Phase 2 Upgrade of the CMS Muon System with triple-GEM detectors

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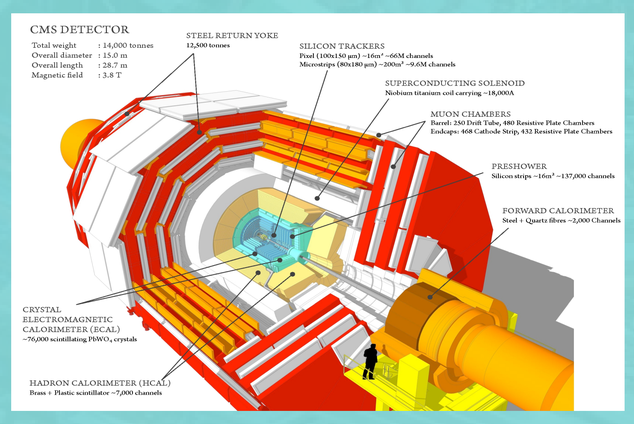
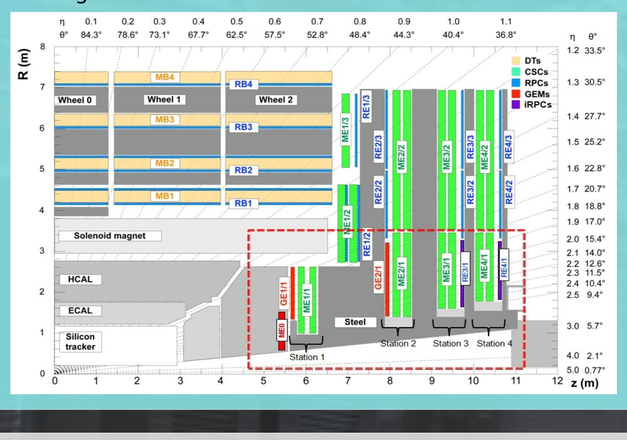
Introduction and Motivation



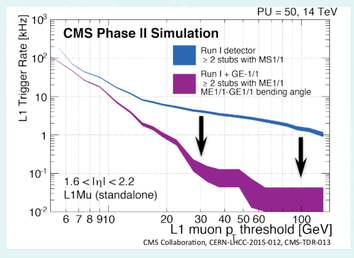
Goals of the muon upgrade

Improve muon momentum resolution, help to reduce the global muon trigger rate, increase muon identification coverage.



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 HL-LHC during Phase2. New detector requirements include high rate capability (~MHz/cm²),and new station must be able to survive high radiation background. The current detector design is not sustainable so that new technologies have been considered, in particular Gas Electron Multiplier (GEM) detectors.

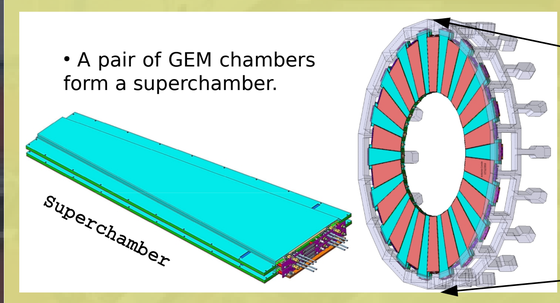
The installation of GEMs (labeled as GE1/1) for LS2, will equip the inner endcap stations, while the installation of the more recent GEMs (labeled as GE2/1 and ME0), which are proposed for LS3, would equip the second endcap stations. This contribution presents only the results of a research on the GE1/1. The installation of the GE1/1 station in the forward region $1.6 < |\eta| < 2.2$.



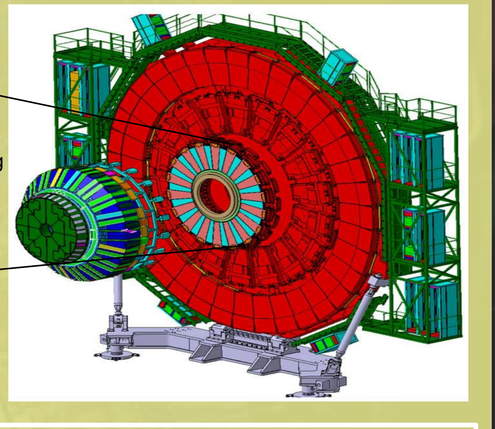
- GE1/1 allows measurement of muon bending angle at trigger level, which original muon system cannot measure.

