HYBRID: Combining Geometric Ray-Tracing and Wavefront Propagation

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Outline

- Introduction
- *HYBRID* code development
  - Near-field – single optics
  - Far-field – entire beamline
  - Distribution
- Optics simulation examples
  - Mirror with figure errors
  - CRLs
  - ISN beamline at APS-U
- Summary

Introduction

- Geometrical ray tracing, e.g., SHADOW, RAY, McXtrace, xrt, …
  - Total intensity, beam size, mirror figure errors, reflectivity
  - Fast, robust, parameter optimization
  - No diffraction
- Wavefront propagation
  - Fourier optics, e.g., SRW
  - Stationary phase, e.g., PHASE
  - Diffraction effects
  - Partial coherent source: multi-electron simulation (SRW)
  - Very slow, result cannot be carried over
- Fast simulation tool for beamline design and optimization
  - Diffraction effects when beam is clipped
  - Simulate mirror figure errors as wave optics
  - Partial coherent source

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HYBRID: Near-field – single optics

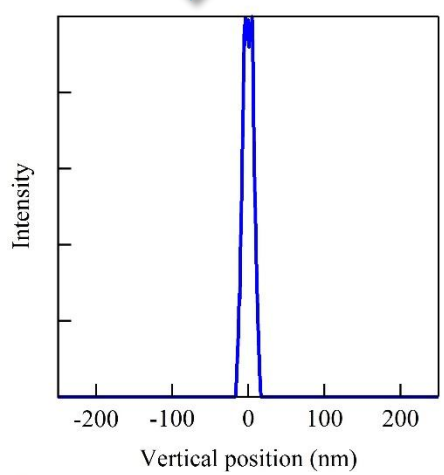
Wavefront Propagation

$$E_{1e}(z_{1e}) = [I_{1e}]^{1/2} \times \exp\left[-ik\left(\frac{z_{1e}^2}{2f_z}\right)\right] \times \exp\{-i2k\Delta h(z_{1e})\, sin[\theta_1(z_{1e})]\}$$

Exit pupil

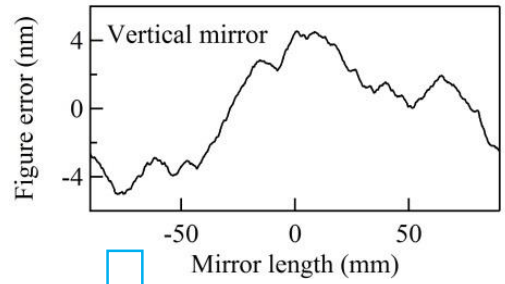
Ray tracing

Ideal optics

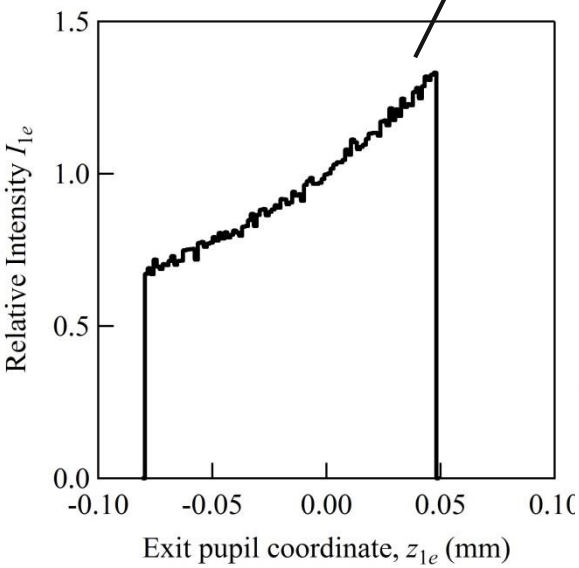


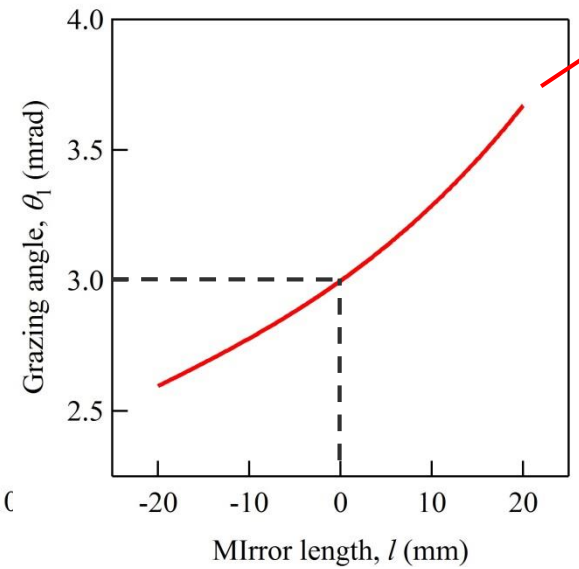
Exit pupil function

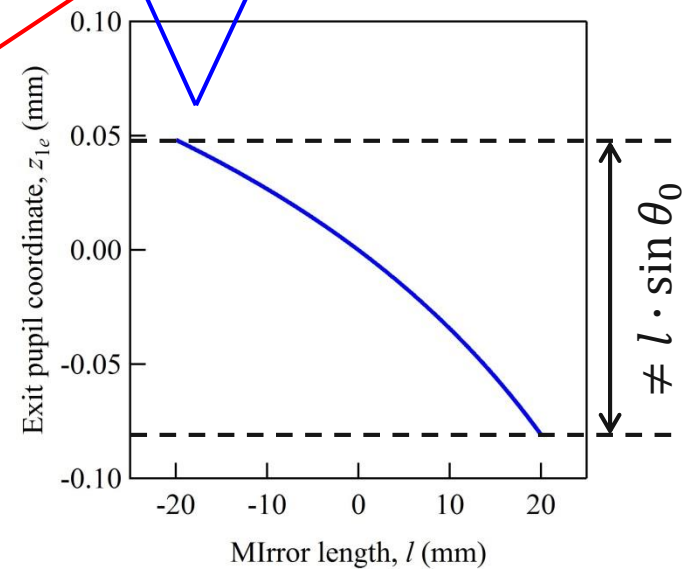
Ideal lens with focal length of f_z



$$E_{1e}(z_{1e}) = [I_{1e}]^{1/2} \times \exp\left[-ik\left(\frac{z_{1e}^2}{2f_z}\right)\right] \times \exp\{-i2k\Delta h(z_{1e})\, sin[\theta_1(z_{1e})]\}$$







