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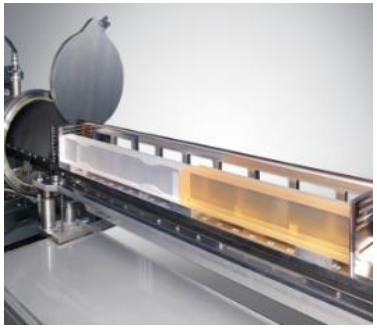
Trends on Montel X-ray Optics and Pinholes for Synchrotron Beamlines

Jörg Wiesmann – Founder & Managing Director

Incoatec GmbH, Geesthacht, Germany

Incoatec: Innovative Coating Technologies



- Founded 2002 by scientists of GKSS Research Center together with Bruker AXS
- Located in the Geesthachter Innovation&Technology Center (near Hamburg)
- 4.100 m^2 building for Production and Development of X-ray Optics and Tubes
- Use deposition facilities for optimized Optics with different sizes, film gradients and precisions
- Offer equipment for home-lab instruments and synchrotron beamlines

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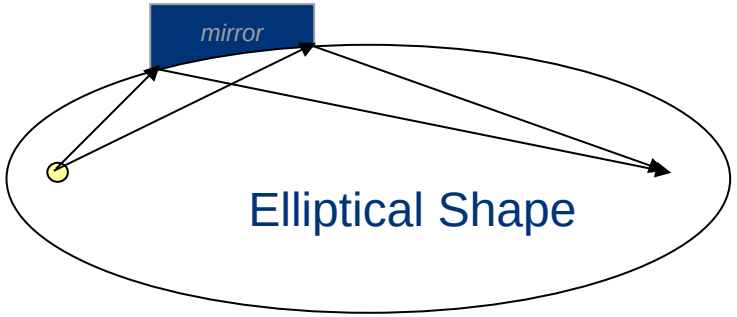
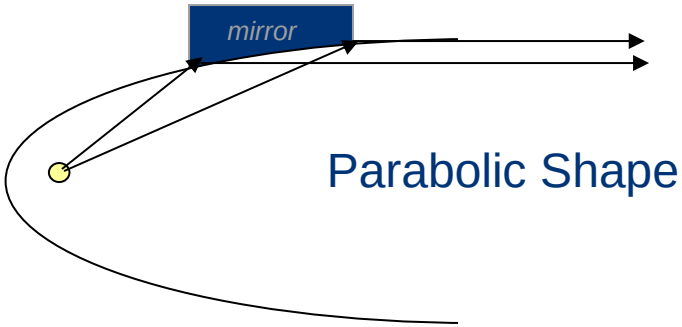
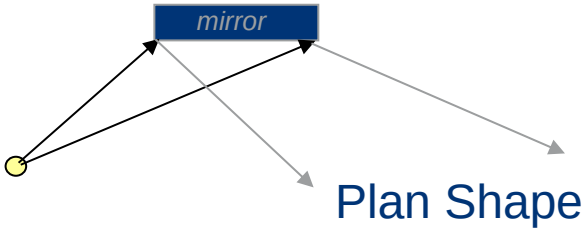
X-ray Optics Design

Key know-how: Multilayer X-ray optics Substrates





For 1- or 2-dimensional beam focusing or collimating



For beam guidance

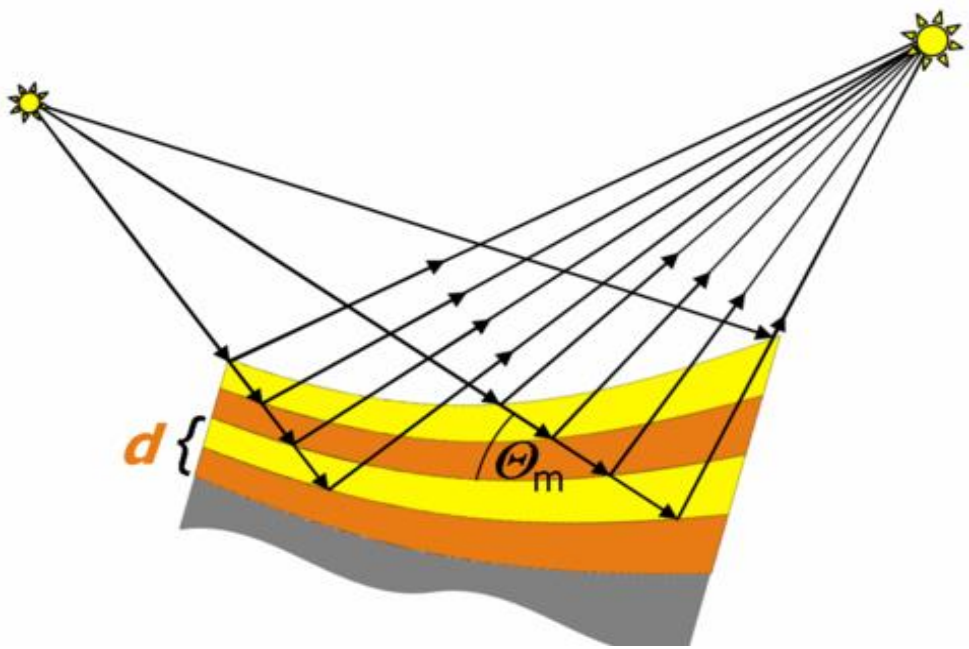
Substrates:

"**prefigured**" (Si, Fused Silica, Zerodur)

slope error
down to 0.2 arcsec ≙ 1 µrad

low roughness
(< 2 Å up to 1 Å)

Key know-how: Multilayer X-ray optics Coatings



$$m \cdot \lambda = 2 \cdot d \cdot \sin\Theta$$

d = 1 – 8 nm

$\theta_m \approx 1.0°$ (Cu-K_α, 8 keV)

$\theta_m \approx 0.5°$ (Mo-K_α, 17.5 keV)

Multilayers act as Bragg reflector

- 100-400 layer pairs
- Interface roughness < 10%
- Tolerance in *d* spacing better +/- 0.2 %

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X-ray Optics Production

Key know-how: Multilayer X-ray optics Magnetron Sputtering

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- Monolayer
- Homogenous Multilayer
- Lateral Graded-Multilayer
- Depth Graded Multilayer
- Stripe-Multilayer

Substrates: Silicon, Quartz, Zerodur …

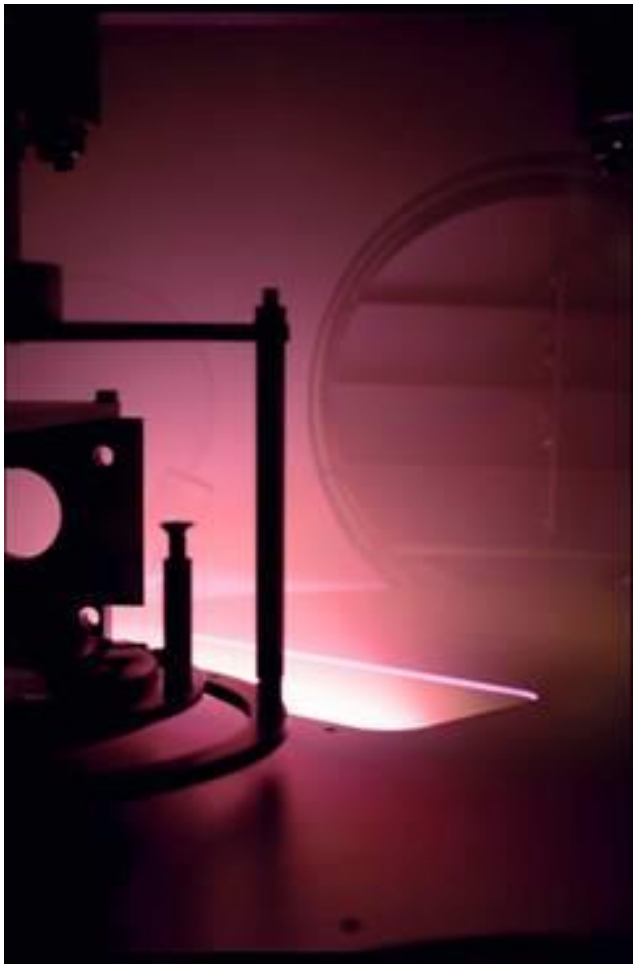
Film thickness: single layer 0.5 … 500 nm

Target materials: wide variety!

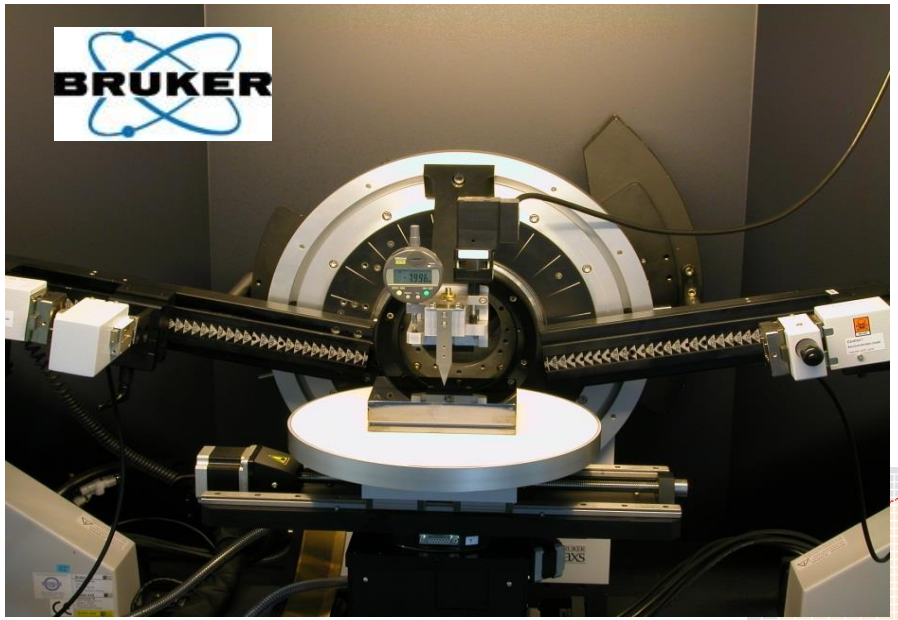
Total reflection: C, SiC, Rh, Ru, Au, W, Cr,...

