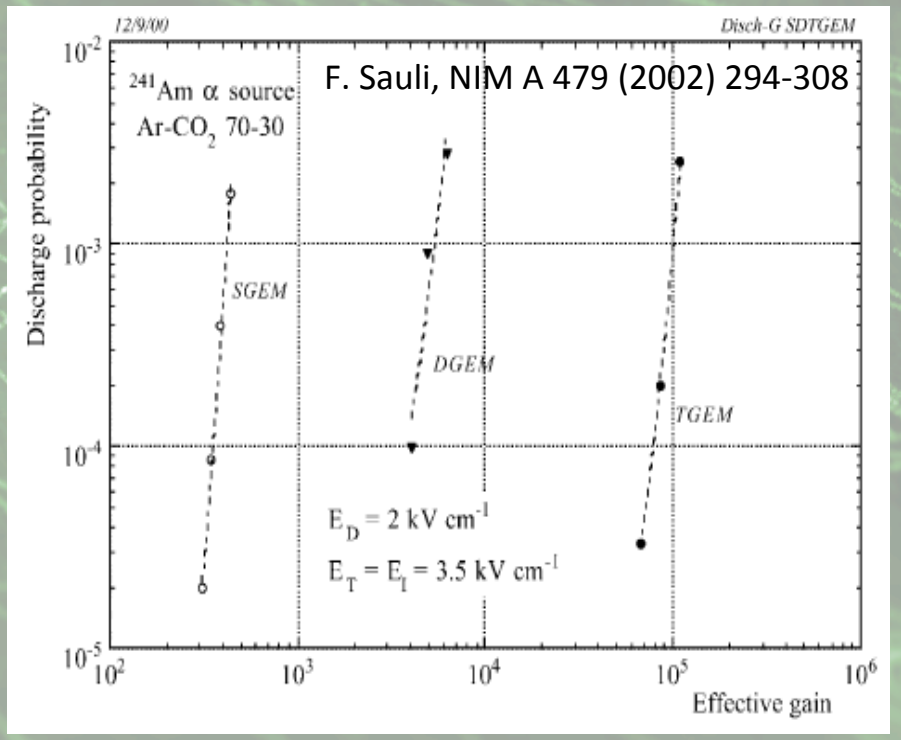
GE1/1 Time resolution < 5 ns in Ar/CO2/CF4 with gap configuration 3/1/2/1

Synchronous measurements shows > 96% probability to detect events in the same clock cycle

10x10 GEM Reference measurements

Discharge probability





@Gain=6.10^5 (3700V/740uA) : ΔV_{GEM1}= 416V ΔV_{GEM2}= 407V ΔV_{GEM2}= 389V

Spare

Monitoring gas purity in GE11 gas tubing:

→ Significant gain drop observed in reference SWPCs (input and output of GE11)

→ Presence of C, O, F, S, Ca and K on the aged wires

Investigations :

