

Triple GEM Detector for the GE2/1 Upgrade of the CMS Muon System

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01 CMS muon spectrometer

- **CMS muon chambers** must detect the traversing track at several points along the track path to measure the deflection of muons as they pass through the chamber's magnet field.

• Phase-II upgrade

- Improved RPC

- Gas Electron Multiplier (GEM)
GE1/1 and GE2/1
ME0: forward muon tagger

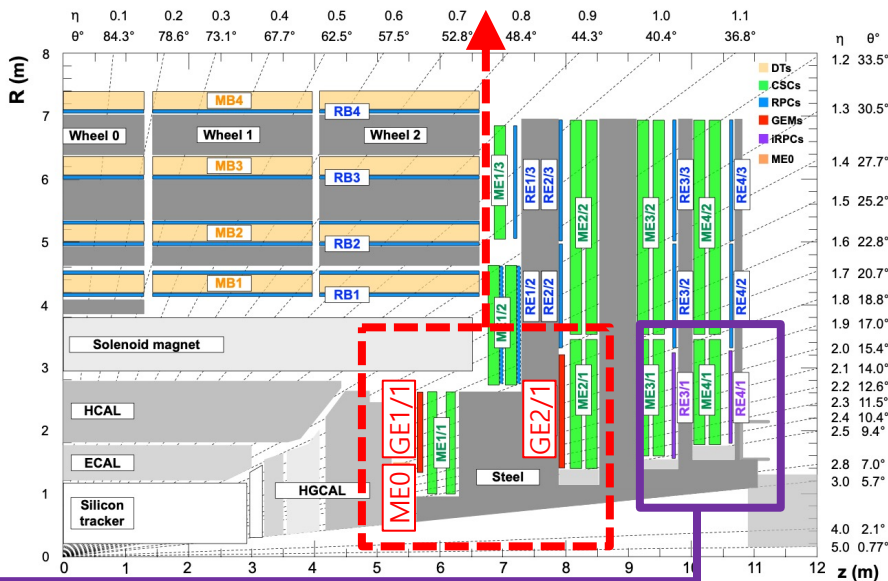
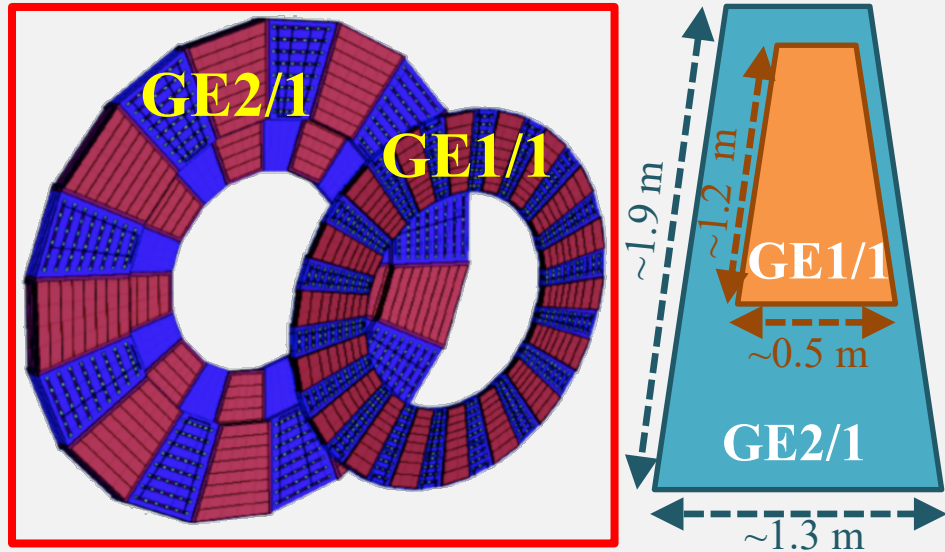
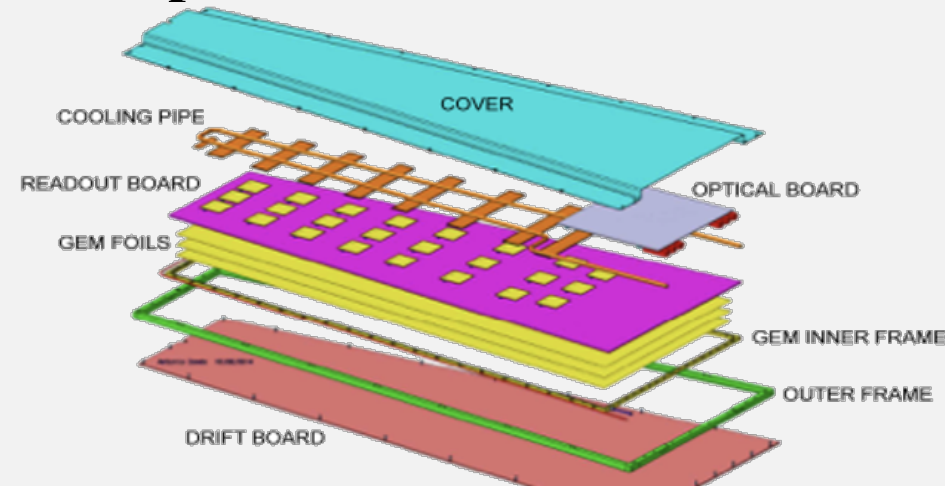


