ELECTRIC-THERMAL MODELING OF LI-ION BATTERY PACKS COMPONENTS AND INTERFACES AS BASIS FOR PASSIVE PROPAGATION RESISTANCE

Paul T. Coman[1,*] | David Petrushenko[2] | Eric Darcy[2] | Ralph E. White[1]

[1]University of South Carolina, [2]NASA JSC

2025 NASA Aerospace Battery Workshop

20-22 Jan 2026

UNIVERSITY OF South Carolina

Molinaroli College of Engineering and Computing

NASA Aerospace Battery Workshop

GUIDELINES FOR PPR

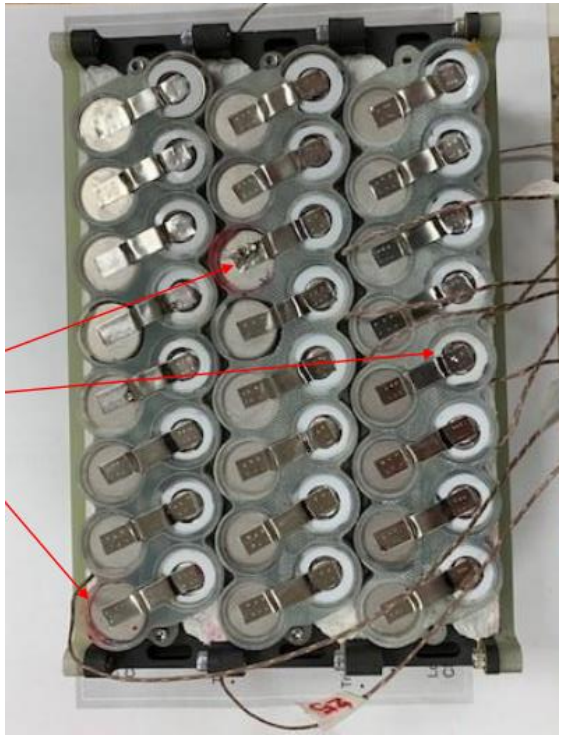
- **Reduce risk of cell can side wall breaches**
  - Without structural support most high energy density (>660 Wh/L) designs are very likely to experience side wall breaching during TR
  - Battery should minimize constrictions on cell TR pressure relief
- **Provide adequate cell spacing and heat rejection**
  - Direct contact between cells nearly assures propagation
  - Spacing required is inversely proportional to effectiveness of heat dissipation path
- **Individually fuse parallel cells**
  - TR cell becomes an external short to adjacent parallel cells and heats them up
- **Protect the adjacent cells from the hot TR cell ejecta (solids, liquids, and gases)**
  - TR ejecta is electrically conductive and can cause circulating currents
- **Prevent flames and sparks from exiting the battery enclosure**
  - Provide tortuous path for the TR ejecta before hitting battery vent ports equipped flame arresting screens

Source: NASA NESC Task Report TI-14-00942 “Assessment of ISS/EVA Lithium-ion Battery TR Severity Reduction Measures” May 2017

FUSES

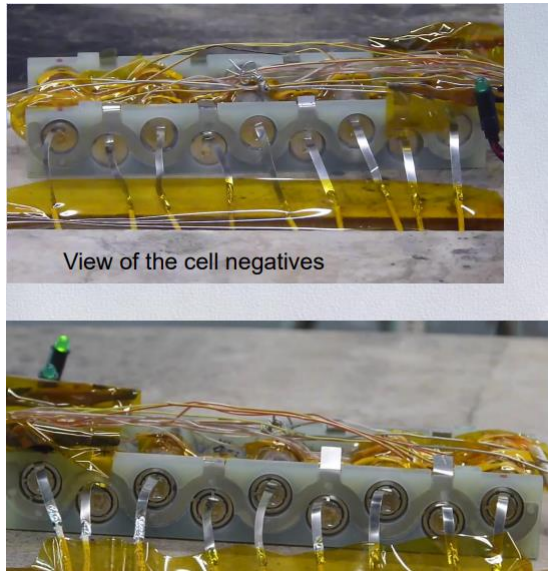
- High electrical conductivity under normal operation to enable efficient charge transfer (e.g., Ni, Cu busplate materials)
- Individually isolate parallel cells during fault or thermal runaway events
- Limit fault current and secondary heating, reducing the likelihood of thermal propagation to adjacent cells
- Support pack-level TR mitigation, protecting neighboring cells from electrically driven heating during side-wall breach or ejecta exposure
- Intentional electrical weak points designed to open (melt) under excessive **current** and associated **heating**

DIFFERENT KINDS OF FUSES/LINKS

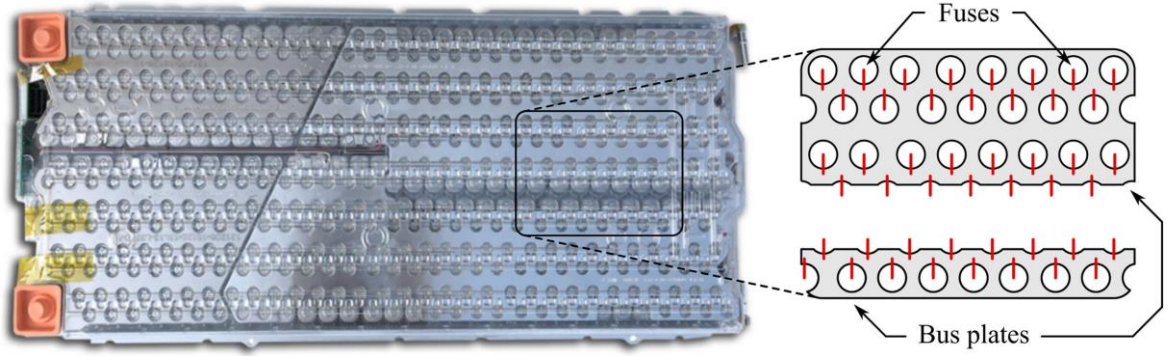


Source: E. Darcy et al. “Safe, High Power / Voltage Battery Design Challenges,” presented at the NASA Aerospace Battery Workshop, Huntsville, AL, USA, Nov. 19, 2019.

J. J. Darst, J. C. Thomas, D. P. Finegan, and E. Darcy, “Guidelines for Safe, High Performing Li-Ion Battery Designs for Manned Vehicles,” presented at the Power Sources Conference, Denver, CO, USA, Jun. 11–14, 2018, NASA Johnson Space Center, Houston, TX, USA, Tech. Rep. JSC-E-DAA-TN56375, NTRS Document ID: 20180003971



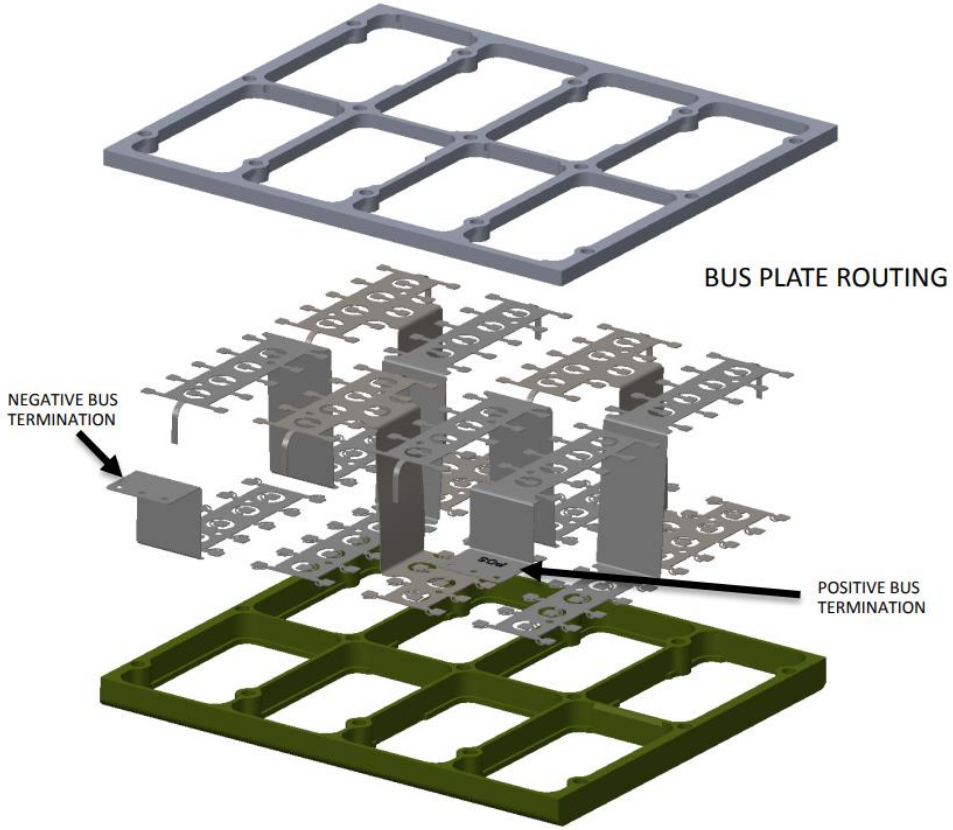
E. Darcy, “Thermal Runaway Severity Reduction Assessment for EVA Li-ion Batteries,” presented at the NASA Aerospace Battery Workshop, Huntsville, AL, USA, Nov. 18–20, 2014,

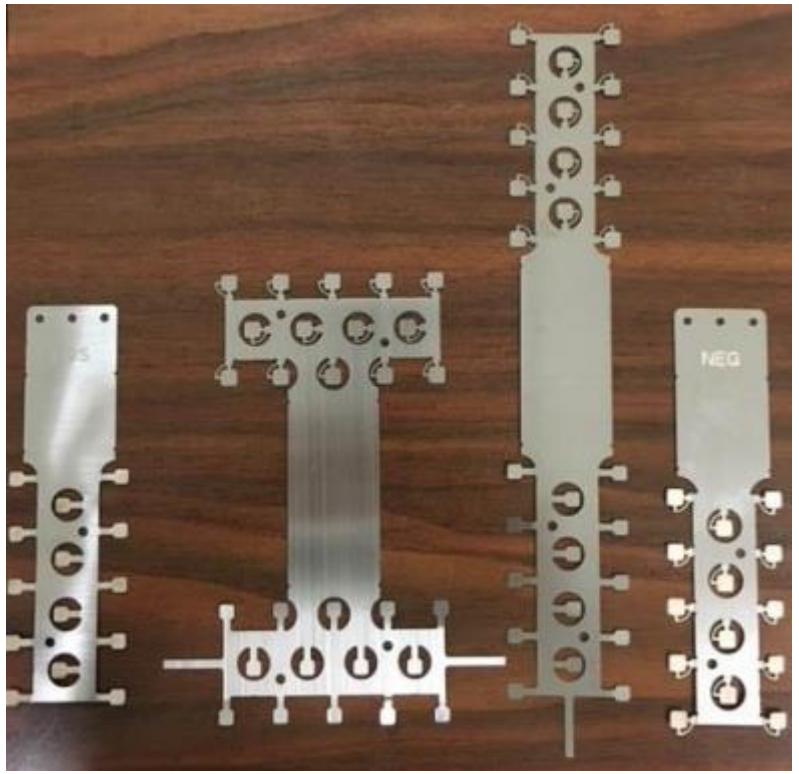


A. Sharma, P. Zanotti, L.P. Musunur, Enabling the electric future of mobility: robotic automation for electric vehicle, IEEE Access 7 (2019) 170961–170991

Molinaroli College of Engineering and Computing
UNIVERSITY OF SOUTH CAROLINA

INDIVIDUALLY FUSE PARALLEL CELLS (EARLY)



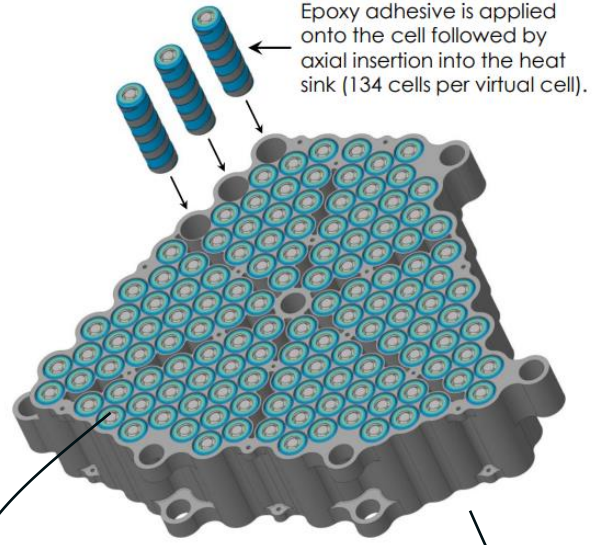


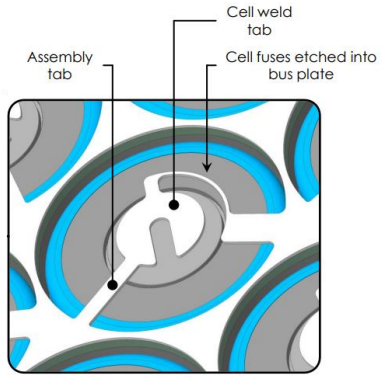
Source: Chuck Haynes, NASA JSC EP&ES, Darcy, Tran, Hagen, Ortiz-Sanchez, Bohot, Walker, NASA Alternative Orion Small Cell Battery Design Support, NASA Battery Workshop, November 18, 2016

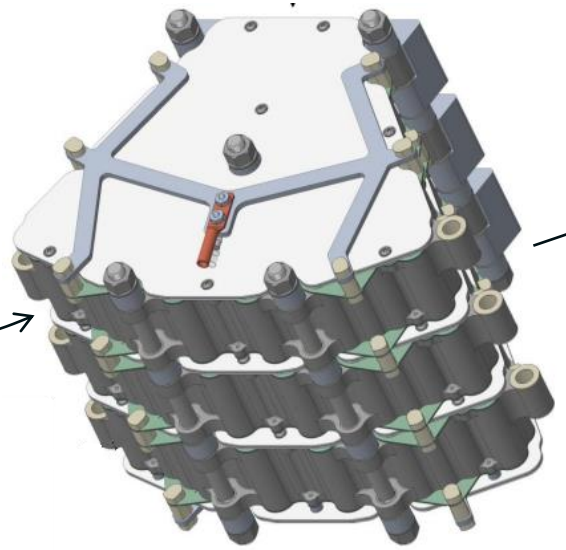
CAN WE PUT MORE COUPLED-PHYSICS INTO OPTIMIZING BUSPLATES?

