First performance of Triple-GEM detectors in the CMS muon system with cosmic rays and LHC collisions

CPAD 2022 Workshop

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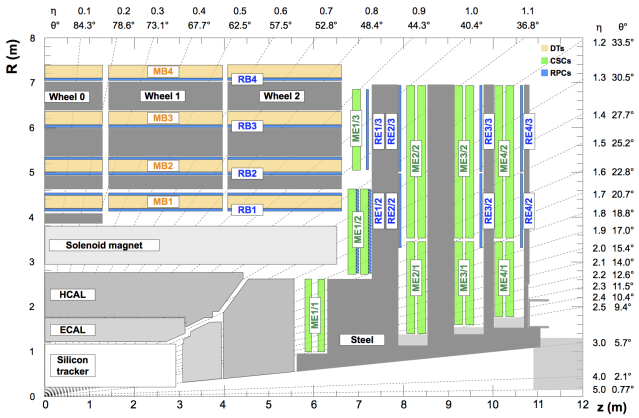
CMS Muon System



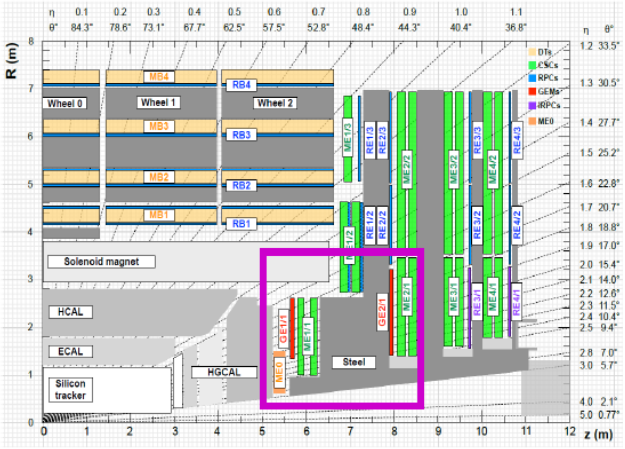
Goal

Muon identification, momentum measurement and muon trigger

Gaseous detectors technologies

- Drift Tubes (DT)
- Cathode Strip Chambers (CSC)
- Resistive Plate Chambers (RPC)

CMS Muon System Ugrade



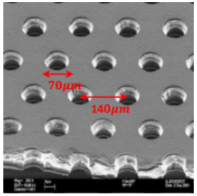
HL-LHC → New muon stations to:

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

Gaseous detectors technologies

- Drift Tubes (DT)
- Cathode Strip Chambers (CSC)
- Resistive Plate Chambers (RPC)
- Triple-Gas Electron Multiplier (GEM)

Gas Electron Multipliers

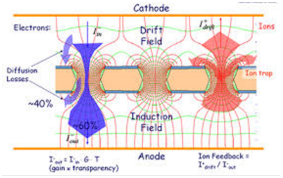


GEM foil:

- 50 μm-thick polyimide foil copper-cladded on both sides
- Holes in hexagonal pattern, with 70 μm diameter and 140 μm pitch

Functioning criterion:

- Ionization happens in the drift region ($E_d \sim$ *few* kV/cm)
- Electrons move towards the GEM holes → inside the holes the electric field is much more intense ($E_d \sim$ *few* $10\,kV/cm$) → amplification region
- Amplified electrons move towards the anode, while the ions go back



https://sal.aalto.fi/publications/pdf-files/twar15_public.pdf

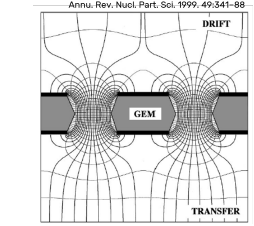
Gas Electron Multipliers

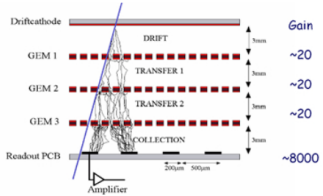
Pros:

- The amplification is localized inside the holes → rate capability up to O(MHz/cm^2)
- GEM foils can be used in cascade to reach higher gains at lower voltages
- Recent studies also prove very high resistance to radiation → up to ∼C/cm^2
- Very good space resolution can be achieved with appropriate readout segmentation → 150 μm

Cons:

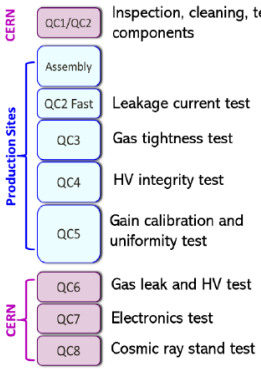
- Discharges can damage the electrodes

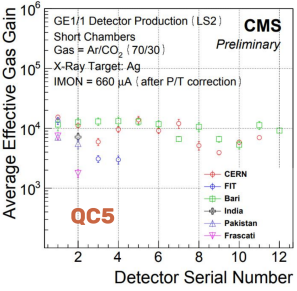


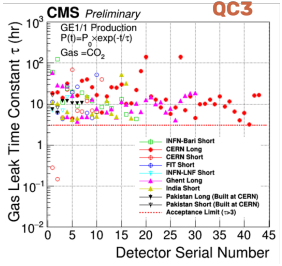


Qualification and production of the GE1/1 station

Production and qualification effort shared between CERN and different GEM institutes







