Metrology and Safety for Batteries at Physikalisch-Technische Bundesanstalt (PTB)

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Germany's National Metrology Institute

PTB

Bundesministerium für Wirtschaft und Energie

BLB+ Braunschweig Labfactories for Batteries and more

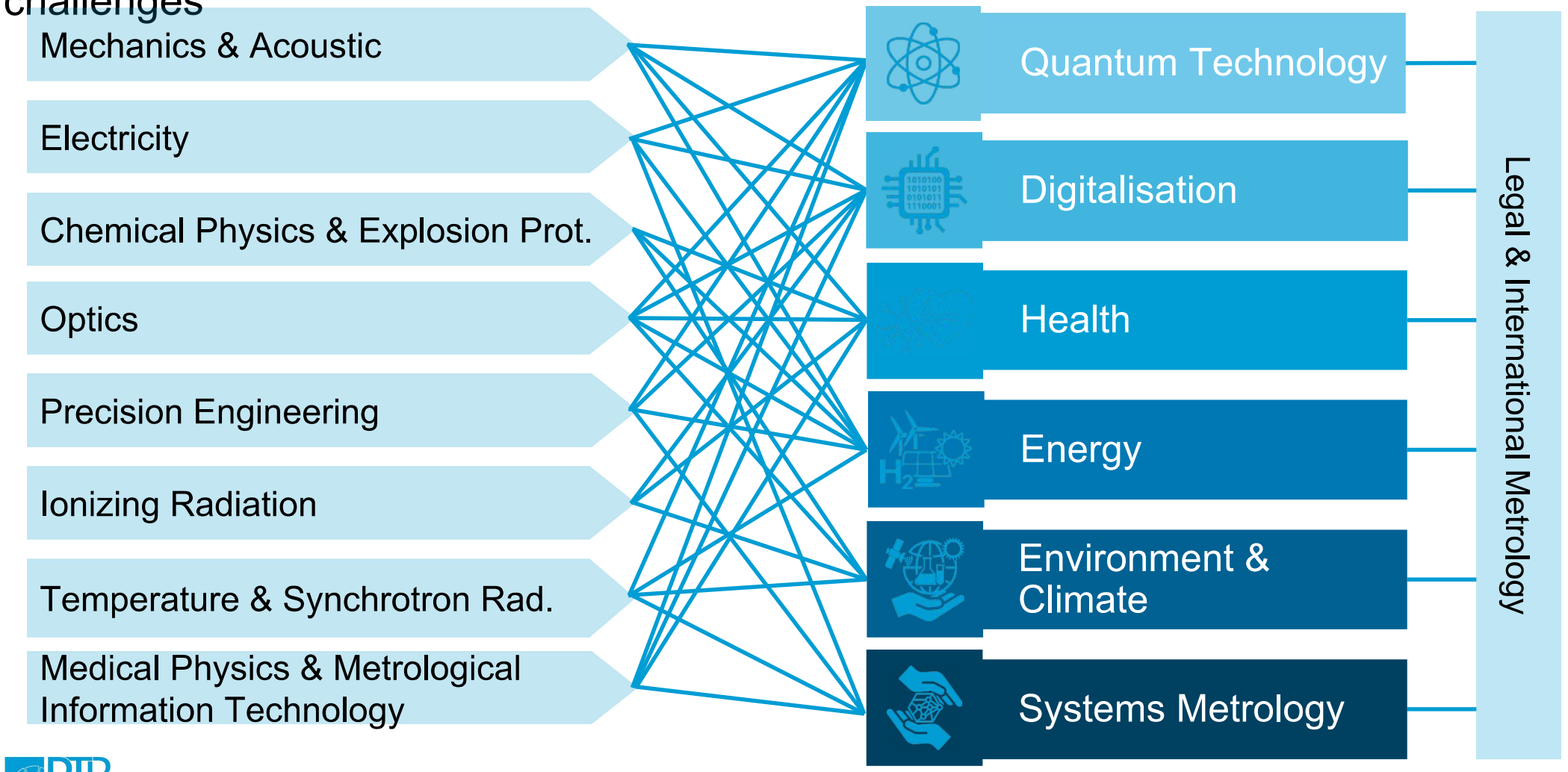
Our research groups

We strive for a circular economy and a sustainable, digitized production and recycling of lithium-ion and next-generation batteries.

