RD51 Mini-Week, 22-26 June 2020

# Update on GE11 construction and commissioning

Federica Simone[1] on behalf of the GEM group

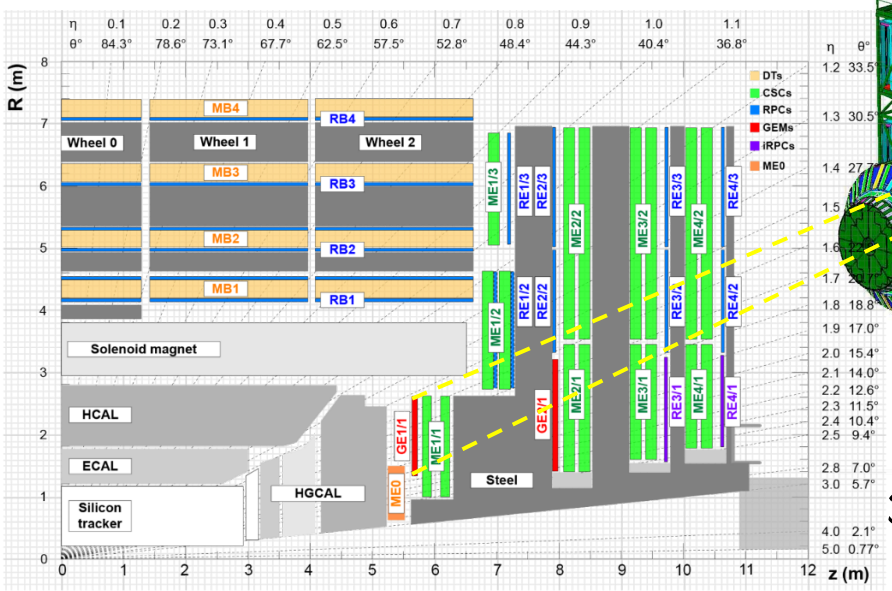
[1] University and INFN Bari, Italy

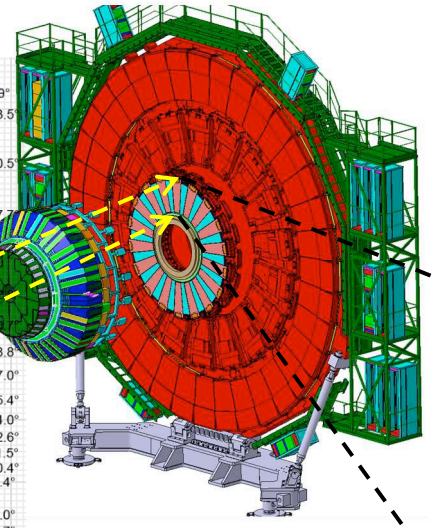
RD51 Mini-Week, 22-26 June 2020

# Outline

- GE1/1 station:
  - Overview
  - Detectors production and quality controls:
    - status and summary of the results
  - GE11 «super-chambers» final QCs:
    - QC6 HV stability tests
    - QC7 Readout Electronics installation and test
    - QC8 Final validation at cosmic ray stand
  - Commissioning:
    - Negative endcap pre-commissioning
    - Plans

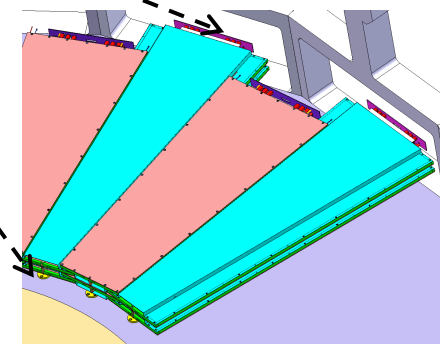
# The phase-I CMS muon endcap upgrade: GE1/1



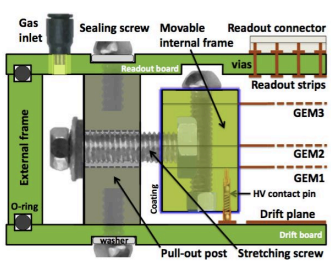



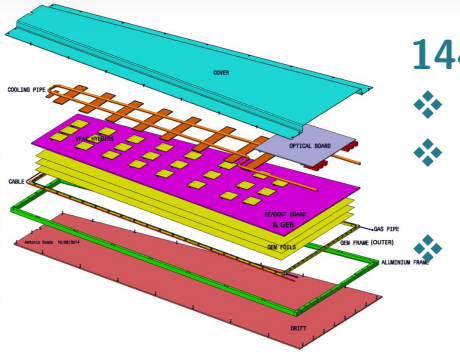
**short and long SCs** to maximise coverage

$1.55 < |\eta| < 2.18$



36 *superchambers* (SC) per endcap

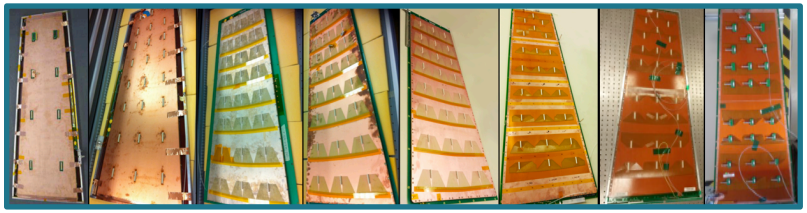


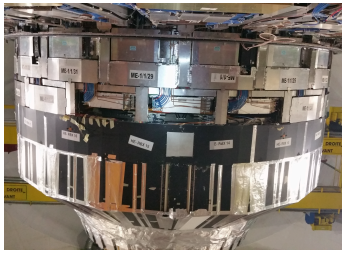



**144 triple-GEM detectors:**

- 3/1/2/1 mm gaps
- mature technology based on mechanical foil stretching
- 10-years-long R&D on design, components and materials (mechanical longevity, outgassing studies, etc.)

# The GE1/1 project





BIRTH OF GE11 PROJECT

GE11 proto. II

GE11 proto. IV

GE11 proto. VI - VII

SLICE TEST INSTALLATION AND COMMISSIONING

2009

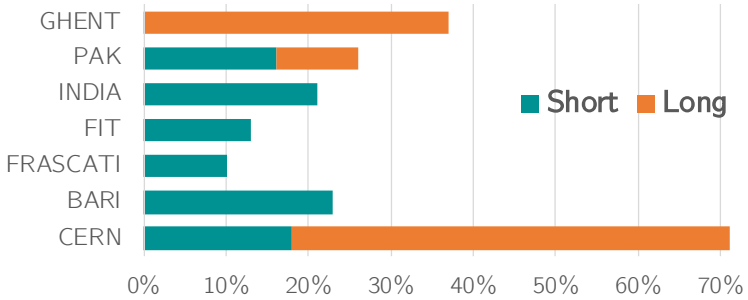
2017

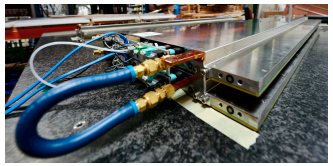
GE11 proto. I

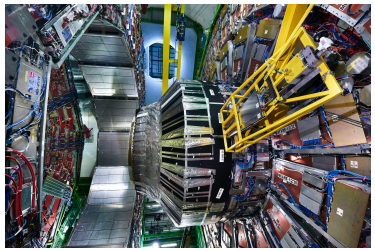
GE11 proto. III
Mechanical stretching

GE11 proto. V

DAQ/ electronics prototyping





we are here!

NEGATIVE ENDCAP INSTALLED!

POSITIVE ENDCAP INSTALLATION

Oct-2017

Dec-2018

Jul-Oct 2019

Jul-Sep 2020

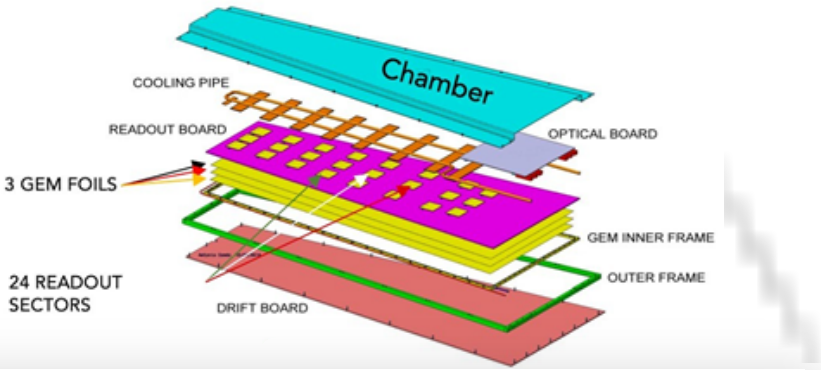
DETECTOR MASS PRODUCTION

SUPERCHAMBER PRODUCTION

# GE1/1 detectors: production and quality controls

**CERN**

- **QC1** — Foils and materials inspection
- **QC2** — 1° HV Test on GEM foils




**Production sites**

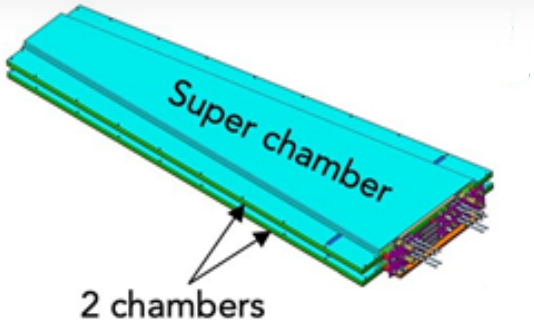
- **Assembly**
- **QC2** — 2° HV Test on GEM foils
- **QC3** — Gas leak test
- **QC4** — HV stability (divider)
- **QC5** — Gain and response uniformity

**Production shared among different sites:**
**CERN**, India, Pakistan, USA (Florida), Belgium, Italy

- ✓ Standardized setups and procedures
- ✓ Network of Institutes ready for GE2/1 and ME0 production (and more institutes joined)

**CERN**

- **QC6** — HV stability (multichannel)
- **QC7** — "Super chamber" assembly
  Readout electronics connectivity test
- **QC8** — Efficiency measurement at the Cosmic Stand



# Production and quality control: status

**CERN**

- **QC1** — Foils and materials inspection
- **QC2** — 1° HV Test on GEM foils

**Production sites**

- **Assembly**
- **QC2** — 2° HV Test on GEM foils
- **QC3** — Gas leak test
- **QC4** — HV stability (divider)
- **QC5** — Gain and response uniformity

**«Single» detectors production summary:**

- ✓ Successful and on-time production of both endcaps from Sep 2017 to Dec 2018
- ✓ In total 161/144 GE11 Detectors:
  - 4 require investigation
  - 2 QC pending
  - ✓ 155 fully validated up to QC5

**CERN**

- **QC6** — HV stability (multichannel)
- **QC7** — RO electronics connectivity test "Super chamber" assembly
- **QC8** — Efficiency meas. at the Cosmic Stand

**«Super-chambers» production:**

- ✓ First endcap 100% completed
  - ✓ Installed last year
  - Commissioning ongoing
- Second endcap: final QCs ongoing

# Quality controls up to QC5: overview

CERN

- **QC1** — Foils and materials inspection
- **QC2** — 1° HV Test

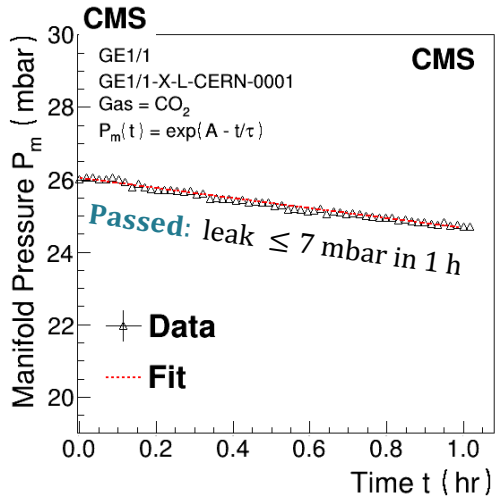
Production sites

- **Assembly**
- **QC2** — 2° HV Test
- **QC3** — Gas leak test
- **QC4** — HV stability (divider)
- **QC5** — Gain and response uniformity

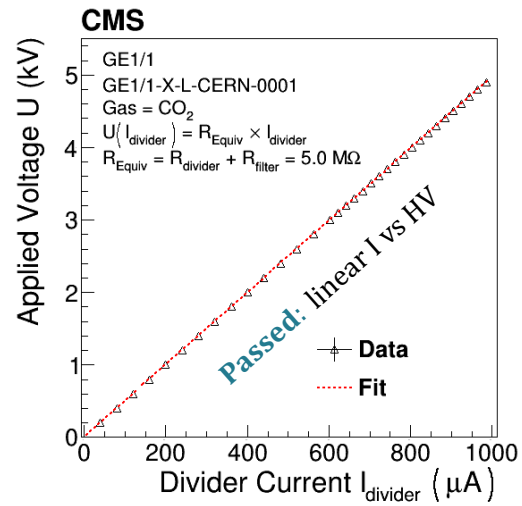
CERN

- **QC6** — HV stability (multichannel)
- **QC7** — Readout electronics connectivity test
- **QC8** — Efficiency measurement at the Cosmic Stand

