2011 OAG-based source properties and beam sizes on beamline 7ID

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XSD Sector 7

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Abstract

This is a short report providing useful calculations on the beam sizes and source sizes on the Advanced Photon Source (APS) 7ID beamline for the current APS operation mode in 2011-3. Estimates of the impact of the L5-20 white beam slits opening is shown. The beam size in 7ID-B, 35 m from the source, is calculated.

PACS numbers: Sector 7 Report 2011-1, v1.1. Revised table 1 on 12-6-11 for typos on the source divergence. This is based from an appendix in MHATT-CAT Internal Report 1999-1 v2, revised February 5, 2001.

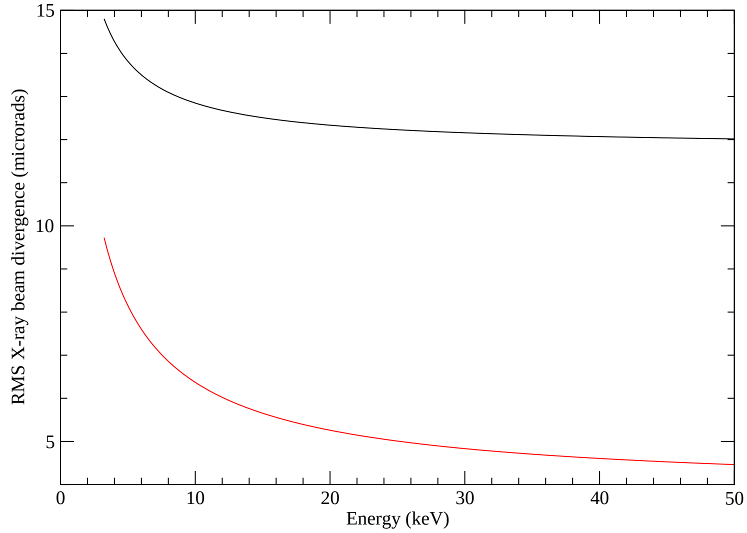


FIG. 1: X-ray beam rms source divergences versus energy.

I hope the calculations here will be helpful in planning experiments at the APS 7-ID beamline. Find below some calculations on the beam parameters from a 2.4 m long undulator as a function of energy. The beam size 35 m from the source is also calculated.

I. SOURCE SIZES, DIVERGENCES AND BEAM PROFILE AT 35 M

The rms electron beam horizontal (x) and vertical (y) source sizes are defined as σ_x and σ_y respectively. [2] The rms electron beam source divergences are similarly defined as $\sigma_{x'}$ and $\sigma_{y'}$ respectively. Table I shows the source parameters as calculated by the APS Operation Analysis Group (OAG) calculators and provided as Process Variables (PV) to every beamlines of the APS. The table shows the name of the PVs on 7ID as well. The accelerator parameters are defined in full details in Ref. [1].

source parameter	Process value (PV)	value
σ_x	S7IDSizeX	0.27 mm
σ_y	S7IDSizeY	0.0115 mm
$\sigma_{x'}$	S7IDDivergenceX	11.8 μrad
$\sigma_{y'}$	S7IDDivergenceY	3.84 μrad

TABLE I: OAG derived electron beam parameters for 7ID on Dec. 2, 2011.

The total X-ray beam divergences are

$$\Sigma_{x',y'} = \sqrt{\sigma^2_{x',y'} + \sigma^2_{r'}}, \quad (1)$$

where $\sigma_{r'} = \sqrt{0.5\lambda/L}$ is the single electron natural divergence of an undulator of total length $L = 2.4$m at a given wavelength λ[2, 3]. Some typical values are given in Table II.

Energy (keV)	$\sigma_{r'}$ (m)	$\Sigma_{x'}$ (m)	$\Sigma_{y'}$ (m)
3	9.27906e-06	1.50114e-05	1.00422e-05
4	8.0359e-06	1.42764e-05	8.90625e-06
5	7.18753e-06	1.38167e-05	8.149e-06
6	6.56129e-06	1.35015e-05	7.60237e-06
7	6.07457e-06	1.32718e-05	7.18652e-06
8	5.68224e-06	1.30969e-05	6.85809e-06
9	5.35727e-06	1.29592e-05	6.59135e-06
10	5.08235e-06	1.2848e-05	6.36992e-06
11	4.84583e-06	1.27563e-05	6.18285e-06
12	4.63953e-06	1.26793e-05	6.02253e-06
13	4.45752e-06	1.26139e-05	5.88346e-06
14	4.29537e-06	1.25575e-05	5.76158e-06
15	4.14972e-06	1.25084e-05	5.65383e-06
16	4.01795e-06	1.24653e-05	5.55784e-06
17	3.89799e-06	1.24272e-05	5.47174e-06
18	3.78816e-06	1.23931e-05	5.39405e-06
19	3.68712e-06	1.23626e-05	5.32358e-06
20	3.59376e-06	1.23351e-05	5.25935e-06

TABLE II: Source divergence vs energy from 3 to 20 keV.

Fig. 1 shows the energy dependence of the source divergence in the horizontal and vertical direction. The energy dependence must be accounted for since the variation can be quite appreciable, specially in the vertical direction. It is caused by the energy dependence of the single electron natural divergence $\sigma_{r'}$.

Similarly, the total rms source size is

$$\Sigma_{x,y} = \sqrt{\sigma_{x,y}^2 + \sigma_r^2}, \tag{2}$$

where the single electron source size is $\sigma_r = 0.25\sqrt{2\lambda L}/\pi$ [2, 3].

Fig. 2 shows the X-ray beam vertical rms source size varies by about 4.3 % over the energy range shown. The X-ray beam horizontal rms source size (270 μm) is not shown since it changes by only by about 80 ppm over the range of energies shown.

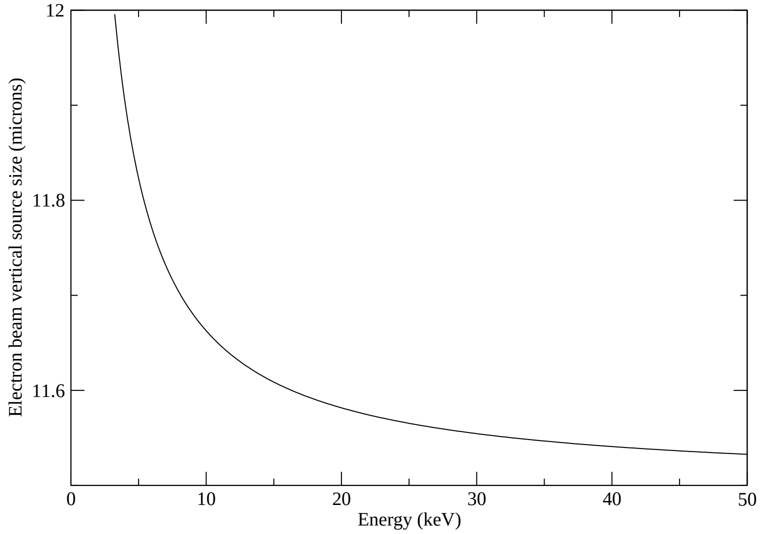
The X-ray beam size at a given distance R_s from the source is thus

$$\Sigma_{x,y}^* = \sqrt{\Sigma_{x,y}^2 + R_s^2\Sigma_{x',y'}^2}. \tag{3}$$

Fig. 3 shows the rms beam size in 7ID-B, 35 m from the source. At 8 keV, the rms spot sizes are 0.241 mm and 0.53 mm, thus one expects the FWHM to be 0.566 mm and 1.25 mm respectively in the vertical and horizontal direction.

A. Flux throughput of the white-beam slits for 10 keV X-ray operation.

The L5-20 white-beam slits in the 7ID-A are placed just upstream of the Kohzu HLD-4 monochromator. They are helpful to control the power incident on the first crystal of the



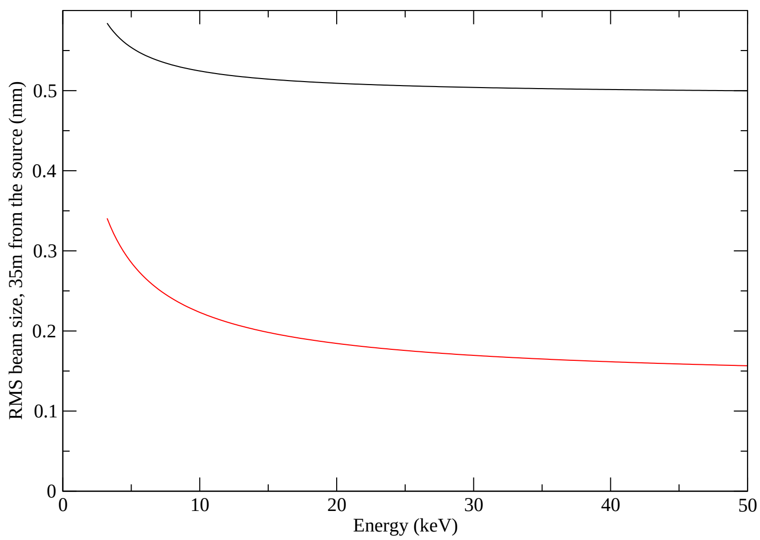


FIG. 3: X-ray beam rms size at 35 m from the source.

monochromator. It is important to remember that the power density spatial profile is much broader than the fundamental flux spatial profile[3]. Because of this, one should keep the white beam slits open enough to transmit most of the fundamental or harmonics of interest, but small enough to minimize the power on the first crystal.

For operation purposes, we should remind ourselves that for a Gaussian source with rms size σ, the total flux transmitted through an aperture Δ is

$$\mathrm{erf}(\frac{\Delta}{2\sqrt{2}\sigma}). \tag{4}$$

Computed values for several values of Δ/σ are shown in Table III. For example, if $\Delta = 4\sigma$,

Δ/σ	Transmitted fractional flux (%)
0.5	19.7
1.0	38.3
1.5	54.7
2.0	68.3
2.35	76.0
2.5	78.9
3.0	86.6
3.5	92.0
4.0	95.5

TABLE III: Some tabulated values of Eq. 4.

then 95.5 % of the flux is transmitted. Also, note that a Gaussian has a FWHM equal to 2.35σ.

The slits are located 26.5 m from the source so we can re-evaluate Eq. 3 at this distance. At 10.05 keV, the beam sizes in the slit plane is 0.434 and 0.169 mm rms in the horizontal and vertical direction respectively. A typical opening of the L5-20 is 0.5 mm by 0.5 mm, so it would accepts 86.6 % of the vertical fan, but only about 40% of the horizontal fan. A vertical opening of 0.5 mm is still very good and transmits most of the flux. Depending on the X-ray optics used for microfocusing, one may open up the horizontal white-beam slit opening.

For more details on the source properties, I strongly recommend reading Ref. [1] and [3]. The former explains in more details the accelerator phase space properties, while the latter shows complex radiation patterns of Undulator A.

B. Transverse coherent lengths.

Note that from these source sizes, one may also compile the transverse coherence of the source given by

$$l_{x,y} = \frac{\lambda R_e}{2\sqrt{\pi}\Sigma_{x,y}}, \tag{5}$$

where $R_e \approx 35$m is the distance source-experiment for ID-B. Eq. 5 takes into account the Gaussian source profile into the computation of the transverse coherence length [4].

Fig. 4 shows the transverse coherence lengths in the horizontal and vertical in ID-B for obsolete source parameters computed in 2001.

[1] Michael Borland, "Explanation of Automatic Source Size Computation for APS Beamlines", Technical report OAG-TN-2004-006, Rev. 1 3-12-2004 (Revised 7-27-2011). See `https://icmsdocs.aps.anl.gov/docs/groups/aps/@apsshare/@acceleratoroperationsphysics/documents/report/aps_1424141.pdf`.

[2] R. Dejus, B. Lai, E. Moog, and E. Gluskin, Technical bulletin ANL/APS/TB-17, Advanced Photon Source, Argonne National Laboratory, 9700 South Cass Ave, Argonne,

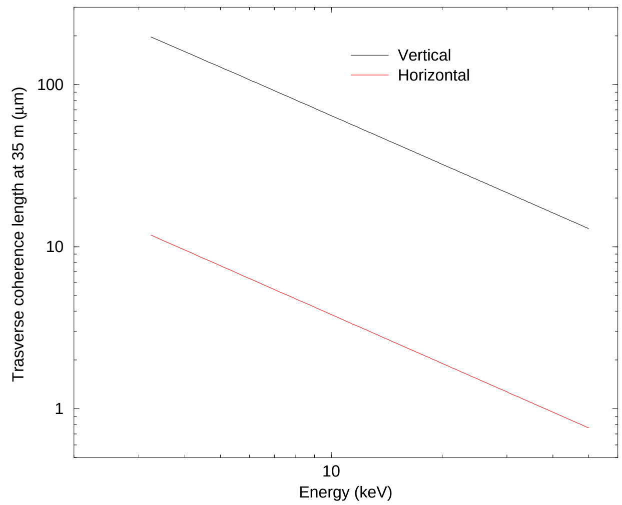


FIG. 4: X-ray transverse coherence lengths, 27 m from the source with old source parameters.

IL 60439 (See `http://www.aps.anl.gov/Science/Publications/techbulletins/content/files/aps_1422142.pdf`).

[3] Roger J. Dejus, Isaac B. Vasserman, Shigemi Sasaki, and Elizabeth R. Moog, Technical Bulletin ANL/APS/TB-45, Advanced Photon Source, May 2002 (See `http://www.aps.anl.gov/Science/Publications/techbulletins/content/files/aps_1421569.pdf`.

[4] J. Goodman, *Statistical Optics*, 1st ed. (John Wiley & Sons, Inc., New York, 1985), pp. 465–532.