JOINT INSTITUTE FOR NUCLEAR RESEARCH

Session-Conference of the Nuclear Physics Section of the Physical Sciences Division of the Russian Academy of Sciences «Physics of Fundamental Interactions»

Longevity studies of the CMS cathode strip chamber with GIF++ facility

D. Kozlov on behalf of CMS Muon group

March 10-13, 2026
Novosibirsk, Russia

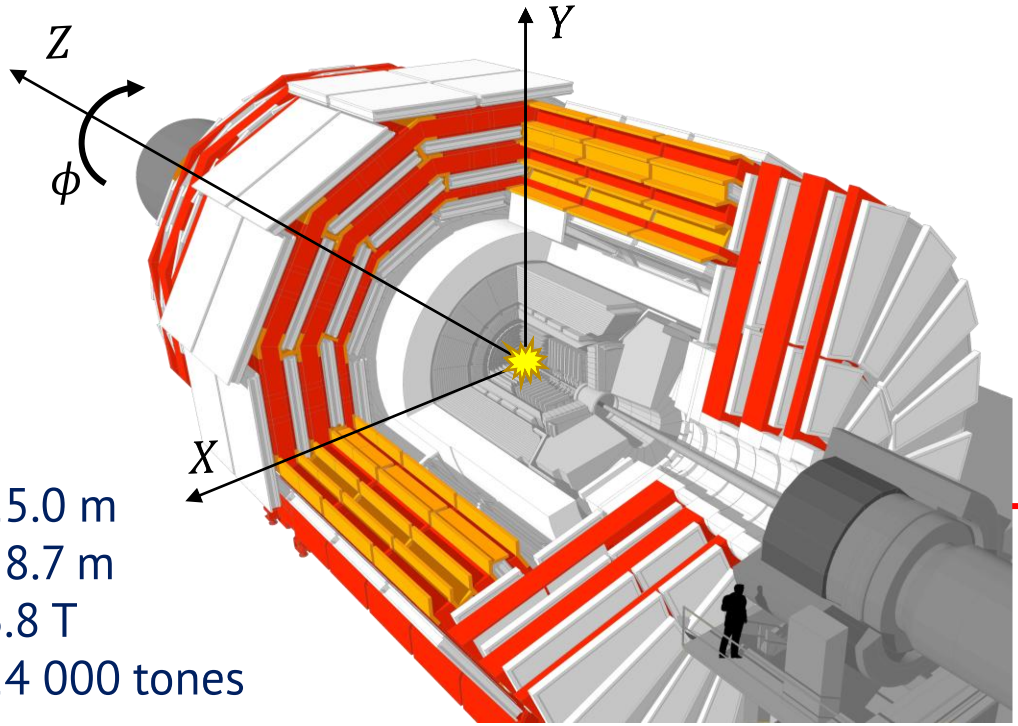
Outline

- CMS detector
- Cathode strip chamber as part of the muon system
- Extreme conditions of High Luminosity LHC
- Aging study of CSC
- GIF++ facility
- Study of gas gain stability
- Conclusions

CMS detector

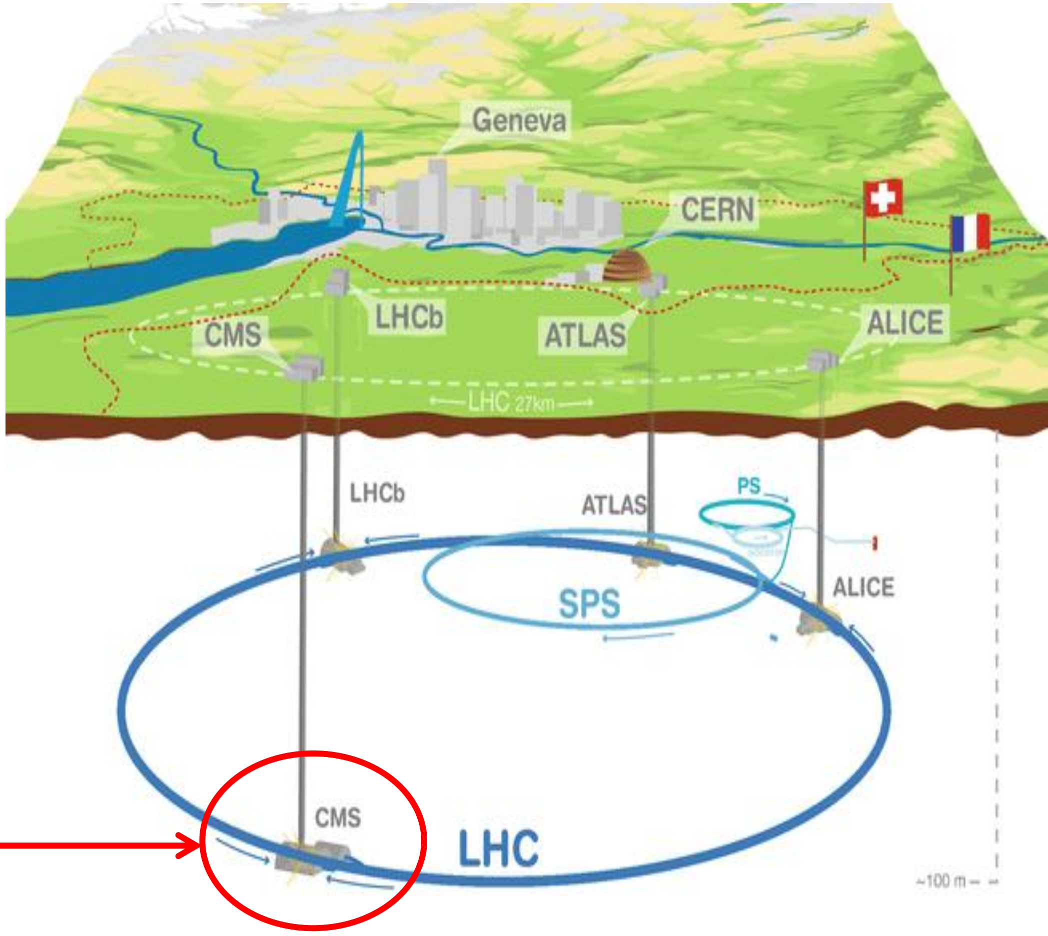
The Compact Muon Solenoid (**CMS**)[1] is one of two general-purpose experiments at CERN's Large Hadron Collider (LHC). The CMS physics program includes studying the properties of the Higgs boson, precision testing of the Standard Model (SM) conclusions, and searching for evidence of new physics beyond the SM.

Composed of the inner Si tracker, Magnet, ECAL, HCAL and **Muon system**.



