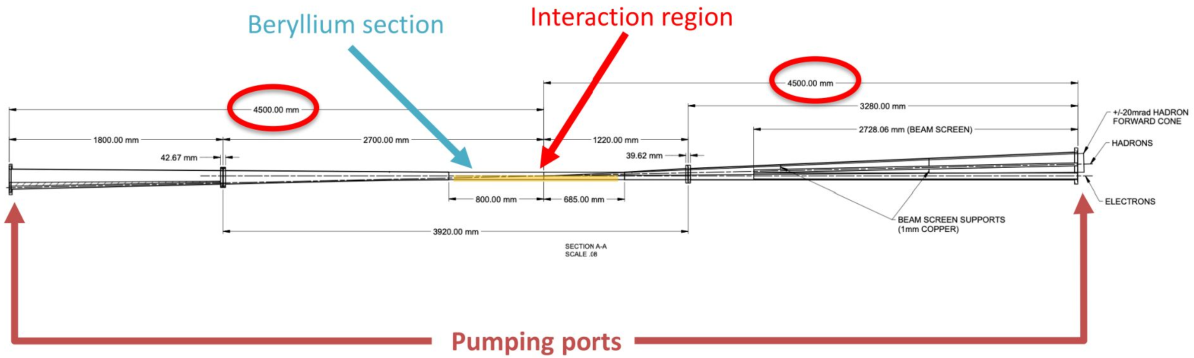
ANSYS Simulation Results

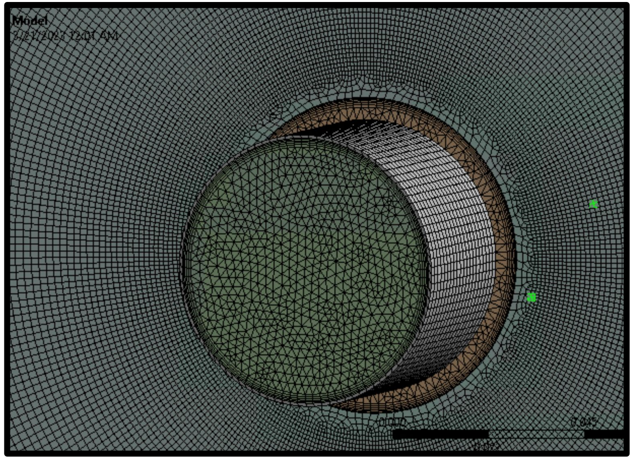
Beampipe Bakeout Update

By Emma Yeats

Bakeout Problem Reminder

- Recent experimental setup had difficulty achieving an gas temperature ≥100°C
  - Pump hot gas in, at ≥100°C, to break water molecule bonds
  - Silicon needs to remain ≤ 30°C
- I've been studying the setup to see if I could find a set of boundary conditions that allowed for a hot enough gas and cool enough silicon. So far I have not included any aerogel layers in the simulations.

