Emittance measurements on future ring light sources

Åke Andersson
MAX IV Laboratory

Outline

- Background to visible SR imaging
- Variations on the imaging technique
- Measurements at the MAX IV 3 GeV ring
- Possible imaging at the future ring LSs

Background

An 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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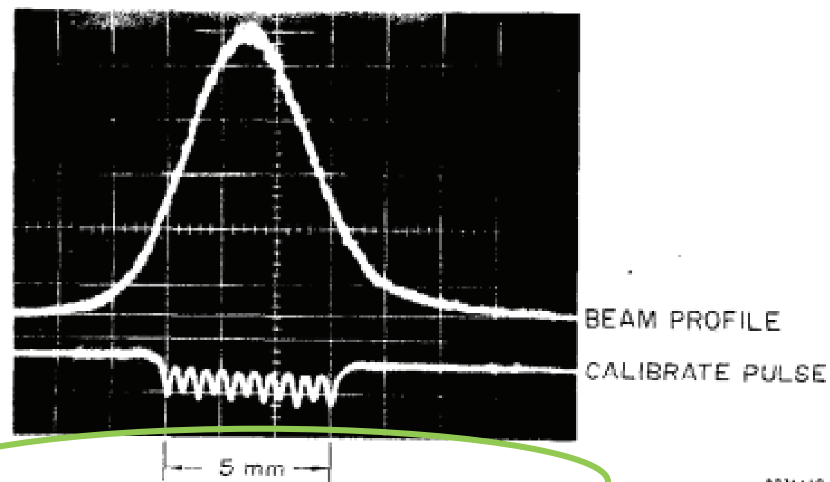

FIG. 9--Scanned horizontal beam profile and calibrator pulses.

Some progress since then!!

Example

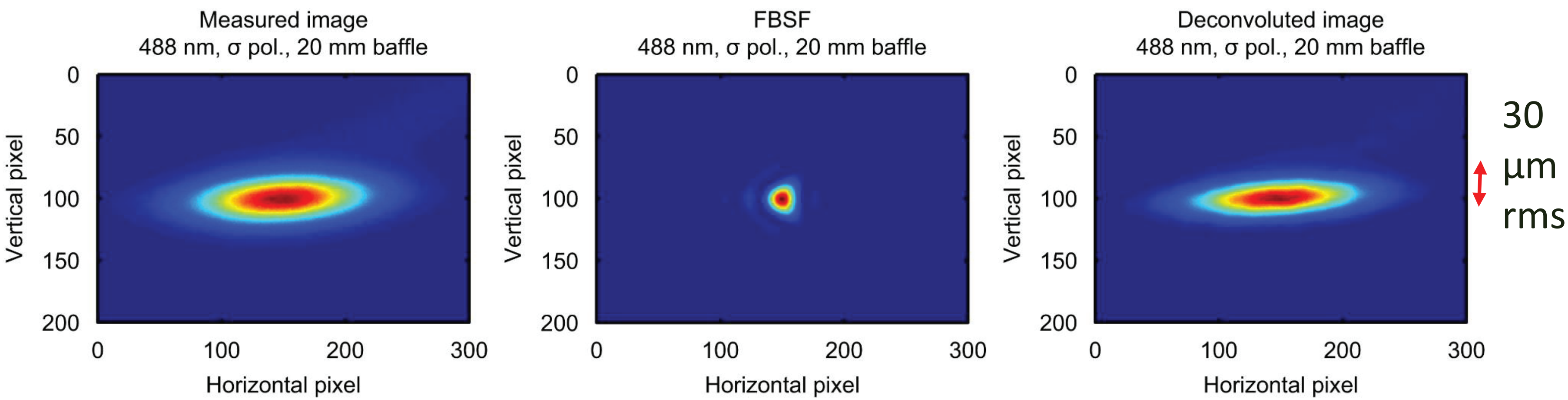

Fig. 4. Example of beam profile measurement with σ-polarized light at 488 nm. Measured image, filament-beam-spread function and deconvoluted image for baffle aperture 20 mm (±5.4 mrad horizontal opening angle). Pixel size 3.75µm.

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!

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Example

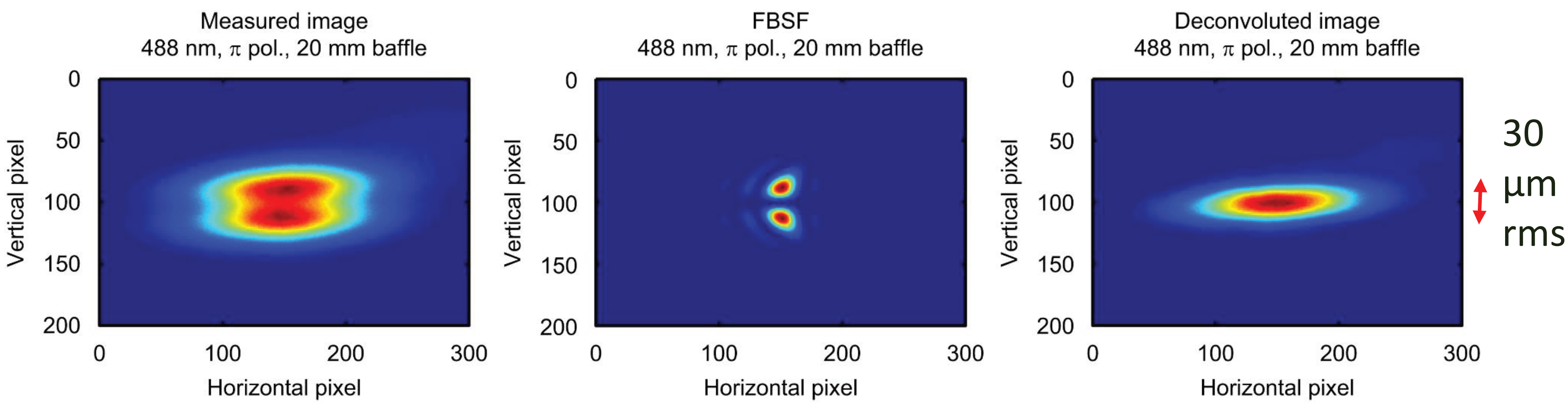

Fig. 7. Example of beam profile measurement with π-polarized light at 488 nm. Measured image, filament-beam-spread function and deconvoluted image for baffle aperture 20 mm (±5.4 mrad horizontal opening angle). Pixel size 3.75µm.

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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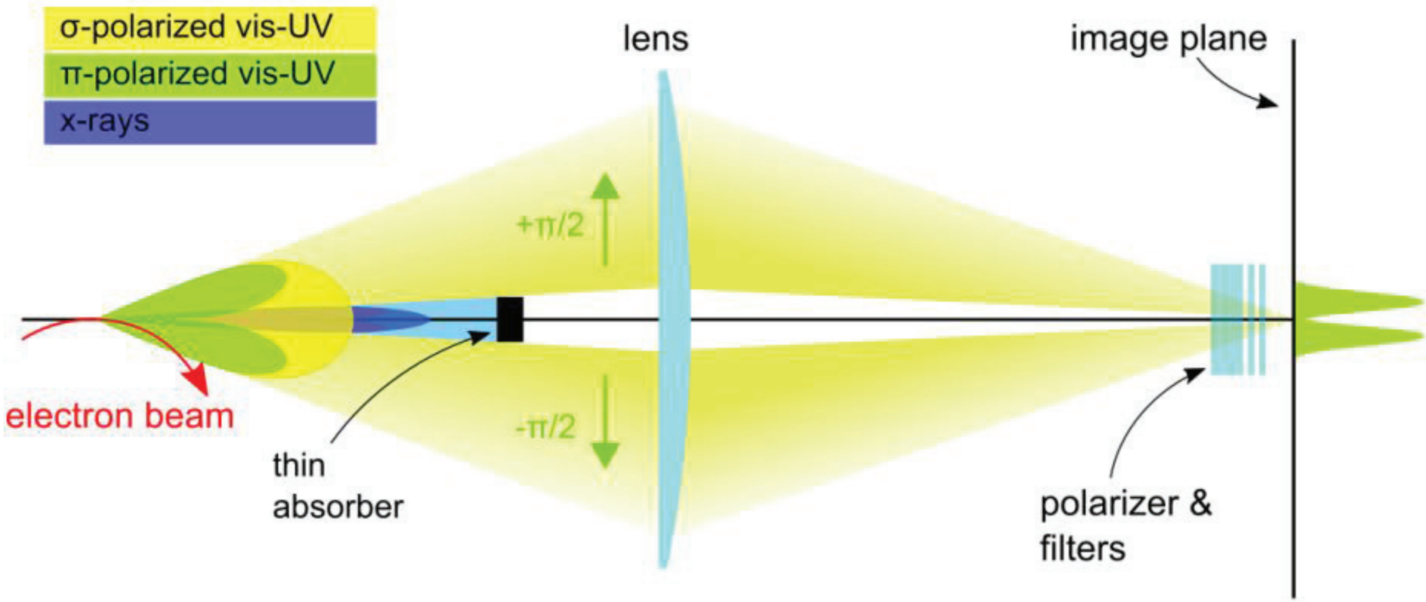
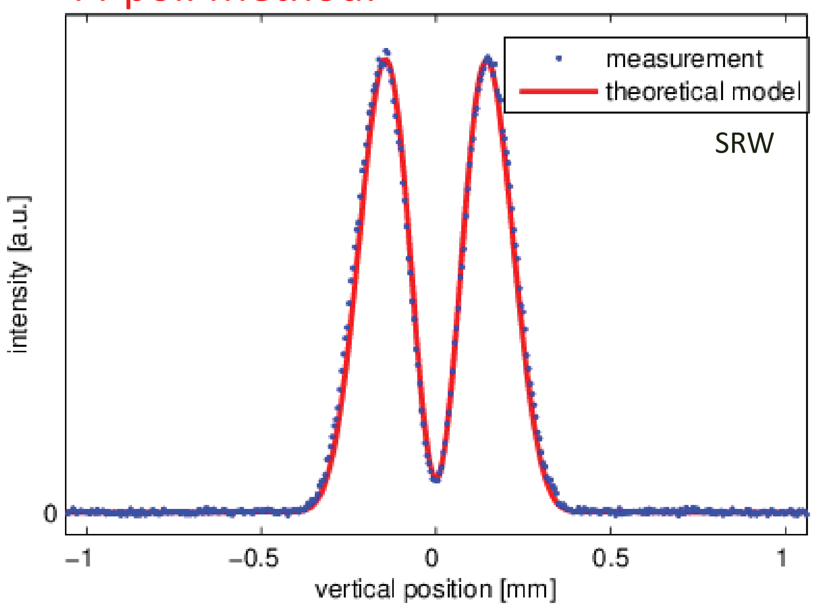
Resolving a vertical beam size < 5 µm



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.

