



# Thermal characterization of HV batteries

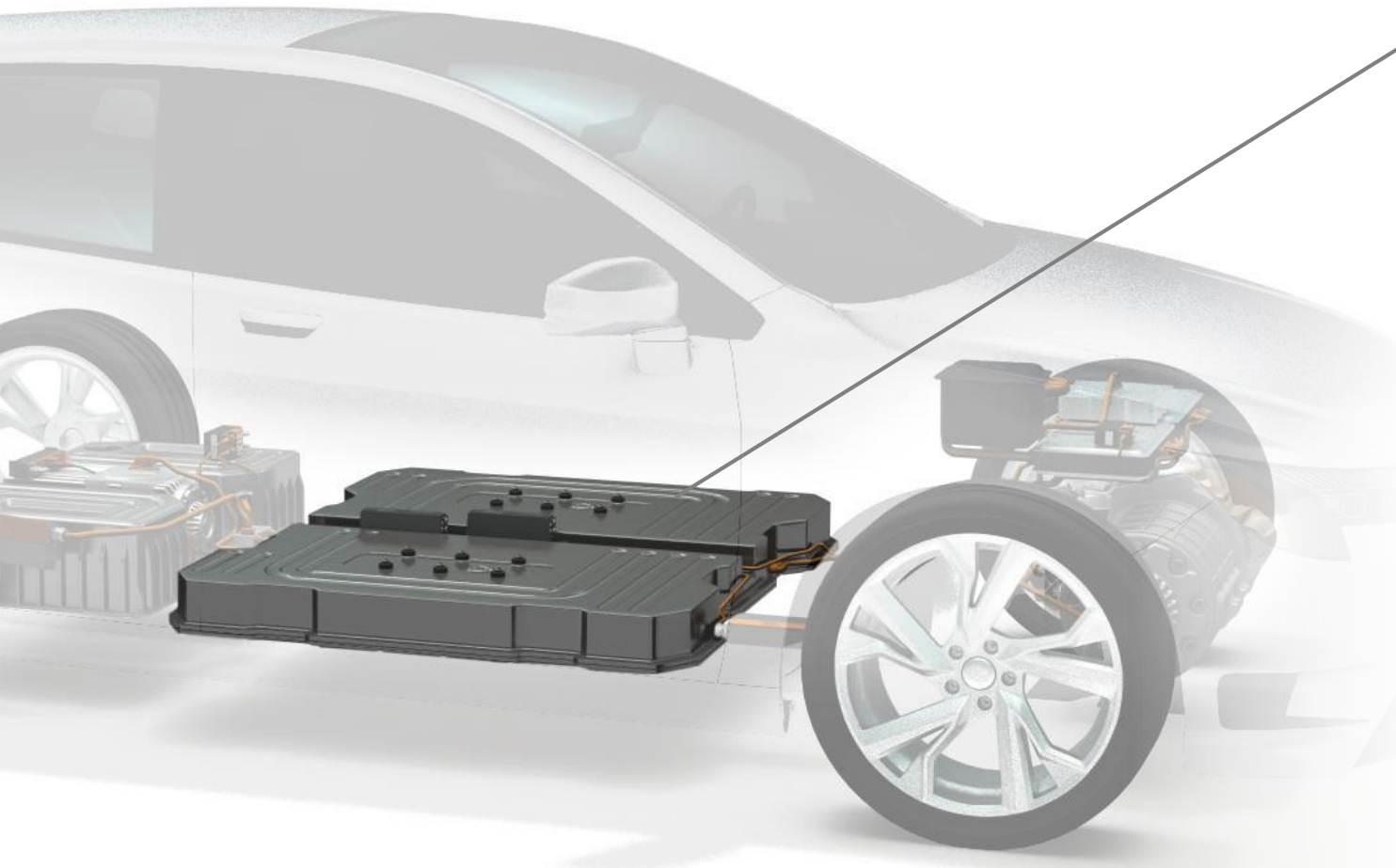
CSM Web Seminars



**CSM** **Xplained**  
measurement technology

Innovative Measurement and Data Technology

# High-voltage batteries in electric and hybrid vehicles



## HV battery

Heart of the electric powertrain:

- ▶ Energy source
- ▶ Energy storage

Negative effects:



Mechanical stress



Charging and discharging

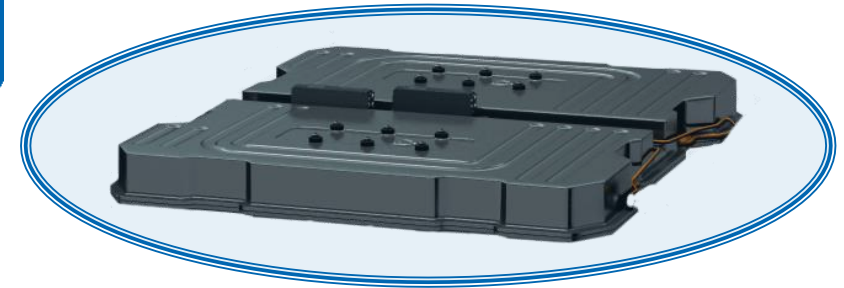


**Extreme heat or cold**

# HV battery thermal management

Crucial for

- ▶ Safety
- ▶ Performance



-25 °C

10 °C

25 °C

80 °C

Possible freezing of  
the electrolytes

High internal resistances  
lead to reduced  
power output

Optimum operating  
temperature range

Higher cell internal resistances  
lead to disintegration of the  
electrolytes

**Thermal Runaway**

# HV battery thermal management

## Series production vehicle

Temperature monitoring with a few temperature sensors

The number of sensors is too small to draw conclusions in the development phase of HV batteries.

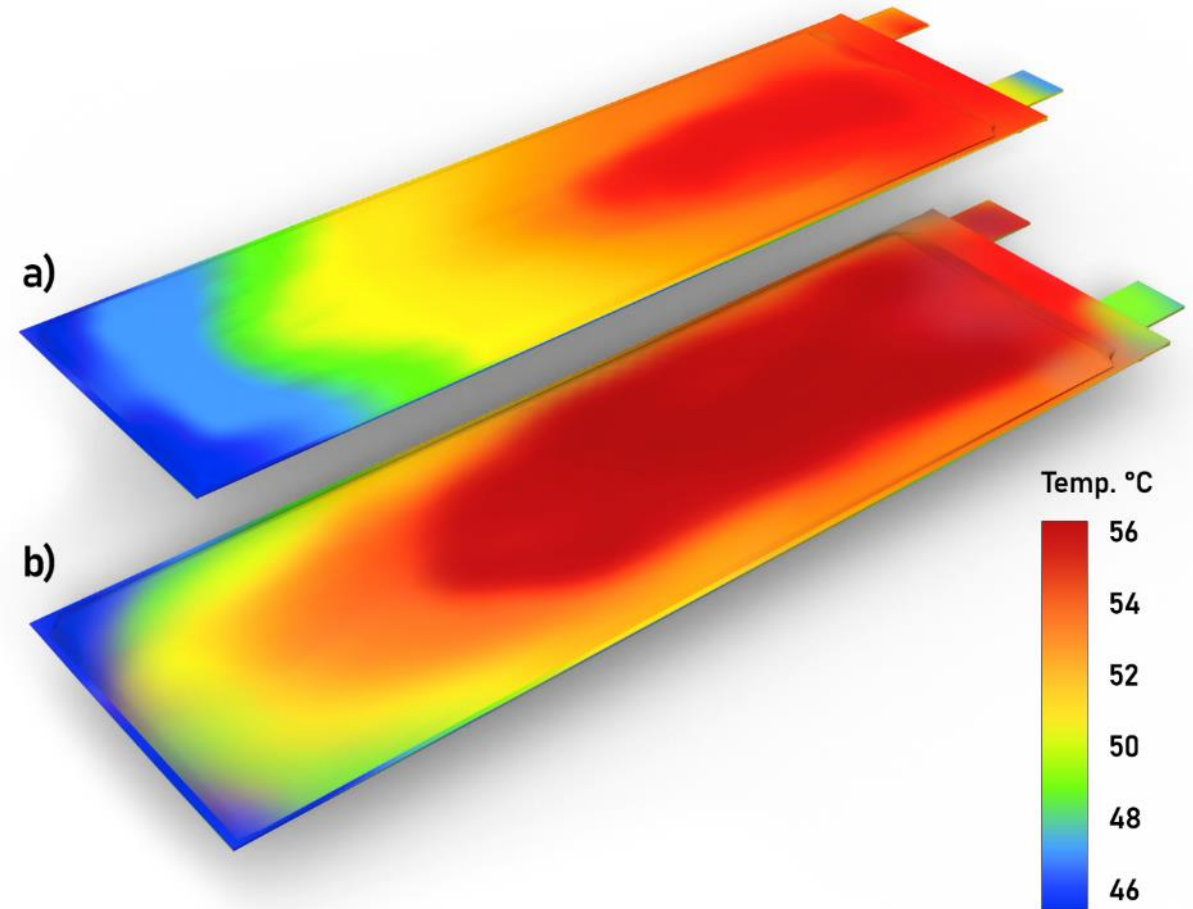
# Development of the thermal management of HV batteries

Oftentimes extensive simulations

- ▶ Verification with real data is needed
- ▶ Only measurements on test benches and in road tests allow realistic testing

## Test scenarios:

- ▶ Thermal characterization of HV batteries
  - ▶ Hot-spot investigations
  - ▶ Testing for thermal failure
- ▶ Verification of cooling systems
- ▶ Verification of temperature models



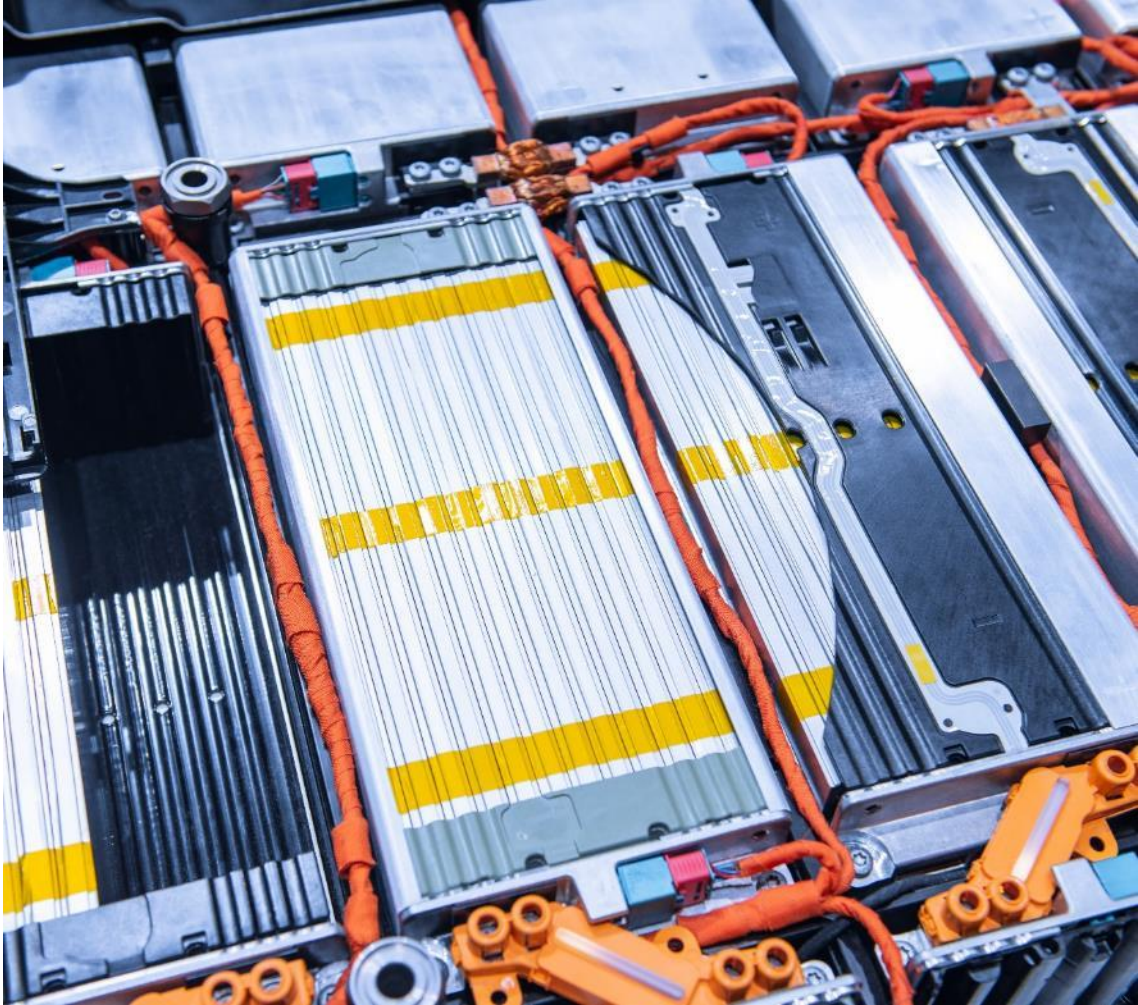
Temperature profile in a pouch cell

a) Simulated

b) Measurement result



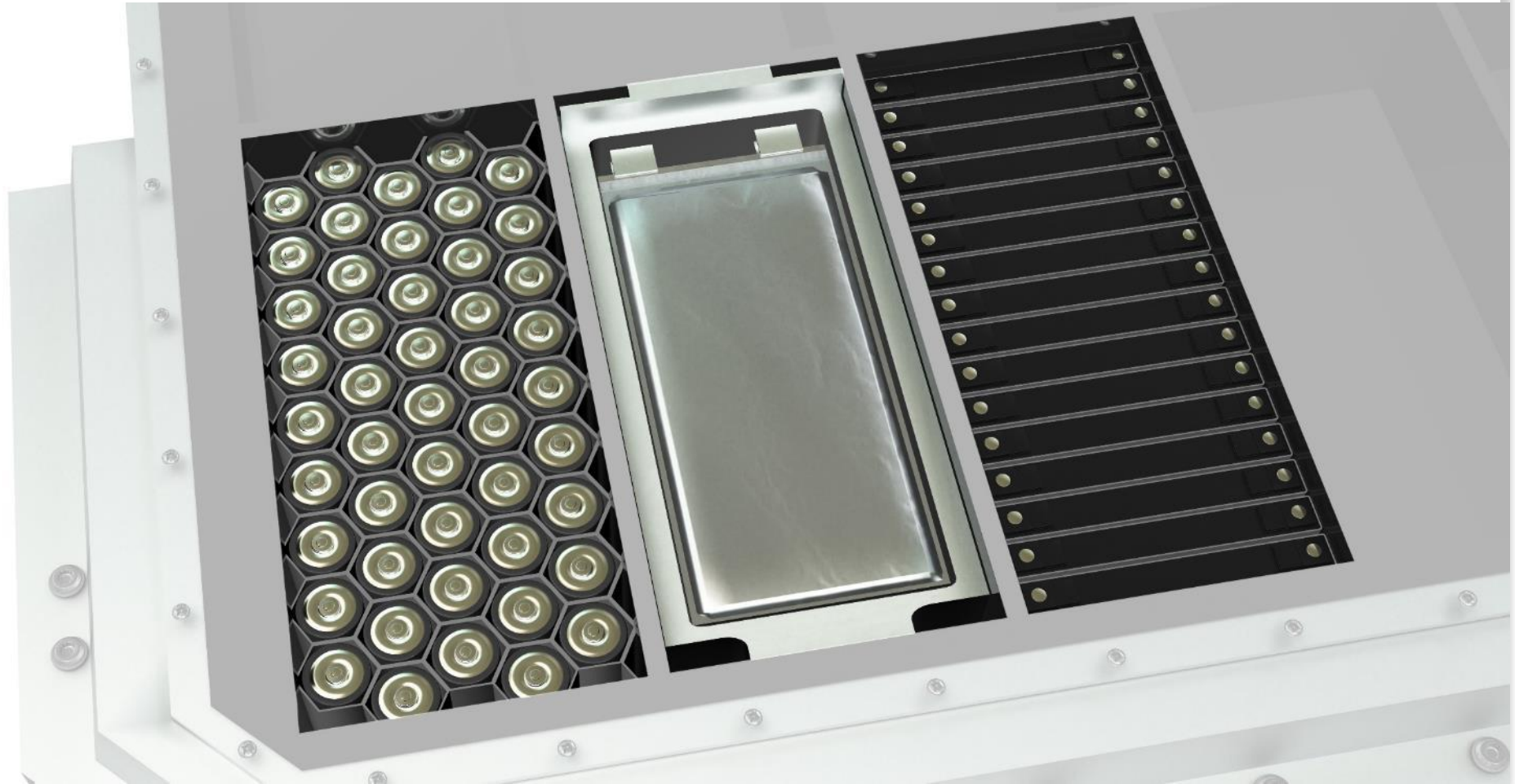
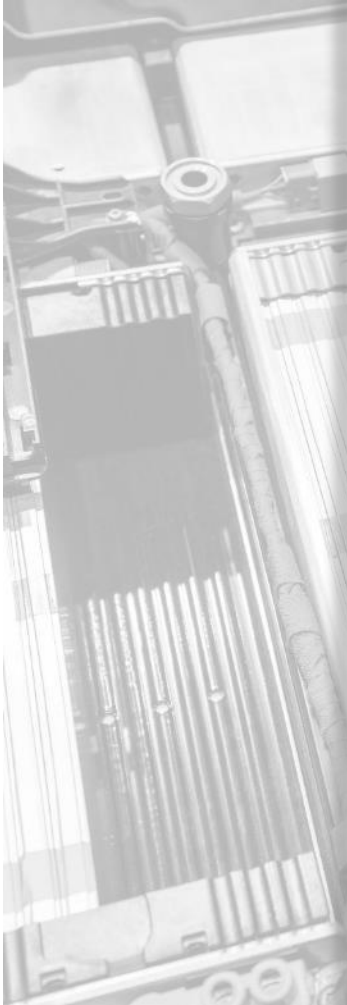
# Requirements for temperature measurements in HV batteries (part 1)



