Synchrotron beamline designs

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Outline

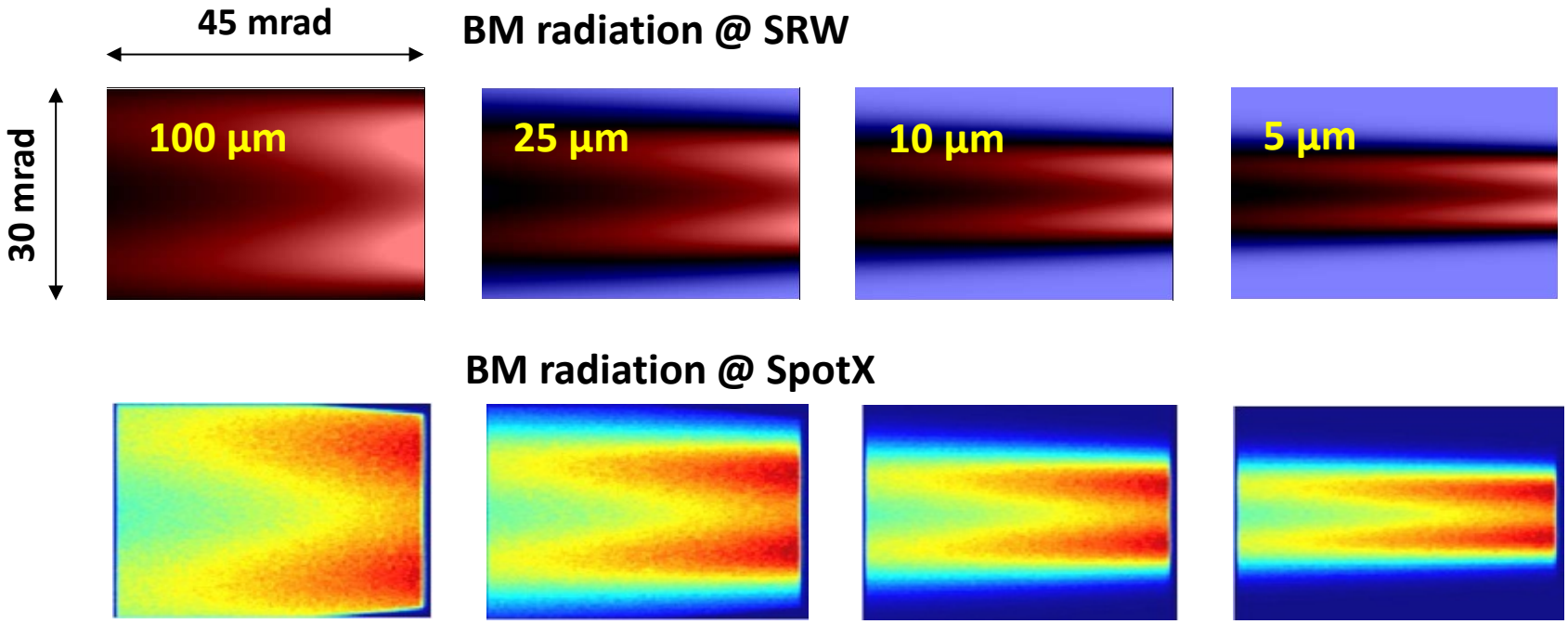
- Simulation tools
- Example of beamline design
  - undulator source
  - crystal monochromator
  - focusing stage
- Conclusions

Simulation tools

- **The ray-tracing SPOTX**
  - **geometrical ray-tracing + dynamical calculation of synchrotron sources (far field) & mirrors, multilayers, crystals, gratings**
  - **full optical simulation of soft and hard X-rays synchrotron beamlines in one go**
  - **thermal deformations, LTP & interferometric measurements, 4^{th} order polynomial surfaces**
  - **electron beam propagation (first order)**
  - **well adapted to evaluate the geometrical aberrations produced by sources and optical shapes**
  - **incoherent : doesn't take into account the beam coherence**

Simulation tools

- SOLEIL, E_0 = 2.75 GeV, BM = 1.72 T



BM = Ray tracing (out of diffractive areas)

Bio-crystallography beamline design

User's specifications (2002)

- Spectral range : E = 5 - 15 keV
  Spot size : ∅ ≈ 100 µm FWHM
  Divergence < 350 µrad FWHM
  Spectral resolution ≈ 10^{-4}
  Harmonics rejection < 10^{-3}
  Distance focusing optics - sample ≈ 3 m

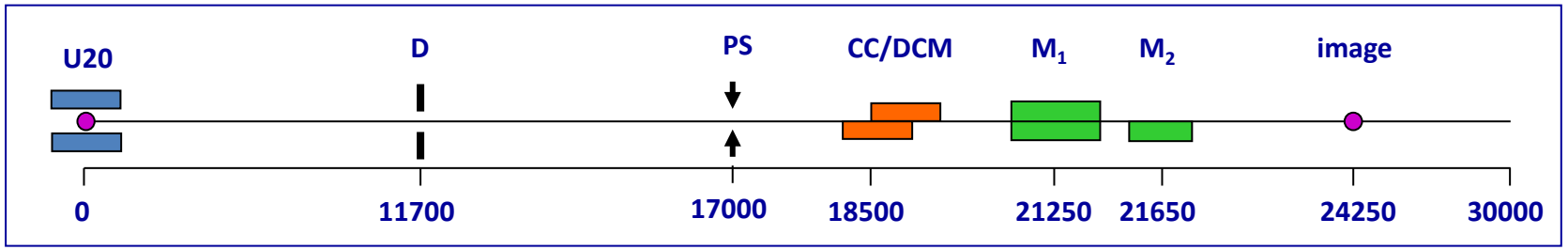
  + Intensity & stability

- Beamline equipment

  Source : U20 undulator on a short section
  Monochromators : channel-cut Si111
  Focusing optics : Kirkpatrick-Baez (≈ 300 & 200 mm CA)

