



Detector Readout and Module (DRM) Plans

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CMB-S4 Collaboration Meeting
May 9-13, 2022



Outline



- Strawperson Detector fabrication plan and status of P6 cost and schedule
- Getting from R&D to Production

Strawperson Detector Fabrication Plan Uses 6 Sites To Reduce Risk

- Each detector type fabricated by at least 2 sites to reduce risk of single point failure
- Develop 6 sites (SLAC starts FY25/26), maximize flexibility to capture existing resources and expertise; minimize need to hire/train new people or procure new equipment
- Build on existing experience and relationships between Labs, Universities and Commercial
- July 2021 request for information (RFI) sent to all fab. sites: production rates, cost, equipment needs, potential for ramp up beyond current rate
- To protect proprietary information we calculated an average rate and cost; used in P6
 - Average rate ~2 science grade wafers per month per site; some sites indicated additional capacity available
 - Average cost per science grade wafer calculated from RFI response is ~\$97K
- Project will optimize the strawperson fabrication plan based on risk, cost and schedule as we proceed through prototype and pre-production stages

Strawperson Production Fabrication Plan Lasts ~Four Years

- Production sequence incorporated P6
- Total detector production cost (in P6) uses the average cost per wafer and the distribution across sites in this plan
- Plan to reoptimize based on performance, risk, cost and schedule at least annually

| Pixels/ wafer | | Number Wafers | name |
|------------------|-----------------|------------------|------------|
| 12 | SAT 30/40GHz | 24 | SAT LF |
| 27 | LAT 20GHz | 4 | LAT ULF |
| 48 | LAT 30/40GHz | 25 | LAT LF |
| 147 | SAT 85/145 | 72 | SAT MF1 |
| 169 | SAT 95/155 | 72 | SAT MF2 |
| 432 | LAT 90/150 | 162 | LAT MF |
| 469 | SAT/LAT 225/278 | 112 | SAT/LAT HF |

DATE FOR PRODUCTION START (CD-3a) DEPENDS ON FY23/24 FUNDING, Columns are ~ 6 Month intervals

Science Grade Wafers

Years are approximate dates

| | 2025 | | 2026 | | 2027 | | 2028 | | 2029 | | Total |
|--|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|------------|------------|
| Site 1 = ANL | 2 | 8 | 8 | 10 | 10 | 12 | 12 | 12 | 12 | 12 | 98 |
| Site 2 = JPL | 2 | 10 | 6 | 18 | 8 | 12 | 12 | 12 | 10 | 12 | 102 |
| Site 3 = SEEQC | 2 | 10 | 12 | 10 | 10 | 12 | 12 | 12 | 12 | 12 | 104 |
| Site 4 = NIST | 2 | 11 | 12 | 12 | 12 | 10 | 10 | 12 | 12 | 12 | 105 |
| Site 5 = SLAC | | | | | 10 | 12 | 8 | 14 | 15 | 15 | 74 |
| Site 6 = Marvell | 2 | 4 | 4 | 5 | 2 | 4 | 4 | 5 | 5 | 5 | 40 |
| Total Science Grade | 10 | 43 | 42 | 55 | 52 | 62 | 58 | 67 | 66 | 68 | 523 |
| ~ Number of wafer modules to test | 15 | 63 | 62 | 81 | 76 | 91 | 85 | 99 | 97 | 100 | 769 |

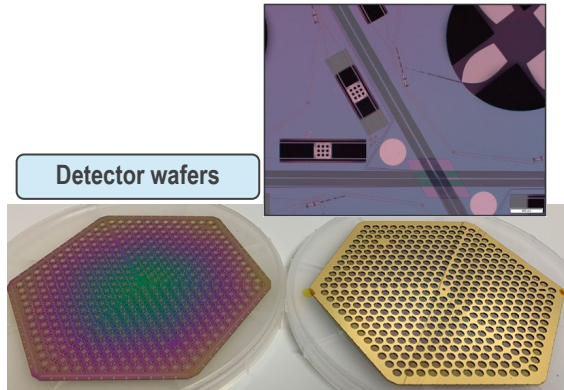
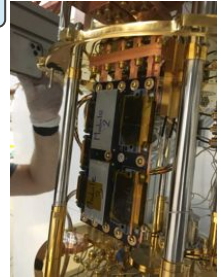
R&D (FY19-present) Addresses Highest Risks

