Status of the GEM GE2/1 Detectors for the CMS Endcap Muon System

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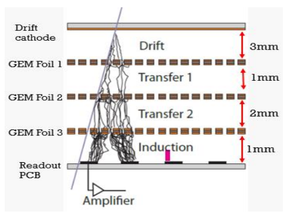
Abstract

The Large Hadron Collider (LHC) upgrade will increase the instantaneous luminosity and deliver it in the range of 5 x 10^{34} cm^{-2} s^{-1} to 7 x 10^{34} cm^{-2} s^{-1}, up to 7 times higher than the nominal value. The most forward regions of the Compact Muon Solenoid (CMS) detector will face significant challenges due to this high luminosity. The muon system of the CMS experiment sets forth enhancement of the forward muon system by introducing the new GEM stations (GE1/1, GE2/1, ME0) in order to improve the tracking and trigger capabilities in this challenging forward region in the presence of high particle fluxes. The pseudorapidity range covered by the GE2/1 detector is 1.6 to 2.4. The successful experience of GE1/1 served as the foundation for the basic design and the production plan for the GE2/1 station. A number of significant improvements have been made to the detector to extend its lifespan, reduce the spread of discharge, and stop crosstalk when heavy ionising particles are present. To ensure optimal coverage and avoid having gaps, GE2/1 chambers are split up into 8 distinct types of modules. Modules M1 to M4 form one back chamber, whereas chambers M5 to M8 build the front chamber. There are 18 GE2/1 super chambers per endcap, each of which is made of two chambers that contain four modules each. Prior to being built as chambers and deployed in the YETS 2023 and (E)YETS 2024, a few of the triple-GEM modules have to be fabricated, qualified, and validated for optimal detector performance. We present an overview of the GEM GE2/1 detector's status in this poster.

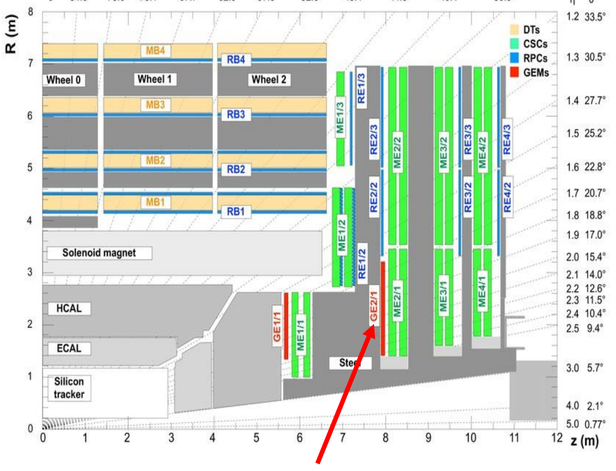
Introduction of GE2/1 Detectors

- For full system 72 GE2/1 chambers. 36 chambers per endcap organized in two layers of 18 super chambers (Total modules 288).
- To prevent dead zones from overlapping, two distinct types of chambers will be arranged in two layers.
- The GE2/1 chamber consists of four modules (either M1, M2, M3, M4 or M5, M6, M7, M8.
- On-Yoke = Front type (M5-M8
- Off-Yoke = Back type (M1-M4)

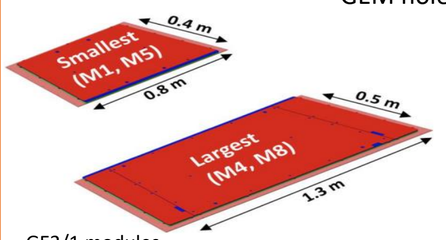
❖ GE2/1 detector technology is same as GE1/1



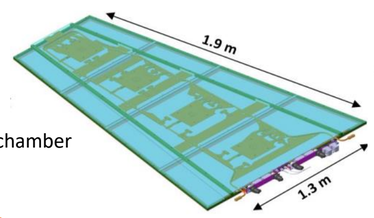
GEM holes



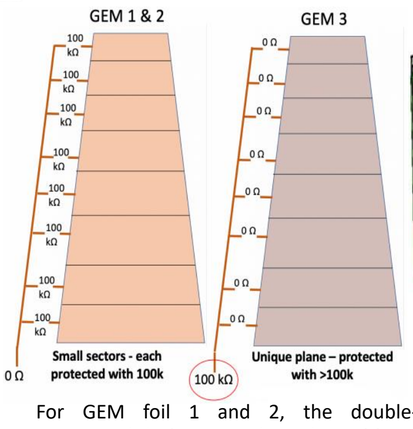
One of the quadrant of the CMS detector. The proposed locations for the GE2/1 detectors in the inner endcap station.



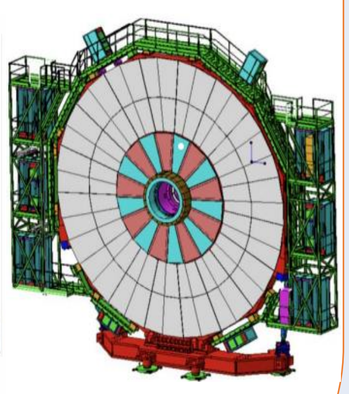
GE2/1 modules



GE2/1 chamber



For GEM foil 1 and 2, the double-segmented design was adopted to mitigate the discharge propagation; for GEM 3 bottom, the single-segmented design was employed to eliminate the crosstalk effect.



