Heater Considerations for CORC Common Coil Test

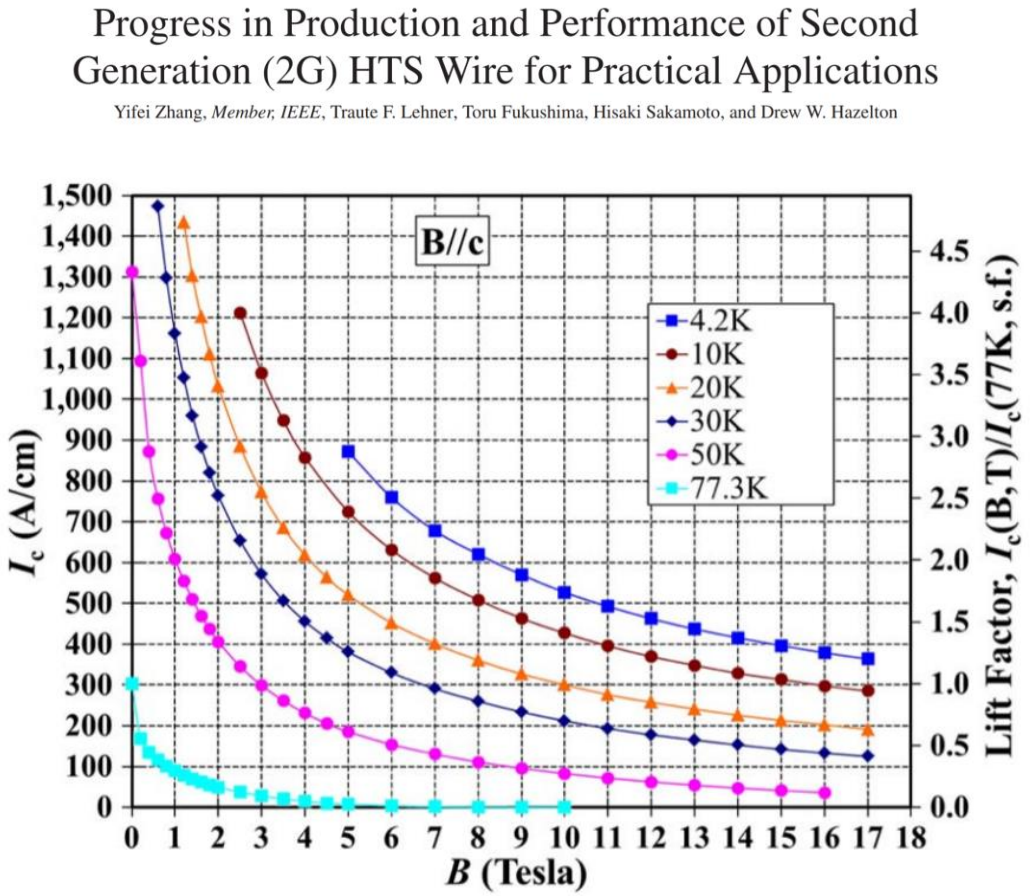
December, 2020

Motivation and Outline

- In 12/10/2020 meeting, discussed need to have quench heaters
- These slides go over several aspects of the quench heater implementation
  - Approximate thermal margin in tests
  - Approximate temperature rise from heater
  - Proposed heaters and possible implementation

Critical current for temperature margin

- 2D interpolation table from digitized SuperPower tapes (old data)
  - *50 micron substrate, 7.5% Zr, 2014 SCS-4050, worst orientation*
- Scale all values to approximate CORC cable – 8 kA at 10 T, 4.2 K
  - Based on values discussed in meeting
    - *"~8-10 kA at 10 T, 4.2 K"*
  - *Would appreciate suggestions for most applicable $I_C(T, B)$ data for newest CORC cables*



