An X-ray beam property analyzer based on dispersive crystal diffraction for next generation light sources

Nazanin Samadi[1], **Xianbo shi**[2], **Cigdem Ozkan Loch**[1], **Goran Lovric**[1]

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IBIC2022, Krakow

September 11-15, 2022

New generation light sources

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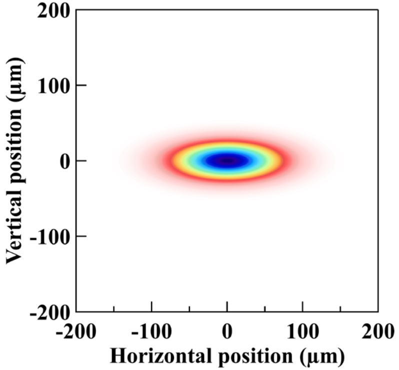
Current SLS Super BM

σ(h × v): 46 µm × 16 µm

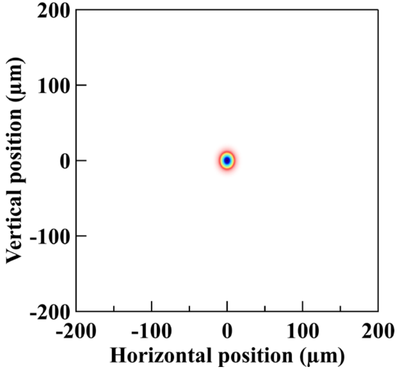
σ'(h × v): 109 µrad × 16 µrad



Future SLS 2.0 Super BM

σ(h × v): 6 µm × 7 µm

σ'(h × v): 28 µrad × 1 µrad



New Source diagnostics challenges

- Electron source diagnostic
  - Real time size and position monitoring
  - Emittance and source size measurements
- Beam diagnostic at beamline
  - Source and optics stability measurements
  - Feedback control on optics
  - Post-correction of experimental data
  - BM and/or undulator

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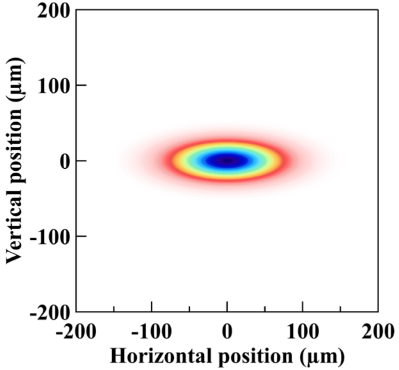

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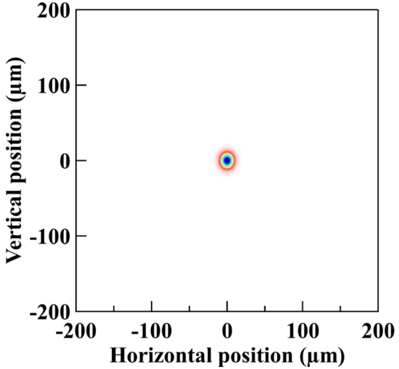

Methods of measuring the source size

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Imaging-based methods

- Pinhole imaging
- Fresnel zone plates
- Compound refractive lenses
- Kirkpatrick-Baez mirrors
- π polarization

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- Double-slit interferometry
- Grating interferometry
- X-ray (multi/lens) interferometry
- π polarization with diffraction obstacle

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Dispersion/diffraction-based method

- K-edge-based ps-BPM system
- ...

N. Samadi, X. Shi, L. Dallin, and D. Chapman, Phys. Rev. Accel. Beams 23, 024801 (2020).
N. Samadi, B. Bassey, M. Martinson, G. Belev, L. Dallin, M. De Jong, and D. Chapman, J. Synchrotron Radiat. 22, 946 (2015).

An X-Ray Beam Property Analyzer Based on Dispersive Crystal Diffraction

Dispersion

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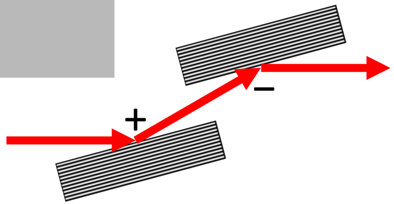

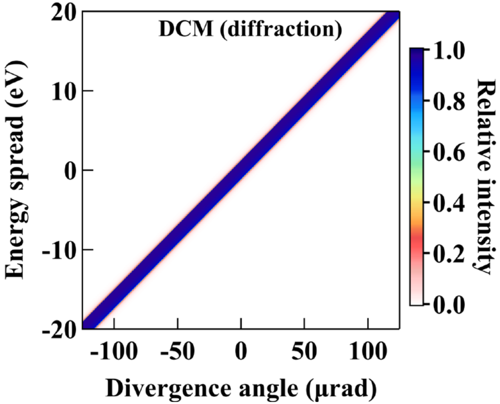

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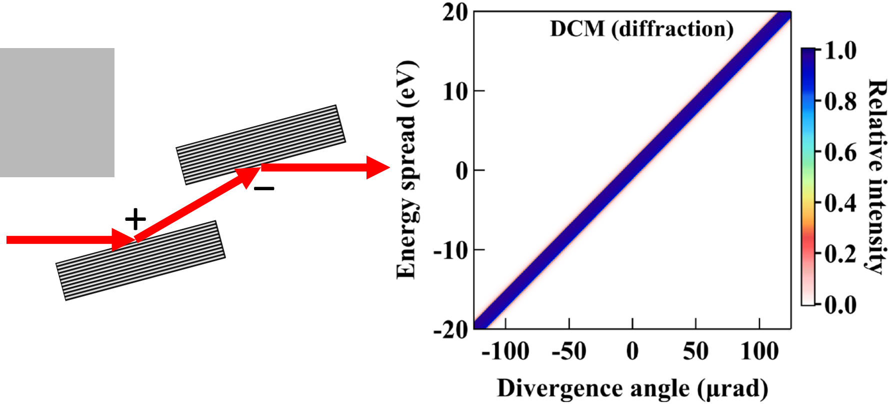

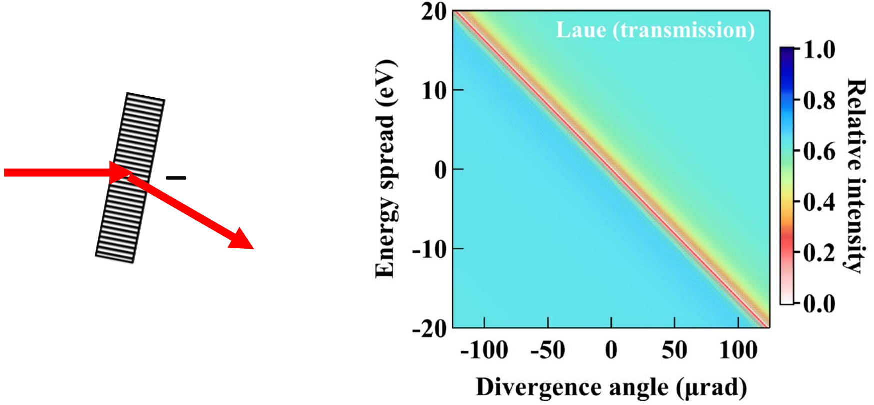

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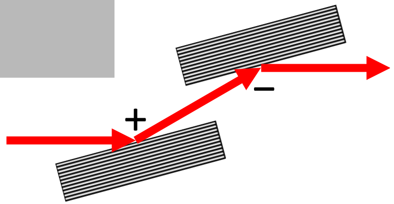

