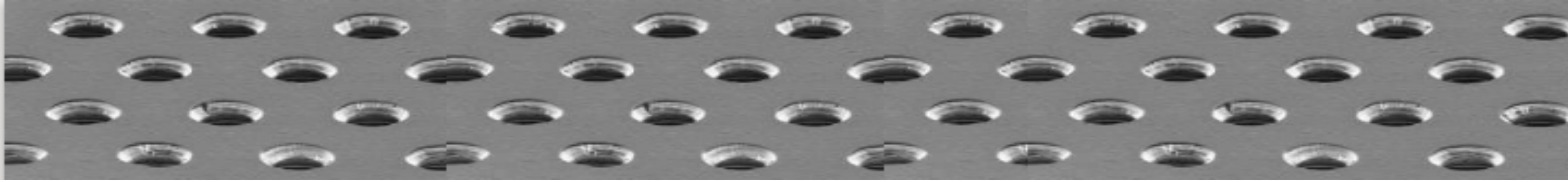


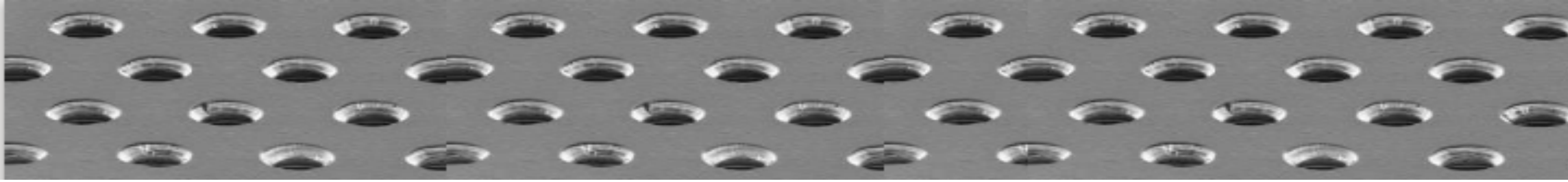
The CMS muon upgrade in preparation for the HL-LHC

By

Aashaq Shah

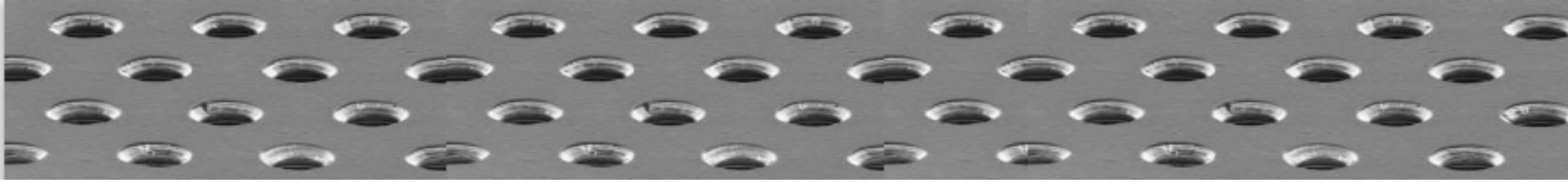
On behalf of the CMS Muon Group

New Perspectives 2020, 20-21 Jun 2020, Fermi National Accelerator Laboratory, Illinois, United States

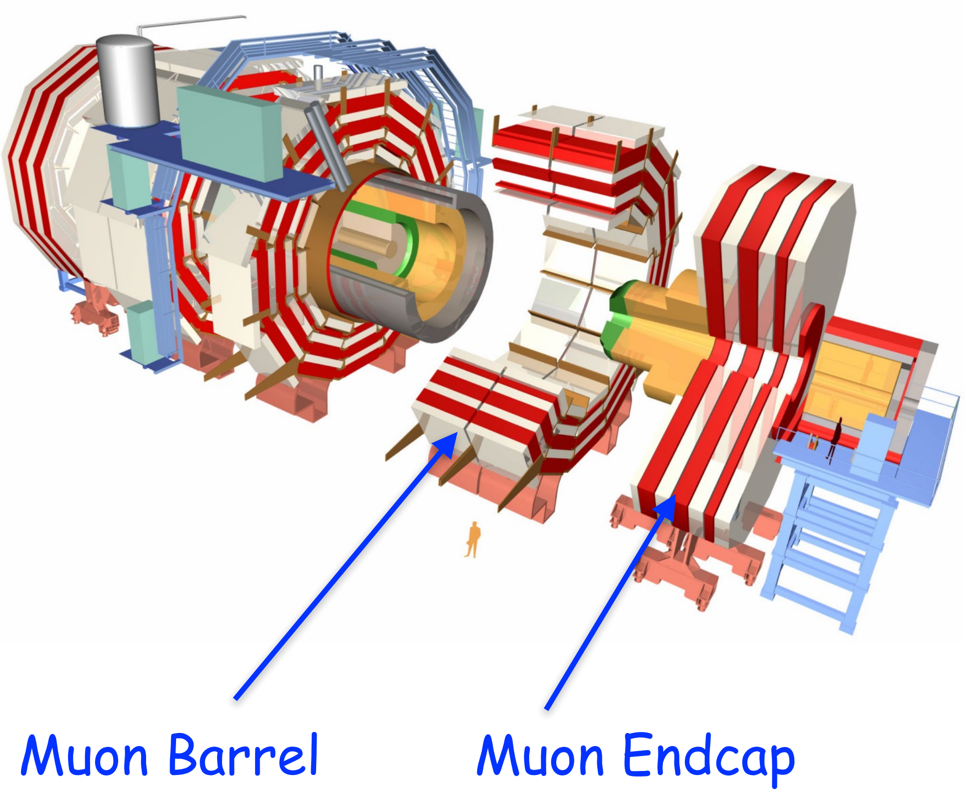


Outline

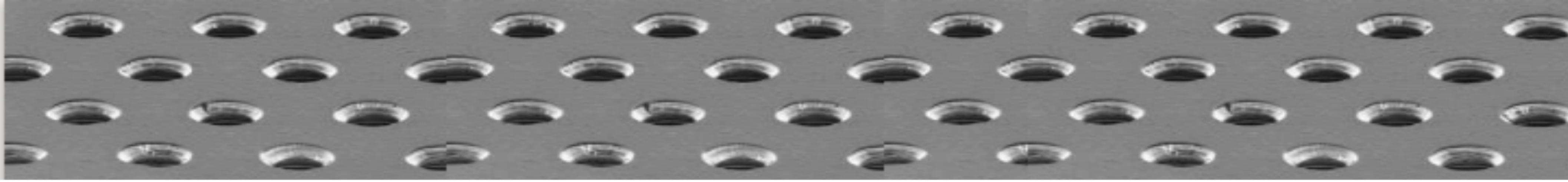
- Introduction
- The CMS Muon System
- Physics Motivation for the Upgrade
- New Detector Technologies and their Integration with the CMS
  - GE1/1
  - GE2/1
  - iRPC
  - ME0
- Summary