ML-Reflector: W, WSi_2, Ru, V, La, Mo, TiO_2, Ni …

ML-Spacer: C, BN, B_4C, Si,…

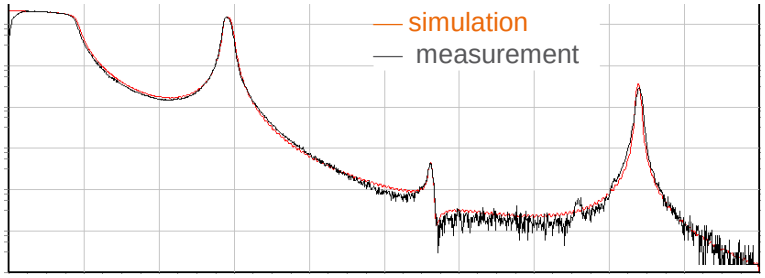


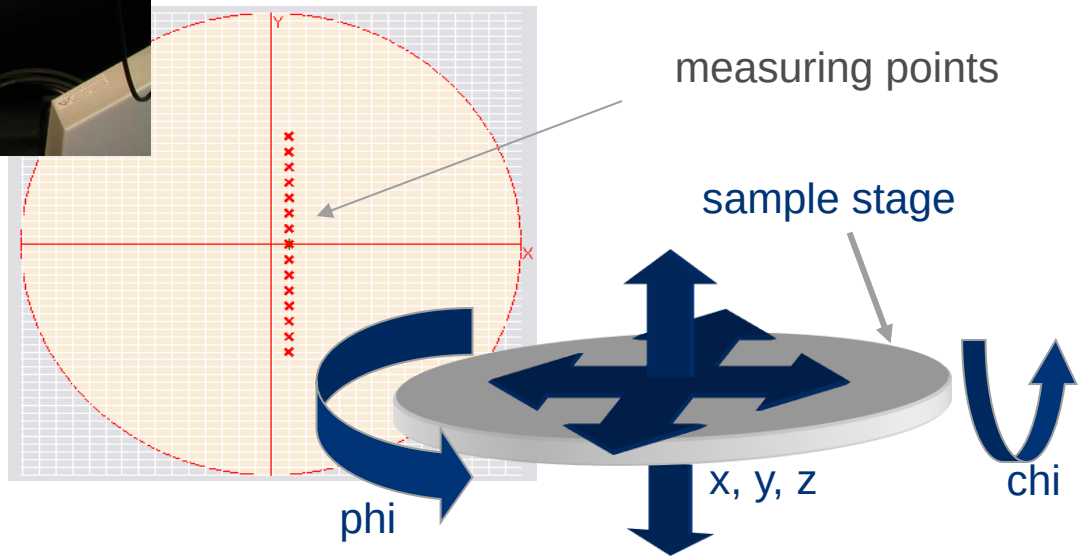
Characterization of Multilayer: Diffractometer for XRR



- D8 from Bruker AXS
- substrates up to 30 × 30 × 4,5 cm³
- motorized table
- full automatic measurement

-> high throughput of test samples





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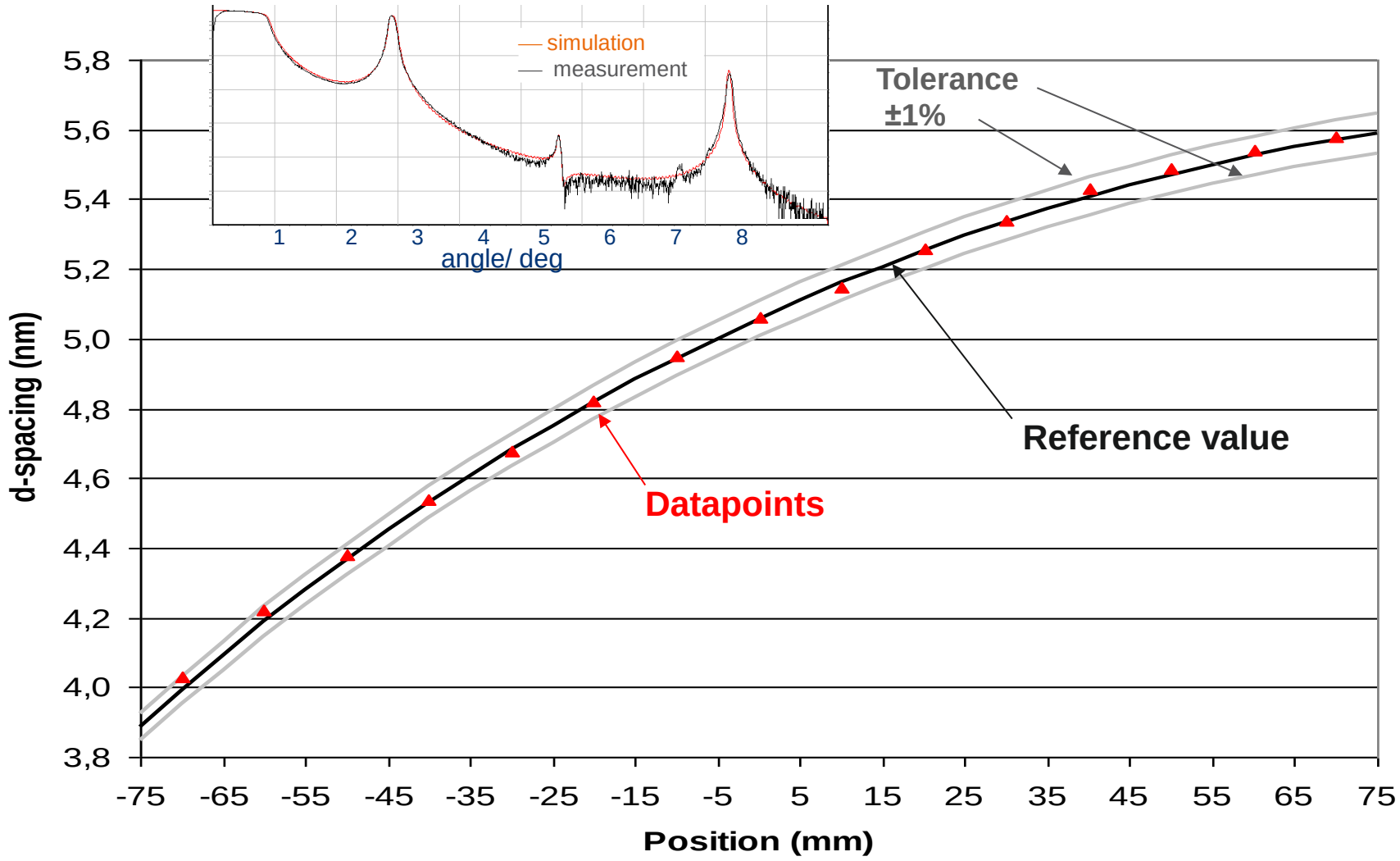

