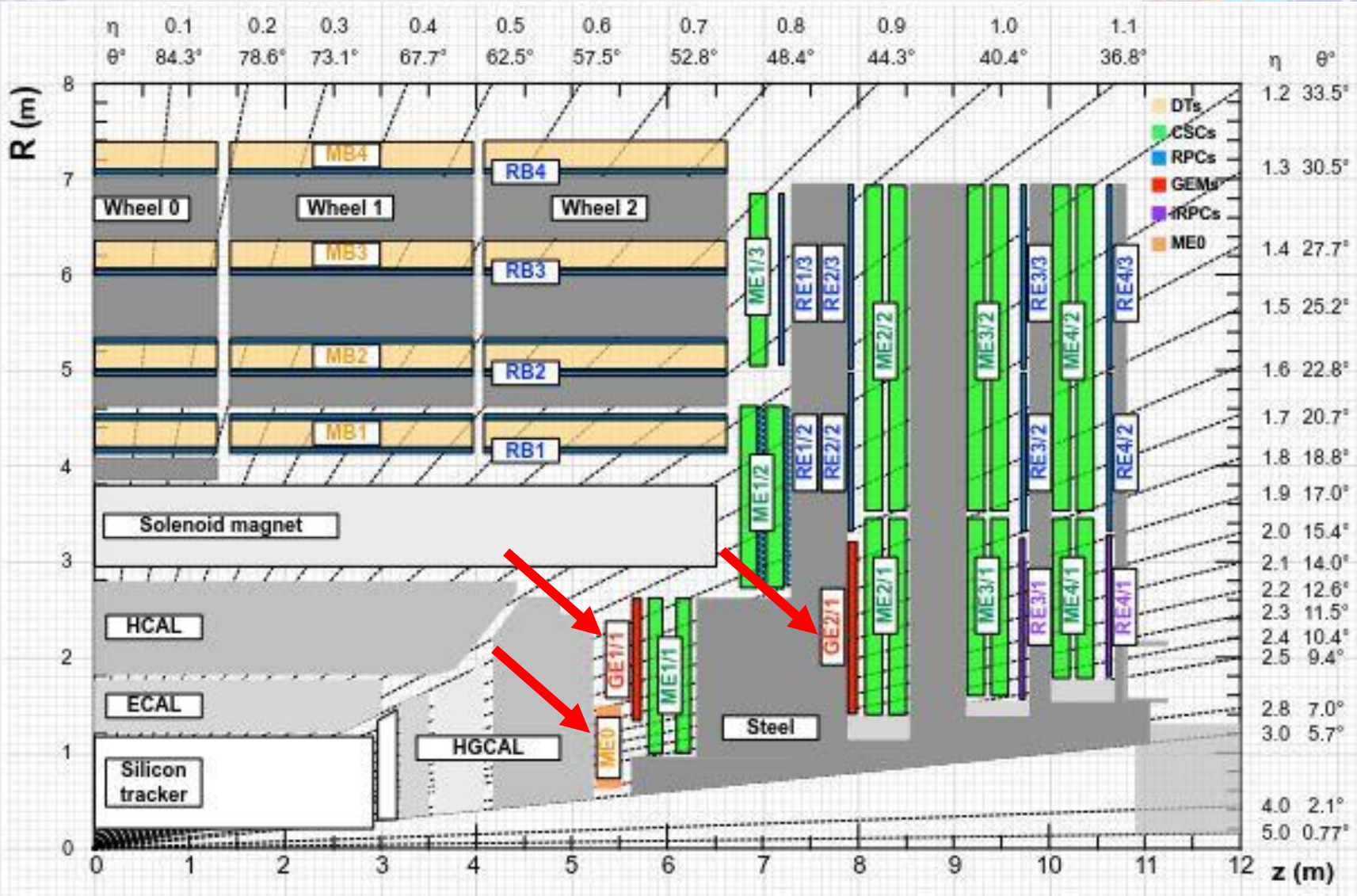
Upgrade of the CMS muon spectrometer in the forward region with the GEM technology

Marek Gruchała

Outline

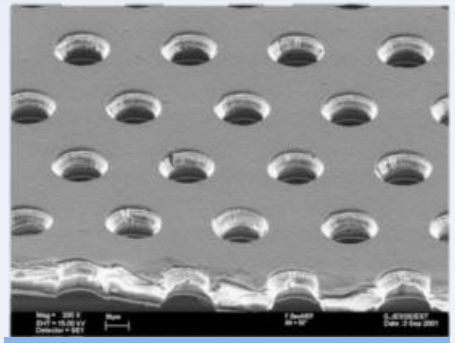
1. CMS GEM Upgrade overview.
2. GEM Technology.
3. GE1/1 project:
    1) Quality certification process of the GE1/1 chambers.
    2) GE1/1 chamber operation parameters.
    3) Superchamber quality certification progress.
    4) Distributed production model & achievments.
    5) Production and installation schedule.
4. GE2/1 project.
5. ME0 project.
6. Summary.

1) CMS GEM Upgrade

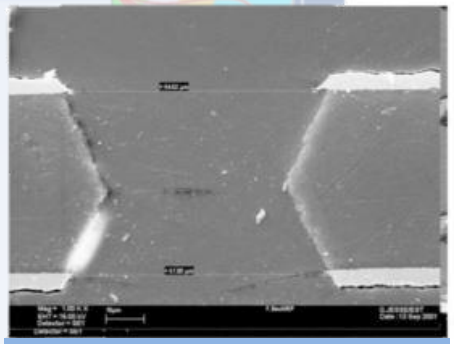


2) GEM Technology

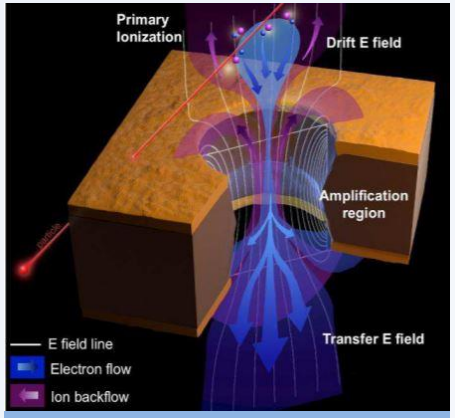
- **What is a GEM (Gas Electron Multiplier)?**
  - Micropattern gaseous detector family.
    - In case of GE1/1 project, the highly resistive kapton foil of 50μm thick, clad on both sides with 5μm copper layer.
- **Why GEM technology?**
  - Rate capability of MHz/cm^{2}.
  - No ageing effect observed up to 1C/cm^{2} accumulated charge.
  - Timing resolution, for proposed Ar/CO_2 gas mixture, is of 10ns or better.
  - Over 97% efficiency of the detector, measured in a series of test beams.
  - Angular resolution below 300 μrad.
  - Space limitations in the endcap region.



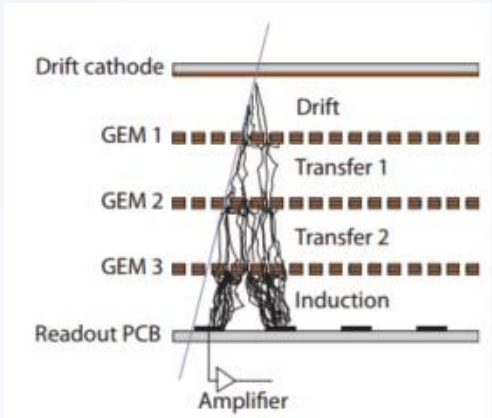
Scanning Electron Microscope picture of a GEM foil surface.



Scanning Electron Microscope cross section picture of a GEM hole.