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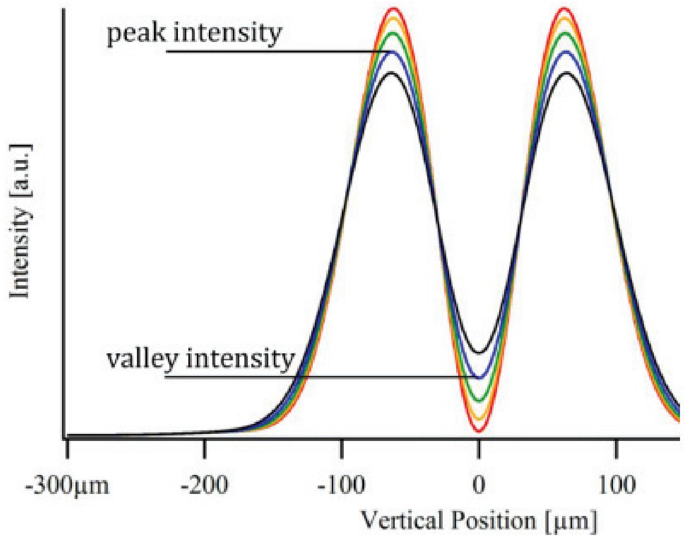
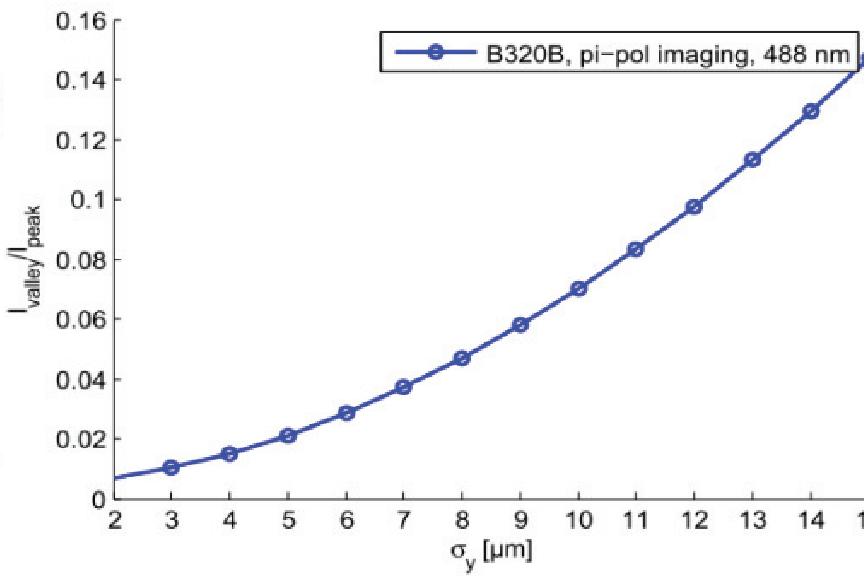
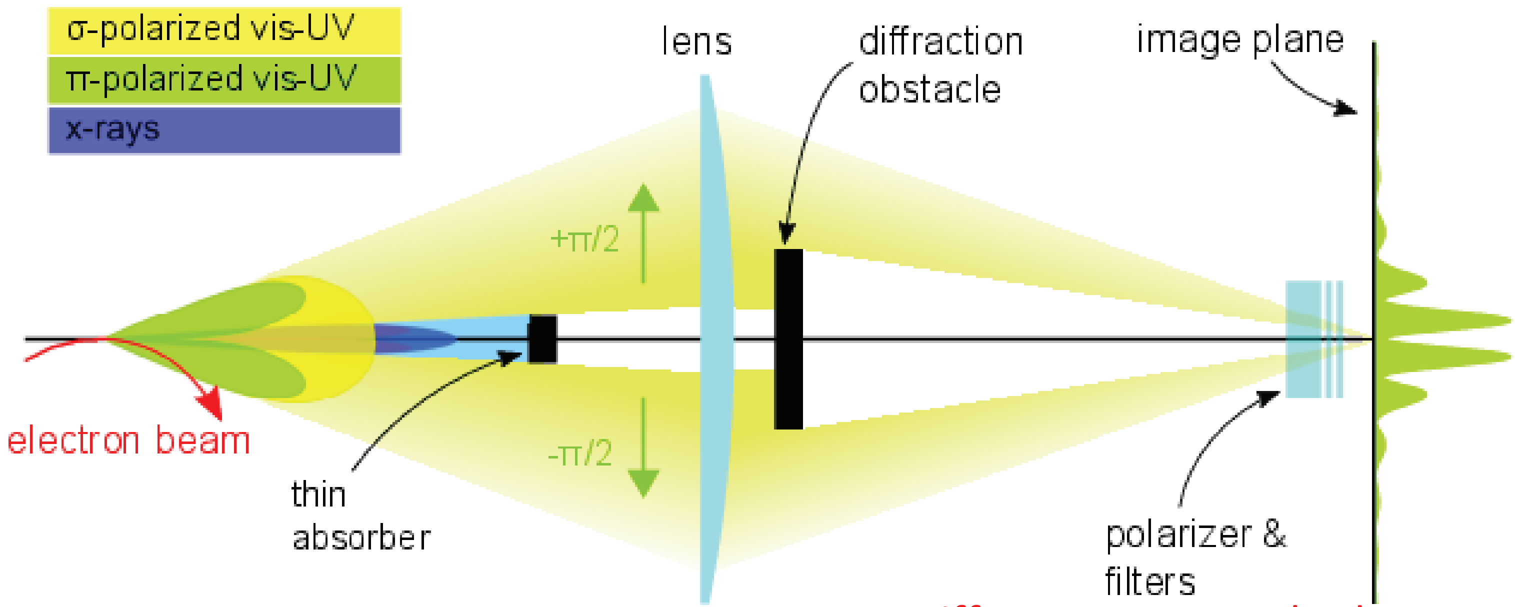
Resolving a vertical beam size < 5 µm

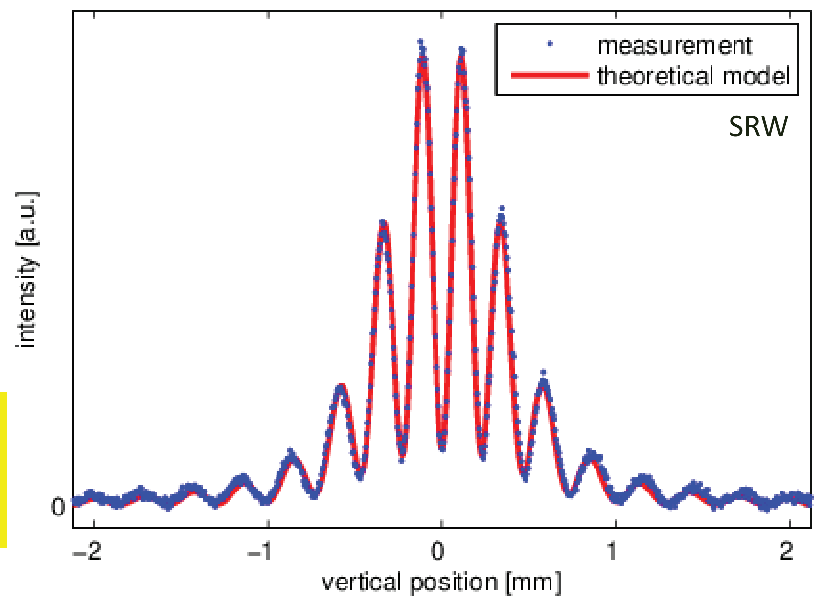




Resolving a vertical beam size < 3 µm



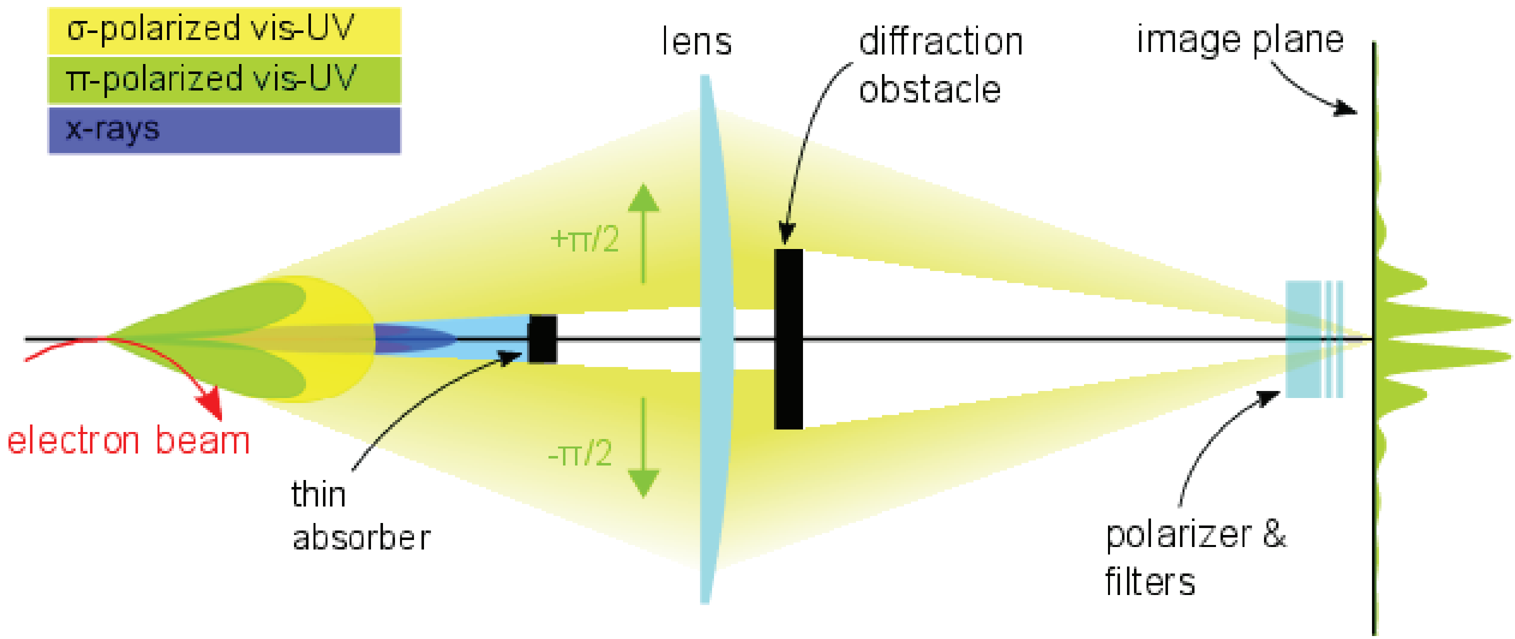
Diffractometer Method:

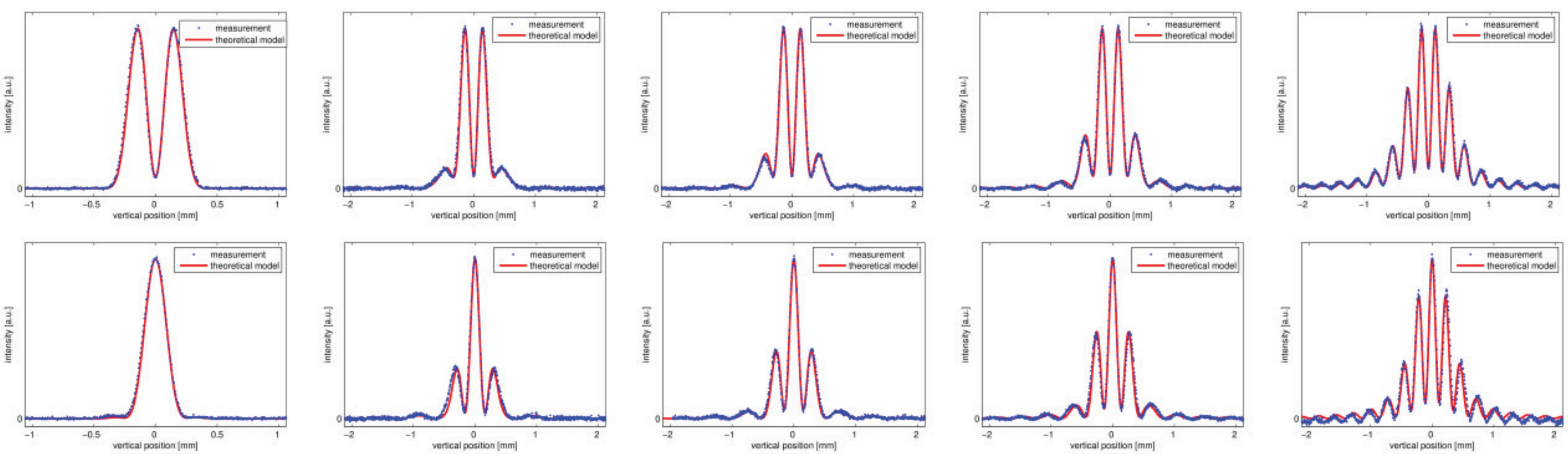


The **diffractometer** method was implemented at the SLS (TIARA collaboration): $\sigma_y = 4.7 \pm 0.1$ µm

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).

Resolving a vertical beam size < 3 µm





J. Breunlin et al, "Emittance diagnostics at the MAX IV 3 GeV storage ring", IPAC 2016.

Vertical profiles at 488 nm for pi- and sigma- polarized SR. Measurement and theoretical calculation. Imaging (left) and with diffraction obstacles of increasing height (4 to 9mm, 1.6 to 3.7 mrad).

→The vertical beam size was measured 11±0.3 µm, corresponding to a vertical emittance of 6.4±0.9 pm rad.

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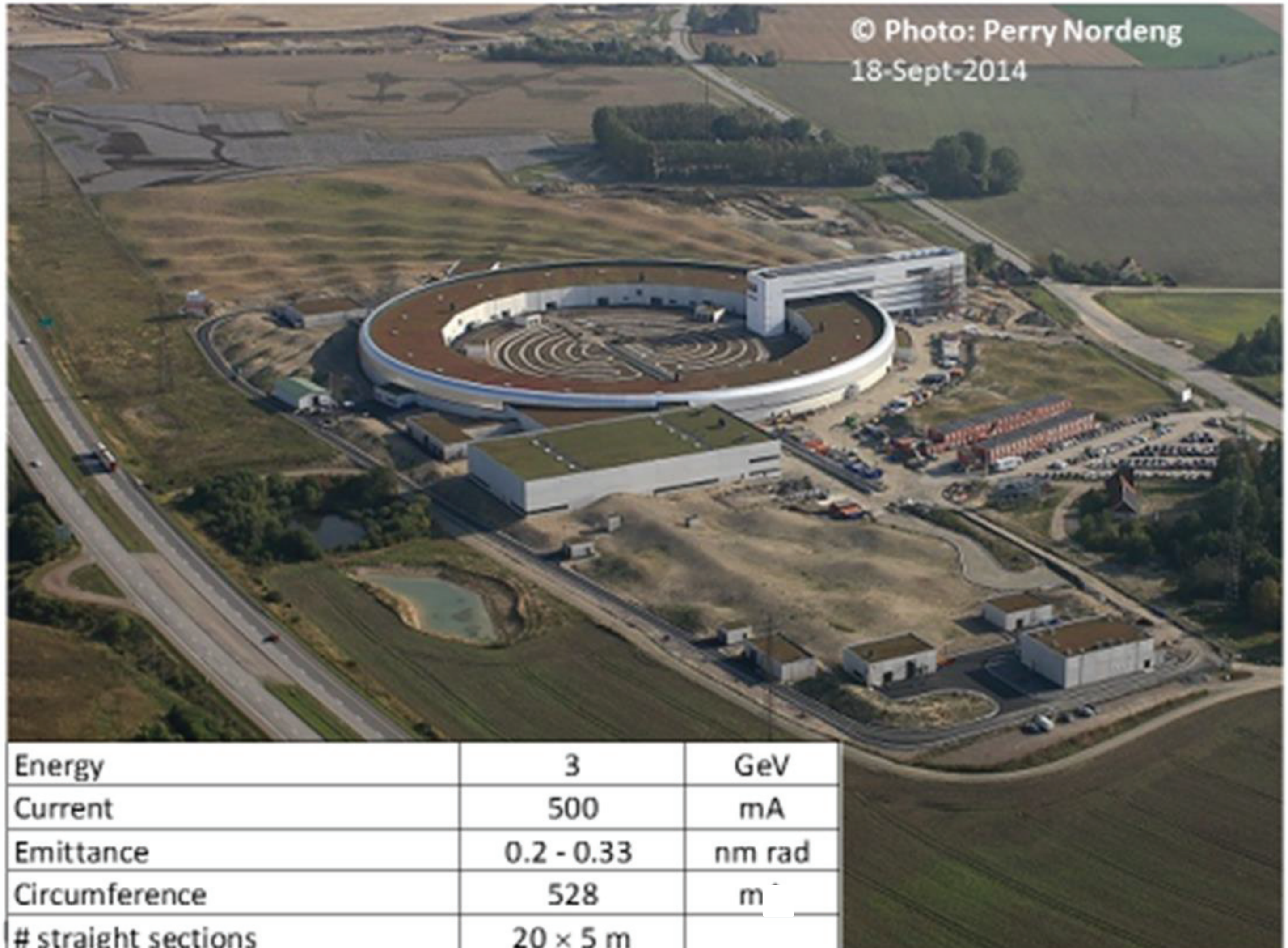
MAX IV 3 GeV ring



Energy	3	GeV
Current	500	mA
Emittance	0.2 - 0.33	nm rad
Circumference	528	m
# straight sections	20 × 5 m	

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MAX IV 3 GeV ring

7-Bend Achromat lattice

- MAX IV, the first realization of the multi-bend achromat (MBA) concept for a synchrotron radiation source.

First ideas, M. Eriksson, 2002

M. Eriksson, "The MAX4 accelerator system", unpublished internal note, (2002). http://www.maxiv.lu.se/publications

In User operation, 2017

Some 3 GeV ring publications:

PRST-AB **12**, 120701 (2009).

Tavares P.F., Leemann S.C., Sjöström M. & Andersson Å., Journal of Synchrotron Radiation, (21), 862-877 (2014).