Key Facts

- Battery production research since 2008
- Joint LabFactory with 14 institutes and 19 Members from TU Braunschweig, TU Clausthal, Leibniz Universität Hannover, Fraunhofer IST and PTB
- More than 200 persons, i.e. professors, research associates, technicians and students working on energy storage systems
- Member of relevant associations and initiatives on a national (KLiB, VDMA Battery Production, ...) and international level (LiPLANET, Batteries Europe, BEPA, SPIRE, CIRP, ...)
- > 750 scientific peer-reviewed publications since 2015
- > 100 battery experts (M.Sc. / B.Sc.) graduate every year
- > 250 visitors each year to the International Battery Production Conference since 2018 | www.battery-production-conference.de

PTB‘s Innovation Cluster | Linking scientific disciplines with cross-cutting challenges



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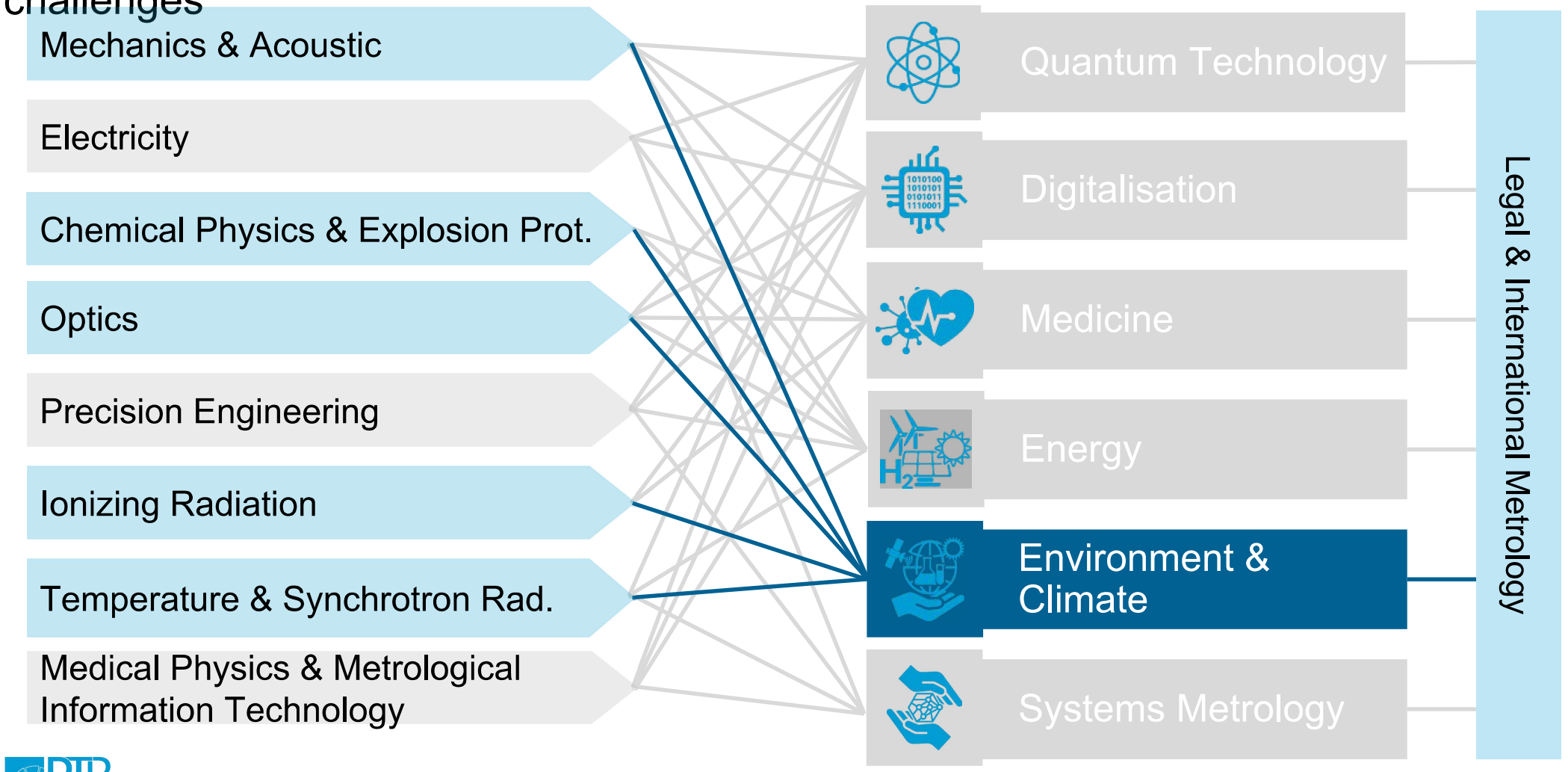


The 3 Principles of Metrology

Guide to the Expression of Uncertainty in Measurement (GUM)

- Measures the level of uncertainty associated with a measurement, providing a numerical estimate of the confidence in the result.
- Helps in assessing the reliability of measurements, leading to better-informed decisions and risk management.

Uncertainty estimation

Metrological tra[illegible]ility

- Ensures measurements are linked to recognized standards, providing accuracy and reliability.
- Verifies instruments meet regulatory norms, ensuring consistency and comparability of measurements.

Ensures that measurements taken by different instruments or in different locations can be compared because they follow the same standardized procedures.

Comparability

Other Principles:
- Advancing for accuracy
- Research for new

International Vocabulary of Metrology (VIM)

PTB

Introduction: Why QI4BEES ?

