Barrel TOF Mechanics, Cooling, Flex

Sushrut Karmakar,
Sam Langley-Hawthorne et al (Purdue)

Matthew Gignac et al (USCS)

Oskar Hartbrich,
Mathieu Benoit et al (ORNL)

Some Content Context

- An update from Sushrut and the Purdue crew
- An update/discussion contribution from Matthew
- A brief update on ORNL flex R&D and what it all means

Barrel Module Assembly Ideas

Matthew Gignac

July 15th 2024

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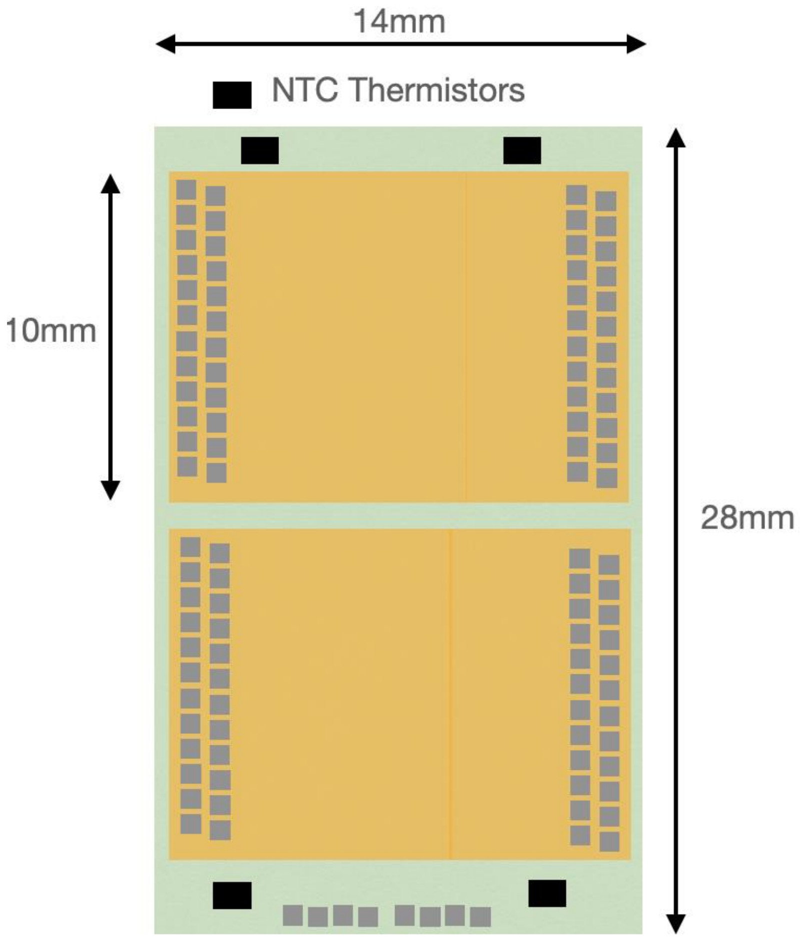
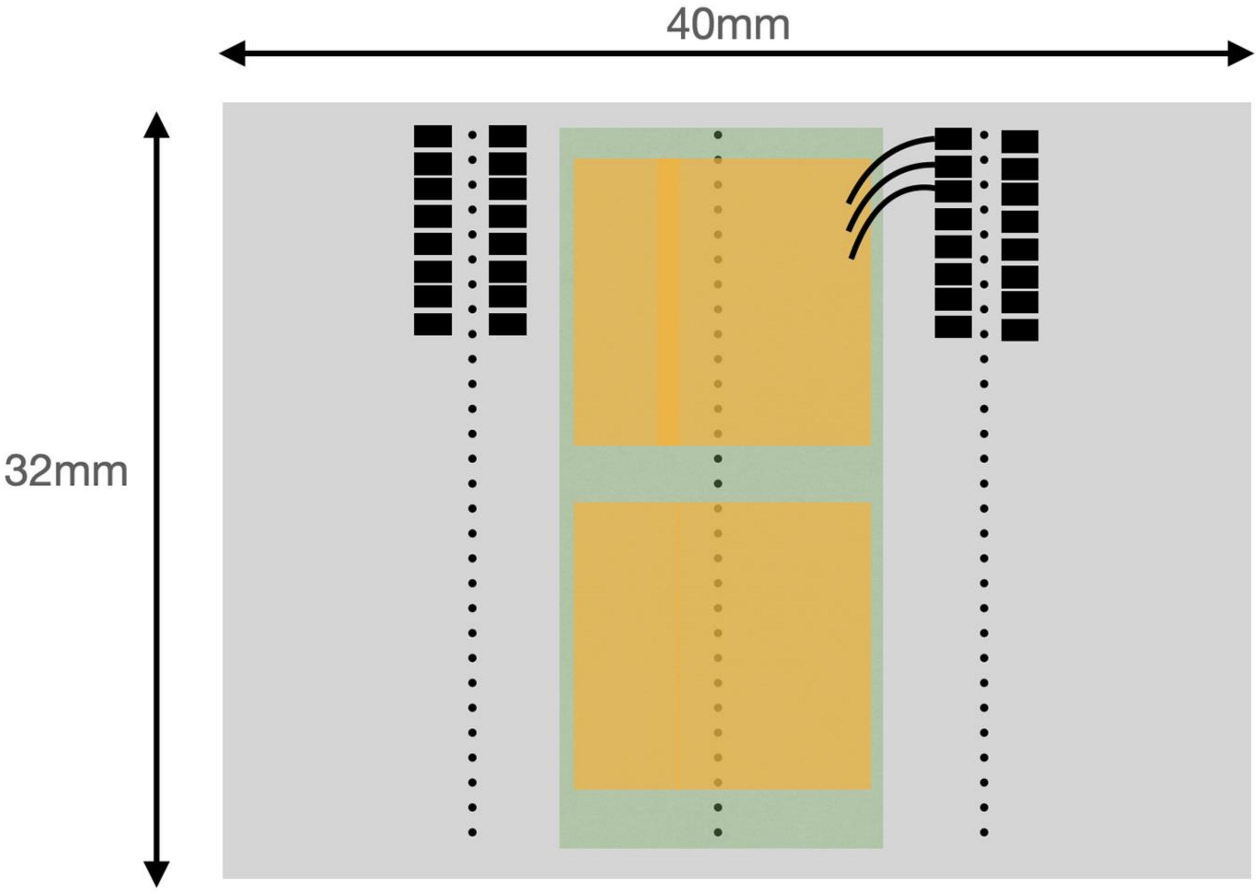
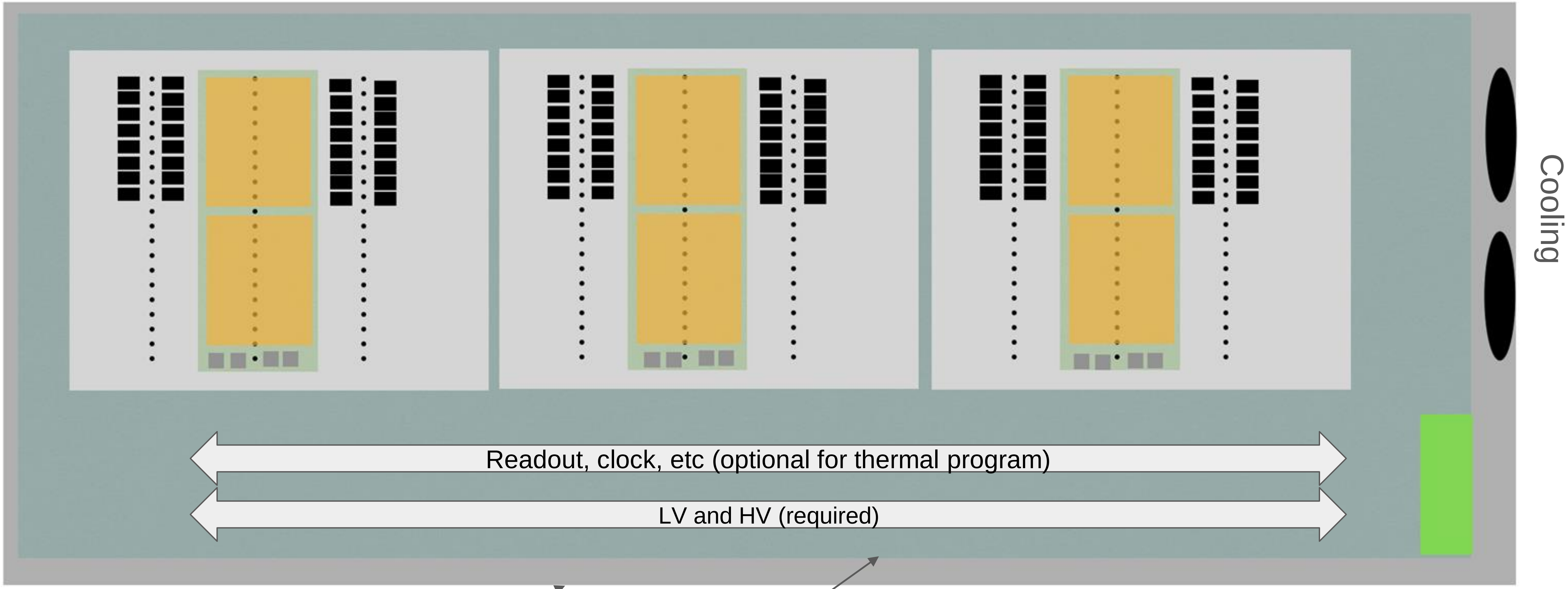
Component dimensions