Standard d-spacing accuracy within +- 1% on 150 mm, best: < 0.2 % on 500 mm

Examples at Synchrotrons

X-ray optics:
Multilayer coating on bendable mirror

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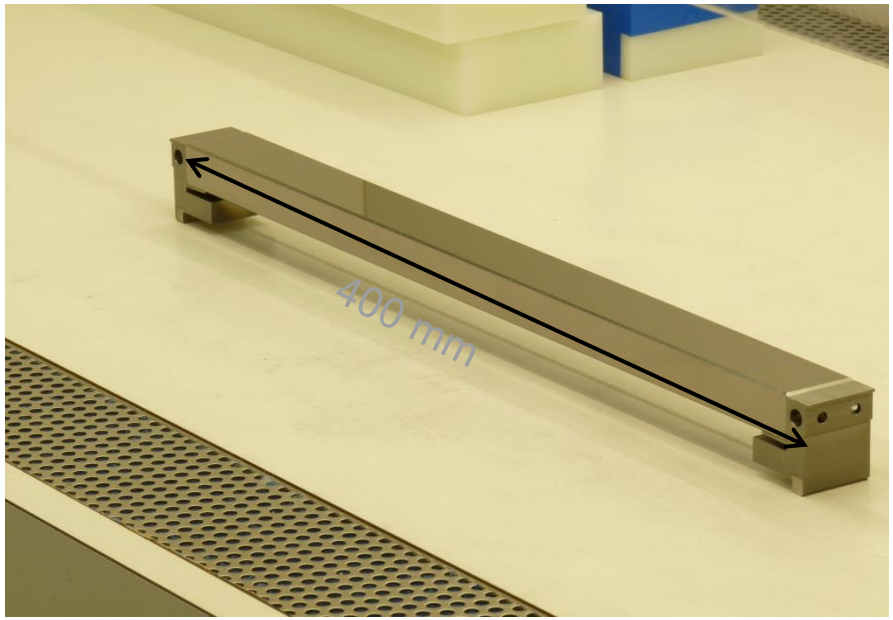
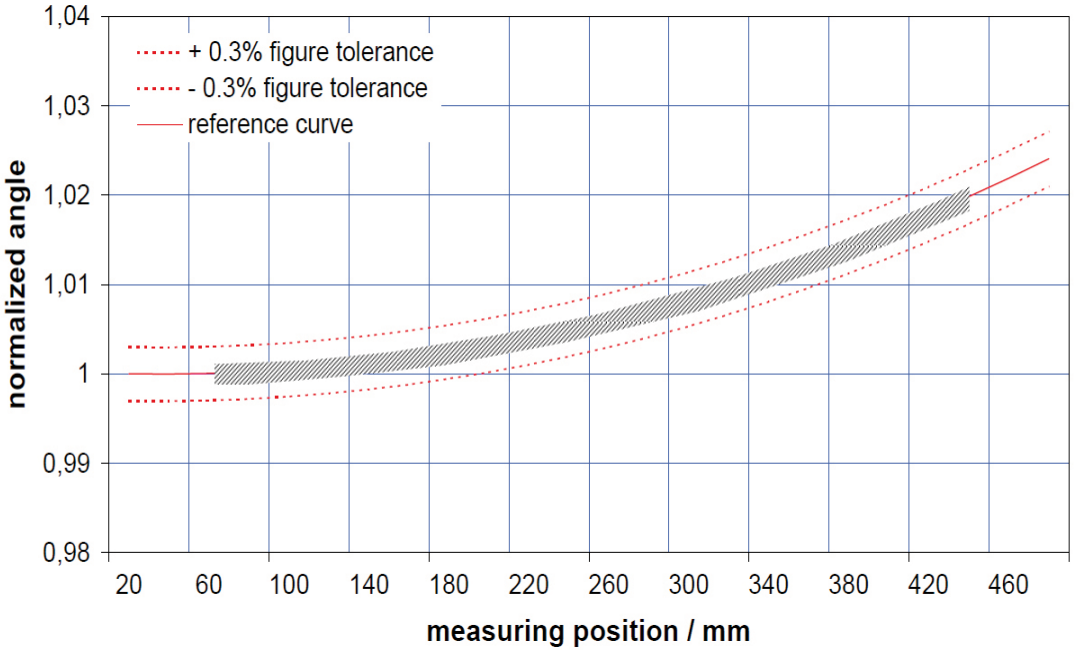
400 mm Si mirror
with graded multilayer coating
(Ru / C, 200 pairs for 7 – 20 keV)





d-spacing accuracy
better 0.2% over 500 mm!

Helmholtz-Zentrum Geesthacht
Zentrum für Material- und Küstenforschung
Dr. Michael Störmer

Applications: Multi-stripe Multilayer X-ray mirror as DCMM

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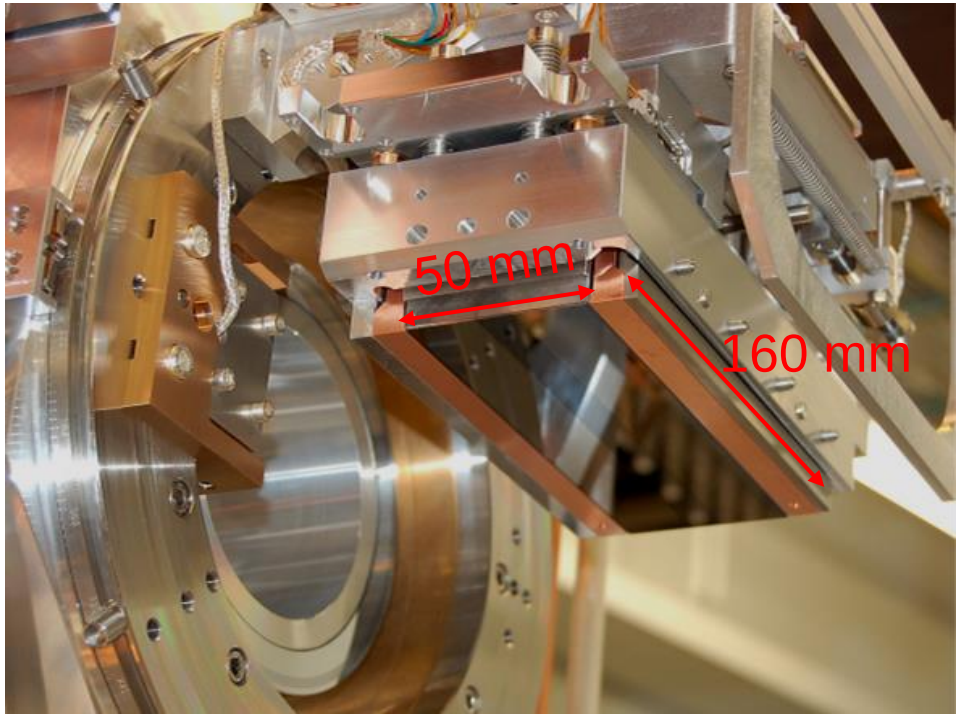
Double crystal multilayer monochromator with 2 stripes or more!



TOMCAT tomography beamline, M. Stampanoni

Swiss Light Source

PAUL SCHERRER INSTITUT
PSI

Stripe A : [Ru/C]100, d = 4 nm

R > 80% for 10 < E < 22 keV

Midspace: Si111 $\Delta_{orientation}$ < 0.01°

σ = 0.1 nm slope error 0.04”

Stripe B : [W/Si]100, d = 3 nm

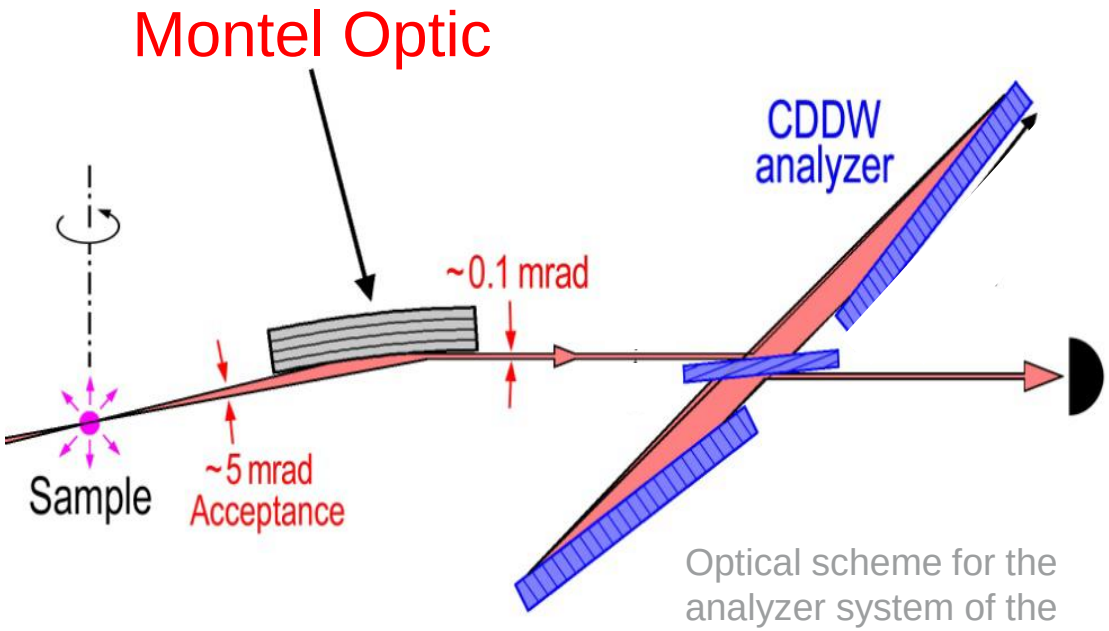
R > 80% for 22 < E < 45 keV

Prefigured Montel Optics

- can be combined with synchrotron, X-ray laser, plasma or metal jet sources
- Optics for typical energies available (5..25 keV; Cu, Mo, Ag, Ga, In, Cr, Co, Fe, …) lower E on request)
- Collimating and focusing or hybrid (line focus), length 60 … 250 mm

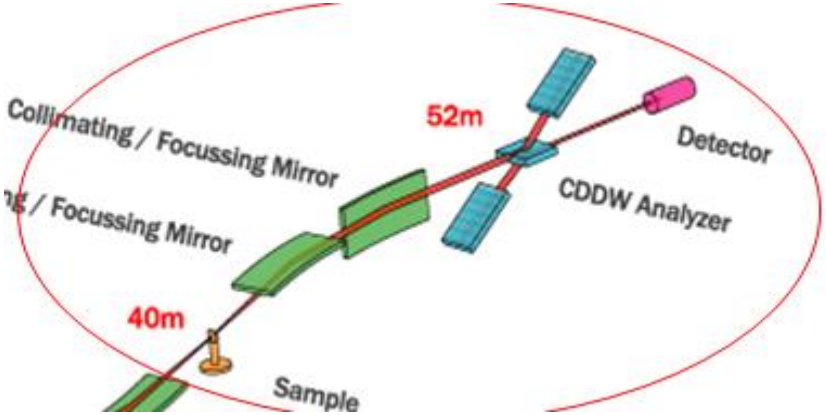
Applications: Montel Optics for inelastic x-ray scattering

Honnicke et al, JSR (2010, 2011)



Optical scheme for the analyzer system of the spectrometer

Reference: LT-XFD_CDR_IXS-00123



Single reflectivity: >70%

double reflectivity: ~ 50%

Angular acceptance: 5 x 5 mrad

Divergence: 0.1 x 0.1 mrad

Some publications with our Montel Optics

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research papers

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Tests and characterization of a laterally graded multilayer Montel mirror

K. Mundboth,[a]* J. Sutter,[a] D. Laundy,[a] S. Collins,[a] S. Stoupin[b] and Y. Shvyd'ko[b]

[a]Diamond Light Source Ltd, Harwell Science and Innovation Campus, Didcot OX11 0DE, UK, and [b]Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439, USA. *E-mail: kiran.mundboth@diamond.ac.uk

2013

Multilayers are becoming an increasingly important tool in X-ray optics. The essential parameters to design a pair of laterally graded multilayer mirrors arranged in a Montel-type configuration for use as an X-ray collimating device are provided. The results of X-ray reflectometry tests carried out on the optics in addition to metrology characterization are also shown. Finally, using experimental data and combined with X-ray tracing simulations it is demonstrated that the mirror meets all stringent specifications as required for a novel ultra-high-resolution inelastic X-ray scattering spectrometer at the Advanced Photon Source.