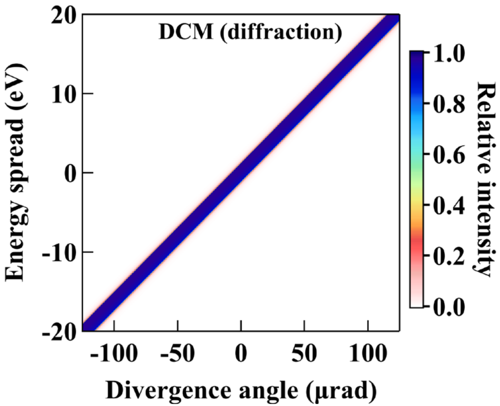

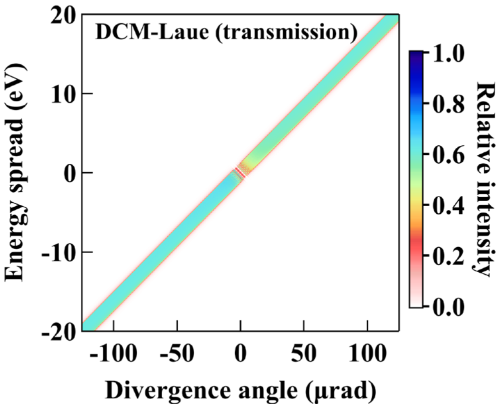

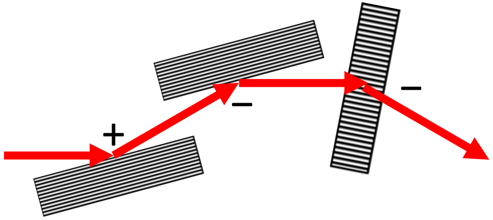

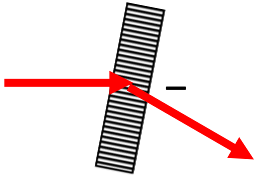

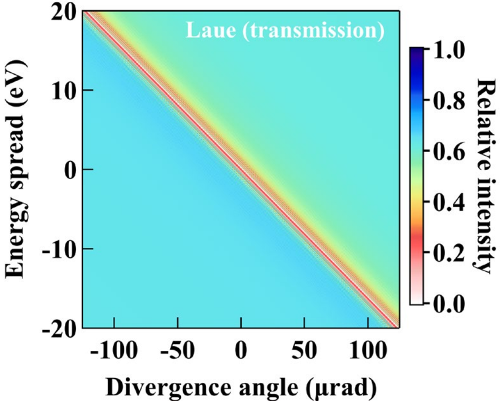

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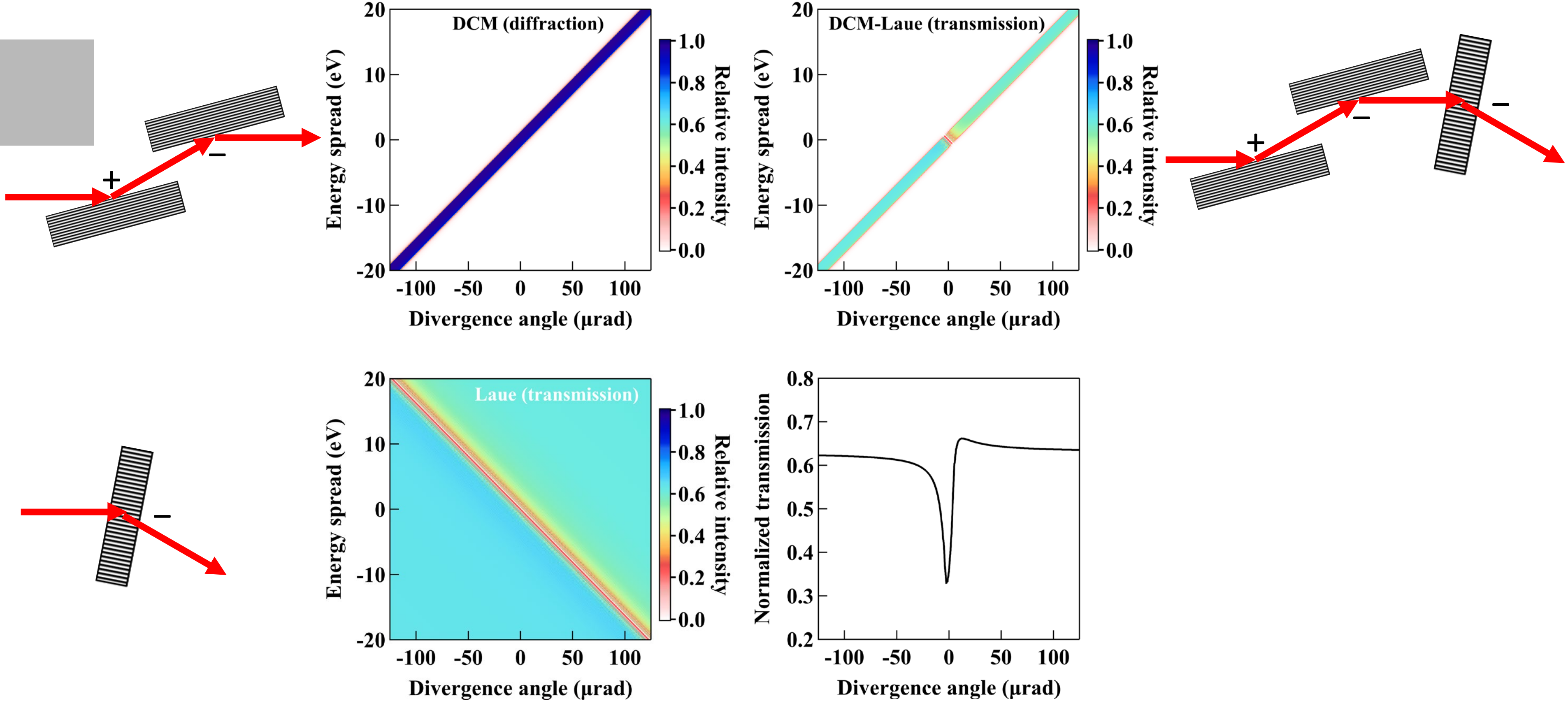

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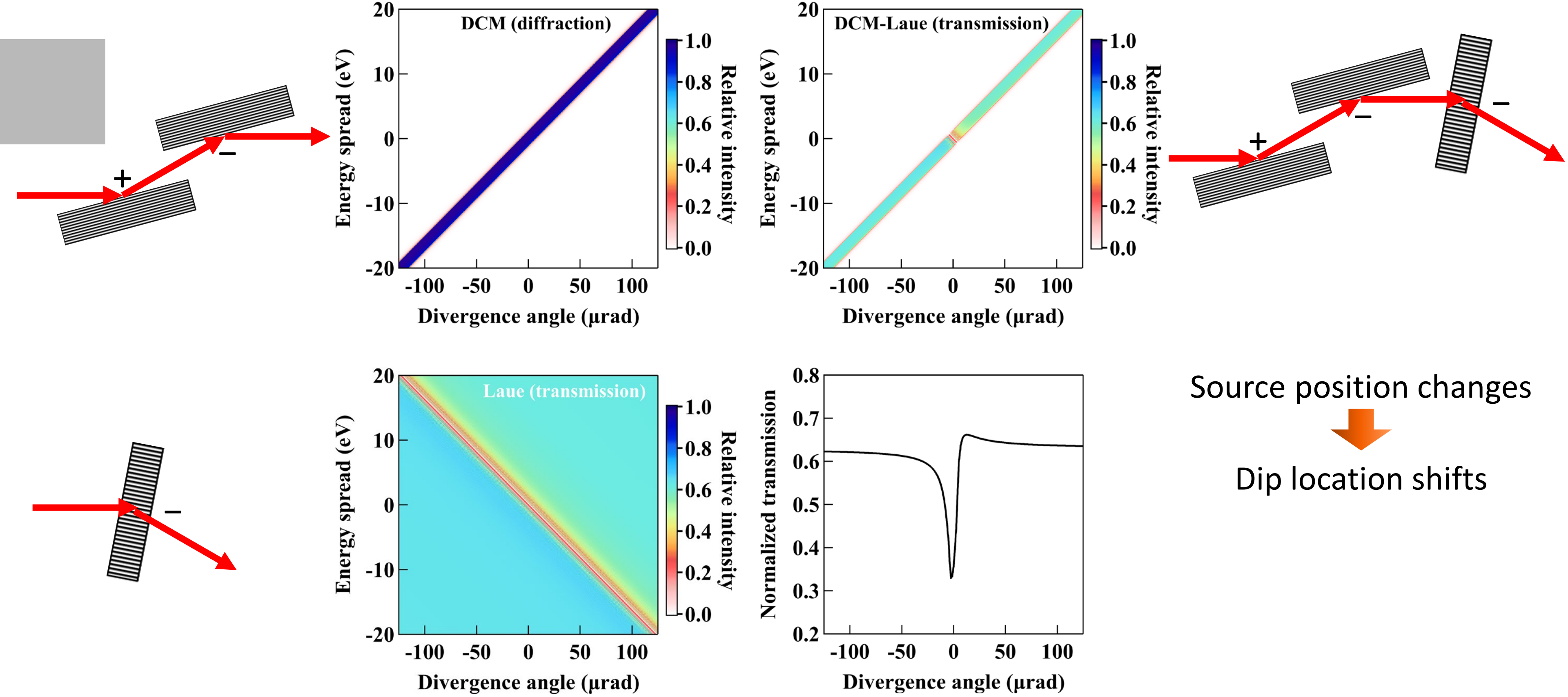