Thermal module: rough sketch


Cooling

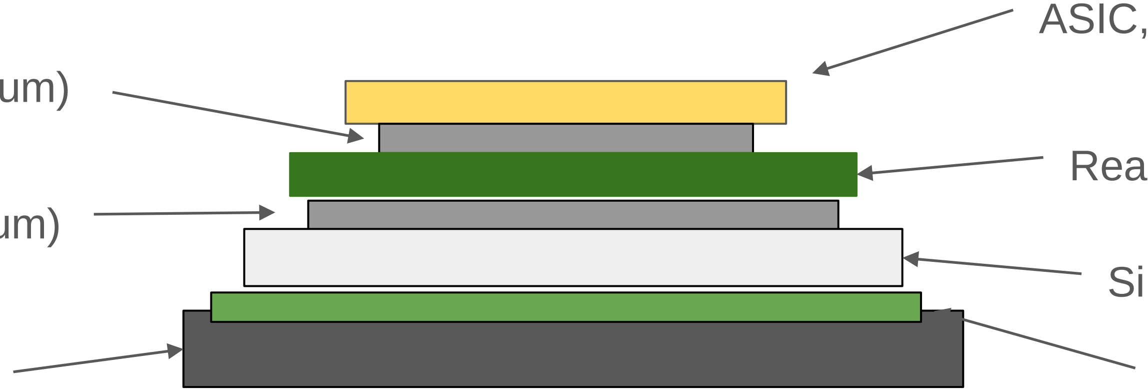
Readout, clock, etc (optional for thermal program)

LV and HV (required)

Module support structure

Hybrid flex

Stack-up for FEA



ASIC, 300um

Glue, 120um (+/- 40um)

Readout hybrid, 400um (+/- 20 um)

Glue, 120um (+/- 40um)

Silicon sensor, ~200um (typical of HPK)

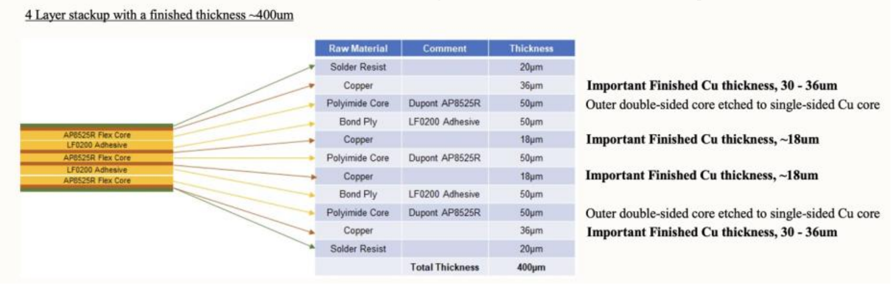
Module support/cooling

Hybrid Flex (~200um)

Open questions:

- Interface between hybrid flex and module support structure unclear to me. Do we need some type of thermal base plate?
- Readout hybrid design, especially the electrical version, still unclear. Suggest to follow ATLAS ITk Strips, 4 layer stack)

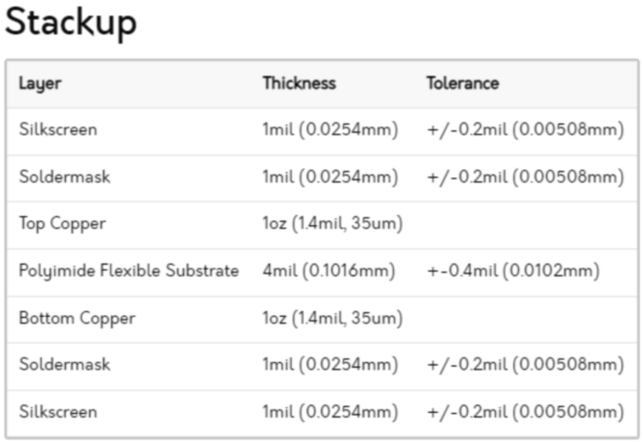
Readout hybrid stack up



4 Layer stackup with a finished thickness ~400um

Raw Material	Comment	Thickness	
Solder Resist		20µm	
Copper		36µm	**Important Finished Cu thickness, 30 - 36um**
Polyimide Core	Dupont AP8525R	50µm	Outer double-sided core etched to single-sided Cu core
Bond Ply	LF0200 Adhesive	50µm	
Copper		18µm	**Important Finished Cu thickness, ~18um**
Polyimide Core	Dupont AP8525R	50µm	
Copper		18µm	**Important Finished Cu thickness, ~18um**
Bond Ply	LF0200 Adhesive	50µm	
Polyimide Core	Dupont AP8525R	50µm	Outer double-sided core etched to single-sided Cu core
Copper		36µm	**Important Finished Cu thickness, 30 - 36um**
Solder Resist		20µm	
	Total Thickness	**400µm**	

Hybrid flex stack up



Stackup

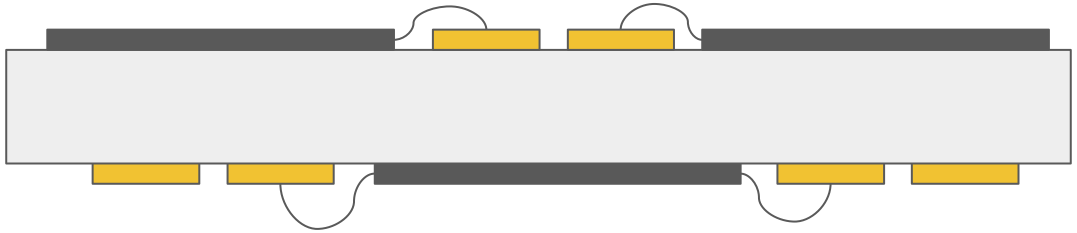
Layer	Thickness	Tolerance
Silkscreen	1mil (0.0254mm)	+/-0.2mil (0.00508mm)
Soldermask	1mil (0.0254mm)	+/-0.2mil (0.00508mm)
Top Copper	1oz (1.4mil, 35um)	
Polyimide Flexible Substrate	4mil (0.1016mm)	+-0.4mil (0.0102mm)
Bottom Copper	1oz (1.4mil, 35um)	
Soldermask	1mil (0.0254mm)	+/-0.2mil (0.00508mm)
Silkscreen	1mil (0.0254mm)	+/-0.2mil (0.00508mm)

Problems with design

- Acceptance holes between sensors (plus their inactive edge area, ~2x500um)
- Electronics need to be placed on top of the sensor surface
  - Thermal path through several layers of materials (PCB, glue, sensor, etc)
  - Introduces temperature gradients on top of the sensor surface that can affect performance
- Obviously desirable to have the ASICs off the sensor surface
- But need to satisfy timing and spatial requirements:
  - Strips need to run along the length of the stave to allow precision measurement in the bending plane
  - Connections to the front-end electronics should minimize path length and be similar across all channels

Alternative bTOF design

- An alternative design can solve both of these problems if we use both sides!



Alternative bTOF design

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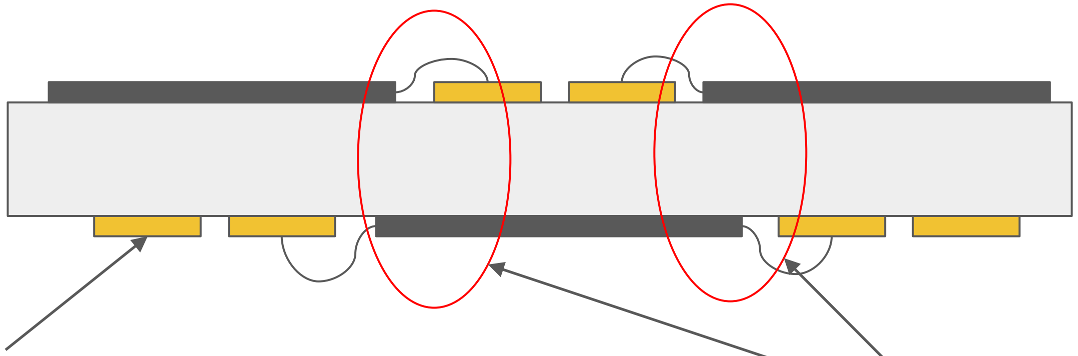

ASICs have direct contact to cooling structure → easier to cool and no temperature gradients introduced onto the sensor surface

Overlap between sensors can be chosen to eliminate acceptance gaps!

Alternative bTOF design

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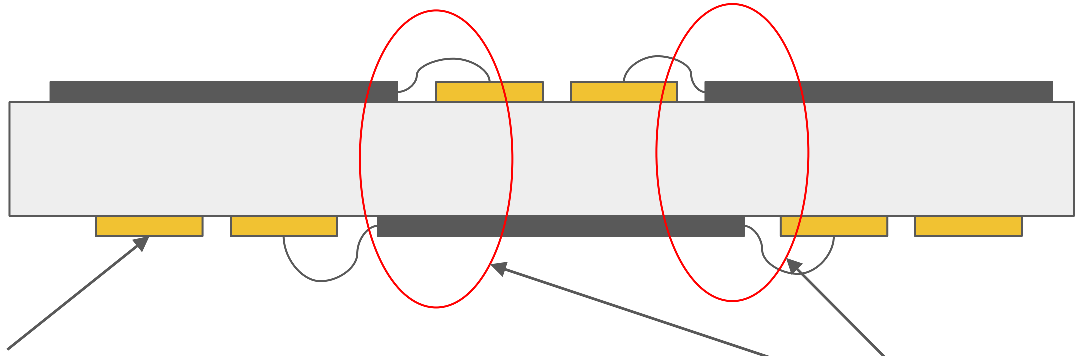


ASICs have direct contact to cooling structure → easier to cool and no temperature gradients introduced onto the sensor surface

Overlap between sensors can be chosen to eliminate acceptance gaps!