## Requirements

# Types of batteries

Different cell types must be able to be tested (round, pouch and prismatic cells)





# Requirements for temperature measurements in HV batteries (part 1)

## ► Temperature measurement at cell level

Exact and reproducible positioning of sensors between individual battery cells



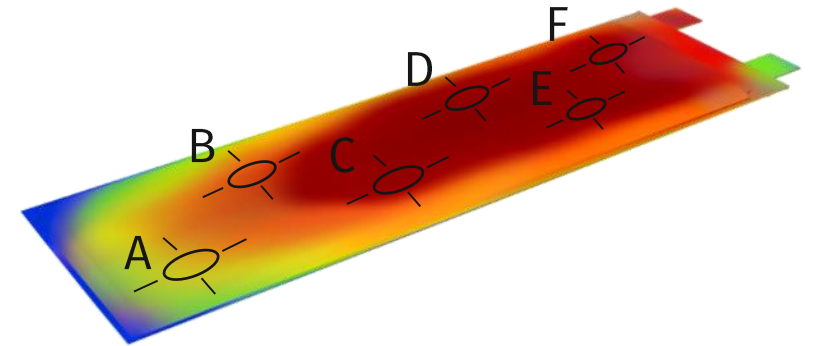


## Requirement

# Precise positioning of the sensors between battery cells

Transfer of data of relevant measuring points from simulations

- ▶ Only exact positioning allows verification of simulation models
- ▶ Positioning must be reproducible on all cells to allow comparative analysis of temperature profiles



# Requirements for temperature measurements in HV batteries (part 1)

► Temperature measurement at cell level

► **Temperature measurement at module level**

Cable routing and measurement technology for several hundred measuring points in a confined space

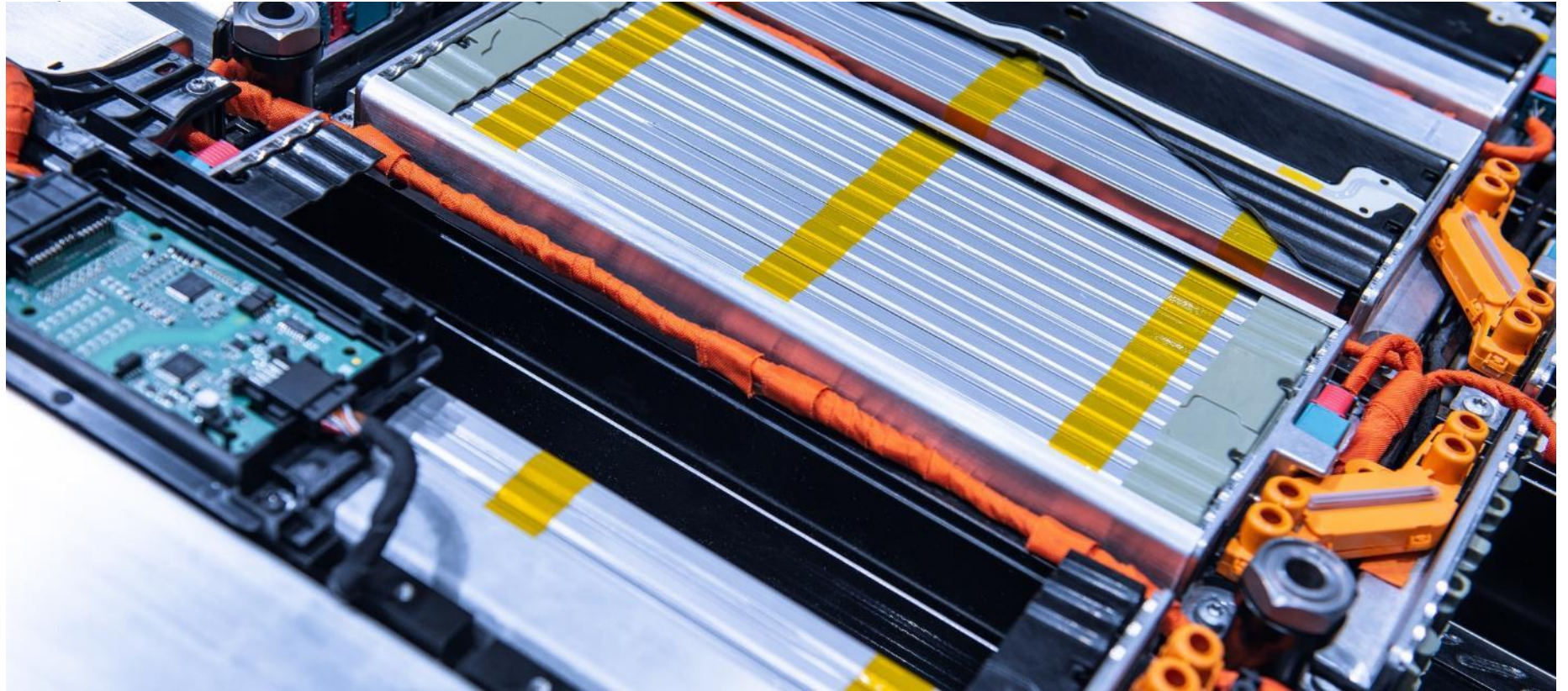




# Limitations due to the design of HV batteries

Maximum battery cells with minimum size and optimized weight

- ▶ Minimal space for sensors, sensor cables and measurement technology within the HV





# Requirements for temperature measurements in HV batteries (part 1)



- ▶ Temperature measurement at cell level
- ▶ Temperature measurement at module level
- ▶ **Temperature measurement at battery level**
  - Busbars
  - Charging electronics
  - BMS

## Requirements for temperature measurements in HV batteries (part 1)



- ▶ Temperature measurement at cell level
- ▶ Temperature measurement at module level
- ▶ Temperature measurement at battery level

**Up to  
50 to 500 temperature measurement  
points at different positions  
inside the HV battery!**

# HV-safe temperature measurement with conventional technology

- ▶ Thermocouples

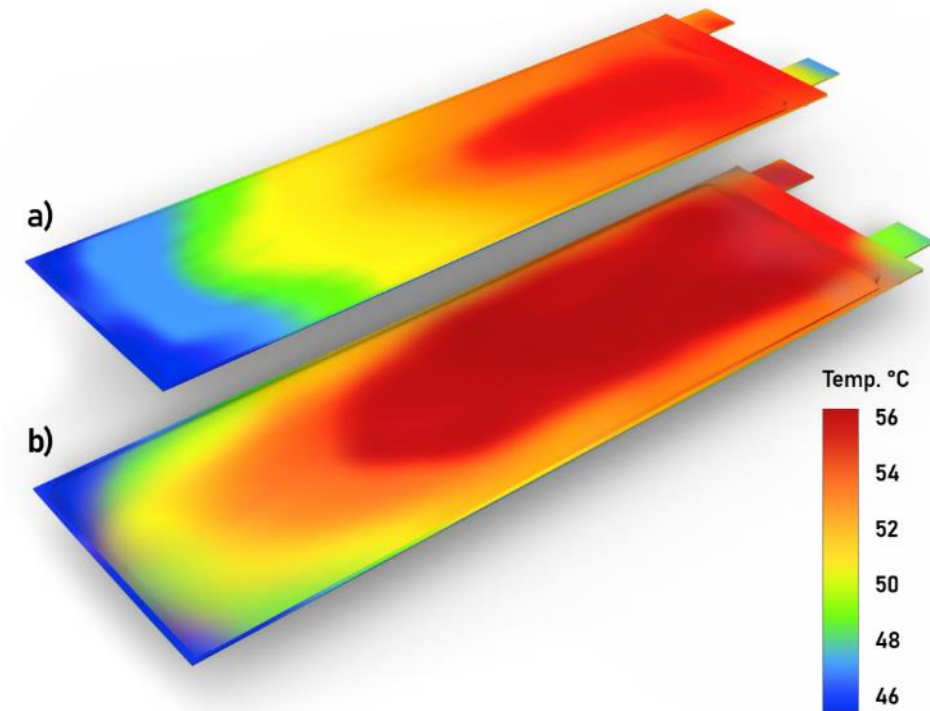




# HV-safe temperature measurement with conventional technology

## ► Thermocouples

- **Measurement accuracy oftentimes insufficient**
- Accuracy: approx.  $\pm 1.5$  K  
or 0.4 % of measured value (class 1)



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## ► PT100 / PT1000 RTD sensors



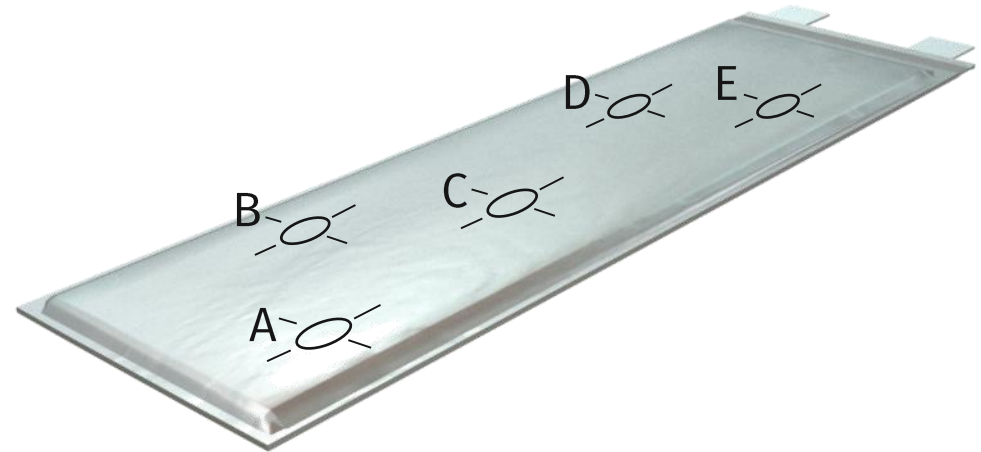
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- **Difficult to position precisely**





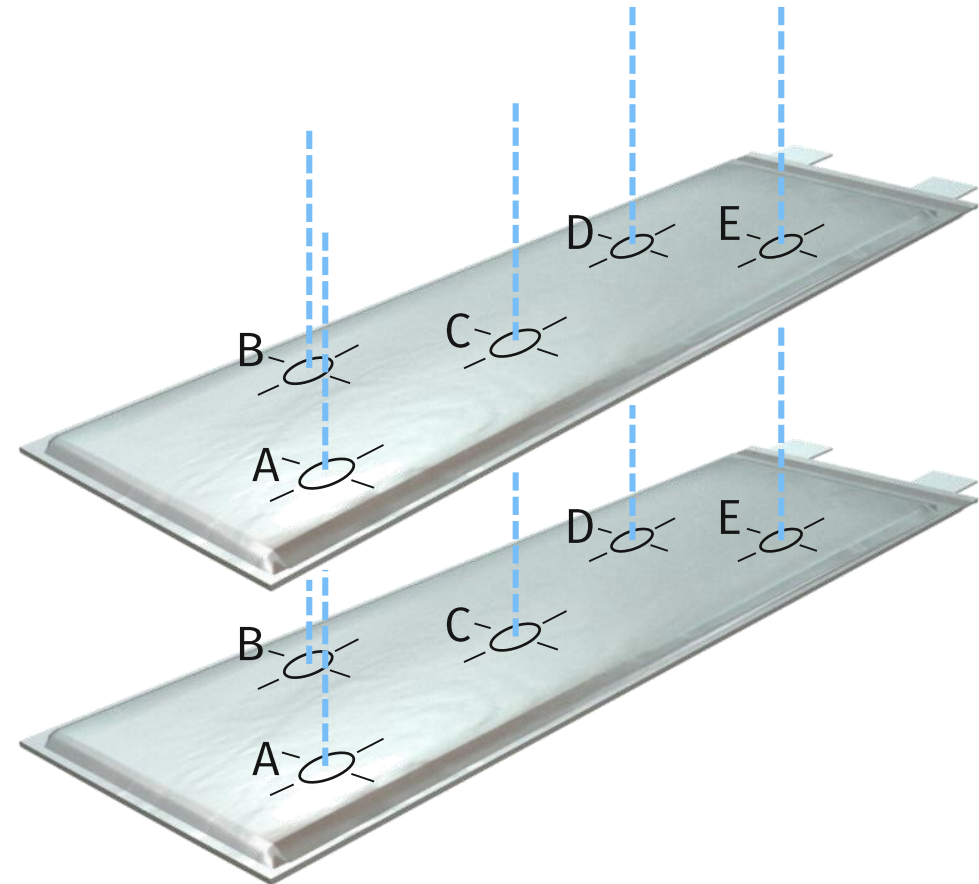
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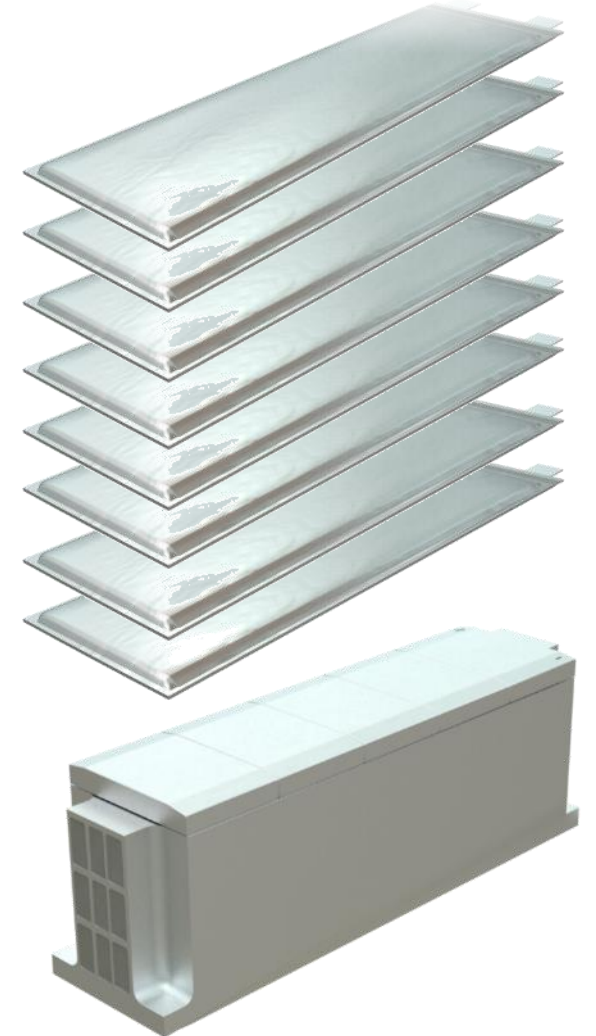
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- **High cabling effort with 4-wire technology**



