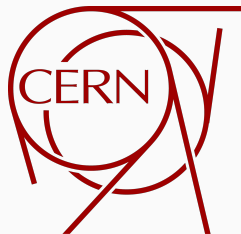


VFAT Temperature Monitoring on an ME0 GEM Module



Erick Yanes and Marcus Hohlmann
(on behalf of the CMS Muon Group)

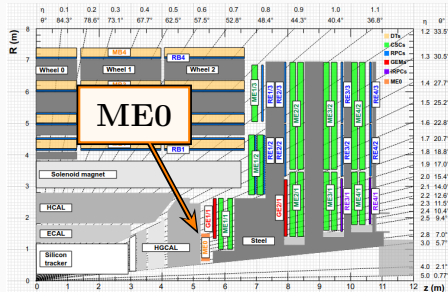
Florida Institute of Technology,
Melbourne, FL

October 23rd, 2025

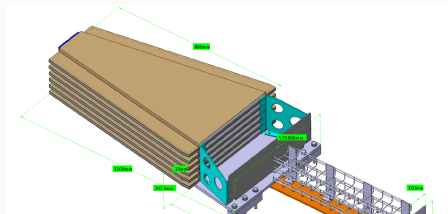
SESAPS 2025
James Madison University,
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- The Large Hadron Collider (LHC) is a pp collider running at $E_{CM} = 13.6\text{TeV}$
- With the High Luminosity (HL) upgrade, the luminosity will increase by half an order of magnitude
- More data will be obtained to investigate exotic physics processes
- The Compact Muon Solenoid (CMS) is one of the detectors being upgraded
- Existing electronics are being upgraded, and three new Gas Electron Multiplier (GEM) detectors are being installed
 - GE1/1 – Currently installed for RUN 3
 - GE2/1 – Early Production Phase
 - ME0 – Production Phase
- ME0 will track muon paths at the highest η
- One ME0 stack is composed of six modules

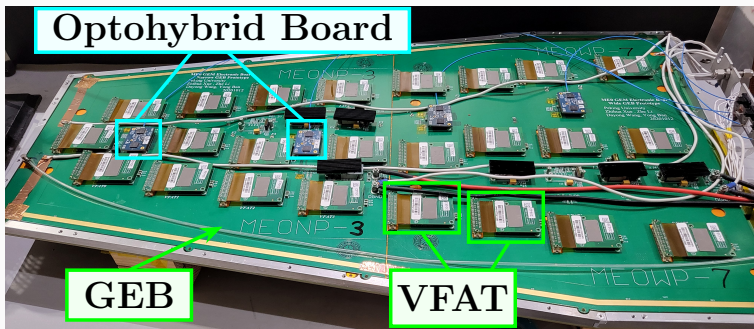


$R - z$ cross section of CMS including HL-LHC upgrade detectors [1]



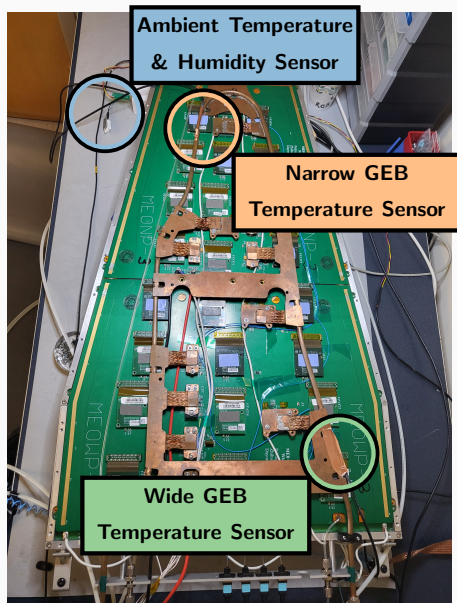
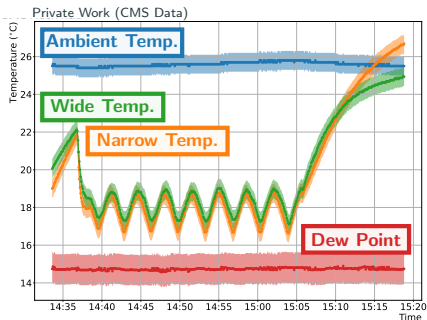
Model of the ME0 detector [1]