RMS values

σ_x (µm)	σ_z (µm)	σ'_x (µrad)	σ'_z (µrad)
388	8.11	14.5	4.6



Bio-crystallography beamline design

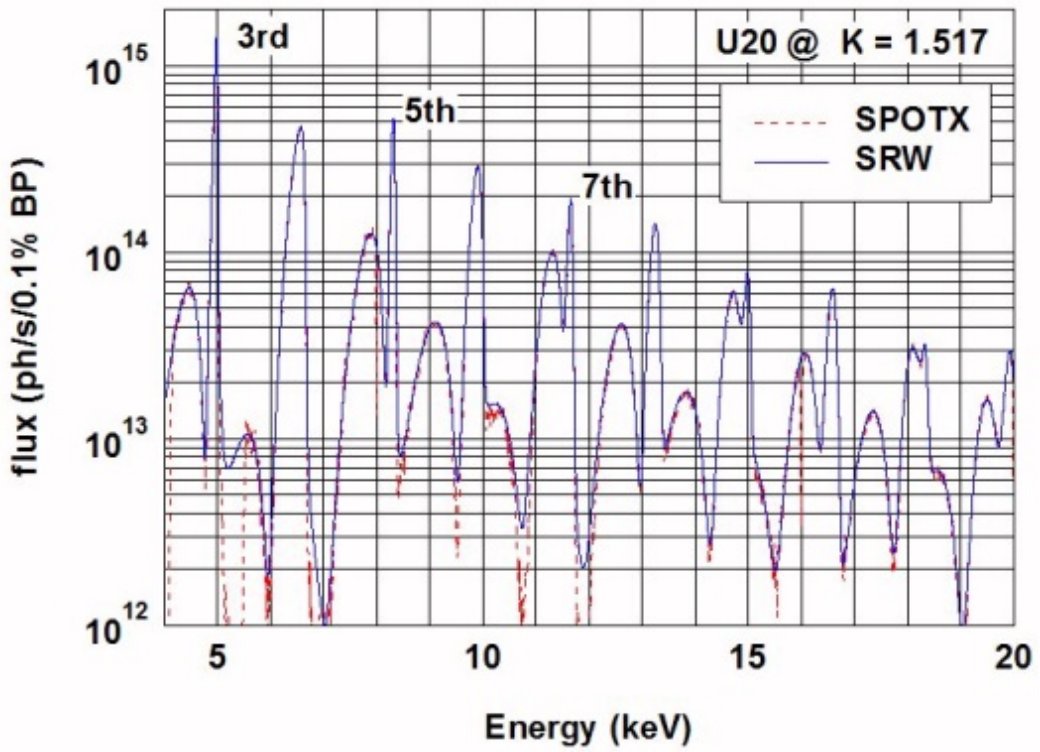
Undulator (U20)+ diaphragm (1×0.5 mm H×V)

- They define the optical axis & aperture of the beamline

- Spectral range

$$K = \frac{1900 \times {E_0}^2 \times n}{\lambda_U \times E} - 2$$

$$K = 0.934 \times \lambda_U(\mathrm{cm}) \times B(\mathrm{T})$$



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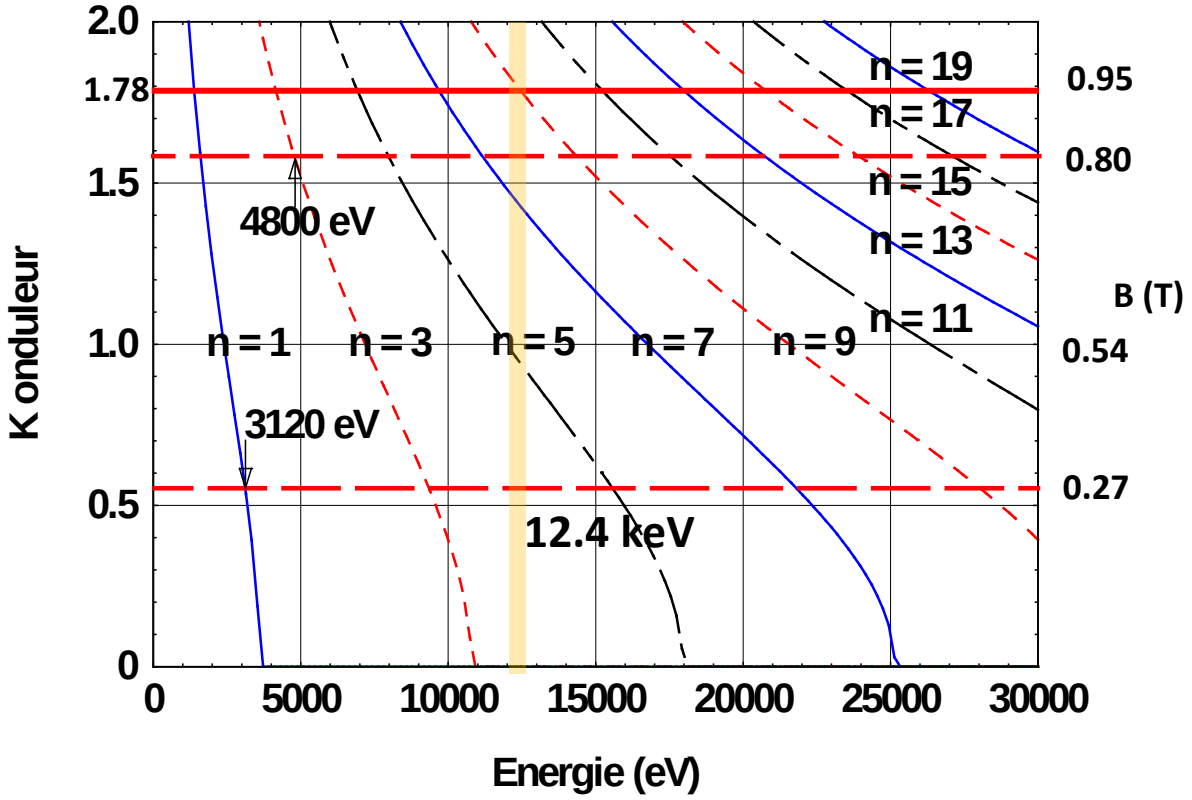
Odd harmonics n
in small apertures

12.4 keV with n = 5, 7 or 9



Bio-crystallography beamline design

Undulator (U20)+ diaphragm (1×0.5 mm H×V)

- They define the optical axis of the beamline

- Spectral working range

$$K = \frac{1900 \times {E_0}^2 \times n}{\lambda_U \times E} - 2$$

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Odd harmonics n in small apertures

