CMS PHASE II UPGRADE USING GEM DETECTORS

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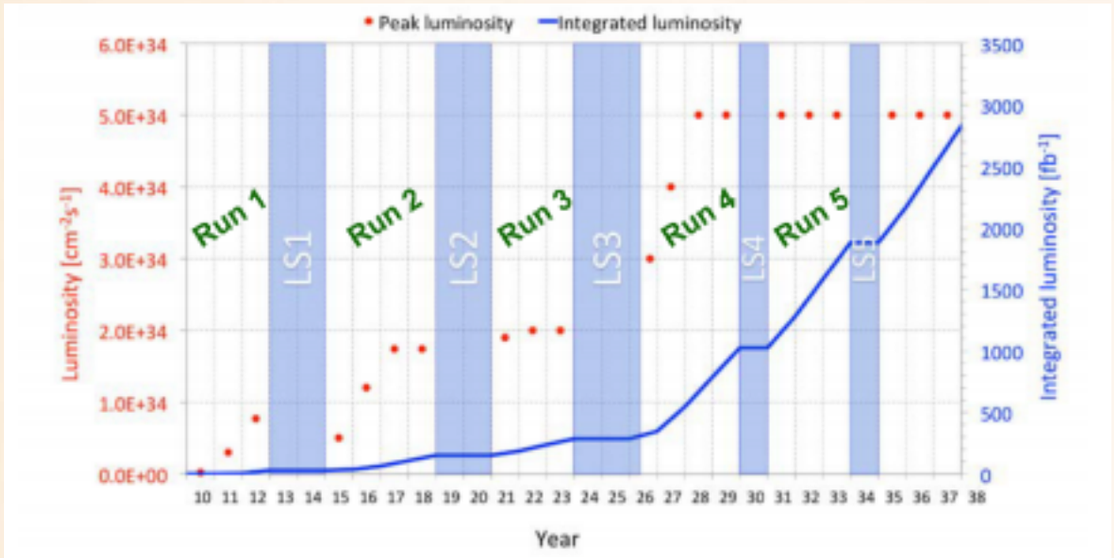
on Behalf of
CMS Muon Group

PHASE II UPGRADE

The Phase-2 Upgrade of the CMS Muon Detectors
CERN-LHCC-2017-012 / CMS-TDR-016



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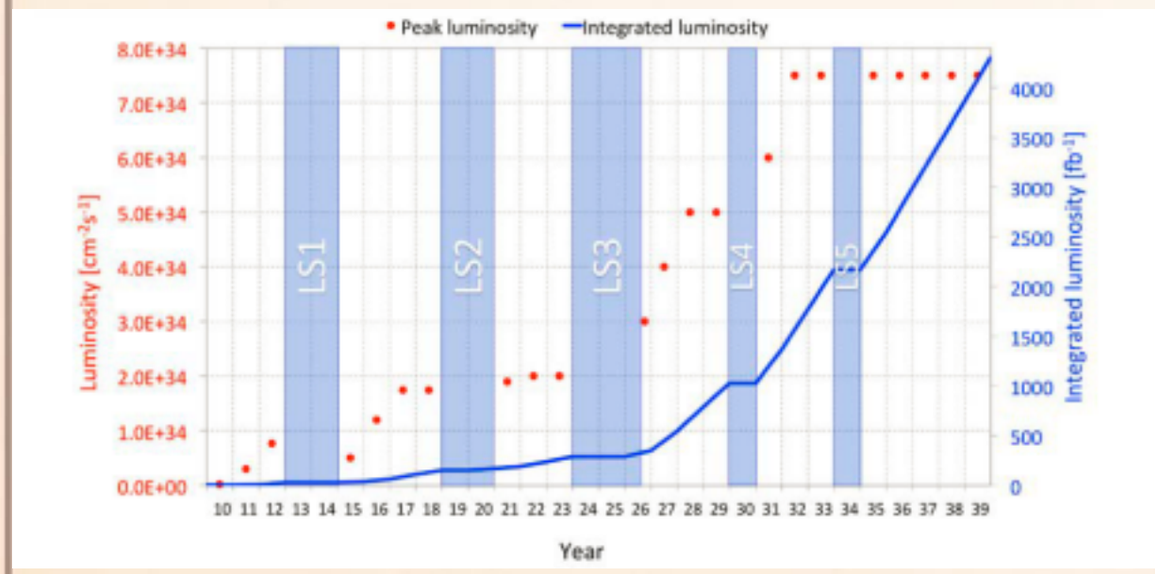
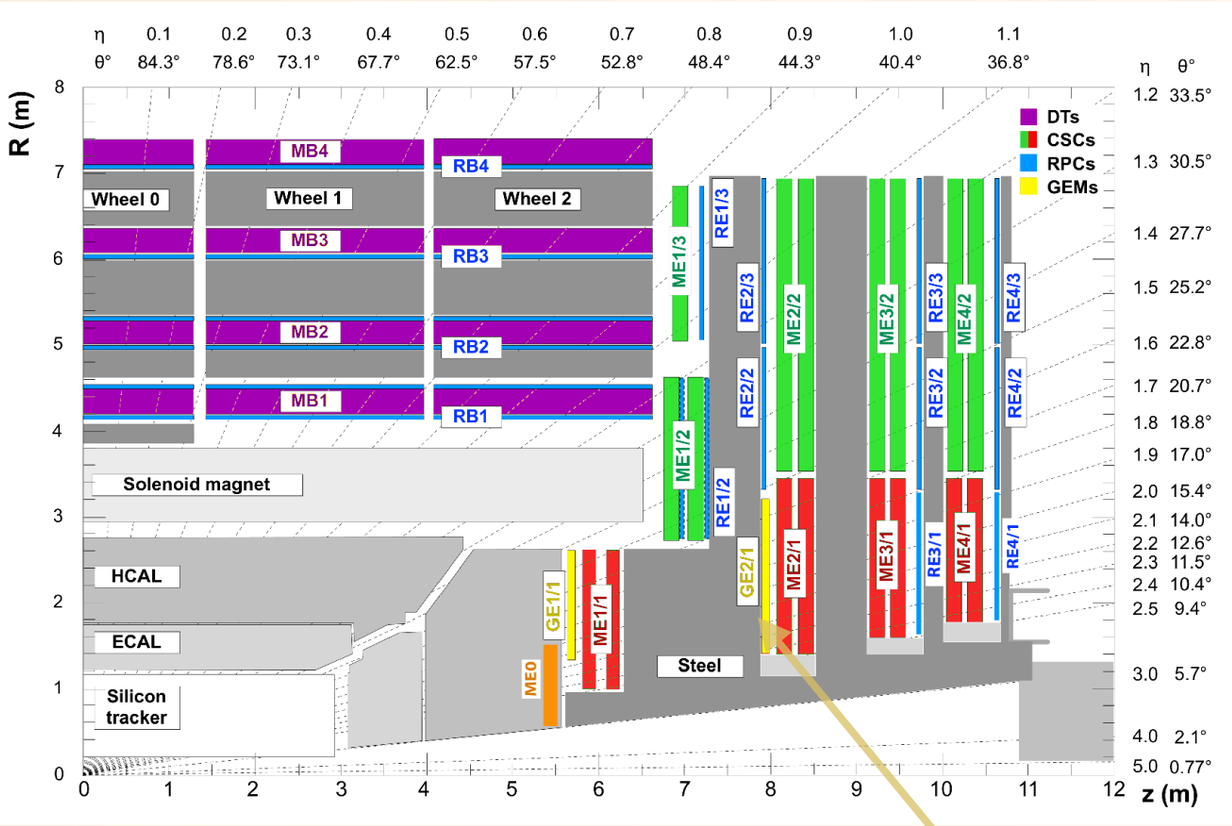


Ultimate

- To extend the sensitivity for new physics searches, a major upgrade of the LHC has been decided, known as High Luminosity LHC (HL-LHC).
- The integrated luminosity will increase ten times with respect to the designed value.
- The center of mass energy of proton-proton collision is expected to be raise from 13 TeV to 14 TeV.
- The high luminosity data taking period with the upgraded LHC is called **Phase II**
- The most sensitive signature of production of new particles often include one or two muons.
- Therefore identification of muon with precision is very important.
- Two major upgrades GE2/1 & ME0 will take place during Phase II in CMS muon station.

MOTIVATION & GE2/1 POSITION



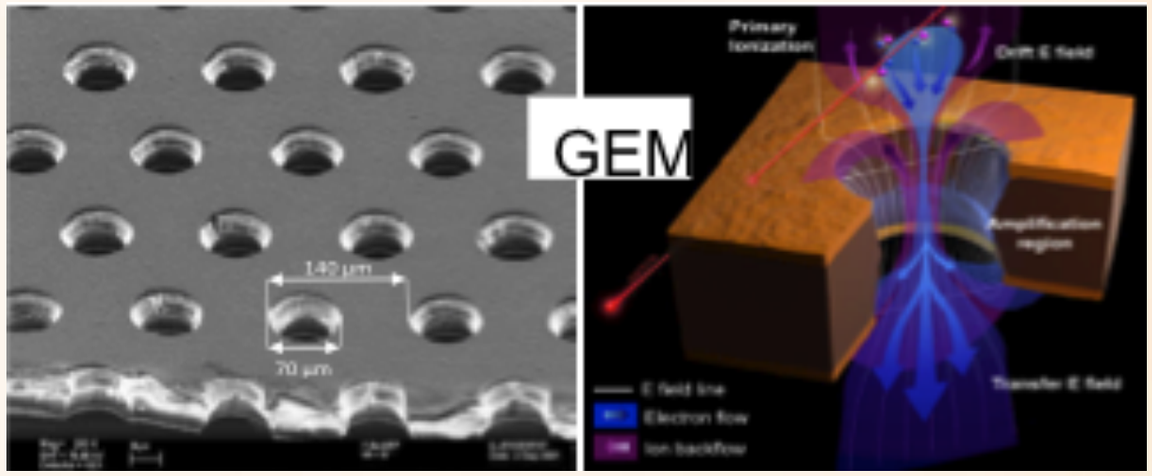
GE2/1

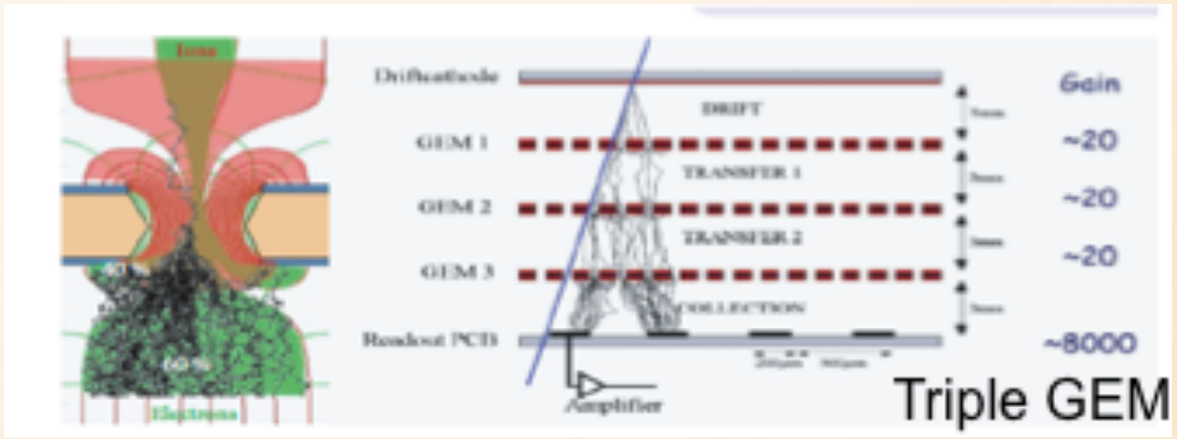
- 1.62< |η| < 2.43
- 2 layers of triple-GEM technology as baseline.

- The GE2/1 upgrade, consists of second ring of GEM muon detectors in the end-cap region next to ME2/1 chambers.
- The GE2/1 chambers partially overlap with GE1/1 chambers and extended to 2.1 < |η| < 2.43.
- By complementing GE2/1 with ME2/1 detectors will increase the no. of hits for traversing muon.
- The increased no. of hits measured per muon in the end-cap is essential to obtain a robust track reconstruction already at the L1 trigger.

