LATR Update
March Meeting

March 10, 2021

Brad Benson, Pato Gallardo, Don Mitchell, Matt Hollister

CMB-S4

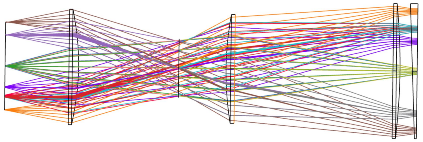
Outline

- Introduction
- Lens design in optics tubes (Pato)
- Cryostat design (Don)
  - Cryogenics and Fast Cooldown (Brad, Matt)
- Next steps and group feedback
  - Optics tube concept and layout
  - Readout mapping

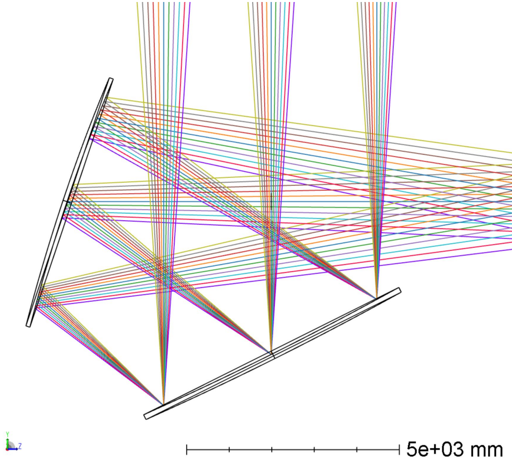
LATR optics tubes design overview

Designing 85x optics tubes for the CD and TMA

Camera layout:



- 3 Silicon lenses
- Alumina wedge for IR blocking and tilt correction

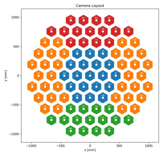


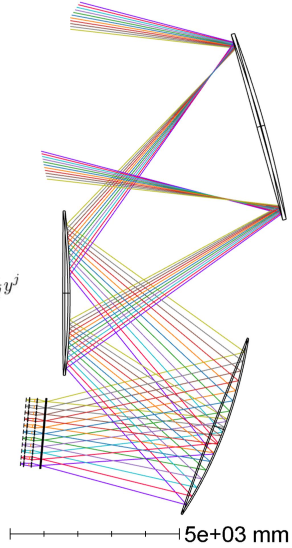
Lens prescription:

- CD: Biconic lenses (for astigmatism)
- TMA: Aspheric lenses (radially symmetric aberrations)

$$z_{\text{biconic}} = \frac{c_x x^2 + c_y y^2}{1 + \sqrt{1 - (1 - k_x) c_x^2 x^2 - (1 + k_y) c_y^2 y^2}} + \sum_{i=1}^{16} \alpha_i x^i + \sum_{j=1}^{16} \beta_j y^j$$

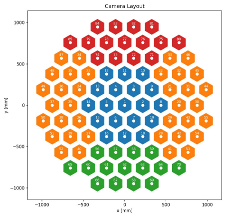
$$z(r) = \frac{c r^2}{1 + \sqrt{1 - (1 + k) c^2 r^2}} + \sum_{j=1}^{8} \alpha_{2j} r^{2j},$$

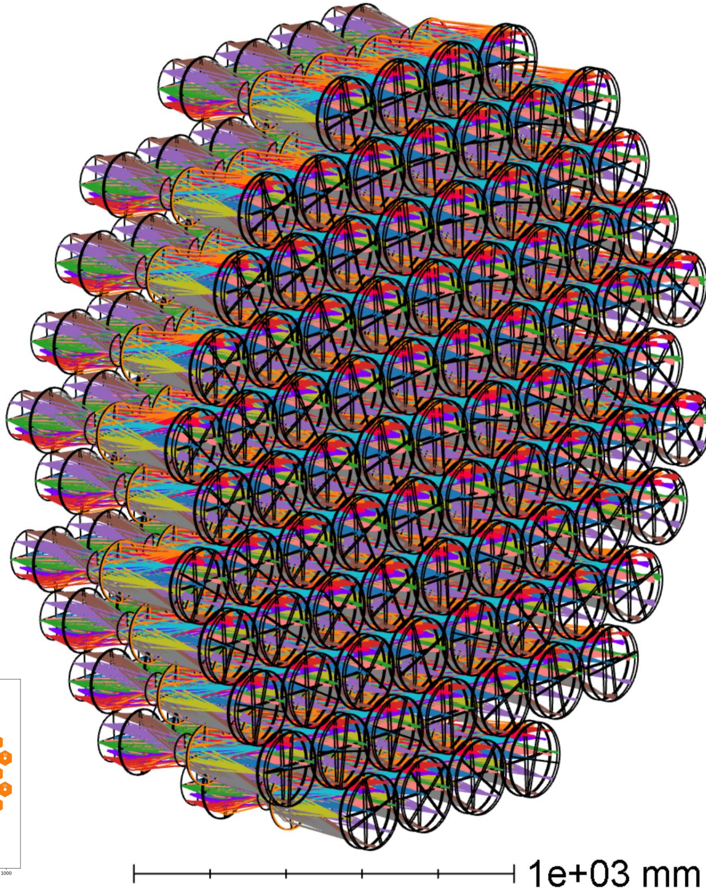




LATR optics tubes design status

- We have built cameras individually optimized, work in progress to group designs to minimize complexity.
- Code to generate TMA grouped camera designs is yielding results (using aspheric lenses), need to fine tune parameters to give a left-right symmetric design.
- Code to generate CD grouped cameras need some development, we have demonstrated ability of optimizing individually, however the groups and minimum number of biconics need to be explored some more.
    - How many biconic lenses?
    - Clockings





LATR optics tubes design challenges

Fabrication complexity:

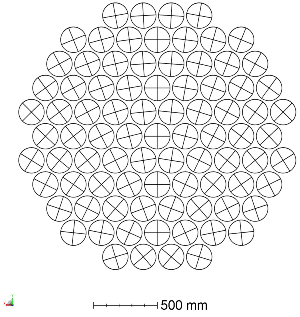
- Silica wedges have a (per tube) clocking, CD and TMA have unique per-tube clockings and wedge tilt
- Biconic lenses also have a specific per tube clocking

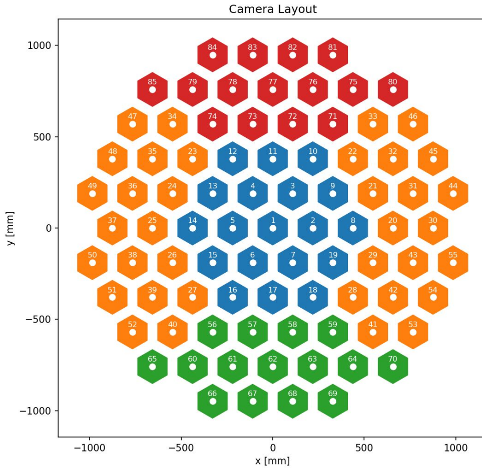
$$z(r) = \frac{cr^2}{1+\sqrt{1-(1+k)c^2r^2}} + \sum_{j=1}^{8} \alpha_{2j} r^{2j},$$

$$z_{\text{biconic}} = \frac{c_x x^2 + c_y y^2}{1+\sqrt{1-(1-k_x)c_x^2x^2-(1+k_y)c_y^2y^2}} + \sum_{i=1}^{16} \alpha_i x^i + \sum_{j=1}^{16} \beta_j y^j$$

Design complexity:

- The CD with biconic lenses seems more complex to design than the TMA tubes, as there are more degrees of freedom
  - What is the minimum number of biconic lenses that yield a good design?
  - Will the 5 groups work in the CD?
- Drawing creation and specification for all tubes. Interfacing with our CAD experts, also Zemax Optics Builder has tools for this.

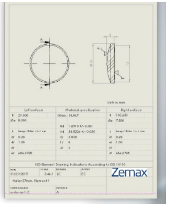




Automatic drawings

Push-button optical drawing creation

Share ISO 10110 compliant optical drawings with a push of a button using an automatic optical drawing design export tool that even works with your own custom drawing templates. Save time by automatically filling optical manufacturing data pulled directly from OpticStudio and reduce rework.



