LBNL update: air cooling studies, beam pipe bake-out

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EICSC Meeting

Feb 28, 2023

Outline

- Internal air cooling project started summer 2022
  - Previous talk: EICSC Meeting 10/10/22
- Beam pipe bake-out studies
  - Previous talk from Brian Eng: EICSC Meeting 6/6/22
    - 5 mm gap between beam pipe and 1st silicon layer

eRD111 air cooling project

Currently led by
Beatrice Liang-Gilman
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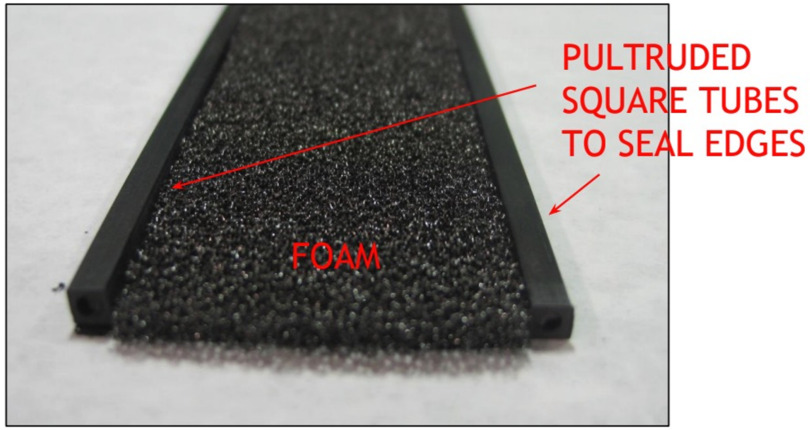
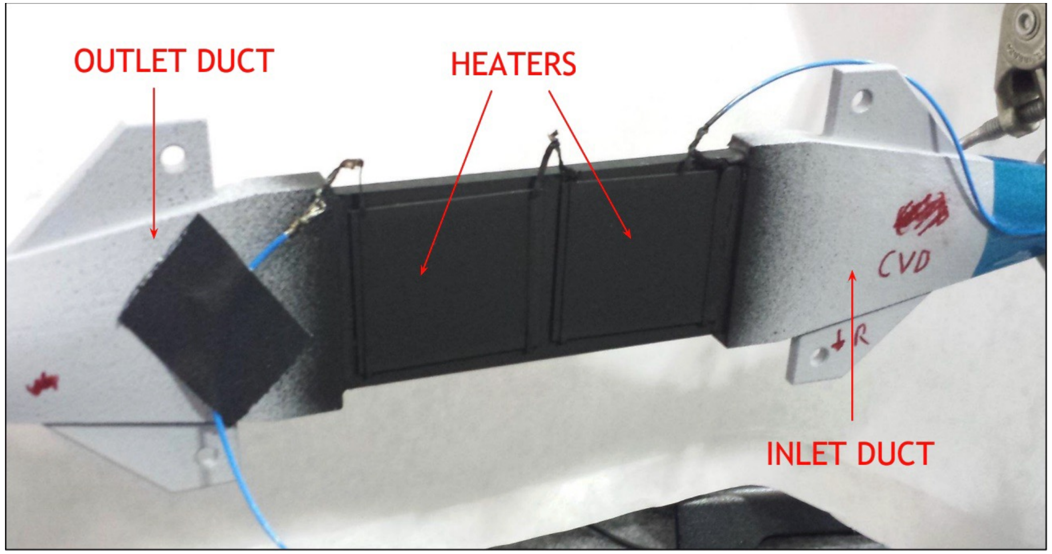
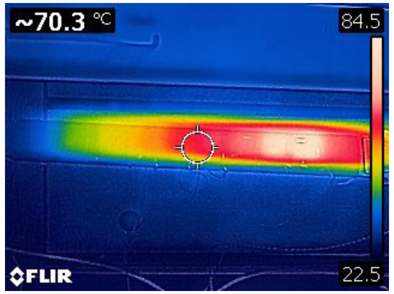
- Is internal air cooling a viable option?
  - Periphery: 1 - 2 W/cm^2
  - Matrix: ~10 mW/cm^2
- Is design stable enough to withstand air?
- Goal: find option with optimized temperature & pressure differences
- Adjustable:
  - Power density
  - Foam types
  - Foam thicknesses
  - Air speed

