NSLS

NATIONAL SYNCHROTRON LIGHT SOURCE

A Virtual Young's Double Slit Experiment

Abdel Isakovic*
Kenneth Evans-Lutterodt
Aaron Stein
BNL,NSLS,NSLS2
Alec Sandy
Suresh Nararayanan
Michael Sprung
APS
James Ablett
SOLEIL
CNF
*Now at Khalifa University of Science, Technology & Research (KUSTAR)

Isakovic, A. F.; Stein, A.; Warren, J. B.; Sandy, A. R.; Narayanan, S.; Sprung, M.; Ablett, J. M.; Siddons, D. P.; Metzler, M.; Evans-Lutterodt, K.. ***J. Synchr. Rad. 2010, 17, 451.***

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BROOKHAVEN NATIONAL LABORATORY

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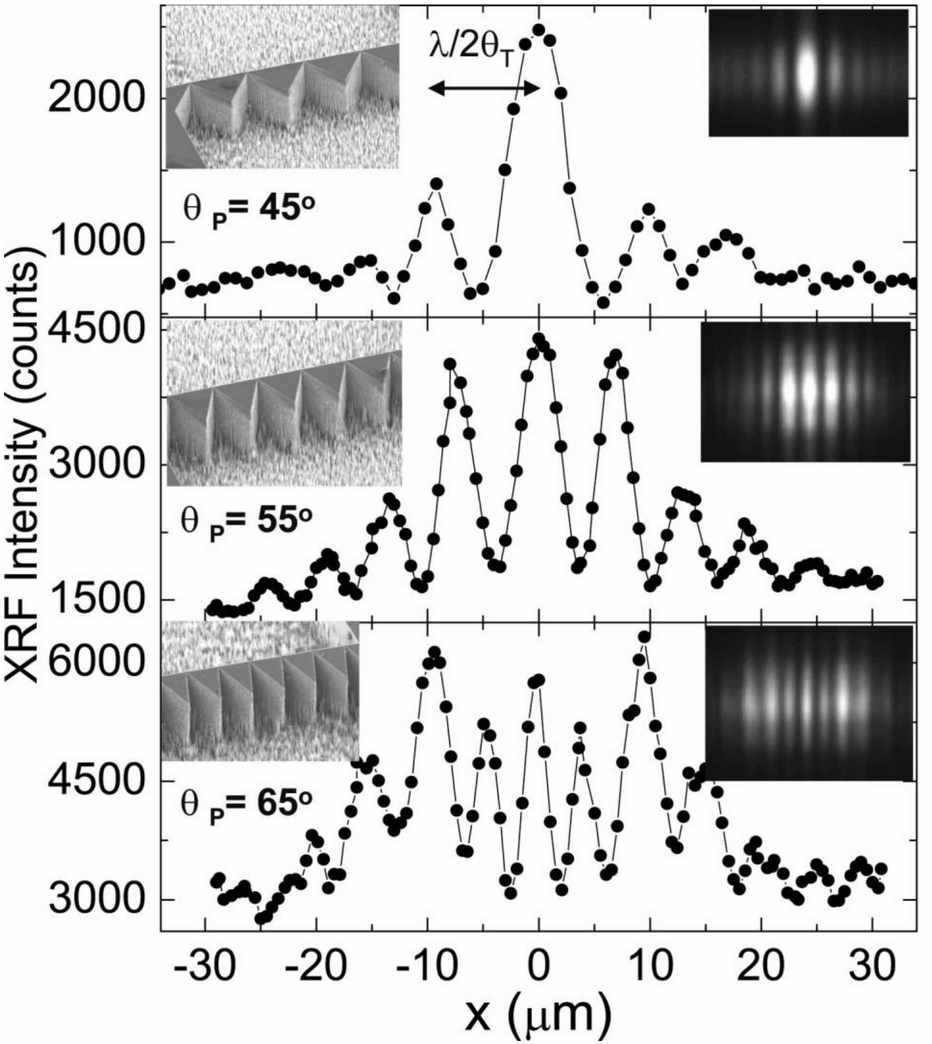
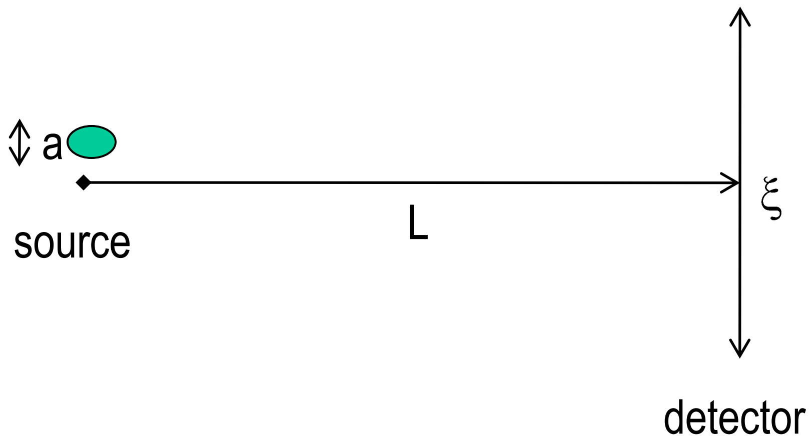
What we are going to explain in this talk



A method to measure the effective source size for hard x-rays

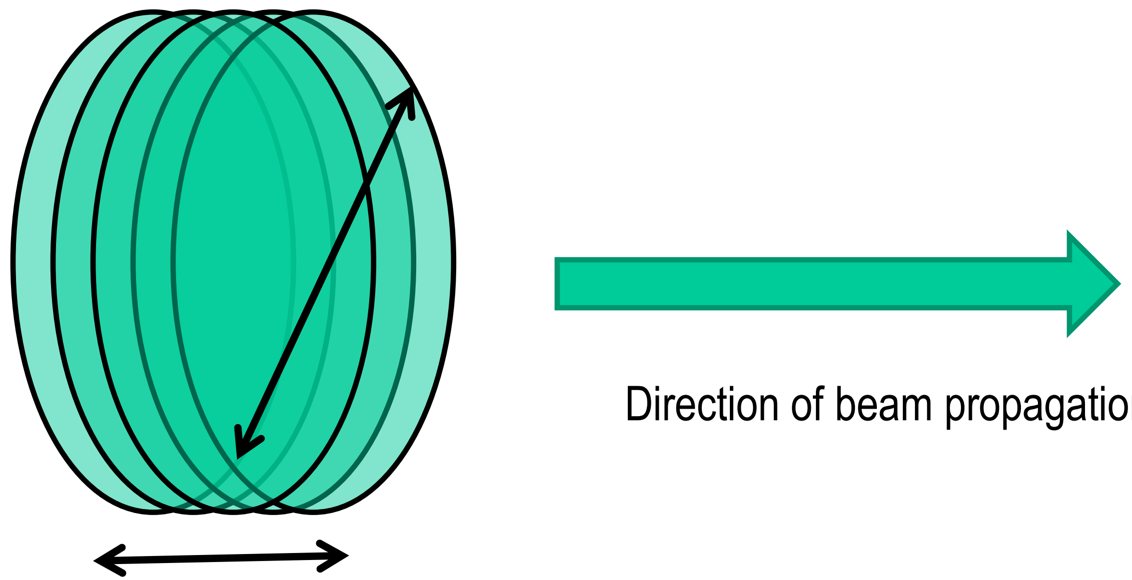
Given a source of size a, emitting light of wavelength λ at a distance L away the transverse coherence length is $\xi \approx (\lambda L)/a$



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

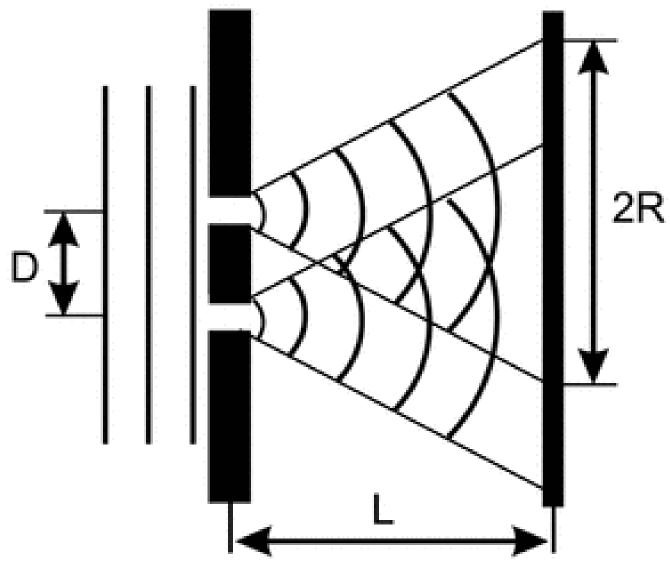
What is coherence; why do we care ?