GEM in CMS: Endcap Station 1 Ring 1 (GE1/1)

- A pair of GEM chambers form a superchamber.

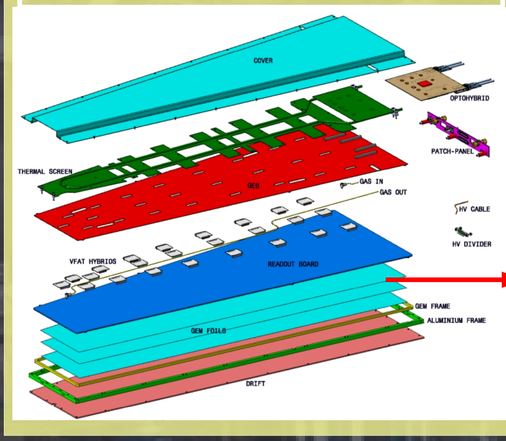


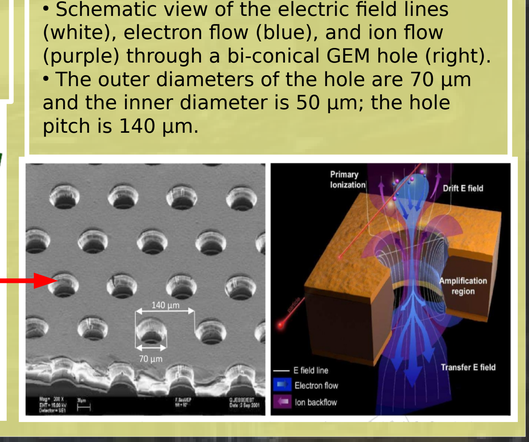
- First CMS muon endcap station where the inner ring is equipped with 18 long and 18 short triple GEM superchambers.



- The mechanical design of a single trapezoidal chamber is shown in the picture below.
- Foil dimension: 1-1.2 x 0.23-0.45 m²
- Gap configuration between the GEM foils: drift/transfer1/transfer2/induction: 3/1/2/1

- Schematic HV segmentation of short/ long GEM foils in 40/47 strips, on the foil side oriented towards the drift board.
- The color scheme indicates which HV segments correspond to the eight η-sectors of the detector.

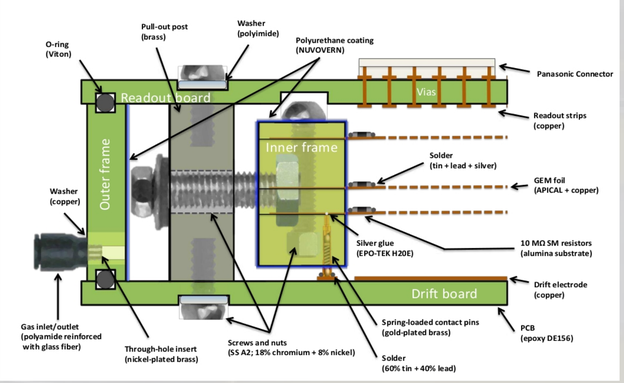




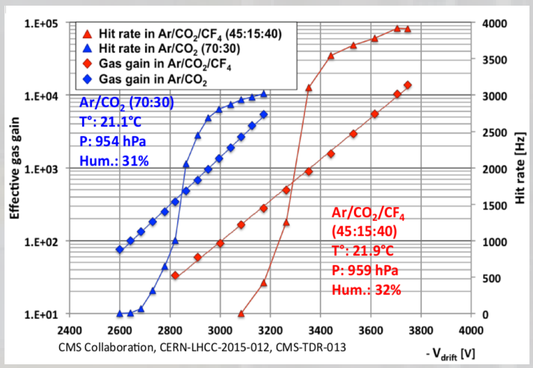
- Scanning electron microscope picture of a GEM foil (left).
- Schematic view of the electric field lines (white), electron flow (blue), and ion flow (purple) through a bi-conical GEM hole (right).
- The outer diameters of the hole are 70 μm and the inner diameter is 50 μm; the hole pitch is 140 μm.

