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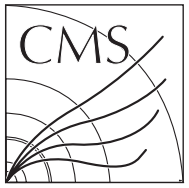

The Compact Muon Solenoid Experiment

Conference Report

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CMS CSC longevity studies at GIF++ setup

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Abstract

The investigation into the longevity of gaseous detectors holds paramount importance, particularly in anticipation of the forthcoming upgrade of the Large Hadron Collider (LHC) to the High-Luminosity LHC (HL-LHC) and the planned alterations to the CMS forward endcap zone. Aging effects are meticulously examined at the Gamma Irradiation Facility (GIF++) at CERN, focusing on two crucial components: the ME1/1 and ME2/1 cathode strip chambers (CSC) within the CMS. These chambers, designed differently, serve as vital detectors in the CMS endcap muon rings situated in the forward region, where they operate under high background rates.

Since its initiation in 2016, the irradiation process of the chambers has resulted in the accumulation of charge per unit length of anode wire exceeding 610 mC/cm for ME2/1 and 800 mC/cm for ME1/1, surpassing the expected charge accumulation at HL-LHC by more than threefold. The chambers were operated with an Ar+CO_2 gas mixture containing varying fractions of 10%, 2%, and 5% CF_4. No effects of CSC aging were detected throughout the observation period.

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1. Introduction

The Cathode Strip Chambers (CSC) are part of the CMS Endcap muon system [1]. There are 540 trapezoidal shape six-layer CSCs of different designs [2,3] composing nine concentric rings in four stations in each Endcap (Fig. 1) [4]. They are shown in green in the figure and have the designation MEx/y where x is the station number and y is the ring number. The chambers operate with the gas mixture 40%Ar+50%CO_2+10%CF_4 and provide precise measurements of the muon tracks in the high η region ($0.9 < |\eta| < 2.4$).

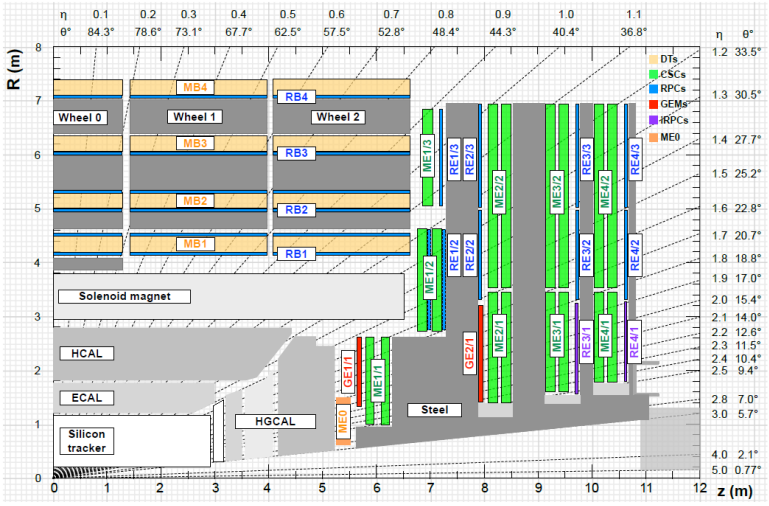

Fig. 1. CMS quadrant R-z cross section [4].

The future LHC upgrade into HL-LHC will lead to a significant background increase in particle detectors. In this regard, it is very important to study the effects of radiation aging in materials and gases of coordinate detectors. Such a study for CSCs has been carried out since 2016 at the GIF++ setup (CERN) [5,6], which has 14 TBq ^{137}Cs gamma-ray source.

