Upgrade of the CMS Muon Spectrometer in the forward region with the GEM technology

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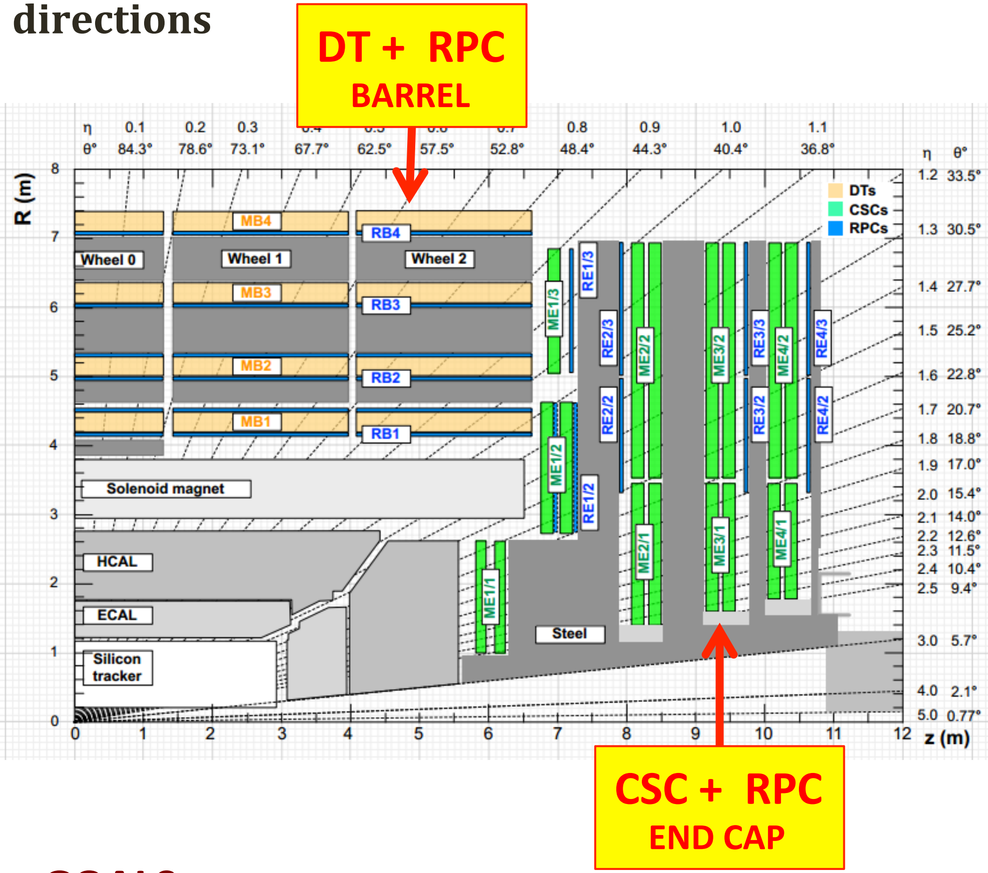
Outline

- The CMS Muon System
- CMS Forward Muon Spectrometer Upgrade
- The GE1/1 project
  - Chambers production and QA/QC
- The GE2/1 project
  - Chamber design and prototype
- The ME0 project
- Summary

The CMS Muon System

Highly hermetic and redundant muon system, at least four stations on a muon path in all directions



3 technologies:

- **Drift Tubes** and **Cathode Strip Chambers** (for tracking and triggering);
- **Resistive Plate Chambers** (for triggering).

Eta coverage:

- |η|<1.6: 4 layers of CSCs and RPCs, DTs
- the |η|≥1.6: CSCs only;

GOALS:

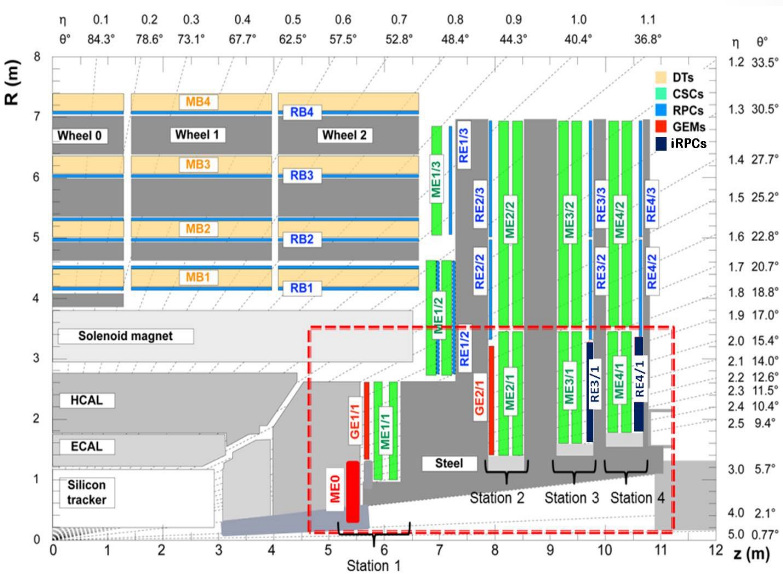
- **robust**, **redundant** and **fast** identification of the muons
- **Level-1 trigger** has access to muon information only
- **Momentum measurement**: the muon system is relevant for high pt muon (>100 GeV) and in the high η region (large lever arm of the muon system)

CMS Forward Muon Spectrometer Upgrade

The forward region |η|≥1.6 is very challenging,

- **Redundancy**: the highest rates in the system vs fewest muon layers
- **Few** handles for the new Track finder postLS2 and for the track-trigger in HL-LHC
- **Rate** : in 10's of kHz/cm^2 and higher towards higher eta and worse momentum resolution
- **Longevity:** Accumulated charge after many years of LHC operation
- **Electronics:** High occupancy/rate and latency increases exceed capabilities of the existing electronics

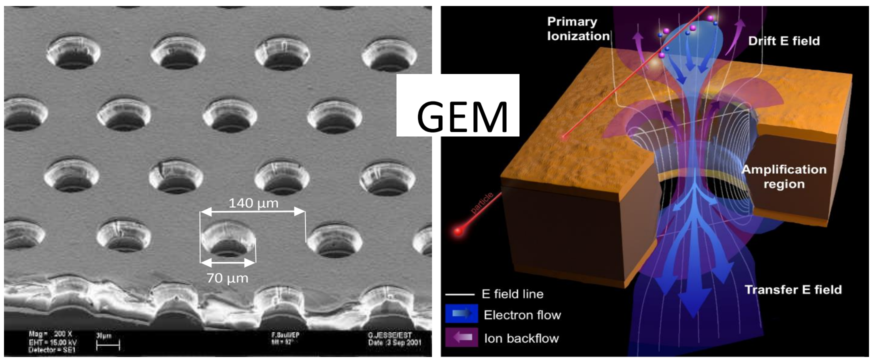
Eta coverage:
- |η|<1.6: 4 layers of CSCs , RPCs, DTs
- the |η|≥1.6: CSCs only;

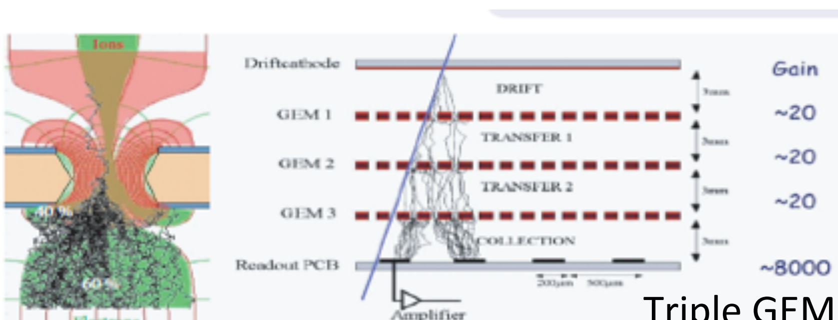


- **Objectives:**
  - Sustain triggering at current trigger thresholds
  - Increase offline muon identification coverage
  - Maintain existing envelope by mitigating aging effects

