The GEM (GE1/1) Phase II Upgrade for the CMS muon system: results from in-situ demonstrator, production detector qualification, and commissioning plans

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during LHC Run-1 the CMS muon system included:

- **Drift Tubes**, for tracking and triggering in the region $|\eta| < 1.2$
- **Cathode Strip Chambers**, for tracking and trigger in the region $0.9 < |\eta| < 2.4$
- **Resistive Plate Chambers**, for triggering in the region $|\eta| < 1.9$

HL-LHC upgrade:

- **Nominal luminosity** up to $7.5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$
- Huge increase in *cavern background* (up to $10^6 \text{ part/cm}^2\text{s}$) and in *pile up* (from 30 to 200) expected

→ Need to upgrade the CMS muon system to preserve the muon triggering and reconstruction capabilities

new muon stations to:

- **Improve the redundancy** in the high $\eta$ region
- **Handle a rate of 10's of kHz/cm$^2$**
- **Survive** to an intense background rate
**Triple-GEM detectors:**

- Gain up to $10^4$
- Hit efficiency up to 97%
- Spatial resolution of 140 $\mu$m
- Time resolution of 7 ns with Ar/CO2 70/30 gas mixture without contaminants
- Rate capability up to 100 $MHz/cm^2$
- Radiation hardness up to 1.56 $C/cm^2$

**The GE1/1 station:**

- Two Triple-GEM detectors coupled into superchambers
- 36 superchambers per endcap
- 144 Triple-GEM chambers in total
- Long a short superchamber versions alternate to maximize the $\eta$ coverage.
GE1/1 Slice Test - Goals

10 Triple-GEM detectors (5 superchambers or GEMINI) installed in the negative endcap in January 2017, with the aim of:

1. Acquiring **installation and commissioning expertise**
2. Demonstrating the **integration** into the CMS online system
3. Proving **operability** of the system
GE1/1 Slice Test - Results

1. The 5 GEMINI were installed successfully in CMS
   a. The experience lead to the development of a dedicated insertion jig for the installation of the full station
   b. Experienced gained in commissioning of detectors, DCS and DAQ systems

2. Full integration in CMS:
   a. DCS → GEMINI operated following the LHC operations, together with the rest of CMS
   b. DAQ → data acquired in central DAQ during cosmics runs and runs with beam
   c. online DQM → Successful test of a full chain processing (i.e., RAW data → Digitization → Reconstruction → DQM)

3. Operability:
   a) Detectors proved to be stable over the full period of operation
   b) The measured reconstruction efficiency and cluster size reached the values expected from qualification
   c) First collision data with GEMs reconstructed in 2018.
GE1/1 Assembly

Production effort shared between CERN and different GEM institutes

Phase I - Preparation of the components in laboratory
- Cleaning of the components
- Preparation of the HV circuit
- Mounting of the pull-outs
- Selection of the O-ring

Phase II - Assembly in clean room
- Fast test of the GEM-foils
- Mounting of the stack
- Closing of the chamber

1 day is enough to fully assemble a GE1/1 detector
GE1/1 QA/QC

CERN

QC1 Material Inspection
QC2 GEM-foils Test

Assembly

QC2 GEM-foils Test (fast)
QC3 Gas Leak Test
QC4 HV Test
QC5 Gas Gain Calibration

Production sites

QC6 HV Stability Test
QC7 Electronics
QC8 Connectivity Test
QC8 Cosmic Test

QC3

Manifold Pressure $P_m$ (mbar)

$P_m(t) = \exp(\Delta - \nu t)$

Data
Fit

Time $t$ (hr)

QC4

Applied Voltage $U$ (KV)

Data
Fit

Divider Current $I_{\text{divider}}$ (µA)

QC5

Effective Gas Gain

$G(l_{\text{divider}}) = \exp(A + B \times l_{\text{divider}})$

X-ray Target: Ag

$T_0 = 297.1 \text{ K}$

$P_0 = 964.0 \text{ mbar}$

$\ln = 4$; $\omega = 2$

Error Bars $\times 10$

Data
Fit

QC5 – Chambers comparison

CMS GE1/1 Production Long Chambers
Tested in Aachen
Gas: Ar:CO$_2$ (70:30)
X-ray Target: Ag
I$H_{\text{RON}}$ = 660 µA (after P/T correction)

Data
Max
Min

Detector Serial Number

CMS

GE1/1
GE1/1-X-L-CERN-0001
Gas = CO$_2$

$U_{\text{equiv}} = R_{\text{equiv}} \times I_{\text{divider}}$

$R_{\text{equiv}} = R_{\text{divider}} + R_{\text{term}} = 5.0 \Omega$
GE1/1 Readiness

All the detectors needed for GE1/1 have been assembled and tested up to QC6.

Still on going:
- Superchamber assembly
- QC7 & QC8

→ Expected to be completed by the end of 2019
GE1/1 Installation in CMS

**Schedule:**

- **Autumn 2019:** installation of 36 superchambers in the negative endcap
- **Spring 2020:** installation of 36 superchambers in the positive endcap

Insertion jig developed from the slice test experience
GE1/1 Commissioning plans

**Phase I – Standalone tests → Summer/Fall 2019**
- DCS and DAQ
  - Connectivity tests and full chain validation
  - Electronics test
- Detectors
  - Power ON

**Phase II – Tests utilizing central infrastructures → Fall 2019/Begnning 2020**
- Detectors Working point definition
- First runs with trigger from the rest of the CMS muon system

**Phase III – Final integration in CMS → Summer 2020**
- Integration in central DCS and central DAQ

Several DAQ and analysis tools developed for the slice test and QC8 are ready to be used for the GE1/1 commissioning!

Example of scurve with VFAT3

New GE1/1 DCS panel
Summary

The GE1/1 station is planned to be installed in the CMS muon system during this long shutdown:

- An intense R&D lead, in the past few years, to the construction of robust detectors, with high performance matching the CMS requests
- A first demonstrator, called Slice-Test, was installed in 2017 in the CMS endcap and reached the goal of full integration into the CMS system.
- The assembly and qualification of the 144 Triple-GEM detectors needed for the GE1/1 station is completed.
- The assembly of superchambers and the final qualification with cosmics is ongoing and planned to be completed by the end of 2019.
- The installation of the negative GE1/1 endcap is planned for fall 2019, while the positive one for spring 2020.
- The commissioning will lead, by summer 2020, to the full inclusion of the GE1/1 system into CMS.

Thanks!