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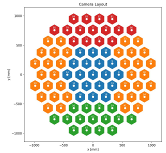
LATR optics tubes design next steps

Next steps:

Define camera groups of designs

1. CD: needs some exploration (~month)
2. TMA: close to have a working system

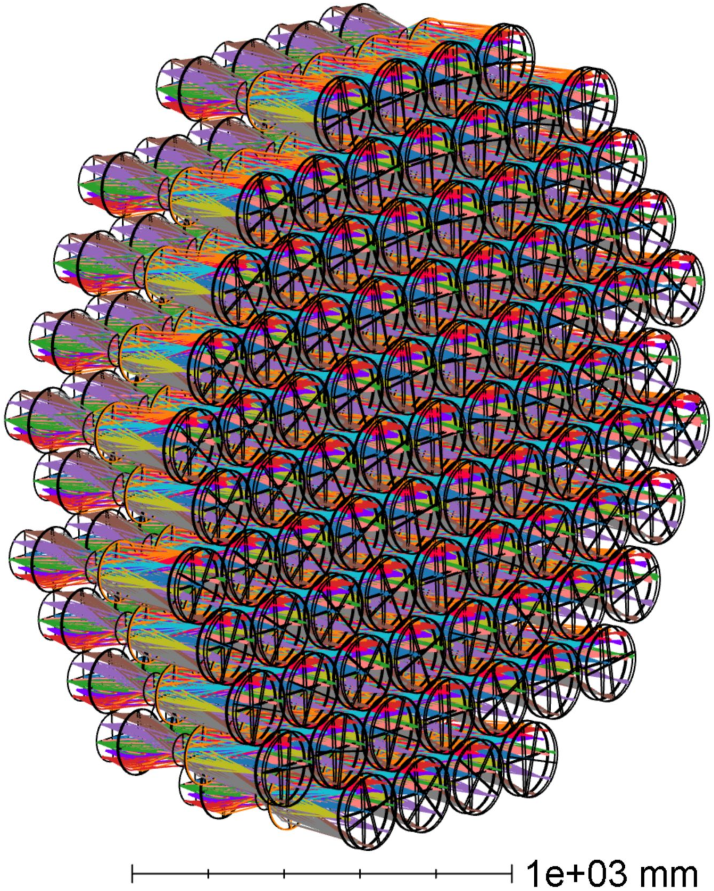


Integrate filters into the Zemax design

Opto-mechanical integration, check for clearances and lens clamping

Drawing creation

System evaluation



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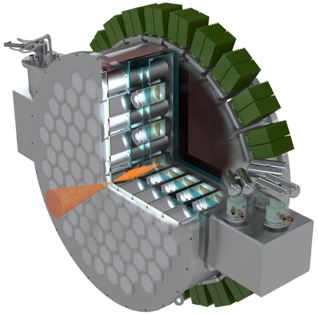
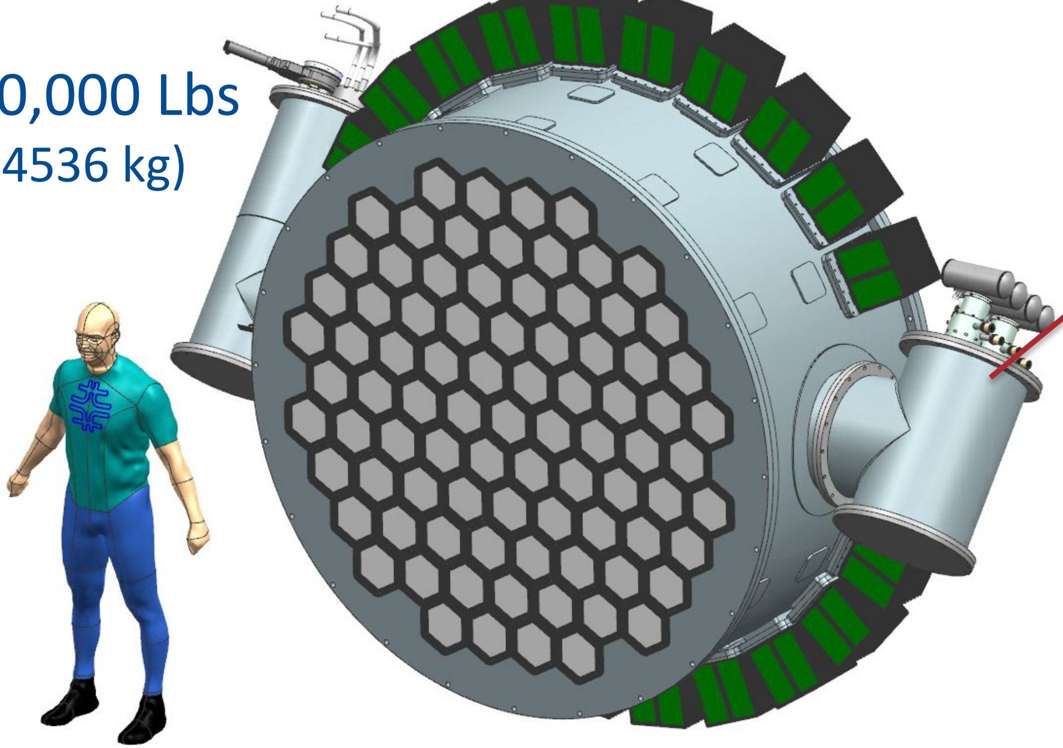
LATR Mechanical Design of the Receiver

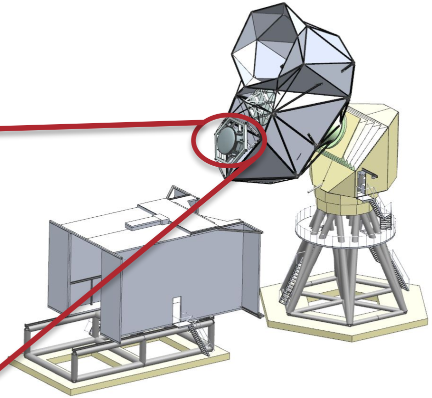


Don Mitchell
Fermilab
March 10, 2021

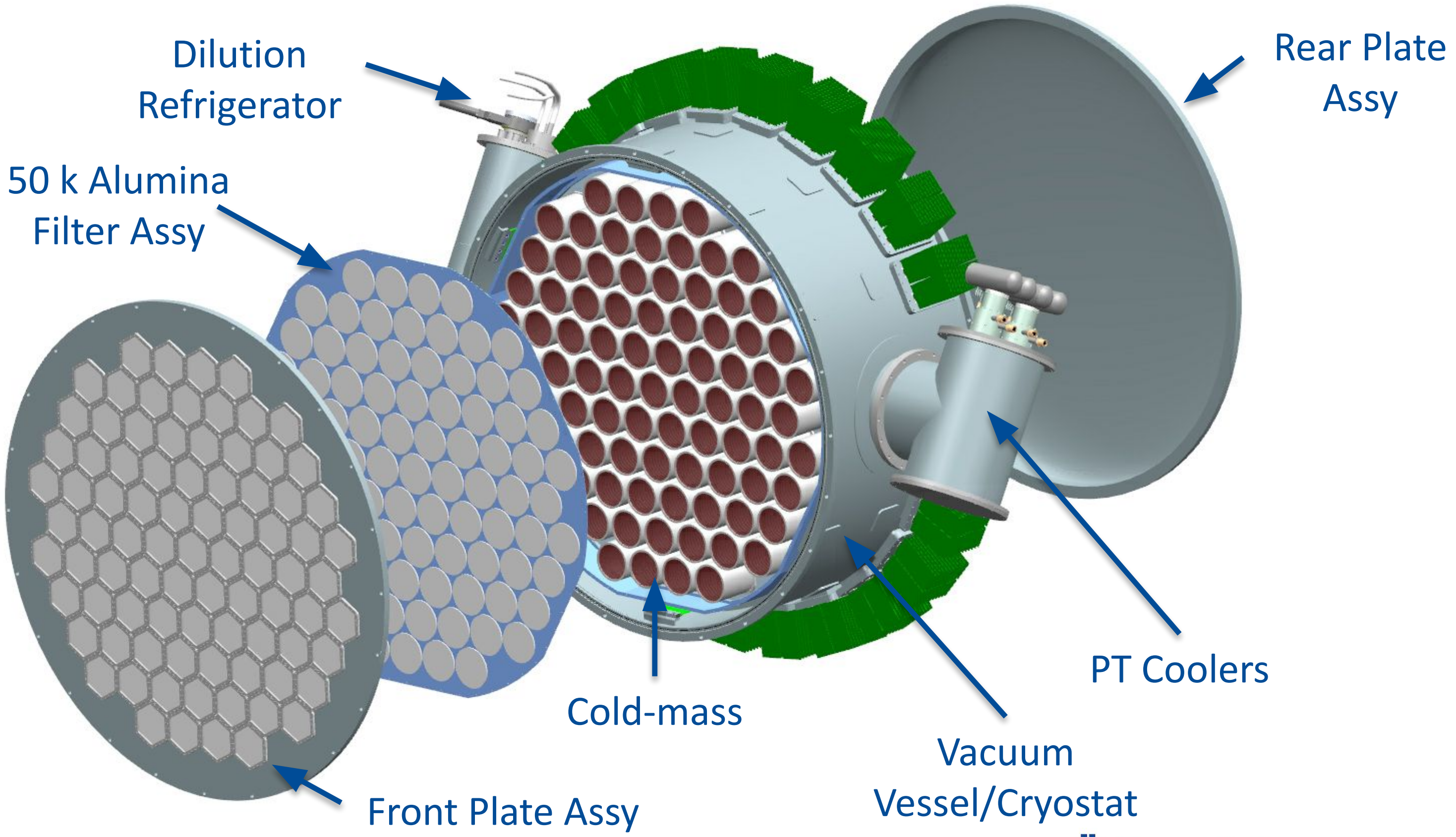
Conceptual Model

<10,000 Lbs
(4536 kg)





