IL NUOVO CIMENTO **44 C** (2021) 45
DOI 10.1393/ncc/i2021-21045-2

Communications: SIF Congress 2020

ME0 project for the Triple-GEM upgrade of the CMS muon spectrometer: Design, preliminary performance and R&D perspective

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received 15 January 2021

Summary. — In the framework of the HL-LHC project, the upgrade of the CMS Muon System envisages the installation of three new muon stations based on the GEM technology, named as GE1/1, GE2/1 and ME0. The CMS GEM Group has developed a novel construction design of GE1/1 triple-GEM detectors; in particular, a new self-stretching technique has been introduced to mechanically stretch the GEM foils without using spacer grids or glue inside the gas volume. As has been observed, the PCB boards get deformed under the internal gas overpressure, introducing irregularities in the planarity of the detector, which could potentially affect the uniformity of the detector performance. New solutions and design upgrades have been implemented to prevent such effects in future GE2/1 and ME0 upgrade projects. The contribution will focus on the novel design solutions based on the PCB pillars and their impact on the performance of the detector. Furthermore, early results of the R&D campaign will be presented regarding the optimization of the detector for the very high hit rate environment and the reduction of the discharge probability.

1. – Introduction

The High Luminosity Large Hardon Collider (HL-LHC) [1] will be an upgrade of the current accelerator present at the CERN laboratory. The delivered luminosity of the accelerator will significantly increase the discovery potential of the experiments at the collider. The experiments themselves have to upgrade their detection systems to cope with the higher luminosity. In particular, regarding the CMS detector [2], an upgrade of the muon system is planned to increase the muon coverage at higher pseudorapidity [3]. A new station, called ME0, will be installed in the pseudorapidity range $2.03 < \eta < 2.80$ of the muon spectrometer, the detectors will exploit the Triple Gas Electron Multiplier (GEM) technology [4], a Micro Pattern Gaseous Detector (MPGD) technology suited to muon detection in high-background environment and with an high radiation hardness.

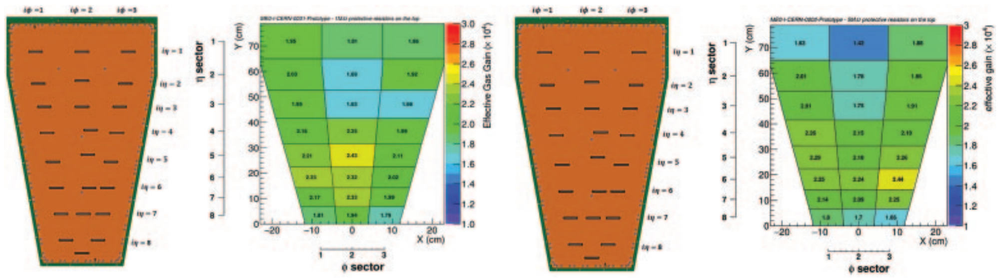

Fig. 1. – 2D mapping of the effective gas gain measurement of the first ME0 module prototype (ME0-I-CERN-0001 on the left) and the second ME0 module prototype (ME0-I-CERN-0002 on the right) as a function of spatial location.

In this pseudorapidity region, during the HL-LHC era, a larger amount of background particle will be delivered with respect to the actual LHC design. From early simulations the maximum expected hit rate on the ME0 detector is 144 kHz/cm^2, while the average hit rate on the detector is expected to be around 21 kHz/cm^2. Each of these particles is supposed to release around 300 electron-ion pairs in the conversion region of the detector, hence a charge of 7.9 C/cm^2 is expected to be collected in the most irradiated area of the detector in 10 years of operation of ME0.

2. – ME0 mechanical design

The CMS GEM Group has developed an innovative method to produce trapezoidal, large-area GEM detectors, notably the self-stretching technique [5, 6]. From the past experience on the R&D and the mass production of the GE1/1 station [3,6,5], the CMS GEM Group has improved the design of large Triple-GEM detectors. In particular, the GEM foils for future chambers will be segmented on both sides in order to reduce the side effects of the discharges occurring inside the detector during the electron multiplication. The introduction of four distance holders (pillars) inside the gas volume has been a further improvement for the gain uniformity of the detectors. The uniformity of the gain along the chamber improved sensibly with a minor loss of active area (around 1.3%). Figure 1 shows the uniformity of two of the first ME0 detector prototypes. The uniformity is around 11% and 13% which is far better than the one of the design without the pillars, which is around 25% [6].

3. – Aging and rate capability studies

As discussed in sect. 1 the detectors placed in the ME0 position will receive a large amount of background particles during their lifespan. This fact raises two major issues: the aging and the rate capability of the detector. Aging means any loss of performance caused by the long exposure of the chamber to irradiation. The CMS GEM Group successfully demonstrated that a Triple-GEM detector with the CMS design and materials can collect up to 1.55 C/cm^2 without any performance loss [6,7] (see fig. 2). Even if this is a big achievement for a gaseous detector technology, reaching the goal of 7.9 C/cm^2 requires to continue the irradiation test for one more year.

