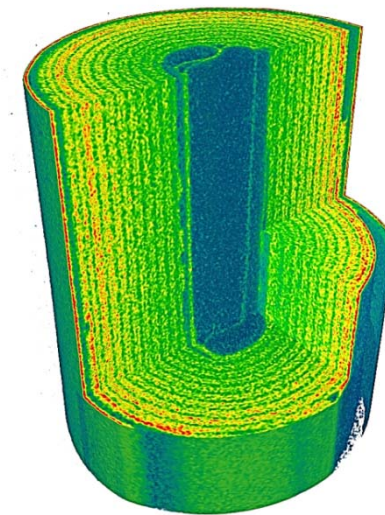
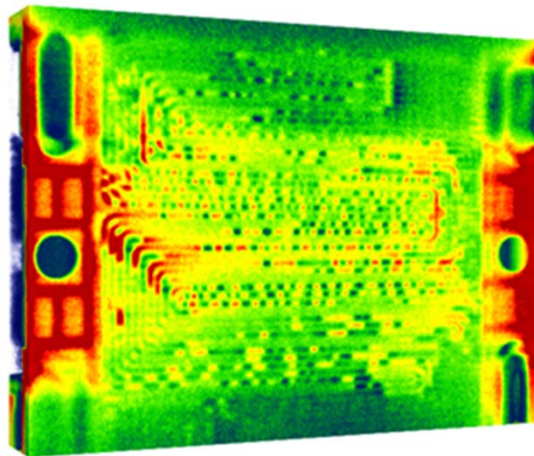


# Zerstörungsfreie Untersuchung von Brennstoffzellen und Batterien mit bildgebenden Röntgen- und Neutronen-Verfahren

Ingo Manke

Helmholtz-Zentrum Berlin für Materialien und Energie



## ÜBERSICHT

- Prinzip der Tomographie
- Eigenschaften von Neutronen und (Synchrotron-)Röntgenstrahlung
- Anwendungsbeispiele
  - Brennstoffzellen
  - Batterien

# Das HZB

**HZB** Helmholtz  
berlin



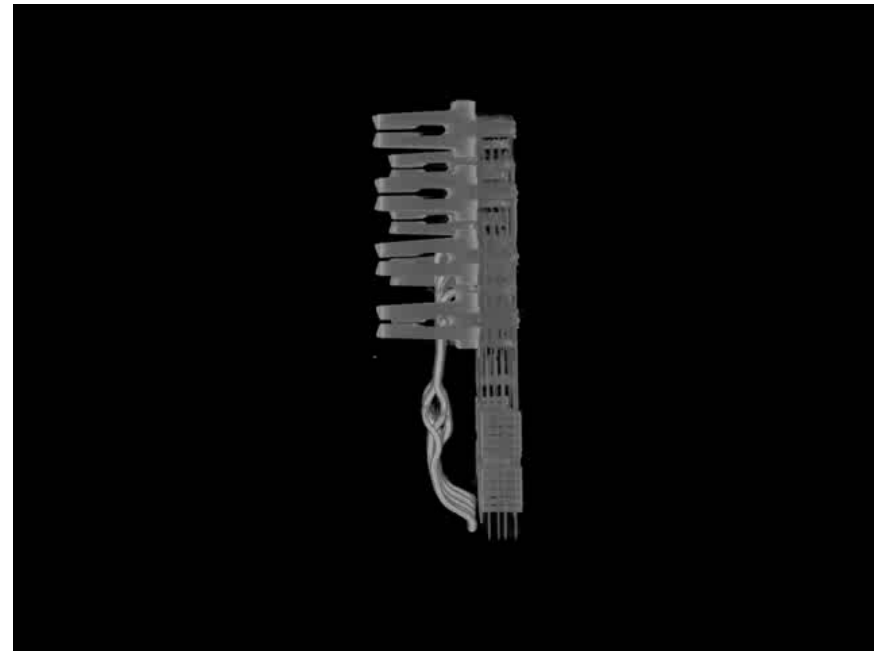
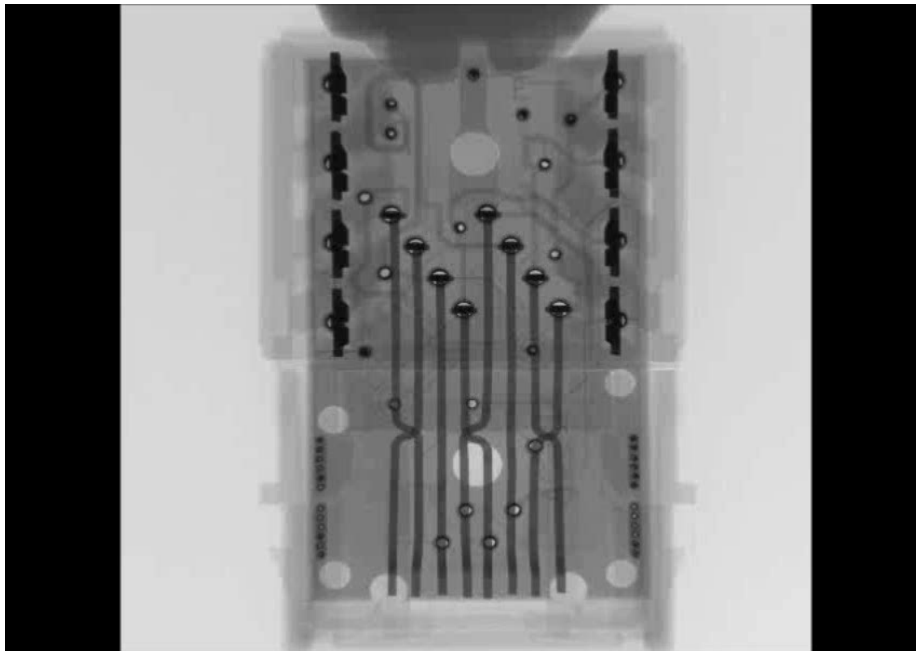


2D

Rekonstruktion

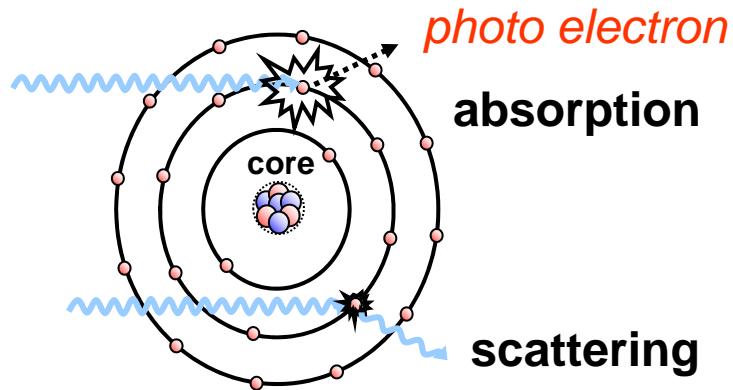


3D

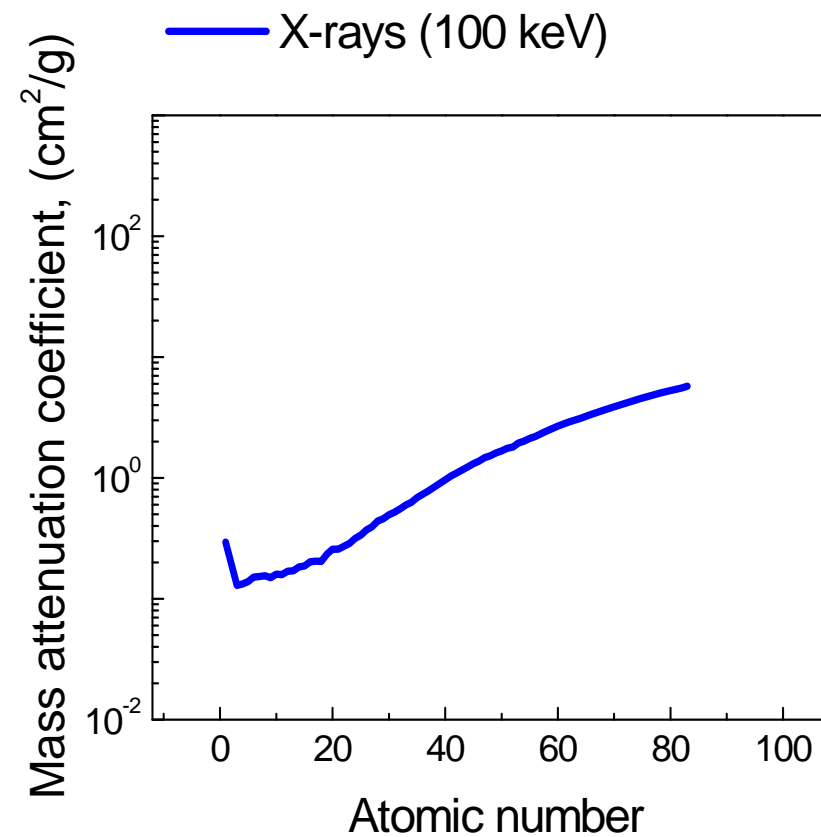
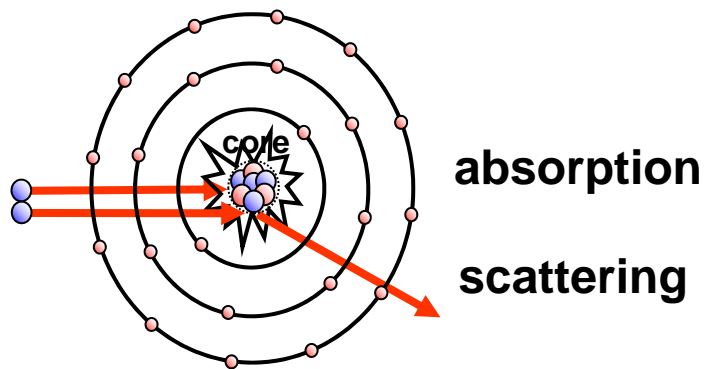


