

excellence in ...  
plastics simulation  
testing equipment  
lightweight products



# Thermal propagation Testing & Simulation of Battery Cell Stacks

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*CAE Grand Challenge 2022*



# Outline

1. Generation of abuse simulation models of a single battery cell using LS Dyna
2. Abuse testing and simulation of a single battery cell
3. Application of a single cell model within the simulation of multi-cell mockups
4. Conclusion and outlook

# Generation of abuse simulation models of a single battery cell using LS Dyna



# Multiphysics of battery cells

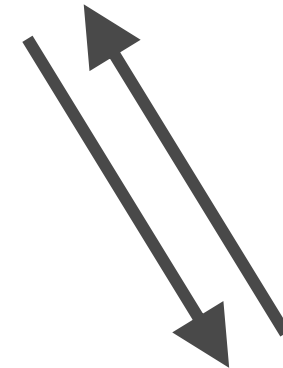
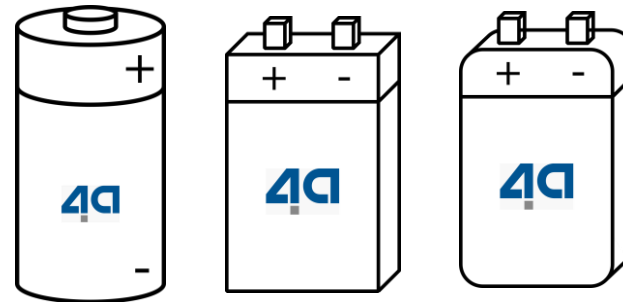
**Thermal**

$\rho$   
 $\lambda$   
 $\underline{q}$   
 $T$   
 $p$   
 $k$

$T$   
 $x$   
 $k_1$   
 $k_2$   
 $k_3$

**Mechanical**

$T_{11}$  in MPa  
 $t$  in s  
 $F$   
 $\underline{\underline{\epsilon}}$   
 $u$   
 $\underline{\underline{T}}$   
 $\underline{\underline{\sigma}}$

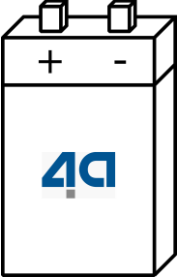
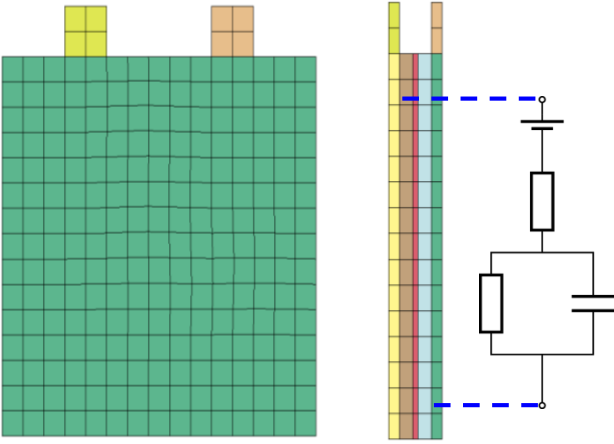
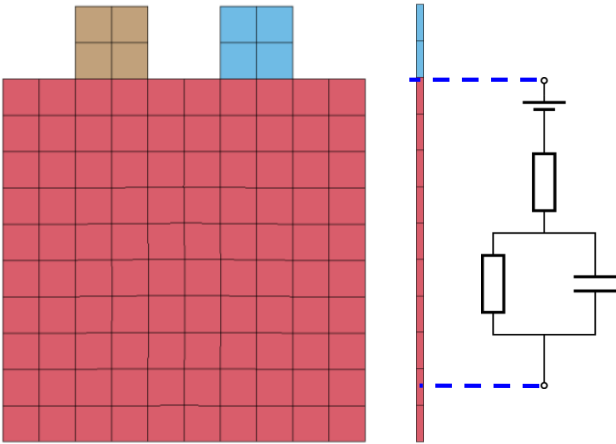
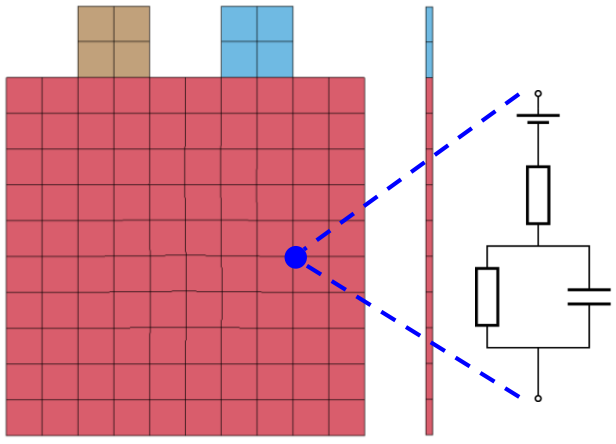


**Electromagnetical**

$R$   
 $U$   
 $I$   
 $C$   
 SOC

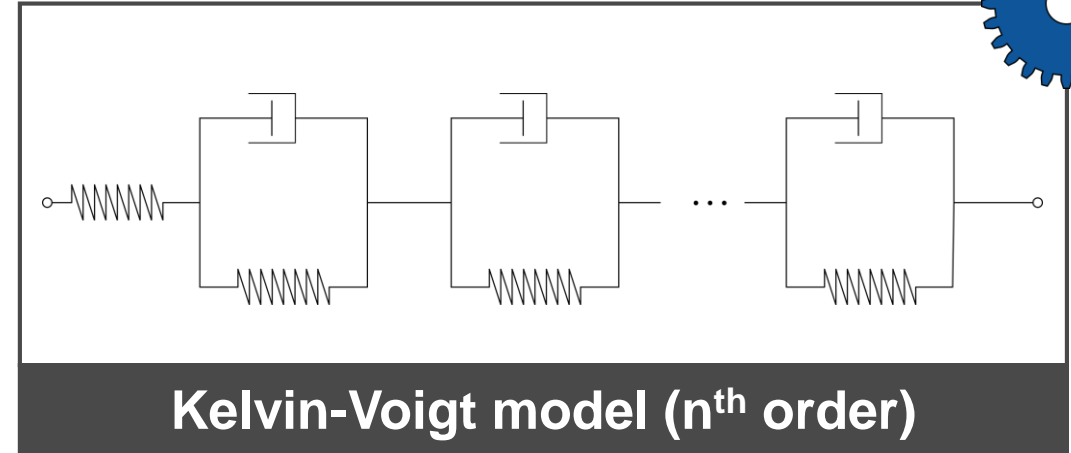
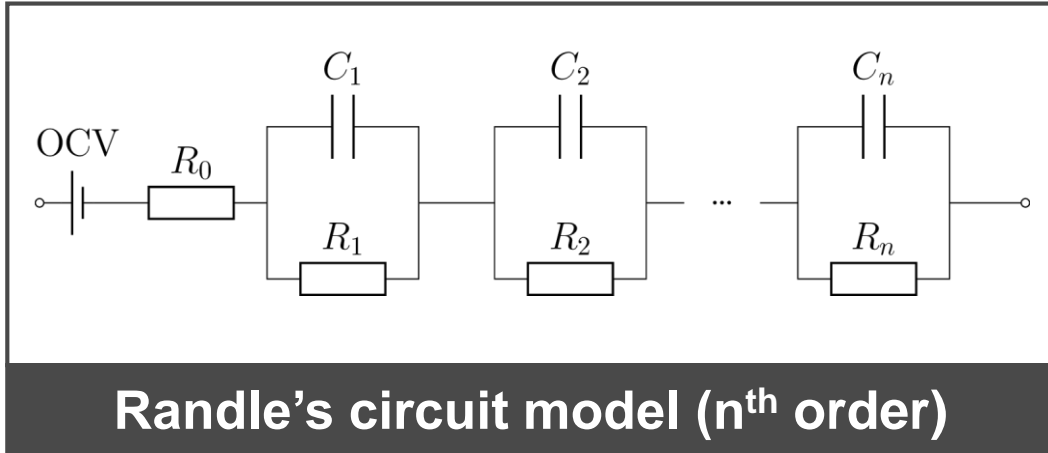


# Modeling approaches in LS DYNA

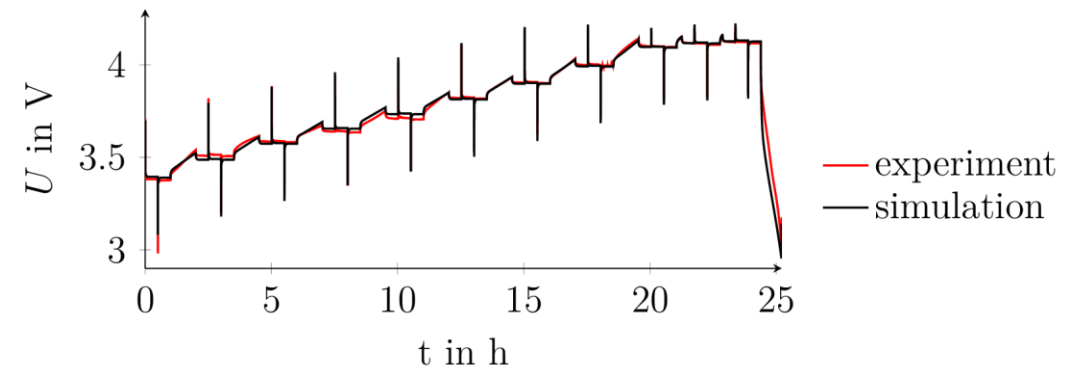
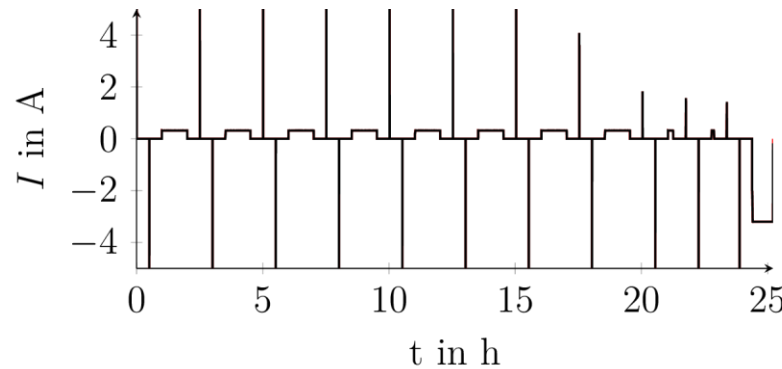
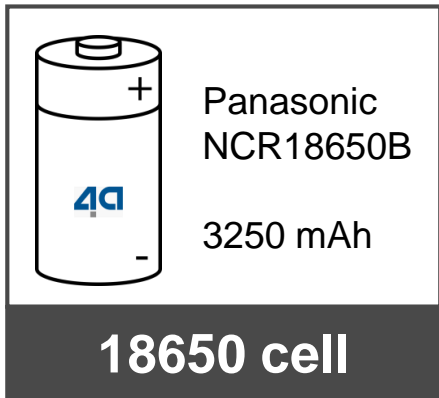
	Solid layer model	Tshell model	Batmac model
			