Design and Performance of GE1/1 Detector

Cross section through inner and outer frames and GEM foils



GE1/1 prototype after mounting readout board on GEM foil stack:

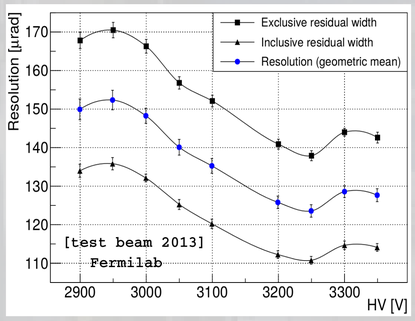


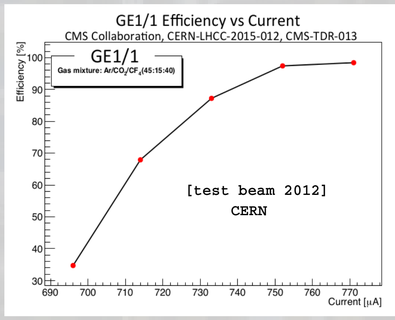
- Measured gas gains and hit rates as a function of high voltage applied to the drift electrode.

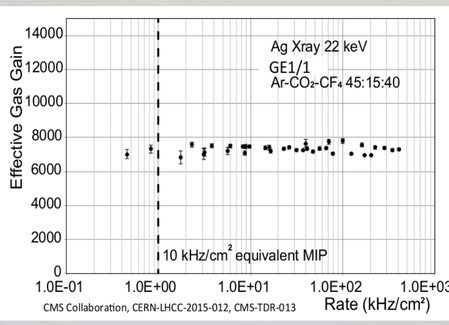
- *The performance* of GEMs has been evaluated in the test beams at CERN and Fermilab.
- At CERN the chambers were operated with Ar/CO2/CF4 (45:15:40) and Ar/CO2 (70:30); and read-out with binary-output VFAT2 front-end chips; at Fermilab, with Ar/CO2 (70:30) and read-out with APV front-end chips.

- *The results* show that the detection efficiency reaches values of 97-98%.

- The angular resolution is in the range of 100-170 μrad with Ar/CO2 (70:30) and read-out with APV analog chips.

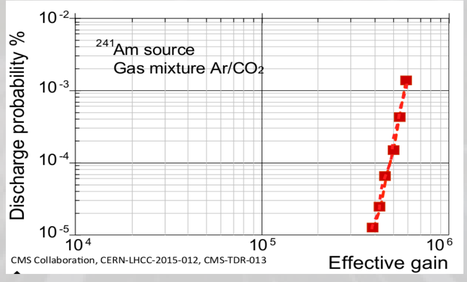




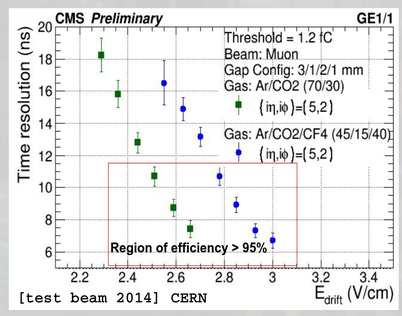


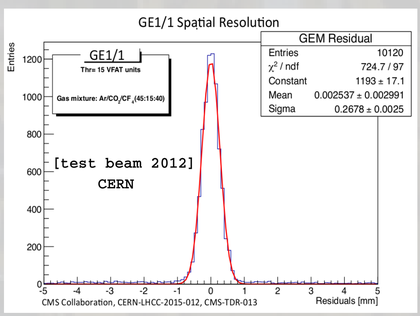
- The rate capability plot is with the Ag X-ray source at 22 keV with Ar/CO2/CF4 (45:15:40). The rate capability has three regions, a flat region (as in plot), then a rise region to a peak, and then a falling region.