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



You can focus to smaller spot sizes if the transverse coherence length is bigger

The classic Young's double slit experiment

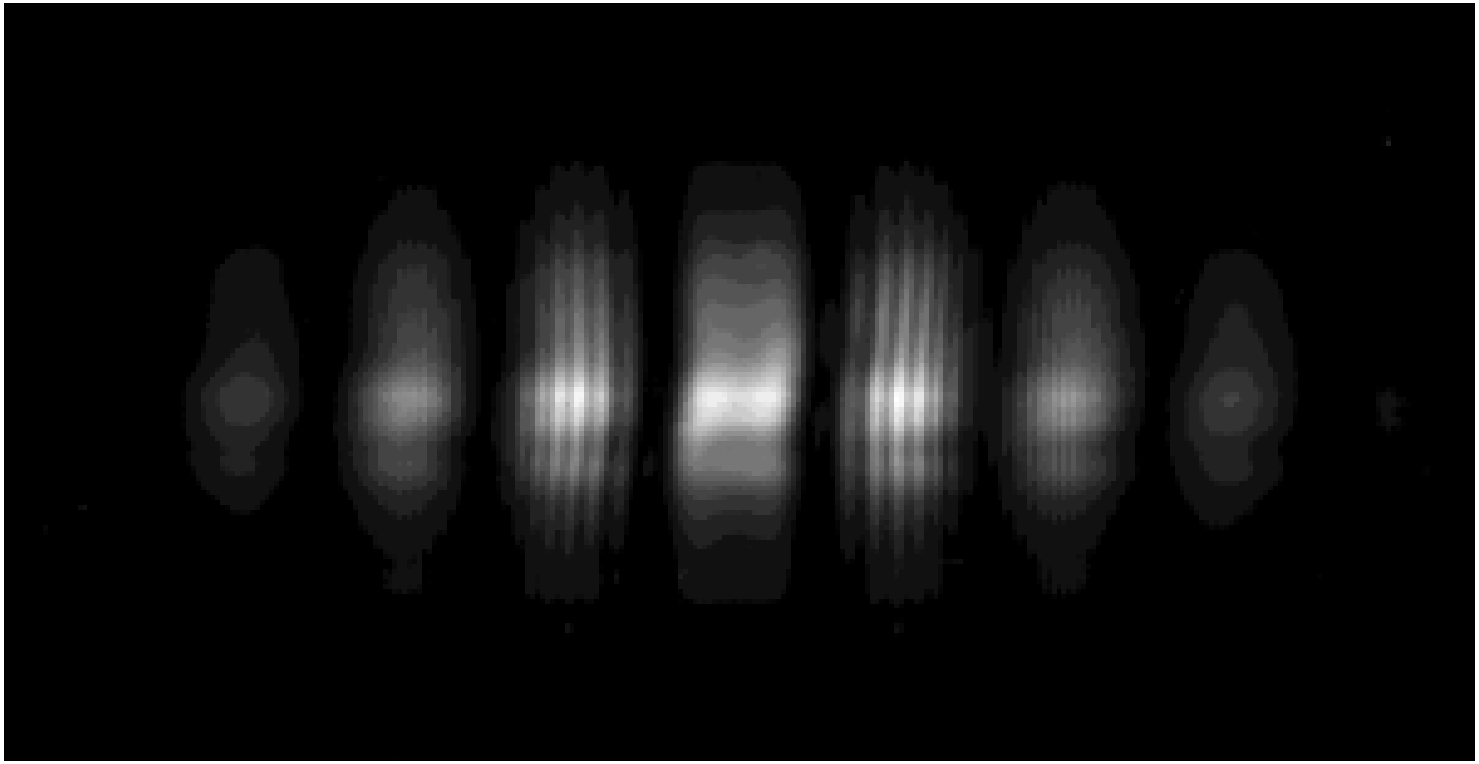


(*b*)

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.

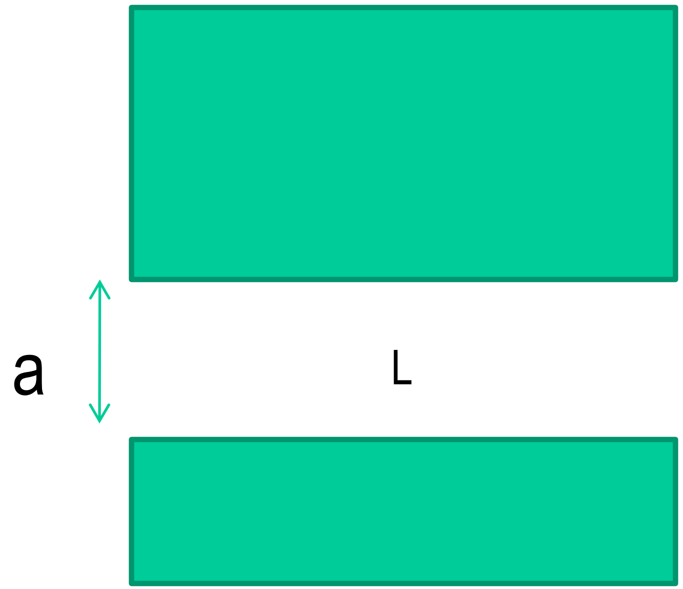
Everything works well in the soft x-ray region
Slits can be defined, just like optical



Mcnulty et. al, @1.5 kev

Why is a hard x-ray pinhole difficult

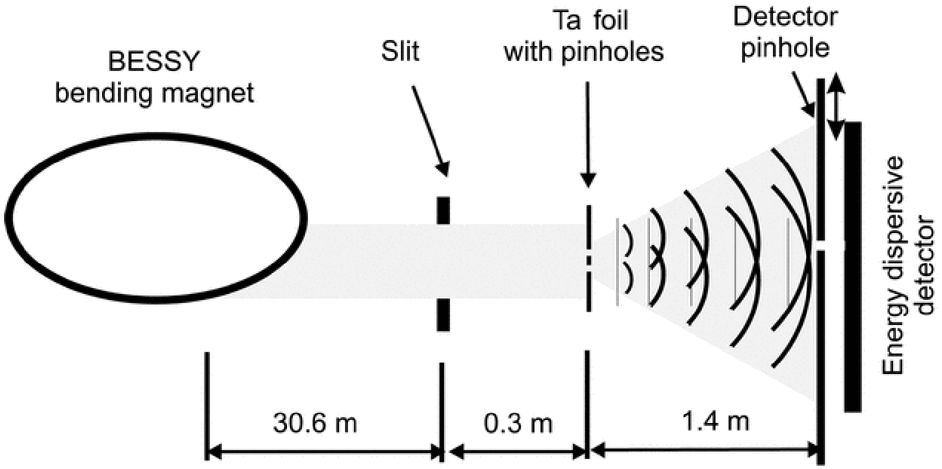
- Hard x-rays require L to be big
- You can get waveguide effects when diffraction causes the slit to interact with itself.
- $a^2/\lambda < L$



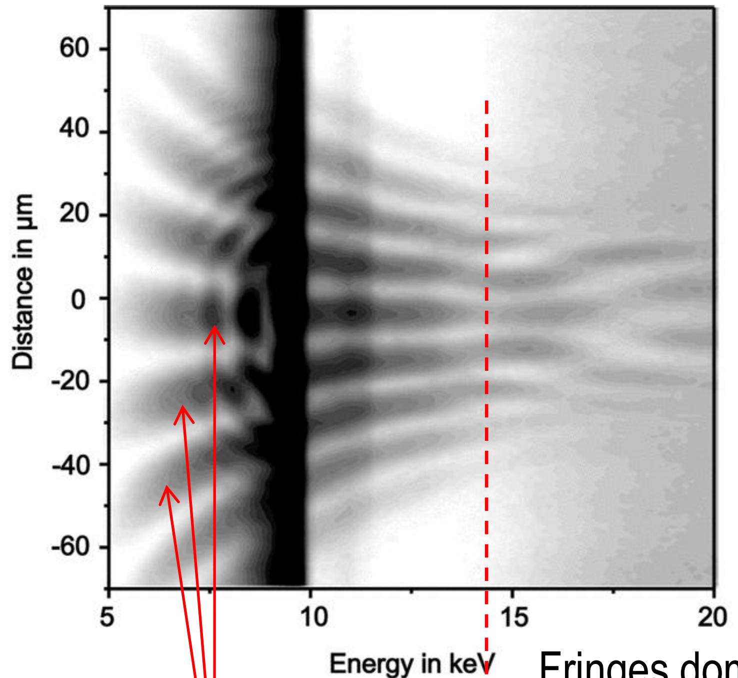
Hard x-ray double pinhole experiment is difficult but possible

Leitenberger, W., Wendrock, H., Bischoff, L. & Weitkamp, T. (2004). J. Synchr. Rad. 11, 190.

