Point Spread Function dominated imaging with SR

Åke Andersson

Outline

- Background & Some examples
- Measurements at the MAX IV 3 GeV ring
- PSF imaging at the coming DLSR?

Background

An early SR imaging publication:

SLAC-PUB-1207
(A)
March 1973

MONITORING THE BEAMS IN SPEAR WITH SYNCHROTRON LIGHT*

A. P. Sabersky

Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

Bringing the Synchrotron Light Out of the Ring

The SLAC storage ring, SPEAR, emits up to 150 kW per beam of synchrotron radiation. The power density on components inside the ring reaches 1 kW per cm^2, so transparent windows struck directly by the synchrotron radiation are out of the question. Only 5×10^{-4} of the total radiated power is visible light at 1.5 GeV. This power can be absorbed before the light passes through a window by having the radiation strike a metal mirror from which the visible light is reflected and in which the x-rays are absorbed.

We then face the problem of thermal deformation of the mirror. The x-ray power is concentrated in an angular cone of approximately 0.2 mrad width in the vertical plane, while the visible light has a divergence of 4 mrad. A slot in the mirror would pass the x-rays, and avoid most of the heating problems, but this is relatively impractical for a fixed mirror, since the vertical position of the beam is uncertain.

Mirror Deformations

A thermal-mechanical analysis[1] and experiments with electron beams show that deformation of a thick metal mirror reaching 10 watts, there has been no degradation of the beam image due to permanent deformation, and no mirror darkening.

The window is polished, fused quartz which produces a wavefront distortion <1/4 λ at 6000 Å.

Alignment

The ideal central orbit of the storage ring lies in a plane perpendicular to the direction of gravity, so it is simple to align the optical axis of the instrument horizontally with bubble levels. There are stainless steel reflecting targets on the floor of the vacuum chamber just below the calculated position of the beam image. The target (Fig. 3) has two diffuse-finish segments which reflect light back towards a source, and a central polished ramp which reflects the light up and away from the source.

The line of sight passes through the center of the collimator in front of the Invar mirror and is centered on the dark space between the reflecting segments.

Although the pre-alignment techniques helped a great deal, it was still necessary to do a final touchup of align-

Basic tasks, but still today extremely important!!!

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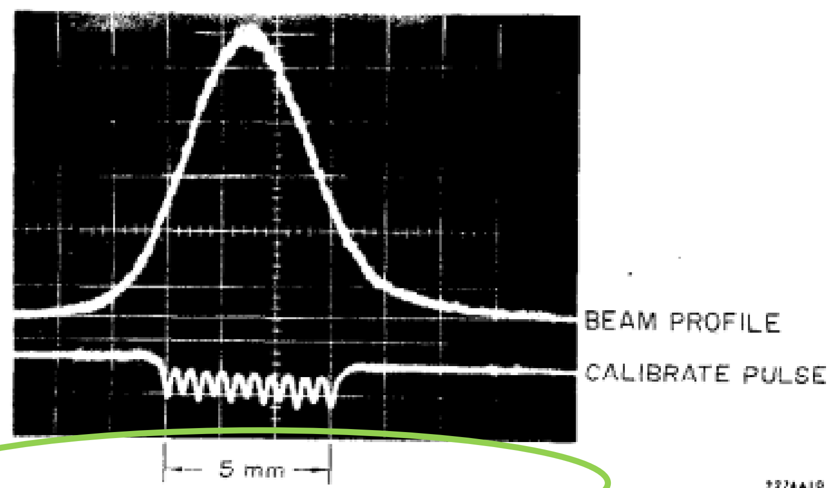

FIG. 9--Scanned horizontal beam profile and calibrator pulses.

On the other hand, at that time, the PSF was probably << the beam size.

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Example

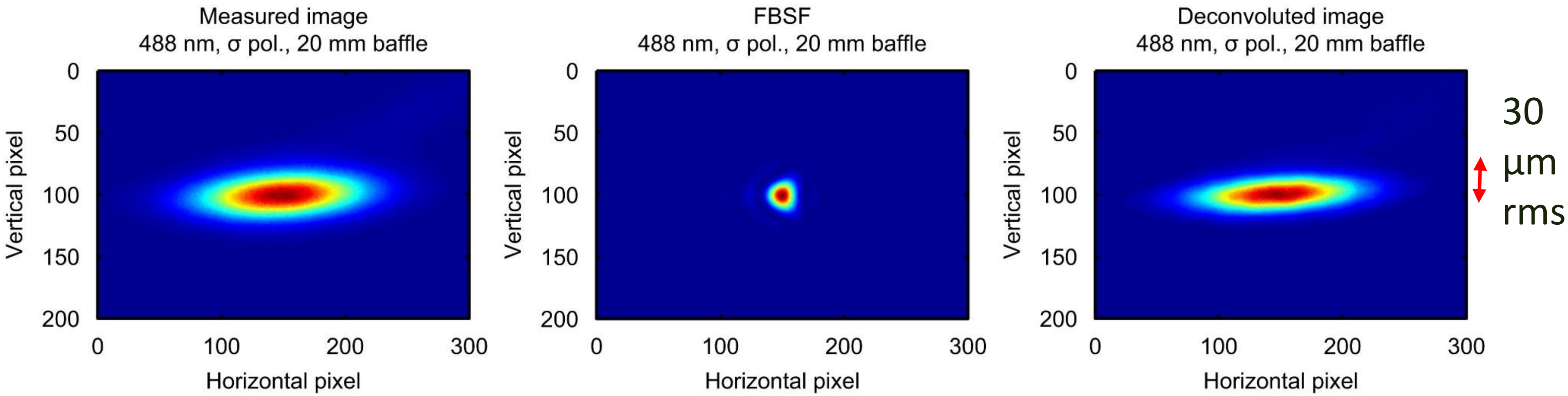

Fig. 4. Example of beam profile measurement with σ-polarized light at 488 nm. Measured image, filament-beam-spread function and deconvoluted image for baffle aperture 20 mm (±5.4 mrad horizontal opening angle). Pixel size 3.75µm.

A. Hansson et al, "Transverse electron beam imaging system using visible SR at MAX III", Nucl. Instrum. Meth. A 671, 94-102 (2012).

FBSF denotes better the image formed by SR from a single electron!

