The Quality Control Procedure of an M5 Module for the CMS GE2/1 GEM Detector

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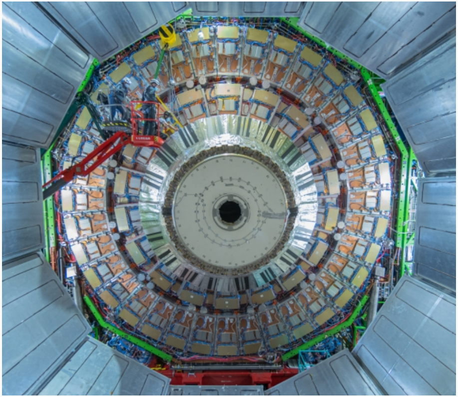
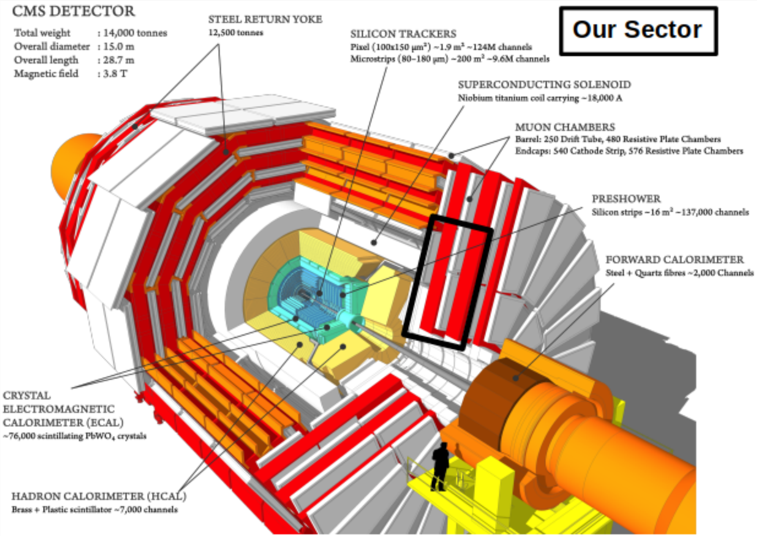
The CMS Experiment

- One of the two general-purpose experiments at the Large Hadron Collider (LHC)
- Studying the Standard Model and searching for exotic physics
- High Luminosity Upgrade of the LHC
  - Increasing the instantaneous luminosity by at least a factor of 5
  - Luminosity given by $L = \frac{N_1 N_2 f N_b}{4\pi \sigma_x \sigma_y}$
  - Increases the amount of data collected and the potential for discovering new physics
- Phase-2 Muon System Upgrade
  - Luminosity increase $\Rightarrow$ increase in muon flux rate in the forward region
  - Three new GEM detector systems are being built and installed in the endcaps of CMS



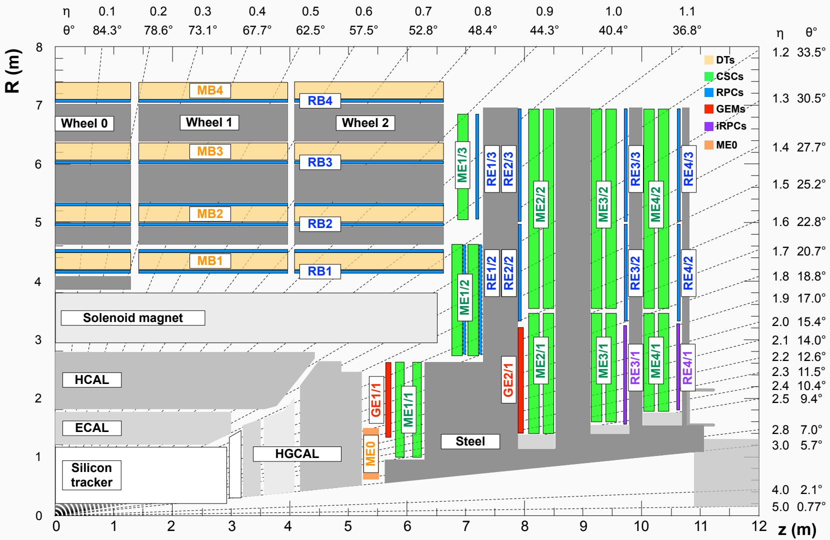
Installation of GEMs in CMS [1]

Our location in the CMS Experiment



The CMS experiment with the endcap highlighted. Adapted from [3]

The CMS Experiment

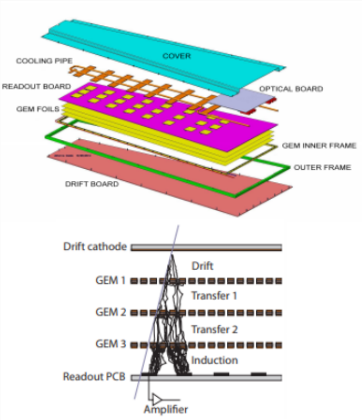


Quadrant of the CMS Experiment [2].