- Drawbacks: limits sensors to two segments (or relatively long, overarching bonds to inner segments), and bonding needs to be performed with sensitive components on backside

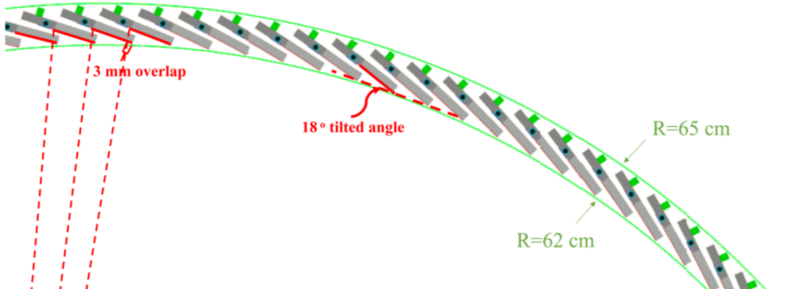
AC-LGAD ToF : Stave Prototype Updates

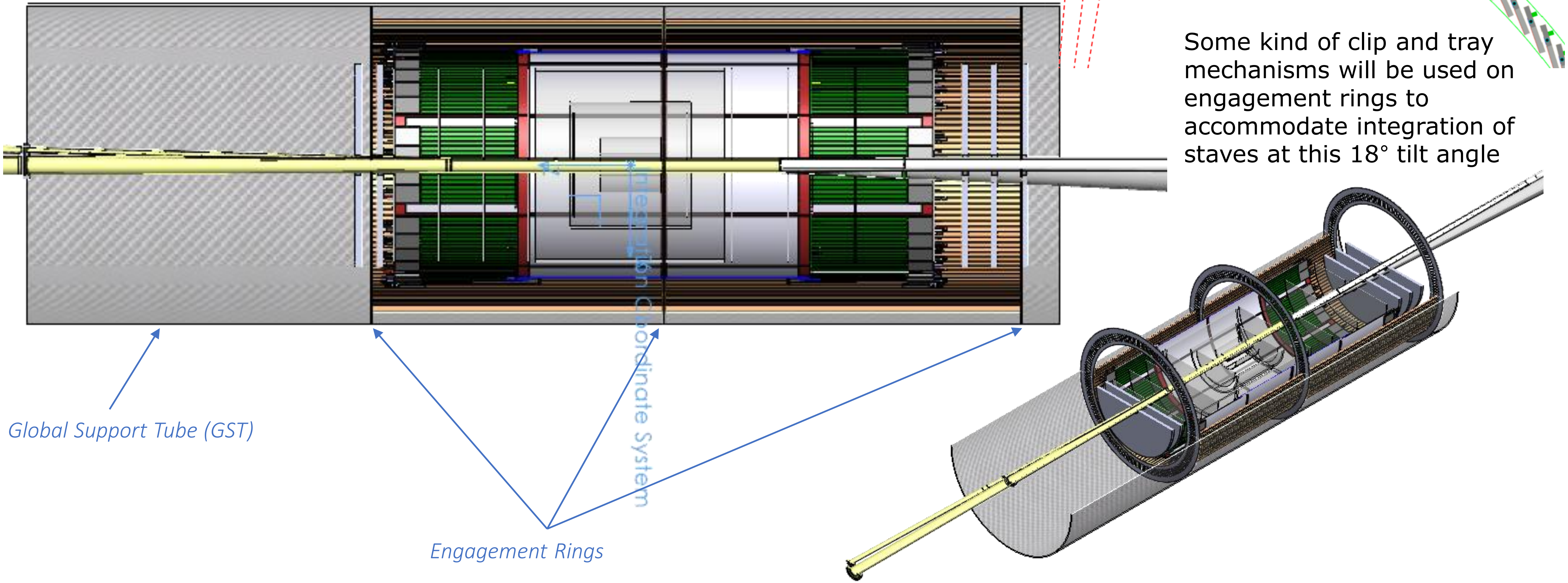
July 24th, 2024

Sushrut Karmarkar, Sam Langley-Hawthorne

AC-LGAD Geometry check and global assembly considerations

This is the geometry that currently exists in the global mechanics CAD from Purdue and BNL (Roland Wimmer)





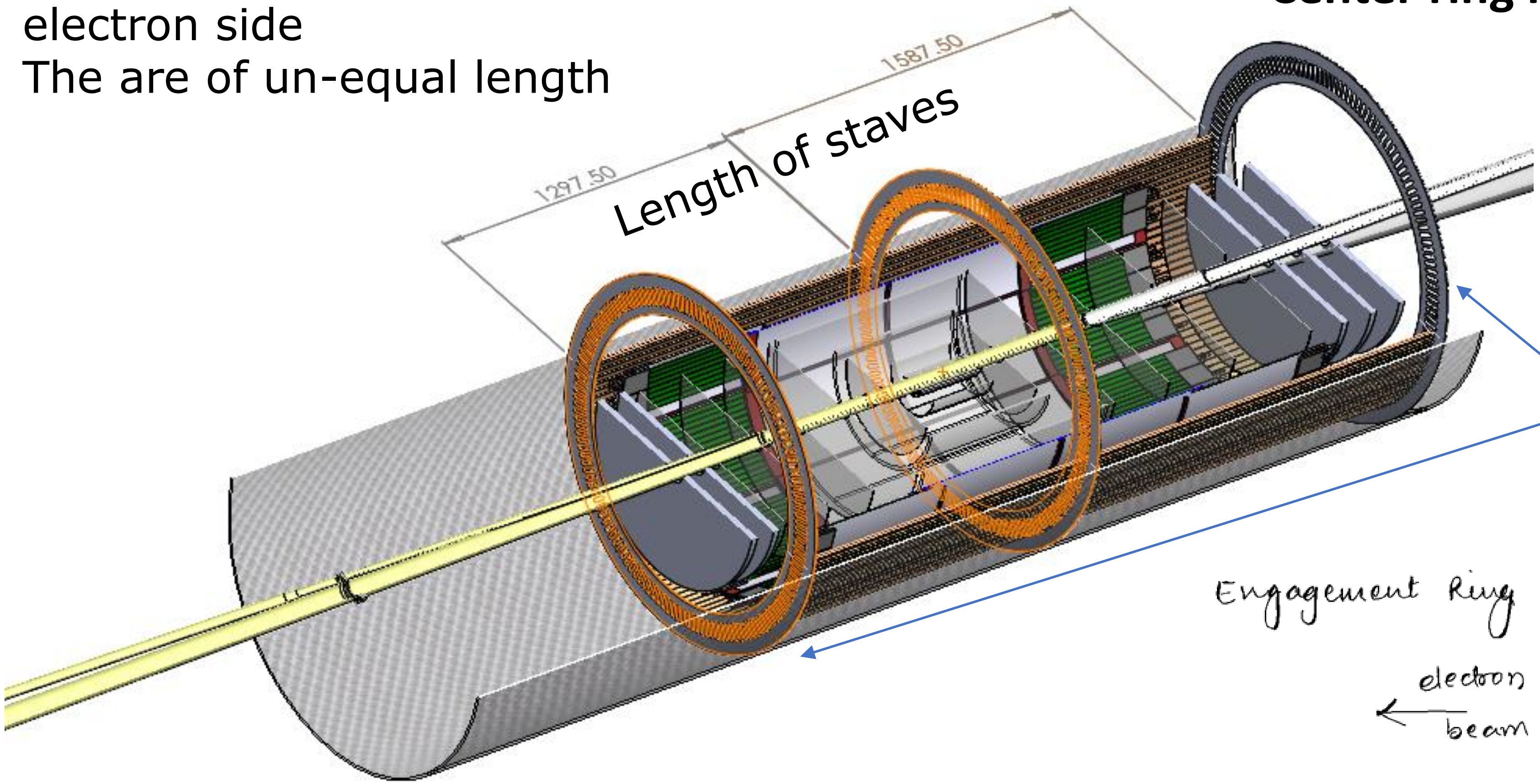
Some kind of clip and tray mechanisms will be used on engagement rings to accommodate integration of staves at this 18° tilt angle

Overall dimensions for AC-LGAD

At the very least we will have two stave designs – hadron side and electron side
The are of un-equal length

Engagement Rings are 5 mm thick

Center ring might be without access holes



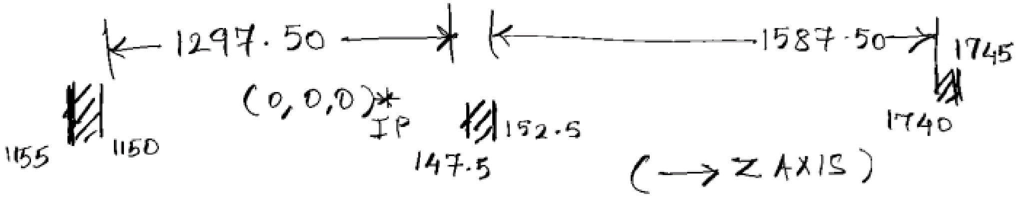
How to compute coverage loss?
The END engagement rings can be moved slightly to accommodate modules – need to figure that out soon

Engagement Ring locations : (NOT TO SCALE)

← electron beam

hadron beam →

Unit: mm



▨ *Cross section of Engagement Ring*

Position of the center ring is fixed by CymbalMPGD

Heat Transfer Simulation Summary

- Updated glycol and water-cooling HTC values
    - Hand-calc estimation of HTC
    - Test Cases
        - -10 C 50% Glycol/Water
        - 0 C 50% Glycol/Water
        - 5 C Water
        - 18 C Water
- ASIC Direct to Hybrid Flex

Next Steps:

- Verify convective heat transfer coefficient values with Ansys Fluent heat pipe simulations

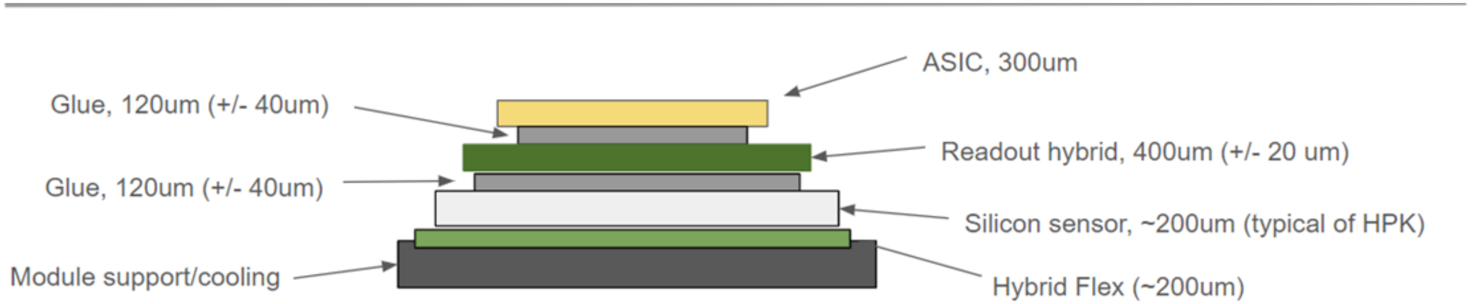
- The heat transfer coefficient in the pipe makes a huge difference on the temperature profiles
- We need a good way to do CFD coupled heat transfer simulations for getting performance metrics for the stave

