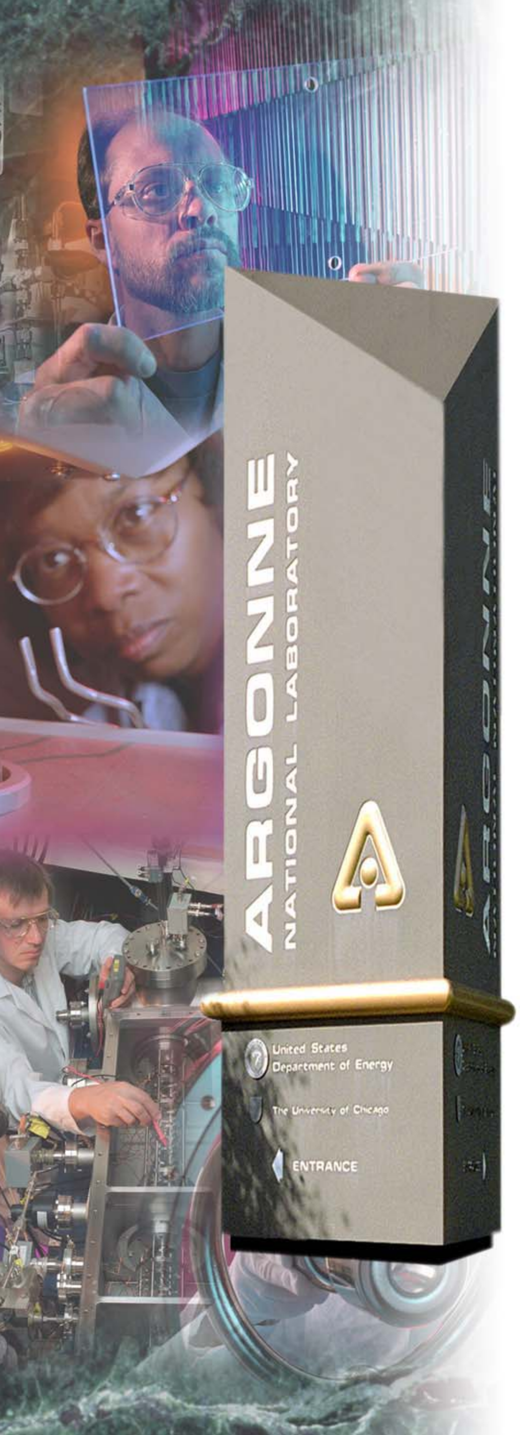

Spatial coherence measurement

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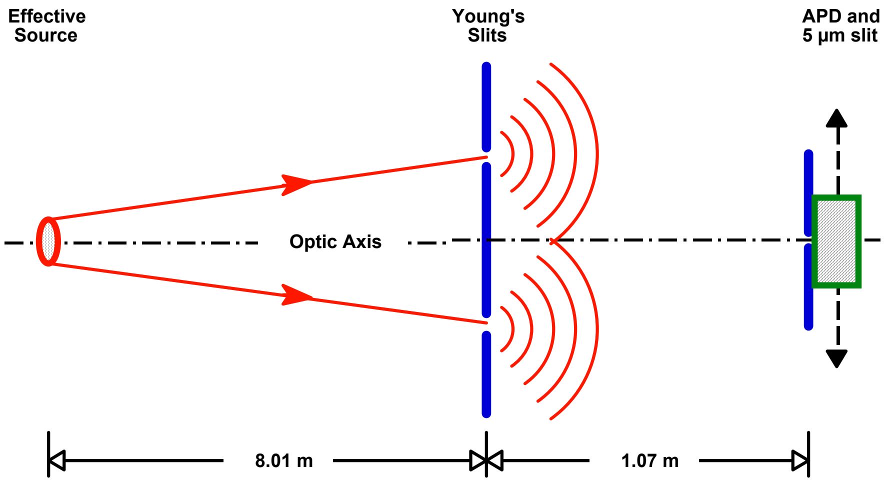
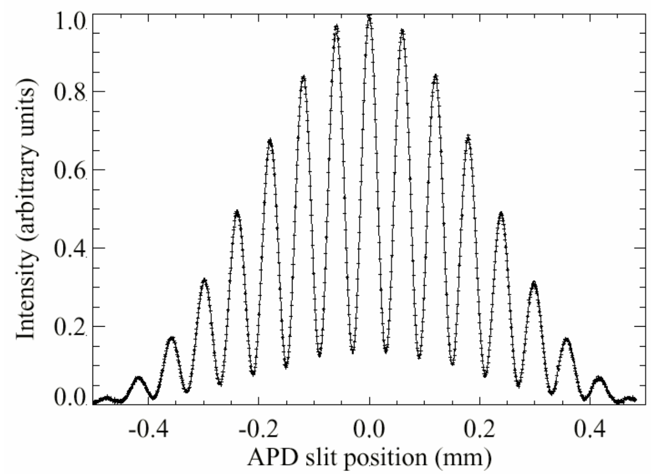
Motivation

- Unique coherence-based experiments relating to holography, microfocussing and phase measurement
- Third generation synchrotrons produce very bright, partially coherent X-rays
- Fourth generation sources, pulsed sources
- Characterisation of spatial coherence is a high priority
- Coherence “degradation” by beamline optics?
- Aim: develop theoretical and experimental program to measure the spatial coherence and phase properties of radiation
- => Cohereometer

