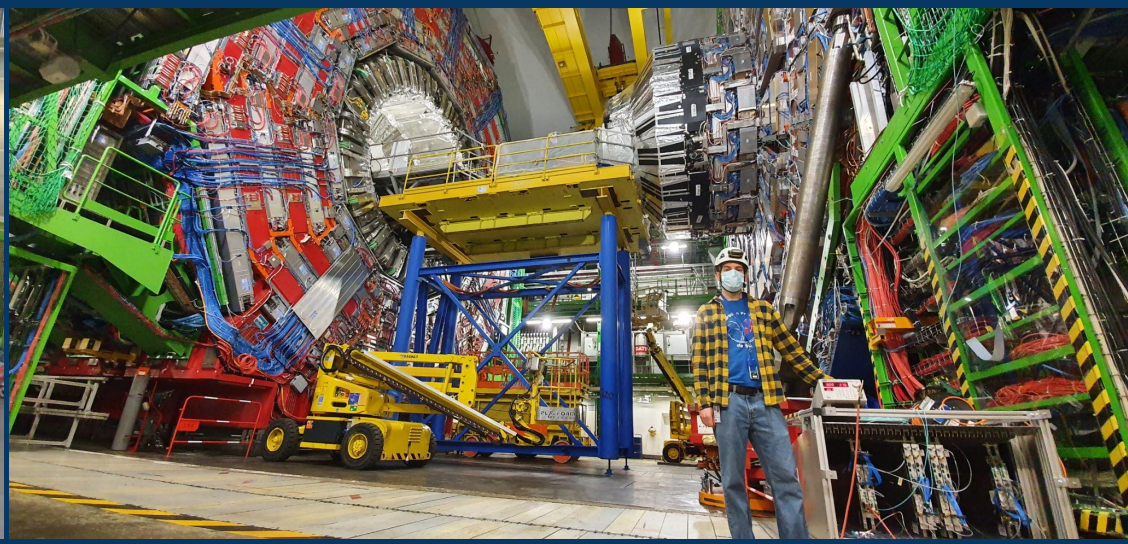
UCDAVIS

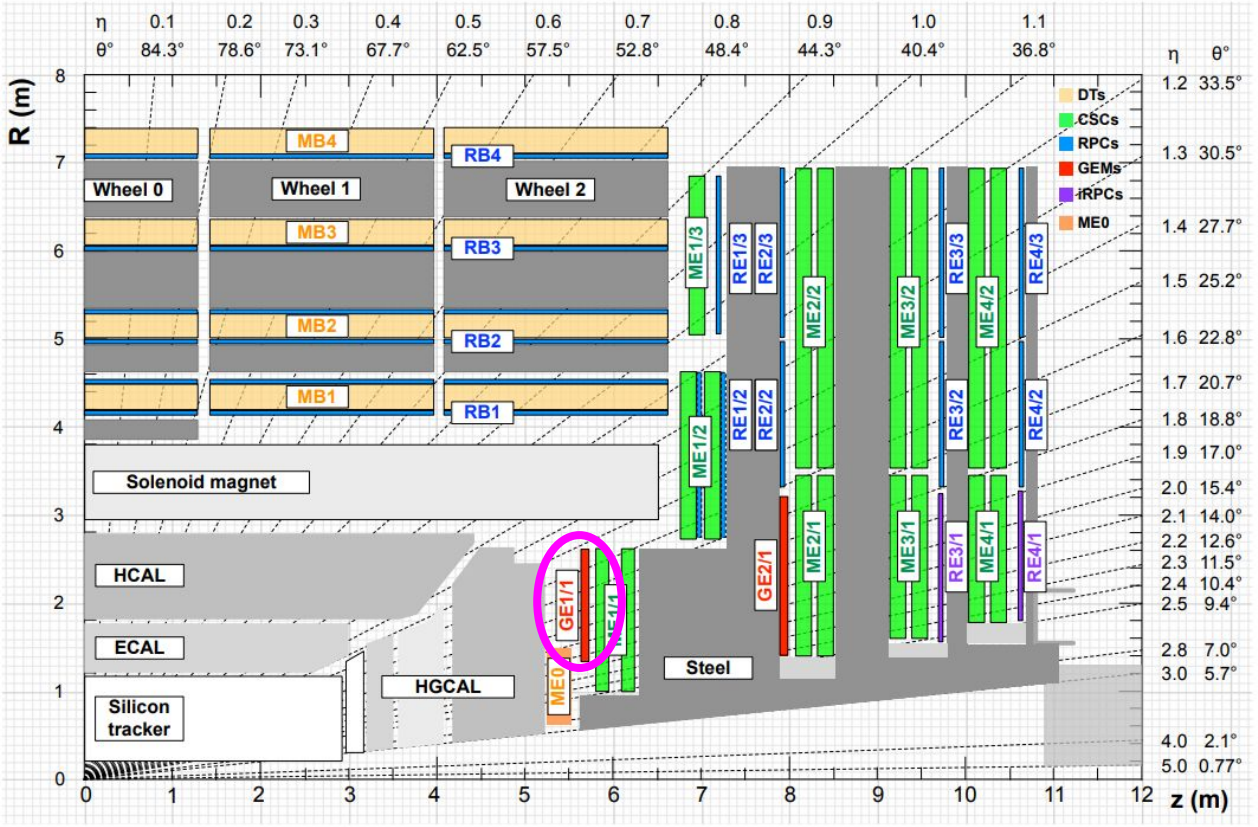


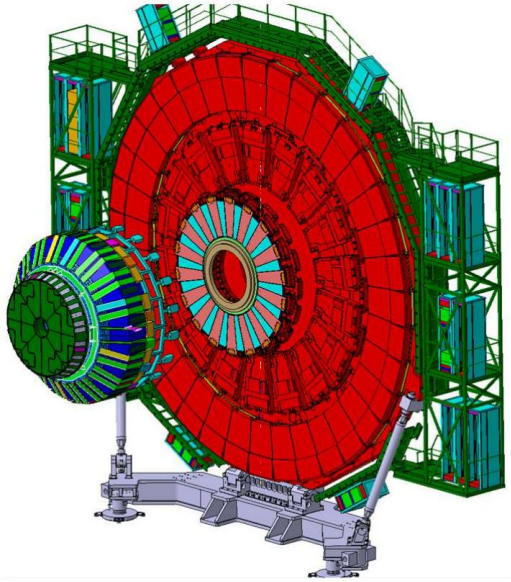
Commissioning of the CMS GE1/1 Detector

Brendan Regnery
on behalf of the CMS Collaboration
Department of Physics, One Shields Avenue, Davis, CA 95616

CMS
Compact Muon Solenoid

CMS: GE1/1



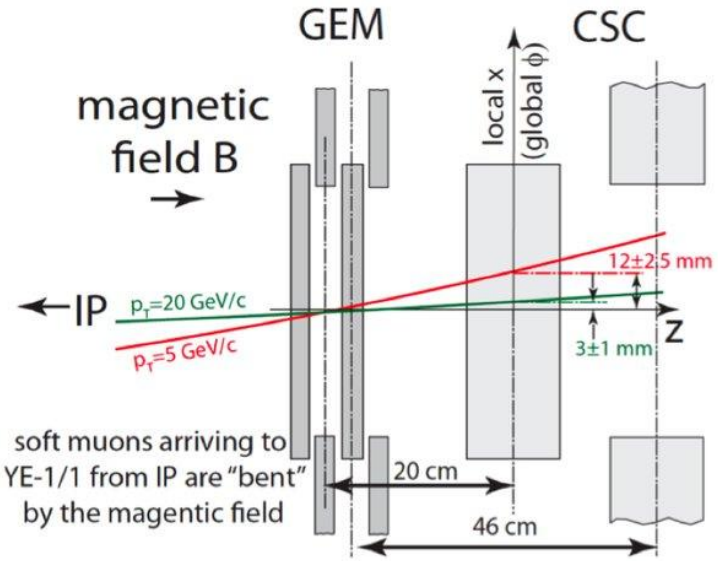


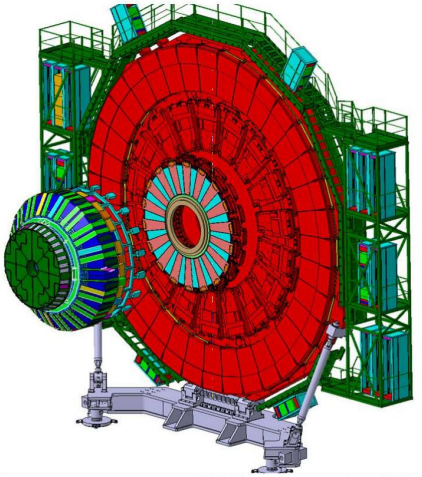
LHC is upgrading to a high luminosity version

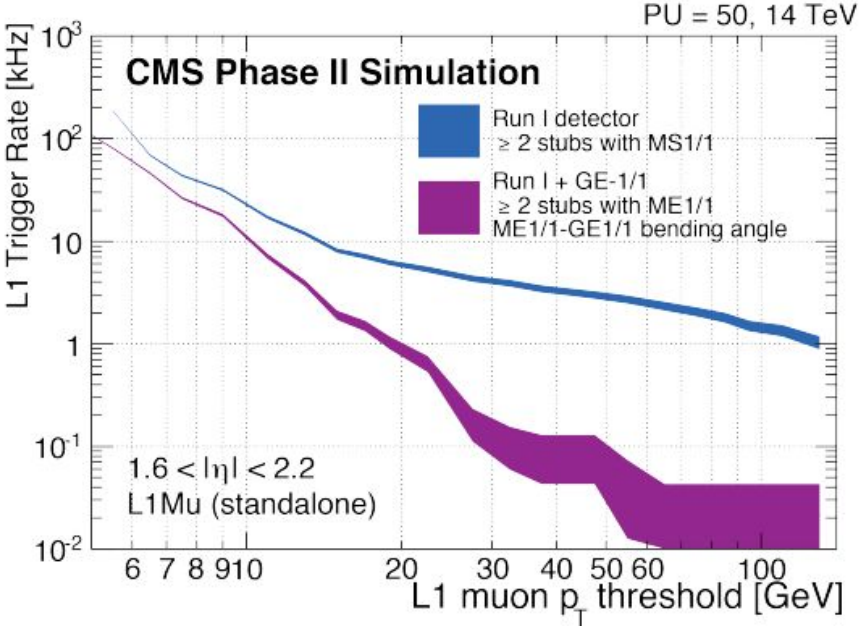
Additional layers needed in muon system to compensate for high rates

First layer installed is the new GE1/1 station

GE1/1 Trigger Improvement







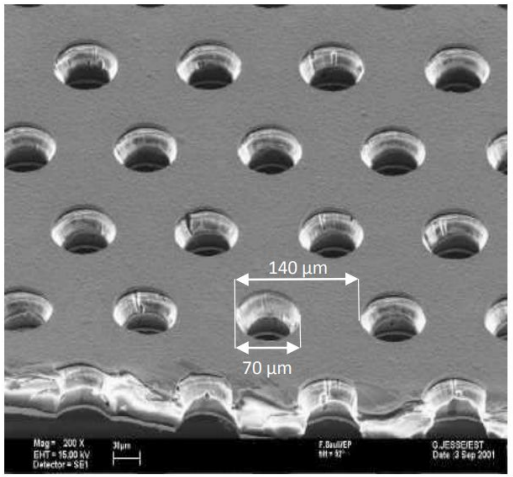
Muon Trigger improvement:

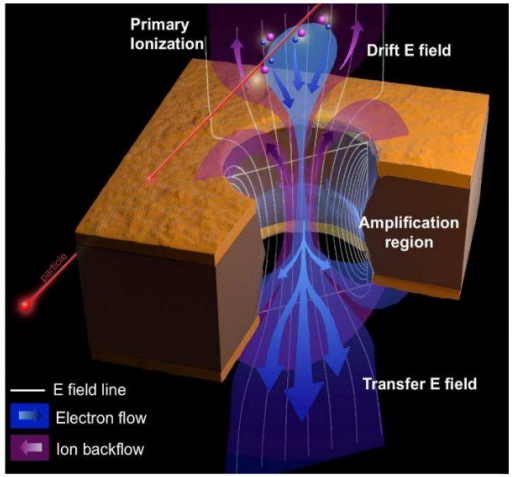
Addition of 2 GEM hits to the 4-6 CSC hits

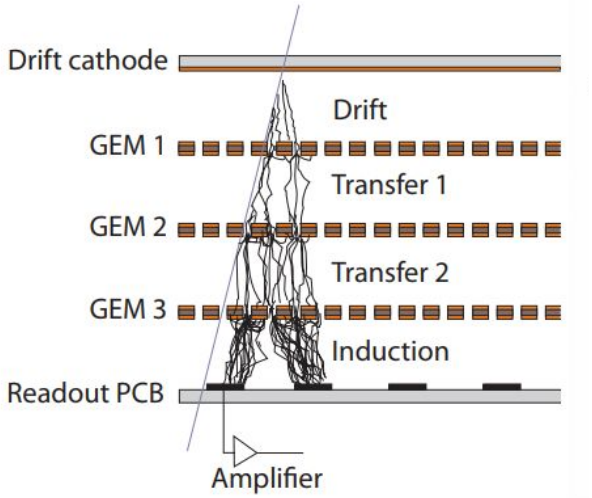
➔ More precise measurement of azimuthal muon bending angle!

