OPERATIONAL EXPERIENCE WITH THE GEM DETECTOR ASSEMBLY LINES FOR THE CMS FORWARD MUON UPGRADE

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on behalf of the CMS Muon Group

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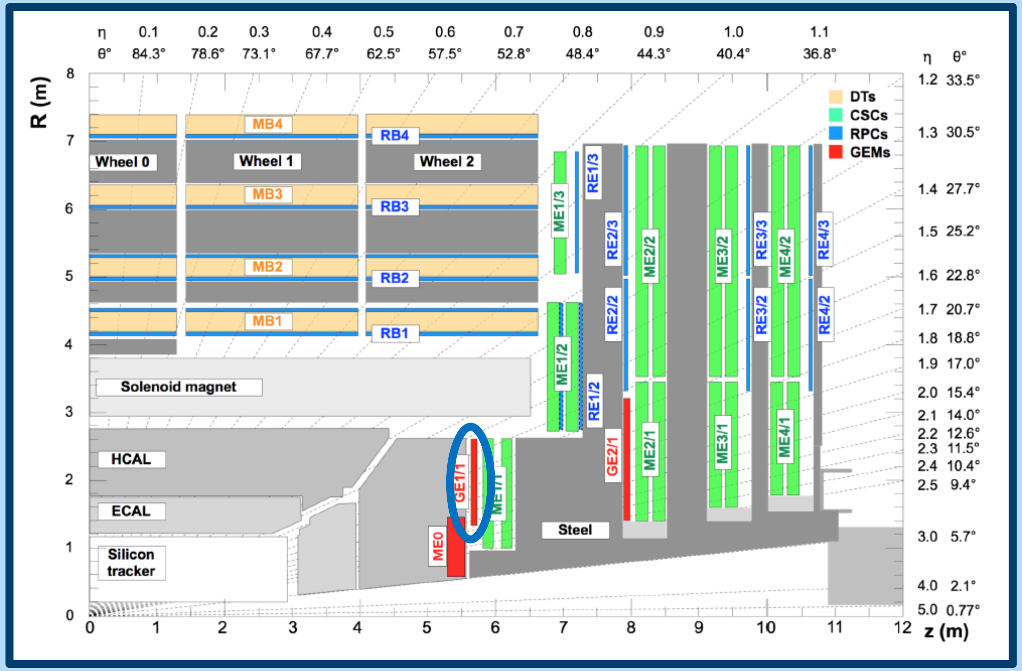
Outline

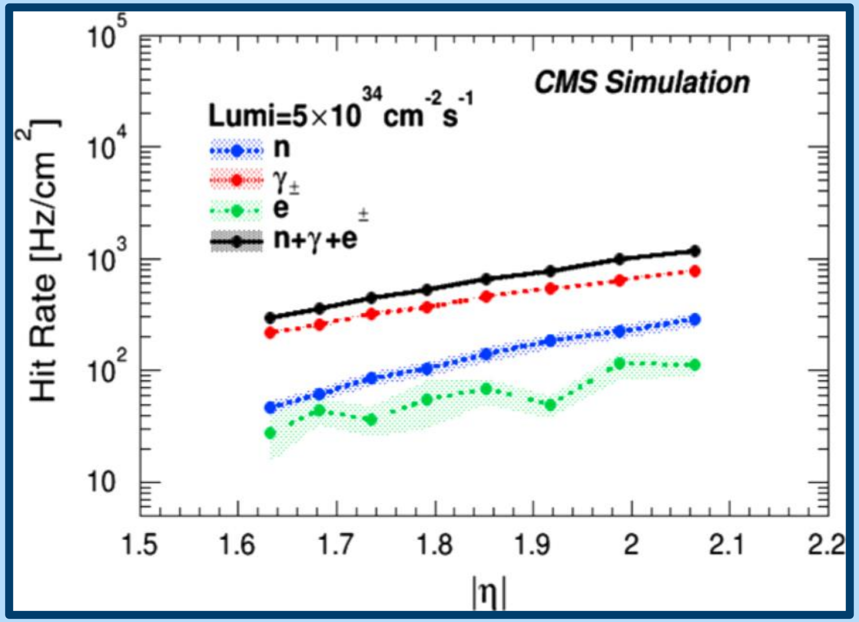
- Motivations
- GEM Technology
- The GE1/1 station
- The GE1/1 slice test
  - *Operational conditions of the system*
  - *Inclusion in the CMS operation*
- The GE1/1 mass production
  - *Quality controls*
  - *Preparation of the assembly sites*
- Summary and timeline of the GE1/1 project

Motivations – The CMS Muon System



LHC luminosity increase up to 5 x 10^{34} $cm^{-2}s^{-1}$ →

- Background rate in the $1.6 < |\eta| < 2.2$ region up to $\sim 1000\ Hz/cm^2$
- With the Run1 muon system configuration it would not be possible to achieve an acceptable L1 trigger rate for muons with $p_T < 25\ GeV$ without increasing the threshold on muon p_T.



Run1 muon system configuration includes 3 technologies:

- Drift Tubes (DTs) and Cathode Strip Chambers (CSCs) → precision position measurements and trigger
- Resistive Plate Chambers (RPCs) → redundant trigger and coarse position measurement

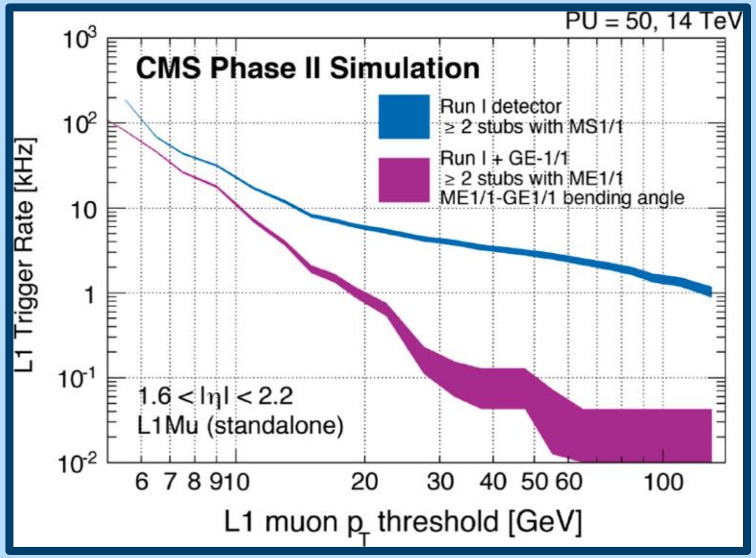
→Installation of triple GEM detectors in the region 1.6<|η|<2.2 scheduled in 2019-2020