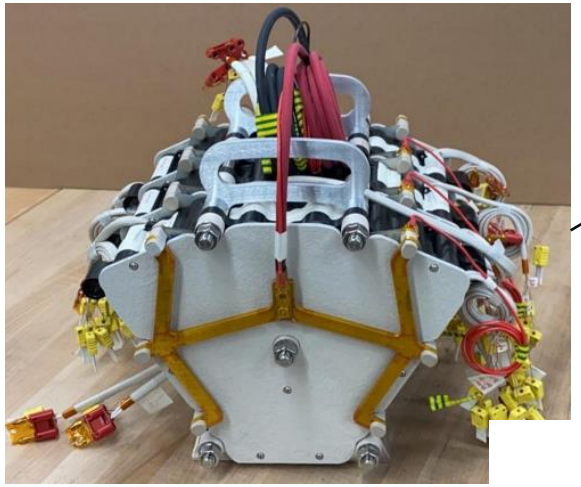
Molinaroli College of Engineering and Computing
UNIVERSITY OF SOUTH CAROLINA

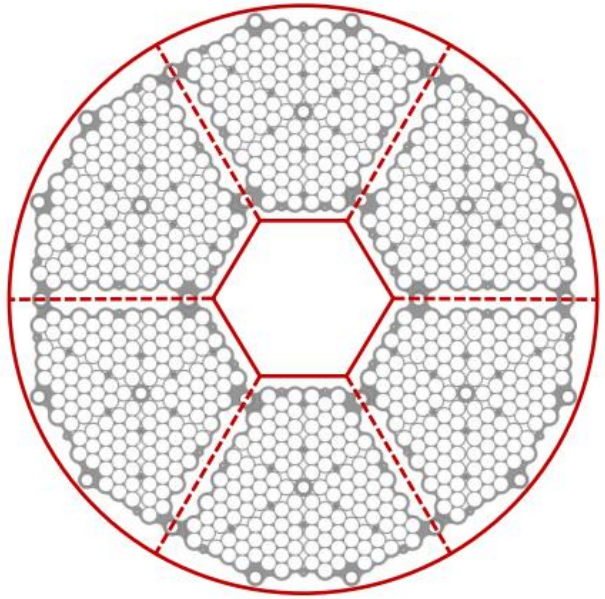
M3 DESIGN (STUDY CASE)







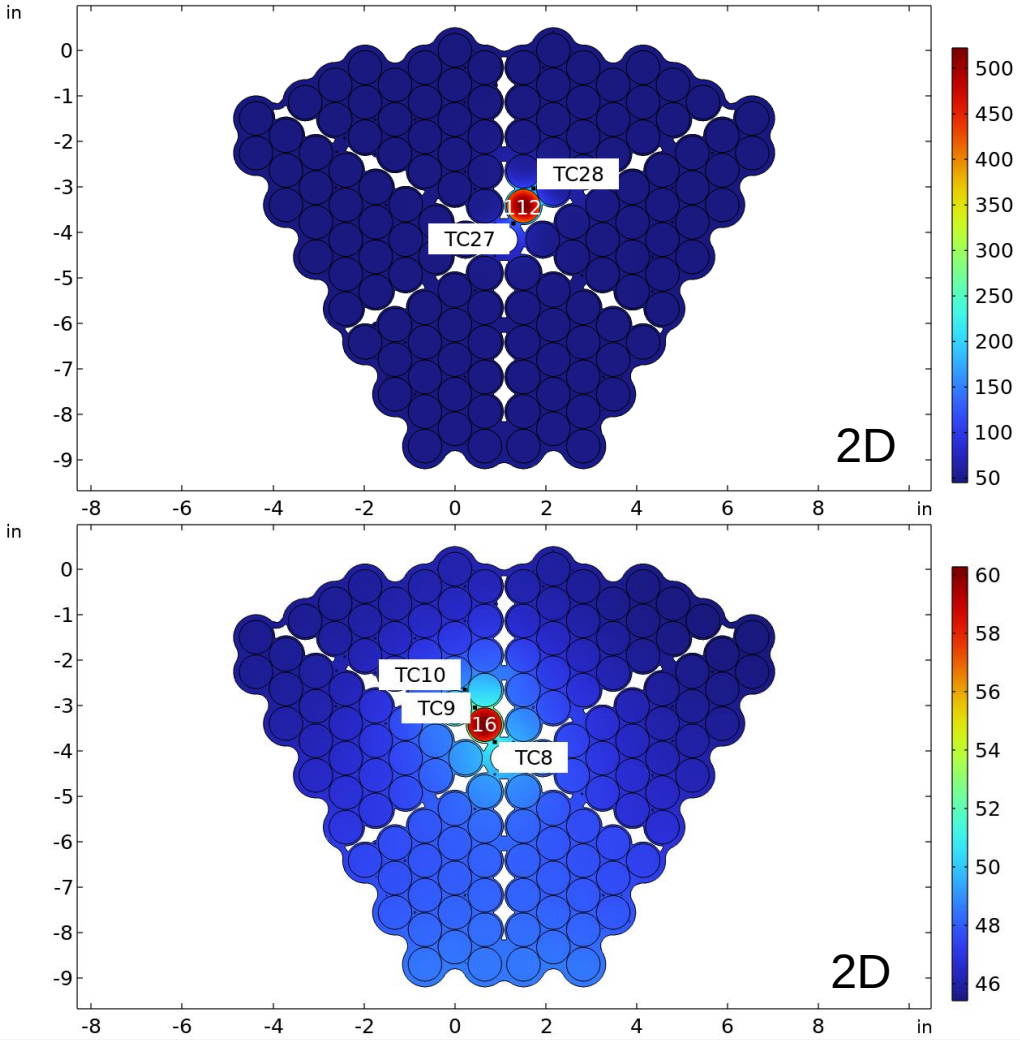




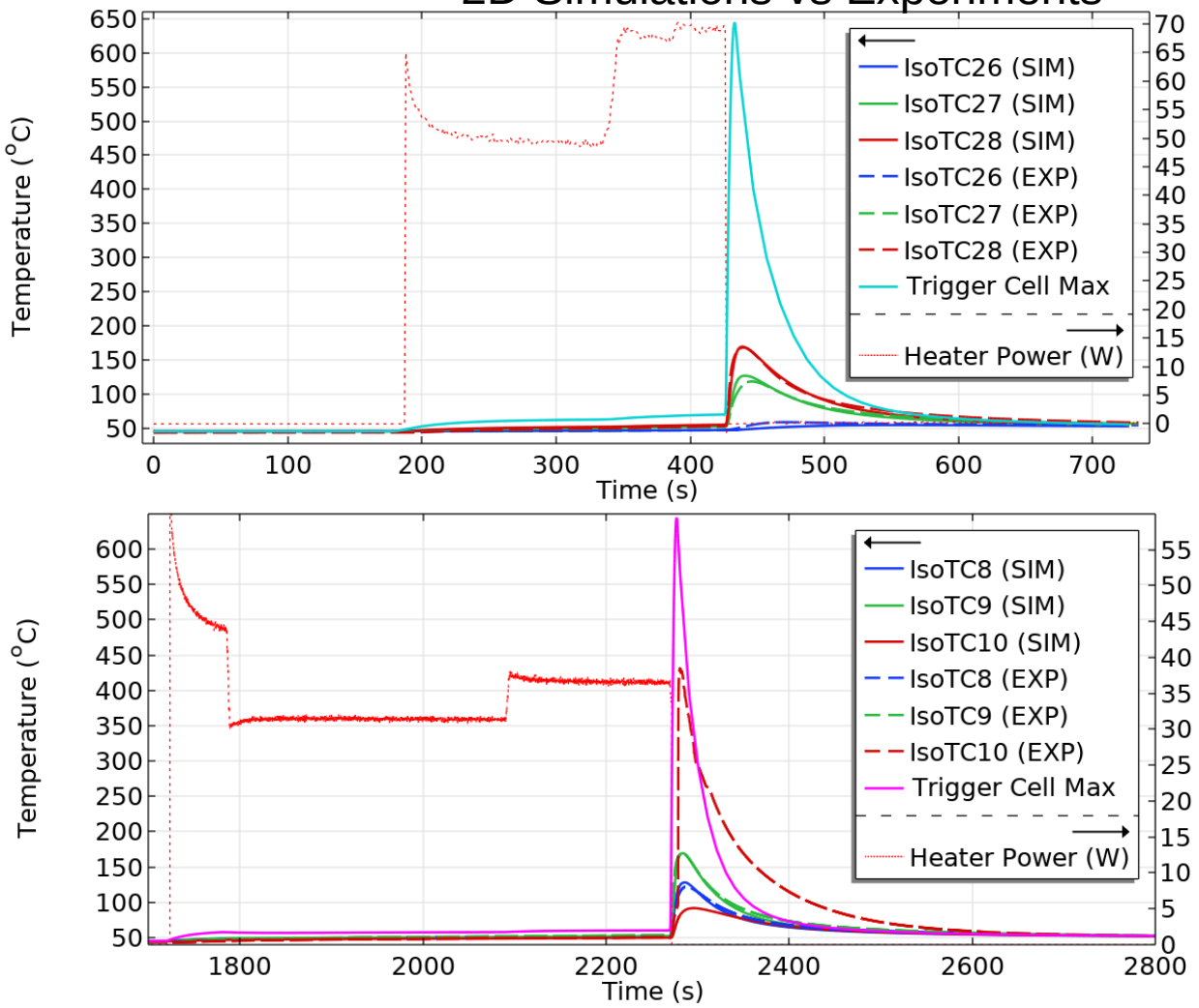
D. Petrushenko, P. Coman, J. Trillo, J. Darst, R. E. White, E. Darcy - M3 PPR Battery Development, NASA Aerospace Battery Workshop, 2022

Molinaroli College of Engineering and Computing
UNIVERSITY OF SOUTH CAROLINA

PPR? YES!

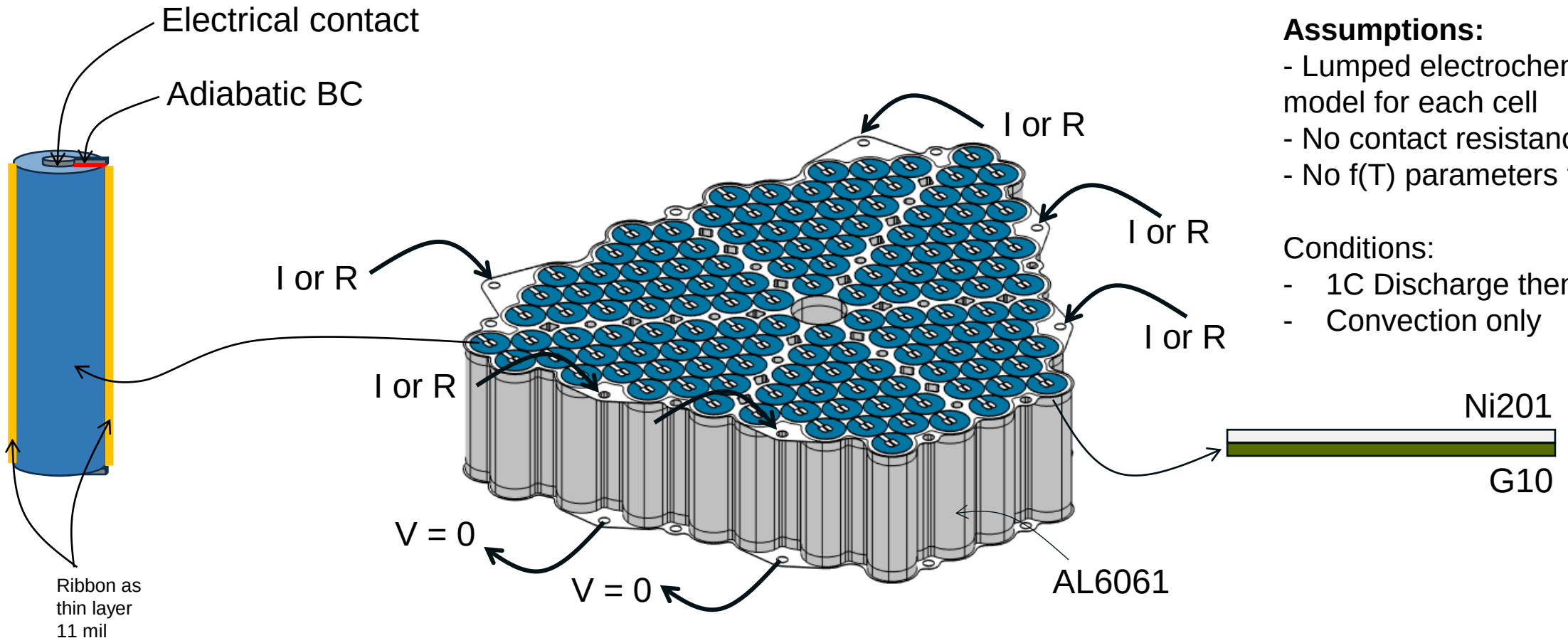


2D Simulations vs Experiments



Check: P. Coman, D. Petrushenko, E. Darcy, R. E. White, Electrical-thermal modeling and electrical design optimization of fuses in a nickel bus-plate for a Li-ion battery pack, Journal of Energy Storage, 86 (2024) 111226

3D GEOMETRY (WITH M35A CELLS)



Assumptions:
- Lumped electrochemical model for each cell
- No contact resistance
- No f(T) parameters for cells

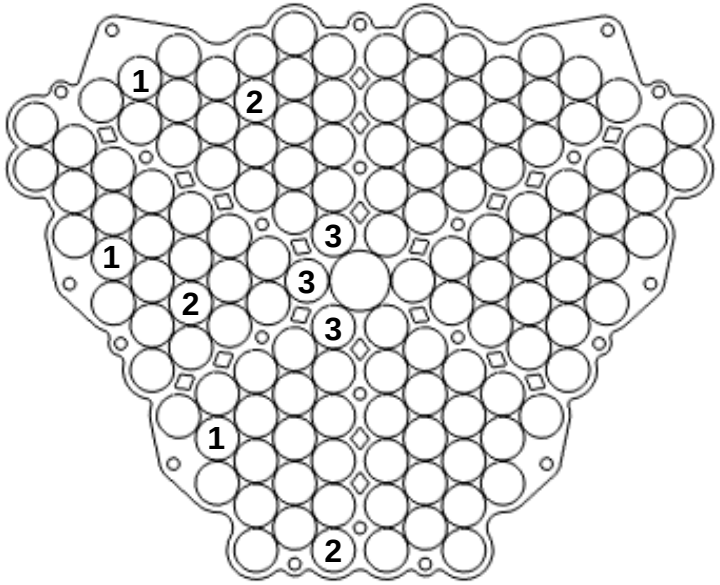
Conditions:
- 1C Discharge then relax
- Convection only

WHY DO ALL THIS?