GEM Detector as technology for the CMS Muon System Upgrade

Micro-Pattern Gas Detectors (MPGD) due to their proven performance at HEP experiment (high rate capability and fine space resolution, high gain stability) are ideal tools for the Upgrade of the Forward Muon Spectrometer in CMS



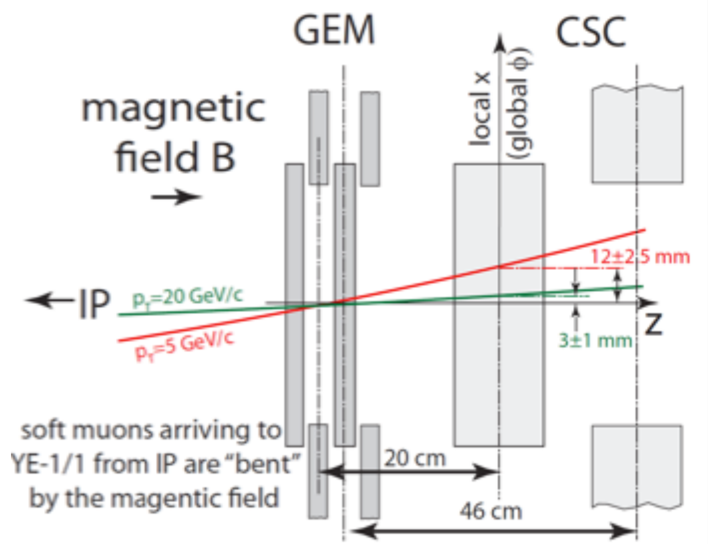


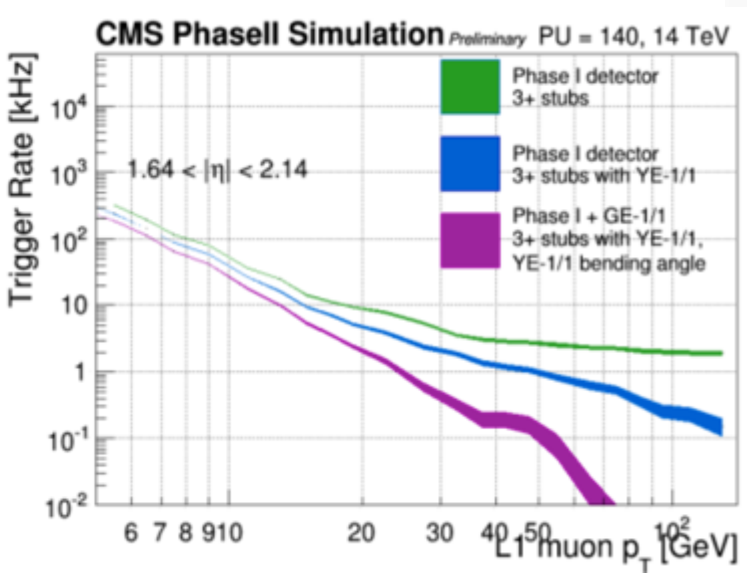
Triple GEM technology as adopted detector

- Maximum geometric acceptance within the given CMS envelope
- Rate capabilities up to 100’s kHz/cm2 .
- Single-chamber efficiency > 98 % for mips
- Gain uniformity of 10% or better across a chamber and between chambers and no loss due to aging effect after 3000 fb^{-1}
- High spatial and good time resolution

Forward trigger using directions

- Use of muon direction measurements within stations improves Level-1 trigger pT measurement
- New GEM stations, **GE1/1 & GE2/1, complement adjacent CSCs** effectively forming large lever arm GEM-CSC detectors
- Region 2.16<η<2.4 remains difficult as GE1/1 only extends to η=2.16
  - **ME0 detector (designed to extend coverage up to η =2.8) provides new triggering capabilities at Level-1:**





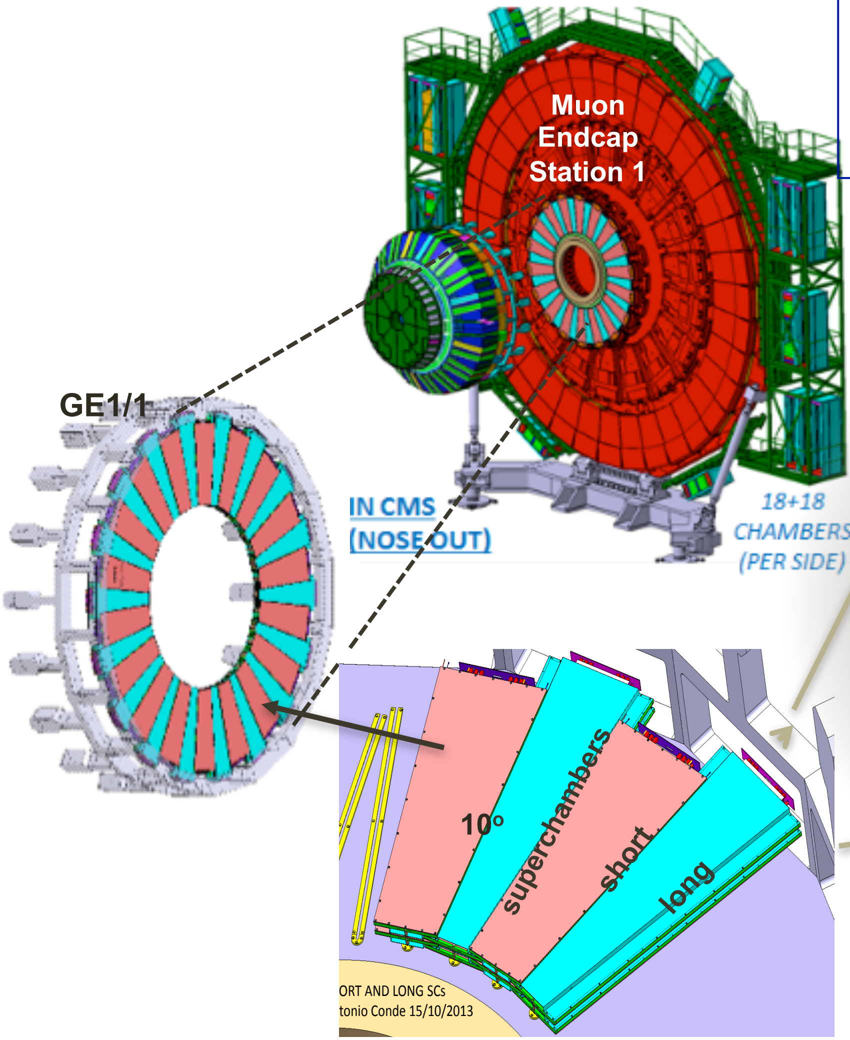
GE1/1 design

GE1/1 in high-η region 1.5<|η|<2.2

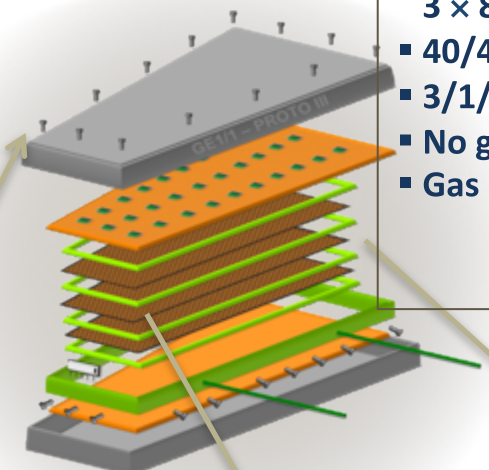
10^0 trapezioidal triple-GEM Superchambers