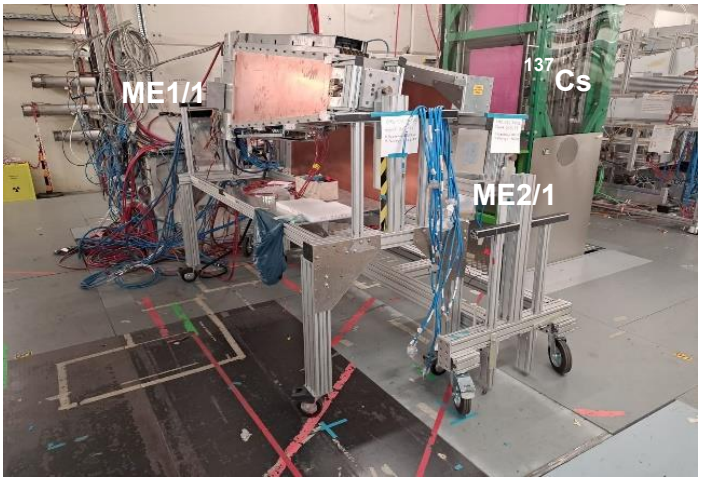

Fig. 2. ME1/1 and ME2/1 CSCs in irradiation position at GIF++.

The SPS CERN beam line at the GIF++ zone enables the testing of detectors positioned within the beam area using muons. ME1/1 and ME2/1 CSCs were chosen for testing due to their high flow of background events within the CMS (Fig. 2).

2. Previous aging studies of CSC prototypes.

Aging tests were conducted previously on various CSC prototypes. In 2000-2001, two full-scale CSCs underwent aging studies at the Gamma Irradiation Facility (GIF) using a 740 GBq ^{137}Cs gamma-ray source [7]. These tests employed a gas mixture 40%Ar+50%CO_2+10%CF_4. One chamber operated with an open-loop gas system while the other one operated with a closed-loop gas system. The accumulated charges ranged from 0.3 to 0.4 C/cm. No aging effects were observed.

Additionally, longevity tests were performed on small CSC prototypes using a ^{90}Sr source. The PNPI group investigated CSC cathode surface degradation, achieving a local charge value of 1.2 C/cm [8]. Another group conducted comprehensive longevity studies comparing different fractions of Ar+CO_2 gas mixtures, including 5%, 2%, and 0% CF_4 [9]. Despite an accumulated charge of 300 mC/cm, no degradation in CSC performance was noted.

This study distinguishes itself by testing CSCs specifically manufactured for CMS. The entire active area of the chamber was irradiated. The operation conditions at GIF++ mirrored those of CMS, including closed-loop gas supply with nominal gas flow, 10% fresh gas injection, sensors for O_2 and H_2O control, as well as identical services and DAQ. Results from the previous work period are documented in Ref. [10].

3. Irradiation

ME2/1 and ME1/1 consist of six identical trapezoidal proportional chambers, or layers, equipped with cathode strip readout (CSCs). During irradiation, high voltage (HV) was applied to four test (irradiated) layers, while the remaining two served as reference layers. In terms of positioning ME2/1 is situated in front of ME1/1 and approximately 1.8 m away from the ^{137}Cs source. Each layer of ME2/1's active area is segmented into three independent high voltage zones, or HV segments, whereas ME1/1 lacks segmentation. The current in the irradiated layer of ME1/1 is approximately 190 μA, while for segment 1 of ME2/1 it measures around 390 μA (refer to Fig. 3).

The accumulated charge per 1 cm of anode wire length for ME1/1 is presented in Fig. 4. There were three irradiation periods of this chamber with different gas components of Ar+CO_2+CF_4 gas mixture: 40%/50%/10% (period I), 40%/58%/2% (period II) and 40%/55%/5% (period III).