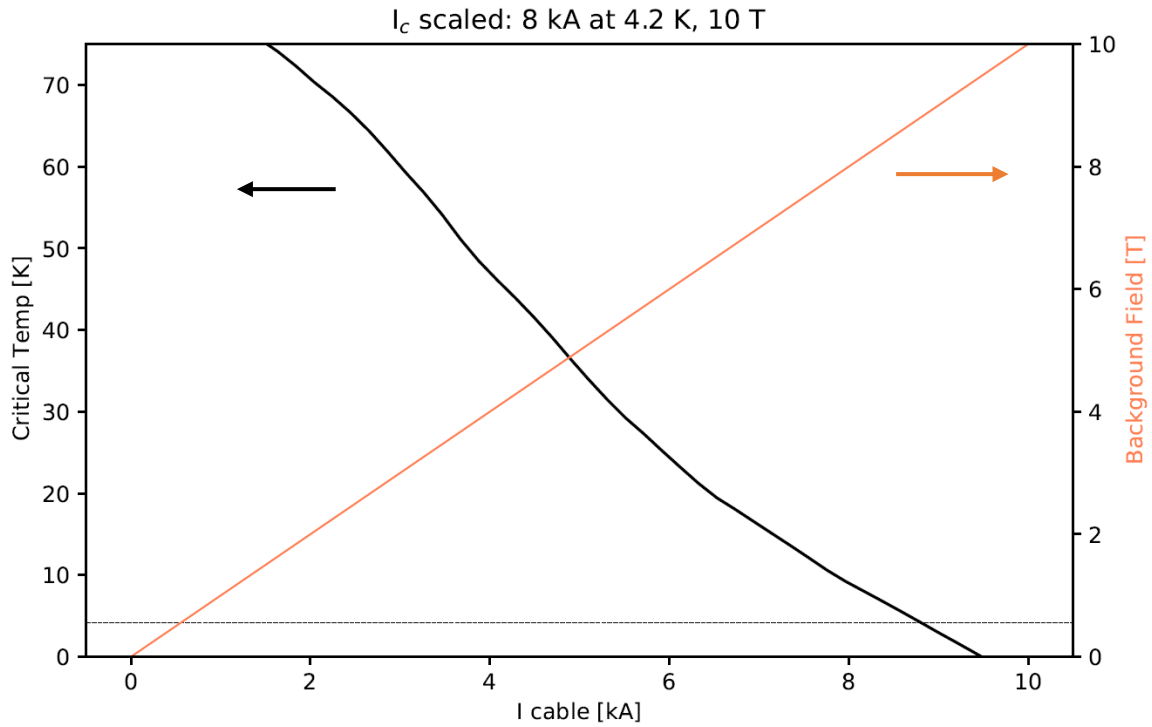
Note – no low field 4.2 K data here

Test and background field

- Assume linear transfer function for background field
  - 10 kA cable current -> ~10 T background field
    - Neglect low-field iron contribution
  - Background field and CORC wired in series
- **Iteratively find what temperature yields CORC critical current equal to the cable current with corresponding background field**
  - $I_C = \mathrm{f}(\mathrm{T}, \mathrm{B})$ -> least squares optimization to find T such that $I_C = I_{cable}$ at B
  - Repeat for each cable current along ramp (each point on x axis in next slide)

Temperature margin

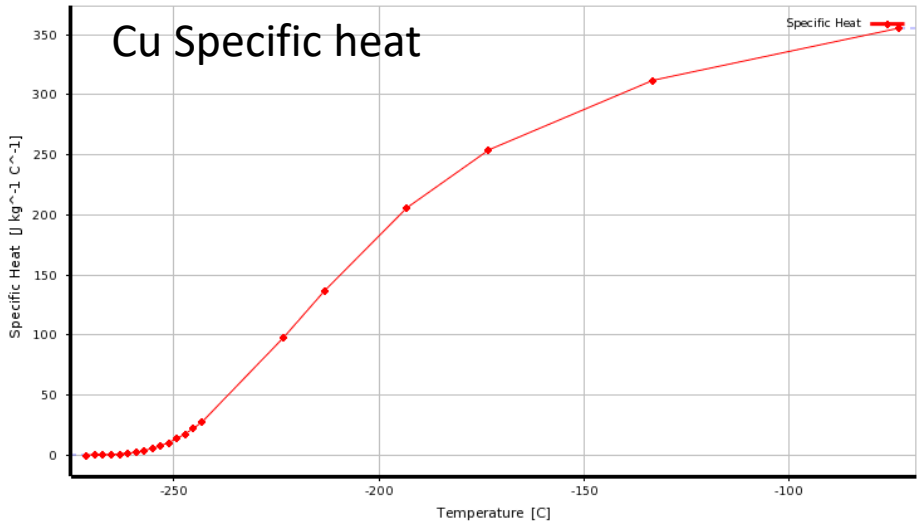
- Shown (left y axis) – required CORC temperature to quench at each cable current
  - Considers increasing background field with I_{cable}(orange, right y axis)
- Want to raise CORC temperature by ~ 20 K to quench at ~ 70% I_c
  - Recall – CORC cable I_C may be > 8kA, still want to induce quench with heater
  - Will be challenging to quench samples with heater at low cable current

