Performance of triple-GEM detectors for the Phase-2 CMS upgrade and a high-resolution GEM telescope measured in a test beam

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The CMS Phase-2 GEM upgrade

In view of the High-Luminosity LHC upgrade, CMS is upgrading its muon spectrometer with new stations of triple-GEM detectors (1):
• GE2/1, for track reconstruction redundancy and displaced muon trigger at $1.8 < |\eta| < 2.4$
• MEO, for muon system extension to $2.4 < |\eta| < 2.8$

Goal of 2021 GEM test beam

Demonstrating the operation and performance on particle beam of the final design CMS Phase-2 GEM detectors with final front-end electronics and DAQ

Electronics and DAQ

Front-end chip

• Full final detector + frontend + DAQ sw operated up to 1 MHz trigger rate
• Custom PCIe back-end based on commercial FPGA
• 1 Gbps Ethernet-based local readout

On-detector “OptoHybrid” board

• VFAT3 ASIC GE2/1; Xilinx ARTIX-7 FPGA
• MEO: FPGA-less board (ASIAGO) [3]
• Xilinx VX13P (CVP-13)

Back-end FPGA

Test beam setup and detectors

Phase-2 production detector GE2/1 M1 module

Phase-2 prototype MEO second-generation, azimuthal segmentation [2]

Test beam setup and detectors

4x tracking detectors 10x10 cm² high-resolution triple-GEM
250 µm strip pitch (expected 75 µm space resolution)
R&D prototype 20x10 cm² triple-GEM Random hole GEM foil sectorization

Test beam setup and detectors

Reconstruction and analysis

Offline reconstruction workflow
1. Transversal and angular alignment on tracking chamber
   - Iterative alignment procedure:
     • Selected chamber under test
     • Track built with remaining three chambers
     • Transversal and angular alignment extracted from residuals
     • Steps repeated until corrections converge
2. Tracks built with all four tracking detectors
3. Transversal and angular alignment of detector under test
4. Efficiency and residual analysis

GE2/1 and MEO detector performance

Noise level of front-end electronics attached to GE2/1 detector: the shielding provided by the GEM and the several ground pins of the VFAT3 plug cards allow to keep the noise below 0.5 fC

346.2±5.9 μm space resolution in angular coordinates measured for the GE2/1 detector

Excellent local efficiency to 150 GeV muons reachable thanks to lower electronic noise at a gain of 2x10^5. Average efficiency limited to 98% by sectorization dead areas.

The inefficiency area due to sectorization is more alarming in MEO (40 GEM foils sector): random hole sectorization can recover dead areas by limiting efficiency dips to a 5%.

Comparison of efficiency profile of MEO second-generation detector with 20x10 random-hole segmented prototype

Conclusion and outlook

The performance of final CMS Phase-2 GEM detectors was demonstrated in particle beam with good tracking performance provided by 10x10 cm² triple-GEMs. An excellent efficiency was observed in the CMS Phase-2 detectors. A random-hole segmented triple-GEM has shown the possibility to recover the inefficiency induced by the segmentation dead area.

The 2022 CMS GEM test beam a full MEO detector with random hole segmentation will be tested and a time resolution measurement on the CMS GEM detectors with final electronics will be performed.