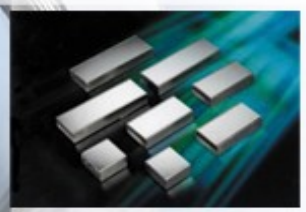
AXO

APPLIED X-RAY OPTICS

Raytracing of real optics:
Tweaking the design of customized X-ray multilayer mirrors



Sven Niese
AXO DRESDEN GmbH
SOS workshop, Trieste, 04.10.2016

Co-Authors

AXO DRESDEN GmbH
APPLIED X-RAY OPTICS
MULTILAYER X-RAY OPTICS
HIGH PRECISION DEPOSITION

Reiner Dietsch
Thomas Holz
Markus Krämer

Fraunhofer IKTS

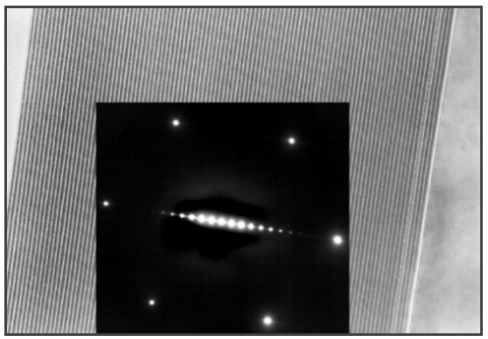
Peter Krüger

Outline

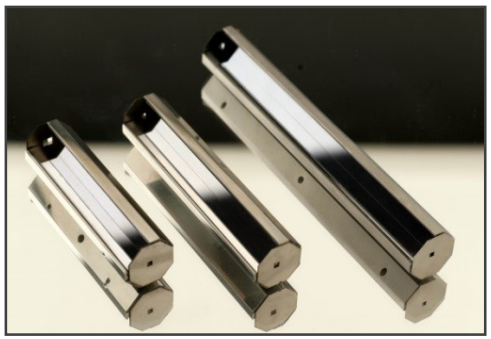
- About what we are doing
  … and why do we need raytracing
- RayT – interactive X-ray tracing
- Examples

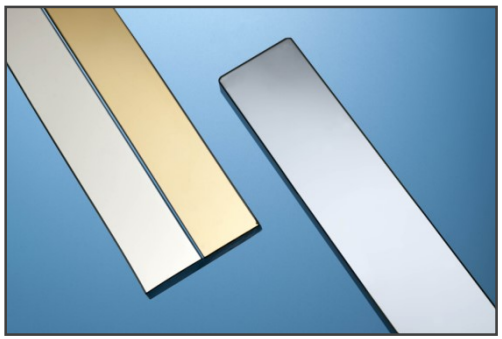
AXO DRESDEN GmbH – an independent company with products ranging

… from high precision (multi)layer depositions

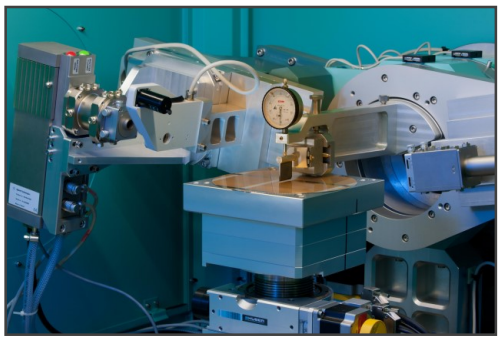


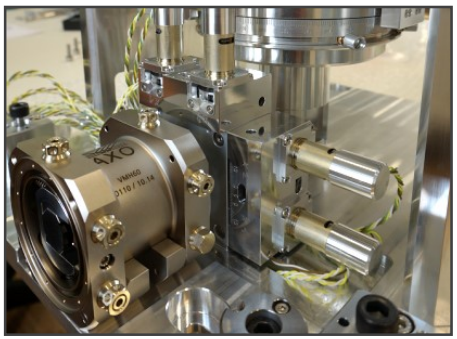
… over various kinds of X-ray multilayer optics



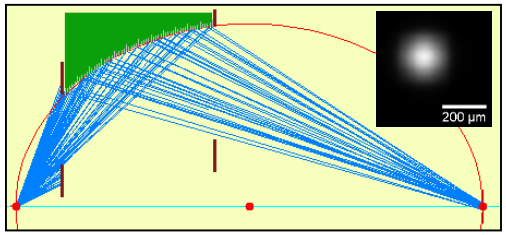


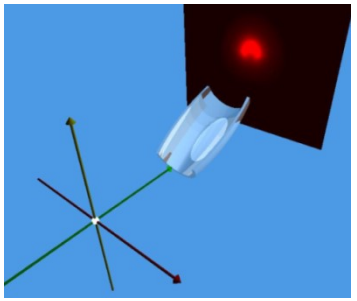
… to complete X-ray systems and upgrades of X-ray instruments.



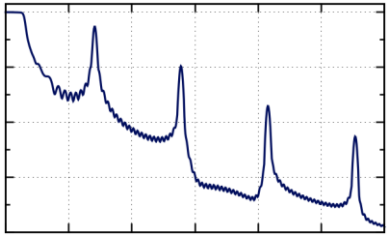


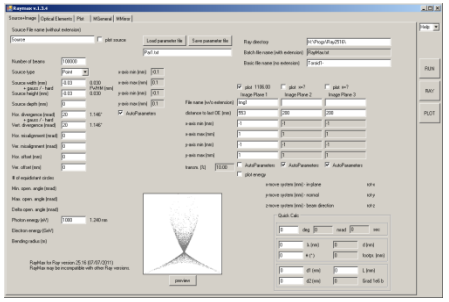
Know-how & technologies: design, fabricate & measure





