PROCEEDINGS OF SCIENCE

The GEM (GE1/1) Phase II Upgrade for the CMS muon system: results from in-situ tests, production detector qualification, and commissioning plans

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In the next years the Large Hadron Collider (LHC) will be upgraded to significantly expand its physics program, increasing the luminosity up to $5 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$, well beyond the design value. An upgrade of the CMS detector is needed accordingly to cope with the expected growth in background rates, with the goal of keeping a high trigger efficiency. In this context, a first new station called GE1/1 will be installed in 2019-2020 in the CMS muon system. It will be composed of 144 Triple Gas Electron Multiplier (GEM) detectors to be integrated in the CMS muon endcaps in the region closest to the beam line. A fundamental operational experience has been already achieved in 2017-2018, when a demonstrator composed of ten GE1/1 Triple-GEM detectors was installed to prove the integration of the GE1/1 system into CMS itself. In parallel, a dedicated production chain has been setup in seven production sites spread around the world, for the construction and qualification of all the detectors for the complete station. This contribution presents overview of the GE1/1 project: the detectors design and performance are discussed, together with the lessons learned from the GE1/1 demonstrator installation, integration and operation. The construction and qualification processes is presented, emphasizing the results obtained with the 144 GE1/1 detectors. Finally, the plans for the installation and commissioning of the full station are outlined.

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1. Overview of the GE1/1 project

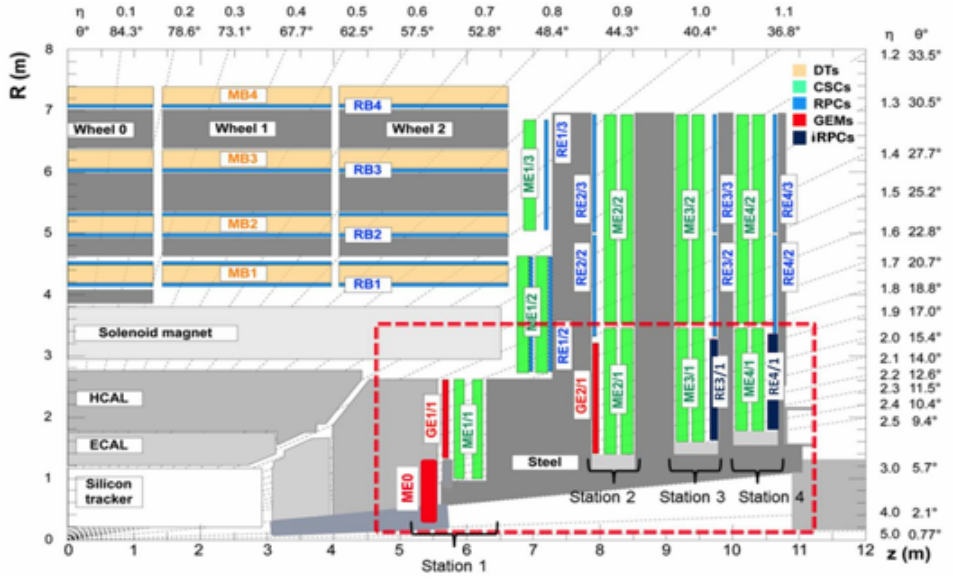

Figure 1: Quadrant of the CMS muon system which enlights the planned upgrades in the forward region.

The forward region of the muon system ($|\eta| > 1.6$) is a very challenging environment, as it is characterized by the highest rates of particles of the entire system, and by the fewer detector layers. Moreover, the rate is increasing towards higher η; thus, a poorer momentum resolution would degrade the trigger performance in the forward region. In order to deal with these challenges in HL-LHC the CMS Collaboration approved the installation of a new layer of chambers, called GE1/1, in the region shown in Fig.1, with the aim of improving trigger and reconstruction performance in the region $1.55 < |\eta| < 2.1$ [1].

The GE1/1 station is going to be instrumented with Triple-GEM detectors, a very mature technology described in detail in Refs. [1] and [2].

2. The GE1/1 slice test: goals and results

In 2017 a demonstrator (slice test) incorporating ten triple-GEM detectors was installed in the CMS muon system (Fig.2) with the aim of acquiring installation and commissioning expertise, demonstrating the integration into the CMS online system as well as proving the operability of the system [3].

The slice test can be considered a success from all the three aspects. First of all, the experience of the slice test highlighted the difficulties related to the insertion of the chambers into the CMS nose and lead to development of a dedicated insertion jig for the installation of the full station. On the other hand, enough experience was gained in commissioning of detectors, detector control system (DCS), and data acquisition system (DAQ).

