Update on GE11 construction and commissioning

Federica Simone¹ on behalf of the GEM group

¹ University and INFN Bari, Italy
Outline

• GE1/1 station:
  • Overview
  • Detectors production and quality controls:
    • status and summary of the results
  • GE11 «super-chambers» final QCs:
    • QC6 HV stability tests
    • QC7 Readout Electronics installation and test
    • QC8 Final validation at cosmic ray stand
  • Commissioning:
    • Negative endcap pre-commissioning
    • Plans
The phase-I CMS muon endcap upgrade: GE1/1

144 triple-GEM detectors:
- 3/1/2/1 mm gaps
- mature technology based on mechanical foil stretching
- 10-years-long R&D on design, components and materials (mechanical longevity, outgassing studies, etc.)

36 superchambers (SC) per endcap

short and long SCs to maximise coverage
1.55 < |η| < 2.18
The GE1/1 project

BIRTH OF GE11 PROJECT

2009

GE11 proto. I

2017

GE11 proto. II

GE11 proto. III

Mechanical stretching

GE11 proto. IV

GE11 proto. V

GE11 proto. VI - VII

SLICE TEST INSTALLATION AND COMMISSIONING

2009

2017

DAQ/electronics prototyping

The GE11 project timeline:

- **2009**: GE11 proto. I
- **2017**: GE11 proto. II - VII

**Negative Endcap Installed!**

**Positive Endcap Installation**

**Superchamber Production**

**Detector Mass Production**

Timeline:

- **Oct-2017**: GHENT
- **Dec-2018**: PAK, INDIA
- **Jul-Oct 2019**: FIT, FRASCATI, BARI
- **Jul-Sep 2020**: CERN
**GE1/1 detectors: production and quality controls**

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<th>QC1</th>
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<td>QC2</td>
<td>1° HV Test on GEM foils</td>
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<td>QC8</td>
<td>Readout electronics connectivity test</td>
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<td>Efficiency measurement at the Cosmic Stand</td>
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**Production shared among different sites:**

- CERN, India, Pakistan, USA (Florida), Belgium, Italy

- Standardized setups and procedures
- Network of Institutes ready for GE2/1 and ME0 production (and more institutes joined)
Production and quality control: status

«Single» detectors production summary:

- Successful and on-time production of both endcaps from Sep 2017 to Dec 2018
- In total 161/144 GE11 Detectors:
  - 4 require investigation
  - 2 QC pending
  - 155 fully validated up to QC5

«Super-chambers» production:

- First endcap 100% completed
  - Installed last year
  - Commissioning ongoing
- Second endcap: final QCs ongoing
Quality controls up to QC5: overview

**QC1**
- Foils and materials inspection
- $1^\circ$ HV Test

**QC2**
- Assembly

**Production sites**

**QC3**
- Gas leak test
- HV stability (divider)

**QC4**
- Gain and response uniformity

**QC5**
- HV stability (multichannel)
- Readout electronics connectivity test
- Efficiency measurement at the Cosmic Stand

**QC6**

**QC7**

**QC8**

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**QC3: gas leak test**

- Passed: leak $\leq 7$ mbar in 1 h

**QC4: HV test**

- Passed: linear $I$ vs $HV$

**QC5: Effective gain**

**QC5: response uniformity**

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RD51 Mini-Week, 22-26 June 2020
Quality controls up to QC5: summary

**CERN**
- QC1: Foils and materials inspection
- QC2: 1° HV Test
- QC4: HV stability (divider)
- QC5: Gain and response uniformity
- QC6: HV stability (multichannel)
- QC7: Readout electronics connectivity test
- QC8: Efficiency measurement at the Cosmic Stand

**Assembly**
- QC2: 2° HV Test
- QC3: Gas leak test
- QC4: HV stability (divider)

**Production sites**
- QC2: Gas leak test
- QC3: HV stability (divider)
- QC4: Gain and response uniformity

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QC5 results and superchamber pairing

QC5 summary: average effective gain

Chambers pairing

- 1 superchamber = 2 triple GEM detectors
- At P5 common HV power supply
- HV point optimization:
  - Chambers sorted by gain at standard HV
  - Adjacent chambers paired
Final quality controls: QC6/7 overview

**QC6: HV stability**

First HV stability test with final HV filter and power supply.

