WBS 1.07.08 - Telescope Mount Assembly

L3 Lead - Clem Pryke

Outline

- Presenter Introduction
- Key L3 contributors
- Breakdown of this L3
- Key Requirements
- Interfaces with other L3s
- Technical Design / Scope
- Prototyping Plans
- Conclusion

Presenter Introduction

- **Clem Pryke, Physics Professor, University of Minnesota**

  25 years of experience in cosmology instrumentation development

  - Telescope mount lead for DASI, QUaD, SZA, Keck Array and most recently BICEP Array experiments
  - co-PI of QUaD, Keck Array and BICEP Array experiments

SAT Mounts - Key Contributors

Eric Chauvin 25+ yrs telescope mechanical design, partial list includes: SPT, DASI, QUAD, SZA, GMT, CCAT, BICEP Array

John Kovac (Harvard-CfA), SAT L2, extensive experience developing and fielding successful small aperture telescopes and mounts

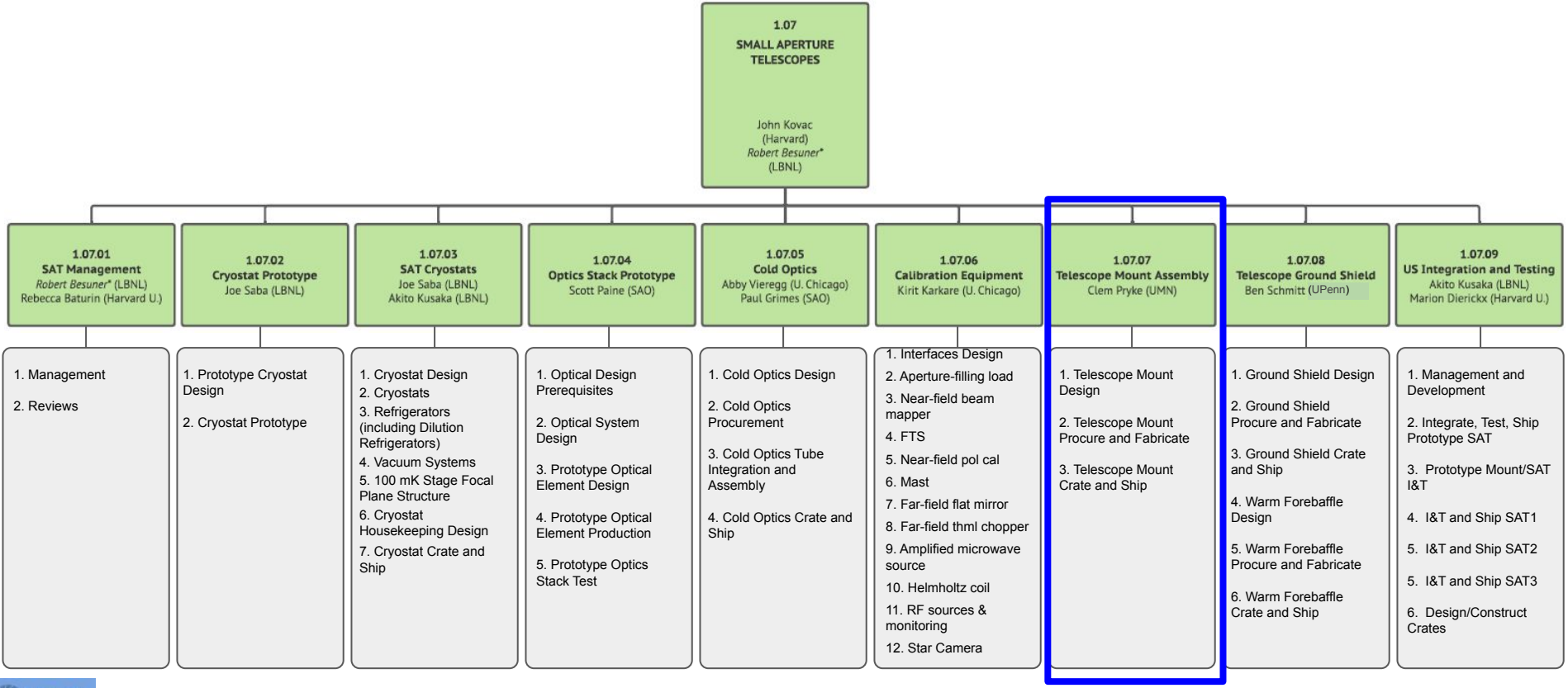
Rebecca Baturin (Harvard-CfA), Project Manager for BART and CMB-S4 SATs

Benjamin Schmitt (U Penn), Project Development Scientist for BICEP Array, BART, and CMB-S4 SATs, SAT-Mount and Mount-Site interface work

Joseph Saba (LBNL), Cryogenics / Vacuum Vessel / Mechanical Engineering, interface between cryostat and mount, integration facility planning

...and thank you to all others in the S4-SAT community who have helped with SAT mount development!

1.07 - SAT Org Chart



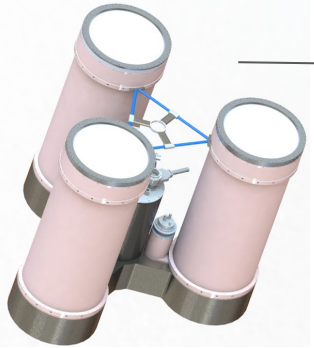
Overview of SAT Mount L4s

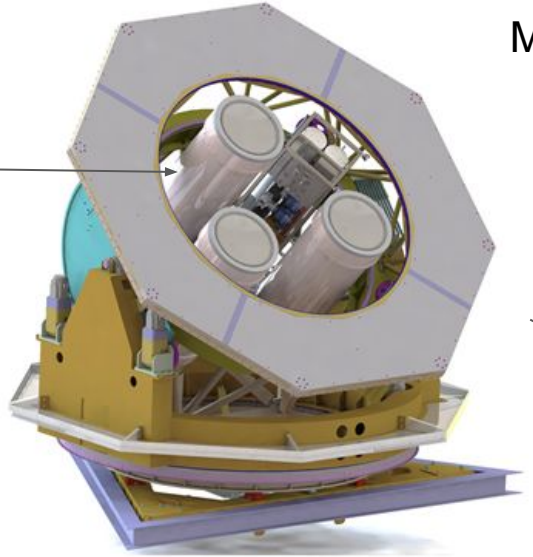
1.07.07: Telescope Mount Assembly

- **1.07.07.01:** Telescope Mount Design
- **1.07.07.02:** Telescope Mount Procure and Fabricate
- **1.07.07.03:** Telescope Mount Crate and Ship

SAT Mount in the Big Picture

Cryostat



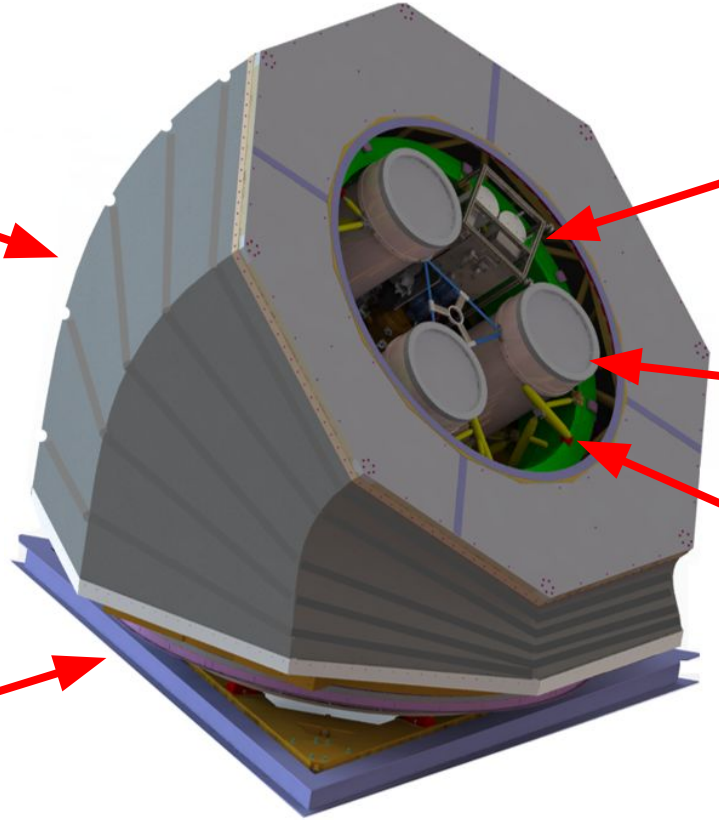


Mount

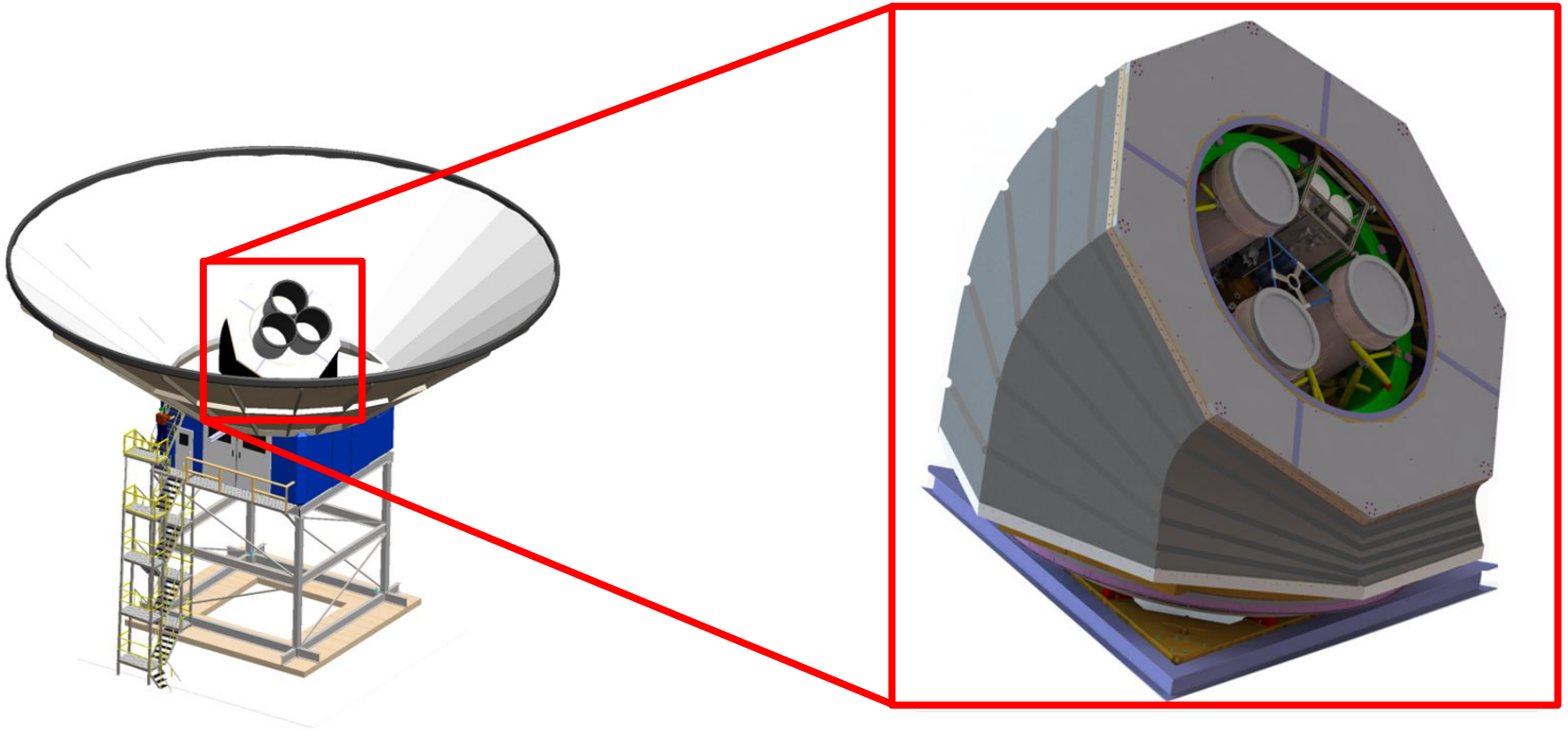
Telescope Mounts in Ground Shields

30/40 GHz
85/145 GHz
95/155 GHz
220/270 GHz

SAT Mount and Receiver (Cryostat)