- Effective gas gain is constant up to 1e3 kHz/cm² (CMS requires 10 kHz/cm²)



- Discharge probability as a function of effective gas gain measured to be 10^{-3} to 10^{-5}





Quality Control of the GEMs

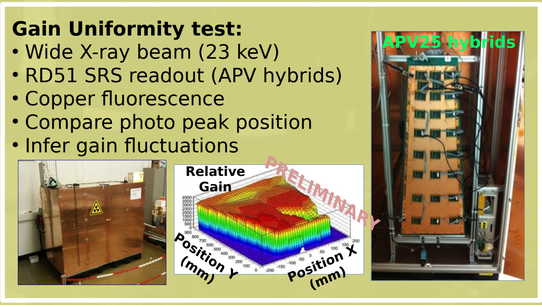
GE1/1 Production and Quality Control

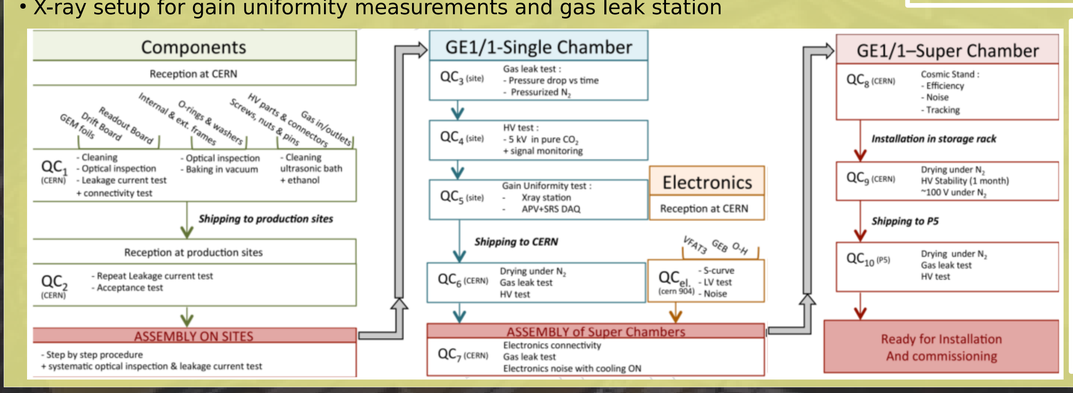
- Component production and quality control (QC1-2)
- Assembly&commissioning of GE1/1 chambers at production sites (QC3-5)
- Assembly&commissioning of superchambers at CERN (QC6-10)

GE1/1 Assembly Sites – Presently, 6 assembly sites are being considered for GE1/1 mass production. All sites will follow the same assembly and quality control protocols and will include the following setups:

- Certified clean room of class 1000 minimum
- GEM foil leakage current measurement station
- X-ray setup for gain uniformity measurements and gas leak station

Gain Uniformity test:
- Wide X-ray beam (23 keV)
- RD51 SRS readout (APV hybrids)
- Copper fluorescence
- Compare photo peak position
- Infer gain fluctuations



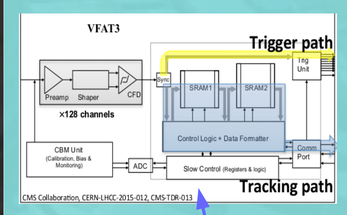


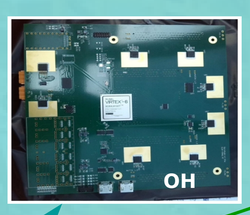
- There will be cosmic stand at CERN for efficiency measurement, track reconstruction, timing analysis, final readout electronics and cooling system.
- Precise assembly includes inspection and cleaning of all parts (ultrasonic bath, baking, sand blast), dust cleaning after step in assembly procedure.

