Module Design and Assembly

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CMB-S4 Collaboration Meeting
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High-Level Overview

- Early design work identified several areas requiring additional R&D in order to satisfy existing system interface requirements (e.g. requirement of superconducting flex cables, module pitch in SATs)

- Does not make sense for early (“CDFG”) detector testing to depend on outcomes of R&D for production modules

- To enable early integrated tests of CDFG detectors + some readout, we are forking the module design:

  - ***“CDFG module” -*** Simple design using shovel-ready hardware that fits in the cryostats identified for CDFG testing (FNAL, Illinois, SLAC)

  - ***Production module -*** Module that we will actually deploy, satisfying all project interface requirements

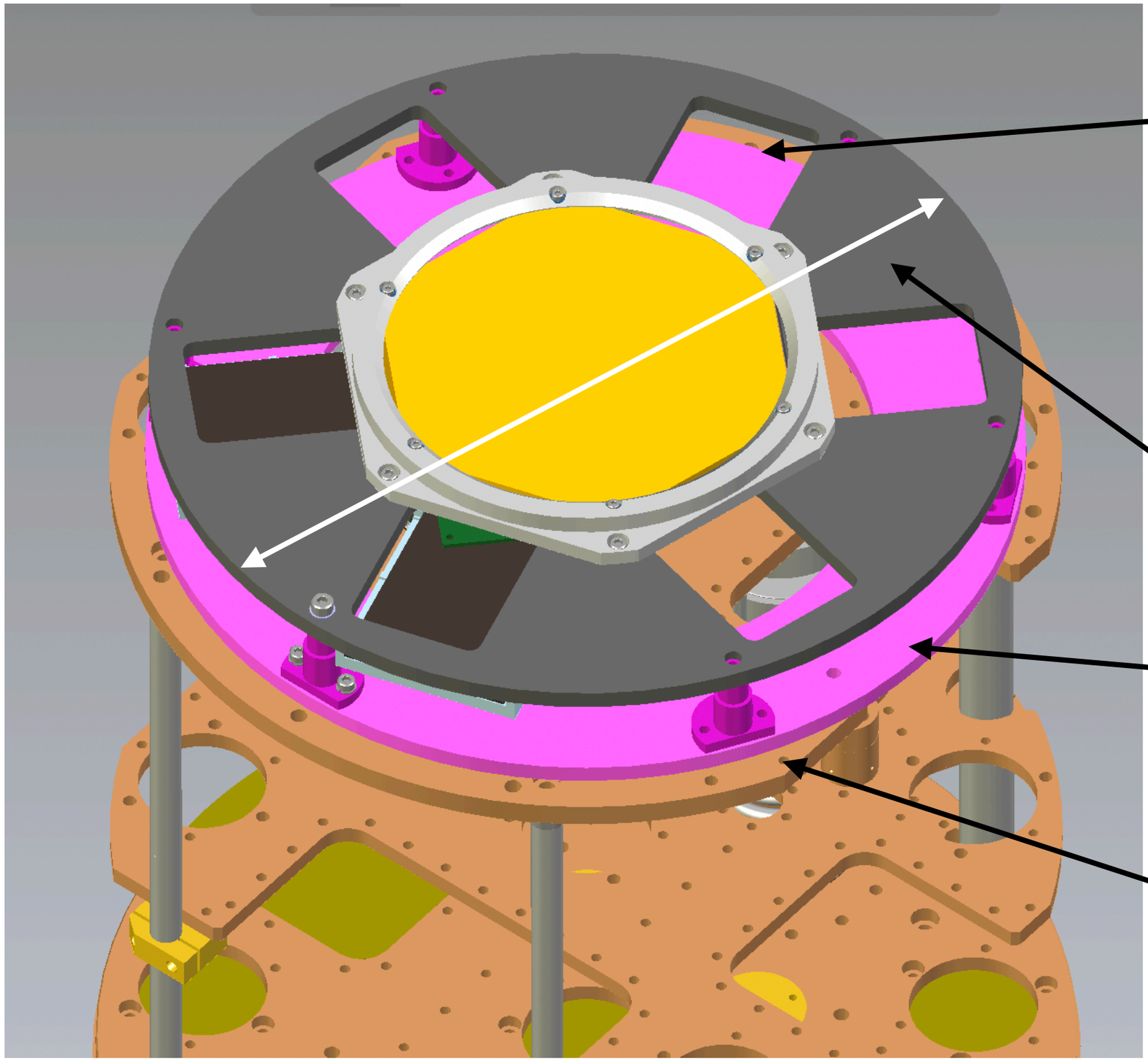
Module R&D Areas

- *Superconducting flex cables are required by readout/module interface*
    - Limit of conventional flex PCB fab (e.g. TechEtch) is around ~9mils pitch; need 4mils pitch; other processes have higher resolution, but higher cost and limited vendors
- *SAT module pitch of 124mm*
    - Forces flex cables on top of backshort with step bond, which complicates mounting and requires wire bonding R&D
    - Limits mechanical space in ways that require some study: less room for magnetic shielding (low-f noise risk) and focal-plane mounting structure (vibrational risk)
- *Readout density and assembly*
    - Packaging readout for SAT HF (1876 detectors) requires significant area of readout electronics
    - Challenging to fit these behind the detector wafer footprint in a way that can be bonded and assembled without elaborate origami

CDFG Testing Module

- See specifications document
- Planar layout a la AdvACT to relax constraint on flex cable
- Use only 2 columns of readout per side of wafer to enable compatibility between SAT and LAT wafer pinouts
- Diameter of footprint needs to be <290mm to ensure compatibility with initial three testbeds (FNAL, Illinois, SLAC)
- Exploring use of SO-style horn arrays fabricated at Michigan (SO shop) to expedite acquisition
- Keep connectors and wiring of readout as similar to deployment module as possible (MicroD 37-pin for bias lines, ZIF for row select, etc.)