Conceptual Model



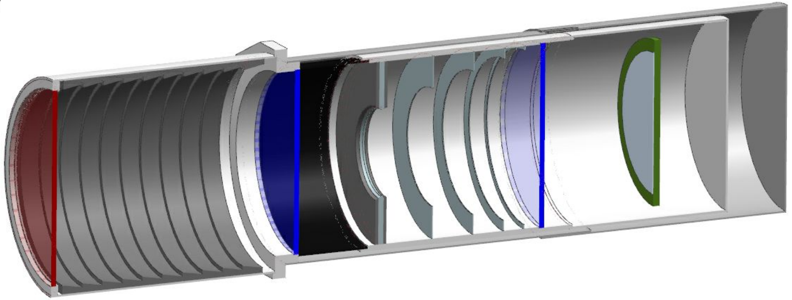
Optics Layout – Preliminary Design from P. Gallardo (85 Tubes)

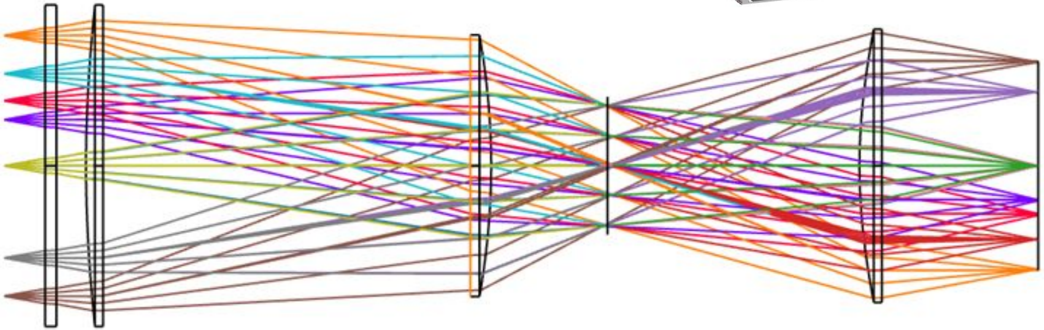
Here a few numbers from the center tube model with aspheres:

L1 active diameter:180mm (though, for optical throughput the more the better)
L2, L3 active diameter: 170mm
FP diameter: 130mm
Stop diameter: 80mm

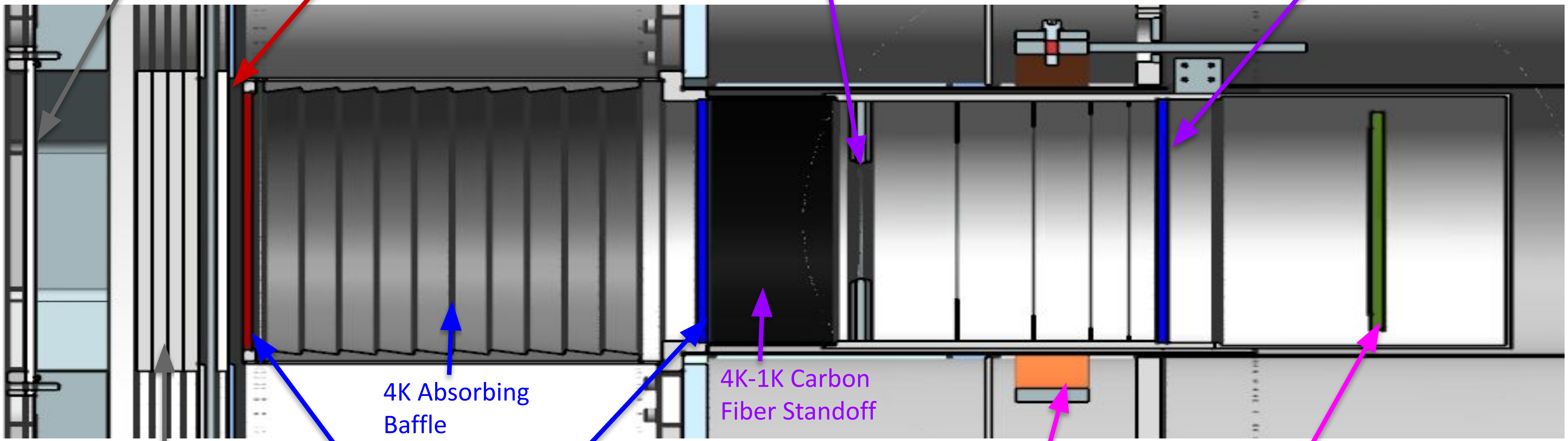
Positions measured from the focus (here the distance is measured fror
facing side of the lens):

L1: 5.08E+01 mm
L2: 2.89E+02 mm
Lyot: 3.74E+02 mm
L3: 5.30E+02 mm
FP: 6.41 E+02 mm