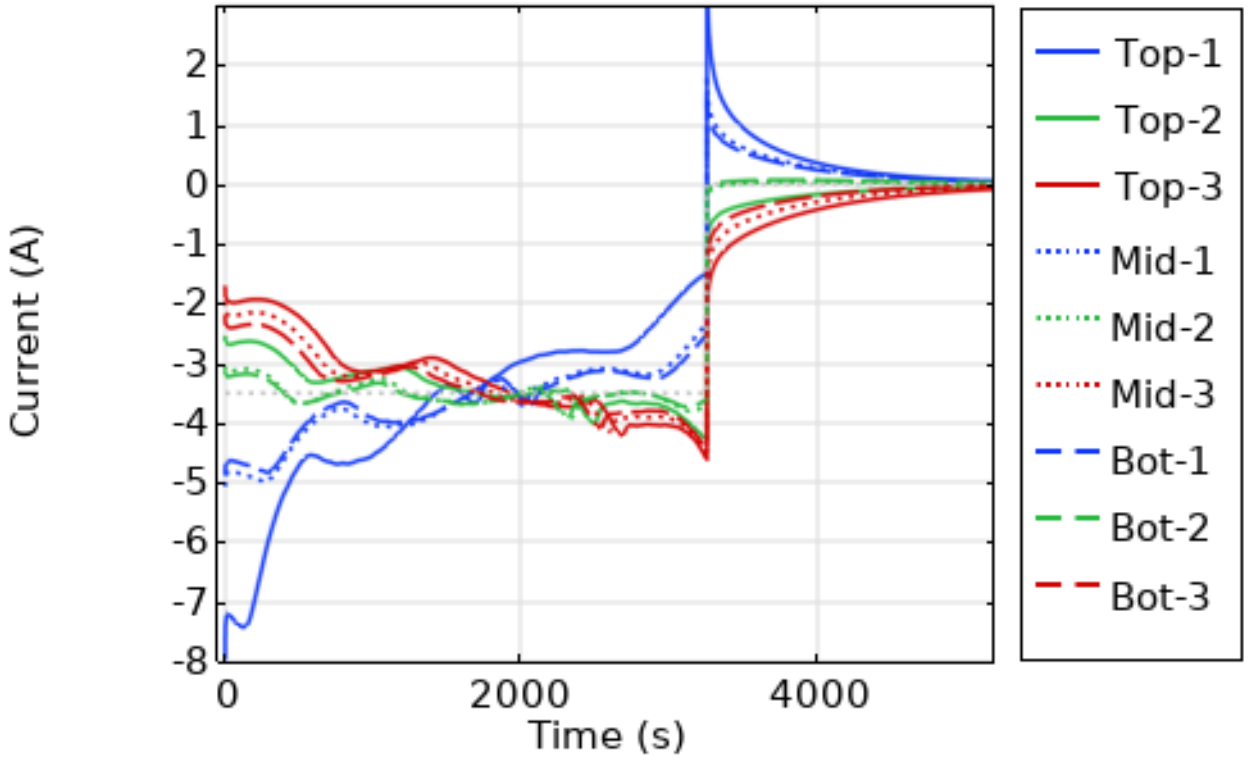
- Thermal gradients increased degradation rate by ~5.2% compared to isothermal conditions[1].
- Usable pack energy decreased by up to ~6% due to cell non-uniformity driven by temperature and impedance differences, especially at higher C-rates[2].
- Cells exposed to 20-45 °C gradients exhibited accelerated lifetime degradation, despite similar short-term capacity, due to non-uniform current distribution[3].
- A 20% cell resistance mismatch (often thermally induced) can reduce cycle life by ~40%, demonstrating the strong coupling between thermal gradients, resistance growth, and aging[4]
- Cell-to-cell temperature differences promote capacity imbalance and localized overcharge, increasing degradation rate and raising safety risk during cycling and abuse conditions[5].

1 Ashwin, T. R., McGordon, A., Jennings, P. A., Electrochemical modelling of Li-ion battery pack with constant voltage cycling, Journal of Power Sources, 341 (2017) 327–339.
2 Offer, G. J., Yufit, V., Howey, D. A., Wu, B., Brandon, N. P., Module design and fault diagnosis in electric vehicle batteries, Journal of Power Sources, 206 (2012) 383–392.
3 Liu, X., Ai, W., Marlow, M. N., Patel, Y., Wu, B., The effect of cell-to-cell variations and thermal gradients on the performance and degradation of lithium-ion battery packs, Applied Energy, 248 (2019) 489–499.
4 Chiu, K.-C., Lin, C.-H., Yeh, S.-F., et al., Cycle life analysis of series connected lithium-ion batteries with temperature difference, Journal of Power Sources, 263 (2014) 75–84.
5 Wang, L., Cheng, Y., Zhao, X., A $LiFePO_4$ battery pack capacity estimation approach considering in-parallel cell safety, Applied Energy, 142 (2015) 293–302.

CURRENT DISTRIBUTION THANKS TO 3D

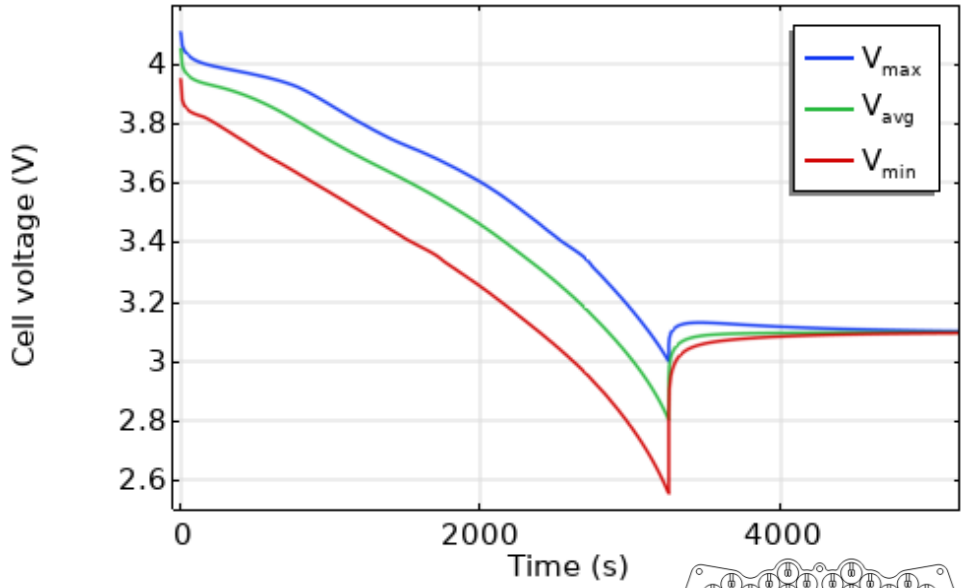


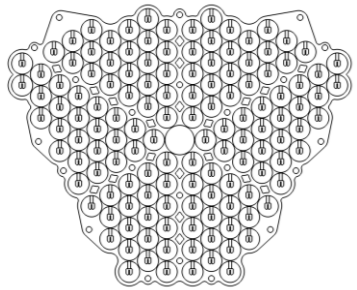
Unclocked Design

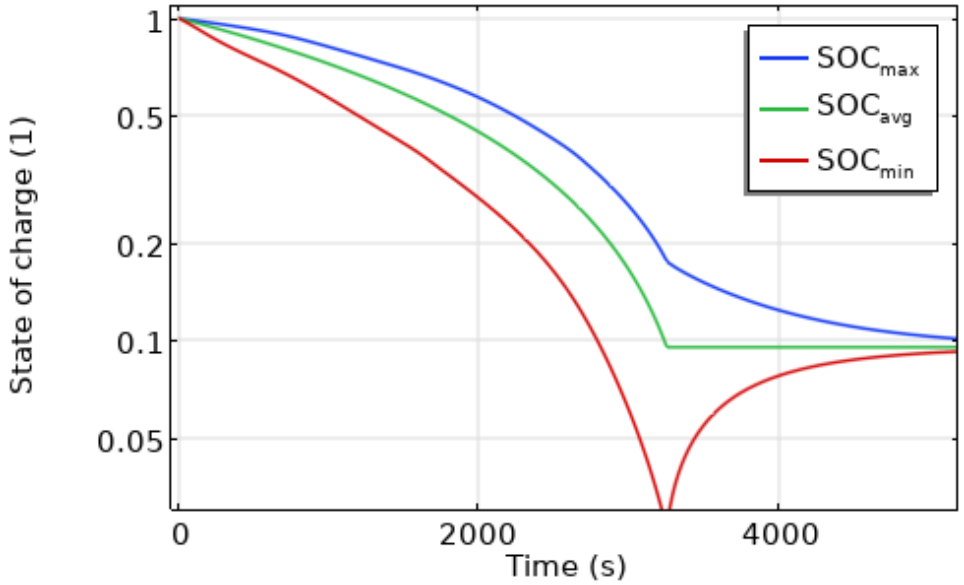


Molinaroli College of Engineering and Computing
UNIVERSITY OF SOUTH CAROLINA

SOC AND VOLTAGES?

