Updates from the Lab

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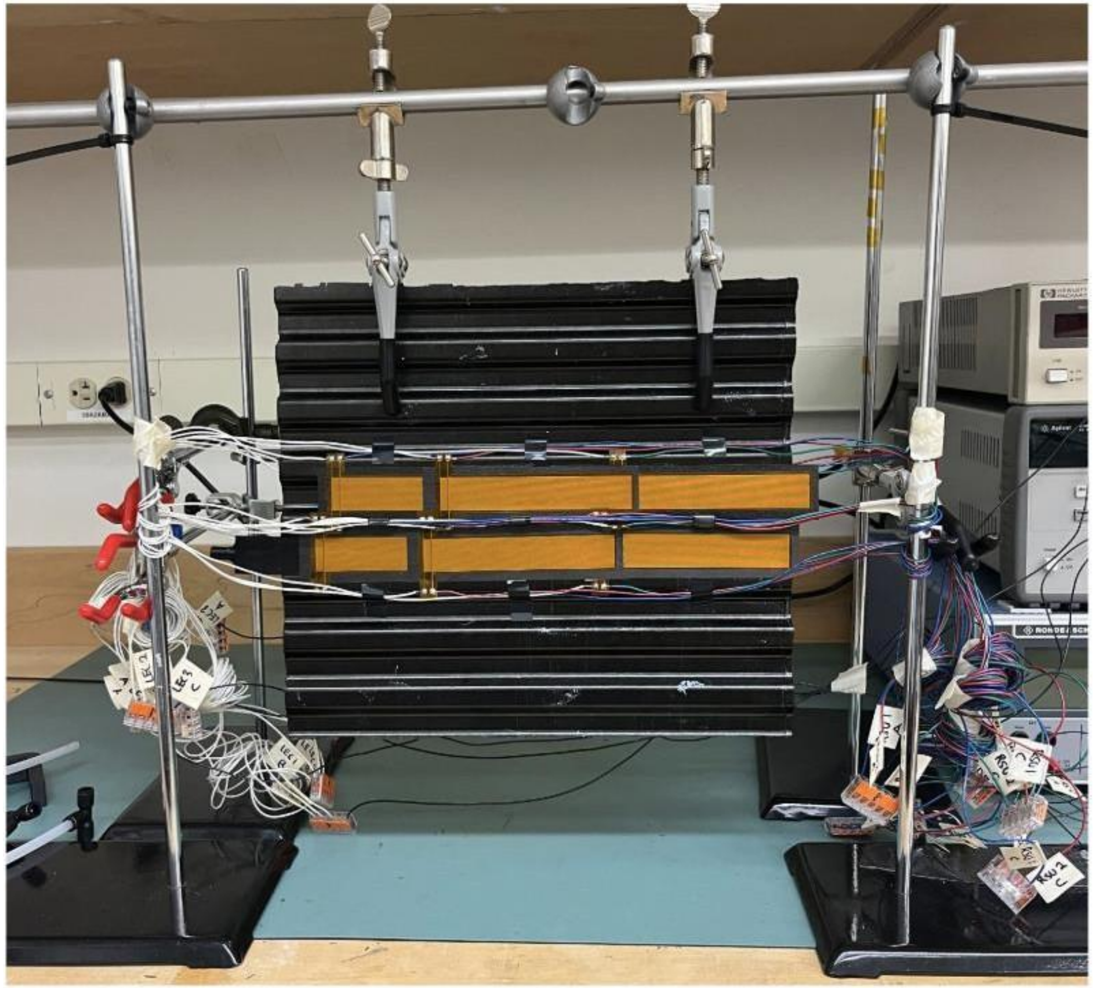
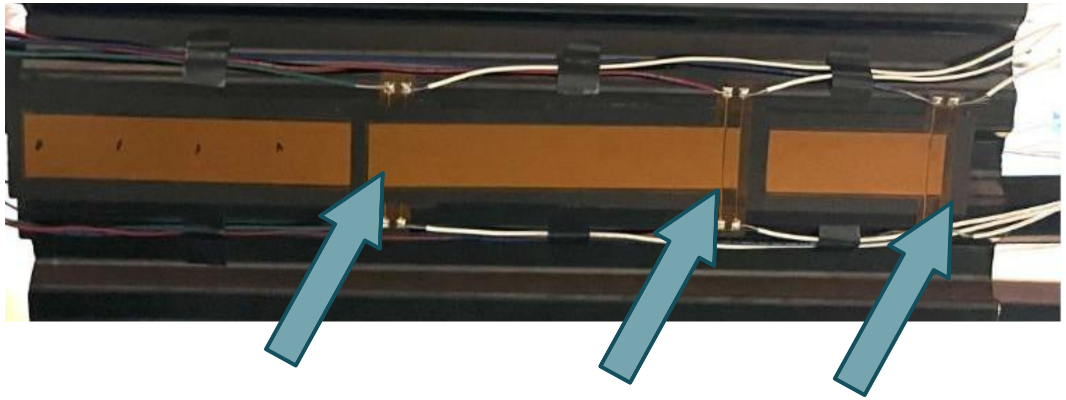
EIC Meeting July 22, 2025

Large Thermal Test Piece

- We want to test how proximity to neighboring rows affects measurements
- Have two channels on the front, one on the back



