Update: ISU Stave Core QA

BOPING CHEN, WILLIAM HEIDORN,
SHUAIYAN KANG, JIE YU

IOWA STATE UNIVERSITY

ISU WEEKLY STAVE QA MEETING

APRIL 27, 2018

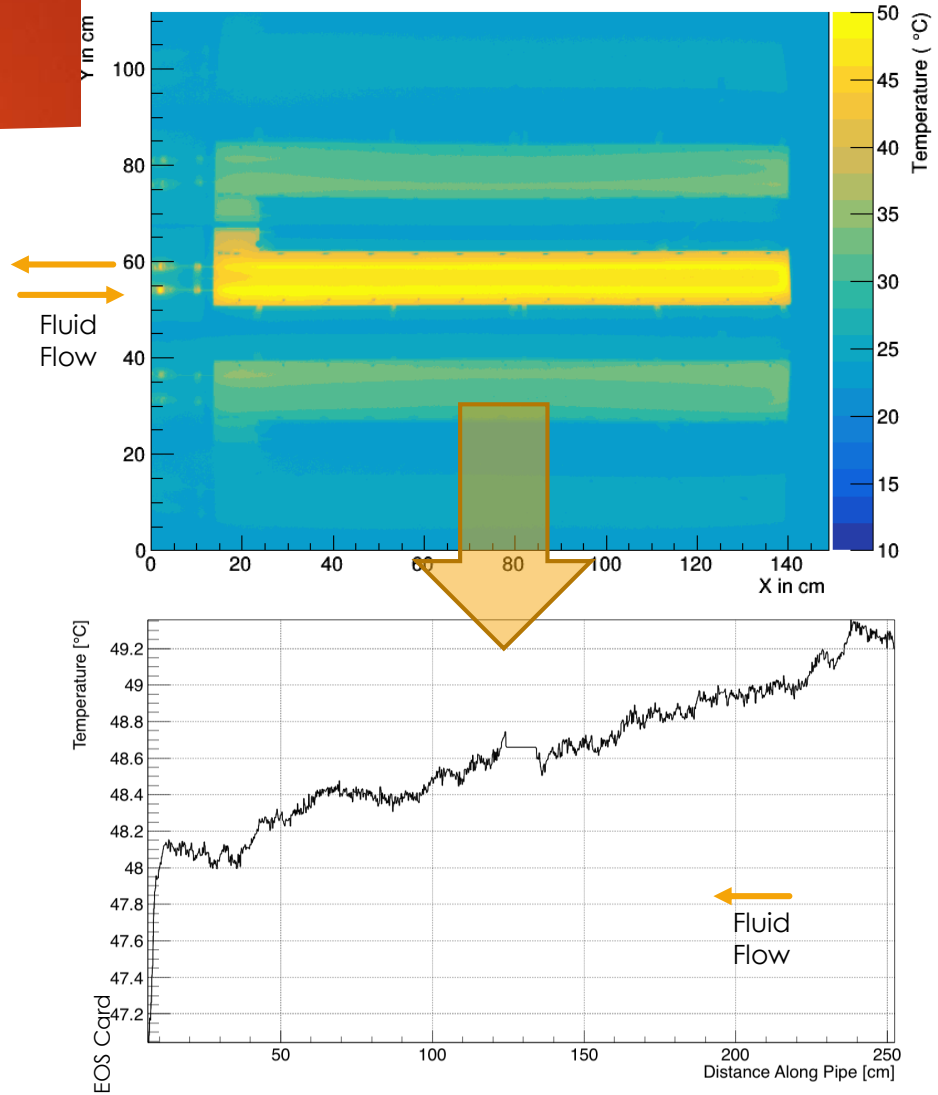
What We Have Been Up Too…

- Stave Core 6 Thermal Measurements
  - Review of Method
  - Hot and Cold Temperature Measurements
  - Comparisons to Previous Flawed Stave 2R
  - Air-Flow Effects
- Stave Core 6 Laser Scanning Measurements
  - Leaks
  - Full Support
  - Edge Support
  - Bending Stiffness
  - Metal Height
- Thermal Measurements of Pipe-Foam Stave
  - Hot and Cold Temperature Measurements
  - Comparisons with breaks in foam structure
  - Fluid Reversal

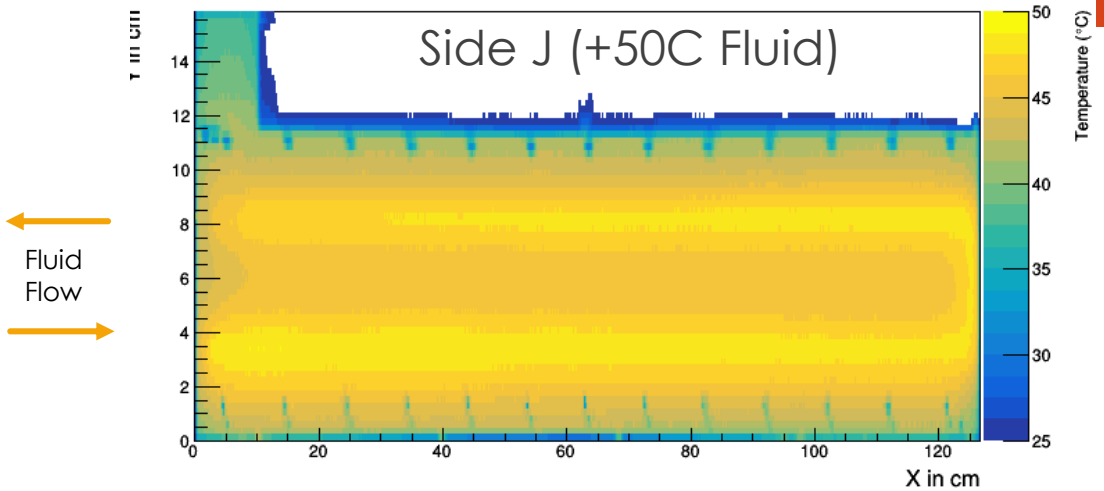
Stave Core 6: Thermal Measurements

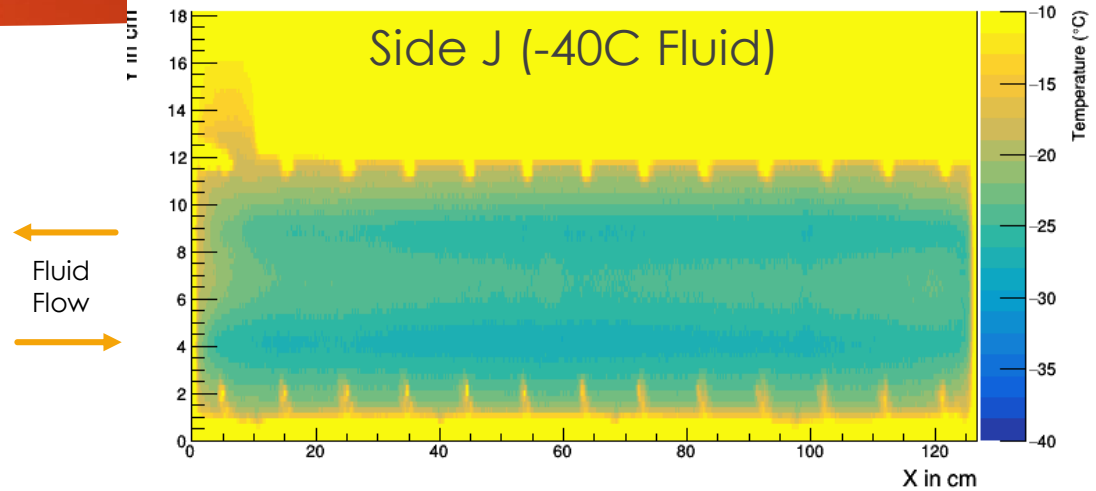
Thermal Measurement Method

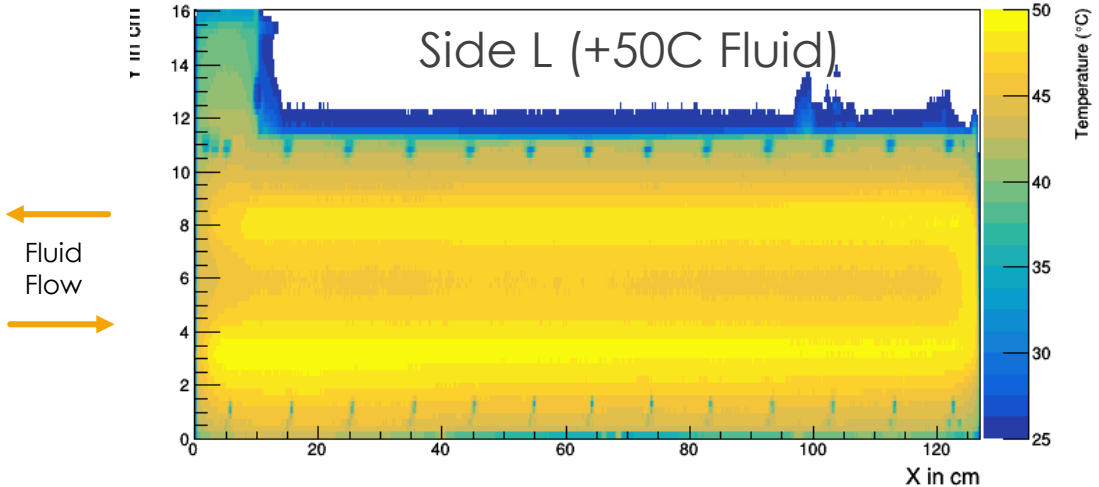
- The thermal measurements were made with fluid flow through the stave of ~1 l/min with high(+50C) or low (-40C) temperature fluid.
- Before data is taken,10 minutes are waited without any nitrogen airflow in the enclosure.
- A series of 200 frames were taken at 25 frames/second with the FLIR A655sc camera with an 80 degree lens
- The 200 frames of raw data are averaged into a single frame using an emissivity value of 0.95 (read_sequence.sh)
- The stave location is then extracted from the image (configFinder.py) and the thermal profile along the cooling pipes of the stave excluding the end regions are found. (frameanal.py)
- The defect finding algorithm is then used to find any defects on the stave and create plots. (defectFinder.py)

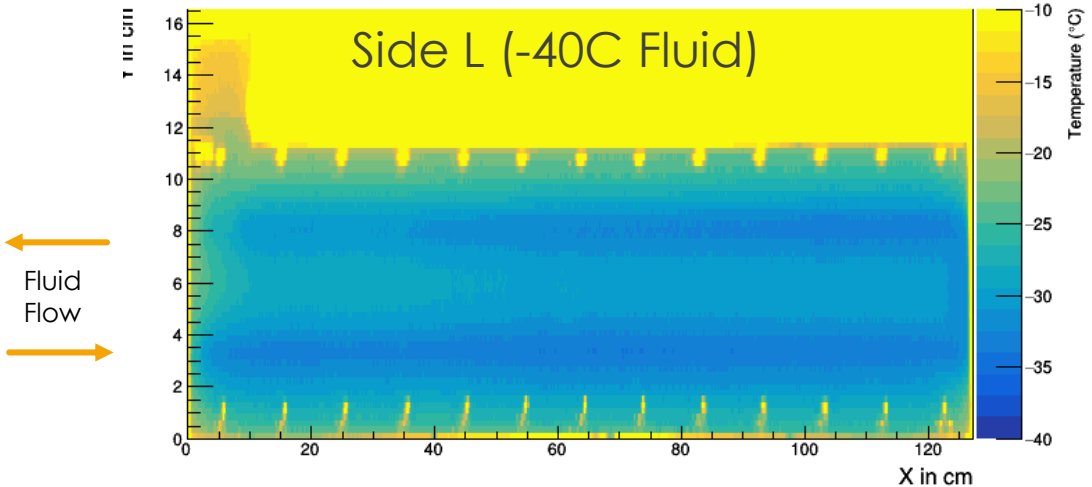


Stave 6: Thermal Measurements
(Thermal images)



