12th Pisa meeting on advanced detectors – May 22-28, 2022

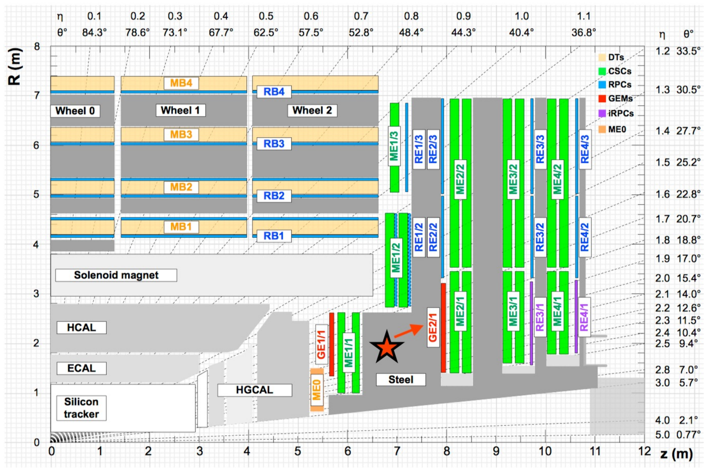
Performance of triple-GEM detectors for the Phase-2 CMS upgrade and a high-resolution GEM telescope measured in a test beam

A. Pellecchia[1,2], P. Verwilligen[2], A. Stamerra[2]
on behalf of the CMS muon group

[1] Università degli studi di Bari [2] INFN Bari

antonello.pellecchia@cern.ch

The CMS Phase-2 GEM upgrade

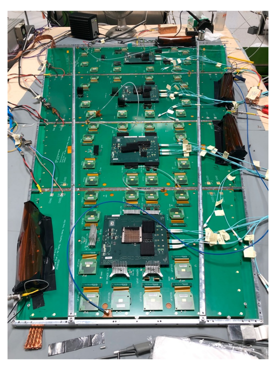


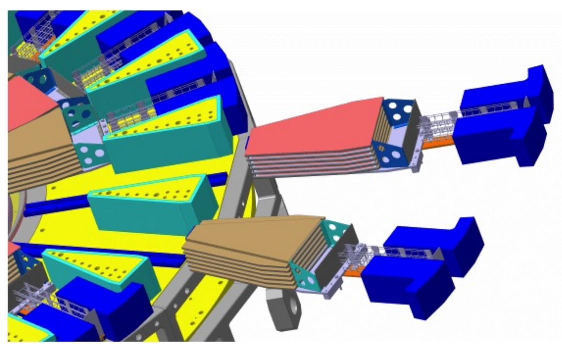
In view of the High-Luminosity LHC upgrade, CMS is upgrading its muon spectrometer with **new stations of triple-GEM detectors** [1]:

- GE2/1, for track reconstruction redundancy and displaced muon trigger at $1.8 < |\eta| < 2.4$
- ME0, for muon system extension to $2.4 < |\eta| < 2.8$