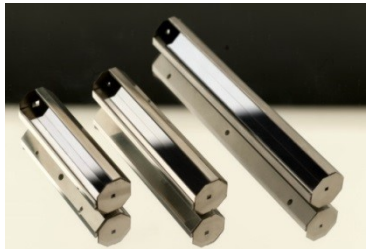
Multilayer simulation & mirror design



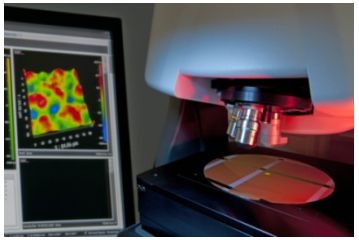


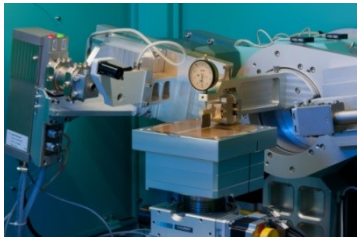
Complementary deposition methods

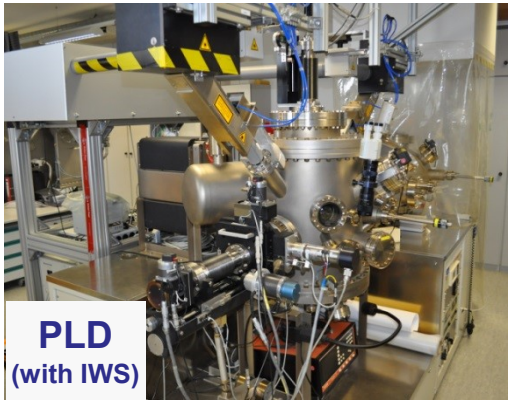
Flexible optics fabrication



Characterization

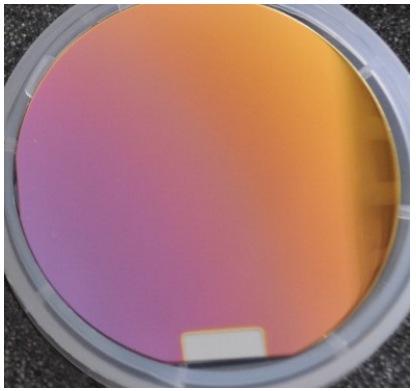


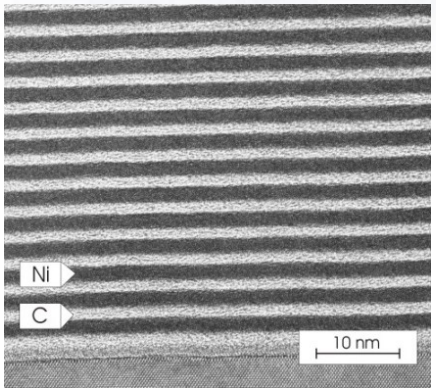


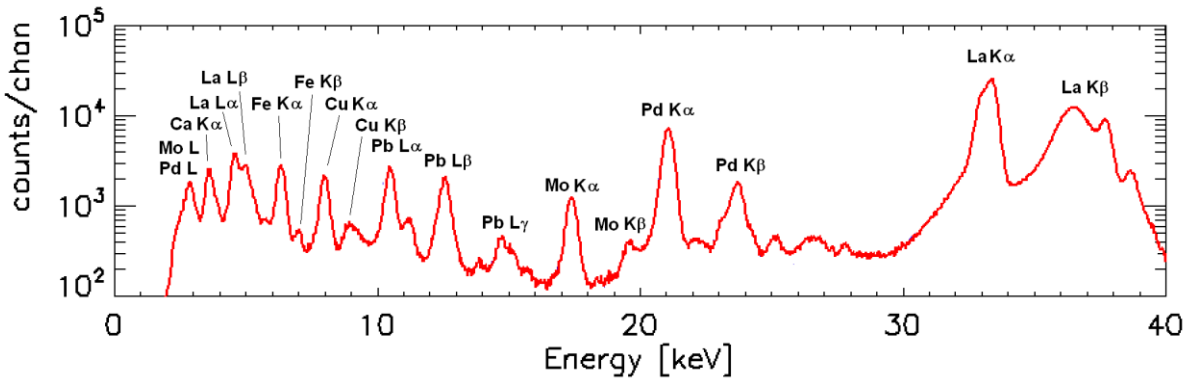


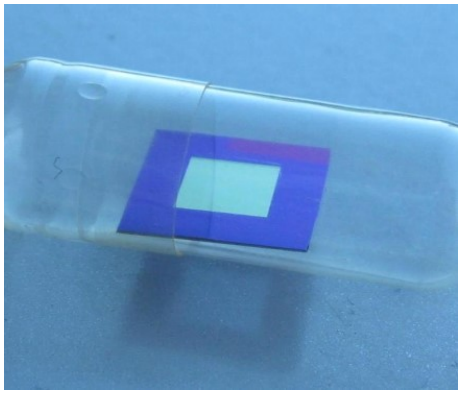
High precision deposition

- **High precision large area deposition**
  (typical: Ø 8” or 500 mm length)
- **Single layers**
- **Lateral and depth-graded multilayers**
- **Thin film multi-element XRF reference samples**
  standard composition or customer specific

