Modules & Testing (MAT) Testing Parallel

Brad Benson (L2 scientist) for WBS 1.05

Paralle Session, Thursday, March 11, 2021

Outline

- Testing Scope
- Requirements
  - Detector, Readout, Modules (DRM) FY21 R&D Plan
  - Production Testing
- Measurement Requirements
- Testing Plans
  - Prototype Testing
  - Production Testing

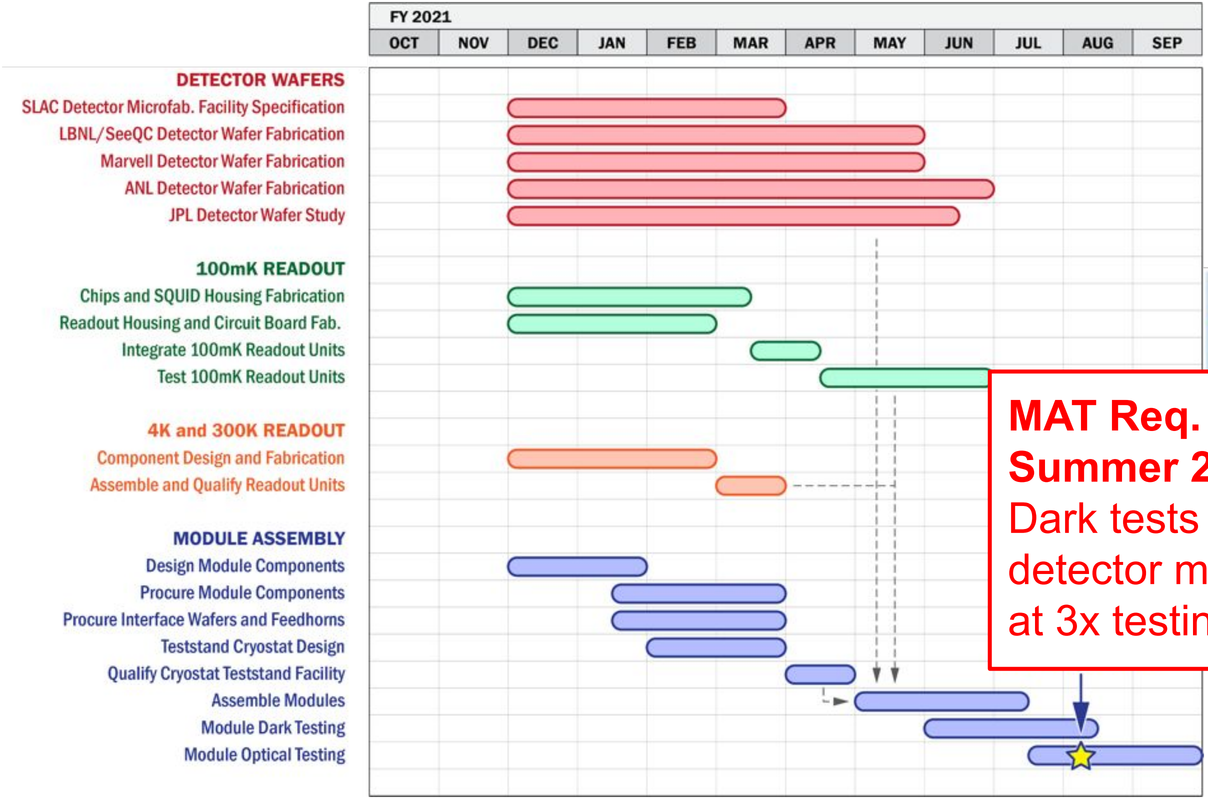
Requirements Overview

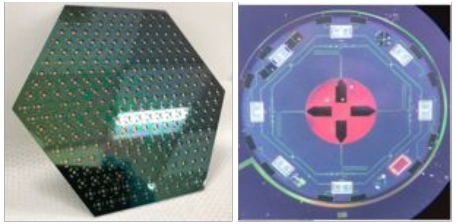
(CQ2)

