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Crash safety assessment from cell to pack level in the Horizon 2020 project LIBERTY

Christoph Breitfuss[1], Klemens Jantscher[1],Patrick Kolm[1], Andrey Golubkov[1], Werner Leitgeb[1], Nick de Bie[2], Yolanda Bravo[3], Eduardo Miguel[4]

Virtual Vehicle Research GmbH, Inffeldgasse 21a, 8010 Graz, Austria

FLANDERS MAKE VZW, Oude Diestersebaan 133, 3920 Lommel, Belgium

VALEO TERMICO S.A. Carretera de Logroño Km 8,9 Apartado de Correos N 615 - 50011 – Zaragoza, Spain

IKERLAN Technology Research Centre, Basque Research and Technology Alliance (BRTA). P° J.M. Arizmendiarrieta, 2, 20500 Arrasate-Mondragón, Spain

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Agenda

- Overview LIBERTY Project
- Contribution to Challenges
- LIBERTY Approach for Crash Safety Assessment
- Safety Testing
- Mechanical Cell Modelling
- Mechanical Cell Stack Modelling
- Mechanical Pack Modelling
- Summary and Outlook

LIBERTY - Overview

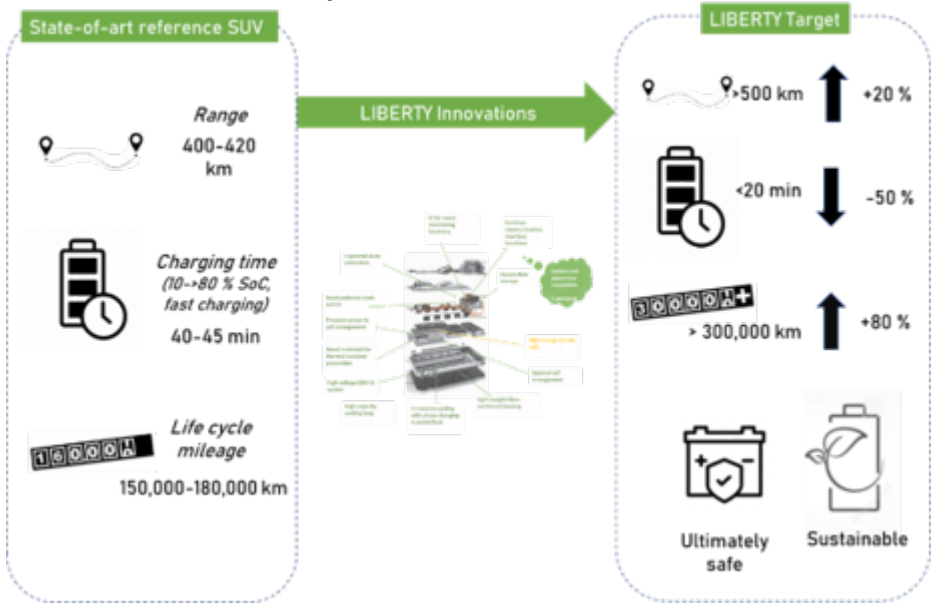
LIBERTY - Lightweight Battery System for Extended Range and Improved Safety

- Overall target: Upgrading EV battery performance, safety and lifetime from a lifecycle and sustainability point of view
- 16 Partners from 7 countries
- Website: www.libertyproject.eu
- Start date: January 2021
- Duration: 42 months

LIBERTY - Objectives

- Lightweight Battery System for Extended Range at Improved Safety
  - Objective 1: To achieve a range of 500 km on a fully charged battery pack
  - Objective 2: To achieve a short charging time
  - Objective 3: To achieve an ultimately safe battery system
  - Objective 4: To achieve a long battery lifetime
  - Objective 5: To achieve sustainability over the battery pack's entire life cycle

Parameter	Benchmark: EQC 2019	Target: LIBERTY EQC
Battery system capacity [kWh]	80	96
Battery system weight based on 80 kWh battery capacity [kg]	650	520
Max. charging power [kW]	110	350
Charging window 10-80% SoC [min]	40	18
Range (WLTP) [km]	417	500
Battery life (no. of cycles to 80% DoD)	500	1000
Mileage [km]	160,000	>300,000



LIBERTY - Consortium

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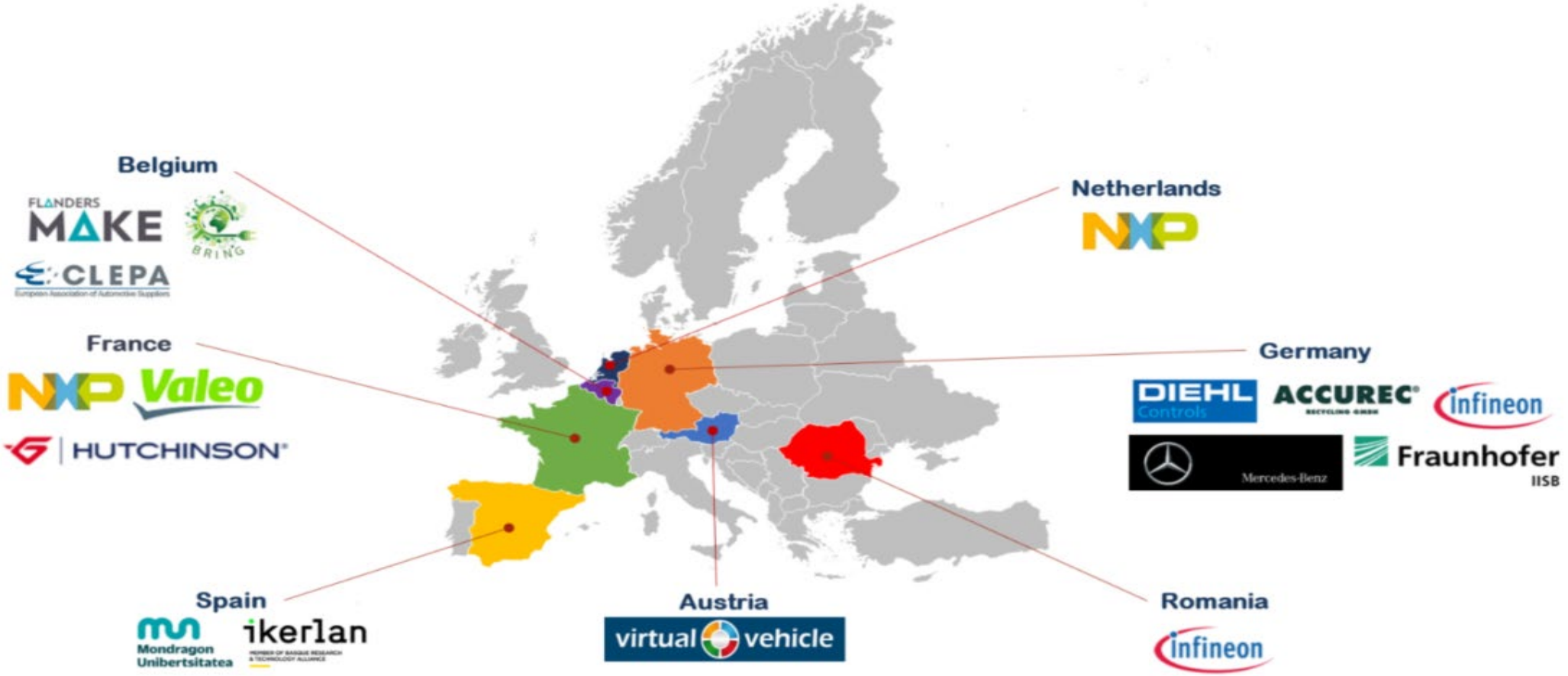

