1K vs 4K SAAs

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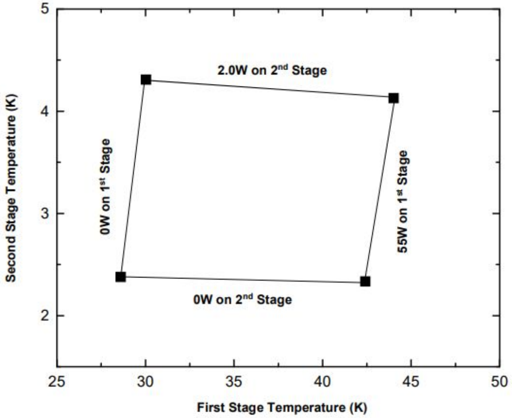
Motivation

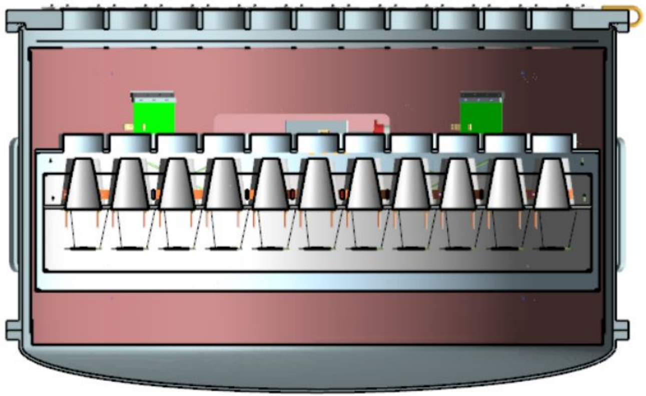
- SQUID Array Amplifer (SAA) needs to be at T < 5 K, somewhere with adequate cooling power and space
- Prior TDM experiments have placed it at nominal 4K, 2K, and 1K stages, depending on available cooling power, space, wiring
- Dilution refrigerator baseline has plenty of cooling power available at 1 K
- There does not seem to be any limitation on whether it needs to be at 4 K or 1 K in the LAT or SAT camera, so we can choose the optimal location
- **Assumption**: we want to make the same decision for both LAT and SAT

Potential Drawbacks of 4K SAA

- 4K SAA is the current assumption, but there are potential drawbacks of this assumption, and potential advantages to moving the SAA to the 1 K temperature stage
- **Temperature margin**
  - Cooling capacity is greater at 4K stage, but also already heavily utilized (e.g. 1.94 W out of 2 W in DSR for LAT)
  - SAA chips MUST reach temperatures < 5 K, which is possible but maybe not easy to guarantee on 4 K stage
- **Location**
  - There is more space on the 4 K stage, but it may be harder to utilize

