Available on CMS information server

CMS CR -2024/320

The Compact Muon Solenoid Experiment

Conference Report

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

20 November 2024 (v3, 29 November 2024)

CMS CSC longevity studies

Victor Perelygin for the CMS Collaboration

Abstract

Cathode Strip Chambers (CSCs) are used in the muon system of the CMS experiment at LHC. There are four muon stations on both endcaps consisting of 540 CSCs operating with 40%Ar + 50%CO2 + 10%CF4 gas mixture. The chamber longevity study is particularly important in anticipation of the future LHC upgrade into High Luminosity LHC (HL-LHC) and the scheduled upgrade of the CMS detector. The CSC longevity is studied with two CMS CSCs ME1/1 and ME2/1 at the Gamma Irradiation Facility (GIF++, CERN). The tests didn't show any degradation in the chamber's performance. The study of the reduction of, or possible replacement of, the CF4 in the working gas mixture is also ongoing, including longevity studies with small CSC prototypes.

Presented at *ICPPA-2024 7th International Conference on Particle Physics and Astrophysics*

CMS CSC LONGEVITY STUDY

E. V. Kuznetsova[1)], V. V. Palichik[2)] and V. V. Perelygin[2)*]

On behalf of the CMS Muon group.

[1)]University of Florida, Gainesville, USA

[2)]Joint Institute for Nuclear Research, Dubna, Russia.

Abstract.

Cathode Strip Chambers (CSCs) are used in the muon system of the CMS experiment at LHC. There are four muon stations on both endcaps consisting of 540 CSCs operating with 40%Ar+50%CO_2+10%CF_4 gas mixture. The chamber longevity study is particularly important in anticipation of the future LHC upgrade into High Luminosity LHC (HL-LHC) and the scheduled upgrade of the CMS detector. CSC longevity is studied with two CMS chambers: ME1/1 and ME2/1 at the Gamma Irradiation Facility (GIF++, CERN). The tests did not show any degradation in the chamber's performance. The study of the reduction of, or possible replacement of, the CF_4 in the working gas mixture is also ongoing, including longevity studies with small CSC prototypes.

*E-mail: perel@mail.cern.ch

1. INTRODUCTION

Cathode Strip Chambers (CSC) are part of the CMS [1] Endcap Muon system covering the pseudorapidity range $0.9 < |\eta| < 2.4$ and form 4 vertical muon stations in the magnet return yoke (Fig. 1, left). The stations, in turn, consist of rings of 36 or 18 trapezoidal CSCs named MEx/y, where x stands for the station number and y for the ring number (Fig.1, right). There are 540 CSCs in both endcaps with the total sensitive area of around 7000 m^2 operating with the gas mixture 40%Ar+50%CO_2+10%CF_4. A CSC consists of 6 identical layers, which operate as a standard multi-wire proportional chamber (MWPC) with cathode strip readout [2,3]. The CMS Muon system provides muon identification and measurement of its transverse momenta, muon triggering and matching muon tracks with the inner tracker tracks [2, 4].

At the High Luminosity LHC (HL-LHC) the instantaneous luminosity at the beam interaction point will significantly increase, and the integrated luminosity will be 10 times higher than it is now [5]. This will cause a considerable increase in the backgrounds seen in the forward endcap region. In addition, during the LHC 2026-2029 shutdown the CMS endcap will be upgraded [4], including the installation of the new hadron calorimeter HGCAL and the new muon station ME0, instrumented with GEM detectors (Fig. 1), increasing the background in the forward region even further. For this reason, the study of the longevity of gaseous detectors and their ability to operate with high background rates is of great importance. For several years, longevity studies have been carried out with ME1/1 and ME2/1 chambers at the Gamma Irradiation Facility (GIF++), CERN [6, 7]. This facility has a ^{137}Cs radioactive source with an activity of 14 TBq (2015), a system of filters to control the radiation dose, and is located at Super Proton Synchrotron (SPS) beamline. The ME1/1 and ME2/1 CSCs have different designs and operate in the region with the highest background rate. The sensitive area of ME2/1 layer is divided into three independent high voltage zones – HV segments, while ME1/1 has no segmentation. Fig. 2 shows the chambers at GIF++ bunker in the irradiation position.

