The ME0 Project

Design, Status, Tests, Schedule, & Milestones

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On behalf of the CMS GEM Collaboration
September 2, 2021

CMS Muon Upgrade Workshop 2021
The ME0 Detector System

- The ME0 detector system is a layered stack of 6 triple-GEM detectors (70:30 Ar/CO₂ fill gas)
- 18 stacks per endcap (36 total stacks; 216 modules total)
- ME0 detector system to increase coverage from 2.0 < |η| < 2.8
- Segmented into 8 readout partitions in η and 3 in φ (24 total RO sectors)

Requirements [1]:

- 97% efficiency
- Rate capability of ≥ 150 kHz·cm⁻²
- Radiation hardness requirement >7.9 C·cm⁻²
- Angular resolution ≤ 500 μrad
- Time resolution 8–10 ns for single layer
- Gain uniformity of ≥ 15% inter-/intra-module
- Sufficiently low discharge rate

Quadrant of the CMS experiment with ME0 highlighted. Adapted from [1].

3D rendering of the insertion of two ME0 stacks [1].
ME0 Frontend Electronics

- GEM electronics board (GEB) in final prototyping stages
  - 11 total preproduction prototypes produced: 5 narrow, 6 wide
  - Optimizing fiber routings
  - Finalizing layout for DC-DC converters

ME0 GEB design w/ patch panel connections [2].

- FPGA-less optohybrid (ASIAGO) with 2 LpGBT chips and VTRX+

ME0 OH v1 [3].

- Plugin cards fitted with VFAT3b ASICs for RO
  - 120 in hand; 66 at CERN for GE2/1, 24 at FIT, 2 at Rice, 2 at Vilinius, 12 at Bari
  - 50 wafers ordered for ME0, packaging expected in 2022

Plugin card with VFAT3b ASIC.

- Power to be distributed by bPOL12V DC-DC converters (currently under testing)
  - Transitioning from the FEASTMP_CLP to bPOL (FEAST production discontinued)
  - bPOL prototype testing looks promising! See [4]
ME0 Frontend Electronics — Test Stands

- Frontend electronics integration test stands at CERN, UCLA, and Florida Tech
- UCLA and Florida Tech use the BittWare CVP13 backend, CERN uses the APEX backend (see Abhisek’s talk)
- **Software/firmware** for integration/testing purposes written and tested
- GEM collaboration moving to integrate the frontend electronics with the chamber

UCLA ME0 test stand.

CERN ME0 test stand.

Florida Tech ME0 test stand.
ME0 Frontend Electronics — Tests & Results

- Full slow control communication with VFATs
- Full readout capabilities of DAQ and trigger data
- Can synchronize, calibrate, and operate all VFATs simultaneously
- Downlink and uplink BER < $10^{-14}$ (measured using FEC errors)
- Downlink and uplink eye diagrams look good:
  - Downlink LpGBT v0 eye diagram.
  - Uplink eye diagram for primary LpGBT [3].
  - Uplink eye diagram for sub LpGBT [3].

ENC measurement for DAQ path. Noise measurement for trigger path.

RSSI monitoring over 24 hours; range of 272–286 μA [3].
ME0 Optohybrid: **ASIAGO** (**ASIC** and **Gigabit Optics**)  
Version 2 under review (see [3]); should be finished by early Sep.  
Using halogen-free material for v2 PCB (ThunderClad 1+FR-15.1)  
Slight changes implemented due to VTRX+ changing  
36 preproduction prototypes planned (preproduction will start when LpGBTs arrive in Sep.)  
All v2 OHs to be tested at UCLA test stand before distribution  
Recent issue: problems with I2C communication with LpGBTs [3]  
  * Issue caused by LpGBT being reset twice during power-on (Schmitt trigger connected to external power-on reset)  
  * Schmitt triggers removed for problematic boards  
  * Reported to LpGBT designers  
Cooling system being designed for the ME0 OH which will connect to the main cooling circuit

Corner of PCB will be cut to avoid connecting to GEB in the incorrect orientation [5].
On-chamber gas distribution.

- GEM technical coordination proposing new on-stack gas system
- Change Control expected (layout and cost to change)
- In the TDR, on-stack gas is distributed in series
- From experience with GE1/1, we know that 6 modules in series will generate an overpressure of \( \sim 25\text{–}30 \) mbar in the first chamber
- Moving to a parallel gas distribution scheme
- Supply and return manifold designed and prototype produced

- To ensure uniform distribution of gas, copper capillaries or impedance needles will be used to keep impedance between manifold and on-chamber patch panel (PP) to 25 mbar
ME0 R&D Milestones

- Several milestones accomplished over previous year [6]
- Delays [6]:
  - Full qualification of new layout is taking time (major performance gains justify waiting)
  - LpGBT v1 delays means frontend electronics delays
- Foil PRR planning to be discussed with respect to vendor qualifications

