Initial Results of X-ray Fresnel Diffractometry for Small Beam Sizes at Diamond Light Source

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Outline

For Diamond-II we need to resolve beam sizes less than 7 µm which is the resolution of the pinhole cameras.

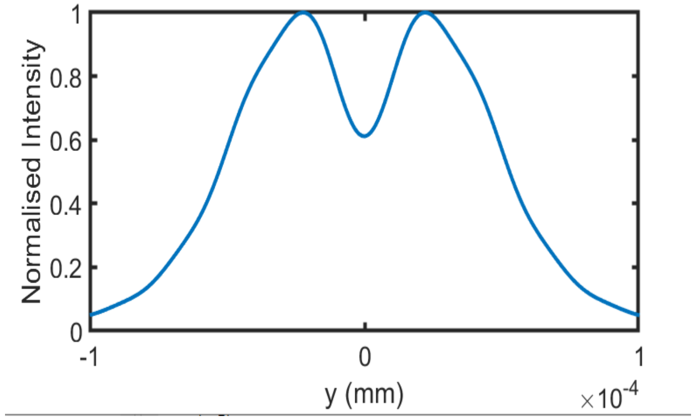
- Description of the X-ray Fresnel Diffractometry Measurement
- Calculations of required apertures and X-ray beam energies for the case of Diamond.
- Analysis of LIGA apertures.
- Numerical calculations.
- Next steps

Theory

- A double-lobed diffraction pattern emerges by a single slit under conditions
  - Distance from a source point to the slit
  - Distance from slit to the observation point
  - Wavelength
- Requires a monochromatic X-ray beam.
- The depth of the median dip in the pattern correlates with the light source size.
- Slit width A required to create a double-lobed PSF with the deepest median dip is expressed as follows (Masaki et al., 2015):
- $A \approx \sqrt{7\lambda \frac{LR}{L+R}}$

λ: wavelength
L: distance from source-to-slit
R: distance from slit-to-screen

- The distance between the two lobes: $P \approx 2\sqrt{\frac{\lambda}{7}\frac{R(L+R)}{L}}$

