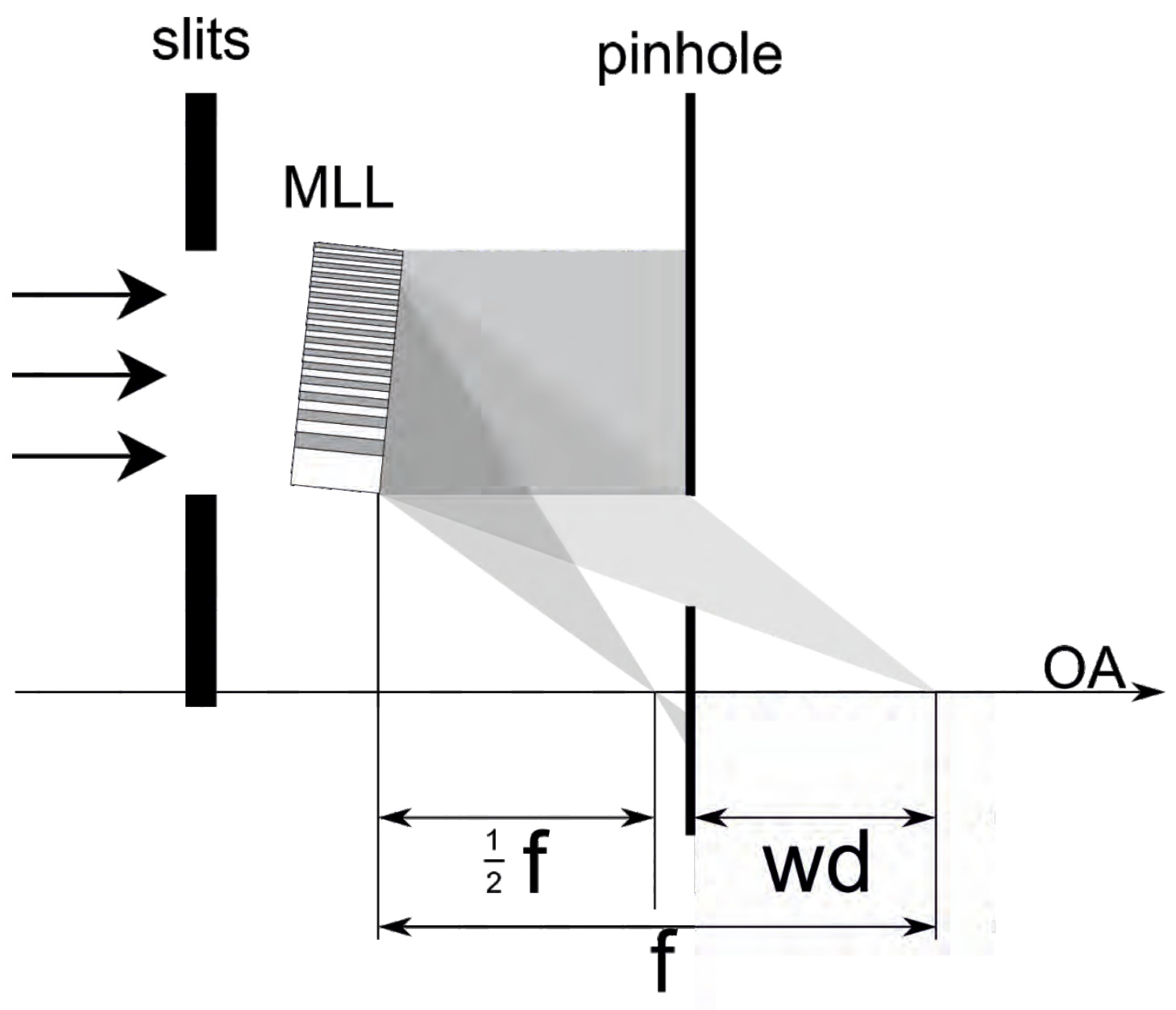
Efficient sub-25 nm focusing and advanced measurement methods using crossed Multilayer Laue Lenses