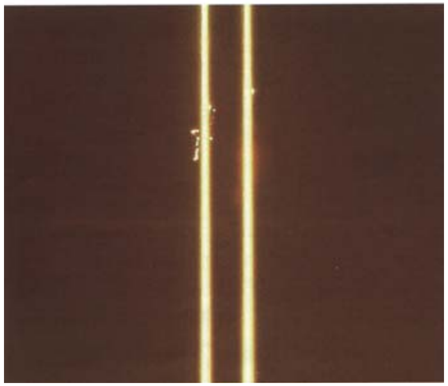
Young's experiment (1.1 keV)



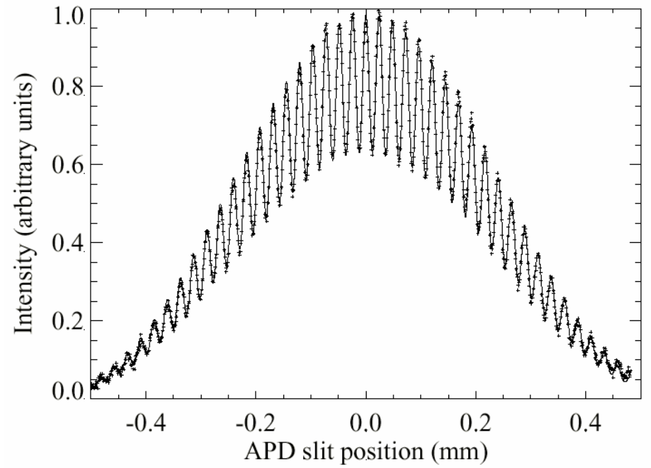
Experiment geometry (top view)



20 µm slit separation



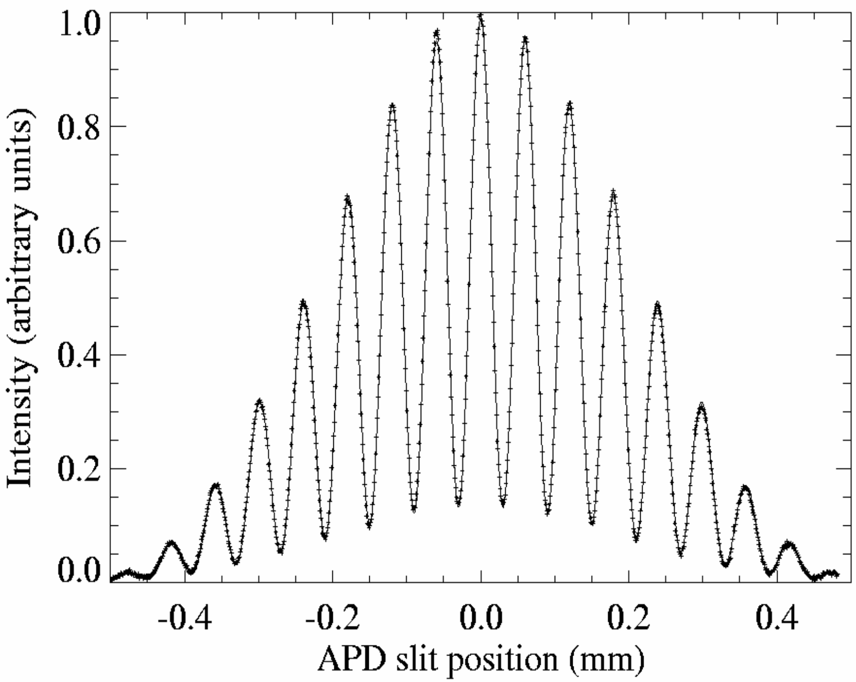
Young's slits (1.6 µm Au, 3 µm wide, 10 µm apart)



