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Longevity studies of the CMS cathode strip chambers

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Introduction

Cathode Strip Chambers (CSCs) are trapezoidal six-layer multi-wire proportional chambers for charged particle detection. CSCs are key detectors in the endcap muon system of the Compact Muon Solenoid (CMS), contributing to muon trigger and tracking (Fig. 1,2). CSC form 4 muon stations in each Endcap (Fig. 3, 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. The CSC chambers operates with a spatial resolution of 45−150 μm, a timing resolution of about 3 ns, and a pseudorapidity coverage of $0.9 < |\eta| < 2.4$ [1,2].

Under High-Luminosity Large Hadron Collider (HL-LHC) conditions: $\sqrt{s} = 13.6$ TeV, up to integrated luminosity 3000 fb^{-1}, and pileup ~200 – CSCs will face extreme background rates, which may provoke radiation-induced degradation of the main detector operational characteristics due to polymer deposits on the anode wires [3,4]. The goal of this study is to investigate the stability of the detector performance, in particular the gas gain, under high radiation background conditions simulating the HL-LHC operation conditions.

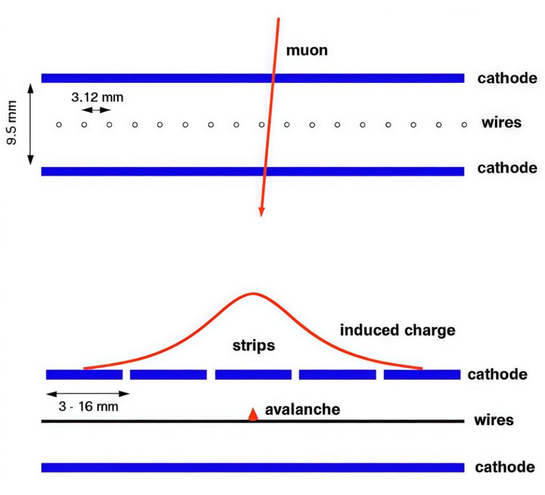

Figure 1. Operating principle of the CSC

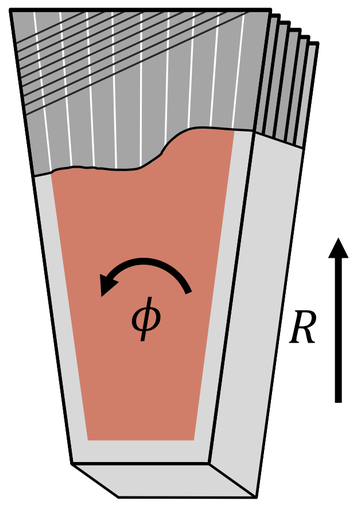

Figure 2. Outline of the CSC

