SVT Cooling

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ePIC Collaboration Meeting

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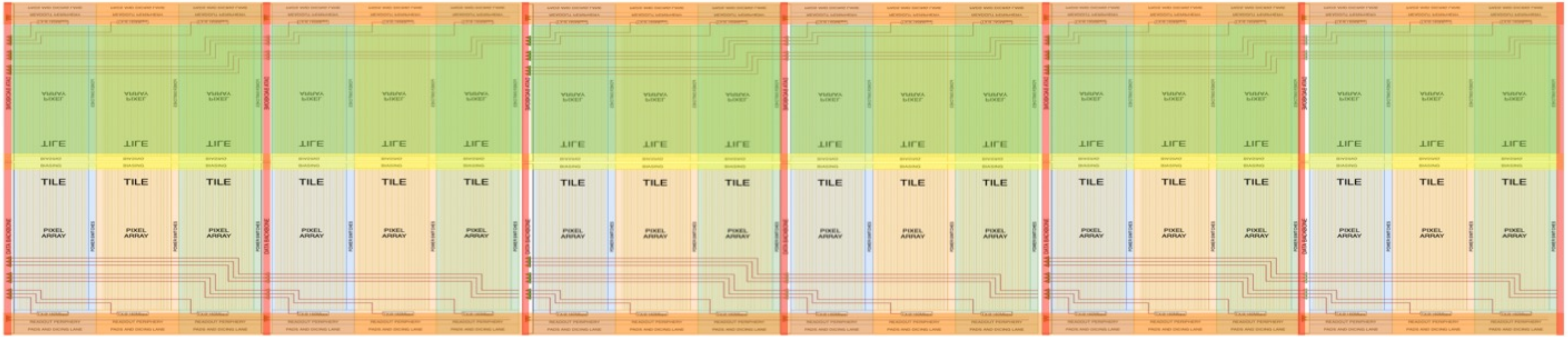
Power Density

From EP R&D WP 1.2 General Reporting Meeting

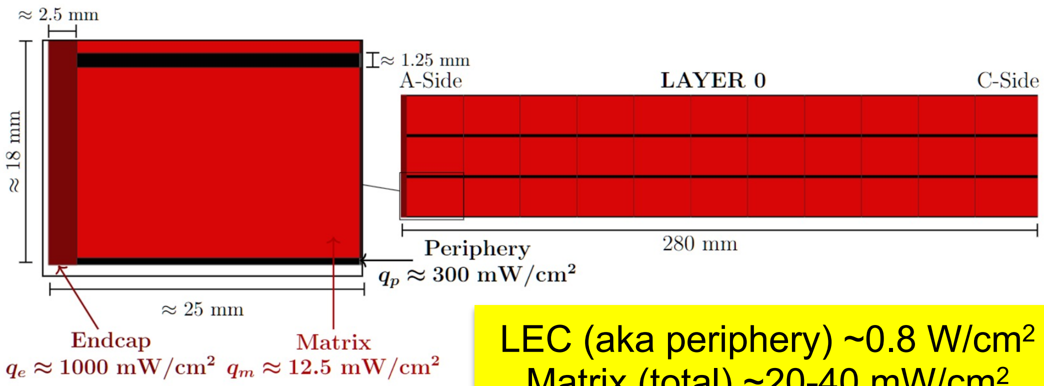
	Power density [mW cm^{-2}]		
	Expected 25 °C	Max 25 °C	Max 45 °C
Left End Cap (LEC)		791	
Active area (RSU)	28	44	[illegible]
Pixel matrix	15	32	51
Biasing	168	168	168
Readout peripheries	432	457	496
Data backbone	719	719	719

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



Sensor heat sources



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

Sensor (ITS3 wafer-scale, EIC LAS)

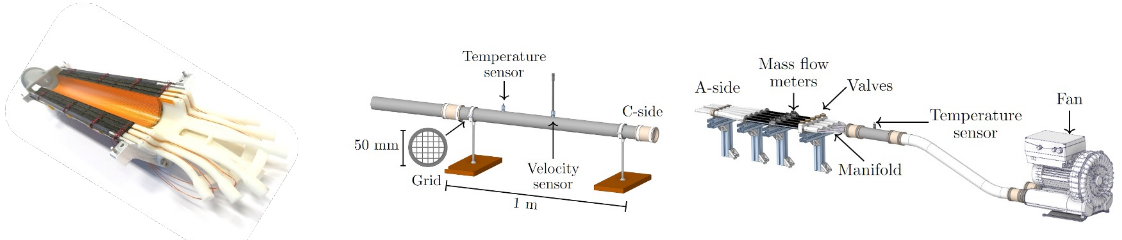
- Matrix → effective zone of particle detection → Lowest heat dissipation
- Endcap → control/configuration/signal/power → Highest heat dissipation
- Peripheries → Power transfer along stitching units → Intermediate heat dissipation
  - ***New information*** → still be worked into current/ongoing cooling tests