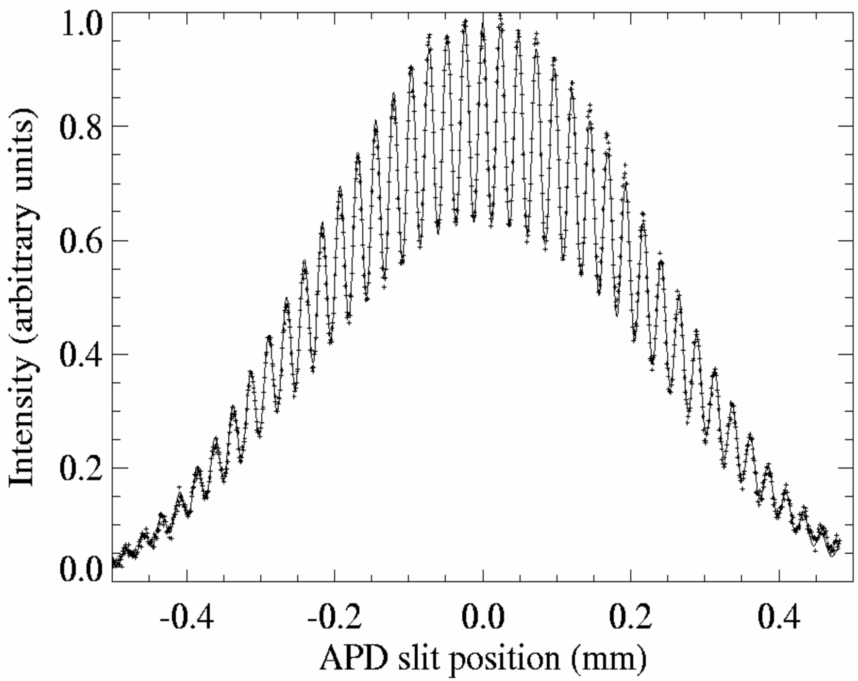
50 µm slit separation

Diffraction profiles and fitting

- **Energy 1.1 keV**   + **data**   —— **fit to data**



Young's slit separation = 20 μm



Young's slit separation = 50 μm

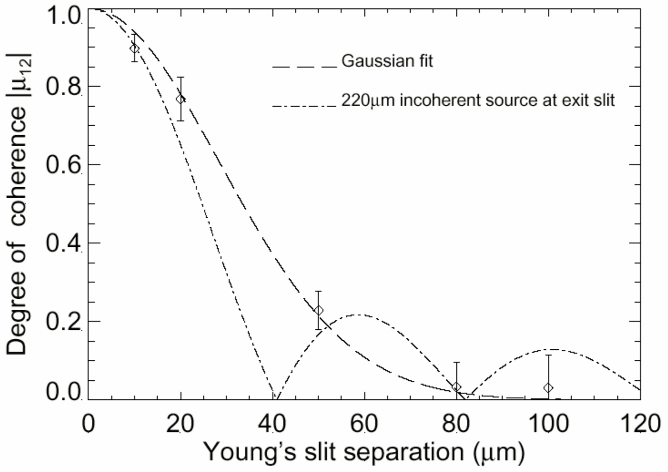
$$|\mu_{12}| = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

Coherence function at beamline 2-ID-B

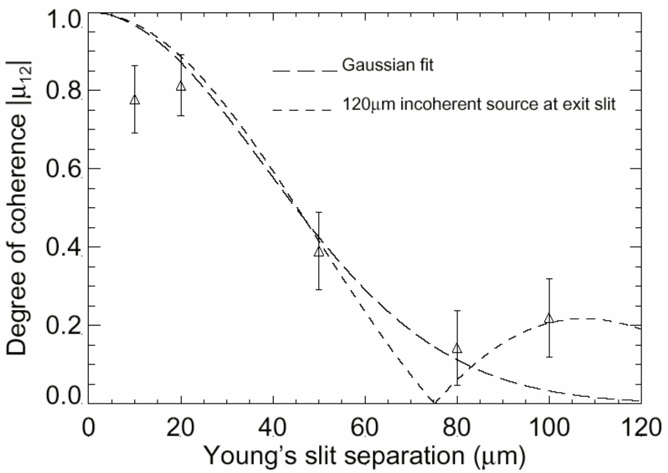
Horizontal degree of spatial coherence $|\mu_{12}|$ measured 8 m from monochromator exit slit. $|\mu_{12}|$ is dominated by beamline optics