Detectors, Readout, Modules Assembly and Test

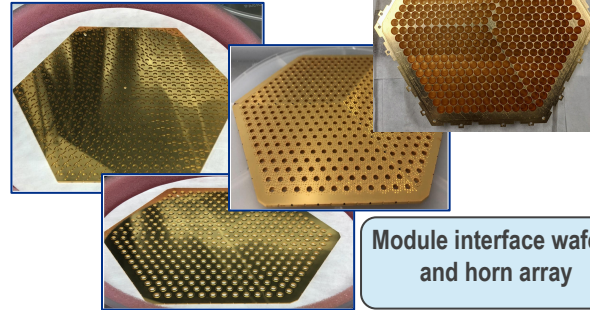
- Develop dual Tc transition edge sensor (TES) arrays at multiple sites to validate processes and qualification for the detector fabrication plan
- Develop readout hardware interfacing to detector design
- Develop module assembly and test capabilities



Readout hardware



Detector wafers



Module interface wafers and horn array

R&D overview

Focus on development of prototype detector arrays, readout and modules

CDFG Goals established in 2020: Define requirements for CDFG wafers (dark only), Fabricate CDFG wafers, Build into modules, perform Dark tests

CDFG wafers: LAT MF and SAT-MF-Like

Rf-coupling wafers turned out to be unexpected bottleneck

FY22: CDFG wafers delivered to FNAL from Seeqc and ANL,
100 mk RO boards from SLAC will arrive in May, dark tests this summer

FY 22/23 Plan: Refine requirements, develop detailed layouts, focus fab sites on specific wafer types, fabricate prototype wafer for dark and optical testing in FY22/23:

Seeqc, JPL - SAT MF2

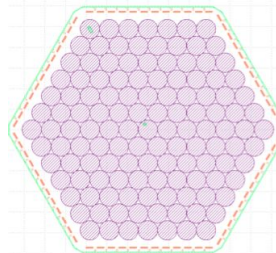
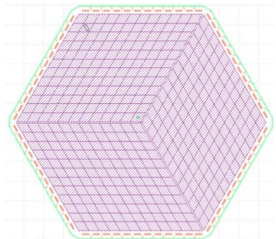
ANL, NIST - LAT MF

UCB - LAT LF

1st CMB-S4 detector wafers: CDFG Wafers

- Developed parameters in May 2020, RFI to Fab sites July 2020
- Based on the detector parameters for LAT mid frequency bands (90/150) - Dark
- Two layouts: LAT MF (5.3mm pitch) and SAT-like MF (9.4mm pitch)
- Wafers will be assembled into flat modules
- Minimum goal: Dark tests
- Optical tests if possible

ANL and Seegc fabricated, tested and delivered CDFG wafers to FNAL in FY22.

