

CMS Experiment, CERN

Assembly and Quality Control tests for GEM Detectors for CMS,
@B904 Lab, Preveessin, CERN.

GEM ME0 Detectors for CMS, CERN

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Abstract :

The LHC will be upgraded in many phases for the high luminosity - LHC (HL - LHC) known as Phase II upgrade that will be between 2026 and 2028 (LS3). After this major upgrade the LHC will operate in higher Energy that will reach 14 TeV (or 7000 GeV / Beam), and the final luminosity will exceed $5 \times 10^{34} / cm^2 s^1$, five times more than the original design value. To handle the increase in background activity and trigger demands, new muon detectors using Gas Electron Multiplier (GEM), ME0, technology are being added and will be installed in the CMS in the LS3 in the interval mention above. In this paper we present a detailed procedure about the assembly process in our site (904 lab, Préveessin site, CERN) and the Quality Control tests (QC3 QC4) as well.



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Introduction

The Compact Muon Solenoid (CMS) experiment at CERN (European Organization for Nuclear Research), is a purpose experiment aiming to measure proton-proton collision or heavy ion collision at the LHC at CERN. The current energy of the LHC now in 2024 is 13.6 TeV or 6800 GeV per beam, and the LHC energy will increase to 14 TeV after the LS3 which will involve major upgrades to the High-Luminosity LHC (HL-LHC) or known by the Phase II Upgrade. The Large Hadron Collider (LHC) will be upgraded in several phases that will allow significant expansion of its physics program. The final luminosity of the accelerator is expected to exceed $5 \times 10^{34}/\text{Cm}^2.\text{S}^1$, five times more than the original design value. The CMS muon system must be able to sustain a physics program for such high luminosity and maintain sensitivity for the Electroweak Physics in the TeV scale as done before. To cope with the corresponding increase in background rates and trigger requirements, the installation of additional sets of muon detectors based on Gas Electron Multiplier (GEM) technology, referred to as ME0, has been planned. The assembly / Production of the ME0 chambers has been started as well as the Quality Control tests (Known as QC Tests) to the chambers is already started at CERN, Prévessin site B904 Lab. The installation and commissioning of the ME0 detectors are expected to be installed between 2026 and 2028. Meanwhile the GE1/1 already in operation in Run 3.

Therefore, CMS was built with several complementary sub-detectors to identify muons, already at trigger level, and to measure their momentum and charge over a broad range of kinematics. To cope with the increase in background rates and trigger requirements, the ME0 Gas Electron Multiplier (GEM) detectors will be installed in the CMS muon spectrometer

The ME0 system will cover $2.03 < |\eta| < 2.8$ using six layers of triple-GEM detectors. The six layers provide good pattern recognition and background rejection. The ME0 system provides unique coverage in the range $2.4 < |\eta| < 2.8$ and strengthens the coverage provided by the CSCs, RPCs and GE2/1 in the range $2.03 < |\eta| < 2.4$. Based on simulation, the muon identification efficiency is estimated to be approximately 95% for transverse momentum as low as 3 GeV. The ME0 system is composed of 18 super-chambers per end-cap. Each super-chamber is mounted on a 15 mm thick aluminum plate to give mechanical strength as shown in Figure 12. Each detector layer is 33.4 mm thick and the 6-layer super chamber is 224.4 mm thick, including shielding. The area of ME0 chamber is same as GE1/1 detector. The readout segmentation of an individual chamber layer is 8 sectors in $-\eta$ and 3 sectors in $+\eta$; each sector contains 128 radial strips.

1 Assembly of the GEM ME0 stack

In this paper you can find the step by step detailed procedure and the material needed for the assembly and Quality Control (QC3 and QC4) of the ME0 - GEM sub detectors to be used in the forward region of the CMS Muon spectrometer during the LS3 shutdown. Usually the assembly Procedure took place in the clean room in B904 lab, CERN - Prévessin site, France and the QC2 as well, where QC4 and QC4 are performed in the Lab.



FIGURE 1 – Clean Room

1.1 Materials used

The materials used are divided into two groups. One group is for the essential components of the GEM detector (ME0 in our case.), and the other one is the tools we use usually to proceed in the assembly.