ePIC SVT DSC (***initial***) estimate: ~1 W per Endcap → ~1 W per Sensor

New estimate: Left endcap (1W) + matrix (6 RSU @ 25-40 mW/cm^2) = **1.6 – 2 W per EIC LAS**

Total sensor power dissipation estimate: 6.4 kW – 8 kW (up from 4 kW)

SVT IB air cooling



(a) Prototype **(b)** Inlet of the wind tunnel **(c)** Outlet of the wind tunnel

ALICE ITS3 cooling test setup

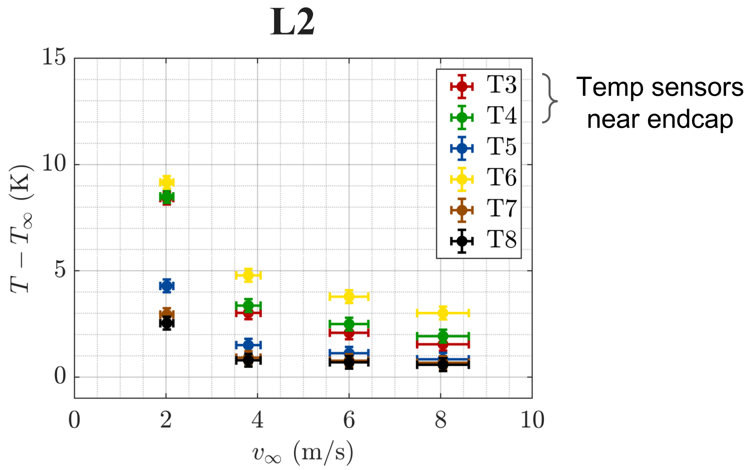
Starting point: Air cooling with carbon foam

Build off of work from ALICE ITS3

ALICE ITS3 has shown that air cooling is sufficient to keep ΔT < 10° C

ePIC changes:

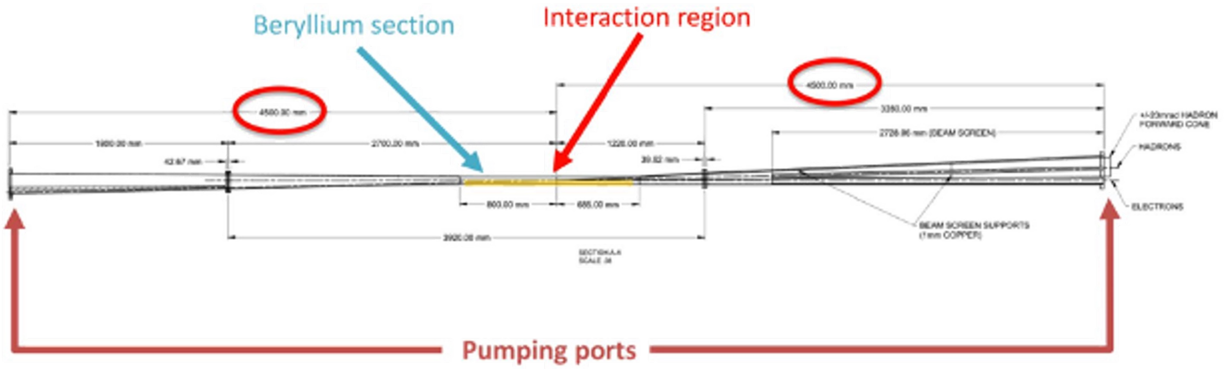
- Adapt to larger radii
- Adapt how air is routed in and out, i.e. suitable redesign of inlets and outlets.