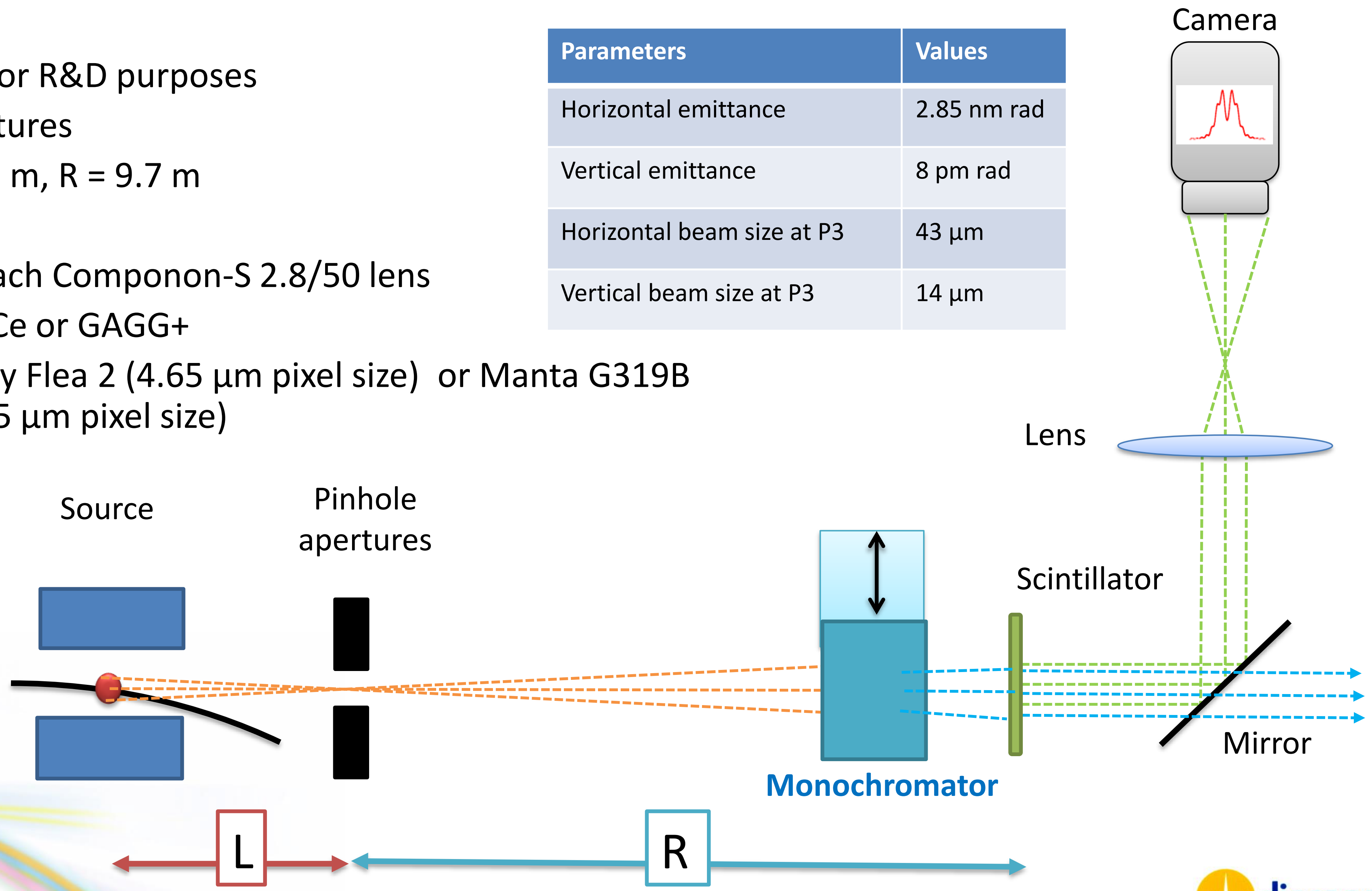


- The only requirement for light sources is that the radiation should be a spherical wave with a flux distribution wider than the slit width.

Experimental Setup

- Pinhole 3 is used for R&D purposes
- LIGA pinhole apertures
- Distances : L = 3.8 m, R = 9.7 m
- Monochromator
- Schneider-Kreuznach Componon-S 2.8/50 lens
- Scintillator: LuAg:Ce or GAGG+
- Camera: Point Grey Flea 2 (4.65 µm pixel size) or Manta G319B (CMOS sensor 3.45 µm pixel size)

Parameters	Values
Horizontal emittance	2.85 nm rad
Vertical emittance	8 pm rad
Horizontal beam size at P3	43 µm
Vertical beam size at P3	14 µm



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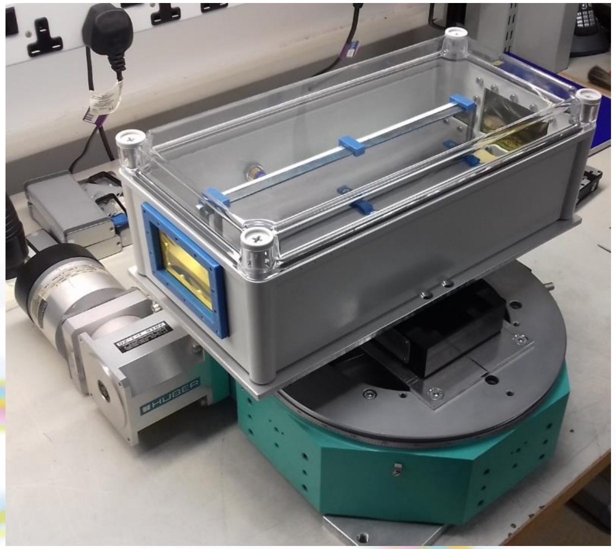
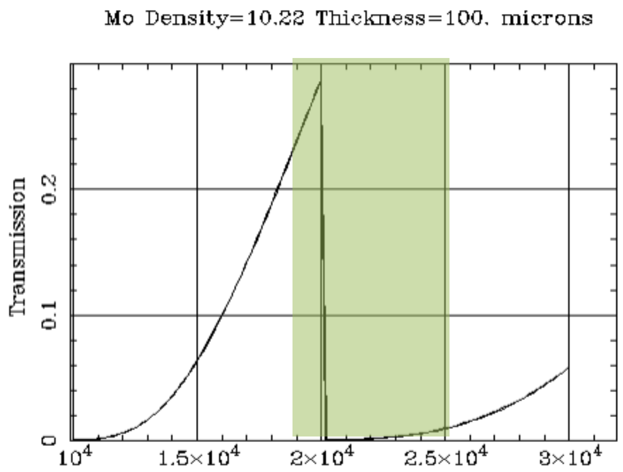
Monochromator