SAT Mount on Tower



Baseline Design/Requirements - Mounts

- **Baseline Design:**
  - A direct adaptation of existing BICEP Array mount
  - BICEP Array mount successfully deployed between Nov 2019 - Jan 2020, and now operating at the Amundsen-Scott South Pole Station
- **S4-SAT Mount Requirements:**
  - Needs to accommodate a single three-tube SAT receiver, rather than four individual BA-type receivers (design updates to continue to allow rear-loading underway)
  - SAT receiver must include mounting points for strut interfaces to the mount structure (similar to BICEP Array)
  - Mount must also accommodate the DR gas handling system and provide sufficient mounting volumes for warm readout interfaces.

CQ1

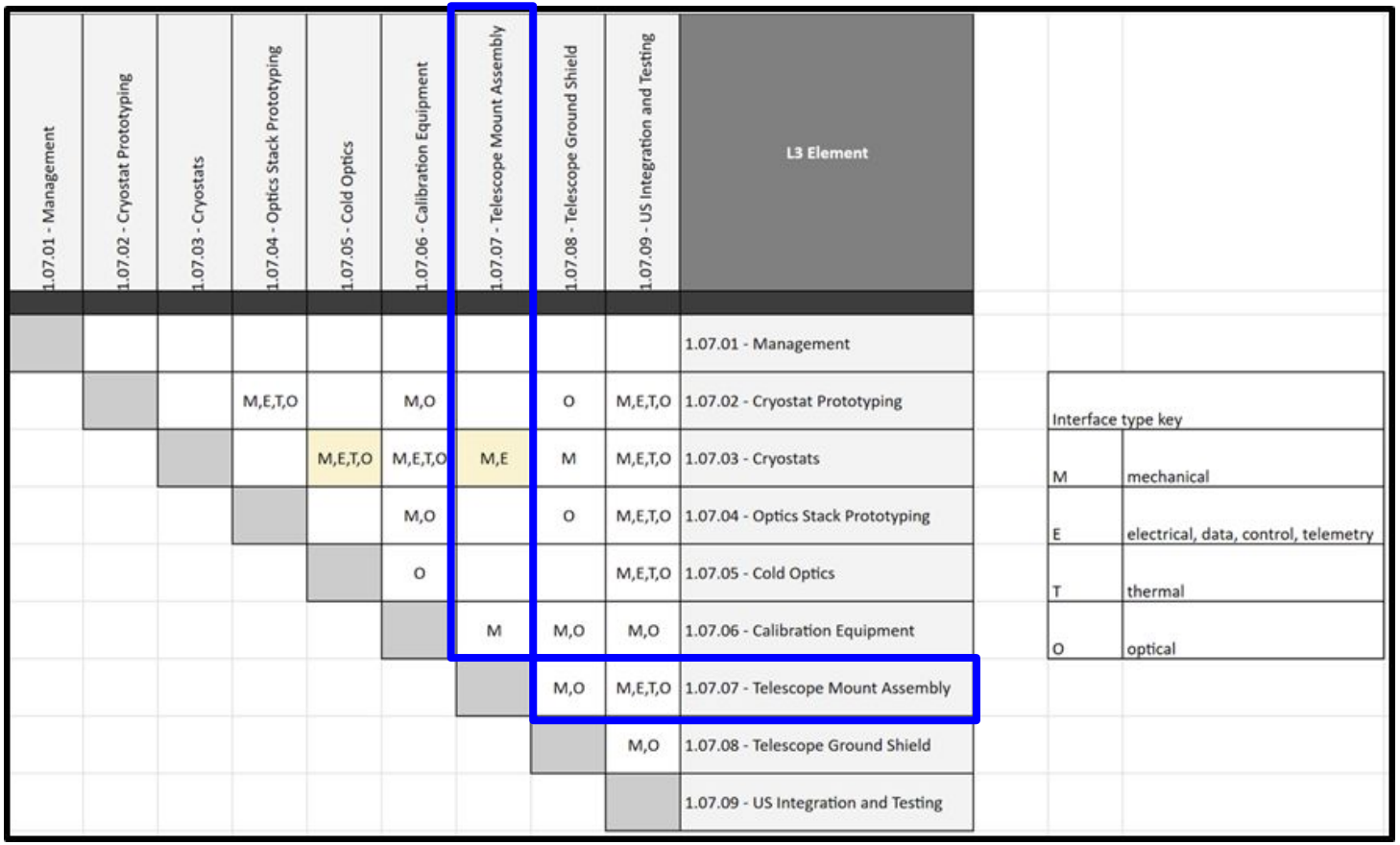
Key Driving Requirements for SAT Mount

Parameter	Value	Notes
Mass of instrument	up to 4500 kg	includes cryostat, DR system, electronics, forebaffle
Motion	3 axis	full boresight rotation of instrument and forebaffle
Scan pointing knowledge	< 15 arcsec rms	$< 1/20$th beamwidth at $\lambda = 1$ mm
Scan speed AZ/EL/TH	$5/1/1$ deg s^{-1}	≈ 3 deg s^{-1} on the sky for fast diff. measurements
Scan accel. AZ/EL/TH	$3/1/1$ deg s^{-2}	turnaround efficiency
Range AZ/EL/TH	$\infty/45 \ldots 110/\infty$	continuous AZ desirable
Shipping envelope	standard double pallet	deployment via C-130 / standard vehicles
Mount mass	< 25 tons	includes instrument, comoving forebaffle and scoop
Survival: wind	70 m s^{-1}	
Survival: temperature	-90 C	
Survival: snow loading	125 kg/m^2	

Existing BICEP Array Mount meets these requirements

CQ1

Inter-L3 Interfaces for Mount L3

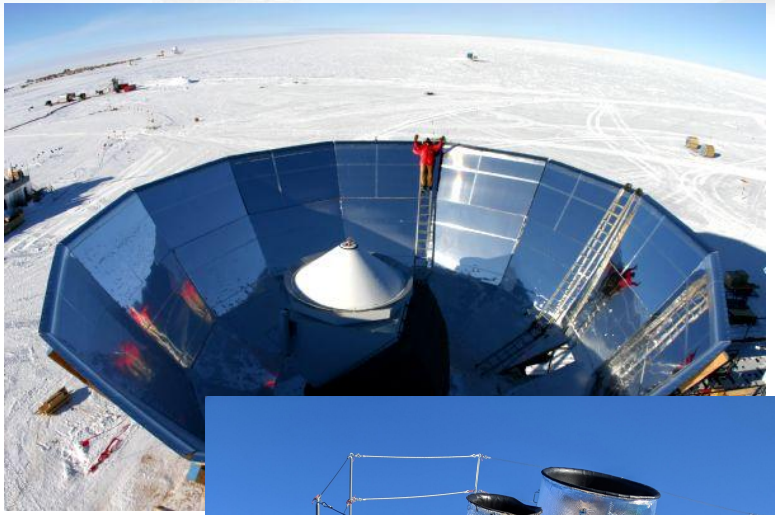


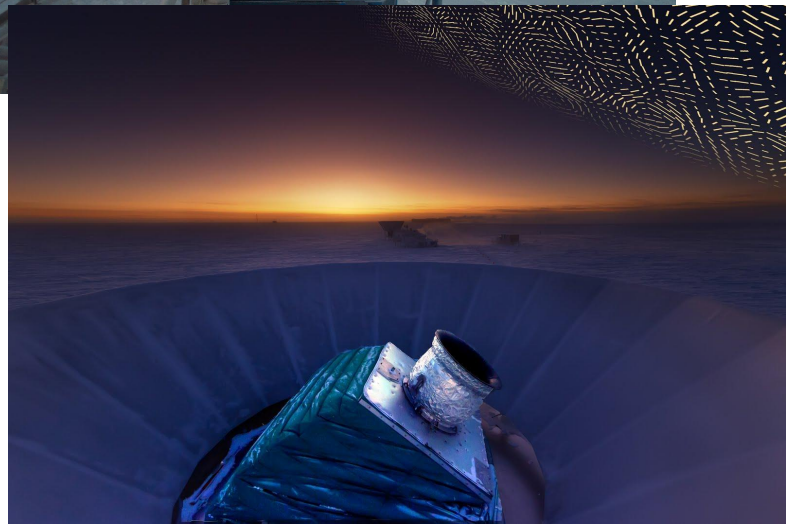
L3 Element	1.07.01 - Management	1.07.02 - Cryostat Prototyping	1.07.03 - Cryostats	1.07.04 - Optics Stack Prototyping	1.07.05 - Cold Optics	1.07.06 - Calibration Equipment	1.07.07 - Telescope Mount Assembly	1.07.08 - Telescope Ground Shield	1.07.09 - US Integration and Testing
1.07.01 - Management									
1.07.02 - Cryostat Prototyping				M,E,T,O		M,O		O	M,E,T,O
1.07.03 - Cryostats					M,E,T,O	M,E,T,O	M,E	M	M,E,T,O
1.07.04 - Optics Stack Prototyping						M,O		O	M,E,T,O
1.07.05 - Cold Optics						O			M,E,T,O
1.07.06 - Calibration Equipment							M	M,O	M,O
1.07.07 - Telescope Mount Assembly								M,O	M,E,T,O
1.07.08 - Telescope Ground Shield									M,O
1.07.09 - US Integration and Testing									