Example

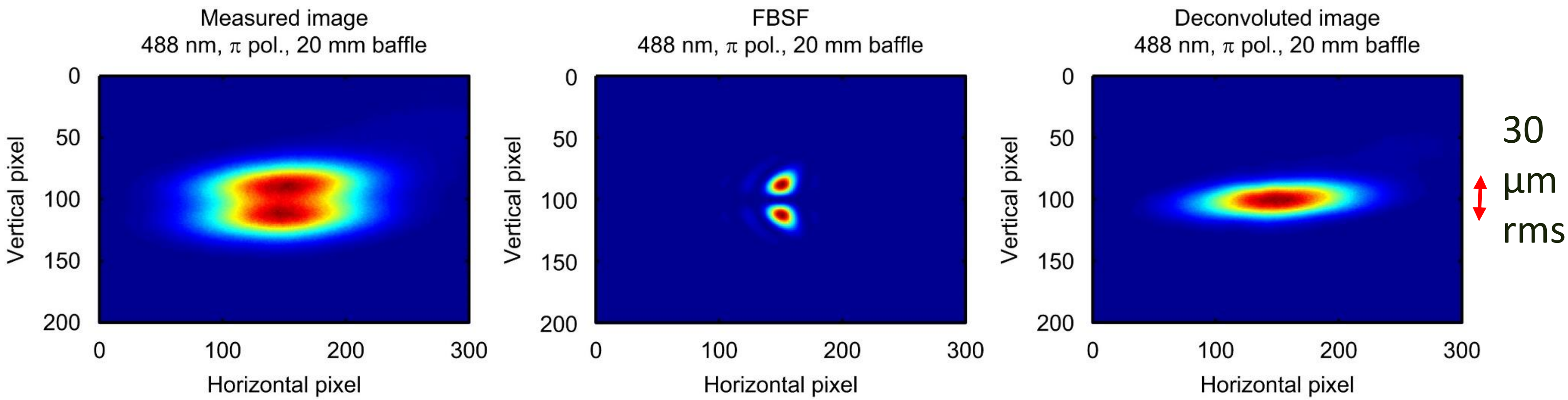

Fig. 7. Example of beam profile measurement with π-polarized light at 488 nm. Measured image, filament-beam-spread function and deconvoluted image for baffle aperture 20 mm (±5.4 mrad horizontal opening angle). Pixel size 3.75µm.

Here the FBSF contributes largely to the measured image.

A. Hansson et al, “Transverse electron beam imaging system using visible SR at MAX III", Nucl. Instrum. Meth. A 671, 94-102 (2012).

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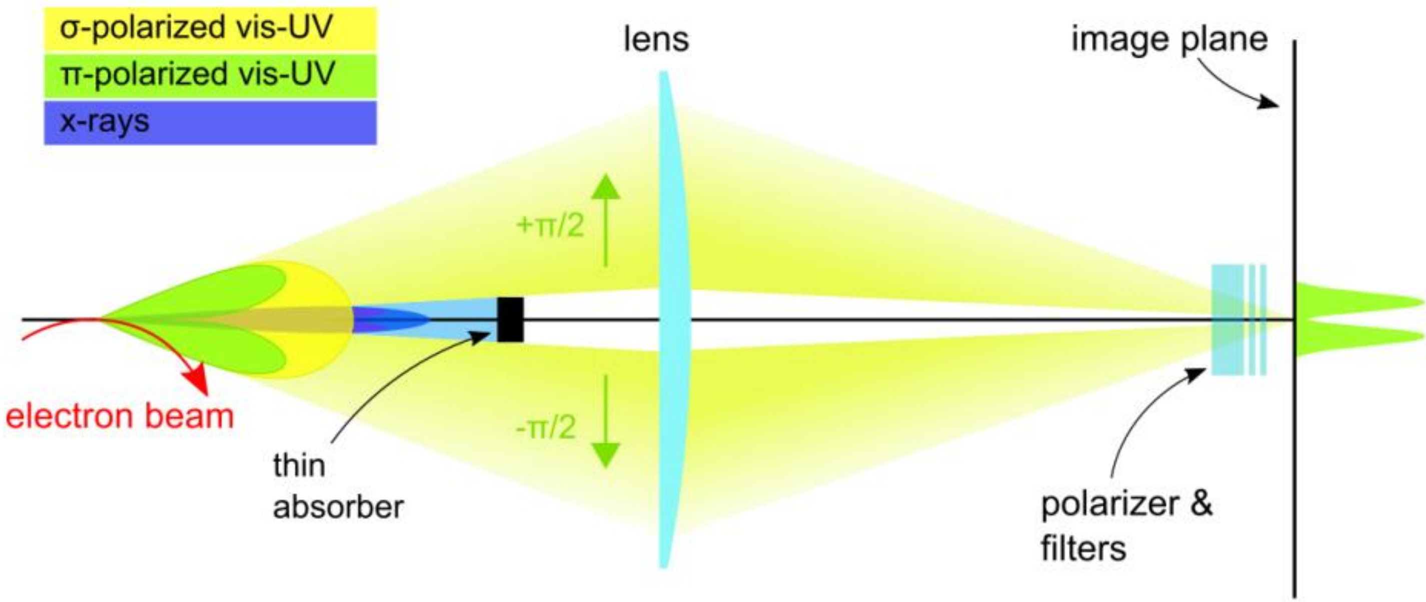
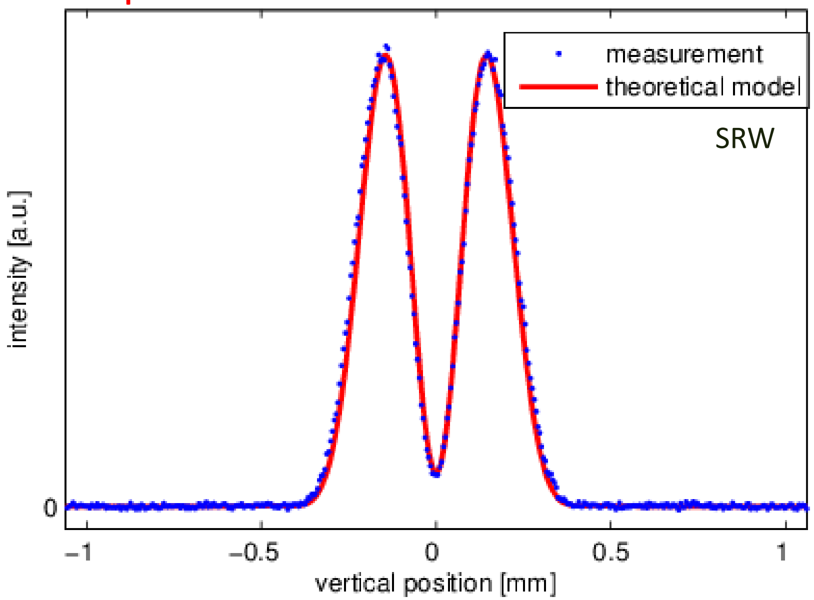
Resolving a vertical beam size < 5 µm



Pi-pol. Method:

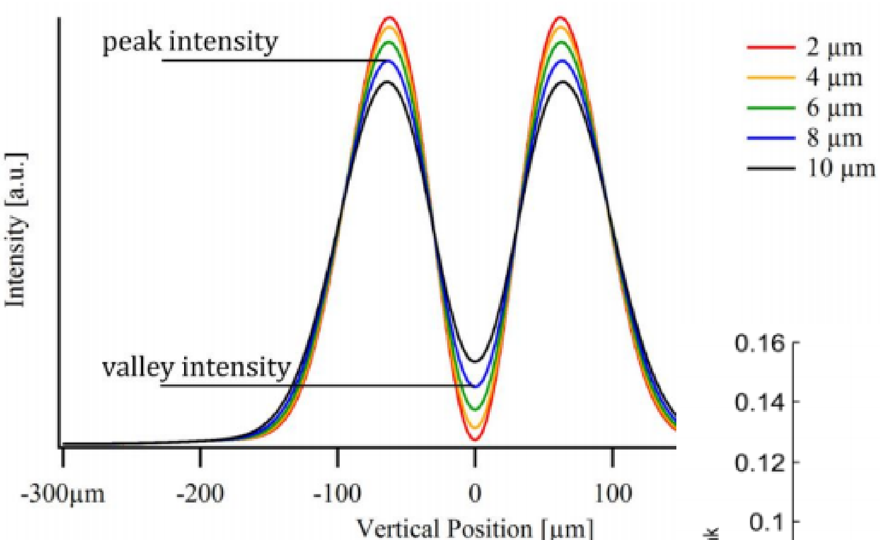


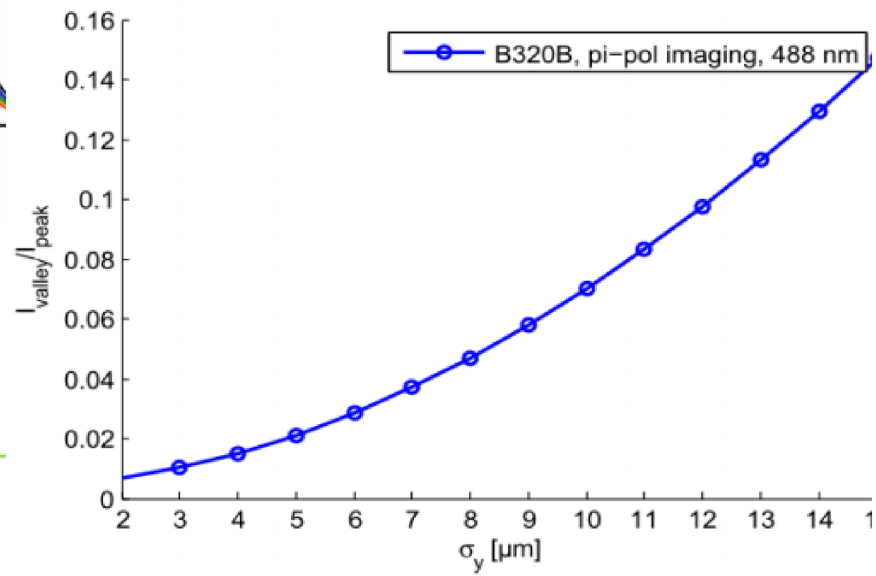
In this case the vertical image profile will be dominated by the FBSF, but can still reveal the true vertical beam size.

Theoretical prediction of the FBSF is crucial. We use the code SRW:

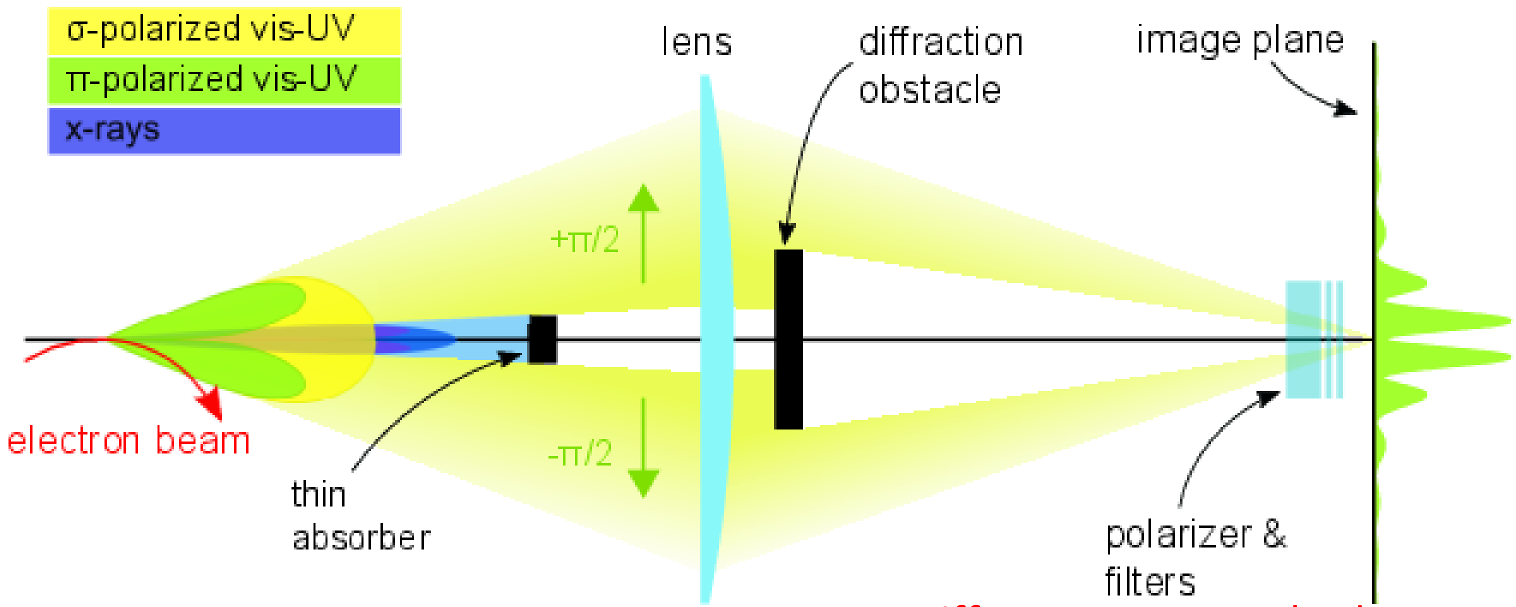
O. Chubar and P. Elleaume, "Accurate and efficient computation of synchrotron radiation in the near field region", EPAC1998, Stockholm, Sweden, p. 1177.

