Optics Modeling and Simulation at APS —Hybrid method combining ray tracing and wavefront propagation

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Advanced Photon Source

MEADOW 2013 workshop

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Outline

- Motivation
- Hybrid method
  - Combining ray tracing and wavefront propagation
  - Including mirror figure error
- Beamline design
  - In Situ Nanoprobe (ISN) beamline at APS
- Summary

Motivation

- New light sources and upgrades with higher brightness, shorter pulse lengths, smaller emittance and partial or full coherence
- New experimental techniques: nano-scale imaging/ diffraction/ spectroscopy, ultrafast/time resolved experiments, coherent diffraction imaging.

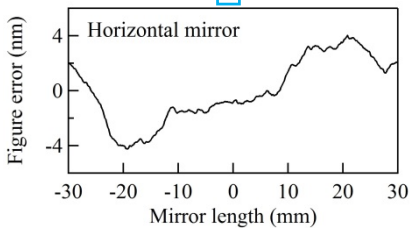
Optics simulation and modeling

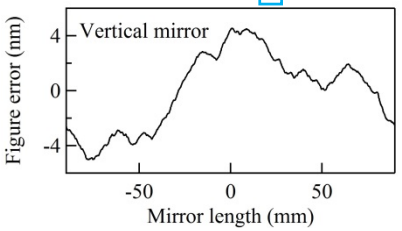
- Geometrical ray tracing, e.g., SHADOW
  - Total intensity, beam size, mirror figure errors, reflectivity
  - Fast, robust, parameter optimization
- Wavefront propagation
  - Fourier optics, e.g., SRW
  - Stationary phase, e.g., PHASE
  - Field amplitude and phase, diffraction effect and beam coherence
  - Partial coherent source: multi-electron simulation

Combining ray tracing and wavefront propagation

$$\text{Plane wave} \times \exp\left[-ik\left(\frac{x^2}{2f_x}+\frac{z^2}{2f_z}\right)\right] \times \exp[-i2k\sin\theta_x \cdot \text{Height}(x)] \times \exp[-i2k\sin\theta_z \cdot \text{Height}(z)]$$

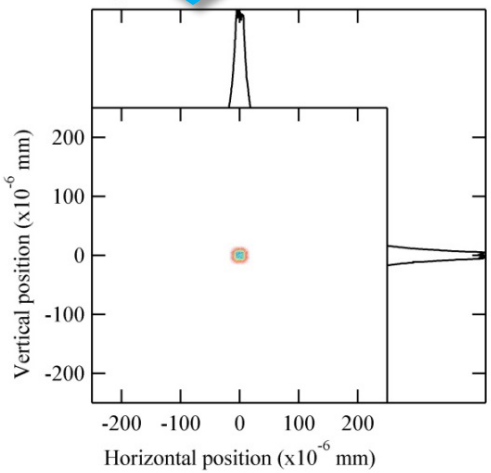
Ideal lens with focal lengths of f_x and f_z





Ray tracing of the beamline

$$E(x,z) \rightarrow \boxed{\text{FFT}} \xrightarrow{\mathcal{F}(u,v)} \boxed{\times \exp\left[-\frac{i2\pi^2}{k}(u^2+v^2)y\right]} \xrightarrow{\mathcal{F}'(u,v)} \boxed{\text{Inverse FFT}} \rightarrow E(x',z')$$



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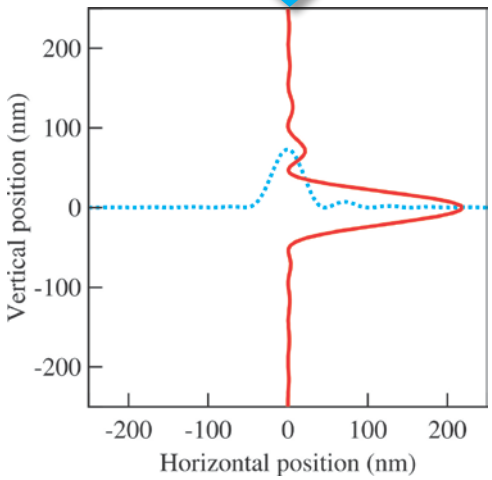

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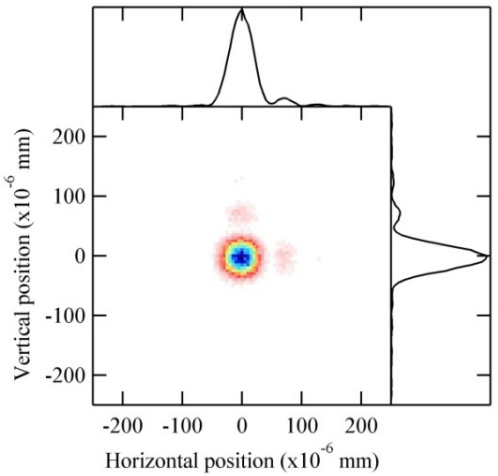
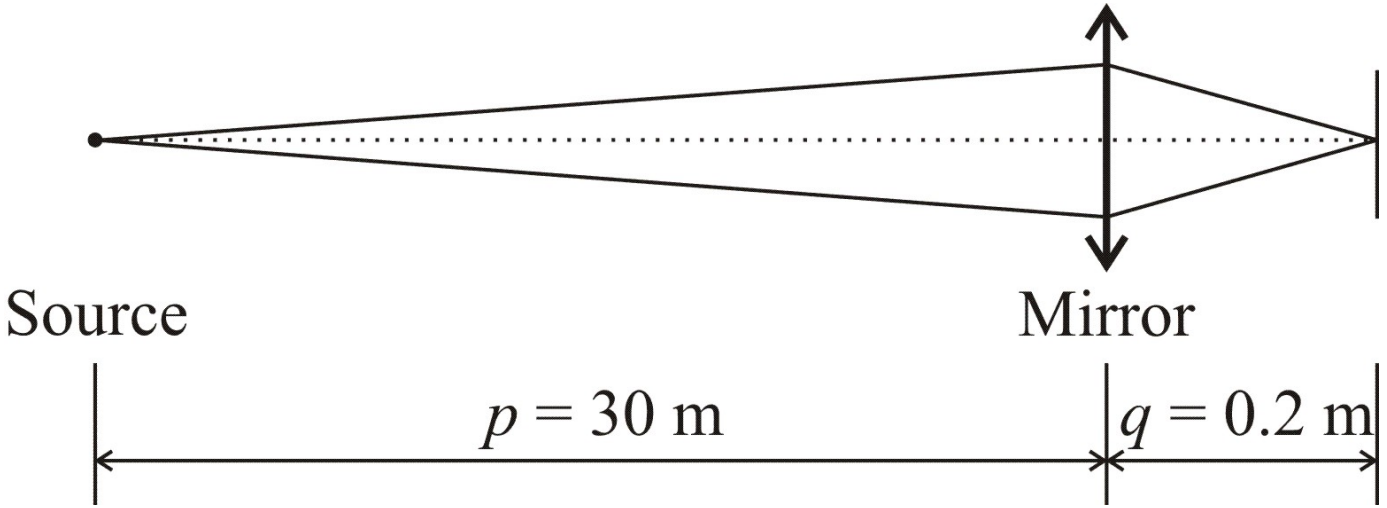