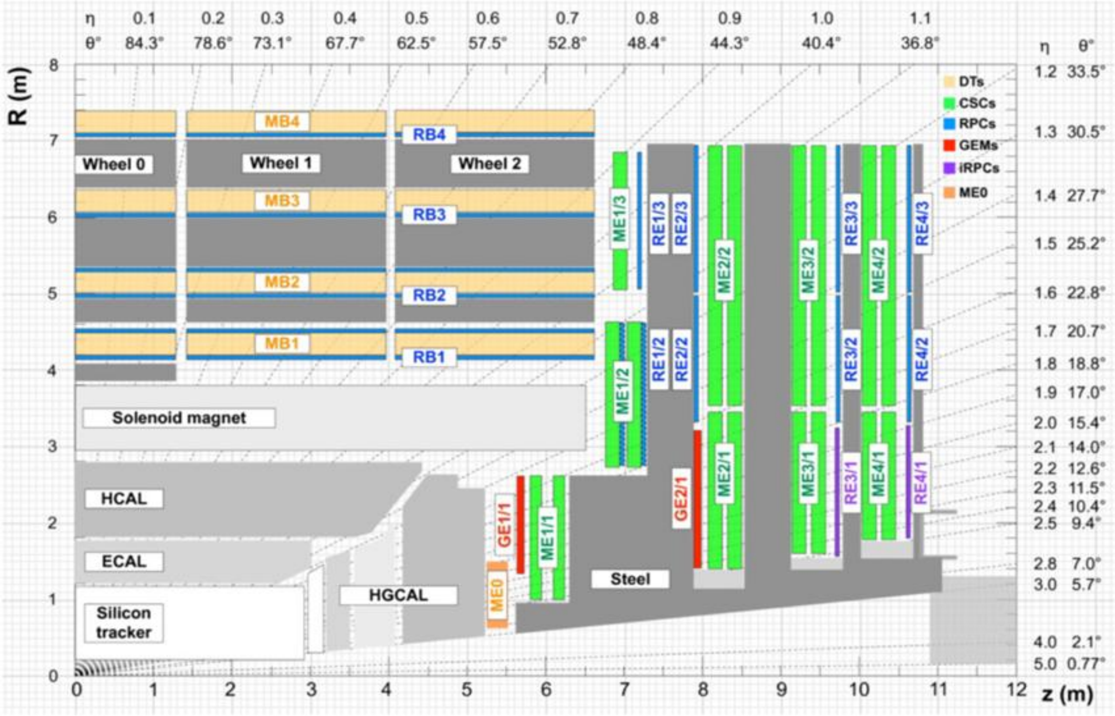
Overall diameter: 15.0 m
Overall length: 28.7 m
Magnetic field: 3.8 T
Total weight: 14 000 tones

Overall view of the Large Hadron Collider



CSC as part of the muon system

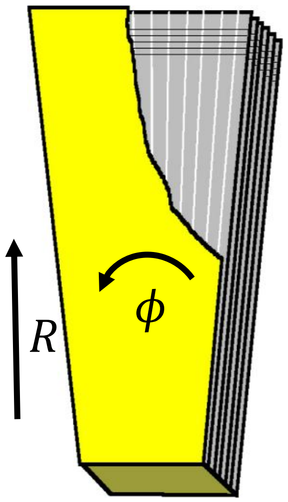
CMS detector quadrant



Muon system employ 4 technologies: Drift Tubes, Resistive Plate Chambers, Gas Electron Multipliers, Cathode Strip Chambers (CSC). The system provides muon identification, momentum measurement and matching with inner Tracker.

CSC are one of the key muon detector in the endcaps contributing to muon trigger and tracking.

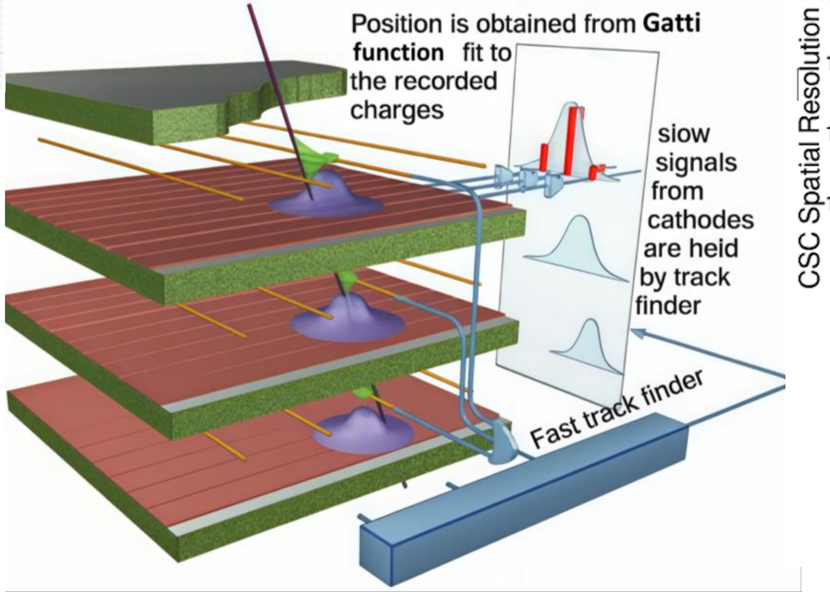
CSC form 4 muon stations in each Endcap (marked green). The stations, in turn, consist of rings of 36 or 18 trapezoidal CSCs named MEx/y, where x stands for station number and y for ring number.

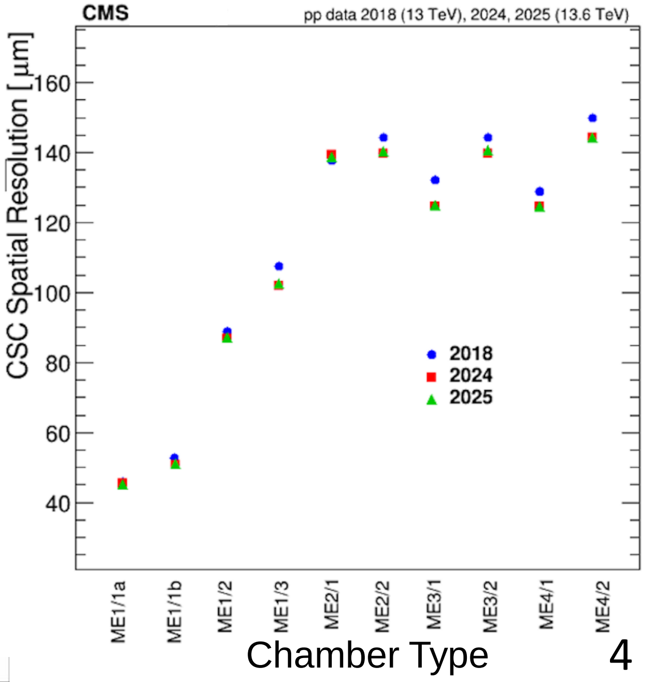


A CSC consists of 6 layers and operates as a standard multi-wire proportional chamber (MWPC) with cathode strip readout. Gas mixture 40%Ar + 50%CO_2 + 10%CF_4.

CSC muon system operation:

- Spatial resolution[2] 45 - 150 μm
- Timing resolution ~ 3 ns
- Pseudorapidity range 0.9 < |η| < 2.4





Extreme conditions of High Luminosity LHC

Changes in conditions

	LHC CMS Fase1	HL-LHC CMS Fase2
Instant. luminosity ($cm^{-2}s^{-1}$)	10^{34}	**(5-7.5) x 10^{34}**
Integrated luminosity (fb^{-1})	300	**3000 (4000)**
Pileup	30	**140 (200)**
Trigger frequency (kHz)	100	**750**
Trigger delay (µs)	3.6	**12.4**

The HL-LHC will deliver a significant increase in luminosity, leading to:

- Higher pileup and trigger rates.
- Increased background rates.

These extreme conditions can accelerate aging effects in detector materials and gas mixtures.
To ensure stable and reliable operation of the CSC throughout the HL-LHC era by thoroughly investigating radiation hardness.