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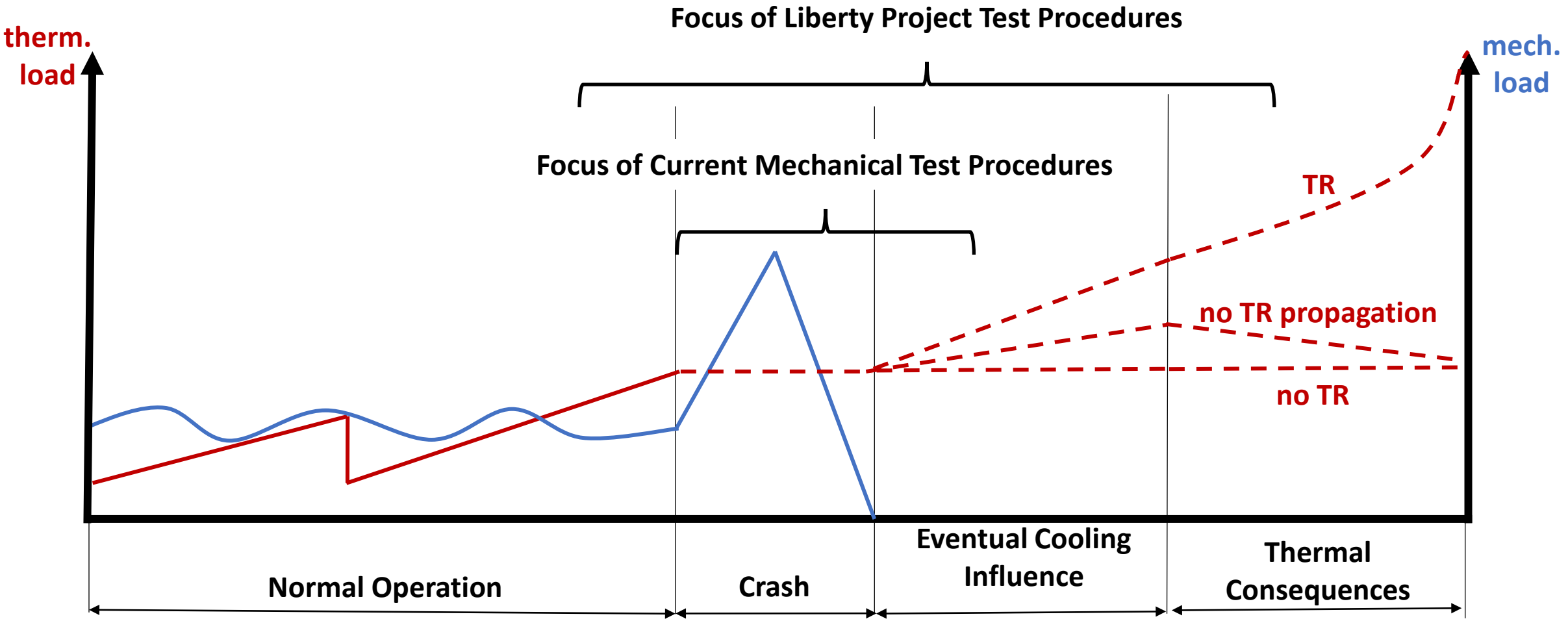
Contribution to Challenges

- *CAE driven solution to maintain crash performance - legal and consumer tests but also in the public opinion*
- *Physically characterizing cells at high speeds*
- *Virtual assessment of performance to avoid failure modes as electrical short circuits*

LIBERTY Approach for Crash Safety Assessment



LIBERTY Approach for Crash Safety Assessment

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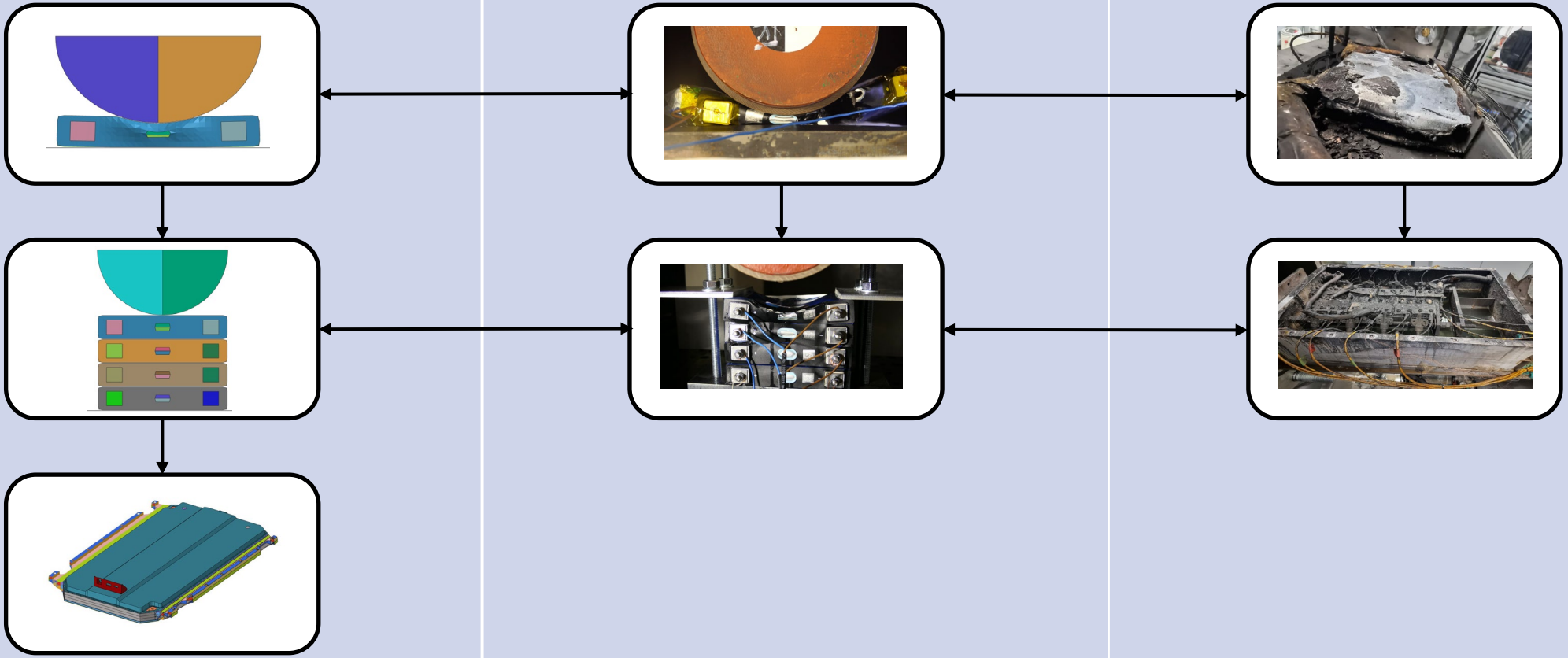
Simulation	Testing	
Mechanical	Mechanical	Thermal Runaway



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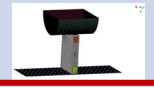
Mechanical Cell Testing

Quasi- static cell tests:

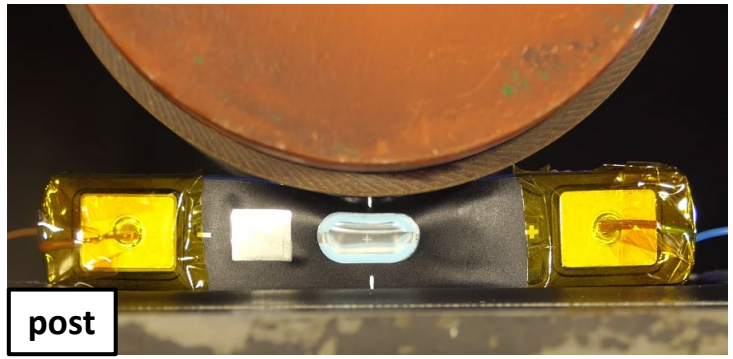
Load Case	Axis	Tests	Boundary	Speed	SOC	Sketch
Cylindrical Indention	X	3	-	1mm/s	0%	
Cylindrical Indention	Y	3	-	1mm/s	0%	
Flat Crush	X	3	-	1mm/s	0%	
Flat Crush	Y	3	-	1mm/s	0%	