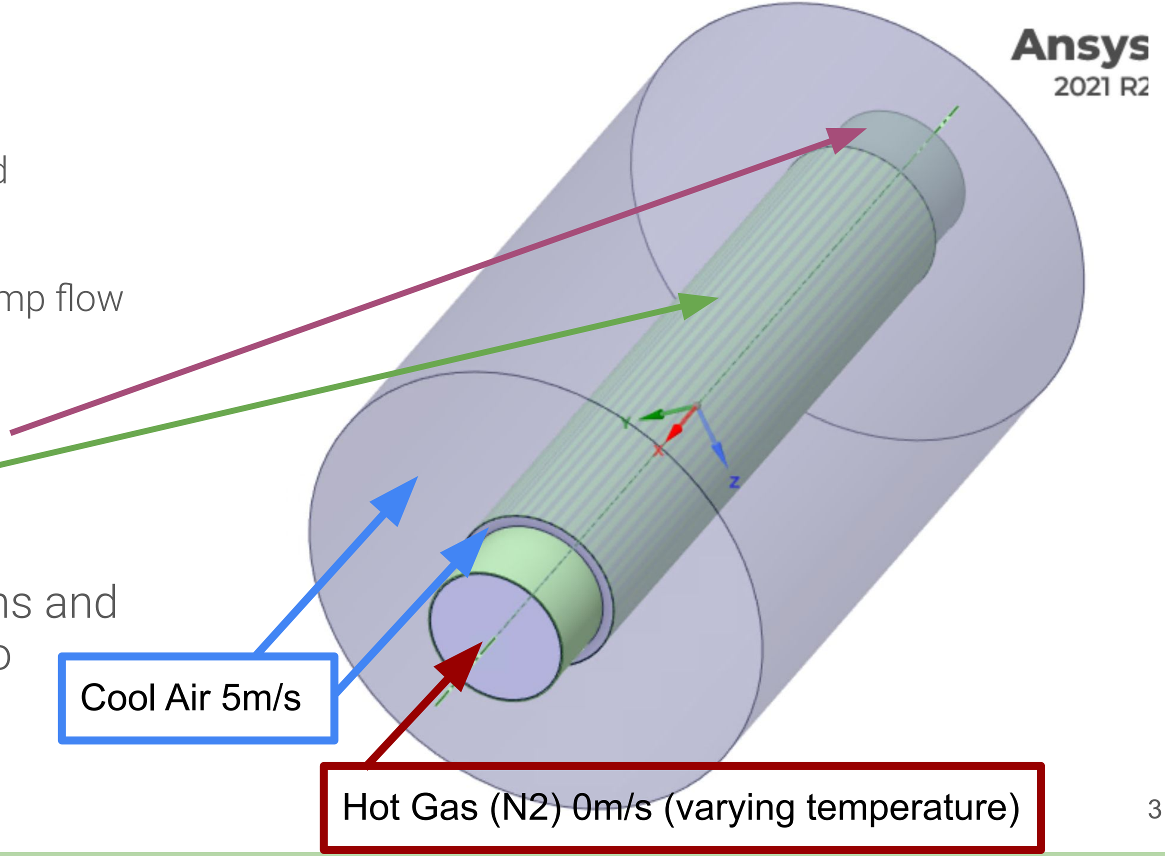




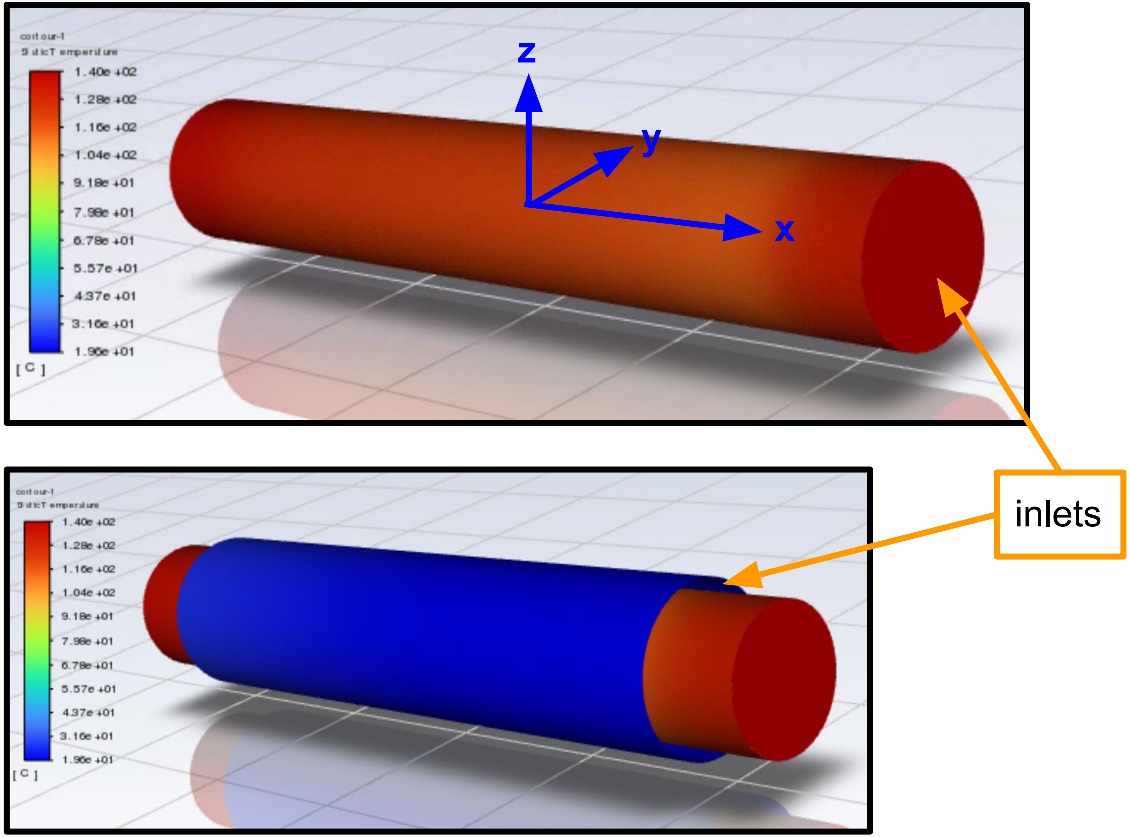
Bakeout Problem Setup

- Initial Conditions at Inlet
  - Cool air temperature 20°C
  - Hot gas temperature varied between 200-140°C.
  - Cool air velocity 5 m/s
  - Hot gas velocity 0 m/s (pump flow rate TBD)
- Materials
  - **Beryllium Alloy Beampipe**
  - **Pure silicon Layer1**
  - Inner Hot Gas N2

Final calculation has 77 iterations and mesh size == 0.002 (designed to optimize for accuracy)



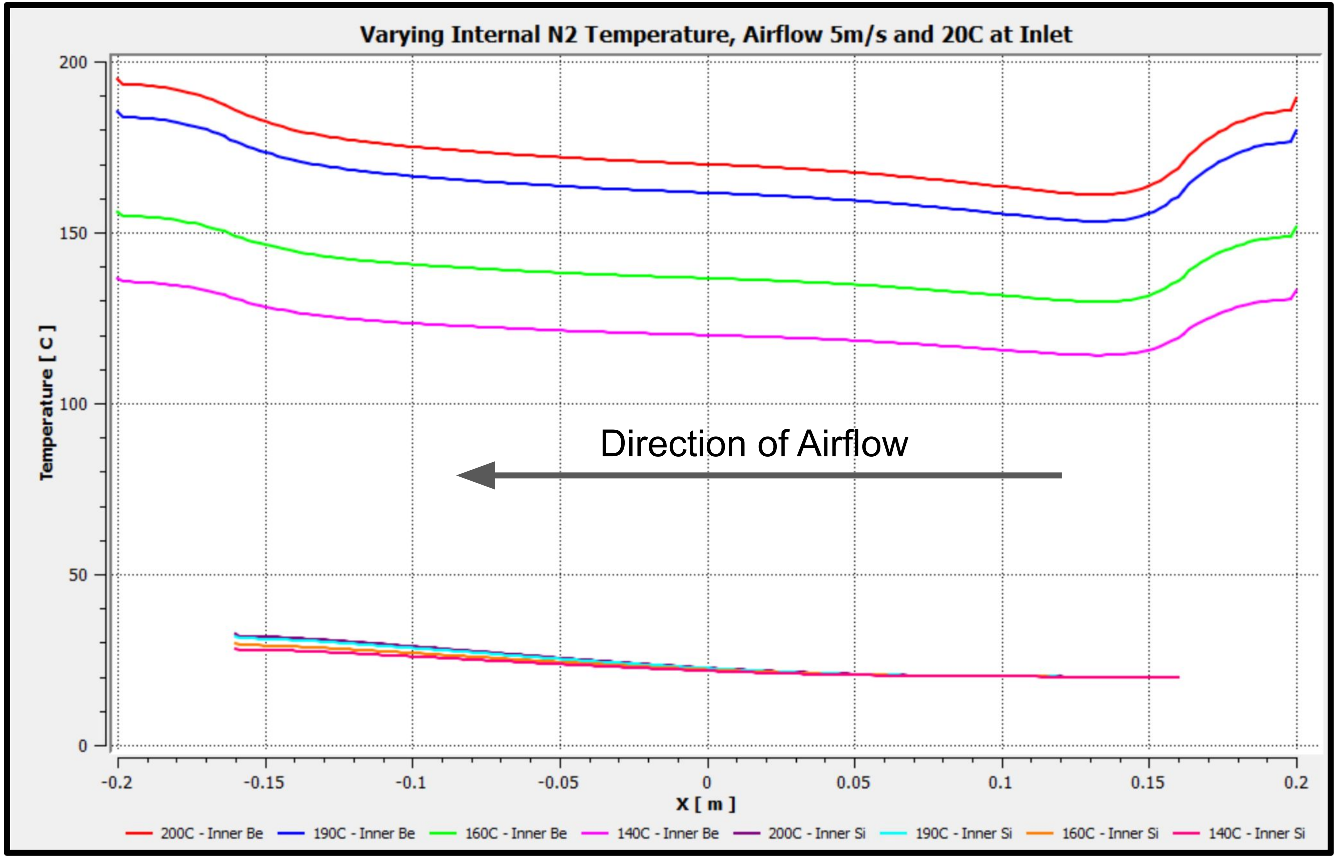
Updated Results

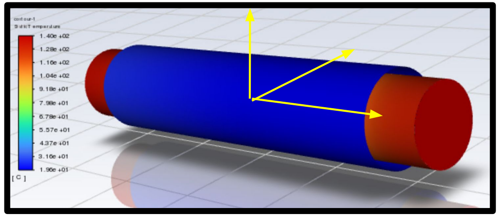


Some thermal contours for the inner surface of the beryllium and the inner surface of the silicon are shown on the left.