Aging study of CSC

Aging represents a critical challenge, driven by the high luminosity of modern accelerators and the resulting intense ionizing radiation.

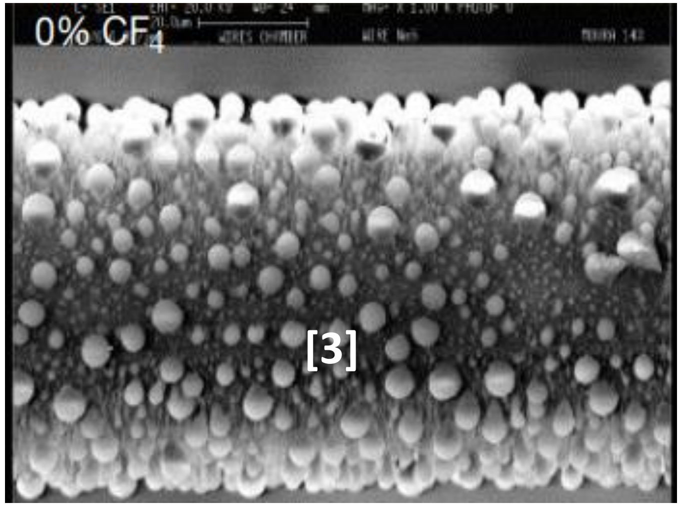
Due to avalanche nature of the CSC gas amplification, formation of chemically active ions or radicals may occur in the CSC gas volume and lead to modification of the electrode surfaces due to, for example, polymer deposit.

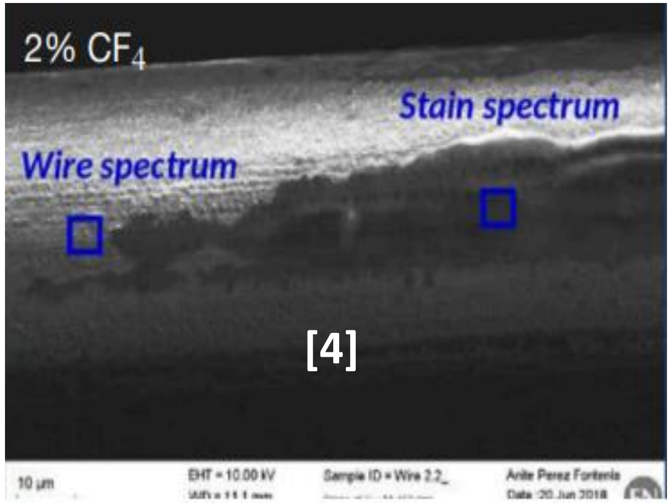
Consequences: These deposits may lead to a variety of operational issues:

- High-voltage instability and the onset of discharges (sparking).
- Dark current increase.
- A significant drop in the gas gain.
- Deterioration of the spatial resolution.

EU F-gas regulation phases down high-GWP gases (like CF_4, GWP~7000) to 1/5 of 2014 sales by 2030 → unstable availability + rising costs.

One of the most crucial type of aging is formation of Si-containing deposits on the anode wires, which leads to increase of the anode wire diameter and so decrease of the gas gain.





Use of CF_4 prevents Si deposits on wires by forming gaseous SiF_4 ($4F\bullet + Si = SiF_4\uparrow$).

Early tests[3] with ^{90}Sr source showed 2x gain drop at 0.25 C/cm without CF_4 (30% Ar + 70% CO_2) due to Si deposits.

Another group showed that if the fluorine content in the gas mixture is below 5%, the carbon deposits appears on anode wires at accumulated charge of 300 mC/cm [4].

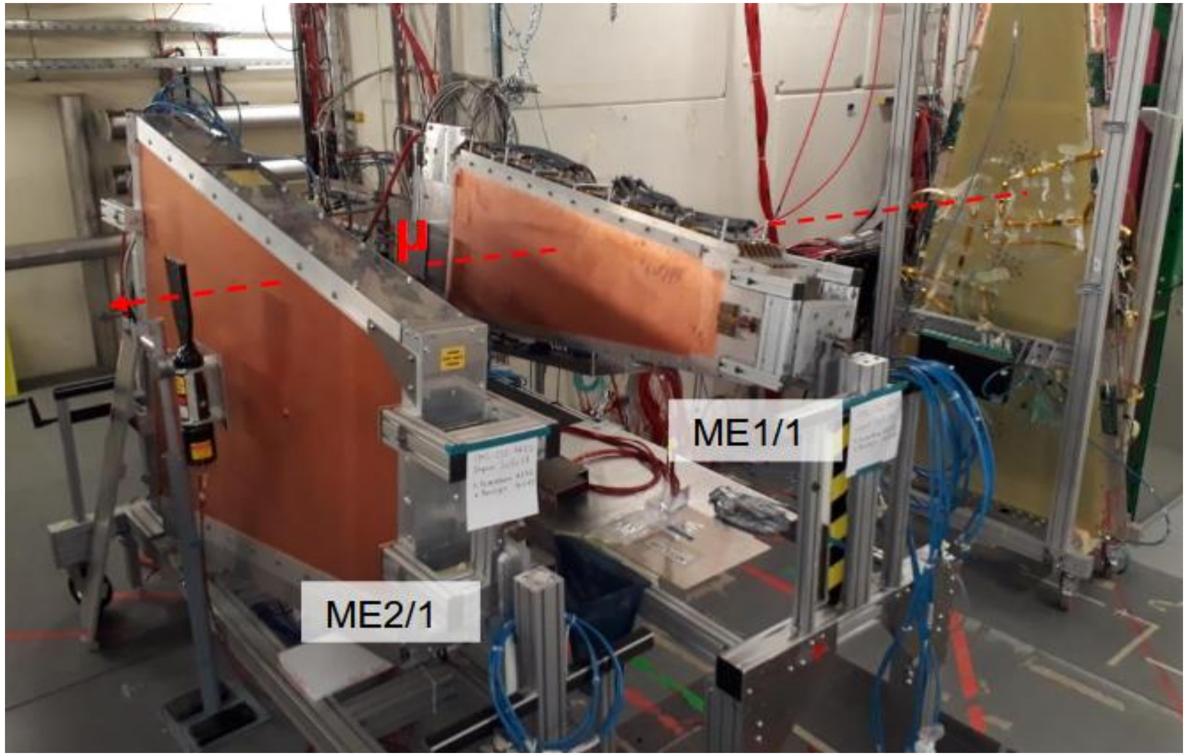
Gas gain monitoring is one of key measurements during longevity test.