2. CSC PERFORMANCE AT CMS

The analysis of CMS experimental data of Run2 and Run3 demonstrates stable and efficient operation of CSCs [5, 8]. Fig. 3 shows that the CSC spatial resolution measured in proton-proton collision data of 2018 and 2024 is in good agreement. The analysis procedure of the CSC spatial resolution calculation is described in Ref. [9]. Depending on the design, the spatial resolution of the chambers is in the range of 46-150 μm. For higher background intensity those values are expected to increase, so studies of CSC performance under the future HL-LHC conditions must be done.

3. POSSIBLE CF_4 REDUCTION AND LONGEVITY TESTS WITH SMALL CSC PROTOTYPES

CF_4 is a greenhouse gas with a high global warming potential (GWP) ~ 7000. There is a strong restriction on the use of fluorinated greenhouse gases (F-gases) in the European Community. Early aging studies with small CSC prototypes showed that the presence of CF_4 in the gas mixture prevents formation of deposits on anode wires [10]. At the same time, the question of the minimum required content of CF_4 in the CSC gas mixture remained open. Recent studies with small CSC prototypes and the 40%Ar+58%CO_2+2%CF_4 gas mixture observed formation of carbon-containing deposits on anode wires at the accumulated charge of 300 mC/cm [11]. No such effect was observed for 40%Ar+58%CO_2+5%CF_4. Even though no degradation of the CSC parameters, such as gas amplification, dark current and strip - strip resistance, was observed in the tests, it was concluded that the mixtures containing less than 5% CF_4 are potentially dangerous for long-term CSC operation.

4. LONGEVITY STUDY OF ME1/1 AND ME2/1 AT GIF++ SETUP

4.1. Irradiation

There are three periods of CSC irradiation at GIF++ with different gas mixtures: $40\%Ar+50\%CO_2+10\%CF_4$ – period I, $40\%Ar+58\%CO_2+2\%CF_4$ – period II and $40\%Ar+55\%CO_2+5\%CF_4$ – period III. During the second period only ME1/1 was irradiated. Table 1 shows the accumulated charge per 1 cm of anode wire for ME1/1 and ME2/1 for different periods of irradiation. The results obtained during period I of chamber irradiation are reported in the papers [5, 12]. The rough estimate of accumulated charge expected for the HL-LHC operation is ~ 400 mC/cm for ME1/1 and ~ 220 mC/cm for ME2/1.

In the longevity tests at GIF++, two layers of each chamber are used for reference and high voltage is not applied to them during the irradiation. They are switched on just for short periods of reference measurements, when the currents of all six layers are recorded. Since the irradiation current is proportional to the gas gain, the regular current measurements are used to monitor the gas gain as a function of the accumulated charge. To avoid dependence on the atmospheric pressure, we calculate the relative current, which is a ratio of the current in an irradiated layer to the average current of the two reference layers. Figure 4 shows the relative currents per layer as functions of the accumulated charge for irradiation during period III. The stability of the relative currents allows us to conclude that an aging effect is not observed for both chambers.

4.2. Measurements with muon test beams

Spatial resolution is the most important CSC parameter. We study the CSC spatial resolution with muon test beams using an external scintillator trigger which selects 15 cm^2 of the CSC sensitive area. The measurements with the muon beam are performed three times per year and the spatial resolution is obtained as a function of the accumulated charge, as shown in Fig. 5 for measurements with two types of gas mixtures, 5% CF_4 and 10% CF_4. A slight degradation of the ME1/1 resolution in period III (2023-2024) is observed. Also, ME2/1 spatial resolution in this period is worse than in period I. This effect requires further study, however, the observed change in the resolution is compatible with evaluated systematic uncertainty of the measurements, so we conclude that no aging effect is observed for both chambers.