- Very Forward ATLAS and TOTEM (VFAT) front-end electronics boards – Digitize and read-out ionization signal from the read-out strips
 - 128 channels (strips) per VFAT
 - 24 VFATs per module
- OptoHybrid (OH) – Collects data from the VFATs and sends to the back-end through optical fibers
 - 2.56 Gbps to Front-end electronics
 - 10.24 Gbps to Back-end electronics
- GEM Electronics Board (GEB) – Route connections between the VFATs and OHs

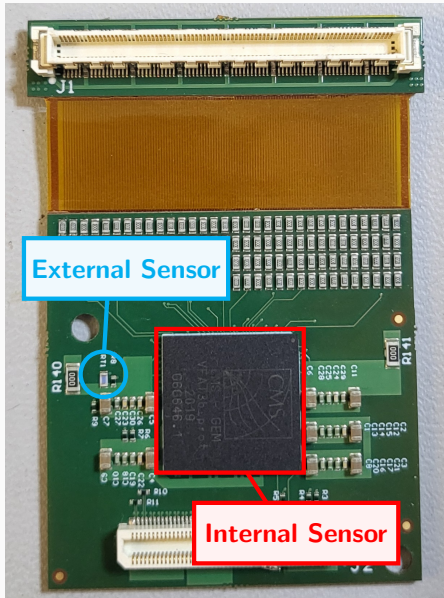


Cooling Circuit Temperature Monitor

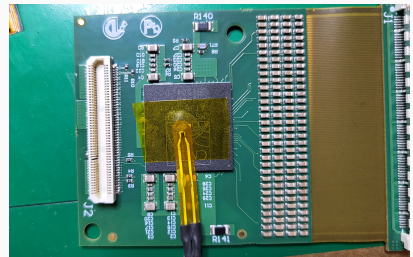
- Prototype cooling circuit on ME0
- Focuses on cooling the OHs
- Does not make contact with all of the VFATs
- Two external temperature sensors
- Ambient temperature and humidity sensor used to calculate dew point
- CW-5200 chiller pumps cold water through the circuit
- Turns on and off to maintain temperature



VFAT Temperature Sensors

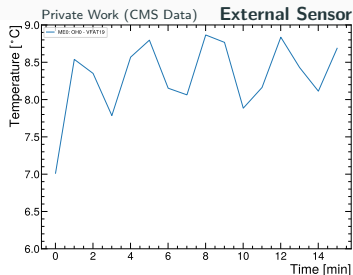
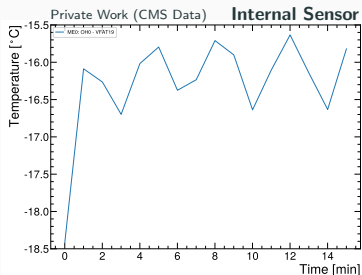
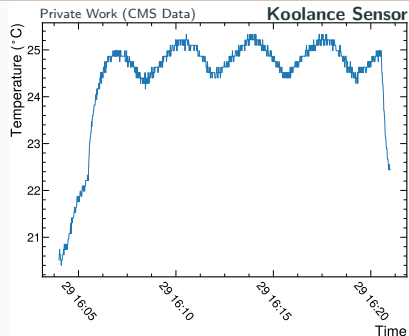


- VFATs have two temperature sensors
- Internal temperature sensor inside the ASIC
- External temperature sensor (RT1) on the PCB
- **Neither temperature sensor is properly calibrated**
 - During VFAT calibration, the internal temperature sensor is not calibrated a priori
 - Constant current source for Rt1 can vary depending on the VFAT or voltage supplied
- Also use a Koolance temperature sensor to crosscheck VFAT recorded temperatures



