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U.S. DEPARTMENT OF ENERGY
Office of Science

ePIC SVT Air Cooling

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March 1, 2024 - UC EIC Consortium Collaboration Meeting

Workforce

This is a team effort 😊

Graduate Students

- Mathias Labonte (UCD)
- Andrew Liggett (UCD)
- Ziyuan Zeng (UCD)

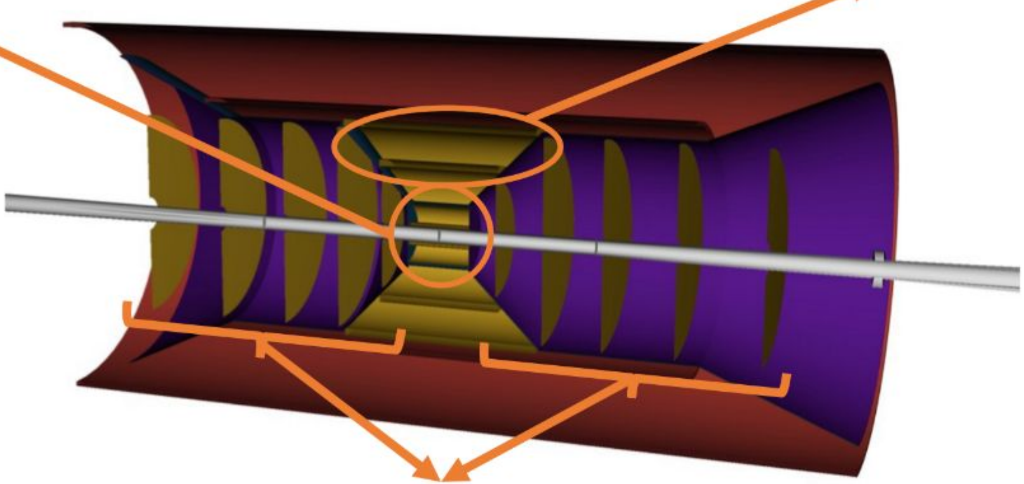
Undergraduate Students

- Elijah Dolz (Berkeley City College)
- Jonathon Tordilla (UCB)
- Malika Golshan (UCB, *graduated*)

The ePIC Silicon Vertex Tracker

Inner Barrel (IB)
- 2 curved vertex layers
- 1 curved dual purpose layer

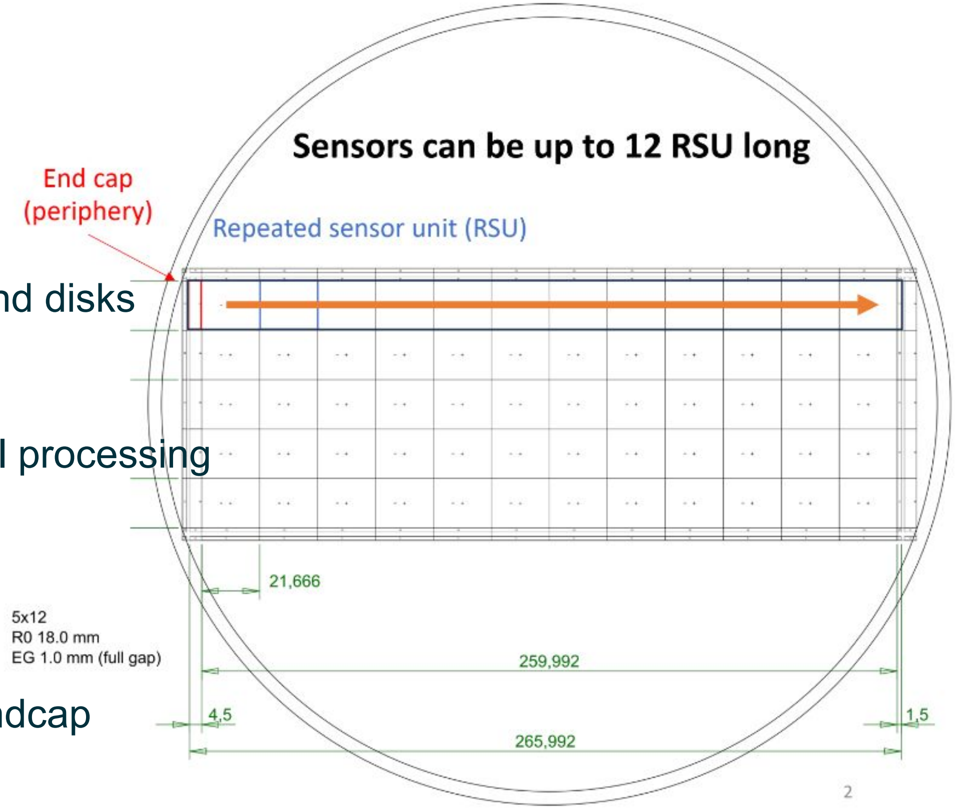
Outer Barrel (OB)
- 1 stave-based sagitta layer
- 1 stave-based outer layer



Electron/Hadron Endcaps (EE/HE)
- 5 discs on either side of IP

A few notes on terminology

- ITS3
  - Silicon sensor design used in ALICE
- LAS
  - Large Area Sensor for ePIC staves and disks
- Endcap
  - High power region of sensor
  - Used for power distribution and signal processing
- RSU
  - Repeated Sensor Unit
  - Sensitive area of detector
- Matrix
  - Multiple RSUs attached to a single endcap