By changing the source absorption filters, we change the background intensity. The spatial resolution as a function of the average CSC current is shown in Fig. 6. The measurements are done in period III. For both chambers the spatial resolution degrades linearly with increasing background intensity.

5. CONCLUSIONS

Cathode strip chambers are part of the CMS Endcap muon system and operate well with good spatial resolution in collision data taking. The forthcoming upgrade of the Large Hadron Collider into High Luminosity LHC and the planned upgrade of the CMS forward endcap zone requires further longevity studies of the endcap detectors. The longevity studies performed with different gas mixtures and small CSC prototypes showed that gas mixtures containing less than 5% CF_4 are potentially hazardous for long-term CSC operation. The longevity studies with ME1/1 and ME2/1 types of CMS CSCs being carried out at GIF++ since 2016 show no signs of ageing so far. Three gas mixtures were tested during the irradiation: 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 total charge accumulated up to now is 890 mC/cm for ME1/1 and 805 mC/cm for ME2/1.

REFERENCES

1. S. Chatrchyan et al. (CMS collaboration), JINST 3 (2008) S08004. https://doi.org/10.1088/1748-0221/3/08/S08004
2. G. L. Bayatian et al. (CMS collaboration), "The Muon Project", Technical Design Report, CERN/LHCC 97-32, CMS TDR 3, 15 December 1997. https://cds.cern.ch/record/343814/files/LHCC-97-032.pdf

3. Y. V. Ershov, A. O. Golunov, I. A. Golutvin, N. V. Gorbunov, A. Yu. Kamenev, V. Yu. Karjavin, S. V. Khabarov, V. S. Khabarov, Yu. T. Kiryushin, A. M. Kurenkov, A. A. Kurenkov, V. P. Ladygin, V. N. Lysiakov, G. V. Mescheriakov, P. V. Moissenz, K. P. Moissenz, et al., Phys. Part. Nucl. Lett. 3, 183–187 (2006). https://doi.org/10.1134/S154747710603006X
4. A. M. Sirunyan et al. (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. https://cds.cern.ch/record/2283189/files/CMS-TDR-016.pdf
5. A. Hayrapetyan et al. (CMS collaboration), 2024 JINST 19 P05064. https://iopscience.iop.org/article/10.1088/1748-0221/19/05/P05064/pdf
6. D. Pfeiffer, G. Gorine, H. Reithler, B. Biskup, A. Day, A. Fabich, J. Germa, R. Guida, M. Jaekel and F. Ravotti, Nucl. Instrum. Methods A 866 (2017) 91–103. http://doi.org/10.1016/j.nima.2017.05.045
7. M.R. Jäkel, M. Capeans, I. Efthymiopoulos, A. Fabich, R. Guida, G. Maire, M. Moll, D. Pfeiffer, F. Ravotti and H. Reithler. PoS (TIPP2014) 102. http://doi.org/10.22323/1.213.0102
8. A.M. Sirunyan et al. (CMS collaboration), 2018 JINST 13 P06015. https://iopscience.iop.org/article/10.1088/1748-0221/13/06/P06015/pdf
9. S. Chatrchyan et al. (CMS collaboration), JINST 5 T03018 (2010). http://dx.doi.org/10.1088/1748-0221/5/03/T03018
10. T. Ferguson, G. Gavrilov, A. Korytov, A. Krivchitch, E. Kuznetsova, E. Lobachev, G. Mitselmakher and L. Schipunov, Nucl. Instrum. Methods A 488 (2002) 240–257. https://doi.org/10.1016/S0168-9002(02)00400-X
11. Emanuela Barberis, Nebojsa Begovic, Nicholas Haubrich, Mikhail Ignatenko, Andrey Korytov, Ota Kukral, Ekaterina Kuznetsova, Armando Lanaro, Andrew MacCabe , Predrag

Milenovic, Dubravka Milovanovic, Guenakh Mitselmakher, Aleksandra Radulovic, Boris Rajcic, Jake Rosenzweig, Bingran Wang, et al., Eur. Phys. J. Plus 139, 166, (2024). https://doi.org/10.1140/epjp/s13360-023-04679-7