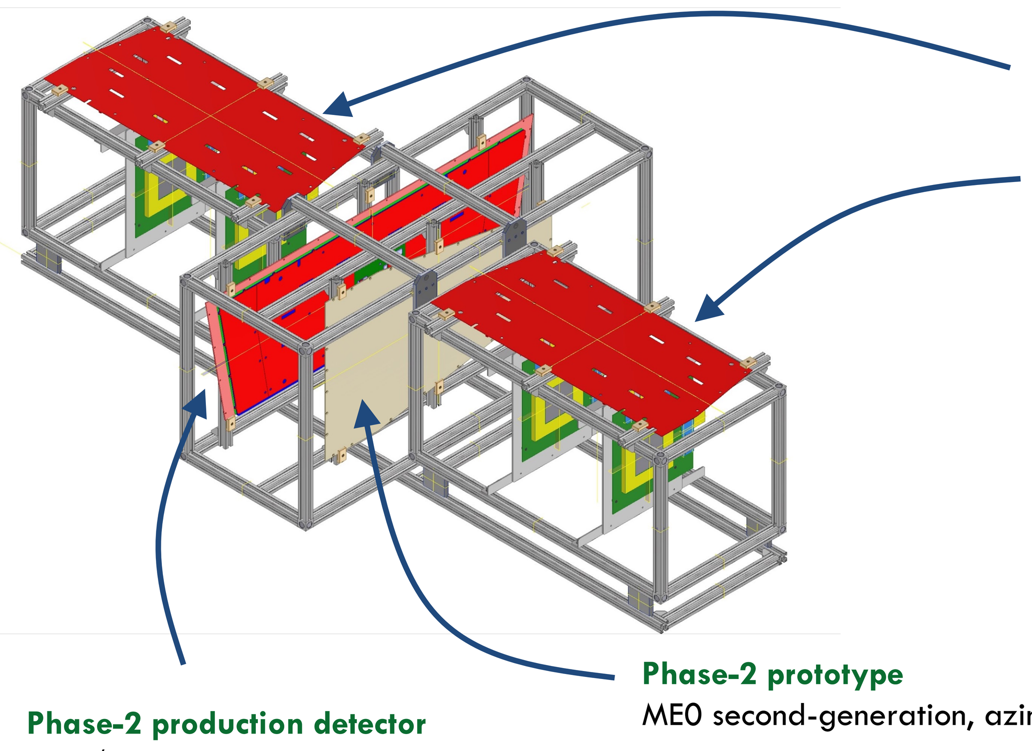
Goal of 2021 GEM test beam

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

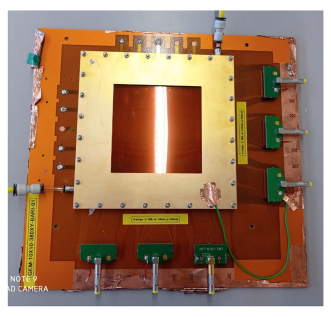




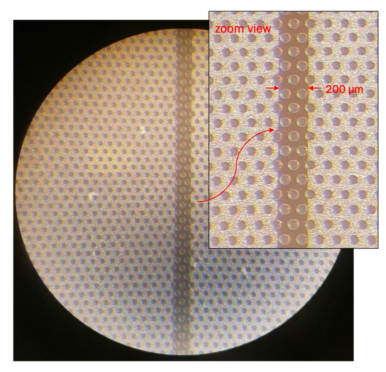
Test beam setup and detectors



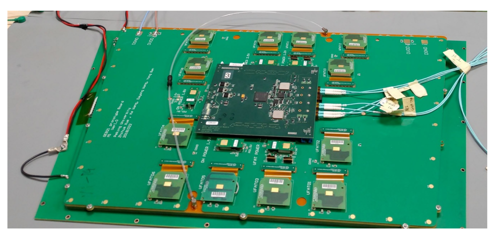
4x tracking detectors
10×10 cm^2 high-resolution triple-GEM
250 μm strip pitch
(expected 75 μm space resolution)



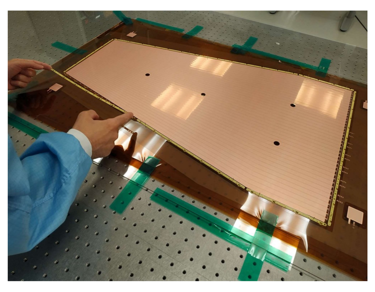
R&D prototype
20×10 cm^2 triple-GEM
Random hole GEM foil sectorization

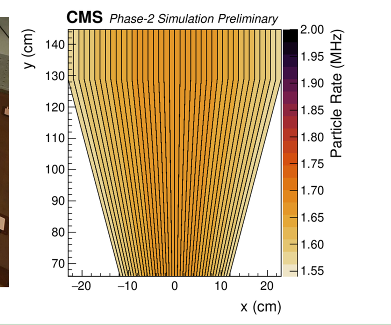


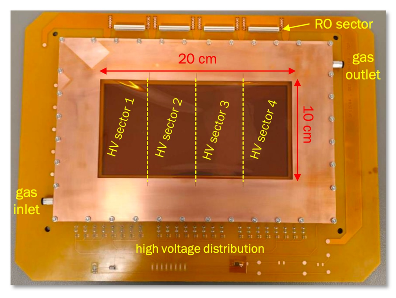
Phase-2 production detector
GE2/1 M1 module



