Bulk residual stress analysis with synchrotron high-energy X-rays



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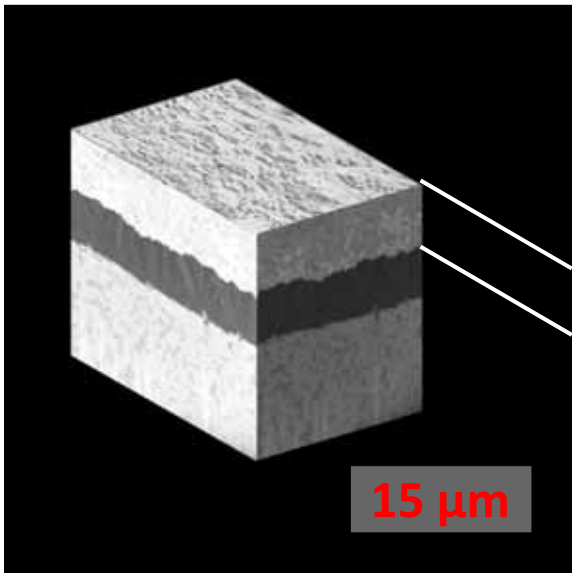
ACCELLERATE R2B Workshop

09.03.2021

Why synchrotron?



micrometer spatial resolution

millisecond time resolution

high penetration

Outline

- GEMS instrumentation for RS analysis
- RS analysis with high-energy X-rays
  - Thin sheets – transmission geometry
  - Thick samples – conical slit cell
  - 3D and near surface – energy-dispersive
- Summary

HZG – Photons at DESY

PETRA III

Diffraction

P07/HEMS – High Energy Materials Science

P61A/WINE – White beam eng. mat.

Imaging

IBL/P05 – Imaging Beamline

P03 Nanofocus end station

New GEMS building with materials science support labs

The HEMS beamline

P07/HEMS – High Energy Materials Science Beamline

- monochromatic
- 30 … 200 keV
- HZG: 67%, DESY: 33%
- ≈ 50 user experiments per year
- focus on engineering materials science
- diffraction, SAXS, 3DXRD

Norbert Schell

Emad Maawad

N. Schell et al., Mater. Sci. Forum 571–572 (2008) 261–266.

P61A/WINE – White Beam Engineering Materials Science Beamline

- white beam: 40–300+ keV
- energy-dispersive diffraction
- near surface and bulk
- imaging

Guilherme Abreu Faria
Gleb Dovzhenko

Outline

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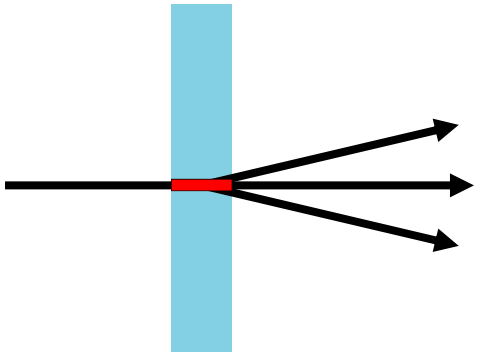
Thin sheets

Transmission geometry

Transmission geometry:

- no depth resolution
- good grain statistics



thickness 0.1 ... 10 mm

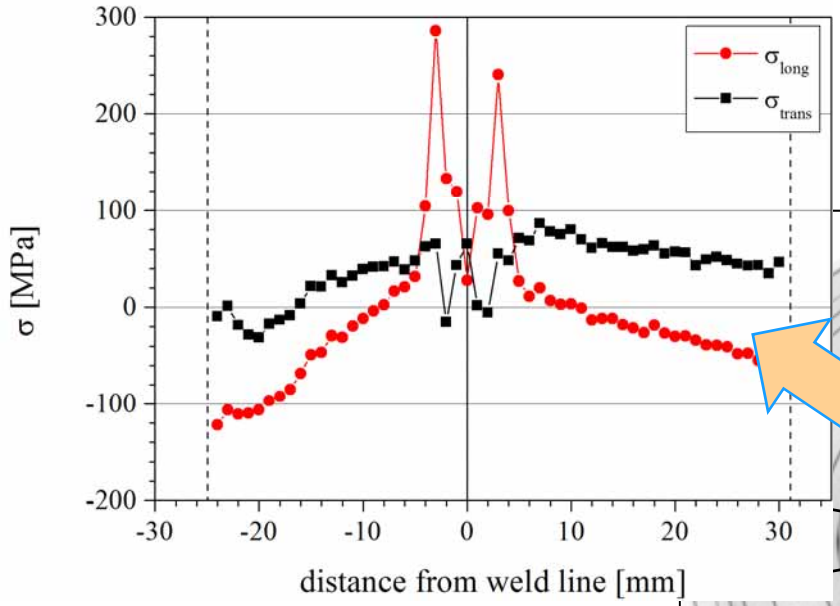
Beam cross section:

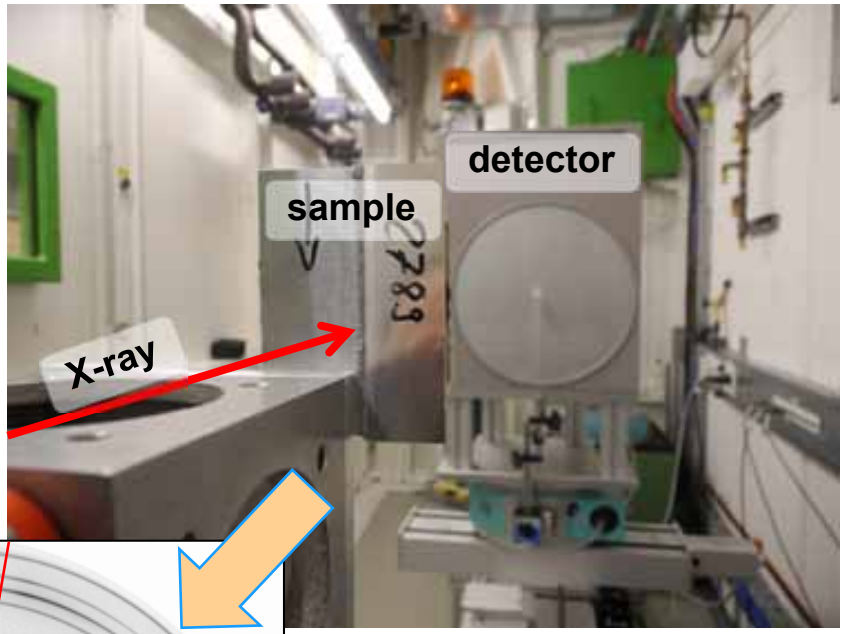
- 10 ... 500 µm without focussing
- down to 2 µm with focussing (high energies)

