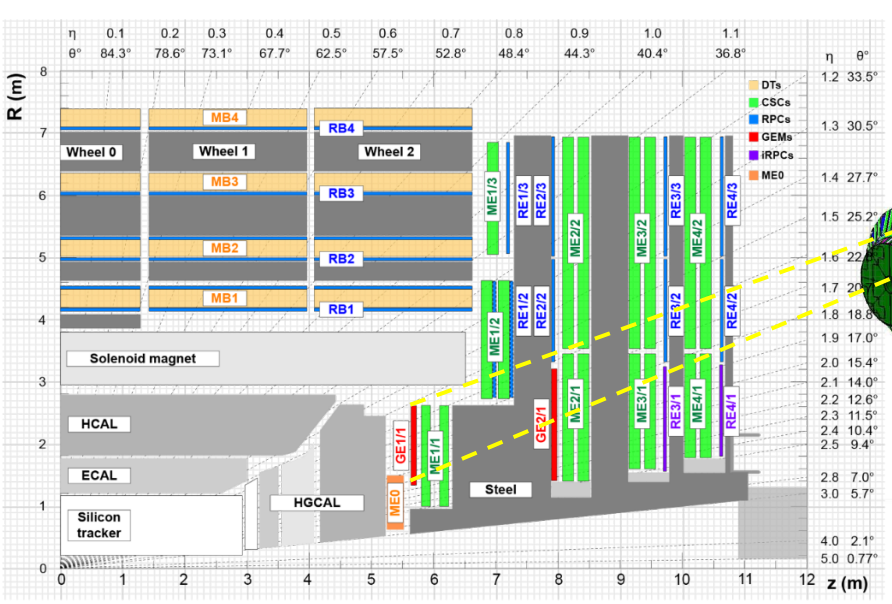
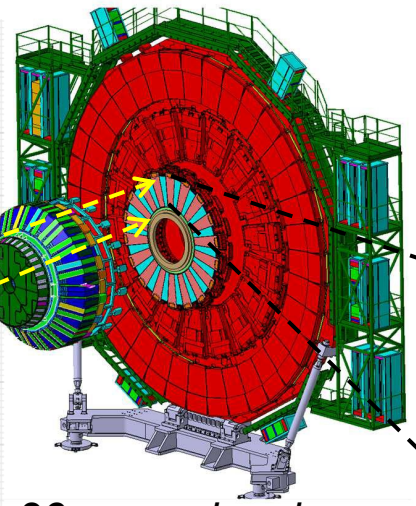
# Status and commissioning of the new GE1/1 station for the CMS experiment

Davide Fiorina[(1)]
(1) Università & INFN Pavia

On behalf of the CMS Collaboration

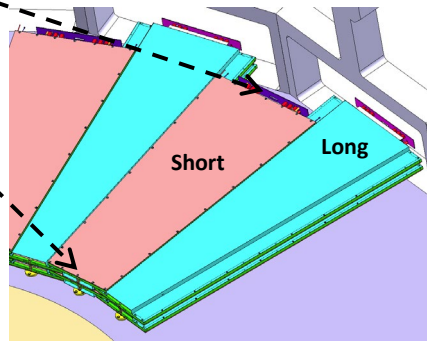
# The phase-I CMS muon endcap upgrade: GE1/1



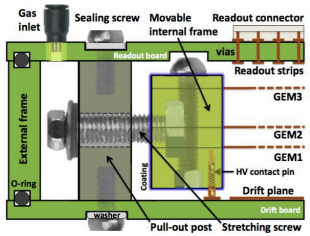
**36** *superchambers* (SC) per endcap

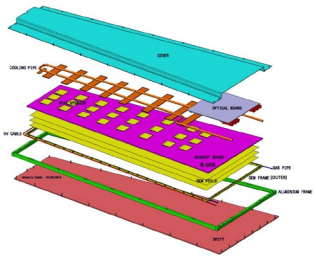
**short and long SCs**
to maximise coverage
$1.55 < |\eta| < 2.18$




## 144 triple-GEM detectors:

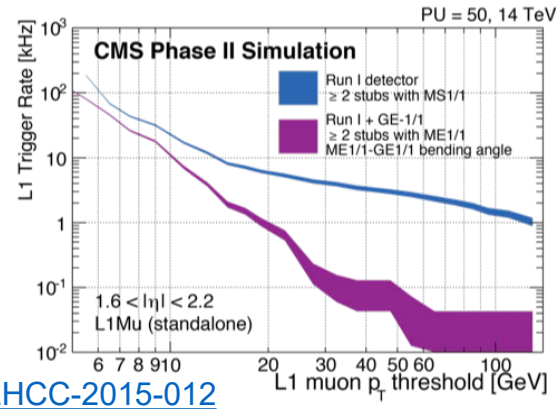
- 3/1/2/1 mm gaps
- mature technology based on mechanical foil stretching
- 10-years-long R&D on design, components and materials (longevity, outgassing studies, etc.)