Keyword	*EM_RANDLES_SOLID	*EM_RANDLES_TSHELL	*EM_RANDLES_BATMAC
Characteristics	<ul style="list-style-type: none"> <li>+ Analysis of the different layers is possible</li> <li>- Computational effort</li> </ul>	<ul style="list-style-type: none"> <li>+ Beneficial modeling of thin cells</li> <li>- Behavior of the layers can not be analyzed in detail</li> </ul>	<ul style="list-style-type: none"> <li>+ Modeling with respect to mechanical and thermal problem</li> <li>- Behavior of the layers can not be analyzed</li> </ul>

# Electrical modelling and characterization

- electrical behavior is covered by a circuit model



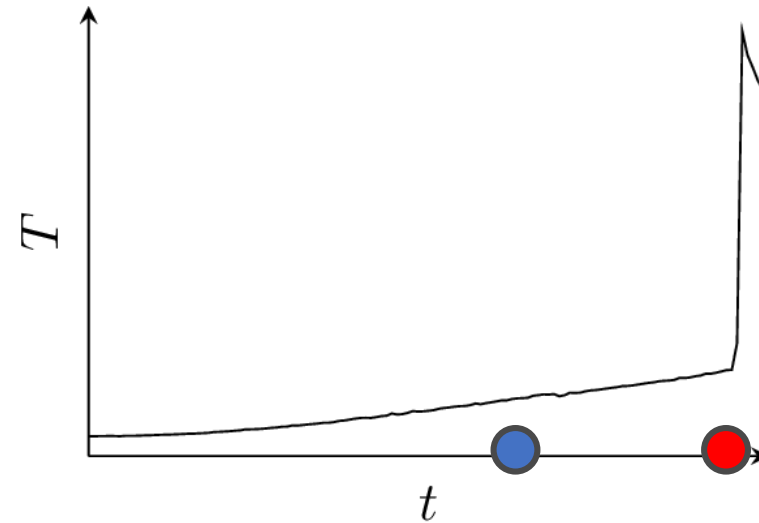
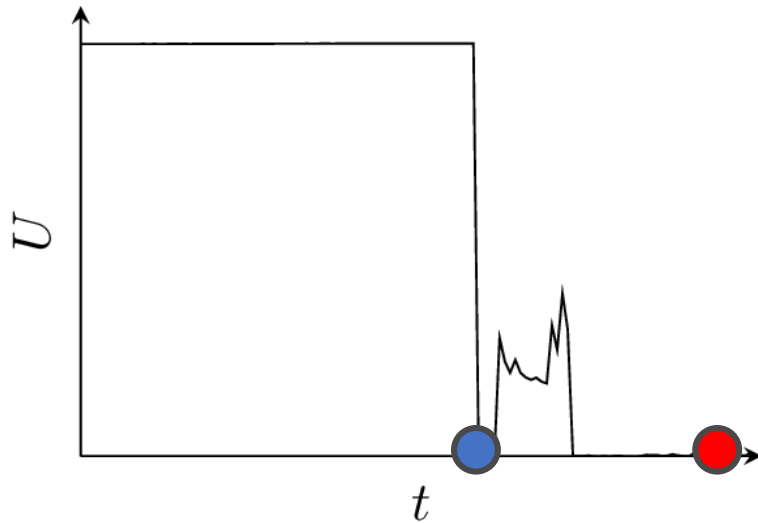
- parameter as well as the OCV-SOC curve are identified from the 4a HPPC test





# Characteristic of the abuse of a battery cell

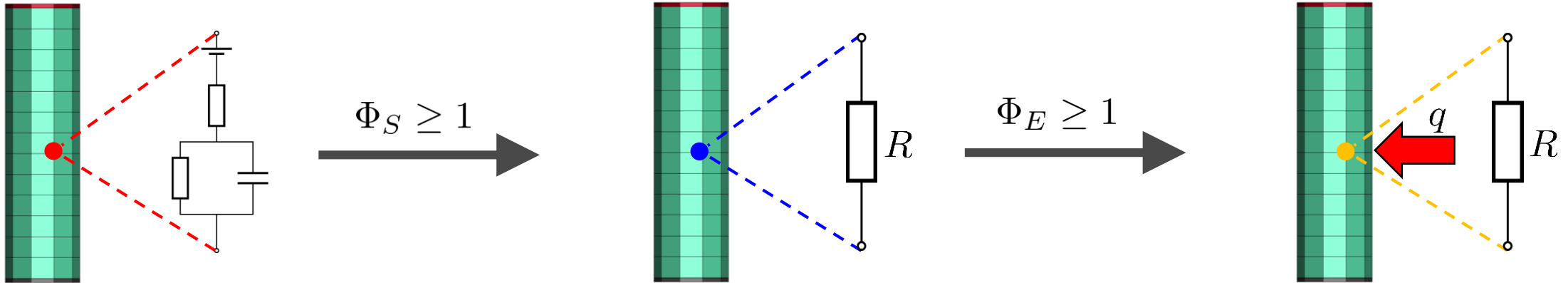
- Course of voltage and temperature because of overheating



- Characteristic points and effects:
  - **Internal short circuit:** drop of the voltage
  - **Exothermic reaction:** spontaneous increase of the temperature

# Abuse simulation of a single cell

- Modeling of the internal short circuit and the exothermal reaction



Initiation criterion:

$$\Phi_S (T, \text{SOC}, \underline{\underline{\varepsilon}}) \geq 1$$

Short resistance:

$$R = \text{const.}$$

**Internal short circuit**

Initiation criterion:

$$\Phi_E (T) \geq 1$$

Additional heat source:

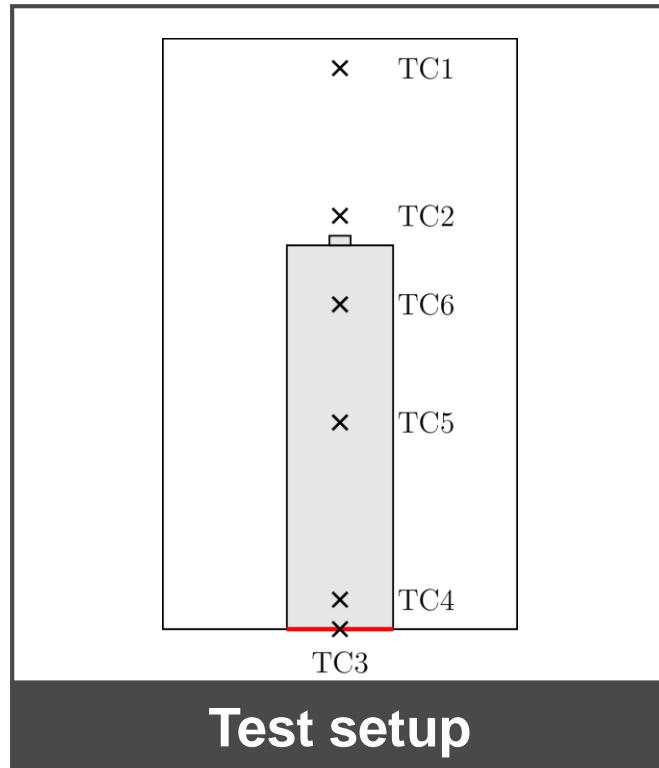
$$q (T)$$

**Exothermal reaction**

# Abuse testing and simulation of a single battery cell

# Overheat test of a single battery cell

- Overheating of a fully charged 18650 battery cell (Panasonic NCR18650B) at the bottom
- Measurement of the temperature at the cell as well as in the chamber with 6 thermocouples
- Measurement of the voltage