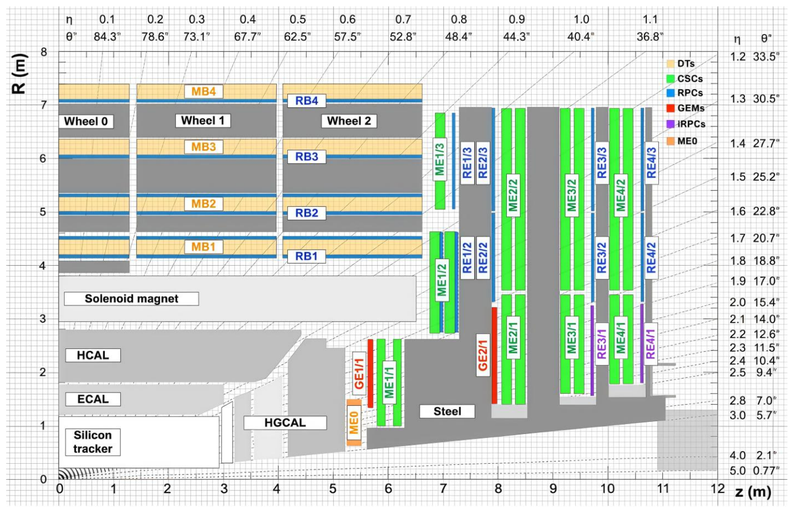

Figure 3. One quarter of the CMS detector

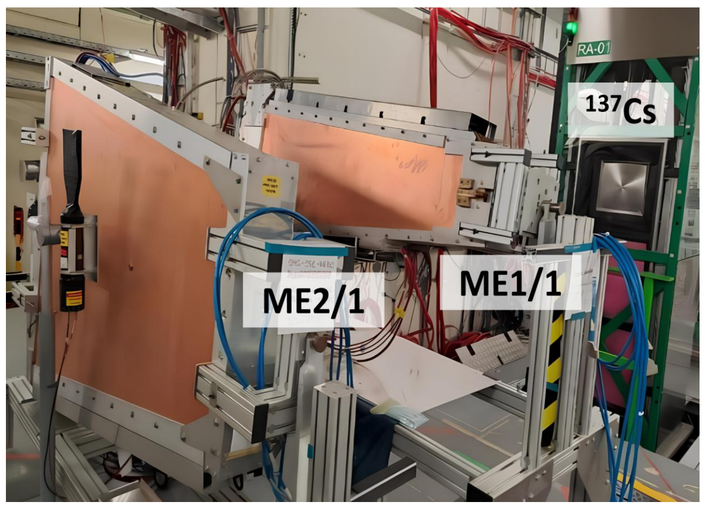

Figure 4. Configuration of the CSCs irradiation on the GIF++ setup

Gas gain monitoring

Two CSCs, ME1/1 and ME2/1, with different dimensions and design technologies which operating in CMS in the region of the high background rates have been exposed to a ^{137}Cs gamma source (13 TBq) at the GIF++ irradiation facility at CERN [5] (Fig. 4). Standard operating gas mixture: 40% Ar + 50% CO_2 + 10% CF_4. Component of CF_4 prevents silicon deposits from forming on the anode wires by reacting with silicon to form volatile SiF_4 gas, which is then carried away from the detector volume. Three gas mixtures with decreasing CF_4 content were used in order to studies aimed on reducing CF4 usage for LHC experiments due to its high global warming potential GWP ≈ 7000. The main characteristics of the CSCs were studied periodically with the SPS muon beam as a function of the accumulated charge. The accumulated charge per unit length is defined as the time integral of the HV layer current divided by the total wire length in the layer. Information on accumulated charges obtained with different gas mixtures is presented in Table 1.

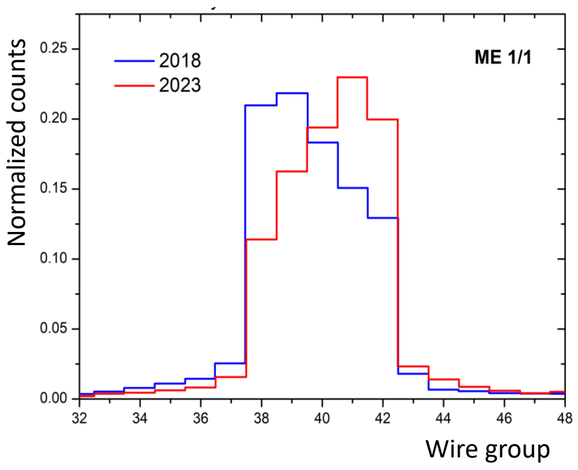

Figure 5. ME1/1 CSC wire group loading with muon beam for different periods of measurement.