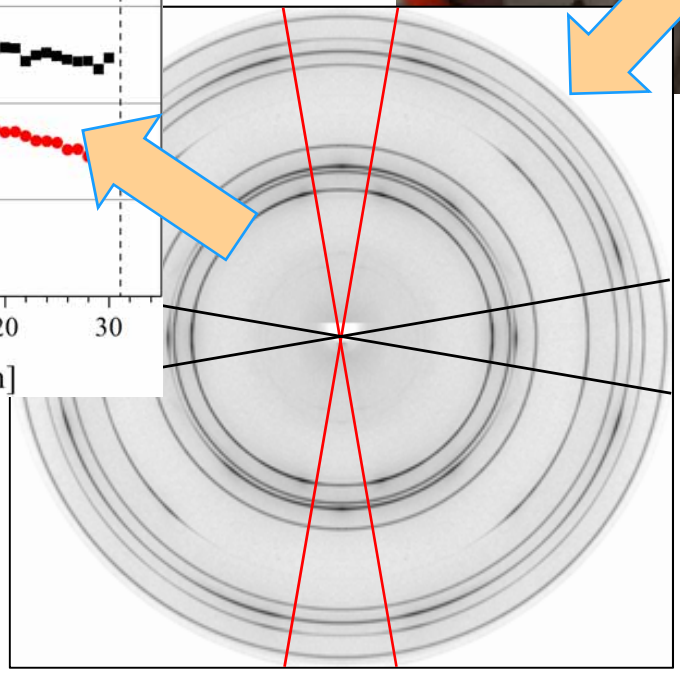
Thin sheets

Transmission geometry

HEX-ray strain scanning in transmission:
easy to measure **two** orthogonal strain directions





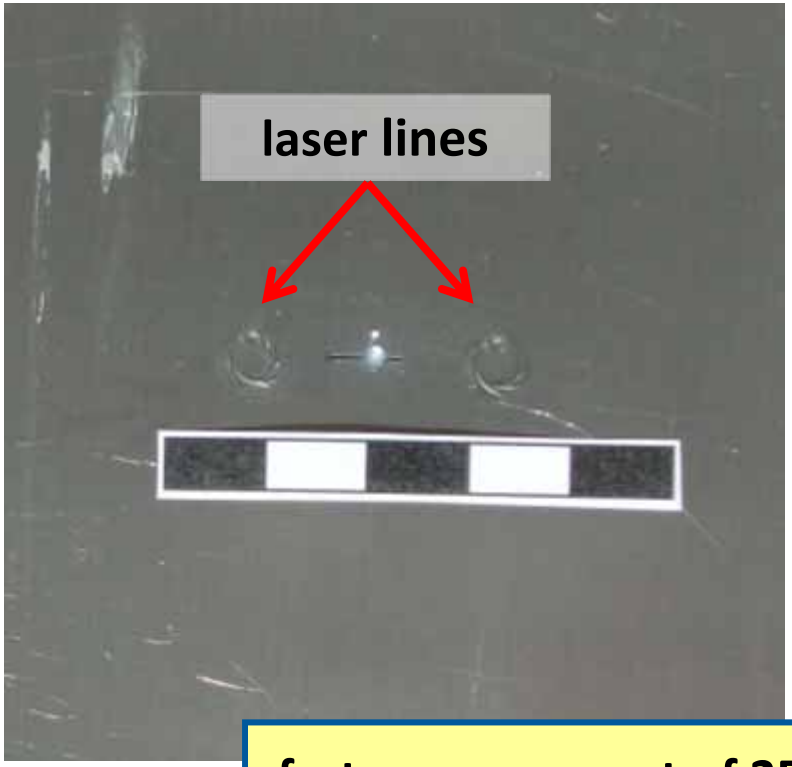


Small laser beam welded AA2198 sample mounted for strain scanning.

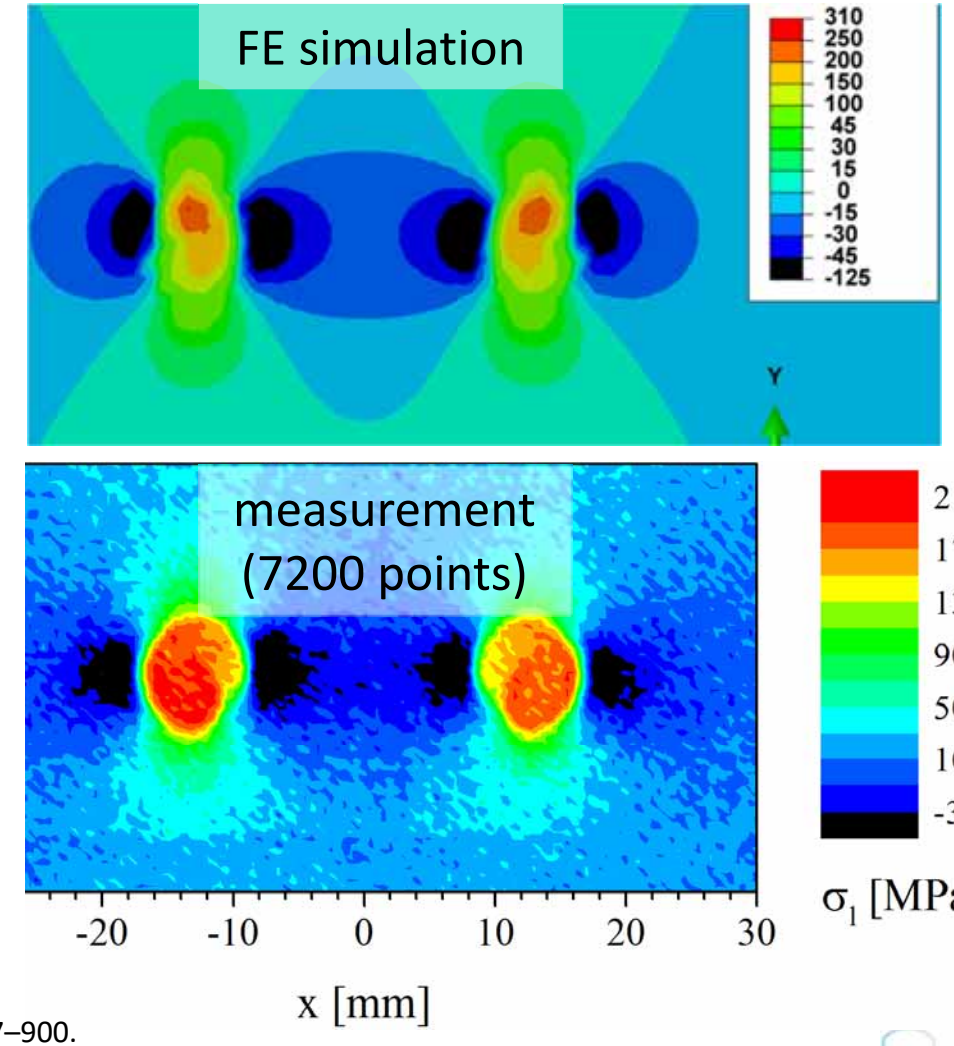
Thin sheets

Transmission geometry

Laser surface treatment of 2 mm thick AA2024 sheets:

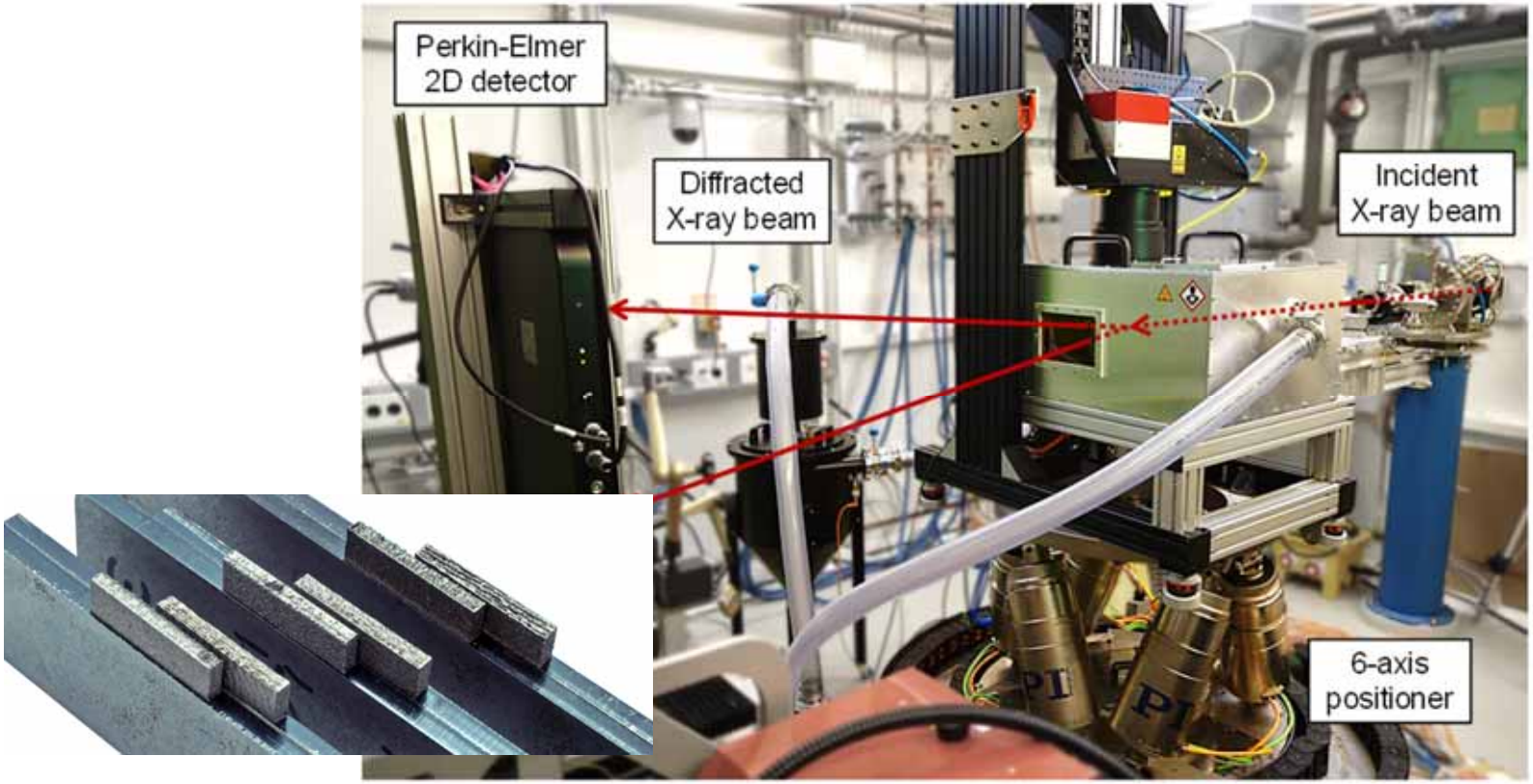


fast measurement of 2D stress maps



N. Kashaev, A. Groth, V. Ventzke, M. Horstmann, S. Riekehr,
P. Staron, N. Huber, Fat. Fract. Eng. Mater. Struct. 44 (2021) 887–900.