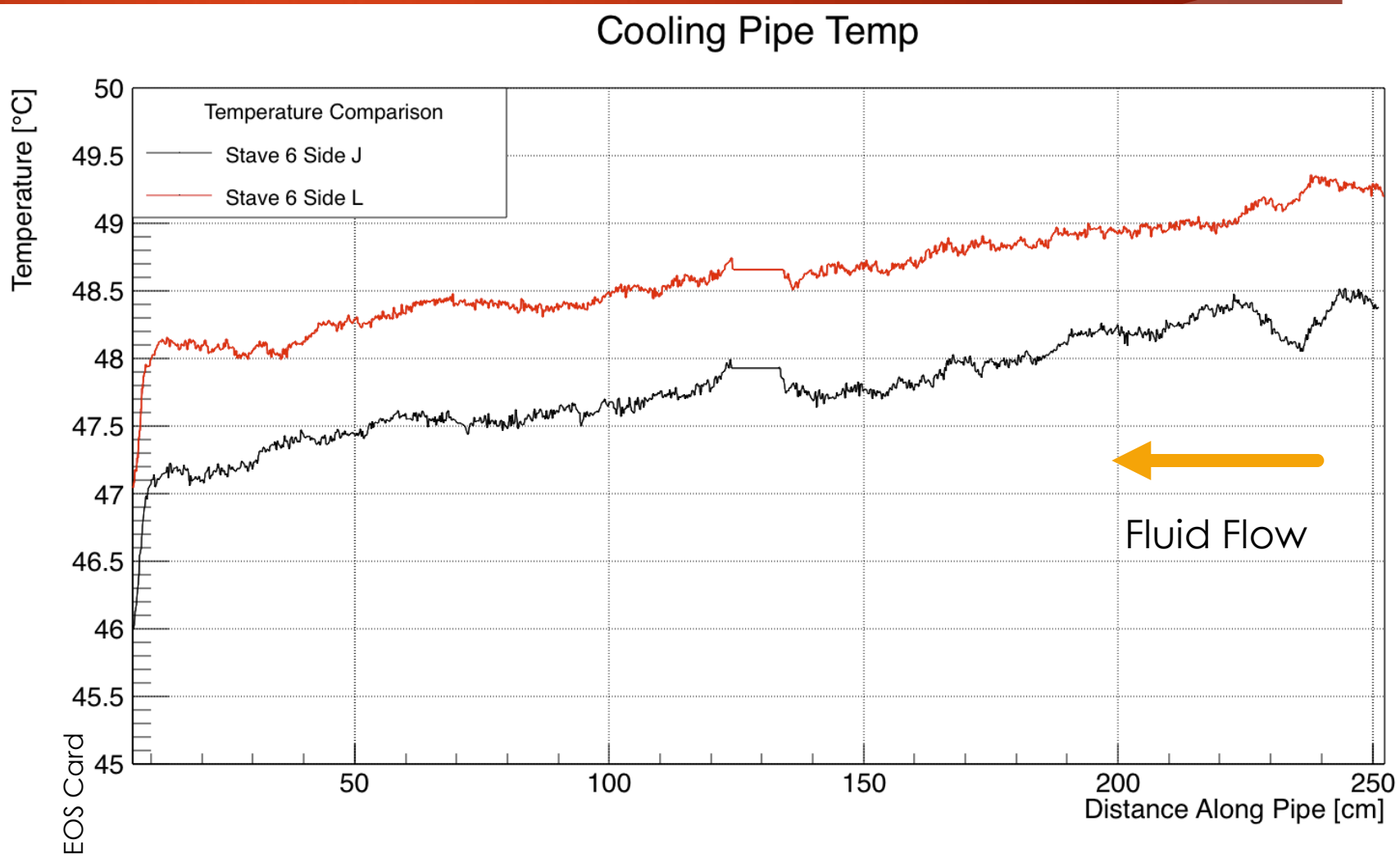






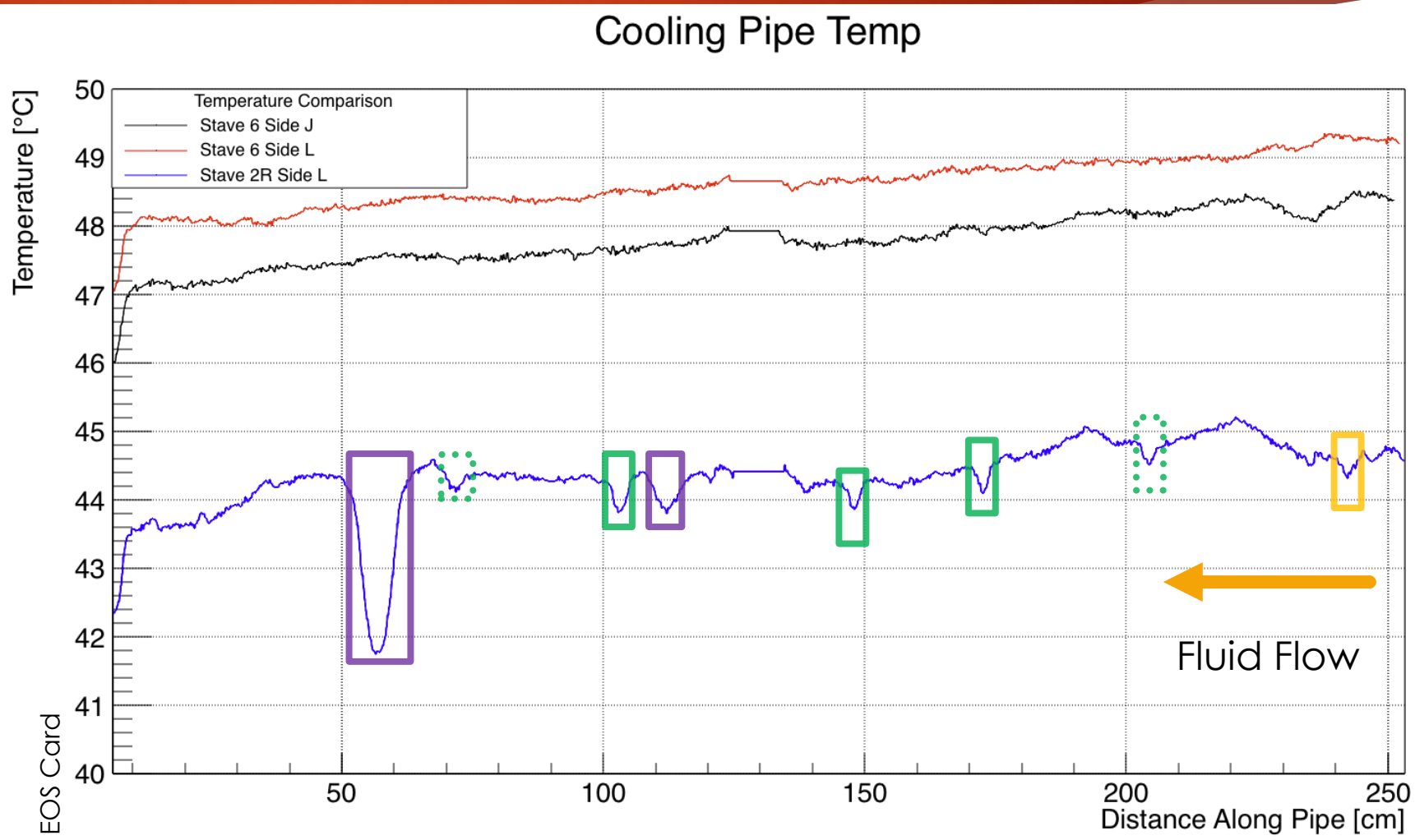
Stave 6: Thermal Measurement Hot

- Thermal measurements were taken on both sides of the stave with 50 C fluid flowing into the stave core
- The defect finder found no flaws
- Linear Fit RMS was found
  - J Side: 0.12 C
  - L Side: 0.09 C



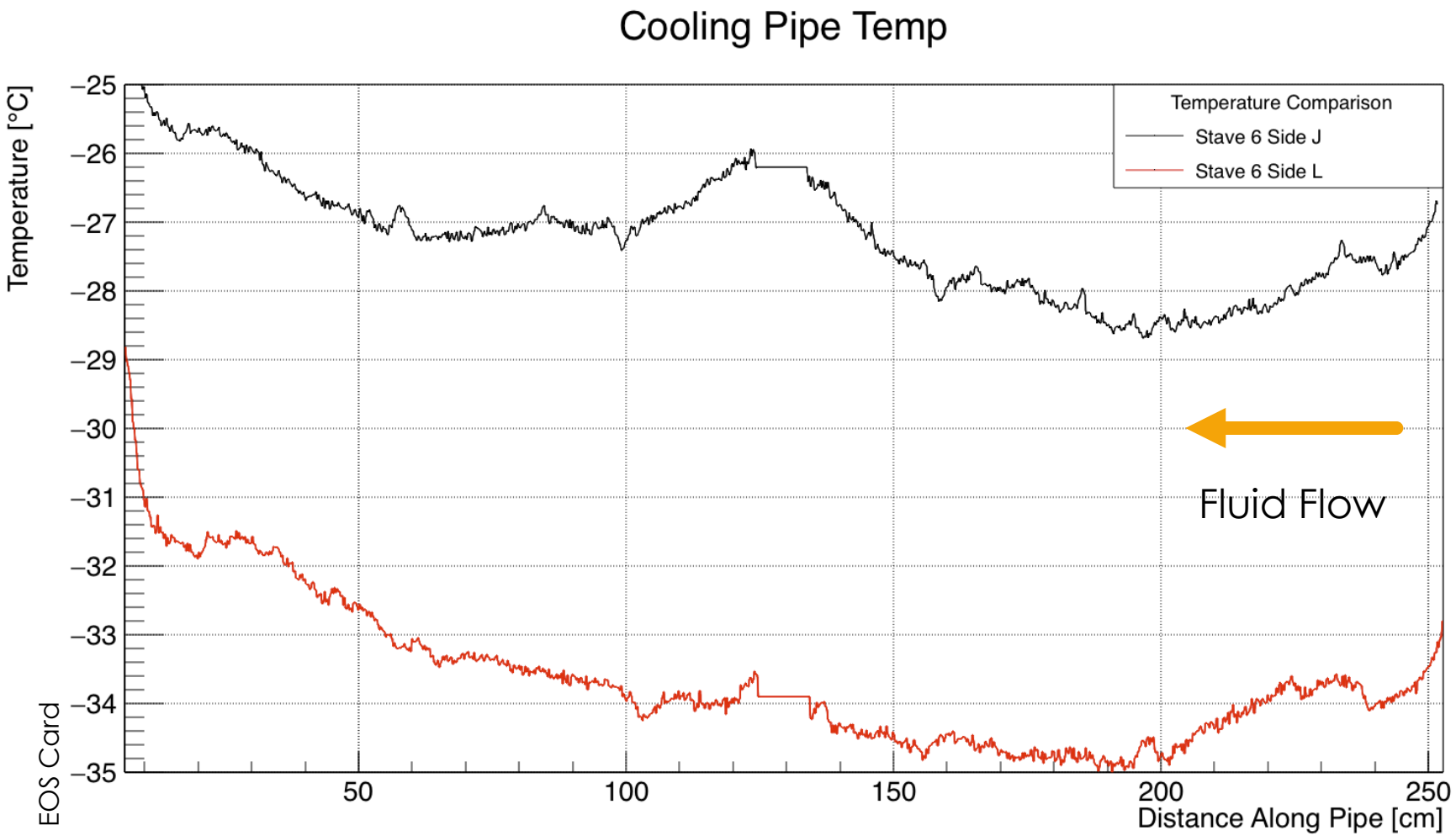
Stave 6 Comparison with Stave 2R Hot

- This is a comparison between stave 6 and 2R with +50C fluid flowing
- The defects found are boxed on the 2R profile
  - **Purple**: Pipe-Foam
  - **Green**: Foam-Facing
  - **Green Dotted**: Partial Foam-Facing
  - **Orange**: Unimplemented



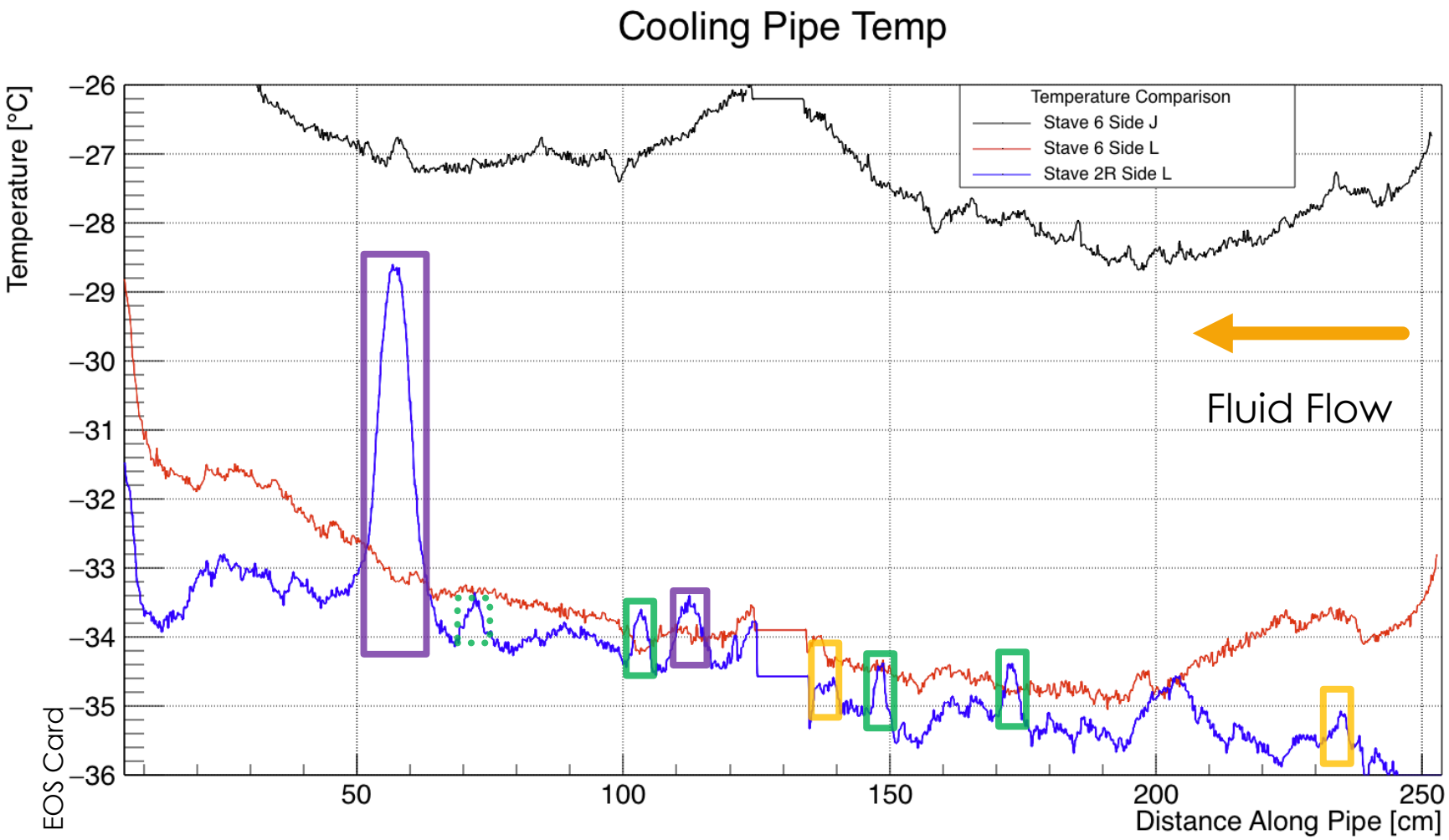
Stave 6: Thermal Measurement Cold

- Thermal measurements were taken on both sides of the stave with -40C fluid flowing into the stave core
- Dry nitrogen was turned off at least 10 minutes before measurements were taken
- The large differences are due to slight differences when the measurements were taken and how long the system had been at low temperature.
  - Next set of studies will be to find what needs to be kept constant to get identical results
- The defect finder found no flaws
- Linear Fit RMS was found
  - J Side: 0.6 C
  - L Side: 0.6 C



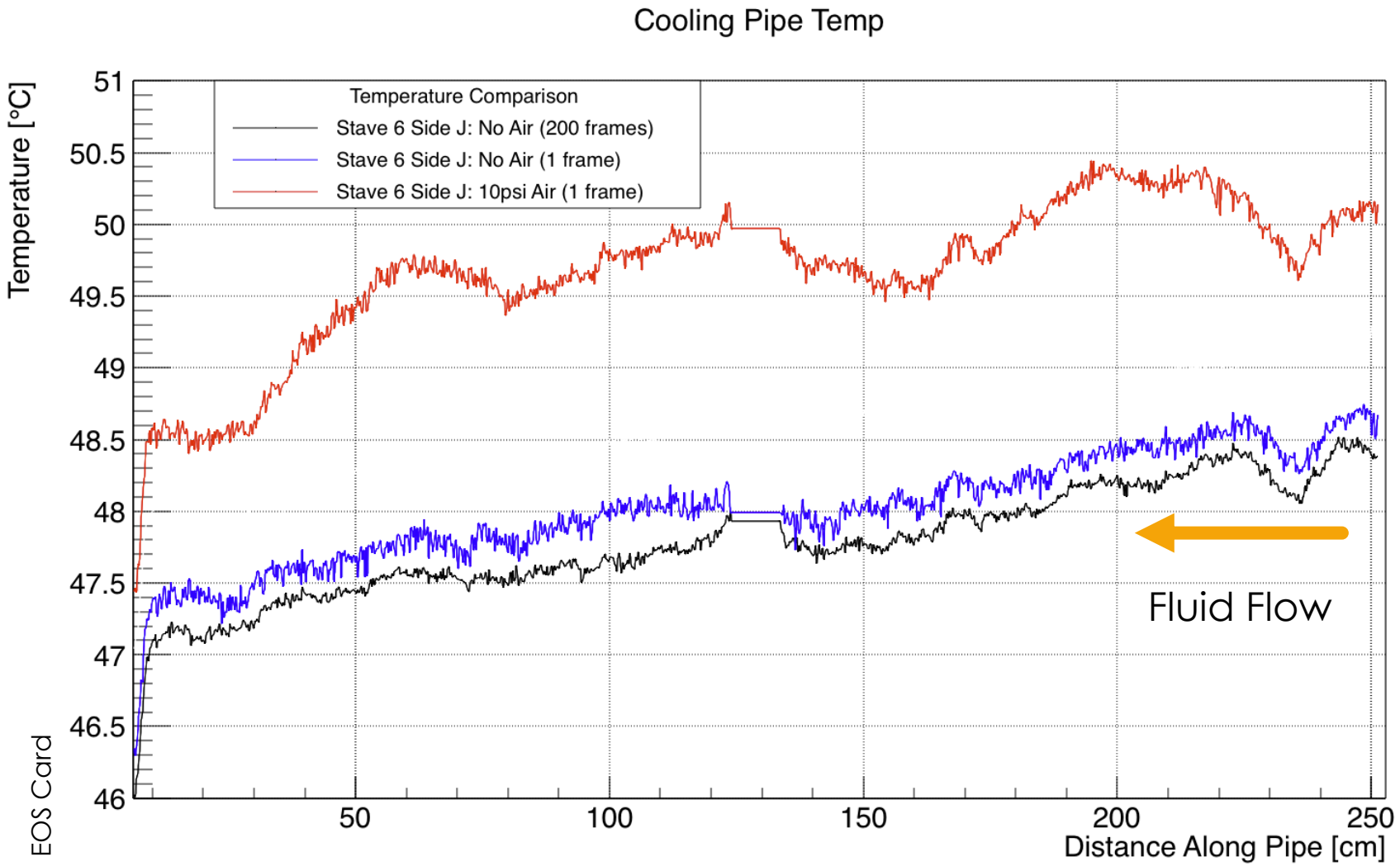
Stave 6 Comparison with Stave 2R Cold

- This is a comparison between stave 6 and 2R with -40C fluid flowing
- Profiles are more chaotic…
- The defects found are boxed on the 2R profile
  - **Purple**: Pipe-Foam
  - **Green**: Foam-Facing
  - **Green Dotted**: Partial Foam-Facing
  - **Orange**: Unimplemented