The experiment



Their results



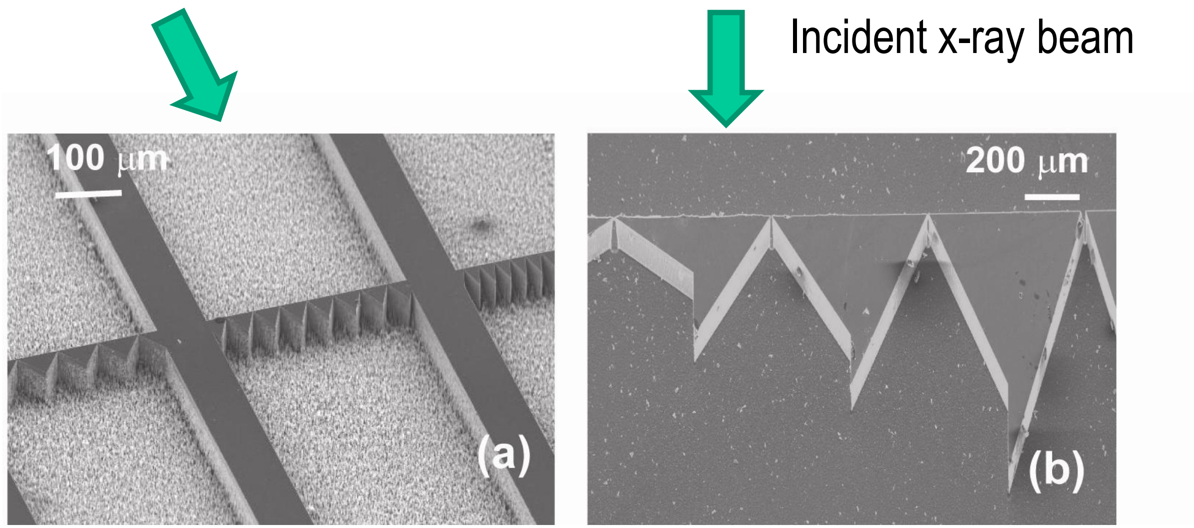
Another approach:
Snigirev, A., I. Snigireva, et al. (2009). "X-Ray Nanointerferometer Based on Si Refractive Bilenses." Phys. Rev. Lett. **103: 064801.**

Fringes due to Interference Between pinholes

Fringes dominated by interference between individual pinhole and transmission through film

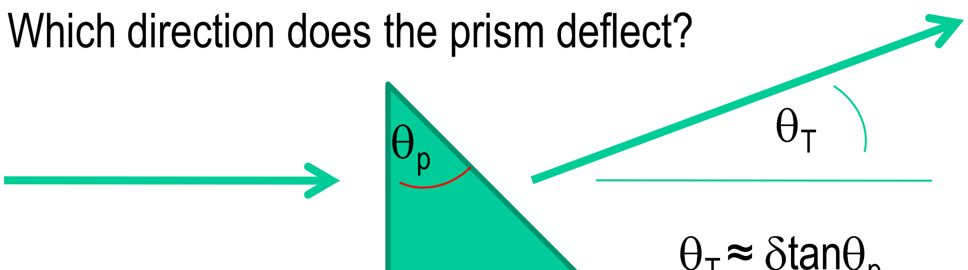
Some Real Biprisms

Incident x-ray beam



Refractive index for hard x-rays is less than one: $n = 1 - \delta + i\beta$, with $\delta \sim 4x10^{-6}$

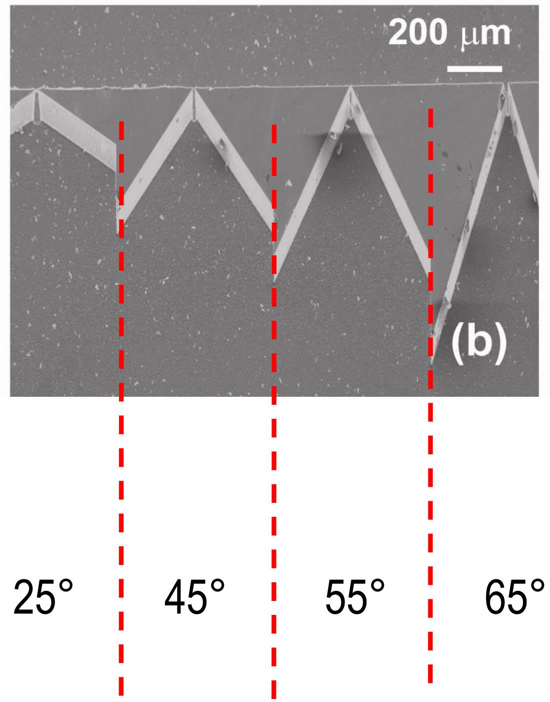
Which direction does the prism deflect?



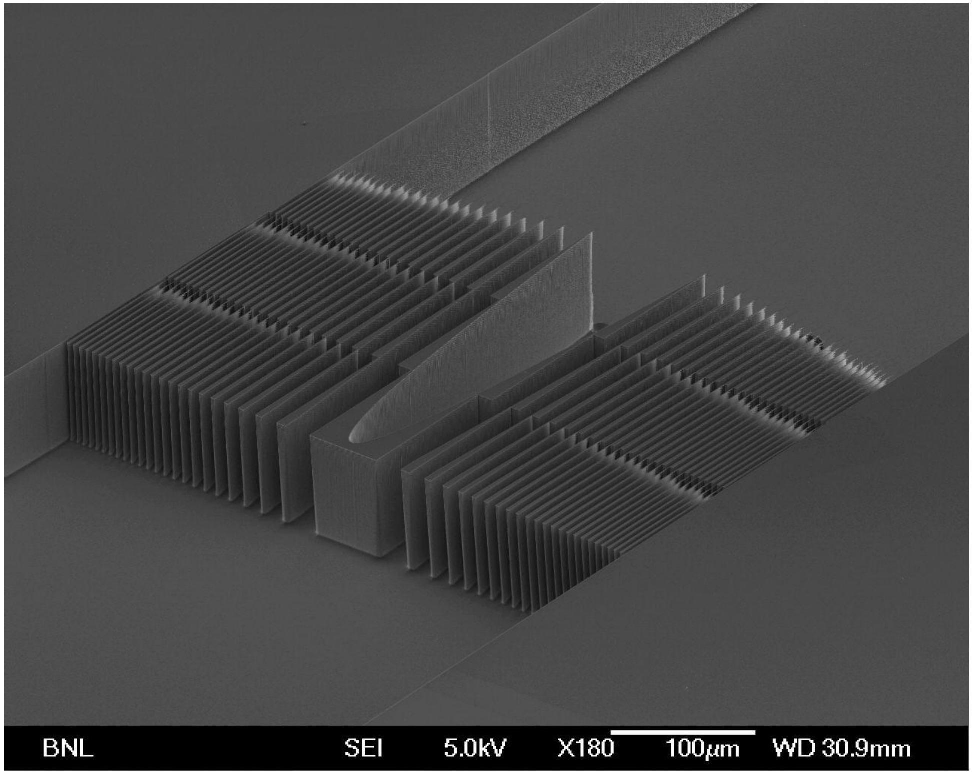
$$\theta_T \approx \delta \tan\theta_p$$