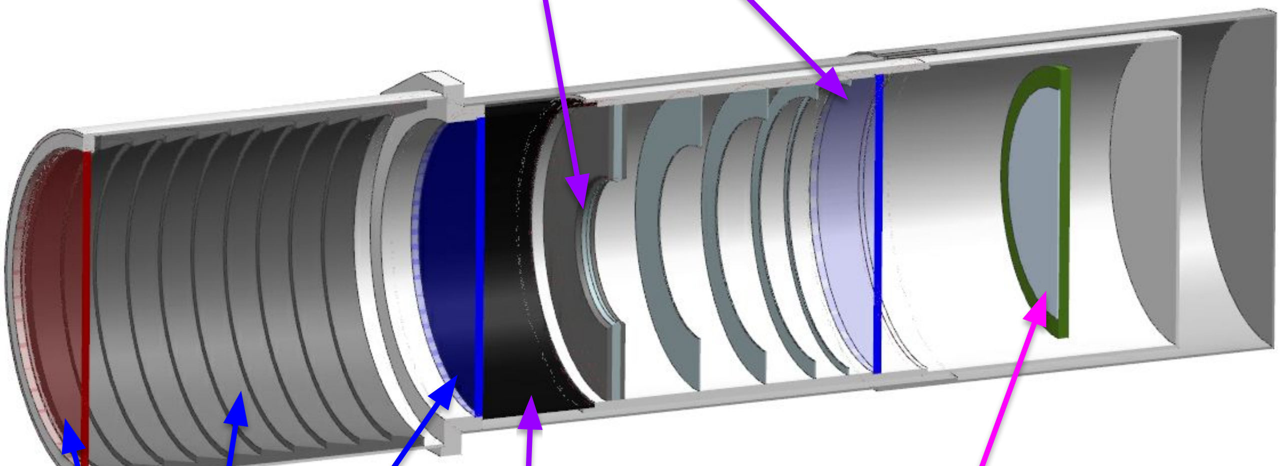




Optics Tube Layout



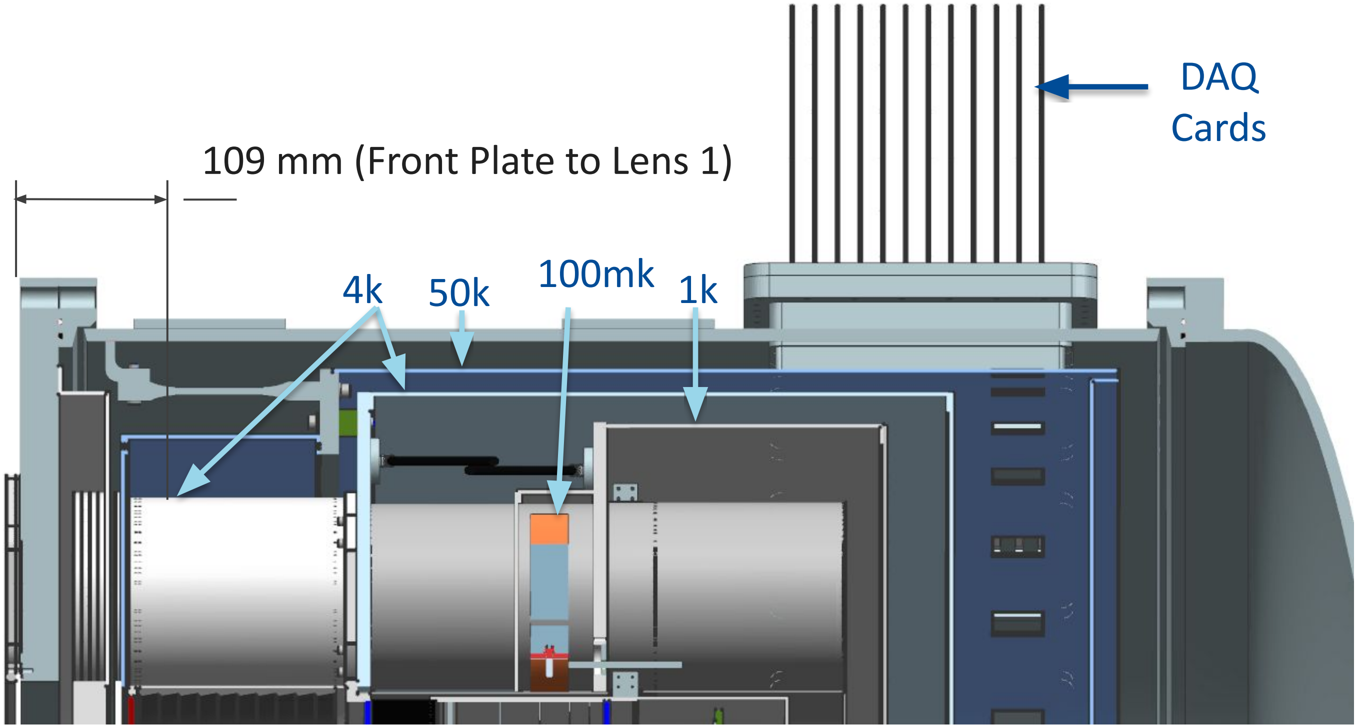
Optics Tube Insert Questions



Overall concept seems reasonable, but some details still to consider / explore / get-feedback::

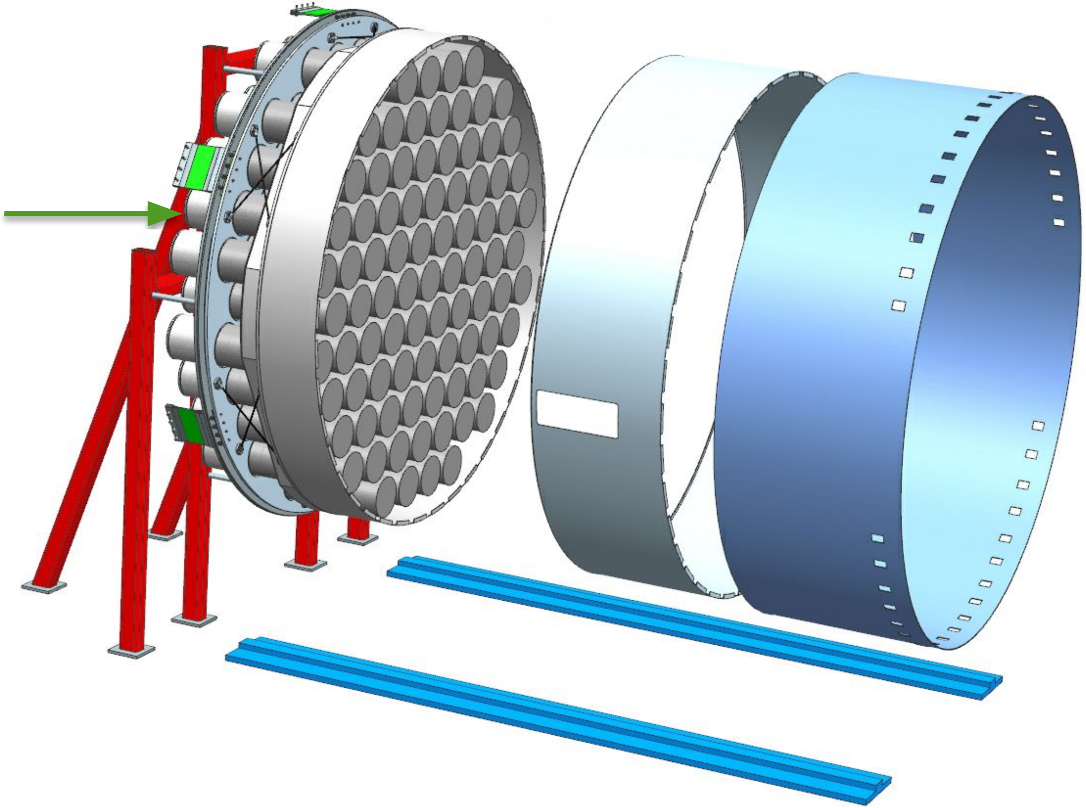
- **Magnetic shielding req:**
  - Concept is for 1K A4K shield going back from L1, and Nb spitoon around. Need specs from flowdown.
- **SSA SQUID location:**
  - Do we want SSAs at 1K plate near detectors? Is there room on 1K plate? How would connection to focal plane look?
- **Radial space:**
  - This looks plausible, but once we add all the details for flanges, interfaces, lens mount, and clearances, will it really fit?
- **Detector Module pre-Install?**
  - Plan is for detector modules to be installed in-situ in the cryostat.

Conceptual Model: Heat Shields



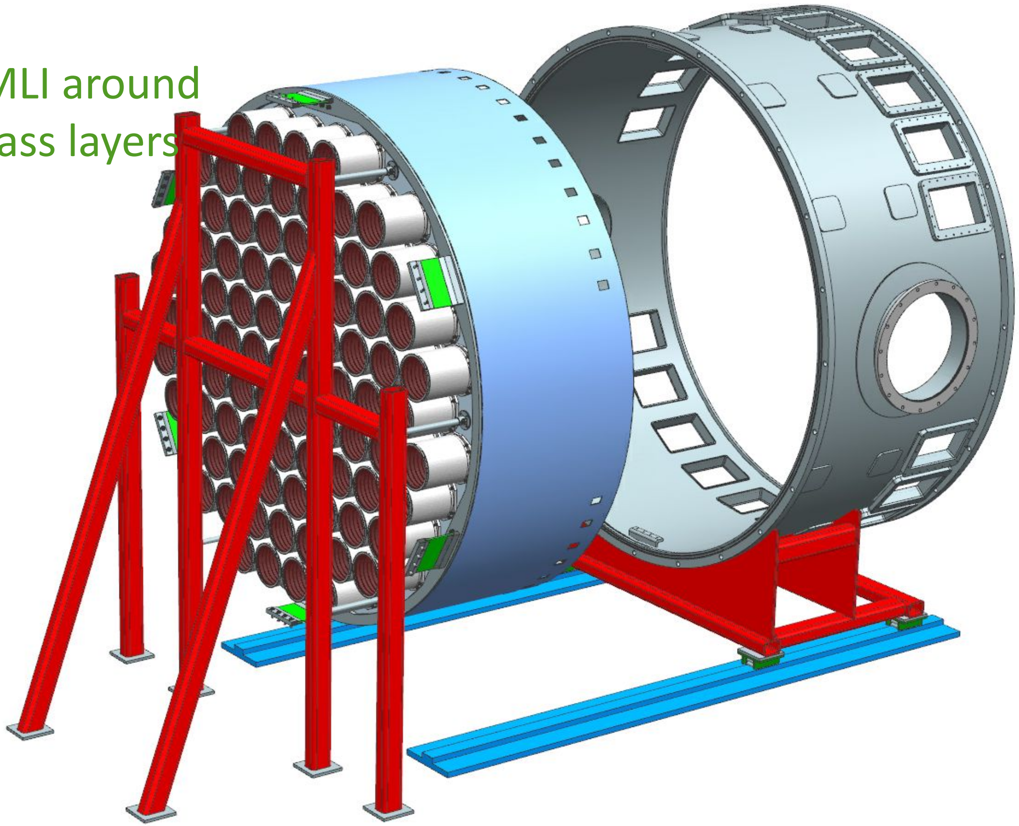
Proposed Assembly Plan: Installation Proposal

