The ME0 Project

Design, Status, Tests, Schedule, & Milestones

Stephen D. Butalla
On behalf of the CMS GEM Collaboration

September 2, 2021

CMS Muon Upgrade Workshop 2021

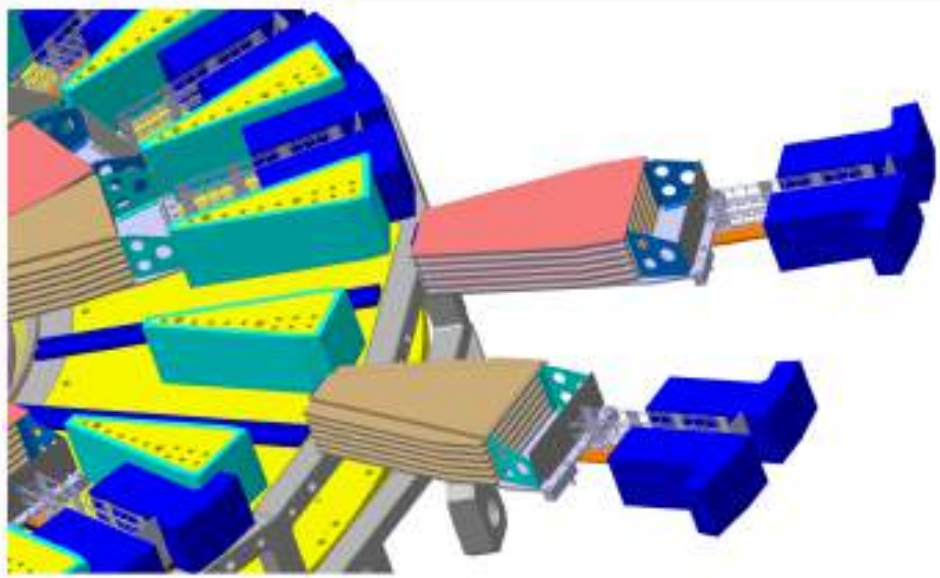
The ME0 Detector System

- The ME0 detector system is a layered stack of 6 triple-GEM detectors (70:30 Ar/CO_2 fill gas)
- 18 stacks per endcap (36 total stacks; 216 modules total)
- ME0 detector system to increase coverage from $2.0 < |\eta| < 2.8$
- Segmented into 8 readout partitions in η and 3 in ϕ (24 total RO sectors)

Requirements [1]:

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

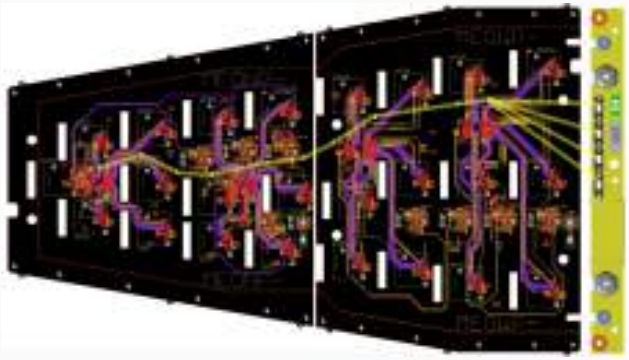
Quadrant of the CMS experiment with ME0 highlighted. Adapted from [1].



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

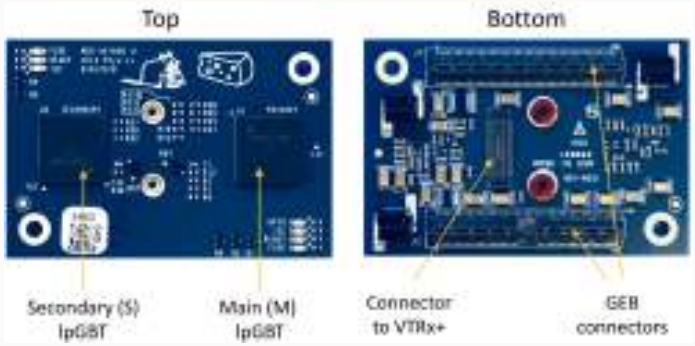
ME0 Frontend Electronics

- 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].