Load Curve for PT420



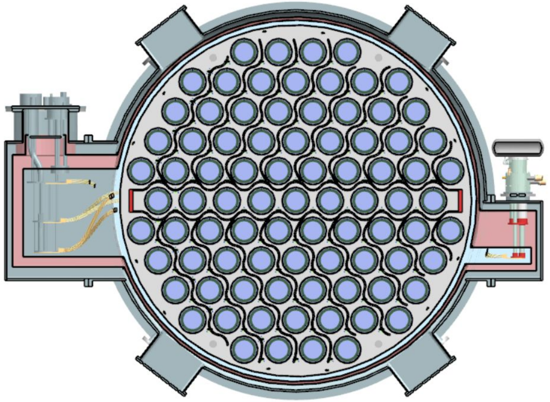


LATR Design

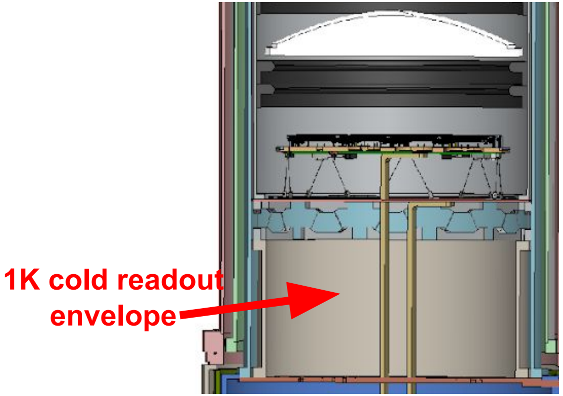
Potential Benefits of 1K SAA

- **Temperature margin**
  - Cooling capacity seems sufficient, and wiring is the dominant heat load for readout on this stage
  - SAA power dissipation is negligible compared to heat lift
  - Meeting temperature requirement T < 5 K will be trivial with SAAs on 1K stage
- **Location**
  - Placing SAAs at 1K puts them much closer to the 100 mK readout and detectors, especially in the LAT
  - This enables easier, shorter cable runs, and potentially easier access to 1 K readout components
  - This more compact arrangement also makes it easier to define a clean RF space containing all readout + detectors
  - This has a possible benefit for locating SAAs within an extra layer of magnetic shielding needed for 100mK space

LATR Design



SAT conceptual design



Current Cryogenic Budget - 4 K SAA

Stage	Heat Lift	SAT Readout Load	LAT Readout Load
100 mK	400 uW	12.8 uW	69.1 uW
1 K	25 mW	172.3 uW	802.4 uW
4 K	2 W	0.8 W	1.6 W
50 K	110 W	16 W	32.5 W

Assumed wiring length and materials	SAT	LAT
L(100mK - 1 K) CuNi clad NbTi twisted pair	0.5 m	0.2 m
L(1K - 4K) - CuNi clad NbTi twisted pair	0.5 m	0.3 m
L(4K - 50K) - manganin twisted pair with stainless steel braid	0.1 m	0.15 m
L(50K - 300K) - manganin twisted pair with stainless steel braid	0.1 m	0.15 m

LAT Heat Loads for Complete Camera (source: DSR)

Stage	Support	Radiative	Optical	Readout	Total	Cooling capacity
80 K	1.3 W	7.2 W	50.7 W	N/A	59.2 W	180 W
40 K	6.0 W	4.6 W	13.2,W	22.3 W	46.1 W	110 W
4 K	0.84 W	0.01 W	0.36 W	0.73 W	1.94 W	2.0 W
1 K	5.01 mW	0.01 mW	6.46 mW	6.33 mW	19.82 mW	25.0 mW
100 mK	68.6 μW	0.1 μW	0.5 μW	45.7 μW	115.0 μW	400 μW

Table 4-12. *Heat loads for the complete camera.*

CMB-S4

Modified Cryogenic Budget - 1 K SAA

Stage	Heat Lift	SAT Readout Load	LAT Readout Load
100 mK	400 uW	12.8 uW	69.1 uW
1 K	25 mW	**353.2 uW**	**1237 uW**
4 K	2 W	0.8 W	1.6 W
50 K	110 W	16 W	32.5 W

Assumed wiring length and materials	SAT	LAT
L(100mK - 1 K) CuNi clad NbTi twisted pair	0.5 m	0.2 m
L(1K - 4K) - **manganin twisted pair with stainless steel braid**	0.5 m	0.3 m
L(4K - 50K) - manganin twisted pair with stainless steel braid	0.1 m	0.15 m
L(50K - 300K) - manganin twisted pair with stainless steel braid	0.1 m	0.15 m

LAT Heat Loads for Complete Camera (source: DSR)

Stage	Support	Radiative	Optical	Readout	Total	Cooling capacity
80 K	1.3 W	7.2 W	50.7 W	N/A	59.2 W	180 W
40 K	6.0 W	4.6 W	13.2,W	22.3 W	46.1 W	110 W
4 K	0.84 W	0.01 W	0.36 W	0.73 W	1.94 W	2.0 W
1 K	5.01 mW	0.01 mW	6.46 mW	6.33 mW	19.82 mW	25.0 mW
100 mK	68.6 μW	0.1 μW	0.5 μW	45.7 μW	115.0 μW	400 μW

Table 4-12. *Heat loads for the complete camera.*

Very conservative assumptions on wiring lengths, so worst-case for heat load

SAA dissipation:
10 uW for SAT (510 SAAs)
40 uW for LAT (1968 SAAs)

Modified Cryogenic Budget - 1 K SAA

Stage	Heat Lift	SAT Readout Load	LAT Readout Load
100 mK	400 uW	12.8 uW	69.1 uW
1 K	25 mW	**181.5 uW**	**400 uW**
4 K	2 W	0.8 W	1.6 W
50 K	110 W	16 W	32.5 W