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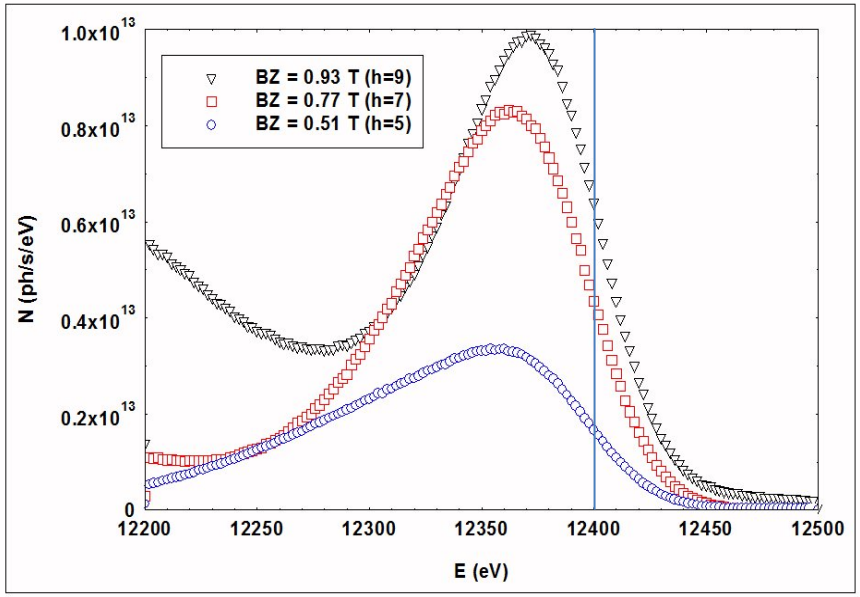


Harmonic after the diaphragm

N ↗ n
N ↘ phase errors
phase errors ↗ n

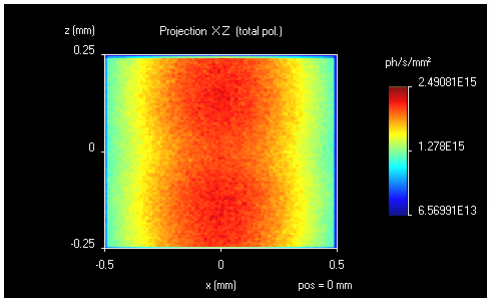
compromise

Bio-crystallography beamline design

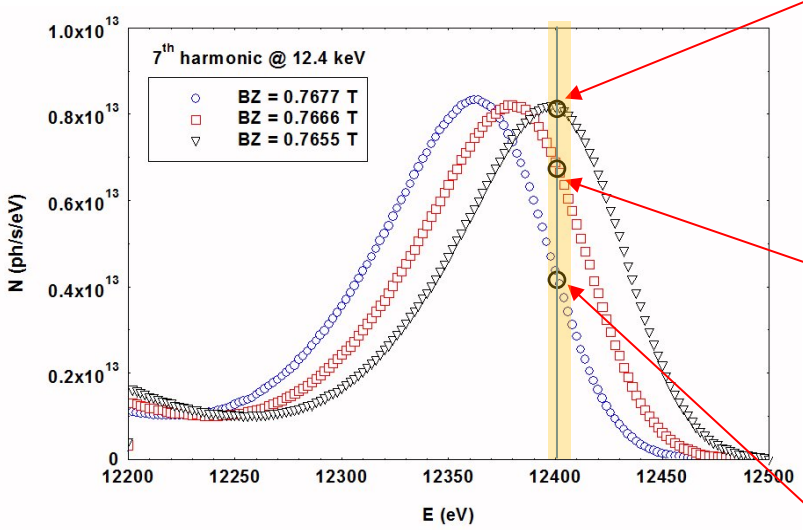
Undulator (U20)+ diaphragm (1×0.5 mm H×V)

- **Harmonic tuning (n = 7)**

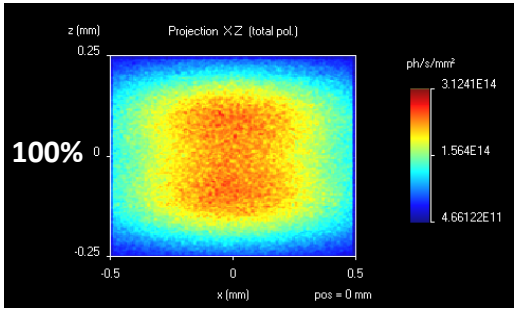
Image after the diaphragm

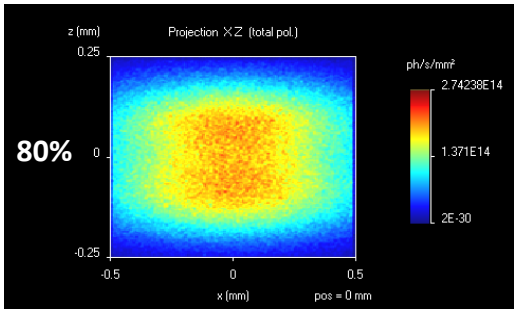


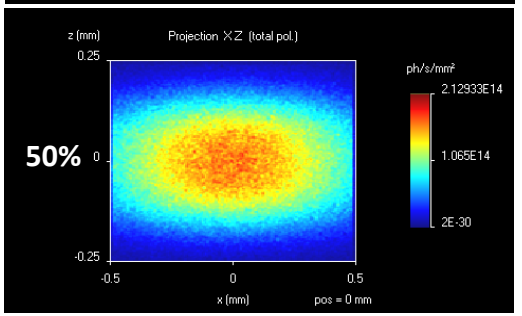
In the harmonic



In 10 eV







Bio-crystallography beamline design

Channel-cut/DCM (Si111)