Long (1.5<|η|<2.2) and short (1.6<|η|<2.2) version

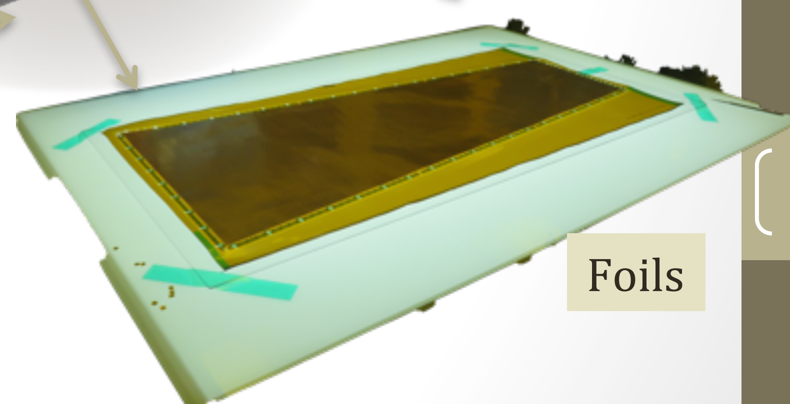
36 superchambers in each endcap (144 modules)



Chamber



- Single-mask technology
- 1D radial strip read-out with $3 \times 8 \times 128$ = 3,072 channel
- 40/47 HV sectors
- 3/1/2/1 mm gap sizes
- No glue in the assembly
- Gas mixtures:
  - Ar/CO_2 (70:30)
  - Gas flow ≈ 5 l/h

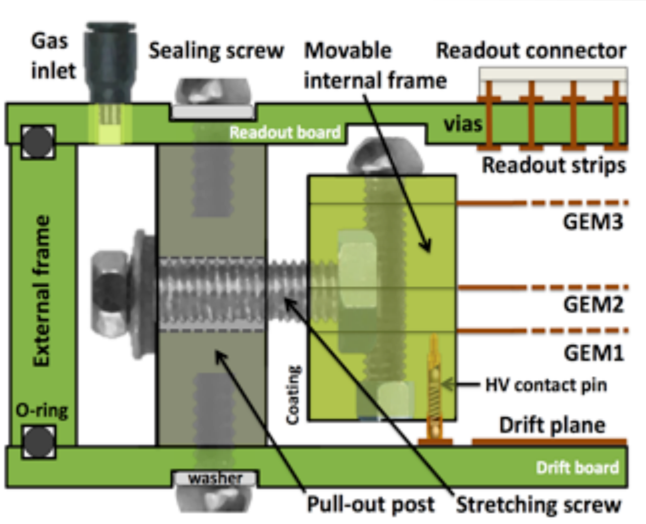


Foils

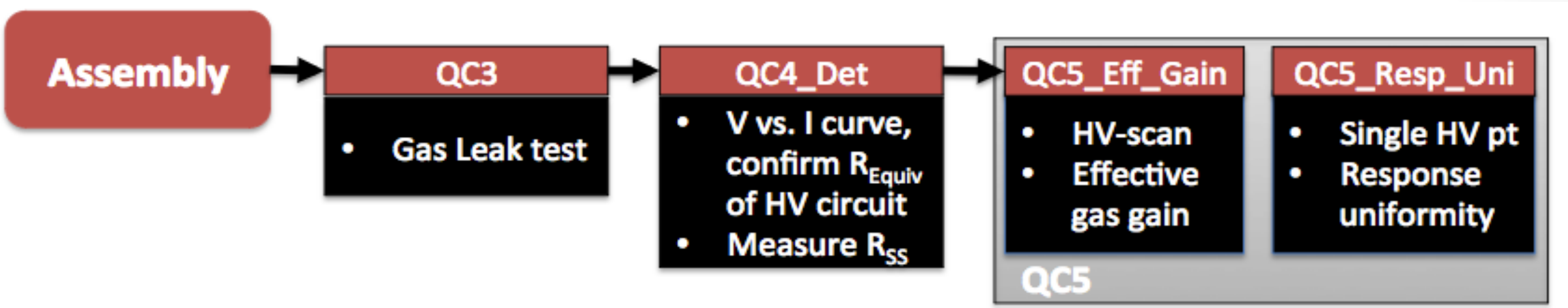
Installation in LS2 (2018-2019)

GE1/1 Chamber construction

- **GE1/1 chambers introduced a novel technique of GEM chambers construction, which avoid the usage of glue**
- **GE1/1 chambers are realizing using GEM foils stretched by means of moveable FR4 frame (internal). Cathode and Readout electrode made by standard single layer PCB. Electrical signal extracted by "vias" on PCB trough 130 pins Panasonic connectors**
- **The internal frames are controlled by "stretching screws"**
- **The tightness of the chambers is assured by an external FR4 frame sealed with o-ring**
- **Chamber assembly have to be performed in clean room (at least class 1000) to avoid GEM foils contamination**
- **GE1/1 chamber production distributed in several production sites**
- **GE1/1 Mass production started in April 2017**



GE1/1 Chamber QC



Partial view of the CERN GEM QA/QC lab

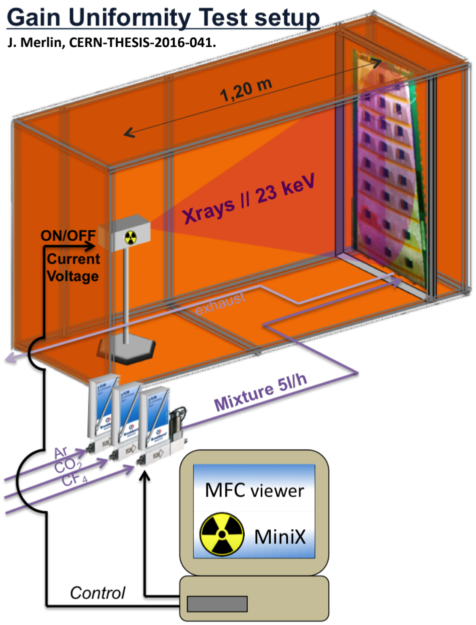
After the installation in CMS access to the GE1/1 chambers will be very limited, all the detectors have to be carefully tested to assess the quality of the performance before the final installation in the CMS apparatus

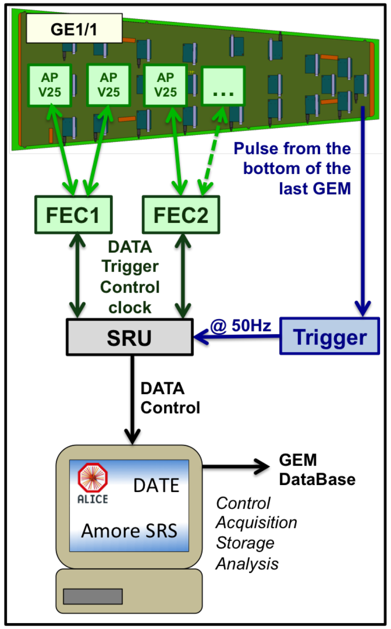
Detailed QA/QC strategy has been draft by the GEM community to assure the best results

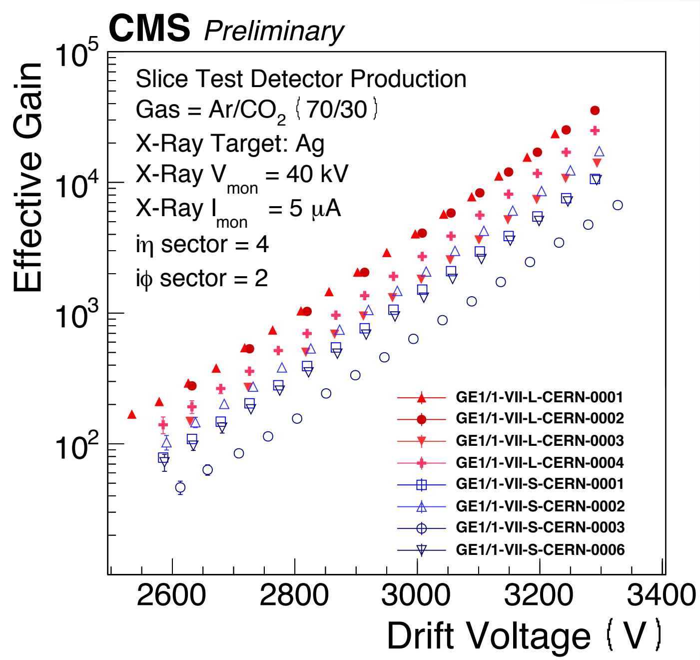
Chamber QA/QC is replicated with the same characteristic at each production site