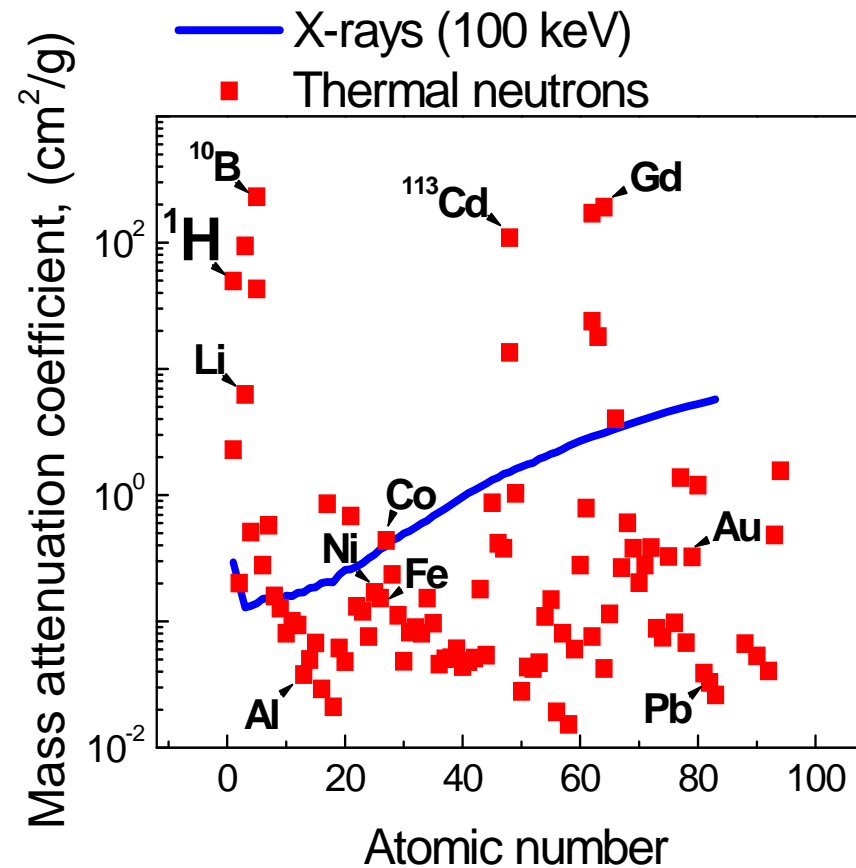
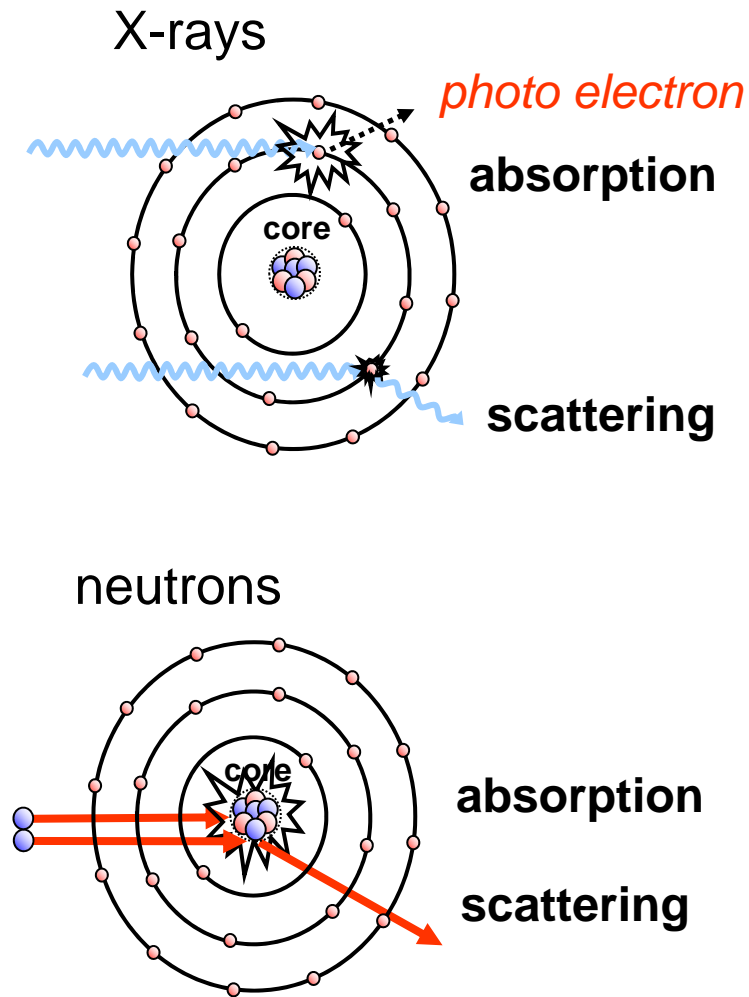
Zerstörungsfrei und nichtinvasiv

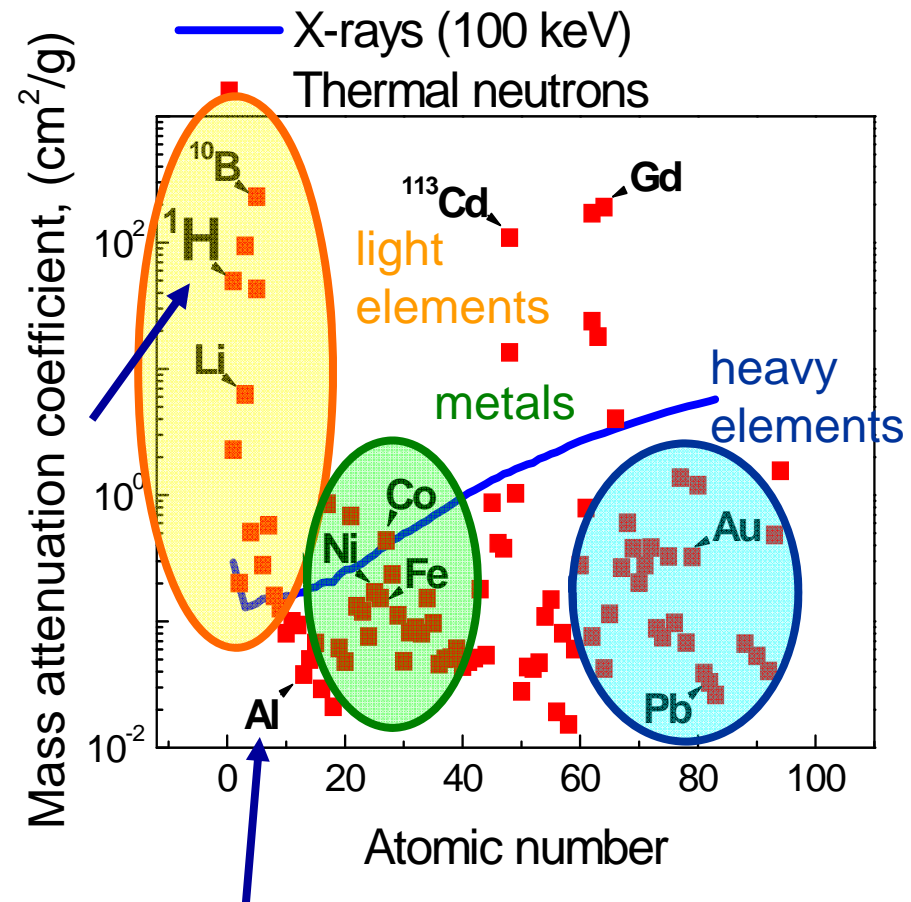
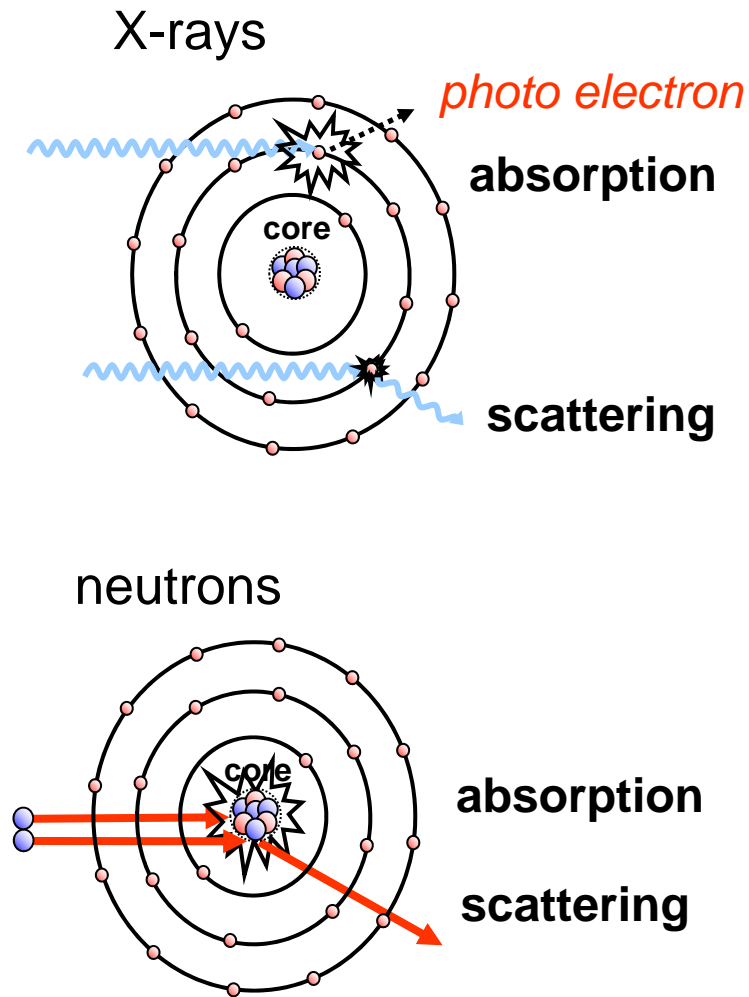
X-rays