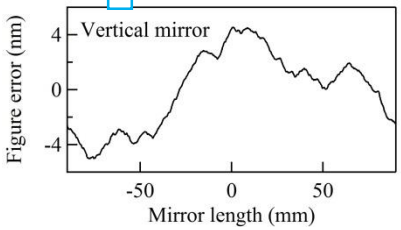
- Intensity scaling
- Grazing angle correction
- Coordinate transformation

HYBRID: Near-field – single optics

Wavefront Propagation

$$E_{1e}(z_{1e}) = [I_{1e}]^{1/2} \times \exp\left[-ik\left(\frac{z_{1e}^2}{2f_z}\right)\right] \times \exp\{-i2k\Delta h(z_{1e})\, sin[\theta_1(z_{1e})]\}$$

Ideal lens with focal length of f_z

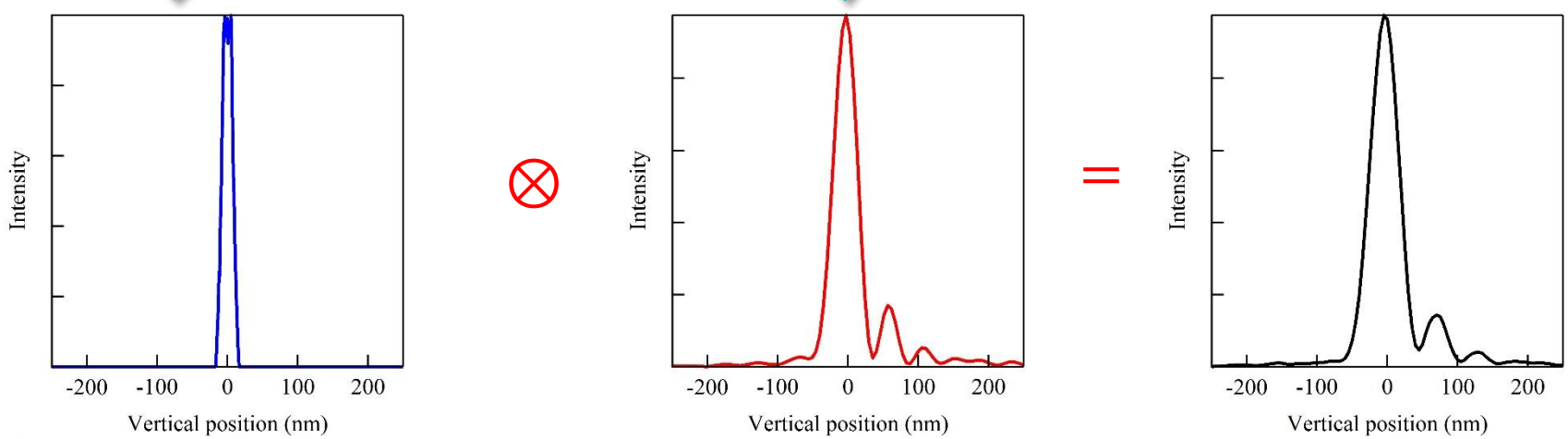


Exit pupil

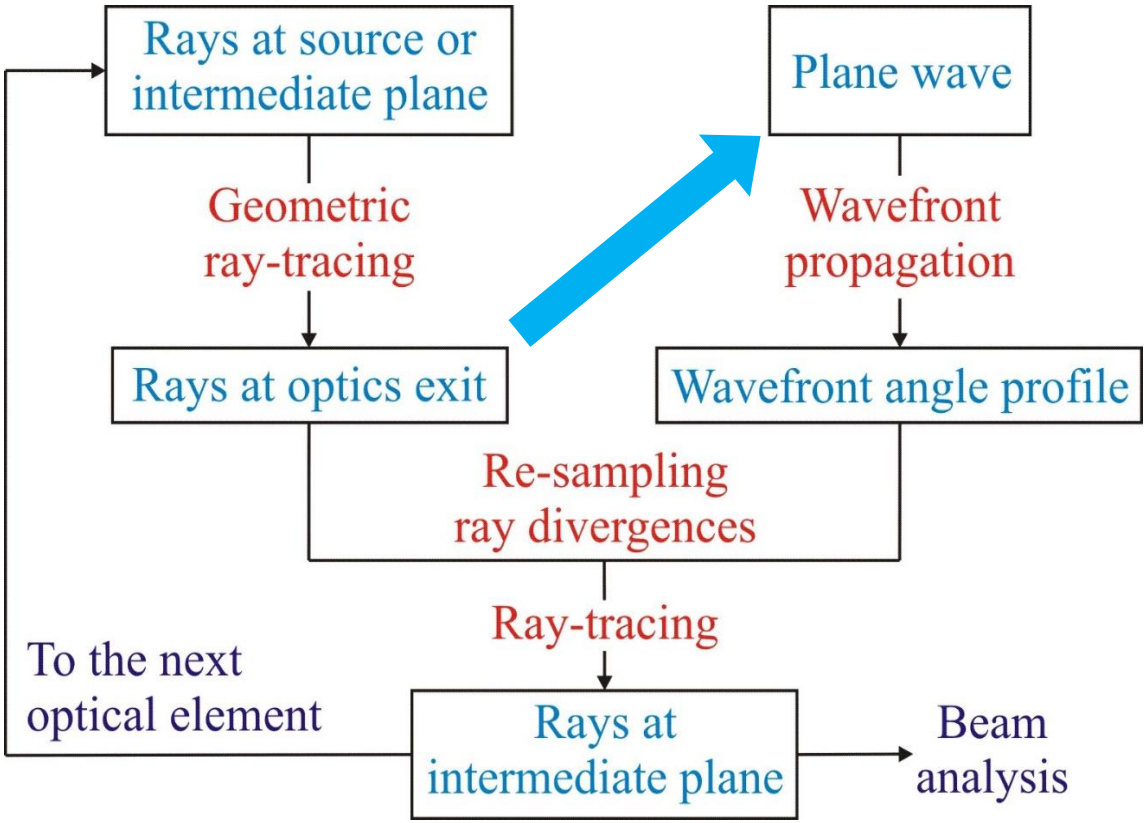
Ray tracing

