



Wir schaffen Wissen – heute für morgen

Christian Grünzweig

Neutron Imaging & Activation Group, Paul Scherrer Institut, Switzerland

Application range of neutron imaging

Outline

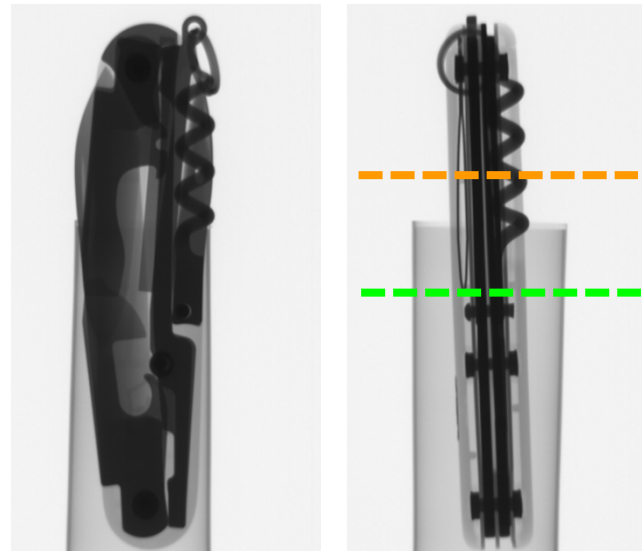
1. Motivation and complementary character compared to X-ray imaging
2. Do we need neutron imaging? Any application range left?
3. The application range and limits of conventional attenuation based neutron imaging concerning
 - the spatial resolution and object dimension
 - the temporal resolution
3. Advanced Imaging techniques and their application range
 - Diffractive imaging
 - Scattering based imaging
4. Conclusion and outlook

Swiss army knife: X-ray vs. neutrons

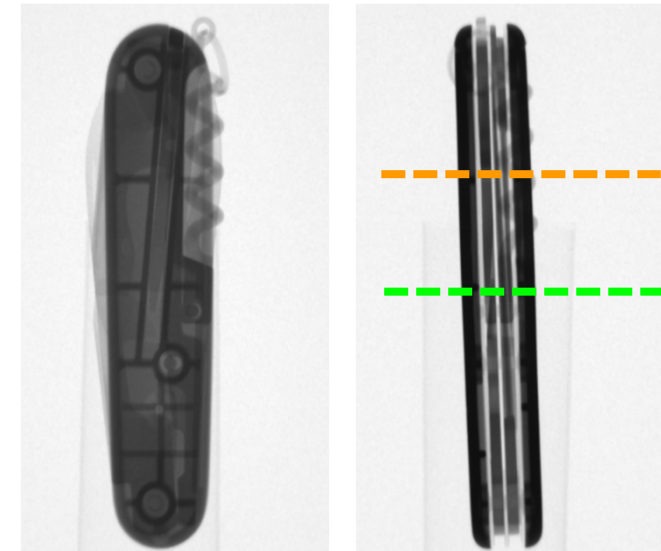


2D Projections

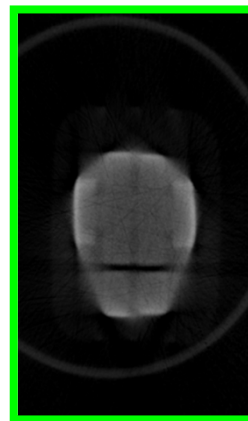
X-rays



Neutrons



3D tomo slices

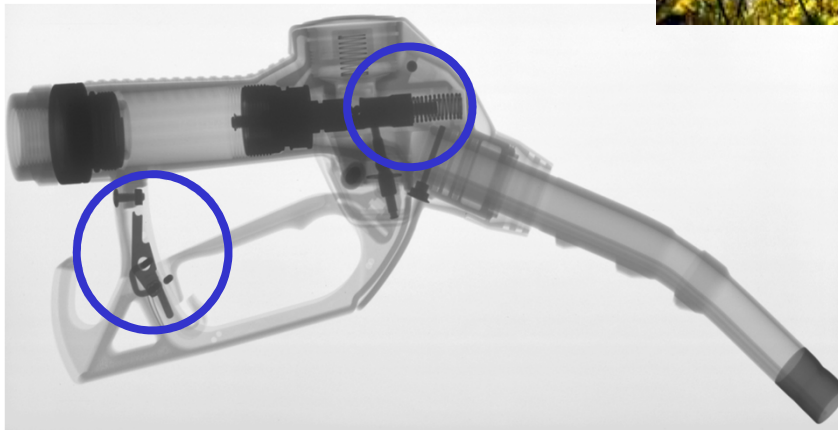


Swiss army knife: 3D lubricant distribution



X-ray vs. Neutrons

X-rays



Neutronen



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Do we need neutron imaging?

Any application range left?

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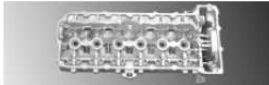
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- › Lithium-ion batteries
- › Aerospace

Applications

X-ray inspection is the inspection standard in many industrial sectors


An overview of the different applications for X-ray inspection is being given on this page. 2D and 3D X-raying number among the procedures for imaging. The applications have been summarized into topics.



Cast parts

Reliable detection of defects in casting parts via X-ray technology.


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Electronics

Inspection of electronics components using 2D und 3D in order to safeguard assembly function.


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Welds

Weld inspection in the field and during production places special demands on X-ray systems.


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Tires and rubber

Flaws in the reinforcement, foreign objects and air inclusions are detected reliably using X-ray systems.


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Fiber-reinforced materials and plastics

The inner construction must be inspected to ensure strength, function and completeness.


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Material analysis

Analysis of soil samples to ensure profitable development of raw materials.

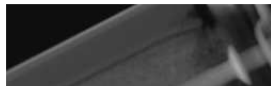
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Cultural assets

Prior to restoring statues, paintings or sculptures, their inner construction is analyzed using X-rays.


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Lithium-ion batteries

eMobility depends on the quality of the lithium-ion batteries. This quality is ensured using X-ray inspection.

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Aerospace

Reliable inspection for a variety of materials and aircraft parts

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Thank you for your attention



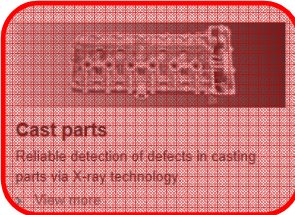
Do we need neutron imaging?


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Massiver Aluminium Zylinderblock

Bild



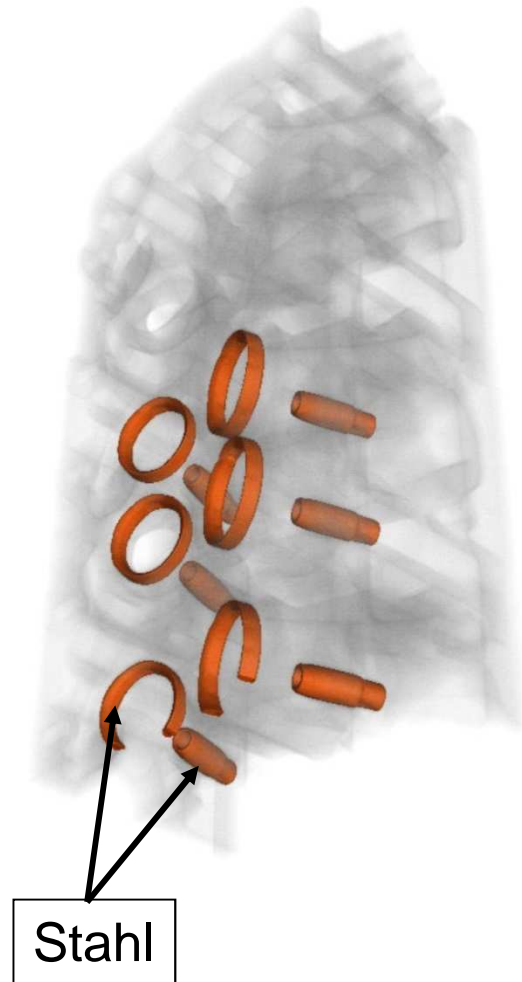
Tomographie

- Aussenaufnahme -



Tomographie

- Segmentierung -



Defects in an Aluminium casting

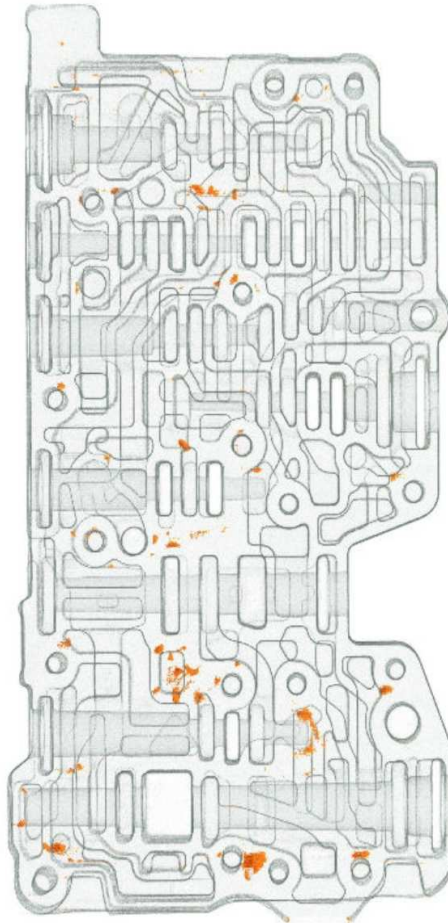
Tomography

- 3D rendering -



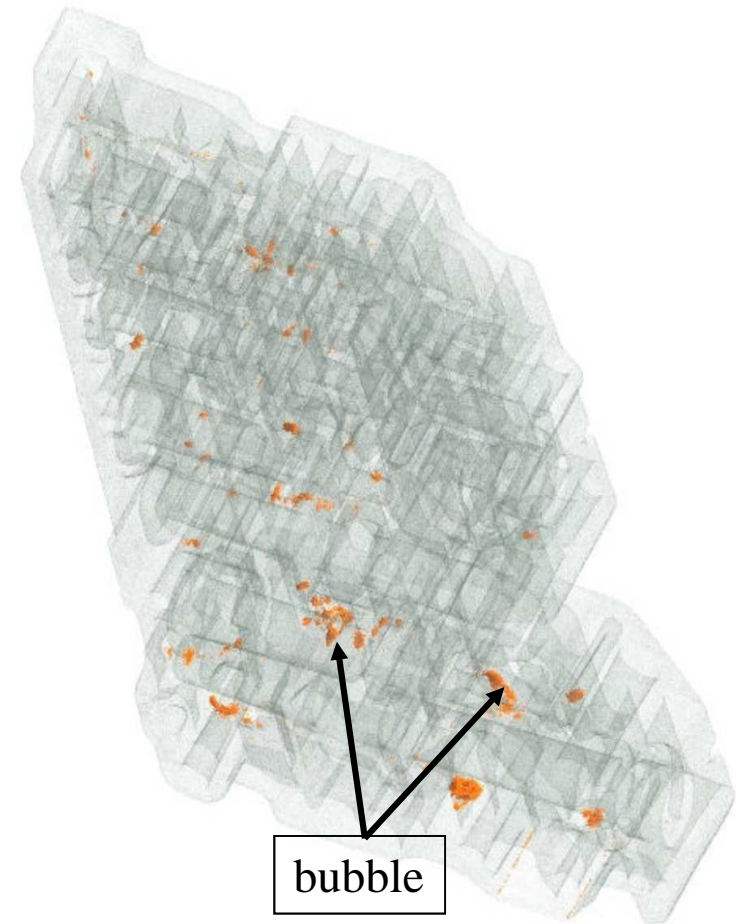
Tomography

- Segmentation -



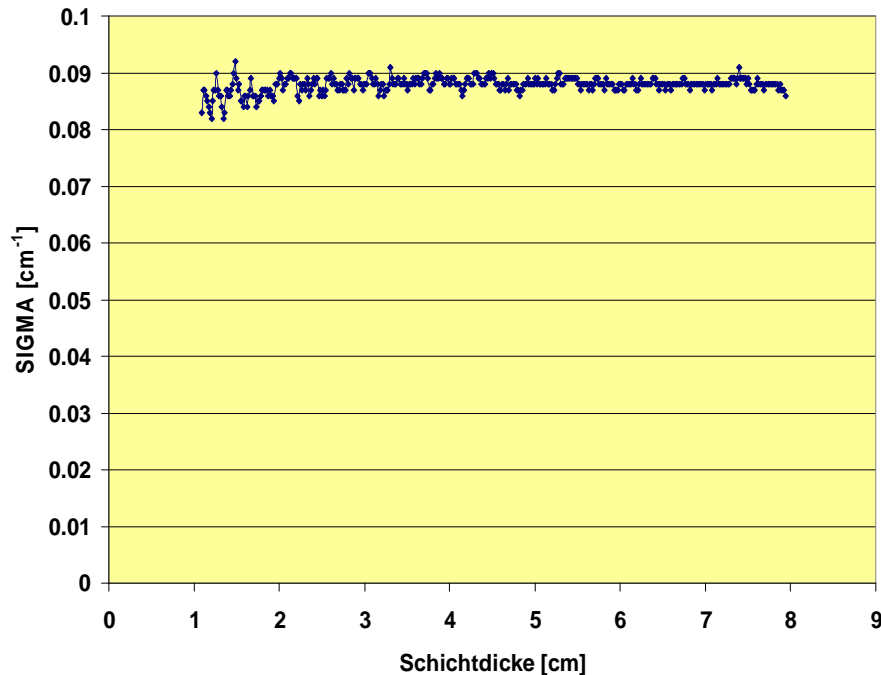
Tomography

- Segmentation -

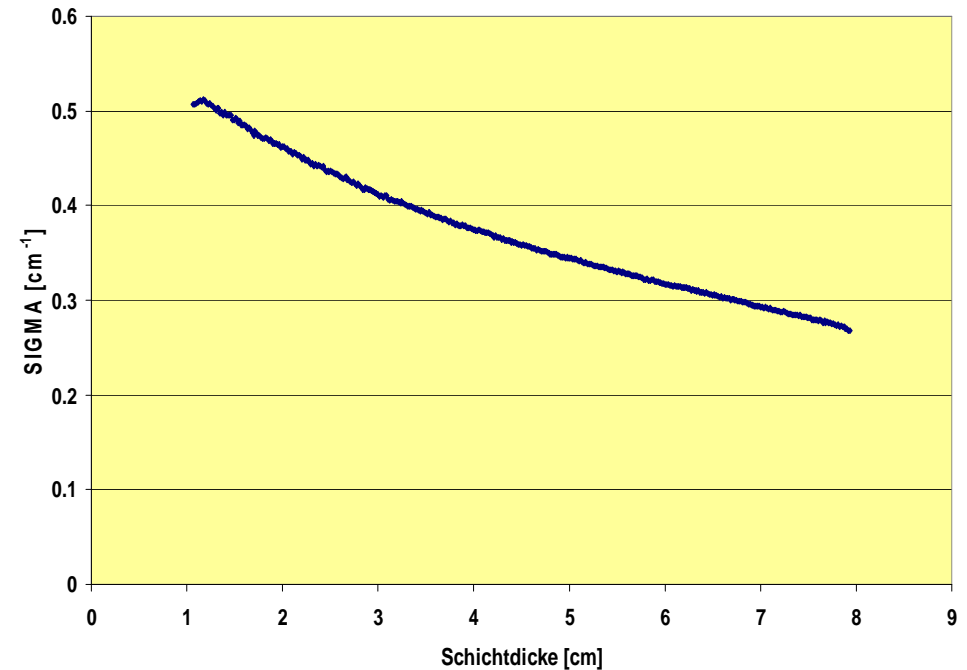


Wirkungsquerschnitt von Aluminium

für thermische Neutronen



für X-Rays



keine konstanten Werte für X-rays -> „beam hardening“ -> Fehler in der Tomographie

Neutronen erlauben eine direkte Quantifizierung der Tomographiedaten

Overview

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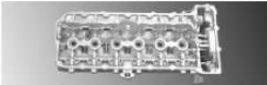
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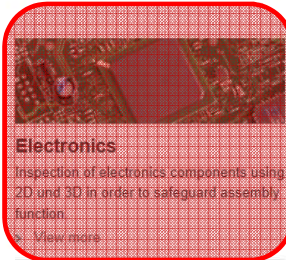
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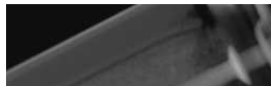
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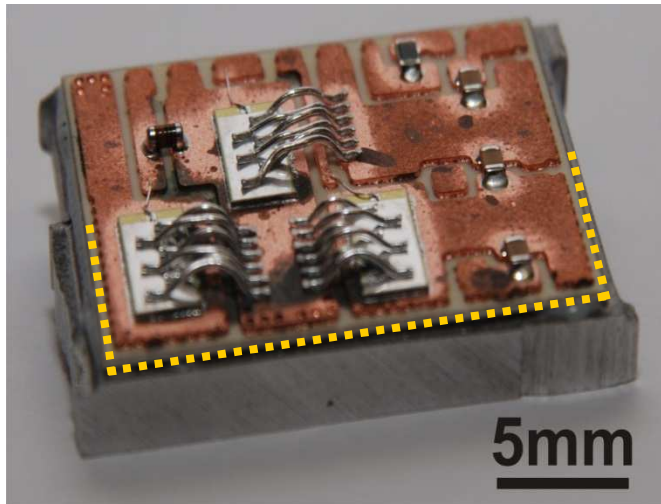
Aerospace

Reliable inspection for a variety of materials and aircraft parts

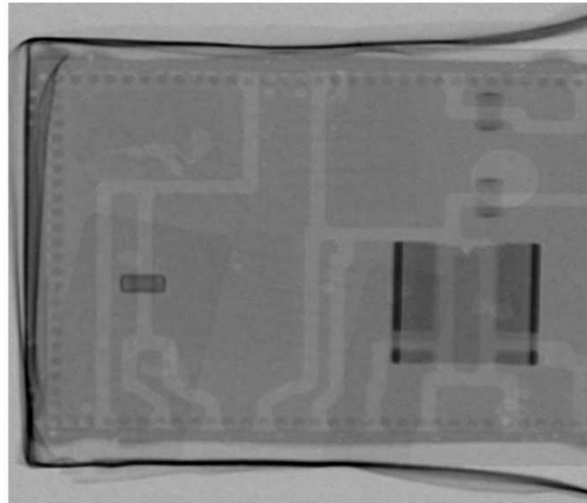
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Degree of utilization of a adhesive joint

Image




Radiography



Micro-tomography

Overview


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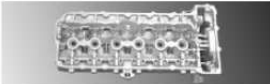
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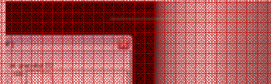
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Material analysis

Analysis of soil samples to ensure profitable development of raw materials.

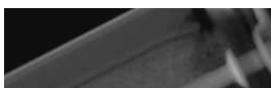
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Reliable inspection for a variety of materials and aircraft parts

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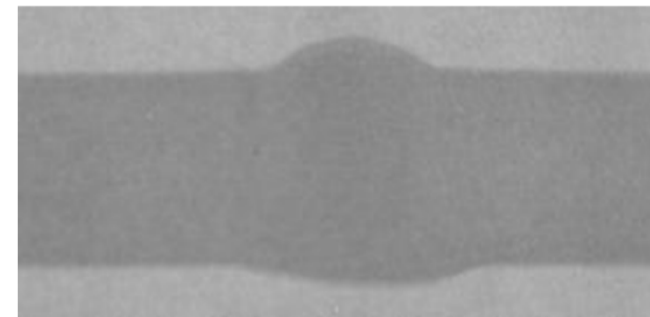
Diffraction Imaging: Bragg edges

$$\sigma(\lambda) = \frac{\lambda^2}{4V_0} \sum_{hkl}^{2d_{hkl} < \lambda} |F_{hkl}|^2 d_{hkl}$$
$$2d_{hkl} \sin \theta = \lambda_{hkl}$$

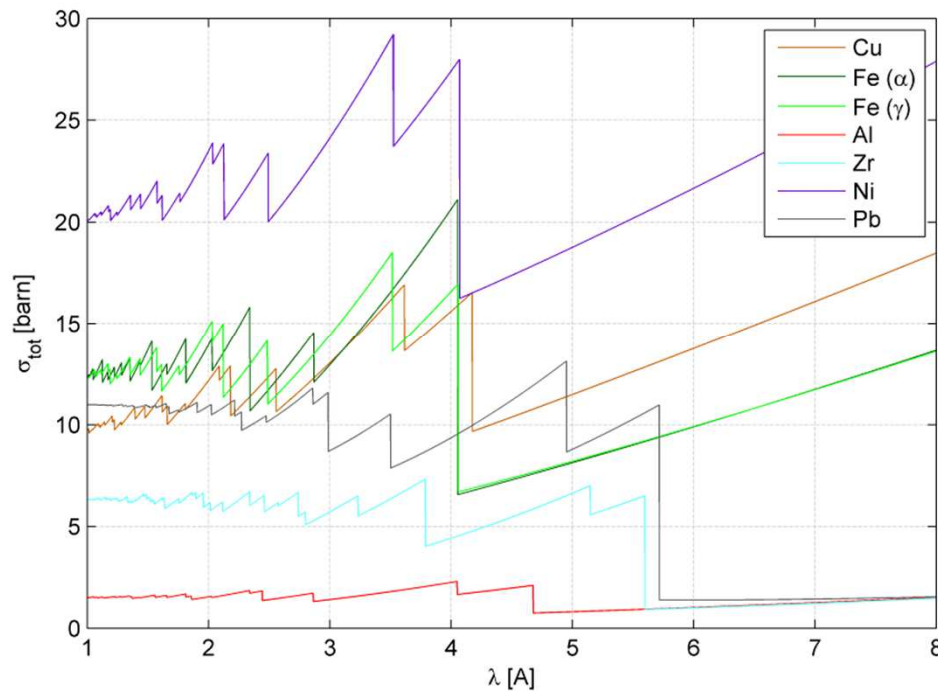
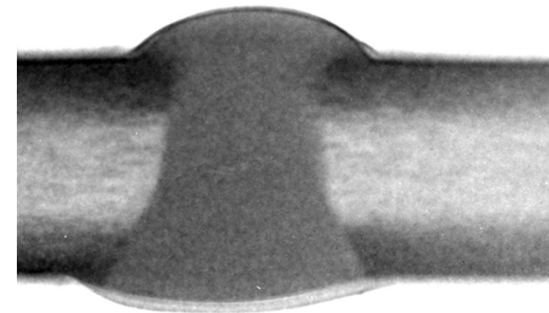
Photo



White beam



Energy selective



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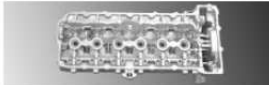
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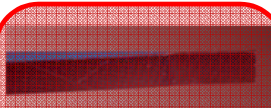
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Tires and rubber

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Fiber-reinforced materials and plastics

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Material analysis

Analysis of soil samples to ensure profitable development of raw materials.

