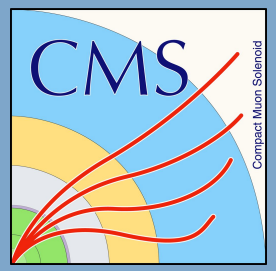
UCDAVIS

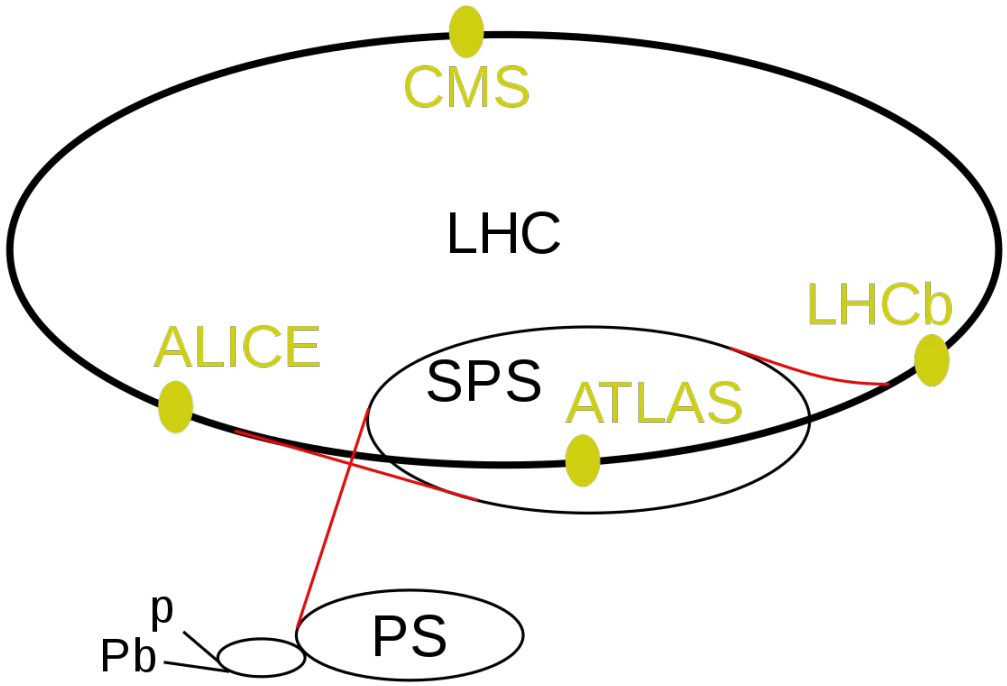
Installation and commissioning of the new GEM muon detectors in the CMS experiment

Brendan Regnery
On behalf of the CMS Muon Project
Department of Physics, University of California, Davis

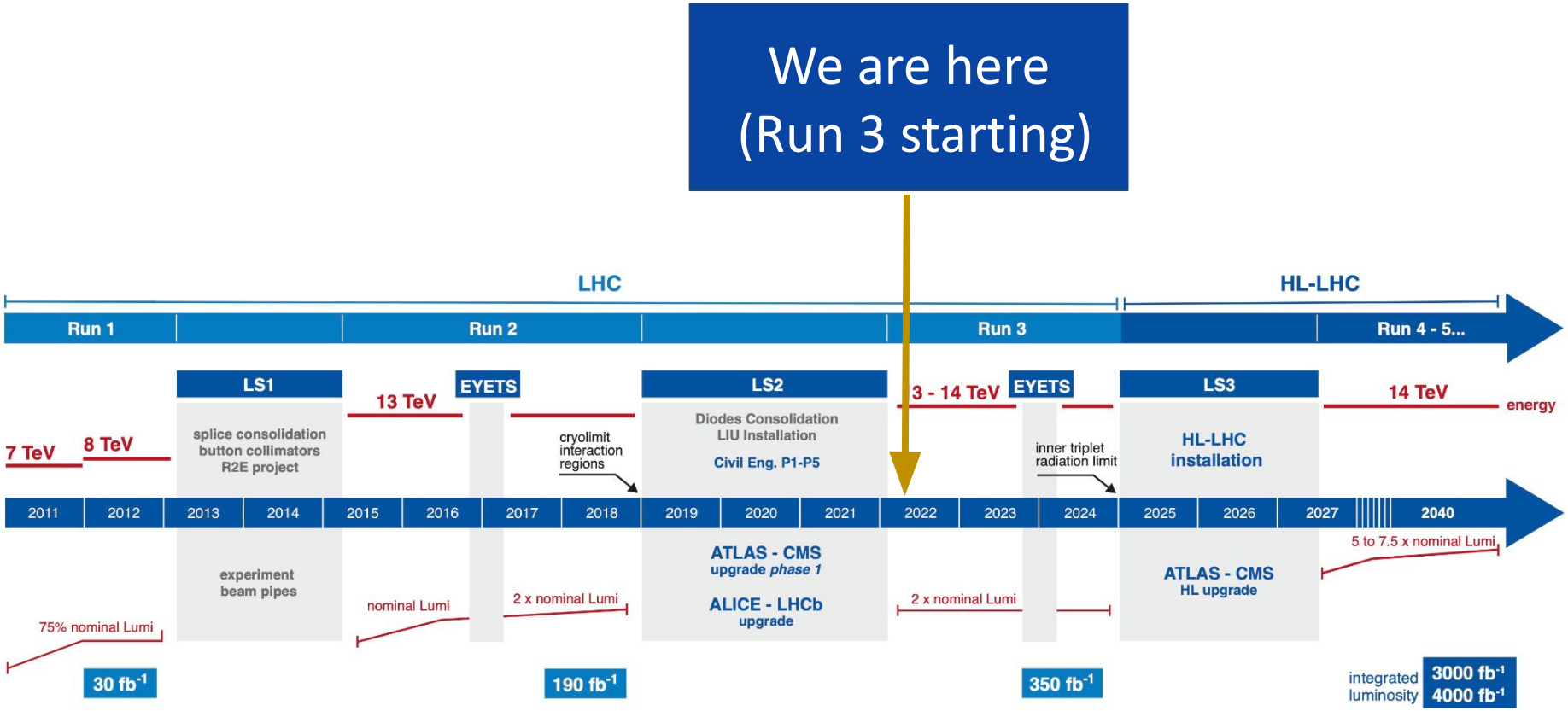


Large Hadron Collider

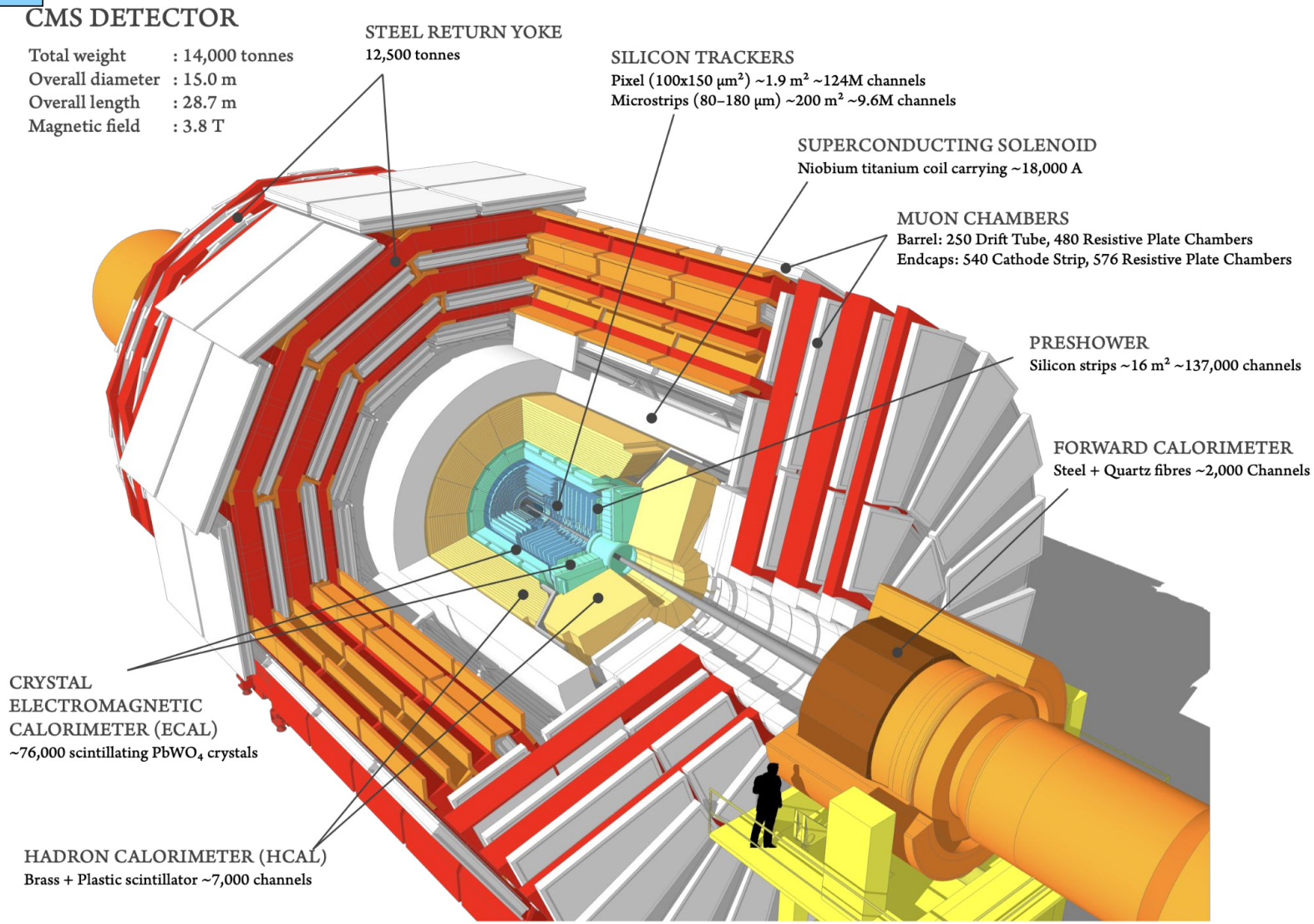
- 27 km proton-proton collider
- 4 experiments at interaction points
- 2 general purpose detectors (CMS, ATLAS)
- 13.6 TeV center of mass energy
- Collisions every 25ns



LHC Timeline

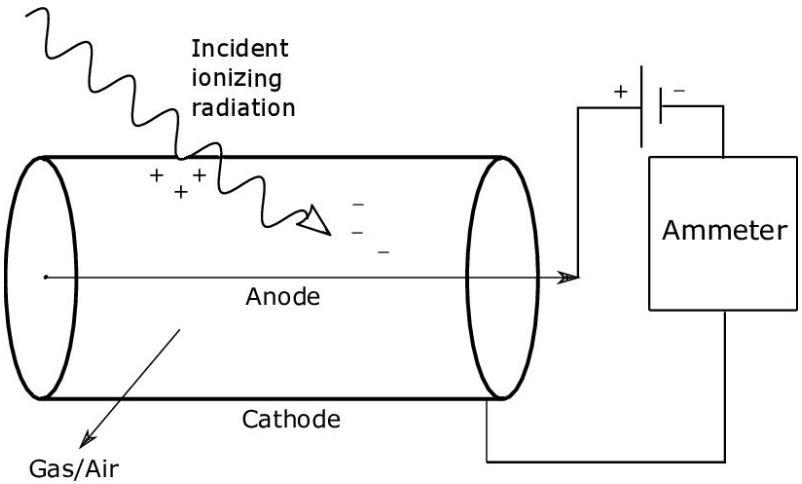


The Compact Muon Solenoid (CMS)



Gaseous Detectors

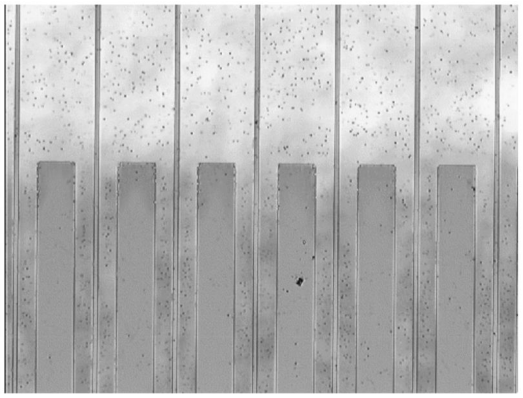
- Gaseous chamber with a sharp electric field
- Used to detect ionizing particles
- Ionizing particles create an electron-ion pair
- Electrons avalanche in sharp electric field creating more electron-ion pairs
- Electrons drift toward the anode and induce a signal

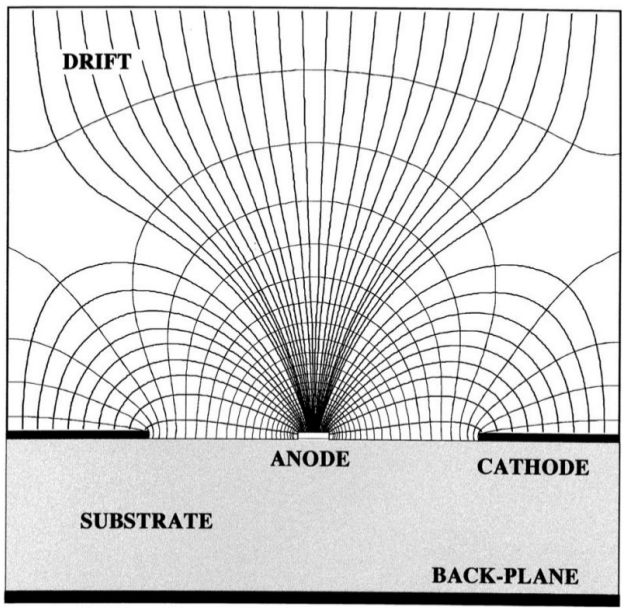


Single Wire Proportional Chamber

Micro Pattern Gas Detectors

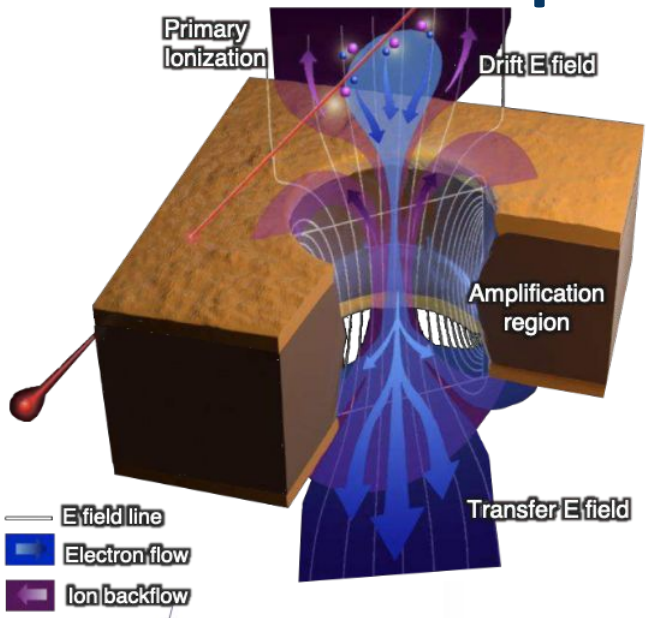
- Wires evolved to strips
- Photolithography made it possible to print conducting strips at 200 µm distances
- A new generation of gas detectors
  - > Small distances
  - > Sharp electric field
  - > Higher rate capabilities
- However, discharges can fuse anode and cathode strips
- New types of MPGDs prevent this

