CMS Phase 2 Forward Muon system Upgrade with GEM

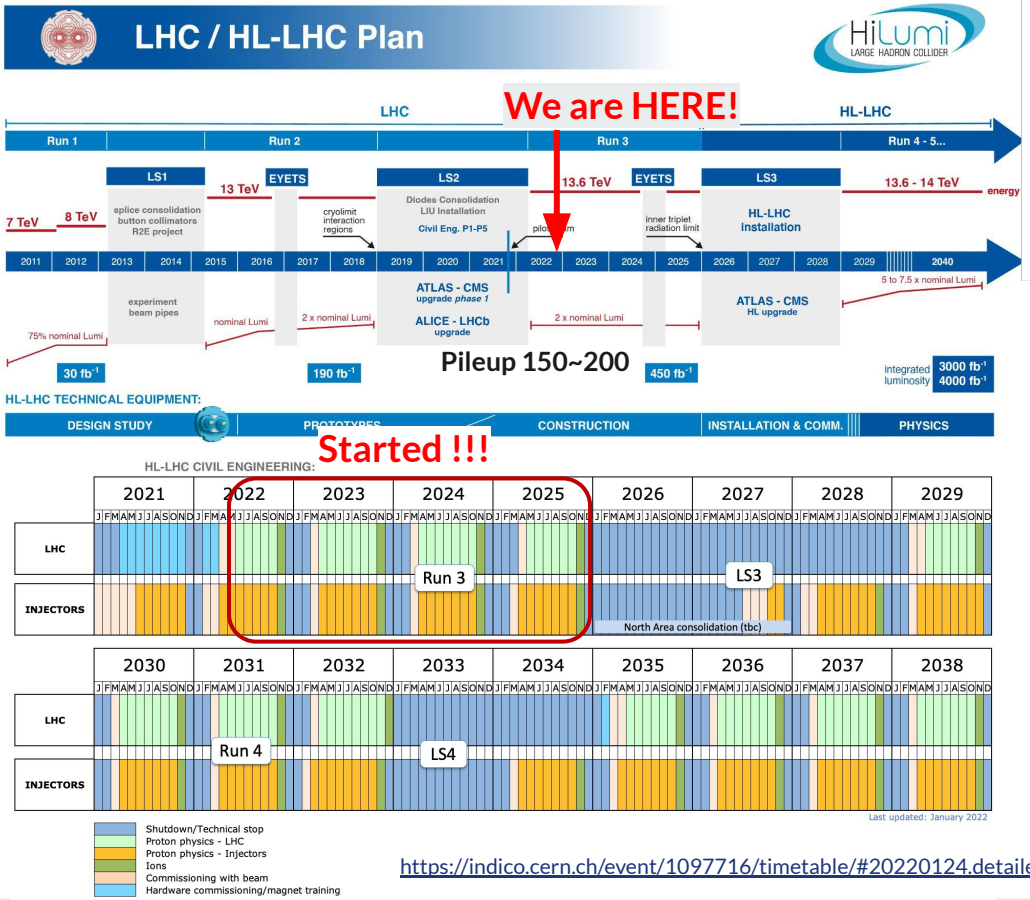
The 2022 international workshop on the high energy Circular Electron-Positron Collider

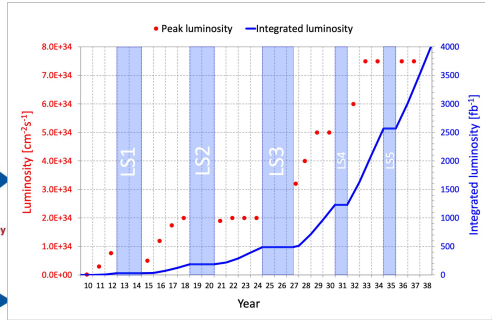
from Oct. 24 - 28

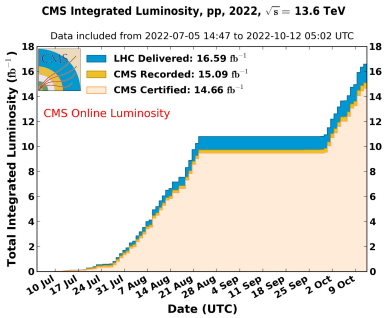
Dr. Donghyun Kim

On behalf of the Korea-CMS GEM QC Team

High Luminosity - LHC



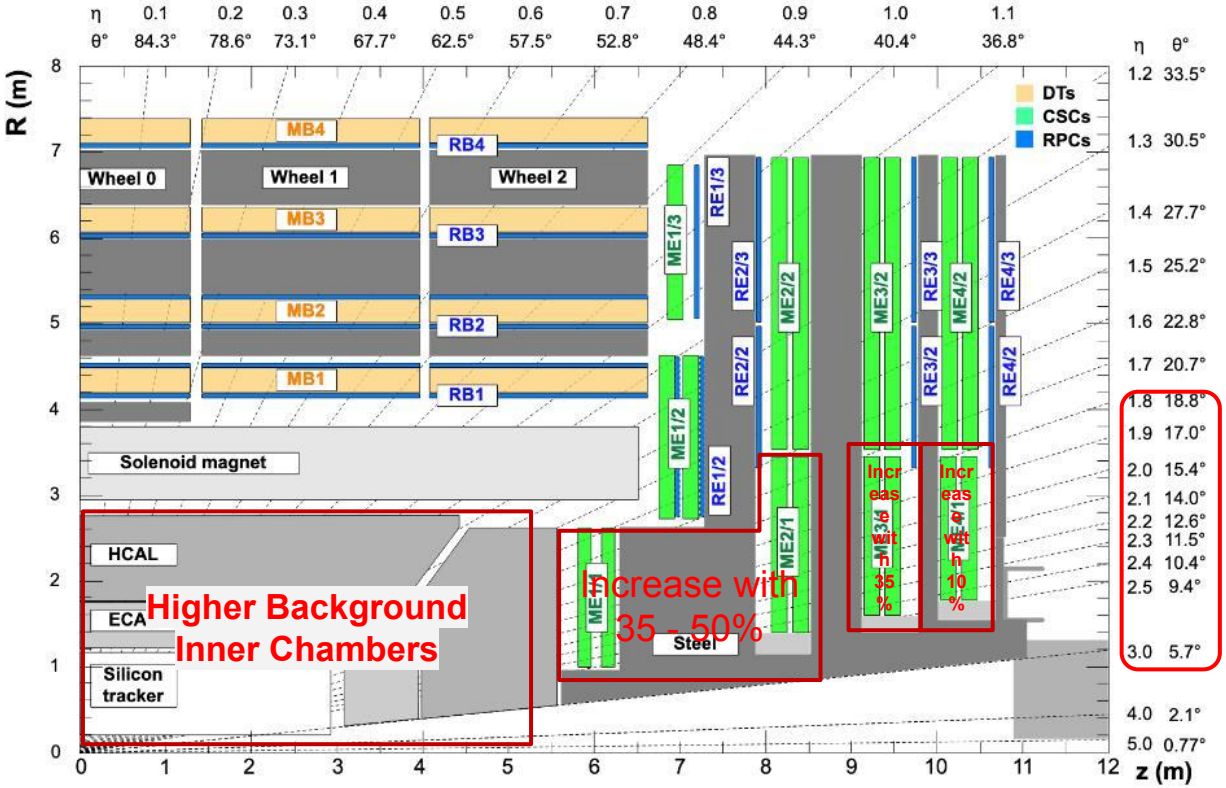




- Since March 2010, LHC has been producing proton-proton collisions at 7 TeV, and then at 8 TeV center-of-mass energy
- After a two-long shutdown, the center of mass energy reached 13.6 TeV. (Run3).
- CMS recorded 15fb^{-1} at 2022
- Integrated luminosity will be increased over 3000 fb^{-1} to get better physics performance.
- High luminosity has the advantage of being able to study new physics, but it also has its weaknesses.
  - ✓ Emit extremely high radiation
  - ✓ Extreme increase in readout signal.

https://indico.cern.ch/event/1097716/timetable/#20220124.detailed

Background variation Run2 Vs Run3

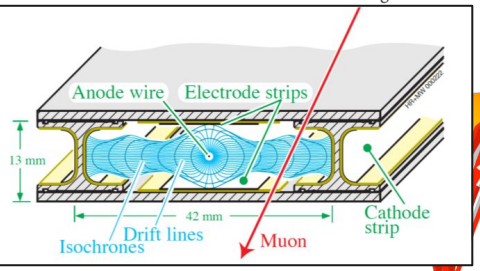


High Eta region -

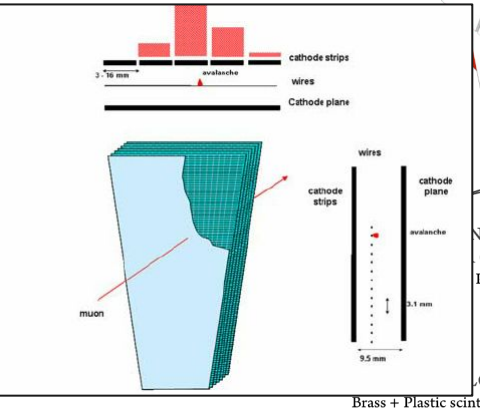
Only CSC Detector

< The layout of one-quarter of the CMS Detector at LHC Run-2>

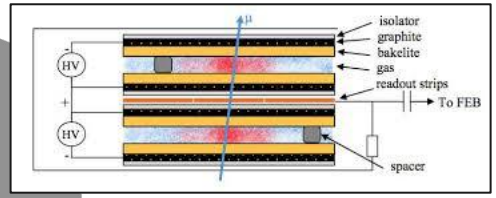
CMS Forward Muon System before LS2(2019)



Drift Tube

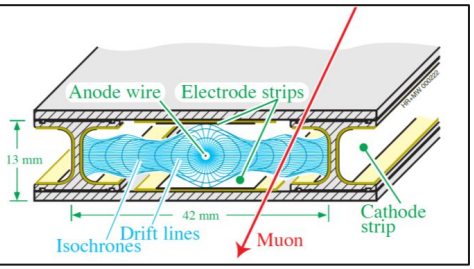


Cathode Strip Chamber



Resistive Plate Chamber

CMS Forward Muon System before LS2(2019)



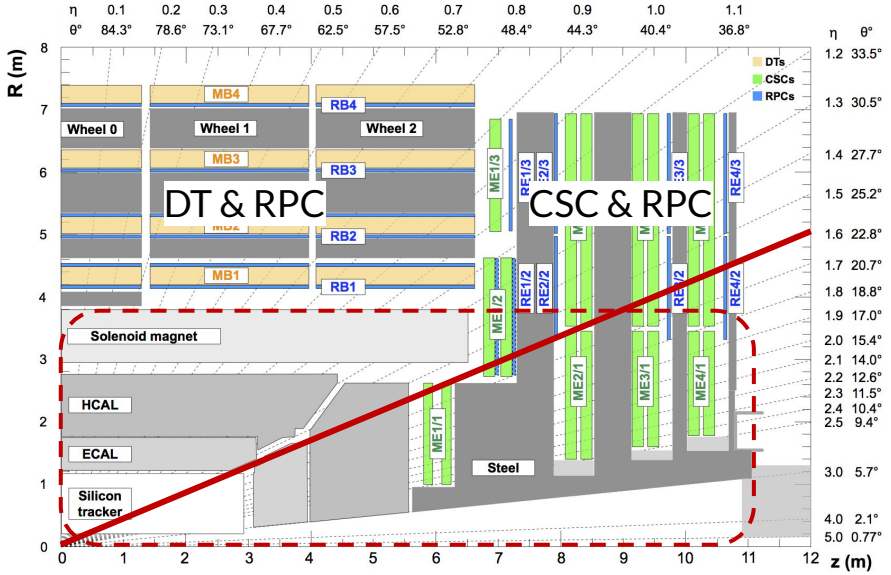
Drift Tube

DT & CSC

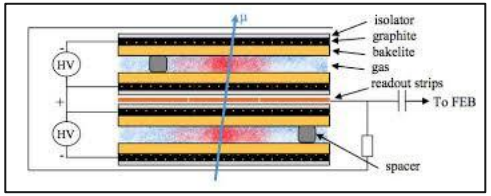
- For triggering and precision position & angle measurement

RPC

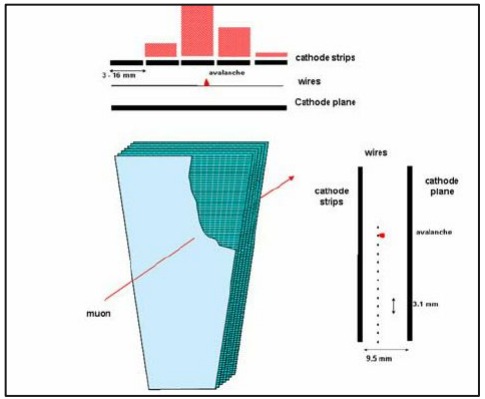
- Only for triggering



< The layout of one-quarter of the CMS Muon system >



Resistive Plate Chamber



Cathode Strip Chamber

Detector Coverage before LS 2

$|\eta|$ < 1.6 : Drift Tubes, Cathode Strip Chambers, and Resistive Plate Chambers