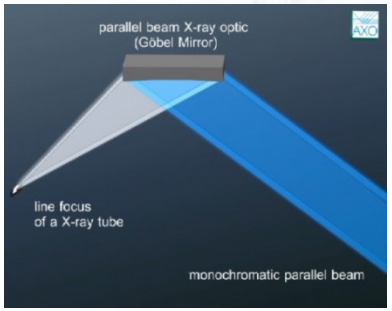


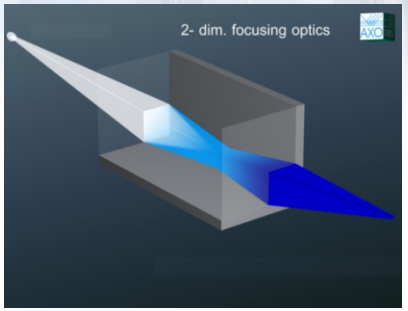




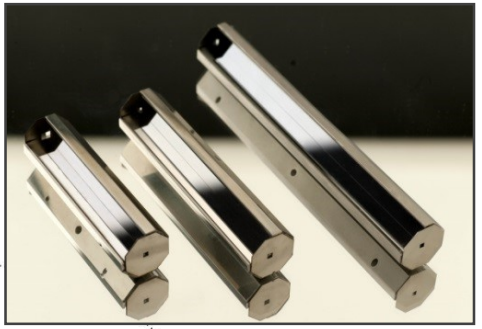


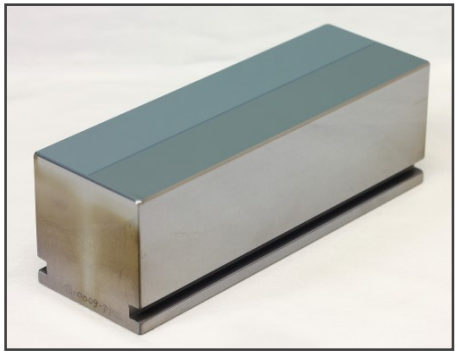
X-ray multilayer optics

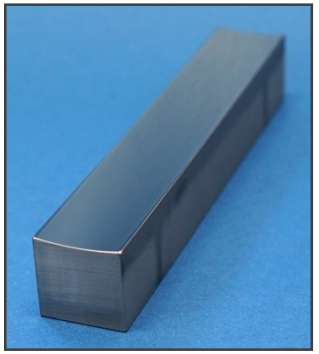


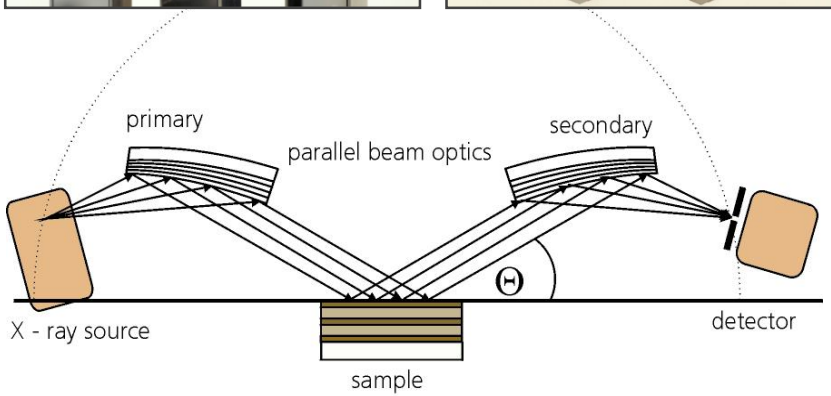


- **Applications:**
  XRD, XRR, XRF, SAXS, XRM …
- **1D/2D focusing / parallel beam optics**
- **For X-ray tubes or synchrotron radiation**
- **Optics shaping:** bending & glue-fixation
  or use of prefigured substrates





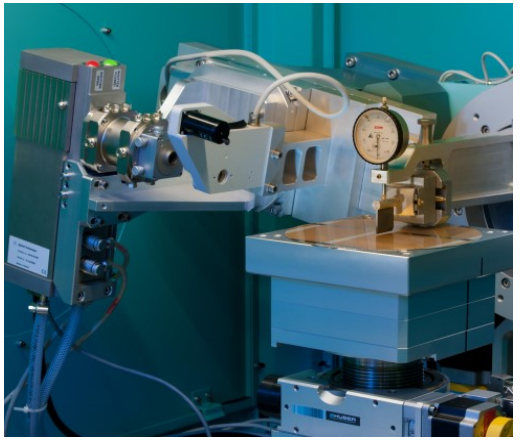




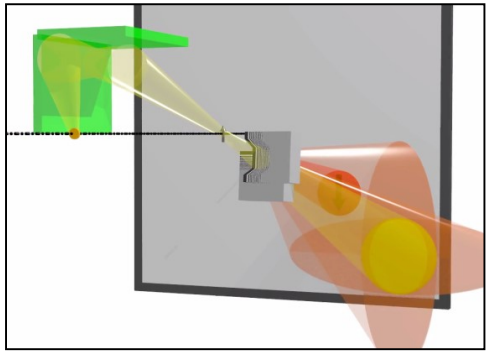
X-ray systems and upgrades

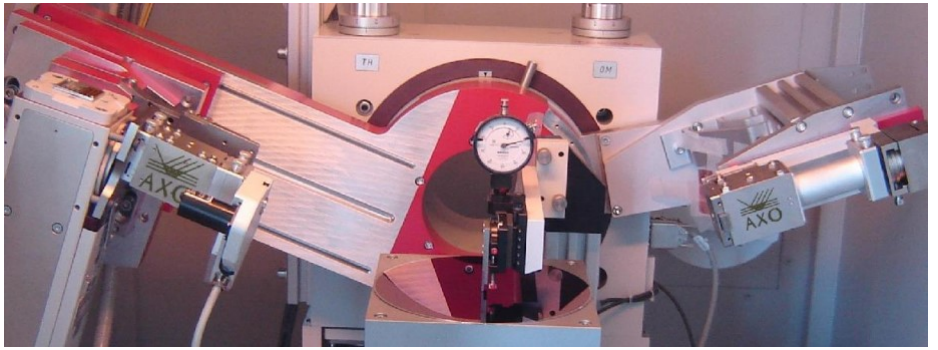
Fraunhofer IWS
Fraunhofer IKTS
HUBER Diffraction and Positioning Equipment

- **Customized XRD/XRR systems with micro focus X-ray sources**
- **Upgrade of all common X-ray systems with advanced X-ray sources & optics**
- **Hard X-ray microscopy with multilayer Laue lenses**



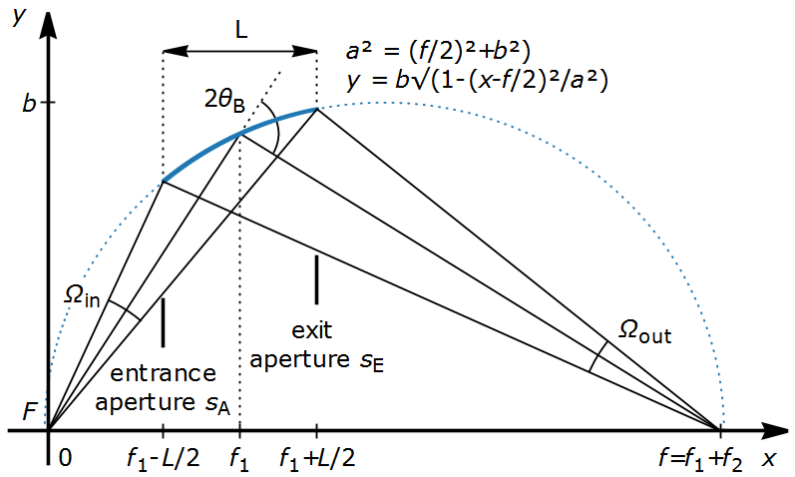
ESRF, BM28





Why do we need raytracing?

- Qualification of optical aberrations (“slope errors”)
- Optimization multilayer properties
- Optimization of mirror geometry



- … considering
  - mirror fabrication methods and tolerances
  - reflectance and bandwidth of the multilayer
  - geometrical parameters, e.g. extended sources, parabola/ellipse parameters, apertures etc.
  - characteristic X-ray lines
  - etc.