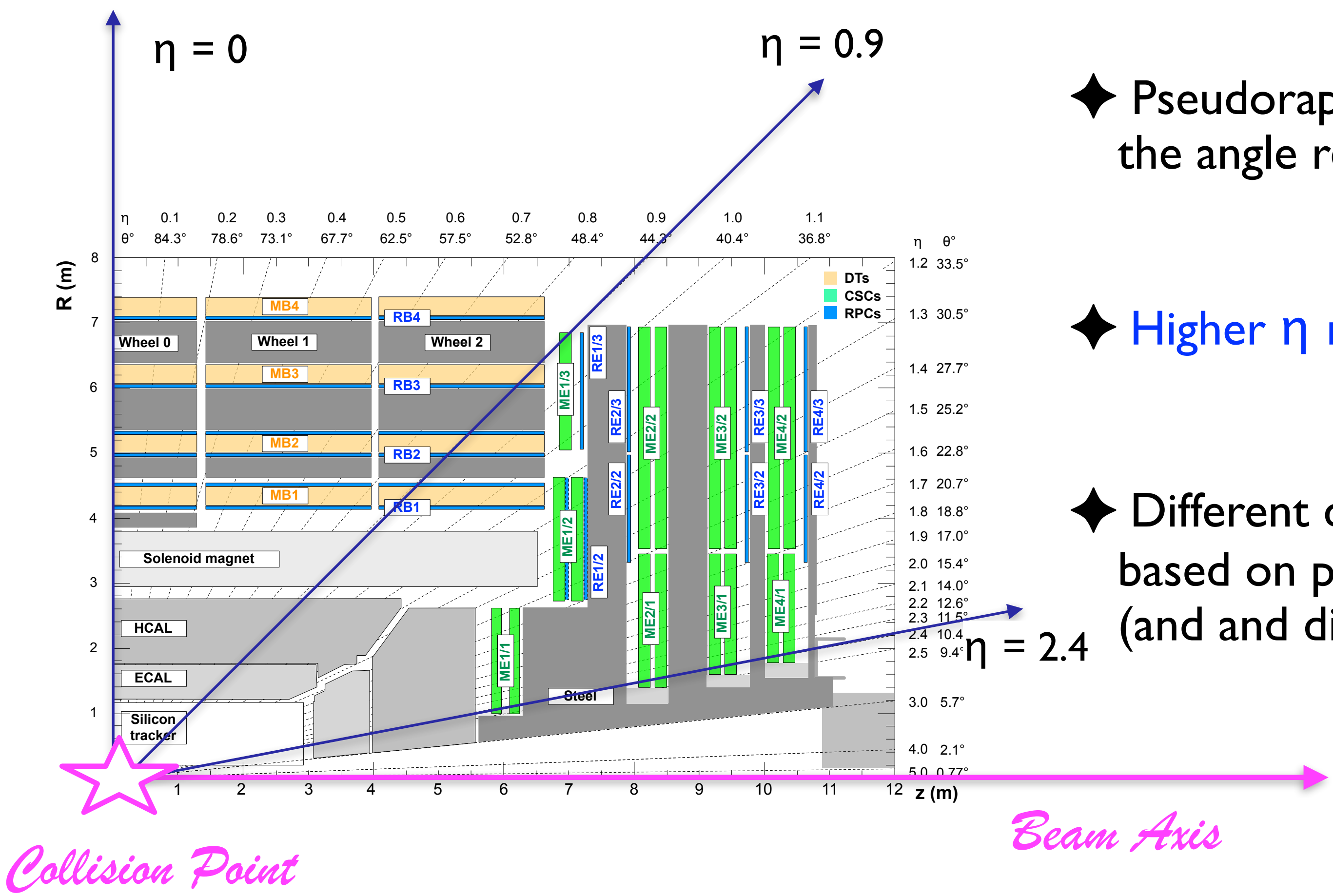
The CMS Experiment



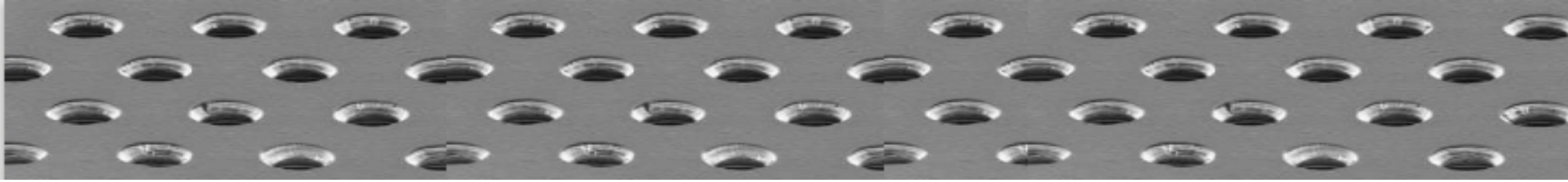
- ✦ Hadrons are copiously produced at LHC
- ✦ Almost all hadrons, electrons, and photons are absorbed in calorimeters
- ✦ Muons hit the outer layers of the detector
- ✦ To increase the discovery potential
  - Trigger, identification and measurement of muons is of great importance in searching for interesting and rare processes



The Present CMS Muon system

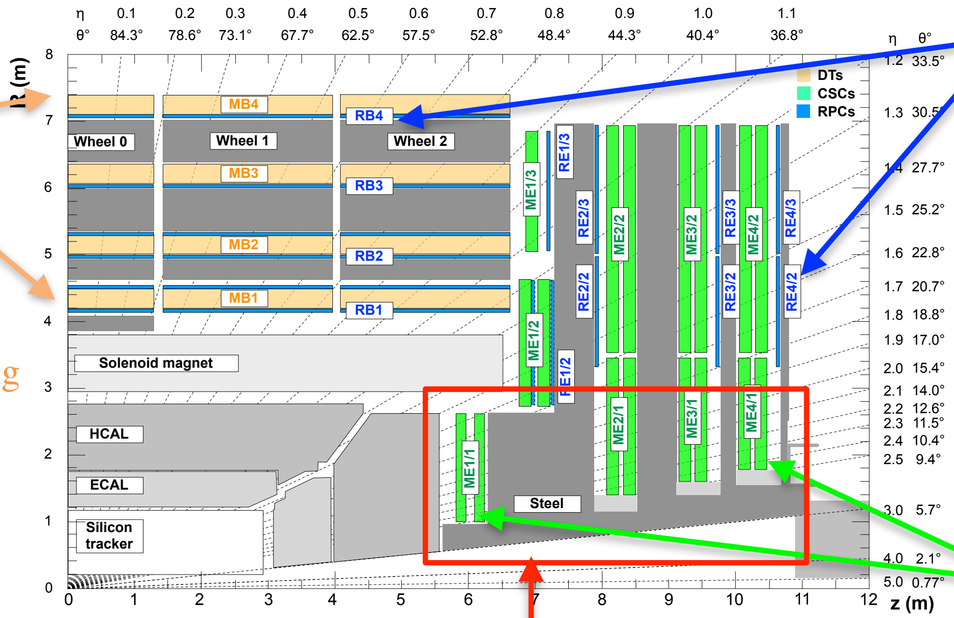


- ✦ Pseudorapidity $\eta = -\ln[\tan(\theta/2)]$ where θ is the angle relative to the beam axis
- ✦ Higher η region has higher particle rate
- ✦ Different detector technologies are chosen based on particle rates in different η regions (and and different magnetic fields)