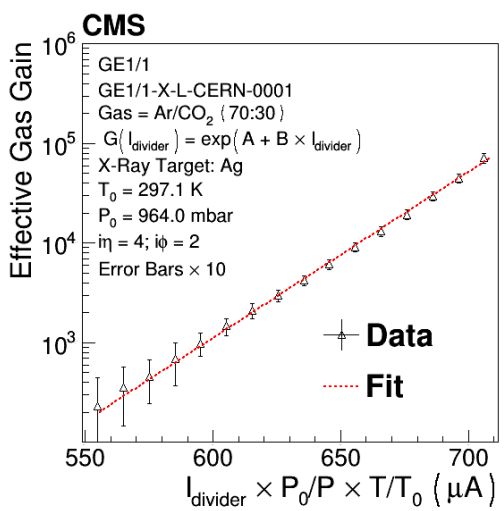
## QC3: gas leak test



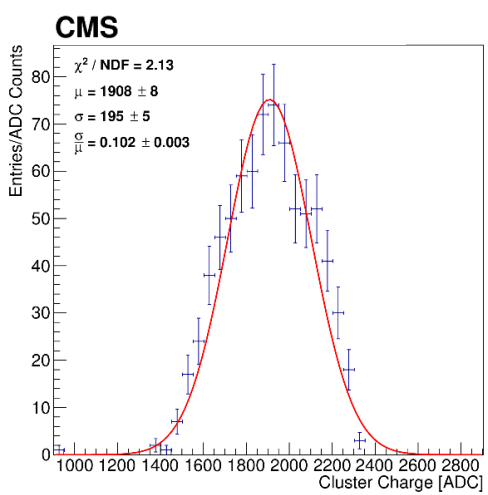

## QC4: HV test




## QC5: Effective gain




## QC5: response uniformity



# Quality controls up to QC5: summary

CERN

- **QC1** — Foils and materials inspection
- **QC2** — 1° HV Test

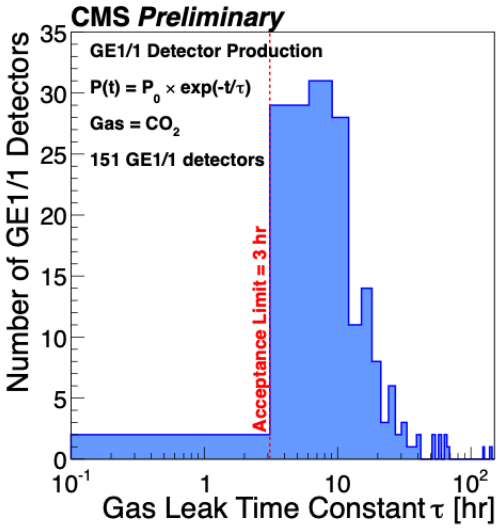
Production sites

- **Assembly**
- **QC2** — 2° HV Test
- **QC3** — Gas leak test
- **QC4** — HV stability (divider)
- **QC5** — Gain and response uniformity

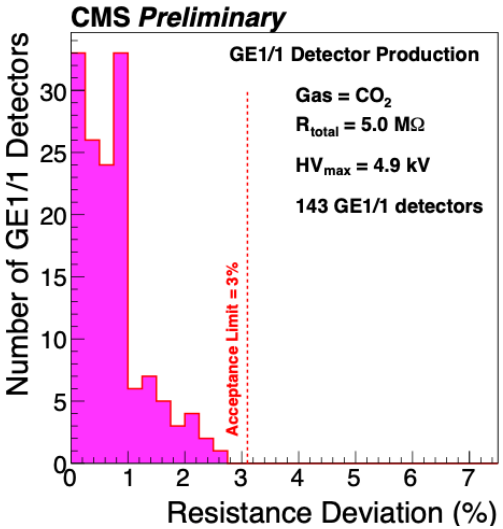
CERN

- **QC6** — HV stability (multichannel)
- **QC7** — Readout electronics connectivity test
- **QC8** — Efficiency measurement at the Cosmic Stand

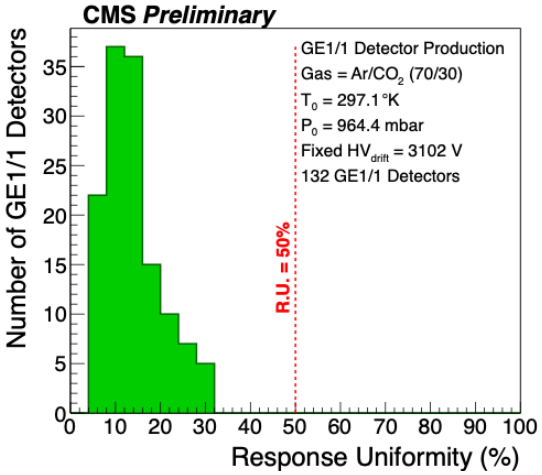
**QC3: gas leak test**



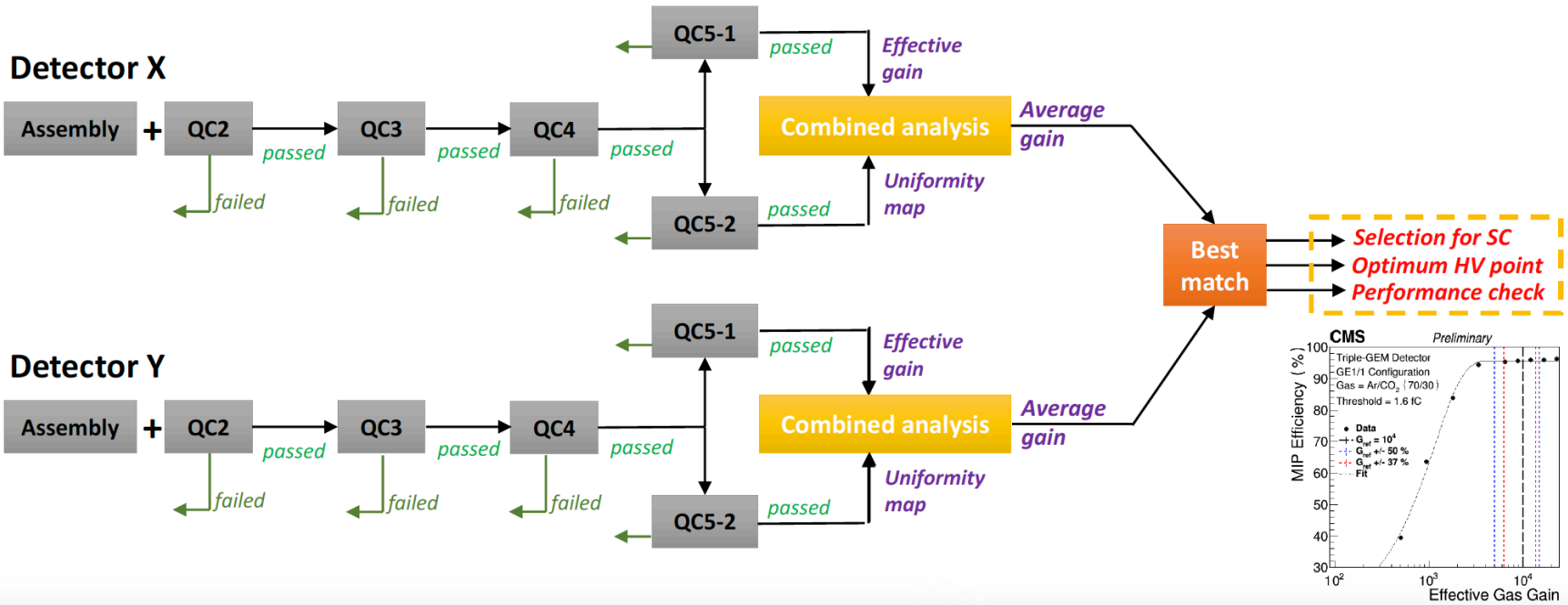

**QC4: HV test**



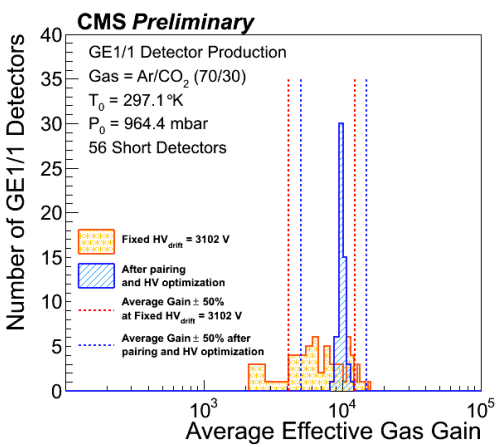

**QC5: response uniformity**

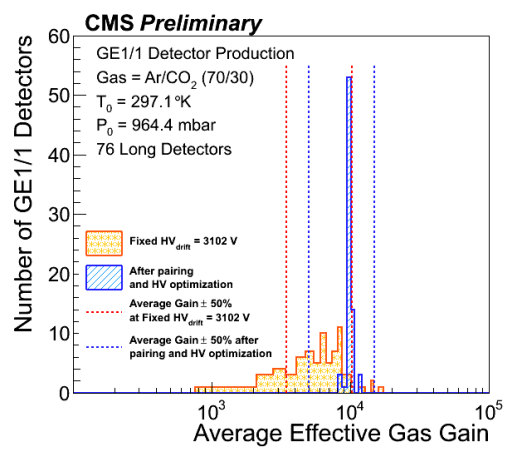


# QC5 results and superchamber pairing




## QC5 summary: average effective gain




## Chambers pairing

- 1 superchamber = 2 triple GEM detectors
- At P5 common HV power supply
- HV point optimization:
  - Chambers sorted by gain at standard HV
  - Adjacent chambers paired

# Final quality controls: QC6/7 overview

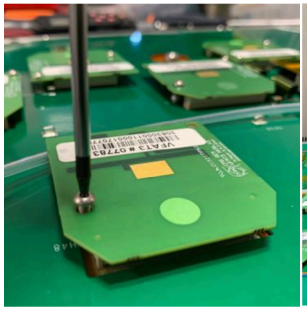
## QC6: HV stability

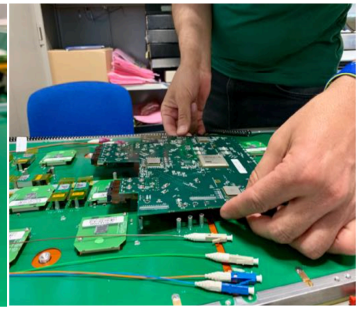
First HV stability test with final HV filter and power supply.

Very long procedure updated to prevent discharges when operating in Ar/CO2

1. Stress test at 550V per foil
2. Continuity test
3. Stress test up to 1000 V per foil
4. HV scan #1 (IV measurement)
5. long-term stability (> 12 hours)
6. HV scan #2 (IV measurement)

## Mounting of readout electronics





## QC7: RO electronics connectivity test

Test the connectivity of the electronics components, monitor the communication stability, check noise level

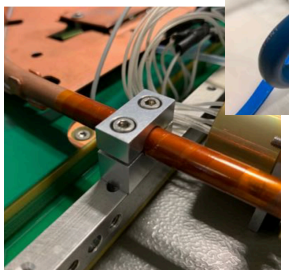
1. Connectivity
2. Calibration
3. Identification of dead/hot channels
4. Global threshold scans (SBIT line) per VFAT
5. ENC measurement (S-curves)
6. Local threshold scans (SBIT line) per channel (to identify disconnected channels)

} repeated after installing cooling plate and chimney

## Common issues and solutions

- Faulty FEASTs (non-working, unstable or inducing noise)
- Defects on the GEBs and/or on the SAMTEC connectors
- Dirty PANASONIC connectors
- Unplugged/damage/problematic VFATs
  → replug or replace components

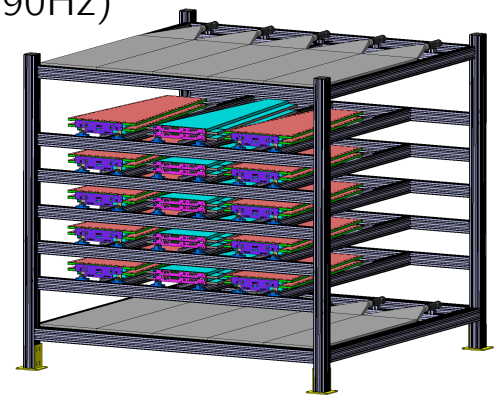
- ground loops created by cooling plate
  → insulation implemented
- Noise issues → optimised chamber grounding (star point)