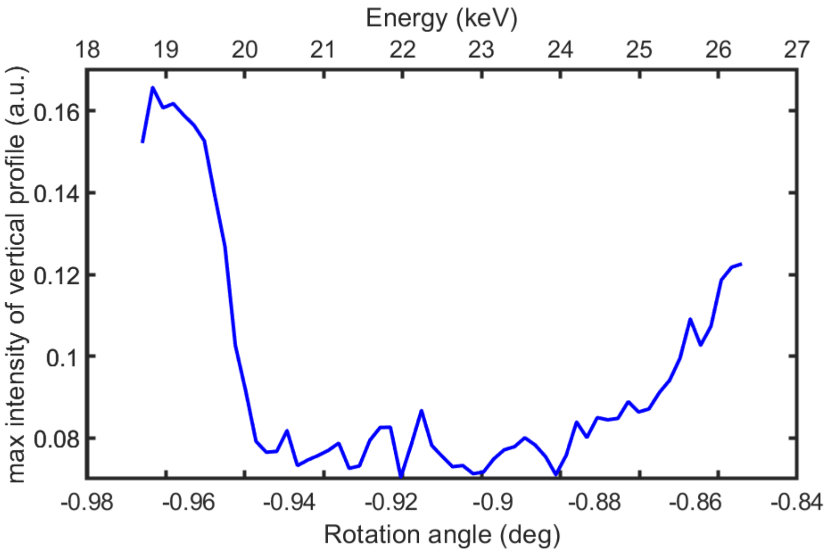
Parameter	Value
Dimensions	300 mm x 50 mm
D-spacing	4.8 nm
Multilayers	Mo/Si with N=100 layer-pairs deposited on float glass
Substrate	Float glass
Number of layer-pairs	100

- Single bounce setup: beam is deflected horizontally and tracked with the imager.
- Bandwidth 2%.