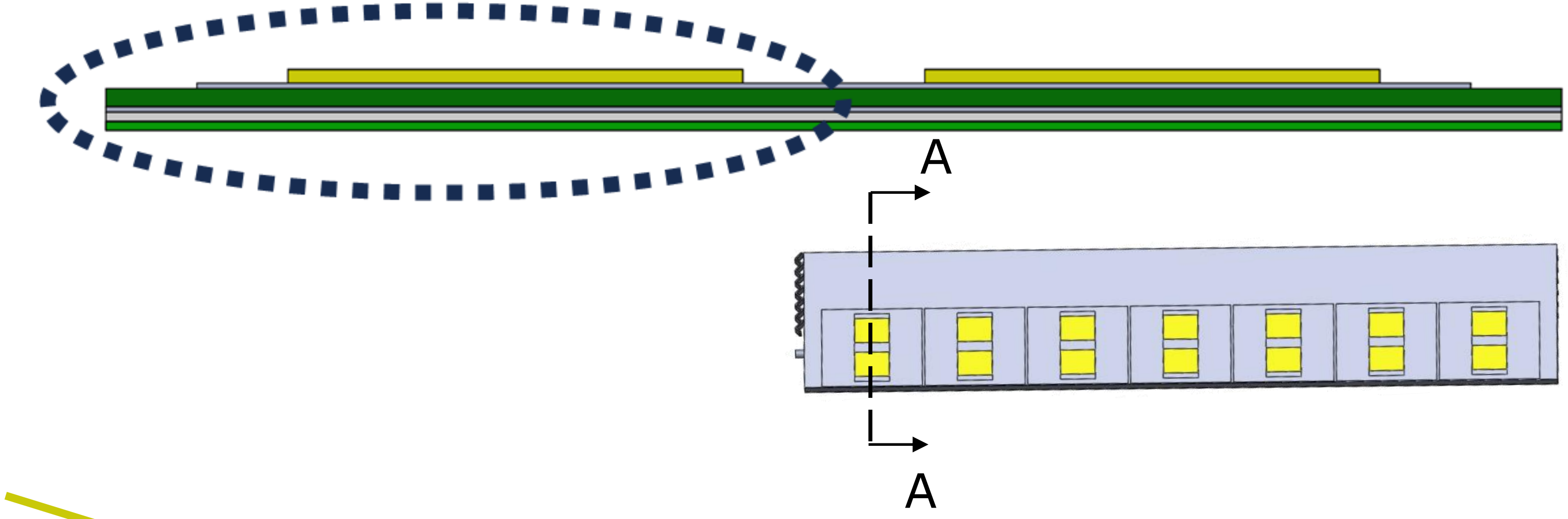
- *Inputs that need refinement from Cooling group at EIC*
    - *What is the inlet pressure at AC-LGAD?*
    - *What is the flow rate available? – currently estimated at 1m/s.*
    - *Currently assumed as flow conditions – Reynold’s number (Re) ~ 250,000 – laminar flow regime*

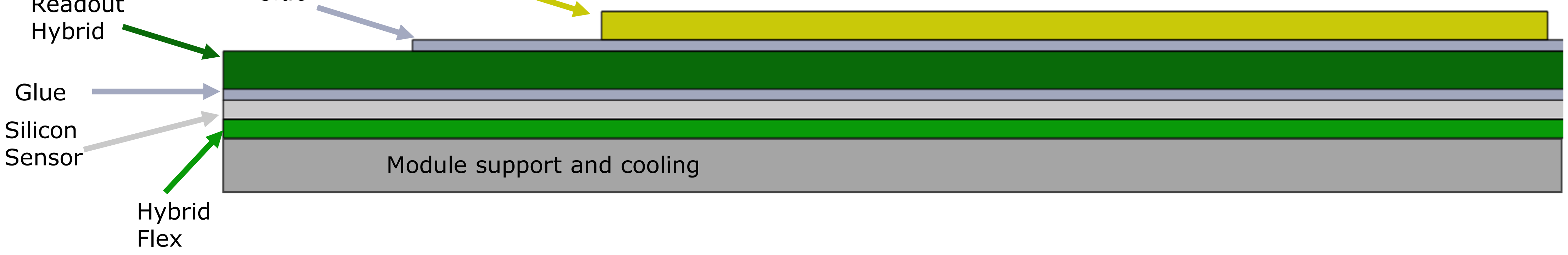
Sensor cross-section set up – Ansys HT

OLD SLIDE for reminder of work on-going

Part Name	Thermal Conductivity (W/mK)	Thickness (µm)
ROC and ASIC (PCB/Kapton properties)	0.97	400 and 300
Silicon Module	148	200
Carbon Face Sheet	Kxx - 180 Kyy - 150 Kzz - 1.36	200
Carbon Foam	25	6420
Loctite Epoxy (Glue)	1.28	120
Stainless Steel Pipe	16	716







Water cooling at +18°C – miniSTAVE and fullSTAVE

OLD SLIDE for reminder of work on-going

Heat transfer coefficient estimated to be (h) ~~1000 W/m²K~~ decaying down to ~~360 W/m²K~~ (at outlet) --

$$h = \frac{k \cdot Nu_L}{L}$$

$$Nusselt\ number\ (Nu_L) = \frac{\left(\frac{f}{8}\right)(Re - 1000)Pr}{1 + 12.7\left(\frac{f}{8}\right)^{0.5}\left((Pr)^{\frac{2}{3}} - 1\right)}$$

- Need better pressure inlet and pressure outlet understanding for refining the simulations further
- Heat transfer coefficients in a pipe for water at room temp and pipe diameter of 5 mm used for the current estimation of h.
- Please can Yi/NCKU help with this – cross check my numbers ?

For laminar flow in a pipe at room temp we found out the Prandtl (Pr) and Reynolds (Re) numbers using (Gnielinski,1976) and first Petukhov eq. (1970) :

$$f = (0.790 \ln Re - 1.64)\text{^}(-2)$$

For flow conditions Re ~ 250,000

L = length (function of x); k = conductive heat transfer coefficient (W/mK)

Heat Transfer Coefficient Calculation

- $Re = \frac{p * u * L}{v}$ (1)
  - p = density of fluid (kg/m^3)
  - u = flow speed (m/s)
  - L = diameter(m)
  - v = dynamic viscosity of fluid(Pa*s)
- Petukhov equation
  - $f = (0.790 \cdot \ln \mathrm{Re} - 1.64)^{-2}$ *(2)*
- Gnielinski equation
  - $Nu = \left[\frac{(f/8)(\mathrm{Re} - 1000)Pr}{1 + 12.7\left(\frac{f}{8}\right)^{0.5}\left(Pr^{\frac{2}{3}} - 1\right)}\right]$ *(3)*

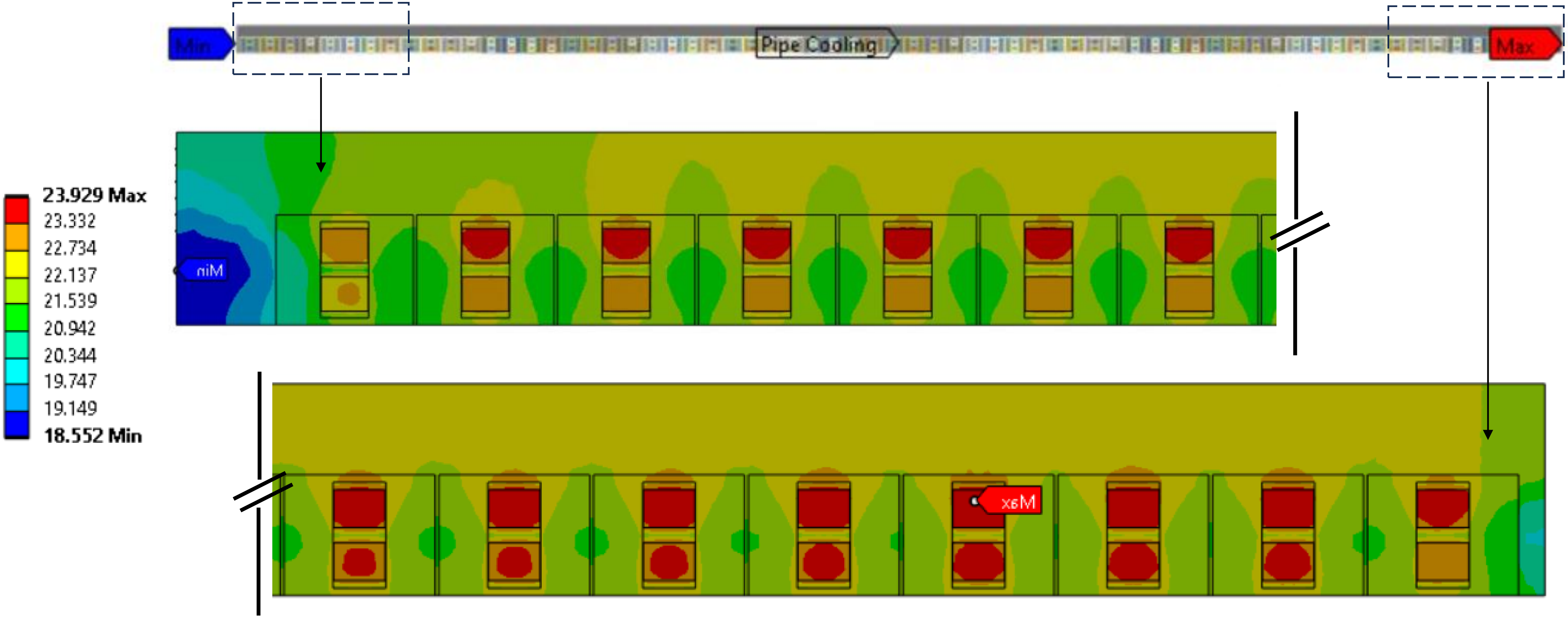
- $Nusselt\ Number(Nu) = \frac{hL}{k}$ (4)
  - h = heat transfer coefficient (W/m^2C)
  - L = characteristic length (m)
  - k = thermal conductivity (W/mC)
- $Q = hA(T_{Wall-}T_{Fluid})$ (5)
  - Q = heat transfer (W)
  - h = heat transfer coefficient (W/m^2C)
  - A = Contact Area (m^2)