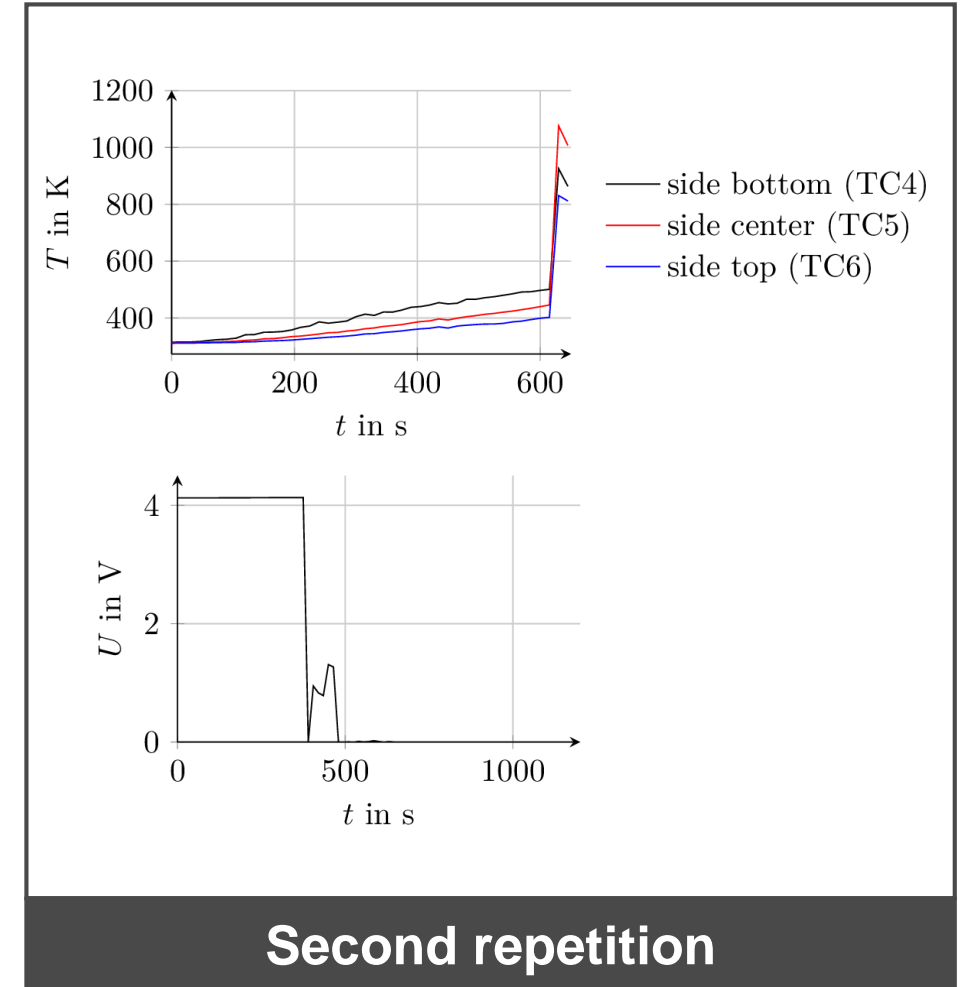
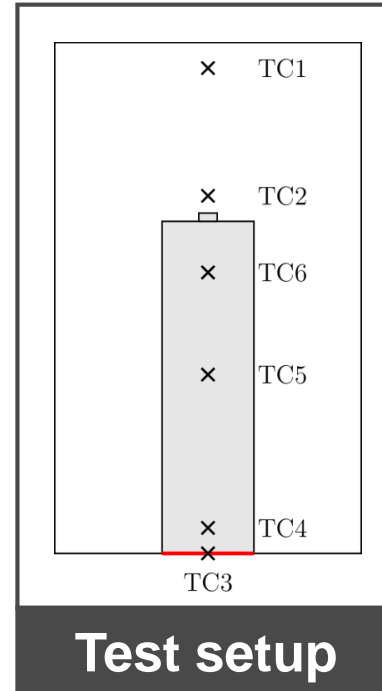
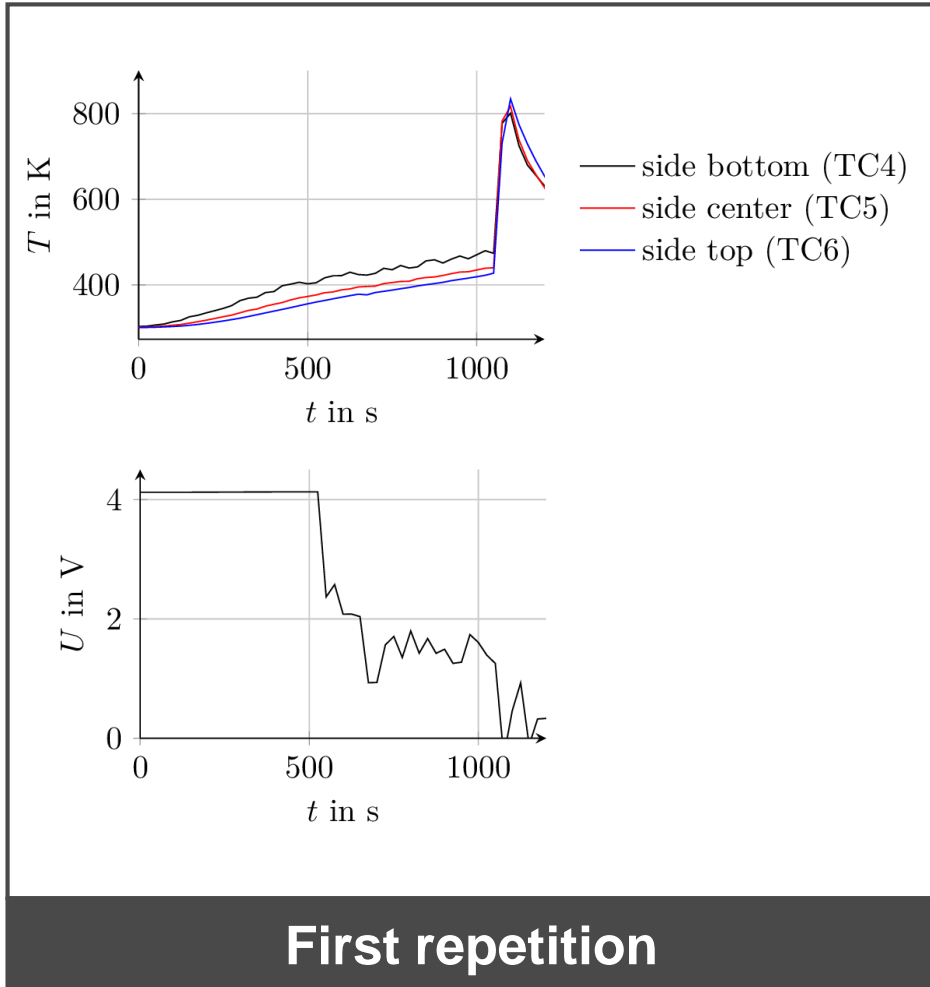
# Overheat test of a single battery cell

18650 battery cell

fully charged  
overheating at bottom

# Overheat test of a single battery cell

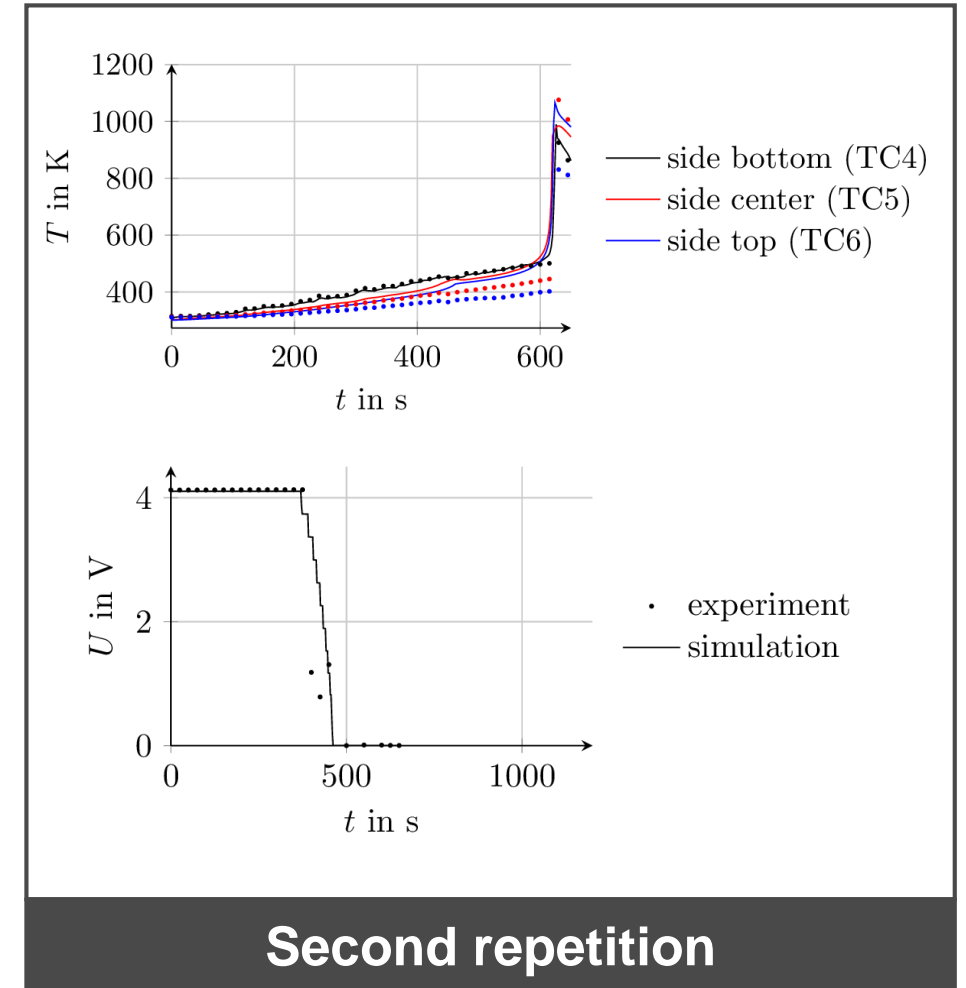
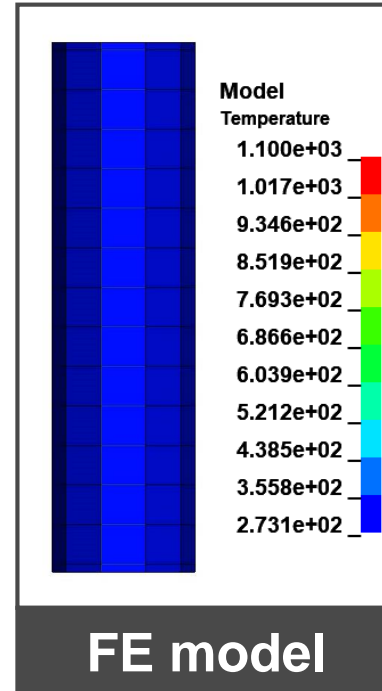
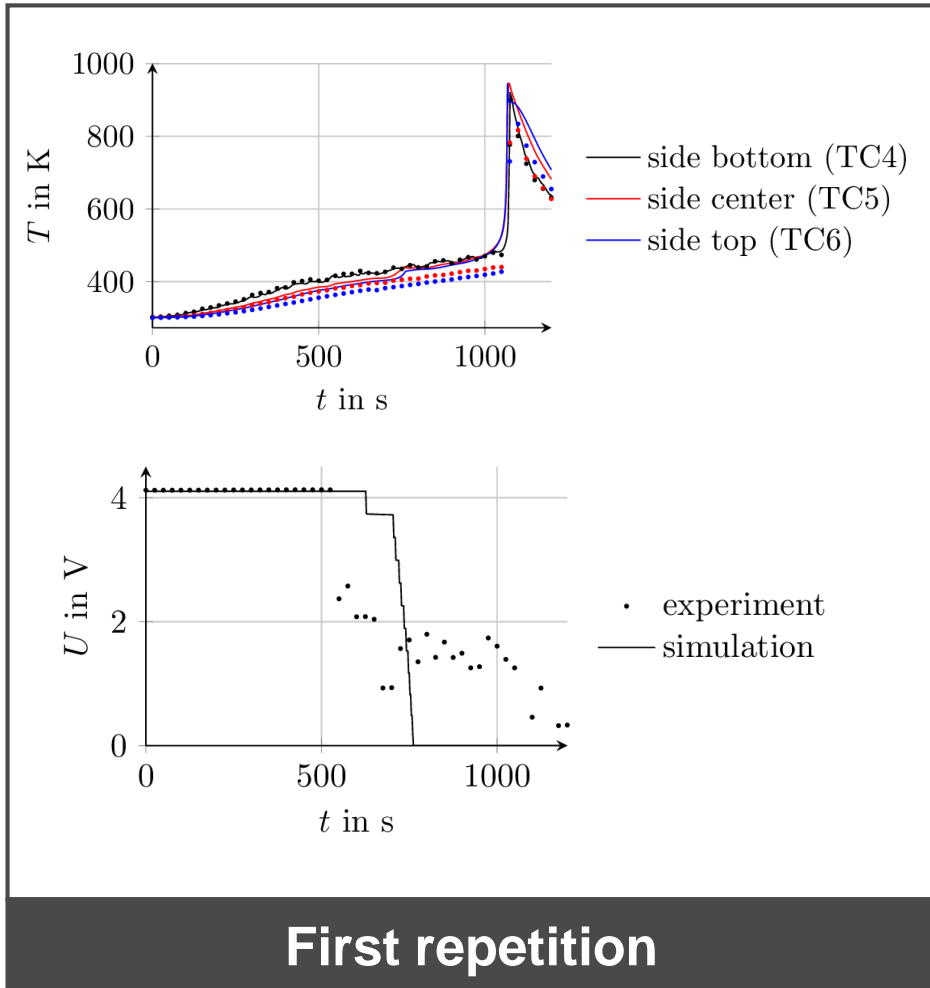
## Experimental results