Quality Infrastructure for Battery Electric Energy Systems

QI is important for:

- Ensuring Safety and Reliability
- Supporting Performance and Innovation
- Market Access and Sustainability

HOW do we contribute @ PTB

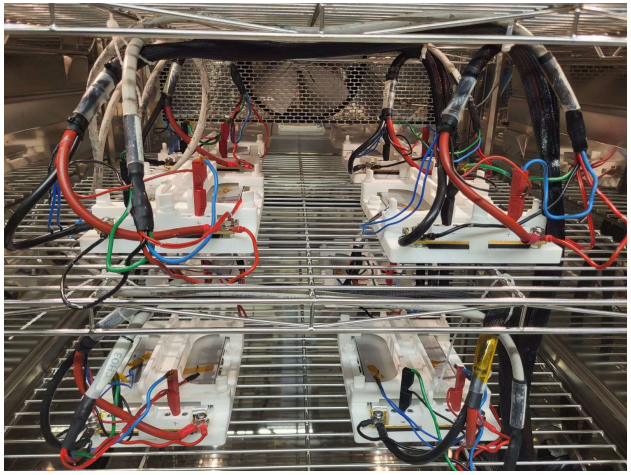
- Electrial Battery Performance
- Current density imaging & quantum-optical sensors
- Safety and explosion protection for batteries
- Analytical characterisation of battery materials under operation
- Conformity assessment with and devekopment of Digital Product Passport concepts
- Chemical analysis of battery electrolytes and recyclates

- Standardization
  - ISO 201/SG 2 “Surface Analysis of Energy Materials”
  - IEC TC 31/WG37 “Electrochemical cells, batteries and capacitors in equipment for explosive atmospheres”

Electrical Battery Performance

Example: QUSEBA project - Quantum Sensors for Battery Quality Assurance

- Battery characterization using magnetometry technology, electrochemical and calorimetric methods
- Improve battery lifetime performance
- Measurements during operation and relaxation for different SOH and aging parameters

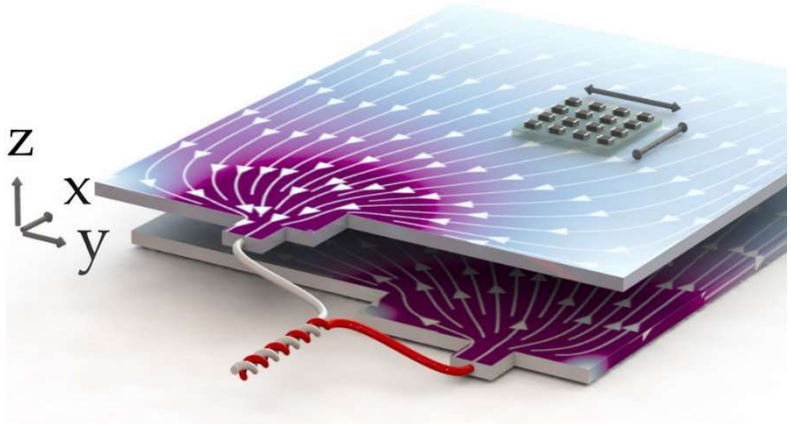


Electrochemical impedance spectroscopy

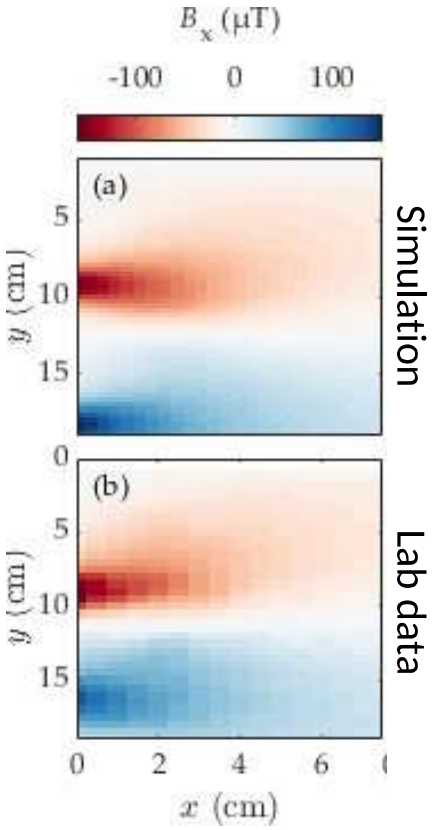
Spatially-resolved isoperibolic calorimeter

SQUID magnetometers, PTB Berlin

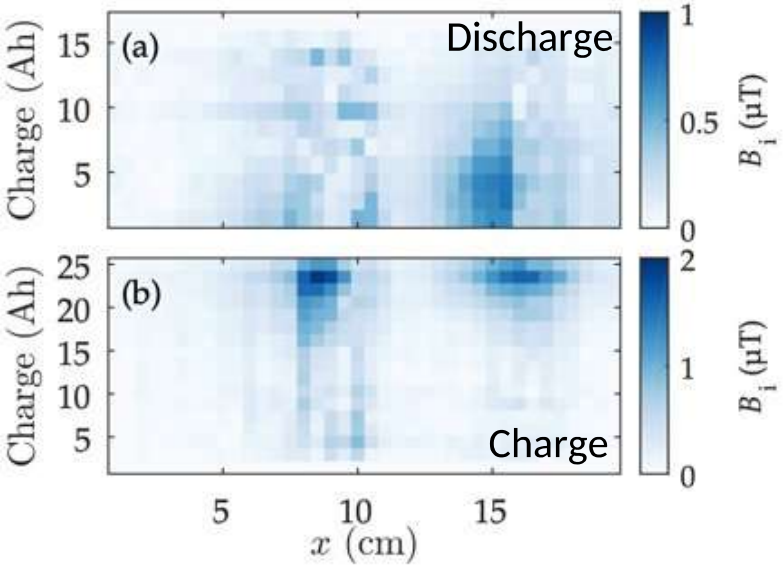
Current-density imaging (fluxgates)