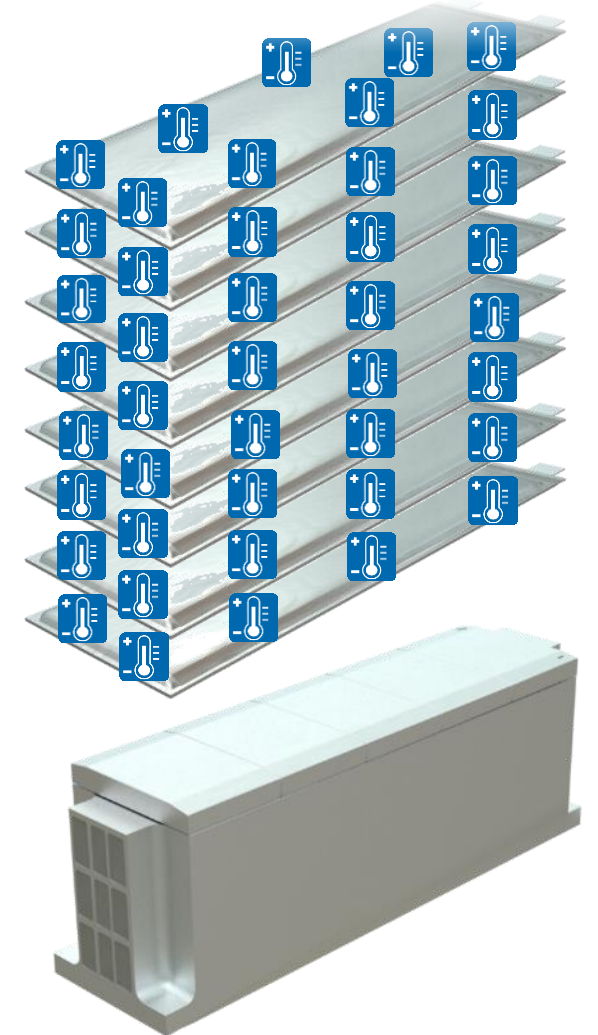
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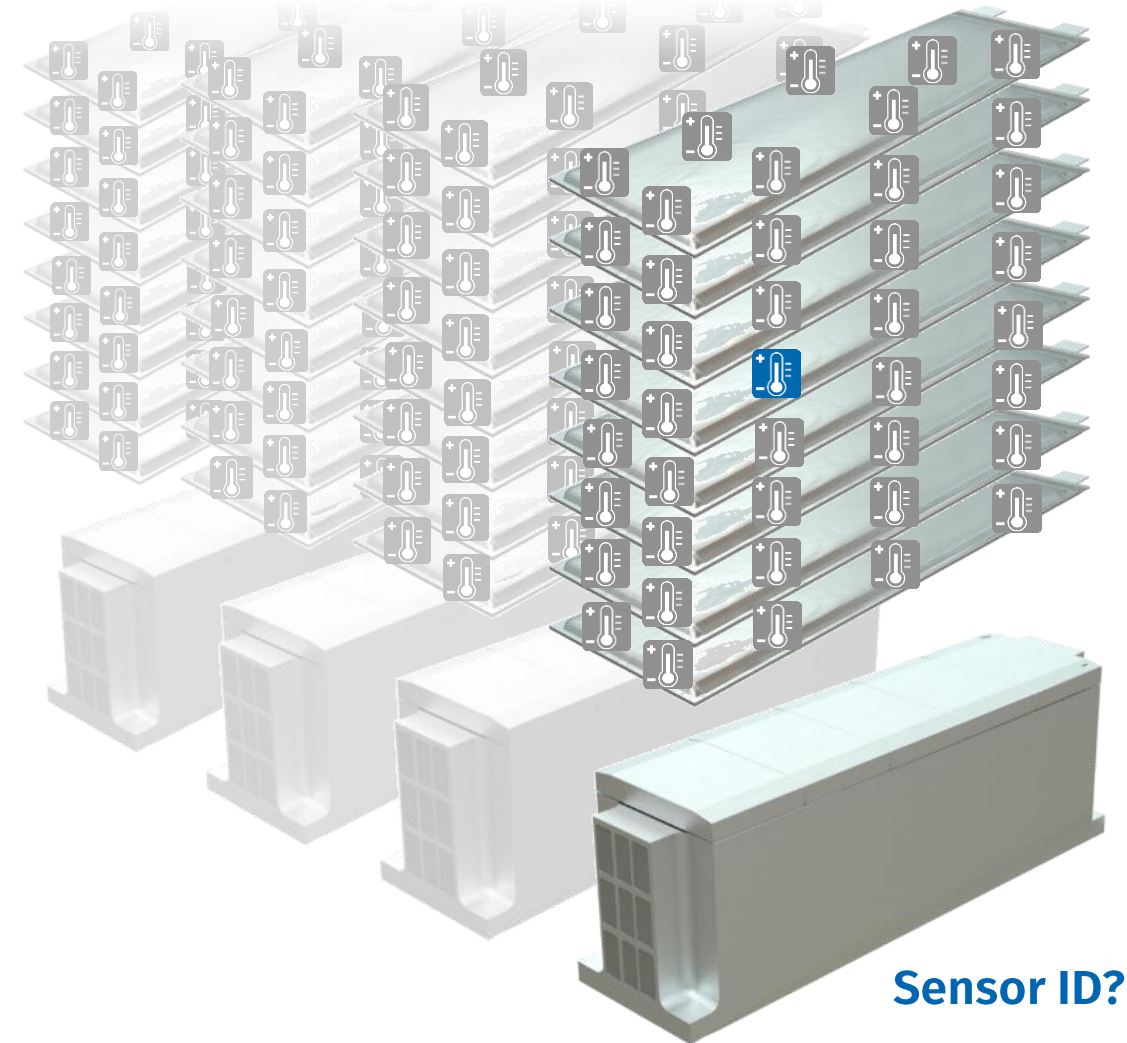
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- **Identification of measurement points difficult**



Sensor ID?

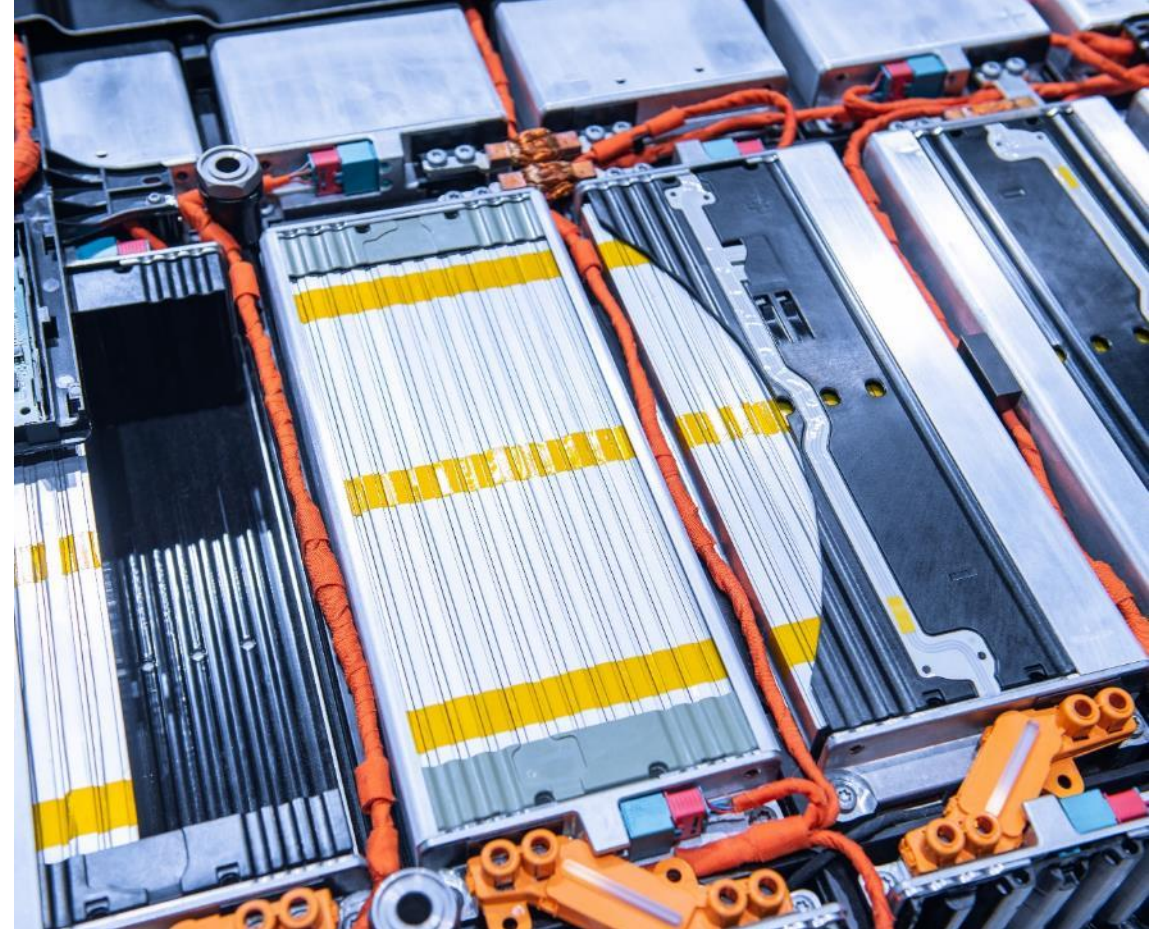
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- **Cable density in confined spaces**





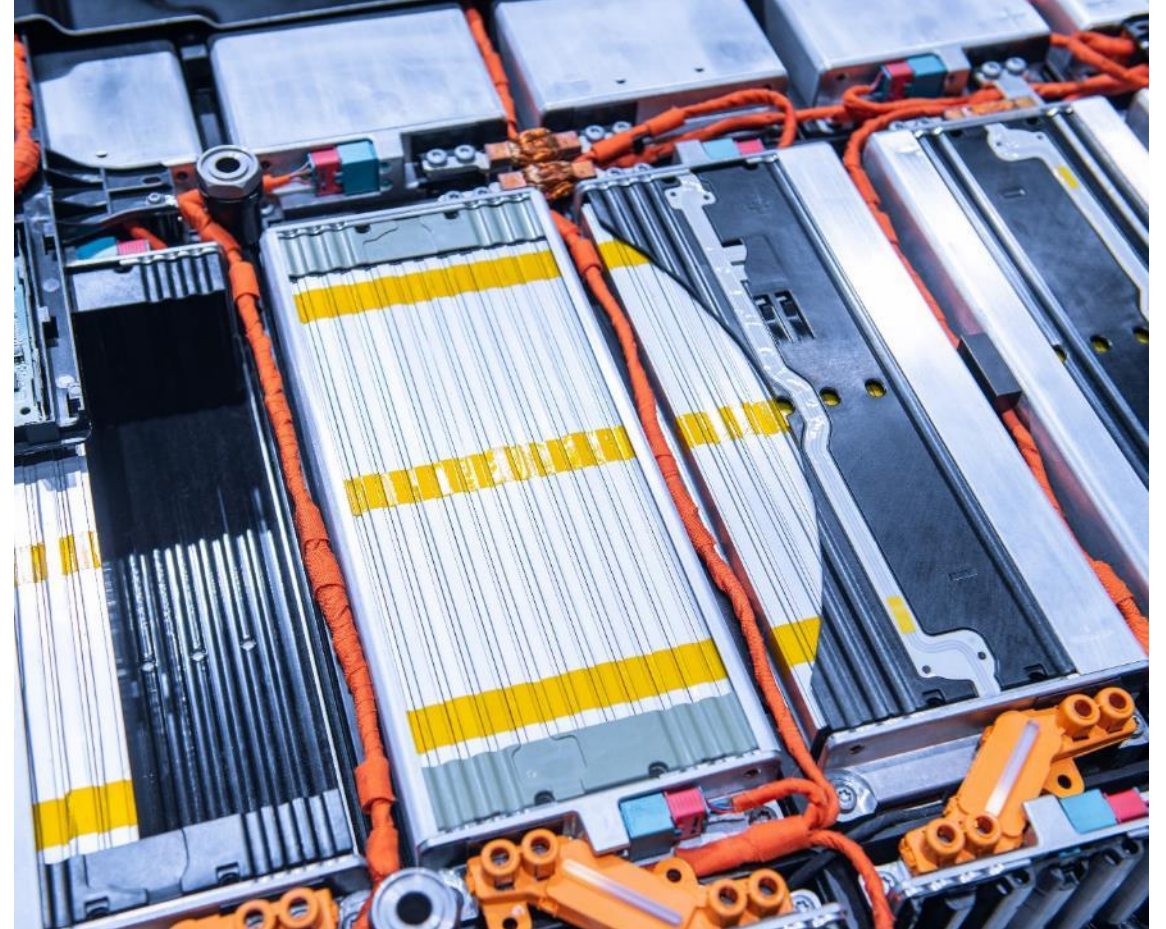
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- **Breakthroughs in battery housing**





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- Difficult to position precisely
- High cabling effort with 4-wire technology
- Identification of measurement points difficult
- Cable density in confined spaces
- Susceptibility of sensor cables to interference
- Breakthroughs in battery housing
- **Large number of required measurement modules (space and weight)**



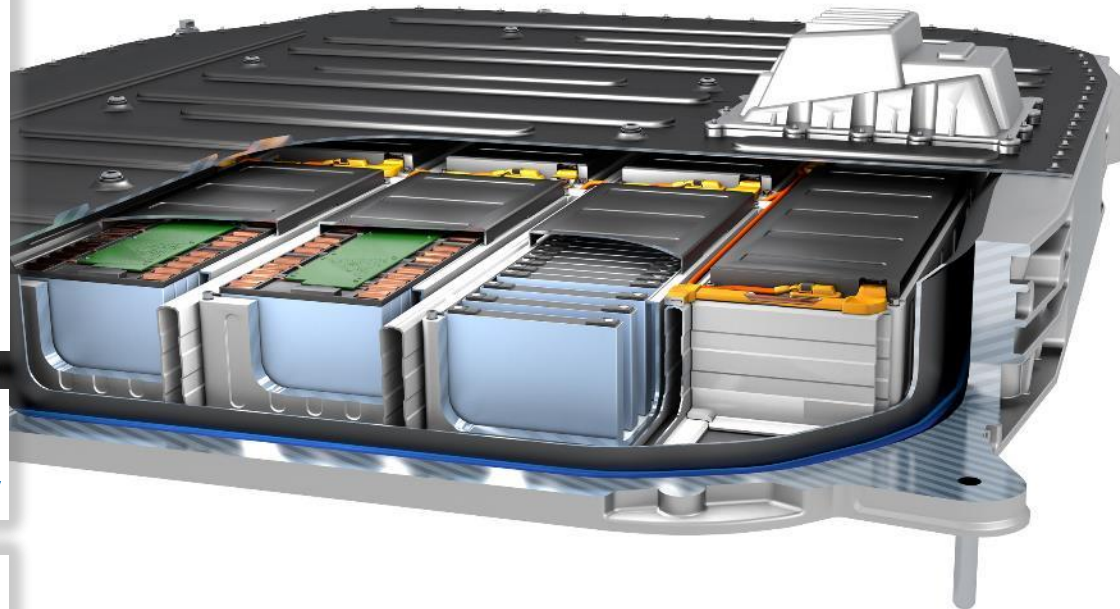
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## ! Temperature measurement

- ▶ Measurement on different cell types
- ▶ Cell level
  - Exact and reproducible positioning
  - Measurement between individual battery cells
- ▶ Module level
- ▶ Battery level

