Technical Documentation Updates

Besuner

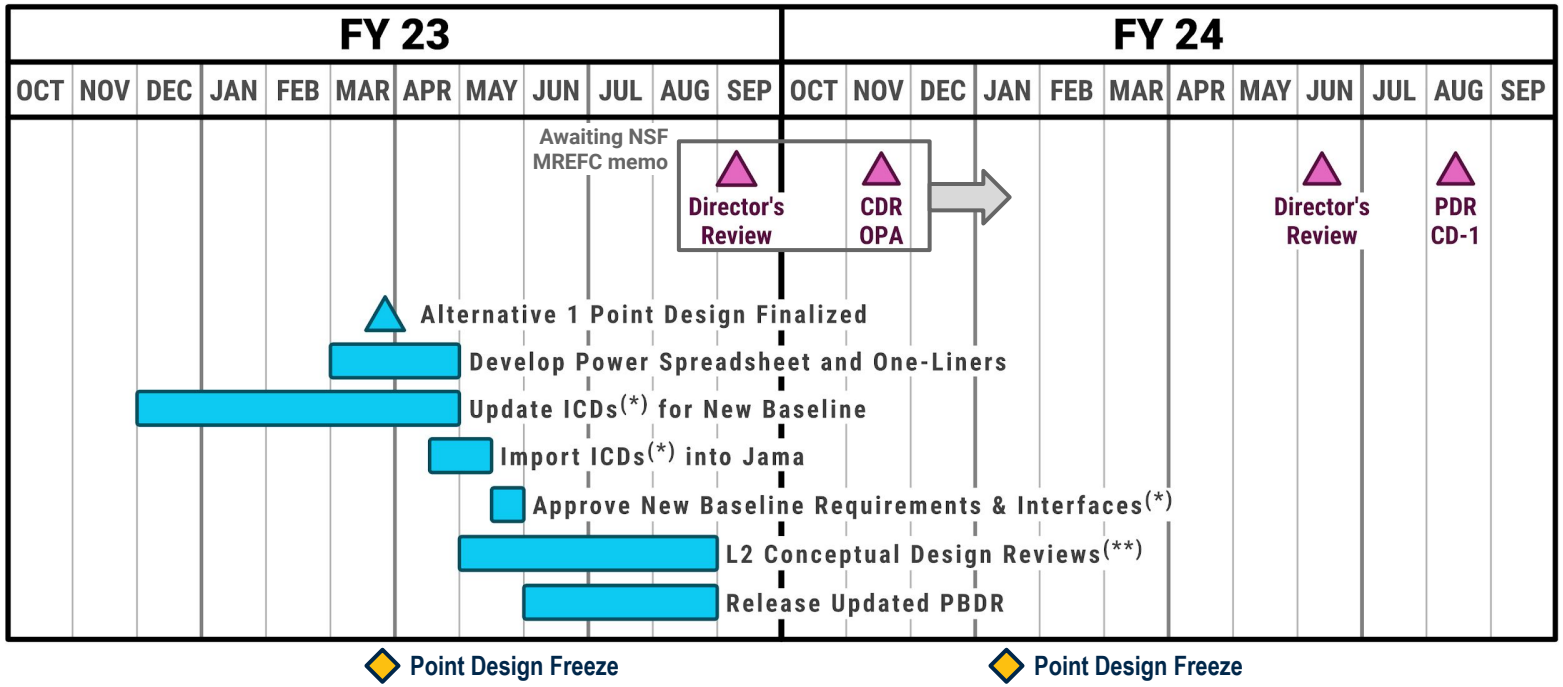
CMB-S4 Collaboration Meeting
April 3-6, 2023

Outline

- Timeline
- Subsystem Conceptual Design Reviews
- Requirements
- Interface Control Documentation
- Documentation of the Point Design
- Tools