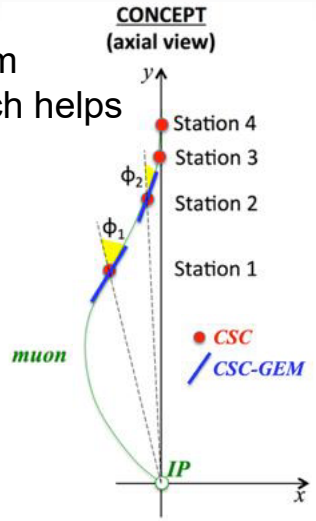


## Impact on the muon trigger

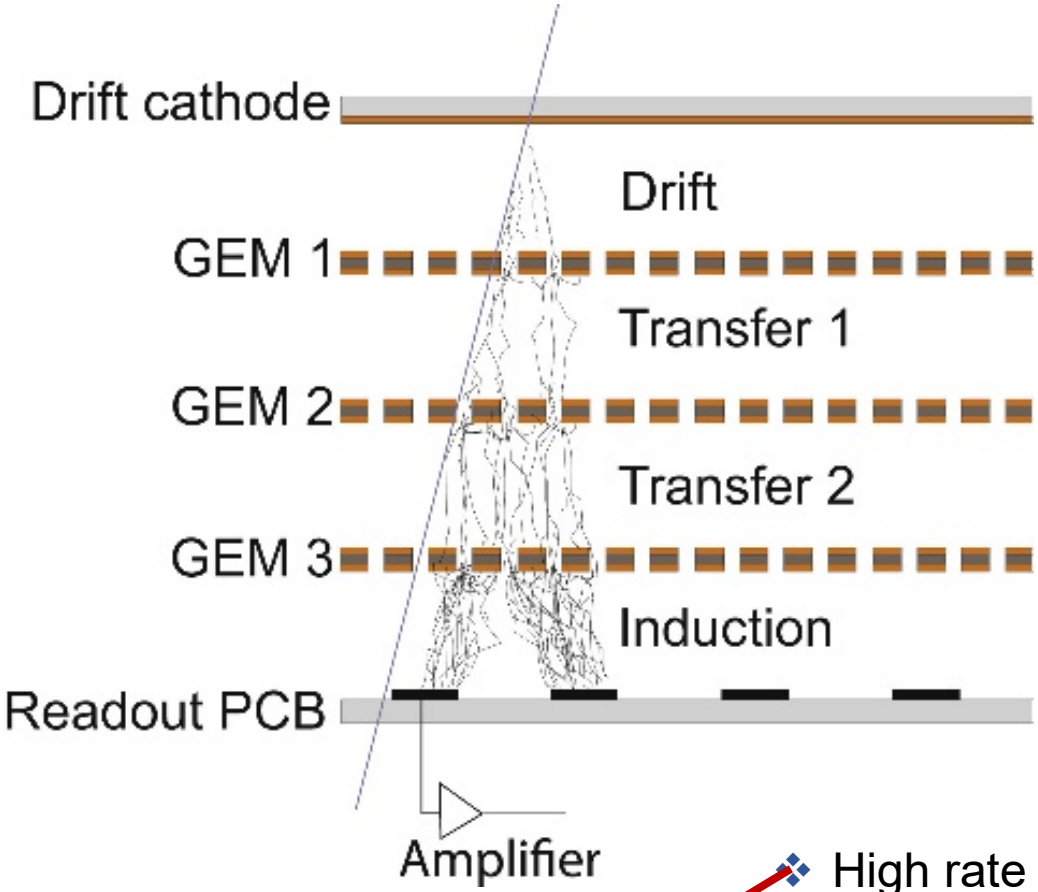
- GEM+CSC allow for muon momentum measurement in a single station, which helps reduce considerably L1 trigger rate