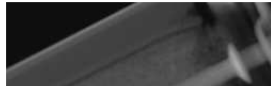
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Prior to restoring statues, paintings or sculptures, their inner construction is analyzed using X-rays.


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Lithium-ion batteries

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Aerospace

Reliable inspection for a variety of materials and aircraft parts.

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GLARE "Glass Laminate Aluminium Reinforced Epoxy"



Beim **Airbus A380** kommt *Glare*
großflächig zum Einsatz.



GLARE "Glass Laminate Aluminium Reinforced Epoxy"

4/3 layers, 0° fiber angle, 97% ultimate load

Field of view: 27 x 27 mm²

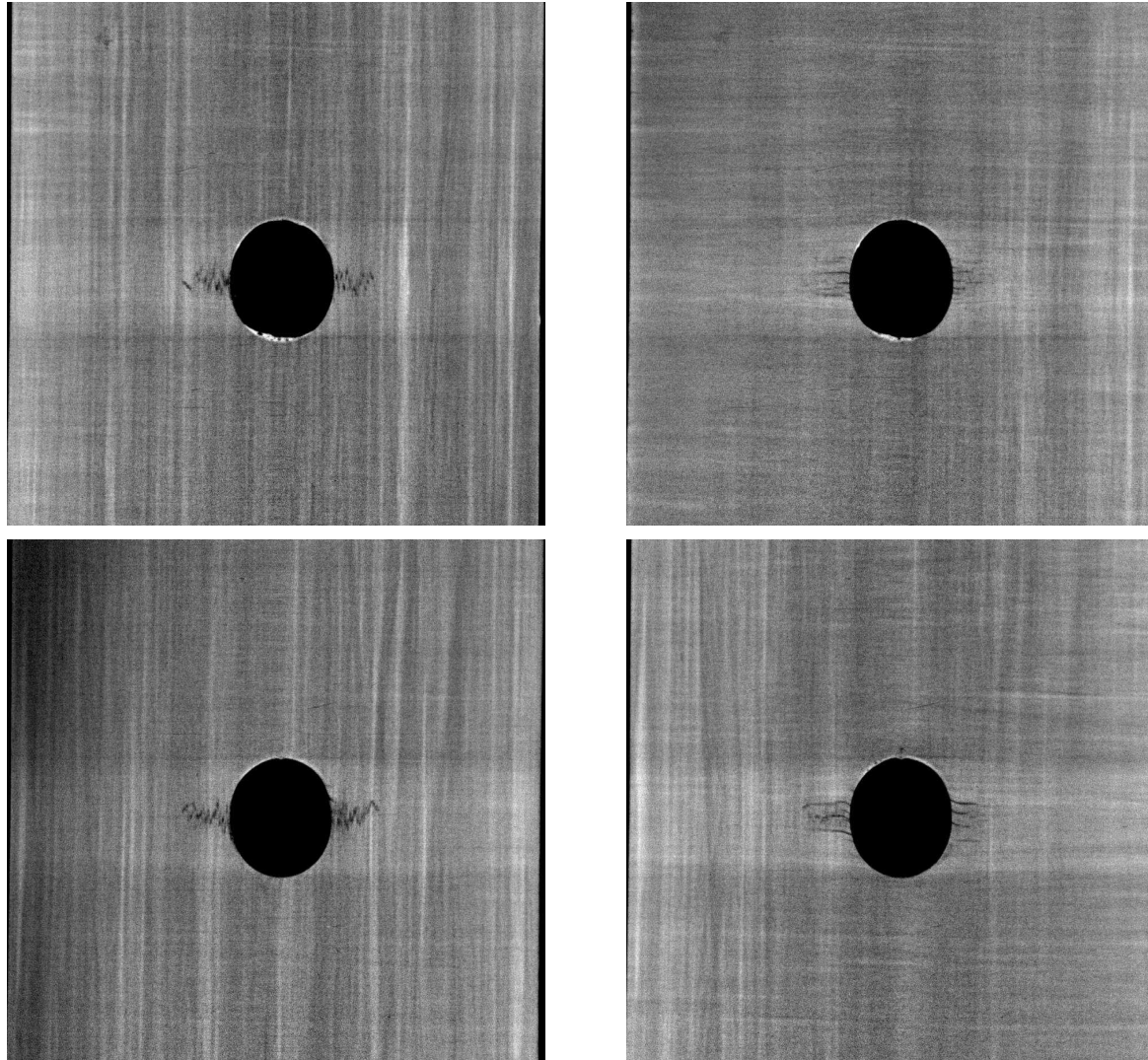
Nominal pixel resolution: 13,5 µm

GLARE "Glass Laminate Aluminium Reinforced Epoxy"

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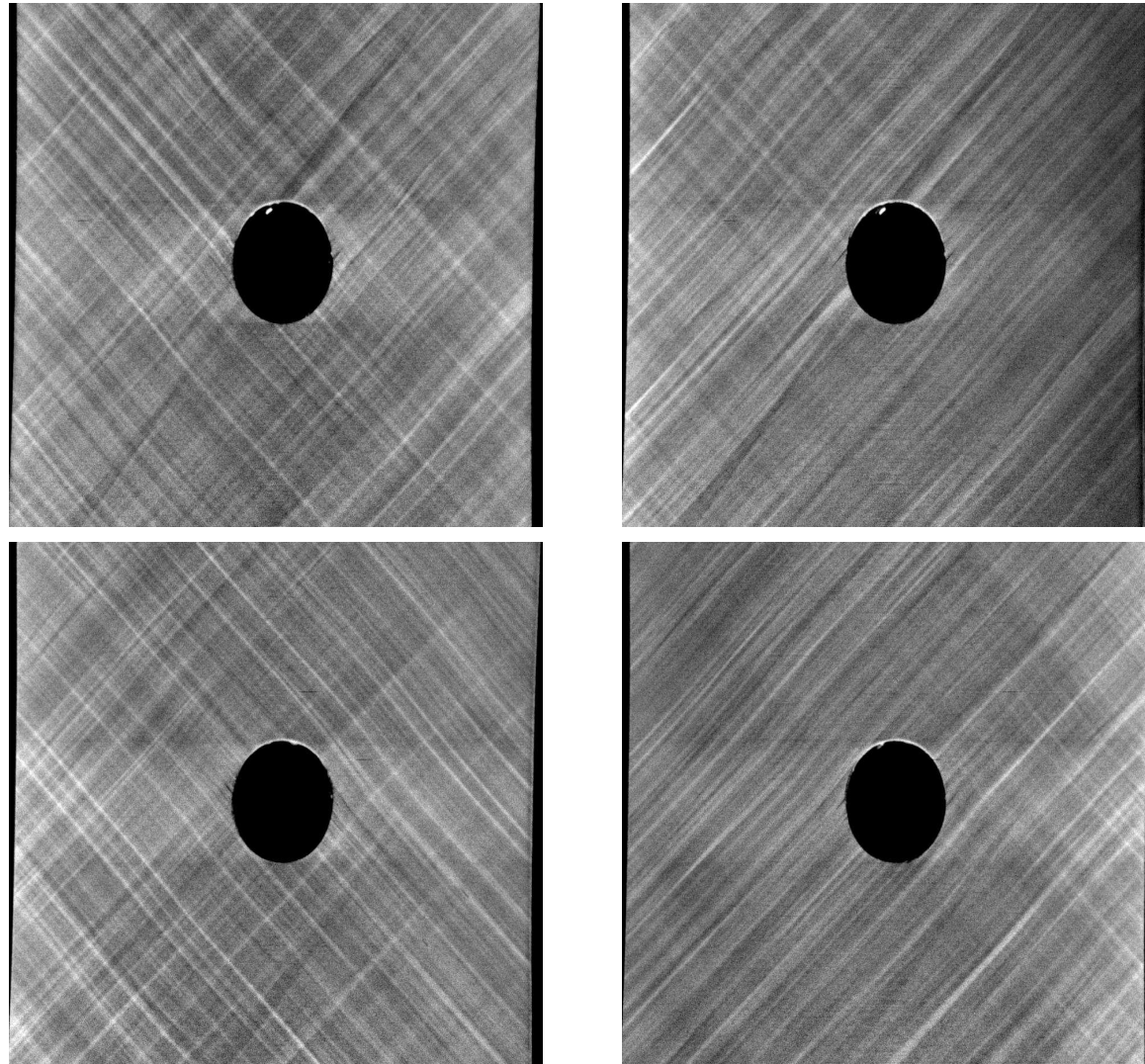


GLARE "Glass Laminate Aluminium Reinforced Epoxy"

4/3 layers, 45° fiber angle, 97% ultimate load

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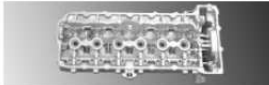
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Tires and rubber

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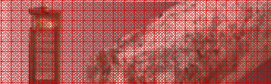
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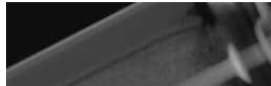
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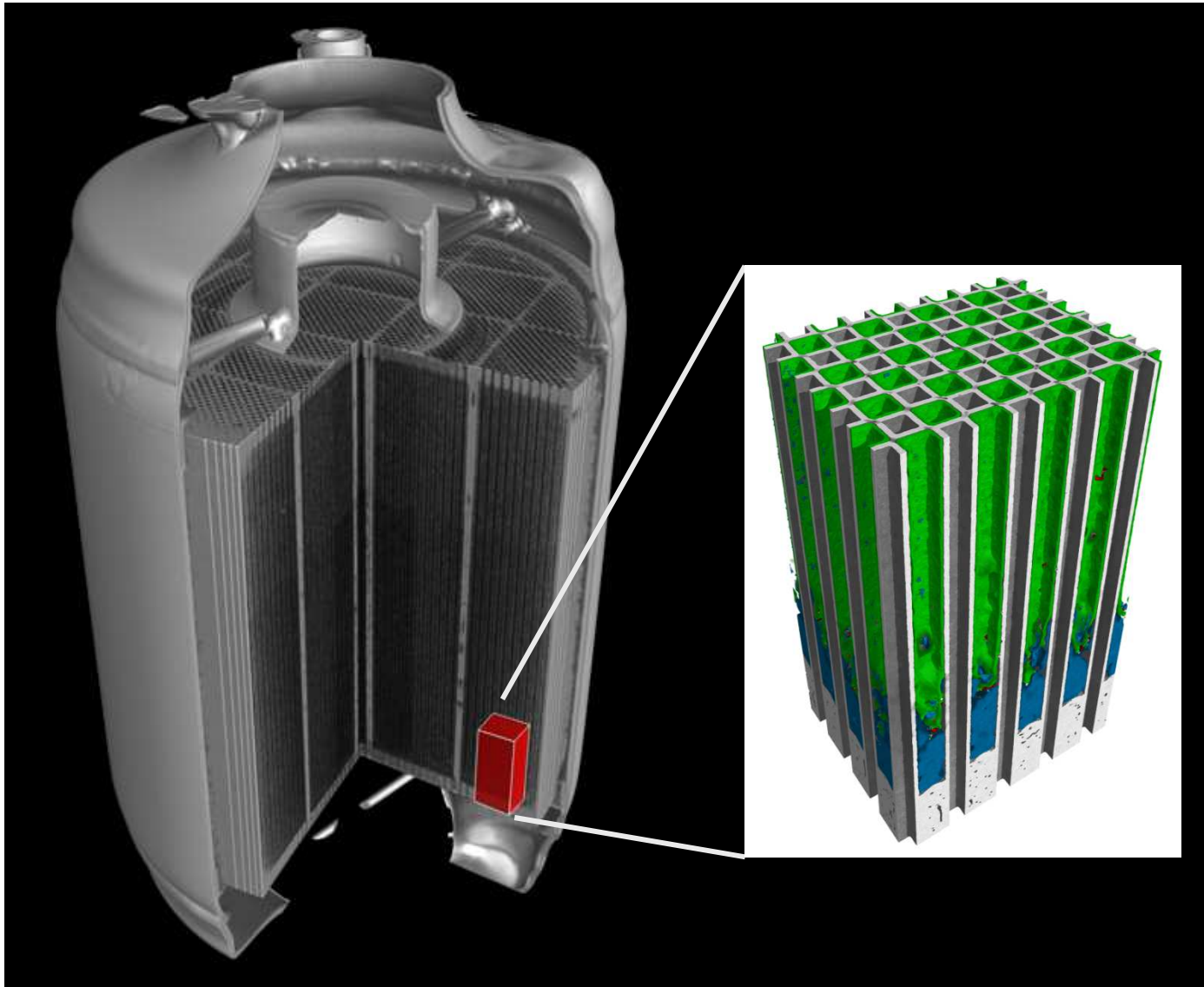


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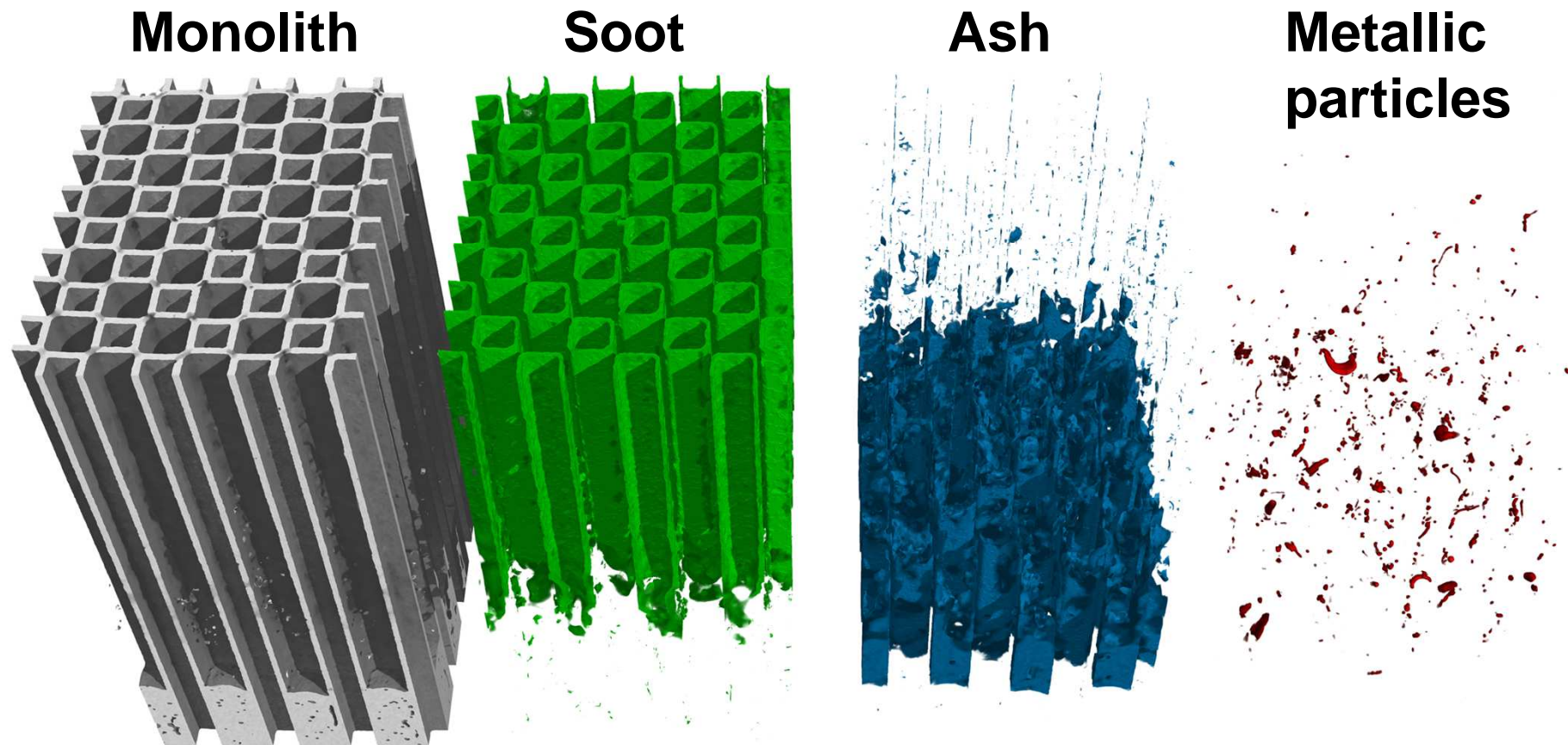
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Diesel particulate filter



Diesel particulate filter, Micro-setup



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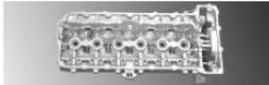
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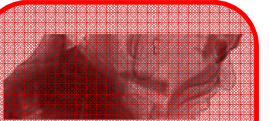
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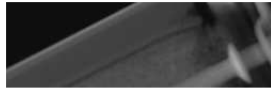
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Cultural heritage

X-rays



Bronze Buddha



Neutronen



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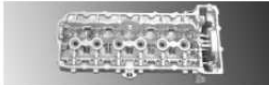
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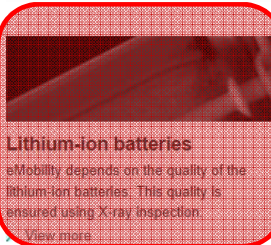
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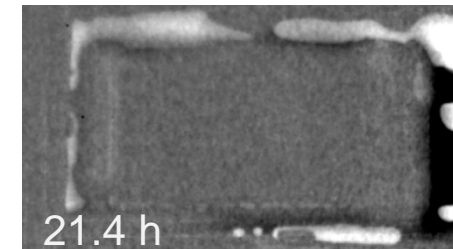
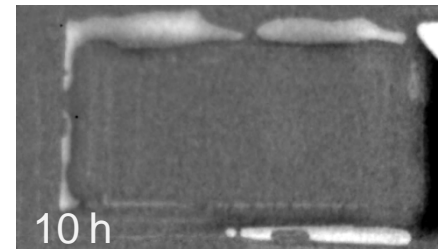
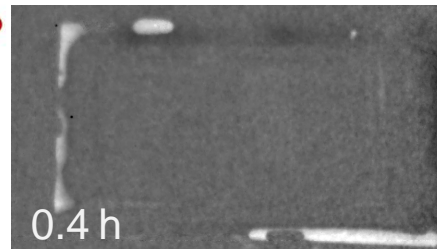
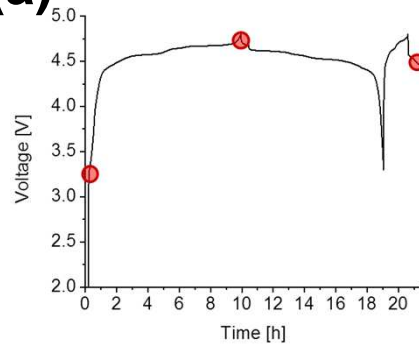
Aerospace

Reliable inspection for a variety of materials and aircraft parts

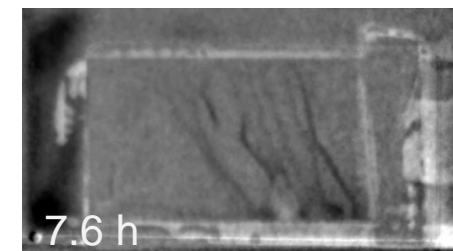
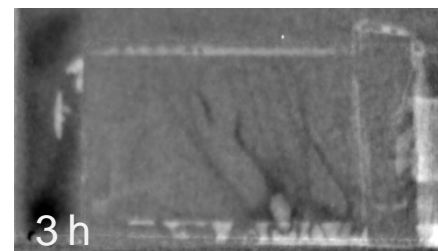
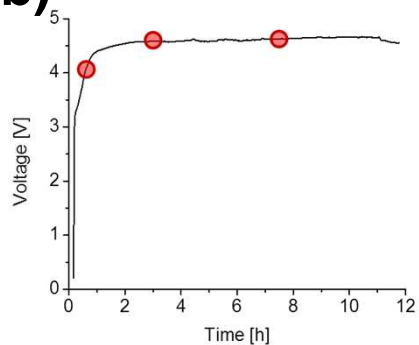
[View more](#)