Resolving a vertical beam size < 5 µm

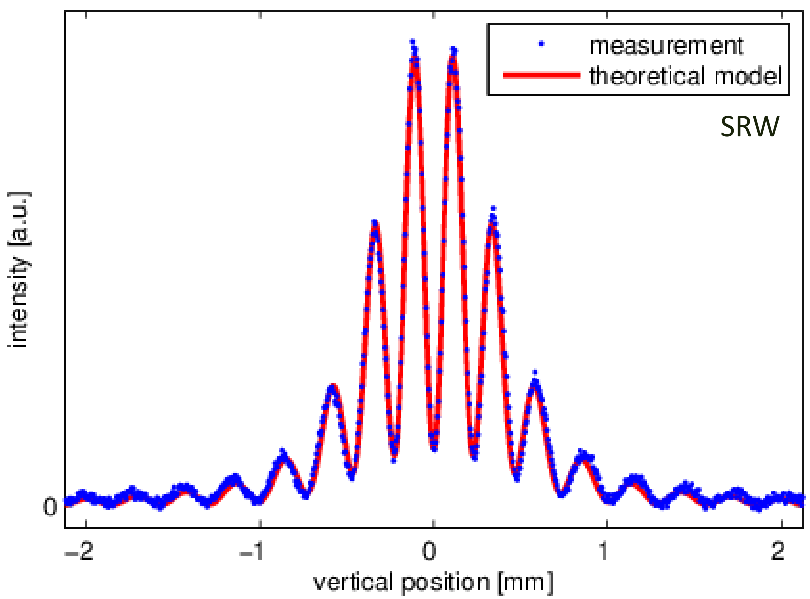




Resolving a vertical beam size < 5 µm



Diffractometer Method:



The **diffractometer** method was implemented at the SLS (TIARA collaboration): $\sigma_y = 4.7 \pm 0.1$ µm

J. Breunlin et al, "Methods for measuring sub-pm rad vertical emittance at the Swiss Light Source", Nucl. Instrum. Meth. A 803, 55-64 (2015).

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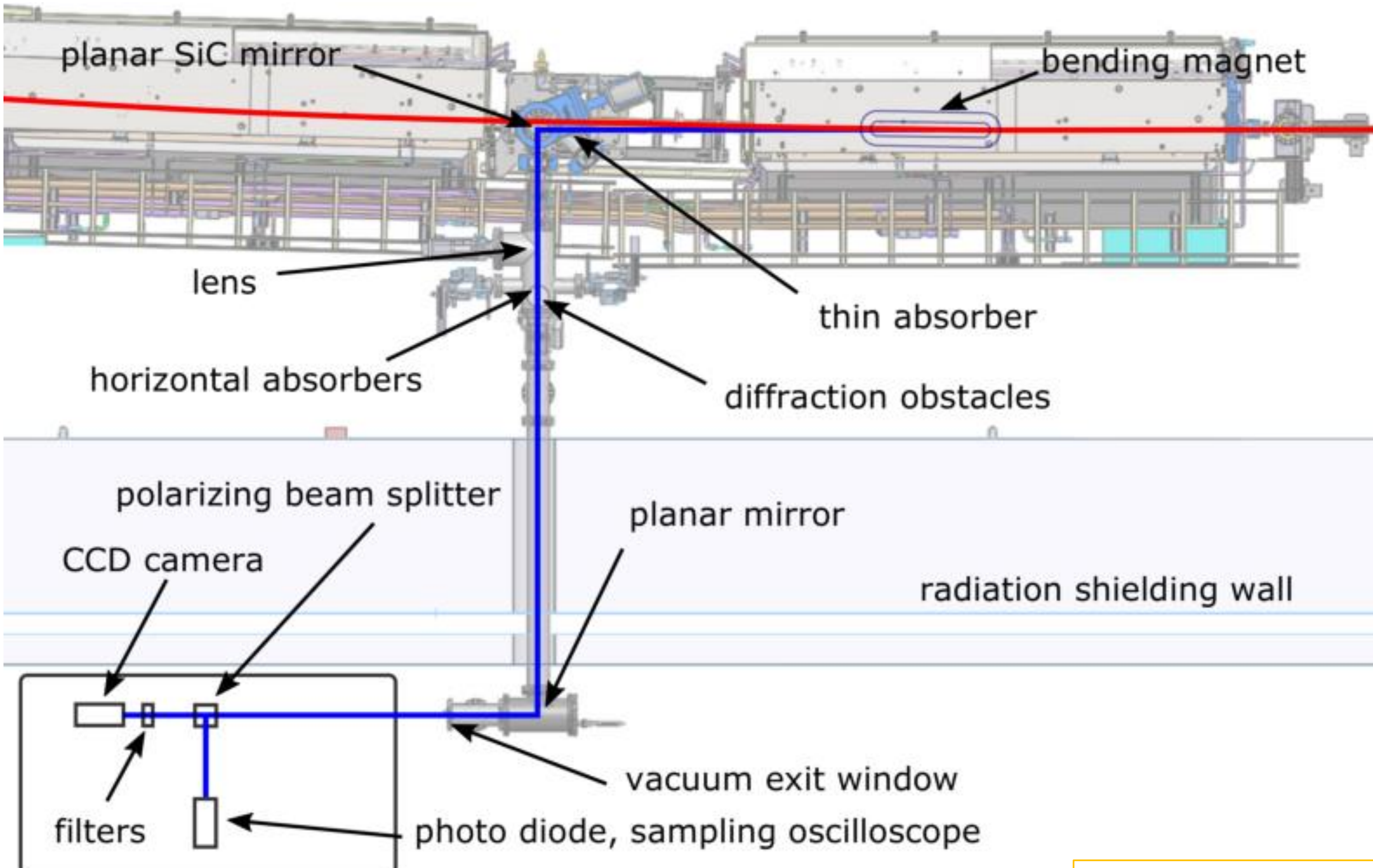
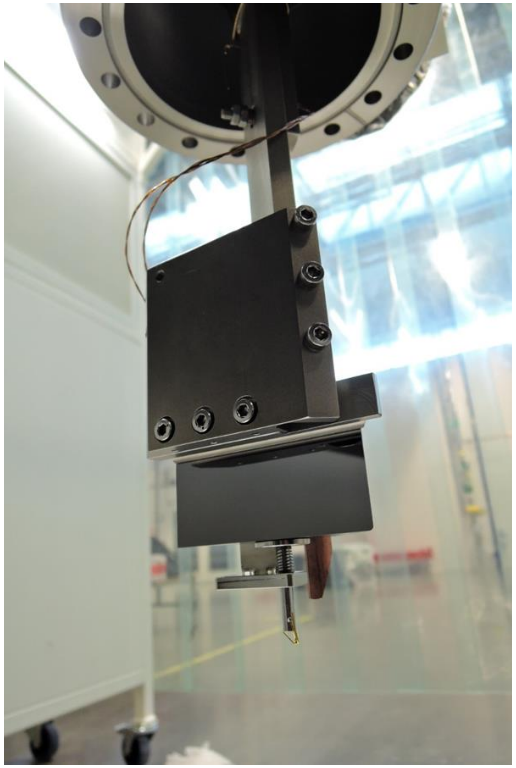
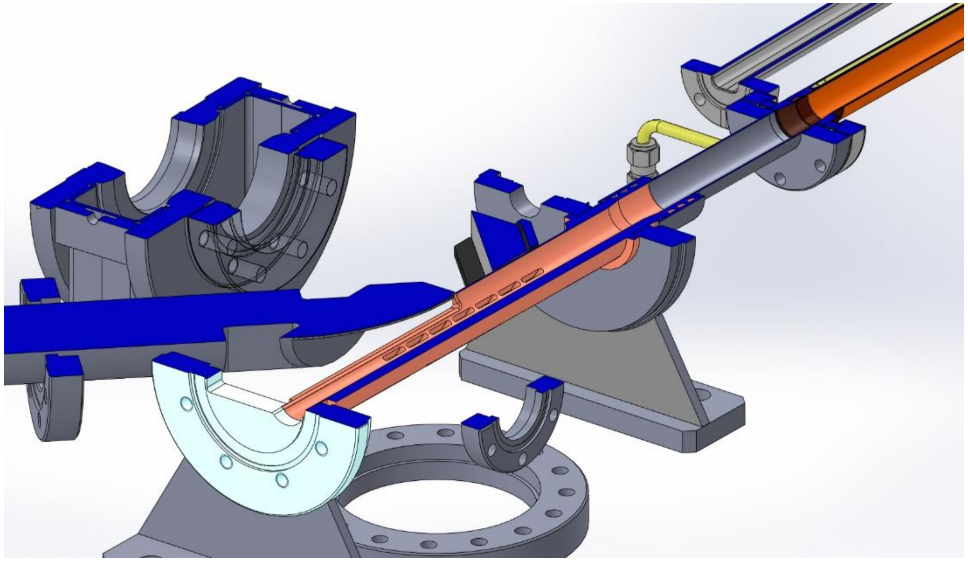
Emittance monitor B320B