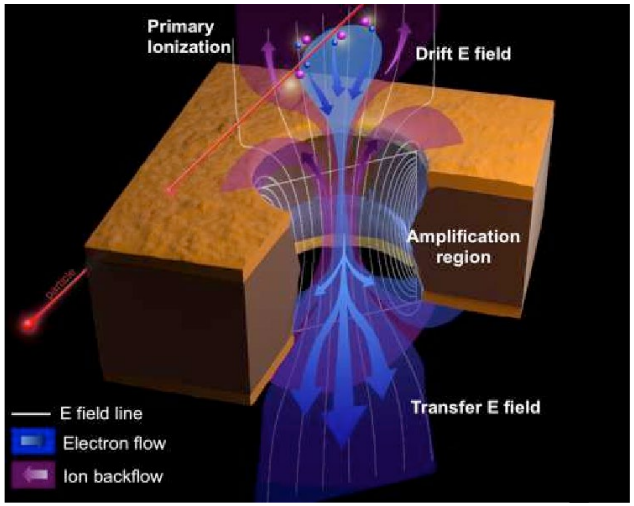


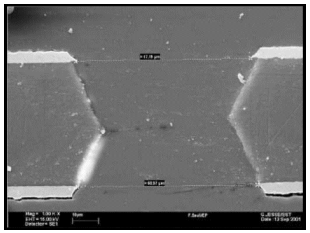



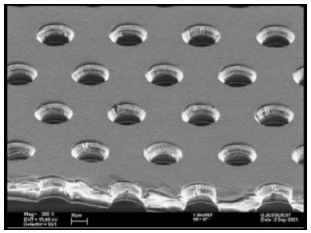

CERN-LHCC-2015-012

# The GEM technology



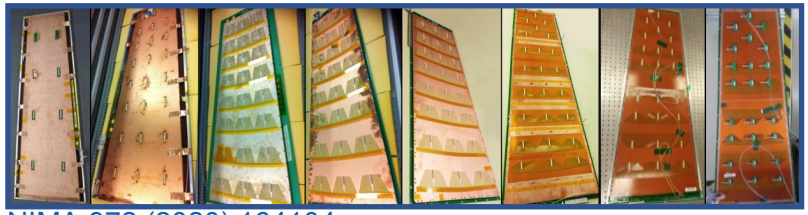


- High rate capability, up to O(MHz/cm$^2$)
- Efficiency > 98%
- Space (time) resolution ≈ 300 μm (8 ns) [1]
- Gas mixture: Ar/$CO_2$ 70/30

More about rate capability studies for Phase II in this poster by L.F. Ramirez

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

# The GE1/1 Project



NIMA 972 (2020) 164104

N. Pozzobon 2019 JINST 14 C11031
JINST 15 (2020) P05023

BIRTH OF GE11 PROJECT

2009

GE11 proto. I

GE11 proto. II

GE11 proto. III
Mechanical stretching

GE11 proto. IV

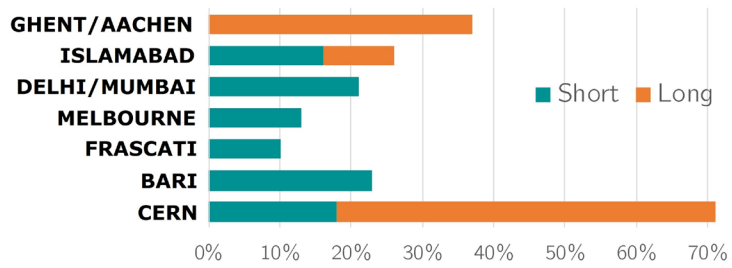
GE11 proto. V

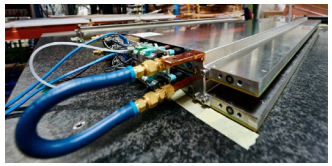
GE11 proto. VI - VII

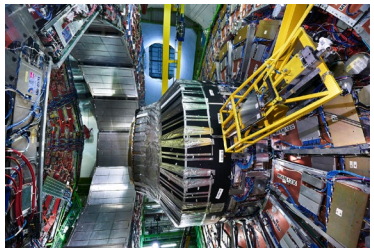
DAQ/ electronics prototyping

SLICE TEST INSTALLATION AND COMMISSIONING

2017





NEGATIVE ENDCAP INSTALLED!

completed!