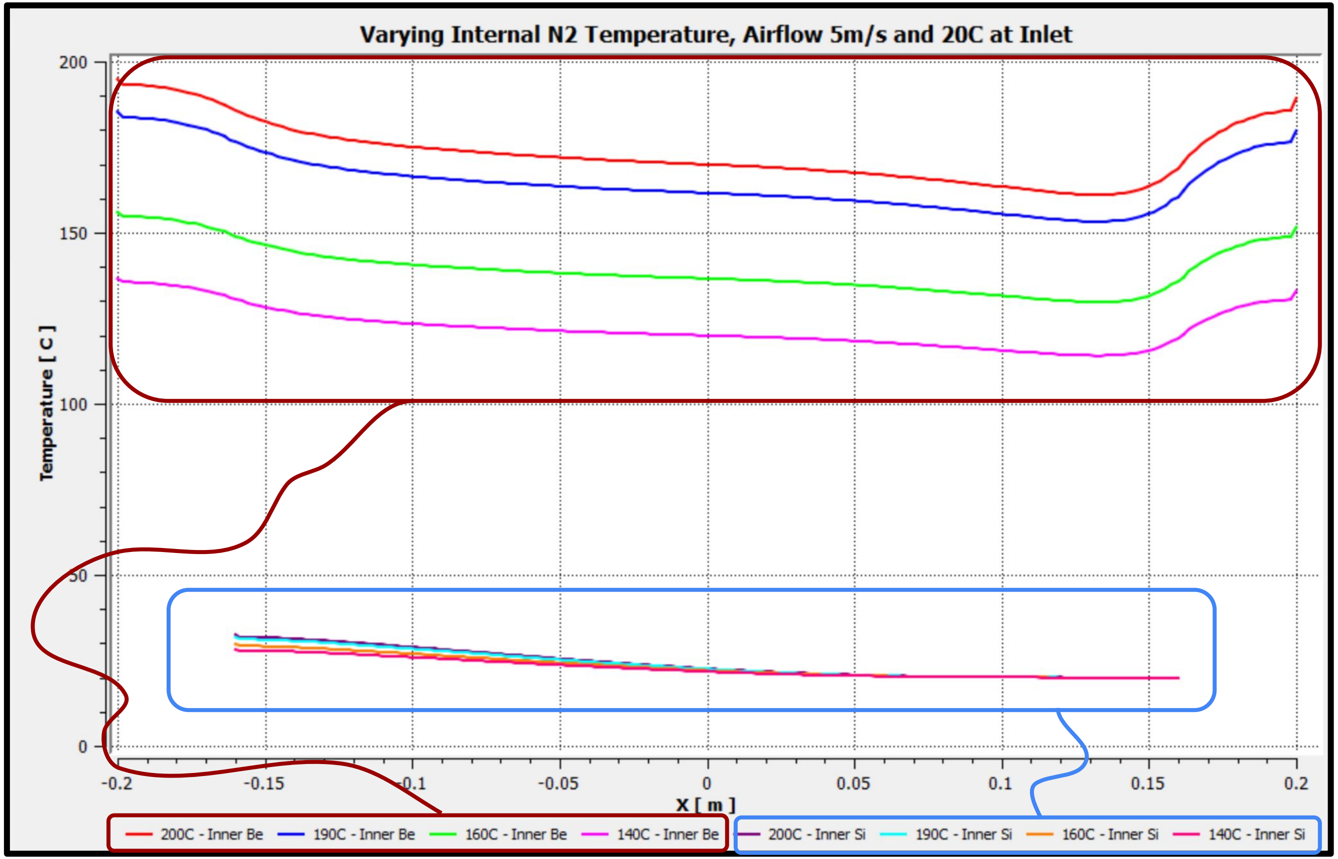
I also transferred this data to a plot for varying internal N2 temperatures.