# Overheat test of a single battery cell

## Comparison of experimental and simulative data

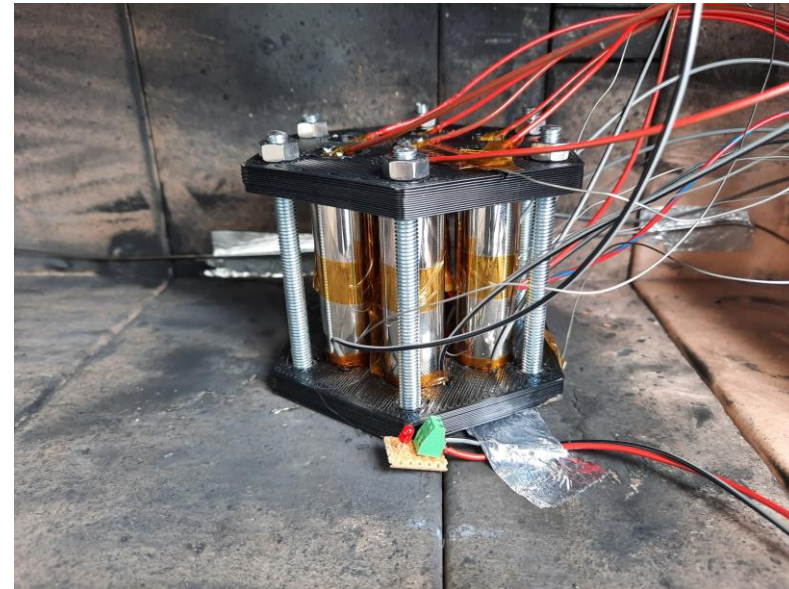
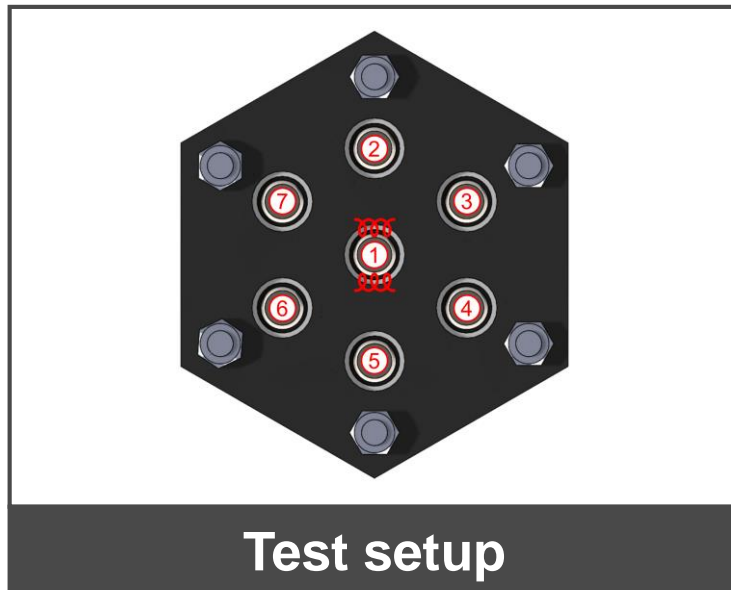


# Application of a single cell model within the simulation of multi-cell mockups

# Mockup with equal distances

## Experimental investigation

- Thermal runaway of the center cell induced by heating with a heating wire
- Temperature and voltage measurement at each cell
- Video recording with high-speed camera



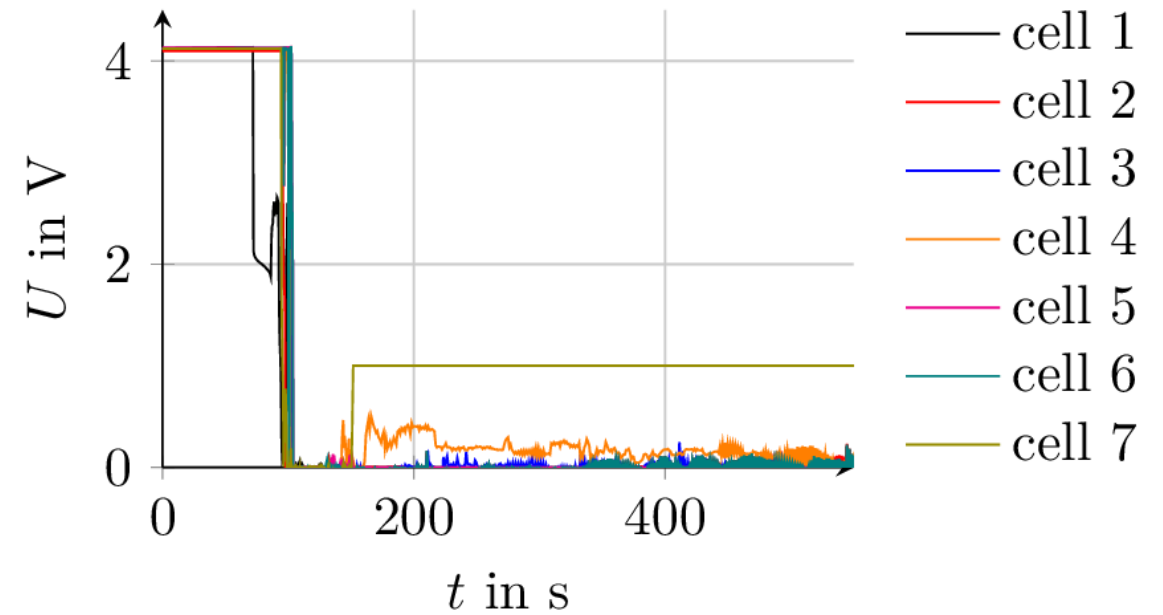
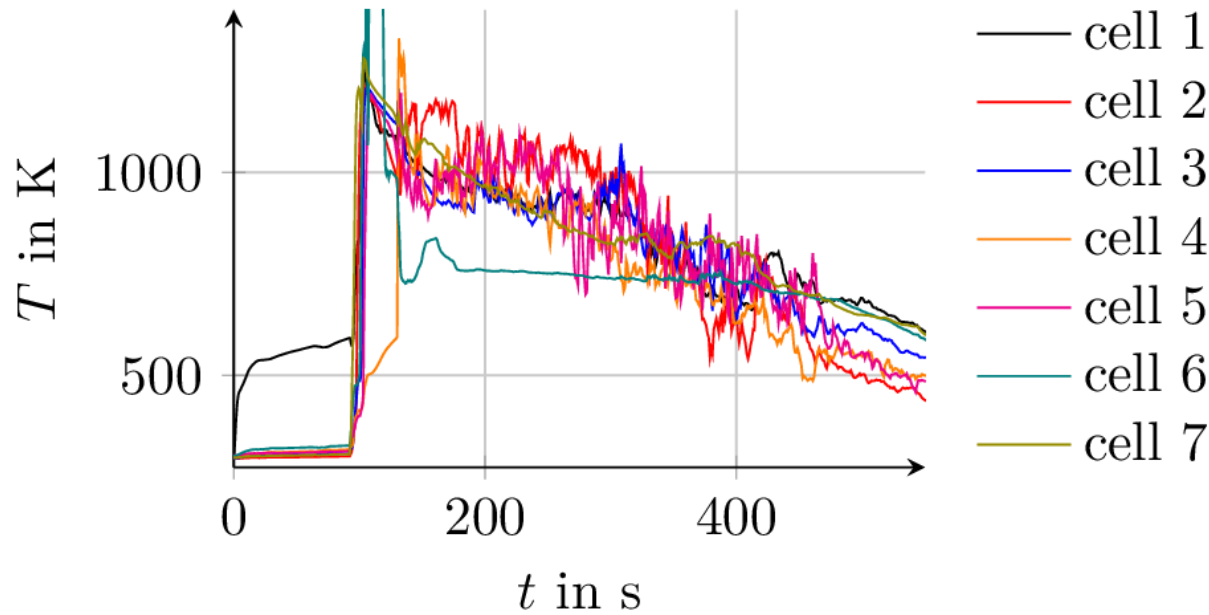
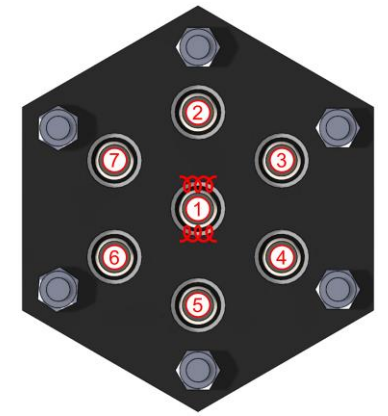
# Mockup with equal distances