After a first phase of local operation, the DCS was fully integrated in CMS, which led to the possiblity of operating triple-GEM detectors following the LHC operations, together with the other

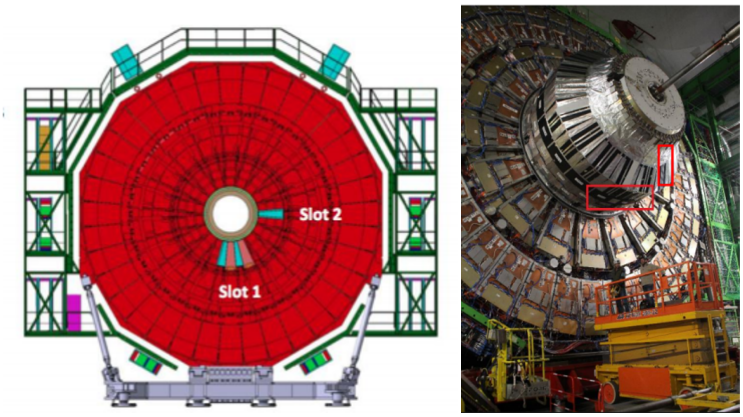

Figure 2: Left: overview of the slice test detectors installed in the CMS endcap. Right: installation locations.

subsystems. The integration of DAQ allowed GEM to take data in central DAQ during cosmics runs and runs with beam. For the online DQM, a successful test of a full chain processing (i.e., RAW data $\rightarrow$ Digitization $\rightarrow$ Reconstruction $\rightarrow$ DQM) was performed, leading to the result in Fig. 3. The detectors proved to be stable during the full period of operations, while the measured efficiency (Fig. 4 left) and cluster size (Fig. 4 right) reached the values expected from qualification (efficiency higher than 97% and cluster size of the order of 1-1.5).

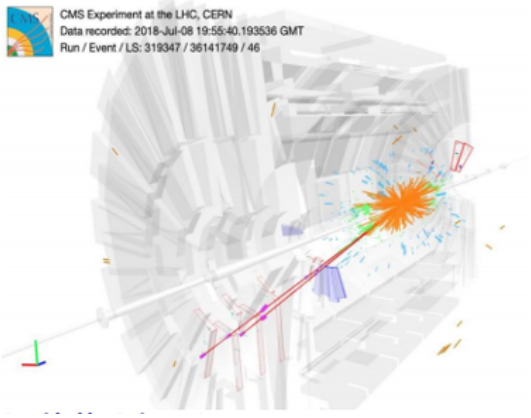

Figure 3: Example of a reconstructed muon in the acceptance of the GE1/1 demonstrator. GEMs are enlighted in purple.

3. GE1/1 detectors assembly and quality controls

In parallel to the slice test activities, the Collaboration focused on the production of the triple-GEM detectors for the full GE1/1 station. The production efforts were shared between CERN and the different GEM institutes shown in Fig. 5.

The production process can be divided in two phases:

- Phase I - Preparation of the components in laboratory

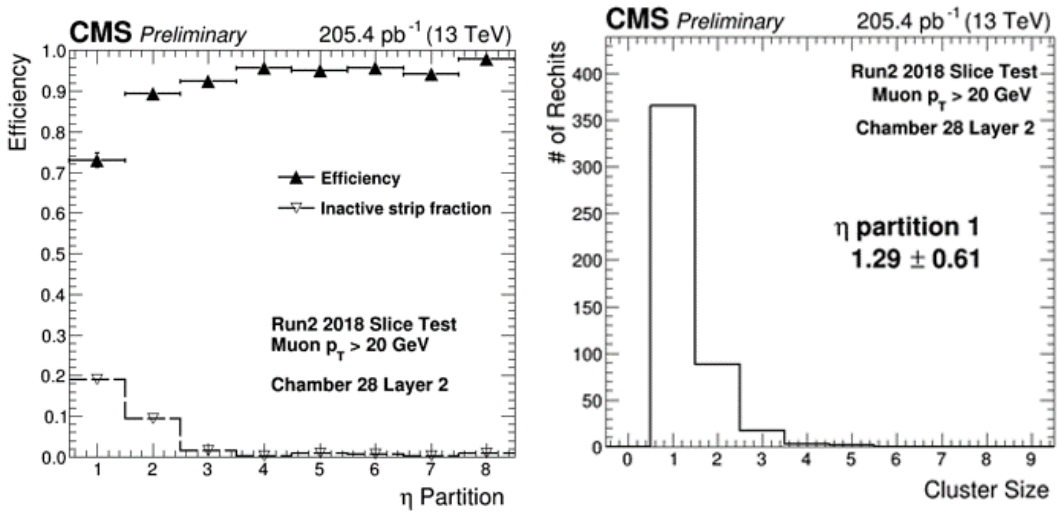

Figure 4: Efficiency (left) and cluster size (right) measured by on slice test detector. In both cases the values expected from qualification are reached (efficiency higher than 97% and cluster size of the order of 1-1.5).

