



Contribution ID: 69

Type: Oral

## Commissioning and running experience with the CMS GE1/1 system

*Friday 23 September 2022 09:20 (20 minutes)*

We present the commissioning and the running experience of the CMS GE1/1 system which has been installed in CMS in October 2020. Since then, GE1/1 has been commissioned and it is now ready for LHC Run-3. The GE1/1 detectors are read-out by the VFAT3 chip which communicates with the microTCA backend through the versatile link. Each detector has 24 VFAT3s, 3 GBTx, 3 VTRx, 2 VTTx, and a Virtex-6 FPGA. All powered by 10 FEAST DCDC converters. We will report on the GE1/1 electronics performance, stability, and the experience acquired over 2 years of commissioning.

### Summary (500 words)

GE1/1 is the first CMS phase-2 upgrade. It consists of 144 long (1 m) triple-GEM detectors which have been inserted in the most forward part of the CMS muon endcap. The first GE1/1 endcap was installed in fall 2019 and the second endcap, 1 year later. In 2021 and 2022 the system has been commissioned. The system is now ready for the imminent start of LHC Run-3.

Each GE1/1 detector is read-out by 24 VFAT3 chips. The VFAT3 chip is a binary chip with 128 channels which outputs trigger and tracking data. The data are then transmitted through a large PCB, called GEM Electronics Board (GEB), to a 10x10 cm<sup>2</sup> mezzanine, the Opto-Hybrid (OH), located at the centre of the GEB. The OH has 1 Virtex-6 FPGA, 3 GBTx and 1 SCA chips as well as 3 VTRx and 2 VTTx optical modules. The OH communicates with the xTCA backend boards, the CTP7, through the versatile link. The whole front-end electronics is powered by 10 FEAST DCDC converters.

During almost 2 years, the commissioning consisted in troubleshooting, operating and analysing the performance of the whole GE1/1 system, including both the detectors and the electronics. Unexpected issues had to be tackled in-situ, like noise, optical links instabilities, etc. In CMS, the commissioning is benchmarked with regular “Global Runs”, where all the CMS sub-systems have to be operated together to record cosmic muons. It is the opportunity to measure the muon detection efficiency of GE1/1 and to check the integration of GE1/1 with the rest of CMS (central DAQ, Level-1 trigger, Detector Control System, ...). In addition dedicated global runs with high rate (up to 150 kHz) of random triggers have been taken to challenge the DAQ system.

One key feature of GE1/1 is the combination of its trigger data with the data of neighbour Cathode Strip Chamber (CSC). The GEM trigger data are combined with CSC trigger data at 2 stages of the CMS Level-1: (i) within the CSC Trigger Mother Board to improve the efficiency of the CSC local trigger and (ii) at the Endcap Muon Track Finder (EMTF) stage. This integration is very delicate as it requires precise timing of both GEM and CSC data, which can only be done in CMS. Note also that the GEM trigger data integration is adding to other important upgrades of the CSC and EMTF triggers.

We will report on the main steps of the GE1/1 commissioning, mainly focusing on the issues related to the GE1/1 electronics: how we improved in-situ the noise level, how to deal with the optical link instabilities, and what solution will be implemented during the next LHC Long Shutdown (LS3). We will also report on the status of GEM-CSC trigger integration and the first performance results with the first LHC collisions of Run-3. Finally, we will briefly present the status of the production of GE2/1, the 2nd GEM station to be installed in CMS within a couple of years, and which greatly benefits from GE1/1 commissioning experience.

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**Session Classification:** Systems, Planning, Installation, Commissioning and Running Experience

**Track Classification:** Systems, Planning, Installation, Commissioning and Running Experience