## Experimental investigation

Mock-up with seven 18650 battery cells  
equal distances

# Mockup with equal distances

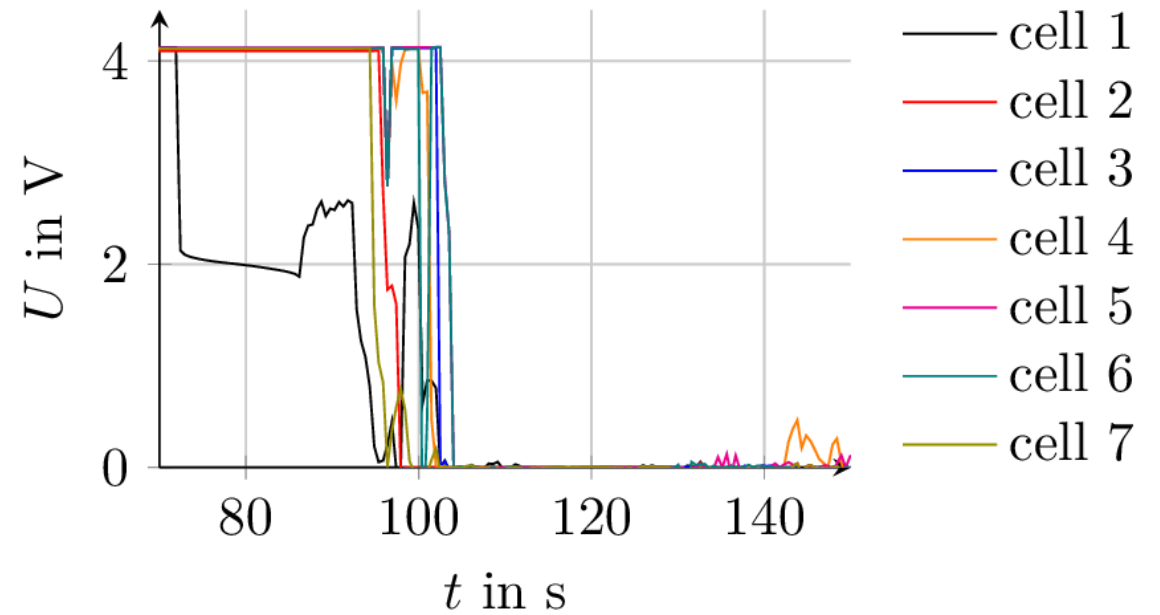
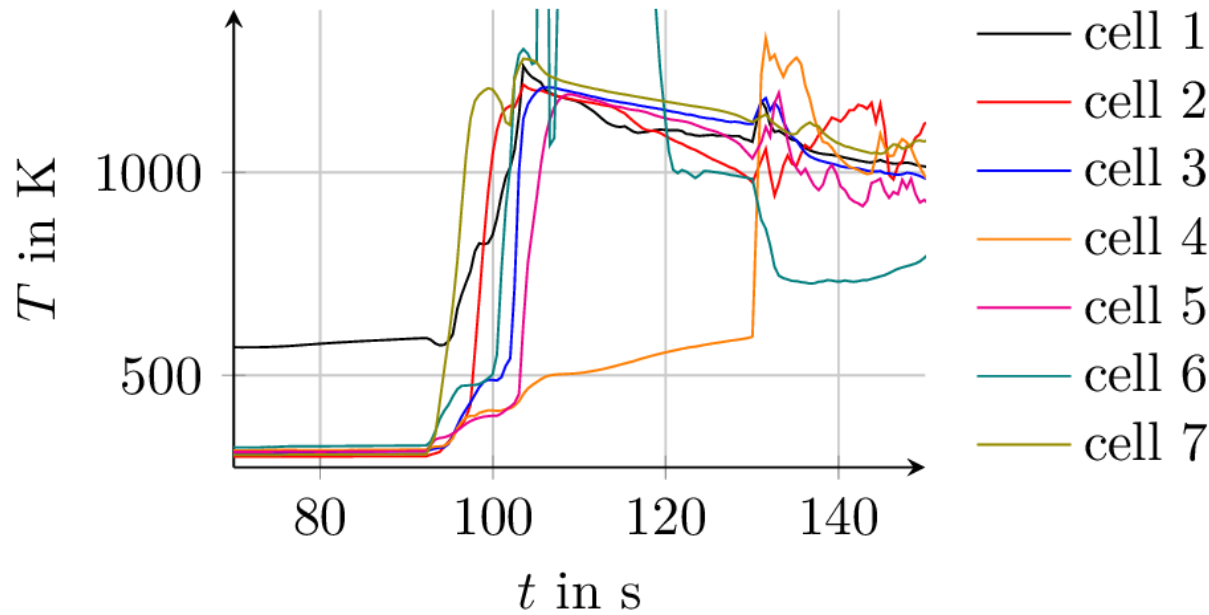
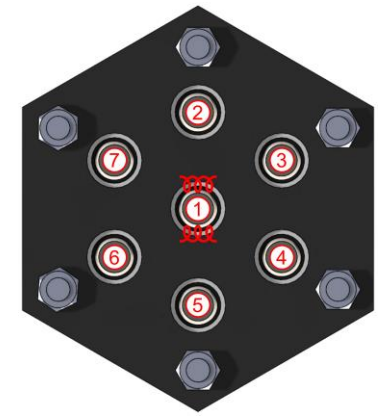
Experimental investigation – behavior of all cells



\*Thermocouple at cell 6 was broken within the test

# Mockup with equal distances

Experimental investigation – behavior of all cells

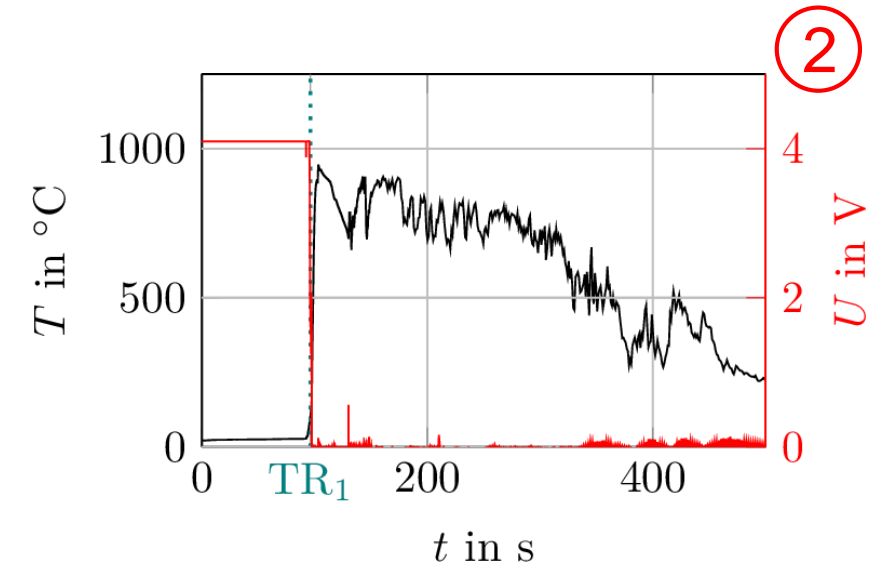
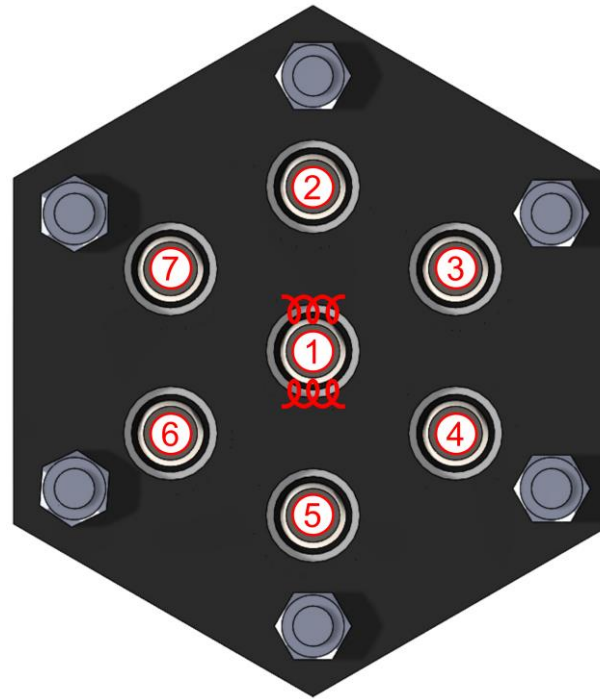
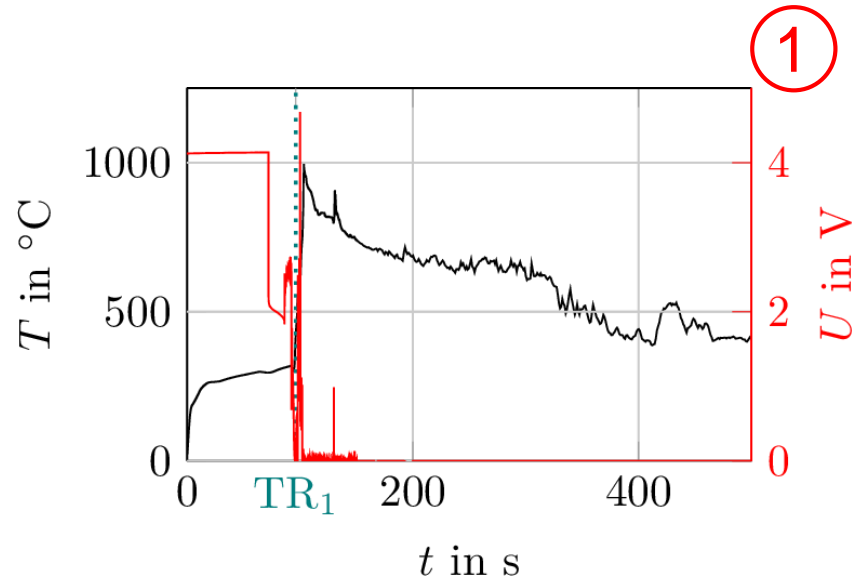