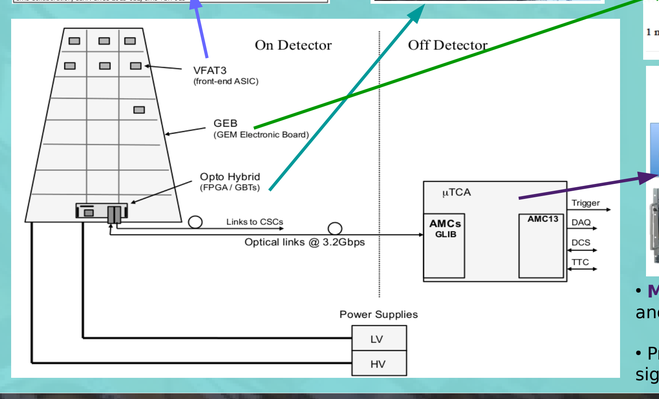
Movie:https://www.youtube.com/watch?v=Ssuqh5GAVZ4&feature=youtu.be

GEM Electronics

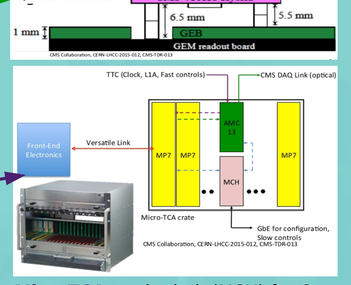
VFAT3: Successor to VFAT2. Tracking&trigger data is fixed latency trigger bits. Improvements with VFAT3 by increasing S/N ratio due to programmable shaping time, decreasing time walk via CFD, comm. at 320 Mbps = 8*VFAT2 rate.







- **GEB** provides power to VFATs
- Signal routing between VFAT3's and optohybrid
- Electrical shielding for detector

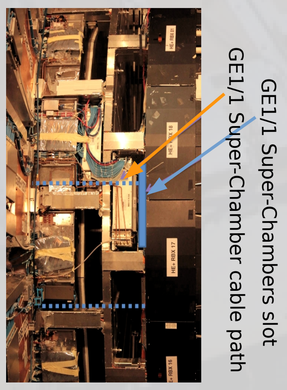


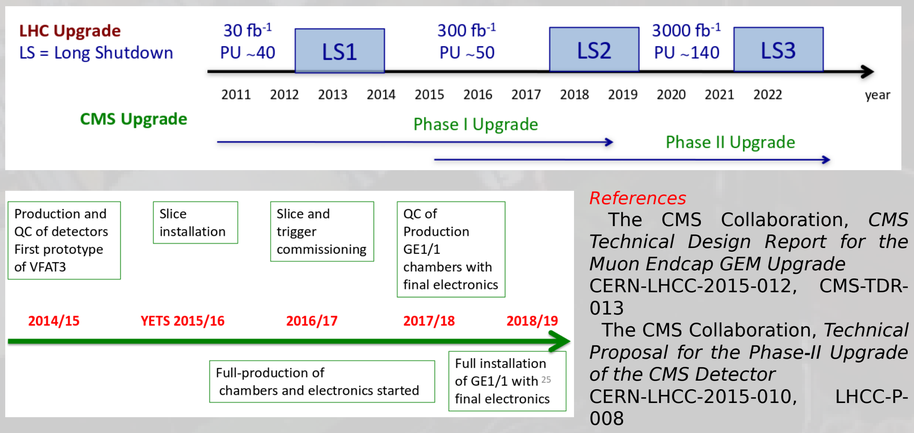
- **MicroTCA** carrier hub (MCH) for Comm. and slow control.

- Provides trigger timing and control signals down link.

Summary and Conclusion

- Facing the High-Luminosity 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.
- CMS recently approved the installation of the GE1/1 station: during LHC Long Shutdown 2 (2018-2019), the $1.6<|\eta|<2.2$ region of the first endcap disks will be equipped with a total of 144 new triple-GEM chambers.
- 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.
- For the GEM electronics, there are two main components of the electronics as On & Off Detector. On Detector electronics connect inputs of the VFAT3 to the GEB. The communication to Off Detector electronics is performed through optical links which is Opto-hybrid plugged into the GEB.
- Test beam measurements yield good results in terms of the detector performance.
- During 2016-2017 year end technical stop of LHC we will install a 40° wedge of GE1/1 in CMS and this operation experiences before full installation in LS2.





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The CMS Collaboration, *Technical Proposal for the Phase-II Upgrade of the CMS Detector* CERN-LHCC-2015-010, LHCC-P-008