The GEM (GE1/1) Phase II Upgrade for the CMS muon system: results from in-situ demonstrator, production detector qualification, and commissioning plans

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on behalf of the CMS Muon Group

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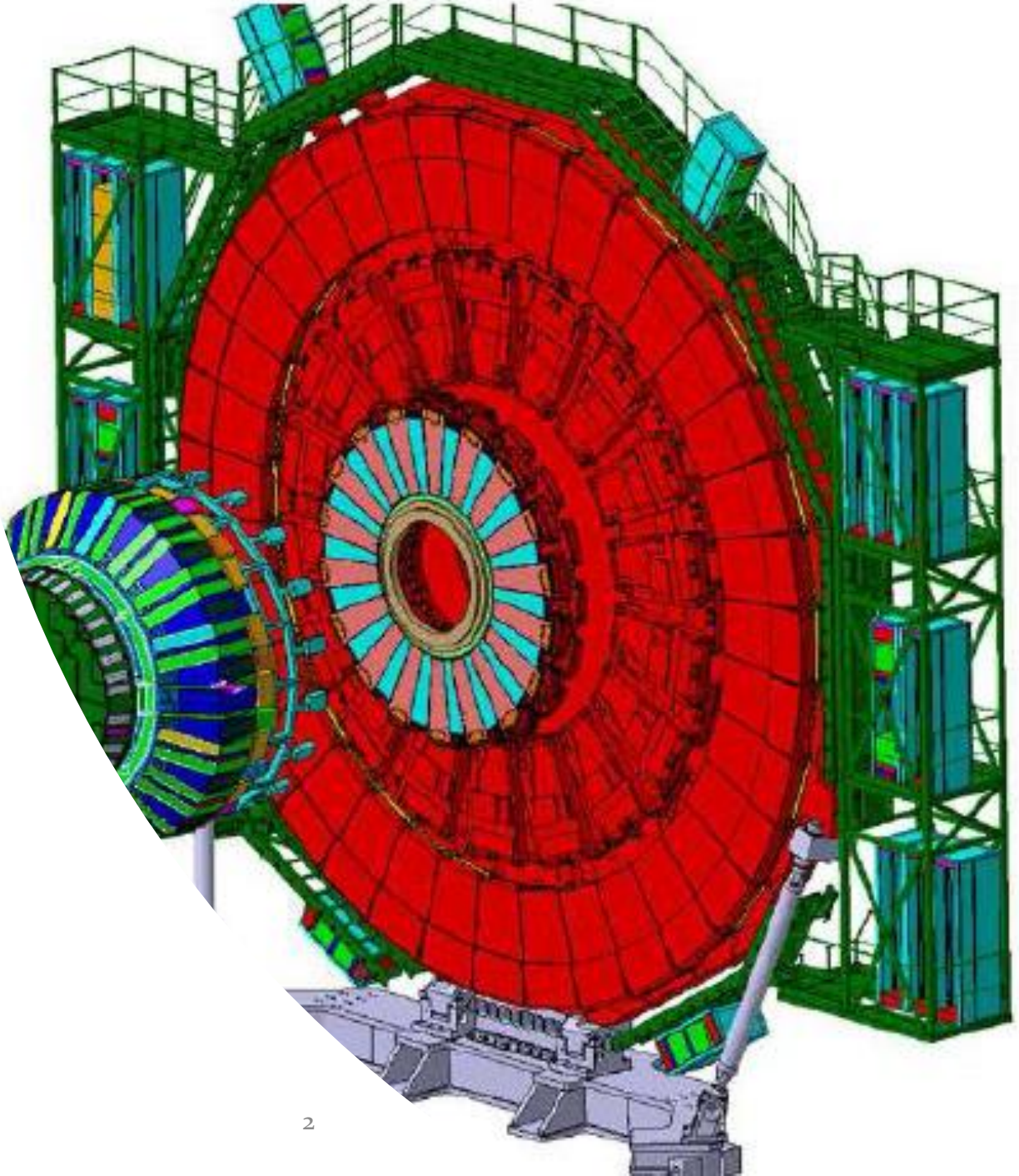
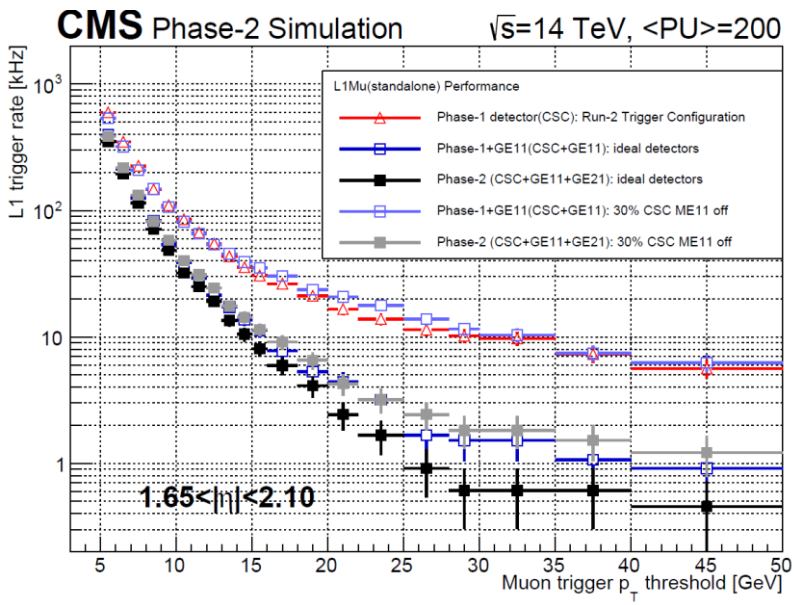


during LHC Run-1 the CMS muon system included:

- ***Drift Tubes***, for tracking and triggering in the region $|\eta| < 1.2$
- ***Cathode Strip Chambers***, for tracking and trigger in the region $0.9 < |\eta| < 2.4$
- ***Resistive Plate Chambers***, for triggering in the region $|\eta| < 1.9$



HL-LHC upgrade:

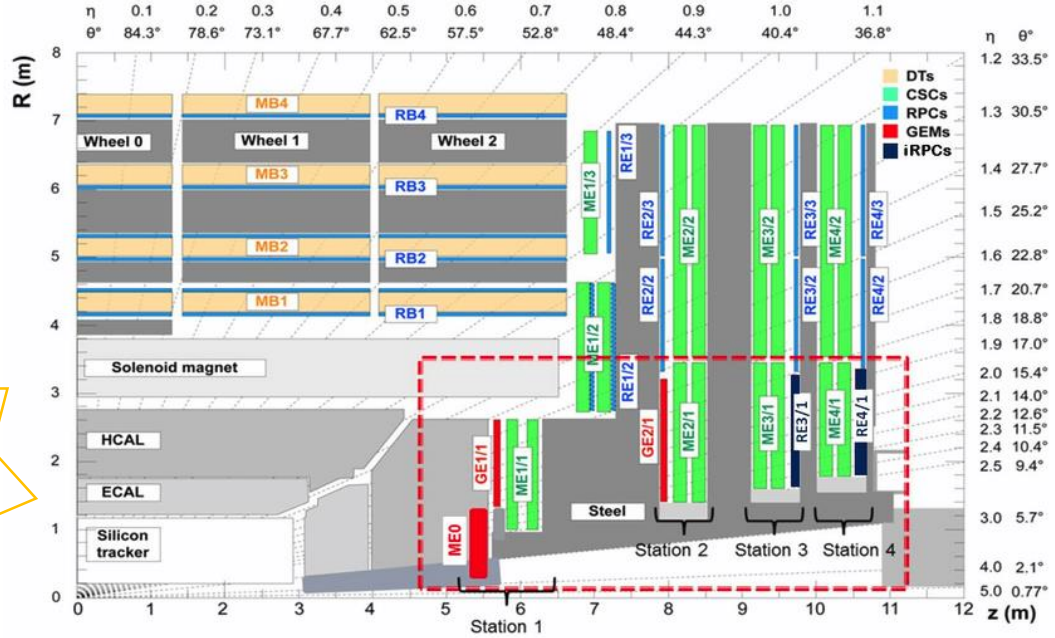
- ***Nominal luminosity*** up to $\mathbf{7.5 \times 10^{34}\ cm^{-2}s^{-1}}$
- Huge increase in ***cavern background*** (up to 10^6 part/ cm^2s) and in ***pile up*** (from 30 to 200) expected

→ ***Need to upgrade the CMS muon system to preserve the muon triggering and reconstruction capabilities***

new muon stations to:

- ***Improve the redundancy*** in the high η region
- ***Handle a rate*** of $10's\ of\ kHz/cm^2$
- ***Survive*** to an intense background rate

→ **GE1/1**

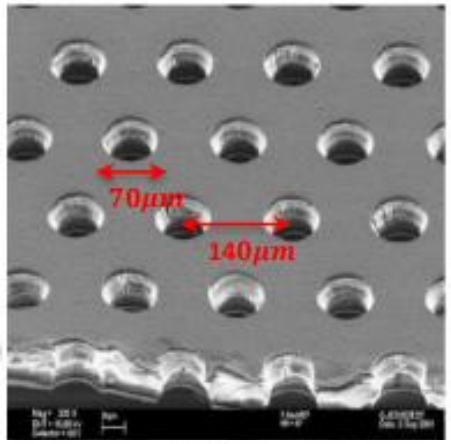


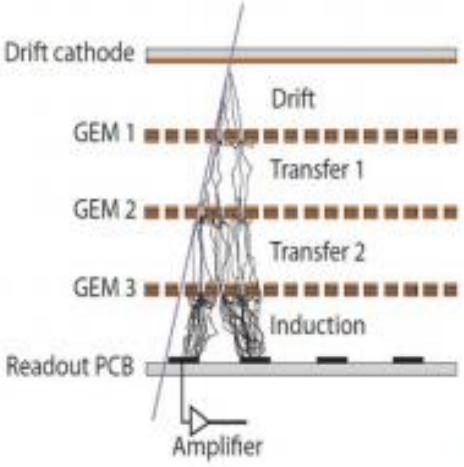
Triple-GEM detectors:

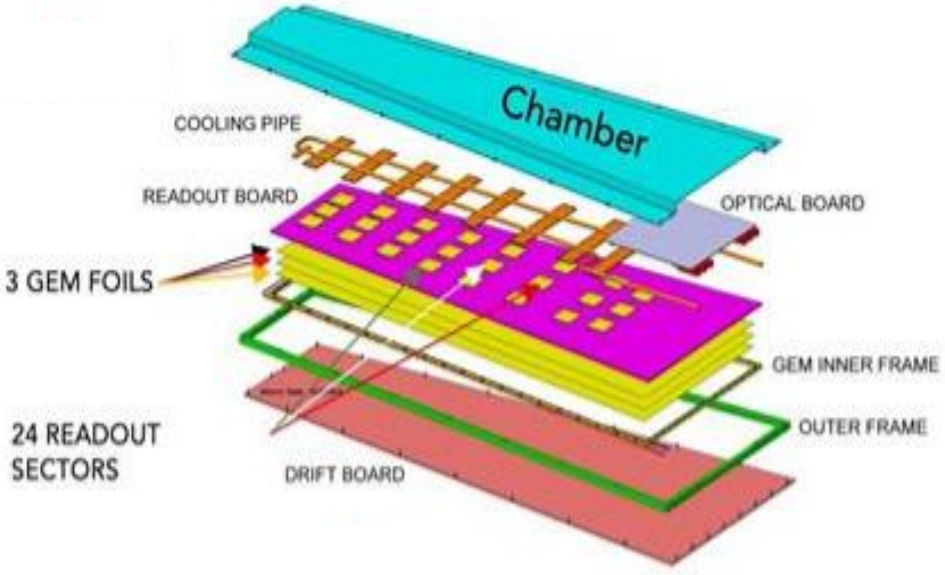
- Gain up to 10^4
- Hit efficiency up to 97%
- Spatial resolution of 140 μm
- Time resolution of 7 ns with Ar/CO2 70/30 gas mixture without contaminants
- Rate capability up to 100 MHz/cm^2
- Radiation hardness up to 1.56 C/cm^2