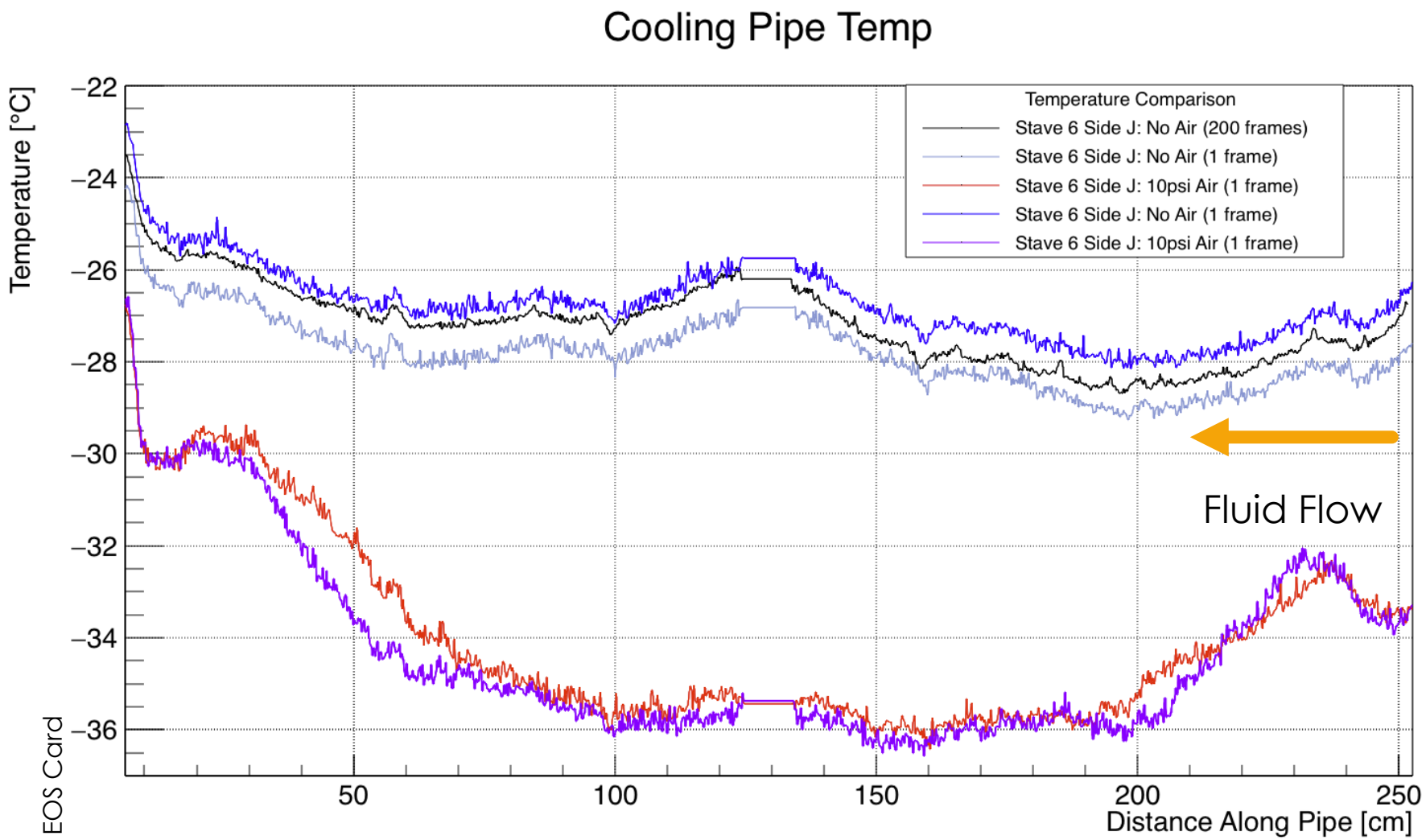
Stave 6: Air Flow Effects Hot

- To stop frosting from occurring during low temperature measurements, dry nitrogen is pumped into the enclosure.
- Air flow rate into box at 10psi: ~40 l/min
- With the nitrogen on there is a definite change of shape thermal profile
- Convection effects the baseline temperature by pulling it further away from ambient



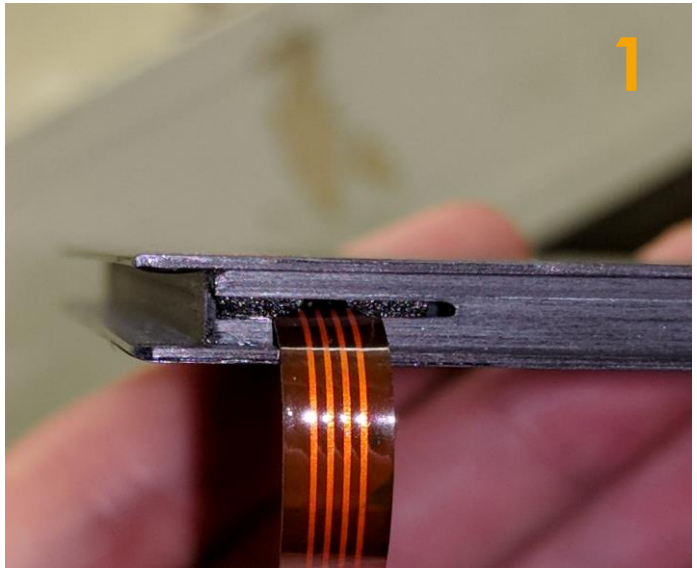
Stave 6: Air Flow Effects Cold

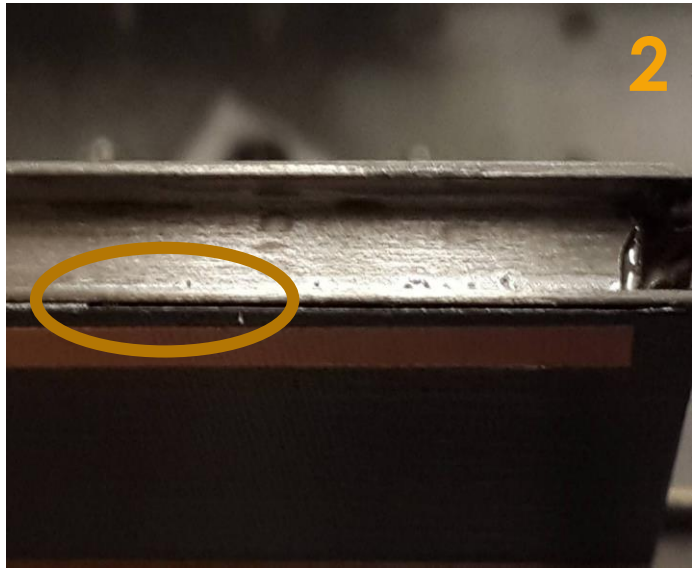
- Air flow rate into box at 10psi: ~40 l/min
- With the nitrogen on there is a definite change of shape thermal profile
- Convection effects the baseline temperature by pulling it further away from ambient
- If you were to timestamp each measurement
  - Red: T = 0 min
  - Grey: T = 33 min
  - Black: T = 35 min
  - Blue: T = 36 min
  - Purple: T = 69 min

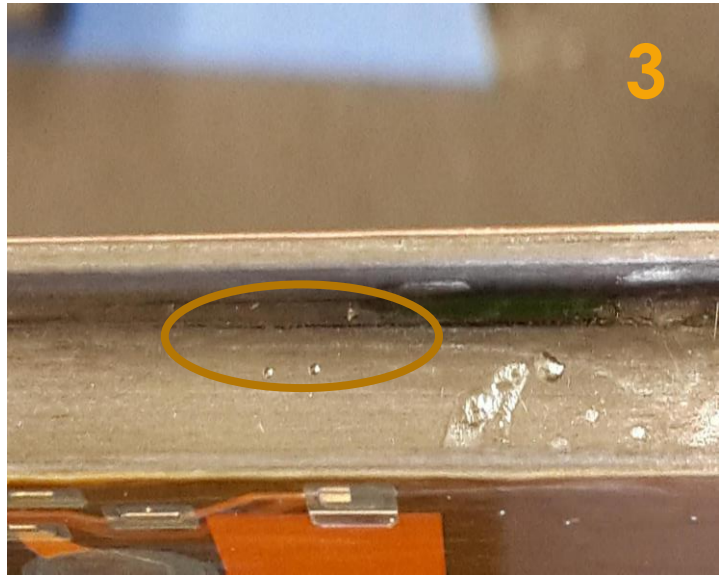


Stave Core 6: Laser Scanning Measurements

Stave 6: Leaks Found

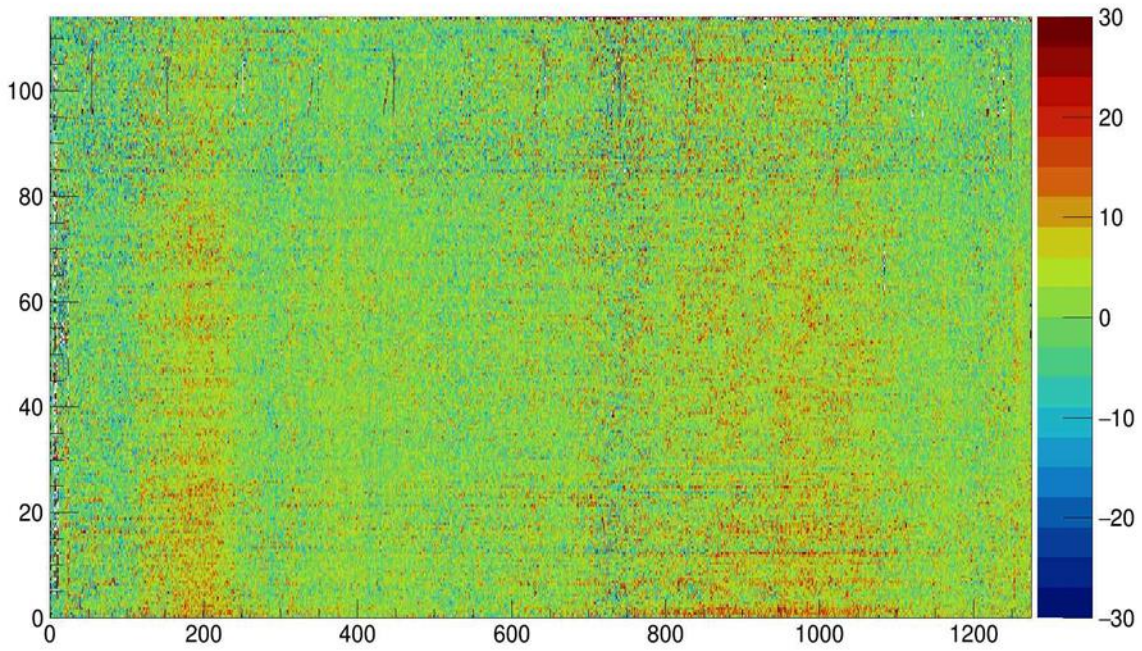






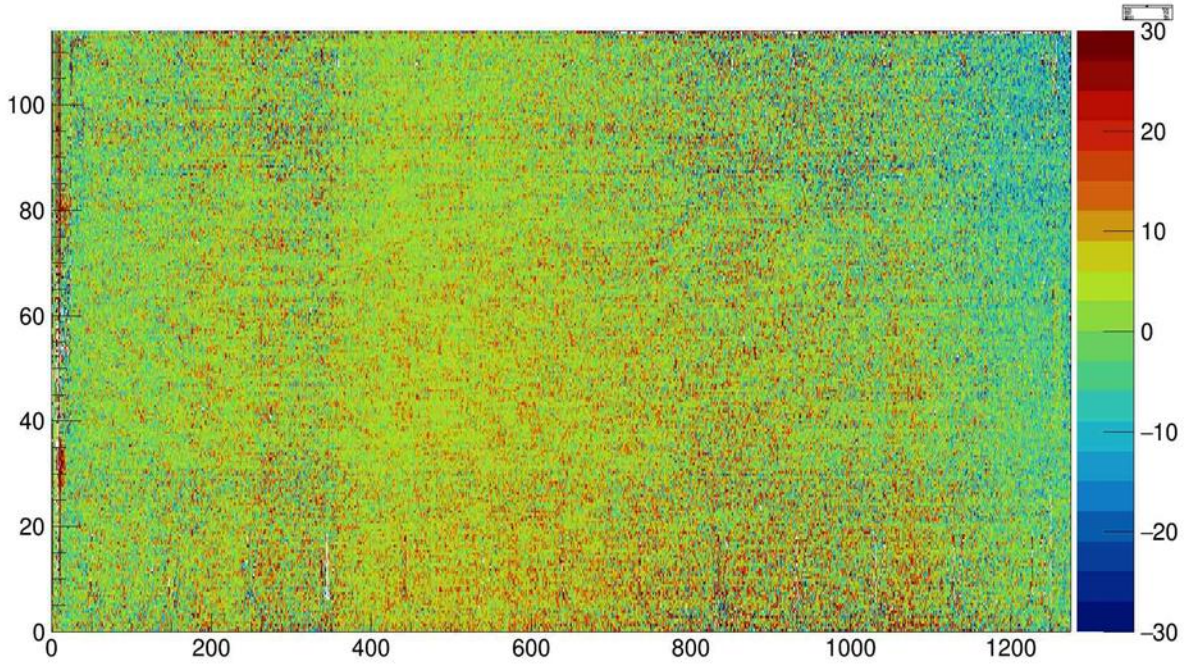
Stave 6: Full Support Pressure Test
(10 supports on both sides of the stave)