GEM: Gas Electron Multiplier

- Gas chambers for detecting ionizing particles
- Foils - insulating layer with conductors on top and bottom
  - Conductors at different potentials
  - Microscopic holes create sharp electric field
- Electrons drift in the gaps and avalanche in the foils' holes
- Electron cloud induces a signal on the readout strips







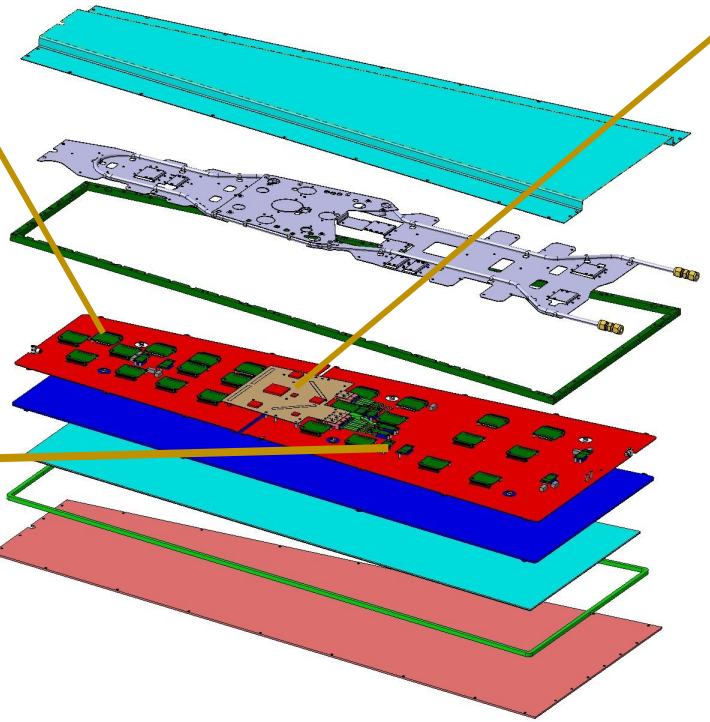
High Rate Capabilities

Less recovery time between particles than traditional wire chambers

GE1/1 Readout Electronics

VFAT3 front-end chips

- 128 readout channels
- Data path w/ full granularity
- Sends trigger data via 8 parallel lines
- Can deliver calibration pulses



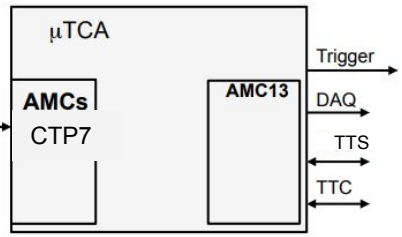
OptoHybrid

- Communication between VFATs and backend electronics via gigabit transceivers (GBTx's)
- Sends slow control commands to front-end electronics (via SCA)
- Transfers tracking and trigger data to backend and CSCs

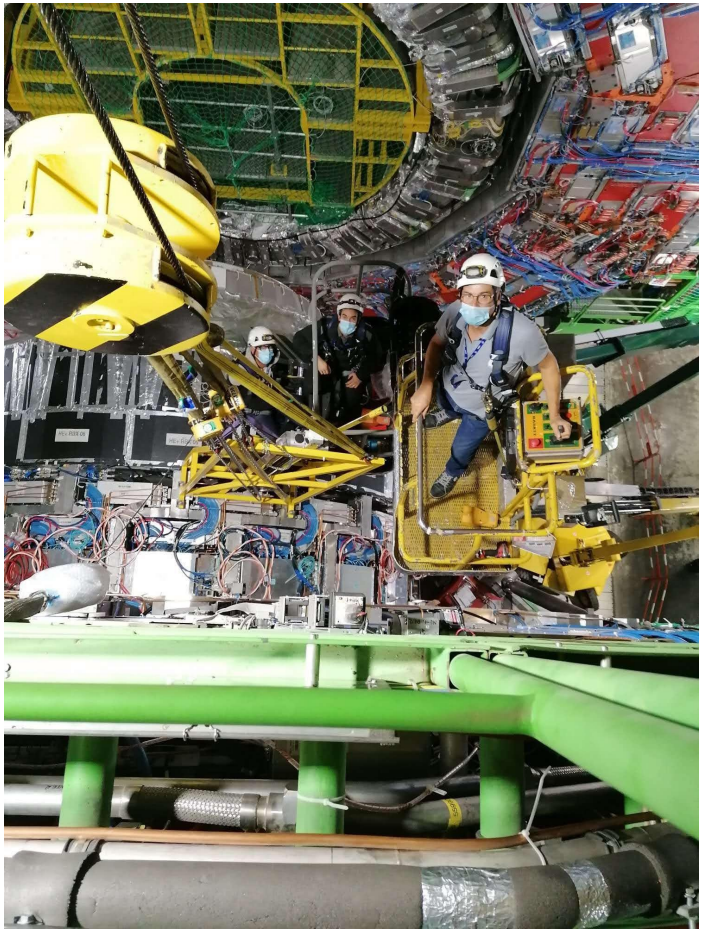
FEASTs

- Radiation hard DC-DC converters delivering a precise output voltage

Backend



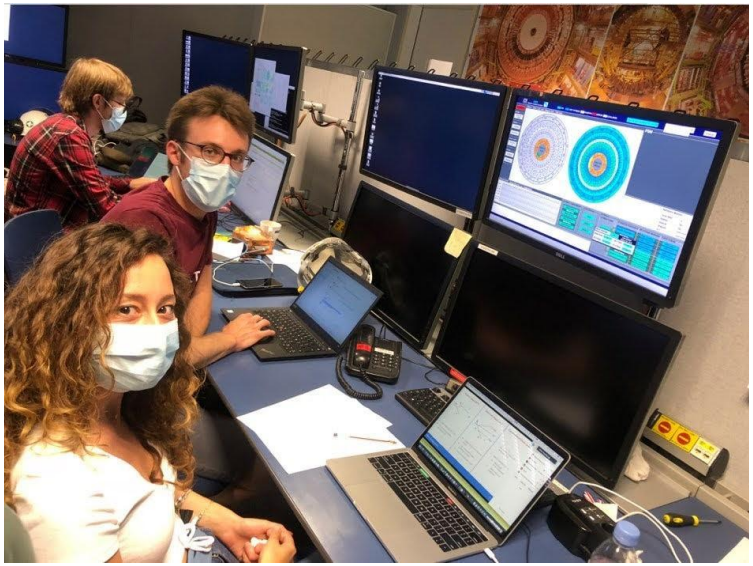
Preparing GE1/1



✅ Production

✅ Installation

Commissioning



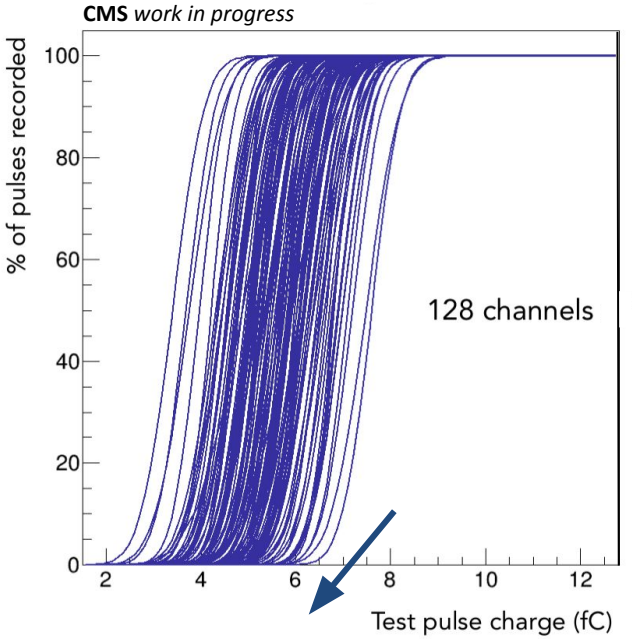
Commissioning

Initial Commissioning

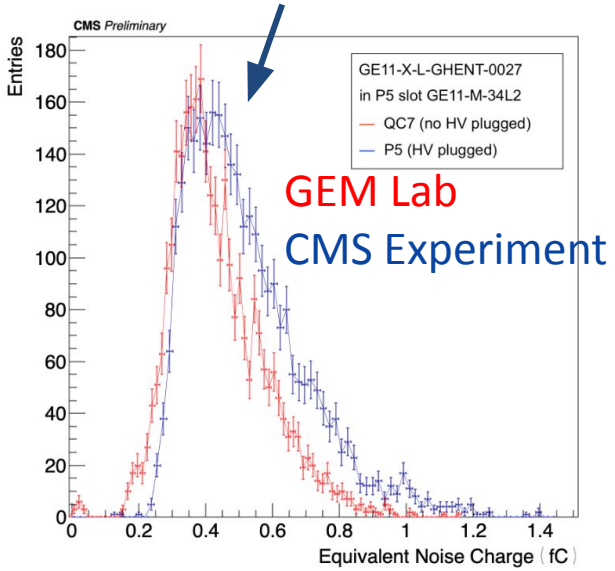
- Test connectivity, mapping, and HV
- Test the electronics
  - SCurves: Pulse channels and measure recorded pulses
  - SBit rates: Rates of triggers sent

Challenges

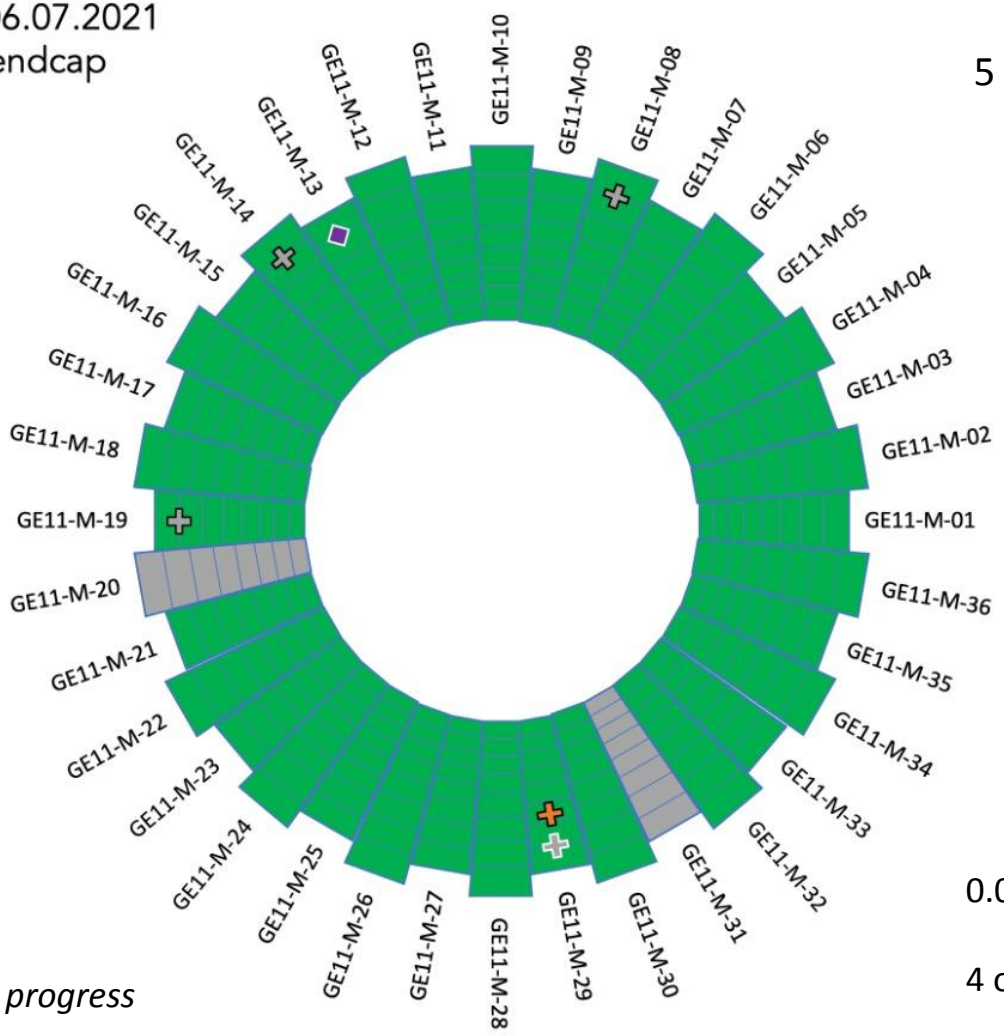
- GigaBit Transceiver (GBT) Instabilities
- Noise Mitigation