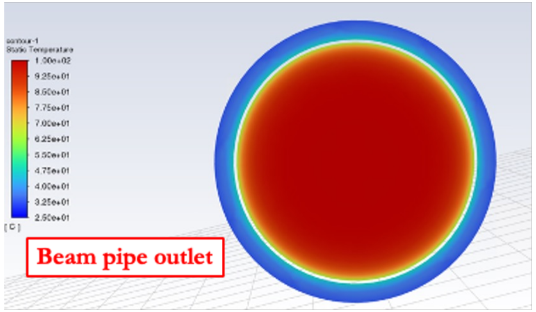


Measurements: endcap = 1 W/cm², matrix = 50 mW/cm²

[ALICE ITS3 presentation at Forum on Tracking Detector Mechanics 2023](#)

SVT IB air cooling: beam pipe bake-out





Previous ANSYS studies at JLab and LBNL: presentations on 6/6/22, 2/28/23

Bench setup at JLab verifies results

Plan to pick this up again with a student @ LBNL this year

Cooling needs for bake-out?

- Need to determine/refine temperature envelopes for materials
  - ALPIDE (ITS2) can **work reliably at 40 C** (did not study further)
  - Initial estimates from climate chamber studies **up to 40 C** at LBNL show the 65 nm DPTS performs reliably (work done by Barak Schmookler & Jonathan Witte)
- ITS3 has done an initial thermoelastic study
  - 16 cycles between 10 – 48 C on ITS3 layer 2 (includes glue, carbon foam, silicon) → no failures
- Similar thermoelastic study will be performed for ePIC SVT IB
  - Larger radii → more joints and failure points to consider
  - Need a cycle test, a longevity test, and a bake-it-til-you-break-it test

SVT R&D: internal air cooling

We have investigated two foam types: Reticulated Vitreous Carbon (RVC) and Chemical Vapor Deposition (CVD)

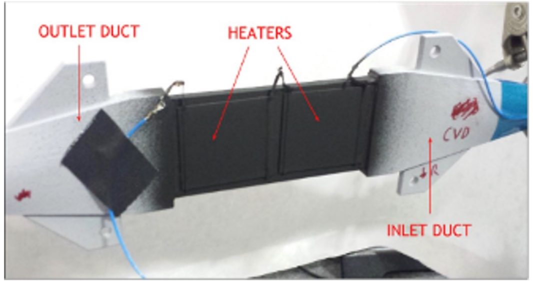
- RVC → insulating, lower X/X_0
- CVD → conducting, higher X/X_0

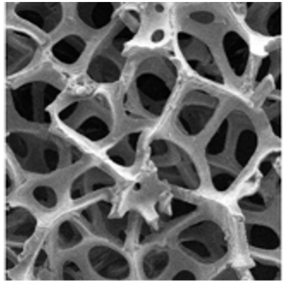
CVD maintains ΔT < 10° C for all tested power densities.

