Status of the installation and commissioning of the new GE1/1 station for the CMS experiment

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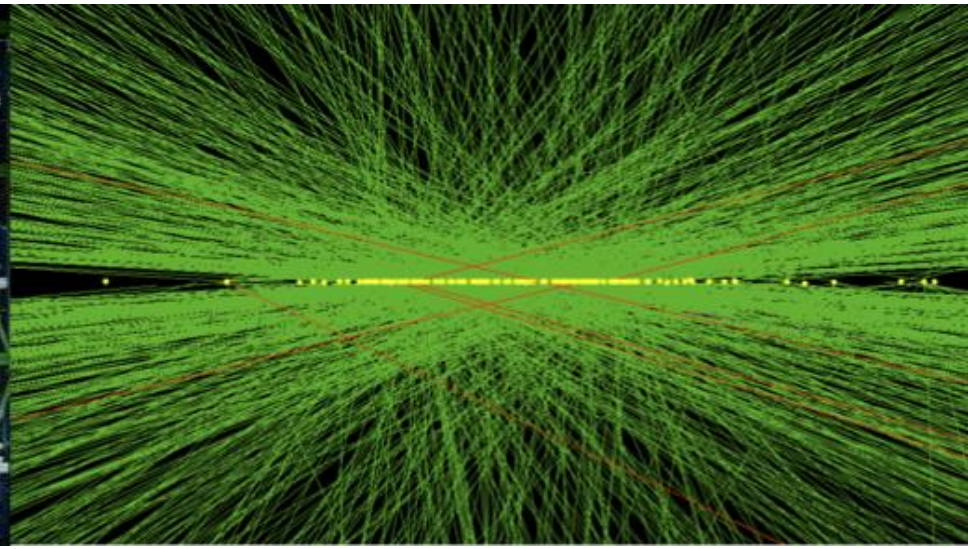


Introduction

Goals of this presentation

Update the community **on the status of the mass-production, installation and commissioning of the new GE1/1 station in the CMS experiment**

Table of contents:

CMS Forward Muon System Upgrade

Run 2 CMS endcap muon detectors:

- CSC + RPC covering $0.9 < |\eta| < 1.6$
- Only CSC covering $1.6 < |\eta| < 2.4$

From 2026: High - Luminosity LHC

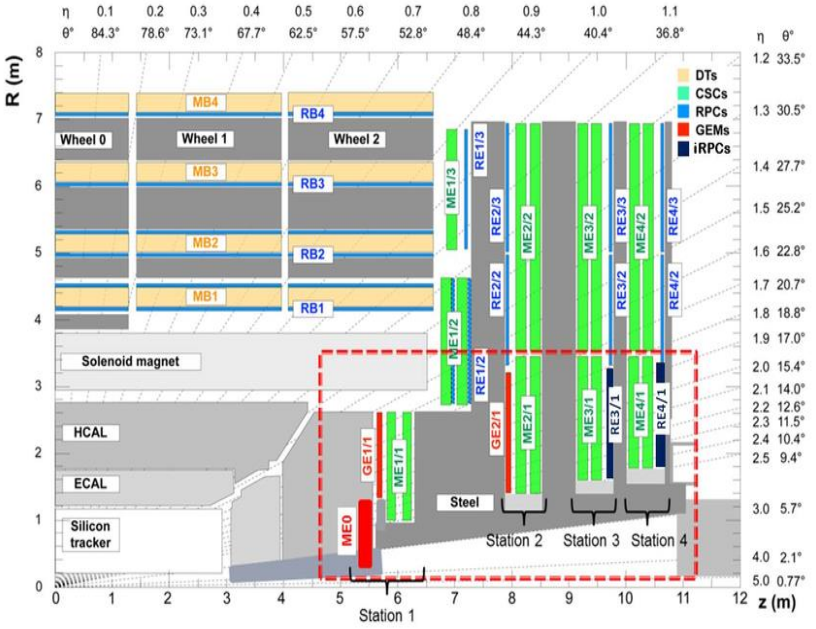
→ Increase luminosity to $5 \times 10^{34}\ s^{-1}cm^{-2}$ $(5 \times \text{LHC design value})$

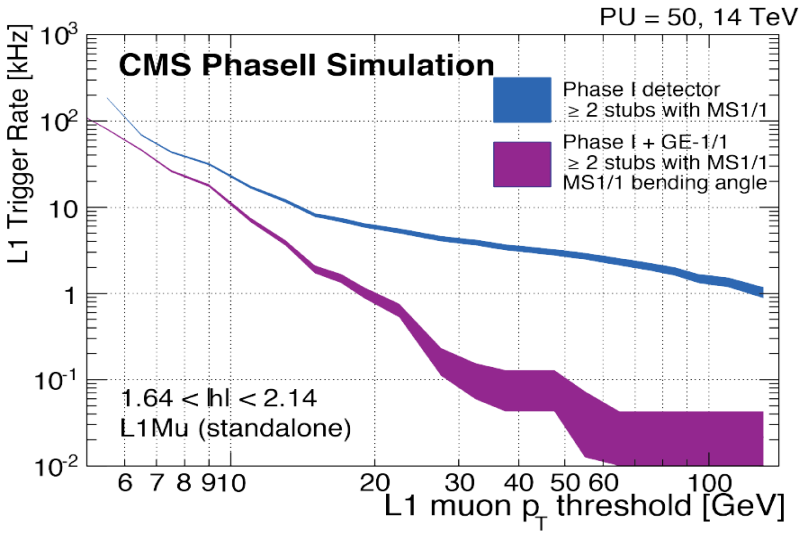
→ Upgrade current Muon Forward System:

- Increase redundancy in endcaps
- Improve p_T measurements in low B field
- Reduce the trigger rates
- Sustain higher particle flux

Future GEM installation $1.5 < |\eta| < 2.8$

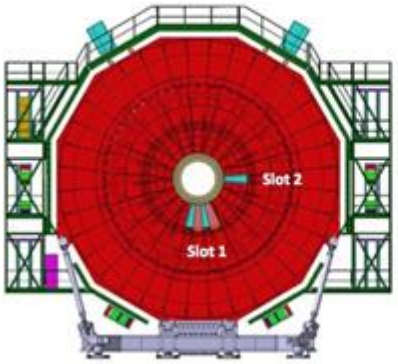
- GE1/1, GE2/1 and ME0 project
- iRPC project





GEM in CMS: integration plans

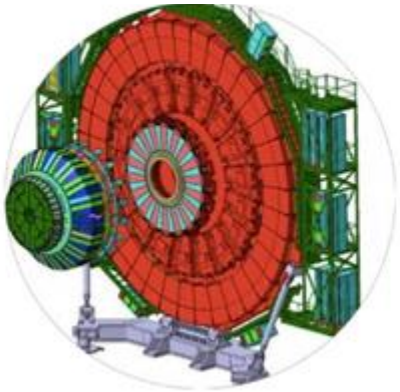
Slice Test



Slice Test = commissioning of 5 GE1/1 detectors in CMS

1 out of 5 with final readout electronics and HV

GE1/1



Installation of GE1/1 during Long Shutdown 2

144 chambers in two endcaps
GE1/1: $1.5 < |\eta| < 2.2$

GE2/1

GE1/1

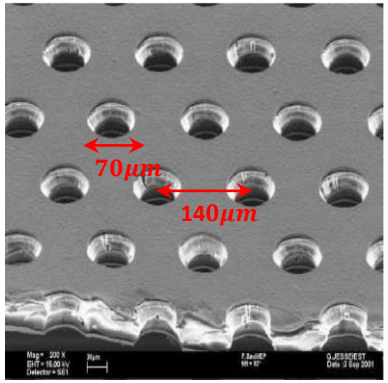
ME0

GE2/1 and ME0 installed by the end of Long Shutdown 3

GE2/1: $1.5 < |\eta| < 2.2$
ME0: $2.0 < |\eta| < 2.8$

Gas Electron Multiplier Technology

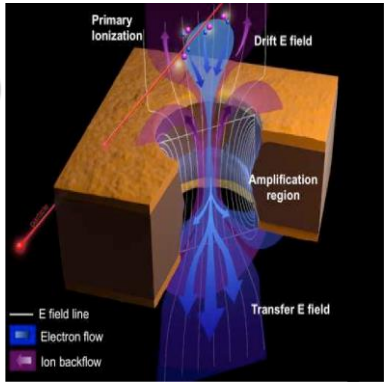
Micro-Pattern Gas Detectors (MPGD) due to their proven performance at HEP experiment (high rate capability and fine space resolution, high gain stability) are ideal tools for the Upgrade of the Forward Muon Spectrometer in CMS



GEM-based technology as adopted detector!

GEM foils:

- $50\ \mu m$ thick copper/cladded polyimide foils
- Holes $(\mathbf{diameter\ =\ 70\ \mu m})$ in hexagonal pattern $(\mathbf{pitch\ =140\ \mu m})$

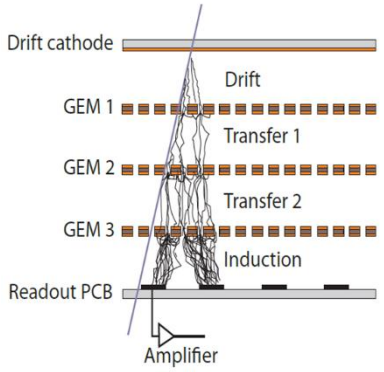


GEM chamber:

- Gas detectors: charged particles ionize gas
- HV applied: amplification process inside holes $(\mathbf{E \sim 60\ kV/cm})$
- One or multiple GEM- foils $(\mathbf{e.g.\ triple-GEM = 3\ foils})$

Performance:

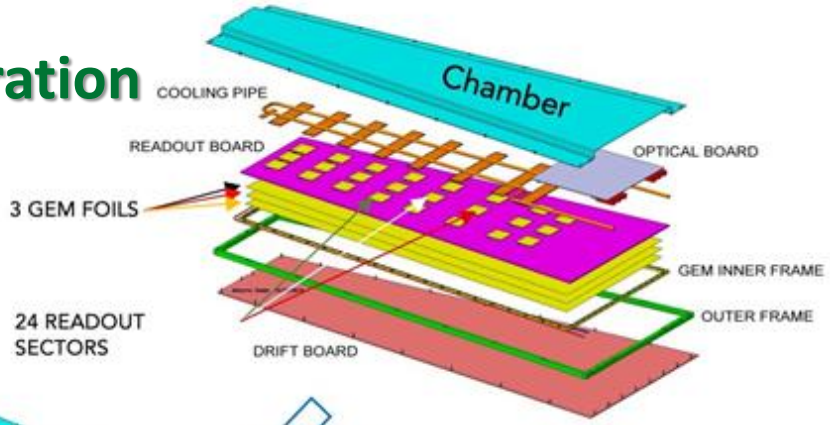
- Rate capability: up to $\mathbf{O(kHz/cm^2)}$
- Triple-GEM chamber efficiency $> 98\%$ for MIPs
- No aging effects after foreseen integrated luminosity of HL-LHC
- High spatial $(\sim 140\ \mu m)$ and good time $(\sim 7\ ns)$ resolution