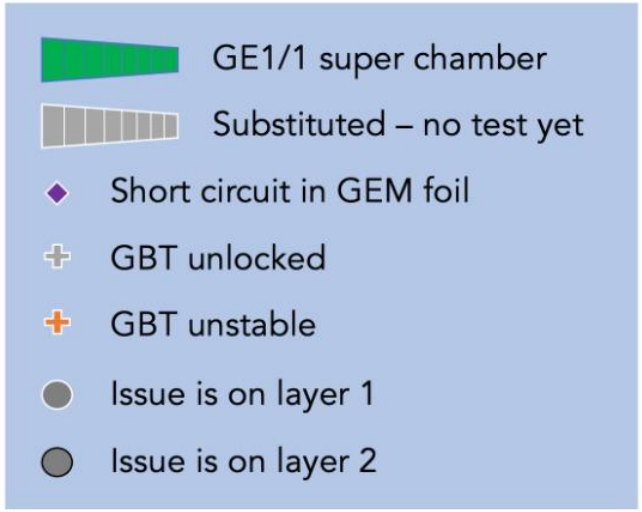
Curve width defines the intrinsic noise level



Negative End-cap Status



5 GBT Communication Issues

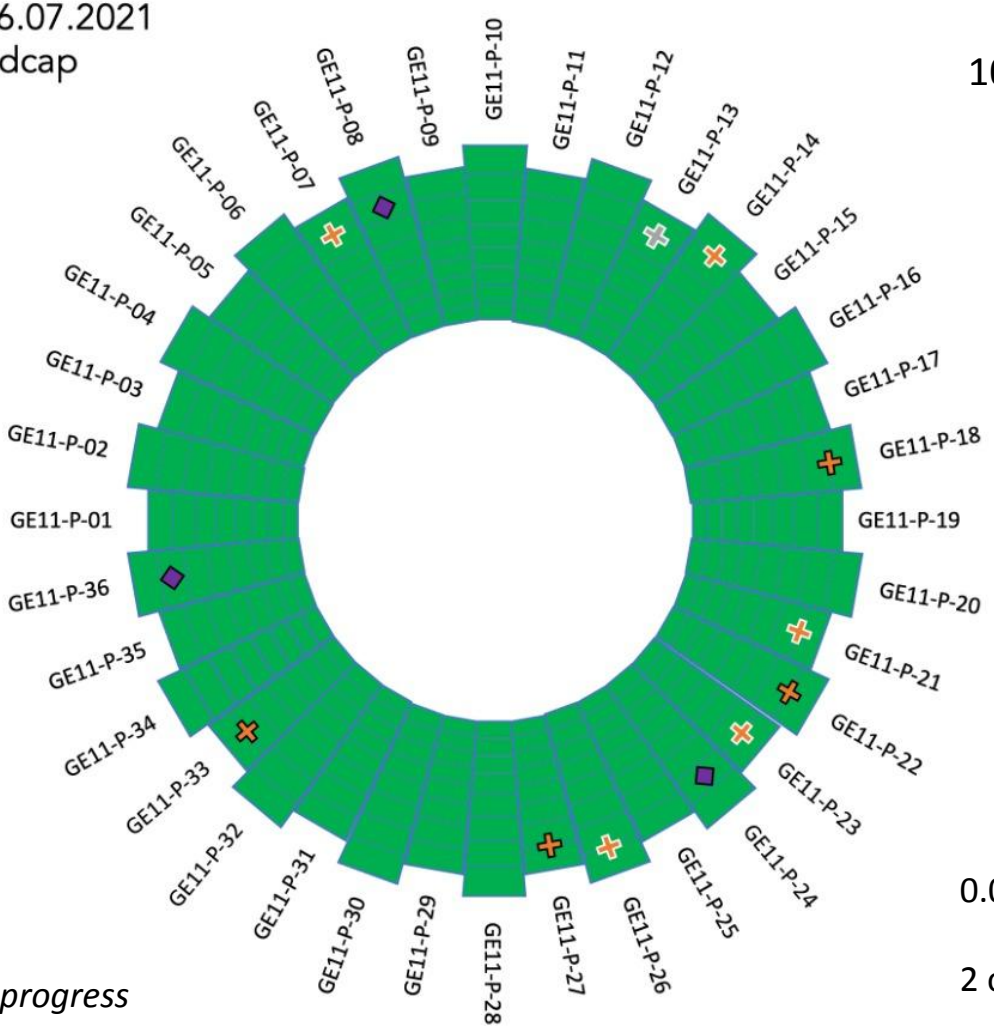


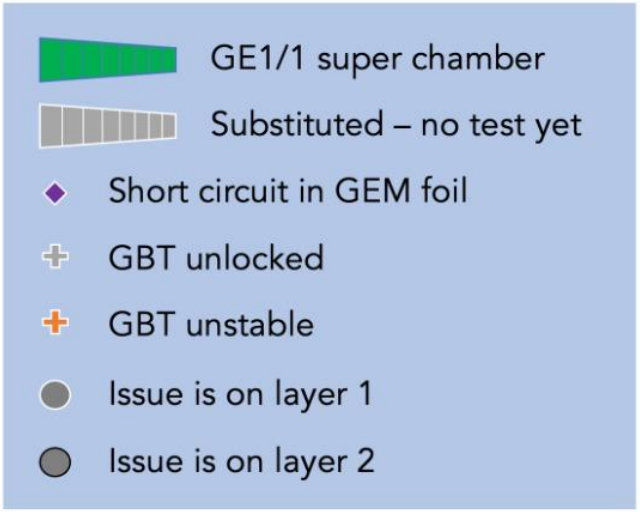
0.043% of trigger lines not working properly

4 of 1728 VFATs with communication issues

CMS *work in progress*

Positive End-cap Status





10 GBT Communication Issues

0.043% of trigger lines not working properly

2 of 1728 VFATs with communication issues

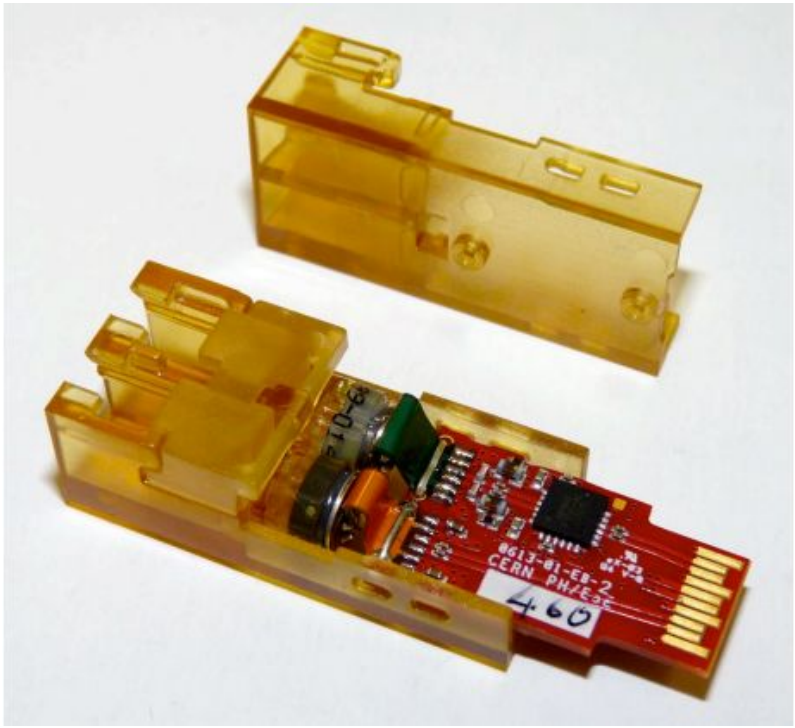
CMS *work in progress*

GBT Instabilities: The Problem

- GigaBit Transceivers (GBT) send information on optical fibers via a versatile link (VTRx)
  - Send data from the detector
  - Receive slow control information
- Around 15 of 144 GBTs have communication issues
  - The affected GBTs change, but the number remains around 15

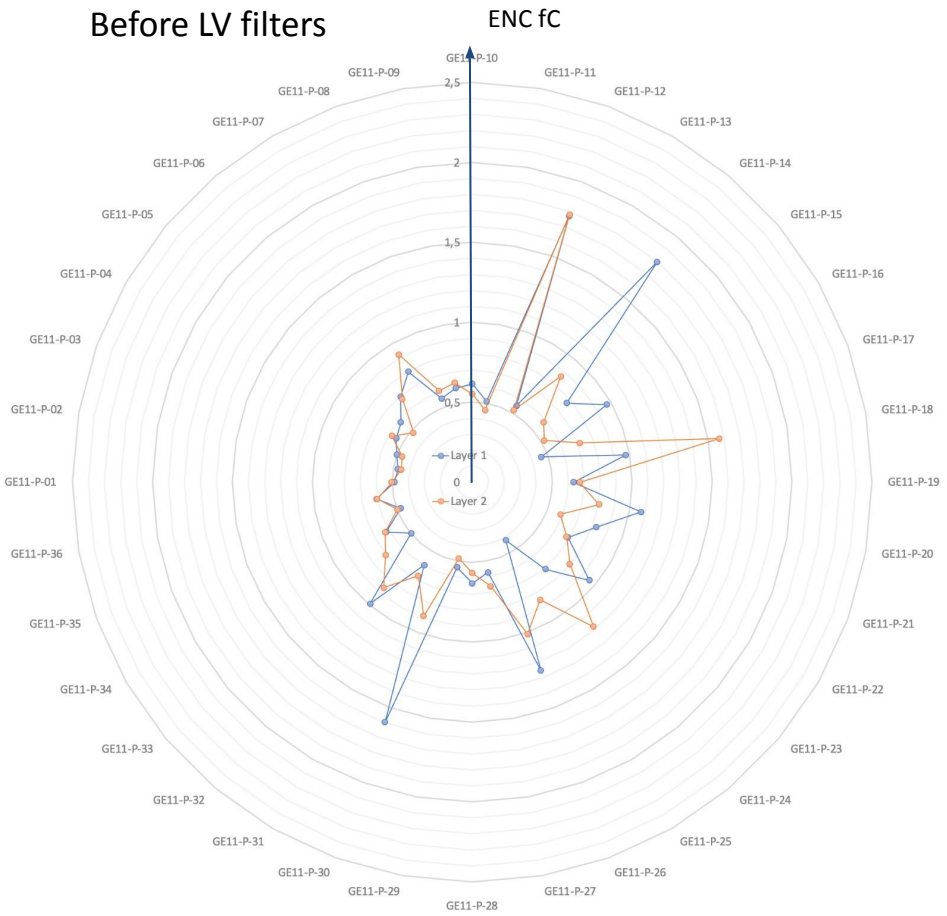
GBT Instabilities: The Cause

- VTRx
  - Photodiode for receiving
  - Laser for transmitting
- Photodiode attached with epoxy which is outgassing
- Deposits cloud the optical fiber causing the instability
- Electronics team has a long term plan defined for baking the VTRx's
- During run 3, GE1/1 will carefully monitor the instabilities