Assumed wiring length and materials	SAT	LAT
L(100mK - 1 K) CuNi clad NbTi twisted pair	0.5 m	0.2 m
L(1K - 4K) - **manganin twisted pair with stainless steel braid**	**1 m**	**1 m**
L(4K - 50K) - manganin twisted pair with stainless steel braid	0.1 m	0.15 m
L(50K - 300K) - manganin twisted pair with stainless steel braid	0.1 m	0.15 m

LAT Heat Loads for Complete Camera (source: DSR)

Stage	Support	Radiative	Optical	Readout	Total	Cooling capacity
80 K	1.3 W	7.2 W	50.7 W	N/A	59.2 W	180 W
40 K	6.0 W	4.6 W	13.2 W	22.3 W	46.1 W	110 W
4 K	0.84 W	0.01 W	0.36 W	0.73 W	1.94 W	2.0 W
1 K	5.01 mW	0.01 mW	6.46 mW	6.33 mW	19.82 mW	25.0 mW
100 mK	68.6 μW	0.1 μW	0.5 μW	45.7 μW	115.0 μW	400 μW

Table 4-12. *Heat loads for the complete camera.*

Need ~ 1m length to reach in LAT

SAA dissipation:
10 uW for SAT (510 SAAs)
40 uW for LAT (1968 SAAs)

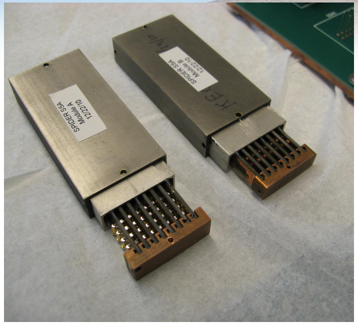
CMB-S4

Challenges: Wiring

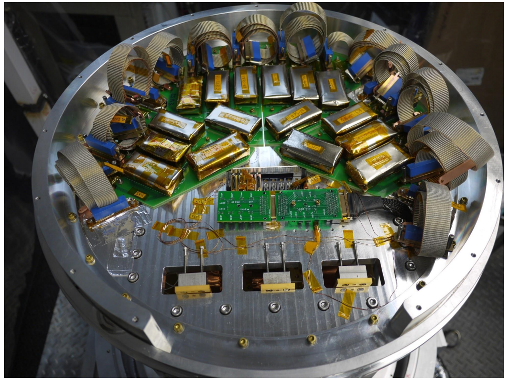
- Need to optimize for heat loads, impedances, and length of wiring runs, heat sinking
- Assume: CuNi-clad NbTi on cold side of SAA, Manganin w/ SS shield on hot side of SAA
  - Possible to add isothermal runs but adds complexity, cost
  - Possible to run NbTi from 1K to 4K but adds complexity, cost
  - May be possible to have manganin without SS shield, for part or all of wiring run (e.g., no shield after entering a ‘clean’ volume)
- Need a range of potential lengths to determine impact on heat loads
- Need to assess impact on readout performance, but is part of an overall budget.
  - (1) The link between SQ1 (sub-K) and SAA has an L/R time constant, set by the SQ1 output impedance and the combined inductance of the cabling + traces + SSA input coil.
  - (2) The link between SAA and ambient has an RC time constant, set by the SAA + cable + warm resistance and the cable + warm capacitance.

Challenges: Space Constraints

- SAAs are mounted in sets of ~ 8 in a compact box with magnetic shielding
  - ~60 boxes in SAT, ~240 in LAT
- Magnetic shielding adds some not insignificant mass and heat capacity wherever the SAAs are located
- These boxes can be arranged, grouped, and connectorized using a ‘SQUID board’ PCB
- Some design and dimensions of these boxes and SQUID boards will be externally set by overall ‘numerology’ of how to connect and group detector wafers to warm readout