Very long procedure updated to prevent discharges when operating in Ar/CO2
1. Stress test at 550V per foil
2. Continuity test
3. Stress test up to 1000 V per foil
4. HV scan #1 (IV measurement)
5. long-term stability (> 12 hours)
6. HV scan #2 (IV measurement)

**Mounting of readout electronics**

**QC7: RO electronics connectivity test**

Test the connectivity of the electronics components, monitor the communication stability, check noise level

1. Connectivity
2. Calibration
3. Identification of dead/hot channels
4. Global threshold scans (SBIT line) per VFAT
5. ENC measurement (S-curves)
6. Local threshold scans (SBIT line) per channel (to identify disconnected channels)

Repeated after installing cooling plate and chimney

**Common issues and solutions**

- Faulty FEASTs (non-working, unstable or inducing noise)
- Defects on the GEBs and/or on the SAMTEC connectors
- Dirty PANASONIC connectors
- Unplugged/damage/problematic VFATs ➔ replug or replace components
- ground loops created by cooling plate
  ➔ insulation implemented
- Noise issues ➔ optimised chamber grounding (star point)
Final quality controls: QC8 overview

Cosmic test stand: a large sized experiment in the lab

- 15 Super Chamber slots + two layers of scintillators (trigger rate $\approx$ 90Hz)
- 92k readout channels with CMS-like DAQ based on uTCA backend
- Services (LV, HV, DAQ system, cooling, FW, SW) as in P5
- Gas mixture: Ar/CO2 (70/30%) + CO2 / Pure Air line
- Dedicated DCS:
  - HV, LV control and monitoring (data stored in DB)
  - environmental conditions and gas mixture monitoring (stored in DB)
- Dedicated Offline DQM

Configuration and test procedures:
- Configuration of DAQ parameters
- Trimming, masks, thresholds @ 100Hz noise
- Before data taking: HV training procedure in Ar/CO2 to prevent discharges

QC8 test:
- HV scan with cosmic muons:
  - $\sim$12h cosmic run for each HV point
- Analysis in CMSSW Framework:
  - Software alignment implemented,
  - Muon track reconstruction for efficiency measurement,
  - Final results stored in DB
Final quality controls: QC8 results

Example of efficiency vs HV scan

![Graph showing efficiency vs HV scan for CMS GE1/1 Detector Production with gas mixture Ar/CO₂ (70/30%)](image)

- (Layer2) Avg frontend threshold = 2.81 ± 0.39 fC
- (Layer1) Avg frontend threshold = 3.26 ± 0.60 fC

Super Chamber ID (Layer) ↔ Chamber ID
- GE11-SCS-0035 (Layer1) ↔ GE11-X-S-PAK-0013
- GE11-SCS-0035 (Layer2) ↔ GE11-X-S-CERN-0004

Efficiency vs thresh. scan

- CMS GE1/1 Detector Production
- Gas mixture: Ar/CO₂ (70/30%)
- Equiv. divider current = 690 μA (Eff. gain ≈ 23k)

Spatial resolution

- CMS GE1/1 Detector Production
- Gas mixture: Ar/CO₂ (70/30%)
- Detector GE11-X-S-BARI-0014
- Avg frontend threshold = (3.44 ± 0.69) fC
Final quality controls: status summary

First endcap: GE11-
- 36 long + 36 short detectors fully validated
- Negative endcap installed in July, September and October 2019

Efficiency summary at QC8 for the negative endcap

Second endcap: GE11+
- 36 long + 36 short detectors validated up to QC5
- final QCs (QC6/7/8) ongoing:
  - 90% of short chambers and 30% of long chambers fully validated
- Installation window for positive endcap: July, August, September 2020
GE11 commissioning

First endcap “pre-commissioning”

After installation, until Feb. 2020

• HV training in pure CO2
• Readout electronics connectivity check and noise measurement
• DCS and DAQ fully operational

Noise comparison: QC7 vs P5

Plans after Covid-19 stop …

• Restart DCS and DAQ, repeat HV training
• Readout electronics calibration
• Switch to Ar/CO2 mixture

