Bending Magnet Synchrotron Radiation Imaging with Large Orbital Collection Angles

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iFAST Low Emittance Rings workshop
13th – 16th of February 2024

MAX IV

Outline

- Introduction
- Theoretical calculations for the MAX IV case
- General formula for very large orbital collection angle
- Measurements
- Preparation for measurements at MAX 4-U
- Summary

Introduction

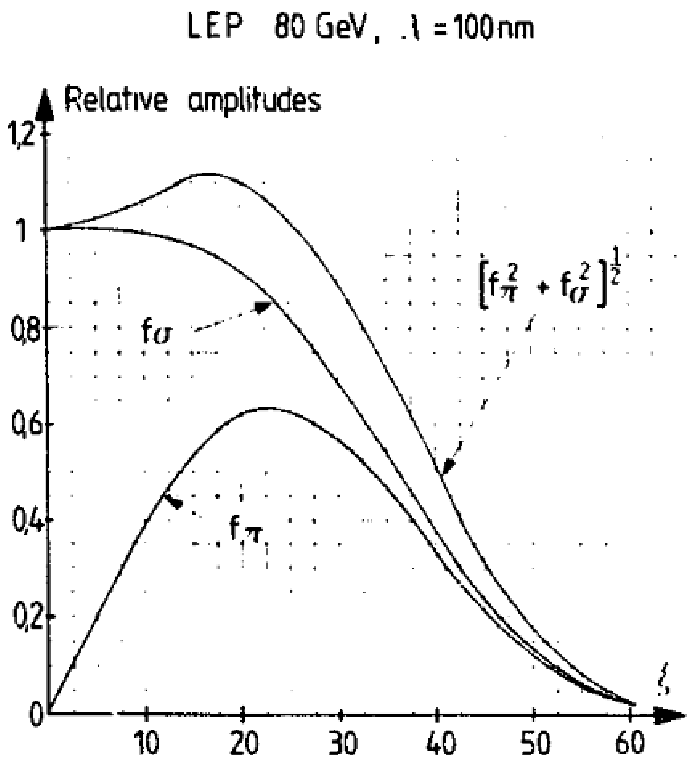
Nuclear Instruments and Methods 203 (1982) 483–493
North-Holland Publishing Company

OPTICAL RESOLUTION OF BEAM CROSS-SECTION MEASUREMENTS BY MEANS OF SYNCHROTRON RADIATION

A. HOFMANN and F. MÉOT *
CERN, Geneva, Switzerland

Received 17 February 1982

This paper deals with general theoretical considerations on diffraction and depth of field phenomena involved in the different cases of radiation by relativistic particles in magnetic fields: undulator, (usual) synchrotron, and "short magnet" radiation, and their effects on beam profile image formation. The image formation of extended polychromatic sources is examined. As an example, the beam cross-section imaging at the CERN SPS is given, and the cases of SPS (e^+e^-) and LEP are envisaged.