Source position changes

Dip location shifts

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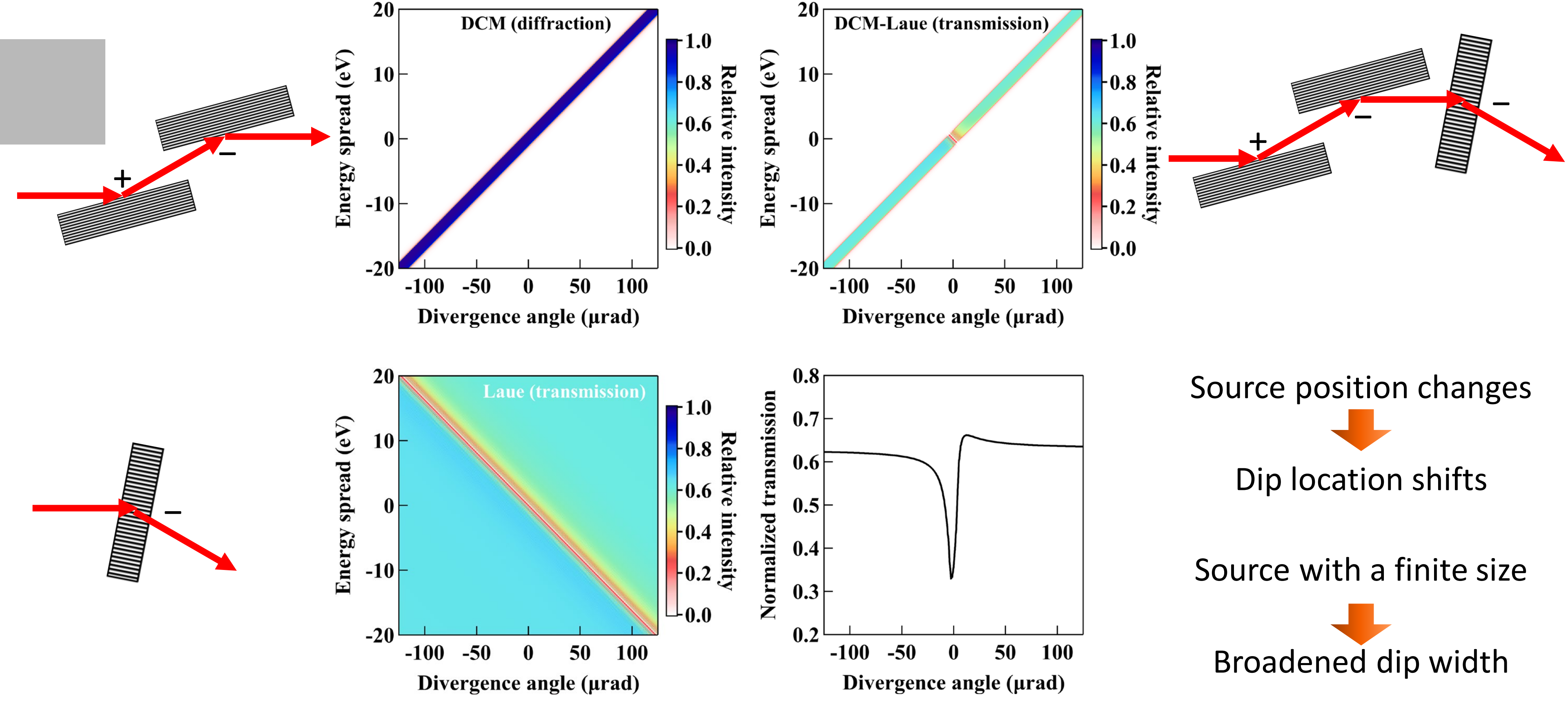

Source position changes

Dip location shifts

Source with a finite size

Broadened dip width

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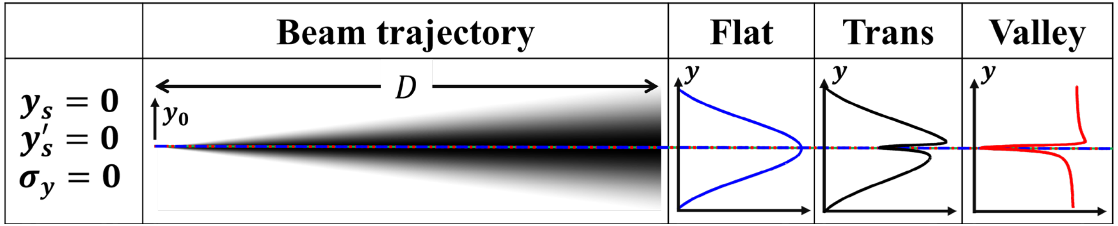
Principle

(a)



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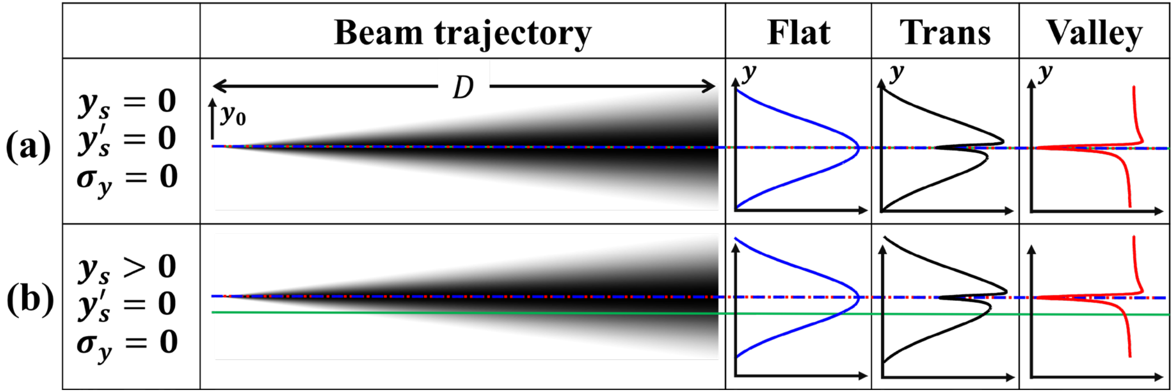

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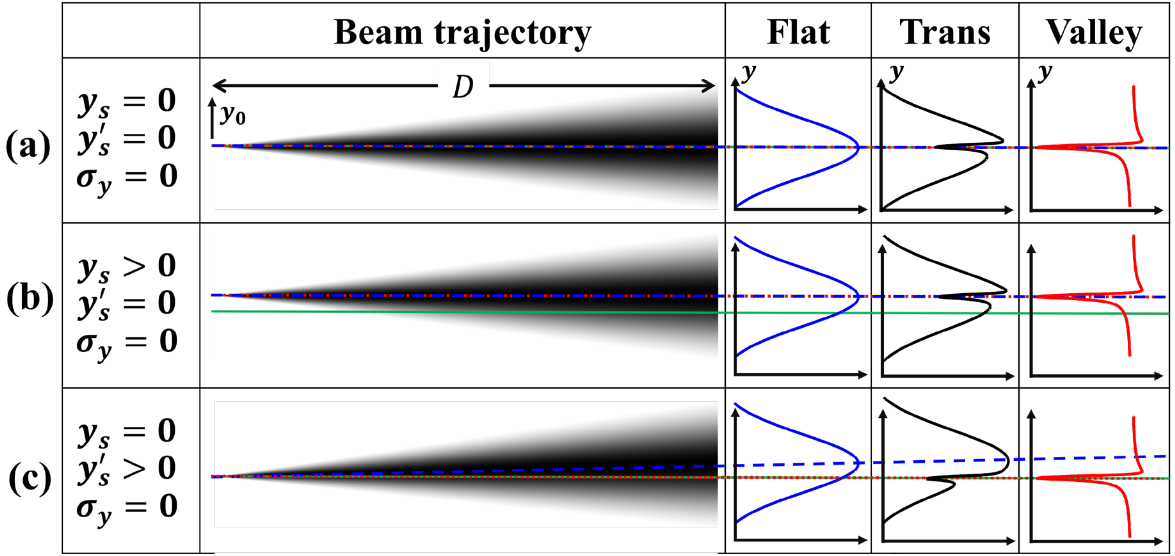