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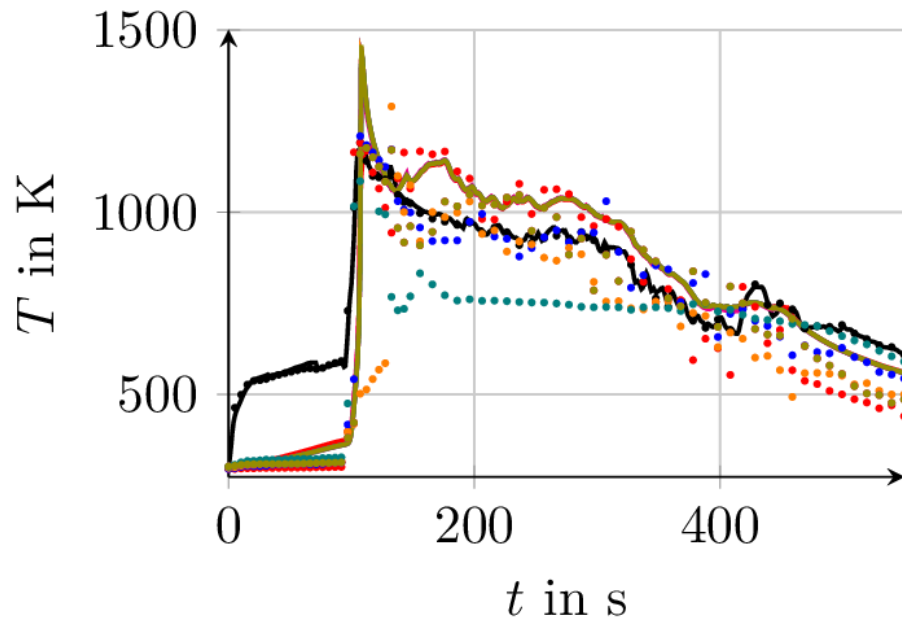
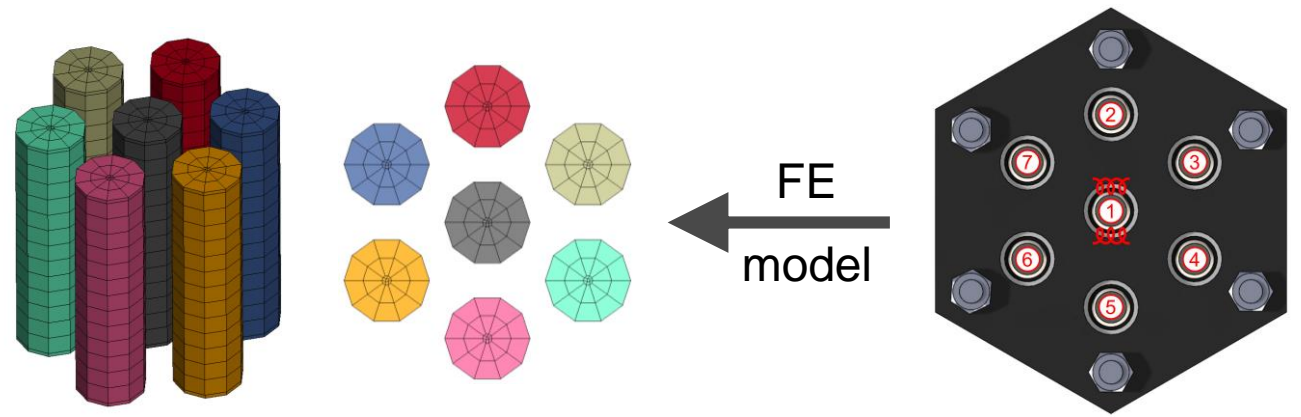
# Mockup with equal distances

Experimental investigation – behavior of cell 1 and 2

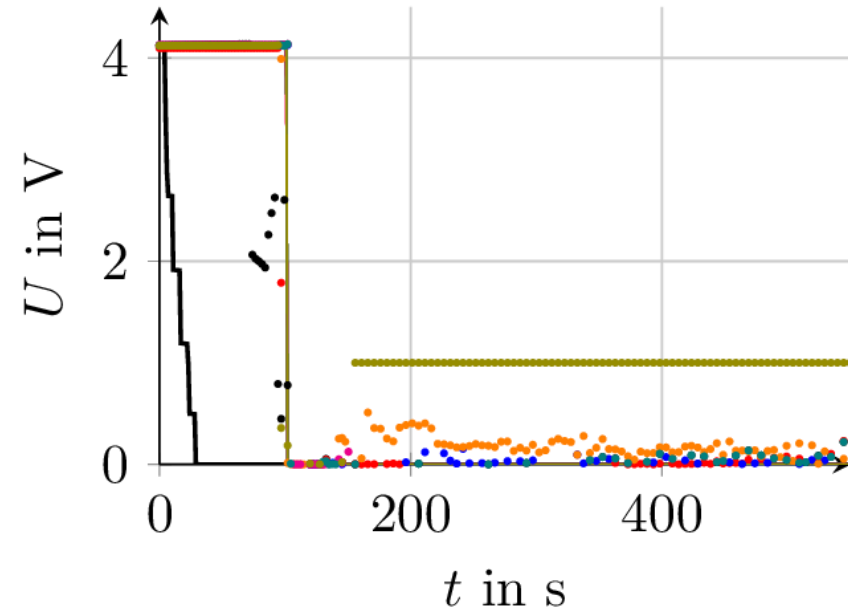


# Mockup with equal distances

## Simulation results



- cell 1
- cell 2
- cell 3
- cell 4
- cell 5
- cell 6
- cell 7



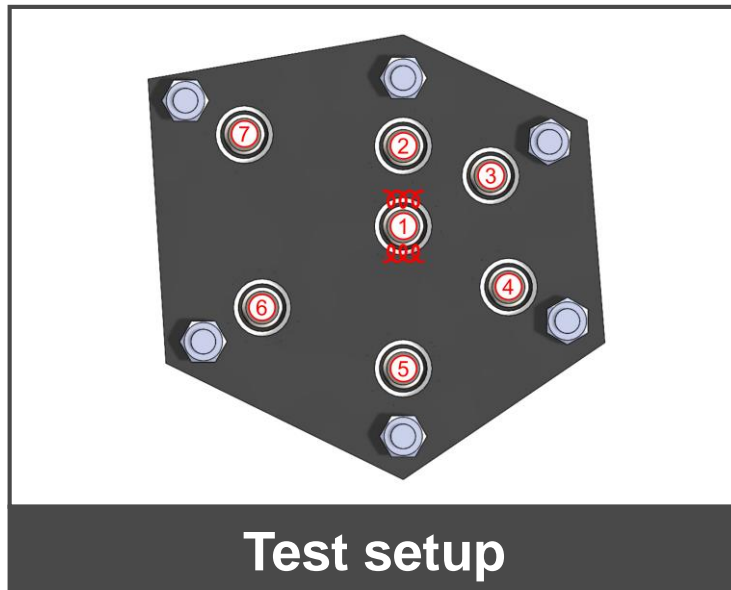
- cell 1
- cell 2
- cell 3
- cell 4
- cell 5
- cell 6
- cell 7

