The effects of state of charge and heating rate on the thermal runaway propagation/mitigation boundary

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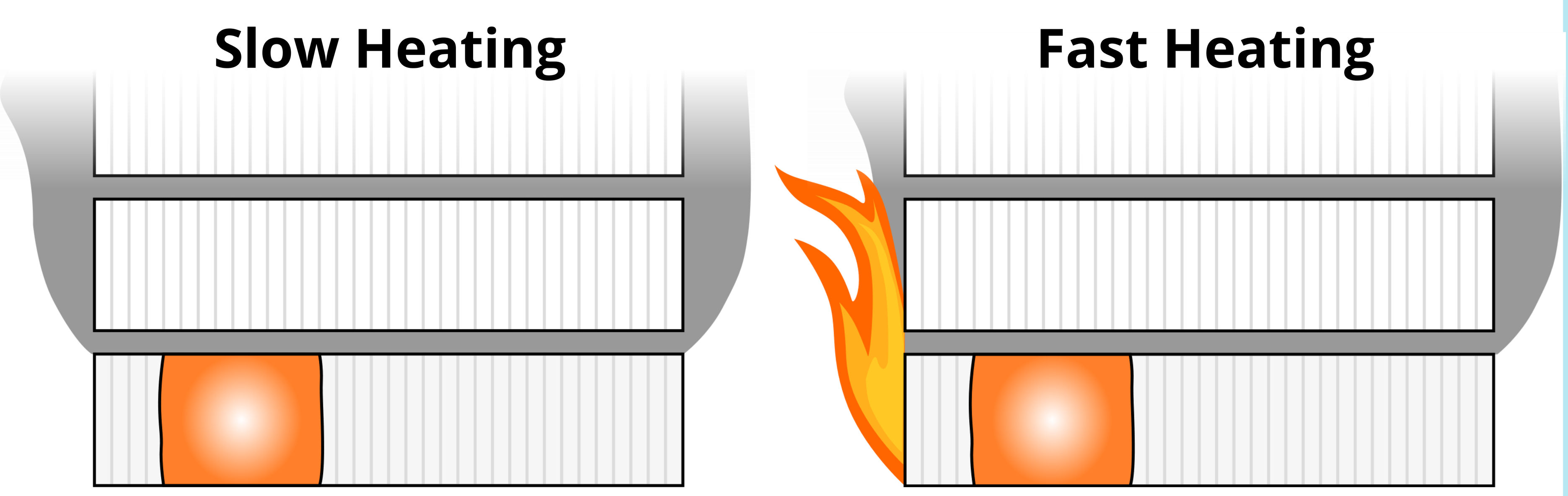
Introduction

- Stationary energy storage systems (ESS) are increasingly deployed to maintain a robust and resilient grid.
- As system size increases, financial and safety issues become important topics.
- Models enable knowledge to be applied to different scenarios and larger scales.
- A large body of work exists (both experiments and simulations) on propagating thermal runaway at the module scale.
- Preventing or containing thermal runaway is critical for safety.
- Module-to-module propagation is a potential entry point for mitigation strategies, but little data is available at this scale.
- Knowledge of module-to-module heat transfer and operating state is needed to understand propagation behavior.
- In this work, we study the effects of heating rate and state of charge (SOC) on propagation behavior in a module with experiments and simulations.[1]