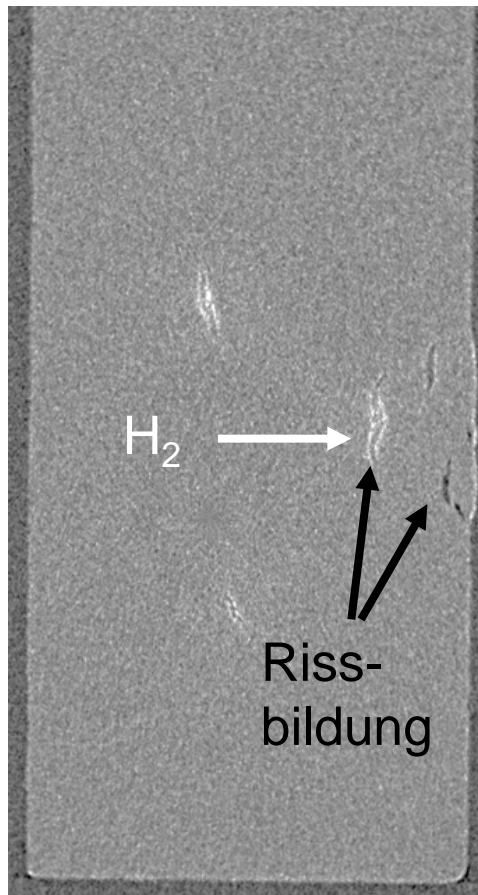


neutrons





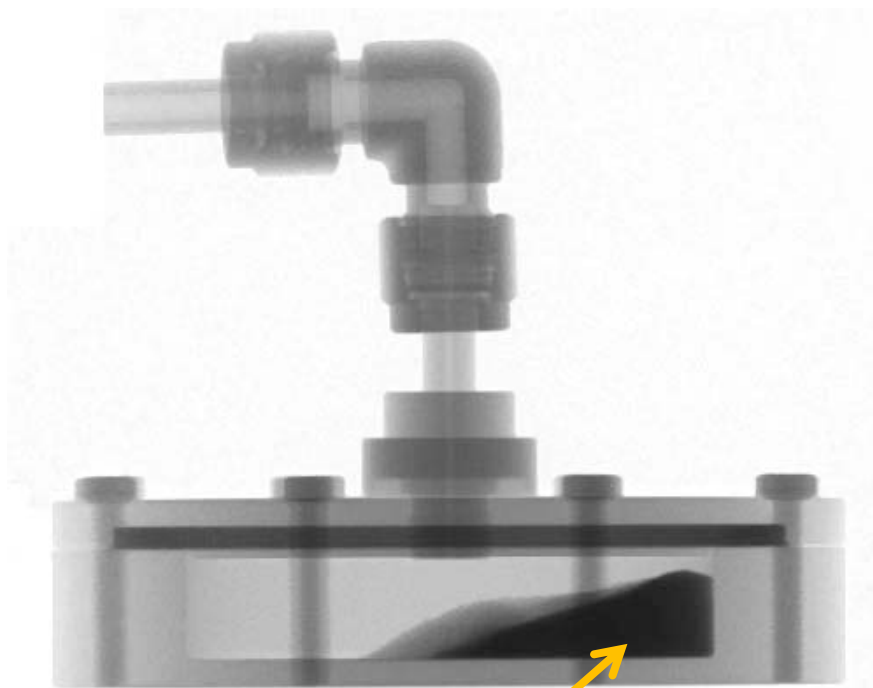




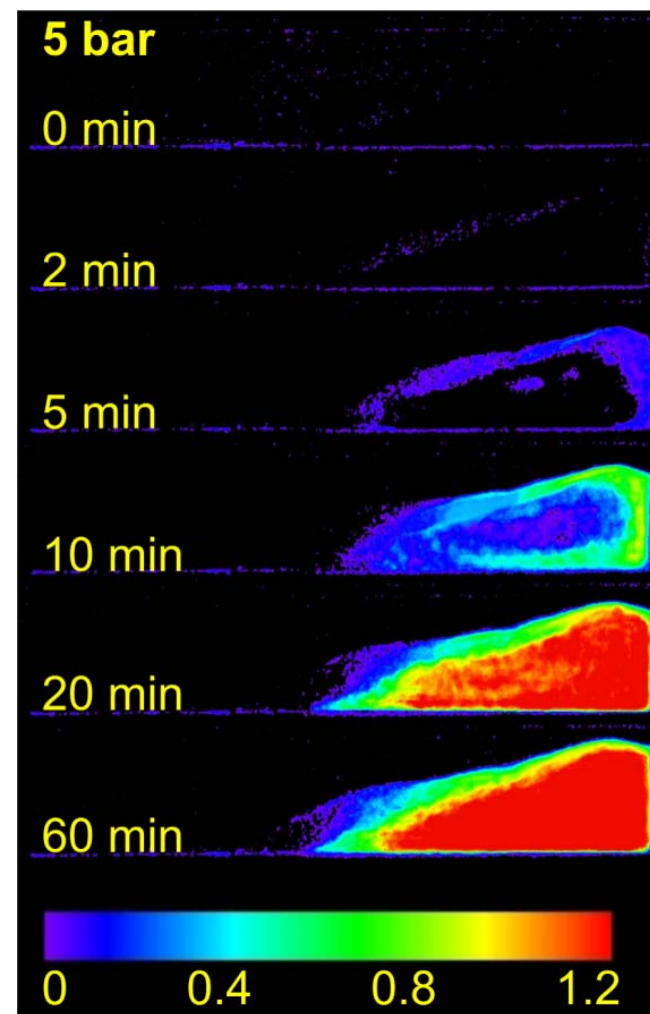
Rot = Wasserstoff

A. Griesche, E. Dabah, Th. Kannengießer, N. Kardjilov, A. Hilger, I. Manke  
*3D-imaging of hydrogen blister in steel with neutron tomography*  
**Acta Materialia**, 78, p. 14-22 (2014)