L side 5-0psi



RMS: 7.4

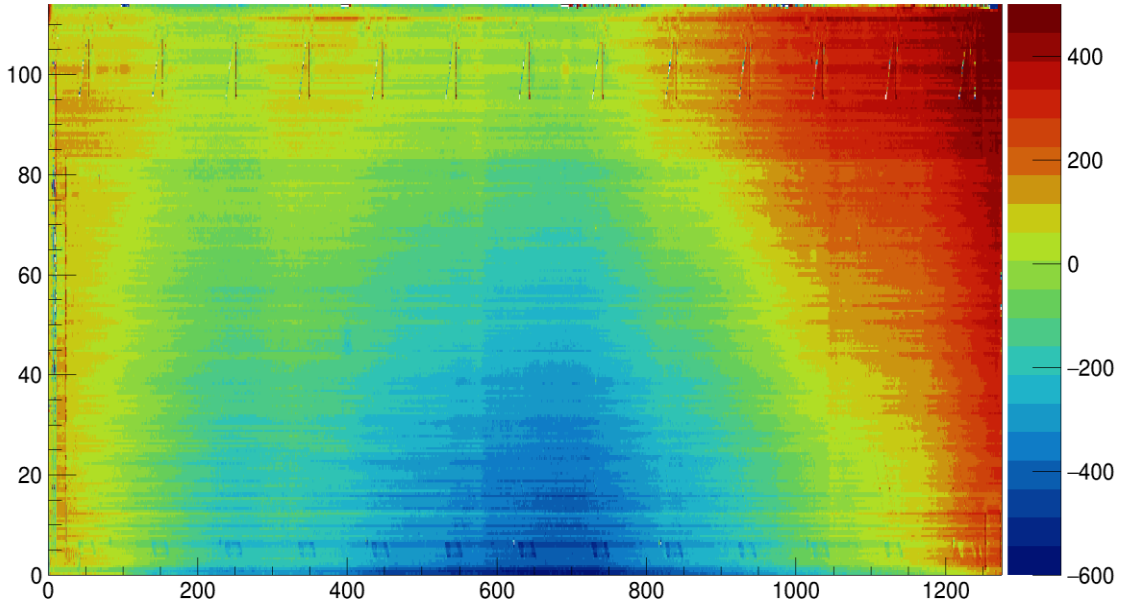
J side 5-0psi



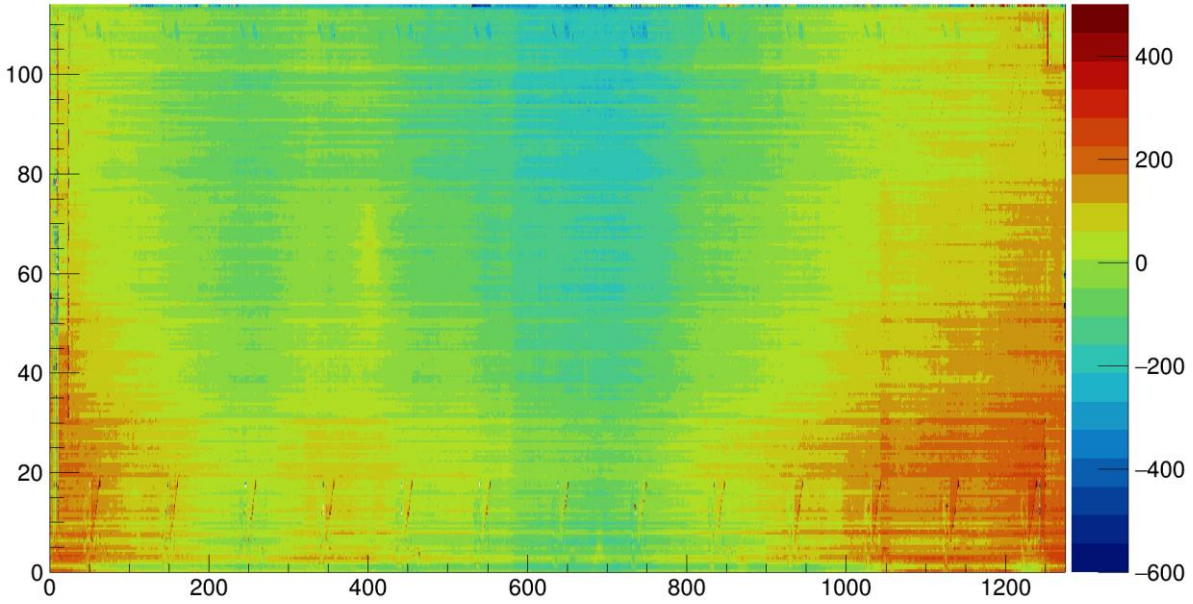
RMS: 9.4

Stave 6: Edge Support
(5 supports one side, 2 supports on other side)

L side

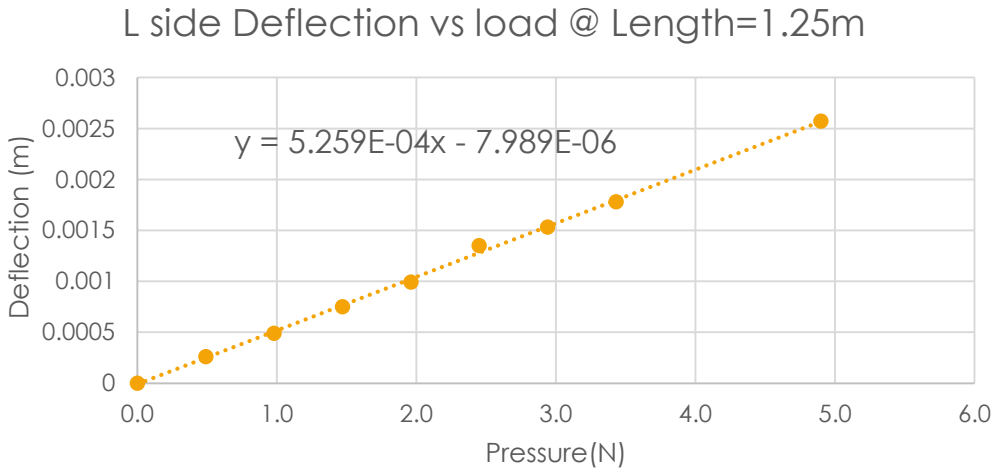


J side

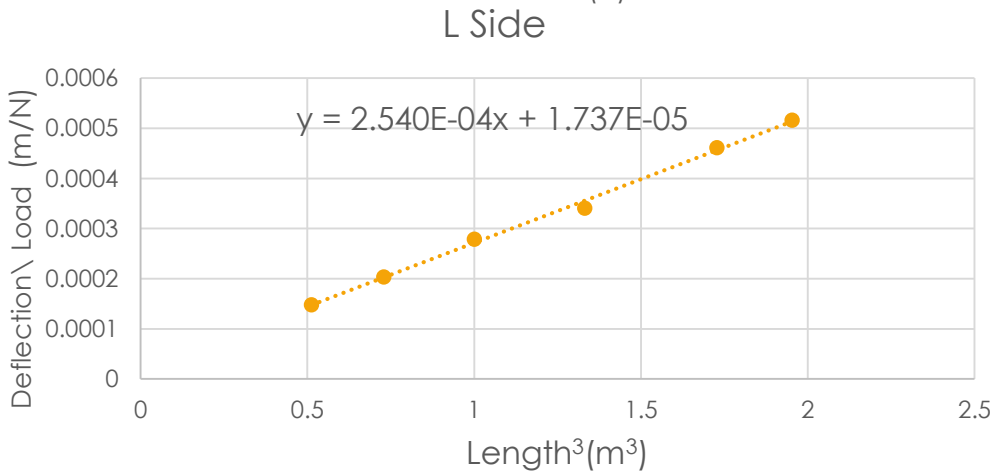


Stave 6: Bending Stiffness

The deflection versus load was measured for each length



The deflection was measured with different loads at several fixed lengths



$$\delta = \frac{1}{48D} L^3 P$$

δ:deflection(m)

L:stave length (m)

P:load(N)

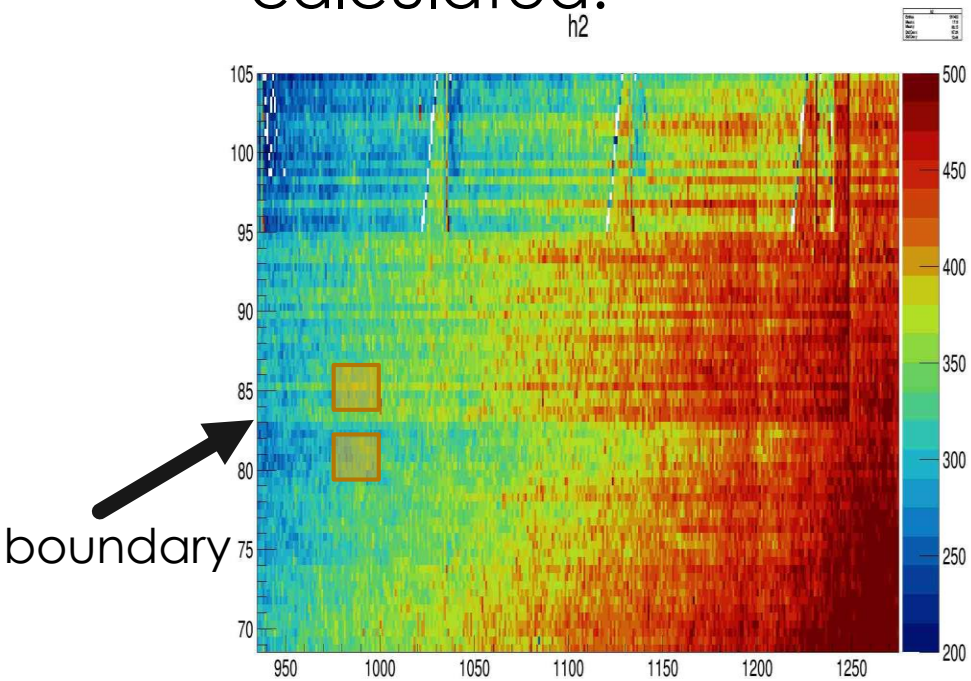
D: bending stiffness(N m^2)

$$\text{L Side}: D = \frac{1}{48 \times 2.54E-4} = 82.01(\text{N } m^2)$$

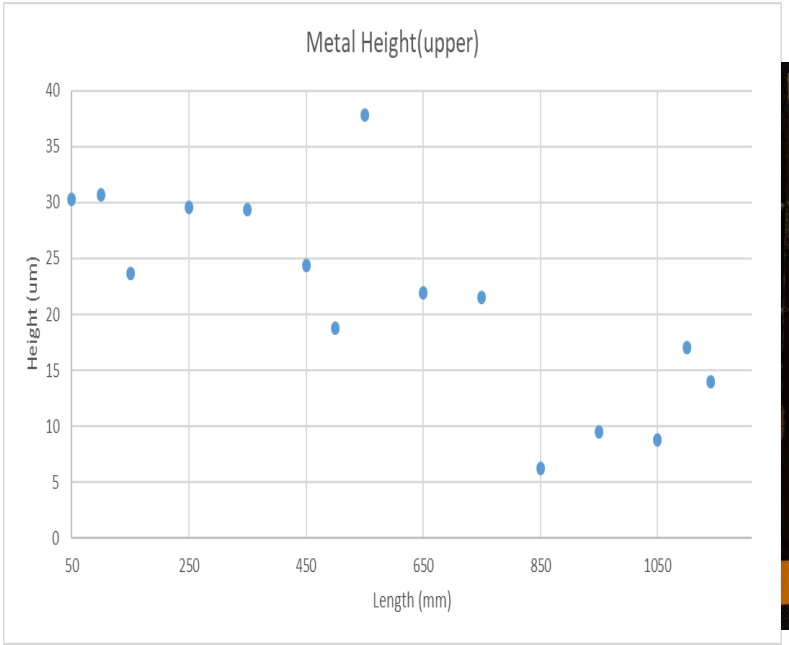
$$\text{J Side}: D = 79.87\ (\text{N } m^2)$$

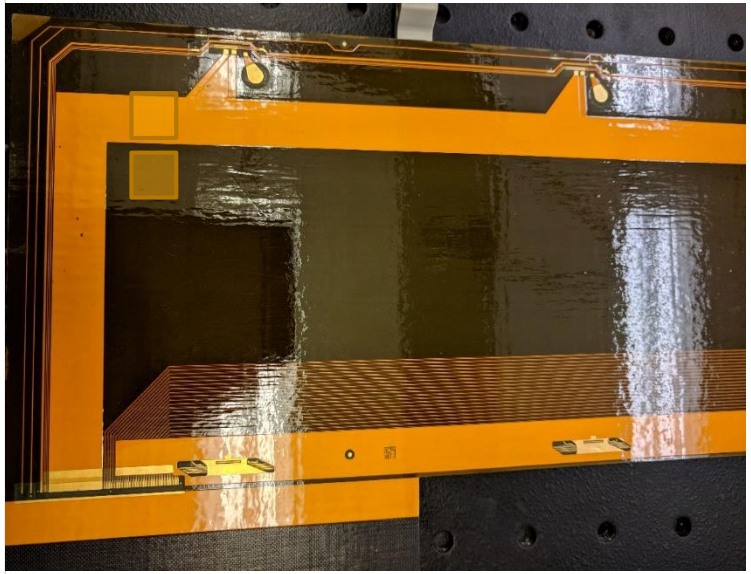
Stave 6: Metal Height (upper)

Method: Two 3*3(mm^2) squares were chosen across from the boundary and the difference of the averaged values were calculated.



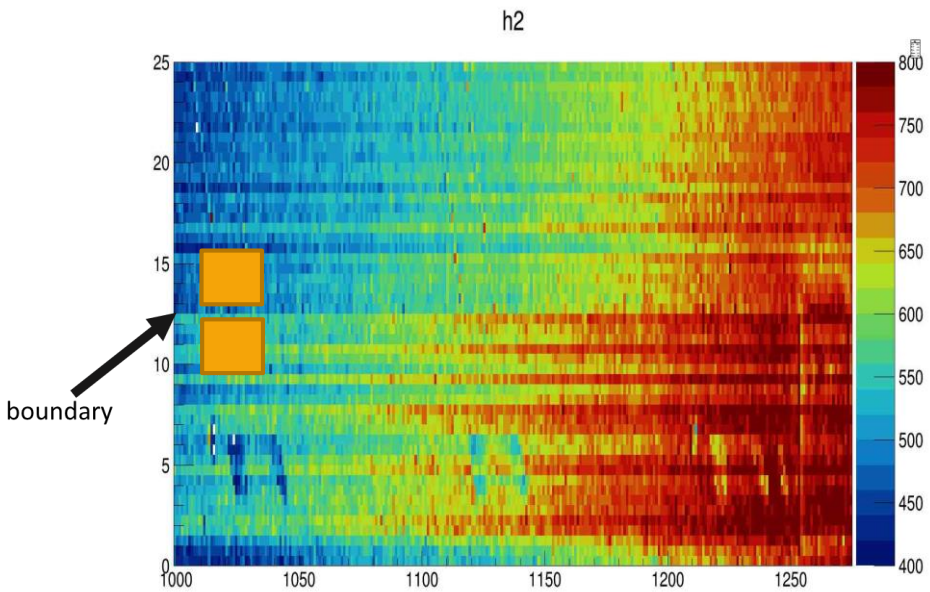
L side 0Psi (zoomed)



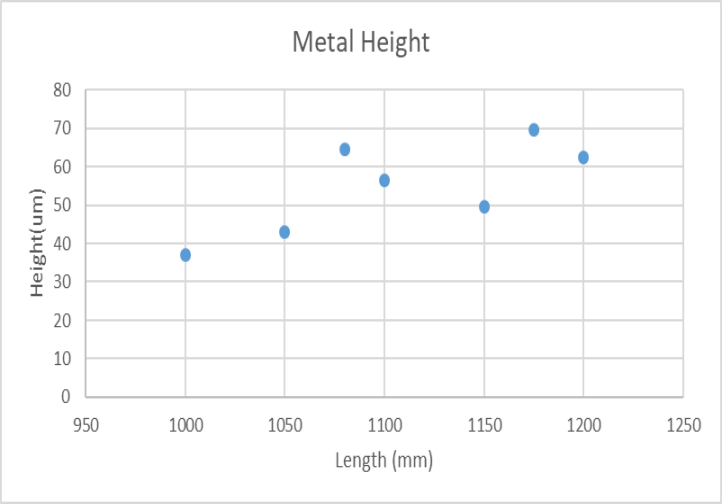


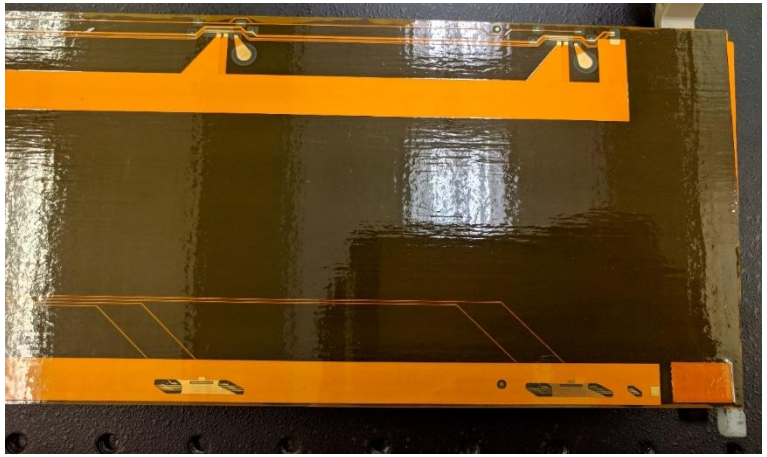
Same area height difference ~8um

Stave 6: Metal Height (lower)



