GE1/1 station of the CMS muon detector: Status, Commissioning and Operation in magnetic field

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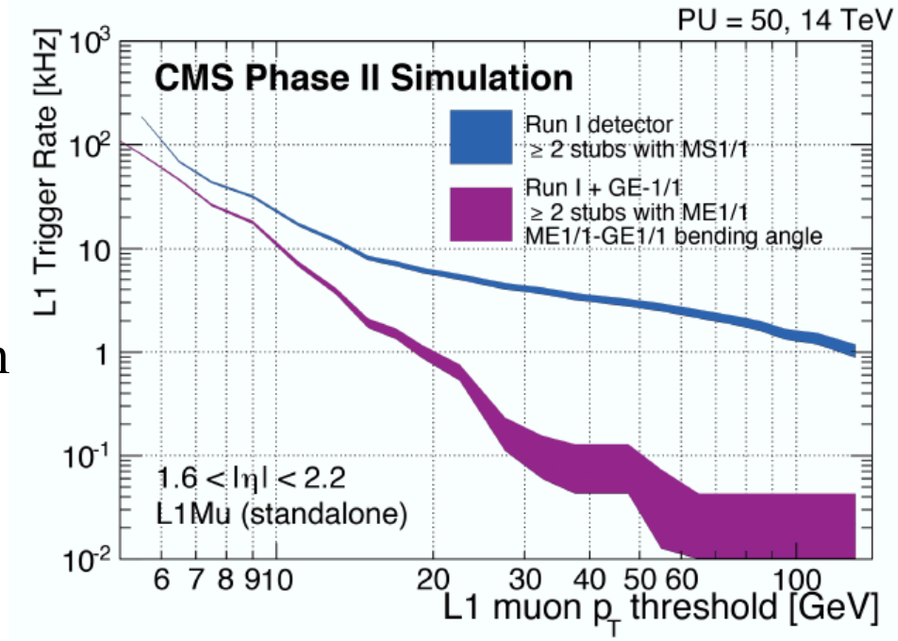
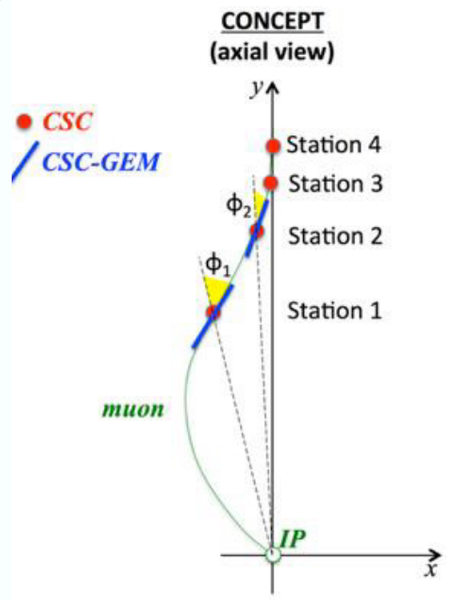
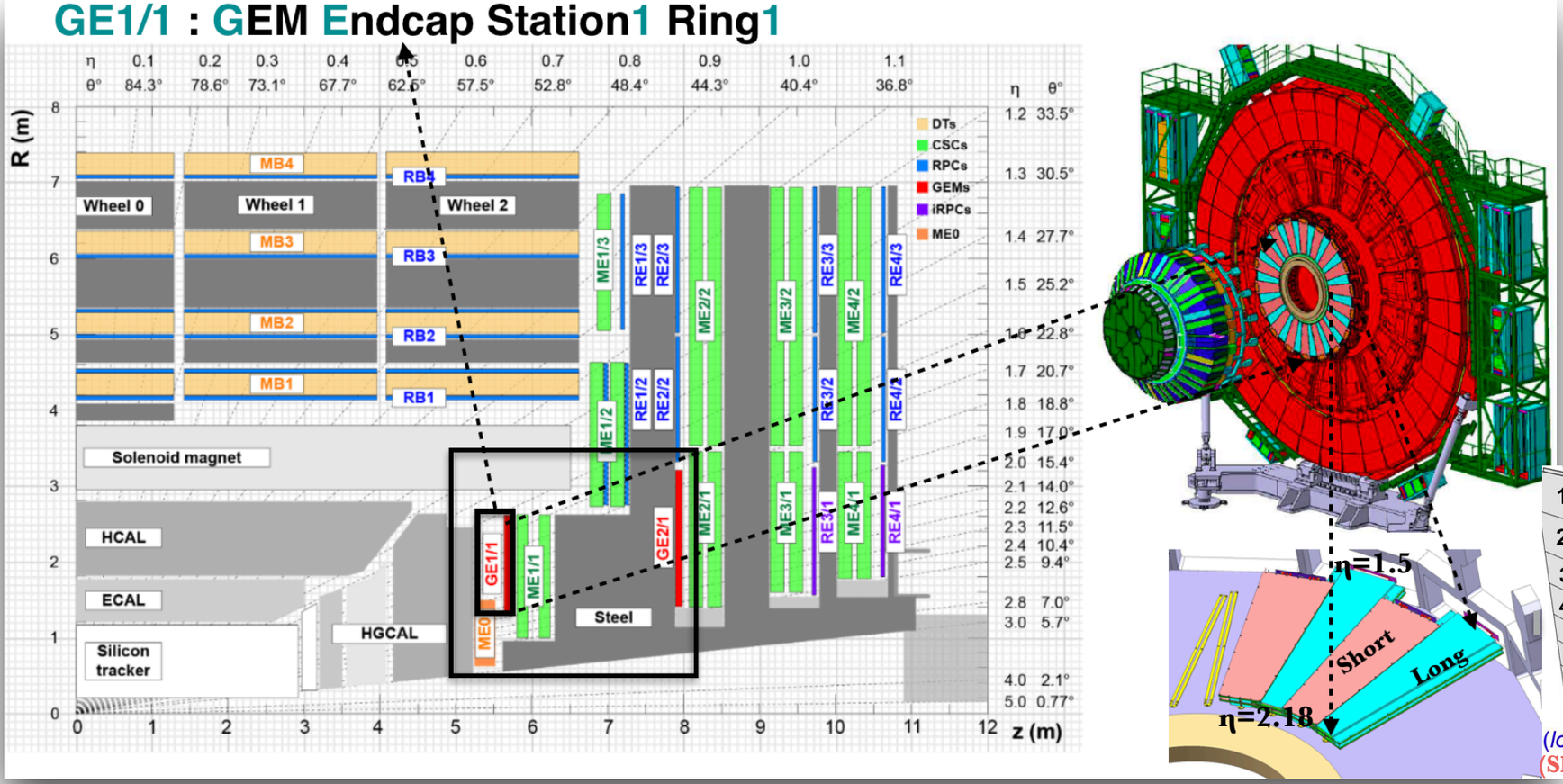
On behalf of the CMS Collaboration

The CMS Phase-I muon endcap upgrade : GE1/1

- To maintain the high level performance in HL-LHC environment, the CMS muon system is being upgraded
  - to increase the muon spectrometer redundancy, to sustain the high radiation in the endcap region
  - GEM+CSC allow for muon momentum measurement in a single station, which helps reduce considerably L1 trigger rate





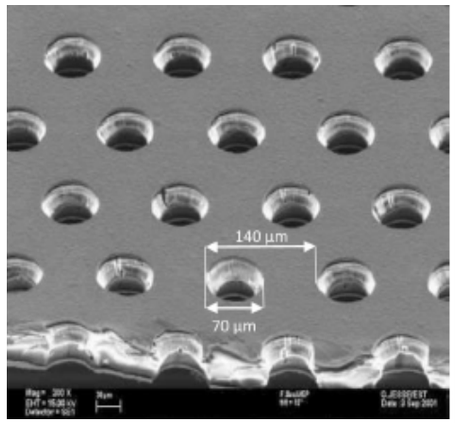


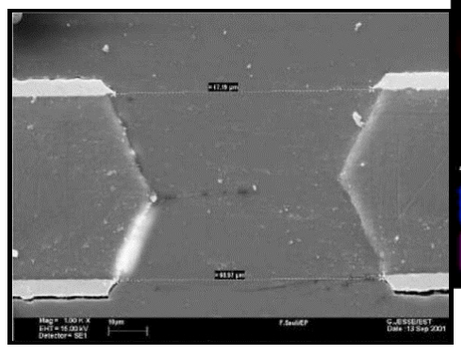
- **144 triple GEM detectors** :
  - coverage1.55 < |η| < 2.18
  - Each super-chamber, consisting of two triple-GEM detectors referred to as layer 1 and layer 2
  - 36 ”super-chambers” per endcap covering 10.15° in φ
  - short and long chambers for maximum coverage
  - segmented with 8η partitions. Each η partition has 384 radial strips