Interface type key	
M	mechanical
E	electrical, data, control, telemetry
T	thermal
O	optical

CQ1,2

20 Year Heritage of SAT Mounts at Pole





Third Generation Mount: BICEP Array

- Developed for the latest generation in the BICEP/Keck telescope series - called “BICEP Array”
- Three axis mount - azimuth, elevation and line-of-sight axis
- Designed by Eric Chauvin working with Clem Pryke and John Kovac
  - Eric has designed many CMB telescope mounts, both at Pole and elsewhere
  - Professional design engineer working on a contract basis
- Intrinsically balanced design - no large counterweights
- “Wide open” internally - azimuth axis 2.5 meter diameter ring bearings (Rotek)
- Pulse tube compressors on the ground - fed via rotary fluid feedthroughs
  - A big change from previous mounts which used hose wraps
  - Way more efficient in terms of space usage but not trivial for pressurized UHP helium
  - (Also electrical and optical fiber slip-rings - but those are standard technology)
- Designed to break down into LC-130 sized pieces for air shipment to Pole
- Steel fab by a company in Italy which have made many CMB telescopes over the years
- Drive system design and integration at University of Minnesota

CQ5

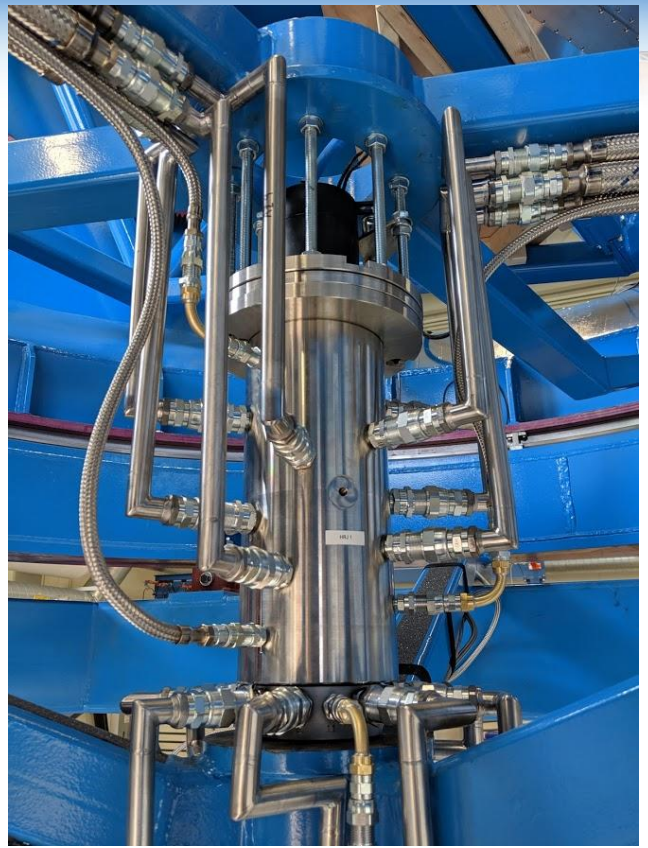
Timeline of BICEP Array Mount Design/Construction

- Started design work 8/2016
- PO for steel fab issued to Colombo 11/2017
- Steel arrives UMN High Bay 9/2018
- Bearings also arrive 9/2018
- Basic structure complete 10/2018
- Drive system installed and 3-axis motion 2/2019
- Receiver winch apparatus working 4/2019
- Helium plumbing in place and receiver with pulse tube running in the mount 5/2019
- Insulation panels arrive 6/2019
- Full DAQ integration, star cameras, forebaffles, nitrogen purge etc. 7/2019
- Boot arrives 8/2019
- Trucks roll out from UMN 9/2019
- Reassembly at Pole 11-12/2019
- Fully operational 2/2020

CQ4,6

This experience informs S4 schedule while re-using the design reduces risk

10 months



Helium rotary joint for 4x pulse tubes

Pulse tube support and DAQ in drum

BART mount project well underway

- Funded by Smithsonian and Harvard (CfA)
- Will go on new BICEP Array Replacement Tower (BART)
- This new mount is very similar to existing but engineers in adaptations for S4 cryostat design:
  - Removable helium rotary joint supports to allow rear loading of S4 large 3-fold cryostat
- This new mount is already in the UMN High Bay
- A copy of the top section of the BART tower steel will shortly arrive - once it does the mount will be built up on top of it.
- This mount will then remain in the UMN High Bay for at least two years
- We can use it to further S4 objectives:
  - Design and implement winch system to raise dummy S4 receiver into the mount
  - Potentially test alternate helium rotary joints

CQ5

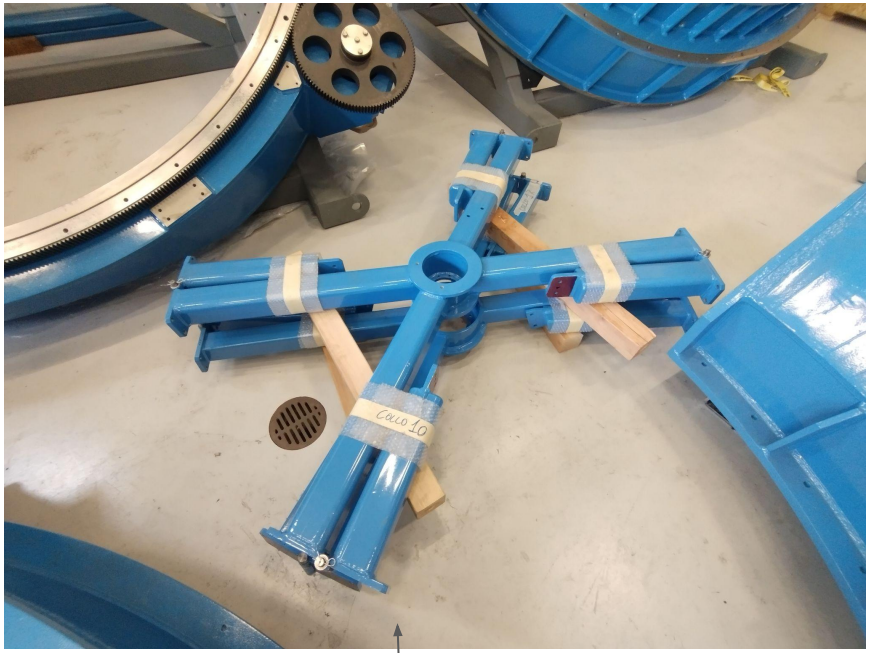
BART Mount Parts

BART Mount parts in UMN High Bay waiting for the tower top section

BART Tower Top Section

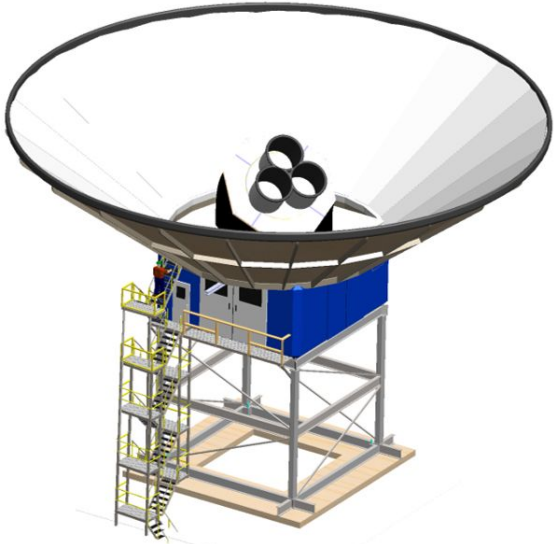
Picture at fabricator in Italy (Upside down). Currently on ship mid Atlantic

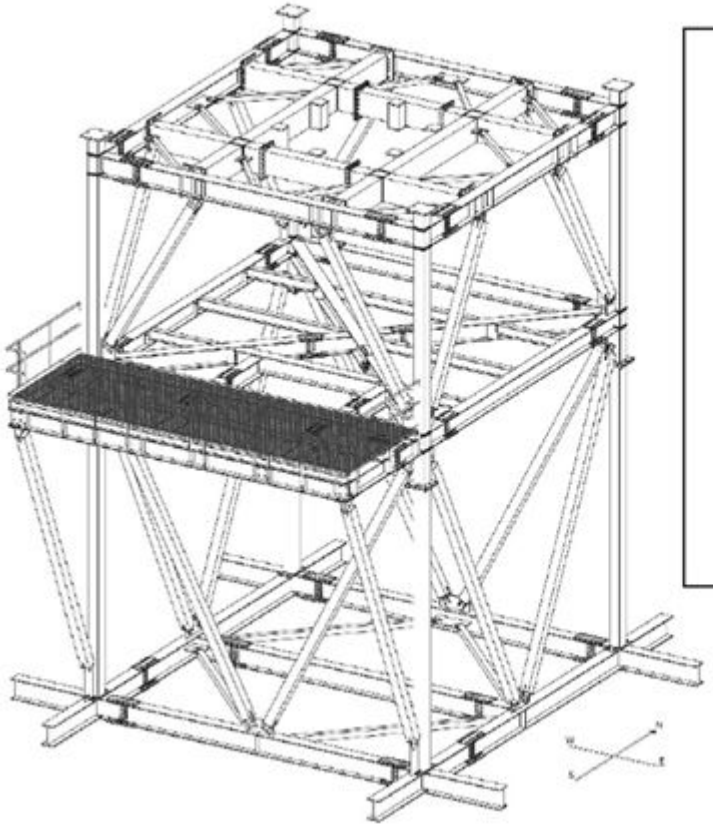
Old fixed rotary joint supports

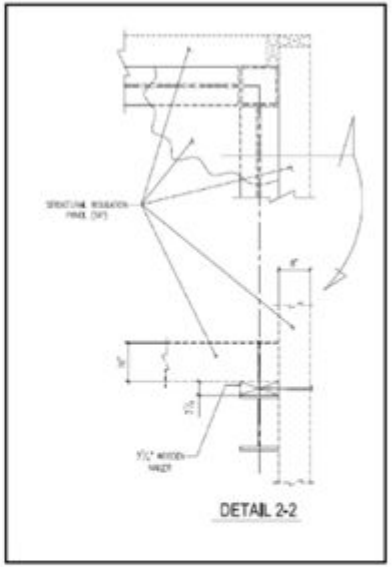


New removable S4 style rotary joint supports

SAT Tower Interface w/ Mount







BART (BICEP Array Replacement Tower) - NSF/Harvard-Smithsonian

- Snow Pad / Wood Raft Footer
- Height for ground pickup / snow accumulation.

Baseline: CMB-S4 (sites) will monitor design and verify it continues to meet requirements.

