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Commissioning and integration testing of the DAQ system for the CMS GEM upgrade

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Abstract

The CMS muon system will undergo a series of upgrades in the coming years to preserve and extend its muon detection capabilities during the High Luminosity LHC. The first of these will be the installation of triple-foil GEM detectors in the CMS forward region with the goal of maintaining trigger rates and preserving good muon reconstruction, even in the expected harsh environment. In 2017 the CMS GEM project is looking to achieve a major milestone in the project with the installation of 5 super-chambers in CMS; this exercise will allow for the study of services installation and commissioning, and integration with the rest of the subsystems for the first time. An overview of the DAQ system will be given with emphasis on the usage during chamber quality control testing, commissioning in CMS, and integration with the central CMS system.

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Commissioning and Integration testing of the DAQ System for the CMS GEM Upgrade

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Abstract. The international CMS collaboration at the CERN-LHC experiment will conduct a major upgrade to its muon detection system to cope with the intense particle flux and radiation levels foreseen during the high-luminosity LHC era. The first CMS approved muon upgrade project (GE1/1) consists on the installation of new detectors in the CMS forward region based on Gas Electron Multiplier (GEM) technology to maintain an excellent muon reconstruction and particle identification in that region. Extensive simulation and test-beam exercises performed during the past few years ensure the optimal detector operation. Integration of five GEM modules into CMS done early 2017 allowed scientists to gain experience on mechanical installation, services and data acquisition (DAQ) infrastructures. This letter presents an overall description of the project with emphasis on the GEM data acquisition (GEM-DAQ) system and results on GEM local calibrations with the detector integrated into CMS for the first time.

Keywords: CMS, Muon, GEM, DAQ.

1 GEM technology

A Gas Electron Multiplier [1] is a thin metal-clad polymer foil, chemically perforated with a high density of microscopic holes. In the case of GE1/1 upgrade project, a triple-GEM configuration proved to be optimal in terms of signal amplification, time resolution and considering the volume constraints in the CMS detector. It consists of a stack of three GEM foils separated with a relative distance of few millimeters, a gas mixture fills the space in-between the foils. Charged particles crossing the detector interact with the molecules in the gas producing electron-ion pairs (primary ionization). Released electrons flow from the drift region towards the GEM foils and are further multiplied (second ionization) due to an intense electric field created in the holes producing an avalanche effect. Electrons reaching the anode induce a charge in the readout strips from where properties such as position and arrival time of primary particles can be inferred. Performance of large scale triple-GEM detectors has been extensively studied in the past using simulation and measurements from test-beam exercises [2]. Experimental measurements indicate an excellent performance of the detector with an efficiency $>97\%$, particle rate capability $>10 \text{ kHz/cm}^2$, timing resolu-

tion <10 ns, angular resolution of $300 \mu\text{rad}$ and a gain uniformity of 15% or better across the entire chamber. In addition, the detectors and electronic components undergo radiation tolerance tests to ensure the correct operation during the lifetime of the LHC project.

2 Overview of the GEM-DAQ system

The GEM data acquisition (GEM-DAQ) system is the collection of hardware and software components for signal readout, communication between front-end electronics and off-detector components including: GEM back-end electronics, central CMS DAQ and the Cathode Strip Chamber (CSC) muon system, the later to improve CMS muon triggering in the forward region. Each trapezoidal triple-GEM chamber is divided into twenty-four sectors (eight columns and three rows). Each sector contains 128 readout strips with inputs connected to a 128-channel-front-end chip (VFAT) [3]. Charge collected in the strips is amplified, analog-to-digital converted and noise suppressed; data from the twenty-four chips are packed and transmitted via electronic links (E-links) running through a flat printed circuit board known as GEM Electronic Board (GEB) to an opto-hybrid device for further processing. The opto-hybrid is also plugged in the GEB and contains a Giga-Bit Transceiver (GBT) chipset, a Field Programmable Gate Array (FPGA) as well as optical receivers and transmitters to provide the link with the off-detector region as shown in Figure 1.

Fig. 1. A sketch showing the main components of the GEM-DAQ system including the front-end electronics and elements for communication with the off-detector region.

A bidirectional optical path runs between the Micro Telecommunications Computing Architecture (μ TCA) located in the counting room and the opto-hybrid, this path is used to send setup and control signals to the VFAT chips and to receive tracking and triggering information. The information from the opto-hybrid is received by CTP7 Advance Mezzanine Cards (AMCs) for further processing, a custom AMC card (AMC13) is used for communication with central CMS-DAQ to provide the trigger and timing control (TTC). A unidirectional path sends fixed latency trigger data from the GEM to the CSC system. A complete description of the electronic components can be found in [4].

3 GEM integration in CMS and local calibration results

Triple-GEM chambers are subjected to rigorous Quality Control (QC) tests [5] before being declared ready for installation and commissioning, some of those tests include uniformity of the gain and checks for gas leaking. Once QC test are passed, super-chambers are fabricated coupling two GE1/1 chambers and parameters such as detector gain, noise levels and cluster size are measured with the final detector electronics.

Five GEM super-chambers were integrated into CMS early 2017. With the GEM-DAQ system fully operational and the services (gas, cooling, cabling, low and high voltage) in place, the system can be operated locally, allowing to perform scan routines on specific GEM devices and configurations, or globally, with the system integrated into the central CMS DAQ infrastructure. GEM local calibration routines are used to check data integrity and response of the VFAT chips to injected signals, results for one of the VFAT chips used in the commissioning are presented in Figure 2.

Fig. 2. Response of a VFAT chip (installed in one of the super-chambers integrated in CMS) to the injection of internal calibration pulses (charge). The magnitude of the charge is controlled internally and a configurable number of pulses are injected. The

total number of times the comparator fired is recorded and normalized to the total number of injected pulses (ϵ). The plot on the right shows the response after adjusting individual channel registers to trim the 99% response point to the same reference value, this in order to reduce any slight differences between channels due to fabrication statistical fluctuations.

4 Summary and future perspectives

A successful installation of five GEM super-chambers into CMS was done early 2017, where invaluable experience was gained on mechanical installation, service integration and DAQ setup that will allow to reduce the time during the installation of the full GE1/1 system (2019). GEM local calibrations indicate a good system performance and provide valuable data for monitoring the system and GEM-DAQ components. The commissioning work will continue in parallel with the regular CMS data taking, this will allow for the GEM system to interact with the rest of the CMS sub-systems for the first time.

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