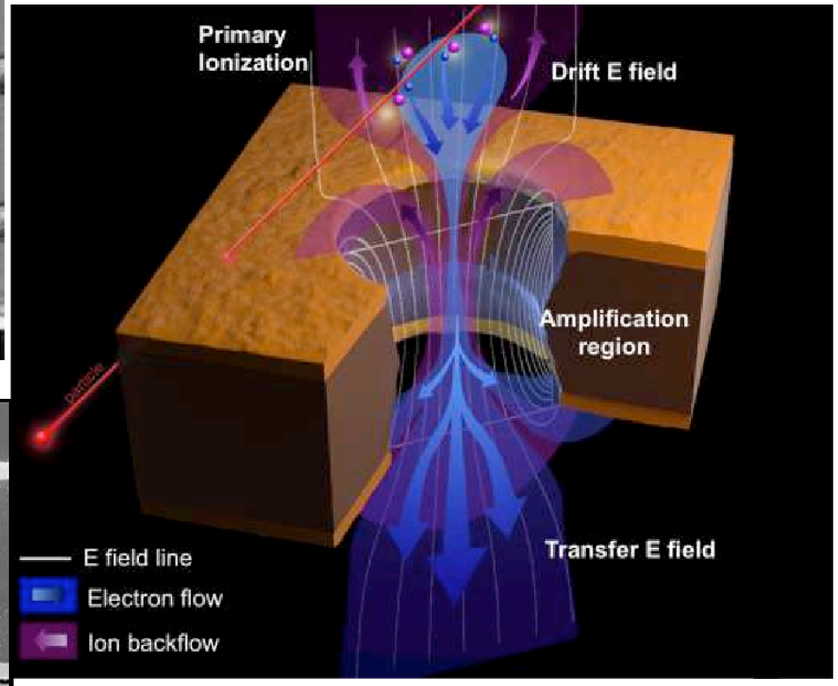
- CMS Technical Design Report for the Muon Endcap GEM Upgrade, CERN-LHCC-2015-012

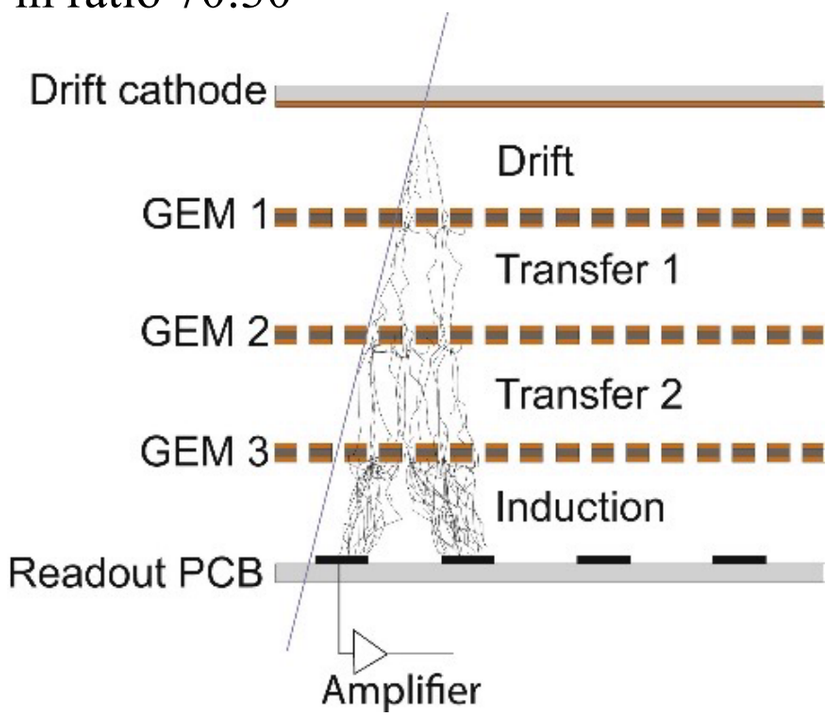
The GEM Technology

- Relies on the triple-GEM structure
- Thin, metal-coated polymer foil with high density of holes
  - insulating layer with conductors on top and bottom
  - 3 main processes : Ionization, amplification and induction.
- Cascaded GEMs allow much larger gains before discharge
- Gas gap configuration is 3/1/2/1 mm for drift, two transfer & induction gap
- Gas : $Ar/C0_2$ in ratio 70:30









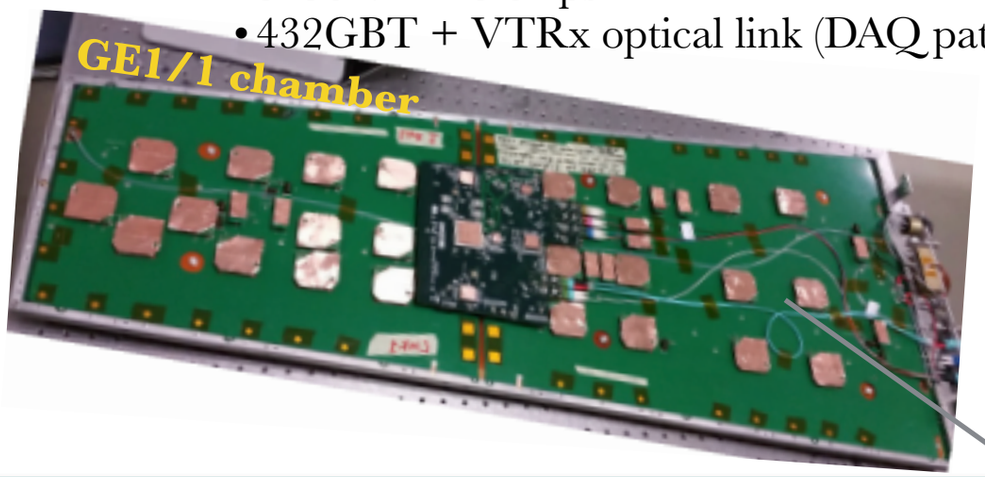
- Key features :
  - High rate capability, up to O(MHz/cm^2)
  - robustness against aging.
  - Efficiency > 98%
  - Space (time) resolution ≈ 300 µm (8ns)

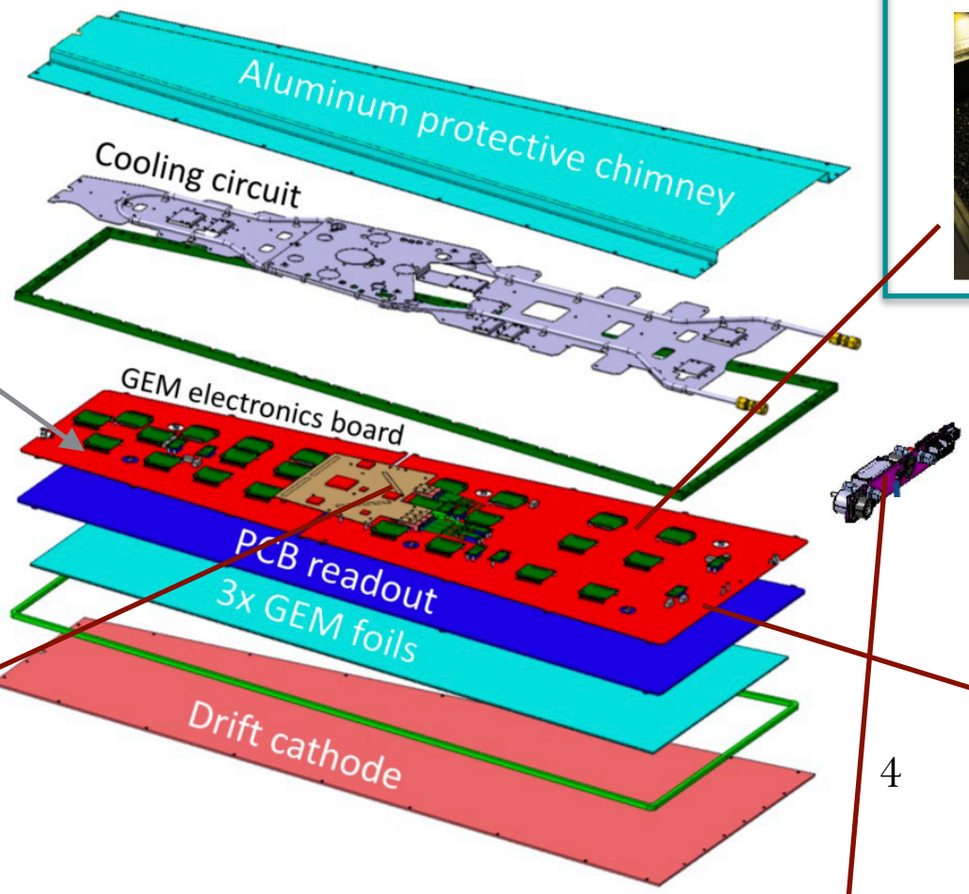
- CMS Technical Design Report for the Muon Endcap GEM Upgrade, CERN-LHCC-2015-012