Keywords: X-ray optics; collimating optics; Montel mirrors; laterally graded multilayers; KB mirrors.

2014

research papers

Performance of a collimating L-shaped laterally graded multilayer mirror for the IXS analyzer system at NSLS-II

Alexey Suvorov,[a]* David S. Coburn,[a] Alessandro Cunsolo,[a] Jeffrey W. Keister,[a] Mary H. Upton[b] and Yong Q. Cai[a]

[a]Photon Sciences, Brookhaven National Laboratory, PO Box 5000, Upton, NY 11973, USA, and [b]Advanced Photon Source, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439, USA. *E-mail: asuvorov@bnl.gov

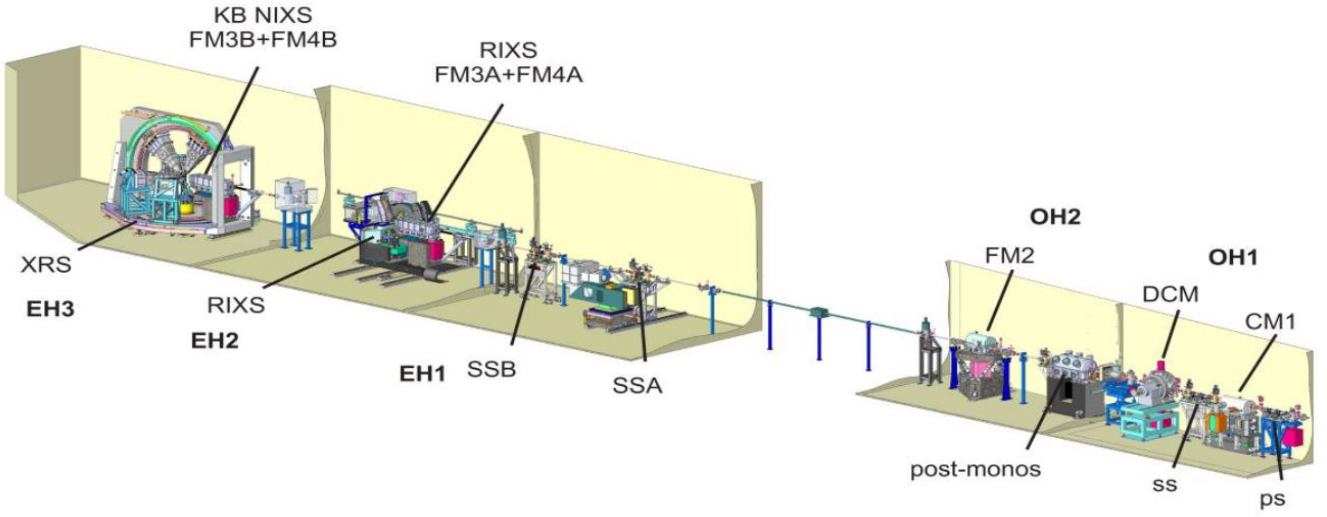
The L-shaped laterally graded multilayer mirror is a vital part of the ultrahigh-energy and momentum-resolution inelastic X-ray scattering spectrometer at the National Synchrotron Light Source II. This mirror was designed and implemented as a two-dimensional collimating optic for the analyzer system. Its performance was characterized using a secondary large-divergence source at the 30-ID beamline of the Advanced Photon Source, which yielded an integrated reflectivity of 47% and a collimated beam divergence of 78 µrad with a source size of 10 µm. Numerical simulations of the mirror performance in tandem with the analyzer crystal optics provided details on the acceptance sample volume in

2018

ESRF: (ID20)

E= 11215 eV

Montel optic: 23 cm



Synchrotron Optics Projects: interface between user and developer / producer

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To be clarified in a project from the beginning with high impact on prizes:

- **Substrates** -> length, quality, characterization, responsibility
- **Energy range** -> multilayer material / multistripes
  (collaboration between user and us)
- **Resolution** -> precision of deposition, substrate quality
- **Characterization** -> test samples, test methods, when,what, where and how

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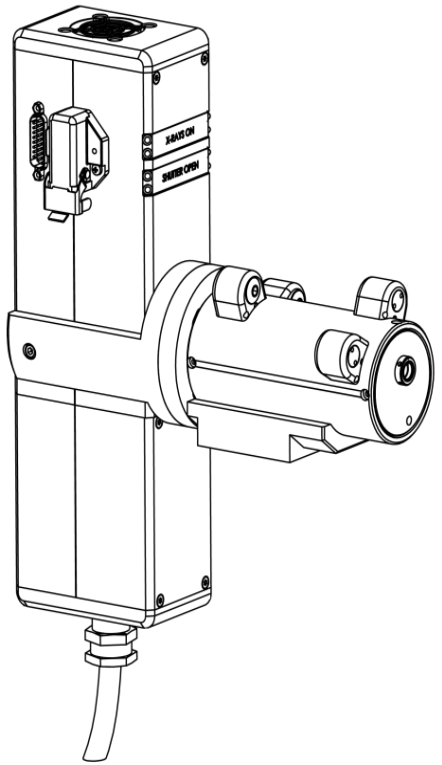
Optics plus Microfocus Sources

Tube + Optics -> Brilliant Microfocus Source

+

+



= IμS

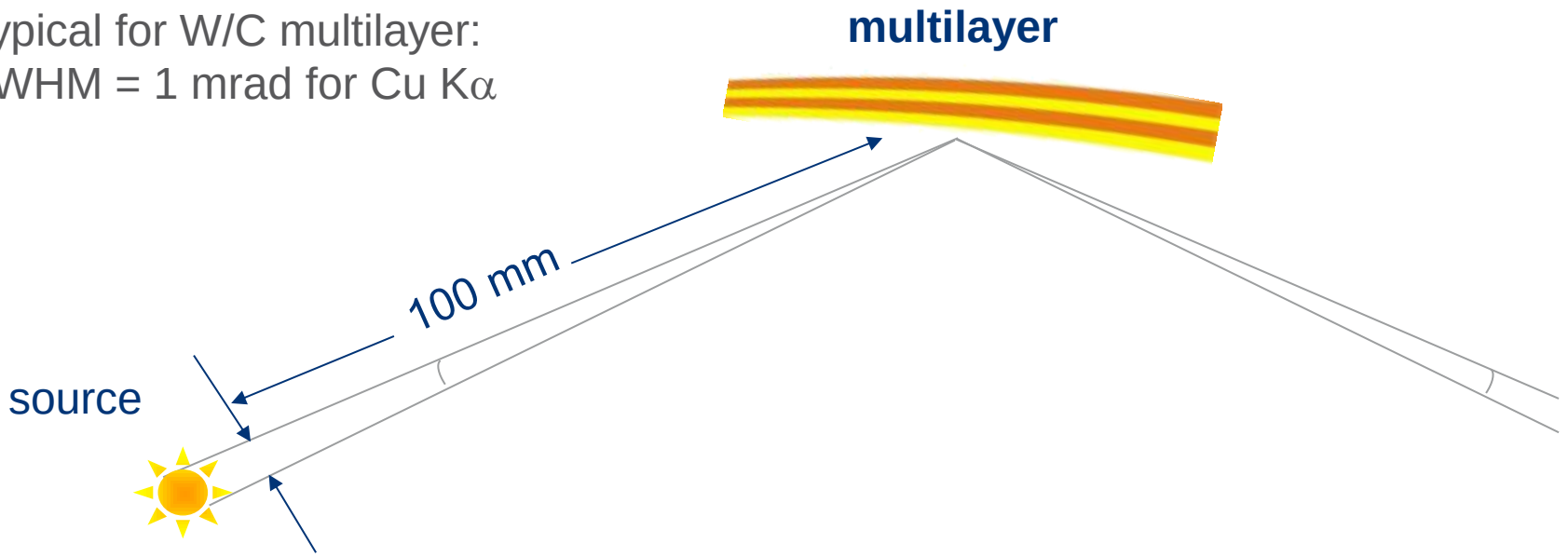
Anode spot ~35 μm, energies up to 60 keV;