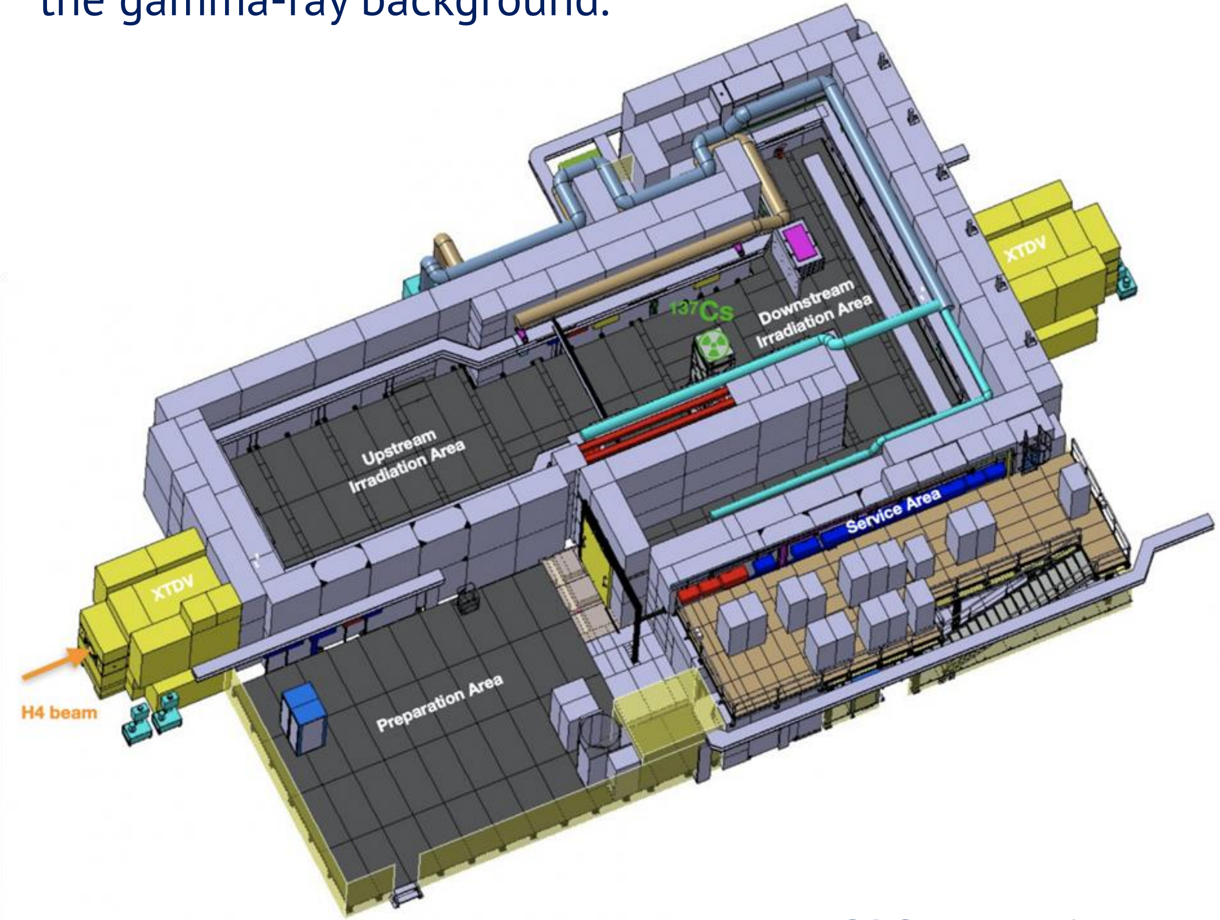
Gamma Irradiation Facility (CERN)

Irradiation test with two CSCs of ME1/1 and ME2/1 types is started in 2016 to study the CSC longevity in HL-LHC conditions[5]. These chambers, designed differently, are situated in the CMS forward region, where they operate under high background rates.

The longevity studies are done at the Gamma Irradiation Facility (GIF++)[6] at CERN with the nominal CSC gas mixture and with mixture containing reduced CF_4 fractions[5].

GIF++ allows to irradiate detectors with an intense ^{137}Cs gamma-radiation source, and to perform unique measurements with the muon test beam with or without the gamma-ray background.





H4 SPS beam line

14 TBq (2015) ^{137}Cs source (E_γ = 662 keV)

Study of gas gain stability

In this analysis, we study CSC gas gain stability as a function of the accumulated charge at the GIF++ facility. The accumulated charge per unit length is defined as the time integral of the layer HV current divided by the total wire length in the layer.

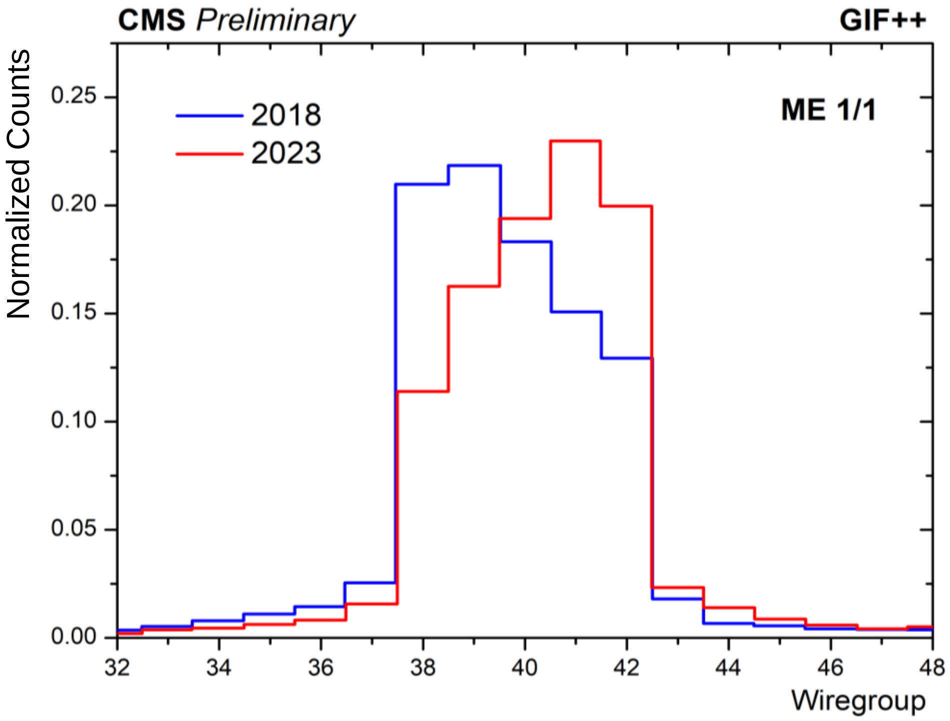
CSCs accumulated charge in different periods of irradiation at GIF++

CSC	Accumulated charge Q (mC/cm)				
	before 2018 (10% CF_4)	November 2021 (2% CF_4)	November 2025 (5% CF_4)	**Total**	**Expected at HL-LHC (3000 fb^{-1})**
ME1/1	330	370	450	**1150**	**400**
ME2/1	310	Not irradiated	710	**1020**	**220**
Period	I	II	III (ongoing)		

Overview of Measurements (2016–2025)

- Irradiation was performed continuously, with measurements carried out during dedicated muon test beam periods
- During irradiation, two out of six layers were kept switched off to serve as a non-irradiated reference
- 3 different gas mixtures with varying CF_4 content were used over the 10-year period
- Gas mixture changes were motivated by laboratory studies aimed at reducing CF_4 content for HL-LHC operation

The measurements with muon test beams were performed without ^{137}Cs background, using a coincidence of scintillator signals to trigger the CSC readout. The scintillator position was aligned to select the same CSC area of 15×15 cm^2 for every measurement. The plot shows the ME1/1 wire group occupancy in the muon beam for different test beam periods. The plot demonstrate reproducibility of the acceptance along anode wires and illustrates the variation in beam profile, which introduces systematic uncertainty.