Different gas detector technologies

- Drift Tube (DT)
- $0 < |\eta| < 1.2$
- 250 chambers
- Spatial resolution 100 μm
- Time resolution 2 ns
- Measurement and triggering

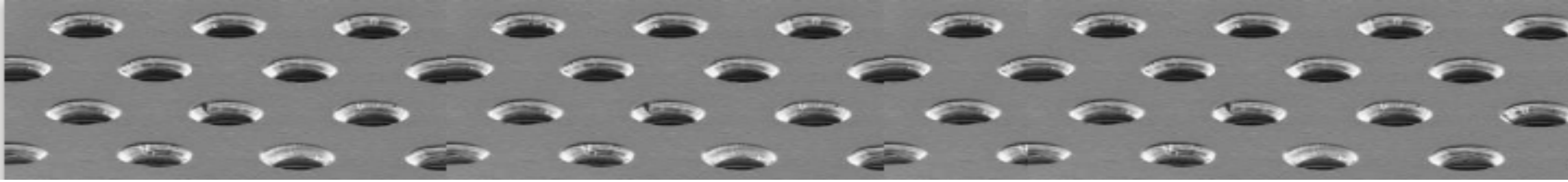


Only one detector technology: Some Regions Presently Unequipped

- Resistive Plate Chamber (RPC)
- $0 < |\eta| < 1.8$
- 480 (barrel) + 576 (endcap) chambers
- Spatial resolution 0.8-1.3 cm
- Time resolution 1.5 ns
- Redundancy and triggering

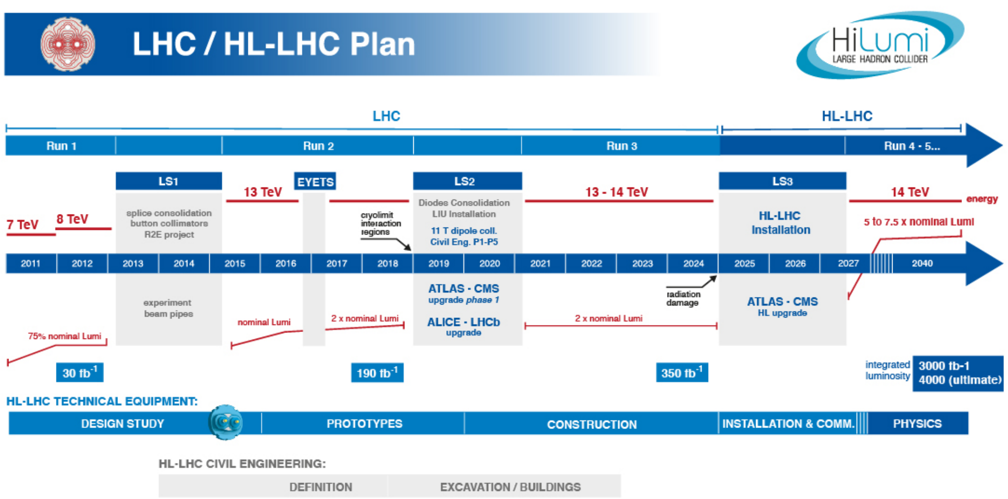
- Cathode Strip Chamber (CSC)
- $0.9 < |\eta| < 2.4$
- 540 chambers
- Spatial resolution 50-140 μm
- Time resolution 3 ns
- Measurement and triggering

The trajectory of a muon passes 4 stations, 2 types of detectors (except for the high η region)
Robust trigger and efficient reconstruction



HL-LHC Scenerio

- Experiments to face high rates
- Gradual increase of the luminosity up to 5-7 × 10^{34} $cm^{-2}s^{-1}$



Upgrades are defined by HL-LHC requirements!

Questions?

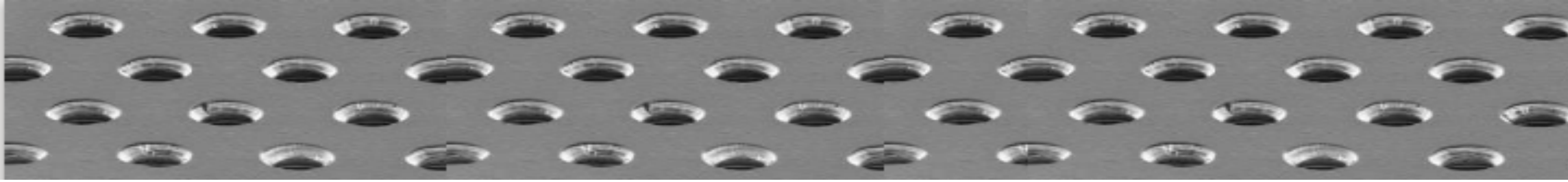
- Would the present Muon detectors survive without loss of performance?
- Is electronics sufficiently fast and radiation hard?

Problems:

- Increase of the background rate in the forward region |η| > 1.6 will lead to rise of the level-1 muon trigger rate
- Studies show that achieving an acceptable L1 trigger rate for muons with $p_T < 25$ GeV after LS2 is not possible without substantial additional efficiency losses in the forward region of the endcap
- Electronics?

Extend Search Sensitivity:

- Improving the current muon system of the CMS

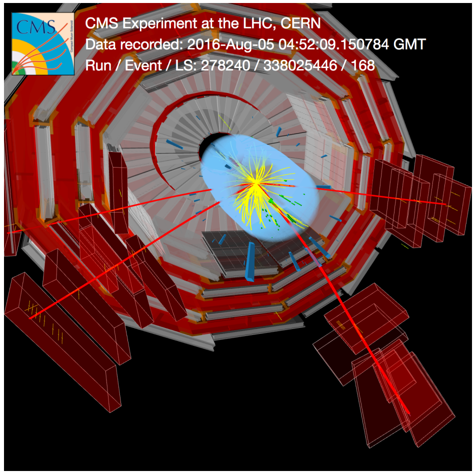


Why (muon) Upgrade?

- Search for new physics (e.g., Exotic signatures like $h \to aa \to 4\mu$, etc.) that may validate/invalidate BSM theories like NMSSM, 2HDM, 2HDM+S, etc.

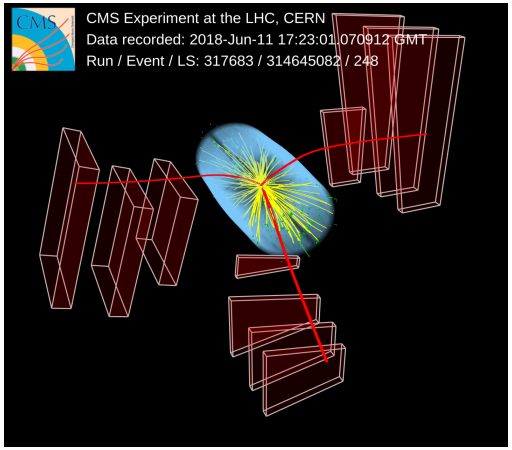
- Access rare decays e.g., tau→3μ, and B→2μ
  - For every billion B_s mesons produced, only about three are expected to decay into two muons
  - Measured branching fraction $\mathscr{B}(B_s \to \mu^+ \mu^-)$ = (3 +1.0/-0.9)E-9, where the uncertainty includes both statistical and systematic contributions

Event in which a candidate SM Higgs boson decays into four muons indicated by the red lines.