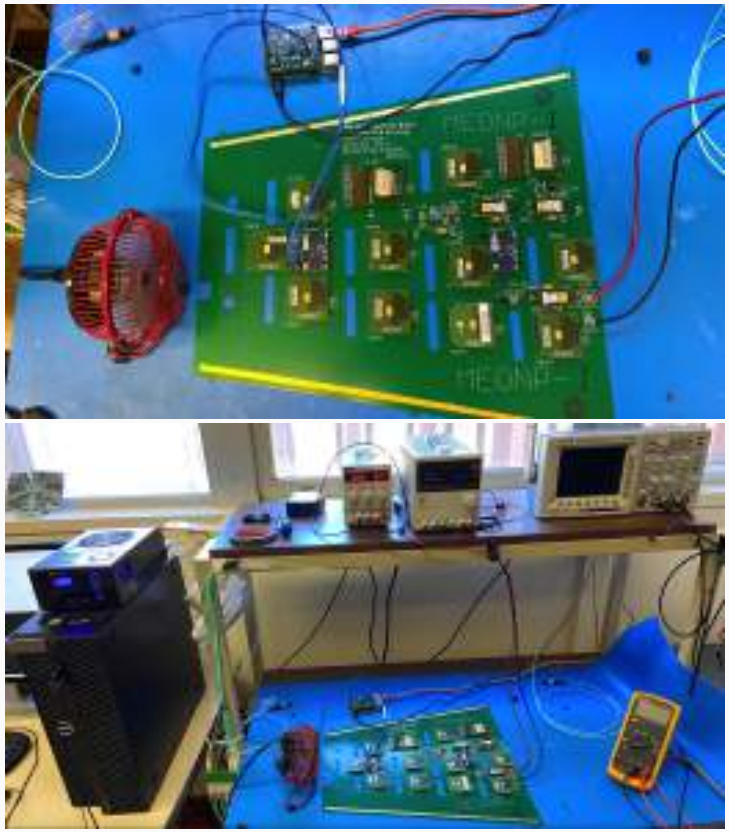
- Plugin cards fitted with VFAT3b ASICs for RO
  - 120 in hand; 66 at CERN for GE2/1, 24 at FIT, 2 at Rice, 2 at Vilinius, 12 at Bari
  - 50 wafers ordered for ME0, packaging expected in 2022

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.

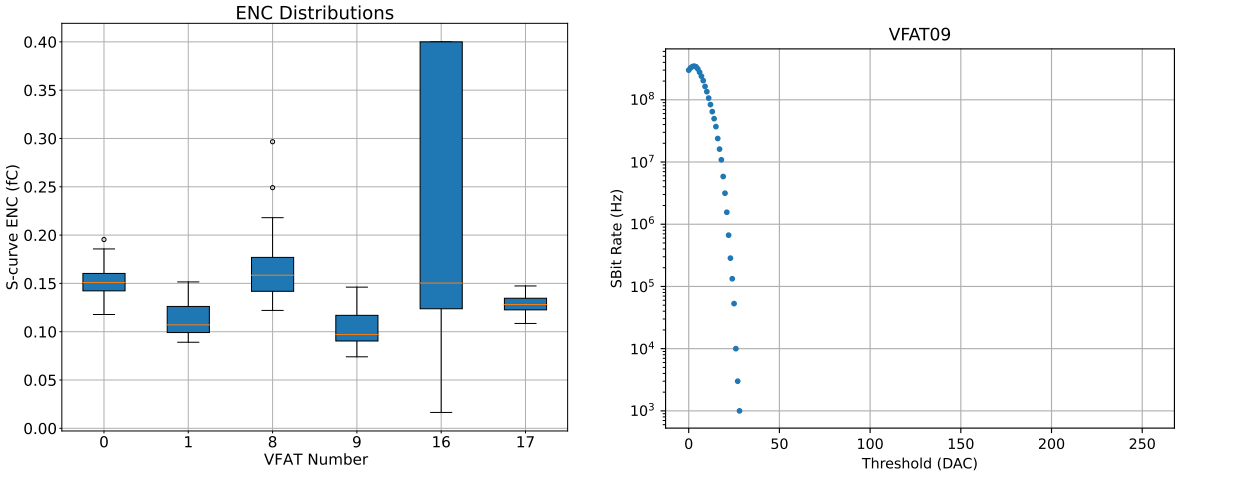
CERN ME0 test stand.

Florida Tech ME0 test stand.

