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Development and performance of large-scale triple GEM detectors for CMS

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Abstract

The international CMS GEM collaboration is studying the feasibility of upgrading the CMS forward muon system by adding layers of triple GEM based detectors. After successful tests of small size tripe-GEM chambers in the period of 2010-2011, the collaboration has designed, built and tested full size GEM chambers for the upgrade purpose. We report on results from test beam and simulation that were conducted to study the performance of the GEM chambers.

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Development and Performance of Large Scale Triple GEM for CMS

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ABSTRACT: The international CMS GEM collaboration is studying the feasibility of upgrading the CMS forward muon system by adding layers of triple GEM based detectors. After successful tests of small size tripe-GEM chambers in the period of 2010-2011, the collaboration has designed, built and tested full size GEM chambers for the upgrade purpose. We report on results from test beam and simulation that were conducted to study the performance of the GEM chambers.

KEYWORDS: CMS; Muon System Upgrade; GEM.

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1. Introduction

The CMS experiment [1] was designed to have a highly redundant muon system using three detection technologies: Drift Tubes (DT), Cathode Strip Chambers (CSC) and Resistive Plate Chambers (RPC). The endcap regions rely on CSC and RPC for $|\eta| < 1.6$. For higher η ($\eta| > 1.6$) regions, the system has limited redundancy and only CSC are installed. In the future running of LHC at full luminosity, the particle rate in the forward region is expected to reach several tens of kHz/cm^2 and the integrated charge will reach several C/cm^2, which make the use of the originally planned RPC technology questionable. To overcome these limitations, the CMS GEM collaboration proposed the Gas Electron Multiplier (GEM) as potential candidate to upgrade the high-η region of the forward muon system. GEM based detectors have demonstrated excellent spatial (100 μm) and temporal (5 ns) resolution, and are able to cope with particle rate up to 10 MHz/cm^2 [2], which make them an ultimate candidate to complement CSC chambers in high-η region. Therefore, their use in CMS is expected to improve muon momentum resolution for high p_T muon and to provide overall highly efficient muon and trigger tracking capabilities in this region.

2. Detector design description

In the past four years, the CMS GEM collaboration conducted an extensive program to demonstrate the feasibility of Triple-GEM based detectors for the high-η region of CMS muon system. After successful test with small size chambers [3], the collaboration has designed, built and instrumented large-area chambers for the upgrade proposal. These trapezoidal chambers, denoted GE1/1, are sectorized in η partitions to cover 10° each in the azimuthal sector and provide radial readout strip with the strips pointing to the LHC beam pipe (Figure 1, left). In this design, the strip pitch varies from 0.6 mm (lower side) to 1.2 mm (upper side) with 8-η sectors. To improve tracking capabilities, two GEM chambers will be mounted face-to-face to form a double layer called "Super-Chamber". Thus each Super-Chamber will provide two impact points for each muon track. The gas