Timeline

See M. Leitner Talk



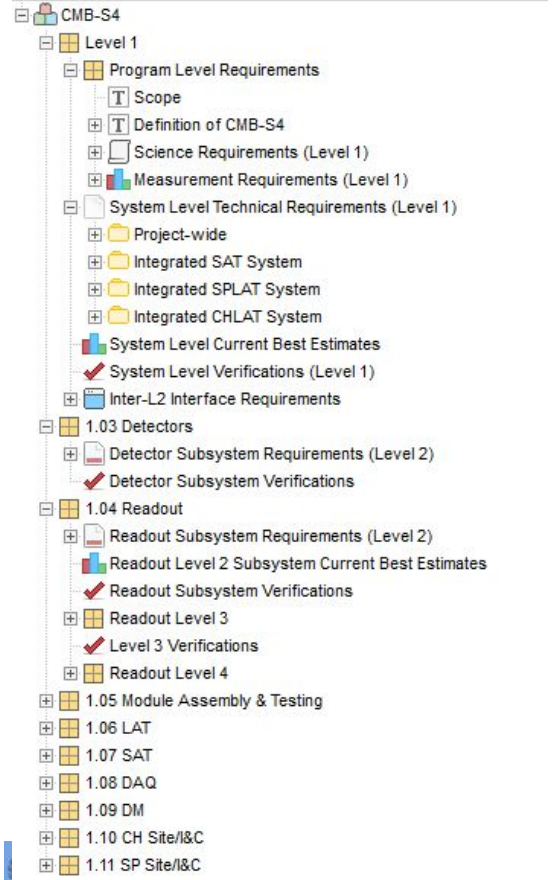
(*) Level-2 ICDs and Requirements plus Level-3 CH-LAT, SP-LAT, and LATR ICDs and Requirements

(**) ~May: LAT, LATR, Sites / Summer: remaining WBS areas (see next slide)

Subsystem Conceptual Design Reviews

- Subsystem Conceptual Design Reviews were successfully held in 2021
- Designs have evolved/matured, and need re-review closer in time to agency reviews
- Try to get at least some of the same reviewers as in 2021 CDRs
- Target timeline of reviews (to be scheduled around reviewees and reviewers)
  - Prioritize NSF scope to ensure readiness for potential NSF CDR as early as November
  - Mid May: Chile and South Pole Sites
  - Late May: LAT incl LATR
  - Early June: Data Management
  - Late June: SAT
  - Early July: DRM (consolidated)
  - Late July: DAQ

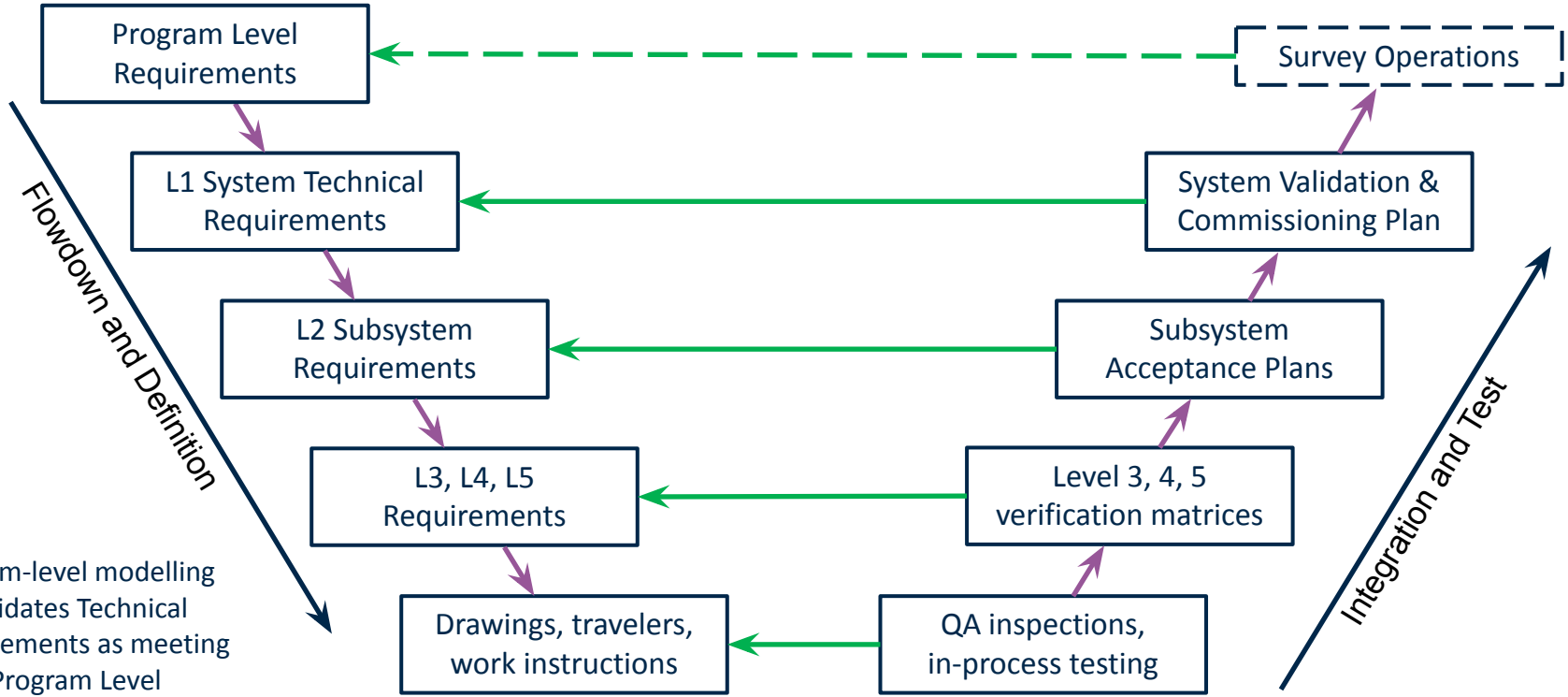
Science Goals, Science Requirements, Measurement Requirements, and Technical Requirements are captured in the Jama Connect tool