- Feasibility study successful
- Patent secured
- Fluxgate array first commercialized product



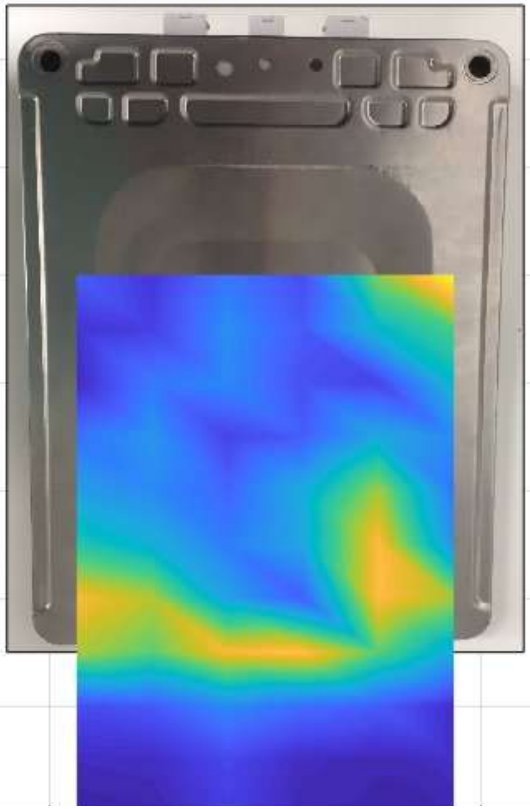
Electrochemical models matched



Deviations depend on SoC

Bason et al, J. Power Sources 2022

Quantum sensor measurements (open-circuit)



Spatially-resolving map of self discharge reveals anomaly of high current density, predicitve of electrolyte leak

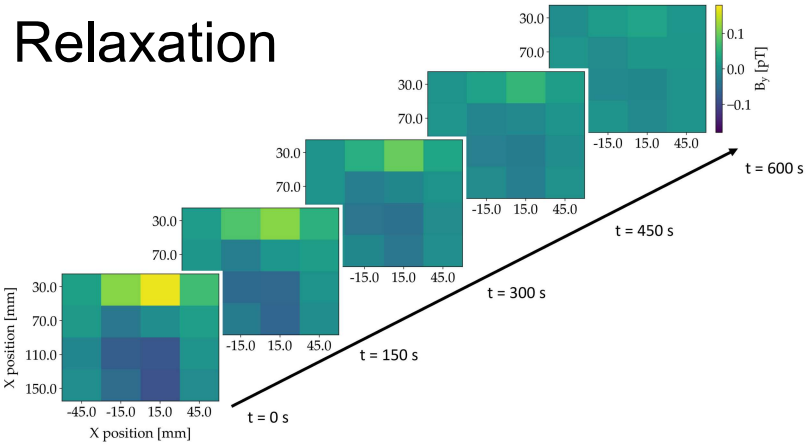
Method

- Completely non-invasive open-circuit sensing can detect relaxation and leakage currents
- pT (and below) range: optical ***quantum sensors*** (OPMs)

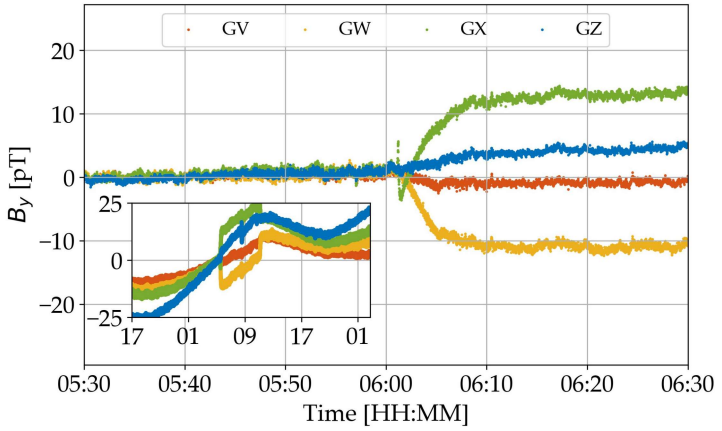
Application areas

- battery manufacture
- R & D in new chemistries and geometries
- QA inFault detection