A. Kubec[1], **S. Niese**[2], **J. Gluch**[3], **M. Rosenthal**[4], **P. Gawlitza**[1], **J. Keckes**[5] **and A. Leson**[1]
[1]Fraunhofer IWS Dresden, Winterbergstraße 28, 01277 Dresden, Germany
[2]AXO Dresden GmbH Gasanstaltstraße 8b, 01237 Dresden, Germany
[3]Fraunhofer IKTS Dresden, Maria-Reiche-Straße 2, 01109 Dresden, Germany
[4]ESRF, 71 Avenue des Martyrs, 38000 Grenoble, France
[5]Erich Schmid Institute for Materials Science, Jahnstraße 12, 8700 Leoben, Austria
Contact: adam.kubec@iws.fraunhofer.de

MLLs for high resolution X-Ray Microscopy

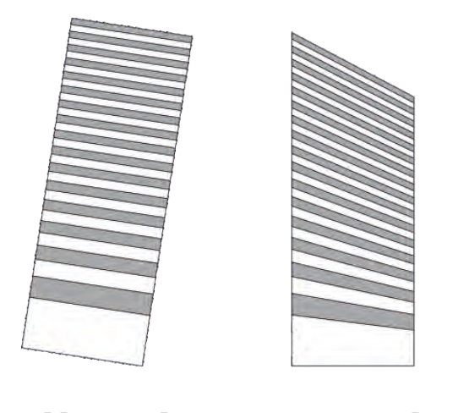
Calculations have shown the potential of Multilayer Laue Lenses (MLLs) to achieve resolutions in the sub 5 nm range with hard X-rays [1,2]. Increasing demand of in-situ experiment capabilities requires working distances in the order of several millimeters. This space is necessary in order to contain the experimental setup and samples. We have developed a low stress multilayer material system for MLL, which allows the multilayer deposition with a thickness of several ten micrometer [3].



Current MLL Design/Properties:

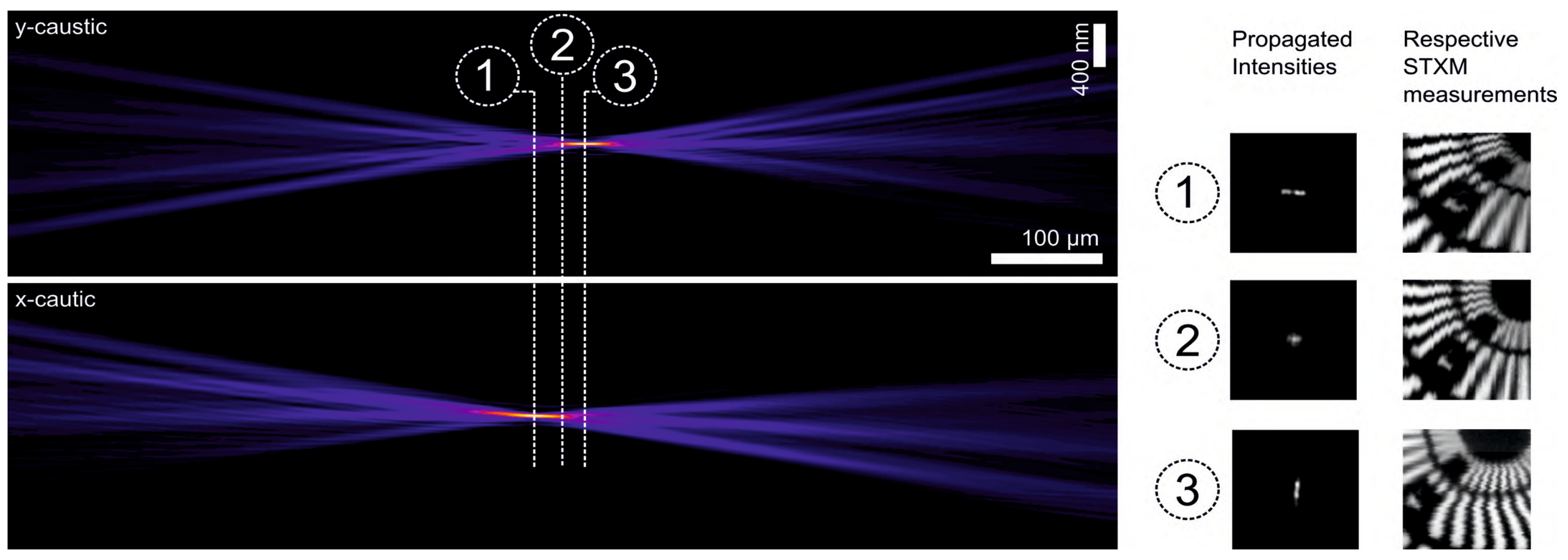
Focal Length:	9 mm @12 keV
Working Distance:	3.1 mm
Stack height:	50 µm
Zone Numbers:	970 - 6970
Individual Layers:	12000
Materials:	Mo/C/Si/C
Sectioning (coarse):	Laser Structuring
Sectioning (fine):	FIB milling
Geometry:	tilted MLL