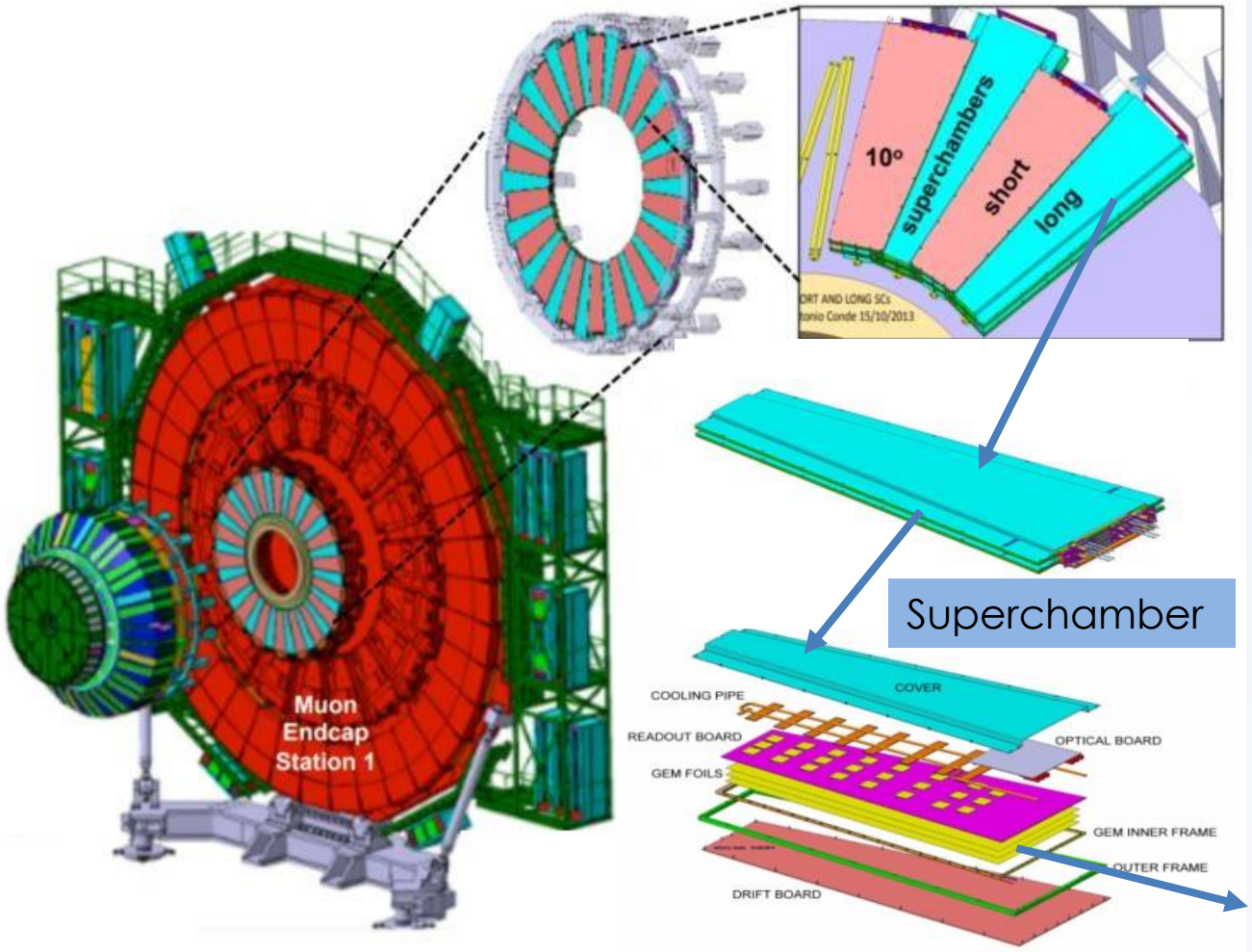


schematic view of the electric field lines (white), electron flow (blue), and ion flow (purple) through a bi-conical GEM hole (right)



Principle of operation of a generic triple-GEM chamber and definition of drift, transfer, and signal induction gap regions within the detector

3)GE1/1 project



Superchamber

Single chamber exploded view

- 72 chambers per endcap (36 superchambers).
- 10° coverage per single module
- $1.6<|\eta|<2.15$ coverage.
- Triple GEM technology used to build the GE1/1 detectors.
- First of the „Phase2" GEM-based upgrade project.
- Foreseen to be installed by 2019 (1st endcap) and 2020 (2nd endcap).

3.1) Pre-assembly, components quality checks

1)Visual inspection

2)Foil HV stability check

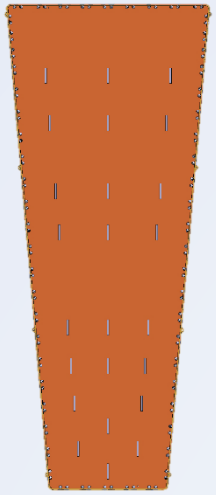
3)Gas leak test.

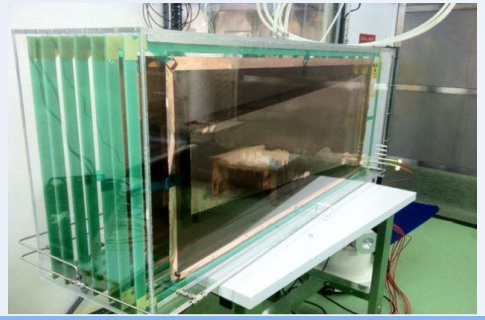
4)HV stability check.

5.1)Gain calibration

5.2)Gain Uniformity

Single chamber quality certification procedure.





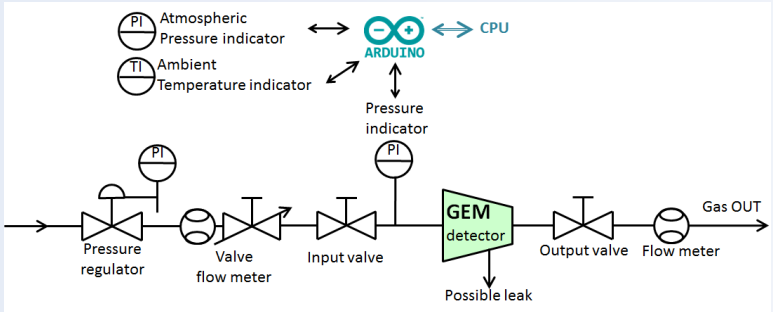
A batch of foils under the test.

- **Single component quality checks:**
  - Connectivity of each individual panasonic connector of the R/O board, using arduino based system.
  - Visual inspection of the components used for the assembly.

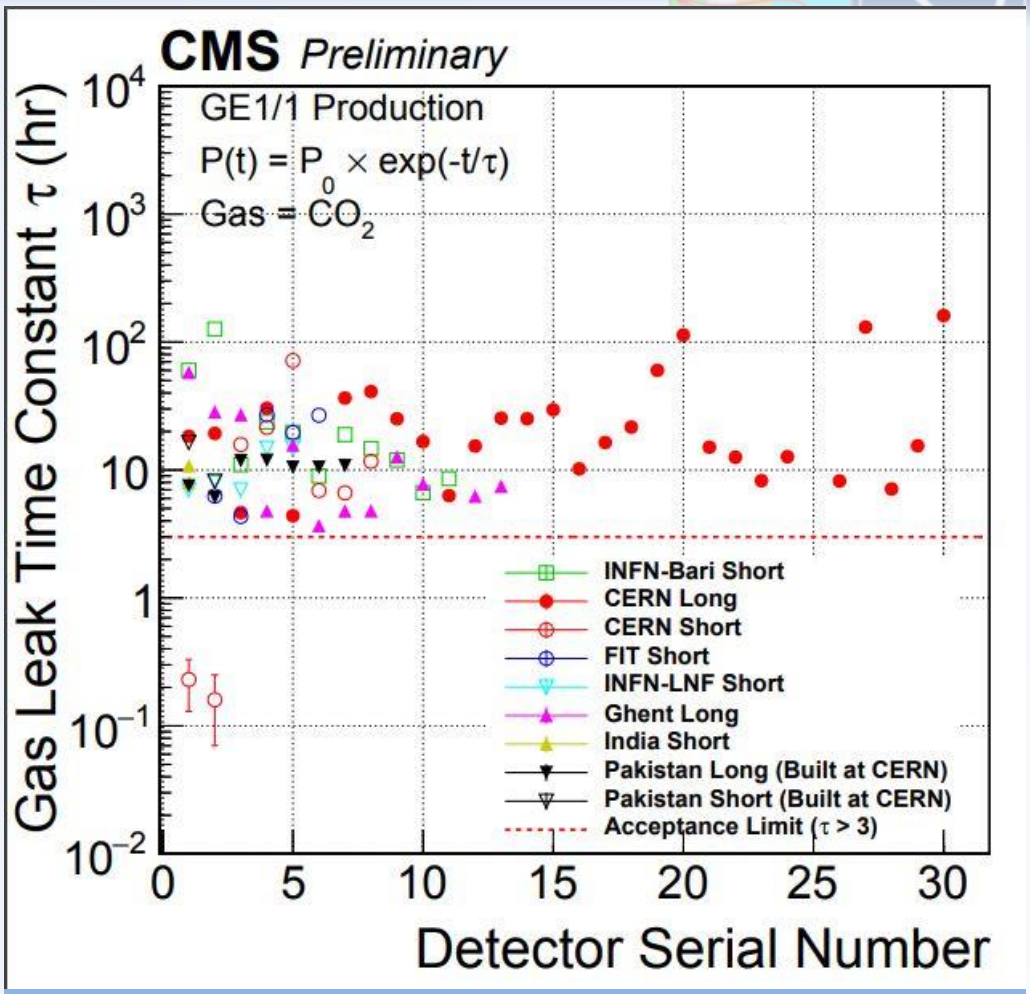
- **Foil test:**
  - Test performed on the foils, enclosed in the tight box, supplied with the pure nitrogen gas.
  - Current of each foil monitored at various voltages, reaching up to 600V across individual foil.
  - Constant monitoring of the current on an individual foil level gives the information about sparking.
  - Only the foils that pass the test can be considered to be used for the assembly.