Experimental Setup – *in situ* selective laser melting



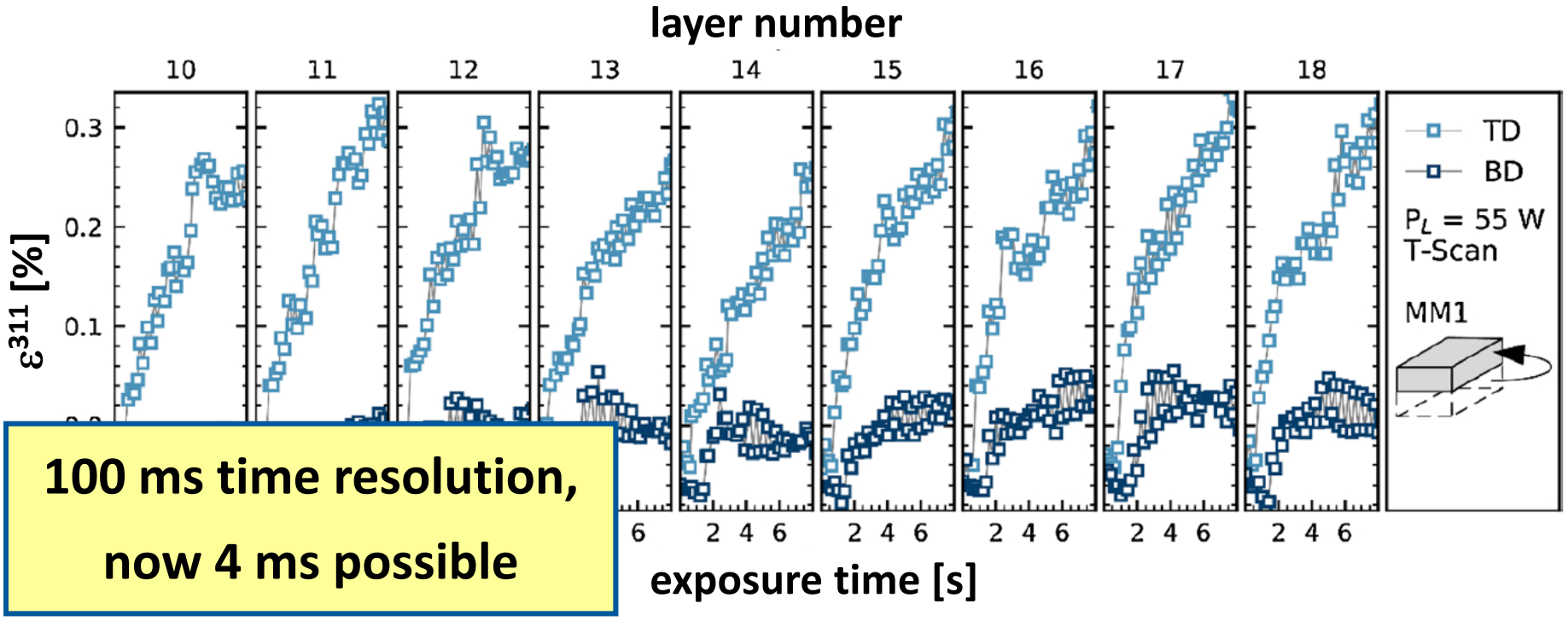
In-situ experiment for selective laser melting
Felix Schmeiser (TUB, Metallic Materials), Erwin Krohmer (TUB, Institute for Machine Tools and Factory Management)

F. Schmeiser, E. Krohmer, N. Schell, E. Uhlmann, W. Reimers, Additive Manufacturing 32 (2020) 101028.

Thin sheets

Transmission geometry

Strain development during SLM, observed with 100 ms time resolution:



100 ms time resolution, now 4 ms possible

Fig. 6. Strain Progression in MM1, measuring position in the center of the sample. Each subplot shows progression for one layer. The data points marked in light blue show the strains in TD, dark blue ones show BD.

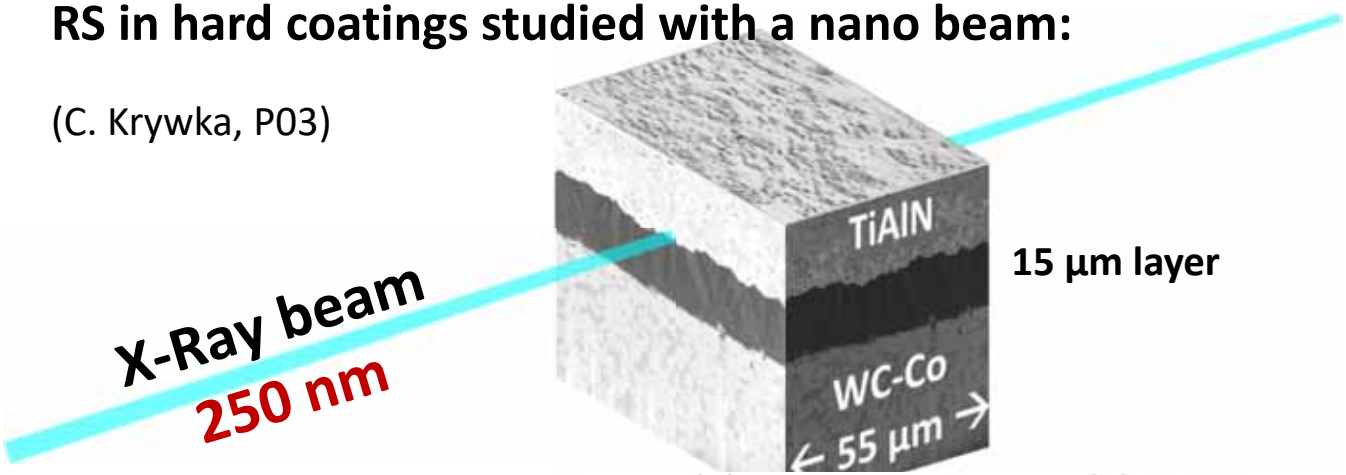
F. Schmeiser, E. Krohmer, N. Schell, E. Uhlmann, W. Reimers, Additive Manufacturing 32 (2020) 101028.

Thin sheets

Transmission geometry

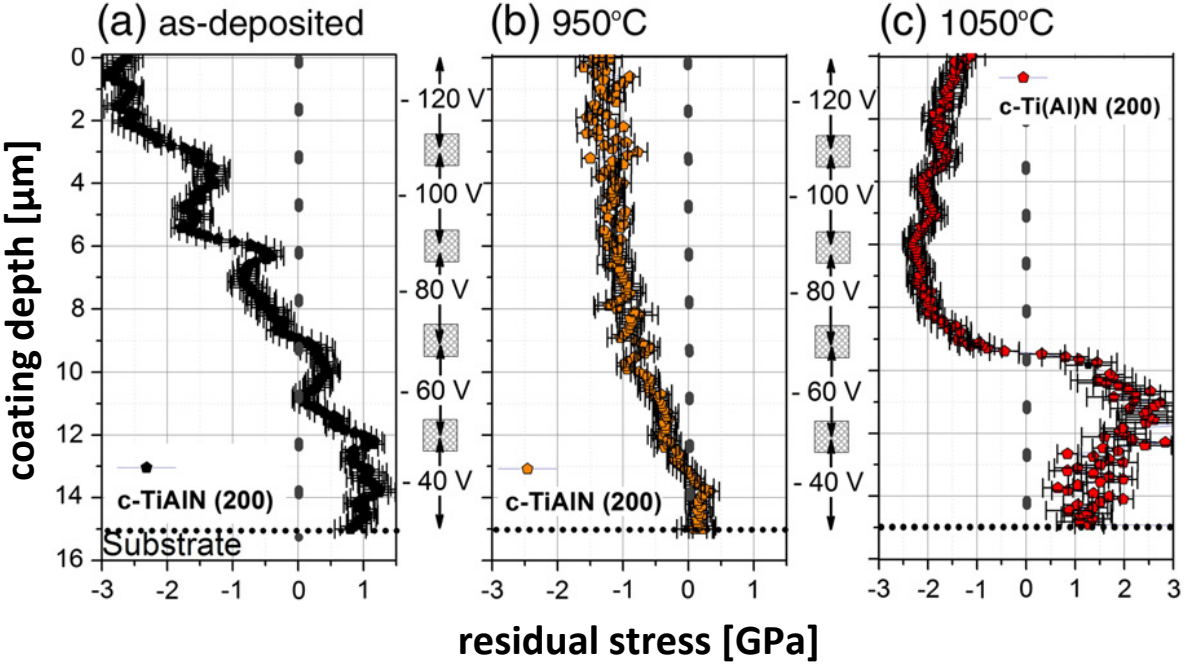
RS in hard coatings studied with a nano beam:

(C. Krywka, P03)



15 µm layer

250 nm resolution possible



A. Riedl et al., Surf. Coat. Technol. 257 (2014) 108–113.

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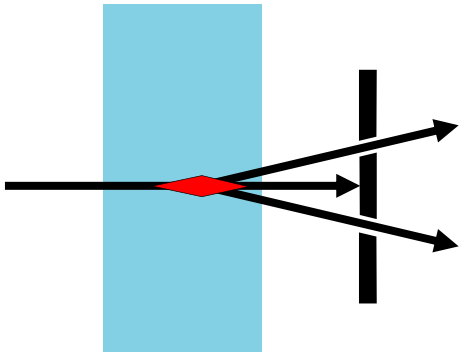
Large samples

Transmission geometry

Conical slits:

- elongated gauge volume
- medium depth resolution
- gauge volume fixed in space

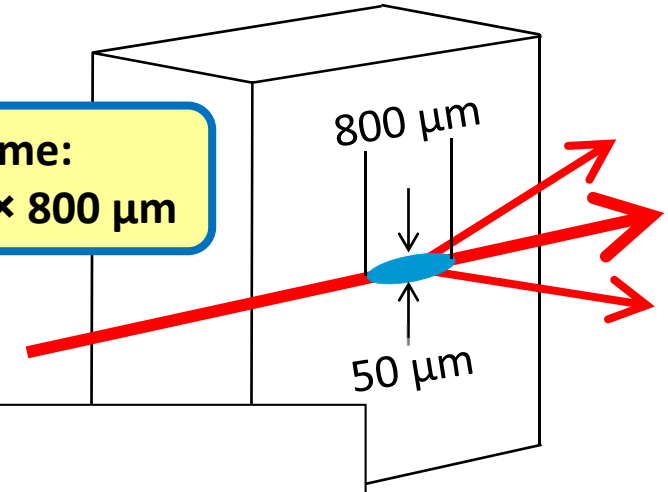


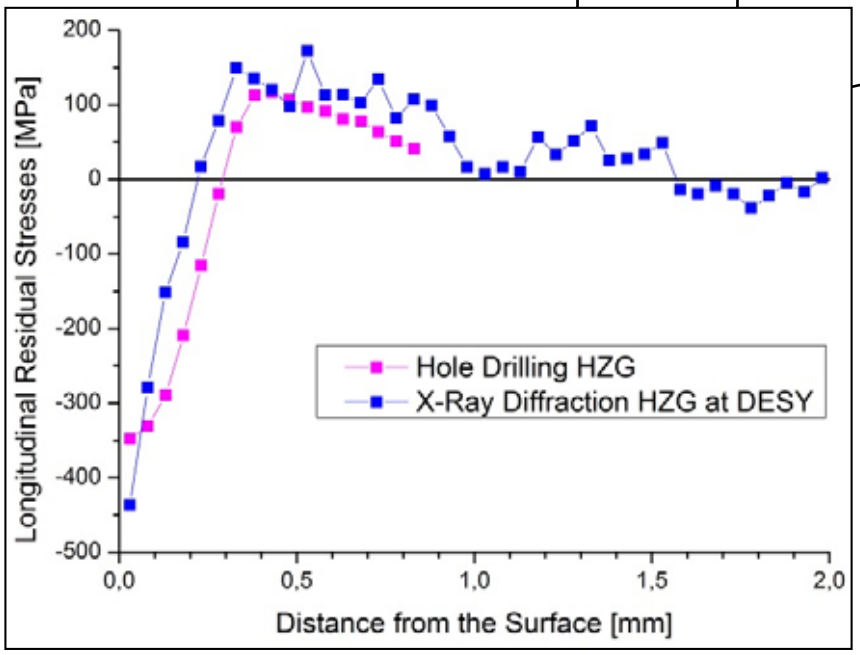
Large samples

Conical slit cell

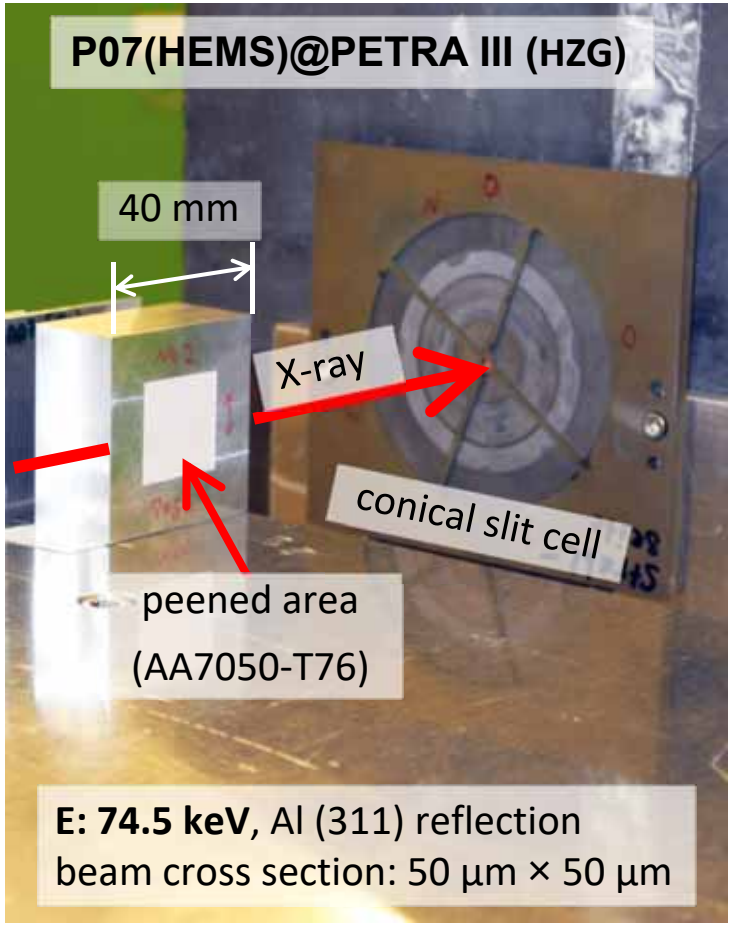
Conical slits for depth-resolved residual stress analysis in laser shock peened Al

