2D focusing in 8-ID-I without closing the white beam slit

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Abstract

Revised version 1.2, including horizontal transverse coherence length on 8-ID-I due to the pinhole and adding an educated guess of the performance of the scheme.

1 Horizontal focusing geometry

Table 1 shows the key geometric distances and source parameters. We want to focus 10.9 keV x-rays to a distance $i = 2.34$ m from the lens. Slit 1 is located upstream of the lens.

Horizontal rms source size	σ_x	275.4 μm
8-ID-A Pinhole diameter	D	270 μm
pinhole distance from source	R_p	26.0 m
lens distance from source	R_l	66.9 m
lens-sample distance	i	2.34 m
si1-lens distance	R_{si1}	0.584 m

Table 1: Useful parameters for 8-ID

If one focuses the horizontal source to the sample area, one expects the rms image size equal to $\sigma_x i/R_l = 9.6\mu$m, thus the FWHM of the focus is $2.35\sigma_x = 22.6\mu$m.

Can an observer at the lens see the full horizontal source? The source angle $\alpha = 2.35\sigma_x/R_l = 9.7\mu$rad, while the pinhole angle from the lens position is $\beta = D/(R_l - R_p) = 6.6$ μrad. Therefore, the pinhole limits the horizontal source size as seen by the lens, and also increases the horizontal transverse coherence length.

An image of the pinhole as focused on the sample would roughly be $\Delta = Di/(R_l - R_p) = 15.4$ μm horizontal FWHM. This is quite consistent with our beam on the sample these days.

To focus horizontally and vertically simultaneously with a 2D lens, we cannot limit the angle from the source as seen by the lens. The slit si1 does this when it is closed tightly. The horizontal angle made by si1hgap γ = si1hgap/R_{si1} must be greater than β, thus si1hgap $> R_{si1}\beta = 3.9\mu$m. But clearly if the slit is so small, slit1 acts as a source and cannot be focused by the lens. The thin lens formula would give 1/2.34 = 1/0.584 + 1/x where x = -0.78 m, thus a virtual magnified image of the slit 1 horizontal aperture. We want the diffraction pattern from slit 1 (w_d) small compared to Δ, so $w_d = 0.886\lambda(i + R_{si1})/a < \Delta$. The opening a should be greater than $0.886\lambda(i + R_{si1})/\Delta = 19.1\mu$m with 10.9 keV x-rays. The focal spot size will be a convolution of w_d and Δ for larger openings and is shown in Table 2. The horizontal transverse coherence length at the lens position assuming a slit opening D of the pinhole (from Goodman) is

$$l_x = \lambda/D * (R_l - R_p) = 17.2\mu\text{m}, \tag{1}$$

at 10.9 keV.

The lens parabolic transmission and finite dead layer thickness spatially filters the beam profile after the lens as

$$I(x, y) = T_0 I_0(x, y) \exp(-0.5(x^2 + y^2)/\sigma_a^2). \tag{2}$$

The RMS absorption aperture of the lens is $\sigma_a = 0.251$ m. Assuming a plane wavefront $I_0(x, y) = I$, over an aperture Δx by Δy, the integrated transmission is $T = 0.9837$ for $\Delta x = 5e-02$ mm and $\Delta y = 0.15$ mm for the Gaussian transmission. The aborption length l is 1 cm, so 8 lens with a dead layer of 30 microns has an apex or dead layer transmission $T_0 = \exp(-.024/l) = 0.976$, so total transmission losses are 96 % for the worst case with $\Delta x = 50$ μm, $\Delta y = 150$ μm. The gain in flux from today's 1D focusing at 11 keV is expected at $50/15 * 0.96 = 3.2$. One would expect a reduction of contrast as we open up si1hgap but an increase in signal to noise up to a peak at perhaps si1hgap = $3l_x$ [1]. It should also have better Ultra Small-Angle X-ray Scattering background horizontally than our 2D focusing at 7.35 keV where si1hgap = 150 μm.

Note that the APS 32-ID low-beta source has $\sigma_x = 114\mu$m, so in this case $\alpha = 4$ μrad, and is smaller than the angle $\beta = 6.6$ μrad of the pinhole as seen from the lens. If a low-beta source was available on 8-ID, beam size smaller than 16 μm would be possible, but simulations would be required for the actual shape and FWHM as the pinhole would cut off the horizontal tails of the beam. Using similar conditions as in Table 1 for 8-ID-I, one can get a focal waist of 9.3μm FWHM on 32-ID. An XOP simulation shows the spectral flux for this mode would be 63% from what it is today after the pinhole (not shown), so the improvement in spot size and coherent flux would require more simulations.

si1hgap or a (μm)	$\sqrt{w_d^2 + \Delta^2}$ (μm)
10	33.2
20	21.3
30	18.3
40	17.1
50	16.5
60	16.2

Table 2: Focal spot size.

References

[1] See Figure 7 in E. Dufresne et al., Phys. Rev. E Vol. 65, June 21, 065107 (2002) DOI: 10.1103/PhysRevE.65.061507.