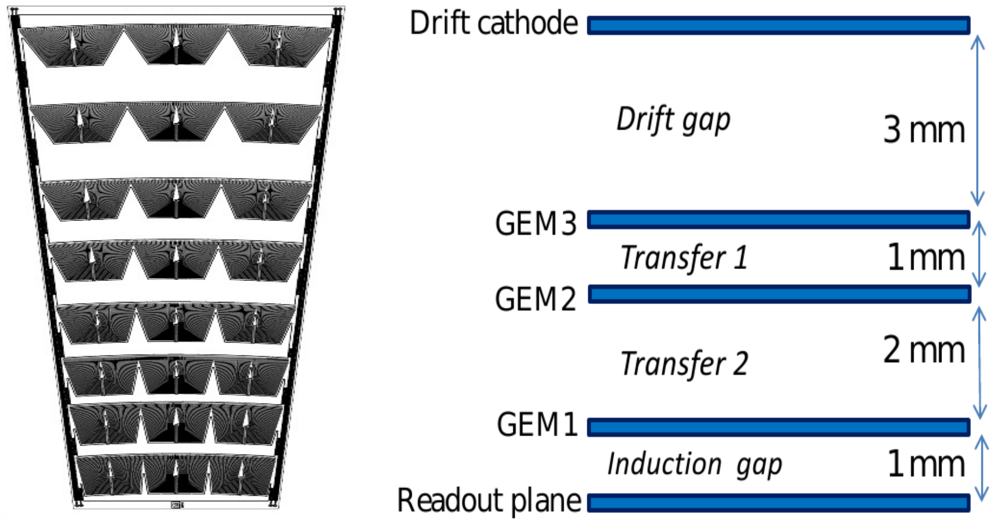

Figure 1. (Left) Drawing of a large trapezoidal CMS GEM chamber showing 8-η partitions, each one composed of 3 sectors. (Right) Cross section of the proposed triple-GEM showing the dimensions of the different gaps.

gap configuration is: 3mm (drift), 2 (transfer), 1(transfer) and 3 (induction) as shown in Figure 1, right, which proved to be optimal for timing purposes. The gas mixtures is Ar/CO_2/CF_4 45/15/40.

The GEM production was achieved with the so-called "Single-Mask" technique, which proved to overcome known limitations with previous standard techniques. The chambers were assembled using a new technique "Self Stretching" that consists of mechanically stretching the GEM foils as part of the assembly procedure without the need to put spacers. Detailed fabrication and assembly procedures can be found in [7, 4].

Two full size chambers were built and tested at the SPS H2 beam line at CERN. In parallel, an extensive simulation program is being conducted by the collaboration to study the performance of the design from individual GEM detectors to larger size chambers. In the following we will report on some results from the test beam and the simulation.

3. Results from Test beam and simulation

3.1 Test beam results

Two large scale GEM chambers were tested in the Fall of 2012 at the SPS H2 beam line at CERN with 150 GeV muon/pion beams. A hodoscope of small-area (10x10 cm^2) double sided GEM chambers was used to predict the hit position in the test chambers (Figure 2). Each tracking chamber has, on each side, 256 readout strips with a pitch of 0.4 mm.

The full scale CMS GEM chamber has a trapezoidal shape with dimensions of 990 x (220-445) mm. The strips are segmented in 8-η partitions. Each partition is sectorized along the ϕ-coordinate into 3 readout sectors each with 128 strips. Thus 3072 channels are readout for the whole test chamber. During the test beam, two readout scenarios were used: digital TURBO/VFAT2 [5] and Scalable Readout System (SRS) developed by RD51 collaboration and based on APV25 [6]

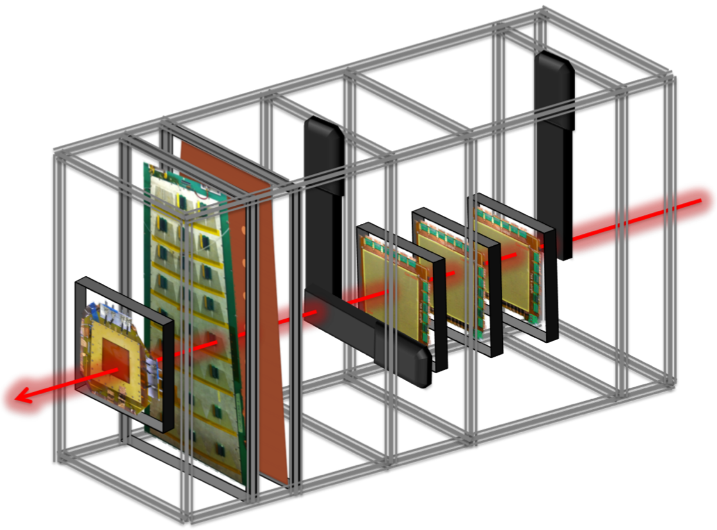

Figure 2. Schematic view of the test beam setup with the three square GEM hodoscope and the trapezoidal CMS GEM chambers.