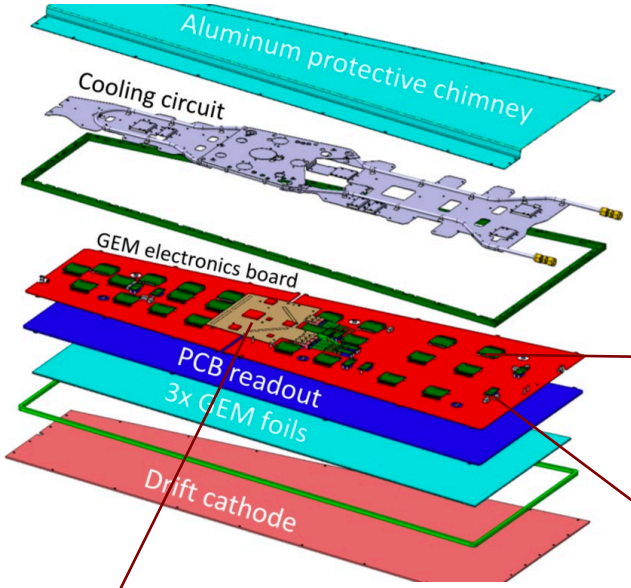
POSITIVE ENDCAP INSTALLATION

Oct-2017 — Dec-2018 — Jul-Oct 2019 — Jul-Sep 2020

DETECTOR MASS PRODUCTION

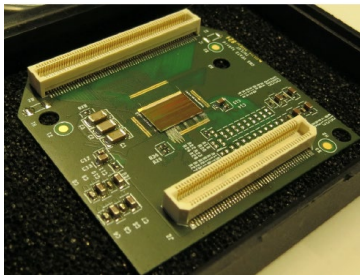
SUPERCHAMBER PRODUCTION

# GE1/1 Readout Electronics



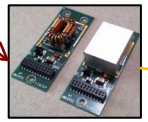

**GE1/1 system:**

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



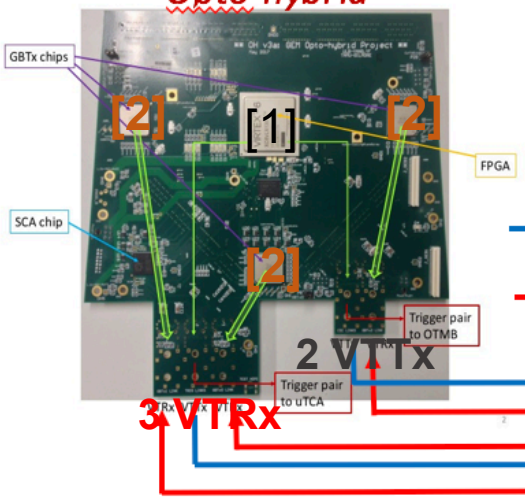
FE chip: VFAT3

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



**[1] Virtex-**
**[2] GBTx**

GE1/1 Electronics



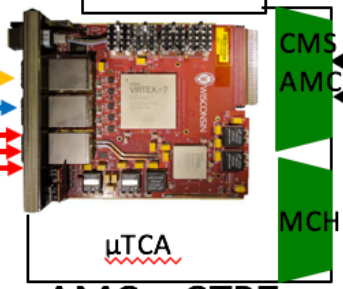

CSC Trigger Mother Board (TMB)

FEAST (DC DC converter, LV VFAT3 & OH)

EMTF

Trigger data (3.2 Gbps – 10b/8b)

GBT links: Traking data (4.8 Gbps)



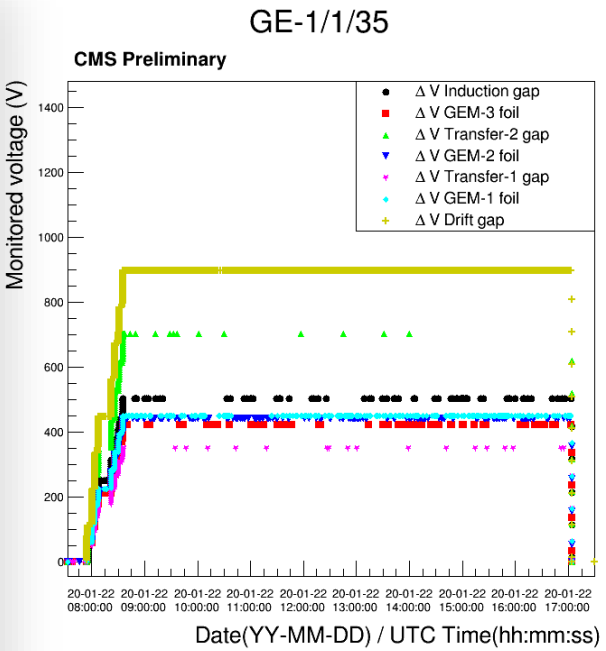

AMC = CTP7

- 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 CMS Triple-GEM detectors

# GE1/1 status and initial commissioning phase (1)

## Services installation: fully completed

- ✓ **High Voltage**: multi-channel power supply. GEM electrodes powered independently. Voltage, current and channel status logged in database.
- ✓ **Low Voltage**: it provides power to the frontend electronics
- ✓ R/O **fibers** and link-to-CSC fibers: optical fibers for readout and trigger
- ✓ Fibers for **temperature sensors**
- ✓ RADMON sensor cables for **radiation monitoring**
- ✓ **Gas system**
- ✓ Water **cooling** for frontend chips and FPGA




## Early commissioning steps

- Detector HV stability:
  - HV training in pure $CO_2$
  - HV training in $Ar/CO_2$ final mixture
- Frontend calibrations using internal pulse: noise, thresholds
- Connectivity tests of GEM-EMTF (Endcap Muon Track Finder) trigger links

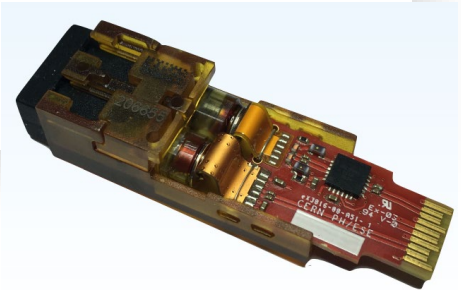
# GE1/1 status and initial commissioning phase (2)

## Main issues found and solutions:

- Electronic noise due to LV system
  - intervention on the LV cables and installation of filters
  - successfully lowered noise level

- High voltage: discharges in the detector
  - Gas Electron Multiplier technology suffers from discharges due to pollution/dust, gain fluctuations and HIP
  - HV training procedure has been implemented to ensure stable detector operation