gauge volume:
50 µm × 50 µm × 800 µm





Bulk residual stress analysis with synchrotron high-energy X-rays

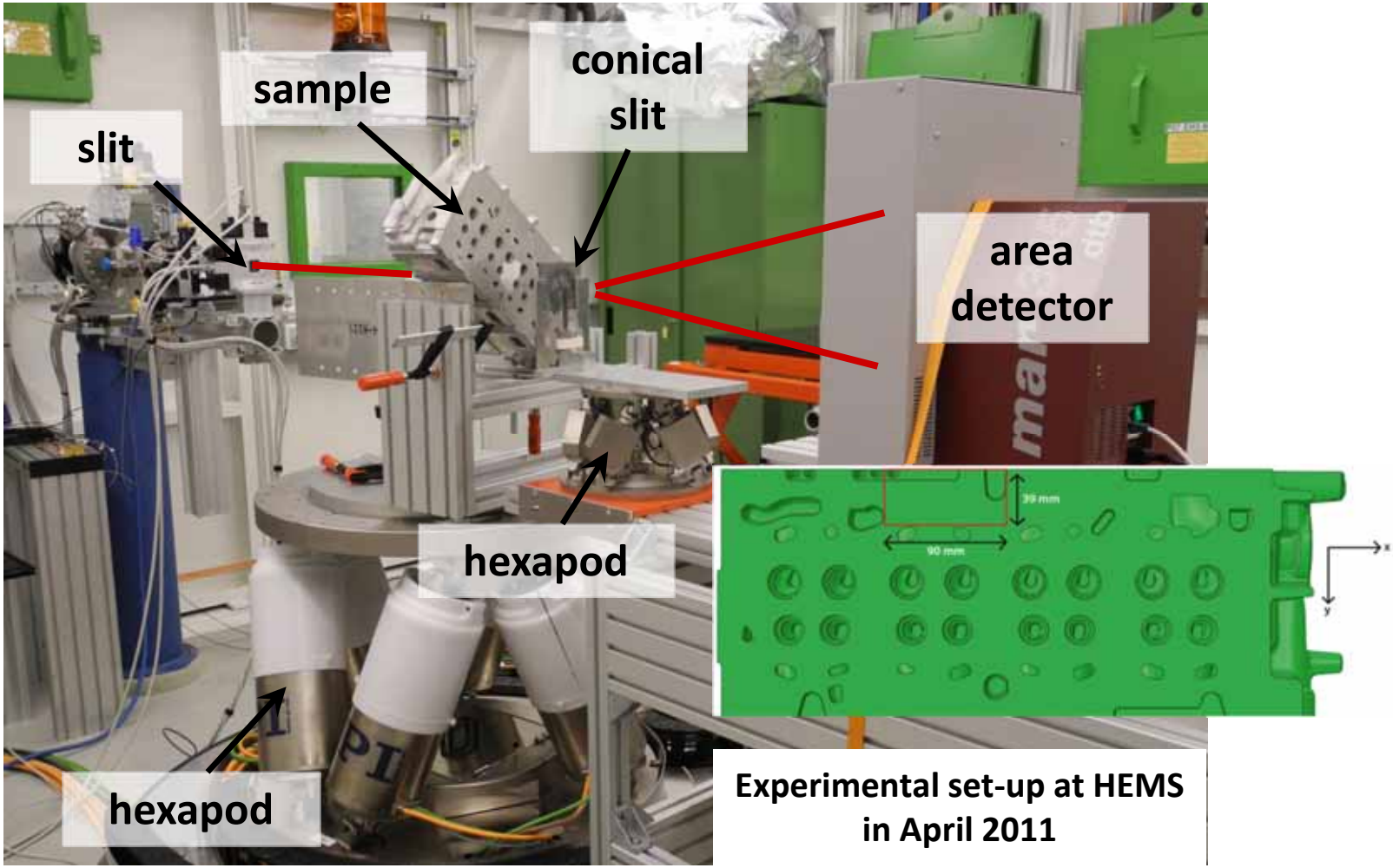


M. Sticchi, P. Staron, N. Schell, M. Meixner, Y. Sano, N. Huber, N. Kashaev, J. Engin. (2015) 0106.

Large samples

Conical slit cell

Cast Al car cylinder head:



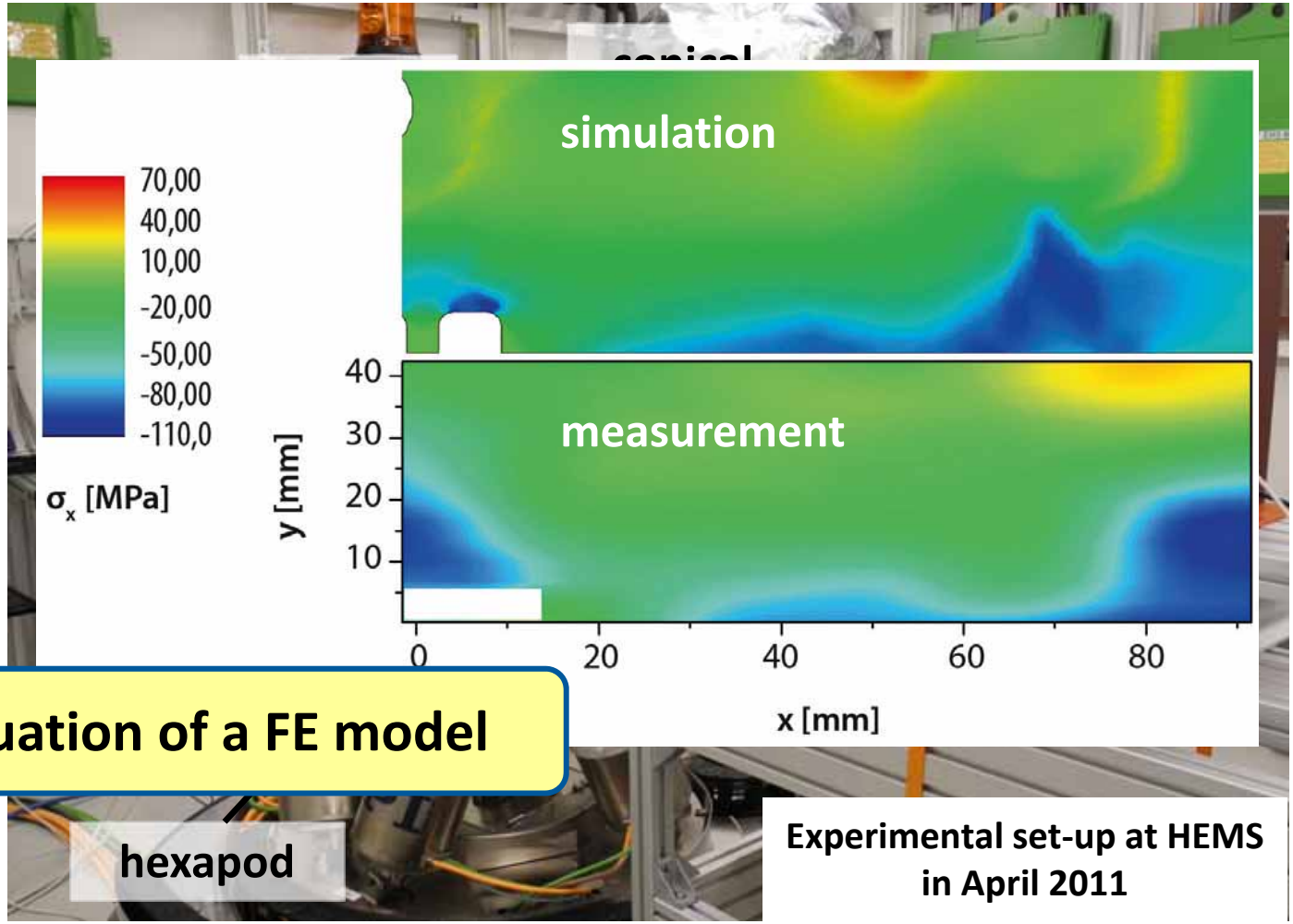
Experimental set-up at HEMS in April 2011

M. Thiry, P. Staron, A. Guirao-Blank, Lightweight Design 8 (2015) 38–43.

Large samples

Conical slit cell

Cast Al car cylinder head:



evaluation of a FE model

Experimental set-up at HEMS in April 2011

M. Thiry, P. Staron, A. Guirao-Blank, Lightweight Design 8 (2015) 38–43.

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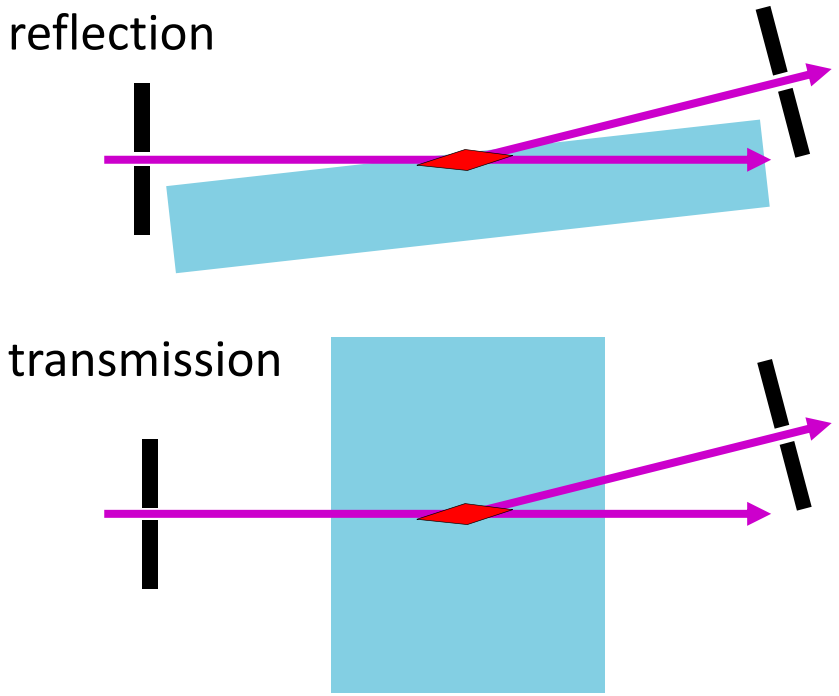
3D and near surface