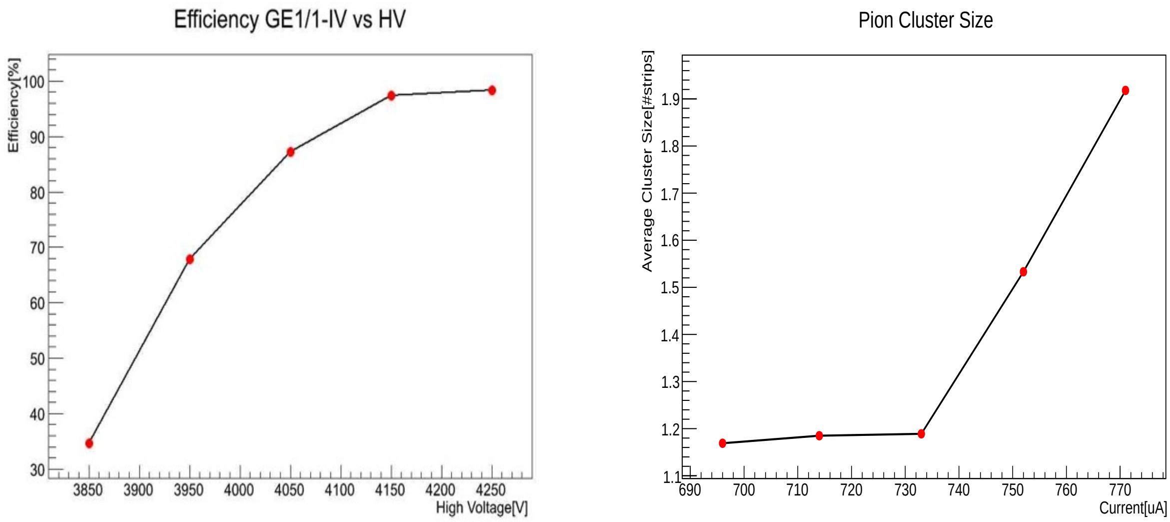

Figure 3. (Left) Detection efficiency as a function of the divider HV. (Right) Cluster size as a fucntion of the HV divider current for an average readout pitch of 900 μm..

chips. In the following we will report on VFAT2 only. The high voltage powering was realized using a ceramic high voltage divider. The CMS test chambers were placed, closed to the tracking hodoscope, on a vertically movable support to allow scanning.

Figure 3 (left) shows the efficiency obtained with the HV scan of one sector. An efficiency of 98 % was obtained when the detector was operated with HV that corresponds to a gain of $\approx$ 7000. The cluster size as a function of the HV divider current is shown in Figure 3 (right) for a readout pitch for 900μ m.

Figure 4 shows the residual between the impact position of the track reconstructed by the hodoscope and then extrapolated to the test chamber and the hit position measured by the test

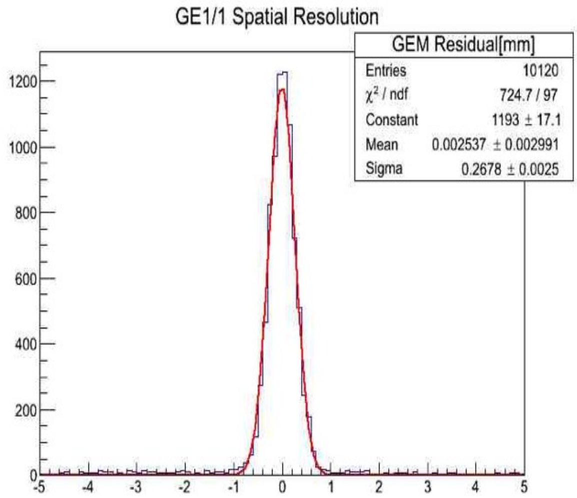

Figure 4. Residual between the impact position measured by the CMS GEM chamber of the one extrapolated by the hodoscope.