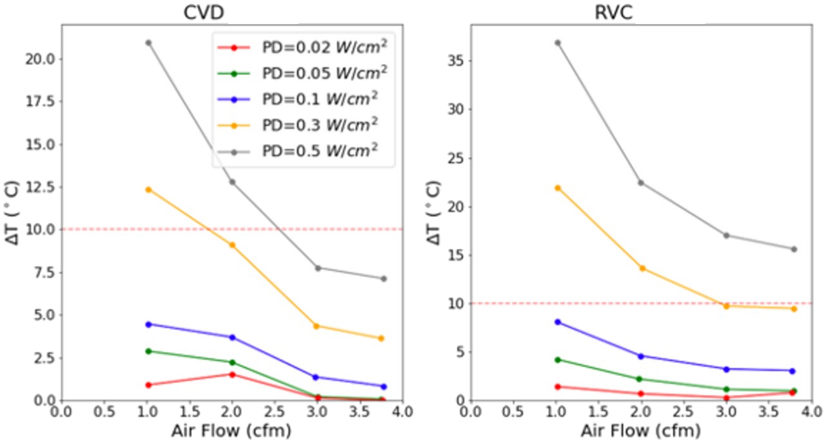
- RVC reasonable

Internal air cooling is viable

- Dependent on mechanical structure → needs further testing/modeling



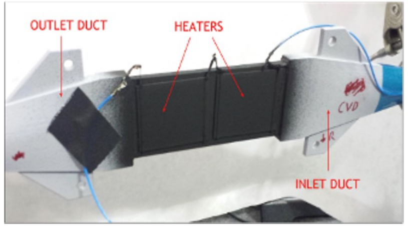




Aiming for ΔT < 10° C

SVT specifics

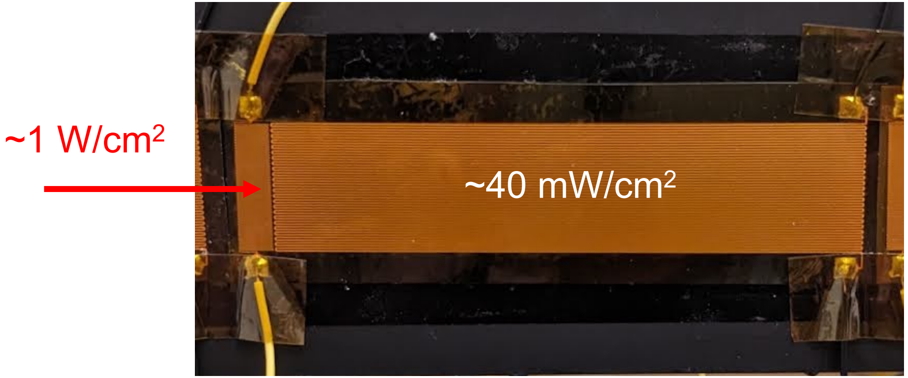
Thermal tests done by Tyler Hague & students

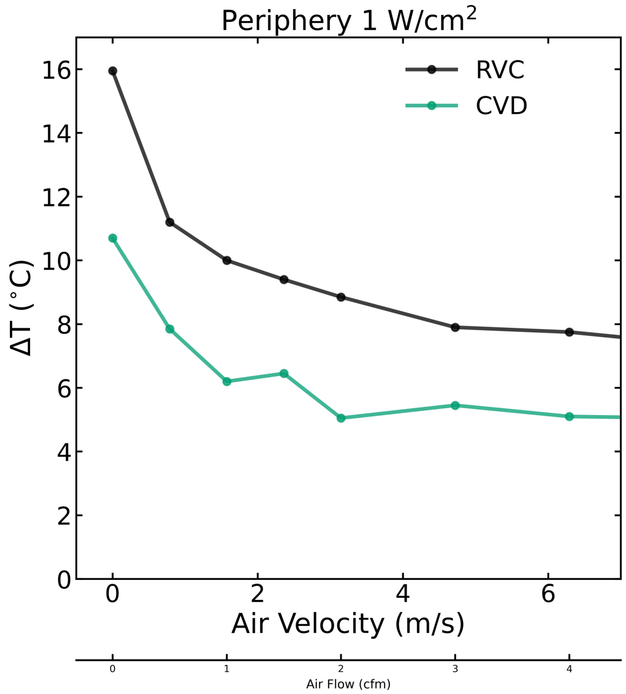


SVT specific heater prototypes, two power zones

Tested just LEC (periphery) on both CVD & RVC

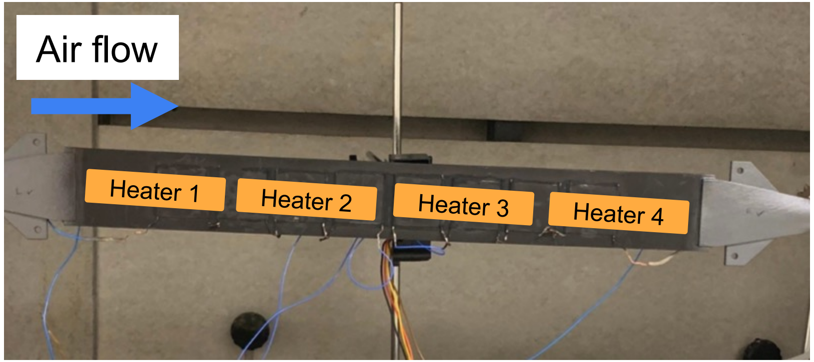
ΔT reasonable even with NO air flow → lots of foam surface area, using boron-nitride in glue for enhanced thermal conductivity