12. B. Wang, Nucl. Instrum. Methods A 958 (2020), 162279. https://doi.org/10.1016/j.nima.2019.06.020

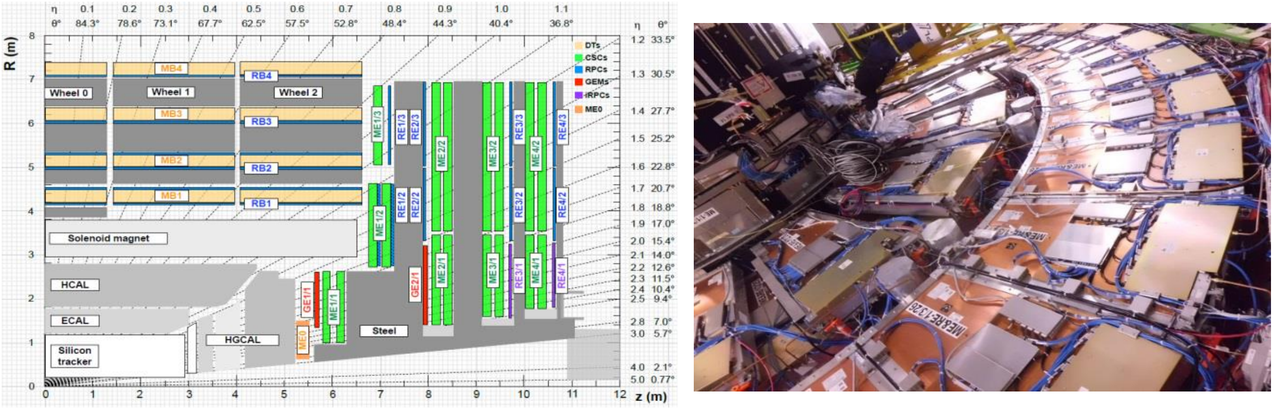

Fig. 1.

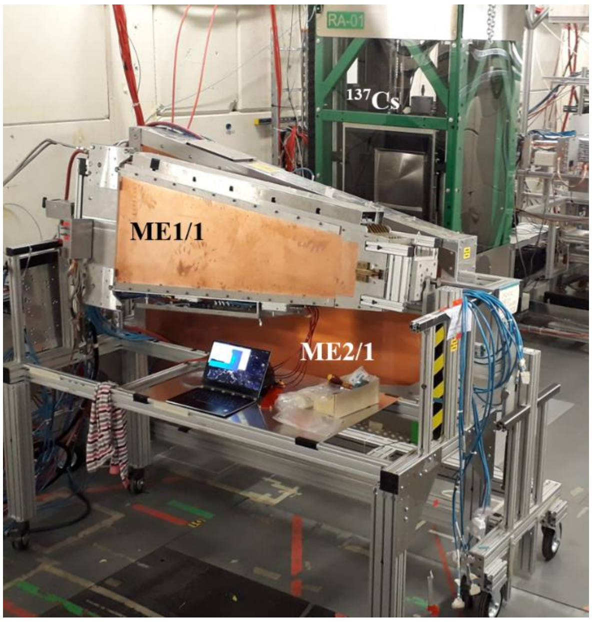

Fig. 2.

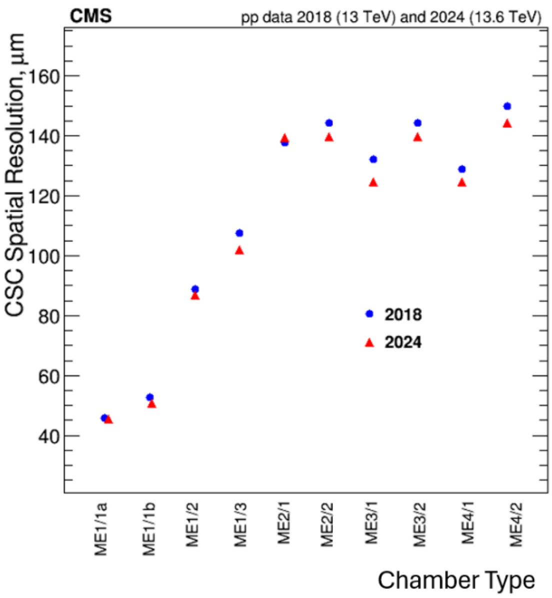

Fig. 3.