## ! Very high Measurement accuracy

## ! Interference immunity



## ! Simple application

## ! Identification of measurement points

## ! Minimal space required

- ▶ Inside the battery
- ▶ Outside the battery

## ! Low impact on the of the battery housing

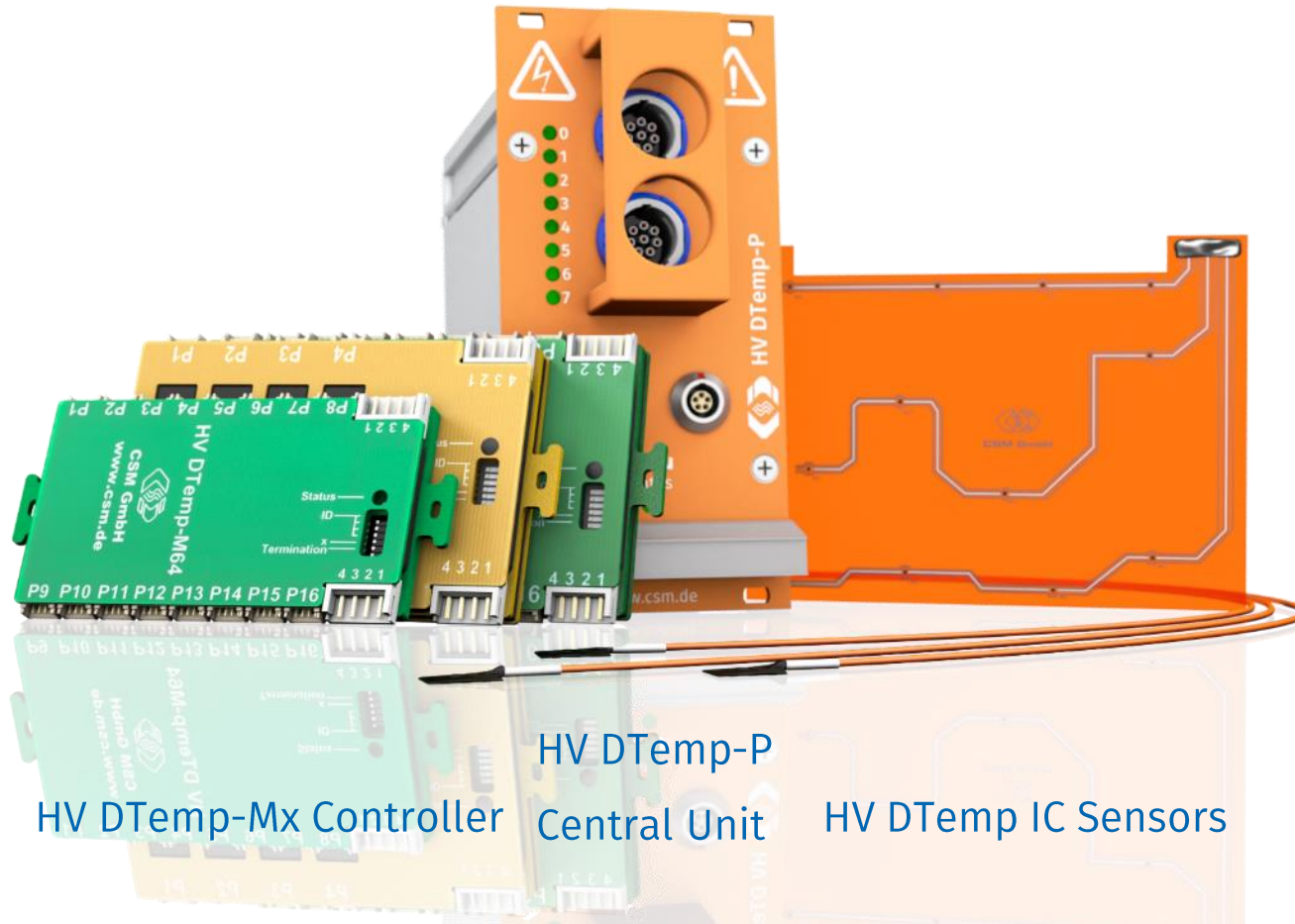
# HV DTemp measurement system

 **Very high  
Measurement accuracy**

HV DTemp  
Measurement System on  
[www.csm.de](http://www.csm.de)



- Digital temperature measurement system
- Up to 512 sensors per measurement system
- Measurement accuracy (total system):
  - $\pm 0.1 \text{ K}$  to  $\pm 0.25 \text{ K}$

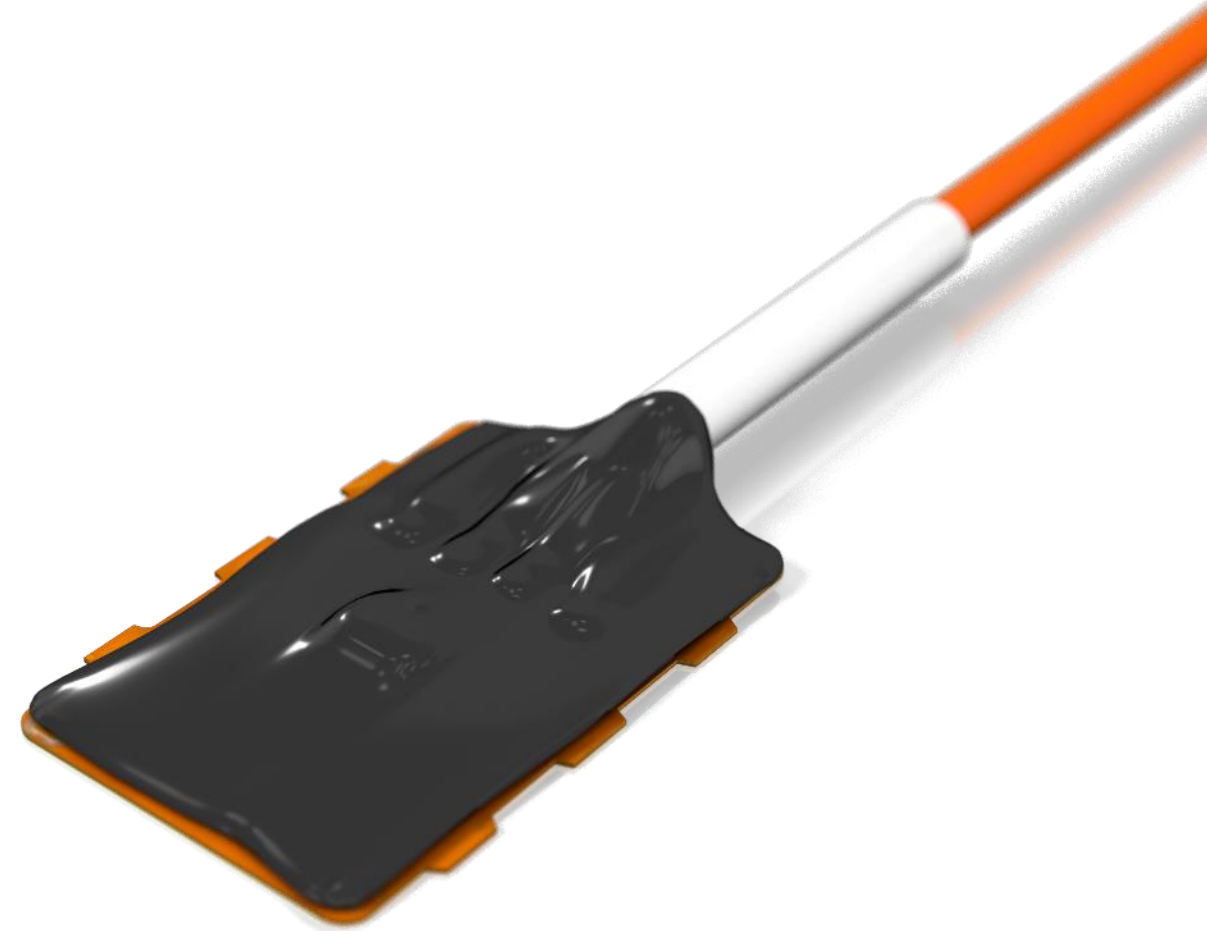


HV DTemp-Mx Controller    HV DTemp-P Central Unit    HV DTemp IC Sensors

# HV DTemp IC-Sensors

## Integrated Circuit (IC) Temperature Sensors

- ▶ Soldered onto an ultra-thin flexible circuit
- ▶ Measure temperatures on their bottom surface
  - Measurement range: -40°C to +125 °C



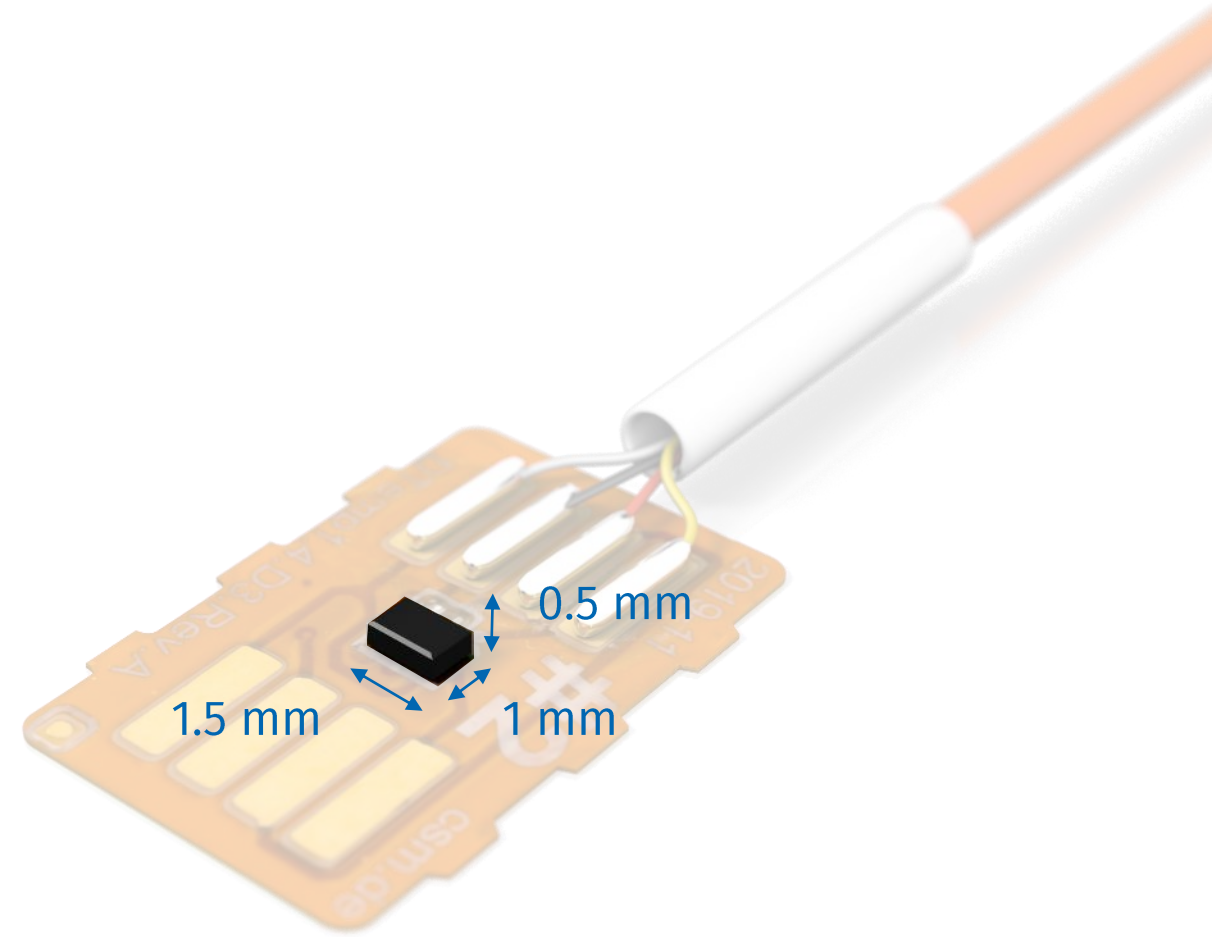
Single sensor



# HV DTemp IC-Sensors

## Integrated Circuit (IC) Temperature Sensors

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- ▶ Sensor dimension (W × H × D)
  - ▶ approx. 1.5 mm × 0.5 mm × 1 mm

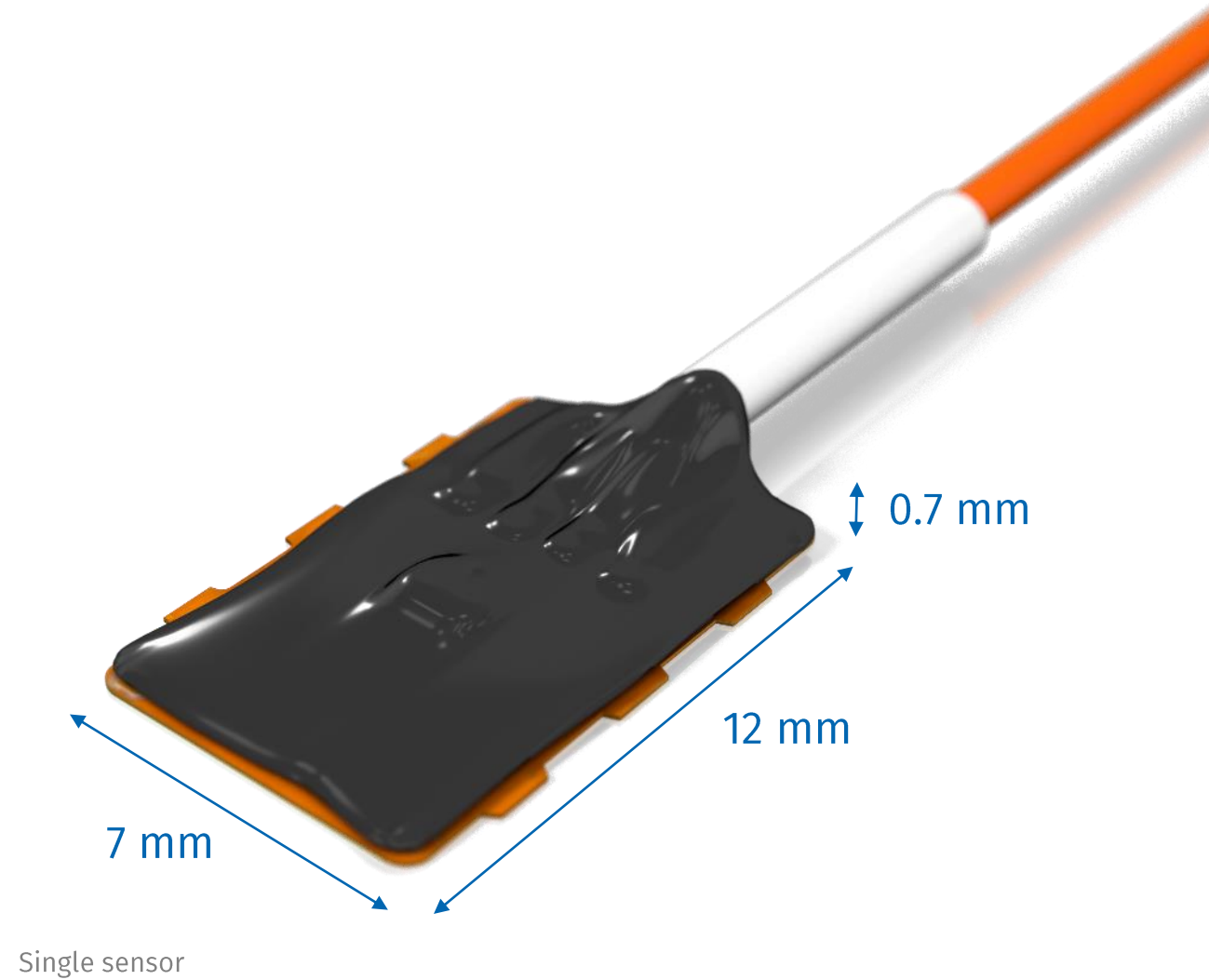


Single sensor (for better view without encapsulation)

# HV DTemp IC-Sensors

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  - Measurement range: -40°C to +125 °C
- ▶ Sensor dimension (W × H × D)
  - approx. 1.5 mm × 0.5 mm × 1 mm
- ▶ Flexible circuit dimension (W × H × D)
  - approx. 7 mm × 0.7 mm × 12 mm



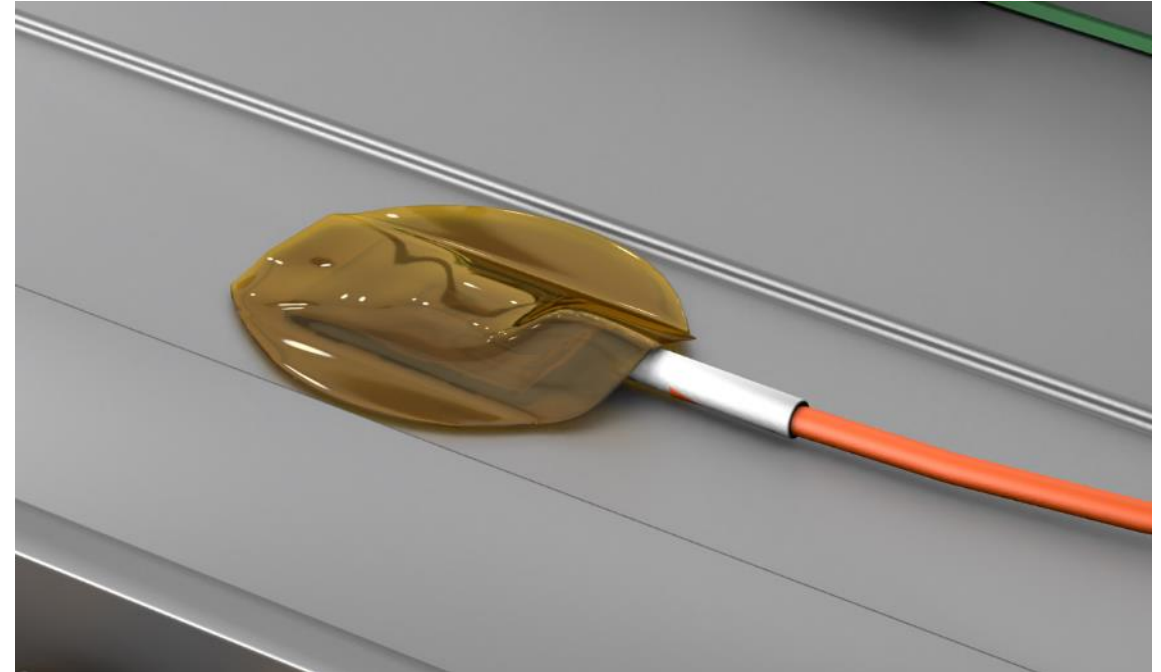
# HV DTemp IC-Sensors

## Integrated Circuit (IC) Temperature Sensors

- ▶ Digital data transmission
  - ▶ Extremely good interference immunity
- ▶ Measurement accuracy:  $\pm 0.1$  K to  $\pm 0.2$  K
- ▶ Contact safety: 1,000 V
- ▶ Can be pressed in between battery cells
- ▶ Clear identification and assignment