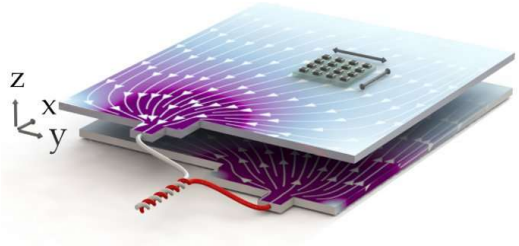
Relaxation

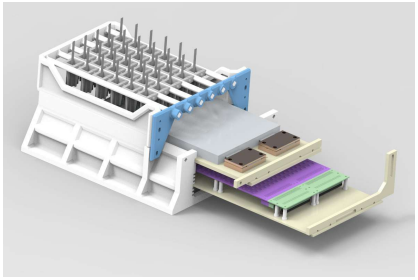


Local transient defects



Roadmap quantum sensing for batteries





2020:
Concept

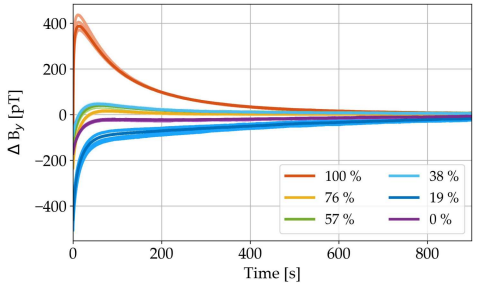
2023:
Lab data

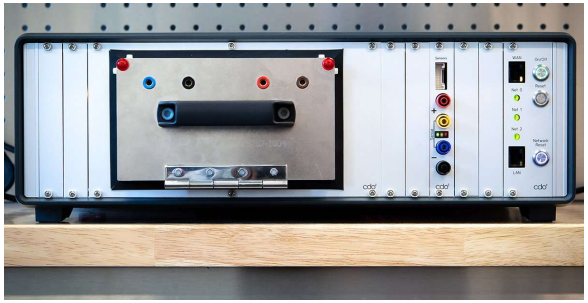
2027:
Test/service for industry

2022/*2028*:
Commercial devices

2032:
PTB reference

2034:
Industry standards





Roadmap quantum sensing for batteries

Patent 2023: Quantum sensors batteries

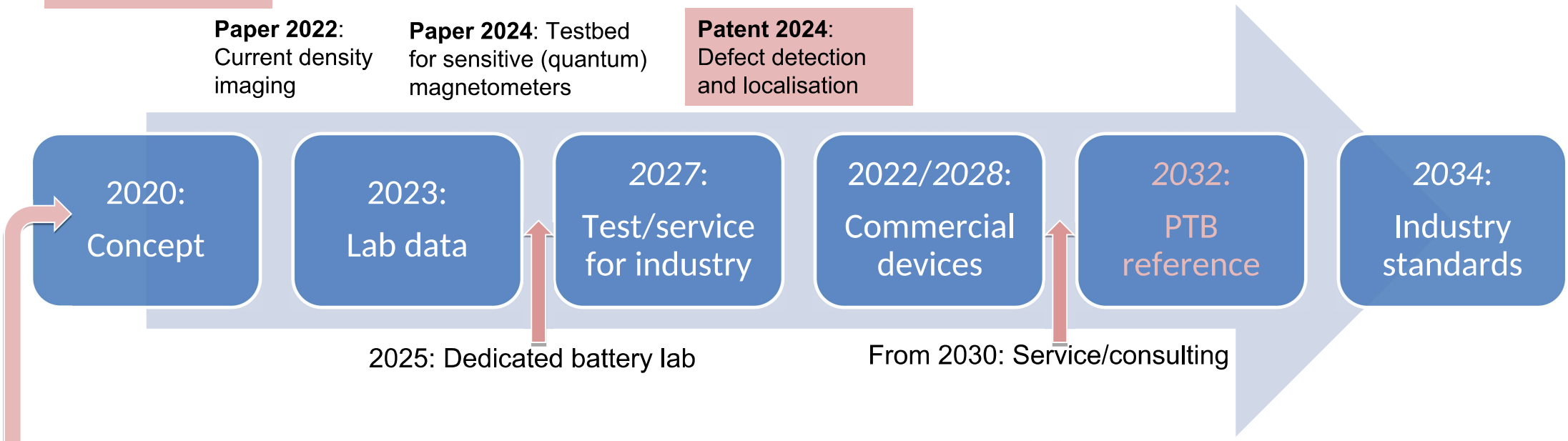
Paper 2024: Modular OPM array

Paper 2025: *Quantum sensing: relaxation and defect detection*

Paper 2022: Current density imaging

Paper 2024: Testbed for sensitive (quantum) magnetometers

Patent 2024: Defect detection and localisation



Projects since 2018 in GB: EPSRC, Innovate UK, Faraday Inst. …

NBank Wir fördern Niedersachsen
Quantum Valley Lower Saxony
2022-24: HTI

Projekte 2023-25:
KoPa QUSEBA
KoPa MMC
GG 2025

CLUSTERS 4 FUTURE Innovationsnetzwerke für unsere Zukunft
Gefördert vom Bundesministerium für Bildung und Forschung
2023-26: QVLS iLabs: QBatt