Power Density

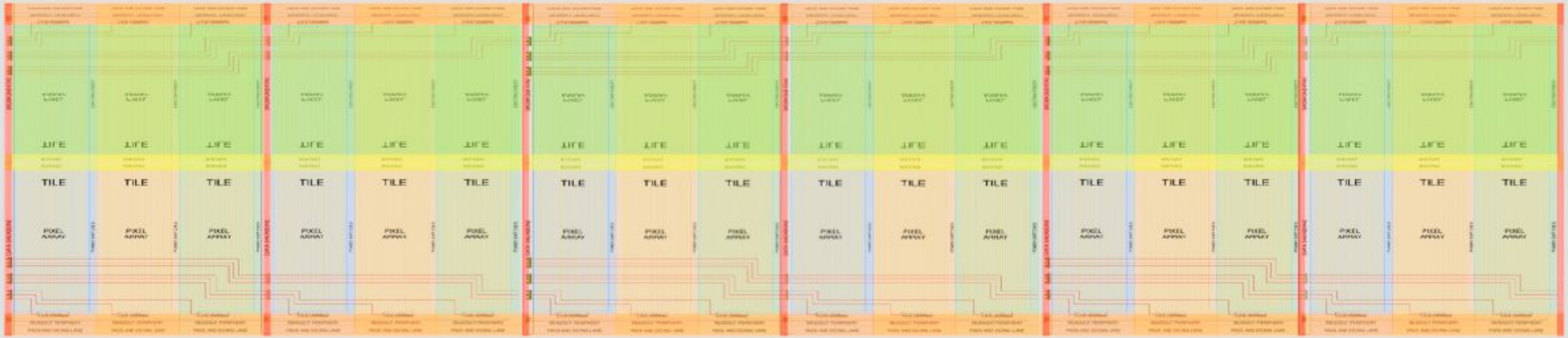
From EP R&D WP 1.2 General Reporting Meeting

*Slide from N. Apadula

	Power density [mW cm^{-2}]		
	Expected 25 °C	Max 25 °C	Max 45 °C
Left End Cap (LEC)		791	
Active area (RSU)	28	44	[illegible]
Pixel matrix	15	32	51
Biasing	168	168	168
Readout peripheries	432	457	496
Data backbone	719	719	719

Table 3.10: Estimates of average power dissipation per unit area over the main blocks composing the sensor.

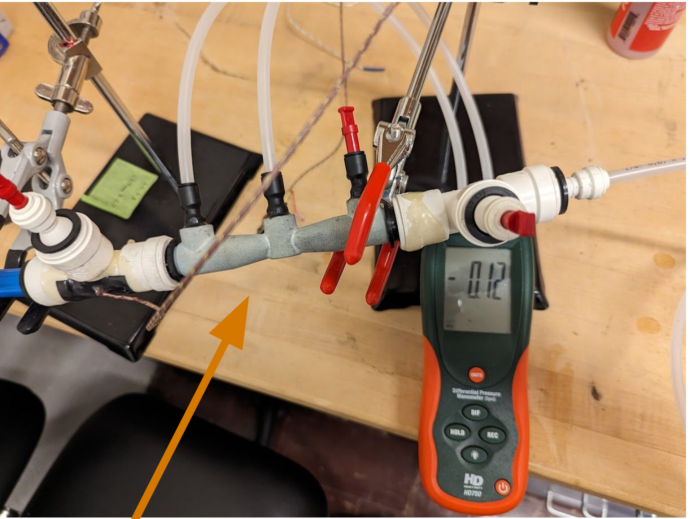
LEC (aka periphery) ~0.8 W/cm^2
Matrix (total) ~20-40 mW/cm^2



Key points for cooling the SVT

- While the sensor design is based on ALICE ITS3, the cooling system used in ALICE is too much material for ePIC
- Total Material Budget - X/X_0 < ~5%
  - Water cooling and associated services are readily available due to cooling other detectors, but water is high material budget
- Current estimate is ~1.6-2 W of power to each sensor
- Need to dissipate ~6.4-8 kW in total
- Aim is to limit temperature increase of sensors to < 15-20 *C
  - ΔT = Power on temperature - Power off temperature