Mounting in LD400 Cryostat



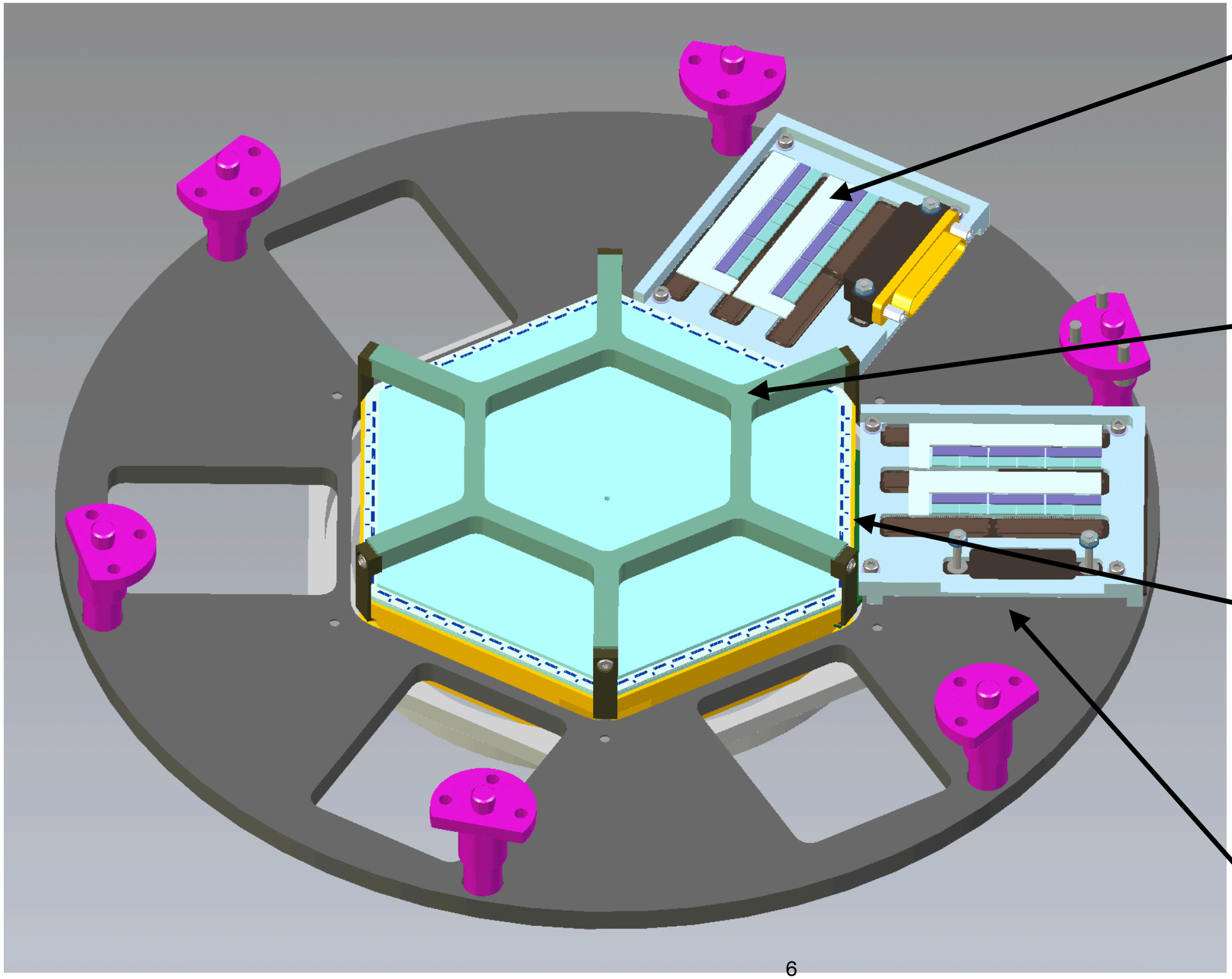
Ports for access to ZIF connectors on back of readout boards

diameter = 270mm

mounting ring (adapt to unique feedthroughs of test cryostats)

mixing chamber stage

Back View



Readout columns (width = 15mm each)

Mounting ring to clamp wafer stack (BeCu or brass springs not shown)

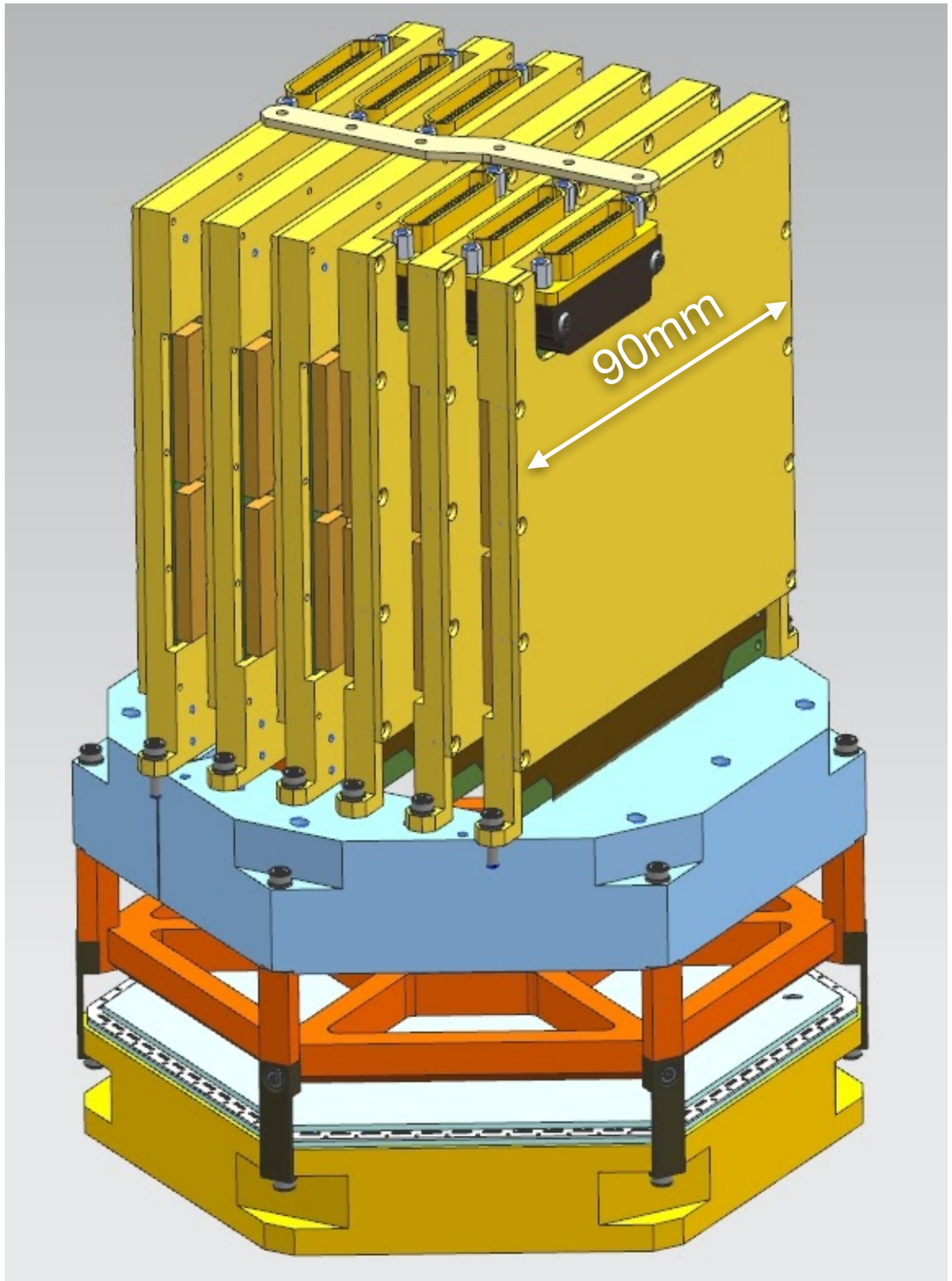
Compatible with direct bonding and short flex cable between readout and wafer