$|\eta|$ > 1.6 : Cathode Strip Chambers only

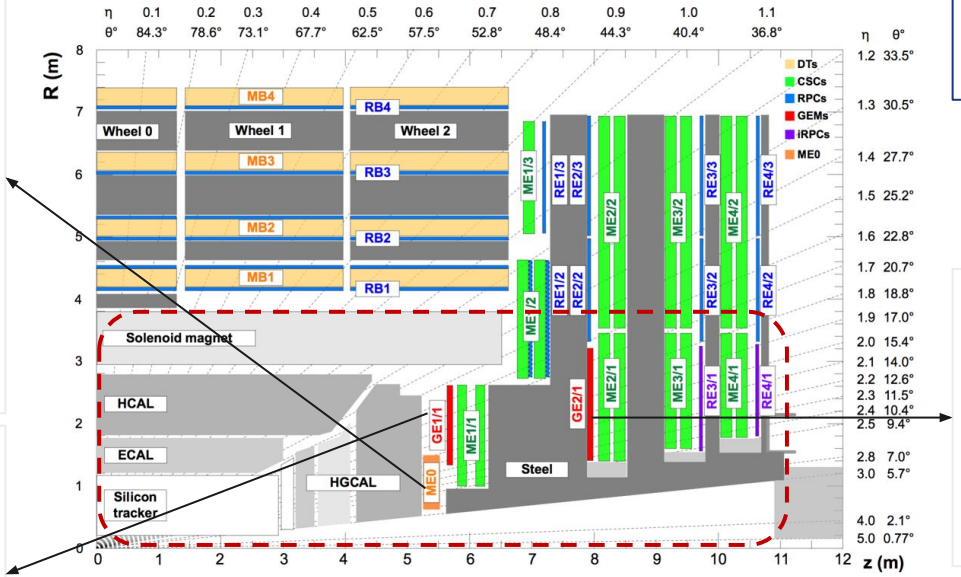
CMS Forward Muon System after LS2

ME0

- Trigger & Reconstruction
- 2 < |η| < 2.8
- A layered stack of 6 triple-GEM detectors.
- 18 stacks per endcap (36 total stacks - 216 modules)

GE1/1

- Trigger & Reconstruction
- 1.6 < |η| < 2.1
- 36 super-chambers
- Covered 10 degrees



< The layout of one-quarter of the CMS Muon system >

Upgrade procedure

GE11->GE21->ME0

GE2/1

- Trigger & Reconstruction
- 1.6 < |η| < 2.4
- 18 super-chambers
- Covered 20 degrees

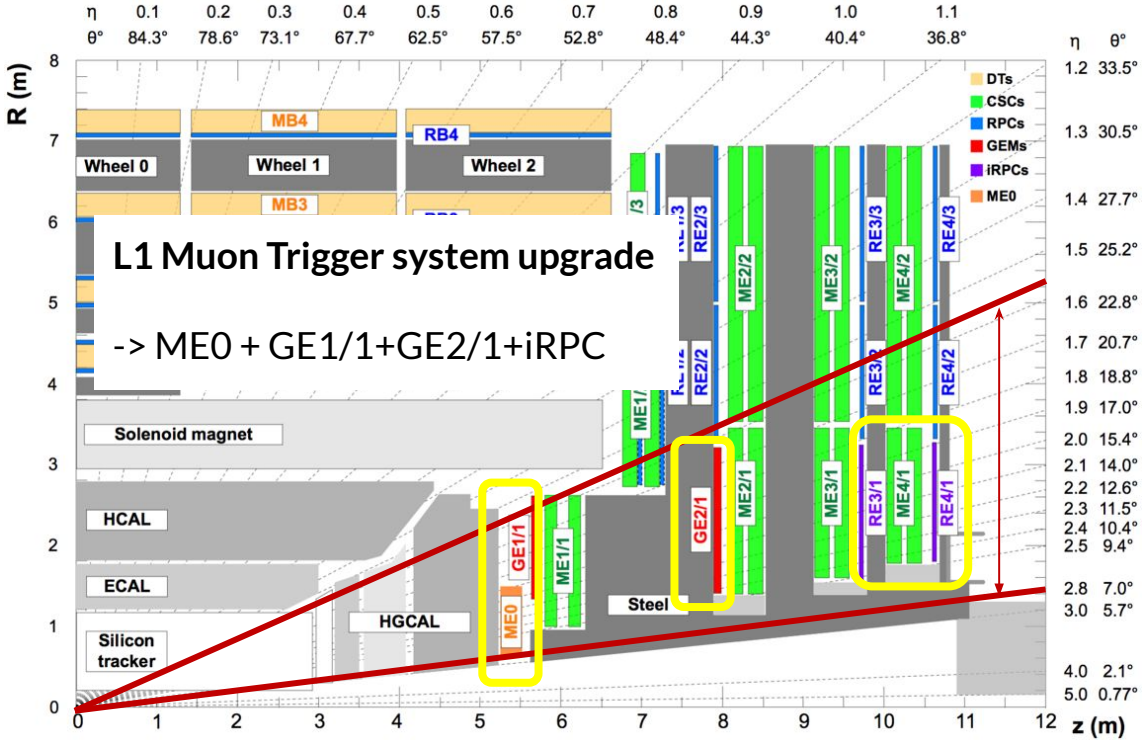
Detector Coverage after LS 2

$|\eta|$ < 1.6 : Drift Tubes, Cathode Strip Chambers, and Resistive Plate Chambers

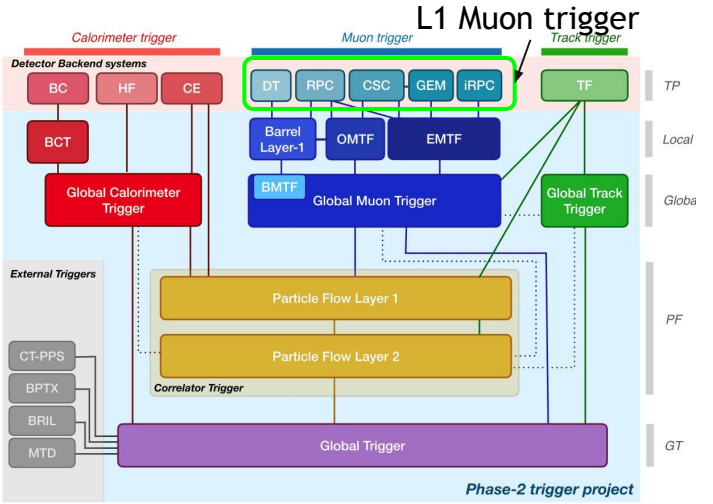
$|\eta|$ > 1.6 : Cathode Strip Chambers, iRPC, and GEM

CMS Forward Muon System Upgrade project with GEM Detector

CMS Forward Muon System Upgrade Project



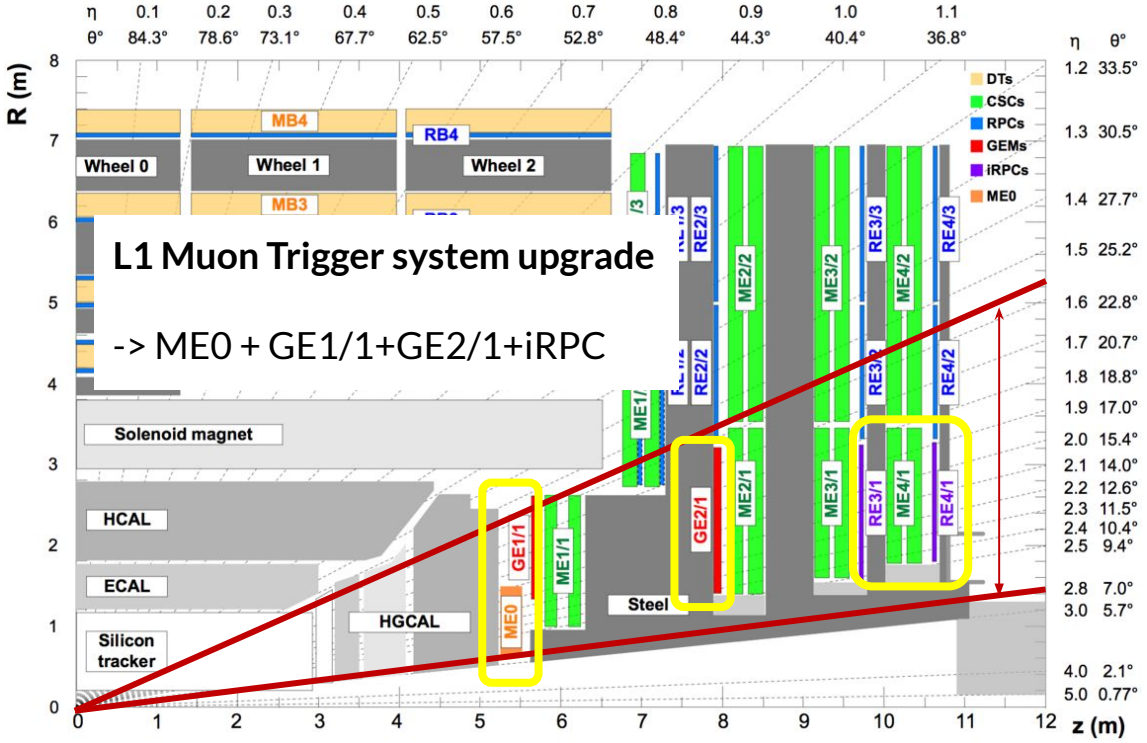
-> Improve Efficiency, P_T Resolution, Timing



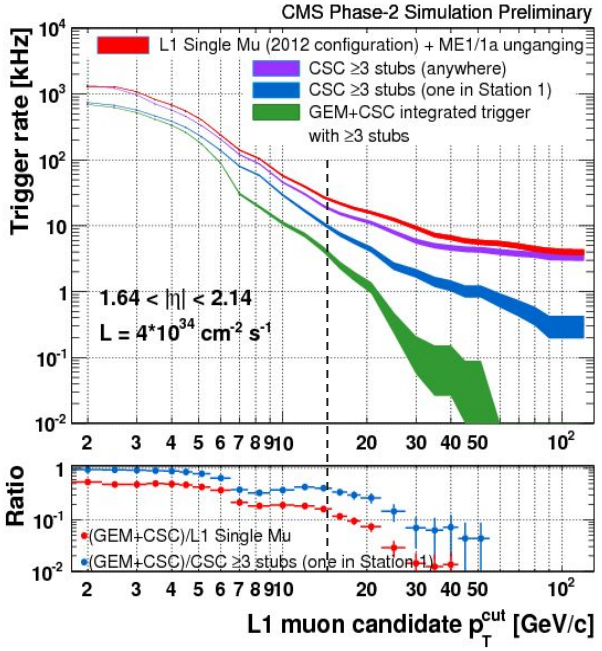
< Diagram of the upgrade CMS Trigger system >

https://cds.cern.ch/record/2759072/files/CMS-TDR-022.pdf

CMS Forward Muon System Upgrade Project

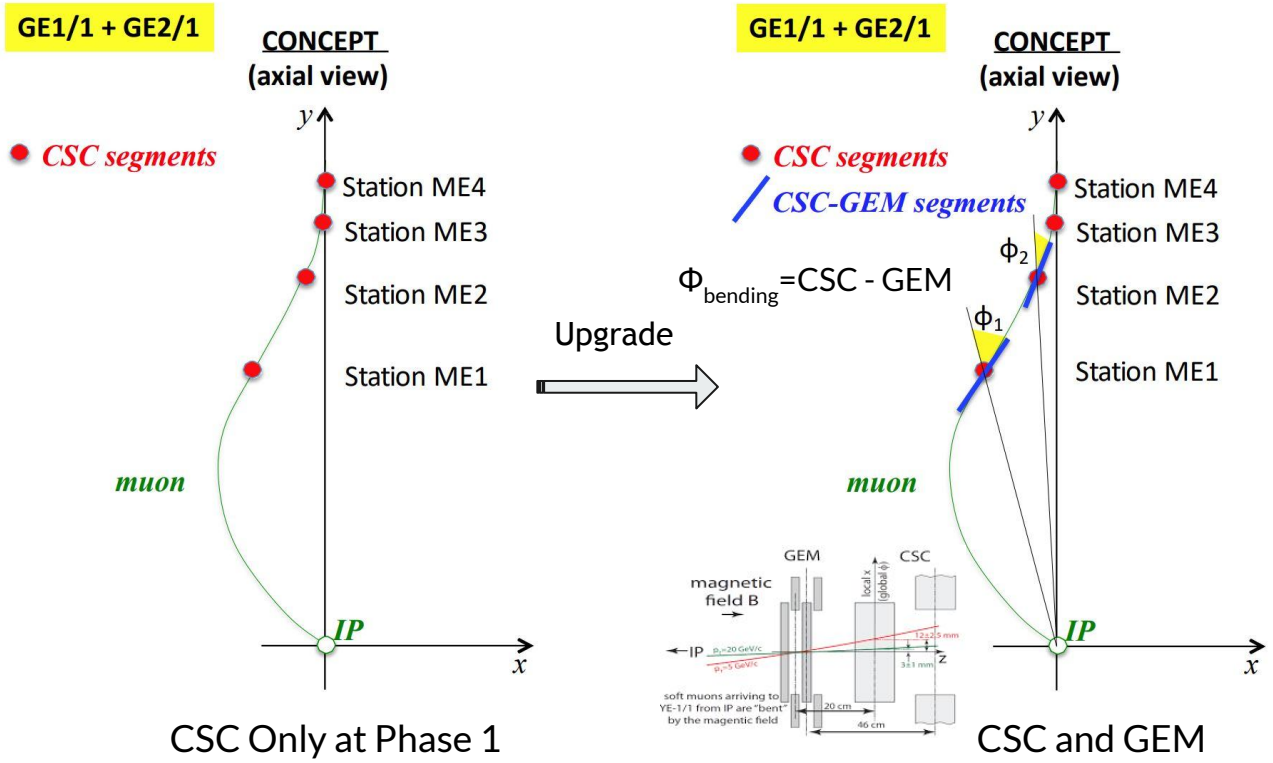


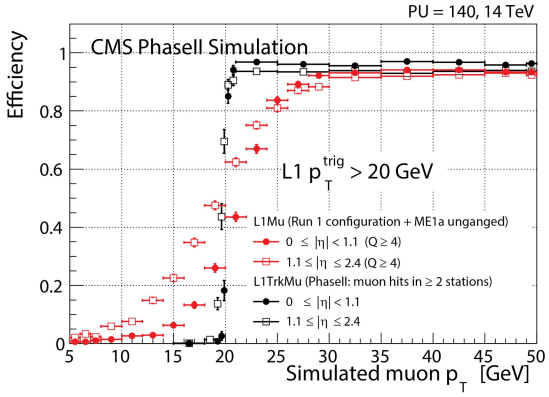
https://cds.cern.ch/record/2759072/files/CMS-TDR-022.pdf

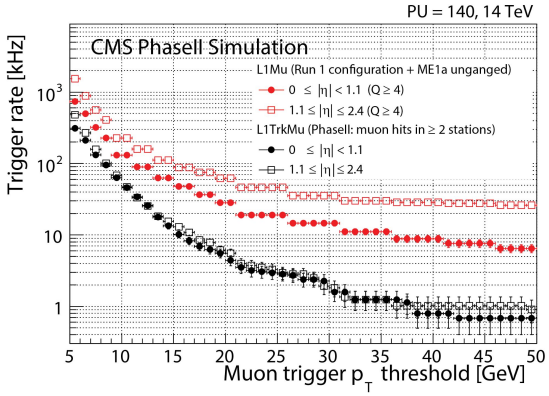


L1 muon trigger rate at a luminosity of 4×10^{34} cm $^{-2}$ s $^{-1}$ as a function of p_T cut.
Adding a GEM detector greatly reduces the trigger rate in the low P_T cut.
15GeV online threshold, trigger rate < 5 kHz, high efficiency.

