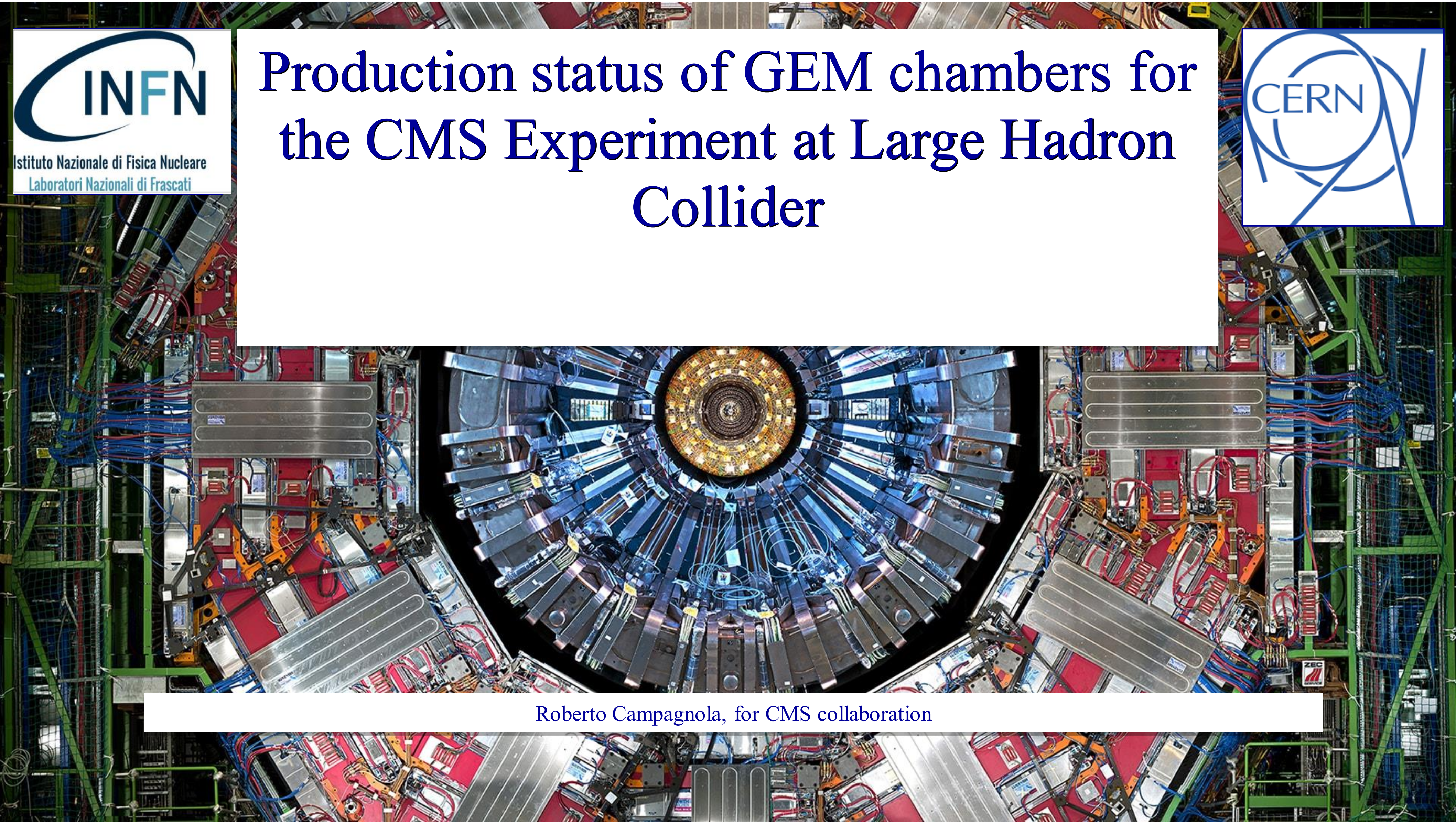
Production status of GEM chambers for the CMS Experiment at Large Hadron Collider



Roberto Campagnola, for CMS collaboration

CMS Muon System for High Luminosity LHC

Luminosity:

$2 \cdot 10^{34}\ cm^{-2}s^{-1}$ → **$5\text{-}7.5 \cdot 10^{34}\ cm^{-2}s^{-1}$**

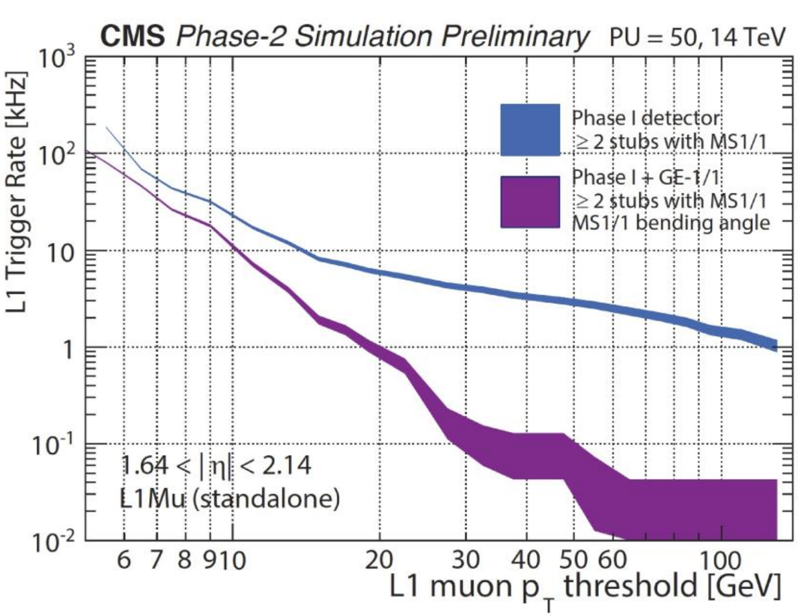
Higher background (**GE2/1** expected hit rate: **672 Hz/cm^2**)

Lower efficiency in muons reconstruction (Run2 efficiency >96%)