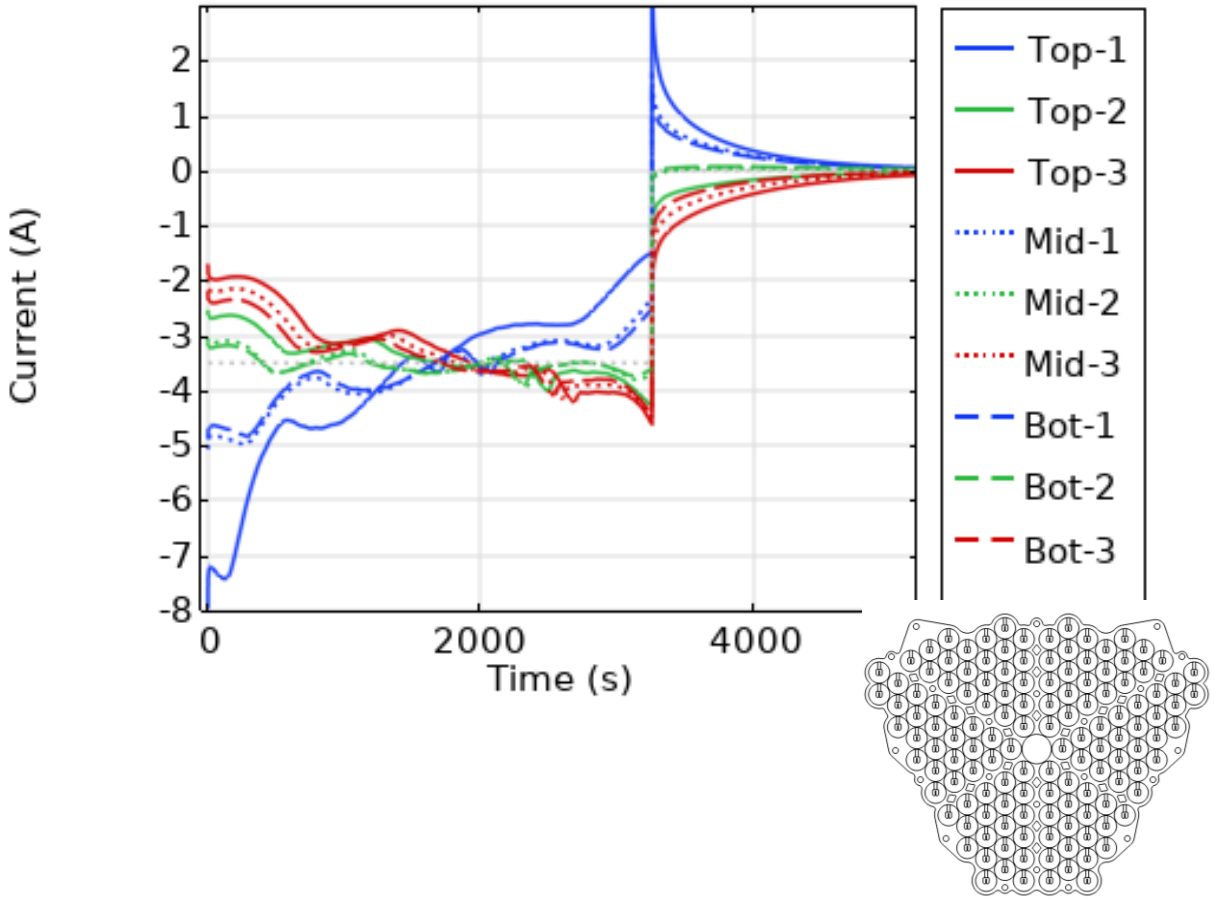




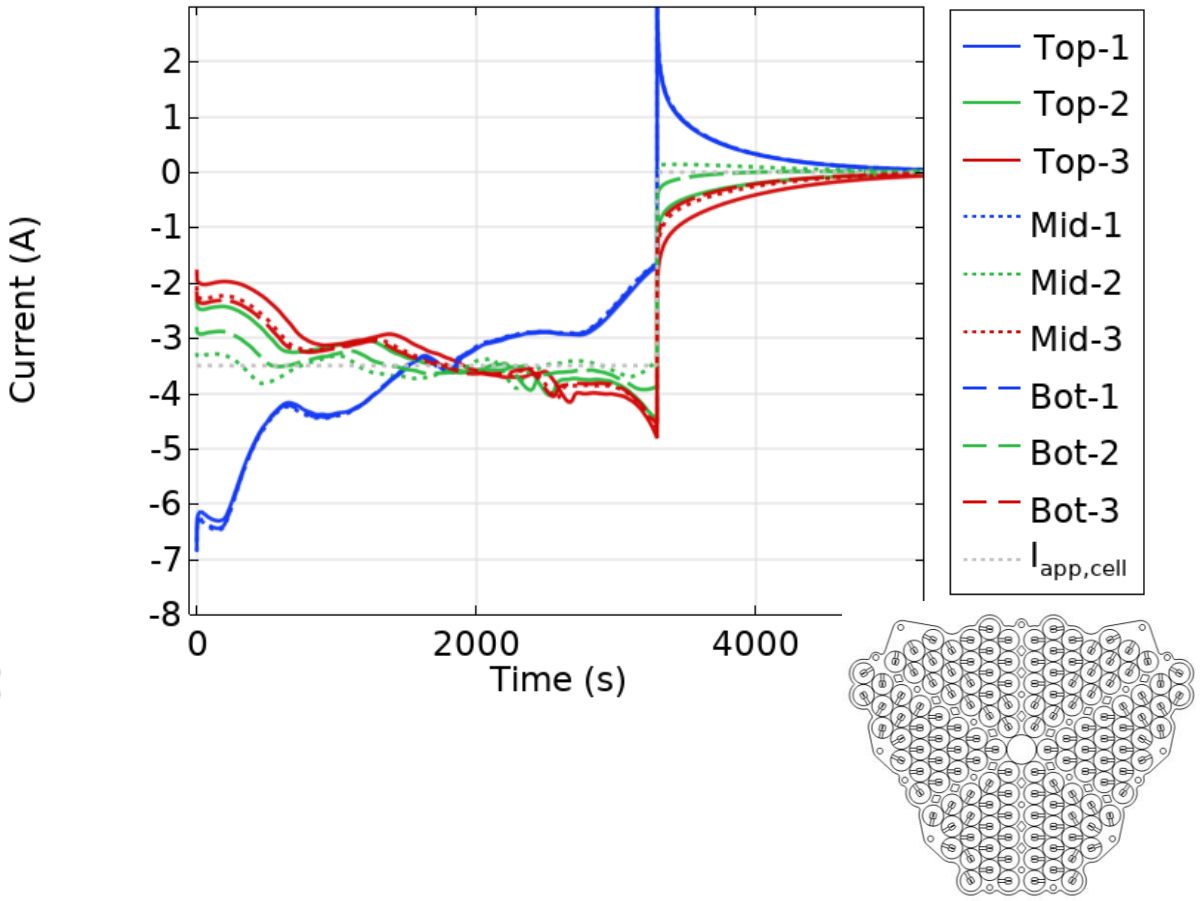


CLOCKING THE CELLS

Var A: Unclocked

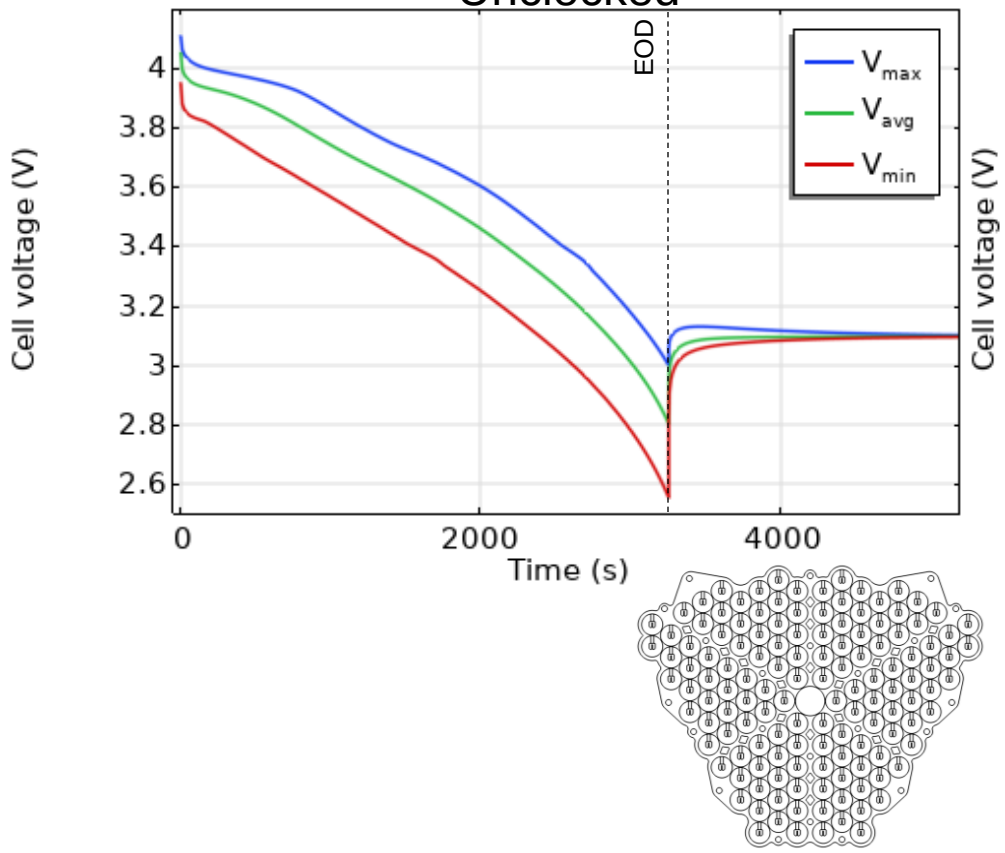


Var D: Clocked

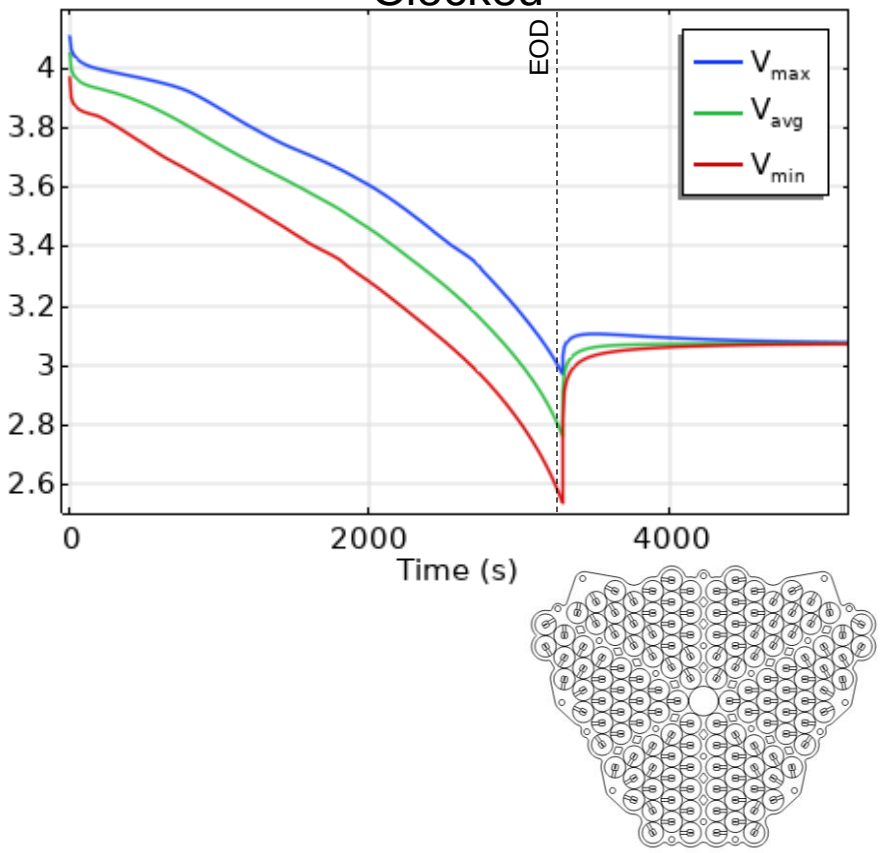


VOLTAGES

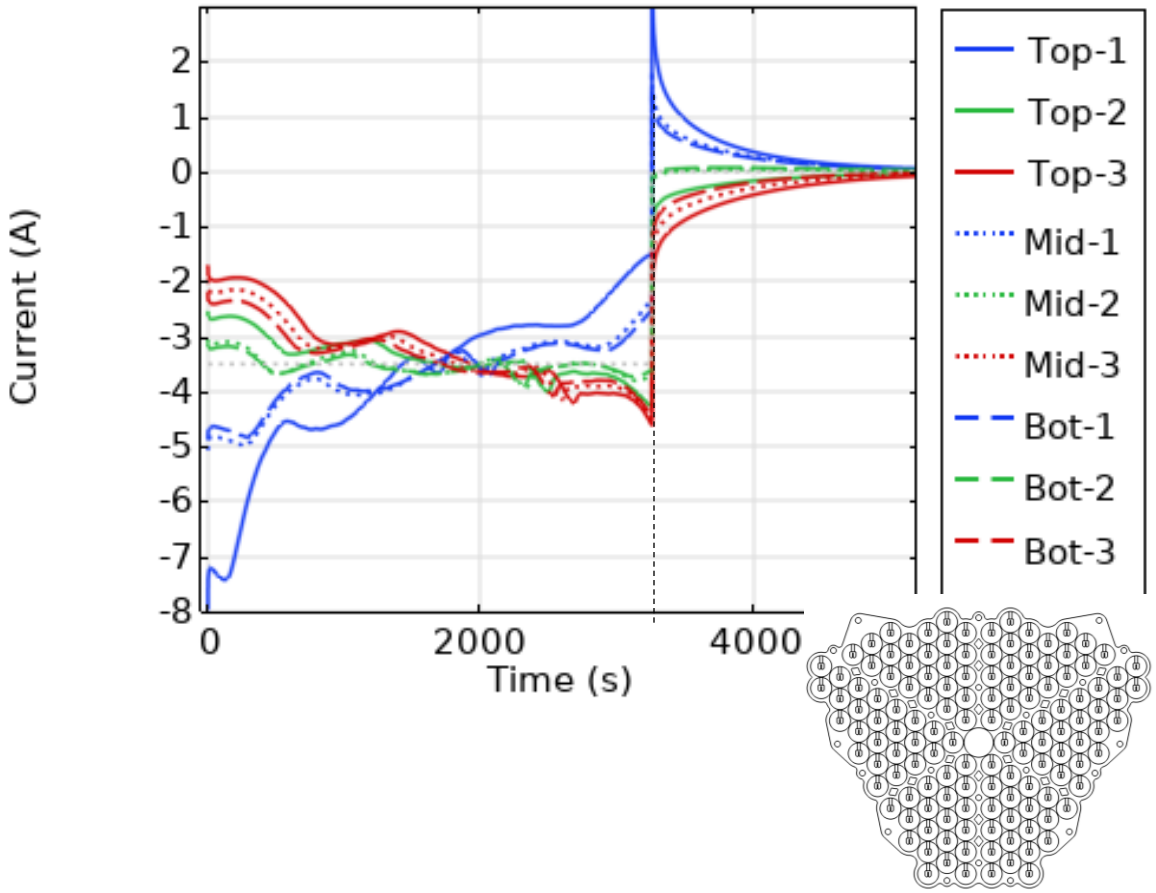
Unclocked

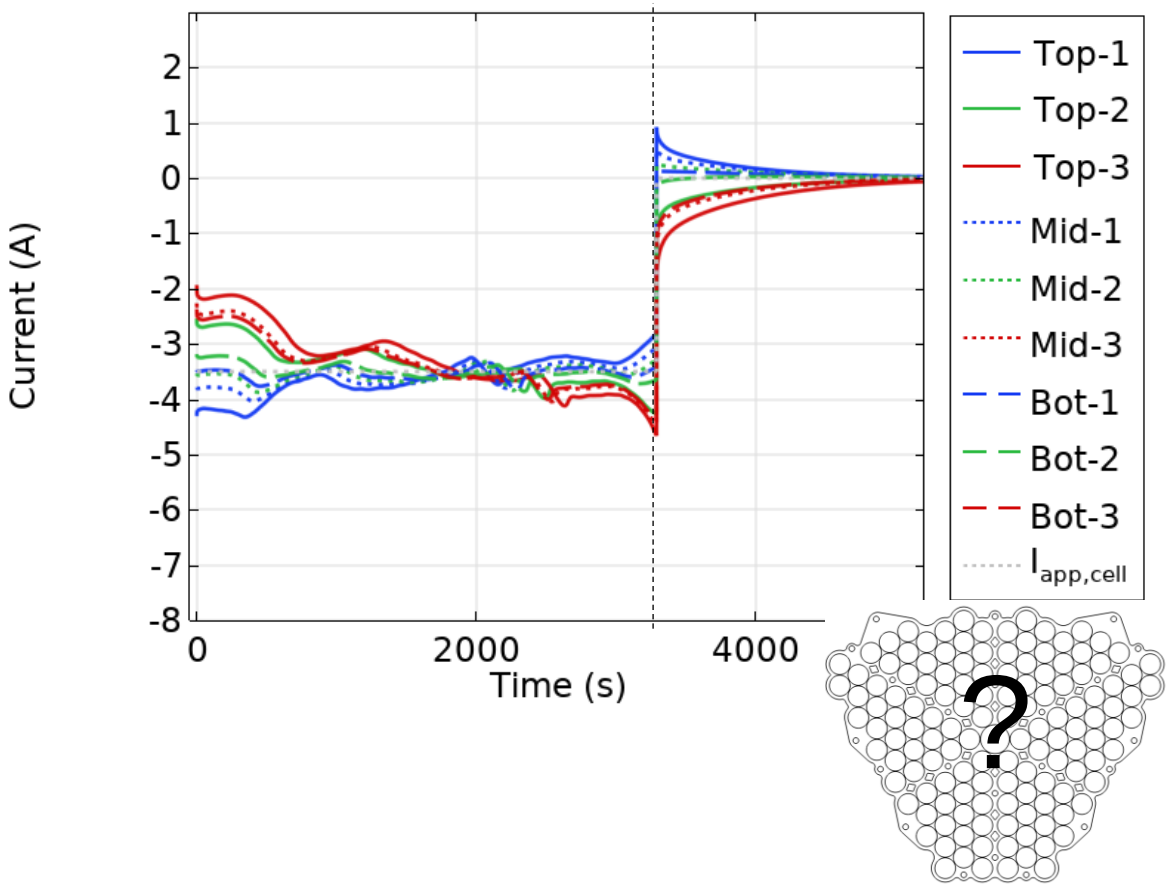


Clocked