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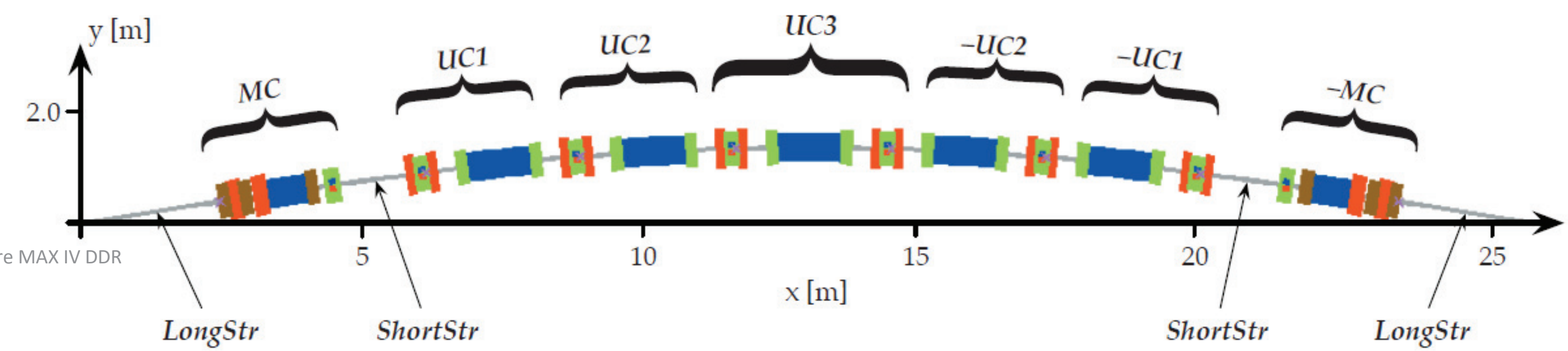
MAX IV 3 GeV ring



Picture MAX IV DDR

7-Bend Achromat lattice

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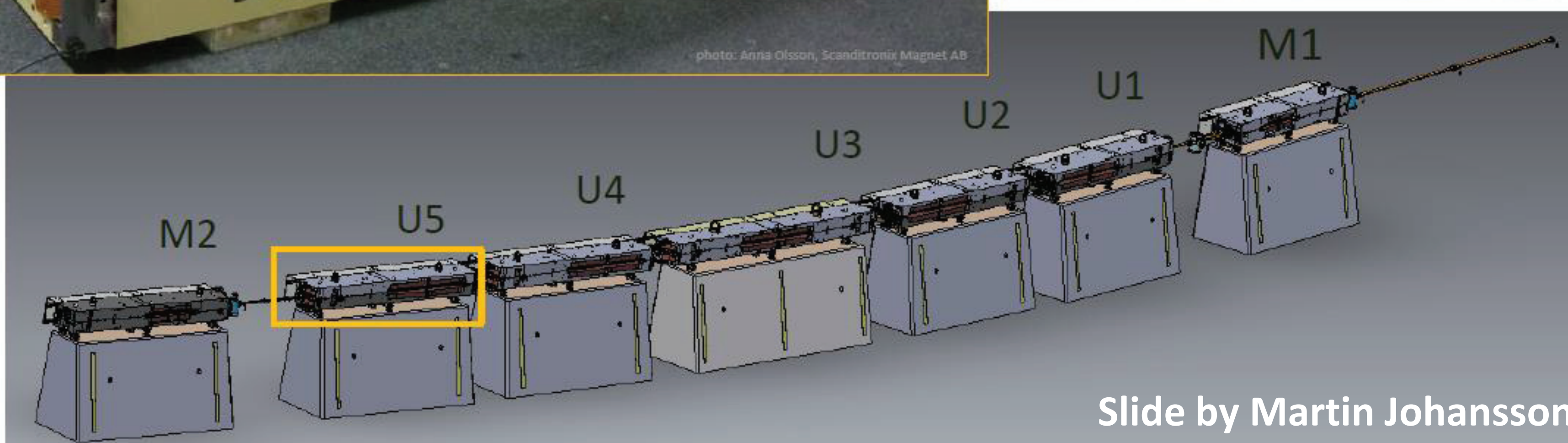
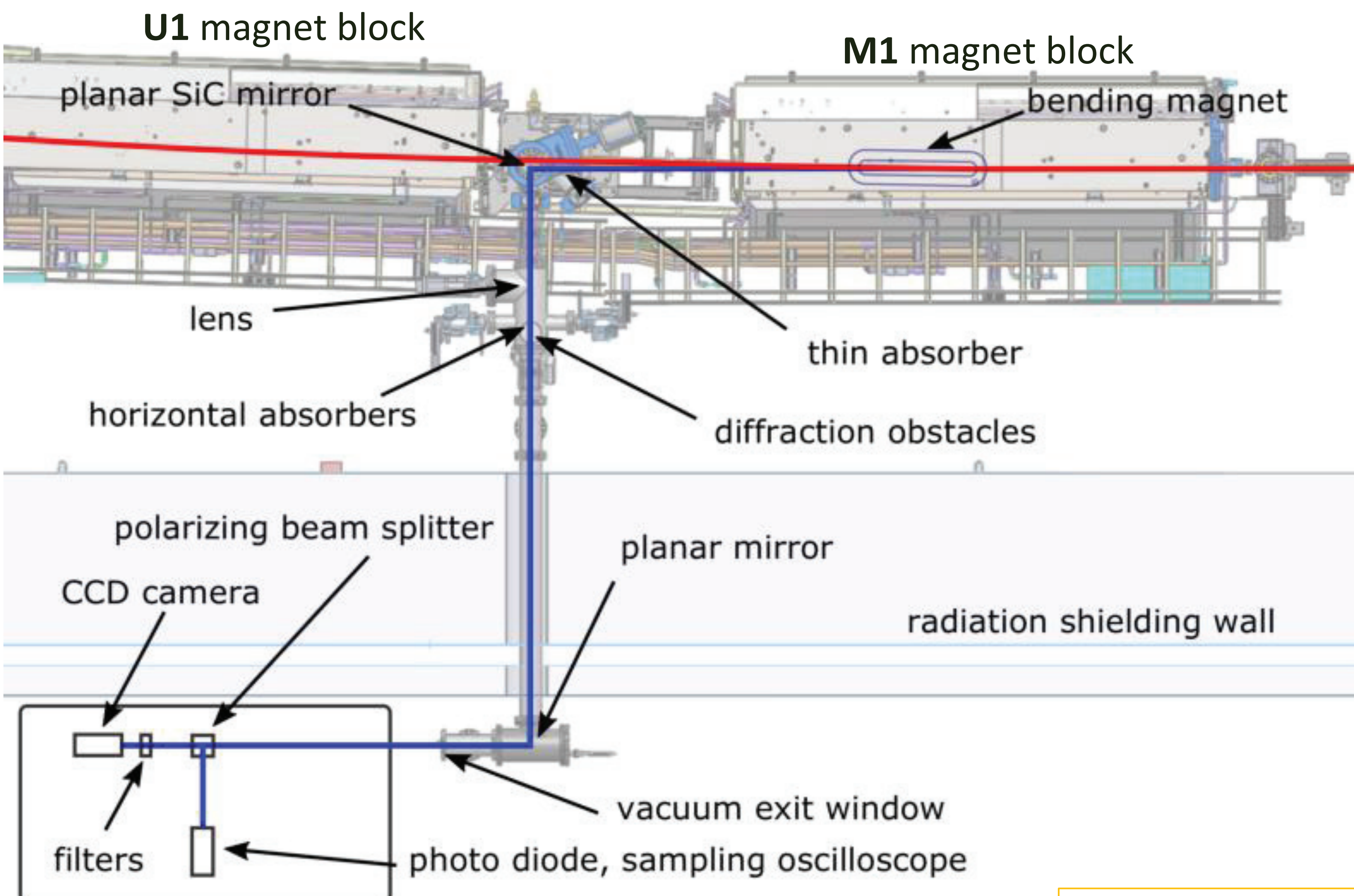
MAX IV 3 GeV ring DC magnets

• Each cell is realized as one mechanical unit containing all magnet elements.
•Each unit consists of a bottom and a top yoke half, machined out of one solid iron block, 2.3-3.4 m long.