Pseudorapidity coverage: 1.62 < |η| < 2.43

Status of GE2/1 Foils, PCBs & Electronics

❖ Two GE2/1 Foil Producers

- MPT workshop (CERN)
- KCMS/Mecaro (KR) produced 296 foils of different module types, including M2, M3, M6, and M7. At this site, GE2/1 production has now stopped.

Foil types for module	Produced foils	Produced readout boards	Produced drift boards
M1	106	10	10
M2	99	10	10
M3	66	10	10
M4	95	10	10
M5	130	20	20
M6	70	20	20
M7	89	20	20
M8	87	20	20

❖ Production Foil and PCBs Status

- For each module M1 to M8, 108 foils are required.
- For each module M1 to M8, 36 readout and 36 drift boards are required.

❖ Production Scheme of GE2/1

QC of individual components — At CERN (Central site)
Module assembly and QC2 to QC5 — At Production sites PKU(China), Ghent (Belgium) Aachen (Germany), Frascati (Italy), Bari (Italy), PU (Chandigarh), DU(Delhi) and CERN
Chamber assembly + QC6 to QC8 + Storage — At CERN (Central site)

❖ GEB (GEM Electronics Board)

- The GEB is a printed circuit board (PCB) designed to host VFAT3s connected to the 12 sectors of the GEM ROB. It routes signals to the Opto-Hybrid (OH), distributes power to the chips, and provides electric shielding to the detector.

GEB

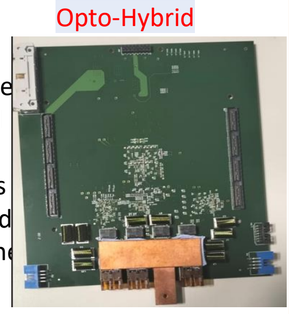
❖ VFAT plug-in card

- VFAT3 ASIC is a binary front-end chip optimized for gaseous detectors whose function is to digitize the analog signals coming from the detector and provide fast trigger and tracking data.

VFAT

❖ OH(Opto-Hybrid) board

- The Opto-hybrid (OH) is located in the middle of the chamber ROB and plugged into dedicated connectors on the GEB. The OH acts as the concentrator board and communication relay for the 12 VFAT3 ASICs.



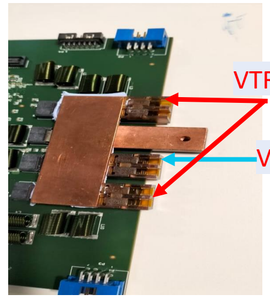
Opto-Hybrid

❖ VTRx & VTTx

- These are attached with the OH board

❖ FEAST

- It distributed the low voltage to the electronics as per their operating voltage.



Detector Components	GEM electronic board	VFAT plug-in card	Opto-Hybrid	FEAST	VTRx	VTTx
Required	288	3456	288	1440	576	288
Produced	336		361	1600	722	361
% Produced	Completed	77%	Completed	Completed	Completed	Completed

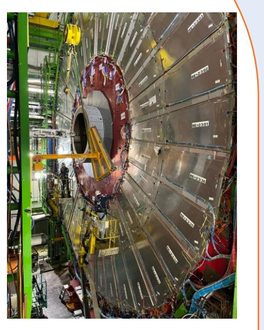
FEAST

Status of GE2/1 Module Assembly

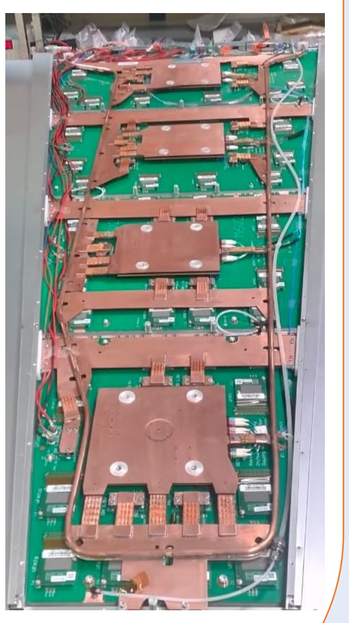
- A total of 98 modules out of 288 are already produced at various production sites.
- A crucial problem of the PCBs (readout and drift boards), lack of passivation was found. Therefore, all 98 of these modules need retrofitting..
- The PCBs are being cleaned and passivated at the CERN MPT workshop. New PCBs with passivation are produced by the Micropack company.
- The full retrofitting process of all these modules and further QC will last between 0.8-1.3 years.
- Till now, 23 modules have been assembled (8 retrofitted + 15 new), of which 21 have passed the QC test.

