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Commissioning of the first chambers of the CMS GE1/1 muon station

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Abstract. The upgrades of the LHC planned in the next years will increase the instantaneous luminosity up to $5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ after Long Shutdown 3, a value about five times higher than the nominal one for which the CMS experiment was designed. The resulting larger rate of interactions will produce a higher pileup environment that will challenge the trigger system of the CMS experiment in its original configuration, in particular in the endcap region. As part of the upgrade program of the CMS muon endcaps, additional muon detectors based on Gas Electron Multiplier (GEM) technology will be installed, in order to be able to sustain a physics program during high-luminosity operation without performance losses. The installation of the GE1/1 station is scheduled for Long Shutdown 2 in 2019–2020; already a demonstrator composed of five superchambers has been installed during the *Extended Year-End Technical Stop* at the beginning of 2017. Its goal is to test the system's operational conditions and also to demonstrate the integration of the GE1/1 chambers into the CMS online system. The status of the installation and commissioning of the GE1/1 demonstrator is presented.

1. Introduction

The CMS muon system [1] employs several detection technologies: Drift Tubes (DTs) and Cathode Strip Chambers (CSCs) are present in the endcaps in the region $1.0 < |\eta| < 2.4$ to provide precise position measurements and trigger, while Resistive Plate Chambers (RPCs) are installed up to $|\eta| < 1.8$ both in the barrel and in the endcaps to provide redundant trigger and coarse position measurement. In addition, among other future upgrades the installation of a new station, the GE1/1 station, based on Gas Electron Multiplier (GEM) technology [2] is scheduled in 2019–2020 in the region $1.6 < |\eta| < 2.2$.

1.1. Triple-GEM detectors

The fundamental element of a GEM detector is the GEM foil, a $50 \mu\text{m}$ thick polymer foil coated with copper on each side and covered with biconical holes arranged in a regular pattern. A triple-GEM detector is composed of a stack of three GEM foils, completed at its ends by a drift cathode and a readout plane, as shown in figure 1. It is operated by applying an appropriate potential to the seven conductor surfaces, so that the electric field between the foils causes the electrons to drift toward the next GEM foil and the field inside the holes causes electron avalanche multiplication. The signal produced on the readout plane is collected by an appropriate electronic.



It has been measured that triple-GEM detectors have a high rate capability up to 100 MHz/cm^2 and a muon detection efficiency of about 97% or more, hence they are suitable for the operation in the environment of the forward muon region.[3]

The voltage can be applied to each detector's stage either using one single high voltage channel per triple-GEM detector and distributing it with a divider, or by supplying the seven high voltage channels independently from each other. The naming convention used for the seven channels is the following: the surface of the first GEM foil facing the drift cathode is named *G1top* (*GEM 1 top*), the one facing the readout plane is named *G1bot* (*GEM 1 bottom*). Similarly the surfaces of the other GEM foils are named *G2top*, *G2bot*, *G3top*, *G3bot*.

1.2. The GE1/1 station

The GE1/1 station consists of 36 chambers per endcap, called *Gemini*, each one spanning 10° . Each Gemini will be composed of a stack of two triple-GEM detectors, called *Layers*.

Its installation is motivated by the increase in luminosity, up to about $5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$, that the Large Hadron Collider (LHC) has scheduled in the next years. As a consequence, the background rate in the $1.6 < |\eta| < 2.2$ region is expected to reach about 1000 Hz/cm^2 , so that achieving an acceptable L1 trigger rate for muons with transverse momentum $p_T < 25 \text{ GeV}$ will not be possible with the current muon system configuration without increasing the threshold on muon momentum.

The GE1/1 station will allow keeping a trigger rate smaller than 5 kHz without increasing such threshold, by adding redundancy in front of the existing ME1/1 station and working combined with CSCs to measure the muon bending angle in the magnetic field.[3]

2. The GE1/1 Slice Test

Even if the full installation of the GE1/1 station is scheduled in 2019–2020, five Gemini chambers have already been installed in the CMS experiment at the beginning of 2017 as shown in figure 2. They consist of the GE1/1 *Slice Test*, whose goal is to prove the system's operational conditions and to demonstrate its integration into the CMS online system.