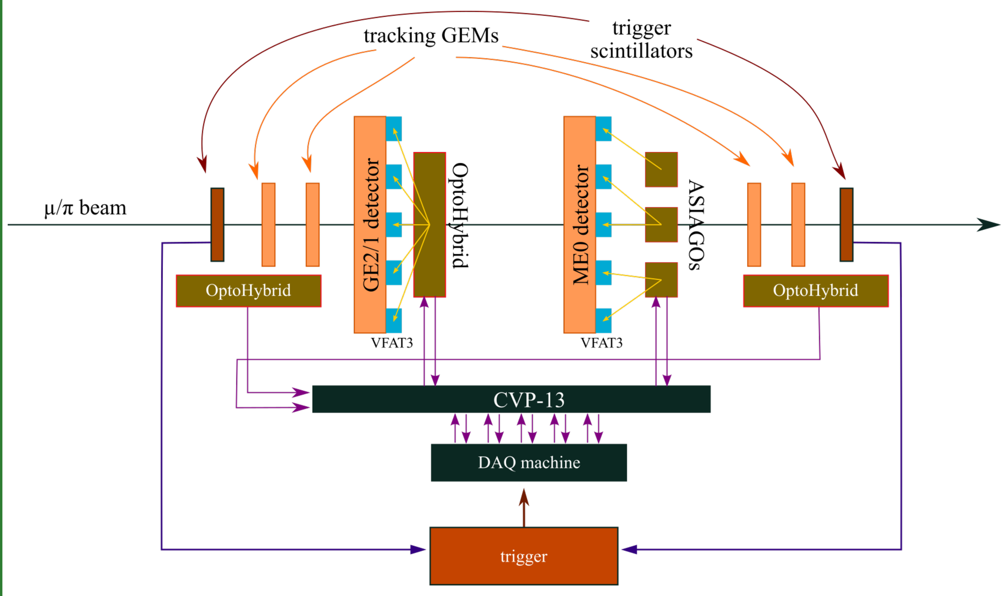
Phase-2 prototype
ME0 second-generation, azimuthal segmentation [2]





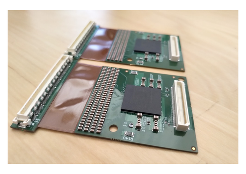


Electronics and DAQ



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

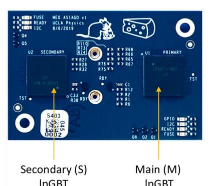
Front-end chip



VFAT3 ASIC

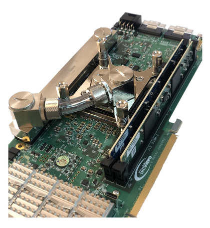
On-detector "OptoHybrid" board

GE2/1: Xilinx ARTIX-7 FPGA



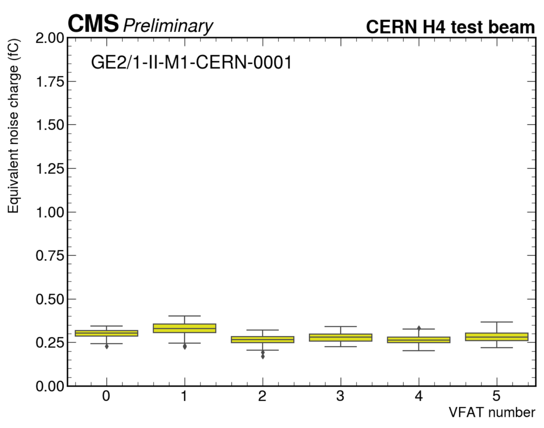
ME0: FPGA-less board (ASIAGO) [3]

Back-end FPGA



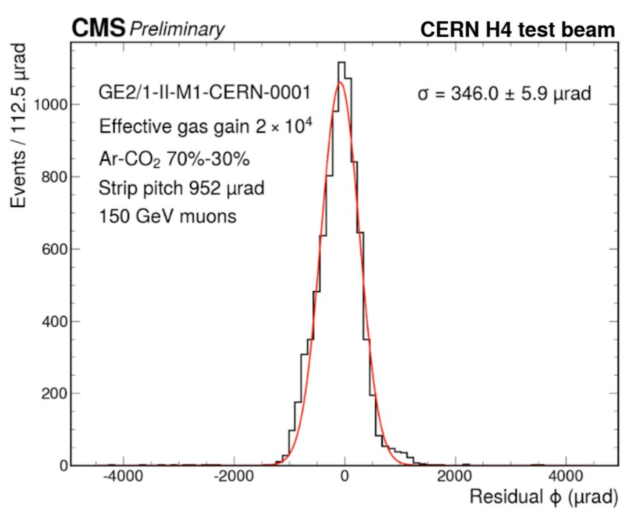
Xilinx VU13P (CVP-13)