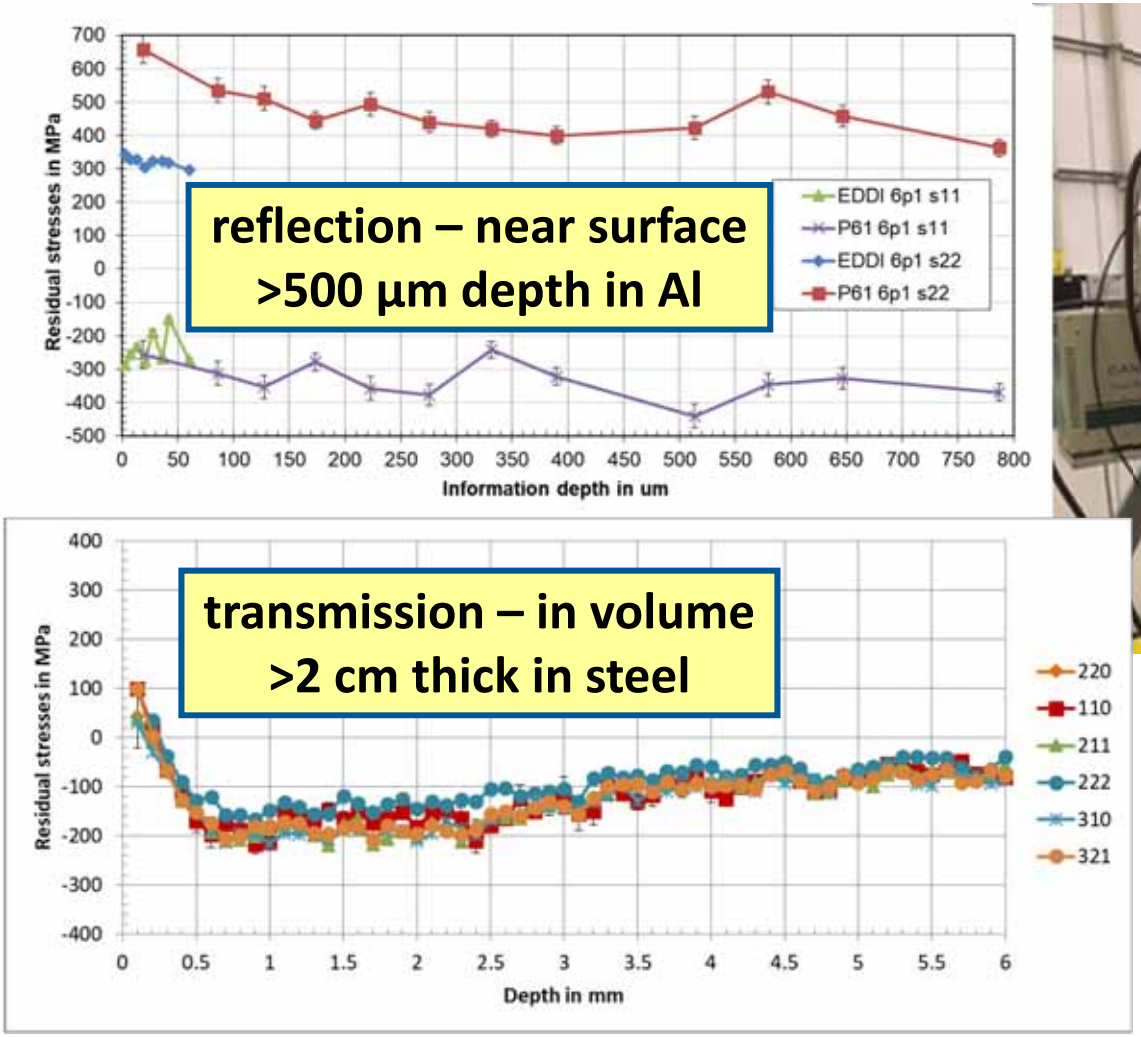
Transmission geometry

White beam:

- elongated gauge volume
- surface sensitive
- large penetration depth
- gauge volume fixed in space



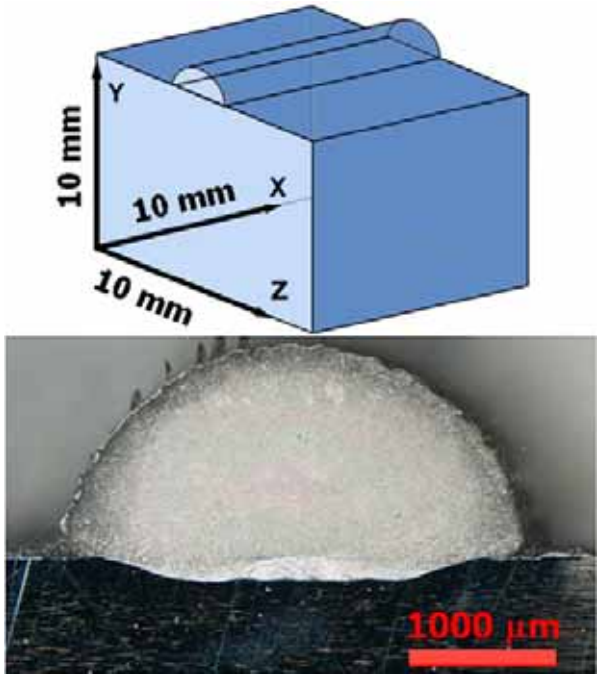
Energy-dispersive diffraction for RS analysis with a white beam:



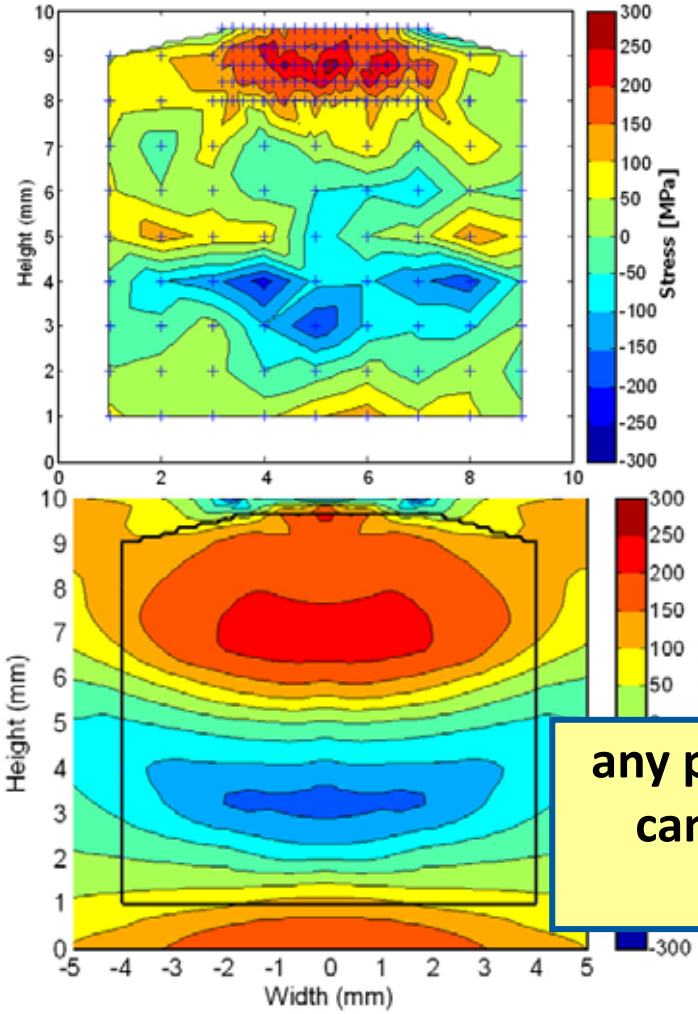
Setup for small samples at Beamline P61A at PETRA III

Residual stresses in laser-cladded steel plates – transmission geometry

measured at ID15A@ESRF



- gauge volume 0.2×0.2×2 mm^3
- energy range 30–250 keV
- 2θ = 5°



σ_z as measured

σ_z FEM prediction

any point in the sample can be measured in any direction

A. Suárez, J.M. Amado, M.J. Tobar, A. Yáñez, E. Fraga, M.J. Peel, Surface & Coatings Technology 204 (2010) 1983–1988.

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Summary

- Transmission geometry
  → good for thin sheets, fast measurement, fast access
- Conical slits
  → thick samples, high spatial resolution
- Energy-dispersive
  → near-surface, large samples, fast measurement
- Best method depends on sample (geometry, microstructure) and problem
  → ask for advice and test measurement

Acknowledgements

Helmholtz-Zentrum Geesthacht
Centre for Materials and Coastal Research

Thank you for your attention!