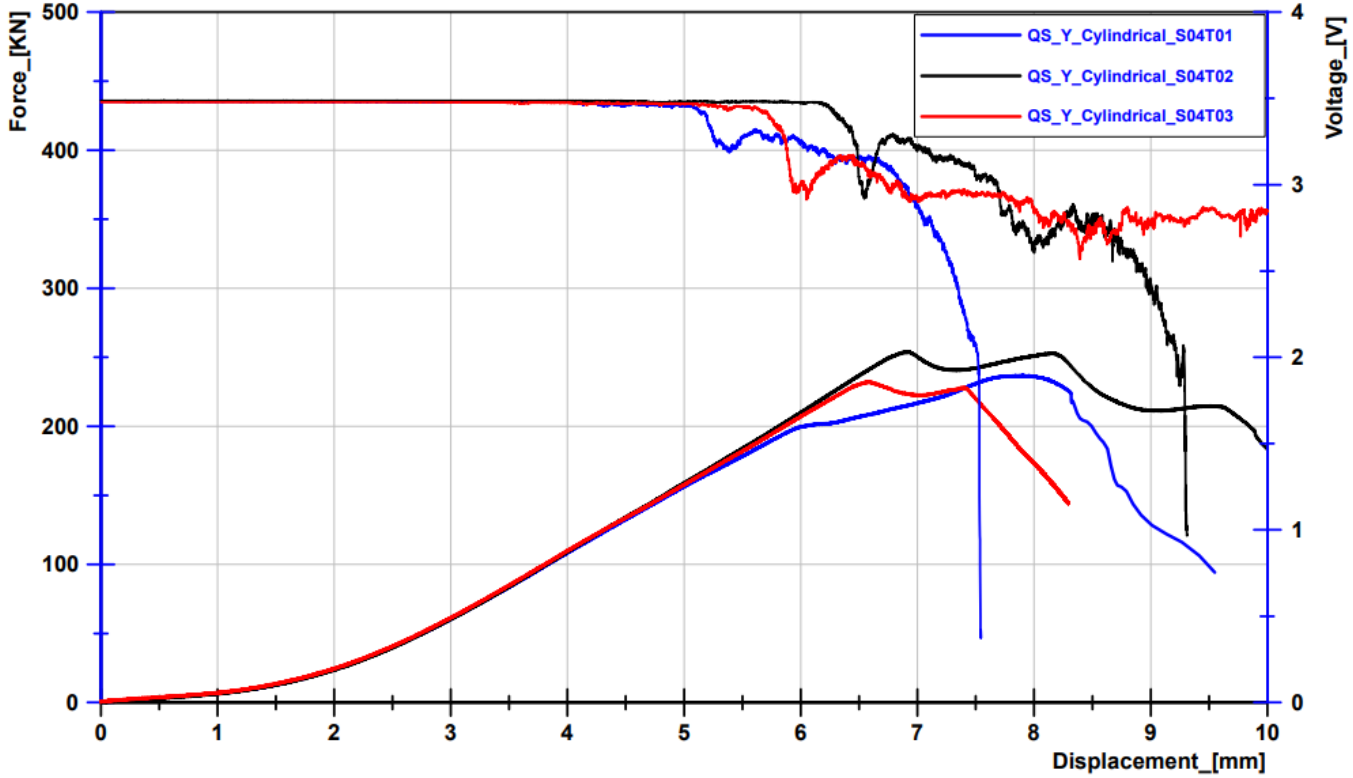
Dynamic cell tests:

Load Case	Axis	Tests	Boundary	Speed	SOC	Sketch
Cylindrical Indention	Y	3	Mass = 91 Kg	3.5 m/s	0%	
Cylindrical Indention	Y	3	Mass = 200 Kg	2.4 m/s	0%	
Cylindrical Indention	Y	2	Mass = 200.Kg	2.4 m/s - without electrolyte	0%	

Mechanical tests performed at TU Graz | VSI - BSCG

Mechanical Cell Testing

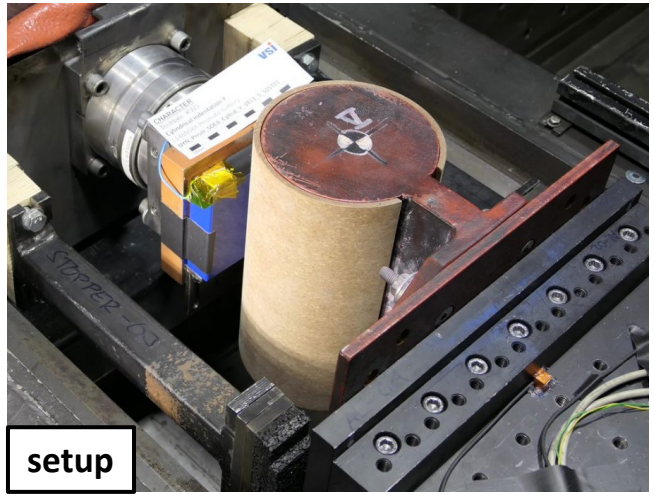




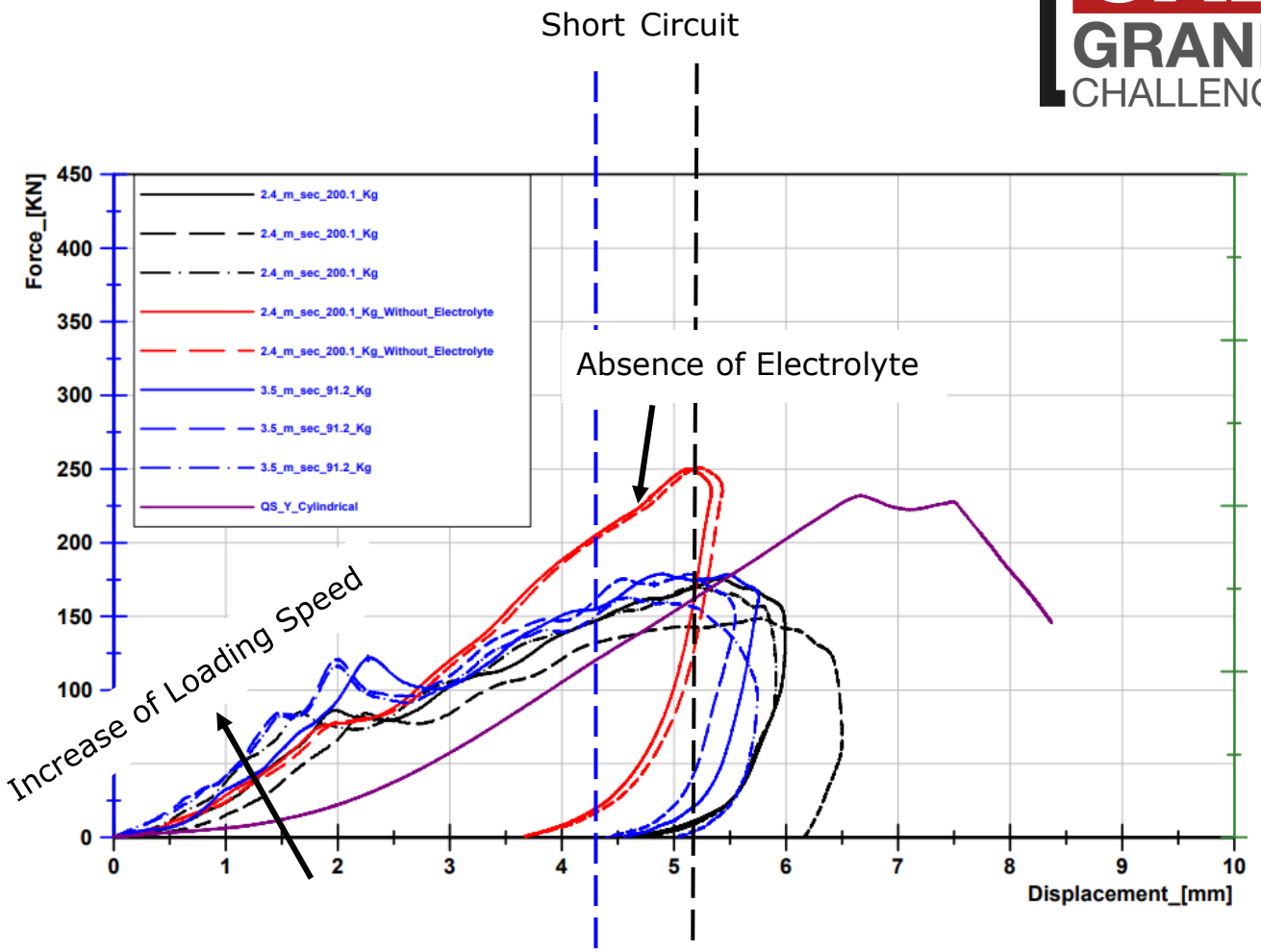
- Good reproducibility
- Slight shift of the peak force
- Cell opening after force drop
- Short-circuit before first force peak
- Cell T01 and T02 opens explosively, jellyroll bursts out