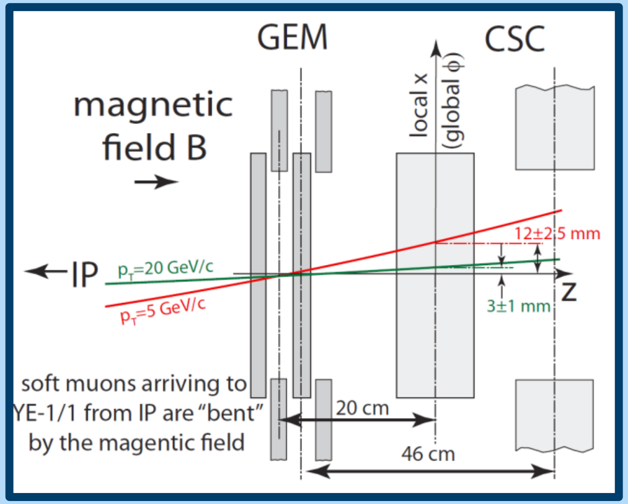
Motivations - The GE1/1 station

GE1/1 will allow to keep <5 kHz trigger rate without increasing threshold on muon's momentum

GE1/1:

- will add redundancy in the $1.6<|\eta|<2.2$ region.
- Will work in combination with CSCs, allowing the measurement of the muon bending angle in magnetic field

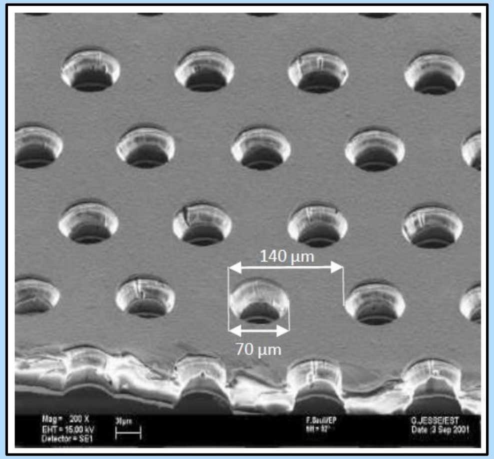




__Top:__ Level-1 muon trigger rates before and after the GE1/1 upgrade at a luminosity of 2×10^{34} $cm^{-2}s^{-1}$, for constant efficiency of 94%.

__Bottom:__ Measurement of the bending angle from CSC and GEM combined.

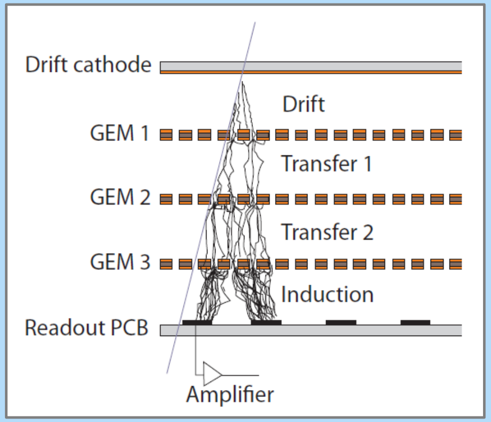
GEM Technology



The GE1/1 station will be instrumented with Triple-GEM detectors →

- A GEM (Gas Electron Multiplier) foil is a 50 μm thick polymer foil coated with 5 μm copper on each side
- Regular (triangular) pattern of holes
- Biconical holes with maximum diameter of 70 μm, interspace 140 μm

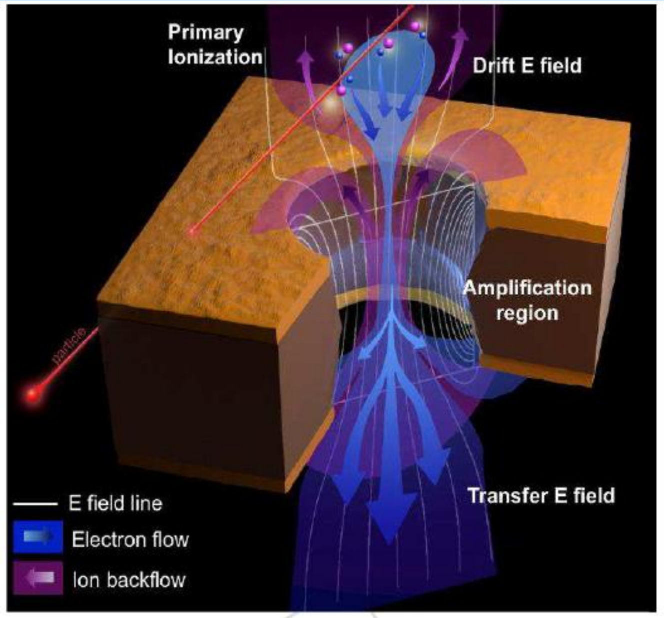
→ Triple-GEM = stack of three GEM foils



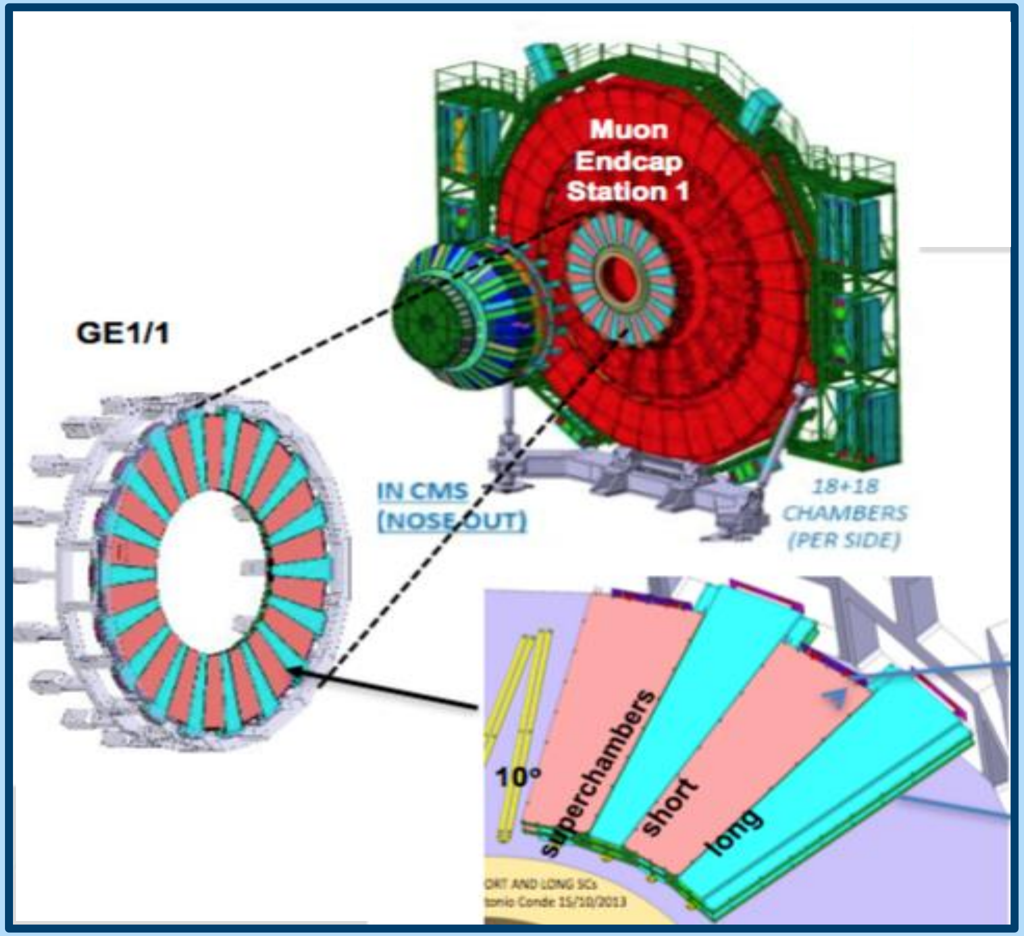
Clear separation of drift and amplification regions:

- Avalanche multiplication of electrons localized inside the holes

→ *Improved Rate Capability (up to 100 MHz/cm^2) and Space resolution (~100s of μm)*



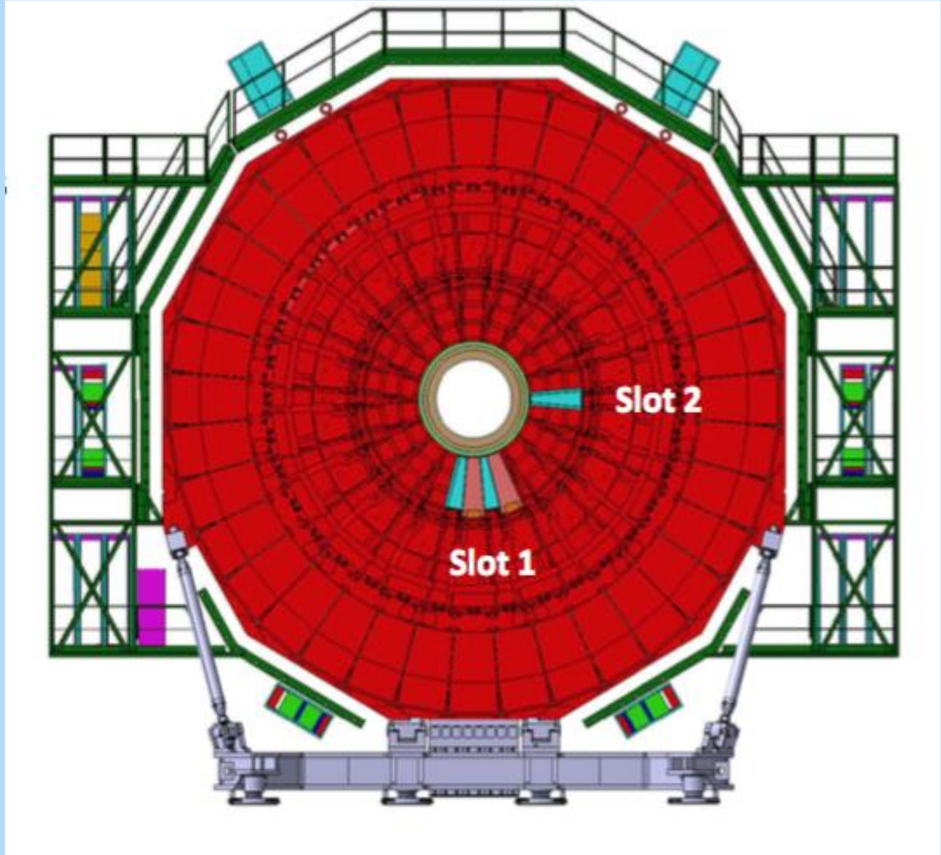
The GE1/1 station



The GE1/1 station will be installed in the first muon endcap station:

- It will be composed of 36 superchambers (GEMINI) per endcap
- Each GEMINI spans 10°
- GEMINI long and short versions alternate to maximize η coverage
- Each GEMINI is composed of 2 Triple-GEM detectors, for a total 144 chambers for the whole system

The GE1/1 slice test



The GE1/1 slice test detectors were installed in one of the CMS endcaps in January 2017.

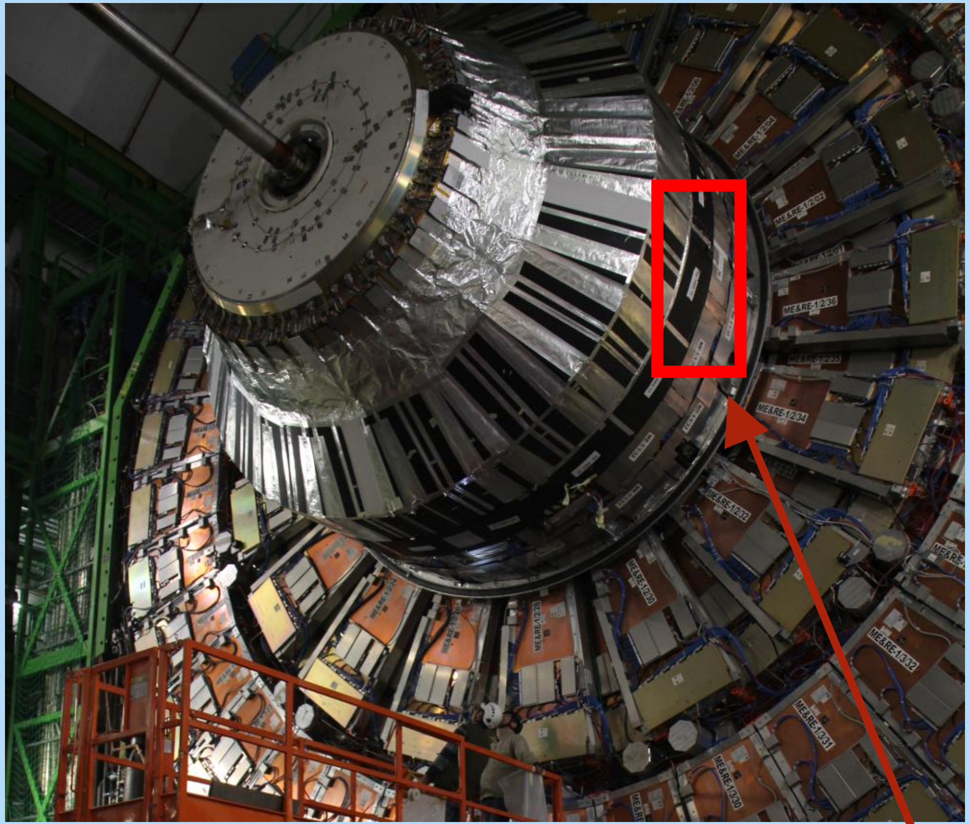
5 GEMINIs, for a total of 10 Triple-GEM detectors were installed, to:

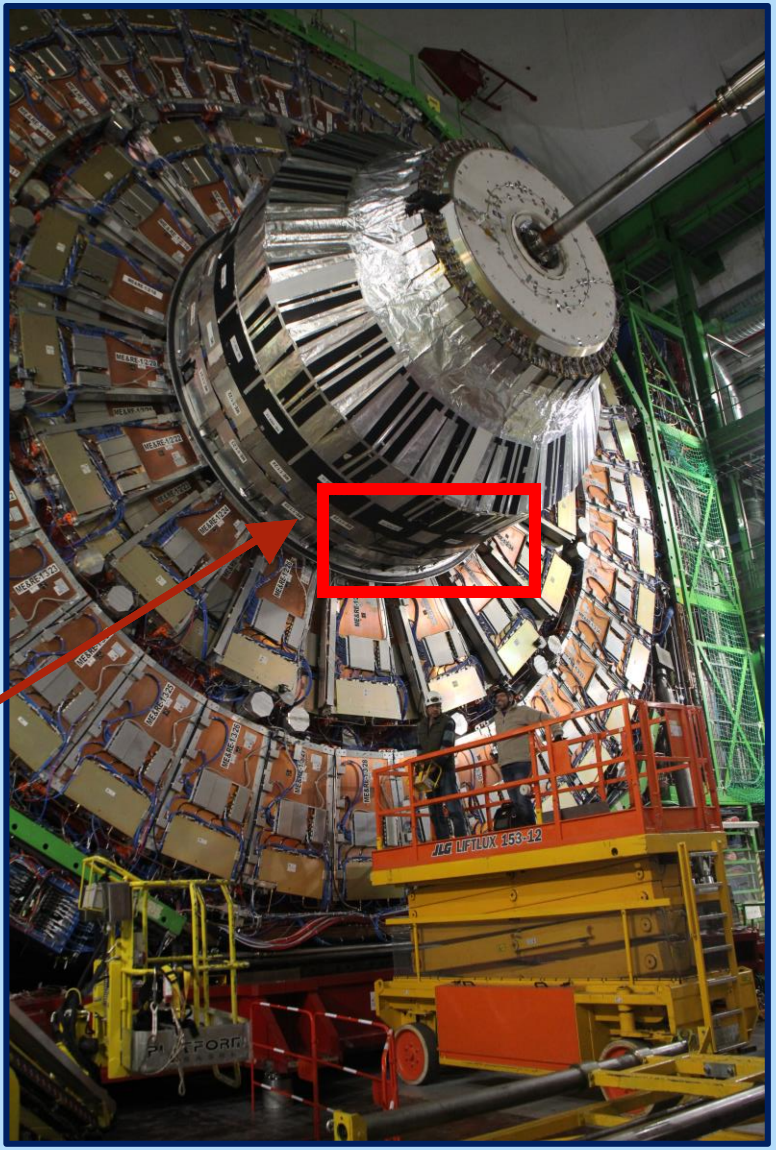
- Acquire installation and commissioning expertise
- Prove the system's operational conditions
- Demonstrate the integration into the CMS online system

System configuration:

- 4 GEMINI powered through a ceramic HV divider
- 1 GEMINI powered with multichannel power supply (7 HV channels per chamber)
- Readout system based on VFAT2 chip and optohybrid (OHv2b) → 3 LV channels for each chamber
- 3 Ar/CO2 70:30 gas lines

Pictures from the installation

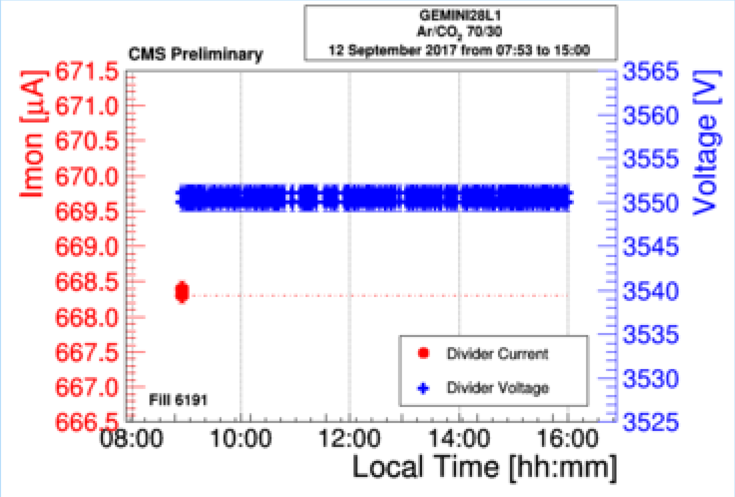




Triple-GEM detectors
installed in this region

GE1/1 slice test – operational conditions of the system

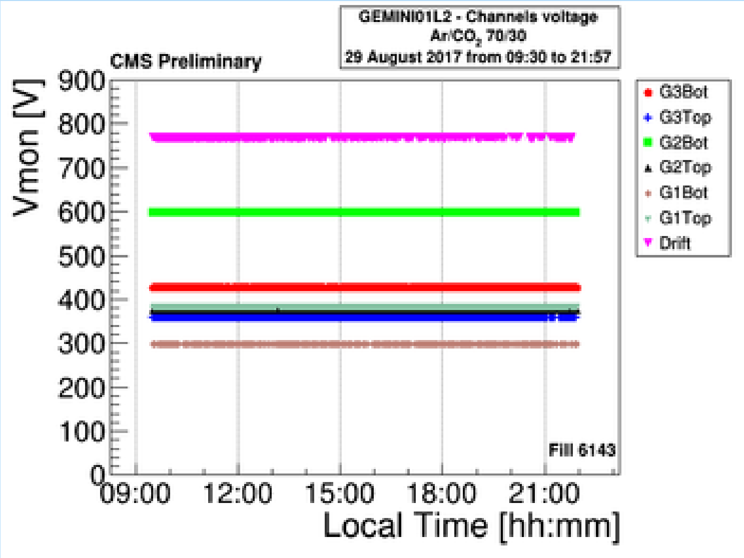
- For the HV systems (both single channel power supply and multichannel) an **overall stability of the order of 1 % or less** has been observed with and without collisions



Left: *overall stability within 10^{-3} observed in a 7 hours period during collisions with the single channel HV system*

- Similar results have been observed for the LV system

Right: *stability within 10^{-3}, observed in a 12 hours period during collisions with the multichannel HV system*