# Final quality controls: QC8 overview

## Cosmic test stand: a large sized experiment in the lab

- 15 Super Chamber slots + two layers of scintillators (trigger rate ≈ 90Hz)
- 92k readout channels with CMS-like DAQ based on uTCA backend
- Services (LV, HV, DAQ system, cooling, FW, SW) as in P5
- Gas mixture: Ar/CO2 (70/30%) + CO2 / Pure Air line
- Dedicated DCS:
  - HV, LV control and monitoring (data stored in DB)
  - environmental conditions and gas mixture monitoring (stored in DB)
- Dedicated Offline DQM

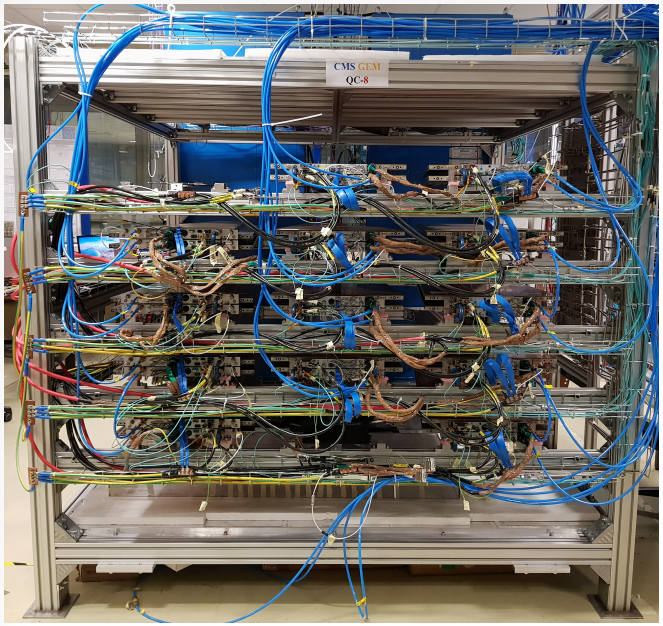


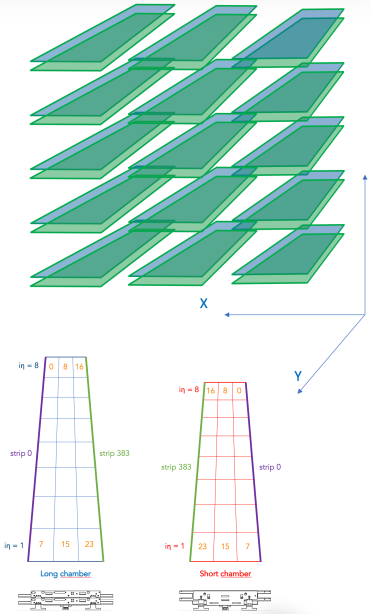
### Configuration and test procedures:

- Configuration of DAQ parameters
- Trimming, masks, thresholds @ 100Hz noise
- Before data taking: HV training procedure in Ar/CO2 to prevent discharges

### QC8 test:

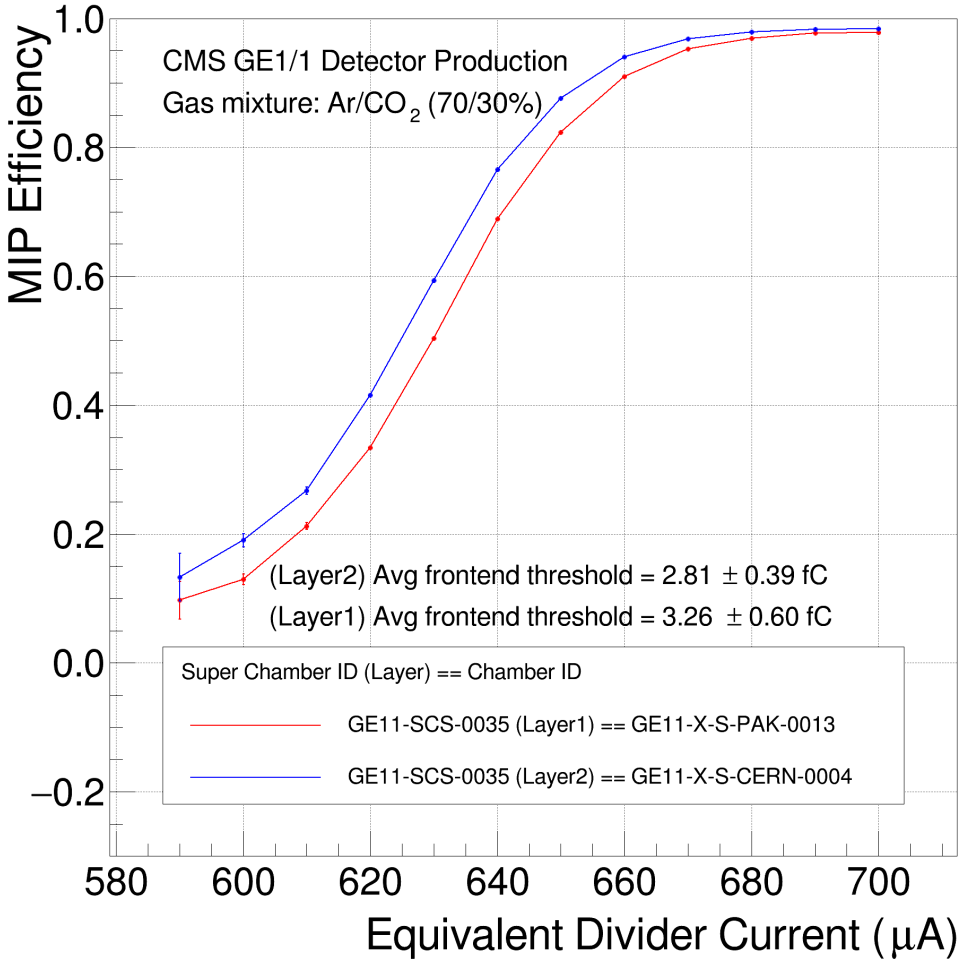
- HV scan with cosmic muons:
  ~12h cosmic run for each HV point
- Analysis in CMSSW Framework:
  - Software alignment implemented,
  - Muon track reconstruction for efficiency measurement,
  - Final results stored in DB



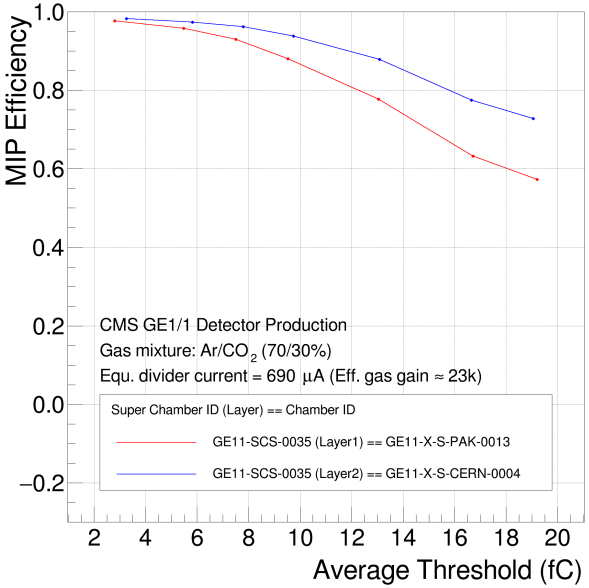



# Final quality controls: QC8 results

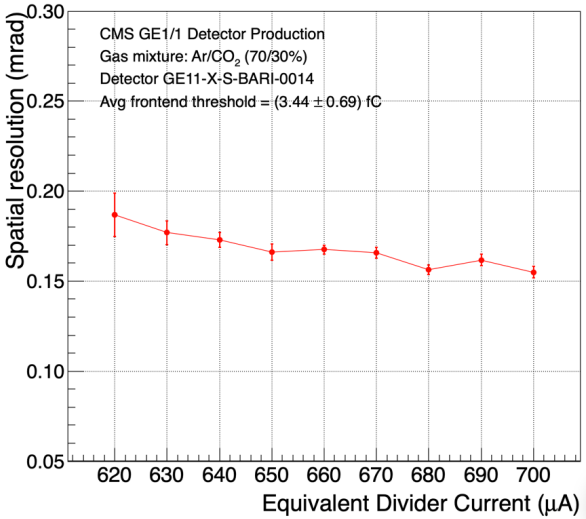
## Example of efficiency vs HV scan




## Efficiency vs thresh. scan



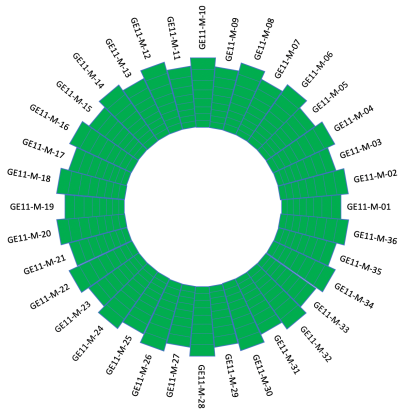

## Spatial resolution



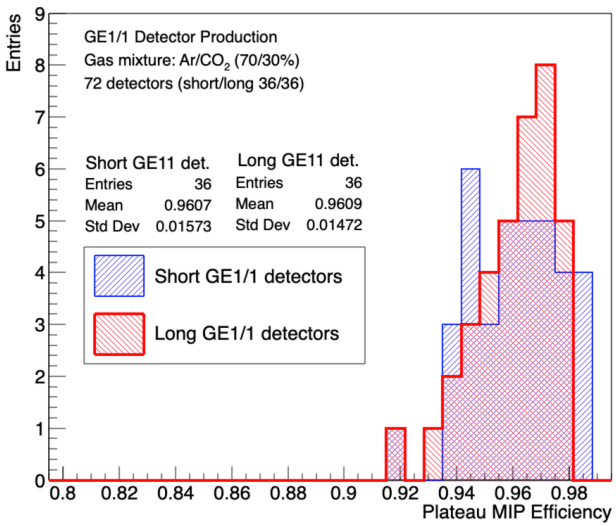
# Final quality controls: status summary

## First endcap: GE11-

- 36 long + 36 short detectors fully validated
- Negative endcap installed in July, September and October 2019

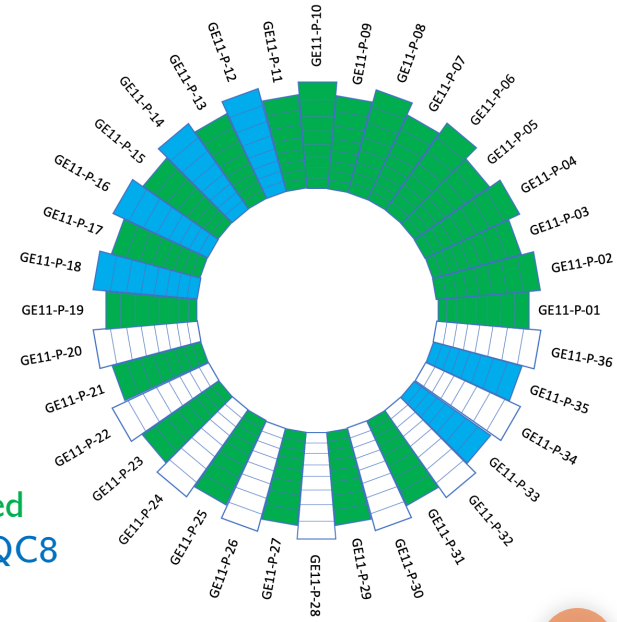



Efficiency summary at QC8 for the negative endcap




## Second endcap: GE11+

- 36 long + 36 short detectors validated up to QC5
- final QCs (QC6/7/8) ongoing:
  - 90% of short chambers and 30% of long chambers fully validated
- Installation window for positive endcap: July, August, September 2020




validated under QC8

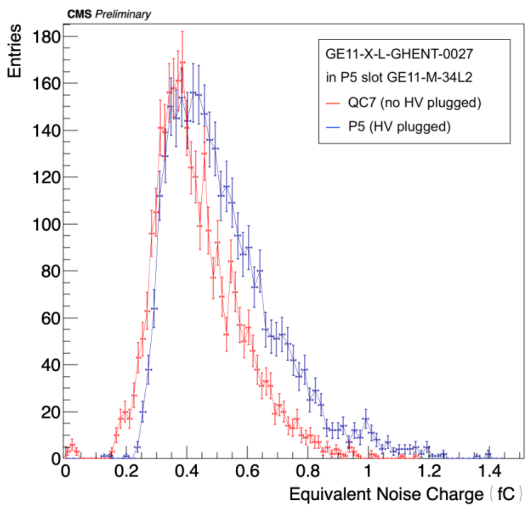
# GE11 commissioning

## First endcap "pre-commissioning"

After installation, until Feb. 2020

- HV training in pure CO2
- Readout electronics connectivity check and noise measurement
- DCS and DAQ fully operational

