PROCEEDINGS OF SCIENCE

Quality control results of the first CMS GE2/1 muon production chambers

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The CMS upgrade for the High Luminosity phase of the LHC (HL-LHC) involves the installation of three GEM stations: GE1/1, GE2/1, and ME0. While GE1/1 has been operational since Run-3's onset, only three GE2/1 chambers are in place as of early 2024 including the previously installed demonstrator chamber. ME0 installation is slated for LHC Long Shutdown 3, with GE2/1 chamber installation resuming post ME0 completion. These GEM stations, coupled with improved Resistive Plate Chambers (iRPC) detectors, are pivotal for sustaining optimal muon triggering and reconstruction. This presentation delves into the production, validation, and performance results of the initial two GE2/1 detectors at CERN GEM lab, showcasing impressive average efficiencies of 98.5% and 99% measured with a six-layer cosmic stand.

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1. Introduction

The Large Hadron Collider (LHC) including the CMS experiment [1, 2] is set to undergo upgrades to prepare for the high-luminosity phase. To manage the increased background rates and trigger requirements, the CMS muon system will be enhanced by adding additional muon detectors based on Gas Electron Multiplier (GEM) technology [3]. The GE2/1 station will feature 72 GEM chambers, composed of 288 modules, covering the pseudorapidity range of 1.62 to 2.43 [4]. Out of the required 288 modules, 96 have been already produced, but later rejected due to the discovery of the copper dust contamination. Currently, the GE2/1 chambers are being retrofitted, and the first two production-grade chambers have been installed earlier this year after successful validation in a GEM cosmic-ray stand.

2. GE2/1 production workflow

All GE2/1 detectors must pass eight stages of quality control (QC) before they can be installed at P5, which is verified for the front-type chambers for installation during EYETS23-24. The QC stages include tests for component acceptance, foil leakage current, module gas tightness, module high voltage (HV) and its stability, module gas gain and its uniformity, front-end electronics validation, and chamber detection efficiency and the HV working point at which the detectors are fully efficient.

3. Quality control results

Figures 1–4 present the QC results for modules that successfully passed various tests. In Fig.1, the gas leak test results for 16 modules are shown, with all modules meeting the acceptance criterion for gas-tightness, defined as $\tau > 3.04$ hours [5]. Figure 2 illustrates the results for 16 modules that passed the threshold for detector acceptance, with D_R (resistance deviation) greater than 3%, where D_R is the percentage difference between the measured resistance and the nominal resistance of the voltage powering circuit [5]. This threshold aligns with the divider tolerance provided by the manufacturer.

Figure 3 presents the verification of gain uniformity for a new GE2/1 module. It shows the effective gain response for each of the four η partitions ($i\eta = 1, 2, 3, 4$) of the detector, as measured using an X-ray source. The observed outliers are attributed to local failures in the automatic fitting of the ADC distribution during front-end electronics validation.

Lastly, Fig. 4 provides an example of an s-bit rate scan, conducted to detect potential issues in the trigger path. This process involves adjusting the discriminator thresholds of each VFAT3 front-end readout chip and recording the firing frequency of the 128 channels. A normal result is a steeply decreasing rate with increasing thresholds, as shown by the plot, which represents a typical good response. The operational threshold is determined based on the accepted noise rate, which is typically below 1 Hz.

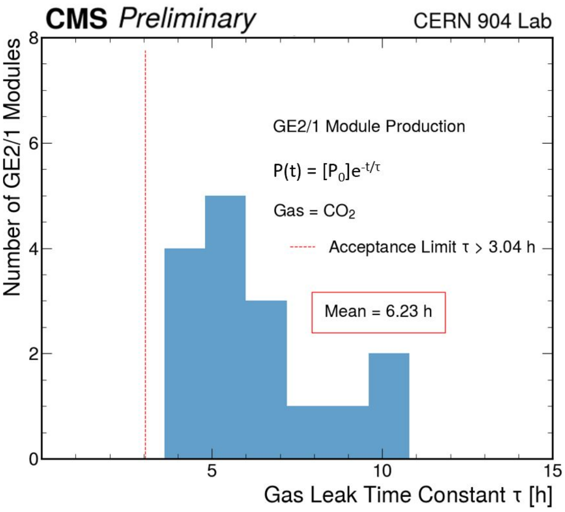

Figure 1: Gas leak time constants of 16 GE2/1 modules currently installed in CMS as measured in pure CO_2. All modules meet the acceptance criterion for a gas-tight module of $\tau > 3.04$ hours [5].