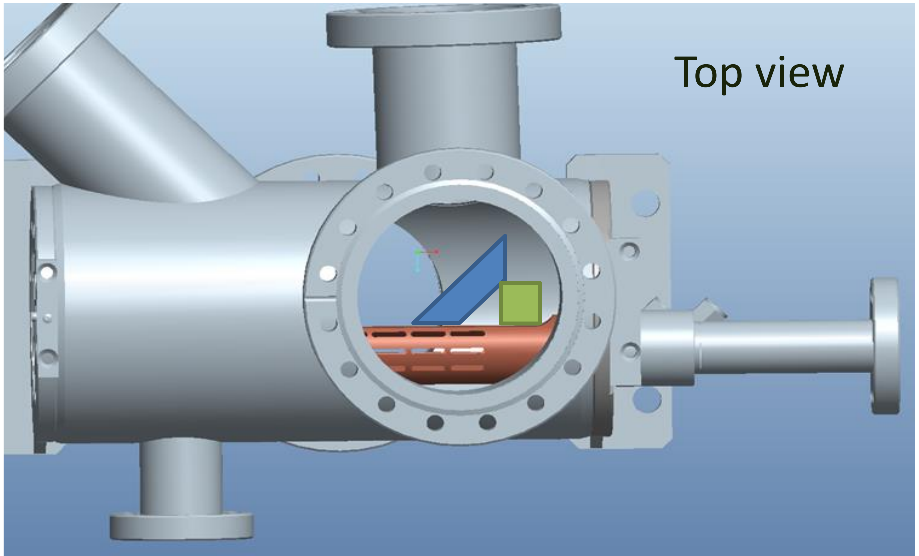


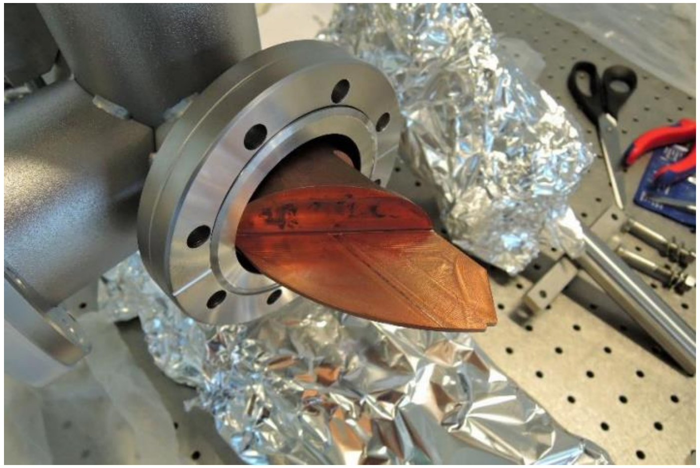
Slide by Jonas Breunlin

B320B Cold Finger Absorber & Mirror









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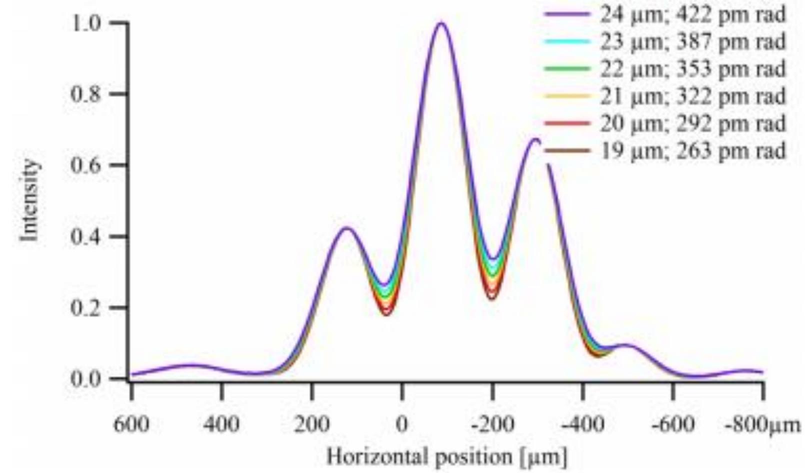
Horizontal & vertical beam size