GE1/1 Chamber QC

QC5 Effective-Gain







X-ray generator using electron gun striking silver (Ag) target;

Detector's copper electrodes excited by incident X-Rays

Photons interacting in detector gas volume, essentially Copper X-Ray fluorescence and Electron bremsstrahlung continuum

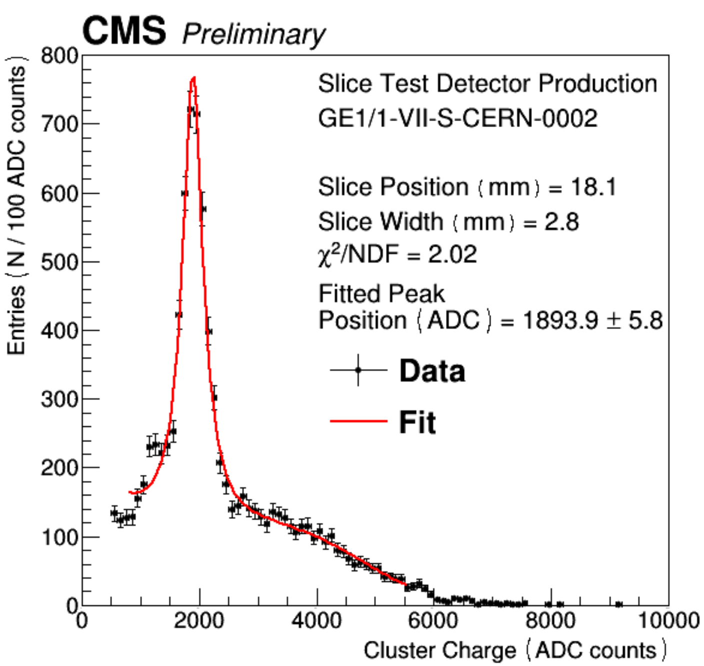
Effective gas gain of GE1/1 chamber measure in a single readout sector.
The Effective gain is defined as:

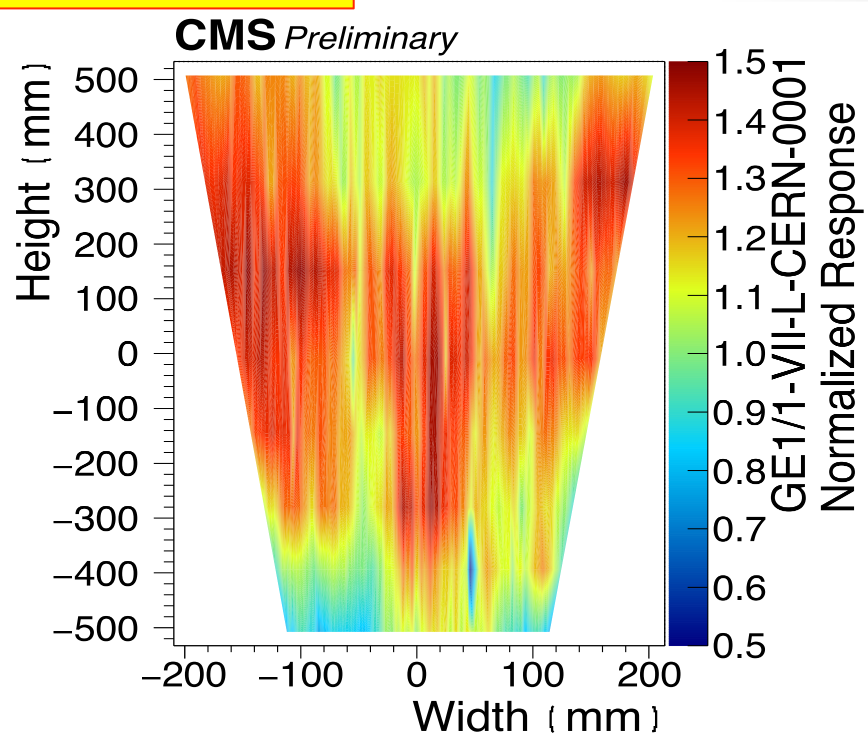
$$G_{Eff} = I_{RO}/(n_p \cdot e \cdot R_s)$$

I_{RO} current collected on the readout
n_p average number of primary electrons with charge e
R_s incoming particle rate

GE1/1 Chamber QC

QC5 Uniformity response





ADC peak for small region (slice of few strips) of the detector

Signal: Cauchy Dist. $f(x;\mu,\sigma) = \frac{A}{\pi \cdot \sigma} \cdot \left[\frac{\sigma^2}{(x-\mu)^2 + \sigma^2} \right]$

Bkg: 5th Order Poly

GE1/1 uniformity map obtained irradiating the detector with Silver X-Ray

The charge cluster ADC spectrum obtained from each slice of the detector is fit to extract the position of the copper fluorescence photopeak in ADC counts

GE2/1 Project

Installation in *EYETS* (2022 and 2023)

The baseline GE2/1 station consists of 36 20^0 Super Chambers, the layout will be similar to GE1/1, but covering much larger surface. (1.62<η<2.43)

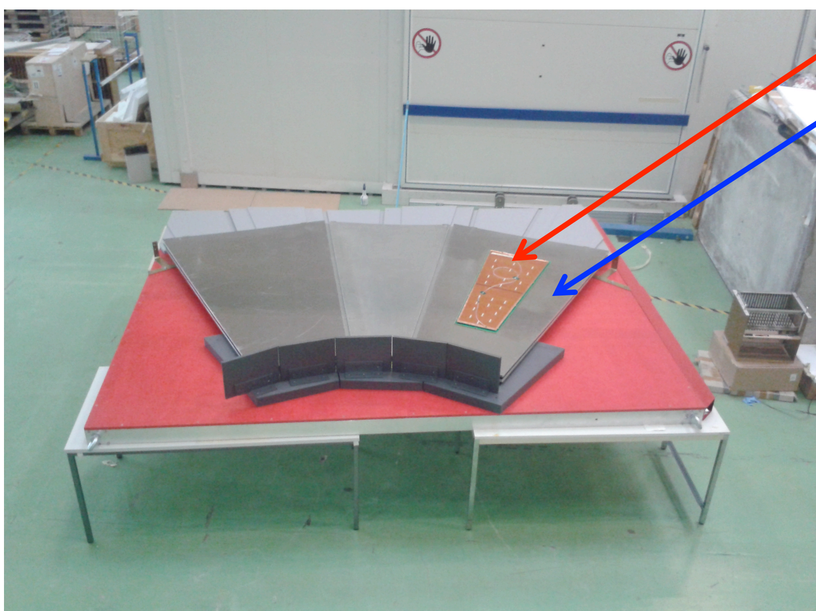
Limits in space make the GEM technology perfect candidate for GE2/1

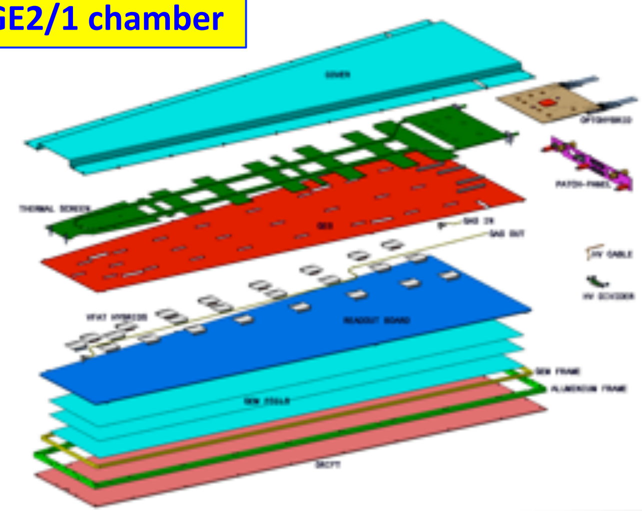
Same technical solution successfully adopted for the GE1/1 (3/1/2/1 mm gaps)