$$E_{1e}(z_{1e}) \rightarrow \boxed{\text{FFT}} \xrightarrow{\mathcal{F}(v_{1e})} \boxed{\times \exp[-i\pi\lambda D v_{1e}^2]} \xrightarrow{\mathcal{F}'(v_2)} \boxed{\text{Inverse FFT}} \rightarrow E_2(z_2)$$

Ideal optics



HYBRID: Far-field – entire beamline



- ✓ Diffraction effects when beam is clipped
- ✓ Simulate mirror figure errors as wave optics
- ✓ Partial coherent source

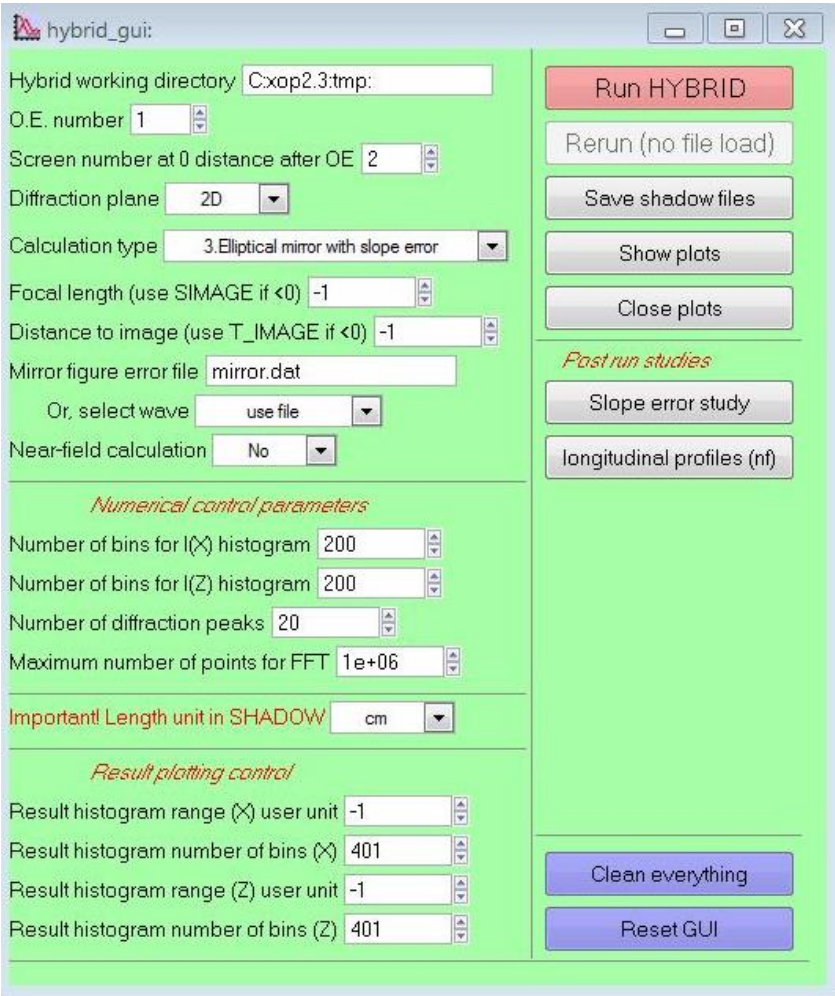
X. Shi, et al., J. Synchrotron Rad. **21**, 669 (2014).

HYBRID: Distribution

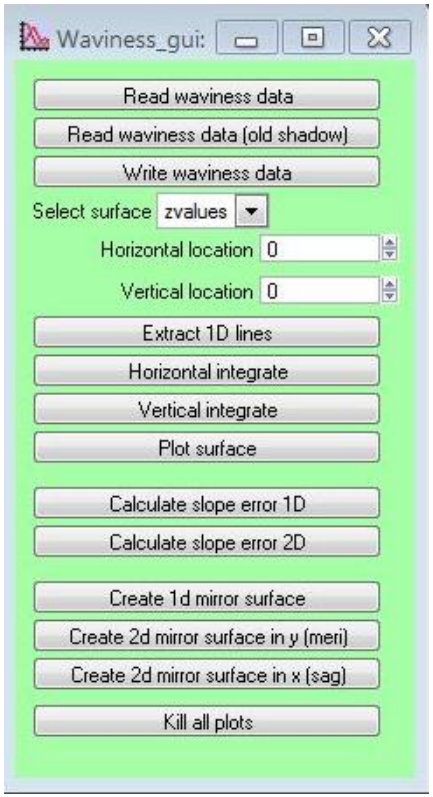
- Igor pro version (master version, developing)