… and from Sept/Oct 2020

Data taking with cosmics

• Latency scan
• Efficiency measurement for optimal HV point tuning (combined with CSC sub-detector)
Conclusions

- Successful and on-time production of both endcaps (> 144 detectors) from Sep 2017 to Dec 2018, tested up to QC5
- 75% of total GE11 detectors have been fully validated
  - complex mechanics + electronics required many changes in final assembly and test procedures
  - we gained valuable experience for GE2/1 and ME0 upgrades

- Last year: GE11- station has been installed. A first commissioning phase already took place
- Finalising the tests on the last superchambers in these days
- Positive endcap to be installed in the coming months
Backup material
GE1/1 detectors: specifications and production

**GE1/1 detectors:**
- Triple GEM geometry (gap 3/1/2/1 mm)
- Big surface O(m2)
- 144 trapezoidal chambers (Long and Short)
- 24 readout sectors – 128 strips each
- Readout electronics based on the VFAT3 frontend chip
- 72 «superchambers» = 144 triple-GEM chambers

**Production shared among different sites:**
CERN, India, Pakistan, USA (Florida), Belgio, Italia (Bari and Frascati)

- Standardized setups and procedures
- New community of GEM experts
- Network of Institutes ready for GE2/1 and ME0 production
First test bench for the GE1/1 project 2017 «Slice Test»

**Slice Test:** 5 super chambers installed in 2017 and operational till the end of Run II. Goals:
- Acquire first operational experience
- Integrate the GE1/1 station in the central CMS services
- Detector Control System (DCS) and Data Quality Monitoring (DQM) integration
Figure 1.22: L1 Muon trigger efficiency for the prompt muon trigger (left) and displaced muon trigger algorithm (right), as a function of a true muon $p_T$ in the region $2.1 < \eta < 2.4$. The L1 trigger $p_T$ threshold is 15 GeV (left) and 10 GeV (right).
Figure 1.23: L1 prompt (left) and displaced (right) muon trigger rates, with and without GEM chambers, as a function of muon trigger $p_T$ threshold in the region $2.1 < \eta < 2.4$. The L1 track based veto is expected to further reduce the displaced muon trigger rate by a factor of 3–8.
GE1/1 quality controls: «QC3» gas leak test

1. Setup

2. Typical output

3. Acceptance criteria

4. Summary of results

QC3 test:
- performed on 151 (144+7 spares) chambers
- 149 validated detectors

\[ P_0 = 25 \text{ mbar initial over-pressure} \]
\[ P(t) = P_0 e^{-t/\tau}, \tau \text{ from exp. fit} \]

\[ \tau > 3h \]
(max leakage flow rate \( \sim 0.02 \text{ l/h} \))
GE1/1 quality controls: «QC4» (I) HV stability

1. Procedure
   - chamber powered in step of 100V through a ceramic divider (pure CO2)
   - powered up to $V_{\text{drift}} = 49$ kV
   - for each step, the current drawn by the divider is recorded $\rightarrow$ V-I curve

2. Typical output

3. Acceptance criteria
   $\Delta R/R < 3\%$
   Deviation w.r.t. ohmic behaviour

4. Summary of results

V-I characteristics of the full HV circuit
$\Delta R/R = \frac{(R_{\text{equiv.meas.}} - R_{\text{fit}})}{R_{\text{equiv.meas.}}}$
GE1/1 quality controls: «QC4» (II) intrinsic noise rate

1. Setup

2. Procedure

- chamber powered in step of 100V (ceramic divider, pure CO2)
- powered up to $V_{drift} = 49$ kV
- for each step, the number of spurious pulses from G3B is recorded

3. Acceptance criteria

$R_{max} < 100 \text{ Hz (} \sim 10^{-2} \text{ Hz/cm}^2 \text{)}$

exp. rate at GE1/1 station > 4.5 kHz/cm$^2$
GE1/1 quality controls: «QC5» (I) effective gain

1. Setup and procedure

- Detector fully irradiated with X-rays
- For each HV point:
  - measure the signal rate
  - measure the current induced on the readout $I_{RO}$

2. Typical output

$$G = \frac{I_{RO, xray \text{ ON}} - I_{RO, xray \text{ OFF}}}{R \times e \times N_p}$$