➢ **Tweaking the design of customized X-ray multilayer mirrors**

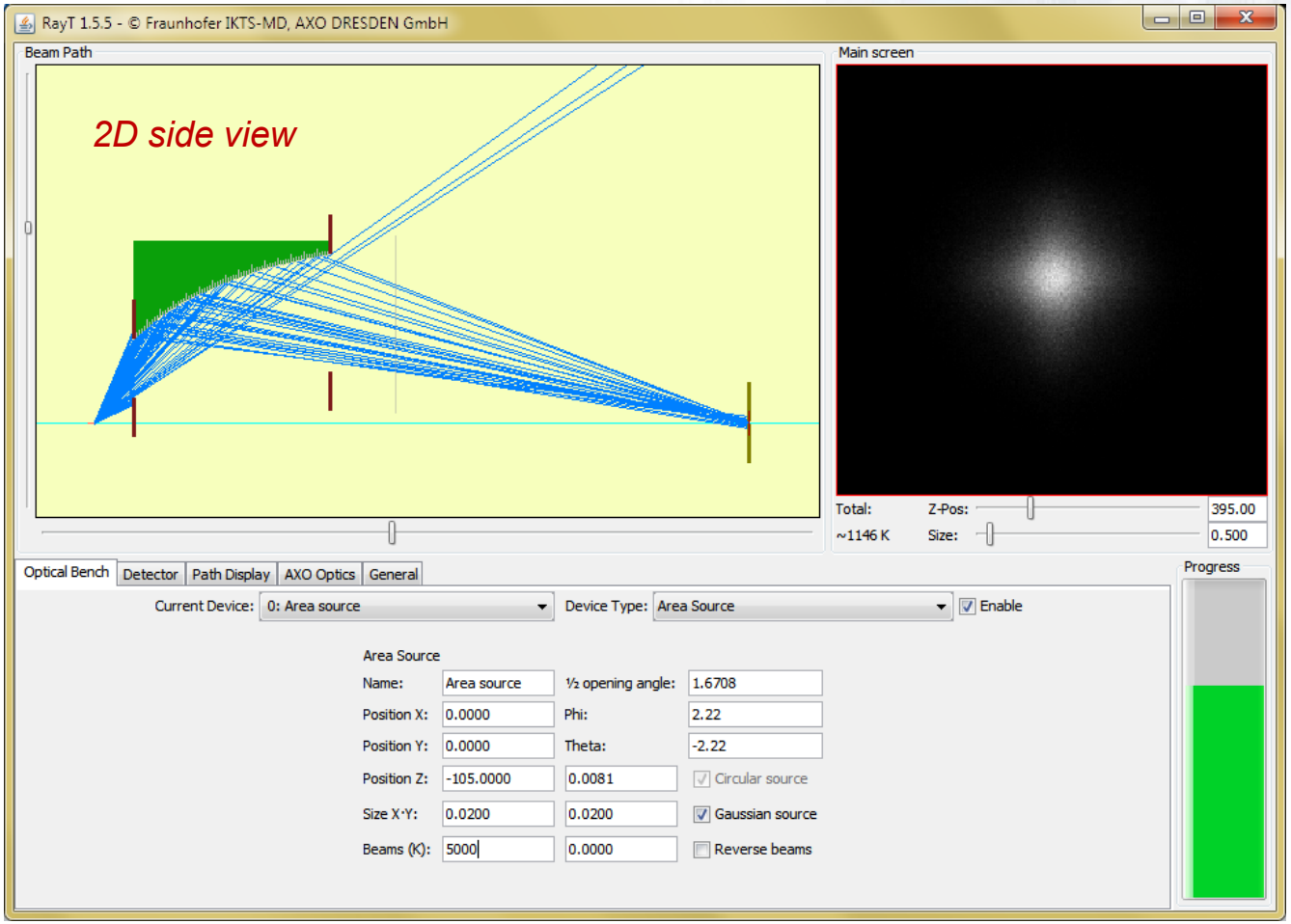
- … using e.g. RAY, IMD and **RayT**

In-house raytracing software RayT

Fraunhofer IKTS

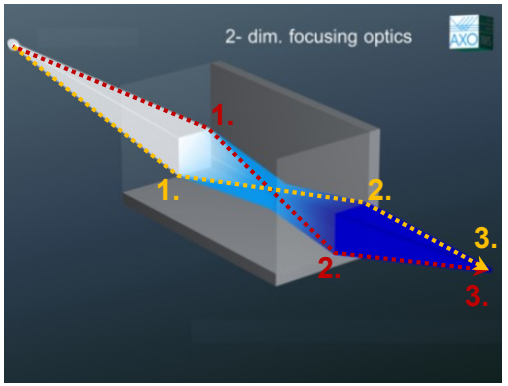
- **Original purpose:** understanding the NanoXCT alignment

- **RayT:** pure 3D geometrical optics
- JAVA software
- Interactive GUI
- Multithreaded
- Internal multilayer database (IMD data)
- Configurations can be stored and loaded
- Not available to the public



In-house raytracing software RayT – Features

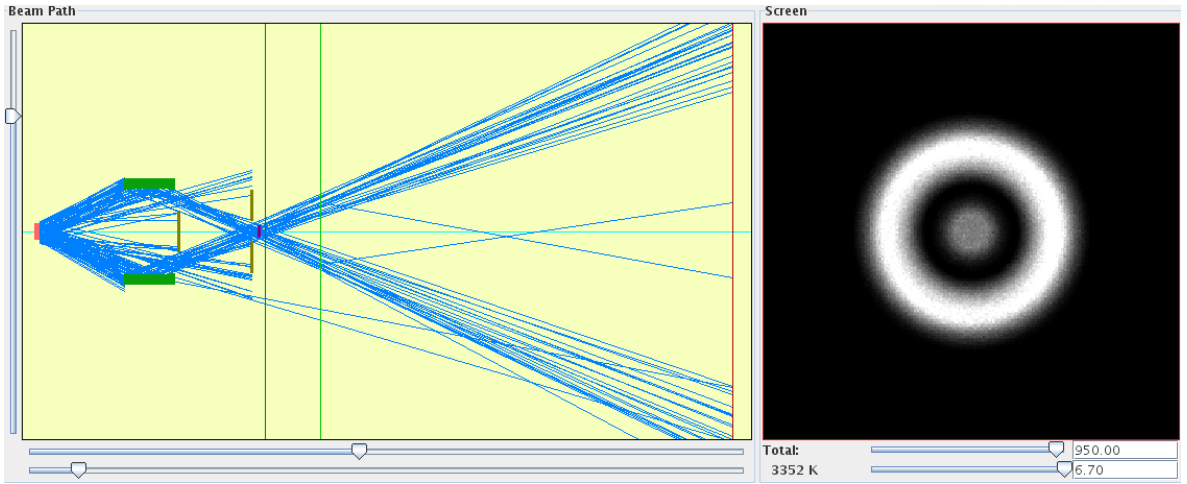
- **Optical bench** consisting of arbitrary **optical elements** at arbitrary positions
  - X-ray source (source shape and size, opening angle, beams, photon energy, …)
  - X-ray screen (size, discretized to N×N pixels, filters, some statistics, DAT export)
  - Simple devices: slit screens, pinholes, beamstops
  - 2D and 1D mirrors: elliptical, parabolic, planar, toroidal
    - multilayer: d-spacing gradient, reflectivity, bandwidth
    - slope error: sinusoidal assumption or measurement
  - Single crystals / CC monochromators
  - Lenses: spherical, cylindrical, ideal (for X-ray microscopy)
  - Absorption object (grayscale image)
- **Each beam**
  - photon energy (one of two, typically $K\alpha_1/K\alpha_2$ or $K\alpha/K\beta$)
  - intersects with next optical element **(no fixed order)**
- **Output: efficiency & beam profiles**