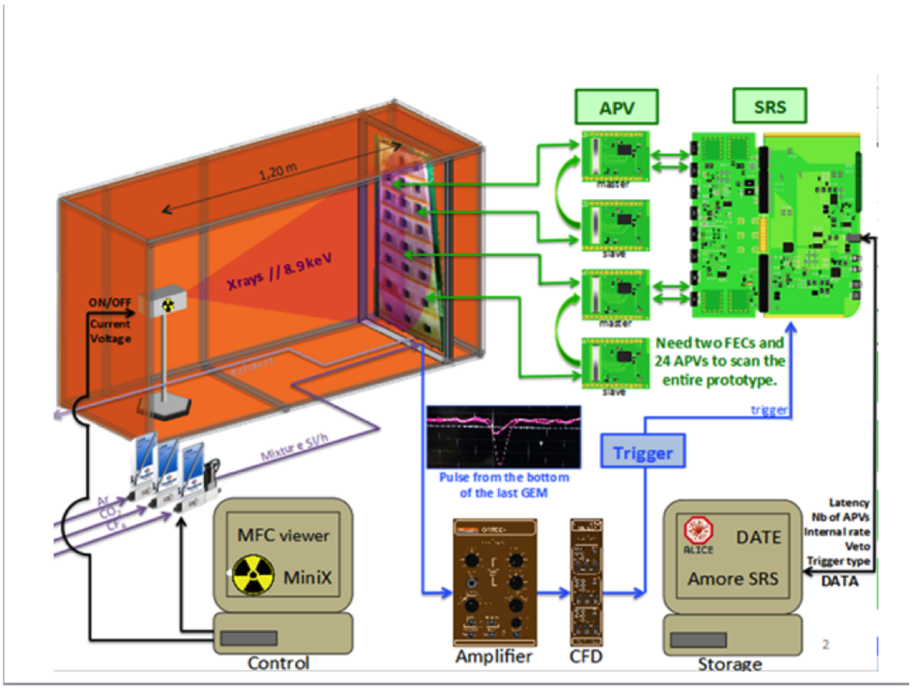

Figure 5. Schematic view of the setup used to study the gain uniformity as part of the quality control procedure.

chamber for an η-sector where the strip pitch is around 900 μm. The measured spatial resolution of 268 μm is in agreement with the theoretical expected value of 260 μm for this pitch using digital VFAT2 readout.

Given the trapezoidal shape, the large size and the varying pitch along the strips, the uniformity of response had to be carefully assessed. This procedure is foreseen to be part of the quality

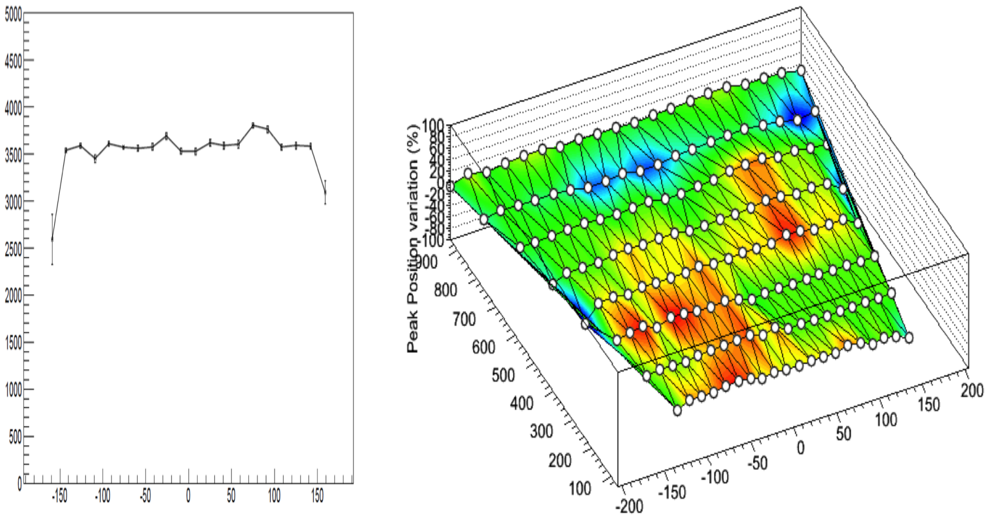

Figure 6. Results from uniformity studies with X-ray beams. (Left) The collectd cluster charge as a function of the position along one η-sector. (Right) The collected cluster charge across the full chamber's active area. Each point represents the mean value of a Gaussian fit to the charge distribution collected by 30 adjacent strips.