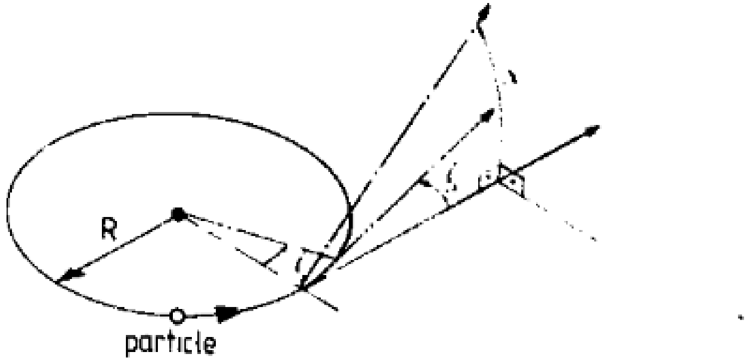


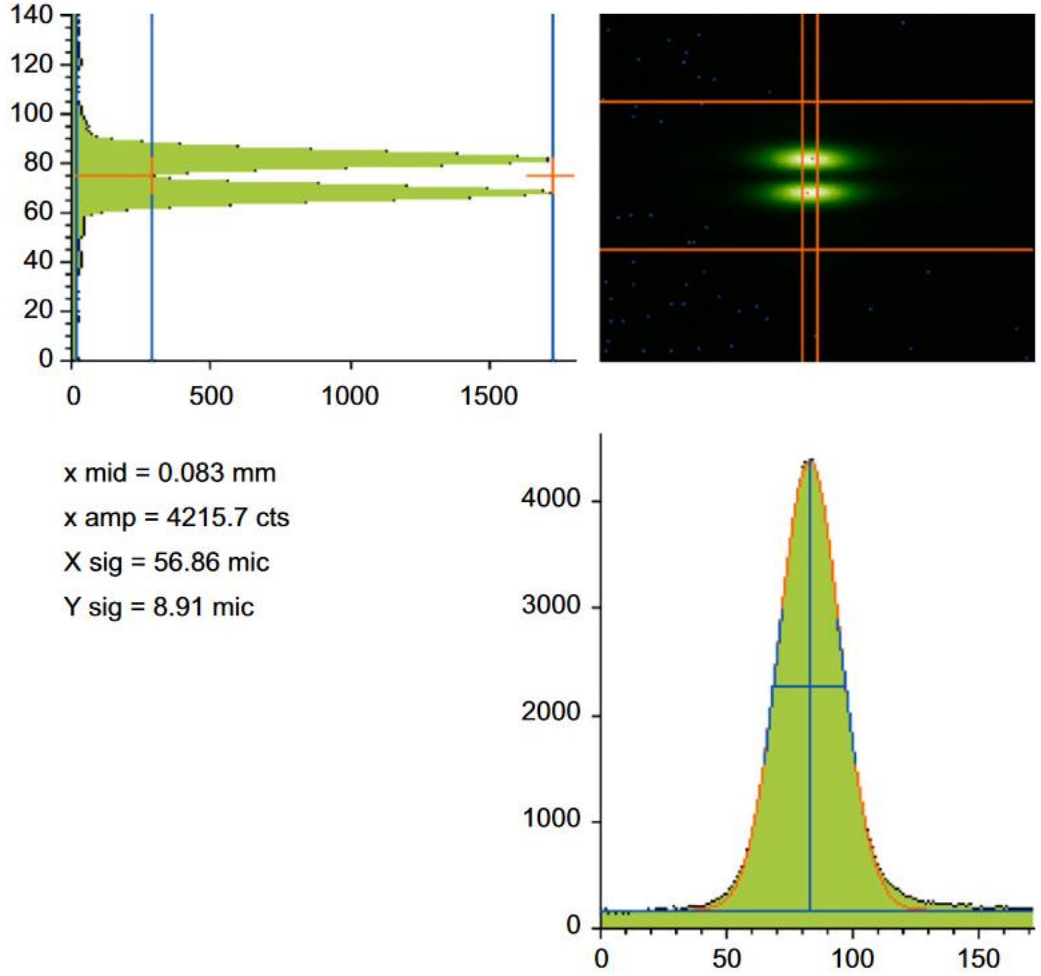
Fig. 4. Coordinates used to describe the synchrotron radiation.

Introduction

The Π – polarization method:

- **Imaging of the SR source.**
- **Usage of visible or near visible SR.**
- **The visibility, or Valley to Peak intensity ratio, gives the σ_y**
- **Introduced as an on-line monitor at Swiss Light Source, in 2007.**
- **Determines vertical beam sizes down to around 5 um.**
- **Best resolution when at largest collection angle in the vertical.**
- **The natural opening angle of the SR limits the vertical resolution.**

Å. Andersson et al. / Nuclear Instruments and Methods in Physics Research A 591 (2008) 437–446



Introduction

Is there a similar method in the horizontal, when σ_x = 5 or 10 µm?

- **Is best resolution reached when at largest collection angle in the horizontal?**
- **Will the horizontal natural opening angle of the SR limit the horizontal resolution?**

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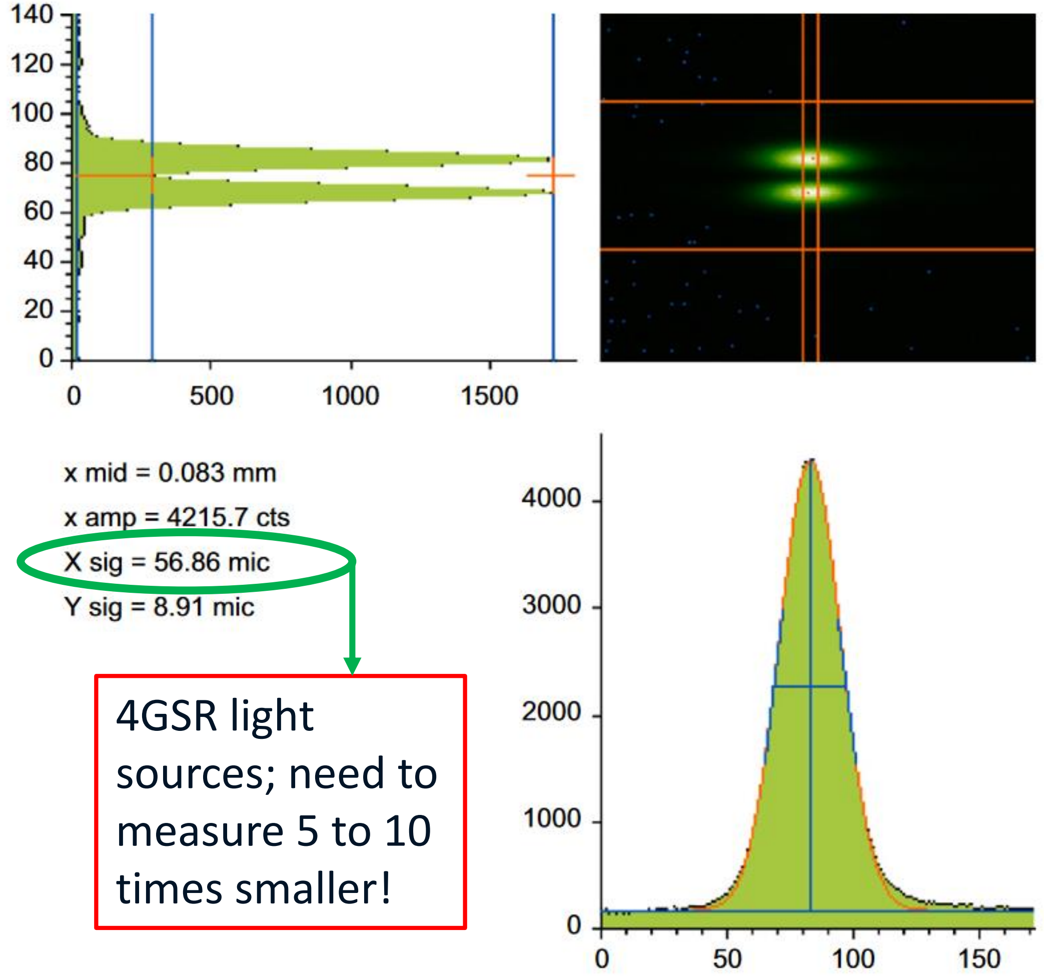