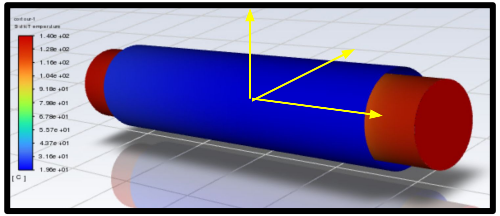
Updated Results



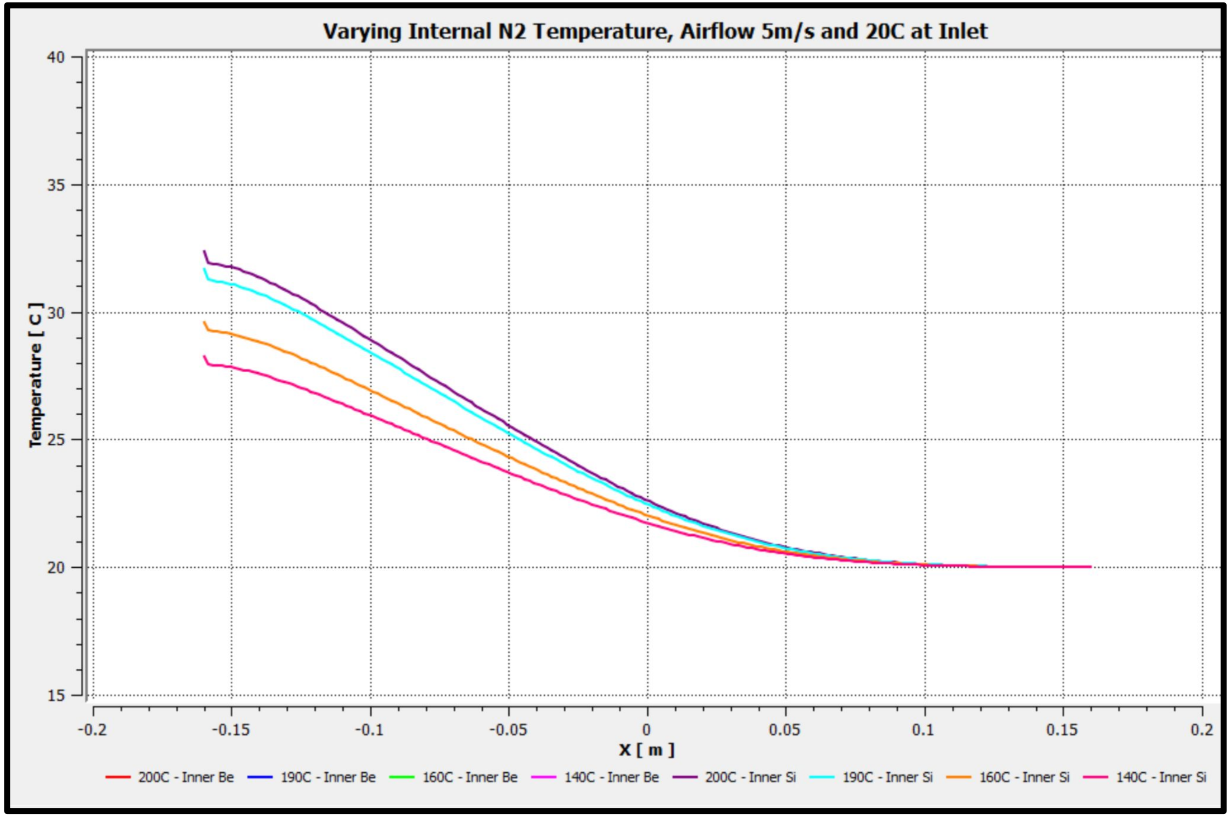


Updated Results





Updated Results



Zoomed in on the Silicon Temperature Distributions above, and thermal contours on the right.

Increasing air velocity decreases the ΔT.

Summary + Future Work

- We now have a range of boundary conditions to serve as a basis for the bakeout, with no aerogel required (but we should double check its effects)!
- Need to verify that my current boundary conditions are up-to-date and possible (ie hot pump flow rate, fast enough airflow, beampipe material, etc)
- Try increasing velocity of hot gas
- Could run a longer simulation if there is much interest

The good news, however, is that we now have a working simulation that I have taken detailed notes on and can reproduce. If changes occur in the setup it should be straightforward to rerun a simulation.

Thanks :)

Old Stuff

ANSYS Simulation Results

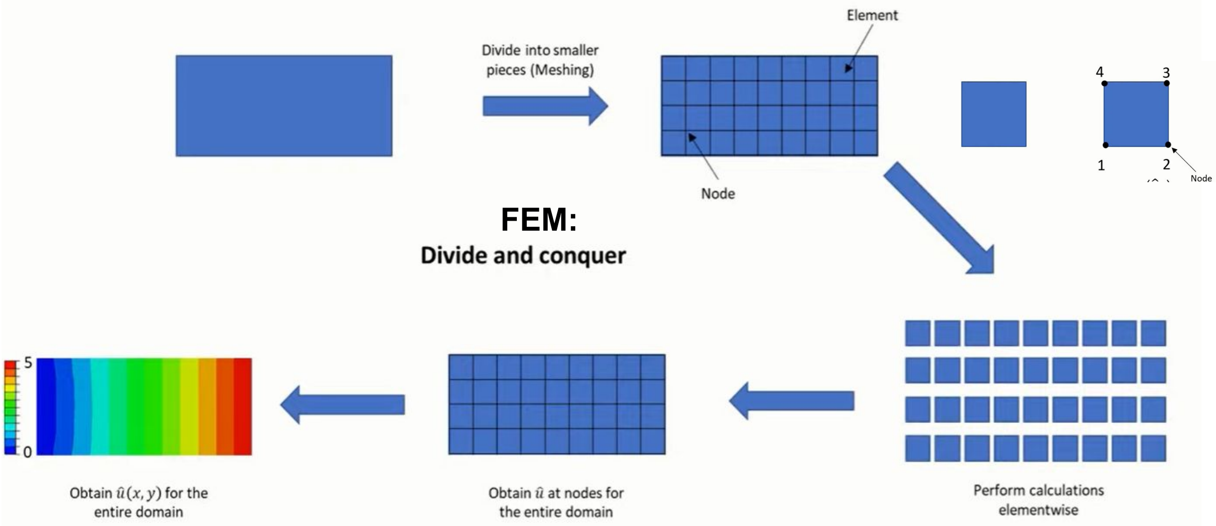
In-Lab Setup and Beampipe Bakeout

By Emma Yeats

Background

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.

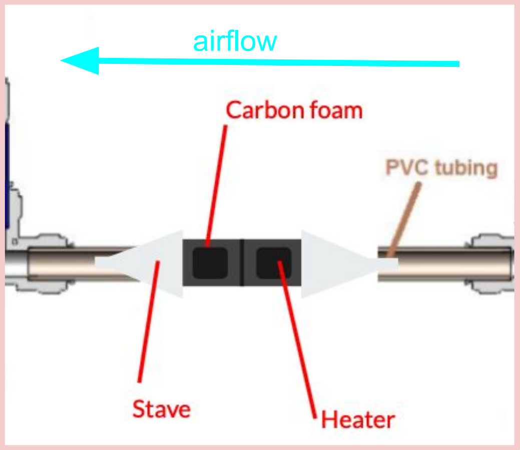
- ❖ Typically used for fluid flow simulations, but we calculated temperature distributions to study the effects of air cooling.

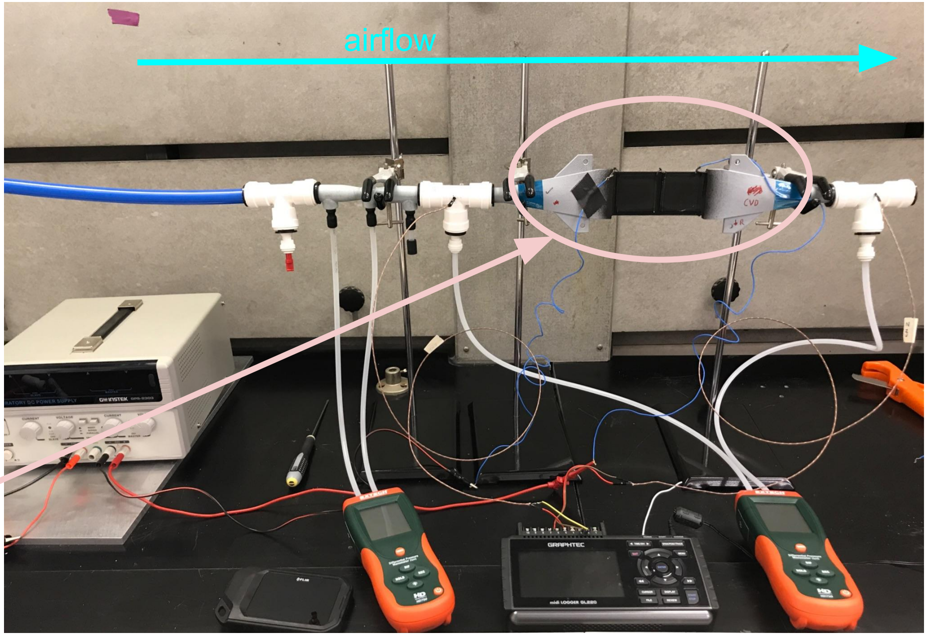
In-Lab Stave Setup

Thermal Simulation

In-Lab Stave Setup

In-lab setup flows air of varying temperature through carbon foam interior to the stave to cool the heater.