Fixed assembly fixture for the construction of the cold-mass



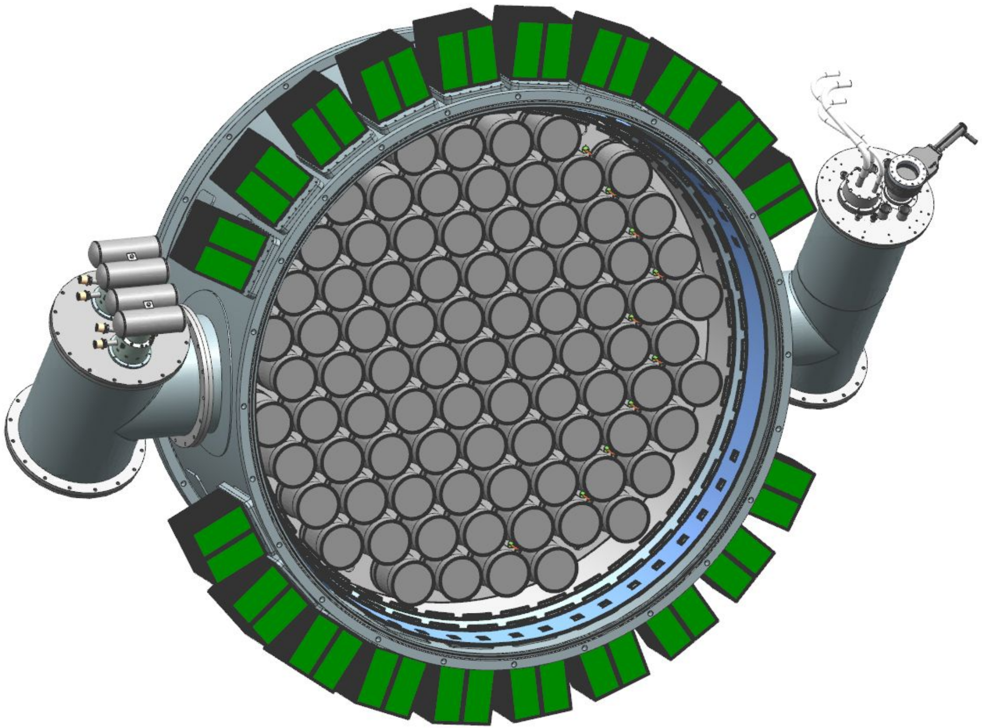
Proposed Assembly Plan: Add Insulation around Coldmass

Wrap MLI around cold-mass layers



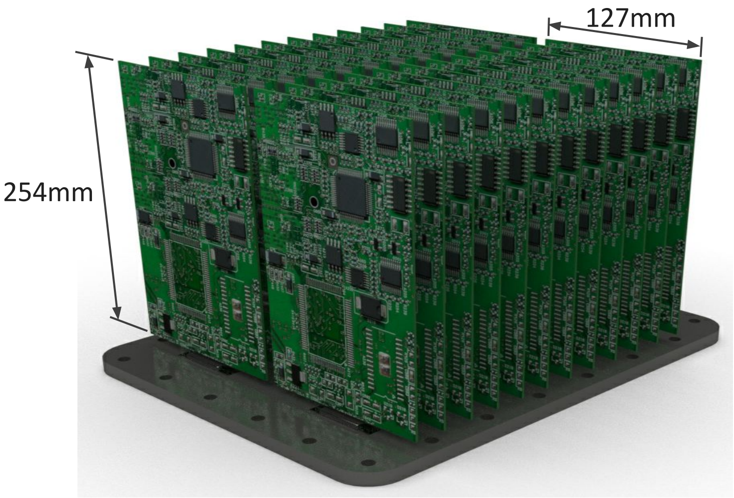
Slide vessel over cold-mass and connect to cold-mass supports

Readout Ports

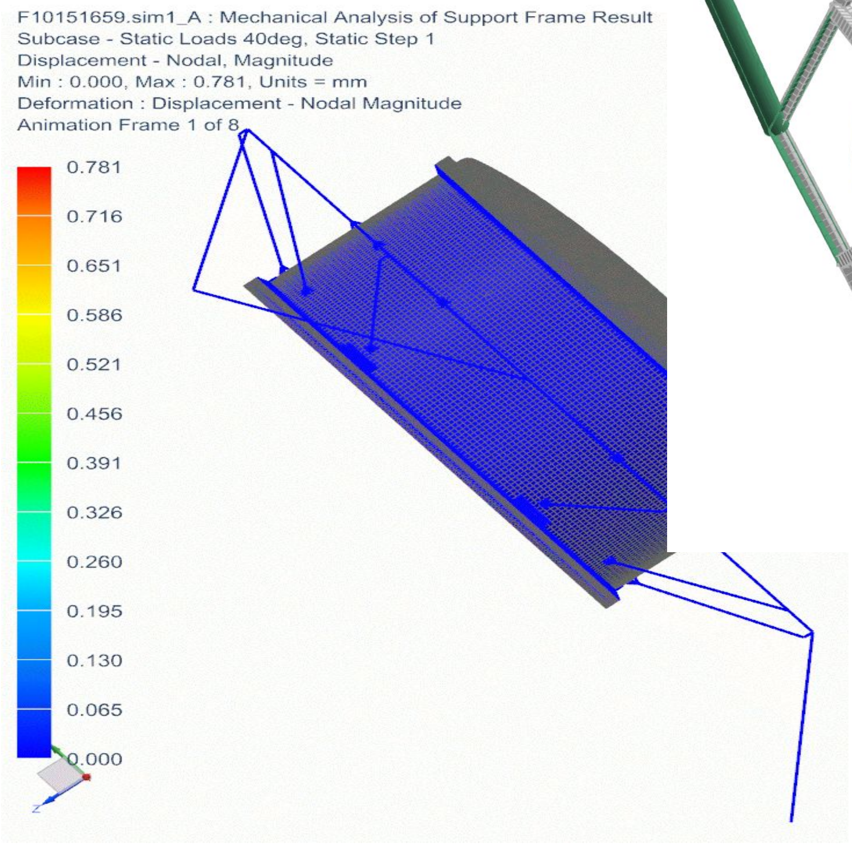


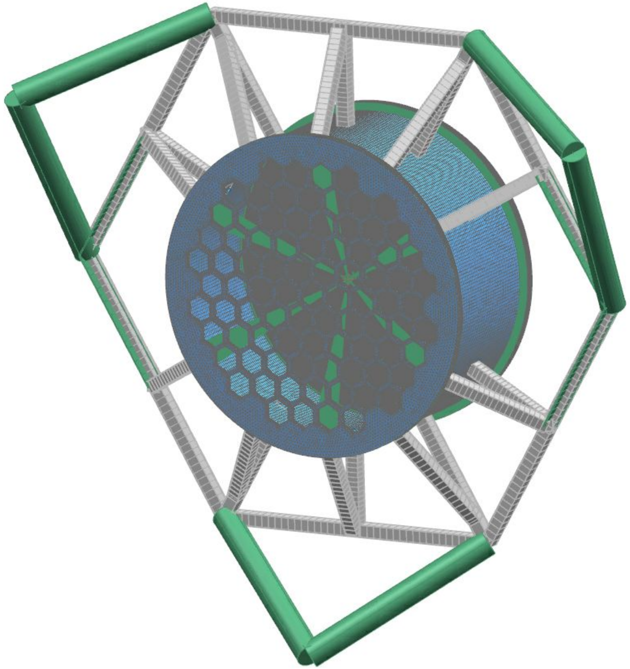
20 Ports:

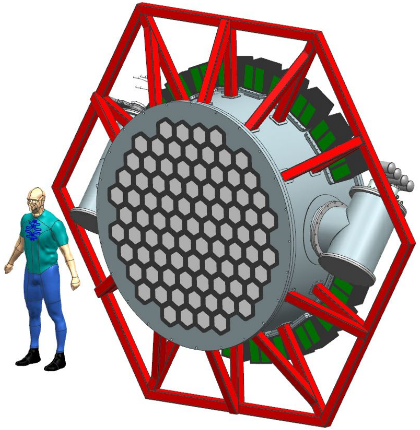
- 24, 100 micro-D pin connectors per port
- 480 Circuit Boards