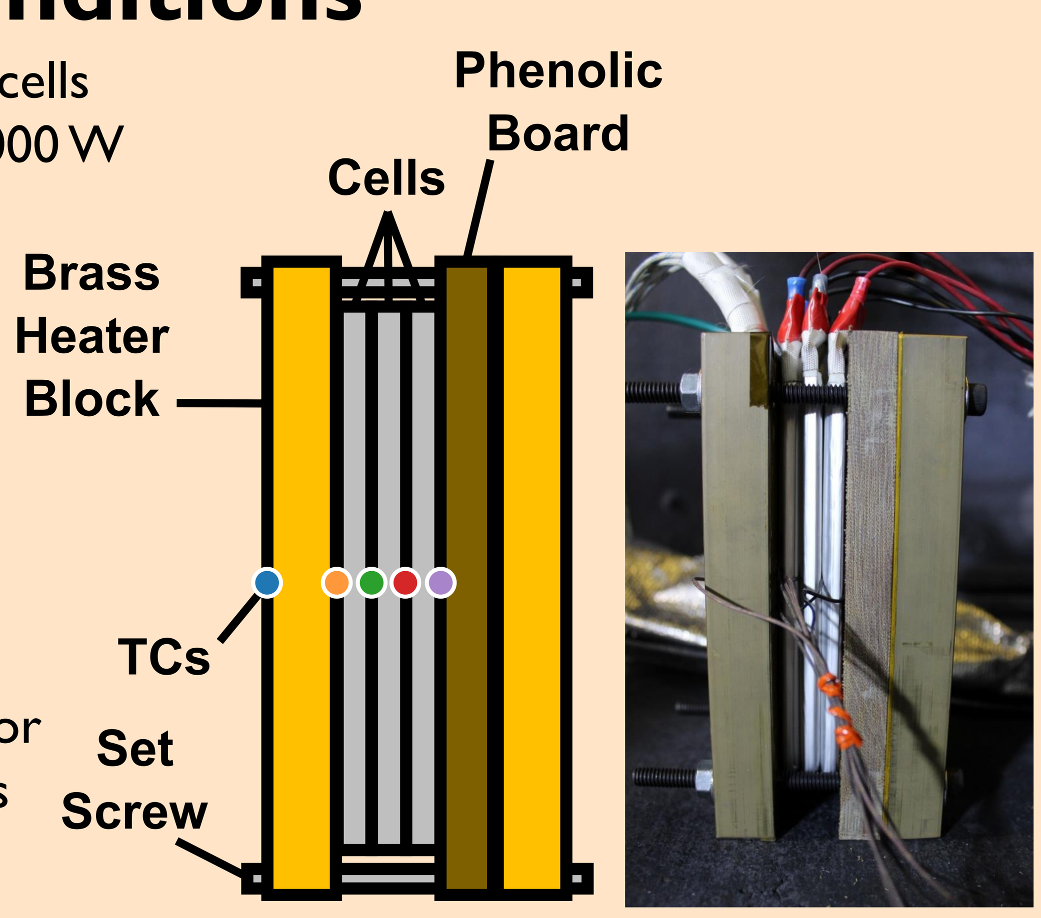
Potential module-to-module heating scenarios



