Production and quality control of the new chambers with GEM technology in the CMS muon system

Elisabetta Soldani

Istituto Nazionale di Fisica Nucleare (INFN-Bari) **On behalf of the CMS Muon Group** Università degli Studi di Bari "Aldo Moro"

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The GE1/1 muon detector upgrade

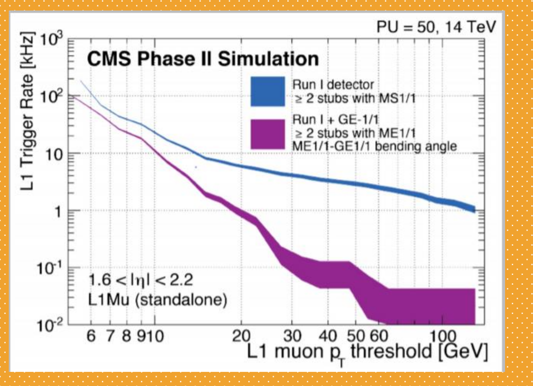


Fig.1 Level 1 muon trigger rates before and after the GE1/1 upgrade at a luminosity of $2{\times}10^{34}$ $cm^{-2}s^{-1}$ for constant efficiency of 94%.

After the upgrade of the LHC injector chain, which is currently planned to take place around 2019, the instantaneous luminosity (L) will approach or exceed $2{\times}10^{34}$ $cm^{-2}s^{-1}$. The installation of an additional station GE1/1, in the first endcap muon, will improve the forward muon triggering and reconstruction in the region with pseudorapidity $1.6<|\eta|<2.2$ in the face of high luminosity.

The muon station GE1/1 based on triple GEM detectors is currently under construction. The installation will be complete during the second Long Shutdown (LS2).

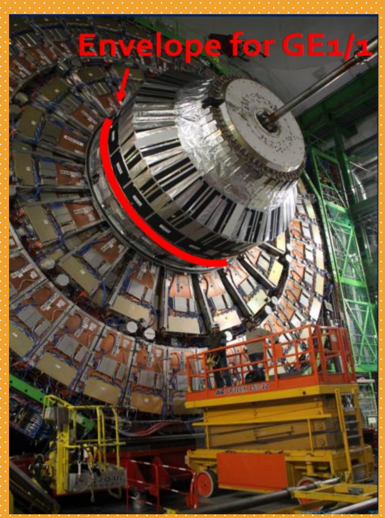


Fig.2 A real image of the GE1/1 station in CMS detector.

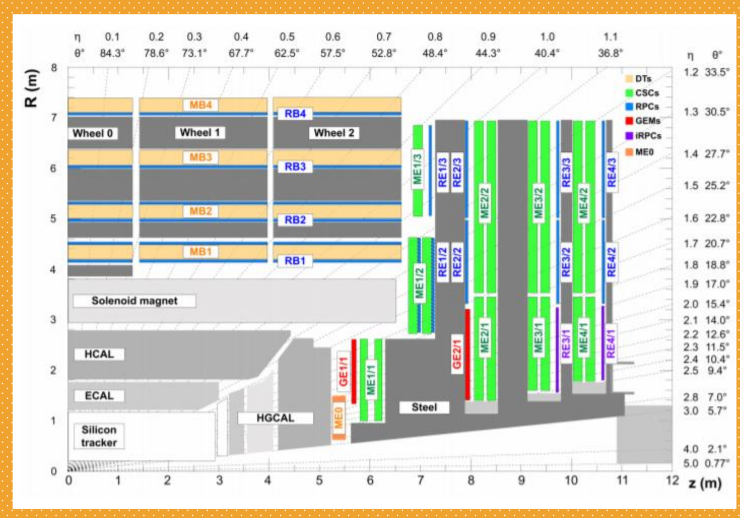


Fig.3 An R-z cross section of a quadrant of the CMS detector, including GE1/1, GE2/1 and ME0 stations.