- Program Level Requirements (Science Goals/Reqts + Measurement Requirements) are approved and under change control
- Technical Requirements at Level 1 and below are currently being updated to reflect the new Preliminary Baseline Design
- May 2023: Change Control Board review and approval of priority Technical Requirements, including:
  - Level 1 (Project-Wide)
  - Level 2 (Subsystems)
  - Level 3 (within the LAT subsystem, i.e. high-level requirements on LATR, CHLAT, and SPLAT)

Requirements Definition And Verification Processes Follow The Systems Engineering V-Model:

Verification plans are essential to requirements development, and are a required part of each CMB-S4 requirement in Jama Connect



System-level modelling validates Technical Requirements as meeting Program Level Requirements

Details of interfaces between subsystems are captured in Interface Control Documents

- ICDs between Level 2 subsystems are drafted and mature, and are currently being refined in google docs to bring them up to date
- These will be migrated into the Jama Connect requirements management tool, reviewed, and put under change control in the May 2023 timeframe
- Interfaces within Subsystems are also being developed with review/approval in the future

WBS 1.04 Readout	WBS 1.05 Module Assembly & Testing	WBS 1.06 Large Aperture Telescopes	WBS 1.07 Small Aperture Telescopes	WBS 1.08 Data Acquisition & Control	WBS 1.09 Data Management	WBS 1.10 Chile Site Infrastructure/I&C	WBS1.11 South Pole Site Infrastructure/I&C	← L2 Elements ↓
E (339)	M, E, T (463)	X	X	X	X	X	X	WBS 1.03 Detectors
	M, E, T (321)	M, E, T (318)	M, E, T (354)	E (324)	X	M, E, T (718)	M, E, T (719)	WBS 1.04 Readout
		M, T, O (345)	M, T, O (342)	X	X	M, E (721)	M, E (720)	WBS 1.05 Module Assembly & Testing
			X	M, E, T (333)	X	M, E, T (336)	M, E, T (330)	WBS 1.06 Large Aperture Telescopes
				M, E (351)	X	X	M, E, T (348)	WBS 1.07 Small Aperture Telescopes
					E (327)	M, E, T (417)	M, E, T (423)	WBS 1.08 Data Acquisition & Control
						M, E, T (426)	M, E, T (432)	WBS 1.09 Data Management
							X	WBS 1.10 Chile Site Infrastructure/I&C

Interface type	
M	mechanical
E	electrical, data, control, telem
T	thermal
O	optical
(Number) in cell indicates docdb number	

Preliminary Baseline Design Instrument Description (PBDID) captures the key implementation details of the point design

- The point design is described as best estimates, not as requirements
- Used as inputs for Simulations and Data Challenges (See previous session materials)
- Consistent with PBDR (next slide) and technical requirements
- Frozen in March 2023 for DC0
- Add'l docs include point design info that does not go into Sims (e.g. electrical power budgets)

See J. Ruhl Talk

pBD Instrument Description - 2023

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C26 Module optical efficiency