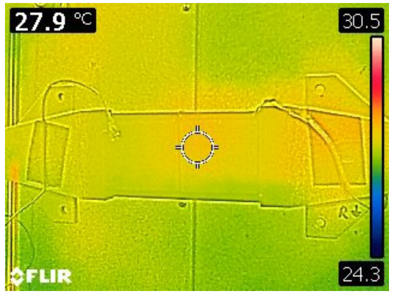


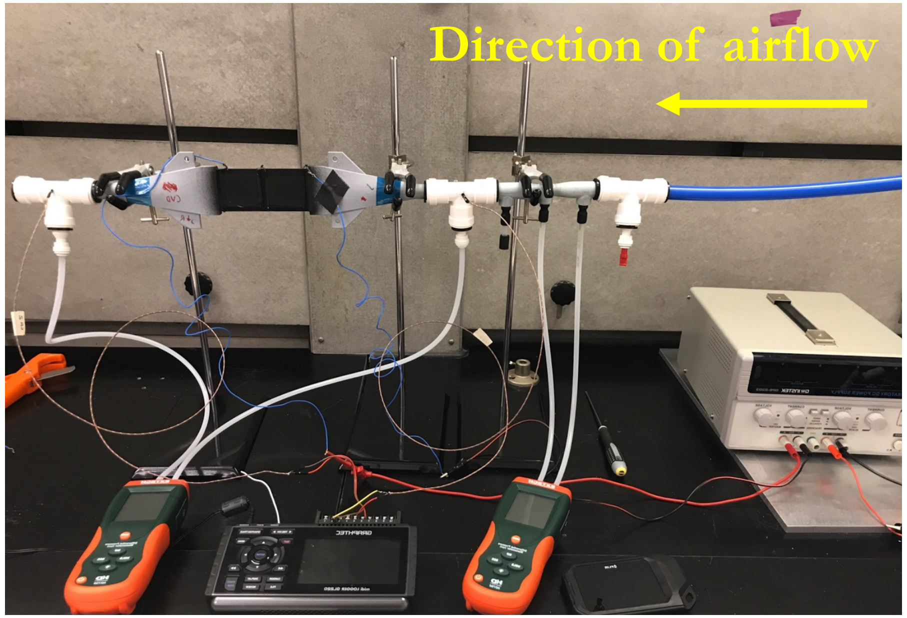


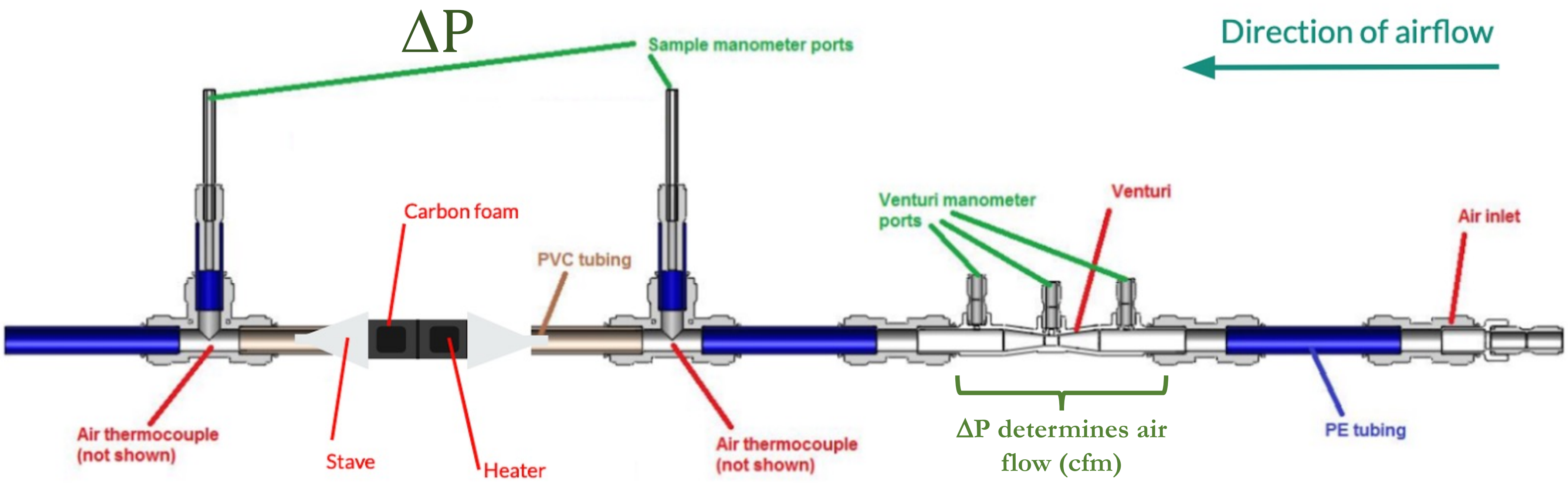
Setup

ΔT: "bright" temp – "dark" temp



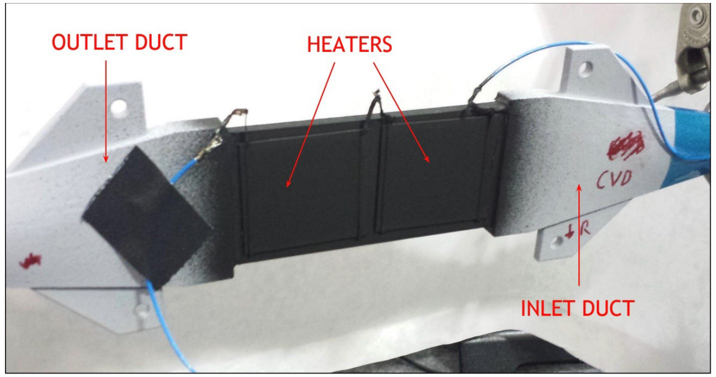


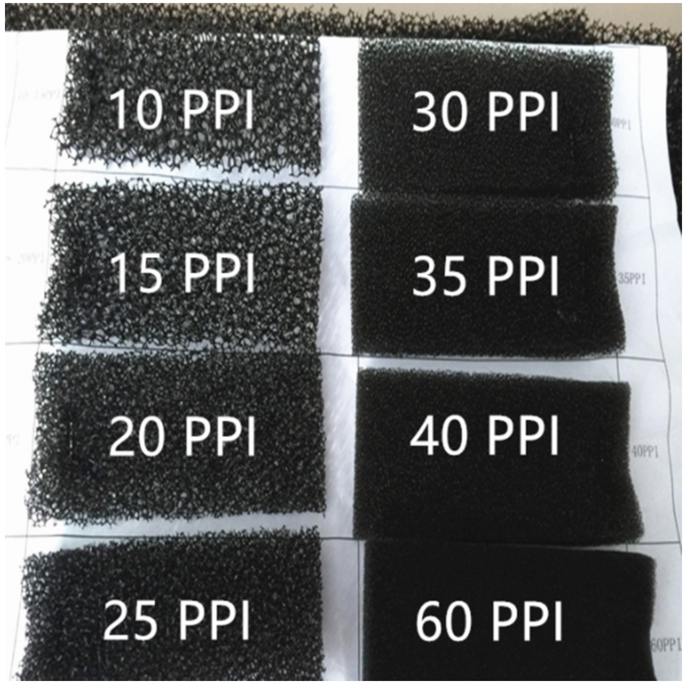


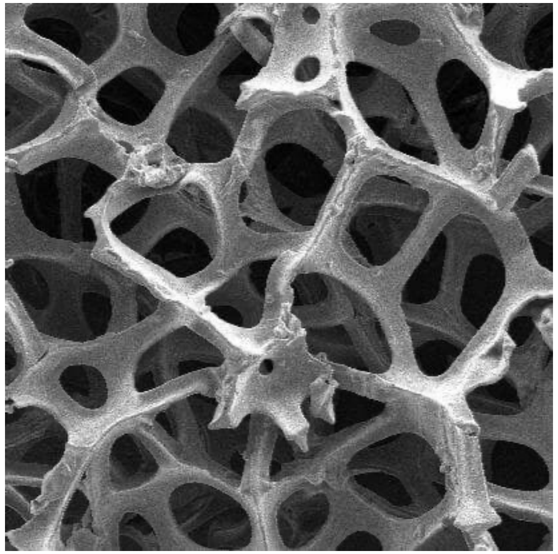


Stave variations

- Foam types:
  - CVD – conducting, denser than RVC
  - RVC – insulating, lower material budget
- Thicknesses: 4 & 6 mm
- PPI(pores per inch): 30 & 45
- Stave lengths: 100 & 500 mm