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<tbody>
<tr>
<td>ME0 R&amp;D: Key detector system design parameters are defined based on performance requirements</td>
<td>ME0.RD.DET.1, ME0.RD.FE.1, ME0.RD.BE.1</td>
<td>2017-03-21</td>
<td>2017-03-21</td>
<td>2017-03-21</td>
<td>2017-03-21</td>
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<tr>
<td>ME0 R&amp;D: Irradiation studies and assessment of performance and longevity with small prototypes completed</td>
<td>ME0.RD.DET.2</td>
<td>2017-07-11</td>
<td>2017-07-11</td>
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<td>2017-07-11</td>
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<tr>
<td>ME0 R&amp;D: On-chamber &amp; off-chamber electronics preliminary principal design complete and interfaces defined</td>
<td>ME0.RD.FE.2, ME0.RD.BE.2</td>
<td>2017-07-25</td>
<td>2017-07-25</td>
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<td>2017-07-25</td>
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<tr>
<td>ME0 R&amp;D: Chamber (stack) prototype mechanical design completed</td>
<td>ME0.RD.DET.3</td>
<td>2018-12-18</td>
<td>2018-12-18</td>
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<td>2018-12-18</td>
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<tr>
<td>ME0 R&amp;D: On-chamber electronics engineering design completed and validated</td>
<td>ME0.RD.FE.3, ME0.RD.DET.4</td>
<td>2019-08-23</td>
<td>2020-08-21</td>
<td>2020-11-06</td>
<td>2020-12-02</td>
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<tr>
<td>ME0 R&amp;D: Full Characterization of sparks for ME0 (a new milestone requested by P2UG)</td>
<td>ME0.RD.DET.4</td>
<td>2019-12-24</td>
<td>2020-04-13</td>
<td>2020-09-29</td>
<td>2020-09-29</td>
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<tr>
<td>ME0 R&amp;D: On-chamber electronics prototype electronics manufacturing and testing is complete</td>
<td>ME0.RD.FE.4</td>
<td>2020-08-21</td>
<td>2021-01-08</td>
<td>2021-01-08</td>
<td>2021-04-09</td>
</tr>
<tr>
<td>ME0 R&amp;D: Integration of the on-chamber and off-chamber electronics and performance assessment complete</td>
<td>ME0.RD.BE.3</td>
<td>2021-01-08</td>
<td>2021-04-02</td>
<td>2021-04-02</td>
<td>2021-06-18</td>
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<tr>
<td>ME0 R&amp;D: Assessment of the electronics performance and integration with the demonstrator chamber completed</td>
<td>ME0.RD.DET.5, ME0.RD.FE.5</td>
<td>2021-03-30</td>
<td>2021-05-28</td>
<td>2021-05-28</td>
<td>2021-08-27</td>
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<tr>
<td>ME0 R&amp;D: Beams and Cosmics testing of the demonstrator chamber and performance qualification completed</td>
<td>ME0.RD.DET.6</td>
<td>2021-08-31</td>
<td>2021-10-29</td>
<td>2021-10-29</td>
<td>2022-02-11</td>
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S.D. Butalla, on behalf of the GEM Collaboration – “The ME0 Project” – CMS Muon Upgrade Workshop – Sep. 2, 2021
ME0 Aging and Rate Studies

- “Additional” R&D for optimizing design to improve discharge protection and rate capabilities [6]
- A large improvement in design proposed to significantly improve rate capabilities
  - Crucial due to more stringent requirements than previously listed in the TDR
- Good progress, but amount of work has sharply increased (built ME0 modules with the new foils with longitudinal segmentation)
- Discharges not really a concern anymore, but full assessment is needed
ME0 R&D Forecasted Schedule

- R&D activities coming to a close ⇒ should be mostly done by end of CY2021 [6]
- ~2 month delay compared to AR-2021
- Major improvements to design projected to significantly improve rate capability and discharge protection
- EDR and ESR planned for early 2022
  - Significant risks to schedule due to high density of activities
  - Additional delays (~1-2 months) are likely
Only a few delays accumulated over the last year [6]
- ~1.5 months, which probably can be mitigated
- Relative to official LS-3 Schedule (will probably change!)
- Float need-by-date for construction is in 40 weeks
- Construction phase started by PRRs, ESR, and EDR