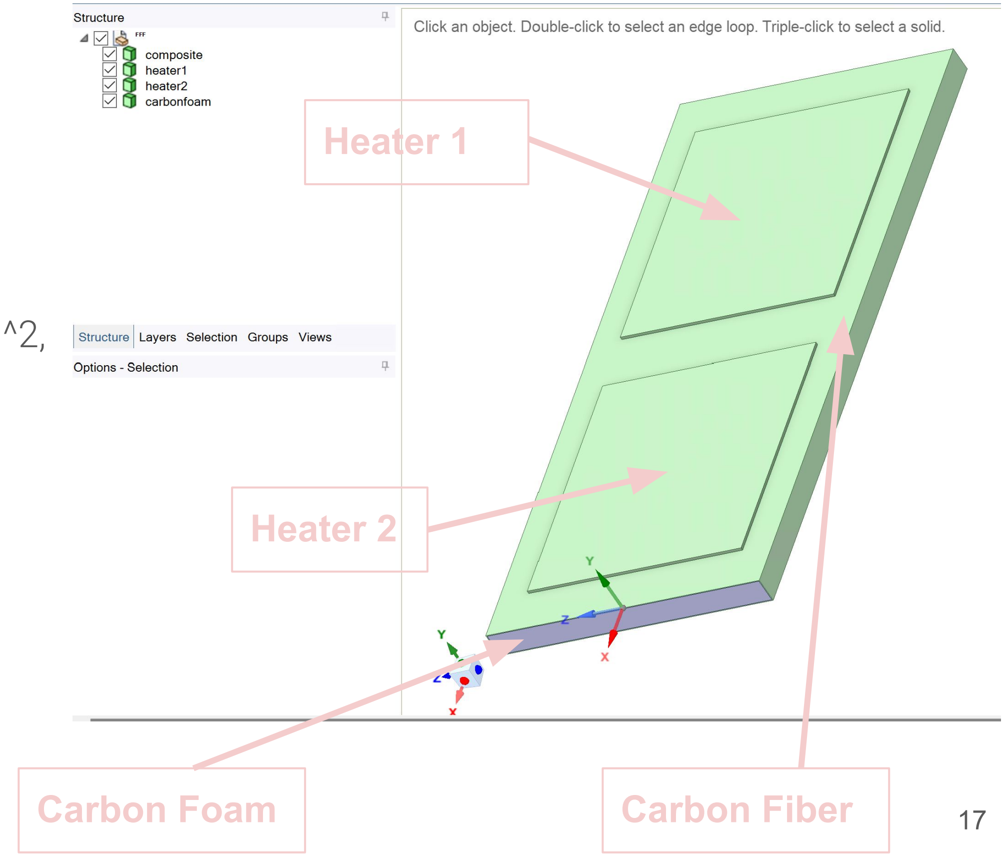




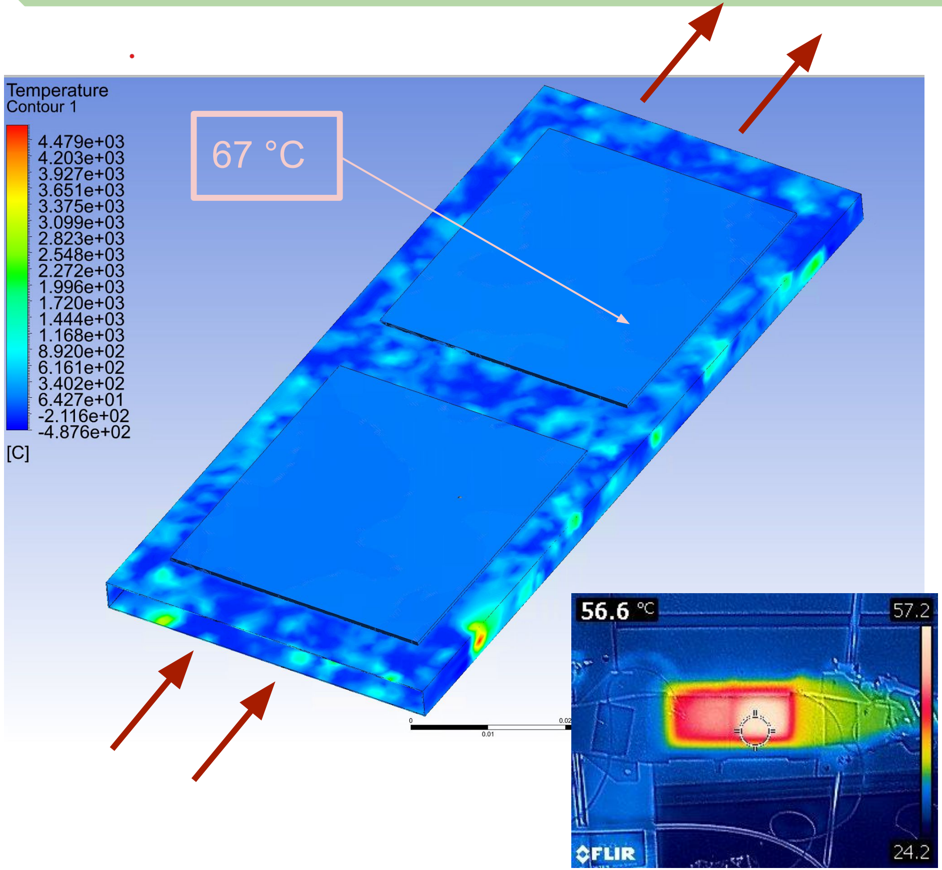
ANSYS Setup

❖ Initial Conditions
  ➢ Heat Output 3000 W/m^2
  ➢ Incoming airflow velocity 5 m/s
  ➢ Incoming airflow temperature 300 K
  ➢ Porous fluid domain with viscous resistance coefficients K=.4462e+8 m^2, c=.15

❖ Materials
  ➢ Carbon foam (porous zone)
  ➢ Carbon fiber
  ➢ Pure silicon



Simulation Results



- Results are close to matching the data found by the in-lab setup.
  - Center of first heater ~325 K (51°C)
  - Center of second heater ~338 K (65°C)

- Porous medium coefficients may need to be adjusted

- Overall, provides a nice benchmark to continue with more air cooling simulations