CMS GEM GE1/1 Project

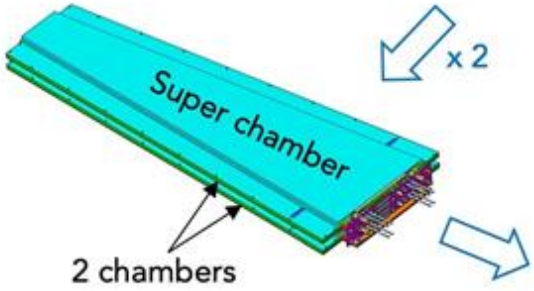
The 1st project of the CMS GEM Collaboration

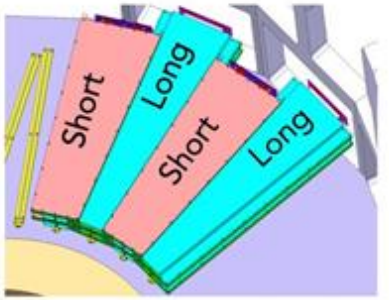
GEM Endcap Ring 1 Station 1



GE1/1 chamber

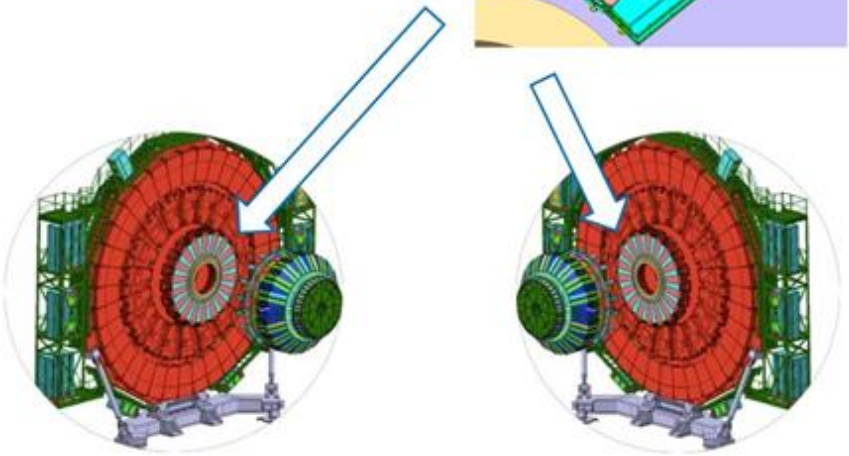
- Triple-GEM chambers
- Gas mixture Ar/CO_2 $(70/30\%)$
- Large area $O(m^2)$
- Covering $1.5 < |\eta| < 2.2$





- 144 trapezoidal Long and Short chambers
- 24 readout sectors per chamber
- 128 radial strips for each sector
- Digital readout

- 72 Super Chambers (2 coupled chambers)
- Each Super Chamber covers $10.15°$ (overlap)



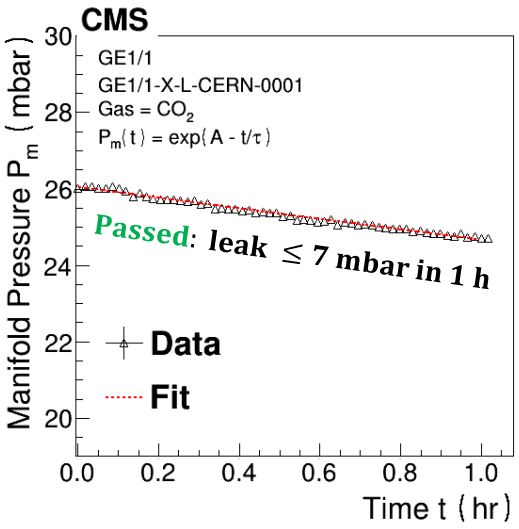
GE1/1 Detector QC Overview

CERN
- QC1 — Material Inspection
- QC2 — GEM-foils Test

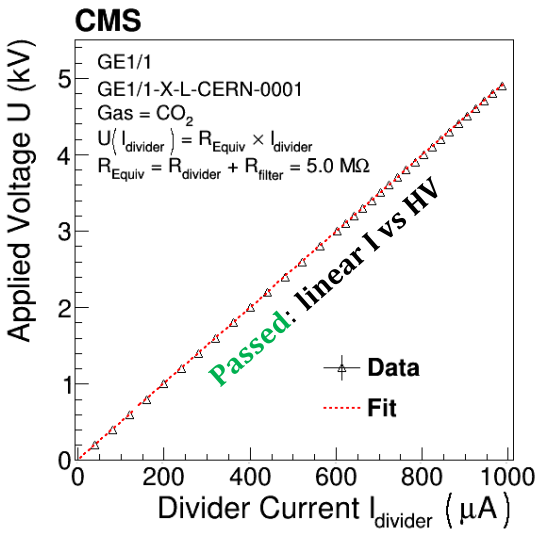
Production sites
- Assembly
- QC2 — GEM-foils Test (fast)
- QC3 — Gas Leak Test
- QC4 — HV Test
- QC5 — Gas Gain Calibration

CERN
- QC6 — HV Stability Test
- QC7 — Electronics Connectivity Test
- QC8 — Cosmic Test