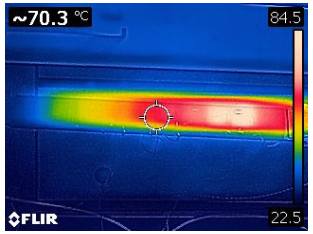


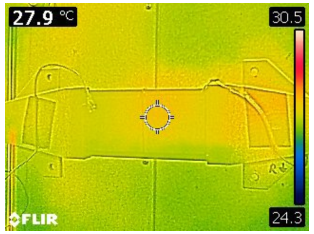




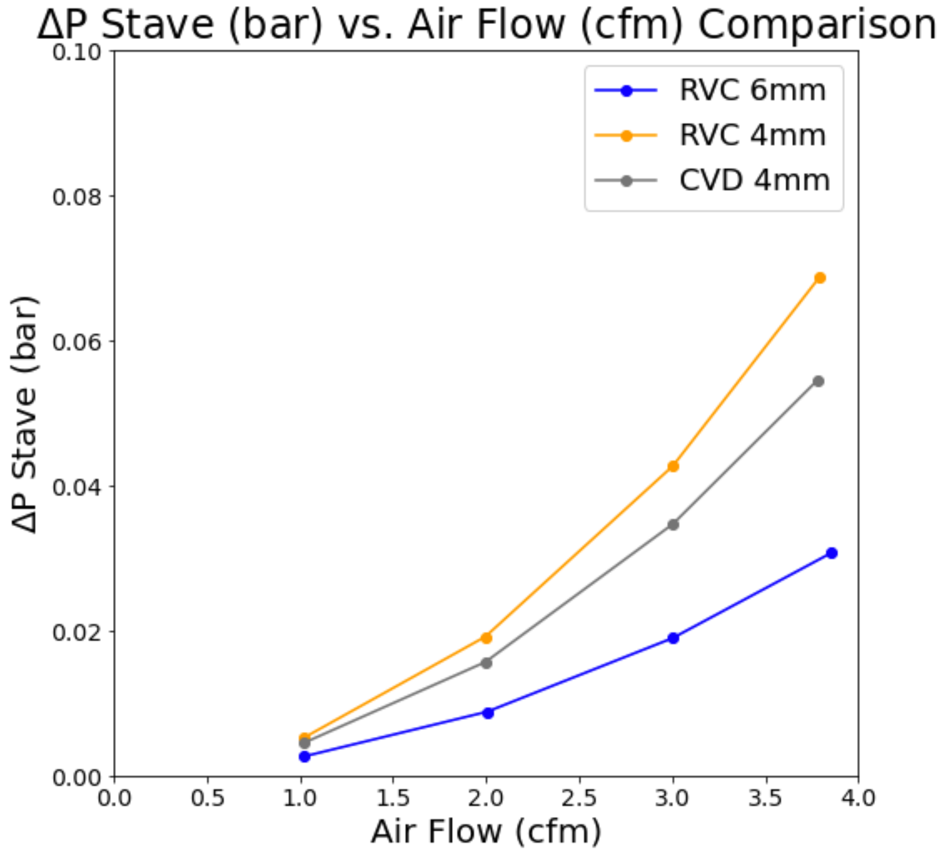
ΔT & ΔP results

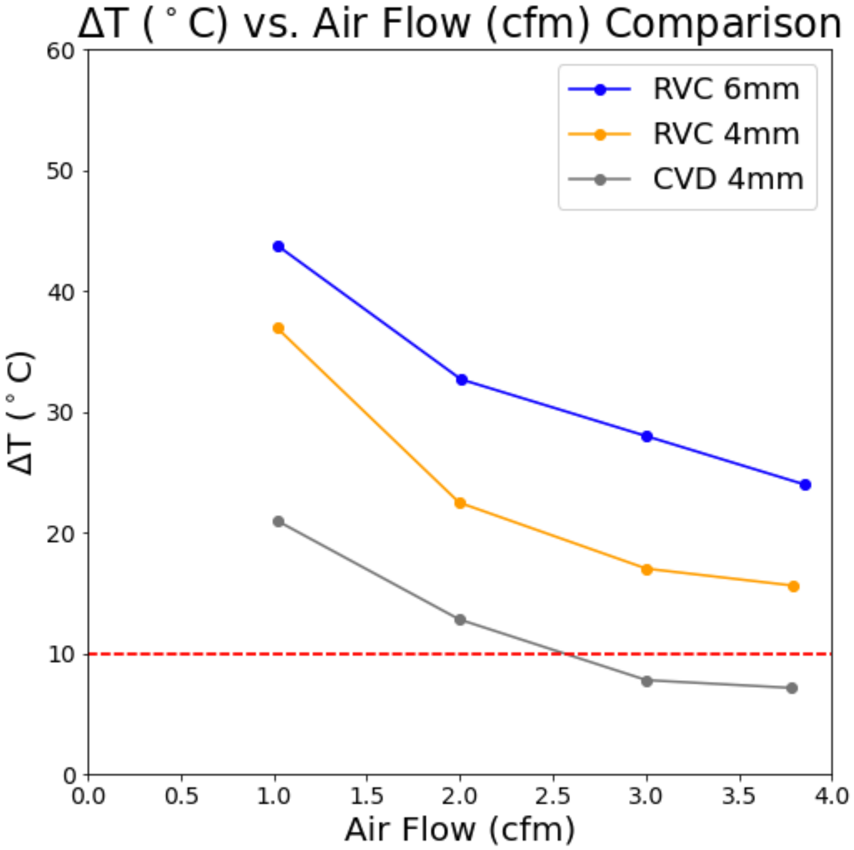
ΔT: "bright" temp – "dark" temp





Power density = 0.5 W/cm^2





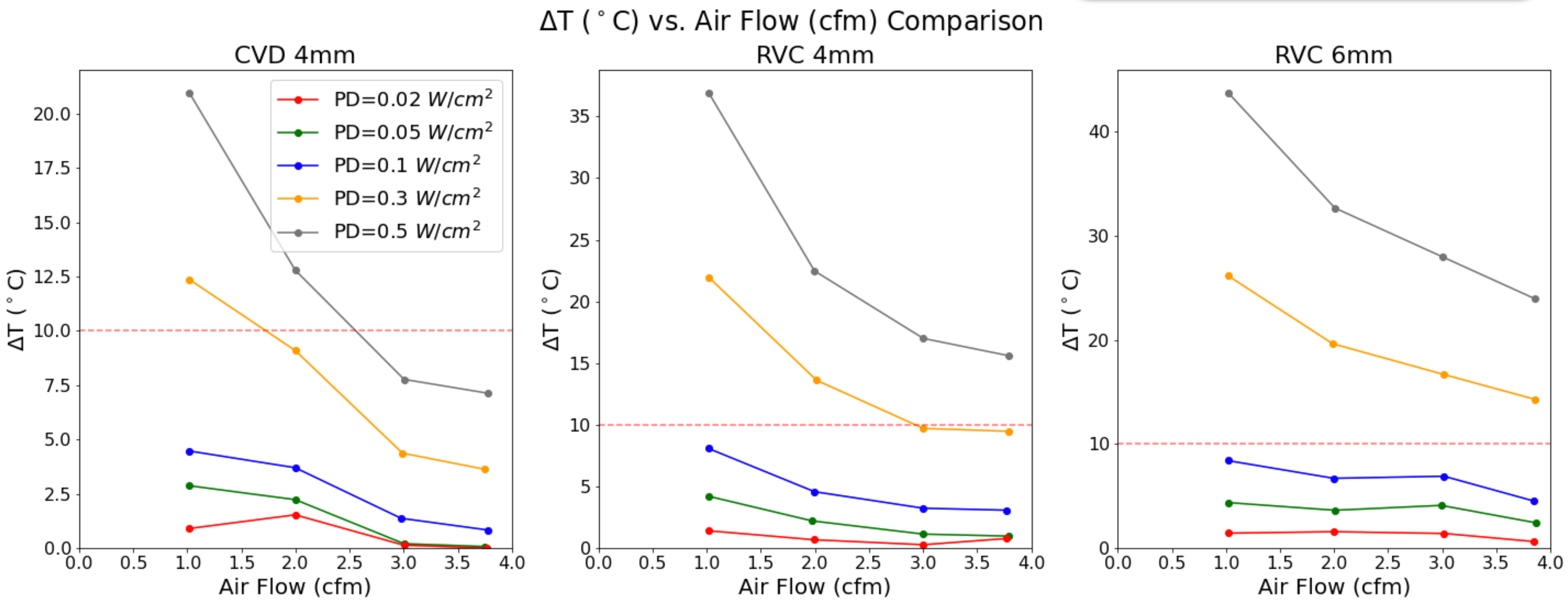
Aim:

- ΔT < 10°C
- ΔP < 1 bar for 1m stave

CVD meets both requirements

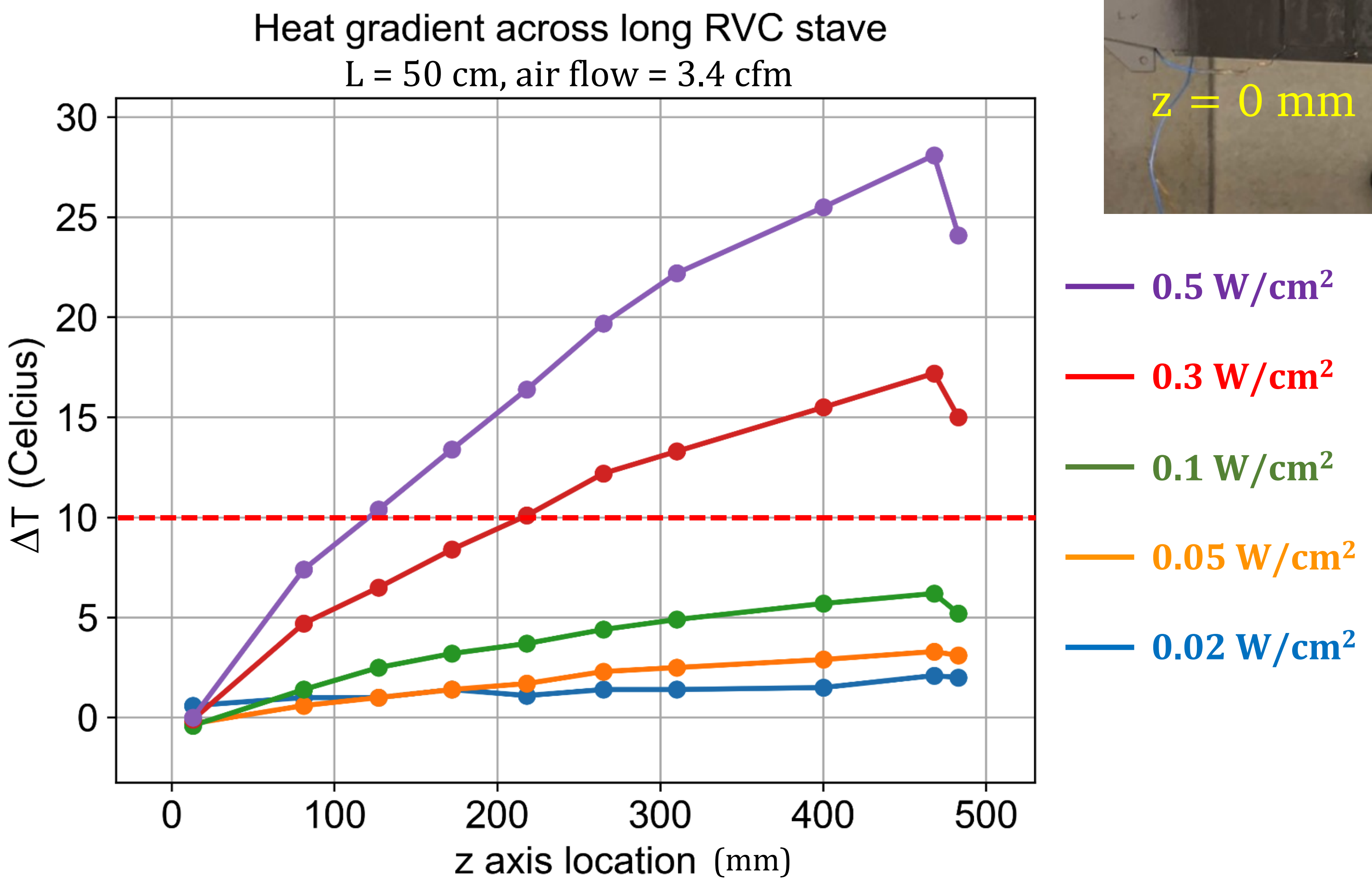
ΔT for different power densities

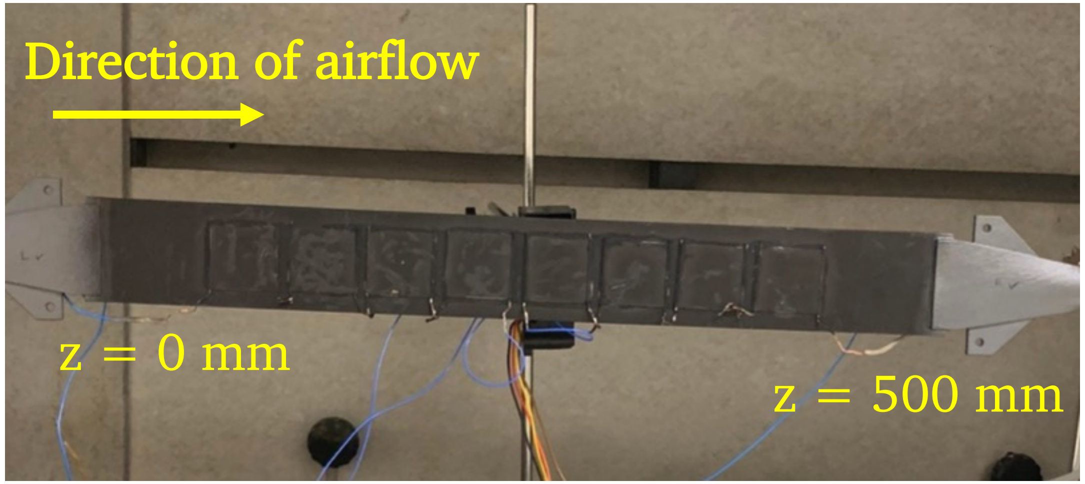
CVD achieves ΔT for all power densities



Pixel matrix < 0.02 W/cm^2, periphery > 0.5 W/cm^2

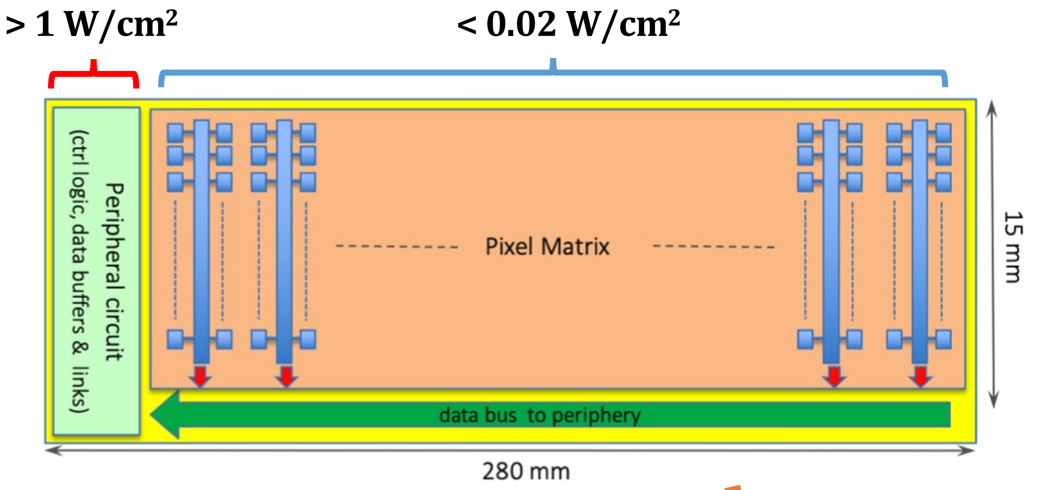
Heat gradient

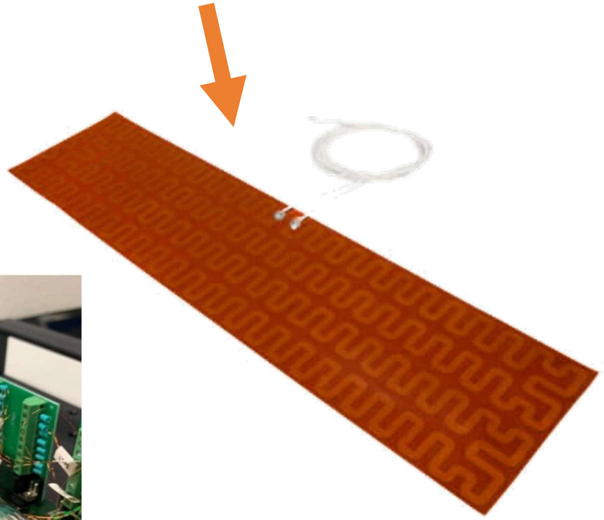




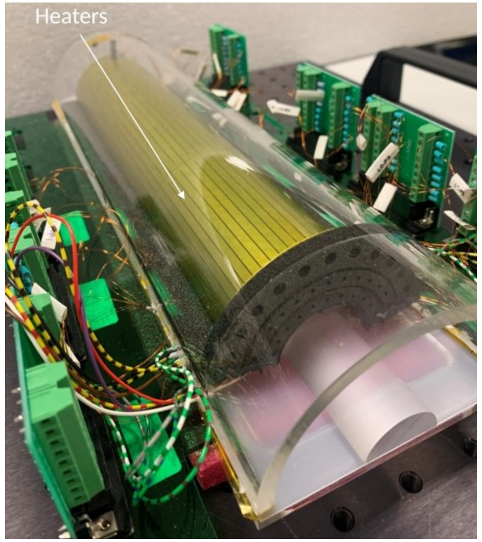
$\Delta T < 10°C$ for power densities $< 0.1\ W/cm^2$

Air cooling: upcoming



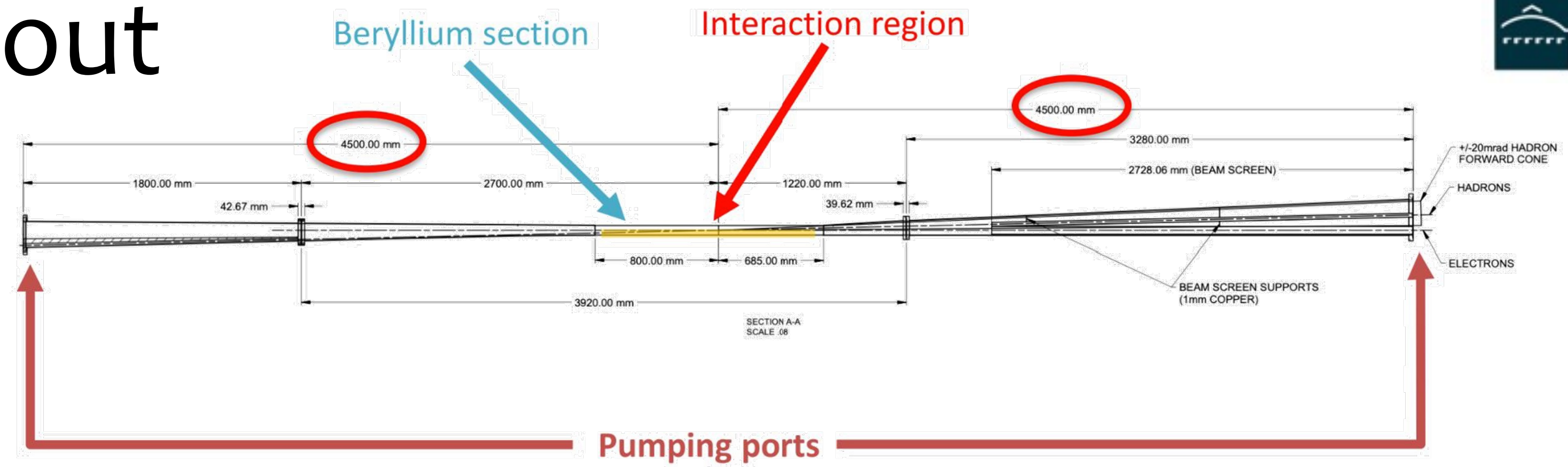


- Increase air flow: new pump
- New "staves"
  - Proper heating & power densities → new heaters
  - EIC sizes
  - Careful attention to material budget
- Wind tunnel for vertex layers
- Combine air & liquid
  - Route liquid cooling near the periphery?



Beam pipe bake-out

No heater around beam pipe: keep material budget low



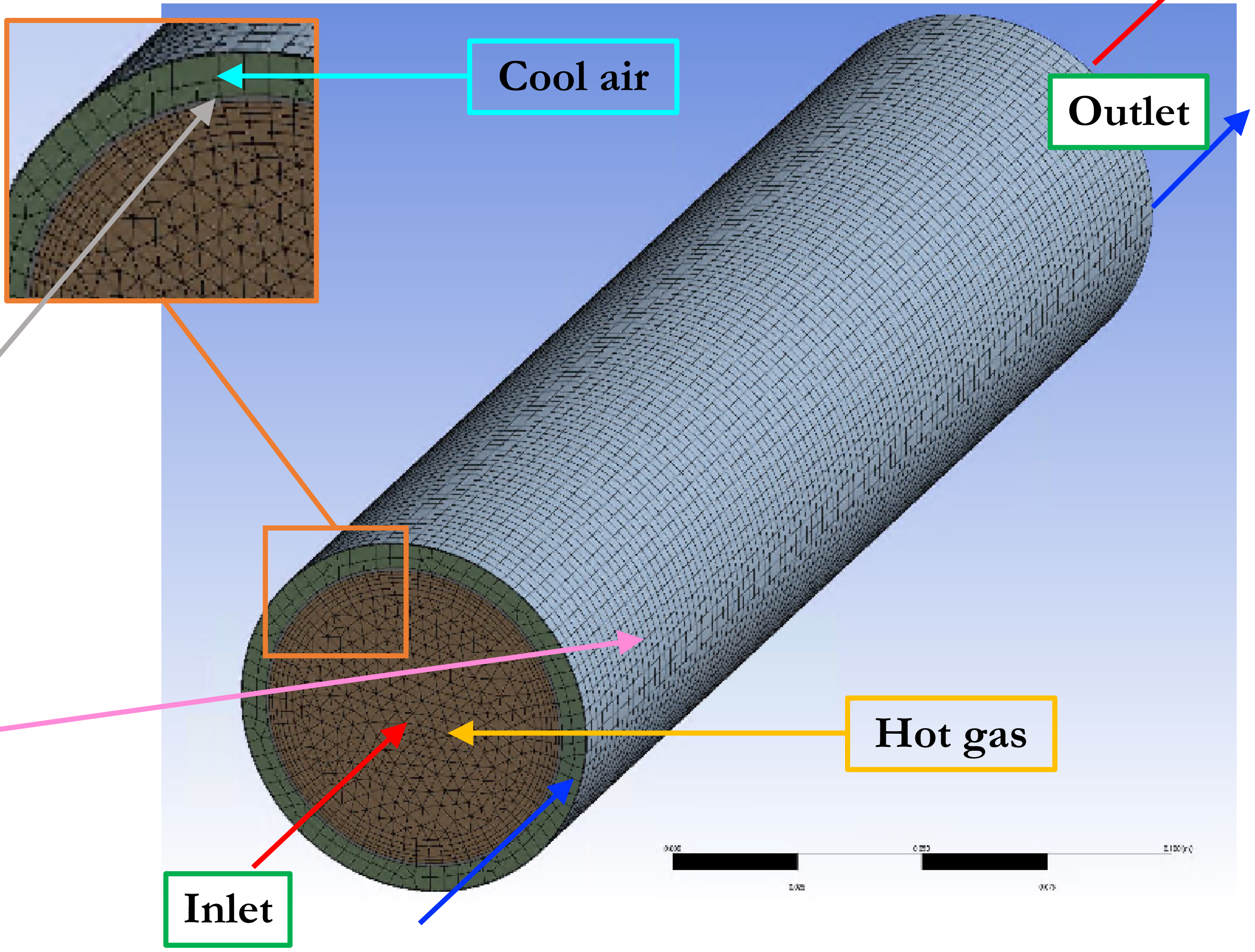
- Need to remove water molecules & other contaminants from interior of beam pipe
  - Pump hot gas in at ≥ 100°C (needed to break water molecule bonds)
- Previous ANSYS study (6/6/22): increase distance between beam pipe & first layer (~5 mm) to keep T at silicon ~30°C
  - **Did not include effects of air cooling on the beam pipe temperature → recent Jlab results indicate this is a significant effect**
- Can we model this in ANSYS to see what hot gas temp is needed to maintain 100°C and keep the silicon cool enough?