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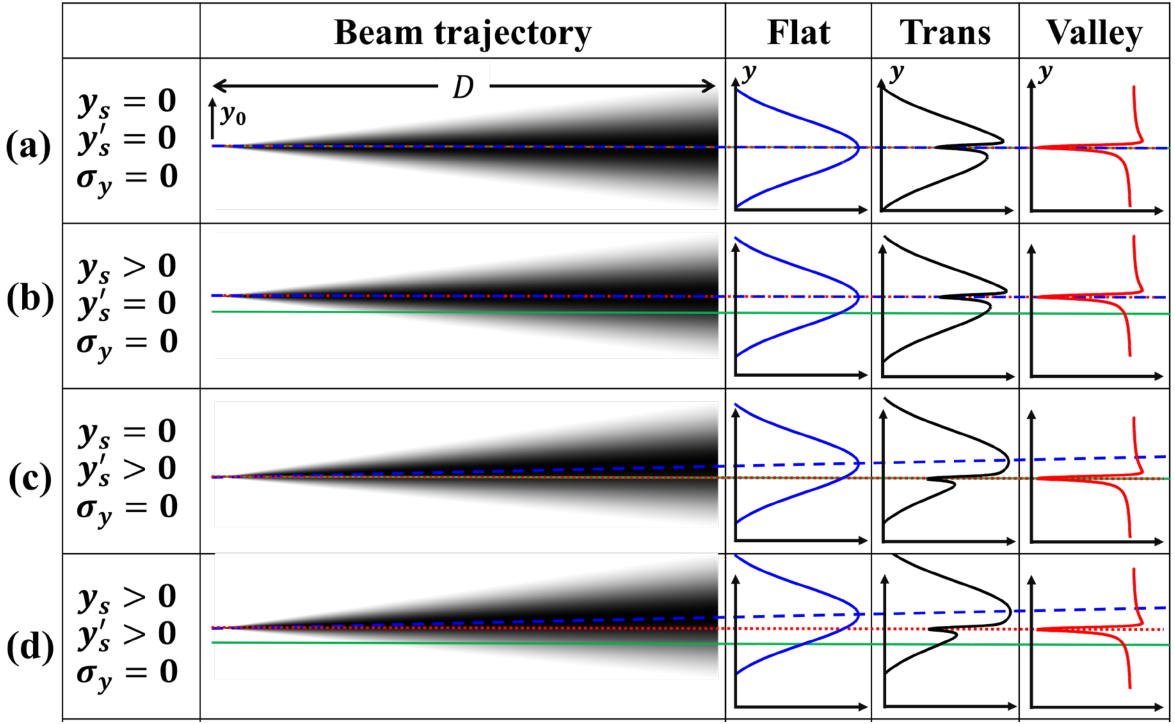

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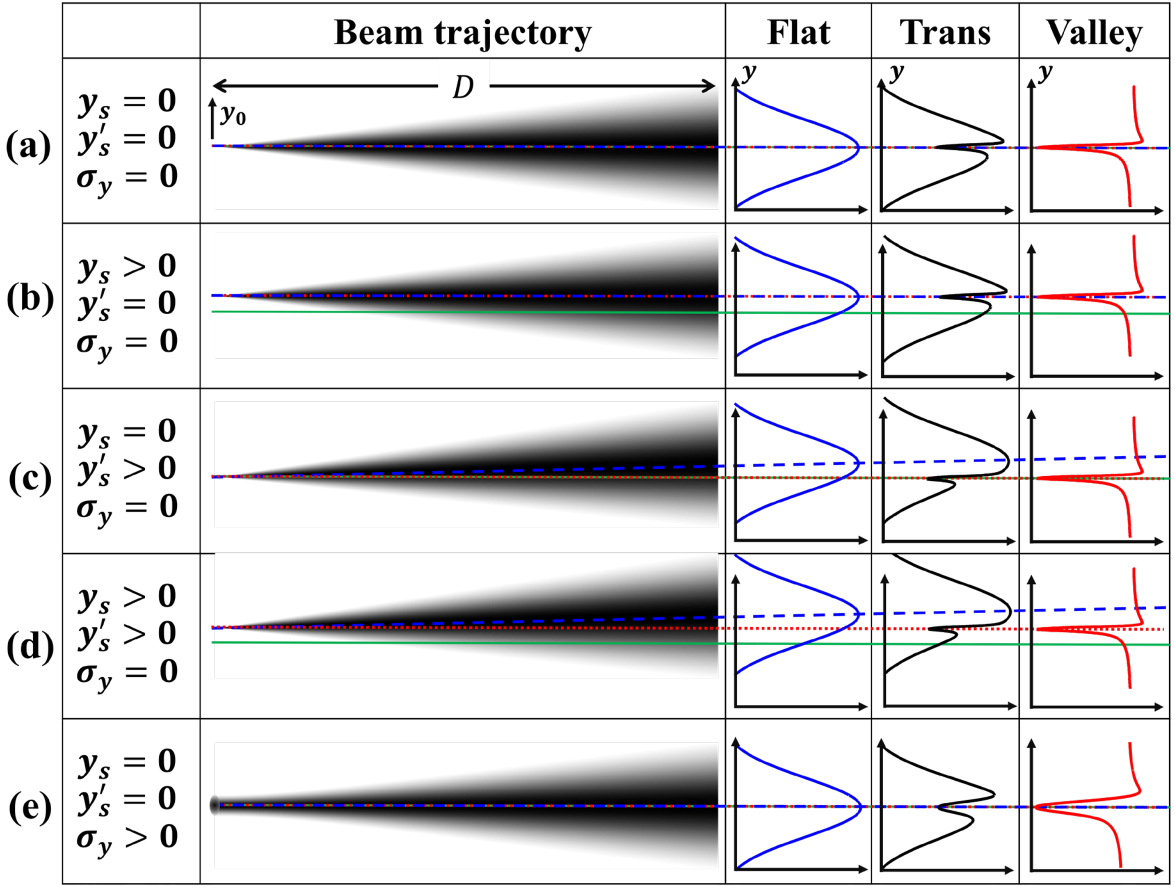

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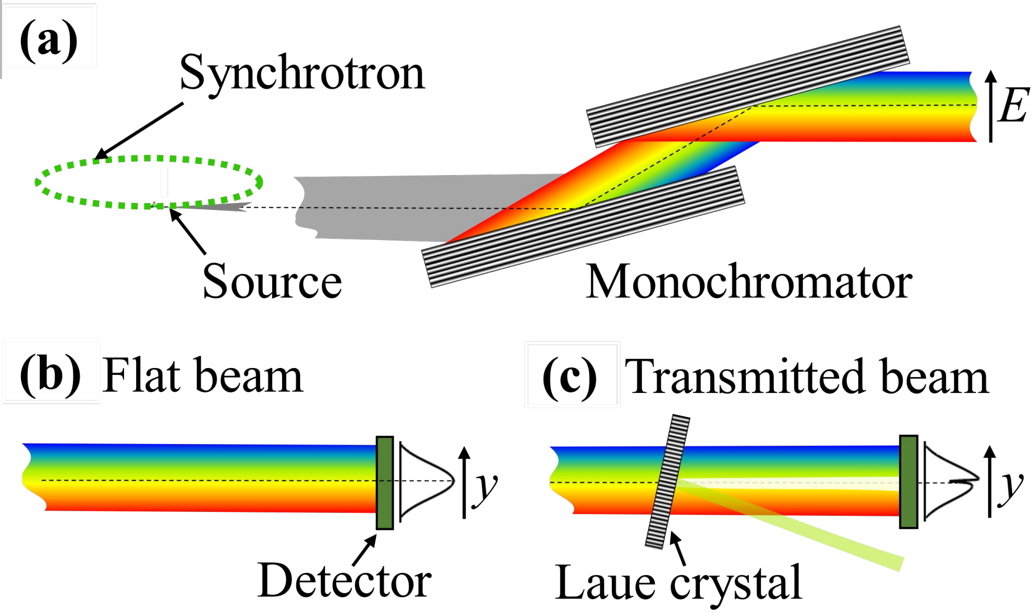
Schematic of the X-ray beam property analyzer setup

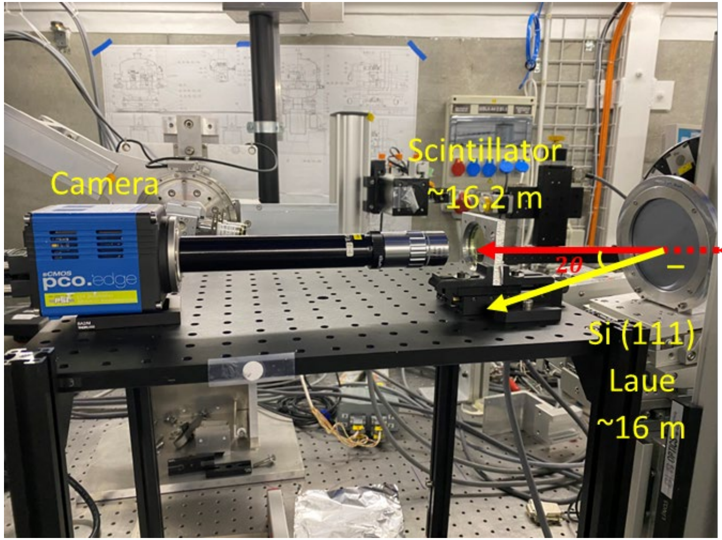


EXPERIMENTS

- Optics beamline (X05DA bending magnet)
  - Proof of principle
  - Varying electron source size
- TOMCAT beamline (X02DA super bending magnet)
  - Real time measurement
  - Compare with Zone plate imaging