Diagram of one quadrant of the CMS detector: future muon system

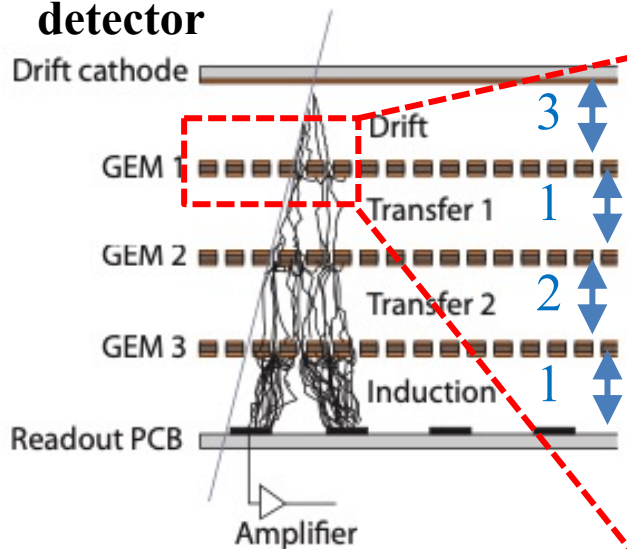


• Triple GEM detector

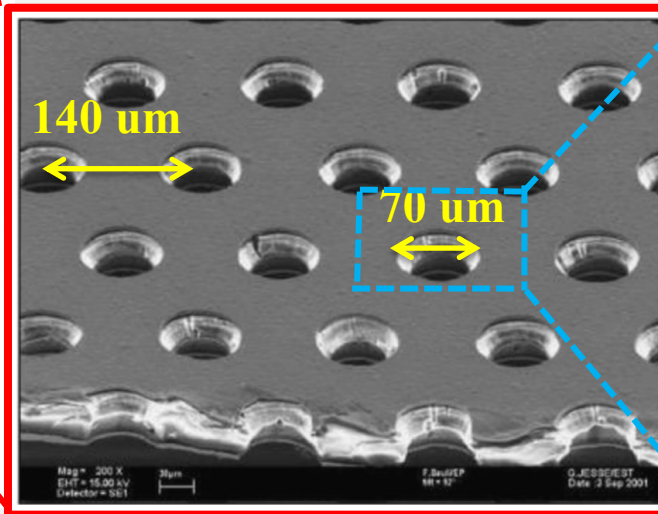


GEM (Gas Electron Multiplier)

