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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- 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 $5 \times 10^{34}$ cm$^{-2}$s$^{-1}$

- Background rate in the $1.6 < |\eta| < 2.2$ region up to $\sim 1000 \text{ Hz/cm}^2$
- With the Run1 muon system configuration it would not be possible to achieve an acceptable L1 trigger rate for muons with $p_T < 25 \text{ GeV}$ 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 $1.6 < |\eta| < 2.2$ 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/cm²) and Space resolution (~100s of μm).
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 $\eta$ 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 GEMINIIs, 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.

- Similar results have been observed for the LV system.

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

<table>
<thead>
<tr>
<th>Production sites</th>
<th>QC1</th>
<th>QC2</th>
<th>QC3</th>
<th>QC4</th>
<th>QC5</th>
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<td>Reception of the components: optical inspection (mostly)</td>
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<td>GEM foils: leakage current/spark test (short and long term stability)</td>
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<td>GE1/1 chamber: gain calibration (absolute value and uniformity)</td>
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<td>GE1/1 chamber: HV stability test (after mounting the final HV connector)</td>
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<td>GE1/1 super-chamber: cosmic test (P5-like system)</td>
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Assembly sites organization

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

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

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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Assembly sites organization

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

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.

QC4: Tools & parts

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

Components material

Electronics rack

Foil Storage

Flowhood inside (floor 10)

Tools & parts

Small table

Large table

Chamber Assembly

QC2 Slow

QC2 Fast

Foil Storage

Plexiglas box

N2

QC2 FOILS

QC3

QC5

X-ray Box

QC4

X-ray control laptop

RESPONSE UNIFORMITY Computers

Lab-view+ Excel laptop

Hospital

Florida Tech CLEAN ROOM

Computers and readout equipment

Optical Table

Components material
Chamber construction is taking place simultaneously at all assembly sites with identical procedures, tools, and specifications.

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

**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.

**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.

Detector components are centrally managed by CERN. Shipment box are sent by CERN to assembly sites.
As shown in the diagram, the Assembly sites organization involves several steps:

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

**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.

**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.

**QC5:**

**Step 1:** In order to establish the absolute gas gain, we measure the gain vs. HV in one readout sector using an X-ray source.

**Step 2:** The gas gain uniformity is validated by reading out all sectors (all strips) using SRS electronics.

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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.

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<thead>
<tr>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
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<tbody>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
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<td>External Assembly Site preparation</td>
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<td>Detector pre-production at CERN</td>
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<td>Detector pre-production at CMS ready</td>
<td>Detector pre-production installation at CMS</td>
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10/25/2017 IEEE-NSS-MIC 2017
Backup
Layout of the GE1/1 slice test readout system

HV divider and multichannel HV system layout