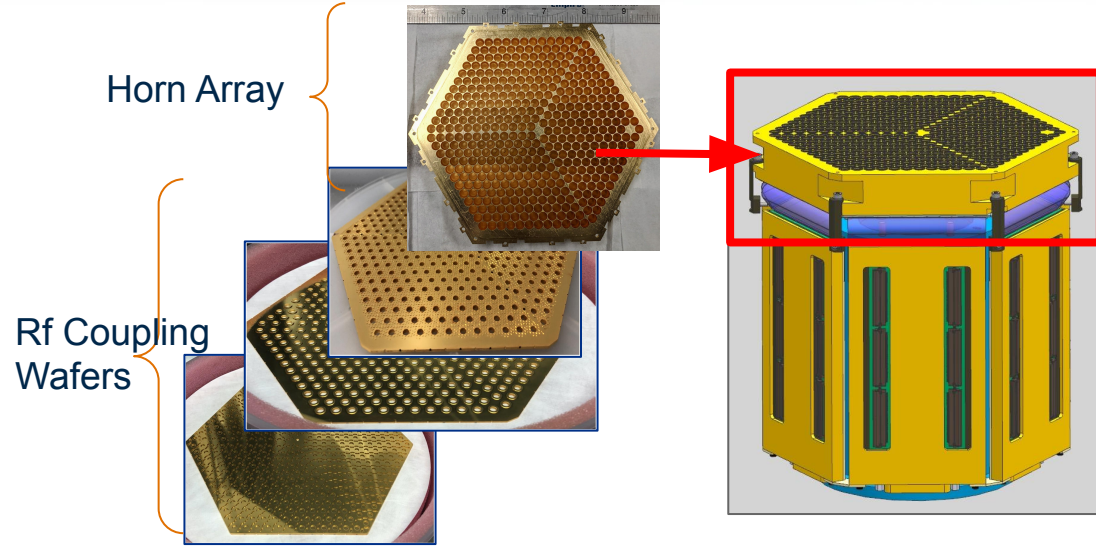


| 90GHz | Parameter | Low | Target | High |
|-------------|---|----------------|----------------|-----------------|
| Science TES | Psat (pW) | 2.8 | 3.5 | 4.6 |
| " | Tc (mK) (at fixed Psat) | 139 | 160 | 184 |
| " | $\frac{T_c^2 P_{sat}}{T_{c,\beta}^2 P_{sat,\beta}}$ | - | 1 | 1.32 |
| " | Rn (mOhms) | 8 | 12 | 16 |
| High-Tc TES | Psat (pW) | 26 | 29 | (readout limit) |
| | Rn | 2*Rn_science | 2.5*Rn_science | - |
| | Tc | 2.5*Tc_science | - | - |

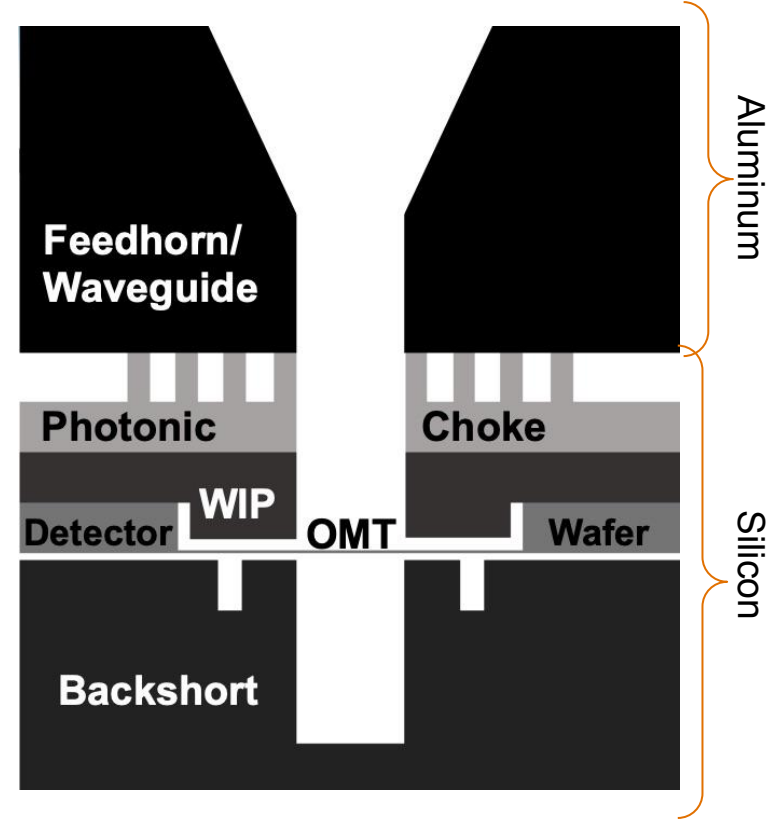
| 150GHz | Parameter | Low (pW) | Target (pW) | High (pW) |
|-------------|---|----------------|----------------|-----------------|
| Science TES | Psat (pW) | 6.0 | 7.5 | 9.9 |
| " | Tc (mK) (at fixed Psat) | 139 | 160 | 184 |
| " | $\frac{T_c^2 P_{sat}}{T_{c,\beta}^2 P_{sat,\beta}}$ | - | 1 | 1.32 |
| " | Rn (mOhms) | 8 | 12 | 16 |
| High-Tc TES | Psat (pW) | 49 | 54 | (readout limit) |
| | Rn | 2*Rn_science | 2.5*Rn_science | - |
| | Tc | 2.5*Tc_science | - | - |

Table 1: Deployment detector parameter targets and acceptable ranges.

CMB-S4 Module Design: Detector Wafer + Readout + Rf Coupling



- Compact prototype module design brings together feedhorns, Rf Coupling wafers, detector wafers, 100 mK readout boards and mechanical support and cooling connections.