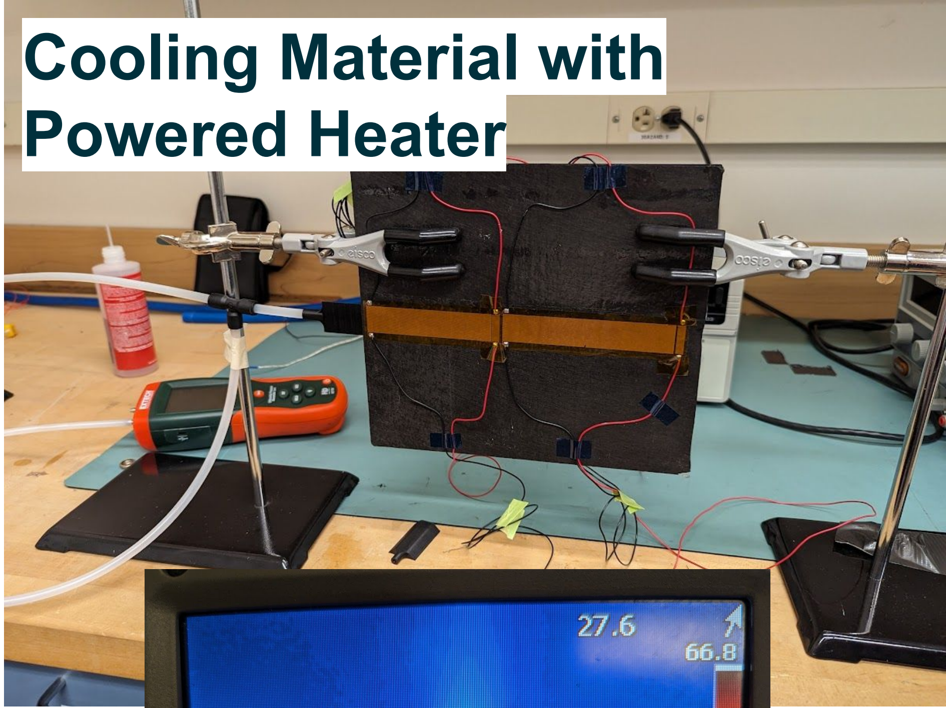
Test Setup

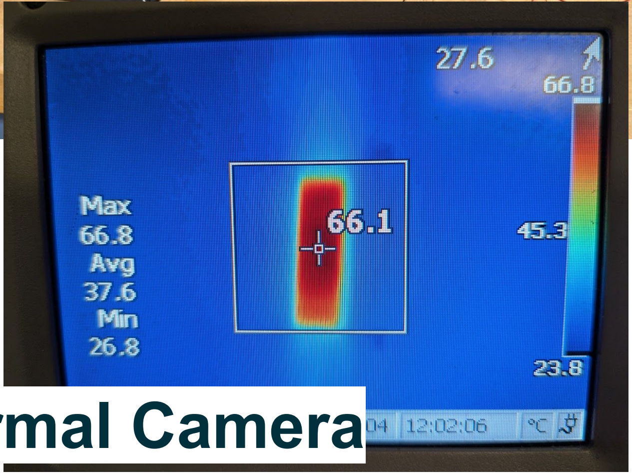


Venturi for Air Flow Rate

Air

Cooling Material with Powered Heater



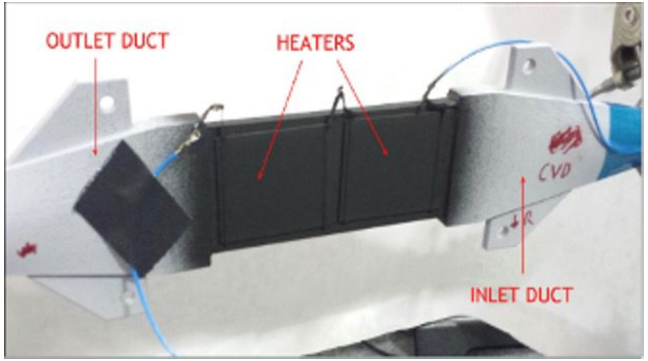


Thermal Camera

Test materials for simulating heat generated

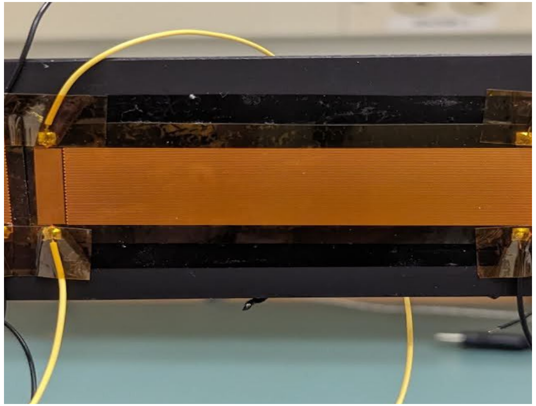
Ceramic Heaters

- High heat output - good for stress testing
- Substantially higher heat output than real sensor
- No localized heating to simulate power regions



Copper Trace Heaters

- More realistic power densities
- Simulates both Endcap and pixel matrix regions
- Fragile



Cooling Materials

Reticulated Vitreous Carbon

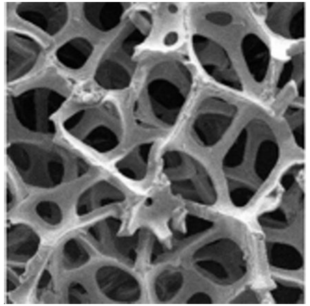
- Insulating carbon foam
- Lower material budget than CVD
- Lower cooling power, but possibly feasible depending on real power density