Gas formation in pouch cells

(a) LNMO/graphite - *sufficient* pouch cell pressure



(b) LNMO/graphite - *insufficient* pouch cell pressure



Outline

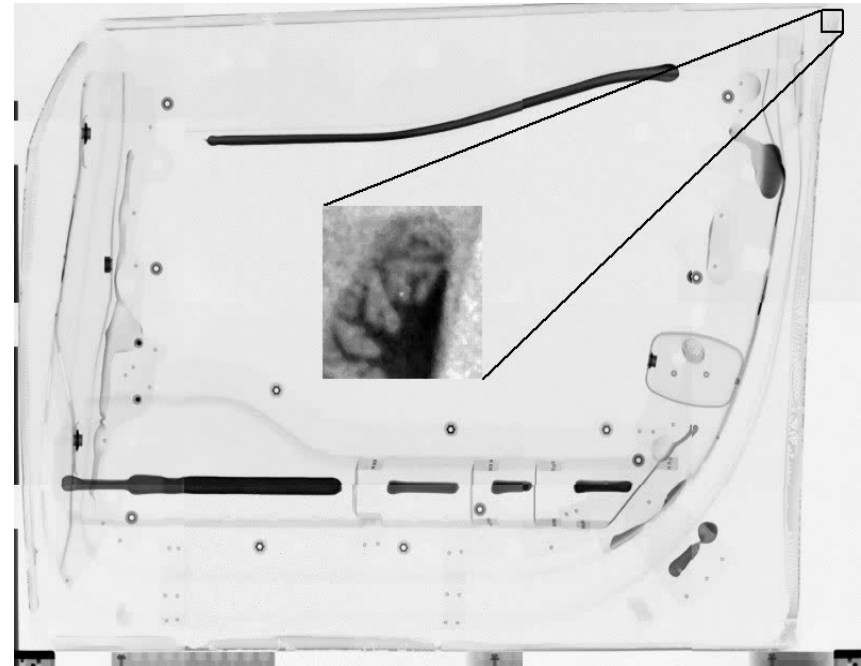
1. Motivation and complementary character compared to X-ray imaging
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Inspection of a glewed car door

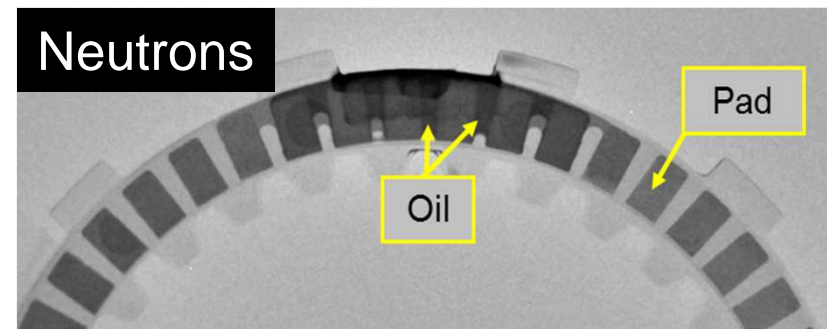
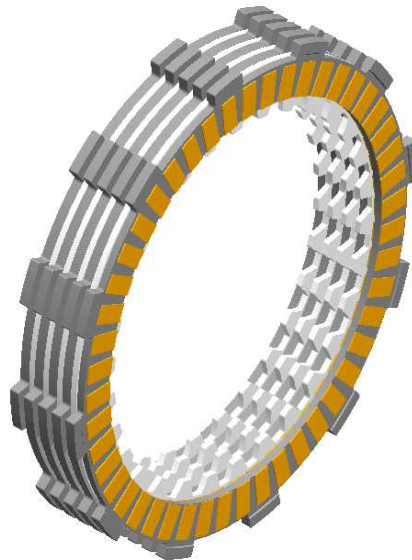
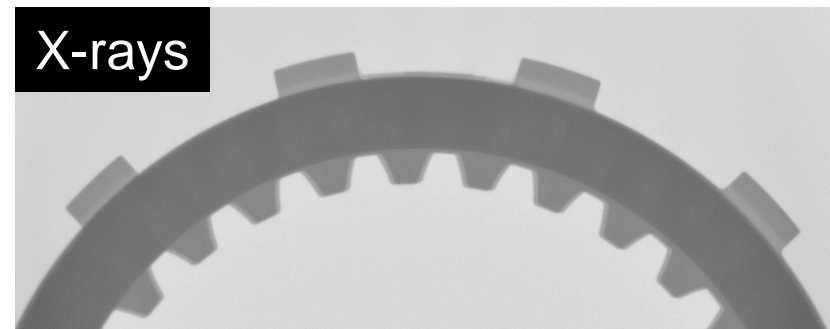
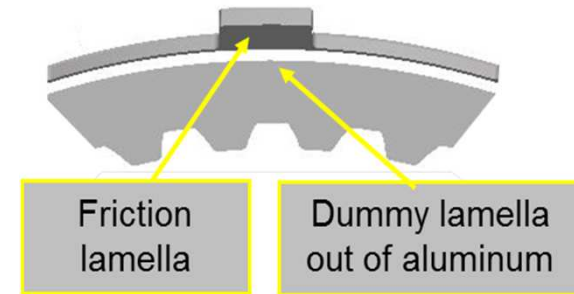
Image



Neutron radiography



Ölverteilung in einer Motorradkupplung



Abschwächung des Neutronenstrahls

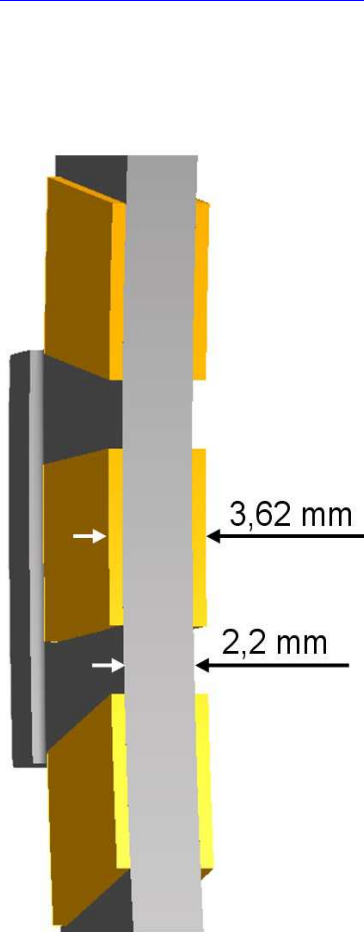
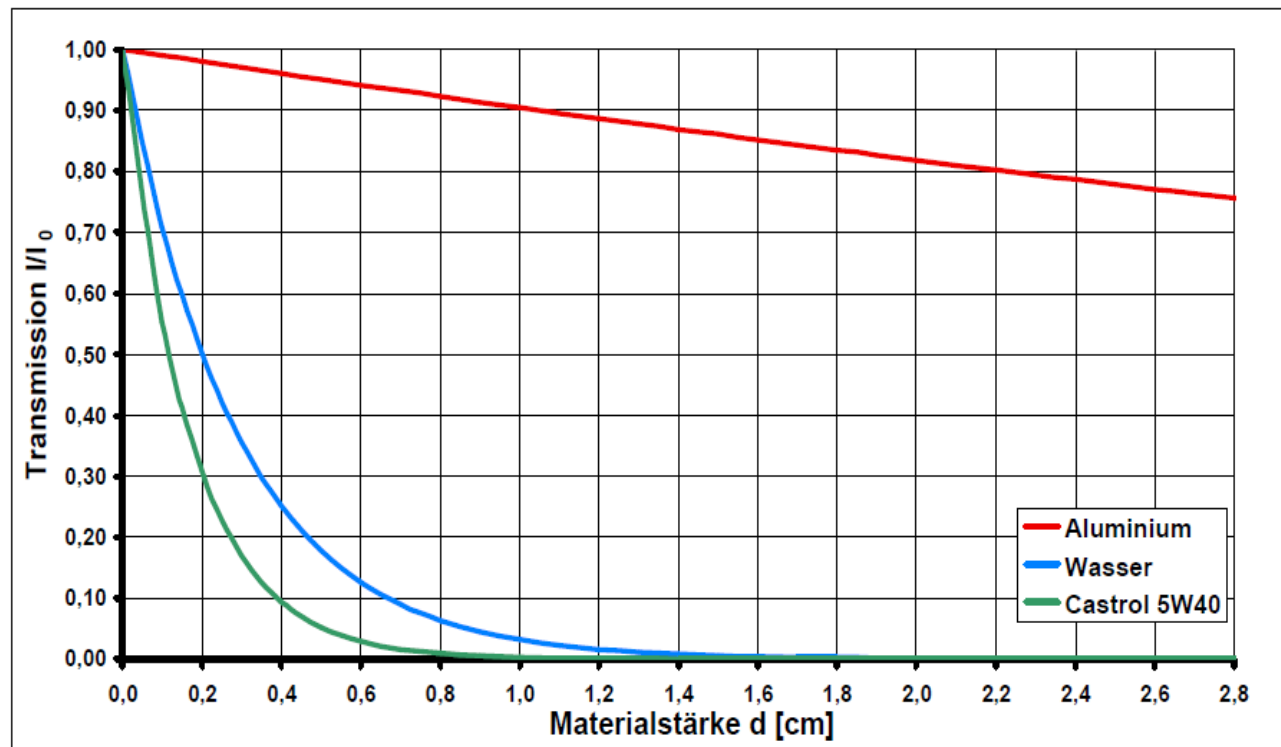


Diagram illustrating the attenuation of a neutron beam passing through a material of thickness d and macroscopic cross-section Σ . The initial intensity is I_0 and the final intensity is I .

$$I = I_0 \cdot e^{-\Sigma \cdot d}$$

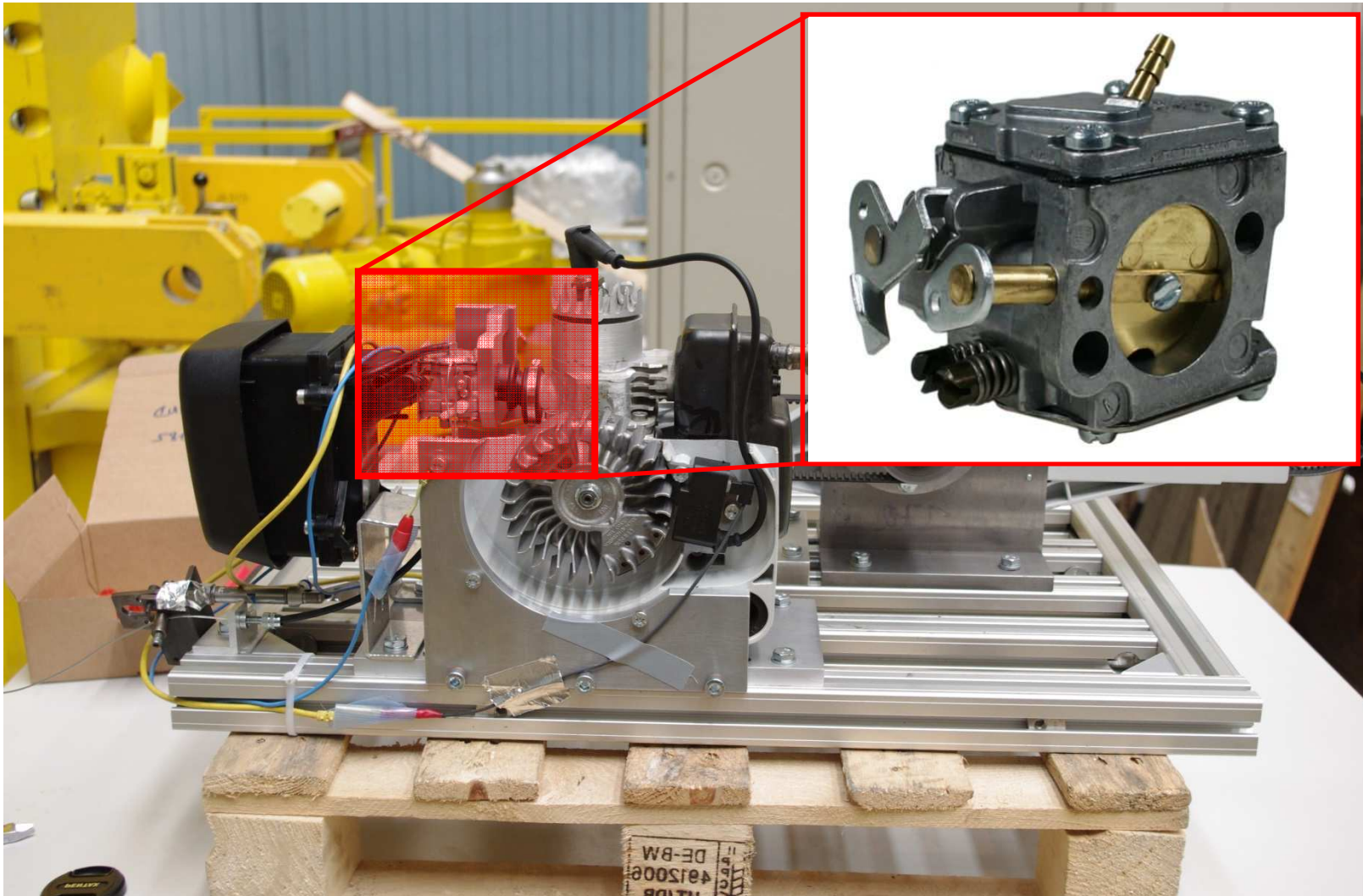


$$\Sigma_{Alu} = 0,1 \text{ cm}^{-1}$$

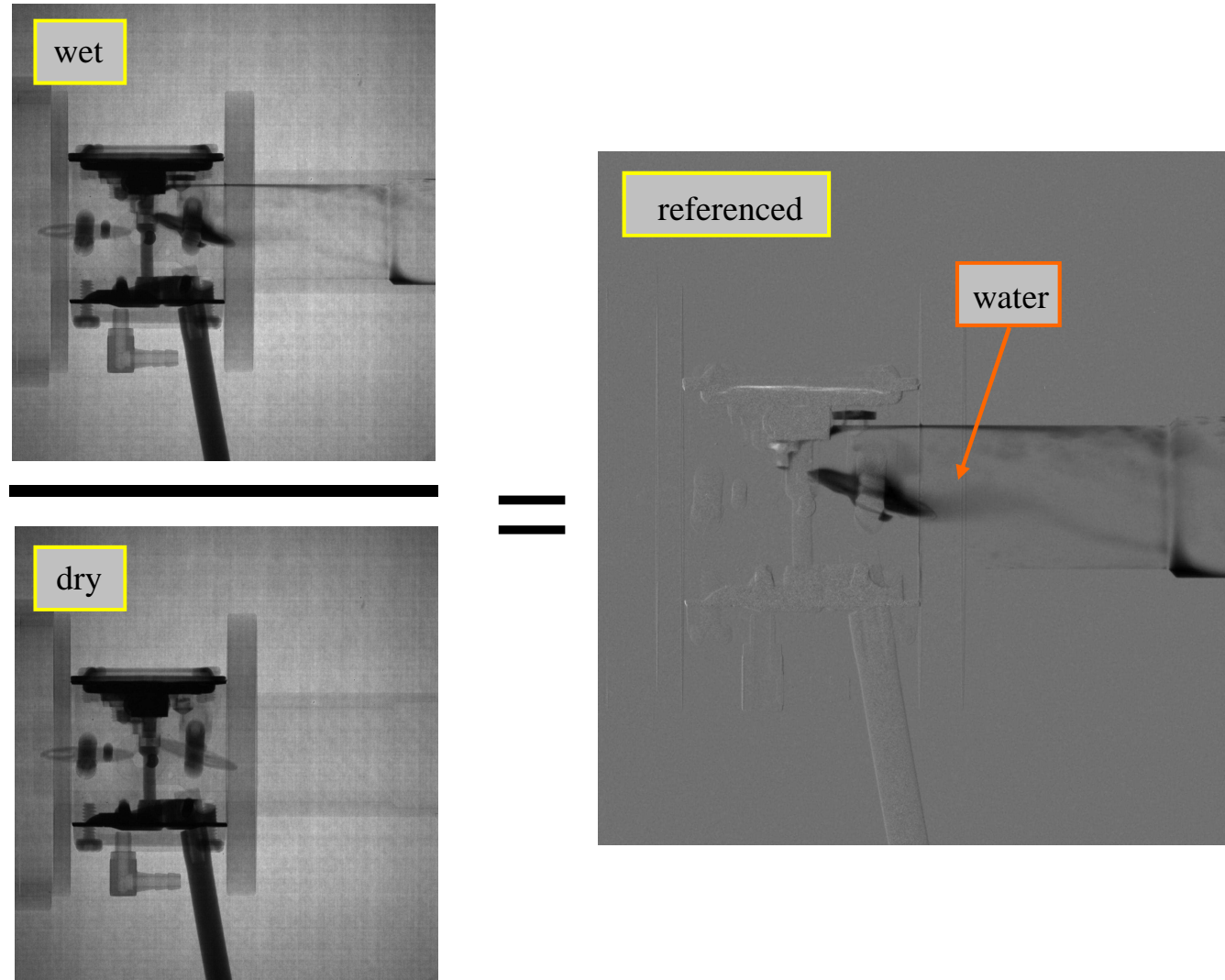
$$\Sigma_{Wasser} = 4,5 \text{ cm}^{-1}$$

$$\Sigma_{\text{Öl}} = 5,9 \text{ cm}^{-1}$$

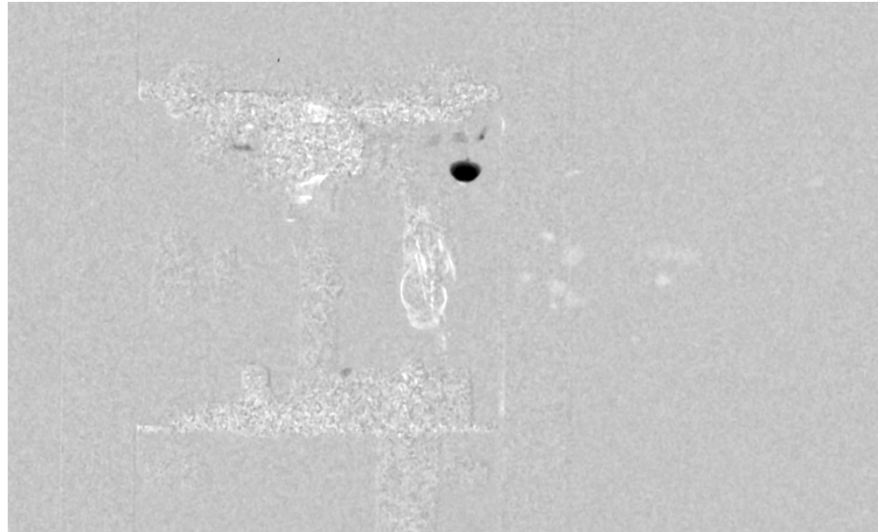
Spray visualization



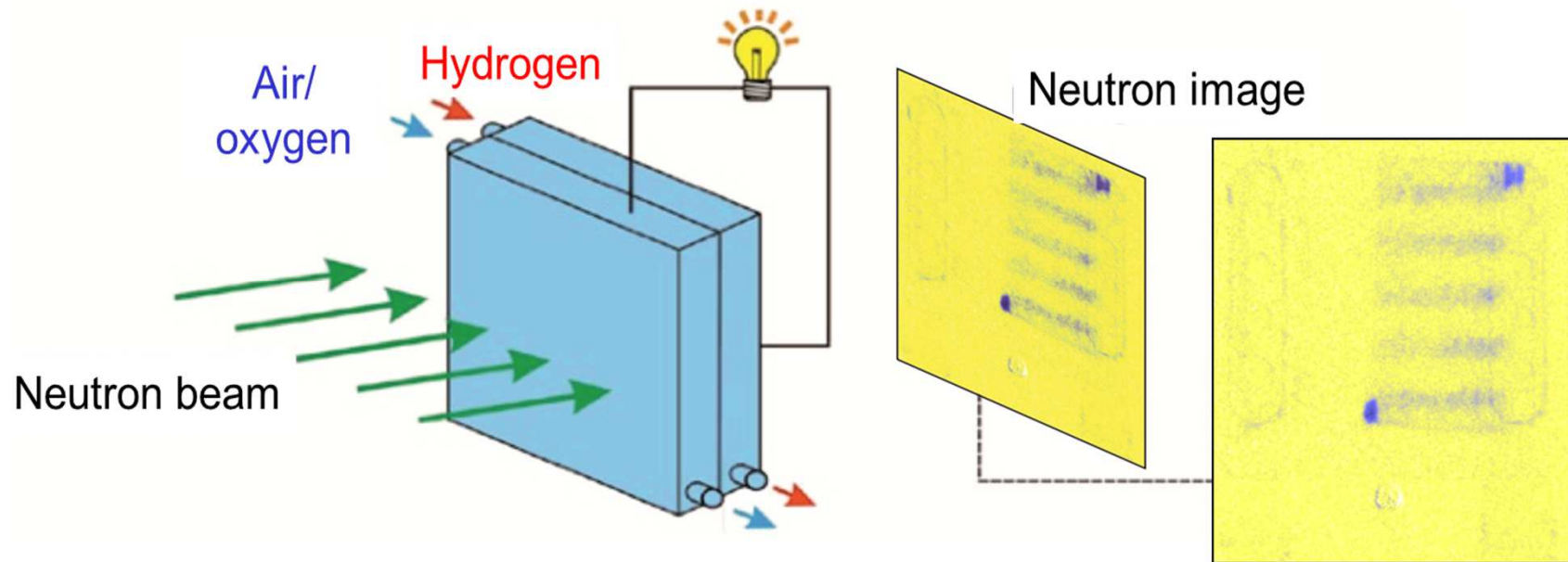
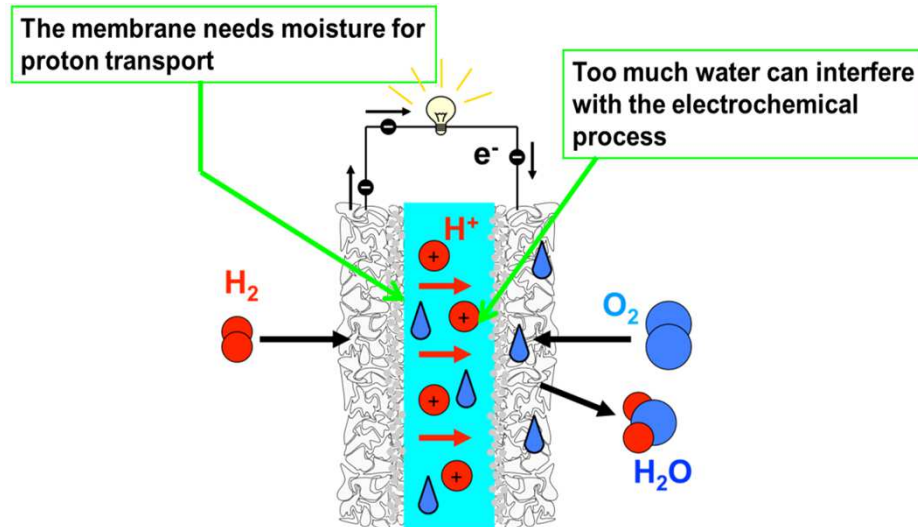
Spray visualization: Referencing