SHADOW

HYBRID

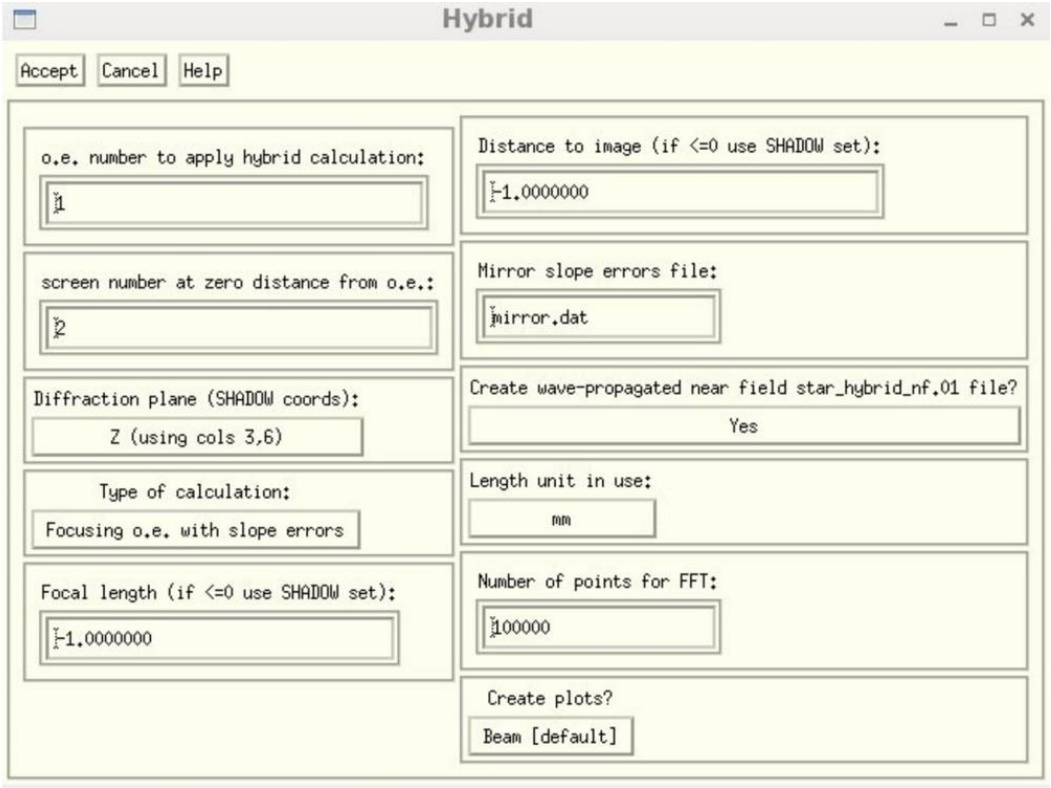


WAVINESS



HYBRID: Distribution

- SHADOWVUI version for general users
  - IDL macro can be applied to individual optics iteratively
  - http://ftp.esrf.eu/scisoft/xop2.3/shadowvui1.12_??_xop2.3.??



SHADOWVUI macro

```
shadow_run, /source
shadow_run, /trace
hybrid, n_oe=1, n_screen=1, calctype=1
shadow_runtrace, previous_oe=1,
        star_file='star_hybrid.01‘
hybrid, n_oe=2, n_screen=1, calctype=0
shadow_runtrace, previous_oe=2,
        star_file='screen_hybrid.0201'
hybrid, n_oe=3, n_screen=2,
        calctype=2, mirrorfile='vkb.dat'
shadow_runtrace, previous_oe=3,
        star_file='star_hybrid.03'
hybrid, n_oe=4, n_screen=2,
        calctype=2, mirrorfile='hkb.dat'
```