- a U5 bottom half →
- ↓ an assembled U5

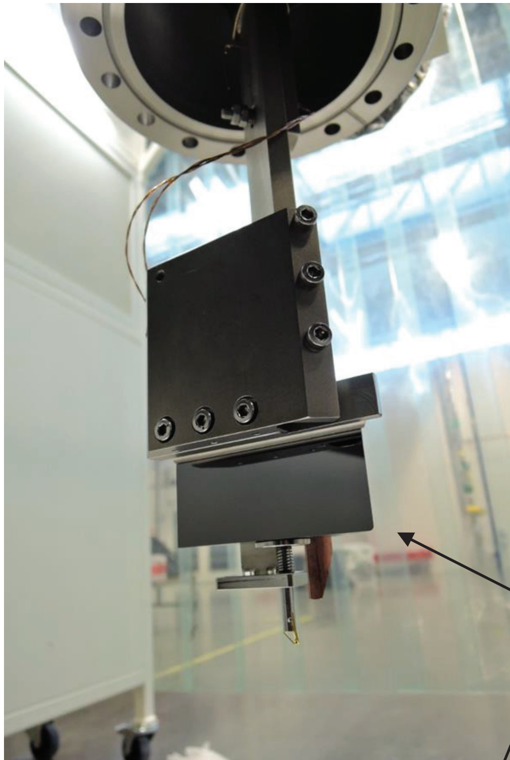


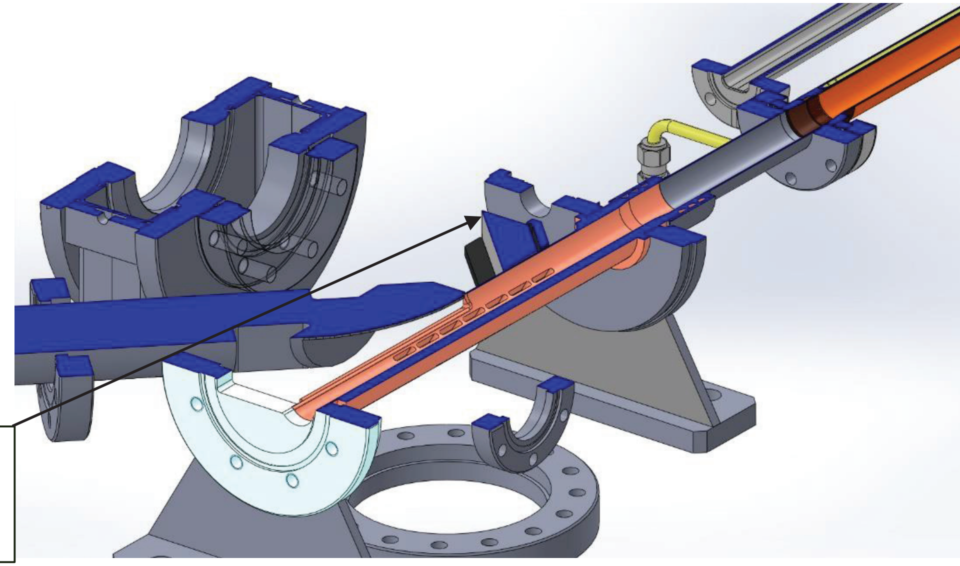
Emittance monitor B320B



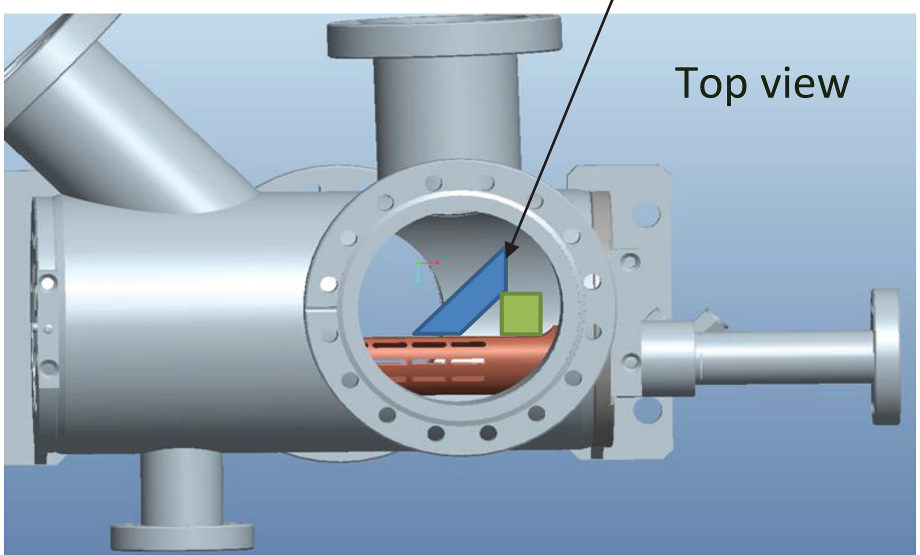
Slide by Jonas Breunlin

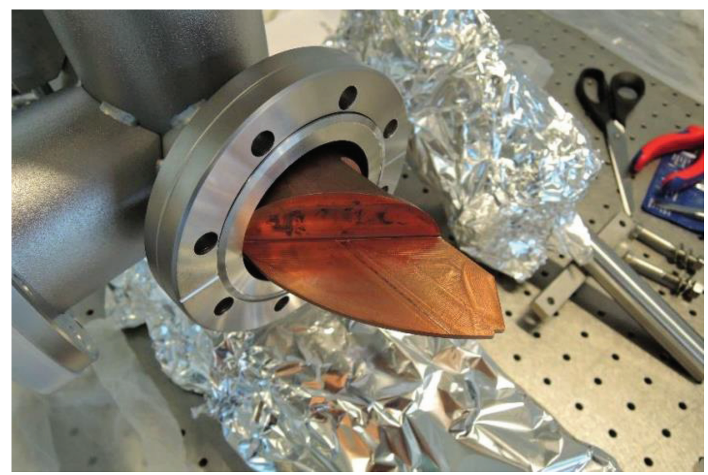
B320B "Cold Finger" Absorber & Mirror





Planar SiC-Mirror





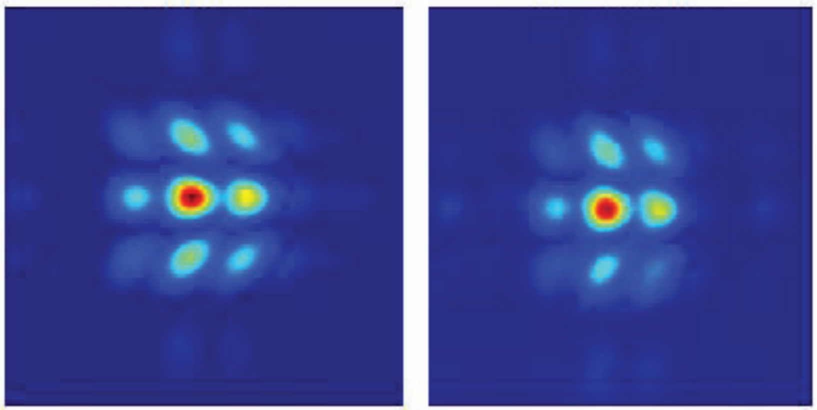
Cold Finger Absorber

Horizontal & vertical beam size

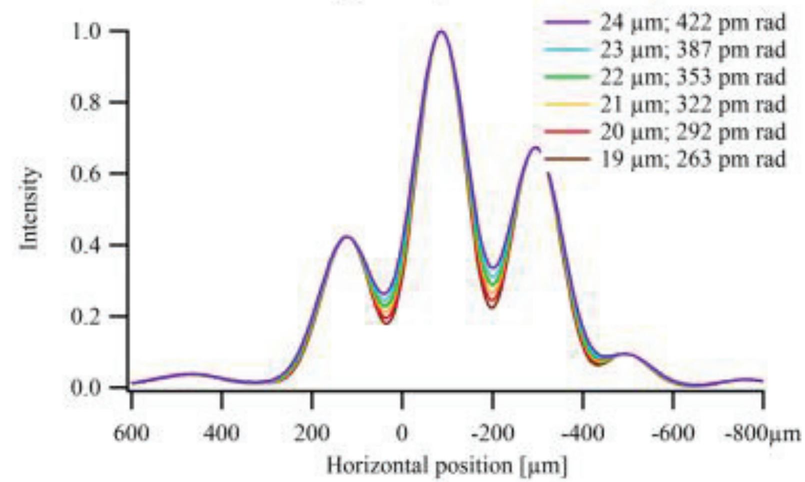
Everyday beam size monitoring scheme:

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

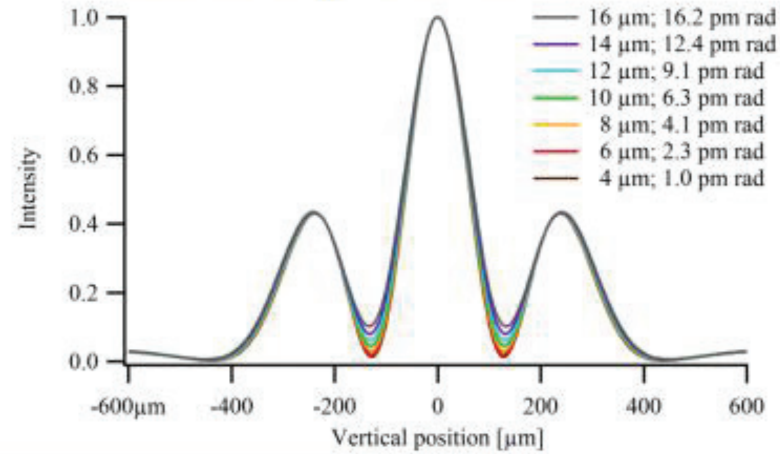
calculation measurement

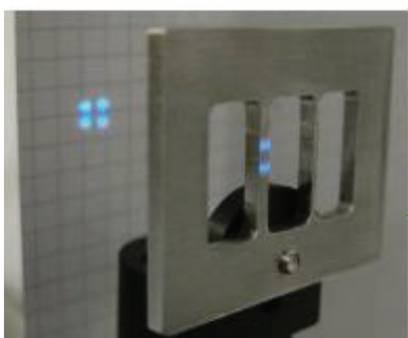


Horizontal intensity profile, sensitive to σ_x



Vertical intensity profile, sensitive to σ_y

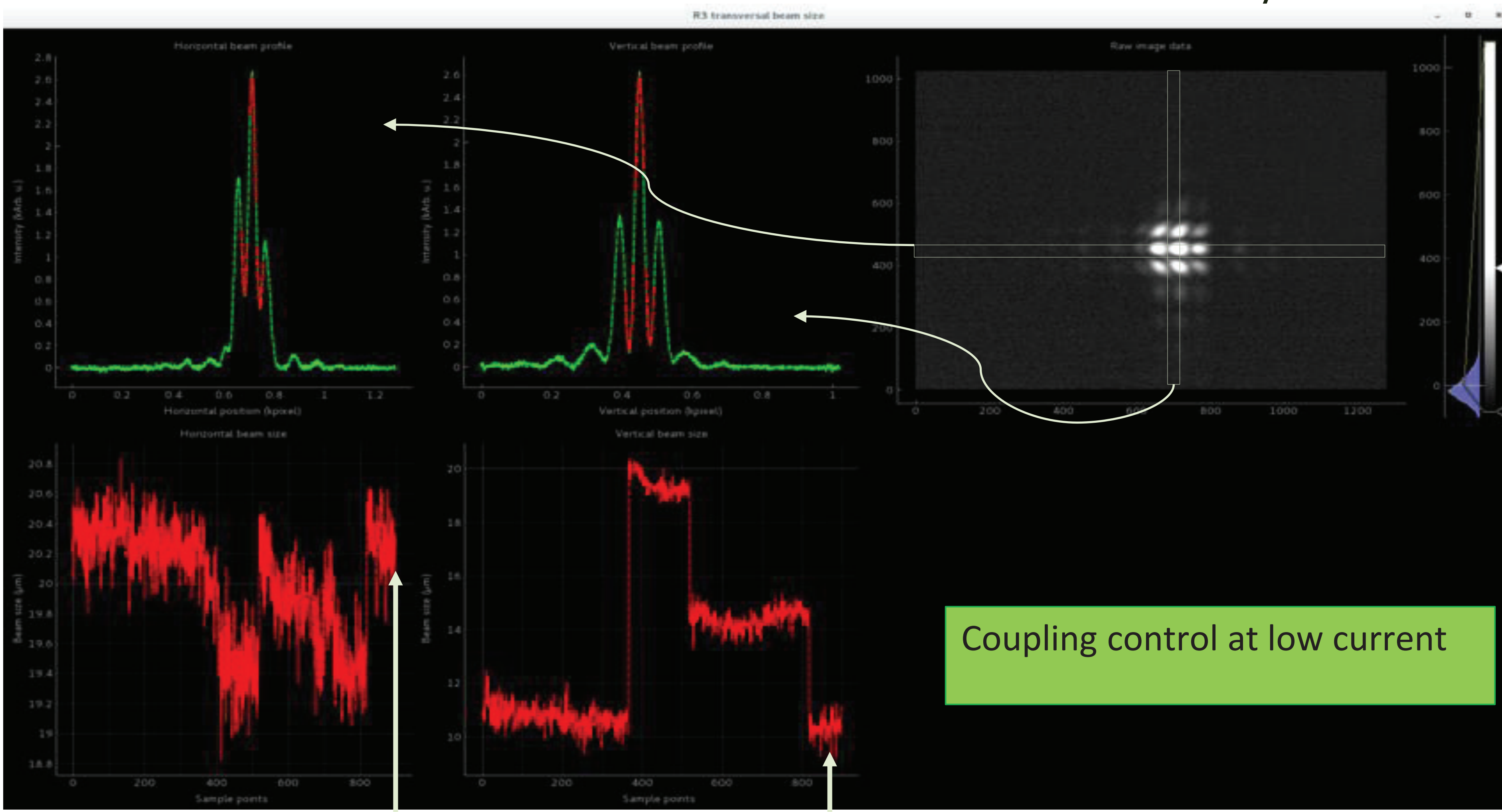




Horizontal diffraction obstacle and ‚footprint' of the SR

Courtesy J. Breunlin

Everyday 2-D measurements where $\eta_x \sim \eta_y \sim 0$



Coupling control at low current

σ_x=20.2 ± 0.2 μm

σ_y=10.2 ± 0.4 μm

ε_x=323 ± 15 pm.rad

ε_y=6.6 ± 1 pm.rad

Beta functions from LOCO;
Errors on emittances includes systematics.