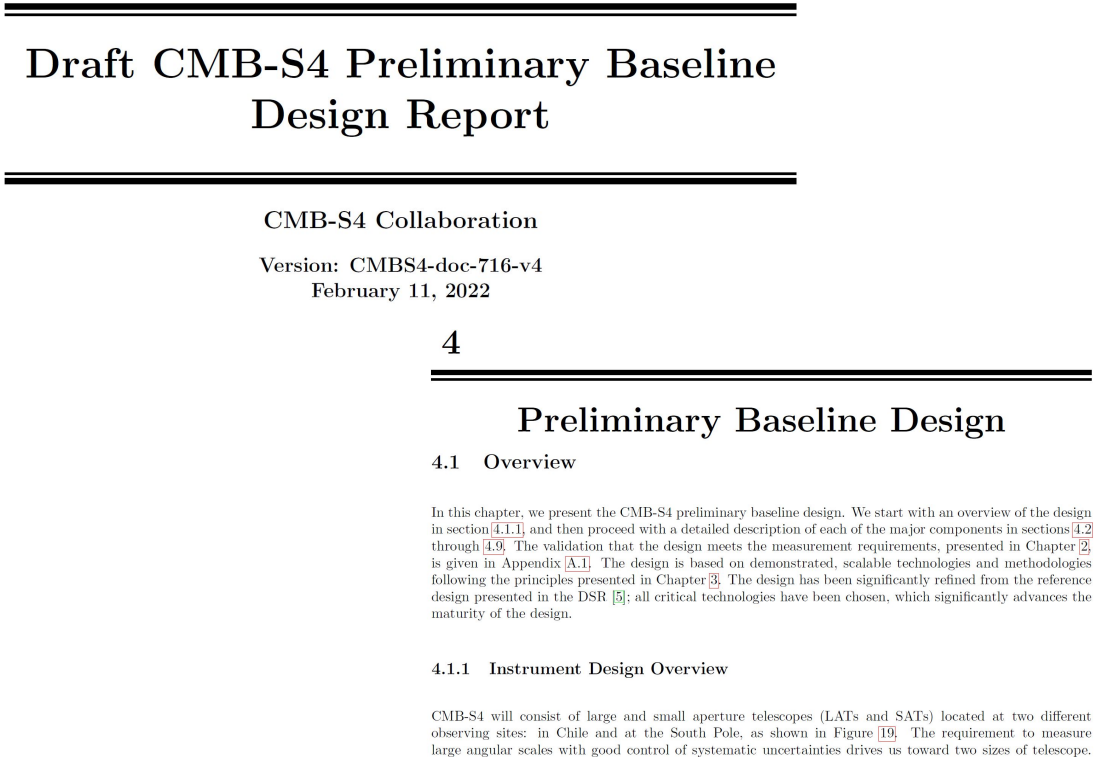
	A	B	C	D	E	F	G	H	I	J	K	
1	Atacama Chile CD LAT				ULF	LF		MF		HF		Notes
2			(Nominal band "numerical" names)	Totals	20	25	40	90	150	230	280	Loading and
3		Single-detector sensitivity / etc										
4			Band Center (on-wafer filters)		20.0	24.75	36.5	91.5	148.5	227.0	285.5	
5			Fractional bandwidth (nu_h - nu_l)/nu_center		0.250	0.263	0.466	0.317	0.276	0.256	0.207	
6			Lower band edge		17.5	21.5	28.0	77.0	128.0	198.0	256.0	
7			Upper band edge		22.5	28.0	45.0	106.0	169.0	256.0	315.0	
8			Band center (at telescope input; includes effect of optics)		20.2	25.0	37.5	92.8	149.7	227.8	285.8	
9			Band center (at CMB; includes effects of optics and atmosphere)		20.2	25.0	37.4	92.9	149.7	227.7	285.6	
10			Poptical (pW) (observing mode)		0.17	0.205	1.094	1.495	4.421	12.326	17.641	
11			n_photon (occupation number)		2.5	1.9	2.6	0.9	1.1	1.4	1.6	
12			Safety factor (Nominal) = Psat/Poptical					3.0				Final Psats a
13			Psat, science transition (pW) (set equal to CHLAT)		0.426	0.519	2.991	4.01	11.079	30.8	44.2	
14			Readout NEI (pA/rtHz)					45				Conservative
15			Readout NEP (aW/rtHz)		1.8	2.0	4.8	5.5	9.0	15.0	18.0	jbolo
16			Johnson NEP (aW/rtHz)		0.1	0.1	0.3	0.4	0.6	1.0	1.2	
17			Phonon NEP (aW/rtHz)		3.0	3.3	7.9	9.1	15.2	25.3	30.3	
18			Photon NEP (aW/rtHz)		4.1	4.4	14.6	18.4	43.2	95.2	132.5	
19			Total NEP (aW/rtHz)		5.3	5.9	17.3	21.3	46.6	99.7	137.1	
20			Detector NET_RJ (uKrtsec) [no horn-horn correlation]		391	367	224	233	187	219	302	
21			Detector NET_CMB (uKrtsec) [no horn-horn correlation]		395	373	232	290	323	716	1767	
22			Pixel pitch (mm)		21.1	16.1		5.3		5.2		