European Commission
2023-26: Qu-Test

quanten technologien
2026-28:BMFTR

contact: Peter.Krueger@PTB.de

Research questions we are currently working on:

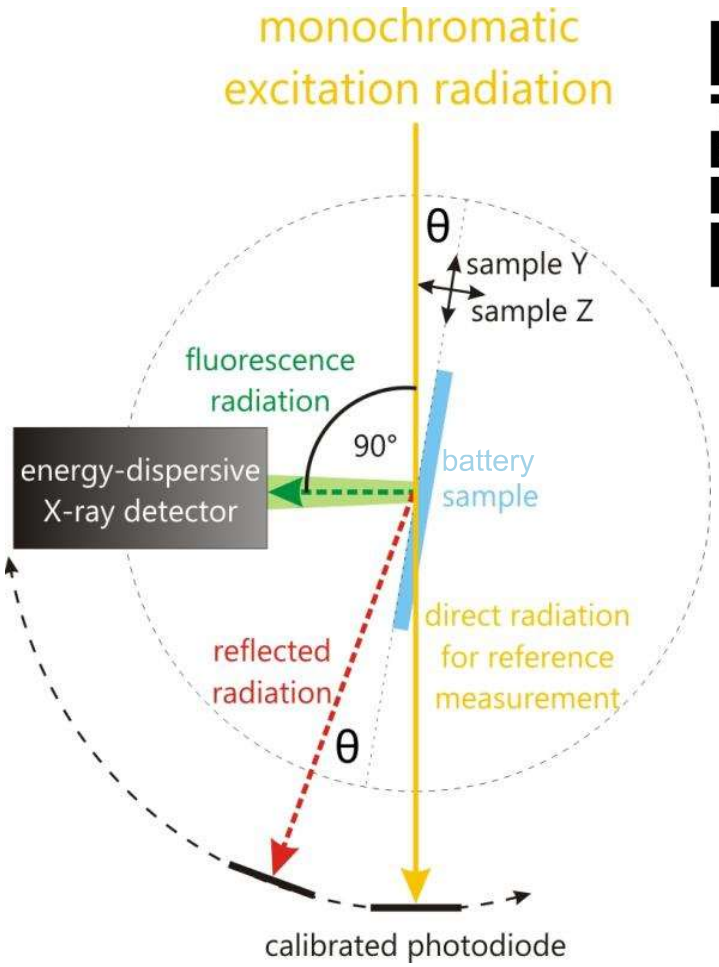
- What are the effects of thermal runaway (in a specific case)?
- How can the effects be reduced to an *acceptable* level?
- How can fault conditions be detected at an early stage?
- How can grid-beneficial and simultaneously secure operation be ensured?

Keywords:

Ageing, misuse, operating conditions, environmental influences, ...

- How can the **state of safety** of batteries be described and predicted?

Reliable analytical characterisation of batteries under operation

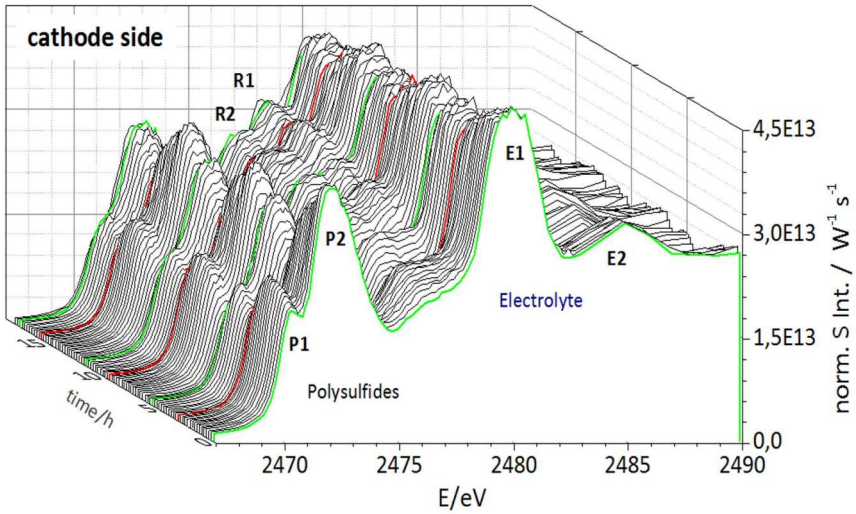


Quantitative x-ray spectrometry:

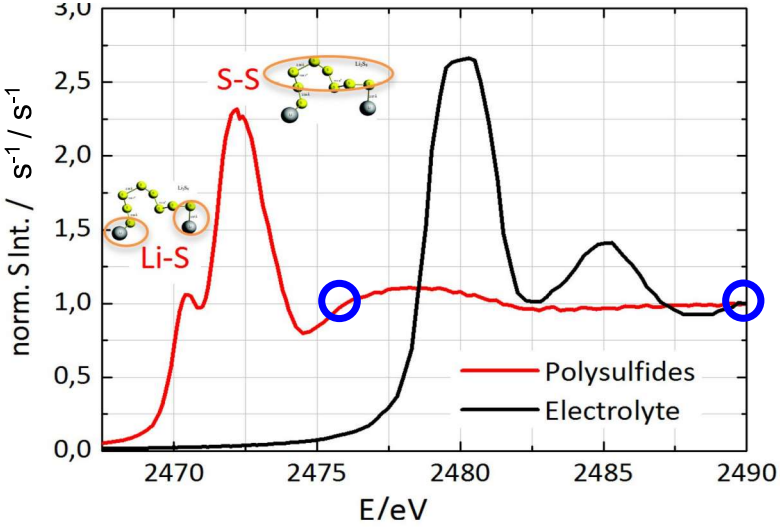
Calibrated instrumentation using well-known synchrotron radiation of characterized beamlines (spectral purity and flux) and knowledge of fundamental x-ray atomic parameters allow the mass deposition of specific elements or speciation to be determined without any reference samples.

- Absolute quantification of S content and S species in LiS batteries

Operando NEXAFS speciation and XRF analysis of polysulfides in LiS batteries

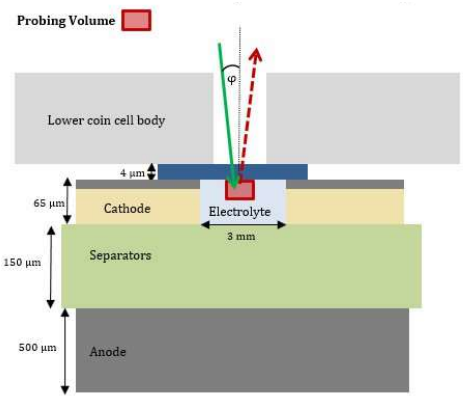


Waterfall plot of NEXAFS spectra for the first three full cycles

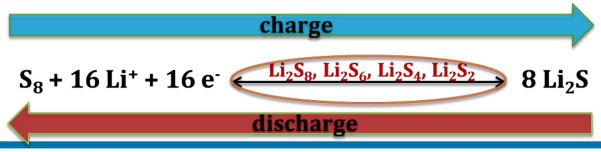


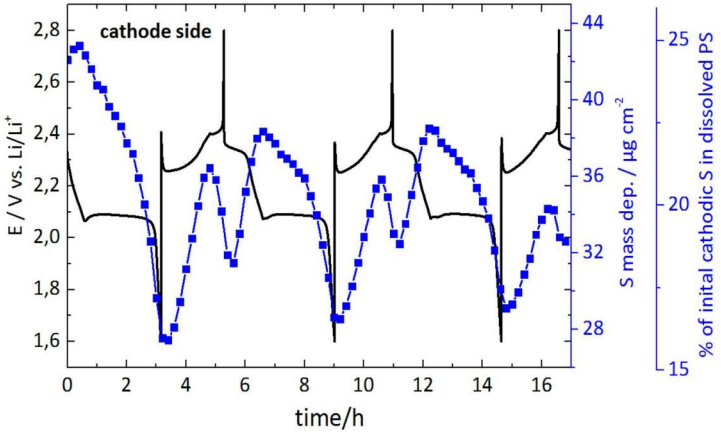
equivalent excitation conditions

Adapted LiS cell configuration



Quantification of sulfur in dissolved polysulfides and calculation of sulfur loss





J. Mater. Chem. A **9**, 10231 (2021)

‘Multidimensional’ challenges call for ‘multidimensional’ answers

HyMetBat

Hybrid Metrology for Sustainable Energy Storage Materials

7/2025 until 6/2028

EURAMET

Industrial partners and stakeholders

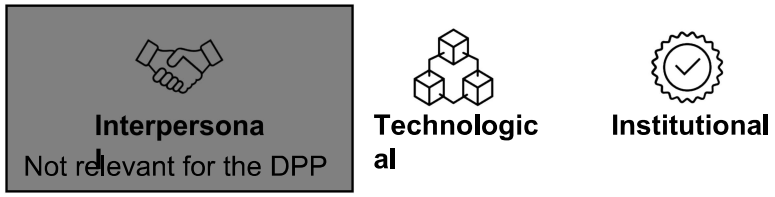
LiB and NaB batteries

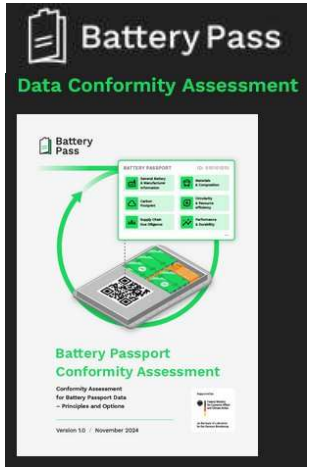
https:// hymetbat.inrim.it

contact: Burkhard.Beckhoff@PTB.de

Conformity assessment in the DPP

- PTB contributes to the DPP standardization within CEN/CLC JTC 24 WG 3 “Security”
- Work so far focused on technological trust
- Institutional trust provided by the QI can be another important contribution to the DPP’s trustworthiness (besides fulfilling regulatory requirements)