- **Bragg law + spectral resolution**

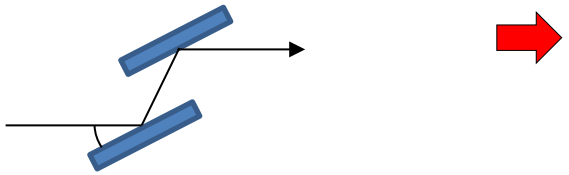
$$m\,\lambda = 2 \times d \times \sin(\theta_{BRAGG})$$

$$E(eV) = 12398.52/\lambda(\text{Å})$$

$$\Delta E/E = (\Delta w \otimes \Delta z')/tan(\theta_{BRAGG})$$

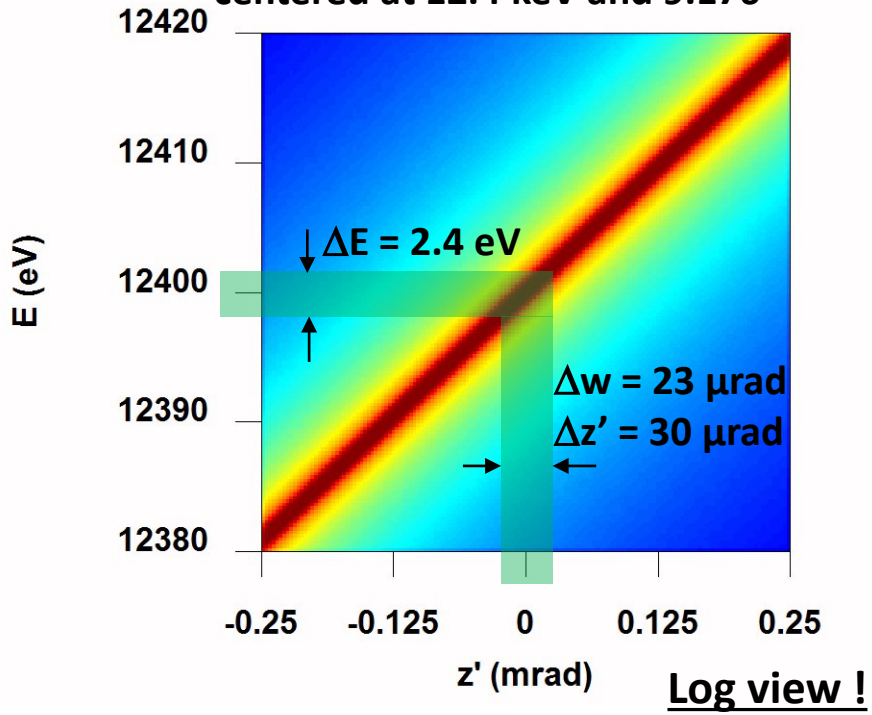
m = 1, 3.. for Si111

- **<u>Si111</u> surfaces in symetric configuration**



θ_{BRAGG} = 9.176° @ 12.4 keV

Channel-cut /DCM Dumond diagram centered at 12.4 keV and 9.176°

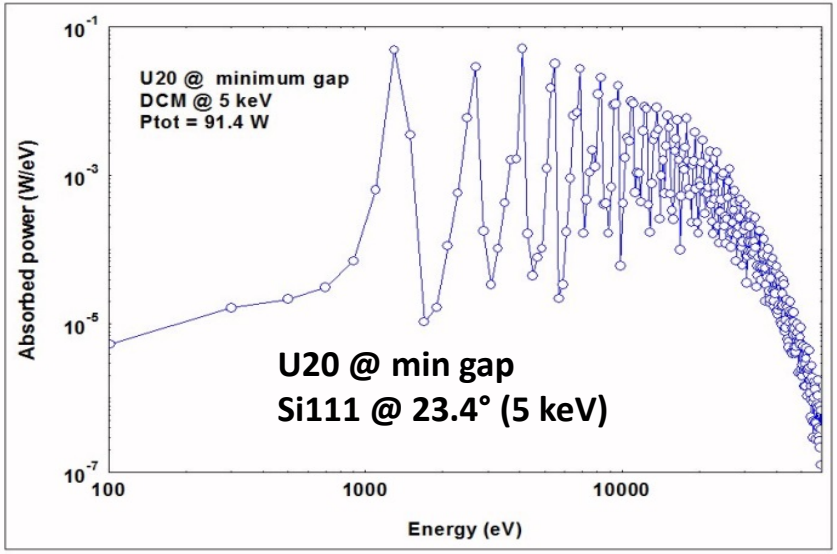


<u>Log view !</u>

Bio-crystallography beamline design

Channel-cut/DCM (Si111)

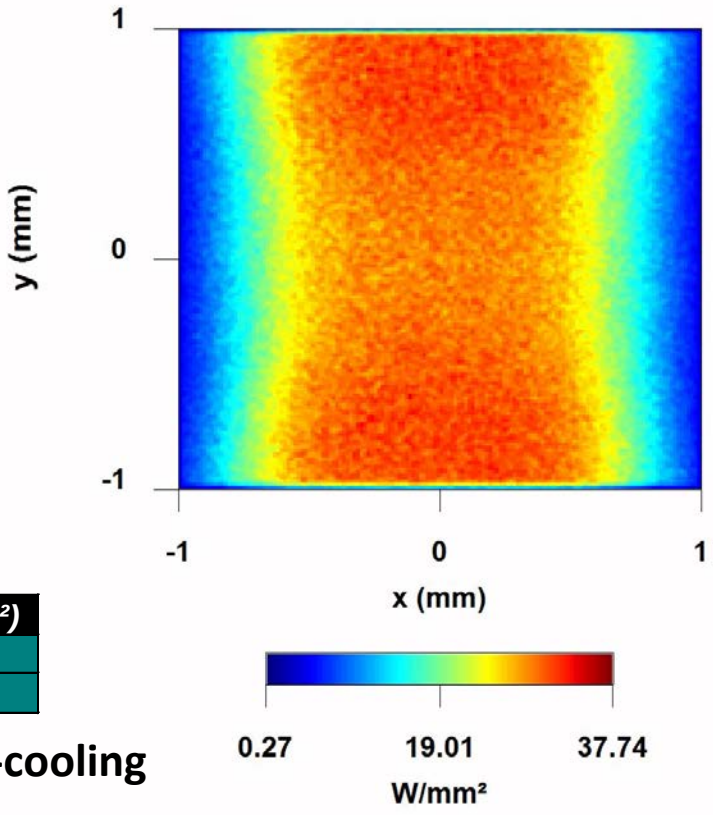
- **Thermal load on the first inner face**