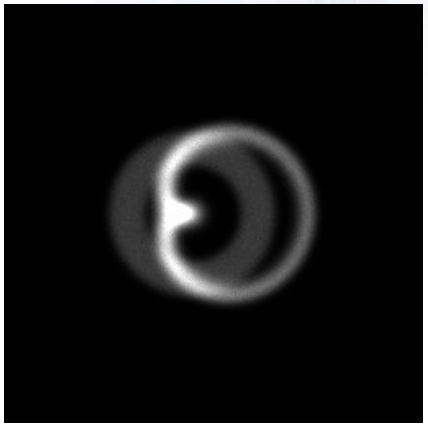
Examples

- X-ray microscopy
- AXO ASTIX
- AXO ASTIX^{++} with slope errors
- Effect of $K\alpha_1/K\alpha_2$ splitting at high photon energies
- Scintillator for high-resolution X-ray camera

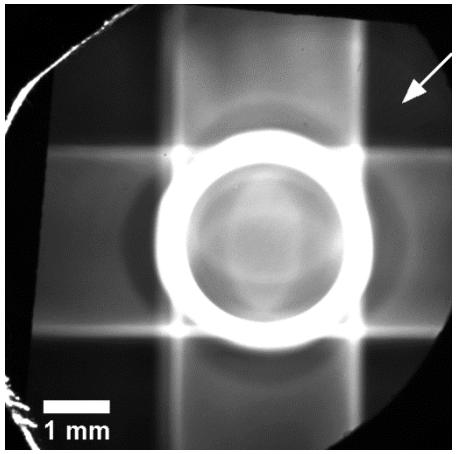
Examples – X-ray microscopy

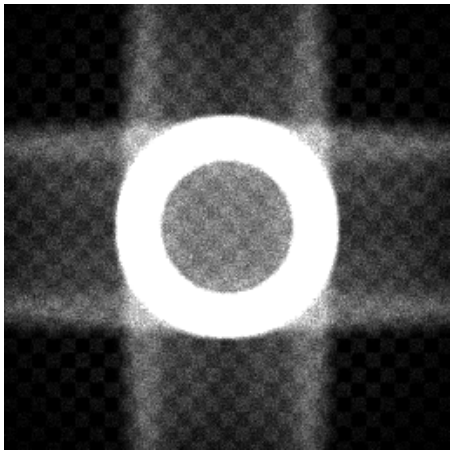


X-ray microscope with Fresnel zone plate (spherical lens)



… X-ray monocapillary alignment

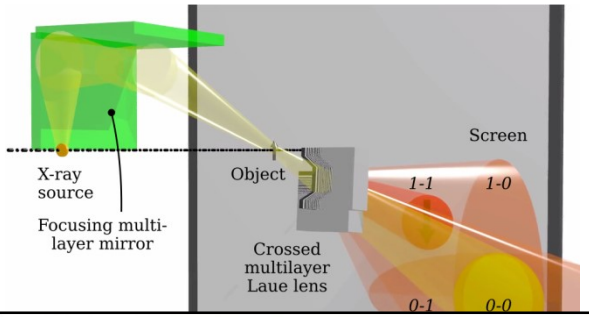


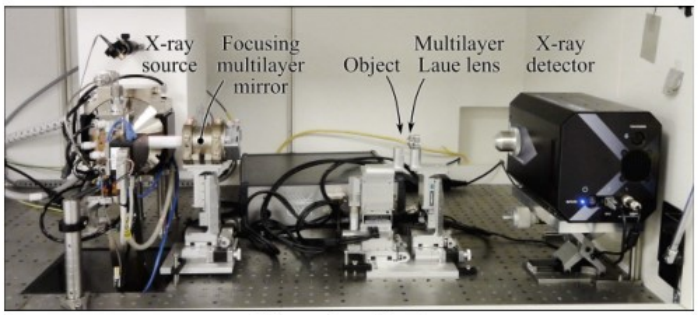


X-ray microscopy with multilayer Laue lenses, modelled as cylindrical lenses with limited probability to refract incident beams.

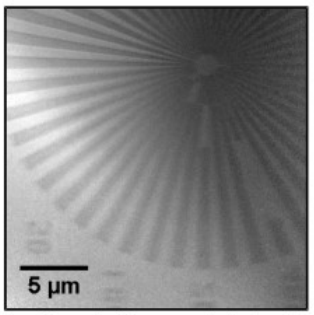
S. Niese: Lab-based in-situ X-ray Microscopy – Methodical Developments and Applications in Materials Science and Microelectronics. PhD thesis, BTU Cottbus, 2014