Readout boxes (PCB not shown)

CDFG Module Next Steps

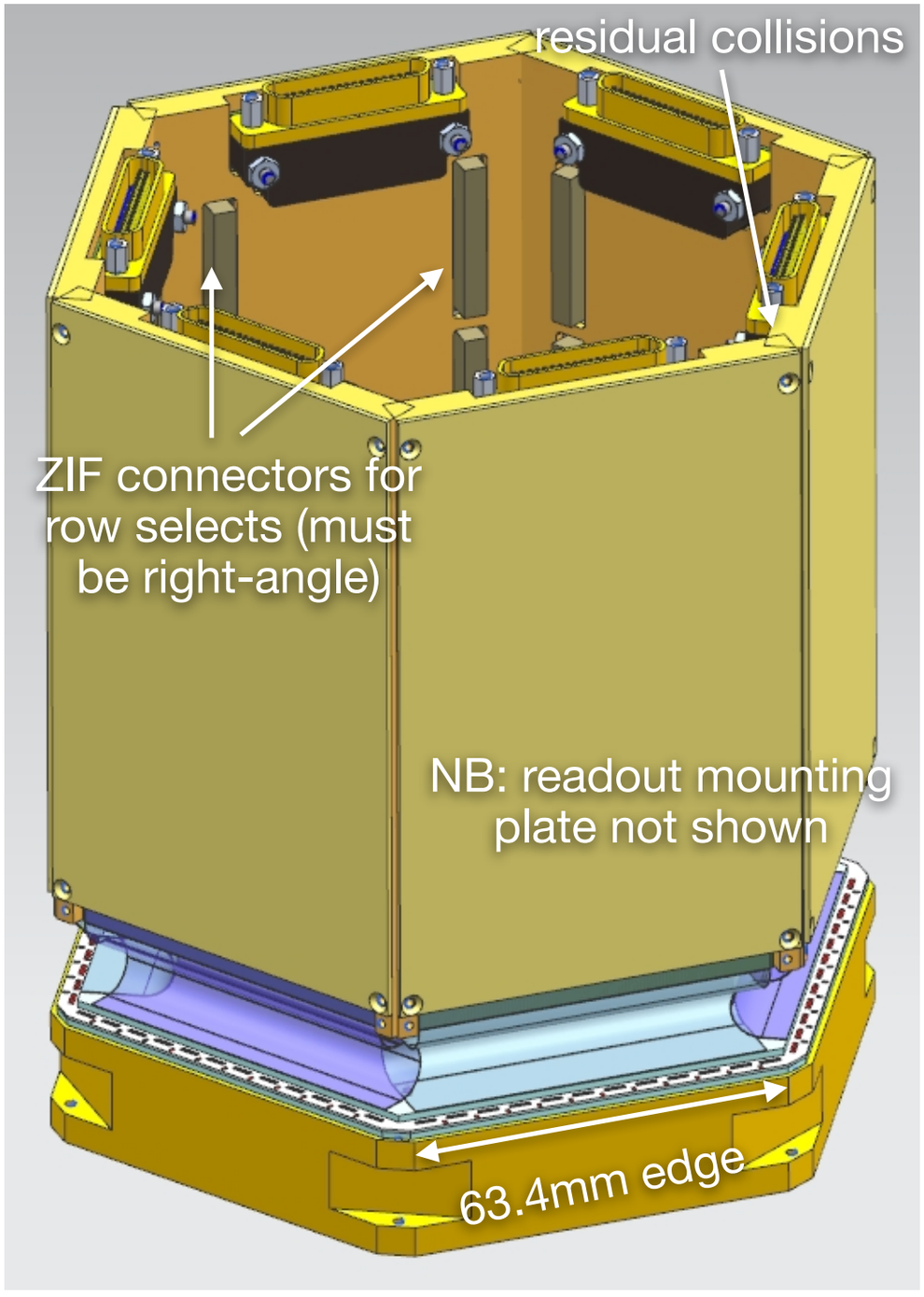
- Final iteration on readout box design with readout working group (G. Haller, Z. Ahmed)
- Quantify minimum magnetic shielding needed for TDM readout in test cryostat configuration
- Simple simulations of magnetic field suppression in SLAC, Illinois, FNAL test cryostats to verify that we meet shielding spec
- Tweak mounting to avoid collisions with wiring feedthroughs, other fixtures, in test cryostats

