Analysis of the Radiation Monitoring System's Initial Data from the GEM Detectors at the CMS Experiment

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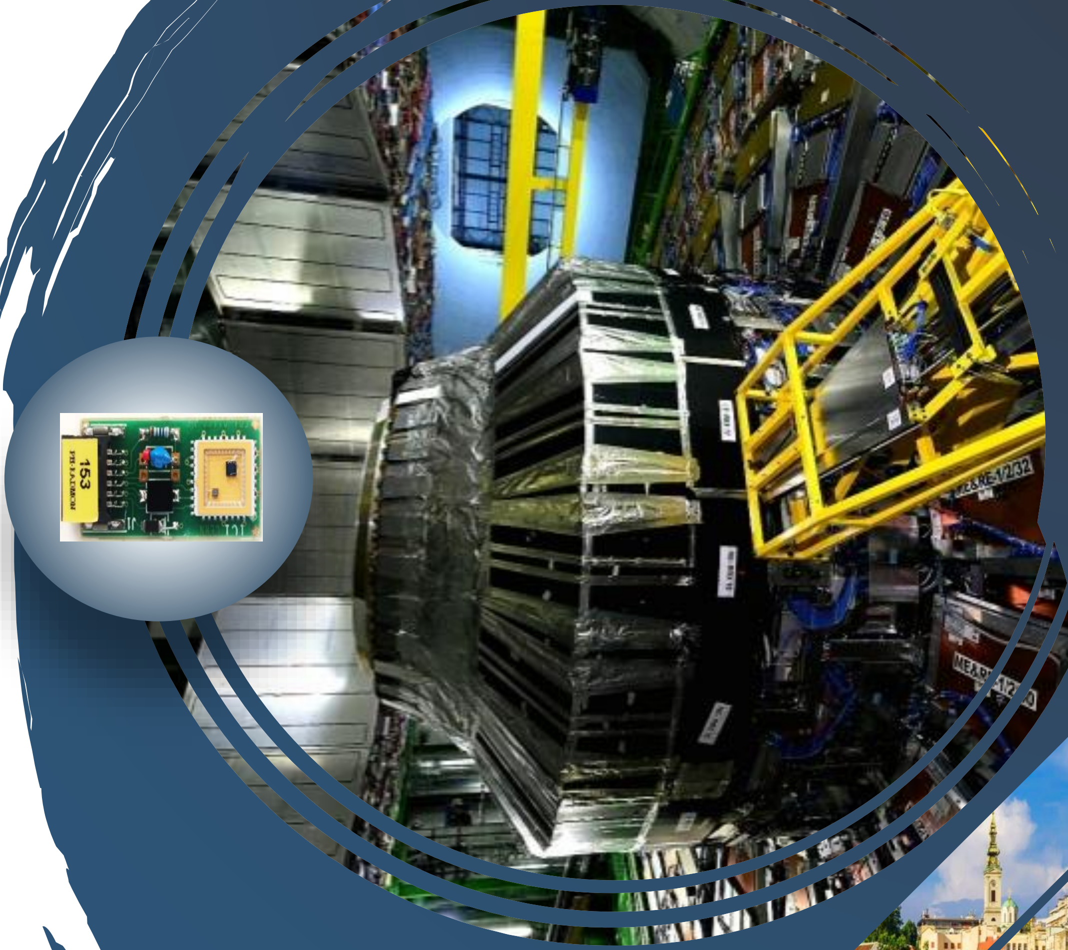

BPU11 CONGRESS

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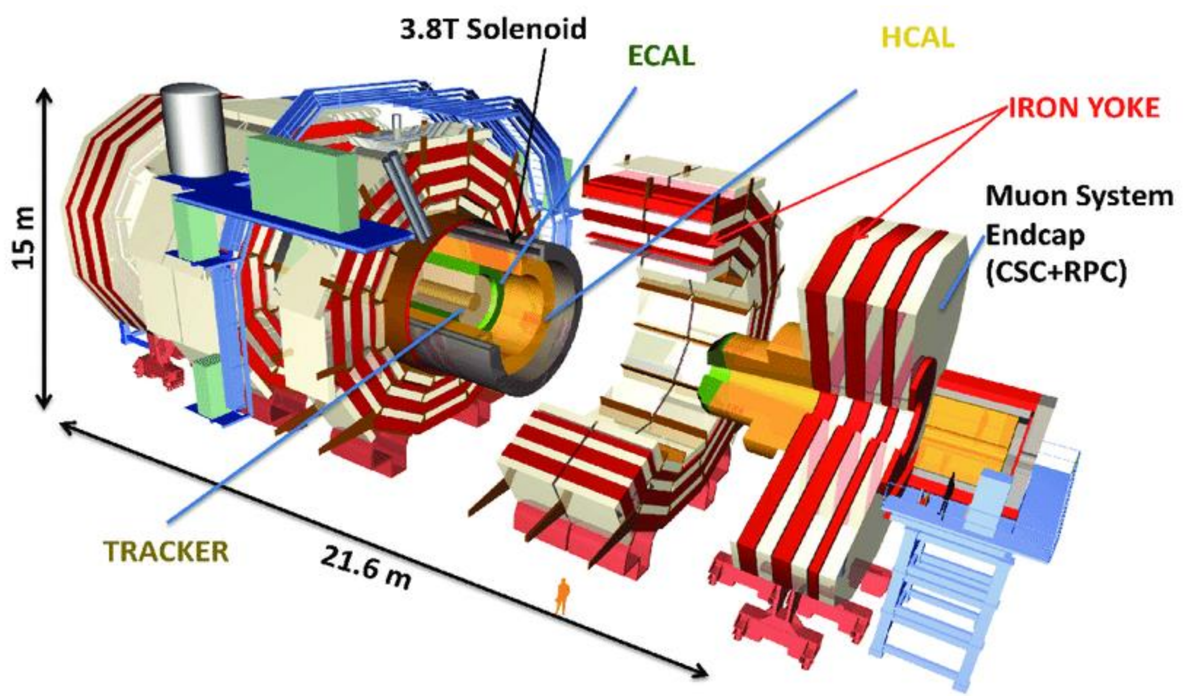
Outline

- Challenges
- GEM Detectors
- Radiation Monitoring System
  - System structure
  - Initial Data before RUN 3