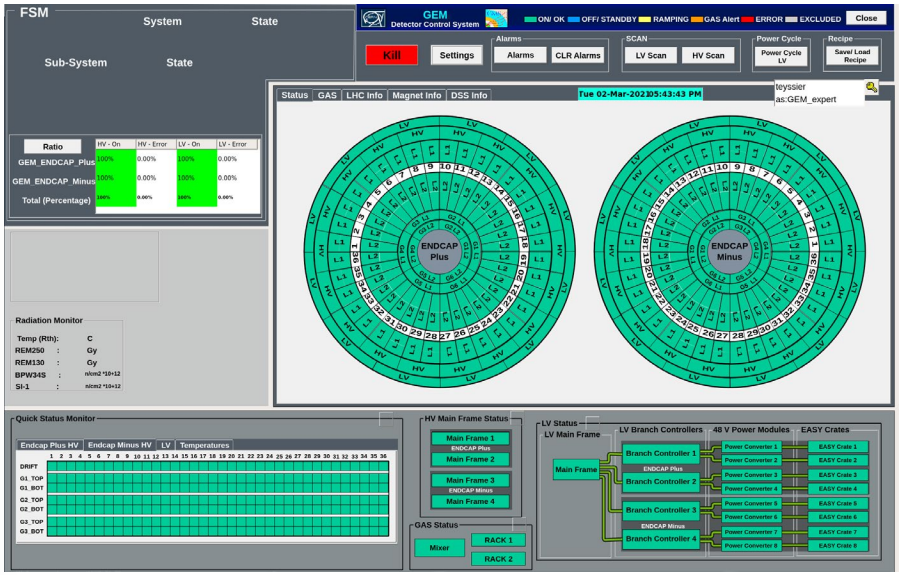
- Instabilities in the frontend communication
  - GBTx not locking: implemented automatic recovery at configuration
  - Issue due to VTRx chip failures, CERN wide problem
    Outgassing of materials damage the optical connection



# Commissioning of online control and monitoring tools:

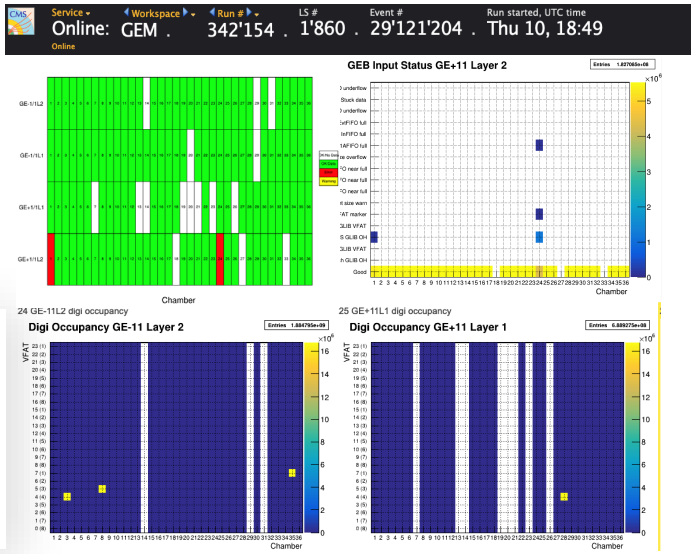
## Detector Control System (DCS)

- DCS: control and monitoring of HV, LV (channels and racks), FPGA temperature, gas system
- Extensive usage of the DCS during HV training and DAQ tests (LV).
- DCS commissioned during CMS data taking runs with cosmics
- Successfully included into central CMS DCS
- Finalising few missing elements (RADMON, temperature, racks monitoring, LV automatic recovery)




## GEM Online Data Quality Monitoring (online DQM)

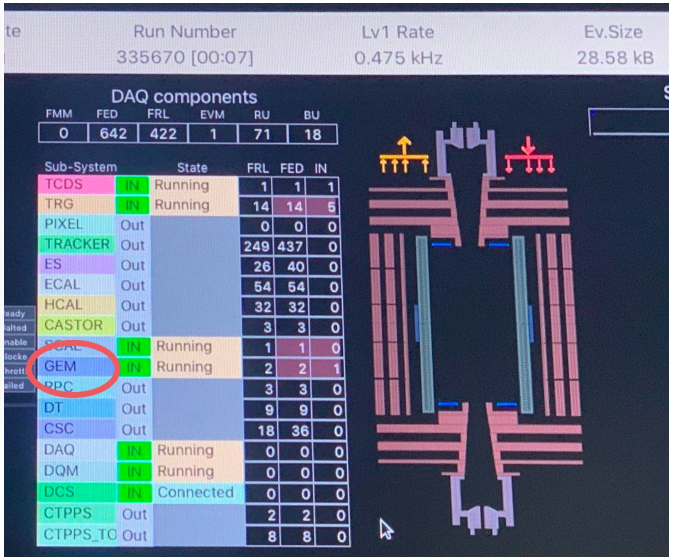
- GE1/1 detectors fully integrated into CMS online DQM
- Online monitoring for DAQ errors, frontend status
- Commissioned during cosmic runs



# CMS cosmic data-taking runs (1)

## Data taking exercises:

- During Long Shutdown, CMS takes **cosmic data** for few days continously
- Purpose is to **test and commission** subdetectors, trigger, DAQ software in view of pp collision runs (2022)