High-level driving requirements include:

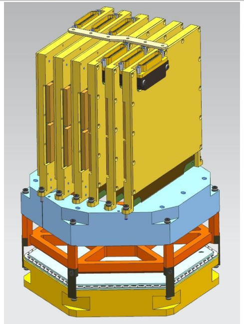
Requirement	Trace	Driver	Verification
Measure: Detector Dark Properties	MR 1.1, 1.2, 2.0, 3.0, 4.0	Verify detector wafer. Electro-thermal properties (e.g., saturation power, loop gain) of the TES need to be within an acceptable range to meet required instrument sensitivity.	Dark measurements of every detector wafer in an assembled detector module at 100 mK operating temperature.
Measure: Detector Module Optical Coupling	MR 1.1, 1.2, 2.0, 3.0, 4.0	Verify detector module optical coupling. Efficiency and frequency response of mm-wave coupling to TES needs to be within an acceptable range to meet required instrument sensitivity.	Mm-wave/optical measurements of every detector wafer in an assembled detector module at 100 mK operating temperature.
Measure: Integrated Module Sensitivity	MR 1.1, 1.2, 2.0, 3.0, 4.0	Verify detector module sensitivity. Sensitivity (efficiency, noise, yield, etc.) of integrated module (with readout) needs to be within an acceptable range to meet required instrument sensitivity.	Dark and optical measurements of every detector module with readout at 100 mK operating temperature.
Rate: Assembly and Testing	Schedule	Detector fabrication feedback. Detector module assembly and testing needs to provide measurements at a rate sufficient for detector fabrication development during all phases of project.	

MAT Requirement: R&D / Proto Testing





MAT Req.
Summer 2021
Dark tests of CDFG detector modules at 3x testing sites



See B. Flaugher's Plenary Detector Talk

MAT Requirement: Production Testing

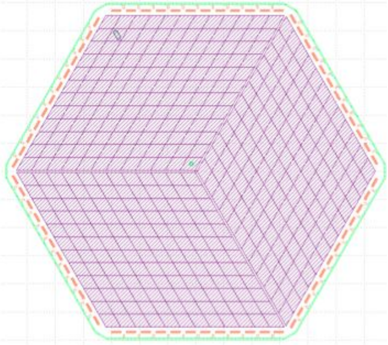
- Rates and detector types discussed with each site and iterated.
- Production rates require minimum ramp-up in capabilities at all sites
- Additional capacity is possible at most sites, with appropriate warning
- Plan to reoptimize based on performance, cost and schedule at least annually

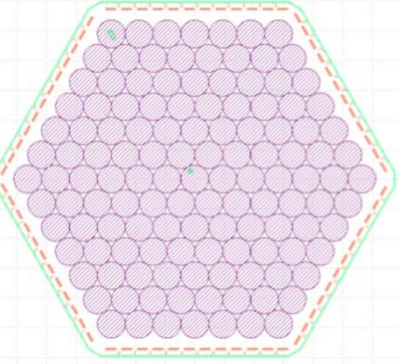
PRODUCTION		Split years into part A and B for transition to new detector type									
	FY23A	FY23B	FY24A	FY24B	FY25A	FY25B	FY26A	FY26B	FY27A	FY27B	Total
Site 1 = ANL	2	8	8	10	10	10	10	8	10	10	86
Site 2 = JPL	2	8	8	8	14	16	16	16	12	6	106
Site 3 = SEEQC	2	8	10	10	16	16	16	16	4	4	102
Site 4 = NIST	2	8	8	8	10	12	14	16	16	14	108
Site 5 = SLAC					8	12	16	11	11	10	68
Site 6 = Marvell	1	3	4	5	4	4	4	4	4		33
Total Science Grade	**9**	**35**	**38**	**41**	**62**	**70**	**76**	**71**	**57**	**44**	**503**
~ Number of wafer modules to test (inc. 12% overage and 67% yield)	**15**	**59**	**64**	**69**	**104**	**117**	**127**	**119**	**95**	**74**	**841**

MAT Req: Assemble and test ~600 detector modules over 3-year period

See B. Flaugher's Plenary Detector Talk

Measurement Req: CDFG Wafer





90GHz	Parameter	Low	Target	High
Science TES	Psat (pW)	2.8	3.5	4.6
"	Tc (mK) *(at fixed Psat)*	139	160	184
"	$\frac{T_c^2\ P_{sat}}{T_{c,0}^2\ P_{sat,0}}$	-	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
"	$\frac{T_c^2\ P_{sat}}{T_{c,0}^2\ P_{sat,0}}$	-	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.