A possible implementation in the Battery Passport has been proposed by the Battery Pass project

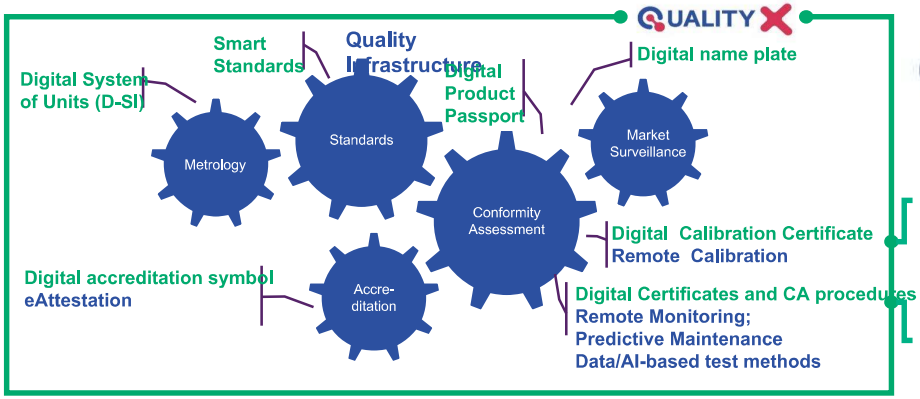
Table 4: Example for communication of results (data for illustrative purposes only)

Attribute	Value	Assessment mechanism applied
...		
Battery Serial Number	992356610548948	Automated self-assessment
Battery carbon footprint	137.00 gCO_2e/kWh	EU conformity assessment; 90 % Third-party assessment / 10% first-party assessment
...		

Source: Conformity Assessment for Battery Passport Data – Principles and Options

Digital transformation of the QI and DPP development

- Interoperability and interconnection of digital QI tools is a prerequisite for a DPP-ready QI
- PTB is one of Germany's central QI actors who started the initiative QI-Digital (www.qi-digital.de)



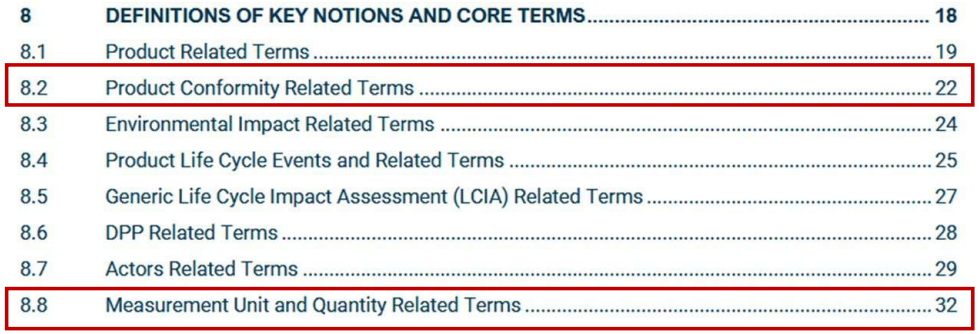
QI DIGITAL

Seamless integration into Industry 4.0 quality assurance processes

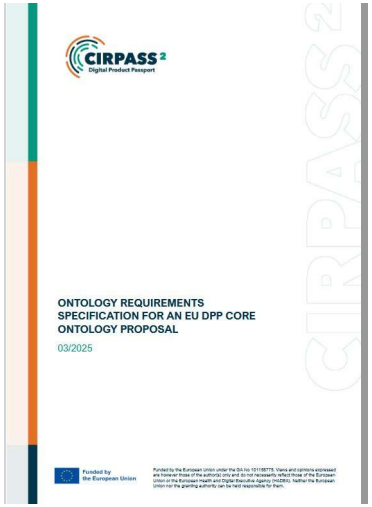
Transparency and **trust** along the value chain.

"The digital transformation of the quality infrastructure supports the energy transition"
tm - Technisches Messen, 92, 9-10, **2025**, 424-430 https://doi.org/10.1515/teme-2025-0040

- CIRPASS 2 is an EU-funded project piloting DPPs in several sectors
- PTB contributes to the DPP core ontology specifications



https://doi.org/10.5281/zenodo.14892665



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Contact: Jens.Niederhausen@PTB.de

Summary (Outlook)

- PTB supports industry and society with accuracy and quality assurance for batteries by means of metrological traceable, quantitative data, methods for characterising key performance and safety parameters across the whole battery lifecycle.

- Various scientific disciplines supply a multi-discplinary research approach, making use of a multitude of measurement methods enabling in-operandi measurements and novel quantum-optical technologies.

- PTB's contributes to recycling strategies, e.g., by the development of a digital battery passport (DBP).

- The DBP, developed within the QI-Digital project, enables standardised, traceable data exchange across the battery value chain. It supports international harmonisation of digital quality infrastructure and facilitates informed decisions for sustainable battery technologies.

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Metrology for eco-assessments batteries

Thanks for your attention.

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