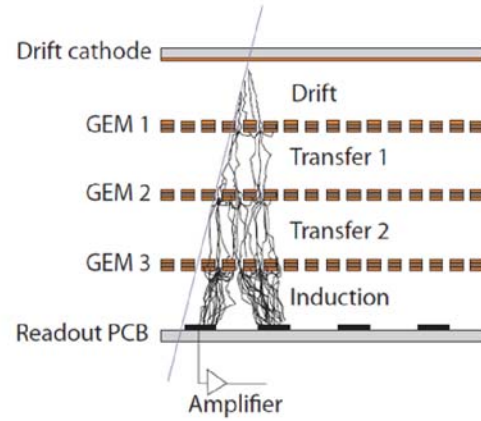


Figure 1: Schematic representation of a triple-GEM detector. From the top down, the drift cathode, the three GEM foils and the readout plane are encountered. The surrounding volume is filled with an $\text{Ar} : \text{CO}_2$ gas mixture. The voltage is applied to the drift cathode and to the top and bottom surfaces of each GEM foil. In the figure the detection of a particle and the subsequent production of charge is also represented.

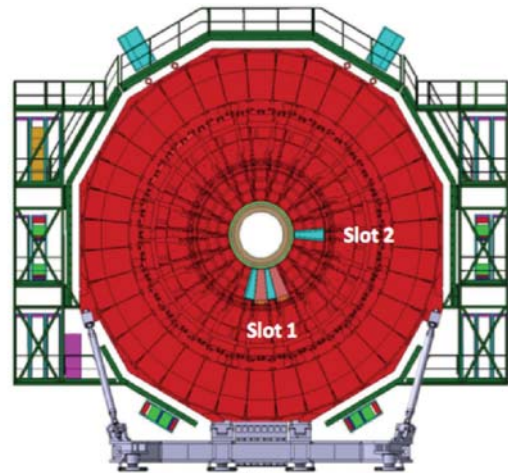


Figure 2: Outline of the negative endcap of the CMS experiment showing the positions where the five Gemini chambers of the Slice Test have been installed. Four of them are placed almost vertically in the portion indicated as *Slot 1*, one of them is located horizontally in the *Slot 2*.

3. The High Voltage system

The high voltage is supplied in two different ways: four Gemini chambers are supplied with a CAEN A1526N module (one HV channel per Layer), and a ceramic divider is used to distribute the voltage to each detector's stage; one Gemini chamber is supplied with a CAEN A1515TG module (one HV module per Gemini chamber) providing seven independent HV channels per Layer. The latter method will be used for the production chambers for the full GE1/1 system.

The stability of the high voltage provided with both methods has been evaluated in the first months of operation, both with and without collisions. Time intervals of 7 and 12 hours during collisions have been taken into account; time intervals of 7 and 10 days without collisions have been considered. In all cases an overall stability $< 1\%$ or better has been observed. As an example, figures 3 and 4 show the monitored voltage during collisions for a Layer supplied with a CAEN A1526N and a CAEN A1515TG module respectively.