ANSYS Setup

Work done by Emma Yeats
(eyeats@lbl.gov)

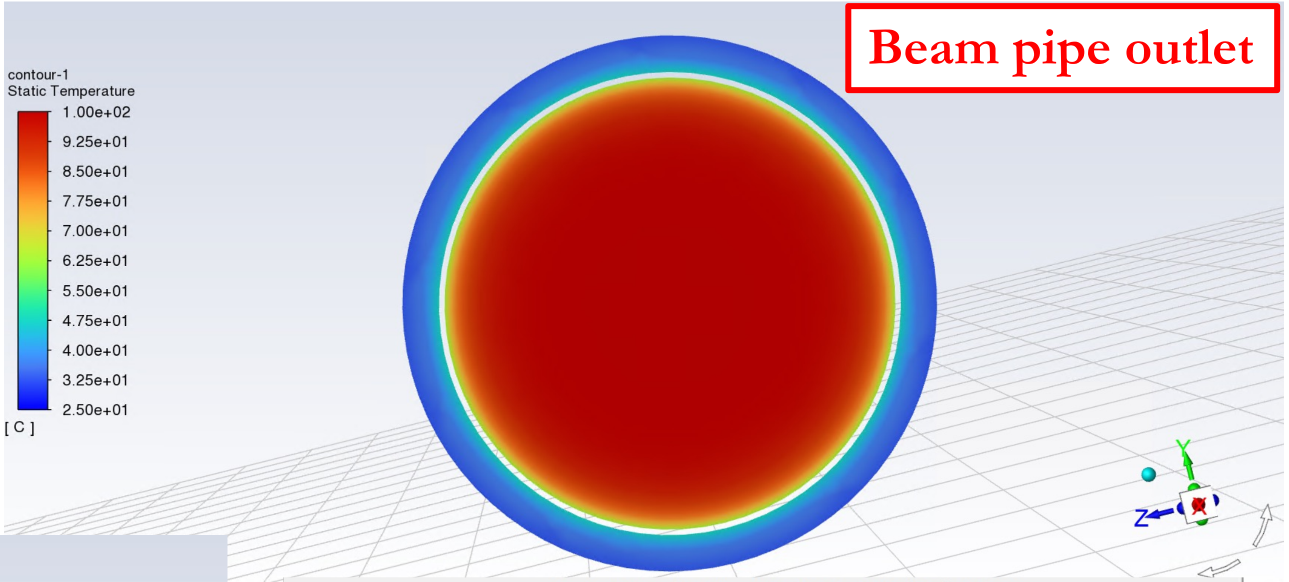
- Initial conditions at inlet
  - Cool air temp = 25°C
  - Hot gas temp = 100°C
  - Cool air velocity = 5 m/s
  - Hot gas velocity = 5 m/s

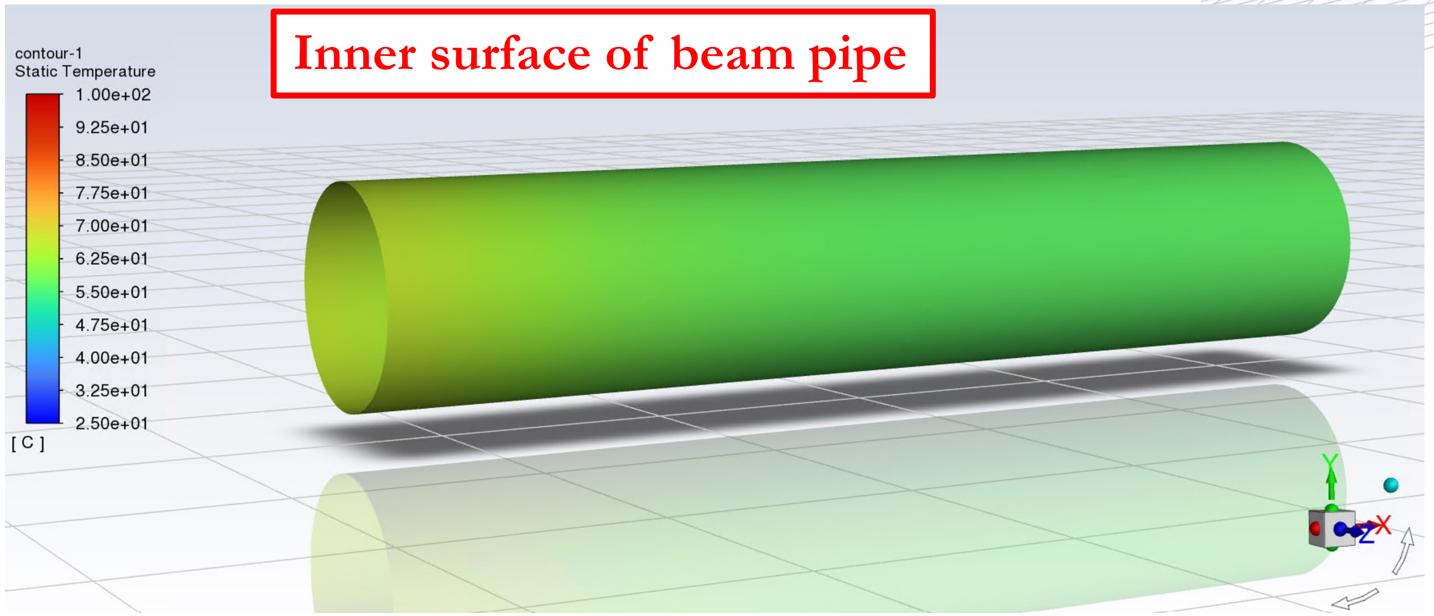
- Materials
  - Beryllium Alloy
  - Silicon