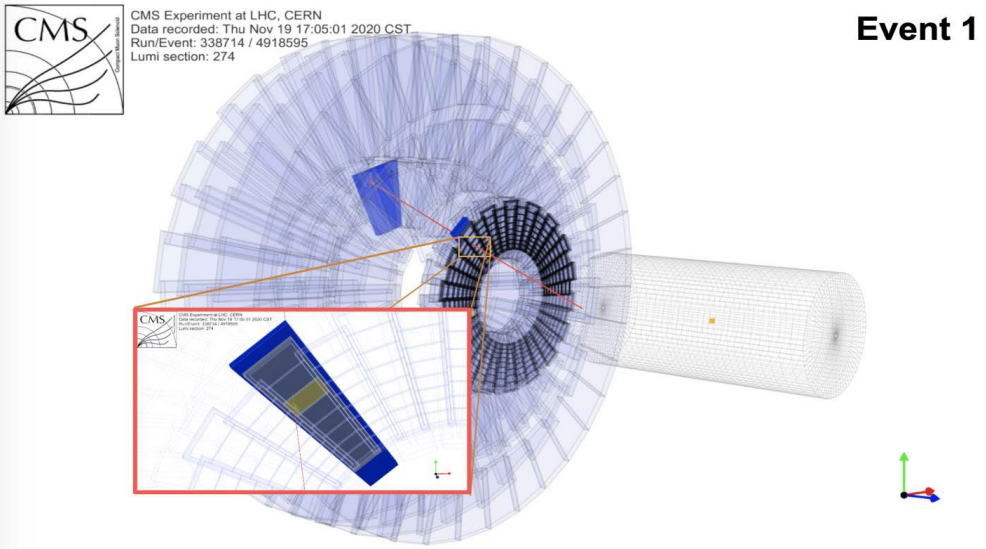



## GE1/1:

<u>September 2020</u>: GEM DAQ included in global data-taking for the first time

<u>2020-2021</u>:

- DAQ software commissioning (under development)
- Calibrations: latency scan
- GEM-EMTF trigger link connectivity tests
- Cosmic muon data taking

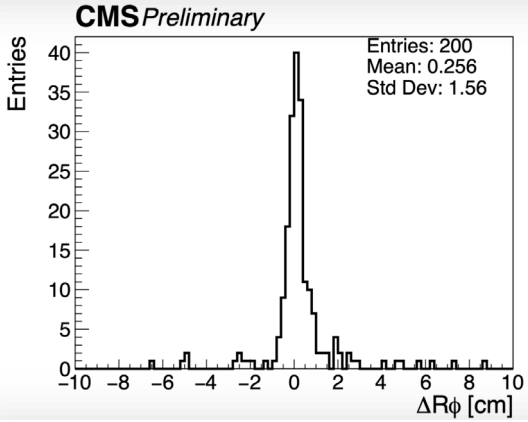



Cosmic ray muon candidate – November 2020

# Commissioning of offline monitoring and prompt data analysis

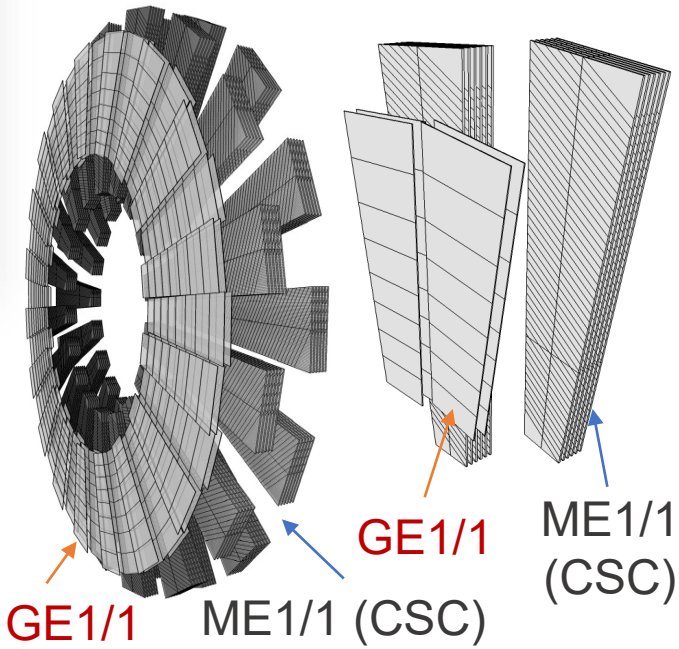
## Detector alignment for data correction

- Run 3: trigger from GE1/1+CSC information
- Important to correct offline for any GEM-CSC misalignment
- Preliminary studies on cosmic muon simulated samples.
- Compared with CMS data taking commissioning runs.