GE1/1 Readout electronics

GE1/1 system

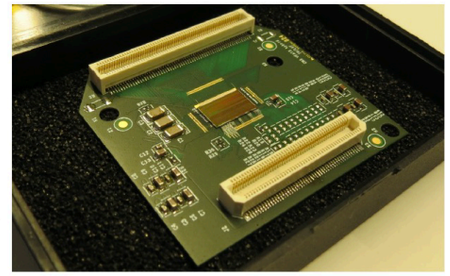
- 72Super-Chambers (SC)
- 3456 VFAT3 chips
- 432GBT + VTRx optical link (DAQ path)





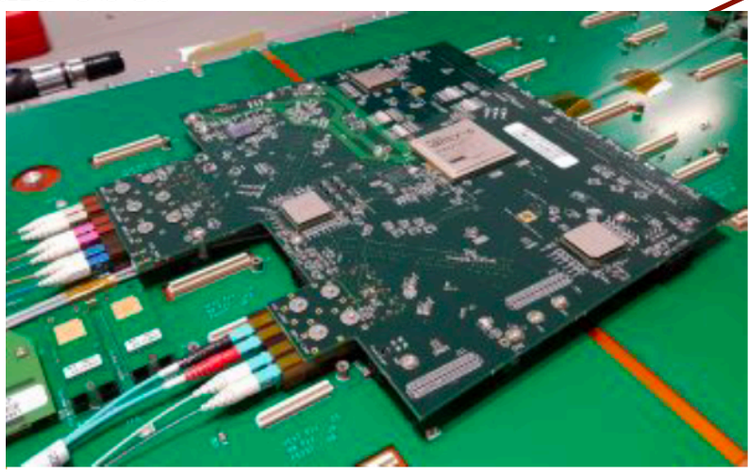
VFAT frontend chip

- 24 VFAT3/chamber
- 128 channels/chip
- Binary readout
- Tracking + Trigger data



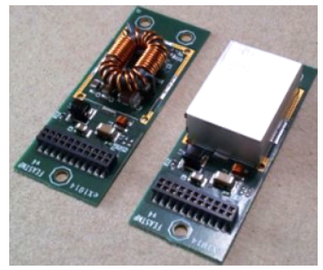
Optohybrid

- Communicate between the VFAT and the backend electronics via GigaBits transceivers(GBTs)
- Send slow control commands to the frontend electronics
- Transfers tracking and trigger data to backend and CSCs

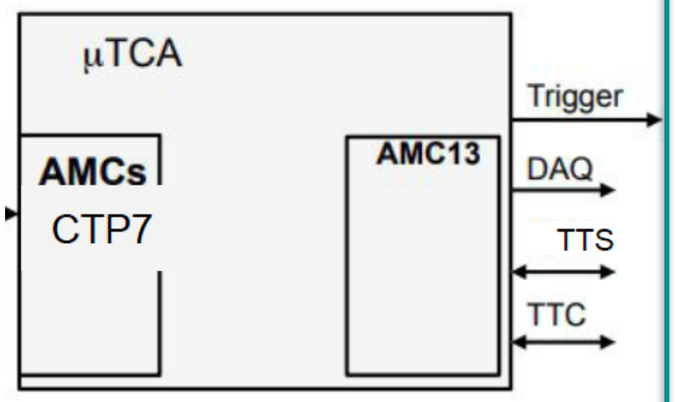


Feast

- DC converter
- LV, VFAT3 &OH

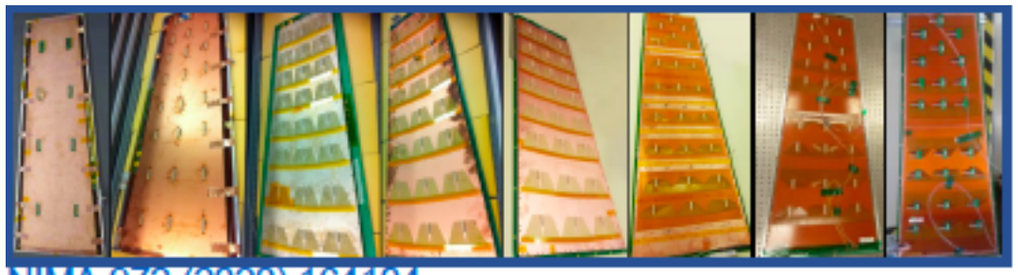


Backend



- VFAT3: A Trigger and Tracking Front-end ASIC for the Binary Readout of Gaseous and Silicon Sensors
- A micro-TCA based data acquisition system for the Triple-GEM CMS detectors

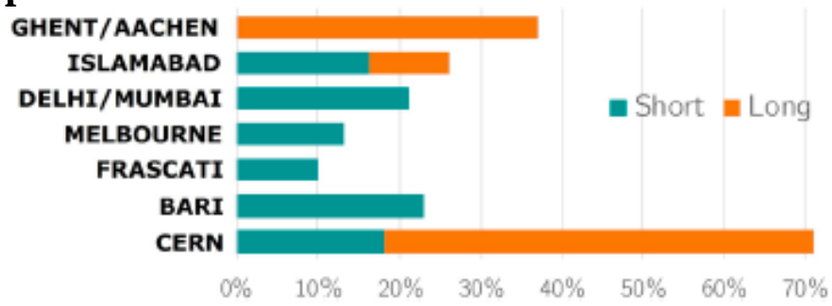
The GE1/1 Project



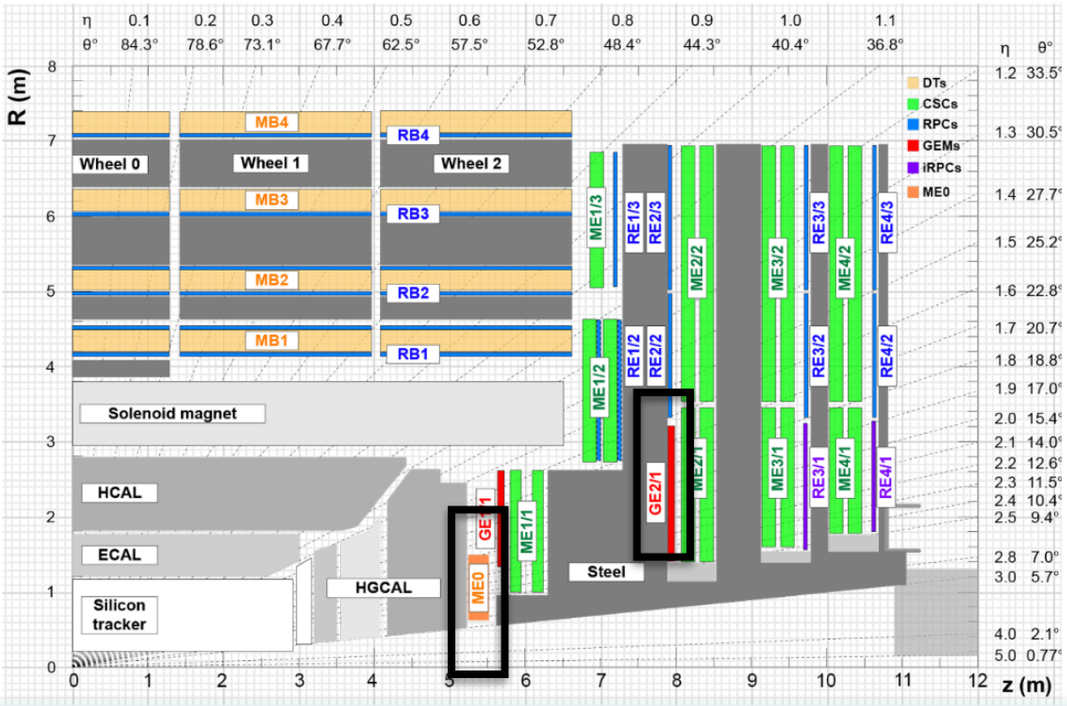
NIMA 972 (2020) 164104

2009

- Birth of GE11 Project
- GE11 proto. I
- GE11 proto. II
- GE11 proto. III Mechanical stretching
- GE11 proto. IV
- GE11 proto. V
- GE11 proto. VI-VII
- DAQ/ electronics Prototype
- Slice test Installation commissioning 2017
- Oct 2017 Detector Mass Production
- Super Chamber Production Dec 2018
- Jul-Oct 2019 GE-1/1 Installed
- GE+1/1 Installed Jul-Sept 2020
- 2021 Commissioning Phase
- 2022



Exciting next few months!