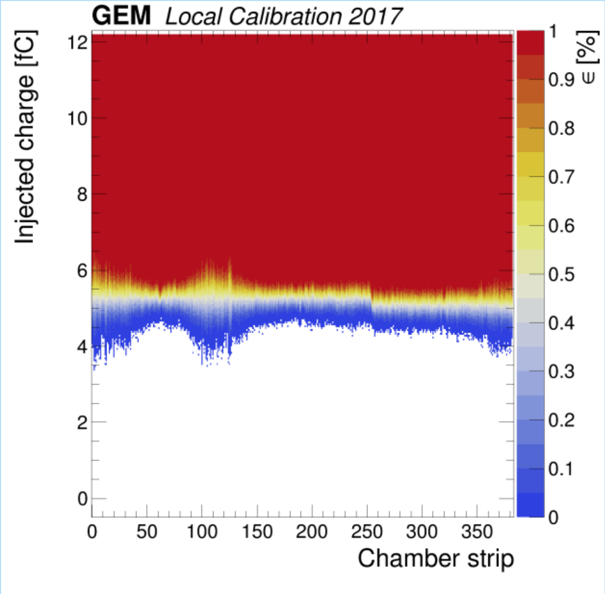


GE1/1 slice test – local calibration of the system

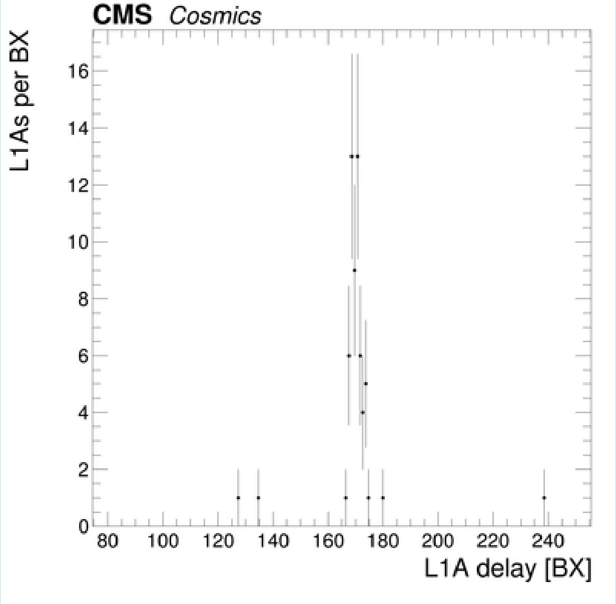
The local calibration of the system foresees mainly 3 steps:

- **Threshold scans** → noise of the channels as function of applied threshold.
- **S-curves** → response of the channels to an injected pulse calibrated to a given charge at a given threshold.
- **Latency* scans** → ratio of events with detected hits over the total number of events, per different latency values.

*The latency is the time difference between the time of arrival of a L1Accept (L1A) and the time at which the related event was stored.



Left: *result of an S-curve performed with one VFAT installed on one slice test chamber*



Right: *Delay between seen S-bit and received L1A for cosmic ray muon data*

GE1/1 slice test – integration in CMS

DAQ integration

- Function manager and MiniDAQ operational
- Preparing the setup for the high rate test

DCS* integration

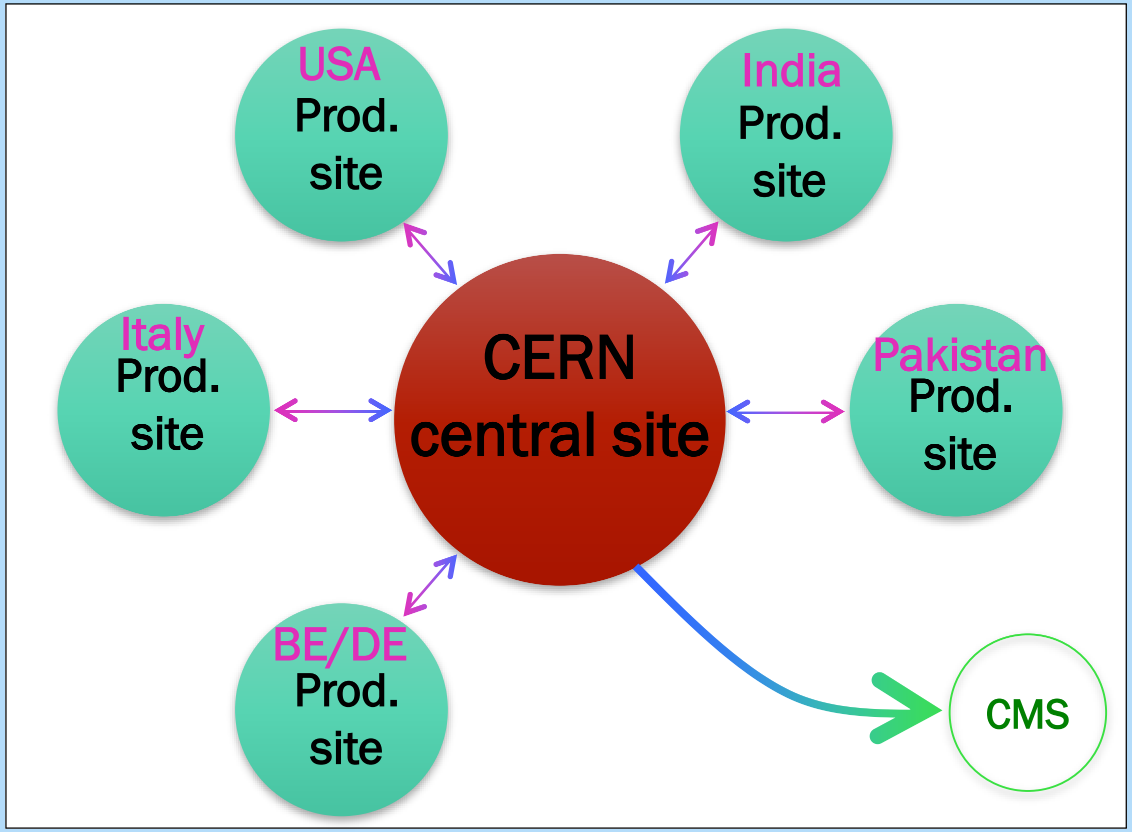
- Local version of the system completely operational
- Protection system, aimed at moving the system in a safe state during injection and magnet ramping, programmed → tests ongoing
- Integration in the automation system under test

*DCS = Detector Control System

The GE1/1 mass production

The mass production for the full GE1/1 station will be shared between CERN and many production sites around the world:

- Share the effort with other institutes, members of the CMS GEM collaboration
- Generate a large community of CMS GEM detector experts over the world