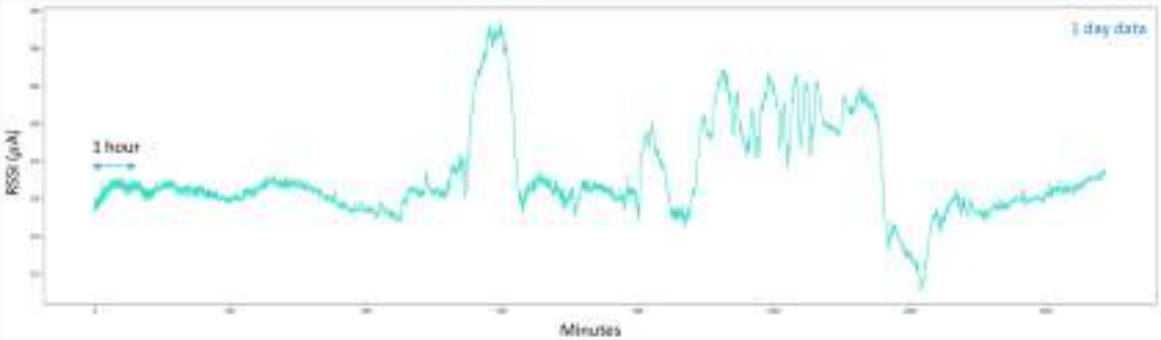
ME0 Frontend Electronics — Tests & Results

- Full slow control communication with VFATs
- Full readout capabilities of DAQ and trigger data
- Can synchronize, calibrate, and operate all VFATs simultaneously

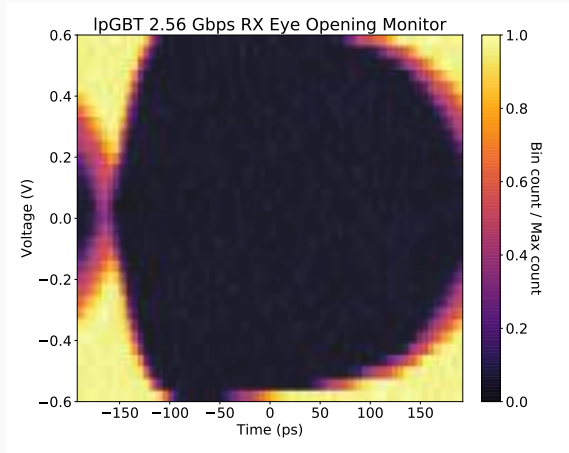
- Downlink and uplink BER $< 10^{-14}$ (measured using FEC errors)
- Downlink and uplink eye diagrams look good:



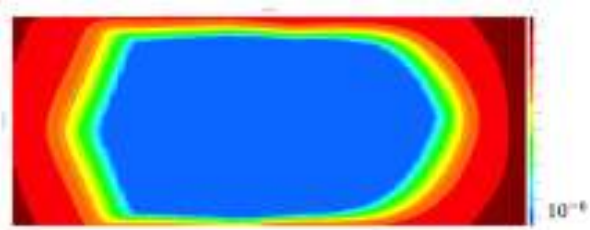
ENC measurement for DAQ path. Noise measurement for trigger path.



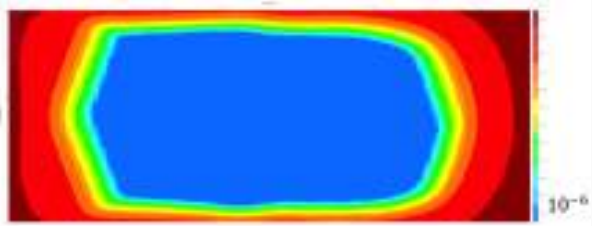
RSSI monitoring over 24 hours; range of 272–286 μA [3].



Downlink LpGBT v0 eye diagram.



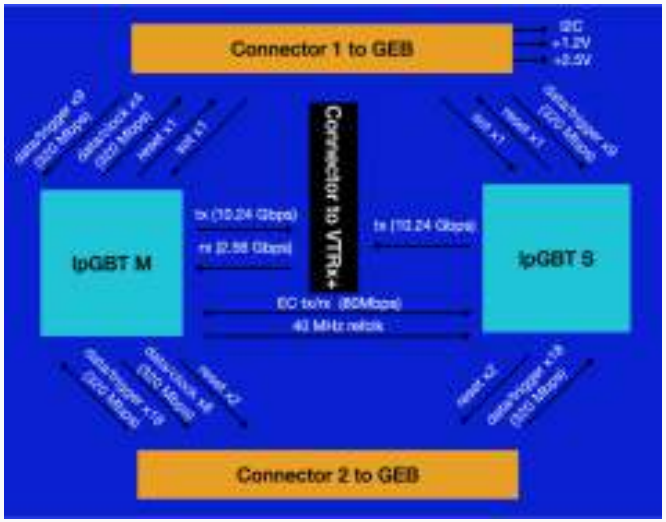
Uplink eye diagram for primary LpGBT [3].