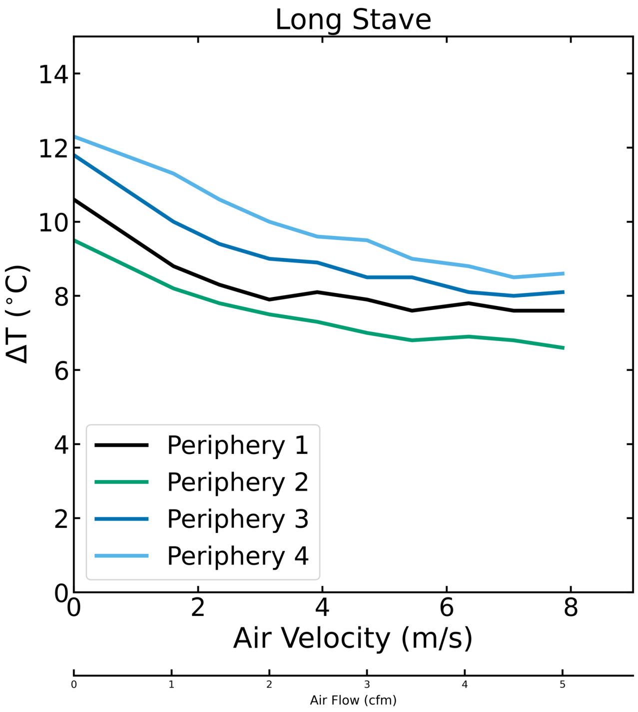




*Air velocity calculated at duct

Carbon foam cooling over 0.5 m

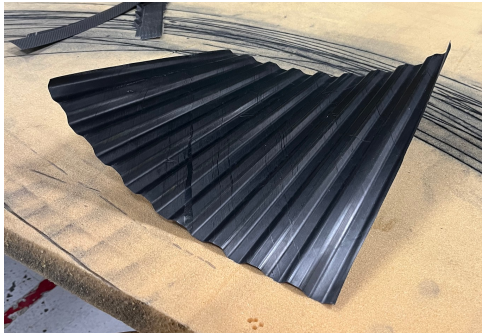




*Air velocity calculated at duct

- CVD 6mm thickness
- Tested 4 LEC (periphery)
- Temperature increases farther away from air inlet
  - Caveat: powered in parallel and so could have slightly difference power densities
- ΔT still reasonable with NO air flow

Towards a corrugated test piece

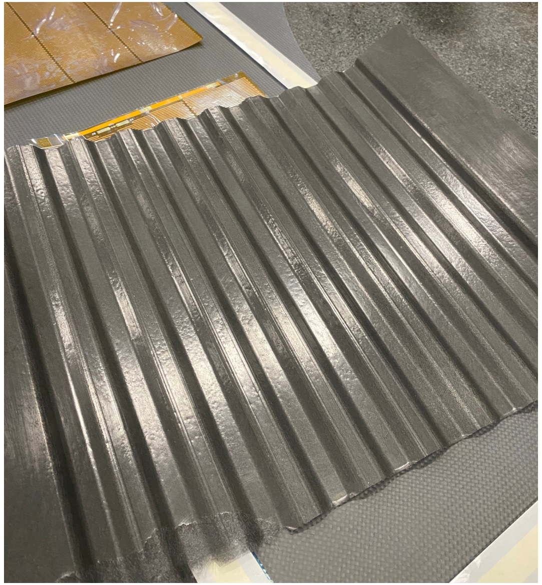


Many iterations over the past few months

- 45 gsm uni-directional (-45, 0, 45) → twisted

- 34 gsm veil with varied resin layers
  - Opted for 2 layers of veil + 5 layers resin

- Ongoing: wet layup with epoxy resin



Corrugated prototype test pieces

Each piece → 2 layers 34 gsm veil + 5 layers resin

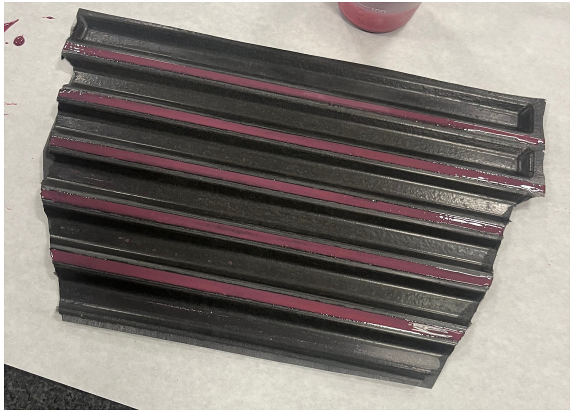
Face sheets glued with 9309 adhesive in 5 mm strips

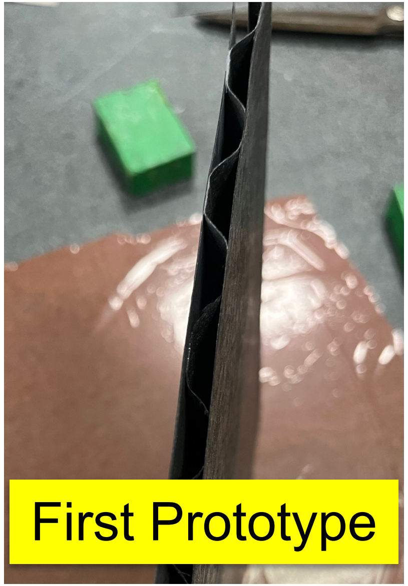
Final size of prototype test piece = 22.4 cm x 20.2 cm