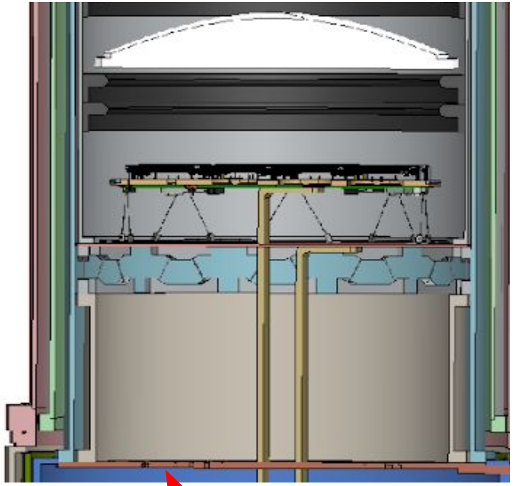


Example SAA box with magnetic shielding



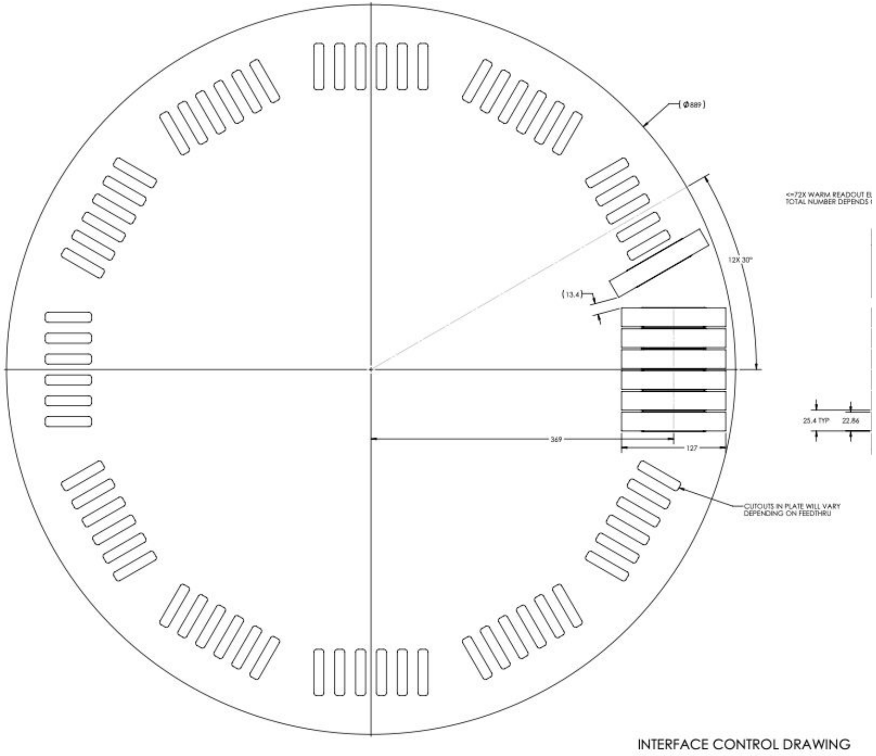
Example SQUID board PCB in BICEP3

SAT Extended Hybrid - Cold and Warm Readout Interfaces



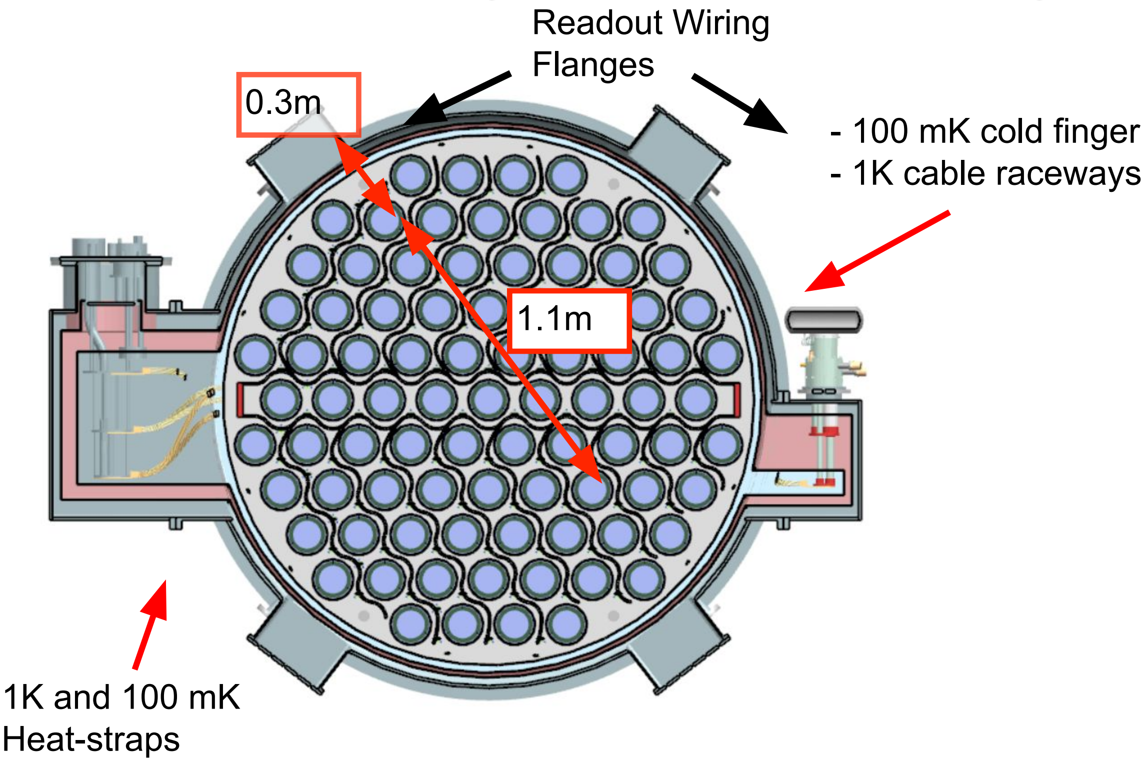
Rough geometry of 1K cold readout envelope: Dia 61 cm, height 37.5 cm