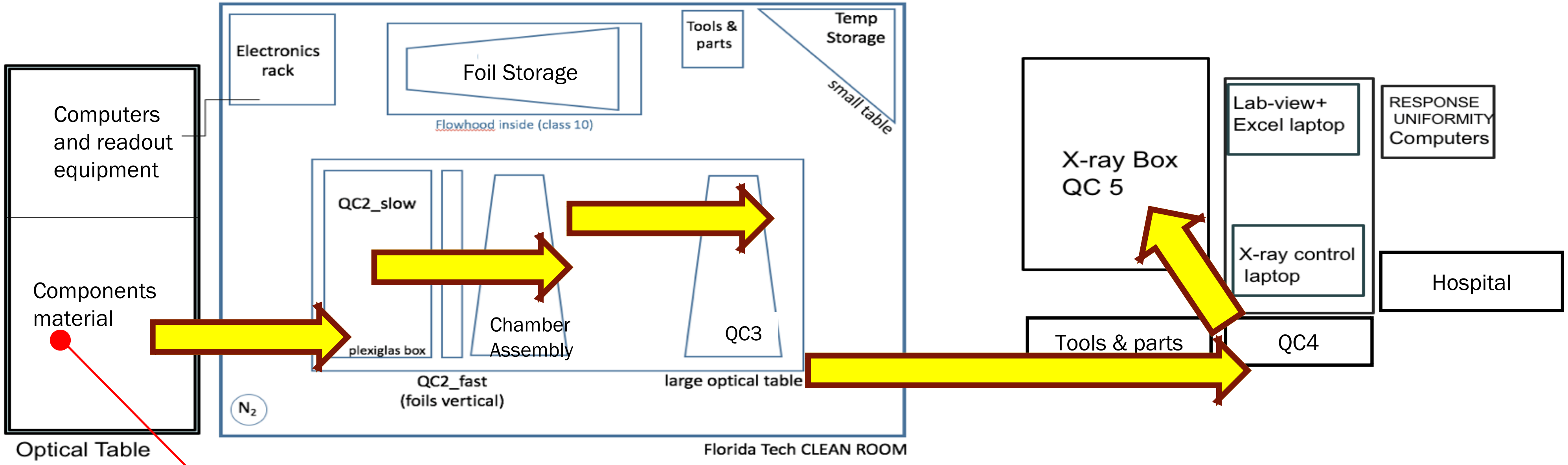


GE1/1 quality controls

The production and quality control activities are shared between CERN and the external sites

Site	QC	Description
CERN	QC1	Reception of the components: optical inspection (mostly)
CERN / Production sites	QC2	GEM foils: leakage current/spark test (short and long term stability)
Production sites	QC3	GE1/1 chamber: gas leak test (pressure drop)
Production sites	QC4	GE1/1 chamber: HV test (IV curve and spurious signal rate measurement)
Production sites	QC5	GE1/1 chamber: gain calibration (absolute value and uniformity)
CERN	QC6	GE1/1 chamber: HV stability test (after mounting the final HV connector)
CERN	QC7	GE1/1 chamber: connectivity test (after mounting the final electronics)
CERN	QC8	GE1/1 super-chamber: cosmic test (P5-like system)

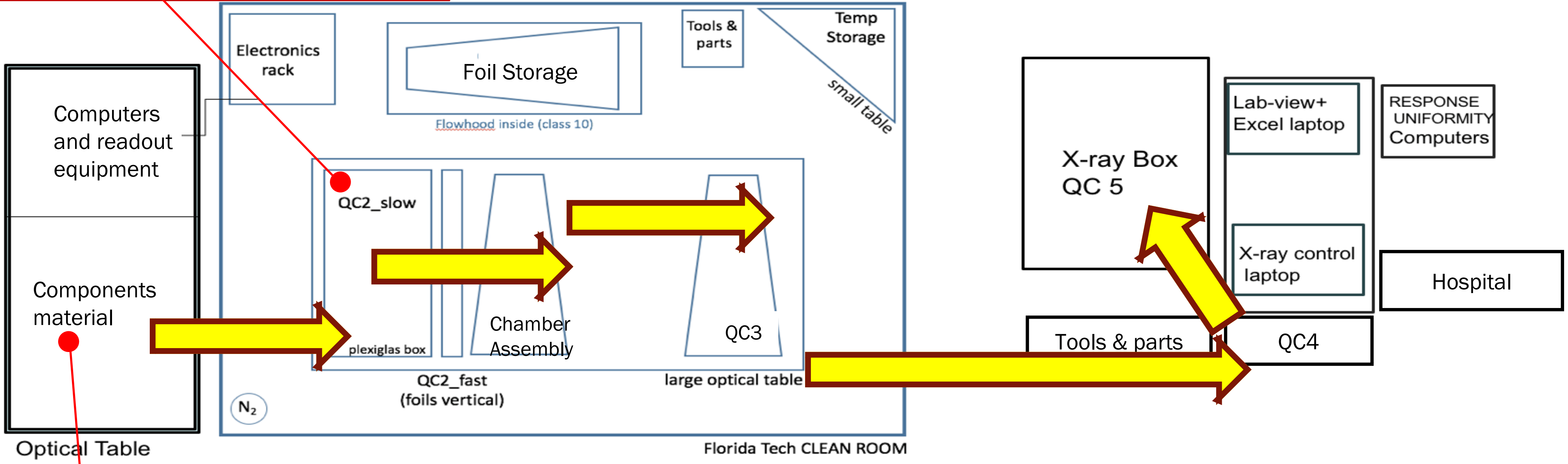
Assembly sites organization



Detector components are centrally managed by CERN. Shipment box are sent by CERN to assembly sites.

Assembly sites organization

QC2: Determine the quality of a GEM foil by measuring the leakage current flowing across the GEM foil.



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Assembly sites organization

GEM foils and detector component assembly. Chamber construction is taking place simultaneously at all assembly sites with identical procedures, tools, and specifications.

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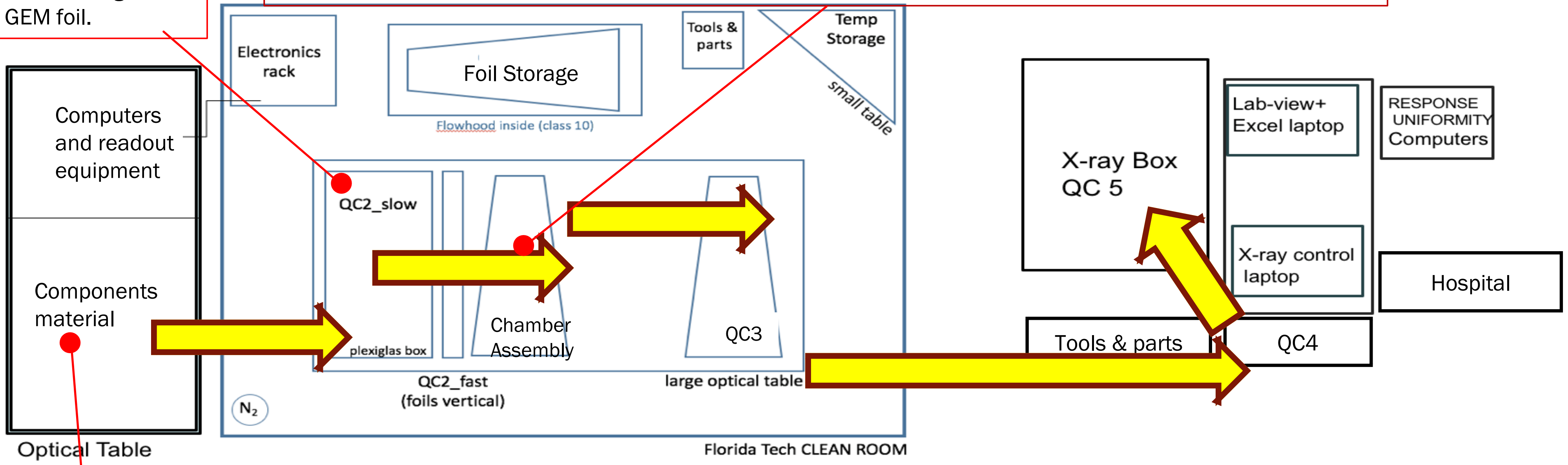