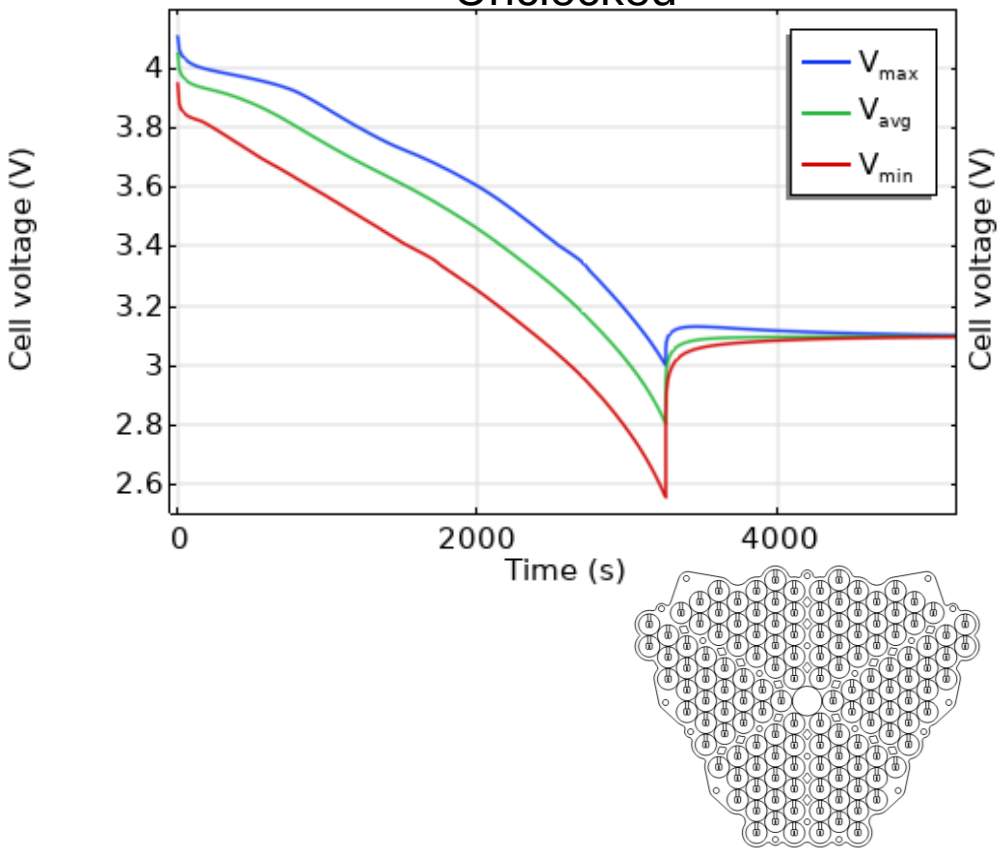
CAN WE ACTUALLY DO MORE? MAYBE…



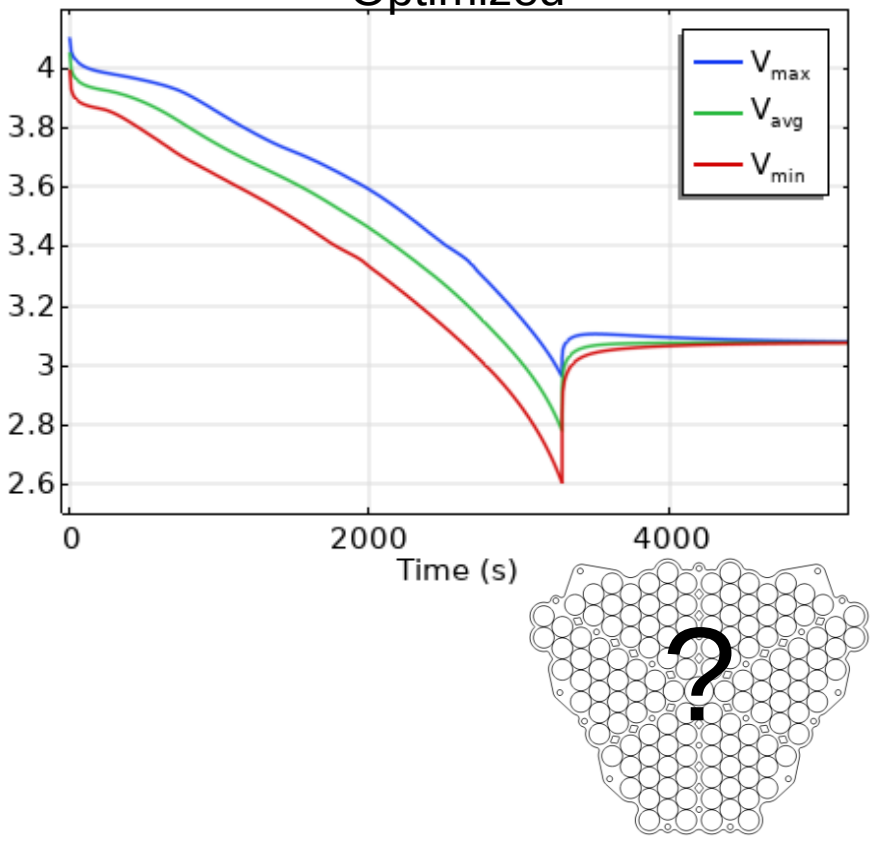


SOC

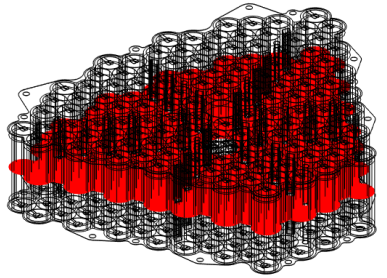
Unclocked



Optimized

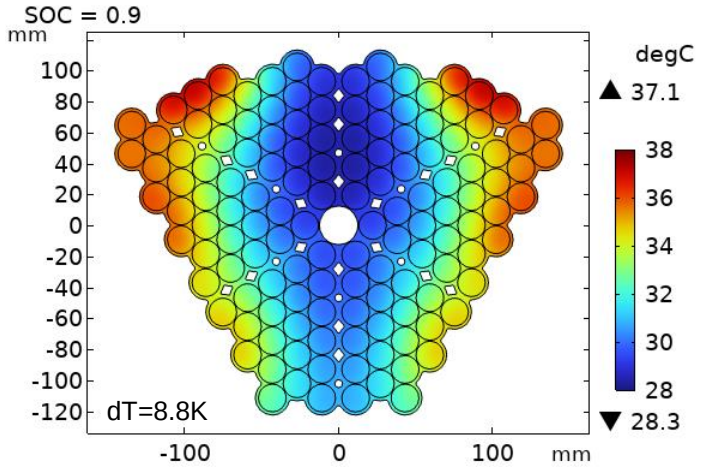


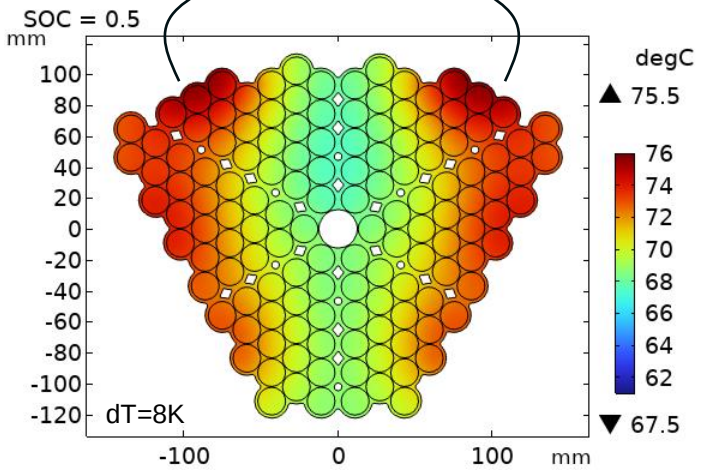
TEMPERATURES – MID-SECTION

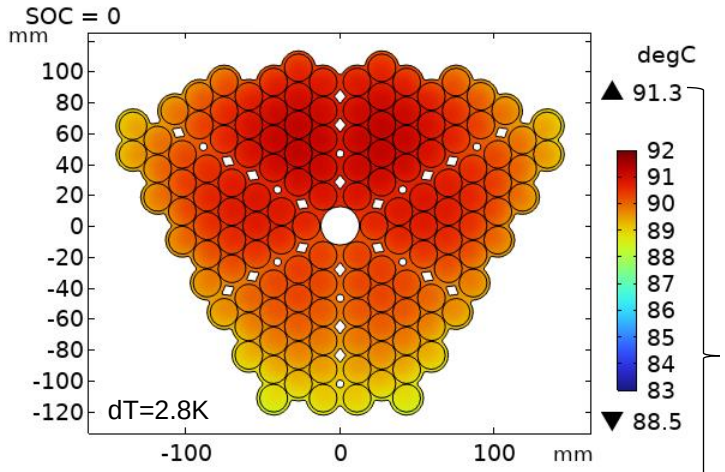


Influence coming from Busplate?