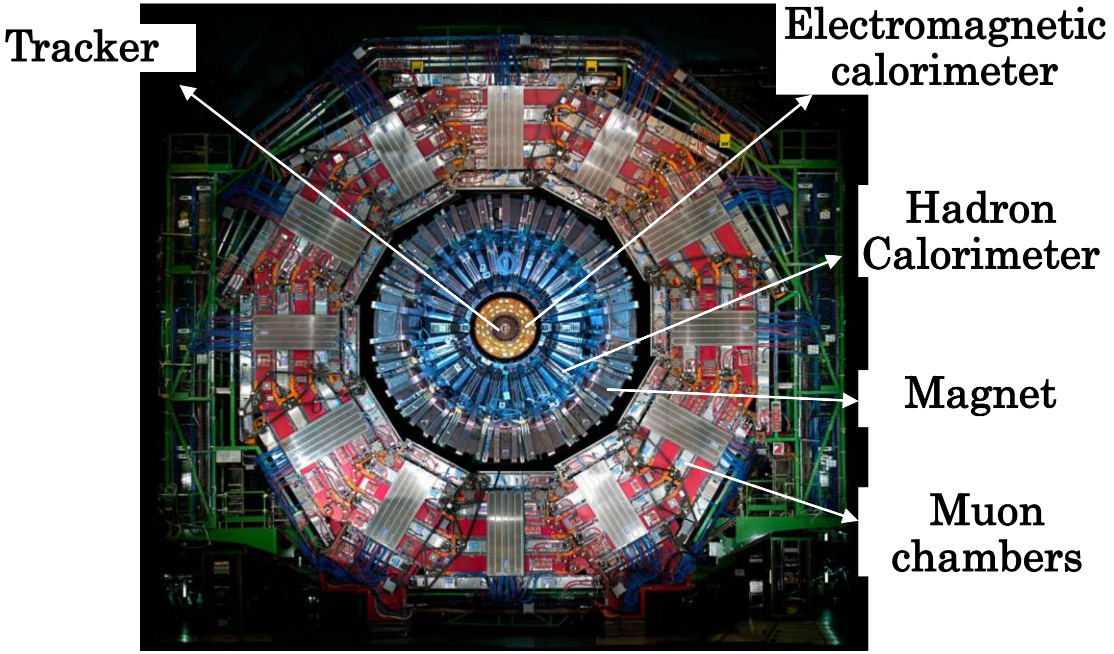
CMS Experiment

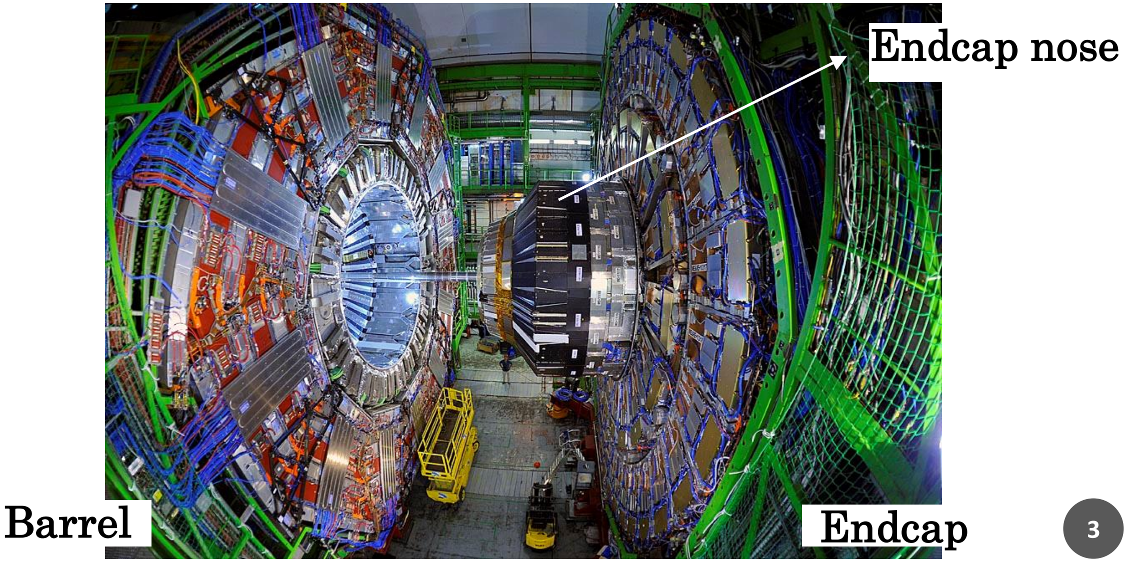
somewhere at the beginning of Long shutdown 2 (2019)



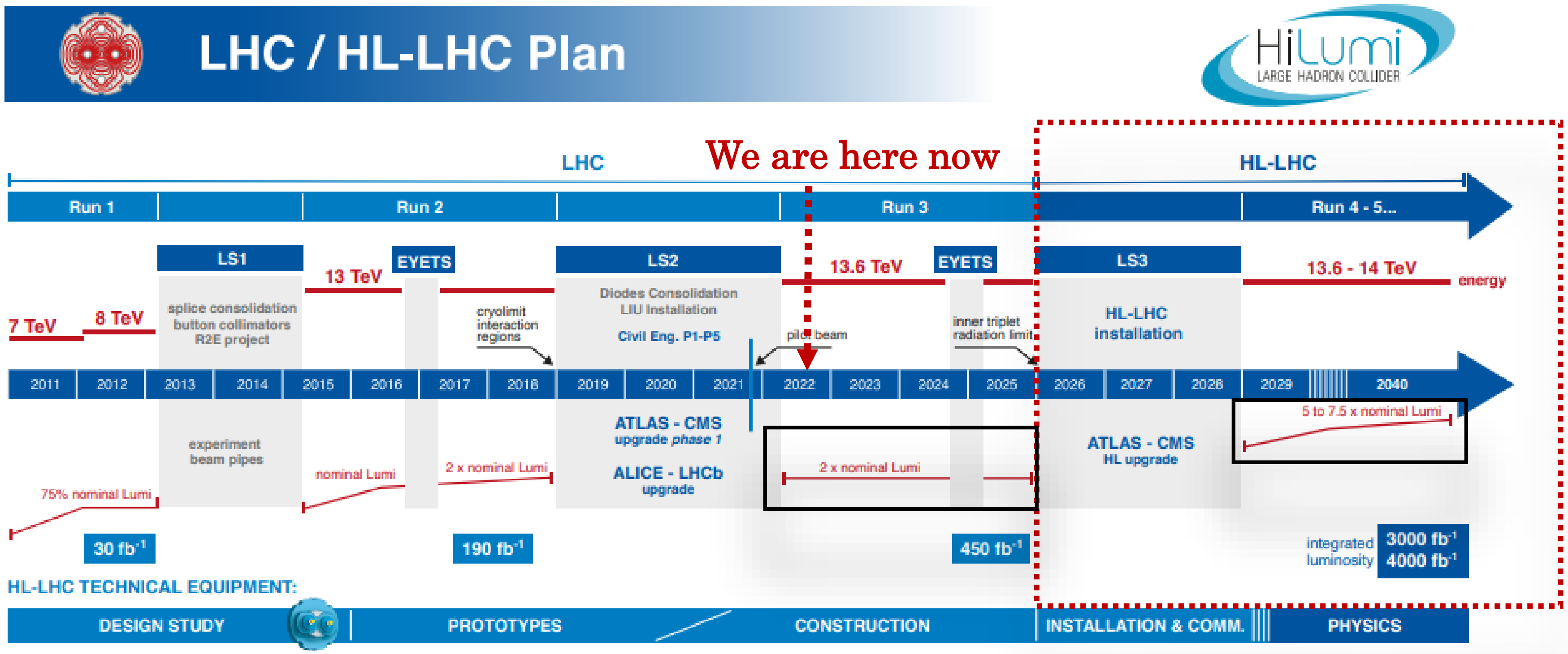
CMS Muon System – 3 detection technologies

✓ Drift tubes (DTs)
✓ Cathode Strip Chambers (CSCs)
✓ Resistive Plate Chambers (RPCs)