- $Q = mc_p(T_f - T_i)$ (6)
  - m = mass (kg)
  - c_p = specific heat of fluid $\left(\frac{\mathrm{J}}{\mathrm{kgC}}\right)$
- Process
  - $Re \rightarrow f \rightarrow Nu \rightarrow h \rightarrow Q \rightarrow Tf$
  - Use iterative calculation in MATLAB to determine temperature increase of fluid using equations 5 and 6

Note: potential for error in calculation, working to confirm values using heat pipe simulations in Ansys Fluent

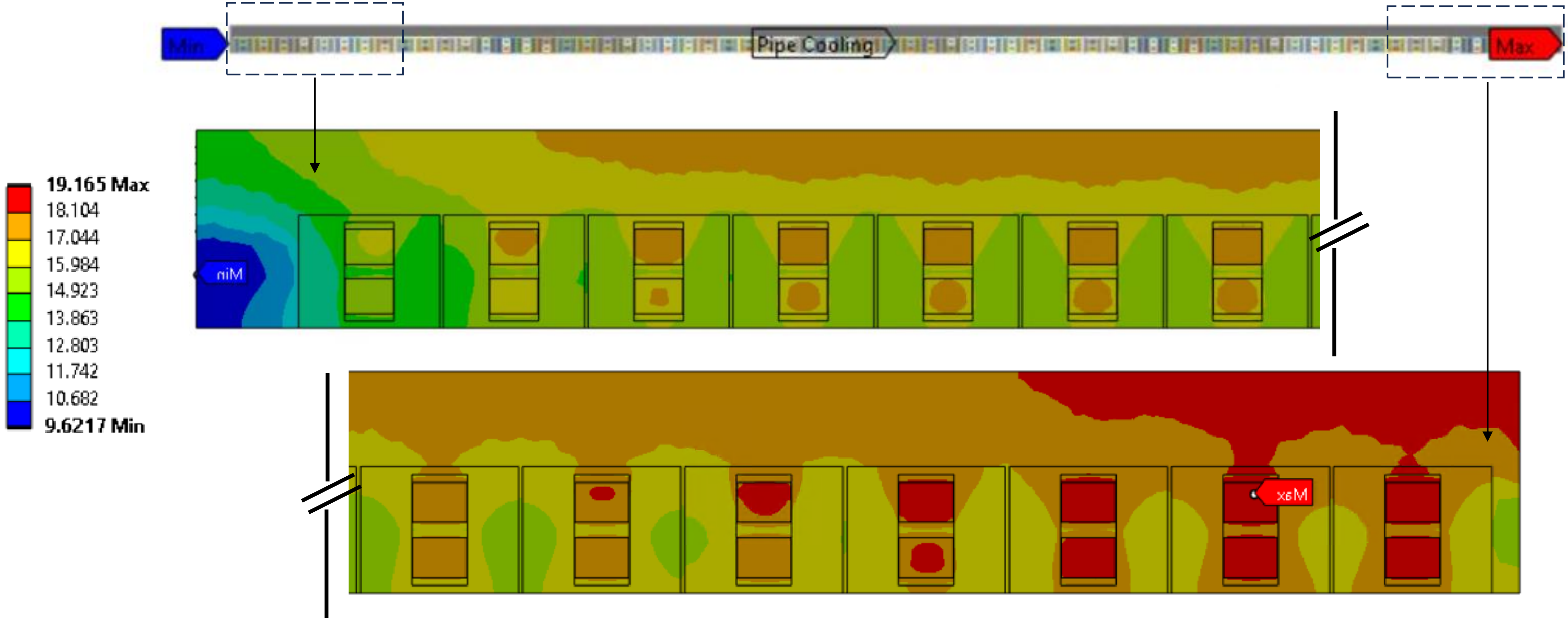
18 C Water Cooling (Full Stave)

HTC Range 3364 to 2942 W/m^2C



5 C Water Cooling (Full Stave)

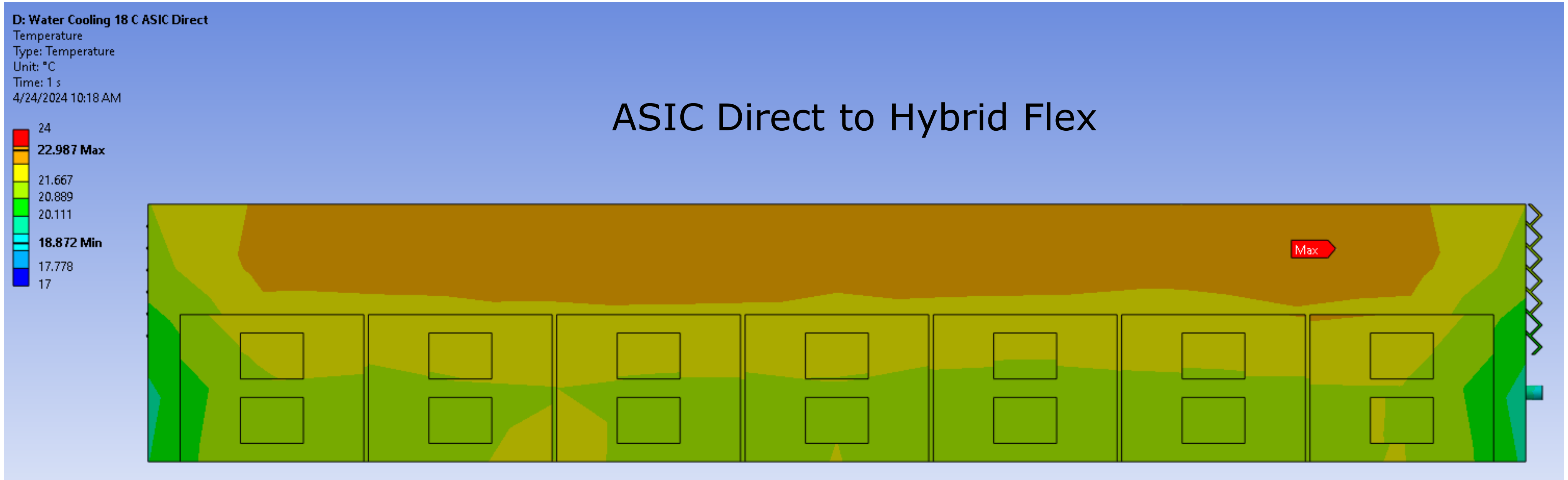
HTC Range 1162 to 799 W/m^2C



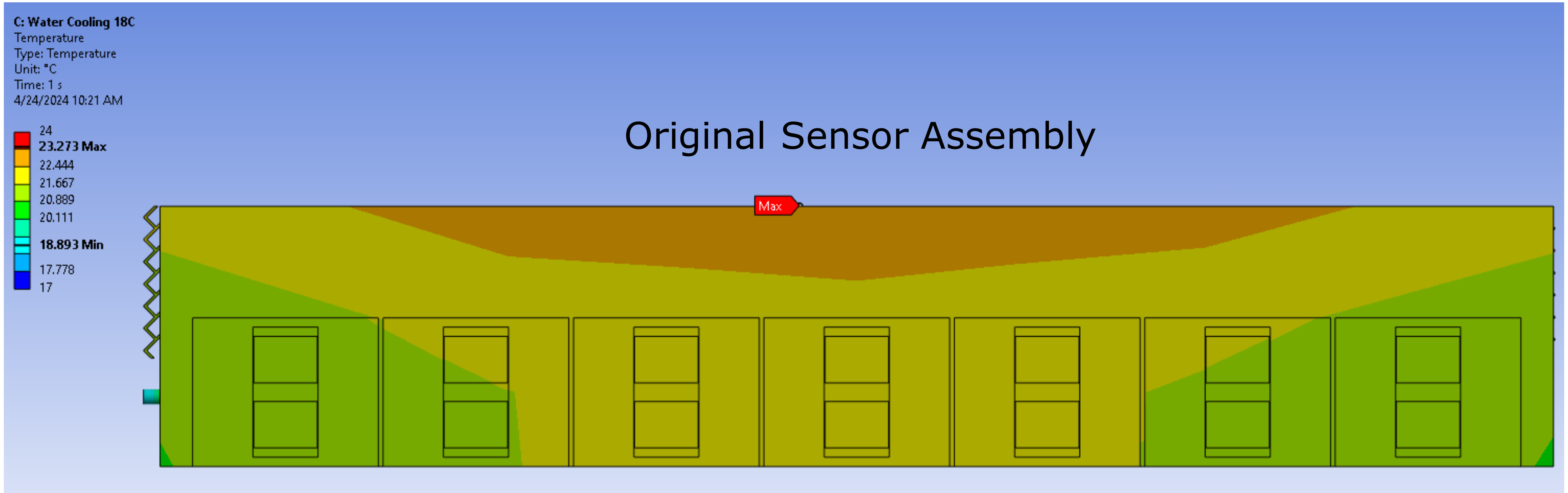
ASIC Direct – miniSTAVE (300 mm long stave results) (18 C Water)

When ASIC is directly on the hybrid flex there is better heat dispersion

This was just a first attempt for miniSTAVE – same simulation for fullSTAVE in progress