Monochromator Calibration





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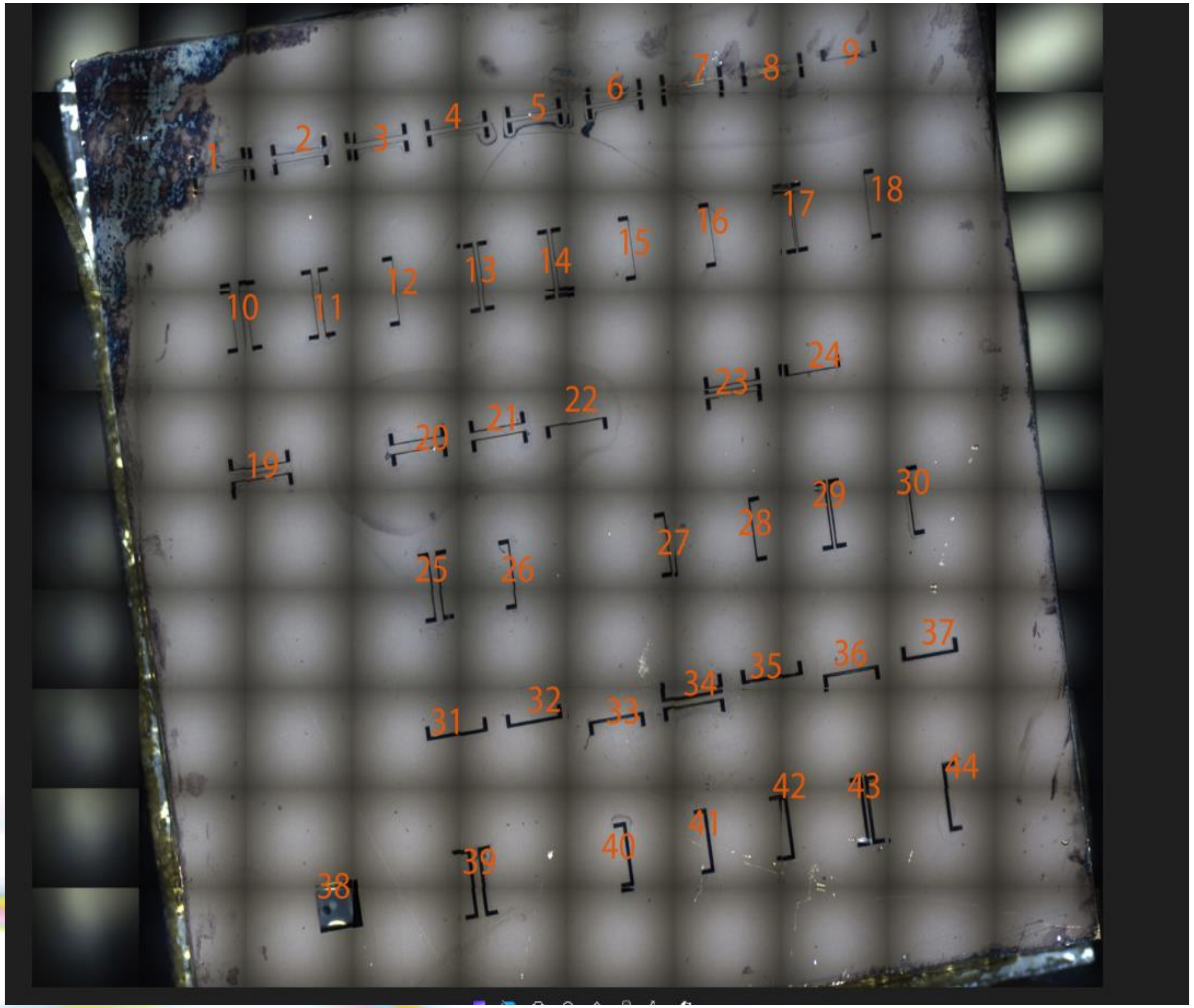
LIGA Slits

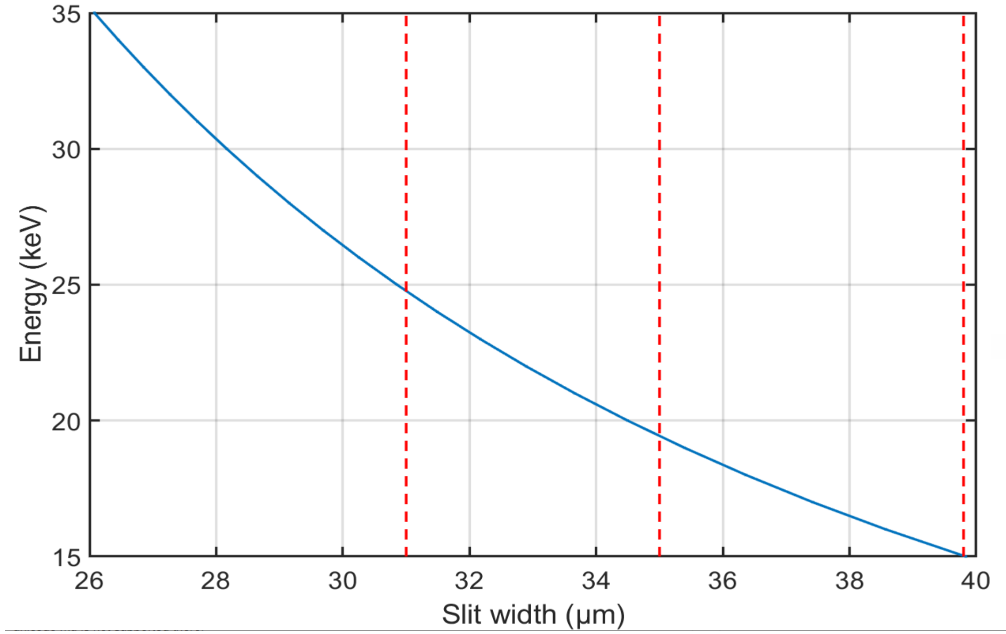


- X-ray lithography, electro-deposition and molding. At the Karlsruhe Institute of Technology, unique LIGA screens are produced. These are made from gold with a thickness up to 250 µm.
- The slit widths design range from 10 µm to 50 µm.
- SEM (Scanning Electron Microscope) to measure the slit size with high accuracy (*courtesy of Matthew Spink, I12 beamline*)