Spray visualization



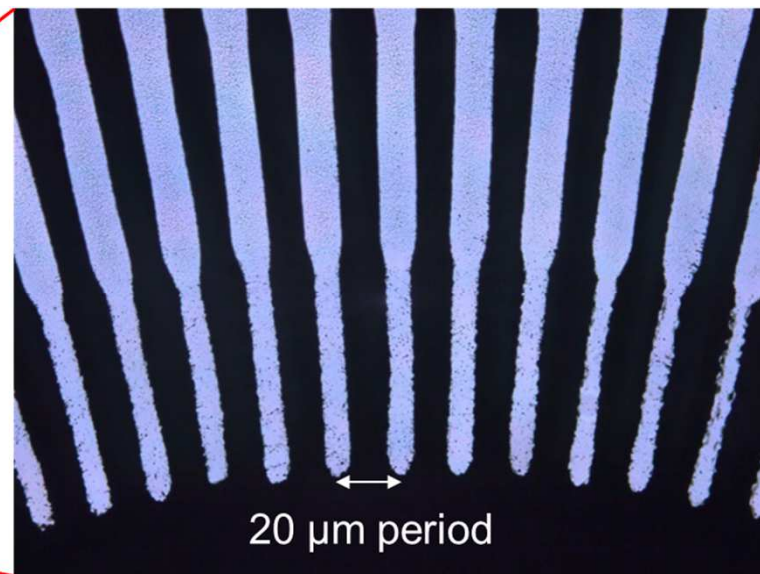
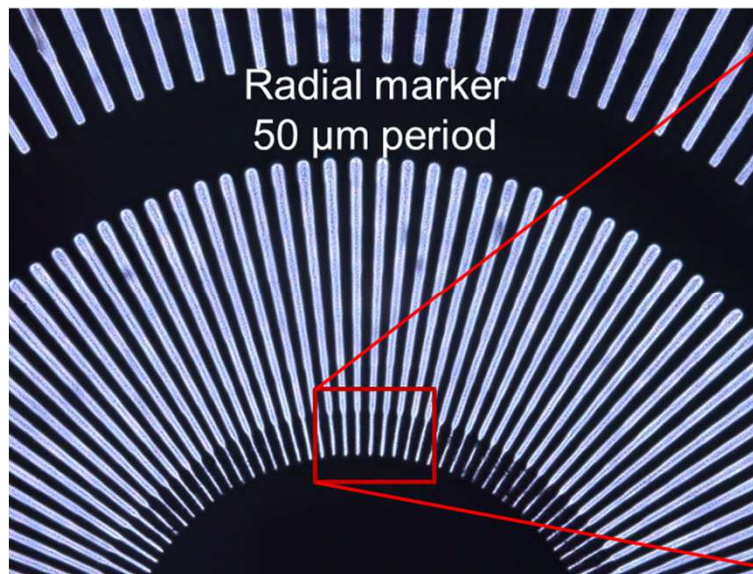
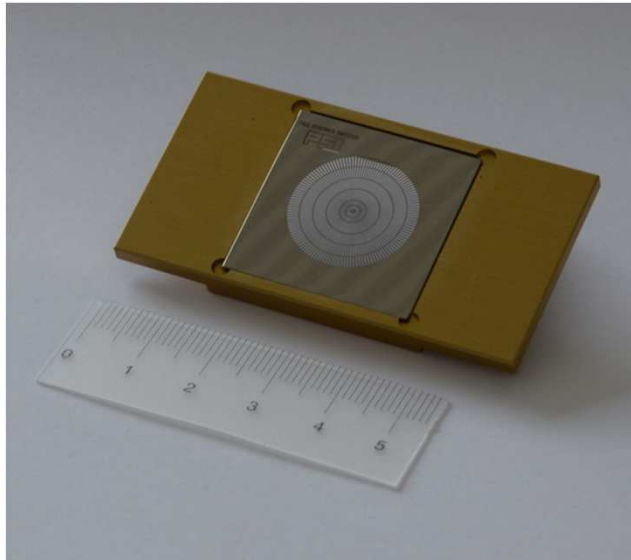
Water distribution within a fuel cell



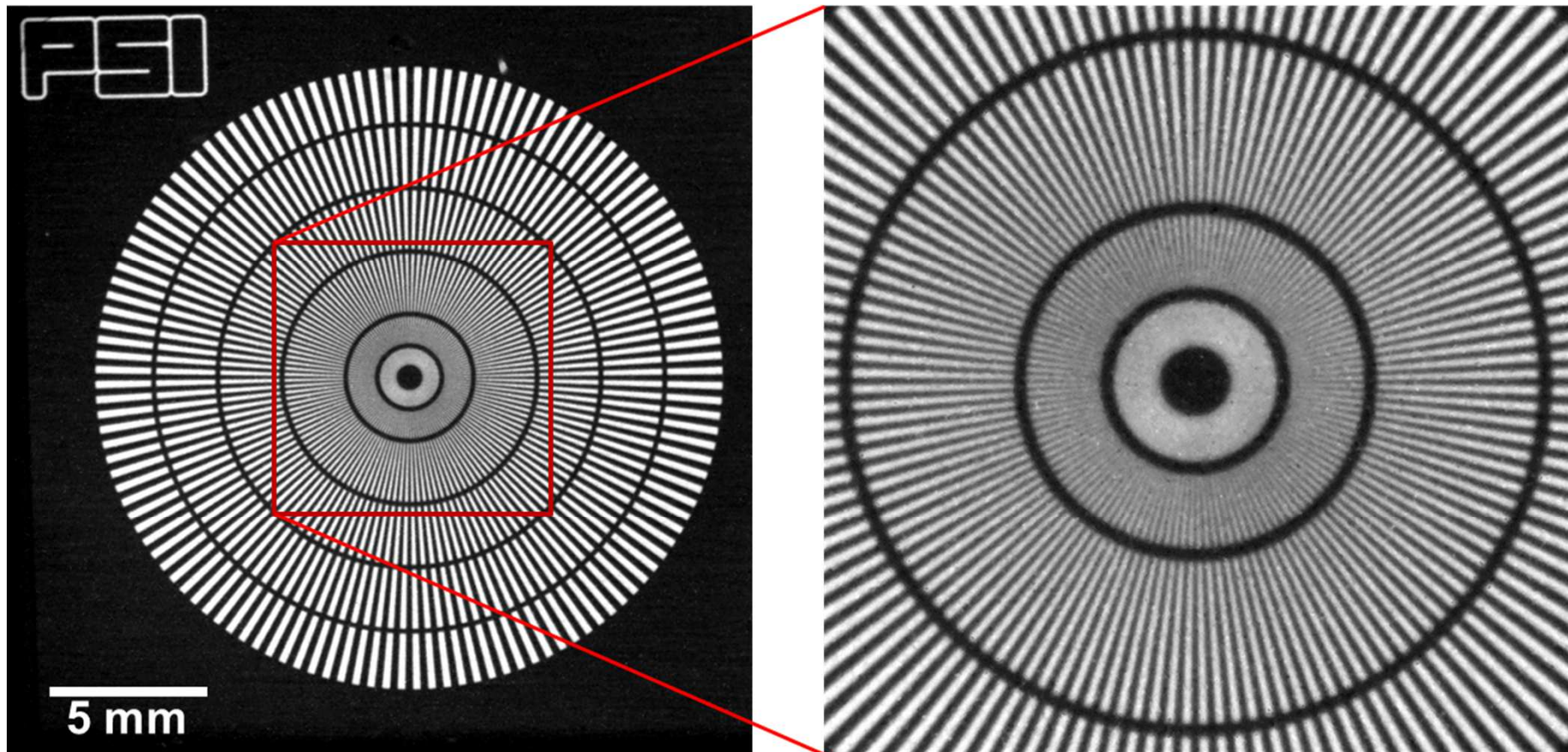
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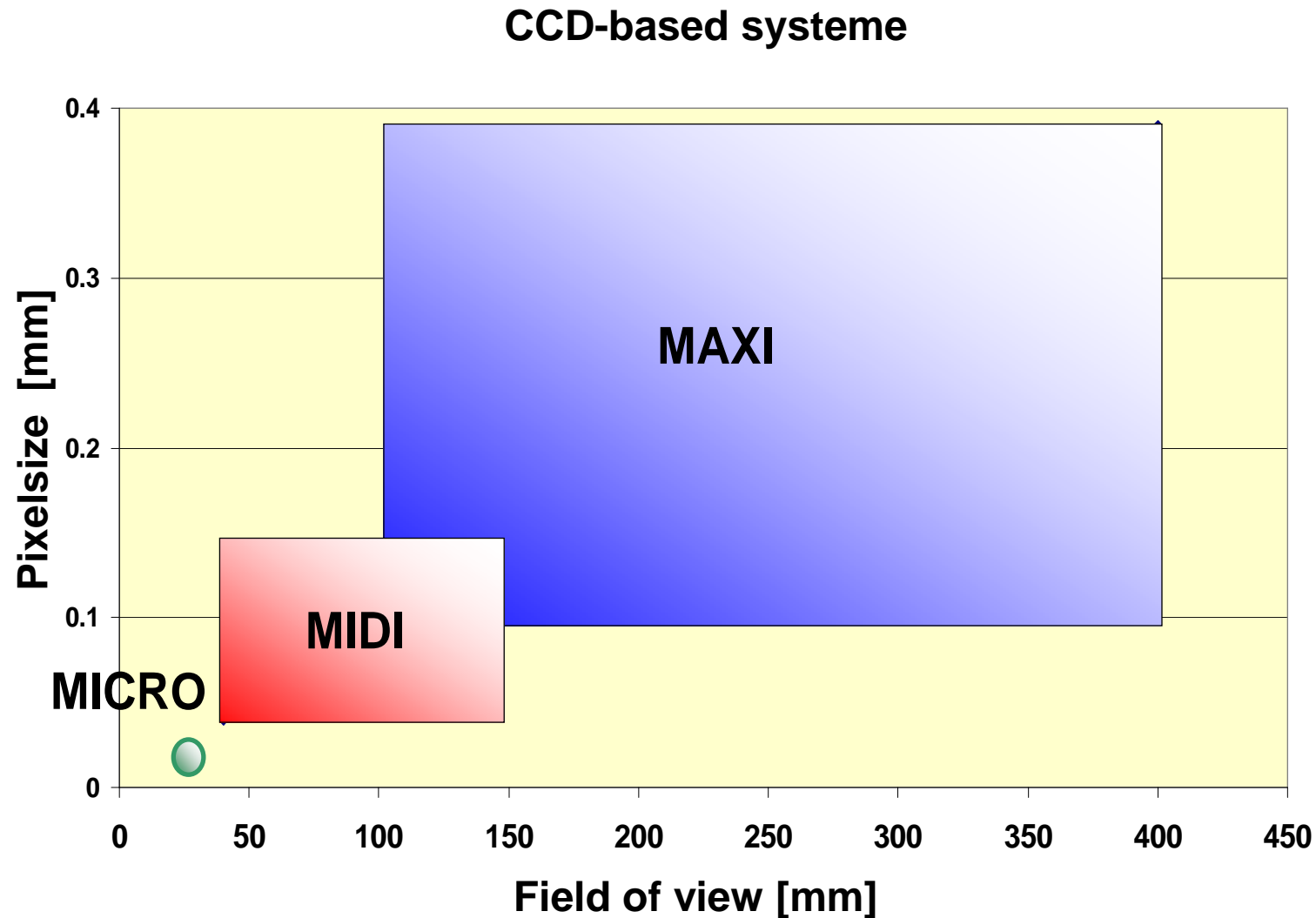
The “new” Gd test object



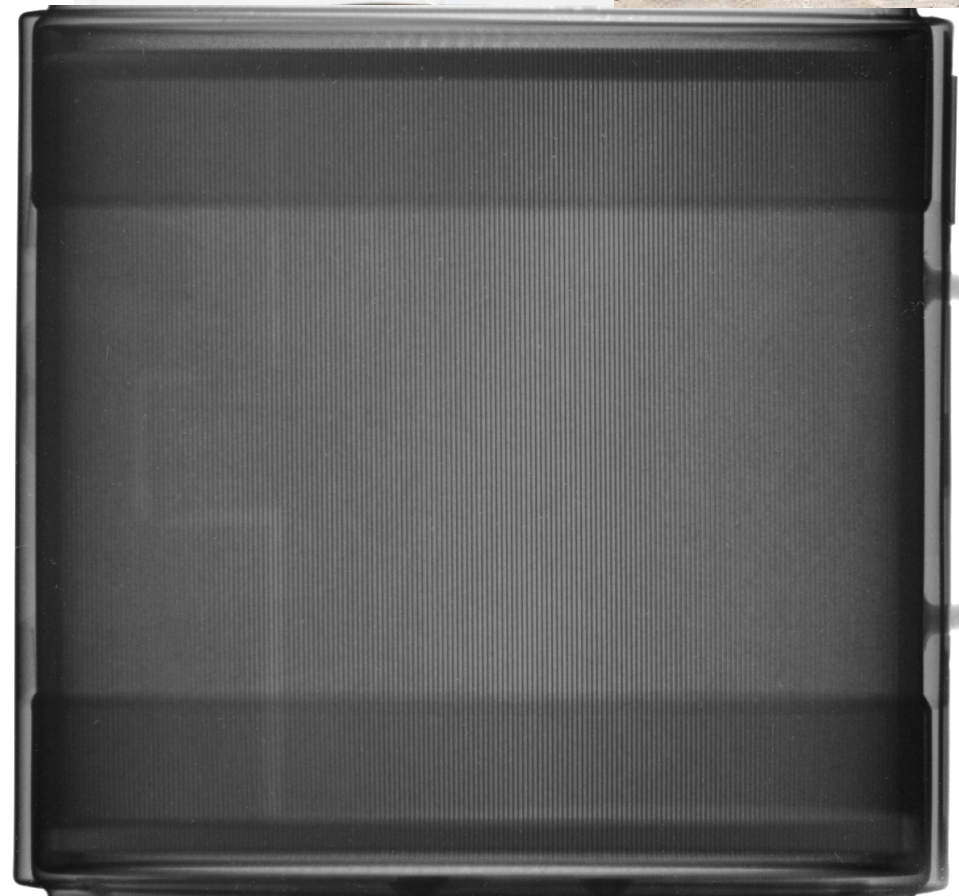
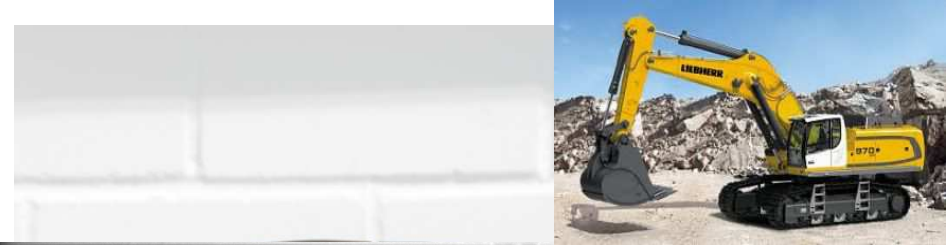
The “new” Gd test object