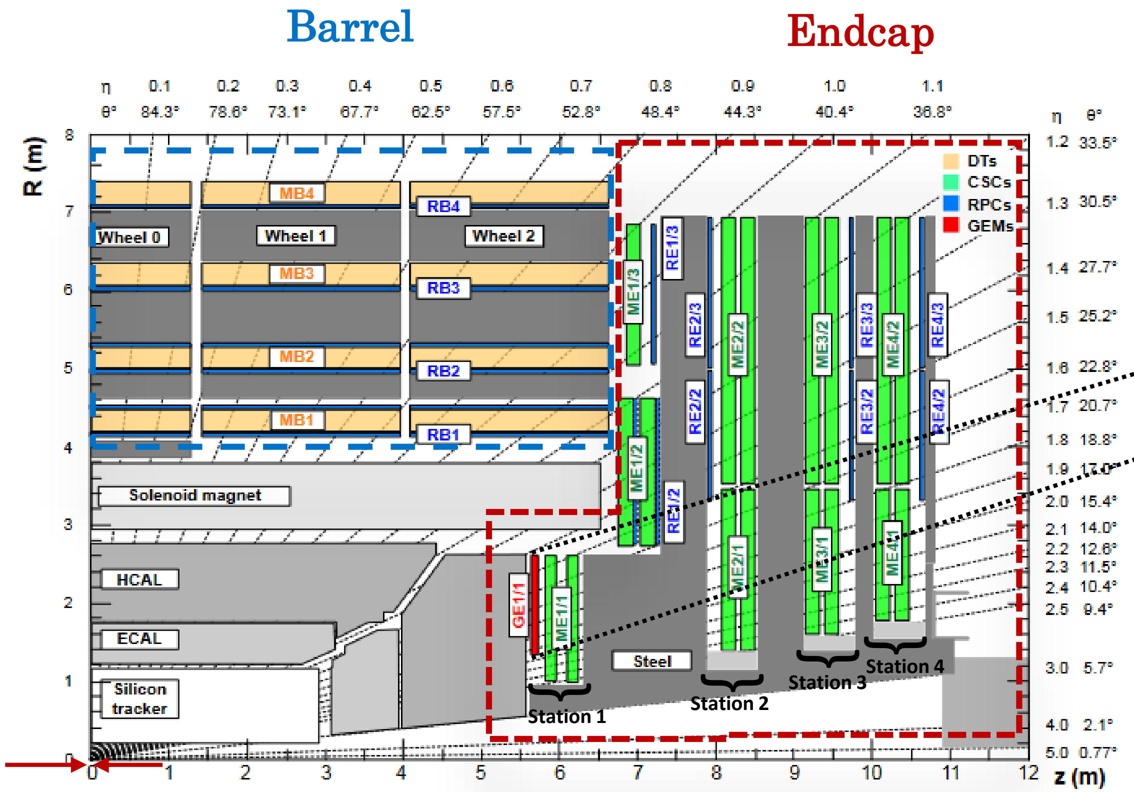
Challenges



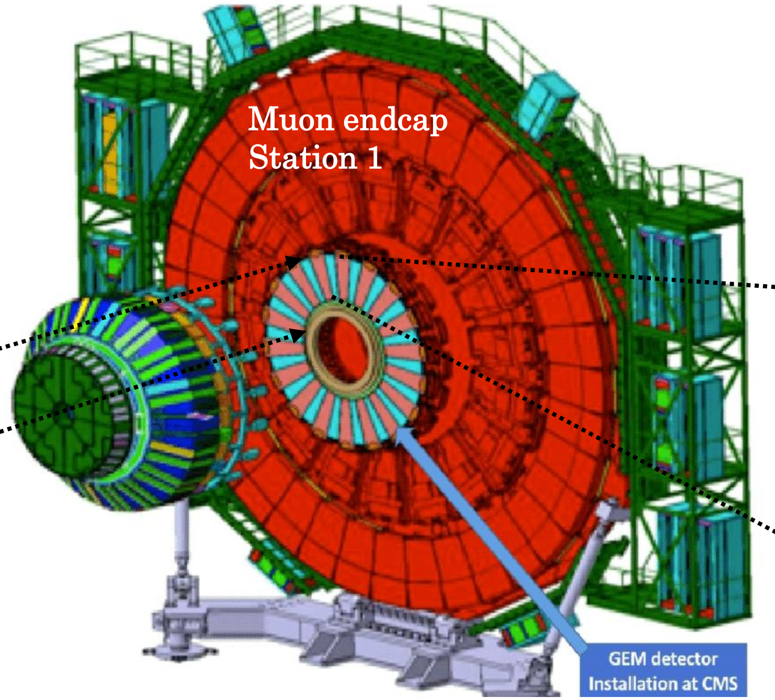
- LHC (RUN 3) – instantaneous luminosity close to $2x10^{34}$ $cm^{-2}s^{-1}$
- HL-LHC (RUN 4 ….) – instantaneous luminosity close to $(5\text{-}7.5)x10^{34}$ $cm^{-2}s^{-1}$
- HL-LHC background – 5 x rates and 6 x total doses with respect to LHC
  - Exceed the primary design tolerances of different components of the detectors - new assessment of the detectors electronics longevity, operation and performance

CMS Muon System goal – maintain excellent triggering, ID and measurement of muons during HL-LHC

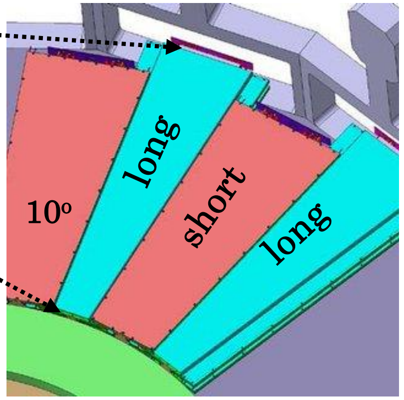
CMS Forward Muon System Upgrade – Phase I



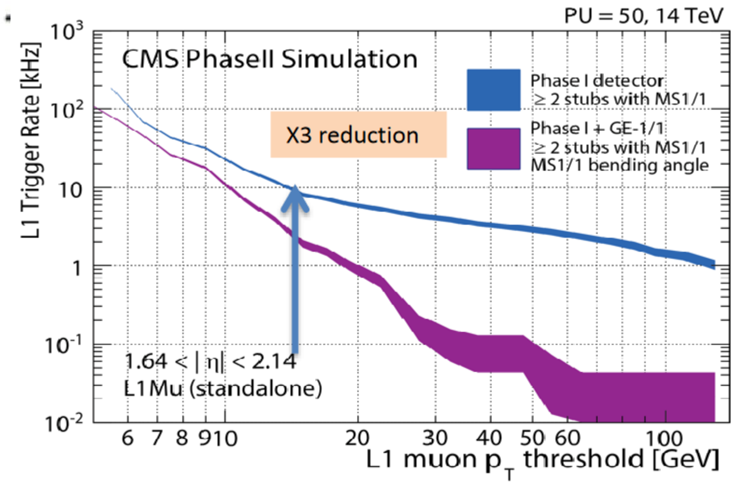
Interaction Point



18 short & 18 long super-chambers (SCs) per endcap



1 SC is made of 2 back to back trapezoidal-shaped triple-GEM detectors



CMS endcap muon detectors:

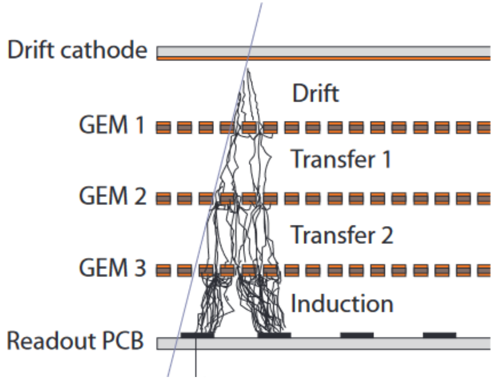
- CSC + RPC covering $0.9 < \eta < 1.6$
- Only CSC covering $1.6 < \eta < 2.4$
- **GE1/1 + CSC covering $1.55 < \eta < 2.18$**