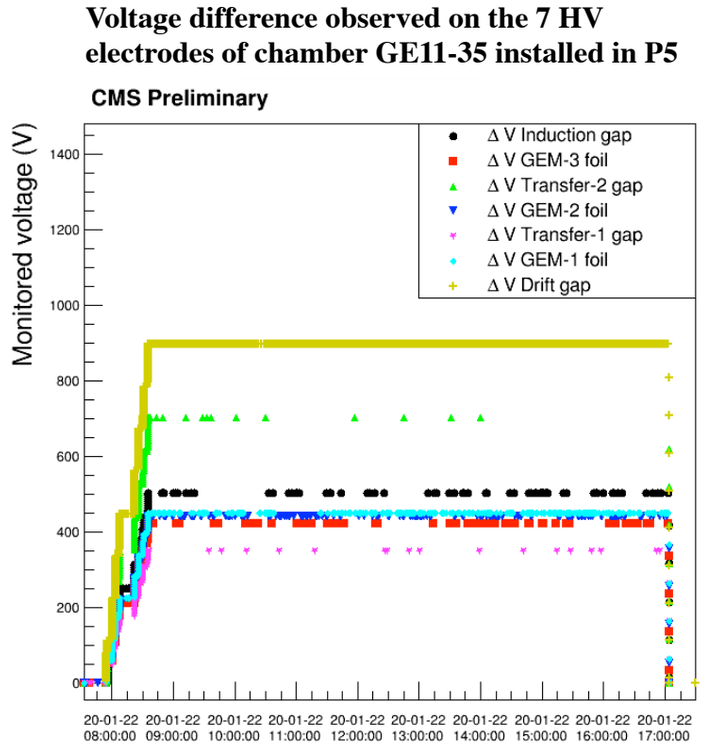


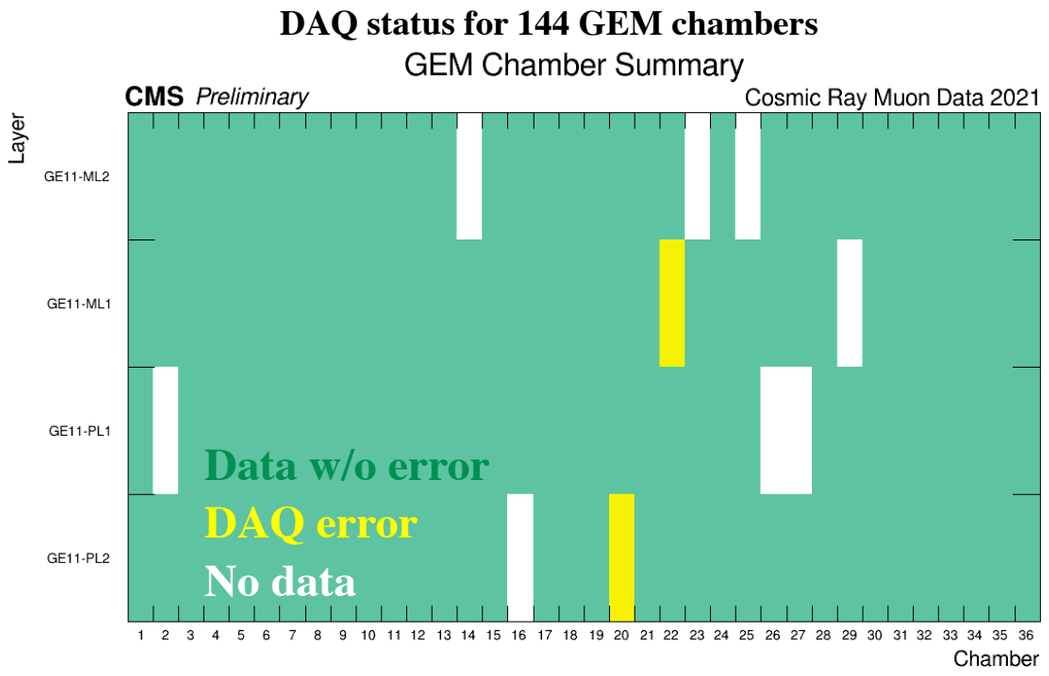
- Future Upgrades:
  - GE2/1
  - ME0

Talk by Sam Abbott on "**Design optimization and initial performance of the GEM GE2/1 detector for the upgrade of the CMS endcap muon system**"

Status : GE1/1 in CMS (1/2)

- Installed 36 Super chambers per endcaps in 2019 and 2020
  - connected to necessary services : **High voltage (HV) and Low voltage (LV)** , **optical fibers** for readout and trigger , fibers for **temperature sensors** , RADMON sensor cables for **radiation monitoring , Gas system** and Water **cooling** for frontend chips and FPGA
  - HV training first in pure CO_2 and than in final Ar/CO_2 mixture
    - Second step repeated after every shutdown and/or mechanical movement to ensure stable operation and clean potential deposits on GEM foils
  - Online monitoring and control tools
    - **Detector Control System (DCS)** : control and monitor HV, LV (channels and racks), FPGA temperature, gas system
    - **GEM Online Data Quality Monitoring (online DQM)** : Online monitoring for DAQ (Data Acquisition System) errors, frontend status





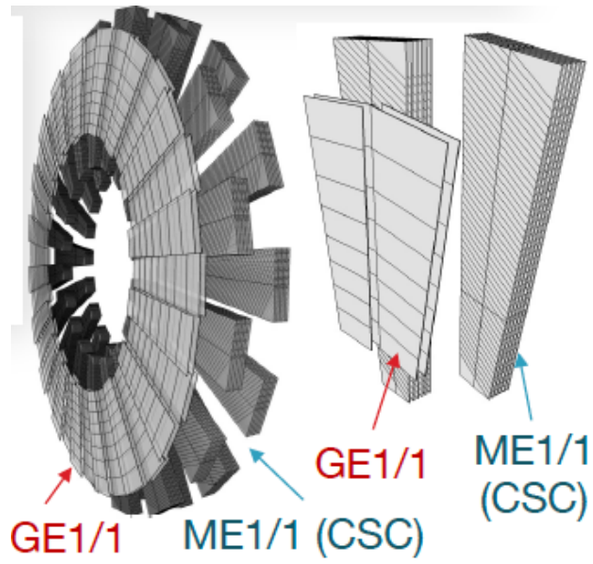
Status : GE1/1 in CMS (2/2)

- Offline monitoring and prompt data analysis

  - **GEM Offline Data quality monitoring (Offline DQM) :** provides early performance information on promptly reconstructed data