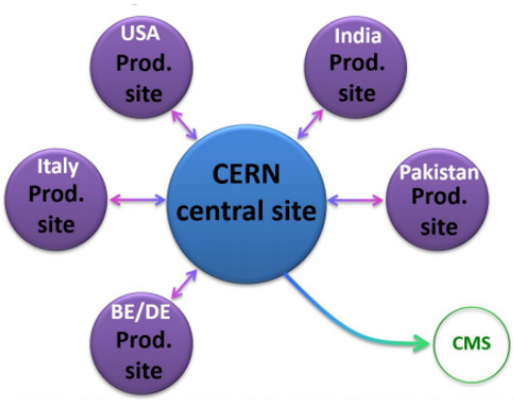

Figure 5: Schema of the sites involved in the GE1/1 production.

  - Cleaning of the components
  - Preparation of the HV circuit
  - Mounting of the pull outs
  - Selection of the O ring
- Phase II - Assembly in clean room
  - Fast test of the GEM foils
  - Mounting of the stack
  - Closing of the chamber

which lead to the full assembly of one GE1/1 detector in about one day.

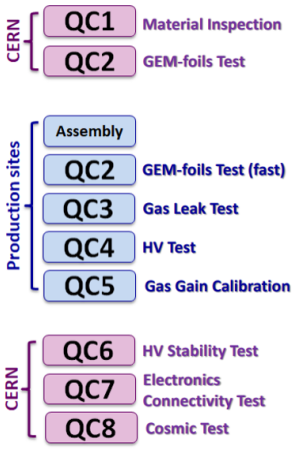

Figure 6: Full list of quality controls (QC) performed on each GE1/1 detector after assembly.

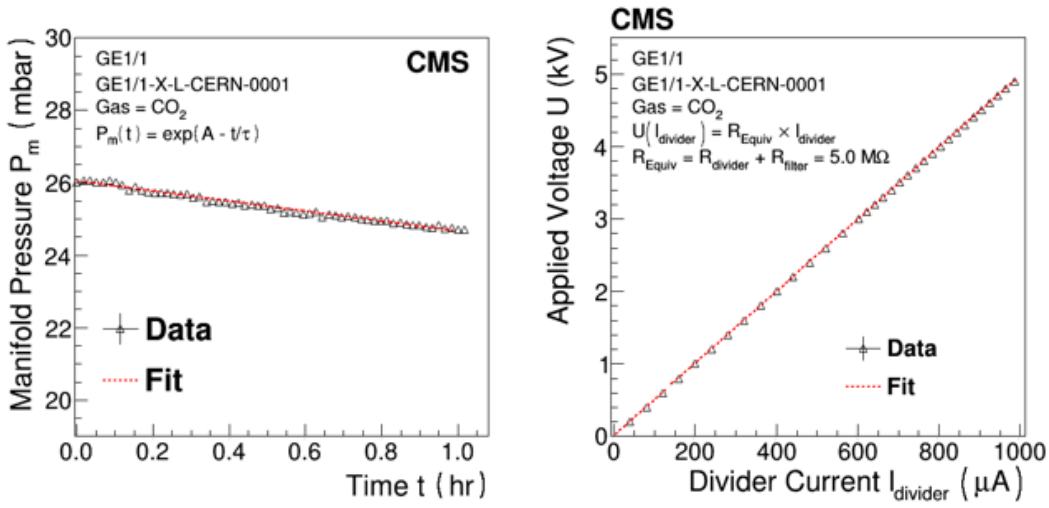

Figure 7: Results of quality controls performed on a GE1/1 chamber. Left: gas leak test (QC3). The detector is validated if the pressure drop in the detector does not exceed 7 mBar per hour. Right: high voltage test (QC4). The result of this test is the Current-Voltage characteristics (I-V curve), which represents the relationship between the current through the HV distribution circuit and the corresponding voltage across it [5].