1.1.1 Tools used

1. Silicon static roller and its sticky mat (x1).
2. Screw driver (T6).
3. Sharp blade.
4. HV insulation.
5. High torque screw driver.
6. digital torque screw driver.
7. Assembly base plate.
8. Plexiglas cover.
9. Polyamide tape.

Here you can find in the figure below the images of the tools used :

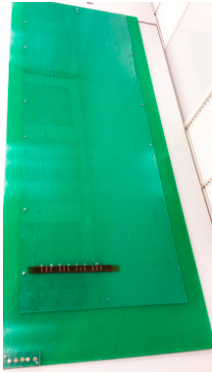


FIGURE 2 – Base plate



FIGURE 3 – Cover plate



FIGURE 4 – Digital screw driver



FIGURE 5 – HV insulation meter



FIGURE 6 – Screw driver (x6)



FIGURE 7 – HV clip

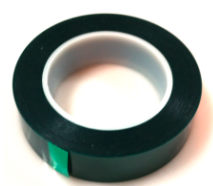


FIGURE 8 – Tape

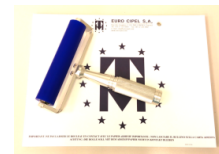


FIGURE 9 – Static roller sticky mat



FIGURE 10 – Sharp blade

1.1.2 ME0 Components

1. Three GEM foils.
2. Prepared internal frame. (All 32 frames including the 3mm ones prepared with the brass inserts).
 - (a) Type A internal frames with brasses ($\times 8$).
 - (b) Type B internal frames ($\times 8$).
 - (c) Type C internal frames ($\times 8$).
 - (d) Type D internal frames ($\times 8$).
3. screws M2x6.
4. screws M2x6 Long
5. Metallic Nuts
6. Guiding pins



FIGURE 11 – Guiding pins



FIGURE 12 – Modified nuts



FIGURE 13 – Screws M2x6 long



FIGURE 14 –
Screws M2x6

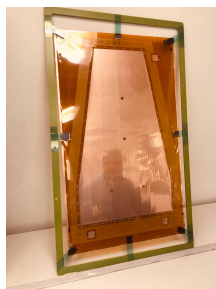


FIGURE 15 – GEM
foil



FIGURE 16 –
IFRAME

1.2 Procedure

Here you can find the step by step procedure for the assembly process :

1.2.1 Preparation of the GEM Foils

1. Align the three GEM Foils in a vertical position against the wall as indicated in figure : 13 .
2. Gently press on the foil using the static roller to remove all the possible dust from the whole foil as indicated in figure 14.
3. Regularly clean the roller using the sticky mat.
4. Flip the foils and repeat 1 2 steps again.

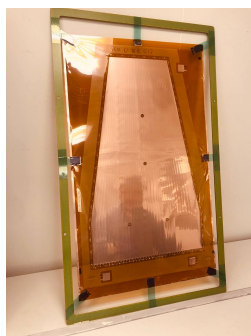


FIGURE 17 – GEM
foil



– Cleaning the
GEM foil

5. Test the Foils again using the HV insulation and the HV clip. Set the insulation meter to 500 V , the resistance of the foils should reach 20 G Ω after few seconds with relative humidity lower than 40%. After the test is done, discharge the GEM foil.

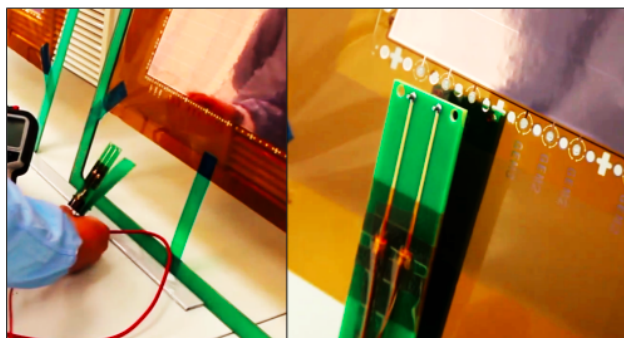


FIGURE 18 – Inserting the HV Clips

1.2.2 Mounting of the GEM stacks

1. To prepare the assembly base plate, place the Plexiglas base plate on the assembly table and fix it with tape as indicated in figure 16.
2. Clean the base plate using the static roller and sticky mat and also with tissue and ethanol as indicated in figure 17.