L side 0Psi (zoomed)





Same area height difference ~14um

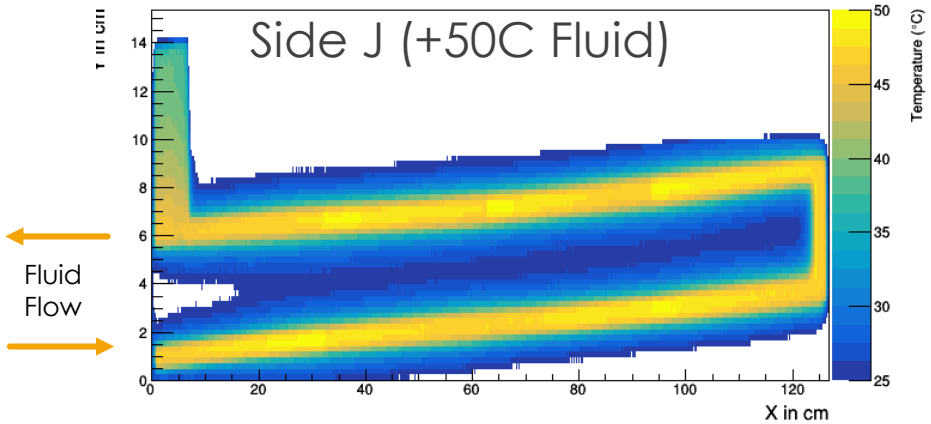
Stave 6: Summary

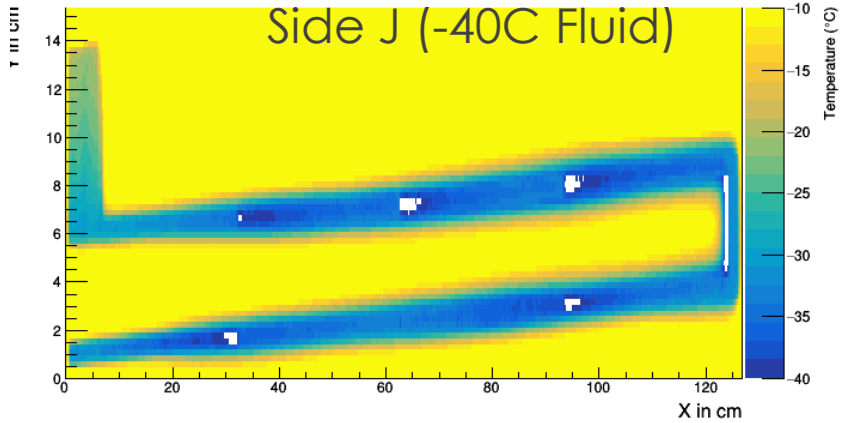
- Thermal Defects- None Found!
- Laser Scanning Defects- None Found!
- Bending Stiffness of Stave
  - J Side- $79.87\ (\mathrm{N}\ m^2)$
  - L Side- $82.01\ (\mathrm{N}\ m^2)$

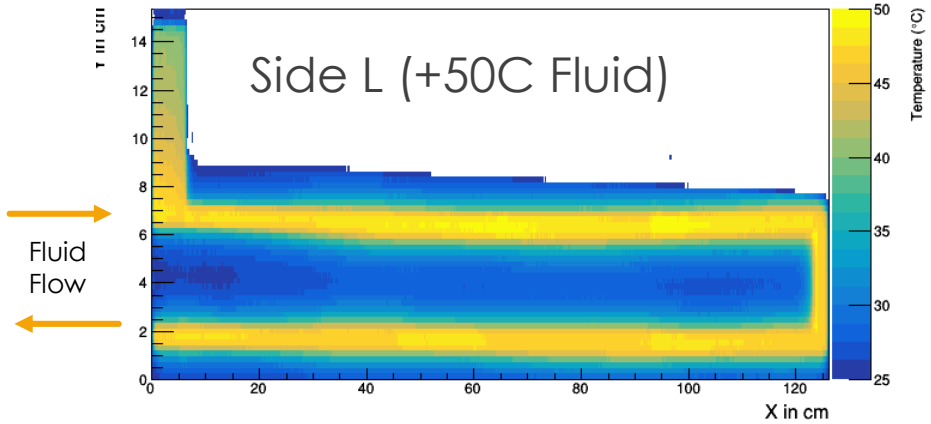
Pipe-Foam Stave: Thermal Measurements

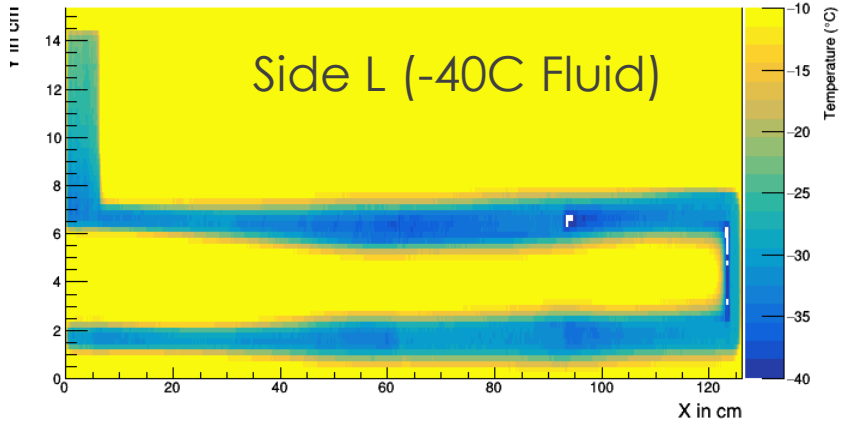
Pipe-Foam Stave: Thermal Measurements (Thermal images)

- Use similar procedure as mentioned(slide 3) for data conversion
- Emissivity problems
  - All profile plots use a thermal data conversion with emissivity = 0.73
  - This is not correct. Small swings in the value (+0.06) can contribute to large absolute changes
    - >1 C with high temp fluids
    - >5 C with low temp fluids
  - Does not significantly effect the relative shapes of the profile



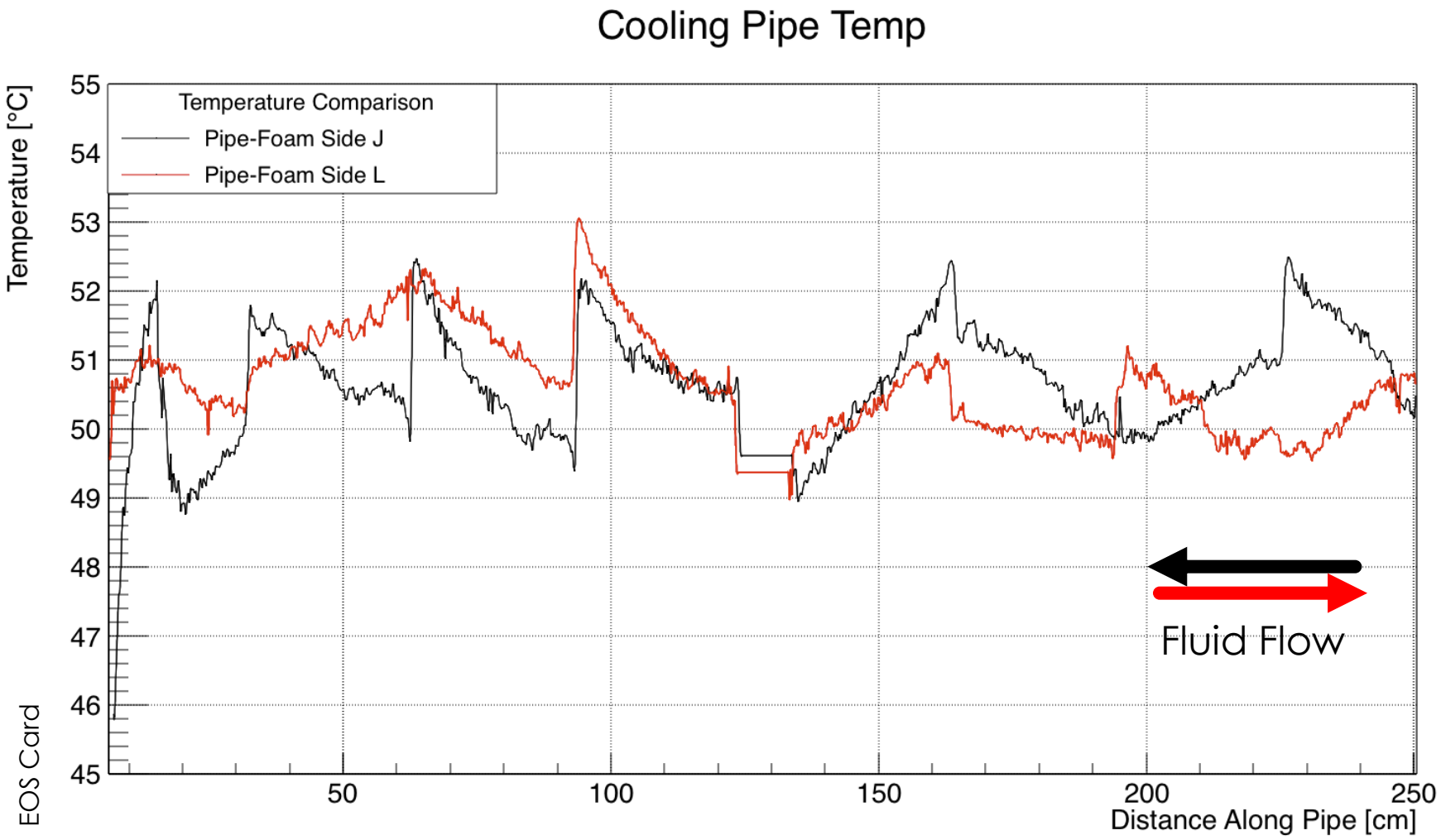






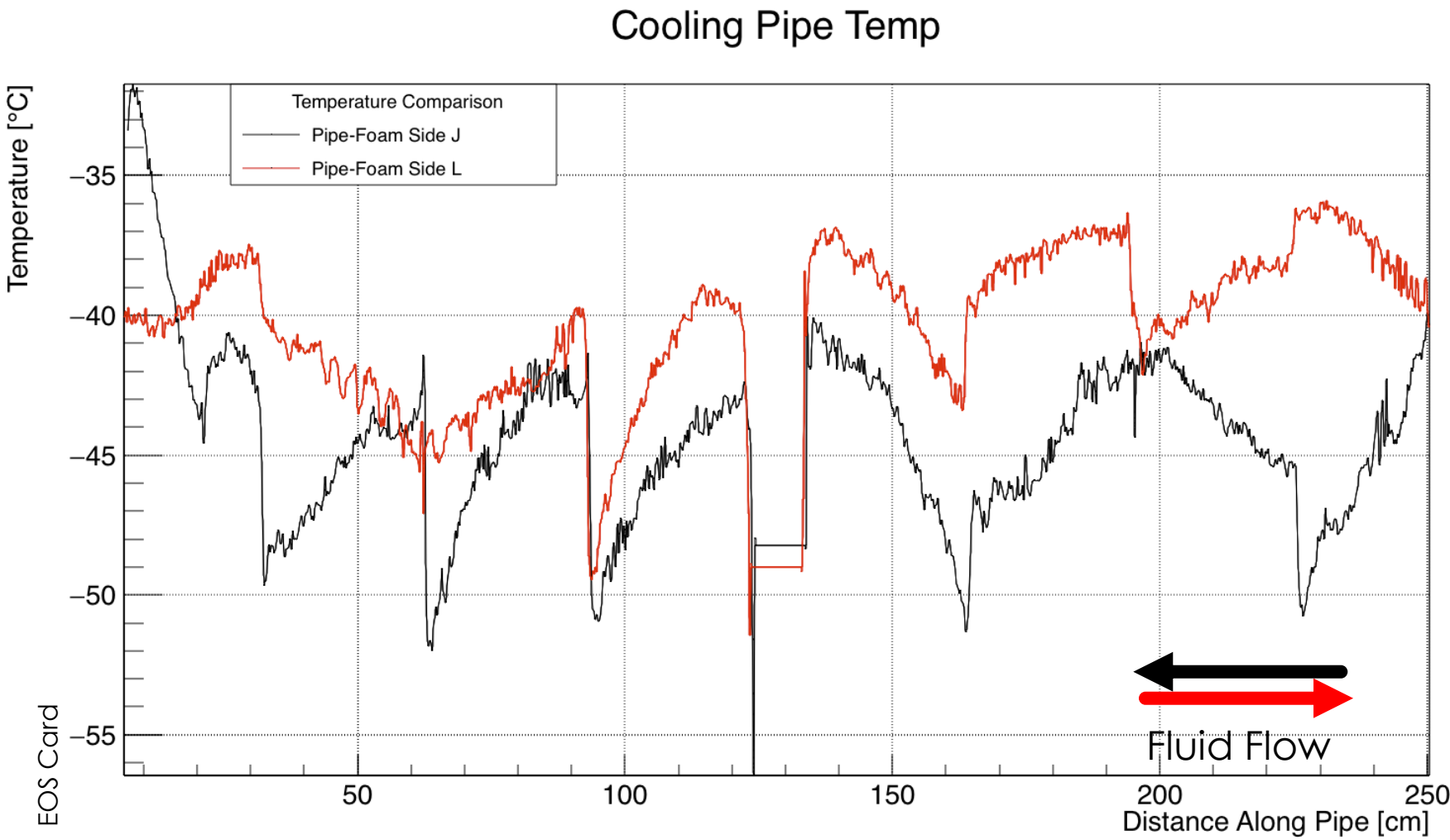
Pipe-Foam Stave: Thermal Meas. Hot

- Hot fluid at around 50C is being pumped through the stave at a rate of around 1 l/min
- Each individual foam chunk that has been viewed through the camera has a distinct sloped chunk of the profile.
- Depending on the flow direction the end of stave card has different effects on the profile