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<td>ME0 Construction</td>
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<tr>
<td>ME0 On-Chamber Electronics Manufacturing and Testing complete, ready for chamber (stack) assembly</td>
<td>ME0.PR.FE.1</td>
<td>2022-03-29</td>
<td>2022-09-07</td>
<td>2022-09-07</td>
<td>2022-11-18</td>
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<tr>
<td>ME0 Chambers for Disk-1 are assembled, tested, and ready for installation</td>
<td>ME0.PR.DET.1</td>
<td>2023-05-04</td>
<td>2023-12-12</td>
<td>2024-04-12</td>
<td>2024-05-23</td>
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<tr>
<td>ME0 Off-Chamber Electronics Manufacturing &amp; Testing complete</td>
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<td>2023-06-08</td>
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<td>2023-06-08</td>
<td>2023-06-08</td>
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<tr>
<td>ME0 Chambers for Disk-2 are assembled, tested, and ready for installation</td>
<td>ME0.PR.DET.2</td>
<td>2024-03-07</td>
<td>2024-10-15</td>
<td>2025-02-14</td>
<td>2025-03-27</td>
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<tr>
<td>All ME0 Stacks Installed in the New Nose. Detector is ready for installation as part of the endcap at Pt. 5</td>
<td>ME0.PR.DET.3</td>
<td>2024-05-23</td>
<td>2026-03-23</td>
<td>2026-03-23</td>
<td>2026-03-23</td>
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<tr>
<td>Construction Project Complete. Ready for Global System Commissioning</td>
<td>ME0.PR.DET.4</td>
<td>2025-09-12</td>
<td>2026-05-28</td>
<td>2026-05-28</td>
<td>2026-05-28</td>
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Summary

- Finalizing GEB design, transitioning to bPOL DC-DC converters, packaging for VFAT3bs expected in 2022
- Firmware and software for integration purposes fully written, implemented, and tested at CERN, UCLA, and FIT
- ME0 OH v2 to start preproduction in Sep. after LpGBTs arrive
- Change control expected for the on-stack gas distribution system
  - First full prototype expected in early autumn
- Several milestones achieved over the past year
- R&D activities almost finished; small delay (~2 months) expected
- New aging and rate capability studies underway due to more stringent requirements
- EDR and ESR projected for early 2022
- ~1.5 month delay for construction, 40 weeks of float
References


S.D. Butalla, on behalf of the GEM Collaboration – “The ME0 Project” – CMS Muon Upgrade Workshop – Sep. 2, 2021
Backup
ME0 R&D Baseline Schedule

- Baseline schedule (approved Mar. 2020) [6]
  - EDR: Oct. 29, 2021
  - ESR: Dec. 1, 2021
  - Separate PRR for foils (Jun. 21, 2021)

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<tr>
<th>#</th>
<th>WBS Code</th>
<th>Title</th>
<th>Master Schedule reference</th>
<th>Expected End</th>
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<tr>
<td>2,358</td>
<td>2.3.3.10.501</td>
<td>ME0 R&amp;D Milestones</td>
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<td>Dec 1, 2021</td>
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<td>2,359</td>
<td>2.3.3.10.501.424</td>
<td>ME0 R&amp;D T5: Key Detector System Design Parameters Are Defined Based on Performance Requirements</td>
<td>MED.R.DDET.1</td>
<td>Mar 21, 2017</td>
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<td>2,360</td>
<td>2.3.3.10.501.421</td>
<td>ME0 R&amp;D T4: On-Chamber Electronics Preliminary Principal Design Complete and Spacs Defined (HM)</td>
<td>MED.RD.EDT.1</td>
<td>May 2, 2017</td>
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<td>2,361</td>
<td>2.3.3.10.501.431</td>
<td>ME0 R&amp;D T4: On-Chamber &amp; Off-chamber Electronics Preliminary Principal Design Complete and Spacs Defined (HM)</td>
<td>MED.RD.EDT.2</td>
<td>May 28, 2017</td>
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<td>2,362</td>
<td>2.3.3.10.501.402</td>
<td>ME0 R&amp;D T3: Key Detector System Design Parameters Are Defined Based on Performance Requirements</td>
<td>MED.RD.EDT.3</td>
<td>July 11, 2017</td>
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<td>2,363</td>
<td>2.3.3.10.501.401</td>
<td>ME0 R&amp;D T3: Key Detector System Design Parameters Are Defined Based on Performance Requirements</td>
<td>MED.RD.EDT.4</td>
<td>Feb 1, 2018</td>
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<td>2,364</td>
<td>2.3.3.10.501.403</td>
<td>ME0 R&amp;D T3: Key Detector System Design Parameters Are Defined Based on Performance Requirements</td>
<td>MED.RD.EDT.5</td>
<td>Apr 19, 2020</td>
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<td>2,365</td>
<td>2.3.3.10.501.404</td>
<td>ME0 R&amp;D T3: Key Detector System Design Parameters Are Defined Based on Performance Requirements</td>
<td>MED.RD.EDT.6</td>
<td>May 1, 2021</td>
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<td>2,366</td>
<td>2.3.3.10.501.405</td>
<td>ME0 R&amp;D T3: Key Detector System Design Parameters Are Defined Based on Performance Requirements</td>
<td>MED.RD.EDT.7</td>
<td>Dec 1, 2021</td>
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● Forecasted R&D schedule [6]:

Full characterization of sparks/rate capabilities (requested by P2UG): Dec. 31, 2021

All final reviews now converge near the end of the CY2022
ME0 Construction Schedule Forecast

- Forecasted construction schedule [6]:

Lost additional ~1.5 months of float to installation since last year, now ~40 weeks
● Aging and rate studies schedule [6]:

[Diagram of the aging and rate studies schedule]