CMS Forward Muon System Upgrade Project







It can be an accurate measurement of Φ direction at the ME1 and ME2 stations.
The installation of the GEMs is aimed at reduce the trigger rate in the region which currently suffering from the highest background rates and a non-uniform magnetic field. This trigger rate reduction could be possible with the improved momentum resolution deriving from precision measurements of the bending angle performed the lever arm between the CSC and GEM. (*CMS-CR-2014-349)

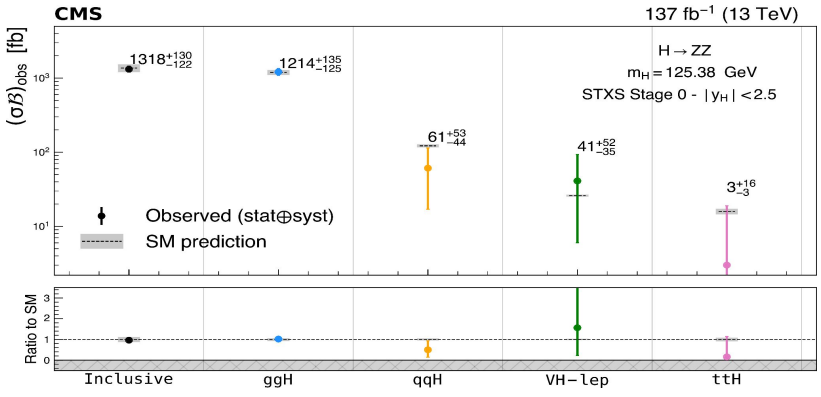
CMS Forward Muon System Upgrade Project

One of the main physics motivations for the CMS forward muon system upgrade has the Higgs boson discovery.

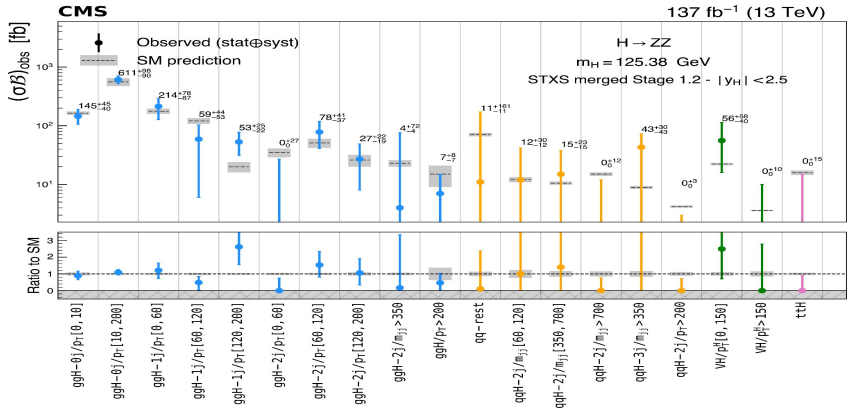
Golden decay Channel of a SM Higgs boson, Higgs -> ZZ* -> Four-muons.

An **increase in η coverage** and **a lower p_T selection cut** for single μ in the forward region would also improve the efficiency for H → 4μ event selection.

17 ~20 % increase in acceptance due to the high eta region coverage by new GEM detectors.

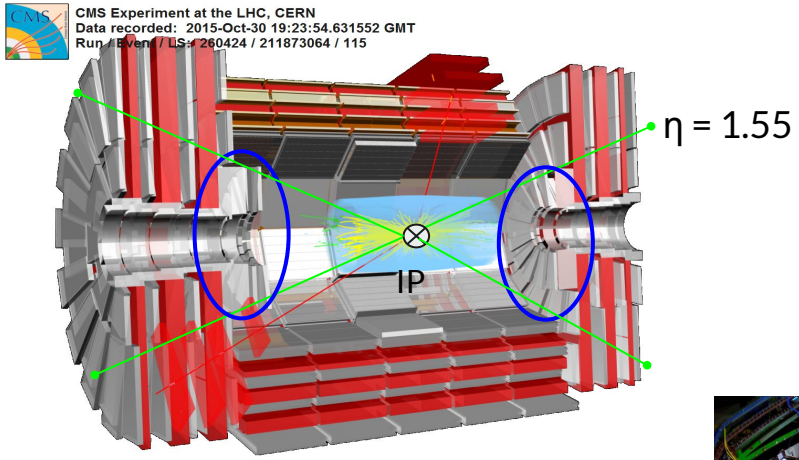


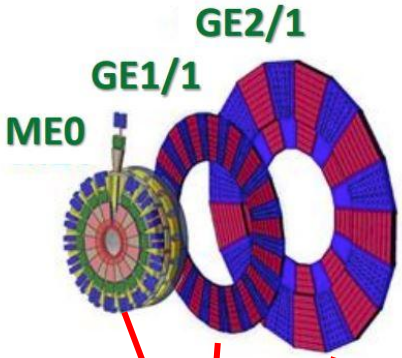
< Measured and predicted cross sections for different Higgs boson production mechanisms >



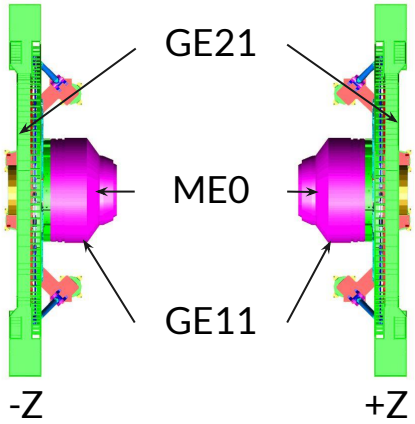
< Measured and predicted cross sections for different Higgs boson kinematic regions >

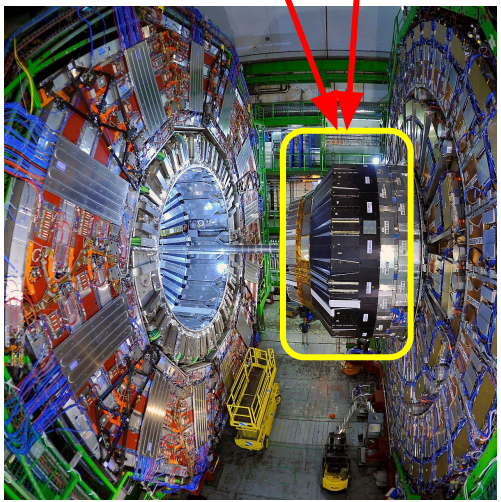
CMS Forward Muon System Upgrade

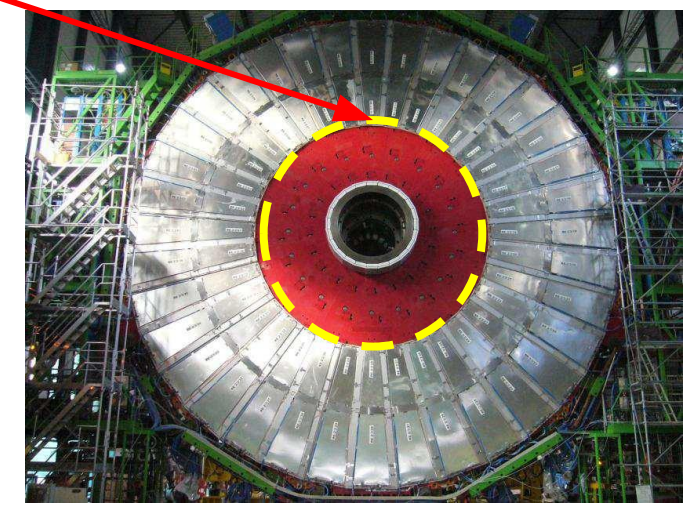




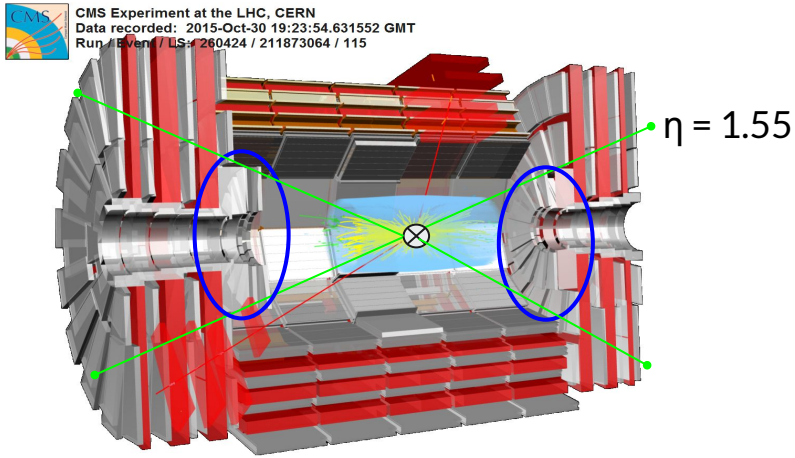
The Muon detector upgrade will preserve and enhance the performance of the CMS muon system in the **Forward** and **High eta** (1.5~2.8) region by installing new forward muon detectors such as GEM (ME0, GE1/1, GE2/1) and iRPC (RE3/1, RE4/1) in the Phase 2.

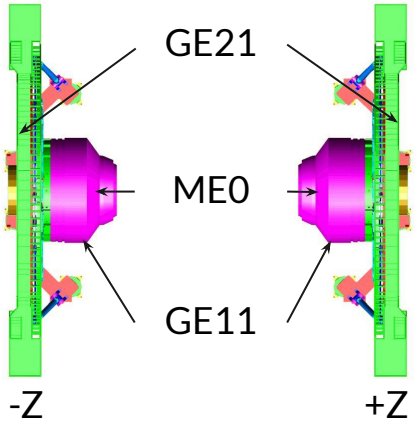






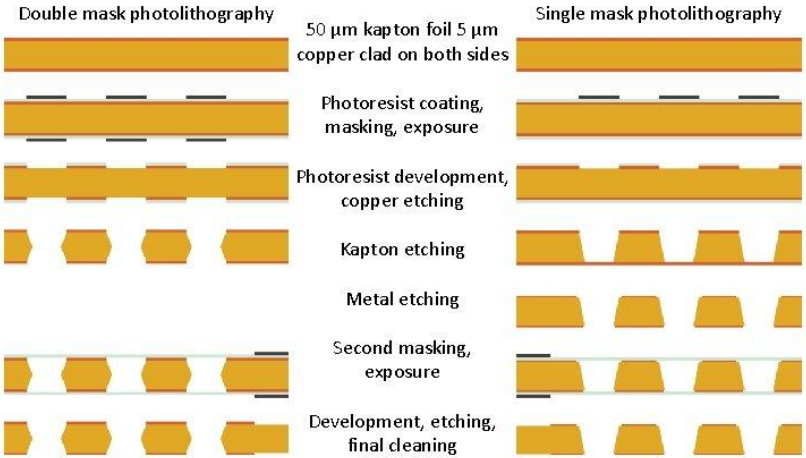
CMS Forward Muon System Upgrade





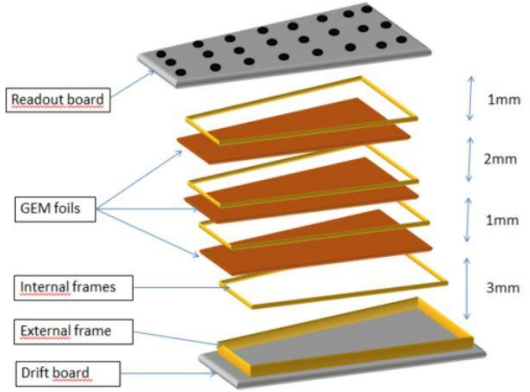
GEM Detector in the CMS

Double mask vs. single mask

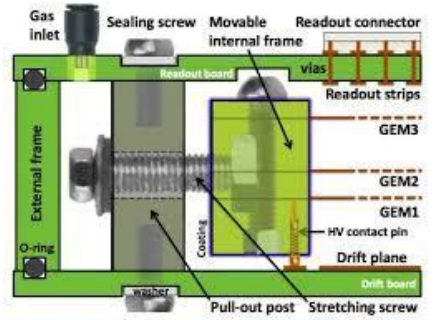


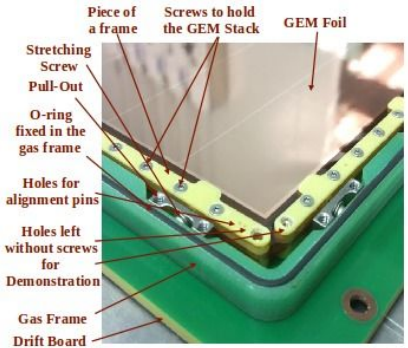
Foil is a product made by two different vendors with different mask types.