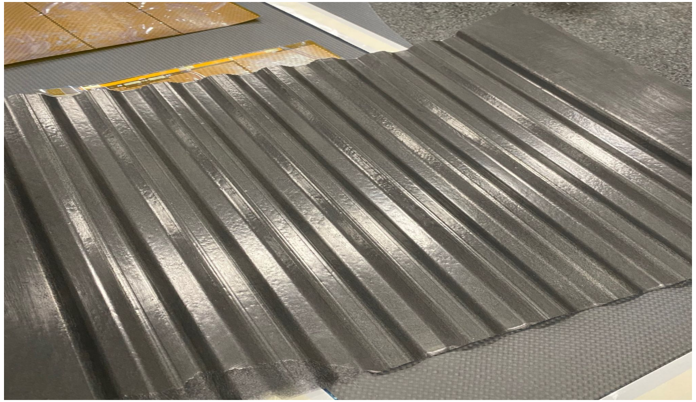
Chemical Vapor Deposition

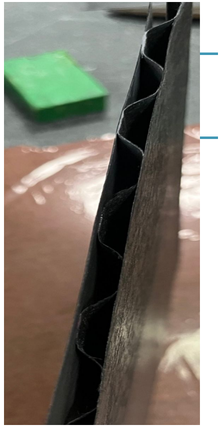
- Conducting carbon foam
- Higher material budget than RVC
- Clearly works for all realistic power densities

Corrugated Carbon Fiber

- Carbon fiber that is bent to create corrugation channels (like cardboard) for directing air
- Even lower material budget
- Doesn’t seem to work well on its own
  - Air flow is approximately laminar, reducing cooling power
  - Need to induce turbulence or increase contact area
  - Testing with foam added for heat conduction and turbulence



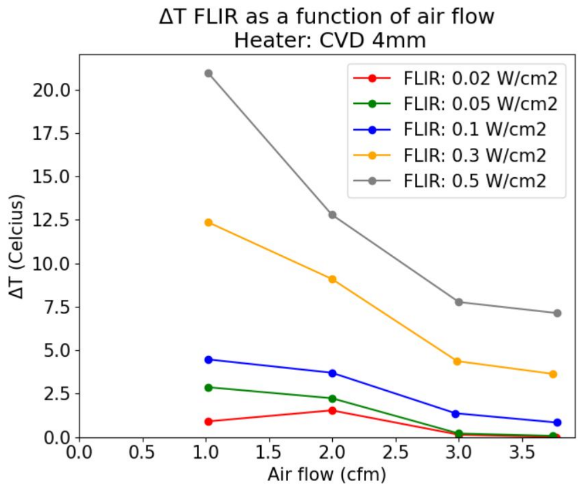


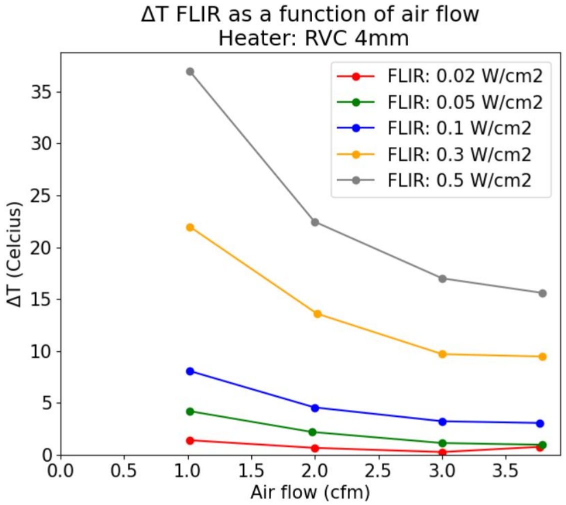


What have we learned so far?

CVD is better than RVC

- Expected, but good to quantify
- Data to right is from summer 2023 with ceramic heaters
- It is important to note that even with realistic power densities, the *total* power is substantially higher than realistic