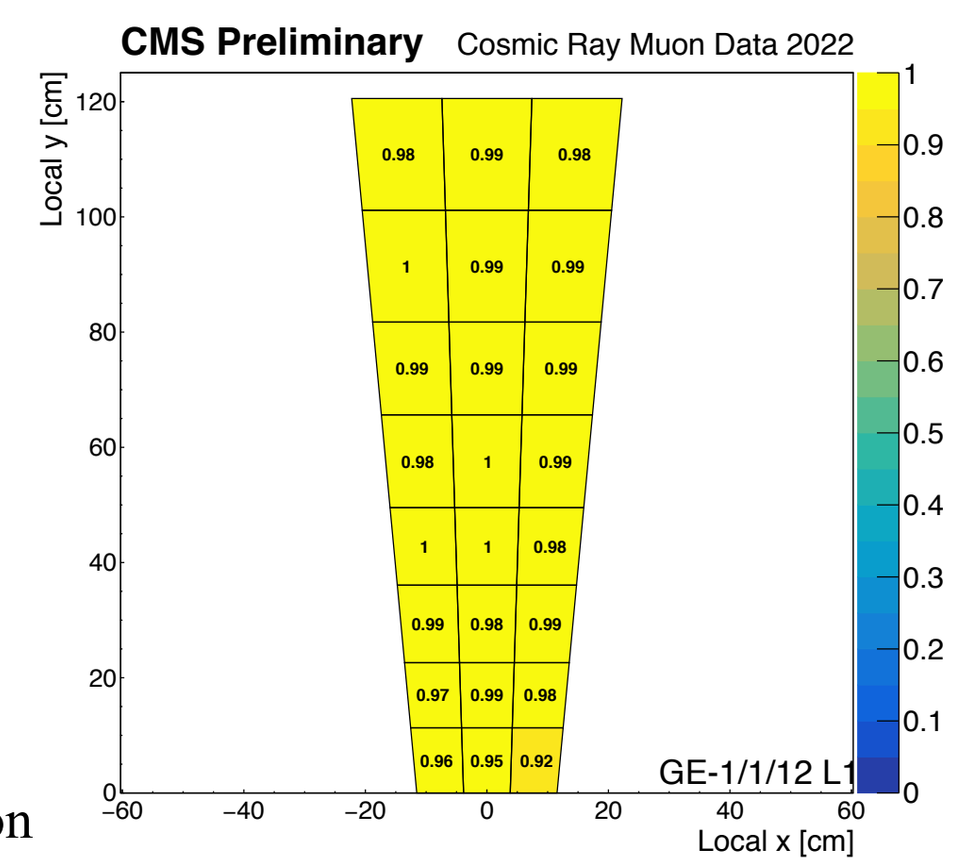
  - **Detector alignment for data correction** : correct muon transverse momentum assignment offline for GEM-CSC system misalignment for Run3 (GE1/1+CSC) muon trigger and reconstruction.

    - Poster by Hyunyong Kim : "**Back-propagation method for GEM alignment**"



  - **Prompt data analysis for GE1/1 performance monitoring :** Analysis of prompt data for feedback during operations and will help to spot issues and will report to DAQ/detector experts within few-days time scale during pp collisions

    - Efficiency measurement
    - Spatial resolution

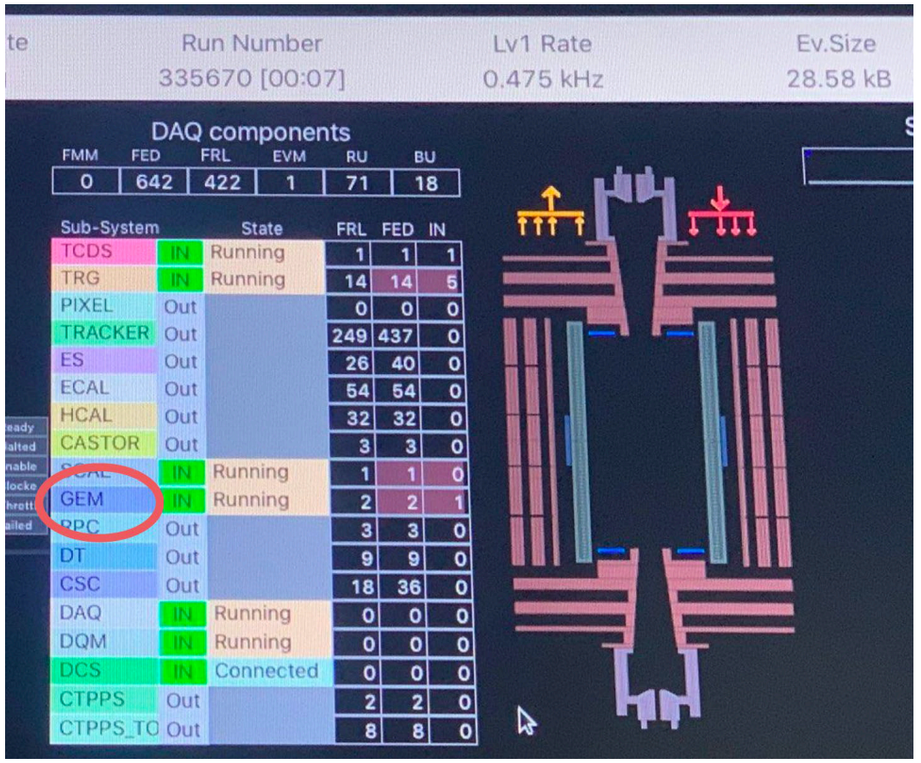


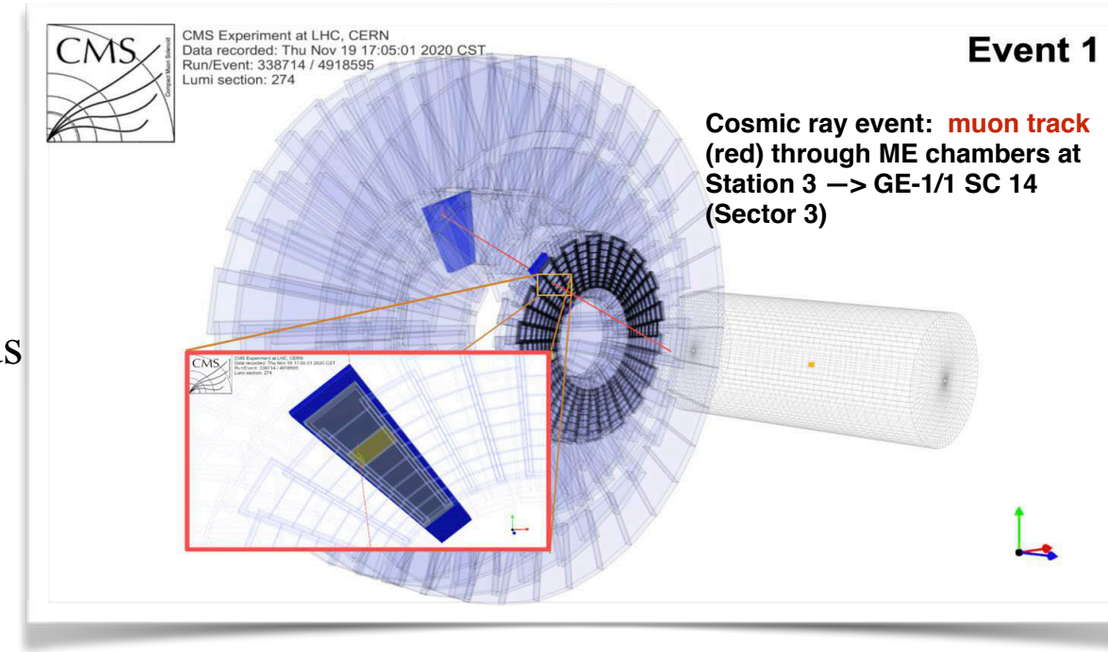
- DAQ, DQM, DCS fully integrated into CMS central system

- Commissioned during CMS global data taking with cosmic-ray muon

Commissioning : CMS cosmic data-taking

- Data taking exercises :
  - During Long Shutdown , CMS takes **cosmic data** for few days continuously
  - Purpose is to **test and commission** sub-detectors, trigger, DAQ software in view of pp collision runs (2022)
  - **September 2020:**
    - GEM DAQ included in global data-taking for the first time
  - **2020-2021:**
    - DAQ software commissioning
    - Calibrations: latency scan
    - GEM-EMTF trigger link connectivity tests
    - Electronic noise optimisation, tuning of frontend thresholds
    - Commissioning of the GEM-EMTF (Endcap Muon Track Finder) and GEM-CSC trigger chains
  - **July-August,2021** : **C**osmic **RU**n at **ZE**ro **T**esla (**CRUZET**)
    - ☆ 6 weeks of continuous data taking