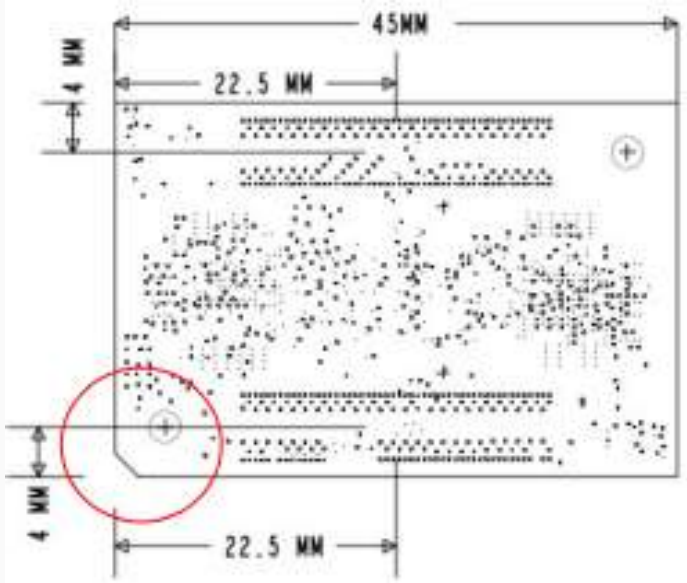
Uplink eye diagram for sub LpGBT [3].

ME0 Frontend Electronics — OH v2 Review

- ME0 Optohybrid: **ASIAGO** (**AS**IC and **G**igabit **O**ptics)
- 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

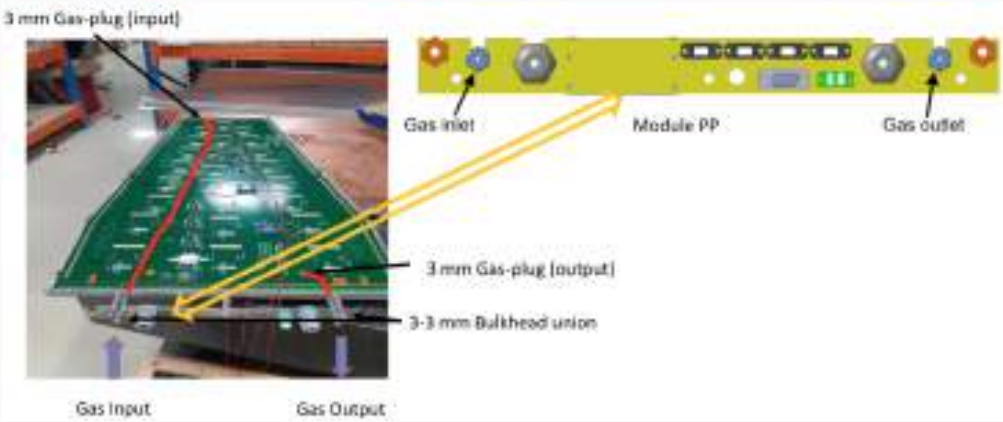


ME0 OH schematic [3].



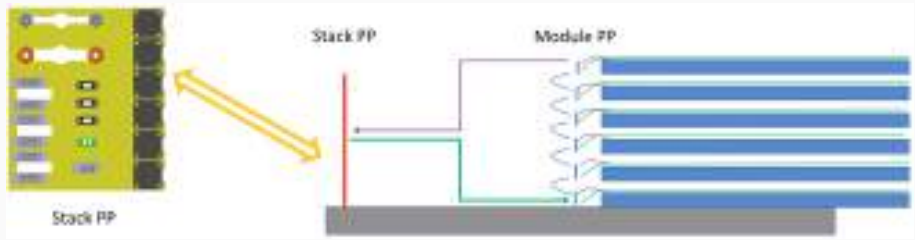
Corner of PCB will be cut to avoid connecting to GEB in the incorrect orientation [5].