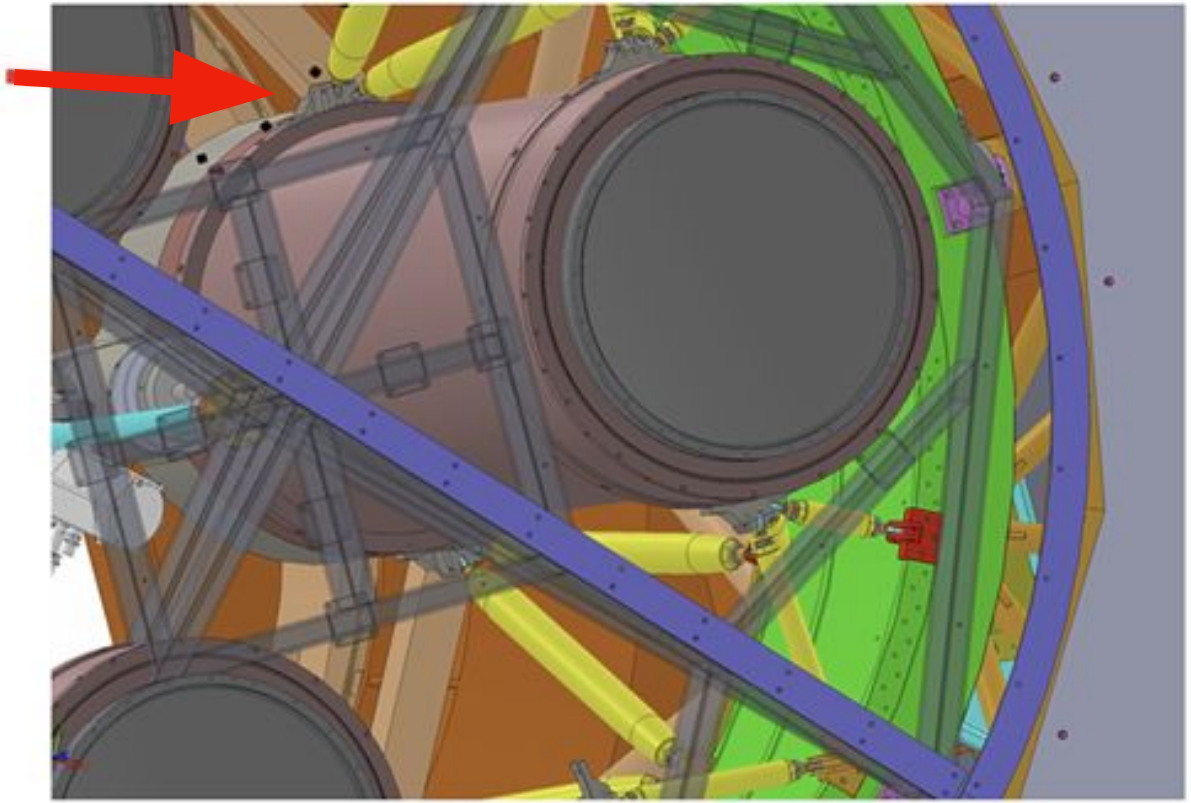
SIPs - Structural Insulated Panels - thermal envelope, site standard.

CQ1,2

Receiver Interface with SAT Mount

SAT Receiver in this configuration held rigidly at the top and bottom of cryostat assembly by struts connected to mount azimuth assembly.

Ex: Mount-Receiver Strut Interface from BICEP Array

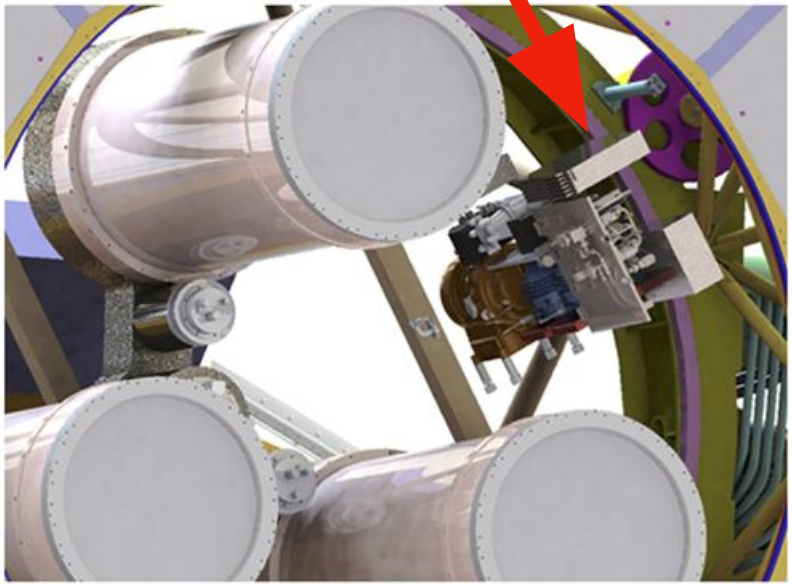


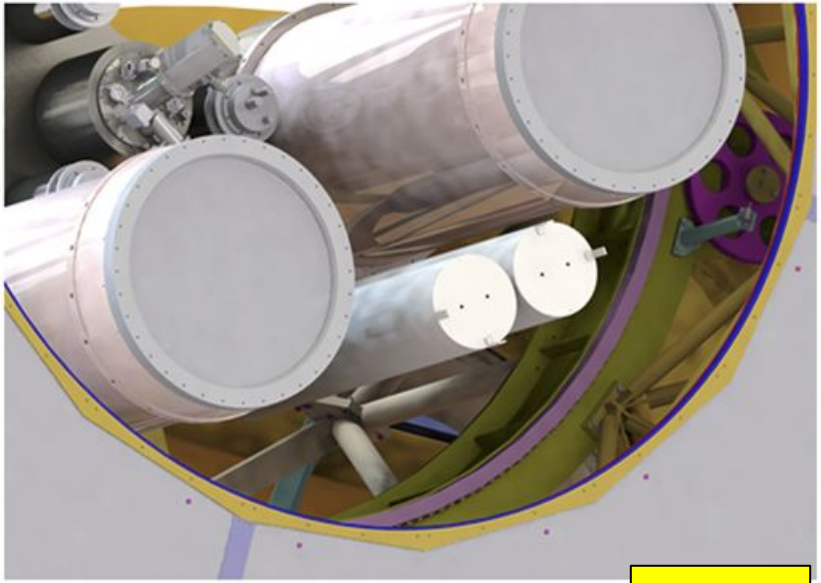
CQ1,2

DR Gas Handling System Interface with SAT Mount

SAT Receiver and DR Gas Handling System components shown on telescope mount without packaging.

- Interface development work to be done includes defining the best grouping into key sub-packages of the DR Gas Handling System, and their exact mechanical interfaces with the mount.
- Detailed work (beyond conceptual) will continue following DR cooling system downselect and final vendor selection.



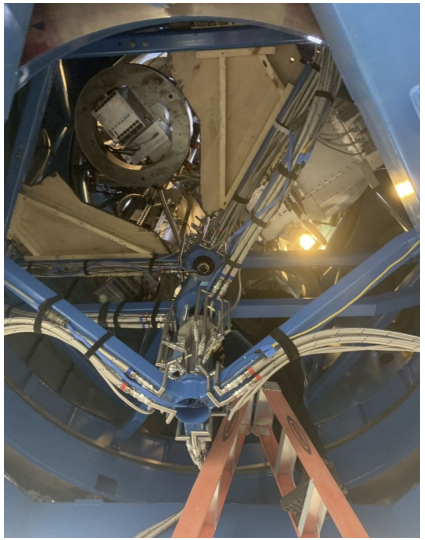


CQ1,2

Prototyping Plan and Path Forward

- Prototype plans focus on retiring risks and refining design elements specific to S4-SATs
- Integration testing will be key to confirm:
  - Mechanical interface compatibility (including hoisting hardware/procedure)
    - Goal is to test early using BART Mount at UMN (requires P6 update)
  - Cryogenic performance (DR+GH / HRJ, subject to scanning dynamics)
  - Operation with active detectors (RFI, EMI)

Left: BICEP Array Mount @ UMN
Middle/Right: BICEP Array Mount and Ground Shield @ Pole



CQ4

Recommendation 5 from last review:

- **Demonstrate rotary high-pressure helium joints or eliminate from design** CDR R5 (RT-125): The project should allocate additional resources towards procuring and testing rotary high pressure helium joints by CD-2 or before. The team should demonstrate the operation of rotary high pressure helium joints with reliability such that the probability of needing winter maintenance is low, or consider telescope mount designs that remove these joints. This issue is a high risk and should be added to the SAT risk registry
- Response: Similar rotary joints ran on the BICEP Array mount during the 2020 through 2022 winter seasons (and 2023 winter ongoing). One winter switch-out was required during each season. These were accomplished with <24 hours of downtime followed by successful seal replacements on the removed units. The situation therefore seems manageable. However, BICEP Array currently has alternate rotary joints on order from Moog/GAT which it is hoped will deliver longer run time between seal changes. CMB-S4 project resources are requested to enable the testing of these units at UMN.
- Recommendation summary: Demonstrate rotary high-pressure helium joints or eliminate from design CDR R5
- Response summary: When funding allows, we plan to test alternative joints, however CMB-S4 can tolerate the level of reliability (and downtime) of the existing joints in use on BA, so we do not consider this a major risk.