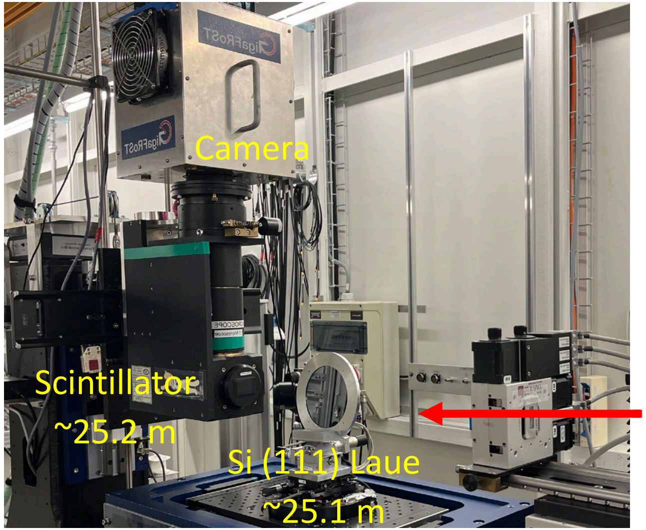
Experimental set up

Optics beamline



- Channel-cut DCM Si (111) at 18 keV
- Detector: sCMOS pco.edge 5.5 with 2×objective, 100 micron Ce:YAG scintillator
  - effective pixel size = 3.25 μm

TOMCAT beamline

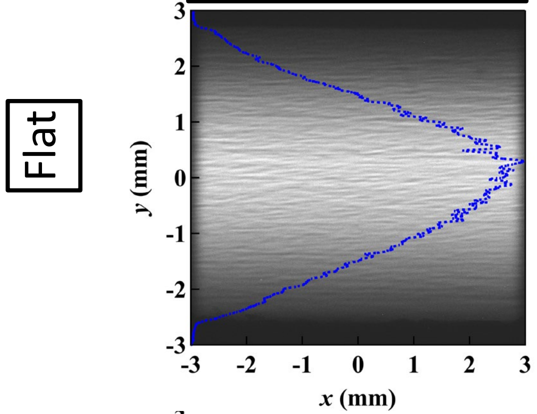


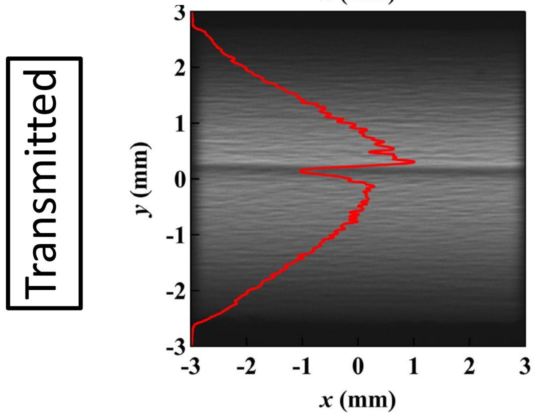
- DCM Si (111) at 20 keV
- Detector: ultra-fast CMOS detector with 1×objective, 500 micron LuAG scintillator
  - effective pixel size = 11 μm

Data analysis – Mono surface finish

Data analysis – Mono surface finish

Optics beamline





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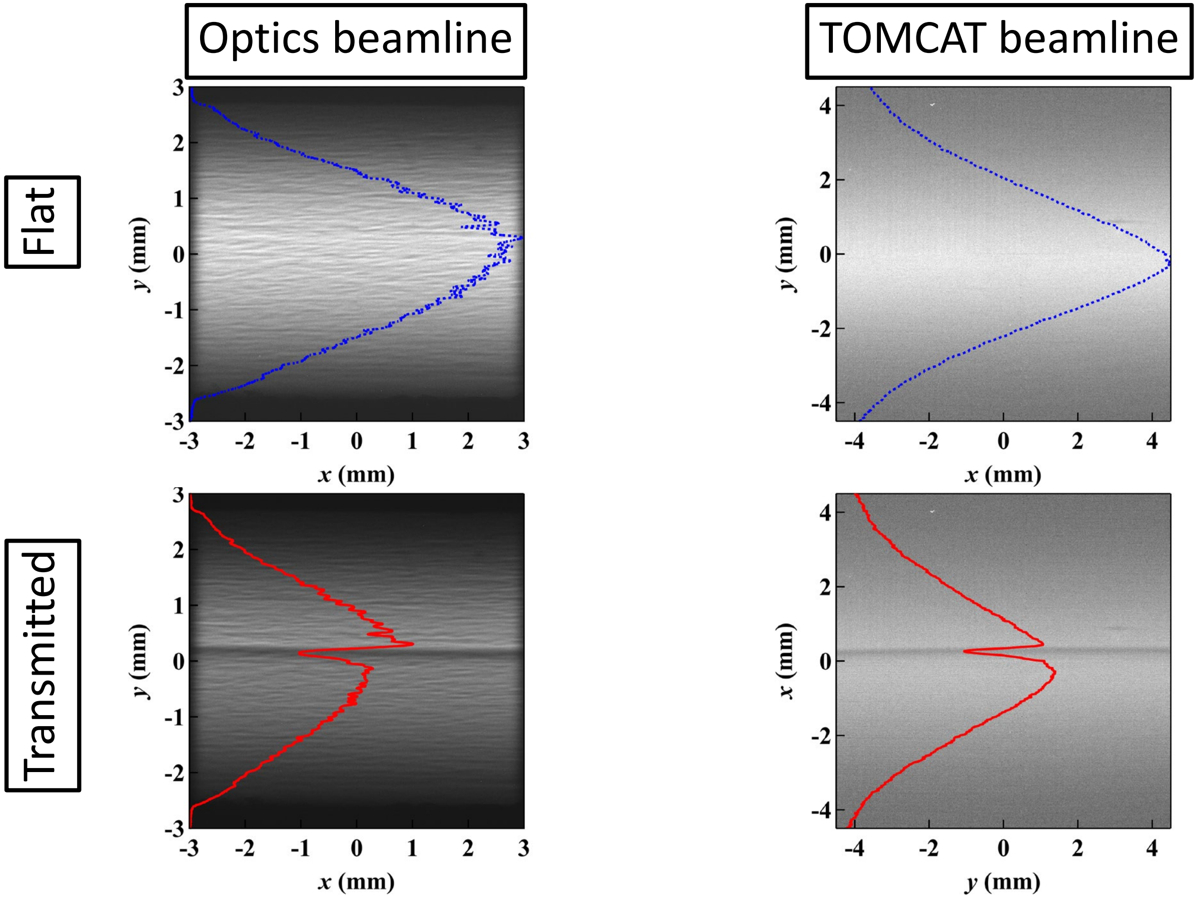
Data analysis – Mono surface finish



Data analysis – extracting information

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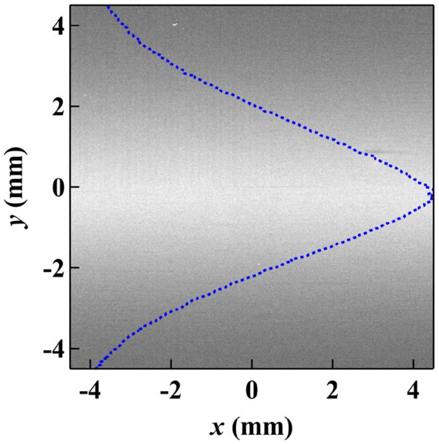
Flat



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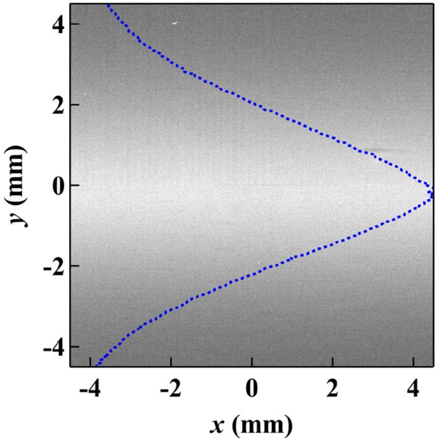
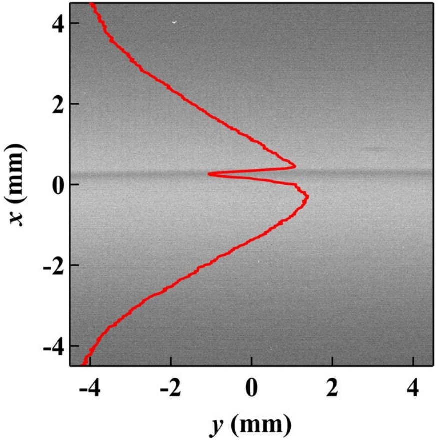


