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CMS CR -2022/166

The Compact Muon Solenoid Experiment

Conference Report

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

04 October 2022 (v5, 17 November 2022)

Production and quality control of the GEM GE2/1 detector for the upgrade of the CMS endcap muon system

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Abstract

The Compact Muon Solenoid (CMS) experiment is a general-purpose detector installed in the Large Hadron Collider (LHC). The future High Luminosity-LHC (HL-LHC) will provide a factor of 7 increase in luminosity compared with the design value of the LHC. To accommodate this increase and to enhance the performance of the CMS experiment, the forward region of the muon system will be equipped with 3 new sets of stations employing triple-foil Gas Electron Multi- plier (GEM) detectors. These three stations, GE1/1, GE2/1, and ME0 will enhance acceptance, longevity, redundancy, and triggering efficiency while operating in the harsh radiation environ- ment of the HL-LHC. The GE1/1 station was installed during the technical stop of 2019/2020. The GE2/1 station will be installed during the year end technical stop (YETS) of 2023/2024. The GE2/1 detector construction started in 2021 utilizing advanced quality controls (QC) and perfor- mance checks. We describe the GE2/1 chamber geometry, the multi-institutional production of chambers, the QC procedures, and the results from these QC measurements.

Presented at *ICHEP2022 41st International Conference on High Energy Physics*

PROCEEDINGS OF SCIENCE

Production and quality control of the GEM GE2/1 detector for the upgrade of the CMS endcap Muon system

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The Compact Muon Solenoid (CMS) experiment is a general-purpose detector installed in the Large Hadron Collider (LHC). The future High Luminosity-LHC (HL-LHC) will provide a factor of 7 increase in luminosity compared with the design value of the LHC. To accommodate this increase and to enhance the performance of the CMS experiment, the forward region of the muon system will be equipped with 3 new sets of stations employing triple-foil Gas Electron Multiplier (GEM) detectors. These three stations, GE1/1, GE2/1, and ME0 will enhance acceptance, longevity, redundancy, and triggering efficiency while operating in the harsh radiation environment of the HL-LHC. The GE1/1 station was installed during the technical stop of 2019/2020. The GE2/1 station will be installed during the year end technical stop (YETS) of 2023/2024. The GE2/1 detector construction started in 2021 utilizing advanced quality controls (QC) and performance checks. We describe the GE2/1 chamber geometry, the multi-institutional production of chambers, the QC procedures, and the results from these QC measurements.

41st International Conference on High Energy Physics - ICHEP2022
6-13 July, 2022
Bologna, Italy

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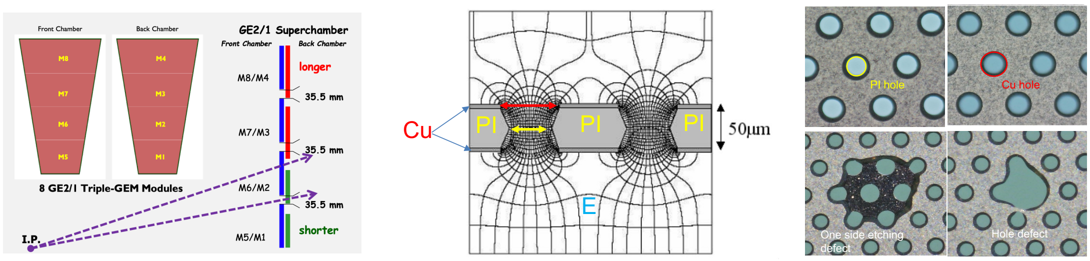
1. Introduction

GE2/1, the second Gas Electron Multiplier (GEM) based muon endcap station of the Compact Muon Solenoid (CMS) experiment, comprises 36 chambers (18/endcap). One chamber is composed of 4 different sized modules to optimize the pseudorapidity, η, coverage as shown in Fig. 1a. GE2/1 will cover the forward range of $1.6 < |\eta| < 2.4$ [1]. The GE2/1 mass production is distributed over seven production sites in six different countries. Each production site had to pass a 2-year certification program before being approved by the GEM group. Well-defined advanced quality control (QC) stages are very important to guarantee the successful performance of modules, which are assembled at various production sites.