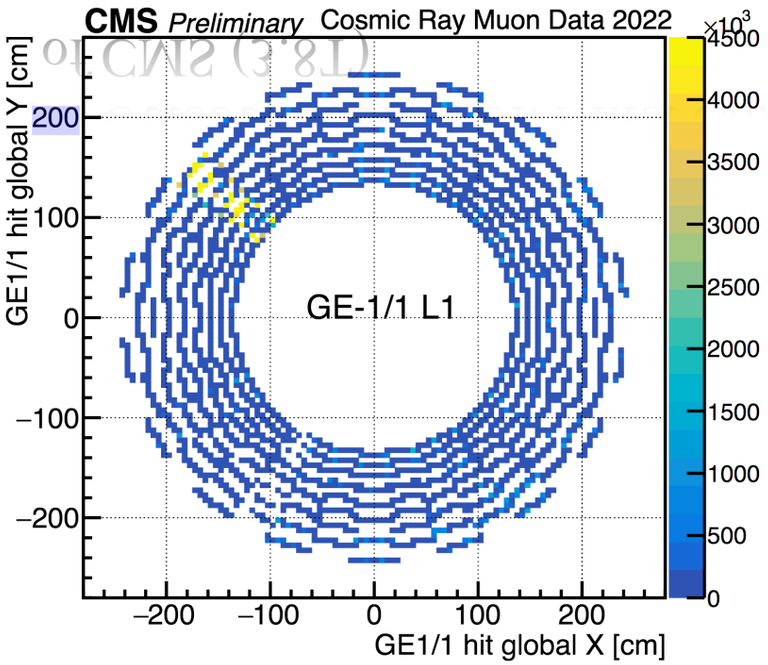


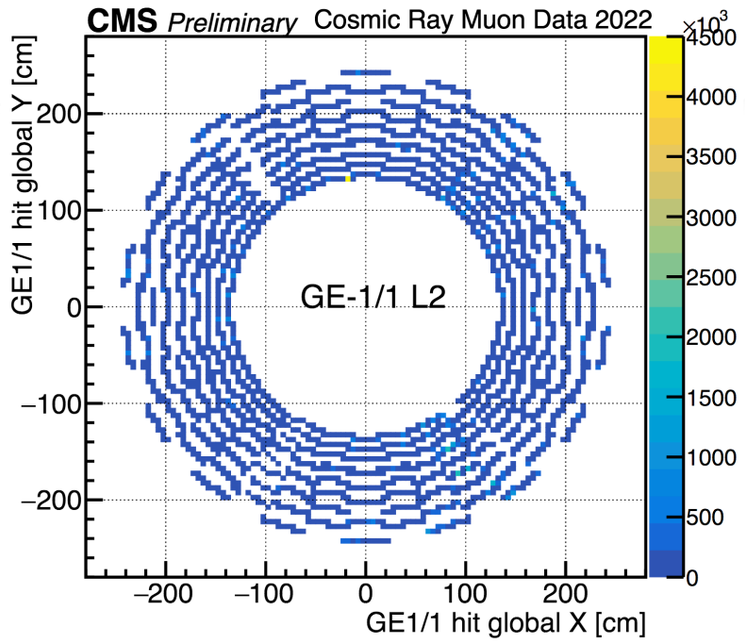


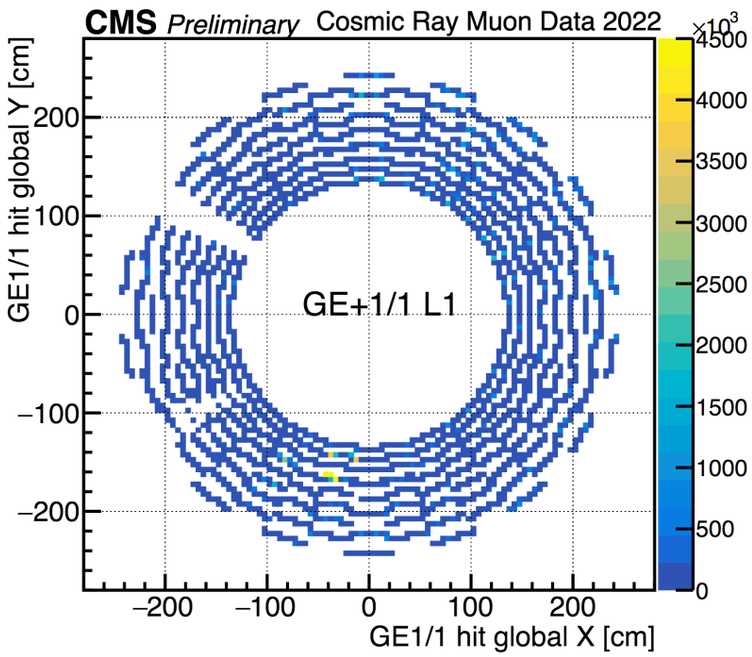
Operations in Magnetic field

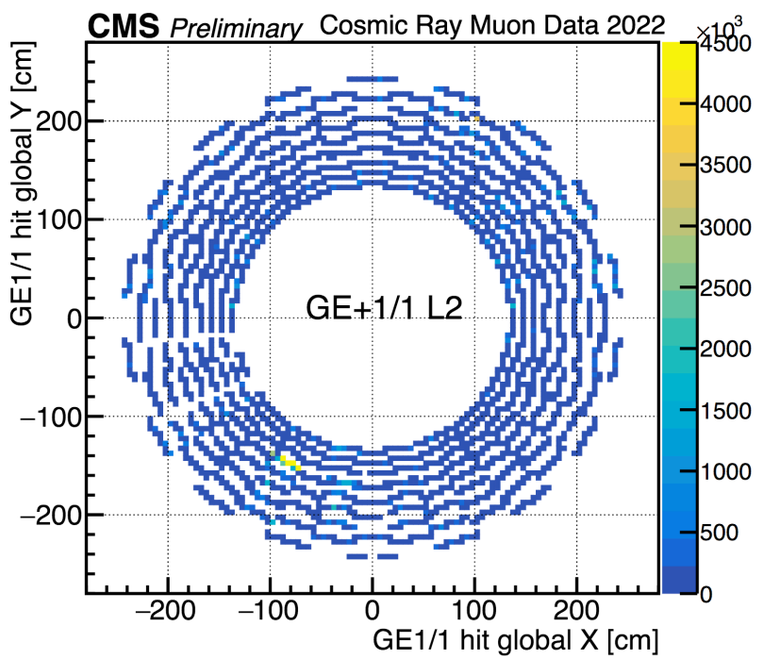
- Cosmic **R**un **A**t **F**our **T**esla (**CRAFT**): Oct, 2021 & Mar-Apr, 2022

- In October 2021, GE1/1 first experience with pilot beam test collisions at √s =900 GeV and magnetic field of CMS (3.8T)









- Occupancies of GE1/1 reconstructed hits in x-y plane during cosmic ray muon runs collected by the CMS detector at 3.8 T in April 2022. All chambers were operated at 700μA.

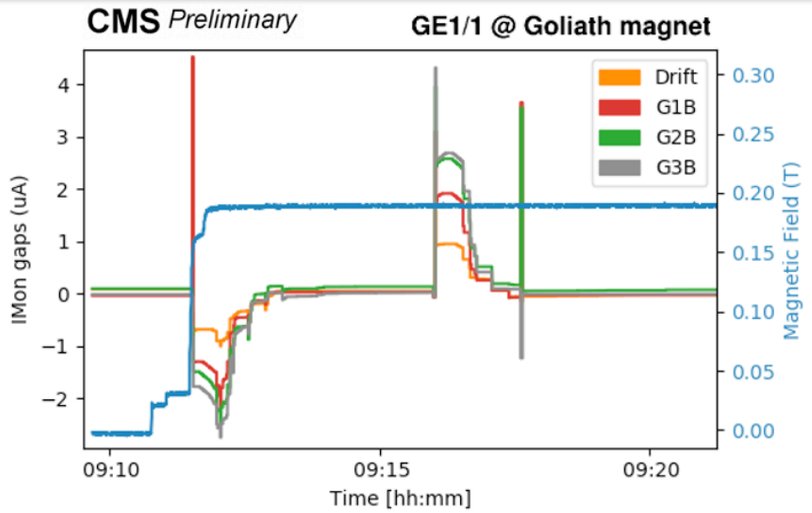
- 143/144 chambers successfully readout

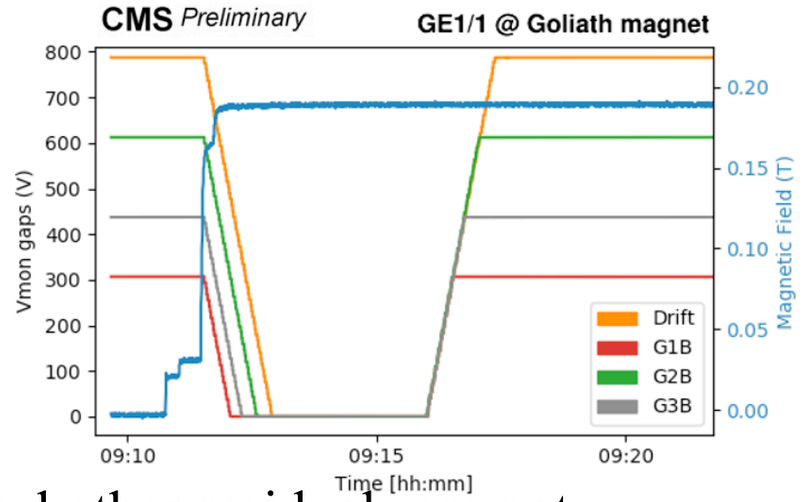
- Reconstructed hits are missing on chambers or VFAT readout chips due to the DAQ system (e.g., LVs were off , or frontend electronics not configured or communication instabilities) or HV off.