Each GE2/1 Superchamber realized with two single chambers

GE1/1 chamber

GE2/1 chamber



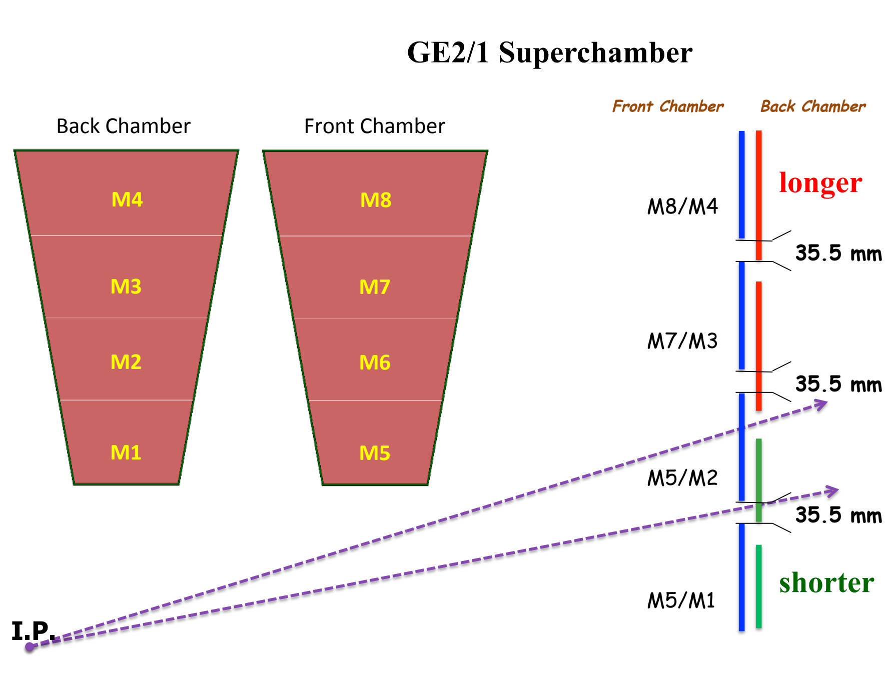


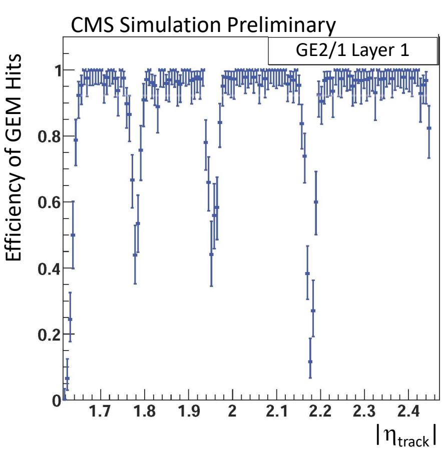
36.4 mm

GE2/1 Project

GE2/1 Chambers will consist of 4 modules each (288 in total)

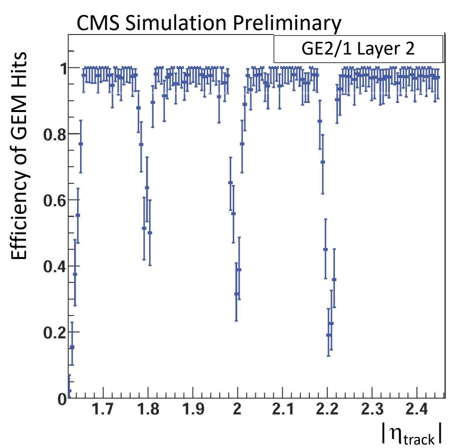
To achieve the maximum coverage modules which realize Front and Back chambers will be staggered,
as a consequence 8 different modules are foreseen for the GE2/1 production





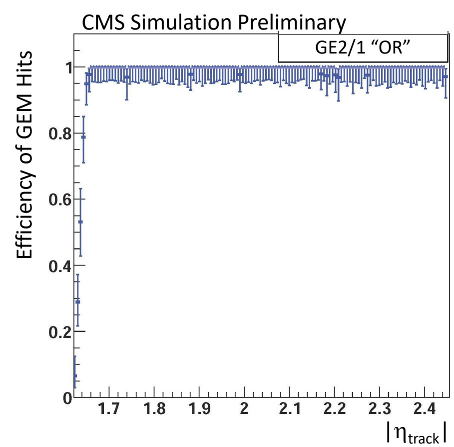
Front Chamber Hits Efficiency

+



Back Chamber Hits Efficiency

=



Super Chamber Hits Efficiency (OR)

GE2/1 Chamber design

GE2/1 design is on going, general chambers dimensions as well as single module dimensions are fixed

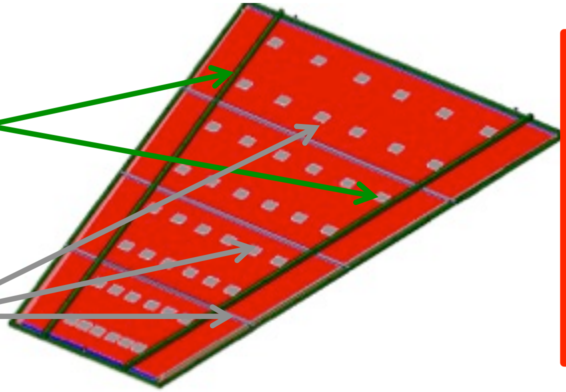
First GE2/1 module (the largest one) already build at CERN, now under test

GE2/1 full chamber in production to fully validate the GE2/1 chamber mechanics

Start of GE2/1 mass production foreseen during second half of 2019, when the GE1/1 production will finish

Two transversal bars, which hold the modules have been added to increase the mechanical stability of the full chambers

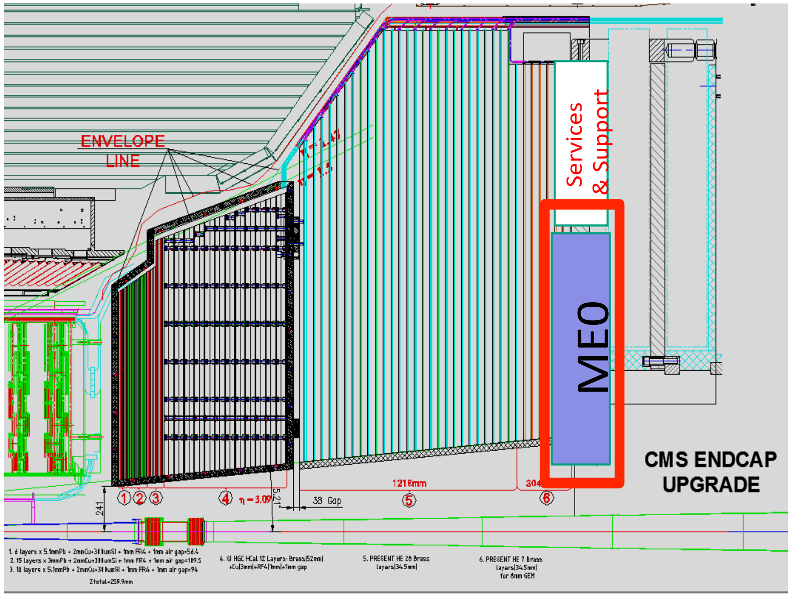
Three stiffener bars to join the modules together



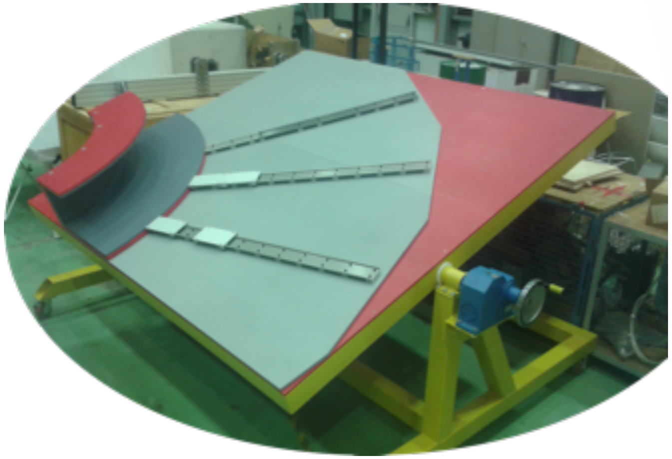
Several synergy are foreseen between the GE1/1 and GE2/1 project (e.g. Same QA/QC strategy, same production sites, same front-end electronics, similar cooling strategy, …….)