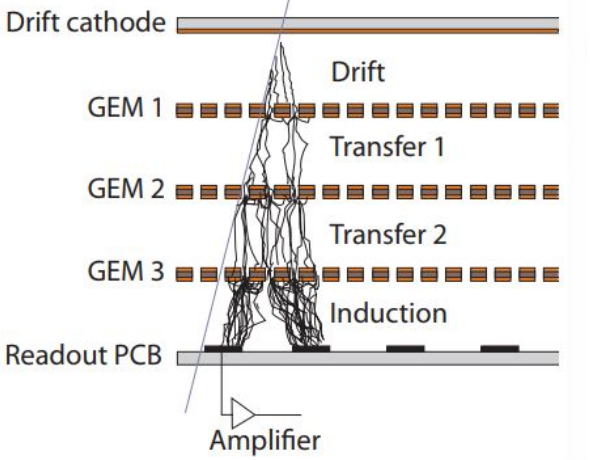




GEM: Gas Electron Multiplier

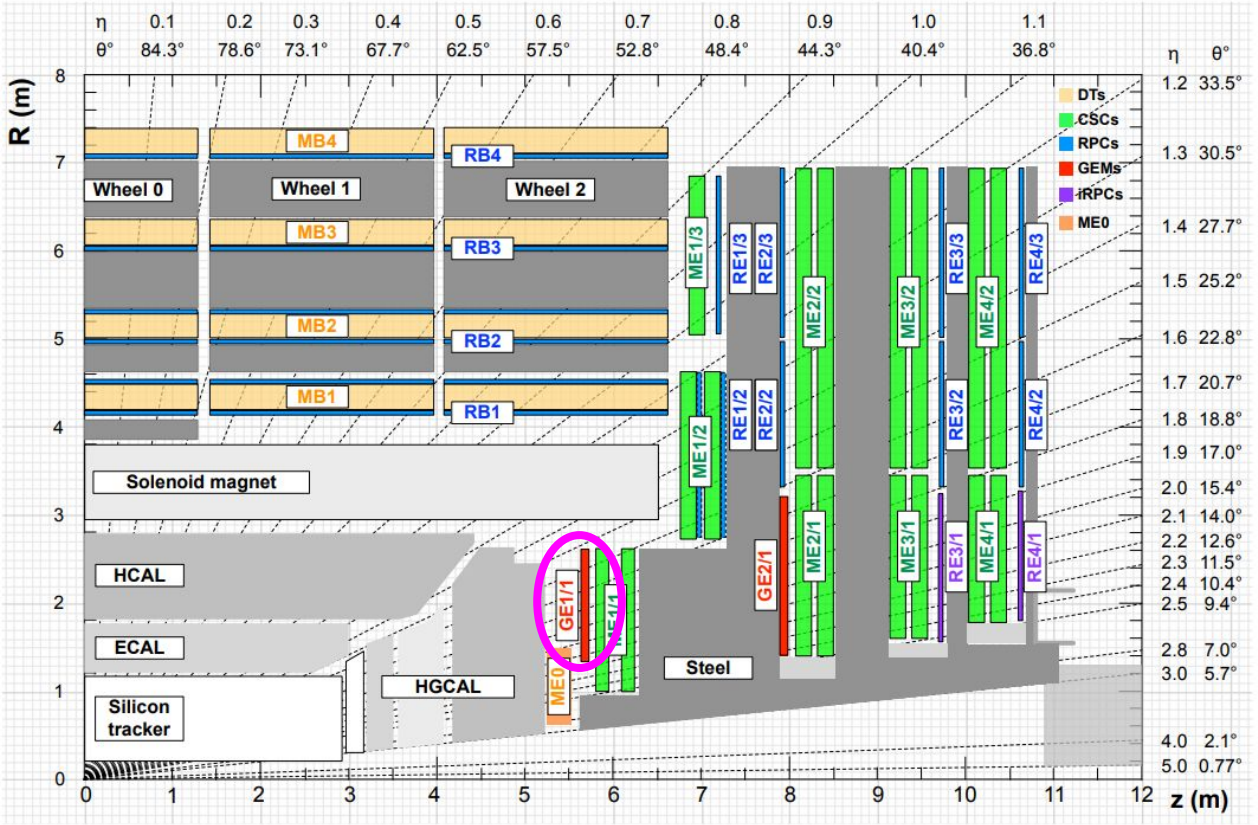
- 70% Ar (ionization) 30% CO_2 (quenching)
- Foils - insulating layer with conductors on top and bottom
  - Conductors at different potentials
  - Microscopic holes create sharp electric field
- Electrons drift in the gaps and avalanche in the foil holes
- Electron cloud induces a signal on the readout strips

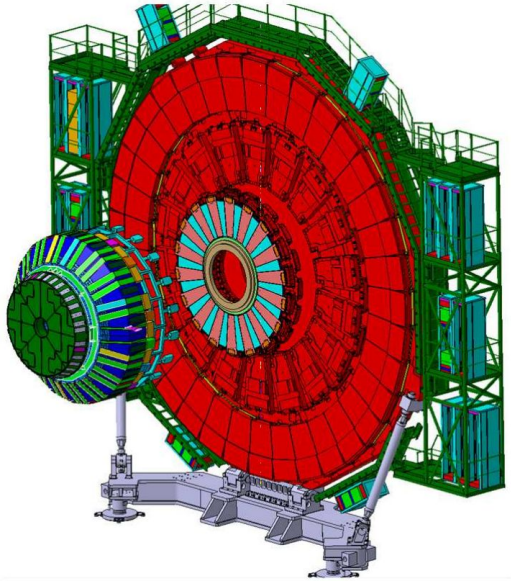




High Rate Capabilities
Less recovery time between particles than traditional wire chambers

CMS: GE1/1





LHC is upgrading to a high luminosity version

Additional layers needed in muon system to compensate for high rates

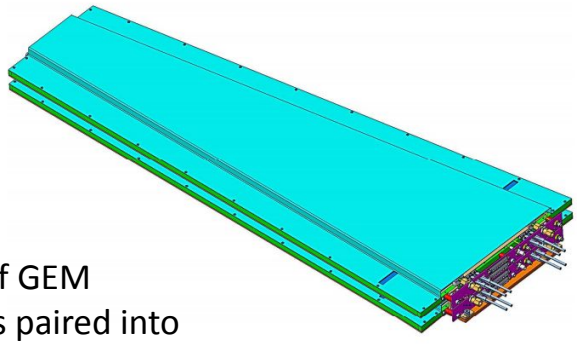
First layer installed is the new GE1/1 station

GE1/1 Trigger Improvement

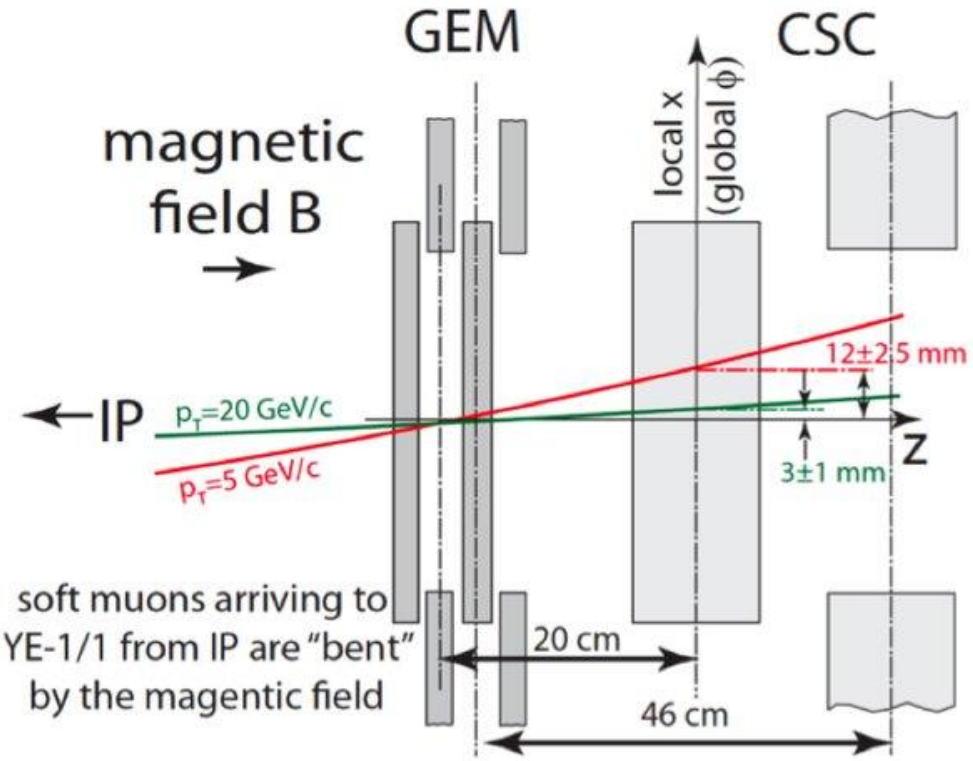
Muon Trigger improvement:

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

➔ More precise measurement of polar muon bending angle!



2 layers of GEM Chambers paired into a “Super Chamber”

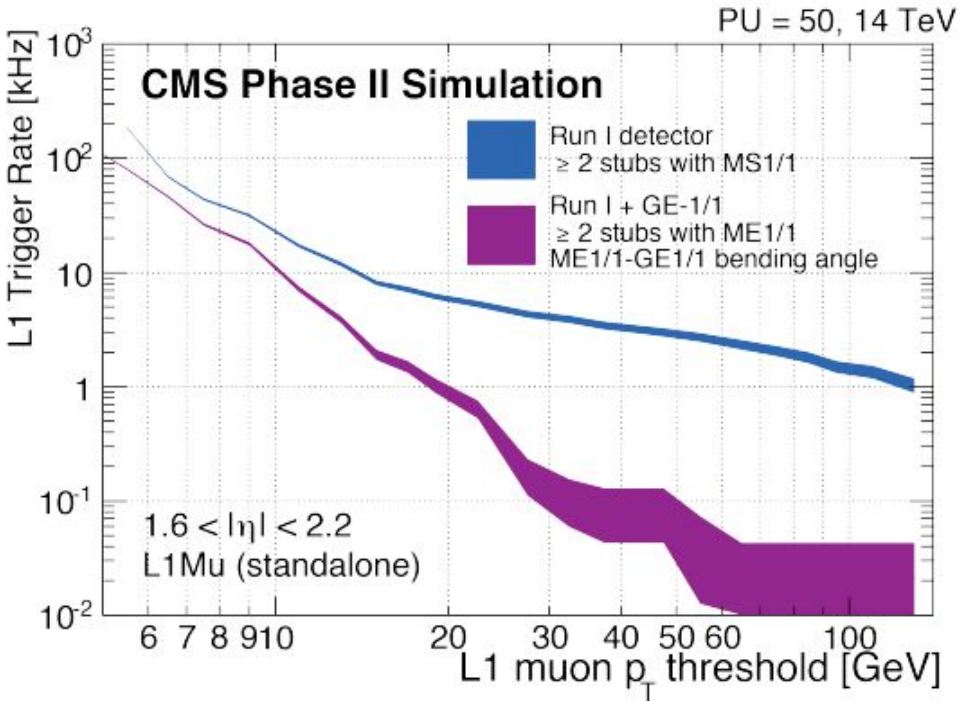


GE1/1 Trigger Improvement

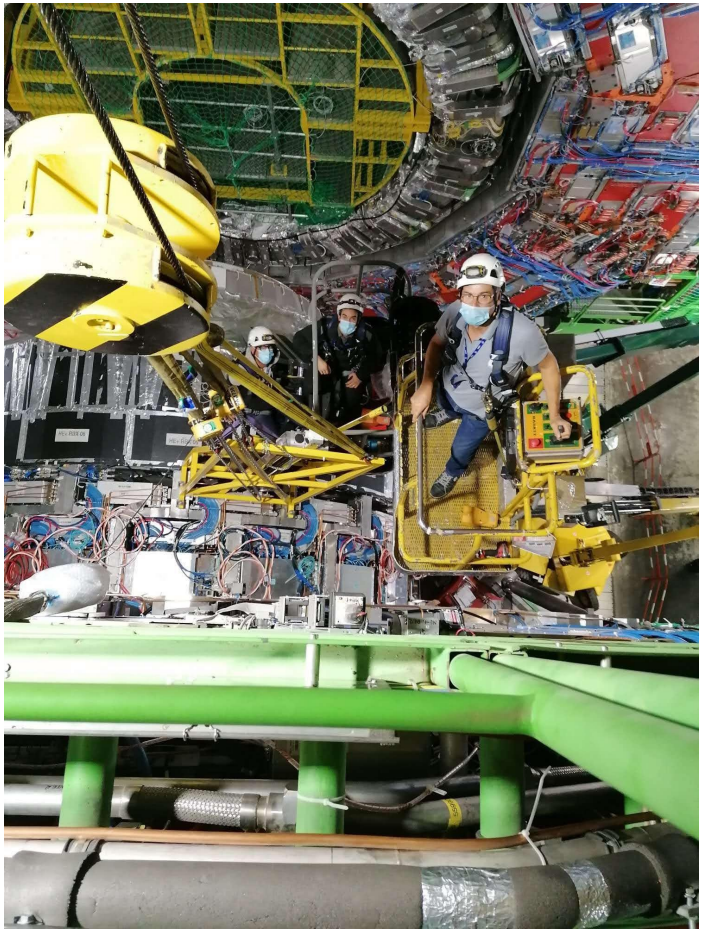
- Better measurement of the bending angle lowers the trigger rate

Why muons?

- Low p_T muons used in standard model measurements
- Important signature in beyond standard model searches