Radiation: Cu, Mo, Ag, Cr, Co, (XRD),
Rh, W (XRF), Ti (special), …

Perfect Match: Multilayer Mirrors and Microfocus X-ray Beams

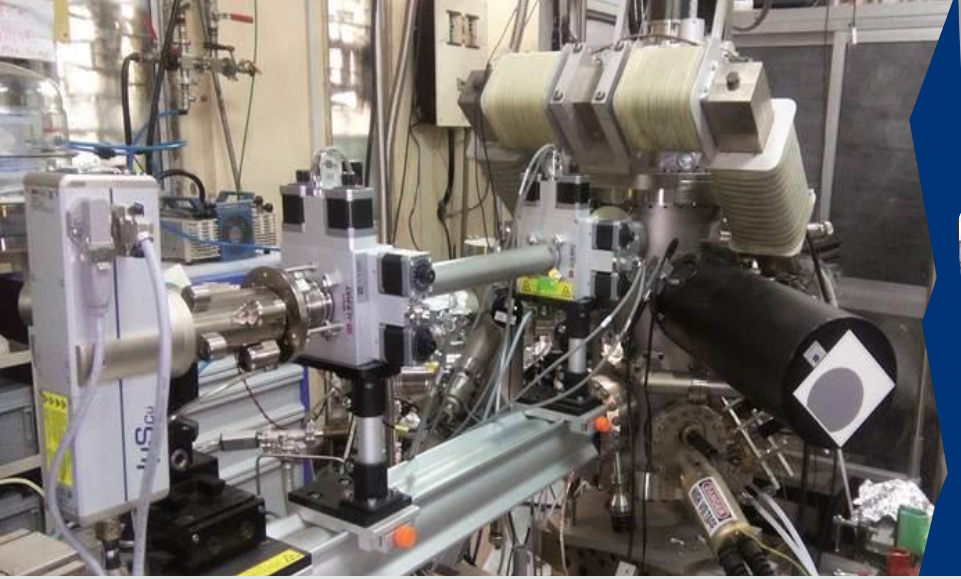
View angle = Bragg peak width

Typical for W/C multilayer:
FWHM = 1 mrad for Cu Kα



100 mm * 1 mrad = 100 μm

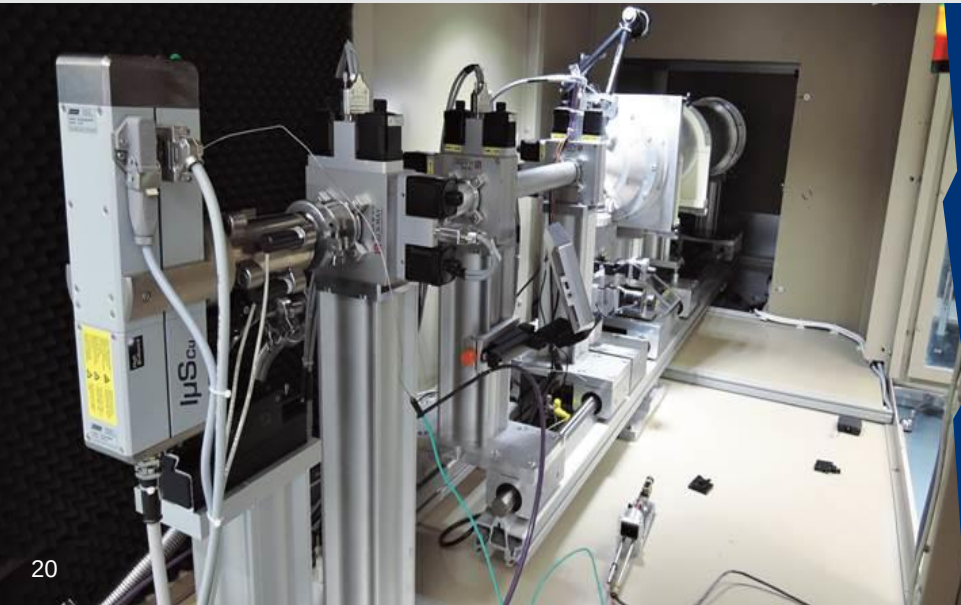
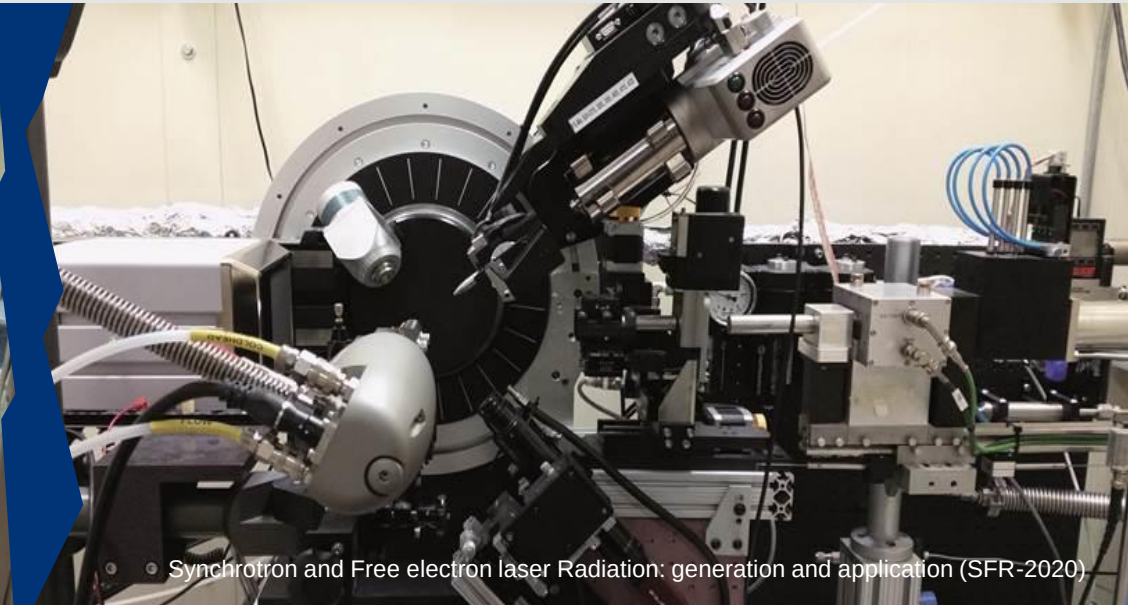
1 mrad = 0.057 deg



Impressions: Special Installations with IμS

Iμs @ Synchrotrons:

for characterizing equipment or measurements during downtime periods

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Calibration of Detectors with Small X-ray Tube

Miniature X-Ray Source iXmini for simple detector calibration all the day

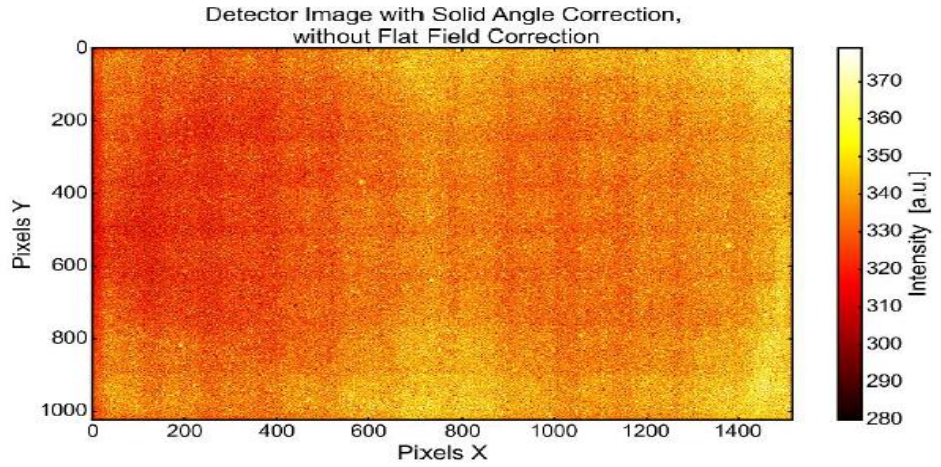
Applications of the iXmini : Accurate flat field detector calibration

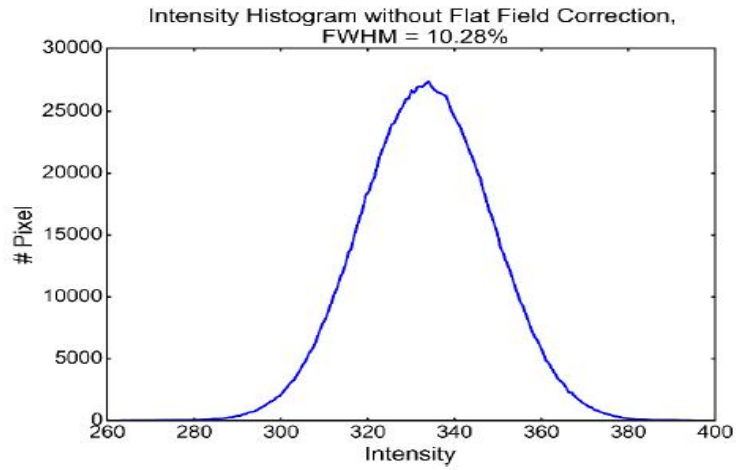
- Non-radioactive calibrant
- No need for fluorescence metal foil and external X-ray source
- Operation in vacuum possible
- Small footprint (120 x 105 x 90 mm^3)
- Typical operation at 10 kV and 10 µA