Classical Neutron Imaging



Maxi setup



Midi setup



Image

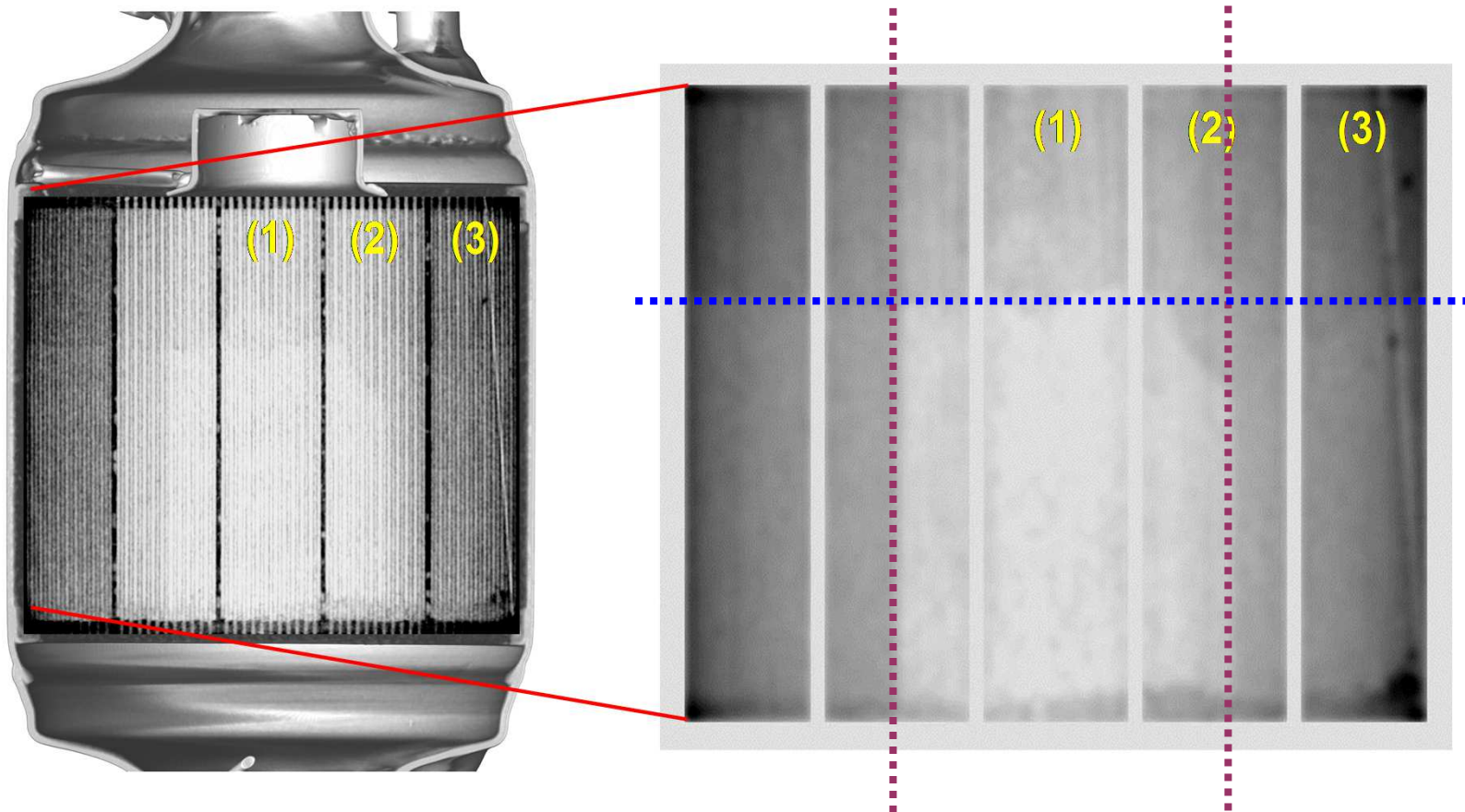


Tomography

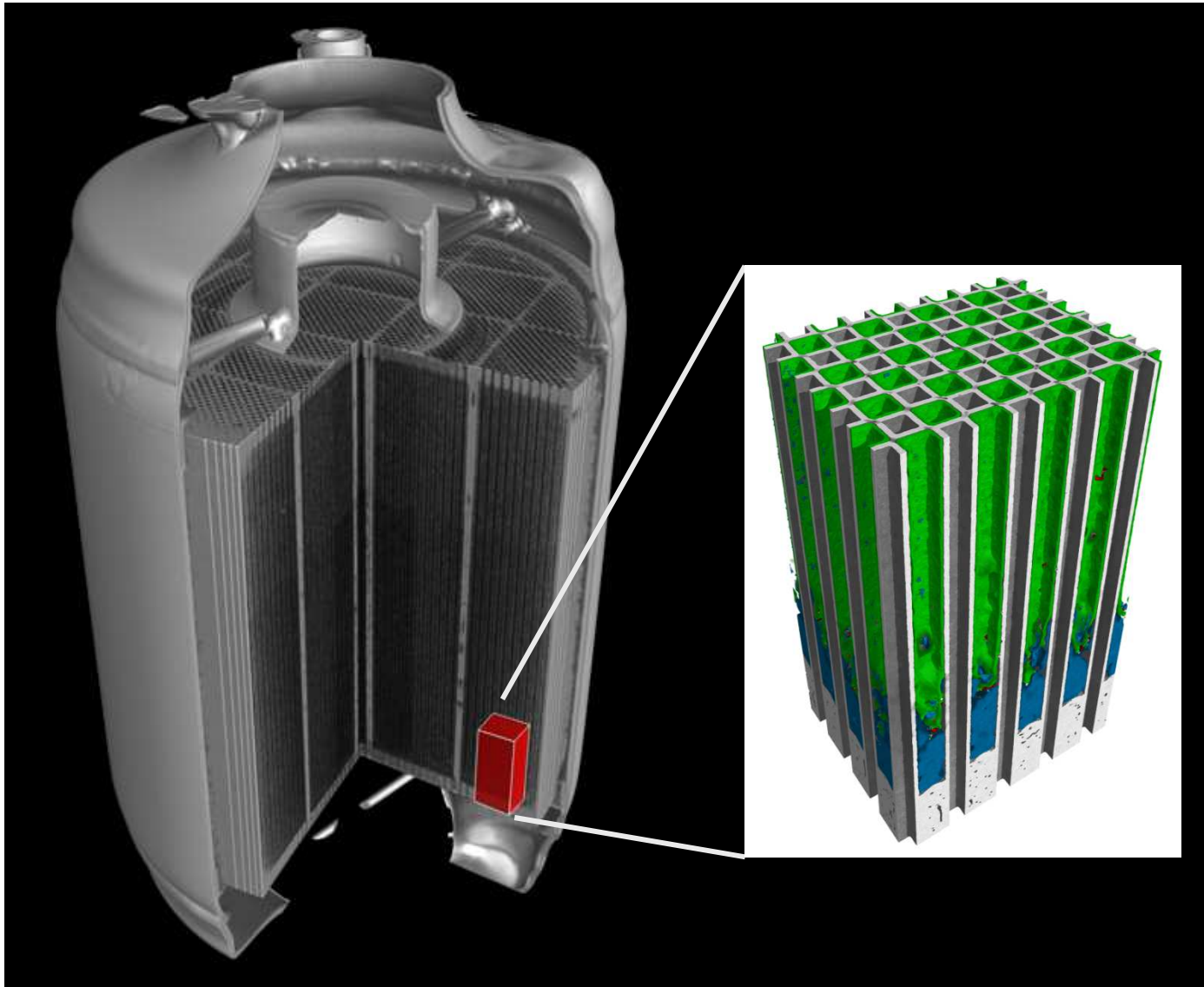


Local loading level

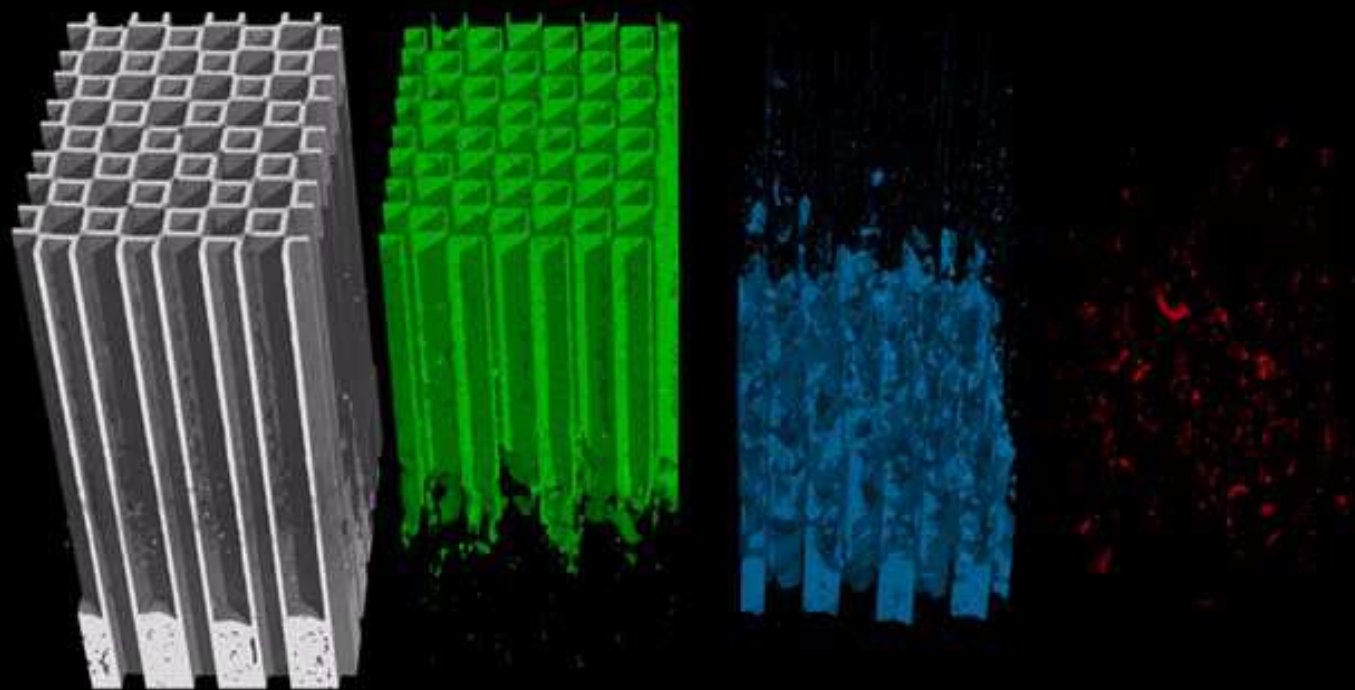
Tomography: vertical slice



Micro setup



Neutron microtomography Diesel particulate filter (DPF)

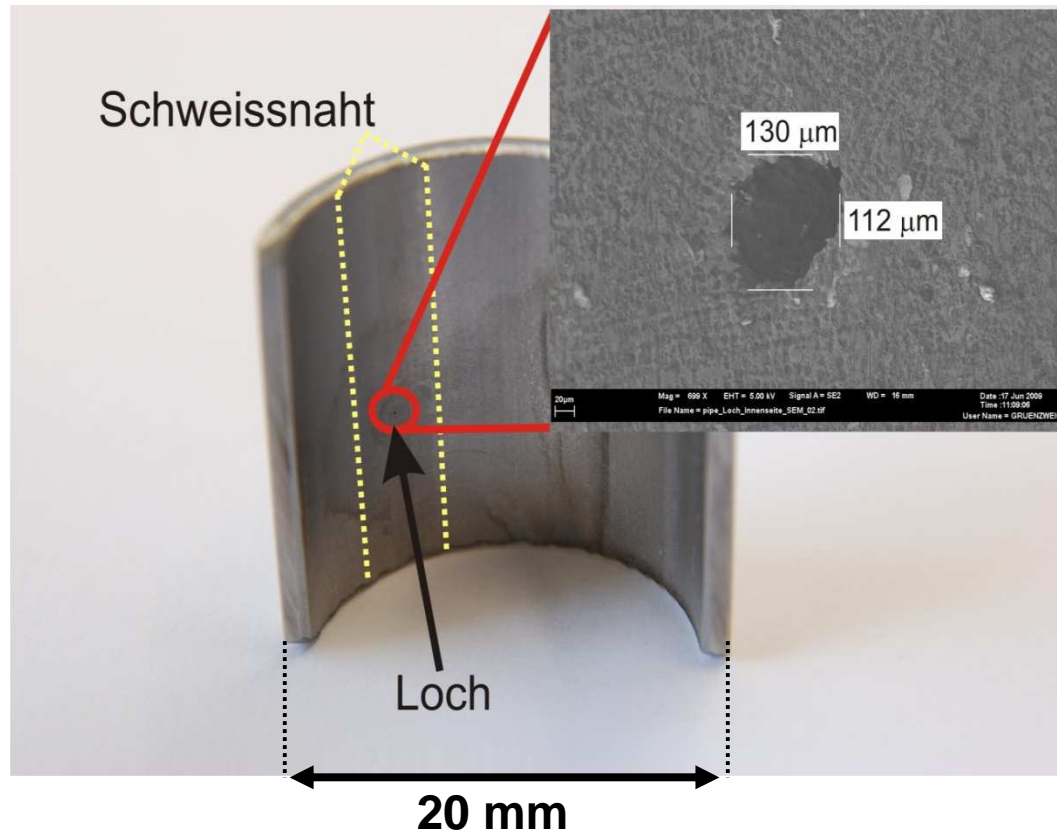


Sample size 10mm × 13mm × 18mm

Voxel size 13.5μm³

Micro-crack in a joint weld

REM-Bild



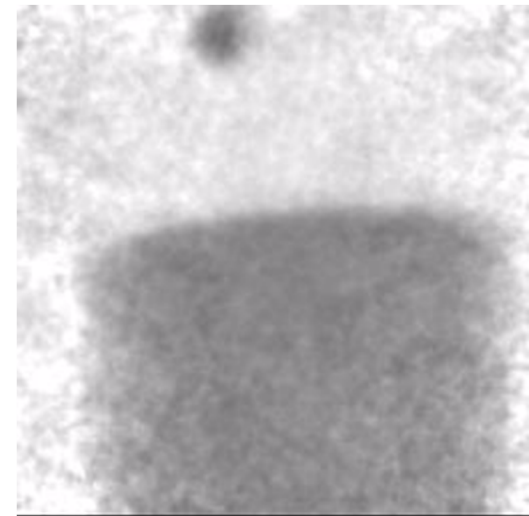
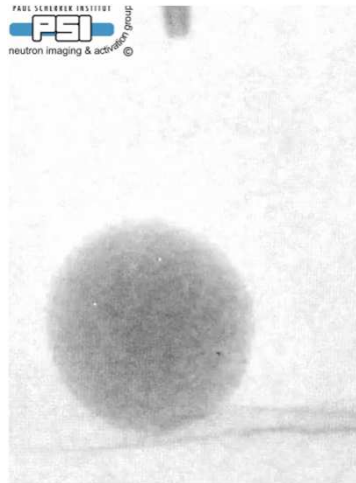
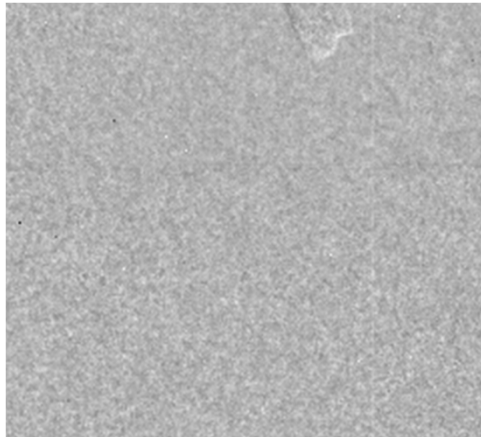
Detailed tomography of swiss watch



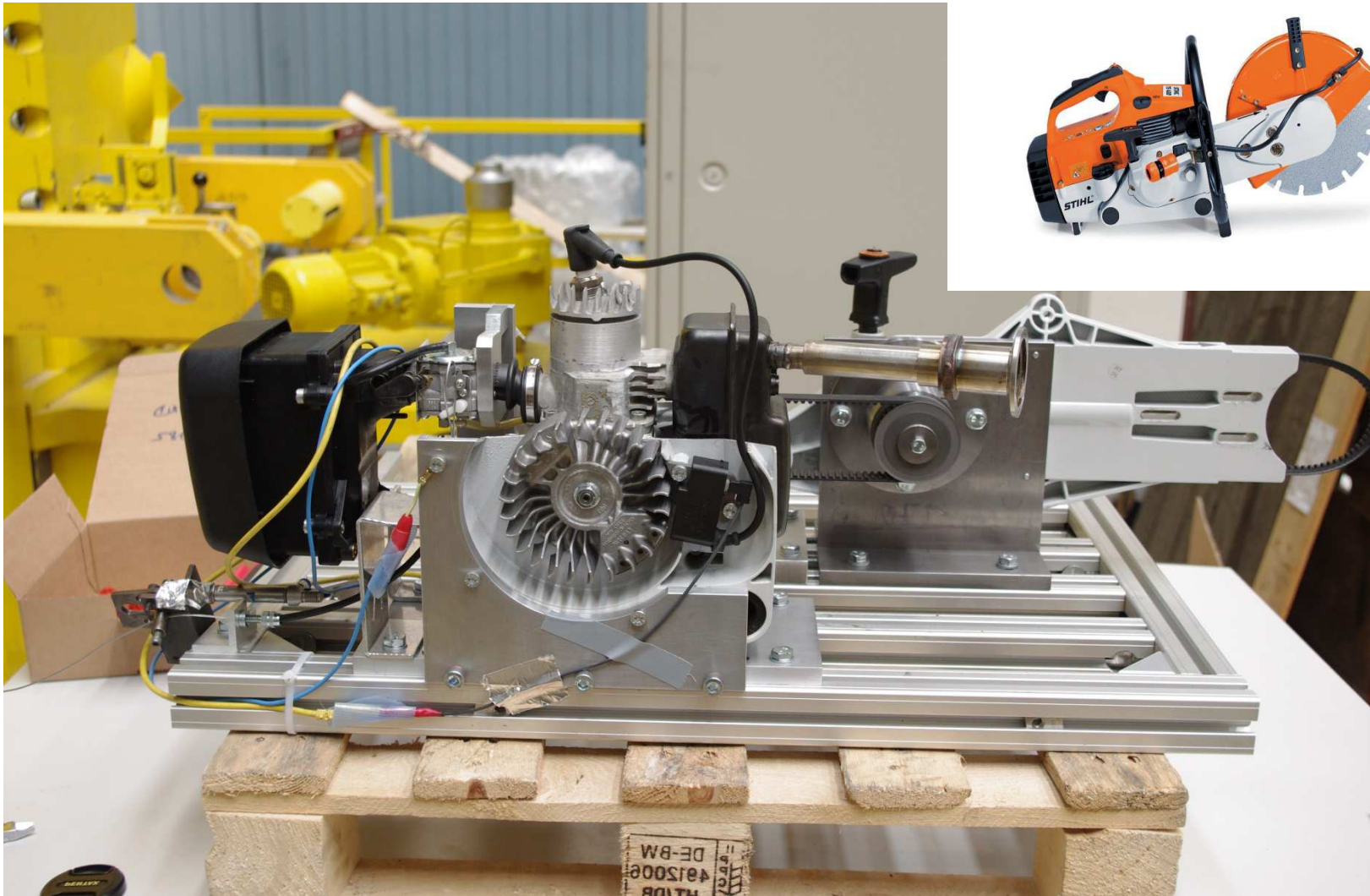
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Transient motions: dNR

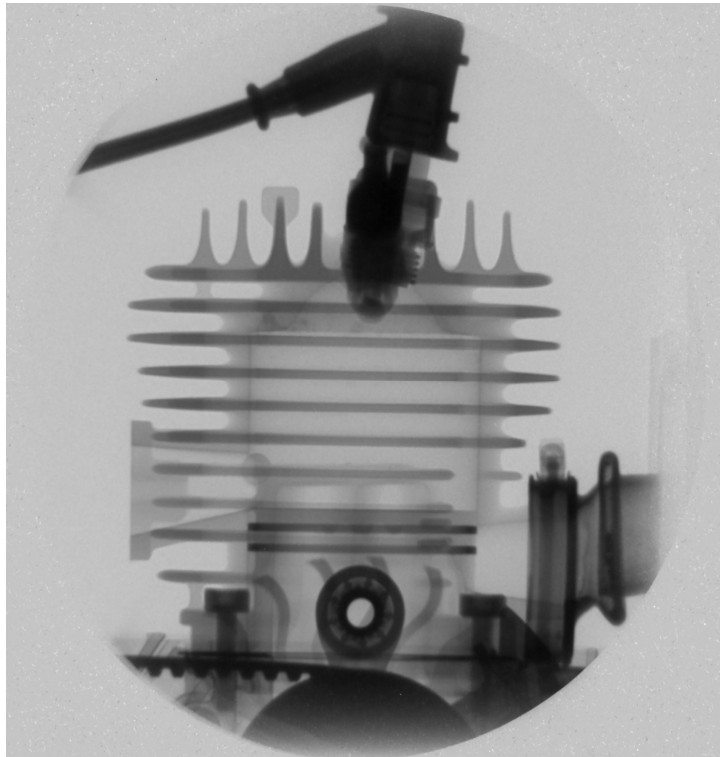


The test bench

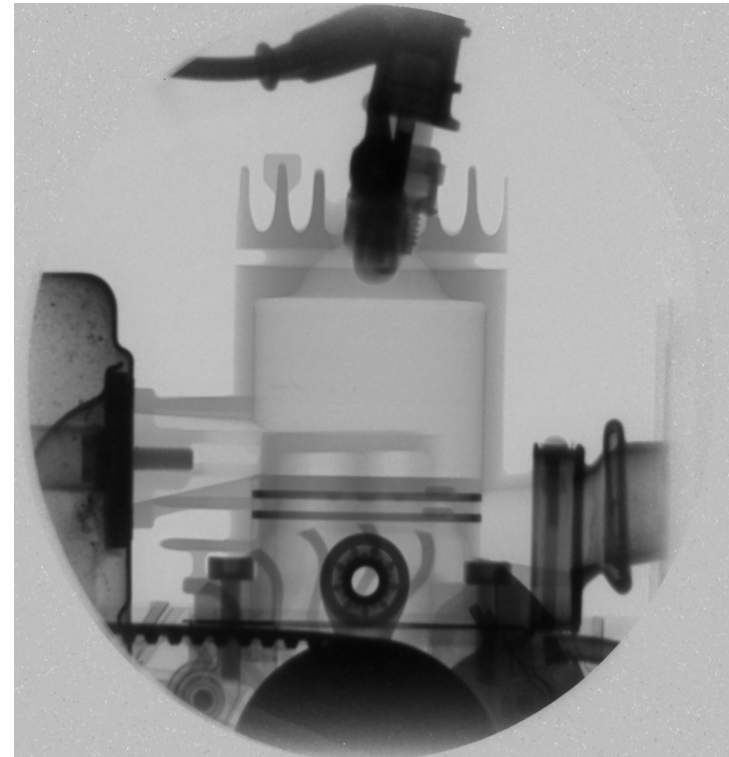


Static images

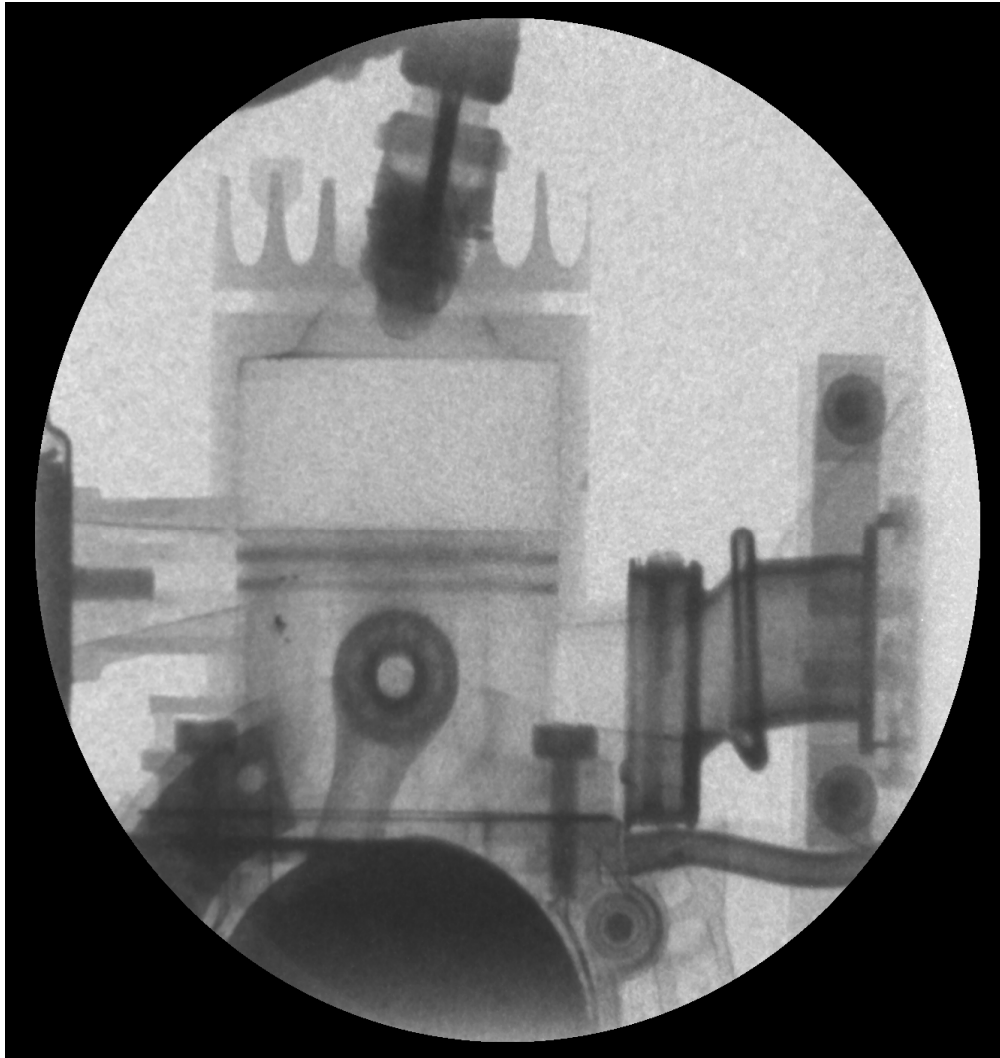
Originaler Zylinder



Bearbeiteter Zylinder



Dynamic Experiment



Max. speed:

[U/min, Hz]
8000, 134

Exposure time single image
50 μ s

Number of images
1000

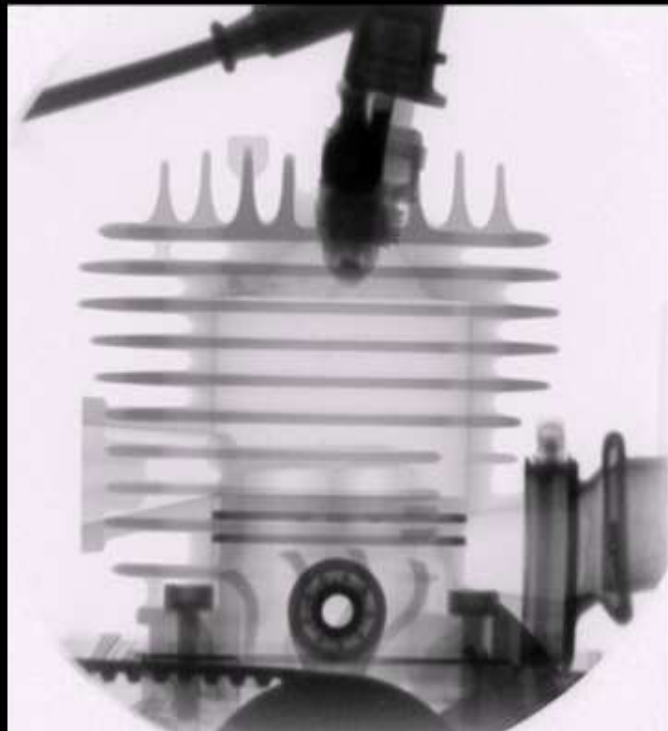
Crank shaft resolution [deg]
2.4

Crank shaft steps [deg]
5

Dynamic Neutron Radiography

fired 64ccm two-stroke engine @ 10'000rpm

STIHL TS 400



Outline

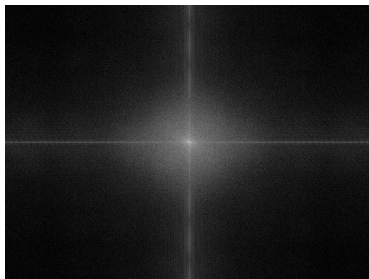
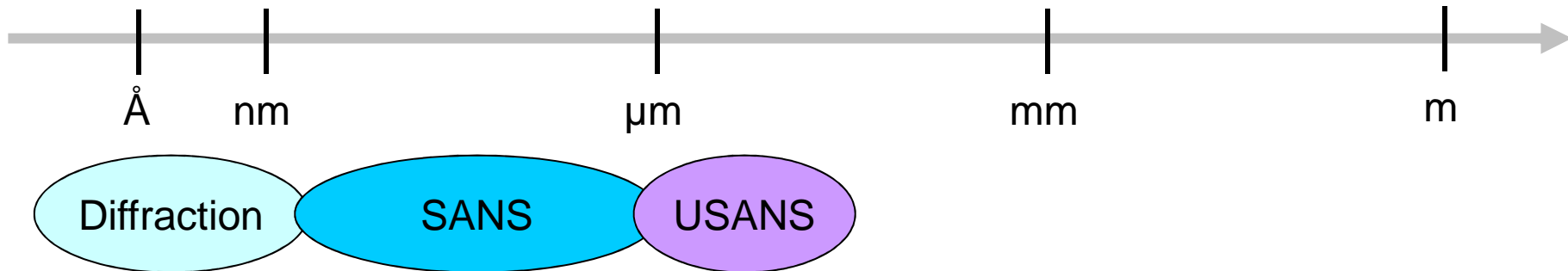
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Length scales and techniques



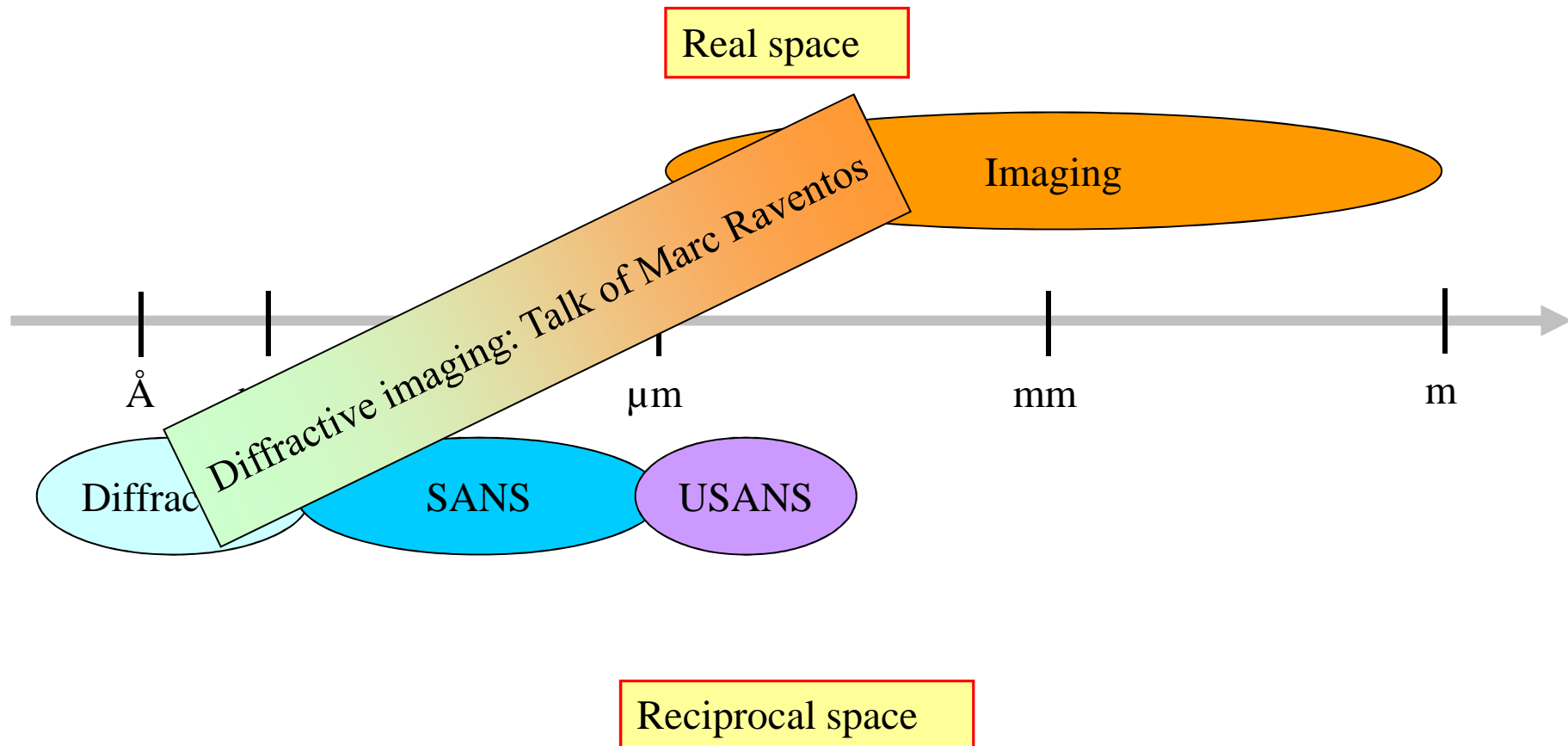
Real space

Imaging

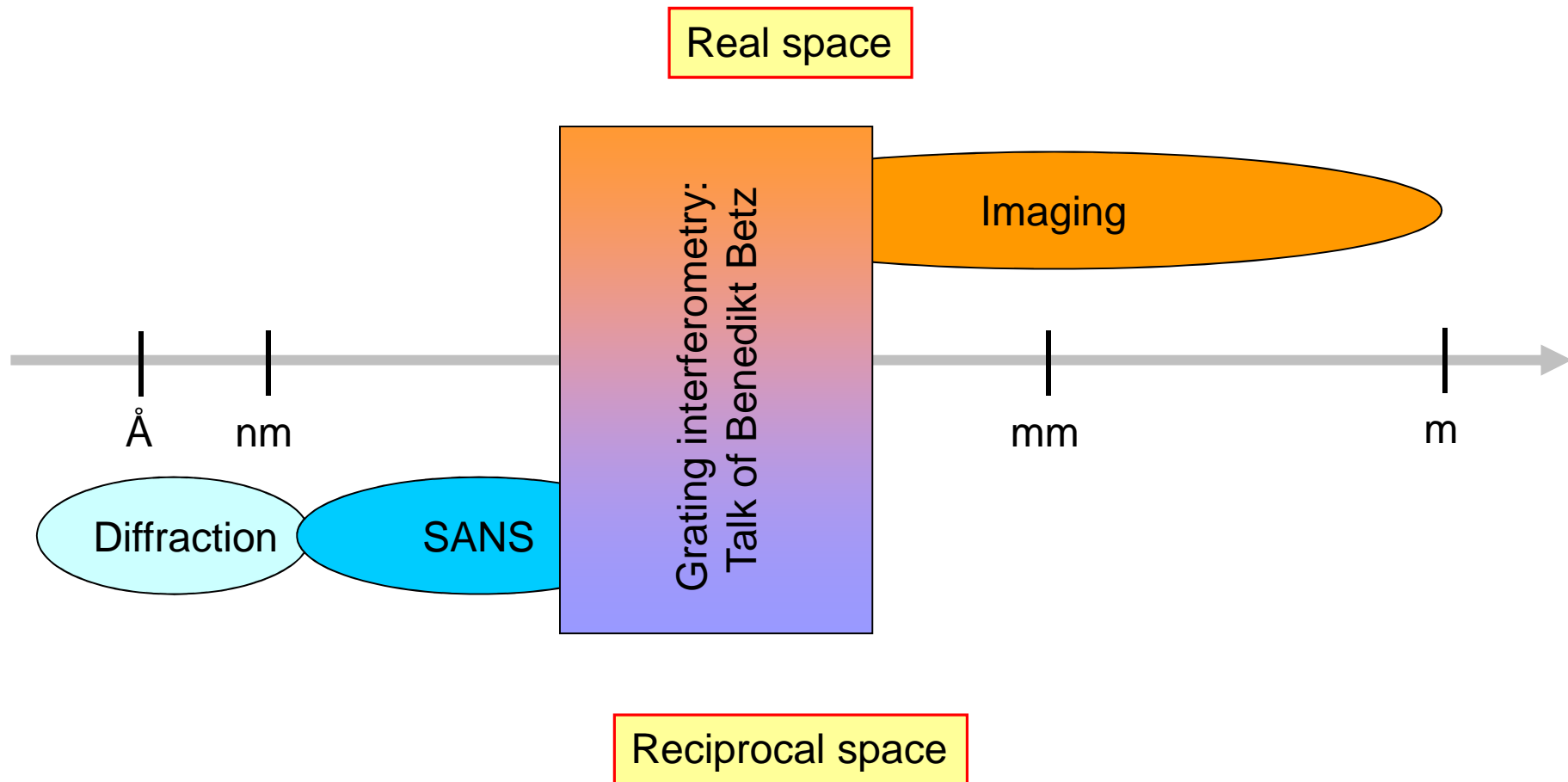


Reciprocal space

Length scales and techniques



Length scales and techniques



Motivation



The electric motor is more than 150 years old

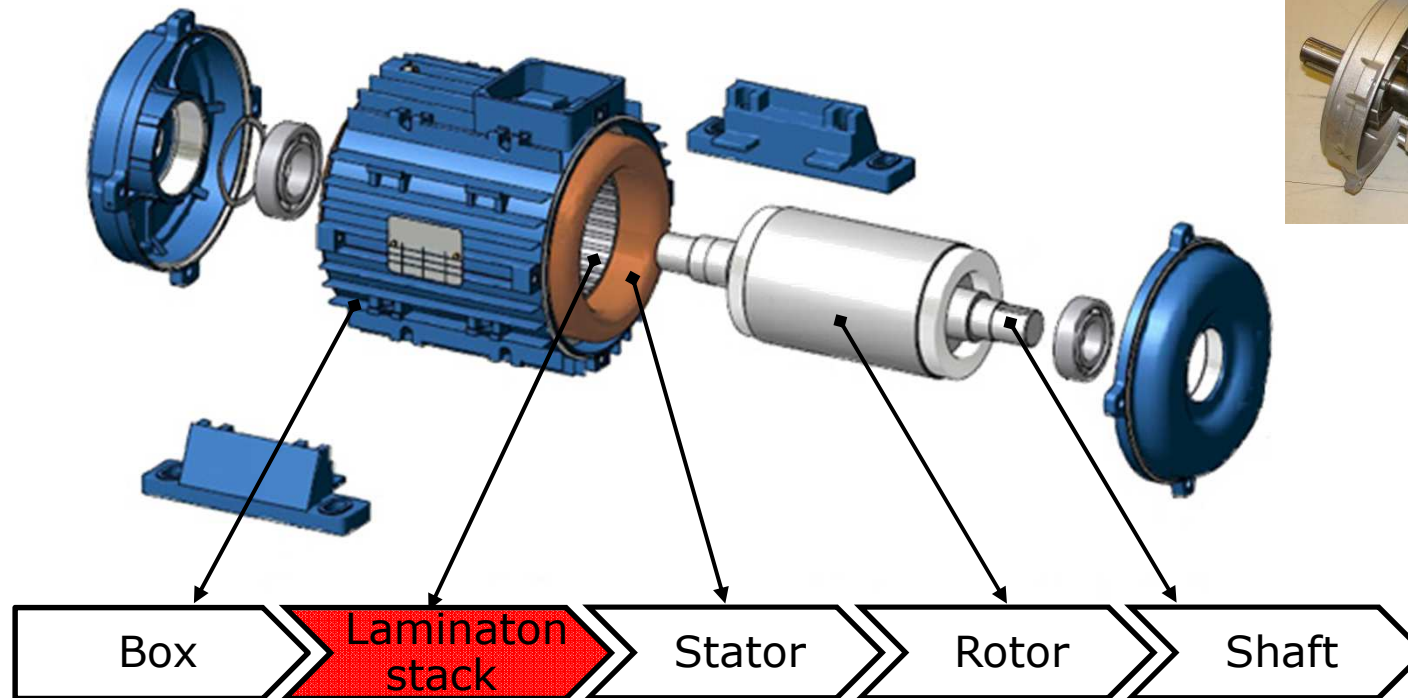
→ steady improvement of electric motors

→ Increasing the degree of efficiency

Motivation



The electric motor is more than 150 years old
→ steady improvement of electric motors
→ Increasing the degree of efficiency

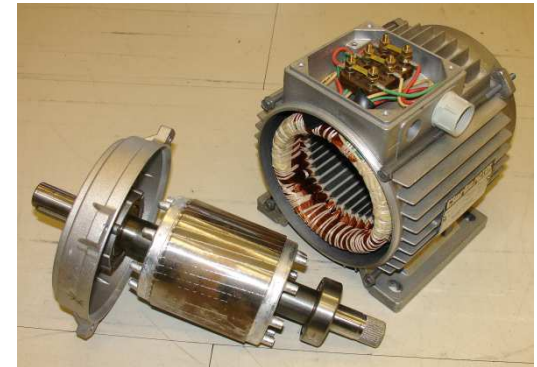
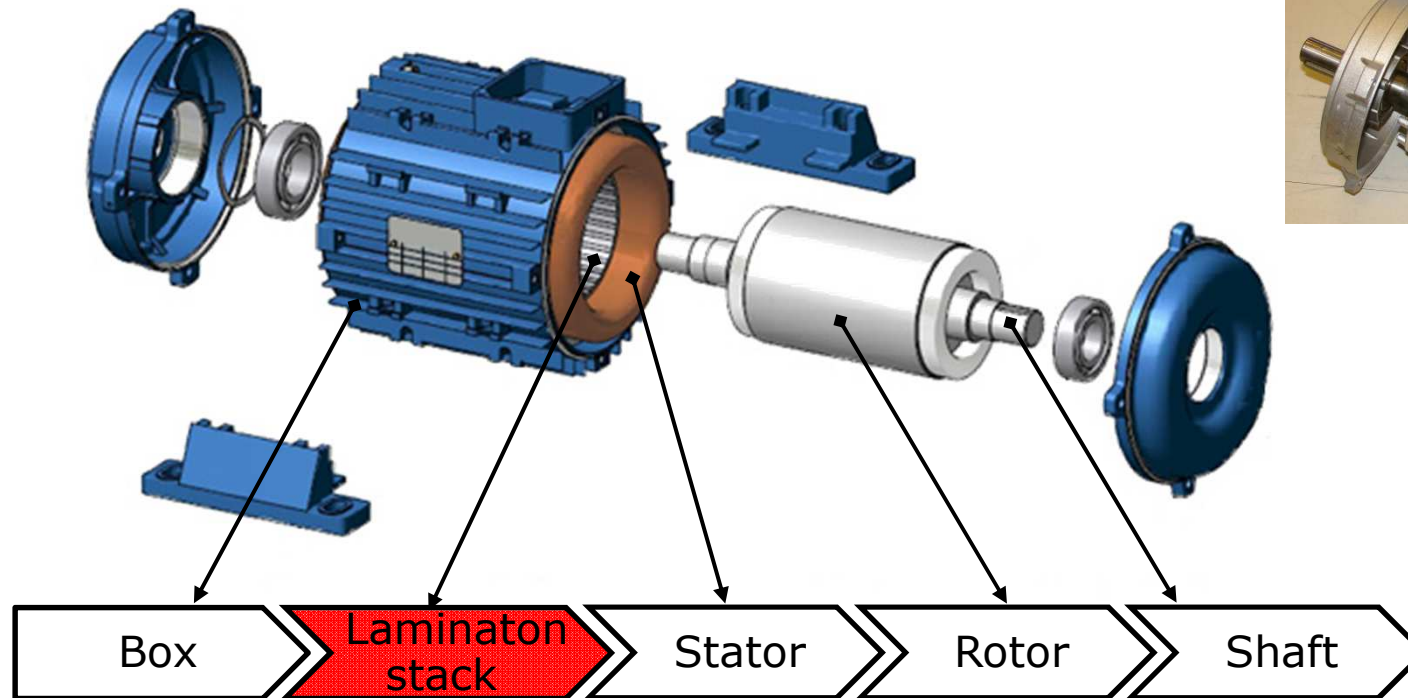