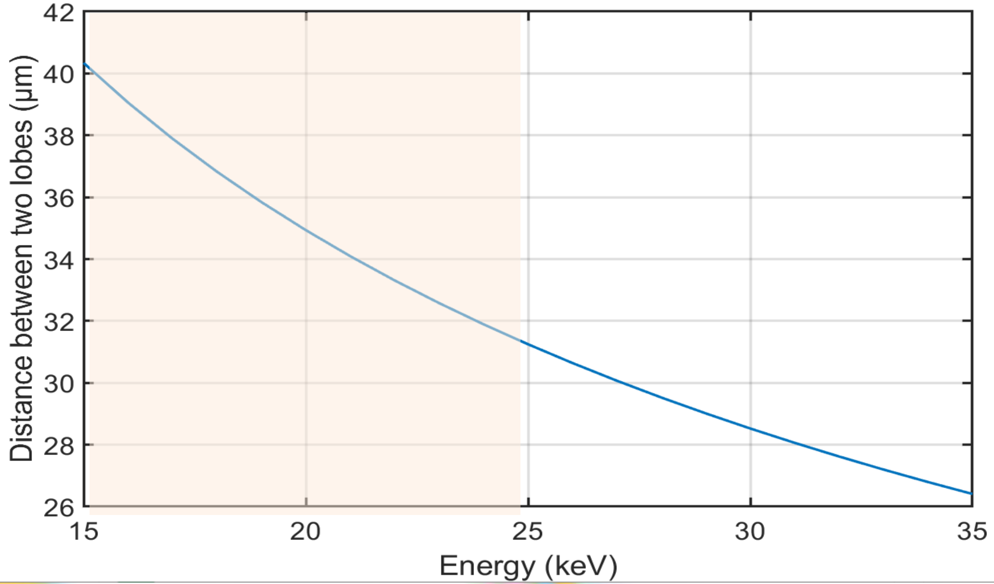
SEM results:

Area	Slit width
1 - 9	4 µm
10 - 18	6 µm
19 - 24	12 µm
25 - 30	15 µm
31 - 37	31 µm
40 - 44	35 µm