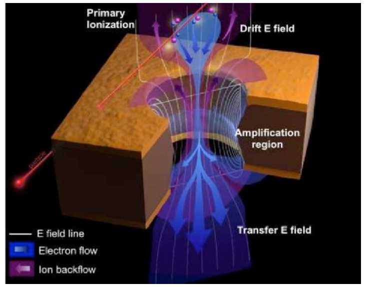
GE1/1 are new forward muon detectors to handle together with CSC at Station 1 with the most difficult region - high background trigger and readout rates, and limited bending

GE1/1 detectors

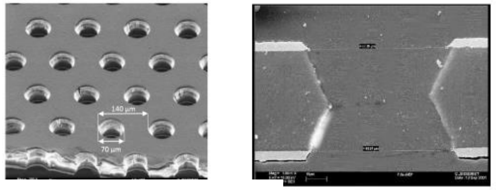
triple-GEM technology

- High rate capability, up to $\mathcal{O}(\text{MHz/cm}^2)$
- Efficiency > 97%
- Space (time) resolution ~ 300μm (8ns)
- Gas mixture Ar/CO_2 70/30

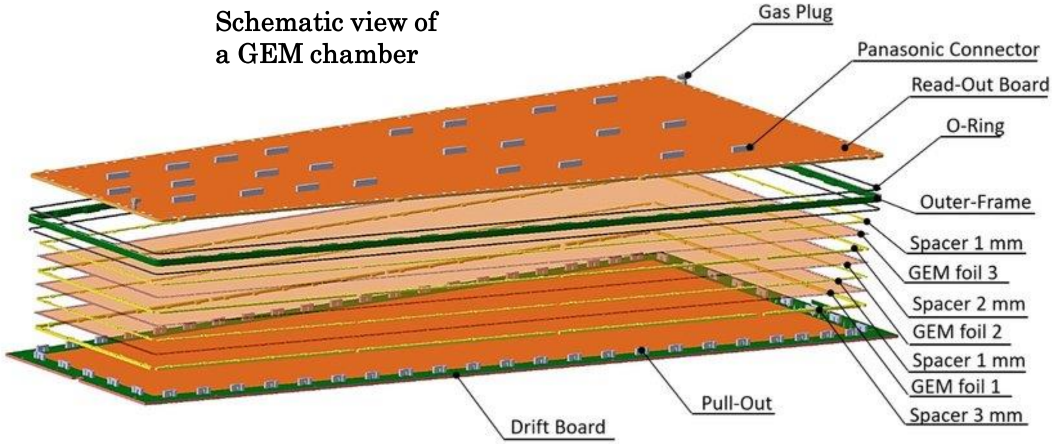




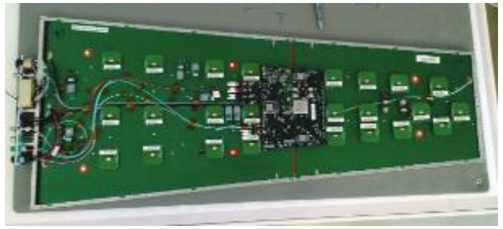
Microscope picture of a GEM foil



Schematic view of a GEM chamber



CMS Technical Design Report for the Muon Endcap GEM Upgrade



assembly of the FE electronics

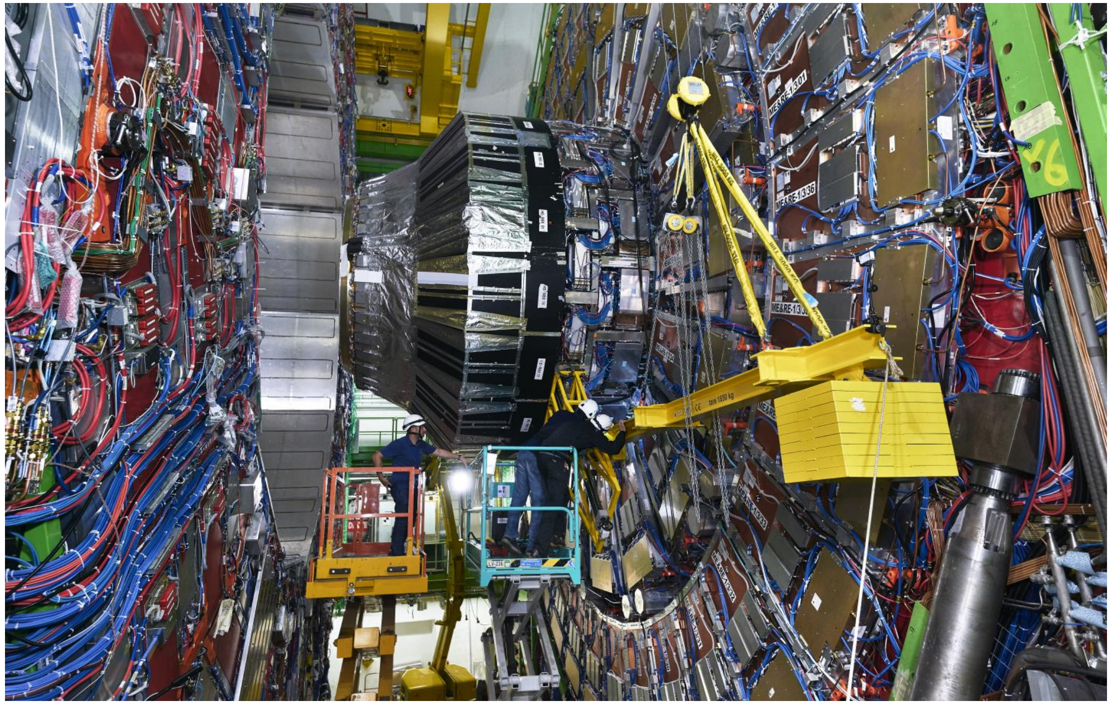
cooling circuit installation

metal enclosure cover attachment

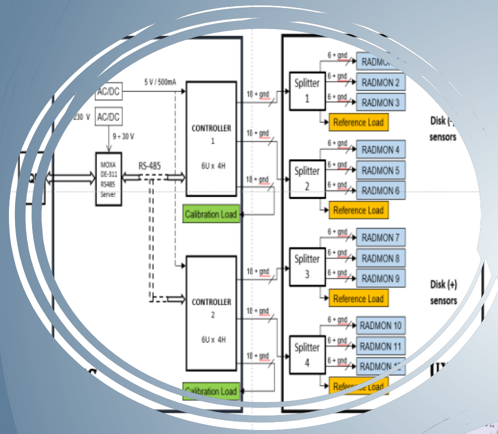
SC assembly

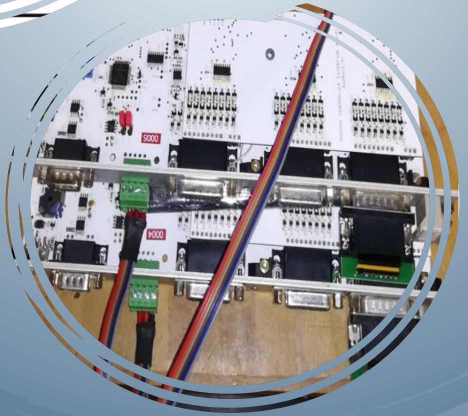
GE1/1 Installation

July-Oct 2019 → Negative endcap & July-Sept 2020 → Positive endcap



RADIATION MONITORING SYSTEM IN GEM DETECTORS

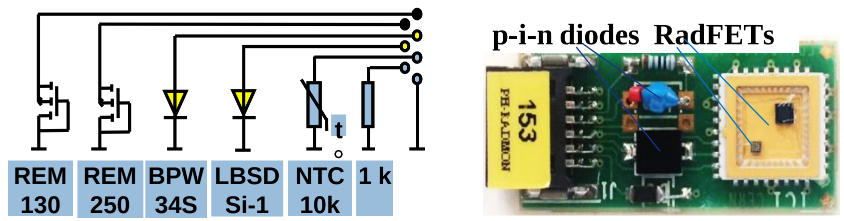




Radiation Monitoring System in GEM Detectors

A monitoring system, designed to measure the radiation dose and particle fluence around the GEM detectors, has been developed and installed in GE1/1 chambers.