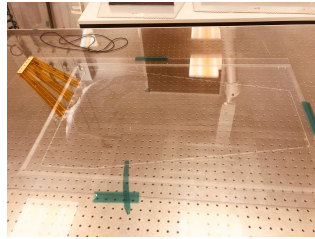


FIGURE 19 – Preparing the Base plate

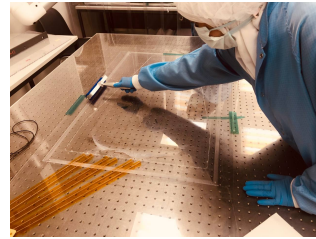


FIGURE 20 – Cleaning the Base plate

3. Put the guiding pins in place all around the trapezoid. Place pins in all the single holes, and in one of the grouped holes (Fig :18).

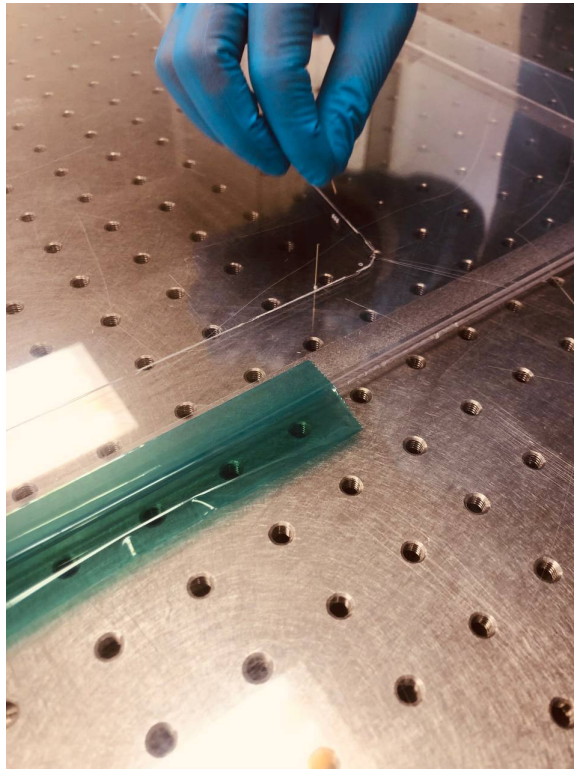


FIGURE 21 – inserting the guiding pins

4. To insert the 3mm internal frame to form the drift gap, use the static roller first to clean all the 3mm sticks from both sides.



FIGURE 22 – The 3mm internal frame with brasses



FIGURE 23 – Internal frames

5. Place the internal frame with brasses on the base plate. Make sure that the orientation and the location of each frame piece matching the shape and the orientation of both single and group holes on the base plate.
6. The flings should always face the outside of the trapezoid where the ME0 label should face the inside of the trapezoid.
7. Place the frame in the right position and orientation as mentioned in step 5 and 6 around the trapezoid using the guiding pins. The final picture of the internal frame is shown in figure 21.
8. Place the GEM1 foil on top of the 3 mm frames using the guiding pins for a proper positioning. Note : Make sure that the foil is well aligned to prevent scratching of the active area with the guiding pins.
9. Cut the tape using sharp blade and remove the frame after making sure that the foil is inserted properly in the right place.