Element	*Trans. P (W)*	*Abs. P (W)*	*∂P_{ABS} (W/mm²)*
Diaphragm	91.4	3951	201
Si111 @ 23.4°	$\cong 2\times10^{-3}$	**91.4**	**31.5**

cryo-cooling

Absorbed power on the 1rst inner face

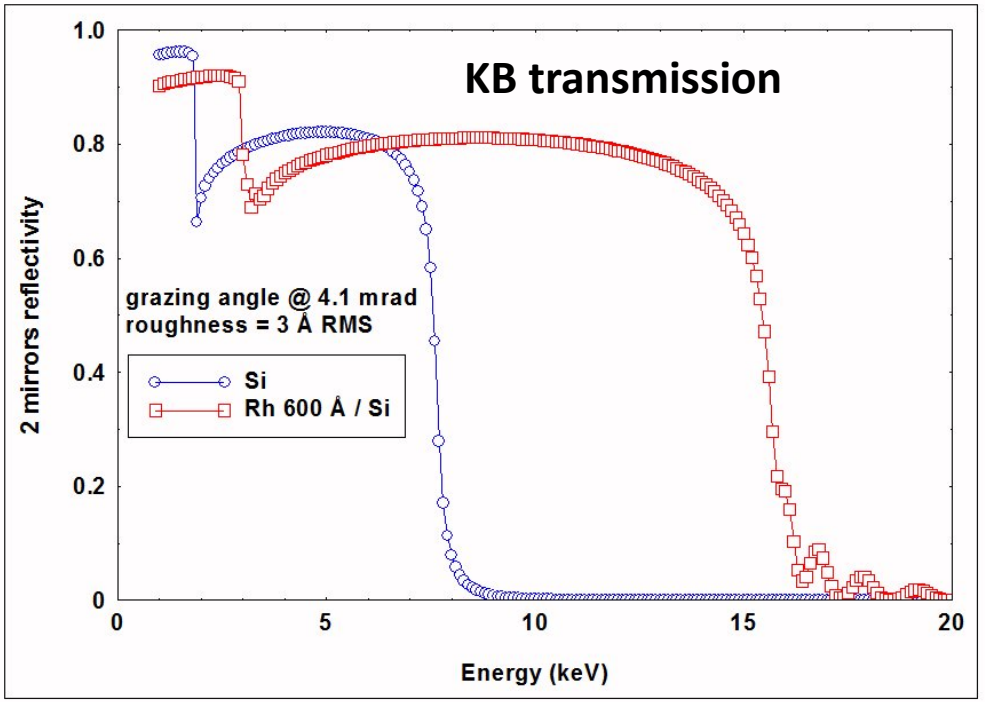


Bio-crystallography beamline design

KB mirrors & focused image

- **To focus the beam on the sample & crystal harmonics rejection**

(variable) elliptical profiles
fixe grazing angle = 4.1 mrad
coating : Rh (dens@93%)
300 mm/ 200 mm mirror lengths



Harmonic rejection

5 – 6 keV : crystal detuning
(or Si stripe)
6 – 15 keV with the Rh stripe

KB trans ≈ 80% (without the curvature)

Bio-crystallography beamline design

KB mirrors & focused image

- **Focused beam sizes**

≈ 14 µm FWHM

$$S_1 = \left(\frac{q}{p} \times S_0\right) \otimes (2 \times q \times \varepsilon)$$

optical mag. mirror defects

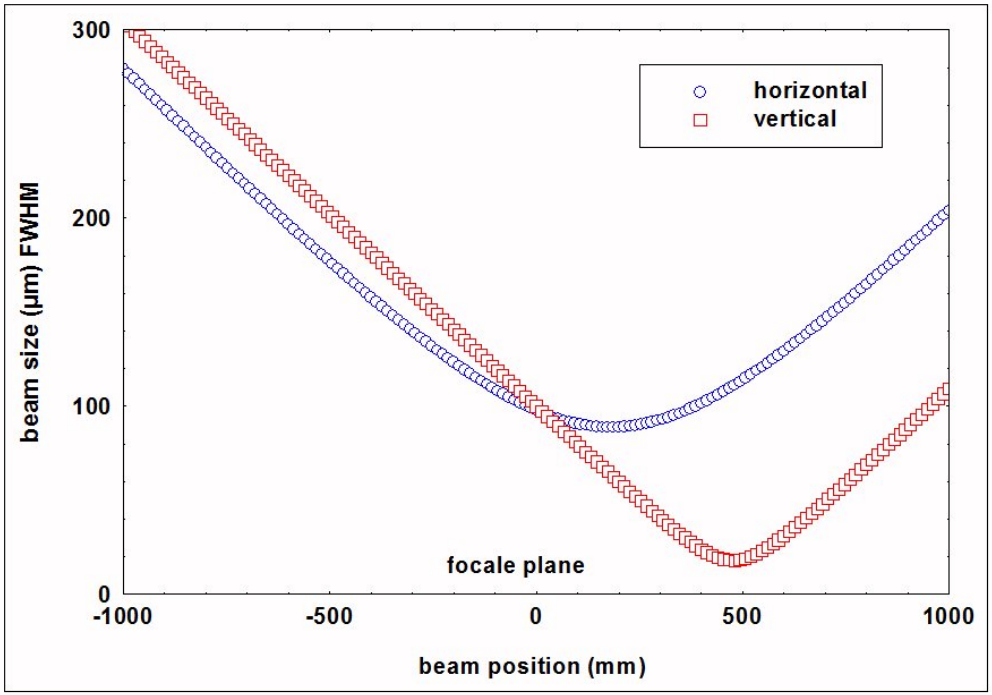
with p ≈ 21.5 m, q ≈ 3 m, ε ≈ 1 µrad RMS