Testing case

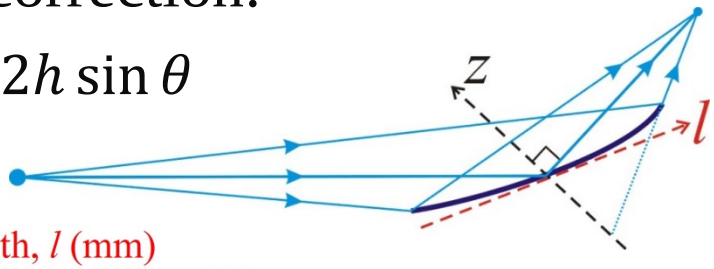


- Source:
  - σ = 2 µm
  - σ’ = 30 µrad
  - E = 10 keV
- Elliptical cylinder mirror
  - Mirror length l = 200 mm
  - Grazing angle at mirror center: θ_0 = 2.5 mrad
  - Demagnification: 150:1

Angle correction and intensity scaling

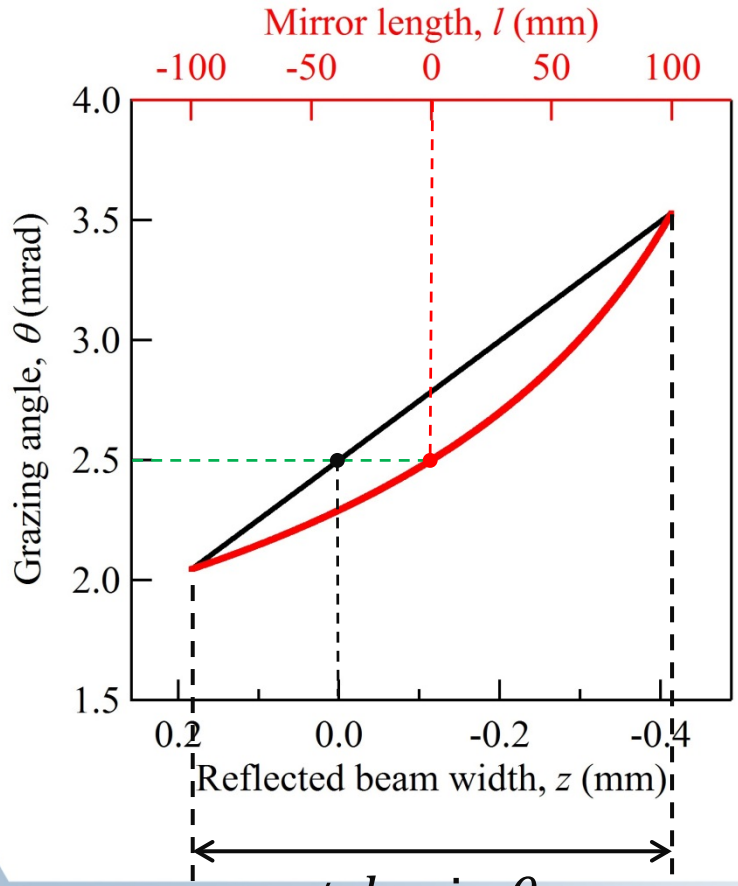
- Grazing angle correction:

$$\Delta\phi = (2\pi/\lambda) \cdot 2h \sin\theta$$

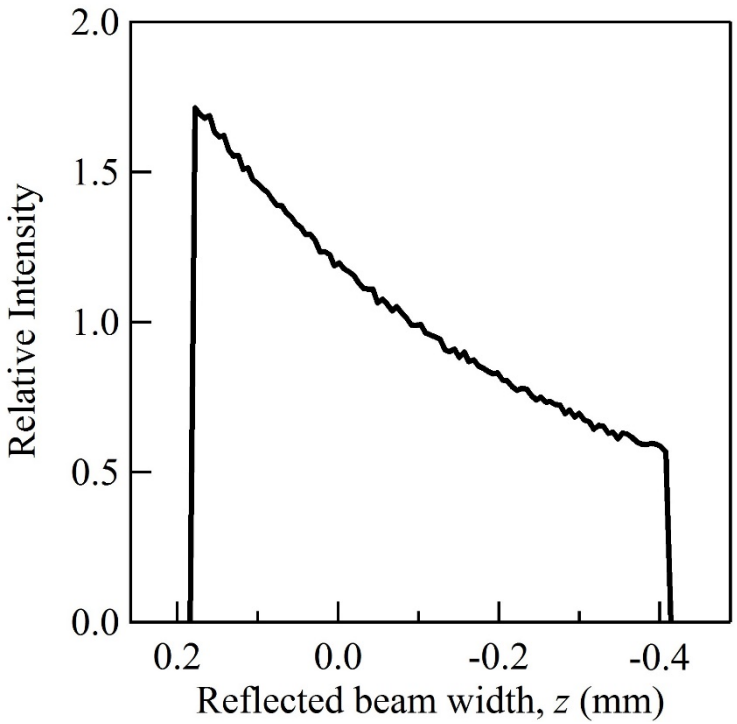


- Intensity scaling

$$E \propto \sqrt{I}$$



$$\neq l \cdot \sin\theta_0$$



Angle correction and intensity scaling: effects on image

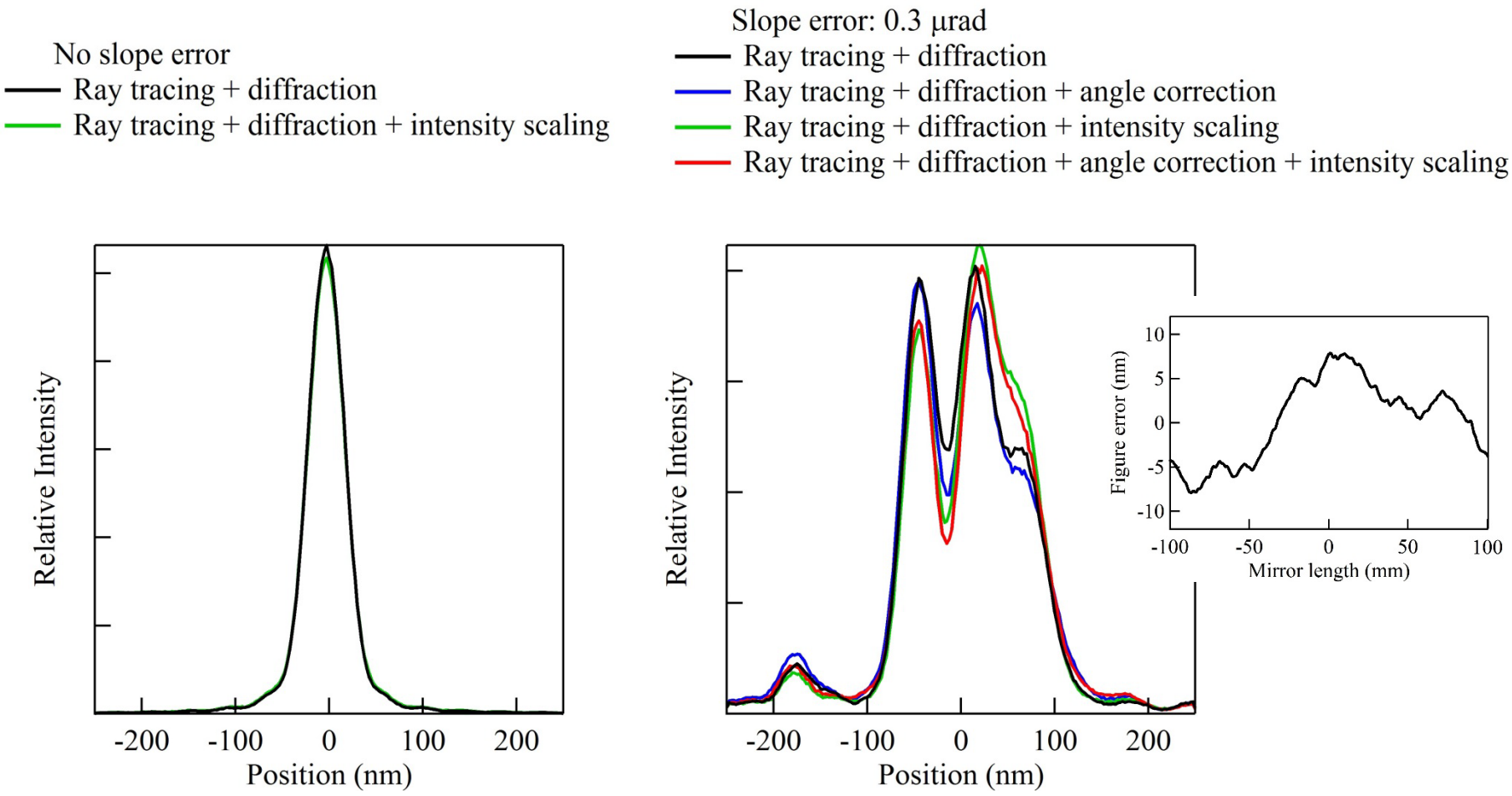
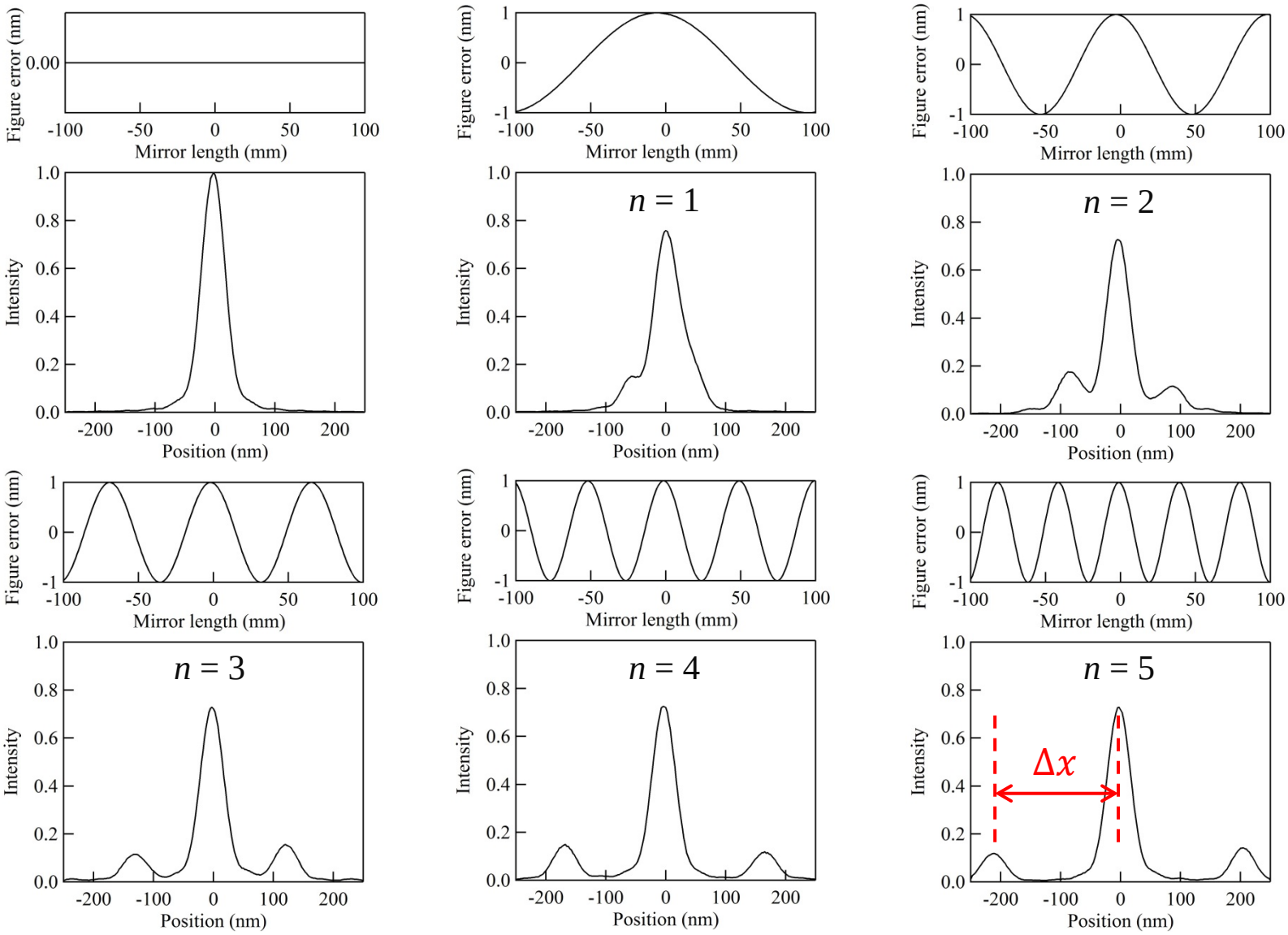
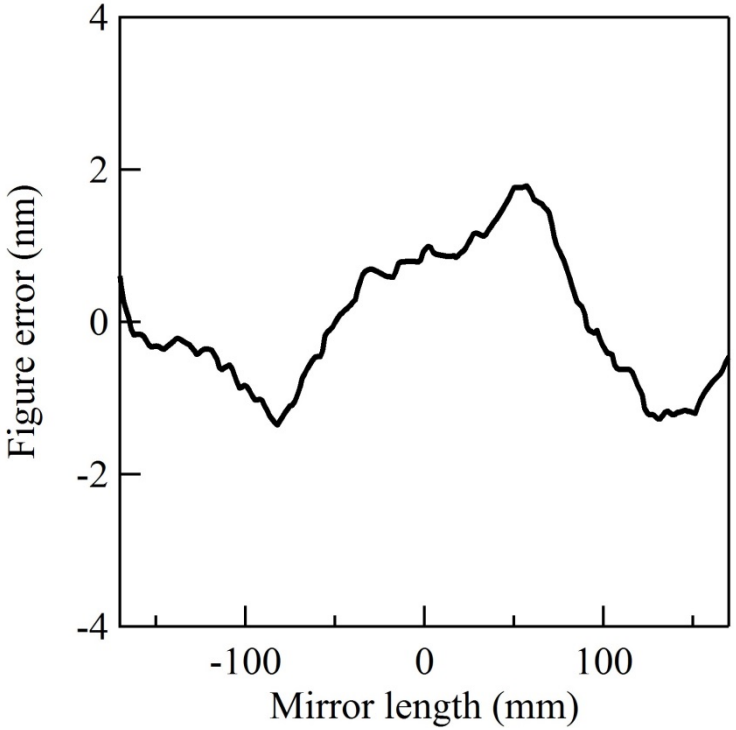