The Radiation Monitoring (RadMon) System consists of 12 RadMon units with active radiation sensors.



Each RadMon unit contains:

→ RadFETs (Radiation sensitive Field Effective Transistors) – absorbed dose (REM250, REM130)
→ p-i-n diodes – 1 MeV neutron equivalent fluence (BPW34S, LBSD Si-1)
→ Thermistor
→ 1kΩ resistor

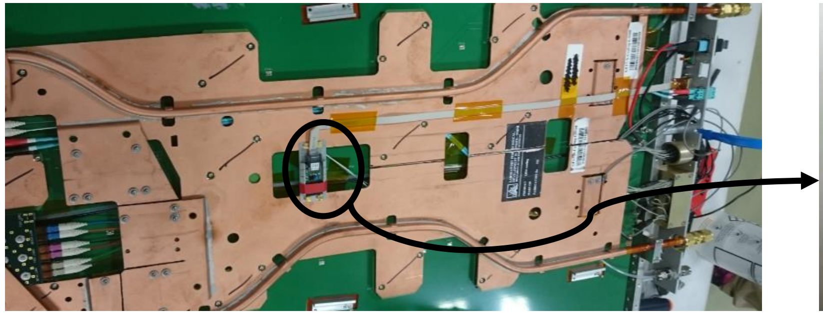
Function	Type	Device	Operating range	Sensitivity/ Resolution	I_{read}
Total Dose Sensor (high doses)	RadFET	REM 250	A few 10^{-1} Gy up to > $2x10^4$ Gy	20 mV/Gy (initial)	160 μA
Total Dose Sensor (very high doses)	RadFET	REM 130	A few Gy up to > $2x10^5$ Gy	3 mV/Gy (initial)	160 μA
1 MeV n eq. Fluence Sensor (high sensitivity)	p-i-n diode	LBSD Si-1	10^{10} cm^{-2} up to $2x10^{12}$ cm^{-2} (almost linear)	$2.1x10^8$ cm^{-2} /mV	10 mA
1 MeV n eq. Fluence Sensor (low sensitivity)	p-i-n diode	BPW34 S	$2x10^{12}$ cm^{-2} up to $4x10^{14}$ cm^{-2} (linear)	$1x10^{10}$ cm^{-2} /mV	1 mA
Temperature sensor	Thermisto r	NTC 10k	-55 °C up to 125 °C	0.1 °C	10 μA
Line checking	Resistor	1 k		1 %	160 μA

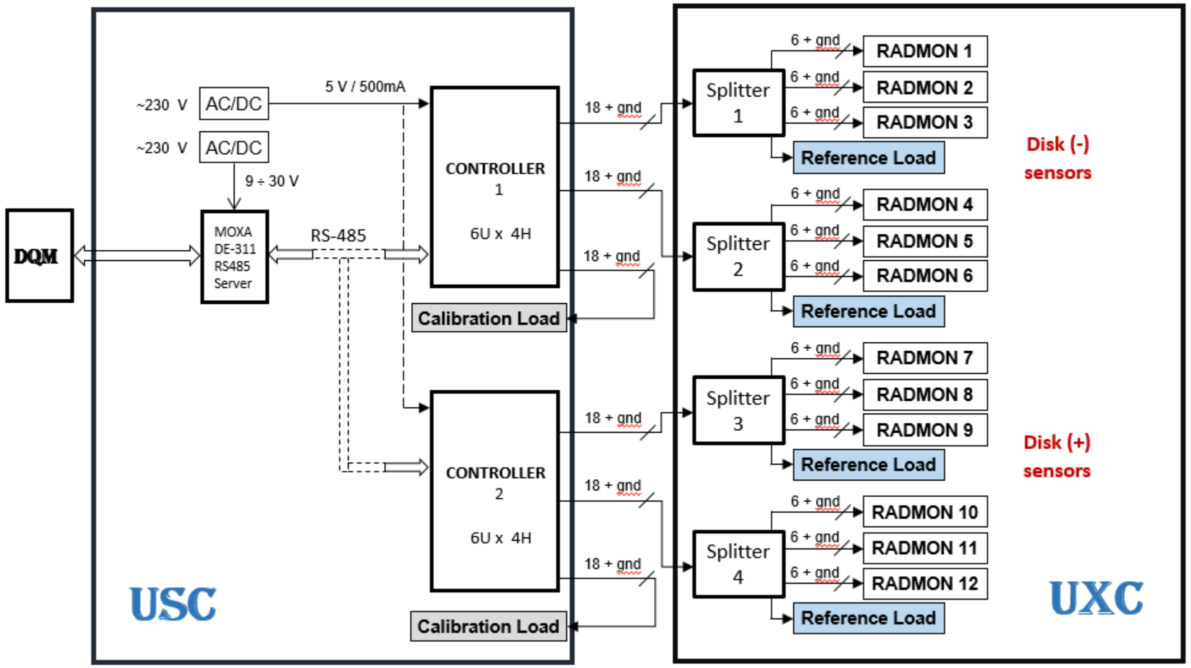
RadFETs and p-i-n diodes have several advantages:

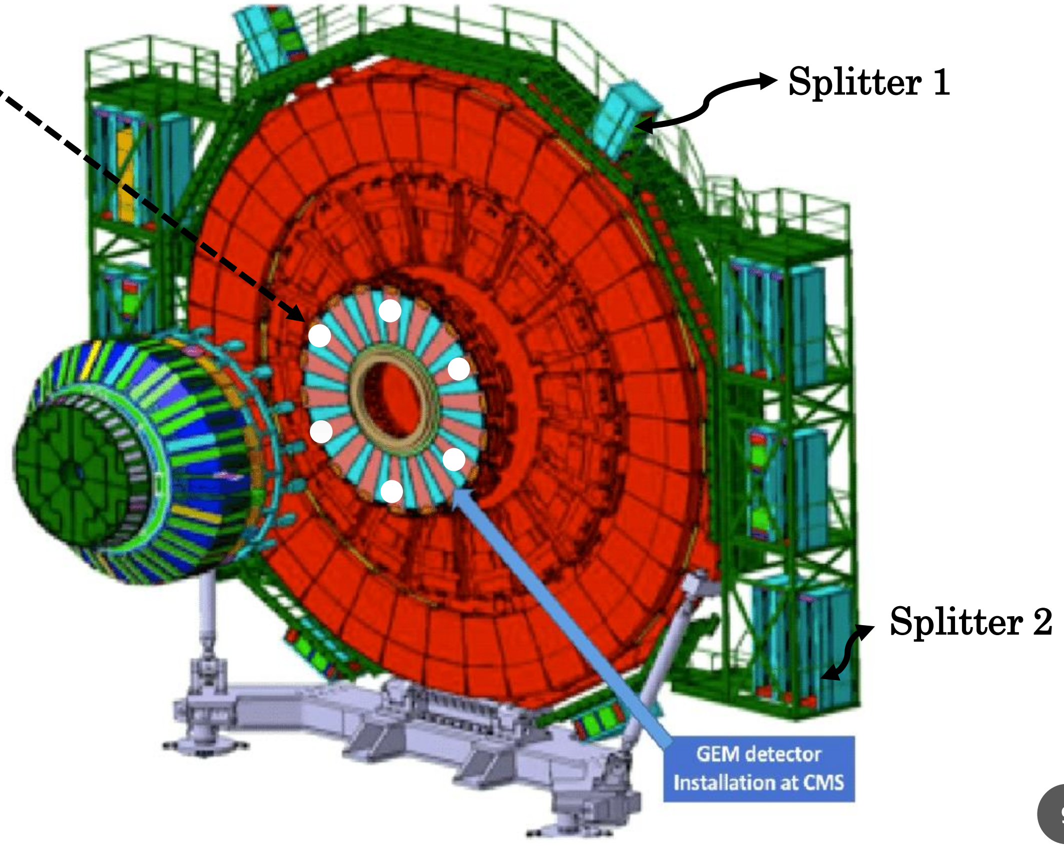
- ✓ Small detector sizes
- ✓ Immediate (online) readout
- ✓ Minimal power requirement