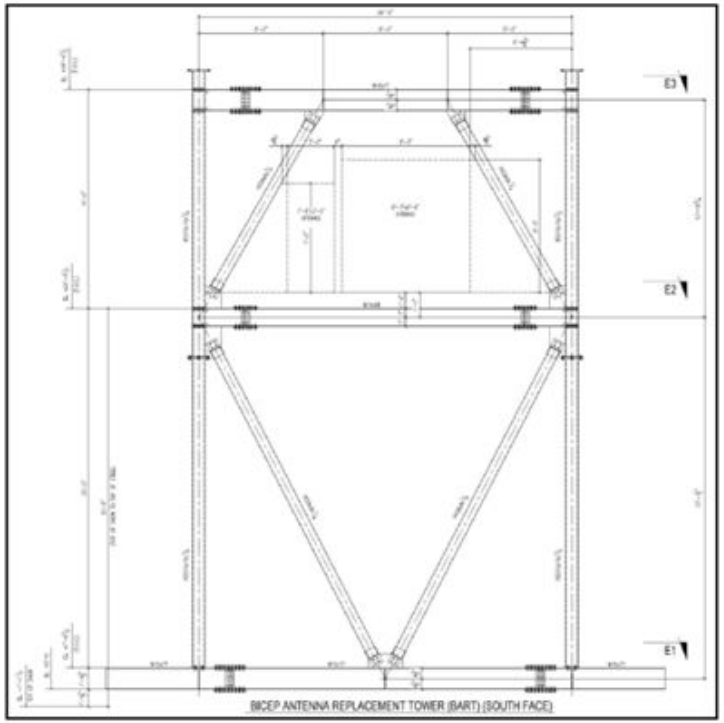
CQ10

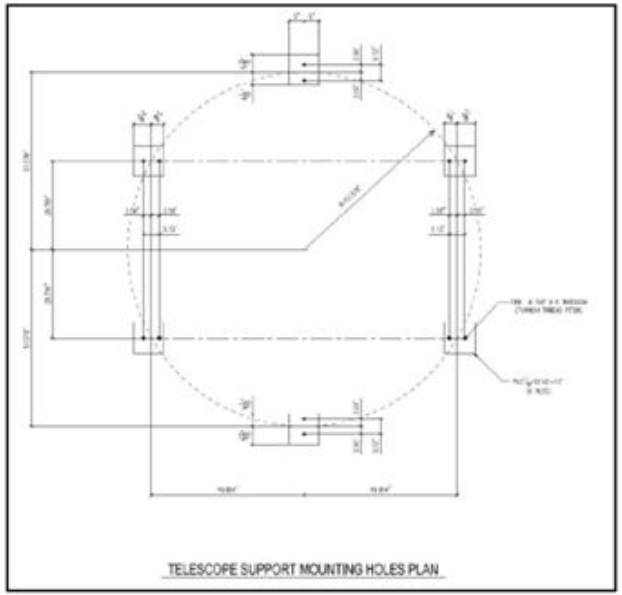
SAT Mount Conclusions

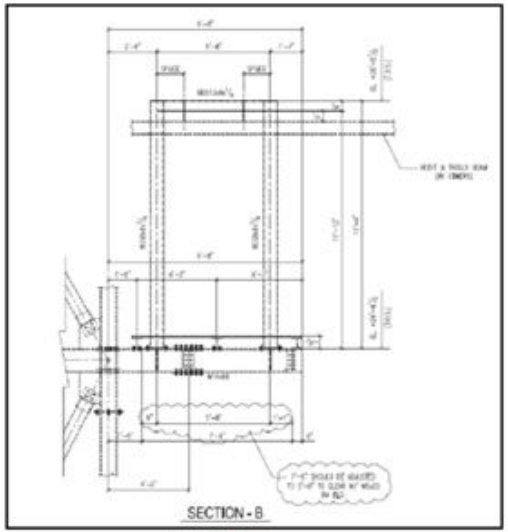
- Existing BICEP Array mount is performing well and is very close to what is required for CMB-S4
- BART mount is under design/construction by experienced team which will prototype design changes required for CMB-S4
  - The opportunity exists to design, develop and test the S4 receiver winch apparatus using this mount - the winch apparatus was a significant issue for BICEP Array.
    - This will require some S4 resources before BART ships (~2 years)
- Helium rotary joints have many advantages and reliability is improving
- Experience says ship complete “kits” to Pole - full up integration of complete SAT system in North America will be key
- The schedule is under development
  - The first mount will take longer, later units will go quicker, looking at opportunities to parallelize
  - Possibility to push additional work back onto the fabricator for later units

Backup Slides

SAT Tower Interface w/ Mount



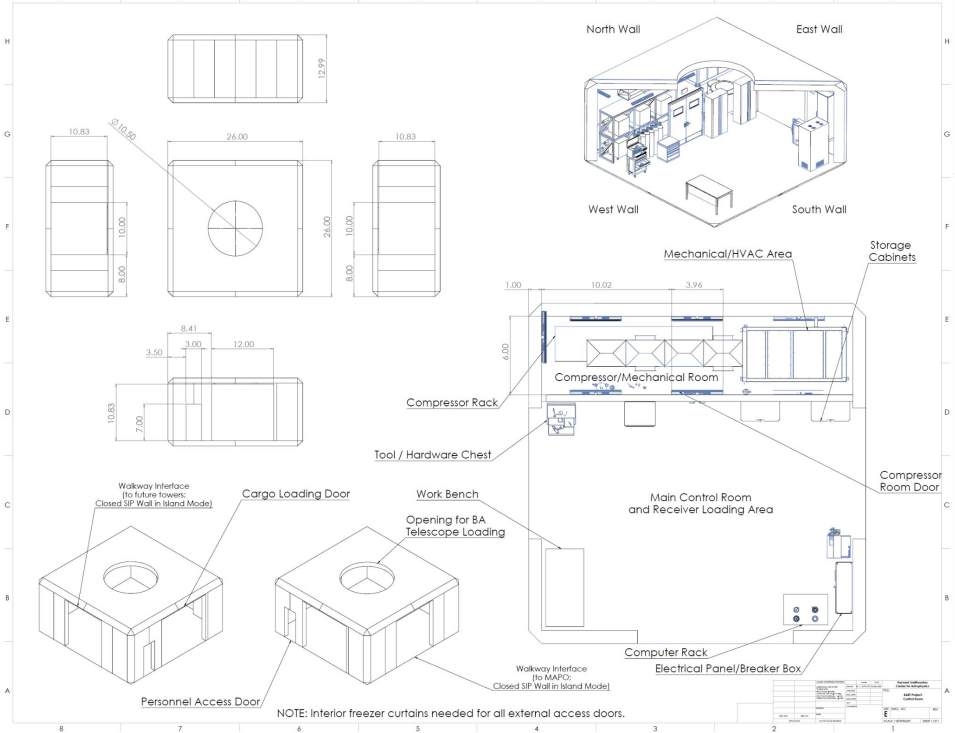




Hoist Frame

- SAT structural interface
- Cargo deck/hoist, Doors/Stairs for operations

SAT Control Room Interface w/ Mount

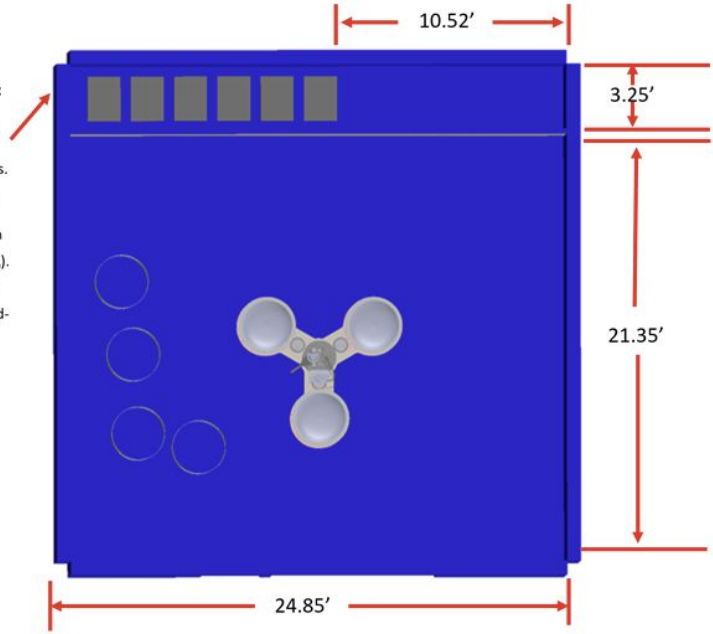


Representative Envelopes for 6 Cryomech Compressors (27" deep x 20" wide footprint, 25" tall).

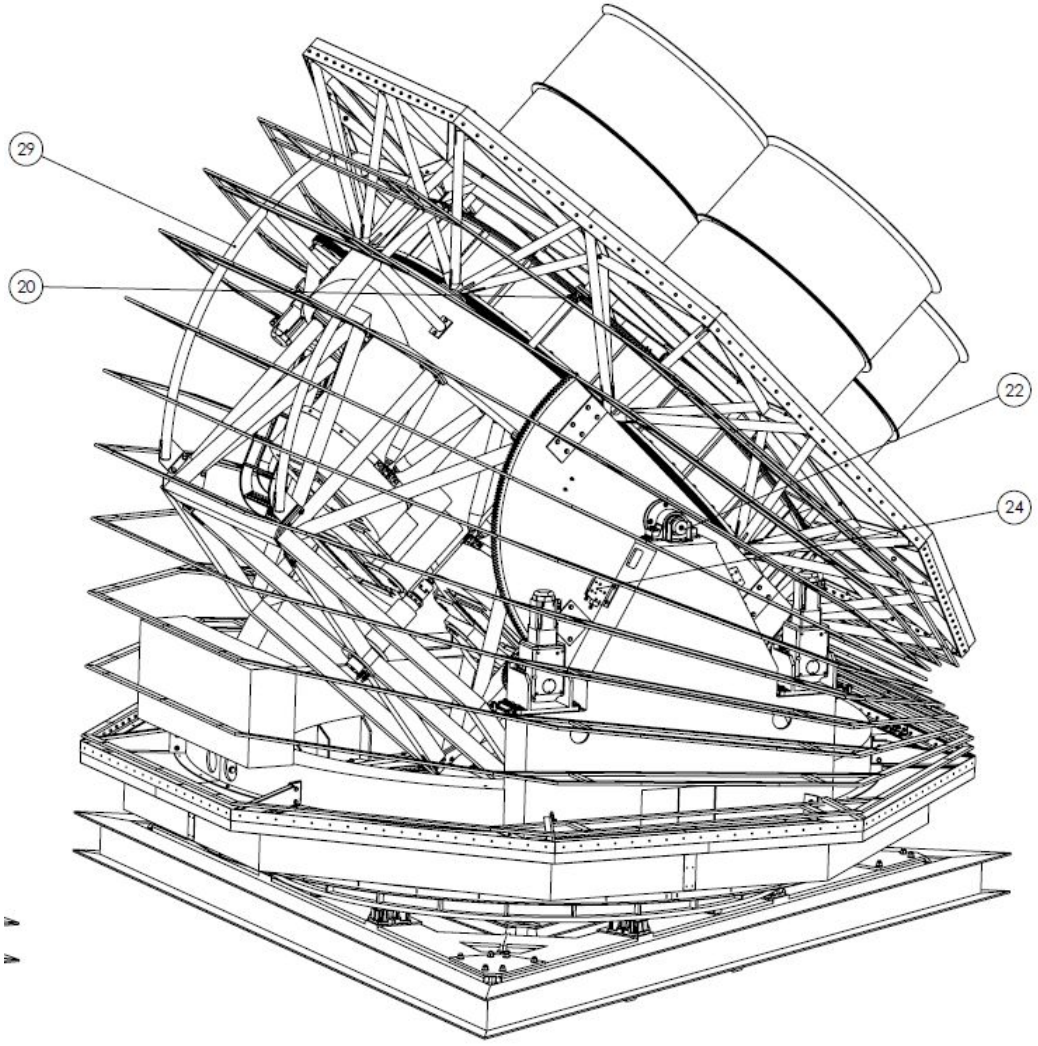
- 6" left in front of compressor for cryogenic hose installation