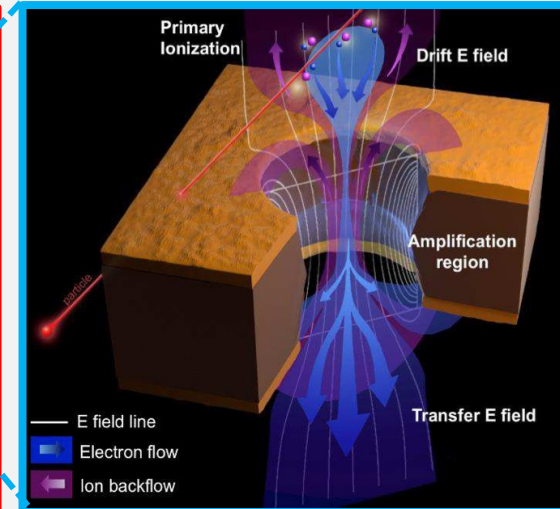
Principle of triple GEM detector



Microscopic view of GEM foil



Schematic view of electric field with electrons & ions

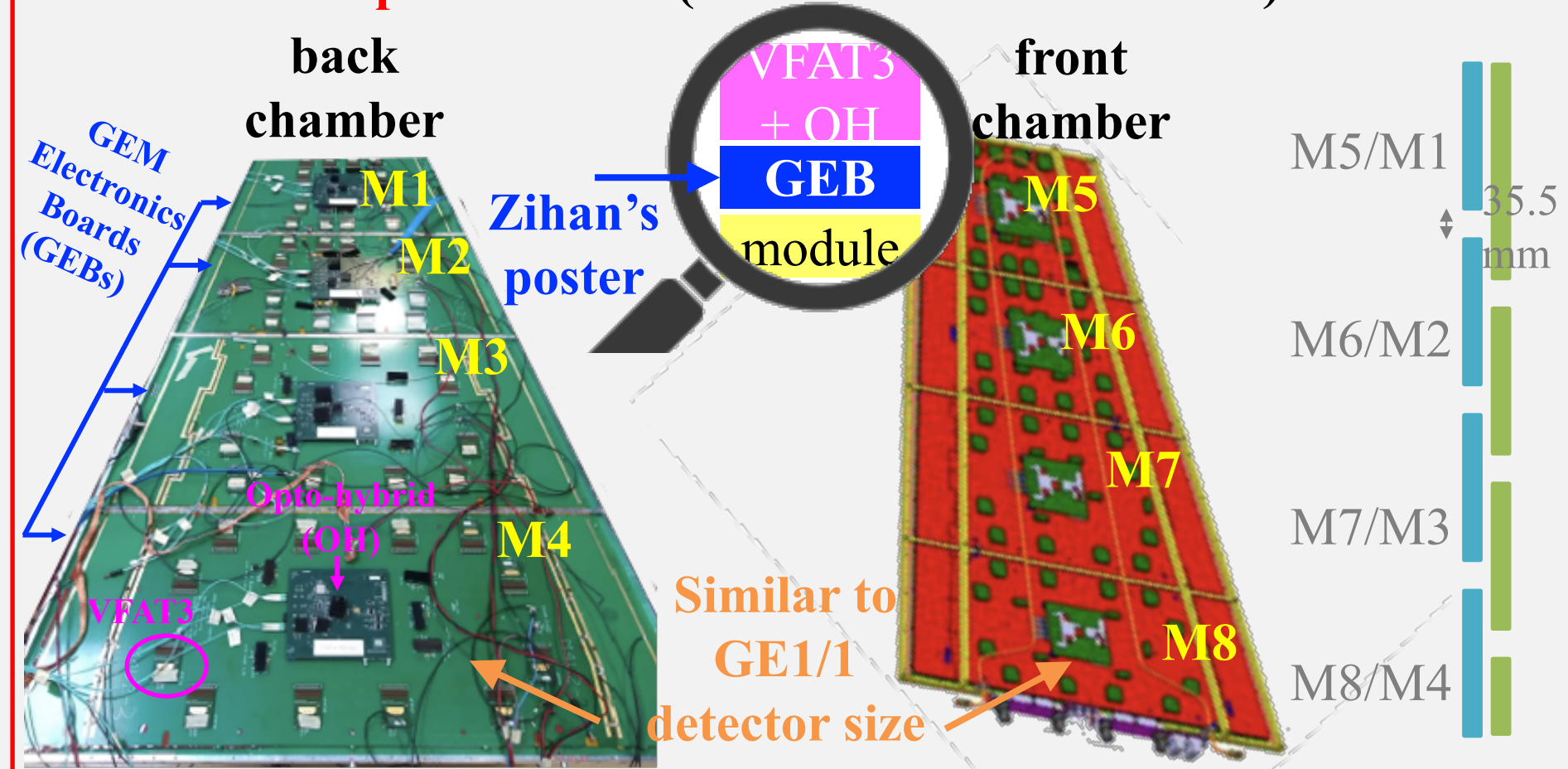


- The foil (e.g. 50 μm thick kapton) is metalized on both sides (e.g. 5 μm copper) and has a pattern of holes (e.g. 70 μm with a 140 μm pitch).
- Gas mixture: 70% Ar + 30% CO₂
- Spatial resolution \approx 300 μm
- Time resolution \approx 10 ns

- CMS Technical Design Report for the Muon Endcap GEM Upgrade, CERN-LHCC-2015-012

- Fabio Sauli, The gas electron multiplier (GEM): Operating principles and applications, Nuclear Instruments and Methods in Physics Research A 805 (2016) 2-24

