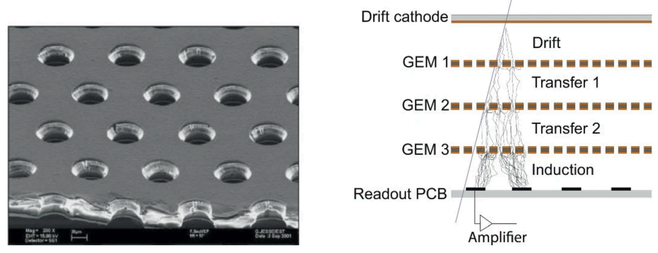
Performance and quality control of the first CMS GE2/1 muon production chambers

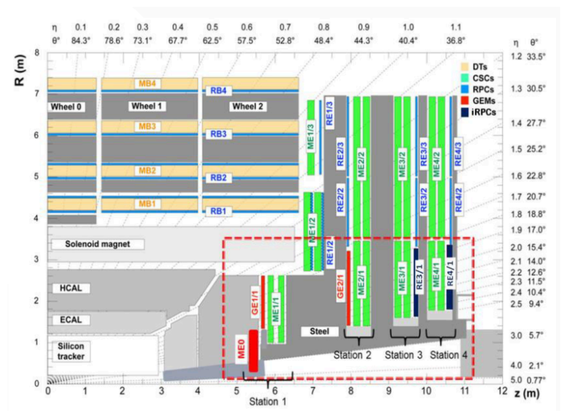
Abigail Warden, UW-Madison, on behalf of the CMS GEM Group

Introduction

The Large Hadron Collider (LHC) will soon be upgraded to prepare for the high-luminosity phase. To cope with the increase in background rates and trigger requirements, the CMS muon system is being upgraded by installing additional sets of muon detectors based on Gas Electron Multiplier (GEM) technology. The GE2/1 station will consist of 72 GEM chambers, comprising 288 modules, covering the pseudorapidity range between 1.62 and 2.43 [1]. The GE2/1 chambers are being produced at this moment and the first production grade chambers were installed at the beginning of this year after being validated in a GEM cosmic-ray stand.



(Fig. 1) (Left) Scanning Electron Microscope (SEM) picture of a GEM foil. (Right) GEM Technology : comprising of three foils separated by 3/1/2/1 mm gaps. Electrons passing through will ionize the gas and create an electron avalanche which is readout by analog signal.



(Fig. 2) A cross-sectional view of CMS, highlighting the high eta region in which the GEM detectors have been/will be installed.

Module Tests and Chamber Assembly

Before being assembled and placed in the cosmic stand, modules need to undergo various tests to ensure smooth performance and meet the required standards in operations. These include :

✓ **Gas Gain Uniformity:**

Check to see that the gas (Ar/CO2 in a 70/30% mixture) is uniformly distributed throughout the entire chamber.

✓ **HV Gain Uniformity:**

Check to see that the high voltage (HV) powering the electrodes is uniformly distributed throughout the entire chamber

✓ **HV Stability :**

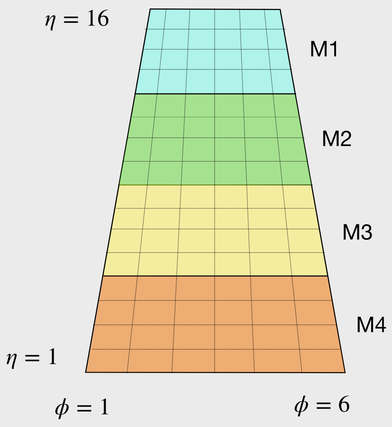
Test the stability of HV by powering the GEM foils at deltaV = 580V for 24hrs and monitoring trip rate

✓ **Electronics :**

Readout electronics connectivity test; monitor communication stability and check noise

The Cosmic Stand

After chamber assembly, chambers are inserted into a cosmic stand and connected to services necessary to operate. A standard cosmic run will last > 12 hrs collecting cosmic muon data.



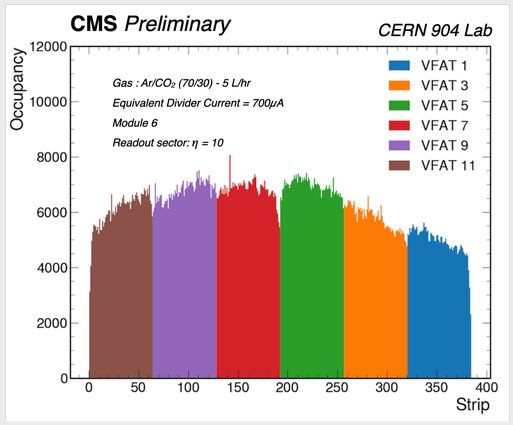
(Fig. 3) Spatial schematic of a GE2/1 chamber. One chamber is composed of 4 modules.
Half of a front-end chip's (VFAT) channels (64) corresponds to one η, ϕ readout sector.