GEM Thechnology

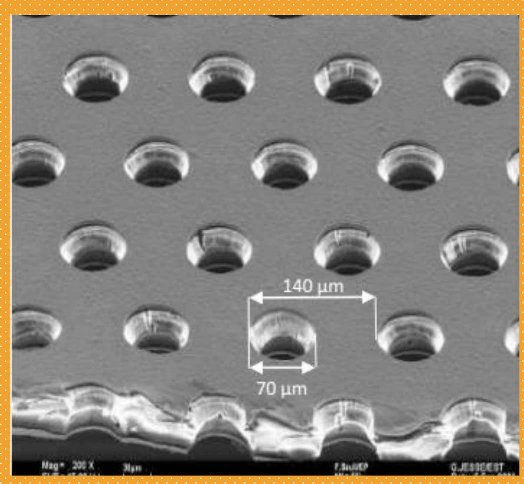


Fig.4 SEM image of a GEM foil

A GEM foil is a thin polymer foil (50 μm), coated with 5 μm copper on each side and pierced with a high density of biconical holes. A large difference of potential applied between the two side creates a high field in the holes causing ionization with the gas molecules.

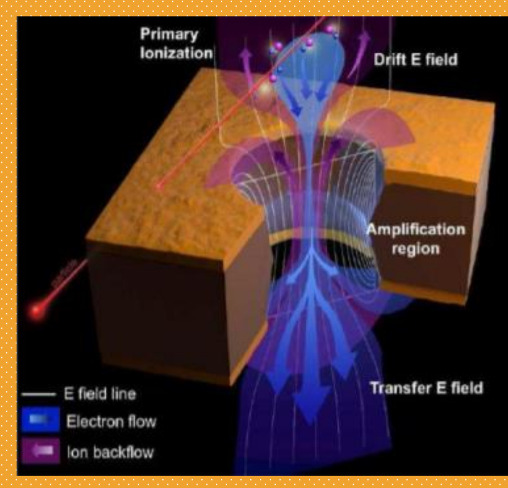


Fig.5 Schematic electric field lines in a GEM hole

A GE1/1 chamber consists of a trapezoidal gas volume containing a large triple-Gem structure between a drift electrode and a readout board (Fig.6). A fraction of the electrons produced in the avalanche leave the multiplication region and transfer into the lower GEM and finally in the induction region where the signal can be collected.

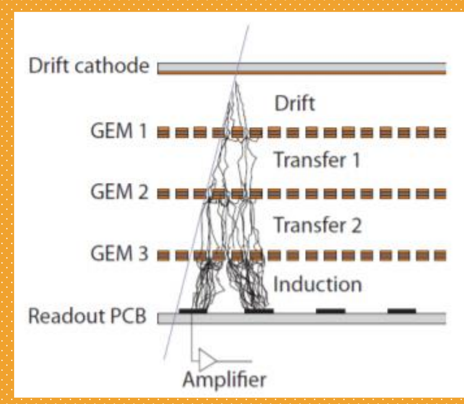


Fig.6 Principle of operation of a triple-GEM chamber with drift, transfer, and signal induction gap regions.

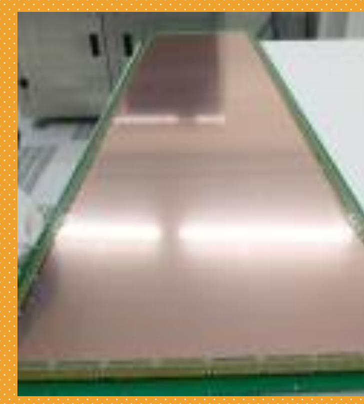


Fig.7 A GEM foil for GE1/1 detector

QUALITY CONTROLS

QC_4 High Voltage Test

QC_4 quality control identifies possible defects in the High Voltage circuit (a ceramic divider that provides power to the GEM foils) and check the linear behavior of the detector. The detector is flushed with pure CO_2 and powered up to 5kV. The QC_4 is passed if the spurious signal rate does not exceed dozens of Hertz.

