Detector R&D

CMB-S4 Detector Prototype, Preproduction and Production Schedule Planning

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Outline

Overall Project Schedule

Detector R&D

Detector Fabrication

High Level Milestones

NSF Level 1 Milestones (DOE Critical Decisions)	Schedule (FY)
Pre-Conceptual Design (DOE CD-0, Mission Need)	July 26, 2019 ★
Preliminary Baseline (CD-1/3a, Cost Range/Long Lead Procurement)	Q3 2021
Preliminary Design Review (CD-2 Performance Baseline)	Q2 2022
Final Design Review (CD-3, Start of Construction)	Q4 2023
Completion of the 1st Telescope, (CD-4a, Initial Operations)	Q2 2026
Project Completion (CD-4, Operations)	Q1 2029

R&D in progress now

★ CD-0 achieved

The schedule driver for the project is the detector fabrication

Now – April 2021 Pre-conceptual R&D and Design Dev.

CMBS4-P03.01.03 Milestones		2492	01-Oct-18	29-Sep-28
MS001	R&D Proposal to DOE & CDR Proposal to NSF	0		21-Dec-18*
MS002	Initial Input to the Decadel Survey	0		29-Mar-19*
CMBS4-P03.01.03.01 Project Milestones		2371	01-Apr-19	29-Sep-28
CD0	L1 - CD0 Approval	0		July 26, 2019
CDRNSF	L1 - NSF CDR Review	0		30-Sep-19
MS029	L2 R&D - Rf Coupling Comparison Study Complete	0		01-Oct-19*
MS030	L2 R&D - CMB-S4 Wafer Design Complete for 90/150 Wafer	0		01-Apr-20*
MS8753	L2 R&D - CMB-S4 Prototype Detector Module Ready for Testing	0		01-Oct-20*
CD0103A	L1 - CD1/3A/ NSF PDR Approval	0		01-Apr-21*
M0007	L2 D&R - Detector and Readouts Preproduction START	0		13-May-21
MS013	L2 Sites - Chile permission for major construction granted	0		20-Dec-21
CD0203B	L1 - CD2/3B NSF FDR Approval	0		31-Mar-22*
MS026	L2 LAT - Camera Design Complete	0		23-Jun-22
MS028	L2 SAT - Preliminary Design Review - SAT	0		16-Feb-23
MS010	L2 D&R - Detector and Readouts Production START	0		09-Jun-23
MS027	L2 D&R - Detector Wafer Production START	0		09-Jun-23
CD03	L1 - CD3 Approval	0		29-Sep-23*
MS009	L2 LAT - LG Telescopes Design Complete	0		15-Dec-23
MS024	L2 DM - Challenge Milestones Complete	0		06-May-24
MS015	L2 Sites - Chile ready for telescope installation	0		08-Jul-24
MS014	L2 LAT - Pre-ship review complete ready for LG Tele 1 to SHIP to Pole	0		14-May-25
MS016	L2 LAT - LG Telescope #2 to SHIP to Chile	0		03-Nov-25
MS019	L2 LAT - LG Telescope #3 to SHIP to Chile	0		20-Feb-26
MS021	L2 LAT - Accept Cam #1 in US Complete	0		01-Sep-26
MS020	L2 D&R - Detector and Readouts Production Complete	0		22-Sep-26
MS017	L2 Sites - Accept LG Tel #1 from contractor	0		08-Jan-27
MS023	L2 I&C - LG Telescope #1/Camera #2 Commissioning Complete at Pole	0		31-Aug-27
MS025	L2 I&C - LG Telescope #3/Camera #3 Commissioning Complete - Chile	0		13-Oct-27
CD04	L1 - CD4 Approval, Start of Operations	0		29-Sep-28

~2.5 years R&D

~2 years pre-production

~3 years production

~2 years assembly, test, deploy

Detector and Readout Development

- Dec. 2018 Review Reference Design: Time Division Multiplexing (TDM) Readout with Horn coupled detectors and MUX factor x32; updated to x64 for Decadal Survey report
  - Conclusion: Detector fabrication is the critical path

- Jan. 2019 Detector and Readout Task force formed and focused on detector fabrication: Phase 1 report
  - Identified 7 potential Fab sites, inc. 3 DOE; sufficient capacity to build the CMB-S4 detectors in ~ 3 years

- Aug. 2019 DOE review to assess existing and planned capabilities of DOE sites.
  - DOE capabilities deemed appropriate
  - Recommended engaging other sites
  - Recommended substantial testing during fabrication

Readout Decision Impacts Detectors and Test Systems

- Resistance of the detectors
  - ~0.7 Ohm for Digital Frequency Multiplexing (fMUX)
  - ~10 mOhm for Micro-Wave Multiplexing (uMUX) and TDM
  - Change of resistance is not viewed as a big impact on fabrication, but once choice is made the recipe will require tuning
- Module design and test systems must match detector and readout choices
- June 2019: Project decision to develop a full system conceptual design for fMUX and uMUX plus the associated cost and schedule so that we can bring them to the same level as TDM in the reference design
- Dec. 2019 assessment of the readout options – early date for readout down select

Detector R&D in progress through April 2021

- DOE provided R&D funding in May 2019
  - Project invested DOE R&D funds to transition DOE facilities toward CMB-S4 fabrication
  - **Focus of this early R&D is on developing DOE site capabilities with fabricating horn-coupled detectors compatible with TDM/uMUX readout (Ref. design)**
  - Will also produce a few detector wafers for readout tests
  - Assess challenges with fabricating low Rn
  - Demonstrate fab of low, mid and high frequency detectors
  - Readout and module development in parallel
  - Testing will primarily use existing infrastructure
- By April 2020: Produce S4 prototype wafers ready for assembly into detector modules
- By Oct 2020 Performance of S4 prototype wafer and detector module fully characterized, changes for final prototype run well understood
- April 2021 DOE CD-1 Review: Cost and Schedule ranges well understood
- June 2021 Pre-production start is defined by a Preproduction readiness review: readout, module design and testing plans

Detector and Readout Preproduction must firm up cost and schedule estimates

- June 2021 – June 2023 Preproduction
  - Only small changes in basic detector, readout and module designs
  - Complete demonstration of all array types
  - Build up sufficient testing capacity to support production
  - Focus is on validating/improving yield and throughput
  - End of Preproduction is defined by a production readiness review, includes readout, module design and testing plans
- March 2022 – DOE CD-2/3B Review : Cost and schedule baseline cast in stone

Detector Production

- July 2023 Production wafer production start
  - Need 432 wafers so plan to produce 500 science grade (15% spares for any post-processing losses) in ~ 3 years
  - Detectors produced in 10 batches of 50 science grade wafers each, every 10 weeks (40 working weeks/year)
  - Task Force Phase 1 found a range of responses consistent with this model, but **Requires multiple fab lines at multiple sites**
  - **Current schedule is agnostic about where the wafers are fabricated and does not specifically address specific detector parameters (frequency bands etc).**

- Module assembly and testing must keep up with detector fabrication: requires multiple sites

- July 2026 Final fully tested module delivered for cryostat integration

Summary and Conclusions

- CMB-S4 requires production of ~ 500 science grade detector wafers in ~ 3 years
- Critical decisions on readout and rf-coupling impact detector wafer designs
- R&D is in progress to bring multiple readout technologies to a similar level of system design, cost and schedule
- Past and current R&D focused on bringing up key capabilities at DOE sites