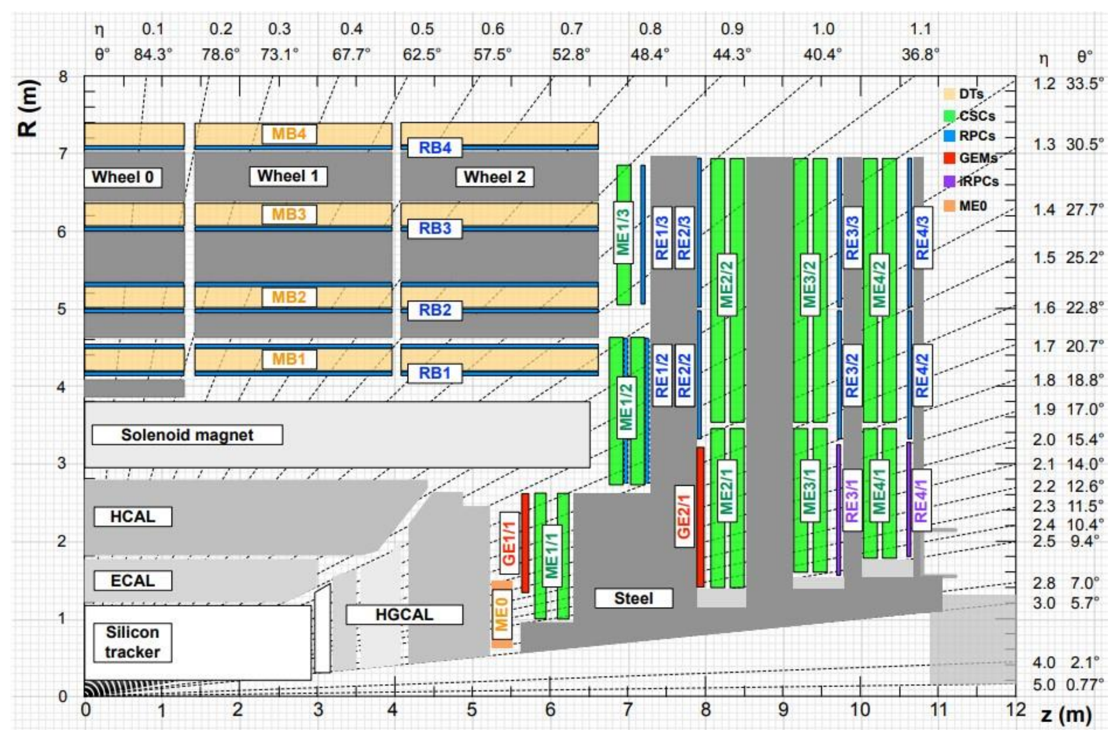
Additional muon stations needed to integrate with neighboring stations and achieve a 10-fold trigger rate reduction.

GE1/1* & GE2/1 → Restore the capabilities of the experiment.

GE2/1 →Extended acceptance in **1.6<|η| < 2.4** region

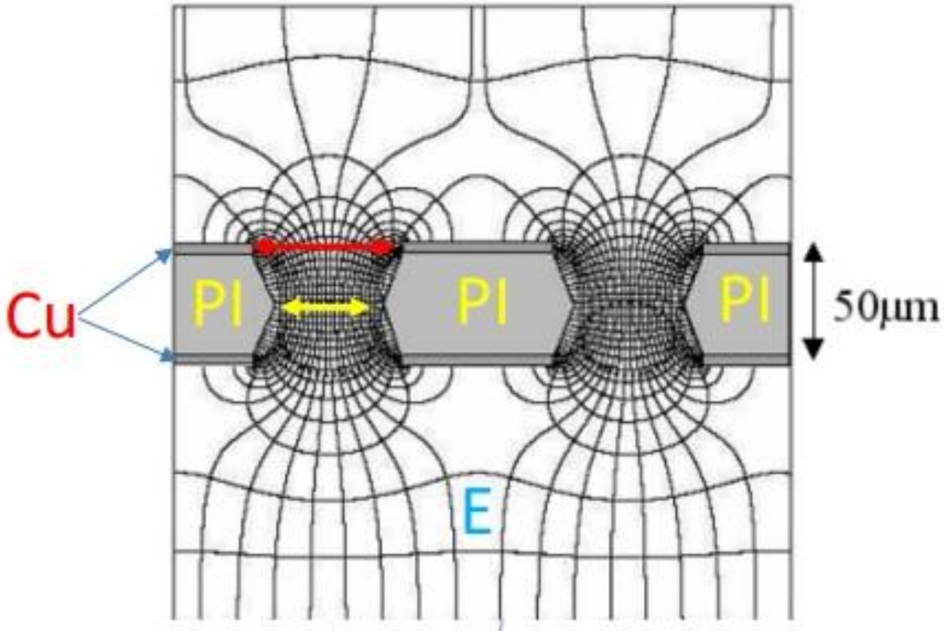


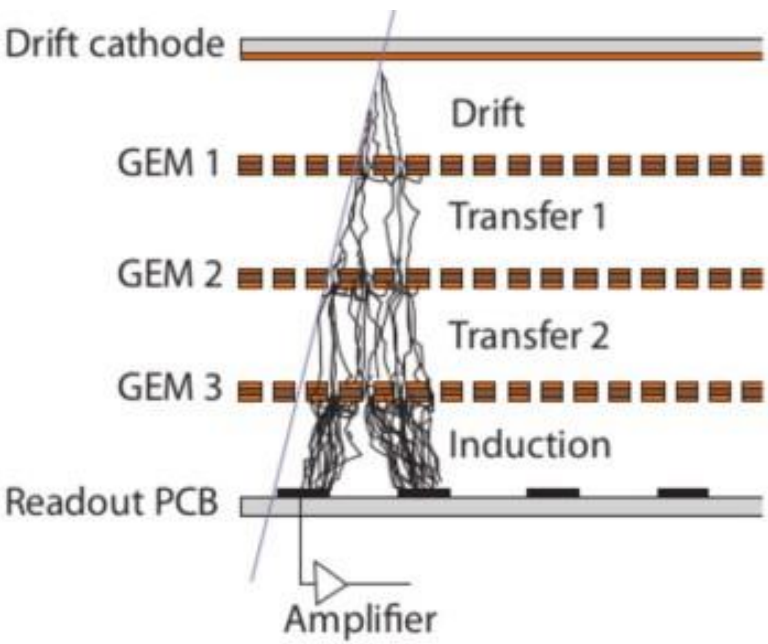
*GE1/1 already operative in Run2



R-z section *of CMS*

Gas Electron Multiplier (GEM)





GEM foil structure

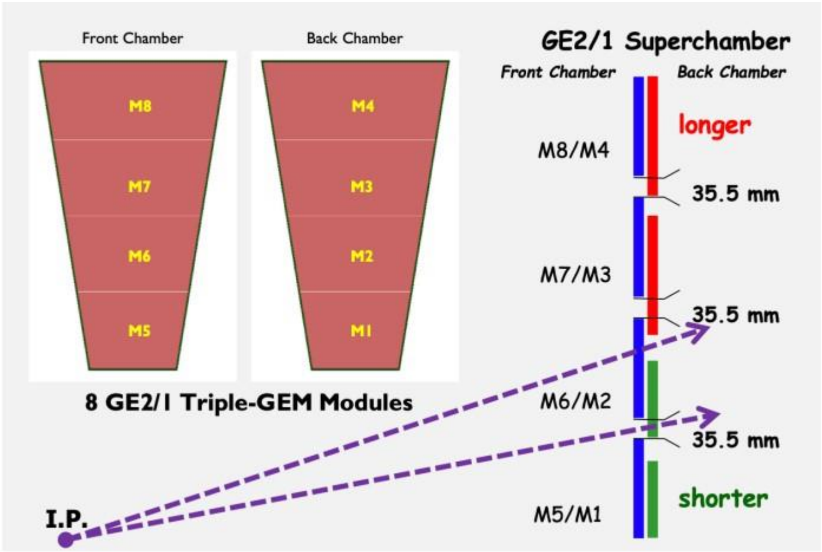
- **Foils produced with photolitographic tecqniques**
- 50 μm kapton layer, cladded with 5μm copper
- Matrix of electronic amplification channels.
- **Holes diameter 50-70 μm**

Why triple GEM detector?