(a) (b) (c)

Figure 1: (a) GE2/1 schematic layout[1], (b) GEM foil structure, (c) Microscopic view of GEM foil and examples of typical foil defects.

2. QC1: Visual inspections at the GEM foil production sites

The visual inspection is the first stage of QC (QC1) process. In QC1, the following items are investigated: (i) The High Voltage (HV) lines and the surface mount resistors (SMD); (ii) the foil surface conditions and any suspicious defects; (iii) polyimide (PI) and copper (Cu) layers hole size measurements in five different foil areas of drift and readout sides.

The PI- and Cu-hole sizes are important for the signal gain since the amplification occurs inside the hole. Each defect position is mapped for further control. A defect size covering less than 10 holes, as in Fig. 1c, is an acceptable.

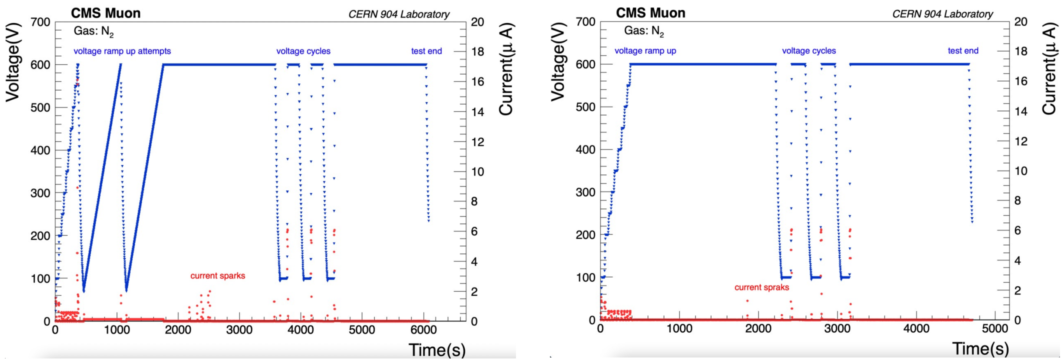
3. QC2: HV stability and leakage current check

QC2 is divided into two parts, QC2a and QC2b. The QC2a test is an impedance and sparks check with 500 V applied. Sparks are counted 6 consecutive times every 30s (twice) then every 1 min (4 times). The foil is acceptable if the final impedance is higher than 10 GΩ and the number of spark is less than 10. If the number of spark is higher than 10, spark counting will be continued for 10 min. If the spark is consistence, the foil should be cleaned with dedicated sticky roller and repeat the QC2a test. If the foil does not pass the repeated QC2a test, it should be sent to the production site for the chemical cleaning.

3.1 QC2b part 1 and part 2

QC2b is tested under nitrogen gas and is conducted in two parts.
Part 1: Foils that passed QC2a are stored in a N_2 box. After reaching the nominal humidity ($< 7\%$), HV is applied across the foils' top and bottom electrodes where it is increased up to 600 V and

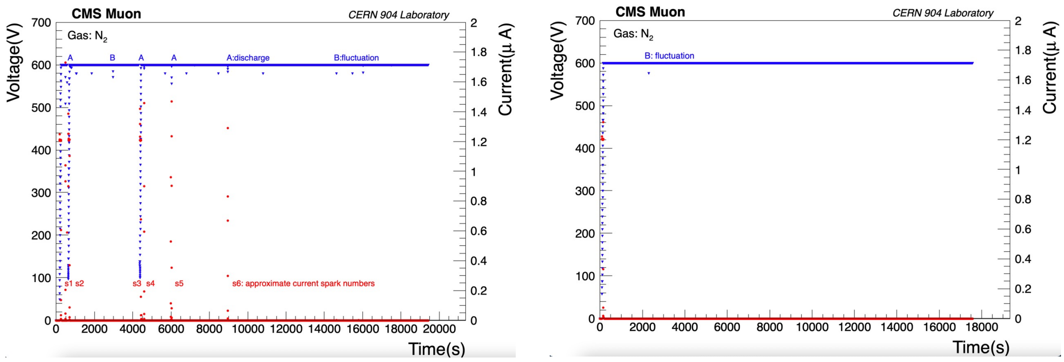
maintained for 90 minutes. During the 90 minutes span there are 3 voltage cycles between 600 and 100 V. The leakage current observed during the test must be less than 20 μA. An example of abnormal part 1 is given in Fig. 2a where the nominal voltage is reached only after the third ramp-up attempt. Sudden current sparks can be caused by dust, deposit, and defects on the foil, which is largely reduced after repeating the test, as seen in Fig. 2b.