Transmitted



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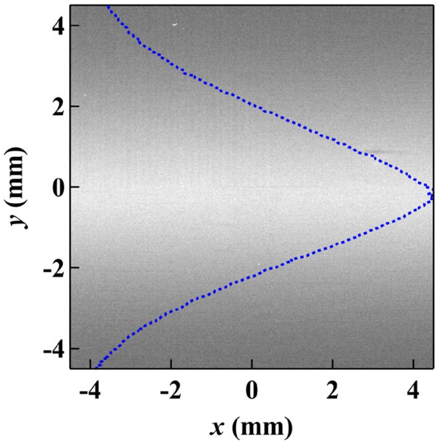

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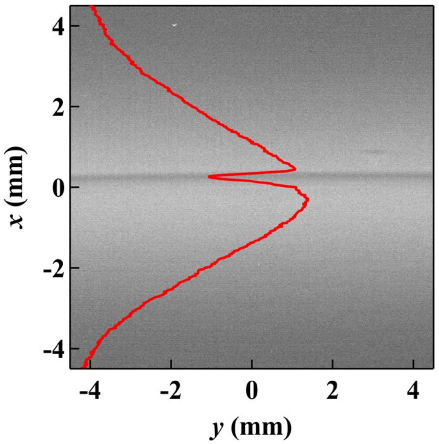

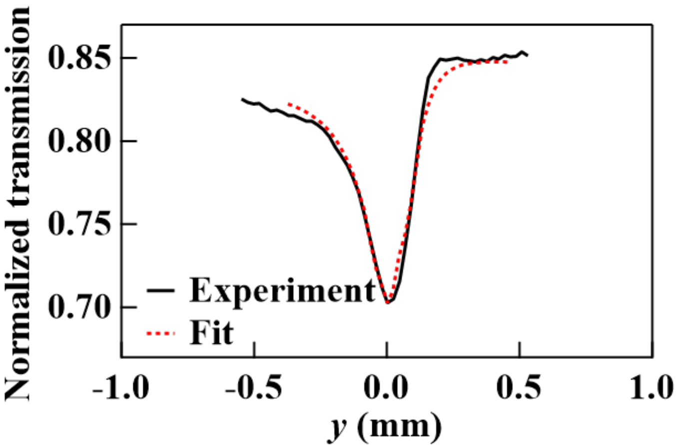

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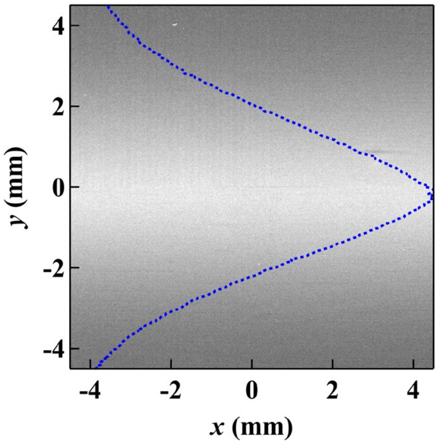

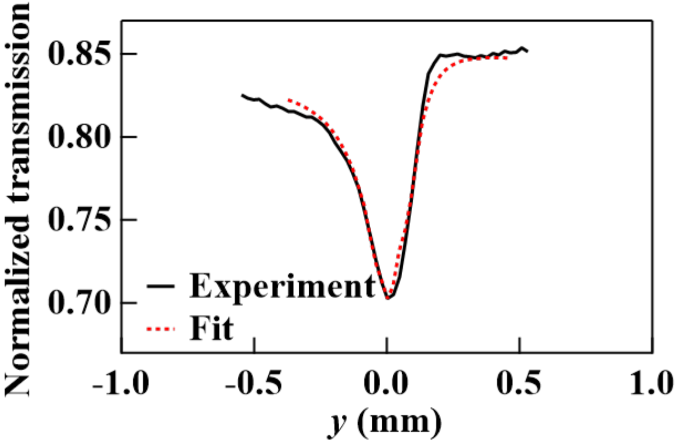

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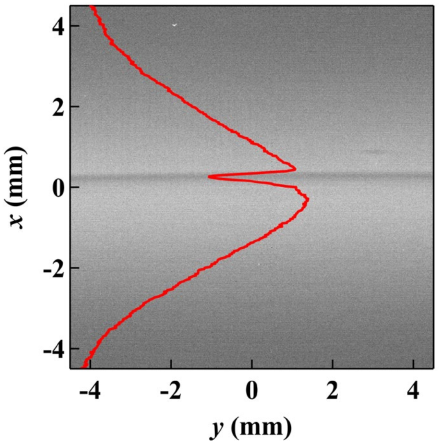


$$err = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[I_p(y_i) * I_s(y_i) - I_m(y_i)\right]^2}$$

$$I_m(y) = I_{\text{trans}}(y)/I_{\text{flat}}(y)$$

$$I_s(y) = \exp\left[-(y - y_s)^2/(2\sigma_y^2)\right]$$

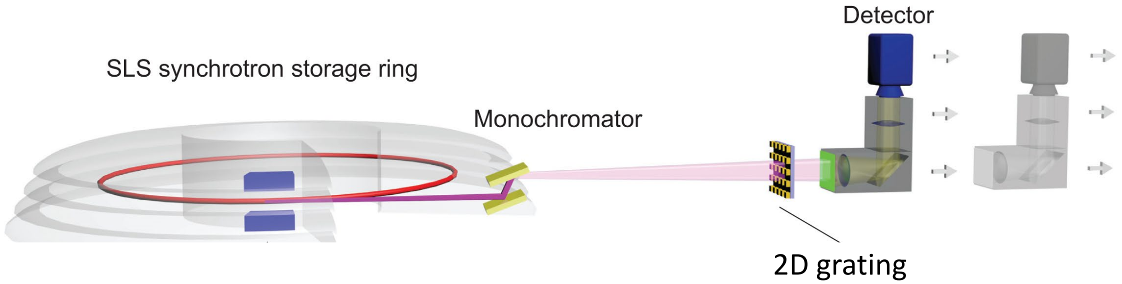
$$\sigma_{y'} = \frac{1}{D}\sqrt{\sigma_{\text{flat}}^2 - \sigma_y^2}$$

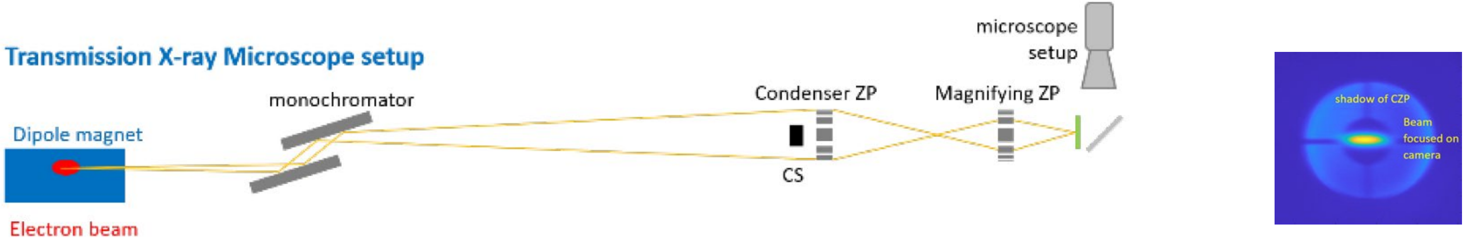
$$y_s' = (y_{\text{flat}} - y_s)/D$$

$$\sigma_{y_e'} = \sqrt{\sigma_{y'}^2 - \sigma_{y_{ph}'}^2}$$

Extracted vertical source sizes (TOMCAT)

XBPA	Zone plate	Grating
17±2 µm (400 ms)	17 µm	15 µm





G. Lovric, P. Oberta, I. Mohacsi, M. Stampanoni, and R. Mokso, Opt. Express 22, 2745 (2014).
C. Ozkan Loch, A. Bonnin, J. Vila-Comamala, N. Samadi, A. M. M. Stampfli, and R. Ischebeck, These Proc. (2022).