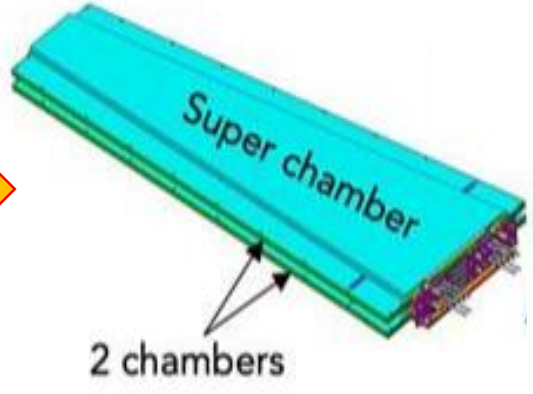
The GE1/1 station:

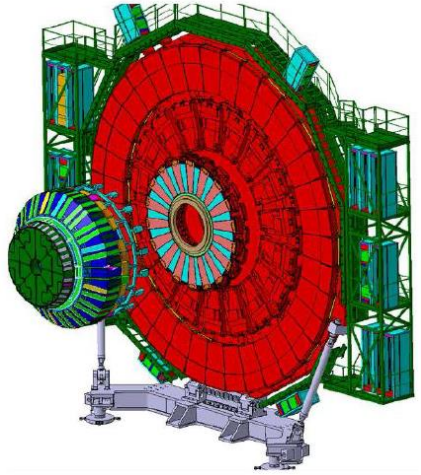
- Two Triple-GEM detectors coupled into superchambers
- 36 superchambers per endcap
- 144 Triple-GEM chambers in total
- Long a short superchamber versions alternate to maximize the η coverage.