• experiment — simulation

# Mockup with different distances

## Experimental investigation

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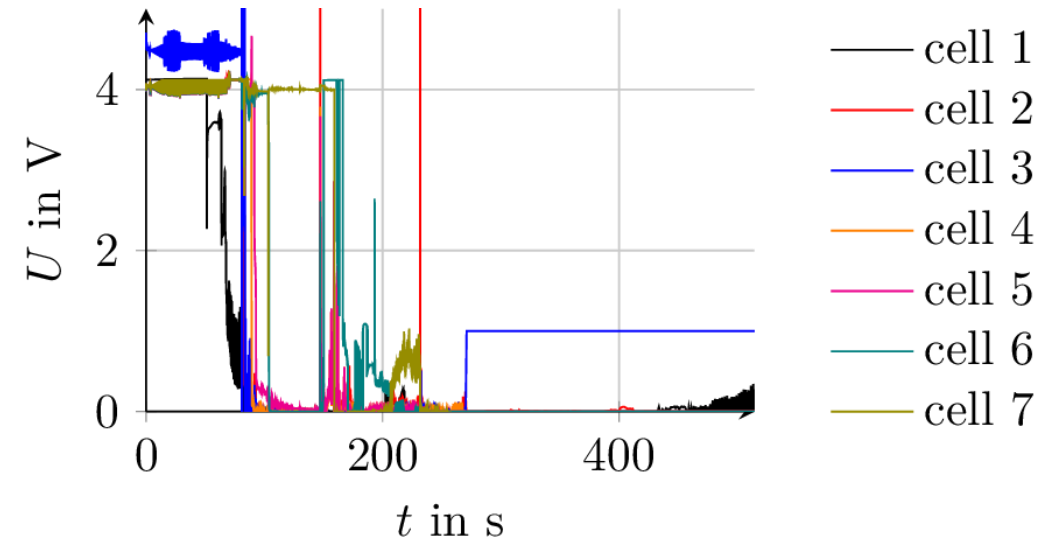
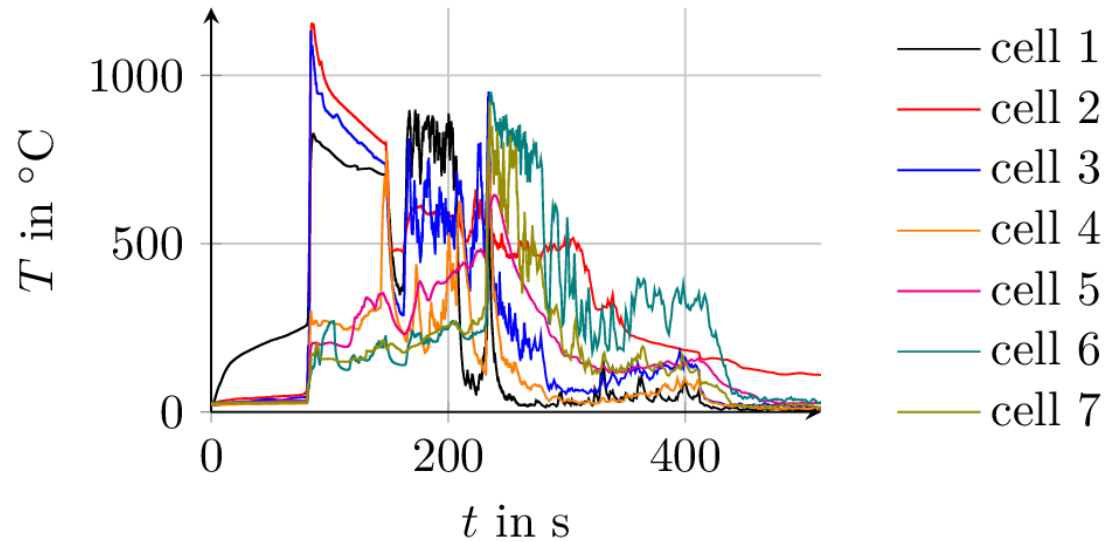
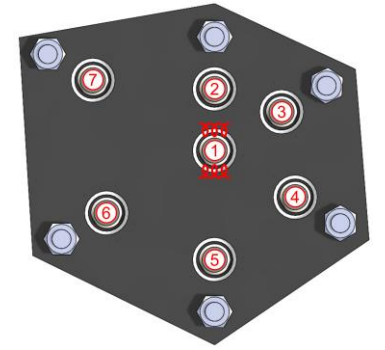
# Mockup with different distances

Experimental investigation

Mock-up with seven 18650 battery cells  
different distances

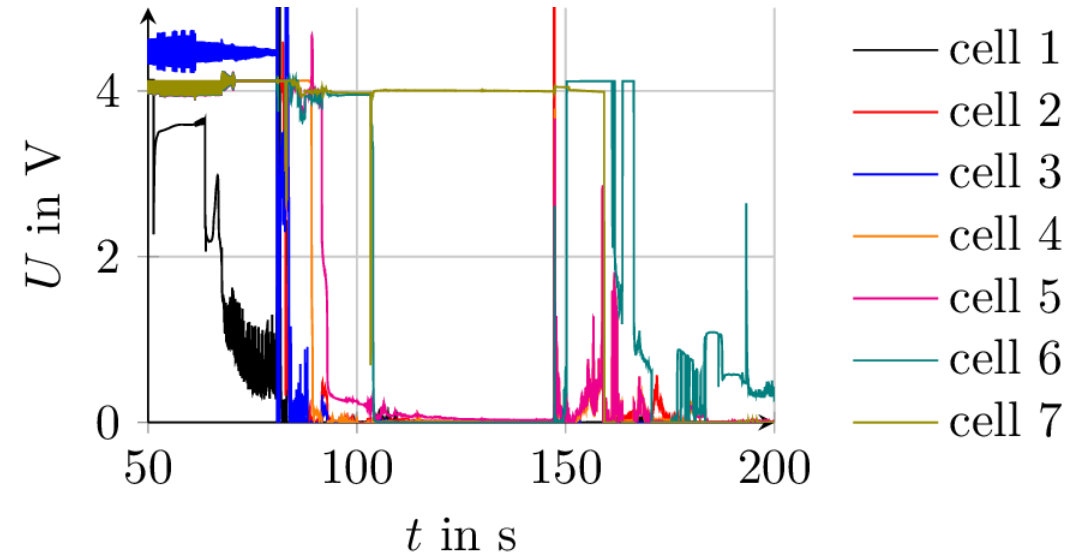
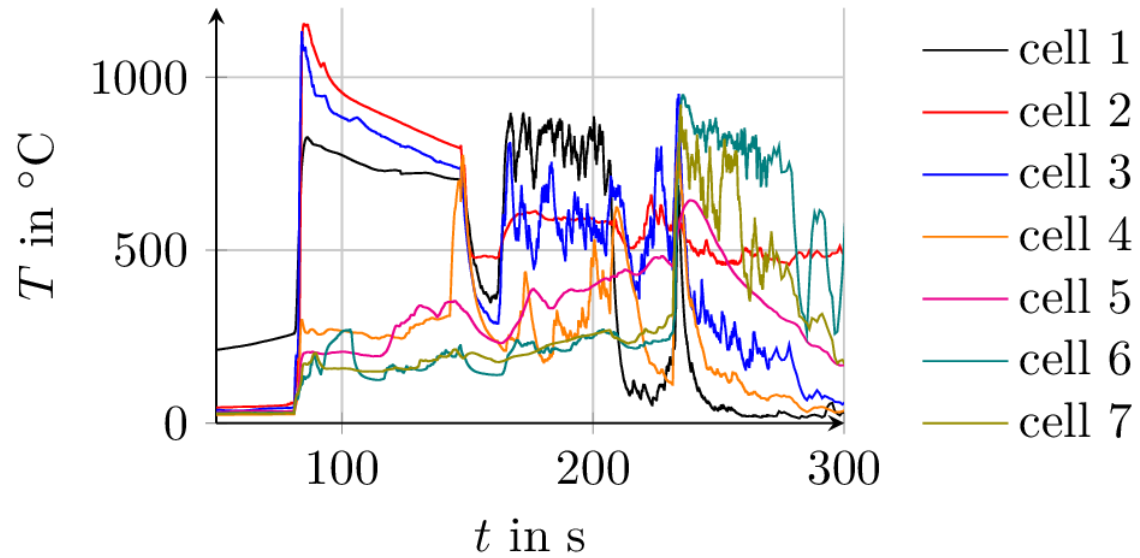
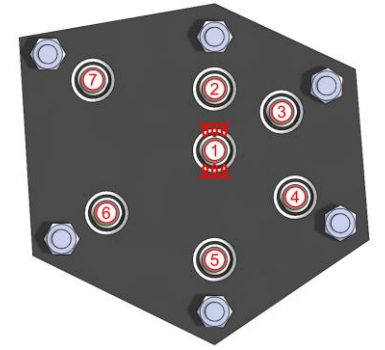
# Mockup with different distances