UNCLOCKED

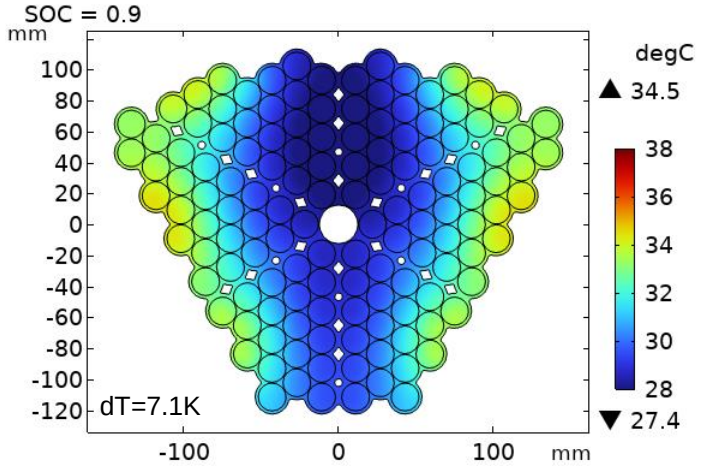


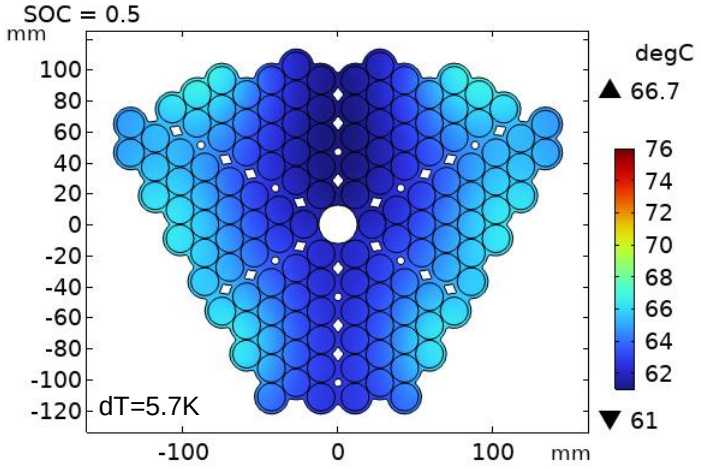


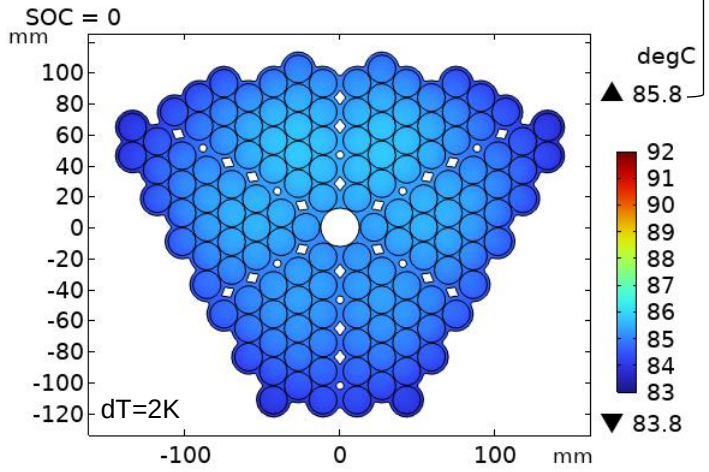


5.5K difference

CLOCKED

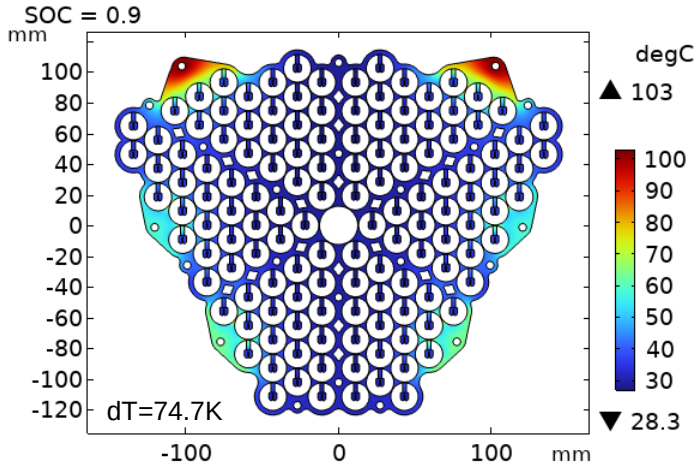


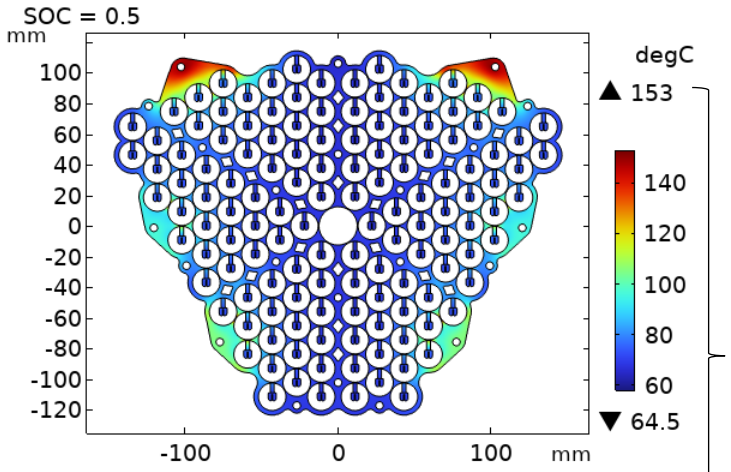


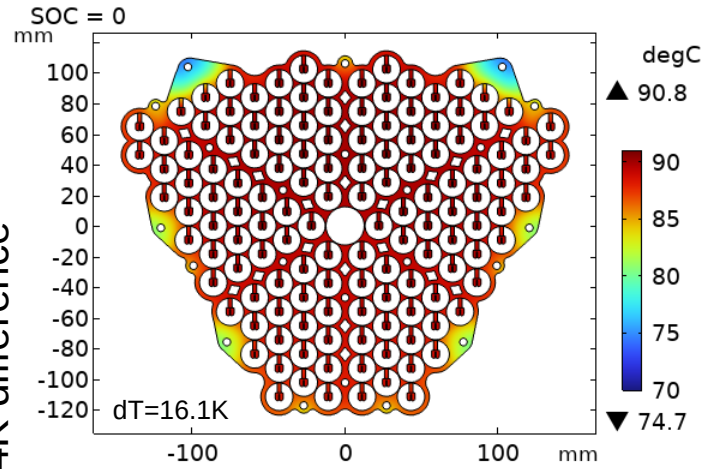


TEMPERATURES – POSITIVE BUSPLATE

UNCLOCKED

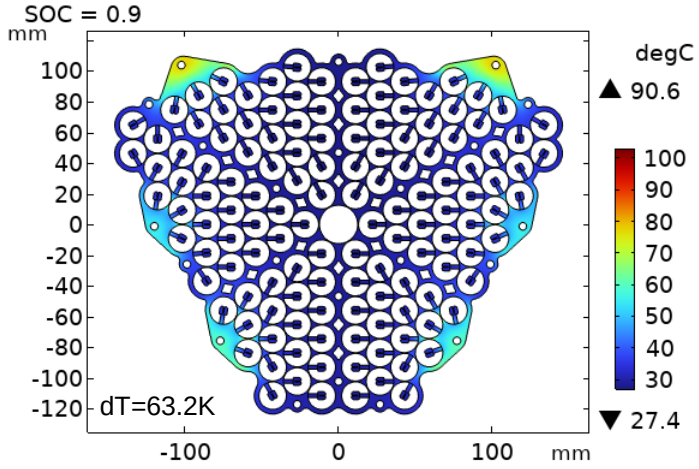


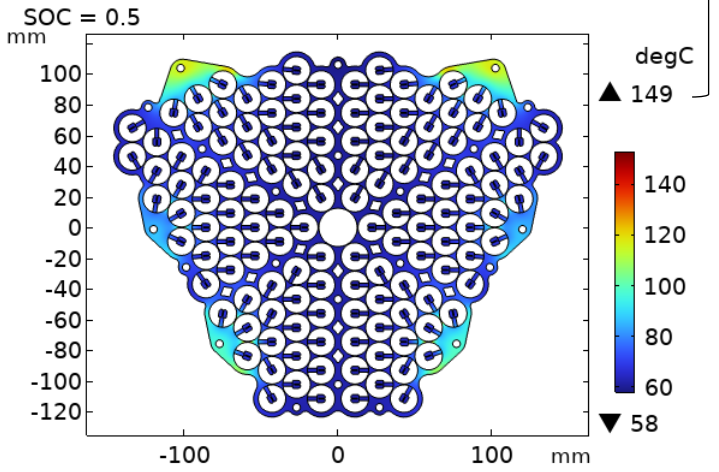


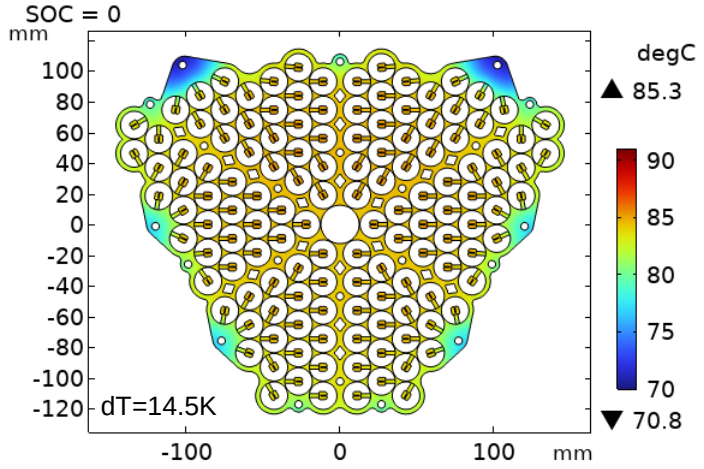


4K difference

CLOCKED

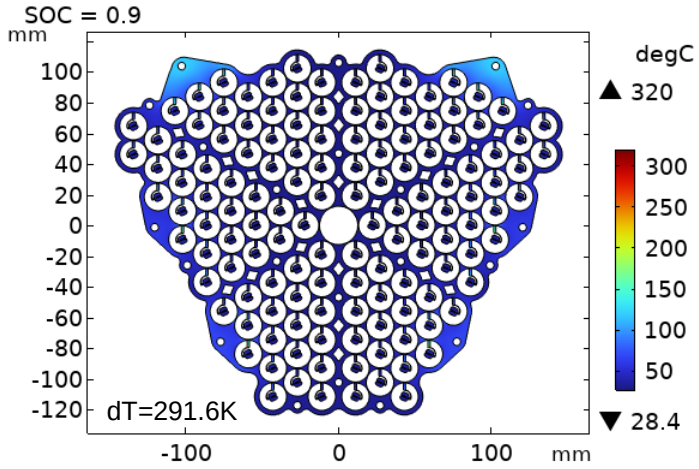


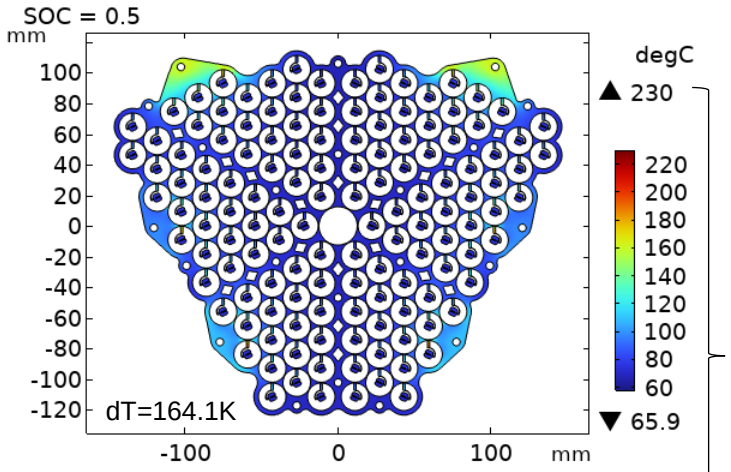


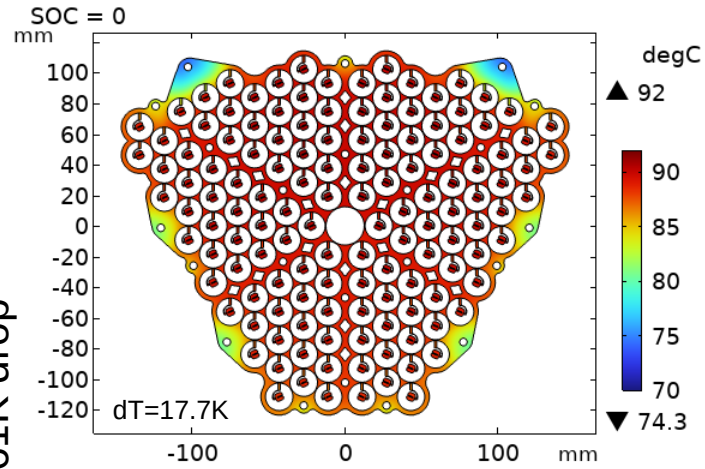


TEMPERATURES – NEGATIVE BUSPLATE

UNCLOCKED

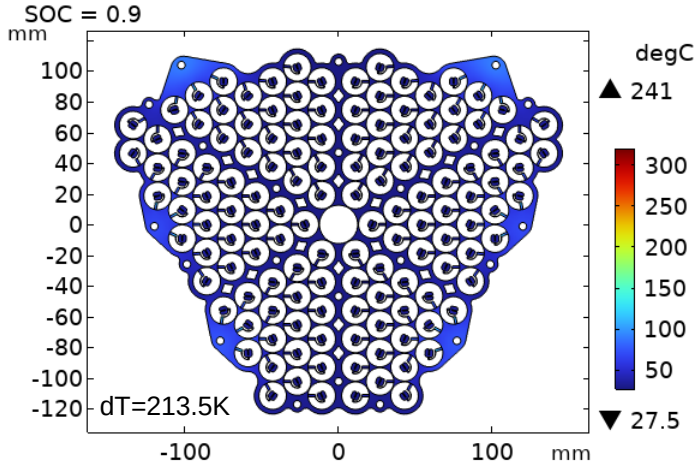


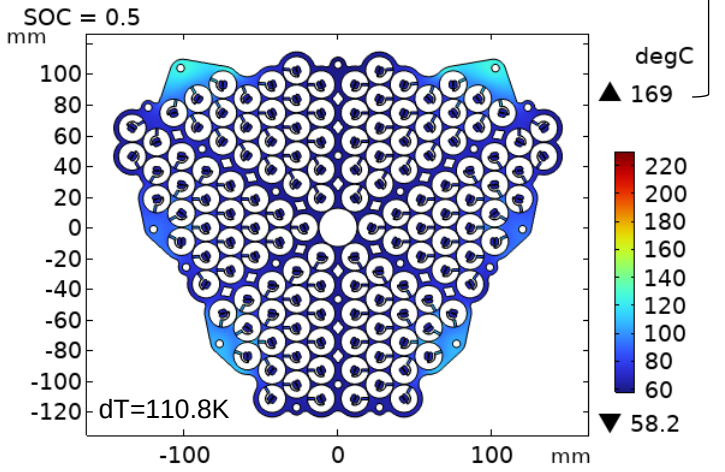