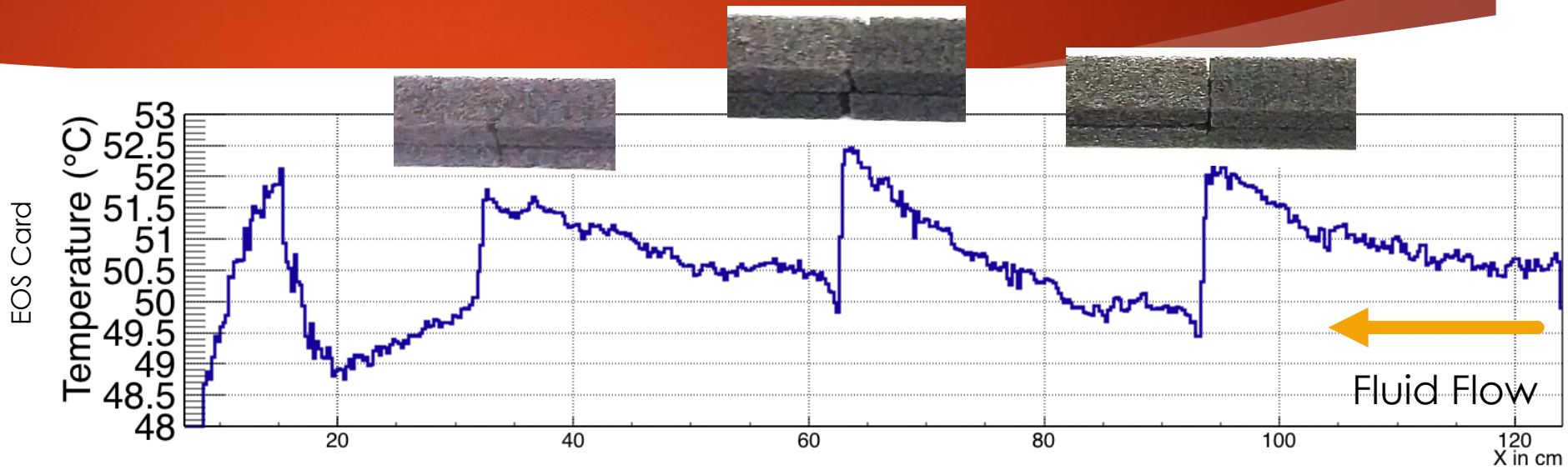
Pipe-Foam Stave: Thermal Meas. Cold

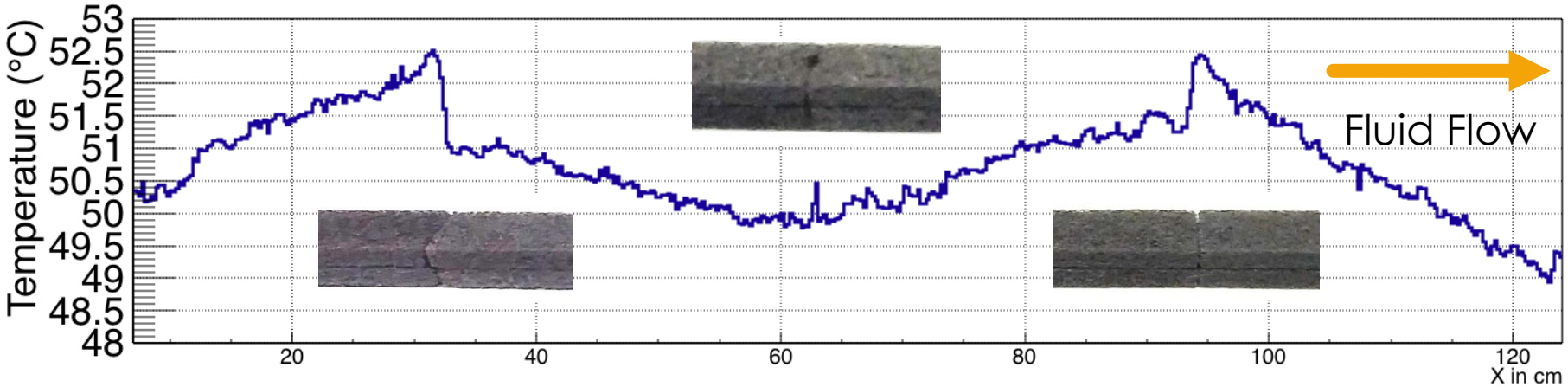
- Cold fluid at around -40C is being pumped through the stave at a rate of 1 l/min
- Parallels structures seen in the hot temperature profile



Pipe-Foam Stave: Comparisons with Structure J Side

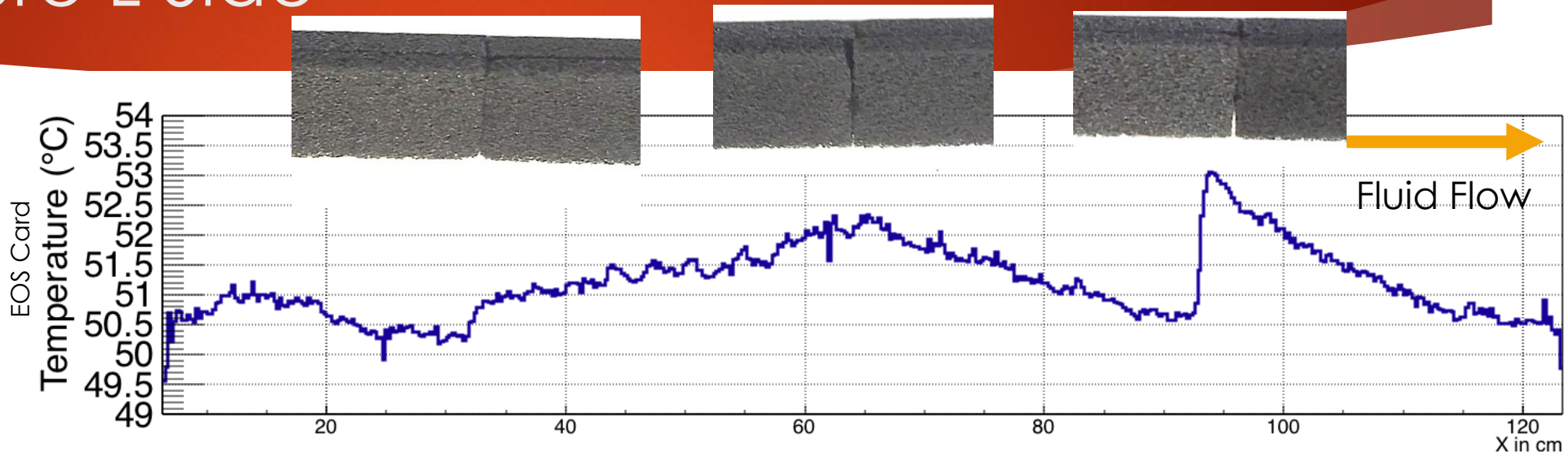
- At each of the 3 seams in the foam the peak is seen corresponding to a crack in the foam.
- The smoothest transition is where the glue has seeped out of the crack
- These changes in slope could be due to differing emissivity along the foam?

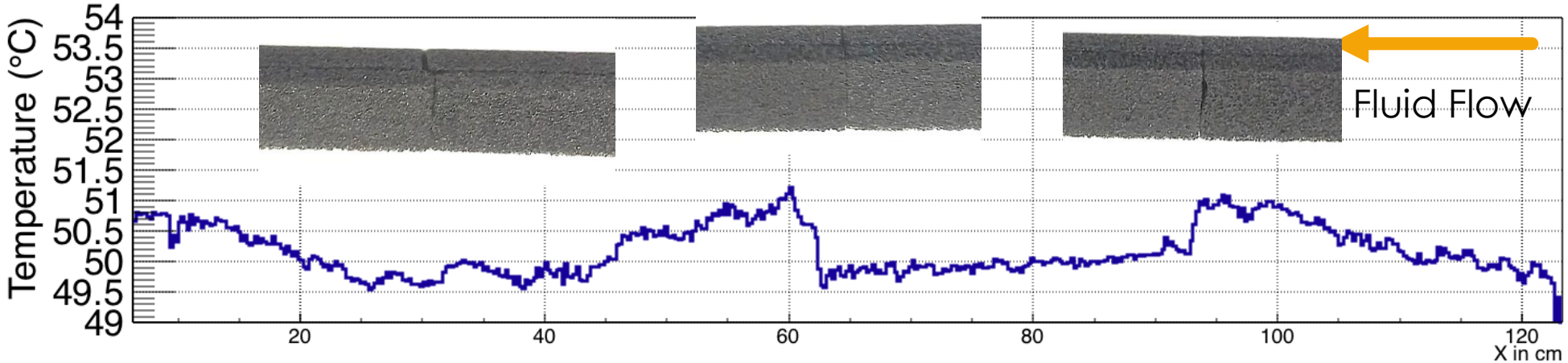




Pipe-Foam Stave: Comparisons with Structure L Side

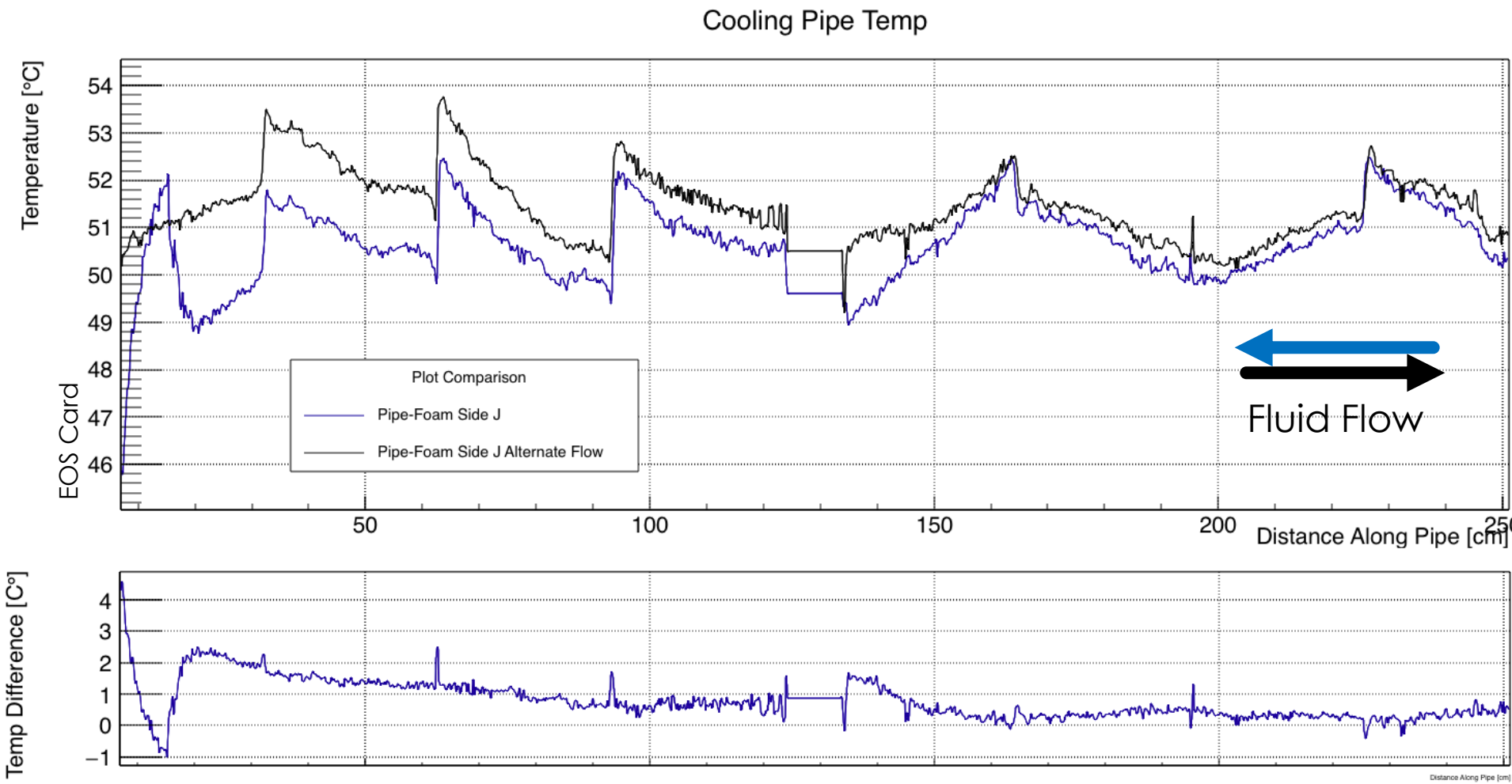
- Each of the peaks again corresponds to foam joints. Though they are less obvious in the thermal profile
- The very obvious peak corresponds with a color change between foam chunks. (May be hard to see on the plot)
- Transitions seem smoother here than on J Side





Pipe-Foam Stave: Fluid Reversal Hot

- Looking at the same image with fluid reversed has little effect on the main structure.
- Main change is located near the end of stave card



Pipe-Foam: Summary

- Actual pipe-foam emissivity is much higher than what was used. Need to find a better way to measure it
- Pipe-Foam Stave has structures that are related to the foam chunks
  - Breaks between each foam chunk are clearly visible
  - Emissivity may vary along each foam chunk
- Fluid reversal has little effect on the thermal profile except near the end of stave card

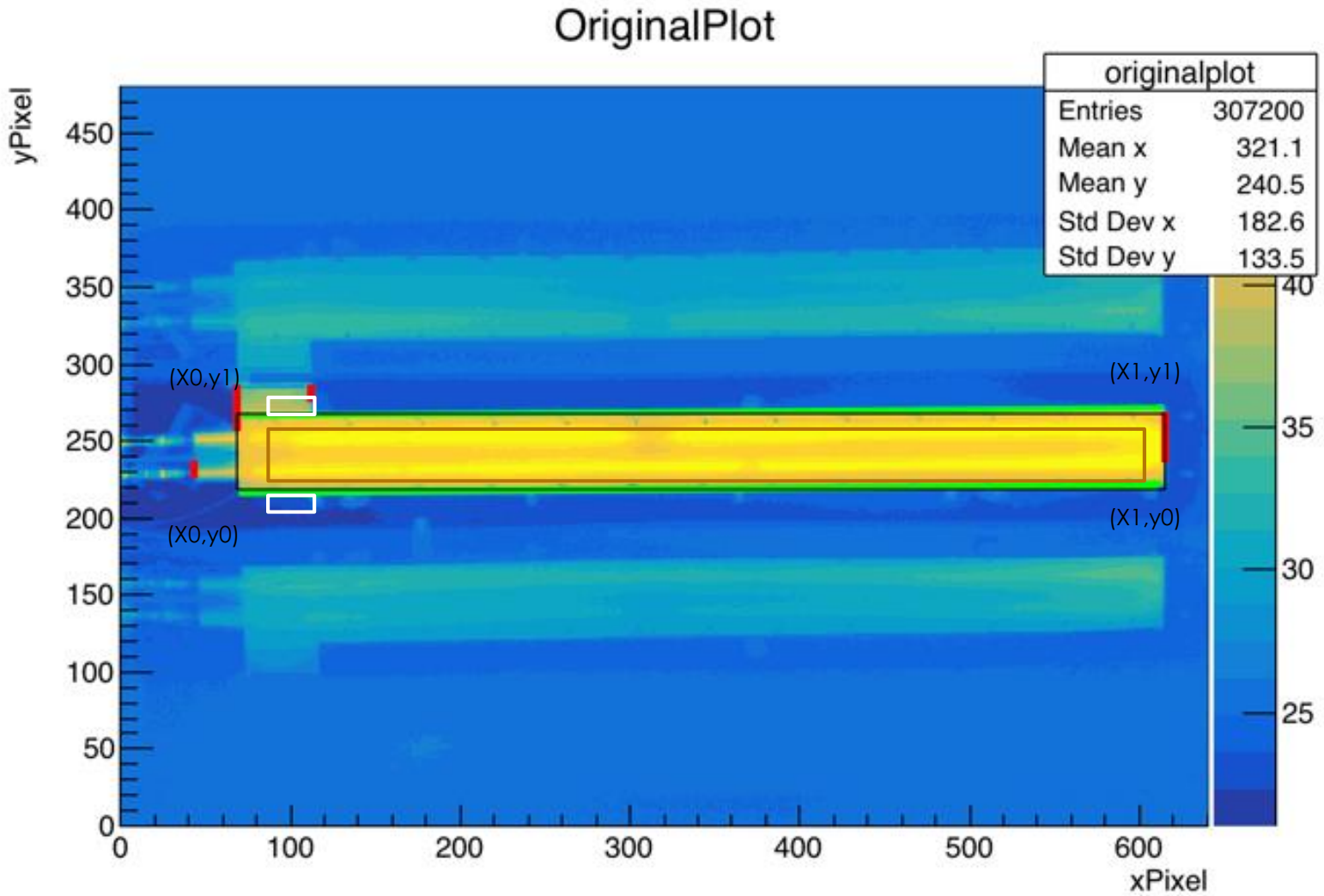
Backup Slides

Backup Slides

- How configFinder.py works…
- How frameanal.py works…
- Diagram of how frameanal.py converts data…
- How defectFinder.py works…
- Thermal measurements on PF Stave reproducibility experiment