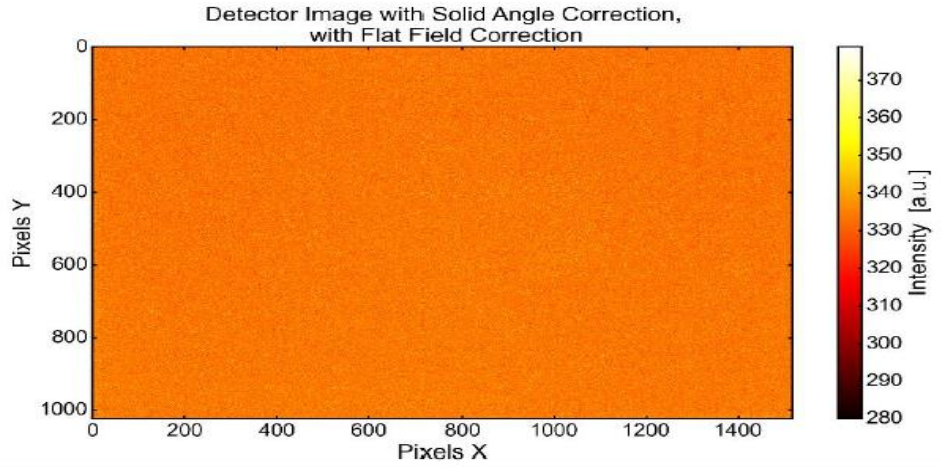
Tube: 3 cm in length, Ø 1.2 cm

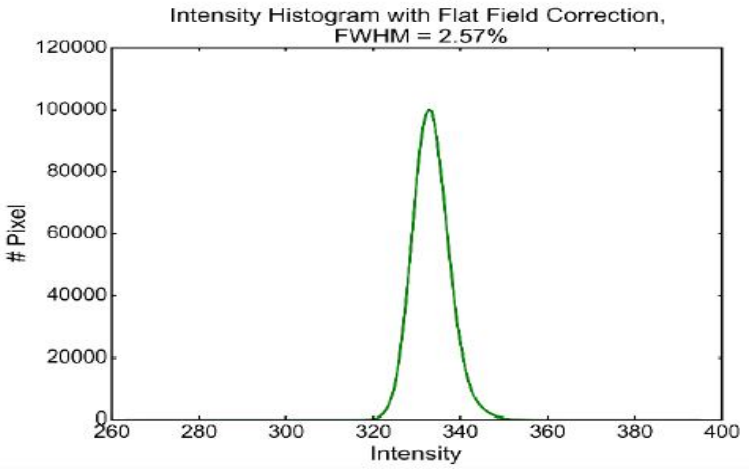
iXmini – Flat Field Correction

Intensity Distribution of a 1000 s Image without and with Flat Field Correction



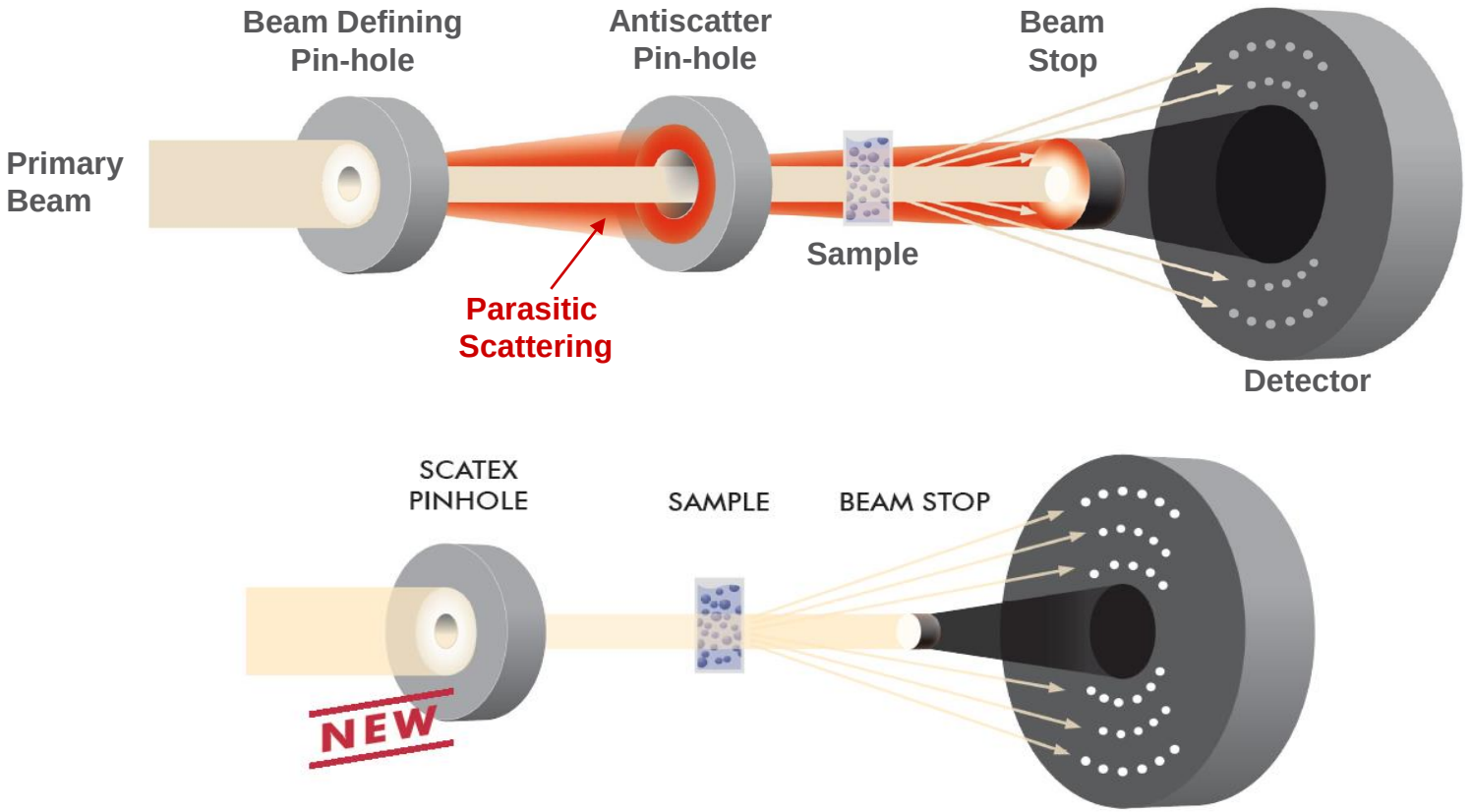






Scatterless Pinholes

Scatterless pinholes for reduction of parasitic scattering (SCATEX)



- Smaller beam stop, thus higher resolution
- Larger beam defining pin-hole, thus more flux
- No antiscatter pin-hole, thus smaller setup

SCATEX at synchrotron: Parasitic aperture scattering at 8 keV

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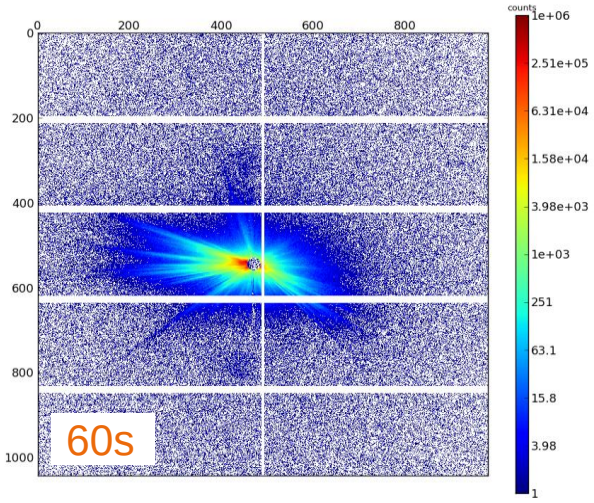
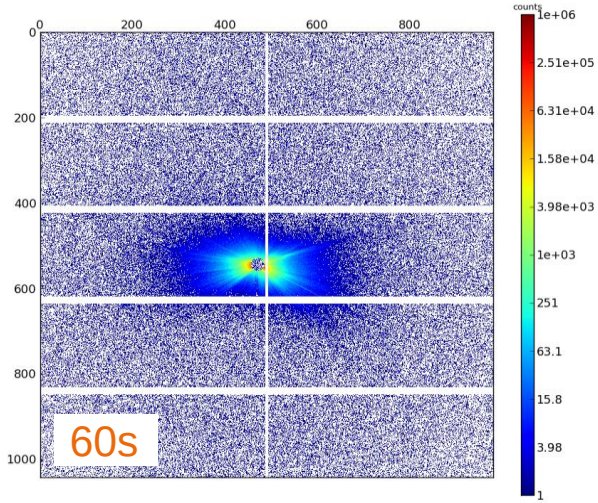
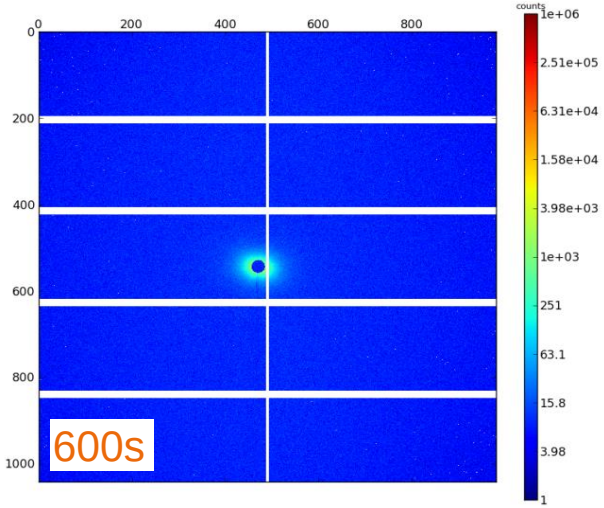
Cu foil 500 µm



Pt/Ir 500 µm



SCATEX 520 µm



- Measurement time with SCATEX was 10x longer !
- SCATEX shows much less scattering into the q-space.
- Scattering pattern of SCATEX is circular -> high overall quality of the pinhole
- Material: Single Crystals of Ge for < 12 keV, Ta for > 12 keV; sizes: 20 … 2000 µm