3.2) Gas leak test

- Gas leak test is performed by constant monitoring of the pressure in enclosed GE1/1 volume.
- Typically the chambers are overpressured of 25 mBar w.r.t the atm. Pressure.
- 25mBar of overpressure is the value expected while operating the chambers in the P5.
- **Aiming to ensure that no pollutants will be introduced to the chamber.**



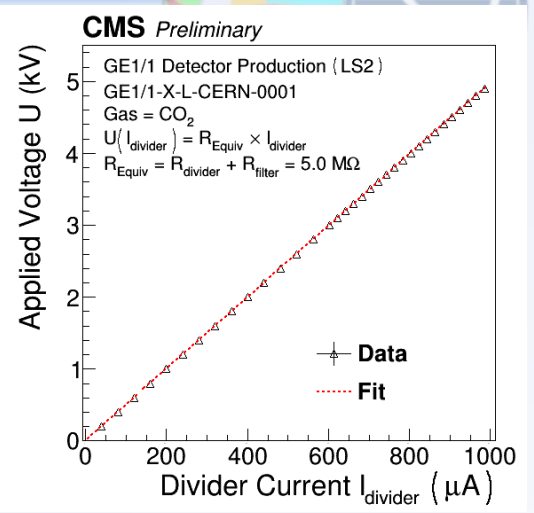
The QC3/gas leak stand



Gas leak parameters of the GE1/1 chambers. The leak parameter tau is defined by fitting the pressure vs time curve with $P_m(t)=EXP(A-t/tau)$, where A is a constant.

3.4) HV stability & dark current monitoring.

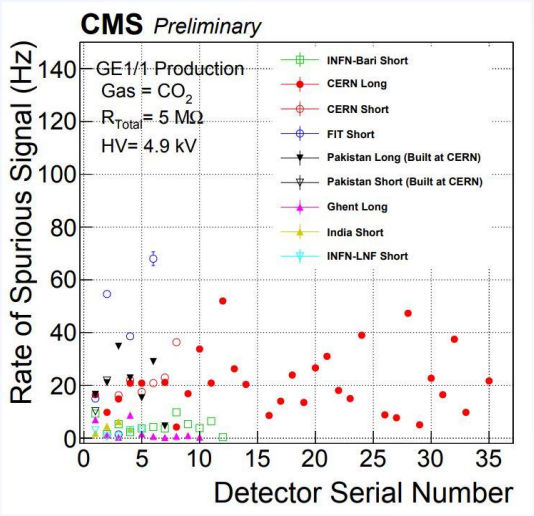
- Chambers are being povered by a HV divider, providing the desired values fo the electric field between the elements.
- Conserved Ohm's law indicates that no current leak takes place at any of the chamber elements.
- Maximum HV point for chamber operation: 4.9 kV
- Chambers are foreseen to operate at much lower voltages in the P5.
- **Stressing out the chambers to ensure their successfull operation in the P5.**



Typical I(V) curve obtained during the GE1/1 quality control.

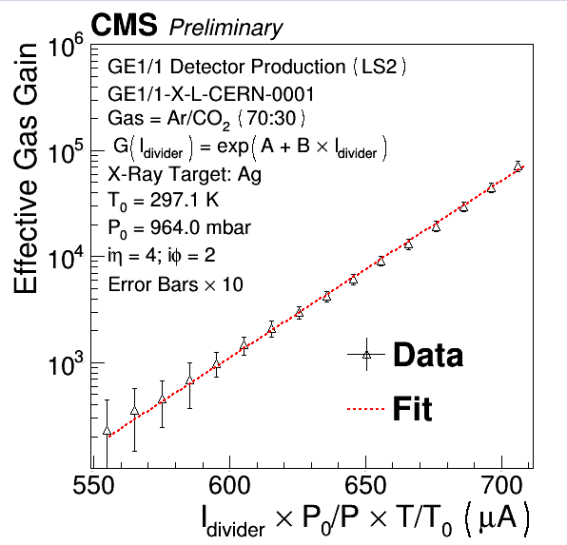
- During the HV stability test also the intrinsic chamber noise, for each HV point is being measured.
- Measured rate of of the intrinsic detector noise level is far below 100Hz over whole electrode surface, resulting in ~ 10^{-2} Hz/cm^2 (detector surface ~ 300 cm^2).
- CMS background rate in order of 1 **k**Hz/cm^2.
- **Negligible value of the chamber nosie w.r.t the CMS nosie present in the GE1/1 endcap region.**

The rate of the spurious signal measured for the detectors assembled in specified sites in Hz vs. the serial number of the chamber. Here the intrinsic noise rate is being measured over whole surface of the GEM3 bottom electrode.

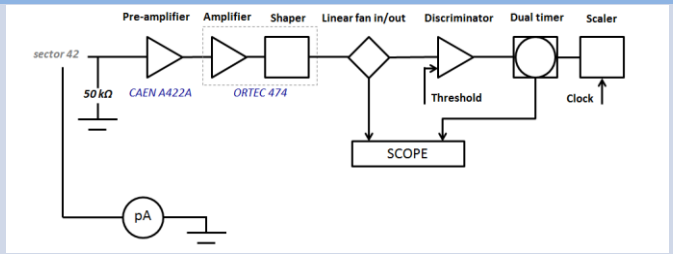


3.5) Gain calibration & uniformity

GAIN CALIBRATION

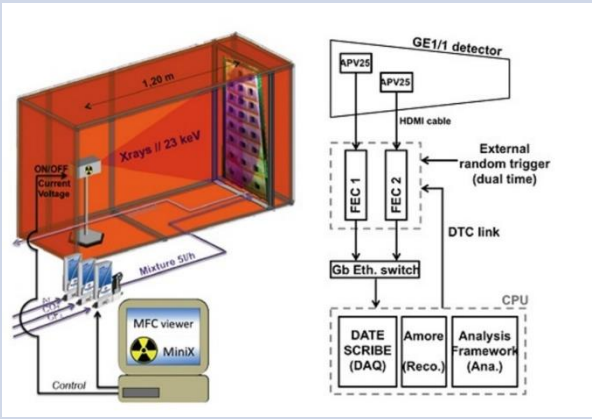


Typical effective gain curve obtained during the GE1/1 quality control. $I_{divider}$ is the current flowing through the HV resistive divider that provide potential to the detector electrodes.

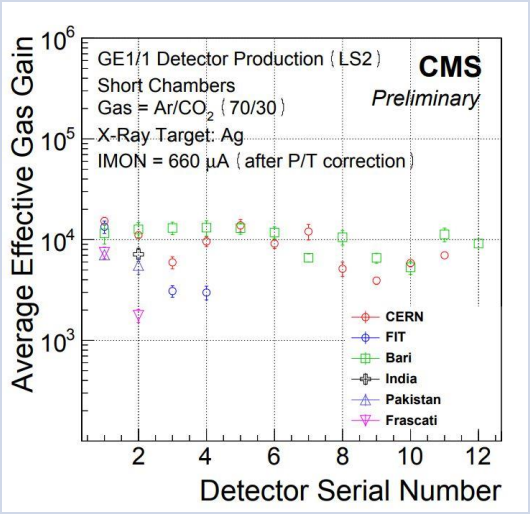


The QC5 Gain calibration stand schema.

GAIN UNIFORMITY

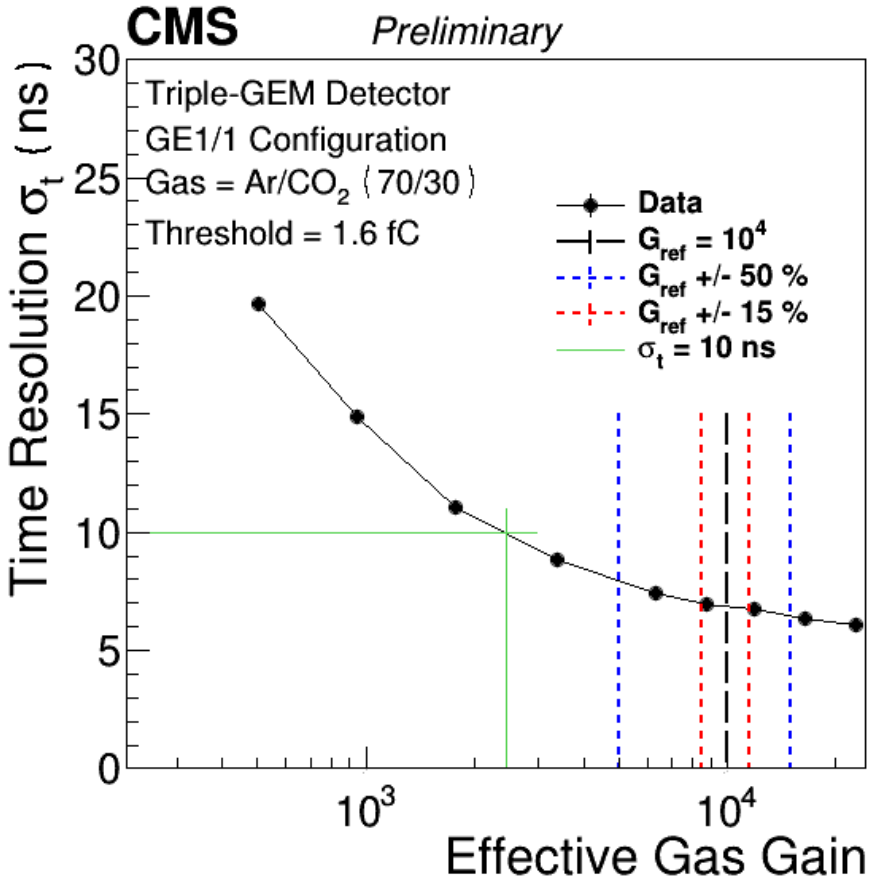


The QC5 Gain uniformity stand schema.

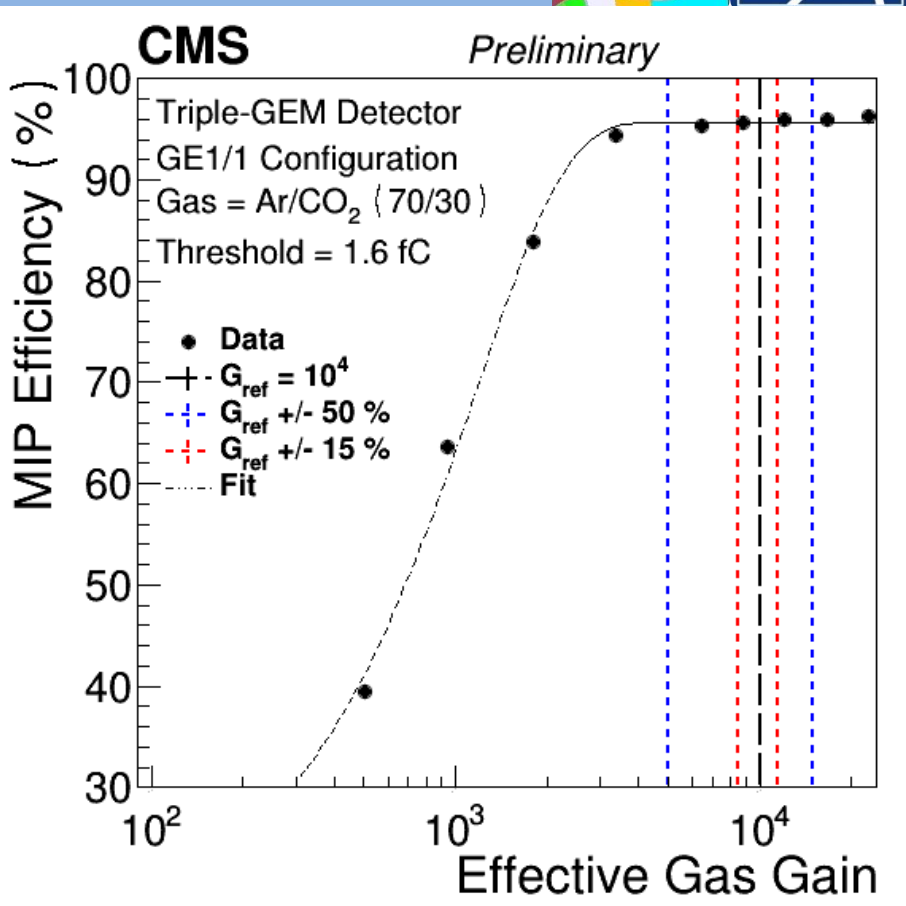


Effective gas gain of the short GE1/1 chambers for a HV divider current equal to 660uA. The error bars represent the standard deviation of the gain distribution for the entire detector plane.

3.6) GE1/1 chamber operation par.



Time resolution of the GE1/1 gap configuration detector vs. The effective gas gain. The black dashed line represents the nominal time resolution at which GE1/1 detectors are foreseen to operate, while red and blue dashed lines represent the time resolutions for the detector operating at +/- 15% and +/-50% of the nominal gain.



Efficiency of the GE1/1 gap configuration detector vs. The effective gas gain. The black dashed line represents the nominal gain at which GE1/1 detectors are foreseen to operate, while red and blue dashed lines represent the extendednominal gain regions of +/- 15% and +/-50 % respectively.

3.7) Superchamber quality checks

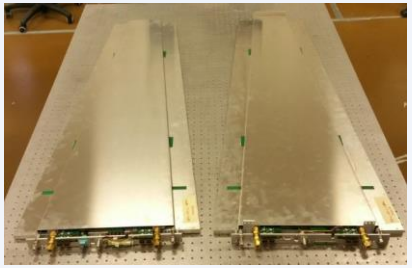
Post Superchamber assembly quality checks, performed at CERN exclusively

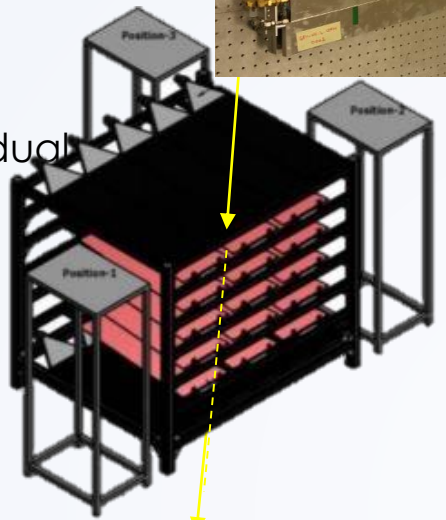
6)SC HV stability

7)Final electronics connectivity

8)Time resolution and efficiency

- After equpping the single GE1/1 detector with SuperChamber support structures, preparation for Multi Channel power supply system and further HV stability check take place.
- Chamber is being equipped with the final electronics and undergoes the connectivity tests.
- Fully assembled SCs, in the state that is foreseen to be mounted in the CMS, undergoes last series of test in the comic stand, composed of two scintillator layers, providing the signal for trigger processing. Muons passing through the stand allow to measure two quantities:
  - The chamber detection efficiency,
  - The time resolution of each individual chamber.





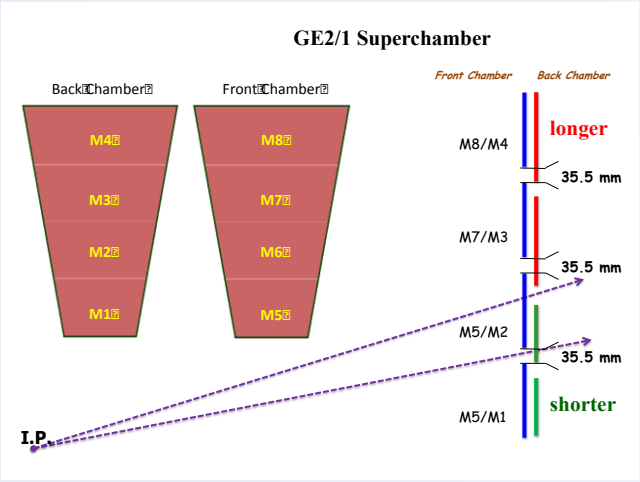
The integral intensity of the vertical muons on the sea level is measrured to be: 1muon/cm^2/min

[1] J.J. Beatty, J. Matthews, S.P. Wakery „Cosmic Rays" [link]

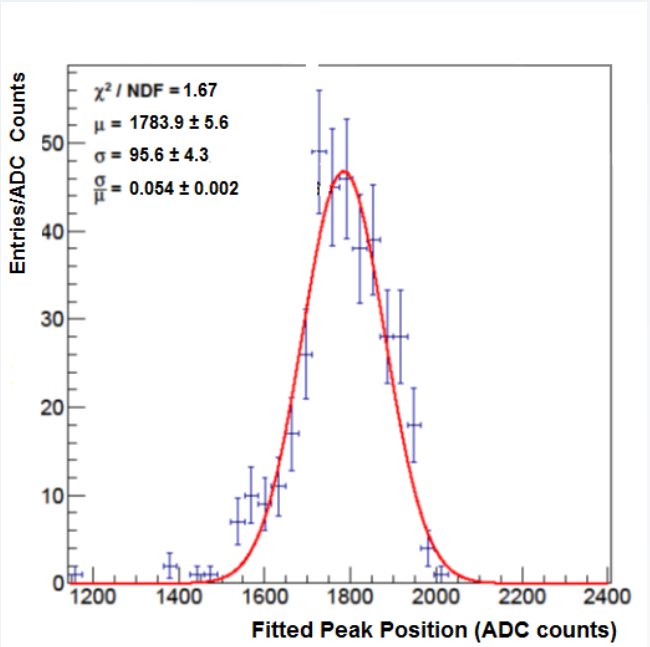
4)GE2/1 project

- The second of „Phase2" CMS upgrade project, based on the triple GEM technology.
- 20° angle coverage units (72 units).
- 1.6<|η|<2.4 coverage.
- 2 layers of chambers made by 8 different modules to maximize the coverage.
- The full chamber segmentation into smaller modules is necessary due to the GEM foil production limitations.
- First endcap is foreseen to be equipped with new GE2/1 detectors by 03/2022, second by 02/2023.

- The biggest module (M4) of GE2/1 detector was succesfully assembled and fully validated.
- GE2/1 project benefits from the same technology as the GE1/1, thus undergoes the same qualification process, using the same stands.



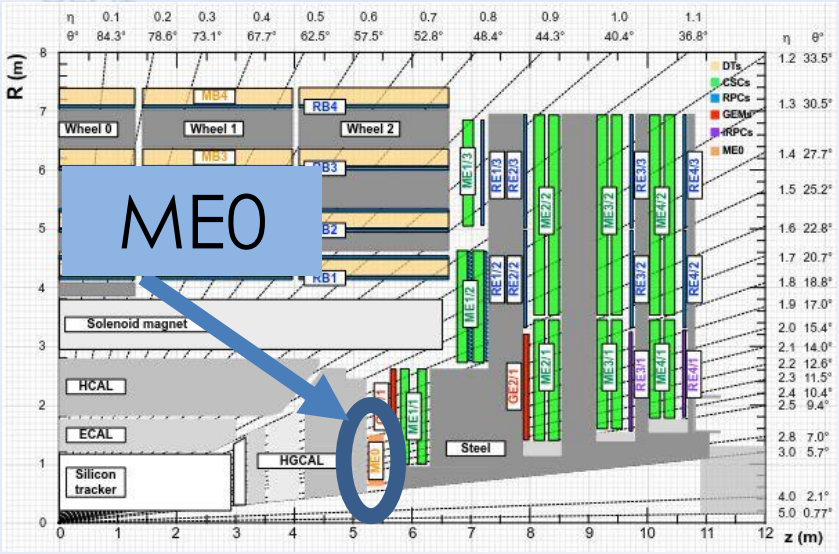
The GE2/1 segmentation scheme.

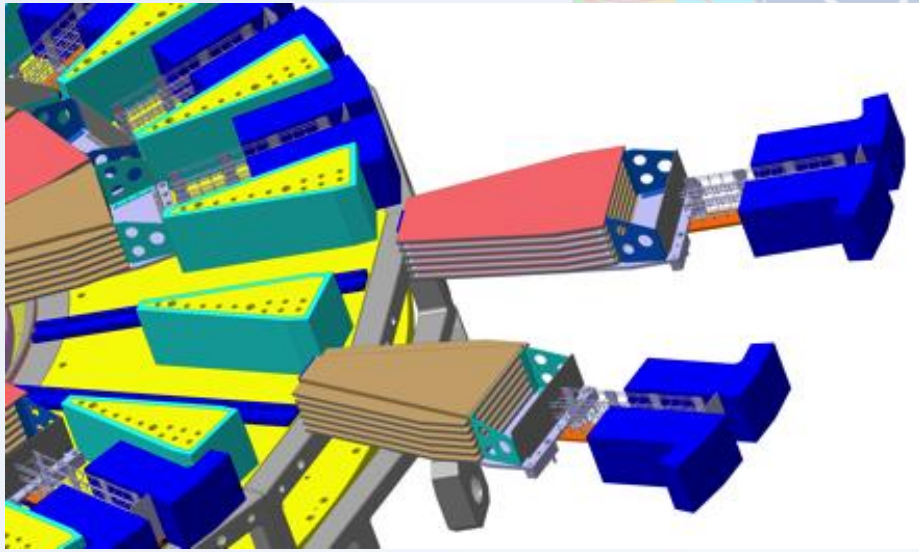


QC5 gain uniformity plot of GE2/1-M4detector. To measure the uniformity, the standard QC5 methodology established for GE1/1 production is followed.

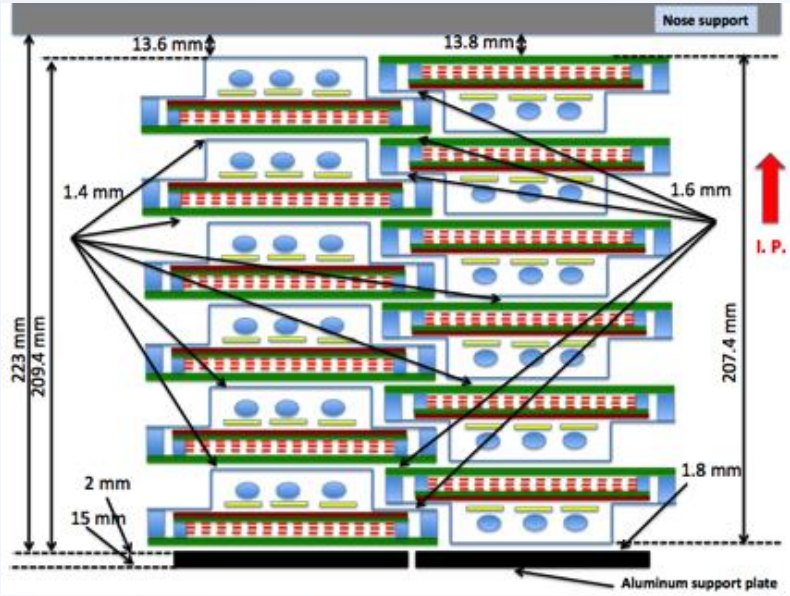
The GE2/1 M4 detector installed in the copper box, used for GE1/1 gain uniformity validation.

3) ME0 project





- The stack consists of six, the same chambers, covering 20° angle,
- 2.0< | η | <2.8 coverage,
- ME0 detector is a standalone system, thus needs much redundancy (6 modules),
- To cope with much higher event background rate w.r.t the GE1/1 or GE2/1 more detectors are needed,
- Installation is scheduled for 2023/2024



Summary

- GE1/1 negative endcap detectors production and validation is finished.
- Superchamber assembly and postassembly QCs are about to be launched.
- Positive endcap chamber production and validation is ongoing.

- GE2/1 chamber prototype fully operational foreseen to be built & validated by the end of the current year!
- First prototype of largest module foreseen for the GE2/1 chamber (M4) assembled & tested: results are as good as the corresponding ones for GE1/1.

- ME0 preliminary layout and R&D studies completed!

Thank you for your attention.

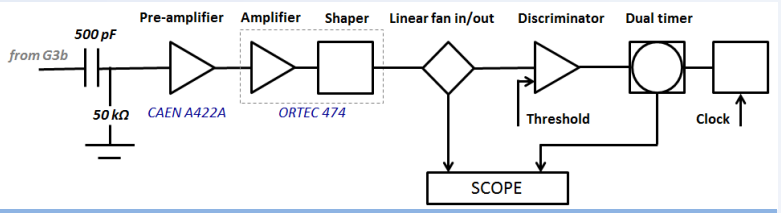
In case of any questions please do not hesitate to contact me.

Contact: marek.gruchala@cern.ch

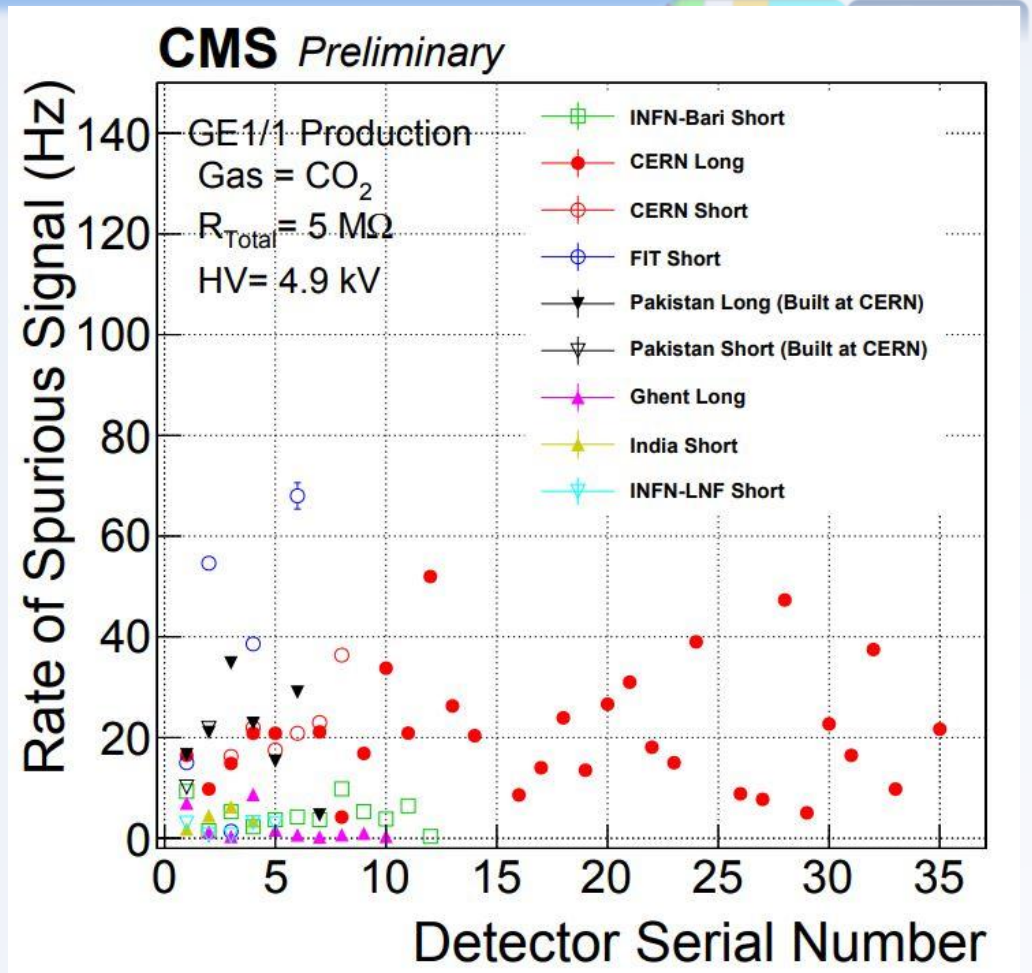
BACKUP

3.4) Intrinsic noise measurement

- During the HV stability test also the intrinsic chamber noise, for each HV point is being measured.
- Measured rate of of the intrinsic detector noise level is far below 100Hz over whole electrode surface, resulting in ~ 10^{-2} Hz/cm^2 (detector surface ~ 300 cm^2).
- CMS background rate in order of 1 **k**Hz/cm^2.
- **Negligible value of the chamber nosie w.r.t the CMS nosie present in the GE1/1 endcap region.**



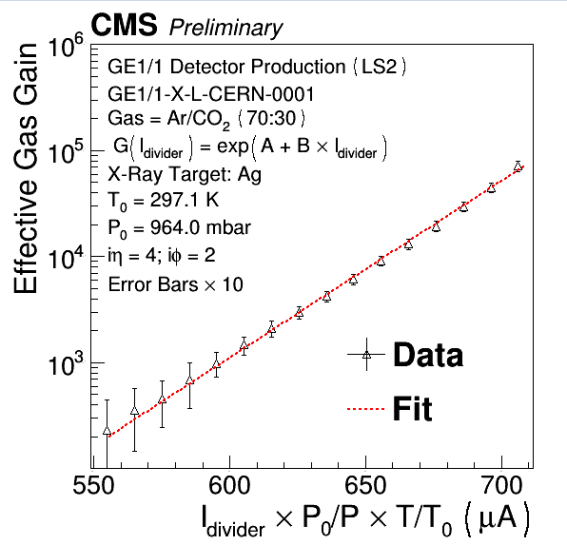
The QC4/HV stand



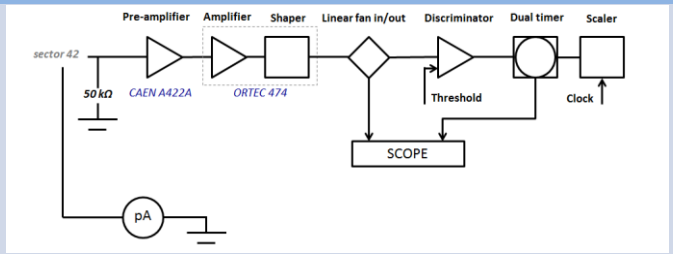
The rate of the spurious signal measured for the detectors assembled in specified sites in Hz vs. the serial number of the chamber. Here the intrinsic noise rate is being measured over whole surface of the GEM3 bottom electrode.

3.5) Gain calibration & uniformity

GAIN CALIBRATION

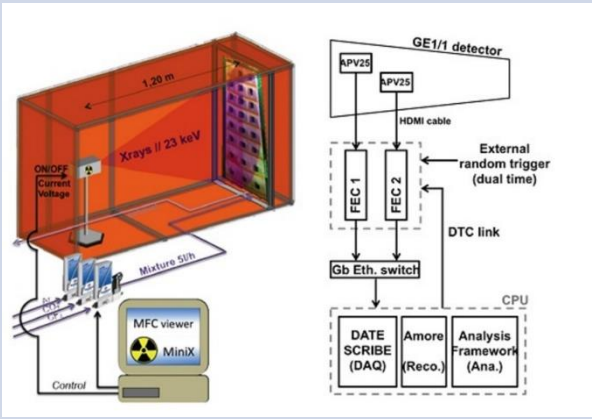


Typical effective gain curve obtained during the GE1/1 quality control. $I_{divider}$ is the current flowing through the HV resistive divider that provide potential to the detector electrodes.



The QC5 Gain calibration stand schema.

GAIN UNIFORMITY



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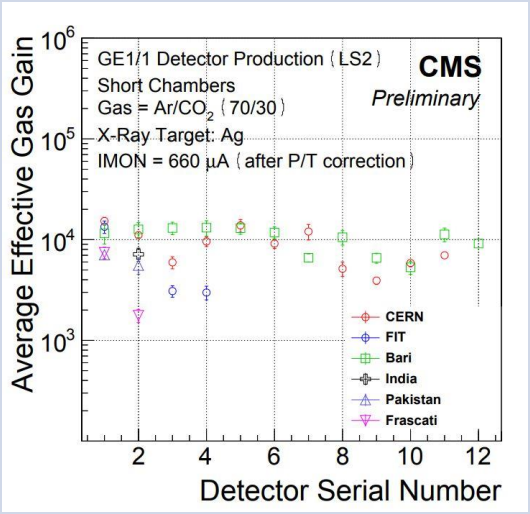
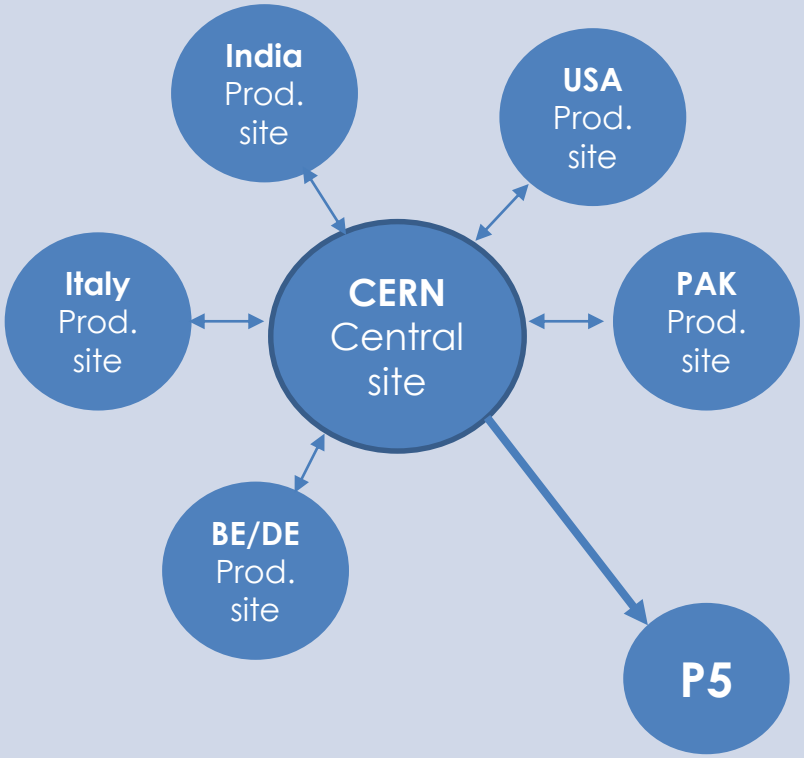


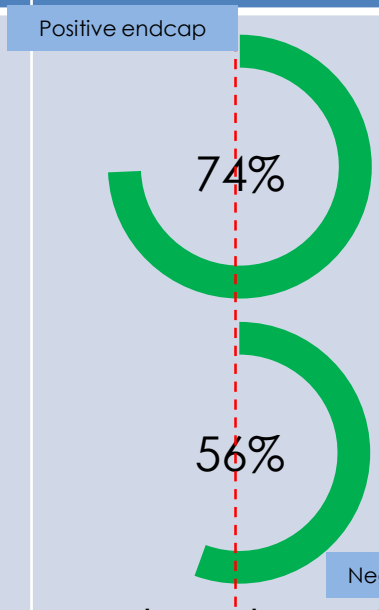
Effective gas gain of the short GE1/1 chambers for a HV divider current equal to 660uA. The error bars represent the standard deviation of the gain distribution for the entire detector plane.

3.8) Site model & achievements

DISTRIBUTED PRODUCTION MODEL



PRODUCTION SUMMARY

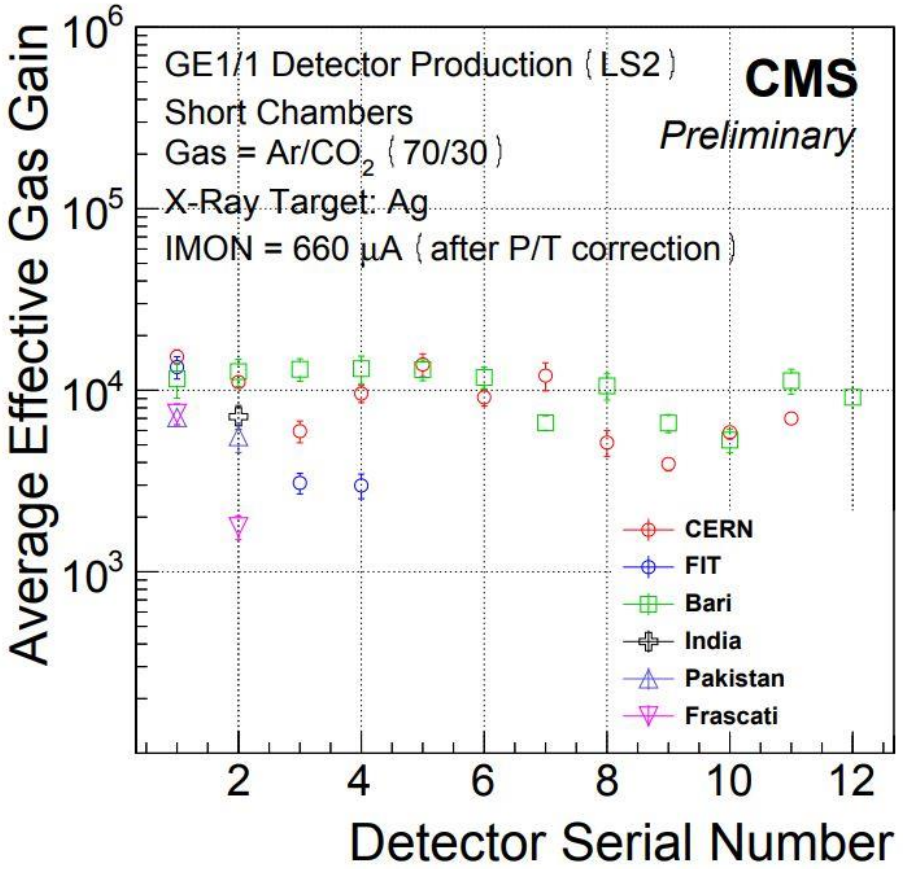


Total chamber assembly progress.

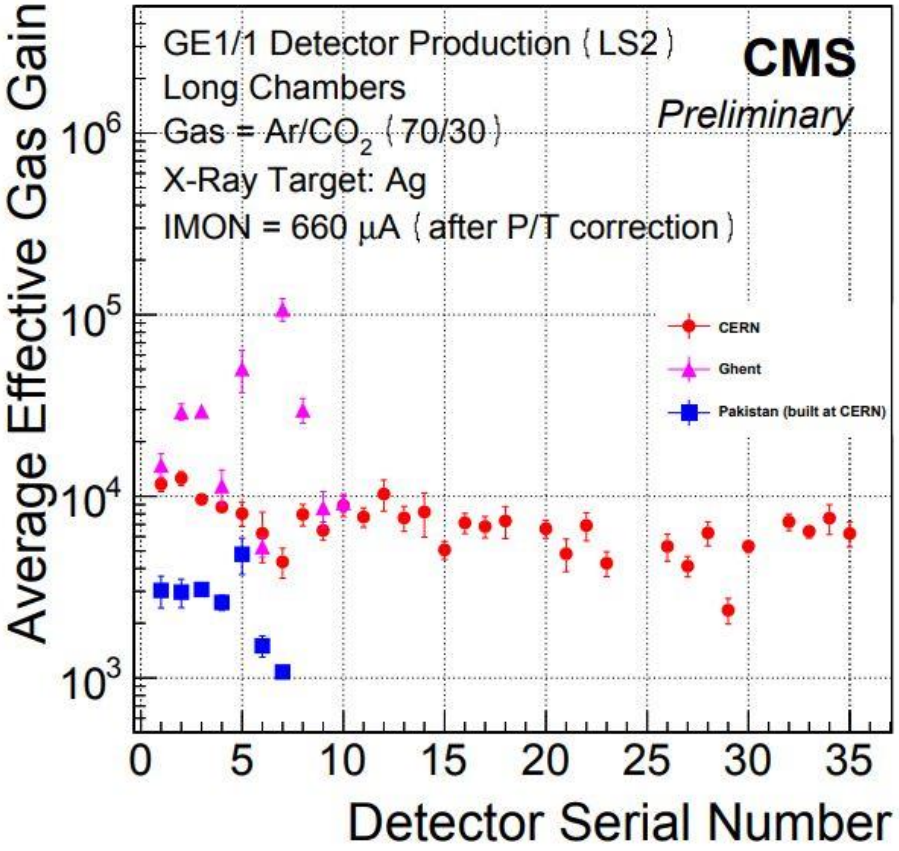
Chamber validation progress.

- chambers for the completition of the superchamber for the first endcap (36SC) are ready & qualified.
- Installation of the first endcap expected by the 07/2019.
- Production for the second endcap is ongoing.

3.5) Gain calibration & uniformity



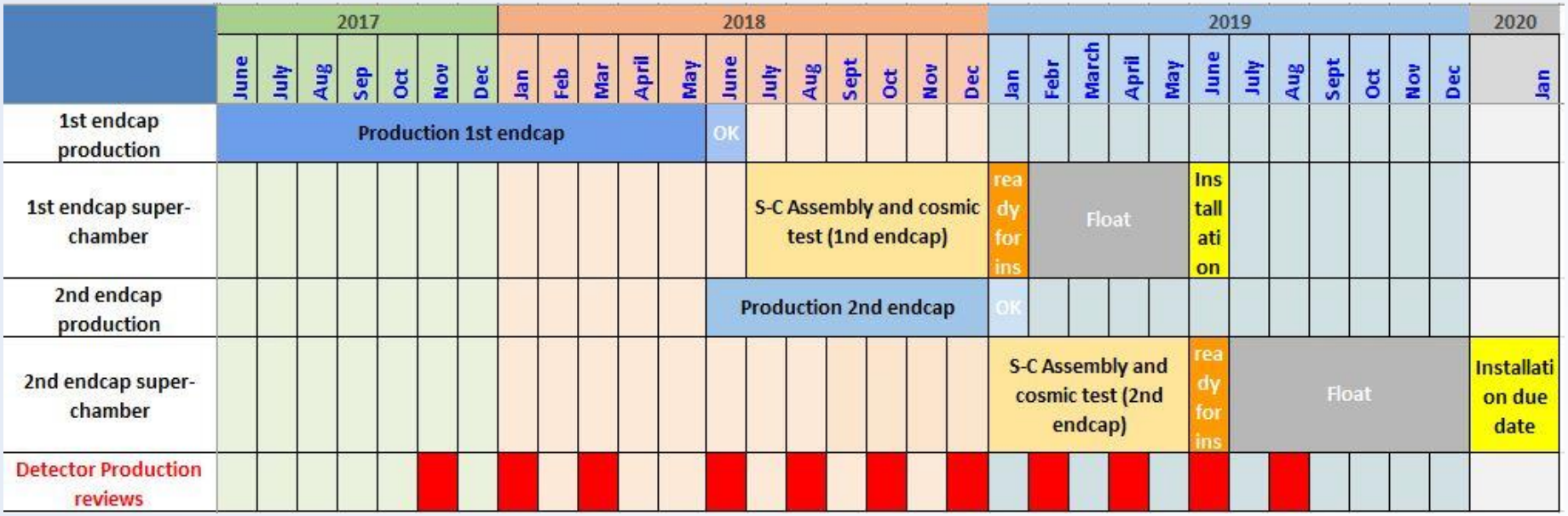
Effective gas gain of the short GE1/1 chambers for a HV divider current equal to 660uA. The error bars represent the standard deviation of the gain distribution for the entire detector plane.



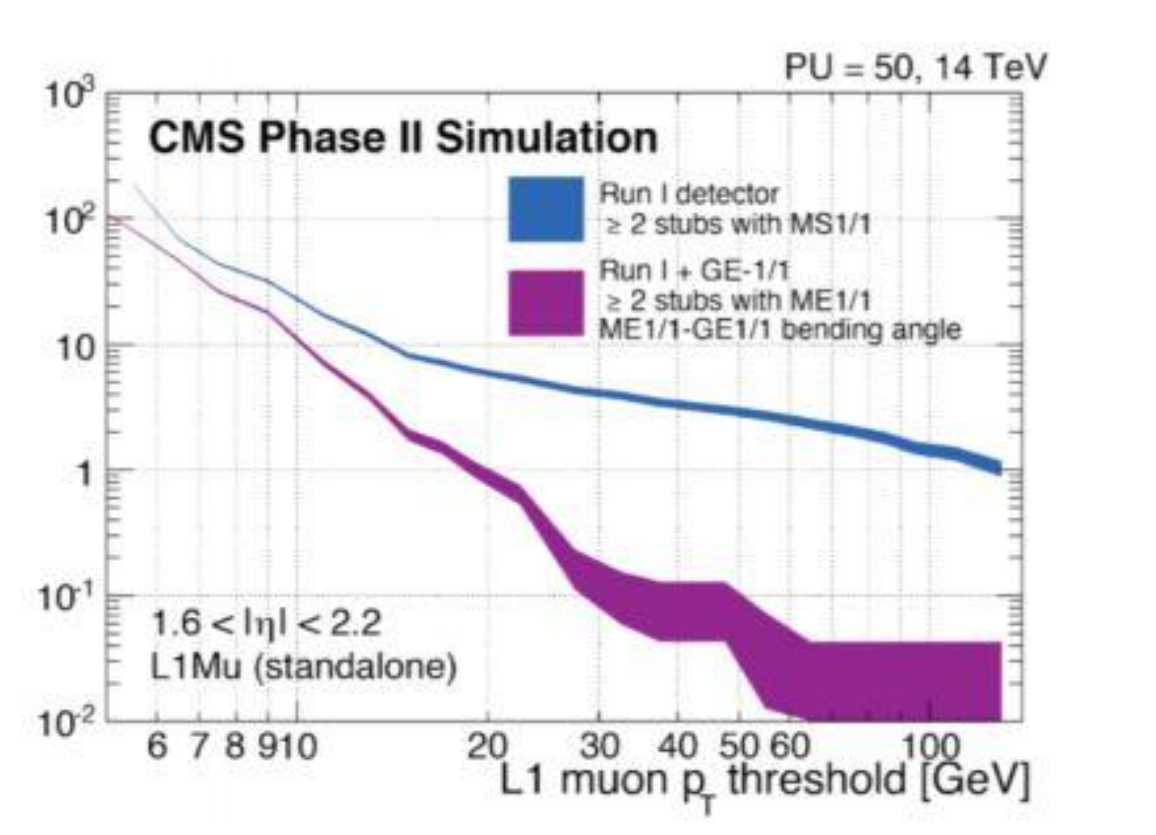
Effective gas gain of the long GE1/1 chambers for a HV divider current equal to 660uA. The error bars represent the standard deviation of the gain distribution for the entire detector plane.

3.9) GE1/1 production schedule

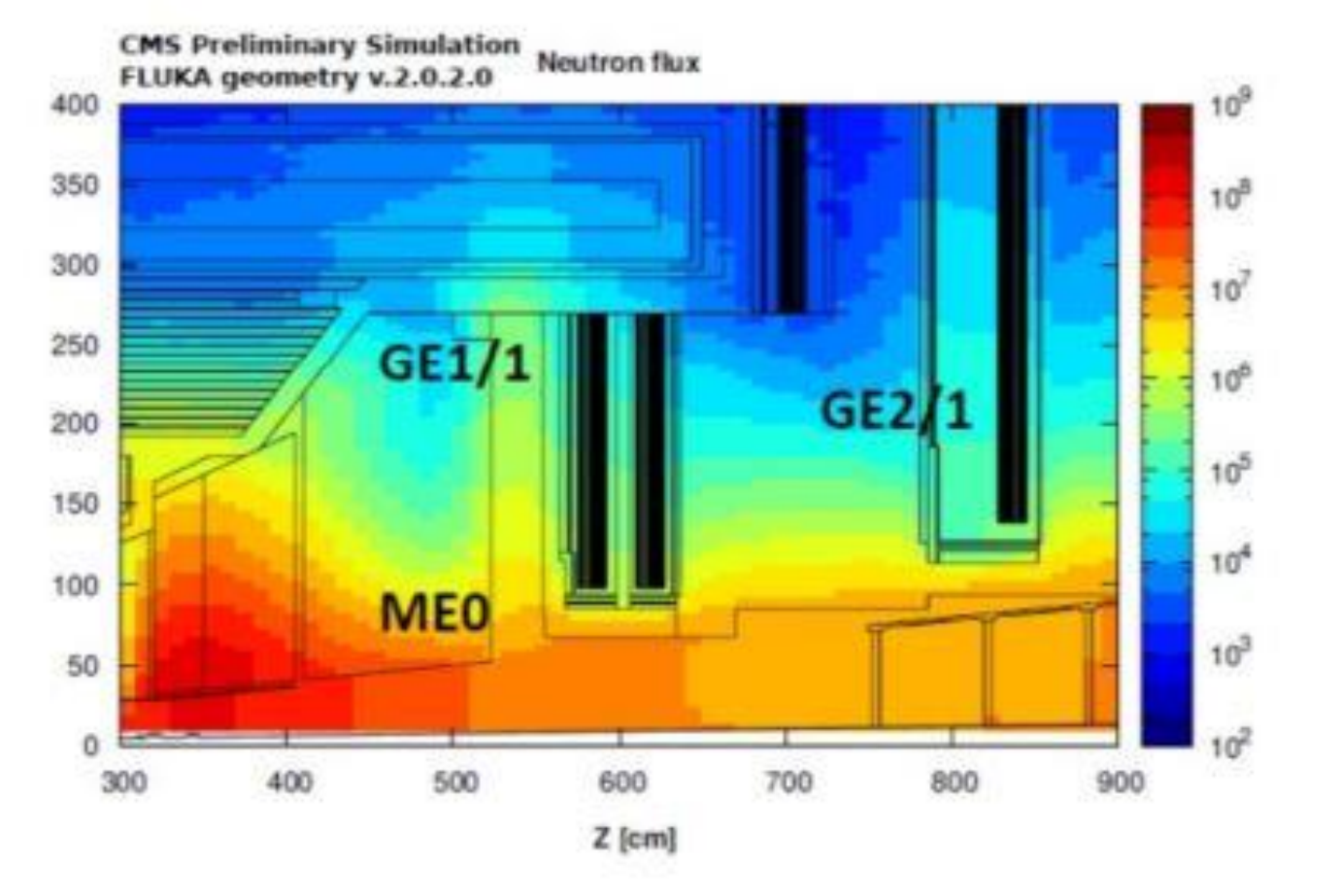
- Installation of the forst endcap is foreseen to take place in the mod 2019.
- Second encap is going to be equipped with the GE1/1 detectors on the beginning of 2020.



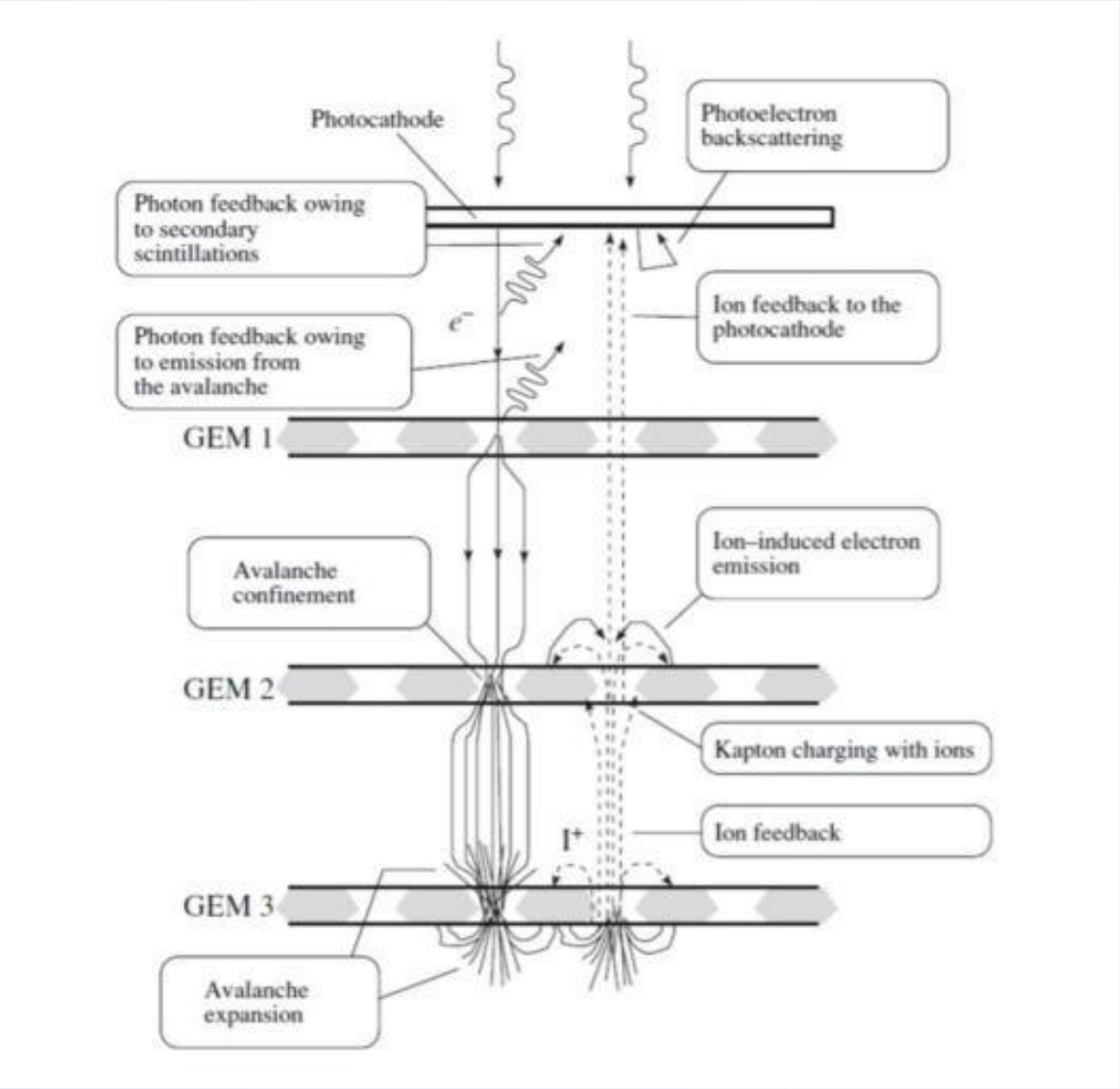
BACKUP


PU = 50, 14 TeV
CMS Phase II Simulation
Run I detector
≥ 2 stubs with MS1/1
Run I + GE-1/1
≥ 2 stubs with ME1/1
ME1/1-GE1/1 bending angle
1.6 < |η| < 2.2
L1Mu (standalone)
10^3
10^2
10
1
10^-1
10^-2
6 7 8 9 10
20
30
40
50 60
100
L1 muon p_T threshold [GeV]

BACKUP


CMS Preliminary Simulation
FLUKA geometry v.2.0.2.0
Neutron flux
GE1/1
GE2/1
ME0
400
350
300
250
200
150
100
50
0
300
400
500
600
700
800
900
Z [cm]
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2

BACKUP


Photocathode
Photoelectron backscattering
Photon feedback owing to secondary scintillations
Ion feedback to the photocathode
e^-
Photon feedback owing to emission from the avalanche
GEM 1
Avalanche confinement
Ion–induced electron emission
GEM 2
Kapton charging with ions
I^+
Ion feedback
GEM 3
Avalanche expansion