Mechanical tests performed at TU Graz | VSI - BSCG

Mechanical Cell Testing



setup



Increased loading speed:

- The cell will be stiffer at the beginning
- Clear and higher first peak
- Earlier short circuit

Absence of Electrolyte:

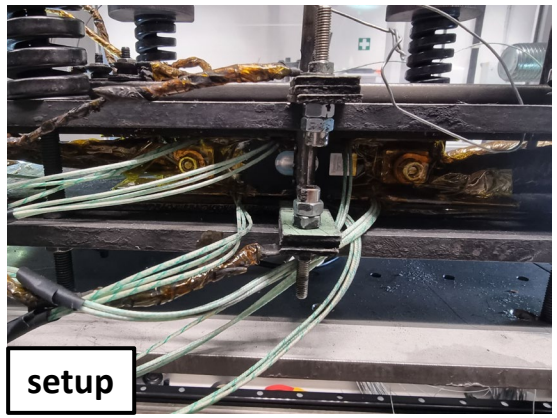
- Reduced or no plateau after first peak
- Stiffer behavior as the deformation proceed
- Max. force value is almost equal to the QS case

Mechanical tests performed at TU Graz | VSI - BSCG

Thermal Runaway Cell Testing

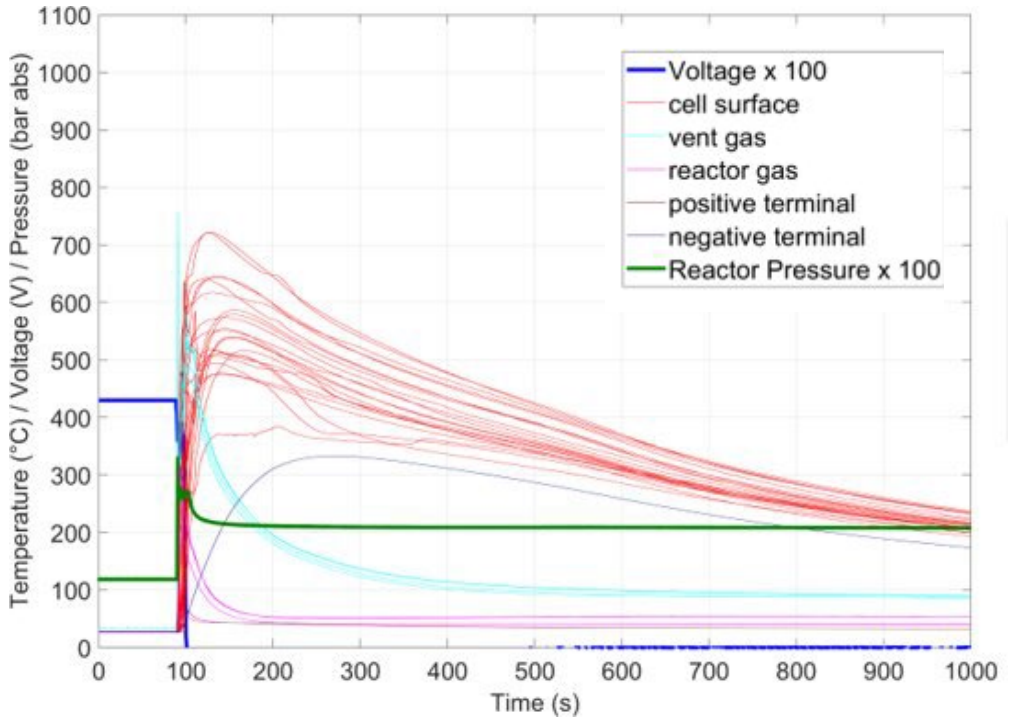
- Six TR-tests on cells performed
  - TR by overtemperature (4 tests) & TR by nail penetration (2 tests)
- Maximum average cell temperature ~571°C in all tests
- ~4.3 mol of vent-gas released per cell

Example test TS0011 - overtemperature



setup

post thermal runaway



Mechanical Cell Stack Testing

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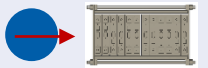
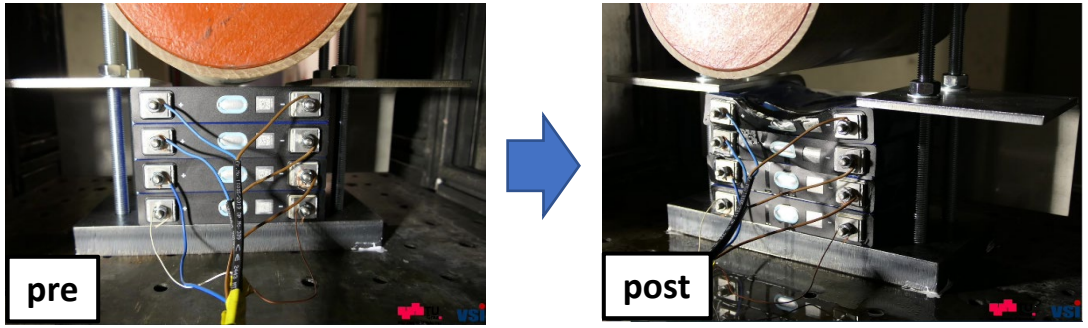
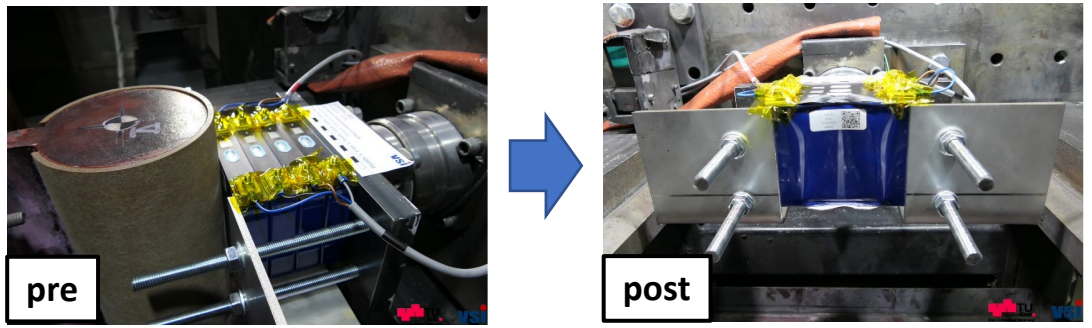
Quasi- static / Dynamic tests cell stack:

Load Case	Axis	Tests	Boundary	Speed	SOC	Sketch
Cylindrical Indention	Y	1	Preforce = 1kN	1mm/s	0%	
Cylindrical Indention	Y	1	Mass = 200 Kg, Preforce = 1 kN	3.5m/s	0%	





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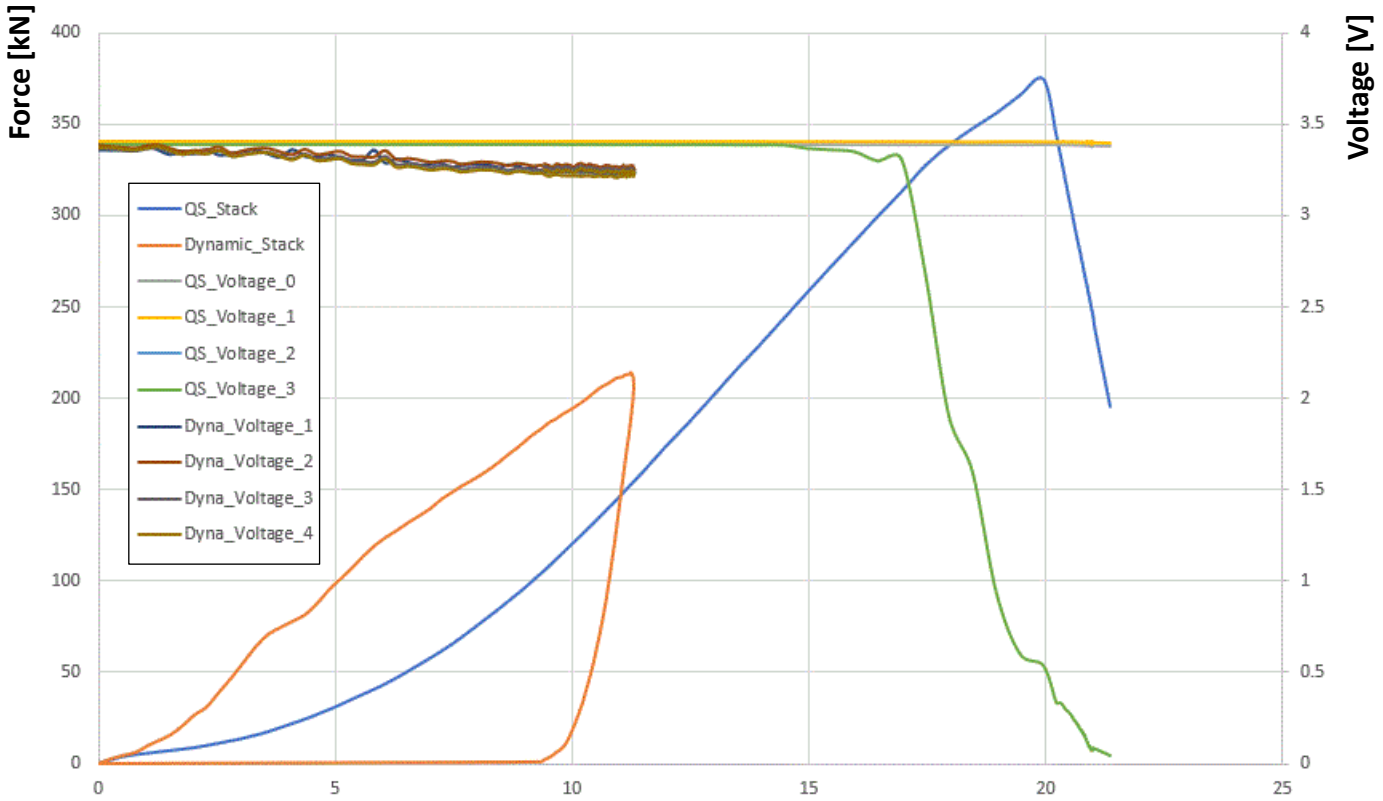
Mechanical Cell Stack Testing

- Max force is higher
- Displacement is doubled
- Short circuit:
  - First cell (quasi-static)
  - Not occurred (dynamic)
- Stack improves the strength and energy absorption.



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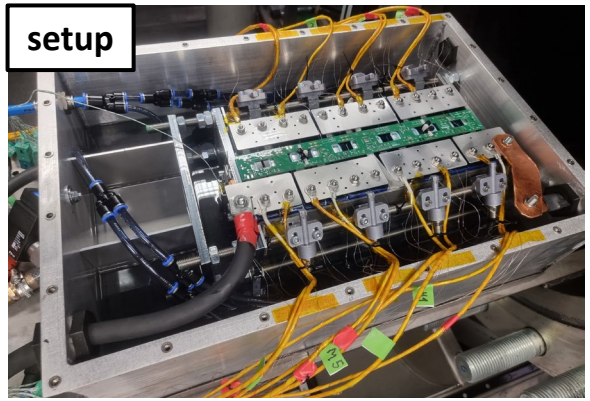
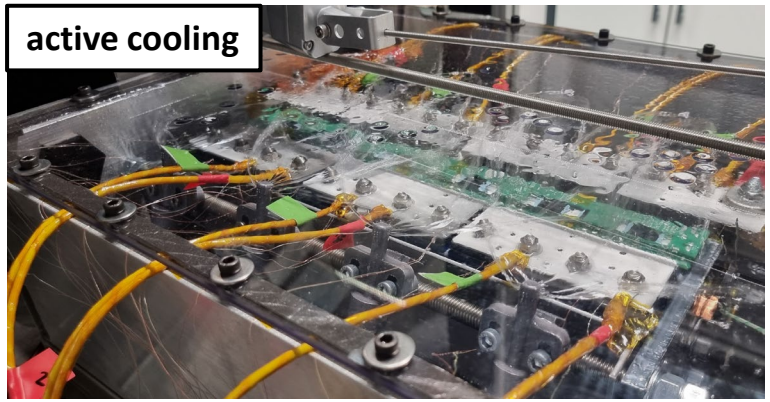
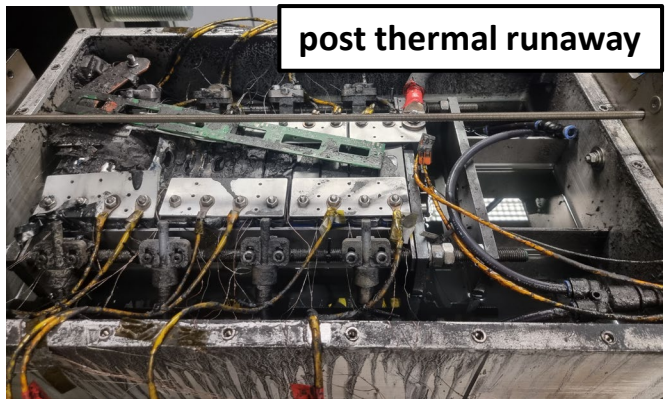
Thermal Runaway Cell Stack Testing

- TR tests with 12-cell
  - Cells partially immersed in cooling oil, cooling through oil spray
  - Primary TR-mechanism → nail penetration
  - Secondary TR-mechanism → heating pad