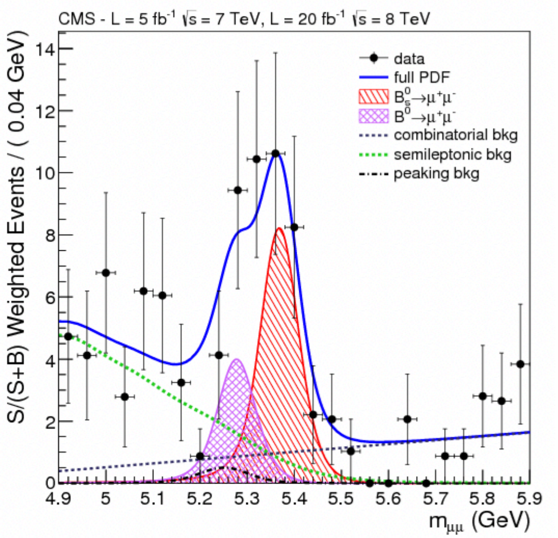
CMS-PHO-EVENTS-2019-008-2

Displays of candidate events with three muons produced from the decay of a strange B meson

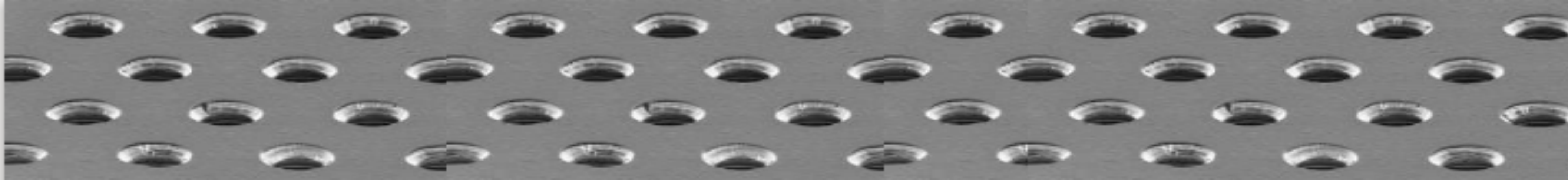


CMS-PAS-BPH-20-001

A very rare decay B→2μ



Phys. Rev. Lett. 111 (2013) 101804



Detector Longevity and Electronics Upgrade

Full-size chambers (DT, CSC, RPC) have been exposed to high rates at the CERN Gamma Irradiation Facility (GIF++)

DT:

- ✦ Muon reconstruction efficiency will remain high, thanks to multiple layers of DT on the path of a muon

Electronics

- On-detector and BE to be replaced in order to comply with HL-LHC requirements
- 940 new front-end boards (OBDT) and 96 back-end boards

CSC:

- ✦ No noticeable performance degradation up to 3 x HL-LHC

Electronics

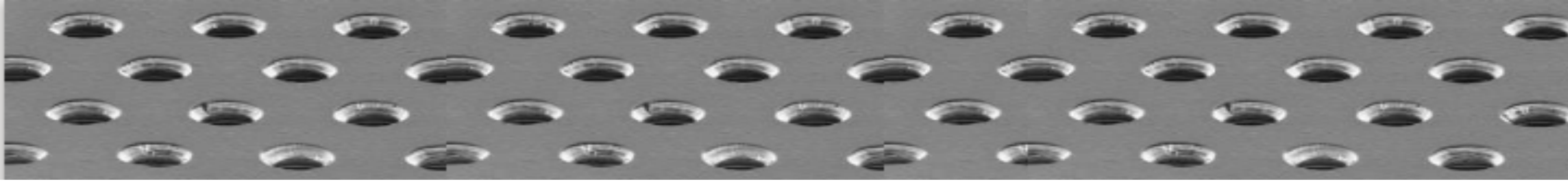
- ✦ Bandwidth of ODMB output (currently 1 Gb/s) insufficient for expected HL-LHC rates
- ✦ Selective on-detector : Upgrade of optical links (high speed new optical links) and redesign of backend (BE)

RPC:

- ✦ No noticeable performance degradation up to 3 x HL-LHC

Electronics

- ✦ Off-chamber readout/control to be replaced
- ✦ Electronic aging of the current Link system: Current output data transmission speed 1.6 Gbps and new Master Link board output data rate : 10.24 Gbps

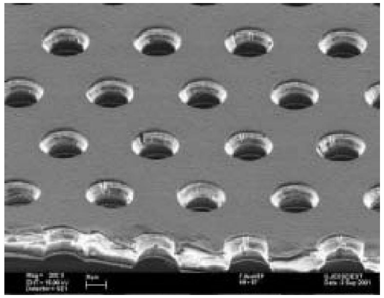


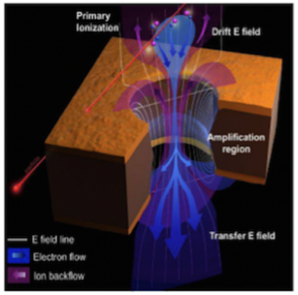
New Detector Technologies: GEM

✦ Gas electron Multiplier (GEM)

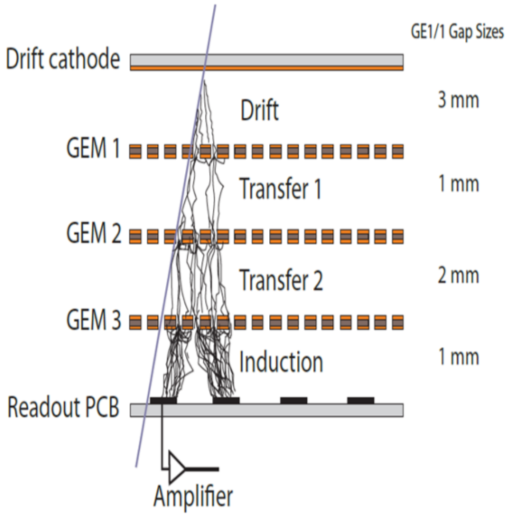
✦ Thin double-sided metal-coated polymer foil chemically pierced by a high density of holes:

- Kapton metal coated~ 50µm
- Pitch~140µm
- Cu thickness~5µm
- Hole density ~50 to 100 mm^{-2}





✦ Avalanches in strong electric filed concentrated in pin holes Known to operate reliably at high rate (MHz/cm^2) and have excellent longevity

