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Development and performance of Triple-GEM detectors for the upgrade of the muon system of the CMS experiment

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Summary. — The CMS Collaboration is evaluating GEM detectors for the upgrade of the muon system. This contribution will focus on the R&D performed on chambers design features and will discuss the performance of the upgraded detector.

The Compact Muon Solenoid (CMS) Collaboration is evaluating the implementation of new muon stations in the high η region of the muon system. Among the technologies considered, Gas Electron Multiplier (GEM) detectors are expected to fulfill the High-Luminosity LHC (HL-LHC) requirements in spatial, angular and time resolutions, as well as in rate capability and radiation hardness [3].

Gas Electron Multipliers are a well-known technology, detailed informations on their operational principle can be found in [1] and [2]. The work of the GEM Collaboration focused therefore on the improvement of the streching technique, the mechanics, the

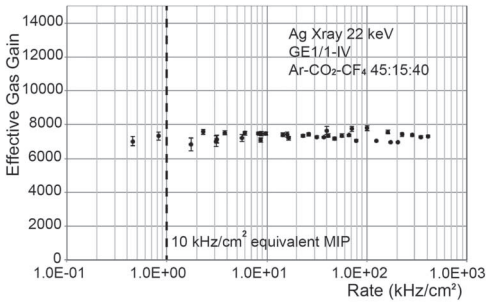

Fig. 1. – Effective gas gain as a function of the incident photon rate measured with the fourth GE1/1 detector prototype, operated with $Ar/CO_2/CF_4$ 45:15:40 and irradiated with a Ag X-Ray source (peak energy 22 keV). The dashed line represent the expected rate in the CMS muon system [3].

assembly procedure and so on. Five generations of full-size GE1/1 (GEM Endcap 1/1) prototypes were developed between 2010 and 2014: the R&D activity led to the design of a final detector that can be assembled in few hours, with foils mechanically stretched and without gluing any component. The gaps configuration has been perfected in order to achieve a higher signal speed.

The results of test beams performed at CERN and at Fermilab show that the developed detector matches the HL-LHC requests in detection efficiency (97–98%), timing resolution (few ns), angular resolution (100–160 μrad), spatial resolution (200–300 μm) and rate capability, as shown in fig. 1 where the dashed line represent the expected rate in the CMS muon system. The presence of a strong magnetic field (up to 1.5 T) does not deteriorate the performance of GE1/1 detector. Aging tests performed at the Gamma Irradiation Facility (GIF) at CERN show no drop in the gain due to accumulated dose up to 10 mC/cm^2, and will continue to investigate charges higher than 100 mC/cm^2 [3], *i.e.* the expected integrated charge value obtained in 20 years of operation of HL-LHC.

In conclusion, the results obtained in several test beams highlight that the R&D performed on GEM detectors led to the development of a prototype capable of sustaining the harsh conditions of HL-LHC. Consequently, a first installation of a demonstrator within the CMS muon system is foreseen for 2016-2017 and, after that, the installation of a full GEM station in the region $1.6 < |\eta| < 2.2$ (GE1/1) is planned for 2018-2019.

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REFERENCES

[1] Sauli F., *Nucl. Instrum. Methods A*, **386** (1997) 531.
[2] Sauli F., *Gaseous Radiation Detectors Fundamentals and Applications*, in *Cambridge Monographs on Particle Physics, Nuclear Physics and Cosmology* (Cambridge university Press) 2014.
[3] CMS GEM Collaboration, *CMS-TDR-013* CERN-LHCC-2015-012 (2015).