- CDFG Wafer Interfaces
  - https://cmbs4-docdb.fnal.gov/cgi-bin/sso/ShowDocument?docid=161
- CDFG Wafer Testing Requirements:
  - https://cmbs4-docdb.fnal.gov/cgi-bin/sso/ShowDocument?docid=226
- For CDFG process, laid out both
- a) detector wafer and module interfaces, and
- b) testing and measurement requirements to characterize detector modules

Measurement Req: CDFG Wafer

150 GHz	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
"	$\frac{T_c^2 \, P_{sat}}{T_{c,0}^2 \, P_{sat,0}}$	-	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.

- CDFG Wafer Testing Requirements:
  - https://cmbs4-docdb.fnal.gov/cgi-bin/sso/ShowDocument?docid=226
  - Defines testing procedures and measurement requirements (see examples)

Section 2.1 – Planned Testing Procedure:

To characterize these parameters, the project plans to take two sets of measurements following the basic procedure below:

1) **Tc Measurement [R(T)]:** Monitor the TES resistance with a small excitation voltage as the detector wafer's temperature is slowly lowered through the expected temperature of the superconducting "science" transition (~150 mK). Measure when the TES resistance changes to measure the superconducting transition temperature, Tc.

2) **Psat, Rn, R-parasitic Measurements [IV Curve]:** Bias the TES detectors with a voltage bias that provides an electrical power expected to be above the Psat of the High-Tc Transition. Cool the detector wafer to 100 mK (+/- 5 mK). Lower the TES voltage bias with a step-size small enough to observe both the High-Tc and Science TES transitions, and measure Psat and Rn for both transitions. If possible, the voltage bias should be decreased low enough to measure the parasitic resistance of the TES+wiring, or limit them to at least a factor of five lower than Rn.

(plus Psat(T), Noise, time constants)

Section 2.2 – Measurement Requirements:

Additional requirements for the above measurements and testing configuration:

1) The above measurements should measure at least 100 TES detectors per wafer, to probe the statistics of variability of the desired parameters.
   a) Assuming a HEX-shaped wafer, the above measurement should measure at least two sides on non-neighboring (or opposite) sides of the detector wafer with approximately equal number of detectors on each side.

2) The detector wafers will be in a light-tight box which is thermally coupled to the detector wafer. This will ensure minimal "optical" (mm-wavelength) power on the detectors, ensuring that the parameters above represent the "dark" properties of the TES, with minimal radiative load.

3) The detector wafer temperature calibration should be accurate to better than 5 mK for temperatures between 100-185 mK, to ensure that the Tc calibration accuracy is well within the range in Table 1.1

(plus several other measurements)

Measurement Req.