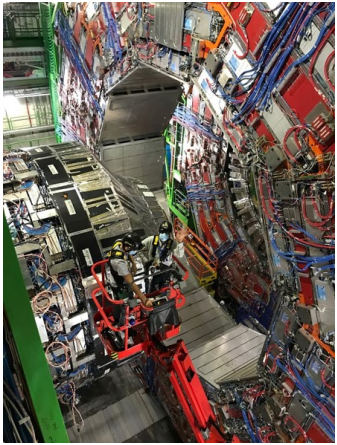
GE1/1 in CMS

GE1/1 project

- 144 Trapezoidal Chambers → coupled in 72 superchambers (36 per endcap), each spans ∼10°
- Long and Short superchambers alternate to maximize the η coverage

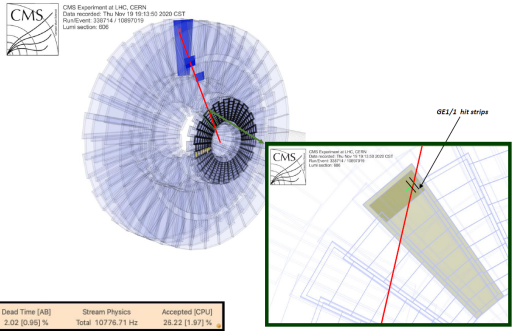
Installation in CMS

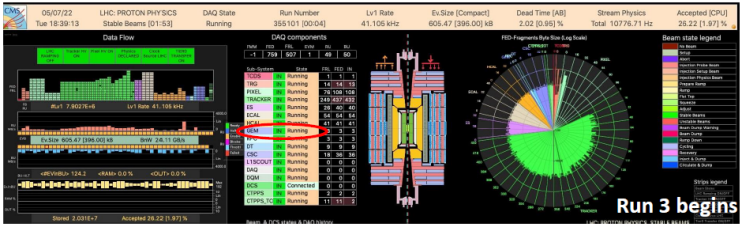
- Negative Endcap: completed in Oct. 2019
- Positive Endcap: completed in Sept. 2020



GE1/1 commissioning

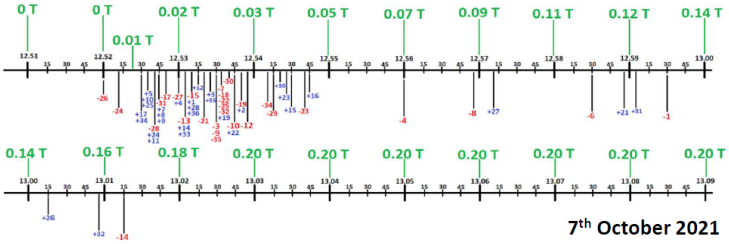
- Integration of GE1 /1 systems in central CMS completed
- Successfully participated in cosmic runs
- In October 2021, first experience with test collisions and magnetic field
- Participating in LHC Run 3: stable beam collisions $\sqrt{s} = 13.6$ TeV





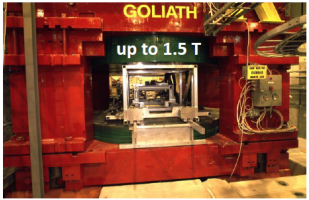
Operation in magnetic field

- Starting October 2021, GE1/1 operated during the CMS magnet commissioning.
- Multiple HV trips detected (red and blue numbers indicate a chamber trip).
  - Trips are induced by discharges, which generate transient short circuits
  - Some of them can lead to a permanent short circuit in one of the HV partition of a GEM foil.
- GE1/1 chambers HV trips correlated with magnet ramp.



Goliath test - 1

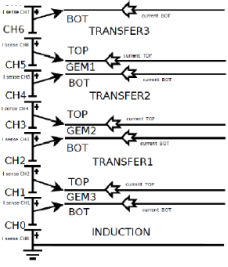
GE1/1 detectors tested in a controllable magnetic field environment: CERN North Area, Goliath magnet.



E-EPC-HPC https://sy-dep-epc-hpc.web.cern.ch/spectrometers/Goliath/general.stm

Goals

- Study of detector response to magnet ramps;
- Define safe procedures for GE1/1 during CMS magnet ramp
- Spare production chambers under test.
- The 7 gem electrodes powered as a “stack”:
  - A single channel exceeding drained current threshold, causes all channels to trip;
- Continuous monitoring HV and magnetic field.
- Several magnet ramps, of both signs.



https://www.caen.it/products/a1515b/

Goliath test - 2

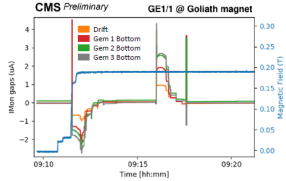
Observation

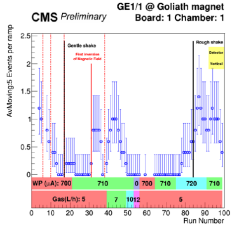
- Electrode trips correlated in time with the magnet ramps
- HV instability persists even after the magnet ramp
- Average number of trips per ramp decreases with time
- Mechanical stress, as in CMS during disk movements, increases the trip rate.