FY22/23 Flat Modules: Don't Require Superconducting Flex Cable

- **Module prototype:** Use “flat” module to facilitate first “string tests” of prototype detectors and readout
- **Optical tests require Rf coupling wafer prototypes:** contract in place for prototype LAT MF, delivery this summer, SAT MF2 will follow.
- **Develop module test sites:** Outfit 3 testbeds with readout and test equipment to characterize and develop integrated detector modules.
- Expect to test ~ 6 wafers from in FY22

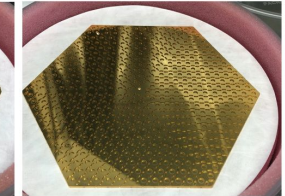
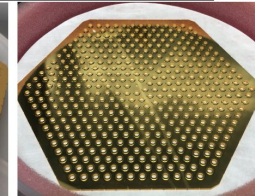
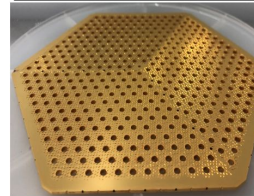
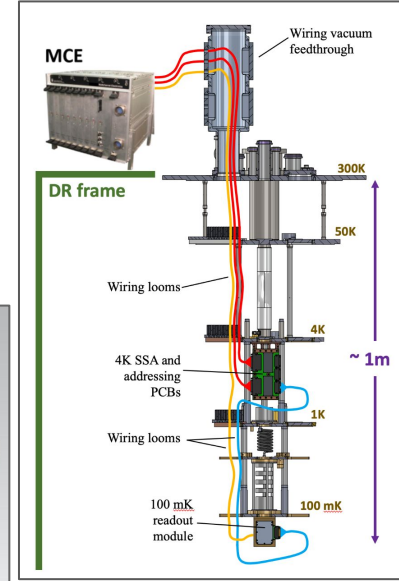
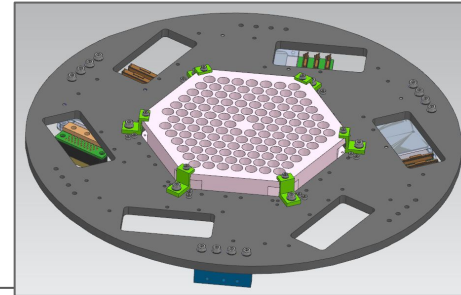
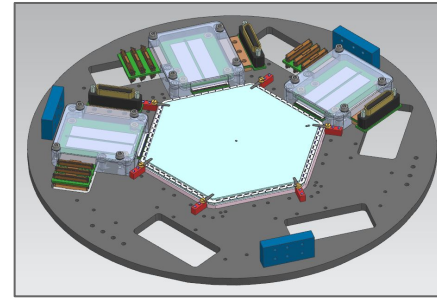


Figure 43: **Left:** A photonic choke wafer. **Center:** A waveguide interface plate. **Right:** A backshort array.



Starting to Use JIRA to Track R&D Planning

| # | Issue | + Create issue | Status | Start date ^D | Due date ^D |
|---|---|----------------|-------------|-------------------------|-----------------------|
| 1 | DRM-1 1.03 Detectors | | IN PROGRESS | 01/Mar/22 | |
| | DRM-33 1.03.01 Detector Management | | IN PROGRESS | 01/Mar/22 | 28/Apr/23 |
| | DRM-42 Finalize FY22/23 SOWs with Fabrication Sites | | DONE | 21/Mar/22 | 29/Apr/22 |
| | DRM-43 Advance the detail in the ICD for LAT MF, SAT MF2 and LAT LF | | IN PROGRESS | 05/Apr/22 | 29/Jul/22 |
| | DRM-44 Finalize first release of the Detector Requirements | | IN PROGRESS | 30/Mar/22 | 31/May/22 |
| | DRM-53 Refine production schedule for SAT Detector wafers | | IN PROGRESS | 11/Apr/22 | 31/May/22 |
| | DRM-4 1.03.02 ANL Wafer Fabrication | | BACKLOG | 01/Apr/22 | 28/Apr/23 |
| | DRM-5 1.03.03 SLAC Wafer Fabrication | | IN PROGRESS | 01/Mar/22 | |
| | DRM-6 1.03.04 JPL Wafer Fabrication | | IN PROGRESS | 02/May/22 | 28/Apr/23 |
| | DRM-7 1.03.05 NIST Wafer Fabrication | | IN PROGRESS | 01/Mar/22 | 28/Apr/23 |
| | DRM-8 1.03.06 LBNL/SeeQC Wafer Fabrication | | IN PROGRESS | 01/Mar/22 | 28/Feb/23 |
| | DRM-9 1.03.07 UCB/Marvell Wafer Fabrication | | IN PROGRESS | 01/Mar/22 | 28/Feb/23 |