From PBDR

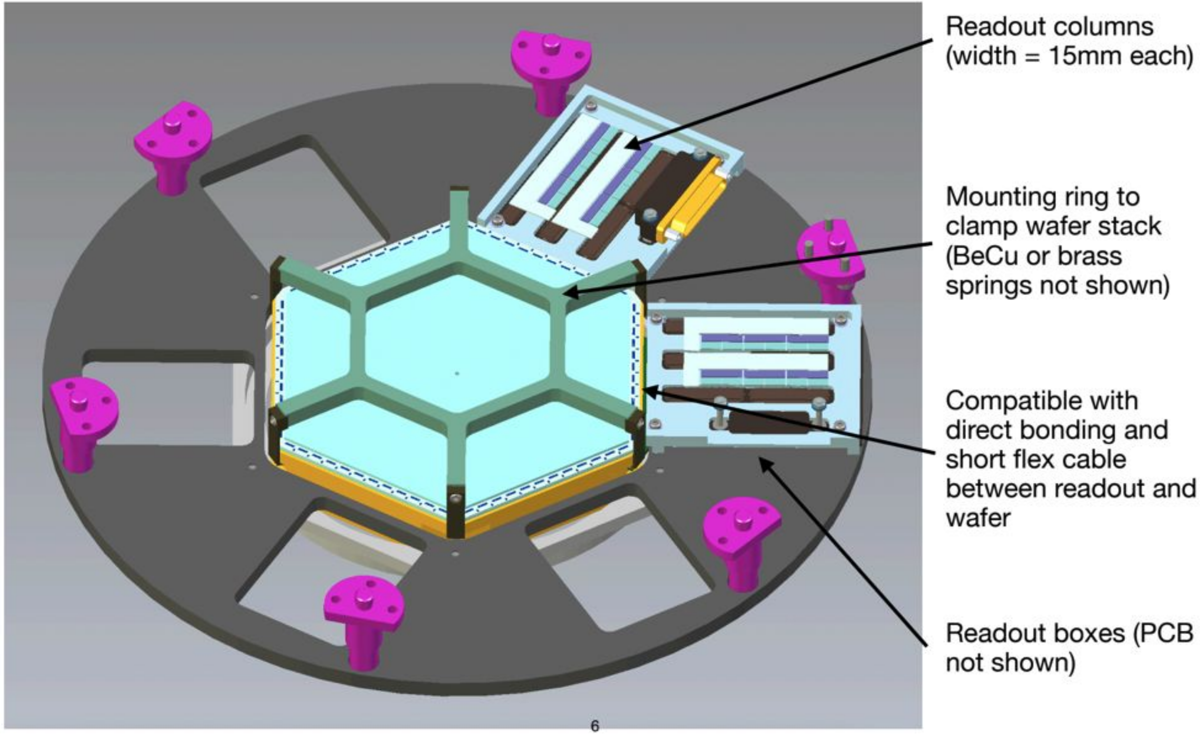
Table 3-4: Testing measurement requirements

Title	Requirement	Origin	Test
NET	Noise equivalent temperature of the detecotr module	Flowdown from sensitivity requirements in each band	In-transition noise and efficiency measurements looking into a cold-load during dark testing.
Yield	Percentage of detectors that can be readout per module	Flowdown from sensitivity requirements in each band	IV measurements of TES during dark testing
TES time constant	Time constant of the TES detector in the transition	Flowdown from sensitivity and systematic requirements in each band	TES response to voltage bias step and flashed-optical source during dark testing
TES properties	Saturation power, superconducting transition temperature, normal resistance of the TES	Flowdown from sensitivity and systematic requirements in each band	IV measurements of TES during dark testing
TES stability	Stability of the TES while in-transition	Flowdown from sensitivity and systematic requirements in each band	In-transition noise looking into a cold-load during dark testing.
RF pickup	RF response of the detectors	Flowdown from systematic requirements in each band	Sweep of RF source around cryostat during dark and optical detector testing
Magnetic pickup	Magnetic response of the detectors	Flowdown from systematic requirements in each band	Sweep of magnetic field around cryostat via Helmoltz coil during dark and optical detector testing
Bandpass	Frequency response of the detectors	Flowdown from sensitivity and systematic requirements in each band	Fourier transform spectroscopy measurements during optical testing.
Beam shape	Spatial response of the detectors	Flowdown from systematic requirements in each band	Beam-shape measurements of horns via VNA setup, with spot checks of modules during optical testing
Cross-polarization	Cross-polarization response of the horn arrays and detectors	Flowdown from systematic requirements in each band	Cross-polarization measurements of horn arrays via VNA setup, with spot checks of modules during optical testing