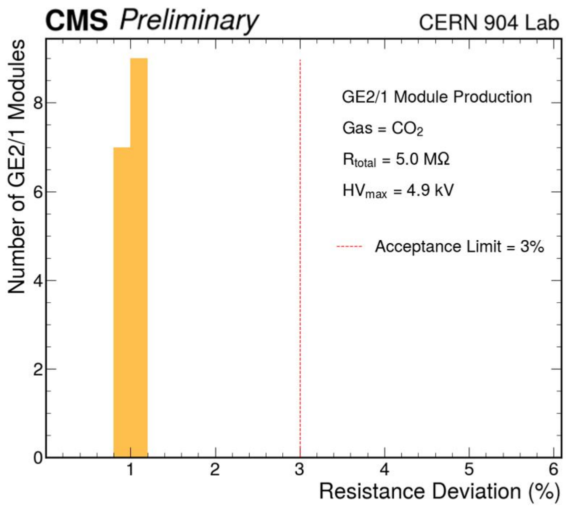

Figure 2: Resistance deviation DR (%) for 16 GE2/1 modules currently installed in CMS as measured in pure CO_2. The test is passed if $D_R < 3\%$ as the threshold for accepting a detector [5].

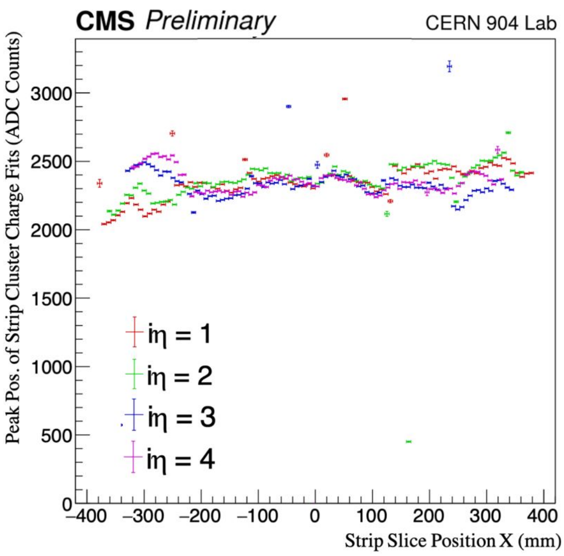

Figure 3: Gain uniformity test for a GE2/1 module currently installed in CMS. Effective gain response is measured for each of the four η partitions ($i\eta$ = 1, 2, 3, 4) using an X-ray source.

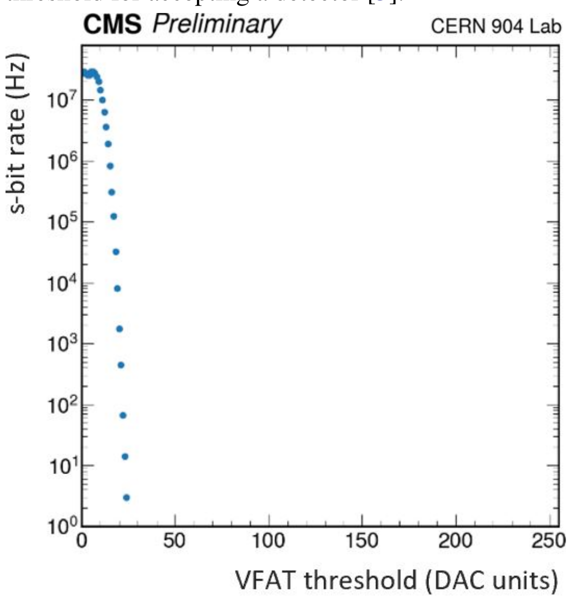

Figure 4: S-bit rate scan used in electronics quality control tests to detect potential issues in the trigger path. The plot shows a typical good response, with the curve used to determine the operational threshold based on the accepted noise rate.

4. Performance in CMS

Four GE2/1 production chambers have been fully validated and two of which have been installed in CMS during the Extended Year End Technical Stop (EYETS) of 2023-24. They are currently fully operational in P5, located in the negative endcap (Sectors 16 and 18). We continue to evaluate the HV stability and discharge rate of these new chambers. We have seen good front-end electronics stability. Latest efficiencies using p-p collision data meet the acceptance criterion of at least 97% [6] when using standalone muon tracks formed from other muon chambers.

5. Conclusion

Two GE2/1 chambers were tested and fully validated using cosmic muon data with high efficiency and operational stability. Their optimal working point was determined to be at an equivalent divider current of 680 µA. After being inserted into CMS during EYETS 2023-24, these two chambers were commissioned and have been participating in data-taking for 2024.

References

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

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