Energy = 1.1 keV
Entrance slit = 50 μm
Exit slit = 220 μm

$$w_c = \left(w_{slit}^2 + w_{source}^2\right)^{\frac{1}{2}}$$

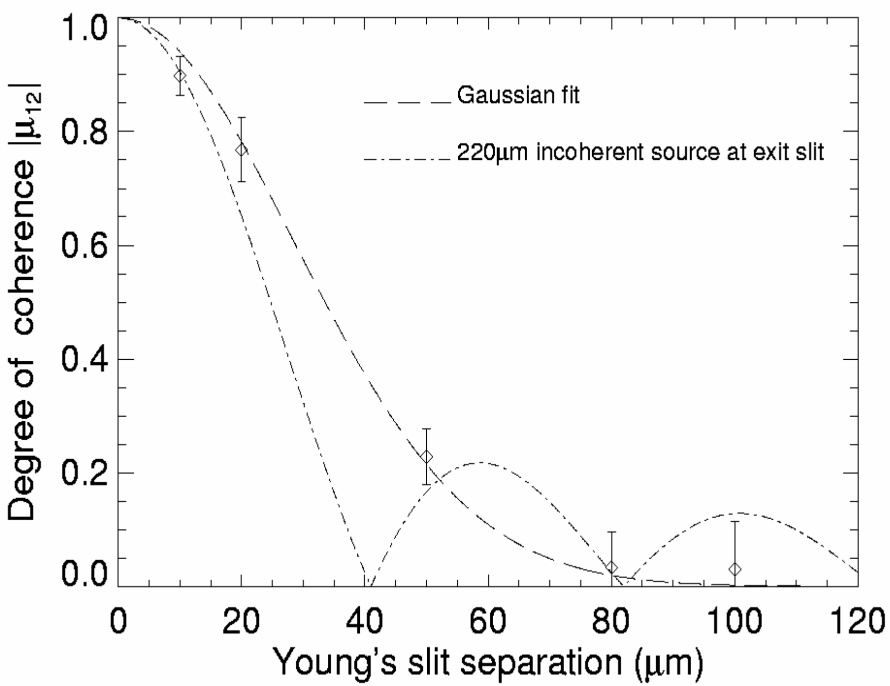


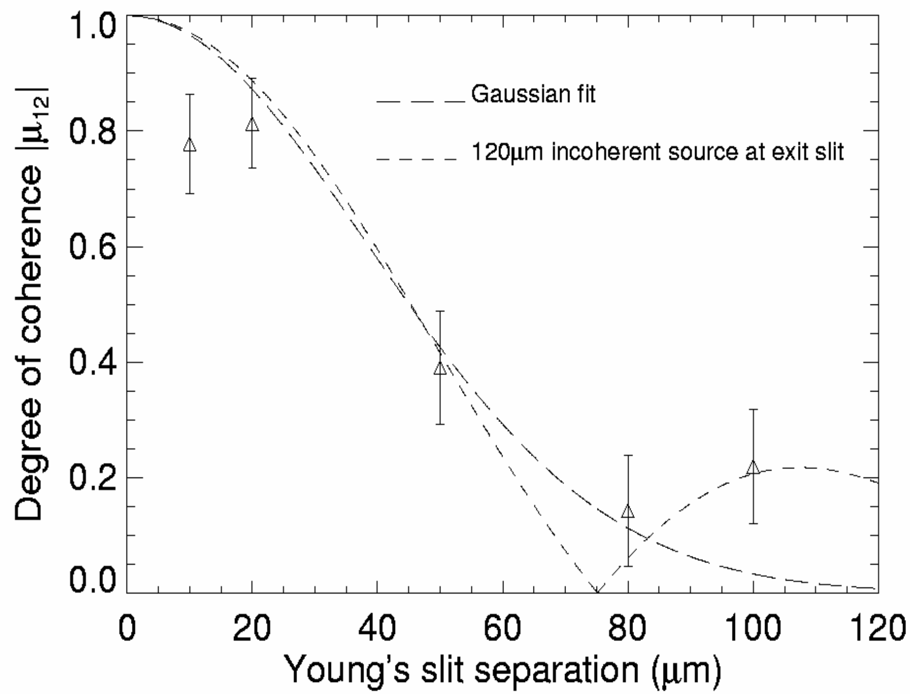
$|\mu_{12}|$ measured with 120 μm exit slit. $|\mu_{12}|$ is dominated by exit slit, producing sinc profile



D. Paterson, et al., *Opt. Commun.* 195, 79 (2001)

Coherence function dependence on exit slit



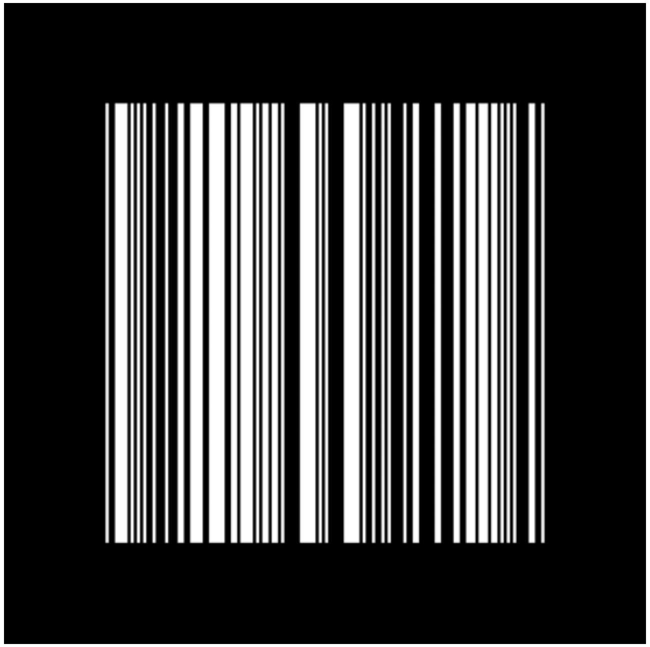


Exit slit at 200 μm
Gaussian profile

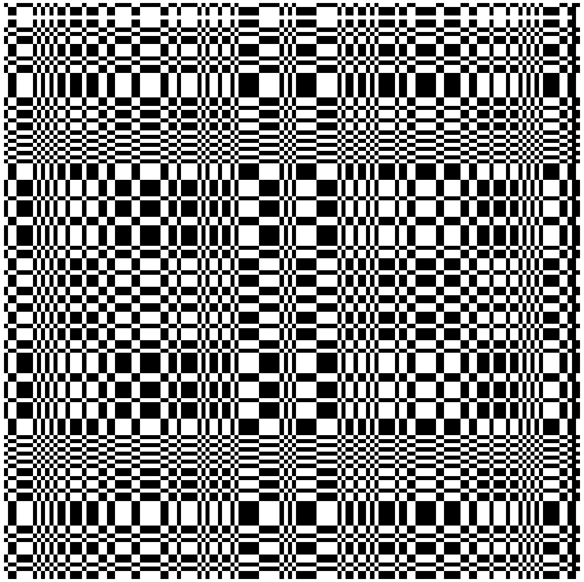
Exit slit at 100 μm
Sinc profile

$$\mu_{12} = \frac{\sin\left(\pi\sigma\Delta / \lambda z'\right)}{\pi\sigma\Delta / \lambda z'}$$

Parallel measurement: Uniformly Redundant Arrays



1D

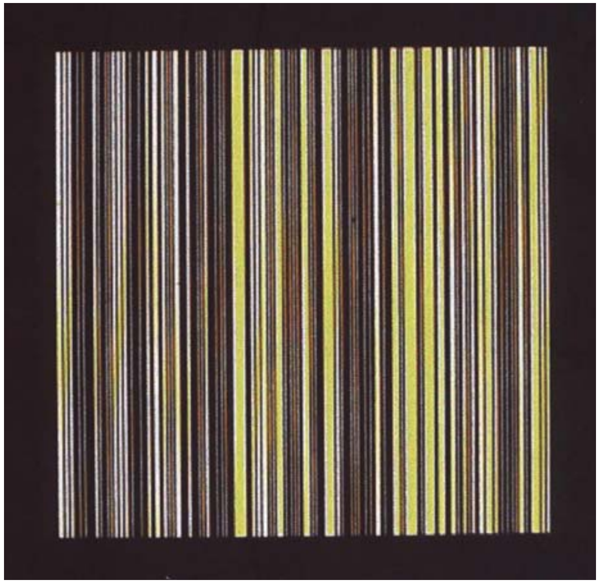


2D

- **All possible aperture separations occur with same frequency**
- **1D URA equivalent to many simultaneous Young's experiments**