What is a GEM detector?

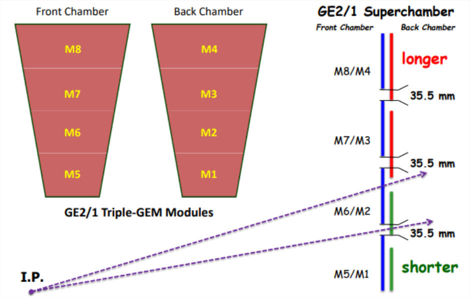
Gas Electron Multipliers (GEMs) use HV foils perforated with a high density of microscopic holes to amplify the primary charge created from incident radiation

- Incident radiation ionizes fill gas, releasing electrons
- Electric field within holes accelerates electrons, creating Townsend avalanches
- Multiple foils increases charge multiplication
- Avalanche-liberated electrons induce signal on the readout

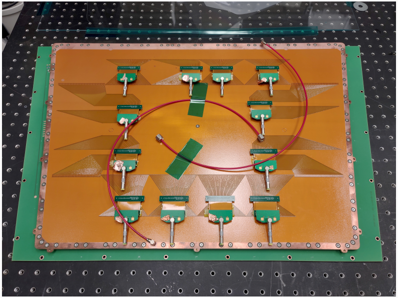


(Top) Schematic of a CMS GE1/1 GEM detector
(Bottom) Schematic of an avalanche in a triple-GEM detector [2]

The GE2/1 GEM Detector



Schematic of the GE2/1 superchamber [2]



The M5 module

- Second generation CMS GEM detector
- 1 GE2/1 made of 4 individual triple-GEM modules
- Back chamber: M1-M4 modules, Front chamber: M5-M8 modules
- Located in the second muon station in the endcaps
- 1 Superchamber = 2 full GE2/1 chambers mounted back-to-back
- 36 superchambers per endcap, with two endcaps = 72 superchambers total

Quality Control Process

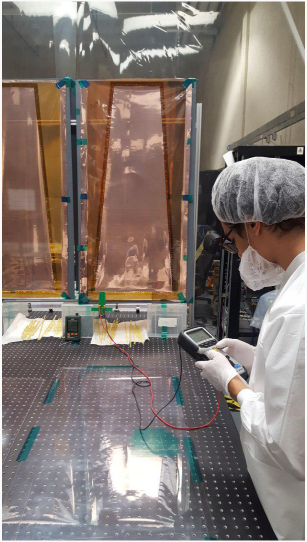
- GE2/1-M5 module assembled at FIT for performing frontend electronics integration tests
- We are qualifying the chamber via the CMS GEM QC procedures to ensure nominal detector operation

Table 1: CMS GEM Quality Control Steps

QC Step	Description	Performed at FIT	Performed at CERN
1	Inspection of materials & PCB planarity testing		X
2a	Leakage current test (long)		X
2b	Leakage current test (fast)	X	
3	Gas Leak test	X	
4	Spurious signal rate and HV divider response	X	
5a	Effective Gain	X	
5b	Gain Uniformity	X	
6	HV test		X
7	Frontend electronics integration and noise test		X
8	Cosmic Ray Stand – detection efficiency, reconstruction		X

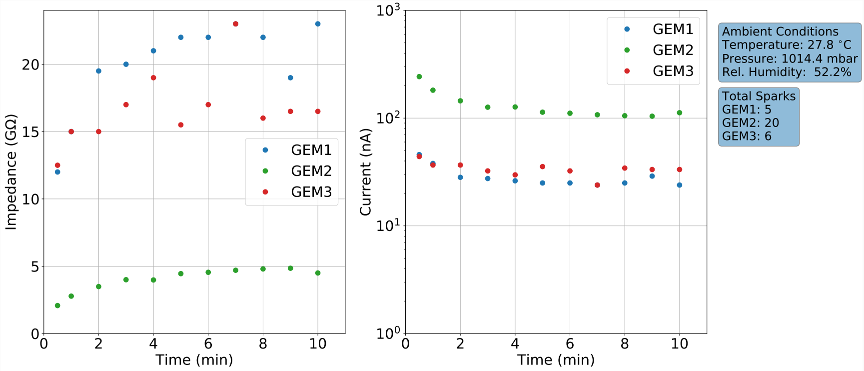
GEM Foil Leakage Current Test

- Ensure GEM foils operate properly before installing in detector
- 550 V applied to top and bottom of a foil using a handheld multi-Giga Ohmmeter (Megger MIT485)
- Measure impedance between the top and bottom of a GEM foil over 10 minutes
- Leakage current calculated via Ohm's Law ($I = V/R$)
- Electrically cleans foils (removes dust or possible surface contaminants)