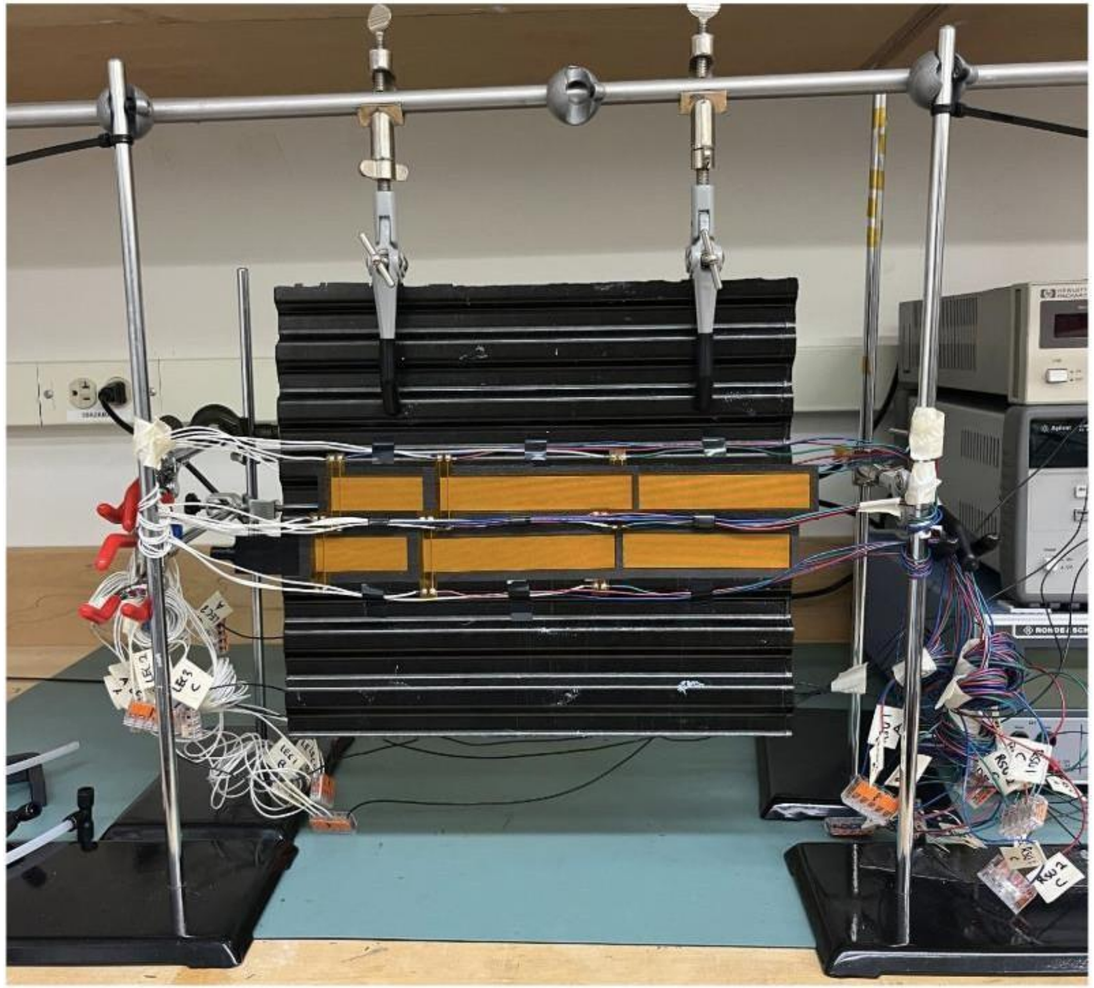


LECs: Left End Caps

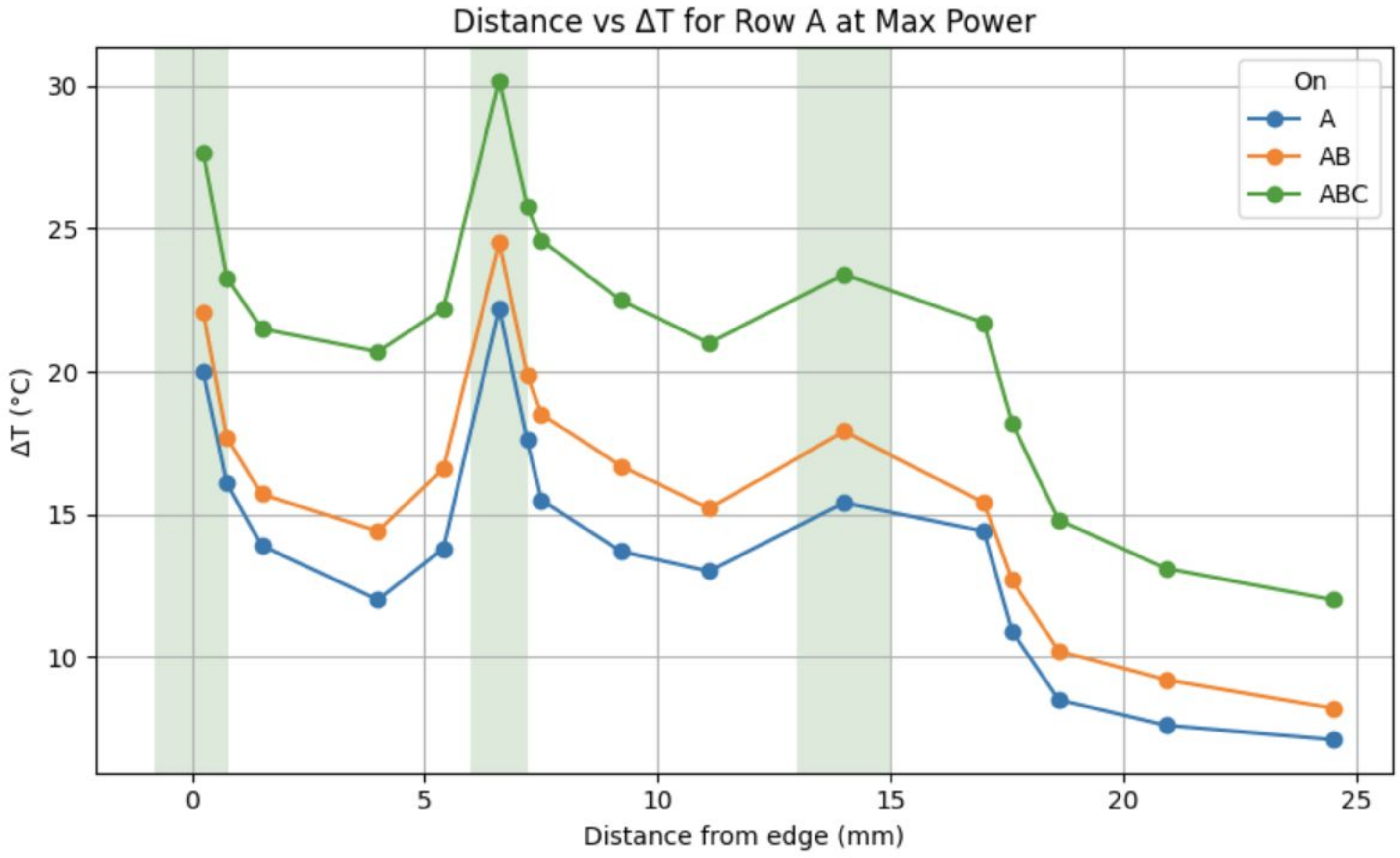
Large Thermal Test Piece

Experimental Setup

- With no air cooling, alternated which rows were turned on and measured the front two rows (A & B)
- Measurements were taken at both Max and Nominal power



Thermal Gradient



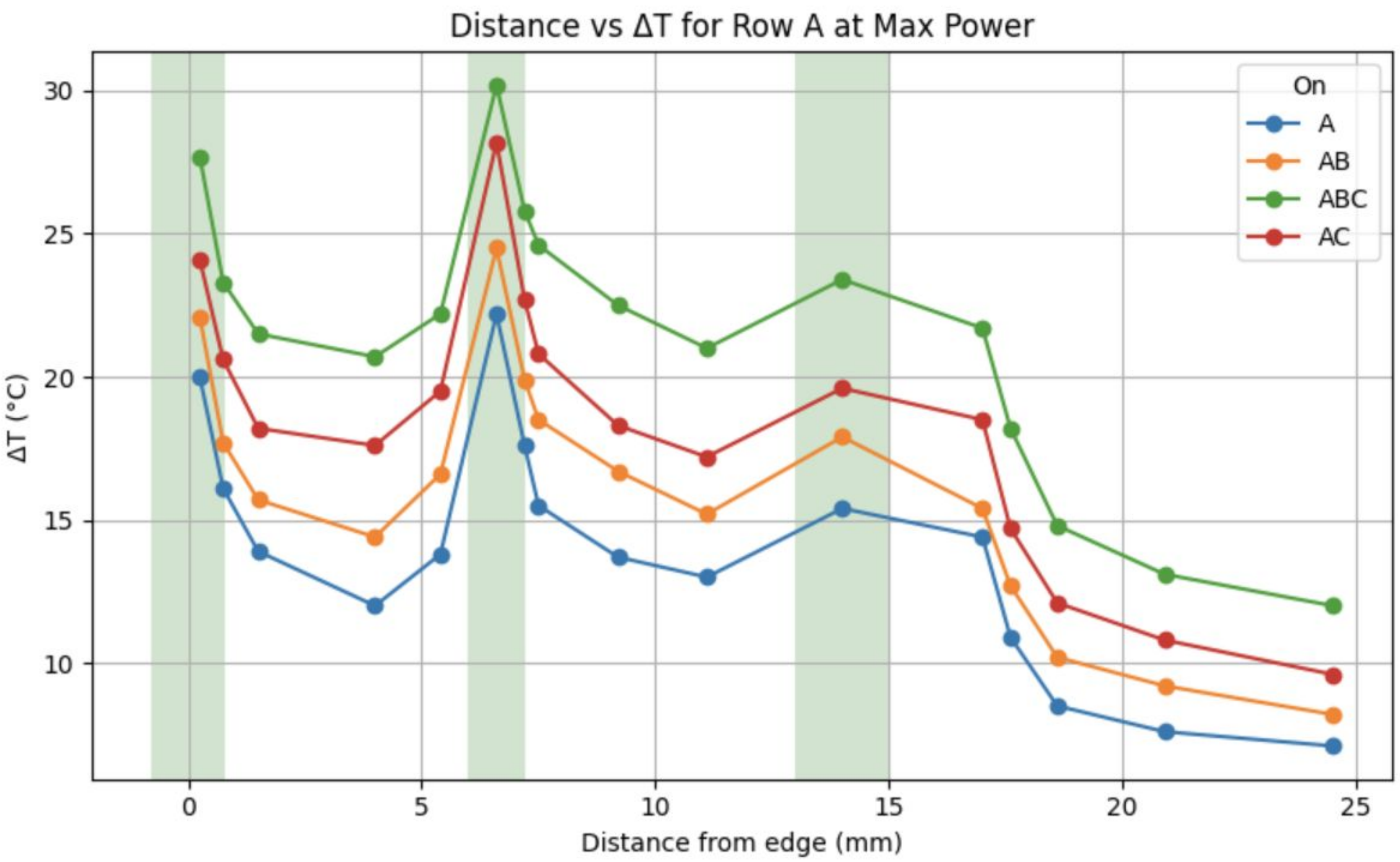
Legend

- Blue: Only Row A powered
- Orange: Rows A & B are powered
- Green: All Rows Powered

Notes

- We see a very large difference between all being powered and just row A
- Modest difference when adding only row B

Impact of Row C



Findings

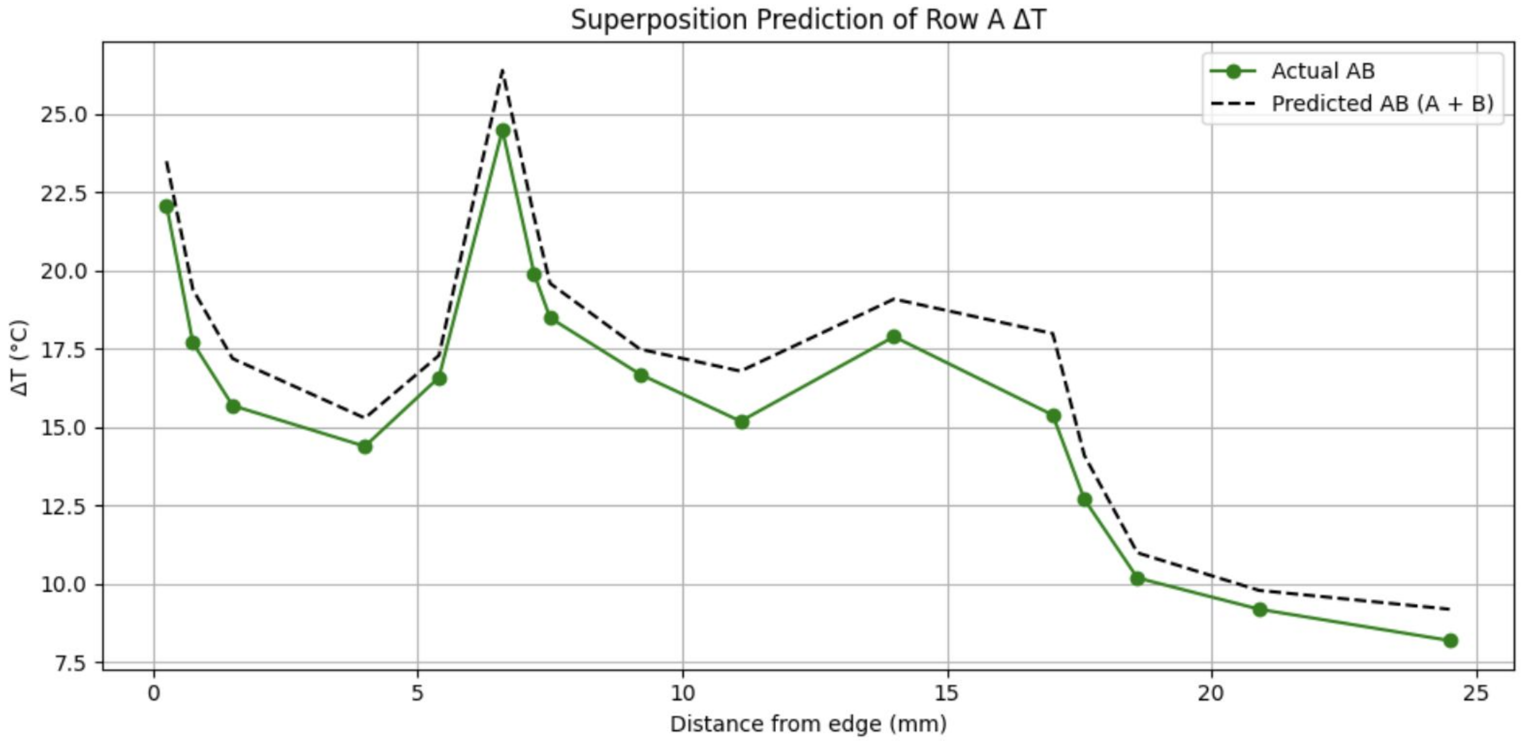
- There is a clear ordering
- Row C has a much greater impact
- **Update:** The Third LEC on row C was spiking to 92C, likely the cause of this anomaly