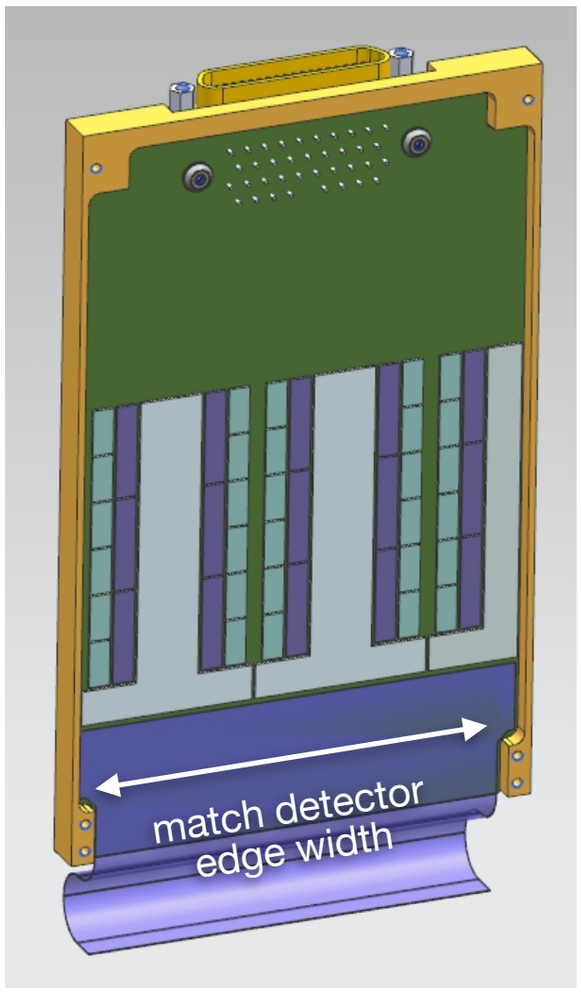
Production Module - v1

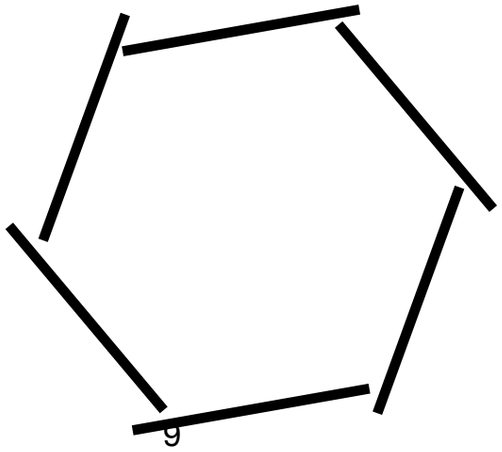


- First module concept that met key interface requirements
- 90-mm width readout boxes on back, barely fit behind wafer footprint
- Flex cable (not shown) requires complicated routing from edge of wafer to box, with 60deg bend
- Long cables are difficult to assemble and fabricate, put pressure on inductance budget