Final weight of prototype test piece = 22.5 g

Density = 497 gsm → ~ 0.12% X/X0

Silicon ~0.05% X/X0, adhesive 0.01-0.02% X/X0



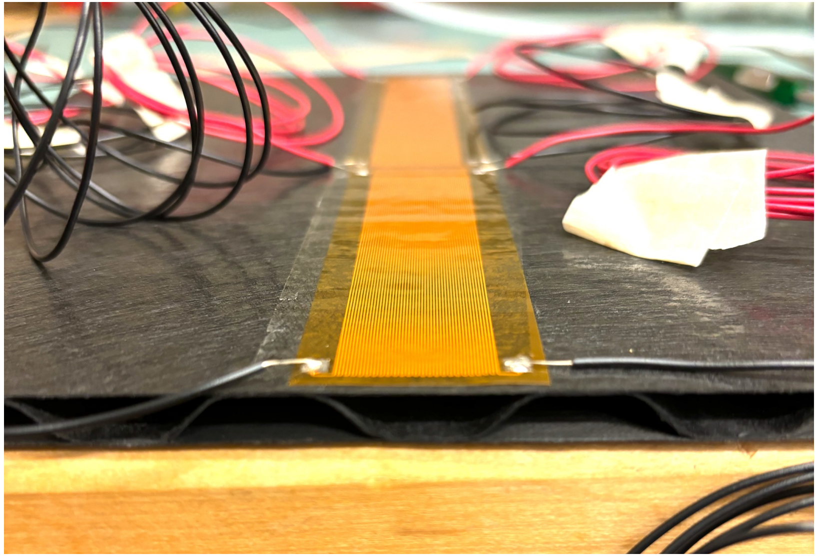


Corrugated carbon fiber thermal tests

Two heaters with separate power zones for LEC (~1W/cm^2) & matrix (~40 mW/cm^2)

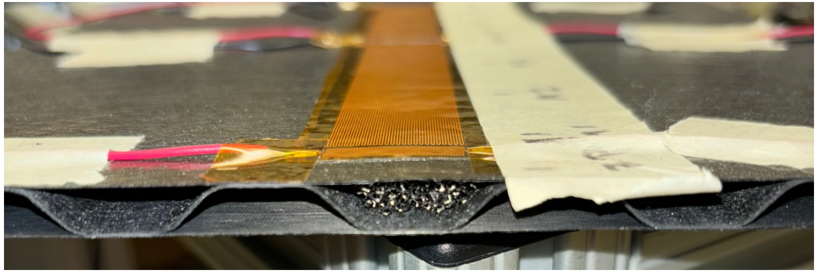
Using 3M 467MP double-sided tape, 60μm thick (used to glue silicon for STAR HFT PXL)

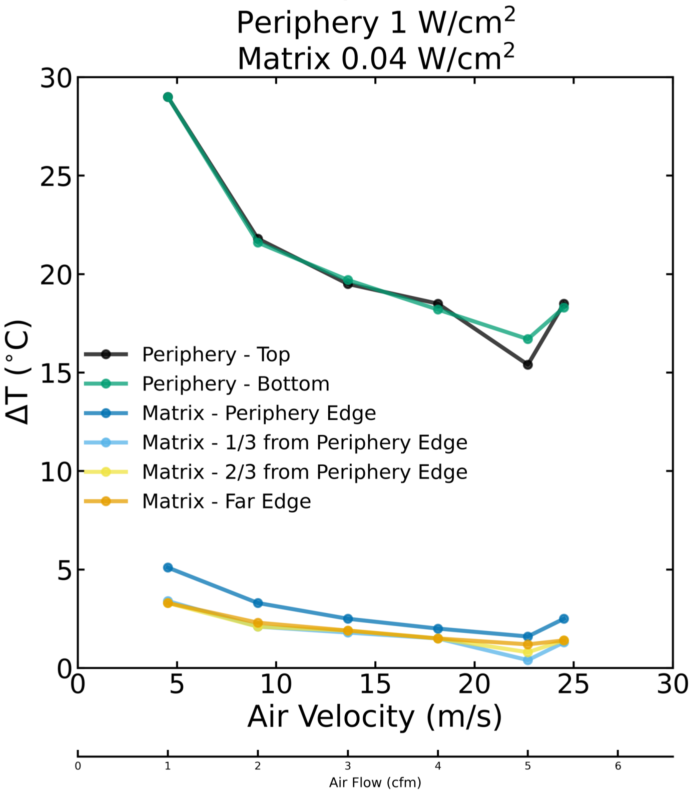
- First step: Put a tube in corrugated channel and blow air through