Receiver Support







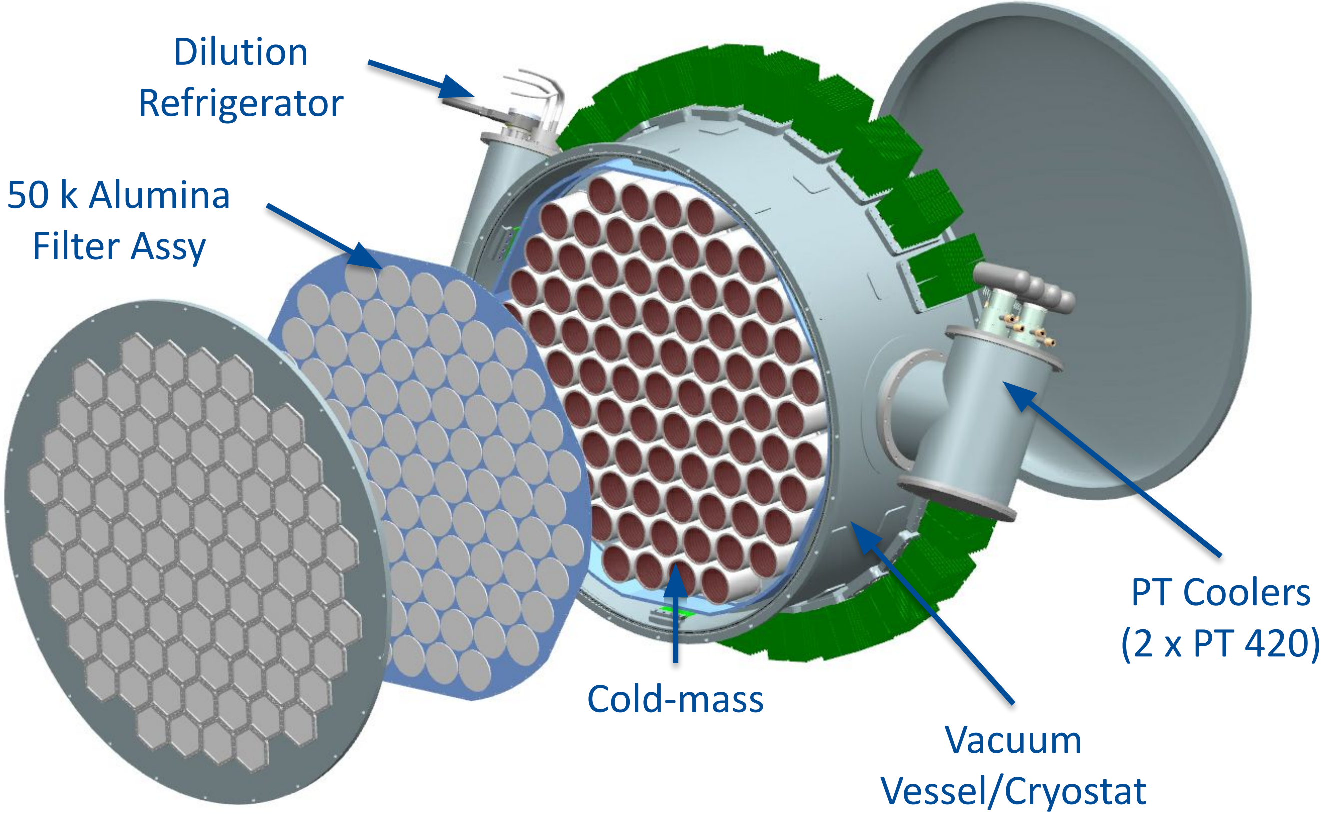
LATR Cryostat Mechanical Design Future Work

- Iterate design of the support structure
- Modal analysis
- Engineer:
  - Supports for cold-mass
  - Cooldown calculations
  - Vessel calcs per ASME B&PV code
  - Iterate on the heat shield designs – assembly issues
- Engage others to integrate the design with other systems
  - Cryogenic
  - Vacuum
  - Optics
- …

LATR Cryogenic Systems

Matthew Hollister
Fermi National Accelerator Laboratory
March 10 2021

Conceptual Model



Heat Load Estimates

Numbers based on scaling from the DSR design to reflect the updated baseline design (major changes being the elimination of the 80-K filters and the move to 85 smaller optics tubes)

Stage	Support	Radiative	Optical	Readout	Total	Capacity
40 K	10 W	16 W	75 W	30 W	131 W	120 W
4 K	860 mW	10 mW	14 mW	1.53 W	2.54 W	4 W
1 K	5 mW	0.1 mW	6.46 mW	0.87 mW	12.4 mW	25 mW
100 mK	69 μW	0.1 μW	0.5 μW	74 μW	144 μW	400 μW

Cooling capacity figures assume 2 x PT420 coolers on the main instrument and a BlueFors SD400 dilution refrigerator cooling the 1-K and 100-mK stages.

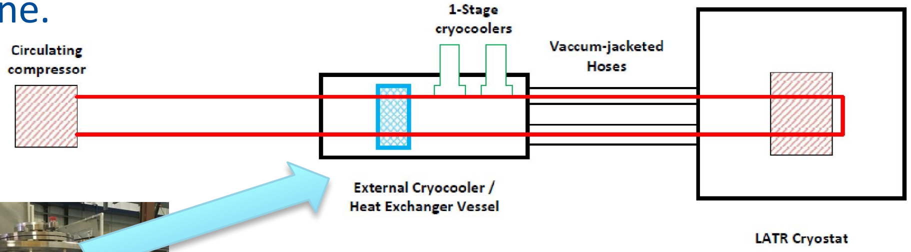
- I.e., assumes PT420 on SD400 is not used to cool main cryostat

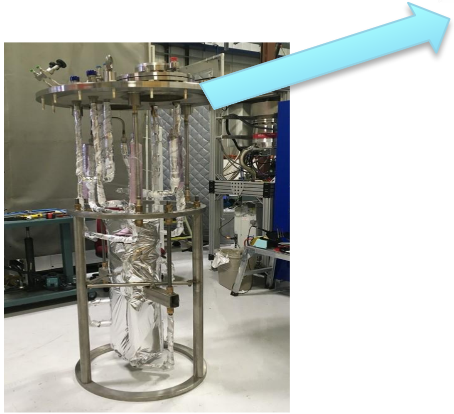
No account is being made for temperature gradients between the cryostat stages and the coolers, so the "useable" capacity is going to be lower.

- E.g., above 40K stage numbers assume components are heat sunk at 50K, but need to ensure gradient requirements are also met

Fast Cooldown System

Large cryogenic mass of instruments will require a method to cool more rapidly than the on board cryocoolers alone.





Room temperature compressor circulates helium through a counterflow heat exchanger, with further cooling provided by one or more single stage cryocoolers.

Cold fluid line connected to internal cryostat structures, removing heat from the distributed network.

Similar systems implemented on large particle physics experiments (SuperCDMS, CUORE…)

Cooldown Estimates

Mass estimates based on conceptual model, materials other than the primary are neglected.

Stage	Mass / kg	Primary Material	Heat Capacity (300 K to 40 K)	Heat Capacity (40 K to 4 K)
40 K	260	Aluminum	44 MJ	n/a
4 K	500	Aluminum	85 MJ	115 kJ
1 K	500	Aluminum	85 MJ	115 kJ
100 mK	450	Copper	36 MJ	87 kJ

Total time 300 K to 40 K	Total time 40 K to 4 K
10 days	2 days

Assuming lumped heat capacities cooled by a 10 g/s fluid flow for 300 K to 40 K, followed by cooling by 2 x PT420 coolers (4 K stage) or 1 x PT420 (1 K and 100 mK stages).

Cryogenic Further Work

- Refine thermal budgets at each stage, including budgets for temperature gradients across structures and between structures and coolers
- Dynamic thermal analysis for cool down, and refinement of the fast cooldown system design

Next Steps for LATR

- Lens design for optics tubes
  - Develop working design for full 85-tubes for both TMA and CD designs, including sensible grouping for design
- LATR cryostat design
  - Adding detail generally working from vacuum window to back, next big steps are setting on concepts for:
    - Optics tube mechanical design concept
    - Stage mounts and FEA
    - Readout wiring and heat sinking is going to be very complex
- Cyogenics
  - Develop more realistic and detailed thermal model to better estiamte heat load and gradients across stages
  - Develop requirements for any fast cooldown system

Backup Slides

LAT - Optical Elements and Requirements

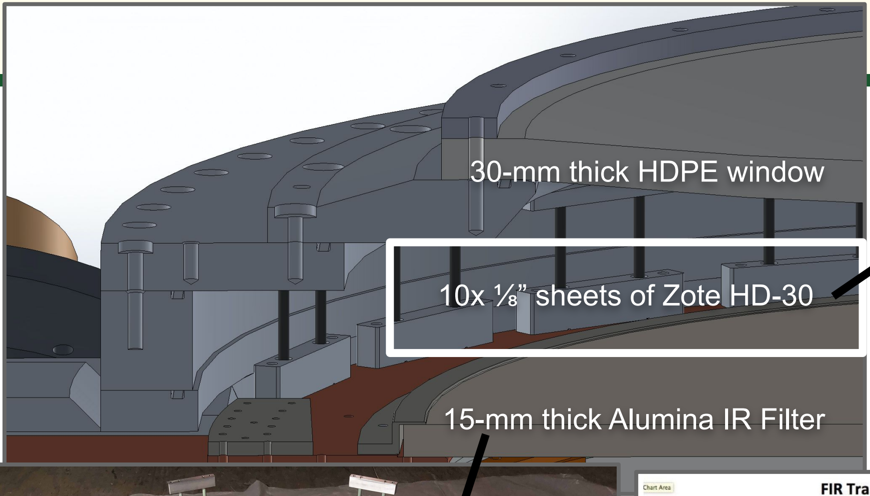
	Temp.	Baseline	AR coating	Alternatives	Count per LAT Tube	Key requirements (roughly ordered in challenge)
Vacuum Window	300K	UHMW	x-teflon	HDPE, HMPE	1	Scattering, absorption, reflection, mechanical robustness
Warm IR-Blockers	300K-50K	Zotefoam	-	Thin film metal	10 or 8 layers, ⅛" each	Scattering, absorption, reflection, thermal cycle robustness
Mid-IR Filter	50K-40K	Alumina	Plastic, epoxy, spray, laser	HDPE	1 (6-mm thick)	Scattering, absorption, reflection, thermal cycle robustness
Lenses	4K, 1K, 1K	Silicon	Metamaterial	HDPE, Alumina	3	Reflection, absorption (freq dep), thermal performance, robustness
Cold Stop and Baffling Elements	4K-1K	Plastic Absorber	-	Carbon Loaded Foam	~5	Absorption, thermal performance
Cold-IR Filter	1K	None	-	Nylon	-	Scattering, in-band transmission, submm rejection, reflection
Edge Filter (at Lyot)	1K	Metal Mesh Low Pass Edge	-	Nylon	1	Scattering, in-band transmission, above-band rejection, reflection
[Coupling Elements to Detectors]	100mK	Feedhorns, etc.	-	-	-	Edge taper, polarization fidelity