12-cell stack





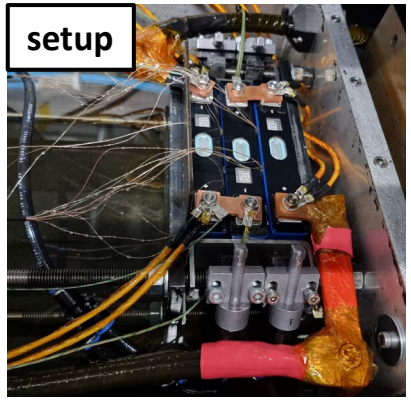


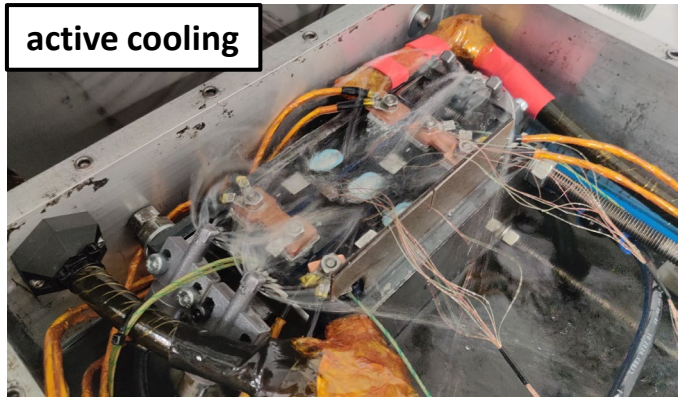
- Primary TR propagates through cells 1 to 6 and stops at passive safety system
- Secondary TR (triggered on other side of stack) propagates through remaining cells 12 to 7
- TR peak temperature in range 400-900°C
- Oil spray alone not sufficient in stopping the propagation

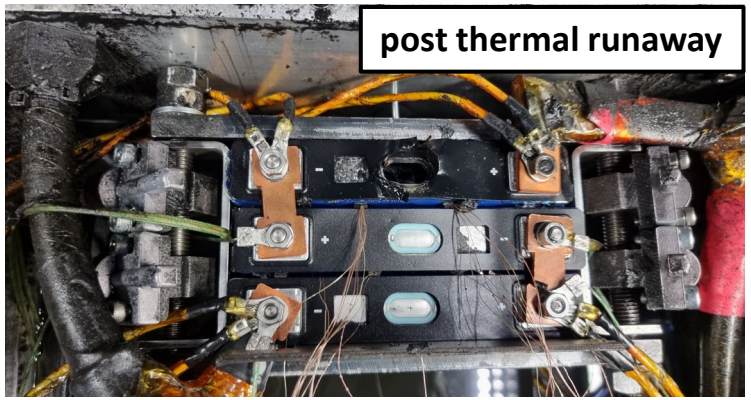
Thermal Runaway Cell Stack Testing

- TR test with 3-cell stack
  - Cells partially immersed in cooling oil, cooling through oil spray
  - Cooling improved from tests with 12-cell stack
    - More powerful cooler and better heat exchanger
  - TR-mechanism → nail penetration

3-cell stack





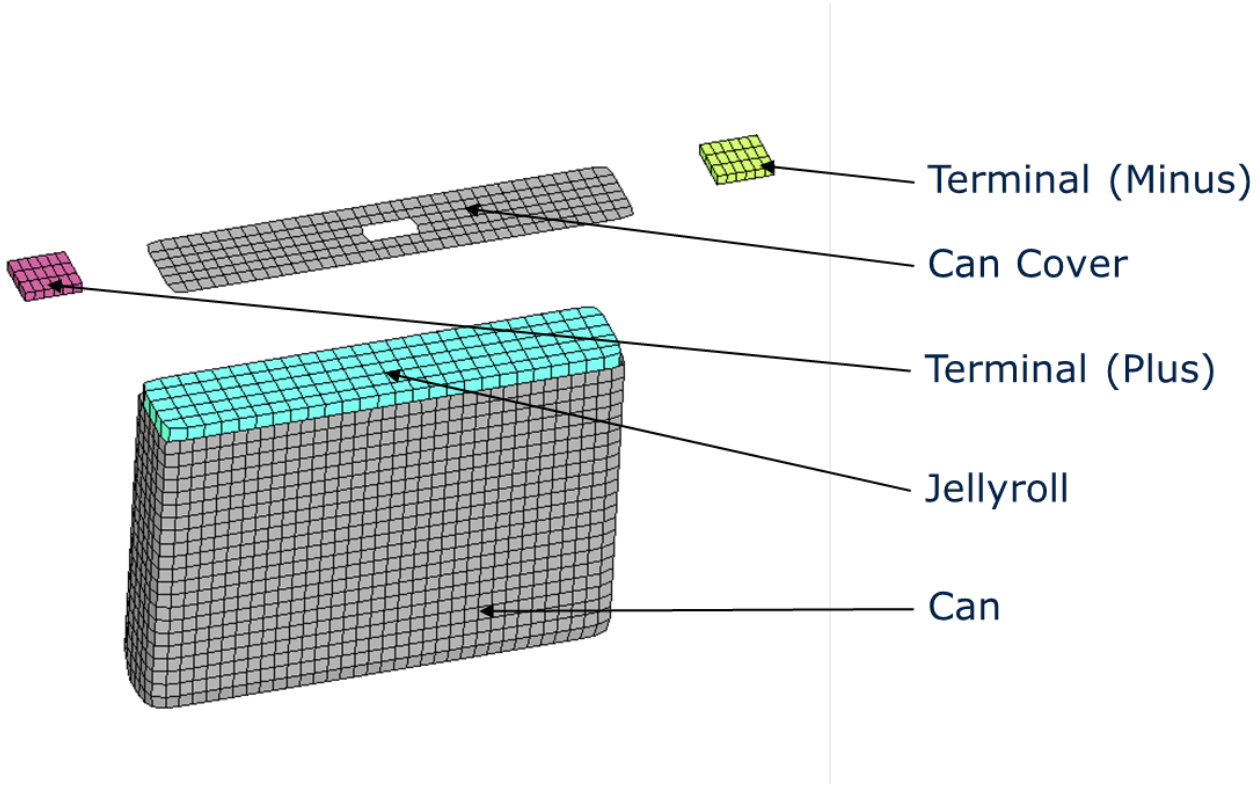


- No TR-propagation from trigger cell to neighbouring cell
- Highest temperature on non-trigger cell ~190°C
- **TR-propagation stopped by oil spray cooling system**

Mechanical Cell Modelling

Macro-mechanical cell simulation model:

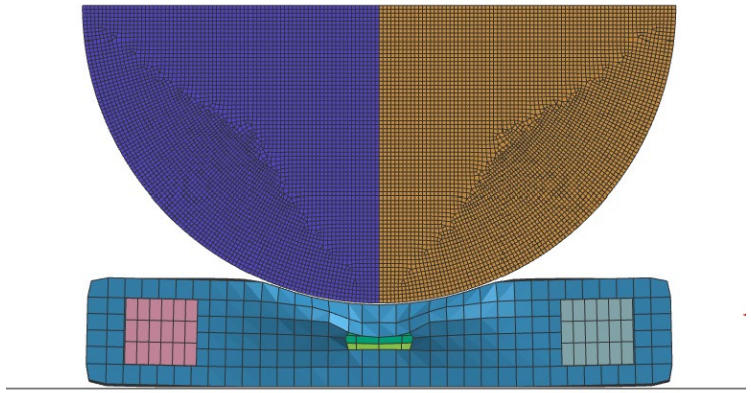
- Nodes: 4 768
- Shells: 2 080
- Solids: 2 688
- Calc. time step: 4.35E-04 ms