Source
S_0 H ≈ 912 µm FWHM
S_0 V ≈ 19 µm FWHM

Image
S_1 H ≈ 128 µm FWHM
S_1 V ≈ 14 µm FWHM

∅100 µm FWHM beam

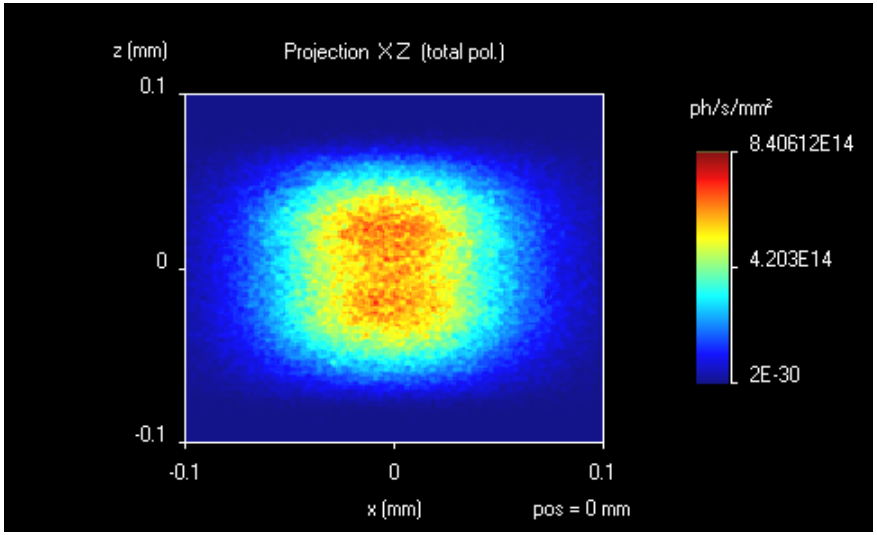
➡ **vertical defocusing !**



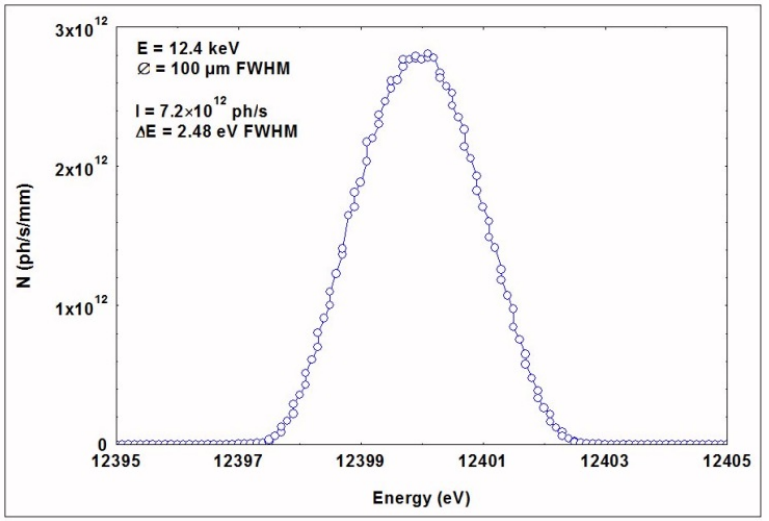
Bio-crystallography beamline design

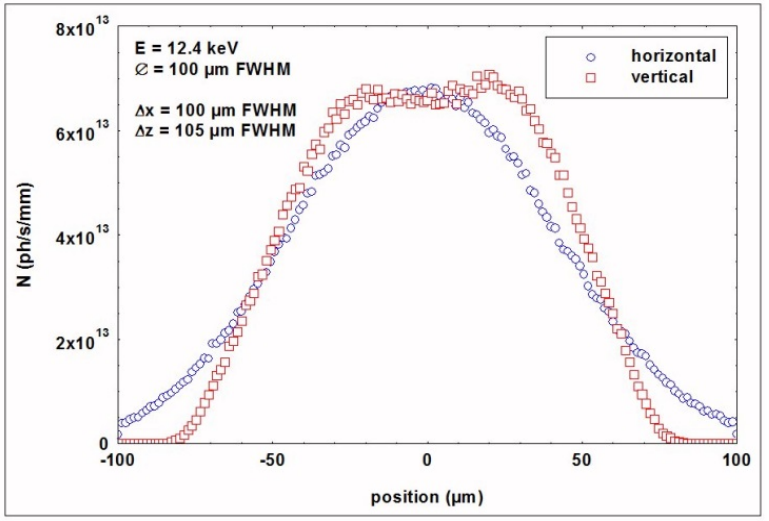
KB mirrors & focused image

- ∅100 µm FWHM @ 12.4 keV



With gaussian slope errors

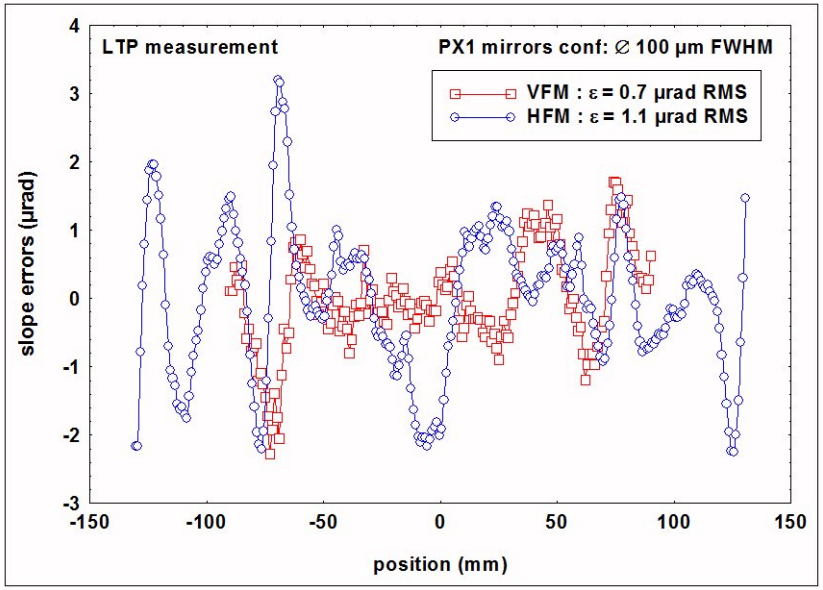




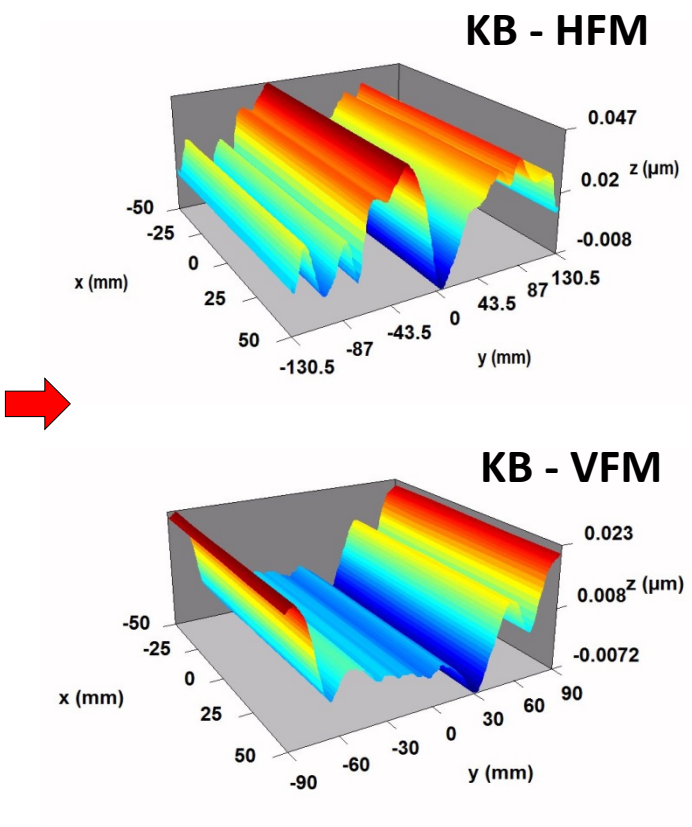
Mirrors manufacturing defects

KB mirrors & focused image

- **Real mirror shapes**



LTP measurement