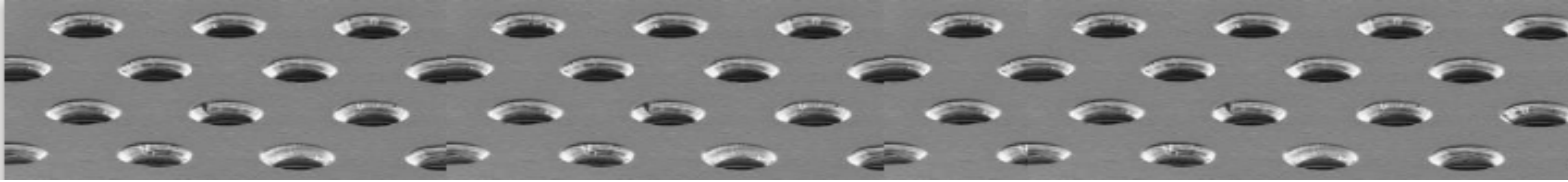


✦ GEM Performance

- Rate Capability ~10^5 kHz/cm^2
- Gas Gain ~10^5
- Spatial Resolution ~100 µm
- Timing resolution ~5-6 ns

D. Abbaneo et al., Nucl. Inst. Meth. A 972 (2020) 164104

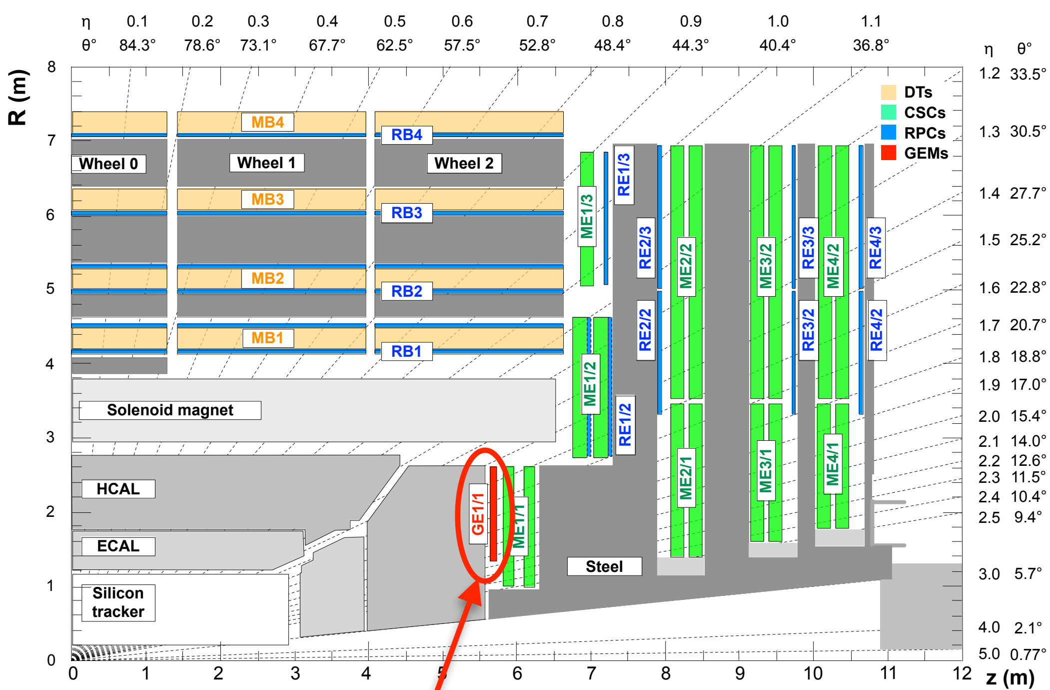
F. Sauli, Nucl. Inst. Meth. A386 (1997) 531-5341



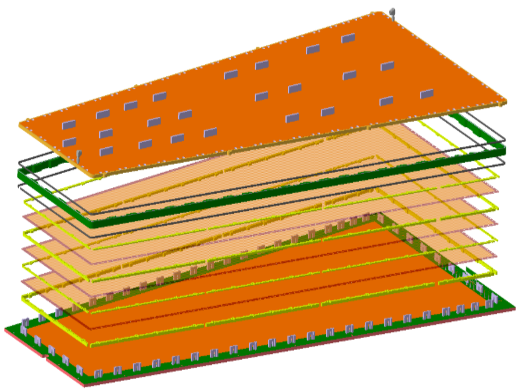
The CMS GEM GE1/1 Station

- The flux in the CMS end-caps is not expected to exceed 10 kHz/cm^2 (for ME0 < 50 kHz/cm^2)
- Two layers triple-GEM to be added at endcap stations: 1 and 2

GE1/1: $1.6 < |\eta| < 2.2$

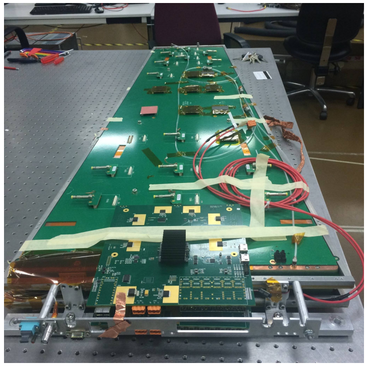


GE1/1 Station



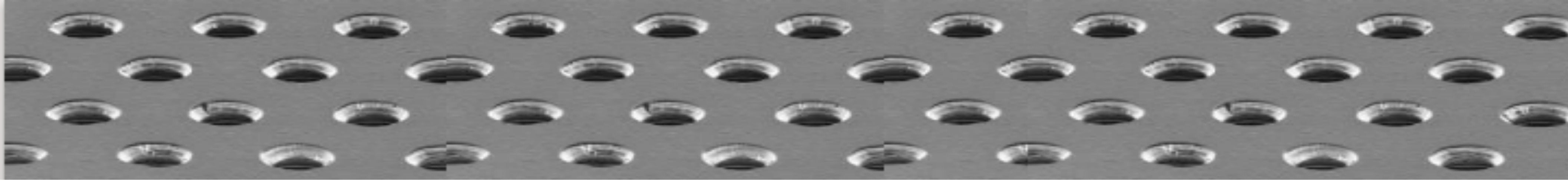
GE1/1 Design:

Exploded view of GE1/1 chamber



A newly assembled GE1/1 detector/super-chamber

D. Abbaneo et al., Nucl. Inst. Meth. A 918 (2019) 67-75



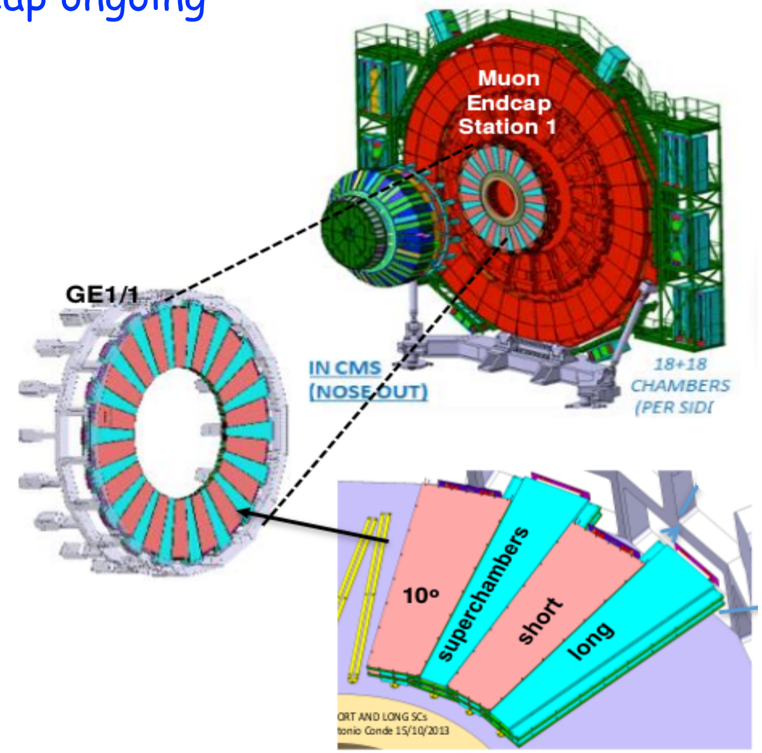
GE1/1 Status

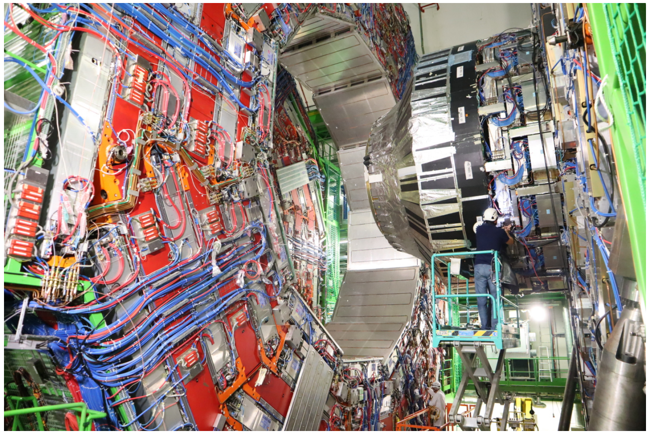
CMS GE1/1 chambers (2018) in the GEM production lab in Prevessin, France

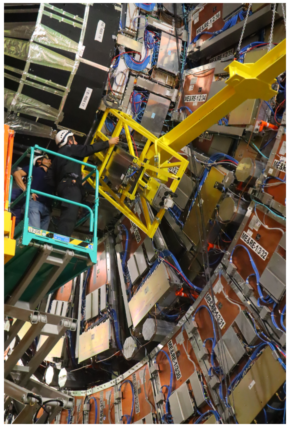
Negative Endcap Fully Equipped With GE1/1 Chambers

Commissioning with the CMS is ongoing

Installation of Positive Endcap ongoing

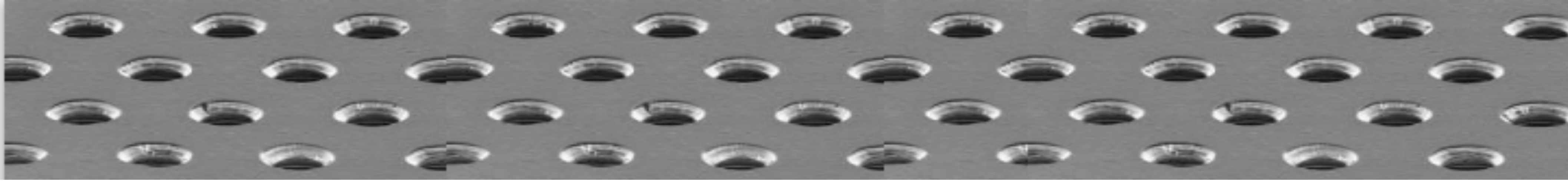






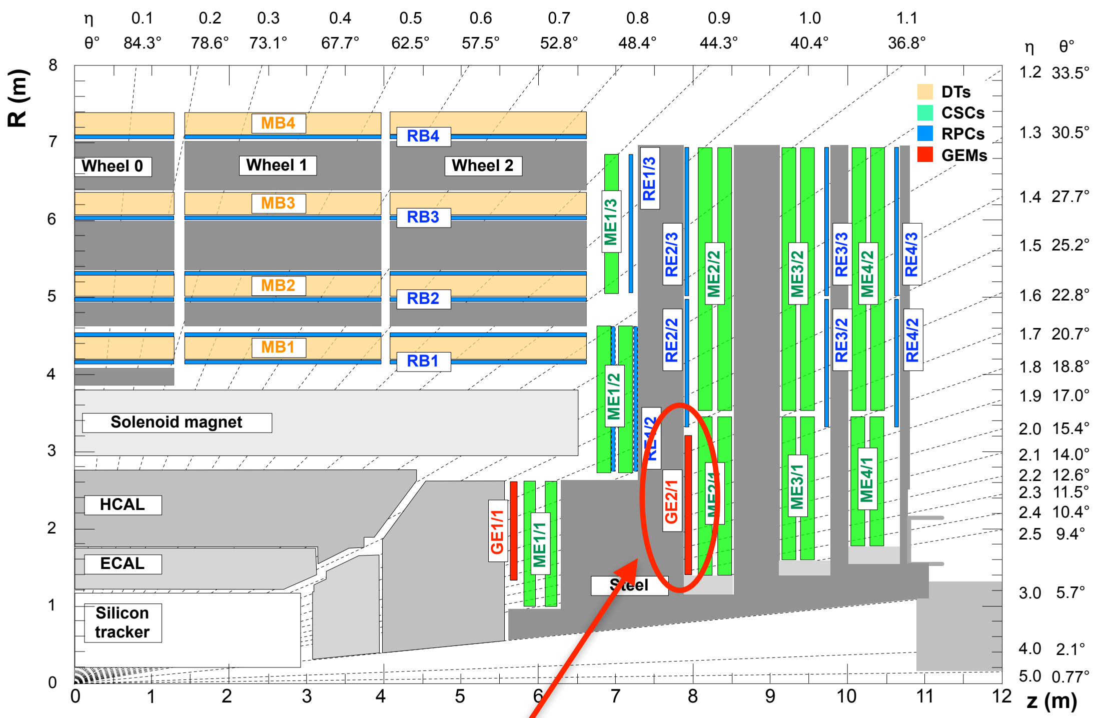
First CMS Gas Electron Multipliers (GEMs) installation (2019)

Installation in LS2



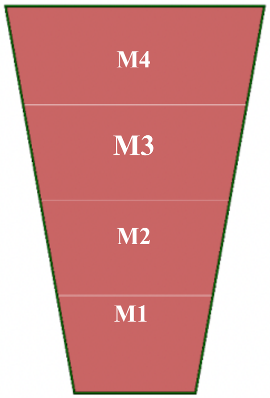
The CMS GEM GE2/1 Station

GE2/1: $1.62 < |\eta| < 2.43$



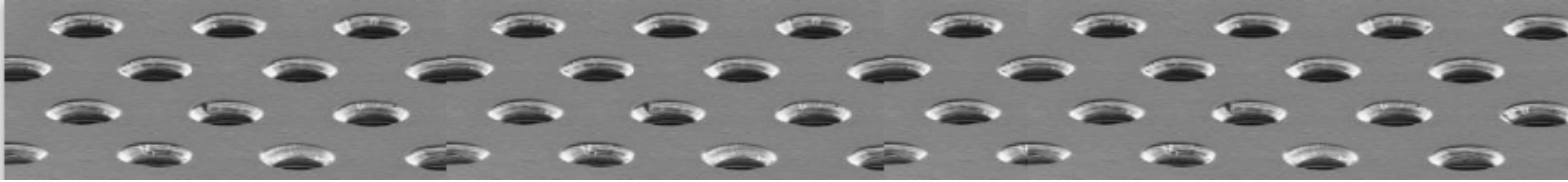
GE2/1 Station

Design Layout



First M4 prototype module built by GEM team at CERN

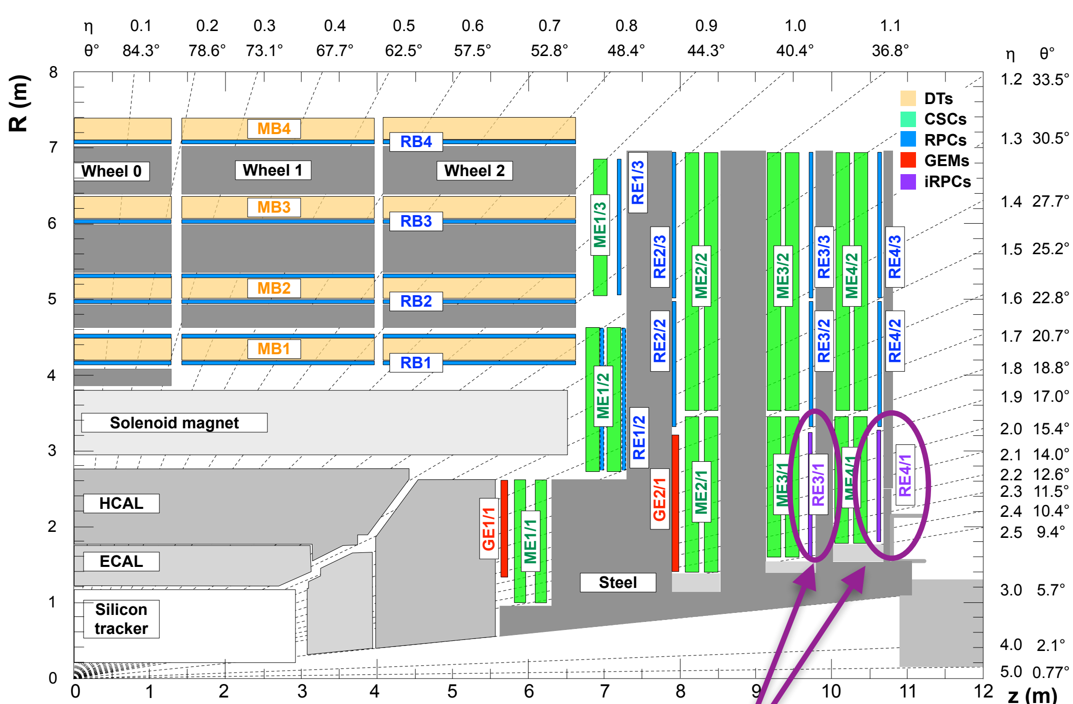
- GE2/1 Chambers will consist of 4 modules each (288 in total)
- Size of each module is roughly same as that of GE1/1 chamber and is similar in structure with GE1/1 super-chamber
- 36 20^0 Super Chambers
- To achieve the maximum coverage modules which realize Front and Back chambers will be staggered, as a consequence 8 different modules are foreseen for the GE2/1 production



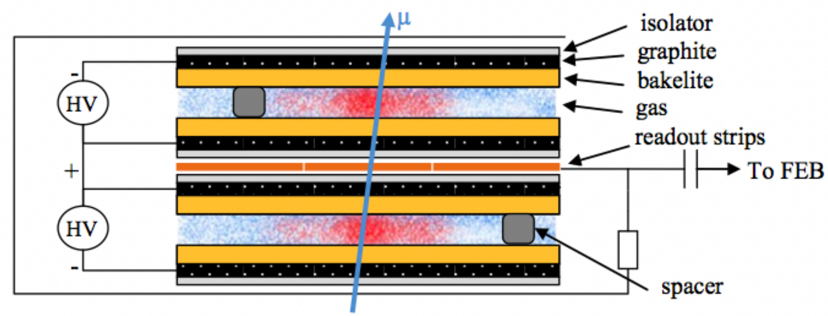
Improved RPC

1.8 < |η| < 2.4 (RE3/1, RE4/1)

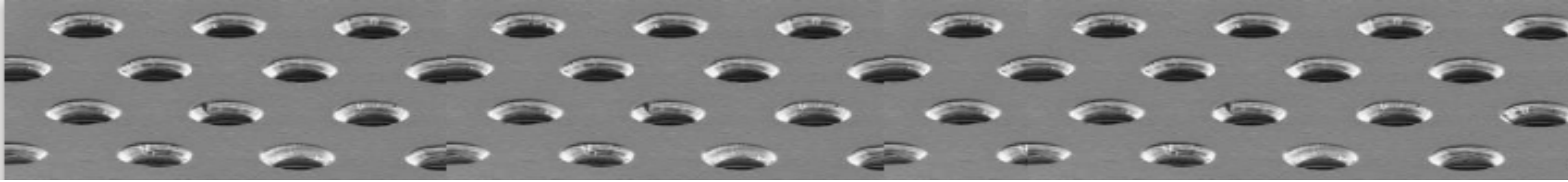
Performs well at 2 kHz/cm² (3xHL-LHC)