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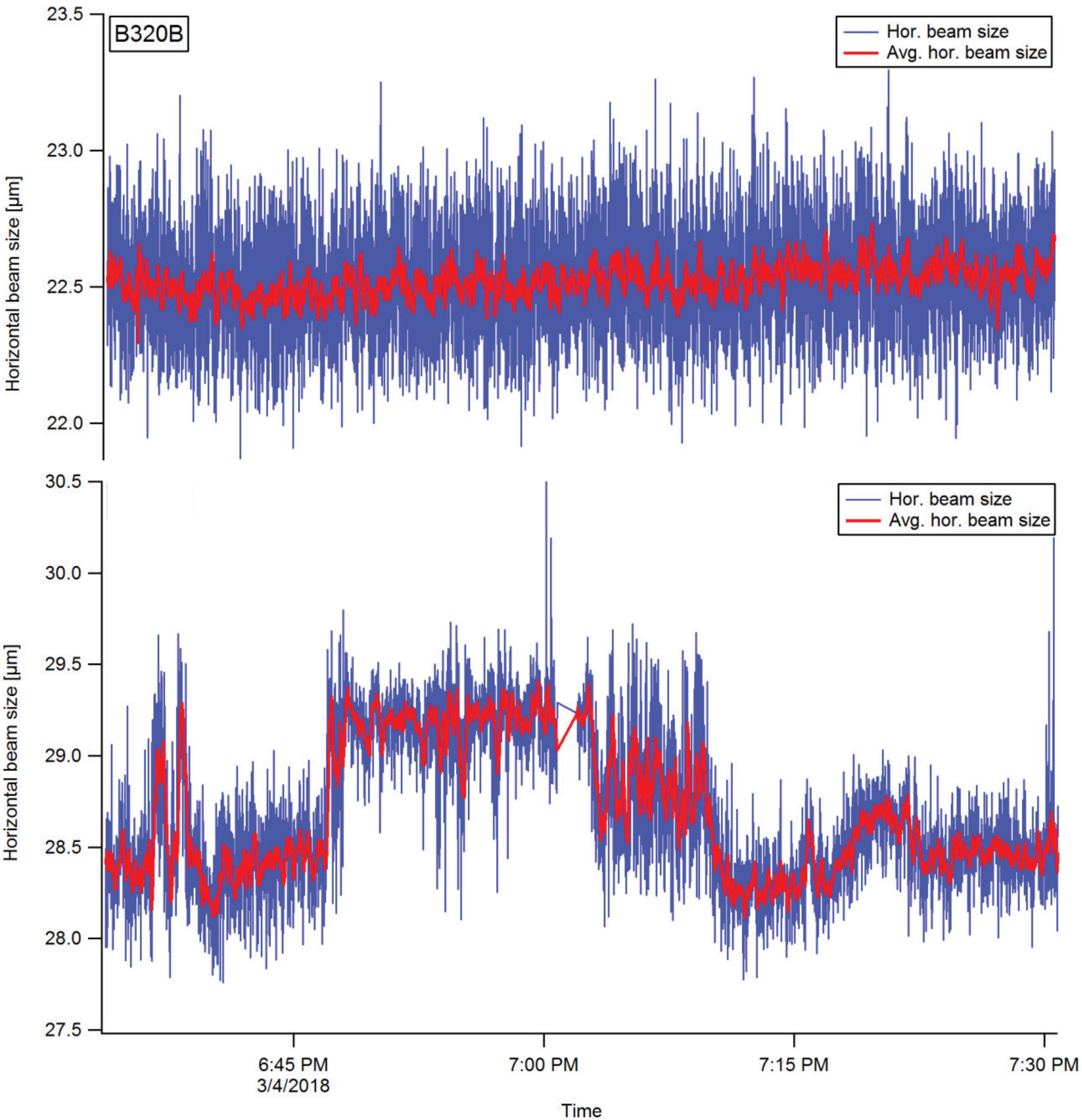
A second monitor, B302B, where $\eta_x \neq 0$

- Will enable us to measure both horizontal emittance and energy spread
- Necessary at higher currents, since we are in the IBS regime

$$\mathbb{E}_x = \frac{\sigma^2_{x,2} - \left(\frac{\eta_{x,2}}{\eta_{x,1}}\right)^2 \sigma^2_{x,1}}{\beta_{x,2} - \left(\frac{\eta_{x,2}}{\eta_{x,1}}\right)^2 \beta_{x,1}} \qquad \sigma_\delta = \left[\frac{\sigma^2_{x,2} - \left(\frac{\beta_{x,2}}{\beta_{x,1}}\right)\sigma^2_{x,1}}{\eta^2_{x,2} - \left(\frac{\beta_{x,2}}{\beta_{x,1}}\right)\eta^2_{x,1}}\right]^{1/2}$$

- Both dispersions and sigmas are measured
- Only beta-functions are provided by LOCO (or by other means)

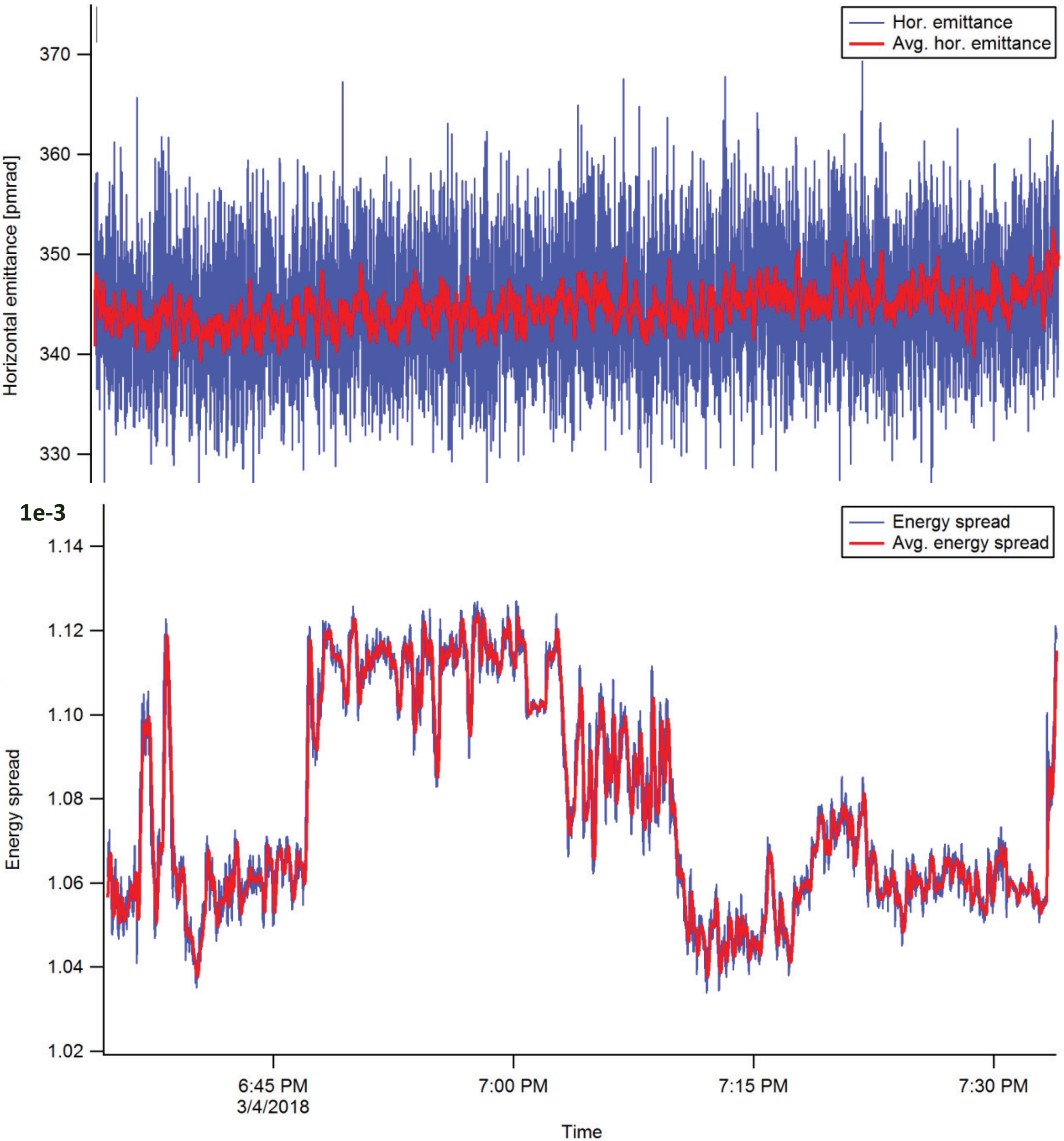
A second monitor, B302B, where $\eta_x \neq 0$



- Recent results from on-line measurements at 150 mA:
- Red is a rolling average over ten seconds (about ten measurements)

Courtesy Robin Svärd, Operator, speciality diagnostics

Combined results, monitors B302B & B320B



- Recent results from on-line measurements at 150 mA:
- Hor. Emittance pretty stable at 345 ± 5 pmrad.
- Relative energy spread changes of less than 2e-5 (!), can be detected.