GEM TECHNOLOGY

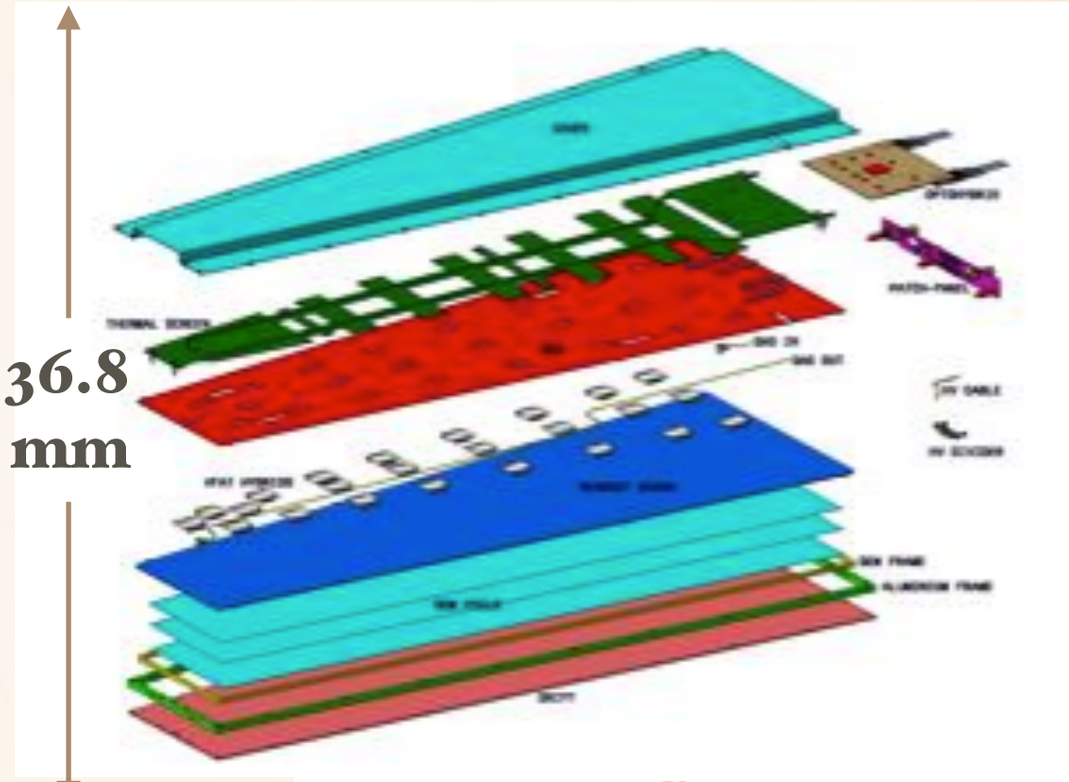
- Triple GEM technology with gap configuration of 3/1/2/1 is adopted.
- Rate capability up to 100 kHz/cm^2.
- Single detector efficiency > 98% for MIPs.
- Response uniformity of 10%-15% across the detector.
- No aging observed with Gamma up to ~1.5 C/cm^2.





GE2/1 DETECTOR DESIGN

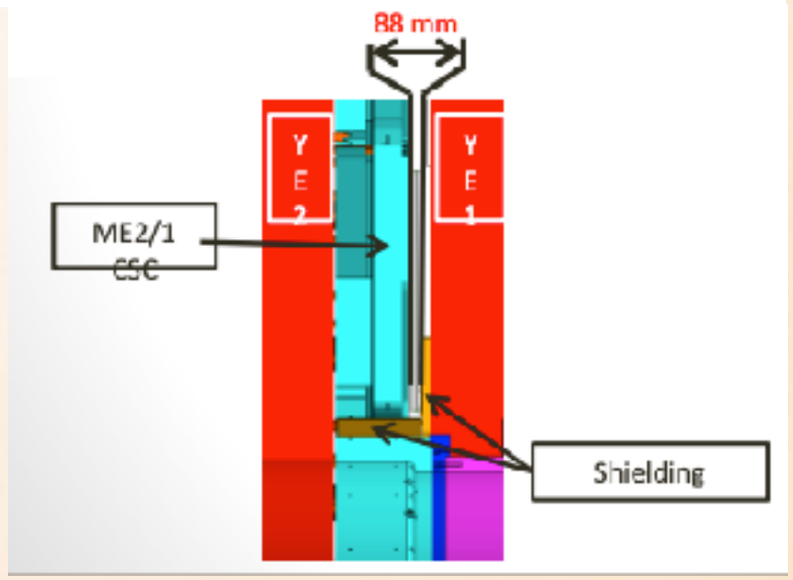
- The GE2/1 station consists of 36 20° super chamber, the chamber will be similar to GE1/1 but cover much large area.



- GE2/1 will be mount in the back of YE1 station.

- GEM technology is preferred due to limited space available.

- Each GE2/1 chamber realized of two single detectors.



GE2/1 MODULES

- Each GE2/1 detector consists of four modules.

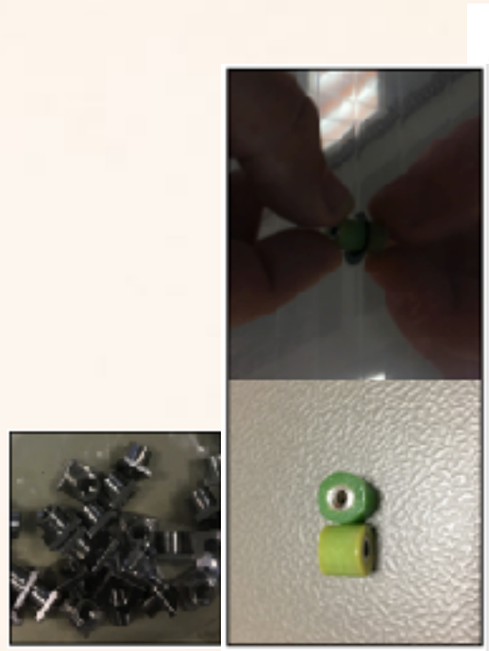
- Reason of making of chamber with several module is:
  1. GEM foil base material limited in size (max 600 mm wide.
  2. PCB producer generally limit the size of PCB ~1500 mm X 550 mm.

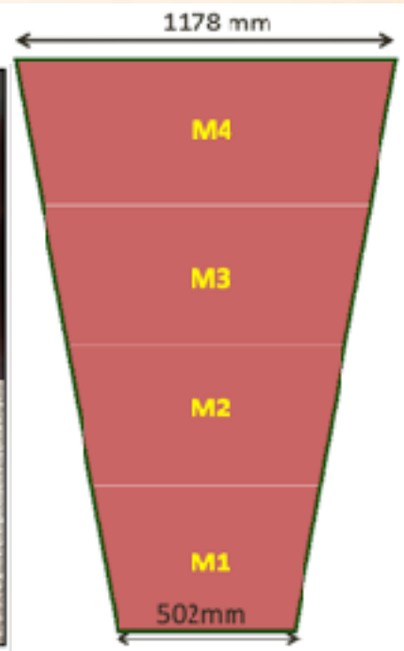
- The maximum PCB size is ~1250 mm X 550 mm (M4).

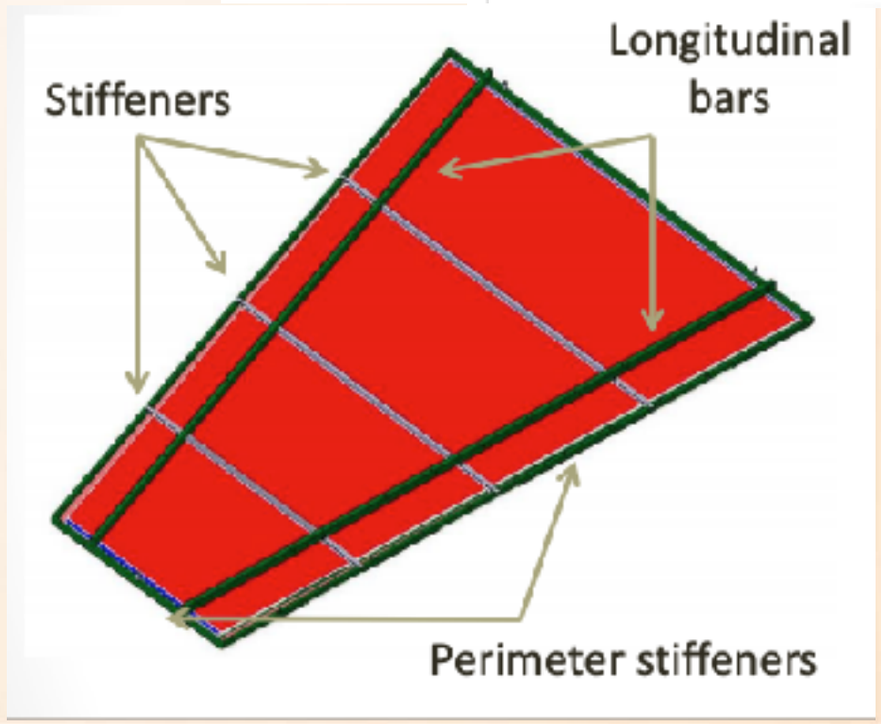
- All Modules are coupled together with the Aluminum bars and stiffeners.

- Dead Area between the two modules is limited to 36.5 mm.

- Few components have been added w.r.t. GE1/1 during assembly like T-shape nuts for stretching & pillar at the center of the detector.

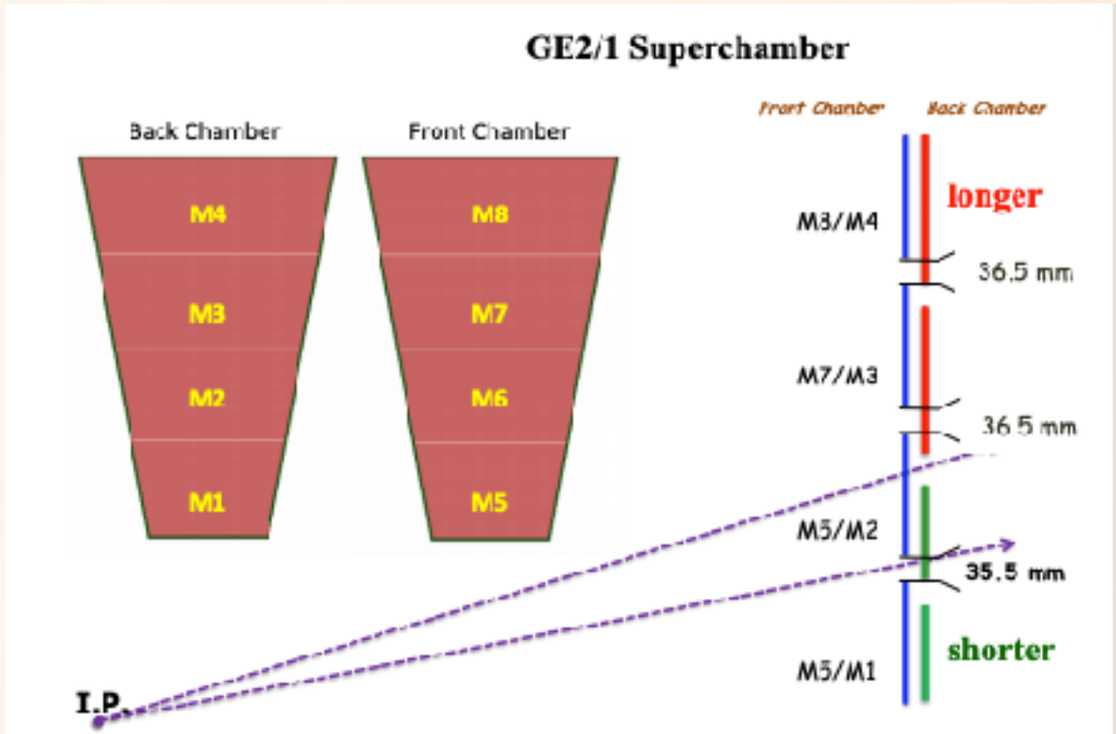


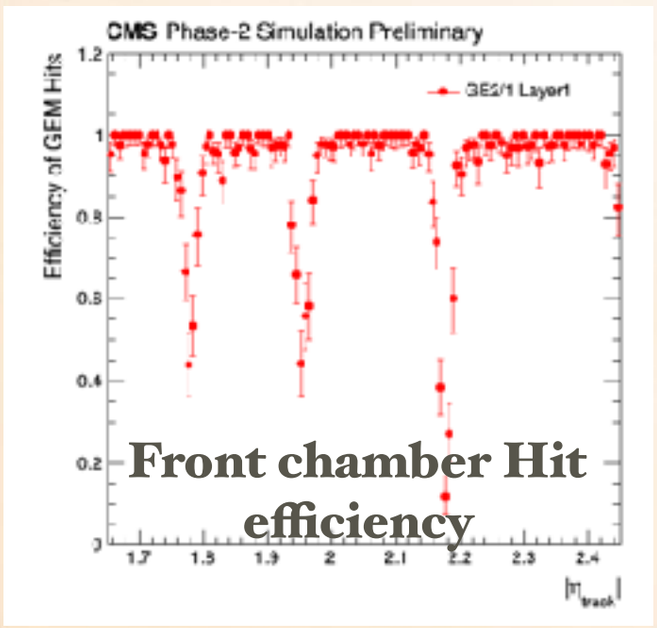




GE2/1 MODULES

- To achieve 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.