The current MLL design has been tested at the ESRF beamline ID13. The MLLs and a custom-made pinhole have been installed in the beamline.



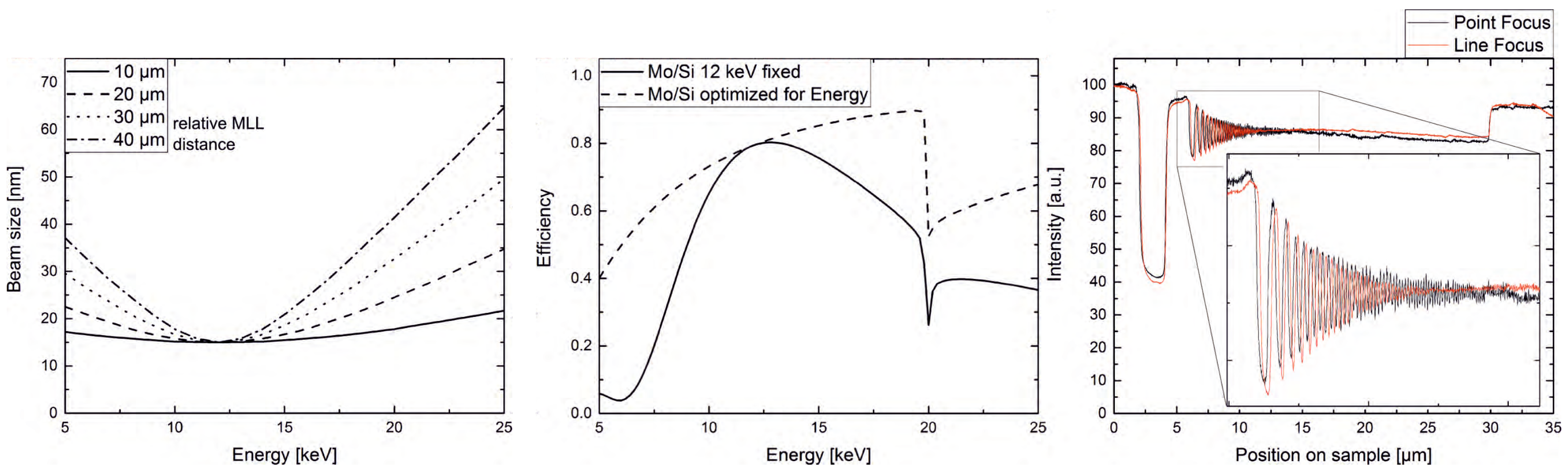
Measured Beam Properties of crossed MLL:

Illuminated Aperture:	40 µm x 40 µm
Focal Profile FWHM:	23 nm and 25 nm
Focal Plane Offset:	50 µm
Maximum Flux on Sample:	2.8 x 10^{10} ph/s
Efficiency(η/η^2):	46%/21% (more than previously measured wedged MLL [4])