X. Shi, M. Sanchez del Rio, R. Reininger, Proc. SPIE, 9209, 920911 (2014).

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Mirror with figure errors

Not diffraction limited

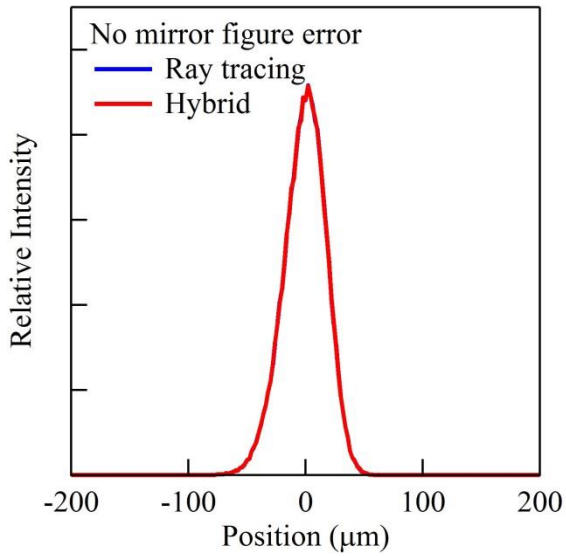
σ = 270 µm

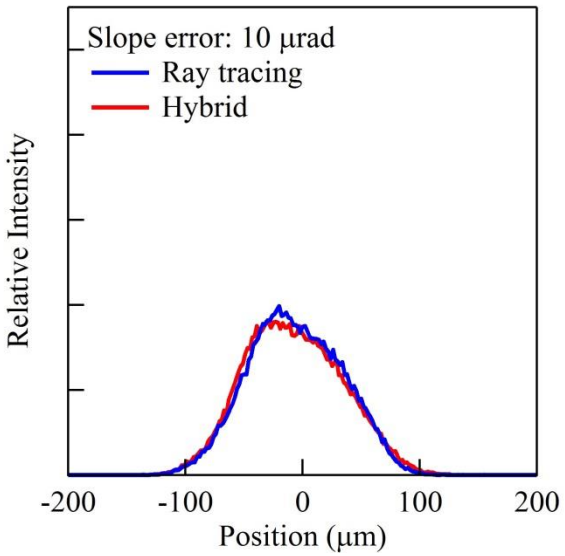
σ' = 12 µrad

p = 30 m

q = 2 m

l = 1 m





Diffraction limited

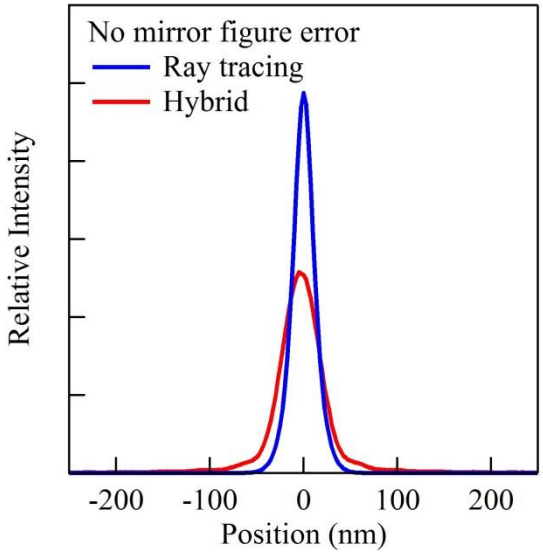
σ = 2 µm

σ' = 30 µrad

p = 30 m

q = 0.2 m

l = 0.2 m



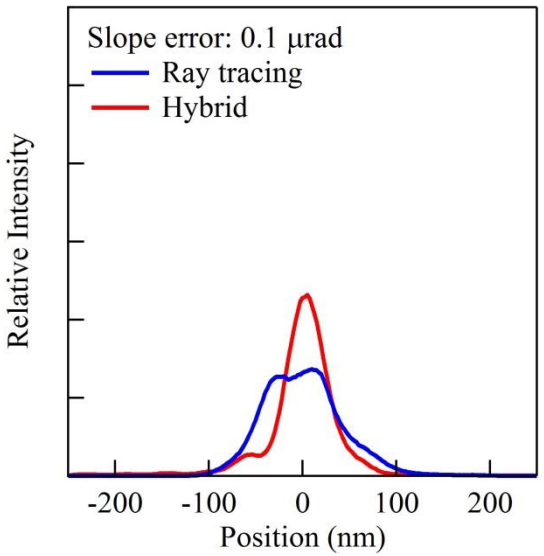
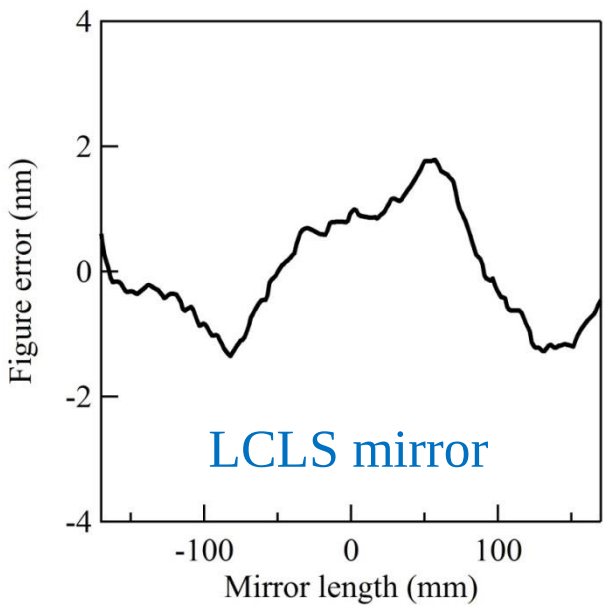
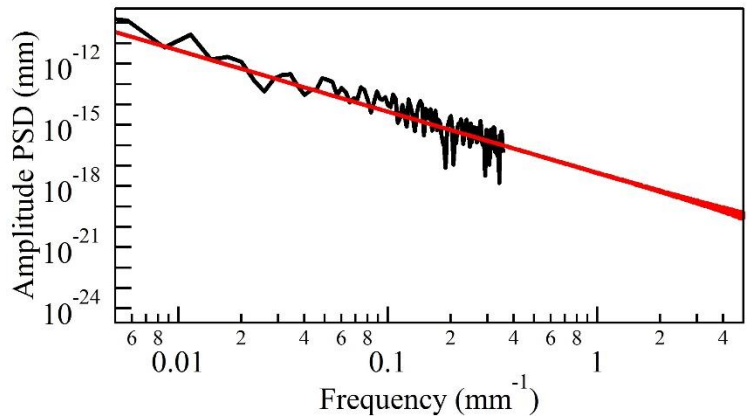
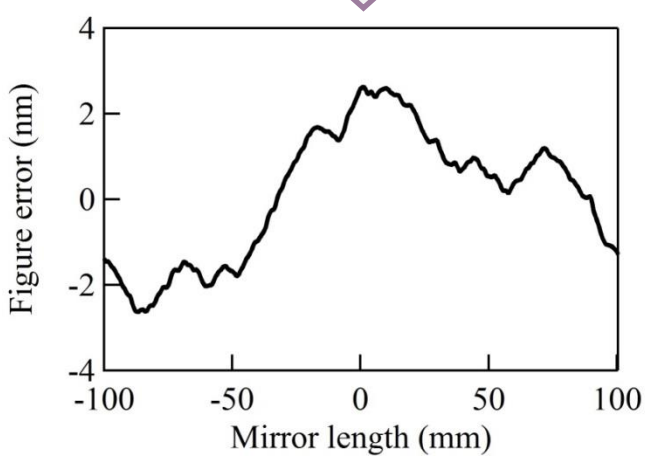


Figure errors - PSD

$$E_{1e}(z_{1e}) = [I_{1e}]^{1/2} \times \exp\left[-ik\left(\frac{z_{1e}^2}{2f_z}\right)\right] \times \exp\{-i2k\Delta h(z_{1e})\, sin[\theta_1(z_{1e})]\}$$







$$\Delta h(l) = \sum_n \Delta h_n(l) = \sum_n b_n \cos\left(\frac{2\pi n}{L} l + \psi_n\right)$$