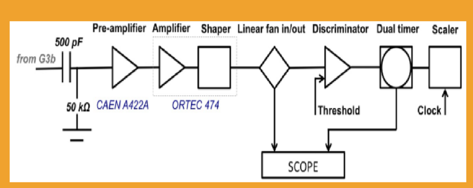
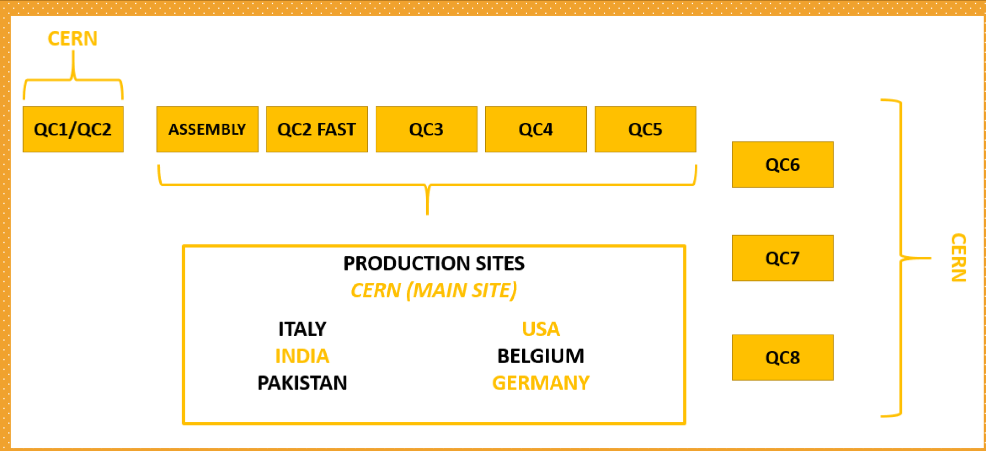


Fig.8 Set up scheme for QC_4

The readout of the detector uses a charge sensitive pre-amplifier connected to the bottom electrode of the third GEM foil. The output is sent to an amplifier+shaper and then to a discriminator. The resulting digital pulses go across a dual timer and then a scaler for the rate measurement.

QC_2 Leakage Current Measurement

The QC_2 test determines the GEM foil quality by measuring the maximum leakage current flowing through the GEM holes. QC_2 test is mandatory before and after assembly.



QC_3 Gas Leakage test

The goal of this test is to quantify the gas leak rate of a GE1/1 detector by monitoring the drop of the internal over-pressure as a function of the time. The pressure drop should not exceed few mbars per hour.

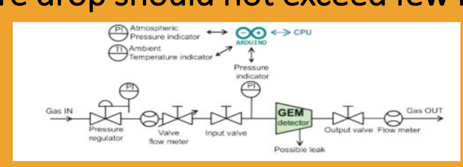


Fig.9 Set up scheme for QC_3

QC_5 Effective Gain Measurements

The effective gain and response uniformity are tested with a X-ray beam with a 23 keV energy. The set up is shown. The measurement of the effective gain consists of comparing the primary current (NeR) induced in the drift gap by the X-ray source with the output current (I) after amplification: $G = \frac{I}{NeR}$

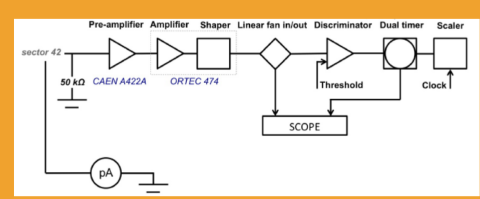


Fig.10 Set up scheme for QC_5

QC_5 Response Uniformity Measurements

The pulse hight distribution is measured on the entire active surface of GE1/1 detector through APV readout chips. The response of each sector of the chamber is required to be uniform in the 15%.

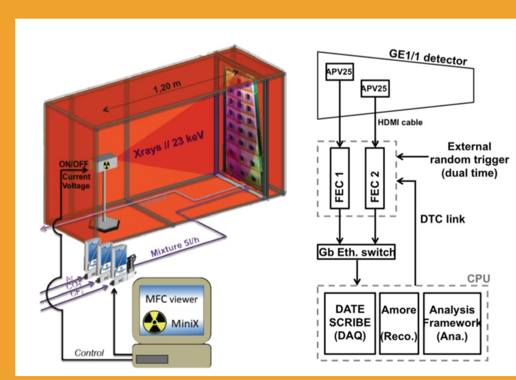


Fig.11 Schematic overview of the QC5 setup

The readout eletronics is based on Scalable Readout System (SRS) developed by the RD51 collaboration. It consists of APV25 Front-End ASICs with 128 channels connected to the readout board of the detector (Fig.11).