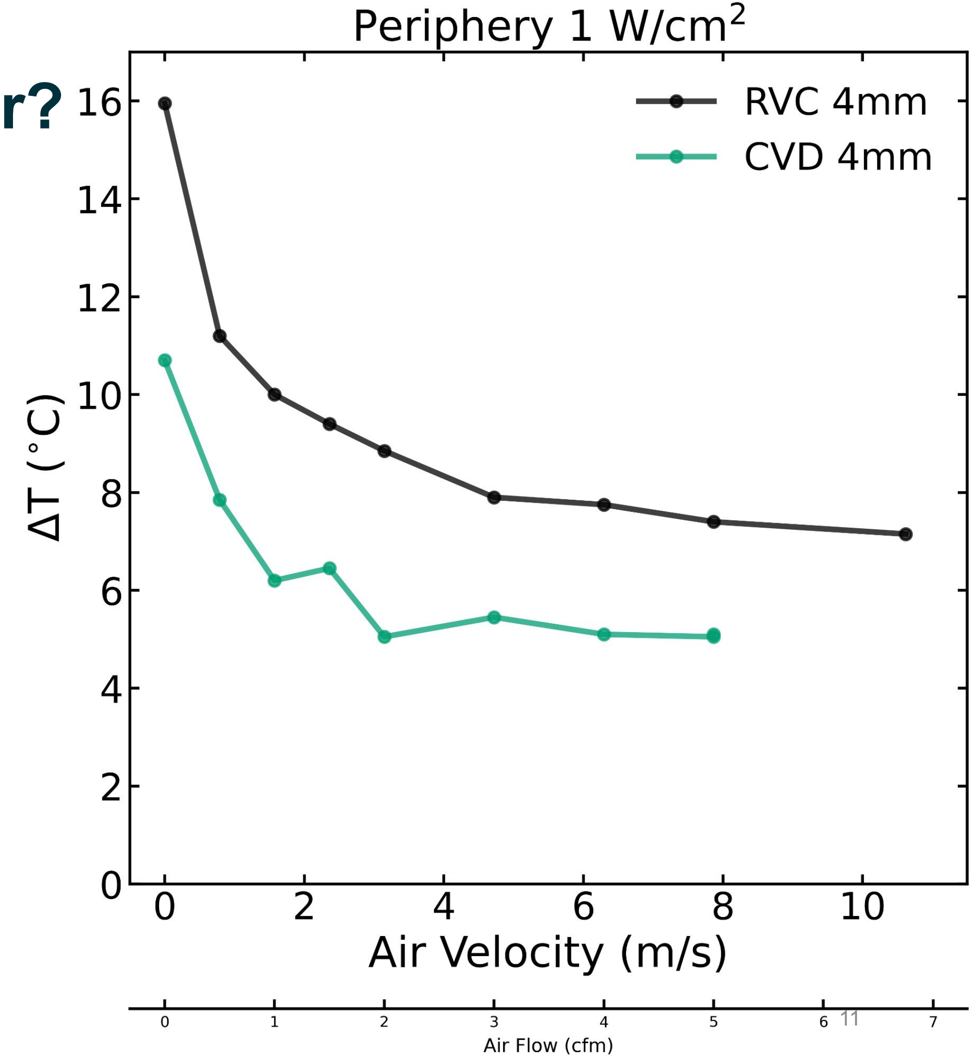




What have we learned so far?

CVD is better than RVC

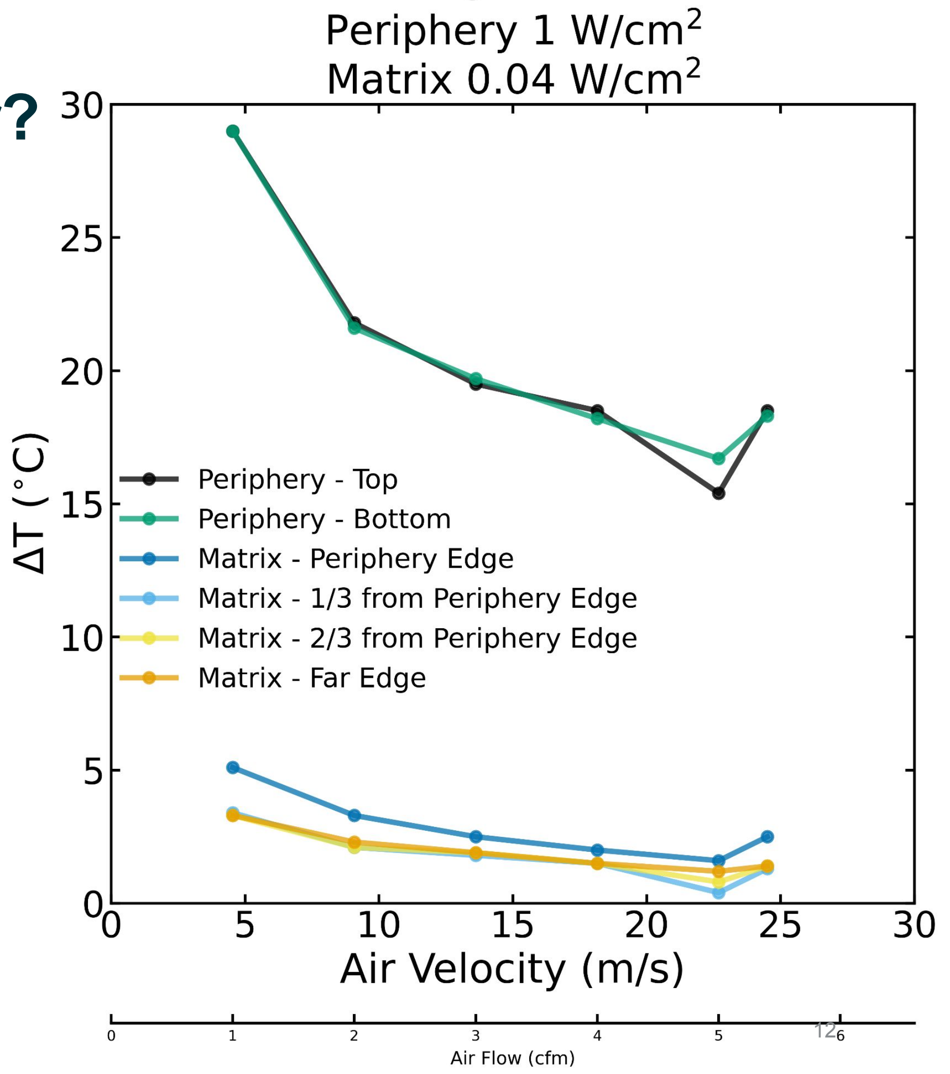
- Data on right uses realistic copper trace heater
- Due to spacing limitations (heater is larger than stave), only the periphery (high power density region) was used
- Shows that CVD is viable, even with *no air flowing*
- RVC becomes viable with only modest air flow
- Suggests that modest air flow quickly reaches a point of diminishing return



What have we learned so far?