Examples – X-ray microscopy with Multilayer Laue lenses

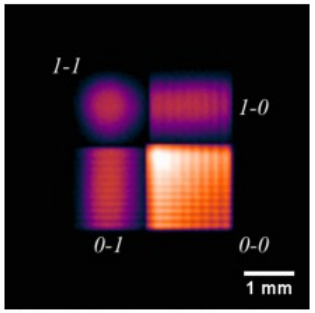




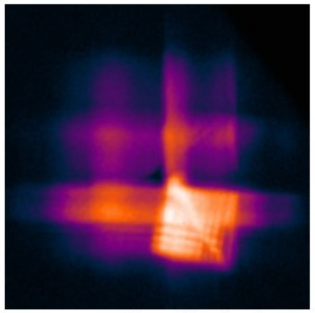
(a) experimental setup



(b) radiograph, Siemens star test pattern



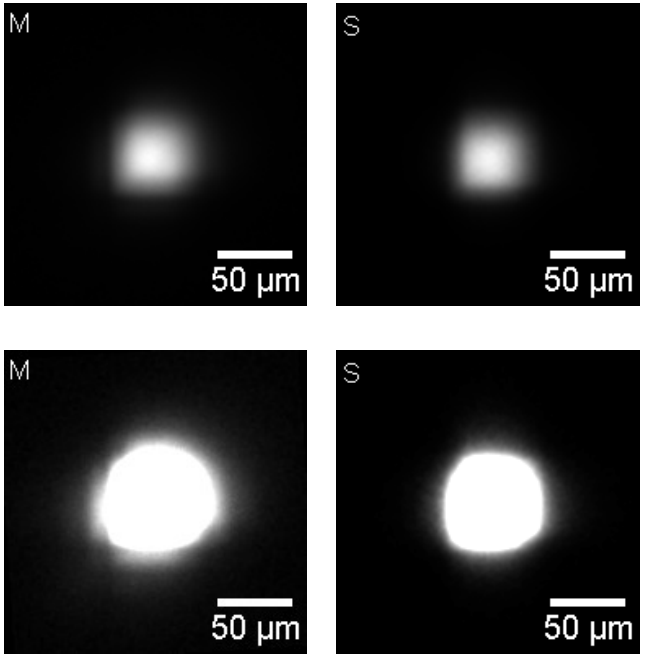
(c) simulation, logarithmic color scale



(d) measurement, logarithmic color scale

Mo Kα 150/150 condenser optics,
Mo rotating anode, 70 µm

Measurement *Simulation*

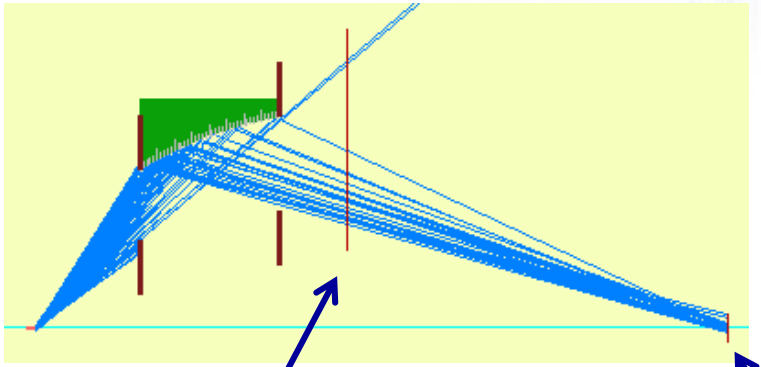


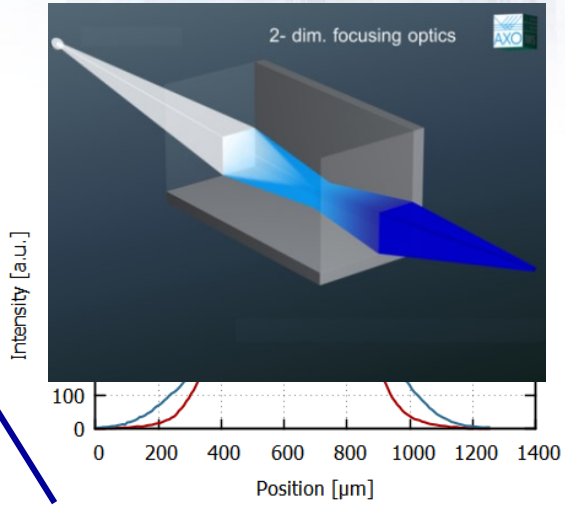
S. Niese et al, A Dedicated Illumination For Full-Field X-ray Microscopy With Multilayer Laue Lenses, AIP Conf. Proc. 1764, 020002 (2016). DOI 10.1063/1.4961130

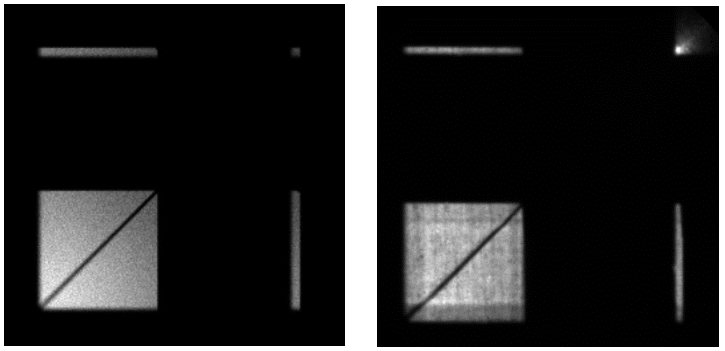
AXO ASTIX (side-by-side) optics

- Complete simulation, including alignment
- Optimize optics
  - multilayer
  - geometry, e.g. b-parameter
- Constraints
  - source size
  - divergence
  - fabrication tolerances
  - …