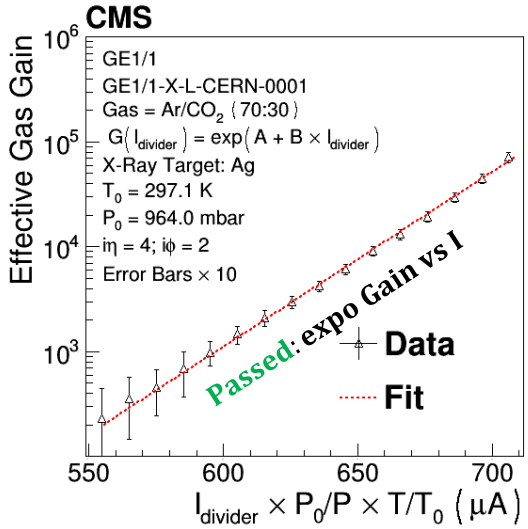
QC3 - Gas Leak Test



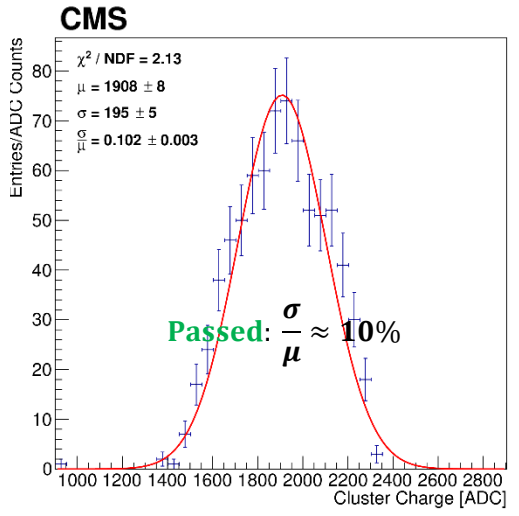
QC4 - HV Integrity



QC5 - Effective Gas Gain



QC5 - Gas Gain Uniformity



GE1/1 Detector QC Overview

GE1/1 Electronics Assembly Procedure

Mounting of the front-end electronics:

~1 hr

- *Mounting of the GEB (GEM Electronics Board)*
- *Routing of the on-chamber services*
- *Installation of the FEASTs + Opto-Hybrid + VFATs*

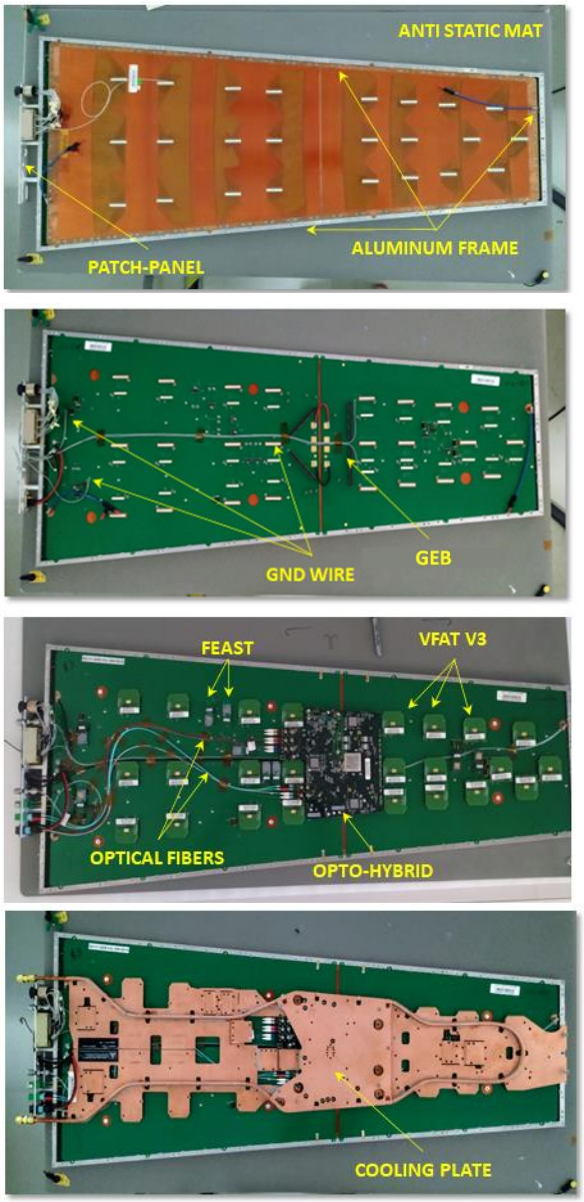
(VFAT is a trigger and tracking front-end ASIC device)

Electronics and connectivity test:

~1/2 d

- *Check connectivity of the electr. components*
- *Calibration of front-end elect. parameters*
- *Monitor the communication stability*
- *Noise level measurement (Equivalent Noise Charge)*
- *Identification the noisy/dead channels*

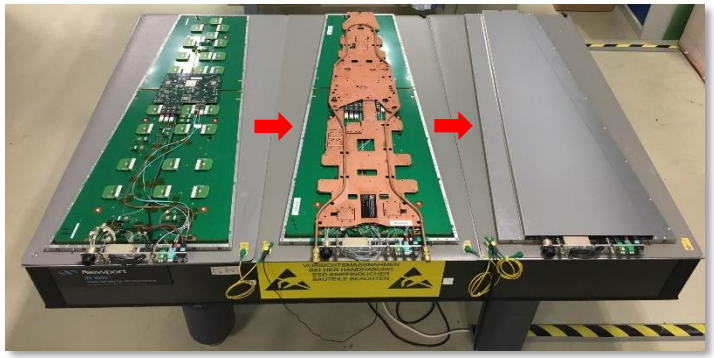
1 day is sufficient to fully assemble and test the GE1/1 on-chamber elestronics