README Pole LAT Chile LATs SATs Deltas Totals-85 Rhomb_HCP_counts OLD - Requirements Ranges

Preliminary Baseline Design Report, Section 4, describes the point design in some detail, by subsystem

See J. Carlstrom talk

- The entire PBDR is to be brought up to date and approved this summer
- Individuals have been assigned sections to review. Besuner took Section 4
- Primary task is to identify areas that need updating to the new experiment configuration (with 3 SATs instead of 6)
- Existing PBDR location in docdb (pdf) CMBS4-doc-716
- Red-lined copy of Section 4 is posted at CMBS4-doc-871
  - L2's are to update their respective sections



Draft CMB-S4 Preliminary Baseline Design Report

CMB-S4 Collaboration

Version: CMBS4-doc-716-v4
February 11, 2022

4

Preliminary Baseline Design

4.1 Overview

In this chapter, we present the CMB-S4 preliminary baseline design. We start with an overview of the design in section 4.1.1, and then proceed with a detailed description of each of the major components in sections 4.2 through 4.9. The validation that the design meets the measurement requirements, presented in Chapter 2, is given in Appendix A.1. The design is based on demonstrated, scalable technologies and methodologies following the principles presented in Chapter 3. The design has been significantly refined from the reference design presented in the DSR [5]; all critical technologies have been chosen, which significantly advances the maturity of the design.

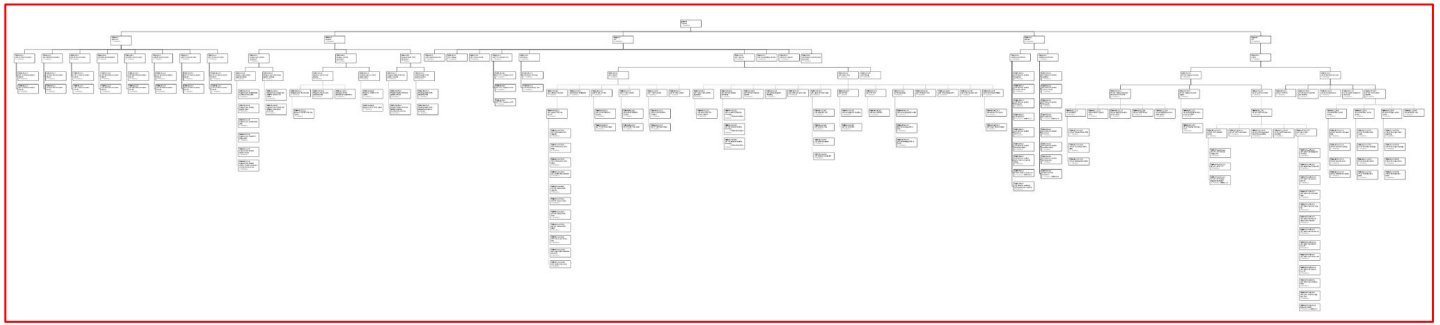
4.1.1 Instrument Design Overview

CMB-S4 will consist of large and small aperture telescopes (LATs and SATs) located at two different observing sites: in Chile and at the South Pole, as shown in Figure 19. The requirement to measure large angular scales with good control of systematic uncertainties drives us toward two sizes of telescope.

Product Tree (in development by Systems Engineer Elliot Newman)

- Hierarchical, product oriented breakdown (not WBS-oriented)
- An engineering tool, not mgmt tool
- Lucidchart allows for tabular spreadsheet data to be graphically displayed
- Useful for planning assembly and test sequencing, analyzing system reliability, etc.