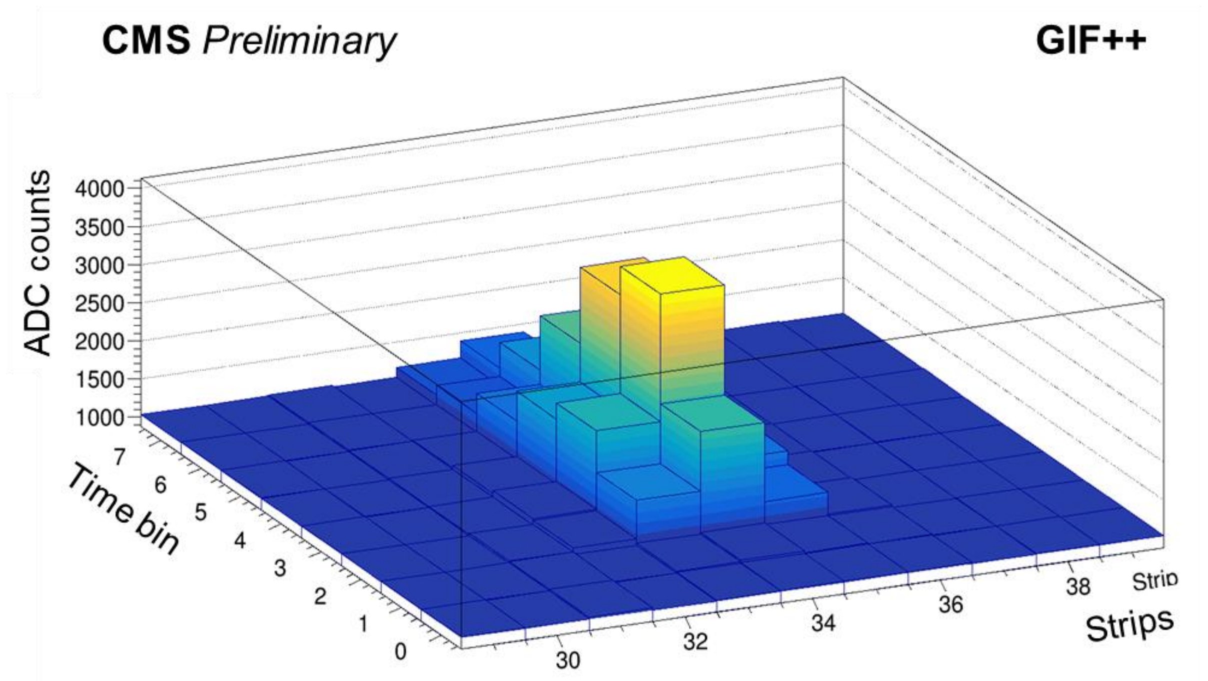
Gas gain proxy

The charge measured from CSC cathode strips is proportional to:

$$Q \sim E_{ionization} \times G$$

where $E_{ionization}$ is the muon ionization energy loss and G is the gas gain. For given electronics and gas composition, the charge distribution measured with energetic muons allow to monitor the gas gain.

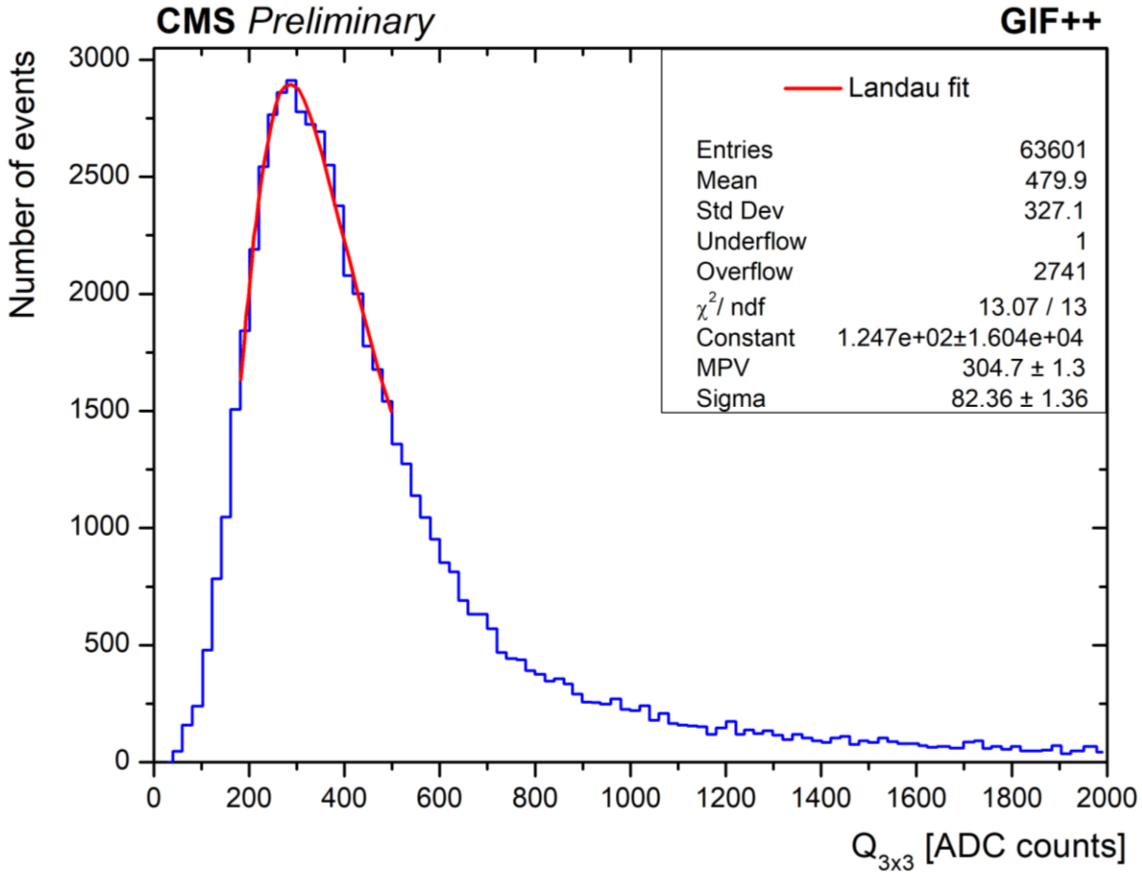
The cathode readout continuously integrates charges at individual strips within 50 ns time bins.



Due to the strip geometry and signal duration, summing charges over 150 ns (3 time bins) and across 3 neighboring strips (around the maximum bin - 9 ADC values total) gives a measurement of the induced charge ($Q_{3\times3}$).