Single mask : CERN / Double mask : Korea-CMS



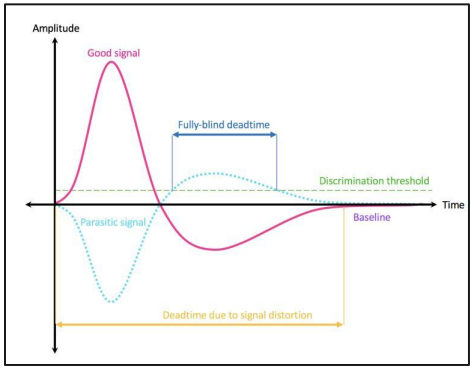
< Triple layer GEM detector with 3-1-2-1 mm gap >

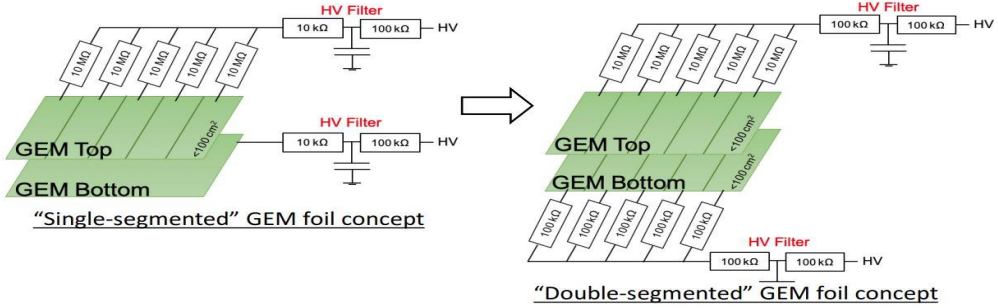


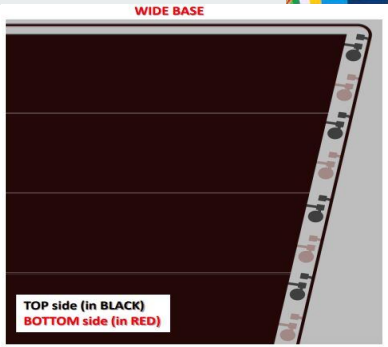


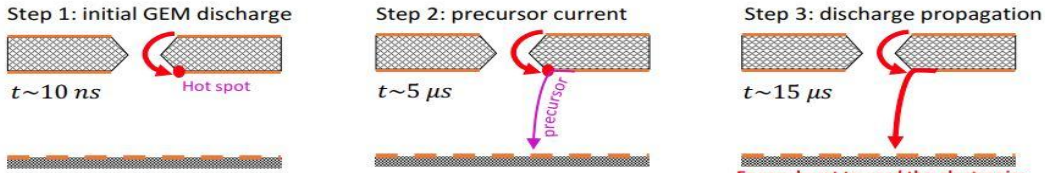
< Mechanical stretching method >

GEM Detector in the CMS









Schematic view of the discharge propagation process

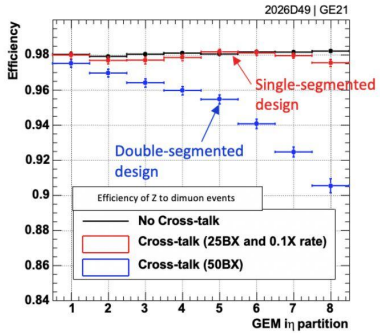
Basic principle:

Regular GEM discharges can heat up the copper rim of GEM holes and provoke the thermionic emission of electrons in the gas (precursor current). If the energy is sufficient, the precursor current grows and become a streamer (secondary discharge in the gaps)

Application of resistors for Discharge and Cross-Talk protection on the readout side.
The most effective mitigation consists of reducing the probability of discharge propagation.

- Foil Segment type

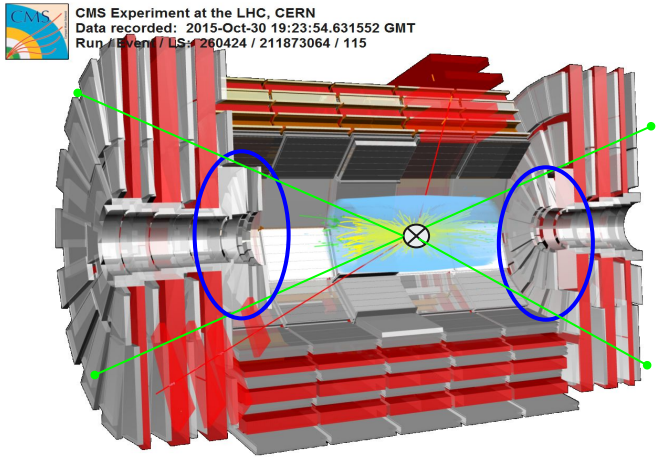
  GE1/1 - Single segment(Drift side only - 10Mohm)
  GE2/1 & ME0 - Double segments(GEM1 & GEM2 only)

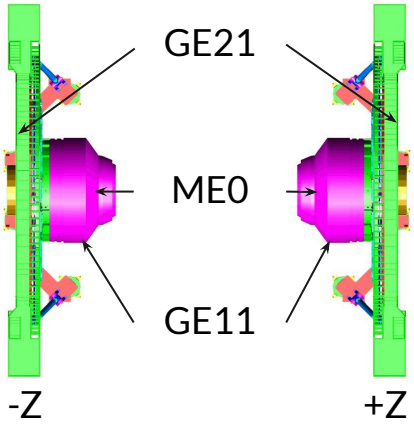


GE 1/1 Installed in the CMS detector

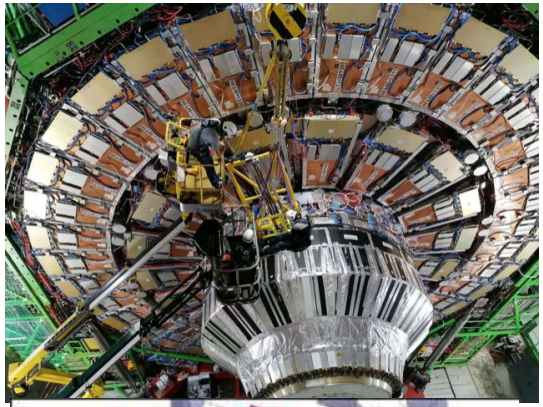
The CMS GEMs are the first GEM chambers with such a large size (an area of about 0.5 m^2) and the largest GEM system ever installed. A first batch of **144 chambers** was installed during Long Shutdown 2 on the first disk of the two endcaps at 23 Sep 2020.

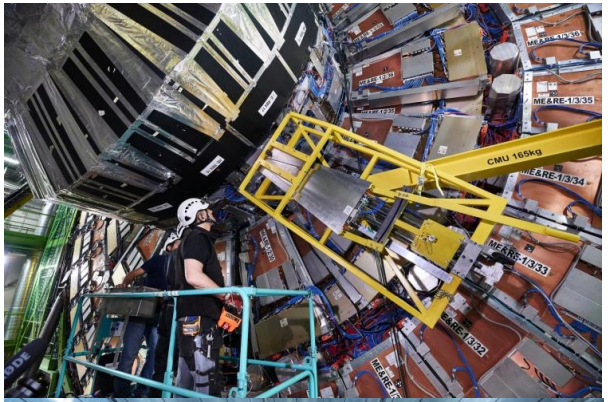
CMS Forward Muon System Upgrade

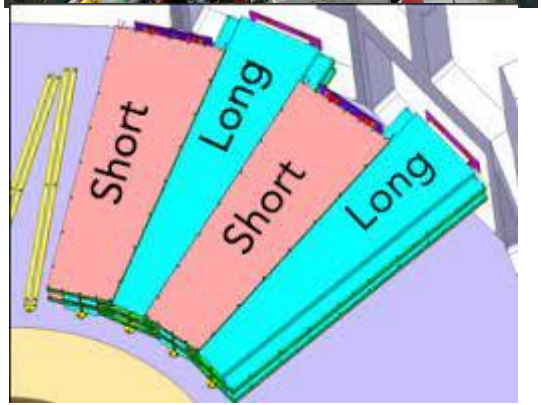


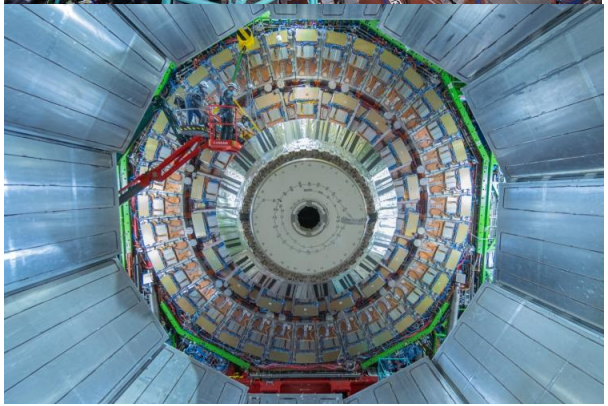


First GEM station (GE11) installed in CMS. 23 Sep 2020.