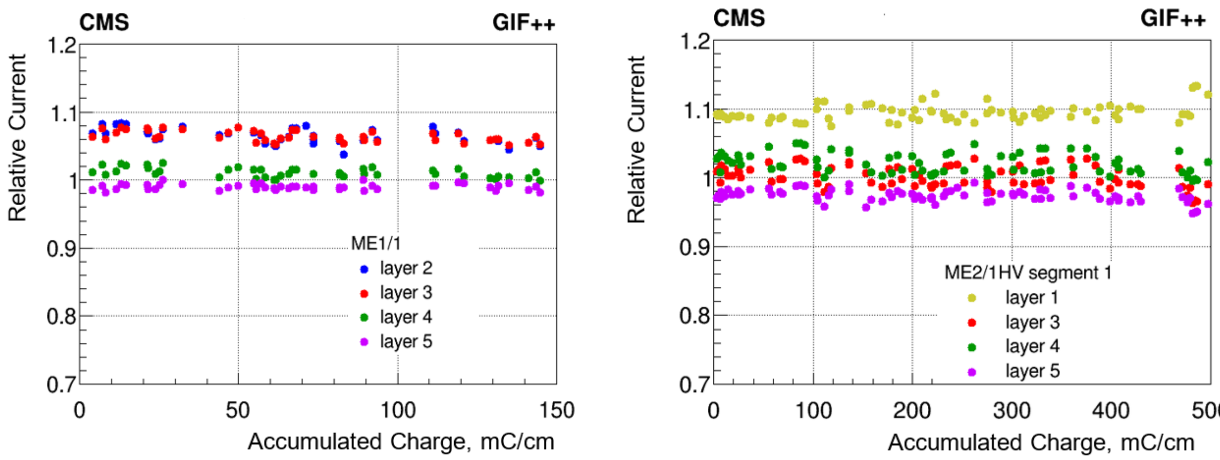

Fig. 4.

