Installation and commissioning status of the new GEM muon detectors in the CMS experiment

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A New Muon Station

The LHC experiments are being upgraded to handle the high particle flux expected at the HL-LHC.

At the **CMS** experiment, the **muon system** is being upgraded to quickly identify high momentum muons. This requires a **precise measurement** of the **muon bending angle**, which can be accomplished with additional layers of chambers.

Three stations of **Gas Electron Multipliers** are being installed in the forward regions, where the particle rates are larger. The first station (GE1/1) has been produced and installed in the experiment.

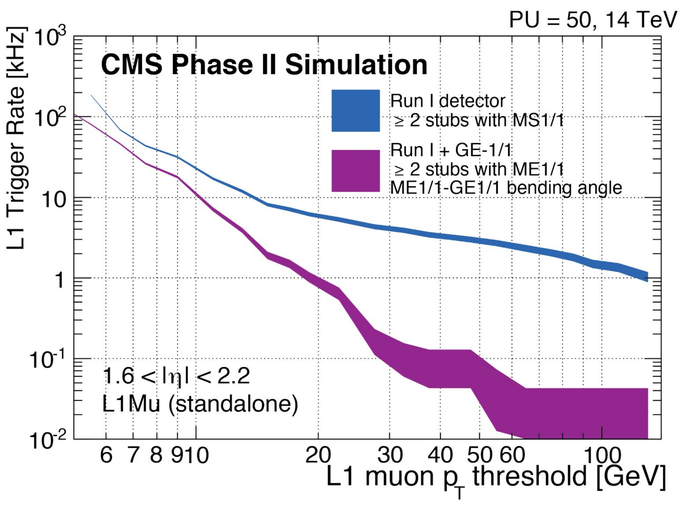

Figure 1: The purple line shows the expected L1 trigger rate with the addition of GE1/1 and the blue line shows the rate without GE1/1 [1]

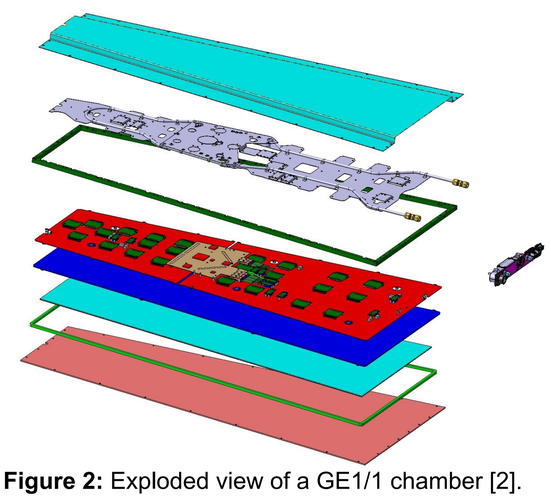

Figure 2: Exploded view of a GE1/1 chamber [2].

Gas Electron Multipliers

GEMs are gaseous chambers for **detecting ionizing particles**.

Key feature: GEM foil. It consists of an insulating layer with conductors on the top and bottom and microscopic holes etched in a regular pattern.

When a voltage difference is applied to the conductors, the **holes create a sharp electric field**. Electrons drift in the gaps, avalanche in the holes, and induce signals on readout strips.

GEMs are capable of handling higher rates than traditional wire chambers.

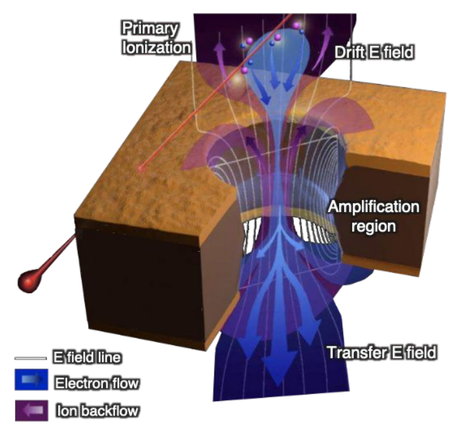

Figure 3: The sharp electric field created inside of the hole in a GEM foil [1, 2]