Summary

Your Partner for X-Ray Optics, X-ray Tubes, Microfocus Sources and Synchrotron Solutions

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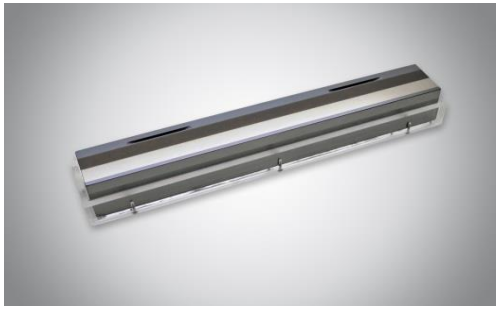
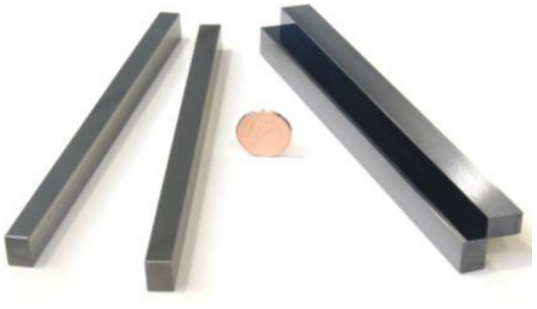
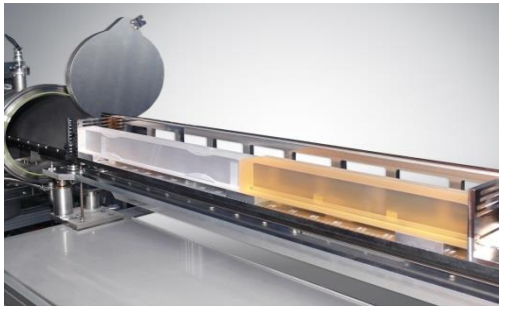
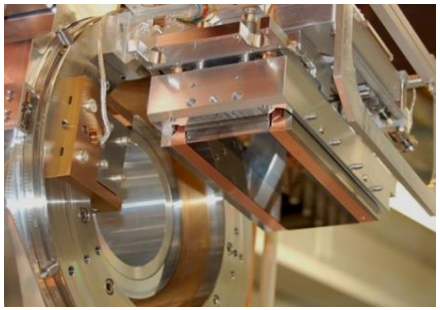
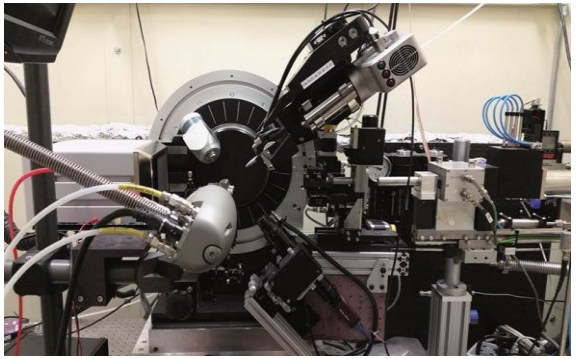








- X-ray Optics
- X-ray Tubes
- Microfocus Sources
- Scatterless Pinholes
- Solutions for Synchrotrons



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- Webpage: www.incoatec.de
- Videos: https://www.youtube.com/user/IncoatecTV
- Social Media: https://www.linkedin.com/company/incoatec
- Incoatec in Russia –> via Bruker Sales Channels

We are ready for new solutions!

Please contact for more information: Jörg Wiesmann · wiesmann@incoatec.de
Incoatec GmbH · Max-Planck-Str. 2 · 21502 Geesthacht · Germany · Tel: +49 41 52-88 9-3 81

THANK YOU !

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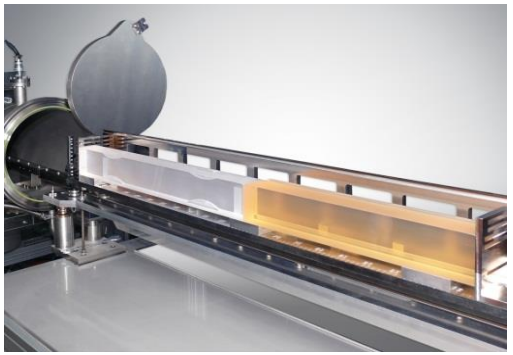
Bonus Material

Range of Solutions

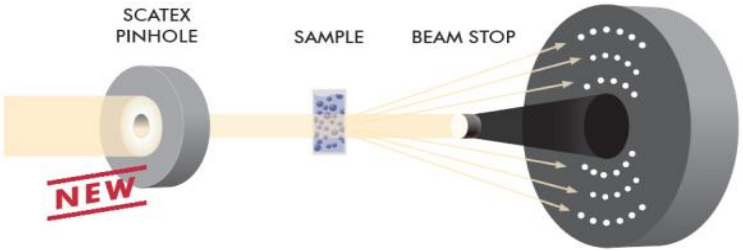
Multilayer Optics for the Lab

- Beam shaping in 1 or 2 dim
- Focusing & collimating
- Optics for XRD (5-25 keV)
- XRF analyzers for low energies (0.2-1.5 keV)



Synchrotron Optics

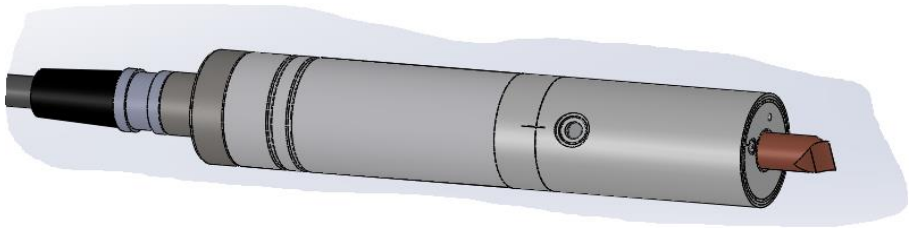
- Thin film deposition
- (graded) Multilayer
- Multi stripe coatings
- Total reflection coatings
- Coatings up to 150 cm



Scatterless Pinholes

- Material:
  Ge for < 12 keV
  Ta for > 12 keV
- Sizes (pinhole diameter):
  for Ge: 100 … 2000 µm
  for Ta: 20 … 1000 µm

Range of Solutions



Microfocus X-ray Tubes

- for Cu, Mo, Ag, Cr, Rh, W, Ti radiation (Others on request)
- Anodes with diamond cooling available

Microfocus Source Iμs

with inhouse-developed X-ray Tube

- High brilliant low power sealed tube
- New 2D optics
- For Crystallography, XRD, SAXS, …

Publications with our synchrotron optics

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research papers

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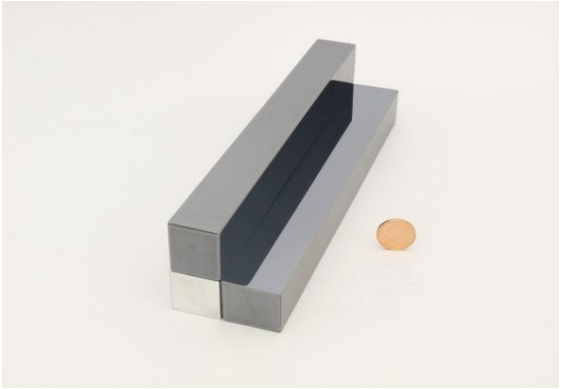
Tests and characterization of a laterally graded multilayer Montel mirror

K. Mundboth,[a]* J. Sutter,[a] D. Laundy,[a] S. Collins,[a] S. Stoupin[b] and Y. Shvyd'ko[b]

[a]Diamond Light Source Ltd, Harwell Science and Innovation Campus, Didcot OX11 0DE, UK, and [b]Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439, USA.
*E-mail: kiran.mundboth@diamond.ac.uk



Multilayers are becoming an increasingly important tool in X-ray optics. The essential parameters to design a pair of laterally graded multilayer mirrors arranged in a Montel-type configuration for use as an X-ray collimating device are provided. The results of X-ray reflectometry tests carried out on the optics in addition to metrology characterization are also shown. Finally, using experimental data and combined with X-ray tracing simulations it is demonstrated that the mirror meets all stringent specifications as required for a novel ultra-high-resolution inelastic X-ray scattering spectrometer at the Advanced Photon Source.

Keywords: X-ray optics; collimating optics; Montel mirrors; laterally graded multilayers; KB mirrors.

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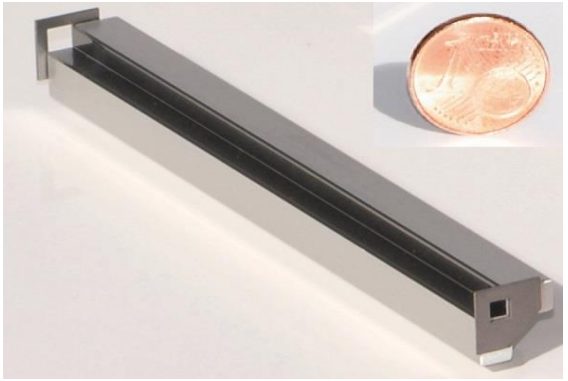
Performance of a collimating L-shaped laterally graded multilayer mirror for the IXS analyzer system at NSLS-II

Alexey Suvorov,[a]* David S. Coburn,[a] Alessandro Cunsolo,[a] Jeffrey W. Keister,[a] Mary H. Upton[b] and Yong Q. Cai[a]

[a]Photon Sciences, Brookhaven National Laboratory, PO Box 5000, Upton, NY 11973, USA, and [b]Advanced Photon Source, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439, USA. *E-mail: asuvorov@bnl.gov



The L-shaped laterally graded multilayer mirror is a vital part of the ultrahigh-energy and momentum-resolution inelastic X-ray scattering spectrometer at the National Synchrotron Light Source II. This mirror was designed and implemented as a two-dimensional collimating optic for the analyzer system. Its performance was characterized using a secondary large-divergence source at the 30-ID beamline of the Advanced Photon Source, which yielded an integrated reflectivity of 47% and a collimated beam divergence of 78 μrad with a source size of 10 μm. Numerical simulations of the mirror performance in tandem with the analyzer crystal optics provided details on the acceptance sample volume in forward scattering and defined the technical requirements on the mirror stability and positioning precision. It was shown that the mirror spatial and angular stability must be in the range <8.4 μm and <21.4 μrad, respectively, for reliable operation of the analyzer.