4GSR light sources; need to measure 5 to 10 times smaller!

MAX IV

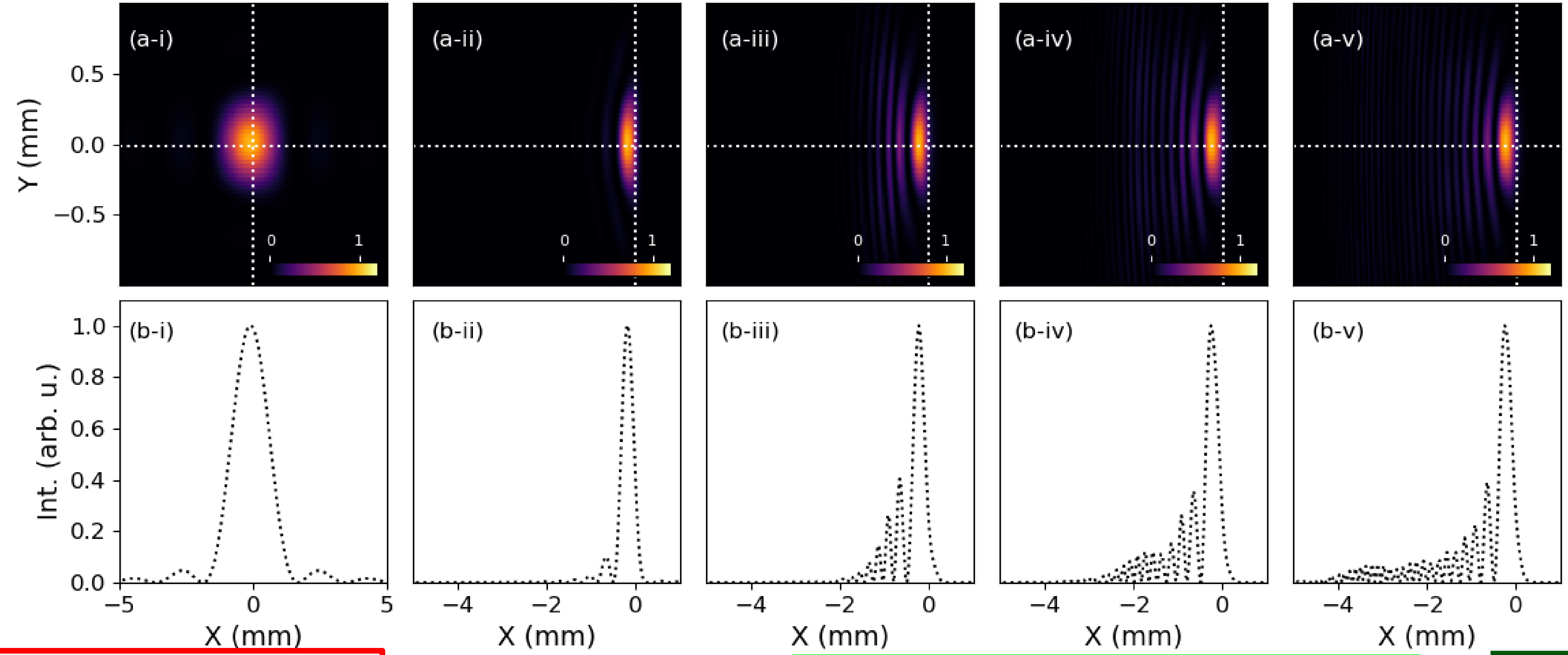
To answer such questions, we joined forces from SOLEIL, NSLS-II and MAX IV