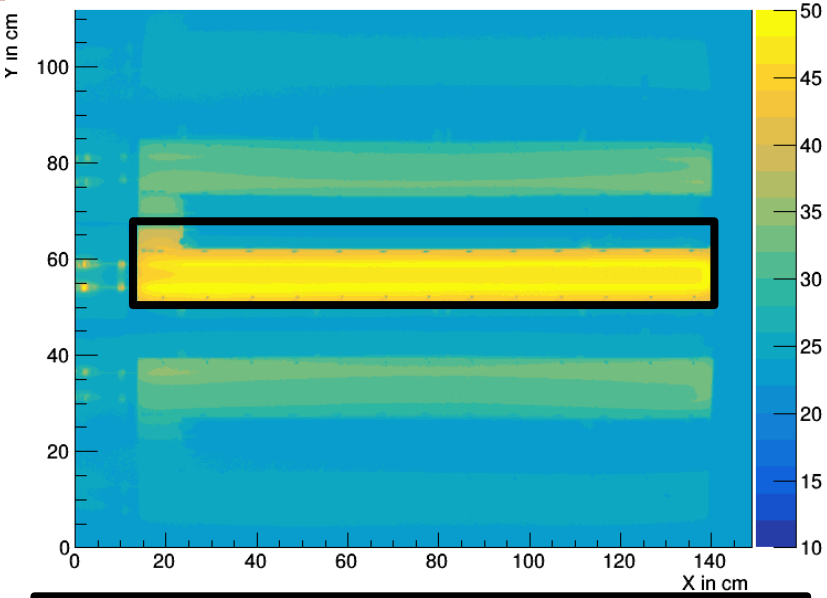
How configFinder.py works…

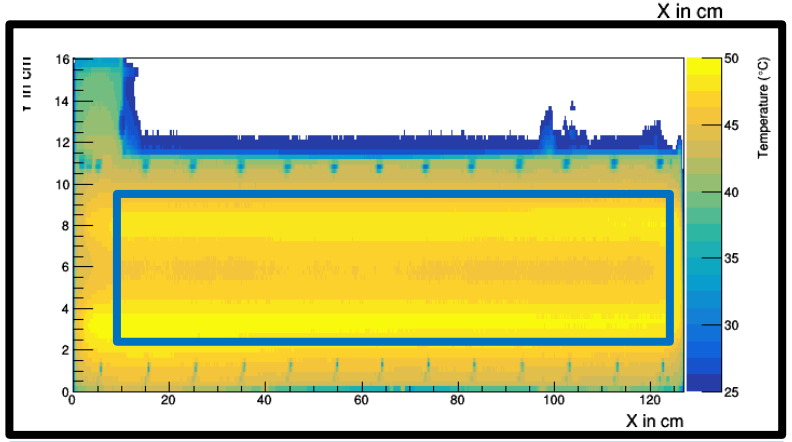
1. Filter image with Canny Edge Detector
2. Find long horizontal lines using Hough Lines(Green)
3. Find short vertical lines using Hough Lines(Red)
4. Determine stave area(Black)
5. Cut stave area to pipe area using predetermined percentages (Brown)
   - Cut on X0 Cut = X0 + 0.05*StaveLength (Removes area without foam)
   - Cut on X1Cut = X1 - 0.023*StaveLength (Removes pipe turn)
   - Cuts on YCut = Y +/- 0.17*StaveWidth (Removes metal attachment points)
6. Determine Temperature of the stave (Hot or Cold)
   - Finds average temperature in the cut area. Currently assumes that Hot = (ChillerSetting 50C) Cold = (ChillerSetting -55C)
7. Determine orientation of the stave (L or J side)
   - Calculates temperature in both regions(White) and compares the average to the stave temperature to find the orientation

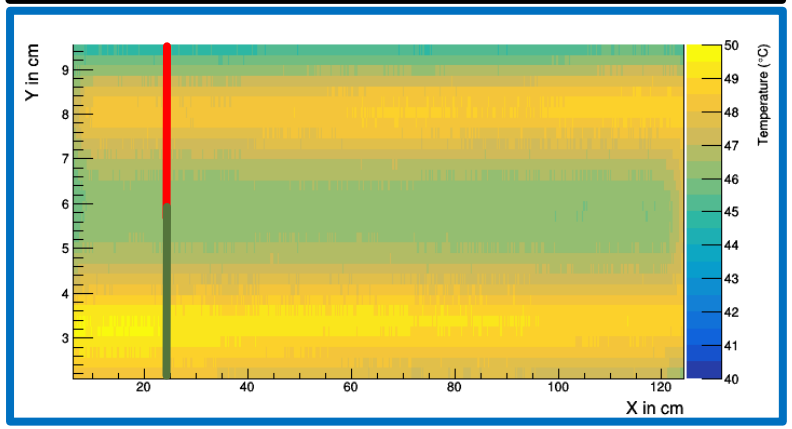


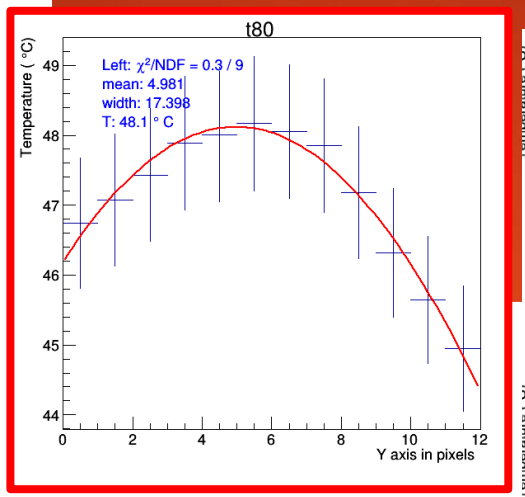
How frameanal.py works…

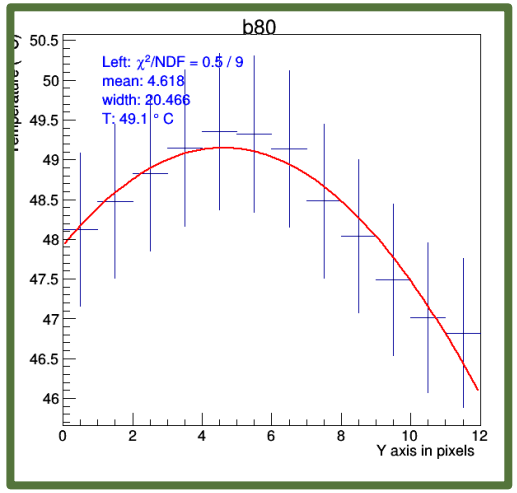
- Takes the image data from the configFinder and creates plots of the stave and the pipe area.
- Using the pipe area temperature data, it finds the maximum along the pipe, by fitting the thermal profile perpendicular to the pipes with a Gaussian peak.
- It does this for both pipes and creates data sets for the thermal profile along the pipes, along with the width, and position of each fit.

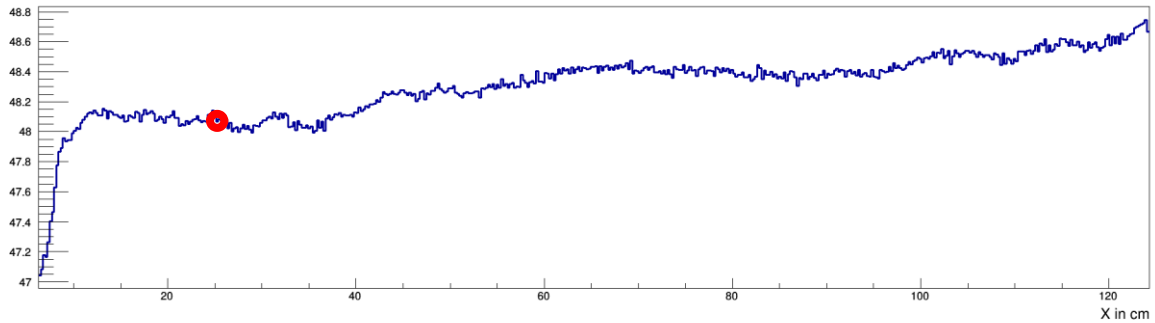

Y in cm
X in cm
Temperature (°C)

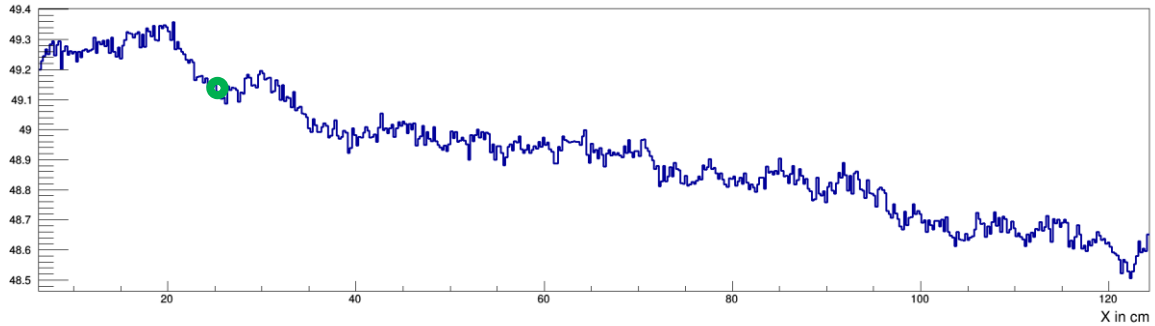

X in cm
Temperature (°C)

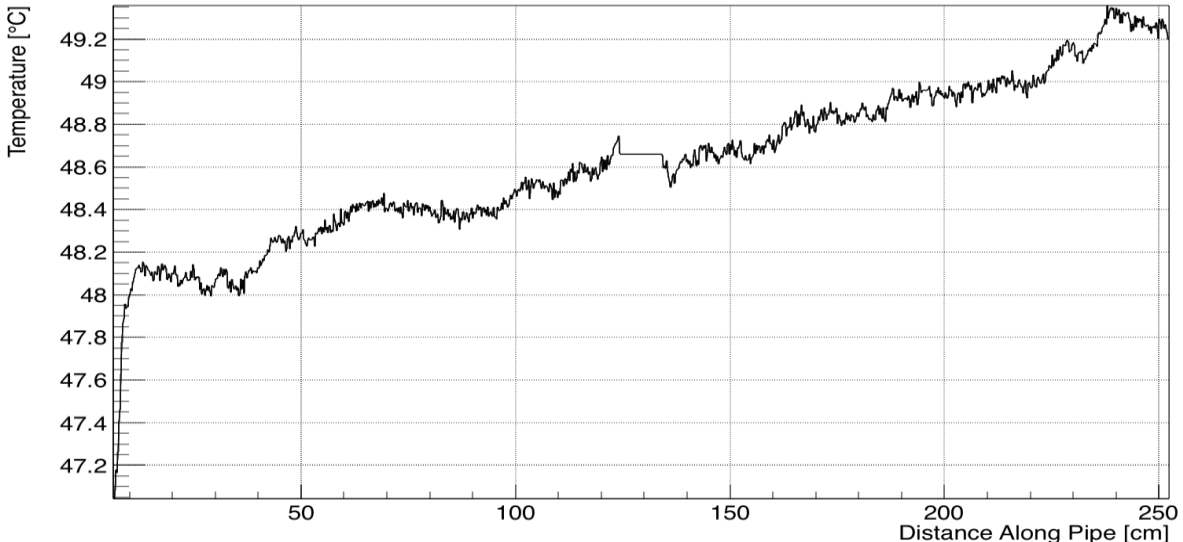

Y in cm
X in cm
Temperature (°C)


t80
Left: χ²/NDF = 0.3 / 9
mean: 4.981
width: 17.398
T: 48.1 ° C
Temperature (°C)
Y axis in pixels


b80
Left: χ²/NDF = 0.5 / 9
mean: 4.618
width: 20.466
T: 49.1 ° C
Y axis in pixels


X in cm


X in cm


Temperature [°C]
Distance Along Pipe [cm]

How defectFinder.py works…

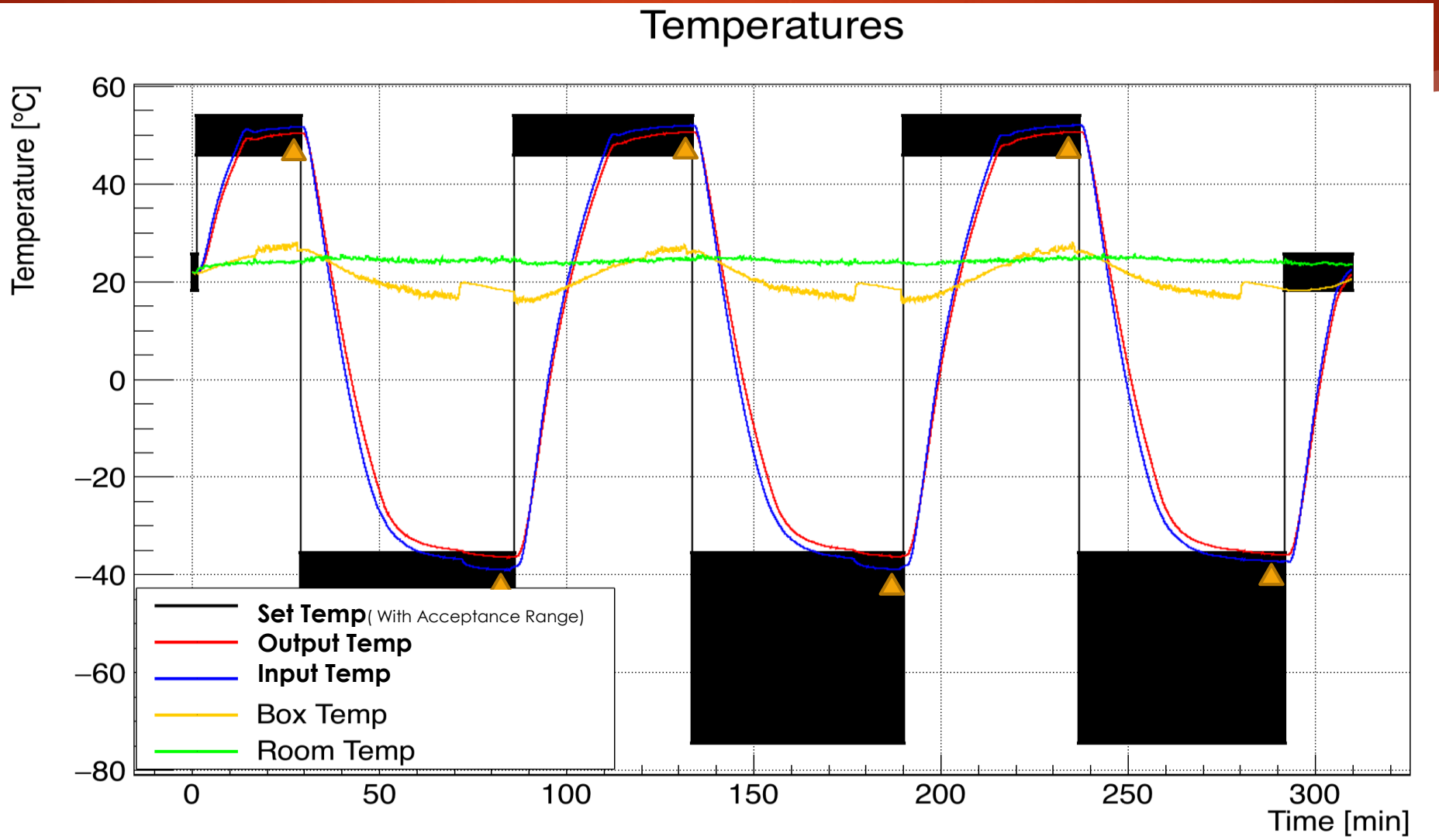
- Prepare Spectra
  - Find Background and get very loose selection of Peaks with TSpectrum
  - Use background subtraction
- Fit Background subtracted spectra
  - Fit with simple gaussian
  - Using prior results-> Fit with offset gaussian
  - Using prior results-> Fit with offset line gaussian
  - Keep best fit of the 3
  - Re-measure peak height from actual spectrum
- Cut resulting peaks based upon:
  - Peak Fit (ChiSq/DegFrdm < 0.05)
  - Peak Position (+/- 2 cm from TSpec results)
  - Peak Width (1<Width<8 cm)
  - Peak Height (Height > 0.2 C)
- Test Results with Stave Core 2 and 2R
  - 85%(11/13) Foam Facing Defects
    - Failures outside spectra region
  - 50%(6/12) Pipe Foam Defects
    - Failures were unobserved peaks
  - Does not detect large scale defects

