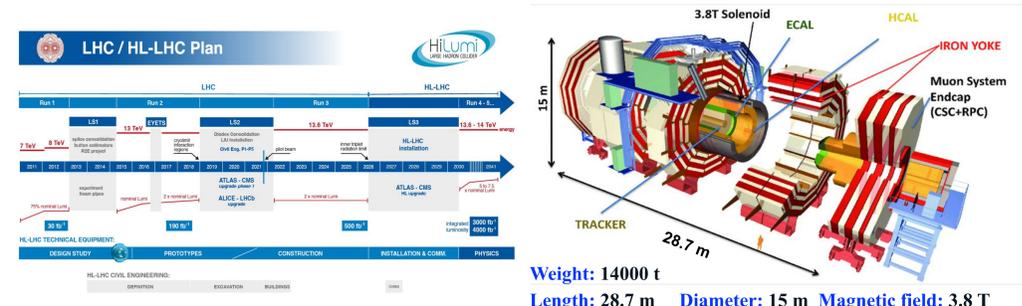


The upgrade of the CMS muon system with Triple-GEM detectors

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1. The CMS Experiment & High Luminosity LHC programme

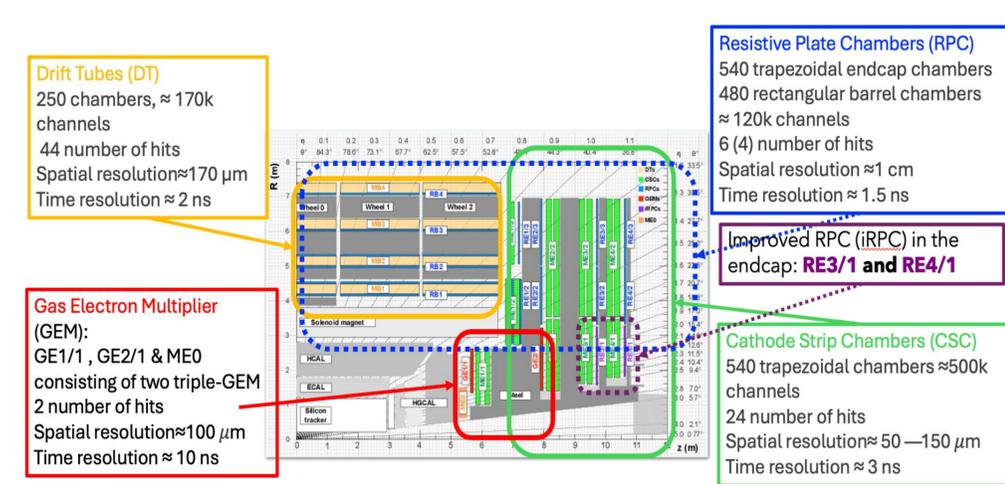


Future increase of instantaneous luminosity up to 5-7.5 times the design luminosity of the LHC ($5 - 7.5 \cdot 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$)

CMS detector must be upgraded to cope with HL-LHC

Some of these upgrades were done in Long Shutdown 2 (LS2), while the rest of the upgrades will be carried out during during LS3.

2. The CMS Muon Spectrometer (Phase 2)



3. The CMS GEM Project

Three Triple-GEM based stations:

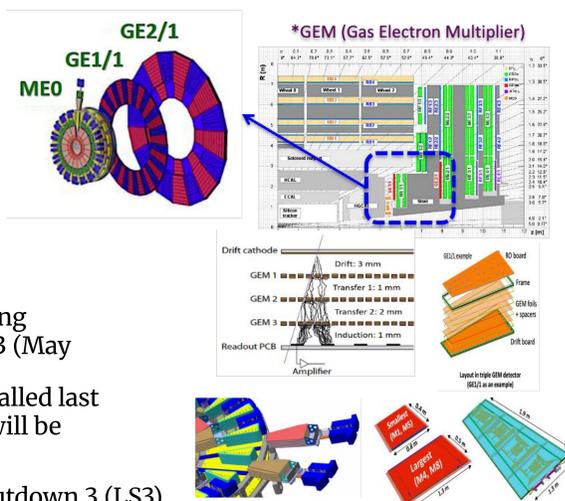
- GE1/1 in region $1.5 < |\eta| < 2.2$,
- GE2/1 in region $1.62 < |\eta| < 2.43$,
- ME0 in region $2.0 < |\eta| < 2.8$

They are partly overlapped in η in order to avoid gaps and increase redundancy!