Corrugated Carbon Fiber alone is insufficient

- When using the corrugated carbon fiber
  - The matrix is ok, due to low power
  - No air speed cools the periphery sufficiently
- Two leading theories as to why
  - The air flow is approximately laminar, so the heat isn't "mixed"
  - With only the fiber surface, there is comparably little contact with the air

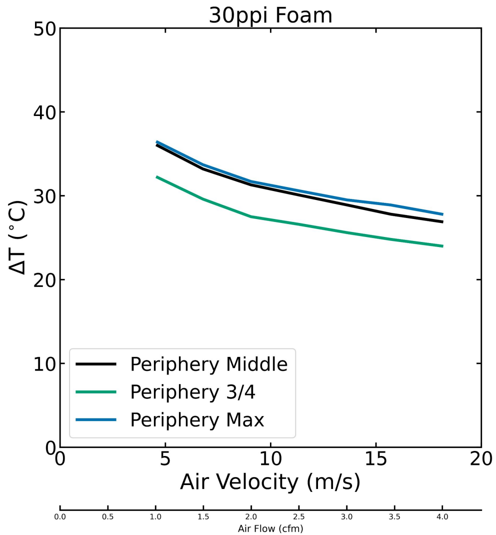


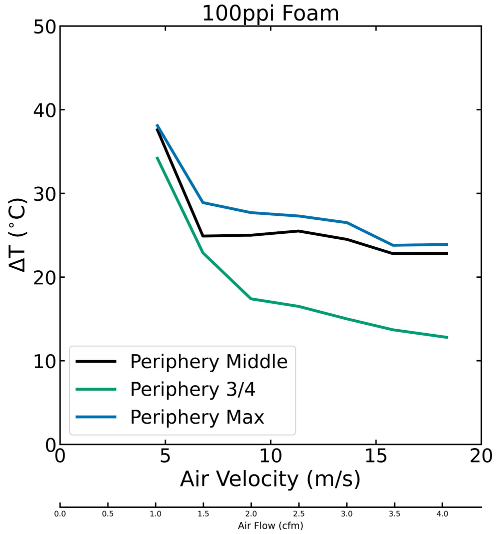
What have we learned so far?

Corrugated Carbon Fiber with a small foam piece is insufficient

- A small piece of RVC foam was placed* beneath the periphery of the heater on the corrugated carbon fiber
  - To create turbulence
  - To allow for heat to be more readily pulled away
- A *slight* improvement is seen with 100ppi foam, but no improvement is seen with 30ppi foam
  - Neither case allows for sufficient cooling

*squeezed into the channel

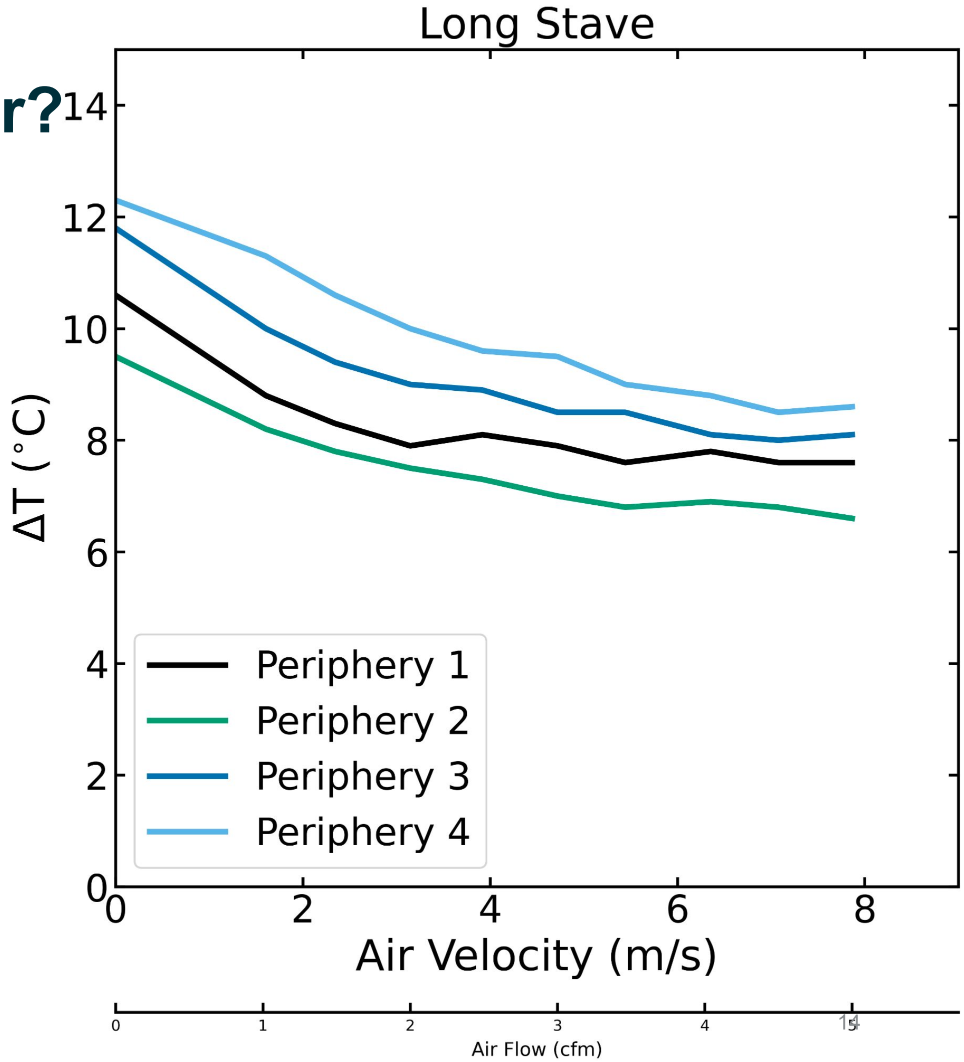




What have we learned so far?