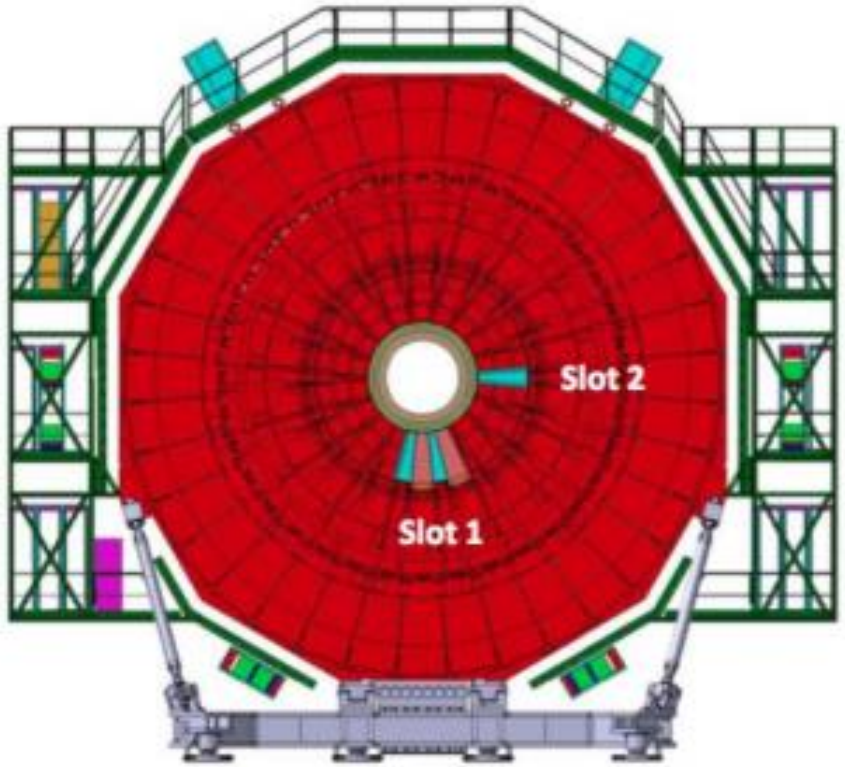


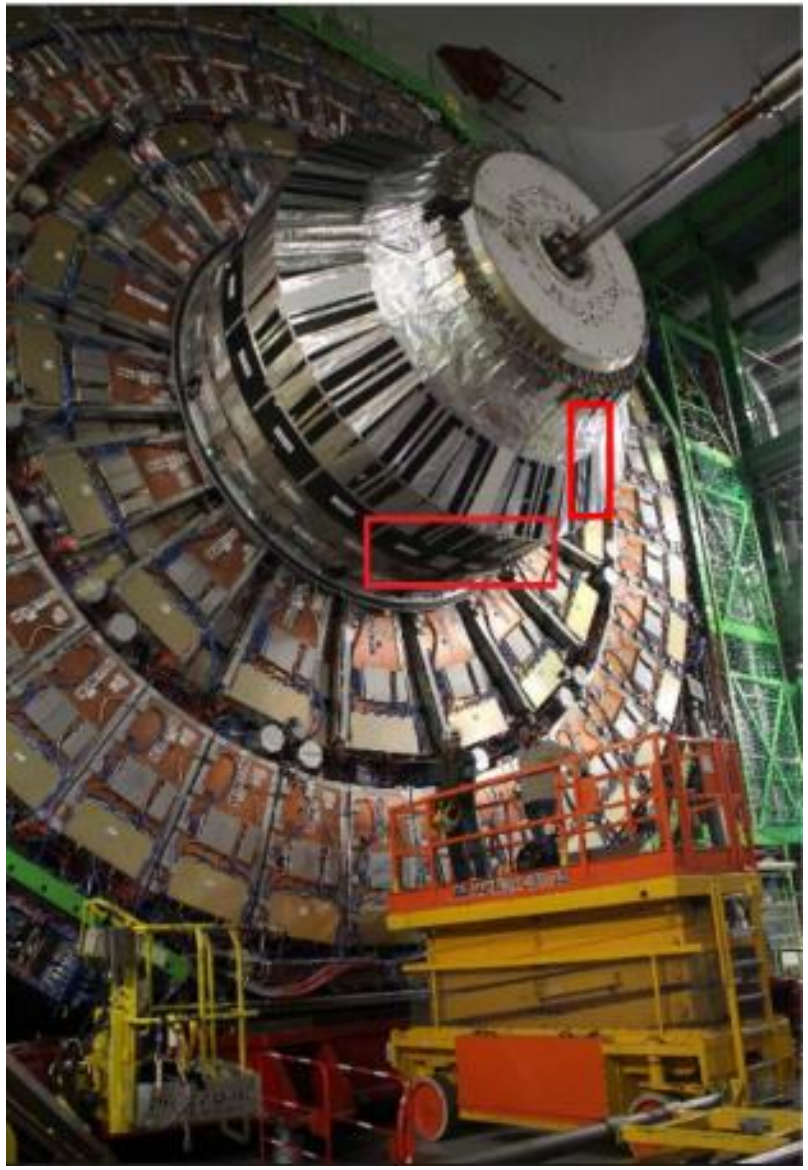


GE1/1 Slice Test - Goals

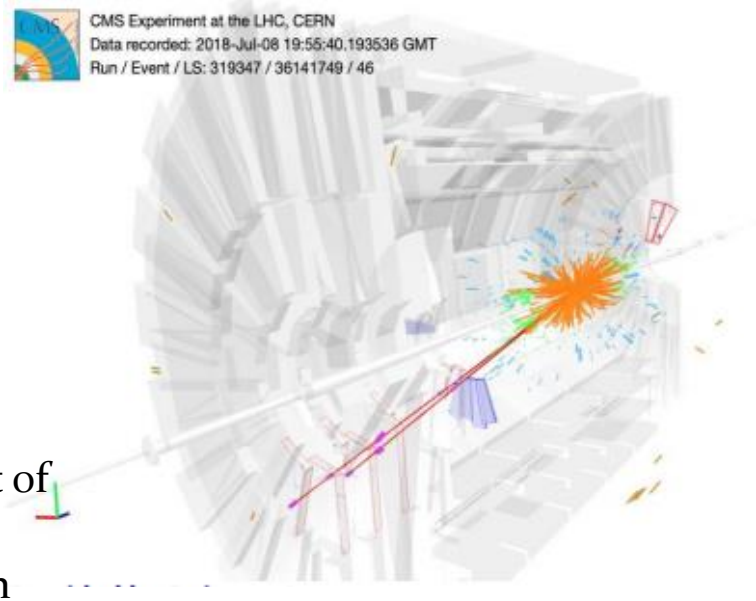
***10 Triple-GEM detectors (5 superchambers or GEMINI) installed in the negative endcap in January 2017, with the aim of*:**

1. Acquiring ***installation and commissioning expertise***
2. Demonstrating the ***integration*** into the CMS online system
3. Proving ***operability*** of the system





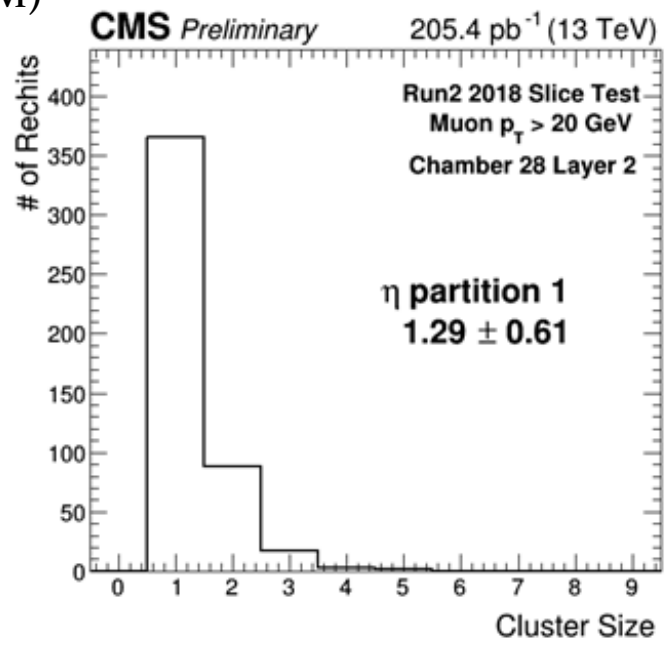
GE1/1 Slice Test - Results

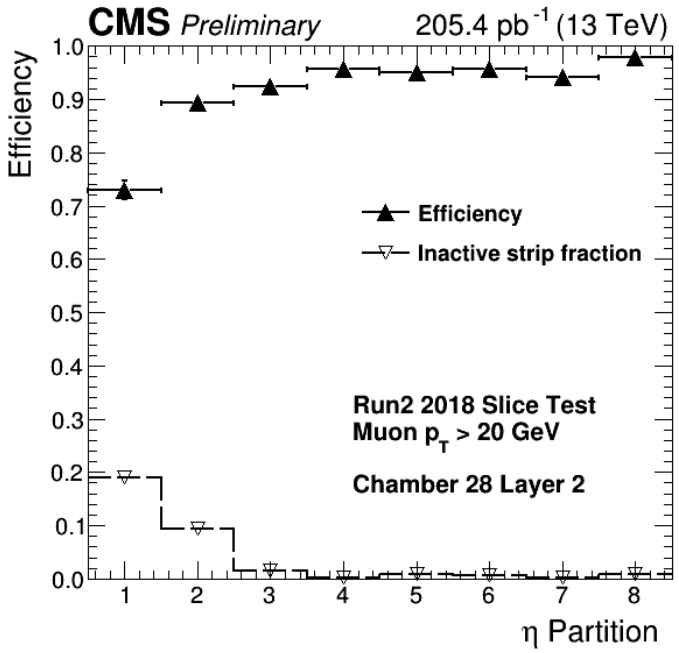


1. ***The 5 GEMINI were installed successfully in CMS***
   a. The experience lead to the development of a dedicated insertion jig for the installation of the full station
   b. Experienced gained in commissioning of detectors, DCS and DAQ systems

2. ***Full integration in CMS***:
   a. DCS → GEMINI operated following the LHC operations, together with the rest of CMS
   b. DAQ → data acquired in central DAQ during cosmics runs and runs with beam
   c. online DQM → Successful test of a full chain processing (i.e., RAW data → Digitization → Reconstruction → DQM)