Noise comparison: QC7 vs P5




## Plans after Covid-19 stop ...

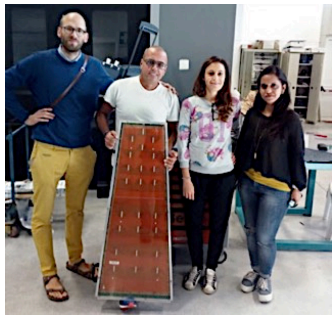
- Restart DCS and DAQ, repeat HV training
- Readout electronics calibration
- **Switch to Ar/CO2 mixture**

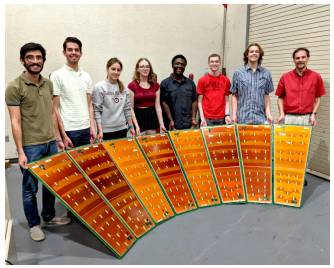
## ... and from Sept/Oct 2020

Data taking with cosmics

- Latency scan
- Efficiency measurement for optimal HV point tuning (combined with CSC sub-detector)

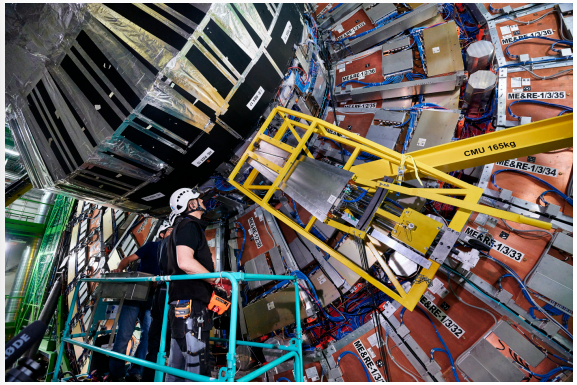
# Conclusions




- Successful and on-time production of both endcaps (> 144 detectors) from Sep 2017 to Dec 2018, tested up to QC5
- 75% of total GE11 detectors have been fully validated
  - complex mechanics + electronics required many changes in final assembly and test procedures
  - we gained valuable experience for GE2/1 and ME0 upgrades

- Last year: GE11- station has been installed. A first commissioning phase already took place
- Finalising the tests on the last superchambers in these days
- Positive endcap to be installed in the coming months



# Backup material

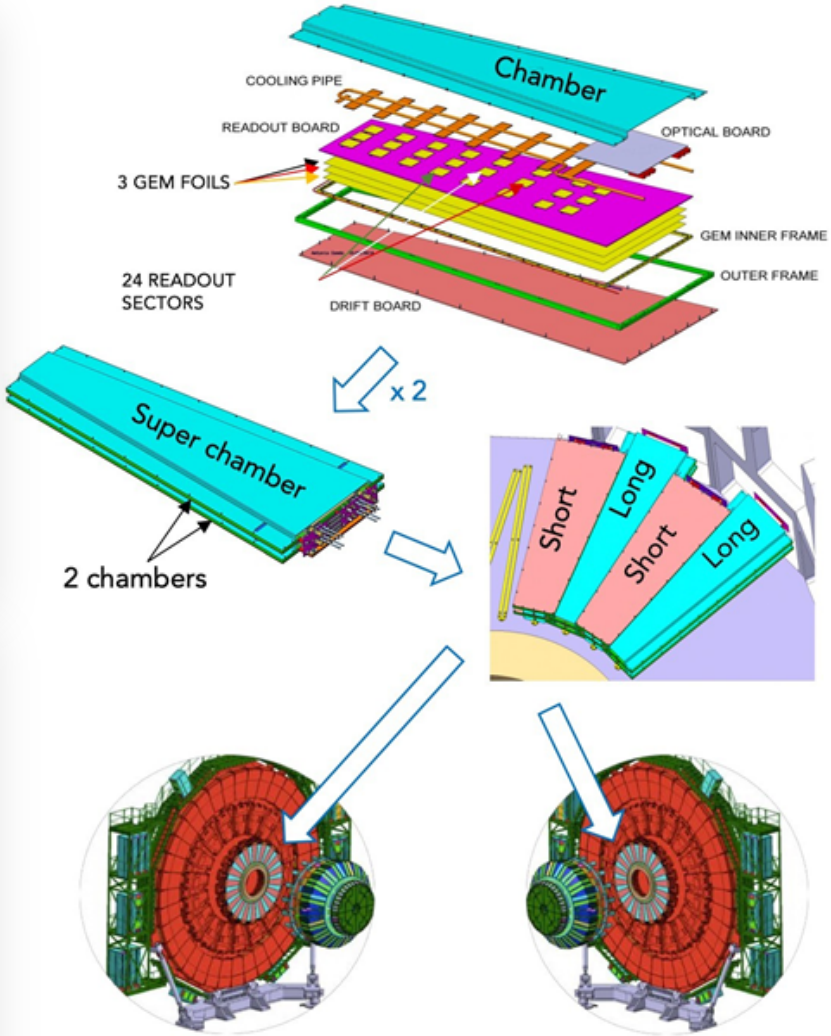
# GE1/1 detectors: specifications and production

**GE1/1 detectors:**

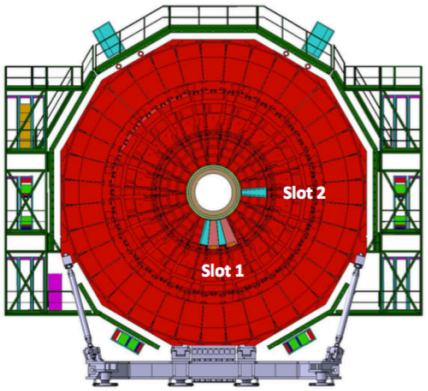
- Triple GEM geometry (gap 3/1/2/1 mm)
- Big surface O(m2)
- 144 trapezoidal chambers (Long and Short)
- 24 readout sectors – 128 strips each
- Readout electronics based on the VFAT3 frontend chip
- 72 «superchambers» = 144 triple-GEM chambers

**Production shared among different sites:**
**CERN**, India, Pakistan, USA (Florida), Belgio, Italia (Bari and Frascati)

- ✓ Standardized setups and procedures
- ✓ New community of GEM experts
- ✓ Network of Institutes ready for GE2/1 and ME0 production

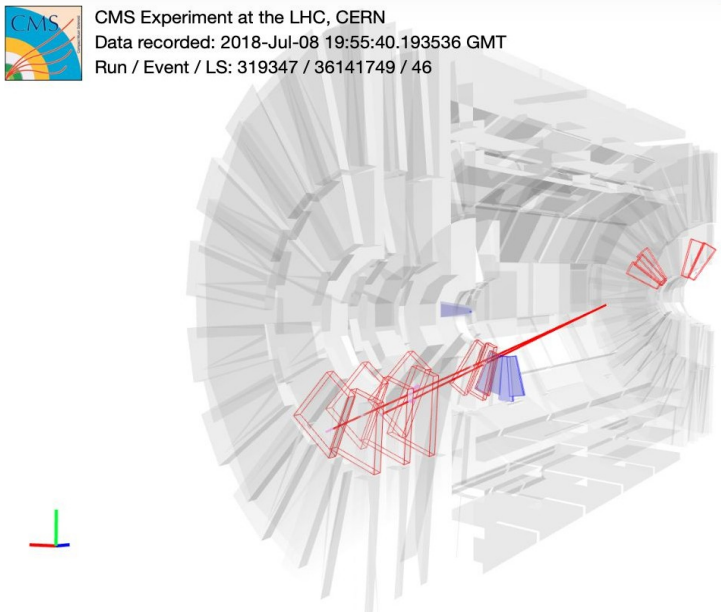


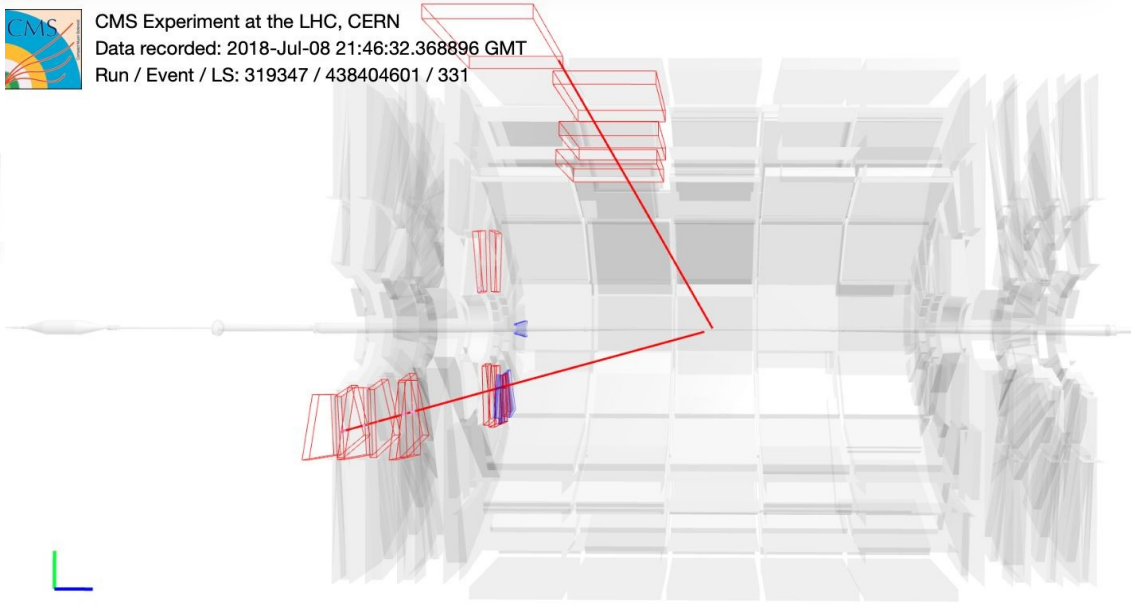
# First test bench for the GE1/1 project 2017«Slice Test»



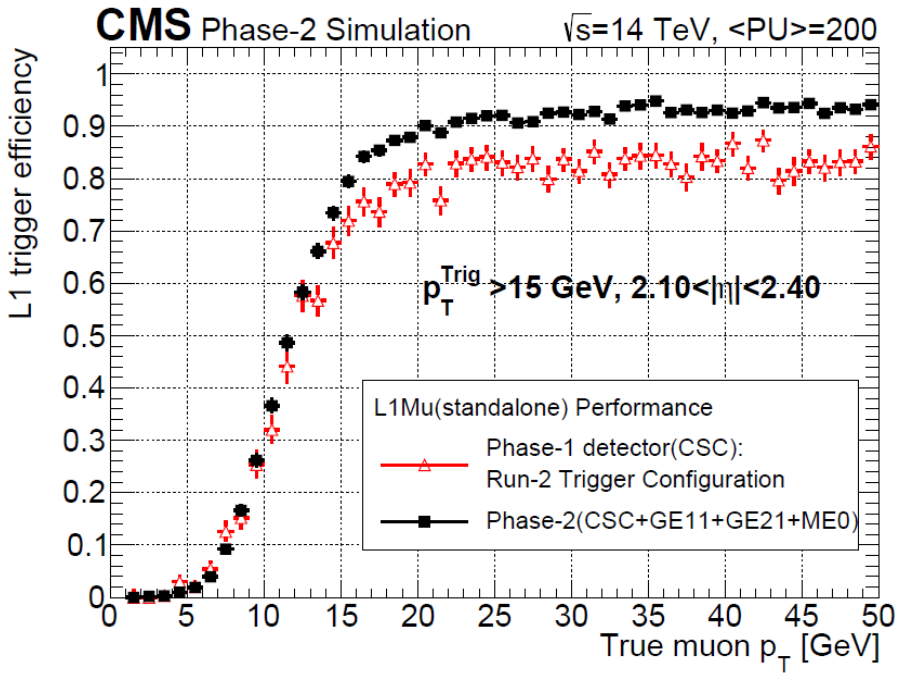

**Slice Test:** 5 super chambers installed in 2017 and operational till the end of Run II. Goals:

- ❖Acquire first operational experience
- ❖Integrate the GE1/1 station in the central CMS services
- ❖Detector Control System (DCS) and Data Quality Monitoring (DQM) integration