Reproducibility

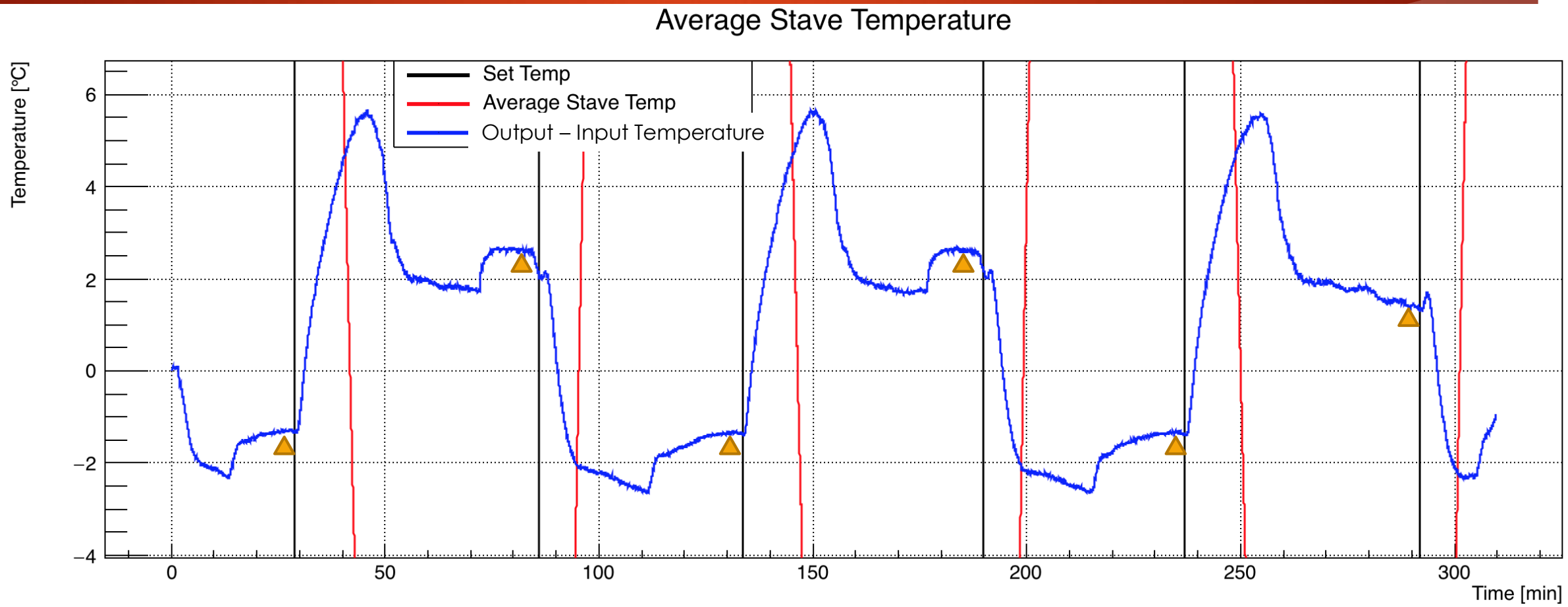
- The PF stave's thermal profile was measured for high(+50C fluid) and low(-40C fluid) input temperatures 3 times.
  - While the chillerctrl program was working toward the set temperature, the airflow was on at ~10psi(40 l/min)
  - Once the fluid reached the trigger temperature and stabilized, the airflow was shut off and the system was left for 10 minutes to stabilize.
  - An image was then taken from an average of 200 frames at a rate of 25 frames/sec
  - The system then looped to the next temperature(high,low,high,low,high,low)
- All variables were measured from the log file to note any differences between the measurements
  - Each measured variable's uncertainty is characterized by its maximum fluctuation over the time in the log file

User Controlled Variables	Variables that we measure
Chiller Set Temperature	Temp In Stave
RPM Booster Pump	Temp Out Stave
Air Flow in Box	Temp in Box
Wait Time	Temp in Room
	Humidity
	Thermal Image

Reproducibility: Variables Plot 1



Reproducibility: Variables Plot 2



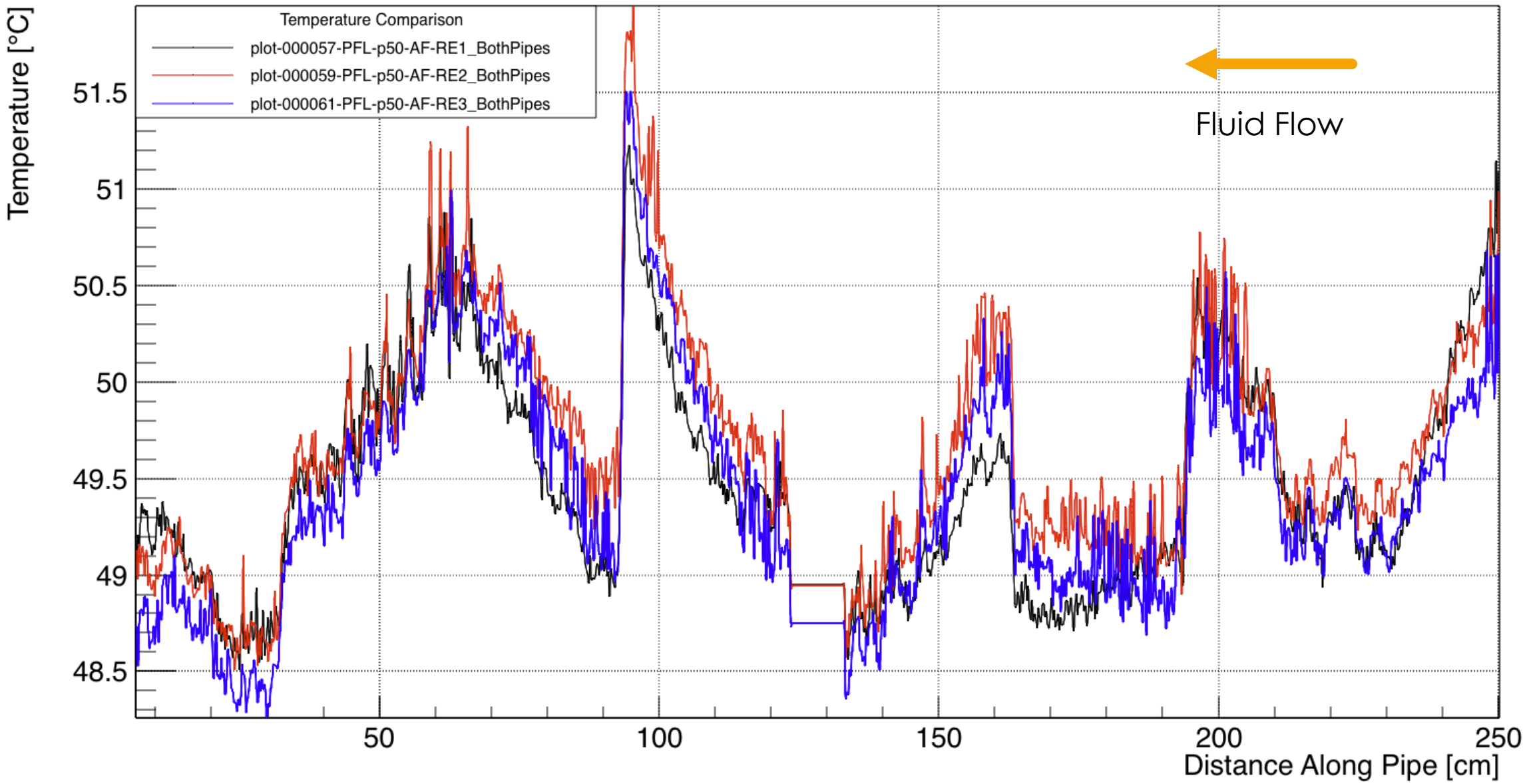
Reproducibility: Hot Temp Variables

- These values are for the hot temperature measurement
- During trial 3, the wait time was slightly longer
- Only 2 significant differences in measured variables
  - Input temperature is different on run 1
  - There is about 1% humidity in run 1

Next Slide: A comparison of the hot temperature profile measurements

(Its good…)

Variable	Uncert.	Trial 1	Trial 2	Trial 3
TSet	0.1 [C]	+50	+50	+50
RPM BP	0.1 [rpm]	21.4	21.4	21.4
Air Flow in Box	~0 [l/min]	0	0	0
Wait Time	1 [min]	10	10	15
Abs Time	1 [min]	27	131	234
TIn	**0.1[C]**	**51.6**	**51.9**	**51.9**
TLoss(out-in)	0.1[C]	-1.29	-1.34	-1.34
TBox	1.5[C]	27.4	26.9	27.0
TRoom	1.0[C]	24.1	24.6	24.7
Humidity	**~0.1 [%RH]**	**1.1**	**0**	**0**


Temperature Comparison
plot-000057-PFL-p50-AF-RE1_BothPipes
plot-000059-PFL-p50-AF-RE2_BothPipes
plot-000061-PFL-p50-AF-RE3_BothPipes
Fluid Flow
Temperature [°C]
51.5
51
50.5
50
49.5
49
48.5
50
100
150
200
250
Distance Along Pipe [cm]

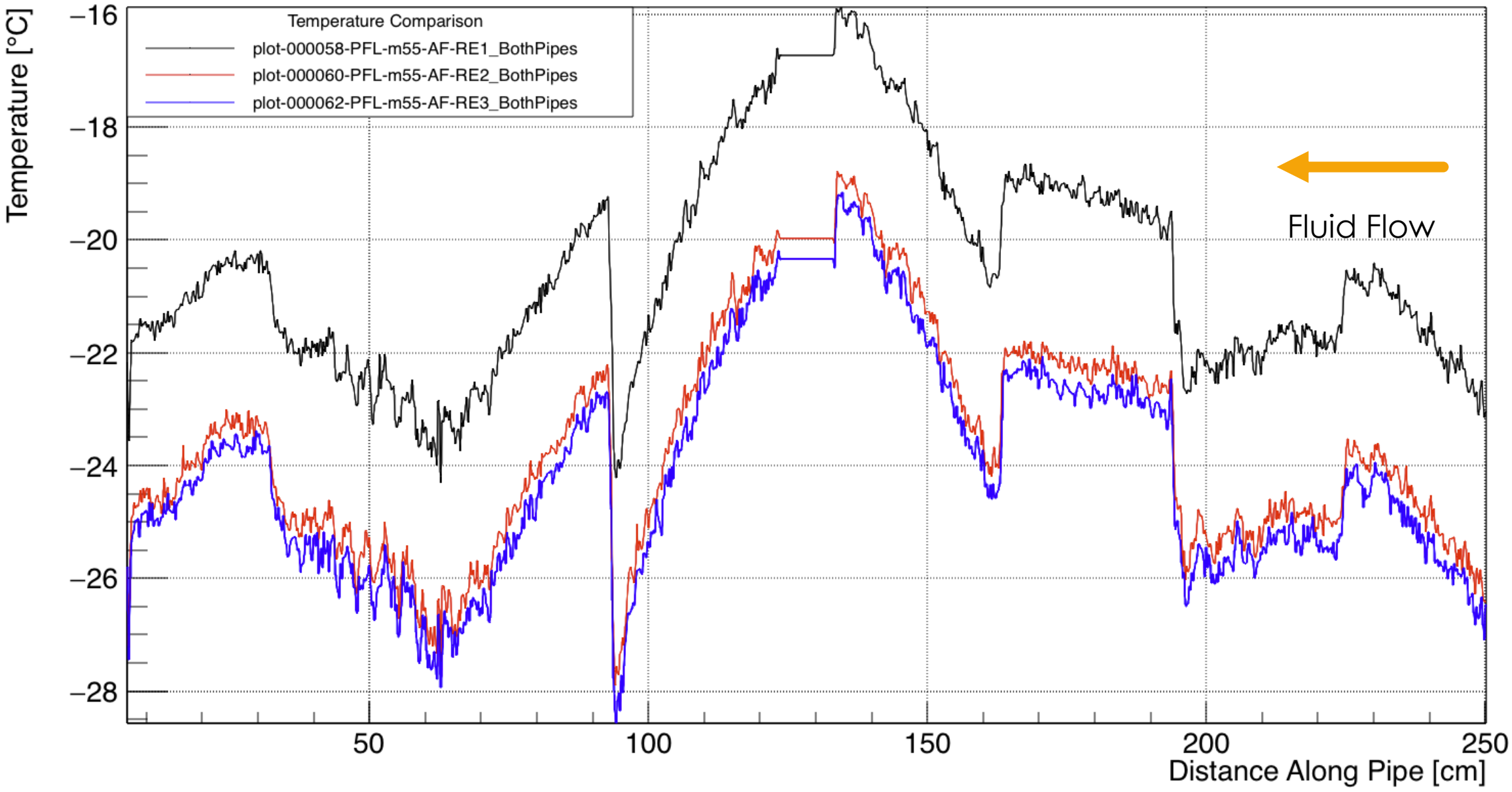
Reproducibility: Cold Temp Variables

- These values are for the cold temperature measurement
- During trial 3, the flow rate was not adjusted
- 2 significant differences in variables
  - Input temperature is different on run 3
  - TLoss is much lower on run 3

Next Slide: A comparison of the cold temperature profile measurements

(Less good…)

Variable	Uncert.	Trial 1	Trial 2	Trial 3
TSet	0.5 [C]	-55	-55	-55
RPM BP	0.1 [rpm]	26.7	26.7	21.4
Air Flow in Box	~0 [l/min]	0	0	0
Wait Time	1 [min]	10	10	10
Abs Time	1 [min]	83	188	290
TIn	**0.1[C]**	**-38.9**	**-38.8**	**-37.2**
TLoss(out-in)	**0.1[C]**	**+2.61**	**+2.58**	**+1.41**
TBox	0.5[C]	18.3	18.5	18.8
TRoom	1.0[C]	24.6	24.1	24.1
Humidity	~0.1 [%RH]	0	0	0


Temperature Comparison
plot-000058-PFL-m55-AF-RE1_BothPipes
plot-000060-PFL-m55-AF-RE2_BothPipes
plot-000062-PFL-m55-AF-RE3_BothPipes
Temperature [°C]
−16
−18
−20
−22
−24
−26
−28
50
100
150
200
250
Distance Along Pipe [cm]
Fluid Flow