Some Real Silicon Biprisms

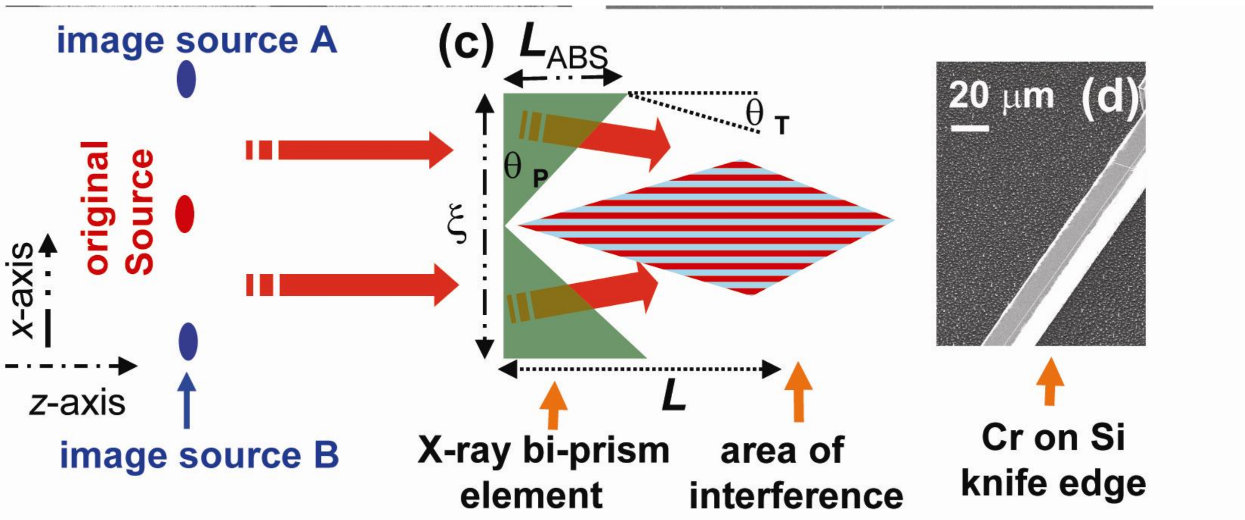
To help you see the different biprisms



Prisms are a lot simpler than kinoforms



A Virtual Youngs double slit experiment

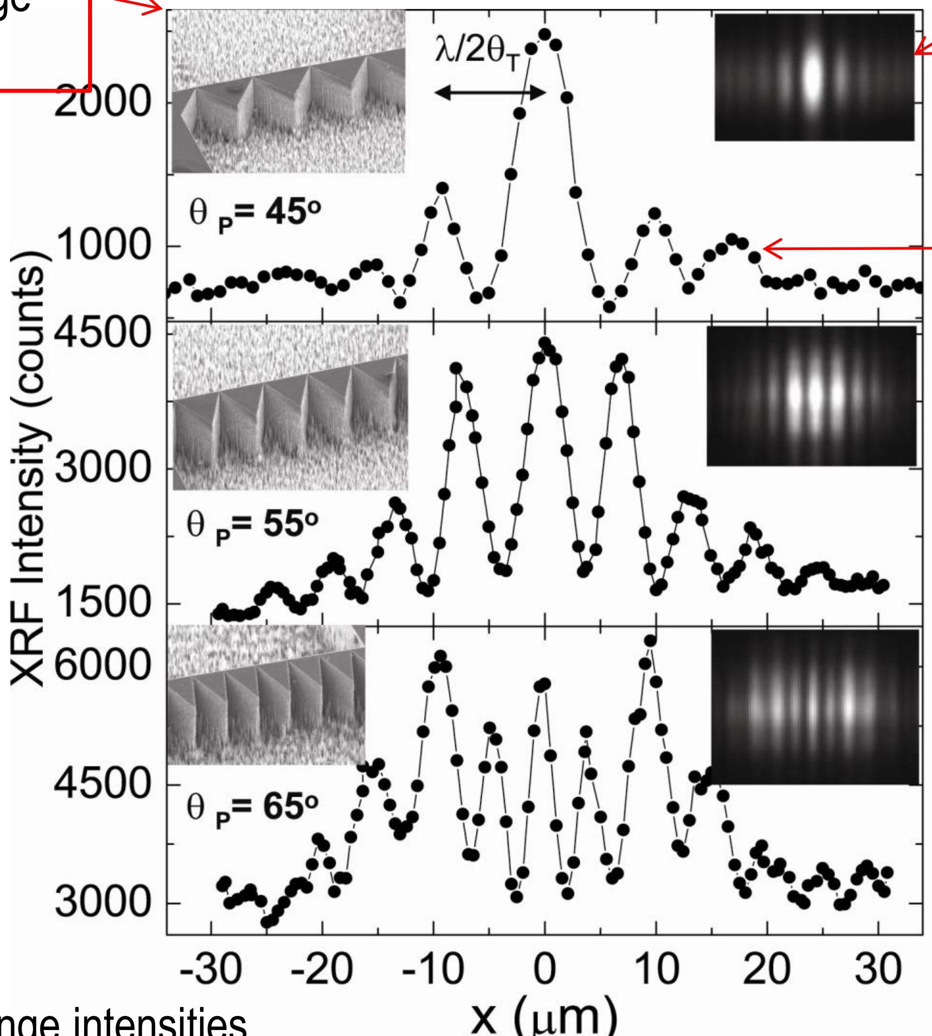


Function of angle

Scanning Electron microscope image of biprism

Visual image of fringes on YAG crystal (Qualitative)

Fluorescence counts from fringes (Quantitative)

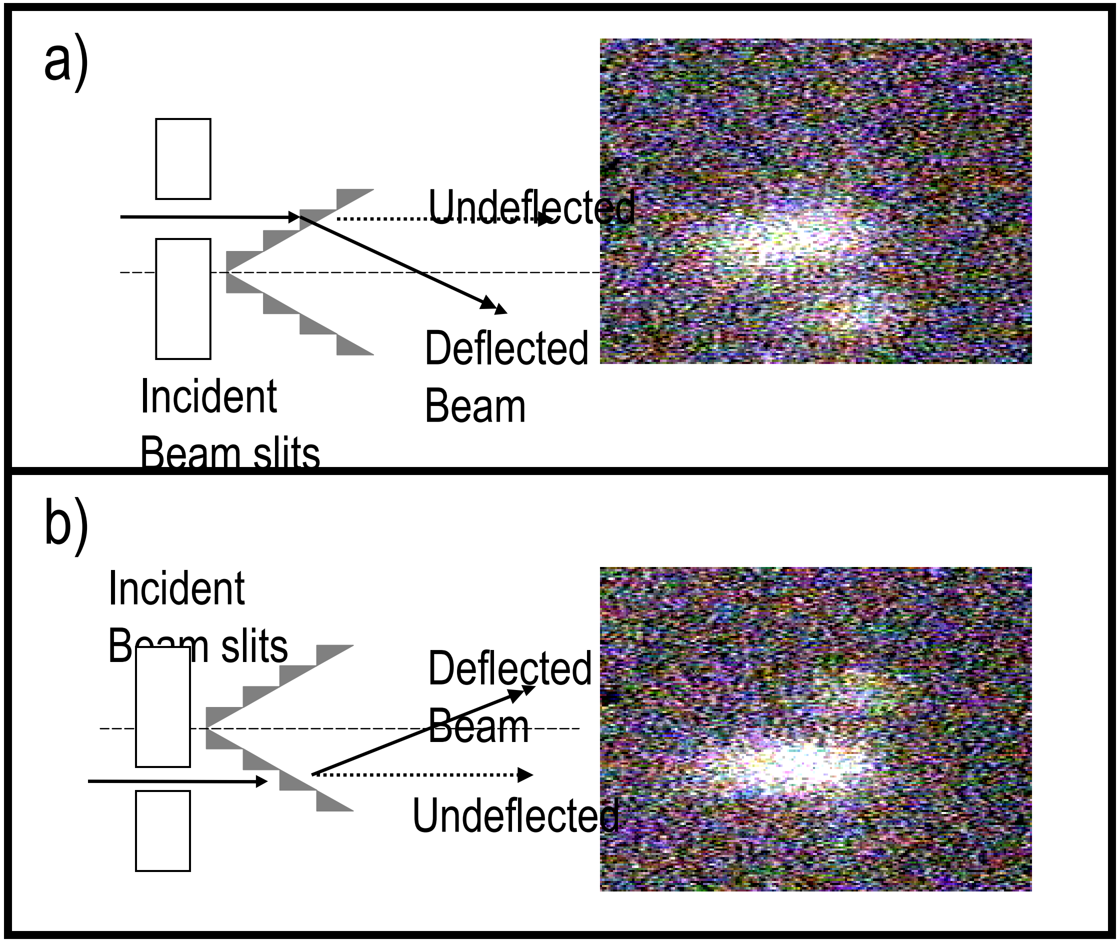


Distance from prism 1.03m

E = 7.35keV

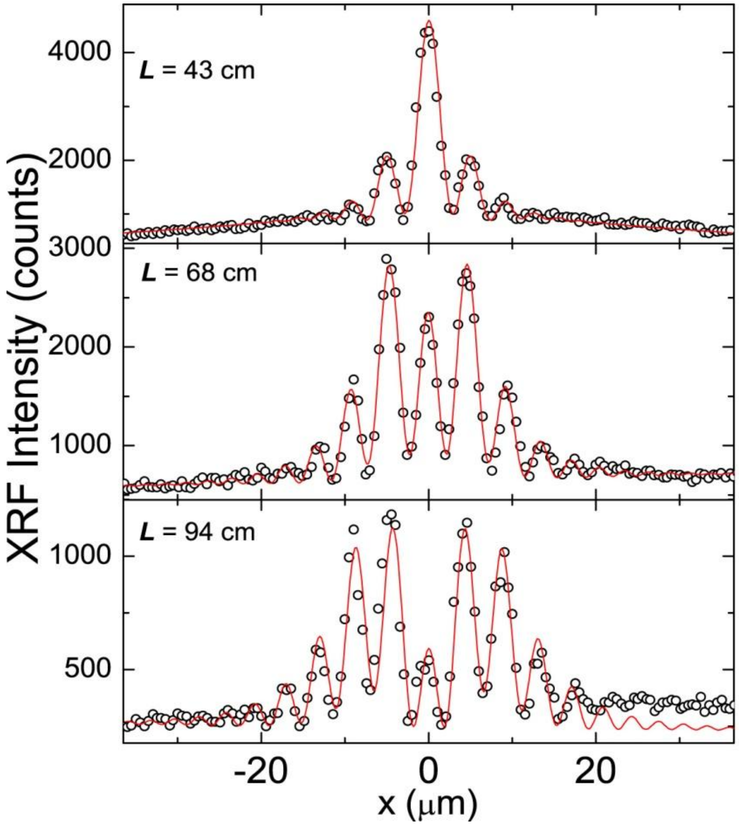
Note non-monotonic fringe intensities

Quality of beamline is important; we could deflect the light at NSLS but did not see fringes