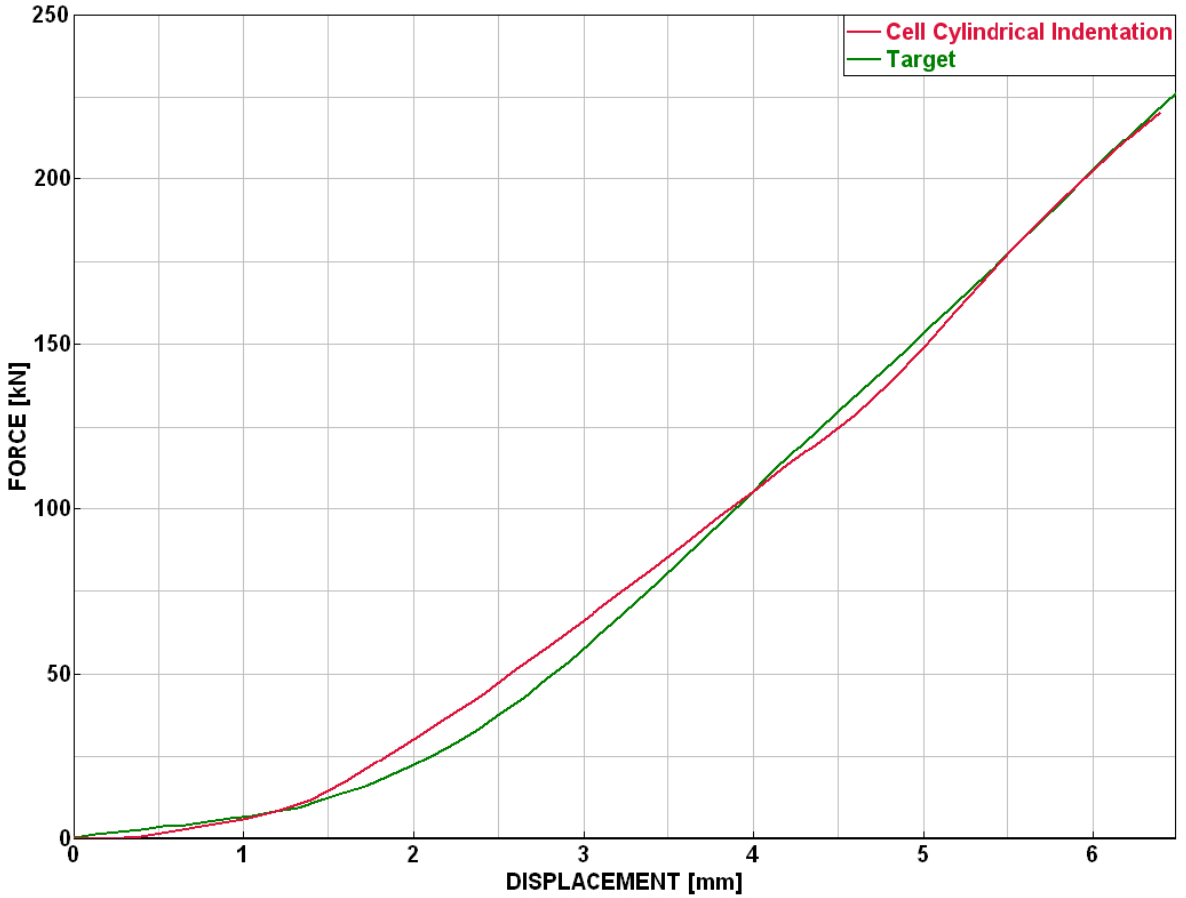


Mechanical Cell Modelling

Validation on quasi-static load cases:

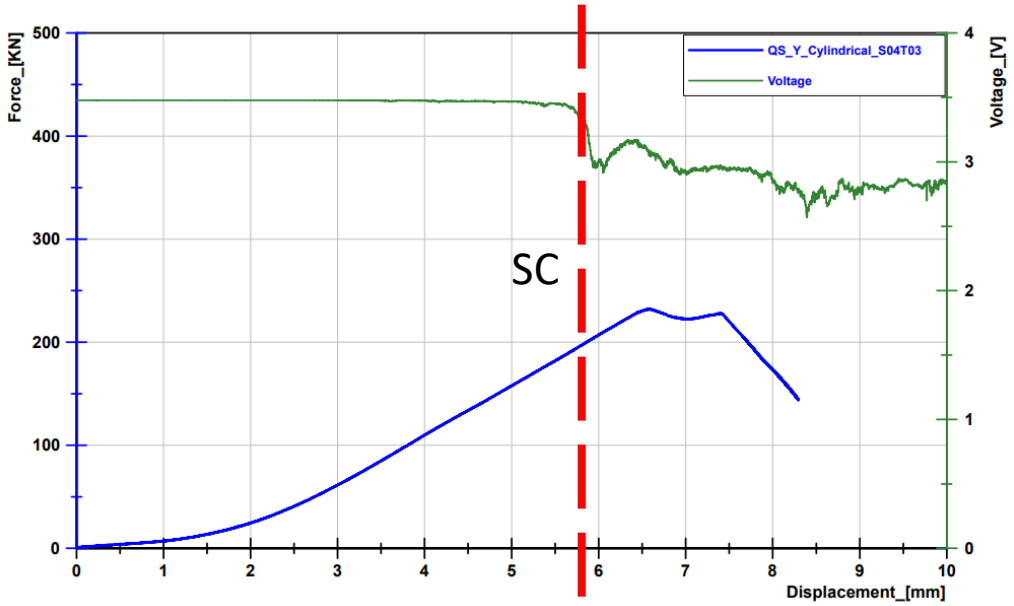
- Worst case scenario
- Less deformation energy at SC