BARI RESULTS

QC_3

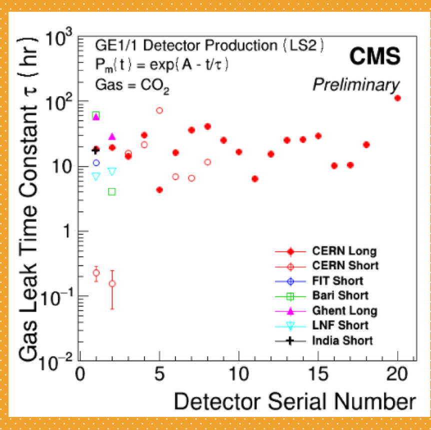


Fig.12 QC_3 results for GE1/1 detectors

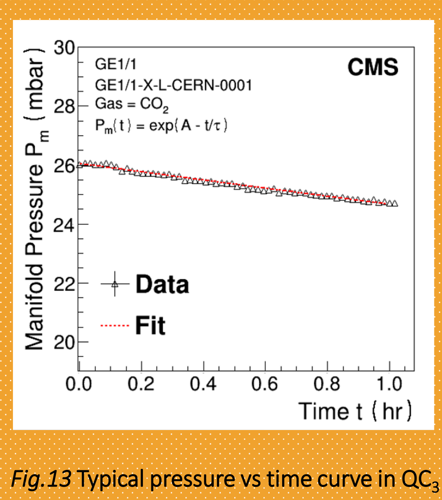


Fig.13 Typical pressure vs time curve in QC_3

The first stage production of the chambers in Bari has provide for the construction of 7 short GE1/1 detectors. All chambers produced are tight. The QC_3 shows a drop pressure under 3 mbar/h for all detectors. In Fig.12, the gas leak rate is showed for all detector in each production site.

Fig.13 shows the exponential fit for the internal pressure monitored in an hour for a GE1/1 chamber produced at Cern.

QC_4

All the GE1/1 detectors assembled in Bari fulfill the QC_4 criteria. The rate of the spurious signal (SSR) is under 10Hz. The linear behavior of the HV is confirmed by a deviation of normalized resistance under 1.8%.

In Fig. 15 the deviation of the measured resistance of the detector from the nominal value quantifies the linear response of the detector with respect to the HV applied, the results are showed for all production sites.

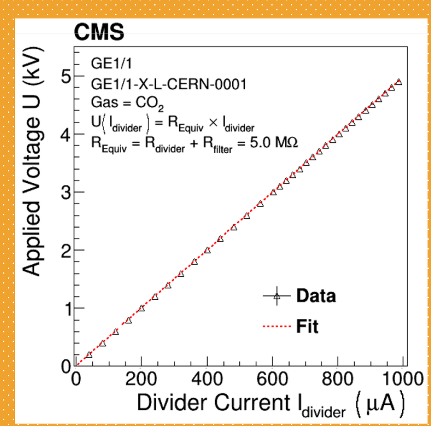


Fig.14 Typical I(V) curve in QC_4

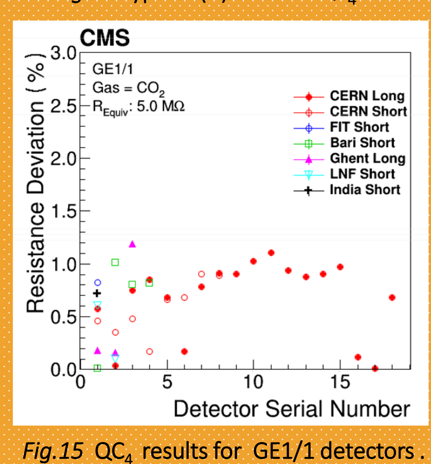


Fig.15 QC_4 results for GE1/1 detectors.