Simple Superposition Model

- Measuring Row A with A+B Turned On
- Naive estimate:
- Sum effect of Row A by itself and Row A with B turned on.
- Not a terrible fit!

Notation: Measuring dT for Row A with B powered on

$$\Delta T_{A_{AB}} = \Delta T_{A_A} + \Delta T_{A_B}$$

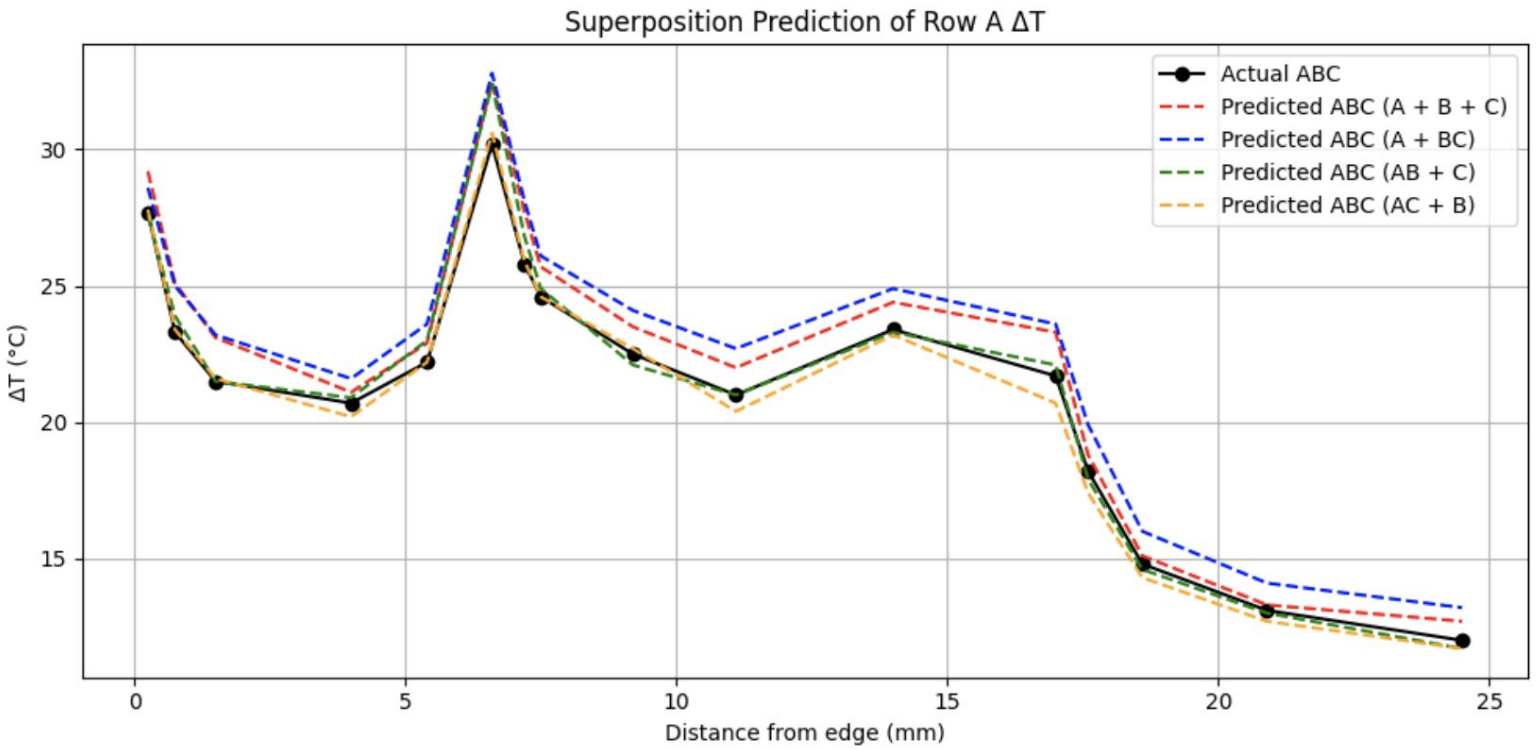


RMSE between actual AB and predicted: 1.41 °C

Simple Superposition Model

$$\Delta T_{A_{ABC}} = \Delta T_{A_A} + \Delta T_{A_B} + \Delta T_{A_C}$$

- Best fit is adding the data from measuring A with only B on plus measuring A with A&C on
- Now we know that Row C was unusually hot, so this may explain this




```
RMSE between actual ABC and A+B+C: 1.26 °C
RMSE between actual ABC and A+BC: 1.62 °C
RMSE between actual ABC and AB+C: 0.69 °C
RMSE between actual ABC and AC+B: 0.44 °C
```

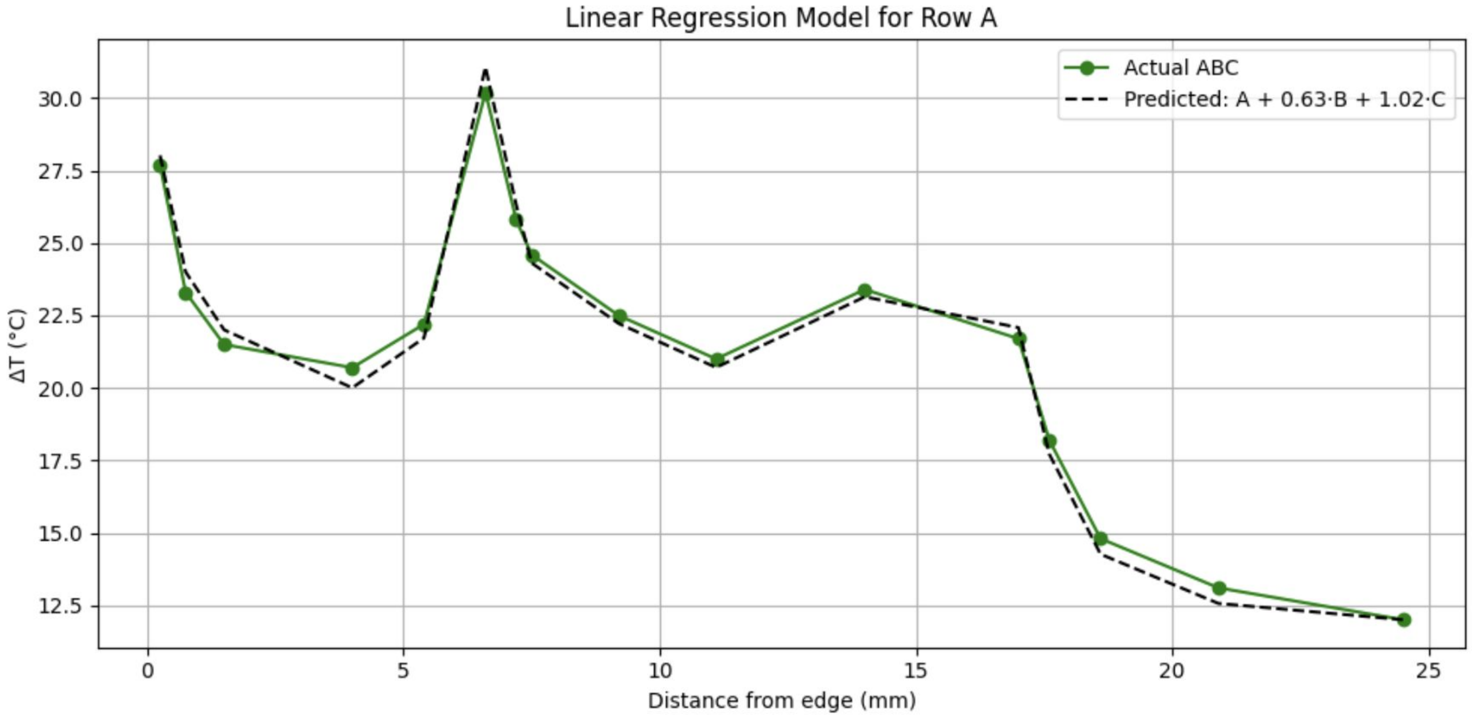
Spatial Coupling

- Want more information about lateral vs cross-carbon fiber temperature effects
- Implement a linear regression to weight the effects of Row B & C
- If α≈1 and β≈1, the system is additive and linear.

$$\Delta T_{A_{ABC}} = \Delta T_{A_A} + \alpha \Delta T_{A_B} + \beta \Delta T_{A_C}$$

Spatial Coupling

- If α≈1 and β≈1, the system is additive and linear.
- But this is not what we see, since If α<1, B's influence is partially suppressed or less effective when just combined.