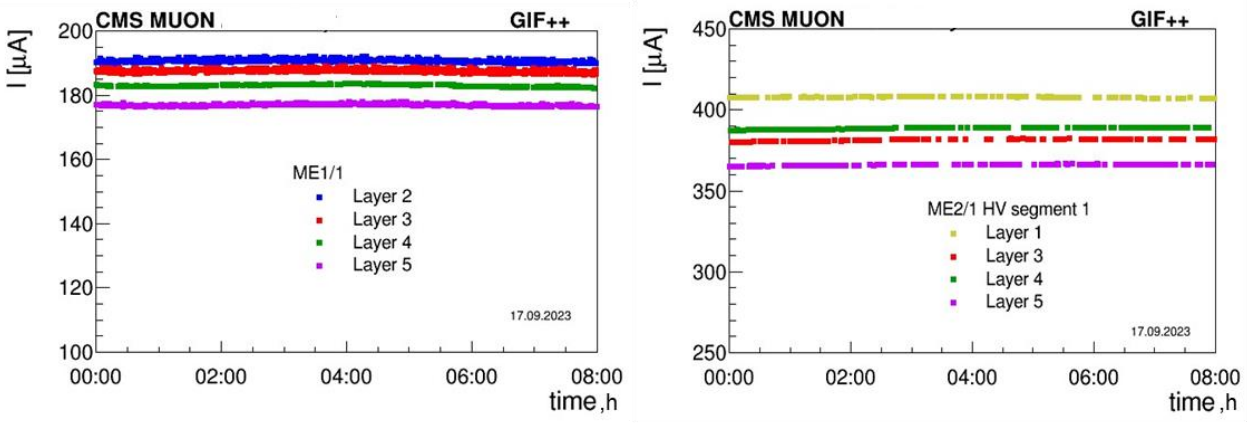

Fig. 3. The current in the irradiated layers of ME1/1 (left) and ME2/1 (right) during irradiation.

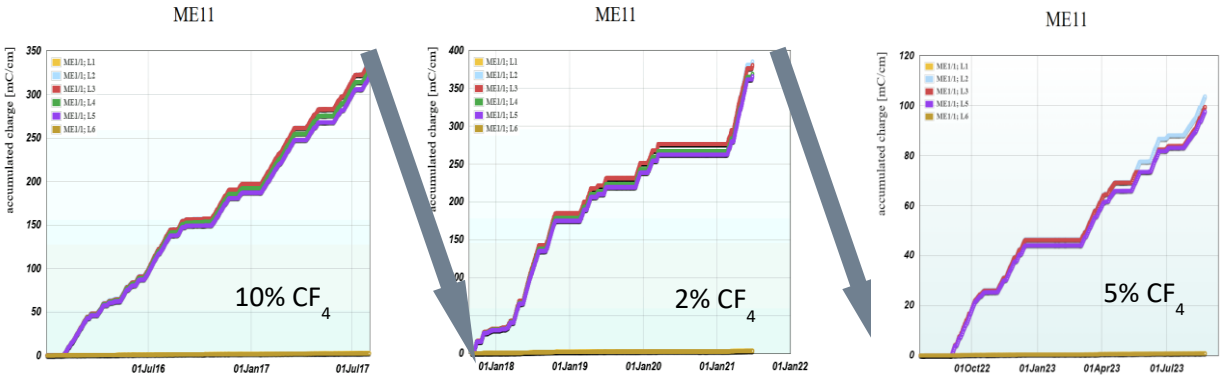

Fig.4. ME1/1 accumulated charge per 1 cm of anode wire length during CSC irradiation at GIF++ with different gas components of $Ar+CO_2+CF_4$ gas mixture: 40%/50%/10% (period I), 40%/58%/2% (period II) and 40%/55%/5% (period III).

Table 1 shows the charge accumulation dynamics in more detail for both chambers. In the first period of irradiation 330 mC/cm for ME1/1 and 310 mC/cm for ME2/1 (mean value for HV segments S1-S3) were accumulated. In the second period (2% CF_4 gas mixture) only ME1/1 was irradiated, and a charge of 370 mC/cm was accumulated. Later with 5% gas mixture the charge reached the values of 800 mC/cm for ME1/1 and 610 mC/cm for ME2/1.

Table 1. Accumulated charge in time for ME1/1 and ME2/1 CSCs.