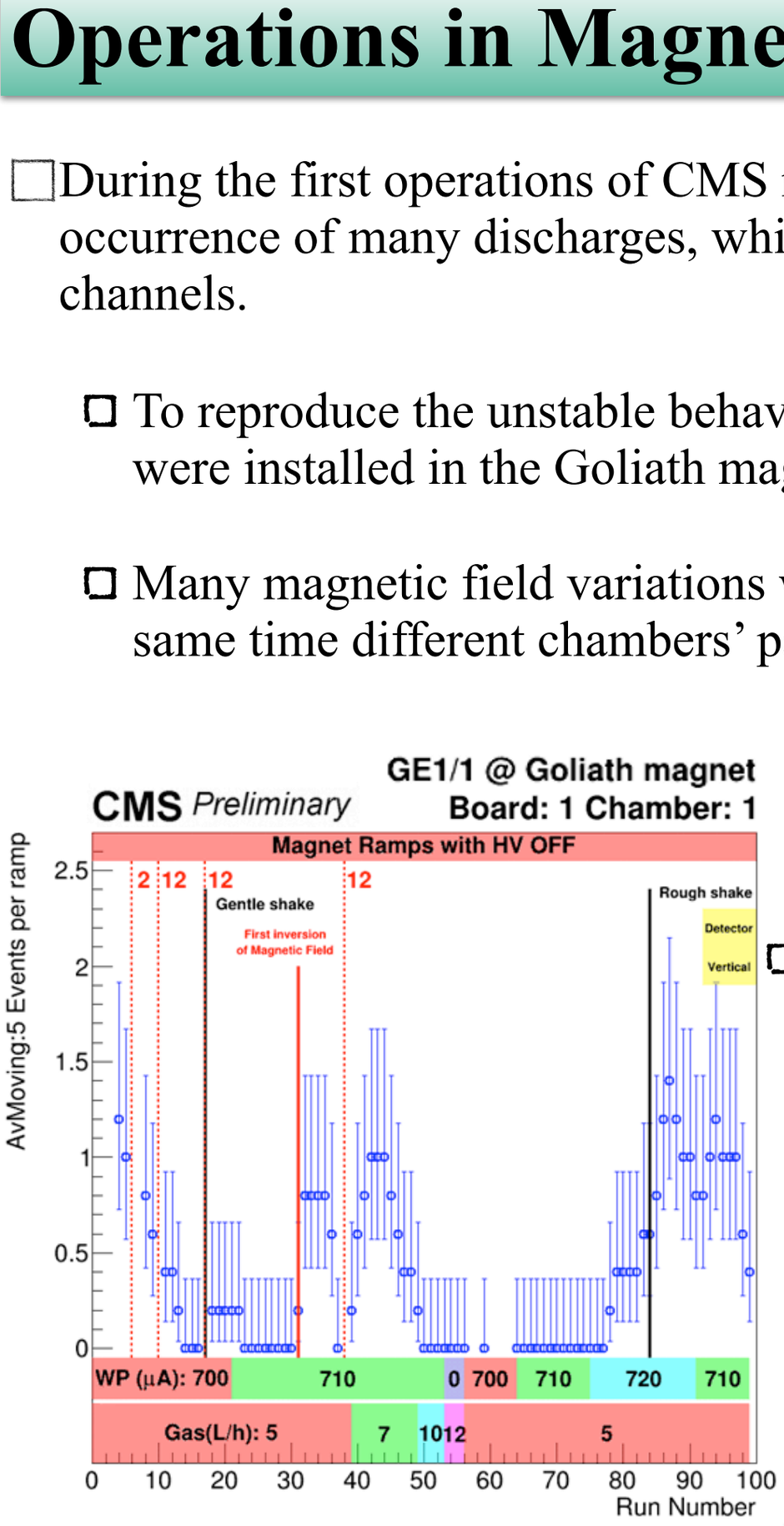
- Few strips were noisy, exhibiting higher occupancies

Operations in Magnetic field : Discharges

- During the first operations of CMS magnet, GE1/1 experienced the occurrence of many discharges, which triggered trips on high HV channels.
  - To reproduce the unstable behaviour 4 GE1/1 spare chambers were installed in the Goliath magnet in the CERN North Area
  - Many magnetic field variations were performed, adopting at the same time different chambers' parameters.







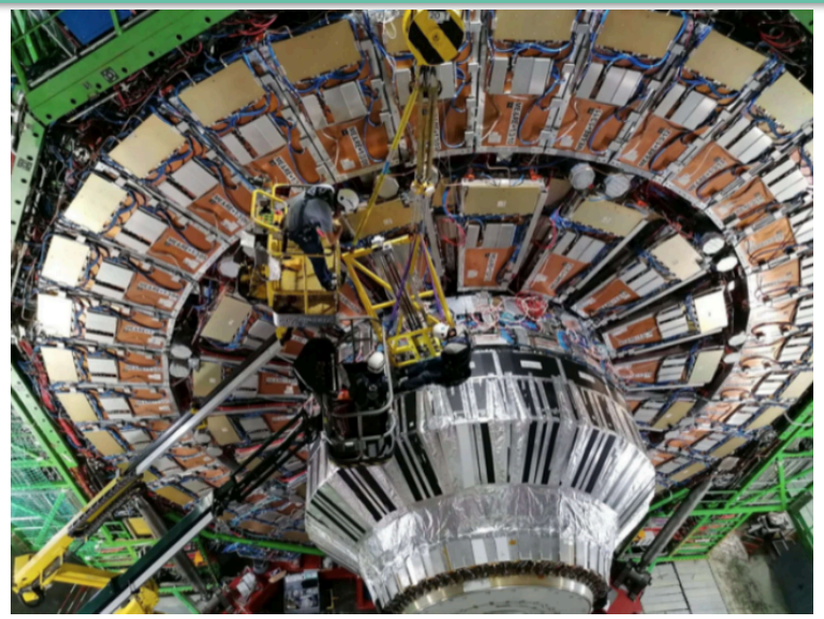
- A short is created when the dust and other residuals are not immediately burned.
  - keep the HV on the foils ON during the magnet ramps, in order to burn the dust as soon as it starts moving
  - increase the I_0 threshold in such a way that the HV trip is triggered only when there is a huge and dangerous discharge, allowing instead the smaller ones useful to burn residuals.
  - not affected by gas flux or HV working point