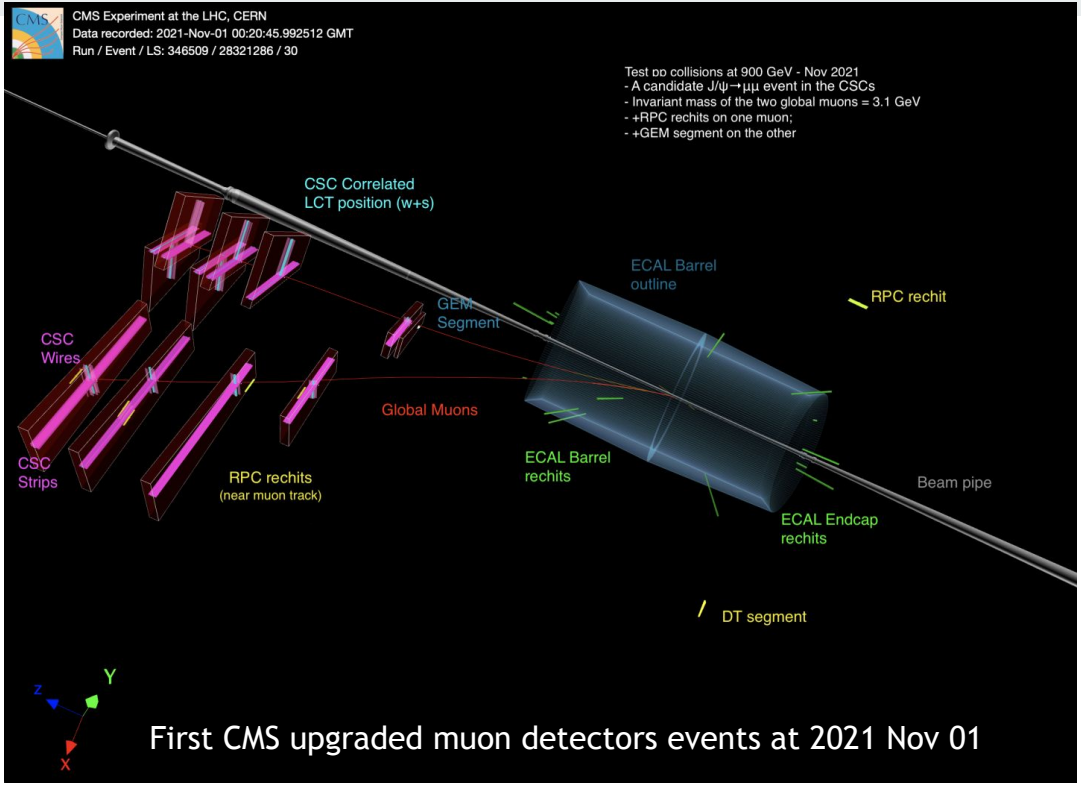






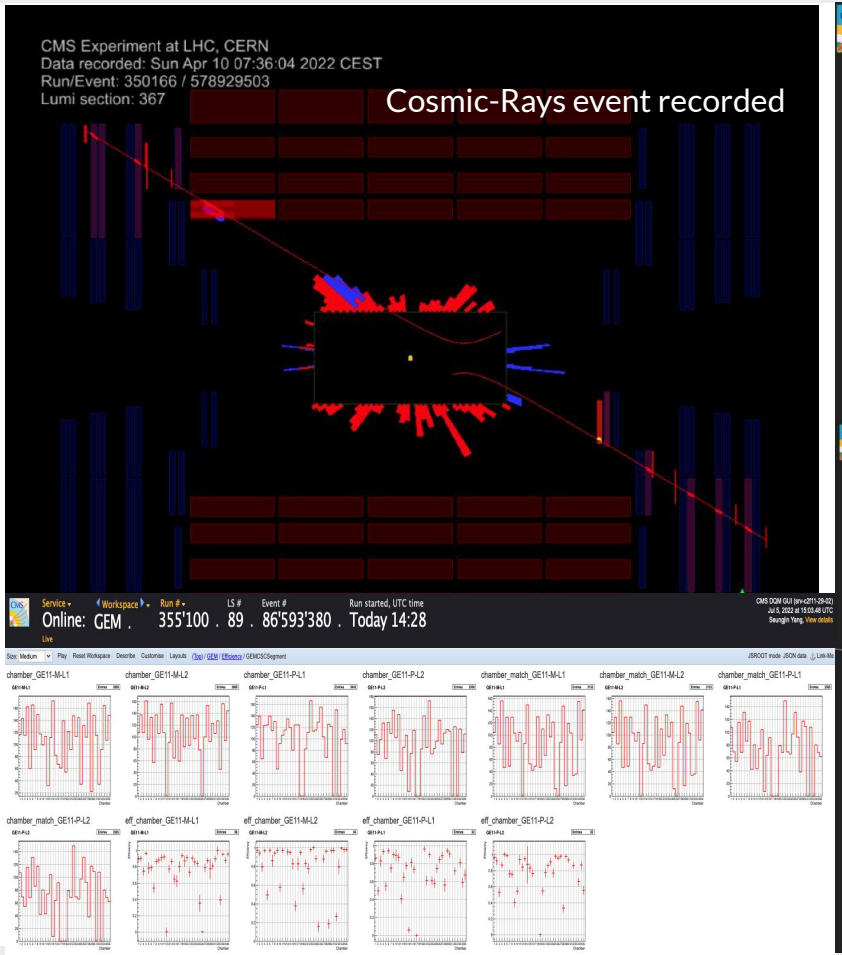


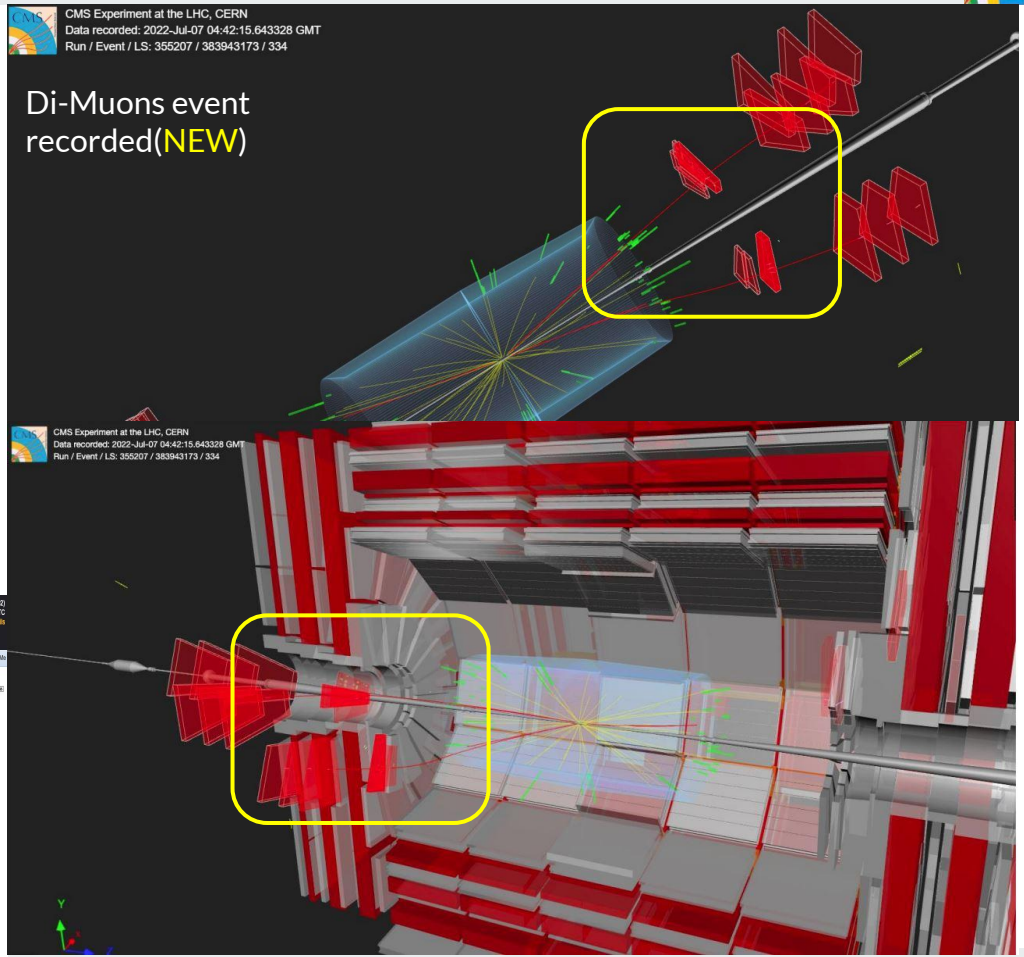
CMS Forward Muon System Upgrade



A dimuon event recorded by CMS. The invariant mass of the dimuon system is 3.14 GeV. The two muon tracks are in red, and the CSC (and RPC+GEM) muon detectors are in pink, All other parts of the CMS detector were also operating, as can be seen from the tracks and calorimeter energy deposits, and these are also indicated.(*https://cds.cern.ch/record/2791600)

CMS Forward Muon System Upgrade

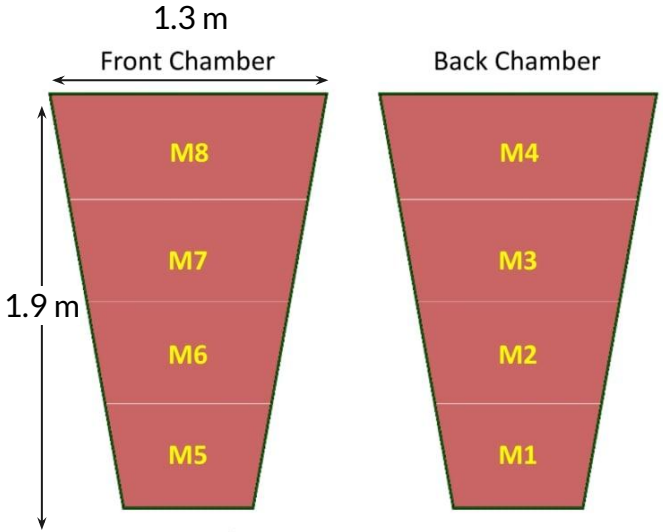


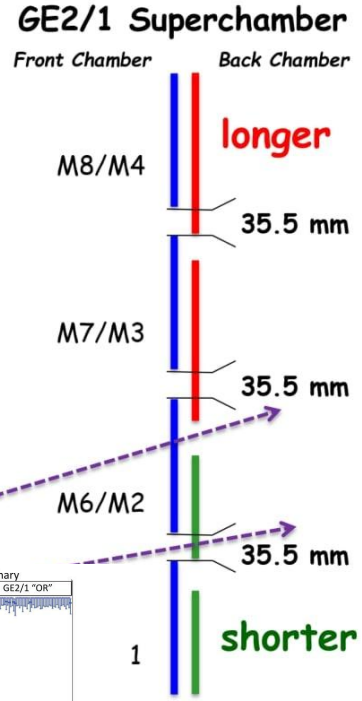


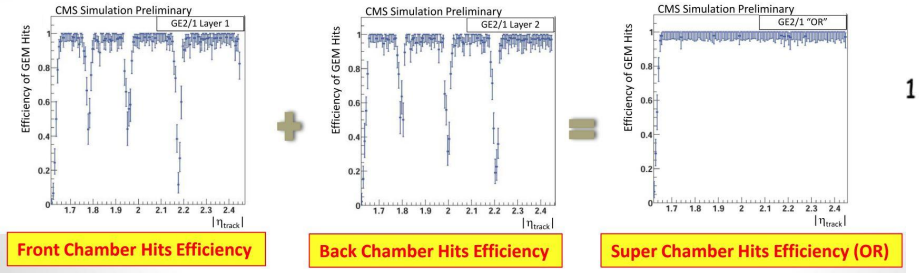
GE 2/1 Project

(GE2/1 Chambers for Disk-1 are assembled, tested, and ready for installation - 2023.08.31)

CMS GE2/1 GEM Detector



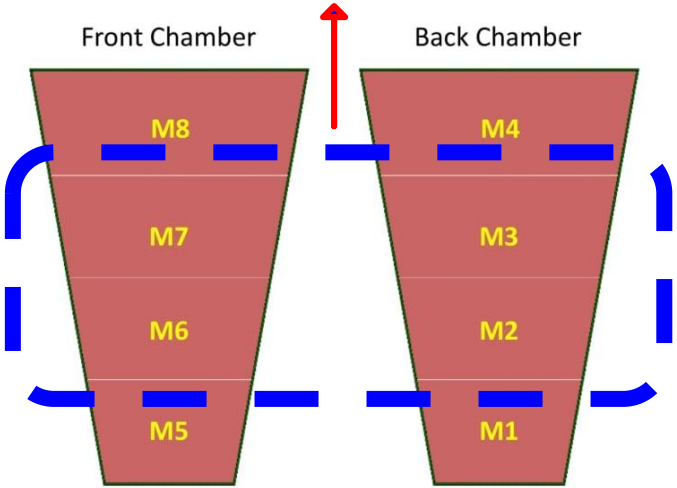




- 20 degrees wide.
- The GE2/1 station consists of **36** Superchamber.(288 modules)
- One Superchamber combined with Front & Back Chambers.
- The chambers consist of eight different modules type. (M1 ~ M8)
- The GE2/1 will be installing in the back of first disk (YE1).
- It will be installed to cover the High eta region 1.6 < |h| < 2.4.
- Gas Mixture - Ar : Co2 (7:3)

CMS GE2/1 GEM Detector

Produce by KCMS

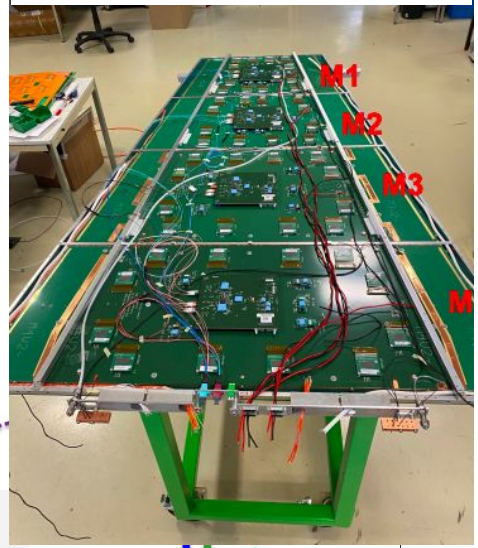


GE2/1 Triple-GEM Modules

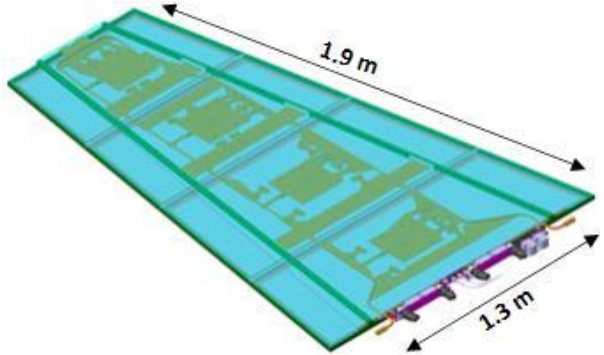
- M2/M3/M6/M7 : Each **108** sheets
- Total Foils : **432** + 64(spare) sheets

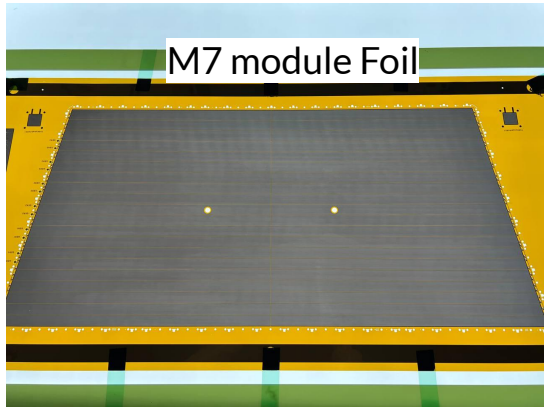
*G12 : 83=72+11(spare) | G3 : 41=36+5(extra)

First GE2/1 Back Chamber



M5/M1 || shorter



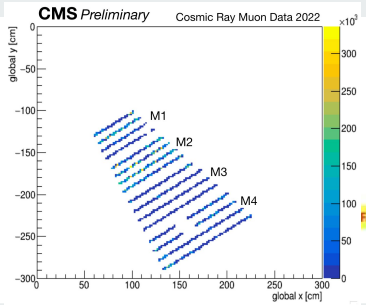


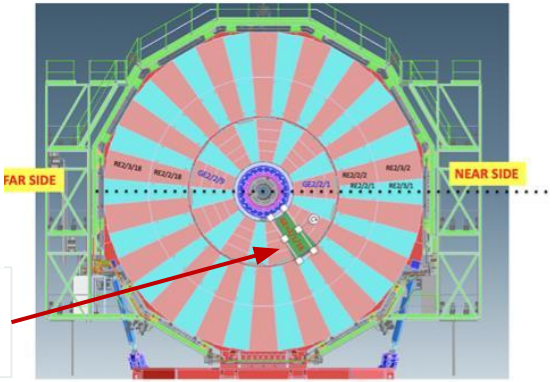
CMS GE2/1 demonstrator

Installation : 8th Nov 2021

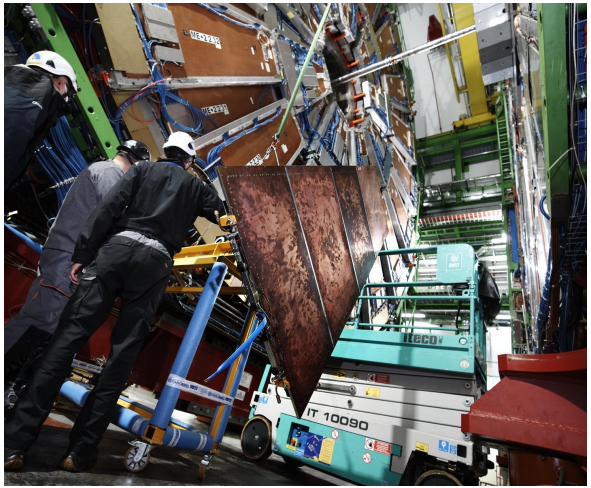
Integrated with central DCS, DAQ and TCDS systems.