Installation in LS3 (2025)

ME0 Project



Extended muon offline acceptance benefits a broad range of physics



- Essential to minimize combinatory in matching muon segments to tracker tracks
  - Can improve p_T resolution for muons
  - Good position measurement essential to reduce impact of neutron backgrounds and combinatorial matches
  - Measurement of bending of muon stubs is important to enable 2D matching - reject incompatible low p_T tracker tracks
- 6-layers and high precision of hit reconstruction of the ME0 detector makes measurements of both position and direction possible

ME0 Project

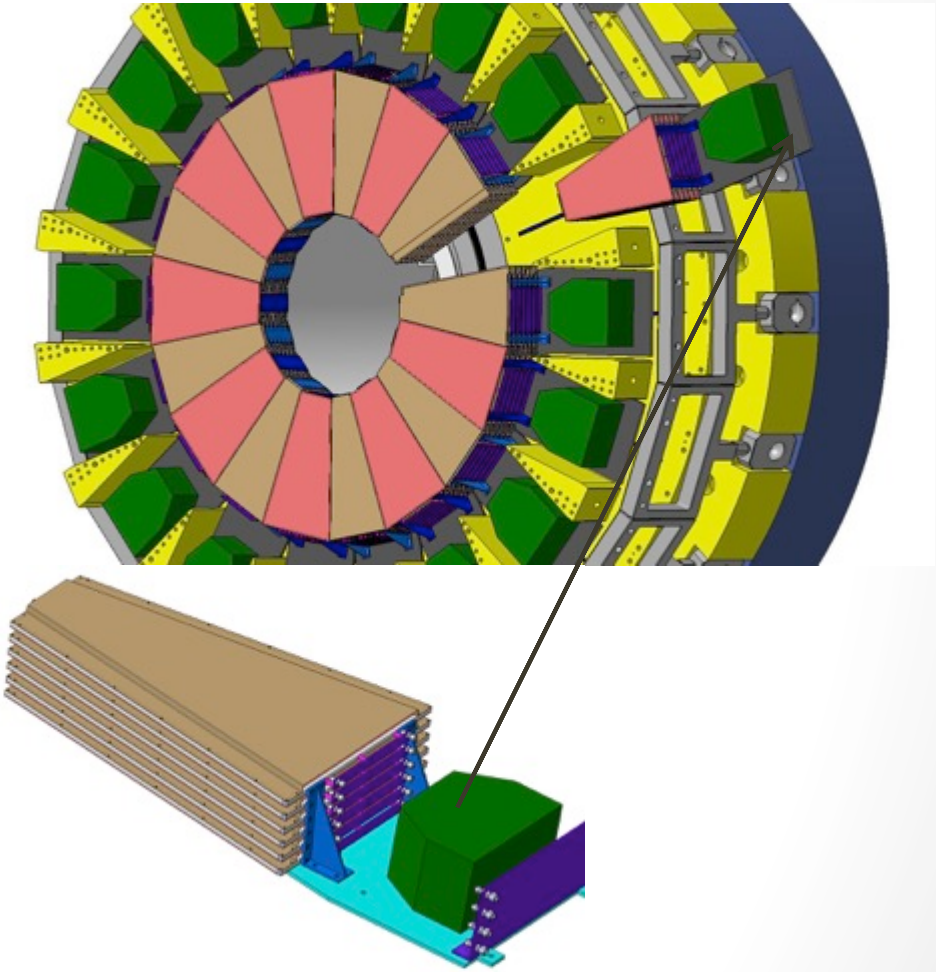
The ME0 detectors consists of 36 20^0 Stacks, similar to GE1/1 with comparable dimensions ($2.0<\eta<2.8$)

Each stack consist of 6 independent modules for a total of 216 modules

Same technical solution successfully adopted for the GE1/1

As per GE2/1, ME0 will profit of several synergy with GE1/1 project (e.g. Same QA/QC strategy, same production sites, same front-end electronics, similar cooling strategy, …….)

Start of ME0 mass production foreseen 2023 just after the GE2/1 mass production

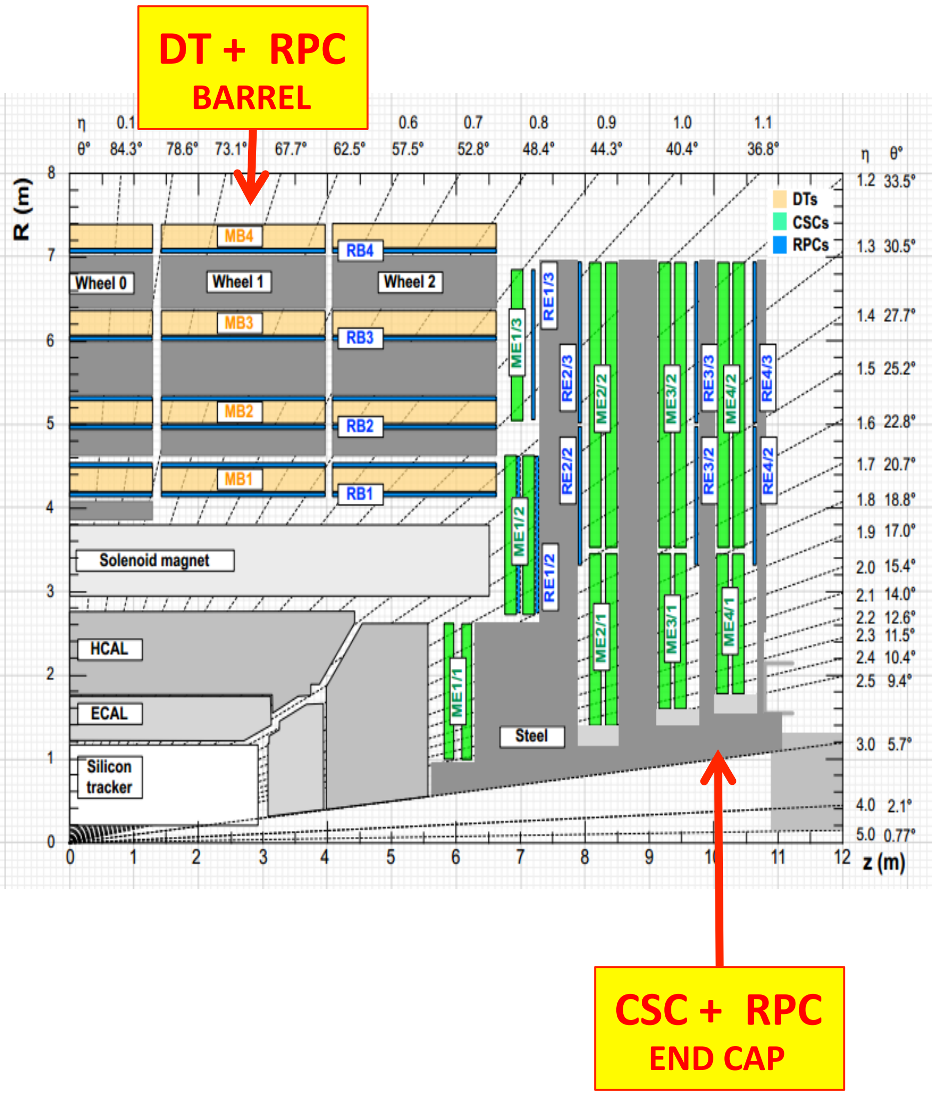


Summary

- During next year the CMS Muon system will go through a series of upgrade in order to cope with the foreseen increasing of LHC performance
- GEM technology has been selected for the upgrade of the first disk of the CMS Muon End-Cap through the GE1/1 project, and for the future GE2/1 and ME0 project
- GE1/1 mass production started in April 2017, conclusion expected end 2018, than GE2/1 and ME0 Production, are expected as natural prosecution of the GEM upgrade project