CSC	HL-LHC Expected ($3000\ fb^{-1}$)	Accumulated charge Q (mC/cm)					
		before 2018	Nov.-2021	Oct.-2022	May-2023	19.07.23	25.08.23
ME1/1	200 mC/cm	330 (10% CF_4)	700 (2% CF_4)	725 (5% CF_4)	770	790	800
ME2/1, S1	130 mC/cm	340 (10% CF_4)		460 (5% CF_4)	575	625	670
ME2/1, S2, S3		300 (10% CF_4)		400 (5% CF_4)	510	550	600
<ME2/1>		310 (10% CF_4)		420 (5% CF_4)	530	570	610

4. Measurements

The formation of deposits on anode wires can lead to corona discharge and increase the anode-cathode current. Periodic CSC current stability tests were carried out with fully open source. During this short period of time, high voltage was applied to all the layers. The current value in a layer (HV segment) normalized to the average current of the two reference layers is called relative current. The results of the tests for ME1/1 and ME2/1 are shown in Fig. 5. The picture shows the data for the period III of irradiation. The relative current is stable in time, and we can conclude that there are no ageing effects in both chambers.

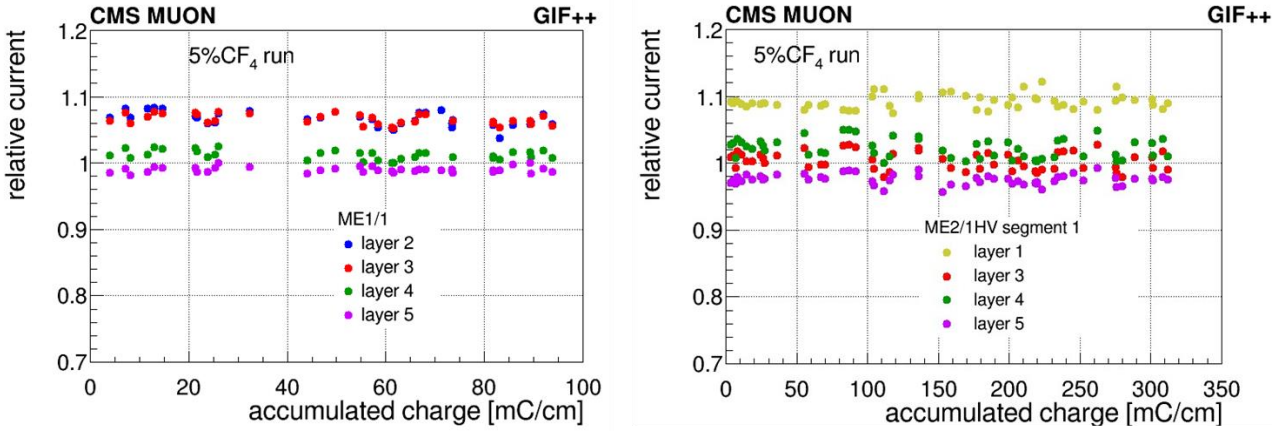

Fig. 5. ME1/1 (left) and ME2/1 (right) plots of the relative currents in irradiated layers vs accumulated charge.

Figure 6 illustrates the relationship between the spatial resolution of ME1/1 and ME2/1 and the mean CSC layer (HV segment) current. These measurements were conducted using a 5% CF_4 gas mixture across different time periods, employing both a muon beam and varying ^{137}Cs source intensity. The reported errors are statistical, and the results have been adjusted to account for fluctuations in atmospheric pressure.