GE1/1 was installed (2019/20) & is taking Data since the beginning of LHC-Run3 (May 2022).

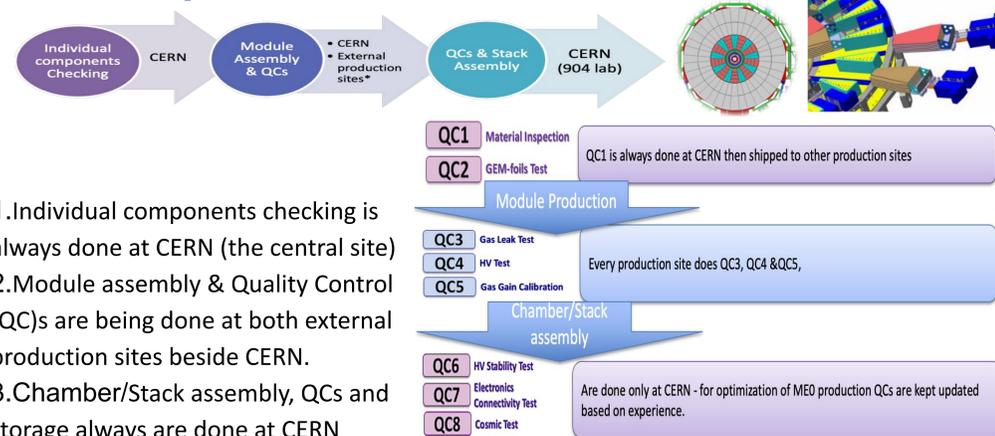
Some GE2/1 Chambers have been installed last Year-End Technical Stop (YETS) and will be completed after 2030

ME0 will be installed during Long Shutdown 3 (LS3) that will start in July 2026.



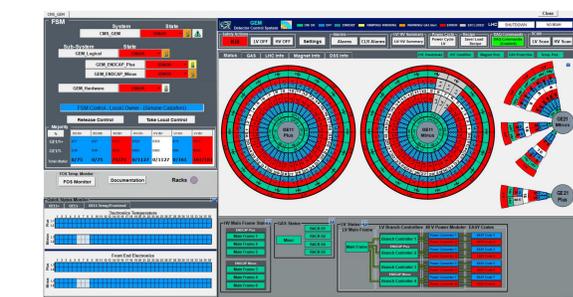
4. GEM Production and Quality Control process

Production Sequences is the same for GE1/1, GE2/1 & ME0

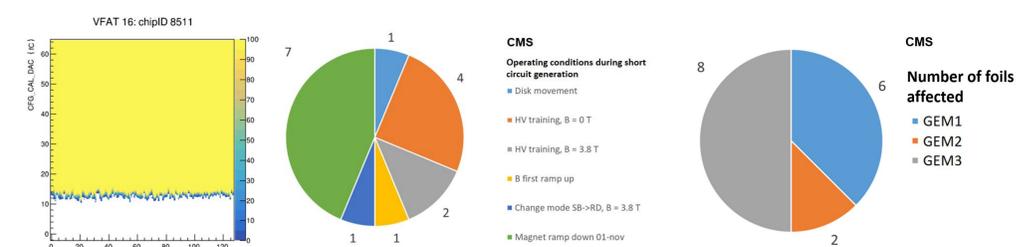


1. Individual components checking is always done at CERN (the central site)
2. Module assembly & Quality Control (QC's) are being done at both external production sites beside CERN.
3. Chamber/Stack assembly, QC's and storage always are done at CERN

5. Commissioning of GEM in CMS



- Deployment and testing of GEM detector control system (DCS)
- Testing of HV and LV power systems
- Electronics calibration scans
- Operations in magnetic field: observed instabilities



6. The GEM Low-Voltage Power System LV PS

Is crucial for the GEM On-detector electronics (VFAT3, Opto-Hybrid (OH), ..)