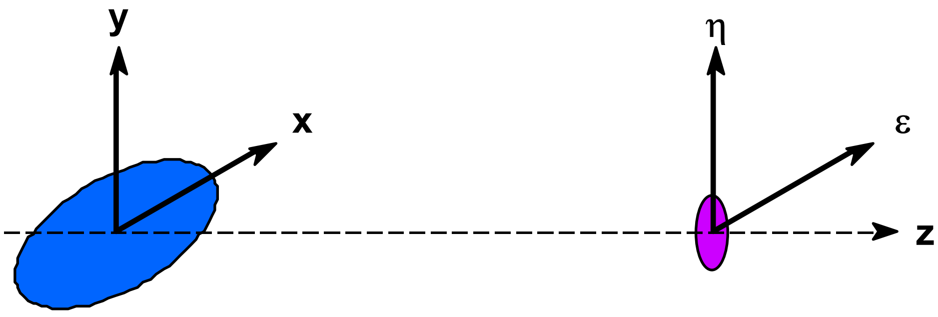
Experiments at APS

- Fast measurement of 1D and 2D coherence functions with URAs and CCDs (< 1 min exposures)
- Performed at APS 2-ID-B (soft) and 2-ID-D (hard x-ray) beamlines
- Measured with 8, 2.5 nm-rad electron beam emittance
- Obtain $|\mu_{12}|$ by Fresnel inversion



1D URA (1.18 µm Au, 2.5 µm min. width)

Coherent field from incoherent source



van Cittert-Zernike theorem

$$\mu_{12}(\varepsilon,\eta) = e^{i\phi} \frac{\int I(x,y)\, e^{-ik(x\varepsilon+y\eta)/z}\, dxdy}{\int I(x,y)\, dxdy}$$

Fourier-invert to obtain source size and shape (assumes symmetry)

$$I(x,y) \propto FT^{-1}\{\mu_{12}\}$$

P.H. van Cittert, *Physica* 1, 201 (1934)
F. Zernike, *Physica* 5, 785 (1938)

Partially coherent field

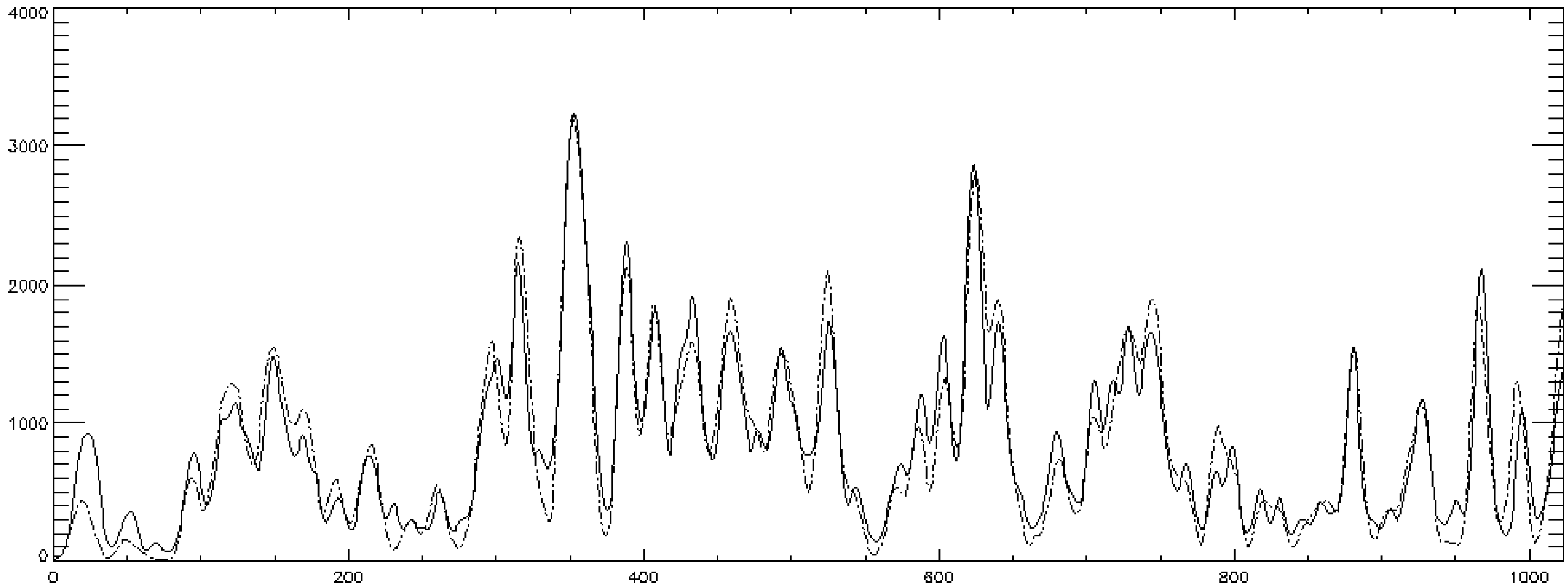
$$I_{par}(\mathbf{r}) = \int G(\mathbf{r}/z) I_{coh}(\mathbf{r}-\mathbf{r}')dr'$$