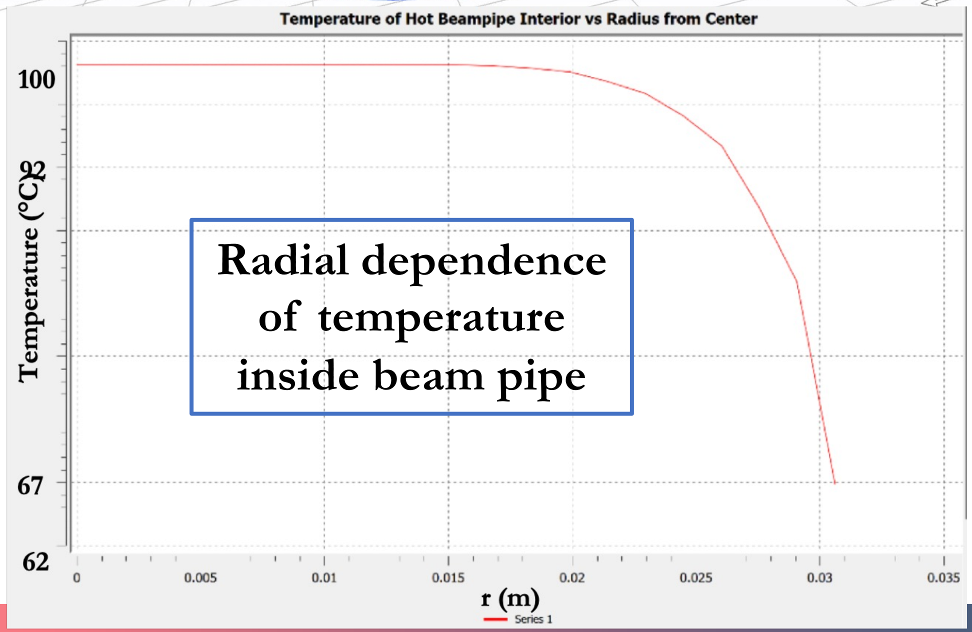


Effect of air cooling on beam pipe

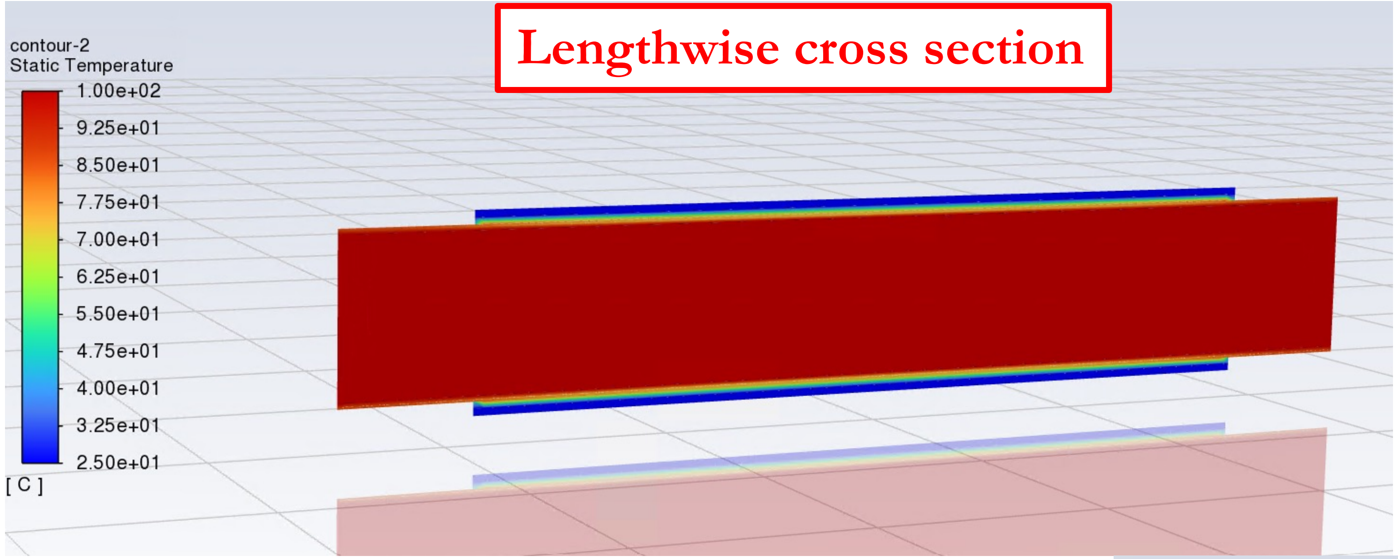
Inner surface cools significantly (60 - 70°C)







Back to basics



Sanity check:

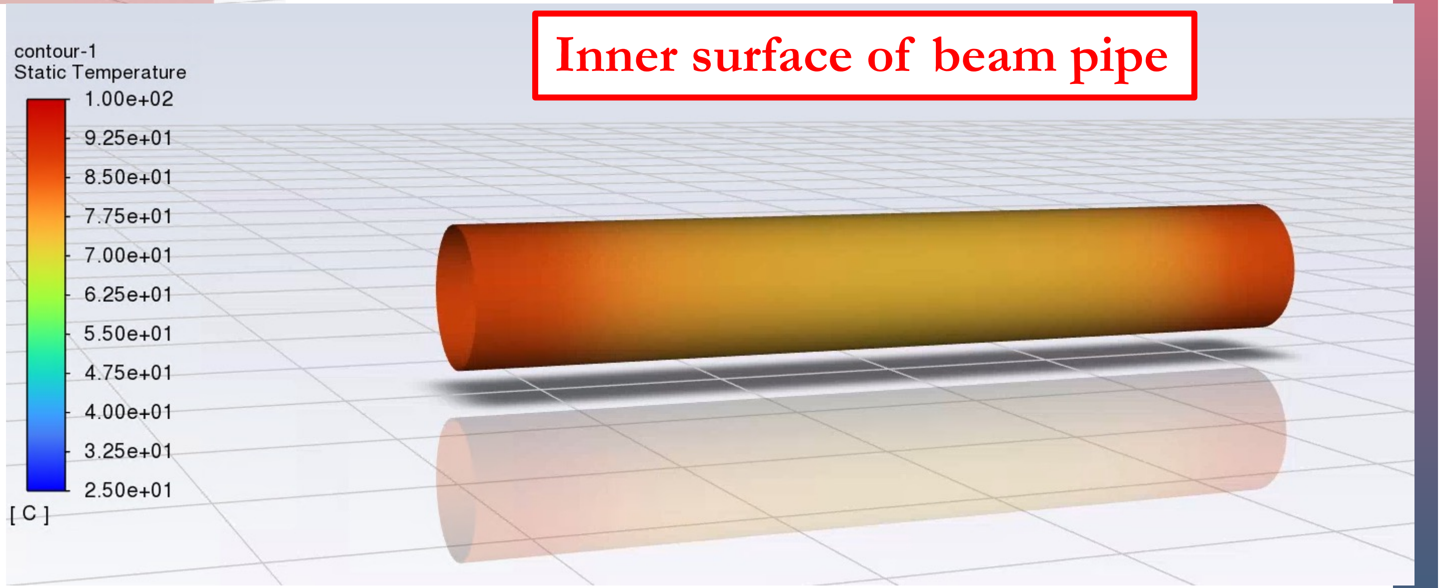
Hot air @ 100°C

Ambient temp outside @ 25°C

No air flow

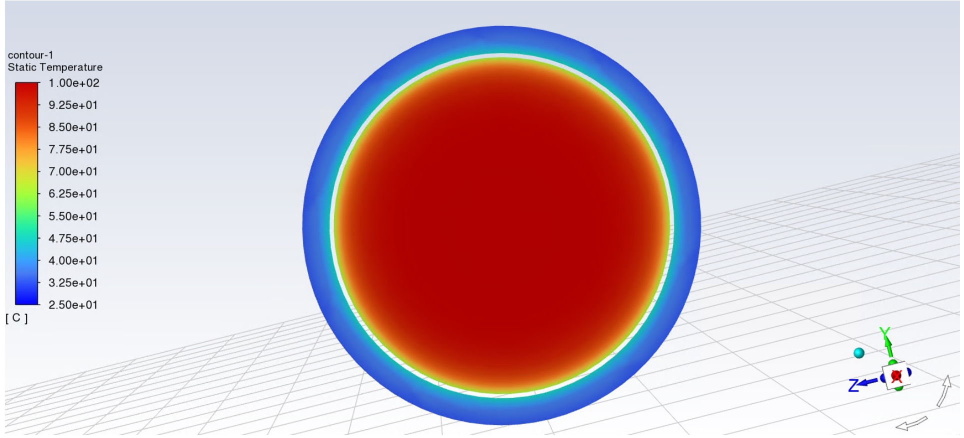
What is the minimum hot gas temperature to keep inner surface of beam pipe at 100°C?

Work in progress



Beam pipe bake-out: upcoming

- Air flow & temperature have a significant effect on inner beam pipe temperature
  - What temperature is needed to keep inner surface of beam pipe @ 100°C?
  - What does that do to the temperature of the silicon?
- Vary air flow & temperatures
  - Want to keep silicon < 30°C



Backups

Part Name	Part Color	ID [mm]	OD [mm]	Thickness [mm]	Length [mm]
Beryllium pipe	Yellow	62.00	63.52	0.76	1470.00
PEEK Support	Red	64.00	66.00	1.00	10.00
Silicon sensor L1	Green	66.00	66.08	0.04	320.50

Table 1. Dimensions from imported STEP file

Ansys Fluent Analysis – Materials

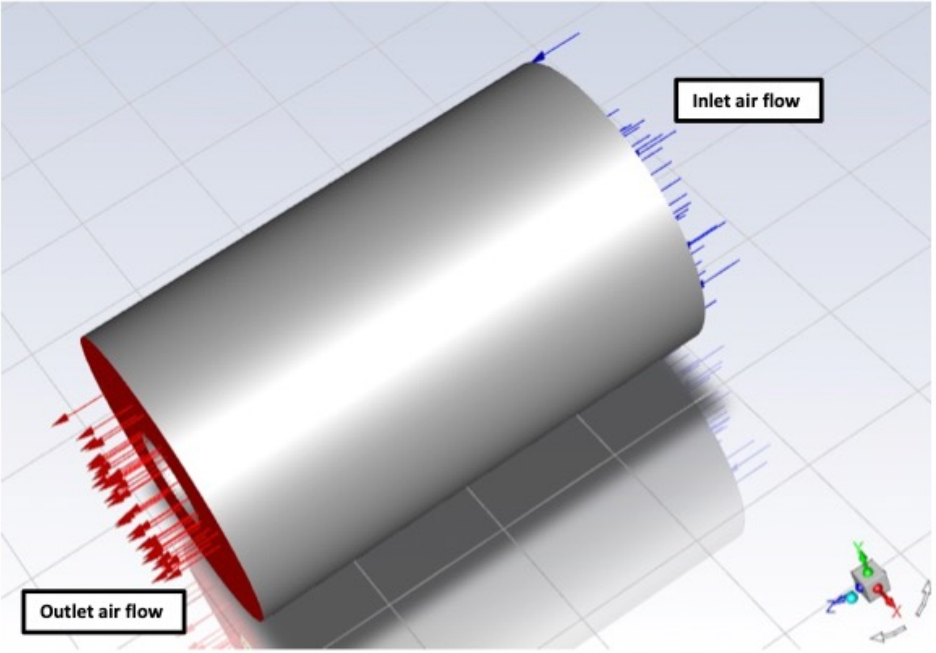
- Materials
  - Air
    - Density: 1.225 Kg/m3
    - Specific heat: 1006.43 J/Kg*K
    - Thermal conductivity: 0.0242 W/m*K
  - Beryllium
    - Density: 1850 Kg/m3
    - Specific heat: 1825 J/Kg*K
    - Thermal conductivity: 190 W/m*K
  - Silicon
    - Density: 2330 Kg/m3
    - Specific heat: 700 J/Kg*K
    - Thermal conductivity: 148 W/m*K