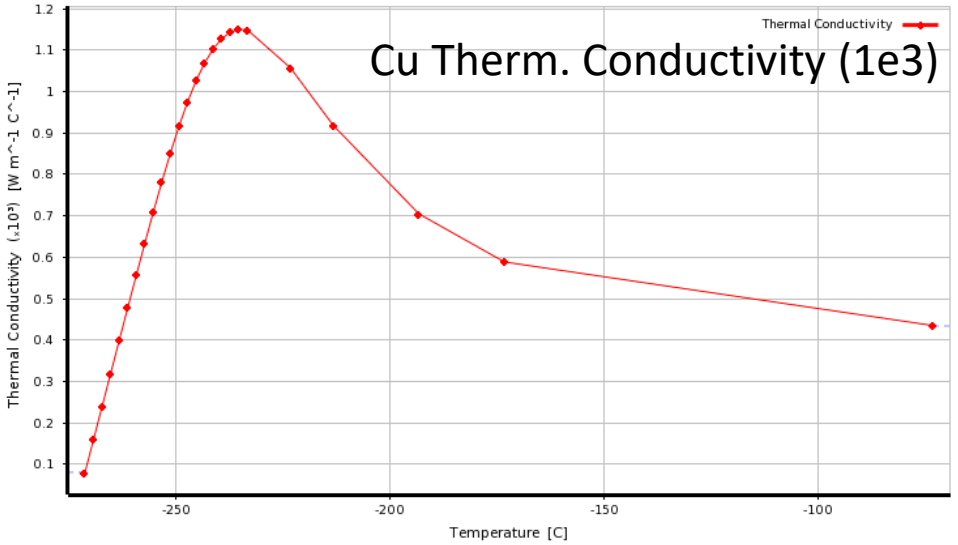


Note – temperature margin (left y axis) calculated with corresponding background field (right y axis) – wired in series, 1 T/kA

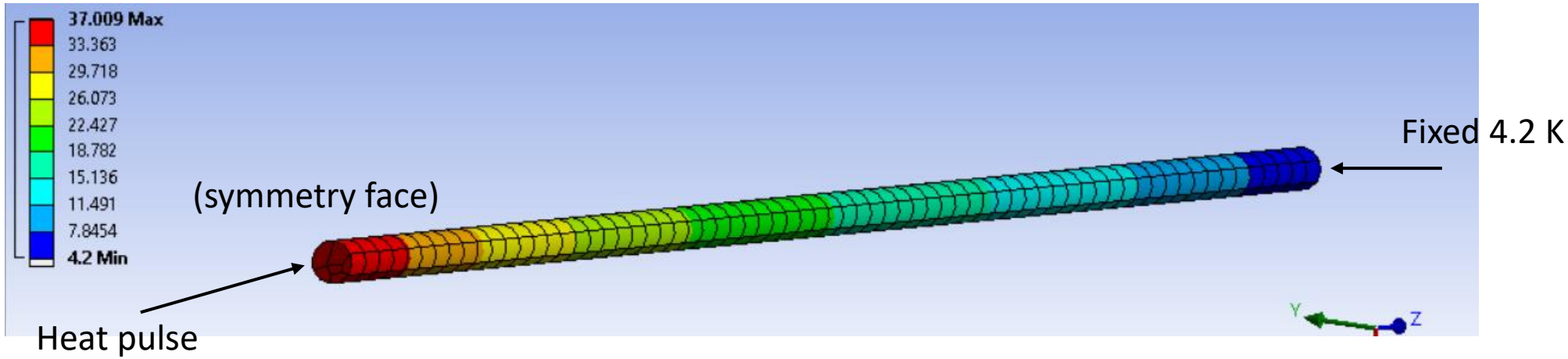
Simple transient simulation

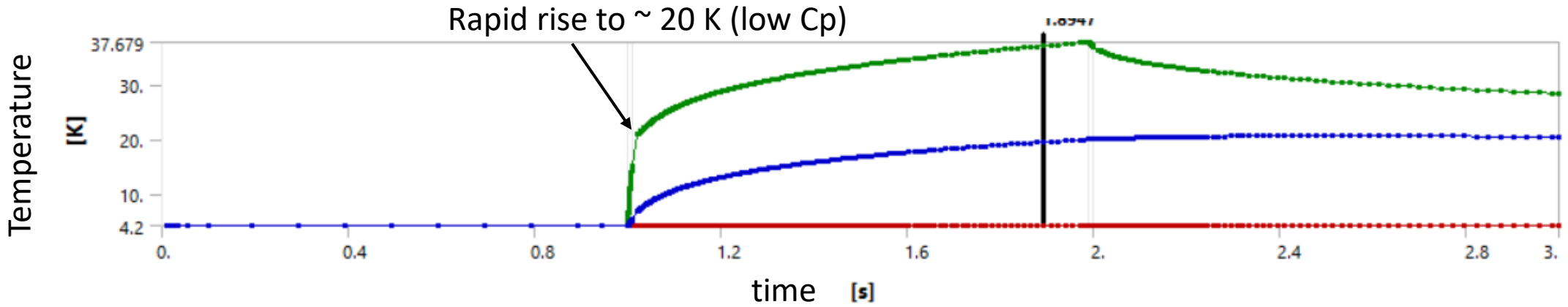
- What is approximate temperature rise for CORC after applying heater?
  - Assume CORC and heater are well insulated – dominated by axial conduction in CORC
  - Treat CORC as long copper cylinder
  - One face – fixed at 4.2 K, other face – heat pulse (10 W total)
  - Temperature dependent conductivity, specific heat (evaluated at fixed B=10T, RRR=150)
- This is not a quench simulation or detailed investigation
  - Trying to get order-of-magnitude of temperature rise