Keywords: X-ray optics; X-ray multilayer mirrors; laterally graded multilayer mirrors.

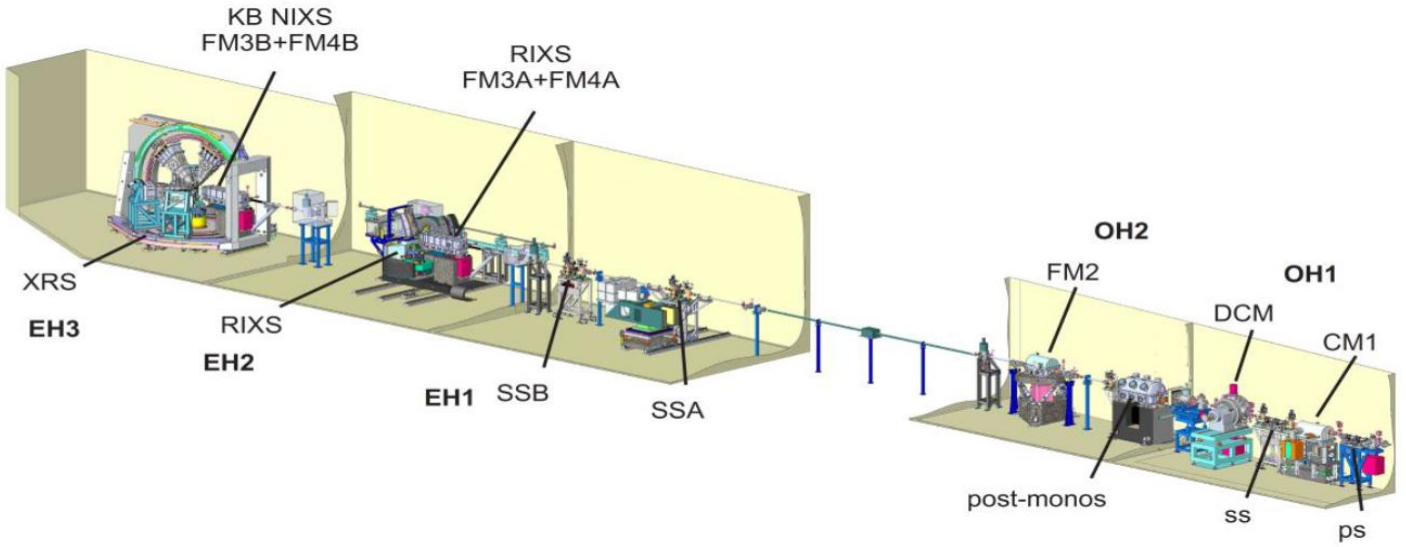
State-of-the-art IXS Beamline

2018

ESRF: Montel Multilayer Collimator Optics for ID20

E= 11215 eV

Montel optic: 23 cm



ID20 beamline is dedicated to the study of electronic excitations in complex materials by means of resonant (RIXS) and non-resonant (NIXS) inelastic X-ray scattering. The MMCO will be part of a novel RIXS spectrometer, which will feature simultaneous energy and polarisation analysis of the beam scattered by the sample. This so-called polarimeter will be optimised at a working energy of 11215 ± 20 eV.

IXT – Incoatecs Microfocus Tube

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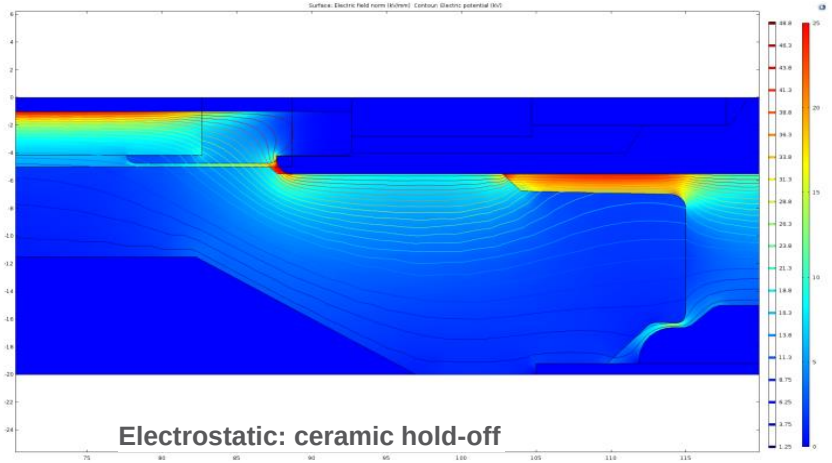
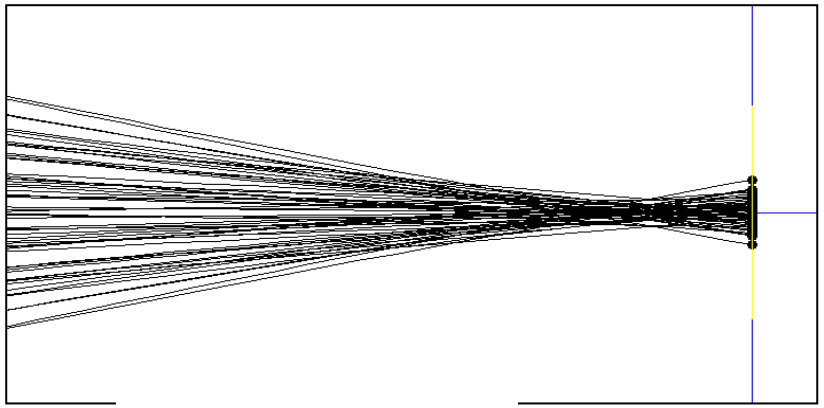
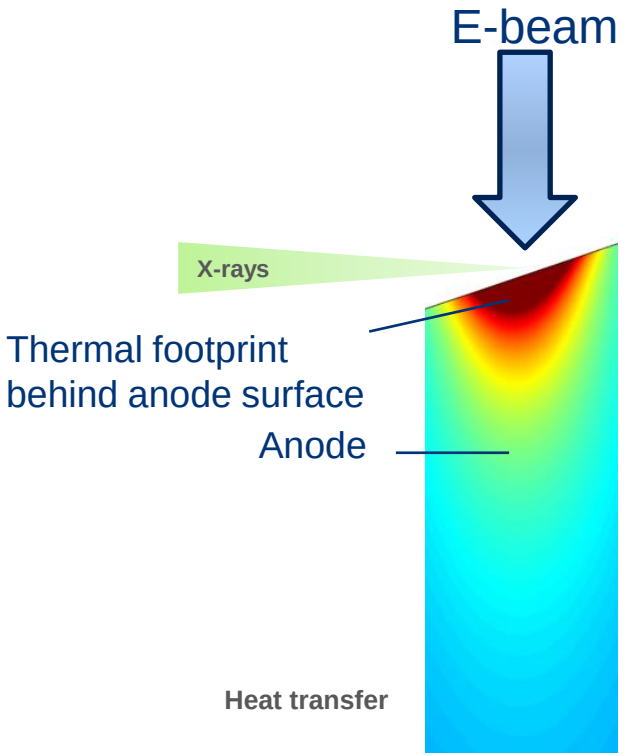
- Simulation of Heat Transfer and Electron Beam Properties for Microfocus Tube



Electrostatic: ceramic hold-off



Ray-tracing: focus optimization



Spot size on anode ~35 µm, energies up to 60 keV;

Anodes for IµS: Cu, Mo, Ag, Rh, W, Cr, Co, Ti, …

iXmini – Homogeneity of Flat Field Emission

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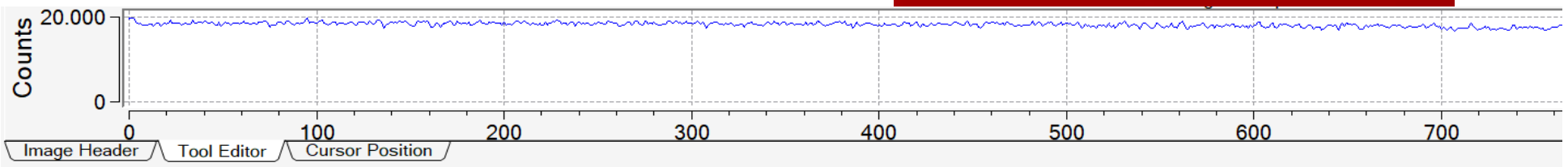
Homogeneity of a 40 s exposure using a modern CPAD detector (High Gain Mode)

- **iXmini**
  - Operated at 10 kV and 10 µA
  - Set at ~350 mm from the detector
- **CPAD Detector (PHOTON III from Bruker)**
  - Calibrated for Flat Field and Dark Current



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