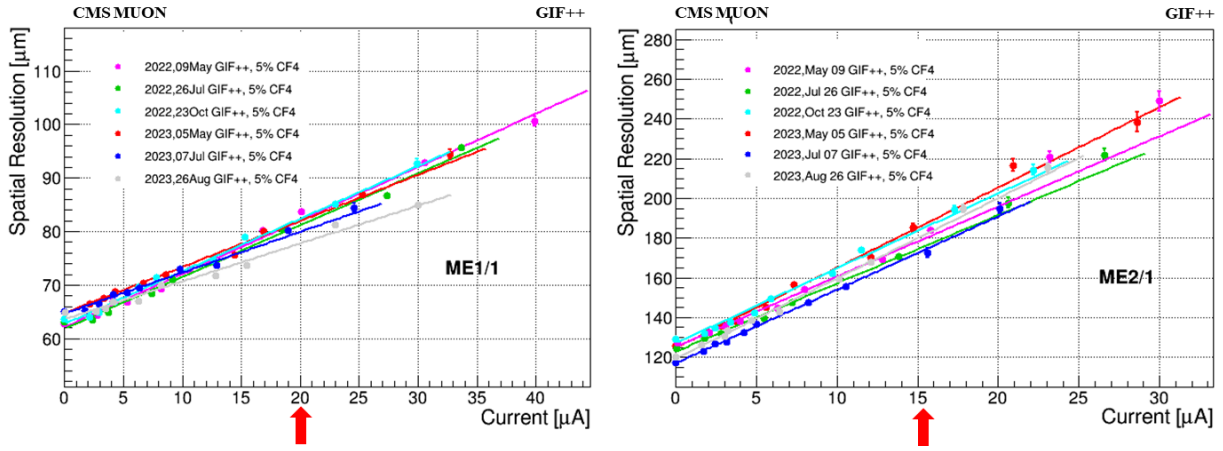

Fig. 6. Spatial resolution of ME1/1 (left) and ME2/1 (right) vs mean layer (HV S1) current. Red arrows mark the values of currents corresponding to HL-LHC background condition.

The method of calculating the values of the spatial resolution of CMS CSC is described in Ref. [11]. The spatial resolution degrades linearly with the layer current increase. Red arrows mark the ME1/1 layer current of 20 μA and ME2/1 S1 current of 15 μA which correspond to the HL-LHC operating conditions for L=5×10^{34} cm^{-2}s^{-1}.

Figure 7 depicts the spatial resolution of the CSC measured with a muon beam across varying accumulated charges. The initial 330 mC/cm (period I) was accumulated using the standard 40%Ar+50%CO_2+10%CF_4 gas mixture. Subsequently, irradiation continued for ME1/1 alone with a reduced CF_4 content (40%Ar+58%CO_2+2%CF_4) during period II, followed by irradiation for both CSCs with a modified 40%Ar+55%CO_2+5%CF_4 gas mixture during period III. Blue points represent measurements taken with a 10%CF_4 gas mixture, while red points represent measurements with a 5%CF_4 gas mixture. The reported errors are statistical, and the results have been adjusted to accommodate fluctuations in atmospheric pressure. Throughout the entire irradiation period, no significant degradation in spatial resolution was observed, even up to the accumulated charges of 700 mC/cm for ME1/1 and 610 mC/cm for ME2/1. However, a slight degradation in the resolution of ME1/1 was noted during period III, although no significant changes were observed in the relative current and dark rate. Further investigation into this effect is warranted.