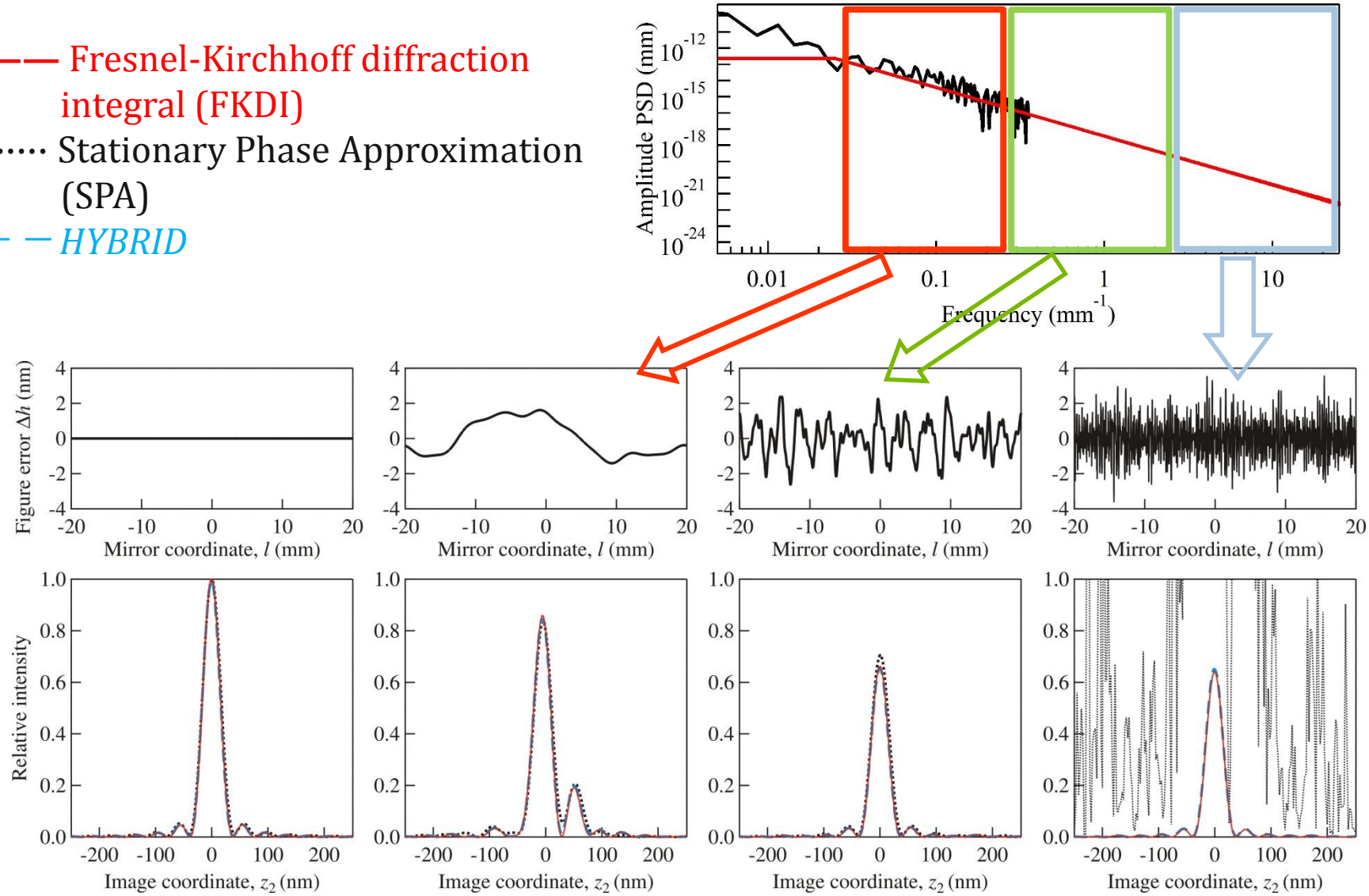
$$b_n = b \times 2.1 \times 10^{-10} \times n^{-1.5}\ \text{mm}$$

Mirror with figure errors

—— Fresnel-Kirchhoff diffraction integral (FKDI)

····· Stationary Phase Approximation (SPA)