Super chamber (front and back chambers)



- PKU is responsible for the design, prototyping, and mass-production of 8 types of GE2/1 GEBs. Our prototypes test results showed excellent performance across all requirements
- To achieve maximum coverage, modules in the front and back chambers will be staggered
- As a consequence, eight different types of modules are needed for GE2/1 production

01 Schedule

Birth of GE1/1 project

negative endcap installed

2009

Oct. 2017

Dec. 2018

Jul-Oct. 2019

Jun. 2020

GE1/1 R&D

mass production

superchamber production

positive endcap installed

GE1/1 first runs with collision

Jul-Sept. 2020

Apr. 2021

Oct. 27 2021

Feb. 2022

commissioning

mass production for GE2/1 M1-M4

mass production for M5-M8

01 GE2/1 production sites

country	Module type	Number of module	comments
Italy	M6 + M8	38 (M6) + 38 (M8)	
Belgium	M1 + M3	19 (M1) + 38 (M3)	
Germany	M1		QC only (no assembly)
India	M2	38 (M2)	
Pakistan	M7	38 (M7)	
Sri-Lanka (new)	M1 + M4	19 (M1) + 38 (M4)	The Sri-Lanka group will work at CERN
China (new)	M5	38 (M5)	Second part of QC5 done at CERN by Chinese groups

- With PKU, Tsinghua University, Beihang University and Sun Yetsen University

CERN

QC 1: material inspection

QC 2: GEM foils test (fast + long)

**Production sites
(e.g. PKU)**

QC 2: GEM foils test (fast)

Assembly preparation + Assembly

QC 3: gas leak test

QC 4: HV test

QC 5: gas gain calibration (gain + uniformity)