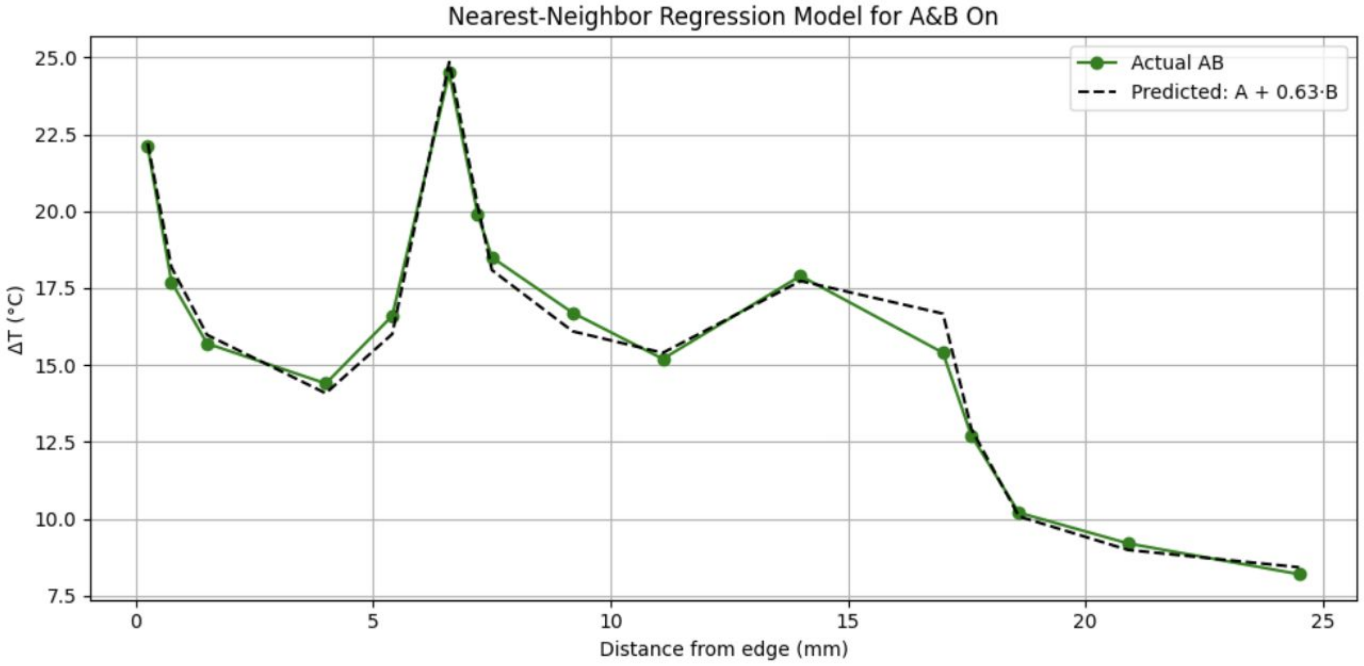

```
Fitted α (B influence): 0.631
Fitted β (C influence): 1.021
RMSE: 0.49 °C
```

Applying Model I

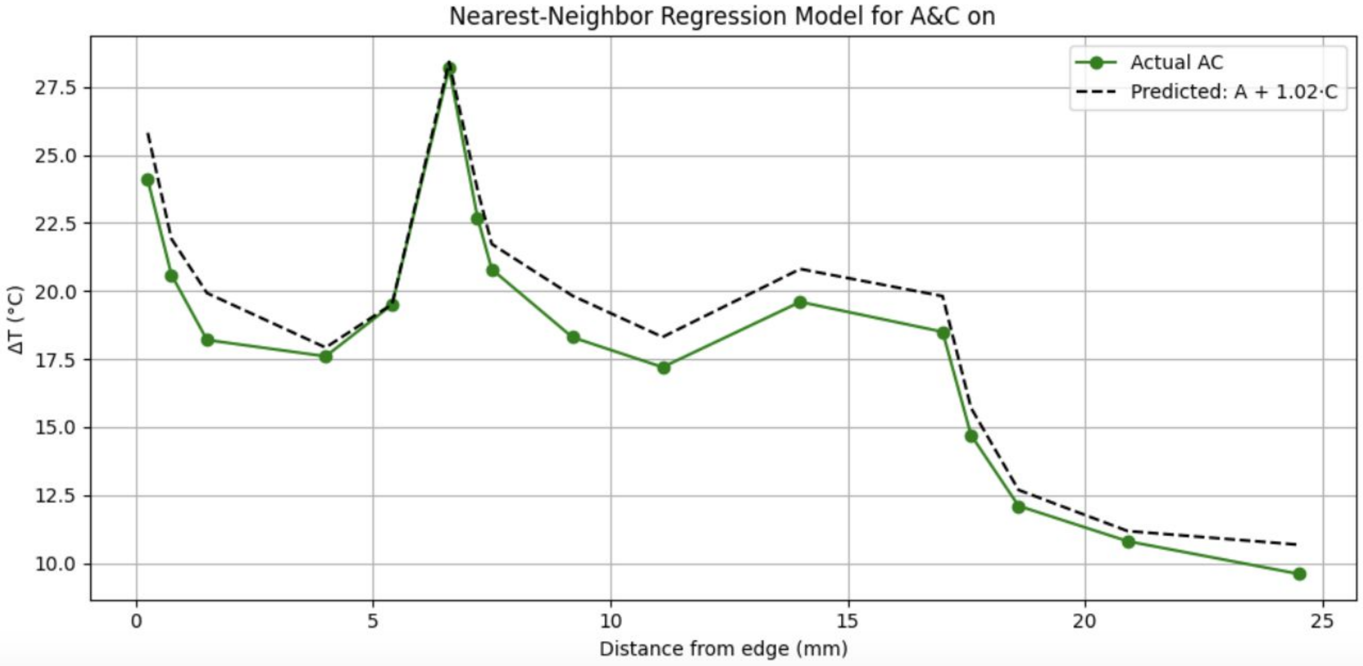
Findings

- Test combinations: Just A and B on (beta term), measure row A
- Fit less accurate when including the back row
- This was the first indication that Row C was unusually hot

$$\Delta T_{A_{ABC}} = \Delta T_{A_A} + \alpha \Delta T_{A_B} + \beta \Delta T_{A_C}$$



RMSE: 0.46 °C



RMSE: 1.09 °C

Model II: Better Fit

Here we explicitly fit coefficients for all three contributions, including A itself at each point

α = 0.843 (A influence)

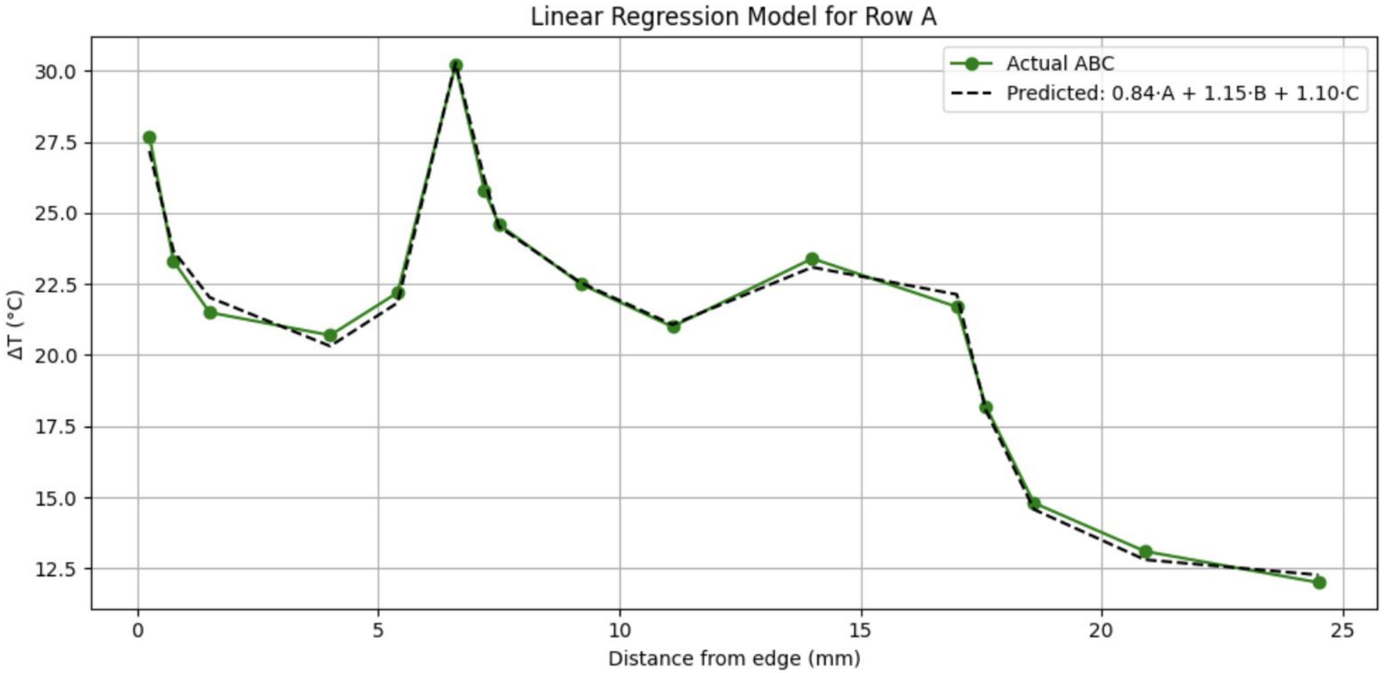
- The self-heating effect of Row A is suppressed when B and C are also on.