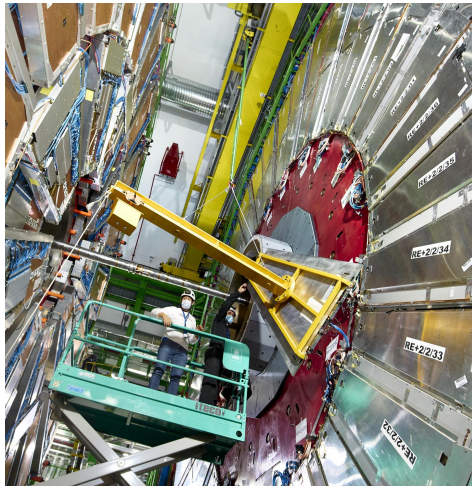
Module : M1 ~ M4

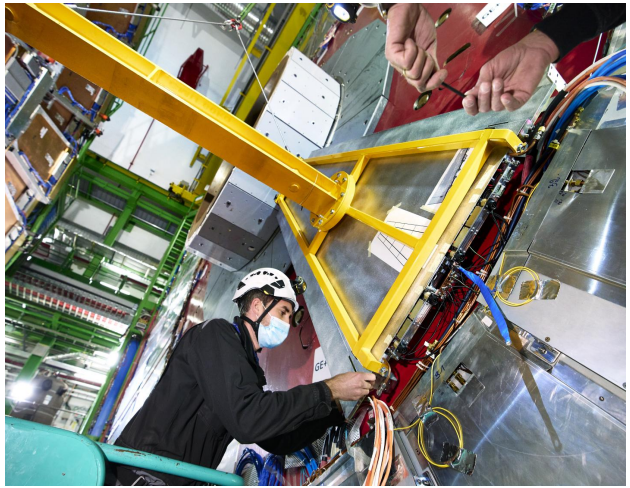




Sector 16, positive endcap for GE2/1 Demonstrator



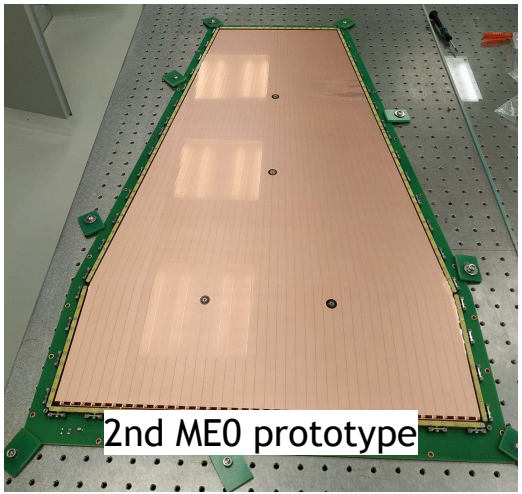


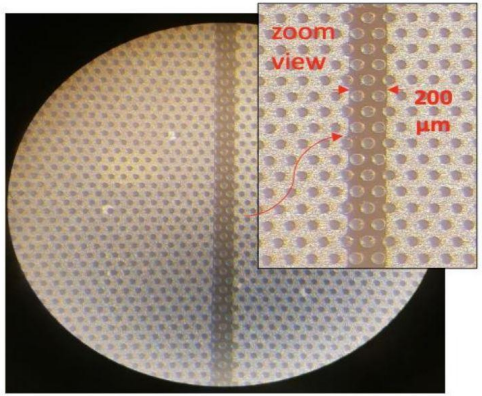


ME0 Project

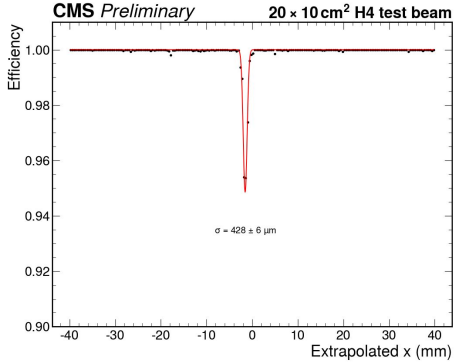
(Still in R&D)

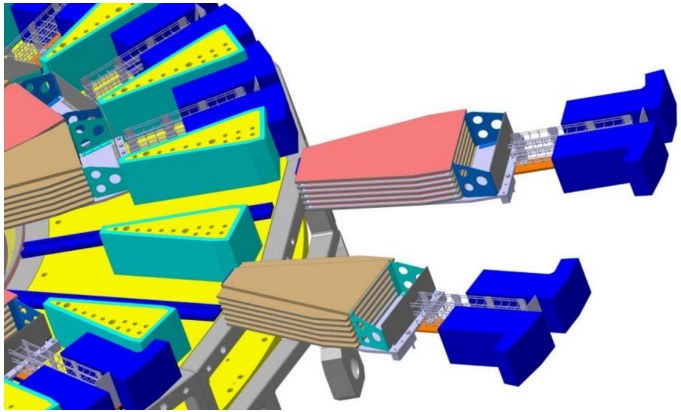
CMS ME0 GEM Detector R&D


2nd ME0 prototype



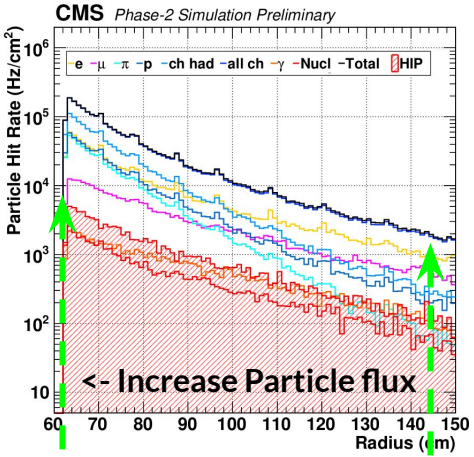
< Random segmentation >

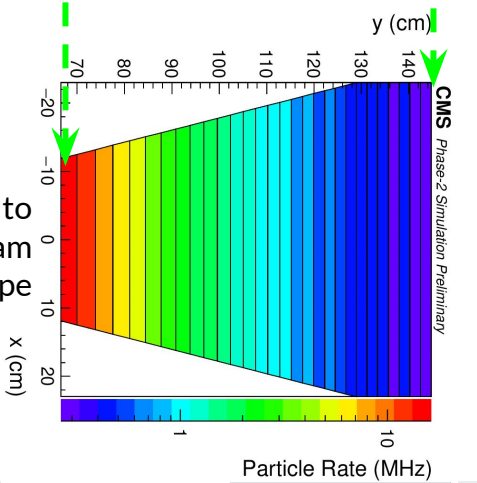




- ME0 will be installed during the LS3(2025).
- It will be installed to cover the High eta region $2.0 < |\eta| < 2.8$.
- Gas Mixture - Ar : Co2 (7:3)
- A layered stack of 6 triple-GEM detectors.
- 18 stacks per endcap (36 total stacks - 216 modules)
- **New HV segment : Vertical pattern.**
- **Random electrode sectorization.**

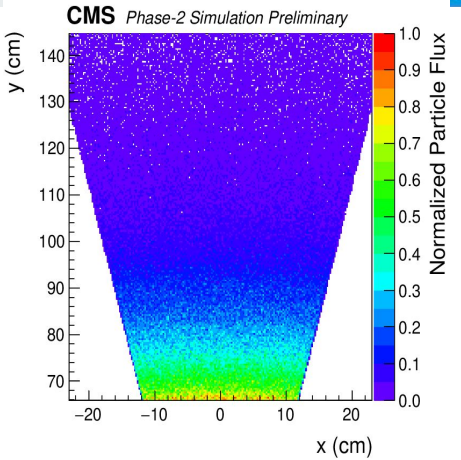
CMS MEo GEM Detector R&D

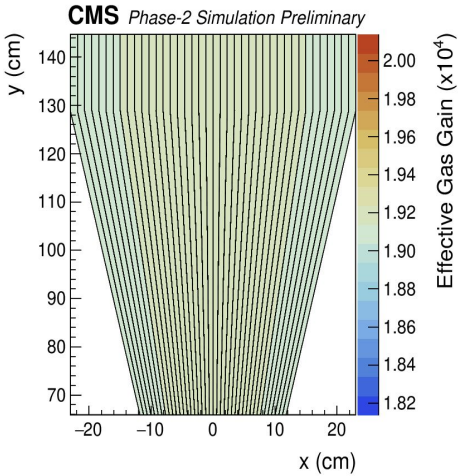


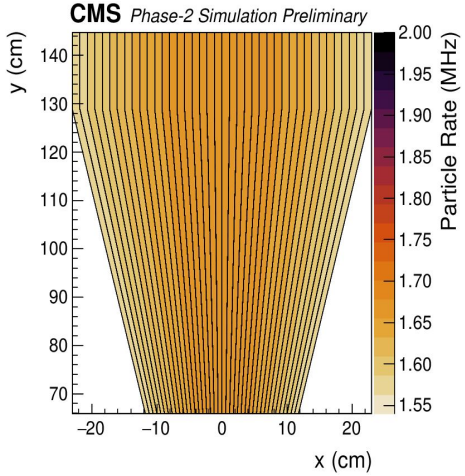


Close to beam pipe

- No dependency with the BKG shape
- Uniform current across all segment
- Uniform voltage drop that can be globally compensated







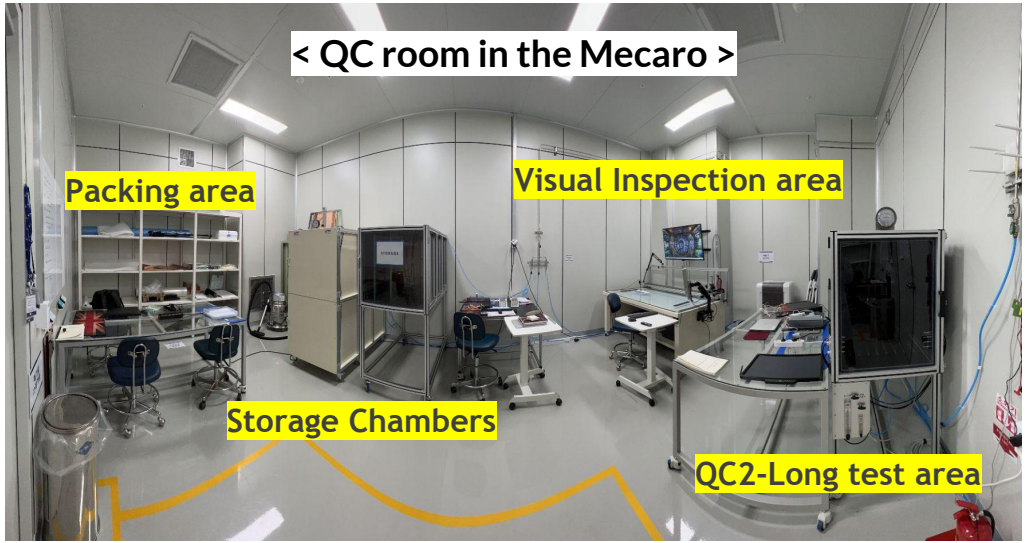
Contribution of Korea-CMS

Contribution of Korea-CMS

- KCMS signed two MOUs with CERN. (GE11, GE21 & ME0)
- GE11 : Supported 90 foils (30 chambers) and Man-power.
- GEM Foils Quality Control (QC) : The Korea-CMS (KCMS) performs GE21 QC activities to select **High quality** foil that meets the specifications and send it to the CMS-GEM group.
- Graduate students of 10 universities are participate. Based on QC activities, we are working with Mecaro company to produce more improved quality foil.

GE2/1 KCMS QC activity

- Investment and upgrade of quality control facilities.

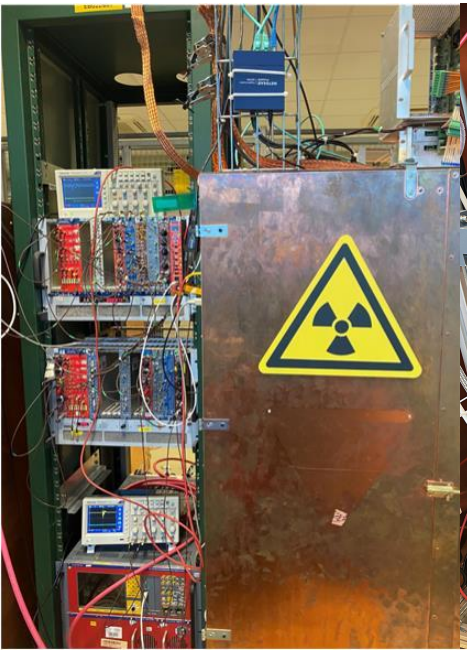


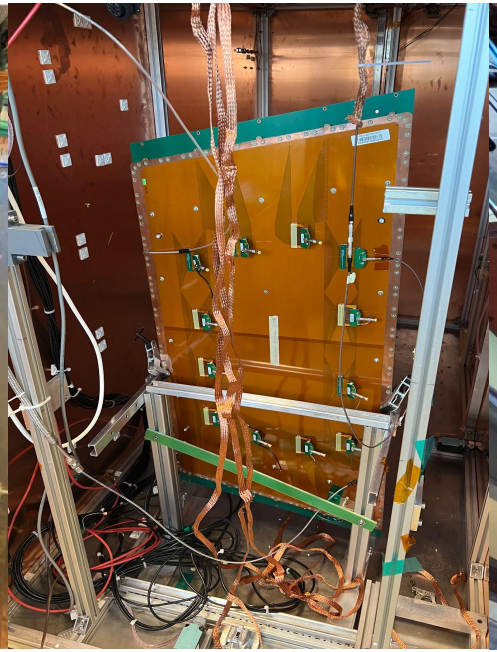
< The photo shows a QC lab located in Eumseong-gun, MECARO >

At CERN

QC in the Muon Detector site

Korean students were dispatched to participate in QC activities.