Simple transient simulation





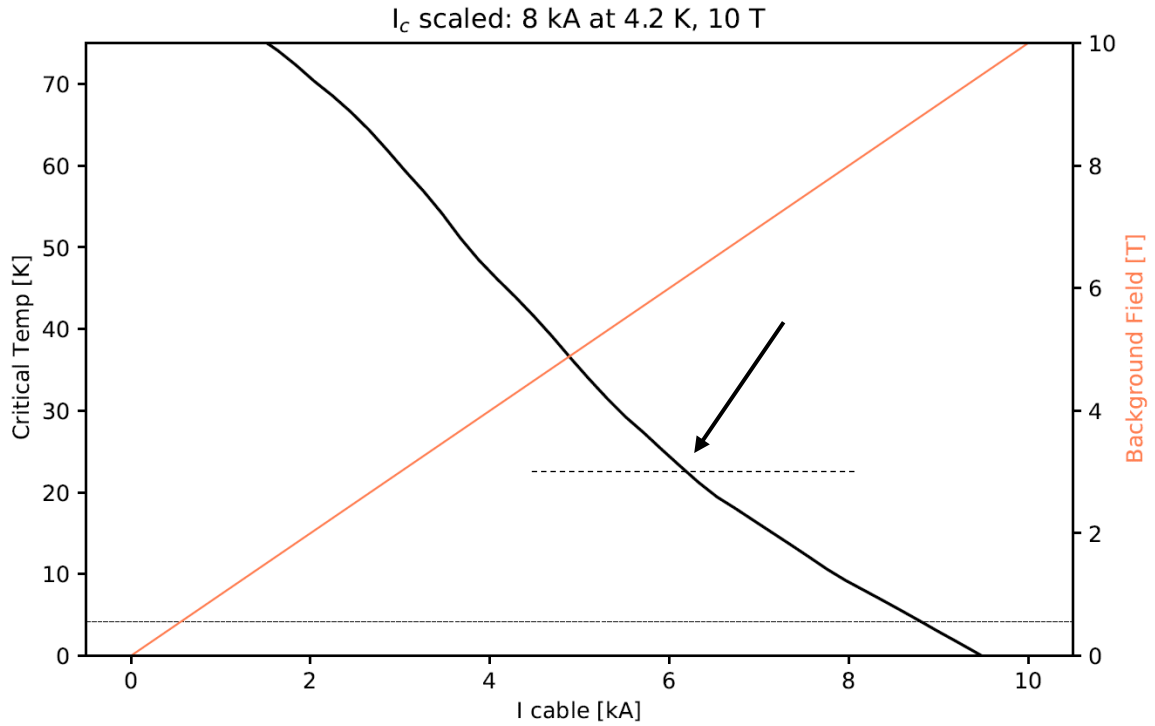
Heat source OFF (0-1 s)

10W Heat source ON (1-2 s)

Heat source OFF (2-3 s)

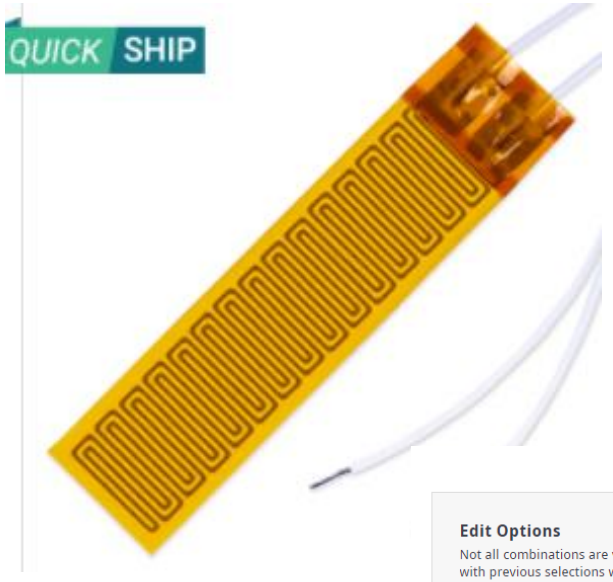
Outcome from analysis

- Seems feasible to rapidly raise CORC temperature above 20 K with 10W heater
  - Heater should still quench CORC even if I_C is on high side (e.g. 10-11 kA vs 8 kA)
  - Will require good thermal contact with heater, good insulation focusing heat into CORC