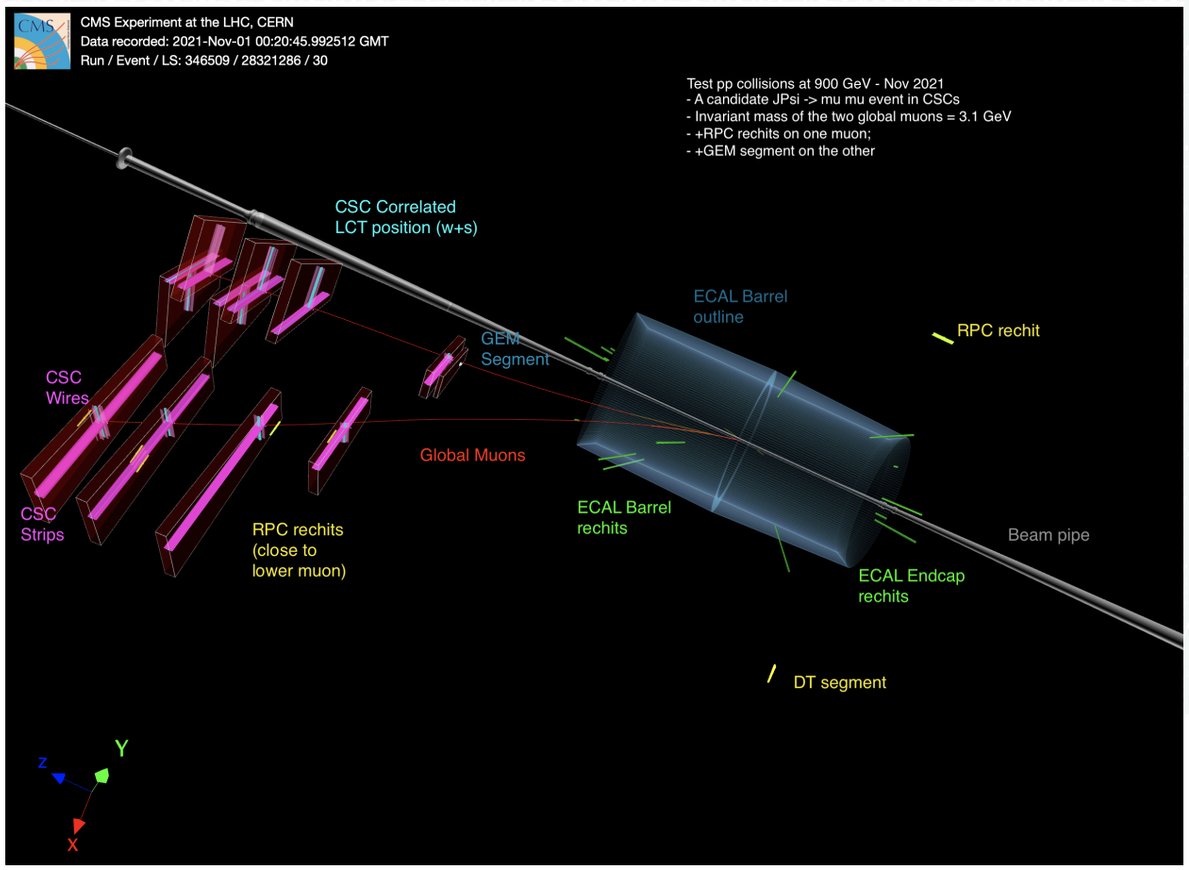
Issues encountered and solution

- **Electronic noise due to LV system :**
  - intervention on the LV cables and installation of filters successfully lowered noise level
- **Instabilities in the front-end electronics :**
  - GBTx not locking: implemented automatic recovery at configuration
  - Issue due to VTRx chip failures, CERN wide problem
    - Outgassing of materials spoil the optical connection
- **High voltage: discharges in the detector**
  - Gas Electron Multiplier technology suffers from discharges due to pollution/dust, gain fluctuations
  - HV training procedure has been implemented to ensure stable detector operation
- **Shorts in different chambers; need to be powered and monitored with special settings :**
  - Re-mapping of HV-system : to get the problematic chambers in some HV boards
  - HV-Extension : added extra boards to the current configuration where swapping is not possible

Summary

- **GE1/1 station:**
  - the completely new technology for a sub-detector introduced into CMS
  - 144 detectors built and validated (Sep 2017 to Dec 2018) using a standardized quality control protocol
  - Successfull installation and will participate in data taking during Run-3 at 13.6 TeV





- **GE1/1 Commissioning:**
  - Full integration (DAQ, DCS, DQM(offline, online), trigger) into the CMS system
  - Joined cosmic runs together with other CMS sub-detectors
    - Operated well in magnetic field of CMS
    - some issues spotted and tackled with possible solutions
- **Next Steps:**
  - Optimization of readout electronics thresholds
  - Detector performance for optimal working point

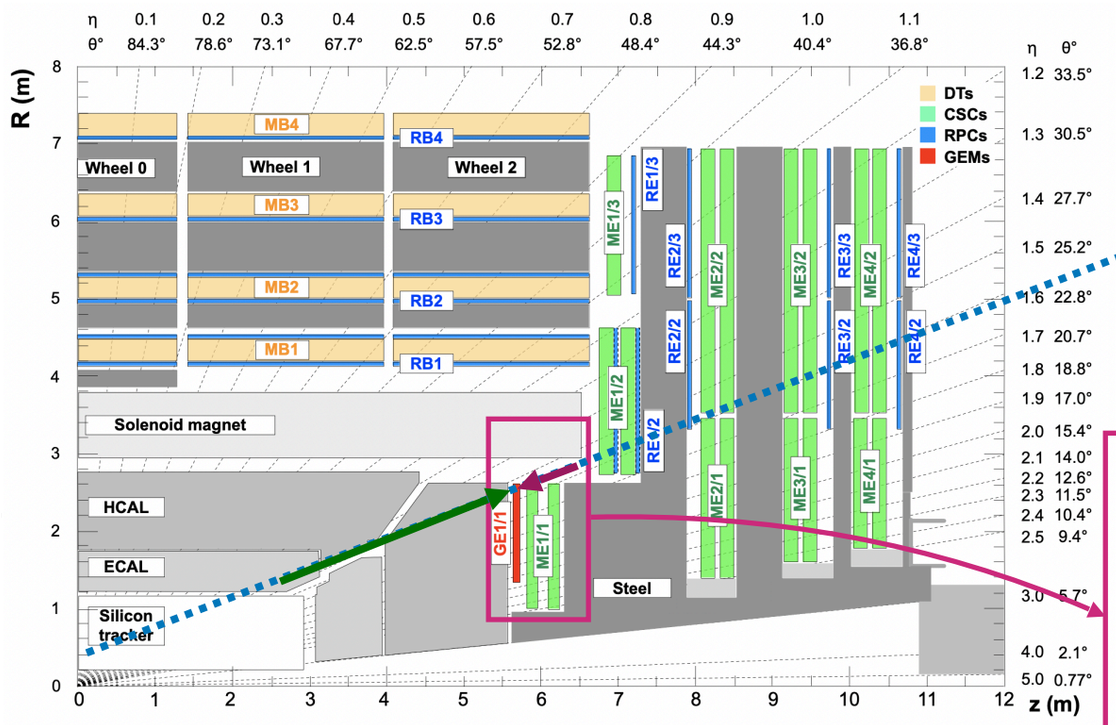
Stay tuned for interesting results….

Thanks

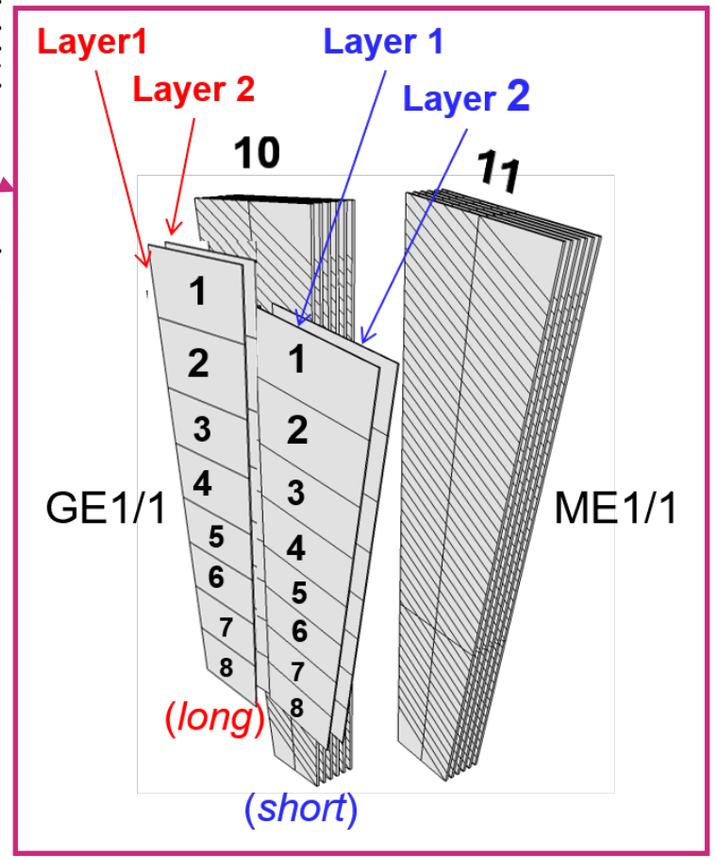
Backup slides

GEM alignment with a back-propagation method

- Exercise of the GEM-CSC alignment with cosmic ray muons collected by the CMS detector at 3.8 T in the following steps
  - ME1/1 alignment: Measure ME1/1 residuals using Inner Tracker tracks
  - GE1/1 alignment: Measure GE1/1 residuals using the ME1/1 segments (back-propagation)



- **Inner Tracker propagation: pass heavy material budget, reference position is inner tracker**
- **Back-propagation: less scattering, reference position CSC**



The GEM chambers have short and long types.