1. Track Reconstruction

i) **Unpacking** : decode raw DAQ data to channel hit info + mapping channels to detector and strip positions

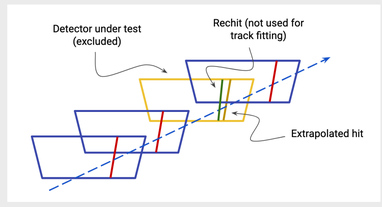
ii) **Local reconstruction** : clustering neighboring fired strips in hits

- monitor the hit occupancy per VFAT (Fig.4) to detect noisy and dead channels
- mask them during hit reconstruction and remove them in the track resconstruction

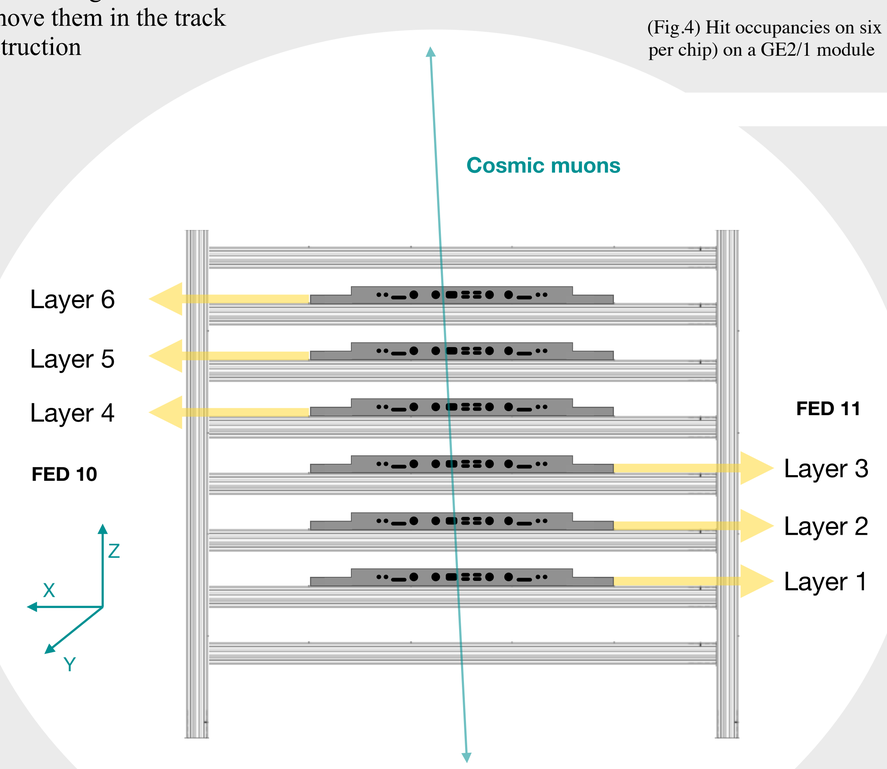


(Fig.4) Hit occupancies on six VFAT chips (64 channels per chip) on a GE2/1 module

iii) **Track reconstruction** : Fit track with tracking detectors and extrapolate it to detectors under test



- require all hits belong to the same module type.
- The track with the best χ^2 is chosen.

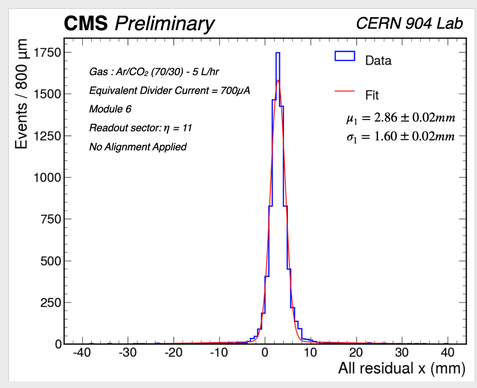


(Fig. 5) Diagram of the layout of GE2/1 chambers in a GEM cosmic-ray stand. 3 chambers are read out by 1 FPGA

2. Match Expected to Measured

$$x_{matchedhit} \ : \ |x_{propagated} - x_{rechit}| < 40mm$$

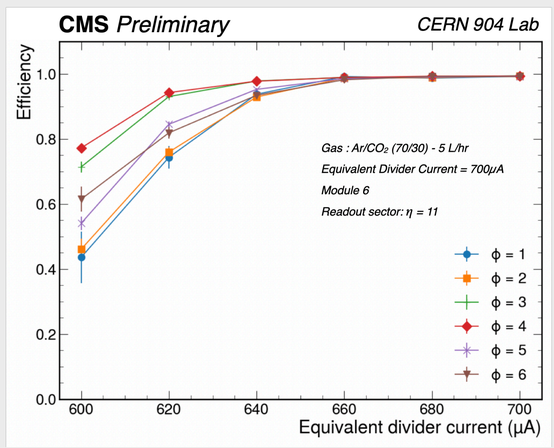
- **Propagated** is where we expect a hit based off of hits in the other detectors
- **Rechit** (truth) is what we measure