CERN

QC 6: HV stability test

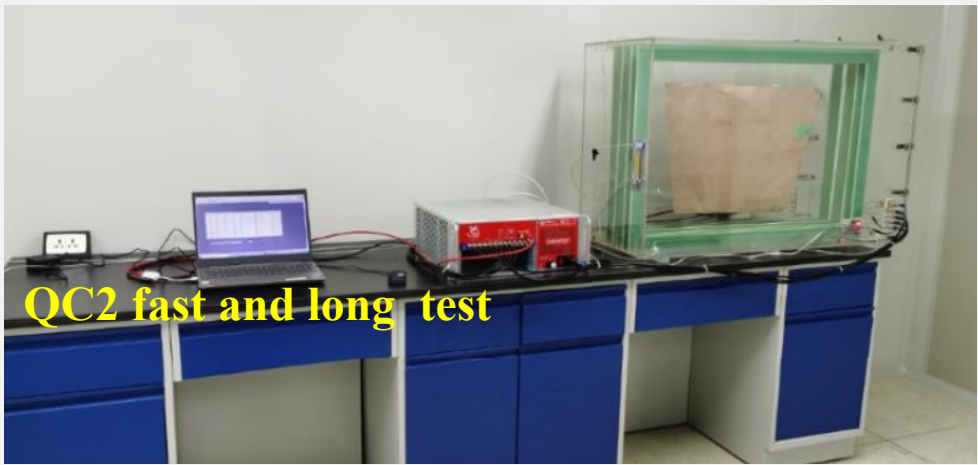
QC 7: electronics connectivity test

QC 8: cosmic ray test

CERN
cleanroom



PKU
cleanroom

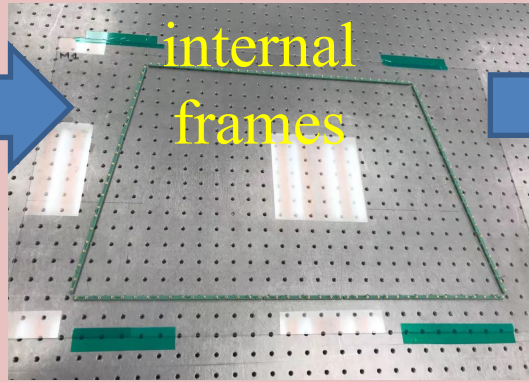


QC2 fast



GEM foil

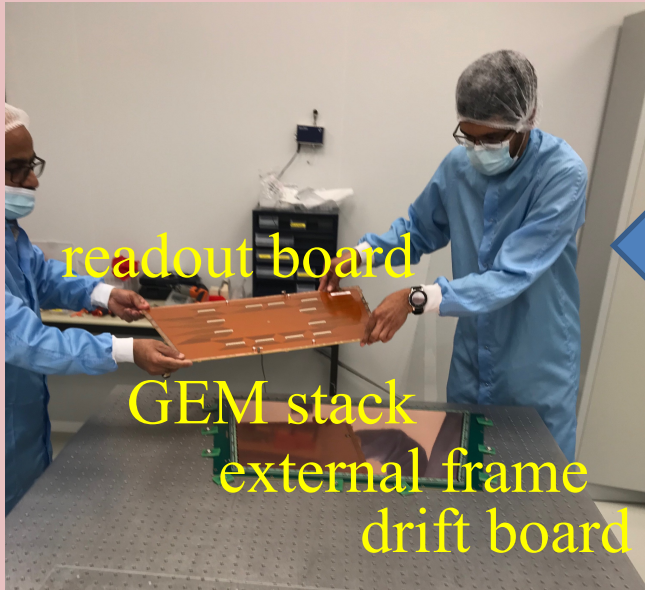
Assembly



internal frames

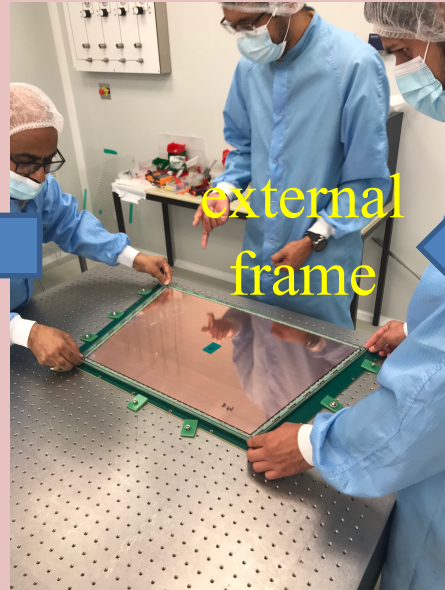


GEM foil



readout board

GEM stack
external frame
drift board



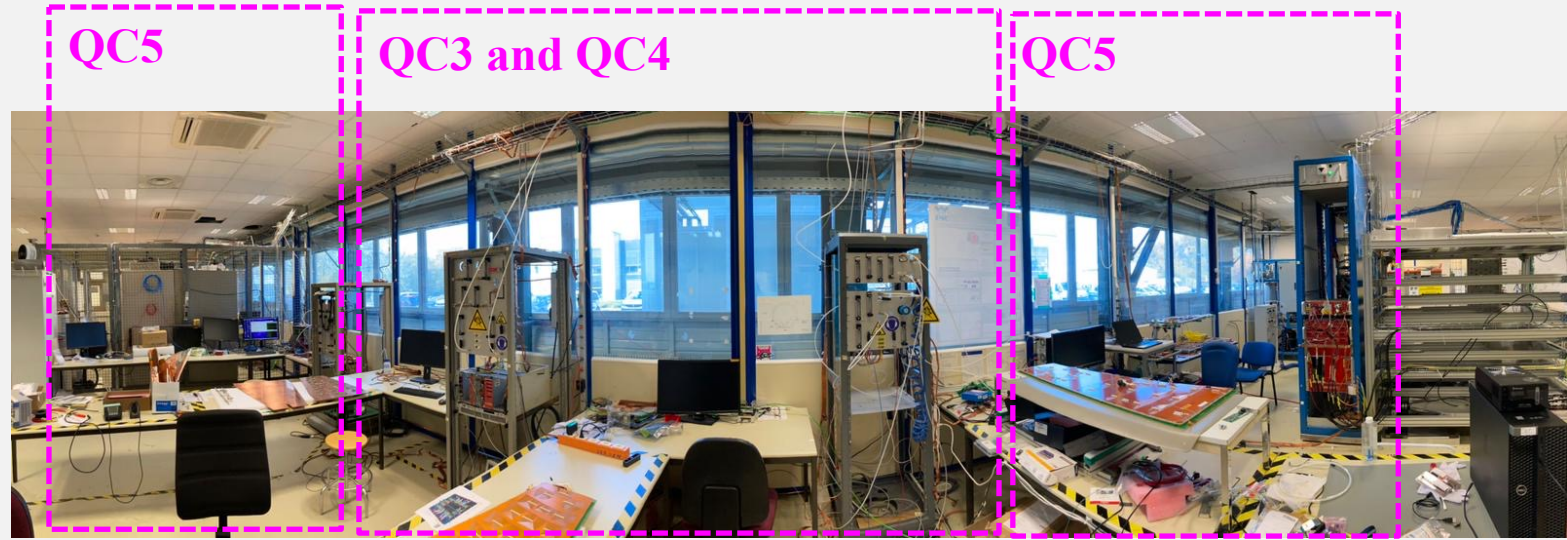
external frame



drift board