$$I_{par} = G \otimes I_{coh}$$ **where** $$G = FT\{g\}$$

$$g = \frac{FT^{-1}\{I_{par}\}}{FT^{-1}\{I_{coh}\}}$$

K. Nugent, *J. Opt. Soc. Am.* A8, 1574 (1991)

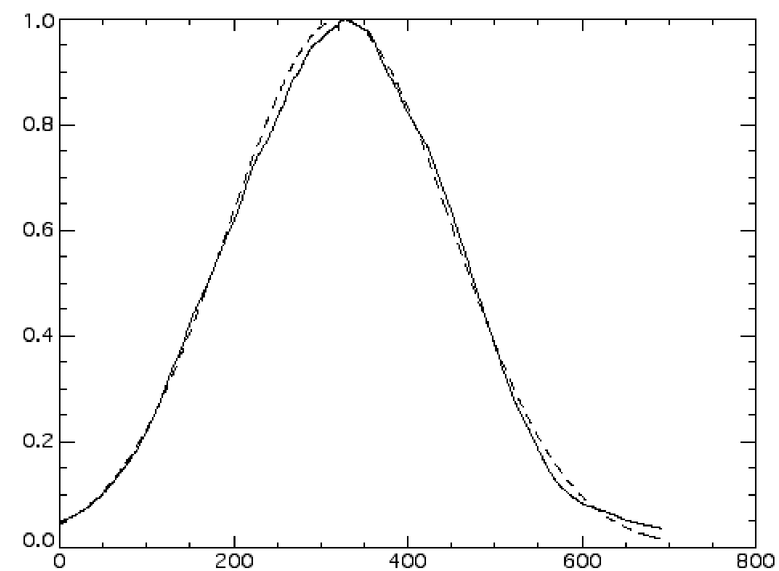
One dimensional analysis

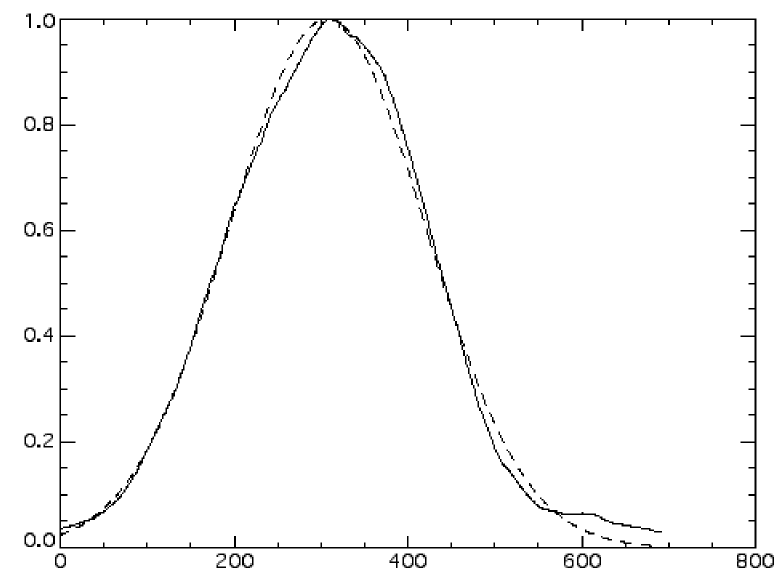


- Vertical diffraction profile collected during low emittance studies
- Energy =1500eV, diffraction distance =1.1 m, 1.21 µm thick 1D URA with 5 µm minimum slit size
- Solid line is experiment diffraction dashed line is simulation with real parameters including source size

Reduced emittance studies

High emittance	**Low emittance**
σ_y = 21 μm σ_y' = 3.9 μrad	σ_y = 11 μm σ_y' = 2.7 μrad
Vertical emittance = 80 pm-rad	Vertical emittance = 28 pm-rad