Backup

Gas detectors technologies in CMS



Drift Tubes (DT)

- Central coverage: |η | < 1.2
- Measurement and triggering
- 12 layers each chamber: 8 in φ, 4 in z

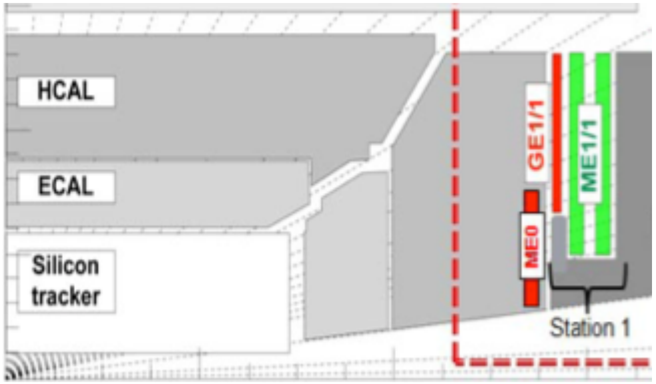
Cathode Strip Chambers (CSC)

- Forward coverage: 0.9 < |η| < 2.4
- Measurement and triggering
- 6 layers each chamber: each with φ, z

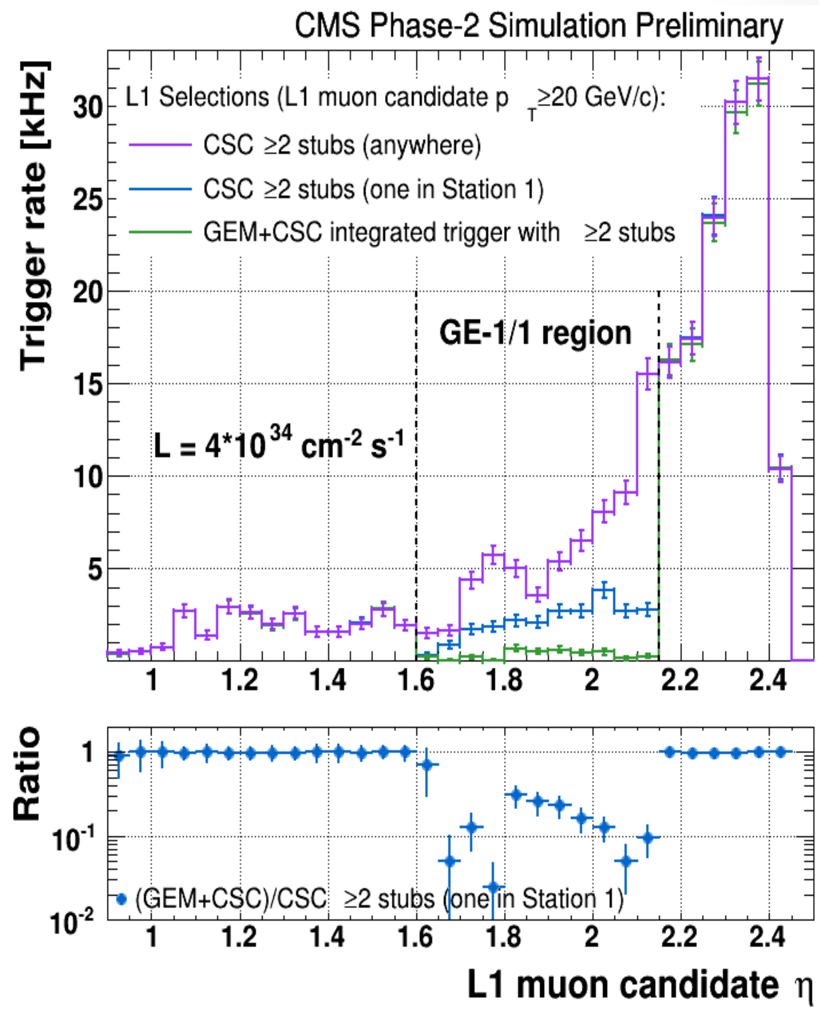
Resistive Plate Chambers (RPC)

- Central and Forward coverage: |η | < 2.1
- Redundancy in triggering
- 2 gaps each chamber, 1 sensitive layer

Trigger in the forward region with the ME0 detector

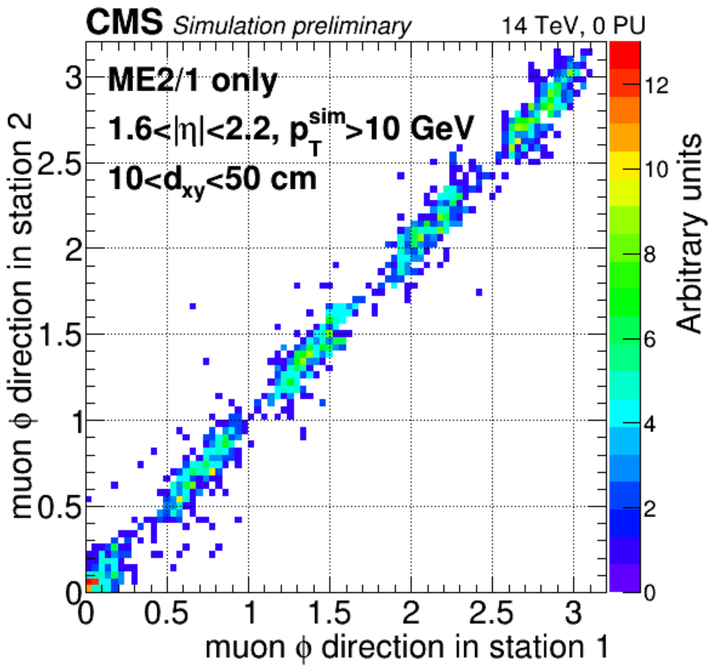


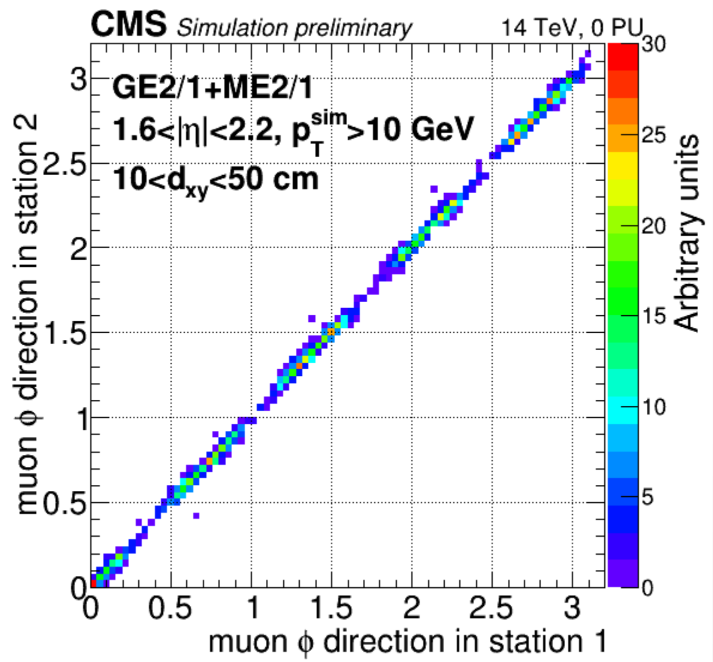
- Region $2.16<\eta<2.4$ remains difficult as GE1/1 only extends to $\eta=2.16$
- ME0 (designed to extend coverage) detector provides new triggering capabilities at Level-1:
  - A GEM-based ~25cm thick 6-layer detector with good position and directionality measurements
- Extend GE1/1-like bending angle measurement for the region $2.16<\eta<2.4$
  - Extends trigger rate suppression (compare blue and green curves on the right) onto the higher eta region