PT ID	Name	Hierarchy (direct parent part	Part Level	Subsystem
CMBS4.2.1.2.2	Readout cryo 100mK row address mechanical enc	CMBS4.2.1.2	4	Readout
CMBS4.2.2	Readout cold 4K electronics	CMBS4.2	2	Readout
CMBS4.2.2.1	Readout cold 4K SSA Module	CMBS4.2.2	3	Readout
CMBS4.2.2.1.1	Readout cold 4K SSA chip	CMBS4.2.2.1	4	Readout
CMBS4.2.2.1.1.1	Readout cold 4K SSA chip carrier	CMBS4.2.2.1.1	5	Readout
CMBS4.2.2.1.2	Readout cold 4K SSA module board	CMBS4.2.2.1	4	Readout
CMBS4.2.2.1.3	Readout cold 4K Mechanical components	CMBS4.2.2.1	4	Readout
CMBS4.2.2.2	Readout cryo to cold to warm cables	CMBS4.2.2	3	Readout
CMBS4.2.2.2.1	Readout 100mK to 4K cables	CMBS4.2.2.2	4	Readout
CMBS4.2.2.2.2	Readout 4K to 300K cables	CMBS4.2.2.2	4	Readout
CMBS4.2.3	Readout Warm 300K electronics	CMBS4.2	2	Readout
CMBS4.2.3.1	Readout Warm 300K row address module	CMBS4.2.3	3	Readout
CMBS4.2.3.1.1	Readout warm 300K row address board	CMBS4.2.3.1	4	Readout
CMBS4.2.3.1.2	Readout warm 300K row address module mechan	CMBS4.2.3.1	4	Readout
CMBS4.2.3.2	Readout warm 300K readout module	CMBS4.2.3	3	Readout
CMBS4.2.3.2.1	Readout warm 300K readout board	CMBS4.2.3.2	4	Readout
CMBS4.2.3.2.2	Readout warm 300K readout mechanical enclosur	CMBS4.2.3.2	4	Readout
CMBS4.3	SAT	CMBS4	1	SAT
CMBS4.3.1	SAT Fluid/Vacuum lines	CMBS4.3	2	SAT
CMBS4.3.2	SAT Cabling	CMBS4.3	2	SAT
CMBS4.3.3	SAT Ground Shield	CMBS4.3	2	SAT



Various Tools for Project Technical Work

- Jama Connect for management of Requirements and Interfaces
- DocDB project document repository
- Relyence Reliability Prediction Software
  - Predicts overall system availability (fraction of time it functions), given the MTBF (mean time between failure), MTTR (mean time to repair), and level of redundancy of all its constituent components
  - Informs projection of total calendar time required to complete the surveys
  - Identifies areas that warrant ready spares or engineering focus to miminize impacts on uptime
- CAD PLM tools (Computer Aided Design Project Lifecycle Management)
  - Master model in SolidWorks, managed using LBNL Windchill system
  - Other sites locally manage their models with their own systems (e.g. Teamcenter at Fermilab), providing periodic updates to Berkeley for integration into the master model
- Technical Notes (template linked from CMBS4-doc-874)
  - Documentation of engineering analyses justifying formulation of requirements or design decisions

Summary

- Project technical documentation is being updated to the new Project Baseline
- Subsystem reviews and document approvals will occur over the next few months
- Effective tools are in use, actively managing technical work products
- The experiment technical design is maturing and advancing
- We are well-positioned for agency reviews and to build this unprecedented CMB experiment!

Backup Slides

Requirements And Technical Budgets Define Experiment Performance

- Requirements
  - Minimum performance measure that a subsystem or component must meet
  - Heirarchical, flowed down from Science Goals to Technical Requirements

- Performance Budgets
  - Resources/parameters that can be allocated (as requirements) among subsystems or components
  - These budgets are managed at a high level and include margin that can be allocated as needed from L1
  - CMB-S4 budgets include:
    - Electrical power
    - Data Bandwidth
    - Cooling power
    - Beam quality
    - Systematic errors
    - Measurement sensitivity
    - Uptime/Downtime
    - Magnetic/RF shielding

Requirement Hierarchy - Requirements At Each Level Meet And Are Traceable To The Level Above