Interference immunity

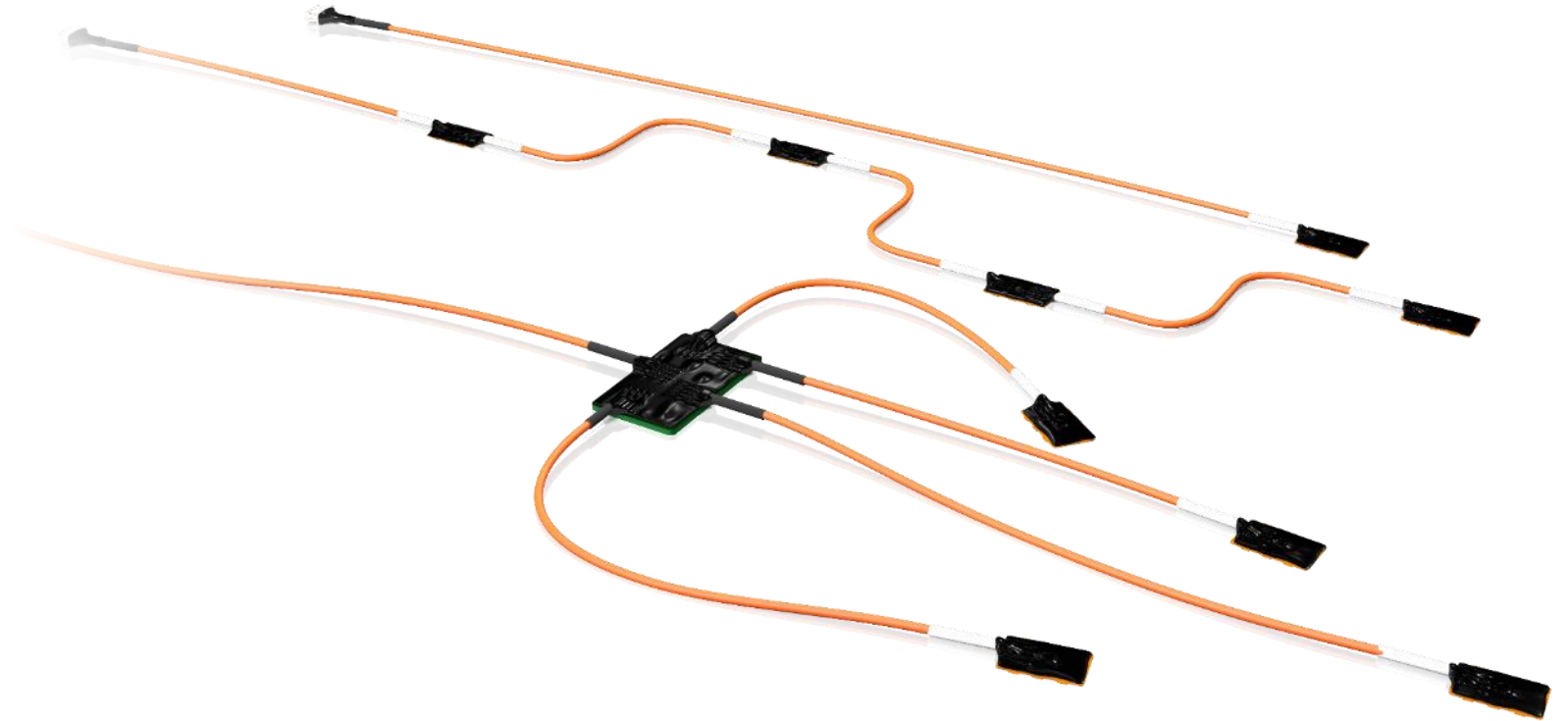


Single sensor on battery module (encapsulated and with Kapton foil)

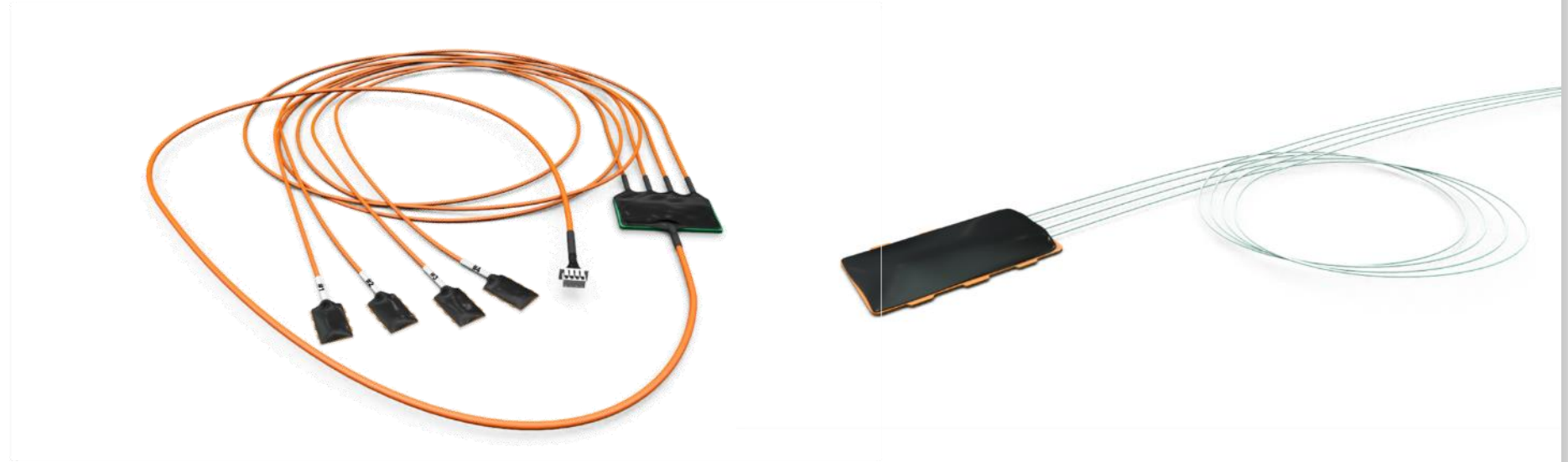


# HV DTemp IC Sensors: Sensor Assemblies

Sensors connected via cables



## Cable variants



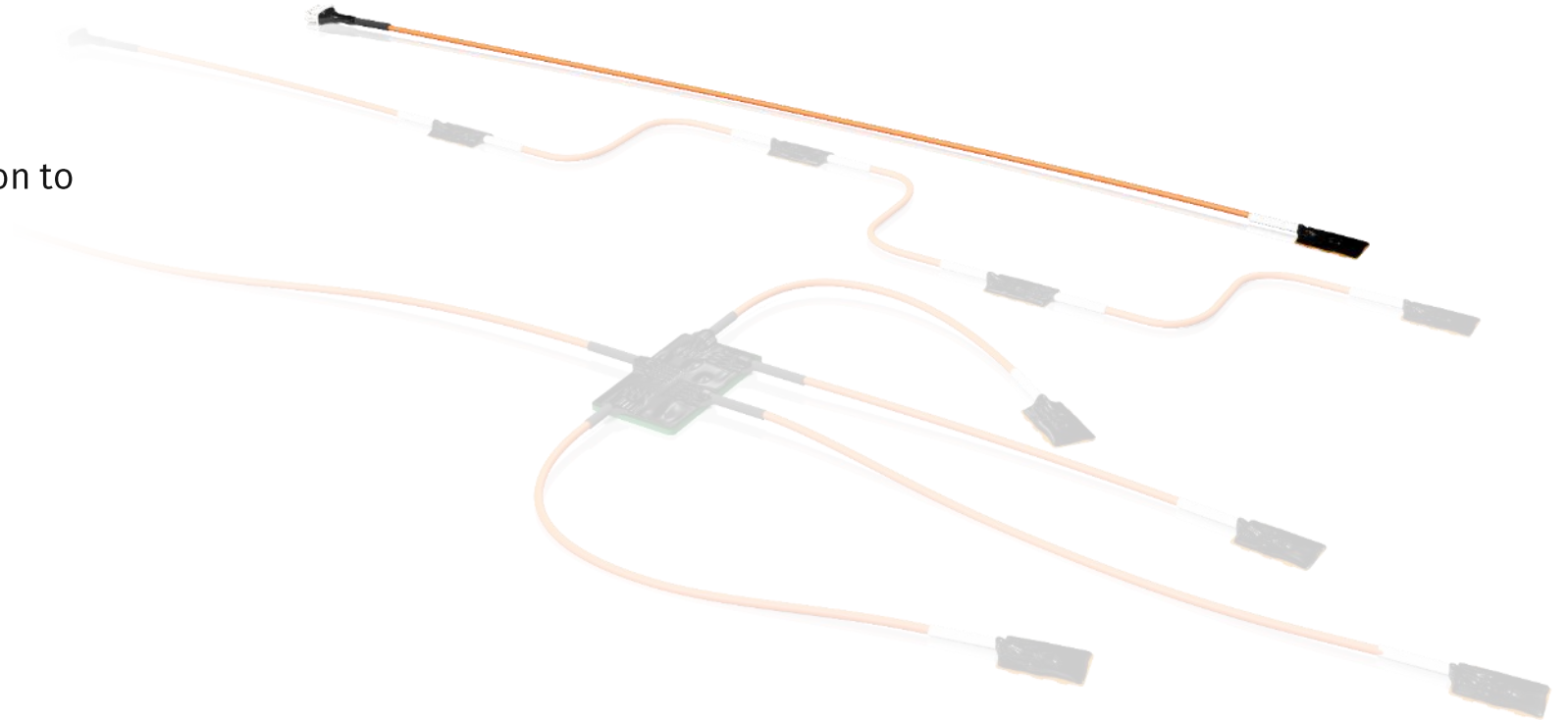
	robust	thin
<b>Contact safety</b>	Up to 1,000 V (-20 to +130 °C)	Up to 1,000 V (-20 to +130 °C)
<b>Cable diameter</b>	L1: 2.8 ±0.3 mm L2: 1.6 ±0.3 mm	L1: 2.8 ±0.3 mm L2: 0.42 ±0.05 mm
<b>Sensor thickness</b> incl. cable connection (potted)	approx. 2 mm	approx. 0,7 mm

# HV DTemp IC Sensors: Sensor Assemblies

Sensors connected via cables

- ▶ **Single sensor**

- ▶ Connecting cable for direct connection to HV DTemp-Mx controller





# HV DTemp IC Sensors: Sensor Assemblies

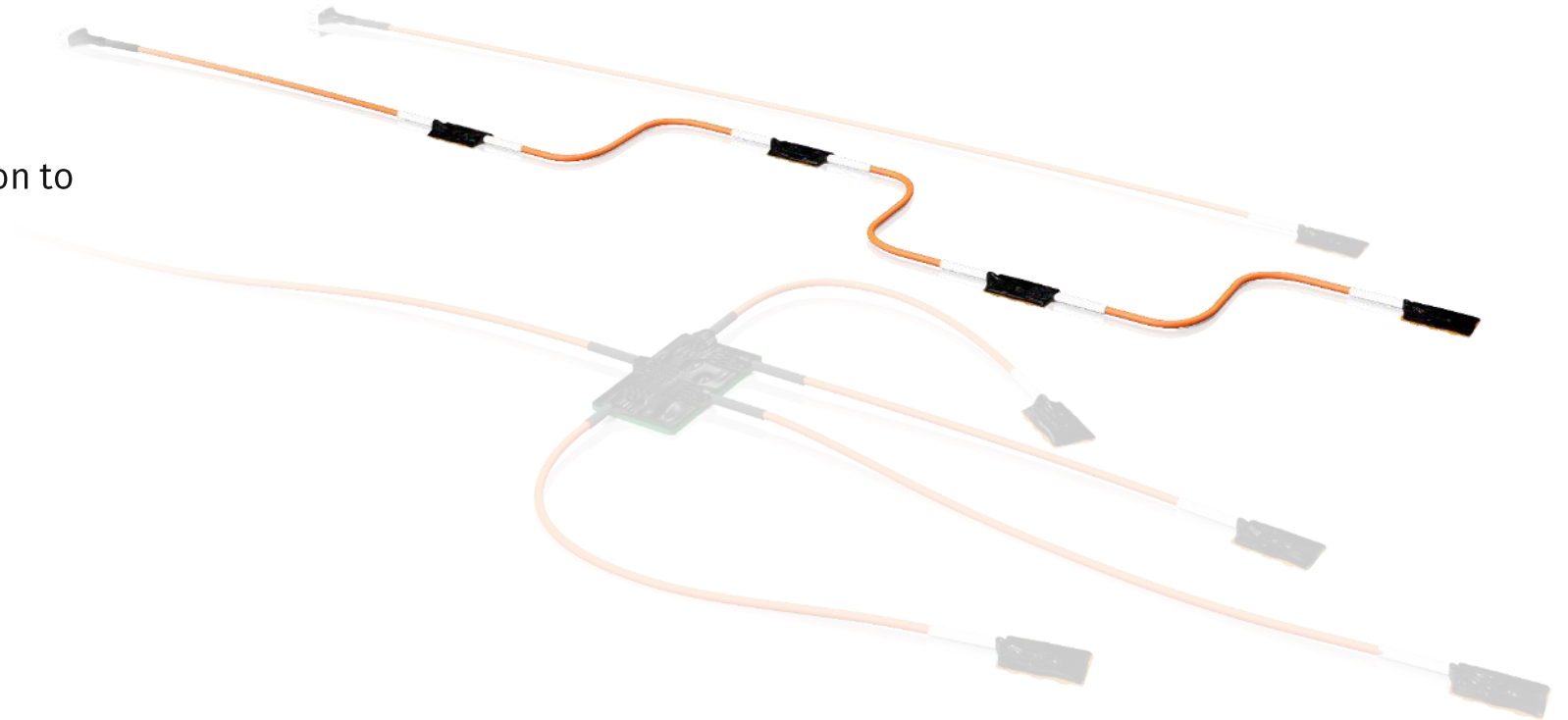
Sensors connected via cables

- ▶ **Single sensor**

- ▶ Connecting cable for direct connection to HV DTemp-Mx controller

- ▶ **Sensor assemblies**

- ▶ Up to 4 single sensors
    - ▶ **Daisy chained**



# HV DTemp IC Sensors: Sensor Assemblies

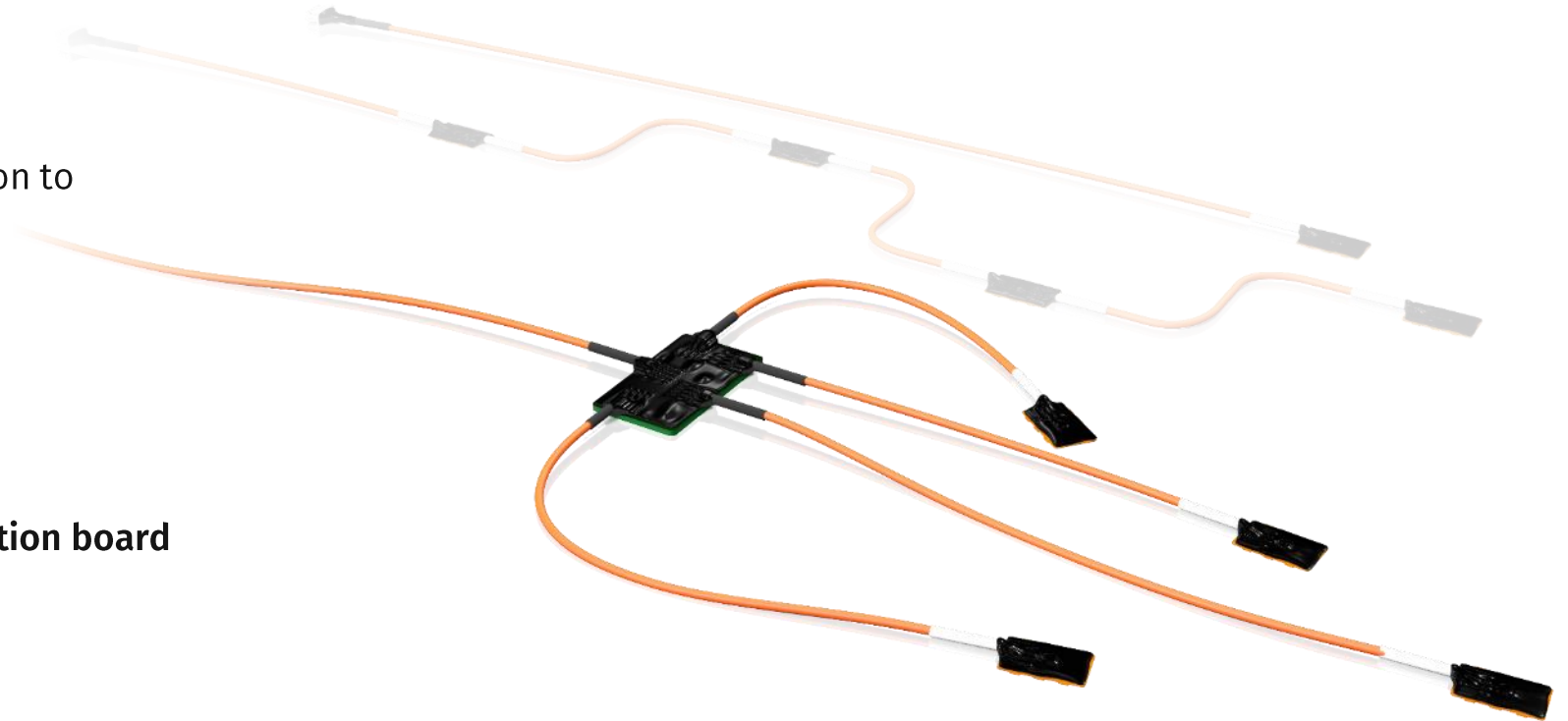
Sensors connected via cables

- ▶ **Single sensor**

- ▶ Connecting cable for direct connection to HV DTemp-Mx controller

- ▶ **Sensor assemblies**

- ▶ Up to 4 single sensors
  - ▶ Daisy chained
  - ▶ **Or connected via a small distribution board**