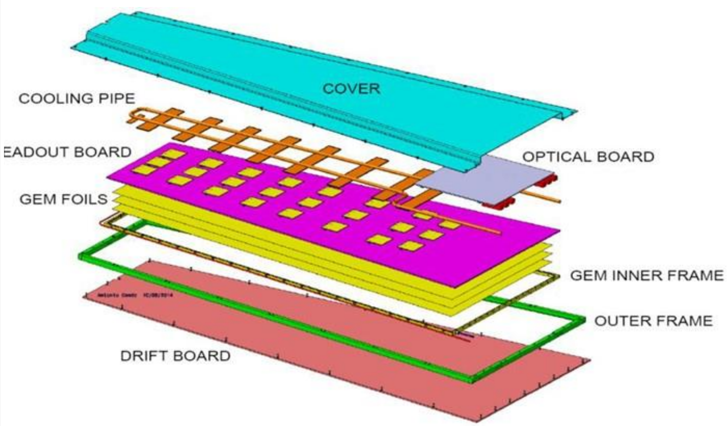
- Spatial resolution O(100 μm)
- **Intrisic rate capability** > 1 MHz/mm^2
- Single stage amplification can be controlled, avoiding discharge while maintaining high gains (~10^4)

GE2/1 Module Layout

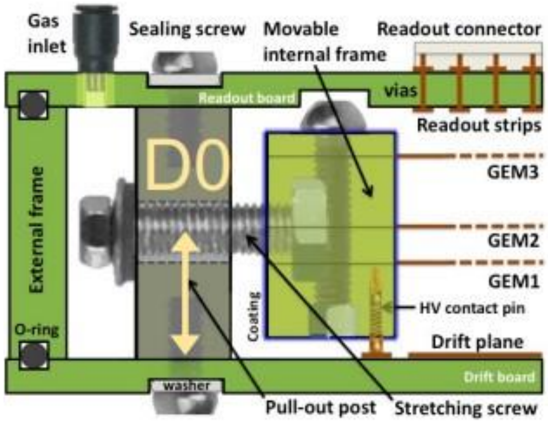
The detector consists of a **stack of three GEM foils inserted between a drift electrode and a readout electrode**, held together by an external frame. Inside the volume, a mixture of Ar/CO2 (70/30) is fluxed. The three GEM foils are stacked at their edges using thin internal frames. **GEM foils are segmented into strips to protect them from irreversible damage, reducing the energy released from a potential discharge**. The modules are divided into 12 sectors, each composed of 128 strips.
Four modules of different sizes form a *chamber*. The construction of 72 chambers is planned (36 for each endcap).



Schema dei 4 tipi di moduli



Esploso di un modulo GE2/1



Tecnica di tensionamento

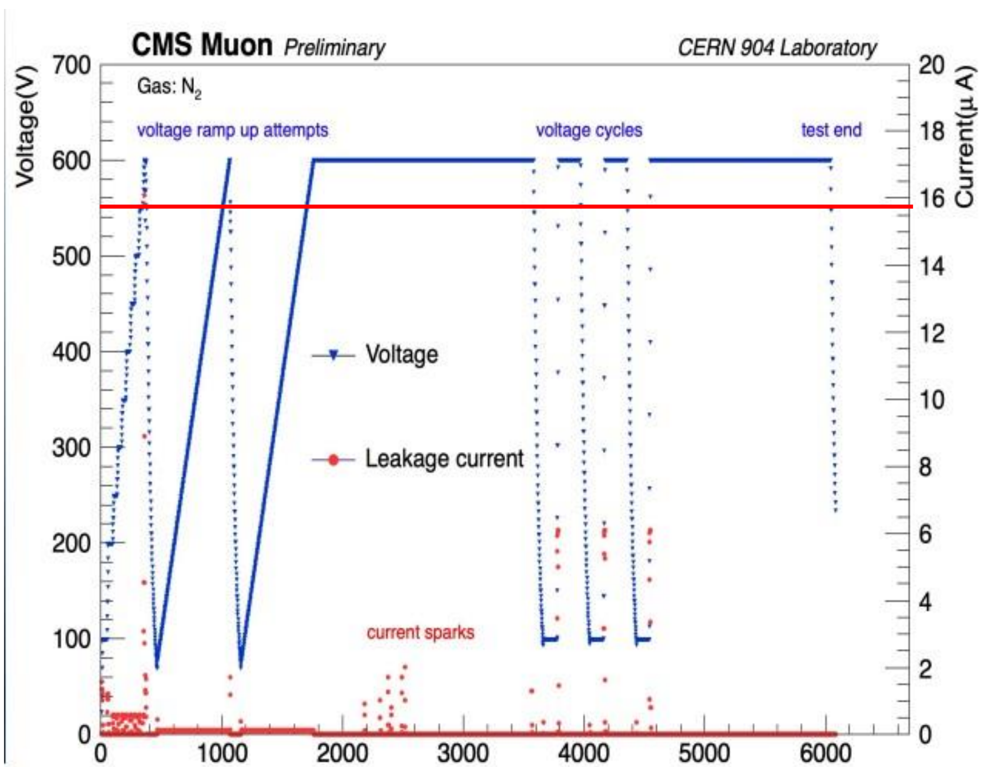
GE2/1 Quality Control

Distributed production across various institutions. All modules undergo quality control following predefined procedures, divided into 8 total phases.

