PSF CHARACTERIZATION OF THE ALBA X-RAY PINHOLES

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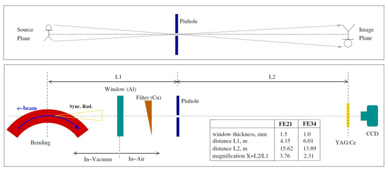
ABSTRACT

ALBA is currently equipped with two x-ray pinhole cameras for continuous beam size monitoring using the synchrotron radiation from two different bending magnets. The first pinhole was installed in day-1 and it is working properly since 2011 as the work-horse for the ALBA emittance measurements, while the second one has been commissioned in 2021 for redundancy purposes. This paper summarizes the exercises to characterize the Point Spread Function (PSF) of both pinhole cameras using analytical calculations, SRW simulations, and experimental measurements.

Introduction



Top: general working principle of a pinhole imaging system.
Bottom: sketch of the x-ray pinhole cameras at ALBA, with the geometrical parameters of FE21 and FE34.

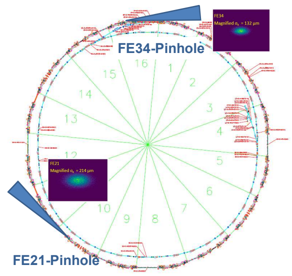
The Point Spread Function (PSF) of an imaging system defines the response of the system to a point-like object, so it defines the minimum size that the system can resolve.

Using an x-ray pinhole, the PSF is given by diffraction and blurring effects, and eventually by the CCD screen pixel:

$$\sigma_{\rm PSF} = \sqrt{\sigma_{\rm blur}^2 + \sigma_{\rm DIFF}^2 + \sigma_{\rm screen}^2}.$$

This report studies the PSF of the two pinholes at ALBA (FE21 and FE34), and using different settings of the Cu filter:

- FE21, with 1.5mm of Al
- FE21, with 1.5mm of Al, and [1.5mm of Al + 0.3mm of Cu]
- FE34, with 1.0mm of Al
- FE34, with 1.0mm of Al, and [1.0mm of Al + 0.3mm of Cu]



	FE21	FE34
hor beam size, μm	55	60
ver beam size, μm	24	25
hor beta function, m	0.52	0.435
ver beta function, m	22.83	25.82
hor dispersion, mm	20.1	37.1
ver dispersion, mm	7.0	11.5
energy spread, %	$1.05\cdot 10^{-3}$	
emittance, nm·rad	4.65	
coupling, %	0.5	
dipole field, B[T]	1.42	
energy, GeV	2.98	

Table 1: Main operation parameters of the ALBA SR and values of the Twiss parameters at FE21 and FE34.

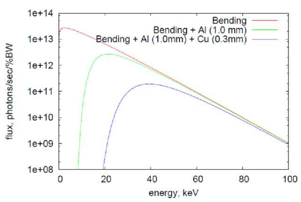
Analytical PSF Calculation

For a given photon energy, and pinhole width "w", this is:

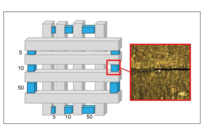
$$\sigma_{\rm blur} = \frac{w(L_1+L_2)}{\sqrt{12}L_1}, \quad \text{and} \quad \sigma_{\rm diff} = \frac{\sqrt{12hc}}{4\pi}\frac{L_2}{E\cdot w},$$

The diffraction contribution considers the energy spectrum given by the ALBA pinholes:

$$\sigma_{\rm DIFF} = \int \sigma_{\rm diff}(E)P(E)dE, \quad \text{with} \quad P(E) = \frac{N_{\rm ph}(E)}{\int_0^\infty N_{\rm ph}(E)\,dE}.$$

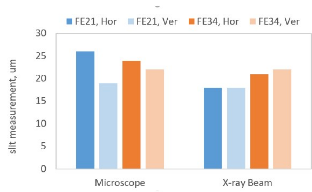


Pinhole Width Measurement



The pinhole block sketch is made of tungsten blocks with shims in between of 5, 10, and 50um.

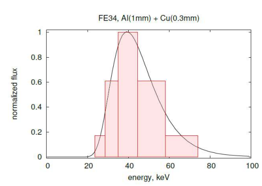
Using the 10um shims, measurements with two different techniques show that the real width is approximately a factor 2 larger (20um).



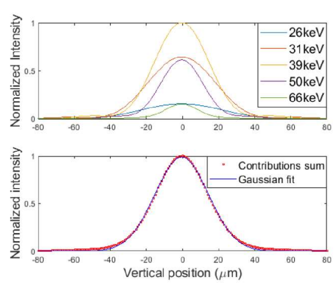
PSF Calculation with SRW

Synchrotron Radiation Workshop (SRW) is a simulation code for beamline design and optimization in the IR, IV, and X-Ray range.

SRW only allowed monochromatic x-ray simulations. In order to study the realistic case, we discretized the x-ray spectrum into different energies.
We weighted these contributions by the normalized spectrum and finally summed up into one contribution.
The PSF is obtained after fitting this profile to a Gaussian file



Normalized transmission spectra for FE34, assuming 1mm and 0.3mm of Cu. The red squares denote the energies and its normalized value considered for the PSF calculations using SRW simulations.



Top: intensity profiles at the screen in FE34 for five different energies for the case with 0.3mm of Cu obtained with SRW.
Bottom: summ of all the contribution (red dots), and Gaussian fit (blue), from where the PSF is obtained

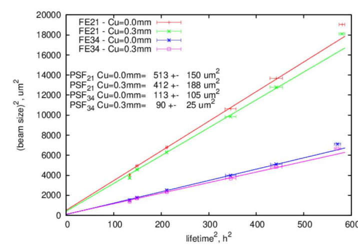
Experimental PSF Evaluation

Following the example in [XX], we can obtain the PSF by measuring the beam lifetime. For an ultra-relativistic case, and in ALBA conditions, the Touscheck lifetime is:

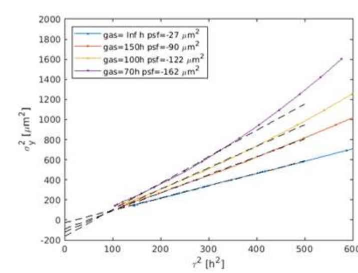
$$\frac{1}{\tau_T} \approx \left\langle \frac{cr_p^2 N_p}{2\sqrt{\pi}\gamma^2\sigma_z\sigma_x\sigma_y\delta_m^2} \right\rangle \quad \rightarrow \quad \sigma_y = k\cdot\tau,$$

Assuming that the beam size at the pinhole is prop. to the average beam size in the machine:

$$\left(\frac{\sigma_{\rm YAG}}{X}\right)^2 = (k\tau)^2 + \left(\frac{\sigma_{\rm PSF}}{X}\right)^2.$$



The assumptions might not always be fulfilled in ALBA, as shown by simulations below for FE34. This produce big error bars in the measurements.



This experiment is performed during different days, and we find big differences in the results (even with negative PSF). The values in the table below show the average and spread of the different experiments performed during last year.

RESULTS AND CONCLUSIONS

The characterization of the PSF at ALBA x-ray pinholes has been done with three different methods: using an analytic calculation, with the simulation code SRW, and with an measured experimentally through the beam lifetime. For FE21, the results with the three techniques agree very well (around 20um). For FE34, the analytic and SRW simulations agree well, but the experimental values are lower; nevertheless, we note the inherently large error bar in the experimental measurement. Note that in all cases, the analytical calculations and the SRW simulations agree very well

	FE21 Al	FE21 Al + Cu	FE34 Al	FE34 Al + Cu
Analytic	24.4	18.9	21.7	15.2
SRW	23.1	18.8	17.8	14.8
Exper.	20 ±16	20 ±14	17 ±13	17 ± 13

The PSF values obtained for the FE21 pinhole are larger than the ones of FE34 because the magnification of pinhole FE21 is larger. Despite this fact, the resolution (in terms of minimum measurable beam size) of FE21 pinhole is better than FE34. Note that σ_{PSF}/X is the minimum beam size a pinhole can measure. Then, using the values from the "Analytic" calculations, the resolution of the pinholes are 6.5 μm (FE34) and 5.0 μm (FE21) in the case with Cu filter of 0.3mm, which would correspond to the minimum beam size measurable at ALBA. Note that the effect of adding in quadrature PSF to the vertical beam size is in the order of few %: using 0.3mm of Cu corresponds to 2% for FE21, and 3% in FE34 for the typical operation values of σ_y = 30μm.

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