Motivation

The electric motor is more than 150 years old

→ steady improvement of electric motors

→ Increasing the degree of efficiency



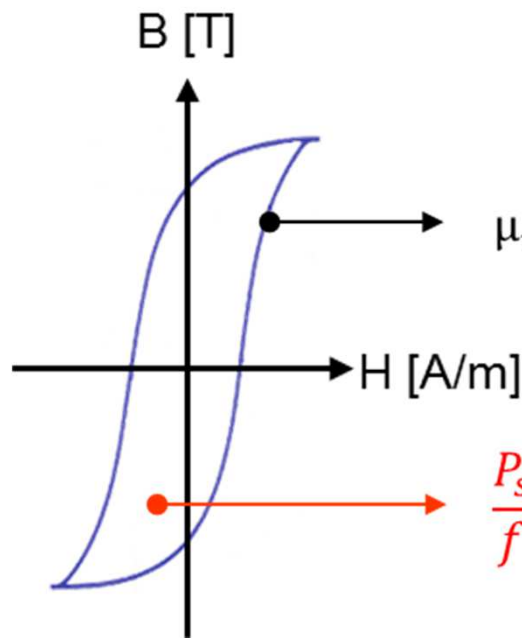
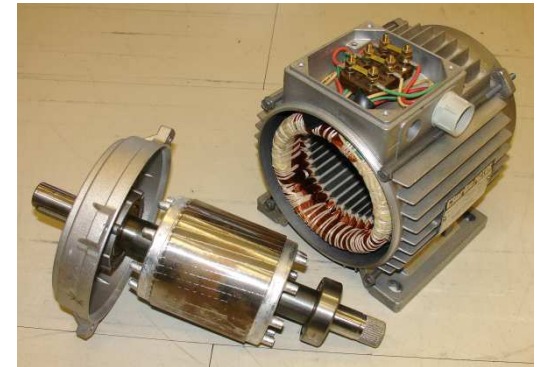
Motivation



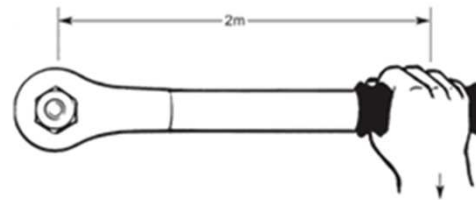
The electric motor is more than 150 years old

→ steady improvement of electric motors

→ Increasing the degree of efficiency



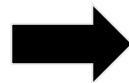
$$\mu_r = \frac{1}{\mu_0} \frac{\hat{B}}{\hat{H}}$$



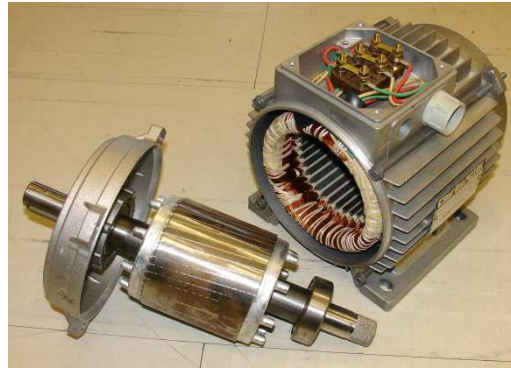
$$\frac{P_s}{f} = \frac{1}{\rho} \oint_{-H}^{+H} B(H) dH$$



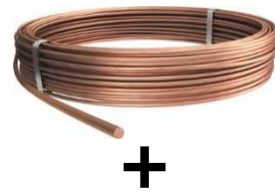
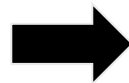
Motivation



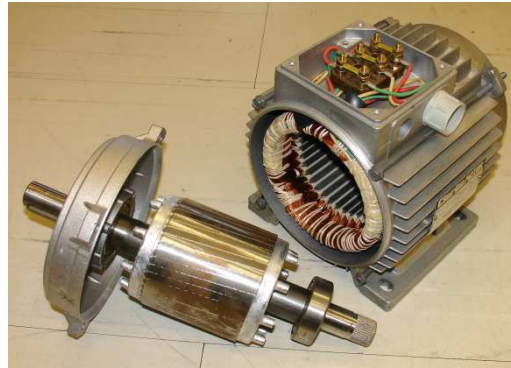
+



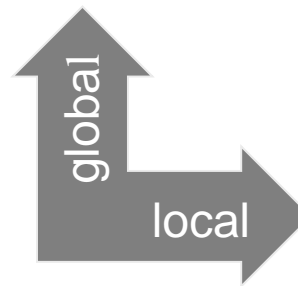
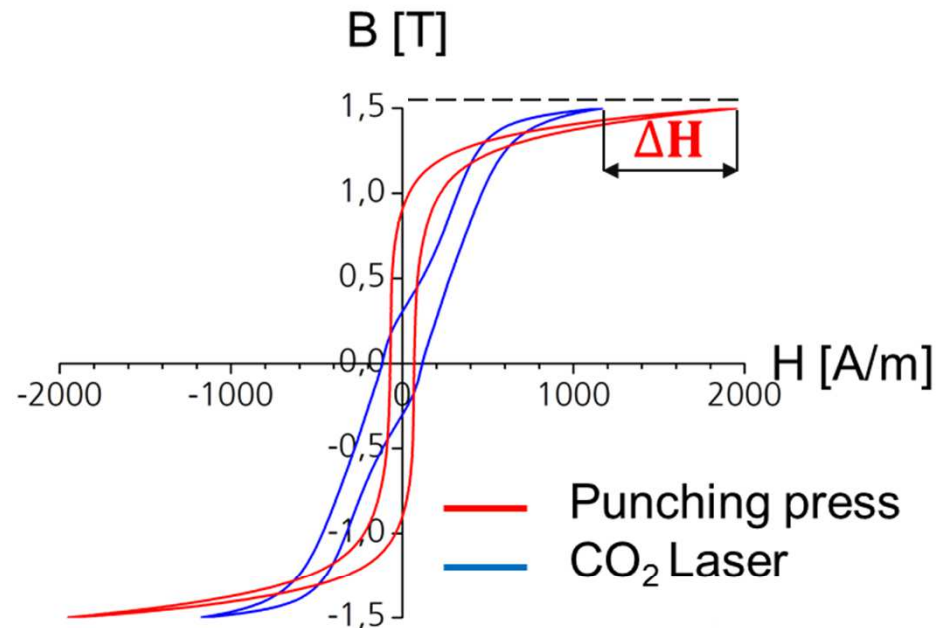
Motivation



+

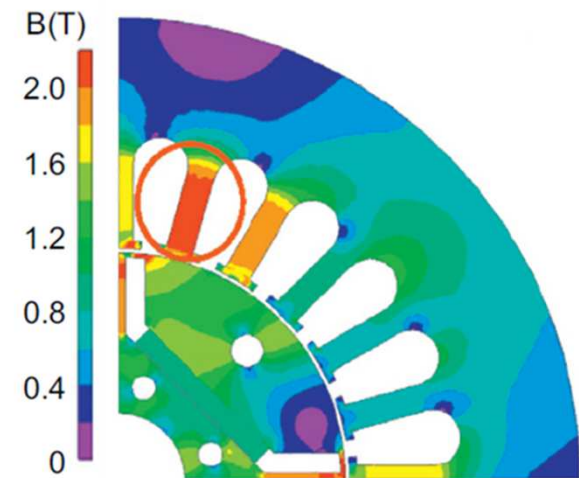


Motivation



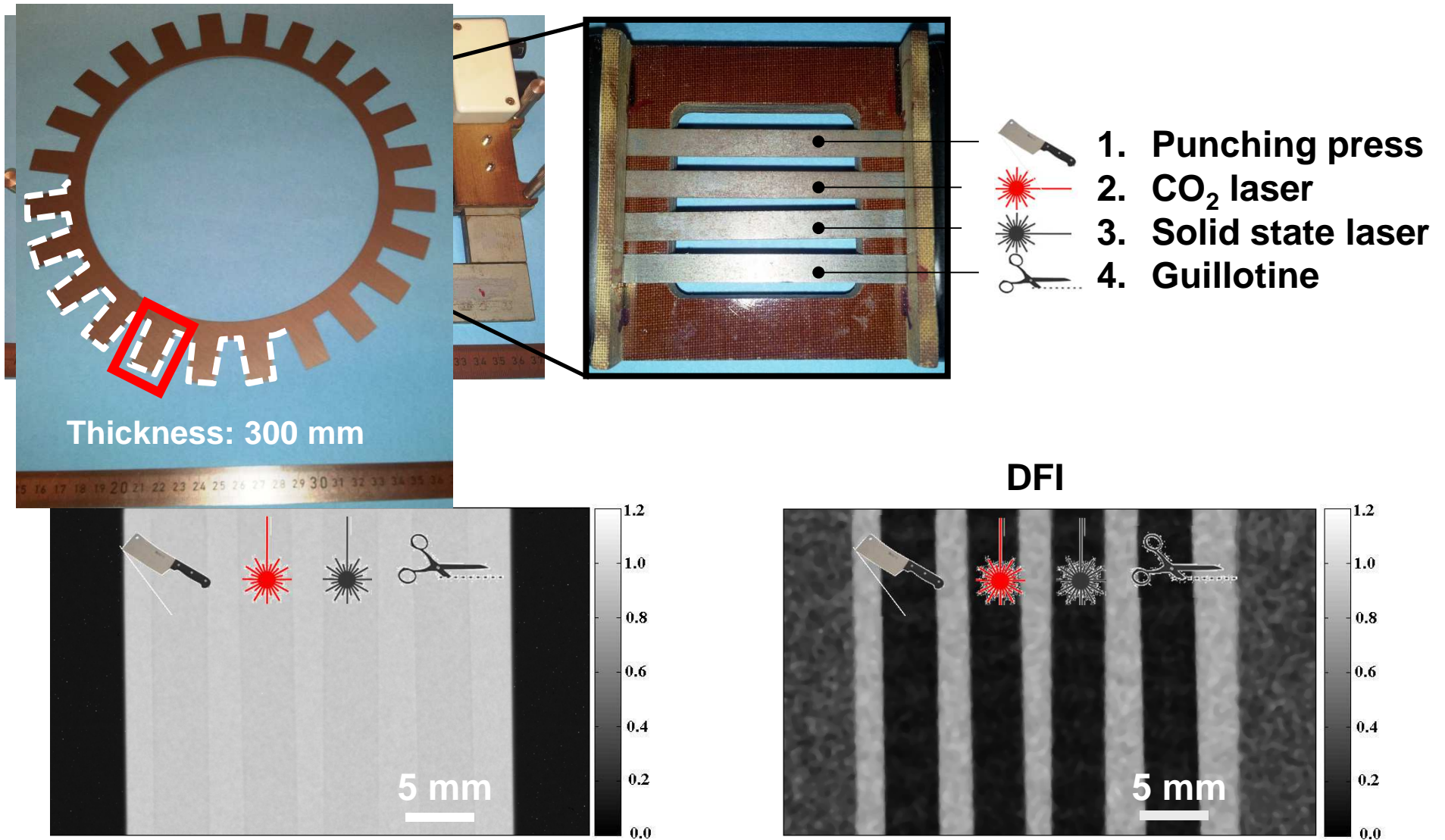
Influence of

- **Microstructure**
- **Domain formation**



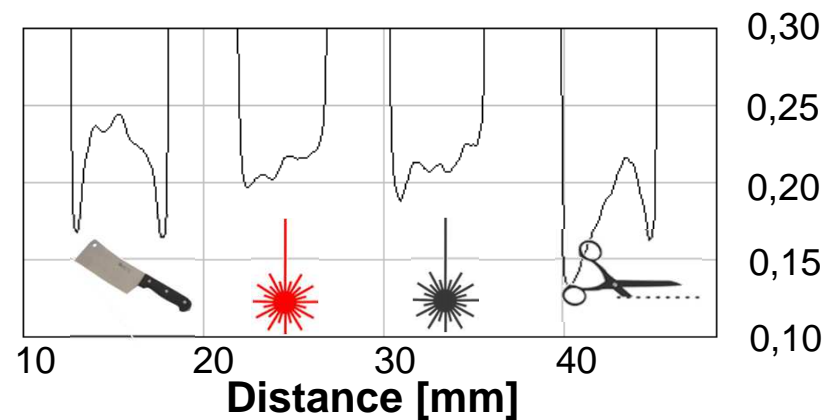
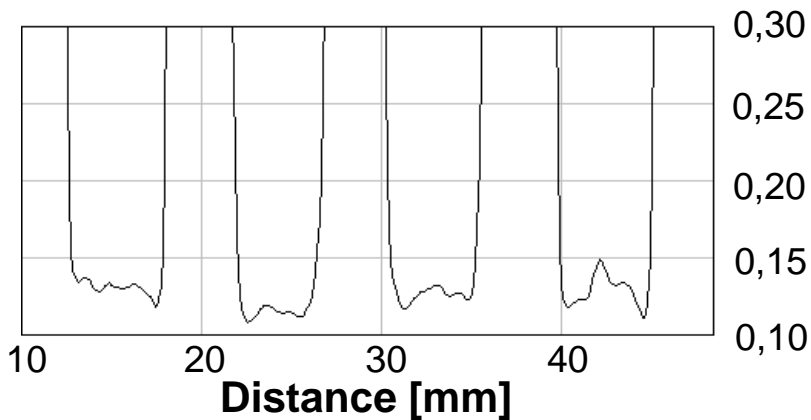
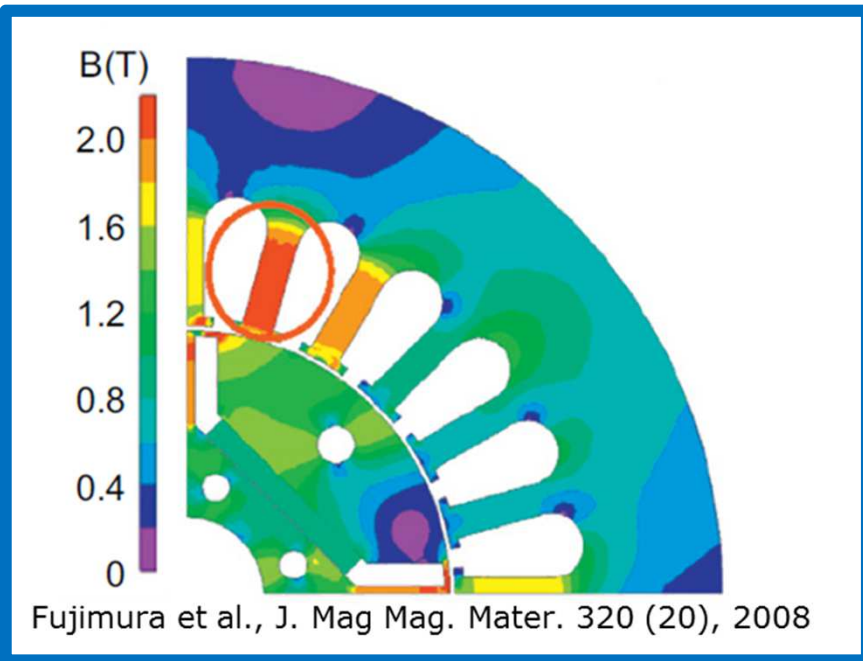
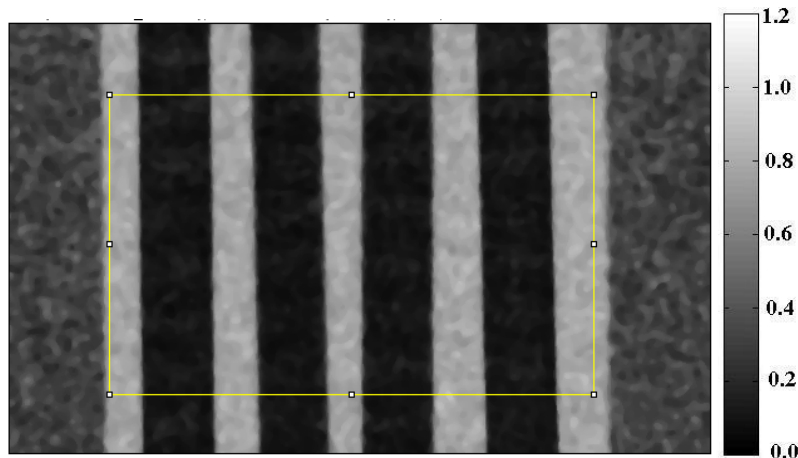
Fujimura et al., J. Mag Mag. Mater. 320 (20), 2008

Samples and environment



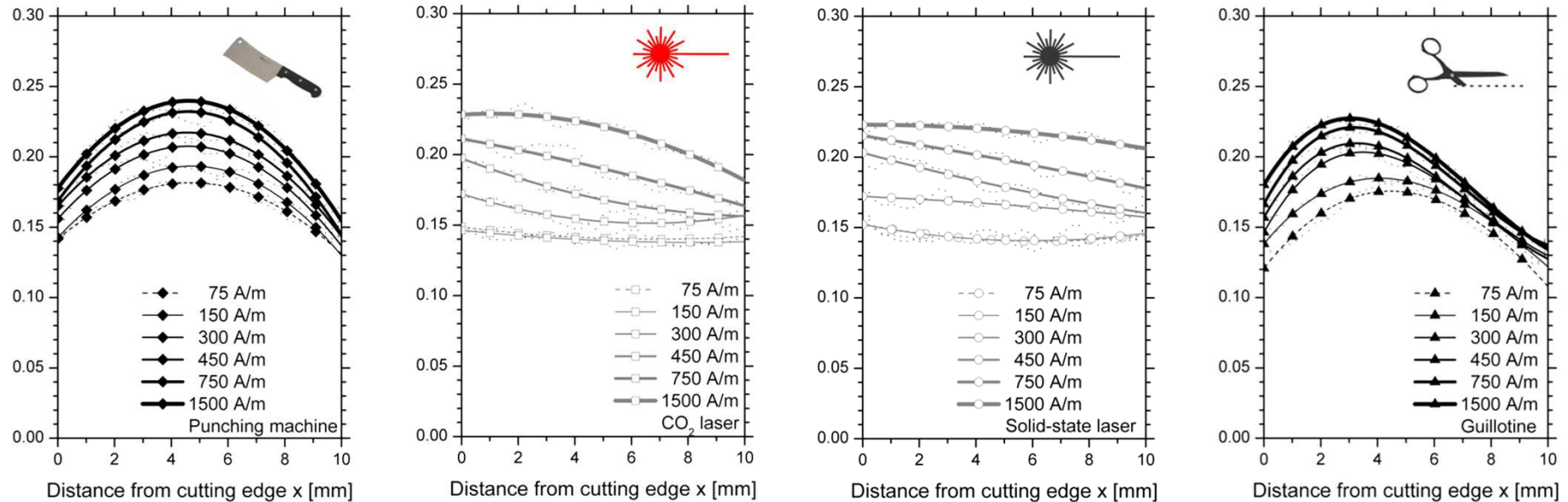
Deterioration effects for different manufacturing techniques

DFI @ 0 A/m



Deterioration effects for different manufacturing techniques

DFI data for 10 mm strip width @ different H fields

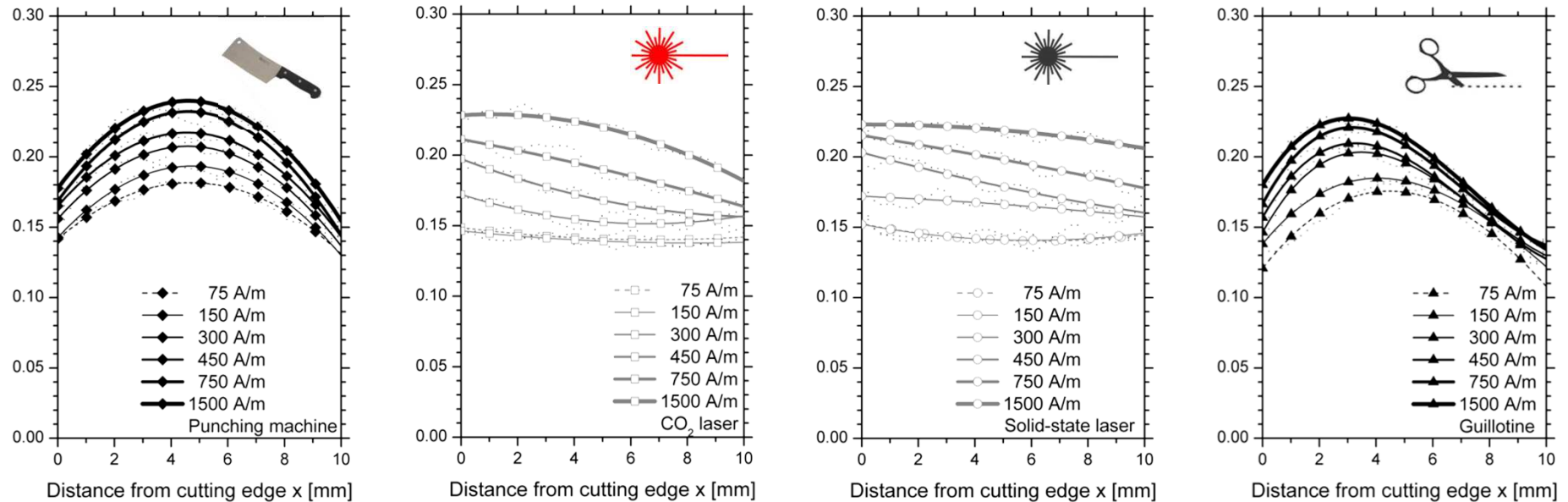


Relation between domain wall density (DFI signal) and applied field

**→ Calibration of the DFI signal with magnetic flux density
from B-H measurements**

Calibration of the DFI with B-H curves

DFI data for 10 mm strip width @ different H fields

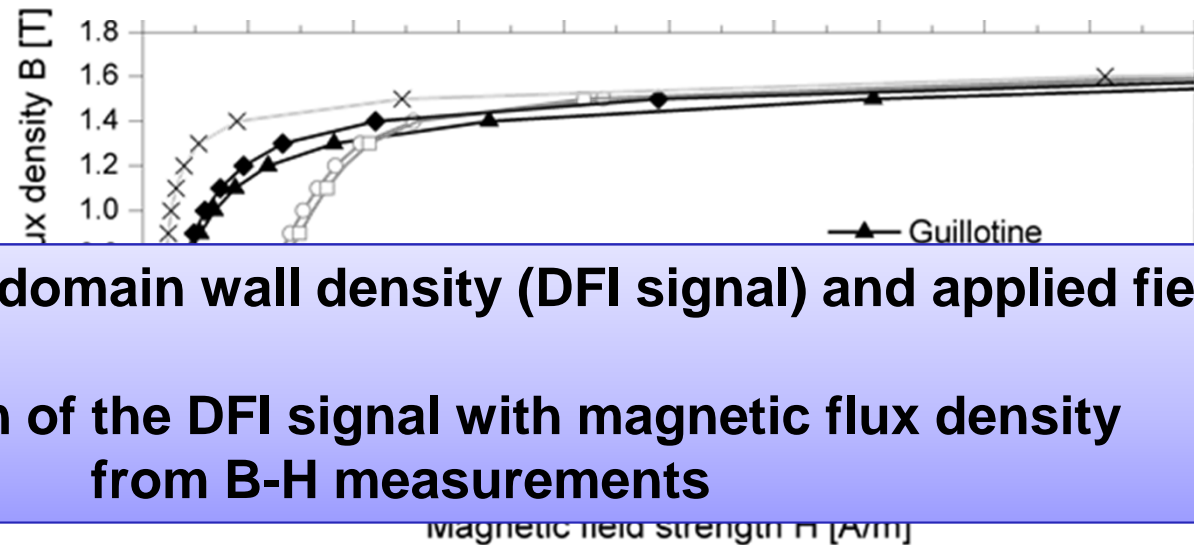
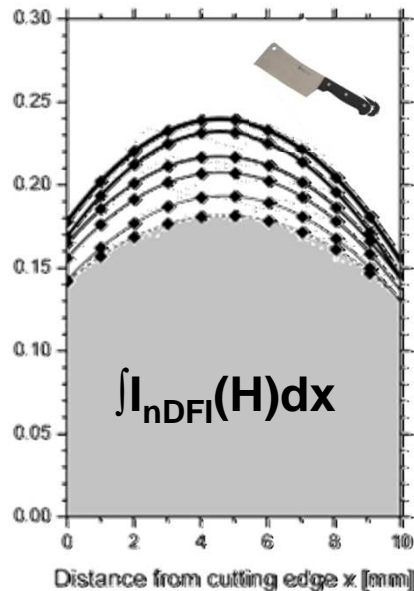