Readout Boxes - v2 in progress

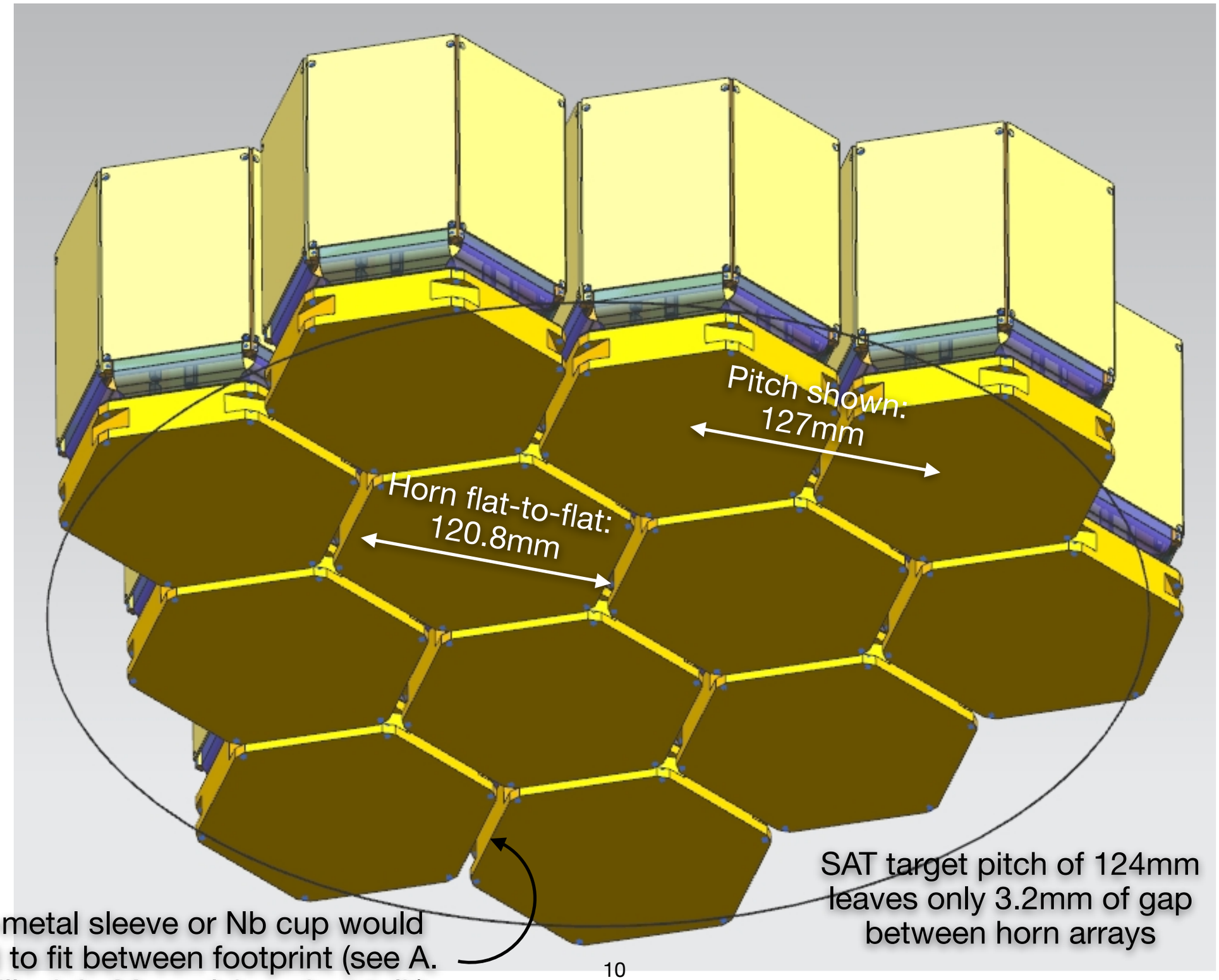






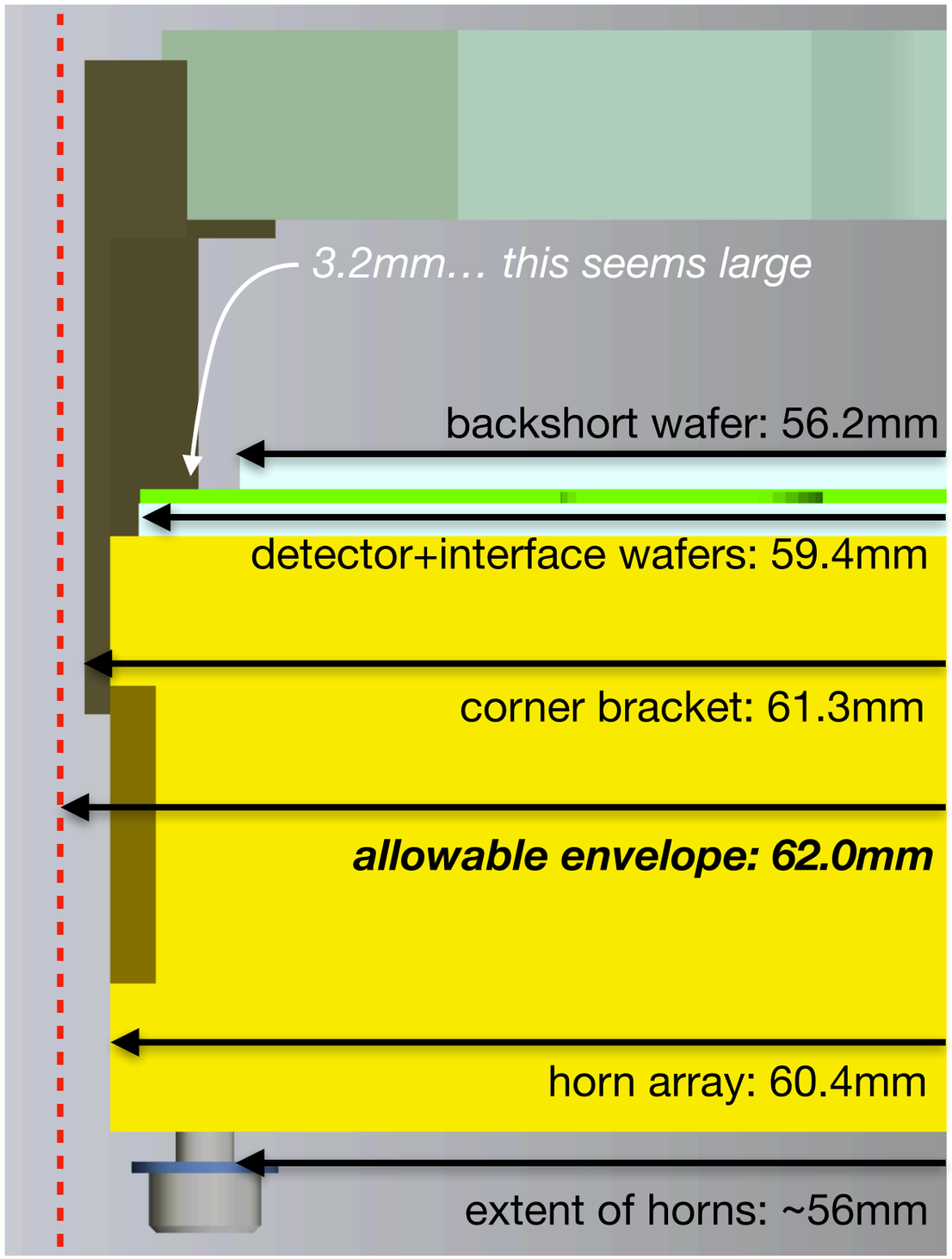
- Achieved significant reduction in box width with denser wiring chips, corrected MUX chip dimensions (90mm -> 65mm)
- Flex cables drastically shortened, eliminated twisting/ routing problem
- Final layout/dimensions of readout box pending final MUX column wiring chip configuration (see G. Haller readout talk)
- Residual collisions in corners, resolve with some combination of fine-tuning box width, removing material, and “pinwheel” orientation
- Include springs on readout mounting plate as on previous slide