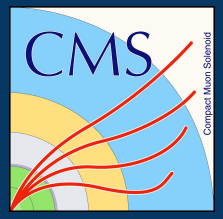
Preparing GE1/1



Production

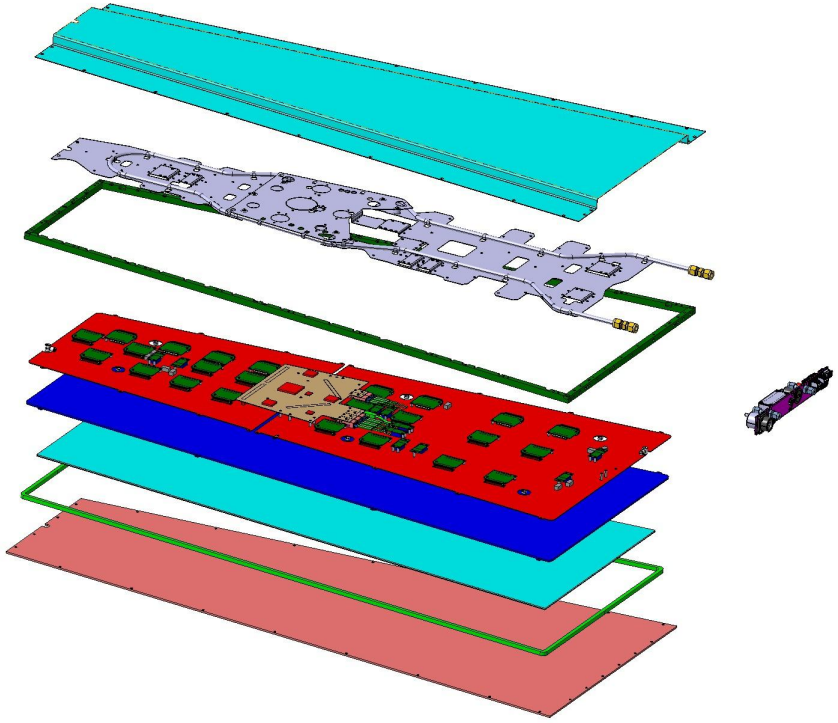
Installation

Commissioning



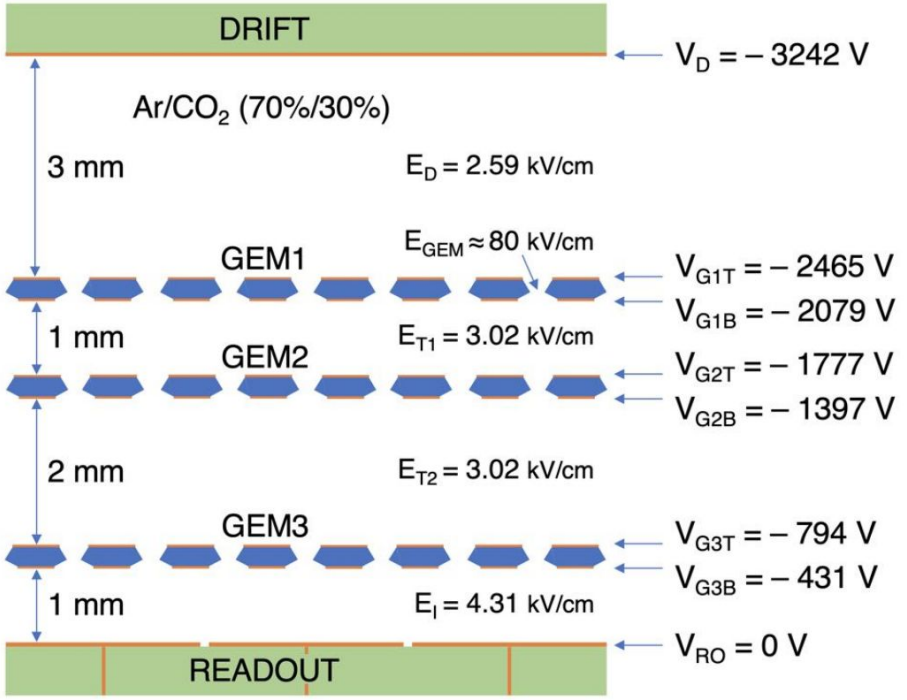
Production

GE1/1 Chamber Design



1 of the two GE1/1 layers

Two layers form a super chamber

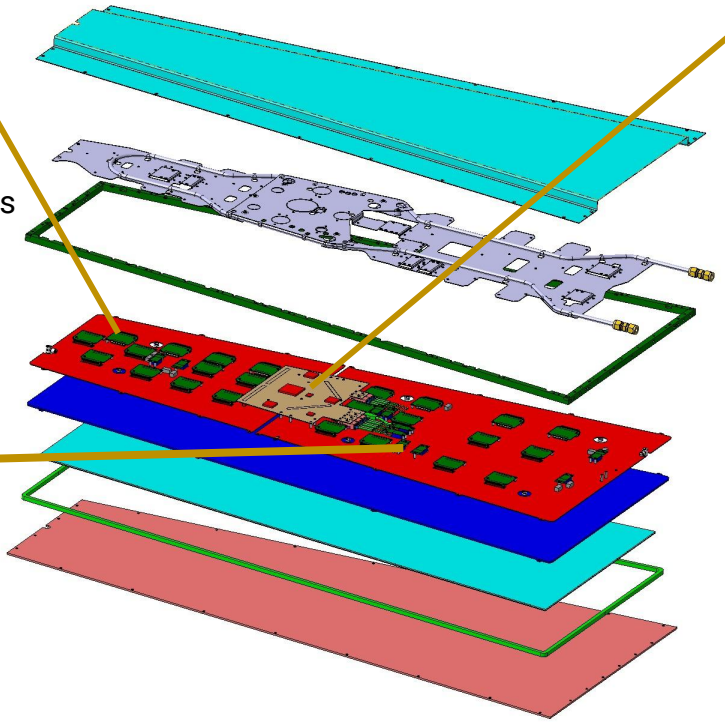


Potentials applied to each foil in GE1/1

GE1/1 Readout Electronics

VFAT3 front-end chips

- 128 readout channels
- Sends trigger data via 8 parallel lines
- Can deliver calibration pulses



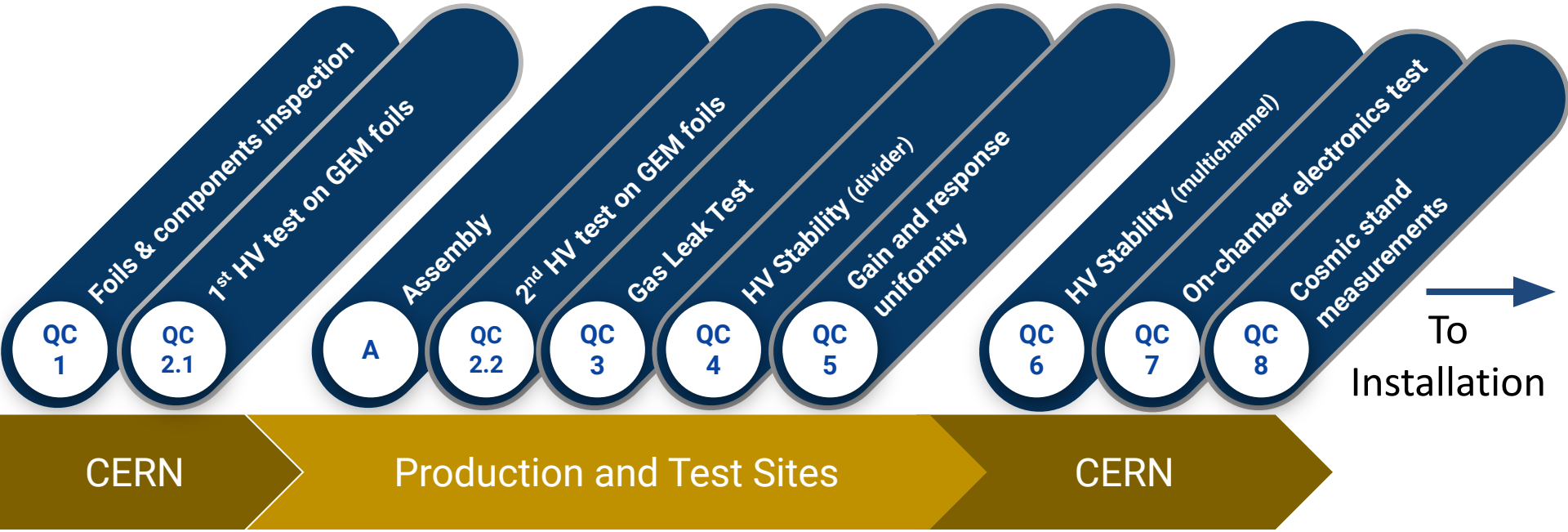
OptoHybrid

- Communication between VFATs and backend electronics via gigabit transceivers
- Sends slow control commands to front-end electronics
- Transfers tracking and trigger data to other subsystems

Radiation hard DC-DC converters deliver a precise output voltage

Data traveling from the chambers

GE1/1 Detector Production



161 chambers produced

144 chambers for installation
17 spare chambers

Paired into super chambers

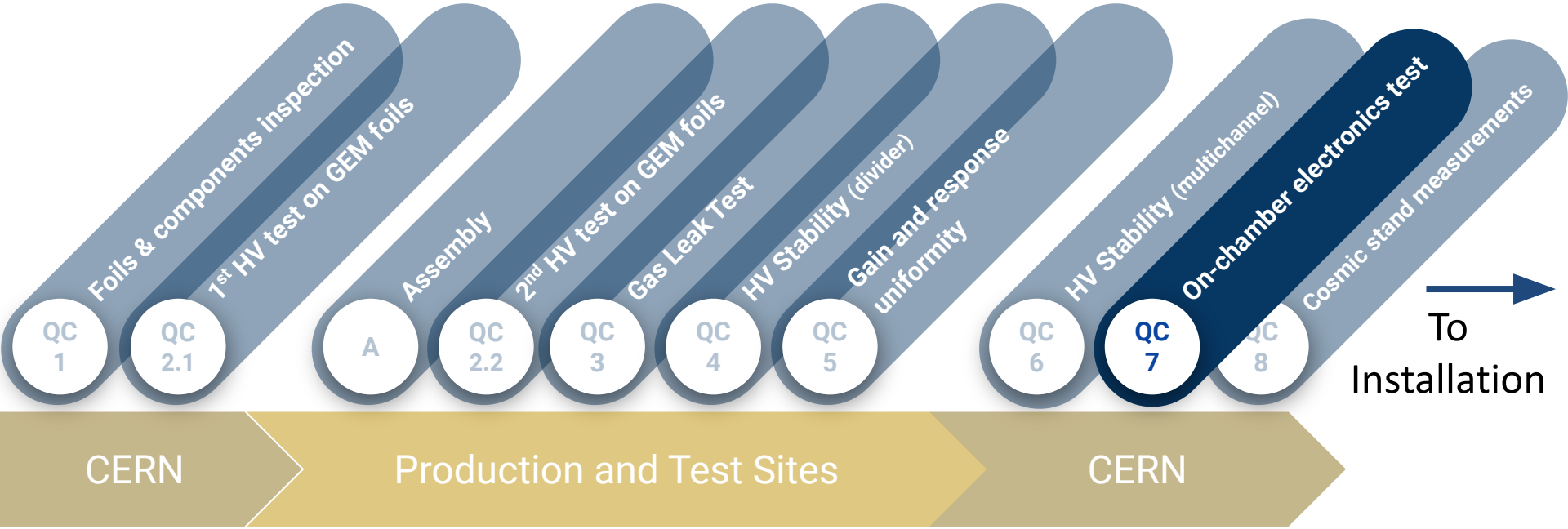
77 super chambers produced

72 super chambers installed in the experiment

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

*QC: Quality Control, HV: High Voltage

GE1/1 Detector Production



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

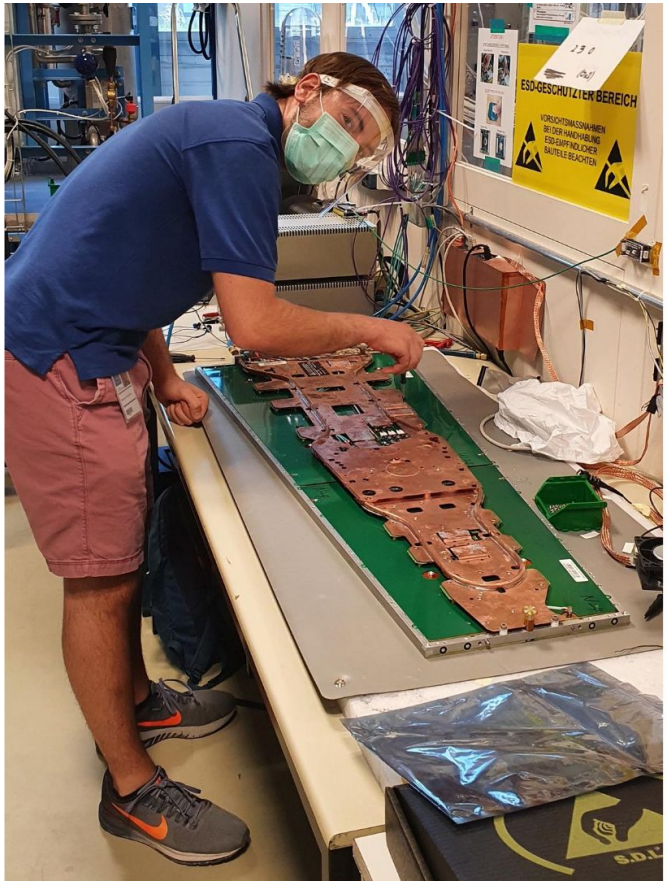
*QC: Quality Control, HV: High Voltage

Electronics Test

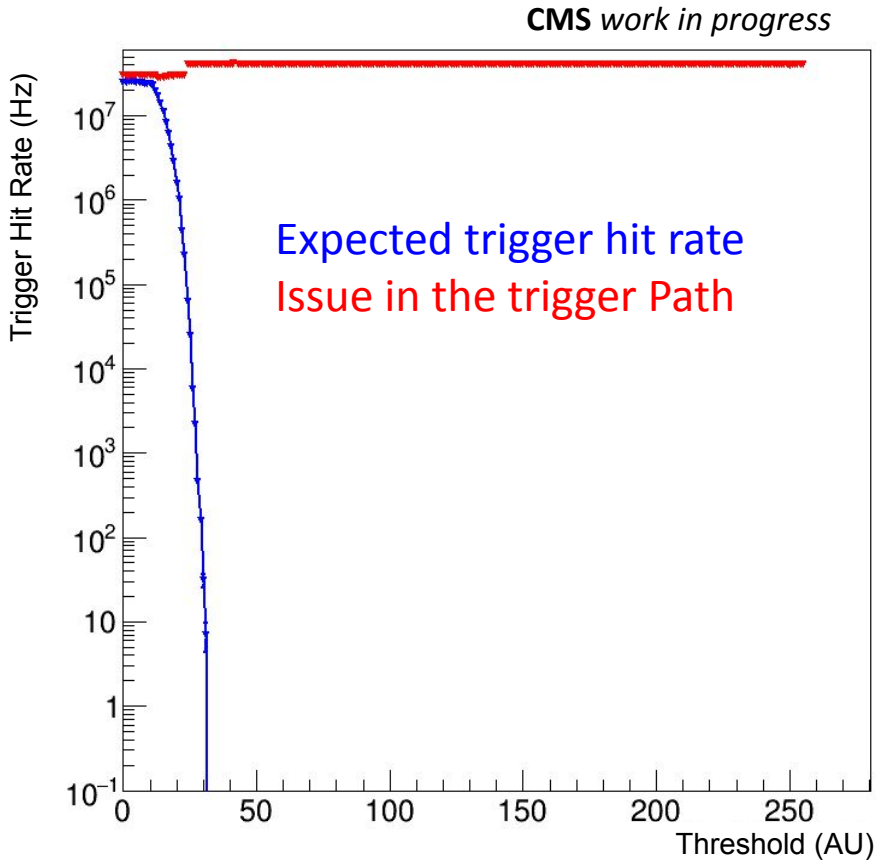
Objective: Test front-end electronics

- Test communication
- Calibrate electronics
- Identify bad connections in trigger or tracking paths
- Measure noise

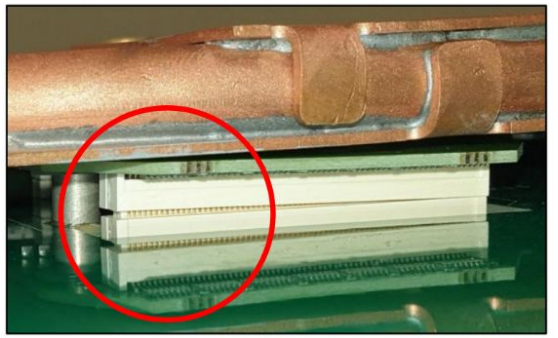
Repeat after installing cooling plate and installing chamber cover



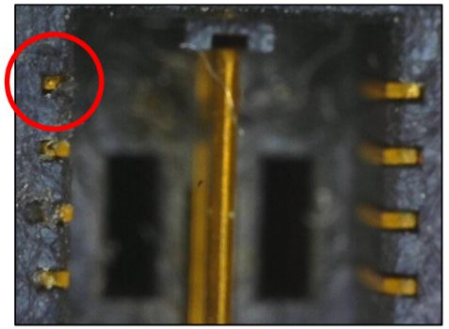
Electronics Test: Trigger Path



Causes of trigger path issues:



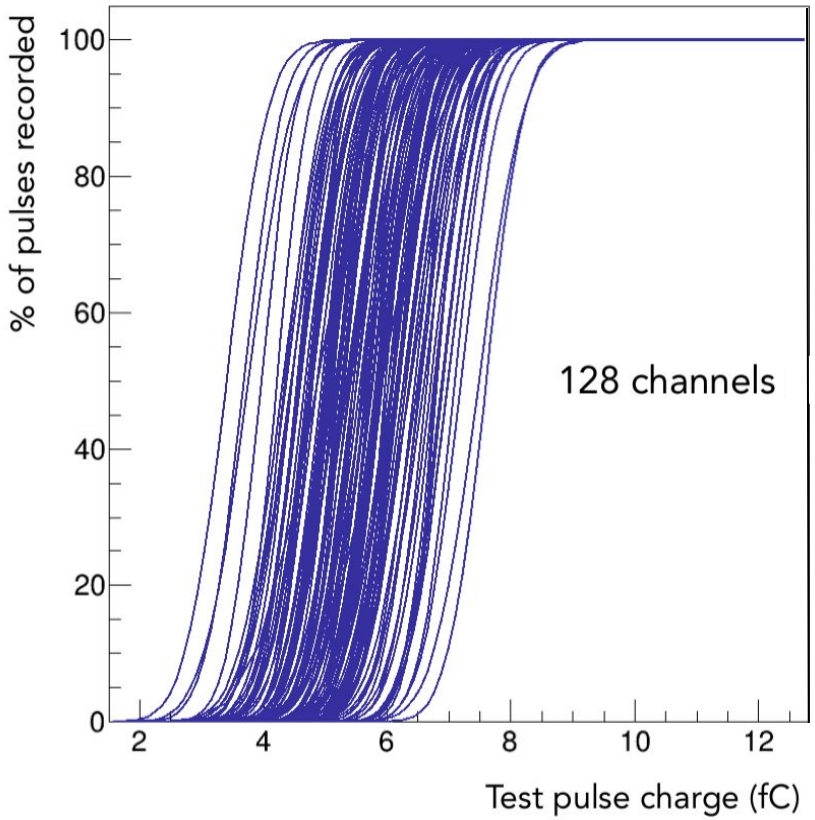
Disconnected VFATs

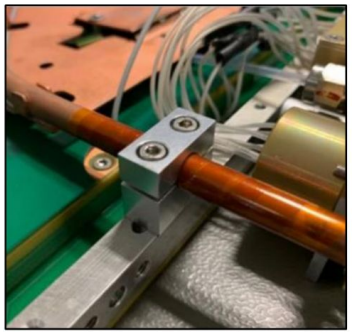


Or issues with OptoHybrid connector

Electronics Test: Tracking Path

CMS *work in progress*



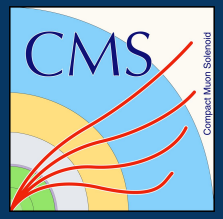


Noise Causes:

- Ground loops on cooling plate
- Faulty electronics

Deliver internal pulses to individual channels and measure the percentage recorded

Noise = width of this ‘s’ curve

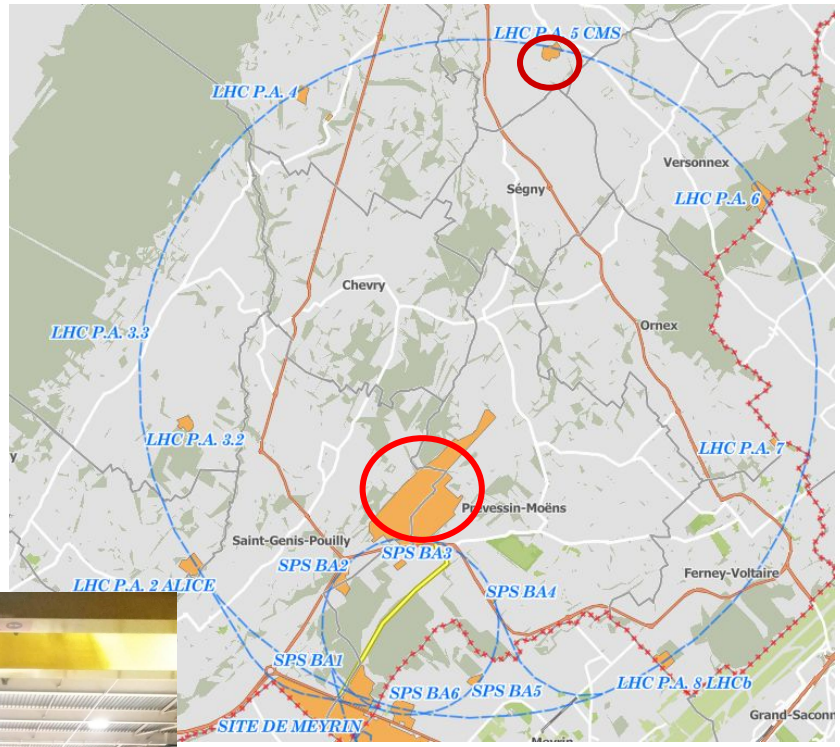


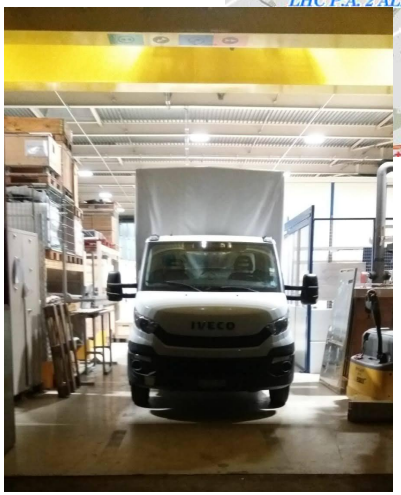
Installation

Transporting the Chambers

GE1/1 Chambers driven 10 km

Then lowered 100m underground





Pre-Installation Electronics Test

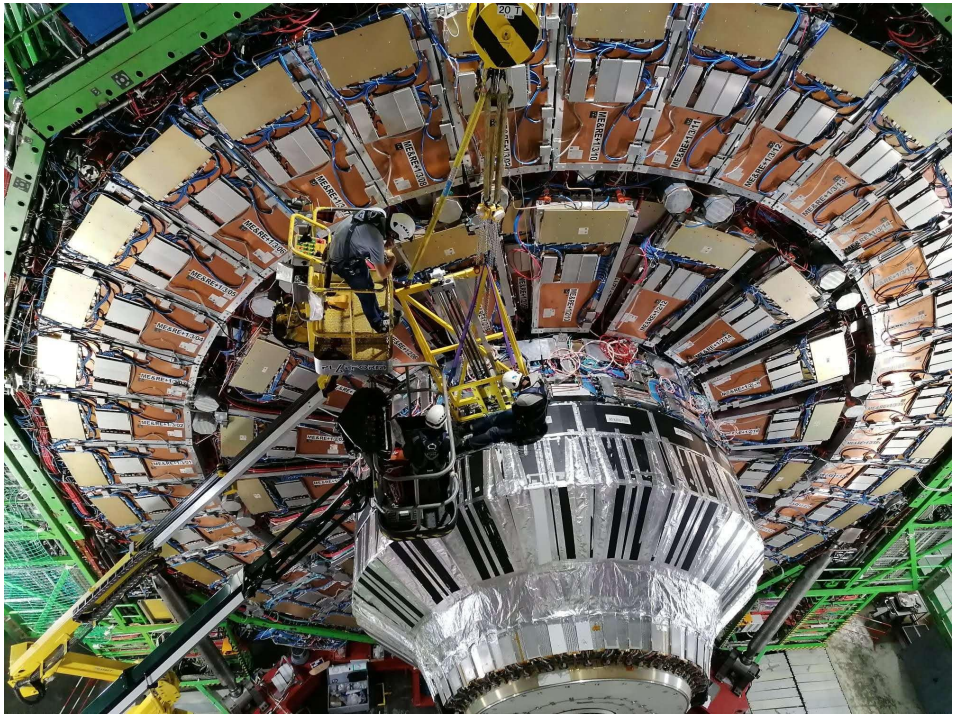
Objective: test front-end connections after transportation to CMS cavern

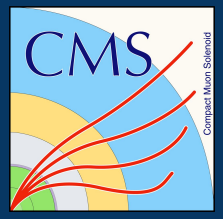
- Must be fast due to lack of cooling
- 20 minute test of tracking and triggering path
- Benchtop power supply and “flying” fiber optic cable
- Made possible with a low level tool to measure the Trigger Hit Rate

Identified 5 problematic chambers
All chambers repaired before installation

Installation

Successfully Installed 144 GE1/1 Chambers during Long Shutdown 2





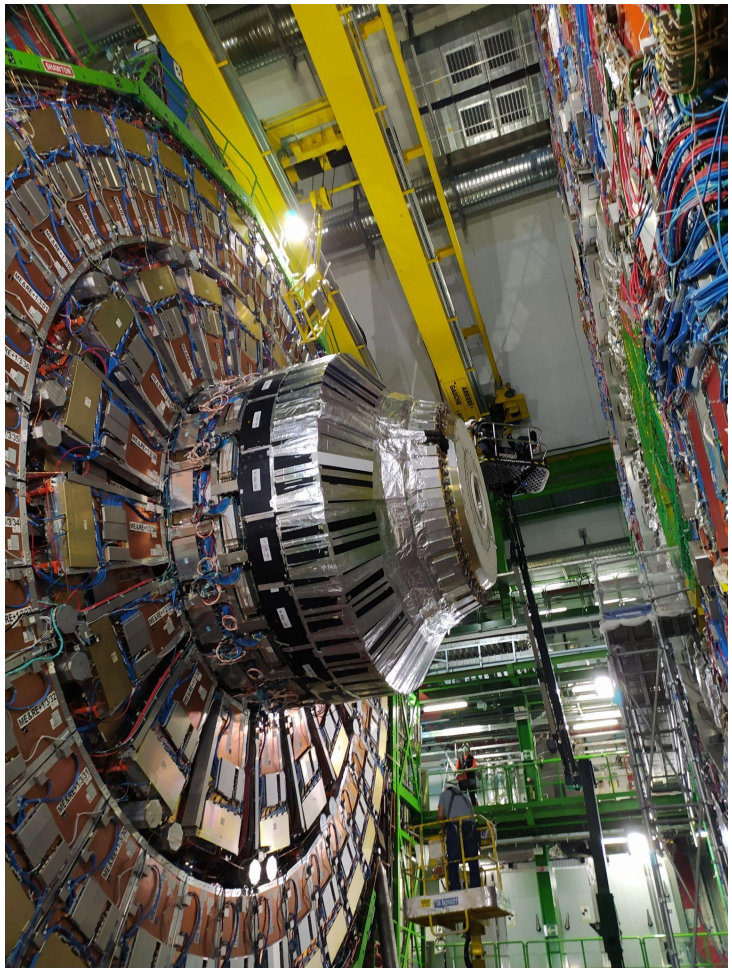
Commissioning

Early Commissioning

- Test connectivity, mapping, and HV
- Test the electronics in CMS
  - New environment
  - New noise sources

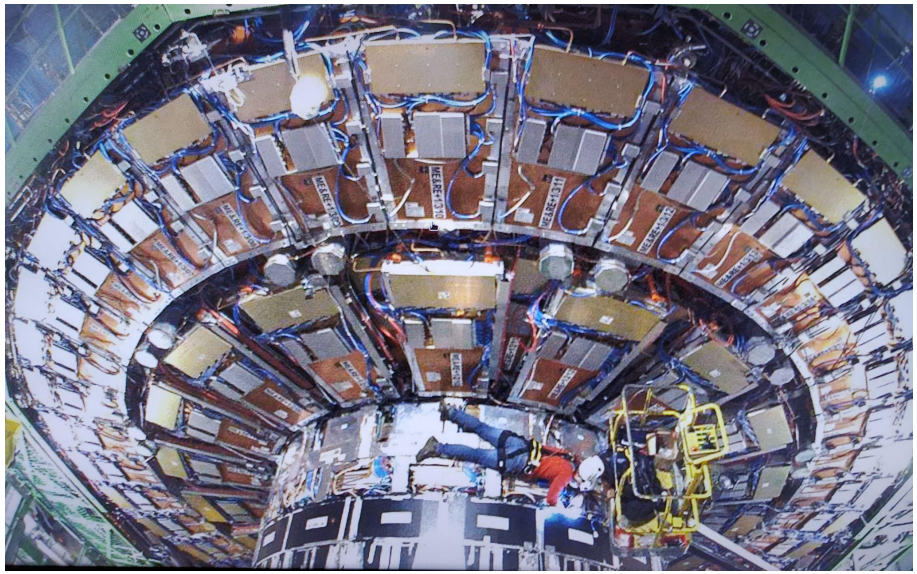
Challenges

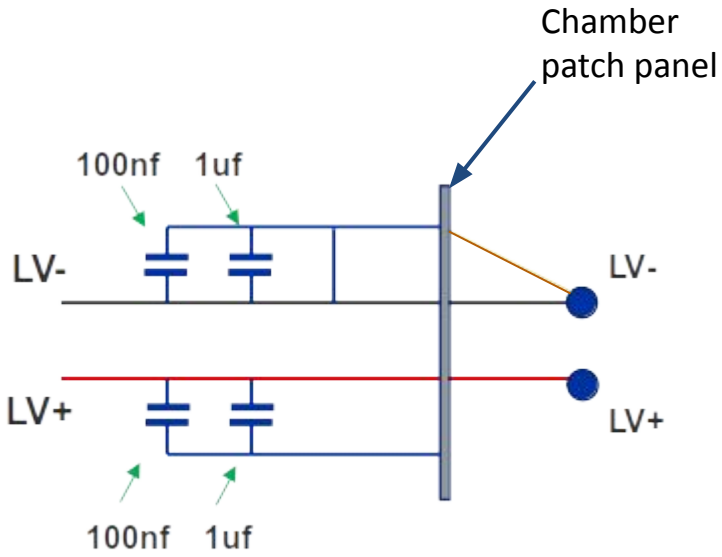
- Noise Mitigation
- Communication Instabilities

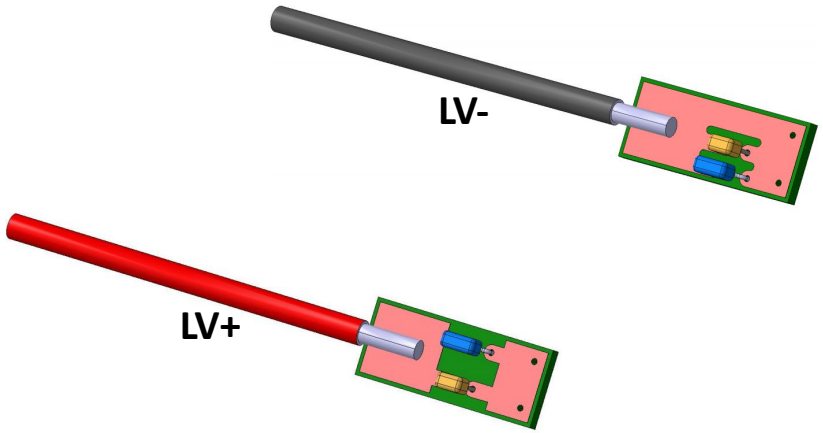


LV Low Pass Filters

- Mitigate high frequency noise in electronics
- 144 chamber-side filters installed May 2021