NOTE: Dimensional envelopes are for current conceptual design only, and are subject to change.

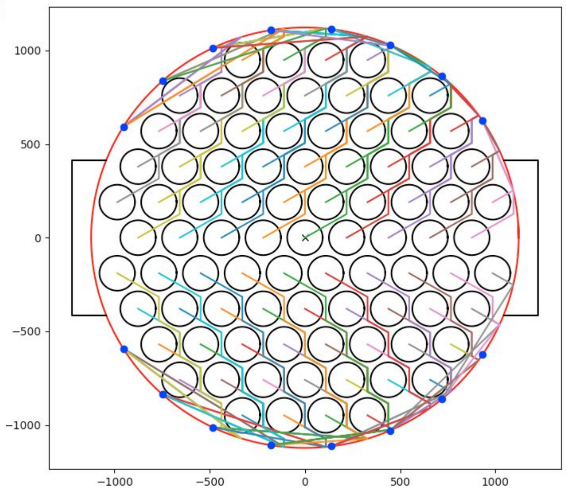


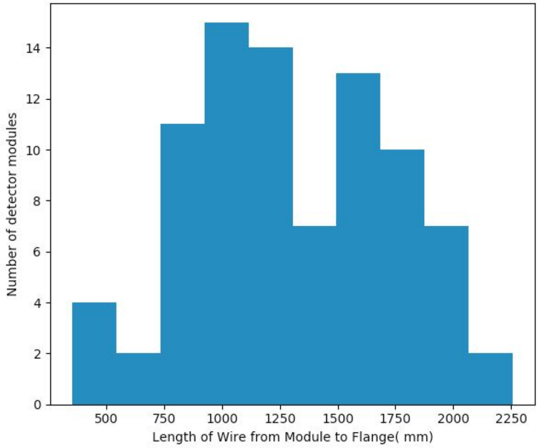
SAT baseplate per tube, 72 connectors per optics tube. Warm readout boards will direct plug in