- **Marie Labat** and **Nicolas Hubert** from SOLEIL
- **Oleg Chubar** from NSLS-II
- **Jonas Breunlin** and **Åke Andersson** from MAX-IV

From theory: Image plane **normalized** intensity distributions from a zero-emittance beam, for different $\Delta\theta_x$, using σ-polarized light. $\Delta\theta_y$ = 7 mrad

λ = 930 nm

$\Delta\theta_x$ = 1.6 mrad | 9 mrad | 15 mrad | 20 mrad | 25 mrad



Diffraction dominated, Fraunhofer-like

Dominated by inherent features of the SR emission process

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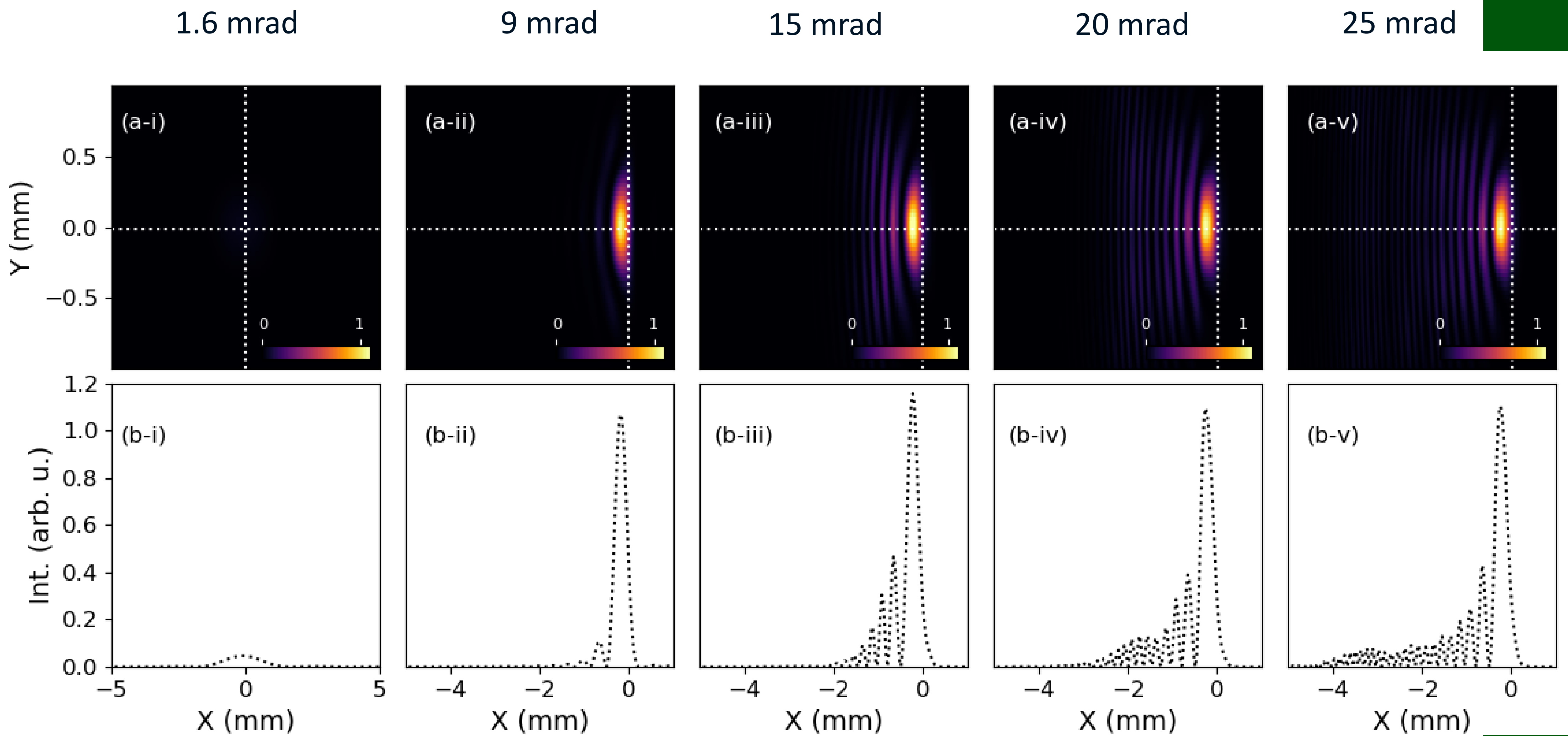
From theory: Image plane **non-normalized** intensity distributions from a zero-emittance beam, for different $\Delta\theta_x$, using σ-polarized light. $\Delta\theta_y$ = 7 mrad