β = 1.153 (B influence)

- B has a stronger than expected influence on Row A.

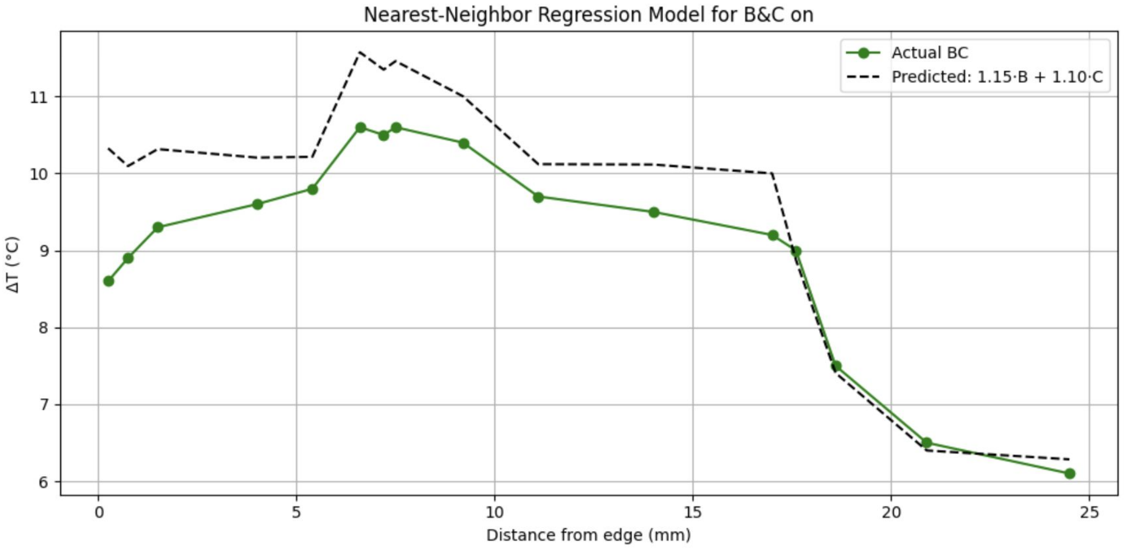
γ = 1.103 (C influence)

- C also has a strong influence on A, nearly as much as B
- We must have asymmetric heating

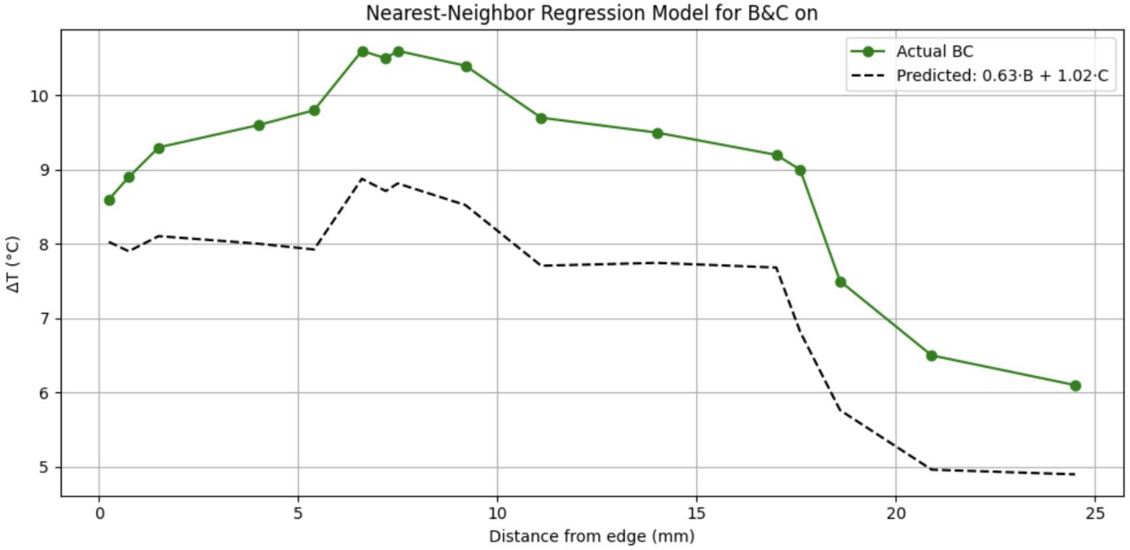


$$\Delta T_{A_{ABC}} = \alpha \Delta T_{A_A} + \beta \Delta T_{A_B} + \gamma \Delta T_{A_C}$$

Comparison with B&C On, Measure Row A



RMSE: 0.79 °C



RMSE: 1.63 °C

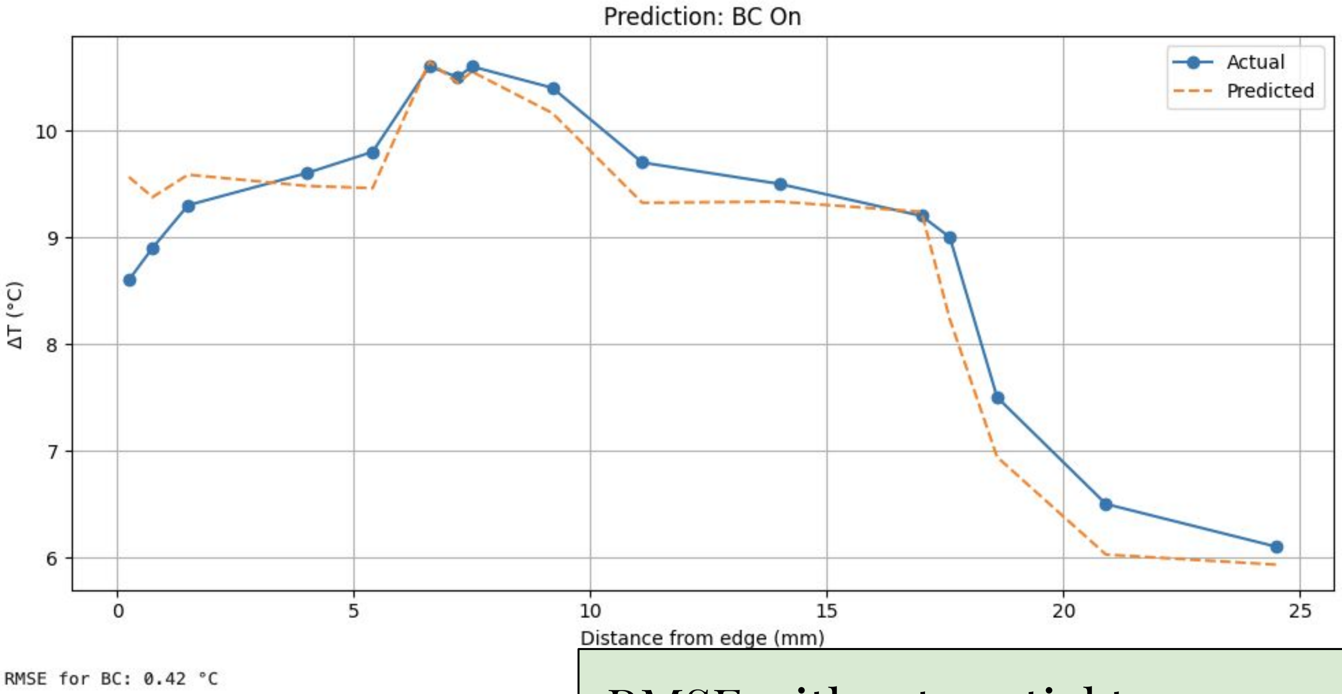
$$\Delta T_{A_{ABC}} = \alpha \Delta T_{A_A} + \beta \Delta T_{A_B} + \gamma \Delta T_{A_C}$$

$$\Delta T_{A_{ABC}} = \Delta T_{A_A} + \alpha \Delta T_{A_B} + \beta \Delta T_{A_C}$$