✓Every RadMon unit has been inserted in metal bracket fixed on the GE1/1 cooling module (long chambers, wide region)

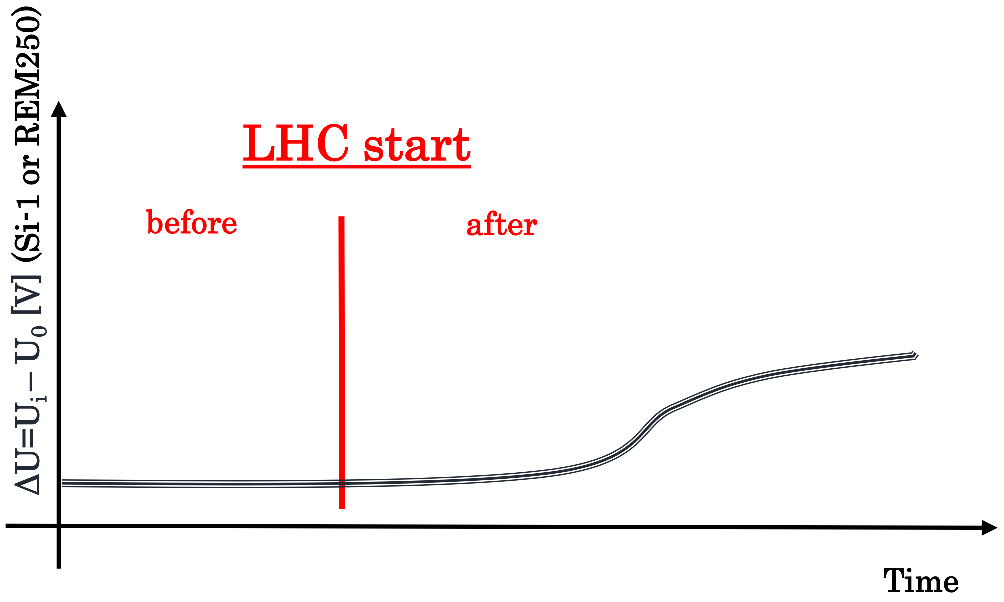
✓6 RadMon units with active radiation sensors are installed in 6 GE1/1 long detectors in each endcap (totally 12 sensors)







Dose and particle fluence measurement



$$\text{Fluence (Si}-1) = (3 \times 10^{11} \times \Delta U - 4 \times 10^{10}) \times 0.62, \;\; \Delta U < 4.1274$$

$$\text{Fluence (Si}-1) = (7 \times 10^{10} \times (\Delta U)^{1.9754}) \times 0.62, \;\; \Delta U > 4.1274$$

$$\text{Dose (REM250)} = \left(\frac{U_i - U_0}{A}\right)^{1/B}, \;\; \text{A \& B are known coefficients}$$

Irradiation with high energetic hadrons can provoke accumulation of local defects in the RadFETs/p-i-n diodes.

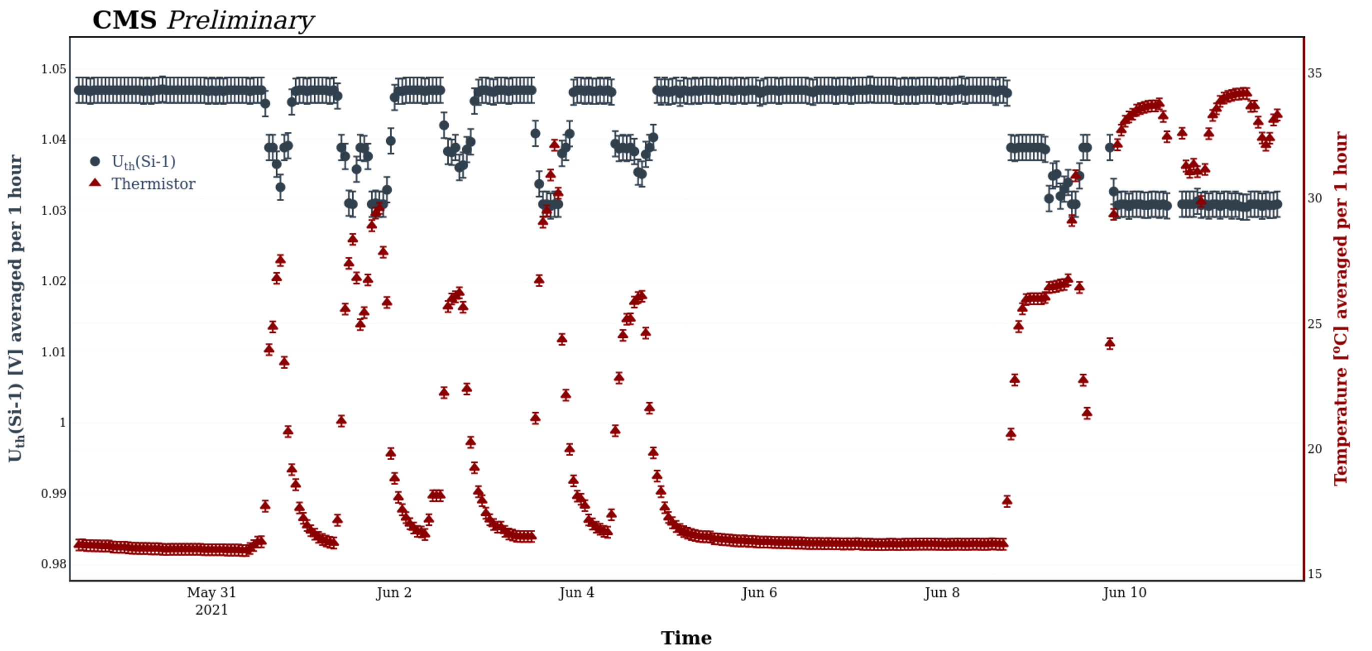
The voltage drop across all radiation sensors is proportional to the measured radiation/particle fluence magnitude.