After the assembly, the detectors undergo a series of quality controls aimed at verifying their performance [3]. A complete list of the quality controls is shown in Fig. 6, while Fig. 7 shows the results of some of these tests. As of today, all the detectors for GE1/1 passed all the quality controls up to QC6. QC7 and QC8 are still on-going, but are expected to be completed by the end of 2019.

4. Installation and commissioning plans for the GE1/1 station

The installation of the full GE1/1 station is currently ongoing. The negative endcap will be completed by autumn 2019, while the positive endcap is expected for spring 2020.

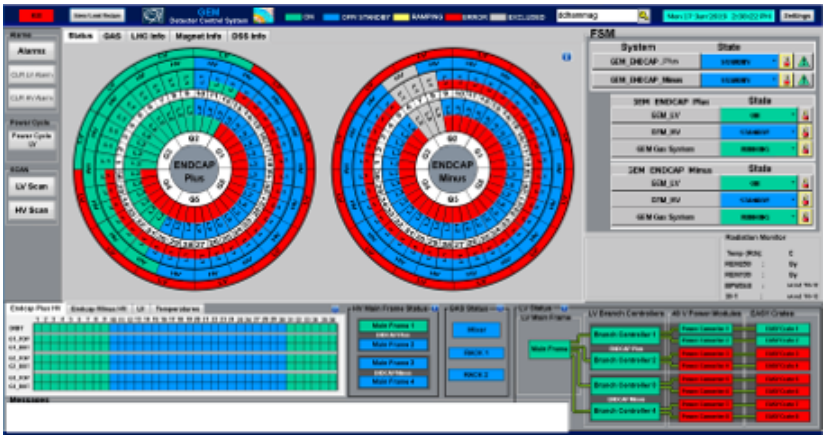

Figure 8: Main panel of the new GE1/1 DCS.

The commissioning plans foresee a first phase, with standalone tests, in particular connectivity tests and full chain validation for the DCS (Fig. 8) and DAQ systems, together with a first power on of the detectors. During this phase we will profit from several DAQ and analysis tools developed for the slice test and QC8, which are ready to be used. An example of the output of these tools is shown in Fig. 9, representing an s-curve performed for a VFAT3 hybrid [4] in QC8.

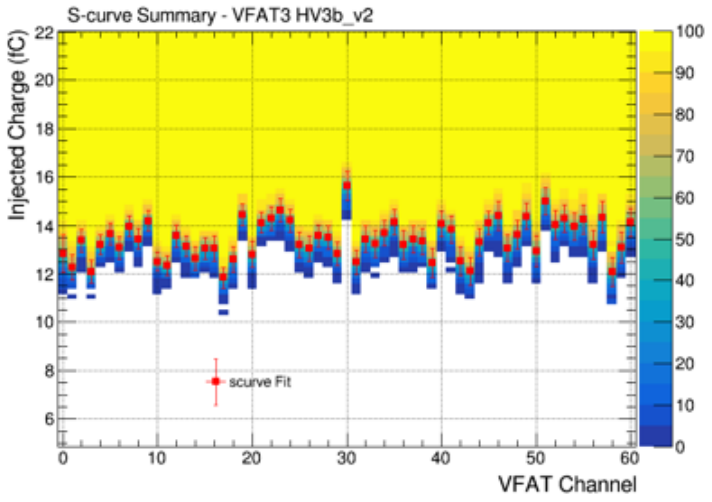

Figure 9: Example of output of an s-curve taken with the tools available for the GE1/1 commissioning. In an s-scurve scan a calibration pulse is sent to an individual channel and it is recorded whether a hit is register. It provides a useful overview of the performance of the readout electronics.

The second phase, which foresees test utilizing the central infrastructures, includes the first runs with trigger from the rest of the CMS muon system as well as the definition of the working points of the detectors. Finally, in summer 2020 we expect to reach the final integration of the DCS and DAQ in CMS.

5. Summary

An intense R&D program led, in the past few years, to the construction of robust detectors, with high performance matching the CMS requirements. A first demonstrator, called the Slice Test, was installed in 2017 in the CMS endcap and reached the goal of full integration into the CMS system. The assembly and qualification of the 144 Triple GEM detectors needed for the GE1/1 station are completed. The assembly of superchambers and the final qualification with cosmics is ongoing and is planned to be completed by the end of 2019. The installation of the negative GE1/1 endcap is planned for fall 2019, while the positive one for spring 2020. We expect that the commissioning will lead, by summer 2020, to the full inclusion of the GE1/1 system into CMS.

6. Acknowledgment

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