Vertical Gaussian σ = 129 μm	Vertical Gaussian σ = 113 μm

Beamline 2-ID-B, Energy = 1500 eV, sou rce to experiment = 60.3 m

Beam profile

Reduced emittance studies

High emittance	**Low emittance**
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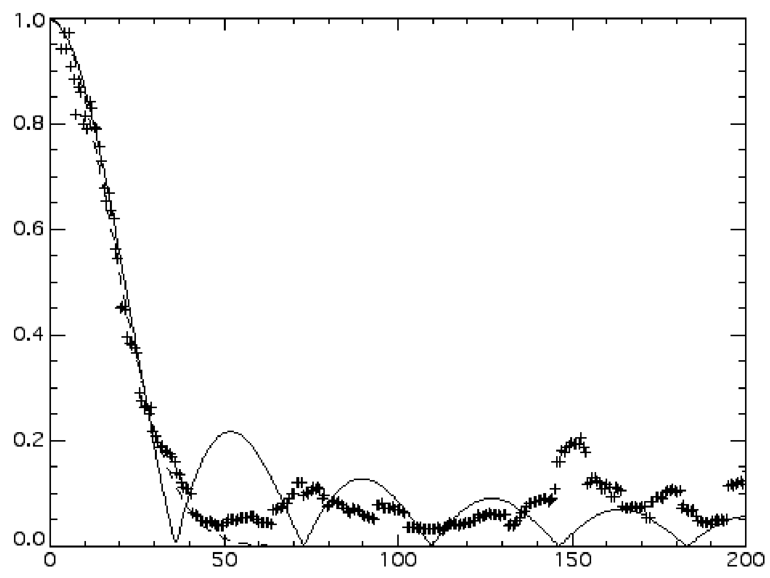
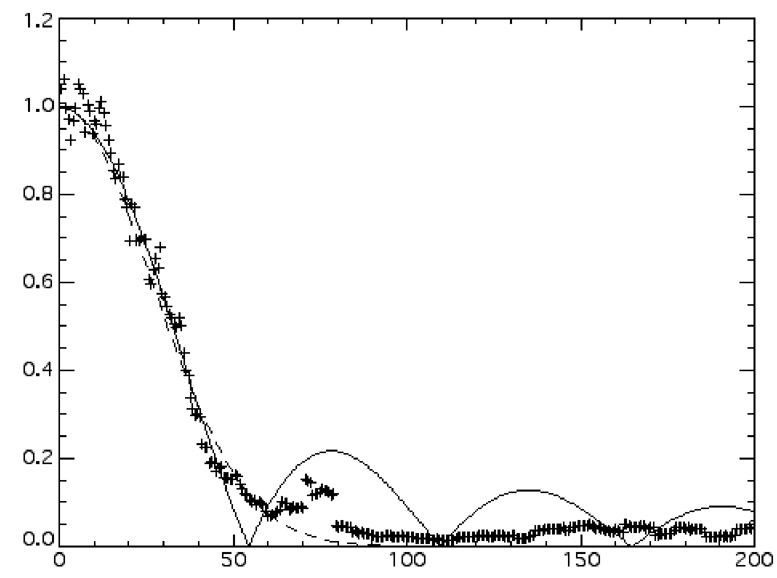
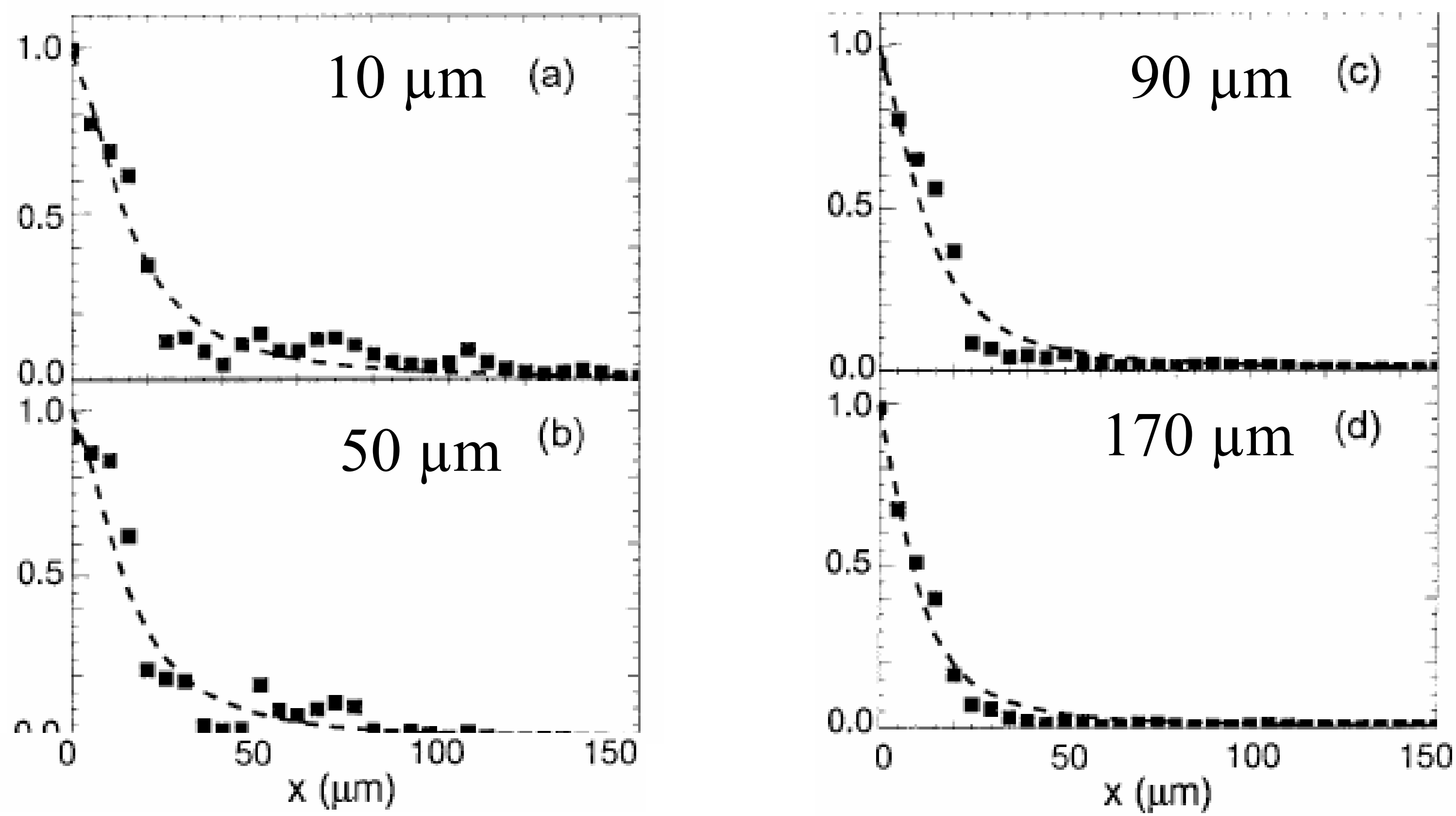