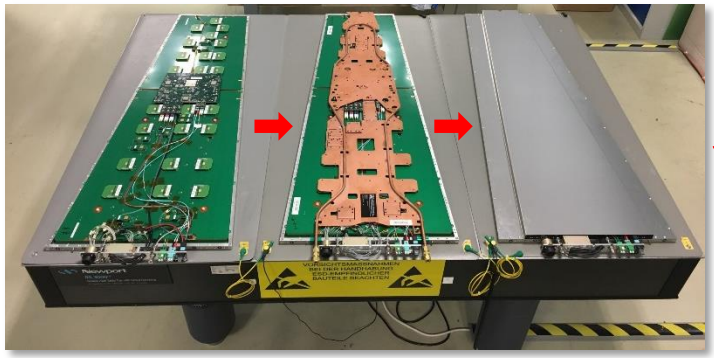


GE1/1 Detector QC Overview

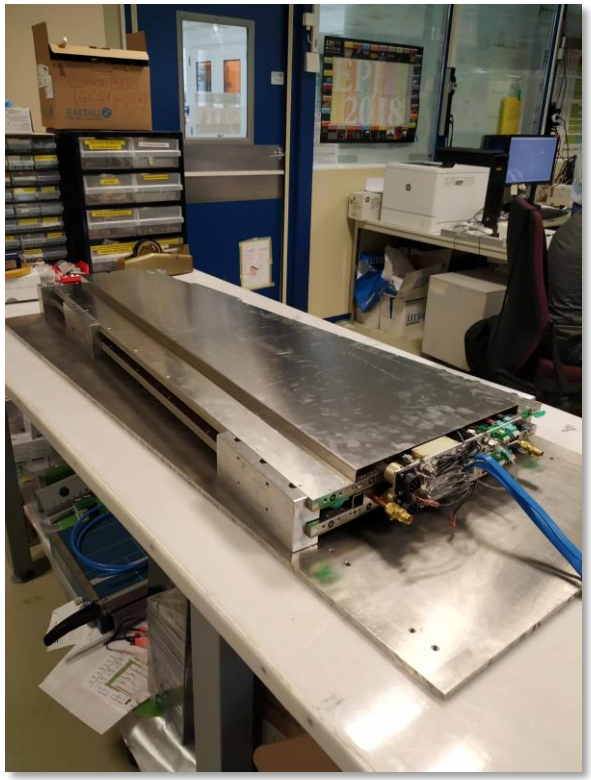
GE1/1 Super-Chamber Assembly

GE1/1 CHAMBER LAYER 1





GE1/1 CHAMBER LAYER 2

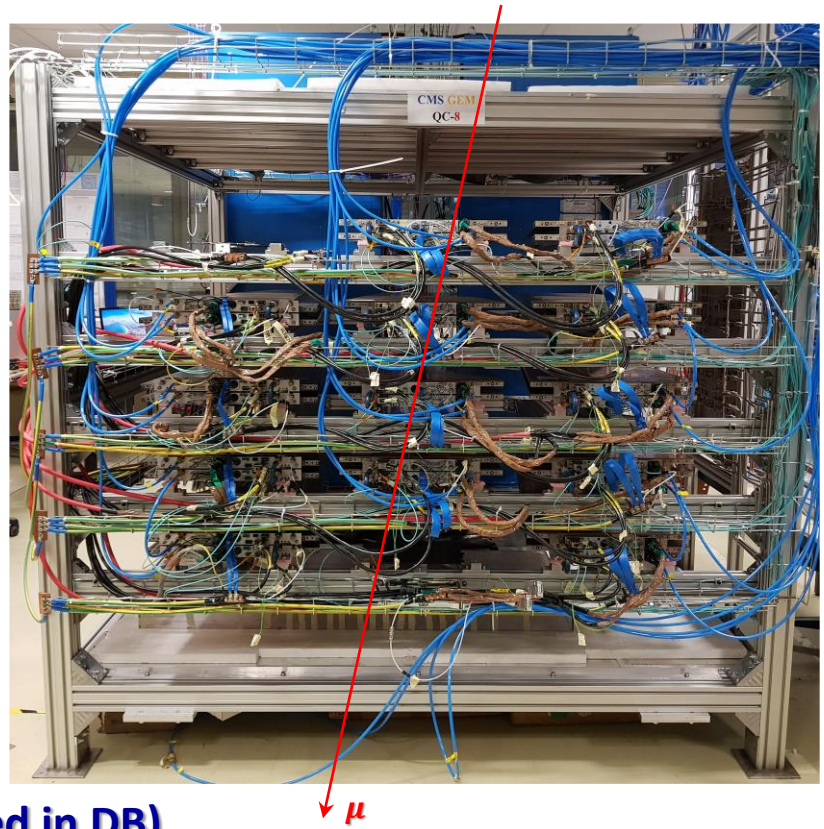


SC ready for the Cosmic Test

A GE1/1 Super-Chamber is obtained by mounting one single chamber onto the other through a custom alignment jig, by fixing the appropriate mechanical supports and interconnecting the two cooling systems.