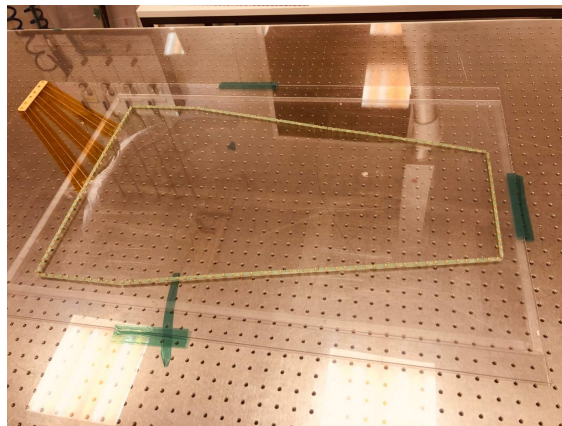


FIGURE 24 – Final picture of the internal frame - Type A

10. Proceed with two persons standing on opposite direction to pre-stretch the foil.

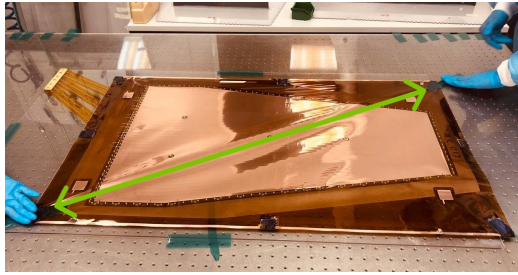


FIGURE 25 – Stretching the foil 1

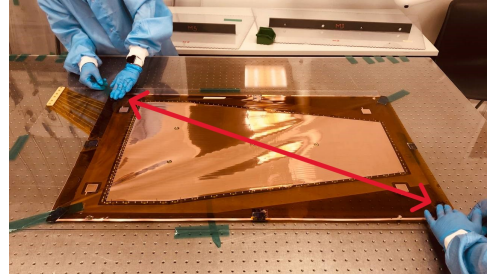


FIGURE 26 – Stretching the foil 2

11. In order to pre-stretch the foil, attach the tape on the Kapton area, on both large and small bases of the trapezoid, and then gently pull it towards you before fixing the tape on the table. The procedure is explained more in figure 22.
12. Measure the impedance of the GEM foil, as it should be greater than $20\text{ G}\Omega$ within few seconds with a 500 V applied voltage. Discharge the foil after this step. indicated in figure 23.

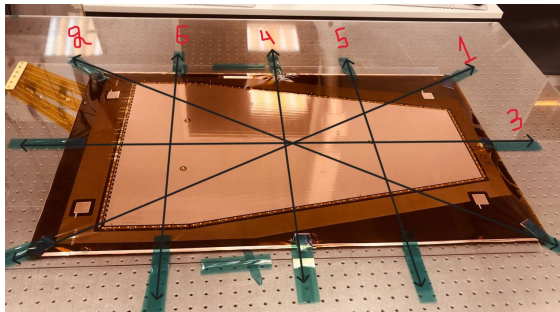


FIGURE 27 – The way to stretch the Foil

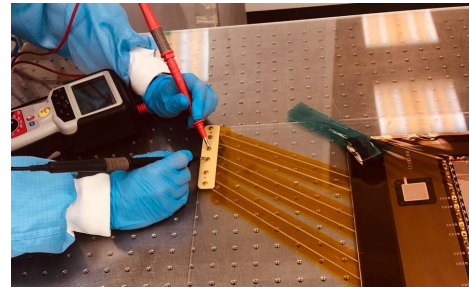


FIGURE 28 – Measuring the Impedance of GEM 1

13. Clean the set of 1 mm thick internal frames (CERN - IFRAME - B - xxxx),using static roller and sticky mat, which will form the first gap between GEM 1 and GEM 2 foils.
14. repeat steps 5,6,and 7.
Note : this 1mm internal frame is without brasses. The final picture is shown in figure 24.
15. Place the GEM 2 foil using the same procedure of inserting GEM 1 foil. (Repeating steps 8-12). as shown in figure 25.