Noise Mitigation

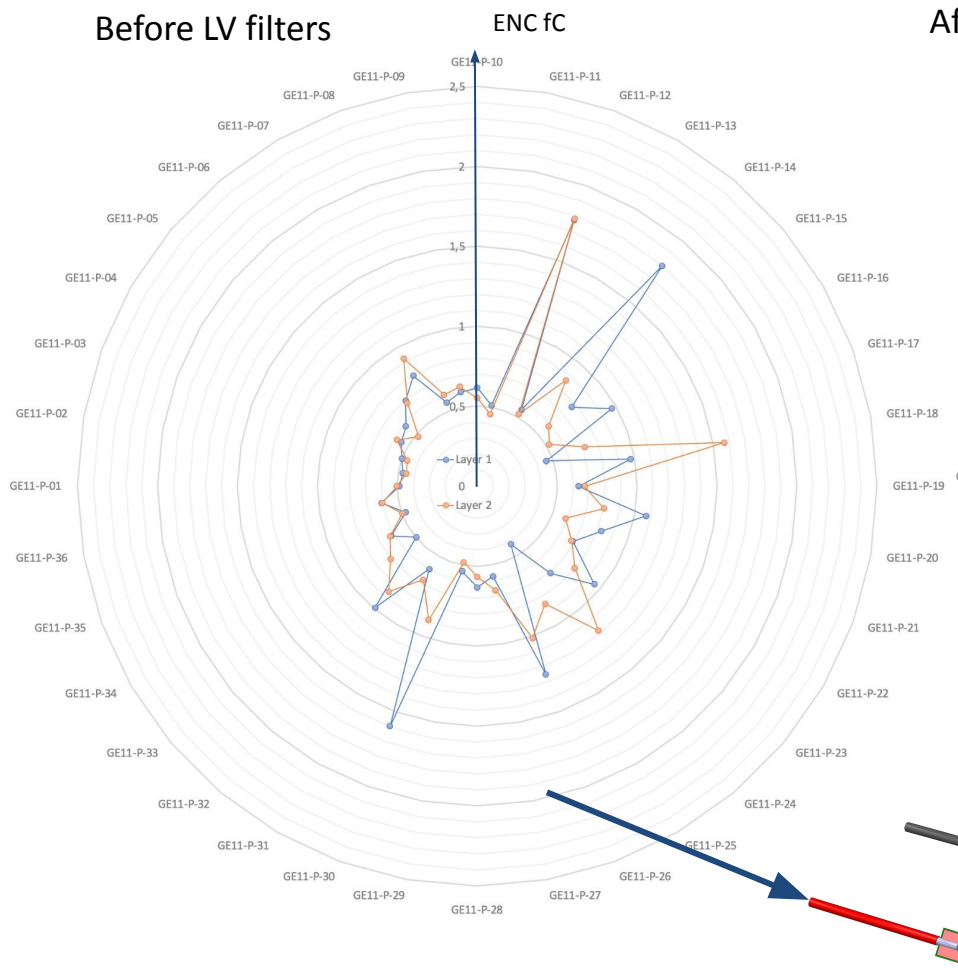
- **Problem:** The noise level in point 5 was quite high after initial commissioning
- **Solution:** Designed LV filters to mitigate noise in readout electronics
  - 144 chamber-side filters installed at the beginning of May
- Detailed noise scans taken throughout the process



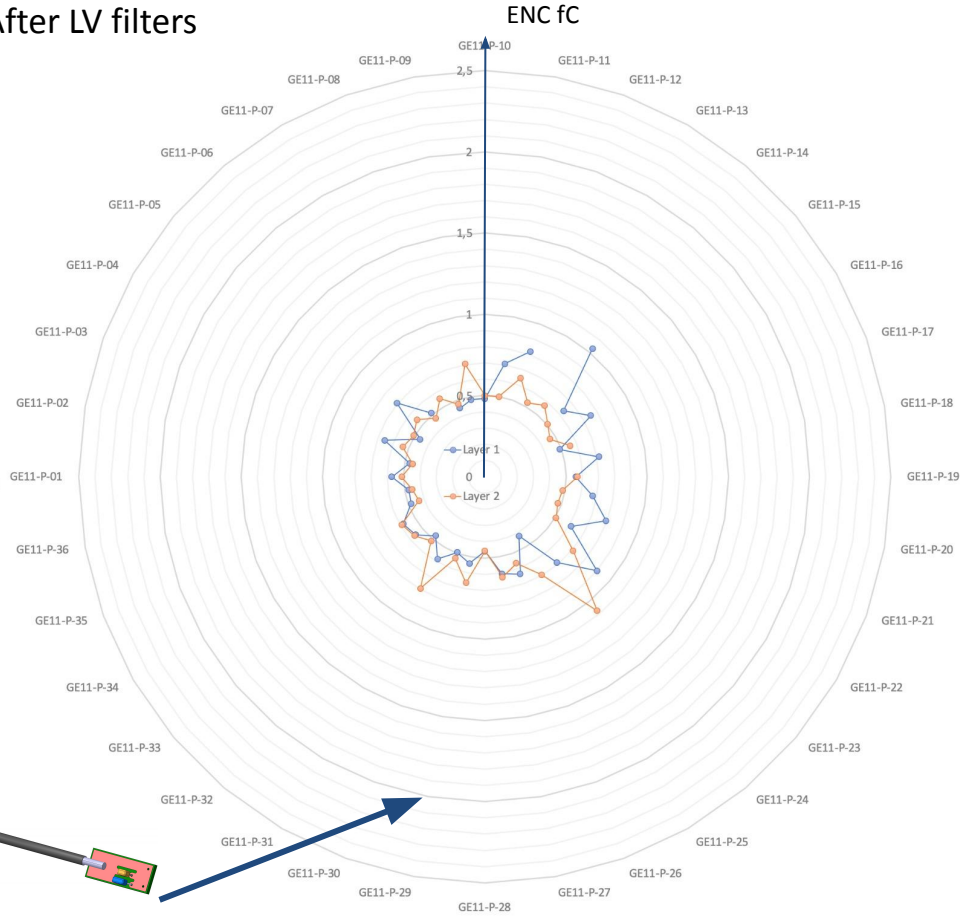
CMS *work in progress*

LV Filter Installation: Positive End-cap

Before LV filters



After LV filters



CMS *work in progress*

Missing chambers due to GBT instabilities

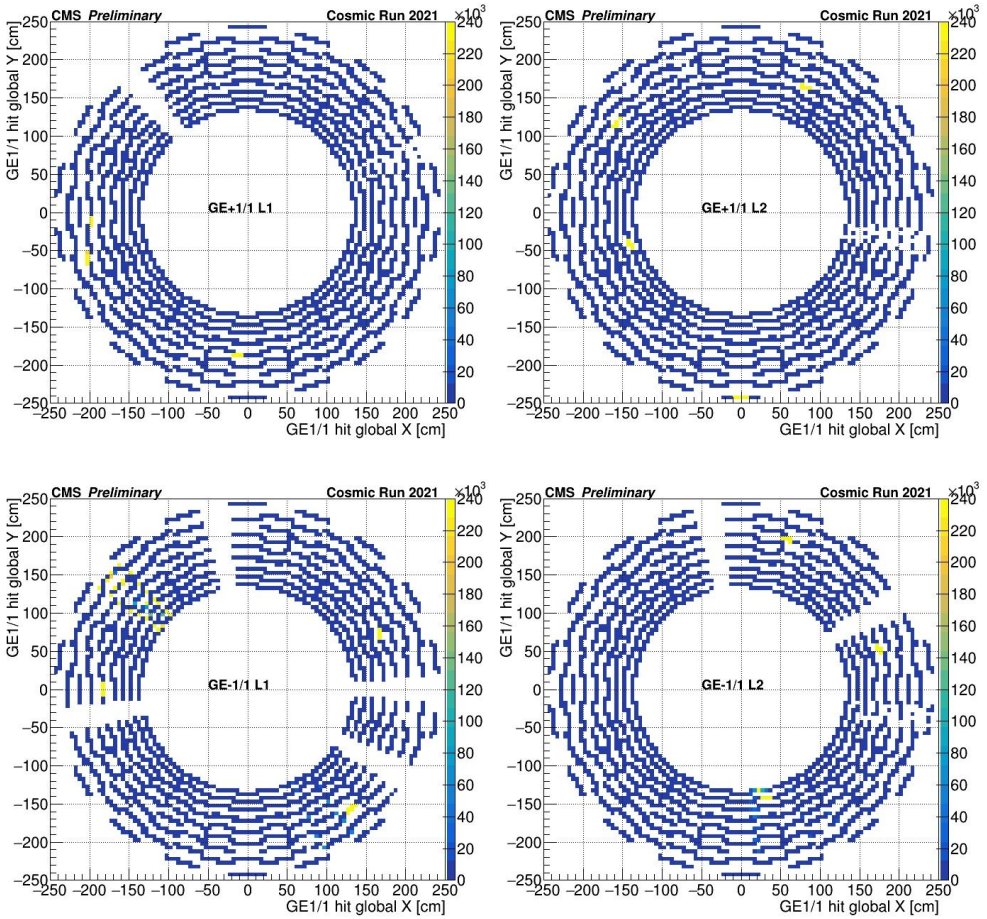
Next Steps

- Continue to perform full scale cosmic runs with the entire GE1/1 system to improve the detector configuration
  - Beginning long cosmic runs in July
- Align (in time) GE1/1 hits with other CMS subsystems and perform trigger tests
- Finish testing and development of the DAQ and DCS software

LHC run 3… Here we come!

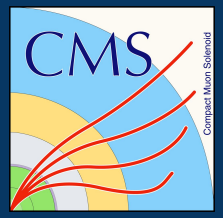
Summary

- 72 Super Chambers have been installed at CMS
- Both end-caps have nearly completed the initial commissioning phase
- Challenges arose during commissioning:
  Noise and GBT instabilities
  - Noise resolved with LV filters and GBT instabilities will remain closely monitored with software



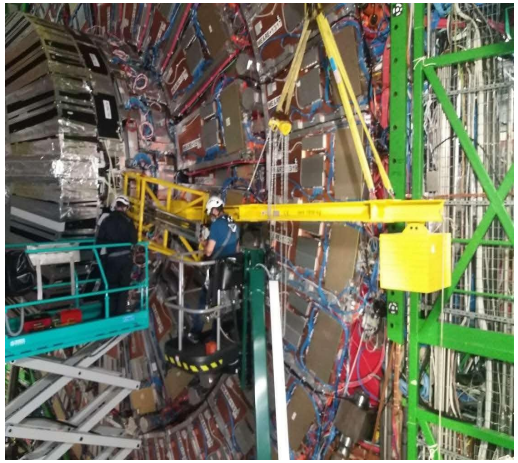
Now taking data with cosmic muons!