TARGET START

Argonne FY22 Deliverables Will Focus on Microstrip Materials and Fabrication Process Development

| <input type="checkbox"/> # | Issue <input type="checkbox"/> | + Create issue | Status | Target st... <input type="checkbox"/> | Start date <input type="checkbox"/> D | Due date <input type="checkbox"/> D |
|---|--|--------------------------------|-------------|---------------------------------------|---------------------------------------|-------------------------------------|
| <input type="checkbox"/> 1 <input type="checkbox"/> | <input checked="" type="checkbox"/> DRM-1 1.03 Detectors | | IN PROGRESS | | 01/Mar/22 <input type="checkbox"/> | |
| <input type="checkbox"/> | <input checked="" type="checkbox"/> DRM-33 1.03.01 Detector Management | | IN PROGRESS | | 01/Mar/22 <input type="checkbox"/> | 28/Apr/23 <input type="checkbox"/> |
| <input type="checkbox"/> | <input checked="" type="checkbox"/> DRM-4 1.03.02 ANL Wafer Fabrication | | BACKLOG | | 01/Apr/22 <input type="checkbox"/> | 28/Apr/23 <input type="checkbox"/> |
| <input type="checkbox"/> | <input checked="" type="checkbox"/> DRM-54 Studies of microstrip materials and fabrication processes | | IN PROGRESS | 01/Apr/22 <input type="checkbox"/> | 02/May/22 <input type="checkbox"/> | 28/Apr/23 <input type="checkbox"/> |
| <input type="checkbox"/> | <input checked="" type="checkbox"/> DRM-55 First iteration studies of microstrip materials properties and i... | | IN PROGRESS | 01/Apr/22 <input type="checkbox"/> | 02/May/22 <input type="checkbox"/> | 31/Oct/22 <input type="checkbox"/> |
| <input type="checkbox"/> | <input checked="" type="checkbox"/> DRM-56 Second iteration studies of microstrip materials properties an... | | BACKLOG | 01/Jul/22 <input type="checkbox"/> | 01/Nov/22 <input type="checkbox"/> | 28/Apr/23 <input type="checkbox"/> |

JPL/CalTech is Developing a prototype SAT MF2 Detector Wafer

| # | Issue | + Create issue | Status | Target st... | Start date | Due date |
|---|--|----------------|-------------|--------------|------------|-----------|
| 1 | DRM-1 1.03 Detectors | | IN PROGRESS | | 01/Mar/22 | |
| | DRM-6 1.03.04 JPL Wafer Fabrication | | IN PROGRESS | | 02/May/22 | 28/Apr/23 |
| | DRM-46 Confirm interfaces to SAT MF2 wafer | | IN PROGRESS | 02/May/22 | 02/May/22 | 31/May/22 |
| | DRM-47 SAT MF2 Bolometer cell layout | | BACKLOG | 01/Jun/22 | 01/Jun/22 | 30/Jun/22 |
| | DRM-48 SAT MF2 Wafer Layout | | BACKLOG | 01/Jul/22 | 01/Jul/22 | 31/Aug/22 |
| | DRM-49 Test fixture design | | BACKLOG | 01/Sep/22 | 01/Sep/22 | 23/Sep/22 |
| | DRM-50 SAT MF2 Wafer Fabrication | | BACKLOG | 01/Sep/22 | 01/Sep/22 | 01/Feb/23 |
| | DRM-51 Assemble wafer into test fixture | | BACKLOG | 09/Feb/23 | 06/Feb/23 | 28/Feb/23 |
| | DRM-52 Optical testing SAT MF2 | | BACKLOG | 01/Mar/23 | 01/Mar/23 | 28/Apr/23 |

LBNL/Seeqc is Developing an S4 Level SAT MF2 Detector Wafer to Deliver to MAT

| # | Issue | + Create issue | Status | Target st... ↑ | Start date ^D | Due date ^D |
|---|--|----------------|-------------|----------------|-------------------------|-----------------------|
| 1 | DRM-1 1.03 Detectors | | IN PROGRESS | | 01/Mar/22 | |
| | DRM-8 1.03.06 LBNL/SeeQC Wafer Fabrication | | IN PROGRESS | | 01/Mar/22 | 28/Feb/23 |
| | DRM-15 SAT MF2 Design and Layout | | DONE | | 01/Mar/22 | 29/Apr/22 |
| | DRM-16 Fabricate first articles of SAT MF2 | | IN PROGRESS | 02/May/22 | 02/May/22 | 30/Jun/22 |
| | DRM-17 Test SAT MF2 Wafer LBL, deliver to FNAL | | BACKLOG | 01/Jul/22 | 01/Jul/22 | 29/Jul/22 |
| | DRM-18 Design update using FNAL Dark Characterization feedback | | BACKLOG | 01/Nov/22 | 01/Nov/22 | 22/Dec/22 |
| | DRM-19 Fabricate second batch of SAT MF2 wafers | | BACKLOG | 04/Jan/23 | 04/Jan/23 | 28/Feb/23 |