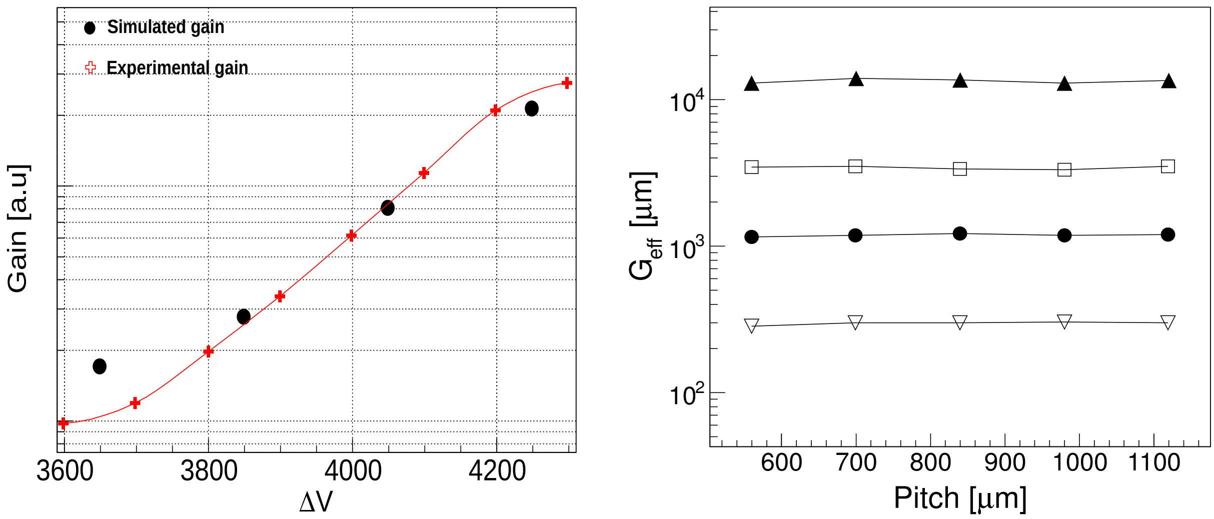

Figure 7. (Left) Normalized gain as a function of the divider HV for both experimental measurement and simulation. (Right) Effective gain as a fucntion of the readout strip pitch for different divider HV values.

controls check during final production. The uniformity test was conducted by scanning the full chamber with a Cu-based X-ray beam at the Gamma irradiation Facility at CERN (figure 5). The test chamber was placed at a distance of 1 m from the X-ray source. The complete setup is detailed in [7]. The prototype was readout using the SRS/APV25 combination and the software used to analyze the data was based on the ALICE DAQ (DATE) package [8].

Figure 6 (left) shows the chamber response across one fixed η-sector. Each point represents the mean value of a Gaussian fit to the charge distribution collected by 30 adjacent strips. The setup allowed a full scan of the chamber. Figure 6 (right) gives the gain across the full active area of the test chamber. Less than 15% variation in the collected charge was measured across the GEM area. Such irradiation facility is crucial for future quality control of GEM chambers during production.

3.2 Simulation results

In the past two years, the collaboration also conducted an extensive simulation effort to study the detector response under different conditions. In the simulation procedure, the geometry is first defined and the electric field map inside the chamber is computed with ANSYS®, a computational fluid dynamics package [9] that uses Finite Element Analysis methods. Then, the Monte Carlo GARFIELD [10] suite was used for avalanche production, signal formation and induction. For each configuration, the corresponding field-map is computed with ANSYS® and loaded as input to GARFIELD. Figure 7 (left) shows the simulated normalized gain as a function of the divider HV values. The simulated values are compared to those obtained previously in experimental measurements taken with the same readout strip pitch of 560 μm [11].

The gain uniformity was also cross-checked with the simulation. Five different configurations were simulated corresponding to five distinct strips pitches: 560, 700, 840, 980 and 1120 μm. Figure 7 (right) shows the gain as a function of the pitch for the 5 different strip pitch values and for four different HV divider values. No more than few percents variation was noticed from one sector to another.

4. Summary and outlook

The CMS GEM collaboration has successfully designed, built and tested full size trapezoidal GEM chambers. Experimental and simulation results proved that the detector performs well. Good detection efficiency, spatial resolution and gain uniformity were successfully proven. These efforts were recently culminated: the CMS collaboration approved the installation of a demonstrator system made of two GEM Super-Chambers covering 20° in the $1.5 < \eta < 2.1$ forward region. This system will be installed in CMS during the 2016 Technical shutdown.

Acknowledgments

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