# Impact of the new muon stations



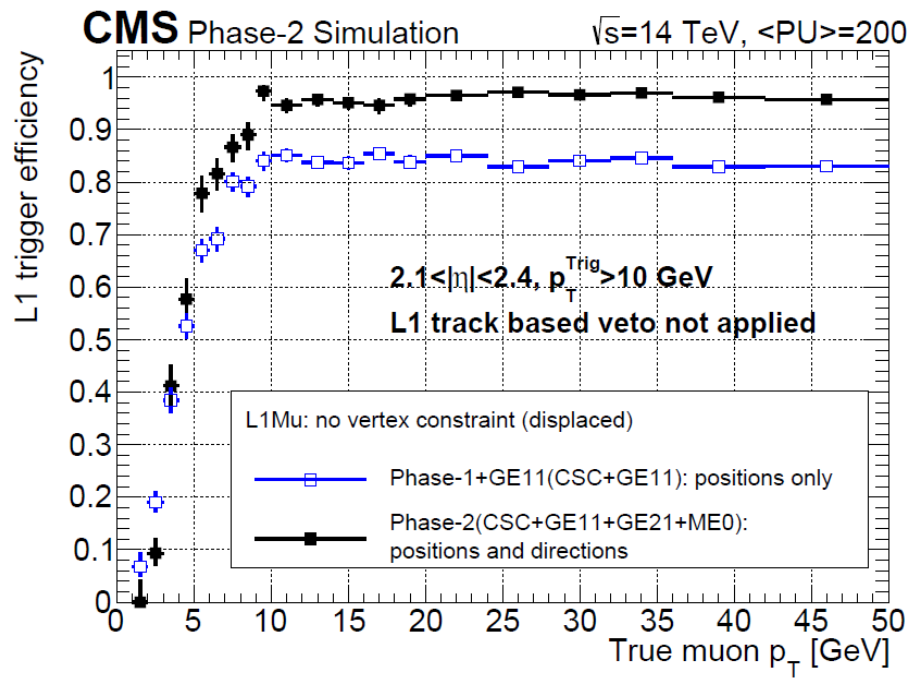
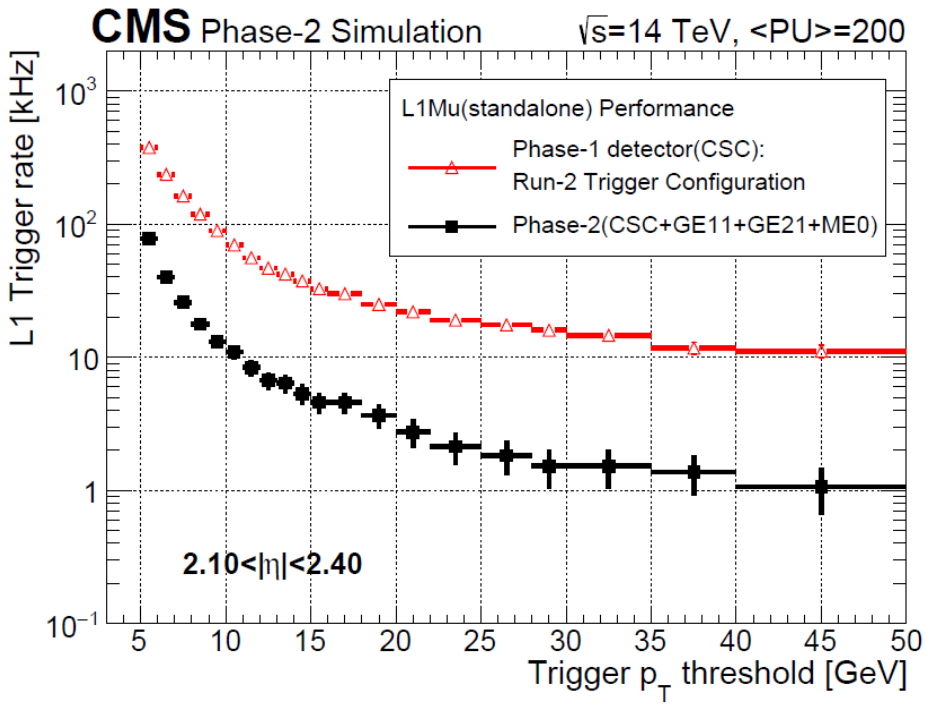




Figure 1.22: L1 Muon trigger efficiency for the prompt muon trigger (left) and displaced muon trigger algorithm (right), as a function of a true muon pT in the region 2.1 < eta < 2.4. The L1 trigger pT threshold is 15 GeV (left) and 10 GeV (right).

# Impact of the new muon stations



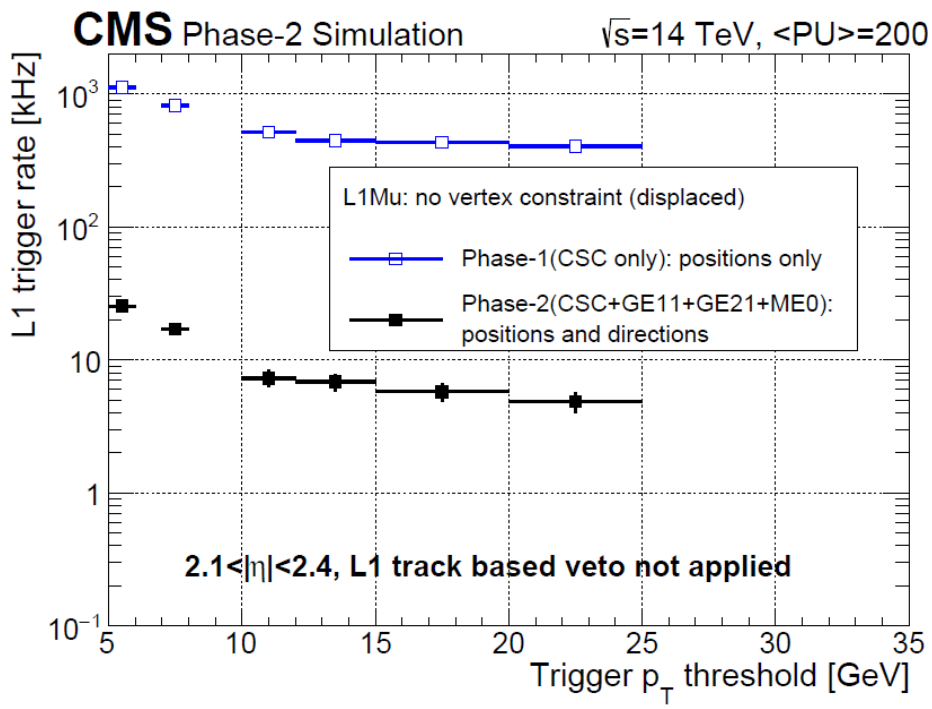
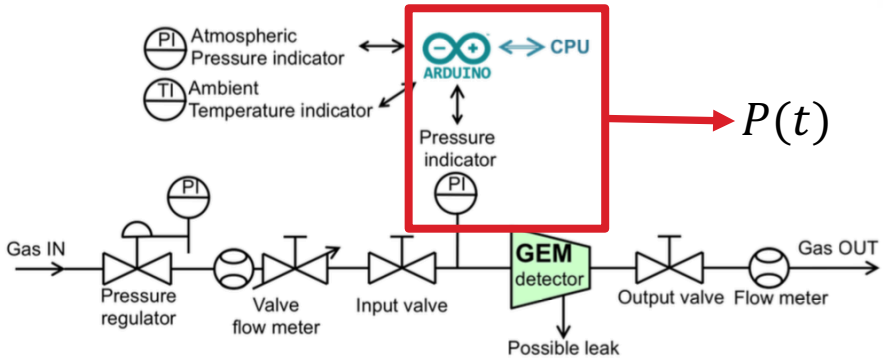



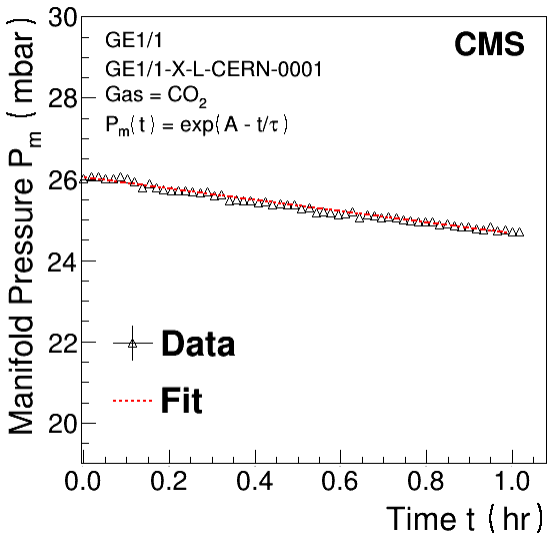

Figure 1.23: L1 prompt (left) and displaced (right) muon trigger rates, with and without GEM chambers, as a function of muon trigger pT threshold in the region 2.1 < eta < 2.4. The L1 track based veto is expected to further reduce the displaced muon trigger rate by a factor of 3–8.

# GE1/1 quality controls: «QC3» gas leak test

## 1. Setup




## 2. Typical output




$P_0 = 25$ mbar initial over-pressure

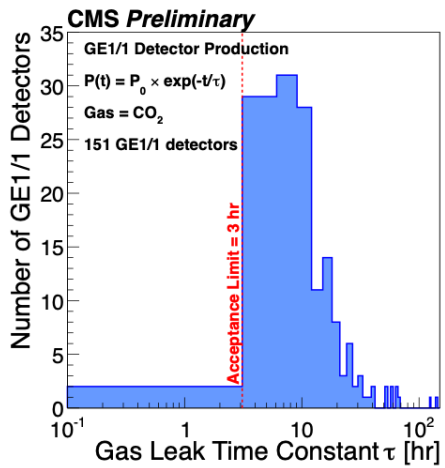
$P(t) = P_0 e^{-t/\tau}$, $\tau$ from exp. fit

## 3. Acceptance criteria

$$\tau > 3h$$

(max leakage flow rate $\sim 0.02\, l/h$)

## 4. Summary of results




QC3 test:

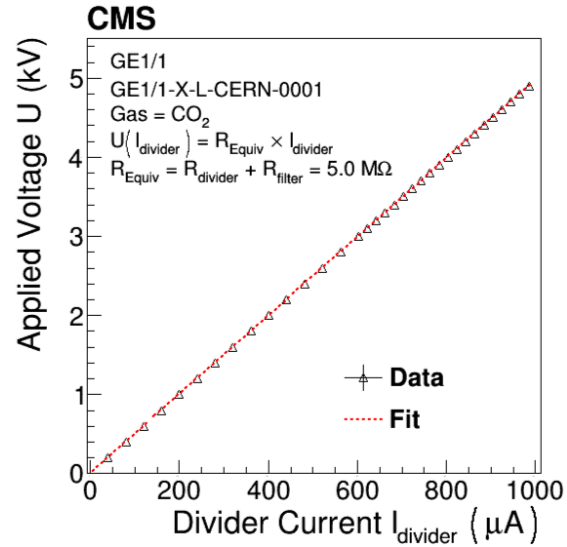
- performed on 151 (144+7 spares) chambers
- 149 validated detectors

# GE1/1 quality controls: «QC4» (I) HV stability

## 1. Procedure

- chamber powered in step of 100V through a ceramic divider (pure CO2)
- powered up to $V_{drift} = 49$ kV
- for each step, the current drawn by the divider is recorded → V-I curve

## 2. Typical output




V-I characteristics of the full HV circuit

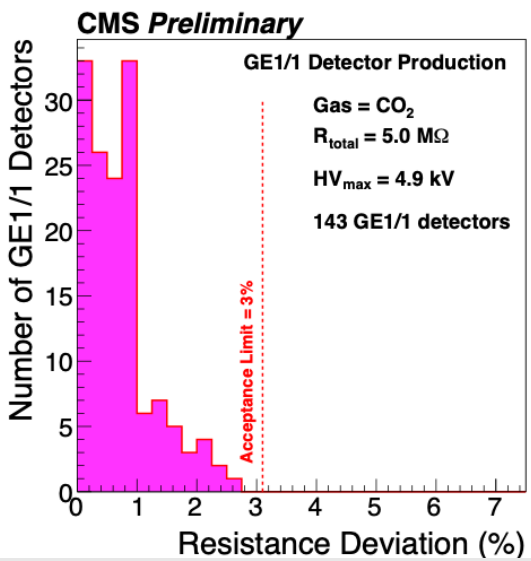
$\Delta R/R = (R_{equiv.meas.} - R_{fit})/R_{equiv.meas}$