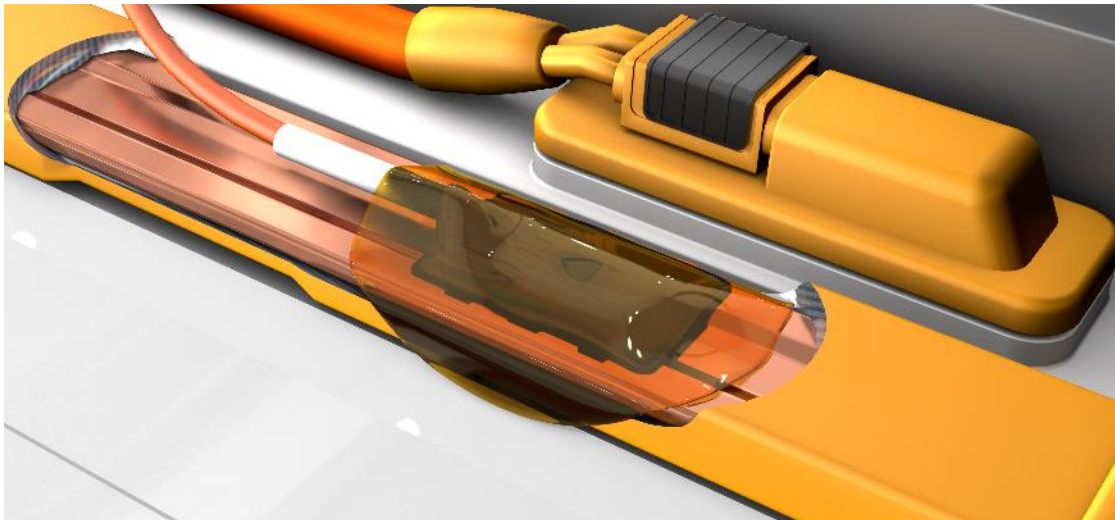


# HV DTemp IC Sensors: Sensor Assemblies

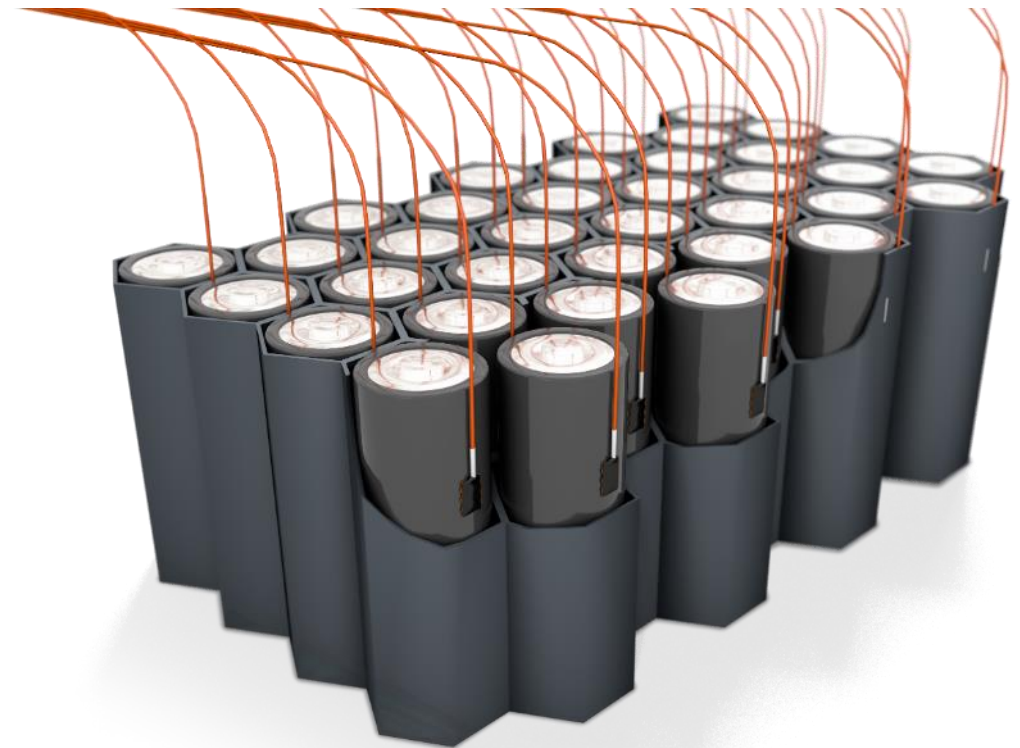
Sensors connected via cables

## Flexible measurements at different locations in the HV battery

- ▶ Between battery cells
- ▶ On busbars, BMS and many more



Single sensor on busbar



Sensor assemblies between round cells

# HV DTemp IC Sensors: Ultra-thin Flexible Circuit

Flexible arrangement on larger ultra-thin flexible circuit

Up to 20 IC sensors connected via trace



IC-Sensors on flexprint carrier film, shaped as stripe



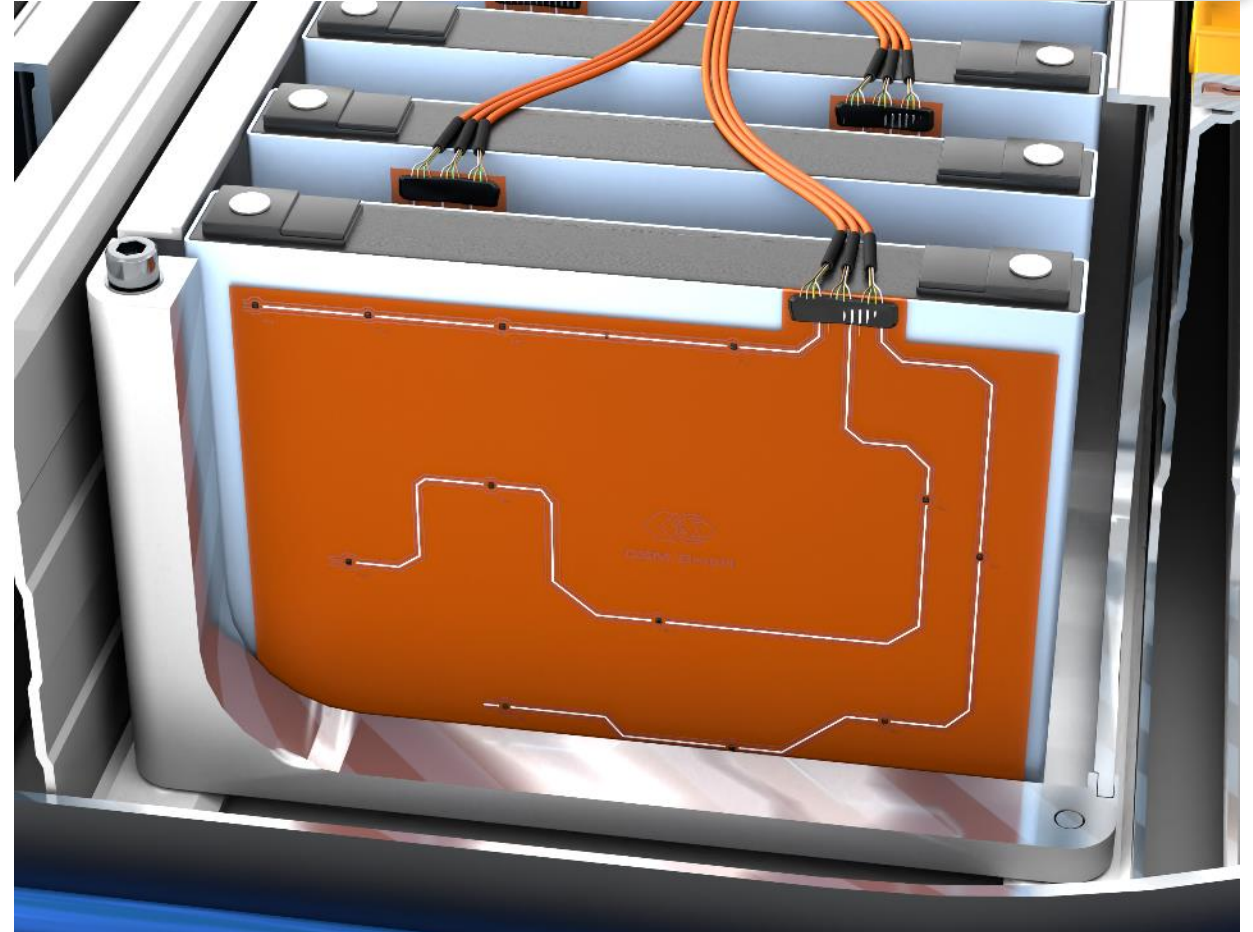
# HV DTemp IC Sensors: Ultra-thin Flexible Circuit

Flexible arrangement on larger ultra-thin flexible circuit

Up to 20 IC sensors connected by conductive bath

## Application-specific layout

- ▶ Exact positioning
- ▶ Reproducible arrangement



IC-Sensors on flexible circuit with customer-specific layout

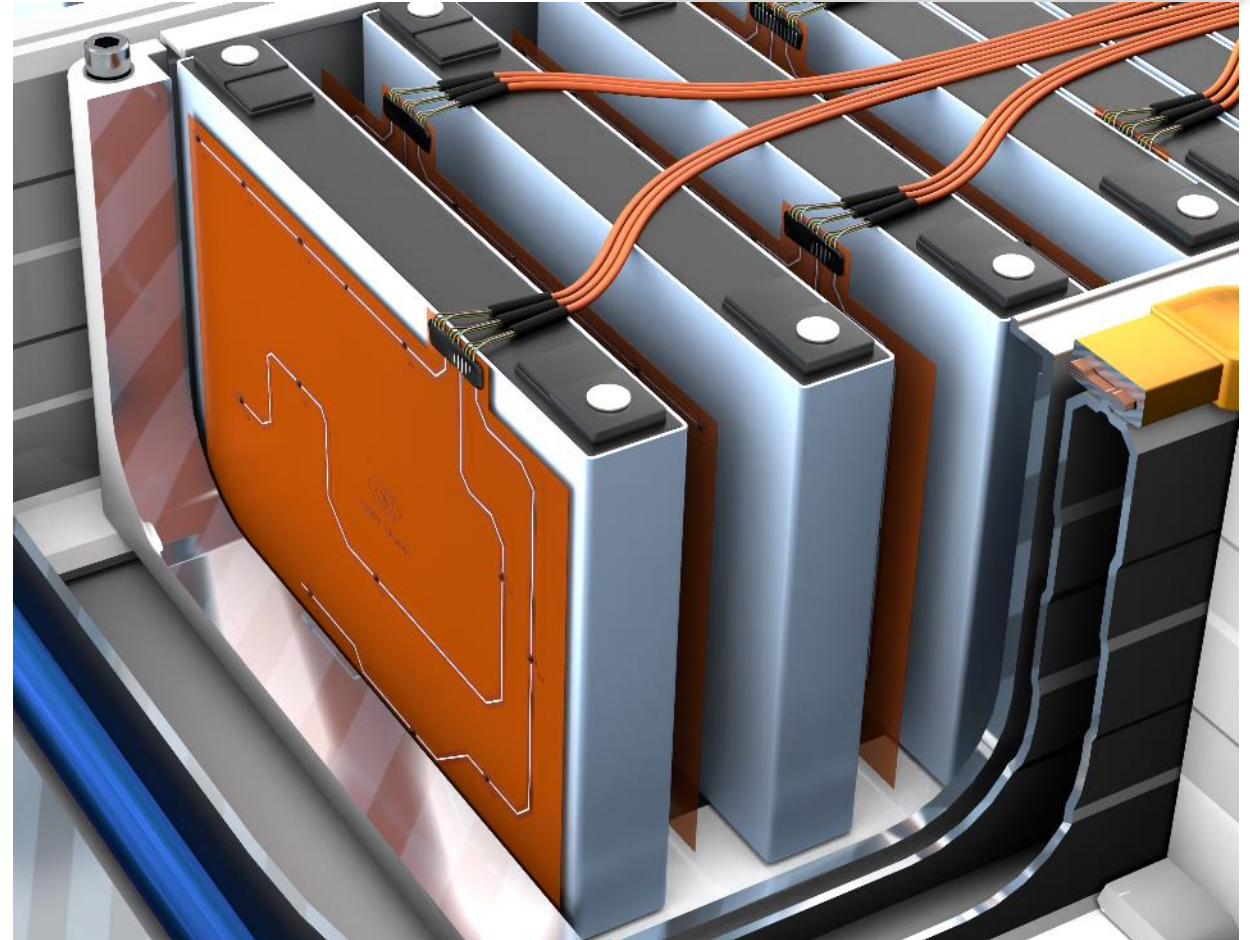
# HV DTemp IC Sensors: Ultra-thin Flexible Circuit

Flexible arrangement on larger ultra-thin flexible circuit

Up to 20 IC sensors connected by conductive bath

## Application-specific layout

- ▶ Exact positioning
- ▶ Reproducible arrangement
- ▶ **Measurement between battery cells**



HV DTemp IC sensors on ultra-thin flexible circuit between prismatic battery cells

# Requirements for temperature measurements in HV batteries (part 2)

## ✓ Temperature measurement

- ▶ Measurement on different cell types
- ▶ Cell level
  - Exact and reproducible positioning
  - Measurement between individual battery cells
- ▶ Module level
- ▶ Battery level