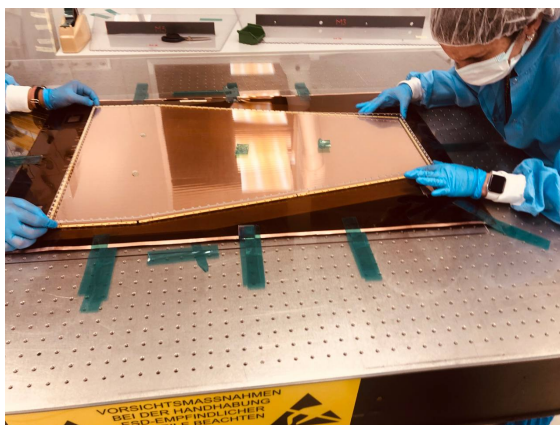


FIGURE 29 – inserting the 1mm frame

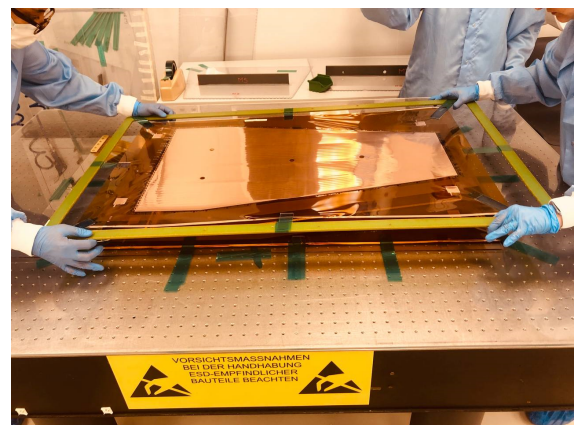


FIGURE 30 – inserting the second GEM Foil

16. Clean the set of 2 mm thick internal frames (CERN - IFRAME - C - XXXX), using static roller and sticky mat, which will form the gap between GEM 2 and GEM 3 foils.
17. repeat steps 5,6,and 7.
Note : this 2mm internal frame is without brasses.

18. At this point you can insert the M2x5 modified metallic nuts (See figure 27) in the dedicated housing of the internal frames. Take the time to double check that all frames are equipped with the nuts and that the nuts are fully inserted in the stack (figure 28).
19. Before mounting the last piece on the large base of the trapezoid, check the impedance of the second foil by applying 550V. After the test is performed, discharge the foil, place the last piece of internal frame and insert the remaining nuts.



FIGURE 31 – Modified Nuts



FIGURE 32 – inserting the Modified nuts

20. Take the third GEM foil and place it on top of the stack as indicated in figure 29.
21. repeat steps 8-12 to the third foil.

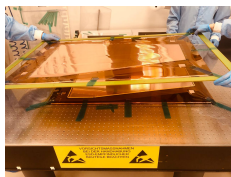


FIGURE 33 – inserting the third GEM foil

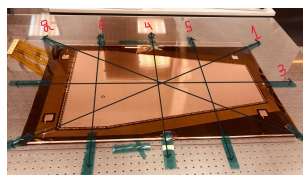


FIGURE 34 – Stretching the foil again

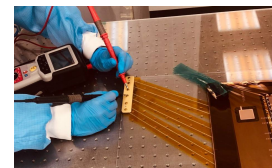


FIGURE 35 – Measuring the impedance of the third GEM Foil

22. Clean the last set of 1 mm internal frames (CERN - IFRMAE - D - XXXX) and place them on the stack so as to form the induction gap.
Note : Make sure that they are aligned properly and not upside down as the screw should fit in their proper places.
23. Measure the impedance again for the third foil with applying 500V and make sure that it increases to above 20 G Ω within few seconds.
24. Time for protecting the GEM stack.

1.2.3 Covering the GEM stack for protection

1. Clean the table using the static roller and the sticky mat.
2. Clean the Plexiglas cover using the static roller and again with tissue and ethanol from both sides to make sure that it is cleaned properly.
3. Place the Plexiglas cover on top of the GEM stack making sure that it is in the right position and orientation.
4. fix the cover using the long M2x6 screws and washers. Put these screws on the edges of each piece of internal frame and on the corners of the trapezoid.
5. All the holes should be equipped with the M2x6 screws and without stressing them much, except the edges and corners as they are already fixed.

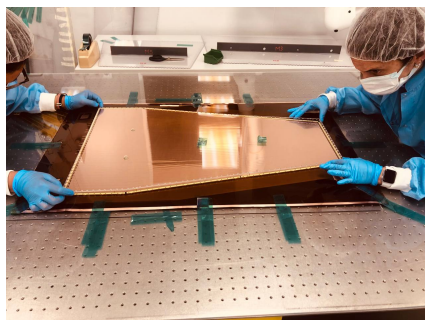


FIGURE 36 – inserting the cover plate for protection

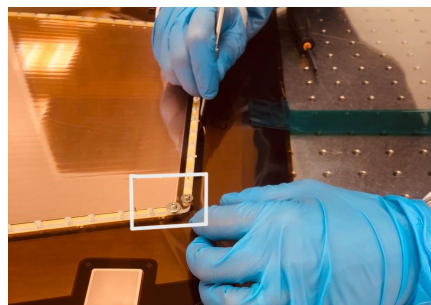


FIGURE 37 – inserting the long M2x6 screws on the ends of the internal frame only

2 Closing the GEM stack.

This is the final step in the assembly procedure and after that the ME0 GEM detector will be ready for the QC's tests.