## 3. Acceptance criteria

$$\Delta R/R < 3\%$$

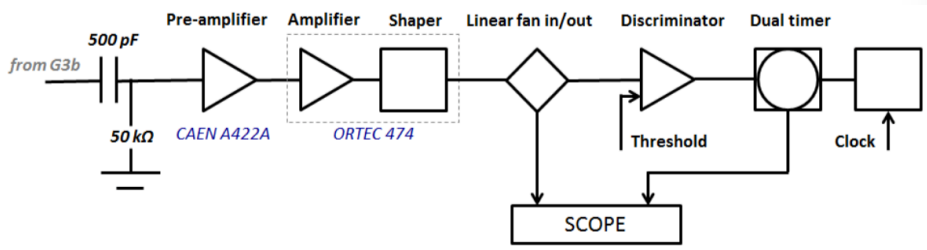
Deviation w.r.t. ohmic behaviour

## 4. Summary of results



# GE1/1 quality controls: «QC4» (II) intrinsic noise rate

## 1. Setup




## 2. Procedure

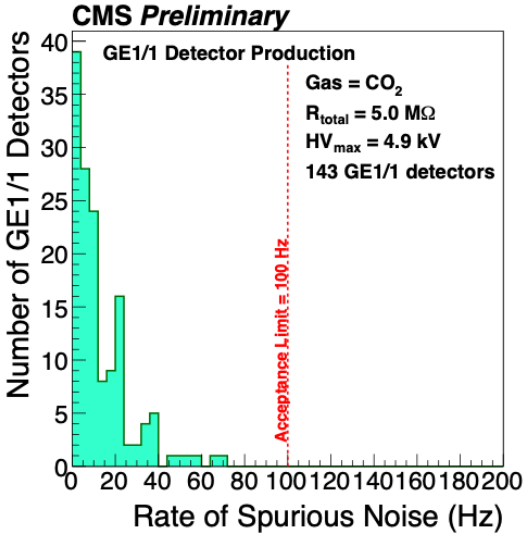
- chamber powered in step of 100V (ceramic divider, pure CO2)
- powered up to $V_{drift}$ = 49 kV
- for each step, the number of spurious pulses from G3B is recorded

## 3. Acceptance criteria

$$R_{max} < 100\ Hz\ (\sim 10^{-2}\ Hz/cm^2)$$

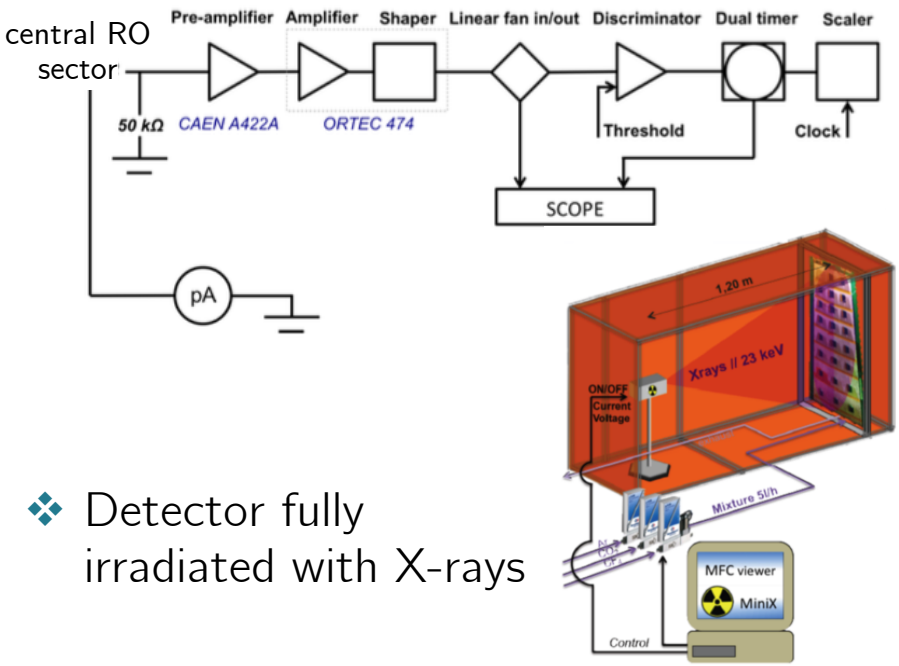
exp. rate at GE1/1 station > 4.5 kHz/cm$^2$

## 4. Summary of results



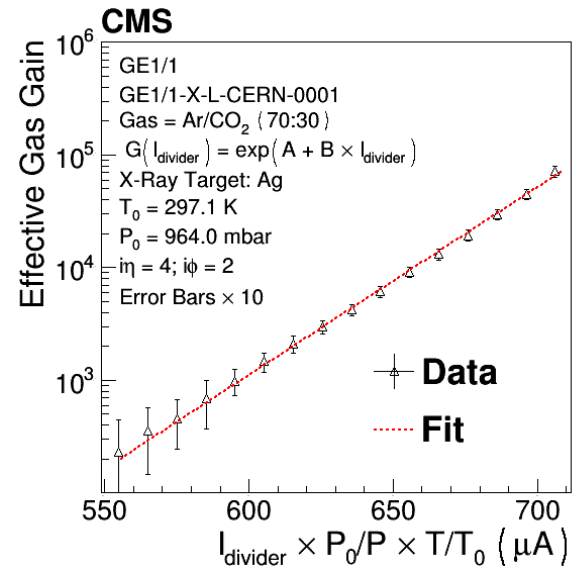
# GE1/1 quality controls: «QC5» (I) effective gain

## 1. Setup and procedure




- Detector fully irradiated with X-rays
- For each HV point:
  - measure the signal rate
  - measure the current induced on the readout $I_{RO}$

## 2. Typical output



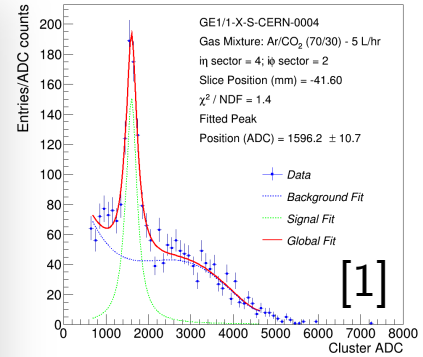

$$G = \frac{I_{RO,\,xray\ ON} - I_{RO,\,xray\ OFF}}{R \times e \times N_p}$$

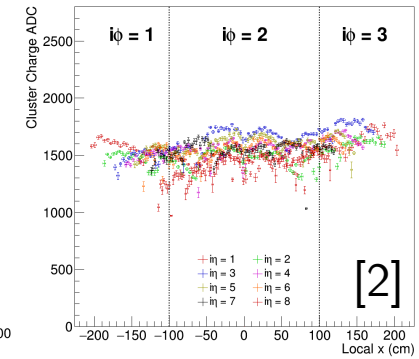
- Signal rate curve plateux assumed as source rate (R)
- $N_p$ = expected number of primary electron-ion pairs

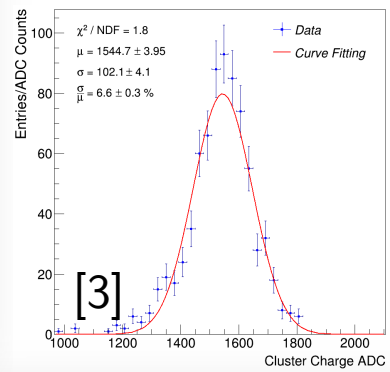
# GE1/1 quality controls: «QC5» (II) response uniformity

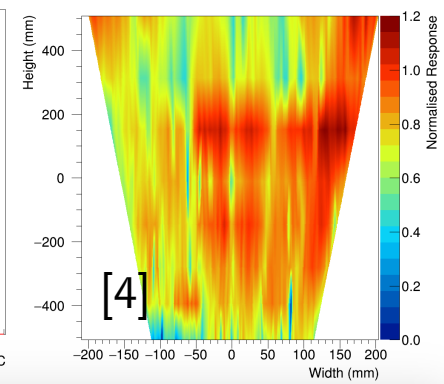
## Response uniformity and gain map

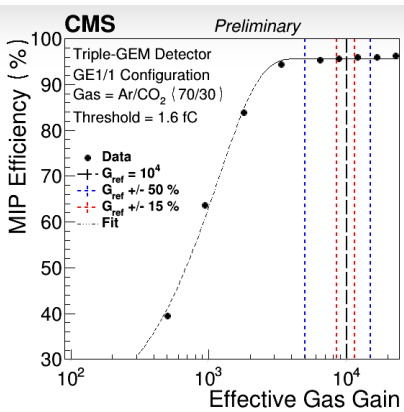
- Detector fully irradiated with X-rays
- RO based on analog electronics (APV25)
- [1] Measure the **copper fluorescence** for every readout channel (3 strips ≈ photon cluster size)
- [2] Compare ionization peak positions
- [3] Distribution of the cluster charge ADC ⟹ $\boldsymbol{R = \sigma/\mu \cdot 100}$ **(Response uniformity)**
- [4] Gain in the central RO sector + uniformity map = gain map ⟹ **avg. gas gain ± std. dev.**

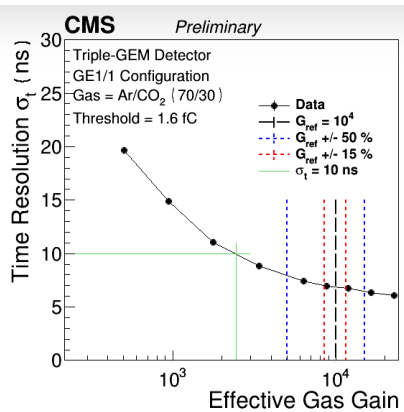


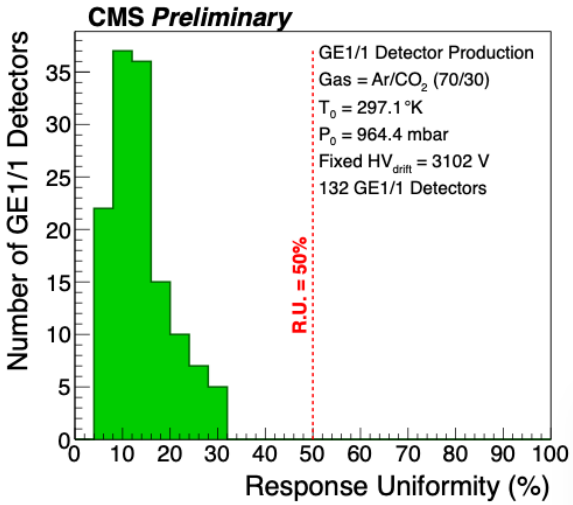

Large active area → gain fluctuations
(foil thickness variations, holes diameter, bending...)

$$\sigma_{gain} \sim 37\%$$

GE1/1 efficiency & time res. **stable** in a large gain range: $G_{ref}$ ± 50% ($G_{ref} = 10^4$)

# GE1/1 quality controls: «QC5» results and SC pairing

## 1. Summary: response uniformity

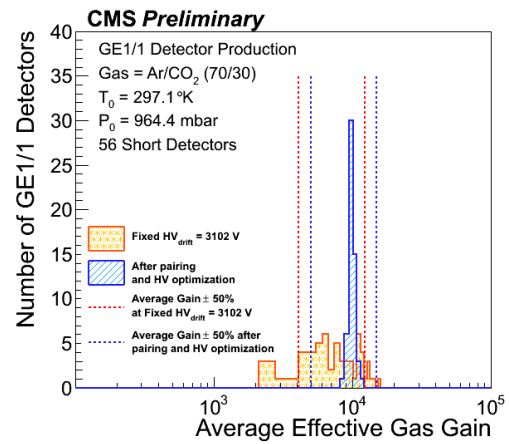


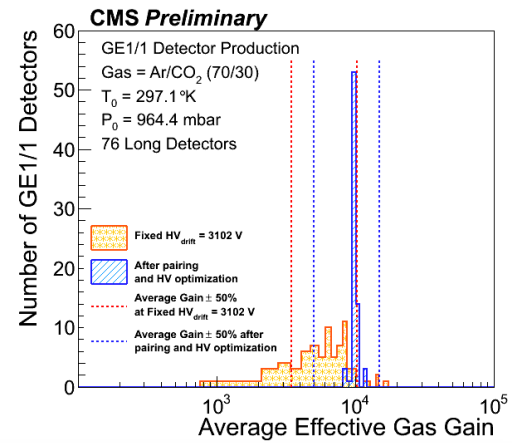

## 2. Acceptance criteria

$$R < 50\%$$

Max response uniformity to ensure stable performances

## 3. Summary: average effective gain




## 4. Chambers pairing

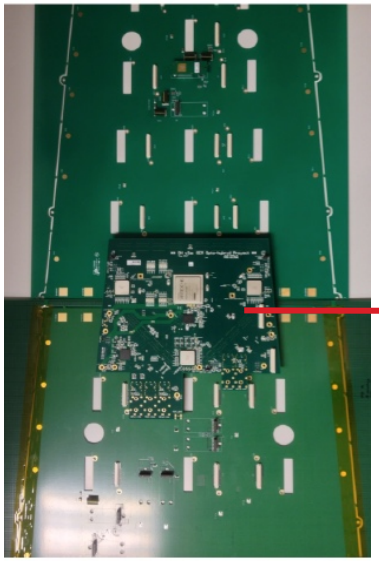
- 1 super chamber = 2 triple GEM detectors
- Common HV power supply ⟹ same HV setting
- HV point optimization:
  - Chambers sorted by gain @ standard HV
  - Adjacent chambers paired
  - Optimal HV = avg between the two