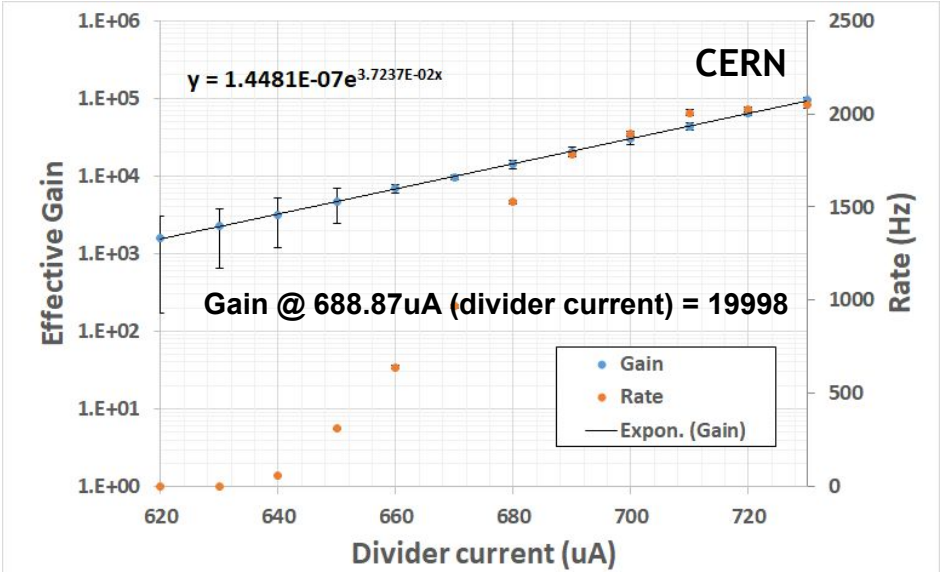


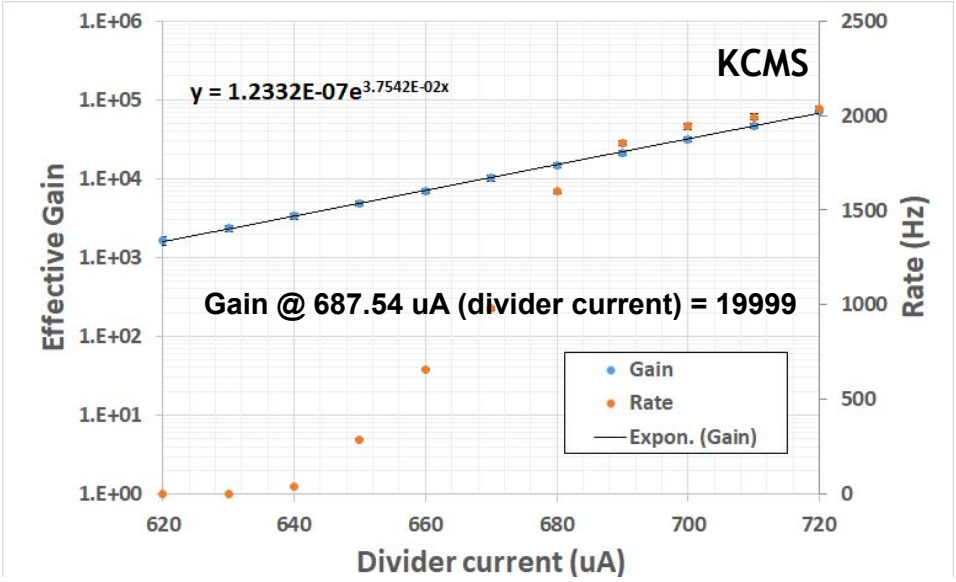
< It shows QC5 Gain measurement bench in the 904 site at CERN >

At CERN

QC5 Gain Measurement

Compare the results for Eff.Gain





< These plots show the variation of Eff.Gain and Rate of M4-0007 (Left) and M3-0001 (Right) detector as a function of divider current
The Eff.Gain measurement results of detector assembled with M3 type foils manufactured in Korea and
detector assembled with M4 type foils manufactured in CERN show satisfactory performance >

Summary

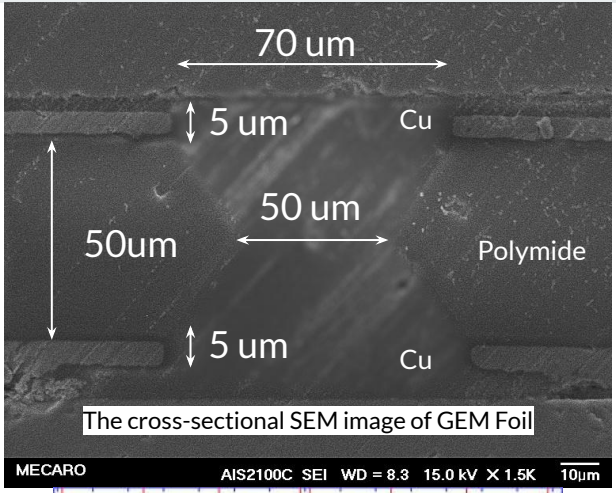
- The CMS has a plan to upgrade the forward muon system to prepare for High-Luminosity.
- Use the Triple layer GEM detectors to upgrade forward muon system.
- It will be improved efficiency, redundancy, p_T resolution, and timing through L1 muon trigger system upgrade.
- The 144 chambers of GE11 was success installed at 23.Sep.2020.
- The KCMS produces, QC, and provides foil. And also man power.

THANK YOU
FOR YOUR ATTENTION

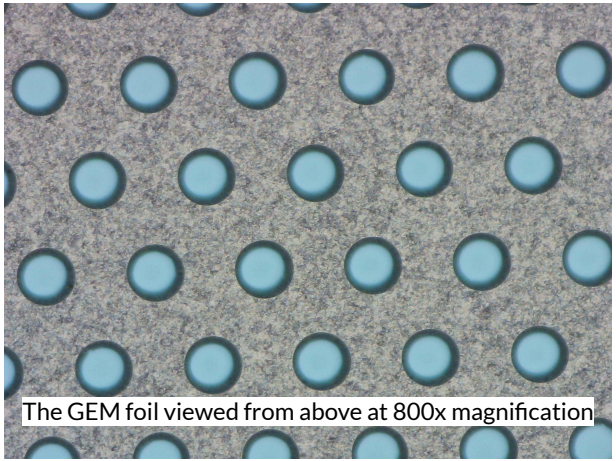
Gas Electron Multiplier

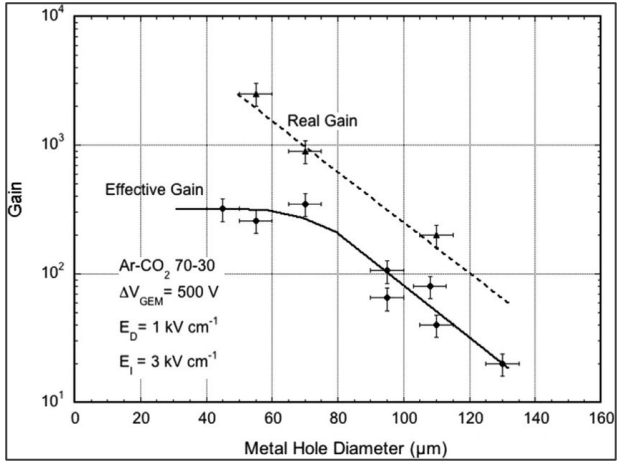
< G.E.M >

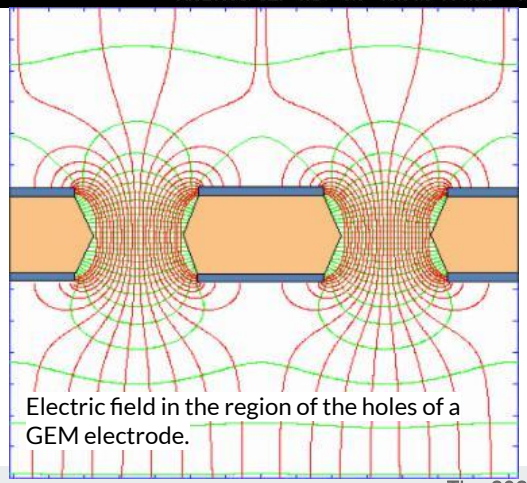
Gas Electron Multiplier(Typically)



The cross-sectional SEM image of GEM Foil

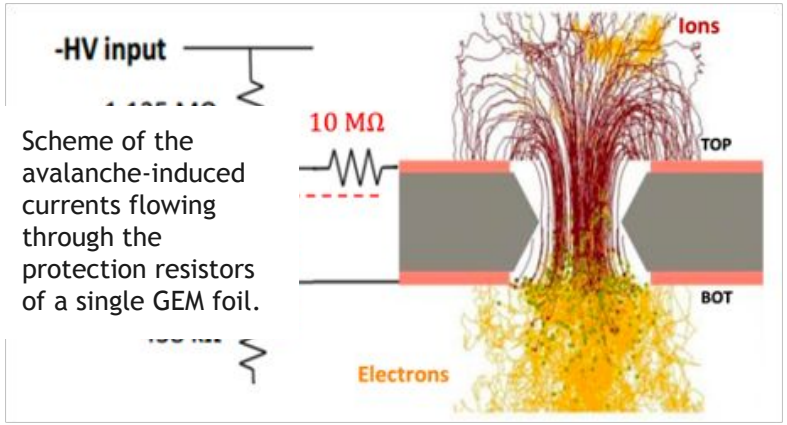

The GEM foil viewed from above at 800x magnification



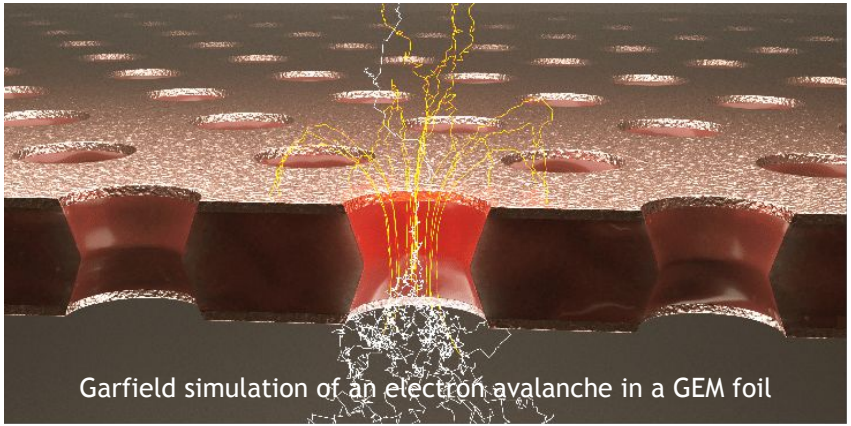

Electric field in the region of the holes of a GEM electrode.

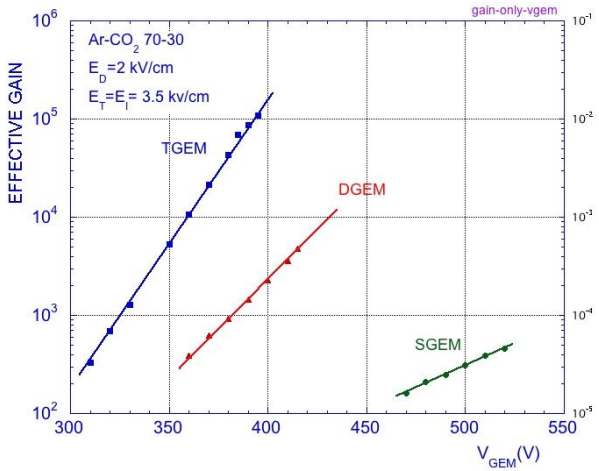
- The most important element of the GEM detector is foil. The performance of the detector depends on how the foil is constructed. Because it affects the gain of the detector.
- The copper conductor of 5 micrometers is adhered to both ends of the insulating polymer (polyimide) with a thickness of 50 micrometers.
- Cu hole - 70 um at 140 um pitch and PI hole - 50 um.(wedge-shaped)
- There are approximately **6400 holes per cm^2** of GEM foil.

Gas Electron Multiplier(Typically)



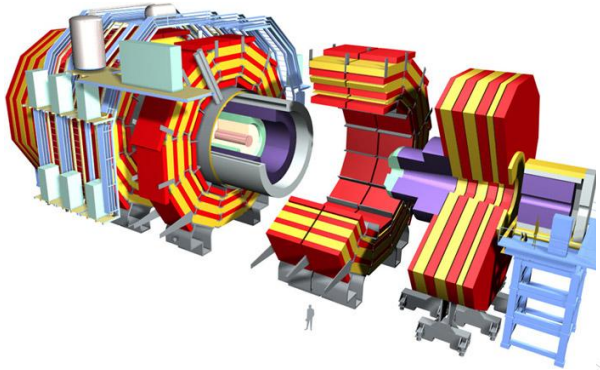
Scheme of the avalanche-induced currents flowing through the protection resistors of a single GEM foil.



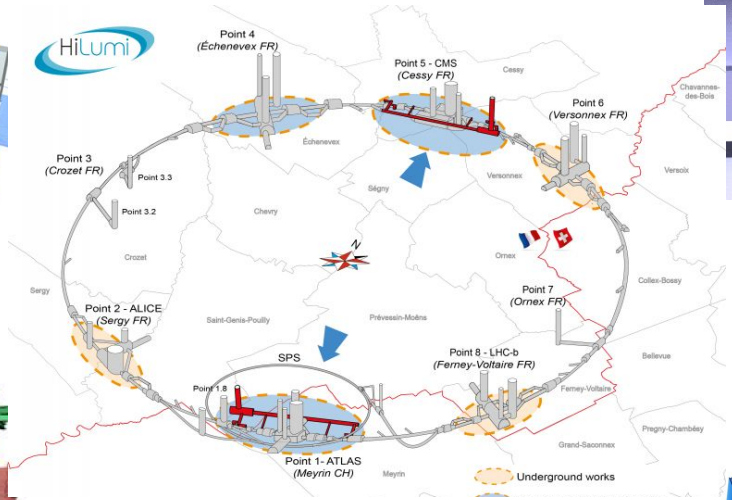


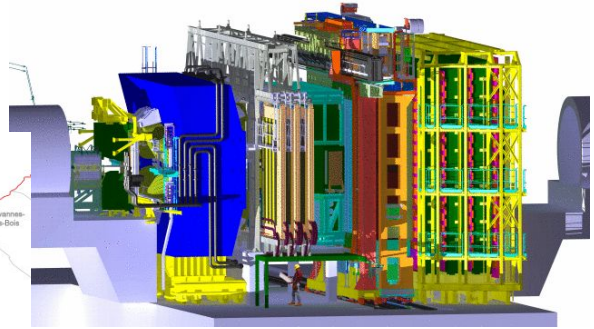
- By applying a potential of 400~500 Volts between the copper layers, an electric field as high as ~ 100 kV/cm is produced into the holes. Electrons begin to accelerate, provoke the ionization of gas molecules, and an electron avalanche occurs.
- Multilayer structure detector : one electron injected makes more than 1000 electrons.(Depends on the Gas-mixture and HV)