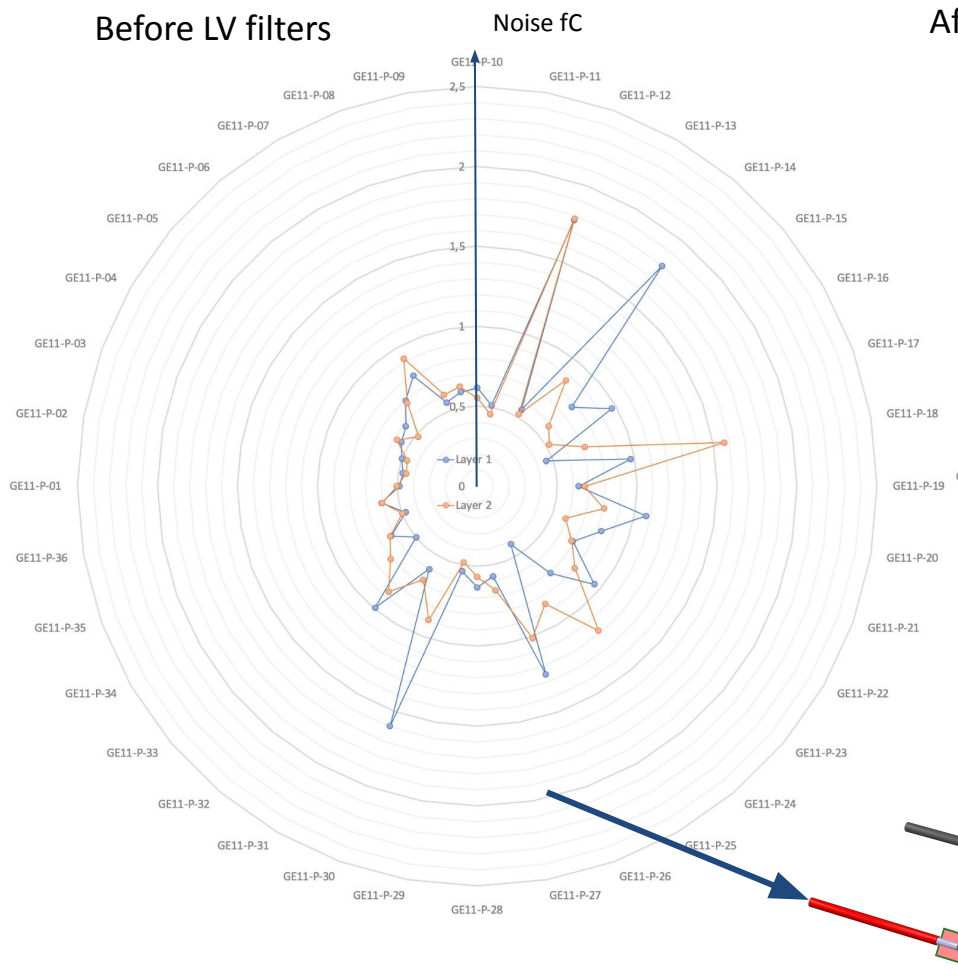




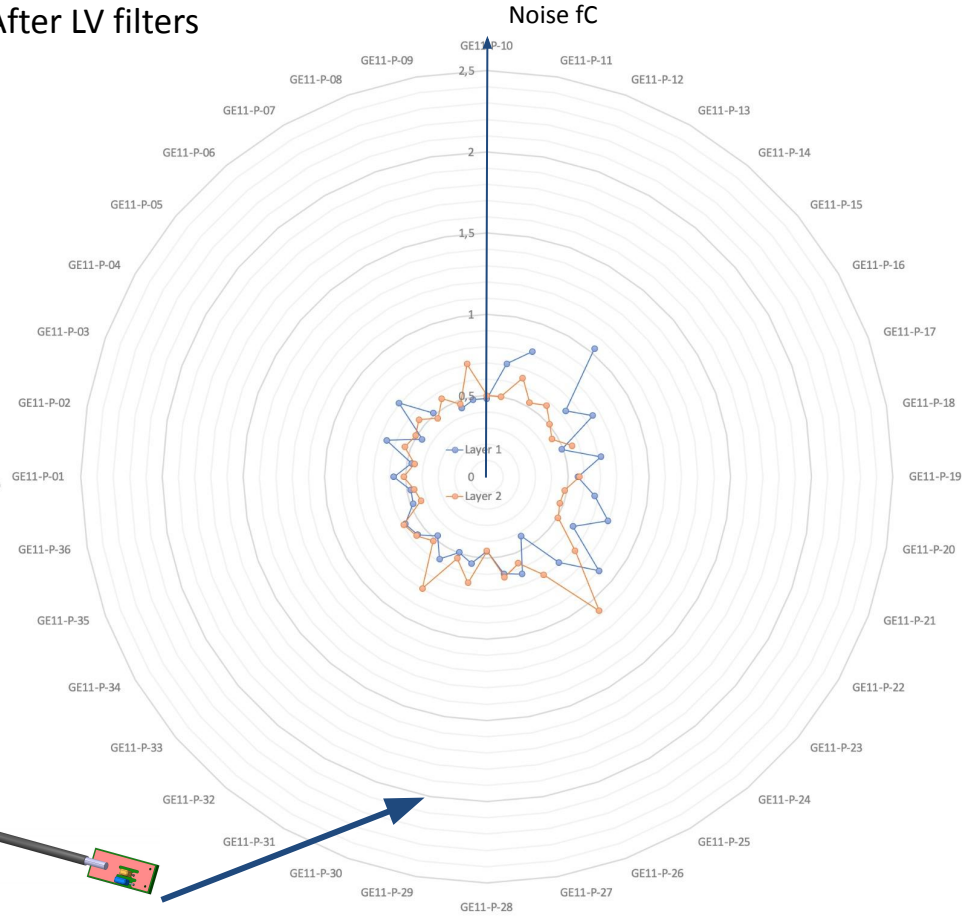


LV Filter Installation: Positive End-cap

Before LV filters



After LV filters



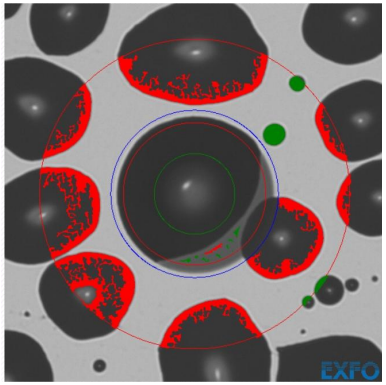
CMS *work in progress*

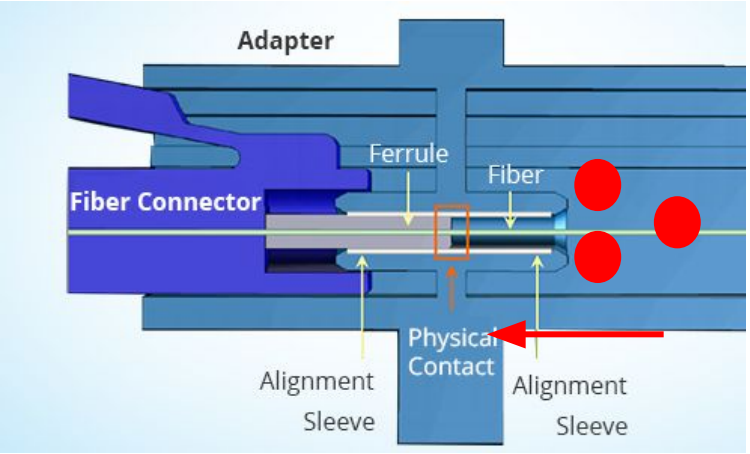
Missing chambers due to GBT instabilities

Communication Instabilities: **The Problem**

- Data sent on optical fibers via a versatile link (VTRx)
  - Send data from the detector
  - Receive slow control information
- Around 15 of 432 VTRx's have communication issues
  - The affected VTRx's change, but the number remains around 15
- The VTRx is used by many detector groups at CERN

Communication Instabilities: The Cause





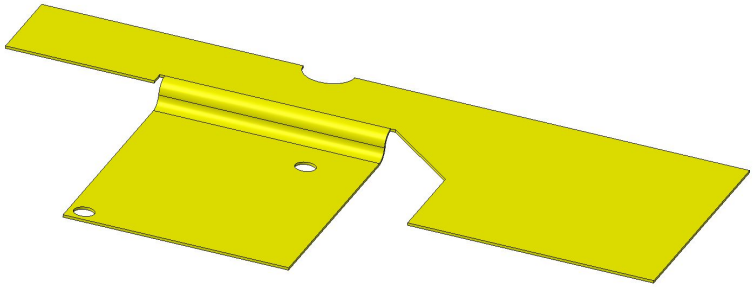
- VTRx: Versatile Link
  - Photodiode for receiving
  - Laser for transmitting

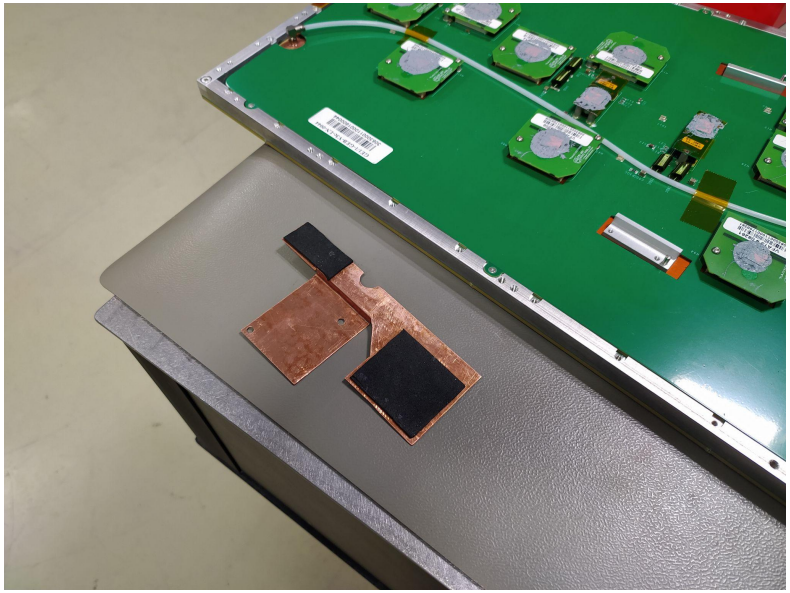
Photodiode is outgassing

Instabilities will be carefully monitored during run 3

Long Term Solution: VTRx Cooling

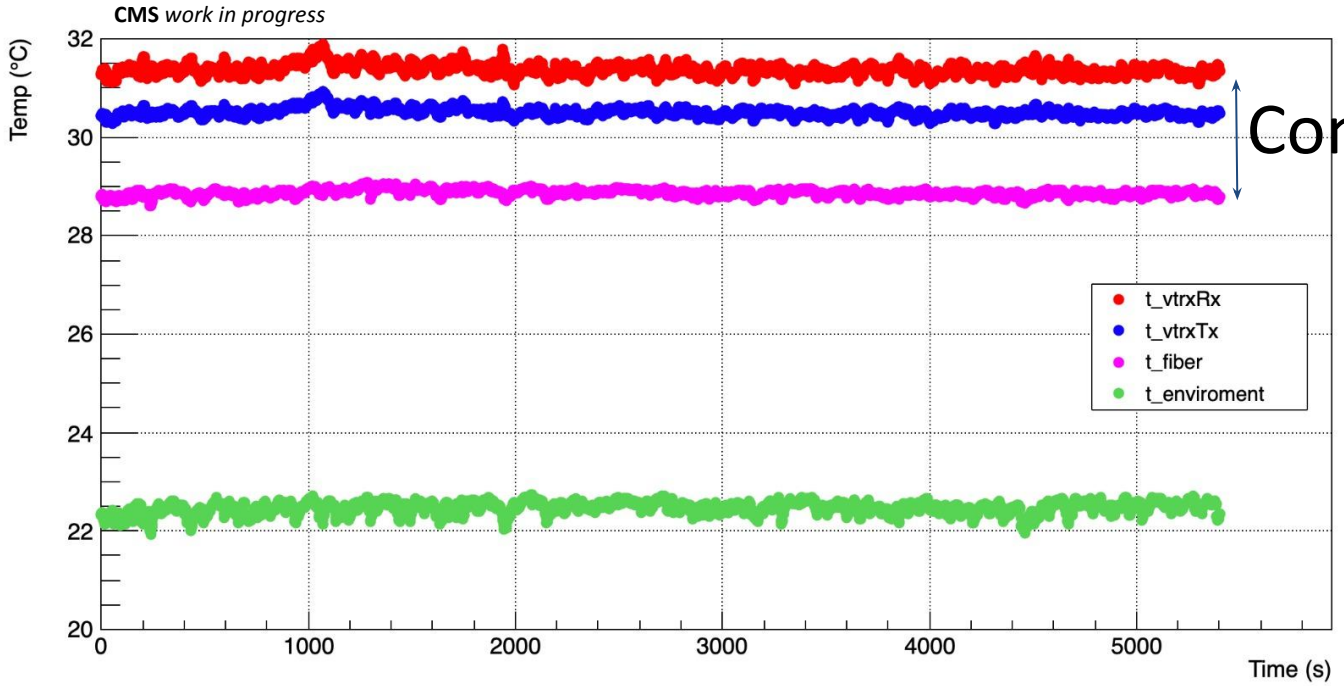
- **Objective:** create beneficial temperature difference between fiber and photodiode
- Recommended by CERN electronics team
- Temperature measured in laboratory with modified VTRx
- Modifications scheduled for Long Shutdown 3





Testing the Cooling

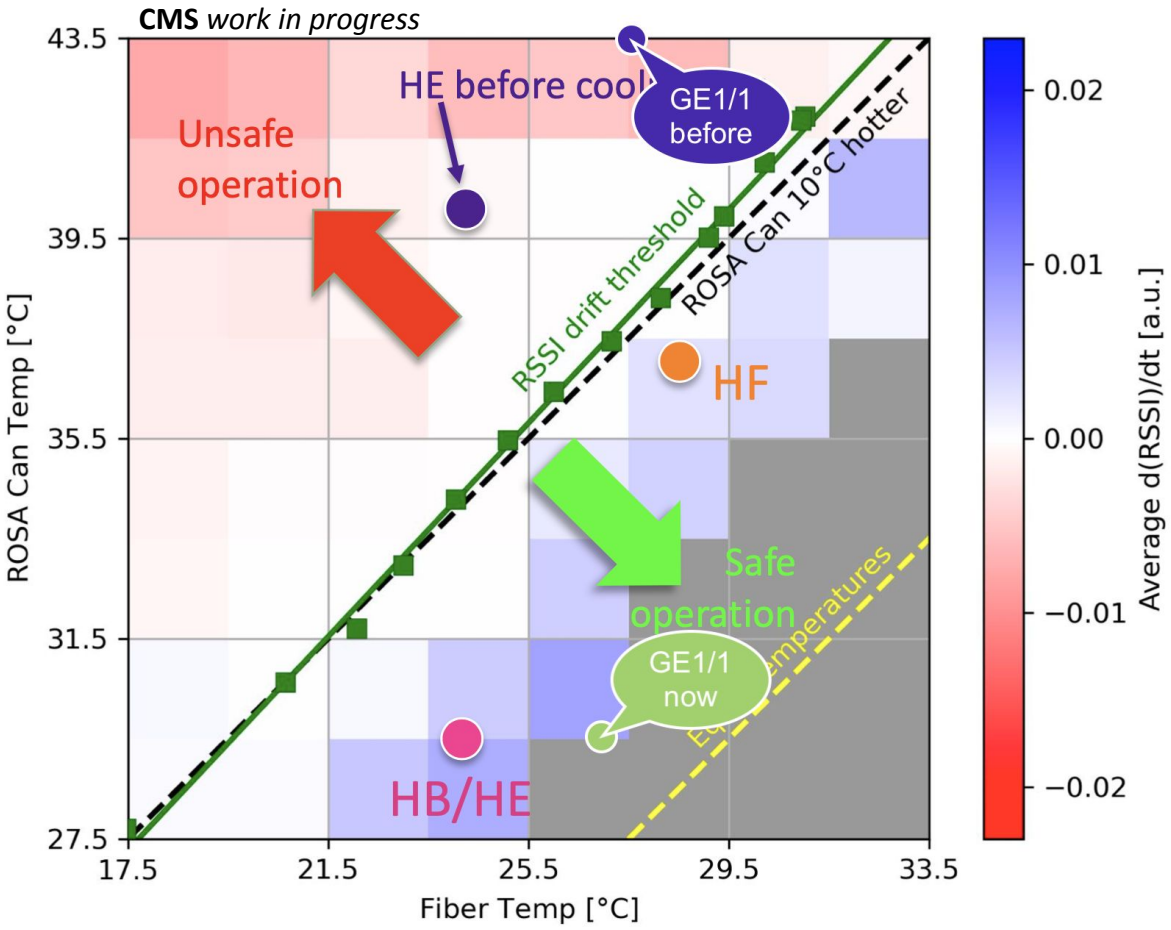
- Cooling with water flowing + ongoing scans



Constantly ≈ 3°C

Comparing the Cooling

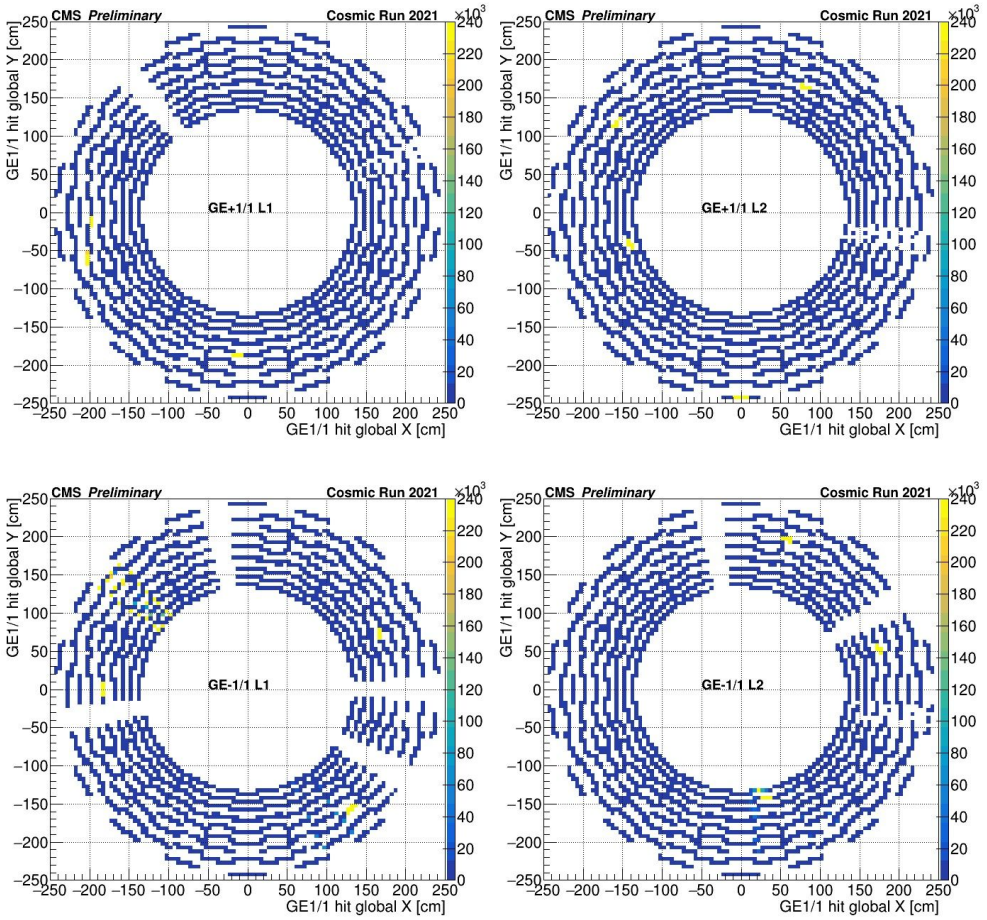
- The temperature gradient is within the threshold
- VTRx cooling is working well
- To be installed *after* run 3