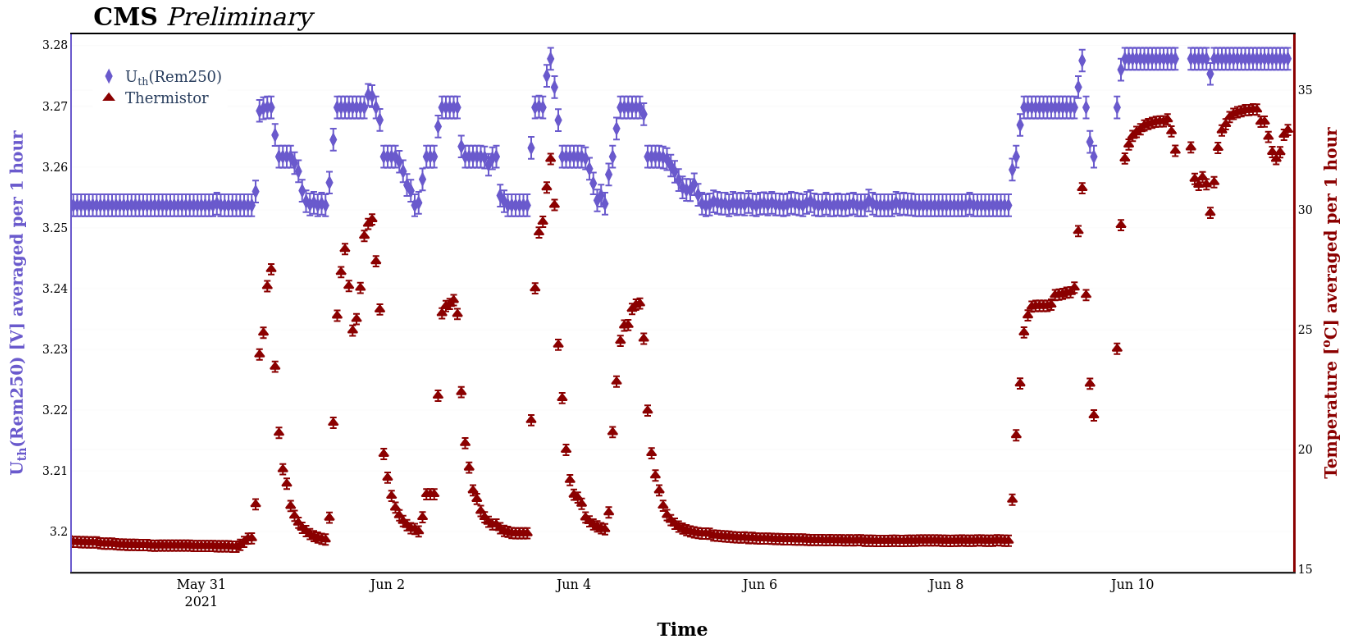
For the RadFETs the relation between the gate threshold voltage shift ΔV_{th} and the radiation dose D can be best approximated by $\Delta V_{th} = A \times D^B$, (resp. $D = (\Delta V_{th}/A)^{1/B}$) . The coefficients A and B depend on the RadFET type as well as on the measured dose range.

The shift of the p-i-n diodes forward voltage ΔV_F is proportional to the 1 MeV neutron equivalent fluence Φ [cm^{-2}]. The relation is generally linear – $\Phi = c\Delta V_F$, where c depends of the diode type.

Temperature Dependence

The plots contain the averaged data per hour for the LBSD Si-1/RadFET (Rem250) and thermistor data which are integrated in RadMon 3 unit installed in the bottom sector of the CMS Negative endcap.