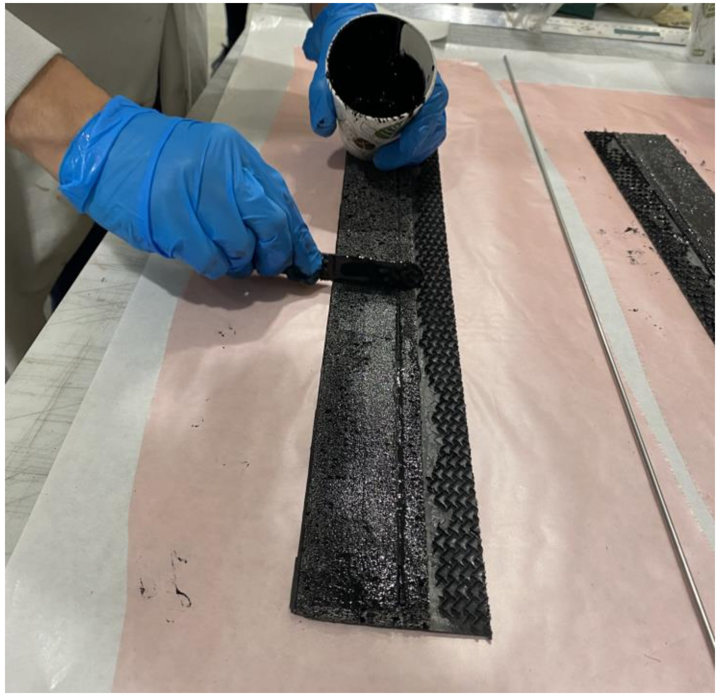
ASIC Direct to Hybrid Flex

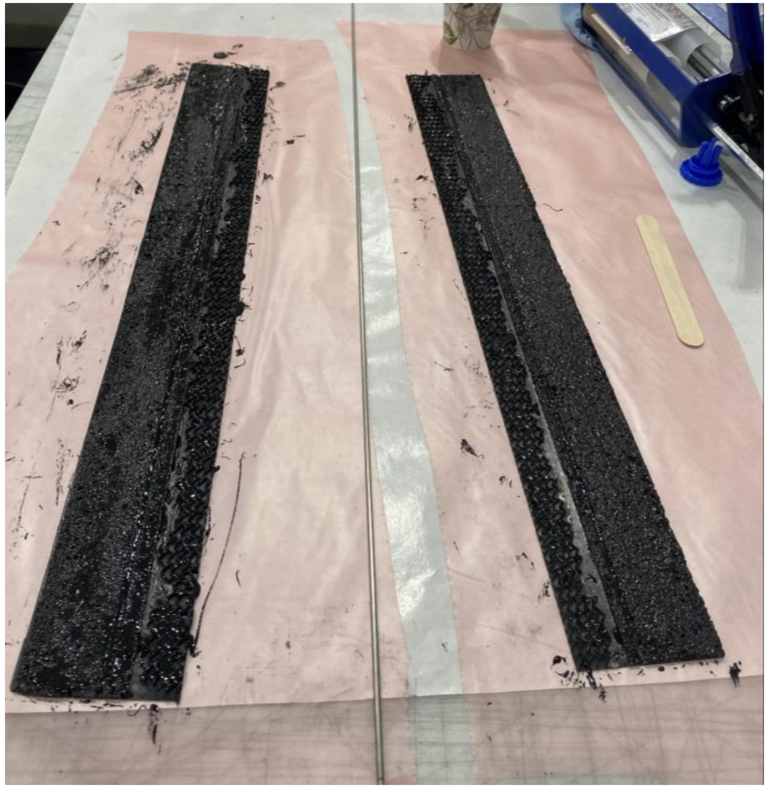


Original Sensor Assembly

Stave Bonding Process

Bonding complete for 590mm stave made from excess material

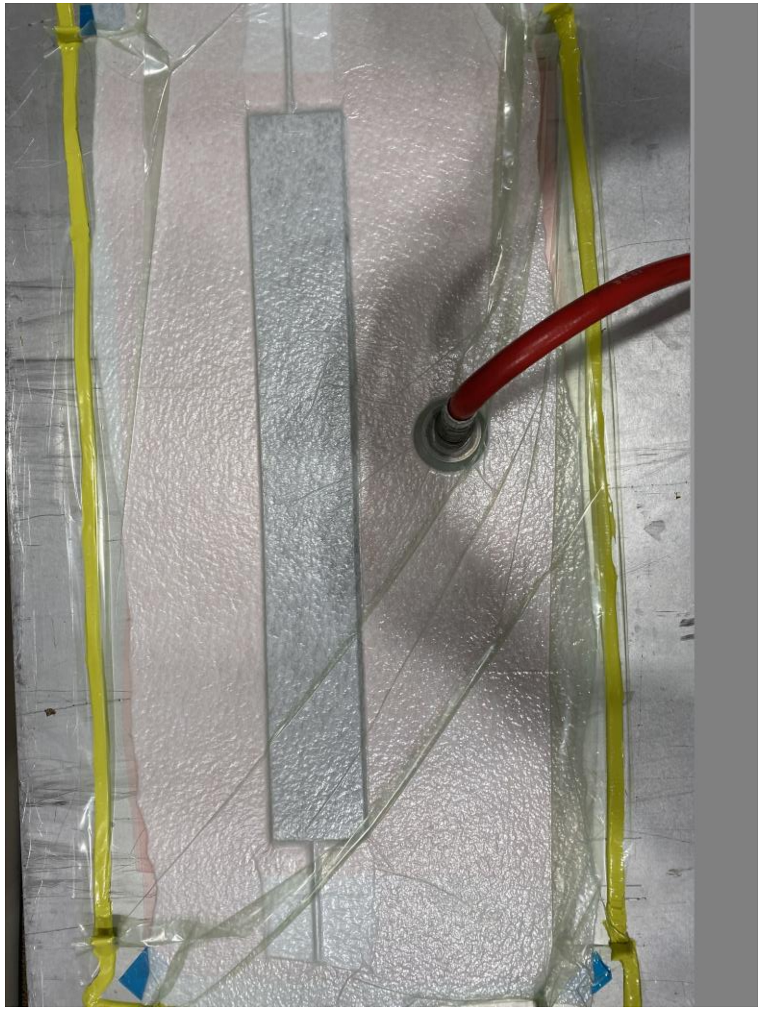




Apply Araldite 2011 mixed with 10% graphite by weight to each half of machined stave