# GE1/1: Readout Electronics

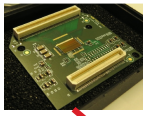
ON - DETECTOR

OFF - DETECTOR

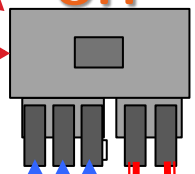
2 - pieces GEB v3 $(1.0 - 1.2m)$



VFAT3



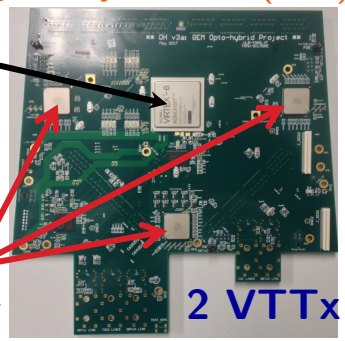
OH

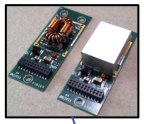


CSC Trigger Mother Board (TMB)

Trigger data
(3.2 Gbps – 10b/8b)

Opto Hybrid v3 (OH)



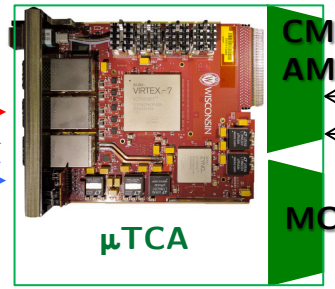



FEAST
(DC DC converter, LV VFAT3 & OH)

/2

/2

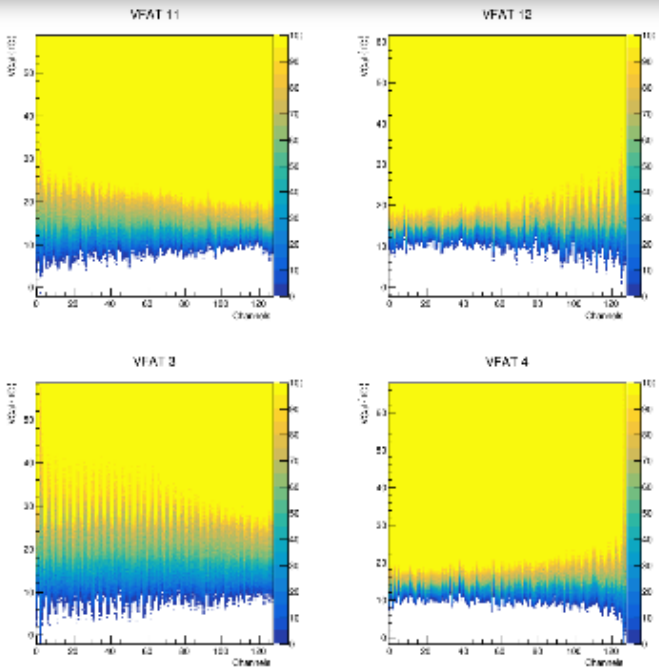
Tracking data
3 x GBT – 4.8 Gbps

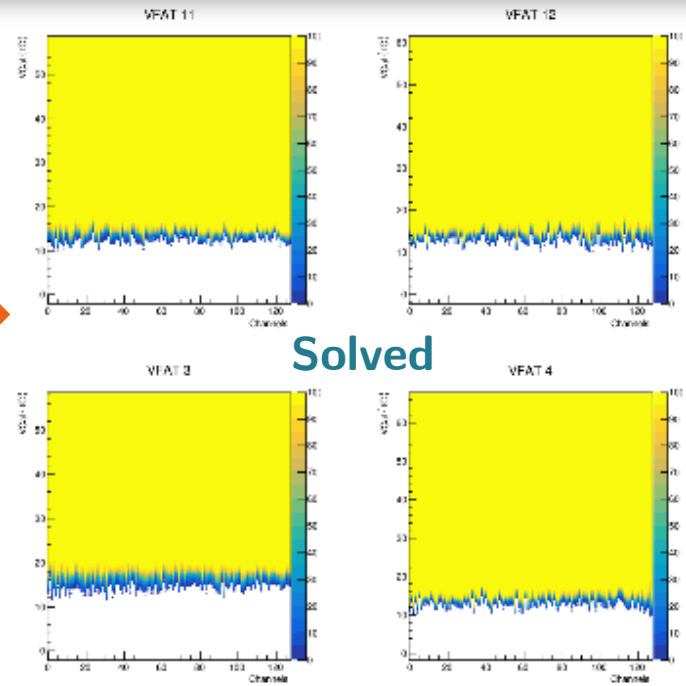



AMC = CTP7 from CMS Trigger upgrade

# QC7 systematic problems and solution implementation (1.1)

**Ground-loops between chamber and cooling plate:**
Scurves depicted high noise level on the electronics due to current loops formed on the cooling plate.



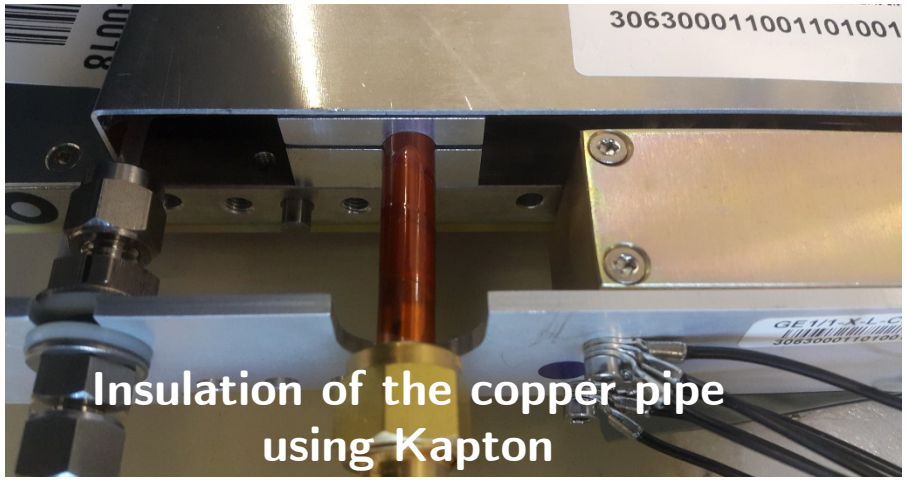

**Solved**

# QC7 systematic problems and solution implementation (1.2)

**Ground-loops between chamber and cooling plate: Solution**
insulation of the cooling plate with a single grounding connection to the star-point


Electrically insulated thermal pad

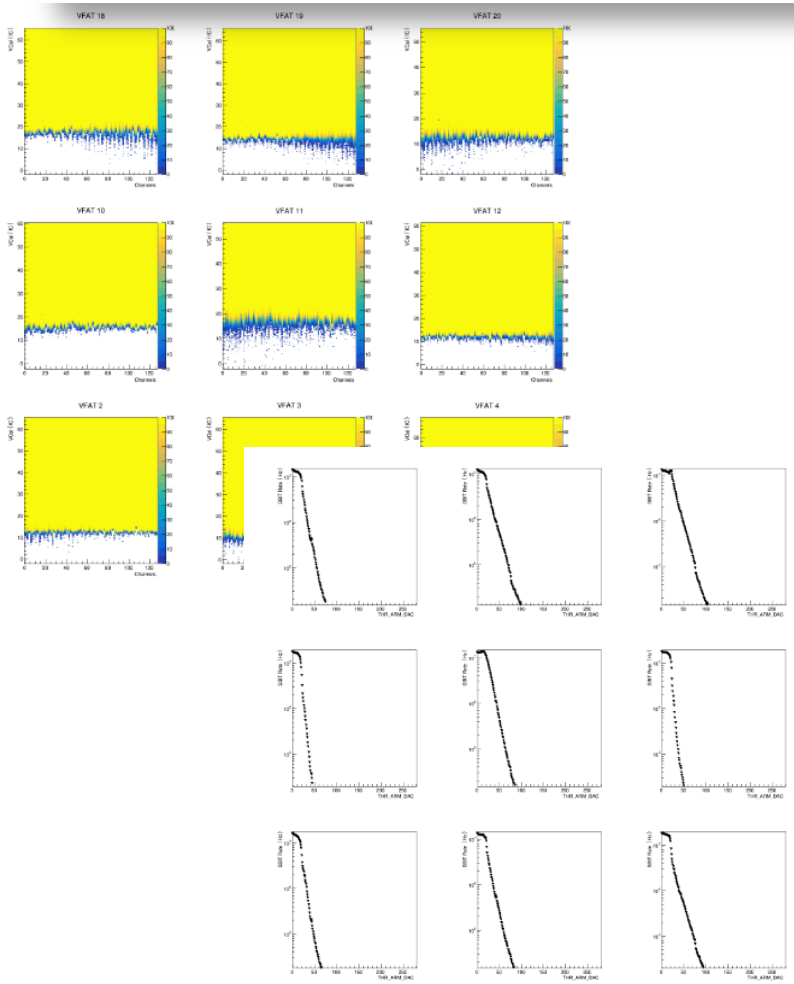
Plastic pillars and washers

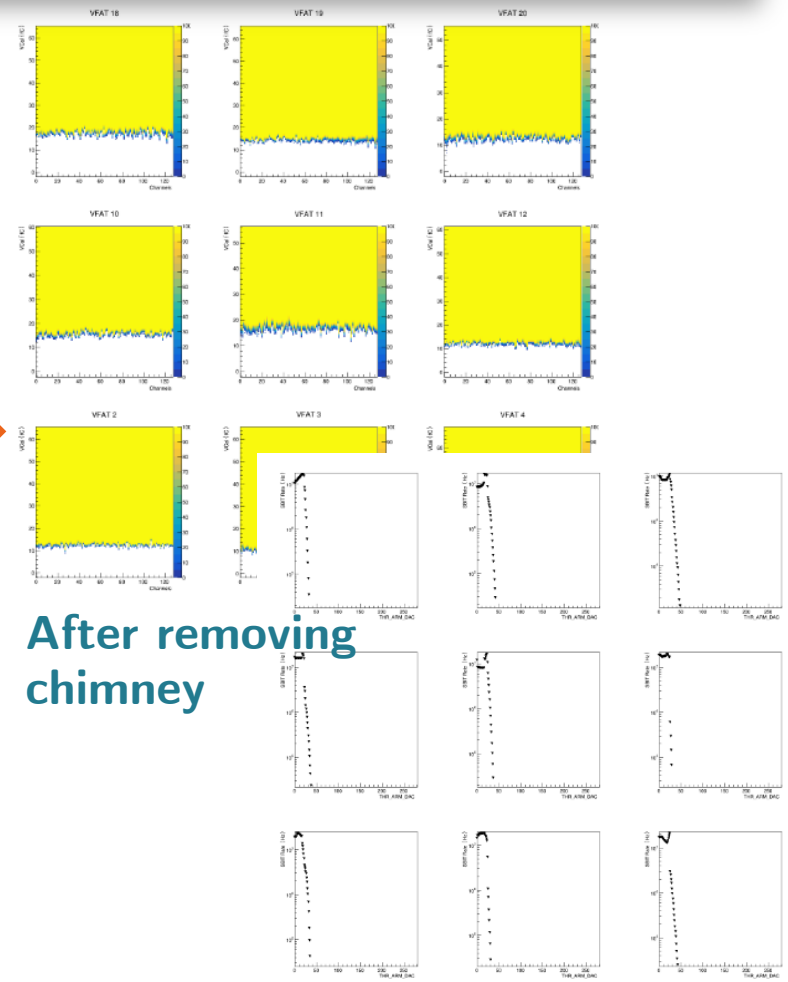



Insulation of the copper pipe using Kapton

# QC7 systematic problems and solution implementation (2.1)

**Ground-loops between chamber and aluminium chimney:**



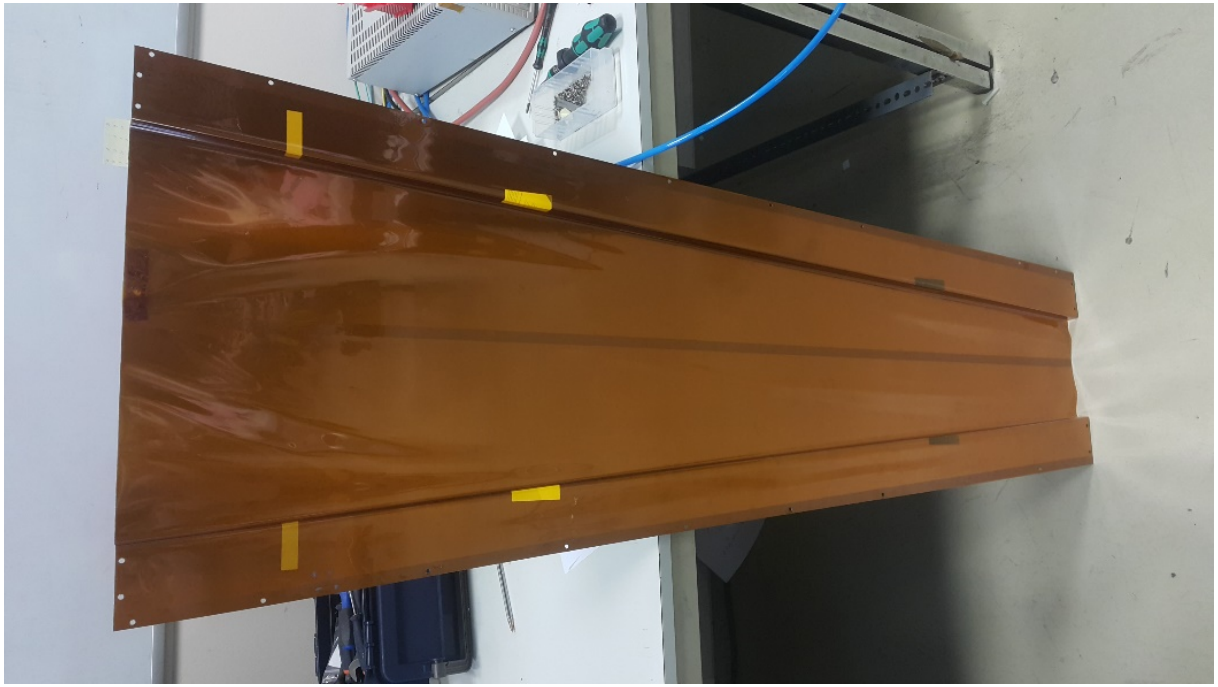




**After removing chimney**

# QC7 systematic problems and solution implementation (2.2)

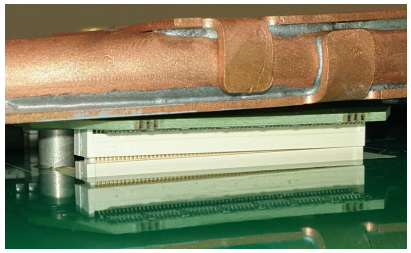
**Ground-loops between chamber and aluminium chimney: solution**