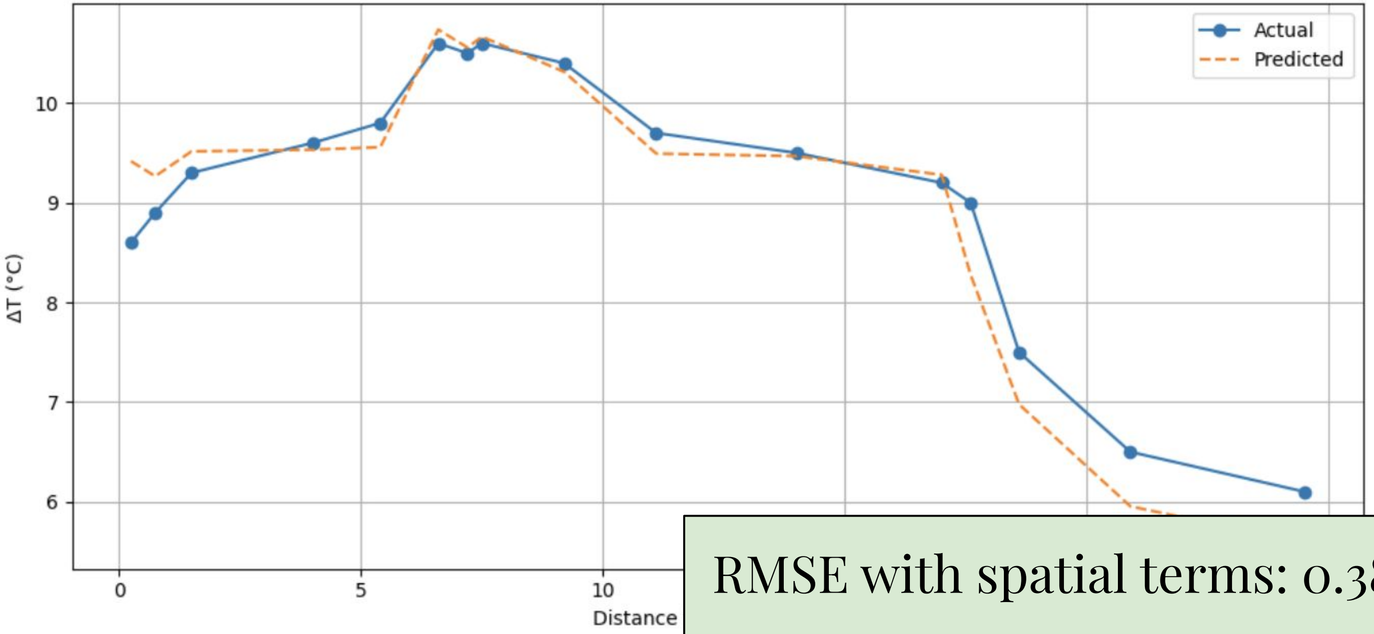
Neither model does a good job with this case, why is this?

Spatial Terms?

- Heat loss varies across the panel (edges are cooler, for example)
- Convective loss might be position-dependent since heaters don't produce uniform heating
- Fit with spatial terms: x & x^2
- Only matters (a tiny bit) with BC



RMSE without spatial terms: 0.42



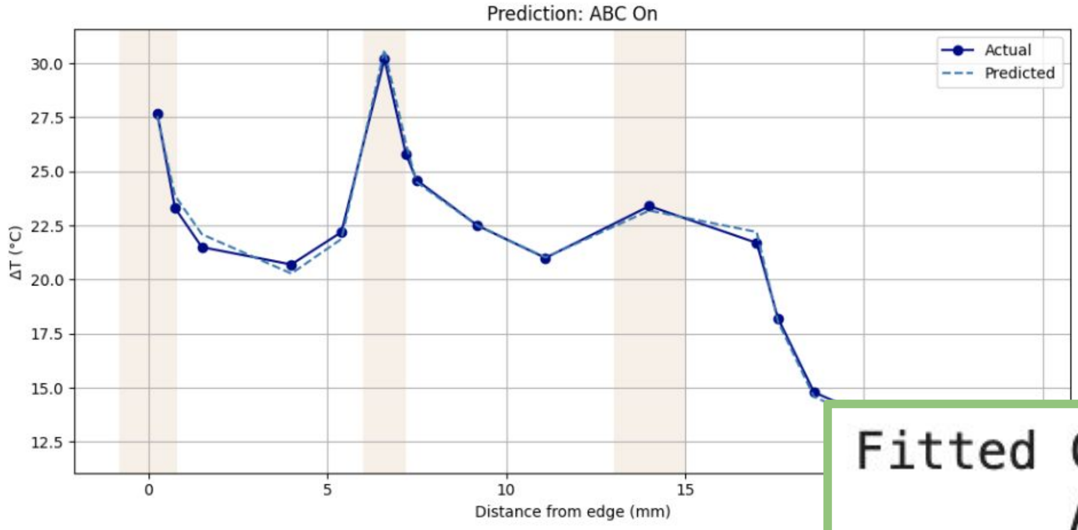
RMSE with spatial terms: 0.38

Final Model: Feature Importance

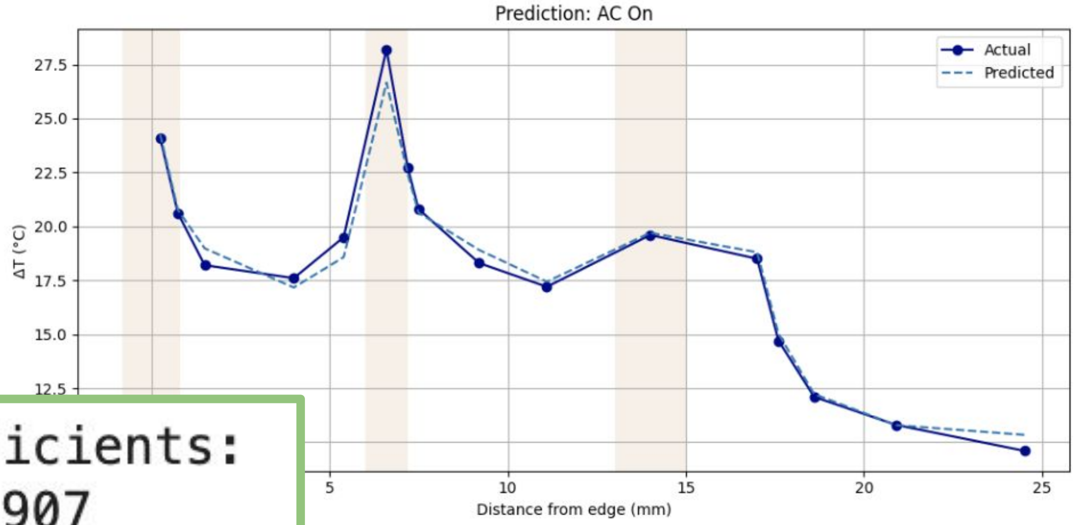
- Using the information about what fits are best, we know what parameters are useful to include
- Uses ALL input data from measuring across Row A to make a prediction, so this includes combinations such as A&C, B&C
- Inputting a matrix to apply the fit, so this is more robust
- Simple model was very helpful in determining feature importance, but this is our final **predictive** model

```
# train
X_all, y_all = zip(*(get_input_matrix(config) for config in ["ABC", "AB", "AC", "BC", "A", "B", "C"]))
```

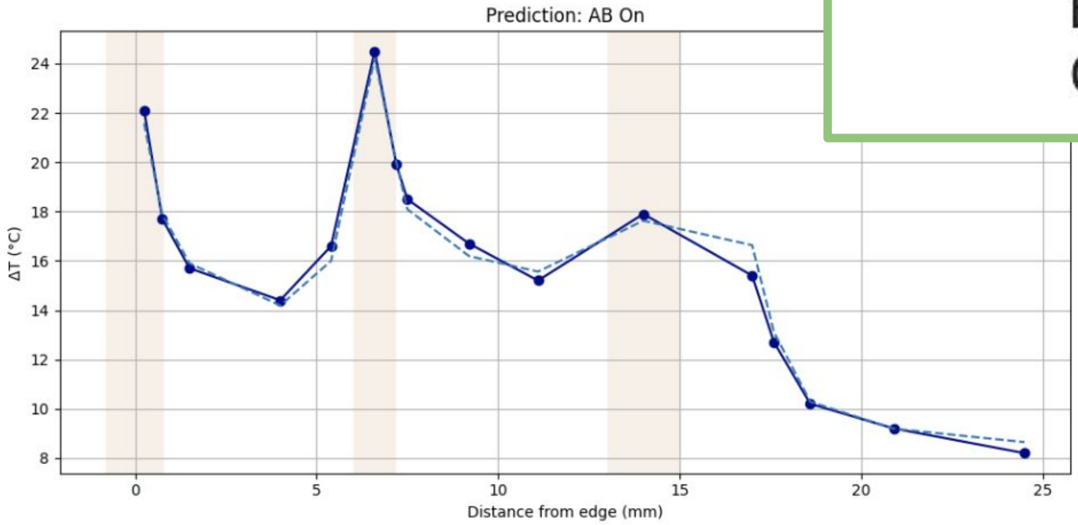
A Better Fit: Train Differently



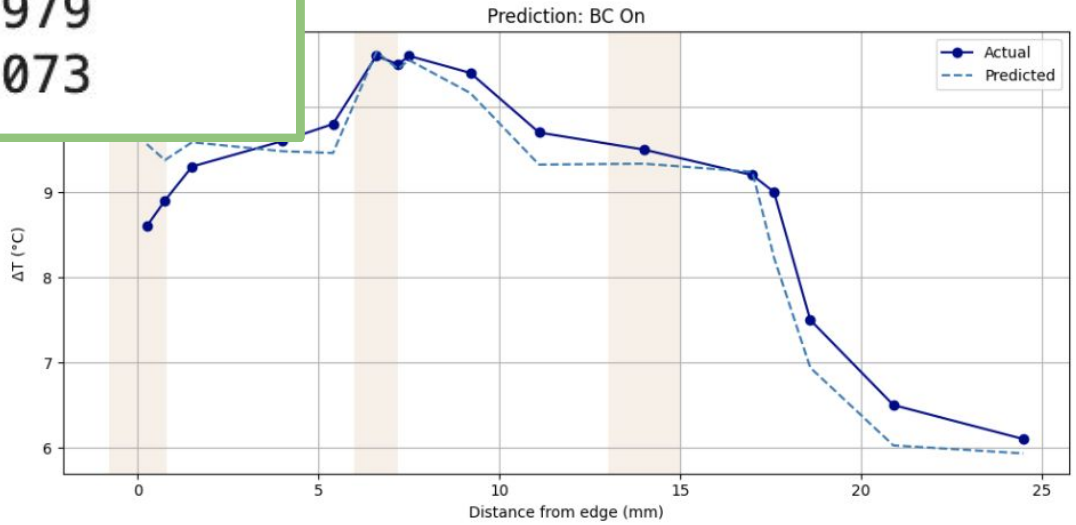
RMSE for ABC: 0.35 °C



Fitted Coefficients:
A: 0.907
B: 0.979
C: 1.073



RMSE for AB: 0.46 °C



RMSE for BC: 0.42 °C

Neighbor Analysis

- Use the same matrix model but **generalize**
- Input # of neighbors on the same side, and # of neighbors on the opposite side to generate a prediction of what measuring an arbitrary row will look like
- We have not measured across row C: goal is that this prediction matches the data when measured