λ = 930 nm



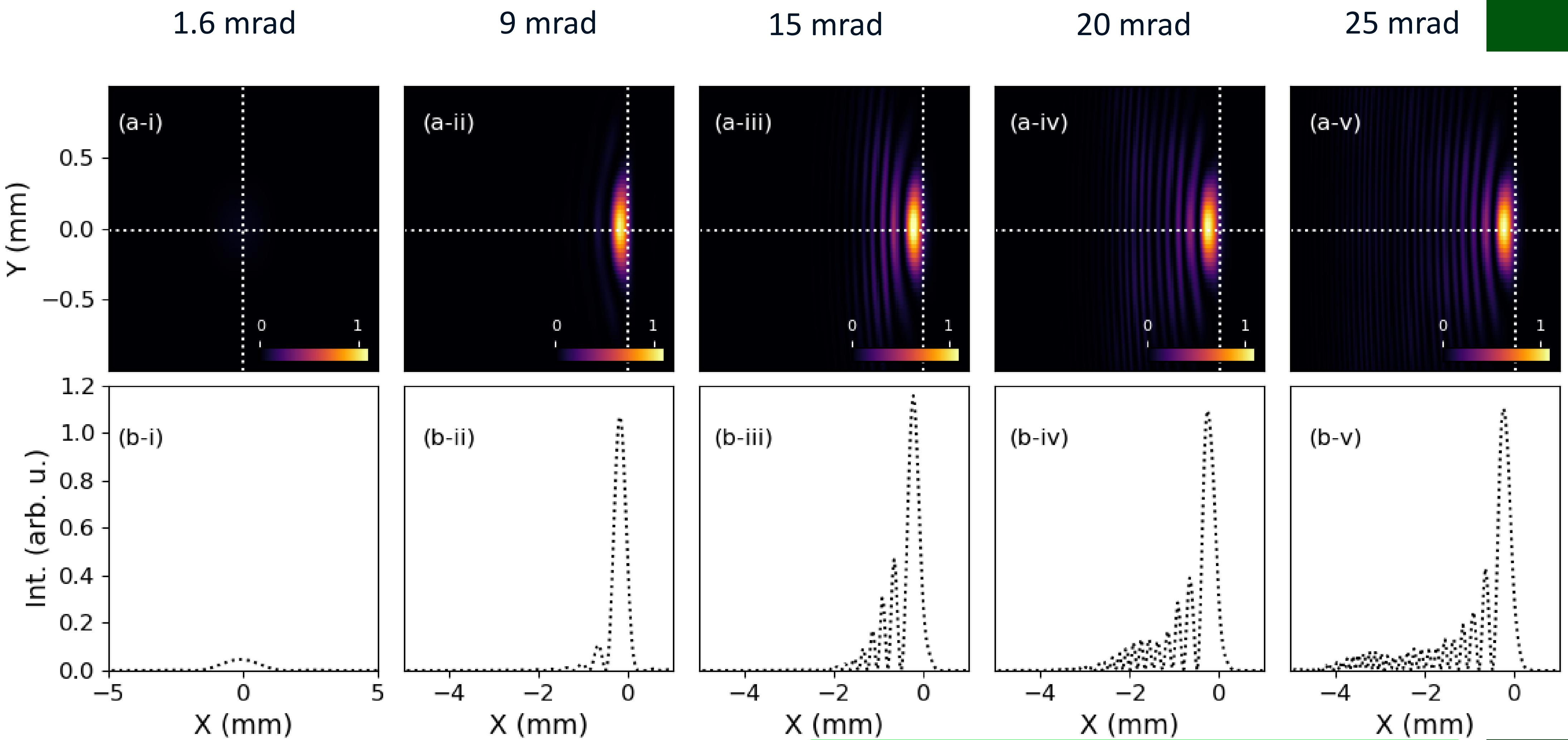
Very low intensity!

No gain in peak intensity by further opening up the collection angle!!

MAX IV

From theory: If we want to **explore the visibility of fringes** as a measure of the beam size, **best resolution possibilities are between 9 and 15 mrad**

λ = 930 nm



The SR horizontal natural opening angle does limit further exploration!

Curiosity: The image plane intensity distribution expression, may be simplified, if $\Delta\theta_x$ is very large:

$$E_\sigma(x,y,\lambda) = -\frac{4i\pi^{4/3}e\rho^{1/3}}{c\lambda^{4/3}} \times \int_{\Delta\theta_y} \mathrm{Ai}'\left[\left(\frac{\pi\rho}{\lambda}\right)^{2/3}(\gamma^{-2}+\theta_y^2)\right]\exp\left(\frac{2\pi i y}{\lambda}\theta_y\right) \times \int_{\Delta\theta_x} \exp\left[\frac{i\pi\rho\theta_x}{\lambda}(\gamma^{-2}+\theta_x^2/3+\theta_y^2)+\frac{2\pi i x}{\lambda}\theta_x\right] \times d\theta_x d\theta_y, \quad (1)$$

$$I_\sigma(x,y,\lambda) = \frac{c^2\alpha I}{4\pi^2 e^3}|E_\sigma(x,y,\lambda)|^2, \quad (2)$$