GEM stack

CERN lab



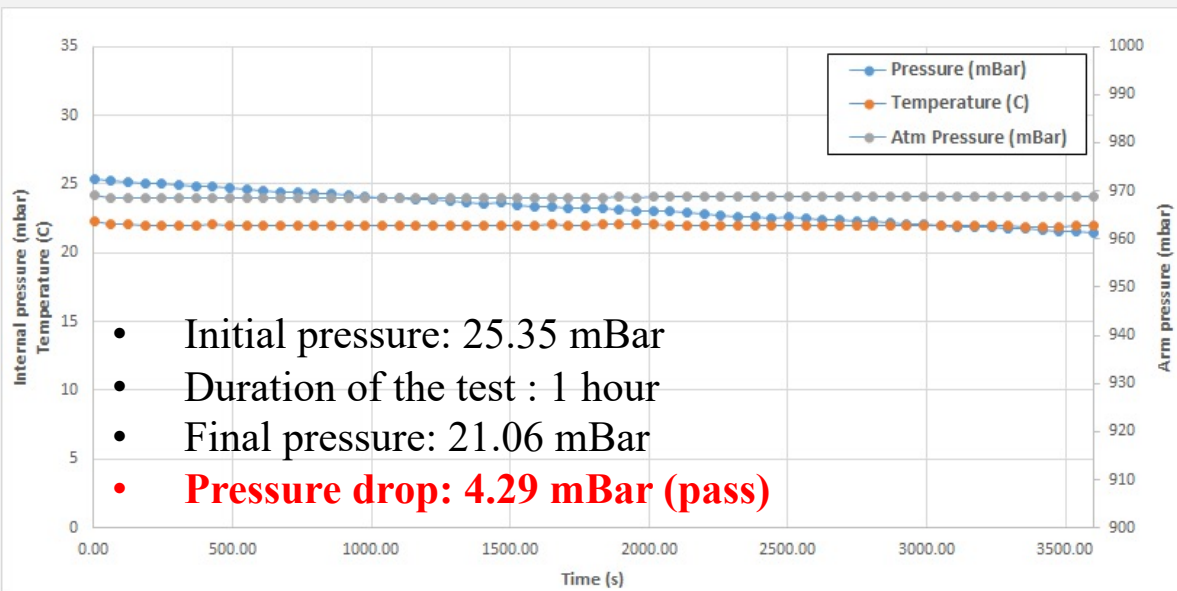
PKU lab



- QC3: gas leakage test
- Pressurize with pure CO2 to 25 mbar above atmospheric pressure
- Leakage should cause pressure drop of less than 7mbar/h
- A proper gas seal is needed so the detector can run in the CMS experiment without affecting other detectors and with a minimal amount of gas leakage

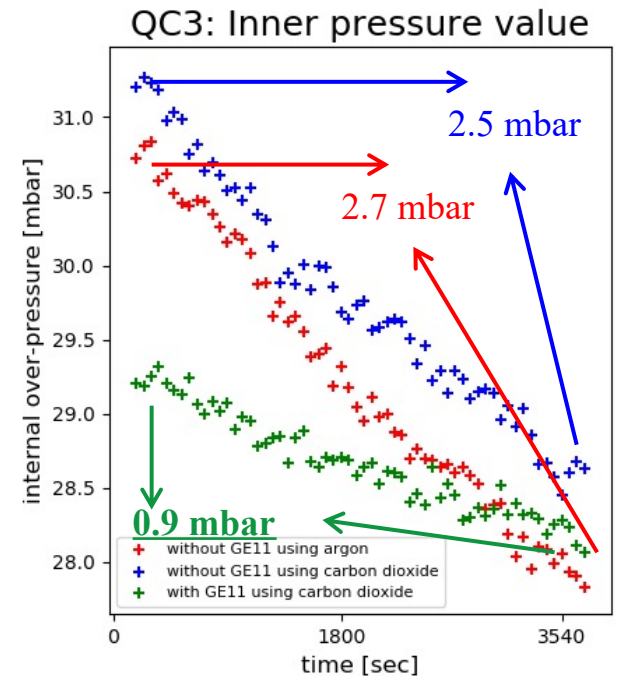
Results (CERN)

module name: GE21-MODULE-M1-0002



Results (PKU)