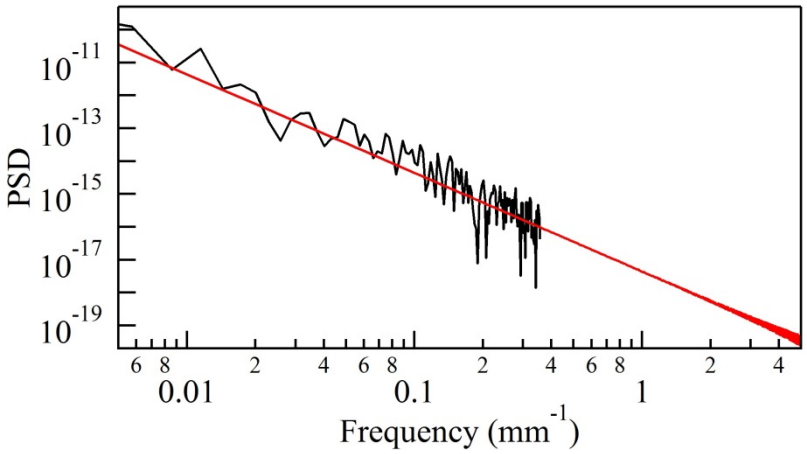
Figure error frequencies – Grating effect

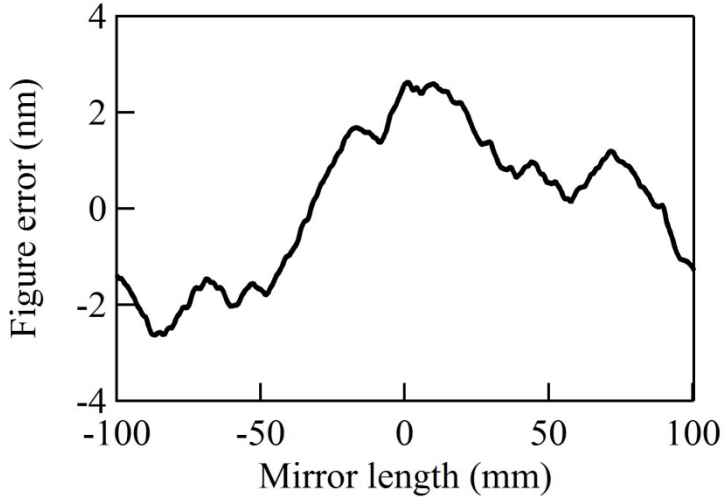


Grating equation: $\Delta x = q\lambda/d\,, d = l\sin\theta/n$

Figure error frequencies - PSD

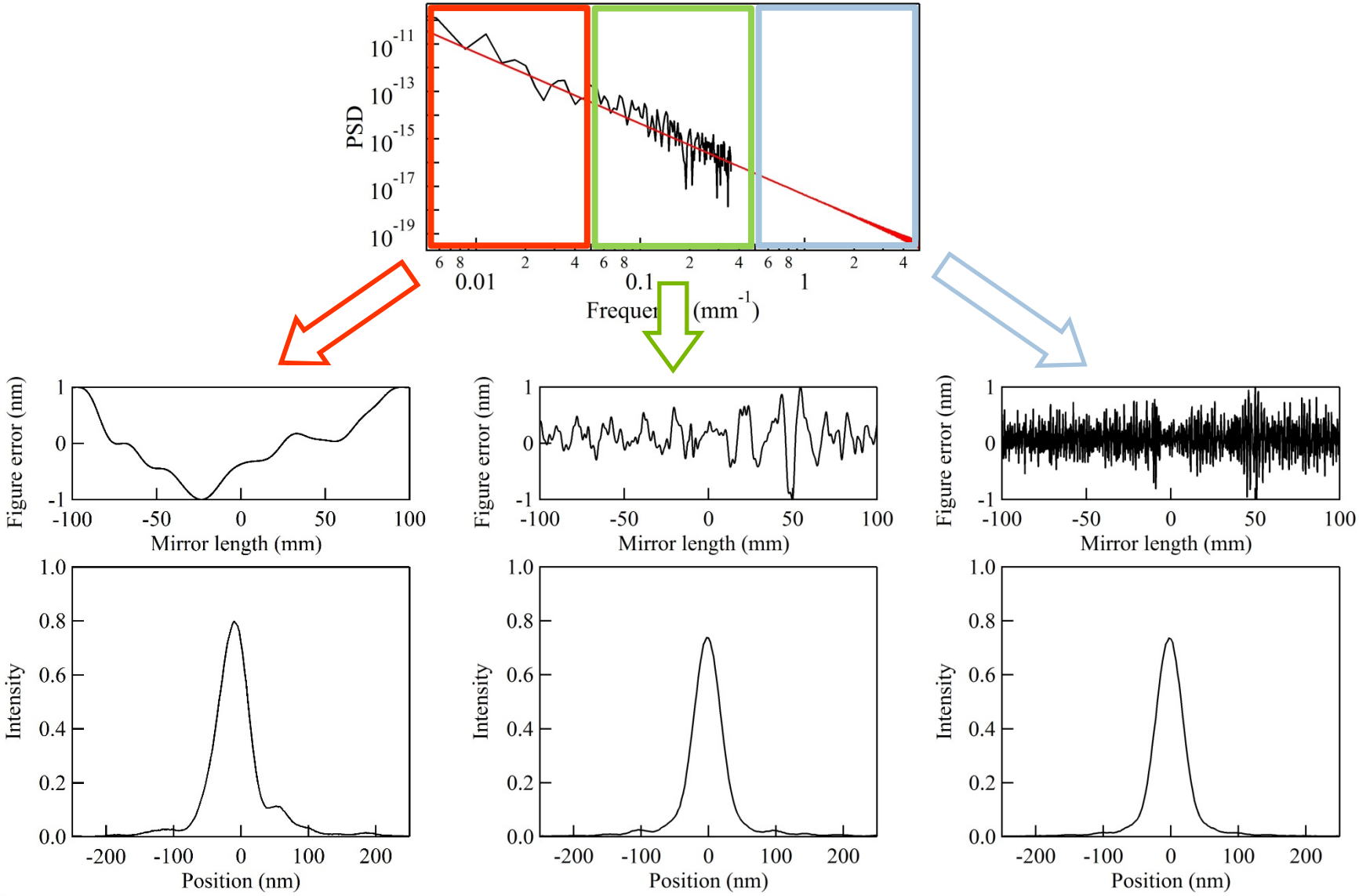






LCLS mirror

Figure error frequencies - PSD



Comparison with pure ray tracing

Diffraction limited

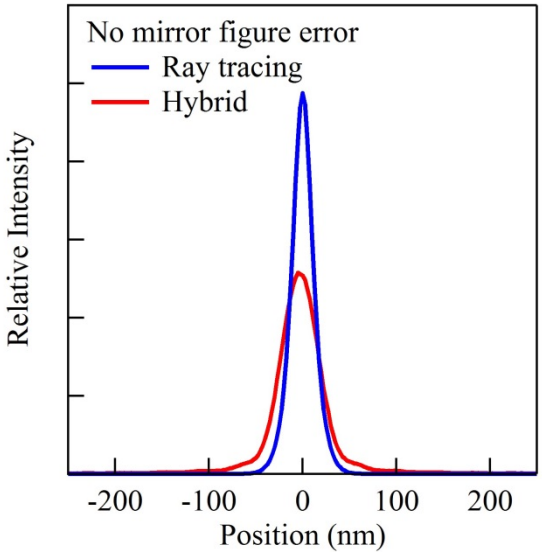
σ = 2 µm

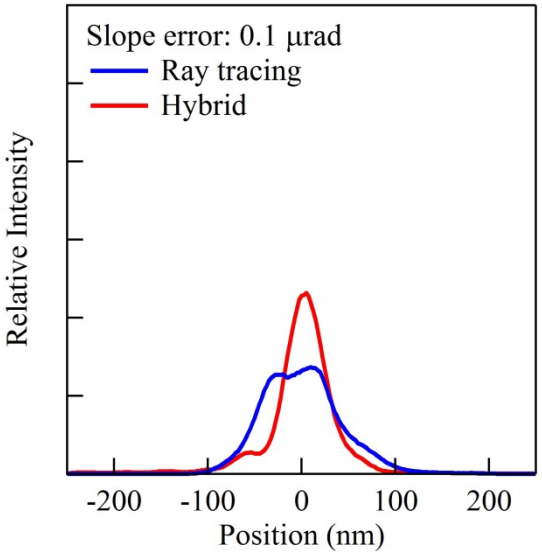