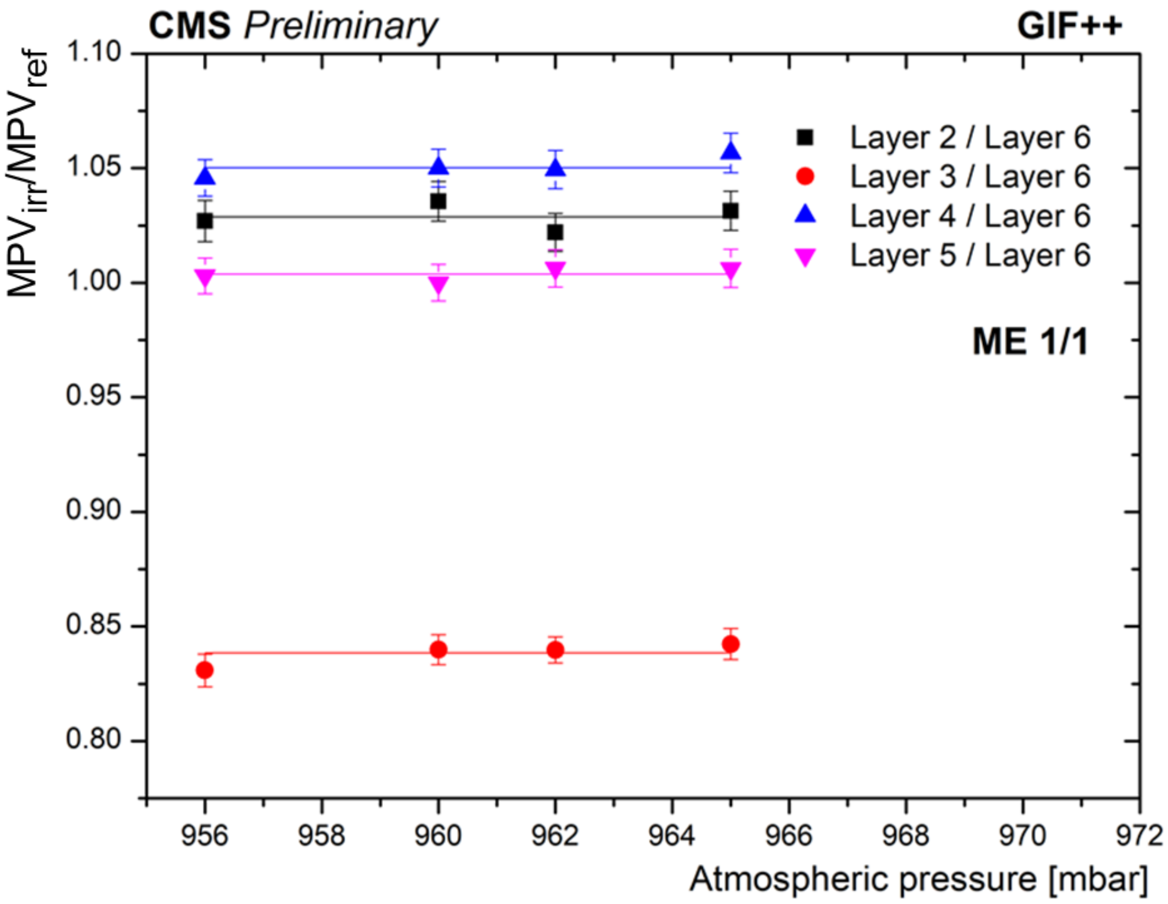
The $Q_{3\times3}$ spectrum is fitted with a Landau distribution to extract the Most Probable Value (MPV).

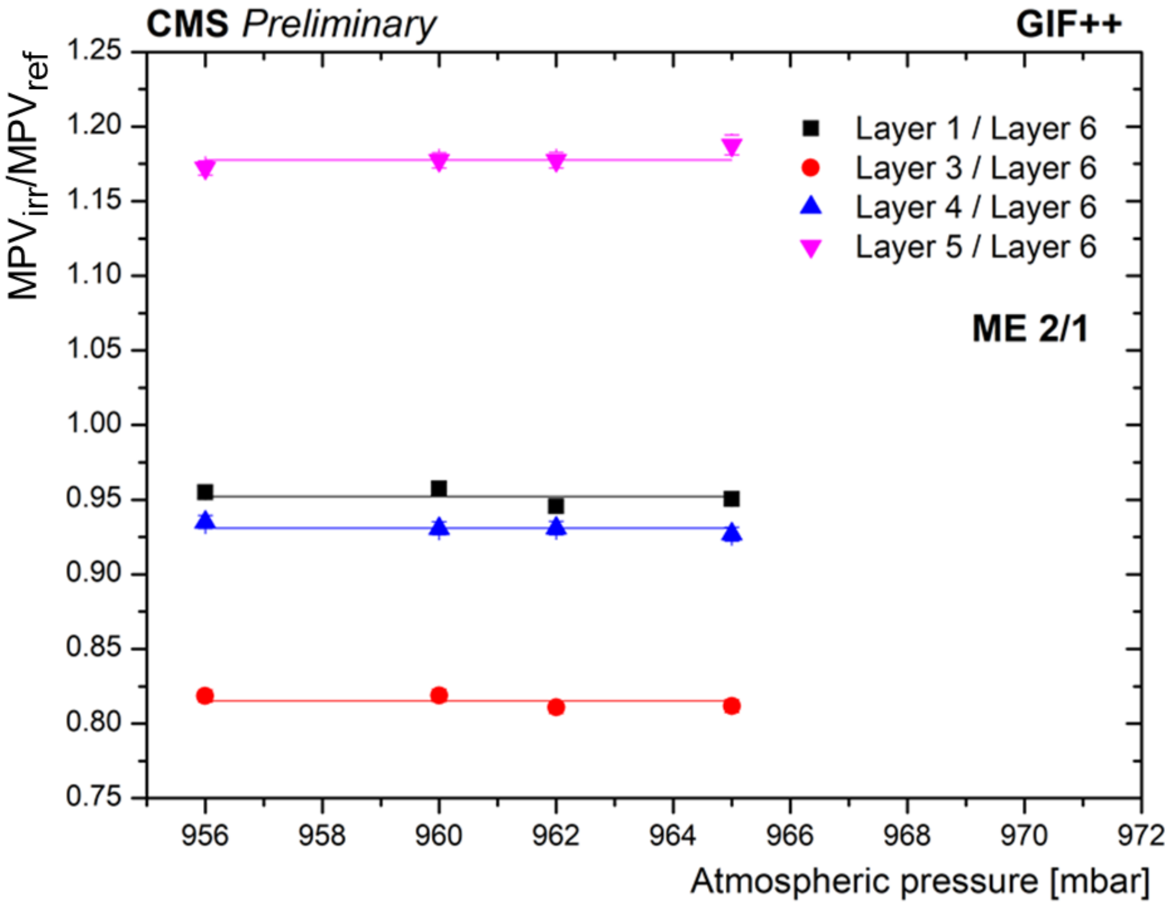
MPV value is used as the gas gain proxy



Ratio MPV_{irr}/MPV_{ref}

The gas gain depends on the gas pressure and temperature. To minimize this dependence, we use the ratio the ratio MPV_{irr}/MPV_{ref} , where MPV_{irr} is for the irradiated layer, MPV_{ref} is for the reference layer (layer 6). Irradiated layers are layers that are under high voltage during the irradiation, while reference layers have HV = 0V. Plots of the ratio as a function of atmospheric pressure for ME 1/1 (left) and for ME 2/1 (right) using April 2024 data are shown here as an example. This ratio does not depend on atmospheric pressure.