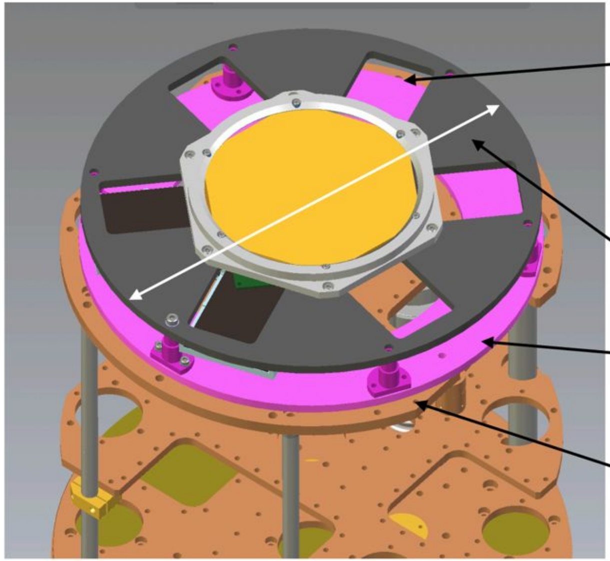
- Will need to continue to develop testing requirements and measurement procedures for next stages of testing.
- Instrument flowdown will affect what type of test equipment is required, e.g.,
  - Required frequency band accuracy would affect what we build to measure bandpasses
  - Magnetic and RF shielding requirements.
  - Warm VNA+CMM measurements of horns.
- More “testing and measurement requirements” documentation will have to be prepared ahead of CD-1

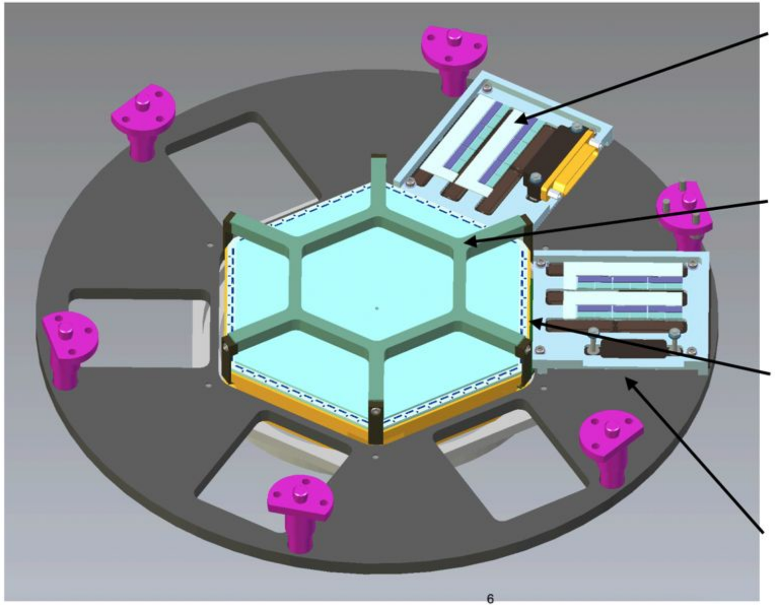
Module Testing: FY21 DRM R&D

- FY21 DRM R&D plan calls for detector module testing of prototype detector wafers by Summer 2021
- Full detector and readout module design will not be ready on this schedule
- Designing intermediate detector and readout module that could still test ~700 detectors / wafer, and fit in baselined prototype DR testbeds