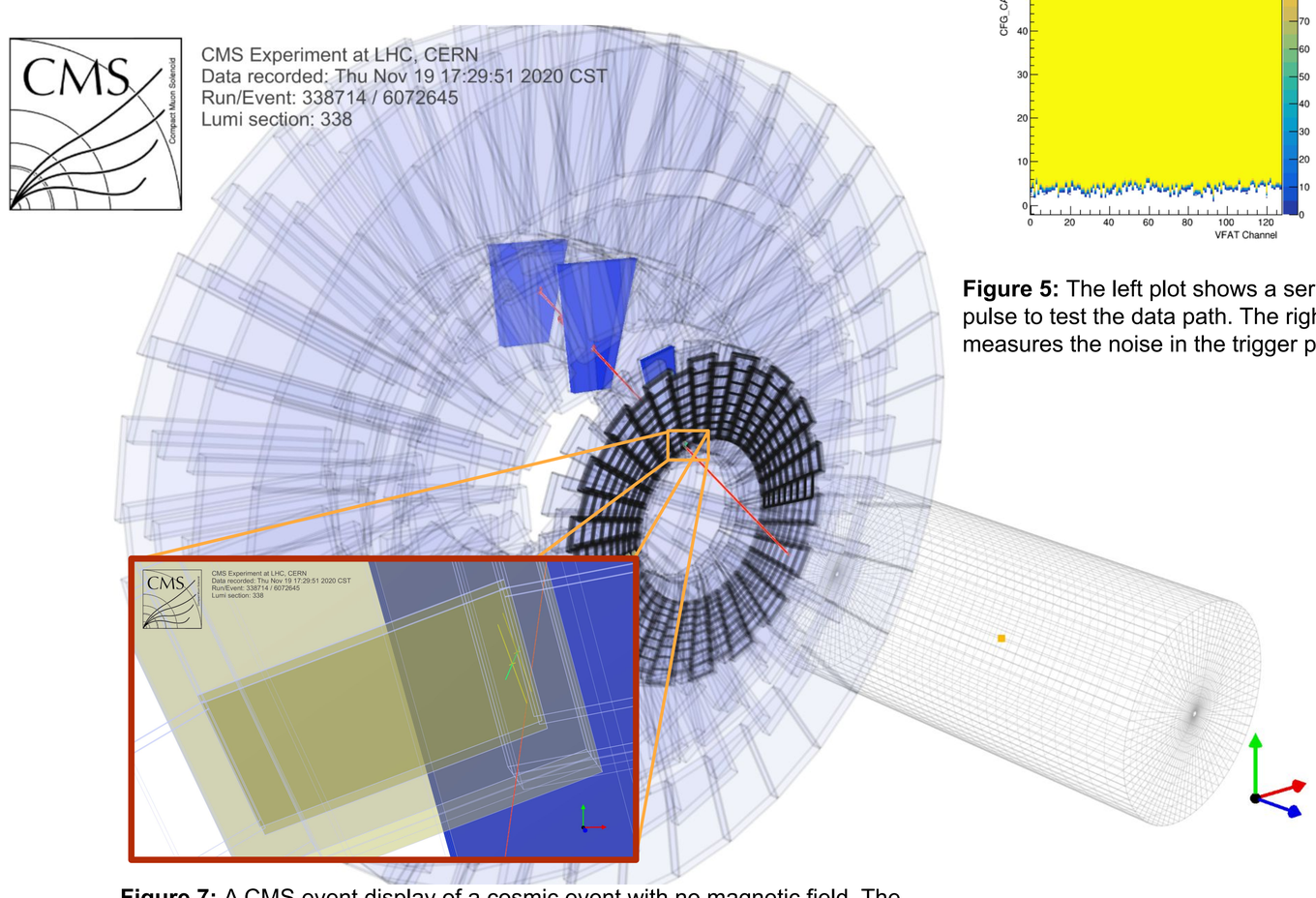

Figure 7: A CMS event display of a cosmic event with no magnetic field. The highlighted ring is the GE1/1 station and the zoomed in picture shows the path through a super chamber

Pre-installation Test

After production, validation, and transportation to CMS: one last series of chamber tests. Check the **connectivity of front-end electronics** to ensure no disconnections in transportation.

Data path: checked with test pulses. Output: **s-curve**.