ME0 On-Stack Gas Distribution

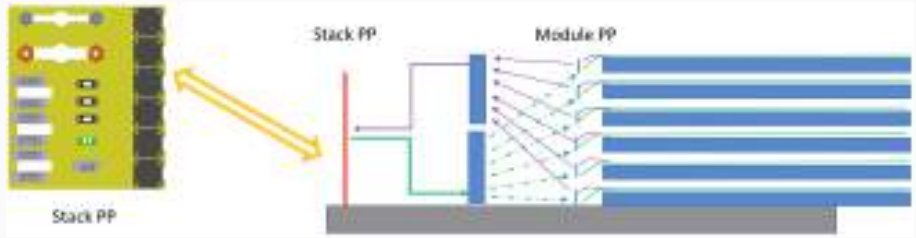


On-chamber gas distribution.

- 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 ∼25–30 mbar in the first chamber
- Moving to a parallel gas distribution scheme
- Supply and return manifold designed and prototype produced



Old design.



New design.

- 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

Milestones (TS/ES)	ID	Baseline (2017) (TDR)	Baseline (2020)	AR (2021)	Completion / Forecast
ME0 R&D					
ME0 R&D: Key detector system design parameters are defined based on performance requirements	ME0.RD.DET.1 ME0.RD.FE.1 ME0.RD.BE.1	2017-03-21	2017-03-21	2017-03-21	2017-03-21
ME0 R&D: Irradiation studies and assessment of performance and longevity with small prototypes completed	ME0.RD.DET.2	2017-07-11	2017-07-11	2017-07-11	2017-07-11
ME0 R&D: On-chamber & off-chamber electronics preliminary principal design complete and interfaces defined	ME0.RD.FE.2 ME0.RD.BE.2	2017-07-25	2017-07-25	2017-07-25	2017-07-25
ME0 R&D: Chamber (stack) prototype mechanical design completed	ME0.RD.DET.3	2018-12-18	2018-12-18	2018-12-18	2018-12-18
ME0 R&D: On-chamber electronics engineering design completed and validated	ME0.RD.FE.3	2019-08-23	2020-08-21	2020-11-06	2020-12-02
ME0 R&D: Chamber (stack) prototype mechanical prototype testing and validation complete	ME0.RD.DET.4	2019-12-24	2020-04-13	2020-09-29	2020-09-29
ME0 R&D: Full Characterization of sparks for ME0 (a new milestone requested by P2UG)			2020-05-29	2021-03-26	2021-12-31
ME0 R&D: On-chamber electronics prototype electronics manufacturing and testing is complete	ME0.RD.FE.4	2020-08-21	2021-01-08	2021-01-08	2021-04-09
ME0 R&D: Integration of the on-chamber and off-chamber electronics and performance assessment complete	ME0.RD.BE.3	2021-01-08	2021-04-02	2021-04-02	2021-06-18
ME0 R&D: Assessment of the electronics performance and integration with the demonstrator chamber completed	ME0.RD.DET.5 ME0.RD.FE.5	2021-03-30	2021-05-28	2021-05-28	2021-08-27
ME0 R&D: Beams and Cosmics testing of the demonstrator chamber and performance qualification completed	ME0.RD.DET.6	2021-08-31	2021-10-29	2021-10-29	2022-02-11
ME0 PRR for the Foil Production		2021-06-14	2021-06-25	2021-09-17	2022-02-11
ME0 ESR		2021-04-27	2021-12-01	2021-12-01	2022-02-11
ME0 Detector EDR		2021-10-28	2021-10-29	2021-10-29	2022-02-11

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 $\Rightarrow$ should be mostly done by end of CY2021 [6]
- $\sim$2 month delay compared to AR-2021
- Major improvements to design projected to significantly improve rate capability and discharge protection
- EDR and ESR planned for early 2022
  - Significant risks to schedule due to high density of activities
  - Additional delays ($\sim$1-2 months) are likely

ME0 Construction Milestones & Schedule

- Only a few delays accumulated over the last year [6]
  - $\sim$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