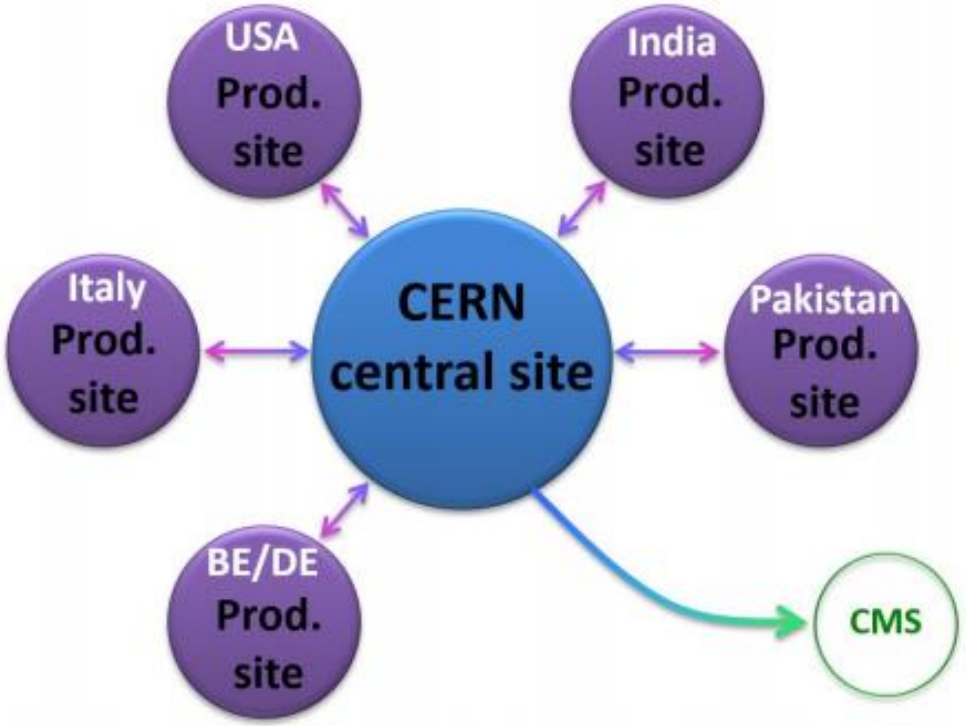
3. ***Operability***:
   a) Detectors proved to be stable over the full period of operation
   b) The measured reconstruction efficiency and cluster size reached the values expected from qualification
   c) First collision data with GEMs reconstructed in 2018.





GE1/1 Assembly

Production effort shared between CERN and different GEM institutes



Phase I - Preparation of the components in laboratory

- Cleaning of the components
- Preparation of the HV circuit
- Mounting of the pull-outs
- Selection of the O-ring

Phase II - Assembly in clean room

- Fast test of the GEM-foils
- Mounting of the stack
- Closing of the chamber

1 day is enough to fully assemble a GE1/1 detector

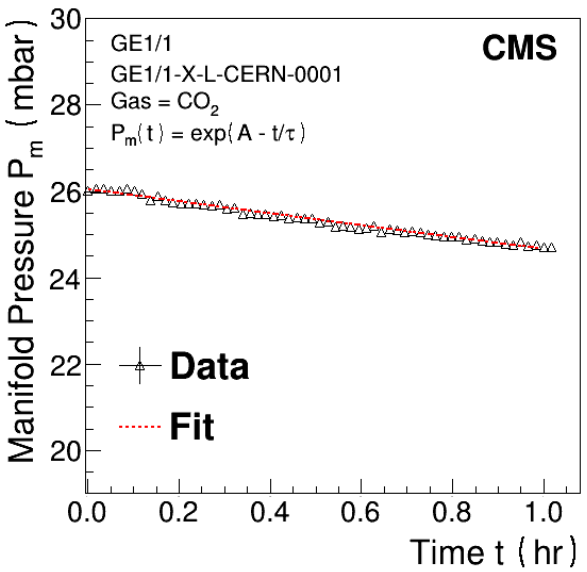
GE1/1 QA/QC

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

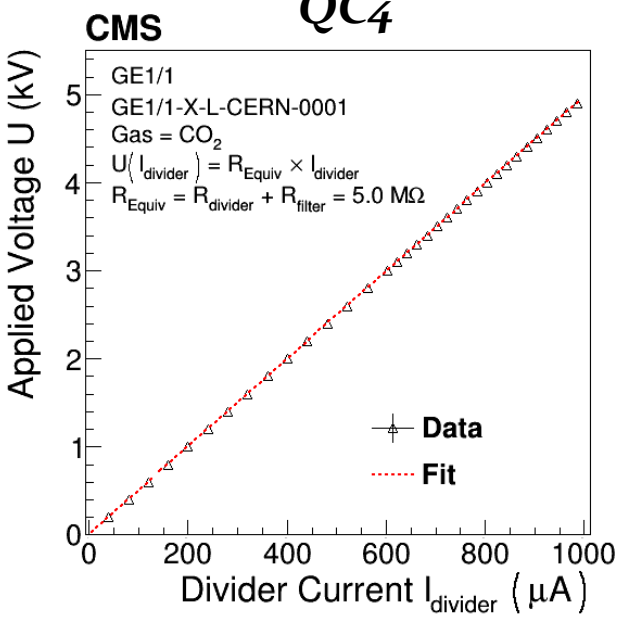
Production sites
- Assembly
- **QC2** GEM-foils Test (fast)
- **QC3** Gas Leak Test
- **QC4** HV Test
- **QC5** Gas Gain Calibration