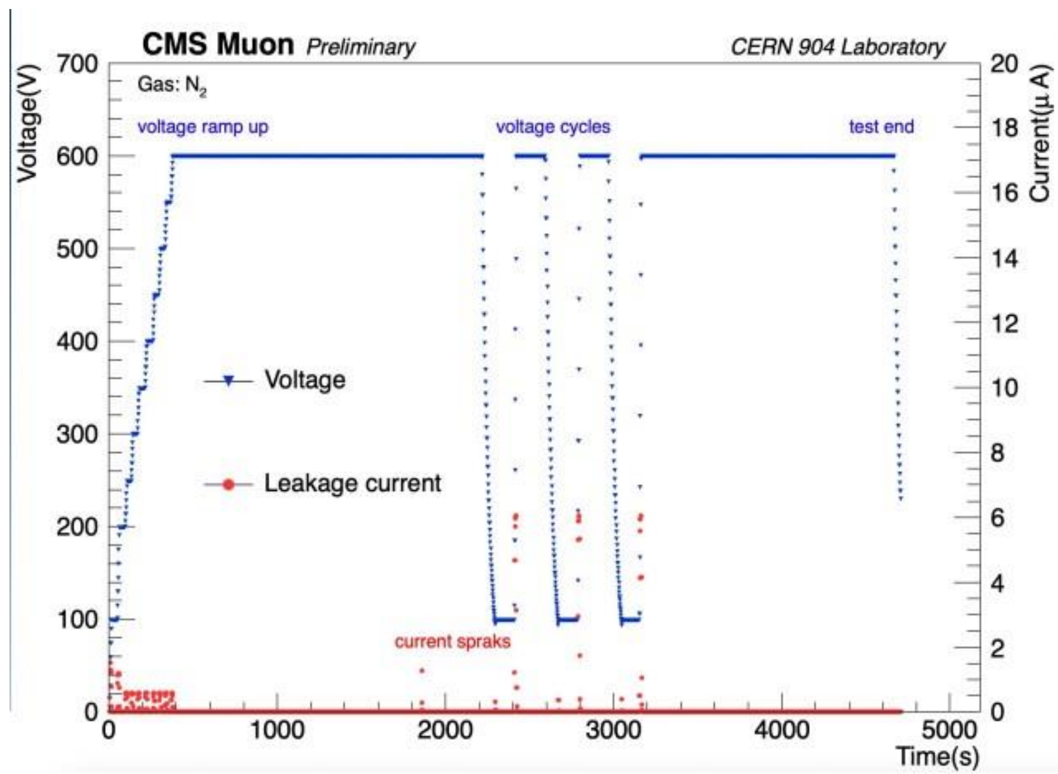
- QC1-2 CERN [Visual inspection and foils hv stability]
- QC3-5 CERN and external production sites [Gas leak, circuit stability, gain and uniformity]
- QC6-8 CERN [chamber stability test, connection test, cosmic test]

QC1-2 for GE2/1

- QC1: Foils visual inspection for: HV trace, SMD resistors, foils surface, PCB planarity
- QC2: Foils HV stability control and leakage current.
- Final impedance > 10 GΩ
- Leakage current <20 μA with HV between 100 - 600 V for 90 minutes in N_2
- Leakage current < 2 μA with HV 600 V for 14 h in N_2



QC2 fallito (sx)

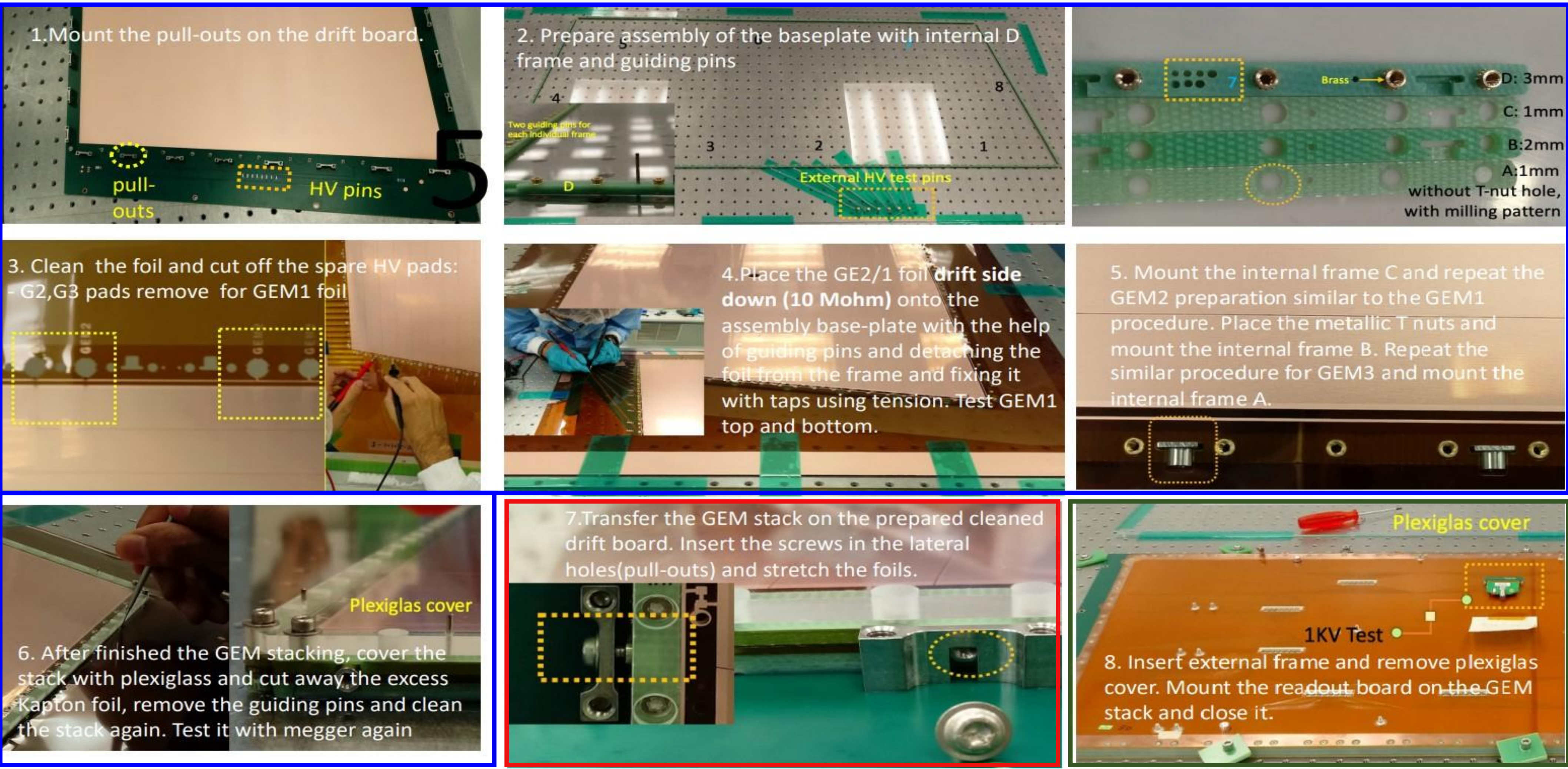


QC2 passato (dx)