CVD likely works for several heaters

- A long 4mm CVD stave has 4 copper trace heaters attached
  - In this plot, only the periphery regions are heated
  - The matrix region will add about ~50% more power
  - The matrix region has been easier to cool due to the power being spread out (still need to check, of course)



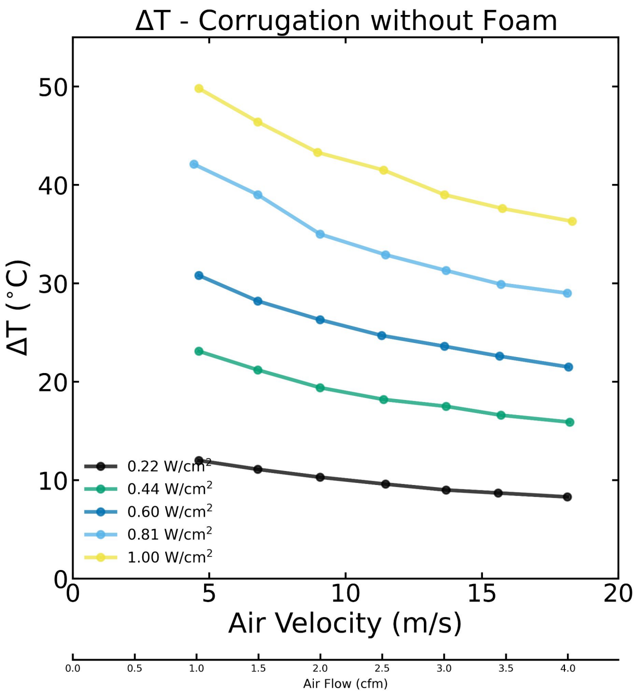
A discussion of the power densities

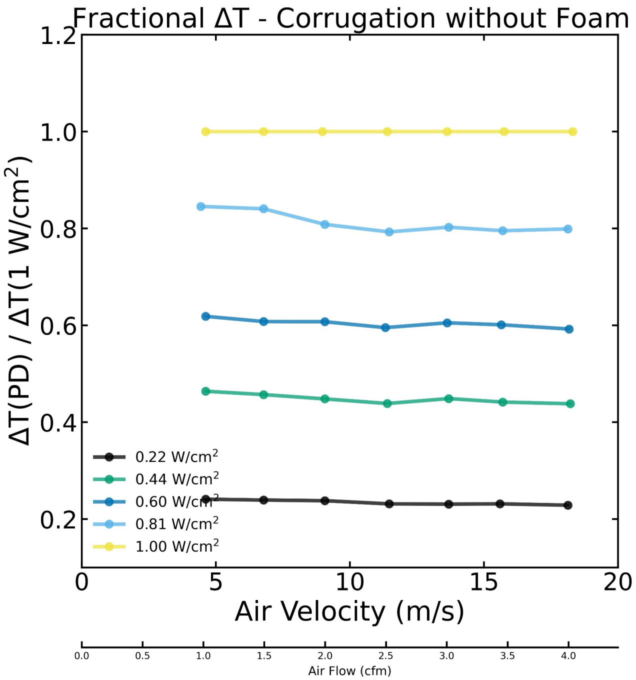
- All plots shown so far have used a nominal 1 W/cm2 for the endcap and 40 mW/cm2 for the matrix
- We have recently been informed that 0.7-0.8 W/cm2 is a more realistic number for the endcap
- It is good that we have tests at higher than nominal, but we also should have tests actually *at* nominal

- As designed for ITS3, each sensor endcap has 6 high bandwidth data lines, the dominant use of power
- ePIC does not need this much throughput
- The inner barrel will use this as designed
- There has been a suggestion that the endcap could possibly be redesigned for the staves and disks, *if we can show that it is worth it*
  - Estimates are that the endcap power density can be roughly halved