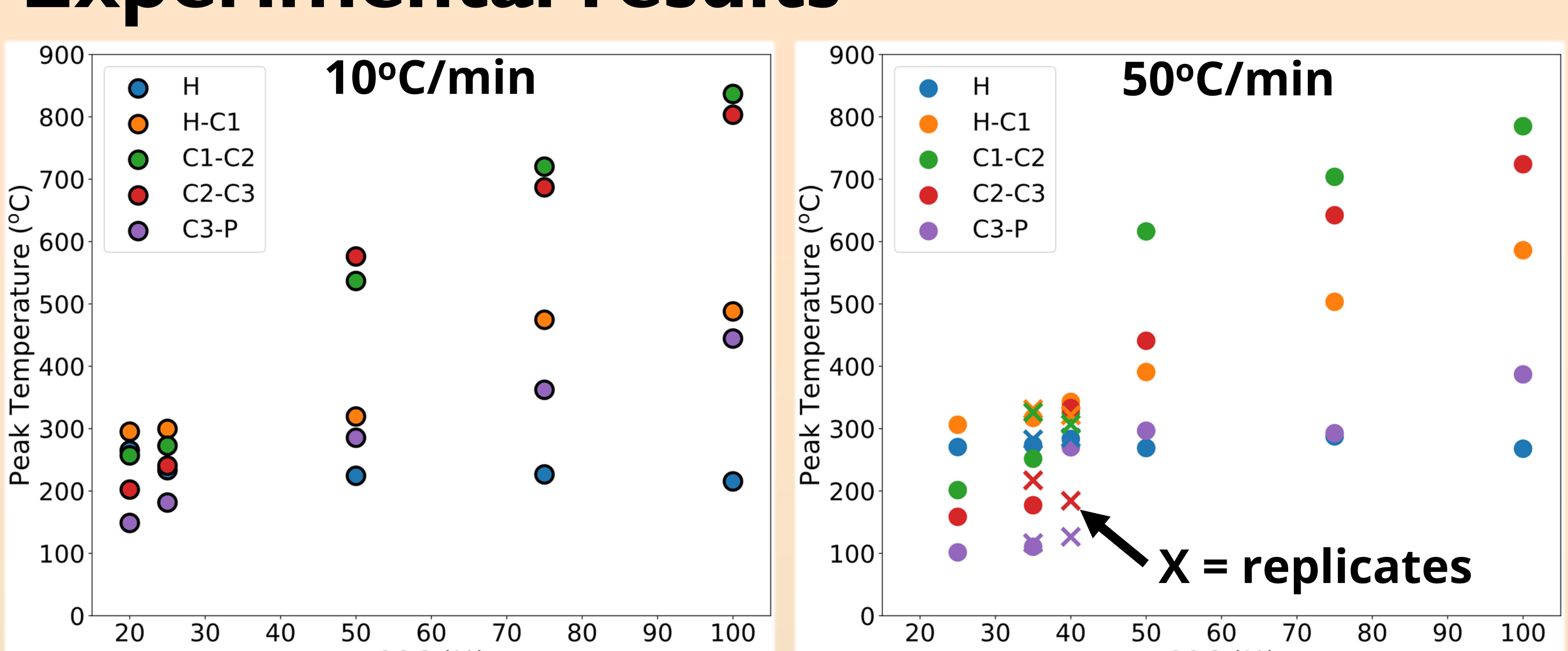
- Modules soak in hot gases from the failing module
- Modules near the failing module are exposed to flaming either directly or through the casing

Experimental conditions

- Pack of three 4 Ah LCO pouch cells
- Heater: brass block with two 1000 W cartridge heaters
- Type K thermocouples (TCs) on centerline
- Two heating rates
  - 10°C/min
  - 50°C/min
- State of charge (SOC)
  - 25%, 50%, 75%, 100%
  - At each heating rate, search for SOC where mitigation occurs (within 5% SOC)