NIST is Developing an S4 Level LAT MF Detector Wafer to Deliver to MAT

| <input type="checkbox"/> # | Issue <input type="checkbox"/> | + Create issue | Status | Target st... <input type="checkbox"/> | Start date <input type="checkbox"/> | Due date <input type="checkbox"/> |
|----------------------------|--|--------------------------------|-------------|---------------------------------------|-------------------------------------|------------------------------------|
| <input type="checkbox"/> 1 | <input checked="" type="checkbox"/> DRM-1 1.03 Detectors | | IN PROGRESS | | 01/Mar/22 <input type="checkbox"/> | |
| | <input checked="" type="checkbox"/> DRM-7 1.03.05 NIST Wafer Fabrication | | IN PROGRESS | | 01/Mar/22 <input type="checkbox"/> | 28/Apr/23 <input type="checkbox"/> |
| | <input checked="" type="checkbox"/> DRM-20 Design/Layout dual TES TC bolometer sweep Chip (LAT MF) ... | | IN PROGRESS | | 01/Apr/22 <input type="checkbox"/> | 01/Jul/22 <input type="checkbox"/> |
| | <input checked="" type="checkbox"/> DRM-21 Fabrication dual TES TC bolometer sweep Chip (LAT MF) and ... | | BACKLOG | 05/Jul/22 <input type="checkbox"/> | 05/Jul/22 <input type="checkbox"/> | 25/Aug/22 <input type="checkbox"/> |
| | <input checked="" type="checkbox"/> DRM-24 Characterization of Bolometer sweeps and pixels chips | | BACKLOG | 26/Aug/22 <input type="checkbox"/> | 26/Aug/22 <input type="checkbox"/> | 28/Oct/22 <input type="checkbox"/> |
| | <input checked="" type="checkbox"/> DRM-25 Design/layout LAT MF prototype arrays | | BACKLOG | 31/Oct/22 <input type="checkbox"/> | 31/Oct/22 <input type="checkbox"/> | 22/Dec/22 <input type="checkbox"/> |
| | <input checked="" type="checkbox"/> DRM-26 Fabrication LAT MF prototype arrays (3 arrays, 1 carry along... | | BACKLOG | 04/Jan/23 <input type="checkbox"/> | 04/Jan/23 <input type="checkbox"/> | 14/Apr/23 <input type="checkbox"/> |
| | <input checked="" type="checkbox"/> DRM-27 Deliver LATMF Wafers to FNAL | | BACKLOG | 21/Apr/23 <input type="checkbox"/> | 21/Apr/23 <input type="checkbox"/> | 21/Apr/23 <input type="checkbox"/> |

UCB is Developing an S4 Level LAT LF Detector Wafer to Deliver to MAT

| # | Issue | + Create issue | Status | Target st... | Start date | Due date |
|---|--|----------------|-------------|--------------|------------|-----------|
| 1 | DRM-1 1.03 Detectors | | IN PROGRESS | | 01/Mar/22 | |
| | DRM-9 1.03.07 UCB/Marvell Wafer Fabrication | | IN PROGRESS | | 01/Mar/22 | 28/Feb/23 |
| | DRM-10 Design LAT LF Single Pixel | | DONE | | 01/Mar/22 | 29/Apr/22 |
| | DRM-11 Design LAT LF Single Pixel Wafer | | DONE | 02/May/22 | 18/Apr/22 | 31/May/22 |
| | DRM-12 Fabricate LAT LF Single Pixel Wafer | | IN PROGRESS | 01/Jun/22 | 02/May/22 | 29/Jul/22 |
| | DRM-45 Design complete LAT LF Array | | BACKLOG | 20/Jun/22 | 20/Jun/22 | 29/Jul/22 |
| | DRM-13 Fabricate LAT LF Array | | BACKLOG | 01/Aug/22 | 01/Aug/22 | 23/Dec/22 |
| | DRM-14 Basic Characterization of Single Pixels | | BACKLOG | 04/Jan/23 | 04/Jan/23 | 28/Feb/23 |