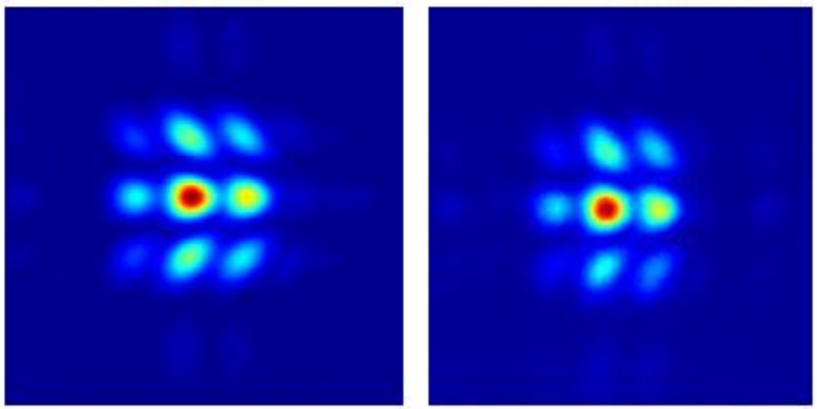
Everyday beam size monitoring scheme:

- Wavelength 488 nm, horizontal acceptance 6 mrad
- Diffraction from
  - Vertical obstacle, 2.1 mrad
  - Horizontal obstacle, 2 mrad

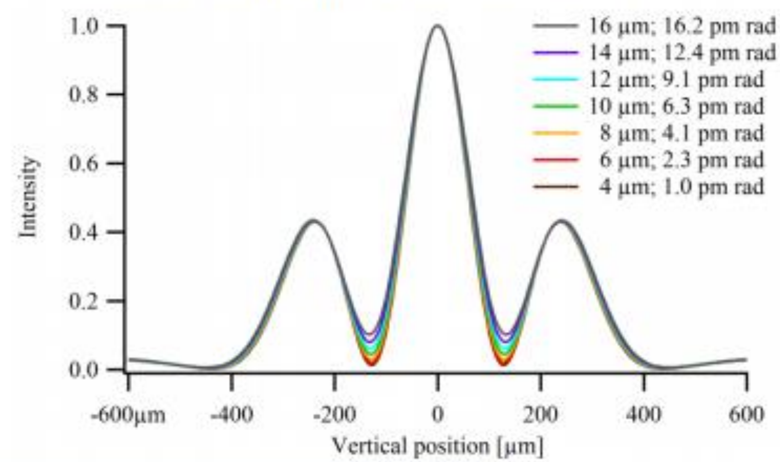
Horizontal intensity profile, sensitive to σ_x



calculation   measurement



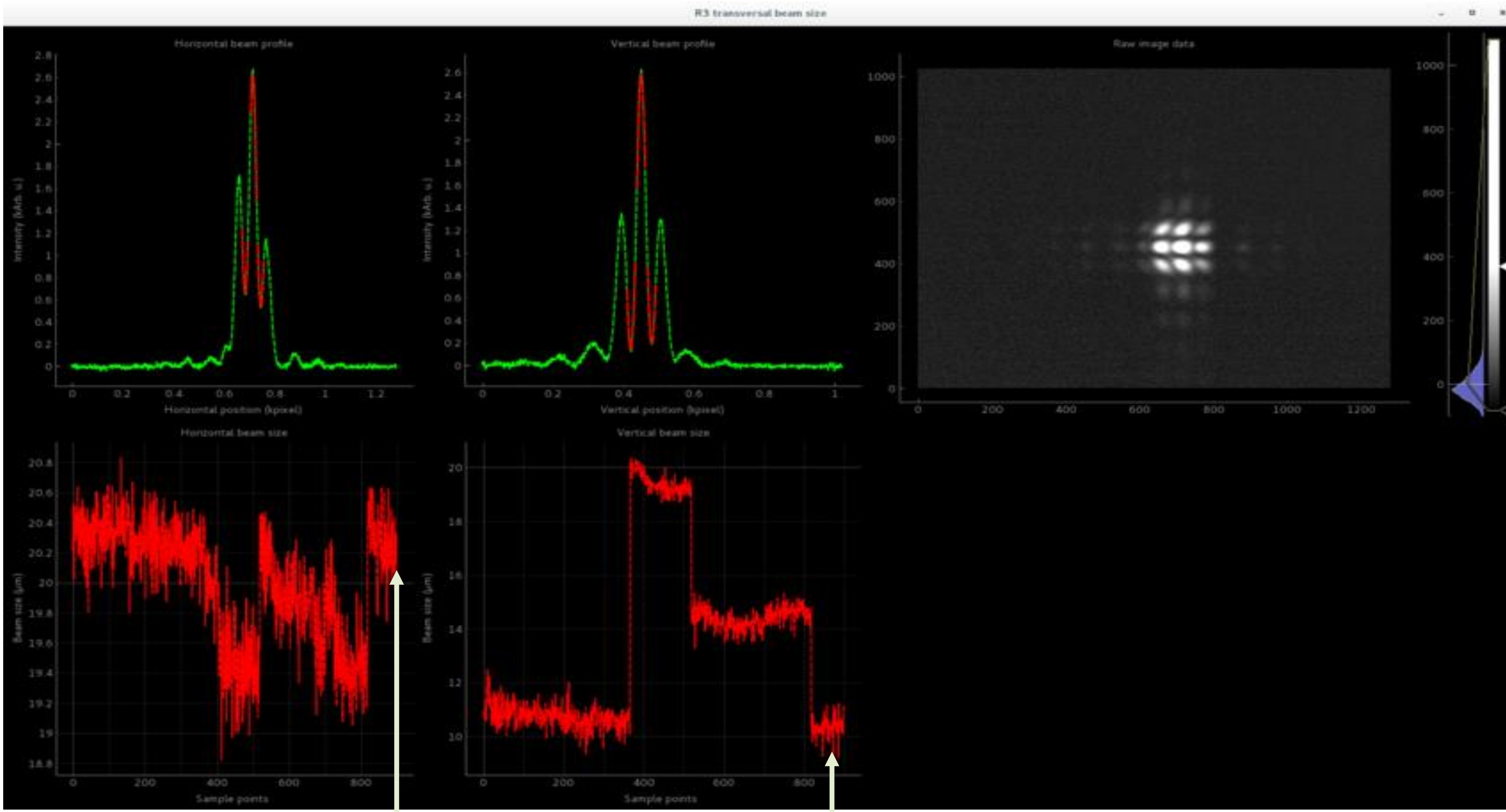
Vertical intensity profile, sensitive to σ_y