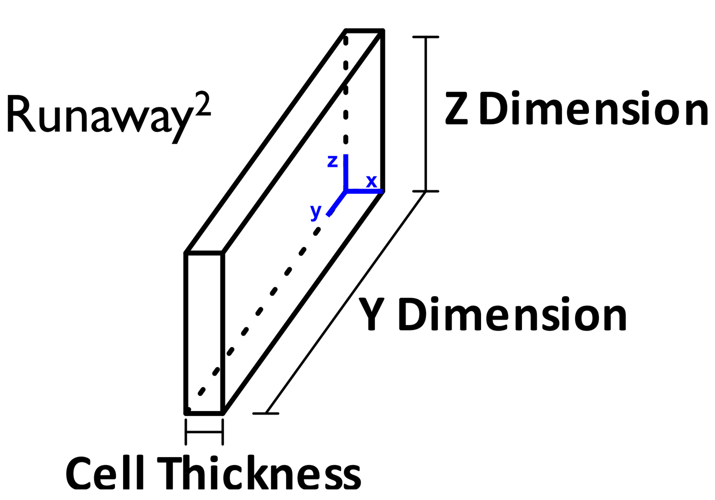
Experimental results



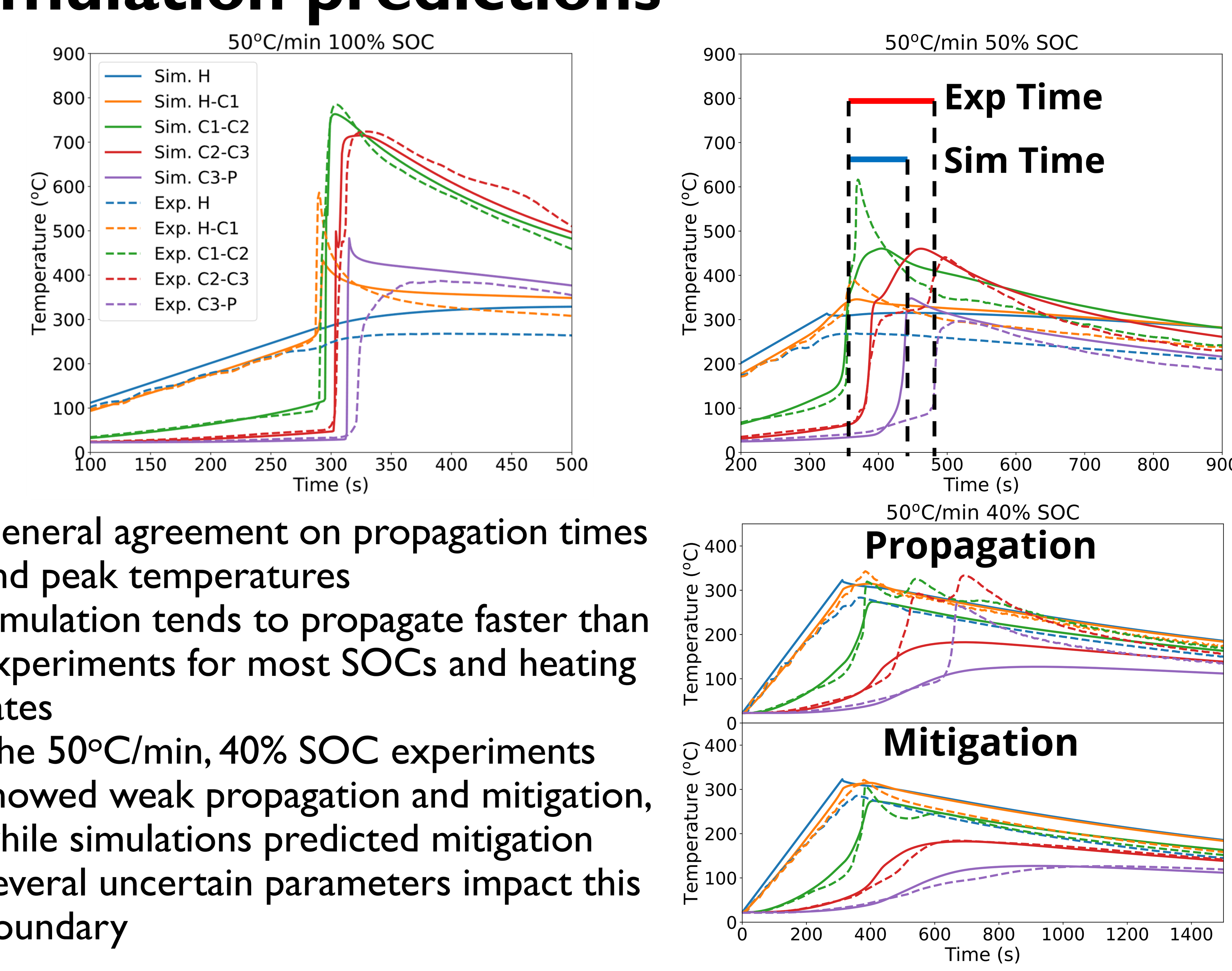
- Thermocouple colors correspond to locations on experimental diagram
- Peak temperature (heat release) decreases with SOC
- Mitigation occurs at 20% SOC for 10°C/min and 35% SOC for 50°C/min
- Replicates showed propagation and mitigation at 40% SOC, 50°C/min

Computational model

- LIM1TR: Lithium-ion Modeling with 1-D Thermal Runaway[2]
- Solution methodology:
  - Quasi 1-D finite volume model thermally lumped in the y and z dimensions (plane of electrodes)
  - Discretized in the x direction (cell thickness)
  - Spitfire[3] for time integration
- Thermal runaway model: SEI decomposition, anode-electrolyte, cathode-electrolyte, intra-particle diffusion Damköhler limiter[1]