Gaussian width: 17.3 +/- 3.6 μm	Gaussian width: 26.5 +/- 4.5 μm
Source width = 180 μm at 8.0 m	Source width = 120 μm at 8.0 m

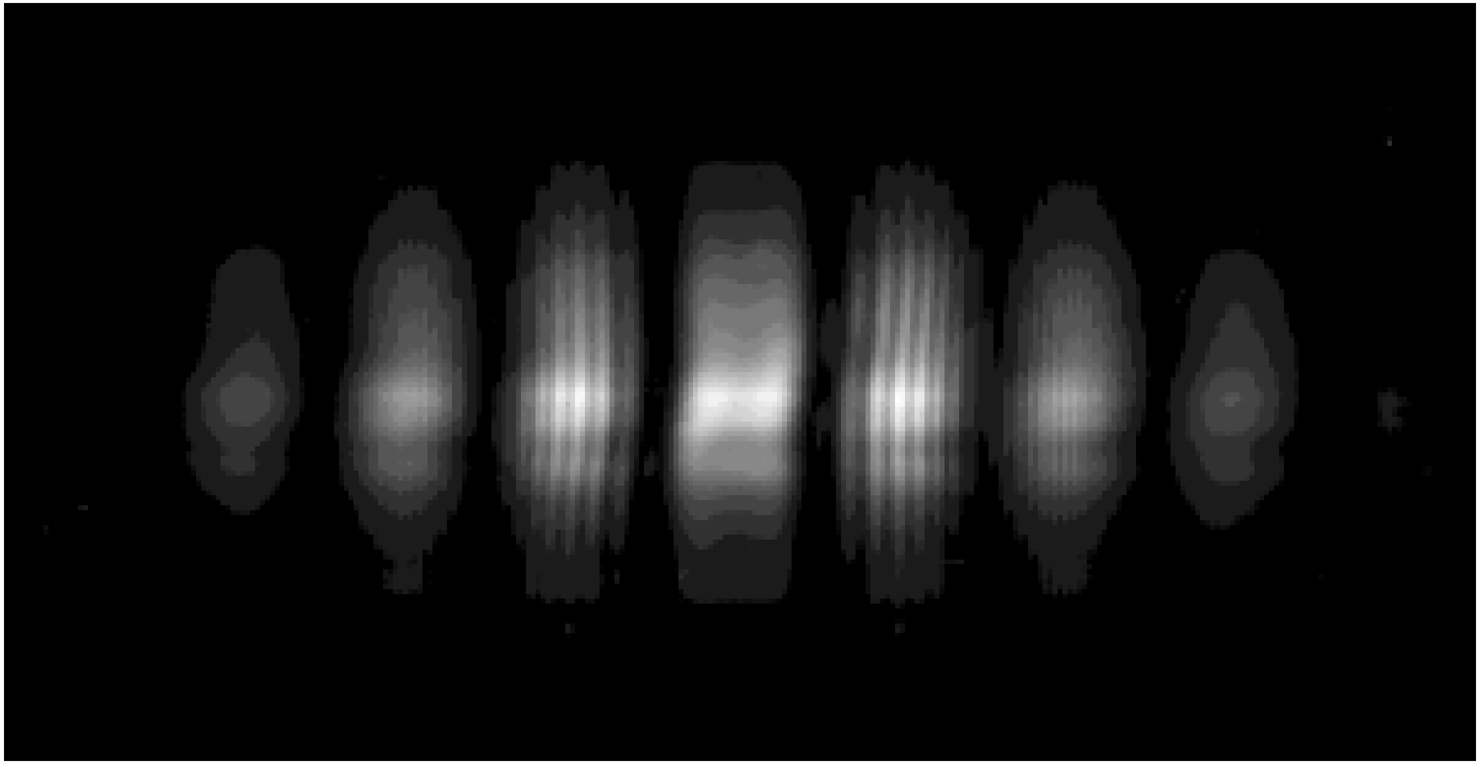
Coherence function

Spatial coherence function with phase URA



Coherence function measured at 8 keV, 43.4 m from slits of size (a) 10 μm, (b) 50 μm, (c) 90 μm, and (d) 170 μm

Coherence "degradation"?



CCD image of Young's interference pattern with 10 μm slit separation at 1.07 m, using 1.5 keV x-rays. Image is 820 μm by 420 μm and fringe spacing is 90 μm.

Condition for full utilization of coherence by experiment: $d_{aperture} < d_{speckle}$

Summary, future work

- **Measurement of complete spatial coherence function of undulator radiation**
- **Speckle effects and coherence “degradation”**
- **Agreement with theoretical expectations**
- **URA can completely map coherence function**
- **Two dimensional measurement possible**
- **Study evolution of spatial coherence in LEUTL**
  - Measurement point after each undulator

Collaborators and acknowledgements

- **APS, X-ray Operation and Research**
  - Ian McNulty, Barry Lai, Cornelia Retsch, and Joe Arko
    - *Beamline 2-ID-B and 2-ID-D*
  - Mike Moldovan, Ralu Divan, and Derrick Mancini
    - *Manufacture of Young's slit arrays and URAs*
- **APS, ASD**
  - Yuelin Li, John Lewellen
- **University of Melbourne, Australia**
  - Optics Research Group
  - Keith Nugent
  - Andrew Peele, Chanh Tran, John Lin, Adrian Mancuso, Tom Irving, Chris Chantler, Phil McMahon