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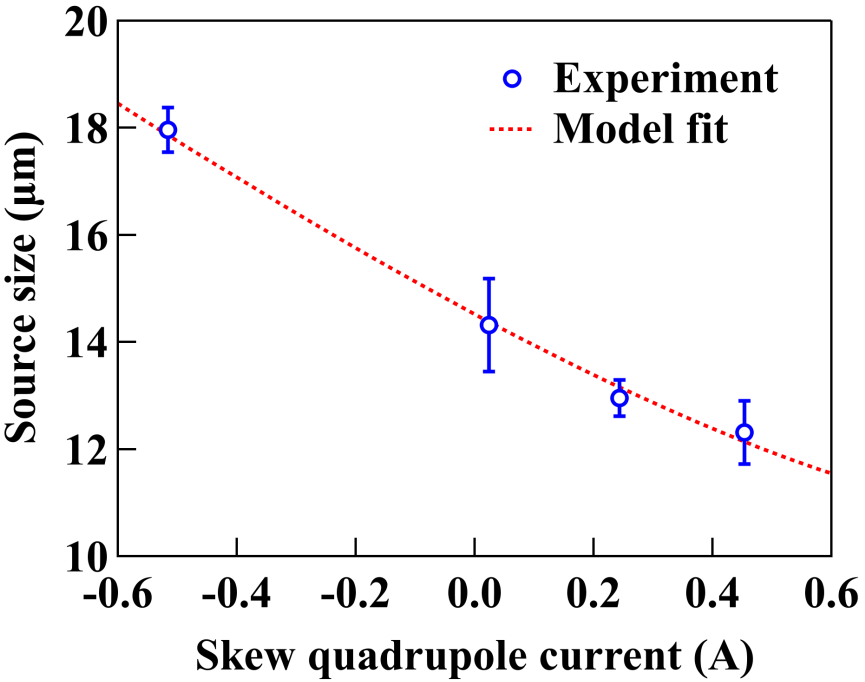
Extracted electron source sizes (optics beamline)

- Electron source size was varied by changing the current in a skew quadrupole (changing the horizontal-vertical coupling)
- A model fitting using the TRACY-2 accelerator library

$$\sigma_{\text{model}} = \sqrt{\sigma_{\text{min}}^2 + \sigma_{\text{ideal}}^2} = \sqrt{\sigma_{\text{min}}^2 + b^2(A - A_s)^2}$$

- Excellent agreement between the measured data and the model fit
  - confirms that the XBPA can provide source size measurements with a high sensitivity (<10%)



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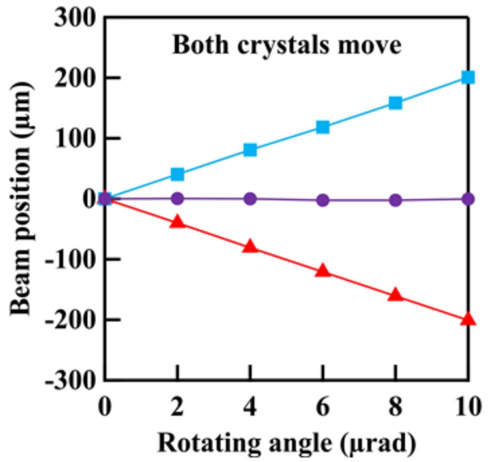
Extracted source properties (optics beamline)

Skew quadrupole current A_m (A)	Source size σ_y (μm)	Source divergence $\sigma_{y'}$ (μrad)	Beam position y_{beam} (μm)	Source position y_s (μm)	Source angle y'_s (μrad)
0.454	12.31 ± 0.59	28.15 ± 0.03	0 ± 0.97	0 ± 1.40	0 ± 0.13
0.244	12.95 ± 0.34	28.39 ± 0.03	-2.05 ± 1.02	5.06 ± 0.48	-0.44 ± 0.10
0.024	14.31 ± 0.87	28.50 ± 0.02	-0.49 ± 0.73	10.82 ± 2.38	-0.71 ± 0.15
-0.516	17.96 ± 0.42	28.70 ± 0.03	0.14 ± 1.92	20.19 ± 1.06	-1.25 ± 0.18

- Measurement sensitivity of less than 10% of a source size of around 10 μm
- Divergence sensitivity is at the 0.1% level
- Drift in the crystal system can give the appearance of a coupled source position and angle motion
  - $y_{\text{beam}} = y_s + Dy'_s$



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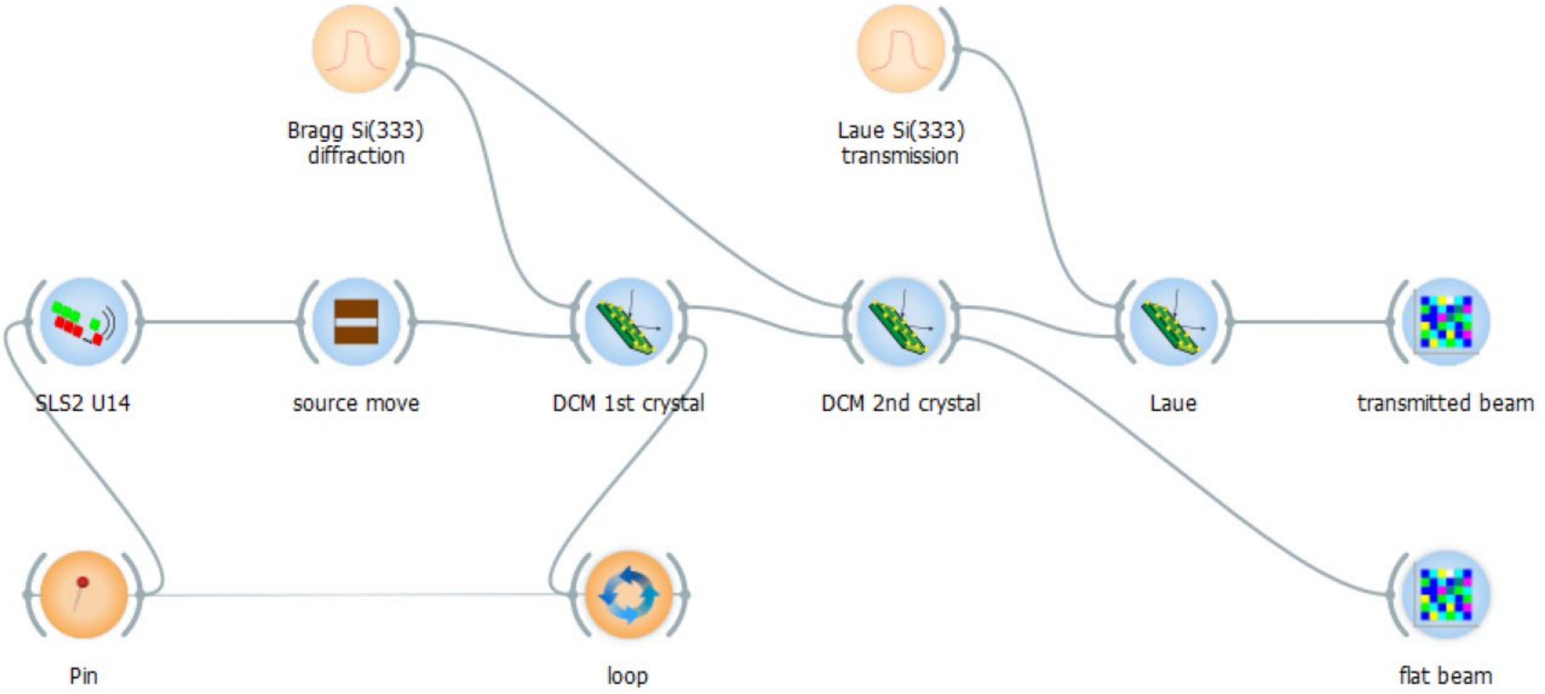
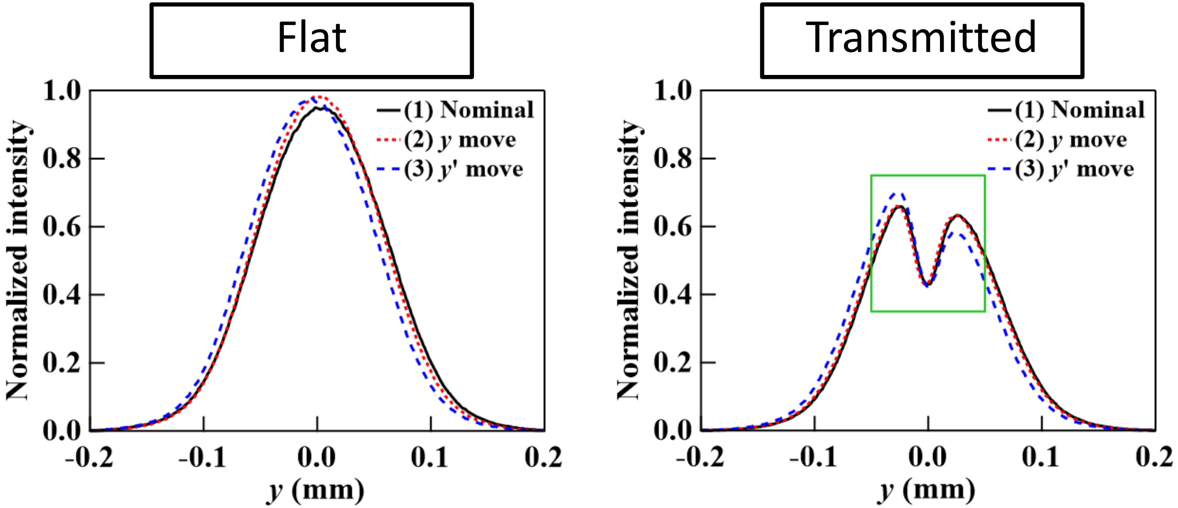
Undulator simulations for SLS 2.0