LBNL

- Solver: CFD Fluid Flow Fluent
- Viscous Model: k-omega, Shear Stress Transport (SST)
- Simulation Iterations: 75
- Precision Option: Single Precision (32 bits)
- Be pipe inner face temp: not held fixed
- Inner hot gas temp: 100 – 200 C
- Air temperature: 26.85C
- Air velocity: 5 m/s
- Thermal heat transfer: forced convection

Ansys Fluid Flow Fluent Analysis – Conditions

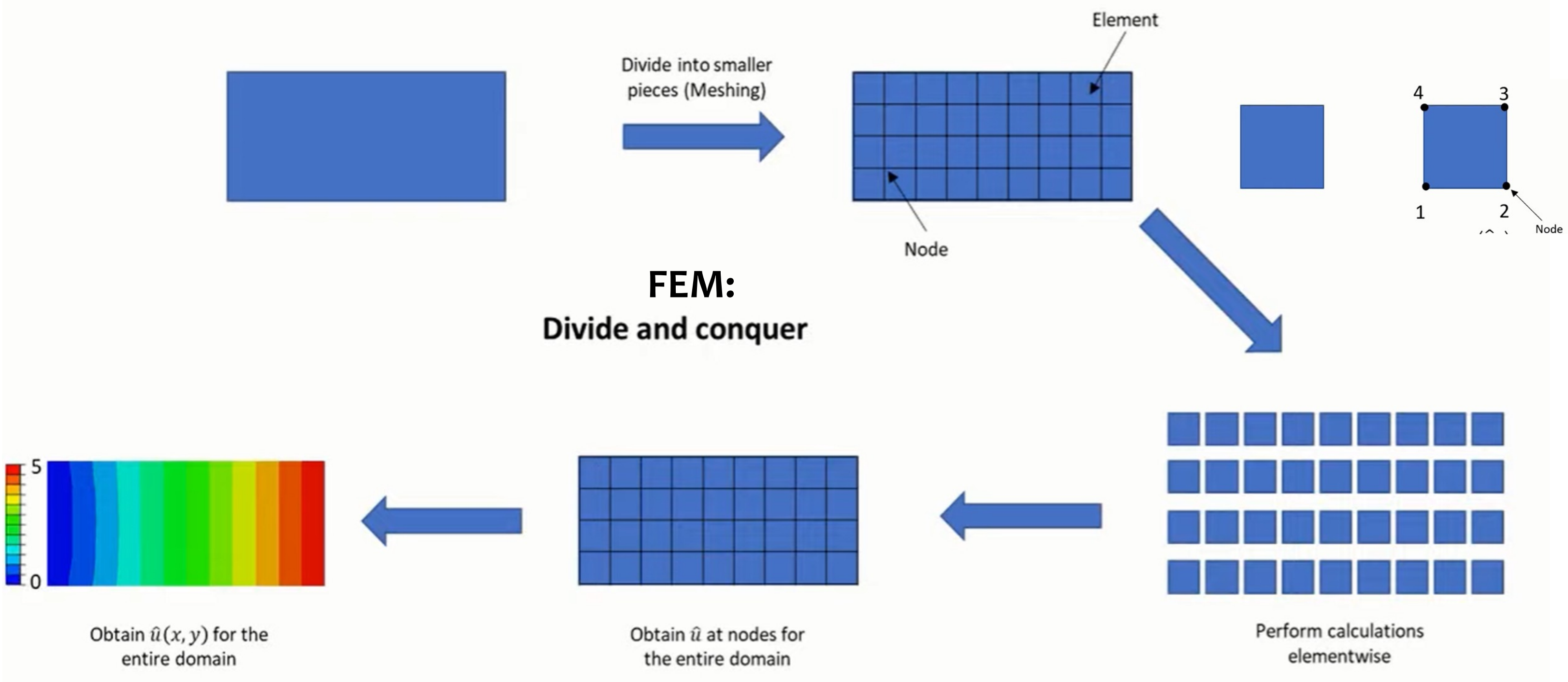
- Solver: CFD Fluid Flow Fluent
- Viscous model: k-omega, Shear Stress Transport (SST)
- Simulation Iterations: 50
- Precision option: Double
- Be pipe inner face temp: 100°C
- Air temperature:20 to 14°C
- Air flow velocity: 0 to 20 m/s
- Thermal heat transfer: forced convection



Boundary conditions setup - Red Arrows represents the output air flow and blue arrows the input air flow

Quick Intro to Finite Element Analysis (FEA)

FEA: Utilizes the general Finite Element Method (FEM) to analyze and calculate the solution to boundary value problems on complex 3D geometries.



FEM: obtains an approximate solution to a set of differential equations, boundary conditions by converting the boundary value problem to a system of linear equations.

ANSYS Fluent

General steps:

- Create your complex geometry in ANSYS's CAD software, SpaceClaim
- Create a mesh

smaller mesh size ↔ more accurate solution ↔ longer computation

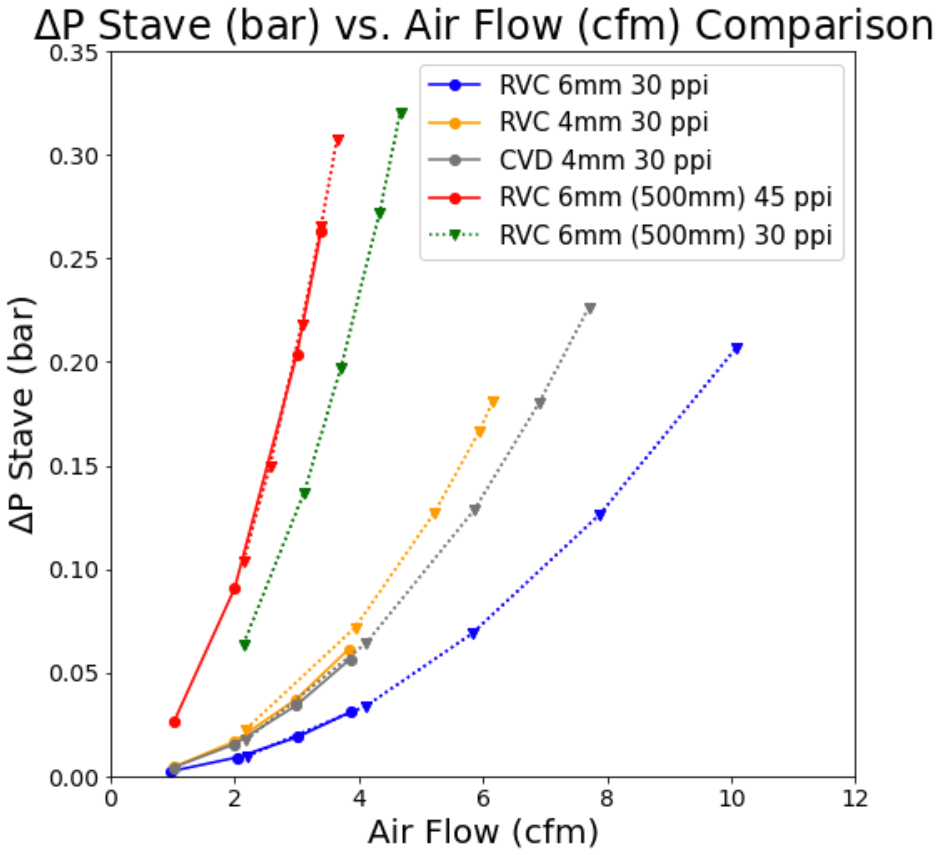
- State initial conditions, materials and domains
- Initialize and calculate. Then check out your results!

