The Compact Muon Solenoid Experiment

Conference Report

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Geant4 simulation of a Triple-GEM detector exposed to the CHARM field at CERN

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Abstract

The ME0 station has been proposed for the installation in the CMS muon system in the region $2.03 < |\eta| < 2.82$, with the aim of increasing the detector acceptance for physics with muons. This region, presently not instrumented, is characterized by a very harsh radiation environment, which can reach rates up to 30 kHz/cm^2 and an integrated charge of the order of 200 mC/cm^2 over ten years of operation. The technology proposed for this station is Triple - Gas Electron Multiplier (Triple-GEM), which has already been qualified for the operation in the CMS muon system. However an additional set of studies focused on the discharge probability is necessary for the ME0 station, due to the characteristic radiation environment mentioned above. A test was carried out in 2017 at CERN's High-Energy-Accelerator-Mixed (CHARM) facility, with the aim of giving an estimation of the discharge probability of Triple-GEM detectors in a very intense mixed field environment, similar to the one of the CMS muon system. A dedicated stand-alone Geant4 simulation was performed simultaneously, in order to evaluate the behavior of the detector exposed to the CHARM field. The geometry of the detector has been carefully reproduced, as well as the background field present in the facility. This contribution will present the results obtained from the Geant4 simulation, in terms of sensitivity of the detector to the CHARM environment, together with the analysis of the energy deposited in the gaps. The results from simulation will be finally compared with the experimental one obtained from the test.

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Geant4 simulation of a Triple-GEM detector exposed to the CHARM field at CERN

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Abstract—A forward muon detector (ME0) has been proposed for the installation in the CMS endcap muon system in the region $2.0 < |\eta| < 2.8$, to increase the muon acceptance. This region is characterized by a very harsh radiation environment, which can reach rates up to few hundreds of kHz/cm^2 . The technology proposed for the ME0 station is Triple-Gas Electron Multiplier (Triple-GEM), which has already been qualified for the operation in the CMS muon system. However an additional set of studies focused on the discharge probability is necessary for the ME0 station, due to the characteristic radiation environment mentioned above. A test was carried out in 2017 at the CERN High energy AcceleRator Mixed (CHARM) facility, with the aim of giving an estimation of the discharge probability of Triple-GEM detectors in a very intense radiation environment, similar to the one in the CMS muon system. A dedicated study with a standalone Geant4 simulation program was performed in order to evaluate the behavior of the detector exposed to the CHARM field. The geometry of the detector has been carefully reproduced, as well as the background field present in the facility. This paper will present the results obtained from the Geant4 simulation, in terms of sensitivity of the detector to the CHARM environment, together with the analysis of the energy deposited in the gas gaps.

Fig. 1. Overview of the CMS muon system upgrade.

1. INTRODUCTION

In order to meet the challenges that the High-Luminosity (HL-LHC) upgrade of the LHC will bring, the CMS Collaboration decided to improve the muon system. Among the new detectors that have been proposed, a muon detector (ME0) at the station 0 of the endcap region should be installed in $2.0 < |\eta| < 2.8$ (Fig.1) during Long Shutdown 3 (LS3). The main motivation for the insertion of the ME0 station is the increase in the CMS acceptance for physics with muons. In particular this short section of muon detector (~ 40 cm in radius) could increase the muon acceptance by $\sim 10\%$ [3].

For these reasons, the technology to be installed in the ME0 station should be able to discriminate muons from neutron and photon background, finding muon stubs among background hits. In particular, the expected background fluxes in the ME0 region can reach up to $\sim 5 \text{ MHz}/\text{cm}^2$.

The technology proposed for the ME0 detector is Triple-GEM detectors [1], similar to those that will be firstly used for the GE1/1 station in LS2. Each ME0 stack will be composed by six chambers, arranged as in Fig.2. The grey part is actually the structure with the six layers of GEM detectors, while the green box is the electronics volume [3].

Fig. 2. Stack of six Triple-GEM detectors for the ME0 station [3].

The qualification of operation of Triple-GEM detectors in a huge radiation environment was already partially performed during the GE1/1 (the first new GEM station) R&D phase, when it was possible to reach an integrated charge of $55 \text{ mC}/\text{cm}^2$ without degradation of performance [4]. A continuation of this test was performed at the GIF++ facility [5] at CERN and in laboratory with X-rays, where an integrated charge up to $1 \text{ C}/\text{cm}^2$ was reached. However a test dedicated to the measurement of discharge probability in an environment similar to the one of the CMS muon system was also necessary to fully qualify the operation of the detectors. Indeed, discharges are the main general problem of Micropattern Gaseous Detectors, including GEM, as they can prevent the detector from working properly.

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2. THE CHARM FACILITY

The facility selected for the discharge probability test was the CHARM facility [6], built at CERN in the Proton Synchrotron (PS) east area (see Fig.3).

Fig. 3. Overview of the CHARM facility along the PS beam line [6].

The CHARM field is produced by the interaction of the 24 GeV/c PS proton beam with a cylindrical copper or aluminium target. The high energy hadrons field produced is mainly composed by neutrons, protons, pions, kaons and muons. In addition, an high intensity flux of gammas is also present.

Fig. 4. Thirteen irradiation positions (black squares) as reproduced in the CHARM FLUKA geometry, cut at beam-height [6].

The intensity of the field is different in the various irradiation positions: for our test the position R3 in Fig.4 was used. The CHARM facility is also equipped with an array of shielding blocks of concrete (in grey) and iron (in brown) [6]. During our test, the full shielding was used, the irradiation configuration is called *R3 with CuCIIC*, where Cu represents the copper target for the beam and CIIC is the shielding configuration.

Fig.5 shows the normalized fluence in the irradiation position: the wider spectrum is from neutrons, going from 10^{-9} MeV to 10^3 MeV. The contribution of the other particles spectra is relevant only for energies higher than 100 keV.

Fig. 5. Energy spectrum of the different particle species present in the irradiation position. The data are coming from a FLUKA simulation [7].

3. GEANT4 SIMULATION

In order to understand the behavior of a Triple-GEM detector immersed in the CHARM field during the irradiation test, a dedicated Geant4 [8], [9], [10] simulation has been performed. Aim of this simulation, first of all, was to obtain an estimation of the sensitivity of the Triple-GEM detector to the CHARM particles, i.e. the probability for a background particle to generate a visible signal into the detector. For this scope, the geometry of the detector, sketched in Fig.6, has been then carefully reproduced including the following elements:

- Standard Triple-GEM detector, 10×10 cm², with gap configuration 3:1:2:1 mm
- Kapton window, 50 μ m-thick, plus PCB (FR4) foil, 1.2 mm-thick, on top, as done during the irradiation
- Gas gaps filled with Ar/CO₂ 70/30.

The detector was then fixed to an aluminum support, included as well in the latest version of the simulation.

Fig. 6. Geant4 geometry of the Triple-GEM chamber used in the present study.

In parallel, the spectrum of every component of the CHARM field in the irradiation position has been obtained from a sampling of the complete spectrum shown in Fig.5.

4. RESULTS

A. Sensitivity

The sensitivity of the Triple-GEM detector to each particle species composing the CHARM field has been then calculated

as

$$S = \frac{N_{signals}}{N_{incident\ particles}} \quad (1)$$

where we assume that the detector fires if at least one charged particle reaches one of the first two gas gaps of the Triple-GEM detectors. Of course, this assumption leads to the estimation of an upper limit for the sensitivity. Fig.7 shows the results in terms of sensitivity as a function of the energy of the incident particle, for the different particle species present in CHARM.

Fig. 7. Sensitivity of the Triple-GEM detector exposed to the CHARM flux as a function of the energy of the incident particle, for the different particle species present.

From the convolution of the sensitivity with the particle spectra, the hit rate is obtained. It is useful to understand which particle gives the highest contribution in each energy range:

- Below 1 MeV: neutrons are dominant
- Above 1 MeV: neutron contribution drops in favour of the different species of charged particles.

B. Energy deposited

An additional analysis has been performed on the energy deposited by the particle into the different gas gaps. Each gas gap has been considered independently and the average total energy deposited has been analyzed. Fig.8 shows the result of this study for the drift gap, as a function of the energy of the incident particle, for the different particle species present.

Overall, this analysis proved that the total energy deposited can reach up to ~ 100 keV for photons and ~ 1 MeV for neutrons, the two predominant components of the CMS background. The next steps of the energy deposited analysis foresee the calculation of the energy deposited by the primary electrons followed by the extrapolation of the number of primaries produced as

$$N_{prim} = \frac{E_{dep}^{prim}}{28\text{ eV}} \quad (2)$$

where 28 eV is the W-value of Ar/CO₂ 70/30 gas mixture.

Fig. 8. Average total energy deposited into the drift gap of the Triple-GEM chamber by particle hitting the detector as a function of the energy of the incident particle.

5. CONCLUSIONS

Along with a discharge probability test for Triple-GEM detectors at the CERN CHARM irradiation facility, a dedicated Geant4 simulation has been carried out to analyze the behavior of the detector in such radiation field. The results of sensitivity and energy deposited in the gas gaps have been presented. The simulation work is continuing in order to extrapolate the number of primaries produced inside the gas gaps by the particle that generates the signal.

6. ACKNOWLEDGEMENTS

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REFERENCES

- [1] CMS Collaboration, "CMS Technical Design Report for the Muon Endcap GEM Upgrade," CERN-LHCC-2015-012 ; CMS-TDR-013.
- [2] F. Sauli, "GEM: A new concept for electron amplification in gas detectors," Nucl. Instrum. Meth. A **386**, 531 (1997).
- [3] CMS Collaboration, "The Phase-2 Upgrade of the CMS Muon Detectors," CERN-LHCC-2017-012 / CMS-TDR-016.
- [4] J. Merlin, "Study of long-term sustained operation of gaseous detectors for the high rate environment in CMS," <http://www.theses.fr/2016STRAE005>.
- [5] "GIF++," <https://ep-dep-dt.web.cern.ch/irradiation-facilities/gif>.
- [6] A. Thornton, "CHARM Facility Test Area Radiation Field Description," CERN-ACC-NOTE-2016-12345
- [7] A. Infantino, "FLUKA Monte Carlo Modelling of the CHARM Facility's Test Area: Update of the Radiation Field Assessment," CERN-ACC-NOTE-2017-0059
- [8] "Geant4 A simulation toolkit," Nucl. Instrum. Meth. A **503** (2003), 250-303.
- [9] "Geant4 developments and applications," IEEE Transactions on Nuclear Science 53 No. 1 (2006) 270-278
- [10] "Recent developments in GEANT4," Nucl. Instrum. Meth. A **835** (2016), 186-225.