Heater option

- Omega Polyimide film heater (~$50)
  - 0.5” width x 2” length
    - Small, but not a “spot” heater
    - Claims 0.01” thickness, not including leads (22 AWG – but should add extra clearance)
    - Claims tight bend radius OK
  - 10 W (at 28 V)
    - Low resistance, may want to measure heater voltage drop
  - https://www.omega.com/en-us/industrial-heaters/surface-heaters/flexible-heaters/p/PLM-Series
- **Any other suggestions welcome**
  - Heater wire also promising (photo from Jeremy Weiss)



Edit Options View all models

Not all combinations are valid. Options compatible with previous selections will be in bold.

Shape: Rectangular

Temperature range: -57°C (-71°F) to 232°C (450°F)

Power Density: 10 W/in2

Power (watts): 10

Supply Voltage: 28 Vac

Diameter: None

Width: 0.5 in

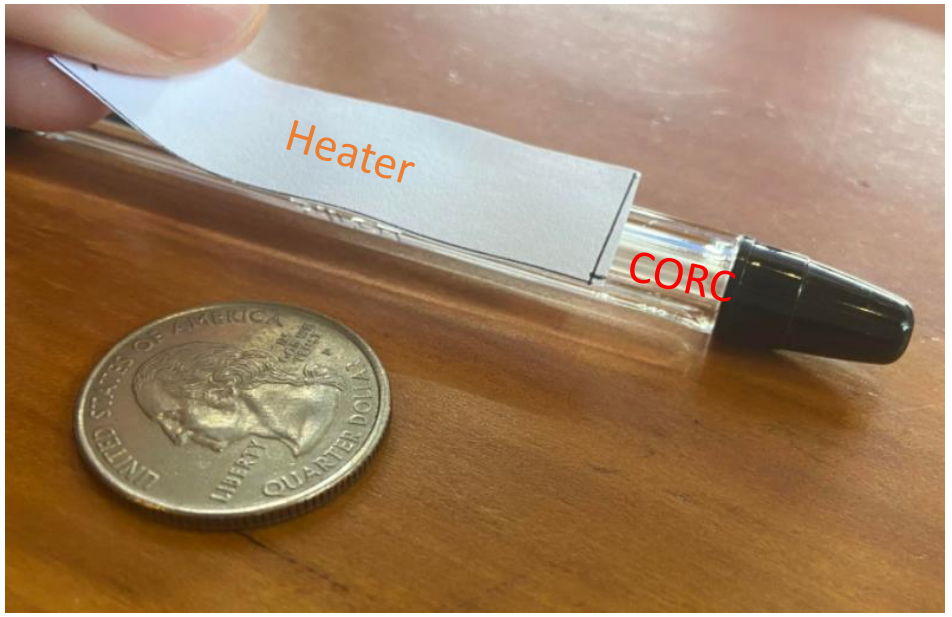
Length: 2 in

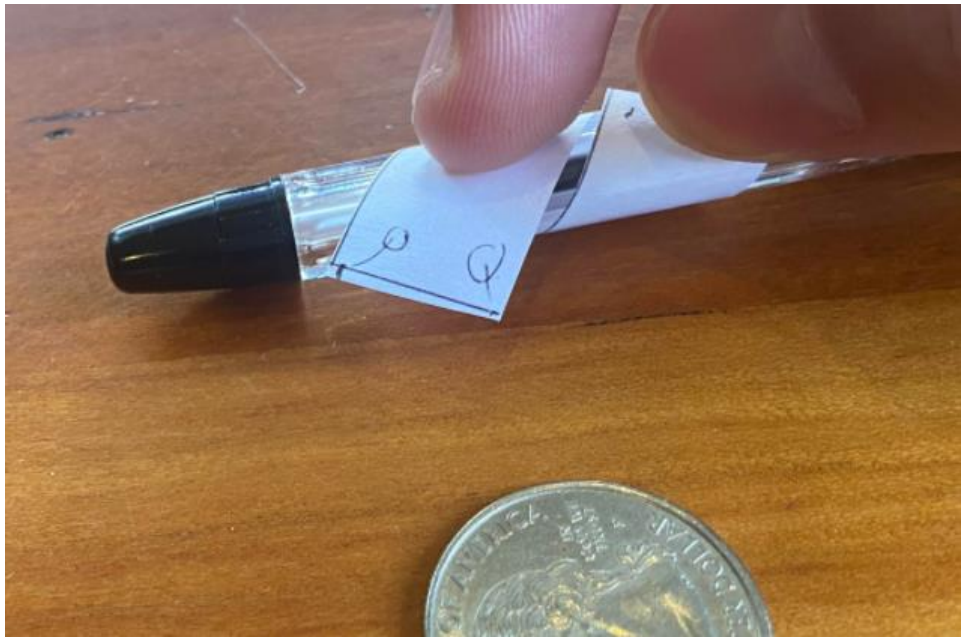