Forward trigger using directions

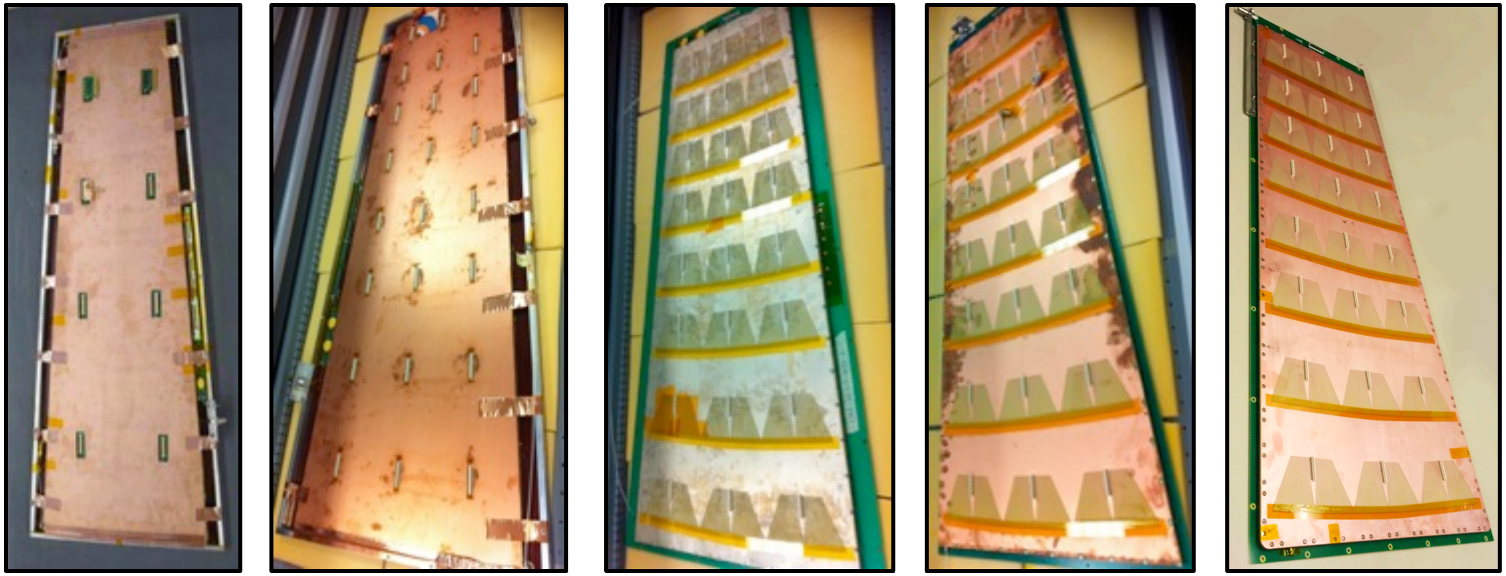
- GE2/1: enables good direction measurement at trigger level in station 2
  - GE2/1 ϕ-segmentation (same as GE1/1) is adequate to obtain direction measurement comparable to that in station 1





- GE2/1 provides important redundancy, this imply that even in the case of ME1/1 reduced performance for aging, trigger rate control associated with the direction measurements will remains available

GE1/1 Prototype history



2010 — 2011 — 2012 — 2013 — 2014

R&D phase — Toward production phase

GE1/1-I
-> first 1m-class GEM detector ever built
-> single-mask technology
-> 99x(22-45) cm^2
-> 1024 readout channels
-> gap config. 3/2/2/2
-> use of spacer grid and glue

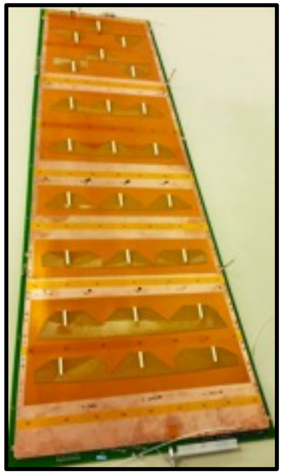
GE1/1-II
-> Optimization of the electric field configuration
-> single-mask technology
-> 99x(22-45) cm^2
-> 3072 readout channels
-> gap config. 3/1/2/1
-> use of spacer grid and glue

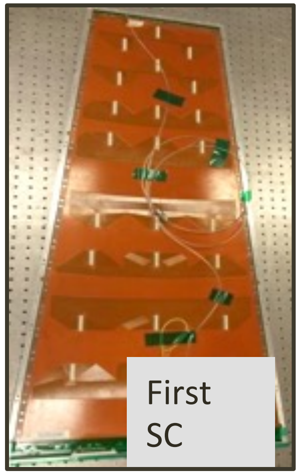
GE1/1-III
-> first use of the self-stretching technique
-> single-mask technology
-> 99x(22-45) cm^2
-> 3072 readout channels
-> gap config. 3/1/2/1
-> No spacers but glue on the external frame

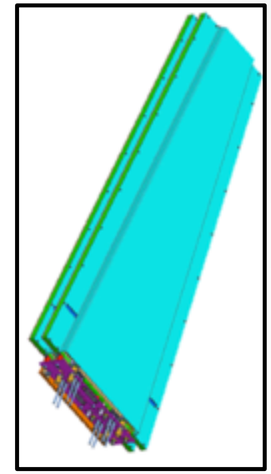
GE1/1-IV
-> Optimization of the mechanics and assembly
-> single-mask technology
-> 99x(22-45) cm^2
-> 3072 readout channels
-> gap config. 3/1/2/1
-> No glue/no spacers

GE1/1-V
-> Optimization of the mechanics
-> stretching apparatus inside the gas volume
-> single-mask technology
-> 99x(22-45) cm^2
-> 3072 readout channels
-> gap config. 3/1/2/1
-> No glue/no spacers

GE1/1 Versus production phase







2015 — **2016** ↑ — **2017-2018**

TDR | **Slice test installation** | **Production phase & installation**

GE1/1-VIII (LS2)

GE1/1-VI
-> Optimization of the mechanics
-> single-mask technology
-> design for long and short detectors
-> 99x(22-45) cm^2
-> 120x(20-50) cm^2
-> 3072 readout channels (new mapping)
-> gap config. 3/1/2/1
-> No glue/no spacers

GE1/1-VII (slice test)
-> Optimization of the mechanics
-> Optimization of the grounding
Optimization of the HV distribution
-> single-mask technology
-> 99x(22-45) cm^2
-> 120x(20-50) cm^2
-> 3072 readout channels
-> gap config. 3/1/2/1

-> External (w.r.t . CERN) production sites certification and chamber components shipment
-> GE1/1 chamber assembly and certification
-> Super chamber mechanics optimization
-> First test with final front-end electronics

-> GE1/1 super chamber assembly and certification with final front-end electronics
-> First batch of Superchamber shipped to P5

- GE1/1 super chambers ready in P5 for installation
- Installation and cabling of all super chambers
- Commissioning in situ with cosmic muons
- Super chamber characterization in situ with cosmic muon
- First data with LHC beam