QC_5

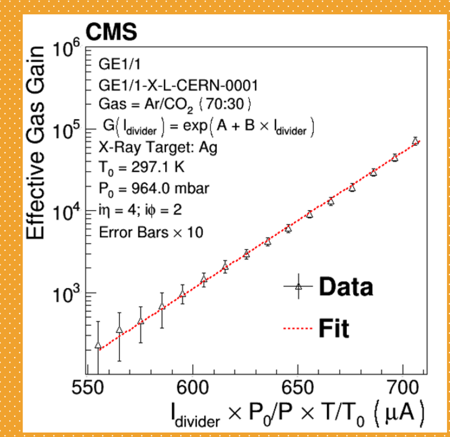


Fig.16 Typical Effective gain curve in QC_5

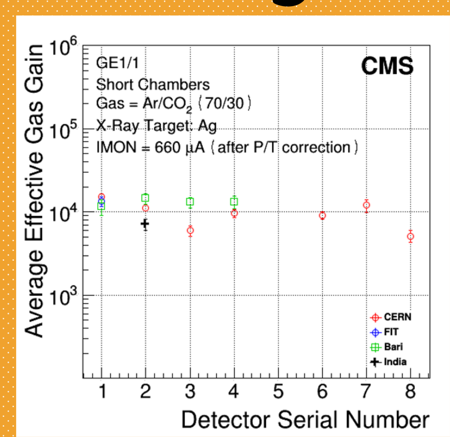


Fig.17 Average Effective Gas Gain for GE1/1 detectors

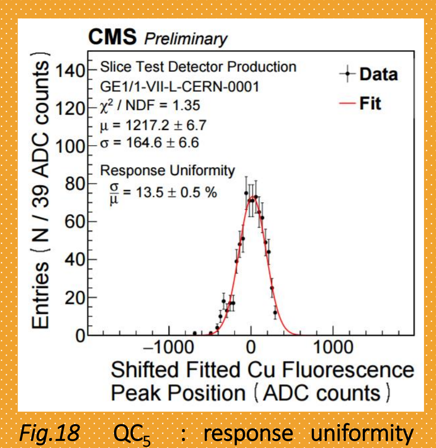


Fig.18 QC_5 : response uniformity results for a GE1/1 detector.

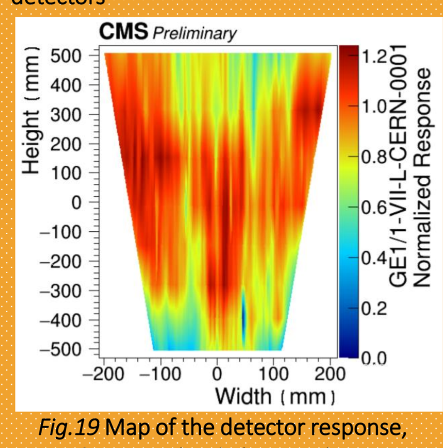


Fig.19 Map of the detector response, i.e. the normalized photopeak energy, across a GE1/1 slice test module.

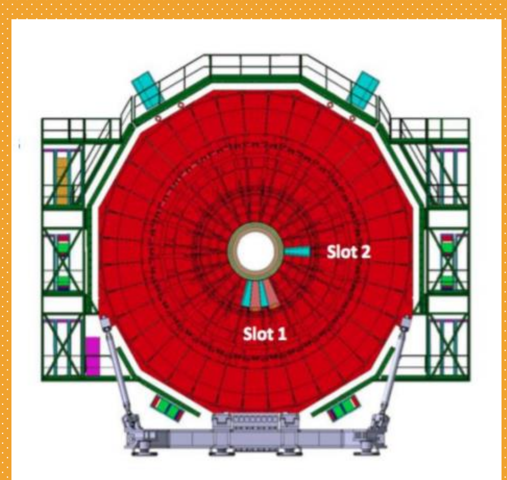
In QC_5 the effective gas gain is normalized with the pressure (P) and the temperature (T) in the production site. In Bari, the measured gain reaches 23k±4k in all chambers. The response uniformity, measured with Gain=600 in each chamber ripples from 21% to 9 %.

The detector is divided in 3072 slices (3 strips for each). The copper fluorescence peak position obtained from the fit of the cluster charge ADC spectrum from each slice is assigned to the corresponding slice. The set of the obtained peak position is then normalized to the average peak position to quantify the response uniformity, defined as RU =σ/μ.