Thickness: 0.01 in

Heater Material: Polyimide

Heater Implementation

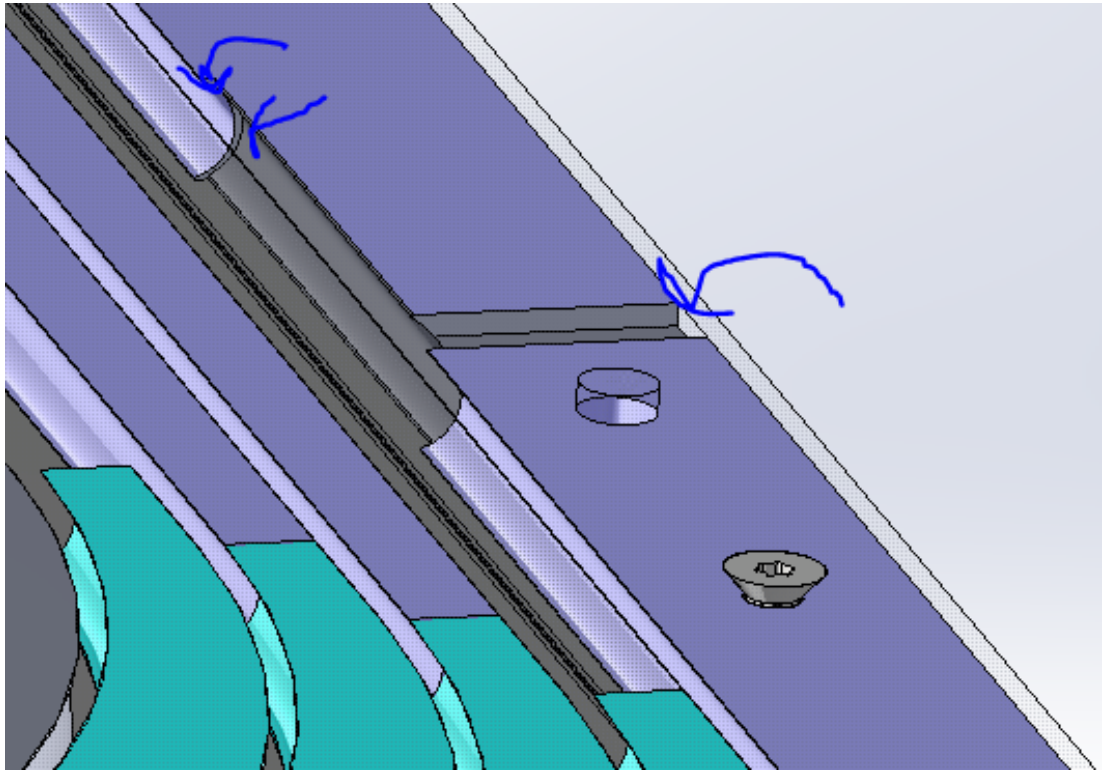
- Easiest to install flat
  - Mock heater =2”x0.5”
  - Would need to add thermal insulation on top of heater to focus heat toward CORC
- **Best to wrap around CORC**
  - Could be challenging to do this while wet-winding
  - **Need to fix heater to CORC while winding**
    - Heat-shrink or Kapton adhesive tape
  - Need to make clearance in neighboring parts for heater





Heater Implementation

- Best to wrap around CORC
  - Need to fix heater to CORC while winding
    - Heat-shrink or Kapton adhesive tape
  - **Need to make clearance in neighboring parts for heater**
    - Note – clearance both for heater (and heat shrink / Kapton tape) and a channel to feed leads out
    - Would need similar clearance in all neighboring parts
    - Requires excess epoxy to fill any void space