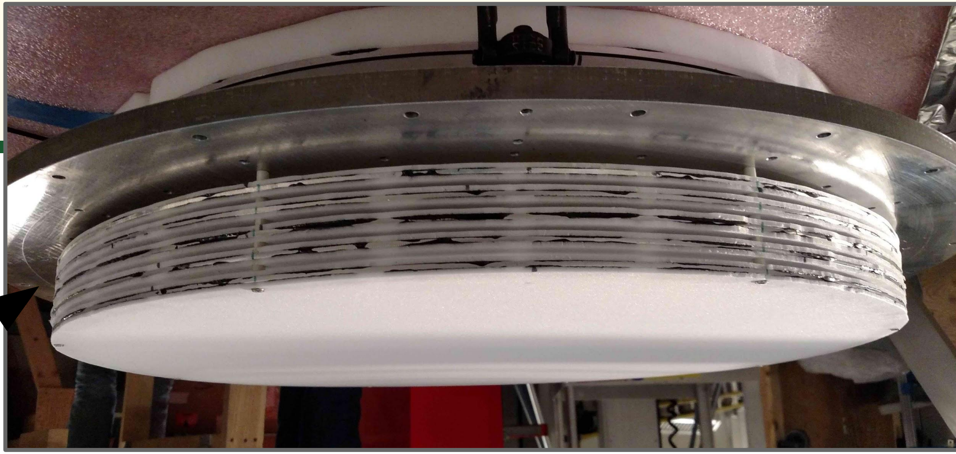
LAT - Required Cold Optical Components

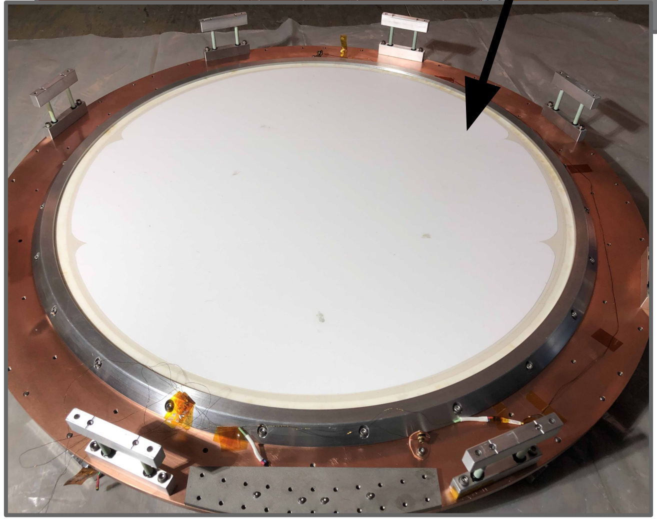
Baseline Filter Config

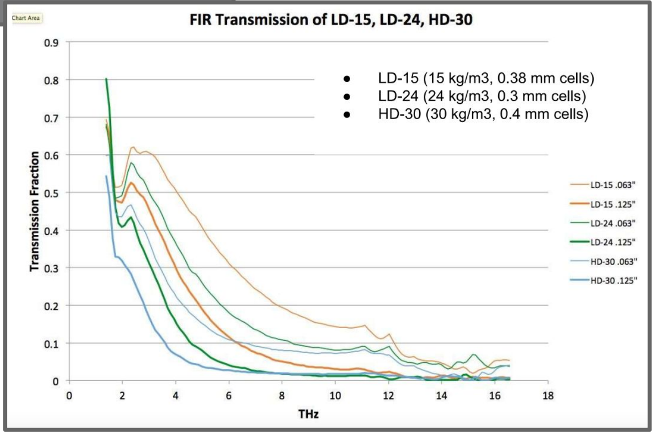
- Vacuum Window (300K, UHMW):
  - 3/16” thick (4.76-mm)
- Warm IR-blockers (300K-50K, Zotefoam):
  - Foam stack of 10 filters, 5x 0.34” = 1.70” thick (43.2-mm)
- Mid IR filter (50K-40K, Alumina):
  - 6-mm thick
- Lenses (3x lenses: 4K, 1K, 1K; Silicon)
  - 1-m long tube: maximum 4-mm thermal contraction
- Cold Stop & Baffling Elements (4K-1K, carbon-loaded plastic)
- Edge Filter (1K, Metal Mesh LPF):
  - ¼” thick (3-mm)

SPT-3G IR Filtering









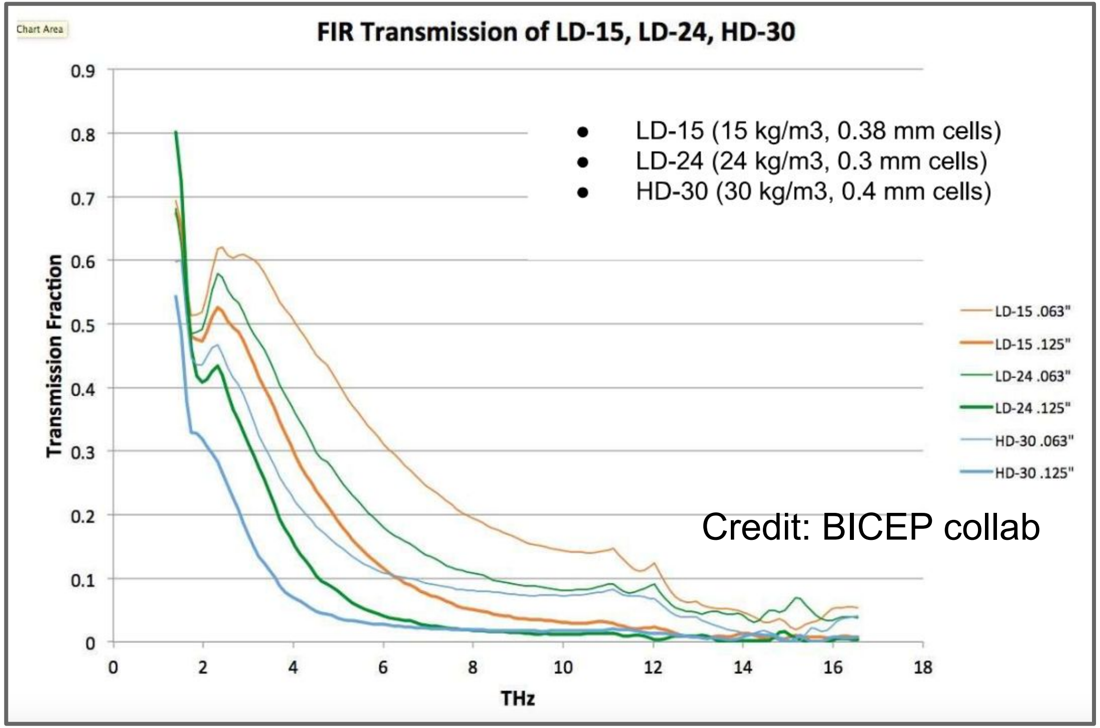
Credit: BICEP collab

- Filtering config similar to BA, except with a 3rd 4K lens and LPF at Lyot stop (see https://arxiv.org/abs/1809.00032)
- SPT-3G first stage head runs at 30 K, indicates <~5-10 W of power coming through window.
- Alumina IR filter runs at 40-K with <0.5K gradient across filter.