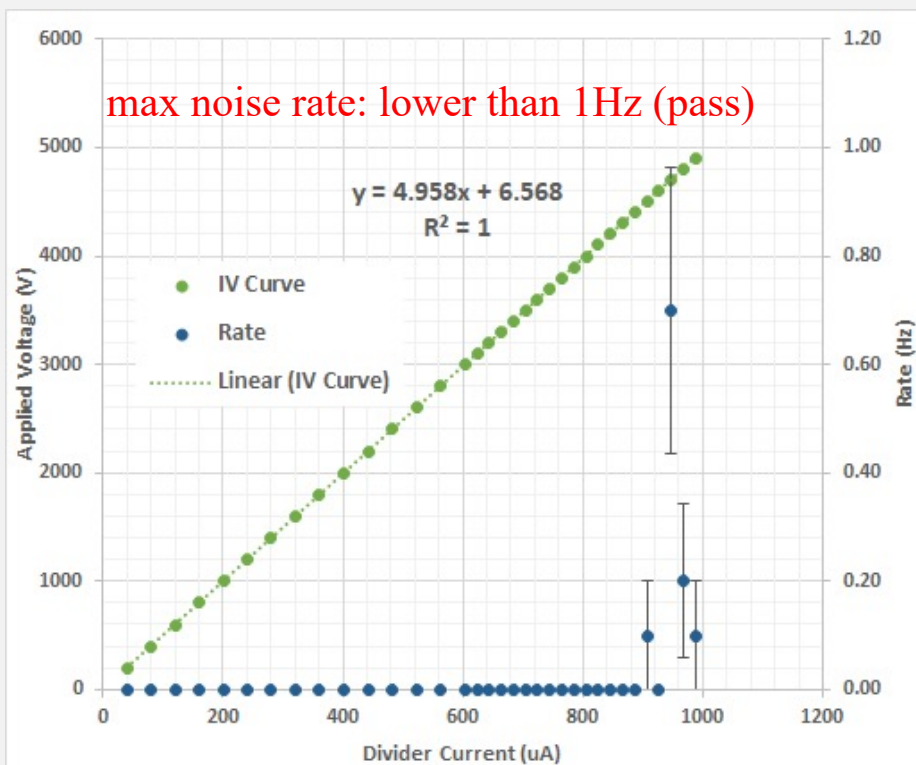
module name: GE1/1 VII-L-CERN-003



- QC4: acquire the noise rate on the characteristic I-V curve of the detector from 200V to 4900V
- Pure CO₂
- should not exceed ~10 Hz

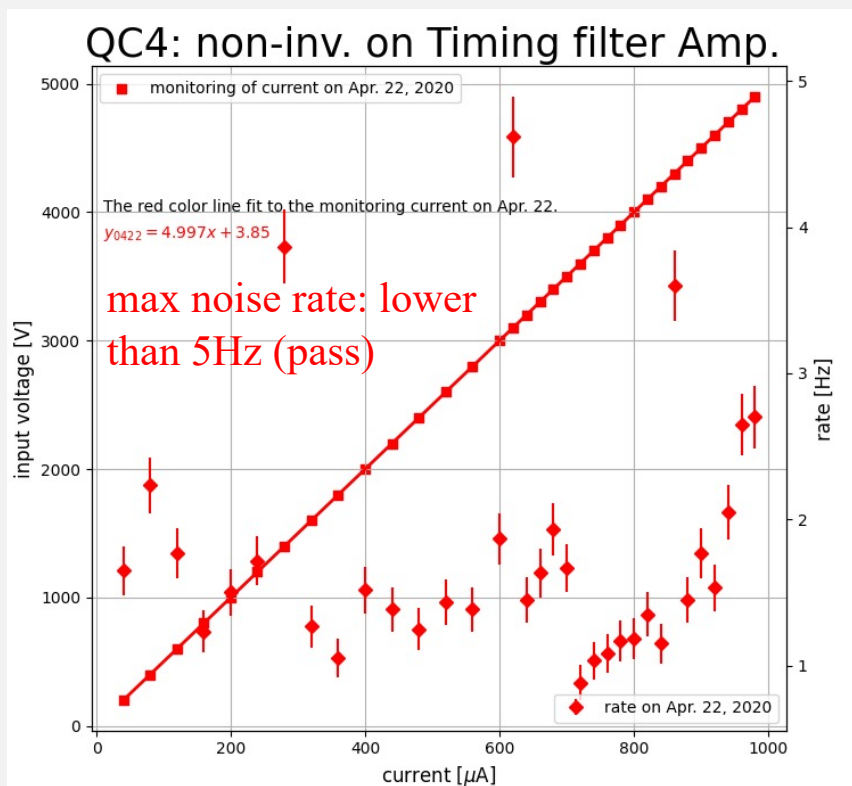
Results (CERN)

module name: GE21-MODULE-M1-0002



Results (PKU)