## ✓ Very high Measurement accuracy

## ✓ Interference immunity

## ✓ Simple application

## ! Identification of measurement points

## ! Minimal space required

- ▶ Inside the battery
- ▶ Outside the battery

## ! Low impact on the of the battery housing



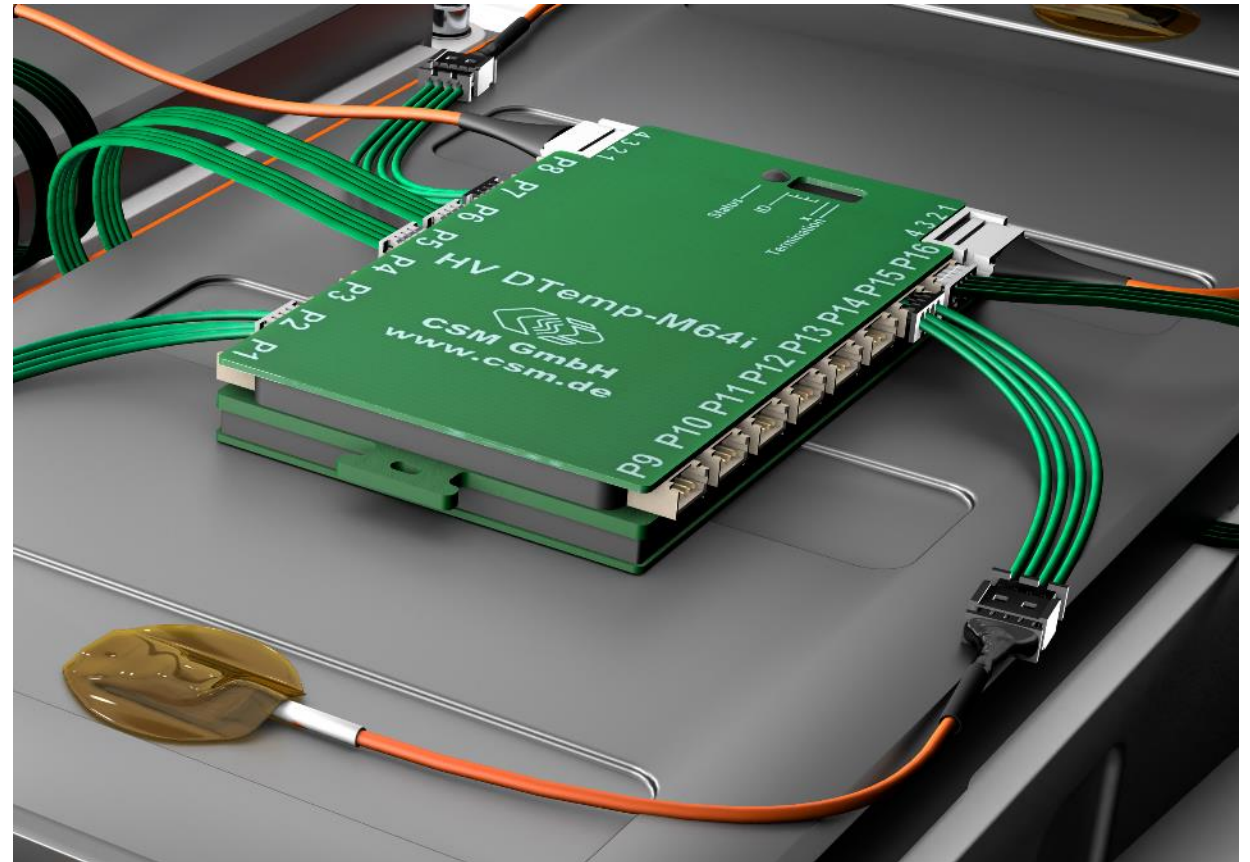
HV DTemp IC Sensors



# HV DTemp-Mx Controller

Connection of the HV DTemp IC Sensors

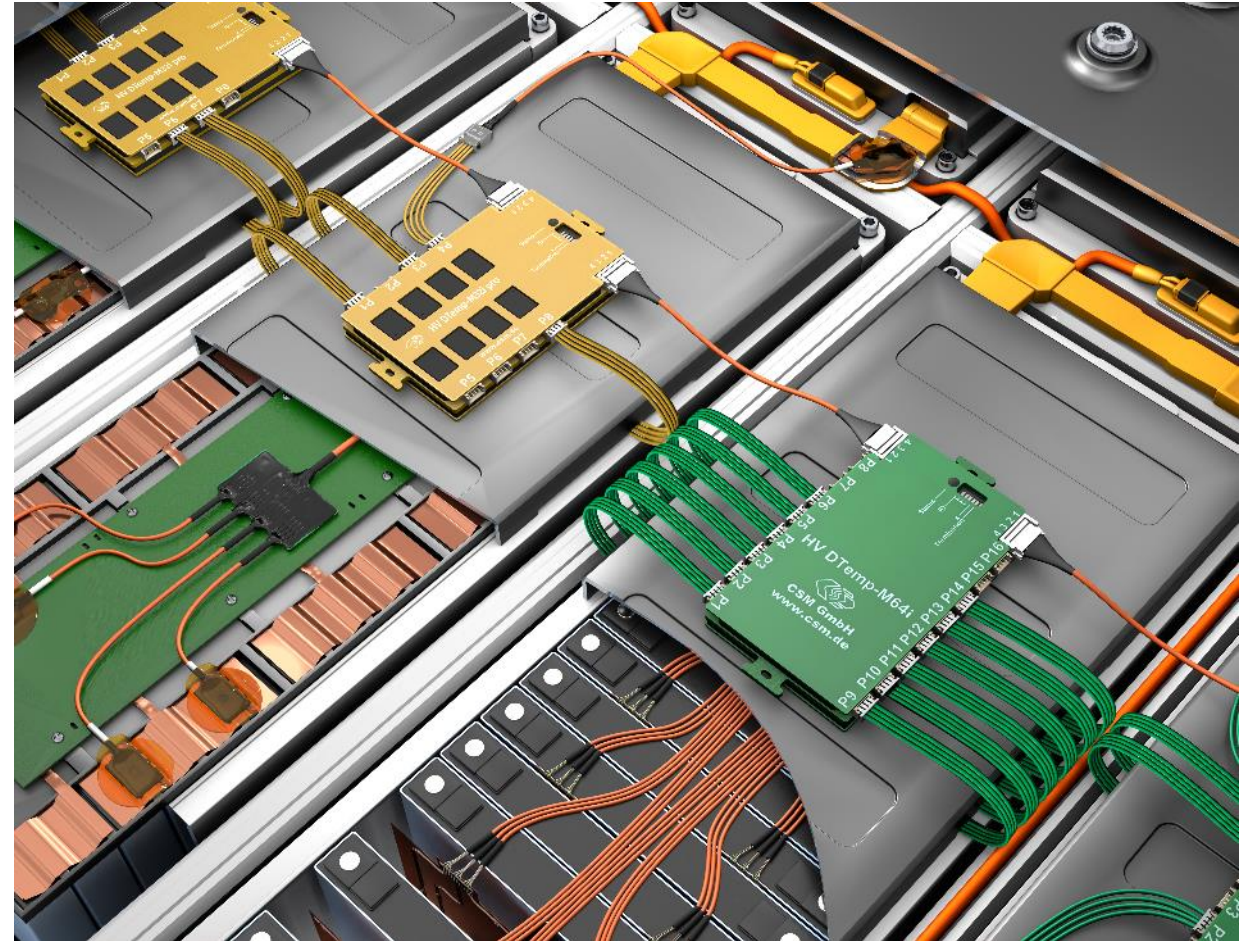
- ▶ Addressing, power supply and transmission of temperature values
- ▶ **Connection of up to 16 sensor assemblies (4 sensors each)**  
= 64 temperature measurement points per controller



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## Connection of the HV DTemp IC Sensors

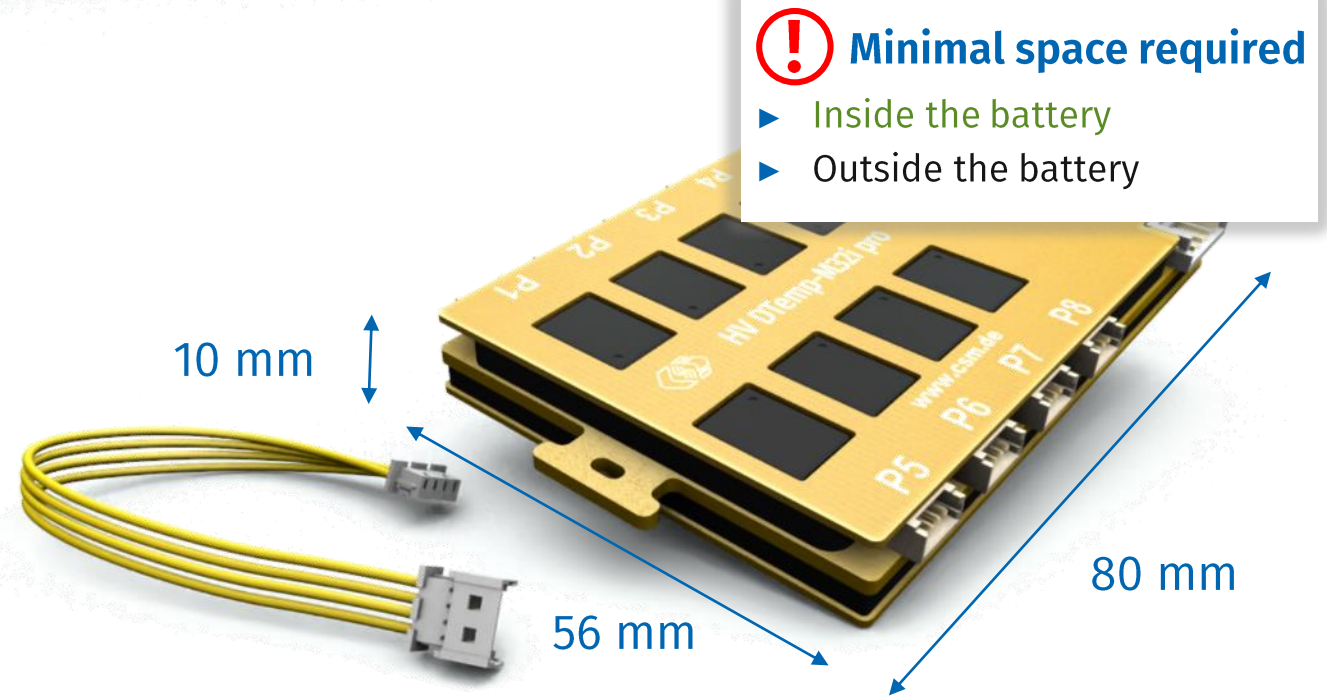
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= up to 512 temperature measurement points**



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## Connection of the HV DTemp IC Sensors

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- ▶ Connection of up to 16 sensor modules (4 sensors each)  
= 64 temperature measurement points per controller
- ▶ Up to 8 HV DTemp-Mx controllers cascable  
= up to 512 temperature measurement points



HV DTemp-M32i pro Controller and connection cable

Type	Galvanic isolation	Number of sensors (variants)	Dimensions (W × H × D)
HV DTemp-M32i pro	1,000 V peak	8 and 32	approx. 80 mm × 10 mm × 56 mm
HV DTemp-M64i	560 V peak	16 and 64	approx. 88 mm × 10 mm × 56 mm
HV DTemp-M64	-	16 and 64	approx. 75 mm × 8 mm × 45 mm

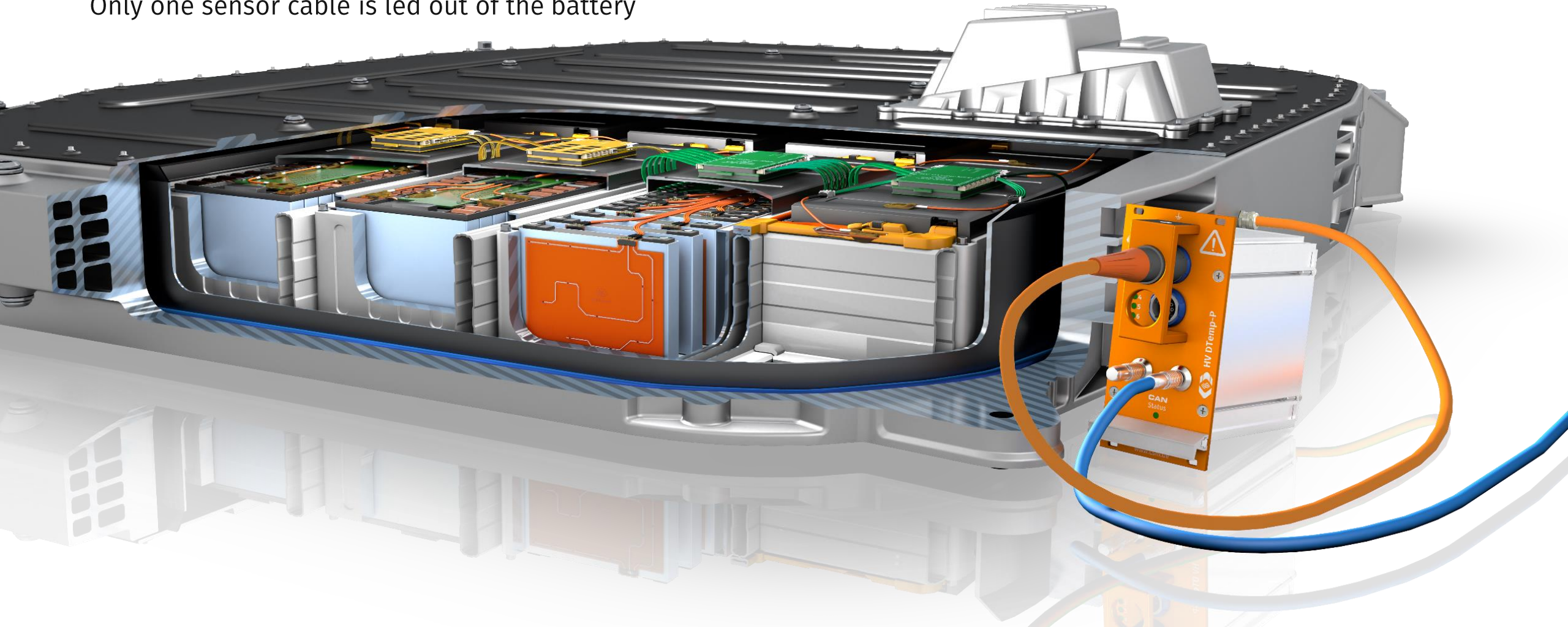


## Sensor cable

Only one sensor cable is led out of the battery



Low impact on the  
of the battery housing





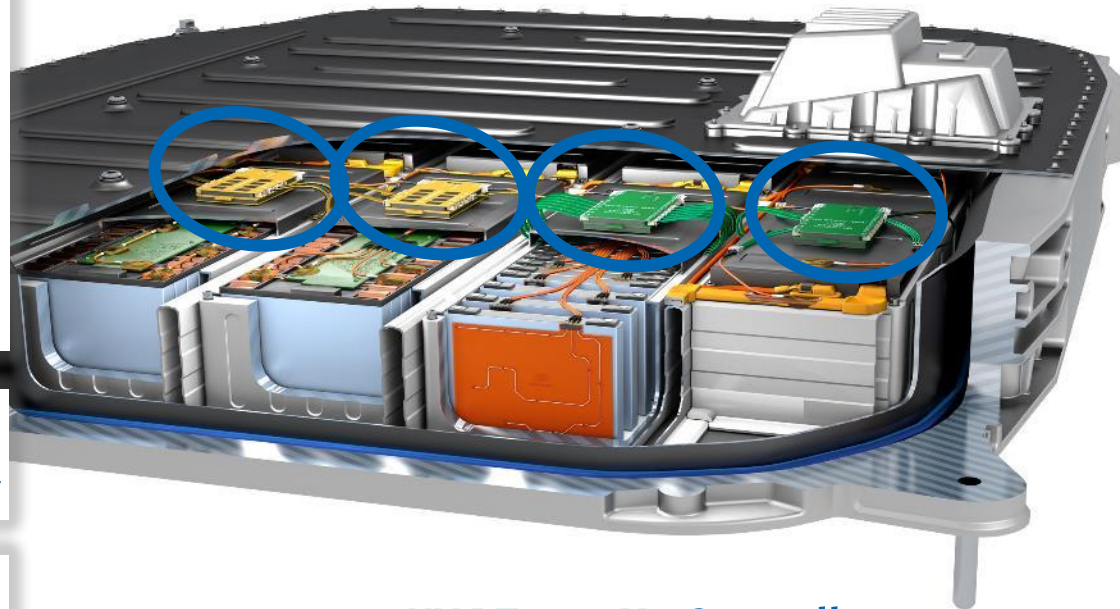
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HV DTemp-Mx Controller

