A classical Hanbury Brown-Twiss experiment with hard x-rays

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Introduction

The classical Hanbury Brown-Twiss experiment has been conducted with hard x-ray synchrotron radiation at the Advanced Photon Source (APS). The measured spatial coherence area of the x-ray beam is in good agreement with the prediction based on the vertical positron beam size.

It has been discussed previously [1, 2] that the high brilliance of third-generation synchrotron radiation sources could provide solid ground for measurement of the second degree of coherence of the radiation beams they produce. In recent years, several attempts to observe two photon correlations in synchrotron radiation have been made [3, 4, 5]. Two of them succeeded, one in the hard x-ray wavelength range and one in the soft x-ray wavelength range. In both cases, sophisticated instrumentation and innovative approaches were applied, but only one significant data point was obtained in each experiment.

In this communication, we describe the results of a classical Hanbury Brown-Twiss experiment [6] conducted at the 3-ID beamline of the APS. We measured the second degree of coherence ($\gamma^{(2)}$) in the vertical direction as a function of the distance between two slits deployed in the x-ray beam. This allowed us to determine the vertical size of the positron beam at the APS storage ring.

Methods and Materials

The experimental setup is shown in Figure 1. It consists of a double-crystal diamond (111) monochromator, a 3 µm-wide horizontal slit, a high-resolution Si crystal monochromator, a Si(111) crystal beam splitter operating in the Laue geometry, and two avalanche photodiodes (APDs) with vertical slit openings of 8 µm each to detect the split x-ray beams. During the experiment, the position of one detector was fixed while the other was moved vertically across the x-ray beam. The high-resolution monochromator uses Si(422) and Si(10,6,4) channel-cut crystals in a nested energy-dispersive arrangement [7, 8, 9].

This system yielded a 5.5 meV bandpass at an energy of 14.413 keV. The beam splitter efficiency was 32% using a 30 µm-thick crystal. The main parameters of the experimental set-up, positron, and x-ray beams are summarized in Table 1. The coherence width was calculated by equation 1:

$$l_{x,y}=\lambda D/2\pi^{1/2}\sigma_{x,y}. \qquad (1)$$

The coherence time was calculated using $\tau_c = \lambda^2/\Delta\lambda$.

Table 1. Experimental parameters

*All positron and x-ray beam sizes correspond to half-width at half-maximum (HWHM) values.

Wavelength	λ	.086 nm
Distance between source and detectors	D	≈ 35 m
Positron bunch length	τ_b	≈ 65 psec
Coherence time	τ_c	≈ .85 psec
Horizontal source size	σ_x	≈ 355 µm
Vertical source size	σ_y	≈ 53 µm
Horizontal coherence width	l_x	≈ 2.4 µm
Vertical coherence width	l_y	≈ 16 µm

A schematic of the timing circuits used in the experiment is shown in Figure 2. Analog pulses from the APDs were converted to proper timing signals by constant-fraction discriminators. The direct coincidence counting rate (R_3) provides random as well as correlated events, whereas the delayed coincidence counting rate (R_4) gave only the random uncorrelated events. The delay time was adjusted to precisely one orbit period of the APS (3.683 µs).

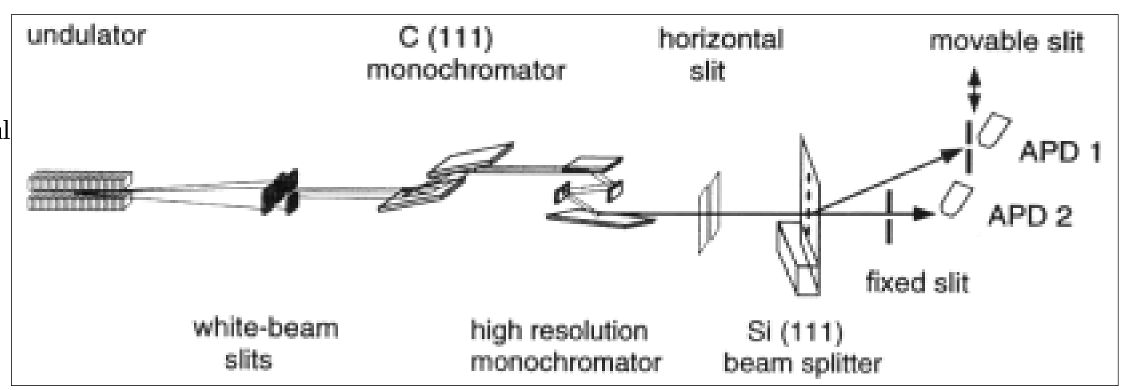

Figure 1: The experimental setup at beamline 3-ID.