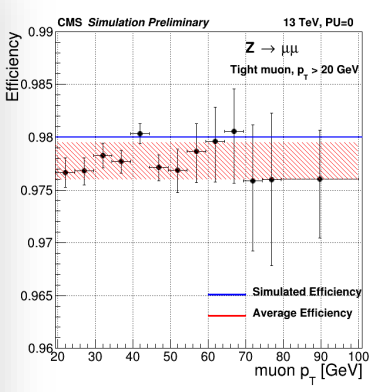

Procedure:

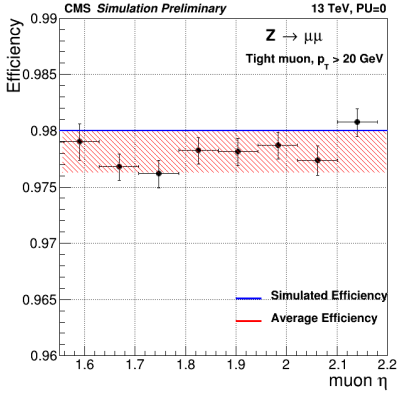
- propagate muon tracks detected by CSC to GEM surface
- look at residuals (distances between propagated hits and GEM muon hits)




## Prompt data analysis for GE1/1 performance monitoring

- Analysis of prompt data for feedback during operations
- Will be used during pp collisions to spot issues and report to DAQ/detector experts within few-days time scale
- Analysis targets:
  - Muon detection efficiency
  - Detector spatial resolution

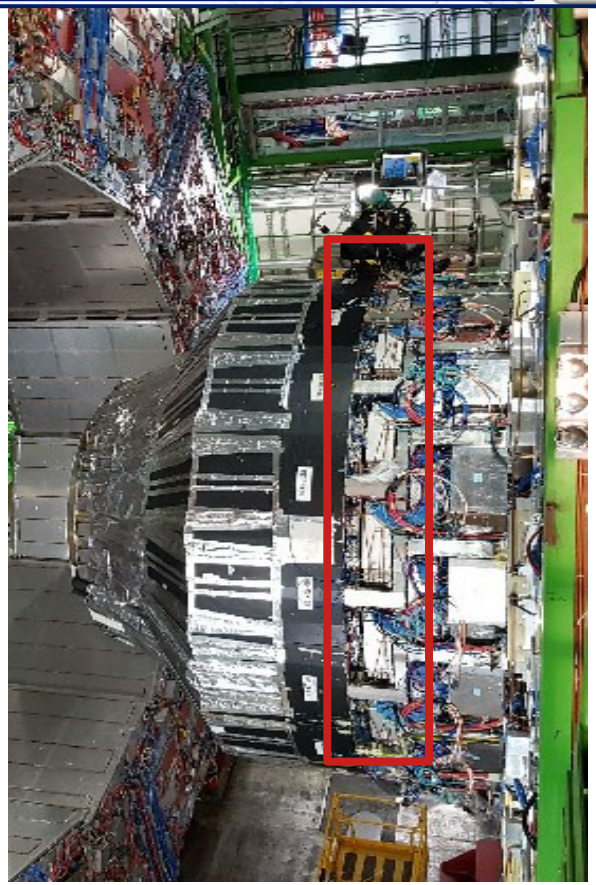


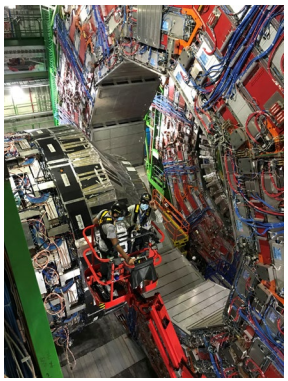



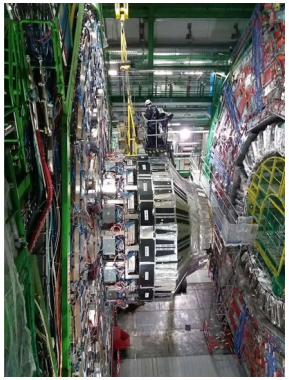
# Next steps – towards Run 3 (1)

## GE1/1 commissioning: next steps

- **Readout:**
  - Electronic noise optimisation, tuning of frontend thresholds
  - Need to understand communication instabilities (affecting < 5% of the entire system)
  - Commission the GEM-EMTF (Endcap Muon Track Finder) and GEM-CSC trigger chains
- **Detector Control System**: Almost ready for pp collision.
- **DAQ software:** final version under development
- **Offline data analysis:** validated using simulation, to be fine-tuned (detector acceptance, muon reconstruction quality, matching criterion on real data)







# Next steps – towards Run 3 (2)

## CMS long cosmic runs:

- Cosmic RUn at ZEro Tesla (CRUZET):
  July-August 2021

- Cosmic Run At Four Tesla (CRAFT):
  Sept 2021

Will allow for **final commissioning** and deep tests of GEM DAQ software

Goal to accumulate sizable samples of cosmic muon events from which to **study the overall detector performance.**

**Towards Run 3 pp collisions:**

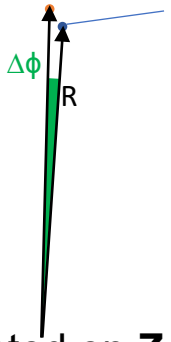
- Pilot beam data taking: Oct 2021
  test collisions at $\sqrt{s} = 900$ GeV

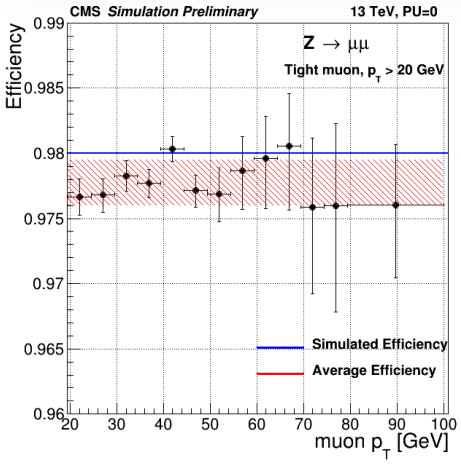
# BACKUP

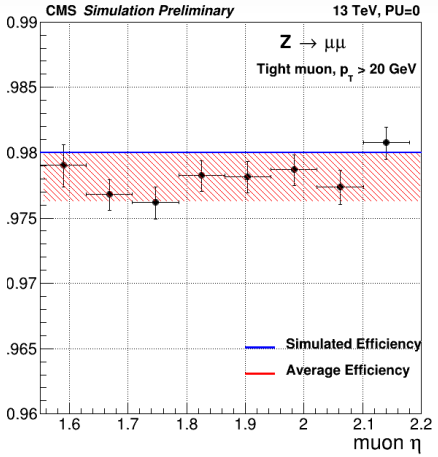
# Commissioning of offline monitoring and prompt data analysis (2)

## Prompt data analysis for GE1/1 performance monitoring

- Analysis of prompt data for feedback during operations
- Will be used during pp collisions to spot issues and report to DAQ/detector experts within few-days time scale
- Analysis targets:
  - Muon detection efficiency
  - Detector spatial resolution



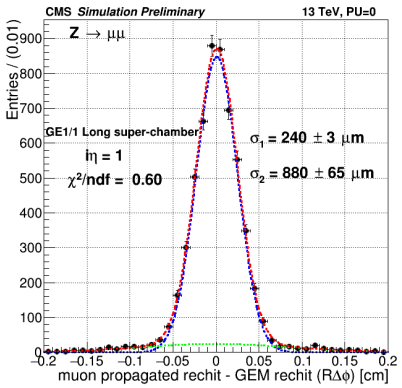



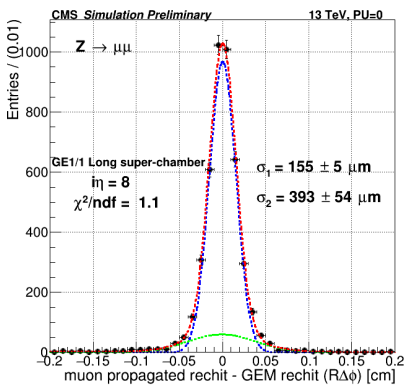

Efficiency measurement validated on **Z→μμ simulation**:

- propagate muon track to GE1/1 surface
- match propagated position with GEM hit in the vicinities ($R\Delta\varphi$<1 cm)
- Eff. = fraction of propagated muon hits matching with GEM hit

GE1/1 spatial resolution on **Z→μμ simulation**:

- residual distribution
- ideal geometry and alignment
- Note: GE1/1 strip pitch changes with distance from the beam pipe



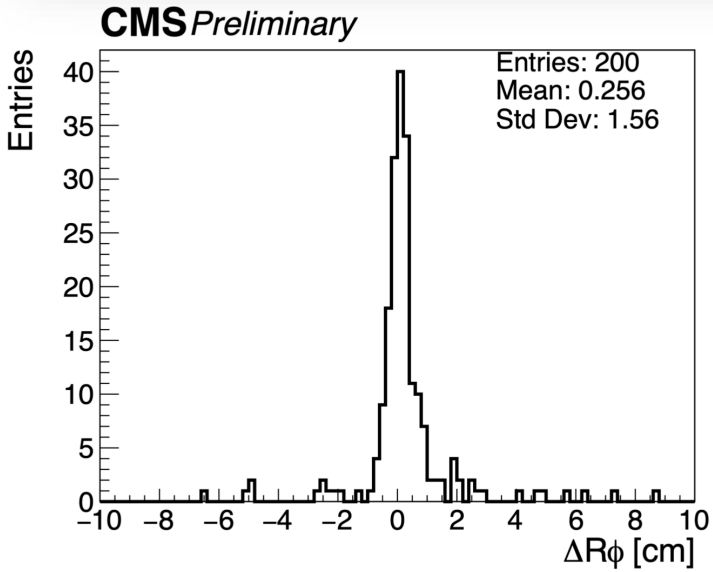
# Commissioning of offline monitoring and prompt data analysis

## GEM offline Data Quality Monitoring (offline DQM)

- GE1/1 integrated into central CMS offline DQM
- Provides early performance information on promptly reconstructed data
- Tested during commissioning runs with cosmic muons

## Detector alignment for data correction

- Run 3: trigger from GE1/1+CSC information
- Important to correct offline for any GEM-CSC misalignment
- Preliminary studies on cosmic muon simulated samples.
- Compared with CMS data taking commissioning runs.

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