σ' = 30 µrad

p = 30 m

q = 0.2 m

l = 0.2 m





Not diffraction limited

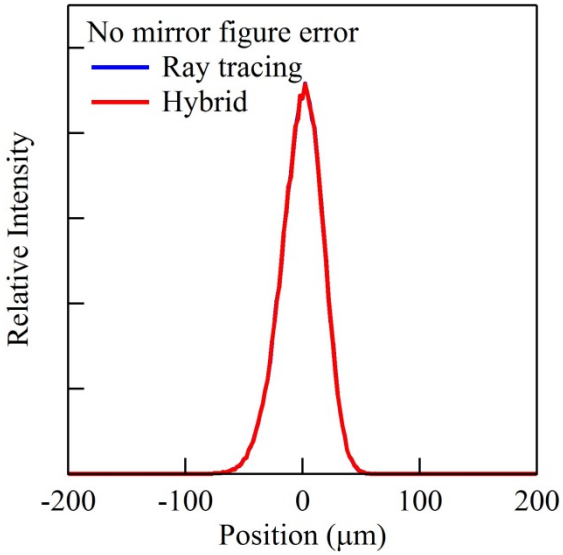
σ = 270 µm

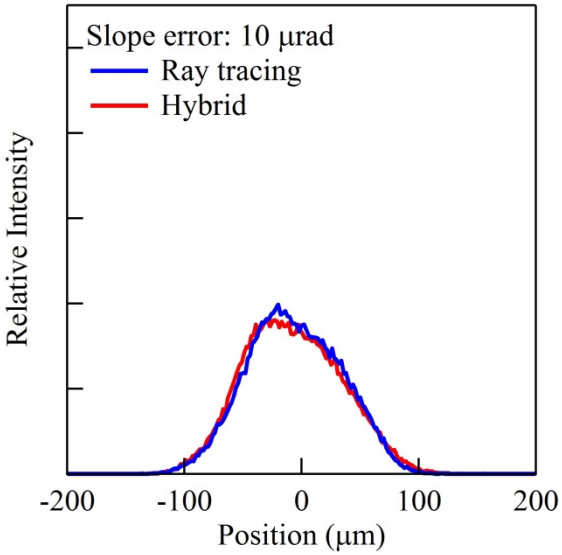
σ' = 12 µrad

p = 30 m

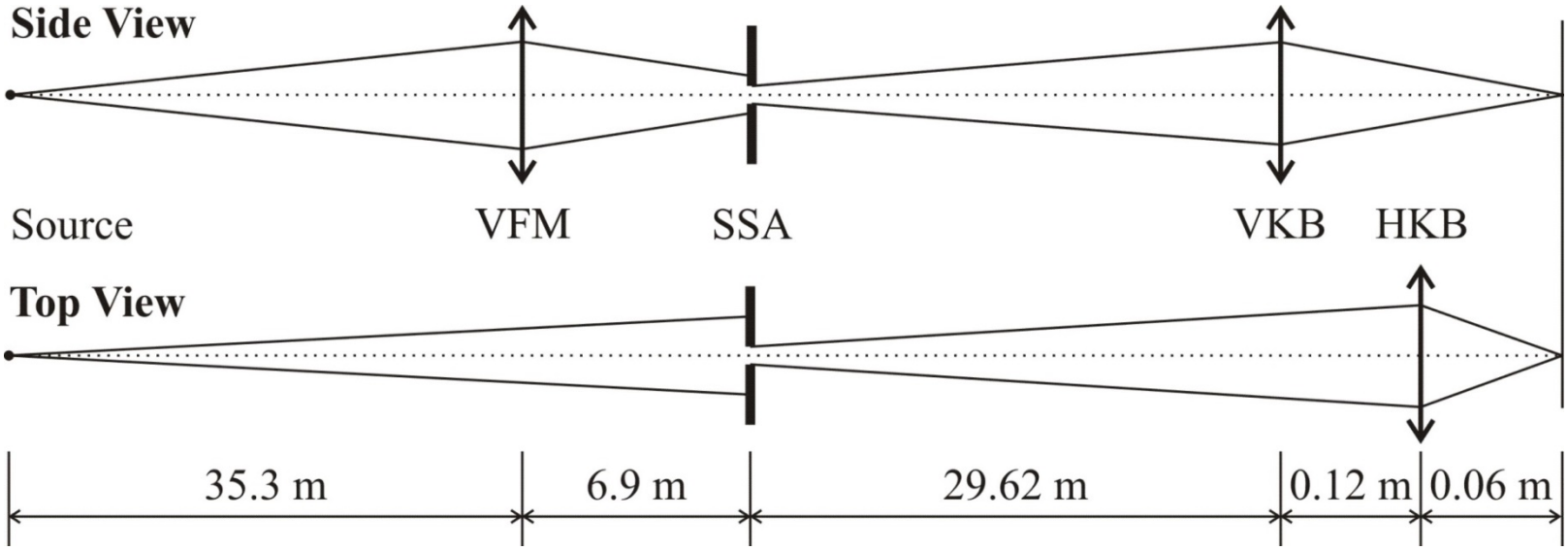
q = 2 m

l = 1 m





In Situ Nanoprobe beamline



Photon (10 keV)	Electron	Total
σ_r = 3.86 μm	σ_x = 274.3 μm	σ_x = 274.3 μm
	σ_y = 10.3 μm	σ_y = 11.0 μm
σ_ξ = 5.11 μrad	σ'_x = 11.27 μrad	σ'_x = 12.4 μrad
	σ'_y = 3.58 μrad	σ'_y = 6.24 μrad