Module Testing: FY21 DRM R&D

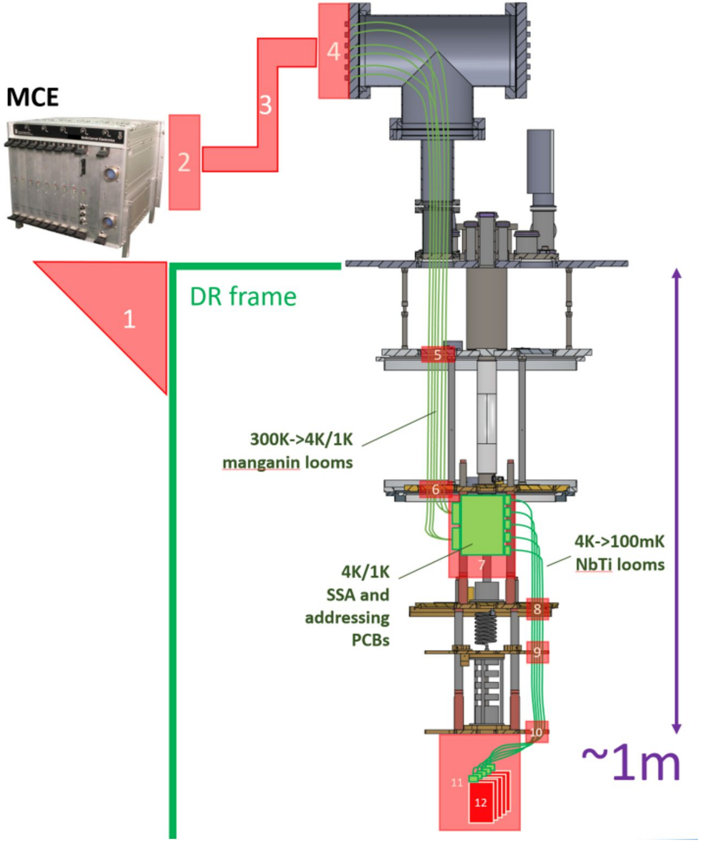




- Interfaces between CDFG Modules with Readout and Testbeds:
    - https://docs.google.com/document/d/1tAaNEKdM7w48QWyMhxsxCdoCrw4UoE-AKaBudAaYjeE/edit#heading=h.qoe9nowjoopt
- Fits in Bluefors and Oxford DR testbeds (FNAL, SLAC, UIUC) which require plate is < 290-mm
-

Module Testbeds: FY21 DRM R&D

- Currently funded to outfit three detector module and readout testbeds with readout chain from 100mK to warm electronics at SLAC, UIUC, FNAL
- Availability of MCE warm electronics at each location in available 100mK cryostats was one of driving criteria for selection.
- Would like to increase the number of testbeds to ~6 as more warm electronics become available, but funding and timescale wouldnt start allowing that until later in 2021.



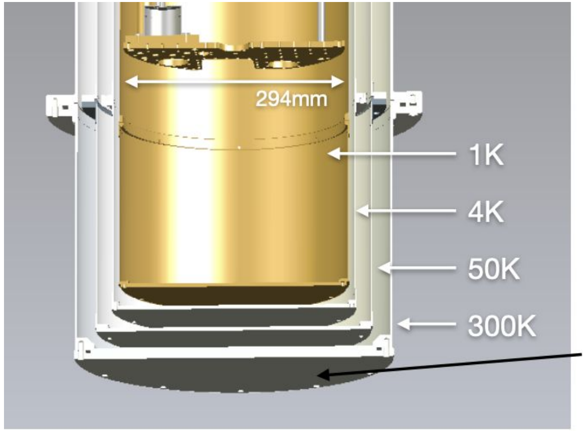
See G. Haller's Readout Parallel Talk

Module Testbeds: FY21 DRM R&D

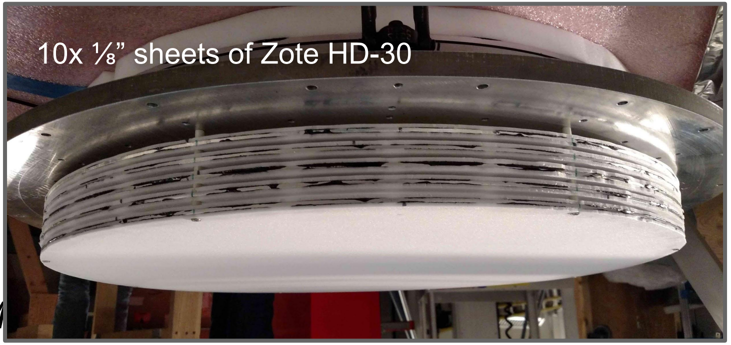
- Also later in 2021, would like to expand some testbeds to have optical capability.
- Requires ~20-cm diameter optical window, very similar to what's being developed for LATR optics tube
- Expecting to be able to leverage aspects of LATR design to make mostly plastic IR filter design
- Can be effectively identical across our Bluefors and Oxford testbed