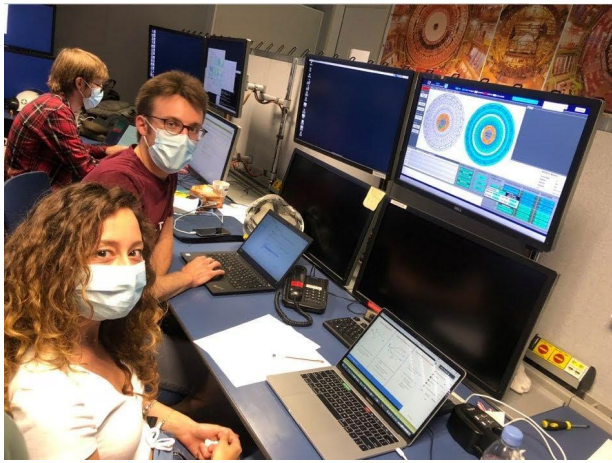
For more GEM talks at APS DPF, see the next talk:
https://indico.cern.ch/event/1034469/contributions/4431743/



Back-Up

Commissioning





1. Connectivity and mapping tests
2. Electronics test
3. HV Tests and training

Initial Commissioning

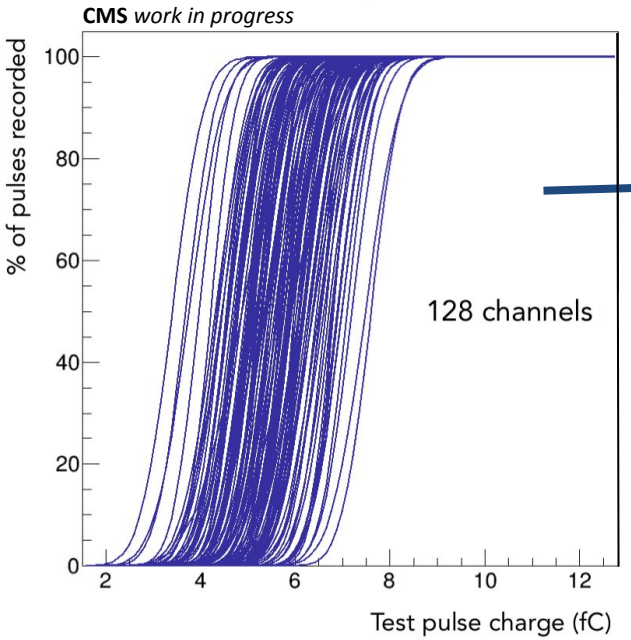
1. Chamber-side LV Filters
2. LV Board Modification

Noise Mitigation

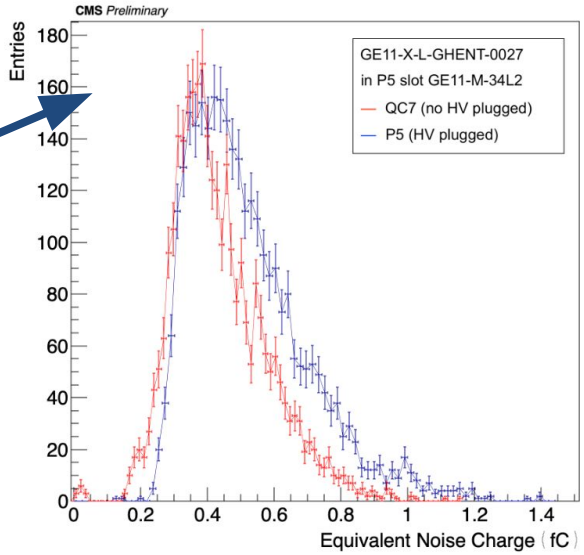
1. DAQ Software Tests
2. Cosmic Runs

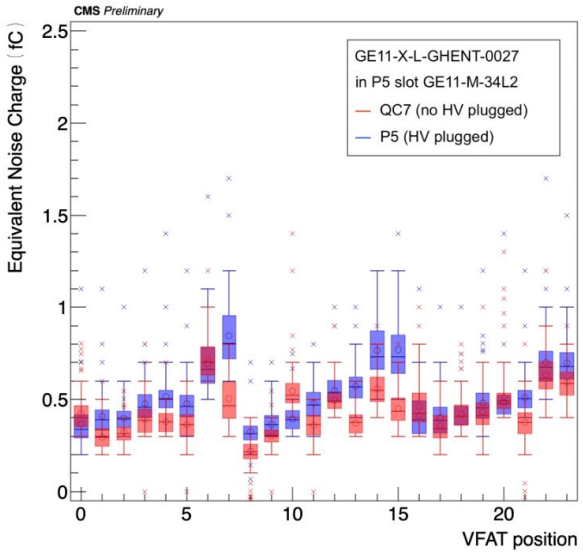
Mid-Week Global Runs

FE Test Example: Tracking Path



Curve width defines the intrinsic noise level



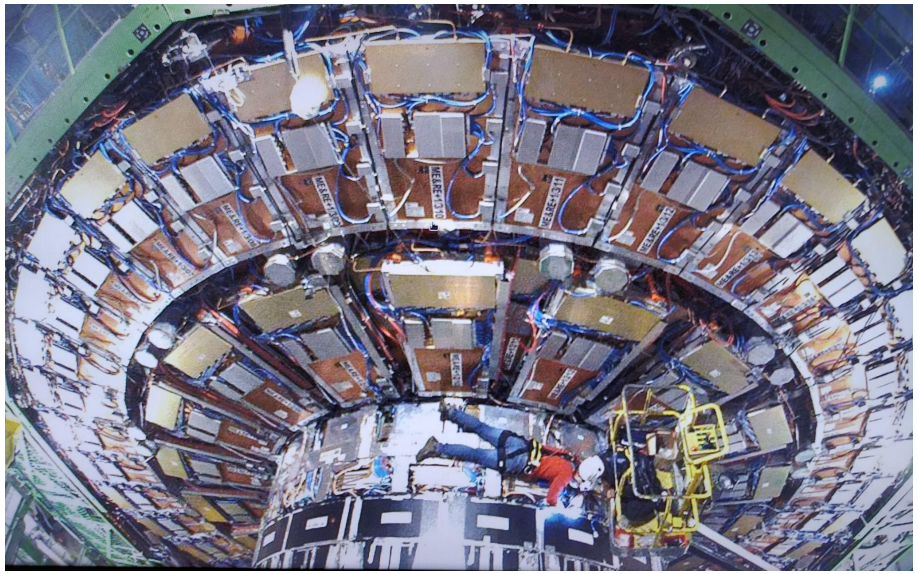


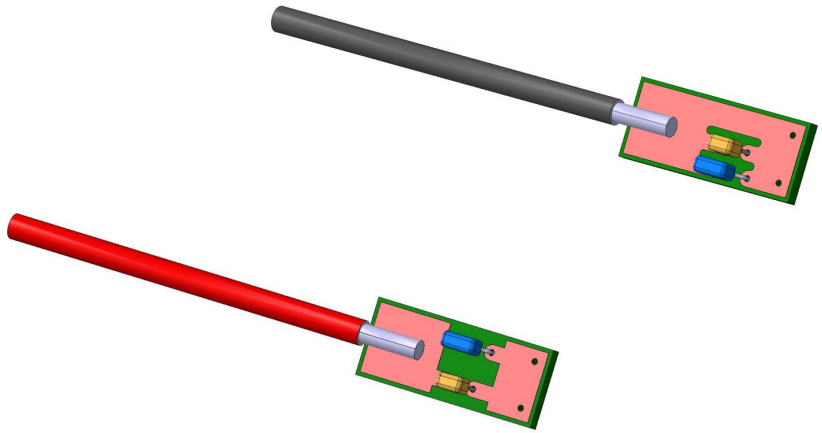
QC7 (GEM Lab)
CMS Experiment

Example of GE1/1 noise level in CMS

LV Filter Installation

- Designed to mitigate noise in readout electronics
- 144 chamber-side filters installed at the beginning of May
- Noise levels decreased in most chambers
- LV filters also installed on LV boards

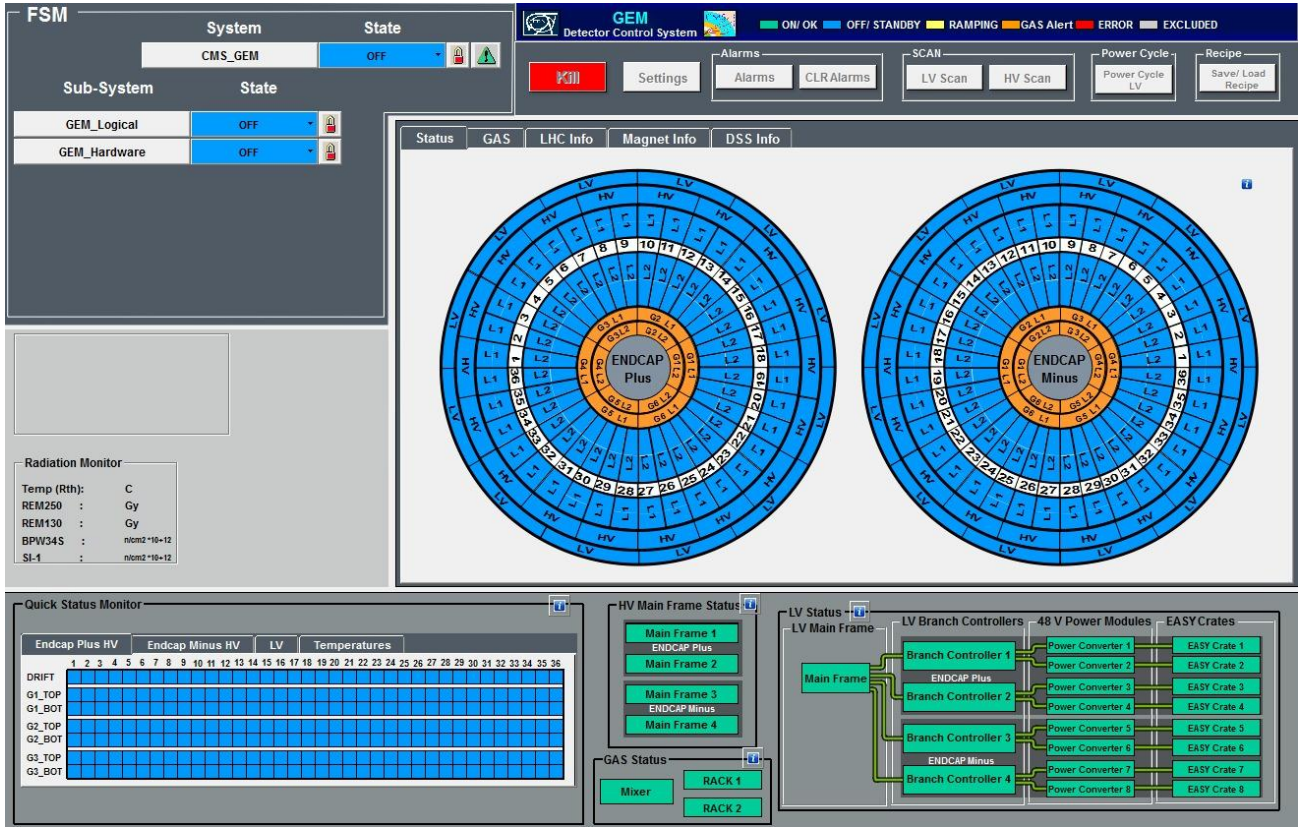




DCS: Detector Control System

We have been testing, developing, and using the DCS during the commissioning process

- ➔ Confirmed LV mappings
- ➔ Confirmed HV mappings (except for newly replaced chambers)
- ➔ Finite State Machine (FSM) added to Central DCS

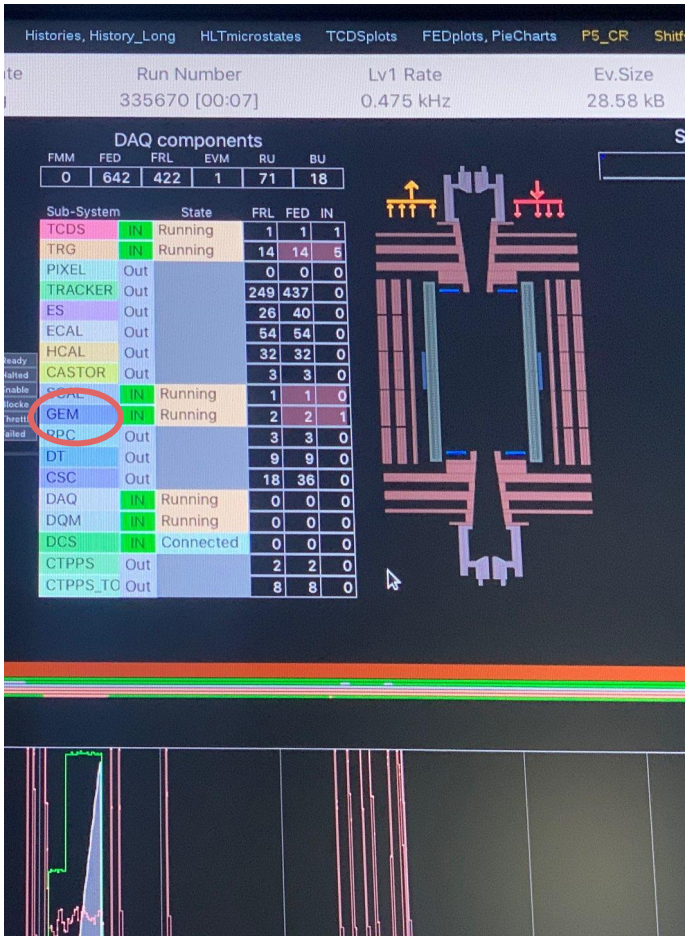


DAQ: Data Acquisition

- **Performing full scale cosmic runs with the entire GE1/1 system**
  - DAQ only tests
  - A few chambers already completed HV training with final gas mixture, so they saw the first cosmics
  - Subsequent cosmic runs used for resolving issues and testing new tools
- **Trigger tests** are on going with other muon subsystems at CMS

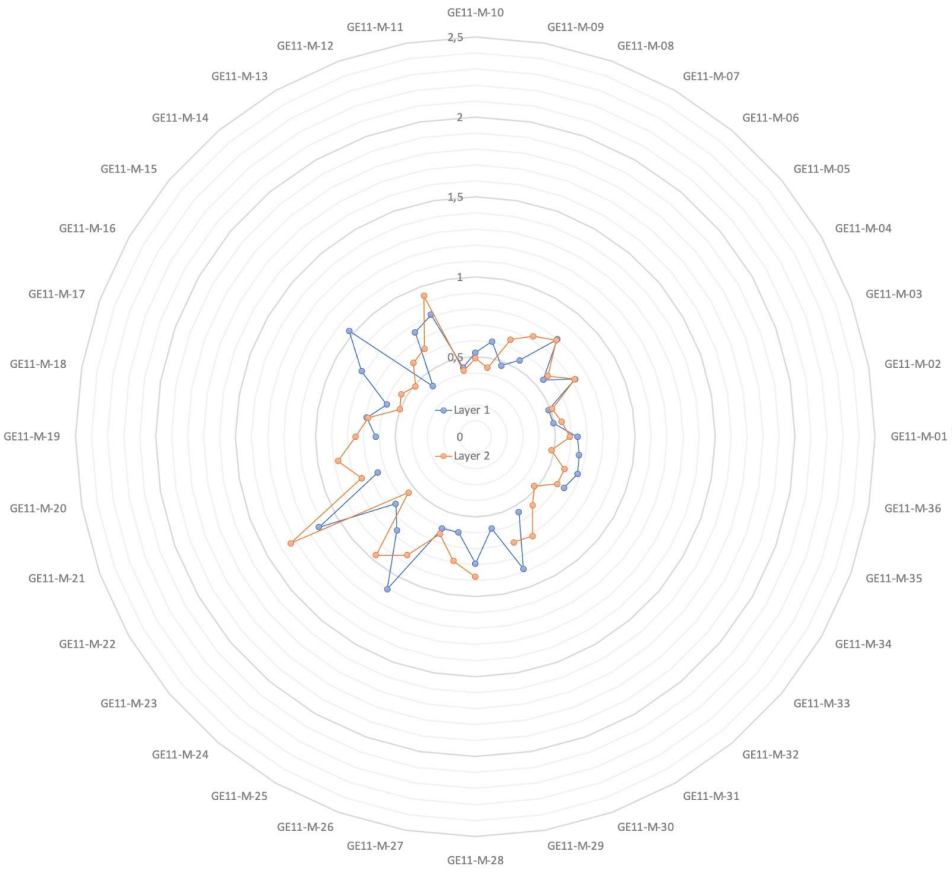
Near future plans

- Finalize DAQ commissioning to prepare for LHC run 3

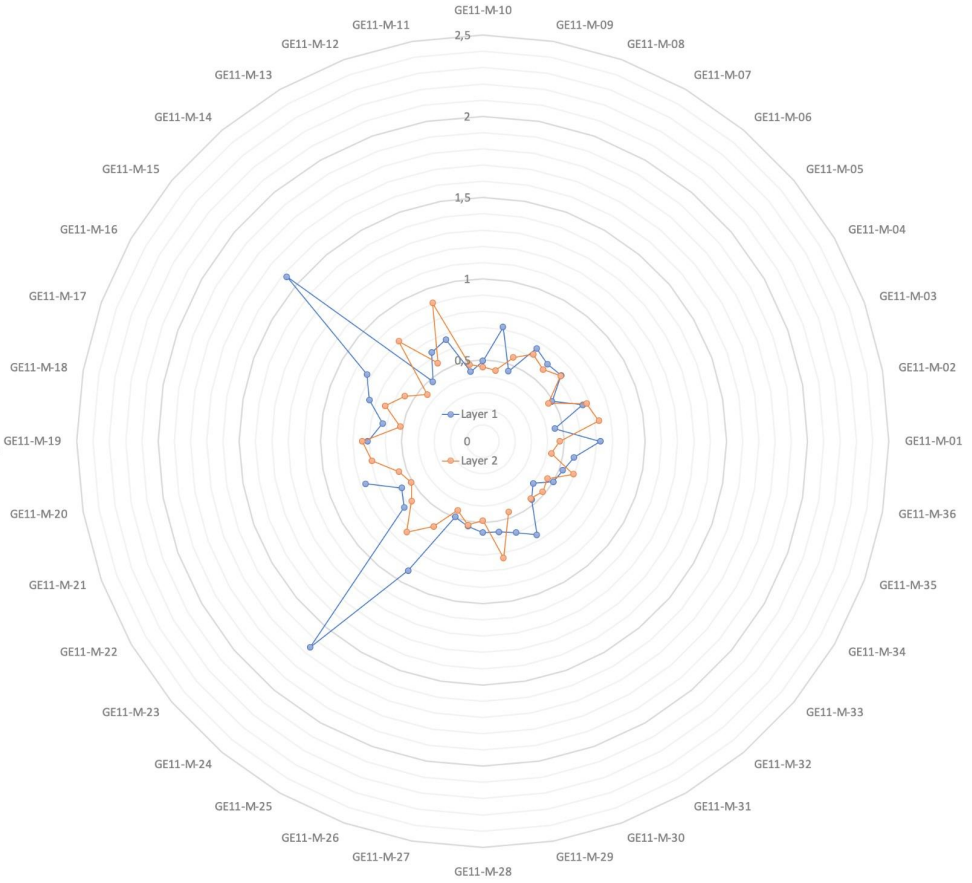


Noise Comparison: Negative

Before LV filters



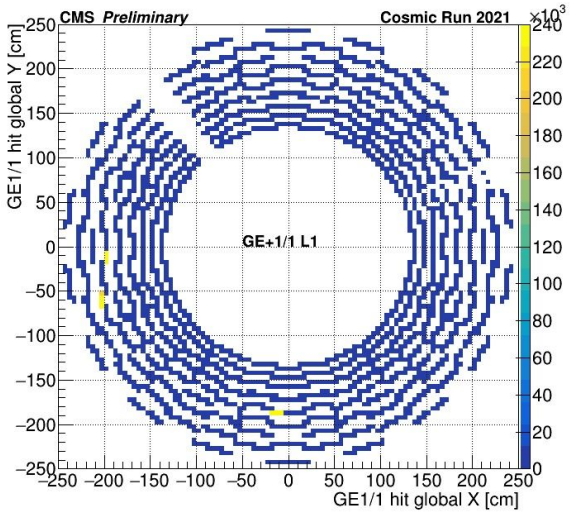
After LV filters

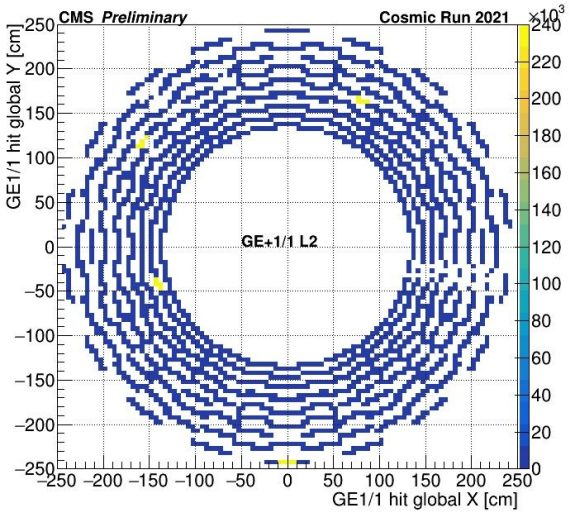


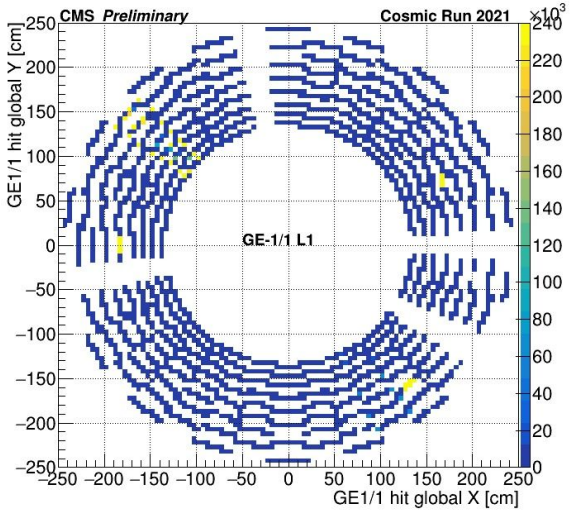
Missing chambers due to GBT instabilities

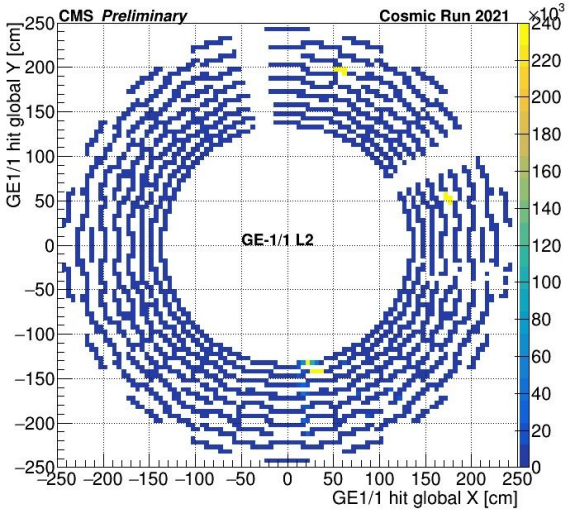
Global Cosmic Runs

- Majority of chambers have now participated in cosmic runs
- Several chambers still not showing occupancy due to communication instabilities
- DAQ software still under development and testing









GE1/1 Detector Production

161 chambers produced

144 chambers for installation
17 spare chambers

Produced around the world: CERN, Pakistan, India, Florida (USA), Belgium, Italy, Germany

Paired into super chambers

77 super chambers produced

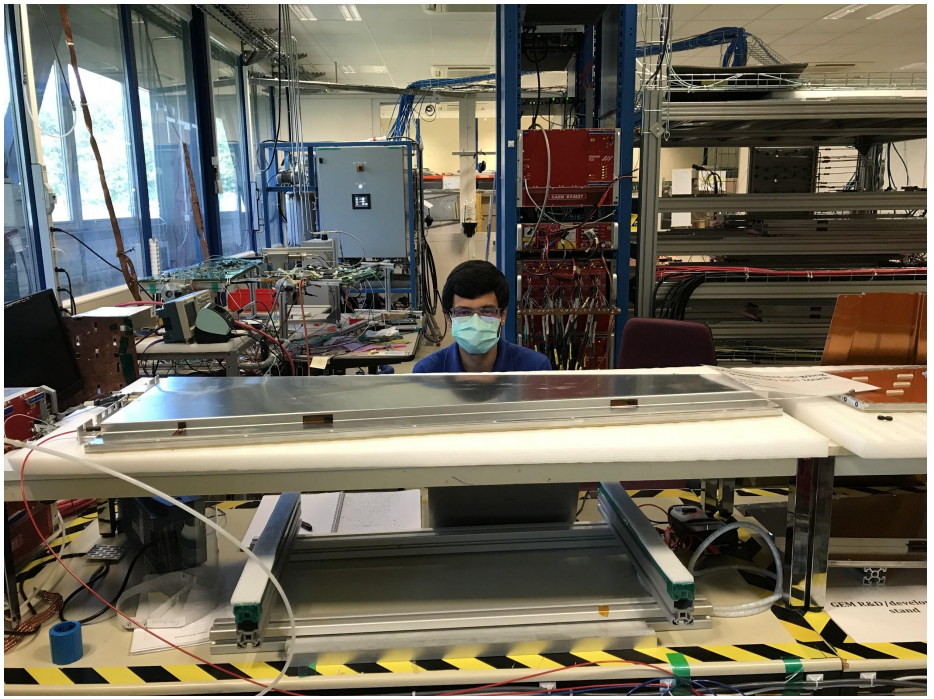
72 super chambers installed in the experiment

*QC: Quality Control, HV: High Voltage

Final QCs: QC6

Objective: Test HV with final filter and power supply

1. Stress test at 550V per foil
2. Continuity test
3. Stress test up to 1000 V per foil
4. HV scan #1 (IV measurement)
5. long-term stability (> 12 hours)
6. HV scan #2 (IV measurement)