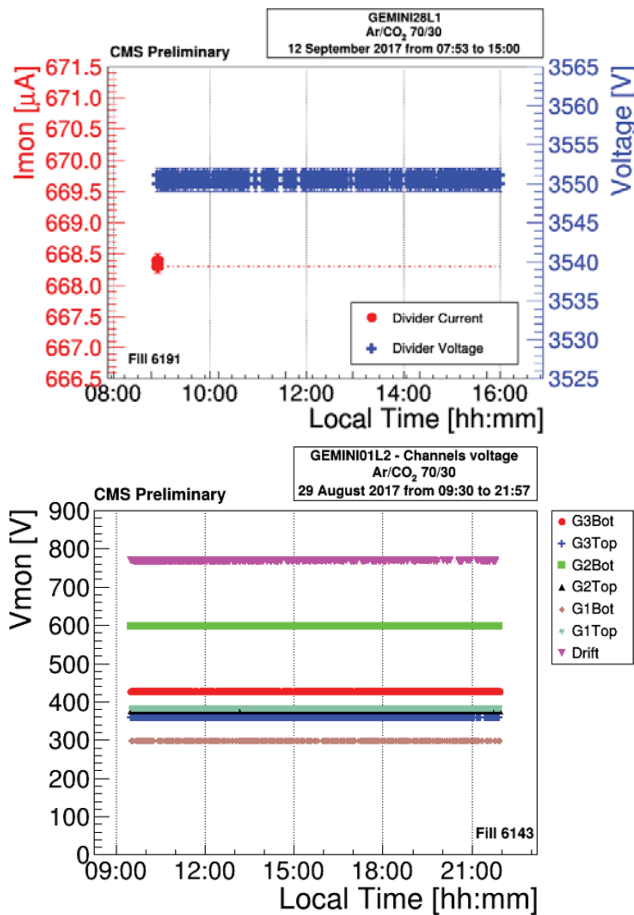


Figure 3: Measured voltage (crosses) and current (dots) through the divider for one Layer supplied with a CAEN A1526N module, in a time period of about 10 hours with collisions. Each marker corresponds to a value that has been archived into the database. Values are archived only if a change is observed, so time intervals without markers indicate that the value has remained unchanged during that time interval. The dashed line is added to complete such time intervals.

Figure 4: Measured voltage during 12 hours time interval with collisions, for one Layer supplied with a CAEN A1515TG module. Each curve corresponds to a voltage applied in a different part of the detector. They are named *Drift*, *G1top*, *G1bot*, *G2top*, *G2bot*, *G3top*, *G3bot* following the naming convention explained in figure 1.1.

4. The Readout and Low Voltage system

The readout system of the slice test is based on VFAT2 chips and OptoHybrids V2B (OH). For the production chambers VFAT3 chips will be used instead of VFAT2. In addition 8 optical fibers for data flow and control are used per Layer.[4, 5] VFAT2 chips are powered with about 3.3 V, while OHs need two low voltage channels of about 4 V and 1.7 V. As a consequence three low voltage channels are necessary per detector Layer.

As an example, figure 5 shows the monitored voltage and current of one of the LV channels powering the VFAT2 chips. Two different modes are clearly visible: when the VFAT2 chips are

powered but in *sleep mode* the current is about 2 A, when they are in *running mode* the current is higher, up to about 6.5 A. Figure 5 shows an overall stability over 10 days.

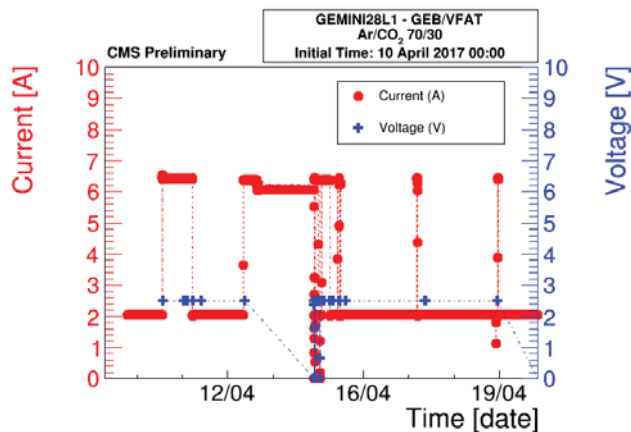


Figure 5: Measured voltage (crosses) and current (dots) supplying the VFAT2 chips of one Layer. Each marker corresponds to a value that has been archived into the database. Values are archived only if a change is observed, so time intervals without markers indicate that the value has remained unchanged during that time interval. Initially the VFATs were in *sleep mode* and moved to the *running mode* on April 11 at about 12 pm. On April 14 both curves assume zero values because the LV has been off for a short time.

5. System Calibration and Timing Performance

Several steps are performed to calibrate the electronics.

Threshold scans scan the number of measured hits per channel as a function of applied threshold.

S-curves scan the response of the channels to an injected pulse calibrated to a given charge at a given threshold. It indicates at which amplitude of the calibration pulse a signal becomes visible, i.e. a conversion between the threshold and the charge, to evaluate the equivalent noise charge of the system. As the threshold value of each strip can be adjusted using programmable registers, this scan allows the perform such a correction in order to level out the response of the channels. Figure 6 shows an example of S-curves performed on a VFAT before and after trimming the threshold.

Latency scans scan the ratio of events with detected hits over the total number of events, per different latency values. The latency is the time difference between the time of arrival of a L1Accept (L1A) and the time at which the related event was stored.

After such calibration, it has been possible to detect the first real muon data. Figure 7 shows the arrival time of some events attributed to the detection of a cosmic ray muon.