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

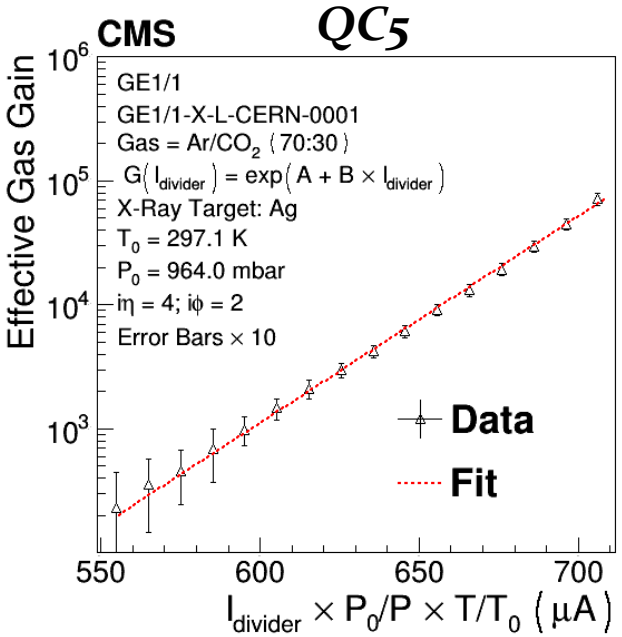
QC3



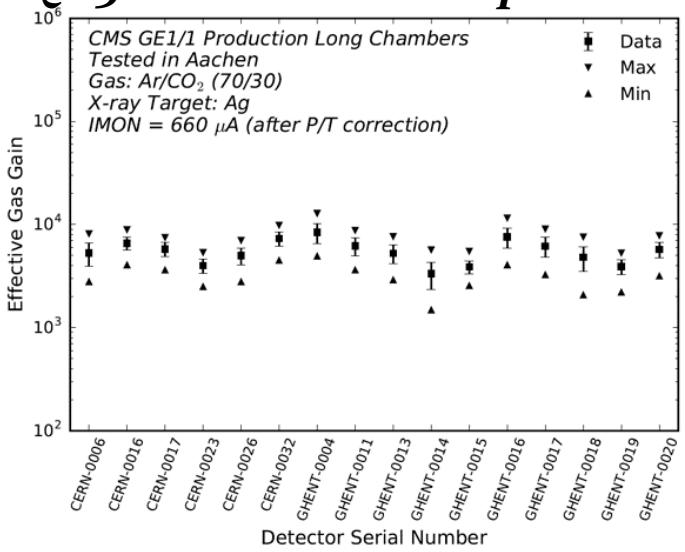
QC4



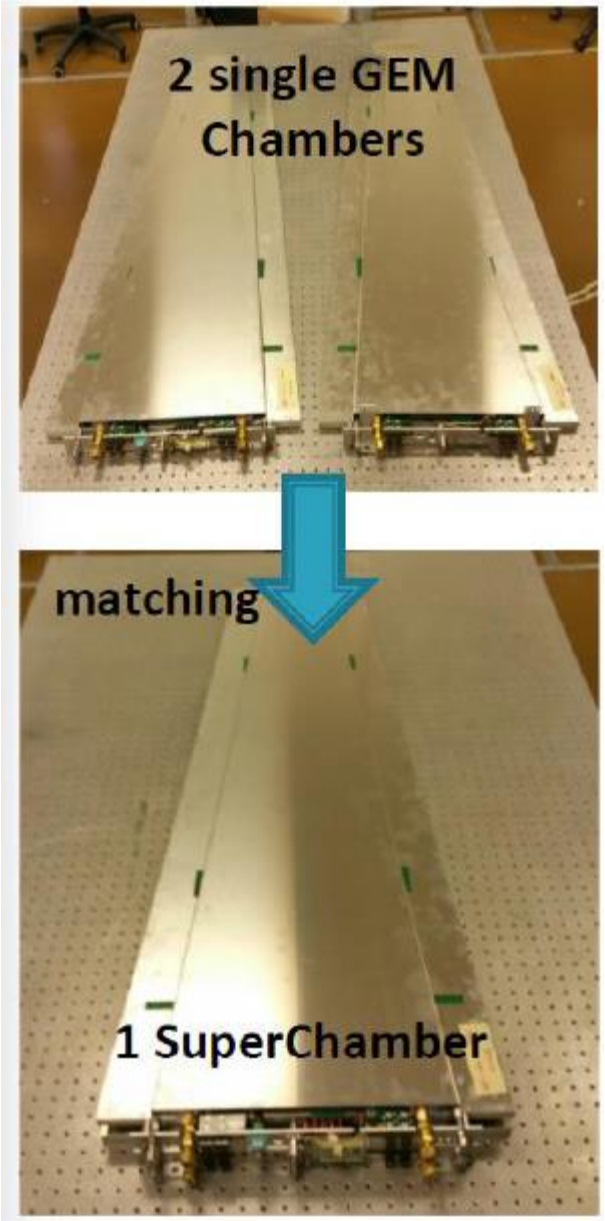
QC5



QC5 – Chambers comparison



GE1/1 Readiness



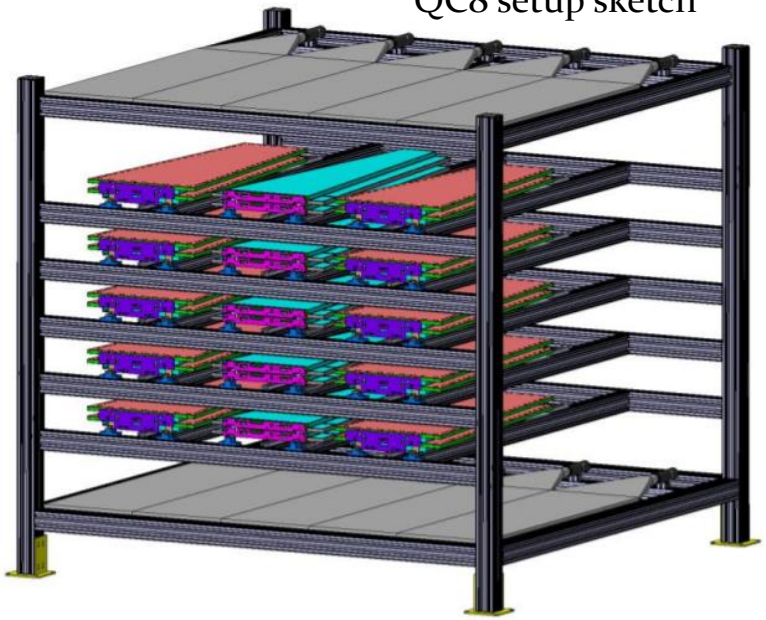
All the detectors needed for GE1/1 have been assembled and tested up to QC6.