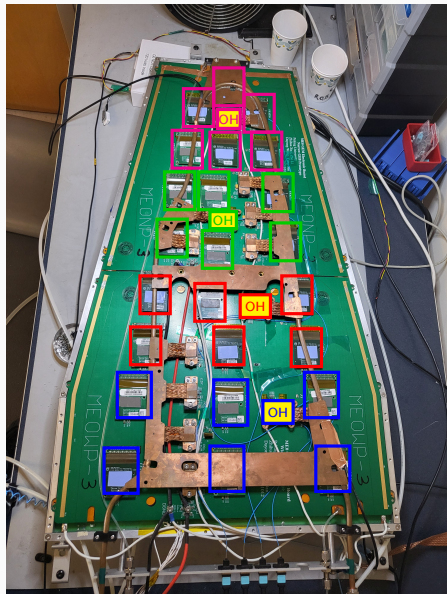
Reading VFAT Temperature Sensors

- Neither the internal nor external temperature sensors are calibrated
- Internal temperature sensors are all subzero and External temperature sensors range from 4 to 40°C
- However, both temperature sensors respond to **changes in temperature** correctly
- Just need to provide an offset to the recorded temperature values

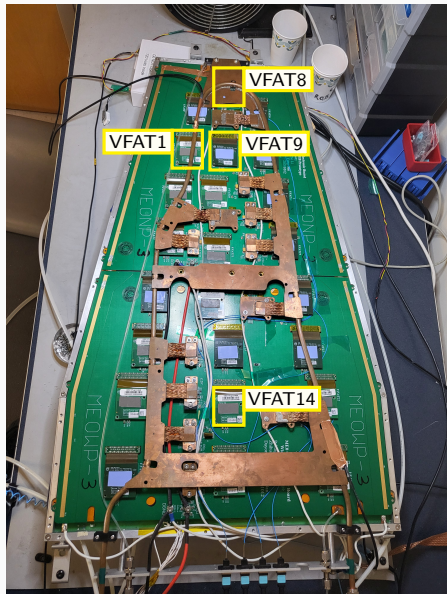


How to use the available temperature sensors to calibrate and monitor the VFAT temperatures during normal operations?

- Need a temperature sensor on the chamber that is similar to the VFAT temperatures
- With cooling on, both the VFATs (in SLEEP mode) and the OHs have a similar temperature ($\sim 26^{\circ}\text{C}$)
- Can use an OH to calibrate the VFATs near it
- Method for calibrating and recording the VFAT temperatures:
 1. Turn on cooling and let it reach a minimum temperature (3 minutes)
 2. Power on and initialize the frontend
 3. Record the temperature of each OH temperature sensor
 4. Record the VFAT temperatures
 5. Find an offset for each VFAT such that for the first measurement
$$\text{OH}_{\text{temp}} = \text{VFAT}_{\text{temp}} + \text{Offset}$$
 6. Get the VFATs as close to normal operations as possible (set them to RUN mode, unmask the VFAT channels, etc.)
 7. Record $\text{VFAT}_{\text{Temp}} + \text{Offset}$ every minute

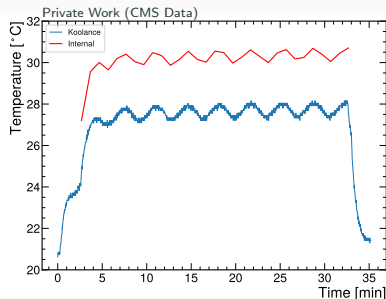


- Recorded four different VFATs with the Koolance Temperature Sensor
- Wanted a mix of cooled and uncooled VFATs
- Choose the following VFATs:
 - VFAT8 – Cooled by large copper plate
 - VFAT1 – Cooled by copper pipe
 - VFAT14 – Uncooled
 - VFAT9 – Uncooled and surrounded by electronics
- Recorded temperatures with the protective metal cover