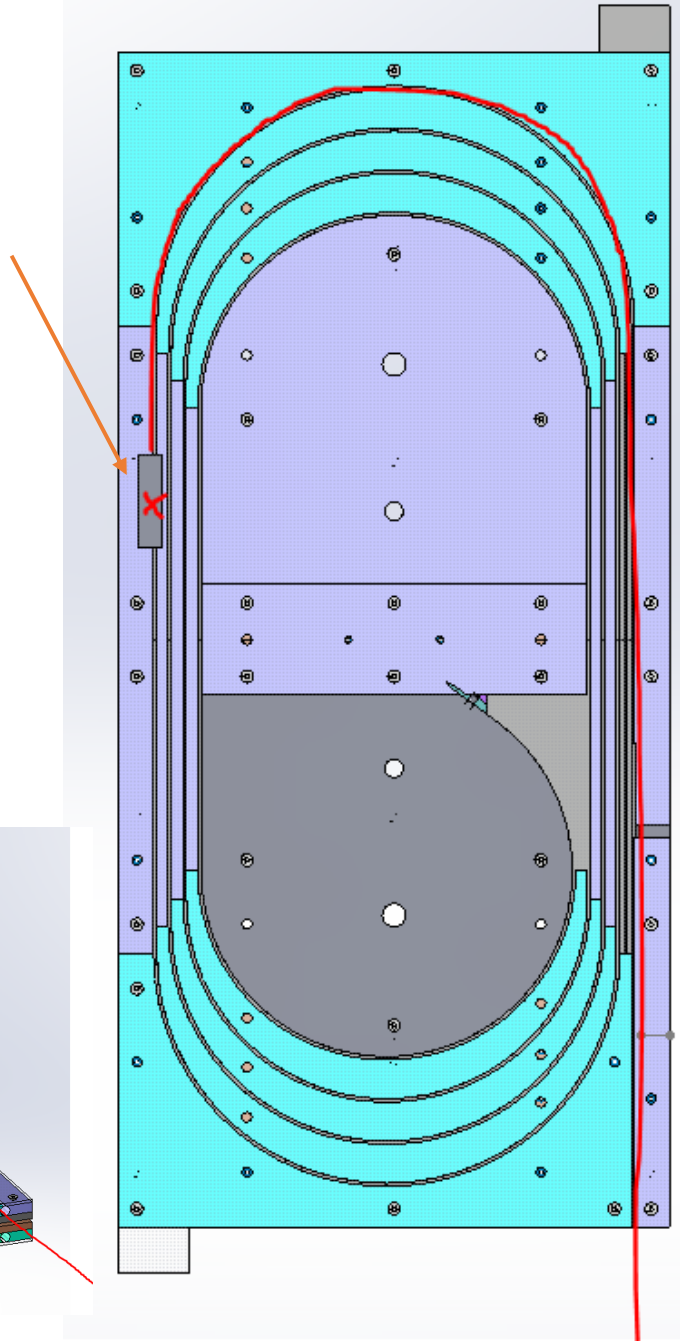


Heater locations

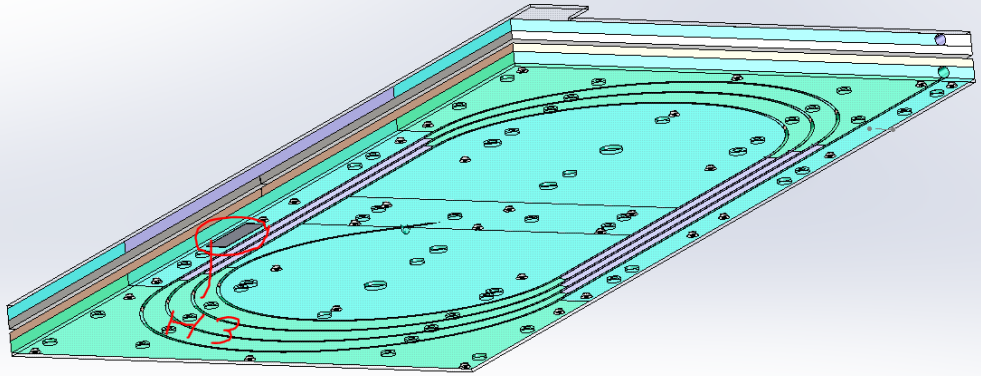
- Hall array test objective: would like to probe the terminal Hall probe response as a function of the quench distance
  - See if terminal Hall probe array can detect current redistribution at “short, medium and long” distances
- Focus on next slides is on heater *locations*, not implementation
  - See last slide – would still prefer to wrap heater around CORC, if possible