SAT Focal Plane Configuration



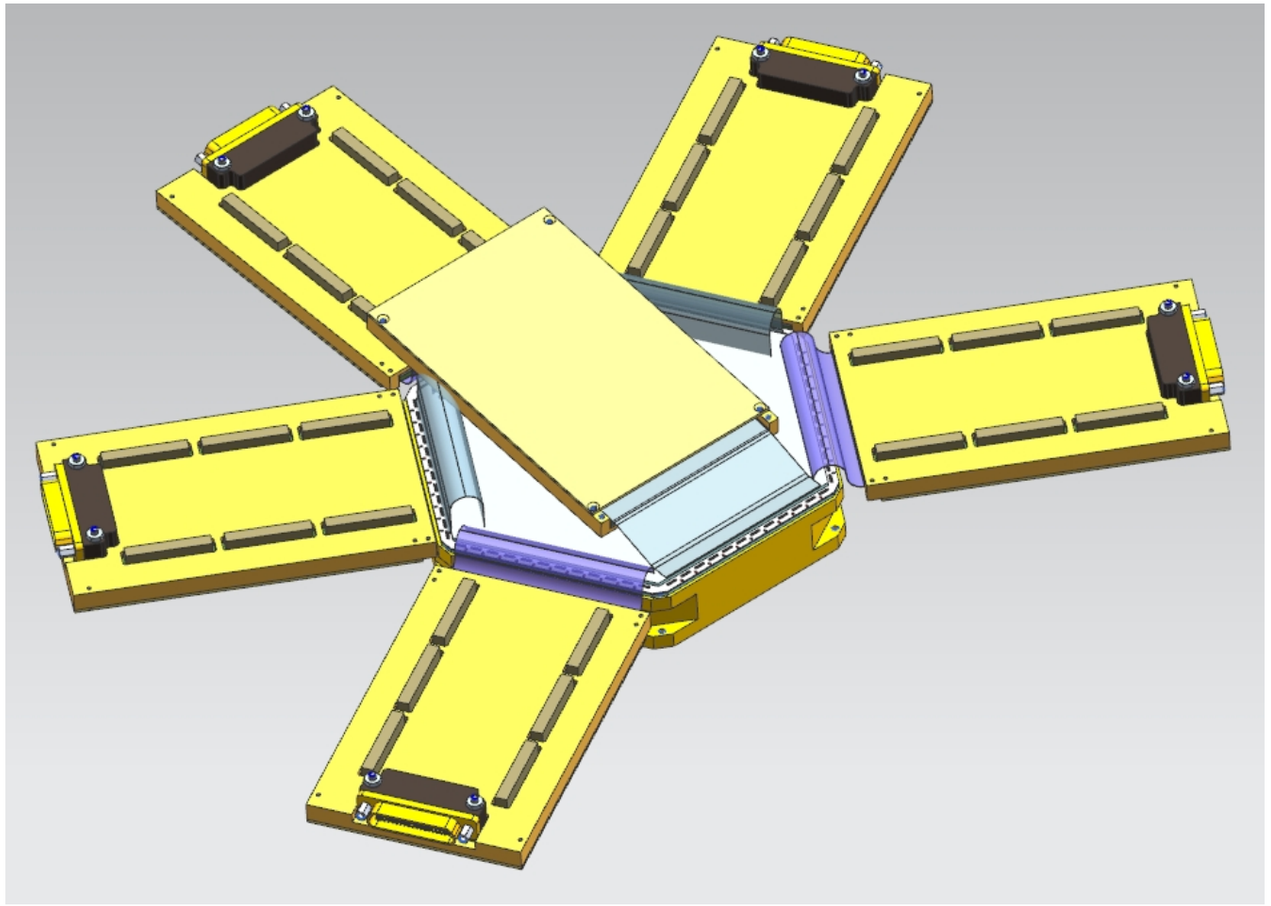
SAT Pitch Problem

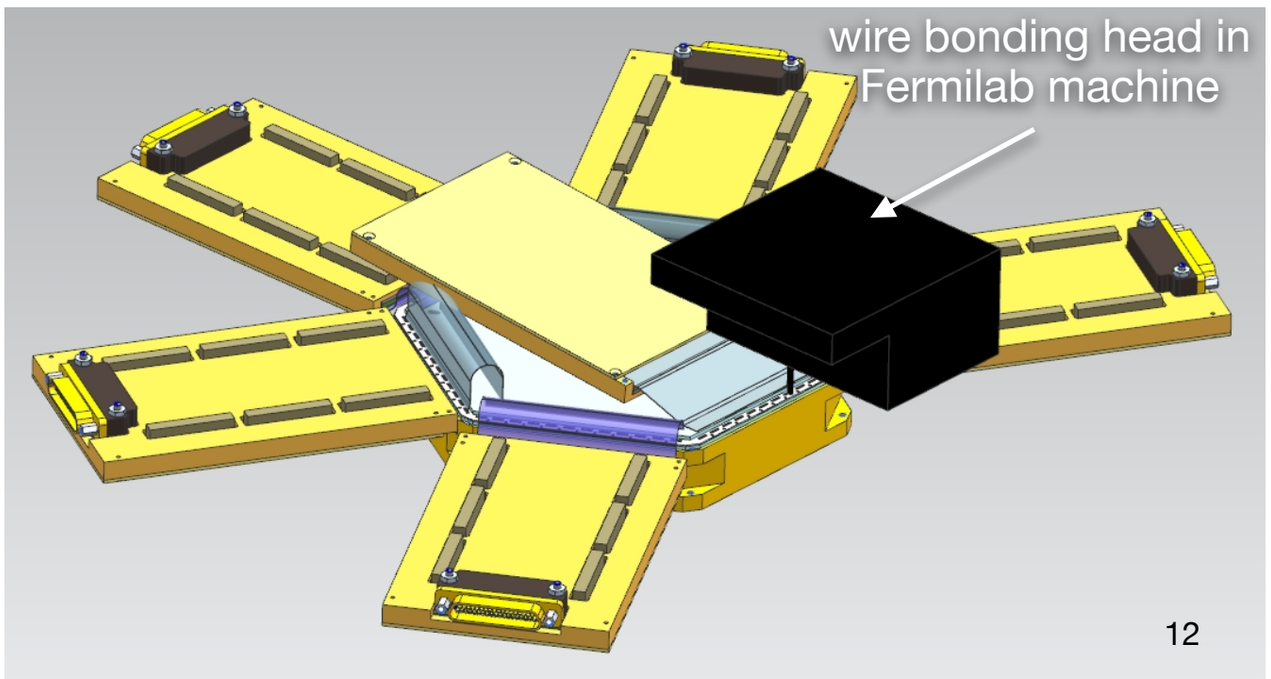
Important radial distances:



- In current design, there is 1.6mm or 0.7mm clearance for focal plane plate + magnetic shield, modulo precise locations. Seems inadequate.
- Possible solutions:
  - Relax 124mm pitch: reduces SAT mapping speed.
  - Shrink detector+interface wafers and horn array, holding backshort and horn array by ~2mm. *No impact to optics*. Reduces area for bondpads and mechanical support of outer horn wall.
  - Eliminate focal plane plate, and expand horn arrays to bolt directly into each other. Probably too radical, but arguably not insane.