Still on going:

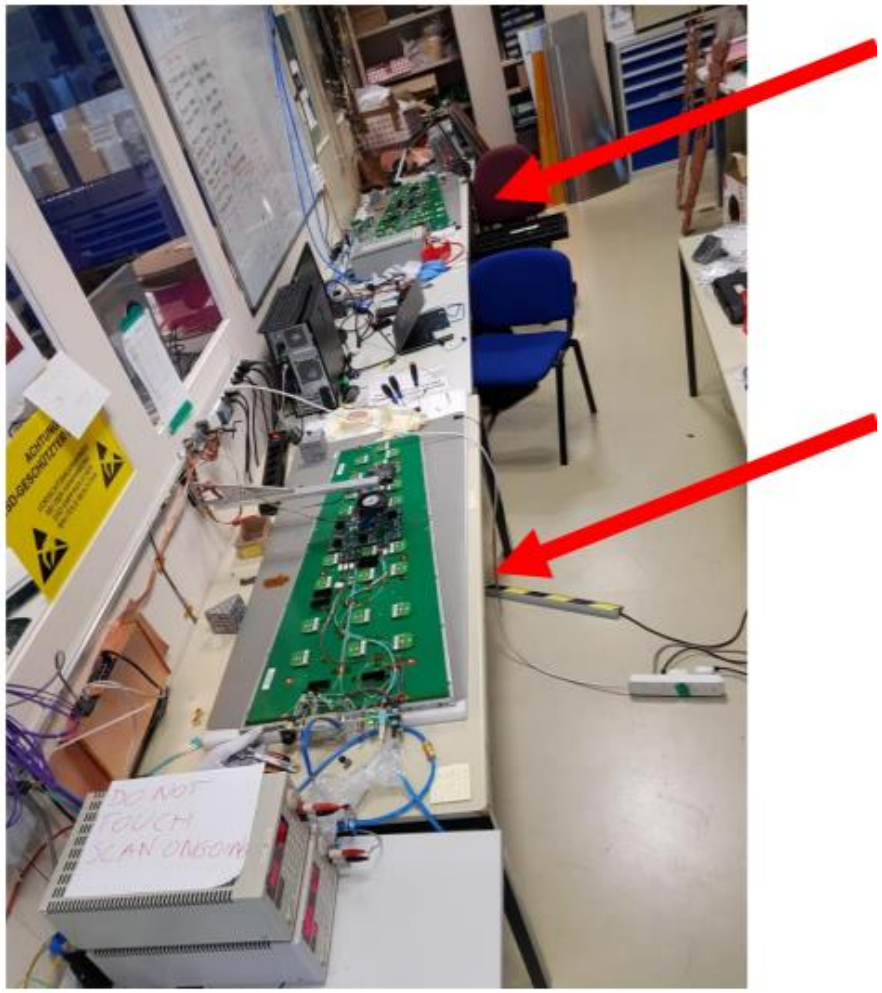
- Superchamber assembly
- QC7 & QC8

→ ***Expected to be completed by the end of 2019***

QC8 setup sketch



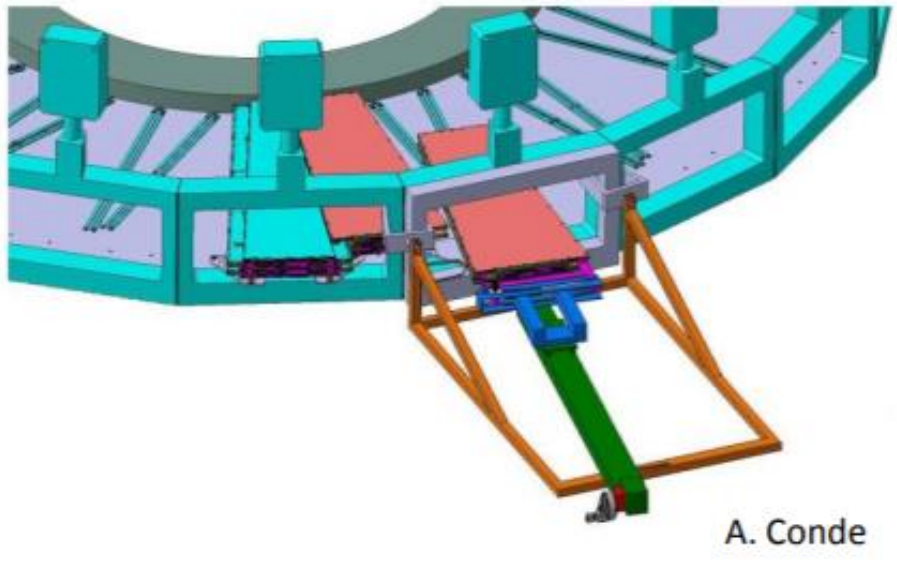
QC7 setups @ CERN lab b.904



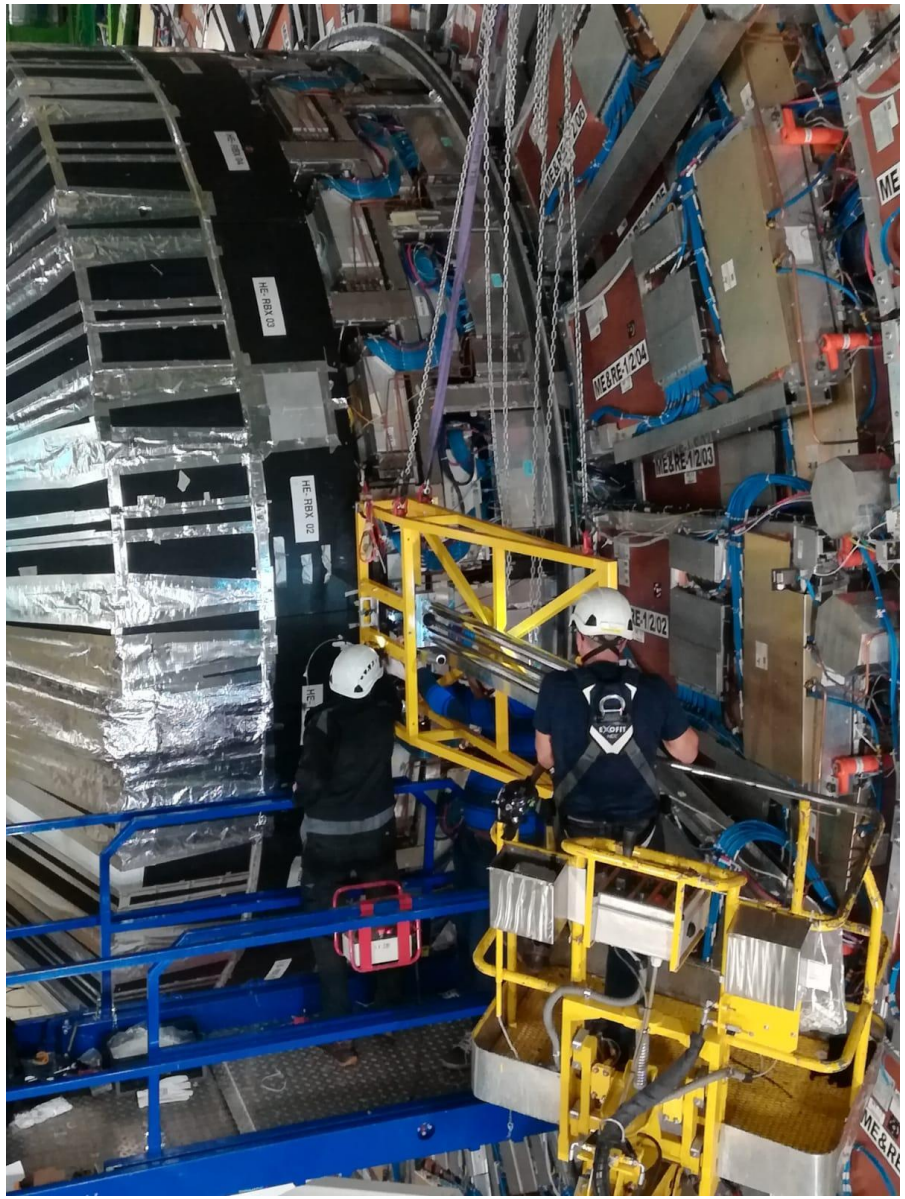
GE1/1 Installation in CMS

Schedule:

- ***Autumn 2019***: installation of 36 superchambers in the negative endcap
- ***Spring 2020:*** installation of 36 superchambers in the positive endcap



Insertion jig developed from the slice test experience



GE1/1 Commissioning plans

Several DAQ and analysis tools developed for the slice test and QC8 are ready to be used for the GE1/1 commissioning!

Phase I – Standalone tests → Summer/Fall 2019

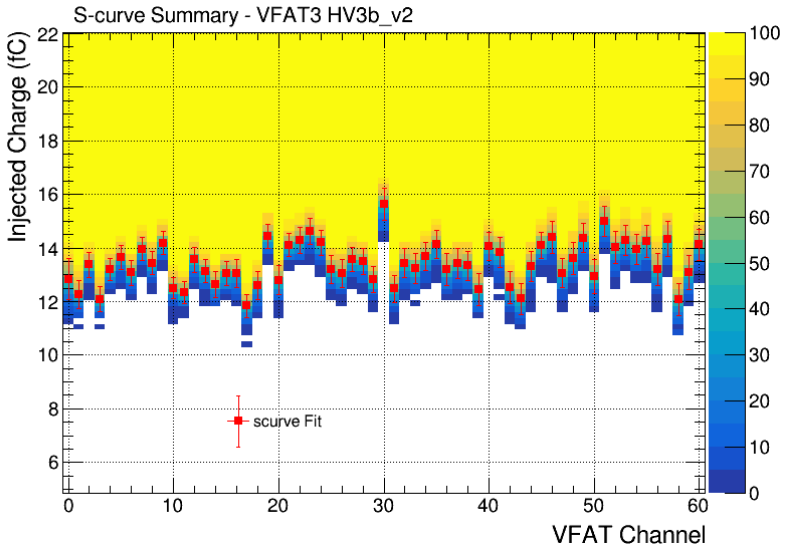
- DCS and DAQ
  - Connectivity tests and full chain validation
  - Electronics test
- Detectors
  - Power ON

Phase II – Tests utilizing central infrastructures → Fall 2019/Beginning 2020

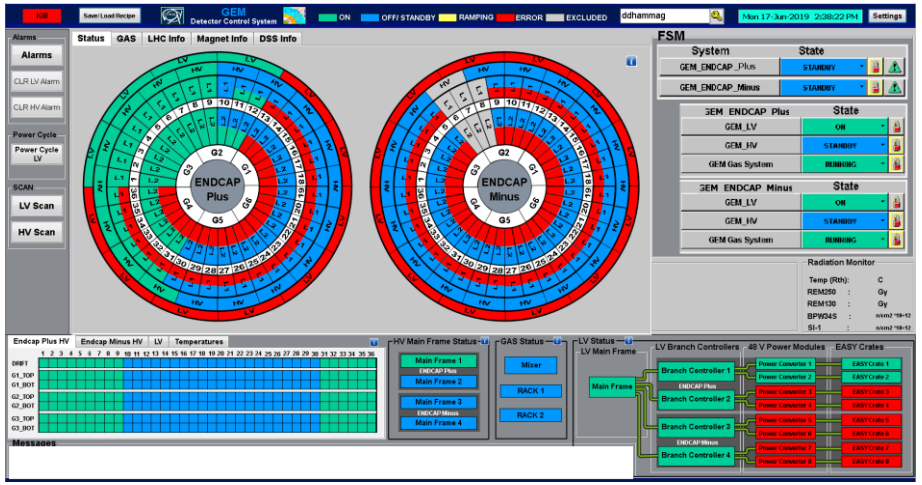
- Detectors Working point definition
- First runs with trigger from the rest of the CMS muon system

Phase III – Final integration in CMS → Summer 2020

- Integration in central DCS and central DAQ



Example of scurve with VFAT3



New GE1/1 DCS panel

Summary

The GE1/1 station is planned to be installed in the CMS muon system during this long shutdown:

- An intense ***R&D*** lead, in the past few years, to the contruction of robust detectors, with high performance matching the CMS requests
- A first ***demonstrator***, called Slice-Test, was installed in 2017 in the CMS endcap and reached the goal of full integration into the CMS system.
- The ***assembly*** and qualification of the 144 Triple-GEM detectors needed for the GE1/1 station is completed
- The assembly of ***superchambers*** and the final qualification with cosmics is ongoing and planned to be completed by the end of 2019
- The ***installation*** of the negative GE1/1 endcap is planned for fall 2019, while the positive one for spring 2020
- The ***commissioning*** will lead, by summer 2020, to the full inclusion of the GE1/1 system into CMS.

Thanks!