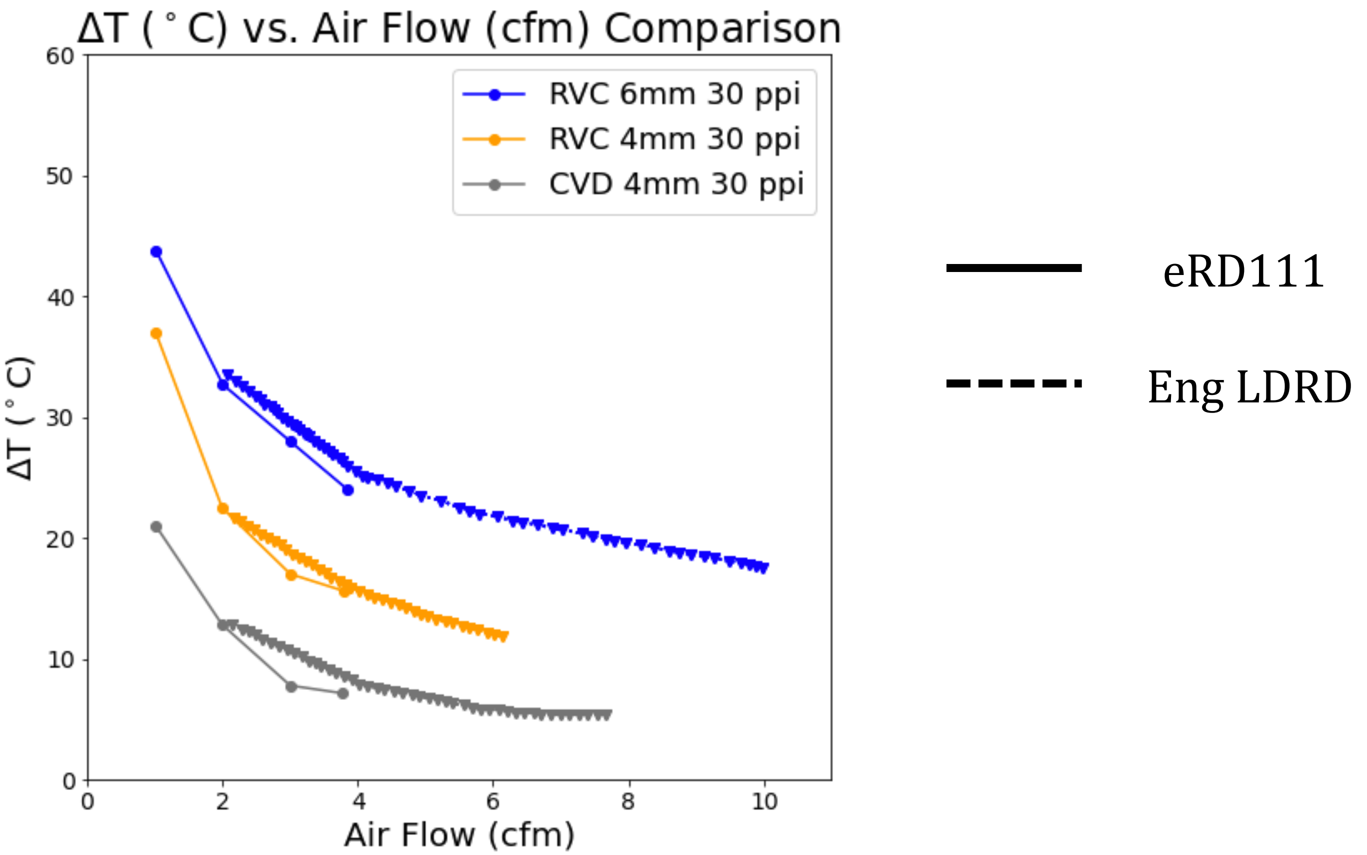
All simulations were solved using ANSYS Fluent software.

- Typically used for fluid flow simulations, but we calculated temperature distributions to study the effects of air cooling.

ΔT & ΔP results

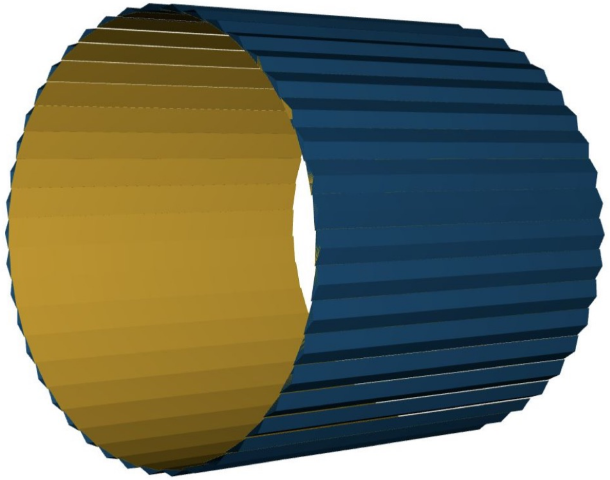
Power density = 0.5 W/cm^2

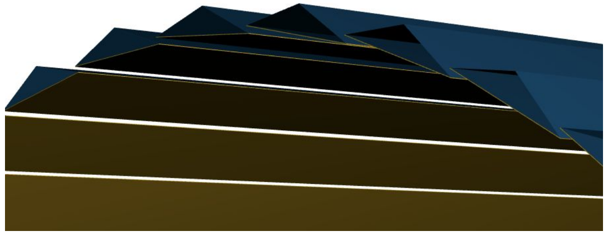




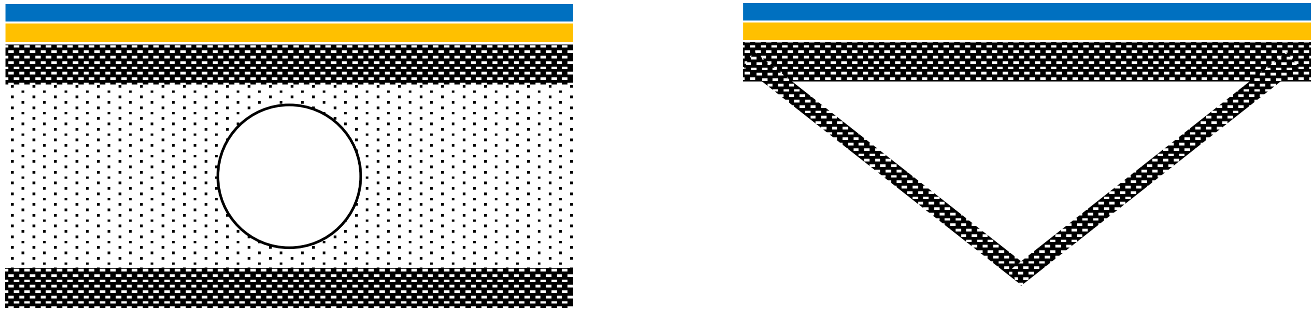
Staves & discs

- Material budget an issue for tracking
  - Longer lengths mean more material (power, support)



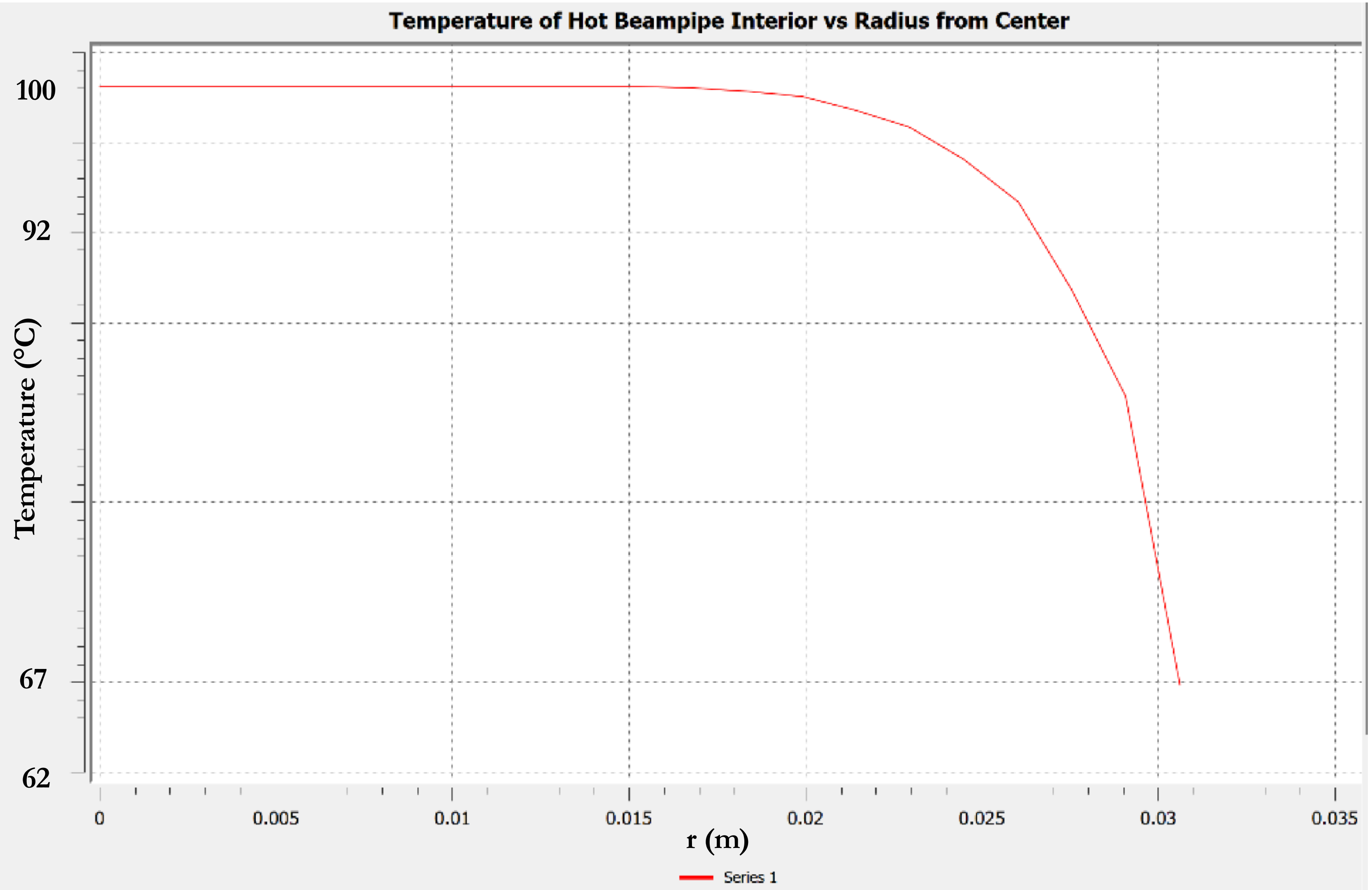


Potential stave & disc cross sections



- FPC/power (aluminum)
- Silicon
- Carbon fiber
- Carbon foam

Not to scale



Temperature of Hot Beampipe Interior vs Radius from Center
100
92
67
62
Temperature (°C)
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
r (m)
Series 1