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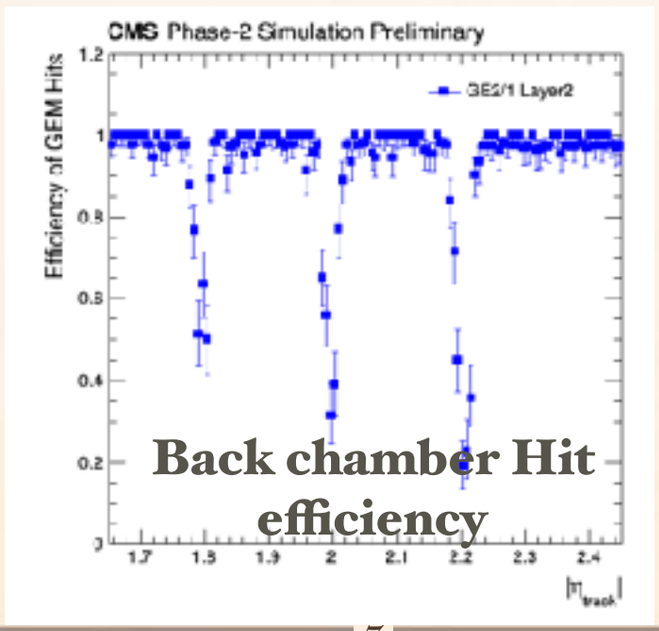

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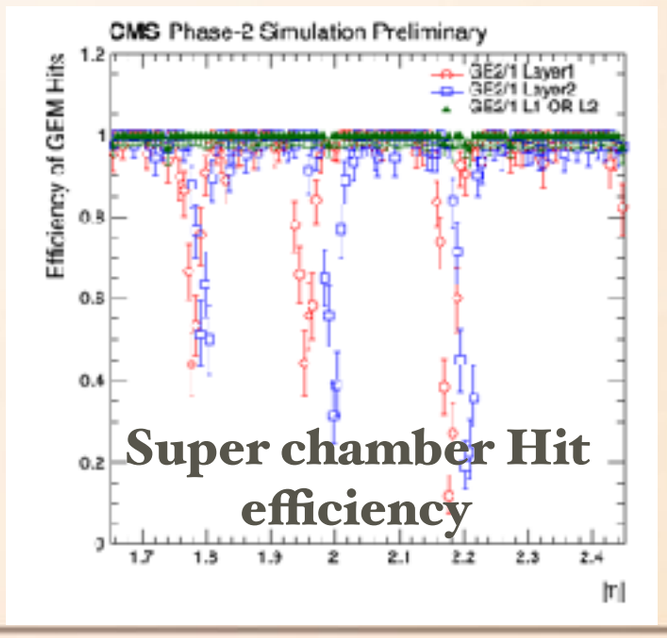
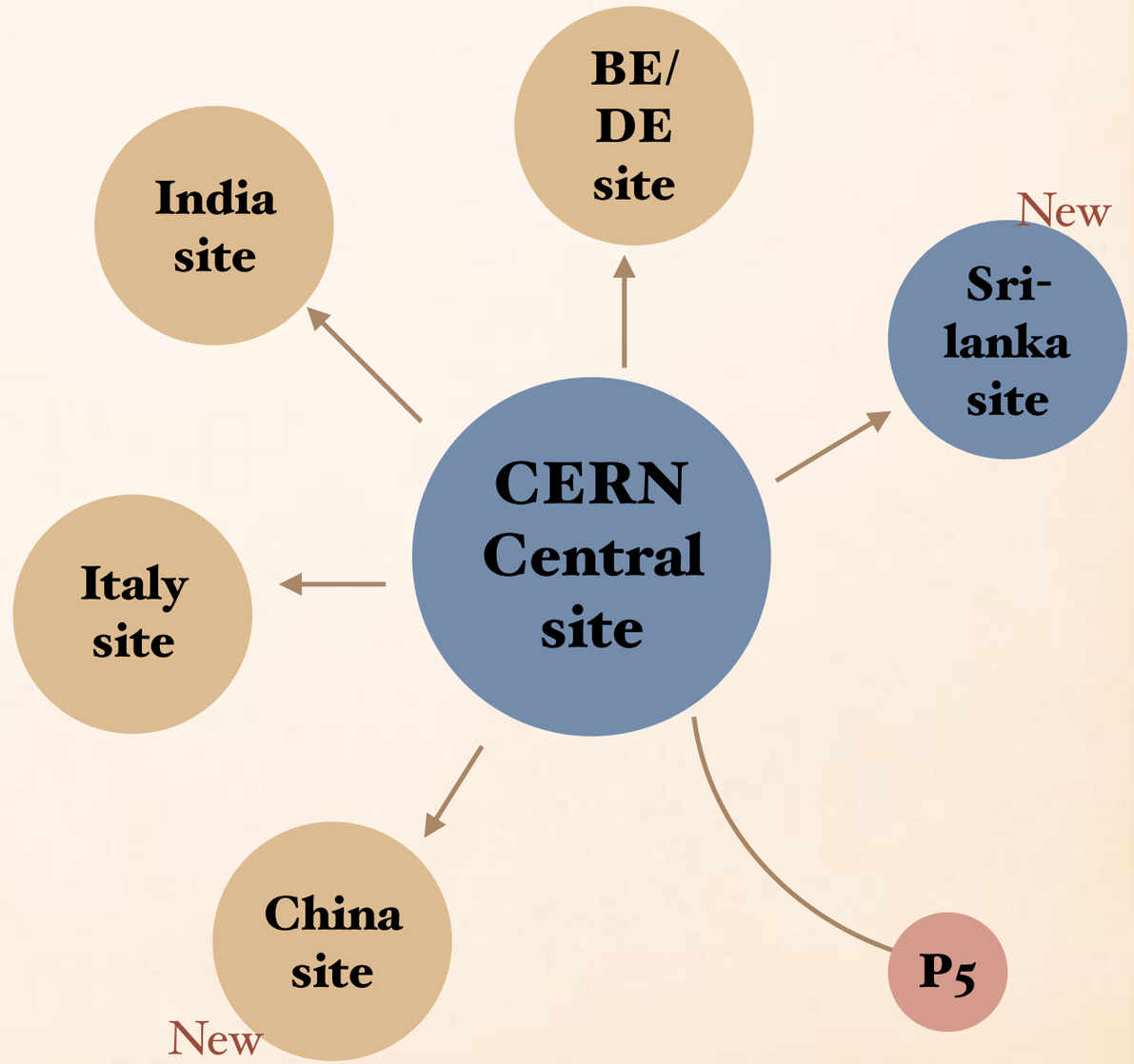


PRODUCTION OF GE2/1 MODULES

- Distribution of production among several sites outside CERN.

- After the completion of GE1/1, a large community of GEM expert is generated.

- Sites assembled GE1/1 detectors are already equipped with the infrastructure can be used for the GE2/1 detector assembly and testing.



PRODUCTION OF GE2/1 MODULES

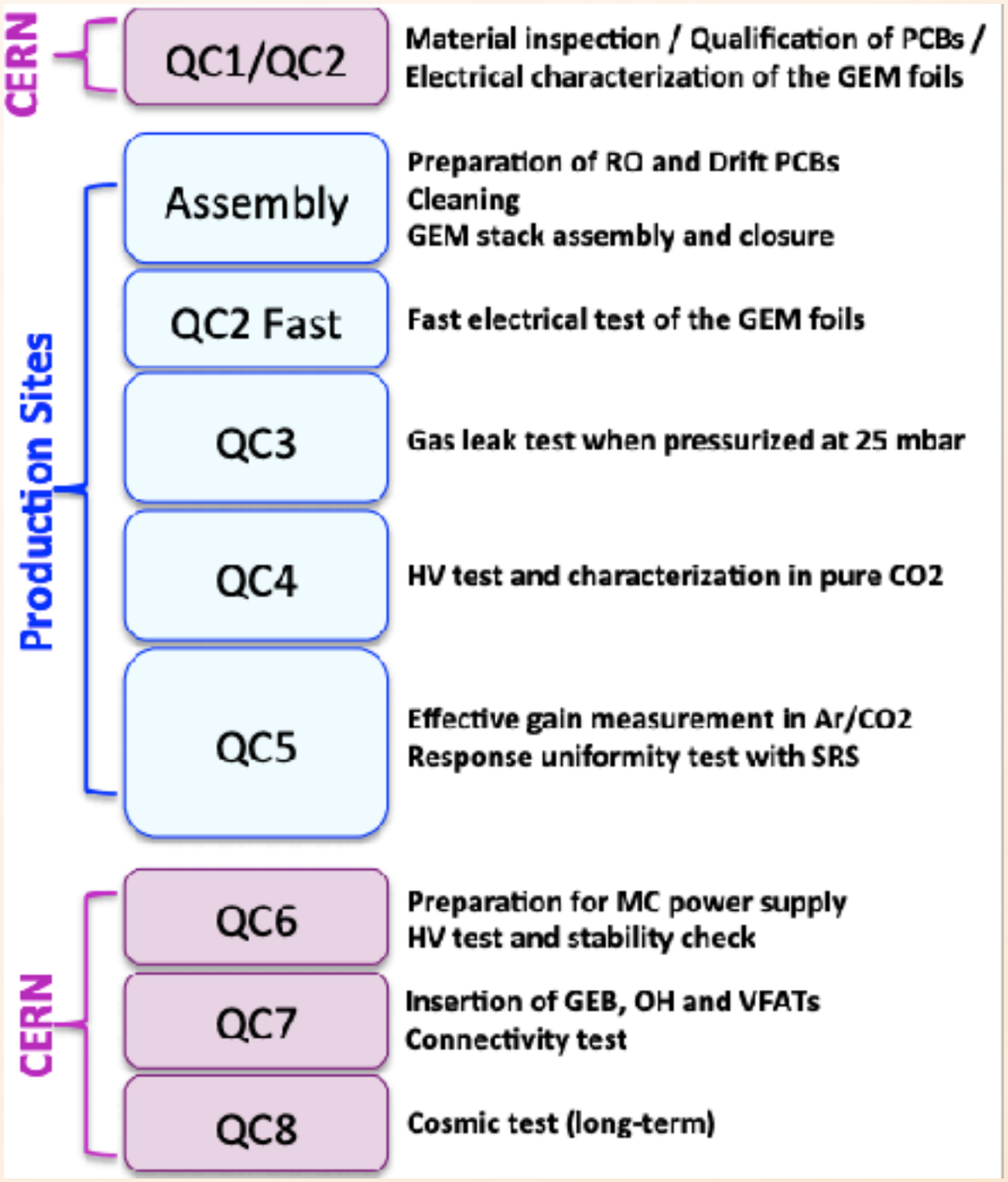
- The production will be divided into four or more sites to speed up the module production rate.

- Already more than four sites are qualified for GE2/1 production.

- GE1/1 production phase demonstrated that the assembly and test of each module can easily be done in 5 working days, with 2 physicists & 1 Technician.