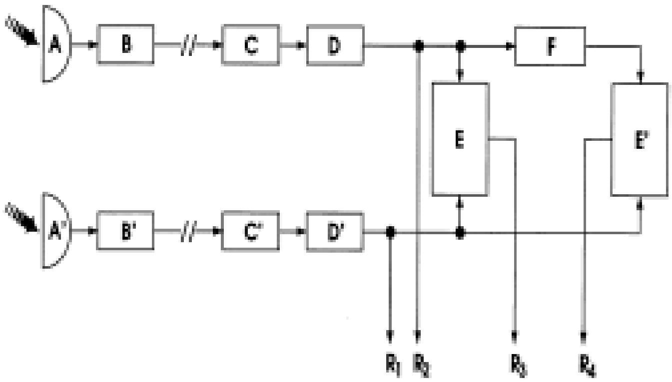

Figure 2: Schematic of timing circuits. The individual components are APD detector (A,A'), preamplifier (B,B'), main amplifier (C,C'), constant-fraction discriminator (D,D'), logic "and" coincidence (E,E'), electronic delay line (F).

The time resolution of the APDs was 1.5 ns, and the dead time of the electronic delay was 15 ns, which resulted in negligibly small (less than 5 x 10^{-4}) systematic errors for the filling pattern of the storage ring in which the positron bunches were 150 ns apart.

Results

Table 2 shows the results of the measurements. The ratio R_3/R_4 is equal to the value of the second degree of coherence, which was measured as a function of the APD slit separations over a 48 µm range.

Table 2. Experimental results.

Slit separation	T(sec)	R_3	R_4	R_3/R_4	$(1/R_3+1/R_4)^{1/2}$
-24	9240	300496	300118	1.0013	0.0026
-12	9240	462434	458846	1.0078	0.0021
0	9240	585631	580256	1.0093	0.0019
+12	9240	448040	443612	1.0100	0.0021
+24	9240	333177	332547	1.0019	0.0025

Figure 3 shows $\gamma^{(2)}$ as a function of the vertical slit separation. The HWHM of this function is approximately equal to 15 µm and, according to equation (1), it corresponds to 49 µm of the vertical positron beam size. The total measurement time for all data points was equal to 12.8 hours. This was sufficient to obtain an acceptable level of statistical errors (*i.e.*, the value of $(1/R_3+1/R_4)^{1/2}$ was several times smaller than (R_3/R_4-1) for data points measured within the x-ray beam coherent area). In the future, more precise data may permit an analysis of the shape of the second-order coherence function.

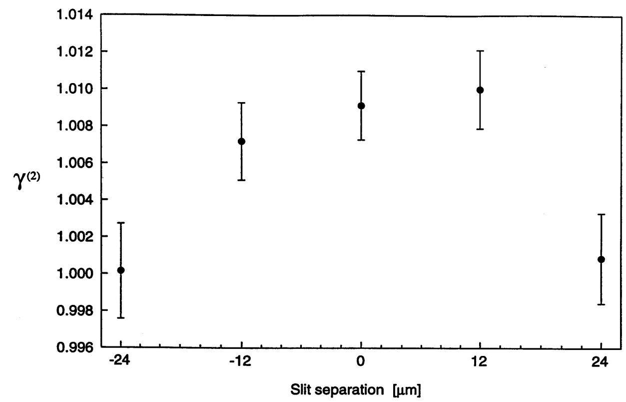

Figure 3: The second degree of coherence $\gamma^{(2)}$ as a function of the slit separation.

Acknowledgments

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