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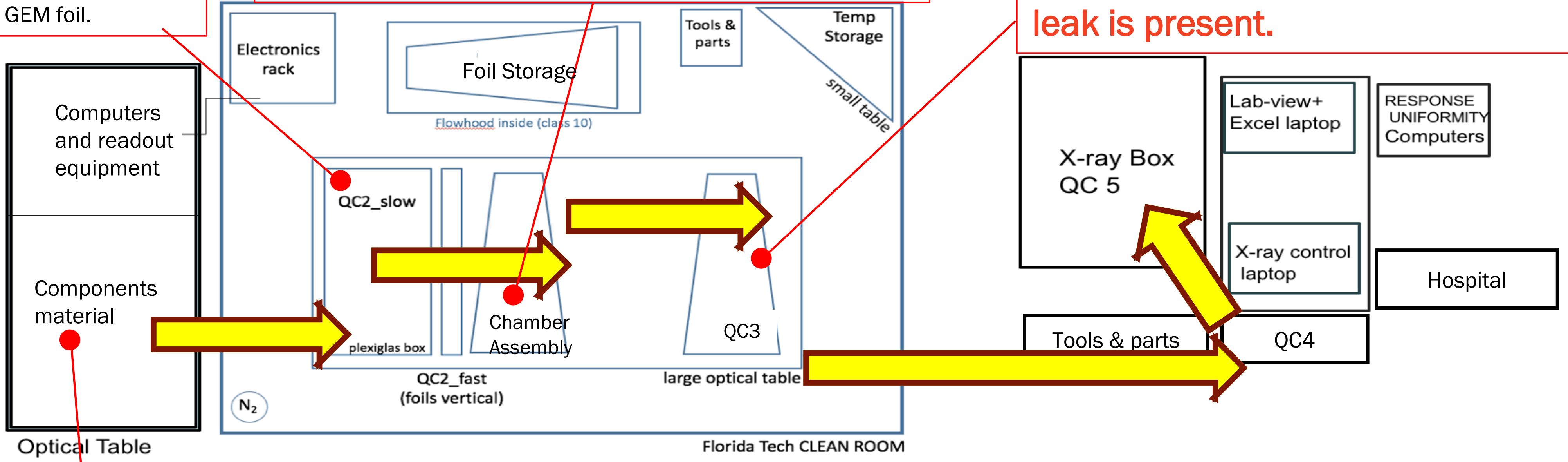
QC3: The pressure drop of every detector (pressurized up to 25mbar) is monitored for 2h and recorded to evaluate if any gas leak is present.



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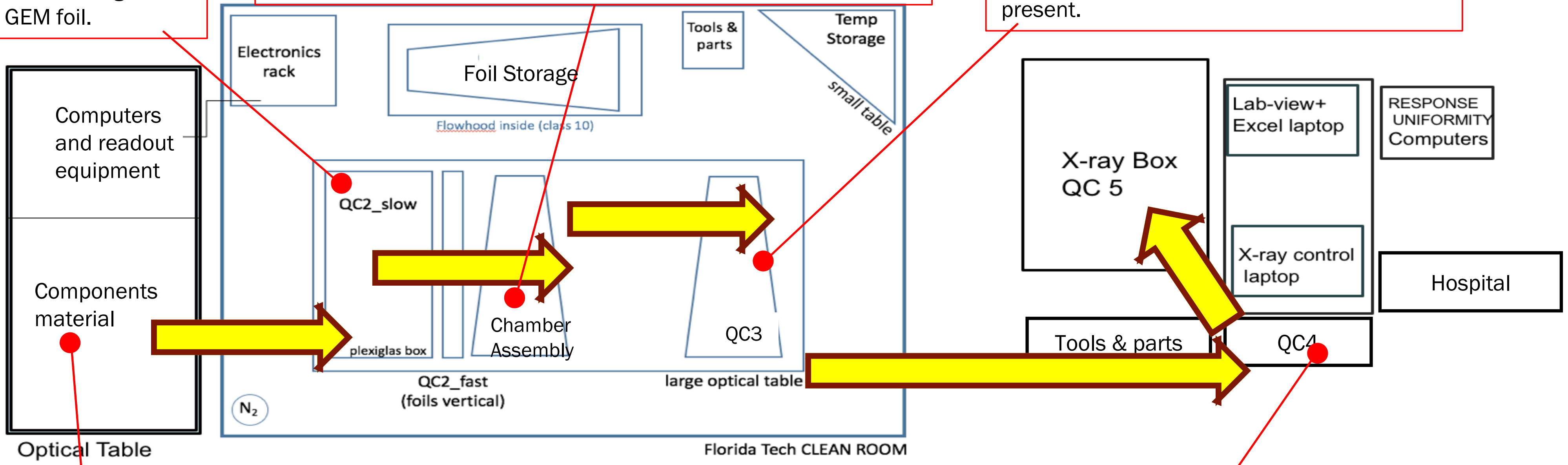

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QC4: Determine the *V* vs. *I* curve and rate of a GE1/1 detector to identify possible malfunctions, defects in the HV circuit, and spurious signals.