material	*T sink [K]*	*T filter [K]*	*thickness [mm]*	*power incident [W]*
Blackbody	290	290	N/A	N/A
HDPE window	290	290	10	5.8
zotefoam filter stack (10 layers)	290	282-164	10x 3.175	4.7 - 0.46
HDPE	40	42.7	10	0.37
nylon	40	43.9	1	0.025
nylon	3	4.3	4	1.76e-3
metal-mesh (200 GHz cutoff)	3	3.0	1	7.7e-7
gold (emissivity of 0.01) with 16 horns of radius 3.5mm with effective area $\lambda^2 = 4\text{mm}^2$ and emissivity of 1	0.1	0.1	N/A	5.0e-8

Table 1: Baseline all-plastic filter configuration.



All bottoms of radiation shields are removable—replace these with plates that have holes and clamping for filter components



Production Testing

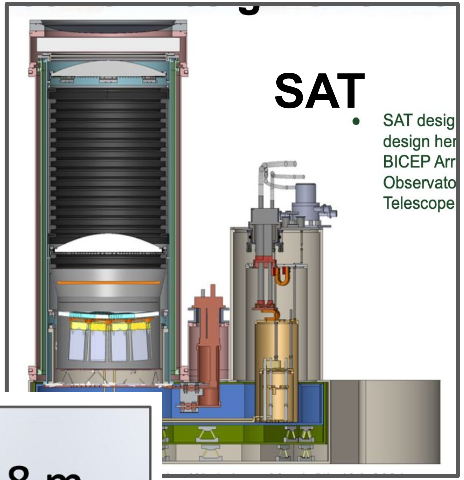
nsition to new detector type						
FY25A	FY25B	FY26A	FY26B	FY27A	FY27B	Total
10	10	10	8	10	10	86
14	16	16	16	12	6	106
16	16	16	16	4	4	102
10	12	14	16	16	14	108
8	12	16	11	11	10	68
4	4	4	4	4		33
62	70	76	71	57	44	503
104	117	127	119	95	74	841

MAT Req: Assemble and test ~600 detector modules over 3-year period

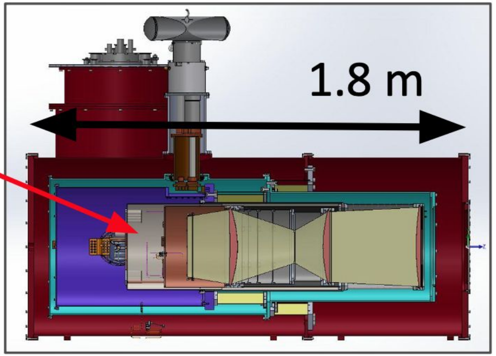
Baseline Plan (from Agency Review):

- After CD-1, design and build 8x new CMB-S4 specific cryostats capable of testing ~6-7x detector wafers modules per cooldown, which will be spread over 2-3 testing sites.

Production Test Cryostats: Shared design with LAT-CR or SAT single tube?