-> No aging during the gas line check

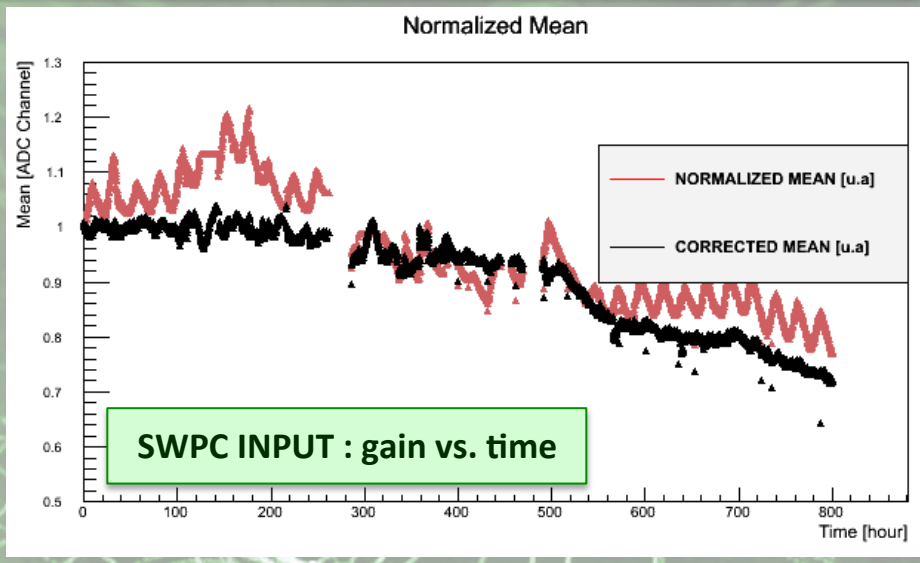
-> Faster aging on output SWPC

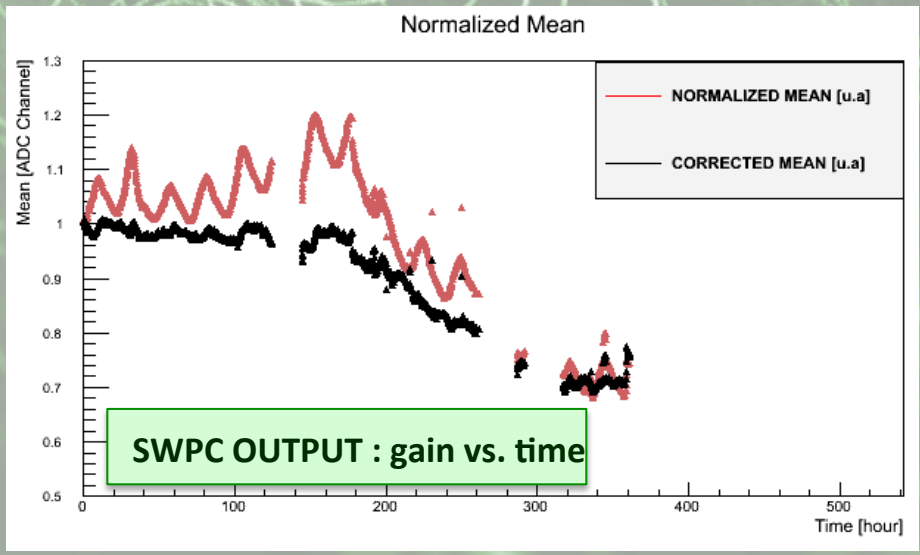
-> gas flow rate < 1 L/h

→ Outgassing from GE11 ?

→ need outgassing studies to identify the source of pollution

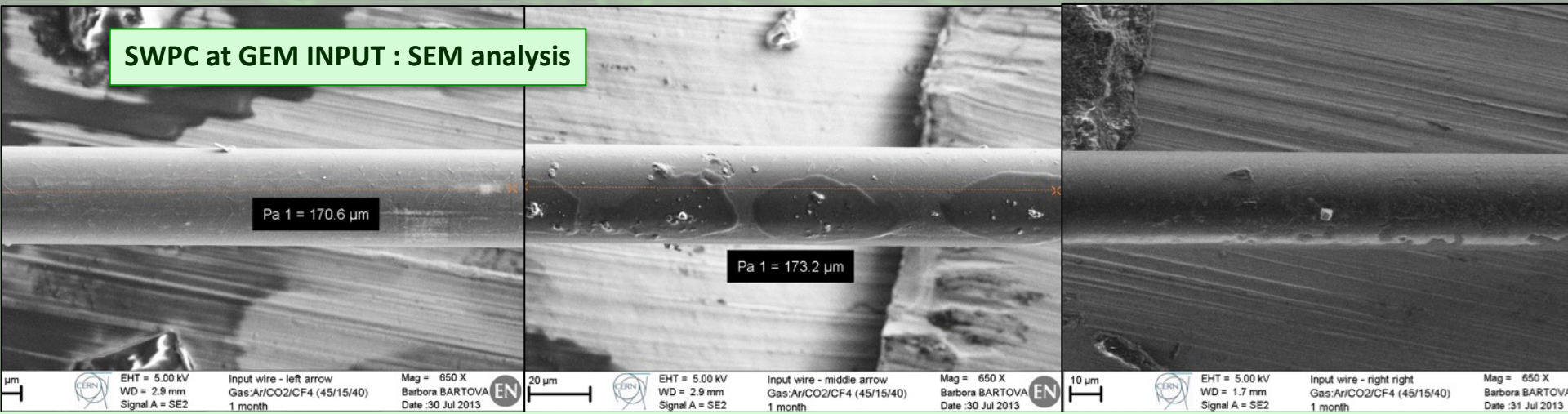
Fast gain drop with the SWPCs but NO aging was observed with the GEM





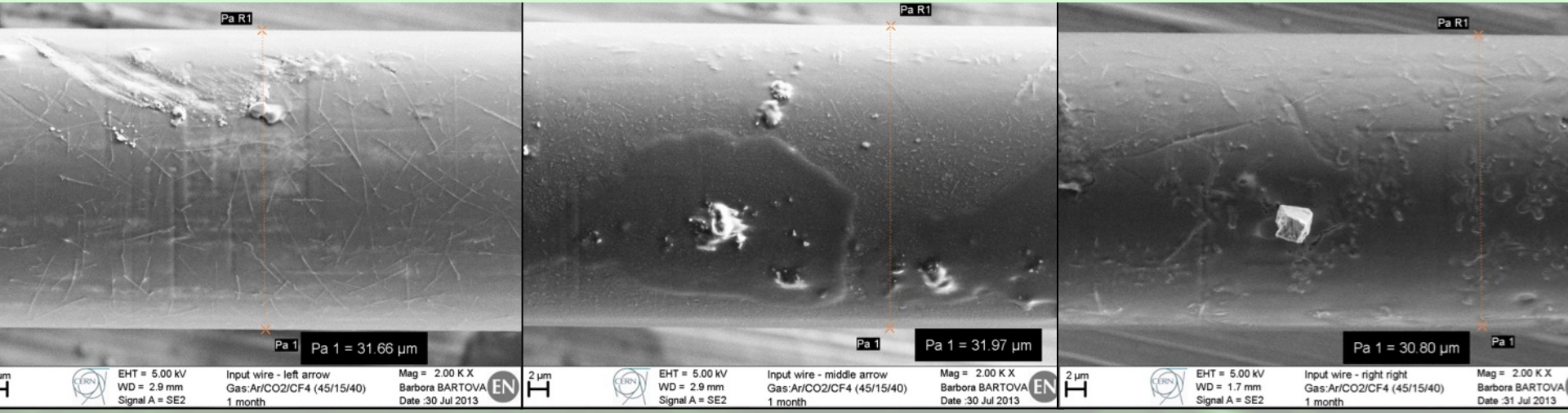
Spare

SWPC at GEM INPUT : SEM analysis



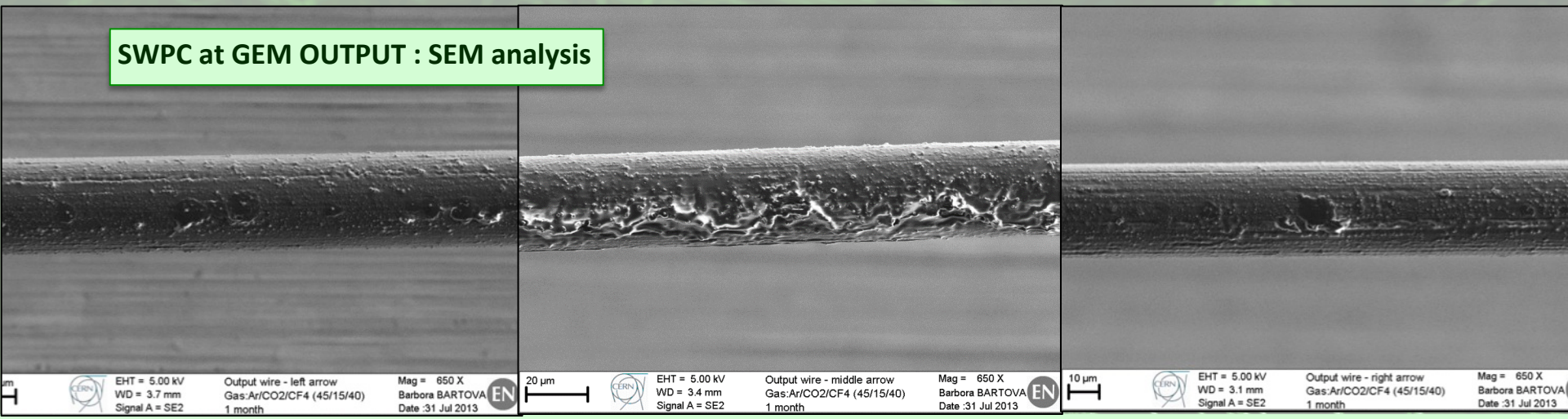
INPUT WIRE (SWPC1) — **Fe^{55}** — **HV**

GAS → **GAS →**



Spare

SWPC at GEM OUTPUT : SEM analysis



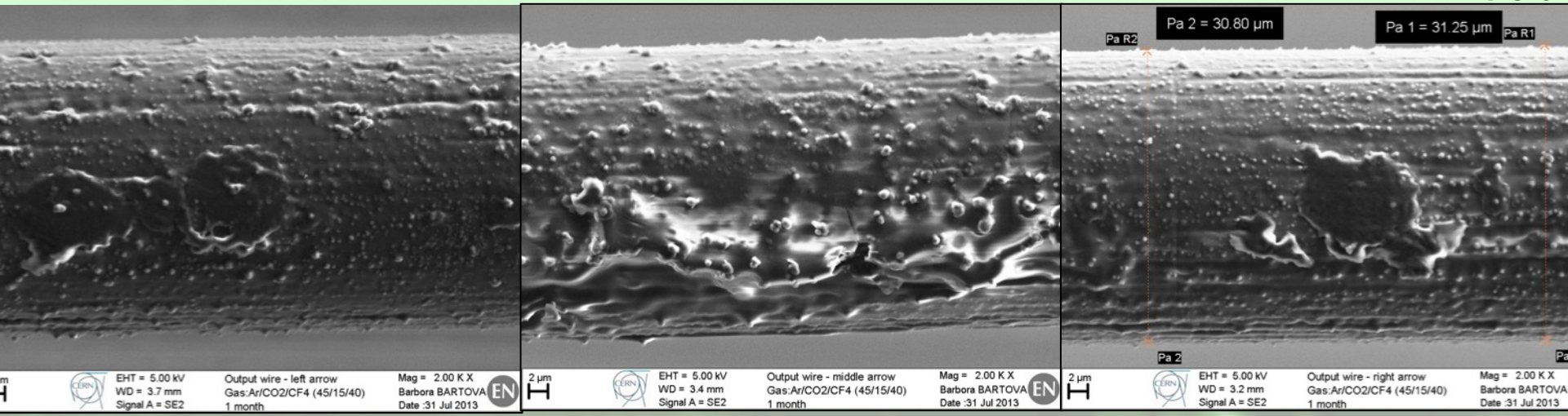
HV

OUTPUT WIRE (SWPC2)

Fe^{55}

← GAS

← GAS



Spare