FOLLOW UP

Slice Test in GE1/1 Station

Five GEM chambers (50° in total) have already been installed at the beginning of 2017. During the test, the stability and the functionality of the HV and LV has been checked. Cosmic ray muons and muons from pp collision has been detected.



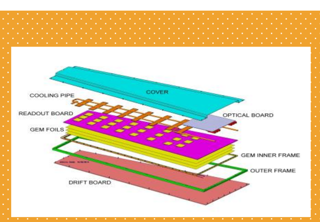
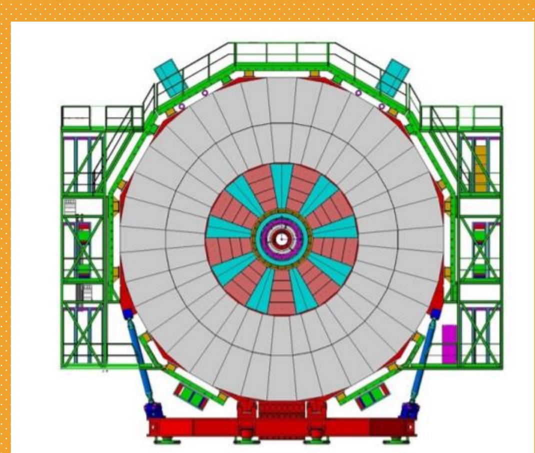


Fig.20 GE1/1 detector components

The New Station GE2/1

New detectors with GEM technology have been already approved for the new station GE2/1 for the Phase2 Upgrade. The detector will be installed during the third Long Shutdown (LS3).



In each muon endcap large trapezoidal triple-GEM chambers will be arranged in a wide planar ring (inner radius ≈ 1.5 m). Each ring comprises two layers with 18 chambers per layer, 36 chambers per endcap.

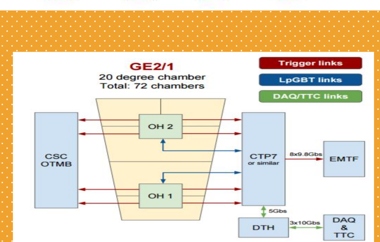
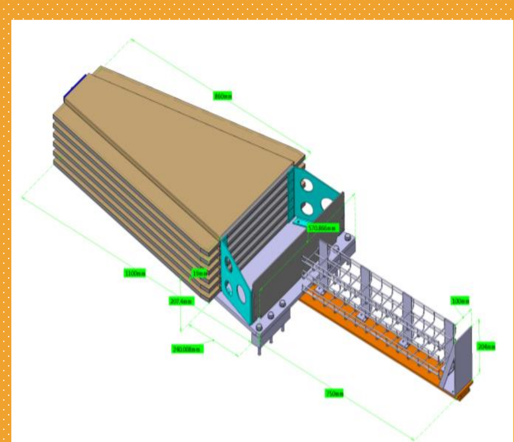


Fig.21 A diagram of the GE2/1 electronics readout system.

The Next Station ME0

For the Phase2 Upgrade, in the region with $2{,}0<|\eta|<2.8$ the ME0 station has been also proposed to improve the muon trigger and the tagging of high-eta muons.



The ME0 station comprises 36 module stacks ,18 per endcap, each composed of six ME0 modules with GEM technology. Each stack is mounted on a 15 mm thick aluminium plate which supports the stack.

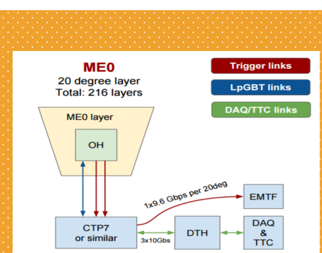


Fig.22 A diagram of the ME0 electronics readout system.

Working in GEM Lab in Bari site

[1] CMS-TDR-013, *CMS Technical Design report for the muon endcap GEM Upgrade*, ISBN 978-92-9083-396-3;

[2] CMS-TDR-016, The Phase-2 Upgrade of the CMS Muon Detectors;

[3] M. M. Gruchala, General Muon Meeting (GMM) Plot approval for LHCC poster ;

[4] CMS Gem Internal Note GE1/1 Quality control;