GE2/1 Chamber Assembly

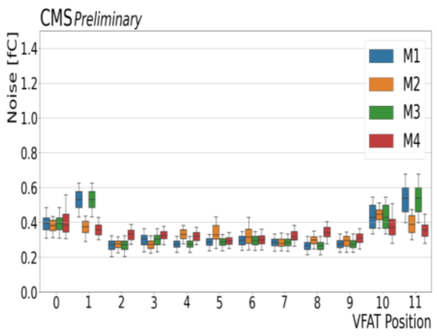
- Four modules are put together to build a chamber.
- Gas pipes and cooling circuits are then installed.
- The readout and temperature-sensing fiber optic sensor (FOS) are then routed.
- Powering cables (high and low voltage) are routed as well.
- Till now, a total of four front chambers have been assembled and are under cosmic test.
- A GE2/1 demonstrator was installed in November 2021 at P5 in the positive endcap with final electronics to check the optimal performance of the detector in the actual radiation background. This should also help to configure the desired update in DAQ, DCS, and DSS.

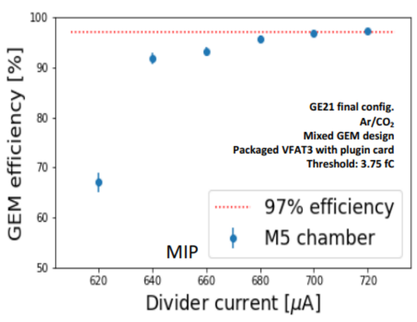


GE2/1 Demonstrator installation at P5



Cooling circuit

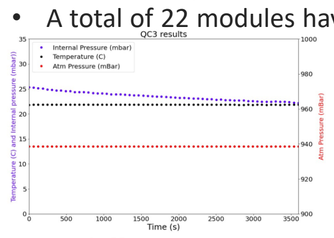




Quality Control Status & Plan at CMS P5

❖ QC3 (Gas Leakage Test):

- The QC3 monitors the pressure drop with the function of time. For CMS pressure drop 7 mbar/h is acceptable.
- A total of 22 modules have passed this test.

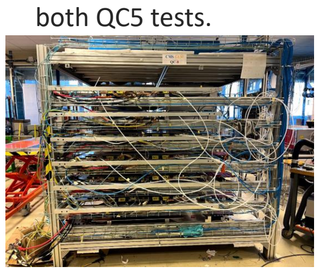


❖ QC5-A (Effective Gain Measurement):

- This test is performed in the presence of Ar:CO_2 in a ratio of 70:30 to measure the effective gain of the detector.
- Nominal gain is up to 10^4 at 700 µA current.

❖ QC5-B (Gain Uniformity Measurement):

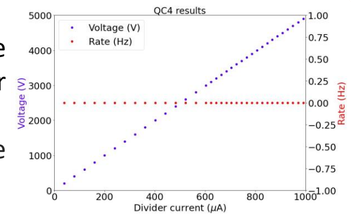
- This test is performed to measure the gain response uniformity throughout the entire module using the SRS-APV25 system.
- Source: Mini X-ray of energy at 22 keV.
- A total of 21 GE2/1 modules have passed both QC5 tests.



Cosmic Stand

❖ QC4 (High Voltage Test):

- This test is performed to see the stability of the detector with high voltage applied
- 21 modules of GE2/1 have passed QC4 test.



❖ QC6 (High Voltage Stability Test):

- A total of 18 GE2/1 modules have passed QC6 test.
- This test ensures the stability of the high voltage and prepares these GE2/1 modules for further electronics connectivity tests (QC7).

❖ QC7 (Electronics Validation Test):

- This test is performed to calibrate and validate the front-end electronics.
- To identify broken components, fix communication failures, and ensure that the number of bad (dead/disconnected/noisy) channels/strips per ETA partition is ≤ 3.
- This test is performed at module and chamber levels.
- A total of 18 GE2/1 front modules have passed QC7 test. The four front chambers have been built from these modules.

❖ QC8 (Cosmic Test):

- This test ensures the optimal efficiency of GE2/1 chambers in the cosmic ray environment.
- The horizontal cosmic stand can be equipped with seven chambers at a time.
- The two best validated GE2/1 chambers will be installed in January 2024 in the negative endcap of the CMS experiment.
- The remaining GE 2/1 chambers will be installed during YETS 2024–2025 and after long shutdown 3 (LS3).

Long tern Plan for GE2/1 (No overlap with ME0, ME0 disk-1 and disk-2 completed at the beginning of 2027)

2026	2027-2028	2029	2030
ME0 Production	GE2/1 module production complete	GE2/1 disk-1 completed at the beginning of 2029	GE2/1 disk-2 completed at the beginning of 2030

Summary

- Two GE2/1 chambers will be installed in January 2024 in the negative endcap of the CMS experiment.
- ME0 R&D is completed and its mass production will begin soon.
- ME0 installation is priority, hence GE2/1 project will be delayed until 2027 .

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[1] CMS Collaboration, The Phase-2 Upgrade of the CMS Muon Detectors: Technical Design Report, CERN-LHCC-2017-012, CMS-TDR-016, (2017).
[2]] Jeremie MERLIN, 2022 P2UG Review, GE2/1 Demonstrator and Production Status, Nov 18th 2022.