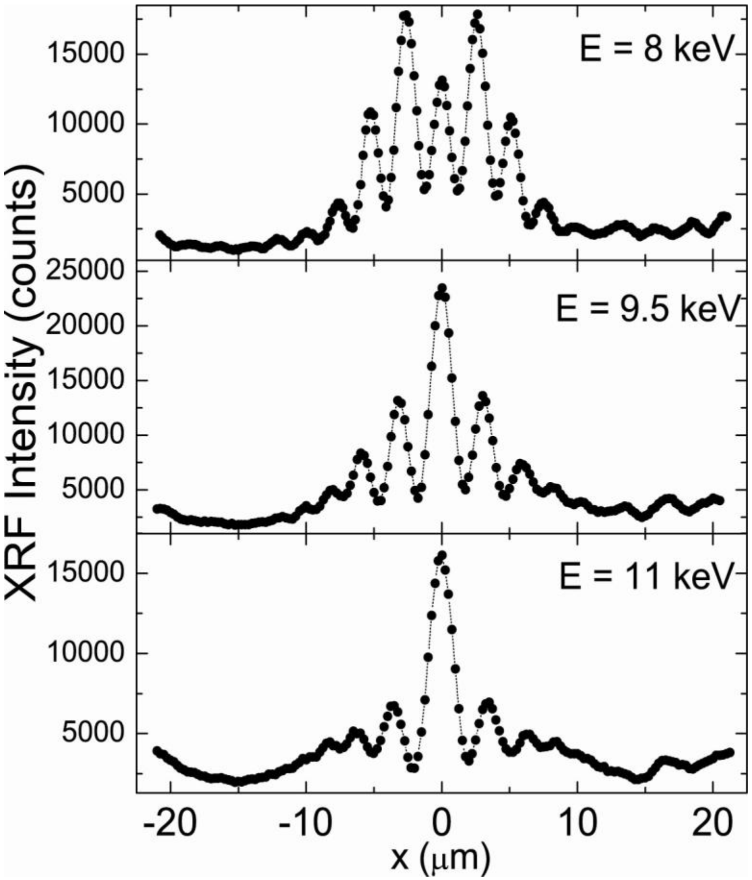
Ablett, J. M.; Evans-Lutterodt, K.; Stein, A. In *Hard X-Ray Fresnel Prisms: Properties and Applications, Design and Microfabrication of Novel X-Ray Optics,' Denver,Colorado, 2004; pp 88.*

Function of distance away from biprism



Lines through data points are **fits** to a function to be described in a few slides

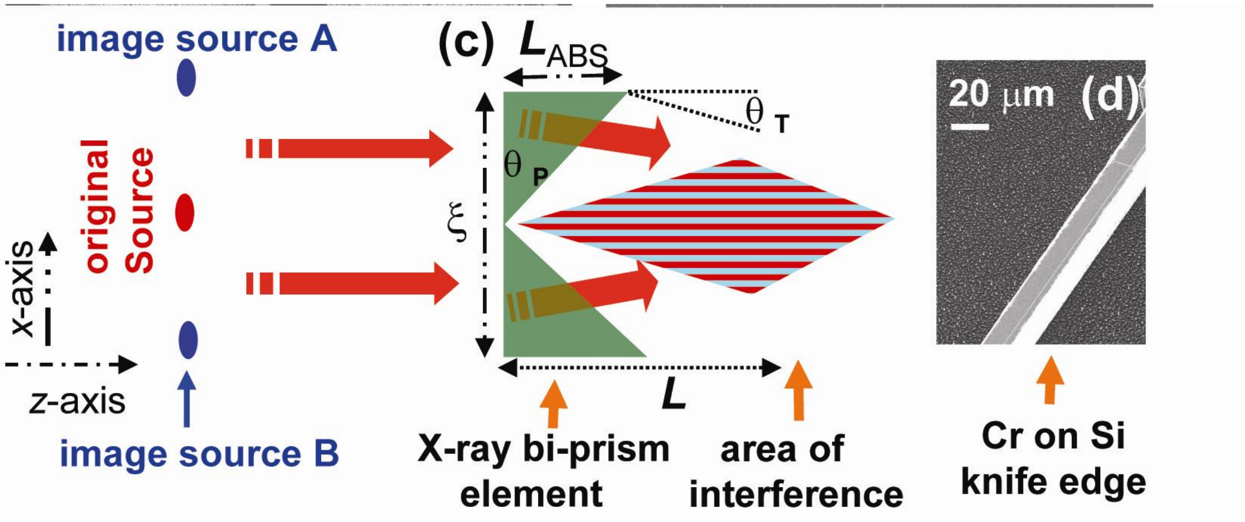
Function of Energy



Distance =0.22m

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=delta/4pi beta)

The analysis: Fresnel Kirchhoff

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

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

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

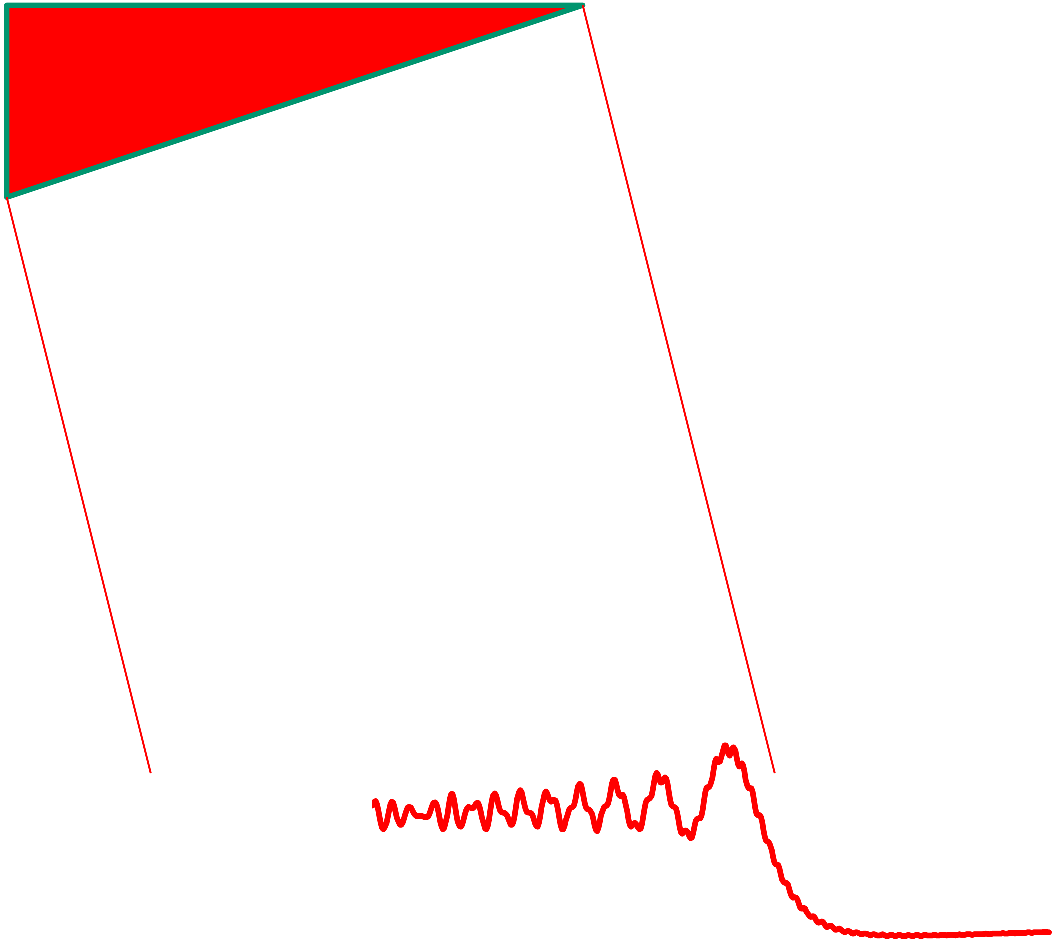
We model the prisms with a transmission function with phase shift and amplitude given by:

$$T(\eta) = \exp(-(2\pi\beta * \mathbf{t}(\eta))/\lambda)\exp(i*(2\pi\delta * \mathbf{t}(\eta))/\lambda),$$