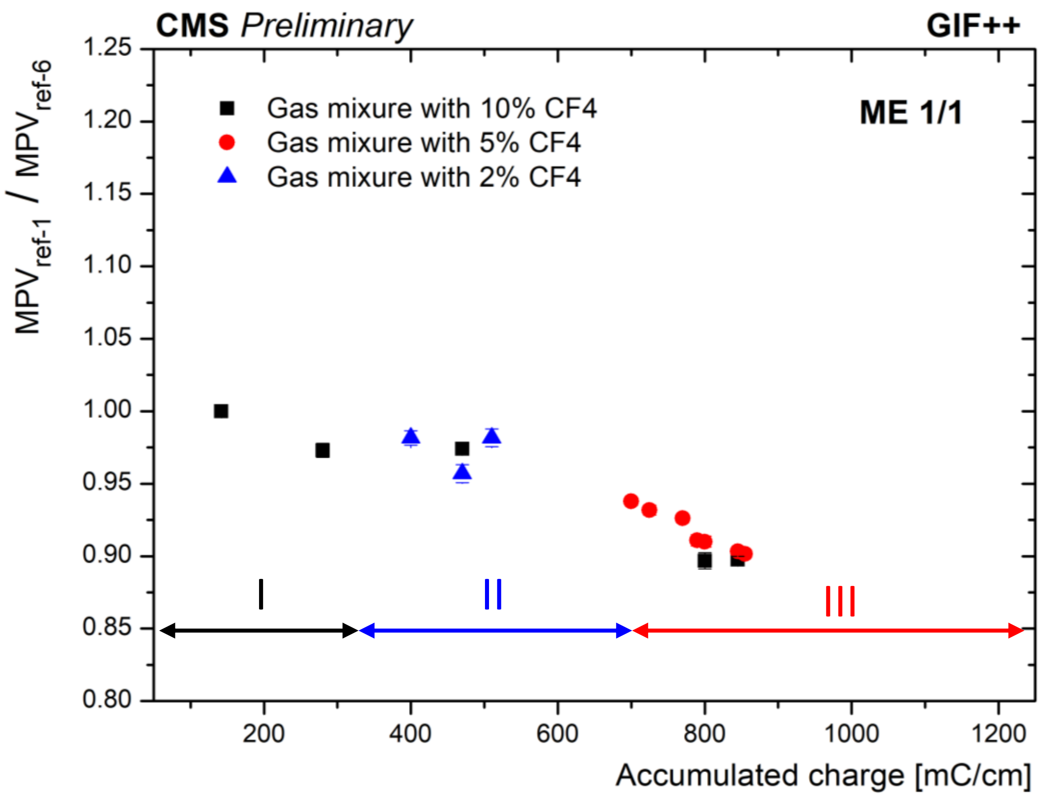


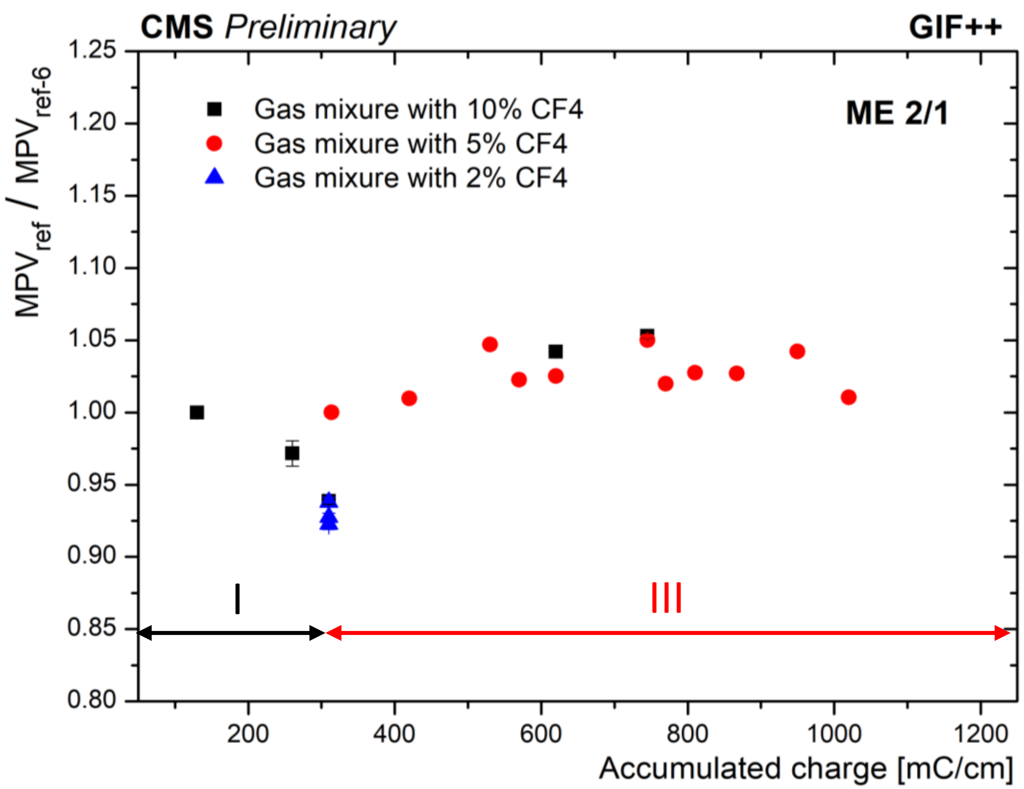


Systematic uncertainty

Plots below shows MPV ratio of 2 reference layers vs accumulated charge in the irradiated layers. Measurements were carried out over a period of 9 years. The main sources of the systematic uncertainty are variation in the muon beam parameters and replacement of the readout electronics boards. Periods I, II and III correspond the time with irradiation with different gas mixtures (10%, 2% and 5% CF_4). The test beam measurements in this periods were performed with various gas mixtures. An estimate of the resulting systematic uncertainty is done using response of non-irradiated layers.

The results are normalized to 1 for the initial measurement. For ME2/1 two sets of reference layers were used - layers 1,6 for irradiation periods I and 2,6 for period II; so the normalization is applied individually for the two periods. The change in the ratio of non-irradiated layer was found to be 10% for ME1/1 and 8% and 5% for ME2/1 during periods I and II, respectively