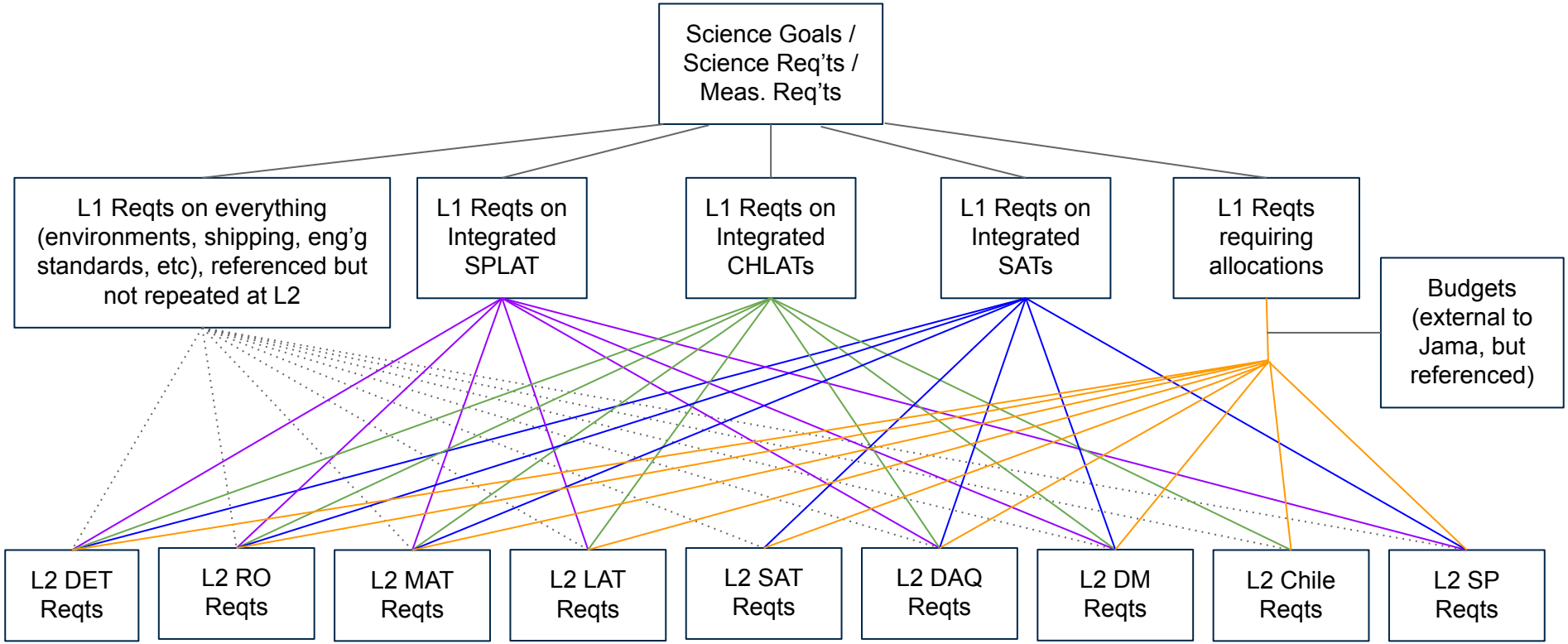
- The level of a requirement indicates the WBS level at which it is applied
- Level 1 System Requirements apply to scope in more than one Level 2 WBS
- L2 Subsystem Requirements only to scope within that Level 2 WBS, and so on to L3, L4

Table 1: CMB-S4 Requirements Hierarchy and Documentation Location. Approval authority for each level of requirement is defined in CMBS4-doc 238.

Requirement Level	Where Documented
CMB-S4 Science Goals	Program Level Requirements (CMBS4-doc-671)
CMB-S4 Science Requirements	Program Level Requirements (CMBS4-doc-671)
CMB-S4 Measurement Requirements	Program Level Requirements (CMBS4-doc-671)
WBS Level 1 Technical Requirements	Jama Connect
WBS Level 2 Technical Requirements	Jama Connect
WBS Level 3 Technical Requirements	Jama Connect
WBS Level 4 and lower Technical Requirements	Jama Connect

L1/L2 Requirements Structure

The level of a requirement indicates the WBS level at which it is applied. L2 requirements are requirements on Level 2 WBSs that apply only to scope within that Level 2 WBS, and Level 1 requirements are those that apply to scope in more than one Level 2 WBS.