PRODUCTION OF GE2/1 MODULES

- Only approved sites can produce chambers.
- A quality control Jamboree procedure has been setup which includes the several steps.
- All sites are equipped with same infrastructure and follow the same procedure.
- Depending upon the sites, the no. of modules will be divided equally.



PRODUCTION OF GE2/1 MODULES

- **Approval procedure and training material for GE1/1 production:**

→ **The Site Checkout Document** is a set of requirements, recommendations, comments and procedures to support the last stages of the approval of GE1/1 production sites:

10+ pages

- *list of managerial practices, items/facilities, recommendations, suggestions.*

→ **The Quality Control Instructions Manual** describes the test stands, procedures and deliverables:

- *step-by-step procedure of all QCs, operation of the setup, usage of HW/SW.*

50+ pages

→ **The Technical Assembly Manual** describes the preparation and assembly:

- *step-by-step procedures of all assembly steps.*
- *instructions to ensure the safety of the sensible components and recommendations.*

60+ pages

→ **The Assembly video tutorial** illustrates the preparation and assembly:

- *step-by-step procedures.*

1h+ video

→ **Assembly Training** at CERN : 10 sessions organized with all production sites from April 2017 to September 2017 + **QC Training** at CERN since 2015.

And 4 sessions are organized for GE2/1 for new production sites China & Sri-Lanka

PRE-PRODUCTION GE2/1 MODULES

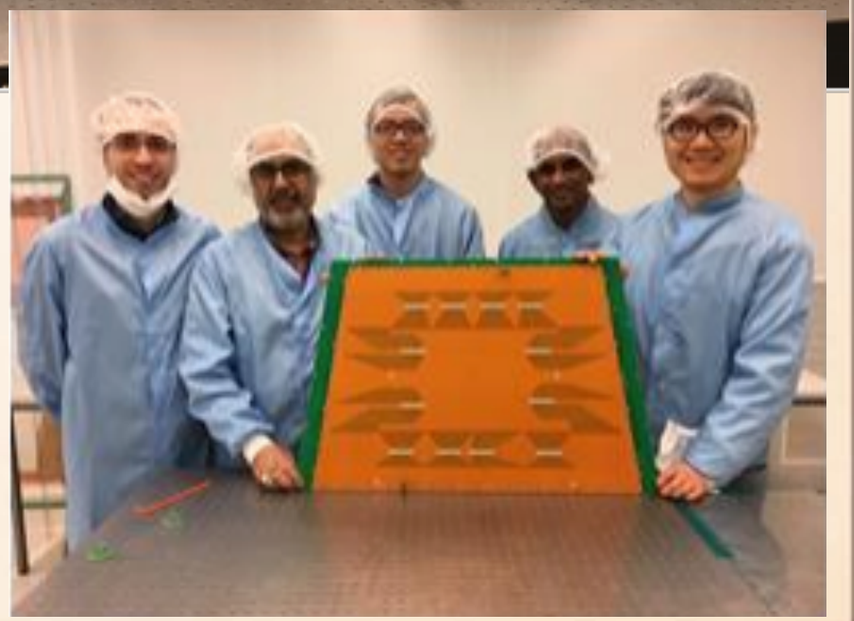
Layout and assembly technique of the GEM chambers for the upgrade of the CMS first muon end-cap station

https://doi.org/10.1016/j.nima.2018.11.061

- Seven GE2/1 modules are assembled using CERN foils and tested and one module (M7) is assembled using the Korean foils.

- Out of 8 modules 4 are used for the training of new production sites (China, Sri-Lanka).

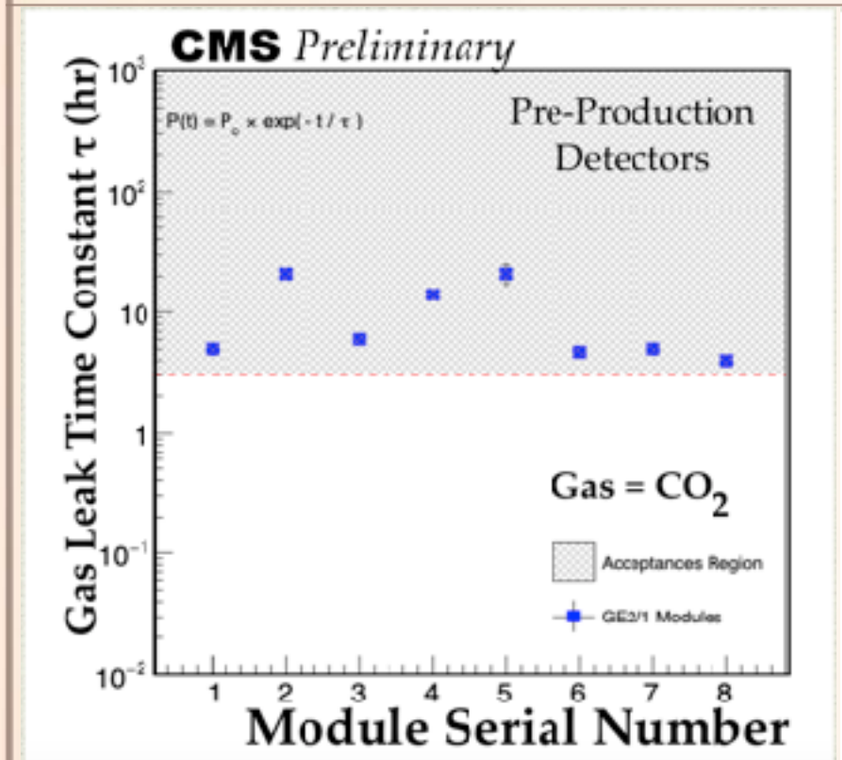
- All the modules are assembled and many of them are tested till QC5 Uniformity.

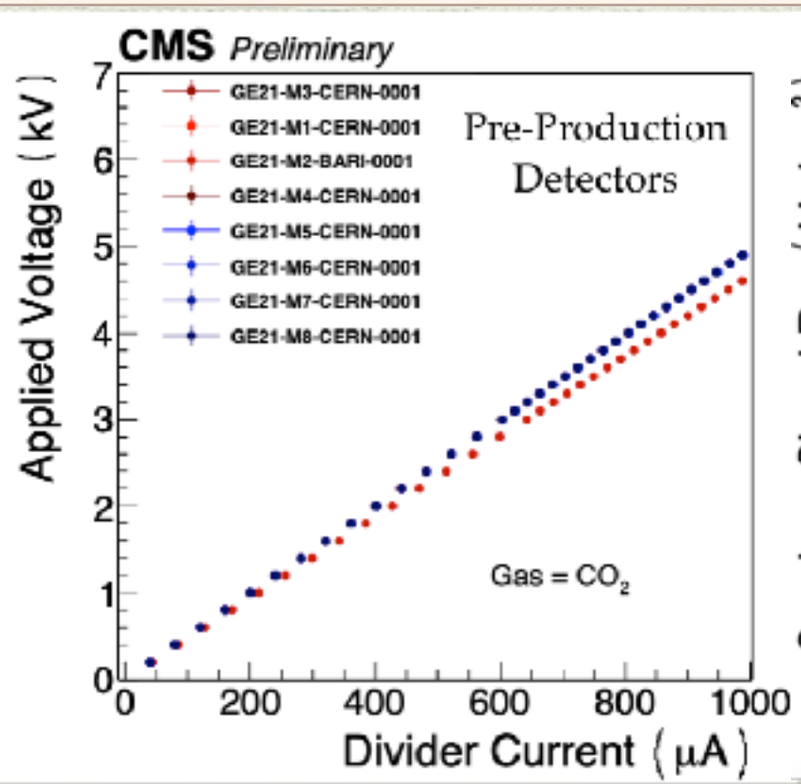


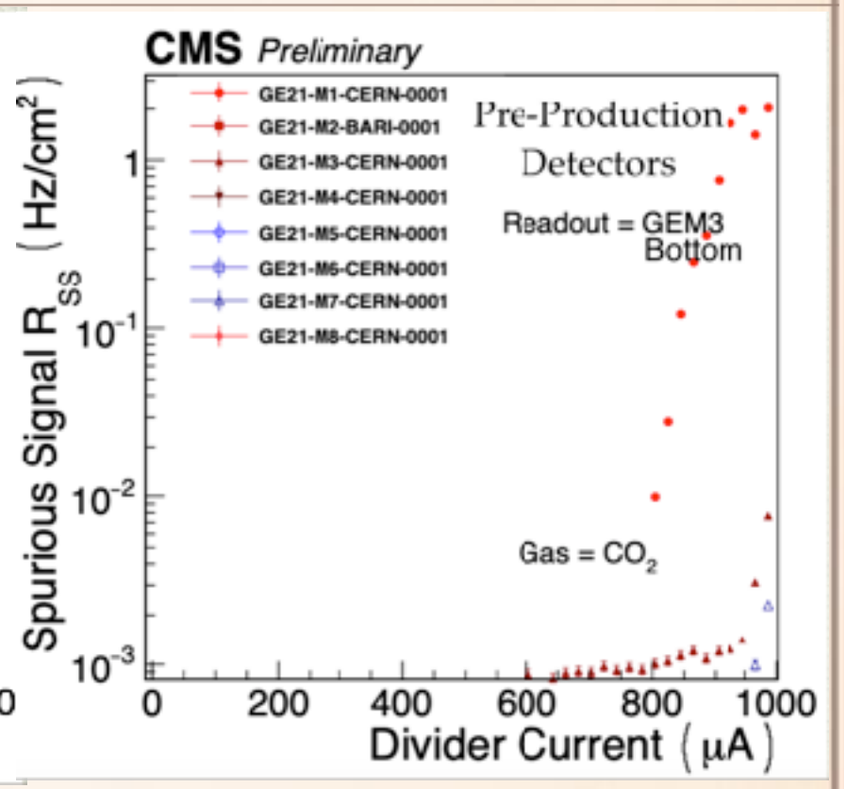
Details in R. Venditti Talk

QUALITY CONTROLS

Updates on Production Status and Performance of GE1/1 Slice Test Detectors for the GEM Upgrade of the CMS Forward Muon System https://indico.cern.ch/event/578210/contributions/2343287/attachments/1359406/2058394/GEM_DPS_NOTE_v3.pdf







Gas Leak Test

- Detector over pressured till 25 mbar.
- Test consists of monitoring of pressure drop with time.
- All modules passed the test showing leakage of less than 7 mbar/hour

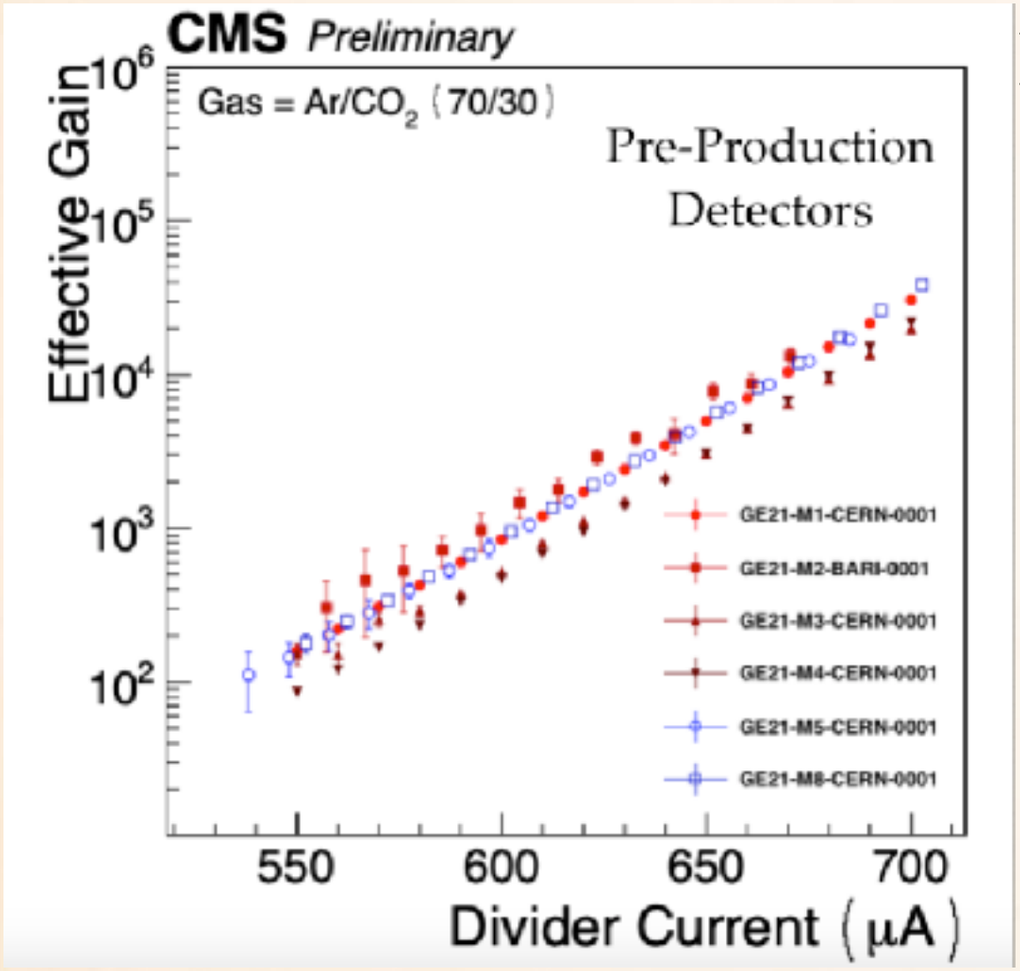
High Voltage Test

- A current is measured across the high voltage divider.
- And resistance is calculated using the Ohm's law.
- No strange behavior was observed during the measurement.