Milestones (T5/E5)	ID	Baseline (2017) (TDR)	Baseline (2020)	AR (2021)	Completion / Forecast
ME0 Construction					
ME0 On-Chamber Electronics Manufacturing and Testing complete, ready for chamber (stack) assembly	ME0.PR.FE.1	2022-03-29	2022-09-07	2022-09-07	2022-11-18
ME0 Chambers for Disk-1 are assembled, tested, and ready for installation	ME0.PR.DET.1	2023-05-04	2023-12-12	2024-04-12	2024-05-23
ME0 Off-Chamber Electronics Manufacturing & Testing complete	ME0.PR.BE.1	2023-06-08	2023-06-08	2023-06-08	2023-06-08
ME0 Chambers for Disk-2 are assembled, tested, and ready for installation	ME0.PR.DET.2	2024-03-07	2024-10-15	2025-02-14	2025-03-27
All ME0 Stacks Installed in the New Nose. Detector is ready for installation as part of the endcap at Pt. 5	ME0.PR.DET.3	2024-05-23	2026-03-23	2026-03-23	2026-03-23
Construction Project Complete. Ready for Global System Commissioning	ME0.PR.DET.4 ME0.PR.FE.2 ME0.PR.BE.2	2025-09-12	2026-05-28	2026-05-28	2026-05-28

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 ($\sim$2 months) expected
- New aging and rate capability studies underway due to more stringent requirements
- EDR and ESR projected for early 2022
- $\sim$1.5 month delay for construction, 40 weeks of float

References

[1] CMS Collaboration, *The Phase-2 Upgrade of the CMS Muon Detectors, Technical Report* **CERN-LHCC-2017-012**, **CMS-TDR-016** (2017).

[2] M. Bianco, "Possible modifications for future ME0 GEBs," presented at the *GEM Phase-2 Electronics Meeting*, Aug. 12, 2021, https://indico.cern.ch/event/1064795/contributions/4478589/attachments/2293706/3900310/ME0_GEB_ChangeDesign_Request.pdf.

[3] J. Carlson, et al., "ME0 Optohybrid v2 Design Review," presented at the *GEM Phase-2 Electronics Meeting*, Jul. 29, 2021, https://indico.cern.ch/event/1062189/contributions/4466997/attachments/2287668/3891468/ME0_OHv2_Review.pdf.

[4] J. Carlson, et al., "BPOL12V Power Efficiency," presented at the *GEM Phase-2 Electronics Meeting*, Jun. 17, 2021, https://indico.cern.ch/event/1047777/contributions/4413040/attachments/2266480/3851710/2021.06.17_Phase2_Update.pdf.

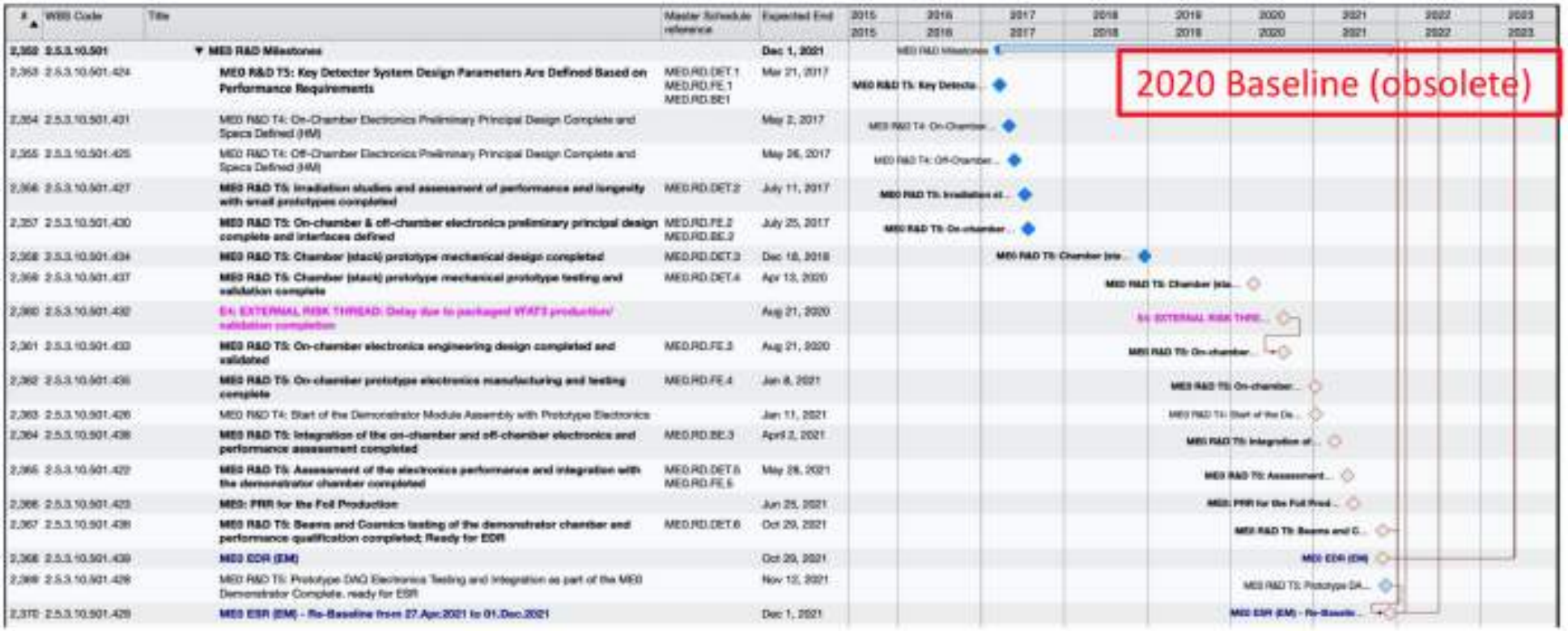
[5] A. Datta et al., "ME0 Optohybrid-v2 Review Status Update," presented at the *GEM Phase-2 Electronics Meeting*, Aug. 26, 2021,https://indico.cern.ch/event/1068179/contributions/4491721/attachments/2298330/3910111/ME0_OH_v2_Review_Status_2.pdf.