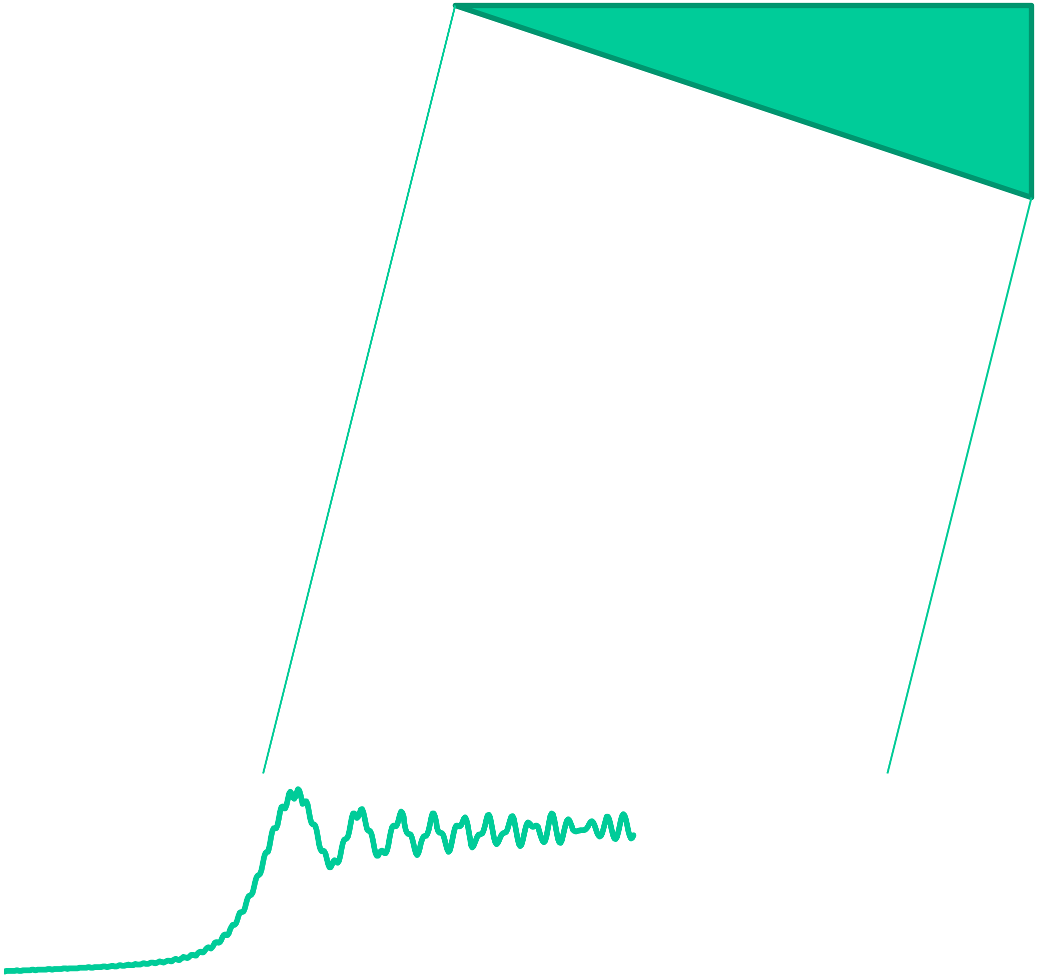
where $\mathbf{t}(\eta) = \text{abs}(\eta)\tan(\theta_p)$ represents the thickness of the prism,
η is the distance from the optical axis.

Also we add a source with a Gaussian distribution.