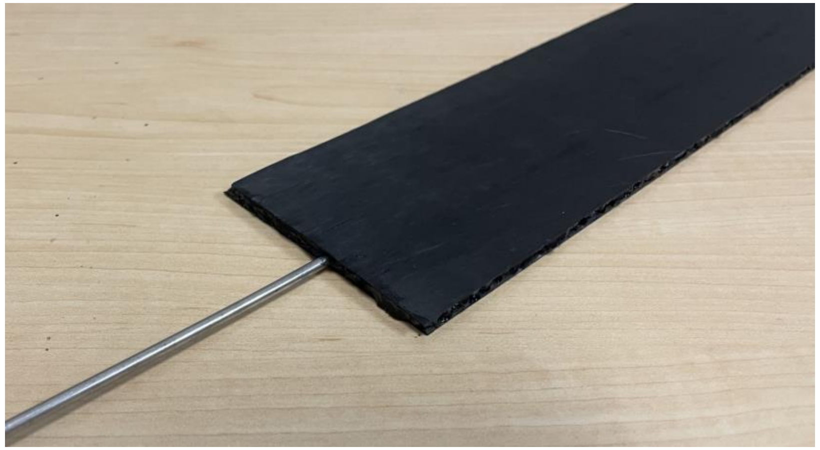
Join stave halves around coolant pipe

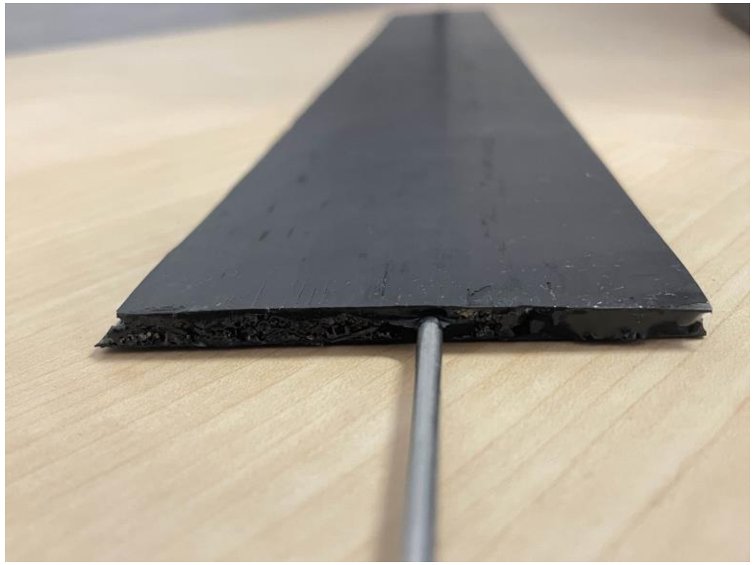
Stave Curing Process



Vacuum bag, cure at room temperature

Cured 590 mm stave

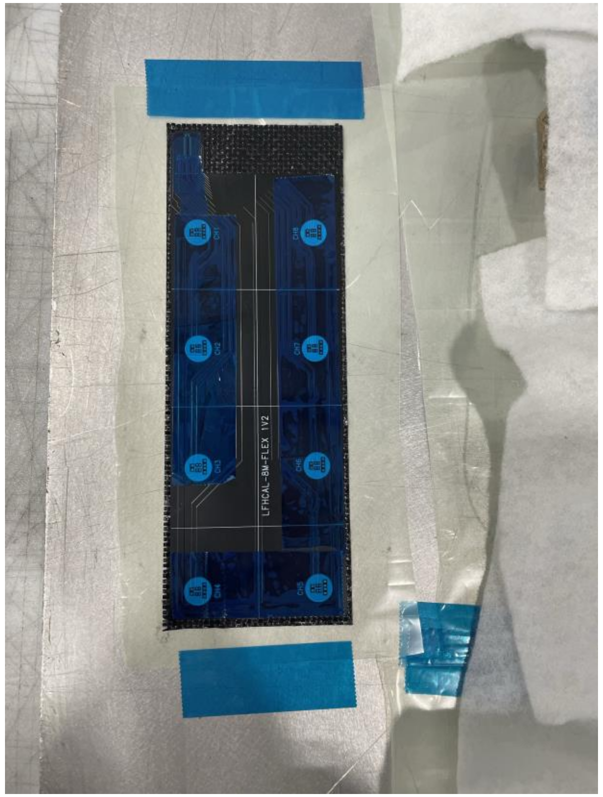




Oak Ridge National Lab PCB Co-Curing Test

ORNL flexible PCB

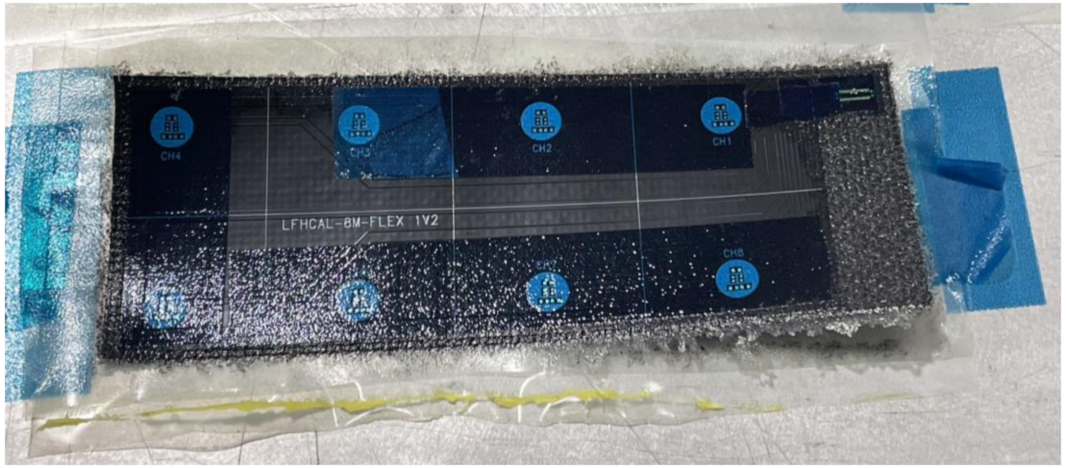
Co-cure test with 1 ply CF pre-preg

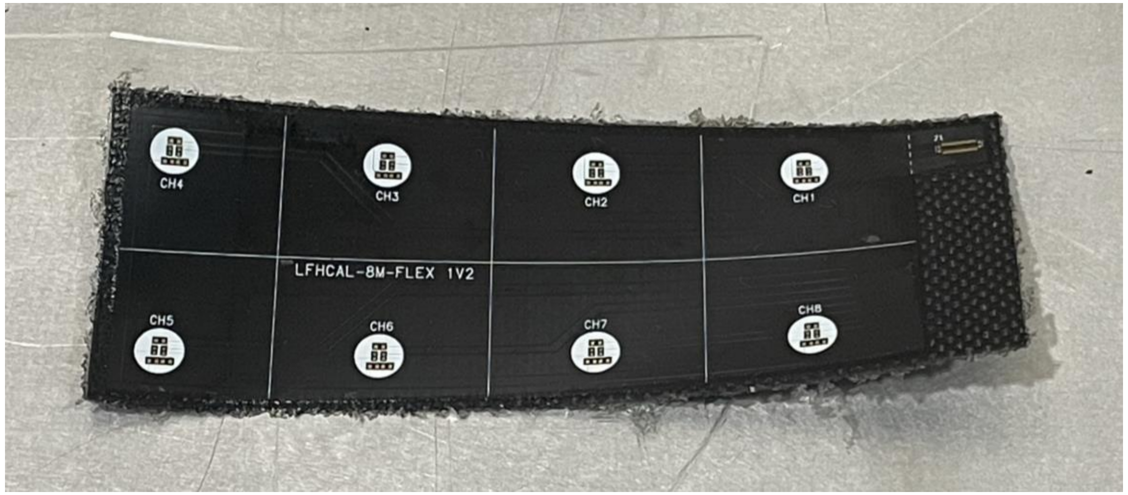


Mask contacts with release tape before curing in autoclave

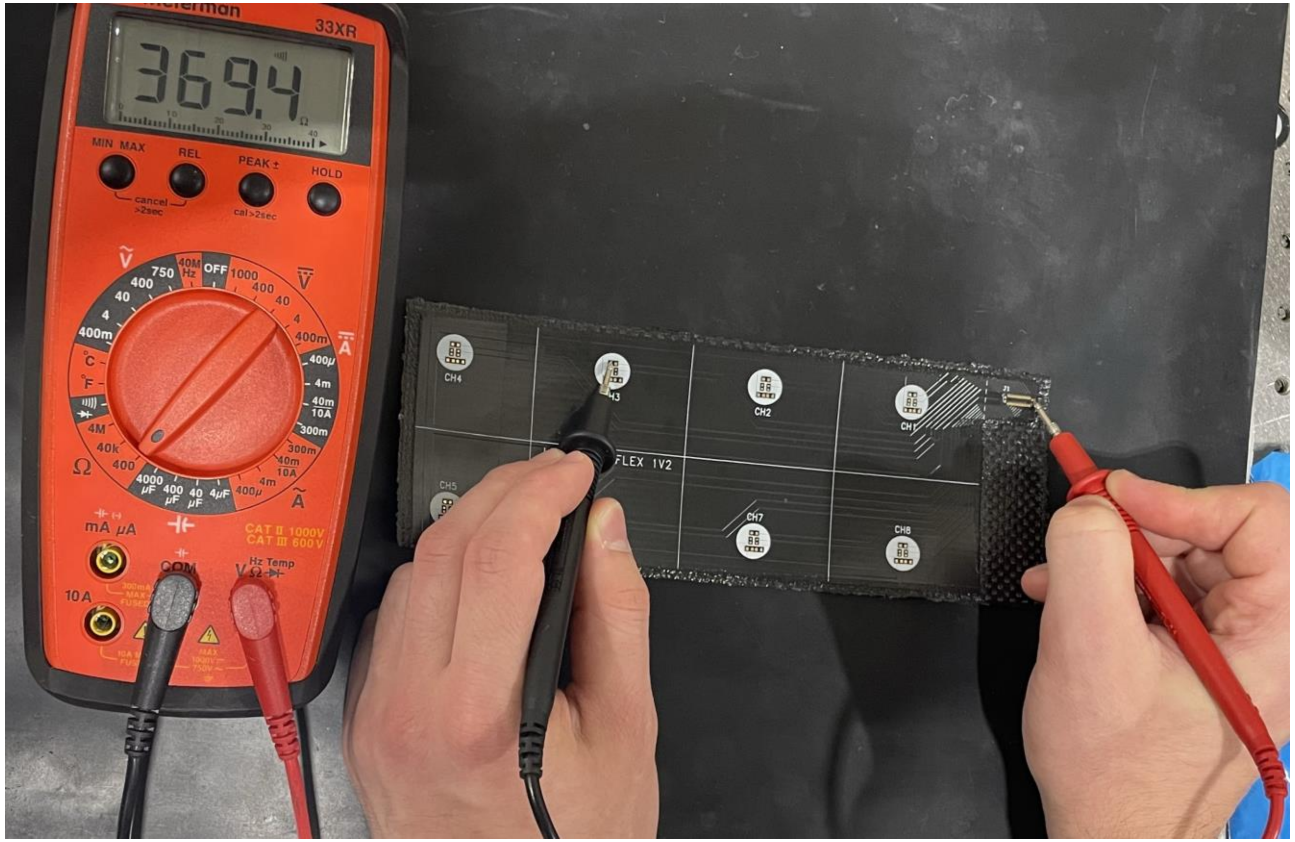
Oak Ridge National Lab PCB Co-Curing Test

Co-cured PCB





Asymmetrical layup (1 ply) causes expected warping



Continuity test successful for all channels post co-curing!

ORNL Flex & Interconnects

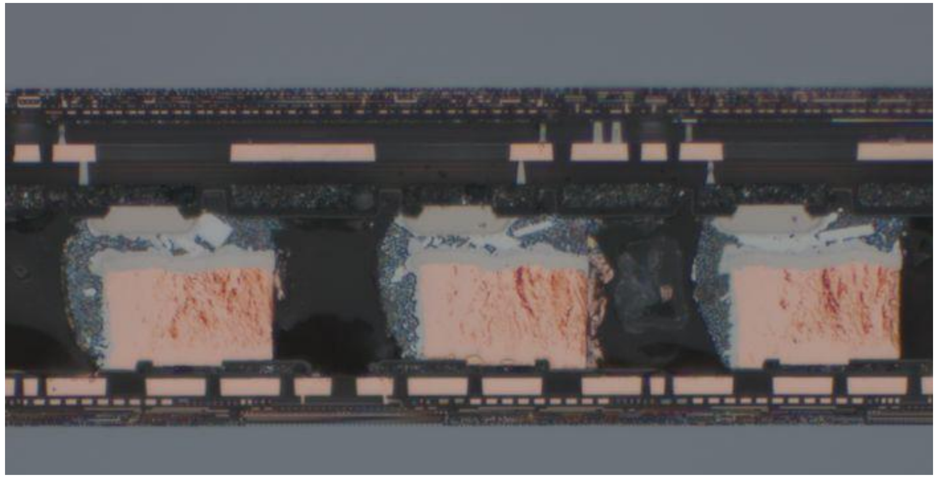
Oskar Hartbrich,
Mathieu Benoit et al (ORNL)

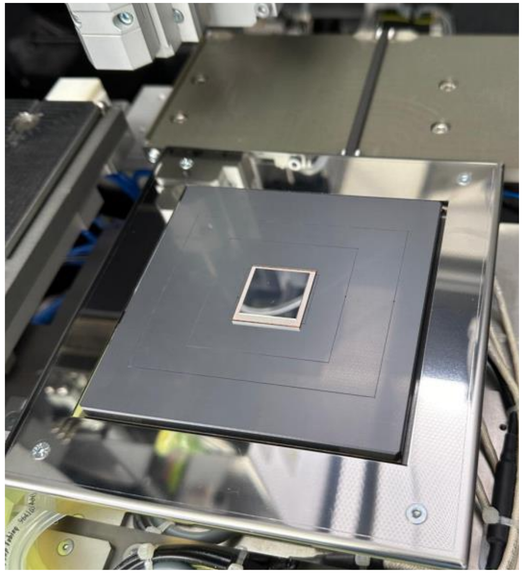
ORNL Barrel Flex PCB (FPC)

- We planned to design and build an FPC prototype to "remotize" an ETROC
  - It seems getting ETROC specs is already difficult
  - Due to delays in CMS-ETL NP project, ORNL does not currently have ETROCs and a readout system on site
- We planned to build another FPC prototype for the thermal module mockup test
  - Delayed from trying to find vendor that can provide peel off film for contact protection during co-curing
  - Can do it ourselves with laser cut kapton foils now – but now design might change?
- Have received FY24 money in June 24
- Have requested some money for FY25, but can largely work on carryover
  - Requested $20k for Hachyia-san at Nara WU for Japanese FPC production
  - Can also pay Japanese manufacturer directly

ORNL Flip-Chip Machine

- SET FC-150 on its way to ORNL
  - Final inspection at manufacturer two weeks ago
- Will be fully equipped for interconnect studies, TOF module productions
  - Have funding for materials and engineering in FY'24 budget
  - Requested some more in FY'25