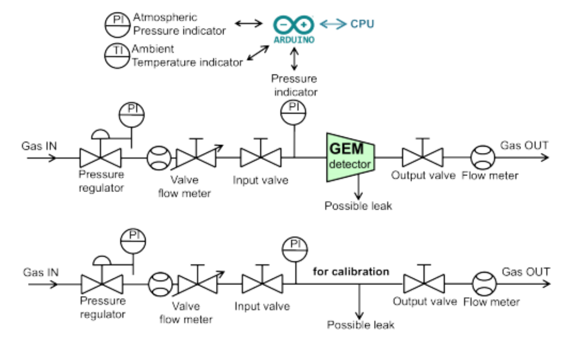


Leakage current test on a GE1/1 GEM foil

GEM Foil Leakage Current Test



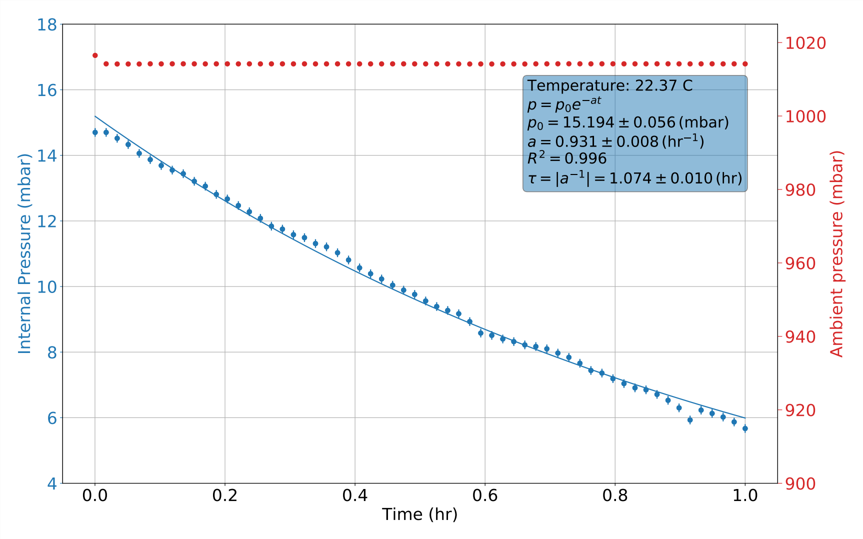
Ensuring Gas-Tightness with a Leak Test



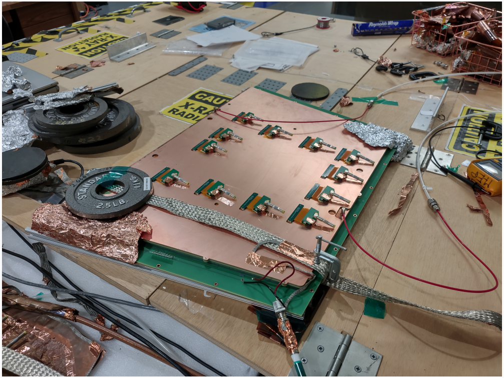
Arduino circuit for data acquisition [2]

- Pressurize the chamber with N_2, seal the outflow line, and monitor gas pressure over an hour
- Why? To ensure impurities don't enter the active volume
- Why? Gas is **expensive**

Leak Test Results



QC 4: HV Test



GE2/1-M5 module undergoing QC4

- Characterize the noise in the chamber
- Fill gas: CO_2
- No radiation source
- Record monitored current at predetermined voltages
- Fit recorded I vs V curve to determine equivalent circuit resistance and HV divider linearity
- Measure the spurious signal rate from GEM3B