Heater 1, Heater 3 locations

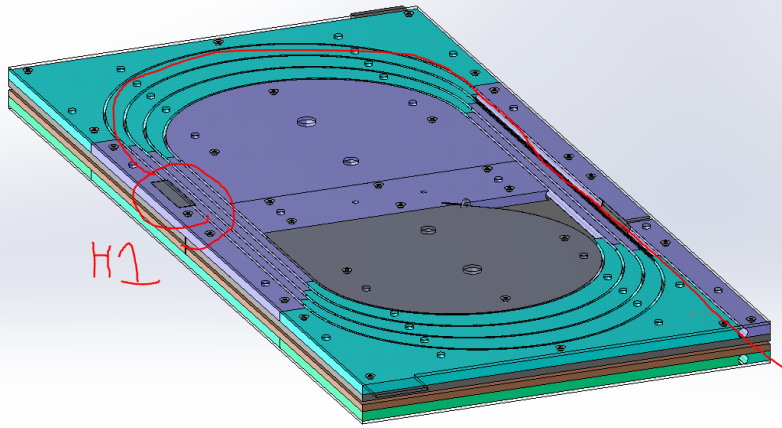
- Install on side after first turn from injection / extraction
  - Both on top (heater 1) and bottom (heater 3) coils
  - These heaters will be “close” and “far” from the terminal Hall probe array



Heater 3 – bottom

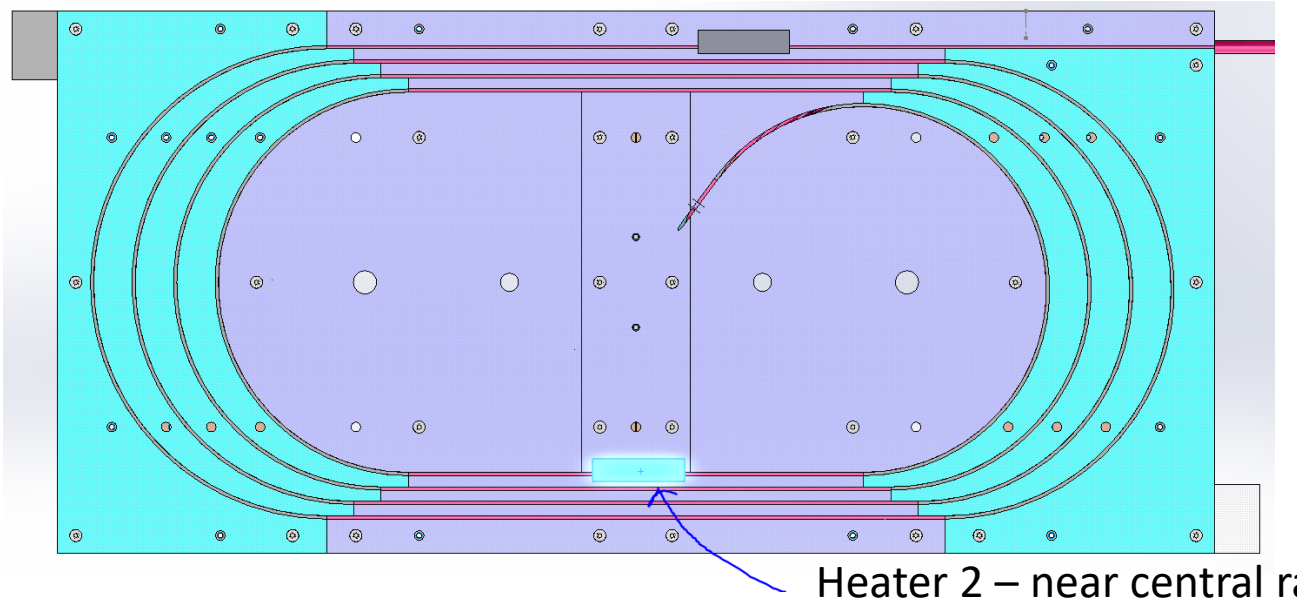


Heater 1 – top



Heater 2 location

- Install heater somewhere near middle of cable
  - “medium” distance between quench and terminal Hall probe array
    - Compared to Heater 1 (close) and Heater 3 (far)
  - One possibility shown, however may be easier to mount heater 2 near central ramp
    - Would not need this on both top and bottom coils, just one side would be OK



Summary

- Quench heater seems feasible in regards to CORC thermal margin
- Need to ensure good thermal contact between heater and CORC
- Need good insulation around heater
- Possible implementation (flexible film heater wrapped around CORC) and heater locations identified (near leads, near cable center)

- More work needed to finalize implementation / design details