Horizontal diffraction obstacle and ‚footprint' of the SR

Courtesy J. Breunlin

Daily measurements of diffraction pattern; σ-pol



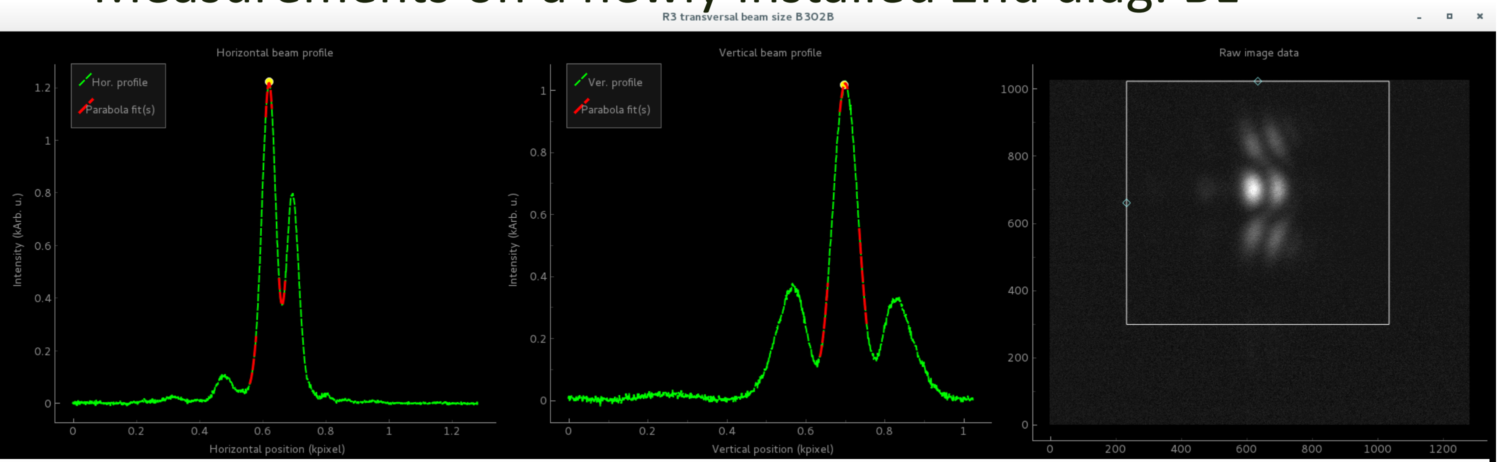
σ_x=20.2 ± 0.2 µm

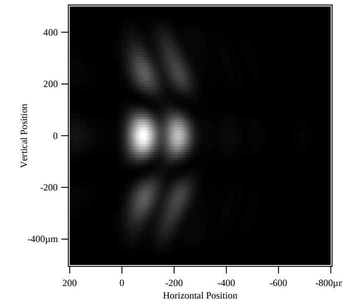
σ_y=10.2 ± 0.4 µm

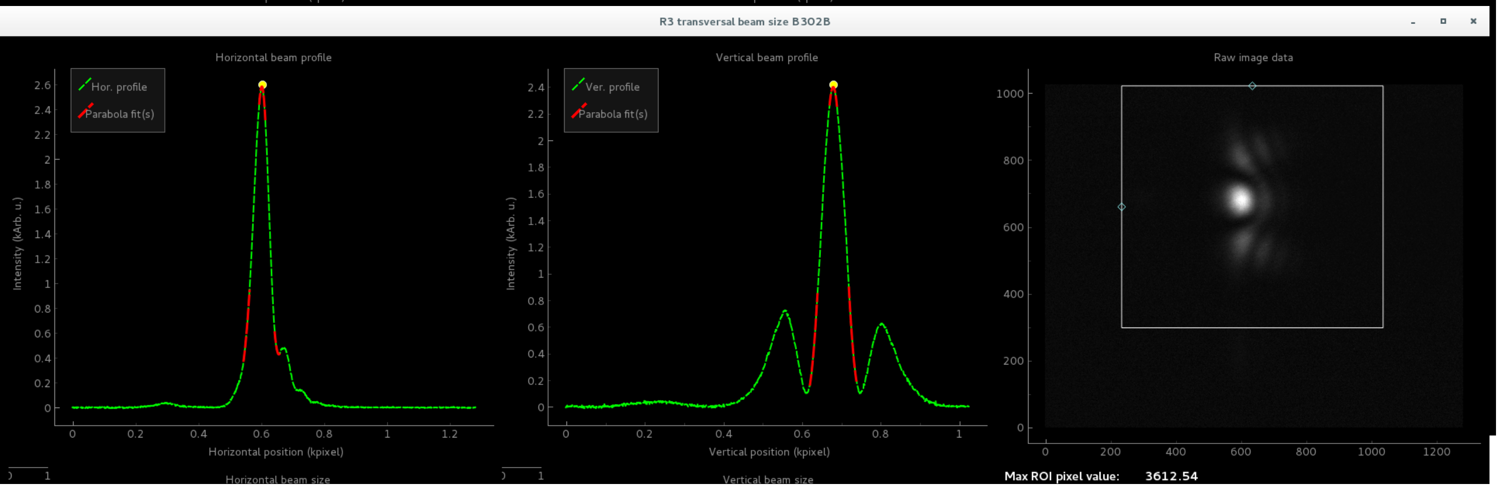
Coupling control => ε_y=6.4 ± 1 pm.rad

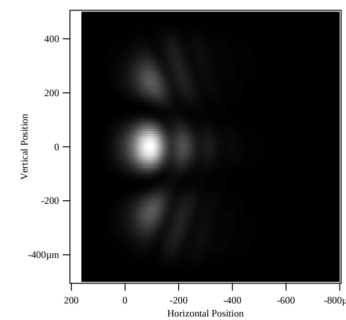
Measurements on a newly installed 2nd diag. BL

Theory SRW









Both images with σ-pol SR @ 930 nm NIR and a thin 1.7 $mrad_V$ x-ray absorber.

Top: Horizontal acceptance 10.66 $mrad_H$; Upright obstacle 2.25 $mrad_H$

Bottom: Horizontal acceptance 12 $mrad_H$; No upright obstacle

Clearly assymetric properties of the emitted SR!