Power Density Tests

Corrugated Fiber without Foam

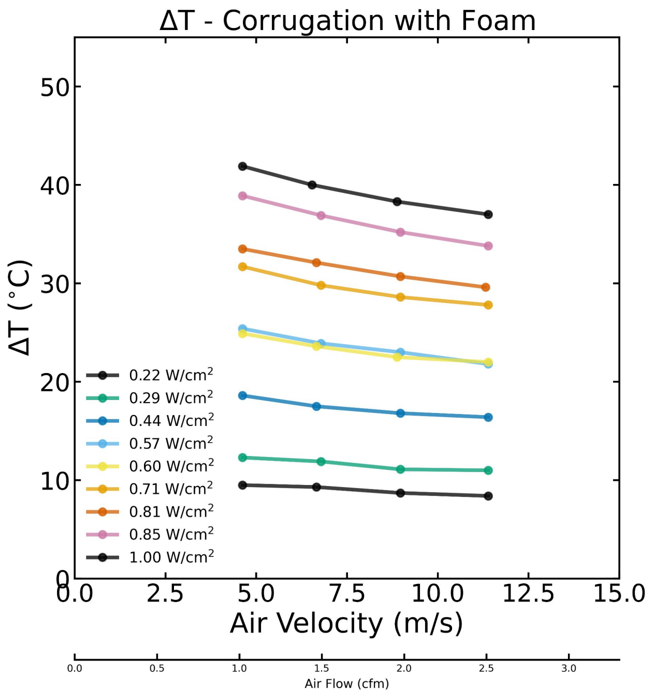


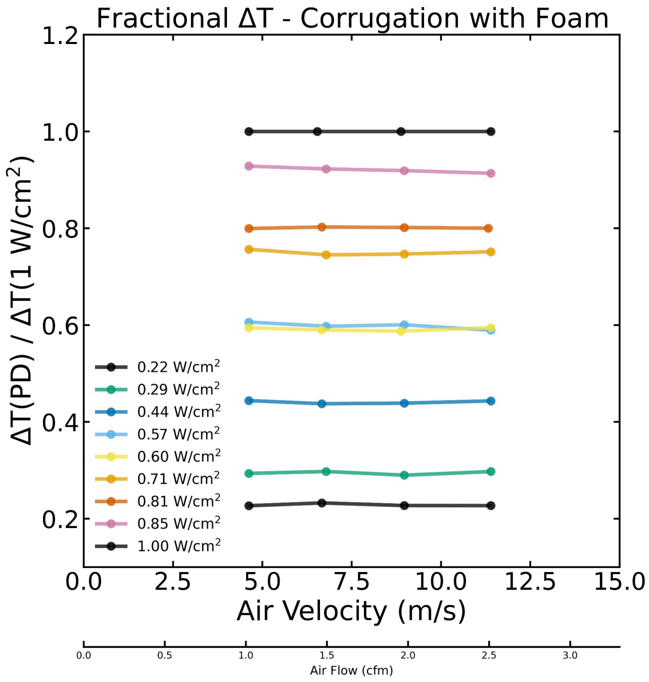


Delta T scales well with power density!

Power Density Tests

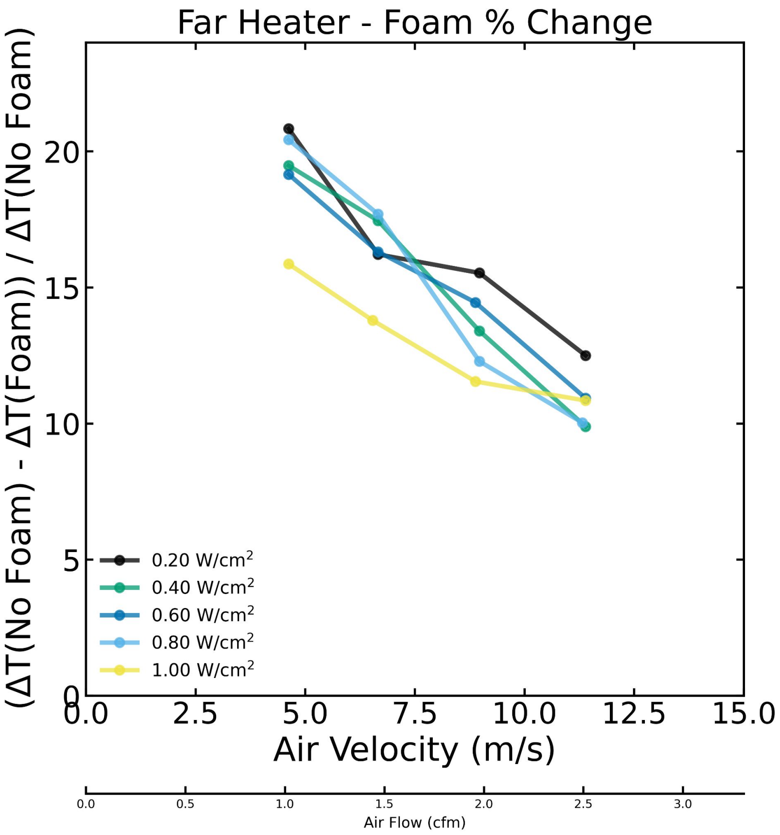
Corrugated Fiber with Foam (30ppi RVC Foam glued with thermal epoxy)





Delta T scales well with power density!

How much does the foam help?



- Biggest improvements are with low air speed, generally where we won't run it
- We expect to run around ~10 m/s
- Improvement drops with increased air speed
  - ~12% improvement at 10 m/s

What comes next?

- Test cooling capabilities for with multiple sensors
- Test with silicon
- Test with smaller corrugations (currently being manufactured)
- Developing a pt100 (platinum resistance temperature detector) based measurement system for more accurate and reliable measurements
  - Raspberry Pi based readout
  - Had previously been worked on by Malika Golshan (UCB), but we ran into difficulties developing a repeatable sensor mounting workflow
    - Other measurement timelines necessitated putting this work on the backburner, but it is now moving up the priority list

Thank You