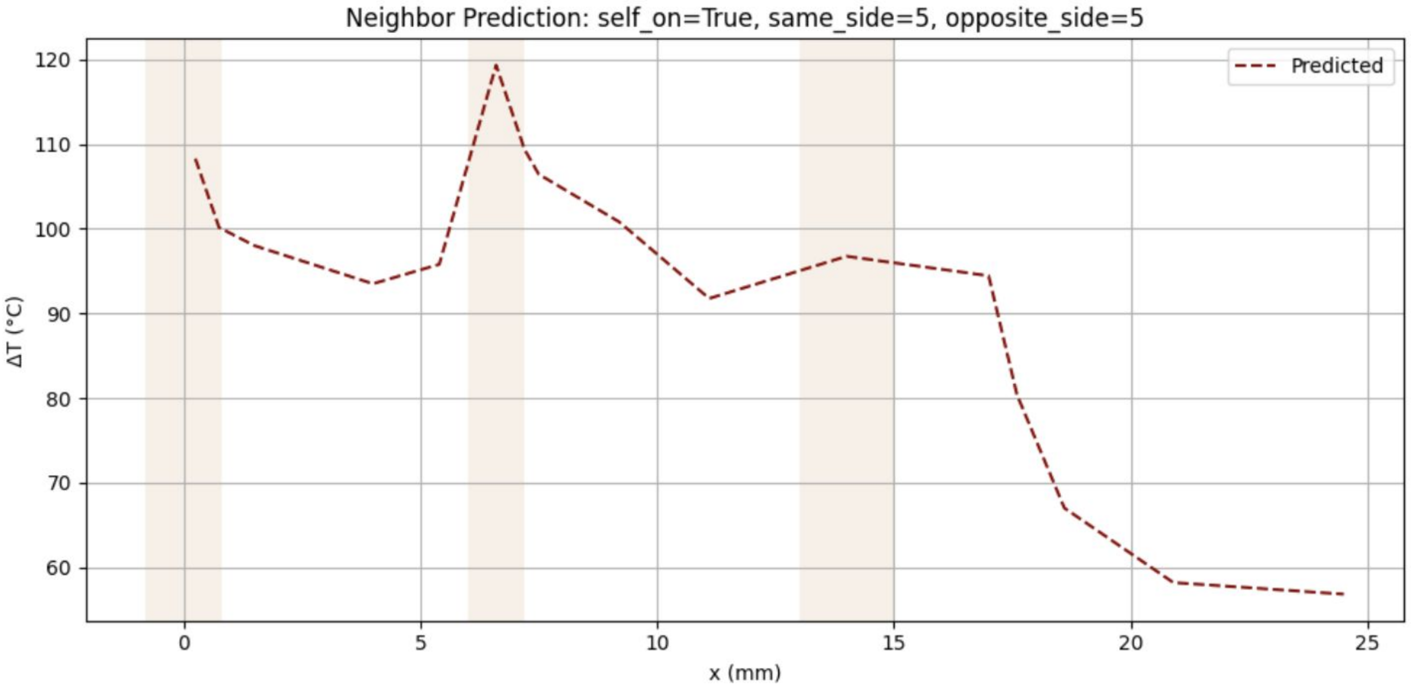
```
# Just A on (measured row only)
predict_with_neighbor_config(self_on=True, same_side_neighbors=0, opposite_side_neighbors=0)

# A and B on (one same-side neighbor)
predict_with_neighbor_config(self_on=True, same_side_neighbors=1, opposite_side_neighbors=0)
```

Neighbor Analysis

Predictions

Self On, 5 additional neighbors on each side: gives dT, not T

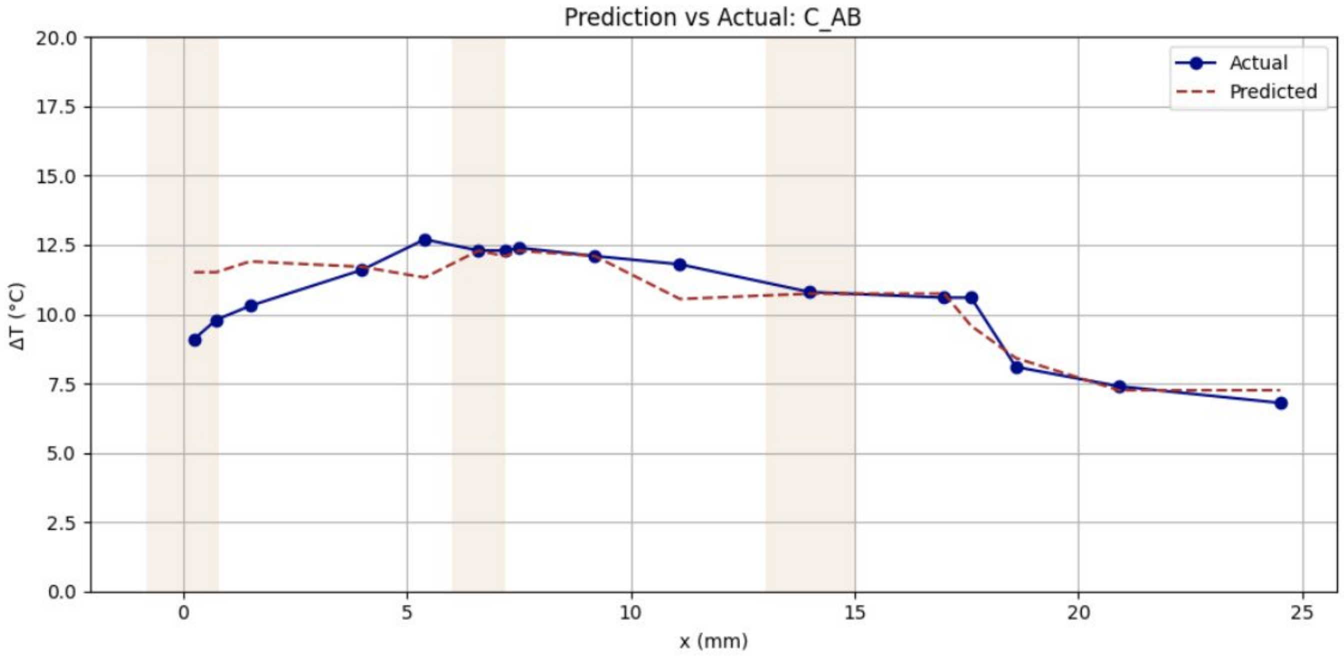
- Don't have the data to account for how neighbor distance affects dT
- Need to add a row a few rows away on the carbon fiber to understand how dT falls off
- It is clear that a dT of 120 is MASSIVE! Definitely too high, but need more data to train the model better



