A Virtual Young’s Double Slit Experiment

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What we are going to explain in this talk
A method to measure the effective source size for hard x-rays

Given a source of size $a$, emitting light of wavelength $\lambda$ at a distance $L$ away the transverse coherence length is $\xi \approx (\lambda L)/a$

1) Simple to use
2) The prisms introduce very little phase error;
3) Can be calculated from first principles
4) Is portable (can be replicated around the world as needed)
5) Fabrication errors can be compensated for by modeling
What is coherence; why do we care?

If we represent a photon wavepacket by disks of constant phase then graphically, crudely:

Transverse Coherence, $\xi$

Direction of beam propagation

Longitudinal coherence

You can focus to smaller spot sizes if the transverse coherence length is bigger
The classic Young’s double slit experiment

The screen at distance $L$ from the slits is in the far field.

If the spacing between the pinholes is smaller than the transverse coherence length we get fringes.
Everything works well in the soft x-ray region
Slits can be defined, just like optical

Mcnulty et. al, @1.5 kev
Why is a hard x-ray pinhole difficult

- Hard x-rays require $L$ to be big
- You can get waveguide effects when diffraction causes the slit to interact with itself.
- $a^2/\lambda < L$
Hard x-ray double pinhole experiment is difficult but possible


The experiment

BESSY bending magnet

Slit

Ta foil with pinholes

Detector pinhole

Energy dispersive detector

Distance in μm

Fringes due to interference between pinholes

Fringes dominated by interference between individual pinhole and transmission through film

Another approach:
Some Real Biprisms

Refractive index for hard x-rays is less than one: \( n = 1 - \delta + i\beta \), with \( \delta \sim 4 \times 10^{-6} \)

Which direction does the prism deflect?

\[ \theta_T \approx \delta \tan \theta_p \]
Some Real Silicon Biprisms

To help you see the different biprisms

25°  45°  55°  65°
Prisms are a lot simpler than kinoforms
A Virtual Youngs double slit experiment
Function of angle

Scanning Electron microscope image of biprism

Visual image of fringes on YAG crystal (Qualitative)

Fluorescence counts from fringes (Quantitative)

Distance from prism 1.03m

E = 7.35keV

Note non-monotonic fringe intensities
Quality of beamline is important; we could deflect the light at NSLS but did not see fringes.

Function of distance away from biprism

Lines through data points are fits to a function to be described in a few slides
No fits here, just data to show the trends as a function of photon energy $E$. As $E$ increases, the overlap region decreases, and the fringe period grows.
A Virtual Youngs double slit experiment

- Biprism is always in the near field
- Countable number of fringes
  \[ N = \frac{\delta}{4\pi \beta} \]
The analysis: Fresnel Kirchhoff

One makes the usual approximation of a “thin” optic (Goodman):

\[
U(x,z) = \frac{1}{i\lambda} \int T(\eta) \left( \frac{\exp(ikr_{01})}{r_{01}} \right) d\eta
\]

where \( k = \frac{2\pi}{\lambda} \) and \( r_{01} = \sqrt{z^2 + (x-\eta)^2} \)

We model the prisms with a transmission function with phase shift and amplitude given by:

\[
T(\eta) = \exp\left( -\frac{2\pi \beta \text{t}(\eta)}{\lambda} \right) \exp\left( i \frac{2\pi \delta \text{t}(\eta)}{\lambda} \right),
\]

where \( \text{t}(\eta) = \text{abs}(\eta)\tan(\theta_p) \) represents the thickness of the prism,
\( \eta \) is the distance from the optical axis.

Also we add a source with a Gaussian distribution.
If you coherently illuminate one prism
And then coherently illuminate the other prism
When you coherently illuminate both prisms together you get a product function

This function is the product of the left (red) prism and right (blue) prism and this function modulates the fringe intensities that we observe
And so now we can understand why the fringes have non-monotonic intensity variations.
Vertical and Horizontal Coherence lengths at APS 8-ID

Vertical fit: 10+/−5 microns

Horizontal fit: 130+/−20 microns
Now for some context
X-Ray Nanointerferometer Based on Si Refractive Bilenses

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We report a novel type of x-ray interferometer employing a bilens system consisting of two parallel compound refractive lenses, each of which creates a diffraction limited beam under coherent illumination. By closely overlapping such coherent beams, an interference field with a fringe spacing ranging from tens of nanometers to tens of micrometers is produced. In an experiment performed with 12 keV x rays, submicron fringes were observed by scanning and moiré imaging of the test grid. The far field interference pattern was used to characterize the x-ray coherence. Our technique opens up new opportunities for studying natural and man-made nanoscale materials.

![Diagram of x-ray bilens interferometer](image)
Lang et. Al. demonstrated fringes

Two-Beam X-Ray Interferometer Using Prism Optics

Yoshio SUZUKI

SPRING-8, MIKAZUKI, HYOGO 679-5198, JAPAN

Fig. 1. Schematic diagram of two-beam interferometer with X-ray prism.
Shearing Interferometer for Quantifying the Coherence of Hard X-Ray Beams

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We suggest we have a robust interferometer for hard x-rays

1) Simple to use
2) The prisms introduce very little phase error;
3) Can be calculated from first principles
4) Is portable (can be replicated around the world as needed)
5) Fabrication errors can be compensated for by modeling
6) Can be designed to match different energies
Function of angle

- Scanning Electron microscope image of biprism
- Visual image of fringes on YAG crystal (Qualitative)
- Fluorescence counts from fringes (Quantitative)

Distance from prism 1.03m
E = 7.35keV

Note non-monotonic fringe intensities

$\theta_p = 45^\circ$
$\theta_p = 55^\circ$
$\theta_p = 65^\circ$

XRF Intensity (counts)

- $x (\mu m)$

$\lambda/2\theta_T$