Source: undulator A, 3.3 cm, 72 periods, K = 0.906, B = 0.294 T

VFM: 400 mm long, 2.5 mrad grazing angle

SSA: 11 × 4 μm^2 (h × v)

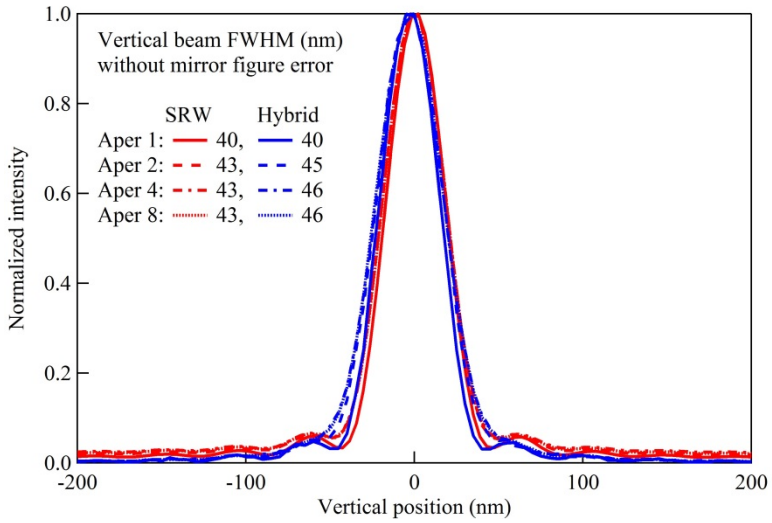
VKB: 180 mm long, 2.5 mrad grazing angle

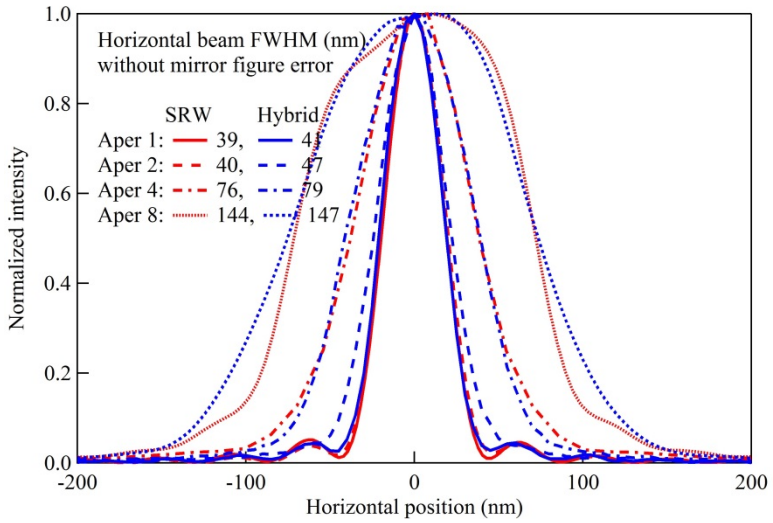
HKB: 60 mm long, 2.5 mrad grazing angle

Comparison with SRW (multi-electron)

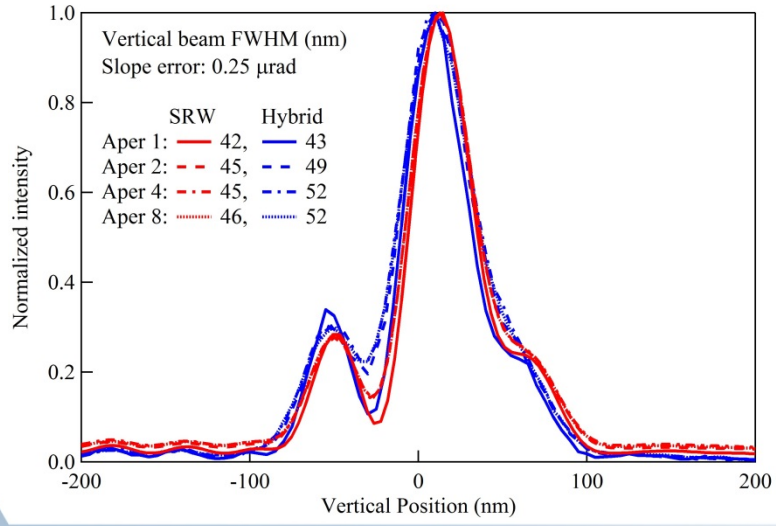
Calculation time: SRW: 32 core × 5 hours
Hybrid: 1 core × 5 minutes