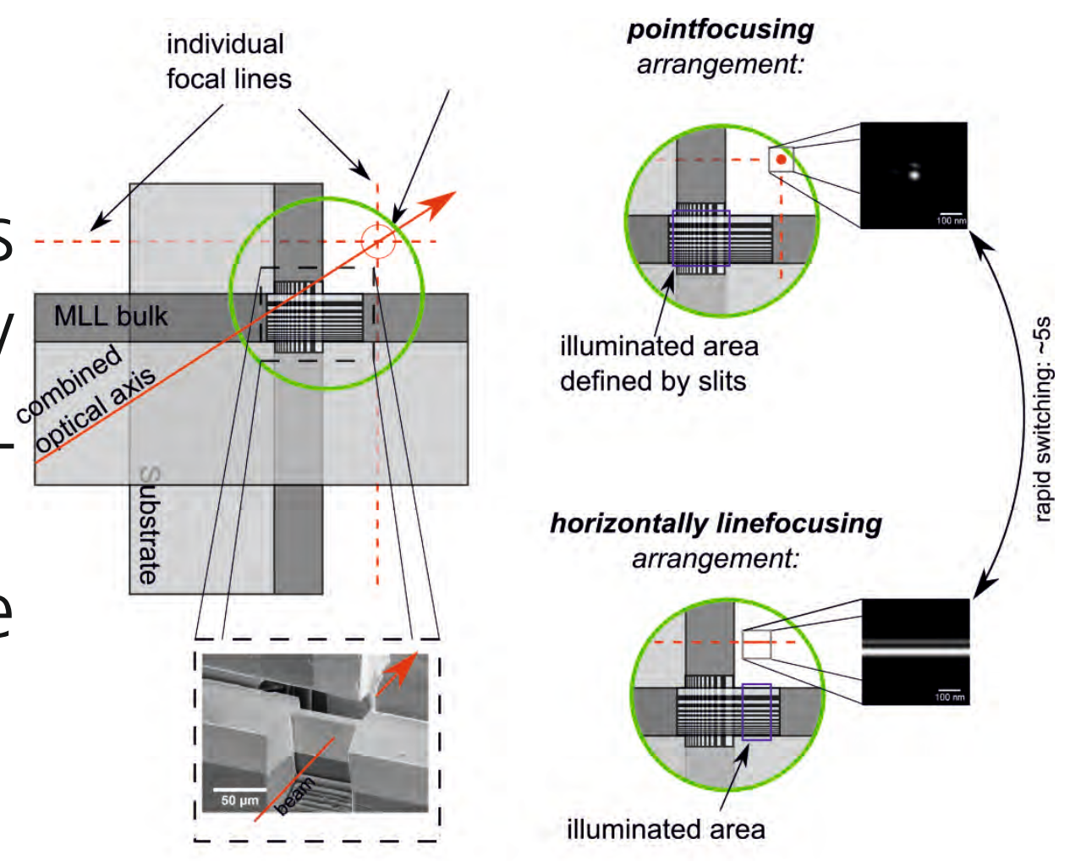
Properties, Methods and Experiments

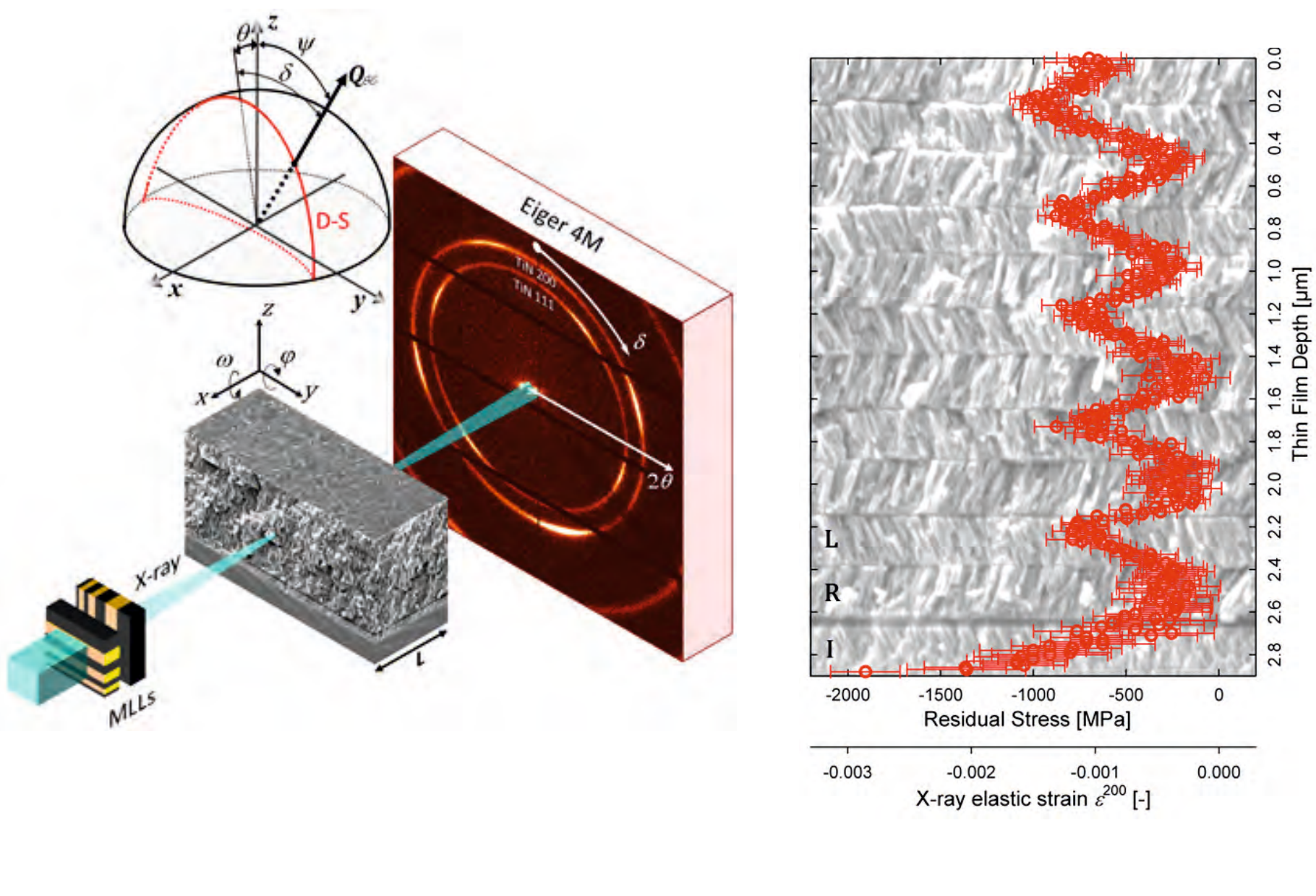
One MLL focuses X-rays only in one dimension. Two crossed MLLs are required for point focusing and their relative distance has to be adjusted precisely. A large relative distance prevents the crossed MLLs to be used at different energies. This is due to the large difference in focal lengths, which scale differently with energy. However, two MLLs with a diffraction limited resolution of 15 nm and a relative distance of 10 µm optimized for 12 keV will produce a nearly symmetrical intermediate beam with a size below 20 nm for X-ray photon energies between 5 keV and 20 keV.



Point and line focus switching:

With large aperture widths the MLL setup allows switching between point and line focus. This is realized by illuminating either two crossed or only one single MLL with the beam defining slits. [5]
The technique enables users to significantly improve measurement statistics for 1D scans.





Sample measurements

Using MLLs a sample with a columnar microstructure was measured. The cross-sectional orientation of the individual columns of the sample changes abruptly. X-ray nanodiffraction revealed the changes in the crystallographic texture as well as in the stress state which is oscillatory with a resolution of 30nm. The results from the point and line-focus measurements indicated practically the same behavior. [6]

Acknowledgments:
The experiments were performed on beamline ID13 at the European Synchrotron Radiation Facility (ESRF), Grenoble, France, in the scope of the Long Term Project MI-1216. We are grateful to Martin Rosenthal at the ESRF for providing assistance in using beamline ID13. We would like to thank the colleagues of the Erich Schmid Institute for Materials Science for the excellent collaboration within the Long Term Project.

References:

[1] J. Maser, et al.: *Multilayer Laue lenses as high-resolution x-ray optics.* (2004)
[2] H.Yan, et al.: *Takagi-Taupin description of x-ray dynamical diffraction from MLL with large NA.* (2007)
[3] A. Kubec, et al.: *Fabrication and efficiency measurement of a Mo/C/Si/C MLL.* (2015)
[4] A. Kubec, et al.: *Point focusing with flat and wedged crossed multilayer Laue lenses.* (2017)
[5] S. Niese, et al.: *Combined point and line focus experiments with multilayer Laue lenses.* (in preparation)
[6] J. Keckes, et al.: *30nm X-ray Focusing Correlates Oscillatory Stress, Texture and Structural Defect Gradients across Multilayered TiN-SiOx Thin Film line focus experiments with multilayer Laue lenses.* (in preparation)