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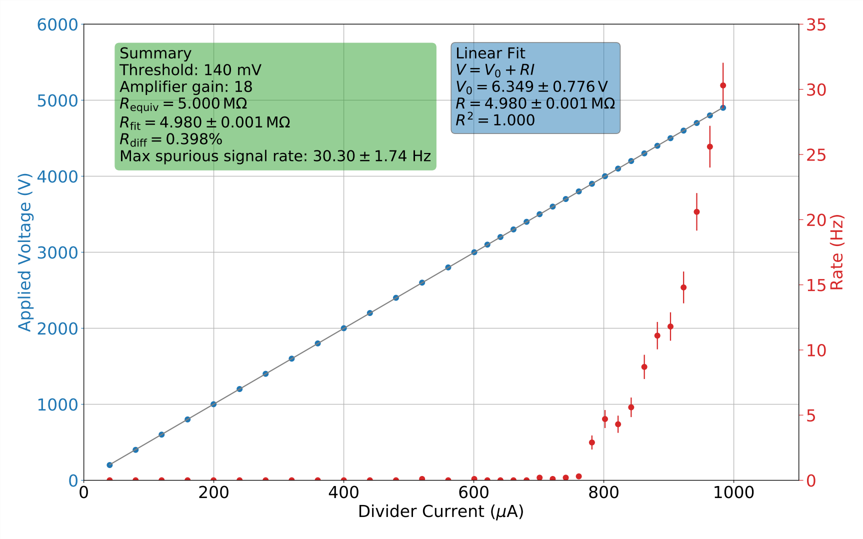
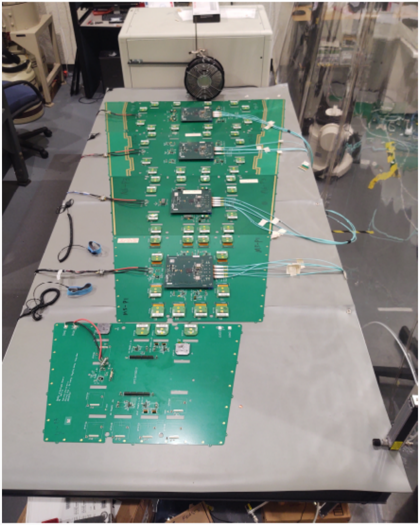
QC 4 Results


Summary
Threshold: 140 mV
Amplifier gain: 18
$R_{equiv} = 5.000\,\mathrm{M\Omega}$
$R_{fit} = 4.980 \pm 0.001\,\mathrm{M\Omega}$
$R_{diff} = 0.398\%$
Max spurious signal rate: 30.30 ± 1.74 Hz
Linear Fit
$V = V_0 + RI$
$V_0 = 6.349 \pm 0.776\,\mathrm{V}$
$R = 4.980 \pm 0.001\,\mathrm{M\Omega}$
$R^2 = 1.000$
Applied Voltage (V)
Rate (Hz)
Divider Current (μA)
0
1000
2000
3000
4000
5000
6000
0
200
400
600
800
1000
0
5
10
15
20
25
30
35

Remaining QC Tests and Future Plans

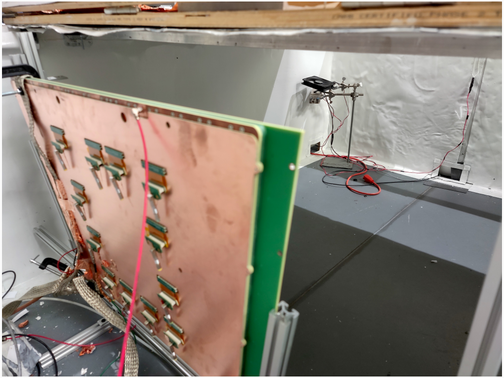
- Conduct effective gain measurements
- Conduct gain uniformity measurements
- Perform noise measurements with frontend electronics on this M5 module to test grounding variations
- Finish building facilities to perform cosmic ray track reconstruction with a full GE2/1 chamber



Florida Tech's frontend electronics test stand

Summary and Conclusions

- GEM foil leakage current test shows nominal foil impedances ($Z \gtrapprox 4$ GΩ) with minimal sparking
- Leak rate test shows a time constant of $\tau = 1.074 \pm 0.010$ hr
- HV divider linearity test shows a fitted resistance of $R = 4.980 \pm 0.001$ MΩ with maximum deviation of 0.4%
- Maximum spurious rate (threshold of 140 mV at 4900 V): $R_{\text{spurious}} = 30.30 \pm 1.74$ Hz
- Effective gain measurement in progress



The M5 module inside the X-ray box for the effective gain measurement

References

[1] A. Sharma, "FIRST GEM STATION (GE11) INSTALLED IN CMS", *CMS News*, https://cms.cern/news/first-gem-station-ge11-installed-cms.

[2] CMS Collaboration, *The Phase-2 Upgrade of the CMS Muon Detectors, Technical Report* **CERN-LHCC-2017-012**, **CMS-TDR-016** (2017).

[3] T. Sakuma & T. McCauley, "Detector and Event Visualization with SketchUp at the CMS Experiment," *J. Phys.: Conf. Ser.*, **513**(022032), doi:10.1088/1742-6596/513/2/022032.

[4] M. Bianco, B. Dorney, & J. Merlin, On behalf of the CMS GEM Collaboration, *GE1/1 Quality Control: Instructions*, Sep. 28, 2016, https://research.fit.edu/media/site-specific/researchfitedu/hep/heplabb/documents/QC_Instructions_20160928.pdf