(a) **(b)**

Figure 2: (a) QC2b part1 failed, (b) QC2b part1 passed.

Part 2: After passing part 1 the foils undergo a 600 V test for 14 h in a N_2 box with the nominal humidity condition. The observed leakage current must be less than 2 μA and the limit on current sparks is three. Simultaneous and sustained discharges in Fig. 3a indicate an instability of foil. Such discharge events can damage the GEM foil itself and possibly prevent the stable operation of the detector. When the foil's condition reaches stability during the part 2 test, current sparks, and voltage fluctuations are also reduced as shown in Fig. 3b.

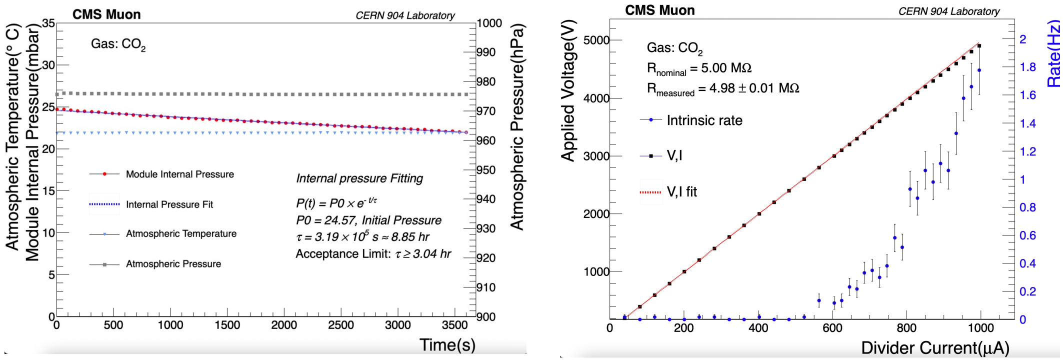


(a) **(b)**

Figure 3: (a) QC2b part2 failed, (b) QC2b part2 passed.

4. QC3: Module gas leak test

QC3 is a gas tightness test after the module is assembled. In addition checking for a gas leak, it also prevents the possibility of contamination from an external source. Gas contamination can affect the detector performance through deterioration of the charge amplification and electron transfer process. The module is flushed with CO_2 for an hour with the gas output is closed. when the internal pressure reaches around ~25 mbar, the input inlet is also closed. The internal pressure changing rate must be less than 7 mbar/h, which correponds to a time constant $\tau > 3.04$ h, as shown Fig. 4a. Time constant $\tau > 3.04$ h condition ensures that the leak rate will remain below 1% of the total incoming flow rate[2].



(a) **(b)**

Figure 4: (a) An example of QC3 passed result, (b) QC4 passed result.

5. QC4: V, I linearity and Intrinsic noise test

QC4 measures the intrinsic noise of the module and the linearity of high voltage versus divider current in Fig. 6b. After flushing the module with CO_2 for an hour, the module's intrinsic noise rate is measured during a HV scan over the range of 200 - 4900 V. The acceptable limit for the intrinsic noise rate is below 100 Hz. To measure the linearity of the applied voltage (V) and divider current(I), V and I data are fitted with a first order polynomial. The slope value of the fit corresponds to the measured resistor value, $R_{measured}$, the register sum of the HV filter and the HV divider corresponds to $R_{nominal}$. To pass the test, the resistor deviation must be less than 3% [2]. A nonlinearity would indicate the presence of unstable parasitic impedance, which can be caused by a defect on the HV circuit or a GEM foil problem. Intrinsic detector noise is caused by detector design defects and imperfection of the electrodes.

6. Conclusion

The GE2/1, a second triple Gas Electron Multiplier based muon station's mass production has started successfully in 2021 with the collaboration of different production sites. To ensure the comparable performance of modules produced at different productions sites, a number of advanced quality control(QC) steps are defined. Steps QC1 to QC4 are critical for module's performance and each example of GE2/1 QC results are presented.

References

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