— — *HYBRID*



X. Shi, et al., Proc. SPIE **9209**, 920909 (2014).

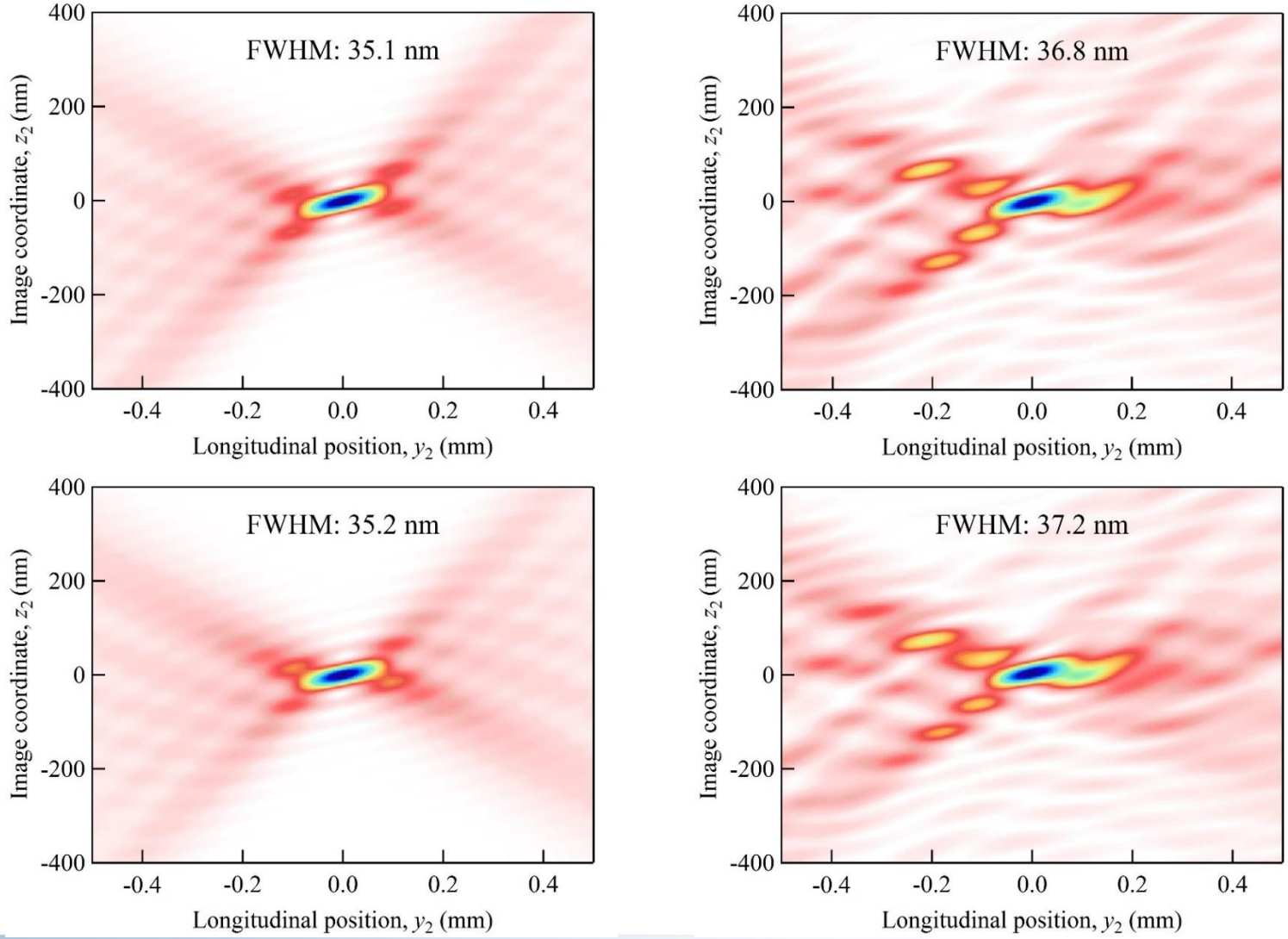
Mirror with figure errors

Ideal mirror

SN-2 mirror

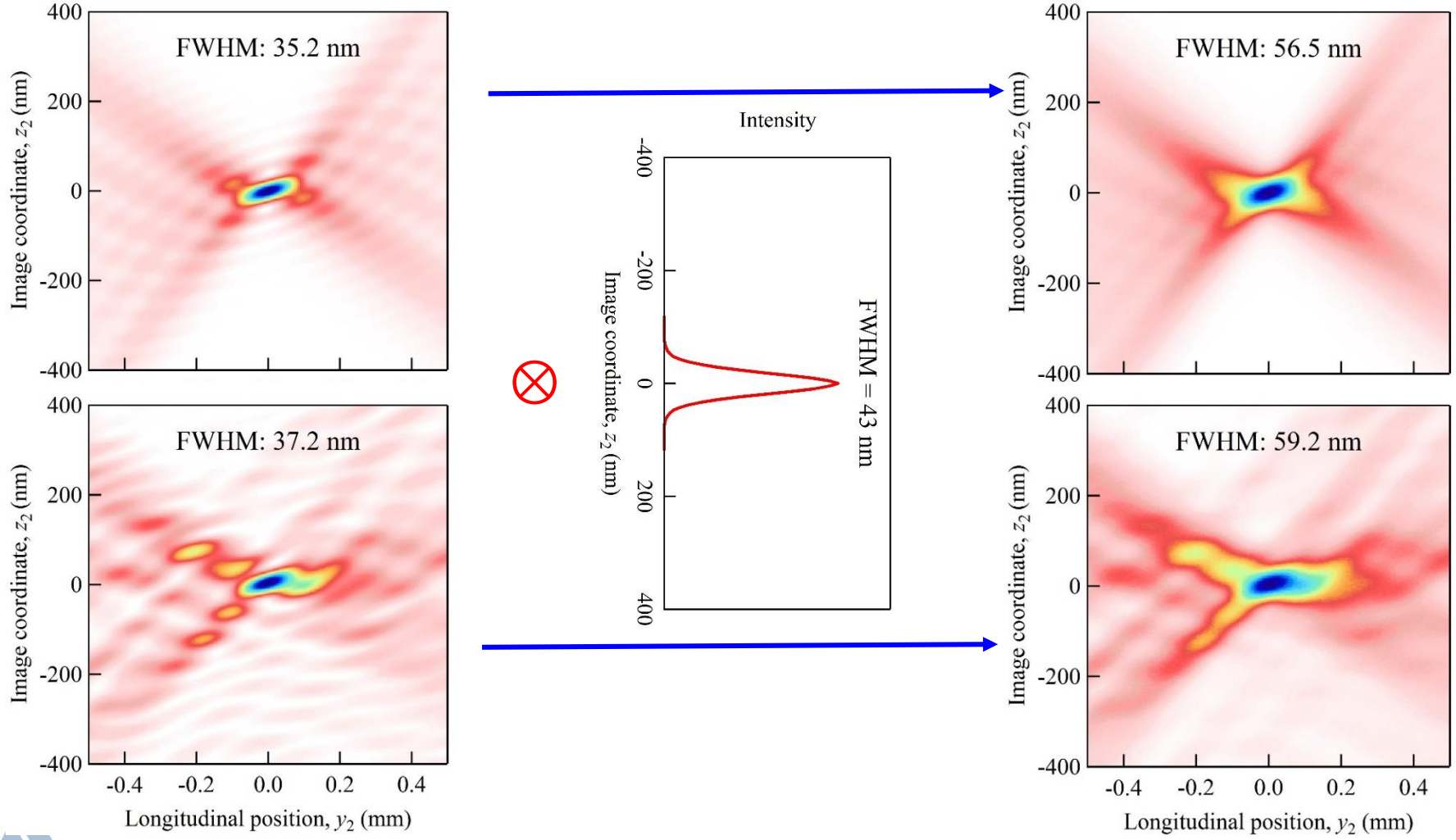
FKDI

HYBRID



Mirror with figure errors

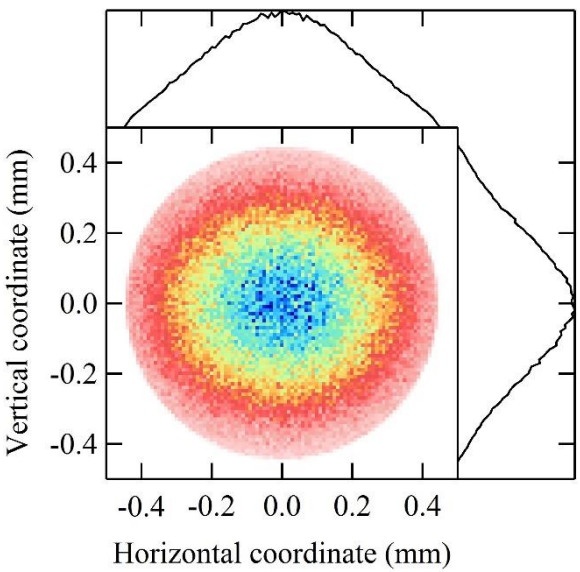
SN-2 mirror illuminated by an extended source which has a Gaussian size of 20 μm (RMS) and divergence of 3 μrad (RMS).



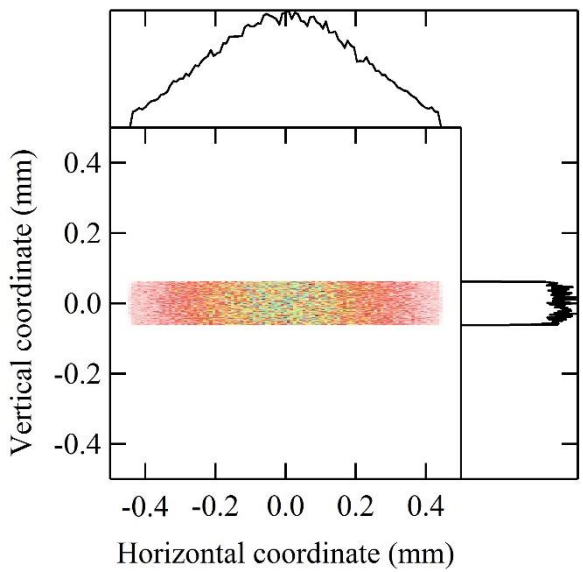
CRLs

- Current APS: E = 7350 eV undulator A, σ_x = 275 μm, σ_y = 12.6 μm
- Be parabolic lenses with R = 0.2 mm and N = 7, at 57 m from source, f = 2.26 m

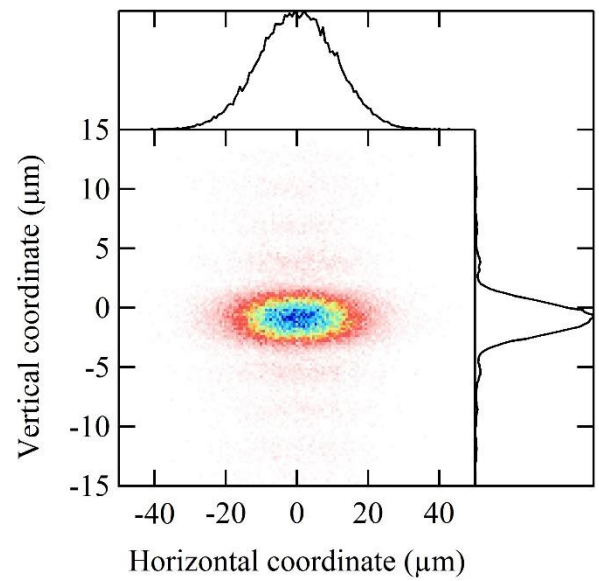
After CRL
without slit



After CRL
with 125 μm slit



Focal size at 2.35 m
FWHM: 25 μm × 3 μm



- CRL was ray traced though individual lenses and the hybrid code was applied once after the CRLs.

ISN beamline: APS-U

- To be published
- Check the following reference for information:
  - X. Shi, et al., J. Synchrotron Rad. **21**, 669 (2014).
  - J. Maser, et al., Metallurgical and Materials Transactions A (2015) accepted.

Summary

- *HYBRID*
  - ✓ Diffraction effects when beam is clipped
  - ✓ Simulate mirror figure errors as wave optics
  - ✓ Partial coherent source
- Recent improvement to *HYBRID*
  - ✓ 2-D simulation
  - ✓ Standalone module for mirror slope error study
  - ✓ Standalone module for simulating longitudinal evolution of the beam profile
- Future planning
  - Implement a more accurate undulator source model (Ryan Lindberg)
  - Evaluate coherence property of the beam (degree of coherence)
- SHADOW+HYBRID+SRW
- Wigner function / cross spectral density propagation (collaboration with Kwang-Je Kim, Ryan Lindberg)

Acknowledgements

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Manuel Sanchez del Rio

BNL

Oleg Chubar

SOLEIL

Cameron Kewish

Thank you!