[6] A. Safanov & M. Hohlmann, "GEM Phase-2 Project: Schedule Status," presented at the *GEM Phase-2 Upgrade Coordination Meeting*, Aug. 27, 2021, https://indico.cern.ch/event/1070338/contributions/4500871/attachments/2301735/3915369/GEM-Milestones-PrepForAR2021-20210901.pdf.

Backup

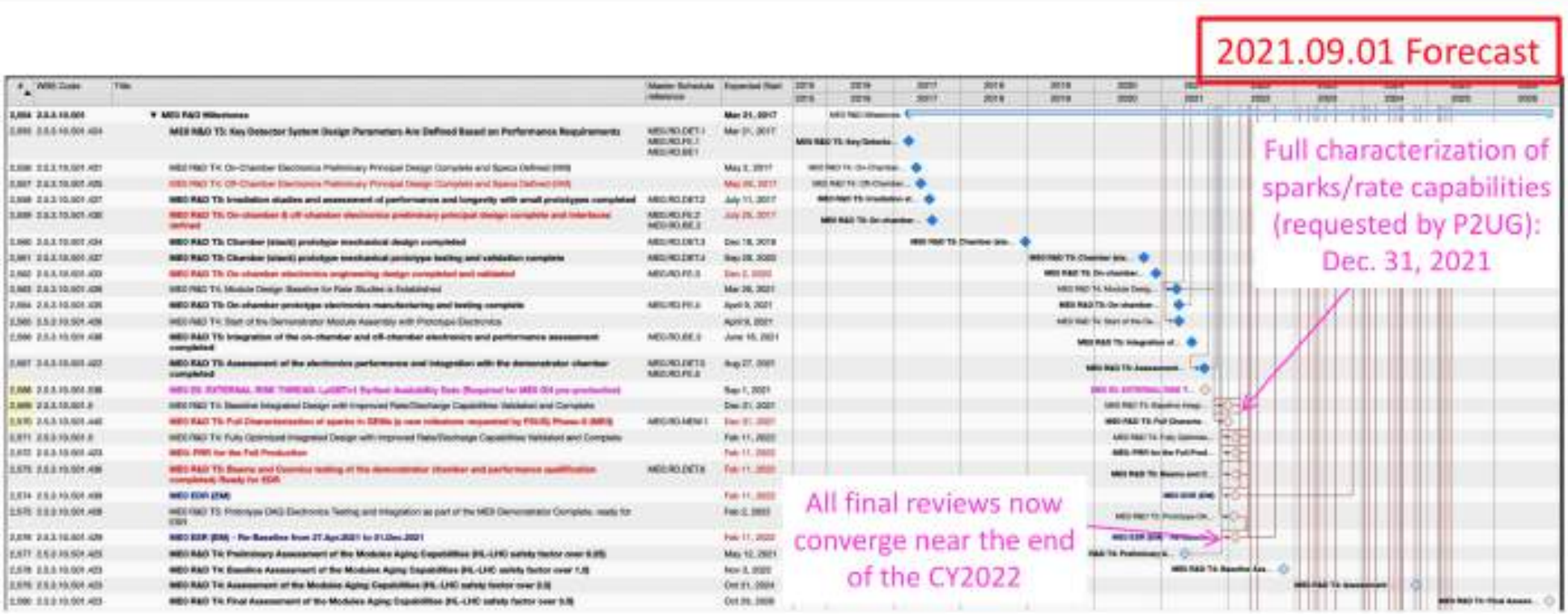