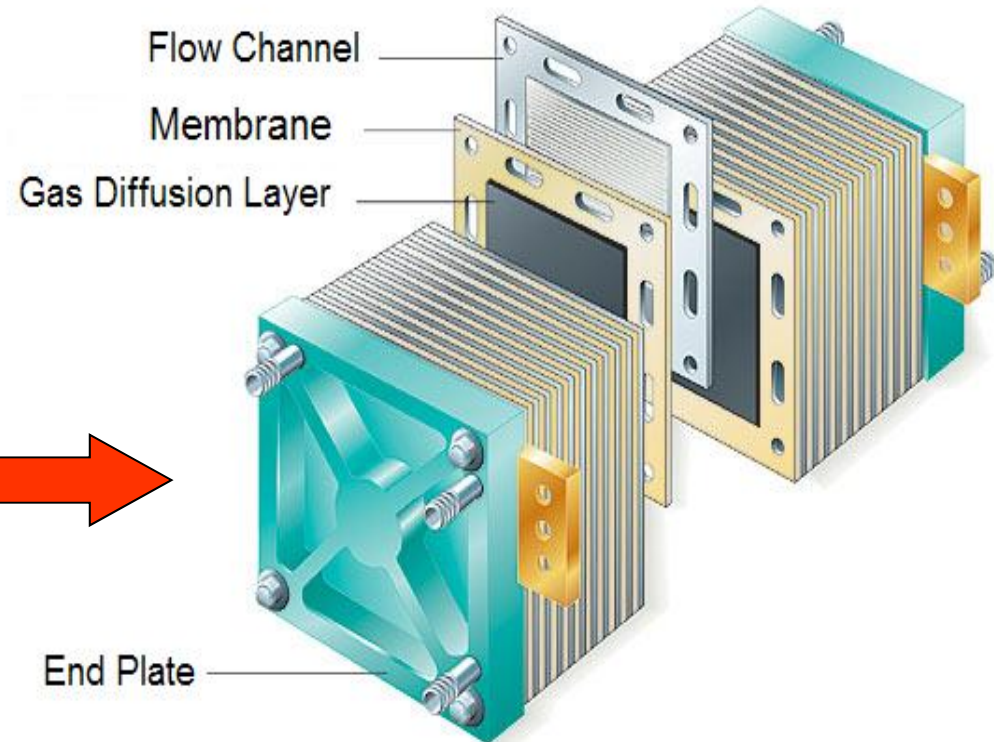




Speichermedium  
 $\text{LaNi}_{4.8}\text{Al}_{0.2}$



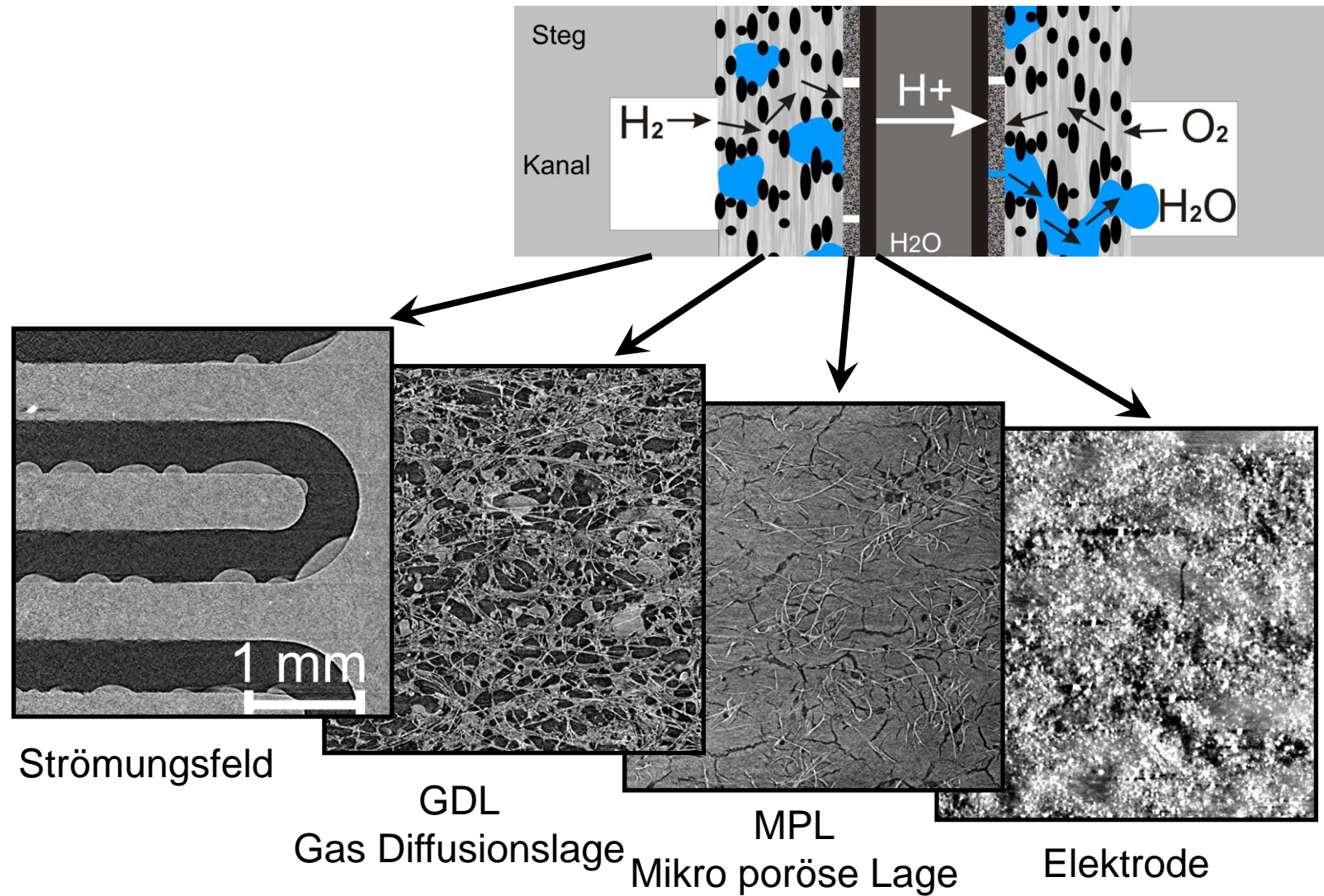
**Polymer-Elektrolyt-Membran Brennstoffzelle (PEM-BZ)**



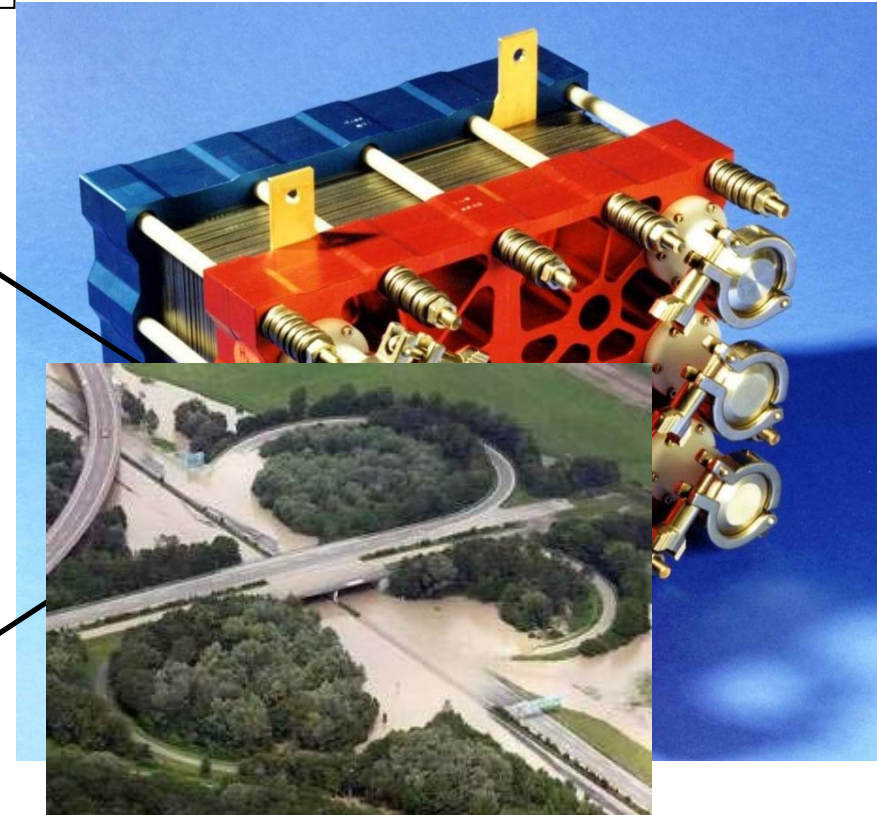
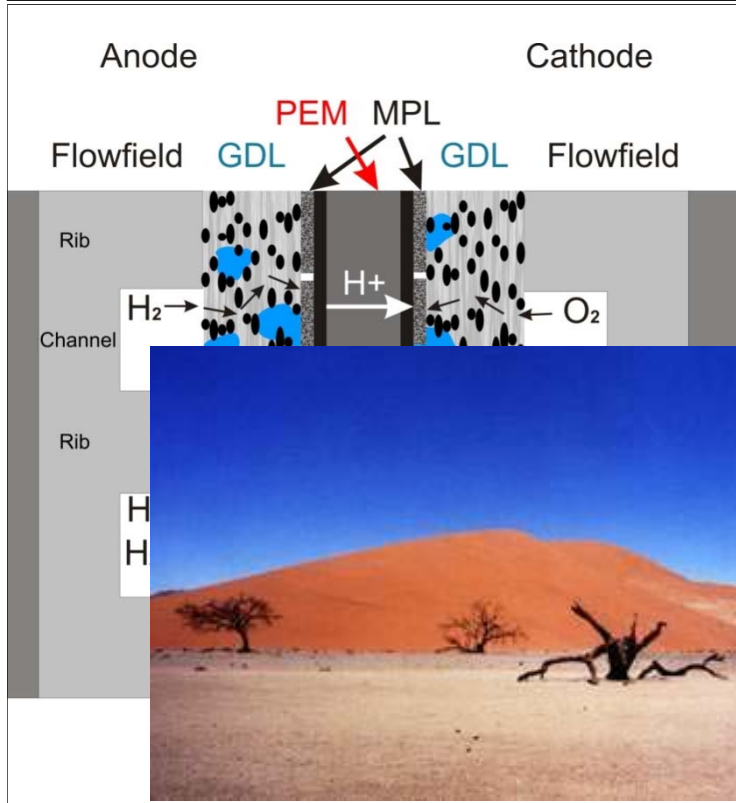
Brennstoffzellen-Stack