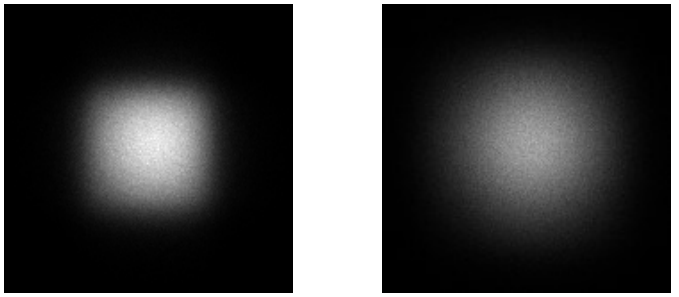
➢ **Estimated focus profile and flux**







Alignment view: simulation vs. measurement

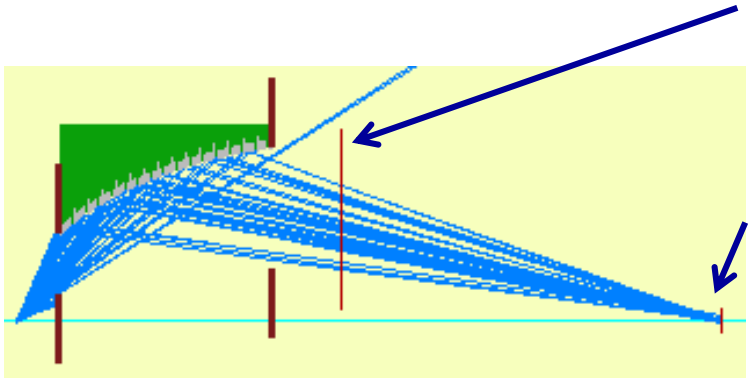


Comparison of two multilayers

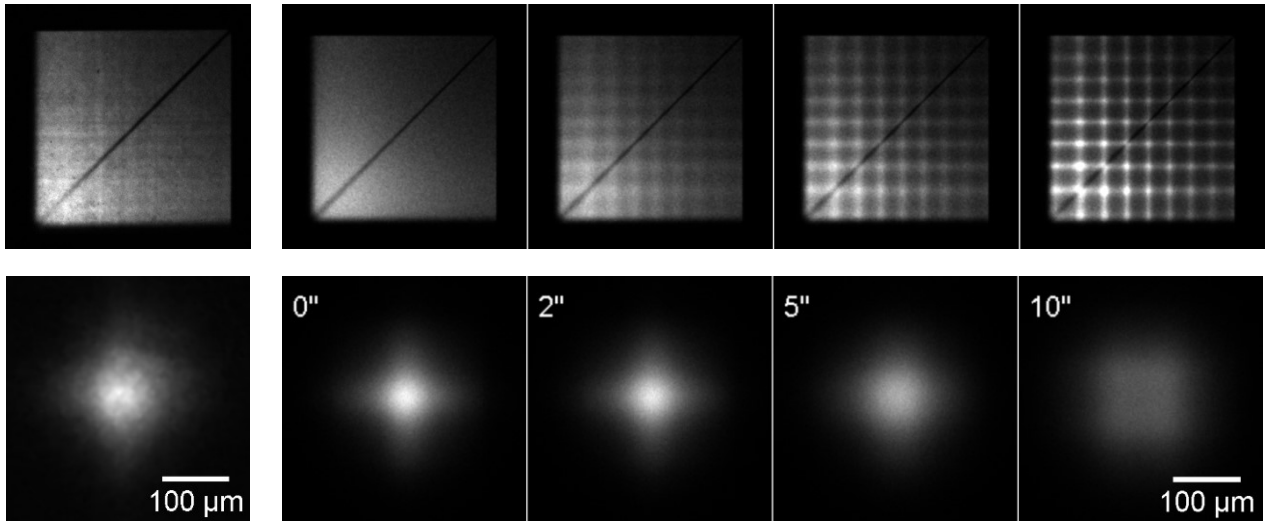
Ni/C	*W/Si*
FWHM: 450 µm	*FWHM: 530 µm*
Beams: 2470k	*Beams: 2560k*

AXO ASTIX^{++}, prefigured optics, virtual slope errors

- Slope errors may be critical at
  - small sources
  - long distances
  - high photon energies
- Assumption: sinusoidal slope error, RMS value stated