Relation between domain wall density (DFI signal) and applied field

→ **Calibration of the DFI signal with magnetic flux density from B-H measurements**

Calibration of the DFI with B-H curves

DFI data for 10 mm strip width @ different H fields

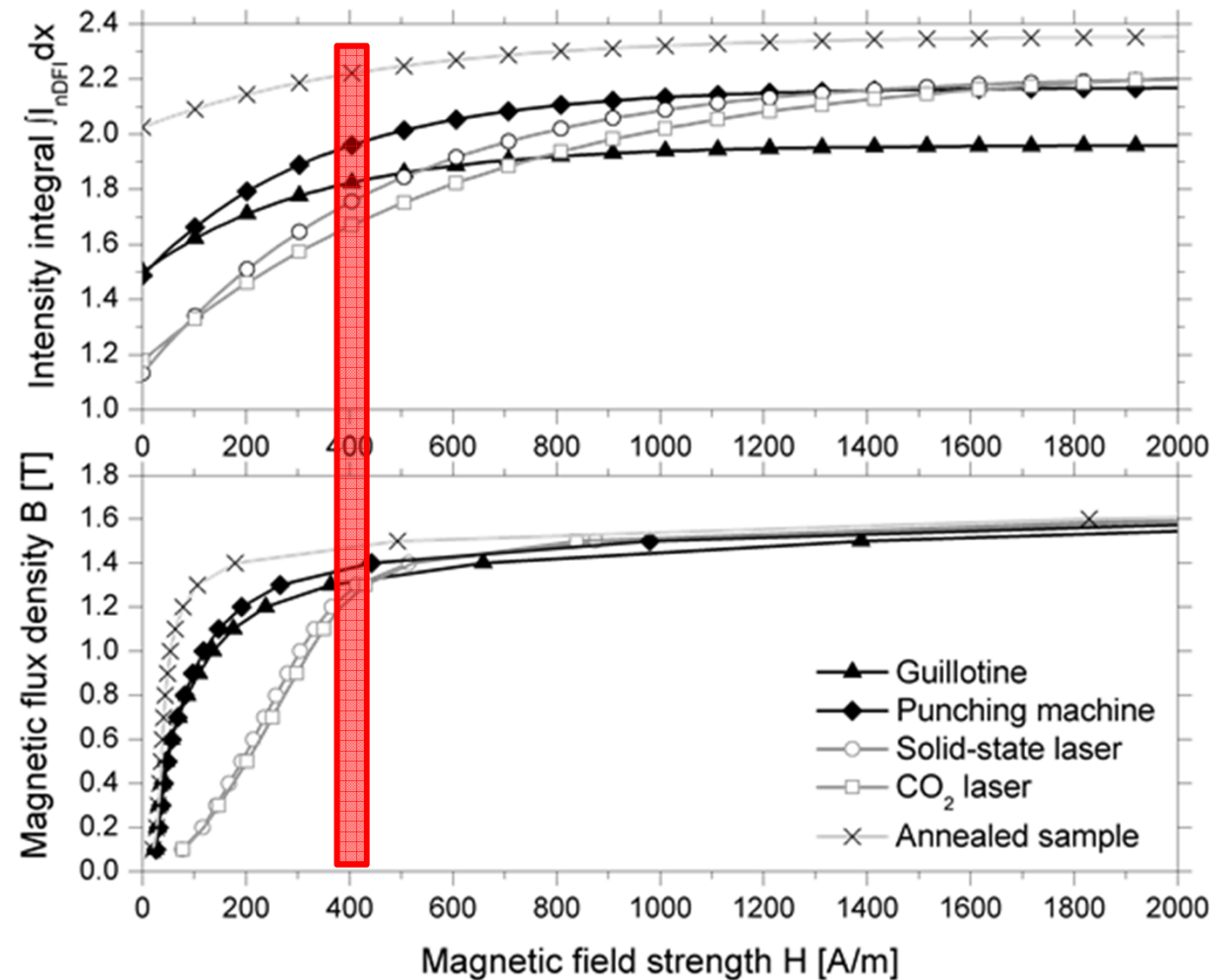
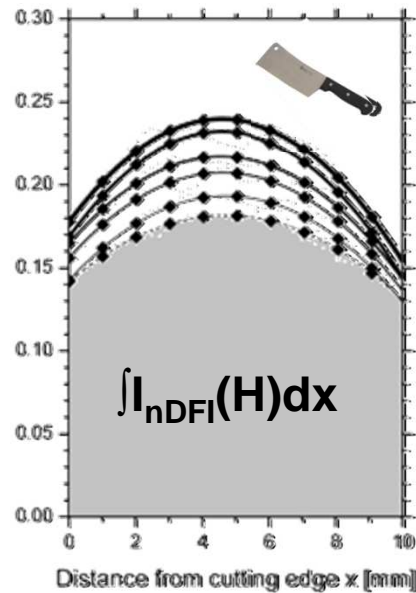


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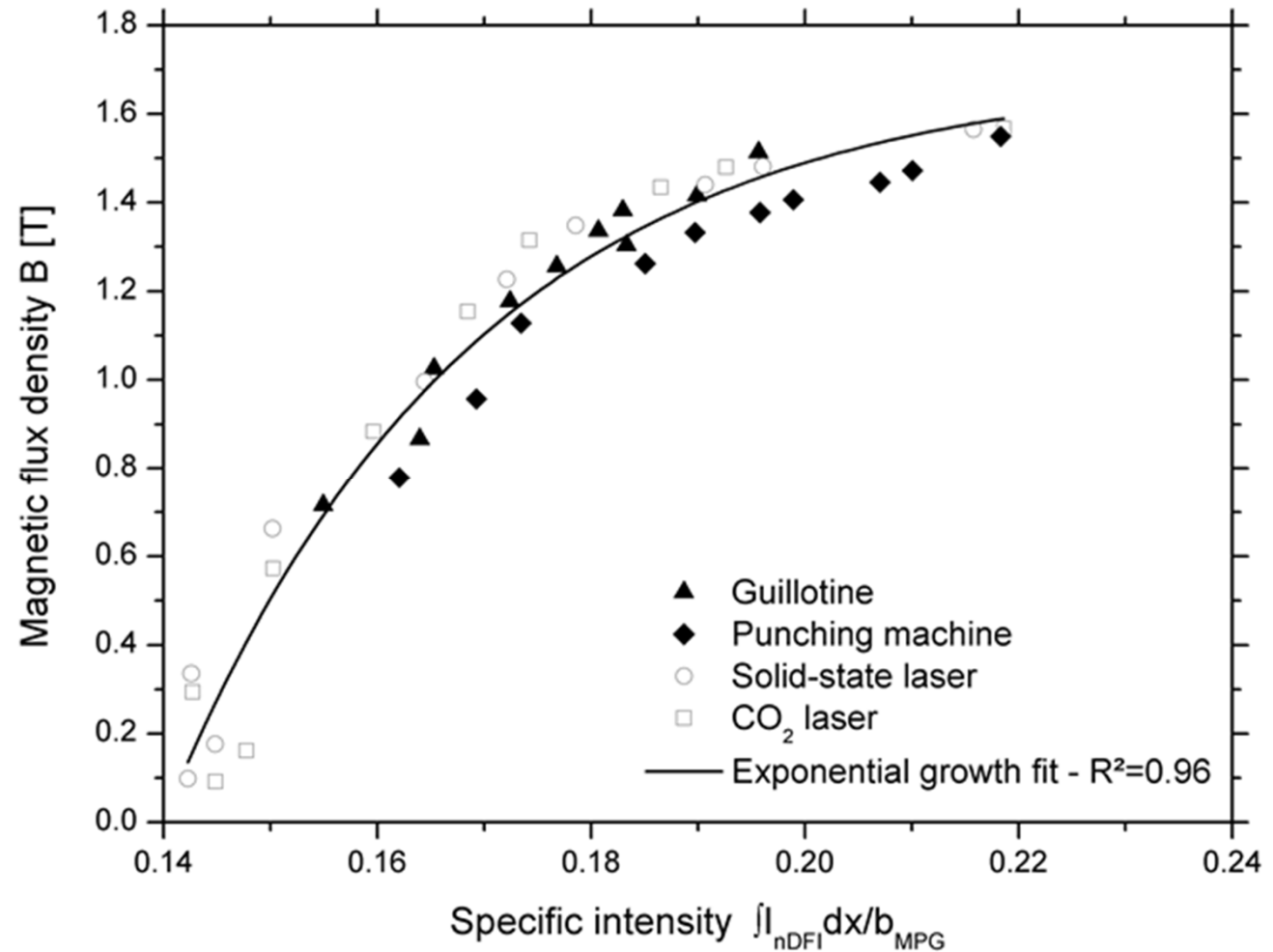
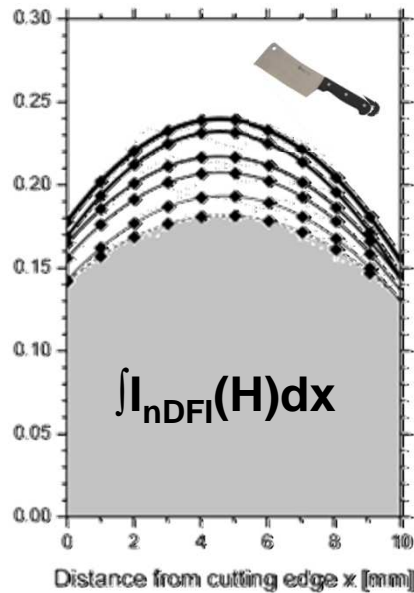
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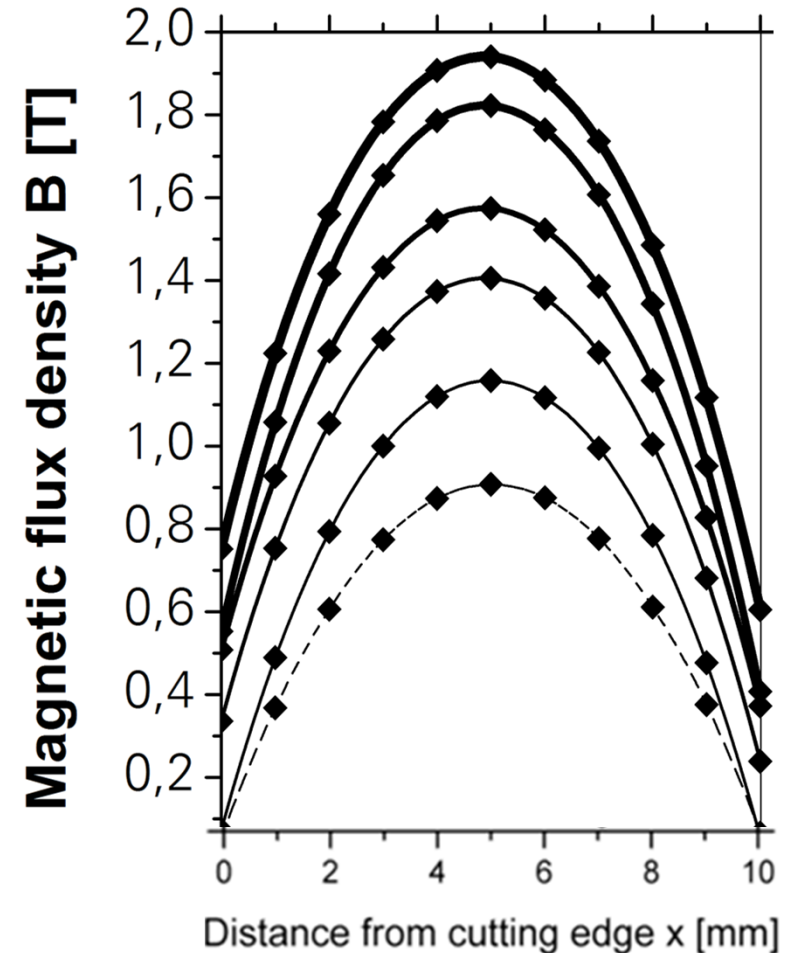
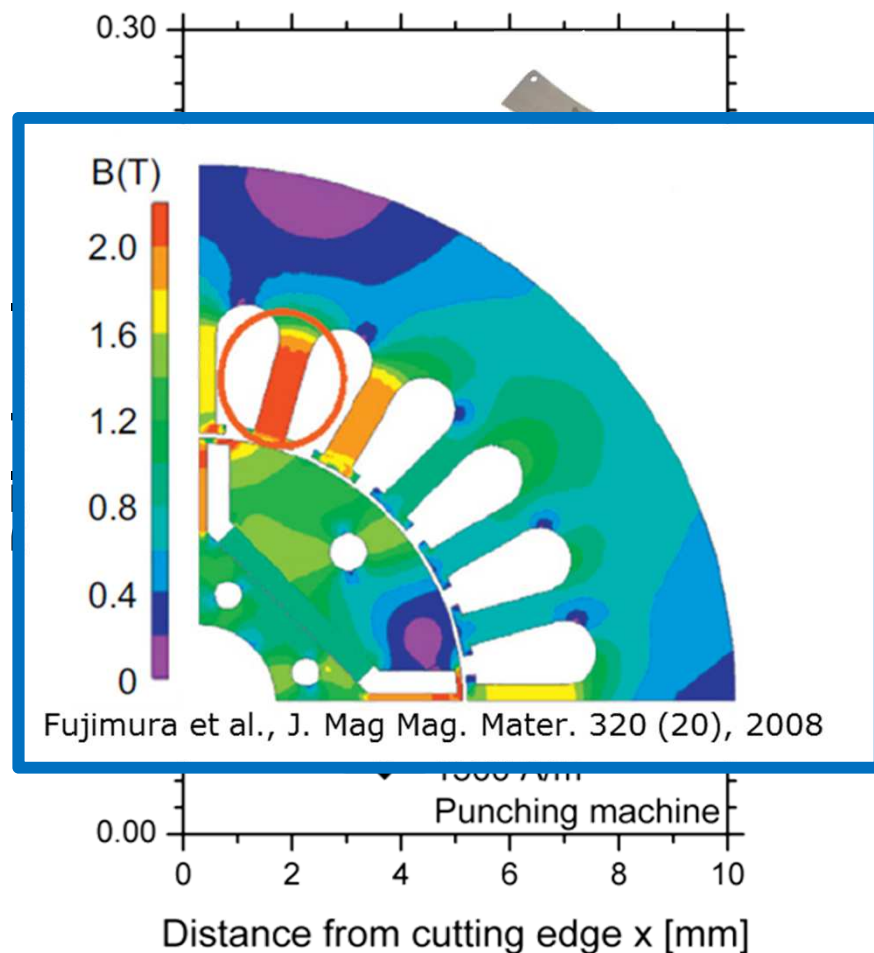


Calibration of the DFI with B-H curves

DFI data for 10 mm strip width @ different H fields

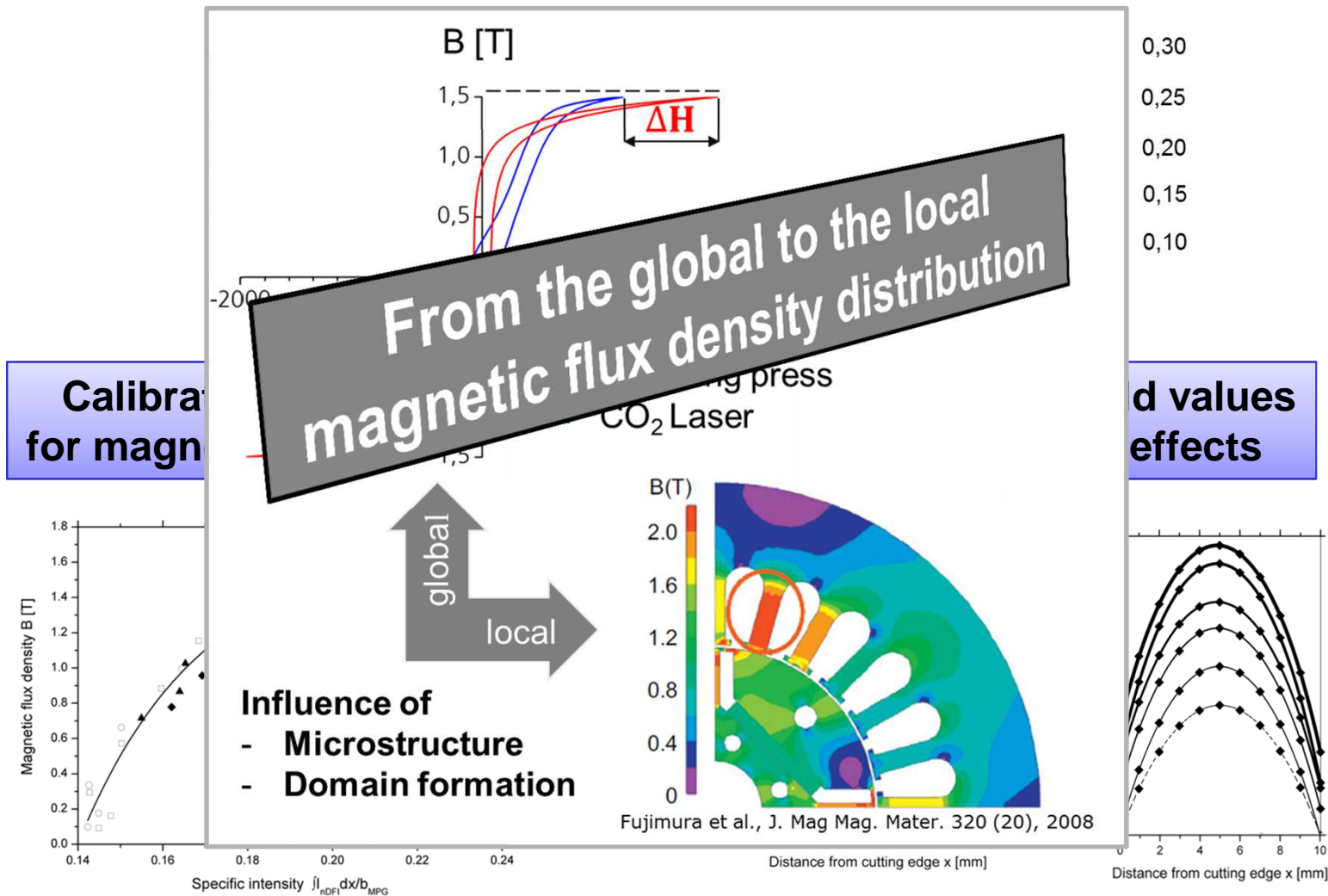


Quantitative DFI information on local magnetic flux density



Quantitative DFI information on local magnetic flux density

Deterioration effects for different manufacturing techniques



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Thank you for your attention