Production Overview

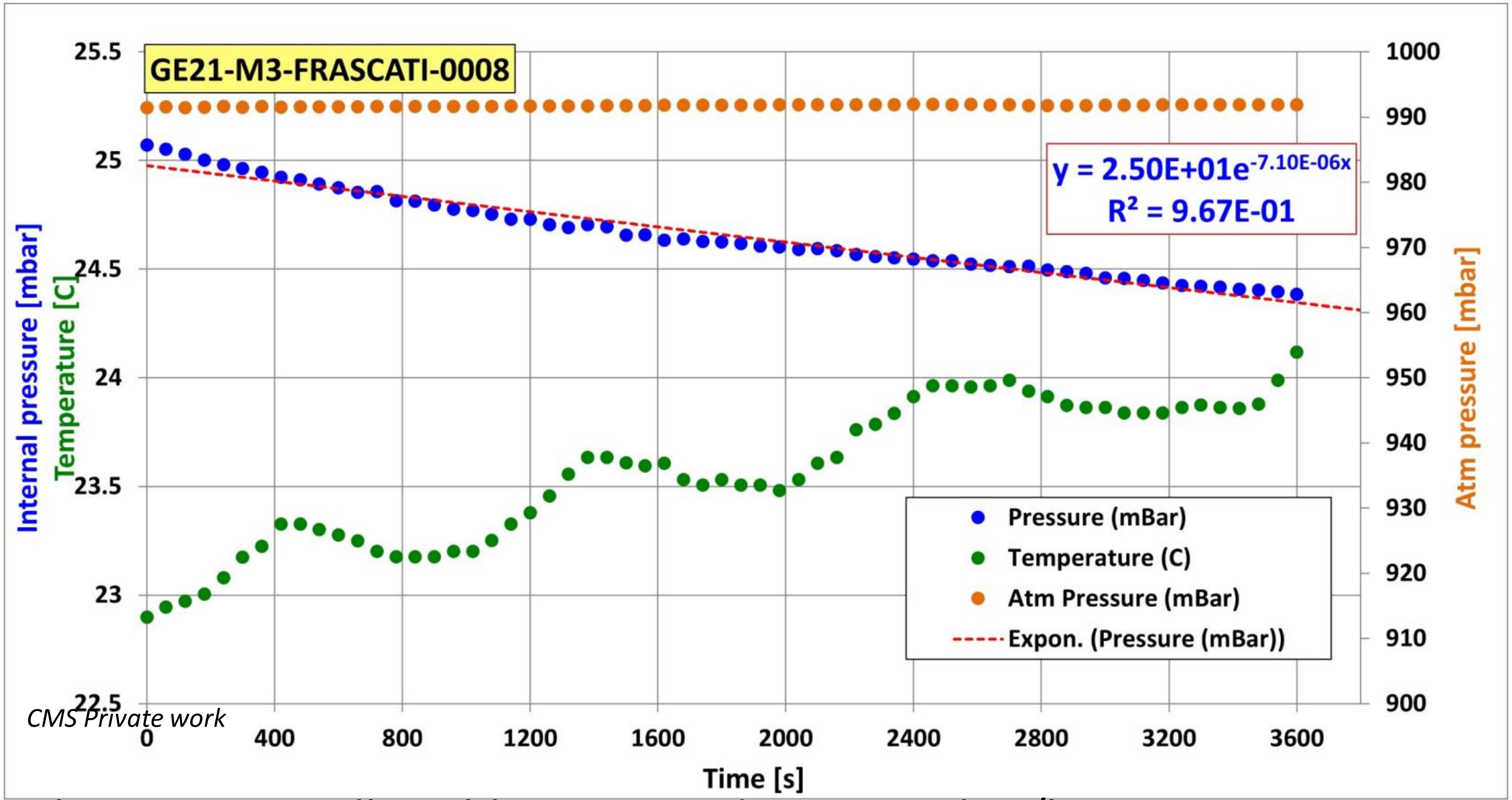
After QC2 is passed, foils are ready for module assembly, in three steps:

- 3 GEM foils stacking (1,6).
- GEM stack moved on drift board, stretching to have uniform gaps between foils (7).
- Closing with ROB (8).



QC3 – Gas Leak test

After assembly, the first test to be performed is the QC3 gas tightness check. The pressure drop inside the module is monitored as a function of time. Efficient gas tightness also prevents contamination from external source that may affect the detector performance (O_2, other electronegative elements and dust can compromise charge amplification and foils integrity).



Assuming constant detector volume during the test, time evolution of internal pressure is expressed by:

$P_{int} = P_0 e^{-t/\tau}$

The maximum allowable pressure drop is 7 mbar/h

QC4 – HV test

QC4 aims to establish the I-V characteristic of the detector to identify any malfunctions and defects in the HV circuit that powers the module.

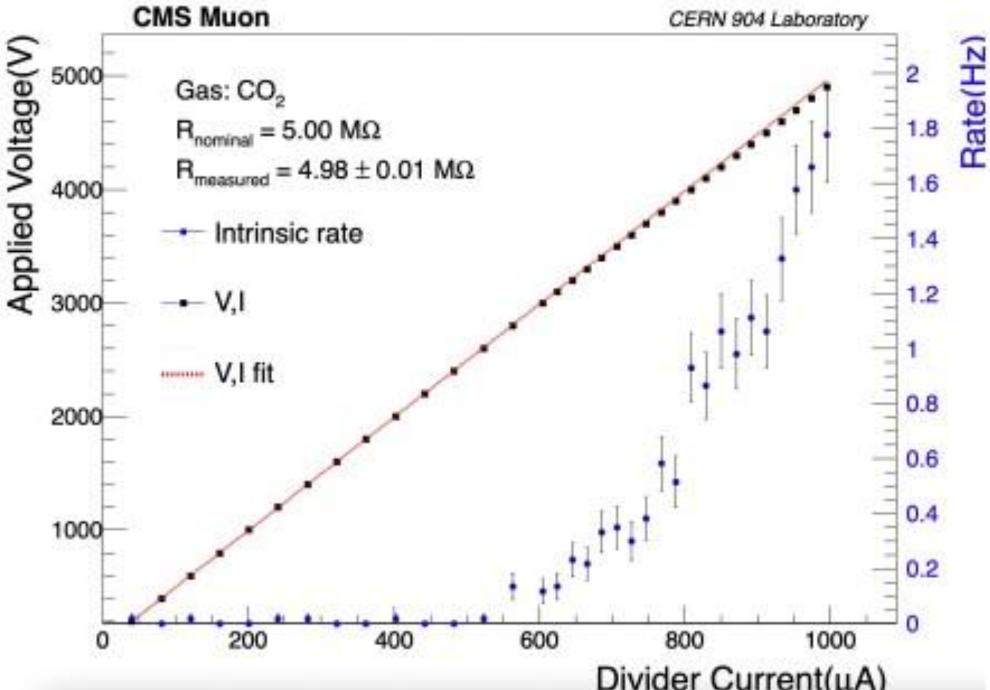
The module is flushed with CO_2 , powered up to 4900 V, and the current through the powering circuit is measured as a function of applied voltage. The test is considered successful if the I-V curve shows a linear behavior..

