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SIRIUS DIAGNOSTIC BEAMLINES

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Abstract

Sirius is a 3 GeV synchrotron light source that is being built by the Brazilian Synchrotron Light Laboratory (LNLS). It will be part of a novel class of light sources with emittances in the sub-nm level. Both horizontal and vertical beam sizes at the dipoles will be of the order of or below 10 μm, creating difficulties for measuring them using conventional techniques. This paper proposes a series of beamlines using different techniques that, combined, will be able not only to resolve beam sizes, but also measure energy spread and local transverse coupling in the storage ring.

INTRODUCTION

Sirius will be a diffraction limited storage ring (for soft X-rays) and will have an emittance in the sub-nm level [1]. To show all of its potential, it is important to have diagnostics capable of measuring such small emittances. Both horizontal and vertical beam sizes at the dipoles will be of the order of 10 μm or below, creating difficulties for measurements using conventional techniques. This article presents a set of beamlines that will be able to resolve not only the beam sizes, but also measure energy spread and transverse coupling. In the next sections we discuss the difficulties in implementing some standard techniques in Sirius, the plans for the first diagnostics beamline and possible future upgrades.

DIFFICULTIES

The diagnostics beamlines for Sirius will be located at the dipoles on the sectors after injection and RF, where no IDs are planned to be installed. It is possible to extract light from 3 out of the 5 dipoles: the first two dipoles in the sector (B1 and B2), and the central dipole BC (see Figure 1). Table 1 presents the critical energy and beam sizes in each dipole.

Table 1: Source parameters for Sirius,considering a horizontal emittance of 0.28 nm rad and 1% coupling.

Source	Critical Energy (keV)	Beam sizes (μm) σ_x	σ_y
B1	3.5	21.5	8.5
B2	3.5	33.4	7.4
BC	11.7	10.6	4.0

From the critical energy, it is clear that any technique employing hard X-rays should use the central dipole as a source point; however, it is in this dipole that the beam sizes are smallest in both planes, making the measurement challenging. For dipoles B1 and BC it is possible to extend a straight

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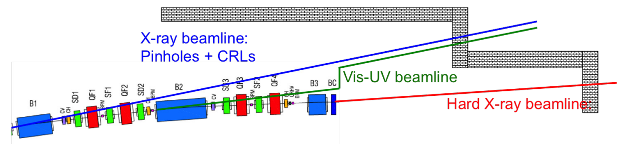

Figure 1: Schematic drawing of the possible beamlines in Sirius coming form 3 dipoles, B1, B2 and BC respectively.

beamline outside the tunnel, as there will be openings on the shielding wall and in those beamlines the first element has to be about 7 m from the source due to space constraints.

For the case of B2 it is not possible to go out of the tunnel in a straight line, however if the beamline has a “knee” (parallel displacement) the opening on the shielding for the beamline from B1 could in principle be used by both beamlines. In this case, they would also share the same hutch, reducing overall costs. This would imply that only techniques using vis-UV radiation could be implemented on a B2 line. The vacuum chamber would also have to be specially made for this particular arc, since for vis-UV radiation a much larger acceptance is needed. In the current design the acceptance for B2 is ±2 mrad in the vertical plane and ±4 mrad in the horizontal; in order to be able to capture the complete fan of vis-UV radiation, the vertical acceptance has to be increased by more than a factor of 2, to ± 4.5 mrad. Furthermore, it will be necessary to either move or remove the vertical corrector that comes right after the B2 dipole in order to install a pumping station. At least one beamline coming from the B2 bending dipole is essential, since this is the only source in which we have a measurable dispersion function (η_x = 38 mm) and thus, where a direct measurement of the energy spread is possible. For B1 and BC the dispersion function is effectively zero.

FIRST DIAGNOSTIC BEAMLINE

For the first beamline, the idea is to have the simplest and cheapest method to measure the horizontal emittance: an X-ray pinhole. This is the most common way for measuring beam sizes, and the beamline would be composed of a set of attenuators and filters, a pinhole array, a phosphor screen and a CCD camera.

For simulations we considered that the pinholes are 5 m away from the source and that the beamline has a magnification factor of 5. In this setup, there is no gain in having pinholes smaller than 10 μm, and having an array with 10, 15 and 20 μm pinholes would cover the optimum size for a broad range of wavelengths. Figure 2 shows the result from a Synchrotron Radiation Workshop (SRW) [2] simulation for the pinholes in Sirius; notice that for most cases the

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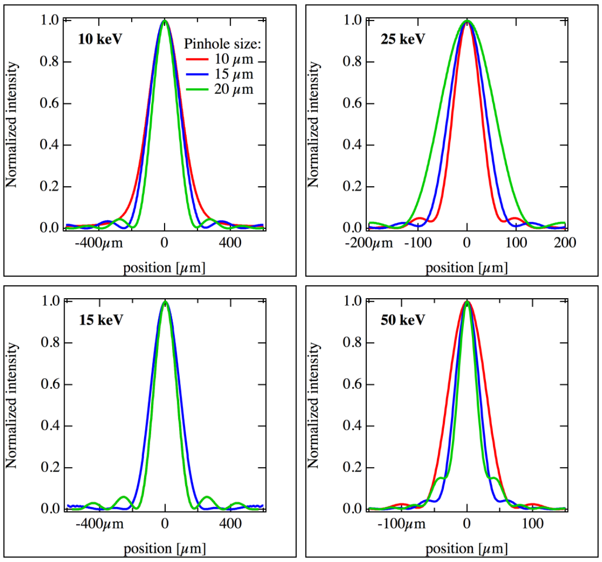

Figure 2: SRW simulations for the pinholes in Sirius, up to 50 keV the diffraction can be nicely approximated by a gaussian. The source-pinhole distance was kept fixed at 5 m and the beamline magnification is 5.

Fraunhofer approximation is still valid and the diffraction pattern can be fitted by a gaussian.

The imaging system contribution to the point spread function (PSF) can be further decomposed into two contributions; PSF_{screen} accounts for the blurring of the final image due to the thickness and grain size of the phosphor screen ($\approx 6-10\mu m$), and PSF_{CCD} is the rms spatial resolution of the camera, which can be approximated by the pixel size divided by the magnification. The pixel size of a standard CCD camera is 4.65 μm, thus $PSF_{CCD} \approx 1\mu m$. Gathering those two contributions, we have $PSF_{imag} \approx 6\mu m$ [3].

Table 2 summarises all the contributions to the total PSF of the system as a function of pinhole size and photon energy. Notice that this beamline can measure horizontal beam sizes however it is not optimal for vertical beam sizes.

Table 2: Total contribution to the PSF at 25 m from the pinhole.

Pinhole Size	**PSF (μm)**			
	10 keV	**15 keV**	**25 keV**	**50 keV**
10 μm	21.9	15.5	10.9	8.1
15 μm	16.0	12.2	9.7	8.5
20 μm	13.9	11.5	10.1	9.4

FUTURE UPGRADES

As possible upgrades for the pinhole beamline and also for an extra diagnostic beamline, two well established techniques, Compound Refractive Lens (CRLs) and the π-polarization, are the best candidates. The first technique allows for the measurements of vertical beam sizes on the B1 dipoles and the second uses vis-UV light and can thus be used to extract light from the B2 dipoles.

Compound Refractive Lens

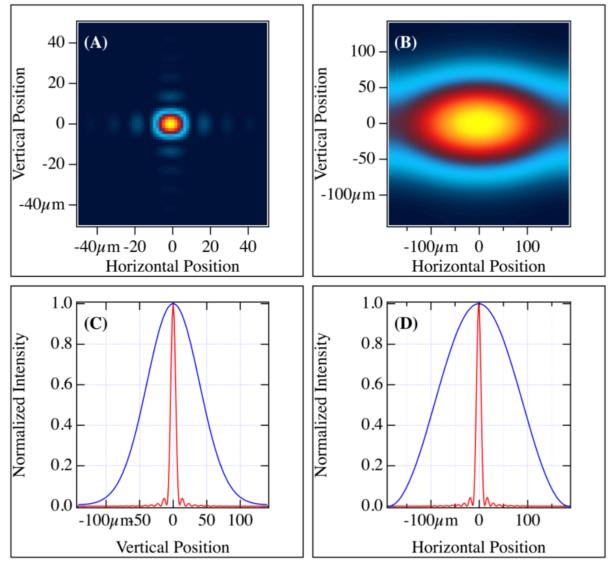

Figure 3: SRW simulations. Plots (A) and (B) are the images of the single and multi electron case on the CCD. (C) and (D) are the projections in the horizontal and vertical planes for the single (red lines) and multi (blue lines) electron cases.

X-ray lenses of Aluminum and Beryllium are becoming more and more common in synchrotron radiation applications [4]. In 2011, a set was installed and succesfully tested in an ESRF diagnostics beamline for measuring the electron beam size [5]. The benefits of those elements are ease of alignment and image quality; however, since the X-ray lenses show chromatic aberration effects, a monochromator is necessary to obtain good results.

For Sirius, if the same beamline used for the pinholes (B1 dipole) is also used for the CRLs, the distance source-refractive lens can be set to about 5 m and the distance lens-CCD to 23.56 m which means the focal length should be $f = 4.12$ m. Using the a set of parabolic Aluminum lens with $R = 50$ μm for an energy of 25 keV it is necessary to stack 7 lenses to achieve the desired focal length. Figure 3 shows a simulation in SRW of this setup. The $PSF = 1.22\lambda f/A_{eff}$ that for the proposed setup is 0.8 μm, given an effective lens aperture of $A_{eff} \approx 300\mu m$, is sufficiently small to measure the beam size in both directions.

This method has great potential to be used for measuring ultra-small beam sizes and is also a good candidate to be used on a diagnostic beamline coming form a BC dipole. A more detailed study including effects of heat load on the monochromator and lenses is still needed.

π-Polarization and Interference Method

The π-polarization method enables the measurement of the beam size by imaging the vertically polarized vis-UV synchrotron radiation [6]. Although the π-polarization is

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an effective method for measuring the vertical beam size, for the horizontal beam size measurement, in Sirius, due to the small horizontal emittance diffraction has a strong contribution and it is necessary to calculate a PSF to be subtracted from the measured σ_x. The calculated PSF_x, for the B2 dipole, is 21 μm for a wavelength of 364 nm and 16 μm for 266 nm, both smaller than the source size (see Table 1).

Despite its several advantages, the resolution of the π-polarized method is limited for very small beam sizes (4 μm or less), as the sensitivity of this method to beam height changes becomes weaker for smaller values. In order to gain sensitivity to small beam sizes we can make use of the interferometric method [7], by introducing a double slit in front of the light beam. The principle of this measurement is the *van Cittert-Zernike theorem*, and is based on the fact that a measurement of spatial coherence of synchrotron light in the vis-UV region is related to the beam size. The π-polarized and the interference methods are essentially the same and can be combined in the same beamline by just adding a set of movable obstacles on the vis-UV light path. An example of the interference measurement in dipole B2 using 266 nm radiation is shown in Figure 4(A) and (B).

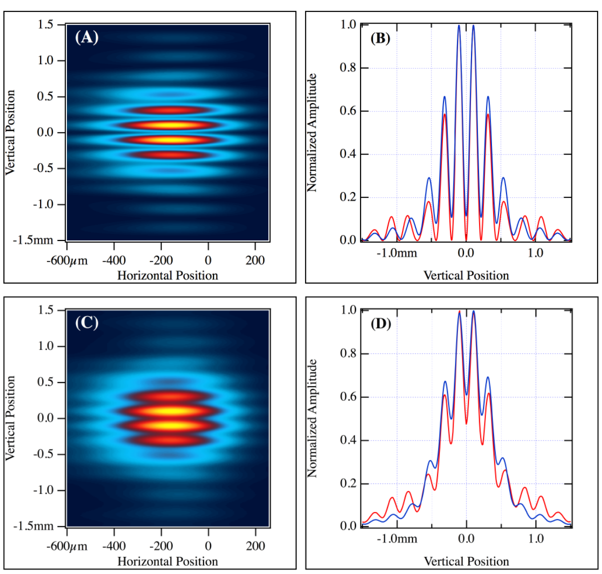

Figure 4: Interference image from dipole B2 (top) and interference with imbalance (bottom) simulated in SRW. (A/C) Image and (B/D) multi (blue) and single (red) electron profiles.

For this same method we can also use a trick to increase the visibility in a controlled way, specially for very small beam sizes, and lift the measured interference pattern out of the CCD noise level, thus increasing the dynamic range of the measurement. The idea is to create an intensity imbalance between the two slits as explained in [8]. For example, using this technique it is possible to lift the fringes in the interference pattern above the noise as shown in Figure 4(C) and (D). Figure 5 (A) shows the valley-to-peak sensitivity increase when using the interference, or Mitsuhashi, method compared to the π-polarization and Figure 5(B) shows how a change in visibility can create an offset in the valley-to-peak curve, making it easier to measure the beam size.

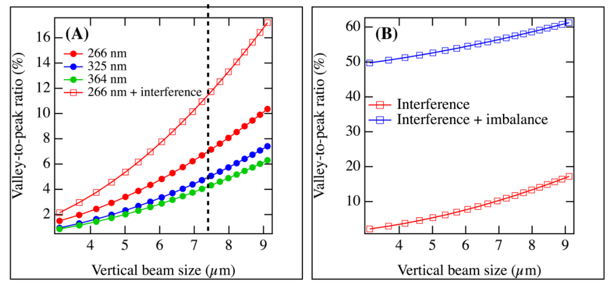

Figure 5: Valley-to-Peak ratios for the beamline in bending magnet B2 for different wavelengths and techniques. (A) Comparison of sensitivity between the pure π-polarization method and the interference method and (B) Increase in the dynamic range given when using an imbalance between the two slits from the interference method. The dashed line corresponds to the nominal vertical beam size at the source point (1% coupling and 0.28 nm rad horizontal emittance).

CONCLUSIONS

This paper presented the plans for the first diagnostic beamline for Sirius, aimed only at measuring the horizontal emittance of the machine. A set of two other beamlines are planned as an upgrade. The techniques used are already established and well tested, and present a way to measure local horizontal and vertical beam sizes, energy spread and also local coupling. Further studies for a third beamline using radiation from a center dipole (BC) are under way.

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