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Irradiation effects on GEM detectors operated at RUN1 and RUN2 at the LHCb experiment

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The GEM detectors with pad readout have been installed in the Muon apparatus of the LHCb experiment, more precisely in the innermost region (R1) of the first muon station (M1) . The GEM detectors have been operated with $Ar/CO_2/CF_4$=45/15/40 gas mixture at a gain of about 4000 with an average particle flux of about 200 kHz/cm^2. During the RUN1 and RUN2, corresponding to about 440 days colliding beams, the triple-GEM have integrated a charge up to 0.6 C/cm^2.
In this work, we present and compare the different effects, on the GEM detectors, obtained in a previous global irradiation test at the Calliope facility of the ENEA-Casaccia (1.25 MeV γ rays flux from a ^{60}Co source) and after their operation in LHCb with the CF_4-based gas mixture.
In both cases, the detectors have been opened and the GEM foils have been investigated by the EN-MME-MM CERN group [1] with a Field Emission Gun Scanning Electron Microscope (FEG-SEM) for a magnified image analysis and an X-Max Energy Dispersive X-Ray Spectroscopy (EDS) for the chemical one.
After the accelerated test at Calliope, where a charge up to 2.2 C/cm^2 has been integrated in 30 days, is clearly observed an etching of the GEM foils due to fluorine: larger effect is visible on the hole diameter of the third GEM foil (from the standard 70 μm up to
80 μm), while minor effects are found on the first and second foils. Fluorine is mostly located on the copper around the holes edge, leading to the formation of a thin non-conductive layer (a fluorine-copper compound). This fluorine etching effect is due to the bad gas flow condition (350 cc/min) with respect to the very high particle irradiation (about 20 MHz/cm^2) used during the Calliope test [2].
On the contrary, the preliminary results on triple-GEM detectors after their operation in LHCb do not show clear evidence of fluorine etching: residues of Sulfur (S), Nitrogen (N) and Oxygen (O) have been found all over the GEM copper surface, the holes edges and on the exposed Kapton inside the amplification holes. The thickness of these depositions varies from few nanometers (first GEM) to about 2 μm (third GEM) and their origin is actually under investigation.

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[1] https://en.web.cern.ch/group/mme
[2] M. A. e. al., "Studies of etching effects on triple-GEM detectors operated with CF4-based gas mixtures," IEEE TRANSACTIONS ON NUCLEAR SCIENCE, vol. 52, pp. 2872-2878, 2005.

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