Intrinsic Noise

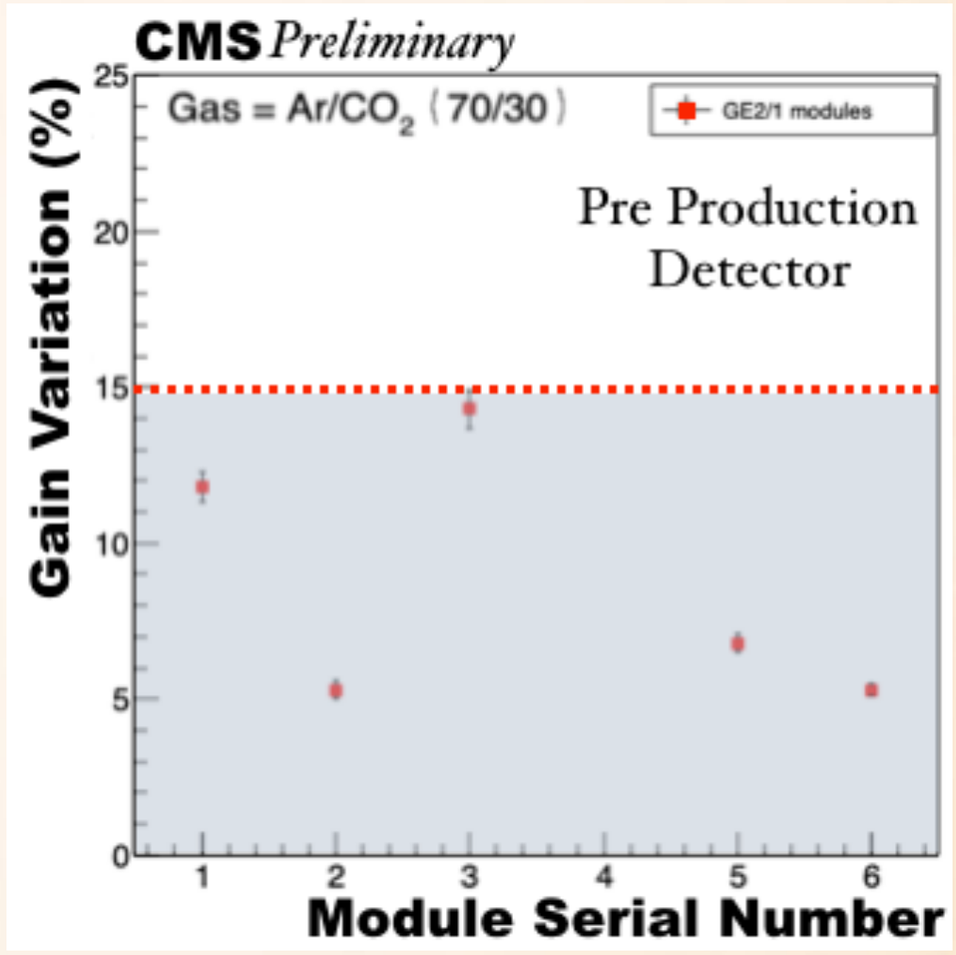
- Along with the IV rate of intrinsic noise was also measured.
- The induced signal on GEM3 bottom was measured with respect to the divider current.
- Rate of intrinsic noise is well below the background rate in CMS

QUALITY CONTROLS



Effective Gain

- The effective gain is defined as the ratio of output current by input current.
- The effective gain of all modules is > 10^4 at 700 uA.



Gain Variation

- The response uniformity defined as the percentage error sigma/mean * 100, sigma & mean obtained from the fitted peak position of X-rays from all strips/slices.
- The response uniformity of all modules tested so far is less than 15 %.

NON-CERN GEM FOILS

- Due to division of GE2/1 detector in several parts, require different size foils.

- And to speed up the production of foils, production could be divided into two or more sites.

- Possible candidates are Korea and India along with CERN.

- Korea is able to assembled & tested 3 chamber of GE1/1 size & 1 M7 module of GE2/1 detector and India built the GE2/1 M1 size detector successfully.

KOREAN GEM FOIL STATUS

- Baseline: KCMS/MECARO to produce M2, M3, M6, M7 foils for GE2/1.

- Validation procedure successfully completed and reported in Phase2 R&D meeting
  1. Long time leakage current measurement
  2. Gain Curve
  3. Rate capability
  4. GIF++ Aging study; 66mC/cm^2 accumulated with no aging effect
  5. Discharge probability of 2.4 $\times 10^{-9}$

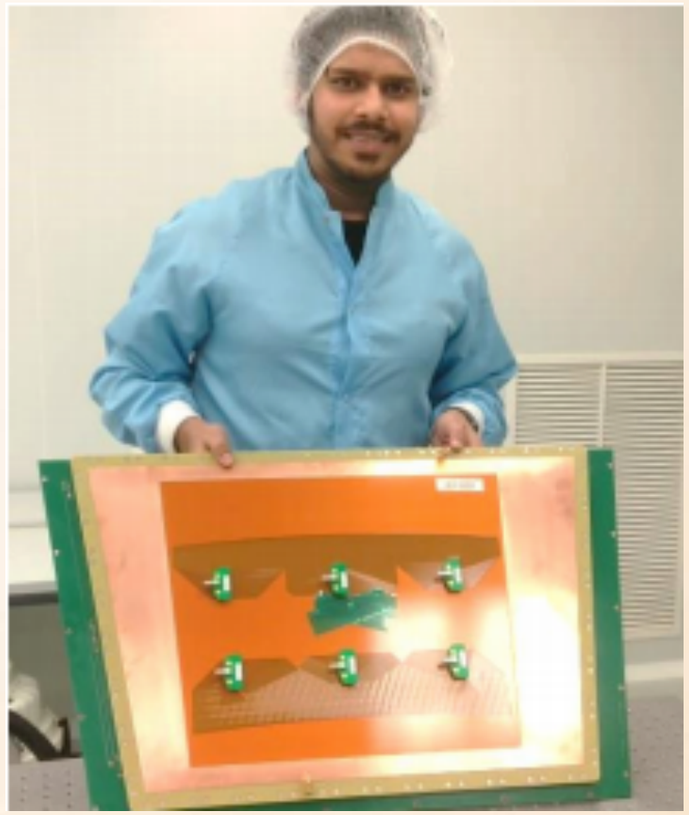
- 124 foils of each module type; 496 foils in total.
  1. 10 foils for each module type for validation.
  2. 108 production foil for each module type (36 module each type).
  3. 6 spares foil for each type.

INDIAN GEM FOIL STATUS

Performance of the triple GEM detector built using commercially manufactured GEM foils in India
arXiv:1806.05016, 2018.

- Baseline: CERN to produce M1, M5 foils for GE2/1.
  Option: Micropack to produce M1, M5 foils for GE2/1

- Validation procedure successfully completed and reported in Phase2 R&D meeting
  1. Long time leakage current measurement
  2. Gain Curve
  3. Rate capability



GE2/1 M1 Module

- Validation still to do:
  1. GIF++ Aging study
  2. Discharge probability

- 124 foils of each module type; 248 foils in total.
  1. 10 foils for each module type for validation.
  2. 108 production foil for each module type (36 module each type).
  3. 6 spares foil for each type.

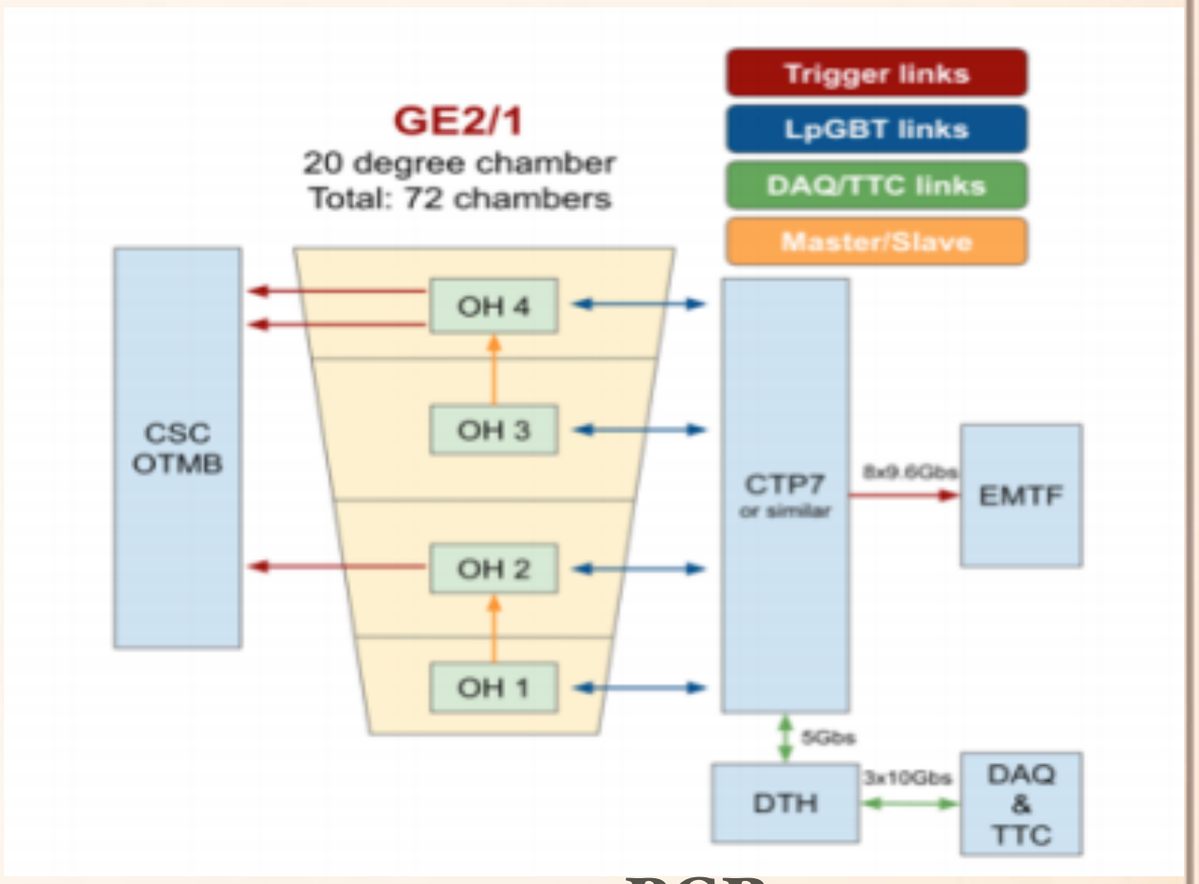
GE2/1 ELECTRONICS DESIGN

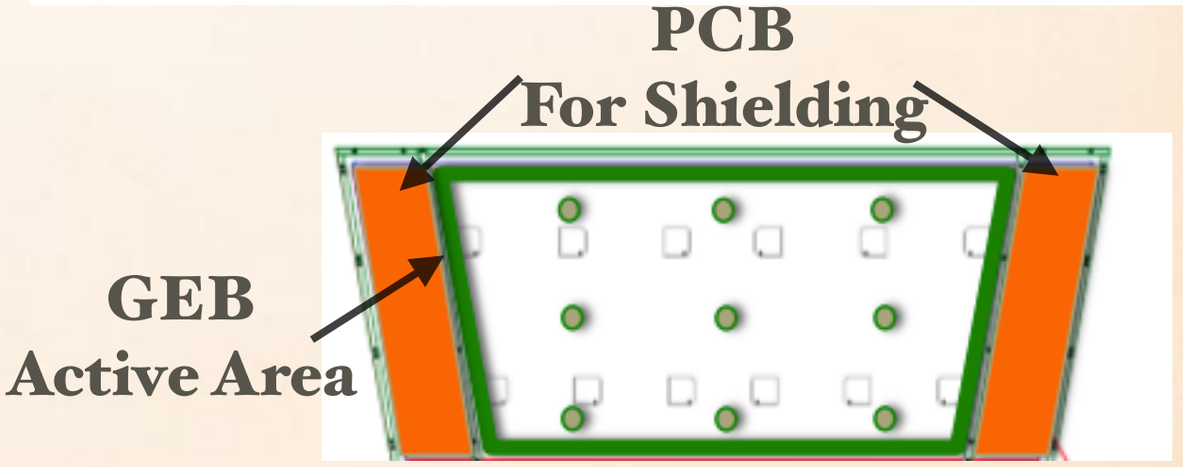
- GE2/1 chamber is divided into four Modules.

- The baseline design comprises of one GEB board for each module but due to limitation of GEB size production two modules on wide side will consists of one GEB along with the two passive PCB act as shielding of the detector.

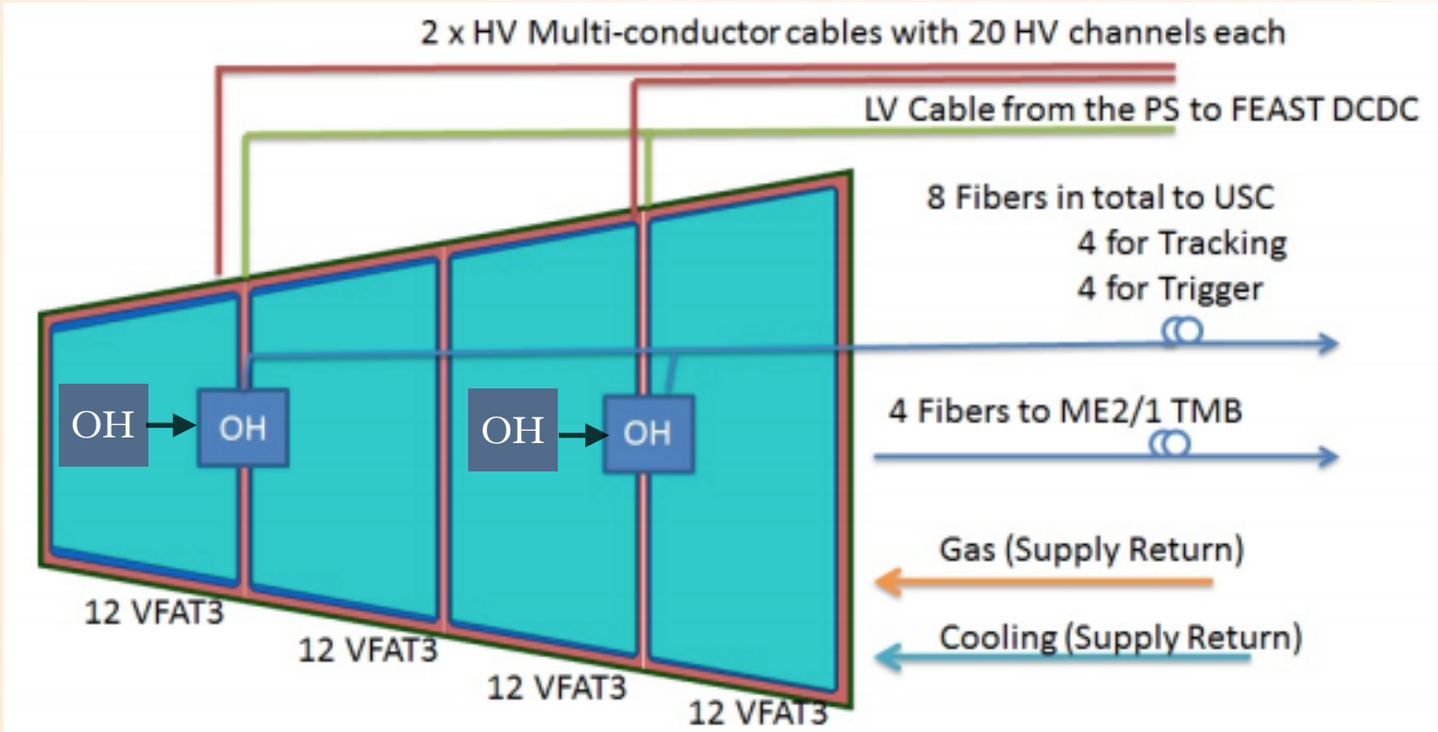
- Each module will equipped with the single OH which reduces the traces and helps in signal transmission with high fidelity

- The VFAT3 chips designed for GE1/1 will also be used for the GE2/1. Each detector will require 48 VFAT3 chips.





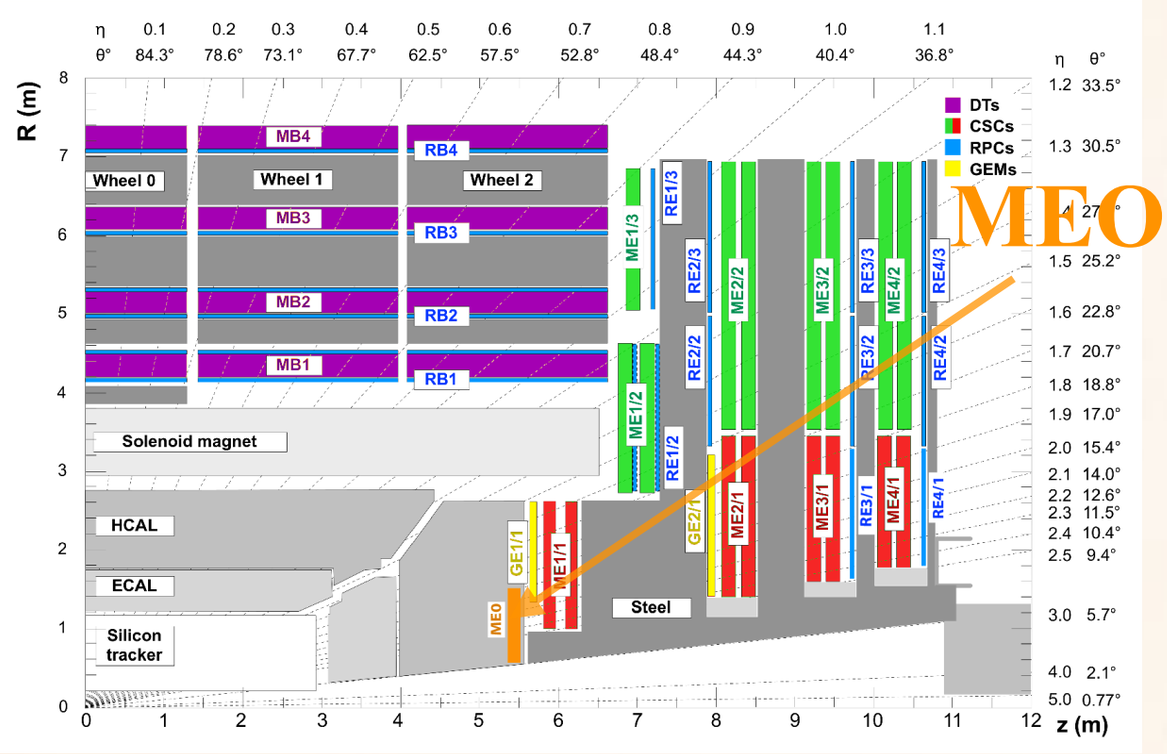
GE2/1 INSTALLATION & SERVICES



- GE2/1 chambers will be installed after LS2 during the Year -End Technical Stop (EYTS)
- First end-cap EYTS 2021-2022 (Feb. 3 week)
- Second end-cap EYTS 2022-2023 (Feb. 3 week)

- The services to power and run the single GE2/1 detector consists of four LV cable to power ON the electronics.
- Four HV cables to power ON the detector.
- Fiber patch cords for the readout and control with eight fibers running from the OH to USC55 and four fibers running to the ME2/1 OTMB.
- Finally the pipes for gas and cooling system and return.

MEO POSITION

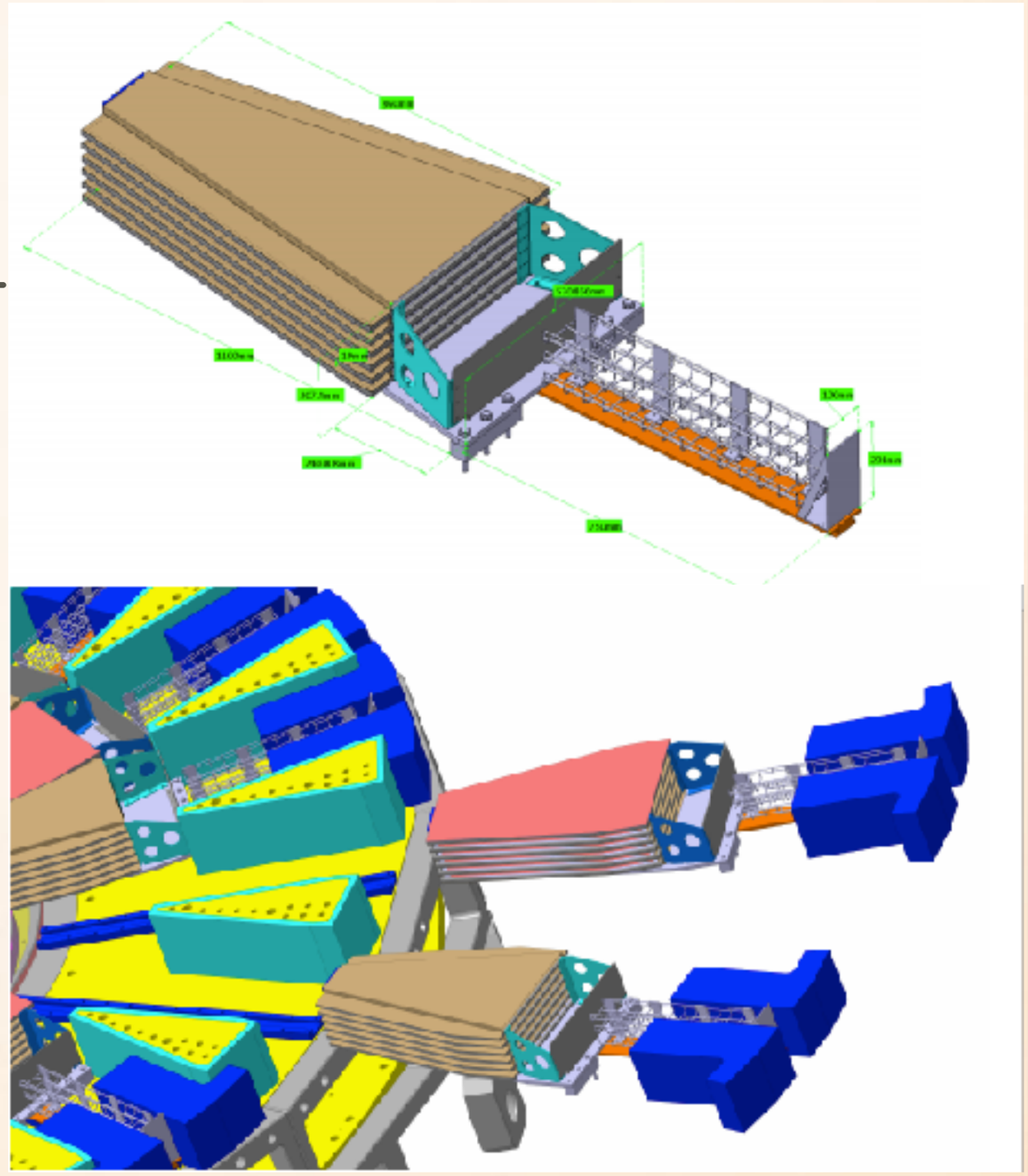


- 2.03 < |η| < 2.8
- Trapezoidal shape with 6 triple GEM layer as baseline to reject the background

- The main motivation of the new ME0 detectors is to increase the geometrical acceptance for muons.
- In 2.03 < |η| < 2.4 along with the CSCs, RPCs and GE2/1, the ME0 detectors will improve muon measurement by adding six hits per track.
- Only the ME0 chambers cover the 2.4 < |η| < 2.8 range. Since six triple-GEM layers are used, an efficient tagging of muon tracks with little background contamination is possible. Even for transverse momenta down to p_T = 3 GeV the identification efficiency is simulated to be approximately 95%.

ME0 DETECTOR DESIGN

- The ME0 module comprises of 18 20° chamber per end-cap.
- Each ME0 chamber having 6 triple-GEM detectors.
- Each stack is mounted on the 15 mm thick aluminum plate to give mechanical strength.
- The ME0 detector is 33.4 mm thick and 6 layer super chamber is 224.4 mm thick including shielding.
- The size of ME0 detector is same GE1/1 detectors.



ME0 ELECTRONICS DESIGN

- The ME0 baseline detector consists of 20° stacks each consists of 6 triple GEM modules.
- The electronics will be based on same architecture as compare to GE1/1 & GE2/1, also the DAQ layout will be a copy of GE2/1.
- Each module uses a single GEB PCB board, The module readout plane consists of 24 sectors 3 columns in φ and 8 partitions in η, each containing 128 strips
- The signal is readout by the VFAT3 chips and in total 24 chips are placed on a single GEB board per module.
- Finally the signal is routed to the single Optohybrid board.

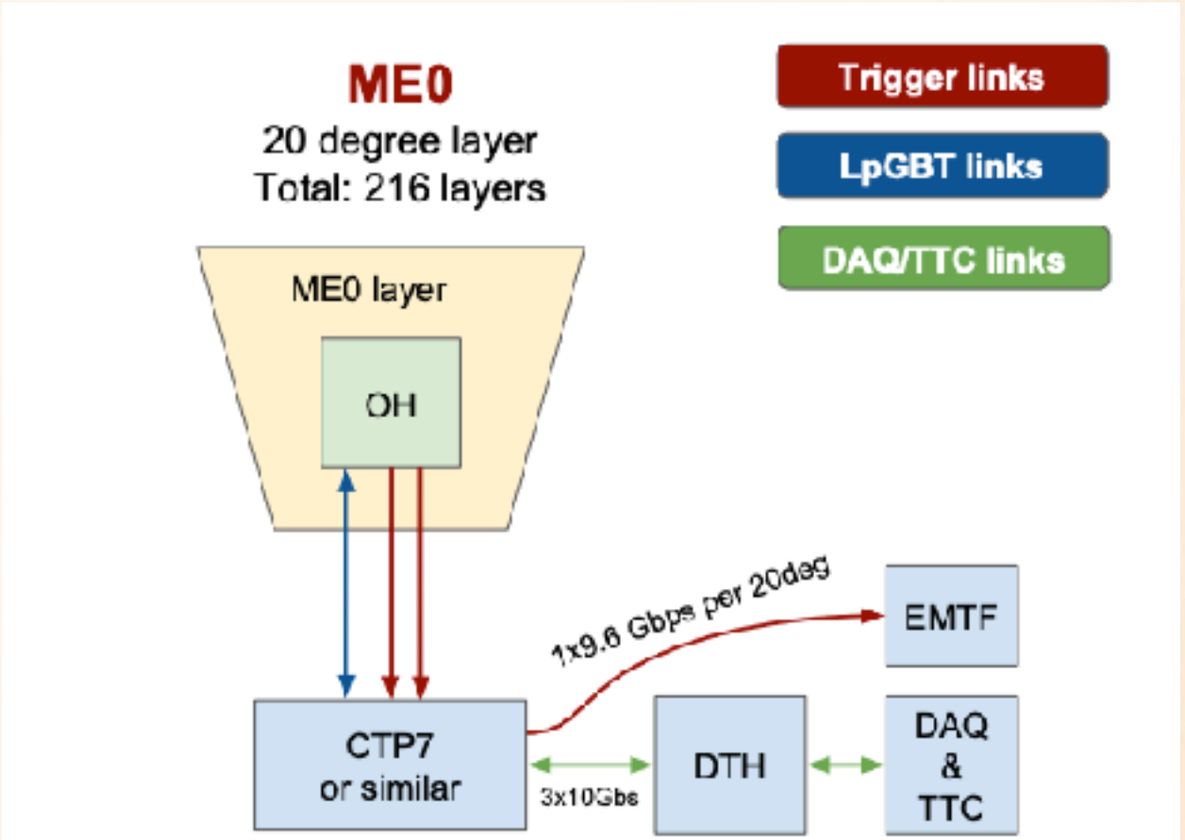


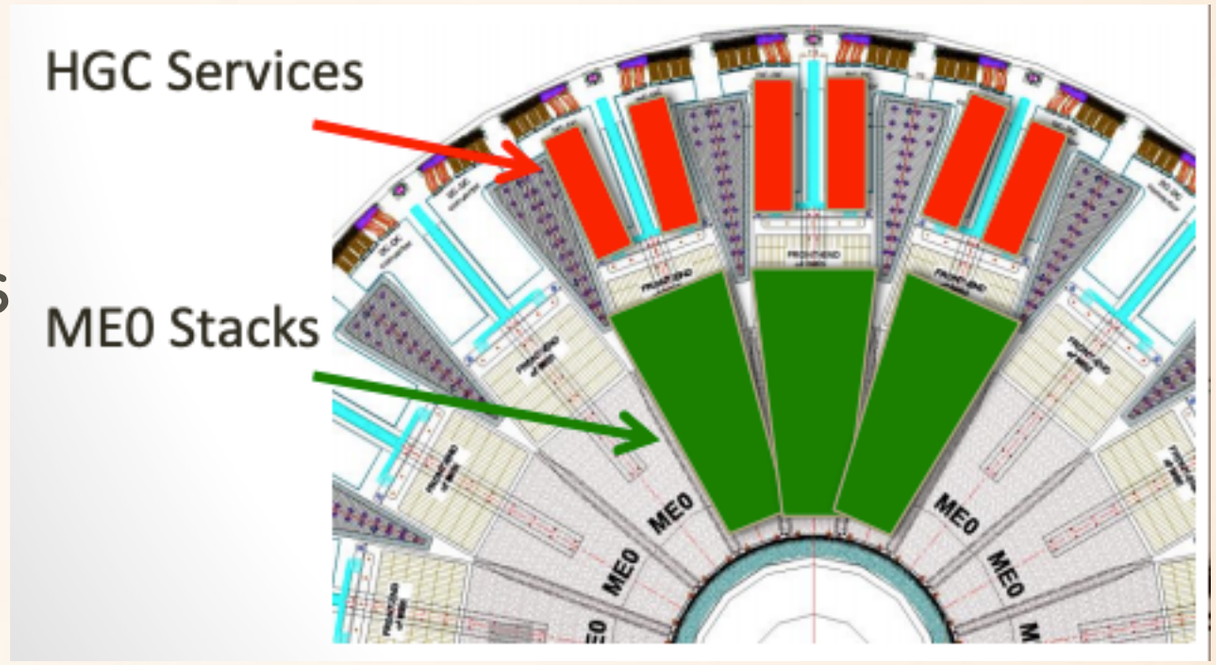
Figure 6.45: Diagram of the ME0 electronics readout system.

ME0 INSTALLATION & SERVICES

- ME0 installation schedule has designed to avoid conflict with HGC installation schedule, in particular with the HGC services installation

- ME0 installation will proceed in bursts of 3 stacks (60 deg) at a time, with HGC following right behind ME0 installation and covering ME0 with HGC services

- First 3 ME0 stack fully tested by Jul 2022, the expected date of the insertion of the3 stacks Feb 2023. (contingency of more than 6 month)



- The service required to power up the single ME0 is 3 LV cable with two channels per cable to power the on detector electronics.

- Three HV cables to power up the six modules.

- Pipes for the gas and cooling supply and return lines.

ME0 PRE-PRODUCTION

In total construction of at least 9 modules would be necessary to meet the expected 2019 ME0 milestone which foreseen usage of new modules

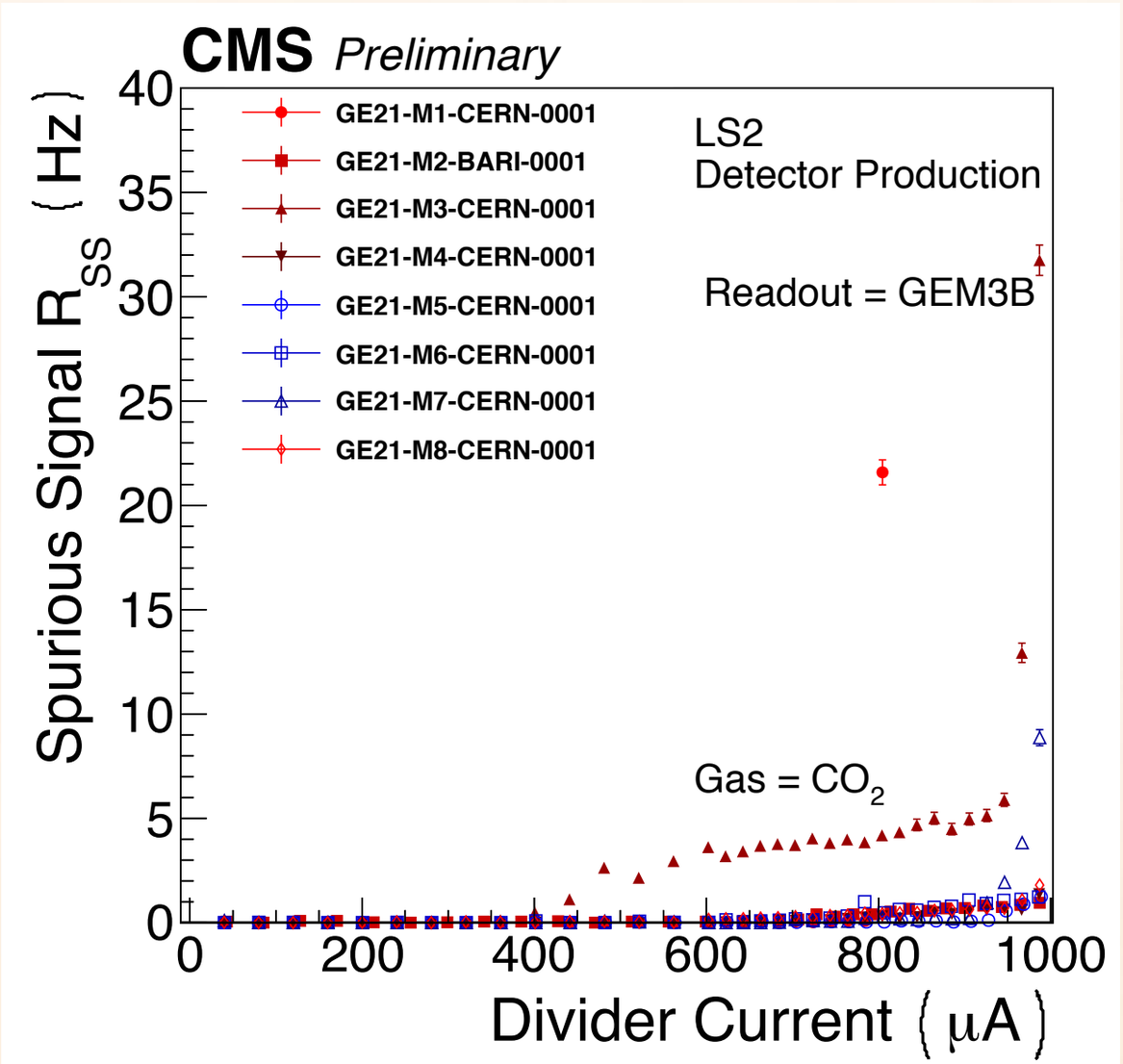
- Neutron irradiation test (Louvain) -> 1 Module
- Stand in FIT for electronic integration -> 2 modules
- First fully operational stack -> 6 Modules
- Aging test for non CERN foils validation for ME0 usage -> one module for each vendors candidate.

SUMMARY & CONCLUSION

- HL-LHC phase requires the upgrade of the CMS muon system to precisely measures the muon, namely GE2/1 and ME0.
- Complete chamber (stack) of GE2/1 module is built and tested for the basic quality controls.
- Two new sites (Sri-Lanka & China) training session for the GE2/1 chamber assembly were organized.
- On chamber electronics prototyping and testing is completed for GE2/1.
- For ME0 the chamber (stack) prototype mechanical designed is completed.
- And on-chamber and off-chamber electronics preliminary principle design is competed.
- A full ME0 stack will be ready by this year.
- Longevity test for GEM chamber is on-going at GIF++/904 lab and no aging is observed till 1.5C/cm^2. Also planning a longevity test on real ME0 detector soon.

THANKS

BACKUP


CMS Preliminary
LS2
Detector Production
Readout = GEM3B
GE21-M1-CERN-0001
GE21-M2-BARI-0001
GE21-M3-CERN-0001
GE21-M4-CERN-0001
GE21-M5-CERN-0001
GE21-M6-CERN-0001
GE21-M7-CERN-0001
GE21-M8-CERN-0001
Gas = CO2
Spurious Signal Rate (Hz)
Divider Current (μA)
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000

GE2/1 MILESTONE

Milestone title	Date	
GE2/1 R&D: Key detector system design parameters are defined based on performance requirements	Mar.17	Achieved
GE2/1 R&D: On-chamber electronics preliminary design completed and interfaces defined	Jun.17	Achieved
GE2/1 R&D: Off-chamber electronics preliminary design completed and interfaces defined	Mar.18	Achieved
GE2/1 R&D: A full size chamber prototype with partially instrumented readout built, tested and performance validated	May.18	Achieved
GE2/1 R&D: Detector design parameters optimization completed, final chamber design is selected for the demonstrator	May.18	Achieved
GE2/1 R&D: On-chamber electronics prototypes engineering design complete	Jun.18	Achieved Sep.18
GE2/1 R&D: On-chamber electronics prototype electronics manufacturing and testing is complete	Oct.18	Achieved Feb.19
GE2/1 R&D: Performance of the demonstrator chamber with prototype electronics is validated	Mar.19	Expect May.19
GE2/1 R&D: On-chamber and off-chamber prototype electronics integration and performance studies completed	Dec.19	Expect on-time
GE2/1 PRR for the On-Detector Services	Aug.2018	Achieved (Jul.18)
GE2/1 PRR for the Foil Production	Nov.2018	Expect in 21.May 19
GE2/1 Detector EDR	Mar.2019	Expect 21.May.19
GE2/1 ESR	Dec.2019	Projected on-time

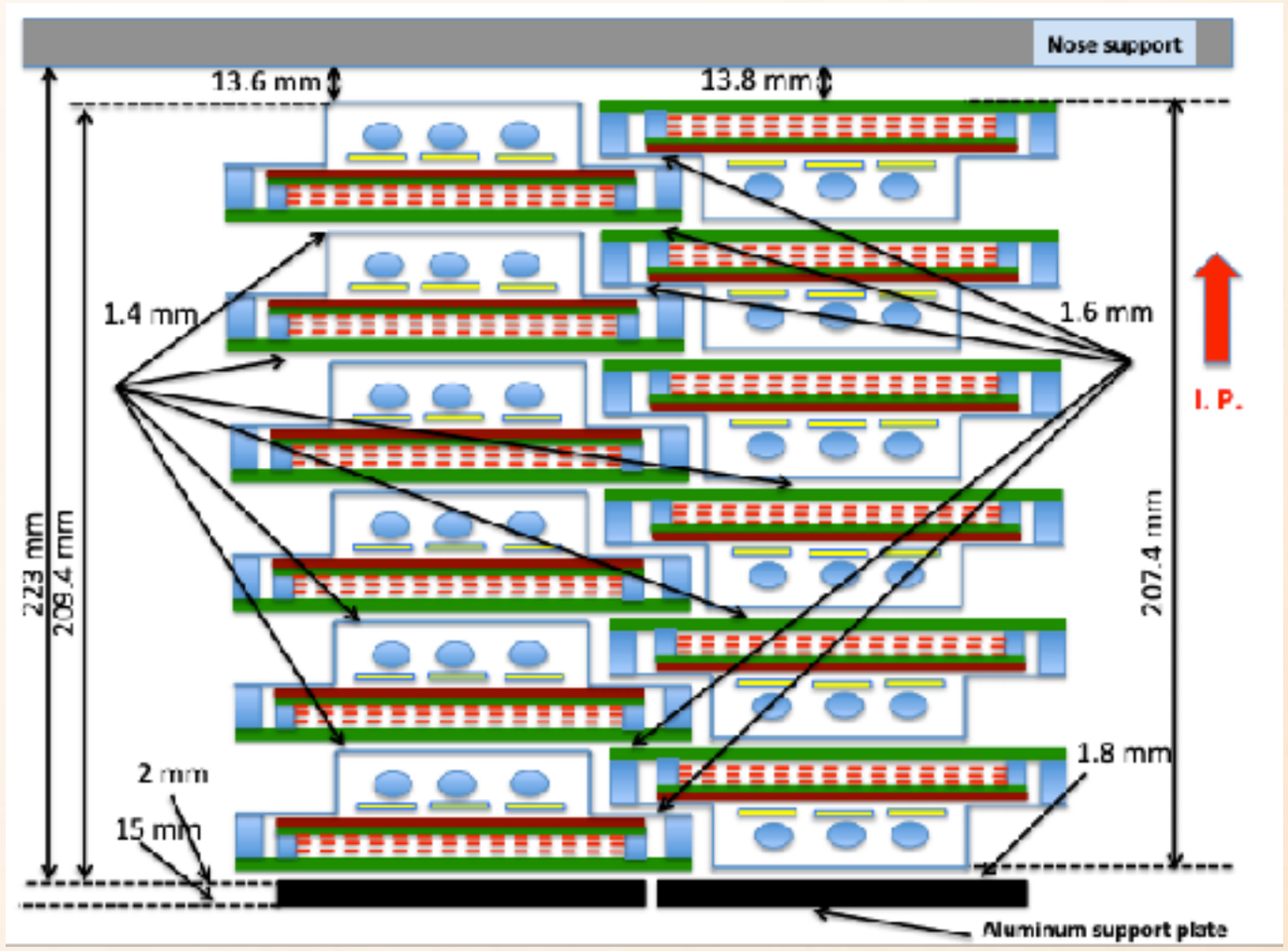
SIX MODULE STACK DESIGN

- The aluminum plate itself installed on rail for ease in sliding stack and modules can overlay with adjacent modules for maximum coverage.

- The modules in adjacent stack out of two stacks is placed upside down to allow overlap of chamber for maximum coverage.

- The thickness of ME0 detector is constrained by the total space of 238 mm in beam direction and this space accommodates the detectors, aluminum plate, and some other clearance.

- Which includes min. of 1.6 mm gap between adjacent modules for easy insertion. Also the additional space of 10 mm from the top of the stack to prevent the damage due to the deformation of end-cap nose in presence of magnetic field.

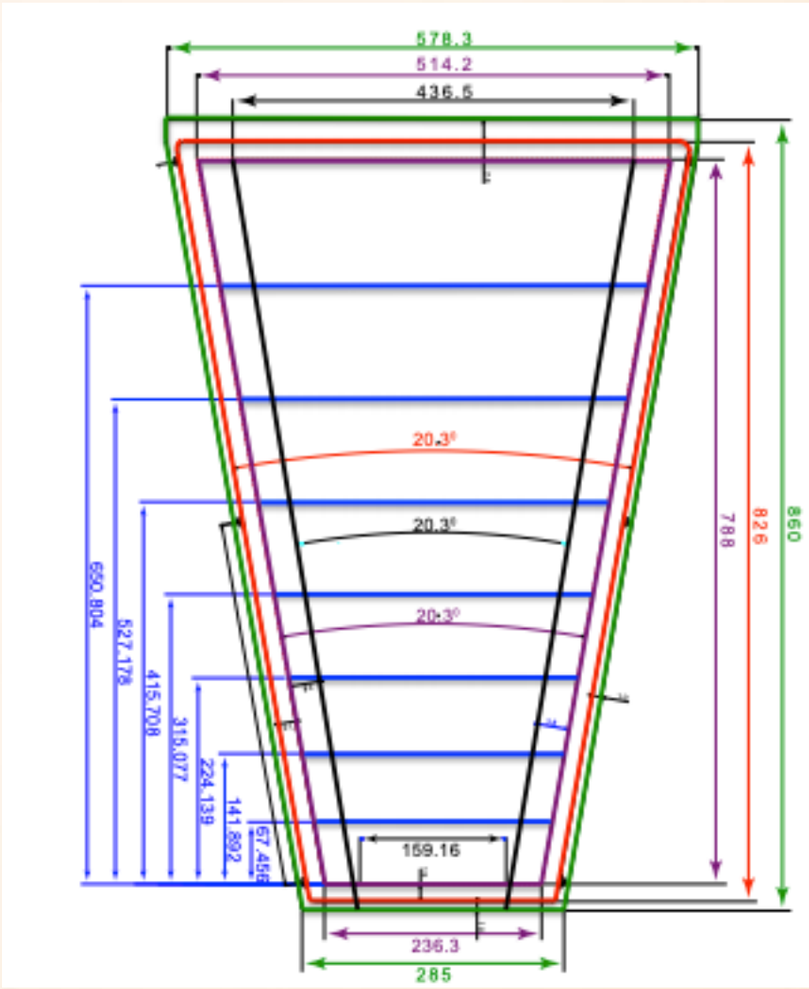


SIX MODULE STACK DESIGN

- The figure shows the mechanical design of ME0 detector and dimensions of drift board, readout board, and active area of ME0 module; the size of chimney and the eta partitions.

- The segmentation of each ME0 chamber layer is 8 rings in eta and 3 sectors in Phi; each sector Phi is in turns divided into 128 radial strips.

- Longevity test for GEM chamber is on-going at GIF++/904 lab and no aging is observed till 1.5C/cm^2. Also planning a longevity test on real ME0 detector soon.



ME0 MILESTONE

Milestone title	Date	
ME0 R&D: Key detector system design parameters are defined based on performance requirements	Mar.17	Achieved
ME0 R&D: Irradiation studies and assessment of performance and longevity with small prototypes completed	Jul.2017	Achieved
ME0 R&D: On-chamber & off-chamber electronics preliminary principal design complete and interfaces defined	Jul.17	Achieved
ME0 R&D: Chamber (stack) prototype mechanical design completed	Dec.2018	Achieved
ME0 R&D: On-chamber electronics engineering design completed and validated	Aug.2019	Expect on time
ME0 R&D: Chamber (stack) prototype mechanical prototype testing and validation complete	Dec.2019	Expect on-time
ME0 R&D: On-chamber electronics prototype electronics manufacturing and testing is complete	Aug.2020	Expect on-time
ME0 R&D: Integration of the on-chamber and off-chamber electronics and performance assessment complete	Jan.2021	Expect on-time
ME0 R&D: Assessment of the electronics performance and integration with the demonstrator chamber completed	Mar.2021	Expect on-time
ME0 R&D: Beams and Cosmics testing of the demonstrator chamber and performance qualification completed	Aug.2021	Expect on-time
ME0 PRR for the Foil Production	Jun.2021	Projected on-time
ME0 ESR	Apr.2021	Projected on-time
ME0 Detector EDR	Oct.2021	Projected on-time