Gaseous Detectors @ LHC

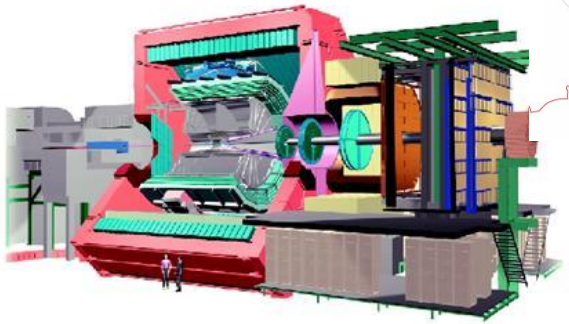


DT, CSC, RPC, GEM **@CMS**

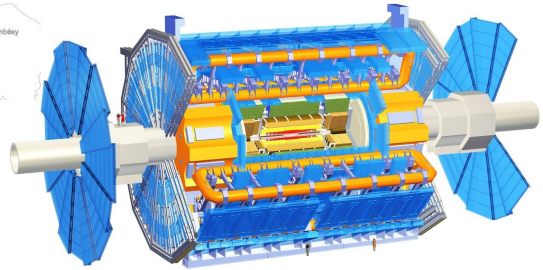




MWPC, GEM **@LHC-b**

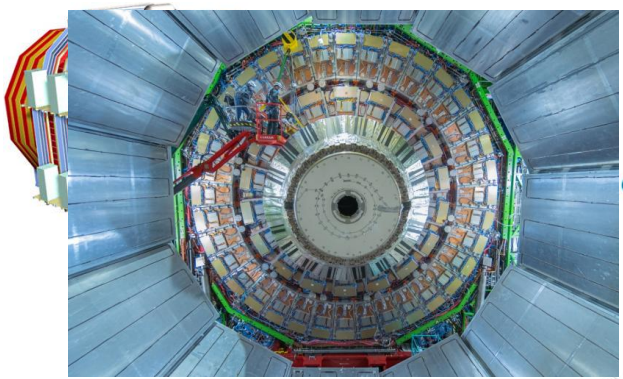


RPC, MRPC, TPC **@ALICE**

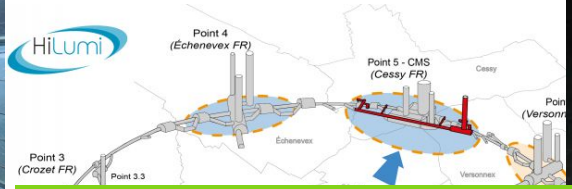


MDT, RPC, CSC, sTGC, MM(MicroMegas) **@ATLAS**

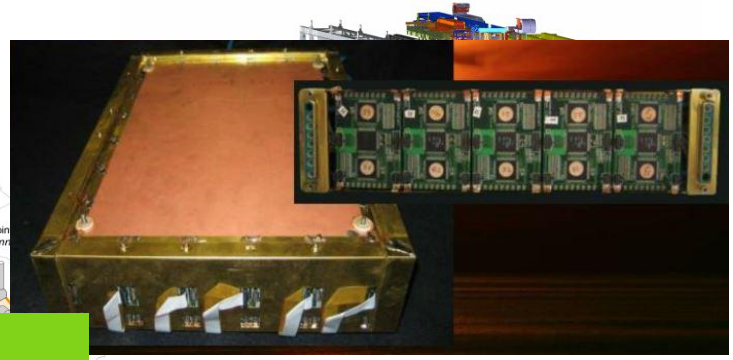
MPGD Technology @ LHC



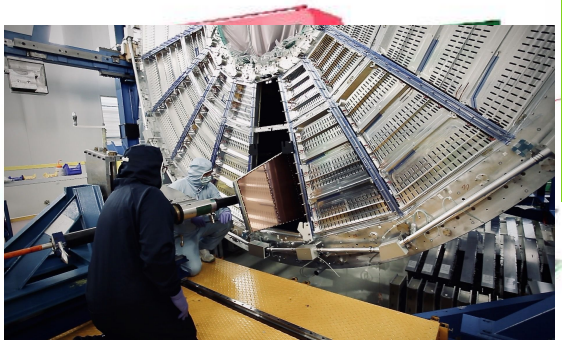
GEM @CMS



M.P.G.D
- Micro Pattern Gas Detector

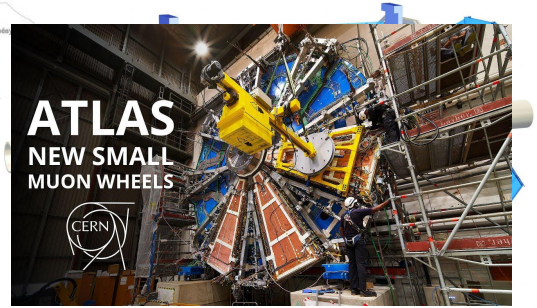


MWPC, GEM @LHC-b



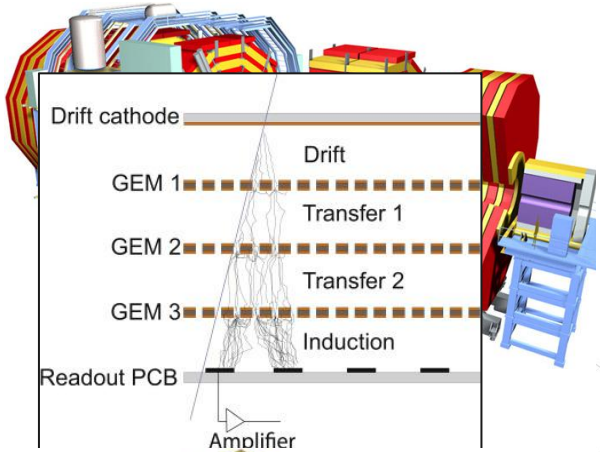
New **TPC** @ALICE

- ✓ High Rate capability (MHz/cm^2)
- ✓ High space Resolution(70um)
- ✓ Good time Resolution(5~10 ns)
- ✓ Cheaper than solid state detectors at equal covered areas.

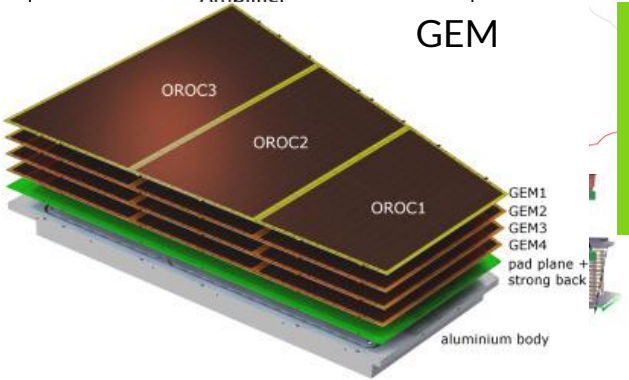


MM(MicroMegas) @ATLAS

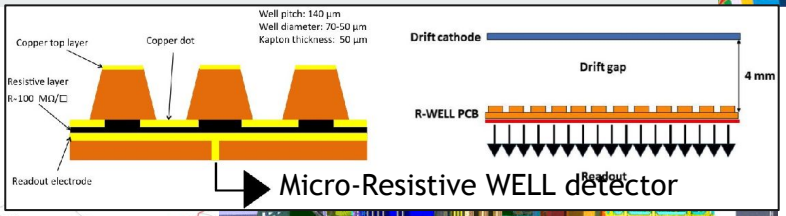
MPGD Technology @ LHC



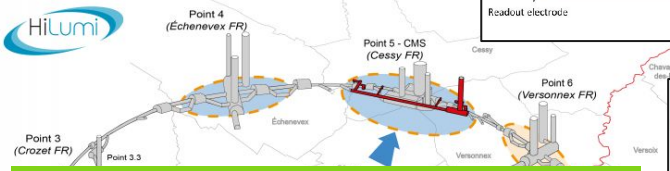
GEM



New **TPC** @ALICE



Micro-Resistive WELL detector



M.P.G.D
- Micro Pattern Gas Detector

- ✓ High Rate capability (MHz/cm^2)
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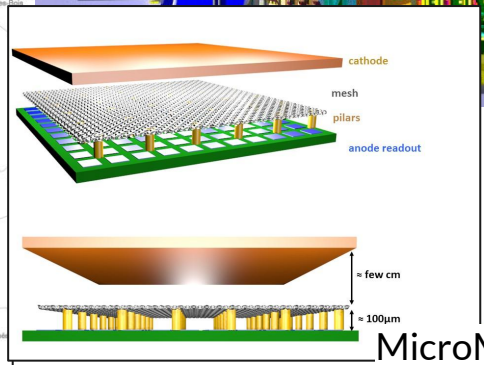
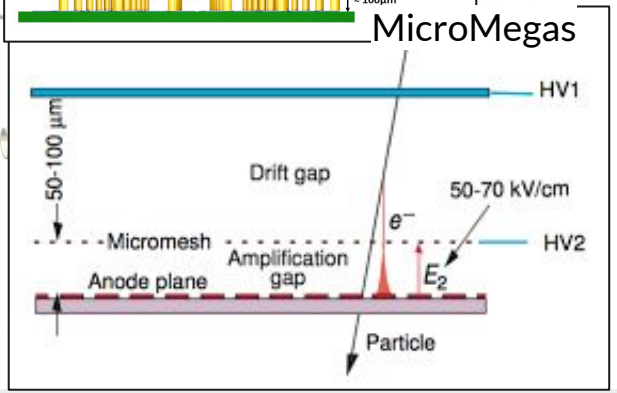
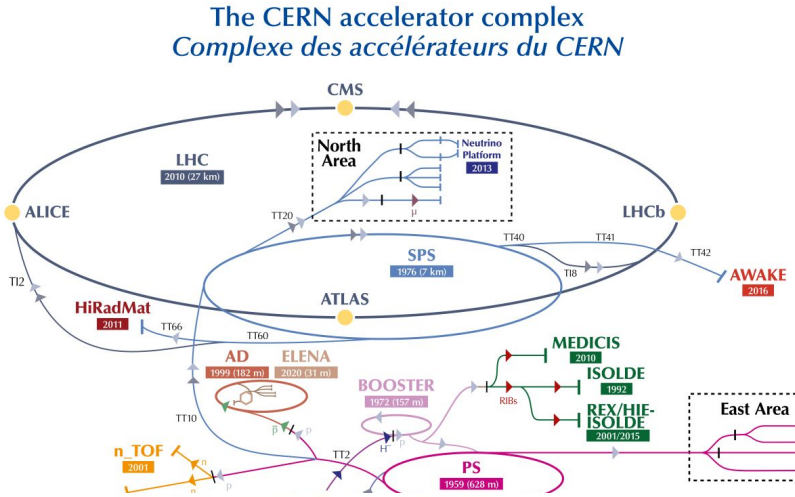
- ✓ Cheaper than solid state detectors at equal covered areas.

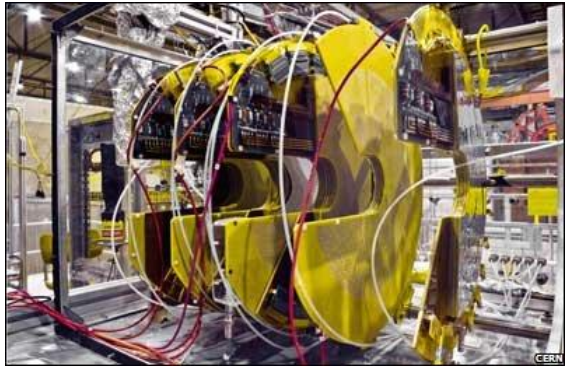


MicroMegas

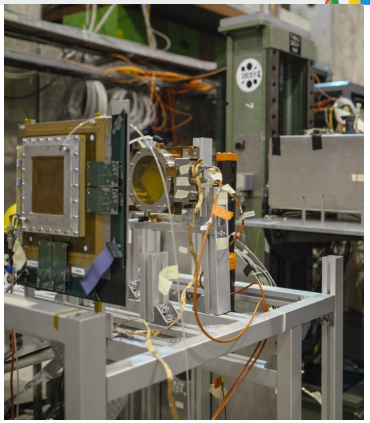


MPGD Technology @ CERN





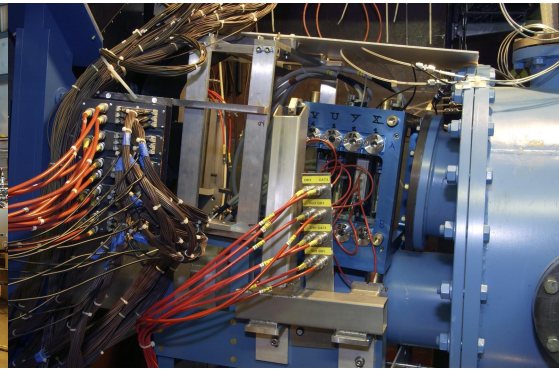
TOTEM - CMS



NA64, NA84 - GEM, MM

COMPASS - GEM, MM

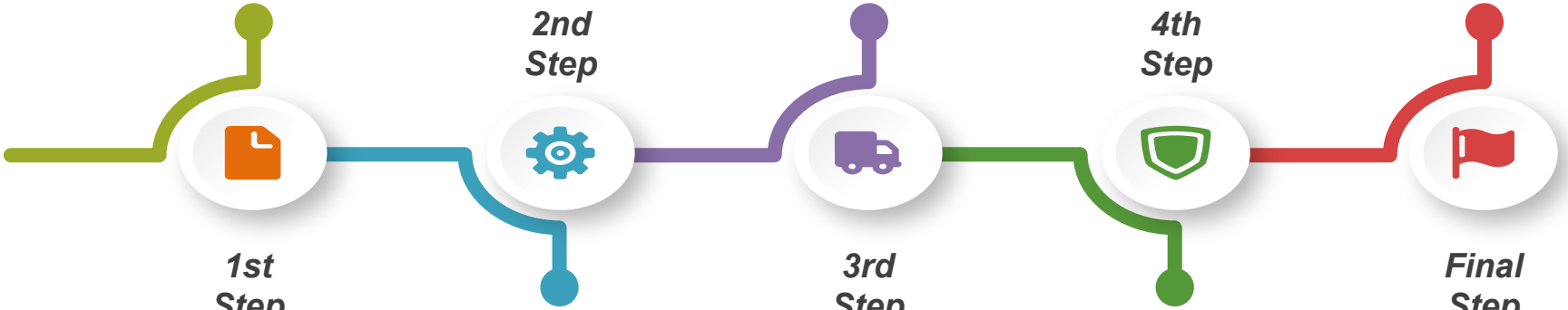
CAST - MM



DIRAC- MSGC

GEM Foils QC by Korea-CMS

- QC Stage -



QC at CERN

GE2/1 KCMS QC activity

❖ **QC2 Activities in CMS Muon site**

- Electrical cleaning of the GEM foils and resistance check
- Long-term monitoring of the GEM foil leakage current

❖ **QC2 Activities in Mecaro production site**

- Electrical cleaning of the GEM foils and resistance check
- Long-term monitoring of the GEM foil leakage current
- Visual test on the optical desk
  - ➢ Hole diameter measurement
  - ➢ Defect check
  - ➢ Surface Contamination Measurements

< QC2 Activities in CMS Muon site 904 Bldg. >