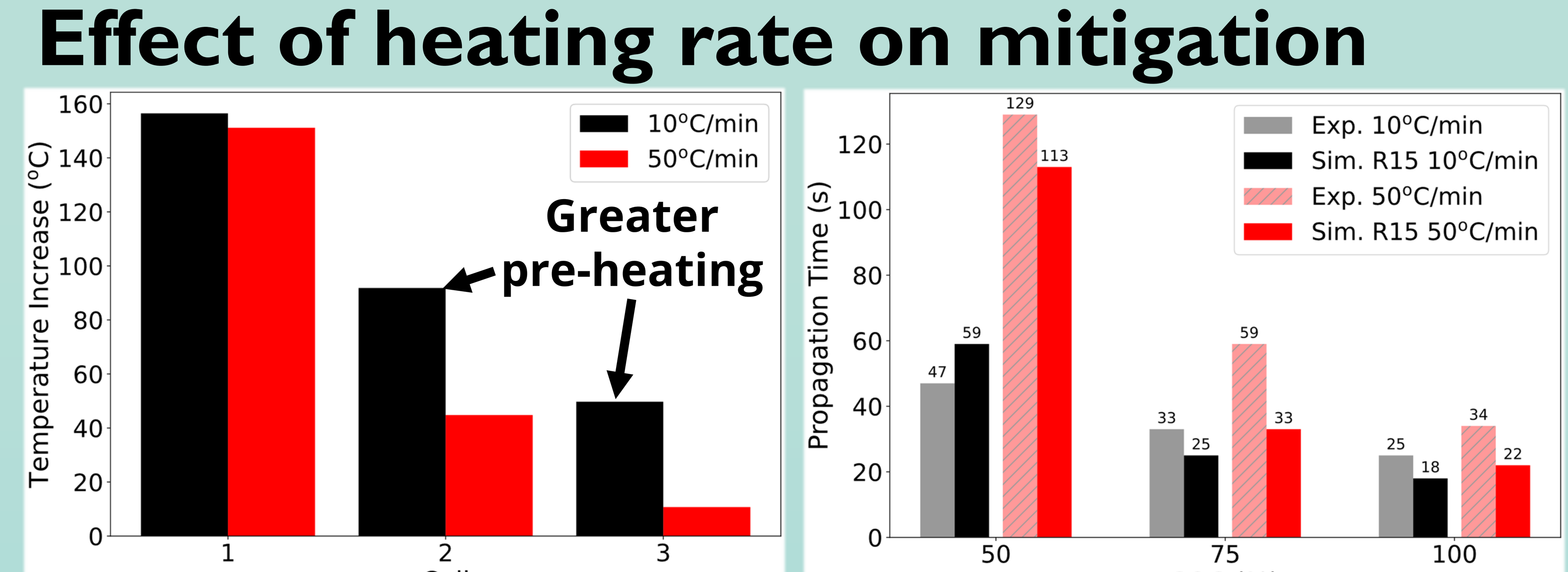


Simulation predictions



- General agreement on propagation times and peak temperatures
- Simulation tends to propagate faster than experiments for most SOCs and heating rates
- The 50°C/min, 40% SOC experiments showed weak propagation and mitigation, while simulations predicted mitigation
- Several uncertain parameters impact this boundary

Effect of heating rate on mitigation



- Critical amount of energy must be added to drive cell into TR
- Above figure shows average cell temperature increase before thermal runaway
- Slower heating rate allows for greater pre-heating of cells before propagation

- More Preheating = Faster Propagation
- In a larger module, preheating of cells deeper into the stack will determine the propagation behavior

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1. A. Kurzawski, L. Gray, L. Torres-Castro, J. Hewson, An investigation into the effects of state of charge and heating rate on propagating thermal runaway in Li-ion batteries with experiments and simulations, Fire Safety Journal, 2023.
2. A. Kurzawski, R. Shurtz, SAND2021-12281, LIM1TR: Lithium-Ion Modeling with 1-D Thermal Runaway v1.0, Report, 2021.
3. M.A. Hansen, J.C. Hewson, E. Armstrong, J.T. McConnell, J.C. Sutherland, R.C. Knaus, Spitfire v1.02.01, 2022, URL https://github.com/sandialabs/Spitfire.