Trigger path: checked monitoring **s-bit trigger rates** due to electronic noise.

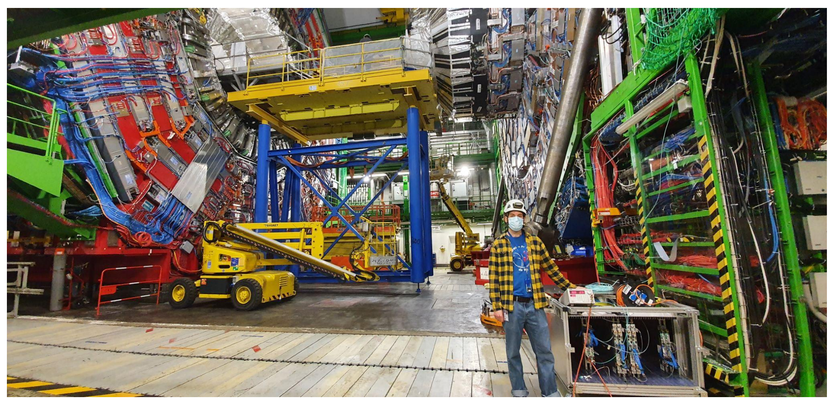

Figure 4: Testing the GE1/1 chambers (inside the trolley) with a bench top power supply and optical fibers routed to patch panel inside the cavern

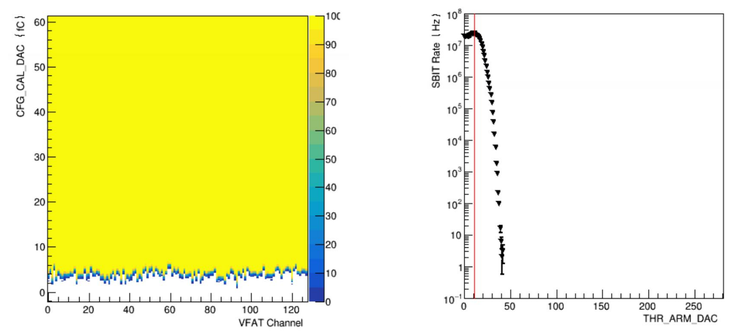

Figure 5: The left plot shows a series of s-curves created by an internal test pulse to test the data path. The right plot shows an s-bit rate scan which measures the noise in the trigger path.

GE1/1 Installation

After passing the pre-installation tests, 144 GE1/1 chambers were installed into the experiment in 2019 and 2020. After installation, the chambers must be tested and prepared for LHC operations. This **commissioning** process is currently ongoing.

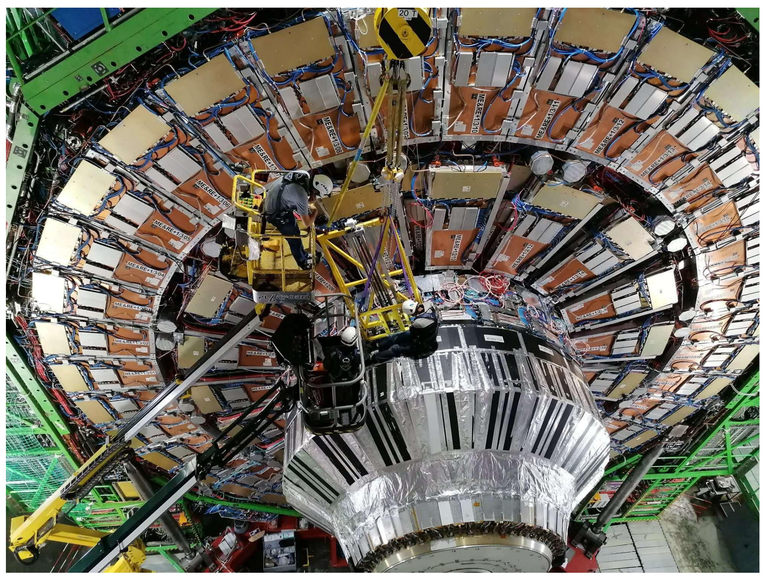

Figure 6: Installation of a GE1/1 superchamber (a pair of chambers) into the CMS experiment