Results: air flow through corrugation

- No issues cooling the matrix
- LEC (Periphery) trending in the right direction
- Next steps:
    - Add foam under the LEC
    - Improve thermal conductivity
    - Better air control





Uptick at highest velocity possibly due to thermocouple breakage

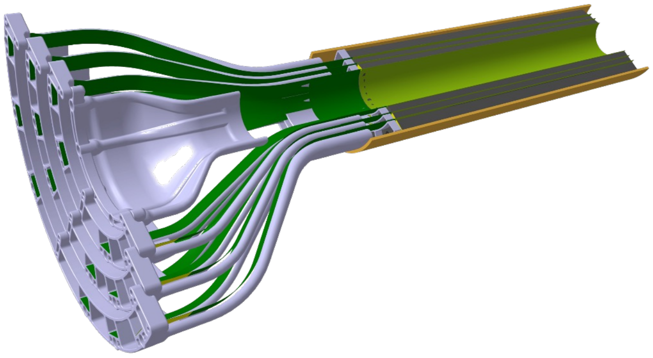
Thoughts about air

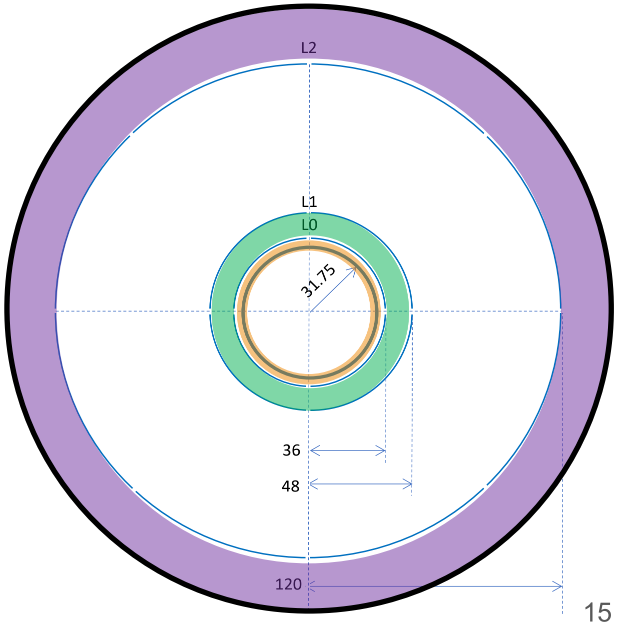
- Previous estimates: Service estimates (work between SVT & project)
  - 1 W per LEC → 1 W per sensor: ~4 kW total, ~400 cfm air, ~12” duct
  - Duct size estimated from standard “noiseless” HVAC equivalent
- New estimates in a “perfect” world
  - Volumetric heat capacity of air (sea level, 0 C) = 0.001297 J/cm^{3}K (*for comparison, water is 3 orders of magnitude better)*
  - ΔT of 10 C
  - 6.5 – 8 kW
  - Needs 1000 – 1300 cfm air & a 16” duct

Nothing is perfect. Let’s make some new assumptions

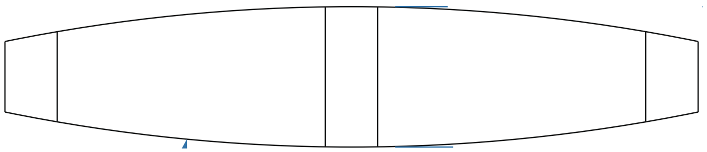
IB total air needs

- Assumptions/Estimates
  - Air flow between BP & L0, L0 & L1, L2 & CF shell
  - No (direct) air flowing between L1 & L2 → too much space
  - 8 m/s air speed
- Need to move 0.12 m^3/s (~250 cfm) air, ~1/2 ton
  - Possible with 10 mm tubes to each section
  - # tubes: 12, 16, 20
- 8 – 10” supply duct