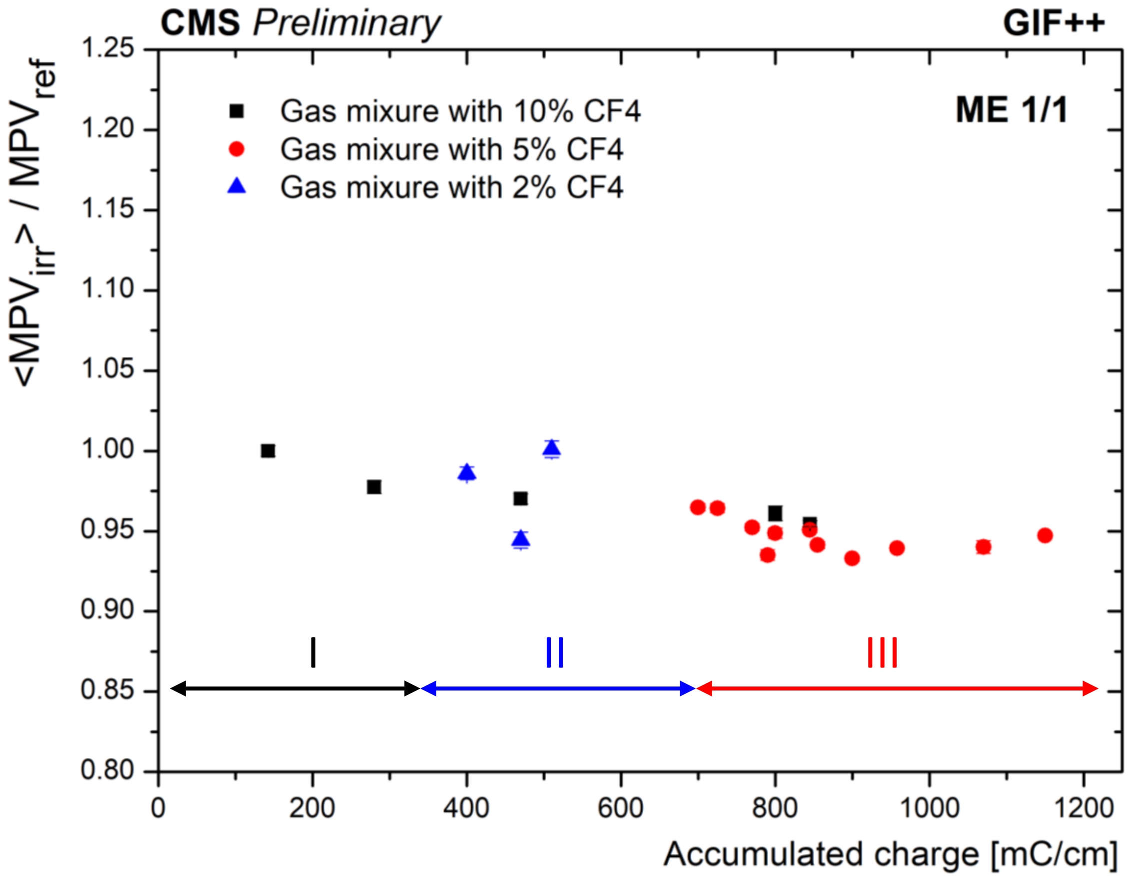


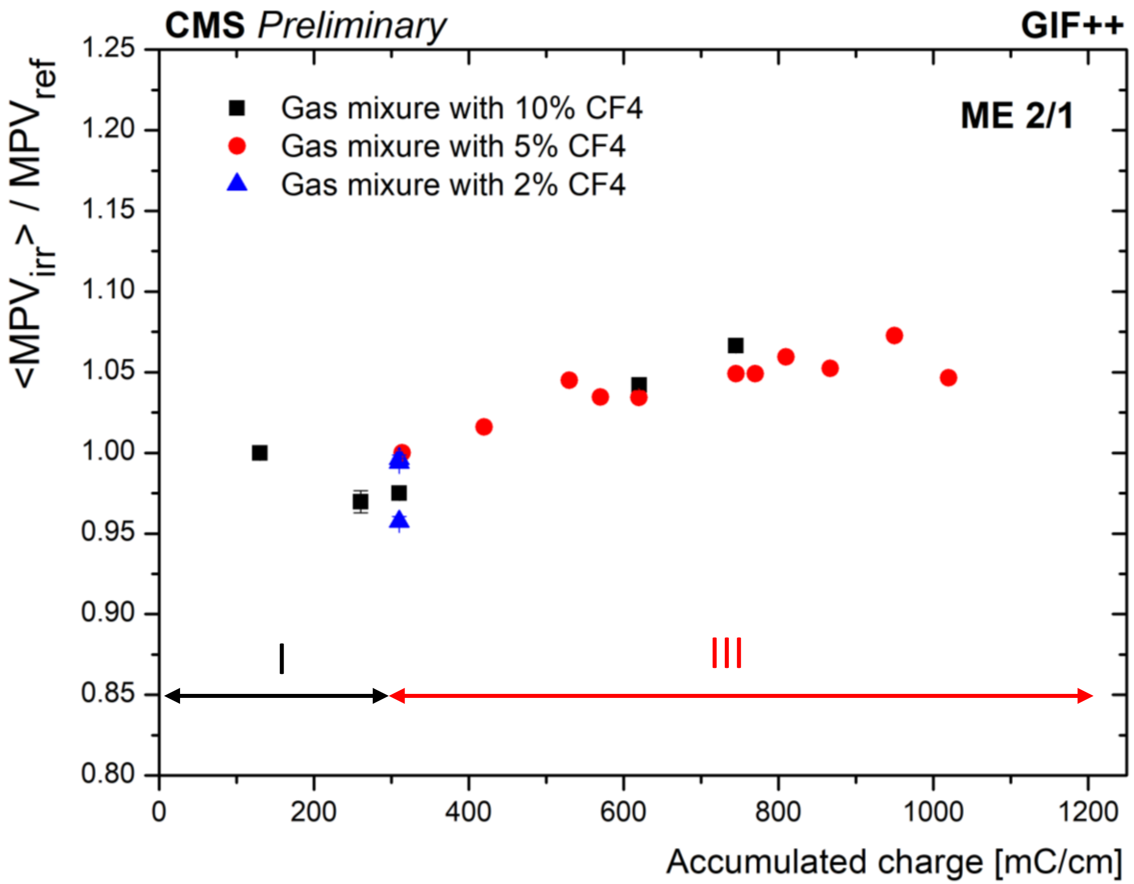


$\langle MPV_{irr} \rangle / MPV_{ref}$ vs accumulated charge

The plots show the ratio of the average MPV value for the four irradiated layers to the MPV value of the reference 6th layer depending on the accumulated charge on the anode wires. Periods I, II and III correspond the time with irradiation with different gas mixtures (10%, 2% and 5% CF_4). The test beam measurements in this periods were performed with various gas mixtures. The results are normalized to 1 for the initial measurement.

The ratios **$\langle MPV_{irr} \rangle / MPV_{ref}$** demonstrate no degradation of the gas gain outside the evaluated systematic uncertainty up to the accumulated charge of 1150 mC/cm for ME1/1 and 1020 mC/cm for ME2/1.





Conclusions

- Longevity studies of CMS CSCs are ongoing at GIF++ with ME1/1 and ME2/1 chambers since 2016.

- By the end of 2025, the accumulated charge per unit length of the anode wire reached 1020 mC/cm (ME2/1) and 1150 mC/cm (ME1/1). The values exceed by at least factor 3 the accumulated charge expected over the entire operation of the High-Luminosity Large Hadron Collider.

- Analysis of the gas gain stability as a function of the accumulated charge revealed no signs of radiation-induced degradation so far.

Reference

1. The CMS Collaboration. (2008). **The CMS experiment at the CERN LHC**. Journal of Instrumentation, 3(08), S08004.

2. CMS Collaboration. **Performance of CMS endcap muon CSC and GEM detector in 2025**: CMS Detector Performance Note. – Geneva : CERN, 2024. – (CMS DP -2025/060).

3. Ferguson T. et al. **Aging studies of CMS muon chamber prototypes** // Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment. – 2002. – Vol. 488, no. 1-2. – P. 240–257.

4. Barberis, E. **Longevity studies of CSC prototypes operating with Ar+CO2 gas mixture and different fractions of CF4** / E. Barberis, N. Begovic, N. Haubrich [et al.] // The European Physical Journal Plus. – 2024. – Vol. 139, no. 2. – Art. 166.

5. E.V. Kuznetsova V.V. Palichik and V.V. Perelygin. "**CMS CSC Longevity Study**", Physics of Atomic Nuclei, 2025, Vol. 88, No.5, pp.973-977.

6. Pfeiffer, D., et al. (2017). **The radiation field in the Gamma Irradiation Facility GIF++ at CERN**. Nuclear Instruments and Methods in Physics Research Section A, 866, 91-103.

Thank you for your attention!