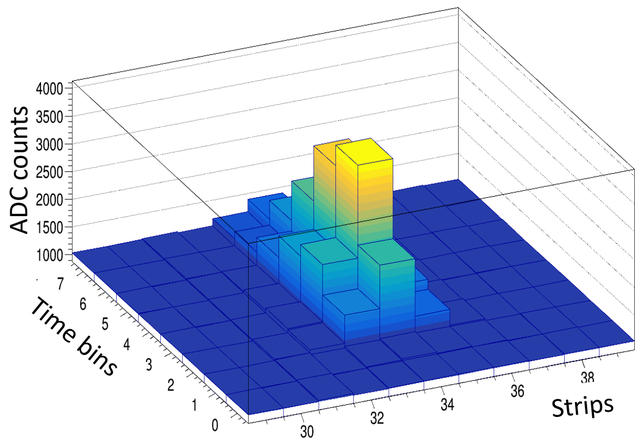

Figure 6. Distribution of charge induced on strips over time

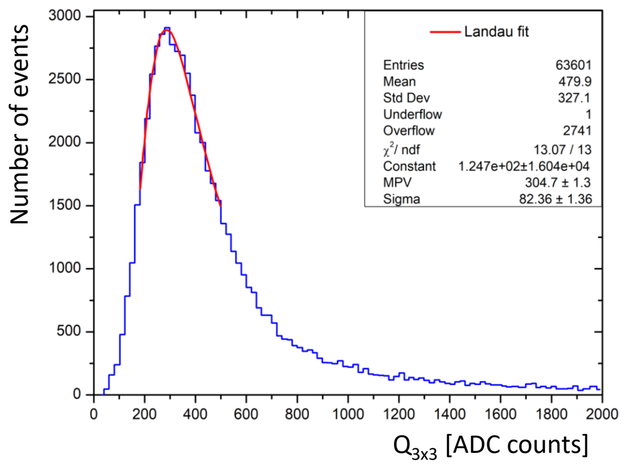

Figure 7. Q_{3x3} induced charge spectrum

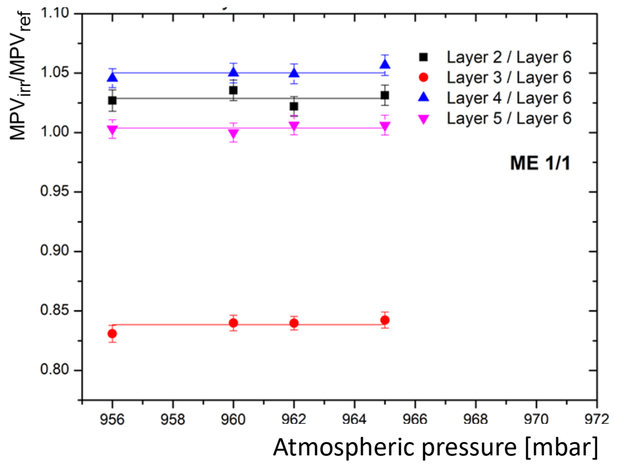

Figure 8 Dependence of the relative gas gain on the atmospheric pressure

The measurements of the CSC performance with muon beams were done without ^{137}Cs background source. Coincidence of 15 × 15 cm^2 scintillators signals were used to trigger the CSC readout electronics (Fig. 5). When a muon passes through the CSC, the charge induced on the cathode is proportional to the product of the primary ionization in the gas and the gas gain:

$$Q \propto E_{ionization} \times G.$$

To monitor gas gain by energetic muons the charge $Q_{3\times3}$ induced on three neighboring strips over 3-time intervals during 150 ns was measured (Fig.6). The $Q_{3\times3}$ spectrum fitted by a Landau function where the Most Probable Value (MPV) was used as a proxy for the gas gain (Fig. 7). Since the gas gain depends on gas pressure and temperature, the relative gas gain $MPV_{irr}/MPVr_{ef}$ is used, where MPV_{irr} corresponds to the CSC layers on which high voltage was ON during irradiation and MPV_{ref} - reference layer where high voltage was OFF (layer 6). Relative gas gain removes environmental dependencies. Fig. 8 demonstrate relative gas of ME1/1 CSC is independent of atmospheric pressure. The temperature dependence is not important in our case because it was measured directly on chamber input.

Table 1. Accumulated charge for ME1/1 and ME2/1 CSCs during GIF++ irradiation periods

CSC	Accumulated charge [mC/cm]				
	Before 2018 10% CF_4	November 2021 2% CF_4	May 2026 5% CF_4	Total	Expected at HL-LHC (3000 fb^{-1})
ME1/1	330	370	472	1172	400
ME2/1	310	Not irradiated	722	1032	220
Period	I	II	III (ongoing)		

Results

The dependence of the average relative gas gain on the charge accumulated per unit length of anode wire was obtained for the ME1/1 and ME2/1 chambers (Fig. 9).