(Fig.6) Distribution of hit residuals on a GE2/1 module. A gaussian is fit to the distribution and the width of the fit is taken to be the spatial resolution

4. HV Scan

- Take an HV scan to determine at which HV working point chambers become fully efficient.



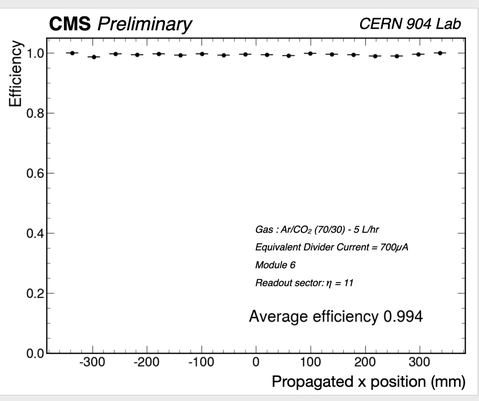
(Fig.7) The efficiency turn on curve for a module set at different HV working points from 600 to 700μA in steps of 20μA.

Electrode	R_equivalent (μA)	Voltage for Eq. Div. Current 600μA (V)
Drift	1.125	675
GEM1	0.56	336
Transfer 1	0.438	262.8
GEM2	0.55	330
Transfer 2	0.875	525
GEM3	0.525	315
Induction	0.625	375
Total	4.698	2819

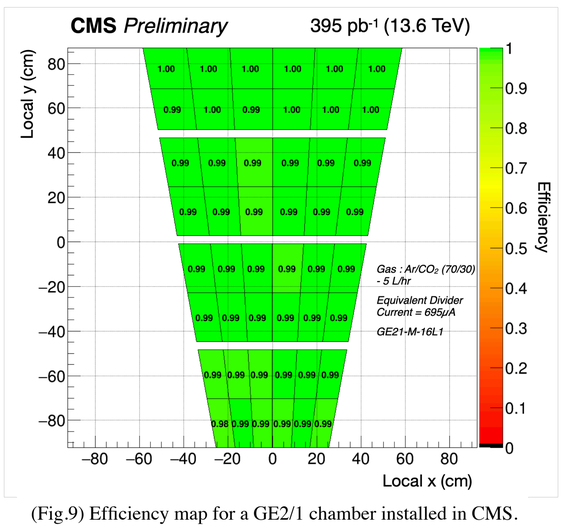
3. Calculate Efficiency

After track reconstruction, calculate efficiency per module for every η readout sector. We target a uniform efficiency through the chamber, reaching at least **97%**

$$\text{Efficiency} = \frac{n_{matched\ hits}}{n_{expected\ hits}}$$



(Fig.8) Detection efficiency for muons as a function of propagated x position in local coordinates

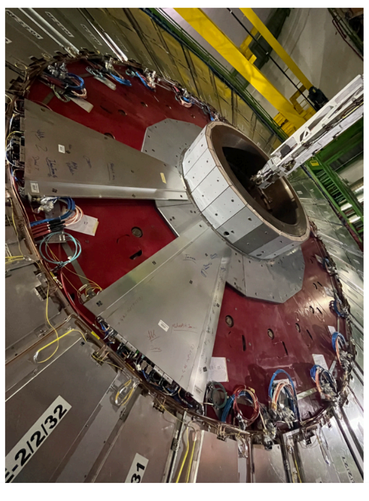


(Fig.9) Efficiency map for a GE2/1 chamber installed in CMS.

Performance in CMS

Two chambers were validated in the cosmic stand in time for insertion during Year End Technical Stop (YETS) 2023-24. They are now fully operational in p5, located in the negative endcap.

- We continue to evaluate the HV stability and discharge rate of these new chambers. Already we have seen good front-end electronic stability.
- Latest efficiencies using p-p collision data are on average 99% when using standalone muon tracks formed from other muon chambers.



Conclusion

Two GE21 chambers were tested and validated using cosmic muon data with high efficiency and operational stability. Their optimal working point was determined to be at an equivalent divider current of 680μA. After being inserted into CMS during YETS, these two chambers were commissioned and have since participated in data-taking for 2024.

[1] A. Colaleo et al., CMS Technical Design Report for the Muon Endcap GEM Upgrade, CMS-TDR-013