VTRx Failure Investigation:
Recent CMS Temperature Studies

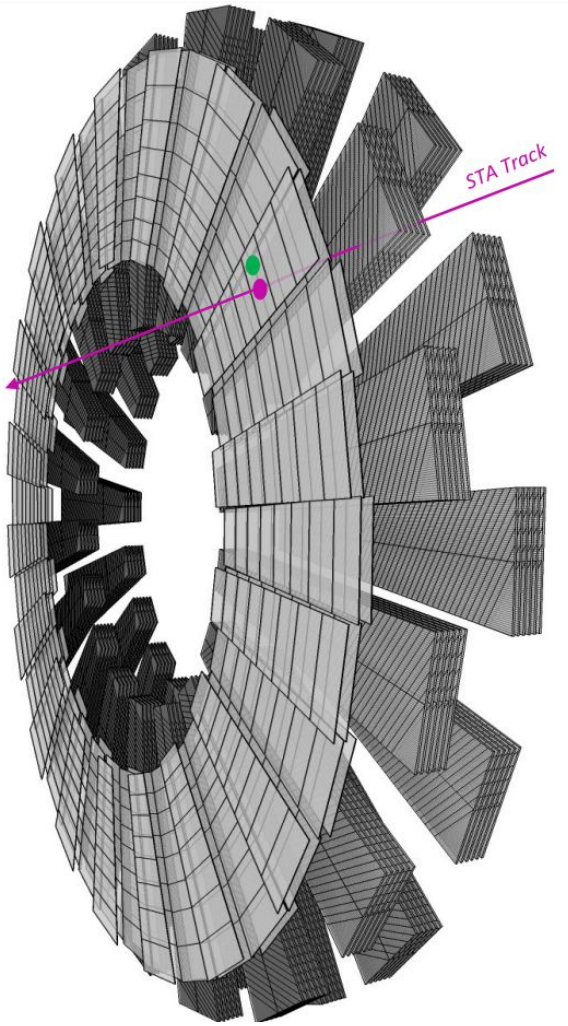
Commissioning with Cosmic Ray Muons

- Align (4D) GE1/1 with other CMS detectors
- Include in the Endcap Muon Trackfinder
- Take data with cosmic runs
  - Cosmic run with no magnetic field
  - Cosmic run at 3.8 T
- Evaluate and improve detector efficiency



Efficiency in CMS

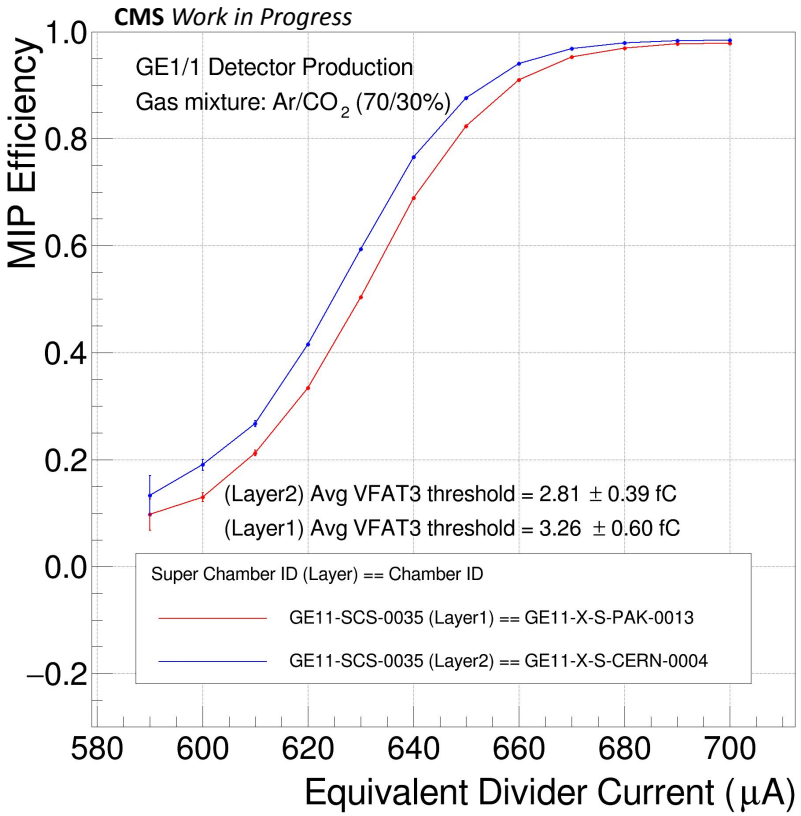
- Measure a track in the Muon system
- Propagate to the GE1/1 system
- Look for (and match to) a hit in the GE1/1 system



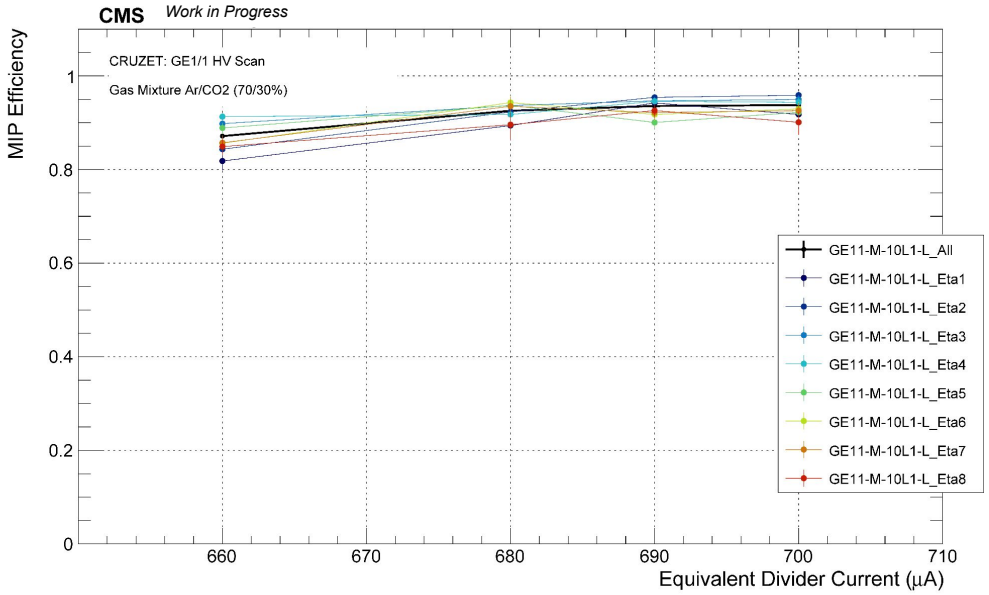
$$\text{Efficiency} = \frac{\text{Matched Hits}}{\text{Total Propagated Hits}}$$

Efficiency in CMS

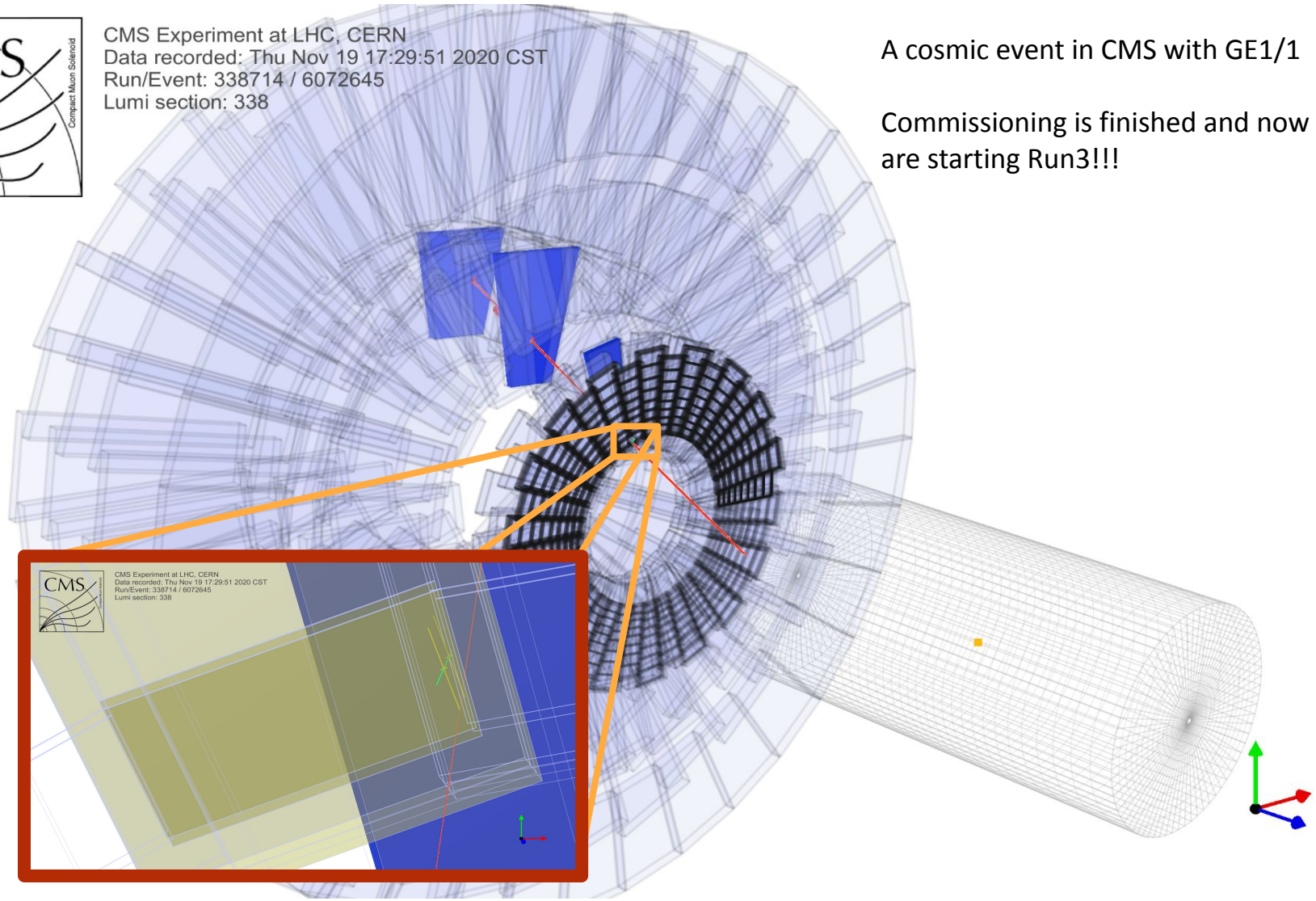
Efficiency observed in the laboratory



Efficiency observed in CMS



*Less data points due to time constraints



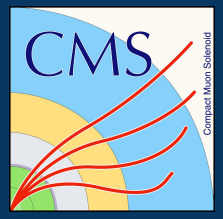
A cosmic event in CMS with GE1/1

Commissioning is finished and now we are starting Run3!!!

Conclusions

- Gas Electron Multipliers are a novel micropattern gas detector
- New GE1/1 station will improve level 1 trigger rates (essential for HL-LHC)
- 144 GE1/1 chambers were installed in CMS (out of 161 produced)
- High noise rate in CMS mitigated with LV filters
- VTRx issue will be resolved with baking and cooling
  - Intervention planned for Long Shutdown 3
- Commissioning phase is finished
- Run 3 is starting!

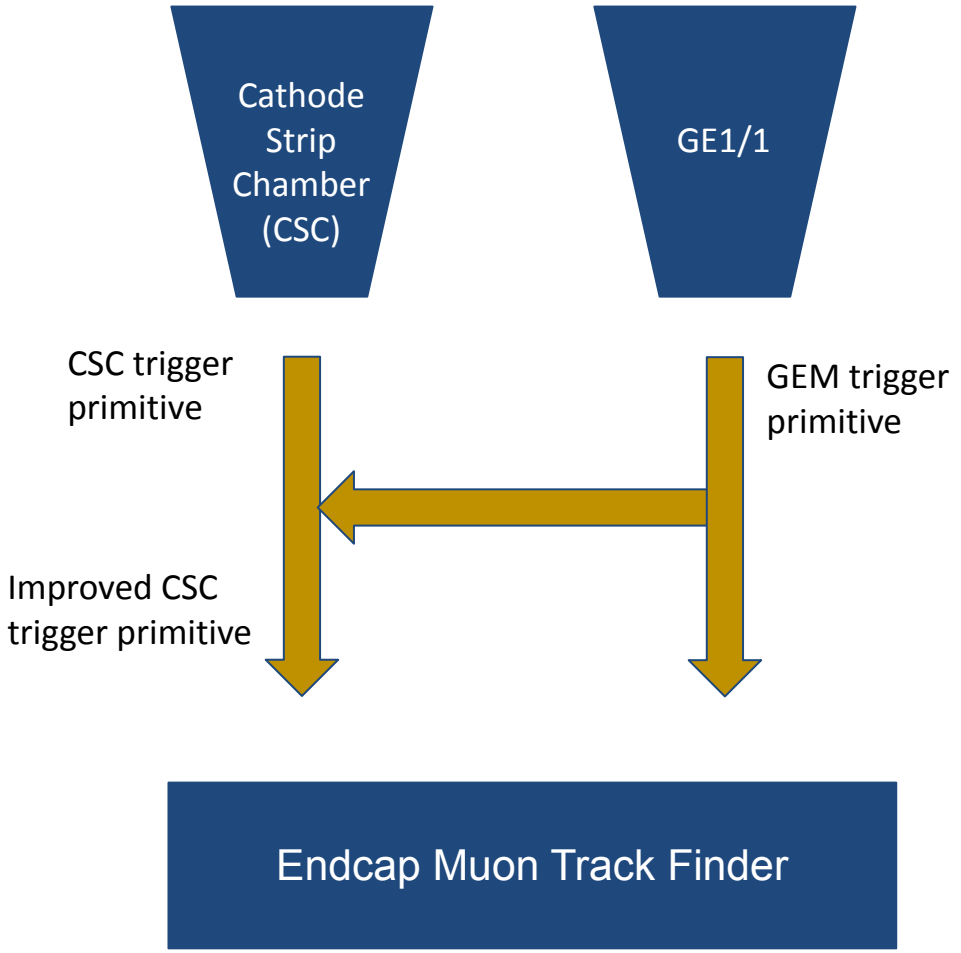

Thank you!
Danke!
Merci!
Grazie!
Grazia!