The systematic uncertainty estimated using reference layers is 10% for the ME1/1 chamber, and 8% and 5% for the ME2/1 chamber during irradiation periods I and III, respectively.

The accumulated charge per unit length of the CSC anode wire reached more than 1.0 C/cm for both chambers, a value more than three times higher than the expected integrated charge for the entire LHC operation period HL-LHC. The Gas gain and other main characteristics [6]. shows no observation of the radiation-induced degradation.

The experimental results confirm the radiation hardness of the CMS endcap muon CSCs to sustain sever requirements of the HL-LHC operation mode

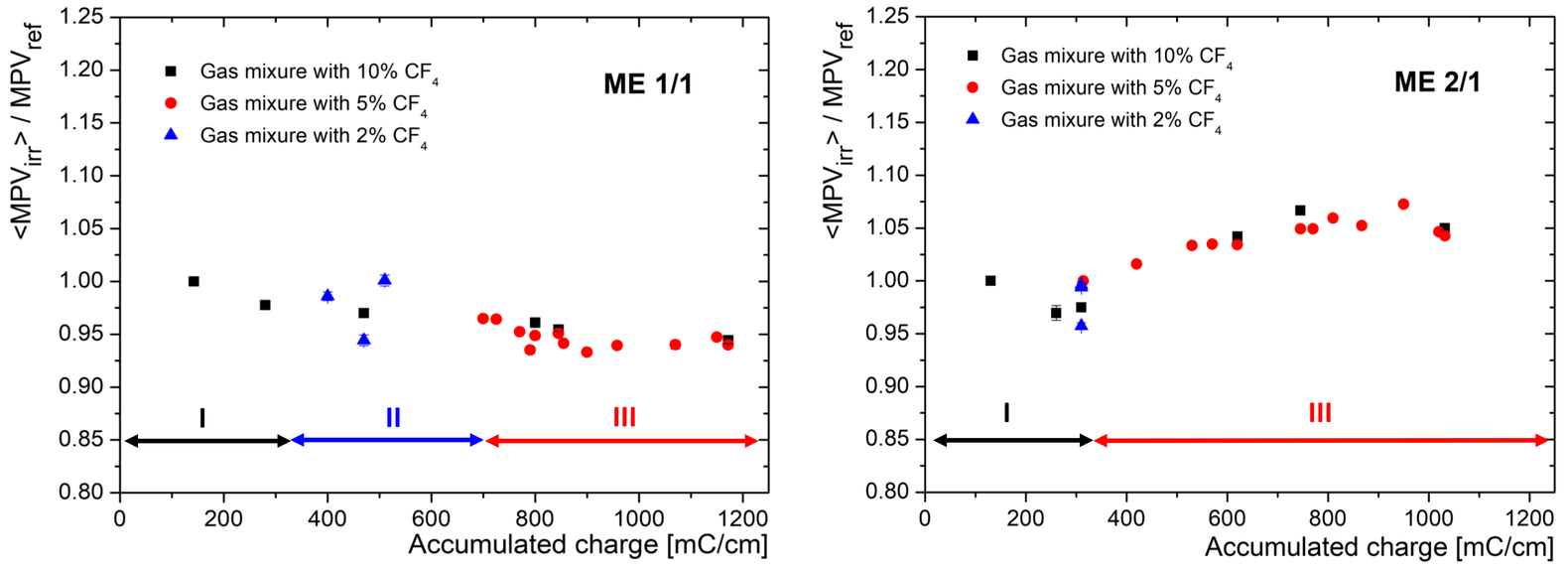

Figure 9. Dependence of the average relative gas gain on the charge accumulated per unit length of anode wire for ME1/1 chamber (left) and ME2/1 chamber (right).

Reference

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