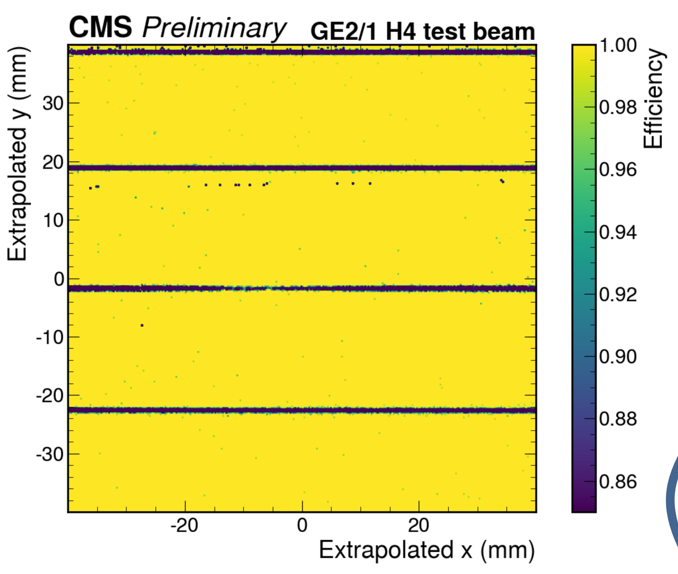
GE2/1 and ME0 detector performance



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

346±5.9 μrad space resolution in angular coordinates measured for the GE2/1 detector

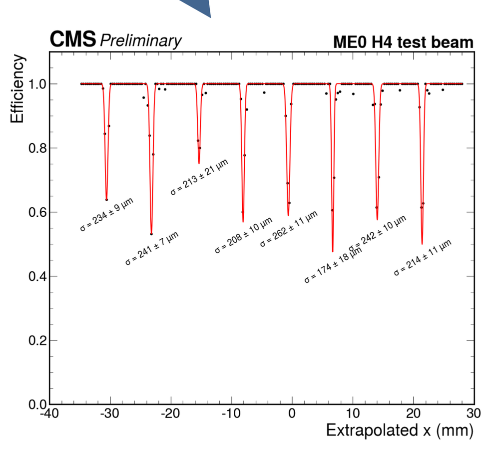


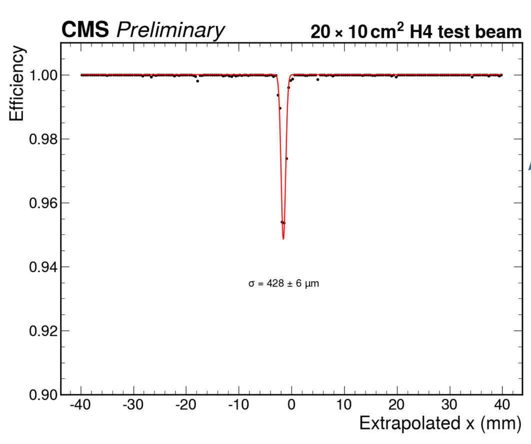


Excellent local efficiency to 150 GeV muons reachable thanks to lower electronic noise at a gain of 2×10^4. Average efficiency limited to 98% by **sectorization dead areas**.

The inefficiency area due to sectorization is more alarming in ME0 (40 GEM foils sectors): **random hole sectorization can recover** dead areas by limiting efficiency dips to a 5%.