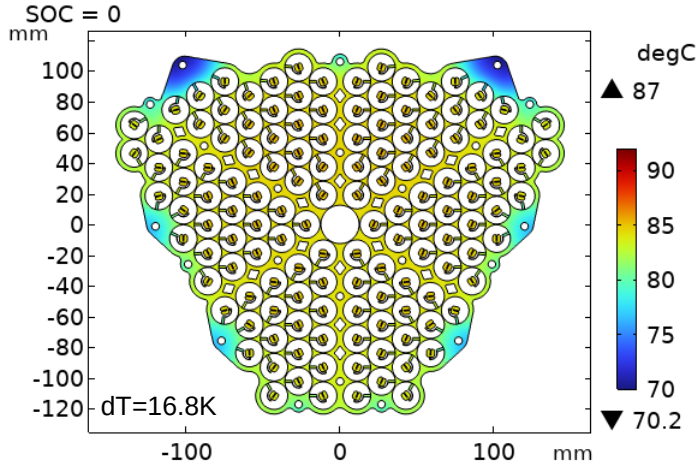


61K drop

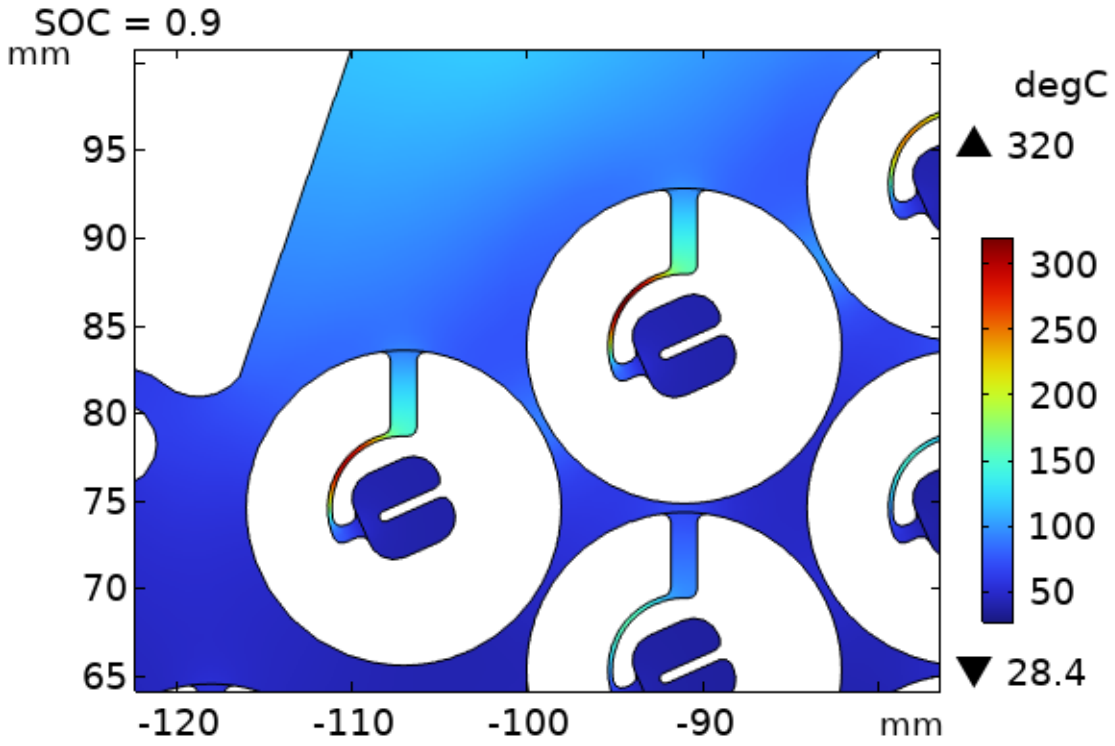
CLOCKED

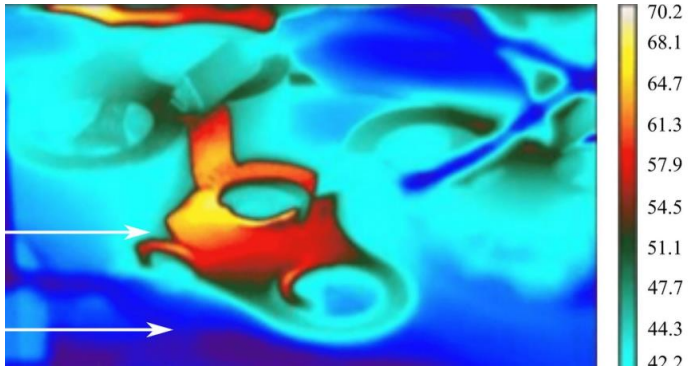






TEMPERATURES – NEGATIVE FUSIBLE LINKS





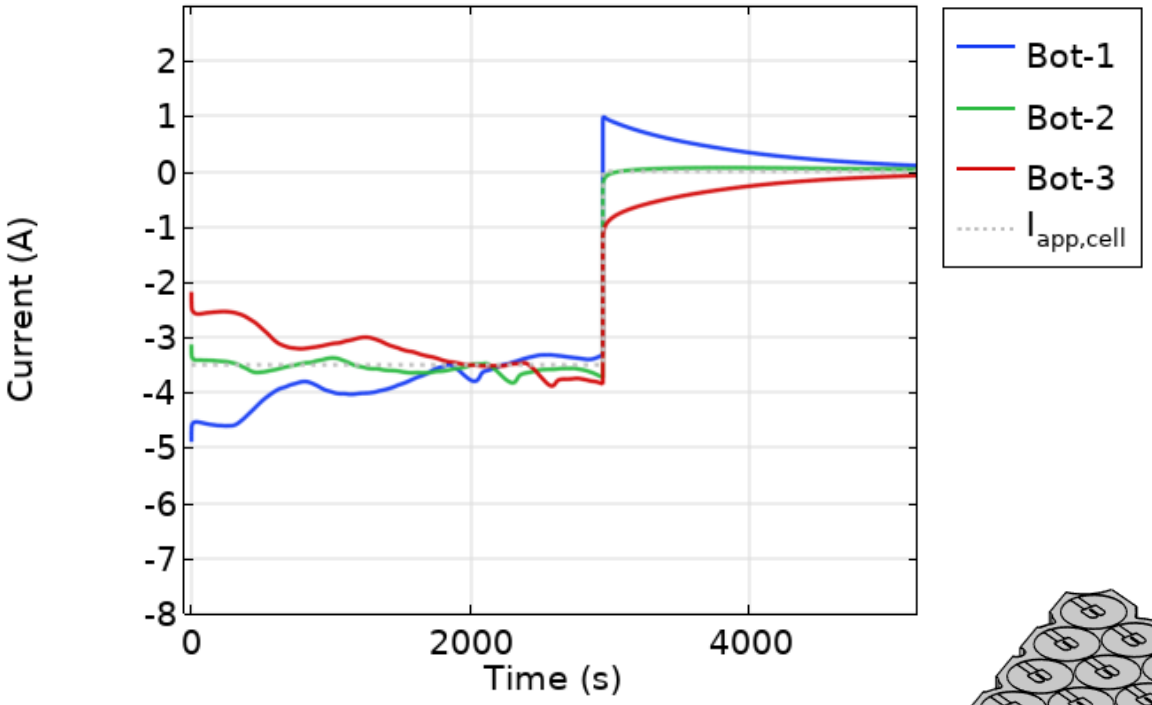
Previous experiments

P. Coman, D. Petrushenko, E. Darcy, R. E. White, Electrical-thermal modeling and electrical design optimization of fuses in a nickel bus-plate for a Li-ion battery pack, Journal of Energy Storage, 86 (2024) 111226

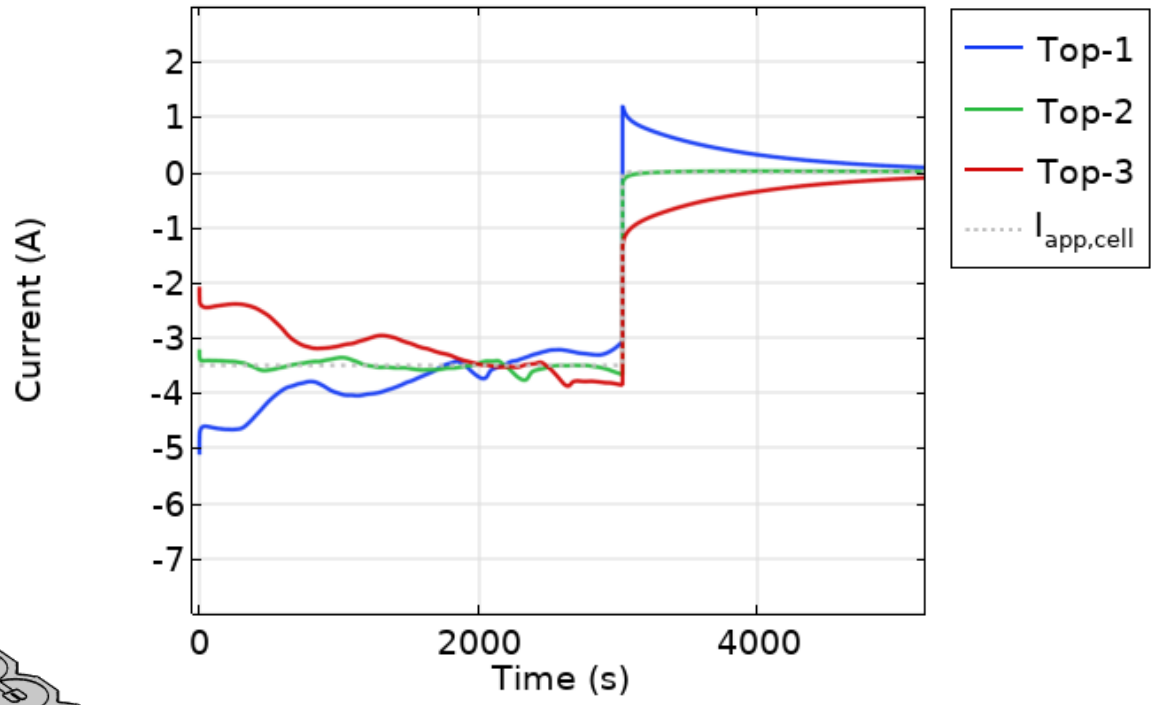
WHAT ABOUT THERMAL RUNAWAY?

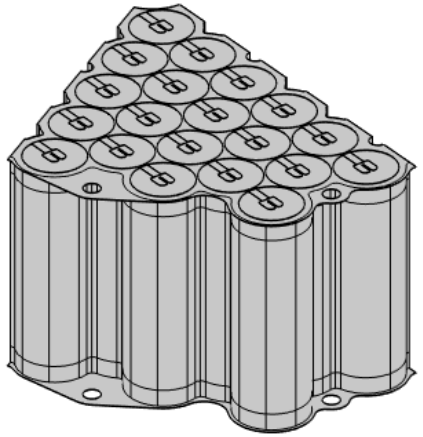
SUBSCALING (BOTTOM LEFT) UNCLOCKED

Full Scale

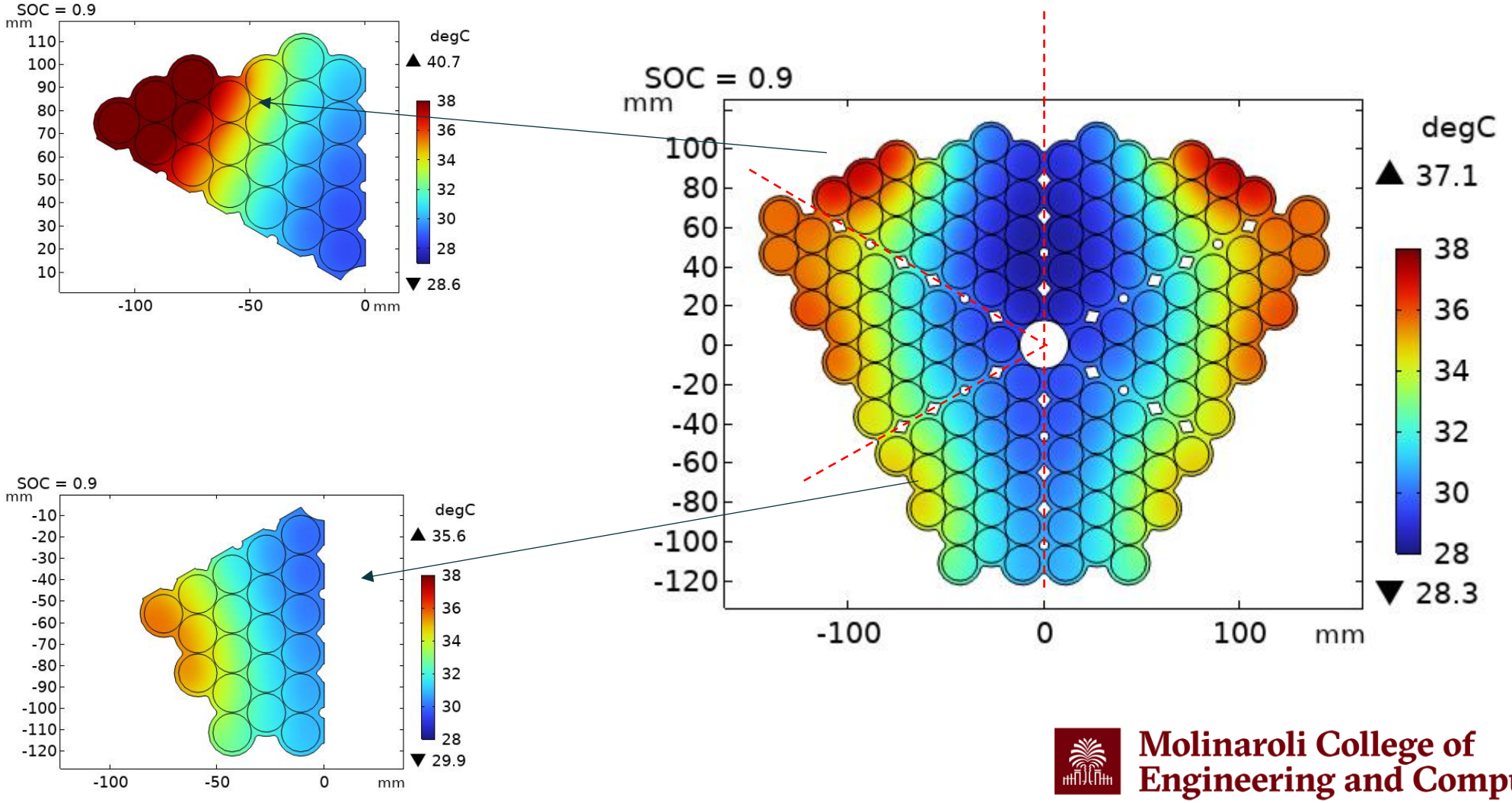


Slice





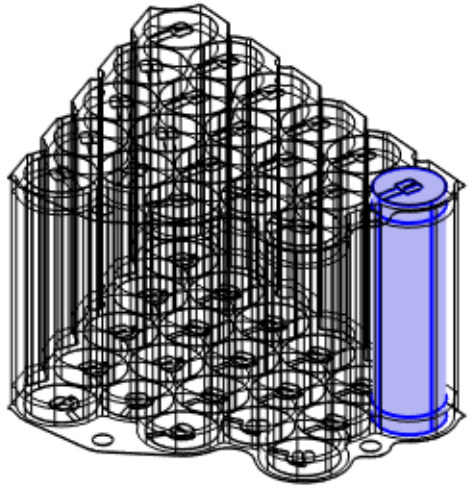
SUBSCALING TEMPERATURE



SHORT CIRCUIT IN CELLS (ACTIVATION AT 60°C)