2.1 Tools

2.1.1 Tools used for this step

1. The GEM stack that we already assembled it.
2. The Prepared Drift Plate.
3. The prepared Readout Plate
4. Short Screws M2x8
5. Long screws M5x8
6. nylon washers

2.1.2 Materials

1. HV insulation meter.
2. Dust Roller and Sticky mat.
3. Torque screw driver.
4. Electronic torque screw driver.
5. Tweezers.
6. Sharp blade.
7. HEPA vacuum cleaner.

2.2 Procedure

1. Clean the GEM stack carefully with the vacuum cleaner and make sure to focus all its corners, holes of the Plexiglas cover plate, and all its parts including the internal frame very well.
2. Remove the excess Kapton foil using the sharp blade as indicated in figure 36.
Note : start from the corners, and then continue to all over the trapezoid.
3. Gently remove the excess Kapton.
4. Repeat step 1.
5. Use the Static Roller to clean gently the active area.

6. Dissociate the stack from the Plexiglas base plate by gently pulling it upward and without touching the active area nor the bottom of the GEM3 as indicated in figure 38
7. Remove the left guiding pins using the tweezers. To make sure that all the pins are removed and no one left, rub your finger along the entire frame.
8. Carefully move the chamber to the assembly jig, where the stretching will be performed
9. Apply sufficient strength to ensure the system will maintain the flatness of the board while performing the stretching of the foils as first to the corners and then to the whole screws as indicated in figure 41 and fig 42.
10. Remove the long M2 screws that hold the Plexiglas cover and the GEM stack together. Replace it with the final M2x6 mm screws as it was done for the other holes in the frame stack. You will need to keep the Plexiglas cover without screws in place to protect the foil. The internal frames will be free to move while stretching the foils.
11. When all the screws are in place, remove the Plexiglas cover.
12. Test the three GEM foils and the three gaps one after the other at 550 V using the dedicated pads on the drift board. Discharge the foil after each test.
13. In the case of GEM foils, the impedance should reach 20 G Ω after few seconds. The impedance of the gaps however should reach more than 100 G Ω immediately after applying the voltage.
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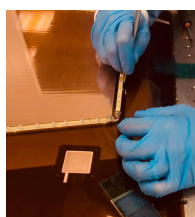


FIGURE 38 – cutting the using the sharp blade.1

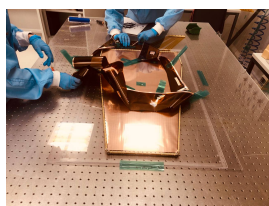


FIGURE 39 – cutting the using the sharp blade.2

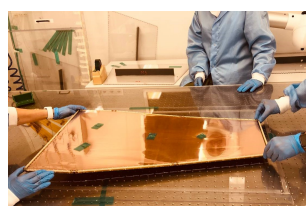


FIGURE 40 – Removing the ME0 stack

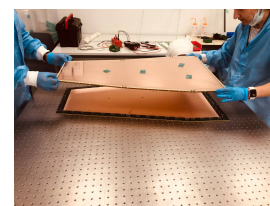


FIGURE 41 – Preparing for the RO

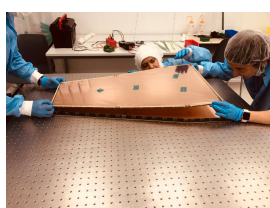


FIGURE 42 – Preparing for RO

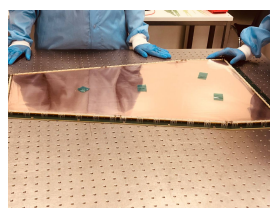


FIGURE 43 – final picture

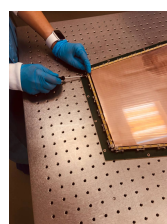


FIGURE 44 – Fixing the corners

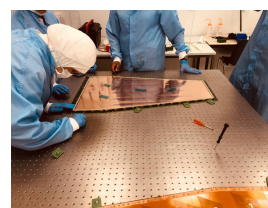


FIGURE 45 – Fixing the corners

2.3 Closing with the Readout Plate

Now it is the final step, by closing the GEM detector by the Readout plate, the GEM detector immediately would be ready for the Quality control tests.