SLAC DMF Construction is on Schedule to Start CMB-S4 Detector Wafer Development in 2023

| # | Issue | + Create issue | Status | Target st... ↑ | Start date D | Due date D |
|---|--|----------------|-------------|----------------|---------------------|-------------------|
| 1 | DRM-1 1.03 Detectors | | IN PROGRESS | | 01/Mar/22 | |
| | DRM-5 1.03.03 SLAC Wafer Fabrication | | IN PROGRESS | | 01/Mar/22 | |
| | DRM-58 Construction of DMF | | IN PROGRESS | | 01/Mar/22 | 29/Jul/22 |
| | DRM-59 Tool Procurements Complete and Delivered | | IN PROGRESS | | 01/Mar/22 | 28/Feb/23 |
| | DRM-60 Start of Process Development for CMB-S4 Detectors | | BACKLOG | 01/Mar/23 | | |

Readout plans

Building detail in JIRA

1st version of 100 mK Ro module

| | | | | | | |
|--------------------------|---|---------------------------------------|--------------|---|-----------|-----------|
| <input type="checkbox"/> | 2 | DRM-2 | 1.04 Readout | 02/May/22 | | |
| <input type="checkbox"/> | | <input checked="" type="checkbox"/> | DRM-28 | 1.04.01 Readout Management | 02/May/22 | 28/Apr/23 |
| <input type="checkbox"/> | | ▼ <input checked="" type="checkbox"/> | DRM-29 | 1.04.02 Cryo 100mK Electronics | | |
| <input type="checkbox"/> | | <input checked="" type="checkbox"/> | DRM-85 | Create design schematics of the 4-Column 100mK Readout electronics with ... | 01/Aug/22 | 03/Oct/22 |
| <input type="checkbox"/> | | <input checked="" type="checkbox"/> | DRM-86 | Fabricate at UC Berkeley (with Nb (niobium)) the 4-Column 100mK Readout ... | 02/Aug/22 | 01/Dec/22 |
| <input type="checkbox"/> | | <input checked="" type="checkbox"/> | DRM-87 | Perform R&D on commercial flex cables | 01/Sep/22 | 01/Dec/22 |
| <input type="checkbox"/> | | <input checked="" type="checkbox"/> | DRM-97 | Design schematic and layout of 2-column 100mK readout module with larger... | 05/May/22 | 01/Aug/22 |
| <input type="checkbox"/> | | <input checked="" type="checkbox"/> | DRM-98 | Fabricate, assembly and test of 2-column 100mK readout module with larger... | 02/Aug/22 | 03/Oct/22 |
| <input type="checkbox"/> | | <input checked="" type="checkbox"/> | DRM-99 | For detector testing: Deliver 3 sets of 120-TES 2-column 100mK readout mo... | 05/Oct/22 | 17/Oct/22 |
| <input type="checkbox"/> | | <input checked="" type="checkbox"/> | DRM-101 | For initial debug: Deliver one 20-TES channel 2-column 100mK readout mod... | 05/May/22 | 01/Jul/22 |
| <input type="checkbox"/> | | ▼ <input checked="" type="checkbox"/> | DRM-30 | 1.04.03 Cold 4K Electronics | | |
| <input type="checkbox"/> | | <input checked="" type="checkbox"/> | DRM-88 | Performance testing of new SA20 SSA's in cryostat at SLAC | 01/Sep/22 | 01/Feb/23 |
| <input type="checkbox"/> | | <input checked="" type="checkbox"/> | DRM-89 | Deliver 3 sets of 4K Readout electronics | | |
| <input type="checkbox"/> | | <input checked="" type="checkbox"/> | DRM-90 | Super-Conducting Chip Procurement | 01/Jul/22 | 02/Jan/23 |
| <input type="checkbox"/> | | <input checked="" type="checkbox"/> | DRM-100 | Deliver SA13 SSA modules to FNAL/UIUC with 100mK-to-4K and 4k to 300K... | 05/May/22 | 25/Jul/22 |
| <input type="checkbox"/> | | ▼ <input checked="" type="checkbox"/> | DRM-31 | 1.04.04 300K Warm Readout Electronics Prototype Development | | |
| <input type="checkbox"/> | | <input checked="" type="checkbox"/> | DRM-91 | Performance testing of first article prototypes | 05/May/22 | 20/Feb/23 |
| <input type="checkbox"/> | | <input checked="" type="checkbox"/> | DRM-92 | Firmware and software Development | 05/May/22 | 13/Feb/23 |
| <input type="checkbox"/> | | ▼ <input checked="" type="checkbox"/> | DRM-32 | 1.04.06 Readout String Test | | |
| <input type="checkbox"/> | | <input checked="" type="checkbox"/> | DRM-93 | Dilution Refridgerator Modification | 01/Sep/22 | 02/Nov/22 |
| <input type="checkbox"/> | | <input checked="" type="checkbox"/> | DRM-94 | Full readout string performance testing in cryostat and support for fabricatio... | 05/May/22 | 20/Feb/23 |

Modules Plan

Building in detail in JIRA

Will use to track progress

Delivery of 100 mK readout modules from SLAC this month will be big milestone: start of module assembly and dark tests!