$\Delta\theta_x$ large →

$$I_\sigma(x,y,\lambda) \propto |E_\sigma(x,y,\lambda)|^2 \propto \left|\int_{\Delta\theta_y} \mathrm{Ai}'\left[\left(\frac{\pi\rho}{\lambda}\right)^{2/3}(\gamma^{-2}+\theta_y^2)\right]\exp\left(\frac{2\pi i y}{\lambda}\theta_y\right) \times \mathrm{Ai}\left[2^{1/3}\frac{(\gamma^{-2}+\theta_y^2)\rho/2+x}{\rho^{1/3}(\lambda/(2\pi))^{2/3}}\right]d\theta_y\right|^2. \quad (3)$$

Details in:

Bending Magnet Synchrotron Radiation Imaging with Large Orbital Collection Angles

M. Labat,[1,*] O. Chubar,[2] J. Breunlin,[3] N. Hubert,[1] and Å. Andersson[3]
[1]Synchrotron SOLEIL, L'Orme des Merisiers, 91 190 Saint-Aubin, France
[2]Brookhaven National Laboratory, Building 741, P.O. Box 5000, Upton, New York 11973-5000, USA
[3]MAX IV Laboratory, P.O. Box 118, SE-221 00 Lund, Sweden

PHYSICAL REVIEW LETTERS 131, 185001 (2023)

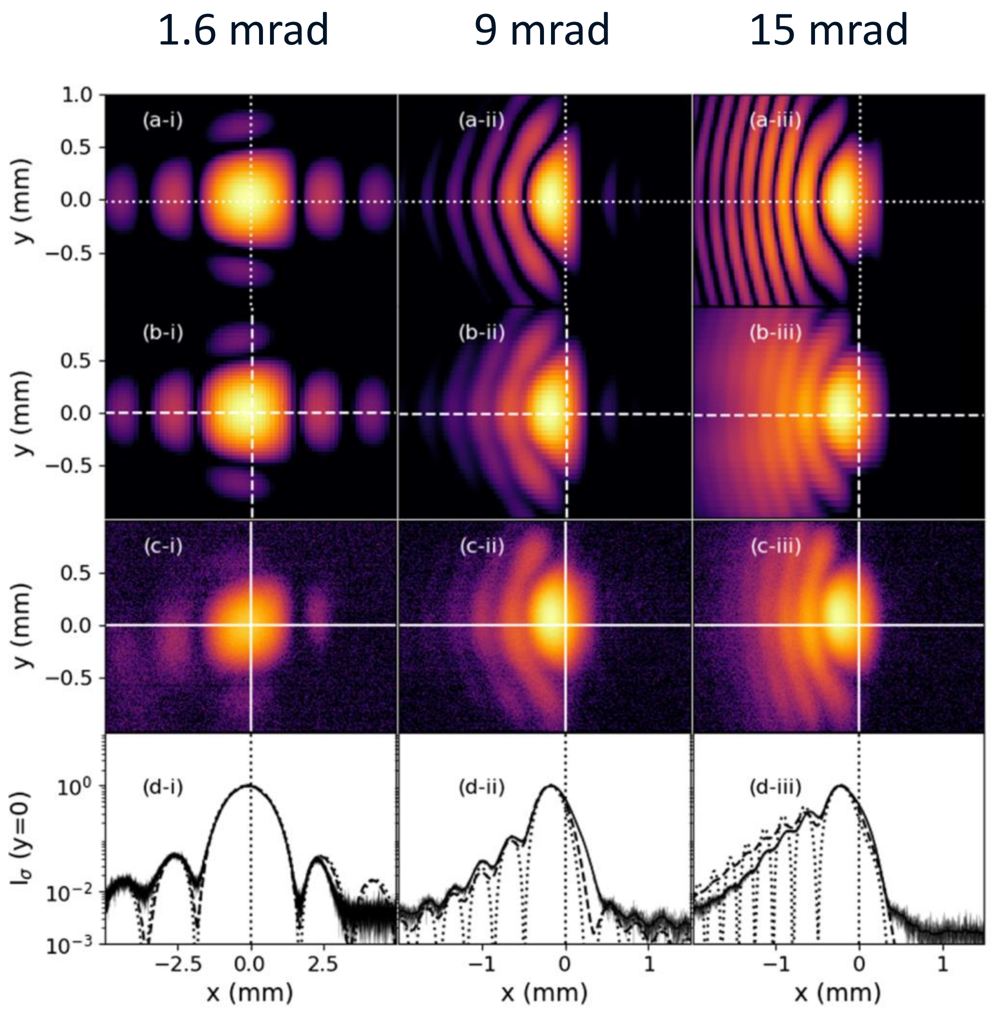
Measurements at MAX-IV:

Intensities are in log-scales for easier comparison to theory.

Theory
Zero emittance

Theory (SRW)
ε_x =336 pmrad

Measured!