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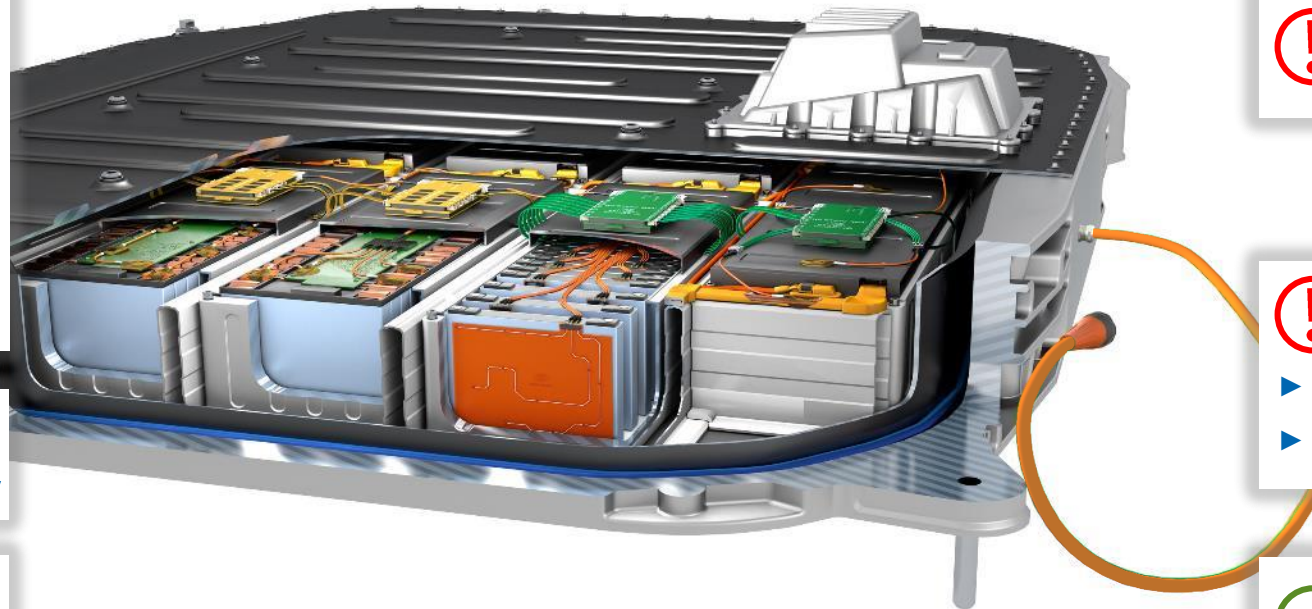
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# HV DTemp-P Central Unit

Control of the overall system

- ▶ Precise identification of the sensors
- ▶ Two galvanically isolated inputs for different HV environments (max. 512 sensors)



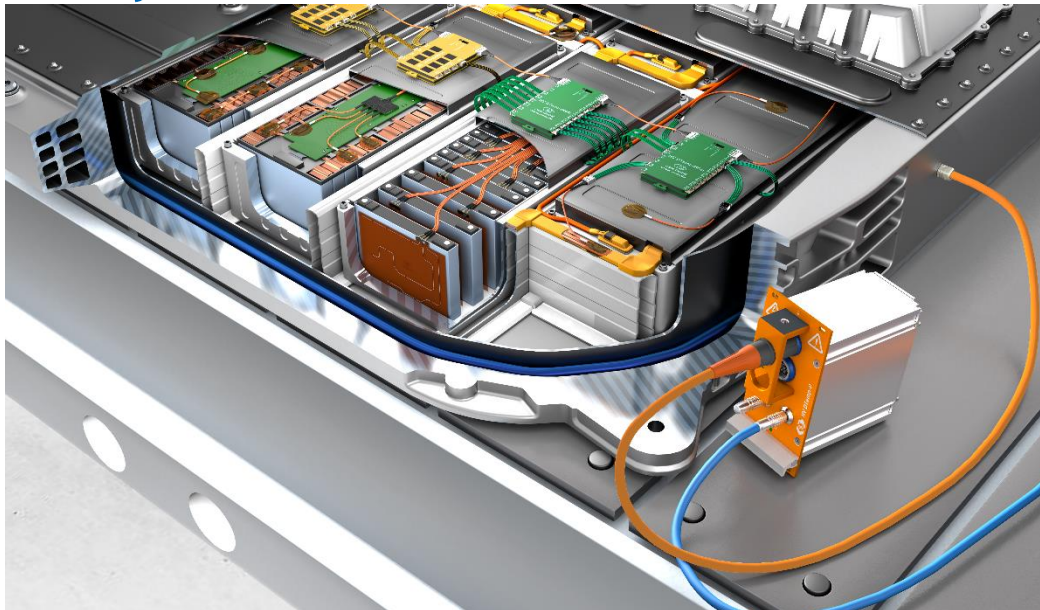
Identification of  
measurement points



# HV DTemp-P Central Unit

Control of the overall system

- ▶ Precise identification of individual sensors
- ▶ Two galvanically isolated inputs for different HV environments (max. 512 sensors)
- ▶ **Only one measurement module outside the HV battery**



✓ **Minimal space required**

- ▶ Inside the battery
- ▶ Outside the battery



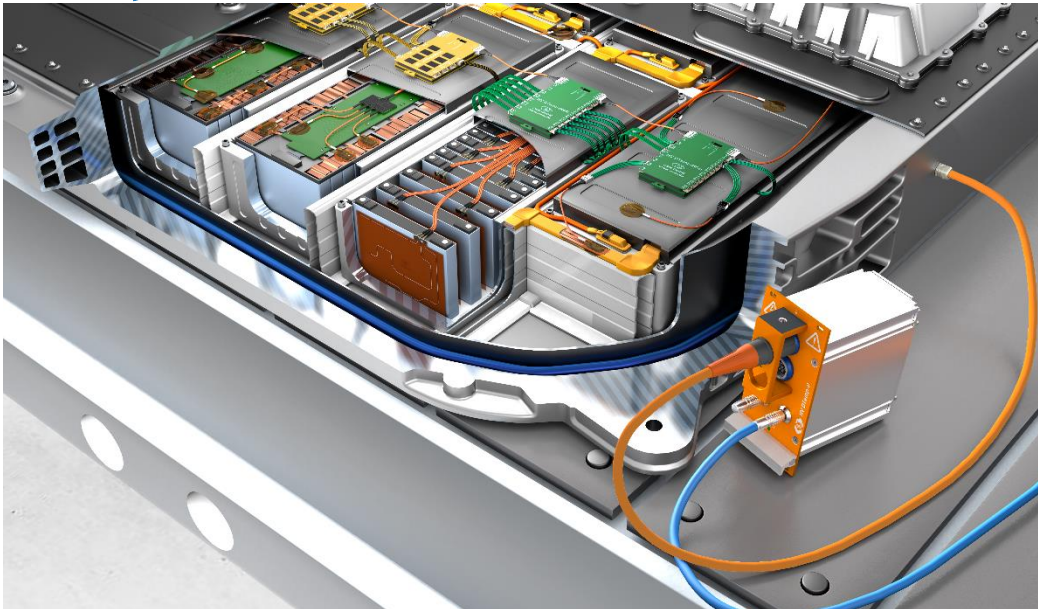
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# HV DTemp-P Central Unit

Control of the overall system

- ▶ Precise identification of individual sensors
- ▶ Two galvanically isolated inputs for different HV environments (max. 512 sensors)
- ▶ Only one measurement module outside the HV battery
- ▶ Configuration and data acquisition via CAN bus
- ▶ **DTempConfig** configuration software





# Requirements for temperature measurements in HV batteries (part 2)

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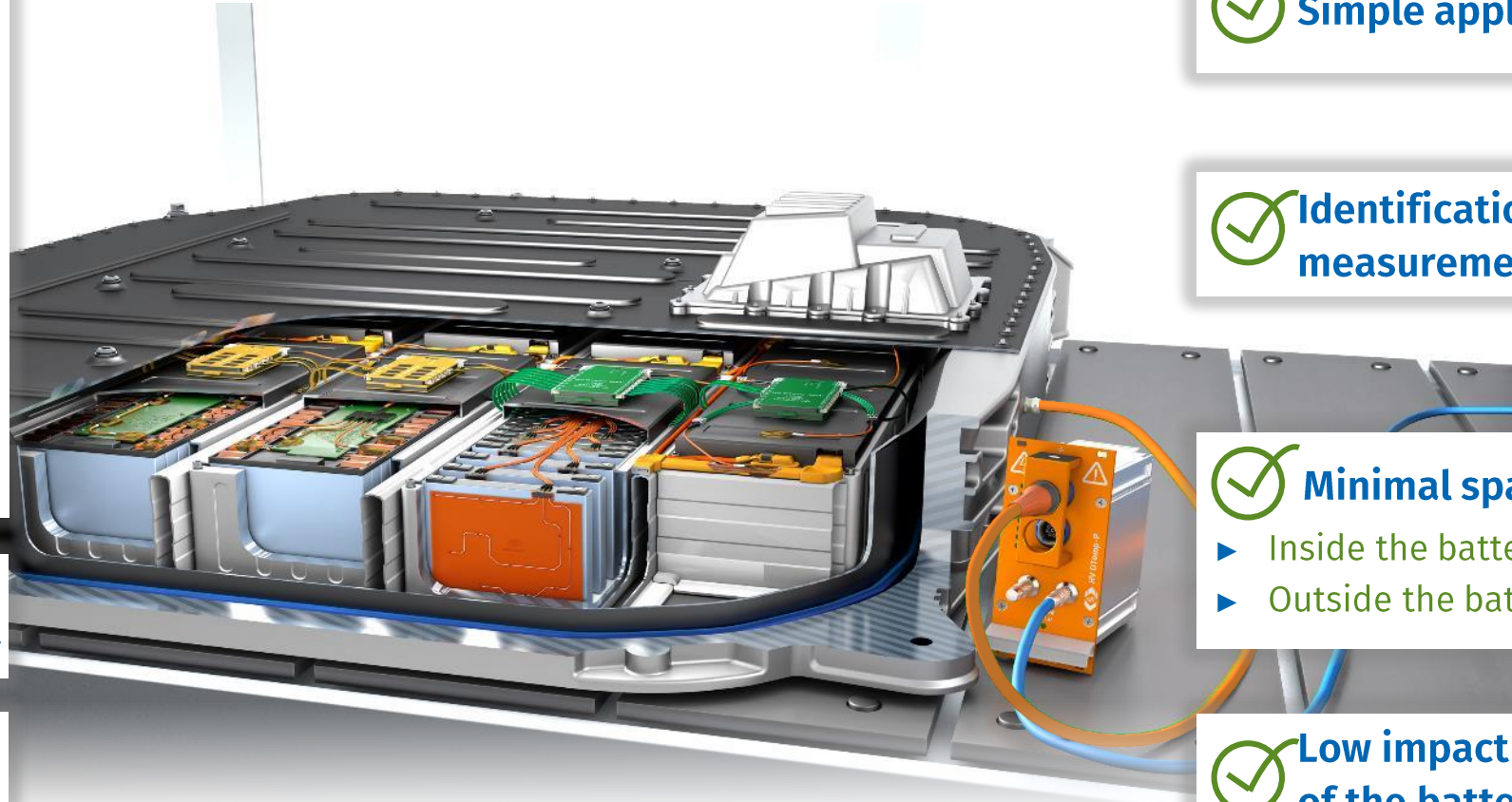
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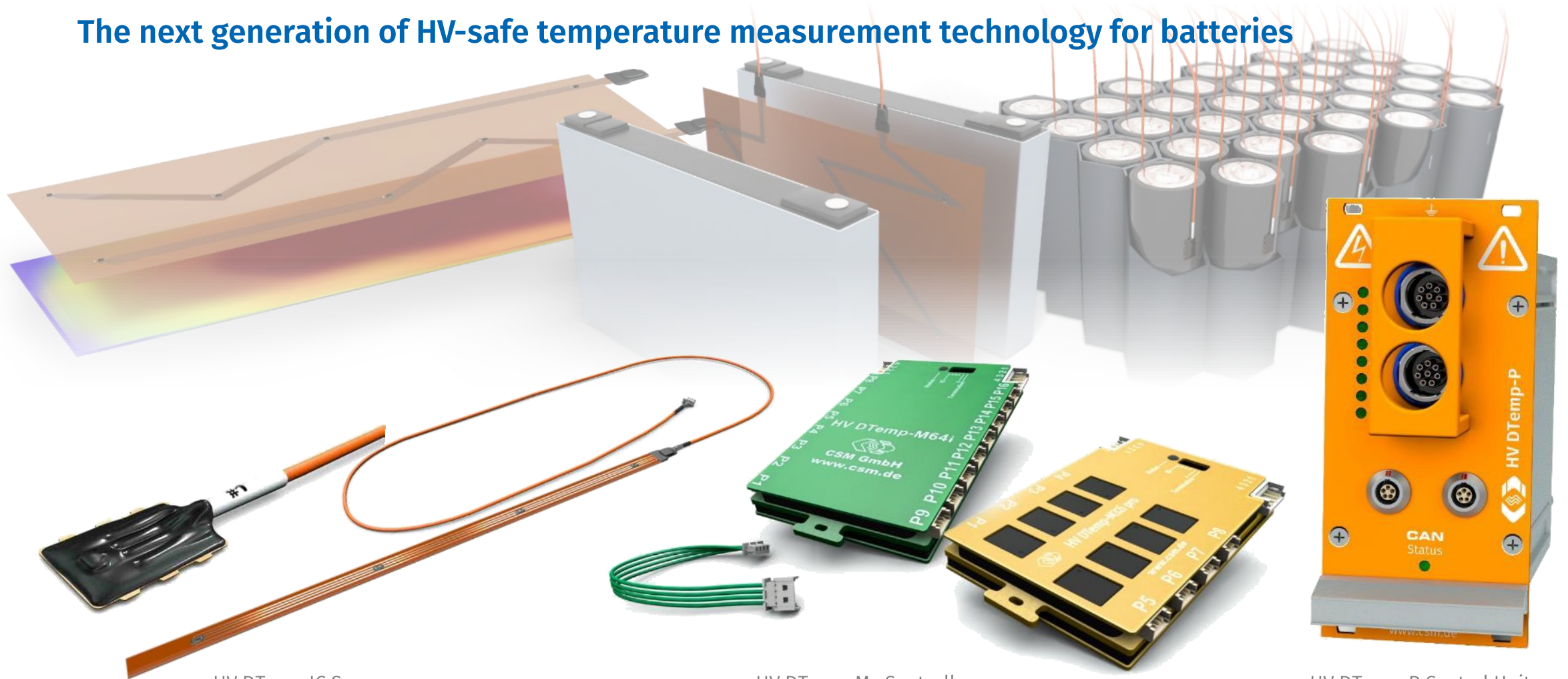


**HV DTemp-P Central Unit**



# HV DTemp measurement system

The next generation of HV-safe temperature measurement technology for batteries



HV DTemp IC Sensors

HV DTemp-Mx Controller

HV DTemp-P Central Unit



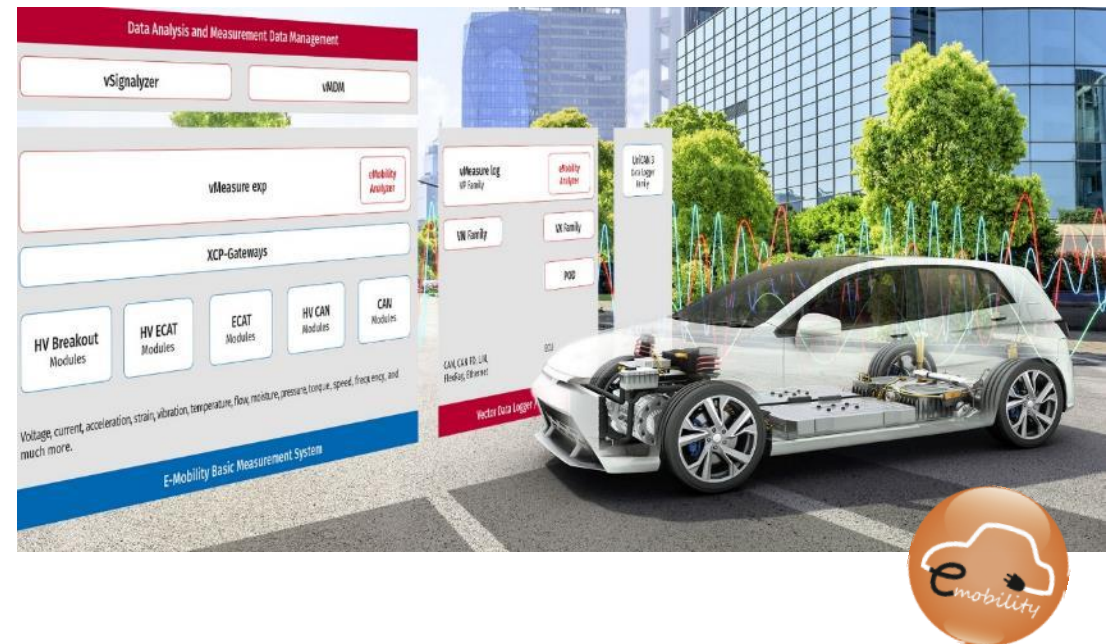
# About CSM

CSM has been setting technological standards for decentralized measurement technology in vehicle development for over 35 years. Our CAN bus and EtherCAT® measurement devices support worldwide renowned vehicle manufacturers, suppliers and service providers in their developments.

Continuous innovation and long-term satisfied customers are our guarantee for success. Together with our partner Vector Informatik, we have developed an easily scalable and powerful E-Mobility Measurement System for hybrid and electric vehicles and are constantly expanding the areas of application. With our high-voltage safe measurement systems designed for fast and synchronous measurements and power analyses, we actively accompany the change to **E-Mobility**.

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