**Anwendung z. B. im  
Automobilsektor**

## Polymer-Elektrolyt-Membran Brennstoffzelle (PEM-BZ)







Trockene Membran verliert  
**Protonenleitfähigkeit**

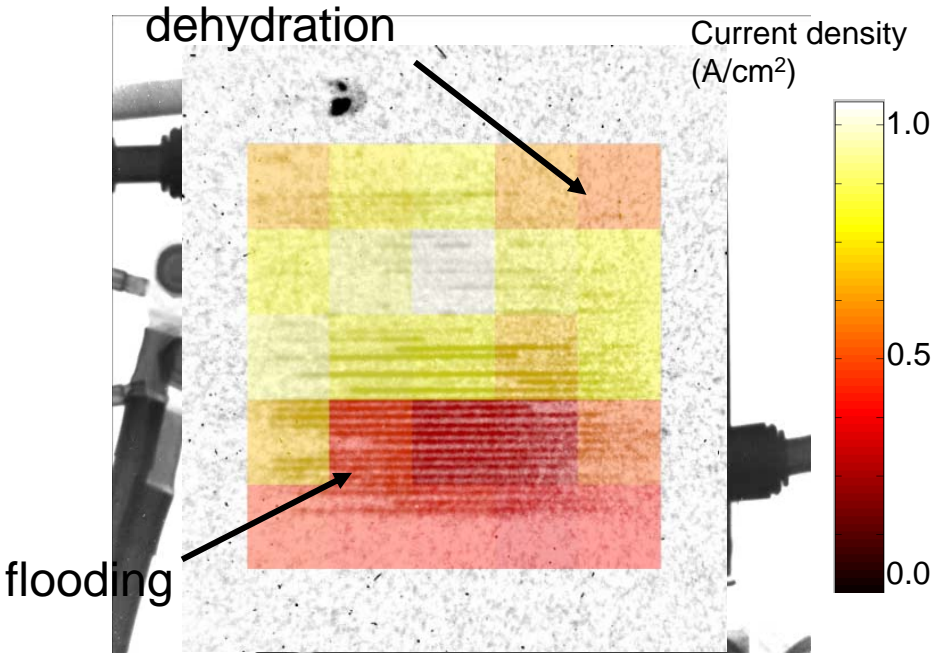
Wasseransammlungen blockieren  
**Gasversorgung**

**Optimierung des Wasser-Managements ist essentiell für die Funktionsfähigkeit**

PEM Fuel Cell (ZSW)      Neutron radiography (fast motion)



← 14 cm →



Simultaneous current density measurement

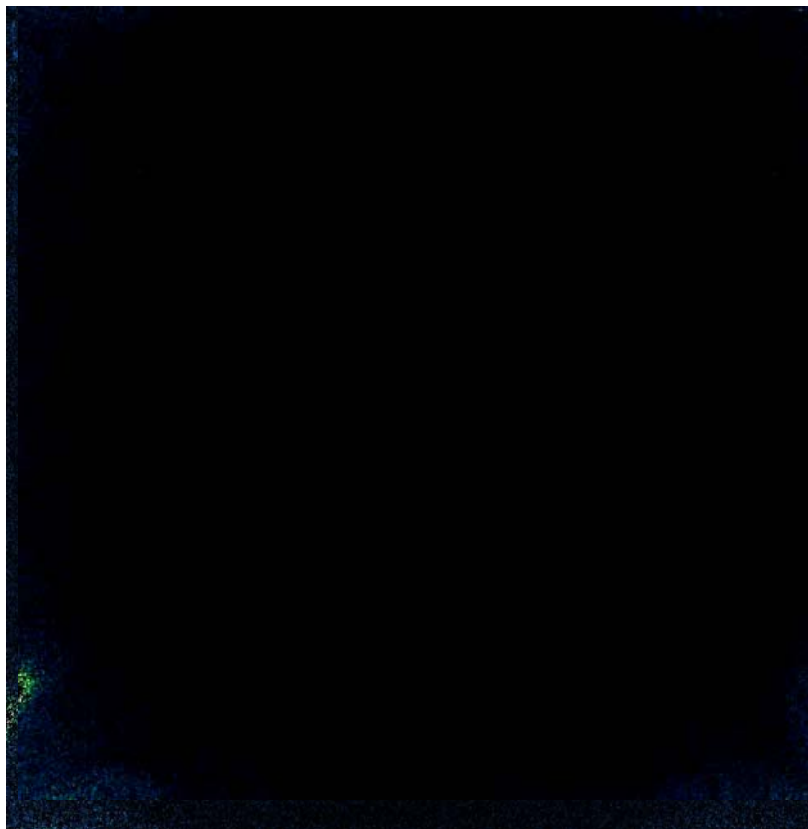
C. Hartnig, I. Manke, N. Kardjilov et al  
Journal of Power Sources **176**, 452-459  
(2008)