Comparison of efficiency profile of ME0 second-generation detector with 20x10 random-hole segmented prototype

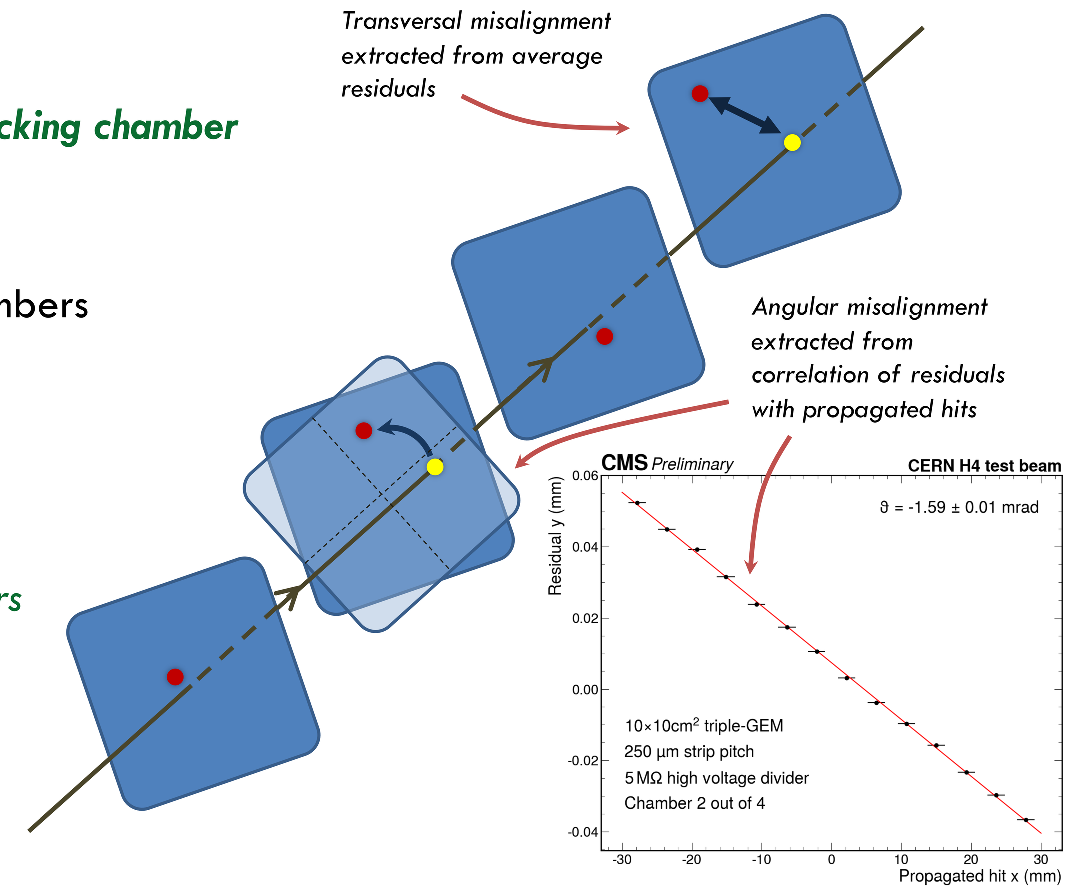




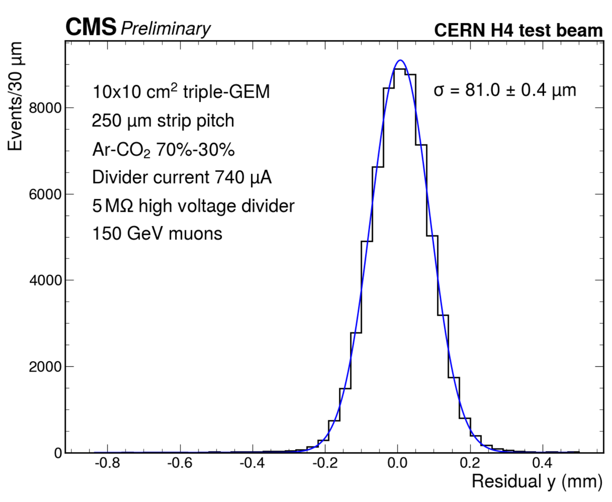
Reconstruction and analysis

Offline reconstruction workflow

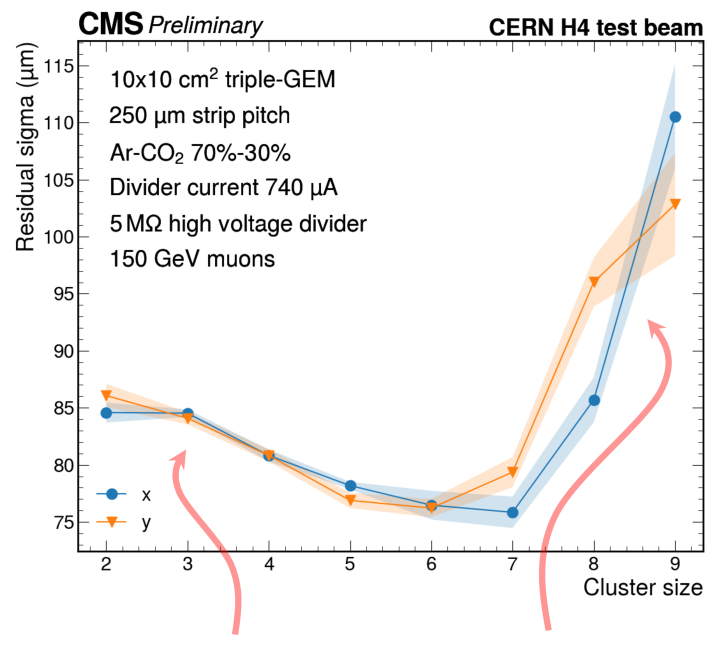
1. *Transversal and angular* ***alignment on tracking chamber***
   Iterative alignment procedure:
   - Selected chamber under test
   - Track built with remaining three chambers
   - Transversal and angular alignment extracted from residuals
   - Steps repeated until corrections converge
2. ***Tracks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



Triple-GEM tracker performance



Residual distribution in the y direction of tracking chamber 2

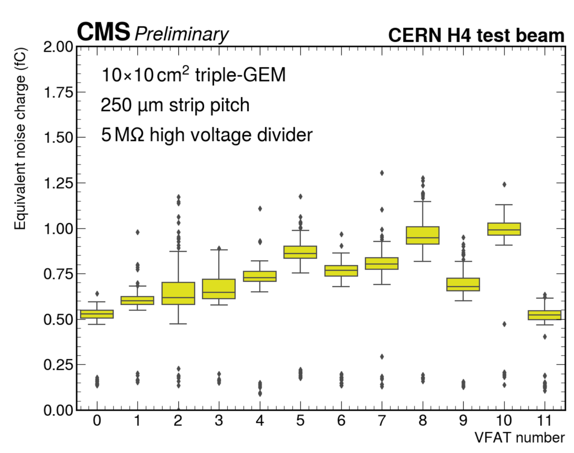


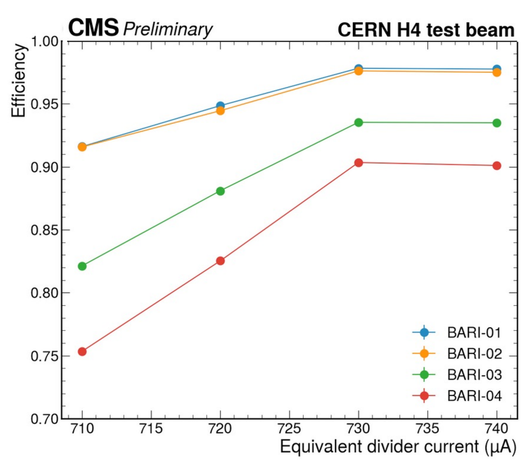
Space resolution of tracking chamber 2 as a function of the cluster size

Average tracker space resolution of 81 μm
Sharp space resolution dependency on cluster size

Low cluster size: **misidentified low-charge clusters** due to high thresholds

High cluster size: asymmetric signal spreading due to **delta rays** in single cluster





Efficiency to muons between 90% and 100% with single chamber

10x10 triple-GEMs operated at 10^5 effective gain, but **efficiency limited due to low S/N ratio**

Conclusion and outlook

The performance of **final CMS Phase-2 GEM** detectors was demonstrated in particle beam with good **tracking performance provided by 10x10** cm^2 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.

In the **2022 CMS GEM test beam** a full ME0 detector with random hole segmentation will be tested and a time resolution measurement on the CMS GEM detectors with final electronics will be performed.

[1] A. Colaleo, *CMS Technical Design Report for the Muon Endcap GEM Upgrade*, CMS-TDR-013
[2] A. Cagnotta, *Novel GEM foil layout for high-rate environment in CMS ME0*, in this conference
[3] A. Datta, *Development of Readout Electronics for the CMS ME0 Muon Detector*, in this conference