The high rate environment expected in the ME0 position of the CMS muon spectrometer is an issue for the correct operation of the GEM detectors. By construction, GEM

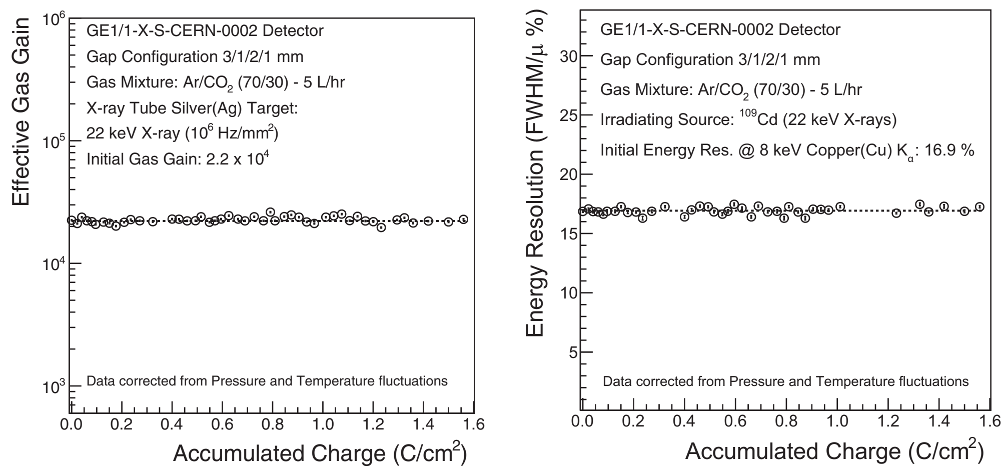

Fig. 2. – Result of the GEM aging test at QC/QA laboratory. The effective gas gain as a function of the integrated charge (left). The energy resolution at the copper fluorescence peak as a function of the integrated charge (right).

detectors collect a part of the avalanche charge on the foil itself. If a resistor is placed between the high-voltage channel and the GEM foil side, the voltage drop induced by the current flowing on the resistor may reduce the voltage across the GEM foils and, thus, its gain. Since resistors have to be used in this delicate place to protect the detector and the electronics from the side effect of sparks, the CMS GEM Group has to study the effect of the irradiation on the detector performance. A study was made on the first two detector prototypes mounting different protection resistors. Moreover, the effect of a high-voltage filter (an RCR filter) was studied. Figure 3 shows the results of the test.

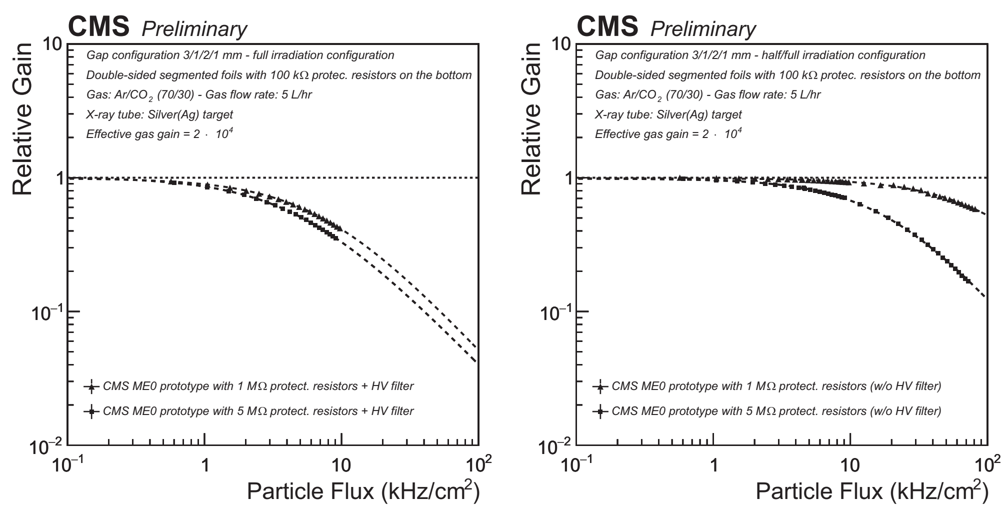

Fig. 3. – Normalized gain value as a function of the hit rate per unit area on the detector. On the left, results of the two prototypes with the high-voltage filters mounted, on the right without any high-voltage filter. The dotted curve is a power-law fit.

The effect of the protection resistor is clear in both measurements. The prototype with 1 MΩ on the top electrode loses around 65% of the gain at 9 kHz/cm^2 with the filter and 50% of the gain at 90 kHz/cm^2 without the filter. The other prototype, that mounts a 5 MΩ on the top electrode, loses around 75% of the gain at 9 kHz/cm^2 when using the filter and loses 92% of the gain at 90 kHz/cm^2 without the filter. It is clear that the effect of the filter is dominant, and this was expected since all the currents created on the electrodes flow through it.

4. – Conclusion and future plans

After the successful mass production of the GE1/1 detectors, the CMS GEM Group improved the design of the chambers to obtain more efficient detectors to be operated in the very harsh environment of the ME0 station. The introduction of pillars increased the gain uniformity across the detector and the double segmentation of the foils reduced the side effect of sparks.

For the right operation of the ME0 detectors, two main issues related to the high background, remain open: aging and rate capability. From the aging point of view, the CMS GEM Group plans to reach the goal without large gain drop. Indeed, advanced aging tests revealed a very high radiation hardness of GEM-based detectors also in the presence of contaminated gas mixture and when irradiated with heavily ionizing particles [7, 8]. The rate capability is now the main issue since the built prototypes cannot operate in such high-background hit rate. A deep study to find the correct high voltage distribution scheme for the correct operation is now ongoing and is also taking into consideration a possible change of the detector design.

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