## GDL Hydrophobizität

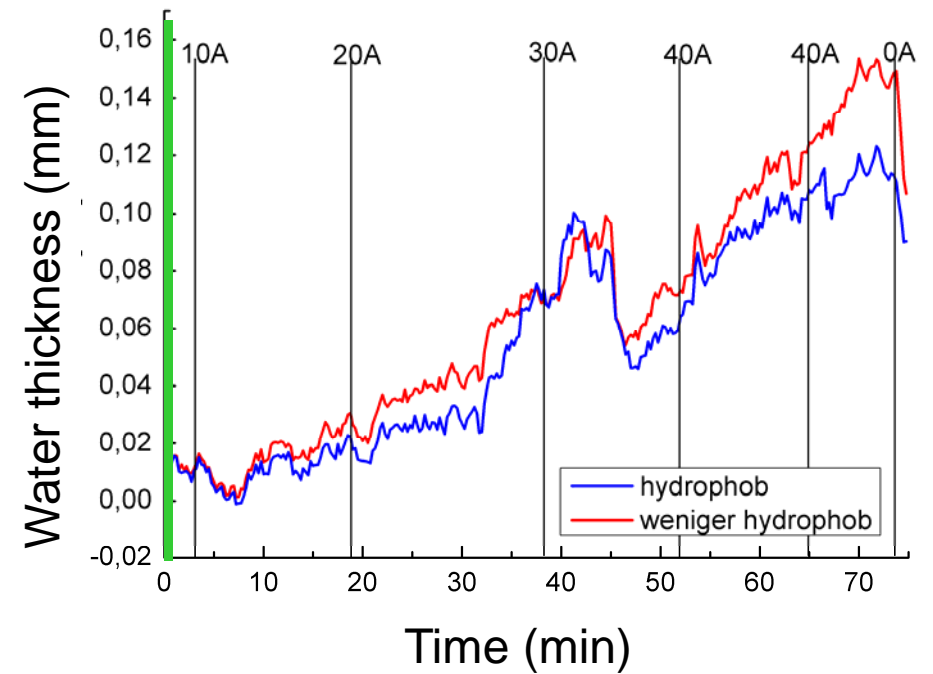
hoch

niedrig

1.5 mm  
1.0 mm  
0.5 mm  
0.0 mm



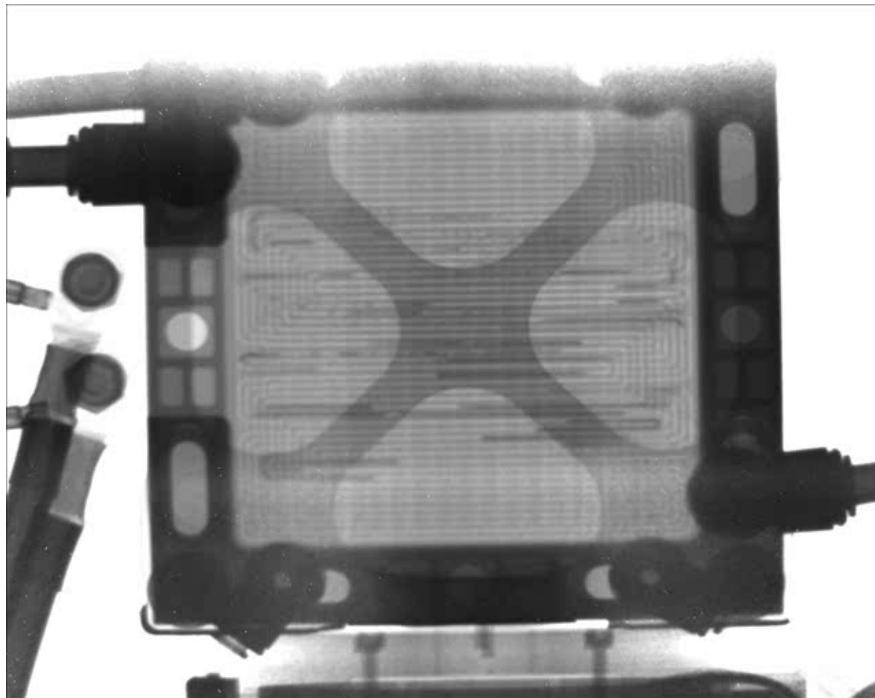
— weniger hydrophob  
— hydrophob



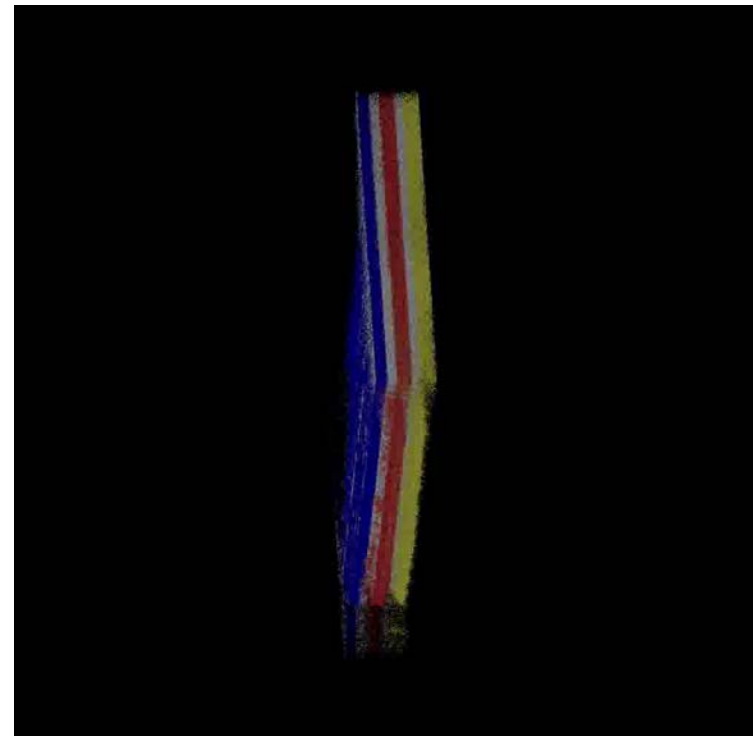
Einzelzellen

Brennstoffzellen-Stacks

2D



3D

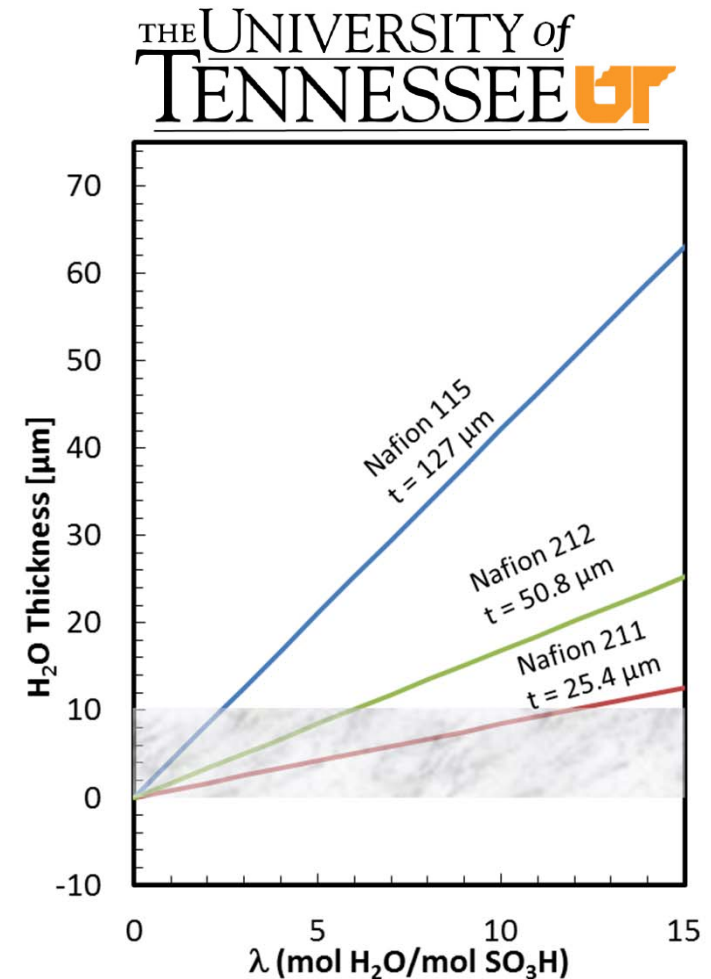
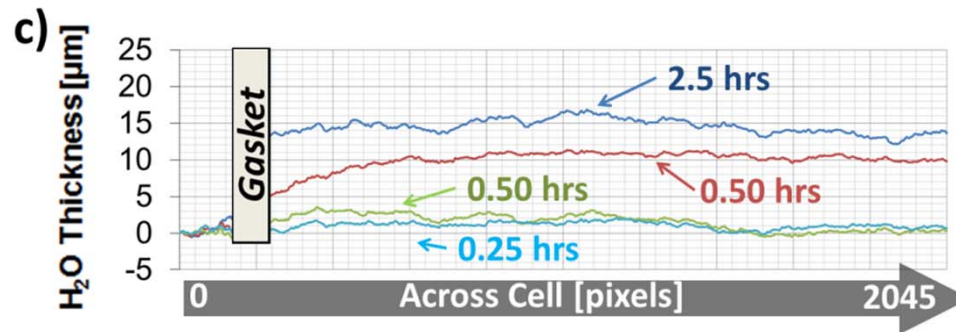
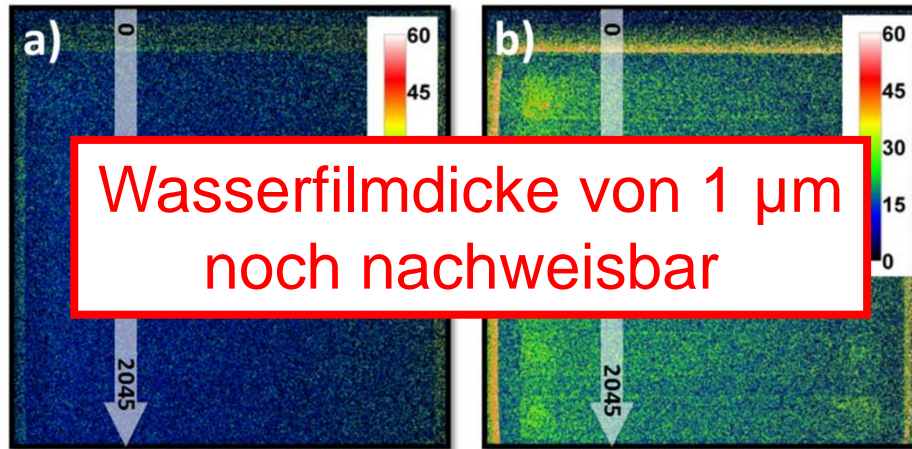




# Quantifizierungsgenauigkeit für Wasser

Membran: trocken

befeuchtet



J.R. Bunn, D. Penumadu et al.