Beampipe Bakeout

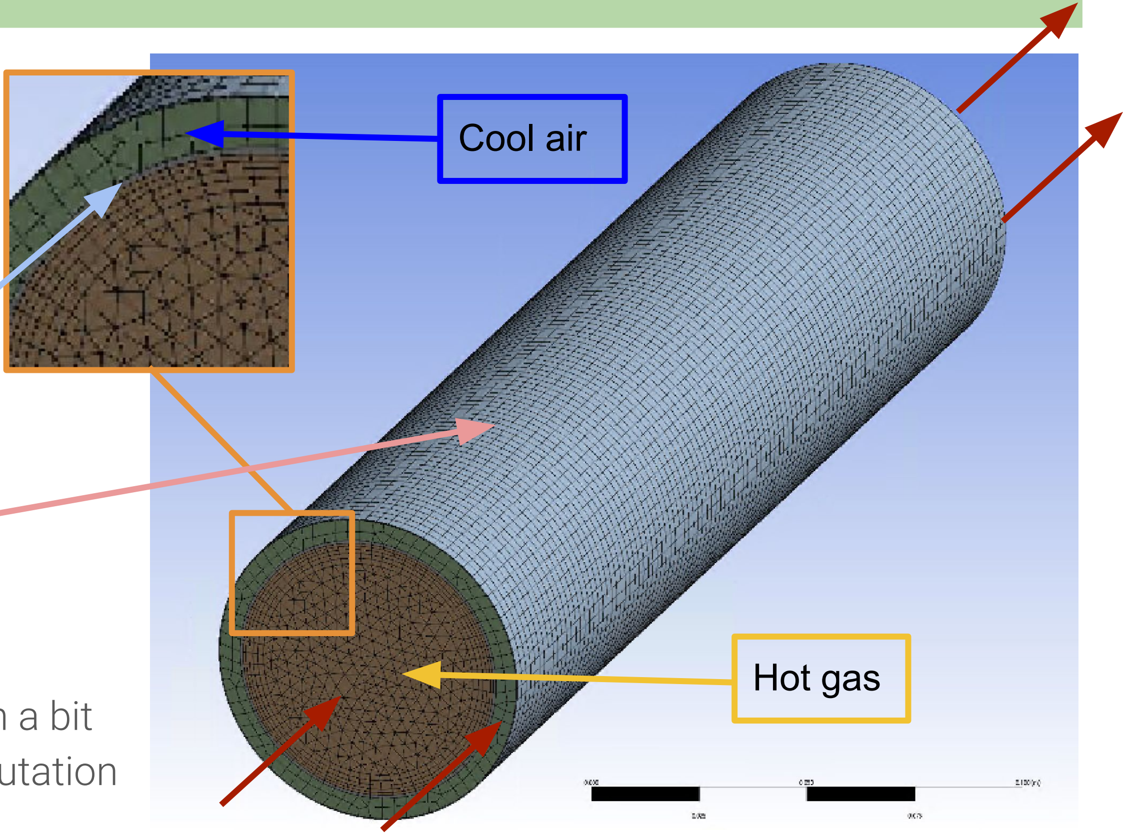
Thermal Simulation

Setup

- ❖ Initial Conditions at Inlet
  - ➢ Cool air temperature 298 K
  - ➢ Cool air velocity 5 m/s
  - ➢ Hot gas velocity 5 m/s

- ❖ Materials
  - ➢ Beryllium Alloy
  - ➢ Pure silicon

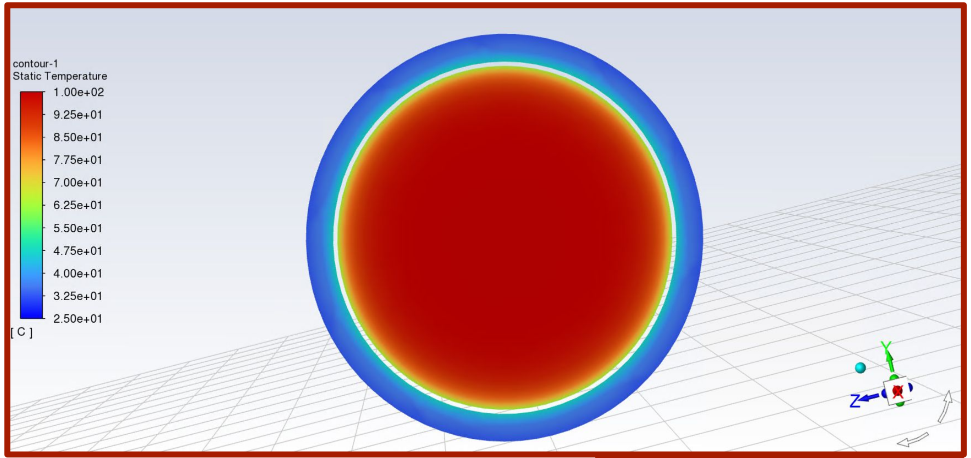
Note: had to make the width of the silicon a bit larger due to limitation in meshing/computation



Simulation Results

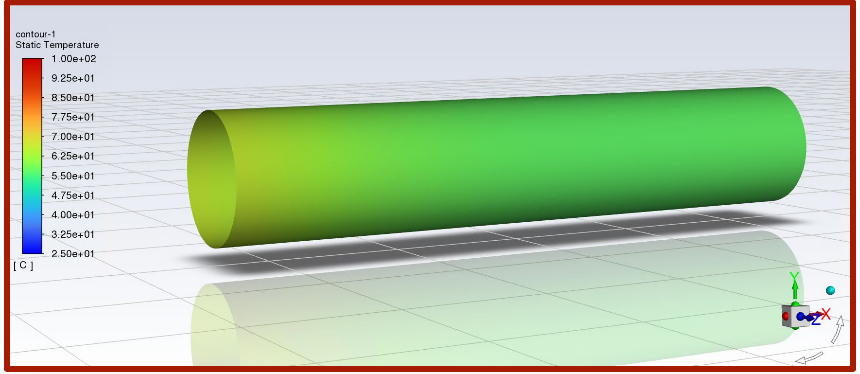
Inner edge cools significantly (60-70°C)

Not great!