Experimental investigation – behavior of all cells



# Mockup with different distances

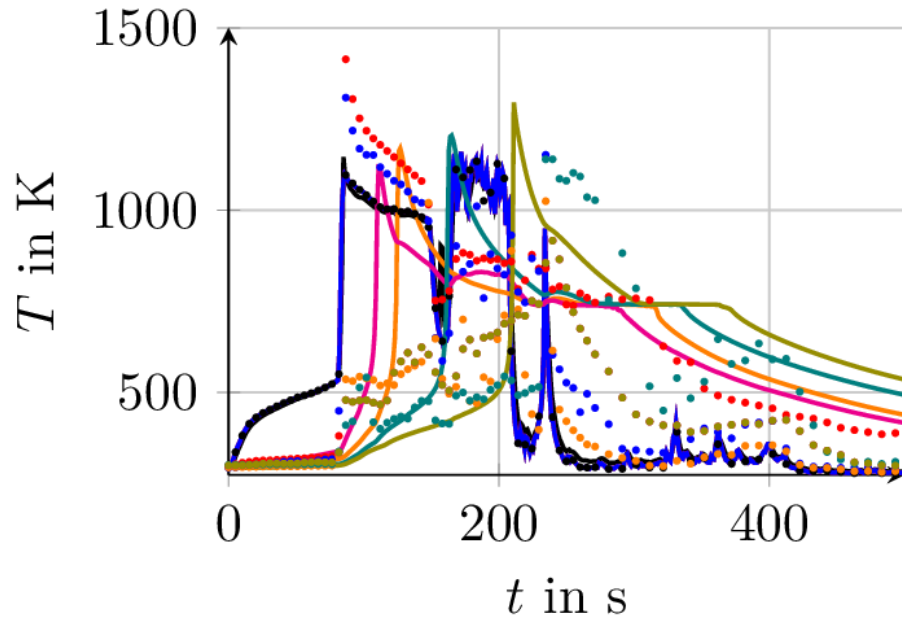
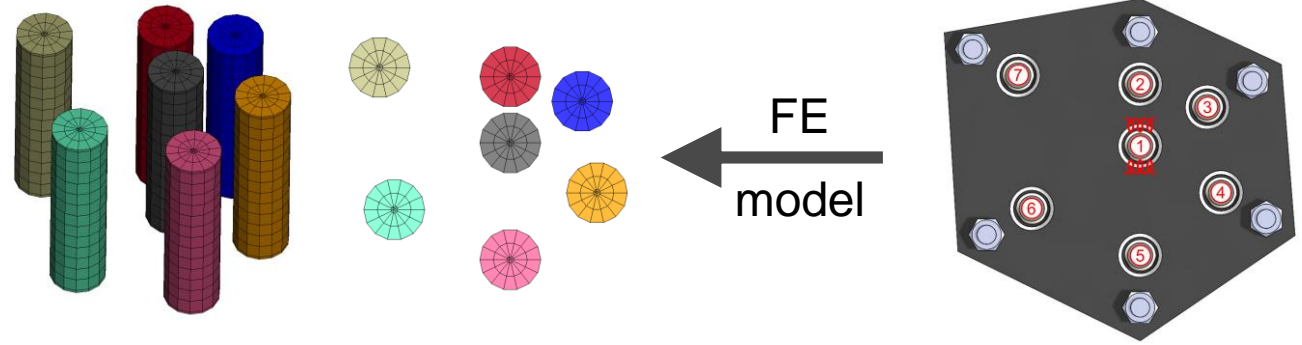
Experimental investigation – behavior of all cells



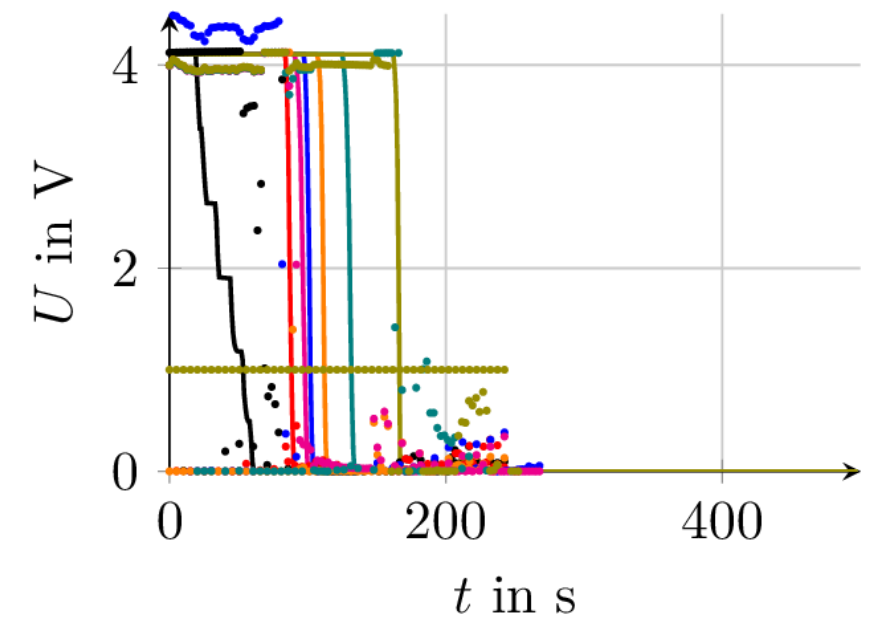


# Mockup with different distances

## Simulation results



- cell 1
- cell 2
- cell 3
- cell 4
- cell 5
- cell 6
- cell 7

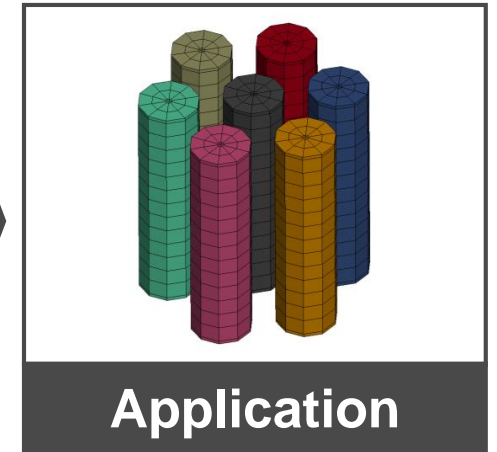
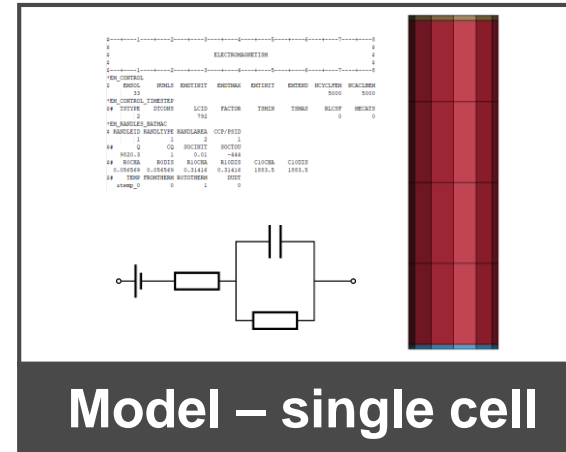
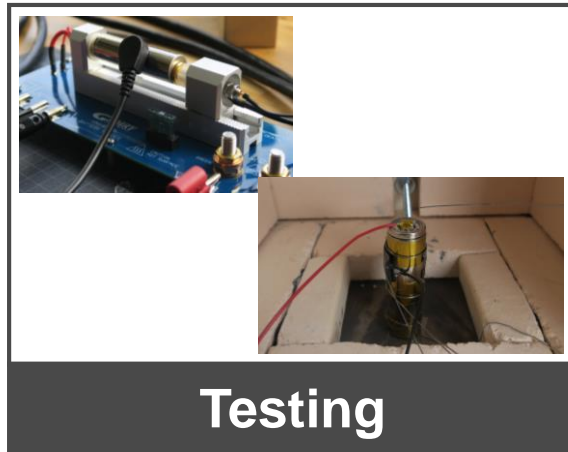


- cell 1
- cell 2
- cell 3
- cell 4
- cell 5
- cell 6
- cell 7

• experiment — simulation

# Conclusion and outlook

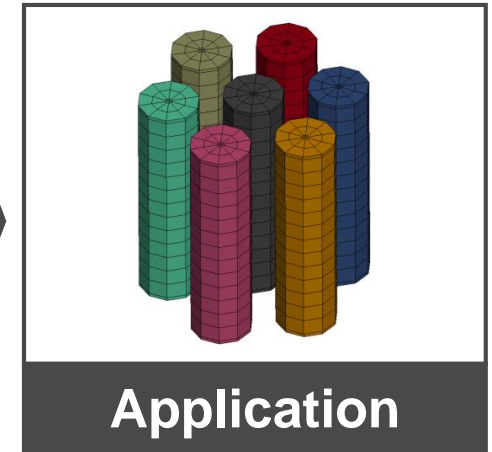
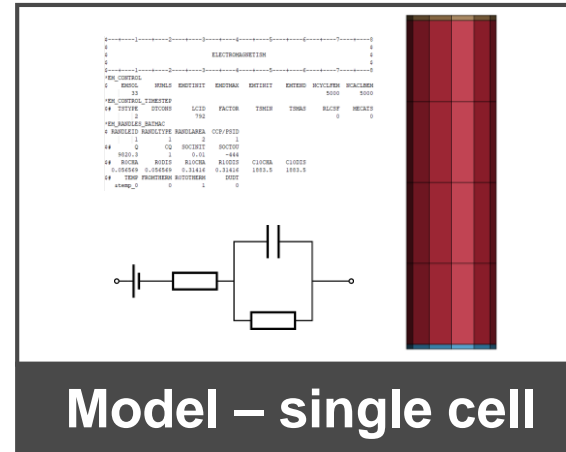
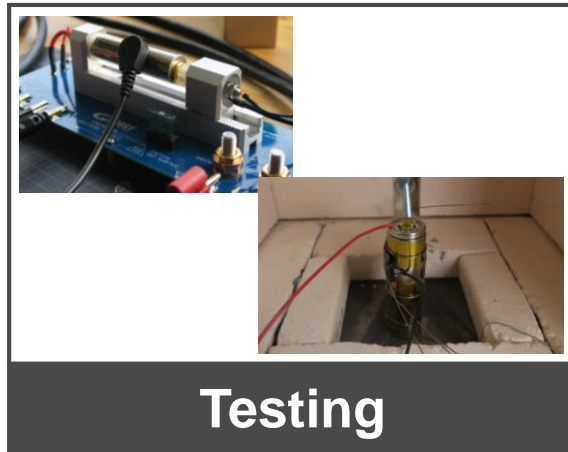
# Conclusion



# Outlook

- Development of test setups for further characterizations of battery cells especially within the thermal runaway
- Automatic identification of the parameters required for the resulting FE model
- Optimization of battery packs addressing the thermal propagation behavior

# Conclusion



# Outlook

- Development of test setups for further characterizations of battery cells especially within the thermal runaway
- Automatic identification of the parameters required for the resulting FE model
- Optimization of battery packs addressing the thermal propagation behavior

**Improve your developments with our expertise in testing and simulation!**





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