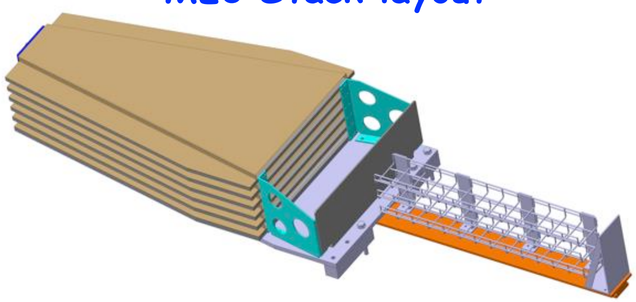
iRPC Stations



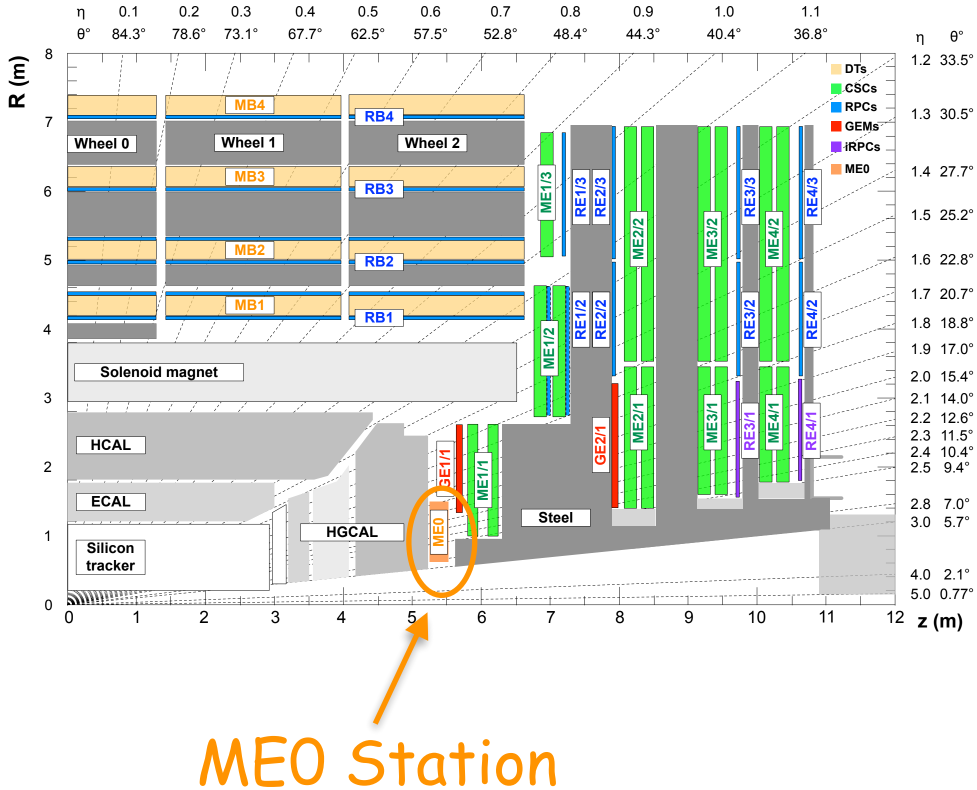
- Endcap stations 3&4; Double-gap RPC units
- 72 new iRPC (improved RPC) with dedicated FE and BE electronics
- Improved performance providing measurements in 2D
- Higher rate capability (lower resistivity, smaller gas gain)
- Better spatial resolution by two-ended strip readout



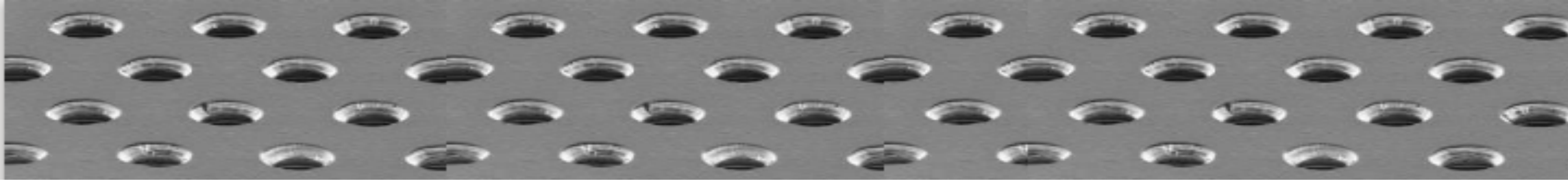
ME0 Station



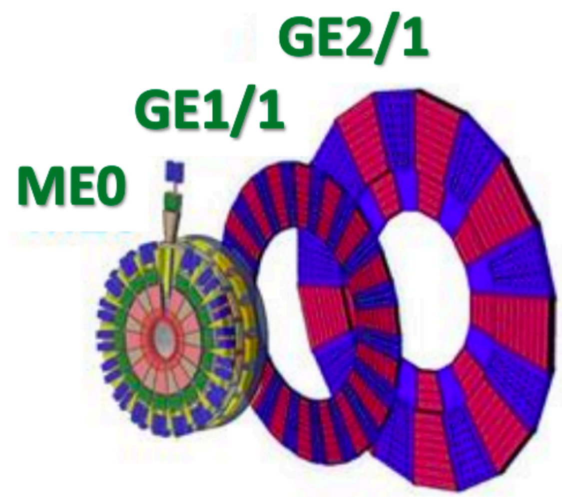
ME0: $2.0 < |\eta| < 2.8$



- Triple-GEM technology
- 20^0 stack is made up of 6 layers
- 18 Stacks per end-cap
- 216 Modules to be producesd
- $2.0 < |\eta| < 2.4$: CSC-ME0 tandem largely reduces trigger rate
- **$2.4 < |\eta| < 2.8$:** enlarged muon geometrical acceptance, taking advantage of the extended acceptance of upgraded CMS inner pixel detector



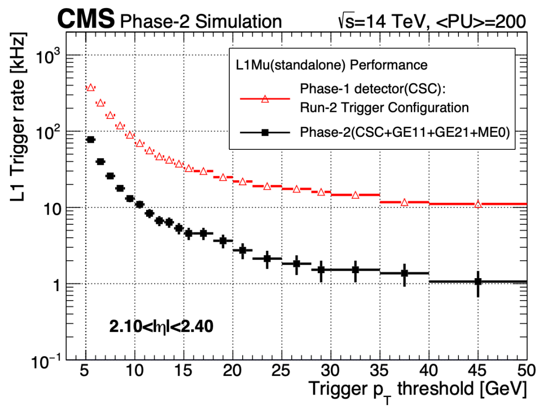
Impact on Trigger



Installation of GE1/1 during LS2 while as GE2/1 and ME0 by end LS3

Deployment of GEM GE1/1, GE2/1, ME0 along with CSC chambers results

- Trigger rate reduction (10 times)
- Increasing physics acceptance



Addition of ME0

- 17% Sensitivity gain detector in lepton flavor violating decay tau→3μ
- 50% Sensitivity gain in double parton scattering in pp→W^+W^-

Present DT, CSC, RPC detectors will stay

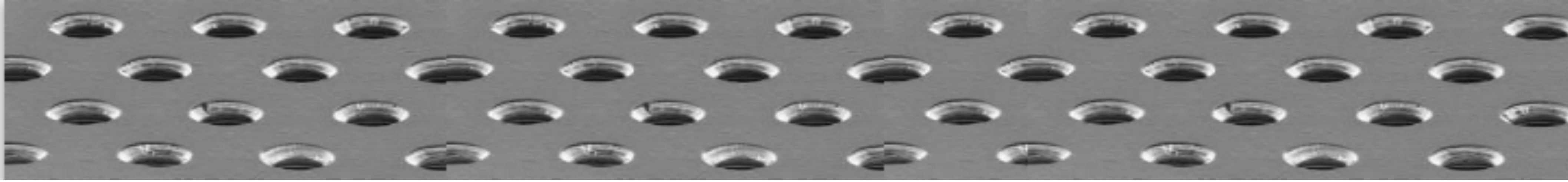
Some electronics to be replaced to meet HL-LHC requirements

The high η region to be enhanced with additional iRPC, GEM and ME0 detectors

Upgraded detector capabilities open windows for new physics opportunities

Thank you!

CMS TDR CERN-LHCC-2015-012, 2015



Back-up