Back-Up

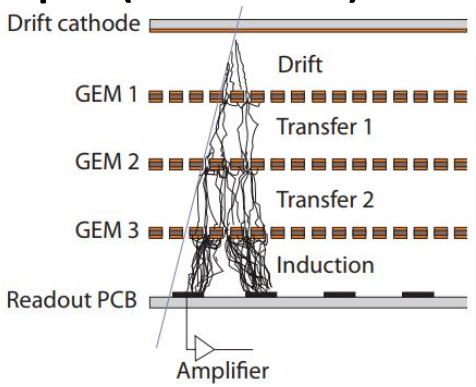
GEM-CSC Trigger

- GE1/1 chambers linked to neighboring CSC chamber
- GEM trigger sent to neighboring CSC
  - Improved CSC trigger primitive
- Non-neighboring chambers matched in Endcap Muon Track Finder



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)



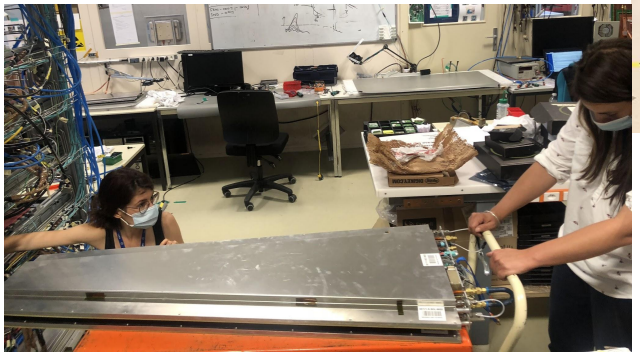
Final QCs: QC8

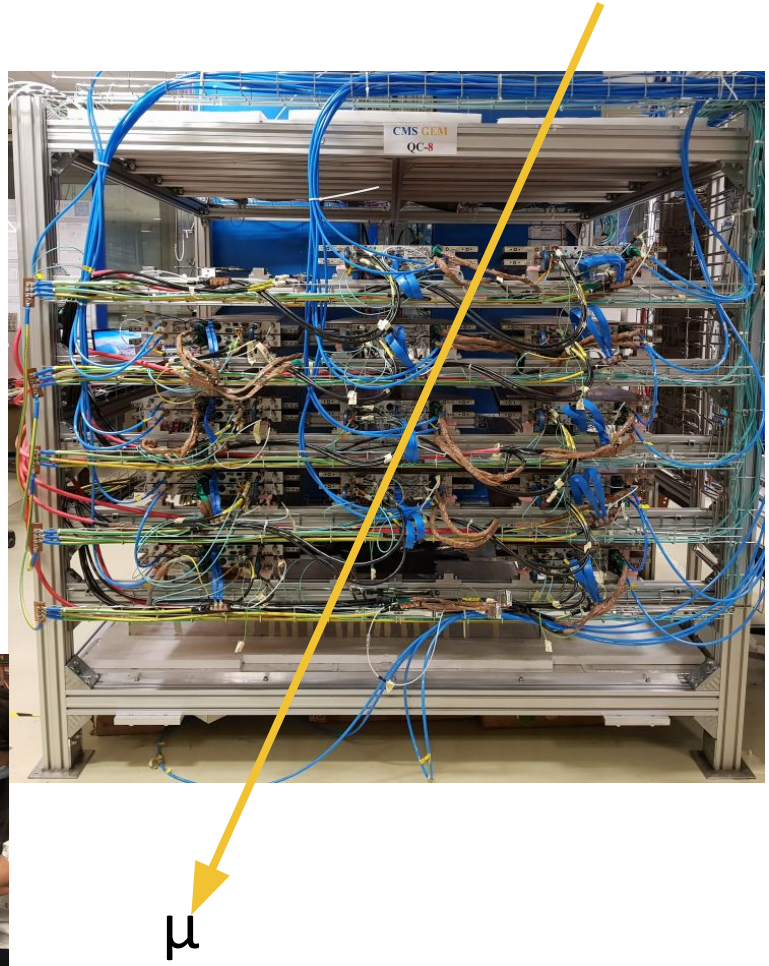
Cosmic Stand

- 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)