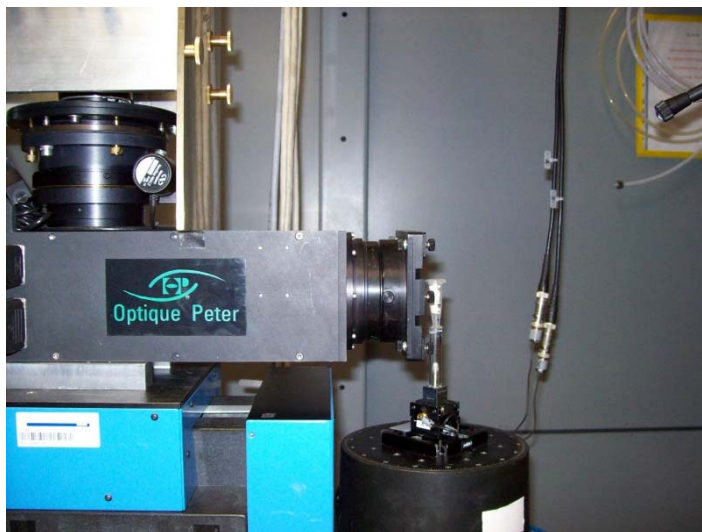
*Detection of water with high sensitivity to study PEM fuel cell membranes using cold neutrons at high spatial resolution*

**Applied Physics Letters**, to be submitted (2013)

## BESSY

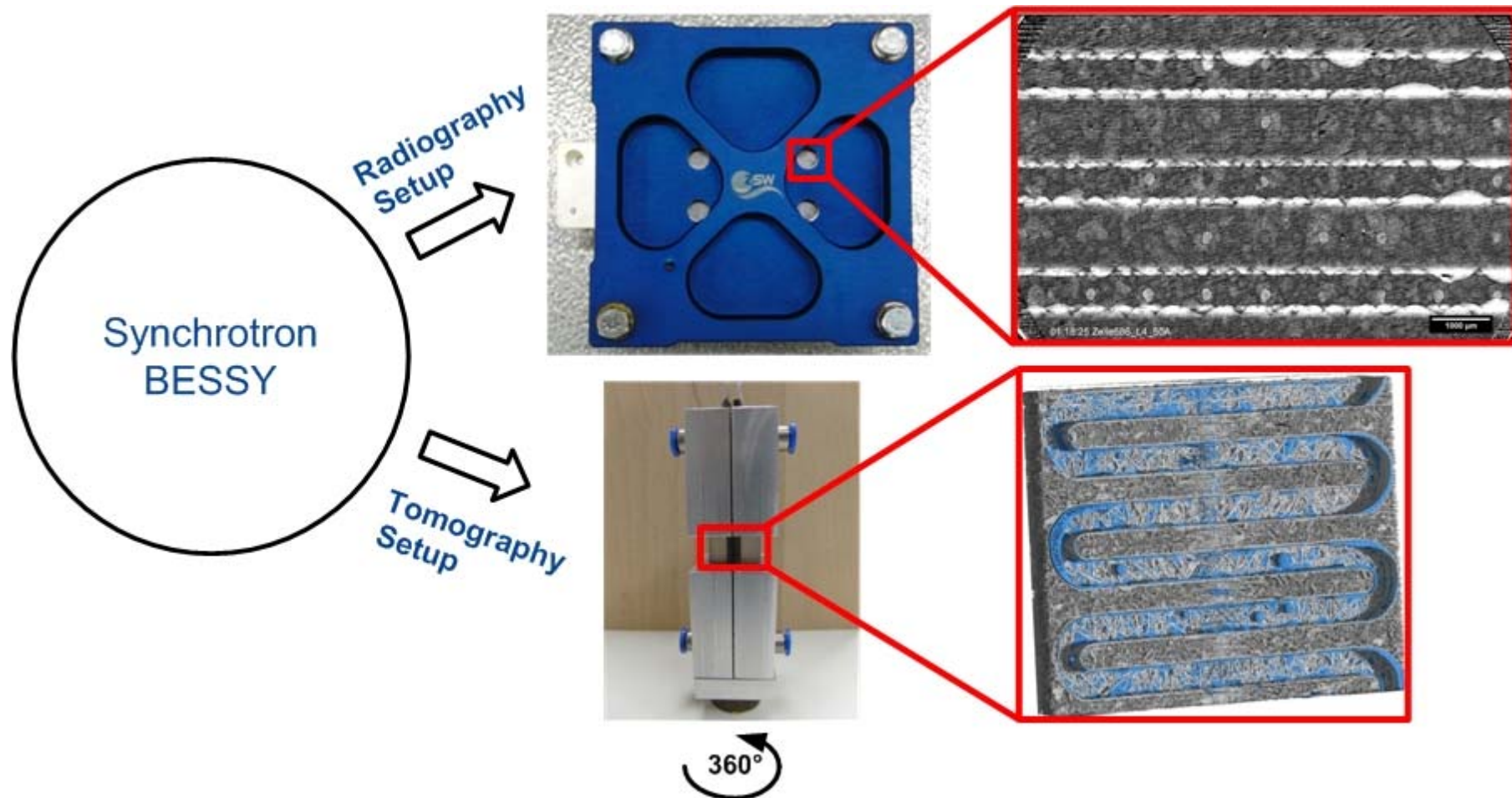


- Hohe Strahlintensitäten
- Monochromatische Strahlung
- Hohe Kohärenz



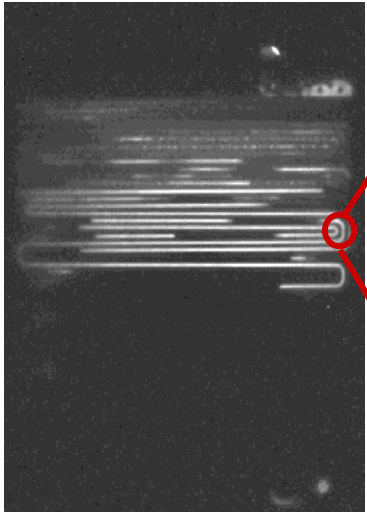
- Hohe Abbildungsgenauigkeit/Bildqualität
- Exzellente Quantifizierungsgenauigkeit
- Elementselektivität

# Synchrotron-Röntgen- Radiographie und -Tomographie



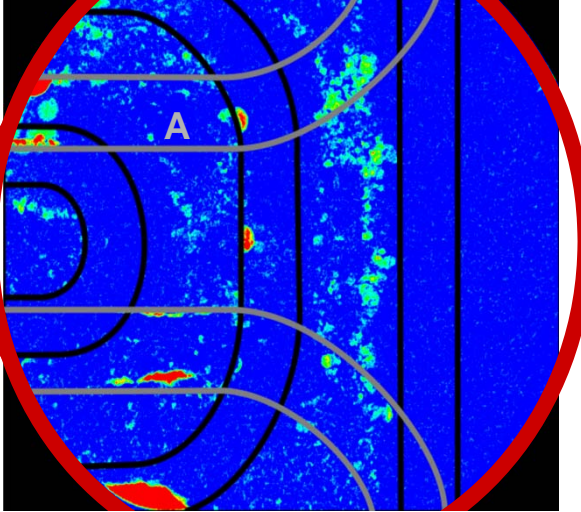
# Synchrotron-Röntgen-Radiographie

neutron radiography

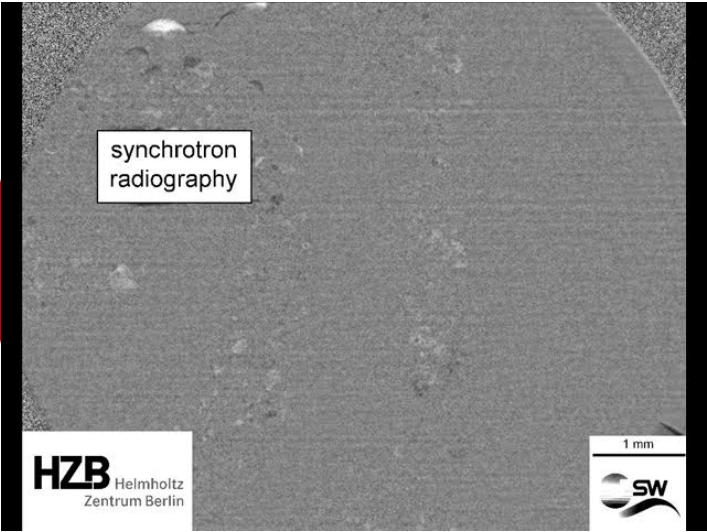


← 120 mm →

In-situ synchrotron radiography

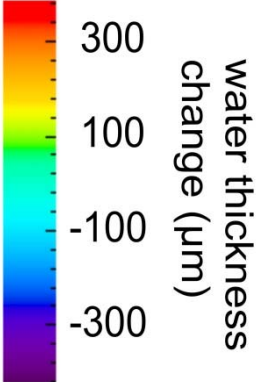
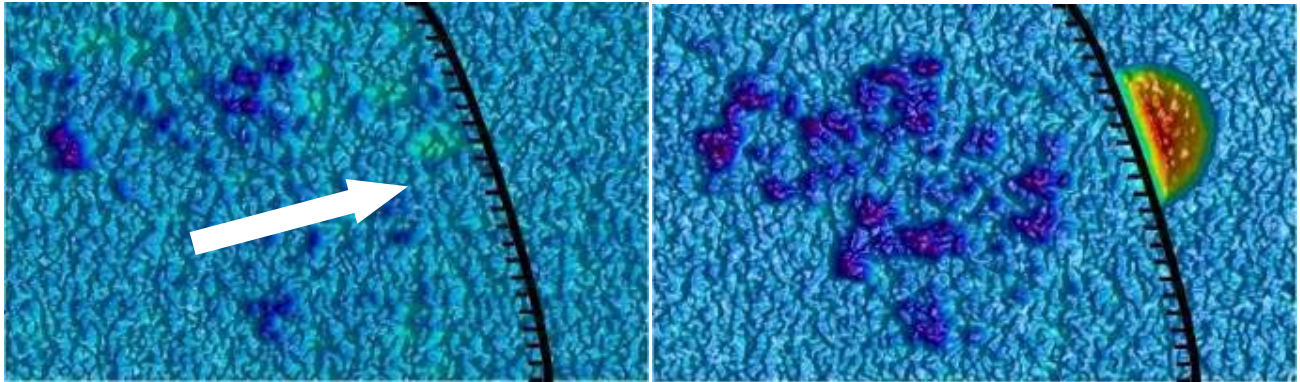