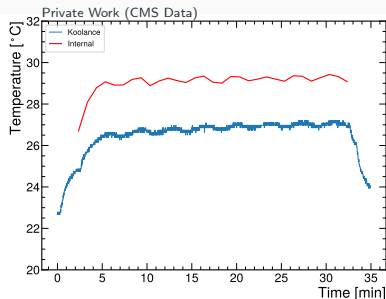
VFAT8

- Expecting to be the coldest, covered by large copper plate
- Cooling circuit does not make contact with this VFAT due to height of cooling circuit bracket
- Koolance sensor averages to 27.5°C
- Internal sensor averages to 30.0°C
- Internal sensor is about +2.5°C off



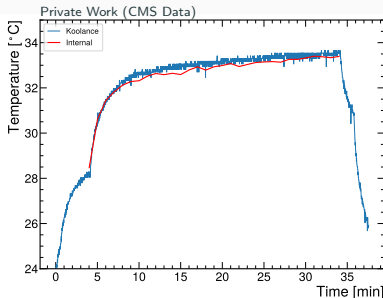
VFAT1

- Expecting to be the 2nd coldest
- Contacts the copper pipe of the cooling circuit
- About 1°C cooler than VFAT8
- Koolance sensor averages to 26.5°C
- Internal sensor averages to 28.75°C
- About +2.25°C off



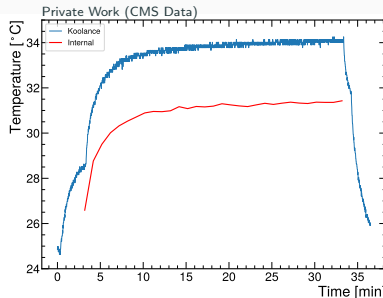
VFAT14

- Expecting to be the 2nd warmest, no contact with the cooling circuit
- Koolance sensor averages to 33°C
- Internal sensor averages to 33°C
- Near perfect temperature agreement



VFAT9

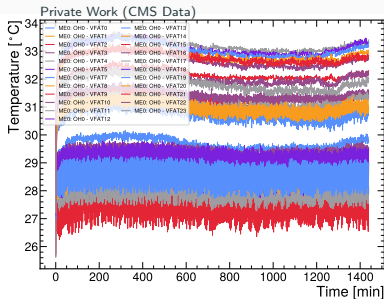
- Expecting to be the warmest, no contact with the cooling circuit and surrounded by electronics
- Koolance sensor averages to 33.5°C
- Internal sensor averages to 31.0°C
- About -2.5°C off



- This method works decently well at calibrating the VFATs
- Able to get within $\pm 2.5^{\circ}\text{C}$ for these VFATs
- These are expected to be the most extreme temperature differences based on amount of contact with the cooling circuit and surrounding electronics
- All VFATs should be within $\pm 2.5^{\circ}\text{C}$ as well
- Moving forwards this method will be used

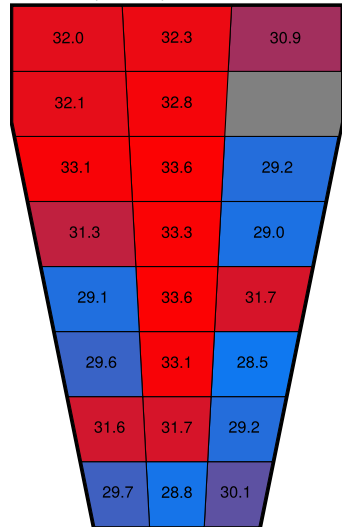
VFAT #	Internal Sensor ($^{\circ}\text{C}$)	Koolance Sensor ($^{\circ}\text{C}$)	Difference ($^{\circ}\text{C}$)
8	30.0	27.5	+2.5
1	28.75	26.5	+2.25
14	33.0	33.0	0
9	31.0	33.5	-2.5

- Performed a 24 hour test
- Temperatures were stable, aside from the chiller cycle
- Noticeable gap between VFATs that make good contact with the cooling circuit and those that don't
- Averaging each VFAT temperature shows coolest VFATs make contact with the copper pipe