Undulator simulations for SLS 2.0

Undulator simulations for SLS 2.0

Changing position and angle



Si (333) DCM

Si (333) Laue

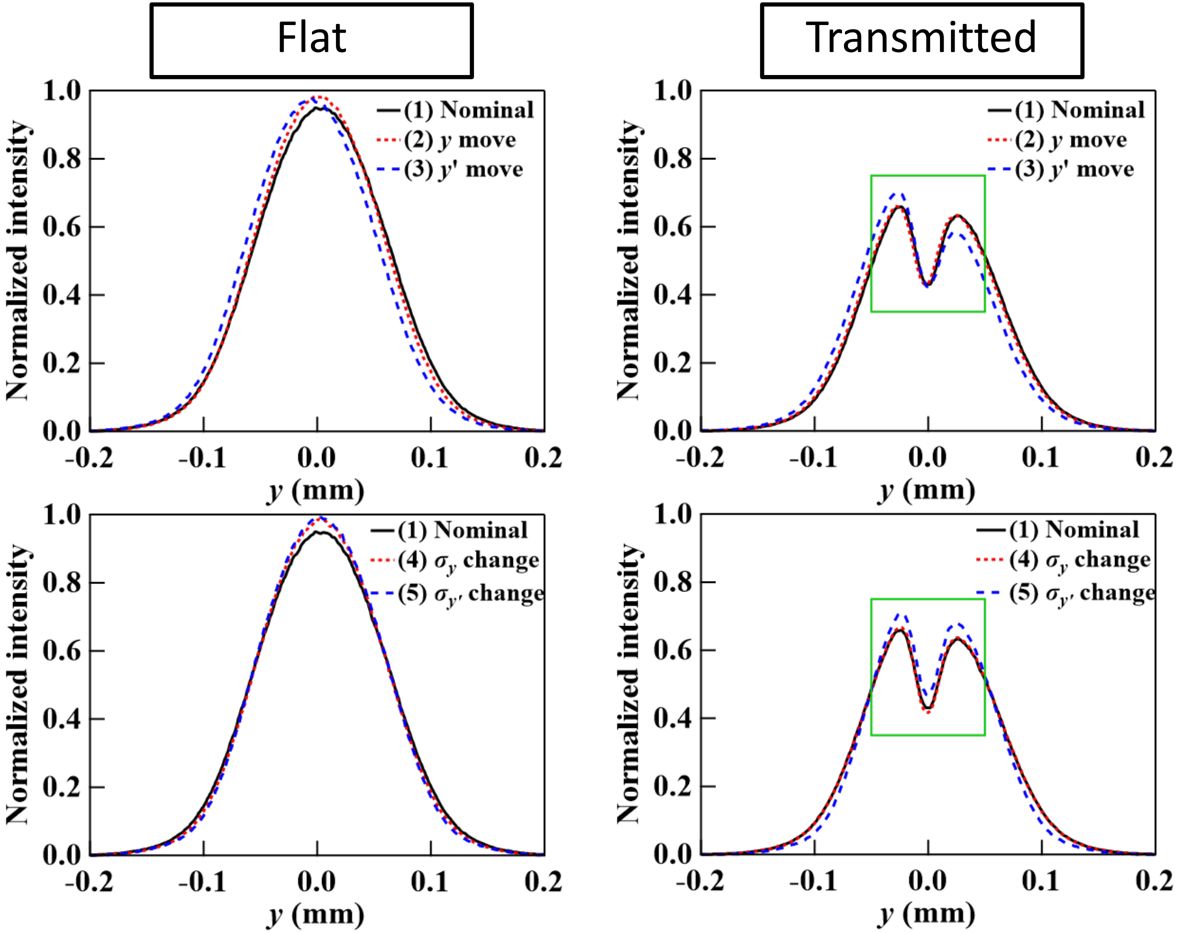
0.25 mm thick

@ 20 keV

Undulator simulations for SLS 2.0

Changing position and angle

Changing size and divergence



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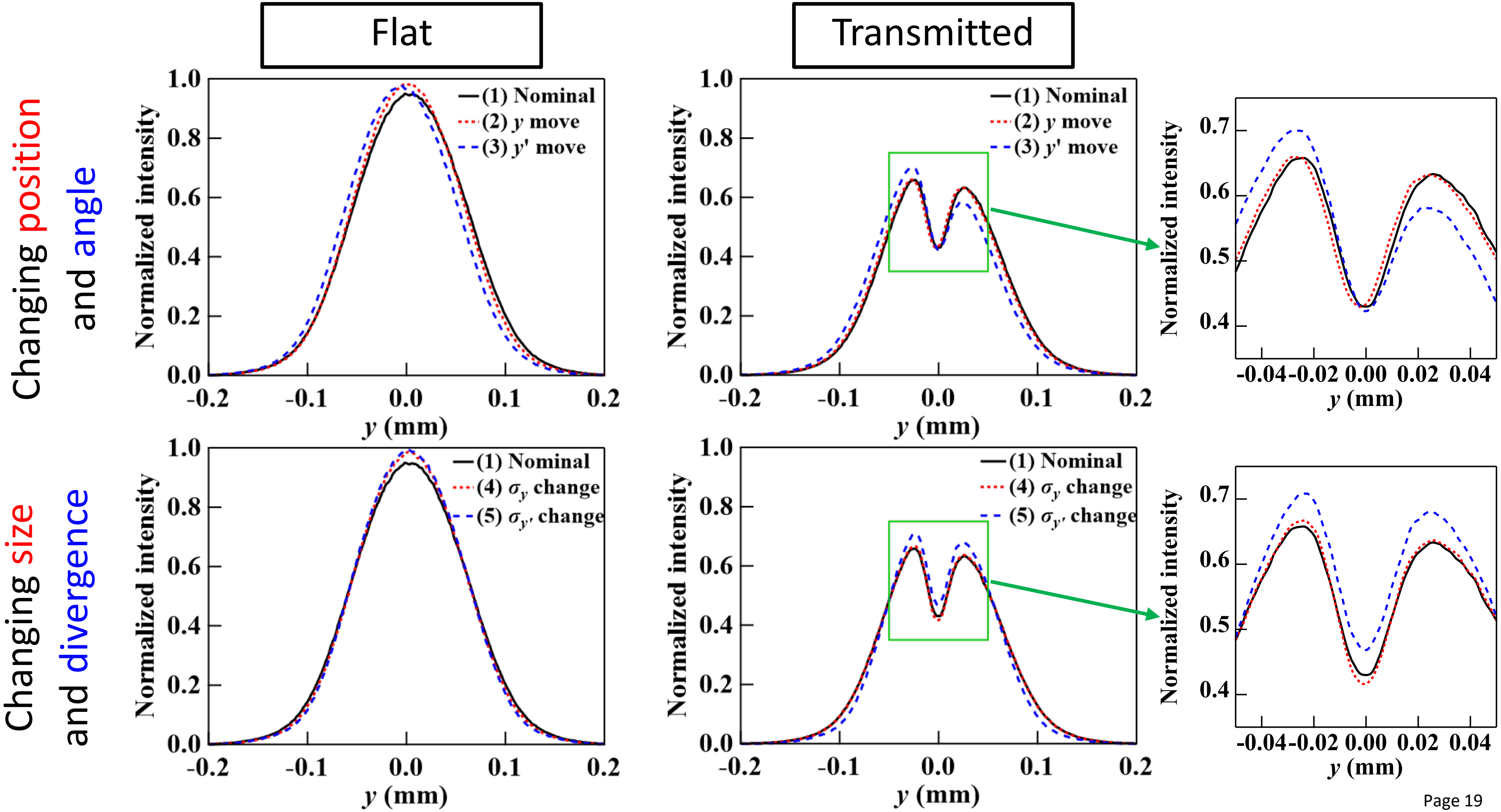

Summary

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  - Beamline diagnostics (vibrations from the source or optics)
  - Correcting experimental data

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- Monitoring device for electron source diagnostic of source size, divergence, position and angle at a dedicated BM beamline
- Monitoring device for beam position and size at ID or BM beamlines
  - Beamline diagnostics (vibrations from the source or optics)
  - Correcting experimental data
- Exploring application for XFELs

Acknowledgment

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Juraj Krempasky
Uwe Flechsig
Philipp Zuppiger
Marco Stampanoni

Xianbo Shi (APS)
Dean Chapman (USASK)

Thank you!

Questions and Comments?

Thickness study: Anomalous transmission