Survey Margin

- Program Level Requirements capture flowdown of Science Goals to Science Requirements to Measurement Requirements
  - Meeting the Science Requirements will achieve the Science Goals (no margin)
  - Meeting the Measurement Requirements will achieve the Science Requirements
    - Zero margin, with pessimistic assumptions about foregrounds
    - Substantial margin possible, depending on actual foregrounds (as shown on Slide 18 of Carlstrom's SC-1 Measurement Requirements to Survey Design talk and PBDR Appendix A-2)
- The technical implementation described in the PBDR satisfies the Measurement Requirements over a seven-year CMB-S4 survey (see PBDR Appendix A-1)
  - That implementation assumes replication of the achieved performance of previous/current experiments, accounting for easily-scaled performance parameters, but no other substantial improvements:
    - Band definitions
    - Number of detectors in each band
    - Lower TES transition temperature (T_c) due to use of dilution refrigerators
- The PBDR point design just meets the current CMB-S4 technical requirements, in Jama
- So just meeting the current technical requirements, CMB-S4 would satisfy the Measurement Requirements in seven years
- Any performance improvements over the PBDR implementation will yield survey margin
- Many opportunities exist for such improvements, our plan to build margin is described on next slides

Steps in our Margin-Building approach

1. Better understand baseline performance of CMB-S4 as described in the PBDR
    a. Characterize previous/current experiments (scaled models of which form the basis for our performance simulations) by breaking down (factorizing) elements that affect their performance to the smallest practical level
2. Examine each factor to understand its quantitative value on those experiments
3. Determine which of these factors offers S4 opportunities to improve upon
4. Study what needs to happen for each factor and what improvements are feasible (enabled by CMB-S4's scale, funding, and previous lessons learned)
5. Document the improvements that are confidently achievable, and how to achieve them
6. Implement design changes and codify in the requirements and Current Best Estimates
7. Roll up the product of these improvements to calculate survey margin

The Project Configuration Management Plan (CMBS4-doc-238) Defines Processes For Controlling Project Technical Scope

- Establishes the Change Control Board
- Defines graded approval and change control thresholds for various levels of document
- L2 leads are included in approvals of ICDs and req’ts that touch their Subsystems

Table 2: CCB Voting Members

Title	Name
Project Director	John Corlett
Deputy Project Director	Gil Gilchriese
NSF Principal Investigator	John Carlstrom
DOE Project Manager (co-chair)	Matthaeus Leitner
NSF Project Manager (co-chair)	Jeff Zivick
Project Engineer	Bobby Besuner
Technical Integration Scientist	Brenna Flaugher
Project Scientist	John Carlstrom
Instrument Scientist	John Ruhl
Data Scientist	Julian Borrill

L2 managers and CMB-S4 spokespeople will be invited to also attend CCB meetings, along with project controls manager, systems engineers, and L3s and others as needed

Impact of Change	Approval Authority
Systems Engineering	
CMB-S4 Science Goals	CCB
CMB-S4 Science Requirements	CCB
CMB-S4 Measurement Requirements	CCB
WBS Level 1 Technical Requirements	CCB
WBS Level 2 Technical Requirements	PE, Instrument Scientist, Lead SE, L2 Manager, L2 SE, CAM
WBS Level 3 Technical Requirements	PE, Instrument Scientist, Lead SE, L2 Manager, L2 SE, CAM
WBS Level 4 and Lower Technical Requirements	L2 Manager, L2 SE, CAM
Interfaces between WBS Level 2 Subsystems	PE, Instrument Scientist, Lead SE, L2 Manager, L2 SE, CAM
Interfaces between Elements at WBS Level 3	PE, Lead SE, L2 Manager, L2 SE, CAM
Interfaces between Elements at WBS Level 4 and Lower	L2 Manager, L2 SE, CAM
Physics and Engineering	
Physics and Engineering Notes	Lead Engineer, L2 Manager or CAM
Construction Drawings	Lead Engineer, L2 Manager or CAM
Technical Procurement Documents	Lead Engineer, L2 Manager or CAM
EH&S Related Notes	EH&S Site Manager, Lead Engineer, L2 Manager or CAM
QA Related Notes	QA Site Manager, Lead Engineer, L2 Manager or CAM