- Signal rate curve plateaux assumed as source rate ($R$)
- $N_p = \text{expected number of primary electron-ion pairs}$
GE1/1 quality controls: «QC5» (II) response uniformity

Response uniformity and gain map

- Detector fully irradiated with X-rays
- RO based on analog electronics (APV25)
- [1] Measure the copper fluorescence for every readout channel (3 strips ≈ photon cluster size)
- [2] Compare ionization peak positions
- [3] Distribution of the cluster charge ADC ⇒ $R = \sigma / \mu \cdot 100$ (Response uniformity)

Large active area → gain fluctuations
(foil thickness variations, holes diameter, bending…)

$\sigma_{gain} \sim 37\%$

GE1/1 efficiency & time res. stable in a large gain range: $G_{ref} \pm 50\%$ ($G_{ref} = 10^4$)
GE1/1 quality controls: «QC5» results and SC pairing

1. Summary: response uniformity

2. Acceptance criteria

\[ R < 50\% \]

Max response uniformity to ensure stable performances

3. Summary: average effective gain

4. Chambers pairing

- 1 super chamber = 2 triple GEM detectors
- Common HV power supply \( \Rightarrow \) same HV setting
- HV point optimization:
  - Chambers sorted by gain @ standard HV
  - Adjacent chambers paired
  - Optimal HV = avg between the two

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GE1/1: Readout Electronics

ON - DETECTOR

2 - pieces GEB v3 (1.0 – 1.2m)

OFF - DETECTOR

CSC Trigger Mother Board (TMB)

Trigger data (3.2 Gbps – 10b/8b)

VFAT3

3 GBTx

2 VTTx

3 VTRx

Opto Hybrid v3 (OH)

Virtex-6

FEAST (DC DC converter, LV VFAT3 & OH)

AMC = CTP7 from CMS Trigger upgrade

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QC7 systematic problems and solution implementation (1.1)

Ground-loops between chamber and cooling plate:
Scurves depicted high noise level on the electronics due to current loops formed on the cooling plate.
QC7 systematic problems and solution implementation (1.2)

Ground-loops between chamber and cooling plate: Solution insulation of the cooling plate with a single grounding connection to the star-point

Electrically insulated thermal pad

Plastic pillars and washers

Insulation of the copper pipe using Kapton
Ground-loops between chamber and aluminium chimney: After removing chimney
QC7 systematic problems and solution implementation (2.2)

Ground-loops between chamber and aluminium chimney: solution
Isolation of Chimney using Kapton foil
QC7 - Frequent issues

- Improper connection of VFATs in the readout board
  - Spotted by threshold scan

- Broken Sbit links:
  Caused by:
  - Dirty VFAT slots
  - Damaged traces in the GEB
  - Bad OH-GEB connection (SAMTEC)

Replaced GEB
QC7 - Frequent issues

- Faulty FEASTs
  - non-working, unstable
  - inducing noise
    - bad shielding around the inductors, noise observable only after chimney installation (completing the Faraday cage)

- Mechanical stress due to cooling plate

  Most of these issues require component replacement/cleaning

  - All steps from 2 to 5 to be repeated
  - Time taken for validation +1h for every debugging attempt
QC8 – typical output and time needed

**Time needed:**
- 1 day for installation and initial configuration
- 5 X 12h-long runs to complete HV scan

**Typical case:**
1 week to validate a full bunch of chambers (average rate 5 SC/week)

- Gas mixture: Ar/CO2 (70/30%)
- Cosmic muon tracks giving hits in columns of 10 “stacked” chambers
- Track-based analysis => Muon track reconstruction
QC8 – typical output

Final validation:
- Efficiency of both chambers in the SC > 90%

Efficiency vs gain

![Graph showing efficiency vs gain for different gas mixtures and chamber configurations in Super Chams ID. The graph illustrates the efficiency of both chambers in the SC, with efficiency values above 90% for various gain values.]
# QC8 – Issues

**High noise related to services in the stand**
- ENC go from $\sim0.5$ fC at QC7 to $\sim4/5$ fC at QC8

**Gain non-uniformity in long chambers**
- Lower efficiency in some readout sectors related to QC5 uniformity map

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F. Simone - CMS GEM workshop – QC7 and QC8 summary