Things to consider:

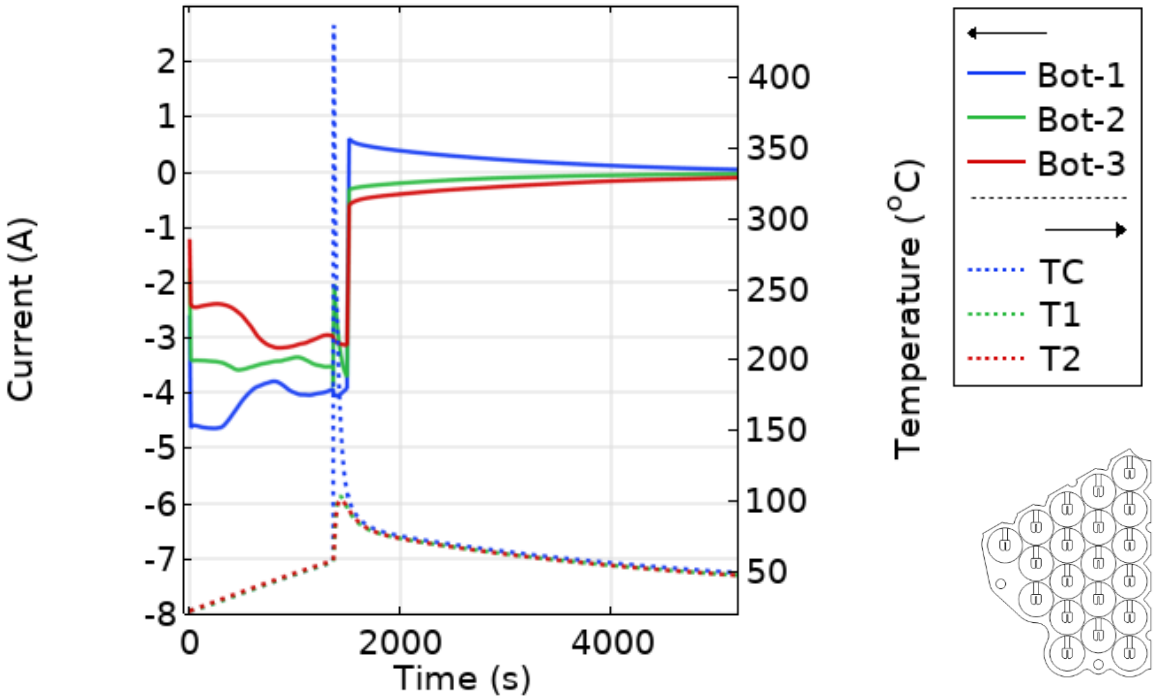
1. 1[S] short after $Q_{TR}(t)$
2. The TC does not “die”, but continue to function (very hard to “cancel” a cell)



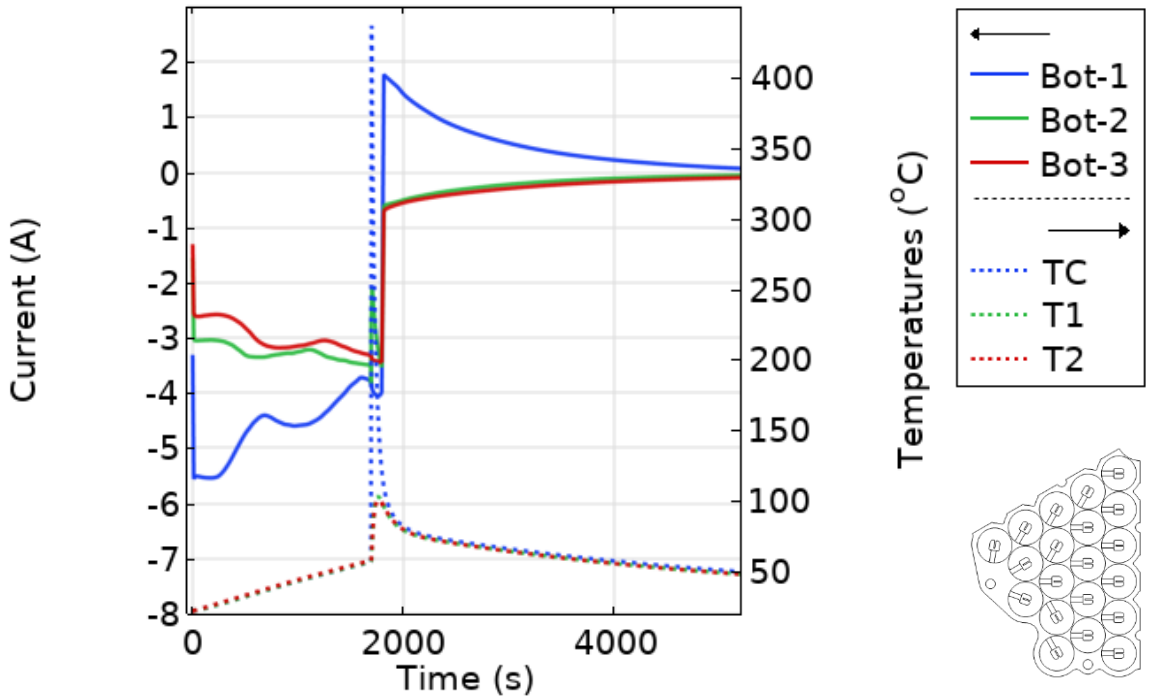
Molinaroli College of Engineering and Computing
UNIVERSITY OF SOUTH CAROLINA

SUBSCALE CURRENTS (CELL 1S SHORT)

Unclocked

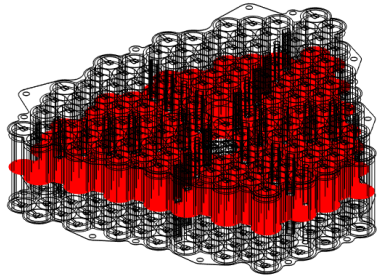


Clocked

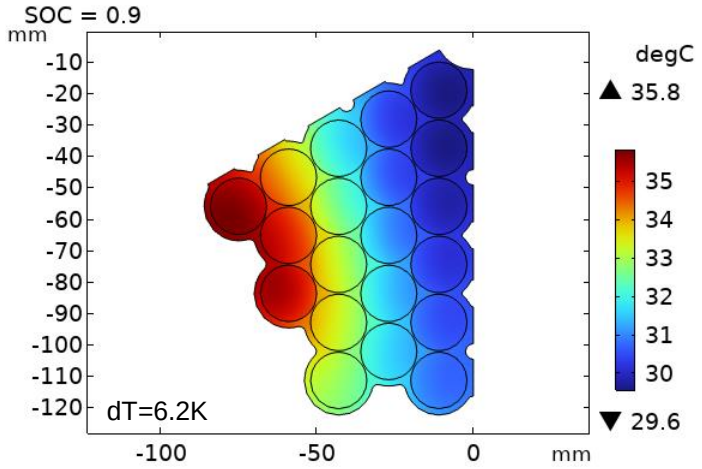


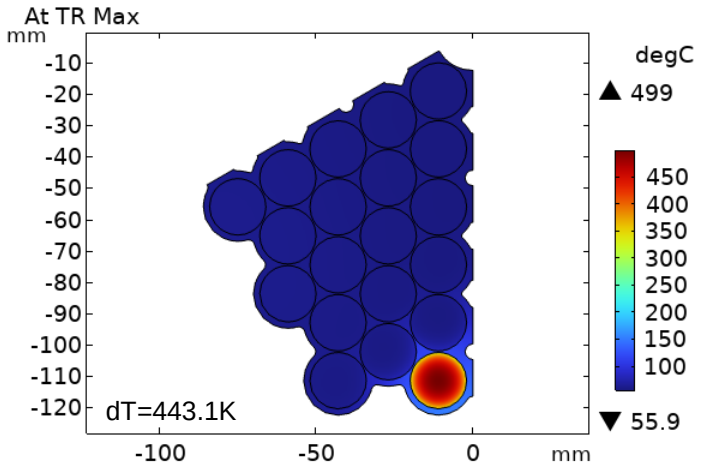
Work in progress

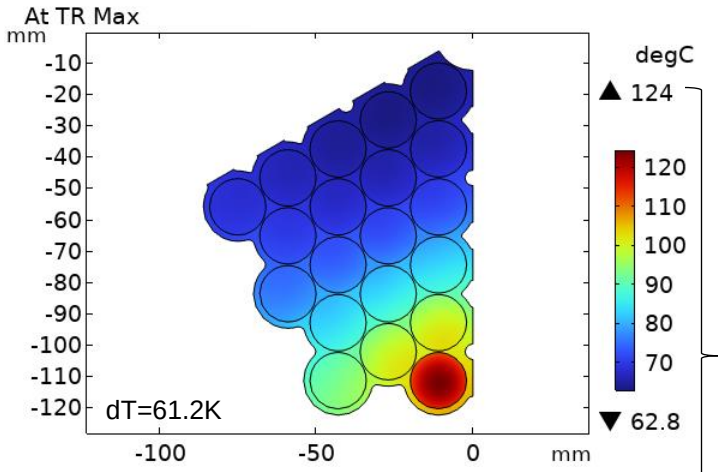
TEMPERATURES – MID-SECTION



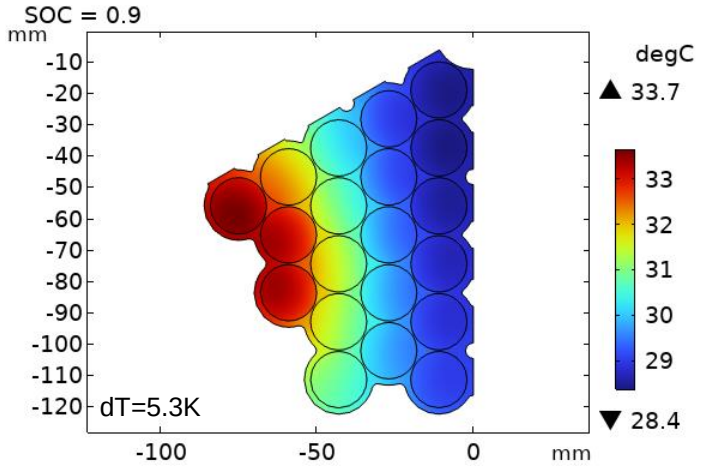
UNCLOCKED

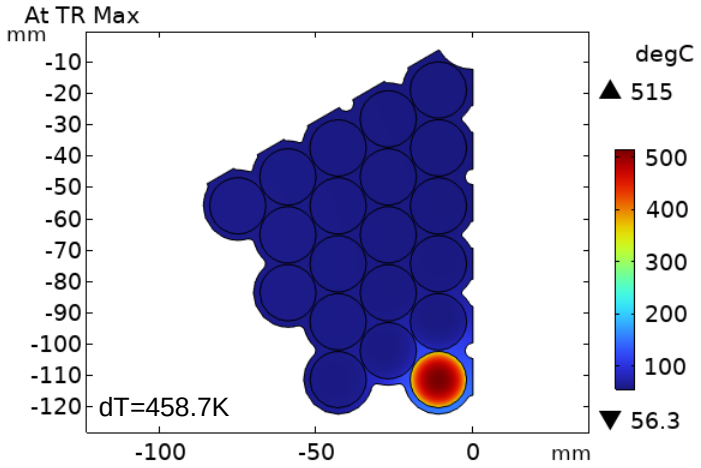


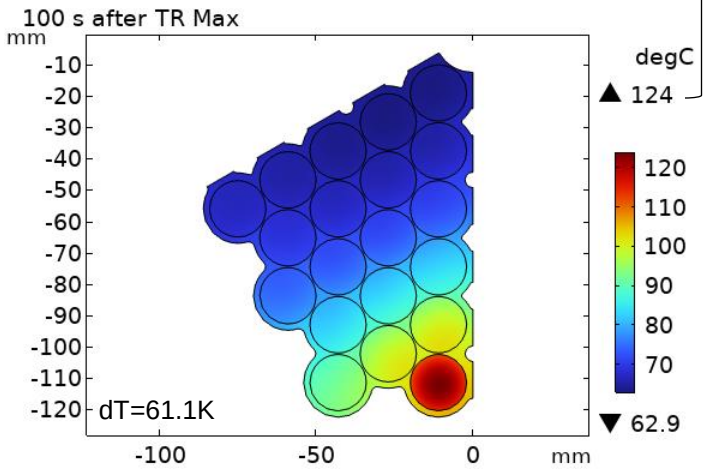




CLOCKED







Almost identical

WRAPPING UP

- 2D simulations of busplates have shown that clocking tabs can reduce voltage loss and temperature when current applied
- Experiments vs. Simulation for 2D match
- 3D simulations have shown the same trend during CC discharge and CR
- Optimized clocking can reduce current distribution even more
- 3D simulations also shown that the heat transfer from busplates also influence and dictate the gradient inside the pack
- Preliminary TR model show that not a big difference during a soft short in a trigger cell (more to come in the future)

ACKNOWLEDGEMENTS & TEAM

- NASA JSC
  - Eric Darcy
  - David Petrushenko
  - Jesus Trillo
  - Jacob Darst

Molinaroli College of Engineering and Computing
UNIVERSITY OF SOUTH CAROLINA

CONTACT

Paul T. Coman
Research Associate Professor
Department of Chemical Engineering
University of South Carolina
301 Main St.,
29208 Columbia, SC

Molinaroli College of Engineering and Computing
UNIVERSITY OF SOUTH CAROLINA