1. After preparing the external plate by the O-ring, Place the external frame between the GEM stack and the aluminum bars.
2. Use the vacuum cleaner on the side of the bars to suck up possible dust produced during the stretching and carefully vacuum the gap between the stack and the bars. Use the static roll to gently clean the top surface of the foil one more time

3. Clean the active area of the readout board with the vacuum cleaner and with proper care so as not to scratch the copper traces. As for the drift, use the static roller to catch the possible dust left on the board.
4. place the readout board on top of the GEM stack, centering the middle first then the corners.
5. Place the polyamide washers in the conical holes and insert the M3 screws. Tighten the screws at 80 nm using the manual torque screw driver.
6. Test again the GEM foils and the gaps at 550 V, Discharge the foils after each test. The final picture of the ME0 :



FIGURE 46 – The ME0 GEM chamber.

3 Quality Control Tests

To test the gas tightness after assembling a detector, it is first pressurized under the safe limit of 25 mbar. The input and output valves are then closed to detect any gas leak in case the over pressure in this volume drops to zero with a time scale which depends on the leak rate and on the initial over pressure. Then an HV test (QC4) is performed to check the behavior of the high voltage distribution circuit of the detector. The effective gain is the central parameter of the detector which depends on the geometrical and electrical properties of the detector. This test is performed with Ar :CO₂/70 :30 gas composition. The gain uniformity of the modules which gives the variation in gain over the active area of the detector.

3.1 QC3 : Gas Leakage Test

The aim of the QC3, Gas Leakage test, is monitoring the overall internal pressure inside the ME0 stack as a function of time. Usually we do the test for one hour. The QC3 gas leak test is divided into two steps : the calibration of the system ; the leak measurement of the detector+system. To perform the calibration of the gas system only, proceed as follows :

- Connect together the input and the output lines the gas system.
- Open the input and the output valves of the gas system.
- Adjust the manual valve of the input flow-meter to allow the CO₂ to flow through the system. Set the input gas flow rate to 5 L/hr. The output flow rate should be immediately visible on the output flow-meter.
- Start the Excel macro named QC3_{ME0}–MODULE–XXXX–YY/MM/DD.xlsm. A new window will

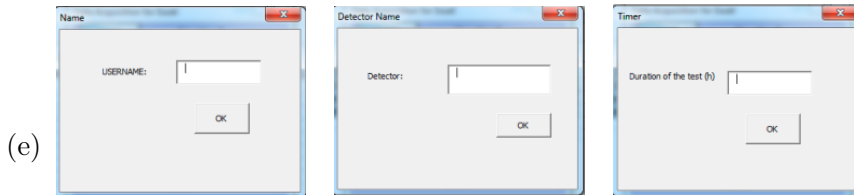


FIGURE 47 – Username Terminal FIGURE 48 – Detector terminal FIGURE 49 – Time terminal

- The DAQ window will appear as well as the Excel sheet that will contain the 430 data (Fig. 3.5). At this point the system is ready to start the acquisition.

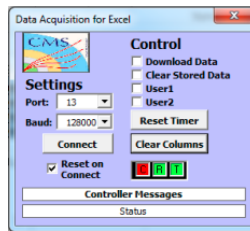


FIGURE 50 – data acquisition terminal for excel

- You need to set to correct over-pressure in the system before starting the recording of the data. To do so, close the output valve of the gas system. You will see that the pressure inside the system is ramping up. As soon as the over-pressure reaches 25 mbar, close the input valve. Then close the valve of the input flow meter.
- Start the recording of the data by pressing the Connect button on the DAQ window (Fig. 47). After this step the Excel sheet will be updated every minute with the new data from

the different pressure and temperature sensors. Do not operate the computer while the test is running under the penalty of loosing the connection between the micro-controller and the Excel file.

10. Leave the system running for one hour as you defined at the beginning . The Excel macro will automatically stop at the end of the test.

The pressure drop in the gas system should not exceed 1 mbar per hour. If the system passes this step you can proceed to the qc4 test TO the ME0 detector . Here you can find some data taken on July 17th, 2024 for the ME0 - MODULE - 0031.