Assembly





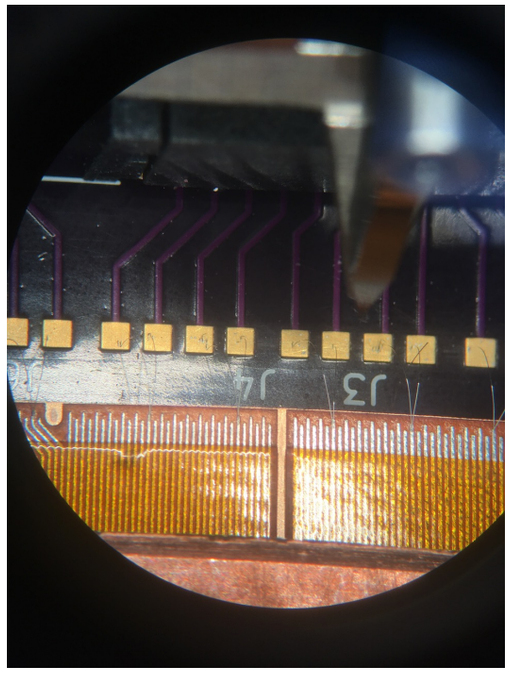
- Because of SAT pitch requirement, flex cables must mount inward (detector wafer is 119mm and pitch is 124mm)
- In order to maintain bondpads on same side of flex cable at both ends, box must fold back into backshort during bonding
- Jig needed to hold boxes during bonding steps
- Head of Fermilab wire bonding machine is non-trivial in size—critical to include in 3D model of assembly

Flex Cables

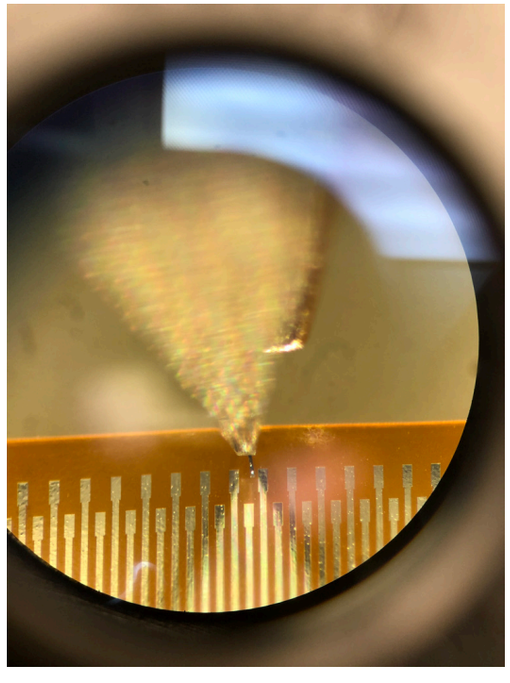
- Superconducting flex cables are key R&D problem; no extant solution meets volume, cost, and trace density requirements
- Considered two options:
    1. Superconducting aluminum, 2mils/2mils trace/space (1-layer) or 4mils/4mils trace/space (2-layer)
    2. Tinned copper, 2mils/2mils
- Explored 15 vendors, remaining options include:
    - SLAC has process that can make 90um pitch Al traces on polyimide substrate; could commercialize
    - Try to tune tin layer on copper substrate to achieve lower Rp

Vendor / heritage	Stack	pitch (trace/space)	R (T=100mK)	Ic	Cost
TechEtch / SPT-3G	polyimide / 9um tinned Cu / polyimide	2mils / 2mils	7-10 mOhm (~4 inches) (expect 50mOhm for RRR~100)	No SC transition observed	~$250
TechEtch / PB2a	polyimide / 50-300uinches tinned Cu / polyimide	2mils / 2mils	Cooling down	Cooling down	~$250
TechEtch / SPIDER	polyimide / aluminum / polyimide	4.5mils / 4.5mils	Bonded, in queue	Bonded, in queue	~$250
Flexible Circuits Technology	polyimide / 1 mil Al / polyimide	4mils / 4mils	fab failed	fab failed	~$250
SLAC	polyimide / Al	90um	TBD	TBD	TBD

TechEtch claims yield drops significantly at <9mils pitch in Al



TechEtch / SPIDER



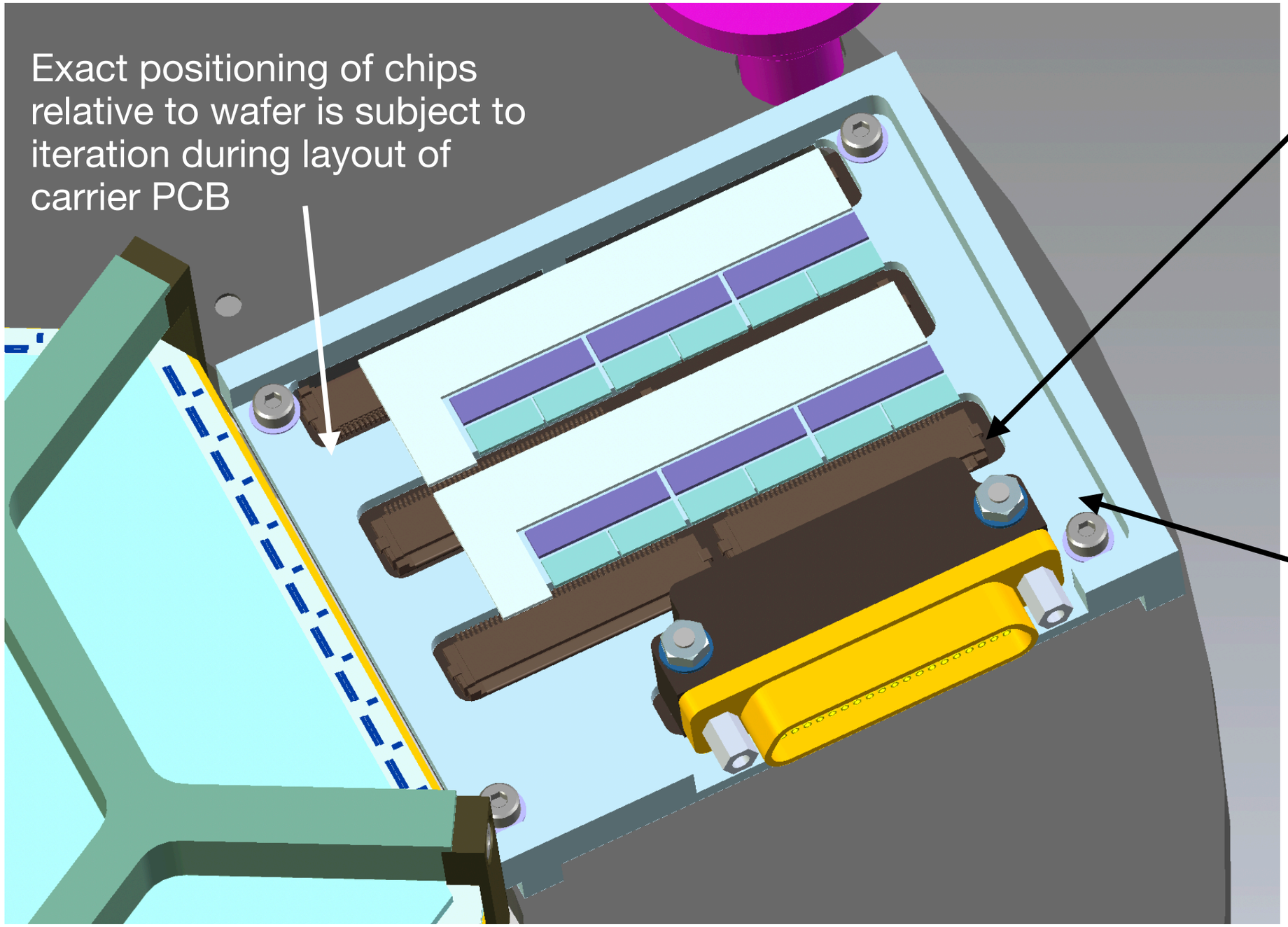
SLAC (90um Al)