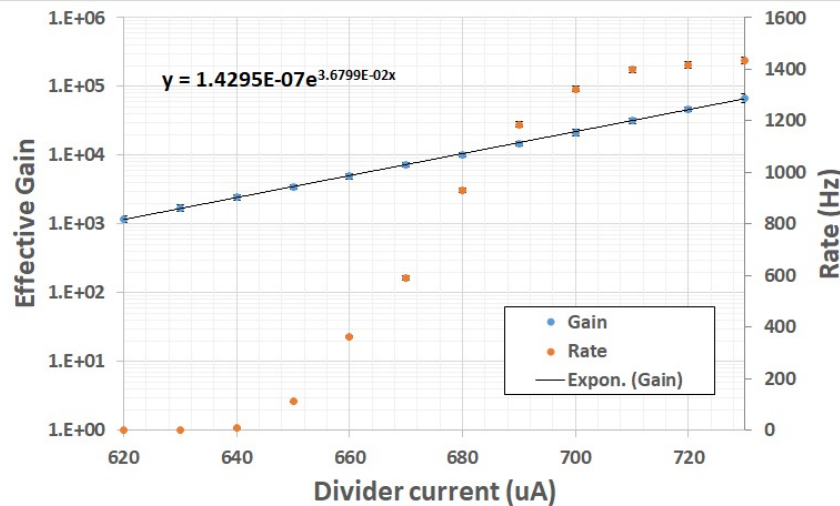
module name: GE1/1 VII-L-CERN-003



- QC5: effective gas gain test with X-ray (stage1 at PKU)
- full detector response uniformity test using the Scalable Readout System (SRS) together with the front-end chip (stage2 at CERN by Chinese people)
- Gas: Ar 70% / CO2 30%

Results for gain(CERN)

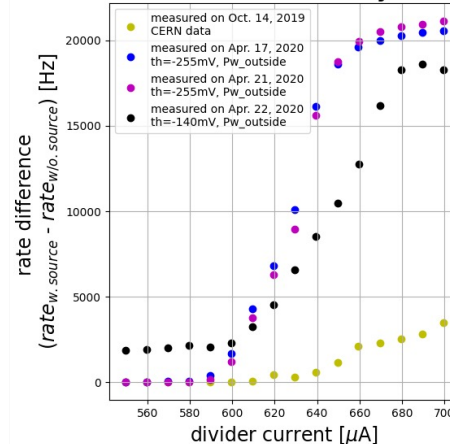
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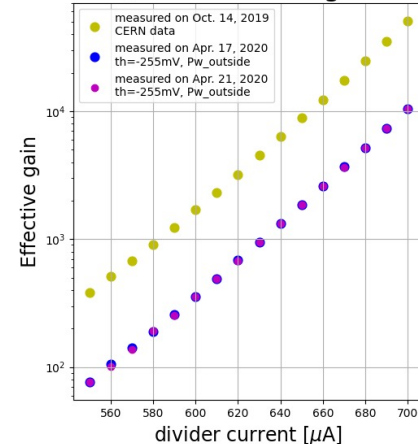
Results for gain (PKU)

module name: GE1/1 VII-L-CERN-003

QC5: rate difference between with and without X-ray source



QC5: effective gain



- The **Triple GEM technology was adopted** for the Phase-II upgrade of part of the CMS forward muon system to accommodate the high trigger rate and to improve the muon track reconstruction performance.
- The **mass production of the GE2/1 GEM chambers is ongoing** and installation will be in the winter of 2023-2024.
- PKU has completed all assembly and test (QC2 - QC5) hardware and software platforms, validated as one of the **official CMS-GEM production sites**, the production of ~ 40 GE2/1 M5 GEM chambers will start in early 2022.
- PKU has also completed the design and prototyping of the 8 different GE2/1 GEBs (M1-M8). The **mass production (~ 320 sets) has started** and will be shipped to CERN upon completion.

01 GE2/1 integration and pre-installation

谢谢