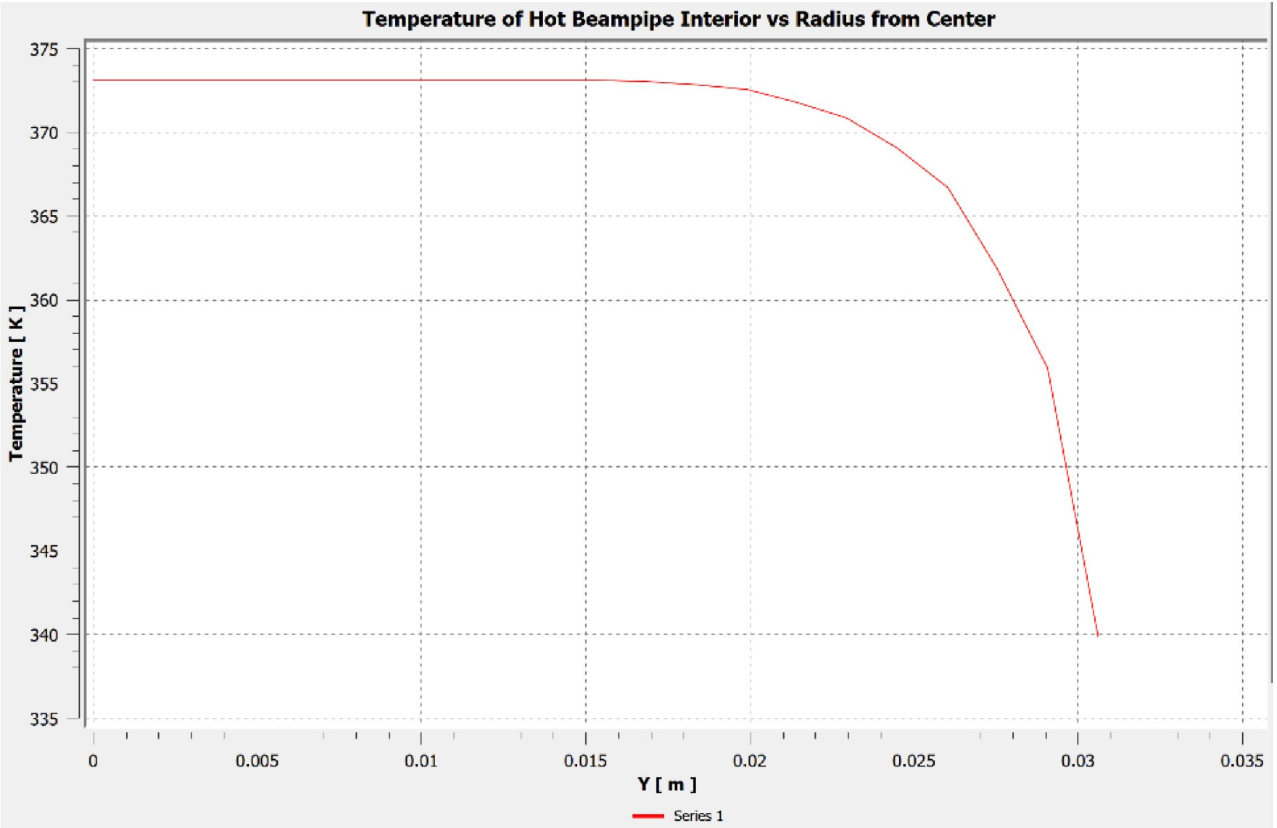
Beampipe Outlet

Inner Surface of Beampipe



Likely need to reoptimize a few parameters, like cooling air velocity, temperature, and hot gas temperature

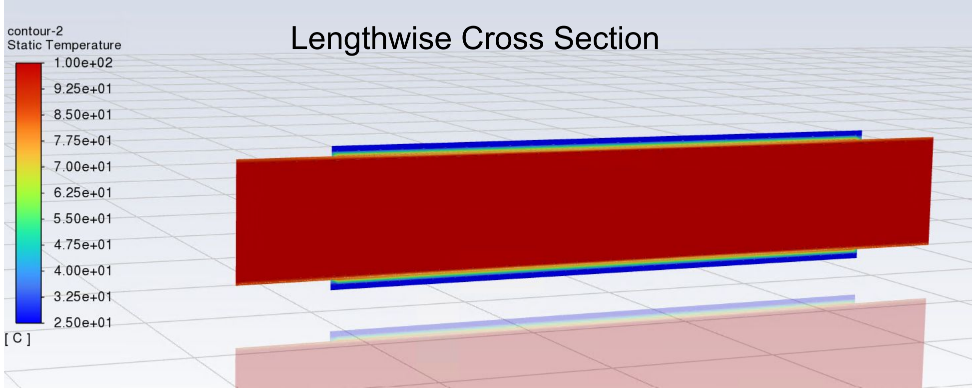
Simulation Results



Sudden drop at edge of beampipe interior (at the outlet).

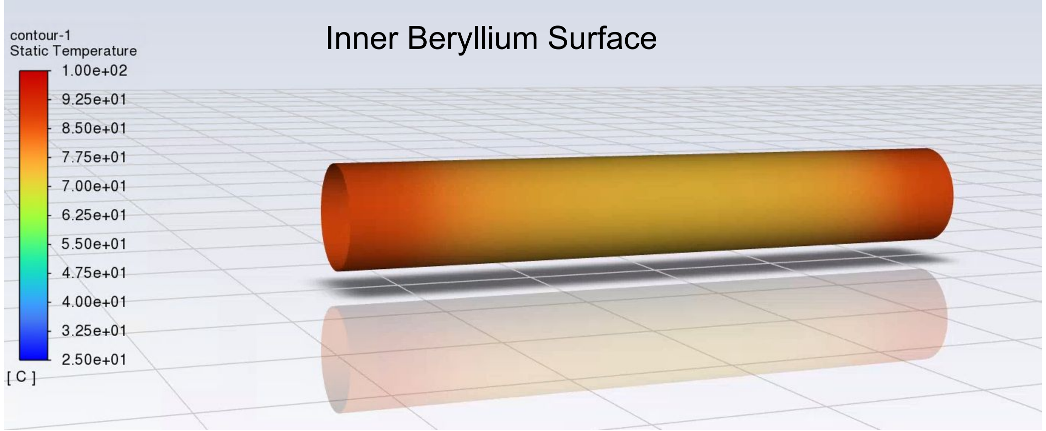
Lowest Temperature is 340 K, or ~67°C

Back to Basics



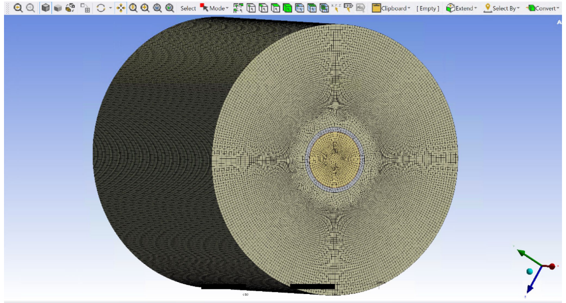
In light of previous results, we wanted to study what would happen if the hot gas was held at constant temperature (100°C) paired with no airflow.