Next Steps

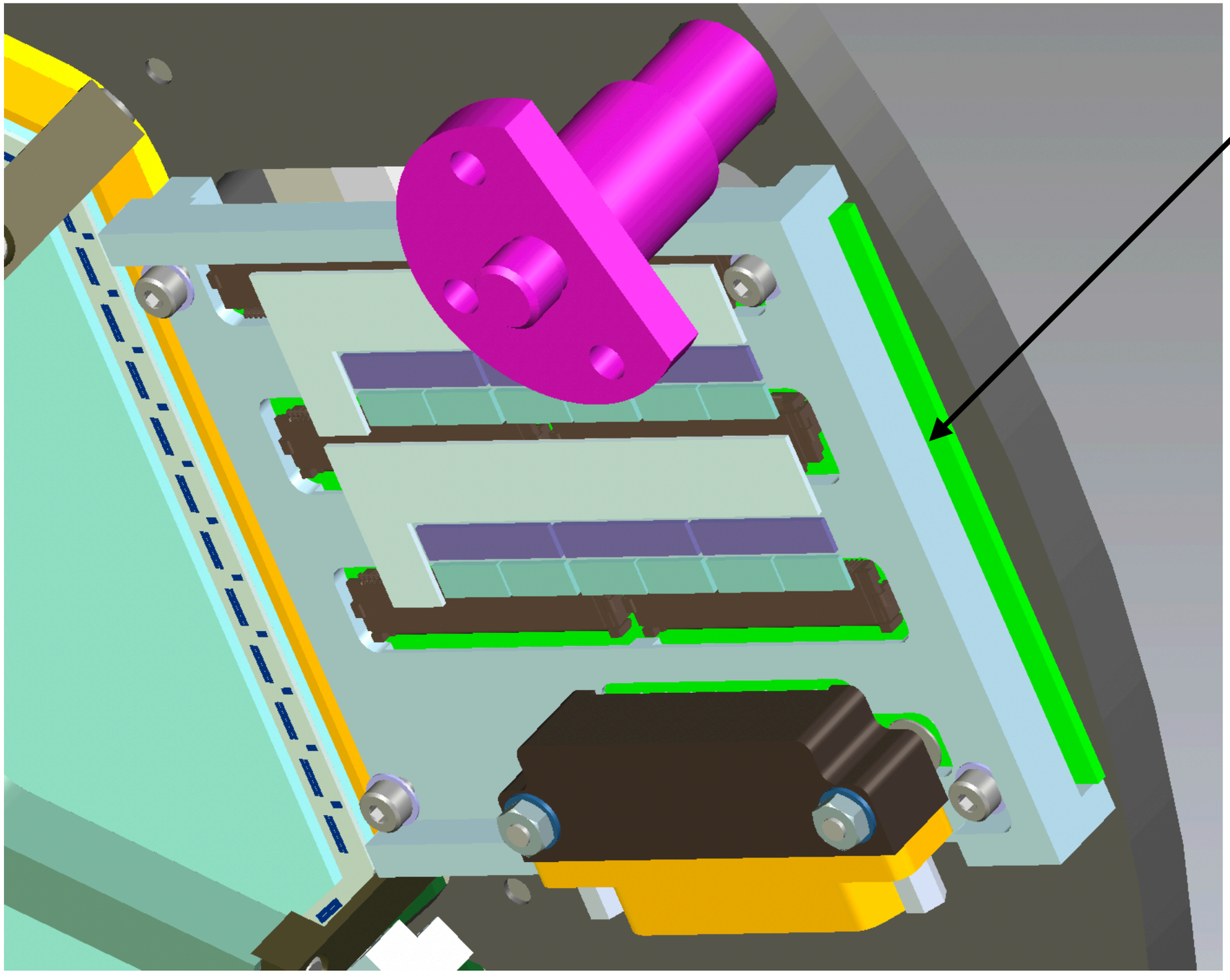
- CDFG test module is straightforward and will proceed in tandem with readout layout
- Production module with readout boxes parallel to each side of hex (v2) is probably viable
- Need to finalize readout box mechanical design together with readout layout
- Flex cables remain a major R&D task
- Further study and implementation of magnetic shielding

Backup

Readout Box Detail



Magnetic Shielding Considerations



Accommodation for sheet of mu-metal for magnetic shielding; annular ring also possible

Level of detail in magnetic shielding strategy for readout in CDFG test module is extremely primitive. Further development and basic simulations needed.

Production Module - Key Interfaces and Requirements

- ***Readout:***
  - MUX chips should be housed in modular boxes, necessitating use of superconducting flex cables
  - Need to control inductance in superconducting wiring to TES (needs spec)
- ***Detectors:***
  - 118.8mm wafer size (hex side-to-side); inherited from SO
- ***SAT:***
  - 124mm wafer pitch (hex side-to-side); allows 2.6mm between edge of silicon and boundary of hex footprint
  - Accommodations for mounting in a curved focal plane (*new this week)*
- ***Modules and assembly:***
  - Assembly and wire bonding must be physically possible
  - High-yield assembly must take 1 technician-day

Module design is highly sensitive to interface mechanical dimensions. Changes of ~1mm can make or break design configurations.