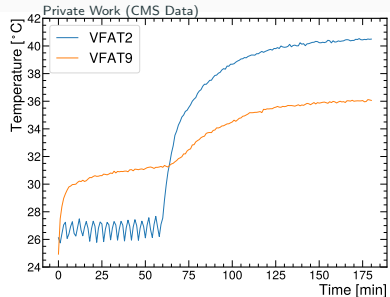
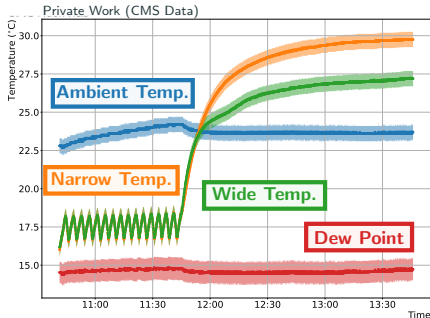
ME0 OH0 Temperatures (°C)

Private Work (CMS Data)

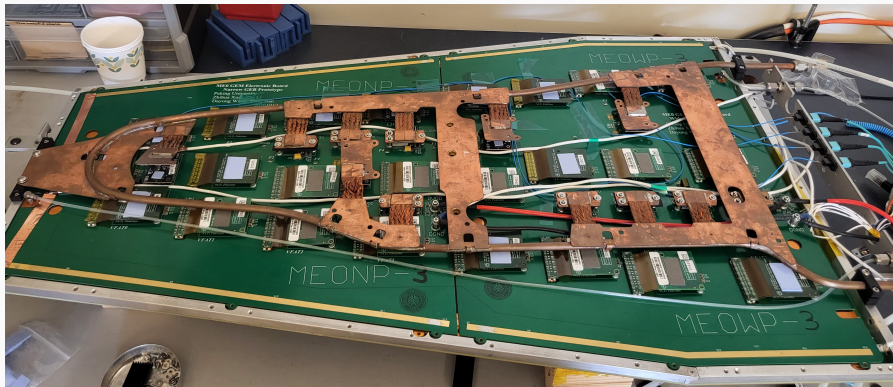


Cooling “Failure” Test

- Did a simulated “Cooling Failure” test
- Monitored the VFAT temperatures for three hours
- First hour, cooling is on like normal
- Afterwards, cooling is turned off
- Narrow GEB gets hotter than the Wide GEB by nearly 3°C
- Most cooled VFATs end up the hottest
- Seems the cooling circuit now retains heat, rather than dissipating it
- VFATs only reach up to $\sim 40^{\circ}\text{C}$, would be more concerned about OH temperatures



- Using this method, saw that the VFAT's temperature sensor can have an error of $\pm 2.5^{\circ}\text{C}$
- With longer tests, reading out all VFAT temperatures show:
 - Touching cooling circuit: $29 - 30^{\circ}\text{C}$
 - Not touching the cooling circuit: $32 - 33^{\circ}\text{C}$
- When cooling is turned off, see the most cooled VFATs (Narrow GEB) become the hottest
- VFATs only reach up to $\sim 40^{\circ}\text{C}$, would be more concerned about the OH temperatures
- Few more tests are planned:
 - Plan to monitor VFAT temperatures on an irradiated chamber
 - Have a large X-Ray box to irradiate the whole chamber at once
 - View if there are changes in temperature when charge enters the VFAT channels
 - Plan to check this method again with a cooling bracket for the OH
 - Does not change these results since it would not change the VFAT cooling
 - Would change the calibration, since OHs would be cooler
 - Want to see if this method of calibration is viable for production modules installed in CMS
- We'd like to thank the DOE Office of Science – HEP and NSF MREFC program for their support of this work



References

- [1] The Phase-2 Upgrade of the CMS Muon Detectors.
Technical report, CERN, Geneva, 2017.
This is the final version, approved by the LHCC.

Backup