If we can find the minimum hot gas temperature needed to give the beryllium a temperature of 100°C, then our results should mirror JLab's (future work)



Summary + Future Work

- Verified simulation results with experimental data (in-lab setup)
- Began study of beampipe bakeout and working towards a more optimized setup
- What's next?
  - Generally, refine mesh and run more iterations (possible new computer?)
  - Check resistance coefficients for porous medium (carbon foam)
  - Apply air cooling simulation to the barrel and disk components of EIC tracker
  - Include a more accurate geometry of the entire beryllium section of the beampipe
  - Verify type of hot gas used inside
  - Test out different hot gas temperatures
  - Test out different airflow velocities and temperatures



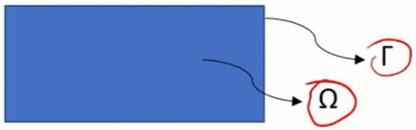
Special Thanks to Youtube Teachers/References

Big shoutout to Ming Zhao on youtube because he’s awesome

- ❖ Singularity Engineering
- ❖ CFD Ninja
- ❖ Solid Mechanics Classroom
- ❖ Ansys-Tutor
- ❖ *Thermal and Mechanical Analysis of Carbon Foam* by Mihnea S. Anghelescu
- ❖ *EIC –Thermal Analysis of Beryllium Section of Beampipe* by Pablo Campero

Backup

Mathematical treatment



- Poisson's equation:

$$\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} = \phi$$

(+ Boundary conditions)

- If $u^e(x,y)$ is an exact solution, then
  - $\frac{\partial^2 u^e}{\partial x^2} + \frac{\partial^2 u^e}{\partial y^2} - \phi = 0$
- Let $\hat{u}$ is an approximate solution,
  - $\frac{\partial^2 \hat{u}}{\partial x^2} + \frac{\partial^2 \hat{u}}{\partial y^2} - \phi \neq 0$
  - Residual $R = \frac{\partial^2 \hat{u}}{\partial x^2} + \frac{\partial^2 \hat{u}}{\partial y^2} - \phi$

- Now the objective is to find an approximate solution $\hat{u}$ such that R is close to zero at each point within our domain Ω

- Weighted-Residual (WR) statement
  - $\int W(x,y)(\frac{\partial^2 \hat{u}}{\partial x^2} + \frac{\partial^2 \hat{u}}{\partial y^2} - \phi)\, d\Omega = 0$ (or)
  - $\int W(x,y)(\nabla^2 \hat{u} - \phi)\, d\Omega = 0$

Integrate by parts

- Weak form of the WR statement
  - $\int W \, \nabla \hat{u} . \hat{n} \, d\Gamma - \int \nabla W . \nabla \hat{u} d\Omega - \int W \phi \, d\Omega = 0$

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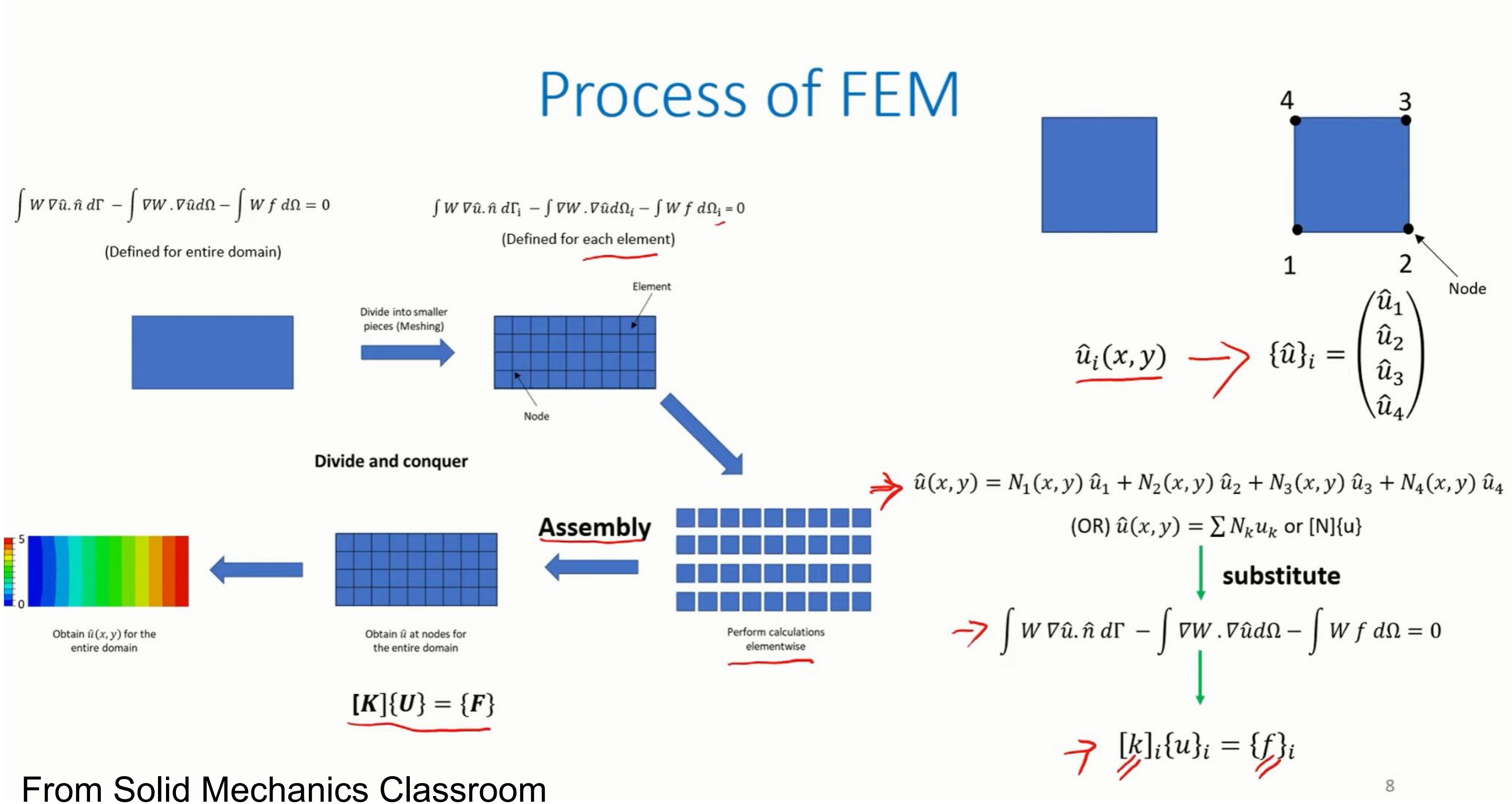
Backup



From Solid Mechanics Classroom