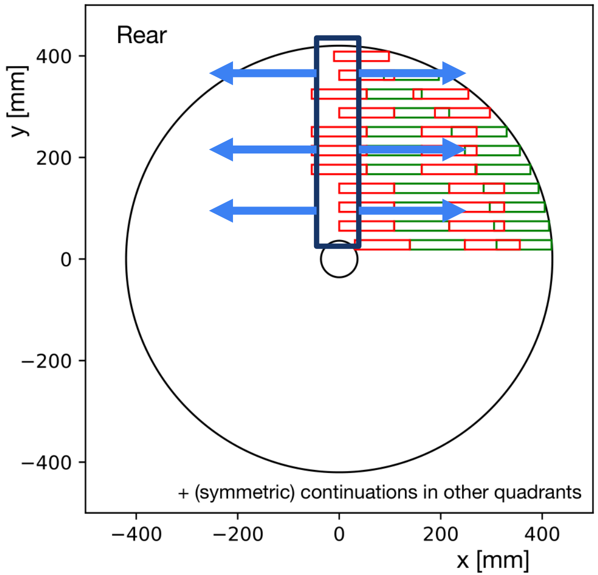
OB total air needs

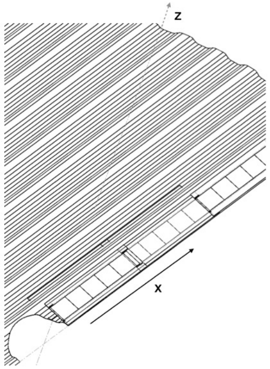


- Assumptions/Estimates
  - 4 x 0.5 cm^2 cross section
  - 8 m/s air speed
- Need to move 0.2 m^3/s (~400 cfm) air, ~1 ton
- 10 – 12” supply duct

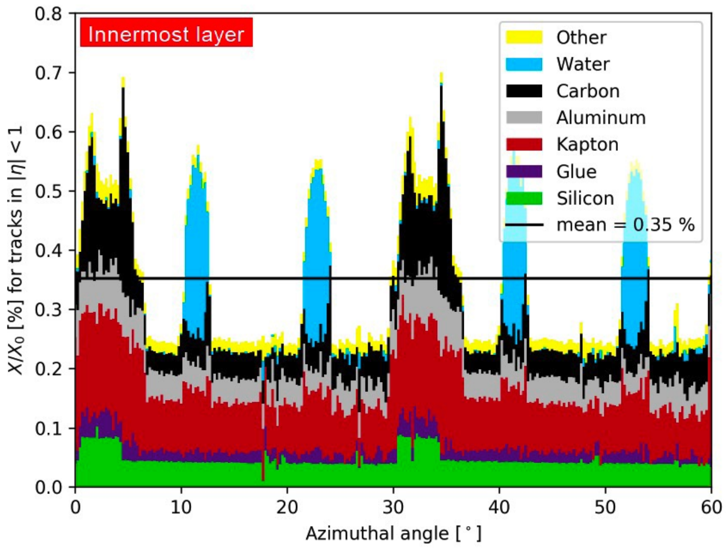
Disc total air needs

- Assumptions/Estimates
  - ~1 cm^2 cross section corrugation (final pitch & thickness TBD)
  - 14 corrugations for ED0 & HD0, 24 for E/HD1-4
  - 10 m/s air speed
- Need to move 0.47 m^3/s (~1000 cfm) air, ~2.5 ton
- 14 – 18” supply duct





Material Budget Implications



- Foam: 5 mm thick 3% RVC foam ~0.08% X/X0
- Water cooling pipe: 1 mm ID tube made with 25 μm Kapton walls is ~0.3% X/X0

- Average X/X0 of water will be less. Depends on number of pipes & coverage
- Foam is less if placed in specific spots, but might not give much benefit if needed along entire length

Summary/To do

- How to bring in air?
  - High pressure, small tubes?
- Iterate cooling for the discs
  - Foam near LEC? Water cooling?
- Work on water cooling routing
  - Maybe simple for OB, more complicated for the discs
- Ongoing and planned (at LBNL)
  - New iteration of corrugation, continuation of corrugated cooling measurements, DPTS
- Next steps → implications for material budget, services, structure, etc.
  - Mechanical tests & FEA, CAD modeling, ANSYS thermal & stress tests

Backups

Further cooling tests & calculations

Initial calculations done for air and water cooling on discs

- Air is feasible through corrugated channels
- Water provides significantly more cooling power and can be routed near endcaps/peripheries
    - Estimated from ITS2 values

Calculations to be verified with bench tests to develop an adequate cooling model

SVT-specific mockups currently being developed for testing

- Corrugated carbon fiber
- Verify cfm needs
- As power numbers get updated → is air enough?
- Water routing specifics – related with tiling specifics