Summary

The installation of the GE1/1 station, based on GEM technology, in the CMS muon system has been scheduled in order to allow to maintain an acceptable trigger rate after the LHC upgrades. A Slice Test composed of five Gemini chambers has started at the beginning of 2017 and is currently under commissioning. The operation and stability of the high voltage and low voltage systems have been verified, the electronics have been successfully calibrated. It has been possible to successfully detect first muon data, coming from cosmic ray muons. Several other aspects being part of the commissioning of the slice test have not been covered here: for example the gas system, cooling system, cable routing and other necessary services have been installed and are working properly. In addition the production of GE1/1 chambers for the full installation of the GE1/1 station is currently in full swing.

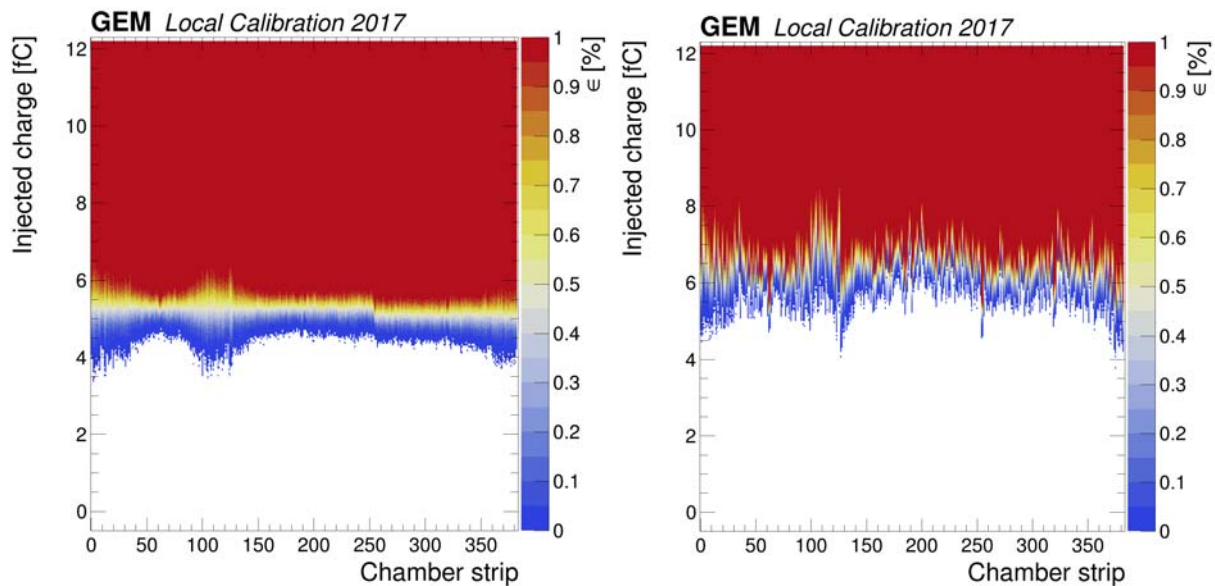


Figure 6: S-curves performed on two VFATs reading one sector [3] of a Layer, before and after adjusting the thresholds of each channel. Before trimming the channels display a dispersion of the 50% of hit-per-pulse ratio, indicating that the effective threshold is not constant across the chips. After trimming the channels display a reduced dispersion of the 50% of hit-per-pulse ratio around the average one.

Acknowledgments

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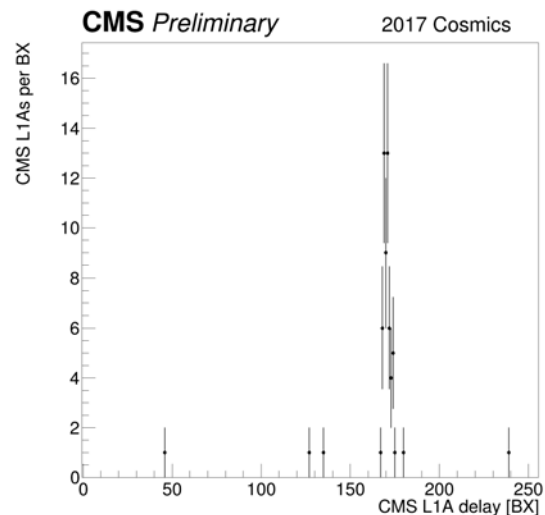


Figure 7: Number of measured hits, integrated over all VFATs, as a function of the delay from a L1A for cosmic ray muon data. The observed delay (175 BX) corresponds to the expected one for cosmic ray muon data.