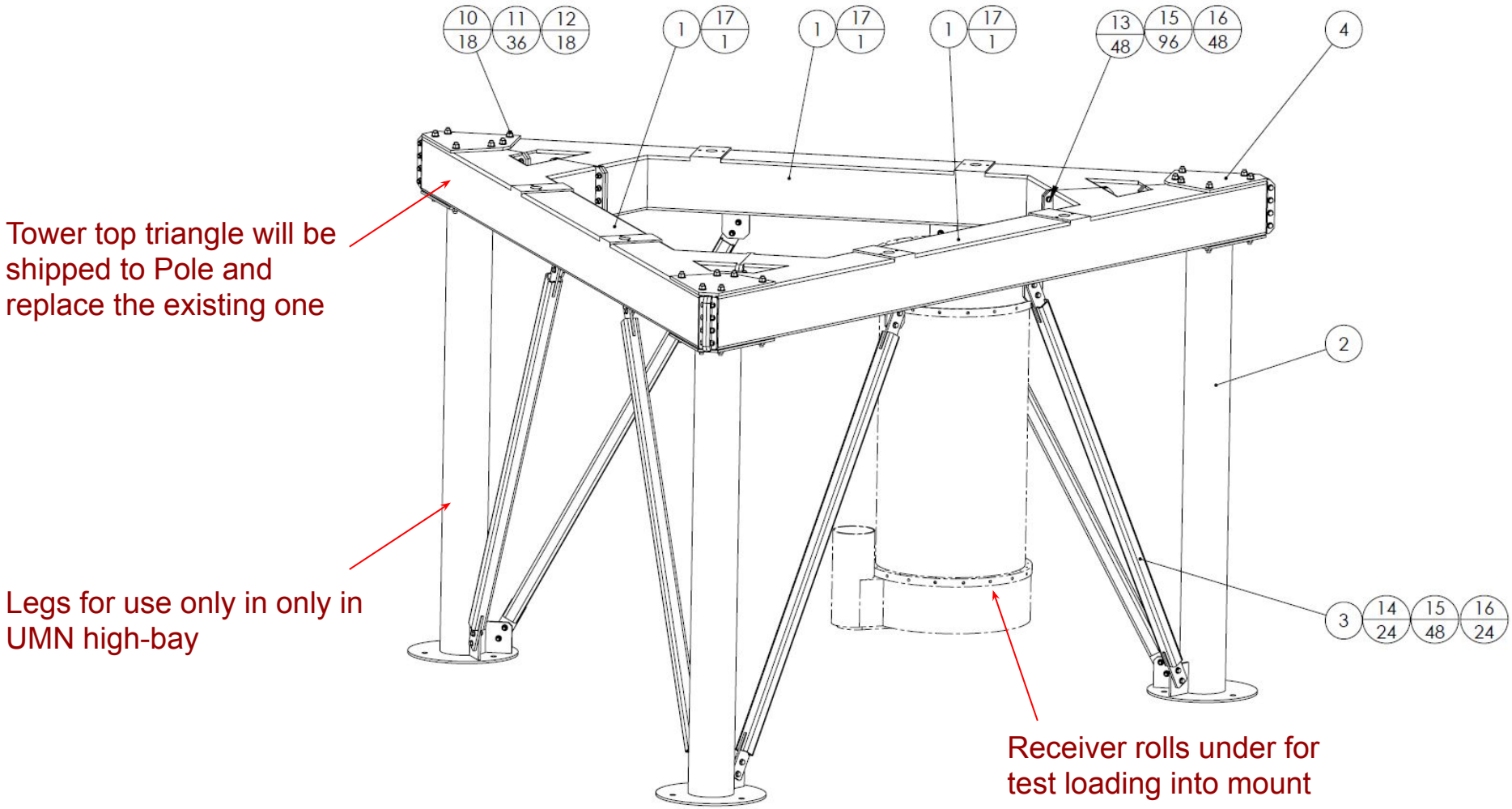
-6" left behind for plumbing hookups.

- 6" spacing between adjacent compressors.
- (Compressor dimensions taken from SMA lab compressors currently running PT410s at CfA).
- Compressor and mechanical area separated from main control room area by thin sound-reduction wall with pocket doors, or industrial sound-damping curtain (currently preferred to maximize workspace footprint).

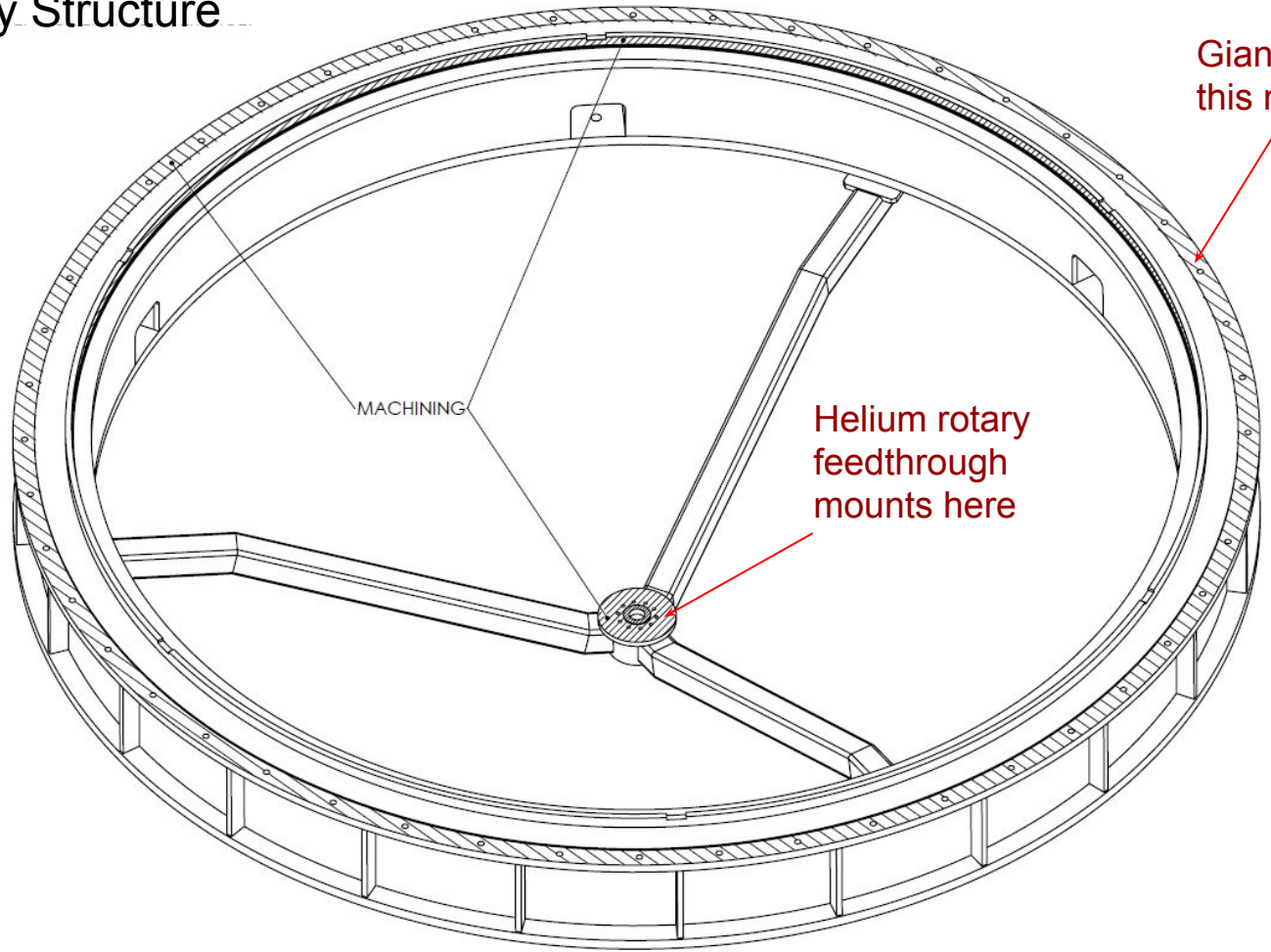


- Provides environmentally-controlled workspace and equipment space.

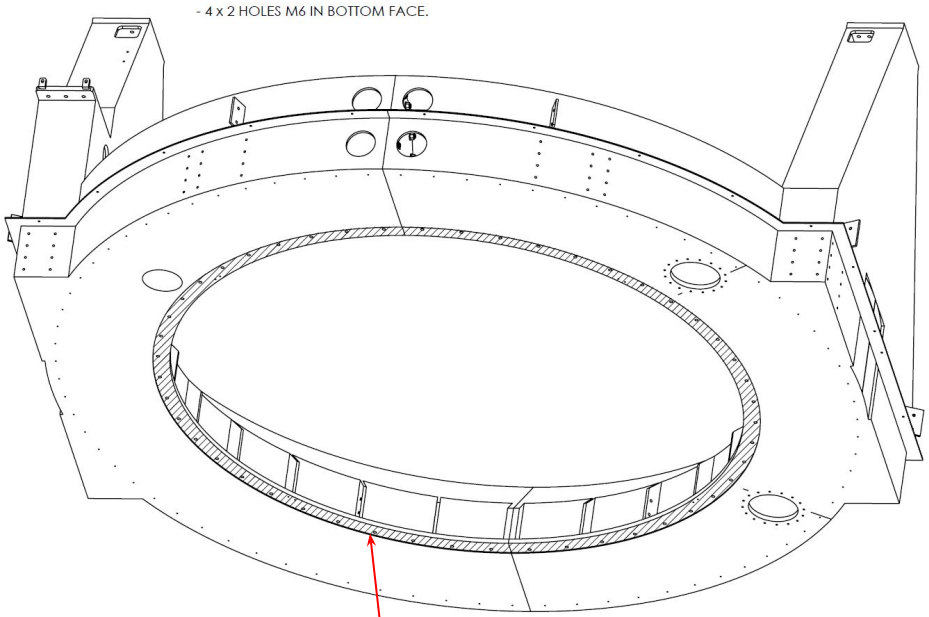

29
20
22
24


10
18
11
36
12
18
1
17
1
1
17
1
1
17
1
13
48
15
96
16
48
4
2
3
14
24
15
48
16
24
Tower top triangle will be shipped to Pole and replace the existing one
Legs for use only in only in UMN high-bay
Receiver rolls under for test loading into mount