$R_{measured}$: fit-derived value

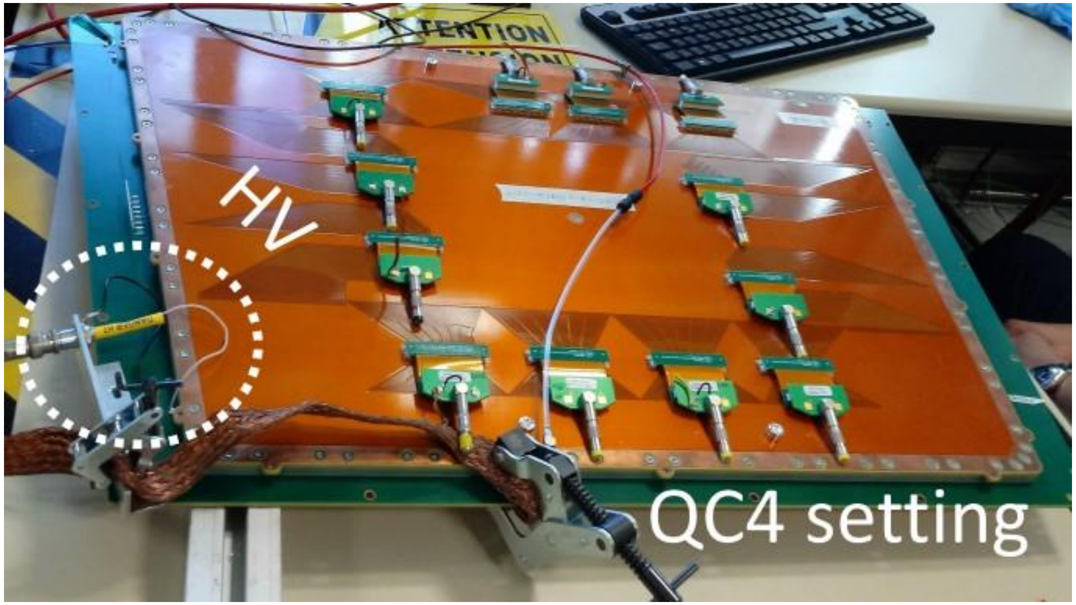
$R_{nominal}$: sum of the HV filter and the HV divider.

Test successful if **deviation less than 3%** .

Non-linearity would indicate a parasitic impedance, caused by a defect in the HV circuit or an issue with the GEM foils..



QC4 Result – I-V Linearity [4]



QC4 setup (904 CERN [4] e Frascati)

QC5 – Gain and uniformity test

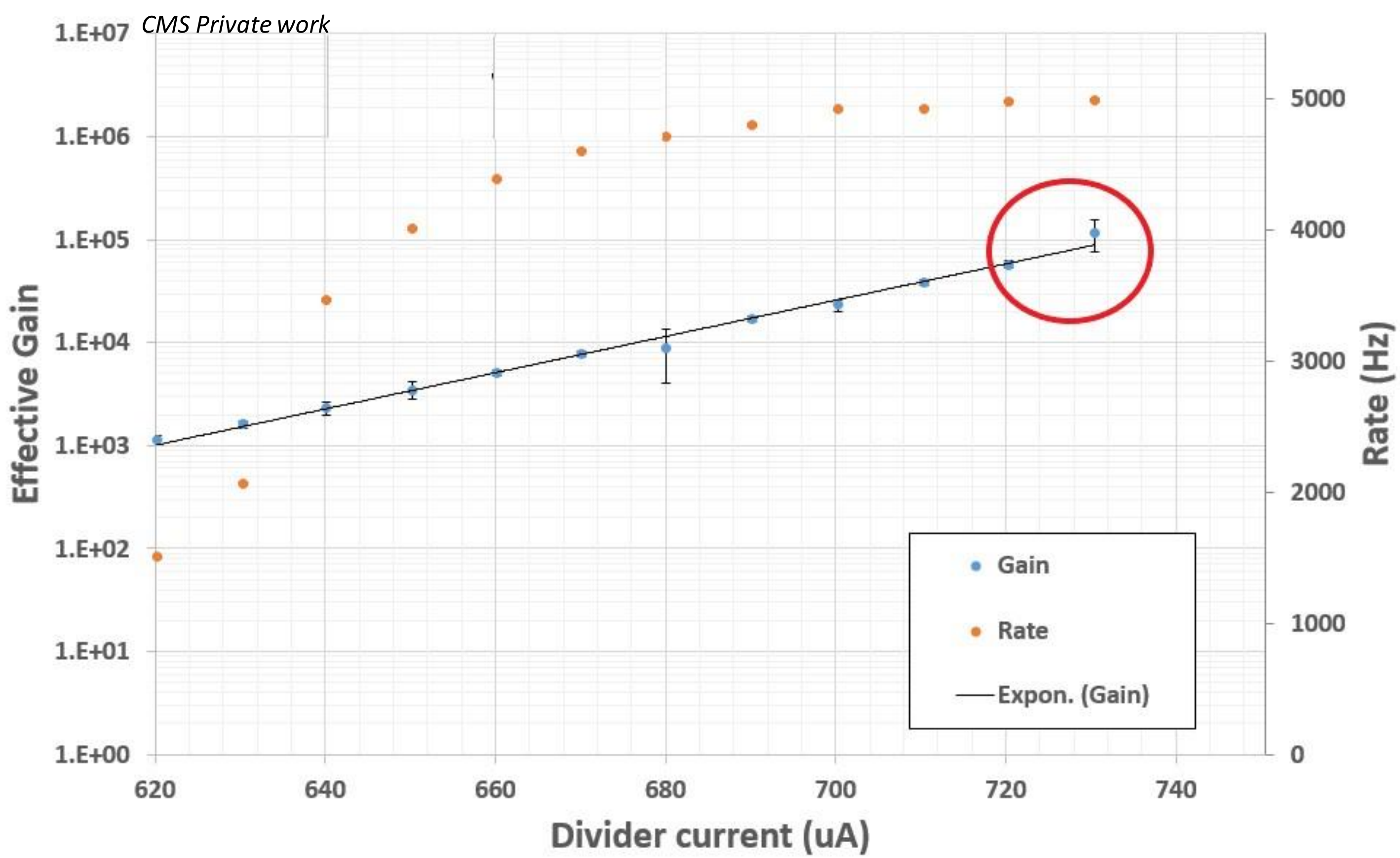
Gain is a critical parameter for gas detector. QC5 test divided into two parts:

- Effective gain measurement as a function of divider current.
- Gain uniformity test across entire module

X-ray source is used to irradiate the whole module and generate a primary current. Test is conducted using a Ar/CO_2 (70/30) mix.