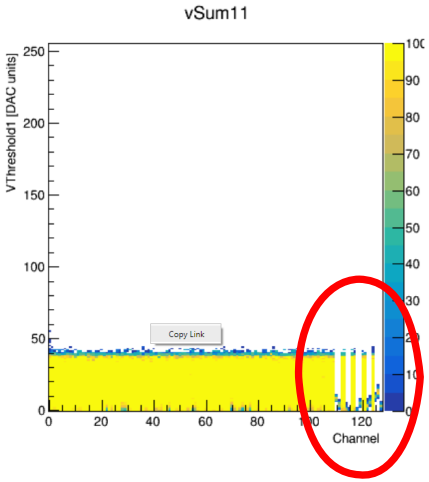
Isolation of Chimney using Kapton foil



# QC7 - Frequent issues

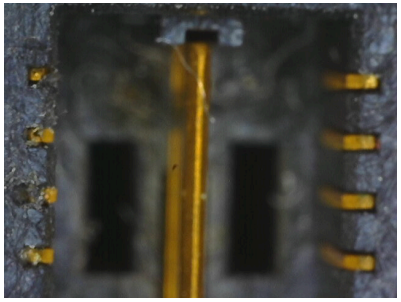
❖ Improper connection of VFATs in the readout board
- ✓ Spotted by threshold scan

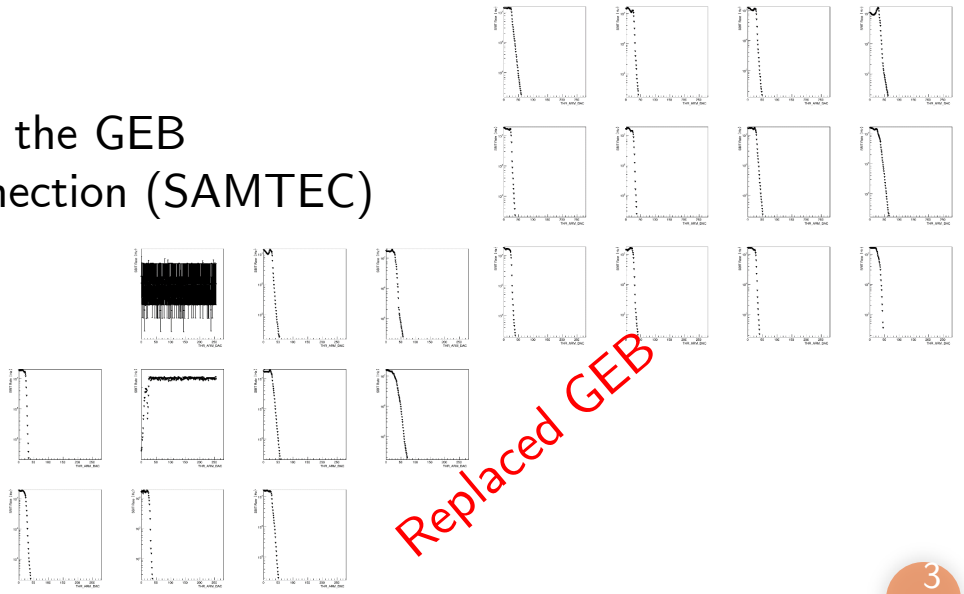





❖ Broken Sbit links:

Caused by: Dirty VFAT slots
Damaged traces in the GEB
Bad OH-GEB connection (SAMTEC)





# QC7 - Frequent issues

❖ Faulty FEASTs
- non-working, unstable
- inducing noise
  - bad shielding around the inductors, noise observable only after chimney installation (completing the Faraday cage)

❖ Mechanical stress due to cooling plate

**Most of these issues require component replacement/cleaning**

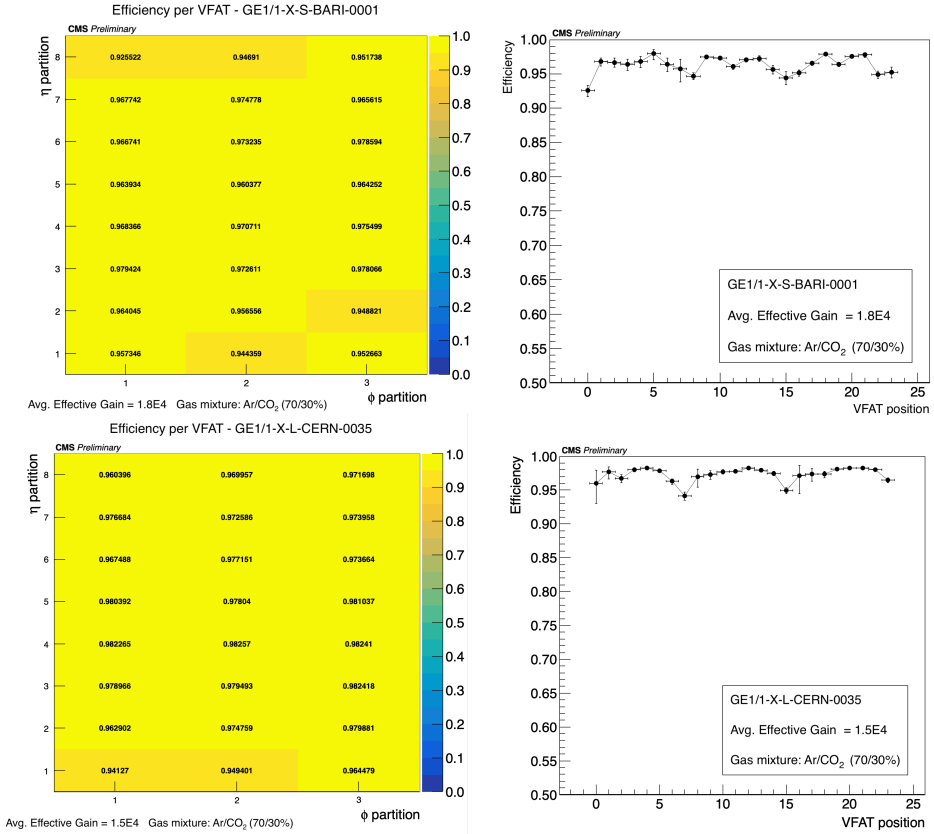
- All steps from 2 to 5 to be repeated
- Time taken for validation +1h for every debugging attempt

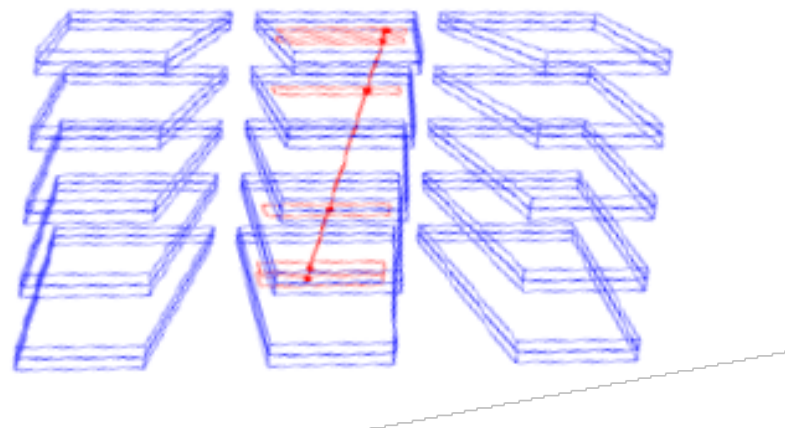
# QC8 – typical output and time needed

**Time needed:**

- 1 day for installation and initial configuration
- 5 X 12h-long runs to complete HV scan

**Typical case:**
1 week to validate a full bunch of chambers (average rate 5 SC/week)



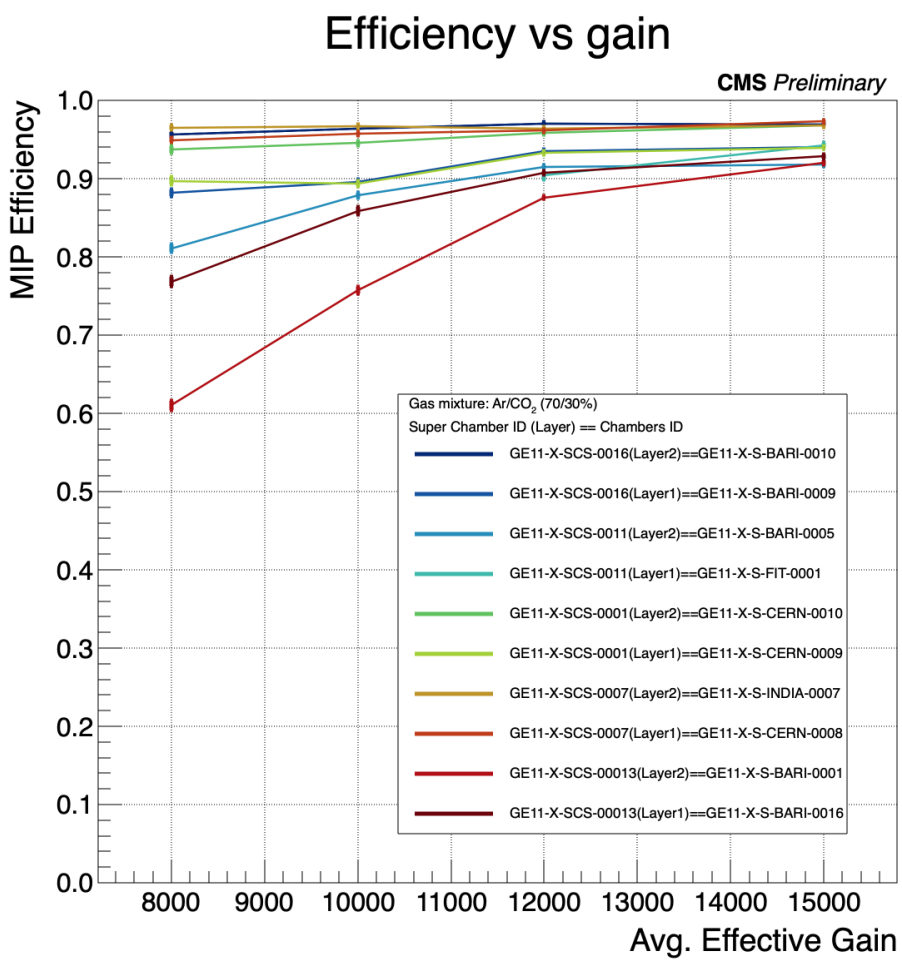



- Gas mixture: Ar/CO2 (70/30%)
- Cosmic muon tracks giving hits in columns of 10 "stacked" chambers
- Track-based analysis => Muon track reconstruction

# QC8 – typical output

**Final validation:**

❖ Efficiency of both chambers in the SC > 90%



# QC8 – Issues

**High noise related to services in the stand**

❖ ENC go from ~0.5 fC at QC7 to ~4 / 5 fC at QC8

**Gain non-uniformity in long chambers**

❖ Lower efficiency in some readout sectors related to QC5 uniformity map