Stationary Structure



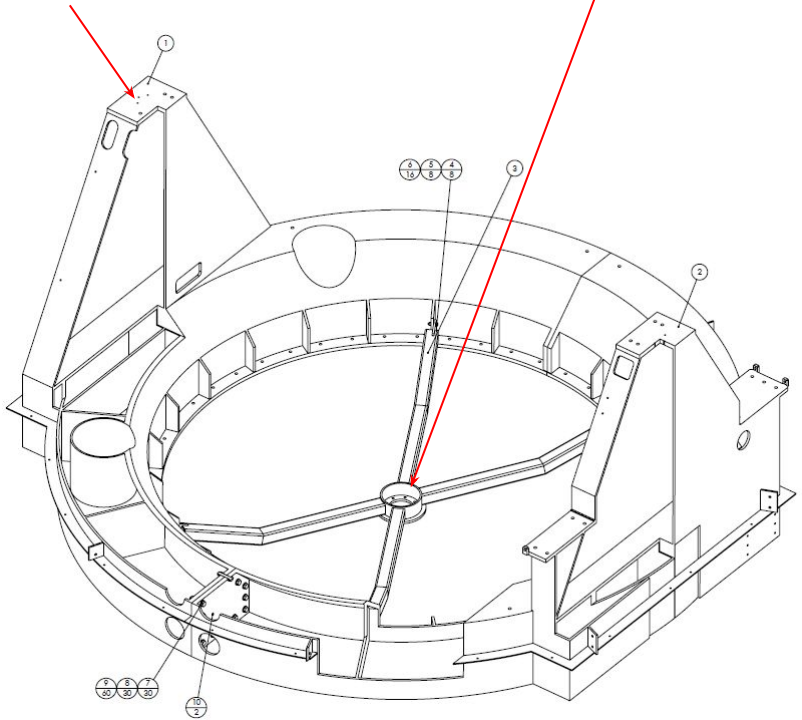
Azimuth Structure



Az bearing attaches here

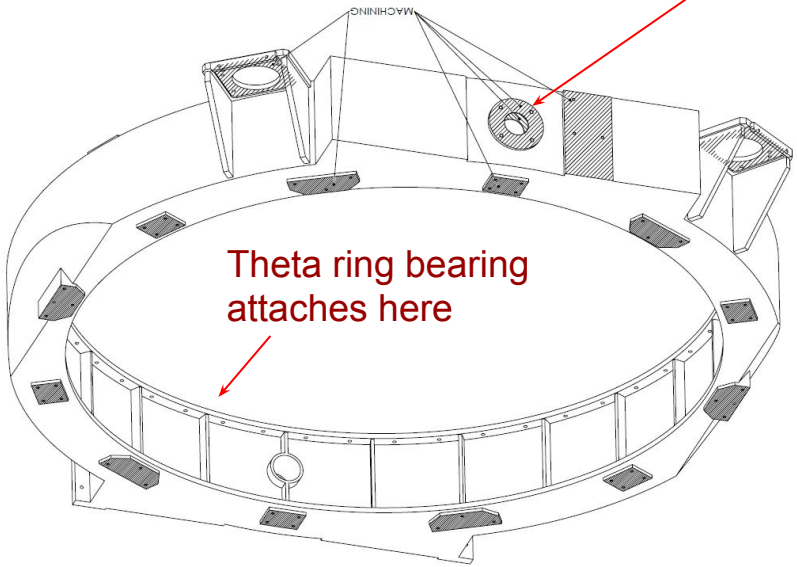
El bearing sit here

Rotary union drive arms



Elevation Structure

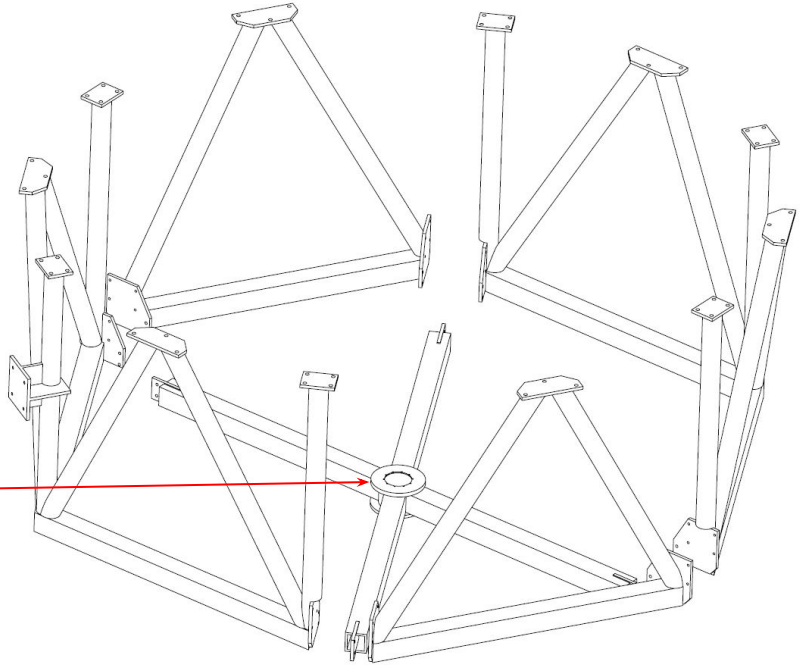
El axis here



Theta ring bearing attaches here

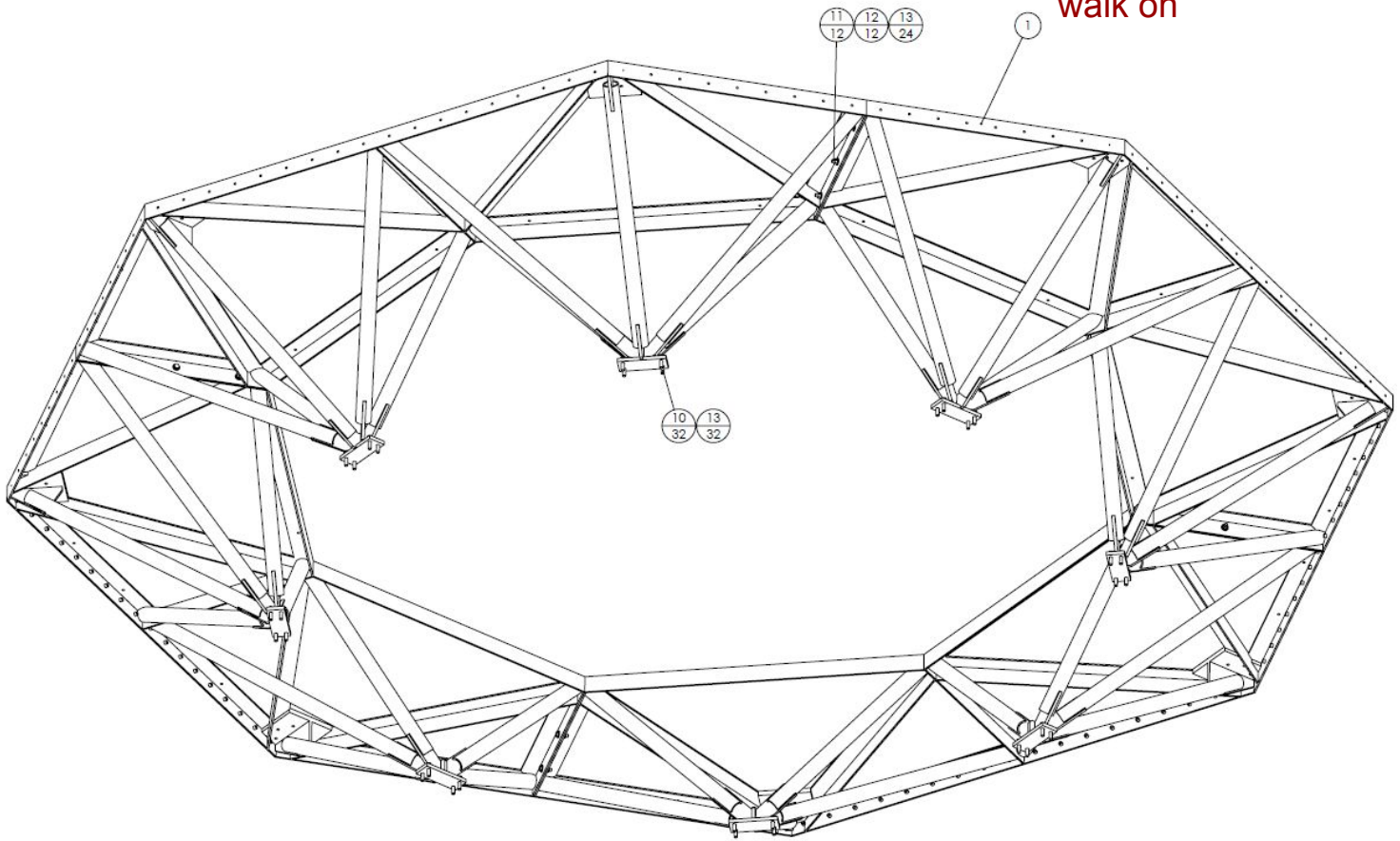
Elevation back up cage

Rotary union here



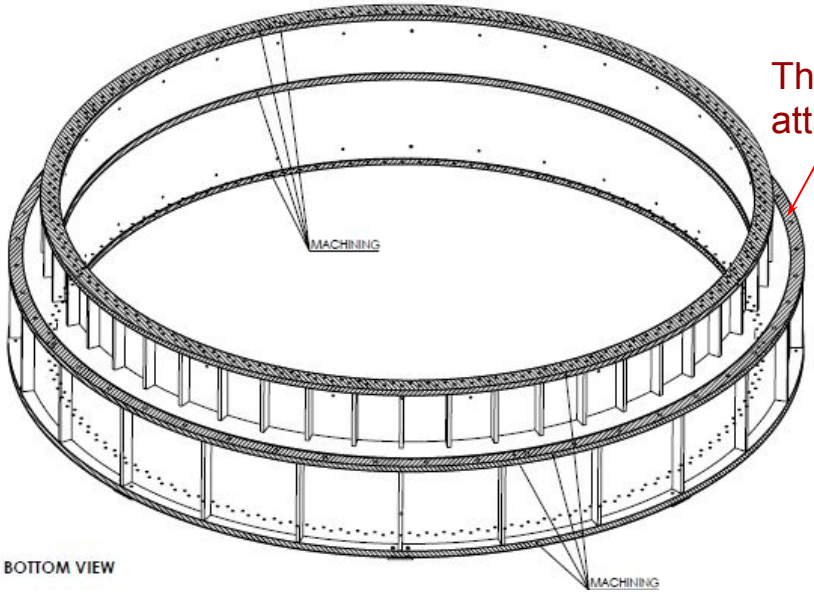
Boot support frame (seen from below)