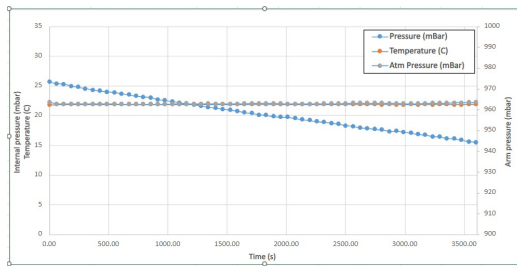


FIGURE 51 – Test failed

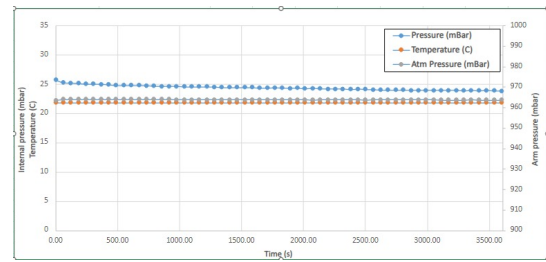


FIGURE 52 – Test passed

3.2 QC4 : Voltage current Linearity

The aim of this test is to measure the voltage vs. current curve to identify possible malfunctions, defects in the HV circuit and spurious signals.

3.2.1 QC4 Part I

The chamber is connected to the QC3 gas system and flushed with pure CO₂. The negative HV (VSET) is provided by a programmable HV power supply (e.g. CAEN N1470) that allows the user to control the current limit (ISET), the steps to ramp up and down the voltage, the maximum voltage, and the trip time. This power supply must be able to deliver a current up to 1 mA with a monitoring resolution lower than 1 μ A in order to identify possible leaks, sparks, or unusual current. fluctuations To perform the QC4 test, proceed as follows :

1. Connect the ME0 Detector to the gas system with pure Nitrogen set the gas flow rate to 2.5 L/hr and let it flush for at least 1 hour.
2. Fix the grounding plate onto the readout board .
3. Connect the Panasonic-to-LEMO adapters with the 50 Ω terminationstoallthereadoutsectors.Connectthegroundingplate to the dedicated pad on the drift PCB.
4. Connect the HV voltage cable to the SHV connector on the detector. In some cases it can be useful to insert a HV low-pass filter to cut the high frequency noise from the power supply. If so, the additional resistance introduced in the system should be mentioned in the log file and in the result file. Set the power supply settings as follows :
 - (a) Ramp up = 50V /s ;
 - (b) Ramp down = 250V /s ;
 - (c) Max voltage = 4999V.
5. Start the Test by making sure that the voltage supply is on on both the Power supply devise and on the window terminal as shown in figure xx start with supplying zero volatage on the window terminal.
6. Run the Program.
7. increase the voltage step by step as the following :



- (a) 1000 V and 222 μA
- (b) 2000 V and 435 μA
- (c) 3000 V and 648 μA
- (d) 4000 V and 861 μA
- (e) 4500 V and 967 μA
- (f) 4900 V and 1052 μA

if every thing goes on the right way (you don,t observe or hear any thing wrong in the detector),
you can start the part two QC4.

3.2.2 QC4 Part II

1. Open the template file *QC-4-ME0-MODULE-XXXX-YYYYMMDD.txt*. Rename the file with the appropriate name where X stands for the number of the module. YYYY the year, MM the month and DD the day.
2. Open the Lab View on your PC
3. Put the text file that you create as a destination to save data in this file.
4. Run the program.
5. Start Recording by pressing the **START** Bottom after being ready.
6. wait at least 1 hour to obtain the graph and to determine the linearity of the plot.



4 References

Technical Assembly Manual for GE1/1 Chambers M. Abbas, M. Bianco , M. Gola, J. A. Merlin, R. De Oliveira, and A. Shah

GE1/1Quality Control : instructions Michele Bianco*, Brian Dorney, Jeremie A. Merlin, CERN
On behalf of the CMS GEM Collaboration September 28, 2016.

Note : All the images used in this paper are taken by me during the work, except for couple of images are taken from the references mentioned above.



5 Conclusion

The HL-LHC phase II requires the upgrade of the CMS muon system. Many chambers, ME0, has already been designed and produced and has been tested in B904 Laboratory, Prévessin site, CERN. Many ME0 chambers passed the Quality control tests (QC2 - QC5). The QC3 test system became operational after my colleague (Abdullah al Sayegh) and I (Abbas JHEIR) worked on fixing it following several days of downtime. After our contract ended our colleagues in the 904 lab are continuing assembling and testing the other modules as before.