Courtesy Robin Svärd, Operator, speciality diagnostics

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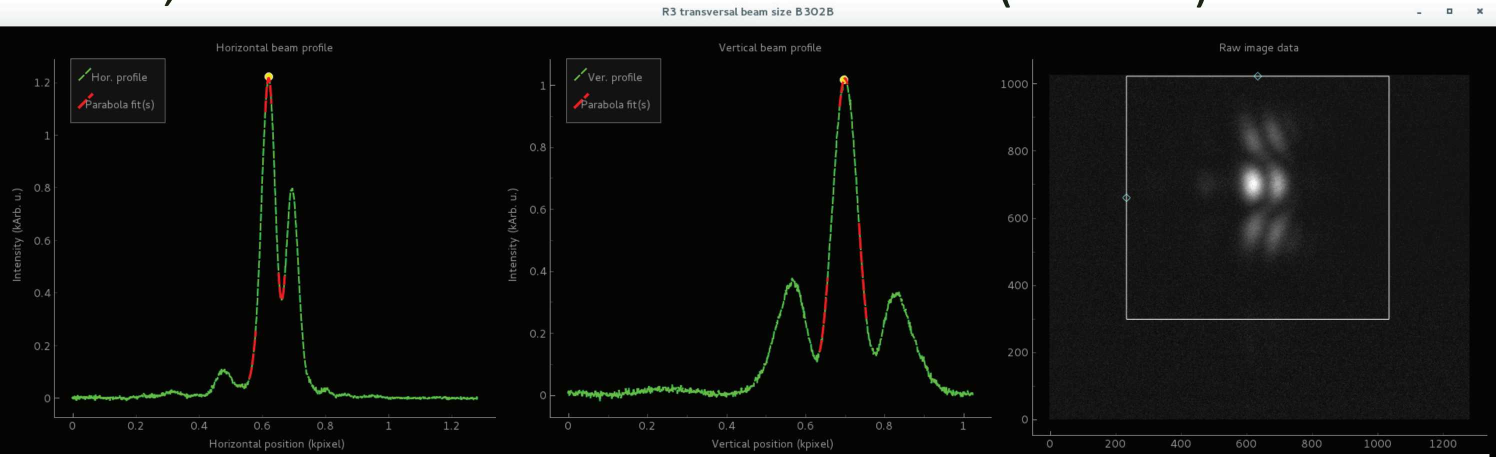
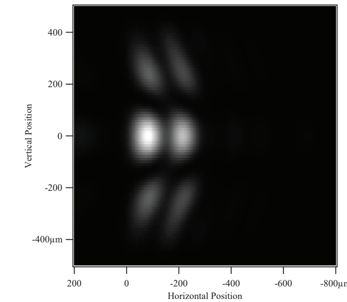
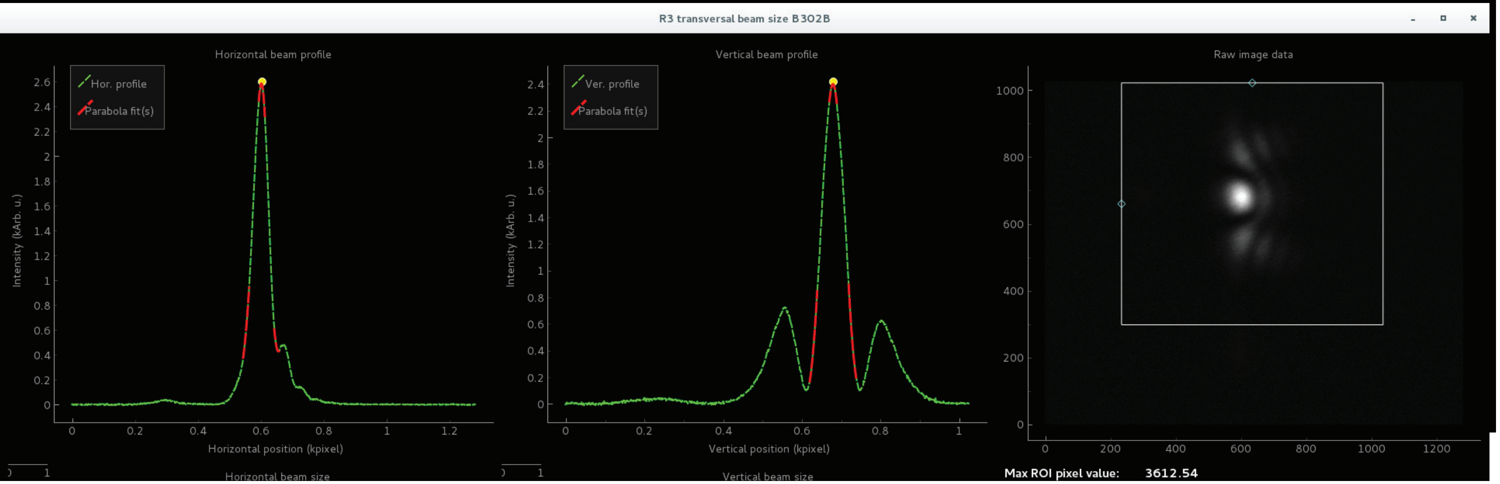
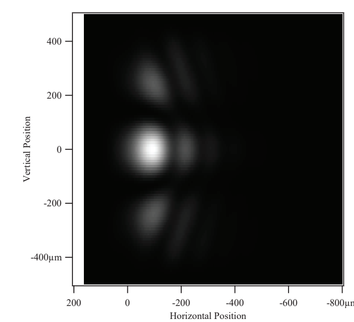
First, some measurements with NIR SR (930 nm) at B302B

Theory SRW









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

Top: Horizontal accept. A=10.66 $mrad_H$; Upright obstacle 2.25 $mrad_H$

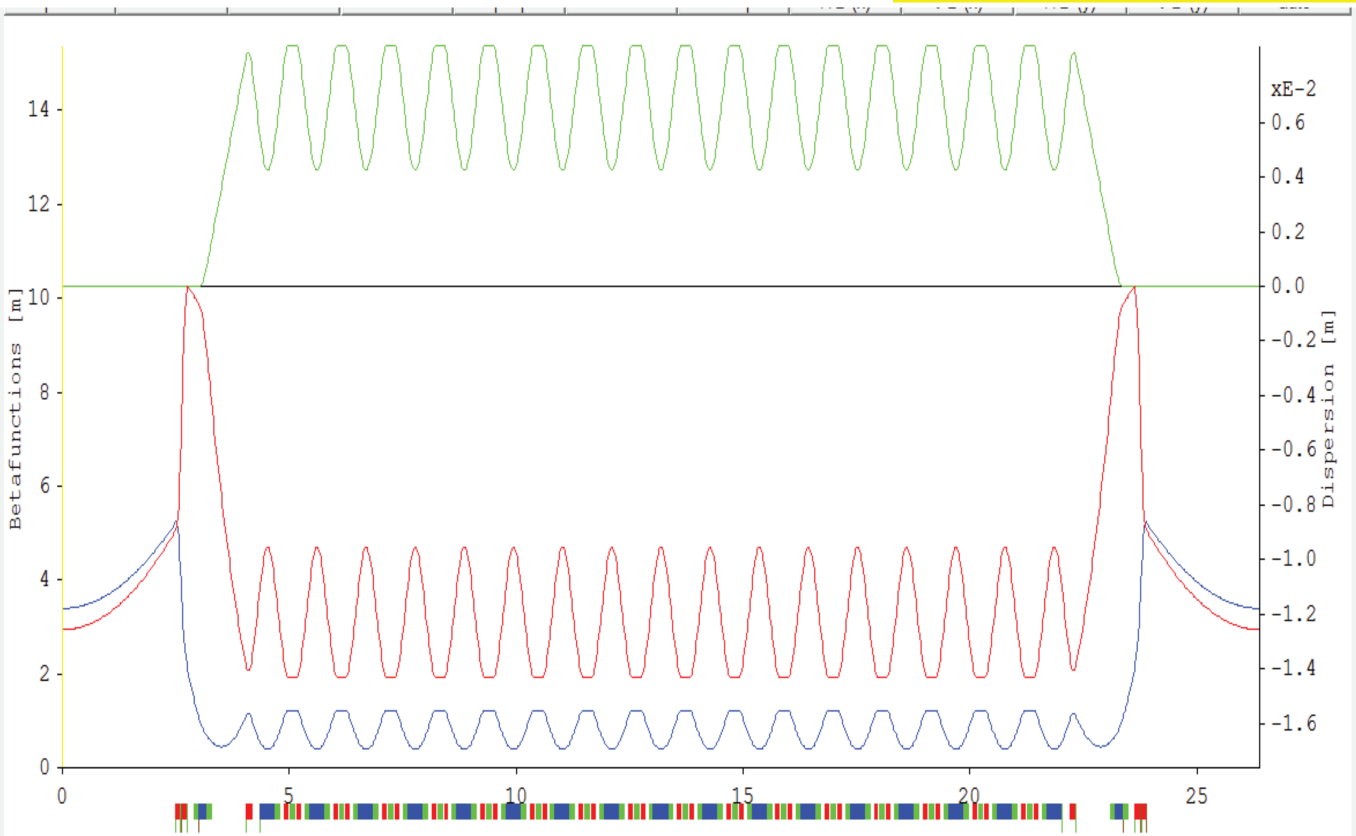
Bottom: Horizontal acceptance 12 $mrad_H$; **No upright obstacle, just pure imaging**

The assymetry is clearly predicted by SRW!!!