ME0 R&D Baseline Schedule

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



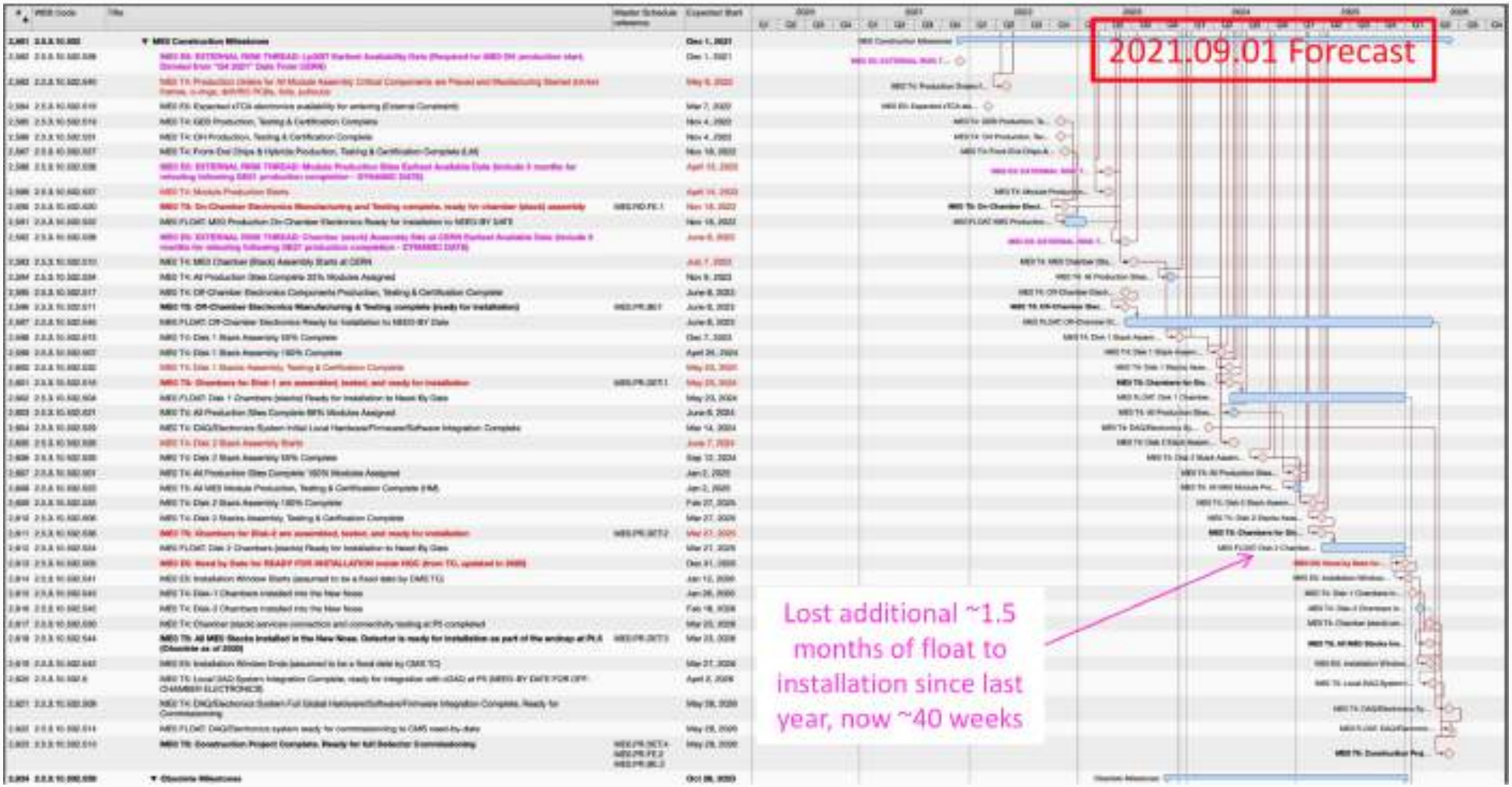
ME0 R&D Schedule Forecast

- Forecasted R&D schedule [6]:



ME0 Construction Schedule Forecast

- Forecasted construction schedule [6]:



ME0 Aging and Rate Studies Schedule

- Aging and rate studies schedule [6]: