

CMS Muon System Phase 2 Upgrade with triple-GEM detectors

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Abstract—The Compact Muon Solenoid (CMS) detector installed at the CERN Large Hadron Collider (LHC) has an extensive muon system which provides information simultaneously for identification, track reconstruction and triggering of muons. As a consequence of the extreme particle rate and high integrated charge, the essentiality to upgrade the LHC has given rise to the High Luminosity phase of the LHC (HL-LHC) project so that the CMS muon system will be upgraded with superior technological challenges. The CMS GEM collaboration offers a solution to equip the high-eta region of the muon system for Phase 2 (after the year 2017) with large-area triple-layer Gas Electron Multiplier (GEM) detectors, since GEMs have the ability to provide robust and redundant tracking and triggering functions with an excellent spatial resolution of order 100 micron and a high particle rate capability, with a close to 100% detection efficiency. In this contribution, the present status of the triple-GEM project will be reviewed, and the significant achievements from the start of the R&D in 2009 will be emphasized.

I. INTRODUCTION

The CMS Muon System, which is designed to detect and reconstruct muons with the best precision, needs an upgrade to handle the high rate and intensive environment of High Luminosity LHC during Phase 2. New detector requirements include a high rate capability (\sim Mhz/cm²), and in addition, a new station must be able to

strips segmented over 24 readout sectors in the (η, ϕ) -plane (ϕ is taken as the azimuthal angle) The GEM foils are produced by single-mask etching technique at CERN, and each foil is divided into 40 and 47 high voltage sectors that are transverse to the direction of the readout strips as shown in Fig. 3b for short and long foils, respectively. The active readout area is 0.345 and 0.409 m² for the short and long chambers, respectively. The high voltage is applied between the copper layers in order to obtain an electric field of the order of ~ 60 kV/cm in the kapton and few kV/cm in the gas gaps.

IV. GE1/1 DETECTOR DESIGN AND PERFORMANCE

The CMS triple-GEM prototypes are produced with very innovative assembly technique based on mechanical stretching of the GEM foils. Initially, the GEM foils are tested for leakage current and the readout boards are checked with a dedicated tool capable of identifying any possible bending damage. Stainless steel nuts are embedded into the frames with the axes of their threaded holes oriented perpendicular to the inner frame and GEM foil surfaces which is shown in Fig. 4, and this allows to assemble a full chamber in few hours time period [4].

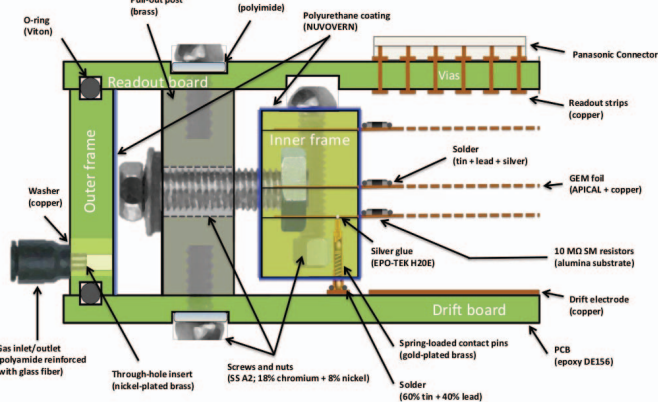


Fig. 4. Cross section through inner and outer chamber frames and GEM foils which shows how the GEM foils are mounted within the GE1/1 so that they can be mechanically tensioned against the brass pull-out posts without any deformation on the drift or readout boards.

The performance of the GE1/1 prototypes was evaluated with many test beams since 2009. The latest test beams have been performed at CERN in 2014 October (H2), 2014 November-December (H4), and 2015 October-November (H4). The chambers were operated with Ar/CO₂/CF₄ 45:15:40 and Ar/CO₂ 70:30 gas mixtures with a gain around 10⁴, and read-out with binary output VFAT2 [5] front-end chips. An efficiency of 98% was achieved when the detector operated with the high voltage that corresponds to a gain about 10⁴ for both gas mixtures used during H2 and H4 test beam 2014 campaign. For H4 test beam in 2015 test beam, the first

superchamber prototype was tested, and also one of the purposes was to test and debug some of the proposed GEM electronics readout system which is shown in Fig. 5. However, completed electronics design will start in 2016 when VFAT3 chips are available. Time response of the detector was measured as approximately 5 ns, using both gas mixtures, Ar/CO₂/CF₄ 45:15:40 and Ar/CO₂ 70:30 as shown in Fig.6 during the test beam campaign in 2014.

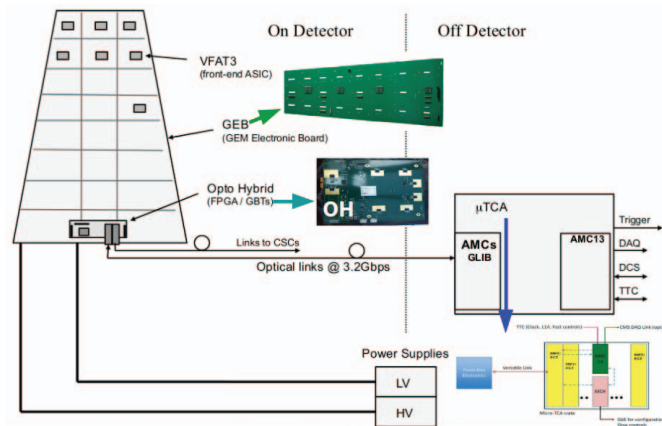


Fig. 5. New GEM electronics design with VFAT3 chip, GEB and Opto Hybrid on detector and μ TCA off detector side.

Test beam measurements yield acceptable results in terms of detector performance so that the measured properties are found to be suitable for the CMS forward muon upgrade.

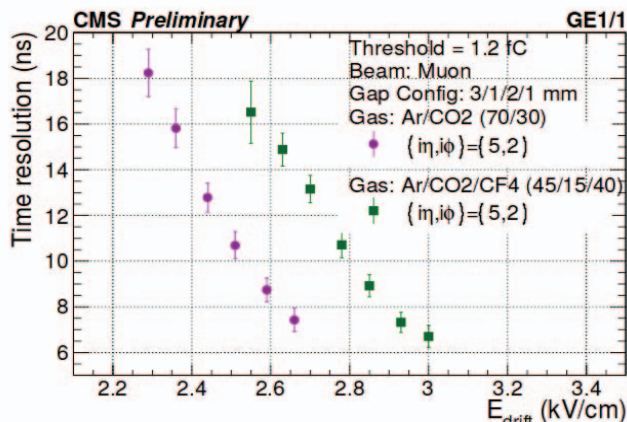


Fig. 5. Time response of the GE1/1 detector with Ar/CO₂/CF₄ 45:15:40 and Ar/CO₂ 70:30 gas mixtures.

V. QUALITY CONTROLS OF THE GE1/1 DETECTOR

A common construction and quality control procedure are required to ensure the performance of each detector. The quality control steps include optical inspection, cleaning and baking of all materials and parts used to build the detector, leakage current tests of the GEM foils, high voltage tests, gas leak tests of the chambers, gain calibration to know the

optimal operation region of the detector, gain uniformity tests, and studying the efficiency, noise and tracking performance of the detectors in a cosmic stand using scintillators. Final procedures are assembly and commissioning of the superchambers at CERN before installation in CMS, and all these steps are shown in Fig. 6. The GE1/1 chamber assembly will be done at several locations inside and outside CERN. At present, six assembly sites are being considered for GE1/1 mass production. All sites will follow the same assembly and quality control protocols, so they include same setups for assembly which needs to be installed clean room at each site, gain uniformity measurement with X-ray source, GEM foil leakage currents measurement at voltages up to 500V which requires a nitrogen-flushed box, and a gas leak measurement to verify gas tightness of the chambers.

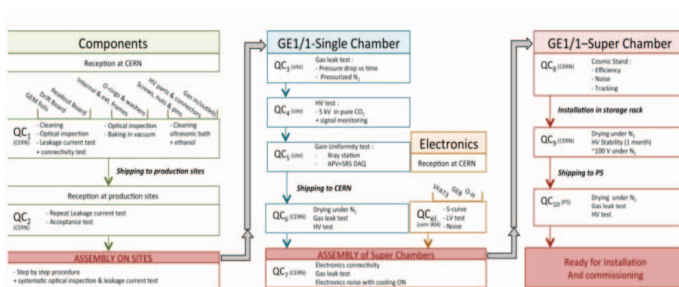


Fig. 6. Quality control steps of GE1/1 detector which include the components, tests of a single chamber and measurements on the GE1/1 superchamber.

The gain uniformity of each chamber is verified in a dedicated setup inside a copper protective box with an SRS/APV25 hybrid based data acquisition [6]. For this measurement, X-ray source is placed such that radiating the full chamber at once. The relative gain of the chamber as function the position along its surface is obtained by this measurement.

VI. SUMMARY AND CONCLUSION

In consequence of High Luminosity phase of the LHC, the CMS Collaboration is planning several muon system upgrades

in order to maintain its high level performance in terms of muon triggering and reconstruction. The installation of GE1/1 station is recently approved by the CMS Collaboration, so during LHC Long Shutdown 2, the region of $1.6 < |\eta| < 2.2$ of the first endcap disk will be equipped with a total of 144 new triple-GEM detectors which form 72 superchambers. Furthermore, during 2016-2017 year end technical stop of LHC, a 40° wedge of GE1/1 will be installed in CMS and this operation gains experience before the full installation in LS2. The CMS triple-GEM prototypes are produced with an innovative assembly technique based on mechanical stretching of the GEM foils. The GE1/1 chamber assembly will be done at several locations inside and outside of CERN, a detailed chamber assembly and quality control work flow are being worked out. Test beam measurements yield good results in terms of the detector performance, and the results achieve the CMS requirements for the upgrade of the muon system with a new GE1/1 station. The performance of the first superchamber which was tested during the H4 2015 test beam is being studied, herewith the new electronics design including also new VFAT3 chip improvements.

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