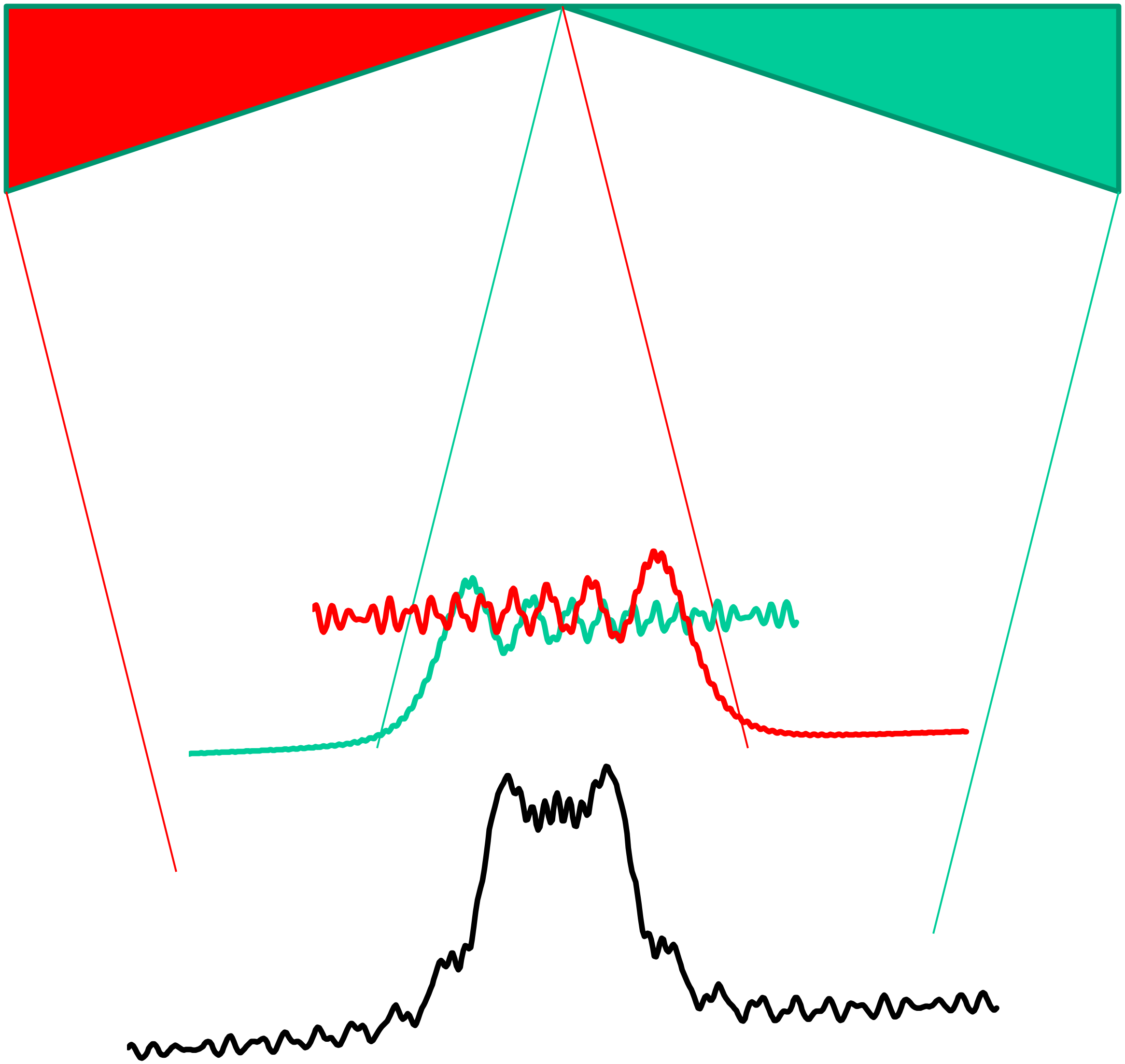
If you coherently illuminate one prism



And then coherently illuminate the other prism

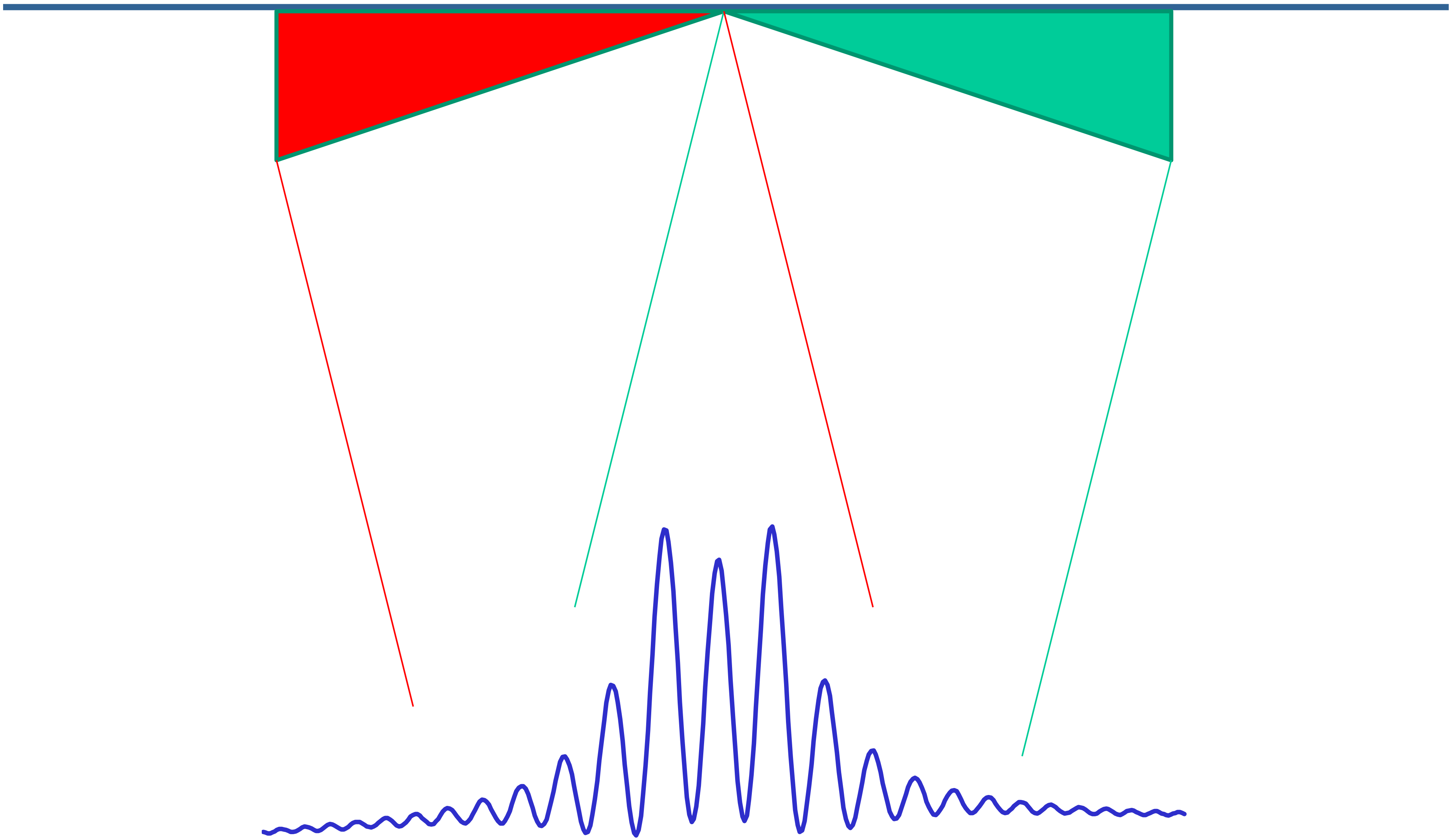


When you coherently illuminate both prisms together you get a product function

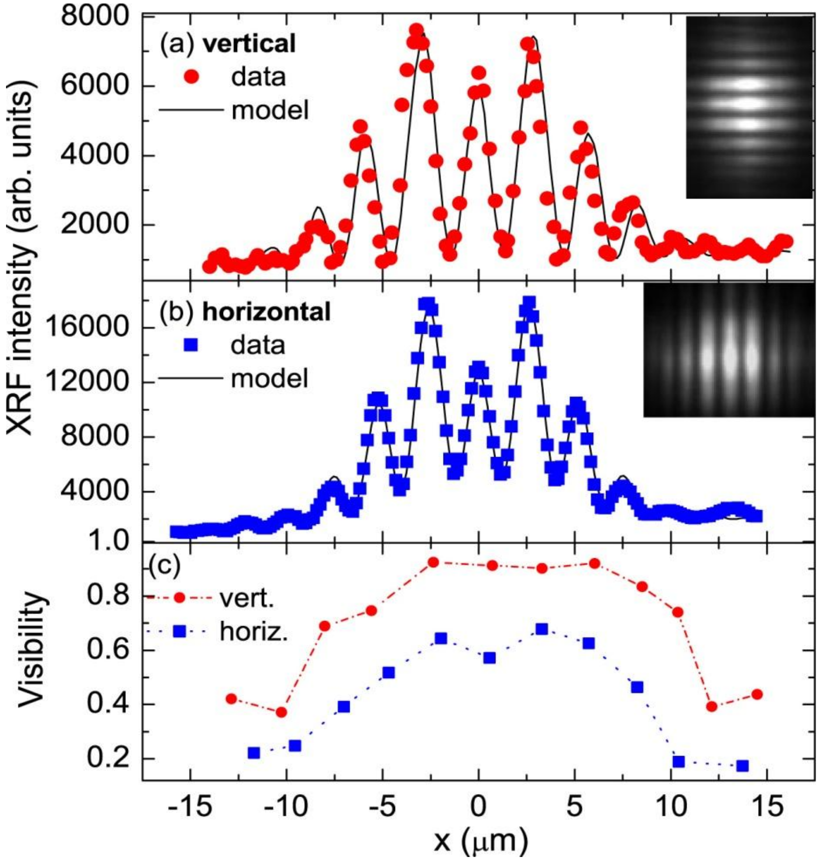


This function is the product of the left (red) prism and right (blue) prism and this function modulates the fringe intensities that we observe

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

PRL 103, 064801 (2009) PHYSICAL REVIEW LETTERS week ending 7 AUGUST 2009

X-Ray Nanointerferometer Based on Si Refractive Bilenses

A. Snigirev,[1] I. Snigireva,[1] V. Kohn,[2] V. Yunkin,[3] S. Kuznetsov,[3] M. B. Grigoriev,[3] T. Roth,[1] G. Vaughan,[1] and C. Detlefs[1]

[1]*ESRF, B.P. 220, 38043 Grenoble, France*

[2]*Russian Research Center "Kurchatov Institute," 123182, Moscow, Russia*

[3]*IMT RAS, 142432 Chernogolovka, Moscow region, Russia*

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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.

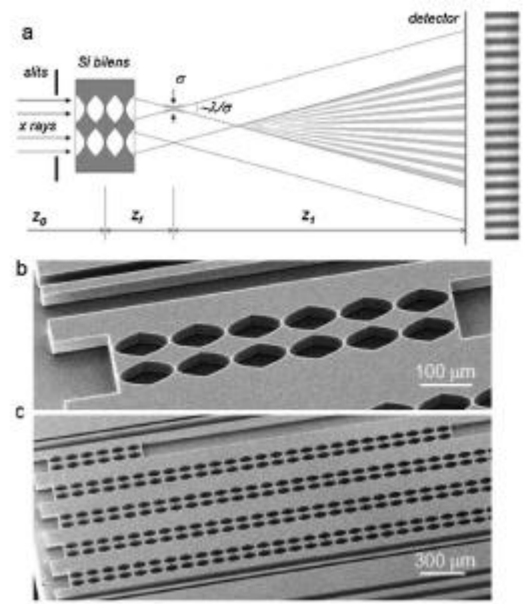
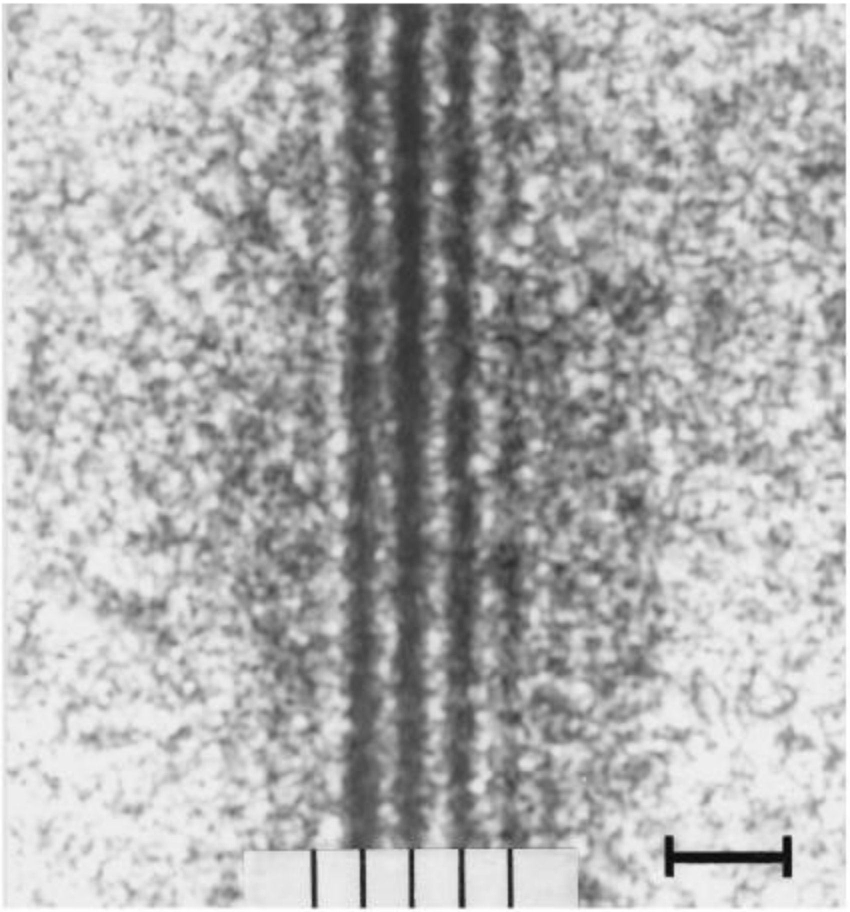


FIG. 1. (a) Schematic view of the x-ray bilens interferometer. (b) Scanning electron microscope micrograph of a single silicon bilens consisting of 6 individual parabolic lenses. (c) General view with five bilens systems fabricated on the same substrate.