Coupling wafer delivery will set schedule for optical testing - expected this summer!

- 3 DRM-3 1.05 Module Assy & Test
 - DRM-34 1.05.01 Module Assy & Testing Management
 - DRM-35 1.05.02 Module Mech Structure Development
 - DRM-61 Design and Fabricate Module Prototype
 - DRM-62 Design and Fabricate Module Assembly Test Jig
 - DRM-63 Develop and deliver the hardware test summary
 - DRM-36 1.05.03 Optical Coupling
 - DRM-64 Develop and Fabricate set of 5x LAT MF coupling wafers
 - DRM-65 Develop and Fabricate set of 5x LAT MF feed horns
 - DRM-66 Develop and Fabricate set of 5x SAT MF2 coupling wafers
 - DRM-67 Develop and Fabricate set of 5x SAT MF2 feed horns
 - DRM-37 1.05.04 Module Assy
 - DRM-38 1.05.05 Test Cryostats
 - DRM-39 1.05.06 Test Equipment
 - DRM-40 1.05.07 Module Testing
 - DRM-76 Dark measurements and characterizations of at least 1x wafer of CDFG LAT ...
 - DRM-77 Optical measurements and characterization of at least 1x wafer of CDFG LAT ...
 - DRM-78 Dark measurements and characterization of at least 1x wafer of CDFG SAT M...
 - DRM-79 Dark measurements and characterization of at least 1x wafers of prototype S...
 - DRM-80 Optical measurements and characterization of at least 1x wafer of prototype ...
 - DRM-81 Dark measurements and characterization of at least 1x wafers of prototype S...

Coupling Wafer / Horn Array Schedule

- Coupling Wafers
 - LAT MF: Set of 5x LAT MF coupling wafers scheduled for delivery from SeeQC by July
 - SAT MF2: If successful, will trigger option in contract for them to fabrication set of 5x SAT MF2 coupling wafers. Delivery in ~Sept/Oct, so could enable SAT MF2 optical tests in Q1 FY23.
 - LAT LF: Requested funds to order a batch of LAT LF SOI wafers, to enable some development of LAT LF coupling wafers by Chapman, to hopefully enable some LAT LF optical tests in early FY23.
- Horn Arrays
 - Modified a set of 3x SO-Modified LAT MF horn arrays that can be used for CDFG module testing.
- These are in Hand!
 - LAT MF: Additionally, have placed PO to have a set of 5x LAT MF CMB-S4 prototypes fabricated. Delivery would be in ~2-months.
 - SAT MF2: design work in progress, would plan to begin fabrication after successful LAT MF fabrication, so sometime this ~summer.

Possible Module Testing Timeline for FY22

| <i>Month</i> | <i>Fermilab</i> | <i>SLAC</i> | <i>UIUC</i> |
|--------------|--------------------------------------|---------------------|-------------------------------------|
| April | Module mechanical cooldown | | Validate readout string performance |
| May | Dark test wafer #1 | | |
| June | Dark test wafer #2 | Receive flat module | Receive flat module |
| July | Debug wafer #2 and install cold load | Dark test wafer #4 | Dark test wafer #6 |
| August | Dark with cold load test wafer #3 | Debug wafer #4 | Debug wafer #6 |
| September | Optical test wafer #3 | Dark test wafer #5 | Dark test wafer #7 |
| October | Optical test wafer #3 | Debug wafer #5 | Debug wafer #7 |

2 months per wafer has a large error bar, will learn a lot with 1st few wafers



Summary

Strawperson Detector fabrication plan builds on fab site expertise,
Cost and schedule incorporated into P6, well documented and uses fab site responses to RFI

R&D is making great progress:

- CDFG wafers delivered to Fermilab, ready to assemble into modules this month
- Flat module design allows early module tests, w/o development of superconducting flex
- 3 module testing sites are nearly ready to test flat modules- Major milestone will be receiving 100 mK Readout modules from SLAC
- Rf coupling wafer fab transition to commercial site is in progress, first articles in July
- Detailed layout and interfaces for SAT MF2 and LAT MF are nearing completion
- Next steps :
 - Assembly and testing of CDFG wafers in flat modules
 - Fabrication of prototype CMB-S4 detector arrays for LAT MF, SAT MF2 and LAT LF
 - Assembly and testing of prototype CMB-S4 flat and tower modules