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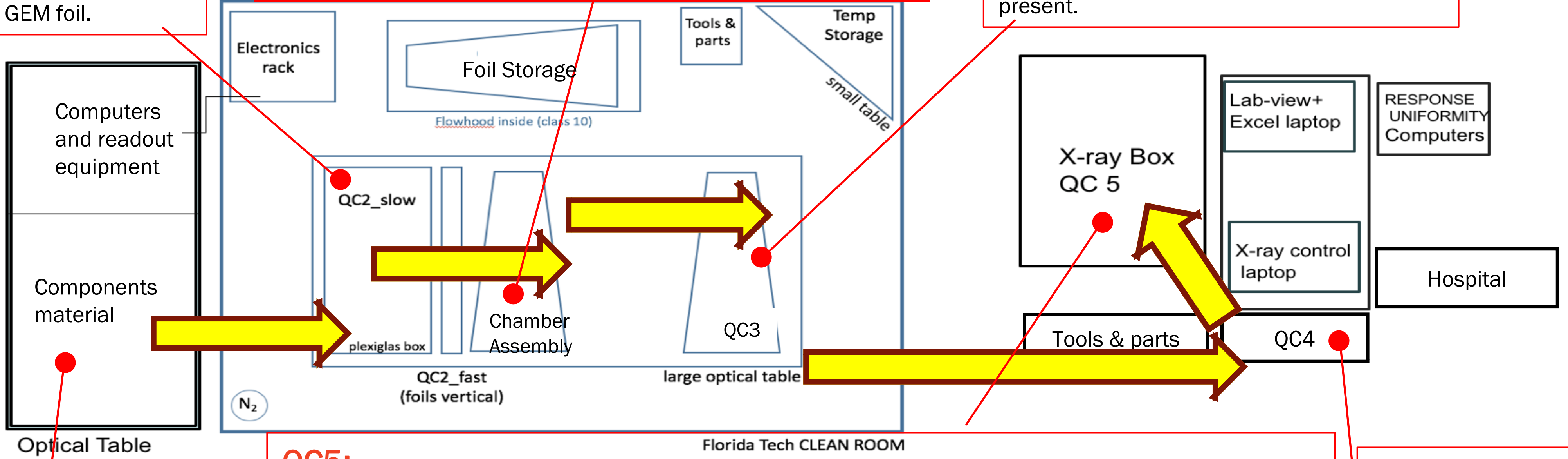

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QC5:
Step1) In order to establish the absolute gas gain, we measure the gain vs. HV in one readout sector using an X-ray source.
Step2)
The gas gain uniformity is validated by reading out all sectors (all strips) using SRS electronics.

QC4: Determine the *V* vs. *I* curve and rate of a GE1/1 detector to identify possible malfunctions, defects in the HV circuit, and spurious signals.

FIT assembly site

Summary and timeline

The installation of the GE1/1 project is planned for LS2 in 2019-2020:

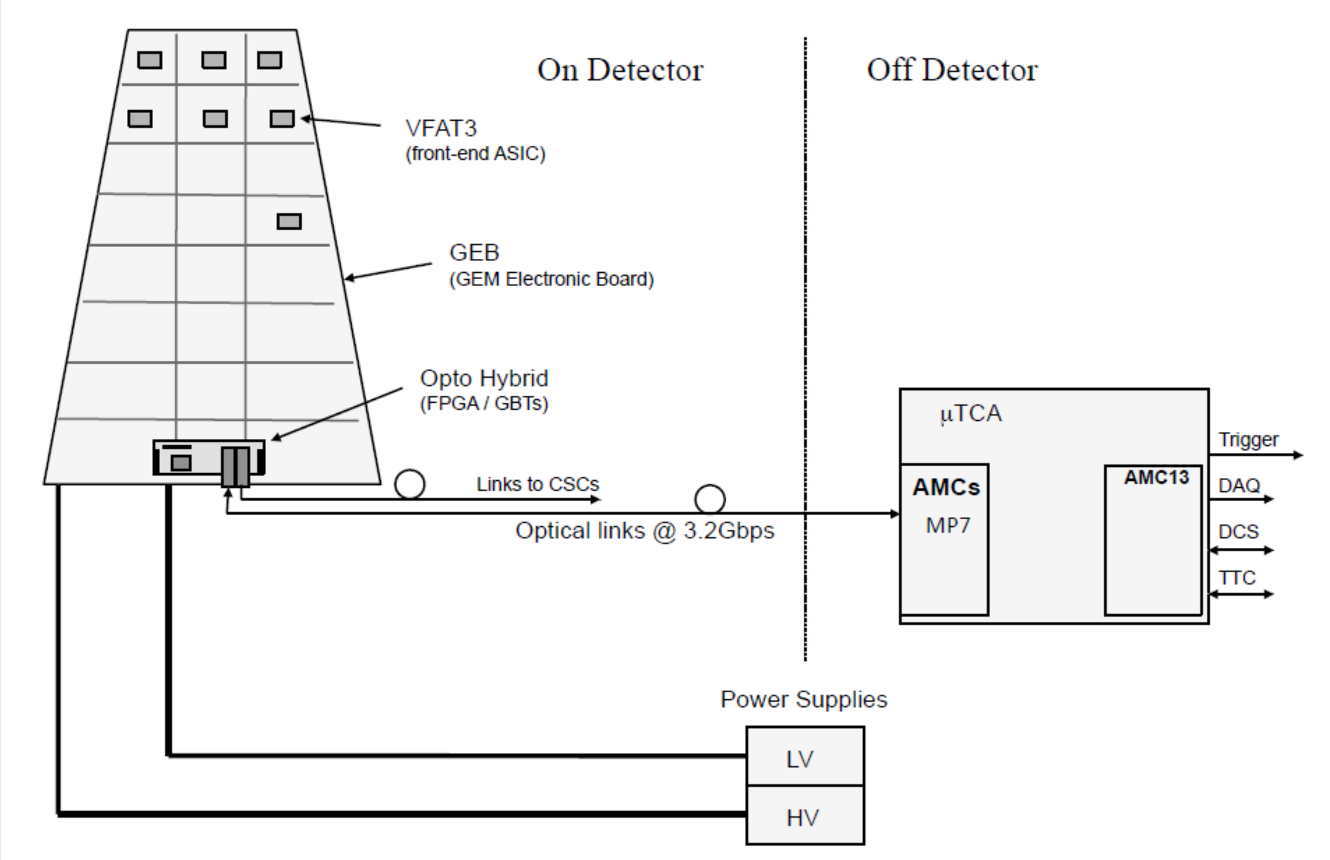
- ***5 GEMINIs were installed in 2017 in the CMS endcap to test the integration and gain operational experience:***
  - The detectors proved to be stable
  - The integration in central DCS and DAQ is on-going
- ***The production of the full station will be shared between CERN and other production sites around the world:***
  - The labs are being completed and certified to host the production
  - The first production kits are being delivered in these weeks.

We are here

2016				2017				2018				2019
Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1
External Assembly Site preparation	External Assembly Site preparation	External Assembly Site preparation	External Assembly Site preparation	External Assembly Site preparation	Assembly sites validation	Start of the production	Production	Production				Installation at CMS
Detector pre-production at CERN	Detector pre-production at CERN	Detector pre-production at CERN ready	Detector pre-production installation at CMS	Detector pre-production Commissioning at CMS	Detector pre-production Commissioning at CMS	Detector pre-production Commissioning at CMS	Detector pre-production integrated in CMS	Data acquisition with detector pre-production in CMS				

Backup

Layout of the GE1/1 slice test readout system



Reference: *VFAT2: A front-end system on chip providing fast trigger information, digitized data storage and formatting for the charge sensitive readout of multi-channel silicon and gas particle detectors*, Proceedings of TWEPP Prague, Czech Republic, 3-7 September 2007, ISBN 978-92-9083-304-8, p.292, P. Aspell, CERN

HV divider and multichannel HV system layout