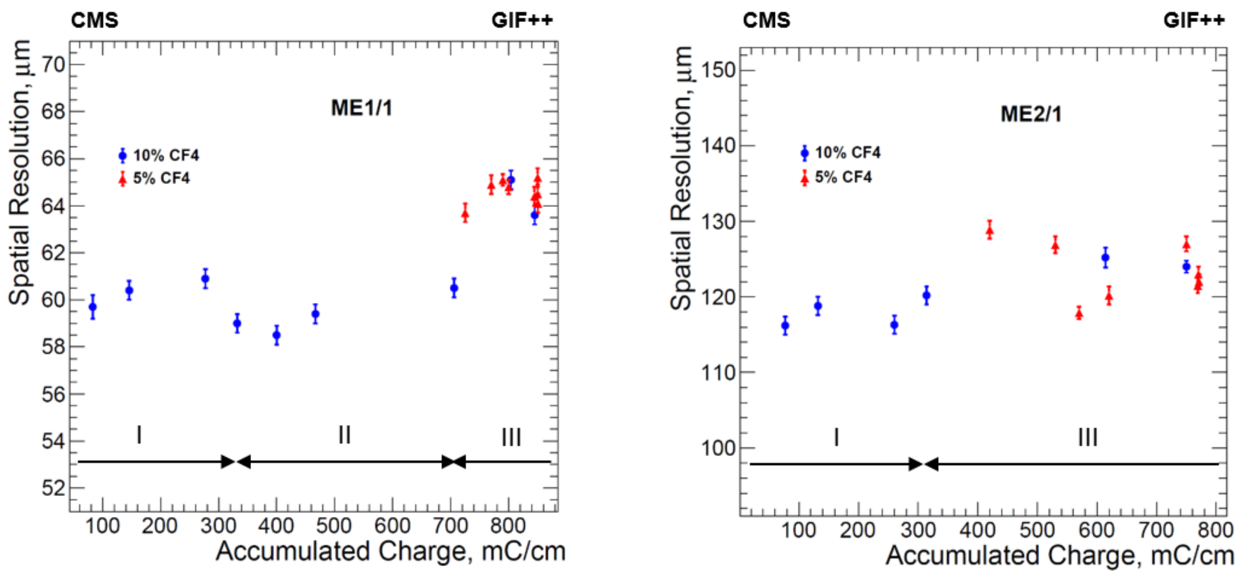

Fig. 5.

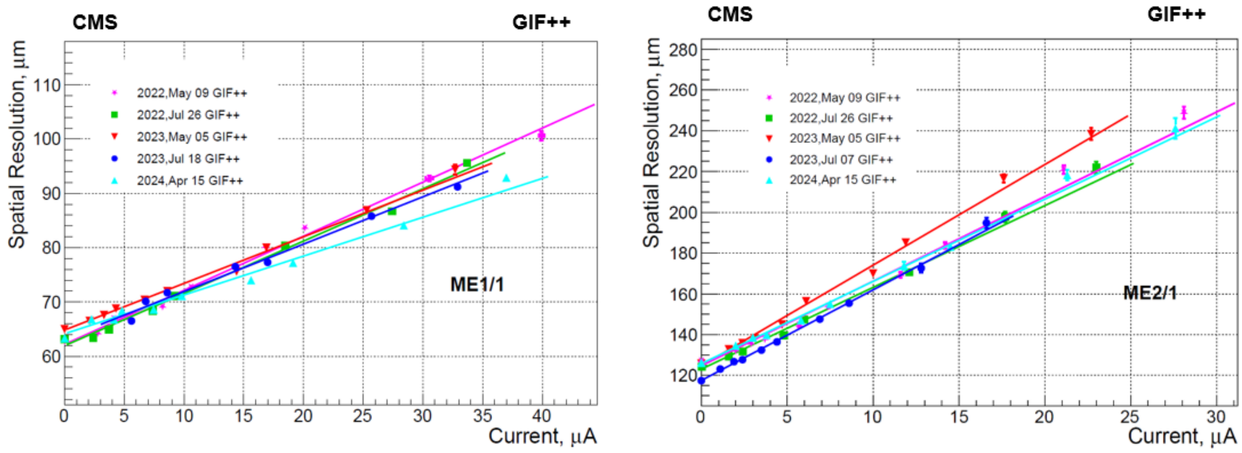

Fig. 6

Fig. 1. Left: CMS quarter view (future upgraded state shown) [4]. Right: photo of the endcap station 1.

Fig. 2. ME1/1 and ME2/1 CSCs at the irradiating position at GIF++.

Fig. 3. Spatial resolution of CSC rings using pp collisions data of 2018 (Run 2) and 2024 (Run 3).

Fig. 4. Relative currents in irradiated layers of ME1/1 (left) and ME2/1 (right) as a function of the accumulated charge shown for irradiation period III.

Fig. 5. Spatial resolution of the ME1/1 (left) and ME2/1 (right) chambers measured with a muon beam as a function of the accumulated charge. Circles represent the measurements done with 10% CF_4 gas mixture and triangles show the measurements with 5% CF_4 gas mixture.

Fig. 6. Spatial resolution as a function of the CSC current measured with a muon beam and ^{137}Cs source for ME1/1 (left) and ME2/1 (right) operating with 5% CF_4 gas mixture.

Table 1. Charge accumulated for ME1/1 and ME2/1 CSCs during different periods of irradiation at GIF++.

CSC	Accumulated charge Q (mC/cm)			
	before 2018 ($10\% \ CF_4$)	November 2021 ($2\% \ CF_4$)	October 2024 (5% CF4)	Total
ME1/1	330	370	190	890
ME2/1	310	Not irradiated	495	805
	Period I	Period II	Period III (ongoing)	