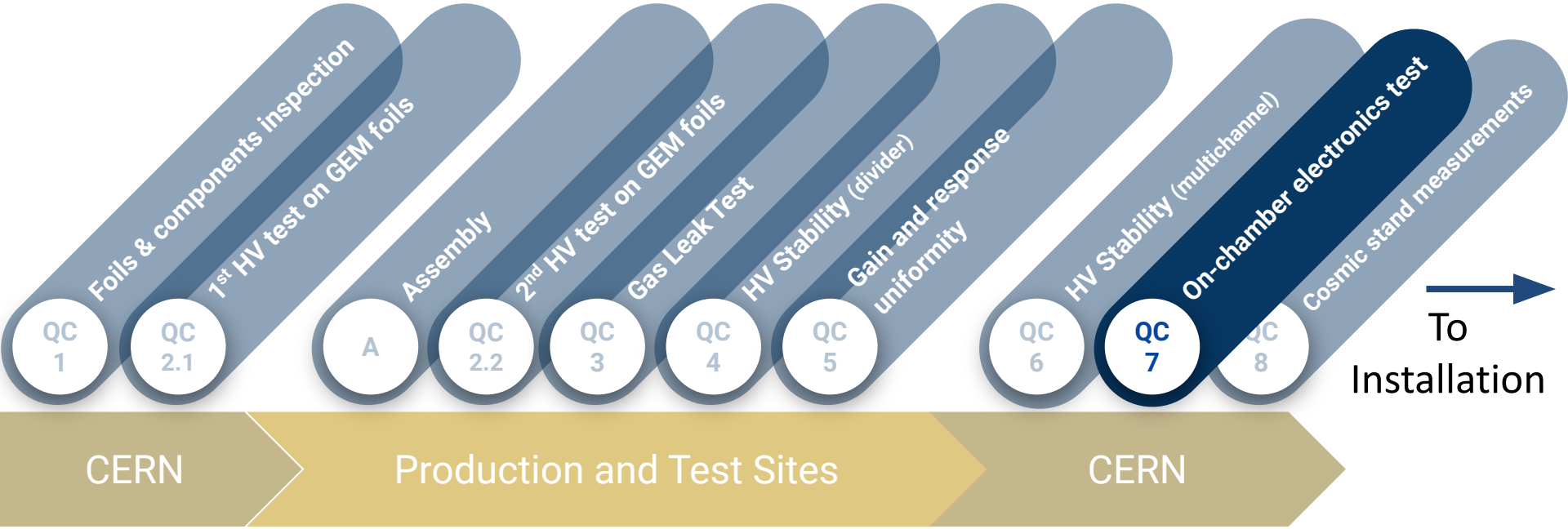
QC8 Test

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





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

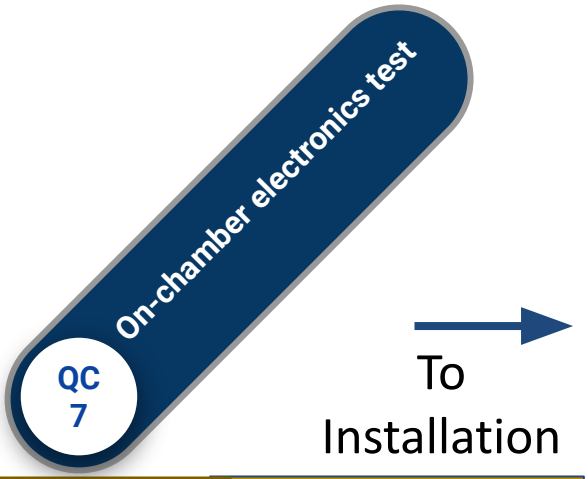
Paired into super chambers

77 super chambers produced

72 super chambers installed in the experiment

*QC: Quality Control, HV: High Voltage

GE1/1 Detector Production



CERN | Production and Test Sites | CERN | CMS Experiment

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

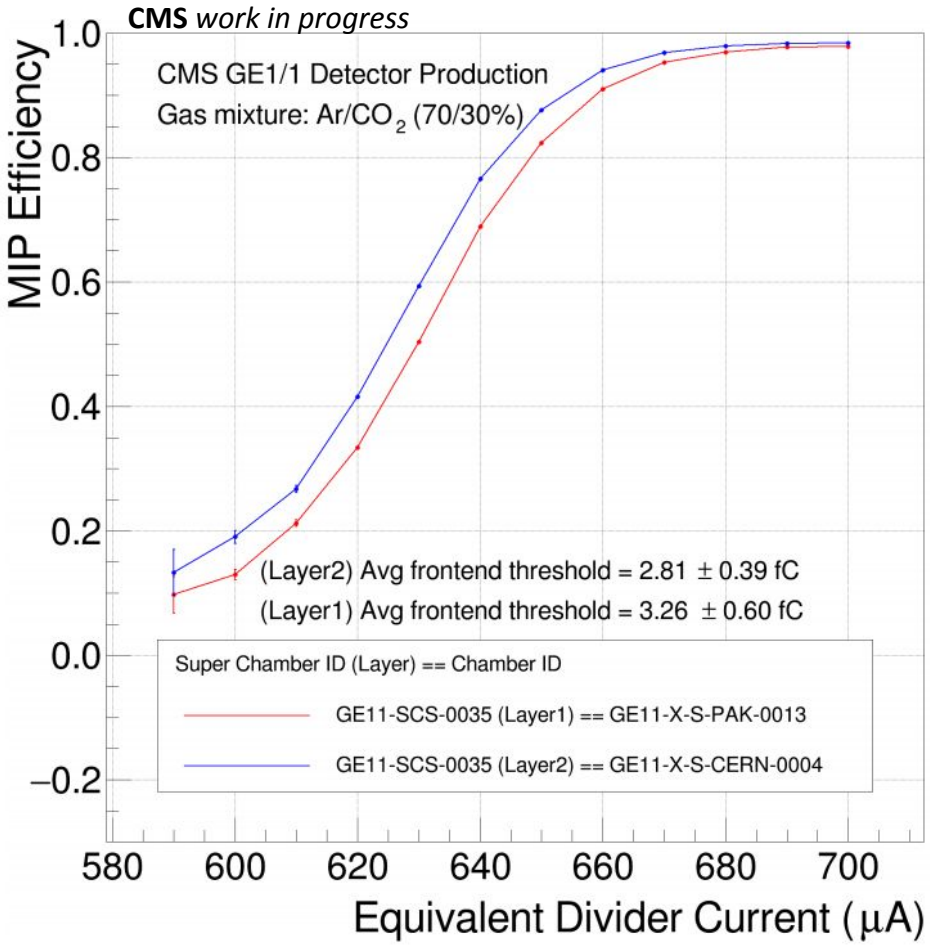
77 super chambers produced

72 super chambers installed in the experiment

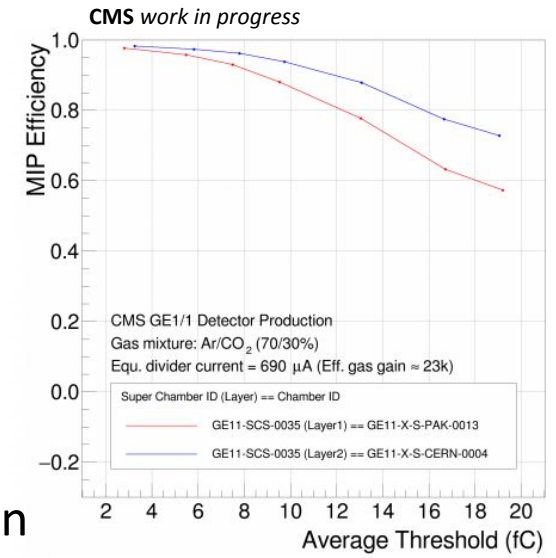
*QC: Quality Control, HV: High Voltage

QC8 Results

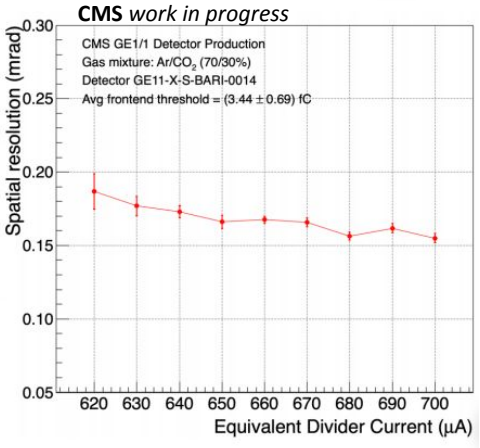
Efficiency vs HV Set Point



Efficiency vs Threshold

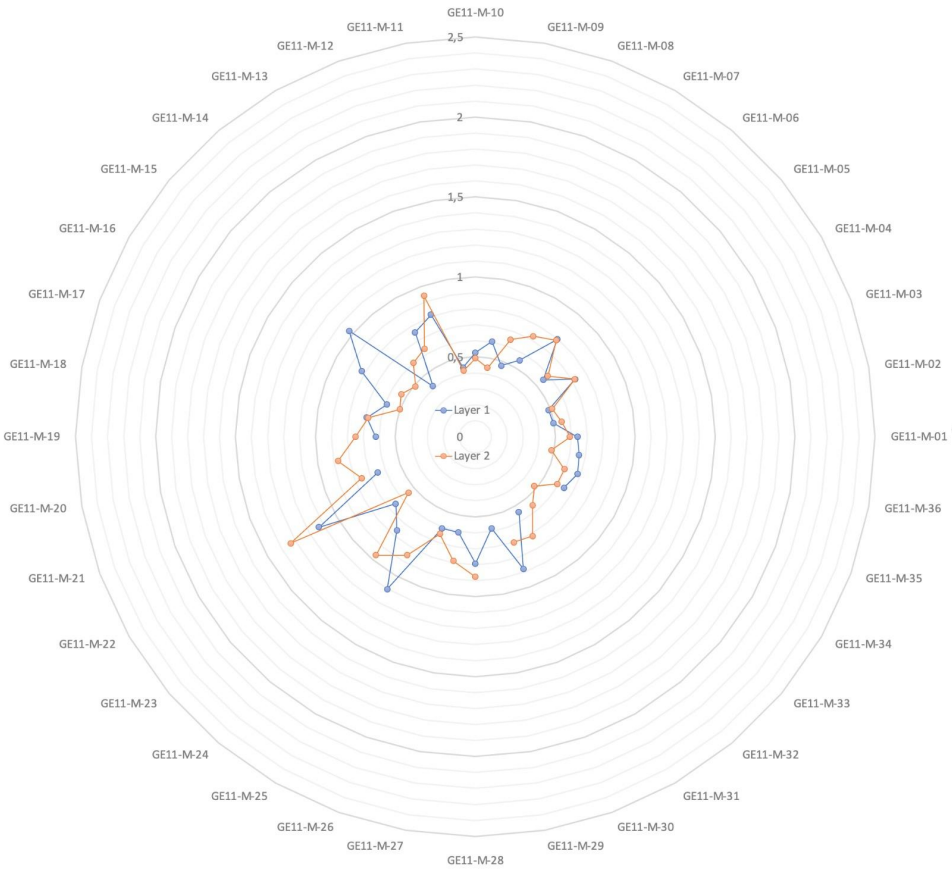


Spatial Resolution

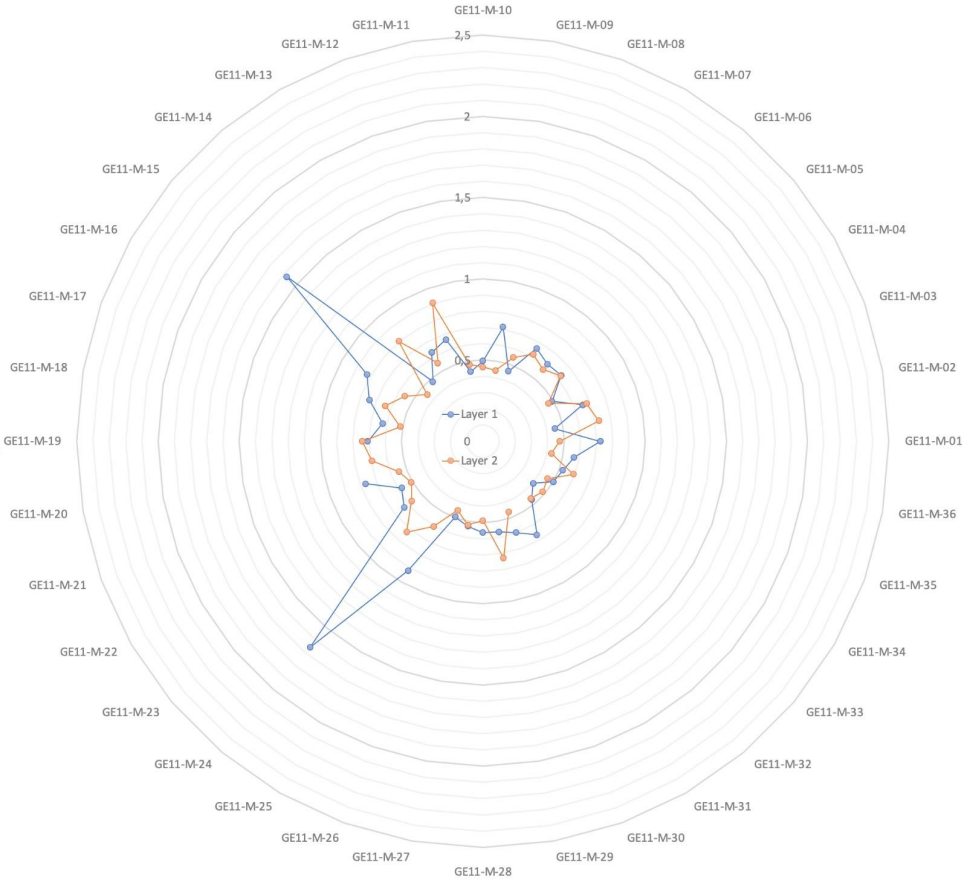


Noise Comparison: Negative

Before LV filters

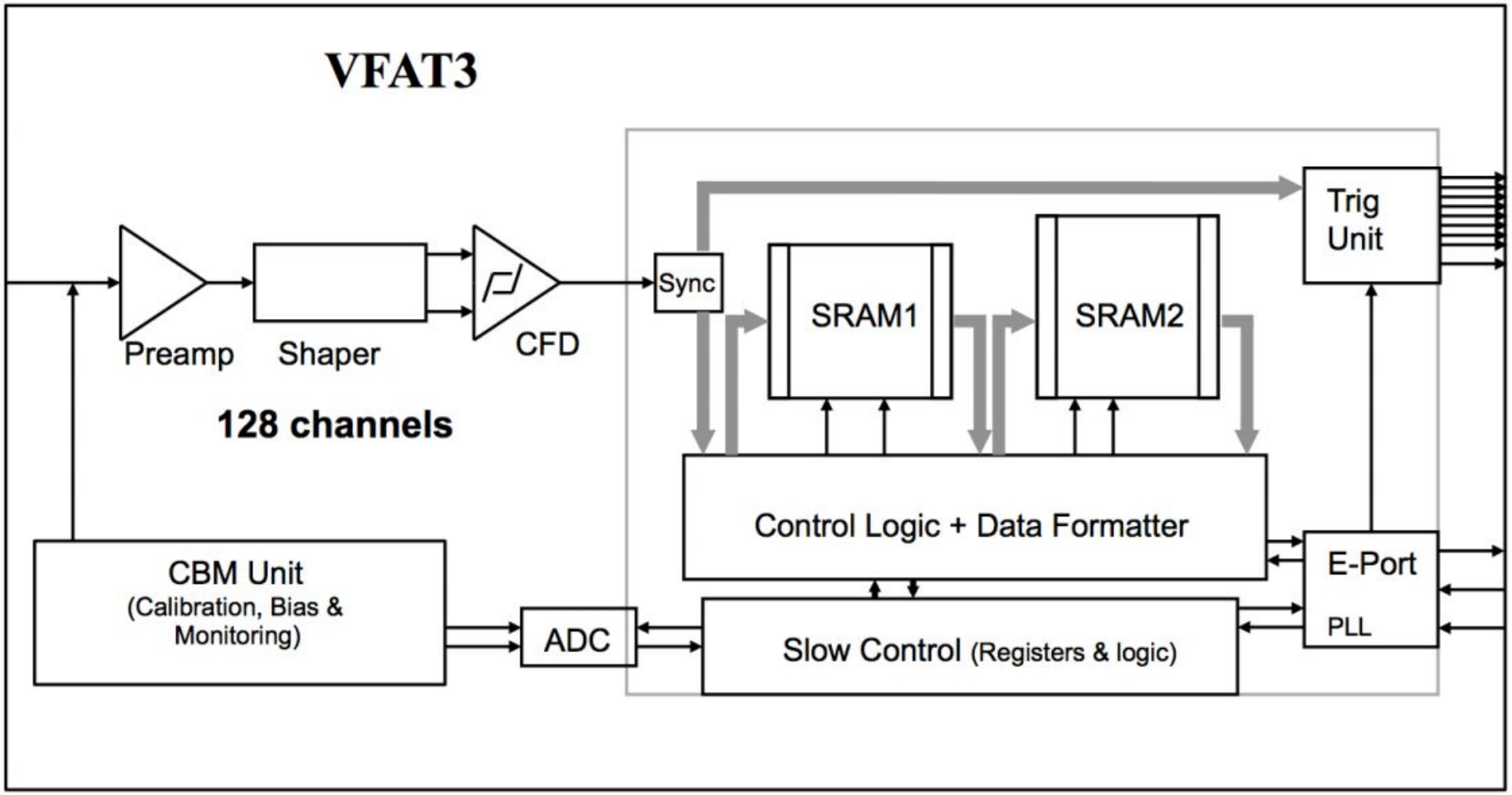


After LV filters

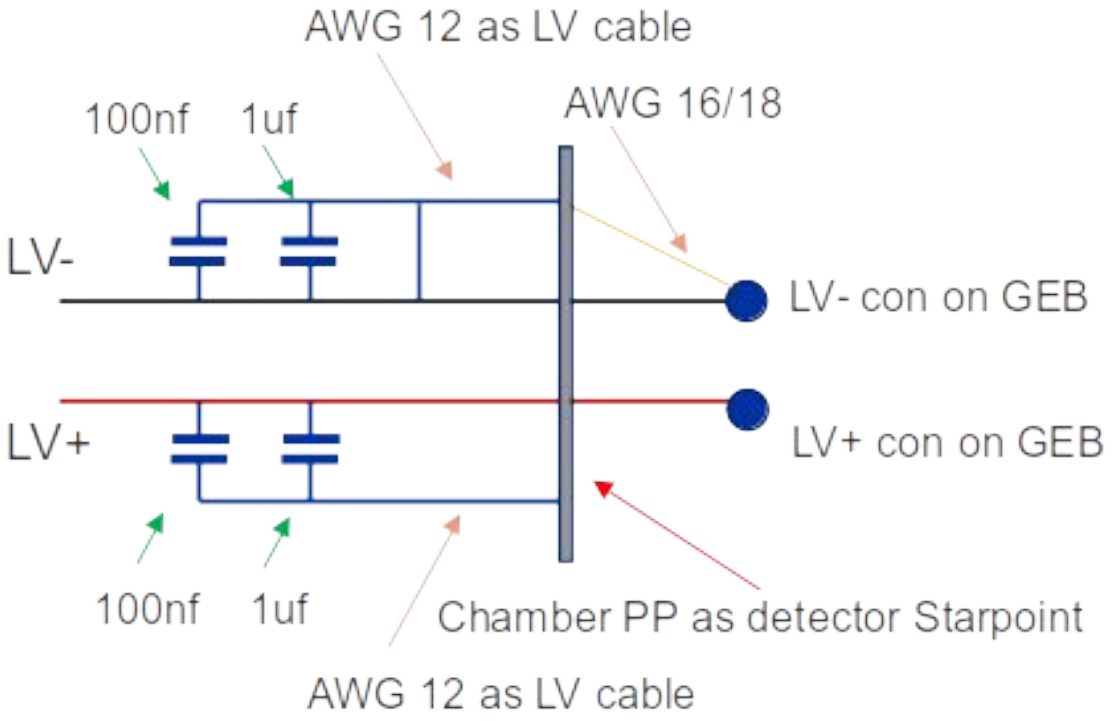


Missing chambers due to GBT instabilities

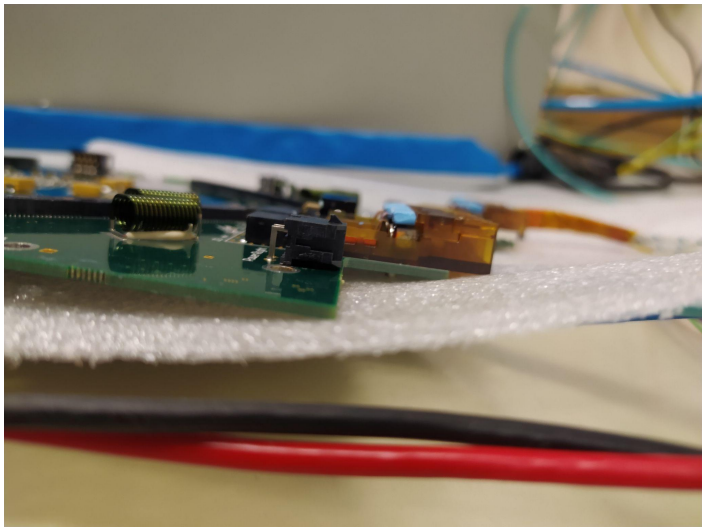
VFAT 3 Circuit

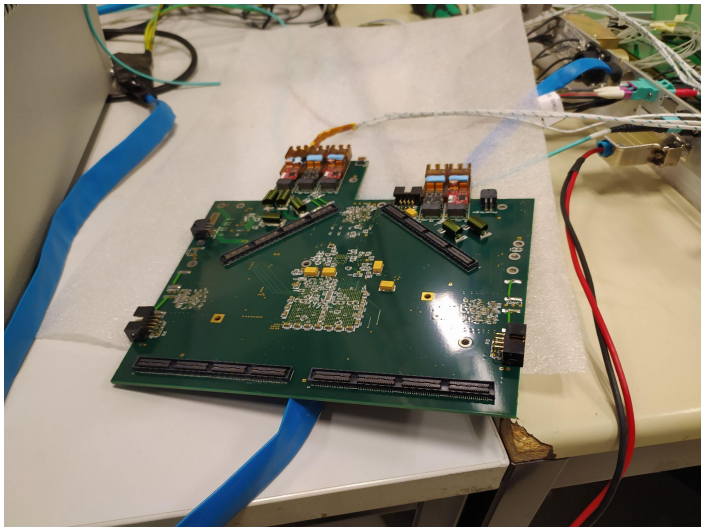


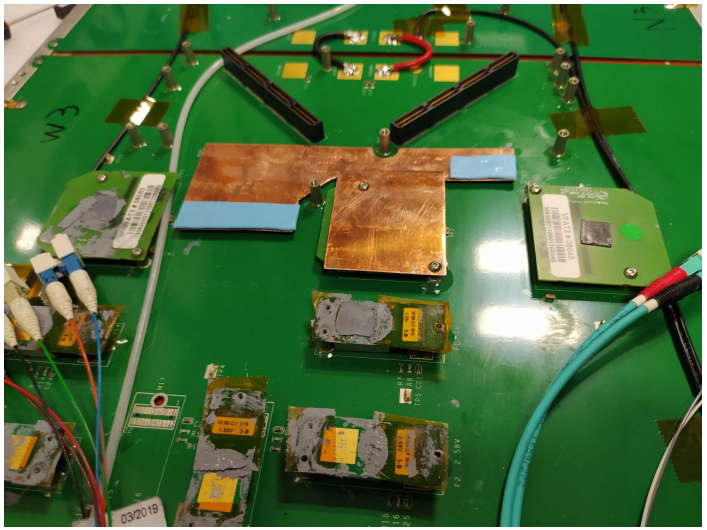
Detailed LV Low Pass Filter

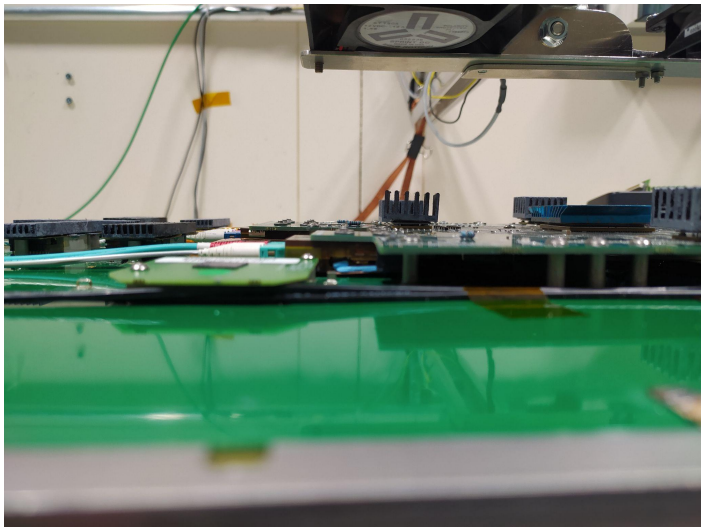


VTRx Cooling: design and fit

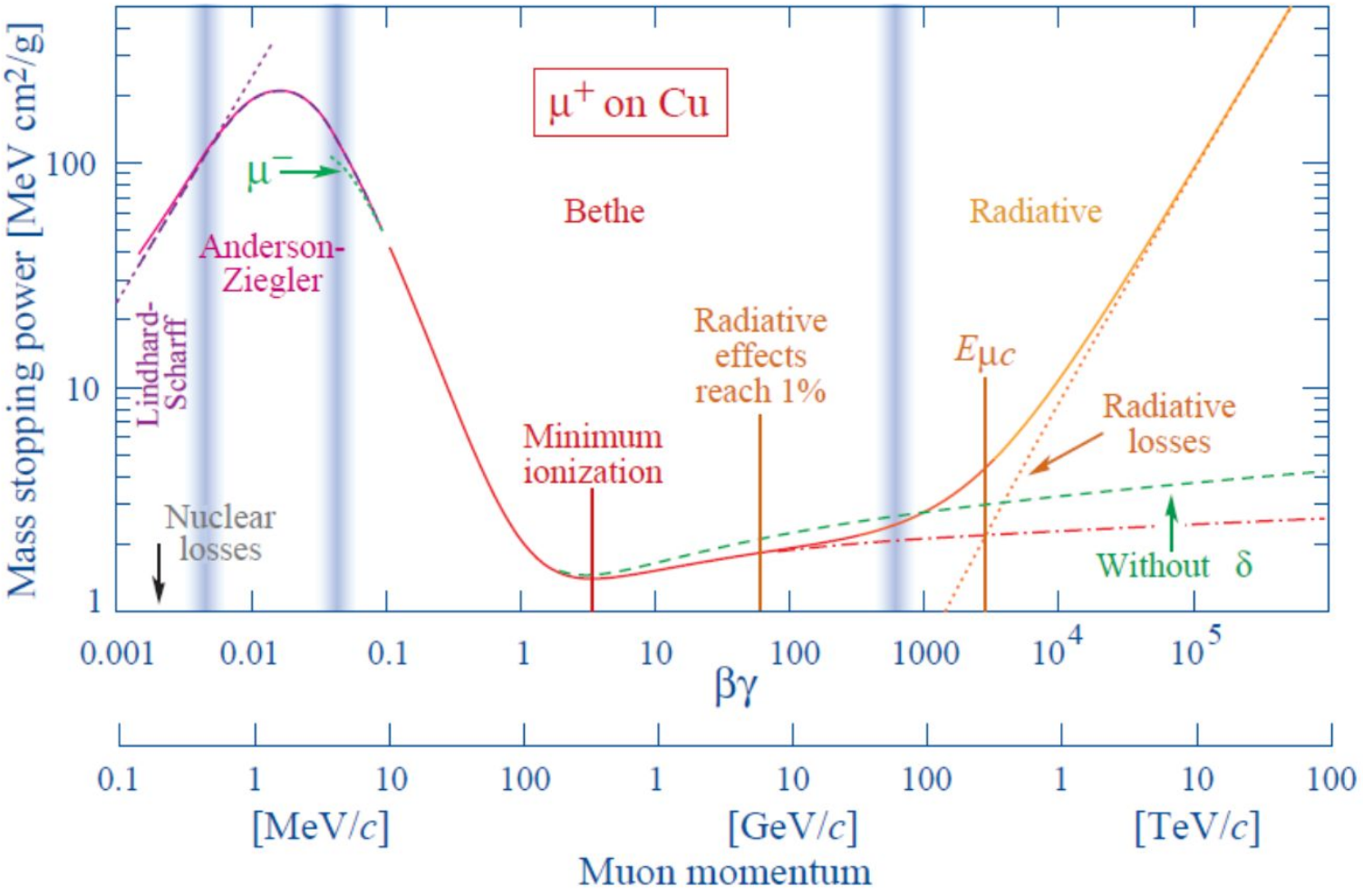








Minimum Ionizing Particles MIPs



GEM/CSC Comparisons

- Rate capability requirements:
  ME11 1 kHz/cm^2, GE11 10 kHz/cm^2
- Time Resolution:
  ME11 < 10 ns, GE11 < 10 ns
- Spatial Resolution:
  ME11 < 1.2 mrad, GE11 < 0.3 mrad