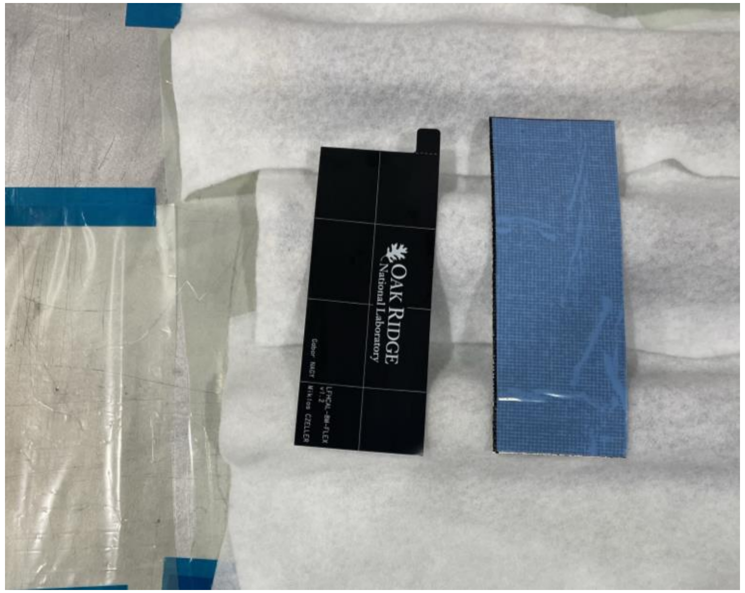


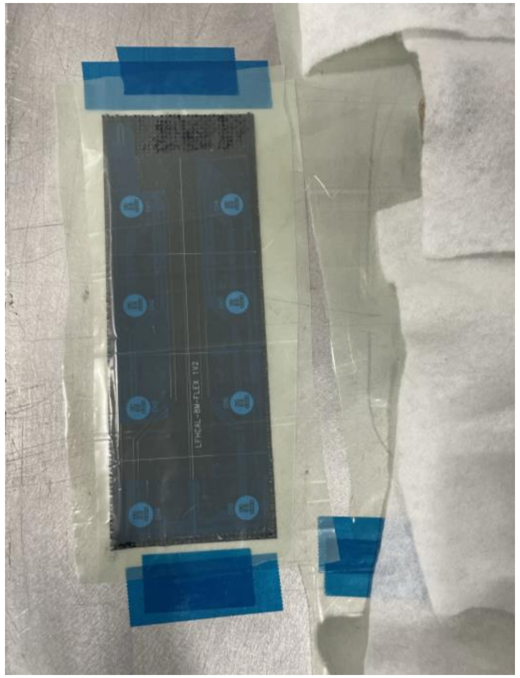


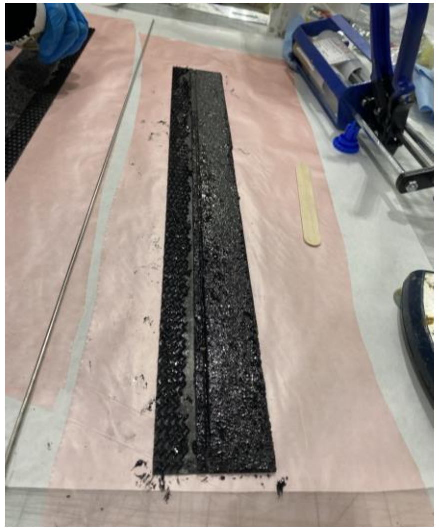
Summary

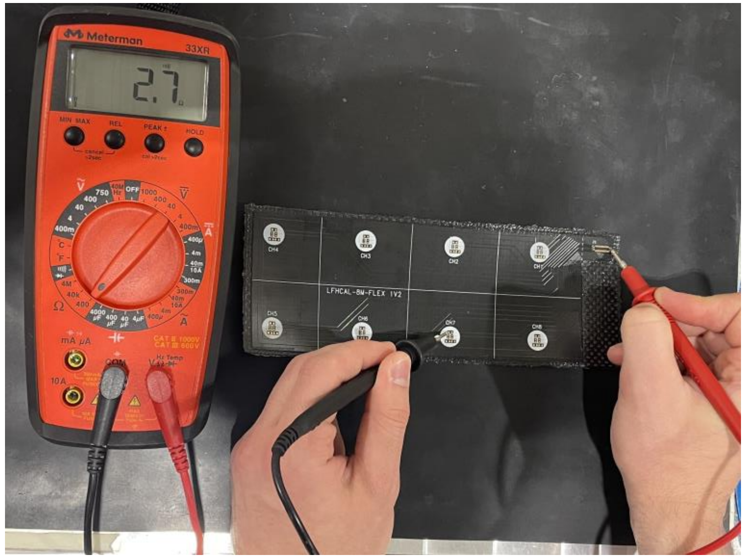
- Are double sided barrel staves better than single sided?
  - Needs more discussion with more experienced experts
- Purdue built mockup mini-staves
  - Extensive cooling simulations
  - Co-curing FPCs onto stave surface works well with test FPCs
- ORNL (basically) has flip-chip bonder on site now.

Backup Pictures









Additional slides

Expected Power from ASICs

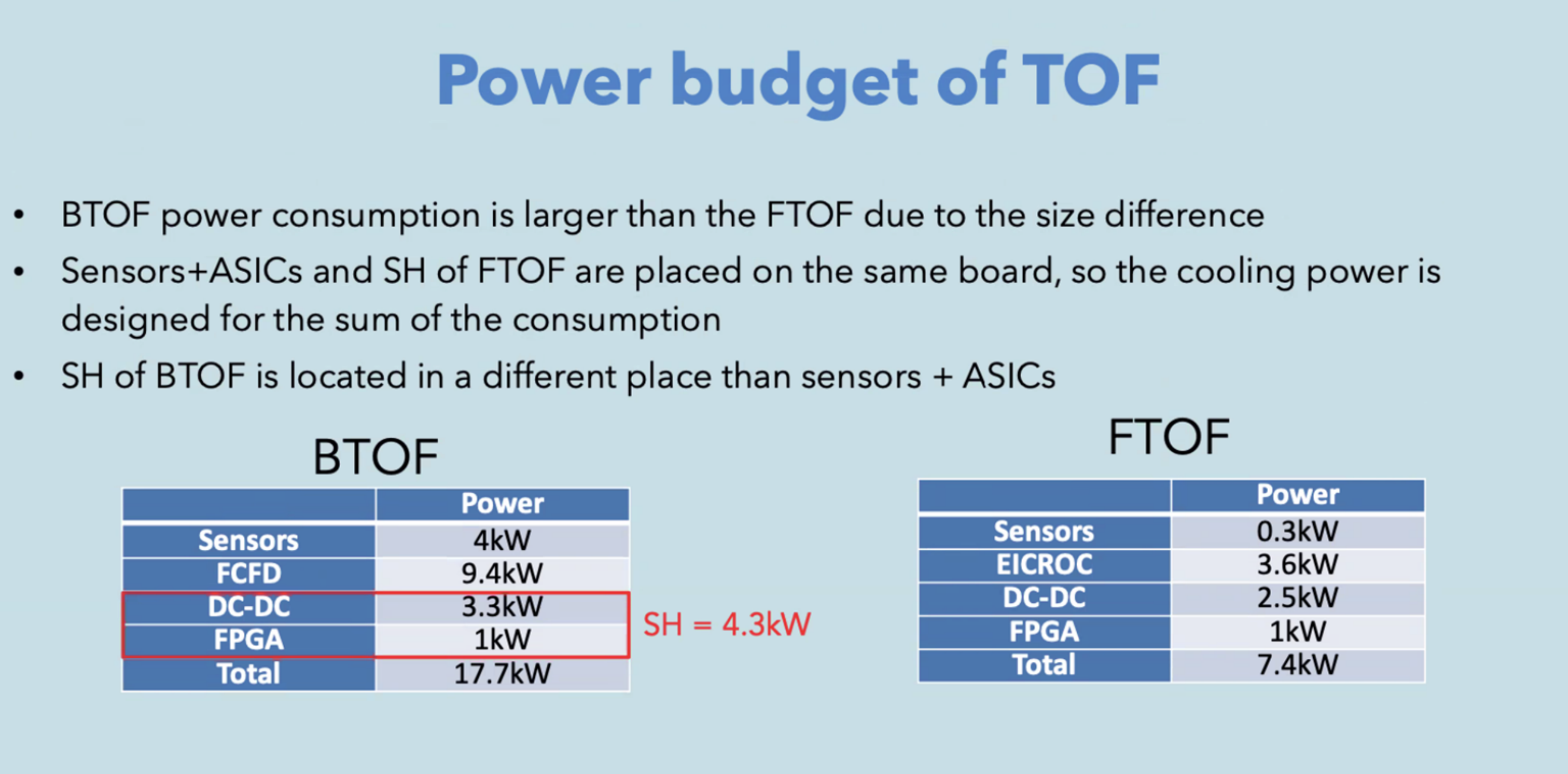
- Each readout hybrid will service 4 sensor segments
    - Each sensor segment will have 64 channels → 256 channels per readout hybrid / sensor
- Depending on the choice of ASIC, the power consumption may vary
    - Target was 1 mW/channel, but this may not be feasible
- As agreed during the collaboration meeting, we can assume 4 mW/channel
    - **1.024 W *per* readout hybrid or sensor**
    - **For thermal mechanical stave: 6 sensors/hybrids x 1.024 W = 6.144 W**
    - **For half-sized staves: 32 sensors/hybrids x 1.024 W = 32.77 W**
    - **For full-sized staves: 64 sensors/hybrids x 1.024 W = 65.54 W**

Sushrut

https://www.sciencedirect.com/science/article/pii/S0168900213009819?via%3Dihub

Expected power: service hybrid

Where did Satoshi get these numbers?



Power budget of TOF

- BTOF power consumption is larger than the FTOF due to the size difference
- Sensors+ASICs and SH of FTOF are placed on the same board, so the cooling power is designed for the sum of the consumption
- SH of BTOF is located in a different place than sensors + ASICs

BTOF

	Power
Sensors	4kW
FCFD	9.4kW
DC-DC	3.3kW
FPGA	1kW
Total	17.7kW

SH = 4.3kW

FTOF

	Power
Sensors	0.3kW
EICROC	3.6kW
DC-DC	2.5kW
FPGA	1kW
Total	7.4kW