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

Stephen Butalla, Merrick Lavinsky, Zackery Wihela, & Marcus Hohlmann
March 19, 2021

The 84th Annual Meeting of the Florida Academy of Sciences

stephen.butalla@cern.ch,
mlavinsky2016@my.fit.edu
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]

Quadrant of the CMS Experiment [2].

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]
- 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

<table>
<thead>
<tr>
<th>QC Step</th>
<th>Description</th>
<th>Performed at FIT</th>
<th>Performed at CERN</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Inspection of materials &amp; PCB planarity testing</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>2a</td>
<td>Leakage current test (long)</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>2b</td>
<td>Leakage current test (fast)</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>3</td>
<td>Gas Leak test</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>4</td>
<td>Spurious signal rate and HV divider response</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>5a</td>
<td>Effective Gain</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>5b</td>
<td>Gain Uniformity</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>6</td>
<td>HV test</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>7</td>
<td>Frontend electronics integration and noise test</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>8</td>
<td>Cosmic Ray Stand – detection efficiency, reconstruction</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
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 \( I = \frac{V}{R} \)
- Electrically cleans foils (removes dust or possible surface contaminants)
Ensuring Gas-Tightness with a Leak Test

- Pressurize the chamber with N\textsubscript{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**

Arduino circuit for data acquisition [2]
Leak Test Results

Temperature: 22.37°C

\[ p = p_0 e^{-at} \]

\( p_0 = 15.194 \pm 0.056 \text{ (mbar)} \)

\( a = 0.931 \pm 0.008 \text{ (hr}^{-1}\text{)} \)

\( R^2 = 0.996 \)

\( \tau = |a^{-1}| = 1.074 \pm 0.010 \text{ (hr)} \)
QC 4: HV Test

- Characterize the noise in the chamber
- Fill gas: CO₂
- 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

GE2/1-M5 module undergoing QC4
QC 4 Results

Summary
Threshold: 140 mV
Amplifier gain: 18
$R_{\text{equiv}} = 5.000 \, \text{M}\Omega$
$R_{\text{fit}} = 4.980 \pm 0.001 \, \text{M}\Omega$
$R_{\text{diff}} = 0.398\%$
Max spurious signal rate: 30.30 ± 1.74 Hz

Linear Fit
$V = V_0 + RI$
$V_0 = 6.349 \pm 0.776 \, \text{V}$
$R = 4.980 \pm 0.001 \, \text{M}\Omega$
$R^2 = 1.000$
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
Summary and Conclusions

- GEM foil leakage current test shows nominal foil impedances ($Z \gtrsim 4$ 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