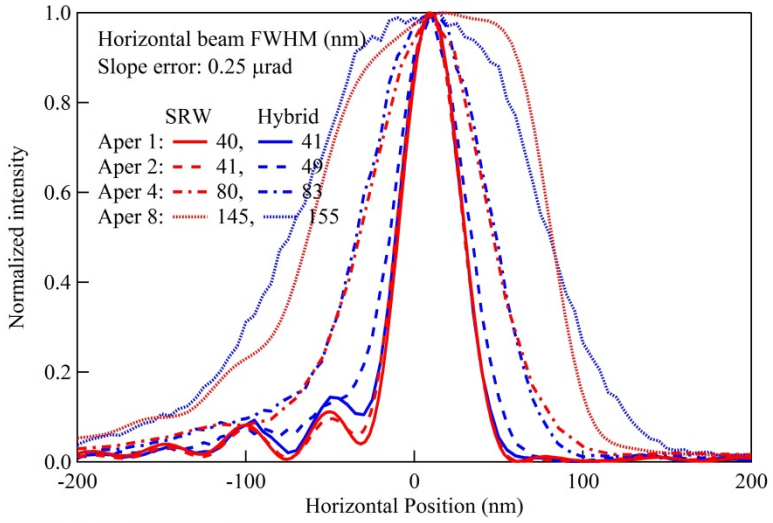
Without figure error



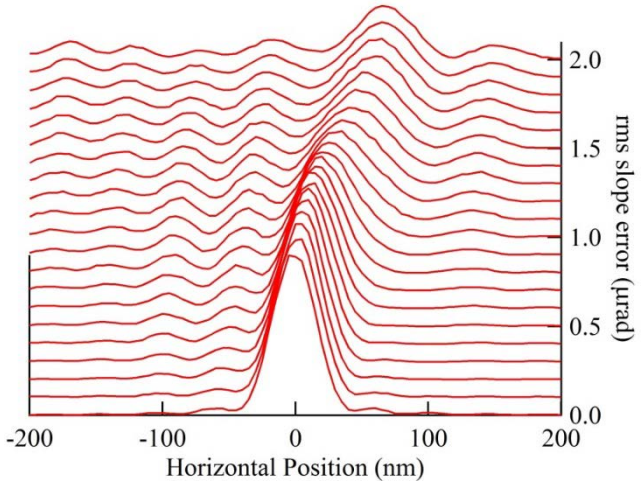


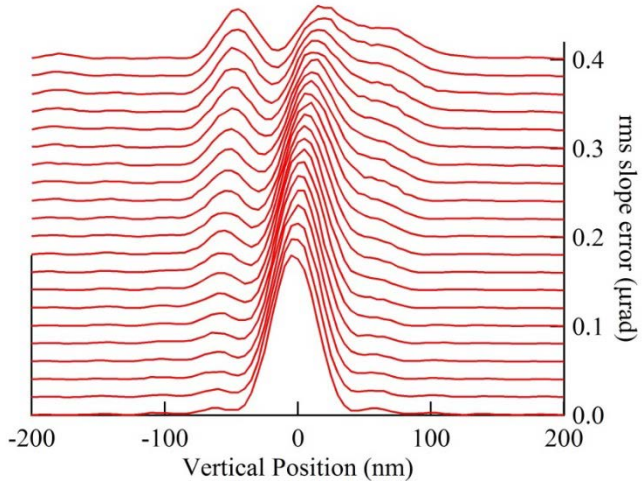
With figure error

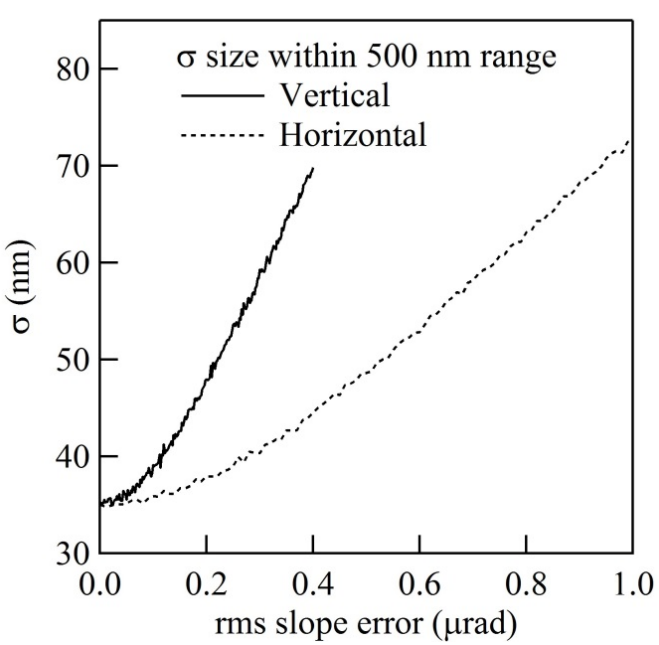


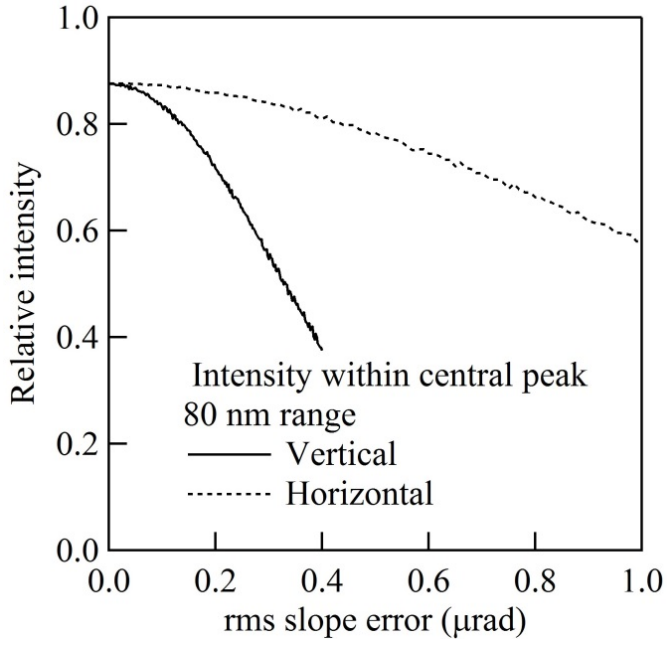


KB mirror slope error studies

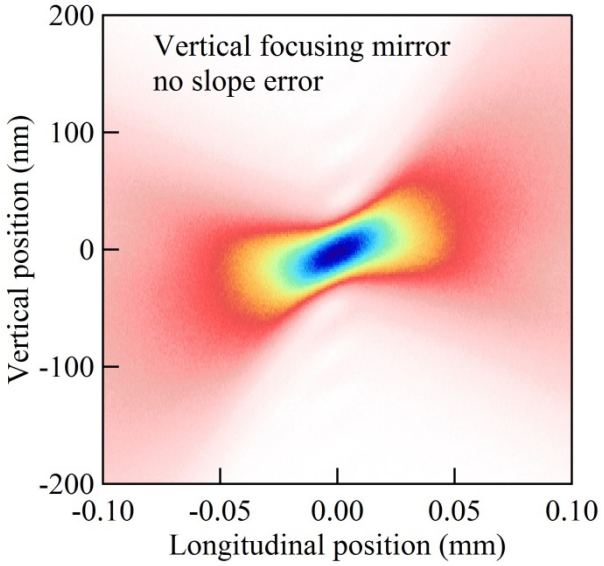


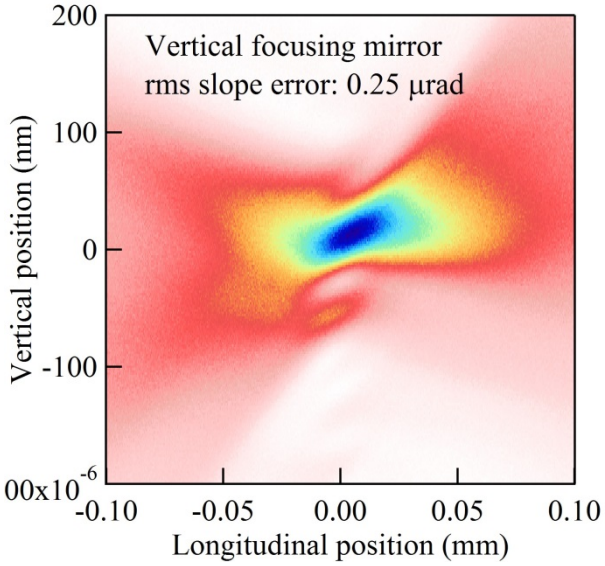


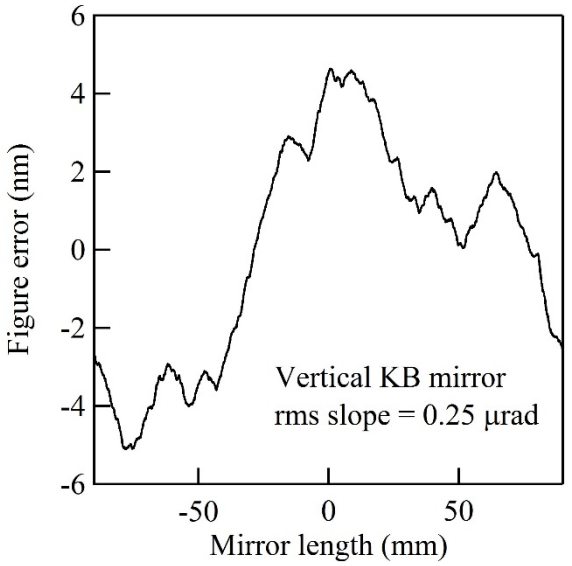


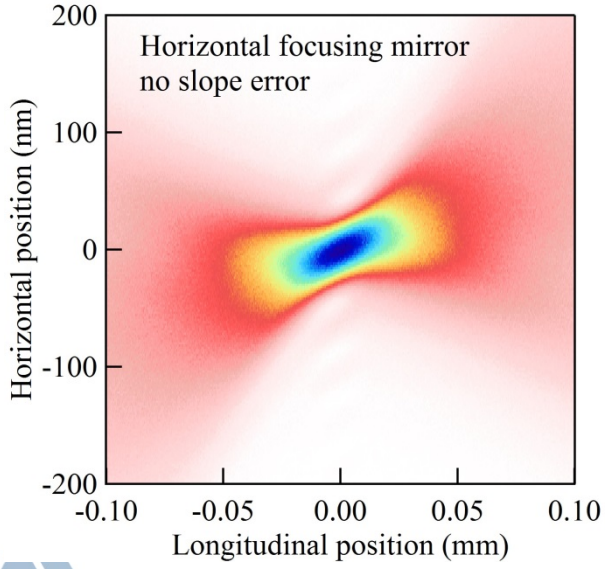


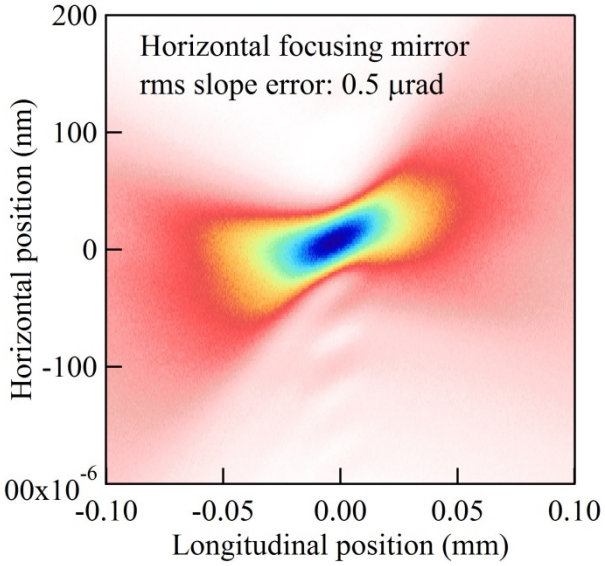
Beam profiles along longitudinal direction