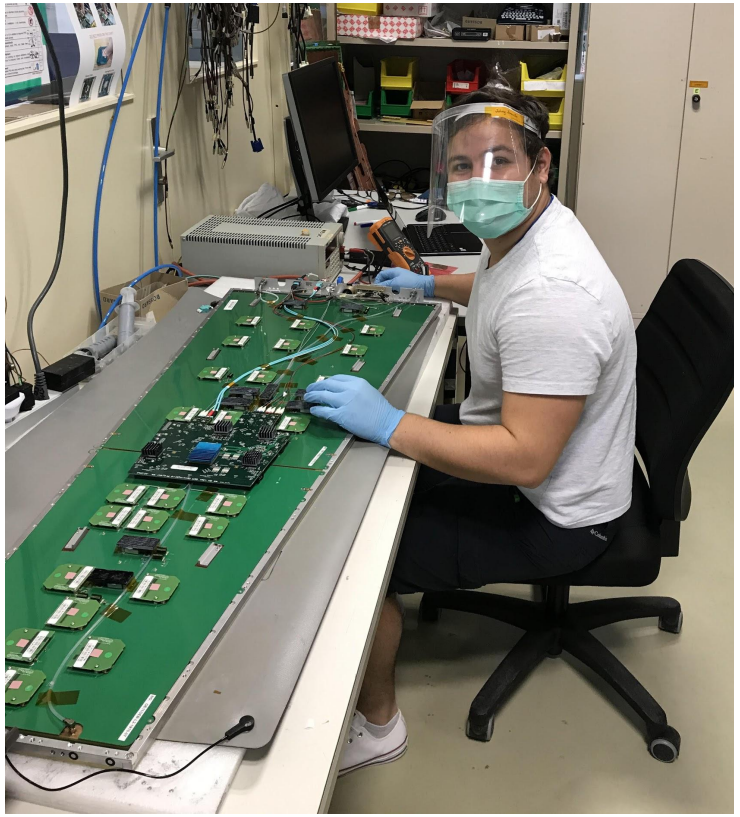


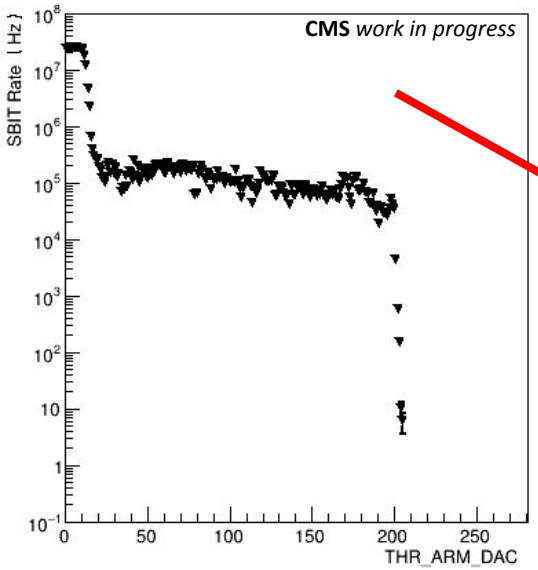
Final QCs: QC7

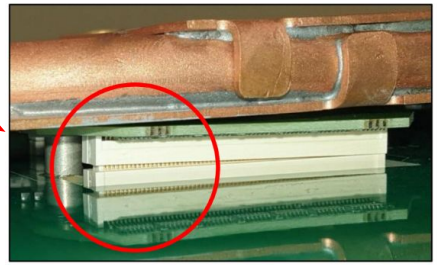
Objective: Test front-end electronics

1. Test communication
2. Calibrate electronics
3. Scan electronics for bad connections or hot/dead channels
4. Global threshold scans (SBIT Rates per VFAT)
5. ENC measurement (SCurves)
6. Local threshold scans (SBIT lines per channel)

Repeat after instal[illegible]nstalling chamber cover

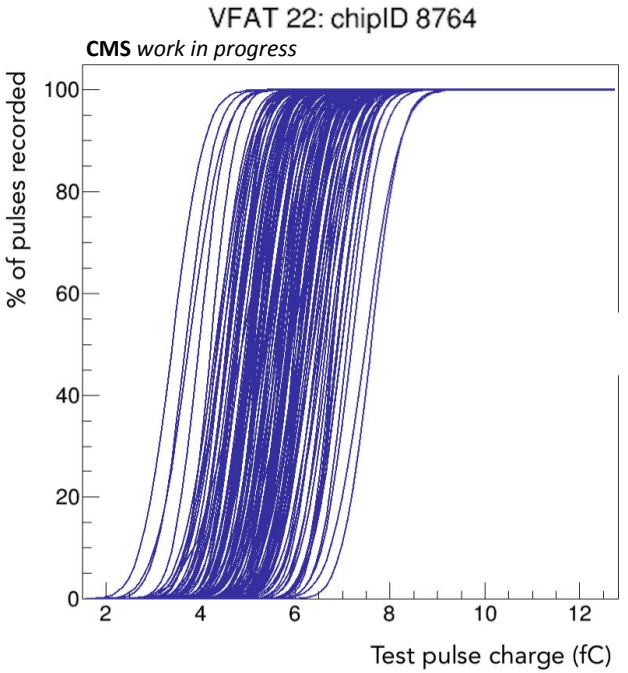




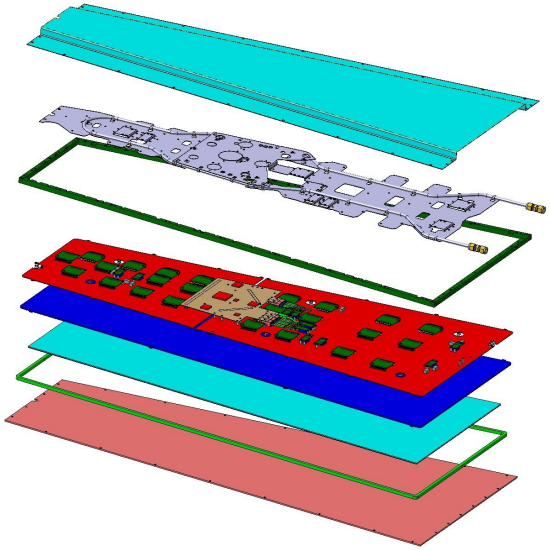


Monitor noise in trigger path

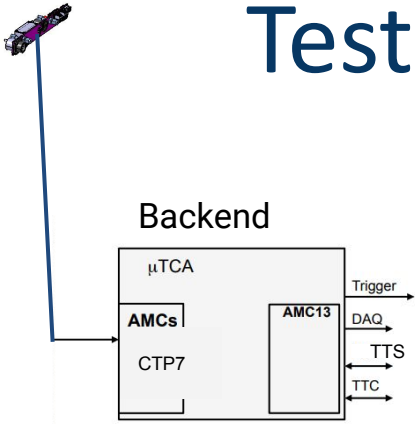
Excessive noise points to a broken trigger path due to a disconnection

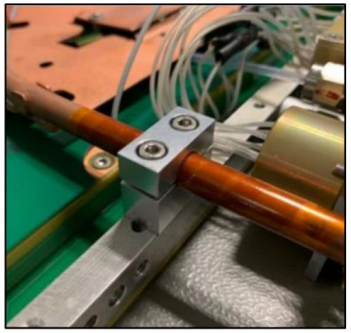


Noise = width of this ‘s’ curve



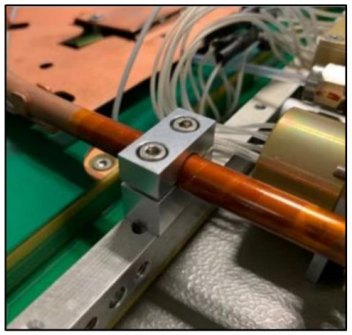
QC7 Electronics Test





Noise in the tracking path due to ground loops on the cooling plate

QC7: Common Issues and Solutions

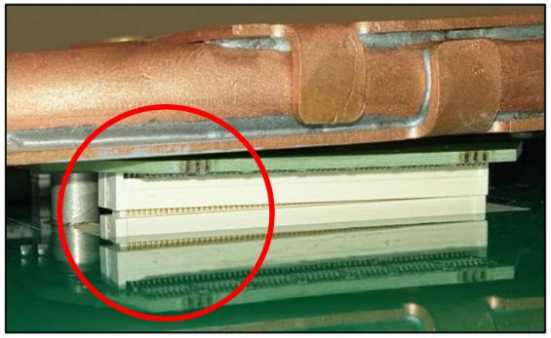


Ground loops on the cooling plate

- Inject noise
- Insulating tape prevents unwanted contacts
- Enlarged screw holes prevent screw-plate contact

Faulty FEASTS

- Inject noise or does not work
- Replace FEASTS



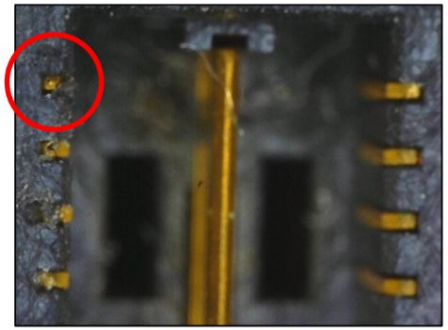
Disconnected VFATs

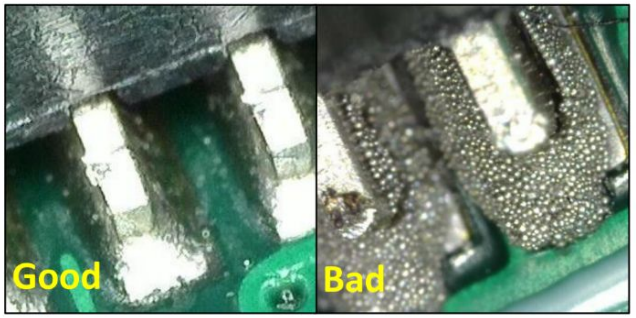
- Create broken SBIT Lines
- Adjust pressure points of cooling plate

Dirty PANASONIC connectors

Issues with SAMTEC connector

- Fix bad soldering
- Replace bad connectors





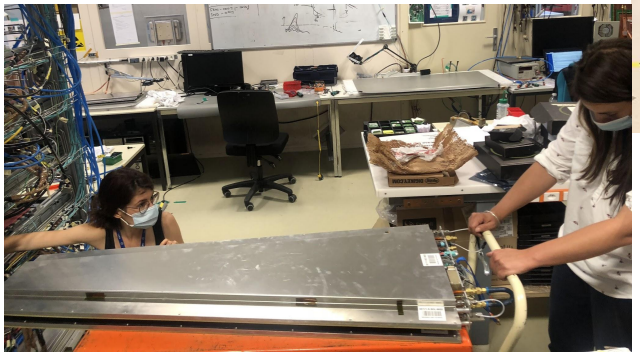
Final QCs: QC8

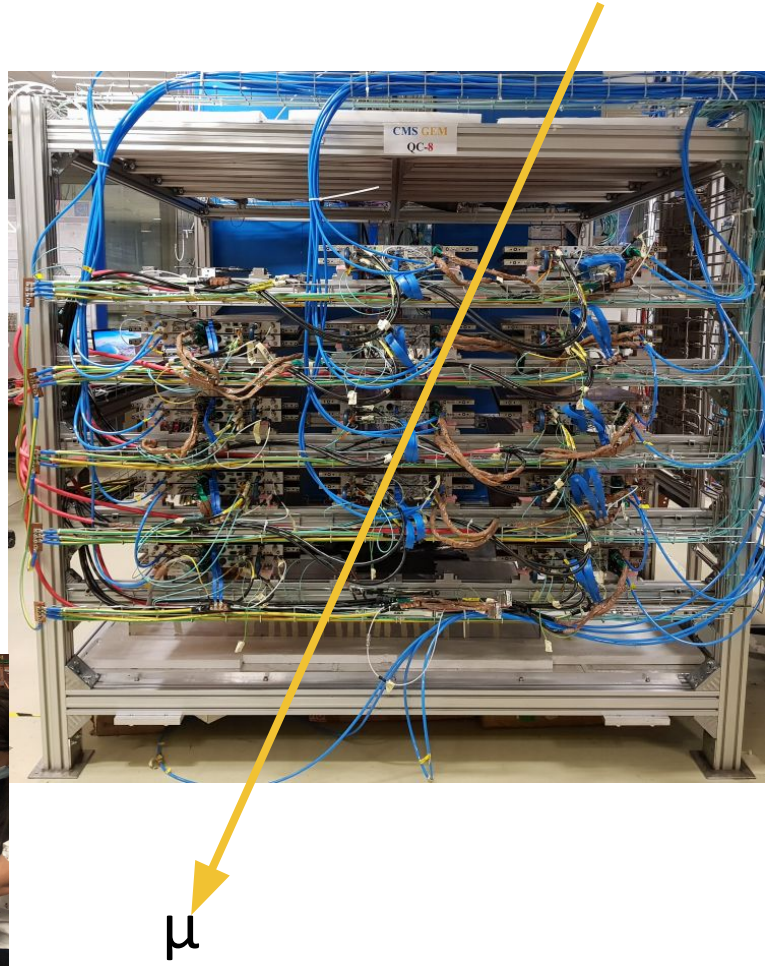
Cosmic Stand

- 15 super chamber slots with 2 layers of scintillators (90Hz trigger)
- 92k readout channels with CMS-like DAQ based on µTCA backend (with CTP7s)
- CMS like environment (LV, HV, cooling, DAQ system, and dedicated DCS)
- Gas mixture Ar/CO_2 70/30% (with CO_2 and pure air lines available)