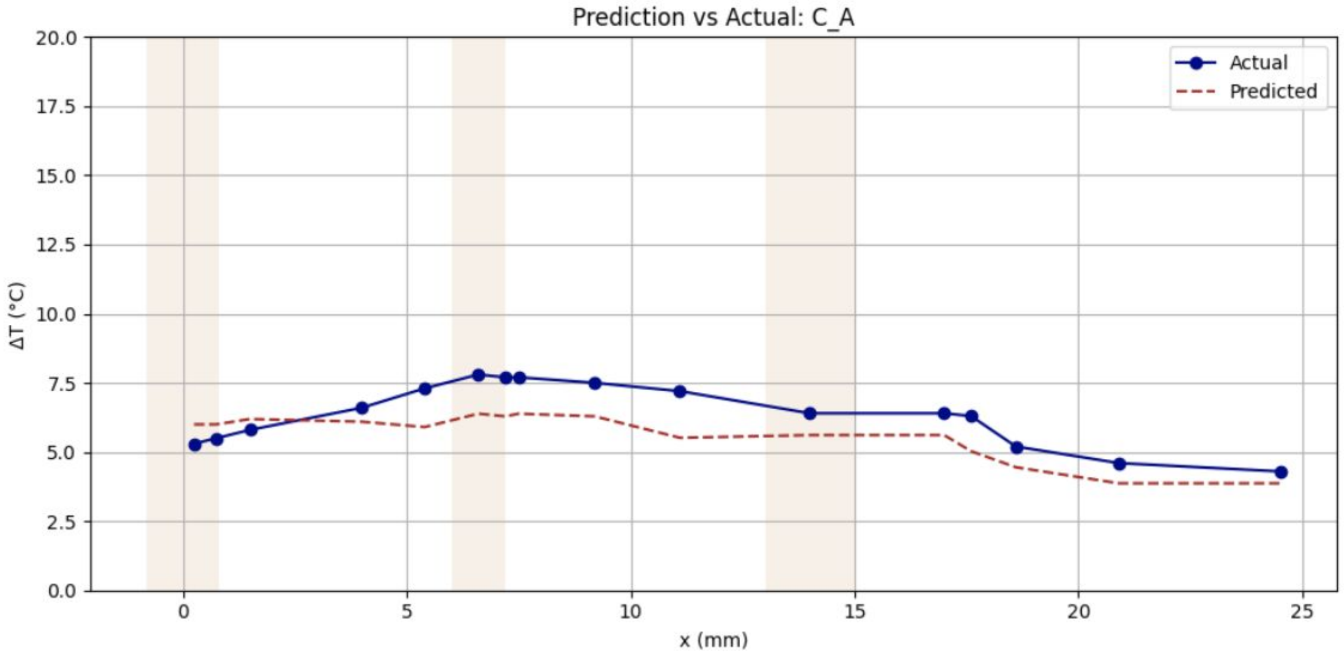
Neighbor Analysis

Comparing Predictions

- Predict Measuring across Row C with A&B on, reasonable fit
- Predict with only A on
- Prediction is coming from Measuring row A with C on, which was very hot, so the discrepancy makes sense
- Accurate to within roughly a degree, so useful even in this unfinished state!

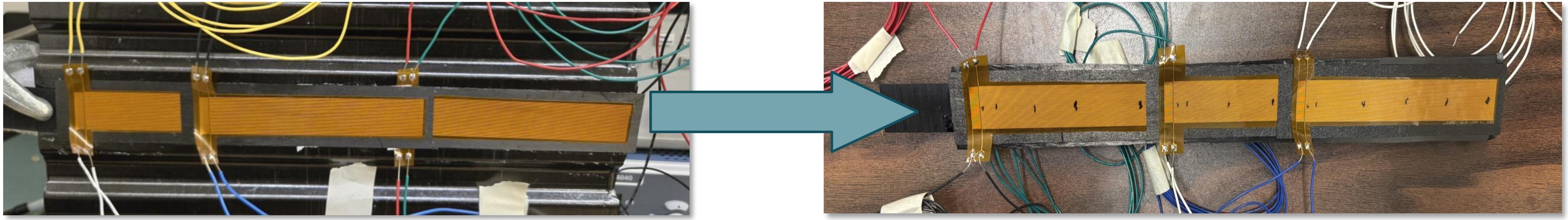


RMSE for C_AB: 1.01 °C



RMSE for C_A: 1.04 °C

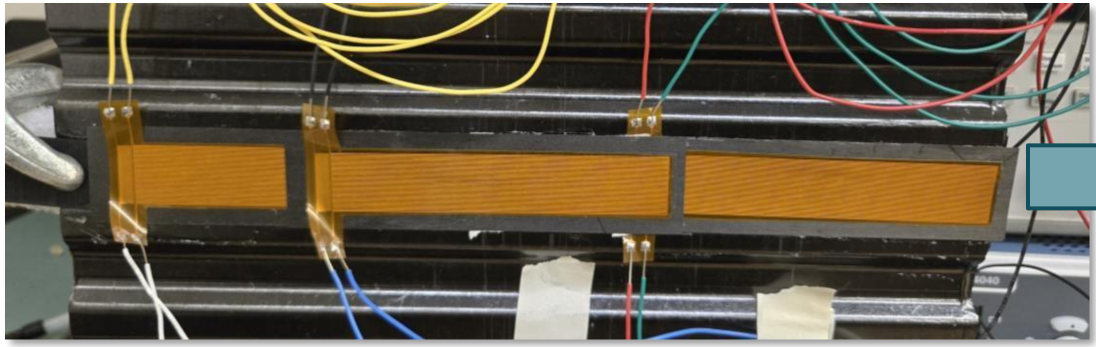
Updating The 3-Channel Test Piece

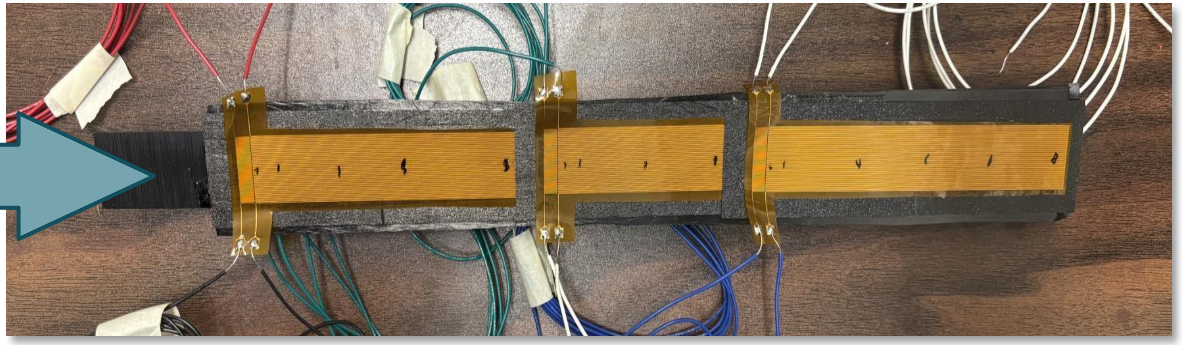


Changes

- Original data taken with the third LEC covered
- All future data will be taken with the third LEC uncovered
- This will both increase the temperature reading at that x-value, and likely impact the conduction through the carbon fiber

Updating The 3-Channel Test Piece





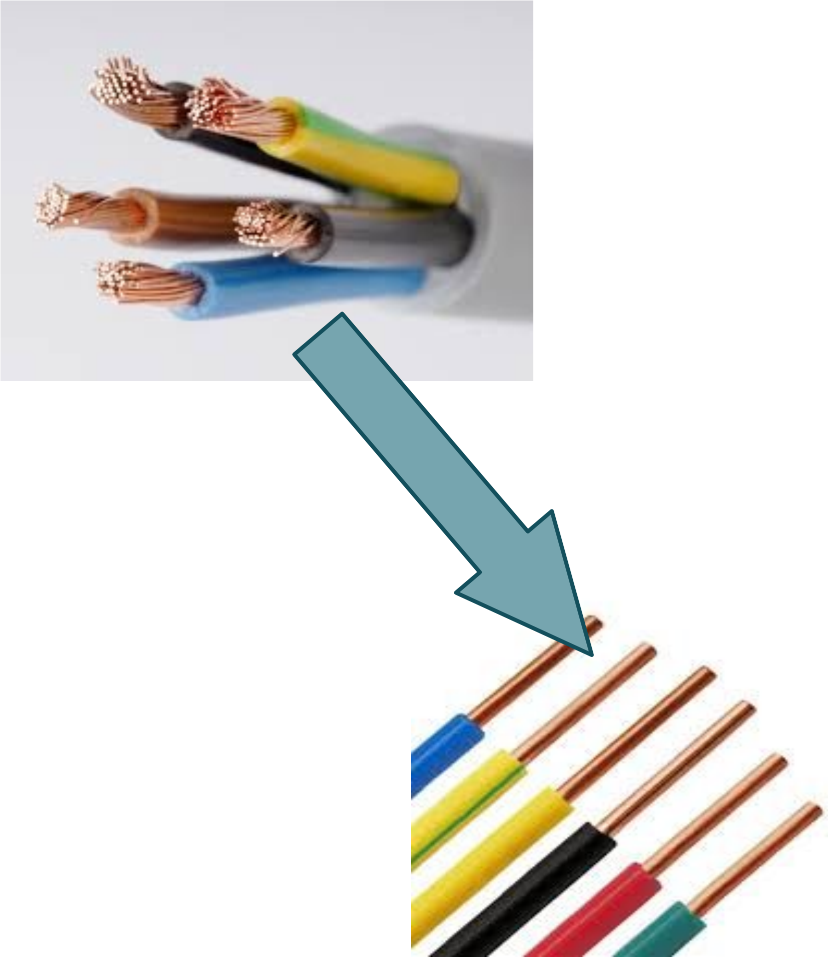
Changes

- As time goes on some heaters stop working, likely due to the wires being used
- Replacing them means resoldering
- This has the potential to introduce excess heat to the the heaters
- The hope is that the wires will still make good electrical contact, while the heaters still make good thermal contact

Updating The 3-Channel Test Piece

Changes

- A larger gauge of wire will be used: the current wires are thin and have multiple strands in their core
- Unfortunately, these inner strands seem to break internally, resulting in a poor connection and variable power draw to each LEC/RSU
- If this doesn't work, I will replace the rows of heaters



What’s Next?

- Replaced the heaters & wires
- New wire is 18 gauge and ended up ripping one of the heaters so a new repair will need to happen
- Retake all data across the three rows to feed into the model
- This should make the predictions match the data accurately, and we will likely see a reduction in the asymmetry of heating between rows B and C as they impact A

What's Next?

- Then, **air cooling** will be added to be setup, and data taken with two channels (A & B) across a variety of air speeds and Max and Nominal power
- We also need to add a **heater a few rows away** to see vertical distance dT
- This will greatly refine cases of say, 5 neighbors, and will be necessary for an accurate model for a full panel of heaters
- Potentially it makes sense to add this row before air cooling?