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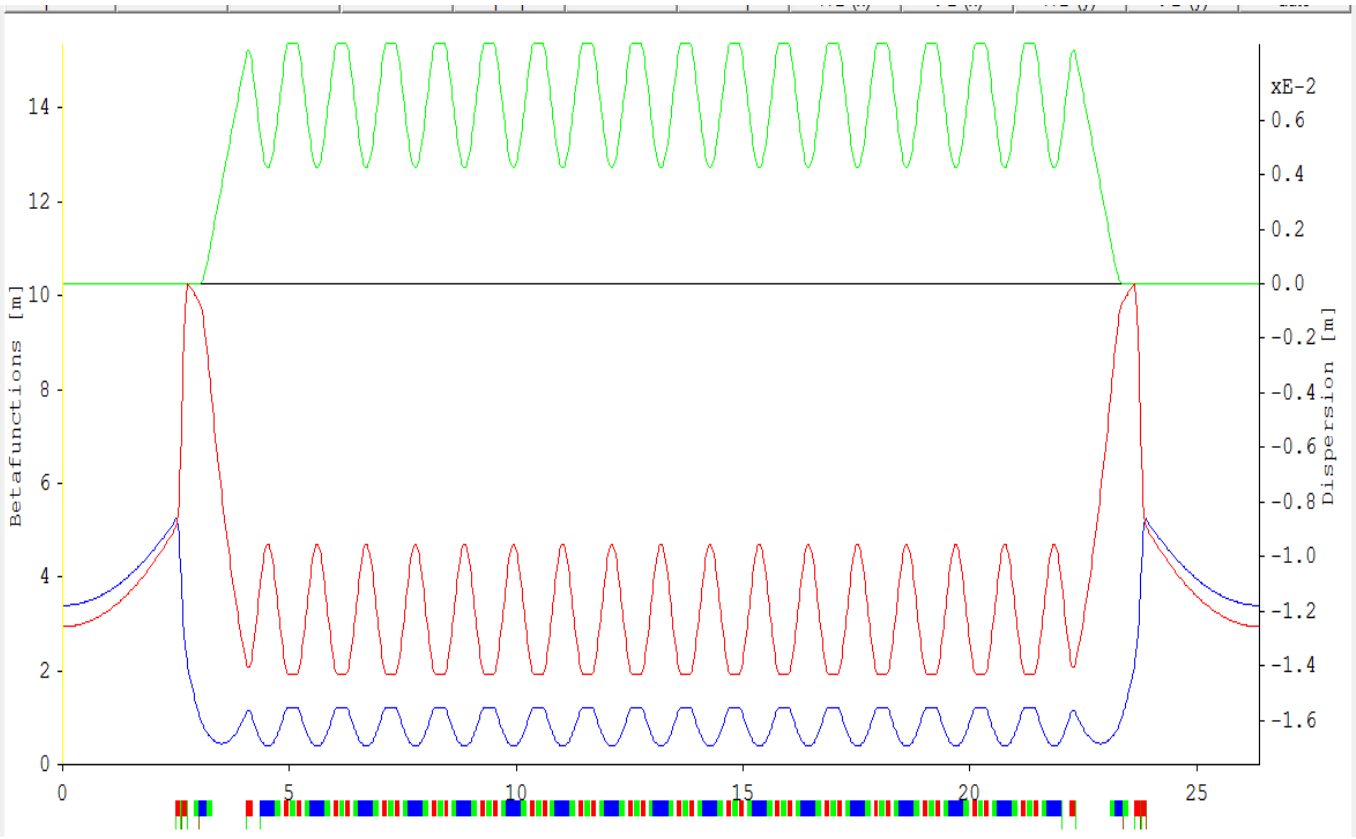
FBSF imaging at the coming DLSR?

Optical functions of a proposed 19-BA lattice, to replace the present MAX IV 3 GeV lattice.



ε_x = 16 pm.rad

In the dipoles:
β_x ~ 0.5 m

=> σ_x ~ 3 µm

Note:
A dipole bends 1 degree = 17.5 mrad

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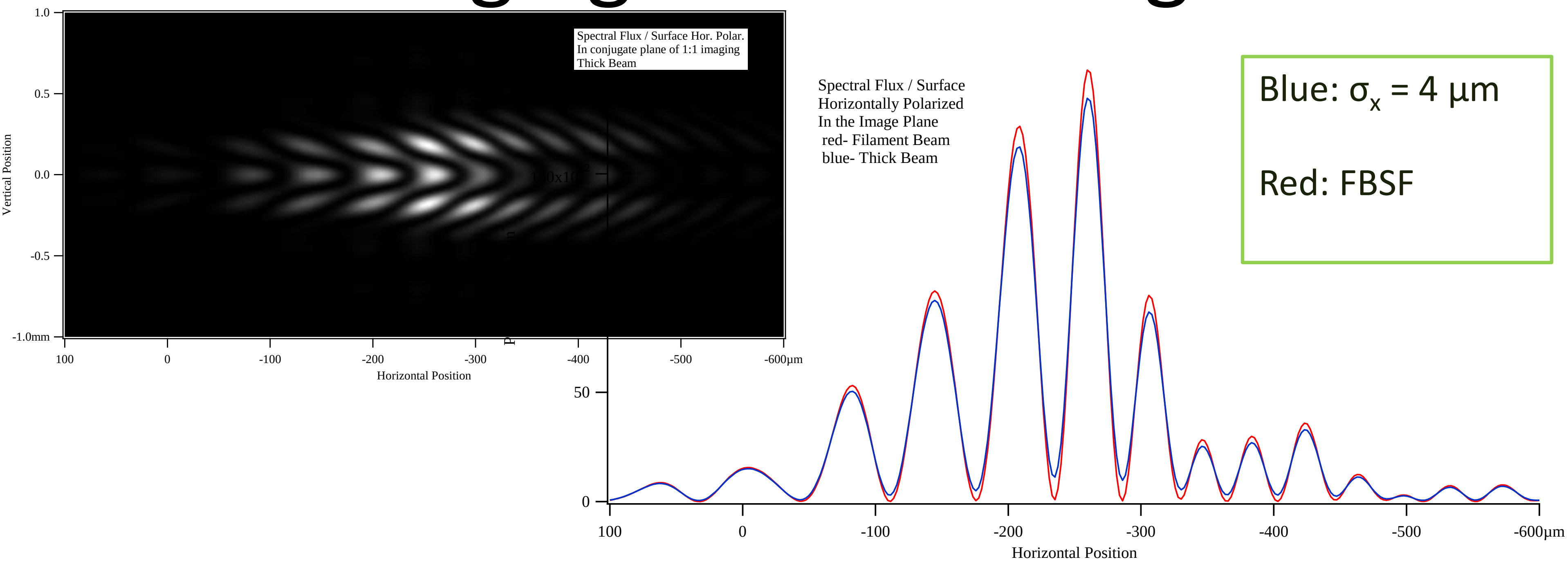
FBSF imaging at the coming DLSR?



Blue: σ_x = 4 µm

Red: FBSF

SRW images with σ-pol SR @ 488 nm and a thin 1.7 mrad$_V$ x-ray absorber.

Horizontal acceptance 14 mrad$_H$; Upright obstacle 6 mrad$_H$

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Conclusions

- FBSF dominated imaging with near visible SR can resolve beam sizes below 5 µm in both planes.
- The method relies on precise calculation of the FBSF, done by the SRW code.
- To reach sufficient horizontal resolution for future SR sources, the method requires rather large horizontal acceptance angle of the beam line, 10 to 15 $mrad_H$, and probably optics for near or mid UV (280 to 380 nm).