λ = 930 nm

Measurements were done at 3 mA, where design **ε_x =328 pmrad**
Best fit for the 9 mrad case was **ε_x =336 pmrad**

Details in:

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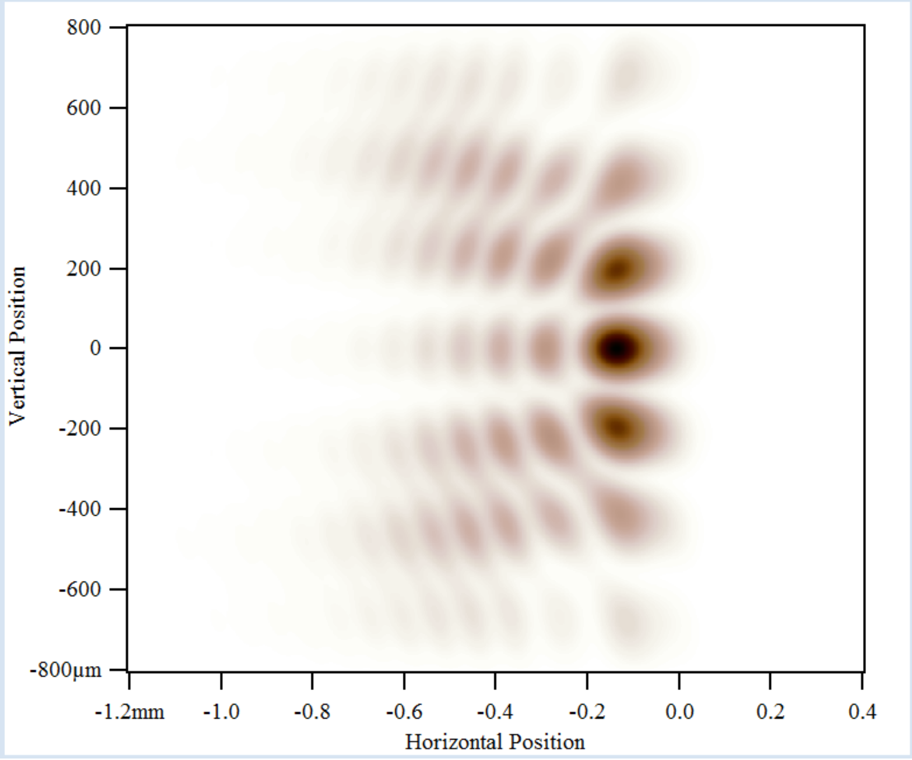
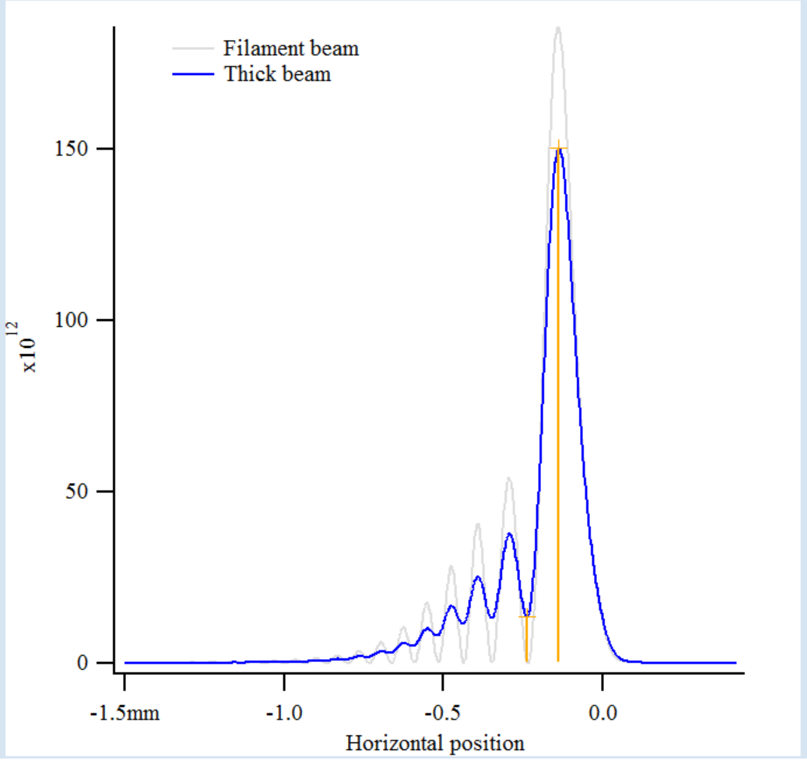
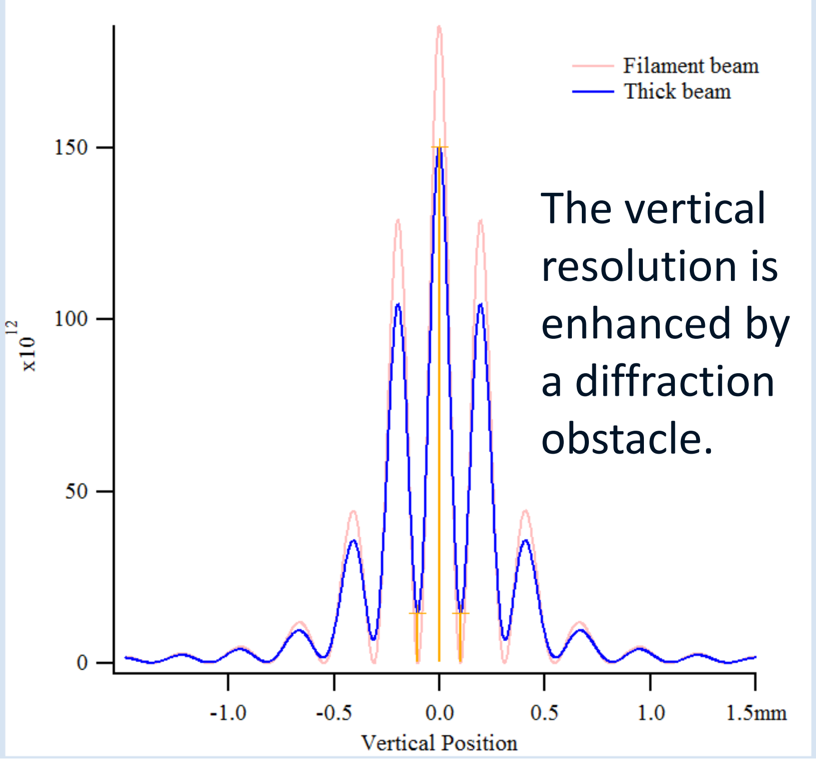
Preparation for measurements at MAX 4-U:

Assuming
$\sigma_x = \sigma_y = 10\ \mu m$

Here we use λ = 365 nm, $\Delta\theta_x$ = 12 mrad, σ-pol light







The vertical resolution is enhanced by a diffraction obstacle.

Summary

- Imaging bending magnet SR with a rather large orbital collection angle, seems to provide a viable method for determining small horizontal beam sizes.
- The image contains an asymmetric fringe pattern, that is diluted to a certain degree, for a given finite beam size.

We had great fun during our collaboration!!!

- **Marie Labat** and **Nicolas Hubert** from **SOLEIL**
- **Oleg Chubar** from **NSLS-II**
- **Jonas Breunlin** and **Åke Andersson** from **MAX-IV**

We all,

Thank You for listening!!!

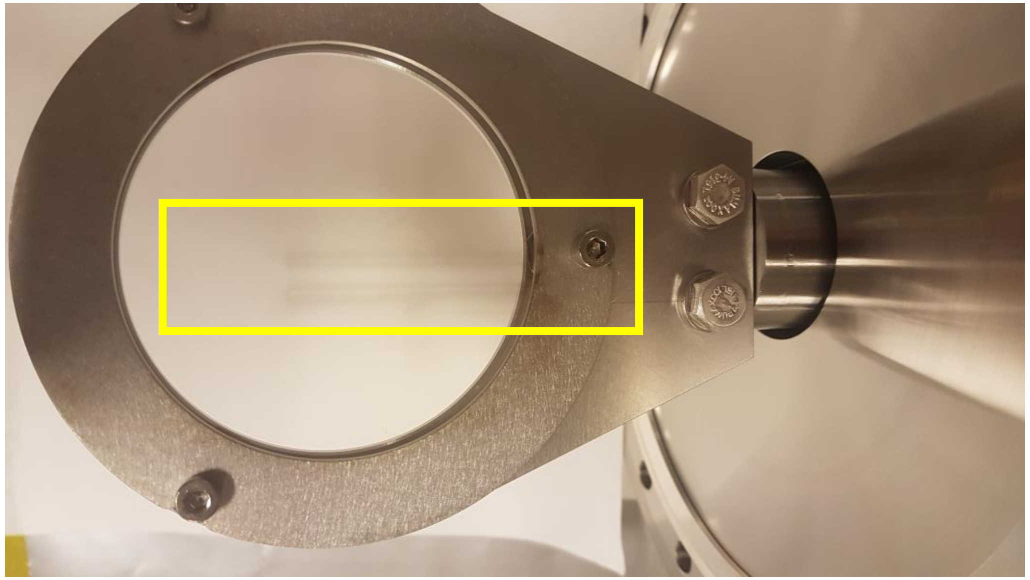
Backup slides

Emittance monitors, for future low emittance lattices

At MAX-IV : Beam size diagnostics in the Visible, or Near-Visible spectral range. **=> Interpret SR emission effects.**

- Many advantages, but one must **avoid bad optical components and possible degradation!**

- **“Sacrificial optics”** for reduced impact by carbon deposition. The deposition is mainly on our lens.



- **“Monochromatisation” is always delicate.** Multilayer colour filters often affect the wavefront => Back to basics: Use spatial separation with **Prism**.