Cosmic Test Overview

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

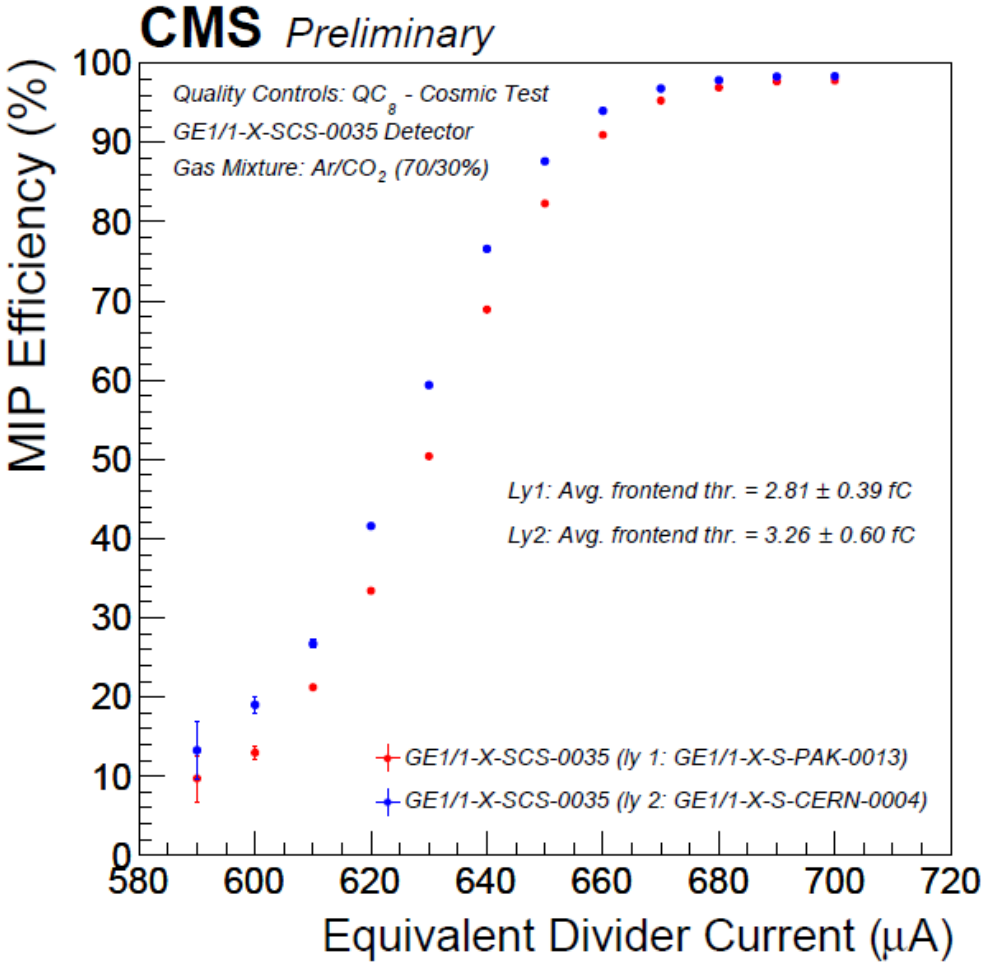


- **15 Super-Chamber slots**
- **2 layers of scintillators (as a trigger - rate $\sim 90\ Hz$)**
- **$92k$ readout channels with CMS-like DAQ based on μTCA back-end**
- **Services (HV, LV, DAQ system, cooling, FW, SW) as in CMS**
- **Gas mixture: Ar/CO_2 $(70/30\%)$ line**
- **Dedicated Detector Control System:**
  - **→ HV, LV control and monitoring (data stored in DB)**
  - **→ environmental conditions and gas mixture monitoring (data stored in DB)**
- **Dedicated Offline Data Quality Monitoring**

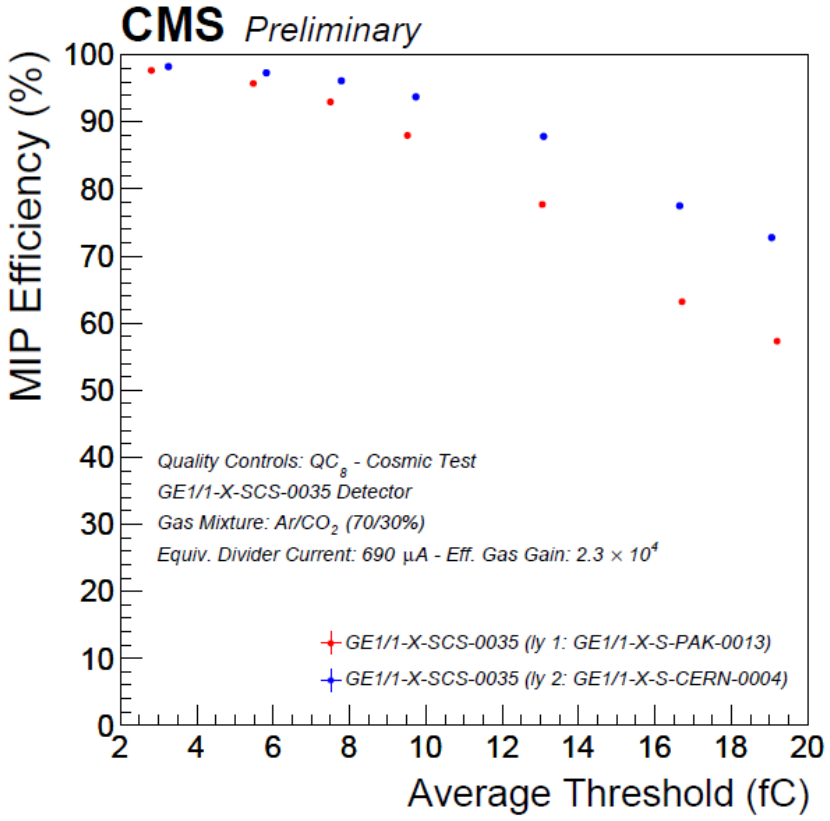
Cosmic Test Result

Results for some of the detectors tested:

Example of Efficiency vs. HV scan



Example of Efficiency vs. THR. scan

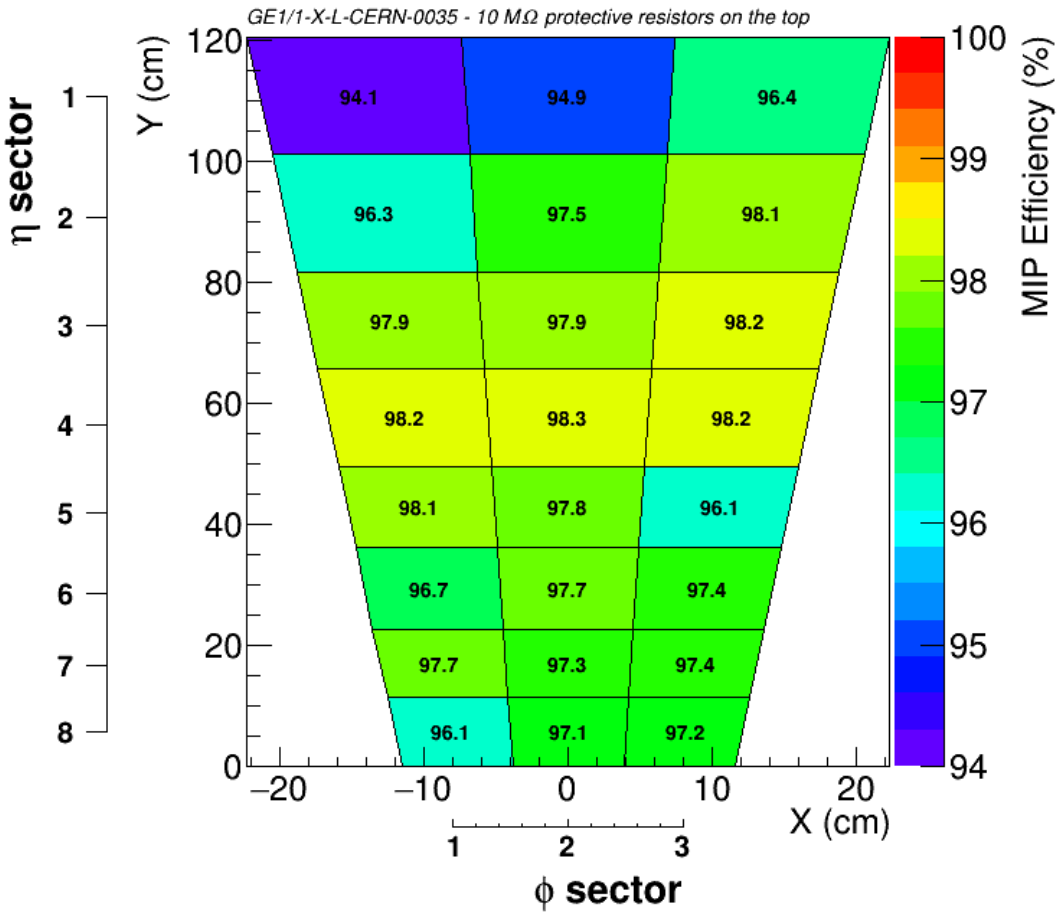


Tip: to get HV at the cathode, just need to multiply the current by $\sim 4.7\ M\Omega\ (700\ \mu A = 3290\ V)$

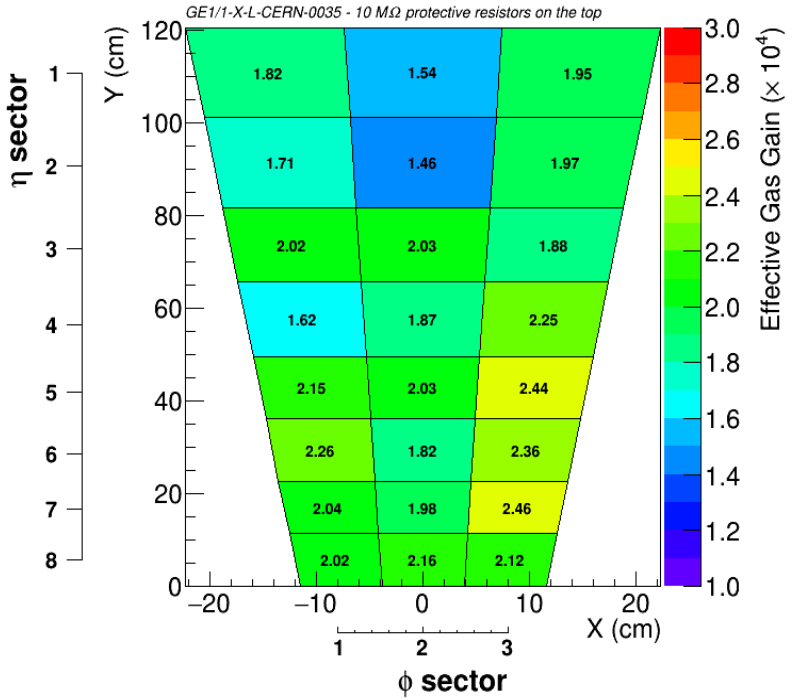
Cosmic Test Result

Results for some of the detectors tested:

Example of Efficiency per readout partition



Example of Gas Gain per readout partition

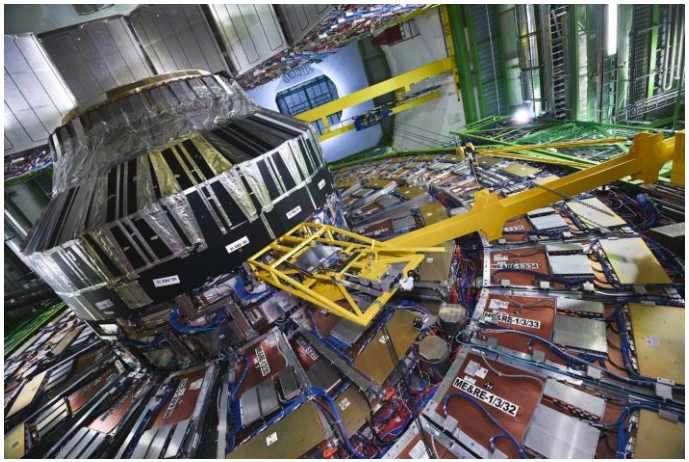


Possibility to generate the *efficiency maps* for all detectors and identify possible weak regions (and correlate with the *gas gain maps* obtained in QC5)

GE1/1 Installation and Commissioning

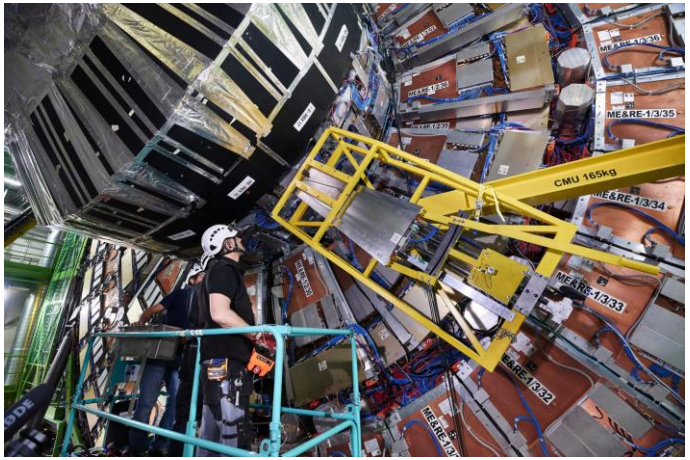
GE-1/1 SCs in the negative end-cap

- **Installation of all 36 Super-Chambers for the first end-cap completed in Oct. 2019**
- **Multiple installation windows from July 2019 to October 2019**
- **Commissioning phase is underway (delayed to the COVID-19 stop)**



GE+1/1 SCs in the positive end-cap

- **Installation of all 36 Super-Chambers for the second end-cap completed in Sept. 2020**
- **Multiple installation windows from July 2020 to September 2020**
- **Installation and commissioning phase delayed to the COVID-19 stop**

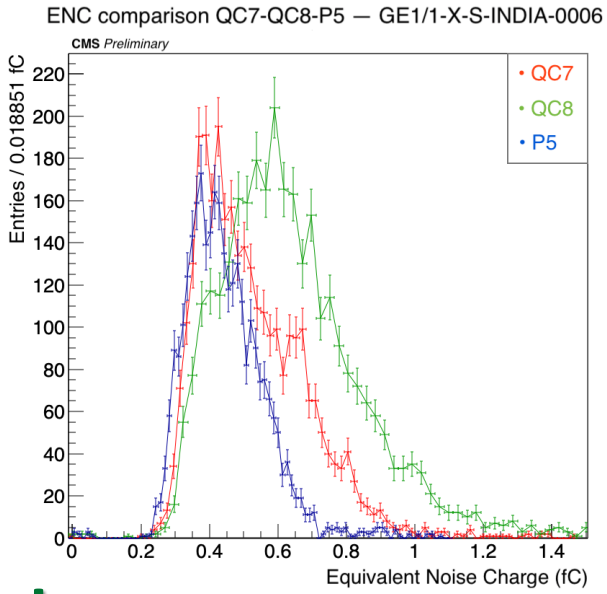


Nice pictures and movies of this story available at: http://cds.cern.ch/record/2684028 & https://www.youtube.com/watch?v=fU0ujGWbeQ0&feature=youtu.be

GE1/1 Installation and Commissioning

First end-cap "pre-commissioning" phase

- HV training procedure in pure CO_2 to prevent discharge successfully performed
- Electronics connectivity checks successful for all the chambers installed
- Optical readout fibers mapping checked
- Noise level assessed for all the chambers installed
- DCS and DAQ fully operational in local mode



Plan for commissioning after COVID-19 stop

- Complete integration of DCS, DAQ, DQM in central CMS system
- Full configuration of the frontend and backend electronics
- High Voltage training of the chambers in final gas mixture $\mathbf{Ar/CO_2}$ $\mathbf{(70/30\%)}$
- Latency and efficiency scans to determine optimal working point (combined with CSC sub-detector)

Conclusions

In the coming years, the CMS Muon system will go through a series of upgrades in order to cope with the foreseen increasing of LHC performance

GEM technology has been selected for the upgrade of the first disk of the CMS Muon end-cap through the GE1/1 project, and for the future GE2/1 and ME0 project

GE1/1 detector mass-production:

- **Successful and on-time production of both endcaps (>144 GE1/1 detectors) from Sept. 2017 to Dec. 2018**
- **72/72 GE1/1 super-chambers have been fully assembled and validated**
- **Complex mechanics + electronics required many changes in final assembly and quality control procedures**
- **We gained valuable experience for the future GE2/1 and ME0 upgrade project**

GE1/1 installation and commissioning:

- **GE1/1 station successful installed in CMS from July 2019 to Sept. 2020**
- **A first "pre-commissioning" phase already took place for the negative end-cap**
- **Commissioning activities fully resumed after the COVID-19 stop**