Possible explanations

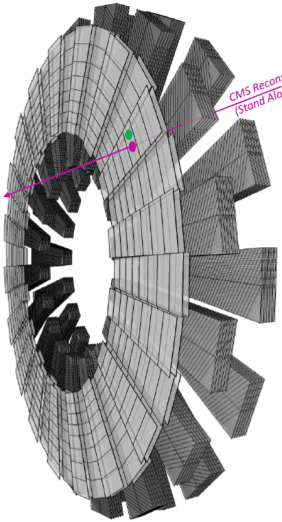
- Microscopic dust particles O(10μm), moved by the magnetic field, cause a discharge in the foil
- The dust particle that originates the spark gets burned during the discharge.

Propagated safety procedure to operation team.





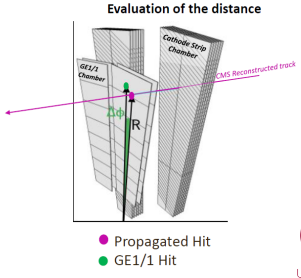
Muon reconstruction - 1



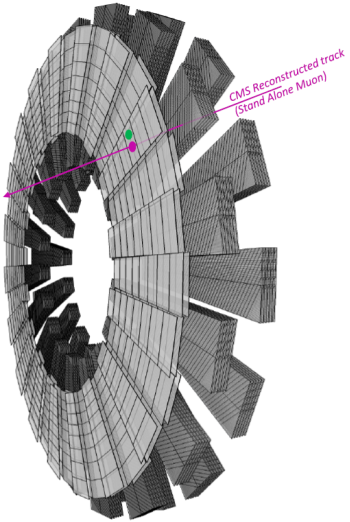
CMS reconstructed tracks are used as a reference to probe GE1/1 performance.

Basic Idea

track propagation on GE1/1 surface to be used as *expected position* to match a GEM hit.



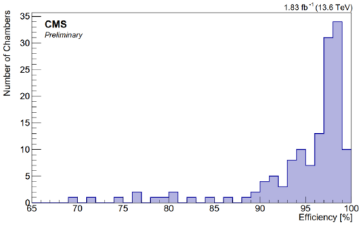
Muon reconstruction - 2

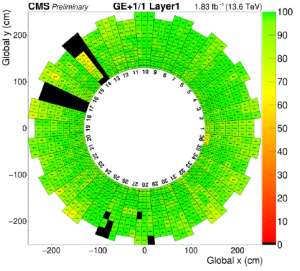


- Muon tracks reconstructed by the CMS muon system (stand alone muons) selection:
  - $p_T > 20$ GeV;
  - At least one segment in ME1/1;
  - χ^2 in range [0.5,2];
  - Track propagation intersects GE1/1 fiducial region;
  - Muon dataset from Z boson decay;
- Search for best GEM hit to match the muon track, with $|R\Delta\phi|<5$
- GEM reco hits have cluster size and hit multiplicity as expected from MC.

First efficiency results

- Efficiency distribution of 140/144 GE1/1 chambers
  - Chambers and front end chips in error at the time of data taking have been excluded from the calculation
- GE1/1 detection efficiency with front end chip granularity
  - Evaluated efficiencies lower than 90% are attributed to:
    - chambers underperforming due to a short circuit in at least one GEM foil;
    - suboptimal HV working point for some of the chambers

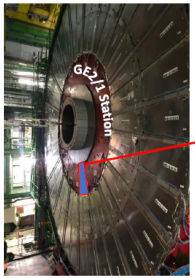


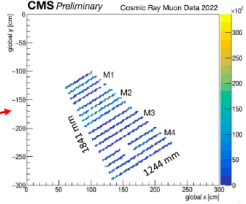


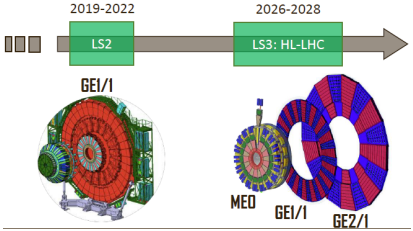
The future: GE2/1 and ME0

GE2/1 and ME0 stations

- GE2/1:
  - Mass production started;
  - Demonstrator chamber installed, included in data taking;
- ME0:
  - High background rate expected in O(100 kHz/cm^2)
  - Final design optimization for the harsh environment.







Summary

- Triple-GEM is the new detection technology adopted for the CMS muon stations GE1/1, GE2/1 and ME0.
- GE1/1 station was installed in during the Long Shutdown 2.
- Currently under commissioning:
  - Operational experience of large size Triple-GEM detectors in magnetic field;
  - High granularity efficiency measured, fine tuning of the working point ongoing;
  - Track-based alignment ongoing, mandatory for triggering on muon.
- GE2/1 and ME0 stations will be installed during the Long Shutdown 3.