LAT-CR



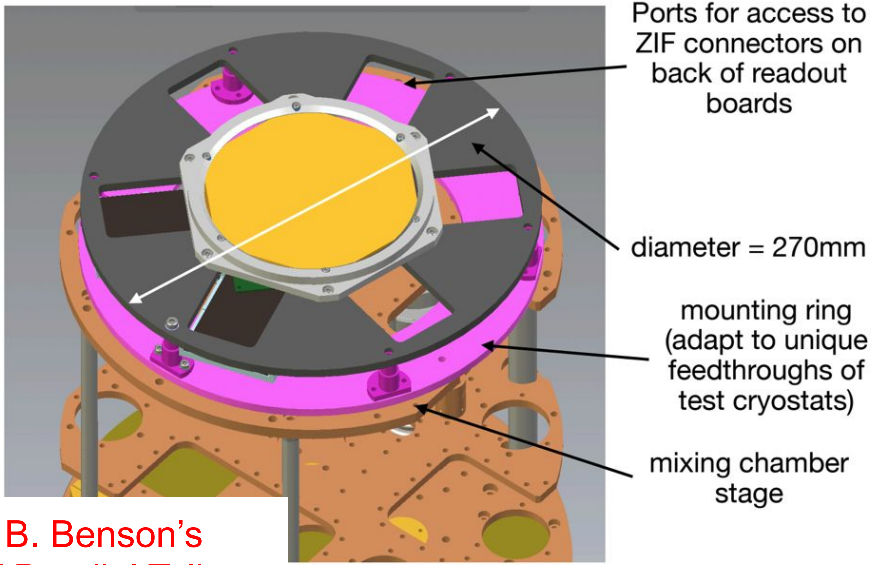
Summary/Conclusions

- Detector Module Testing
  - Need better requirements documents and flowdown to determine how well we will need to measure different characteristics
  - For FY21 DRM R&D, started outfitting 3x testbeds detector module and readout testing..
  - Expecting to expand number of testbeds later in 2021, after new warm readout electronics are developed (See G. Haller’s Readout Parallel talk)
  - Optical testing modification should be straightforward between testbeds.
    - Next step will involve designing and building early required test equipment (e.g., cold-loads, FTS, etc.), effort has been delayed to later 2021 to match project schedule.
  - Production testbeds will be designed after CD-1 to line up with FY25 production testing schedule.

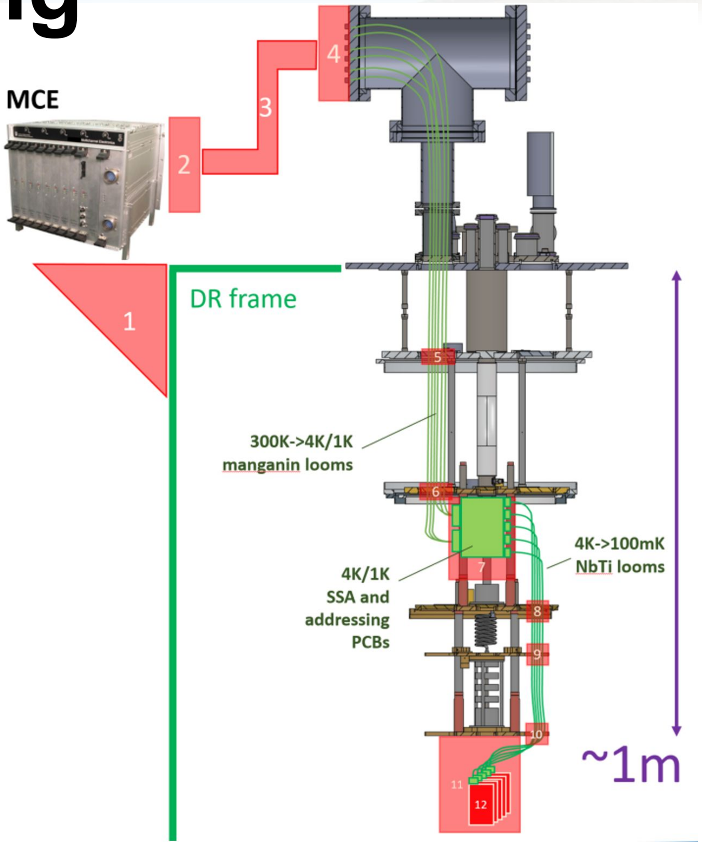
Extras

3) Detector Module Testing

- For FY21 DRM R&D, working with readout on module design and readout chain to outfit 3x testbeds in collaboration for dark detector module testing.
- Expansion to new testbeds bottlenecked by having requisite TDM warm electronics in available DR cryostats



See B. Benson's MAT Parallel Talk



See G. Haller's Readout Parallel Talk