Possible imaging at the future ring LSs

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

Tavares P.F., Andersson Å. & Bengtsson J., J. Electron Spectrosc. Rel.d. Phenom. (2017) https://doi.org/10.1016/j.elspec.2017.09.010



ε_x = 16 pm.rad

In the dipoles:
β_x ~ 0.5 m

=> σ_x ~ 3 μm

Magnet design study: Talk tomorrow by Dr. A. Vorozhtsov

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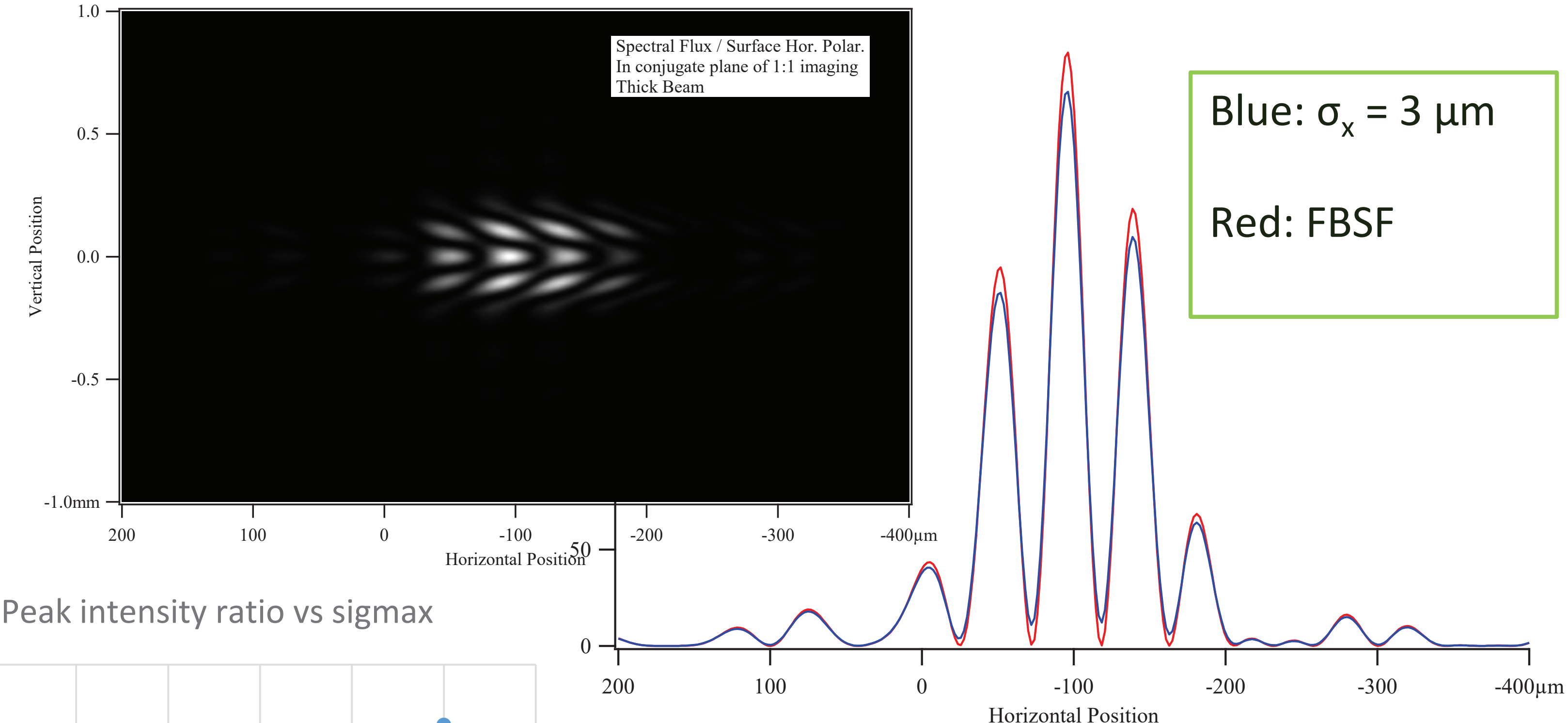
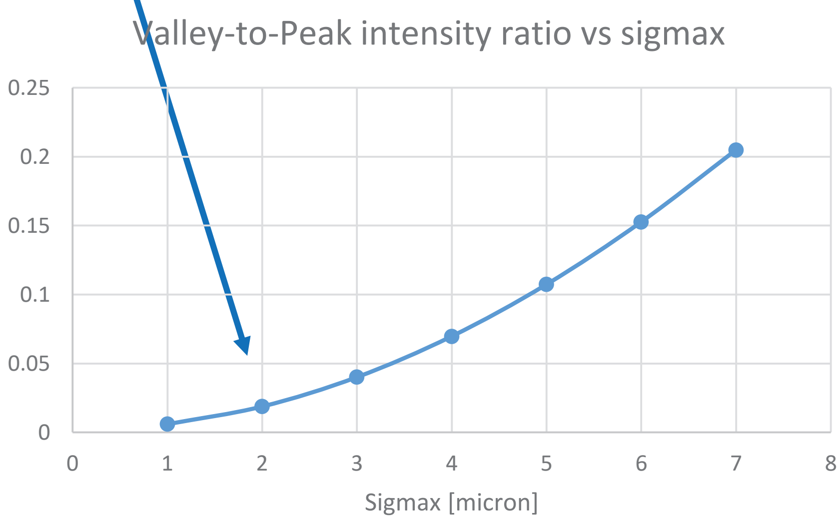
Possible imaging at the future ring LSs



Sensitivity is OK!



SRW images with σ-pol SR @ **266 nm** and a thin 1.7 mrad$_V$ x-ray absorber.

Horizontal acceptance ±4 mrad$_H$;

Upright obstacle ±2 mrad$_H$

Conclusions

- Imaging with visible or near visible SR has been shown to resolve rms beam sizes below 3 µm in the vertical plane.
- The methods rely on precise calculation of the Filament Beam Spread Function, FBSF, performed by the SRW code.
- We have demonstrated horizontal beam size measurements at the MAX IV 3 GeV ring, at 150 mA, that resolves the emittance to 345 ± 5 pmrad, and the relative energy spread to around 1e-3 with 2e-5 resolution.
- To reach sufficient horizontal resolution for Future ring Light Sources, with emittances in the 10 -20 pmrad region, the same method can be applied, if a horizontal acceptance angle of ±4 mrad can be extracted and Near UV radiaton (200 - 300 nm) is used.

Acknowledgments

I would like to thank the **MAX IV team** and especially:

Mikael Eriksson, who made it possible to measure these small emittances, by realizing the first MBA lattice light source

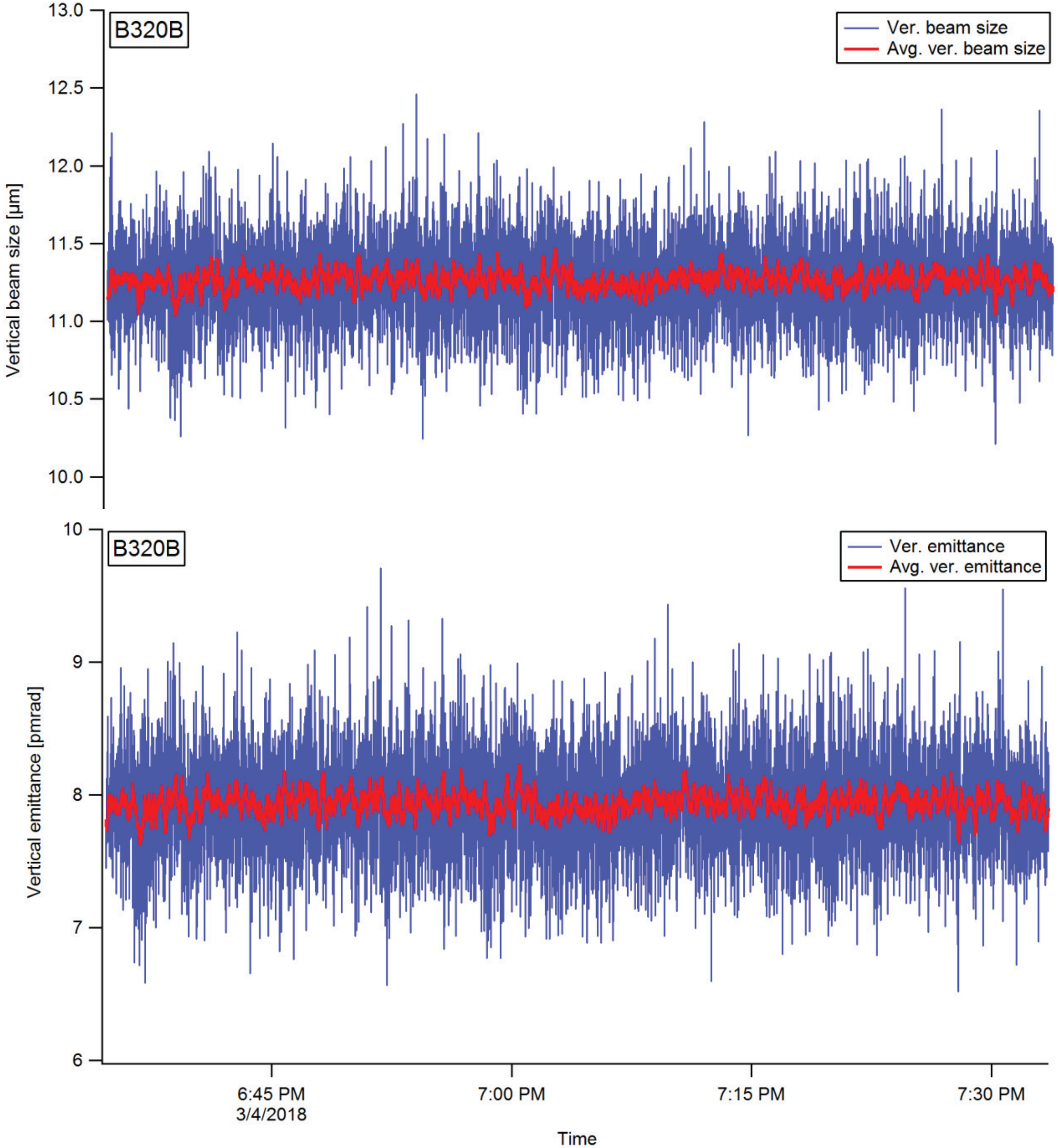
Oleg Chubar, for continuos support

Jonas Breunlin and **Anders Rosborg**, former PhD students

Robin Svärd, operator & diagnostics specialist

Backup on vertical emittance

From first monitor, B320B, ε_y = 8±0.5 pm.rad



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Courtesy Robin Svärd, Operator, speciality diagnostics

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