Attaches to elevation structure and has panels on the front to walk on

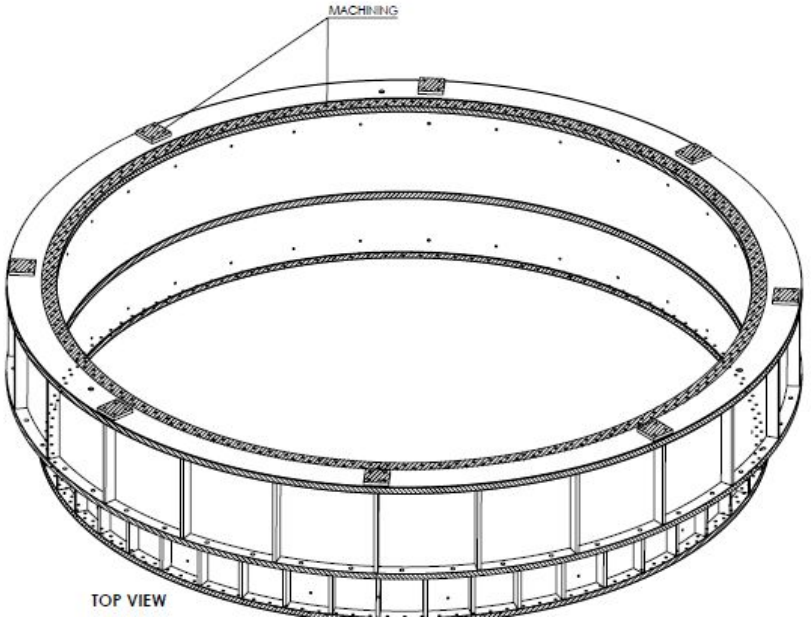


Theta ring/drum

Attaches to elevation structure and has panels on the front to walk on



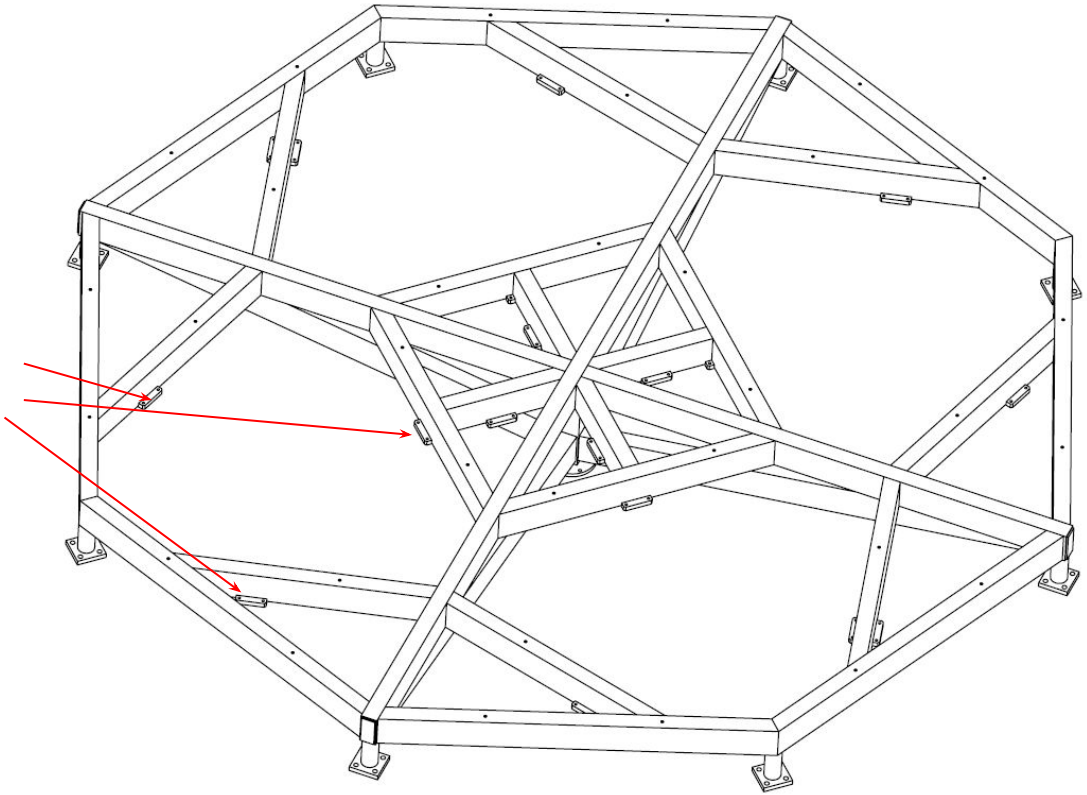
Theta bearing attaches here



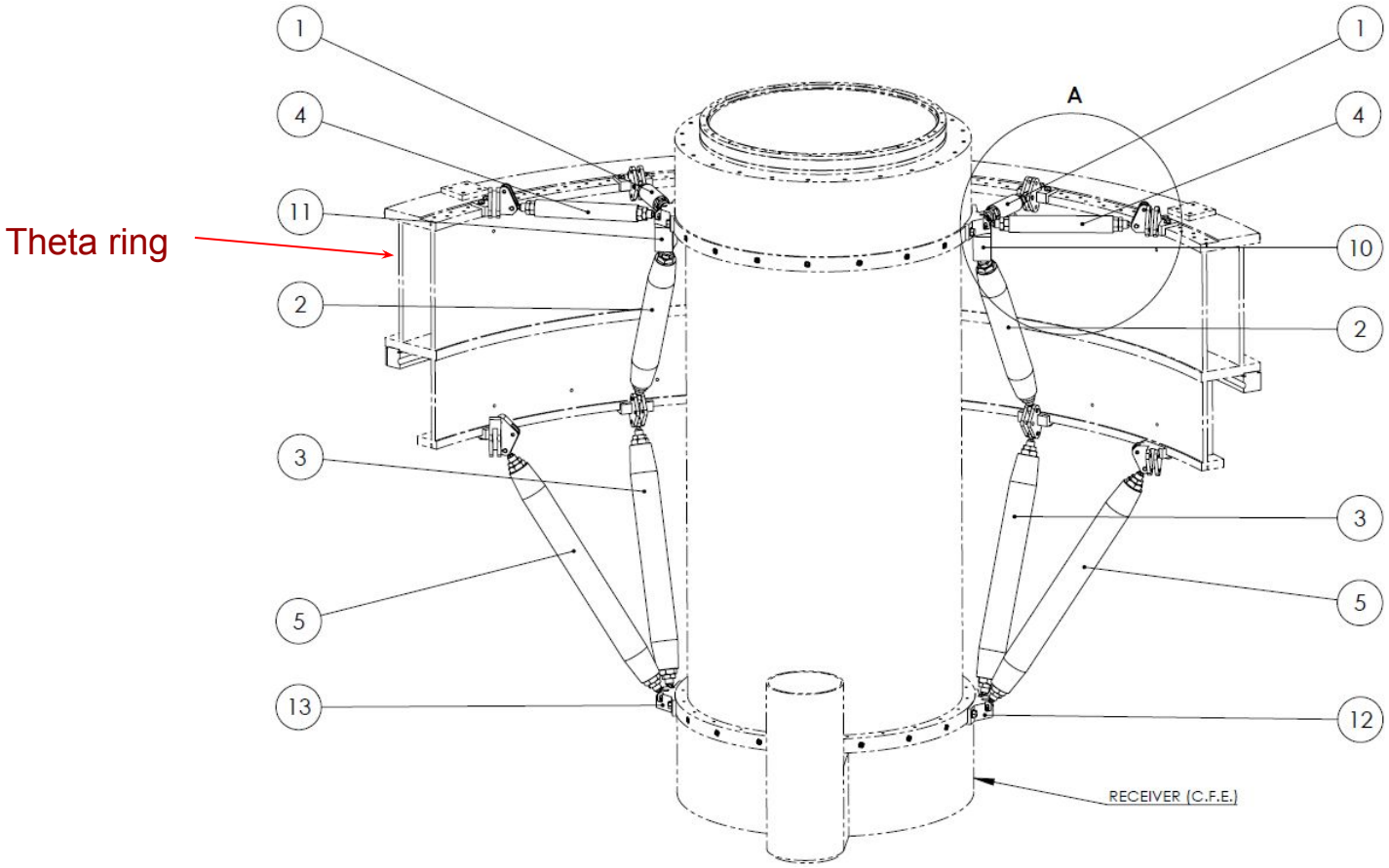
Theta frame

Attaches to theta ring - supports panel on front to walk on - and the forebaffles

Receiver hoisting pulleys mount here



Receiver harness

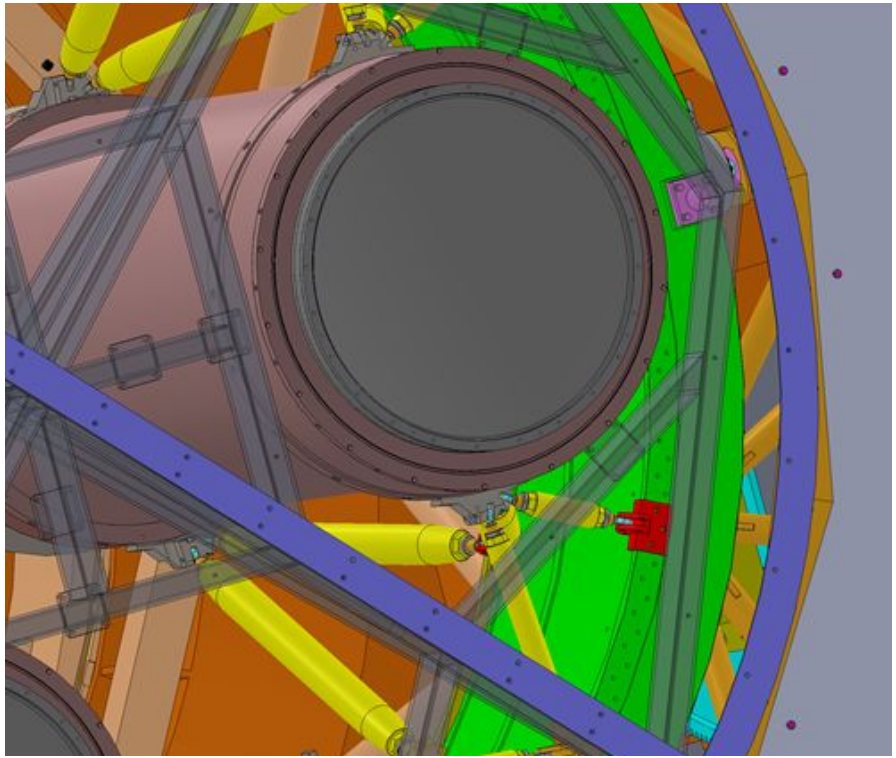


Heritage: BICEP Array Mount Integration and Deployment

BICEP Array Mount @ UMN
(Aug 2020)

BICEP Array Mount @ Pole
(Jan 2020)

Receiver Integration with SAT Reference Mount



COLINEARITY OF SAT RECEIVER

- Colinearity is not a major issue as each SAT optics tube has its own pointing model. The main pointing requirements are on the rigidity (flexure < 1 arcmin) and repeatability (variation < 20 arcsec) of each SAT tube's pointing.

- Because of the large SAT beam sizes, these requirements are fairly relaxed compared to most telescopes, and are met by this reference mount design.