Commissioning Tasks

Commissioning starts on a small scale by testing the connectivity, mapping, front-end electronics, and high voltage. Subsequently, detailed **noise measurements** are performed. The whole GE1/1 system is then tested on a global level by measuring the **detector efficiency with cosmic rays**. The ultimate goal of commissioning is to **finalize the detector configuration** for use in Run 3

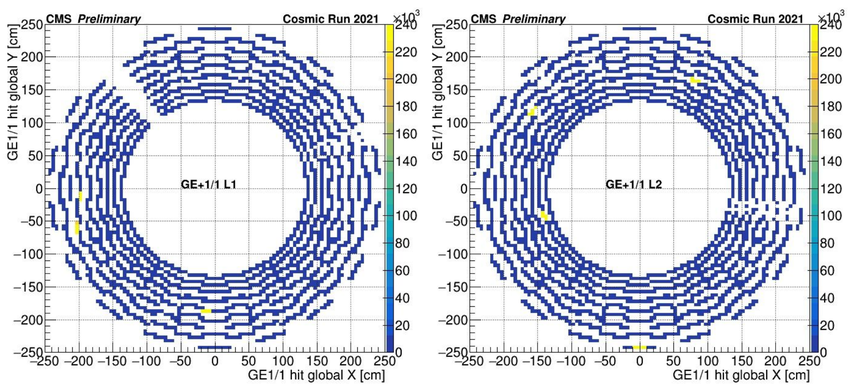

Figure 8: These plots show the occupancy of GE1/1 chambers during a cosmic run. They show the two GE1/1 layers on the positive end-cap.

Commissioning Challenges

Two notable challenges arose during commissioning:

- High noise levels
- VTRx instabilities

The noise levels were mitigated with **LV filters** installed on the chambers and LV boards. The **VTRx** allows for communication with the chamber by transmitting and receiving optical signals. The photodiode responsible for receiving optical signals outgases, which can leave a residue on optical fiber and interrupt signals.

Conclusions

Over 10 years of research and development resulted in the installation of 144 GE1/1 chambers in the CMS experiment. These chambers are now being commissioned. This is a milestone for the GEM community, but there is still work to do for GE1/1. The DAQ and DCS systems are still being finalized and additional cosmic runs are necessary to finalize the HV settings. These developments will take place over the next few months as GE1/1 prepares to enter Run 3.

Next Steps

The next step in the GEM upgrades is also underway with the installation of the GE2/1 demonstrator. This fully operational GE2/1 chamber will be operated during Run 3 while the rest of GE2/1 is in mass production.

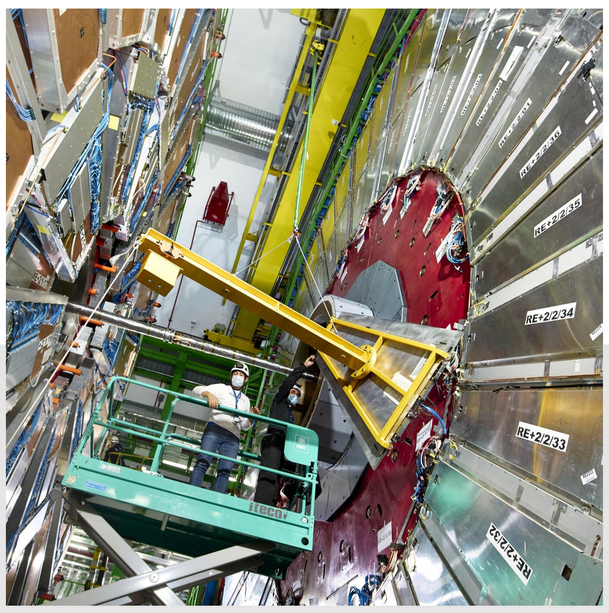

Figure 9: The demonstrator will be used to test an operational GE2/1 chamber in real conditions while the rest of GE2/1 is undergoing mass production

References

[1] CMS Collaboration, "CMS Technical Design Report for the Muon Endcap GEM Upgrade," CERN-LHCC-2015-012, CMS-TDR-013

[2] G. Mocellin, "Performance of the GE1/1 detectors for the upgrade of the CMS muon forward system," July 2021