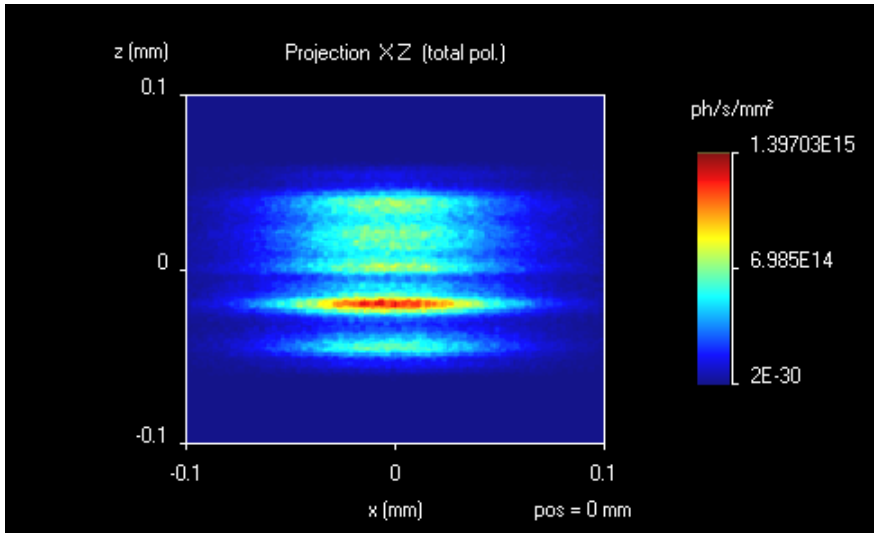


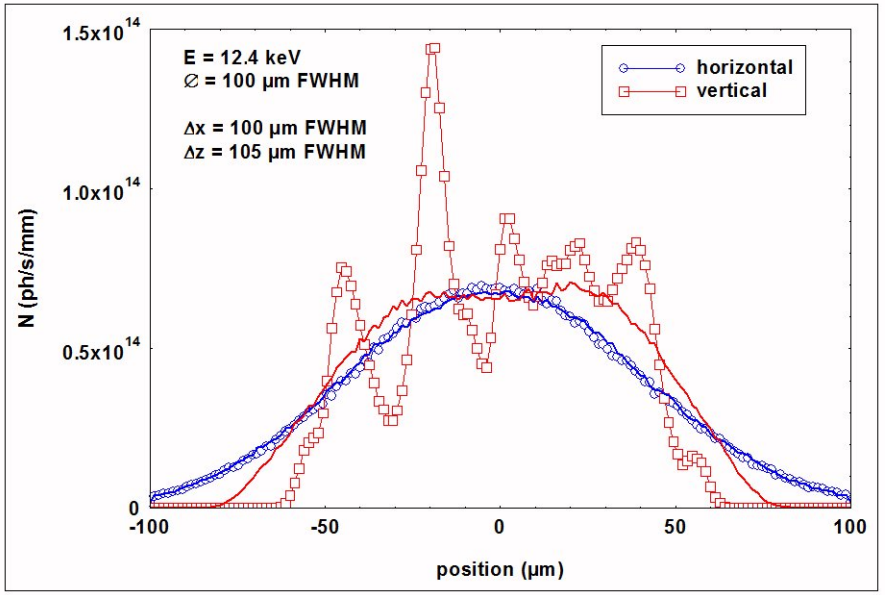
Ray-tracing

Mirrors manufacturing defects

KB mirrors & focused image

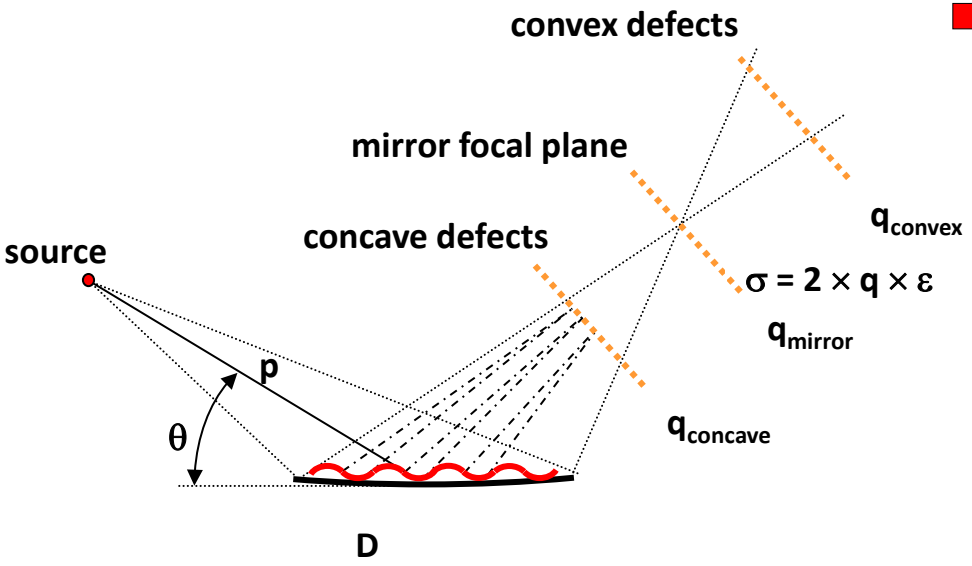
- **∅100 µm FWHM @ 12.4 keV**



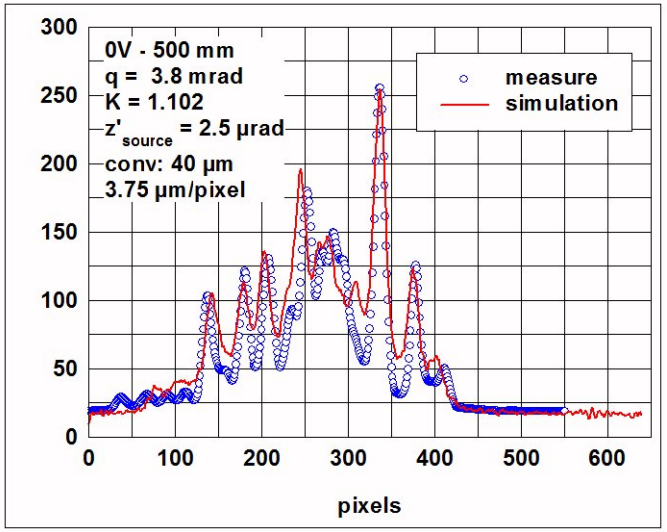


With real slope errors

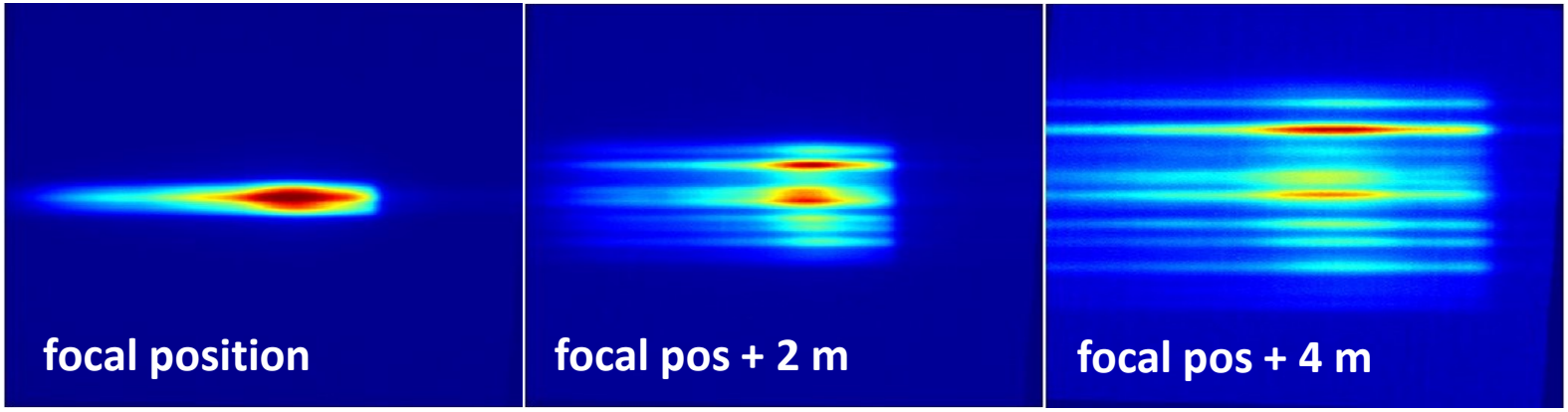
Mirrors manufacturing defects



Low frequencies : manufacturer slope errors with fixed phases

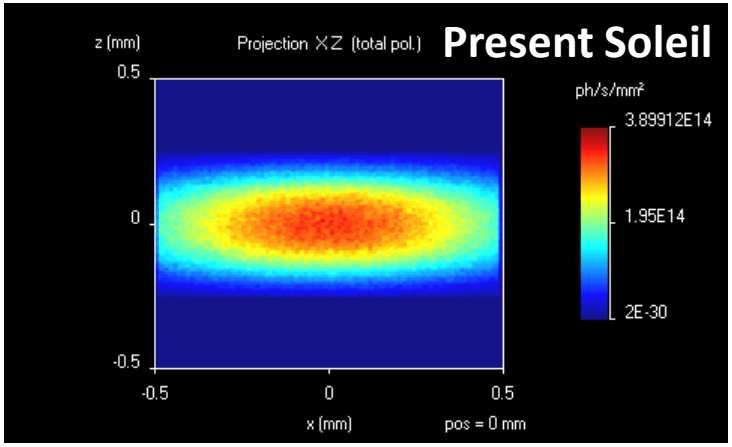


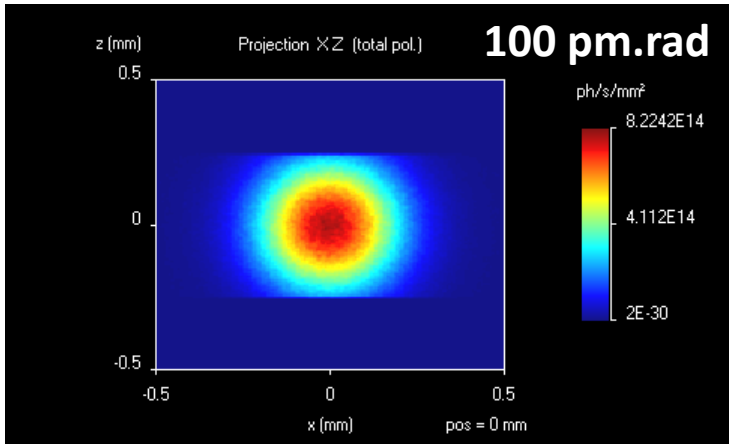
Vertical focusing mirror (Swing): measures



Round beam comparison (conclusion)

- **@ diaphram (11.7 m / source) : E = 12.4 keV**





- **@ sample : E = 12.4 keV**

Sample location	Present	upgraded
Flux (ph/s)	7×10^{12}	1.1×10^{13}
size (µm FWHM)	80×20 (H×V)	3×3 (H×V)
div (µrad FWHM)	350×280 (H×V)	330×250 (H×V)
ΔE (eV) FWHM	2.5 eV	2.5 eV

s_0 = 10 µm RMS
p = 19 m
q = 2 m
ε = 0.3 µrad RMS

Flux dens. ×280

Acknowledgements

Mourad Idir for the collaboration in the design of hard X-ray beamlines at Soleil

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Florian Meneau & SWING beamline team for the collaboration in mirror slope measurements

Thank you for your attention