← 7 mm →

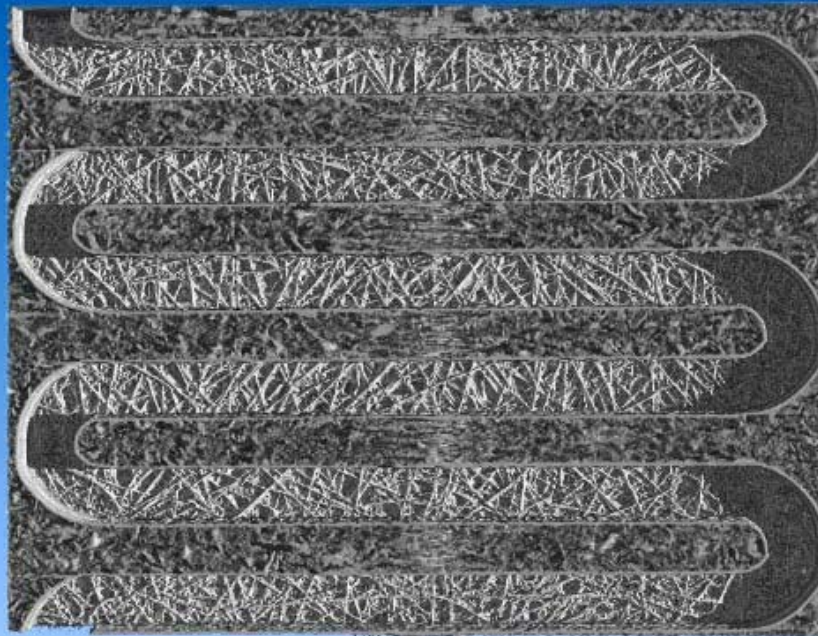


Water droplet dynamics

150 times fast motion



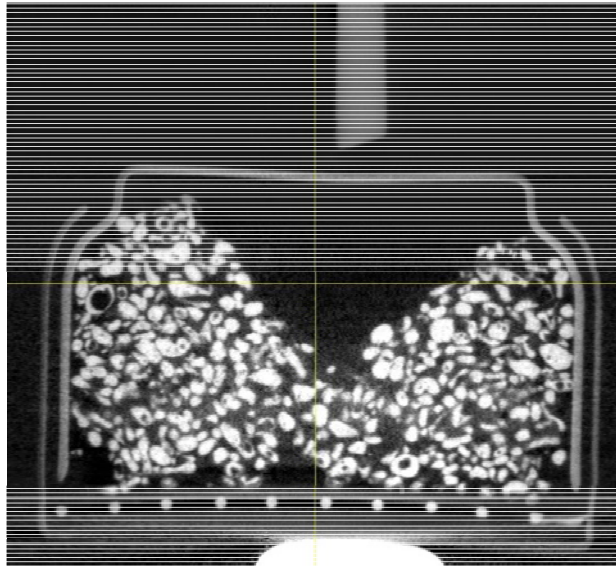
I. Manke et al., **APL** 90, 174105 (2007), Ch. Hartnig et al., **APL** 92, 134106 (2008)  
Ch. Hartnig et al., **J. Power Sources** 188 (2009), I. Manke et al., **APL** 92, 244101 (2008)



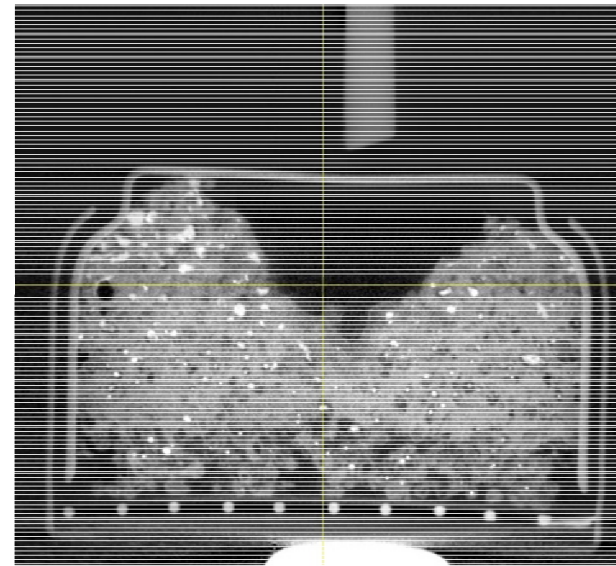
1mm  
┆

Quantifizierung der Wassermengen  
mittels Differenz-Tomographie

Voll geladen



Entladen



Neuwertig



Überladen



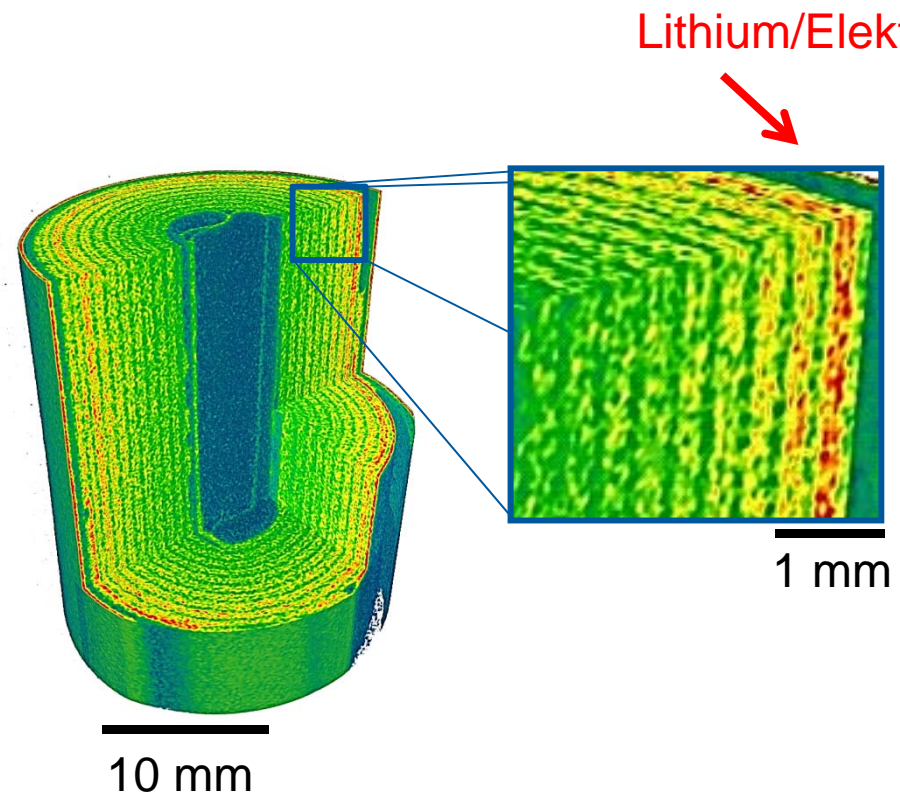
## Neutronen-Tomographie

LiJ-Batterie



Lithium

LiCoO<sub>2</sub>-Batterie





# Acknowledgements



**Bundesanstalt für  
Materialforschung  
und -prüfung**

B. Müller, A. Kupsch,  
A. Lange, M. Hentschel



W. Lehnert, W. Maier, D. Froning



V. Schmidt, R. Thiemann,  
G. Gaiselmann



N. Kardjilov, A. Hilger, F. Wieder,  
Ch. Tötzke, T. Arlt, H. Markötter  
R. Grothausmann, J. Banhart



J. Scholta, M. Messerschmidt,  
M. Klages, J. Haußmann,  
R. Kuhn, Ph. Krüger,  
F. Häussler, S. Kleinau

# Vielen Dank für Ihre Aufmerksamkeit!