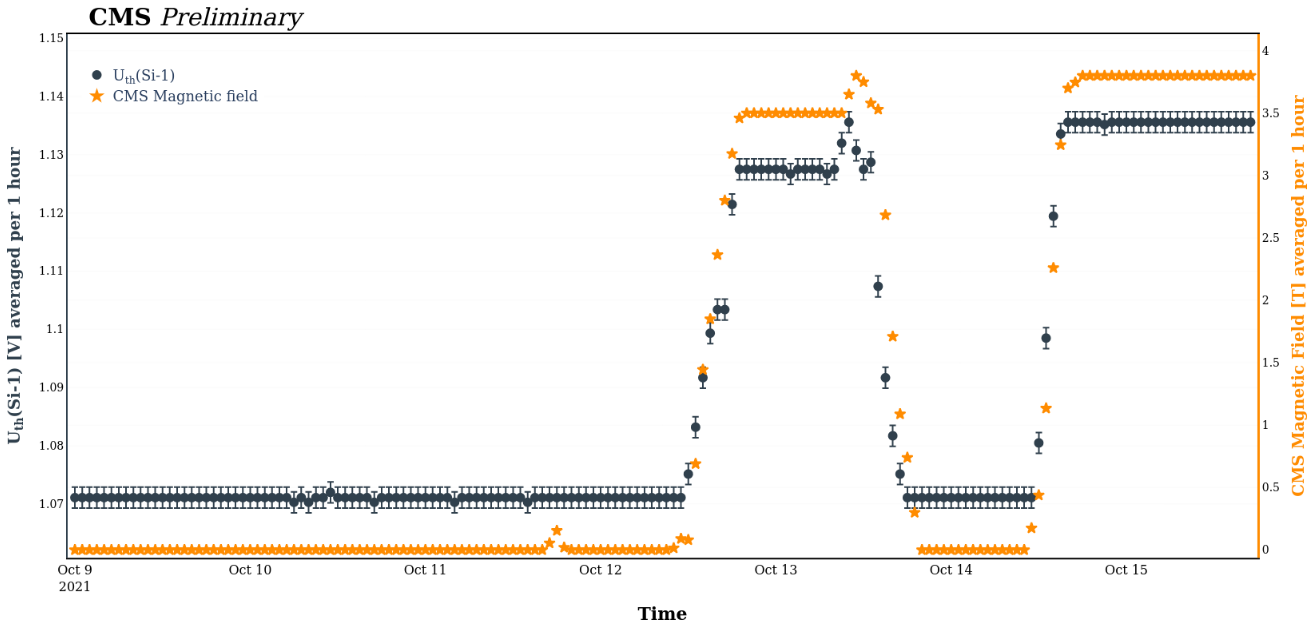


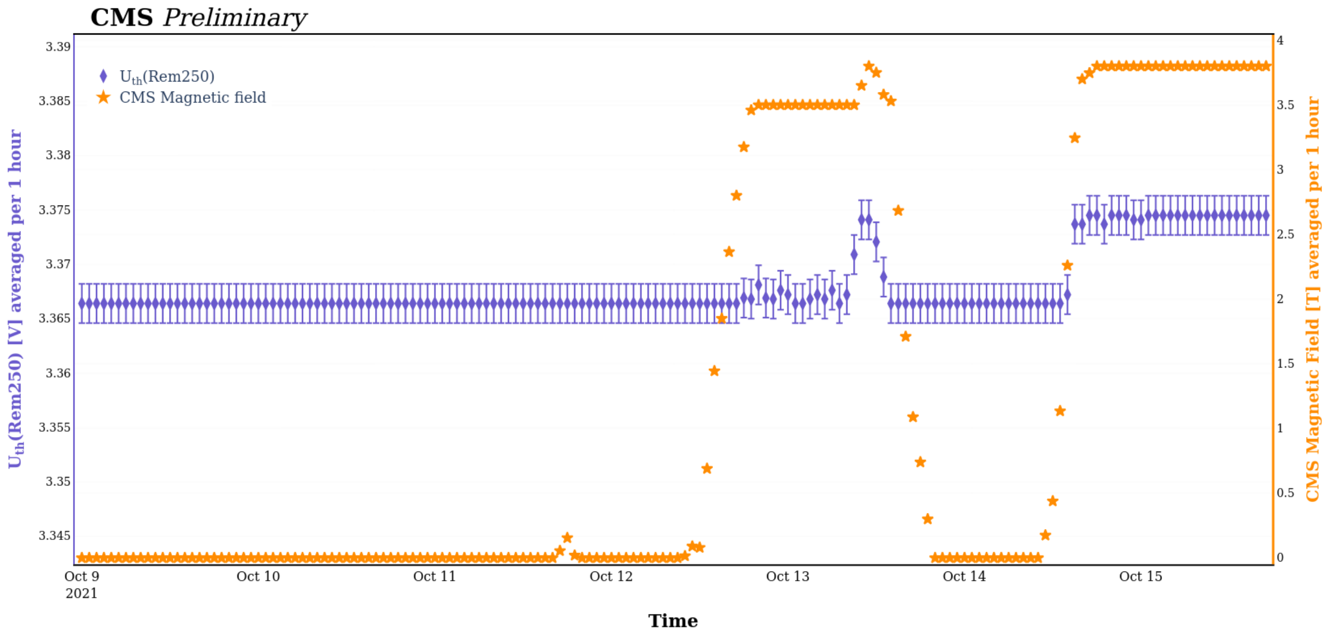


- The uncertainty of threshold voltage of sensors is ±0.0018V considering both the precision of the ADC in the controllers and data averaging
- The uncertainty of thermistor measurements is estimated to be ±0.22°C
- No presence of magnetic field

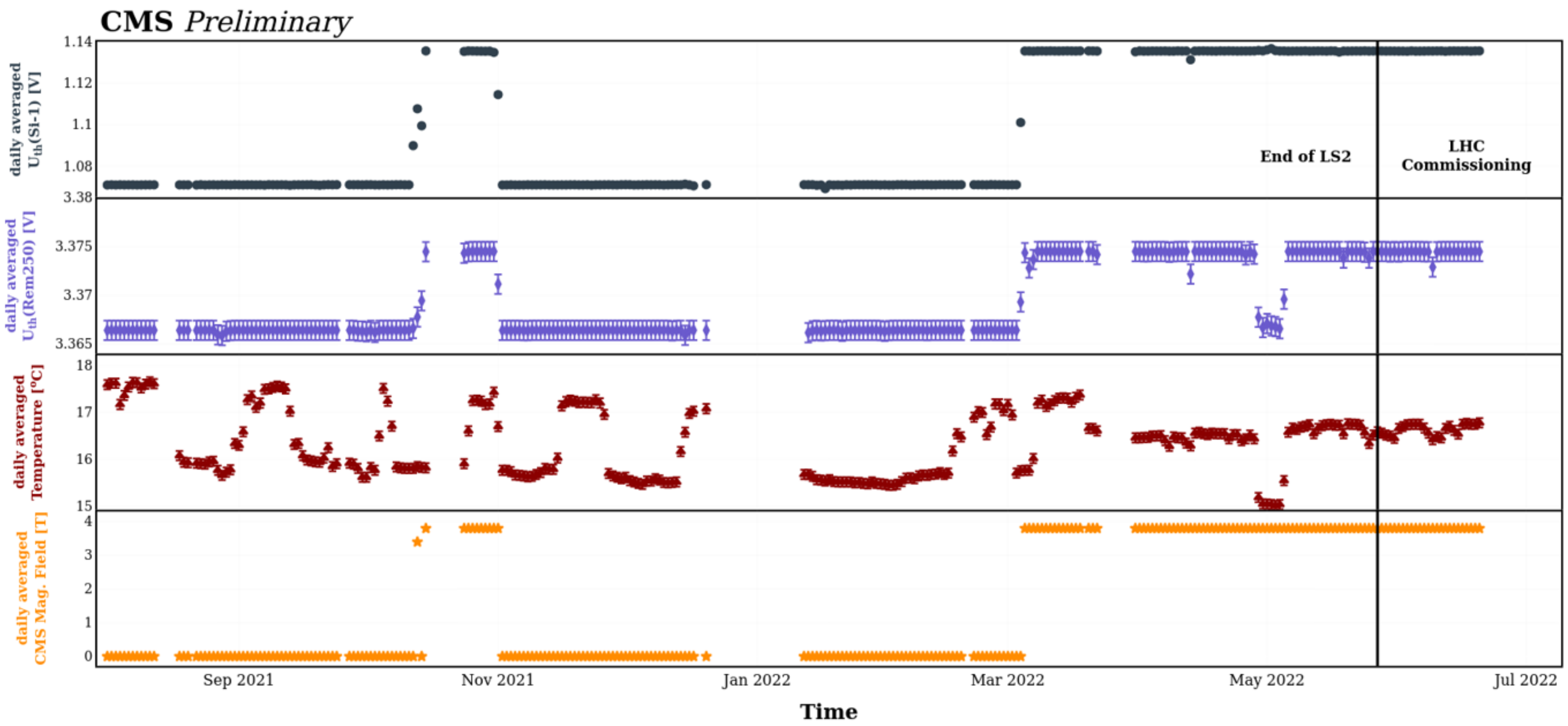
Dependence on the CMS Magnetic Field

The plots contain the averaged data per hour for the LBSD Si-1/RadFET (Rem250) and the CMS Magnetic field during one week from the "warming up period of the CMS Magnet" performed in October 2021.





- The uncertainty of threshold voltage of sensors is ±0.0018V considering both the precision of the ADC in the controllers and data averaging
- The temperature during the presented period fluctuated within 0.3°C
- The p-i-n diode and RadFET are integrated in RadMon 6 unit installed in the top sector of the CMS Negative endcap.



- Daily average threshold voltage values for the p-i-n diode (Si-1) and RadFET (Rem250) active sensors in relation to the temperature and the CMS magnetic field during the last ten months of LS2 (Aug 1 2021 until May 26 2022 inclusively) and the beginning of the LHC Commissioning period (27^{th} May 2022 until 20^{th} June 2022)
- The uncertainty of threshold voltage of radiation sensors is evaluated to be ±0.0004V due to data averaging and precision of the ADC integrated in the controllers while the uncertainty of thermistor measurements is estimated to be ±0.1°C.
- The increase of forward U_{th}(Si-1) at given forward current in magnetic field observed in p-i-n diodes can be attributed to magneto-resistance as well as to the increased charged carrier recombination [1]. The observed change of U_{th}(REM250) in magnetic field is due to similar effects as in p-i-n diodes.

[1] *I. Mandic´, F. Ravotti, Member, IEEE, M. Glaser, I. Serˇsa, J. Hartert, S. Franz, V. Cindro, I. Dolenc, A. Gorisek, G. Kramberger, and M. Mikuz, "The Effect of Magnetic Field on Readout of Diodes Used as NIEL Counters ", IEEE Transactions on Nuclear Science (Volume: 58, Issue: 3, June 2011)*

Conclusion

- The threshold voltage values of the active radiation sensors are well determined before the start of LHC RUN3:
  - Calibration (offset) of the voltage threshold for each sensor has been determined at the CMS magnetic field
  - Temperature correction is required to achieve lowest possible uncertainty

- The radiation monitoring system of GEM is fully tested to measure the total dose and neutron flux in the area of the GE1/1 chambers installed at Station1 in the region of the endcaps.

Acknowledgements

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THANK YOU