QC8 Test

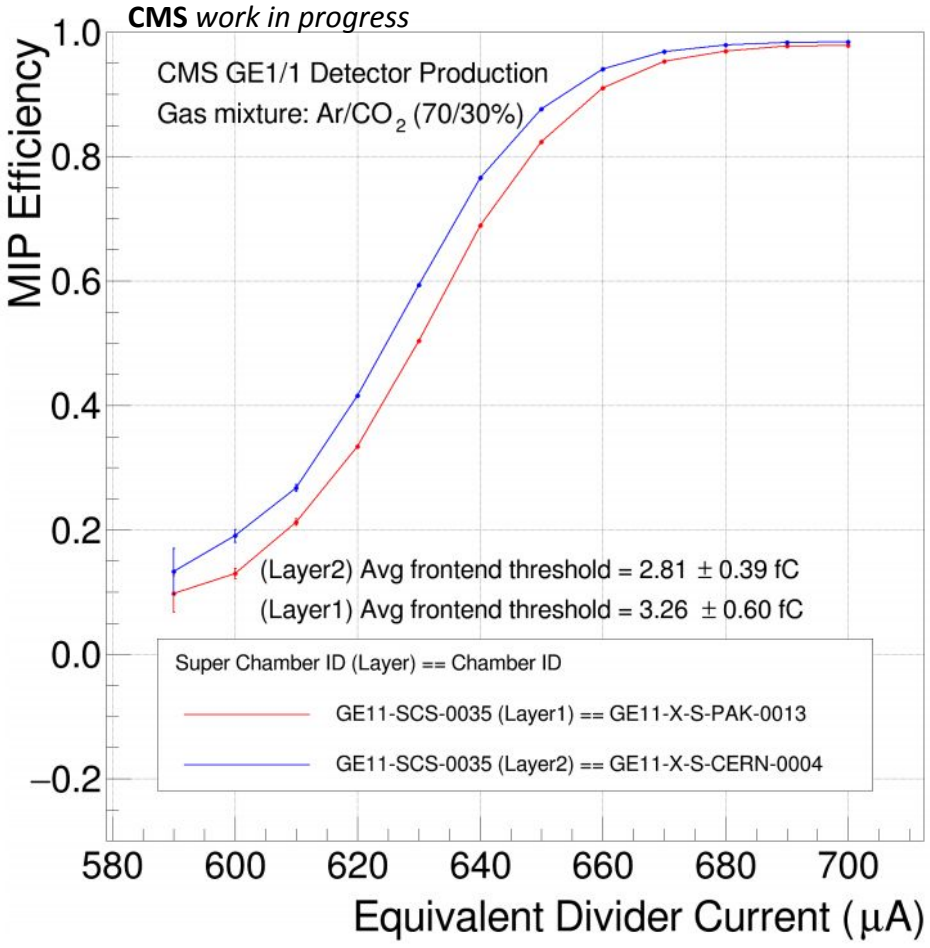
- HV scan with cosmic ray muons (12h runs for each HV point)
- Analyze efficiency with CMSSW



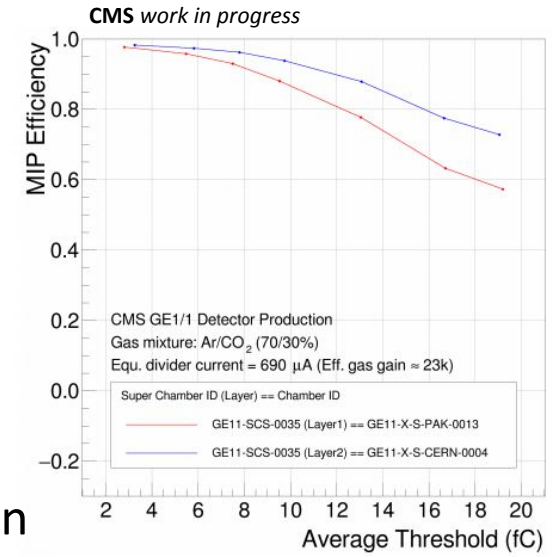


QC8 Results

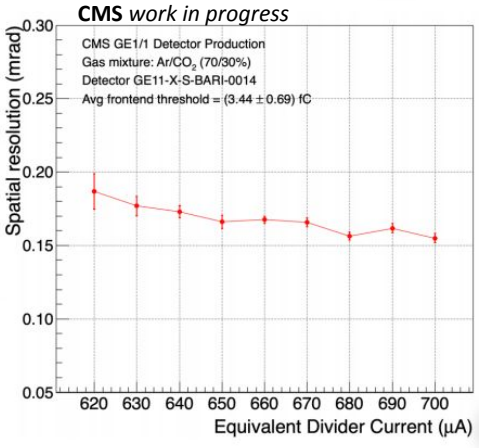
Efficiency vs HV Set Point



Efficiency vs Threshold



Spatial Resolution

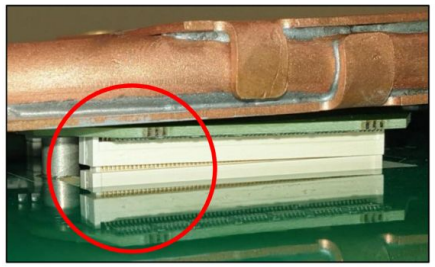


Fast Electronics Test

Objective: test front-end connections after transportation to CMS cavern

- Before Installation
- 20 minutes test of tracking and triggering path

```
VFAT 0 - TU line 0 -- Unexpected number of Sbits : 9
All sbits: 0 0
All sbits: 5 0
All sbits: 5 1
All sbits: 5 2
All sbits: 5 3
All sbits: 5 4
All sbits: 5 5
All sbits: 5 6
All sbits: 5 7
```

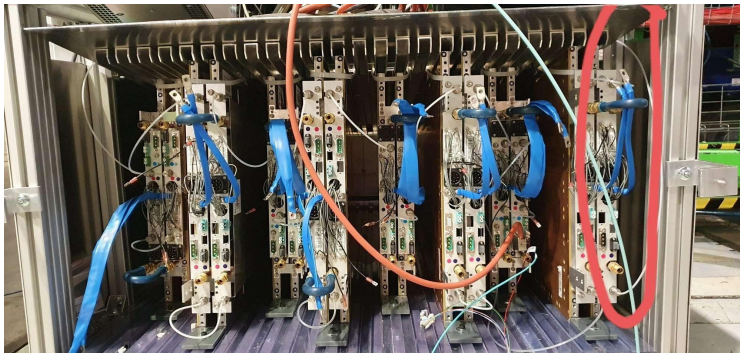


Identified 5 problematic chambers that were able to be repaired before installation

“Trolley Test”

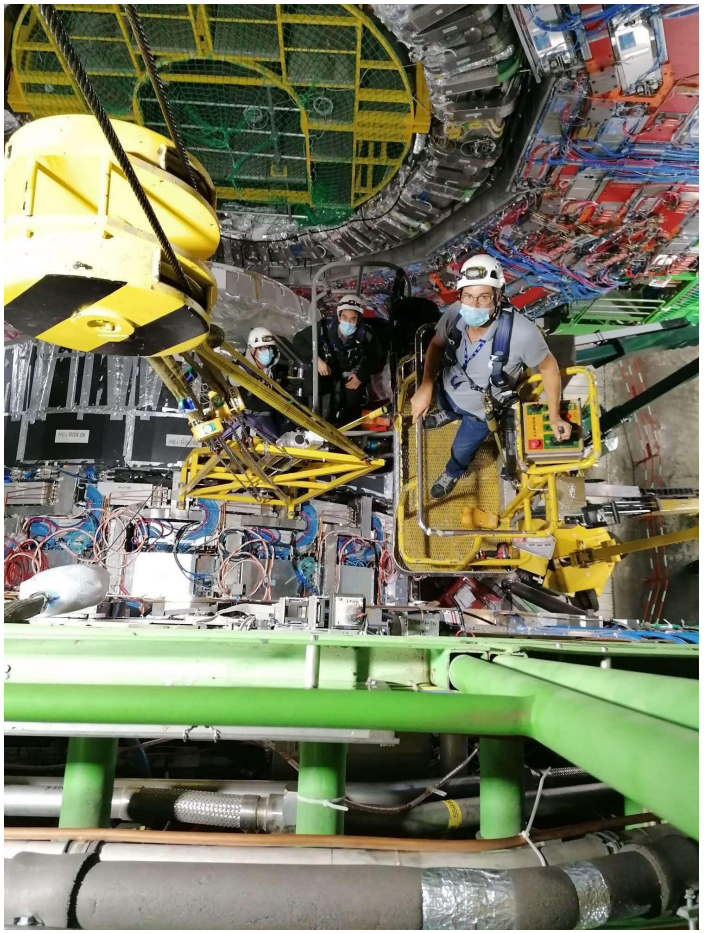
Objective: test front-end connections after transportation to CMS cavern

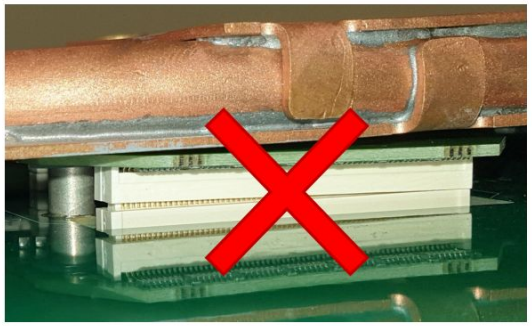
- Procedure:
  - Test communication
  - Write common calibration values
  - Look for any disconnections in trigger path
  - Scan for any disconnections in the tracking path
- Test designed to be as short as possible



“Trolley Test” Results

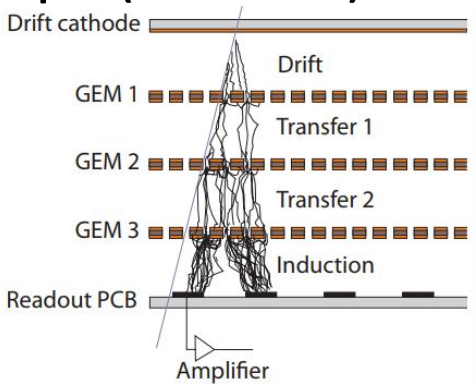
- 5 Chambers returned for repairs
  - 1 due to high LV current drawn
  - 3 due to “broken” SBIT lines
  - 1 due to VFAT communication problem
- All 5 super chambers were repaired
- All 36 super chambers now installed in positive end-cap!





High Voltage Training

- Flush chambers with CO2 at 18 L/H
- Check at 50V across the foils for any short-circuits
- Individually train GEM foils for 8 hours
  - Ramp at 3 V/S to 600V on the foil
  - Note stable voltages
  - Repeat for the other two foils
- Stabilization of drift, transfer, and induction gaps (4 hours)
  - Drift gap with 900 V
  - Transfer 1 and Induction at 600 V
  - Transfer 2 at 800 V
- All fields on with Drift at 3760 V (12 hours)



GE1/1 Electronics