LATR Design and Wiring



LAT Wiring - A. Bender, 2020-10-23





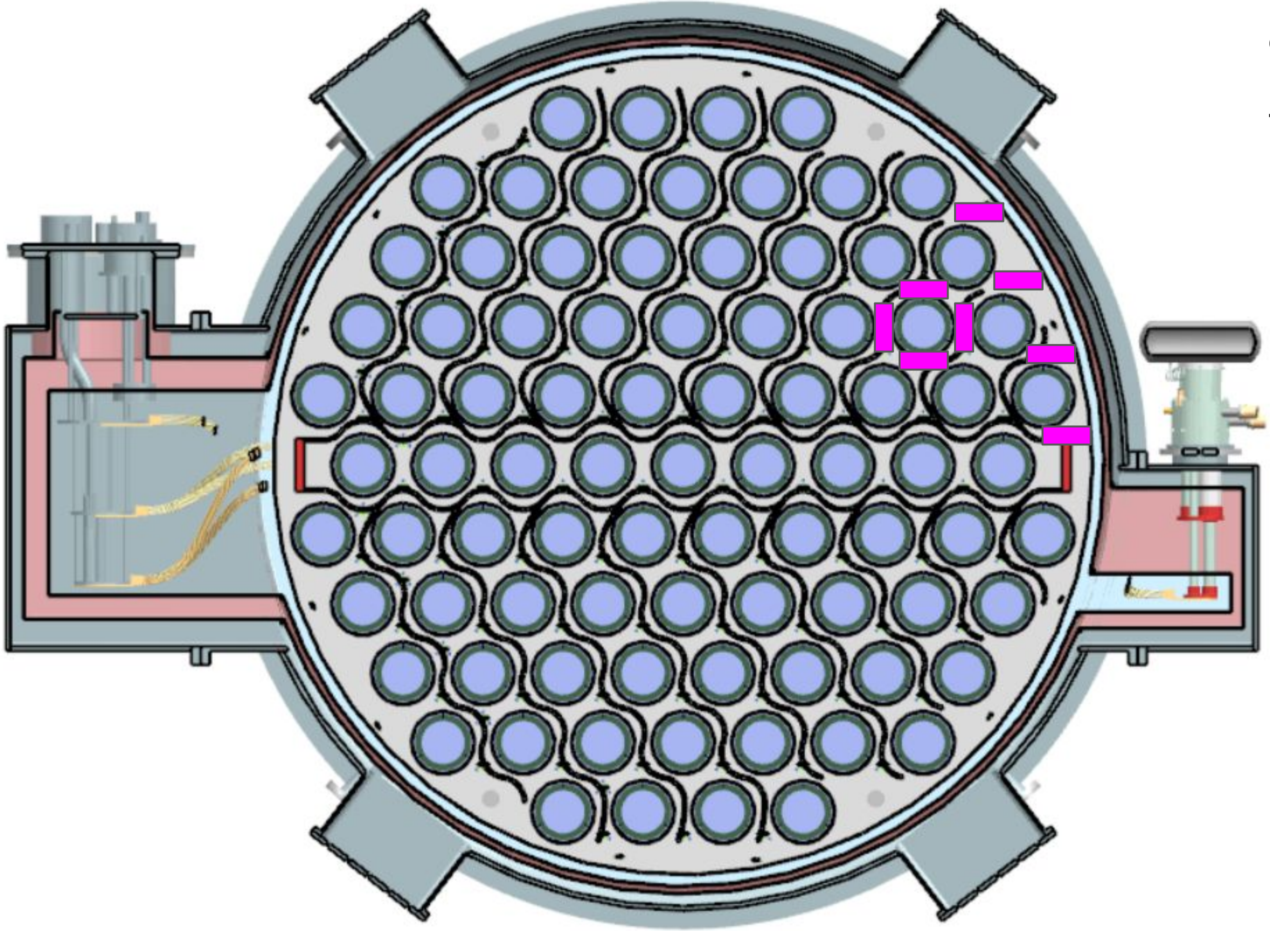
LATR-Readout IPO Meeting, Nov 4, 2020

Conclusions and next steps

- We seem to have the freedom to choose to put the SAAs at the 1K or 4K stage, in both the SAT and LAT
  - **Assumption**: We want to make the same 1K/4K decision for both LAT/SAT
- There are a number of benefits to placement on the 1 K stage
- Need to generate a complete list of limiting factors and driving requirements for each temperature stage in the LAT and SAT, based on system and readout requirements, and a more detailed preliminary design
  - Cooling power budget and margin
  - More precise temperature requirement for SAA
  - Overall mass, volume, and placement
  - Wiring design, requirements, and limitations
  - Anything else we are missing?