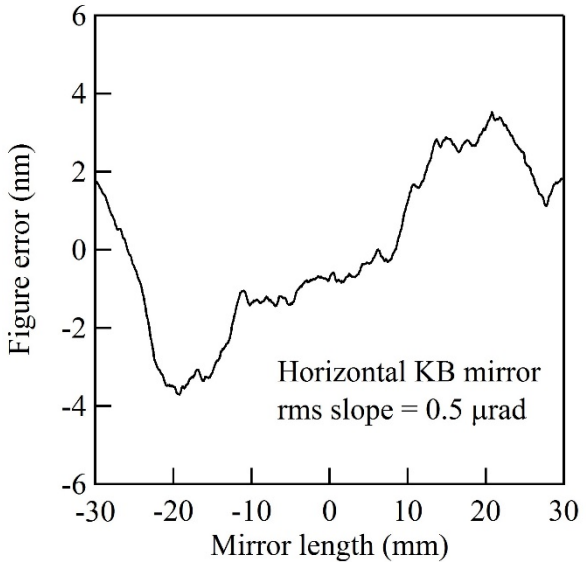












Summary

- ✓ The hybrid method combining ray tracing and wavefront propagation is demonstrated and compared with existing codes. It will be implemented in SHADOW.
- ✓ The effects of mirror figure error are studied. A bank of real metrology data will greatly benefit the community.
- Full 2-D simulation is needed for certain cases (toroid mirror).
- Coherence properties are the next focus.

Acknowledgements

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