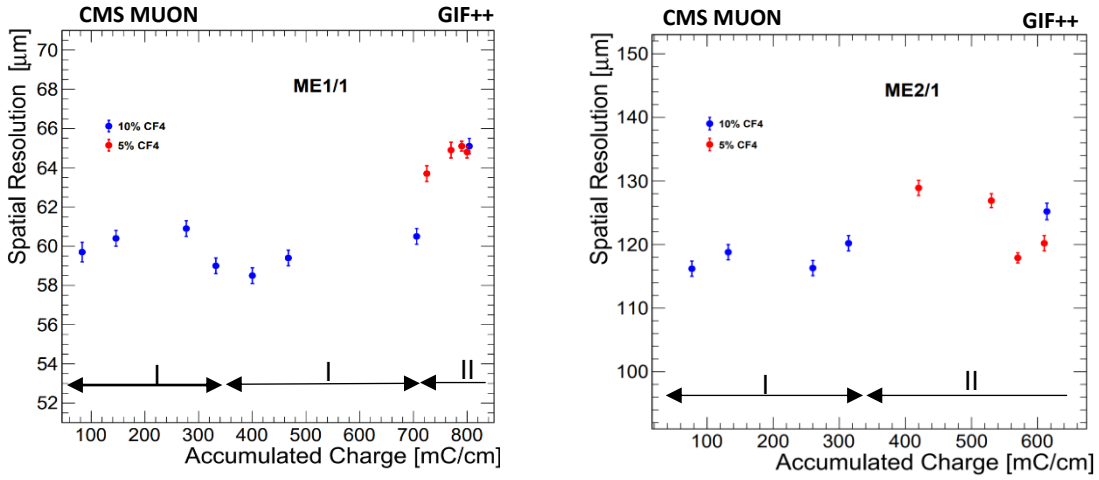

Fig. 7. Spatial resolution of ME1/1 (left) and ME2/1 (right) CSCs measured with a muon beam as a function of the accumulated charge.

5. Summary

The longevity studies conducted on the CMS cathode strip chambers (CSC) ME1/1 and ME2/1 at GIF++ (CERN) since 2016 show no signs of aging. Throughout the irradiation period, three gas mixtures were employed: 40%Ar+50%CO_2+10%CF_4, 40%Ar+58%CO_2+2%CF_4 and 40%Ar+55%CO_2+5%CF_4. The accumulated charge for ME1/1 reached 800 mC/cm, while for ME2/1 it reached 610 mC/cm - more than three times the charge expected during HL-LHC

operation. The relative current and dark rate in irradiated layers remained stable as the accumulated charge increased. No significant degradation of the spatial resolution was observed throughout the irradiation period up to 700 mC/cm for ME1/1 and 610 mC/cm for ME2/1. However, a slight degradation in ME1/1 resolution beyond 700 mC/cm was noted. Filter scan tests revealed a linear correlation between CSC spatial resolution and background increase, suggesting an approximate 40% deterioration in resolution under HL-LHC background conditions at maximum instantaneous luminosity for these chambers.

References

[1] CMS Collaboration, The CMS experiment at the CERN LHC. JINST 3 S08004 (2008).

[2] CMS Collaboration, The CMS Muon Technical Design Report, CERN/LHC 97-32, CMS TDR 3; ISBN 92-9083-121-3.

[3] Y.V. Ershov, Cathode strip chamber for CMS ME1/1 endcap muon station. Phys. Part. Nucl. Lett. 3, 183–187 (2006).

[4] CMS Collaboration, The Phase-2 Upgrade of the CMS Muon Detectors Technical Design Report. CERN-LHCC-2017-012, CMS-TDR-016, 12 September 2017, pp. 1-367. ISBN: 978-92-9083-457-1.

[5] D. Pfeiffer et al. The radiation field in the Gamma Irradiation Facility GIF++ at CERN. Nuclear Inst. and Methods in Physics Research, A 866 (2017) 91–103.

[6] M.R. Jäkel et al. CERN GIF++: A new irradiation facility to test large-area particle detectors for the high-luminosity LHC program. PoS (TIPP2014) 102.

[7] Acosta D. et al. Aging Tests of Full-Scale CMS Muon Cathode Strip Chambers. Nucl. Instr. Meth. A. 2003. V. 515. P. 226–233.

[8] M.E. Buzoveria et al. Investigation of the cathode plane radiation damage in the prototypes of multiwire proportional chamber from the CMS experiment. Phys. Atom. Nucl.82(9), 1252–1262 (2019).

[9] E. Barberis et al. Longevity studies of CSC prototypes operating with Ar+CO_2 gas mixture and different fractions of CF_4 Eur. Phys. J. Plus 139, 166 (2024).

[10] B. Wang. Longevity studies and Phase2 electronics upgrade for CMS Cathode Strip Chambers ion preparation for HL-LHC. NIM A 958 (2020).

[11] CMS Collaboration, Performance of the CMS cathode strip chambers with cosmic rays. JINST 5 T03018 (2010).