Lang et. Al. demonstrated fringes



1. Lang, A. R.; Makepeace, A. P. W., Production of synchrotron X-ray biprism interference patterns with control of fringe spacing. *J. Synchr. Rad.* ***1999, 6, 59.***

Jpn. J. Appl. Phys. Vol. 41 (2002) pp. L 1019–L 1021
Part 2, No. 9A/B, 15 September 2002

Two-Beam X-Ray Interferometer Using Prism Optics

Yoshio SUZUKI
SPring-8, Mikazuki, Hyogo 679-5198, Japan

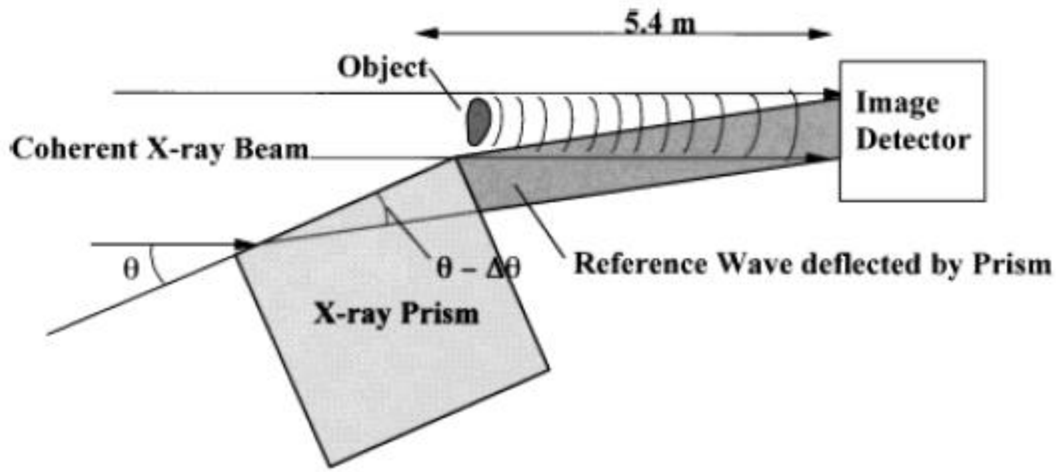


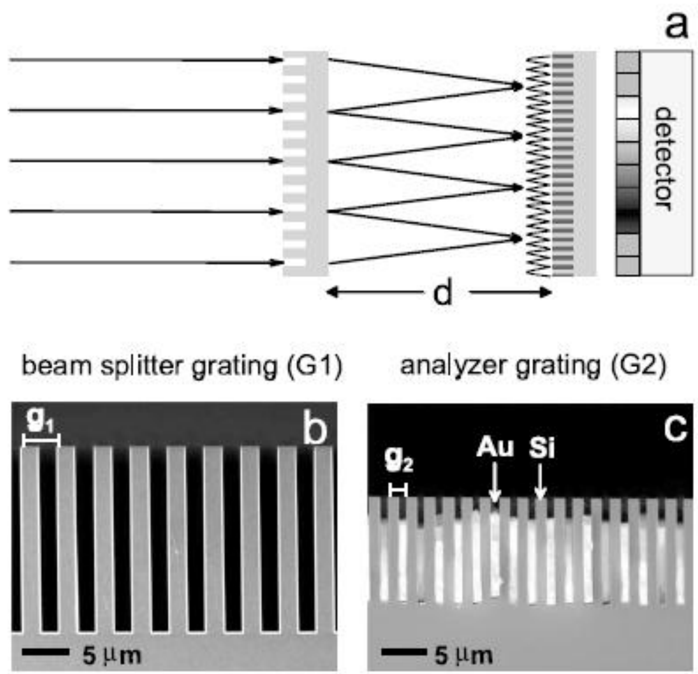
Fig. 1. Schematic diagram of two-beam interferometer with X-ray prism.

Shearing Interferometer for Quantifying the Coherence of Hard X-Ray Beams

F. Pfeiffer, O. Bunk, C. Schulze-Briese, A. Diaz, T. Weitkamp, C. David, and J. F. van der Veen
Paul Scherrer Institut, CH-5232 Villigen, Switzerland

I. Vartanyants
HASYLAB, DESY, Notkestrasse 85, D-22607 Hamburg, Germany

I. K. Robinson
Department of Physics, University of Illinois, Urbana, Illinois 61801, USA
(Received 26 January 2005; published 26 April 2005)



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

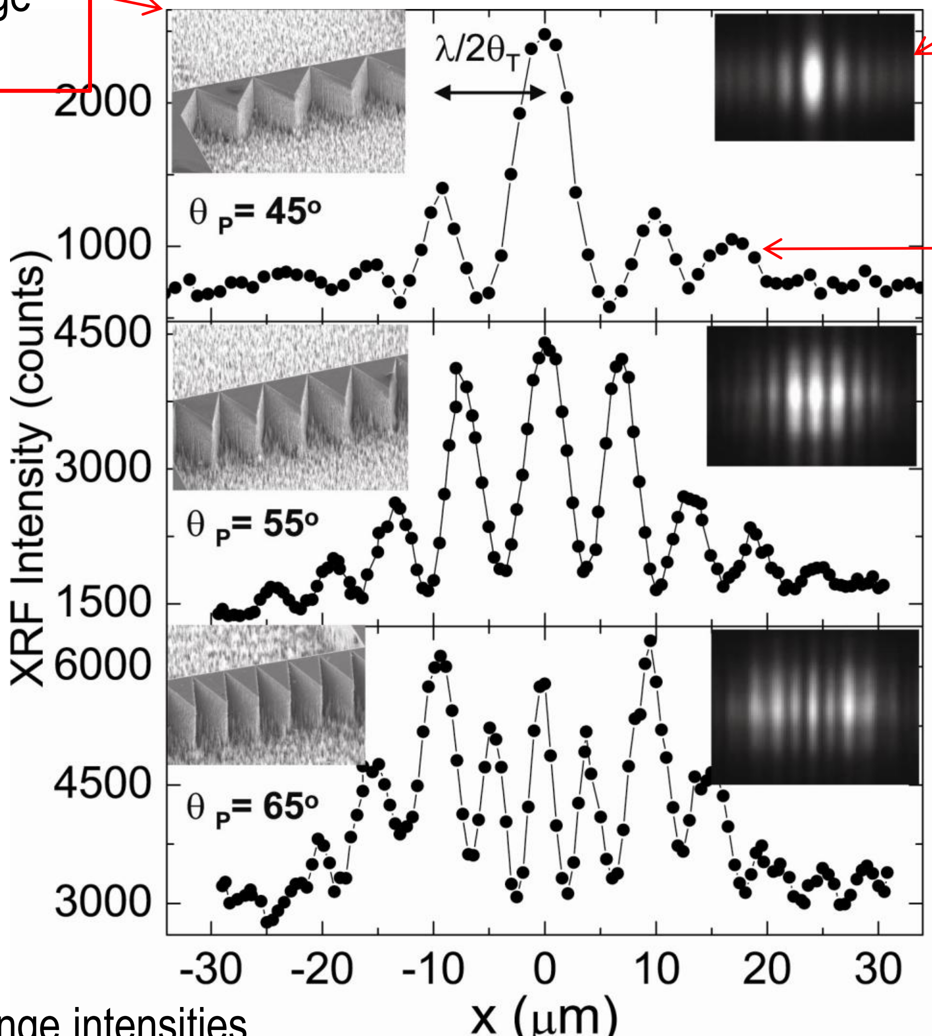
1) Simple to use
2) The prisms introduce very little phase error;
3) Can be calculated from first principles
4) Is portable (can be replicated around the world as needed)
5) Fabrication errors can be compensated for by modeling
6) Can be designed to match different energies

Function of angle

Scanning Electron microscope image of biprism

Visual image of fringes on YAG crystal (Qualitative)

Fluorescence counts from fringes (Quantitative)



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