Backup

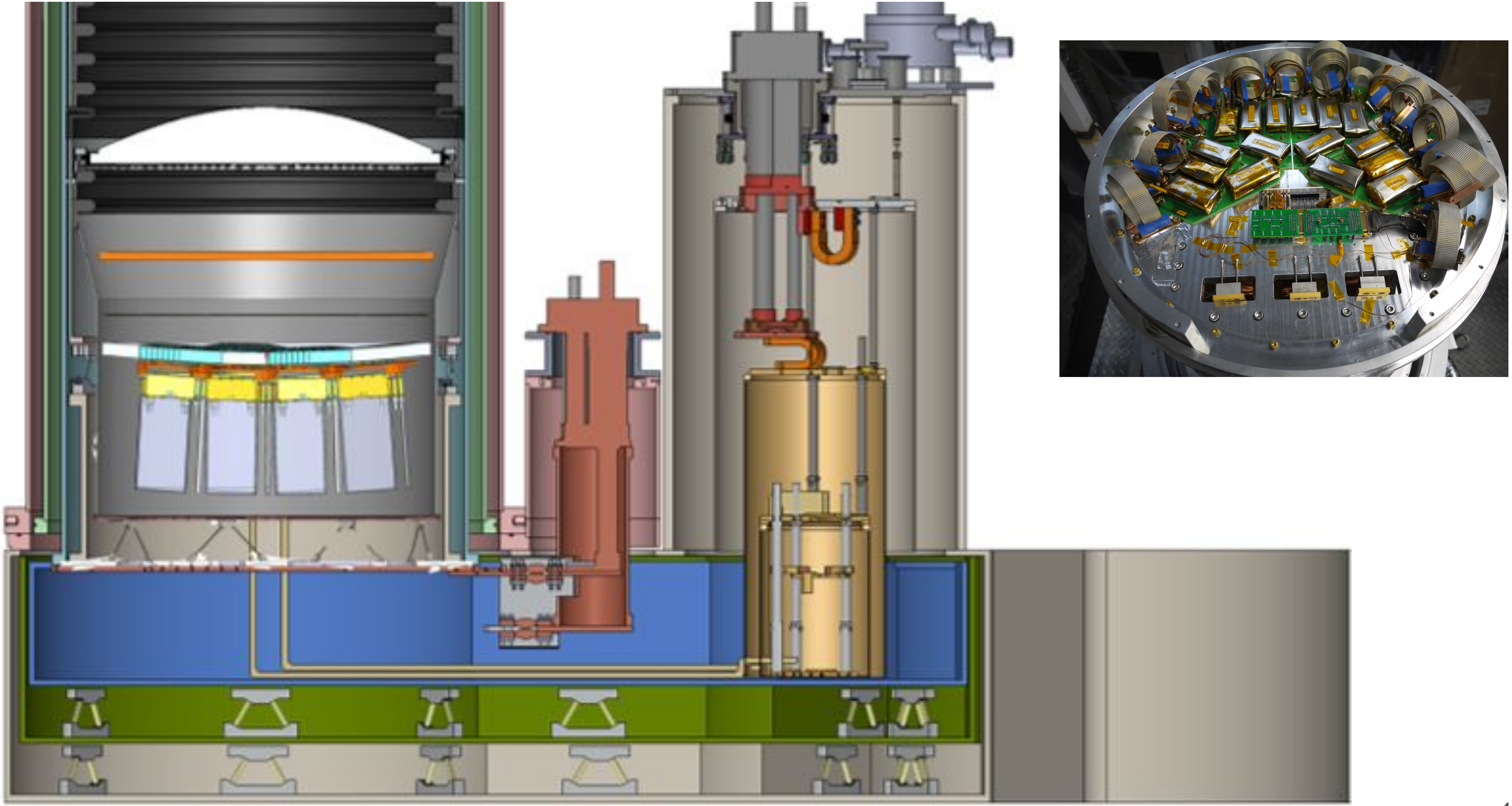
LATR Placement



Detector wafer is ~130-mm diameter

Tube-spacing is ~209-mm

SAT Placement



SAA Screening for 1K SAAs

- Screening would still be primarily done at 4 K
- Need to have some sampling of performance at colder operation temperature, but this seems similar to the screening plan for 100 mK SQ1 mux chips
  - Primary concern is possibility of resonances that can develop at colder temperatures and cause poor behavior, but should be identified and fixed with spot checks on SAA design and newly fabbed wafers
- Need to know expected Ic, Vpp of SAAs at base temperature for warm electronics design, so that they will be capable of running and reading out ‘overperforming’ SAAs
  - Main concern is saturating amplifier, can always ‘detune’ SAA slightly

SAA Temperature Requirements

- Need a firm upper limit on SAA temperature
- Going from 4 K to 1K operation boosts modulation depth by ~ tens of percent, but this is probably a negligible effect for readout performance
- If SAA is at nominal 4 K stage and runs hotter than ~ 5 K, performance can fall off a cliff and no longer meet requirements
- Any other relevant temperature requirements between 4K and 1K?
  - Magnetic shield is Nb, Tc 9K
  - NbTi wiring has Tc ~ 10 K
  - 1K stage will likely not be cold enough to guarantee getting below Tc of Al, 1.2 K