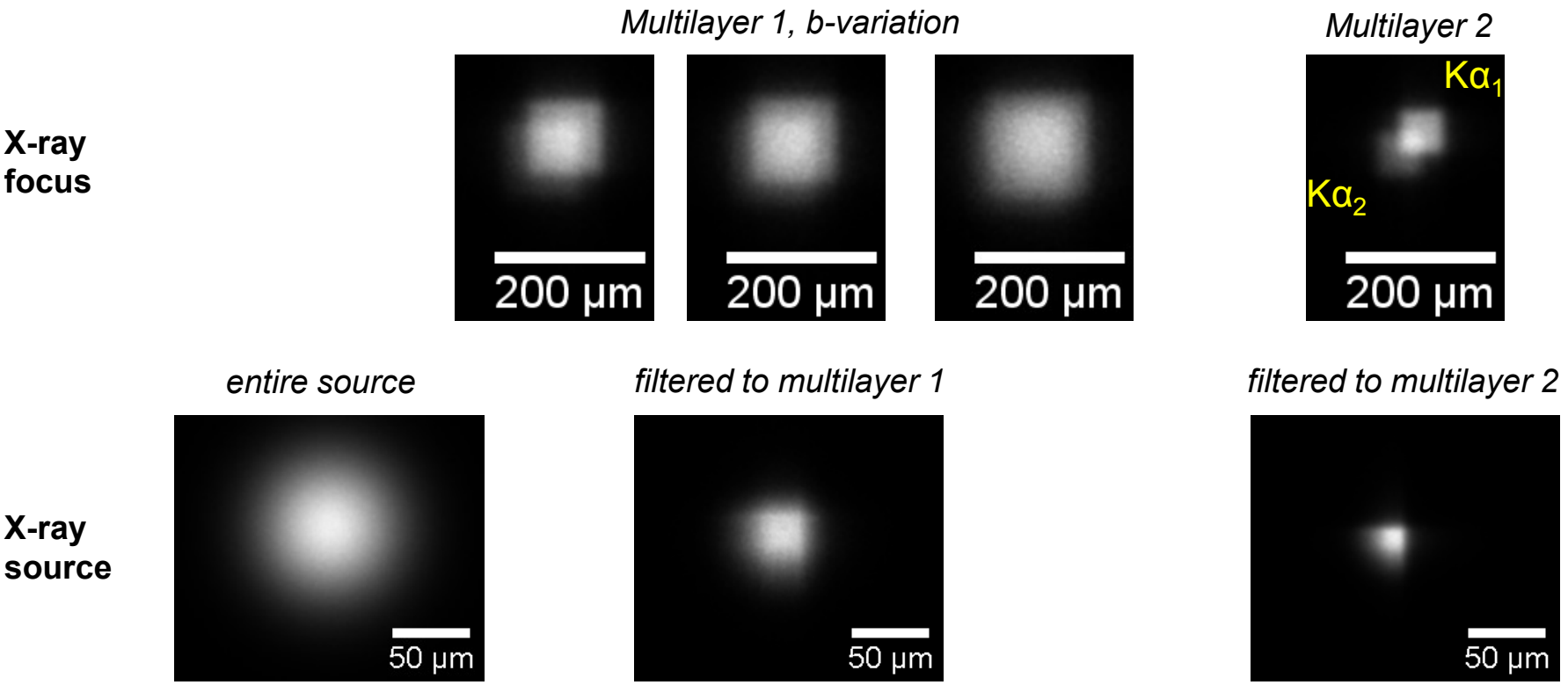


Measurement *Focussing Ga Ka 105/395 SCD optics, 20 µm source*



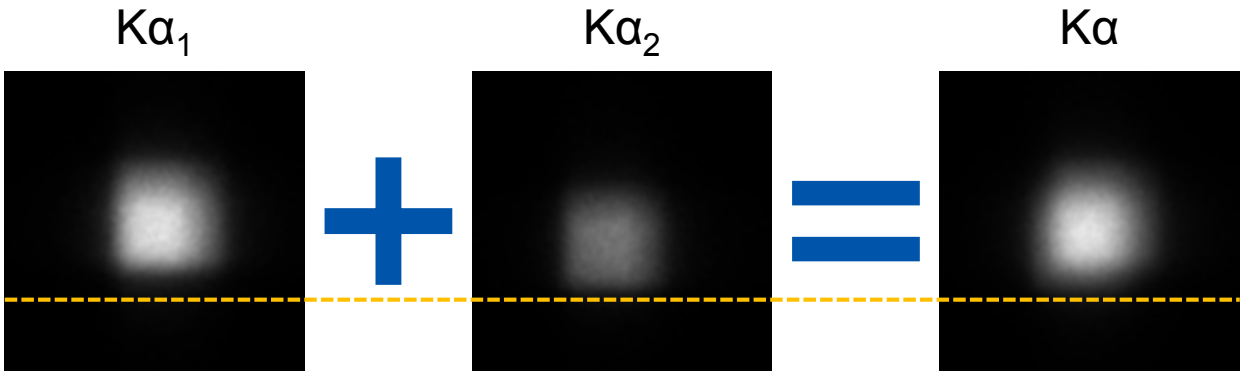
Effect of $K\alpha_1/K\alpha_2$ splitting at high photon energies

- Photon energy splitting $K\alpha_1/K\alpha_2$: Cu = 0.25 %, Ag = 0.79 %
- Example for Ag rotating anode, Ø 70 µm, focusing optics



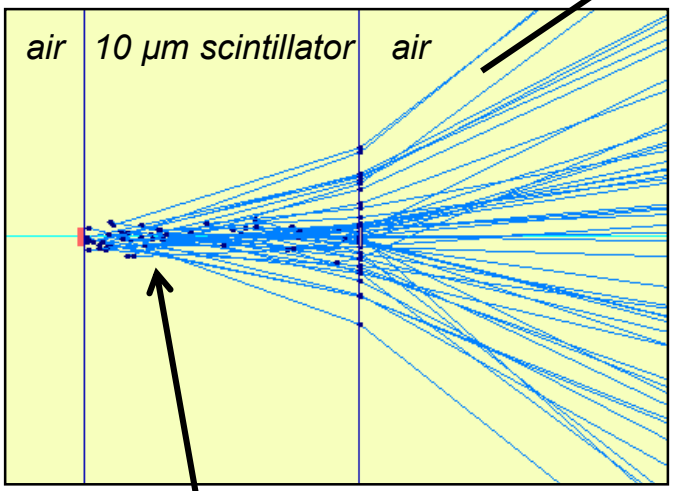
Effect of $K\alpha_1/K\alpha_2$ splitting at high photon energies

- Remember Mo Ka condenser optics?

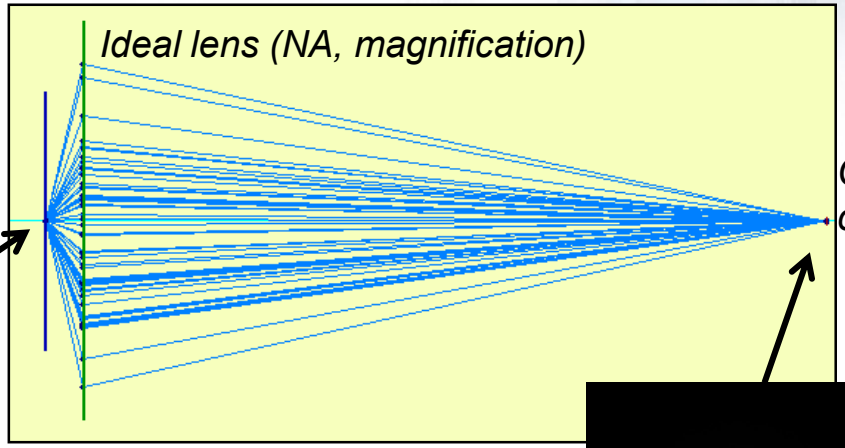


Scintillator for high-resolution X-ray camera

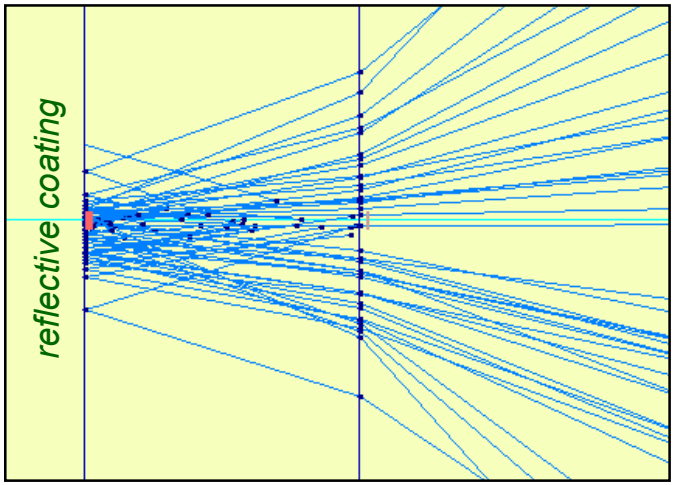
- Study of scintillator thickness, reflective coatings, scintillator materials etc.

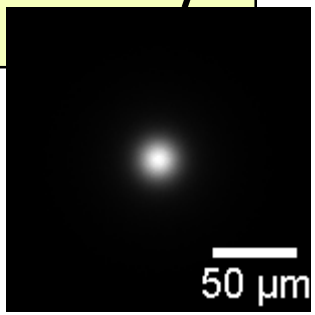


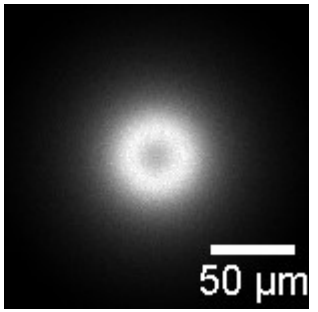
0.7 µm Gaussian source with given attenuation length



CCD/CMOS camera







Summary

- **RayT:** inhouse (X-)ray tracing at AXO DRESDEN
- Main purpose: design of multilayer X-ray optics and optical systems
- We are happy to share results, but not the software

Gasanstaltstr. 8b
01237 Dresden, Germany

Web www.axo-dresden.de
E-Mail contact@axo-dresden.de

Phone +49 351 250897-20
Fax +49 351 250897-66

SPONSORED BY THE
Federal Ministry of Education and Research
ALLIANZ INDUSTRIE FORSCHUNG
ATRENE