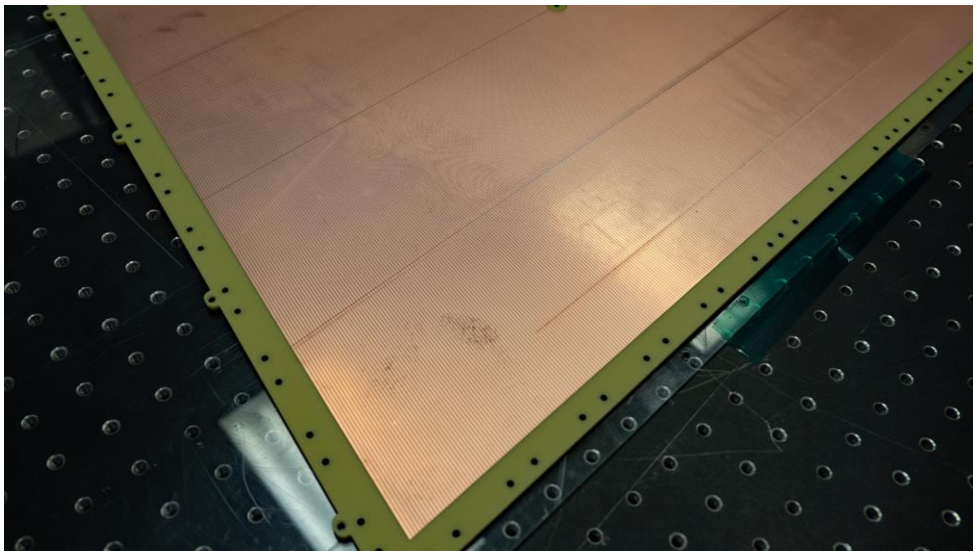
The charge collected by each strip segmented on the ROB is measured.

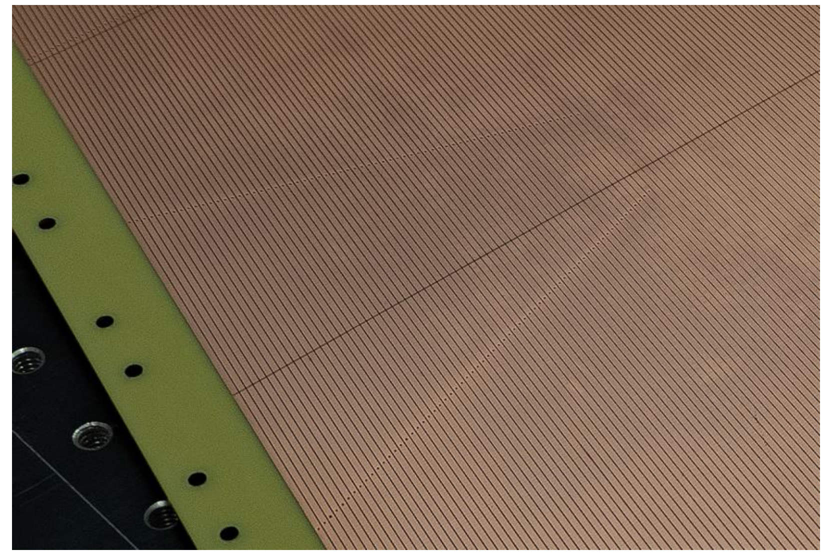
If the charge distribution has the same shape for each strip, then the detector is uniform



RO Boards

RO boards are made of 3.2 mm glass-reinforced epoxy laminate coated on both side with a 35 µm thick copper layer. Each RO board hosts 1536 copper strips for reading out the amplified signals from the GEM stack. The strips are separated from each other by a 200 µm gap without copper, referred as the inter-strip gap.



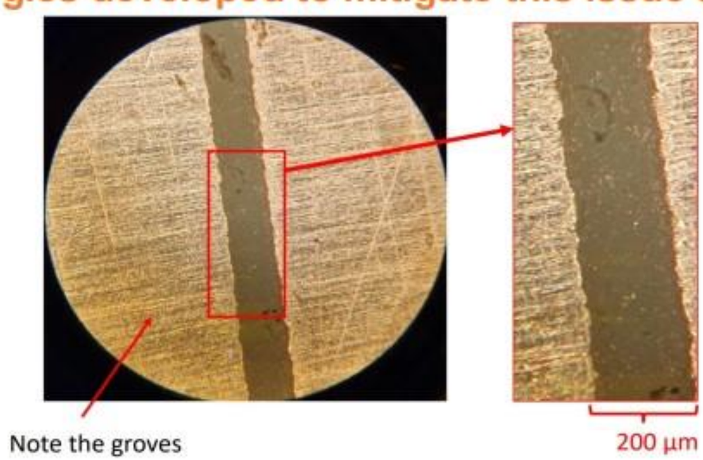


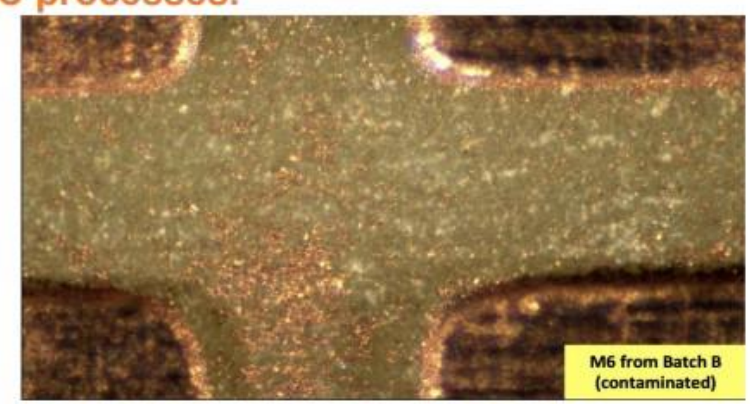
The strips are separated from each other by a 200 µm gap without copper, referred as the inter-strip gap.

RO Boards dust issue

❑ ***Issues on RO and Drift PCBs (Full production at Micropack, IN)***

- Assembly challenges due to dust pollution.
- **Impact Statistics:** Approx. 30% of PCB batches affected in 2021-2022, increasing to 80% in 2023.
- **Problem Identification:** Shorts appearing during detector closure during spring-summer 2023 production led to intensive investigations.
- **Discovery and Challenges:** On September 1, 2023, with the help of the CERN MPT Workshop, microscopic copper dust (a few µm) were identified between strips → Copper dust could not be seen with the lab QC microscope; Too small to be removed with mechanical cleaning in lab.
- **Strategies developed to mitigate this issue and improve QC processes.**





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credits: Gul Gokbulut (Ghent University)

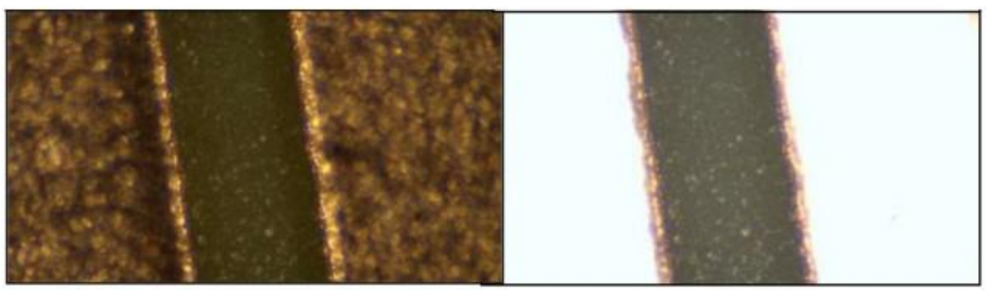
Retrofitting

- A retrofitting procedure was established with the help of the CERN MPT Workshop:

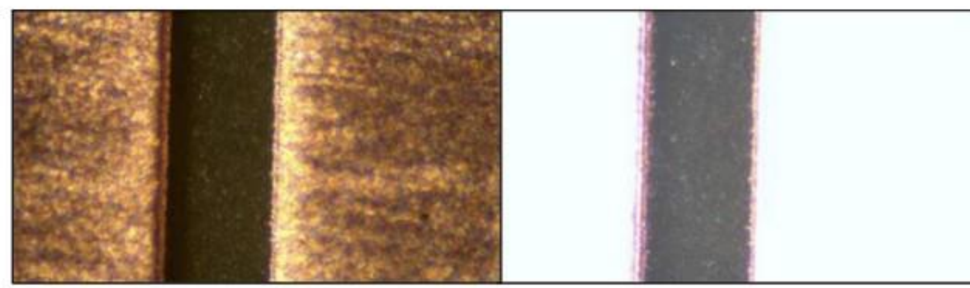
Mechanical Cleaning: Tissue soaked with pure ethanol or isopropyl alcohol → Water Jet Cleaning → Micro-Etching → Chromic-Acid Passivation

- **The procedure has also been applied successfully by Micropack in the last batch of 40 (20+20) PCBs.**
  - They are implementing this process systematically for the future production.

Cleaning at Micropack



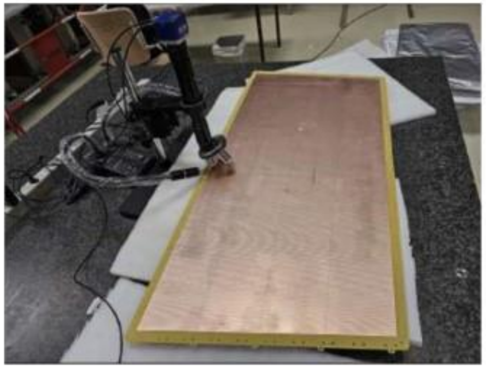
Cleaning at CERN MPT



credits: Gul Gokbulut (Ghent University)

PCB Validation

RO (+ Drift) PCB validation



- ❑ **Visual inspection**
- ❑ **Microscopic inspection (NEW)**
  - Inspection on several points on the PCBs with different light intensity
  - Bottom-left picture; The same QC is required to Micropack
- ❑ **Strip continuity/shorts (UPDATED)** Bottom-right picture

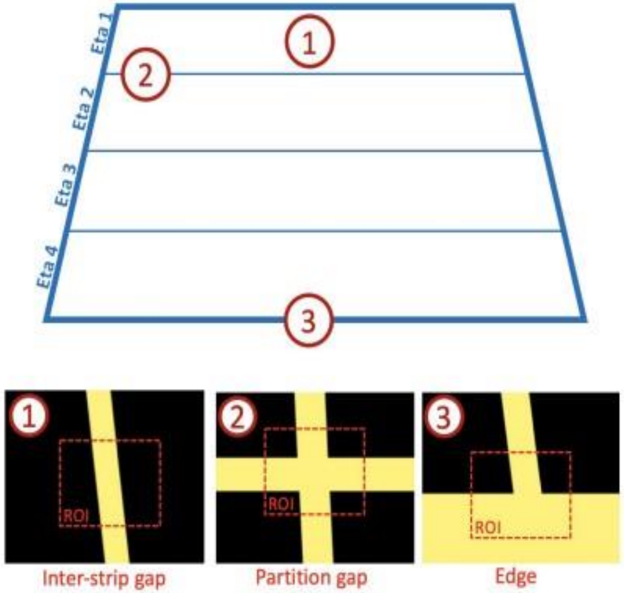
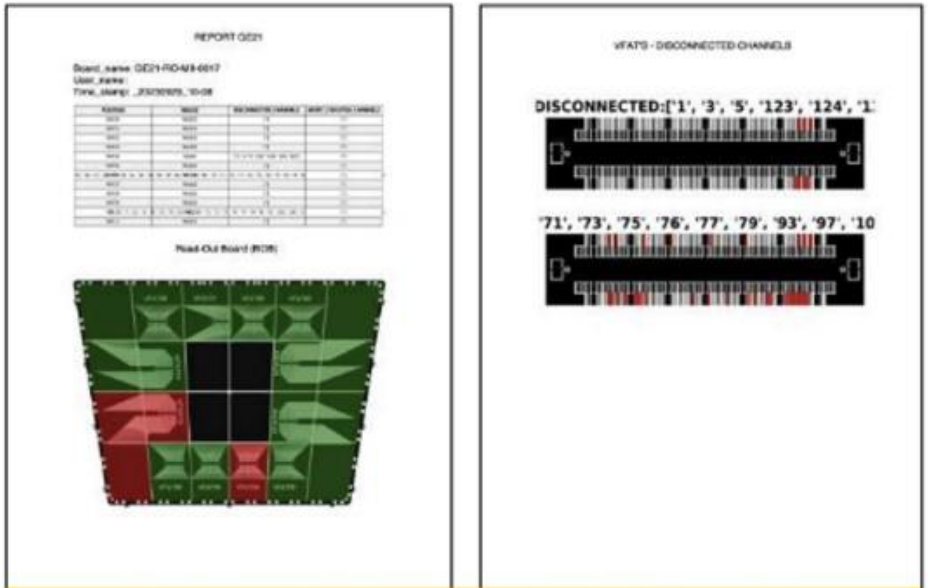


Fig.4: Schematic of a GE21 readout board showing the difference test locations



Example of PCB strip continuity/short report

credits: Gul Gokbulut (Ghent University)

Conclusion

- After comparing with new microscope setup several ROB from different batches, preliminary tests confirm that the new digital microscope setup can identify the presence of copper residues and other micrometer size contaminants that could be trapped between readout strips.

- New cleaning procedures are ready for upcoming batches for ME0 production.

- Retrofitting of previous GE21 modules

HL-LHC CMS

Riferimenti

1. CMS collaboration, The Phase-2 Upgrade of the CMS Muon Detectors, CERN Tech. rep. 2017. https://cds.cern.ch/record/2283189
2. A. Colaleo et al., CMS Technical Design Report for the Muon Endcap GEM Upgrade. Tech. rep. 2015 https://cds.cern.ch/record/2021453
3. M. Abbas, M. Abbrescia, H. Abdalla et al., Quality control of mass-produced GEM detectors for the CMS GE1/1 muon upgrade , Nuclear Inst. and Methods in Physics Research, A 1034 (2022) 166716
4. Kim, Mi Ran. *Production and quality control of the GEM GE2/1 detector for the upgrade of the CMS endcap muon system*. No. CMS-CR-2022-166. 2022.

THANK YOU