Instead of building new independent LV PS for GE2/1 and ME0, we plan to extend the current LV power system of GE1/1 by adding extra modules to power GE2/1 and ME0 chambers.

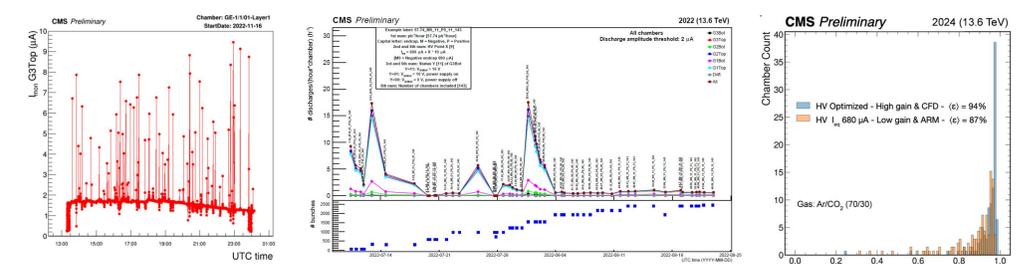
The LV power system of GEM are based on CAEN commercial modules with some modifications to adapt the GEM detectors requirements.



The modules of LV system of GEM are distributed between Underground Services and Experimental Caverns (USC, UXC) of CMS experiment.

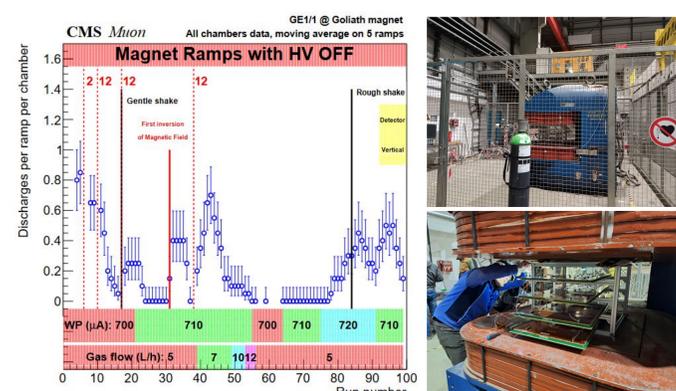
Before installation in CMS cavern, all LV-modules are undergoing some tests in lab to verify the required specifications

7. GEM Operations in CMS during the data taking



- Observation and mitigation of discharge rate in presence of LHC beam collisions
- Study of generation of short circuits in GEM foils
- Optimization of detectors' efficiency (HV scan)

8. Tests on detectors to improve the data-taking



- Feedback from GEM operations to production and development
 - Series of tests of GEM detectors in magnetic field in CERN North Area
 - Special data taking runs in CMS to simulate presence of short circuits

References:
[1] M. Abbas et al., Quality control of mass-produced GEM detectors for the CMS GE1/1 muon upgrade, Nucl. Instrum. Meth. A 1034 (2022), p. 166716. doi:10.1016/j.nima.2022.166716.
[2] M. Abbas et al., Impact of magnetic field on the stability of the CMS GE1/1 GEM detector operation, JINST 18 (2023), p. 11029. doi:10.1088/1748-0221/18/11/P11029.
[3] M. Abbas et al., Study on discharge and short circuit generation in CMS GE1/1 triple-GEM detectors during Run 3, JINST 20 (2025), p. P05035. doi:10.1088/1748-0221/20/05/P05035.