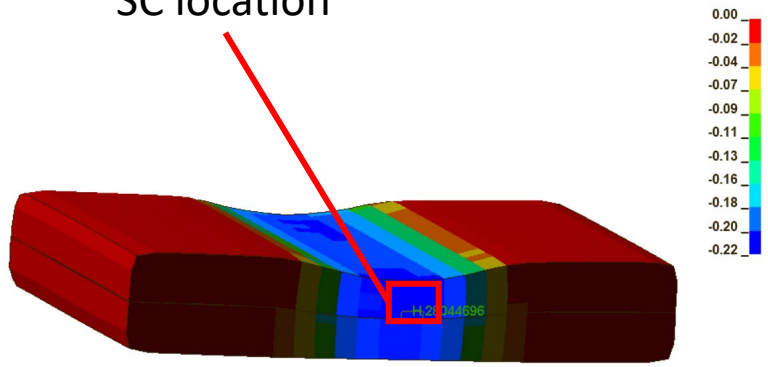
Virtual Short Circuit Detection

- Strain based short-circuit criterion



SC location

Failure strain

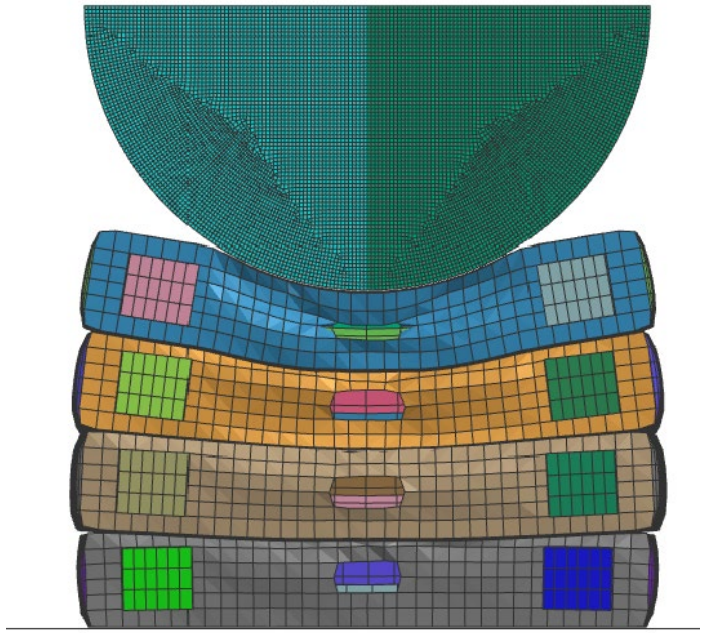


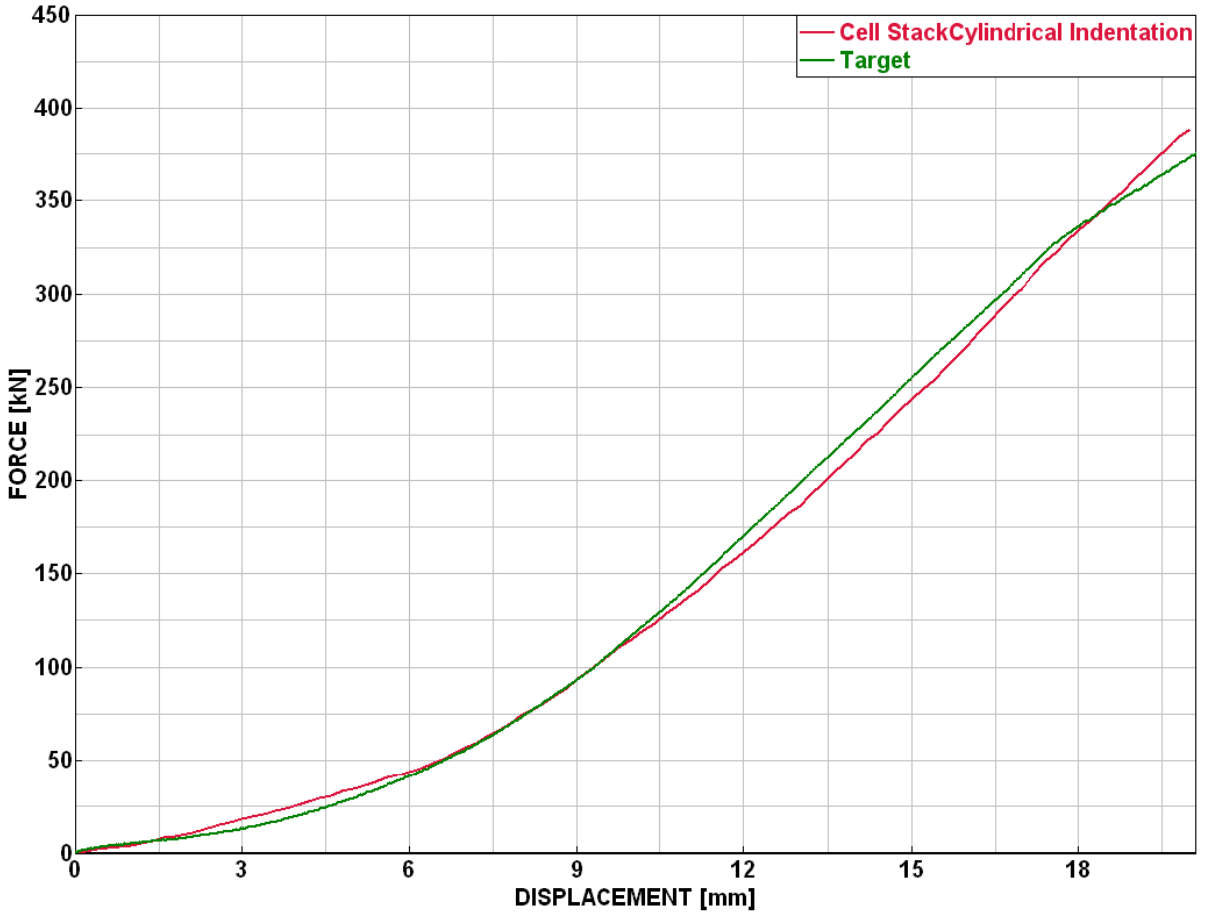

```
Time:              2023-04-05 16:26:48
-------------------------------------------------------------------------------------------------------------
Damage detected: YES


Damaged groups:
  'Jellyroll_solids'->StrainYNegative; TH:    0.22000
-------------------------------------------------------------------------------------------------------------
GROUP                  ELEMENT ID   FRAME TIME   FUNCTION                 VALUE
-------------------------------------------------------------------------------------------------------------
Maxima of states
StrainY < all >

Jellyroll_solids       28044696     6.400        StrainYNegative          0.25844
Jellyroll_solids       28043637     5.200        StrainYPositive          0.00153
-------------------------------------------------------------------------------------------------------------
First Occurrence of critical events

Jellyroll_solids       28044696     5.800        StrainYNegative          0.22242
-------------------------------------------------------------------------------------------------------------
All:

Jellyroll_solids       28044696     5.800        StrainYNegative          0.22242
Jellyroll_solids       28044696     6.000        StrainYNegative          0.23415
Jellyroll_solids       28044152     6.000        StrainYNegative          0.23139
Jellyroll_solids       28042943     6.000        StrainYNegative          0.23077
Jellyroll_solids       28044337     6.000        StrainYNegative          0.23003
Jellyroll_solids       28044322     6.000        StrainYNegative          0.22647
Jellyroll_solids       28042928     6.000        StrainYNegative          0.22580
```

Mechanical Cell Stack Modelling

Revalidation necessary:

- Cell stack reacts stiffer than single cell
- Source?

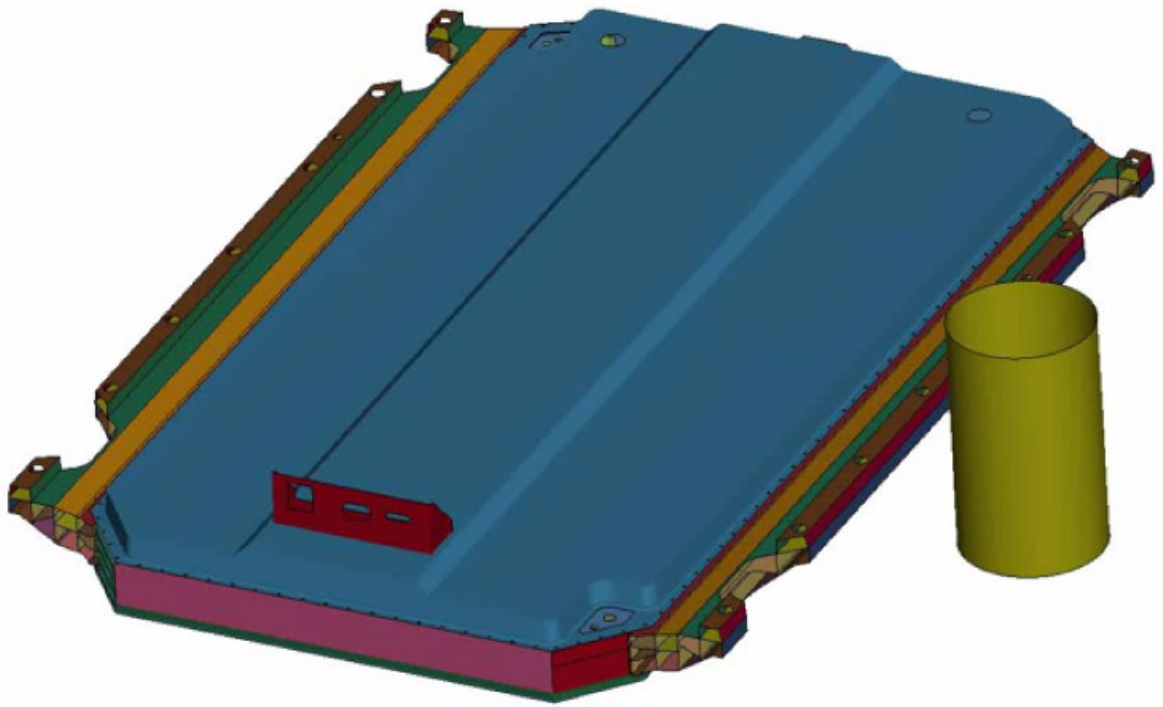




Mechanical Pack Modelling

Pack simulation model:

- Nodes: ~7 560 000
- Shells: ~1 440 000
- Solids: ~1 120 000
- Included Cells: 416
- Calc. time step: 2.01E-04 ms



Summary and Outlook

- Hybrid approach for safety assessment realized
- Pack model will be completed
- Maximum loading for pack without SC will be determined
- Advanced safety testing procedures will be suggested

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Thank You!

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