Window Loading and Zotefoam IR Filters

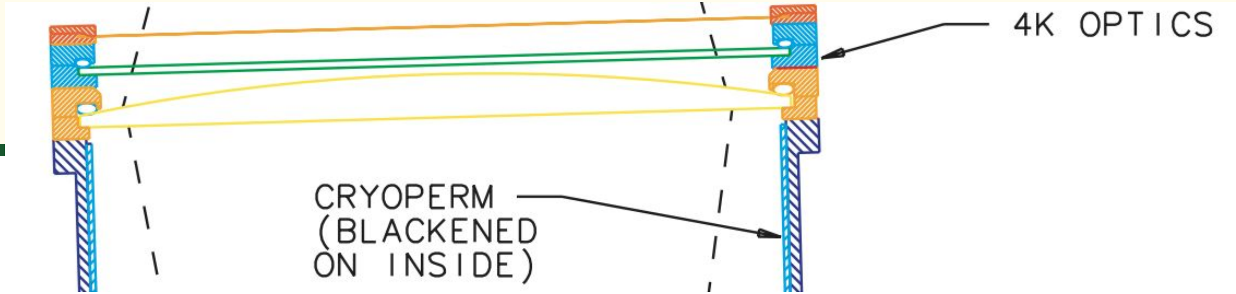
- For SPT4, we should experiment with other types of Zotefoam with smaller cell size.
- Loss in CMB bands is expected to be scattering dominated, when cell size approaches wavelength. Scattering ~ (lambda/d)^6.
- Scattering loss might not be negligible at 1mm for HD-30, e.g., for PPA-30 (0.3-mm cell size) CSO measurements by Kooi (1998) suggests 4% loss at 300 GHz from 1” thick zotefoam.
- LD-24 (perhaps MP-24) appear to be an acceptable IR filter replacement with smaller cell size:

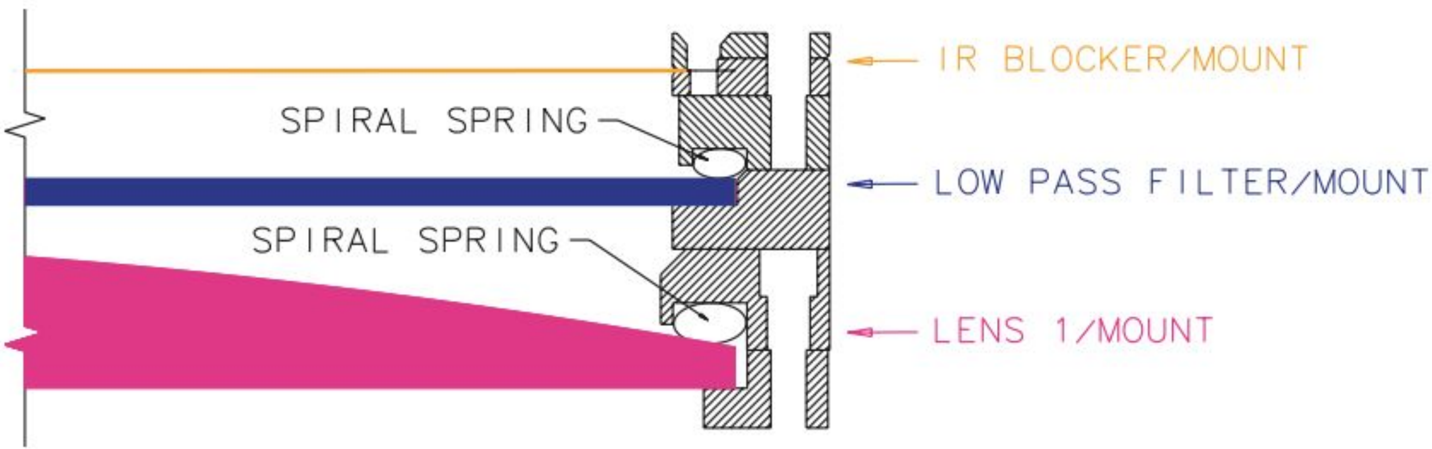
Cell size (mm)	Typ.	Min	Max
HD-30	0.4	0.25	0.7
LD-24	0.3	0.15	0.4
MP-24	0.2	0.1	0.3



http://www.zotefoams.com/wp-content/uploads/2016/01/TIS01.pdf

Lens Mount





- Follow lens mount scheme from Thorton et al. 2008 (https://act.princeton.edu/sites/act/files/halpern_spie_7020_70201r.pdf)

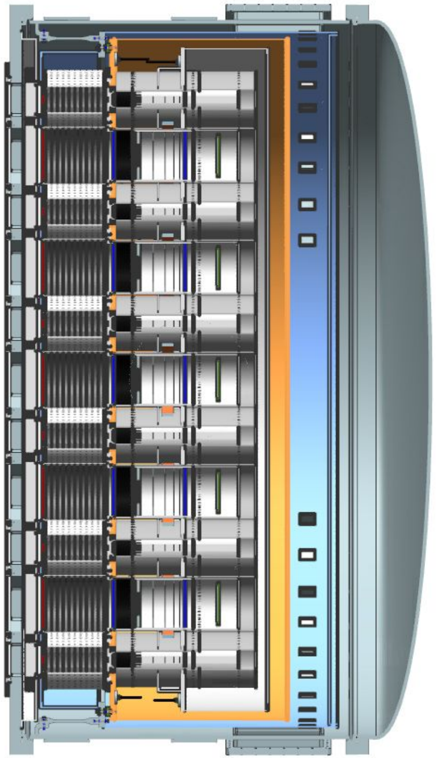
LAT: Window to 4K Lens spacing

Spacing between top of front plate to front of first 4K lens

- Vacuum window: 3/16” thick UHMW (not included in total)
- Front Plate: 1.5” thick + 0.6” deflection
- Zotefoam filter stack: 1.70” thick
- 300-50K space: 0.25”
- 50K filter: 0.25” thick (6-mm)
- 50-4K space: 0.25”
- 4K optics tube contraction: 0.16” (4-mm)
- Total distance (top of front plate to top of first 4K lens:
  - 4.71” (=2.1” + 1.7” + 0.75” + 0.16”)

Coldmass Layout

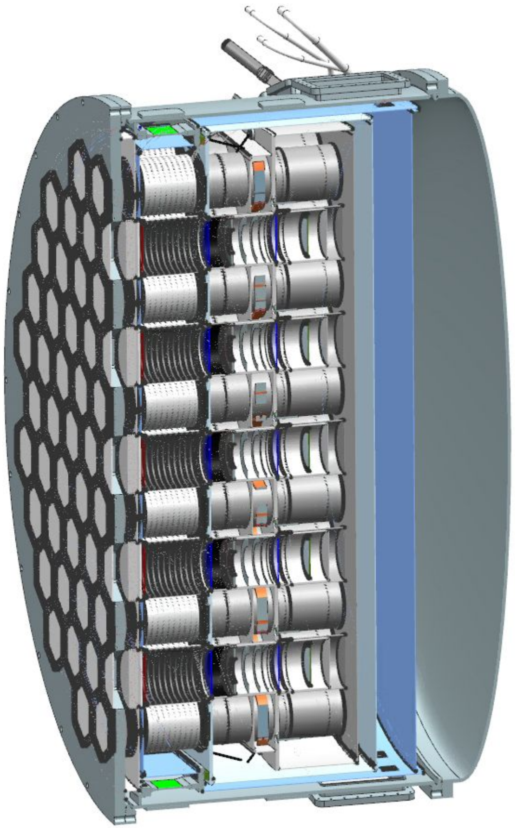
50k

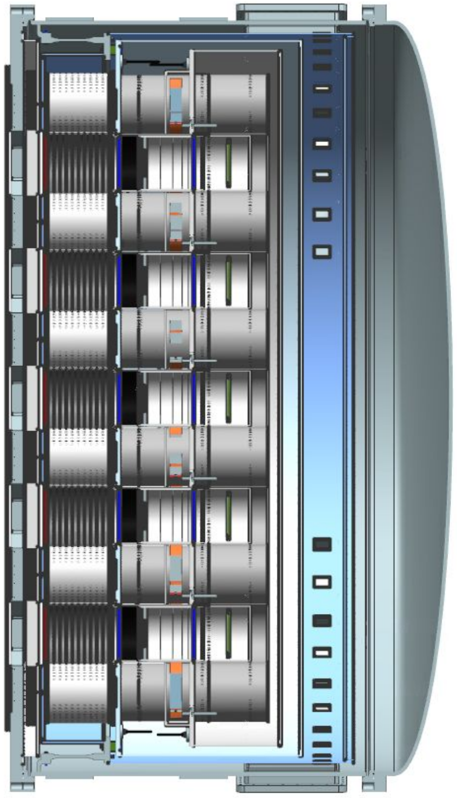


4k

1k

Conceptual Model





Conceptual Model: 1k Shield Connection to 4k Shield