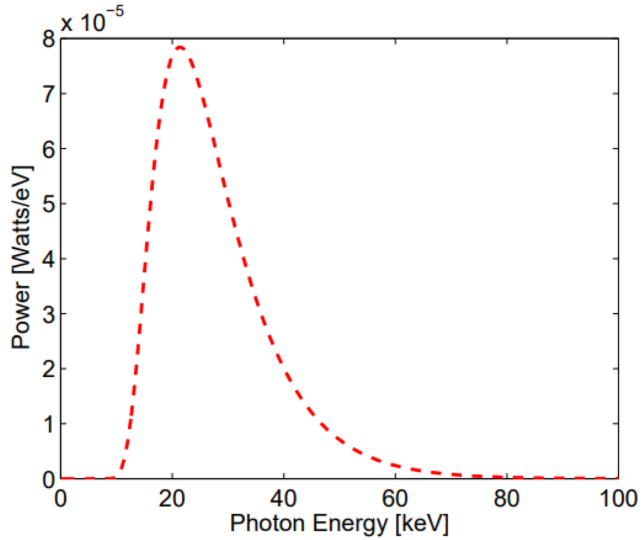
Optimised Slit Width with Energy



$$A \approx \sqrt{7\lambda \frac{LR}{L+R}}$$

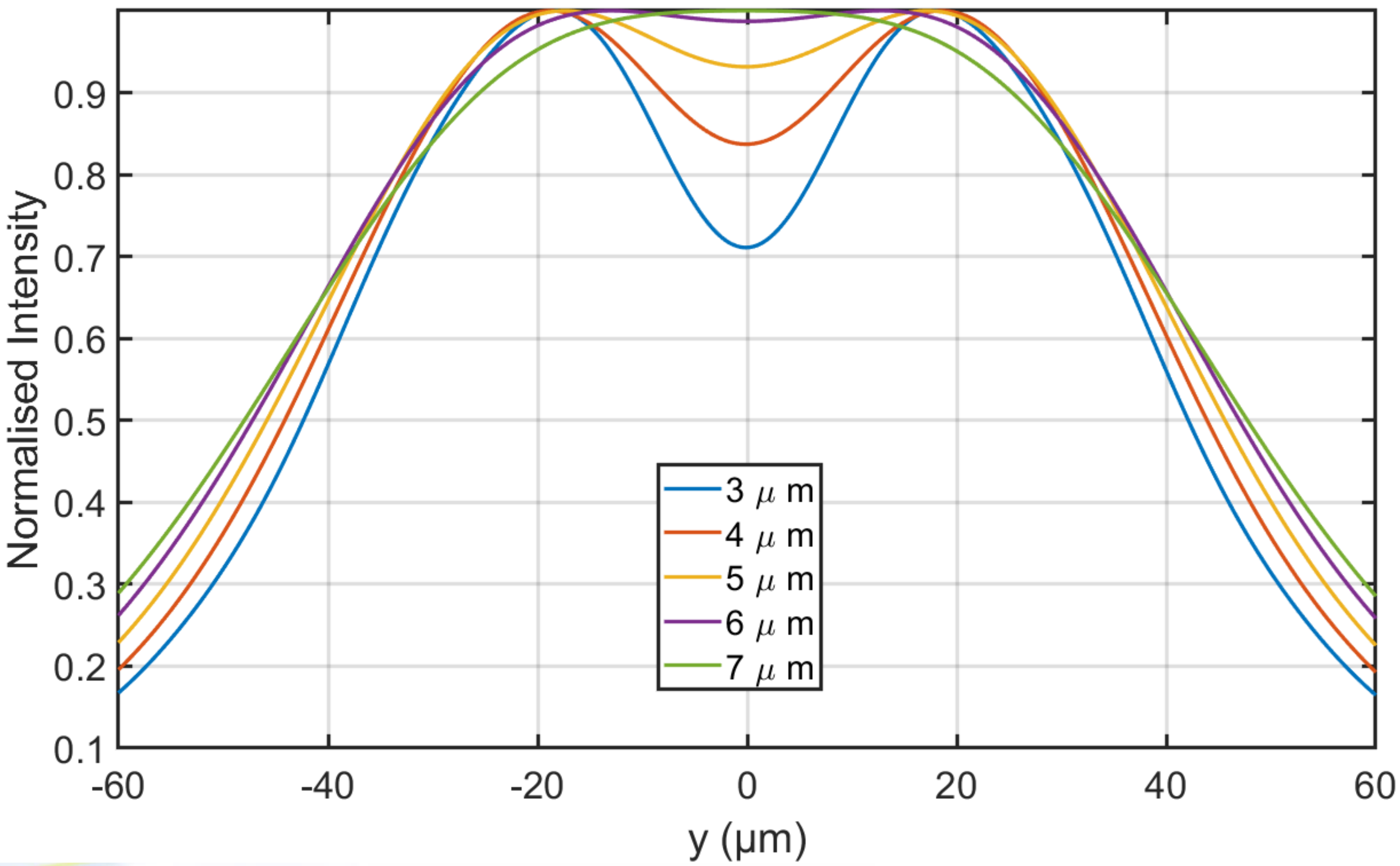


- Energy range from the transmitted spectral power is between 15 – 35 keV.
- The available slits in this energy range are 31 µm , 15 µm and 40 µm (vertical red lines in the plot of slit width – energy).
- The distance between the lobes for these cases is expected to be between 32 µm to 40 µm (shaded area in the plot energy – distance between two lobes).



Transmitted spectral power distribution through 1 mm aluminium window from Diamond bending magnet using XOP.

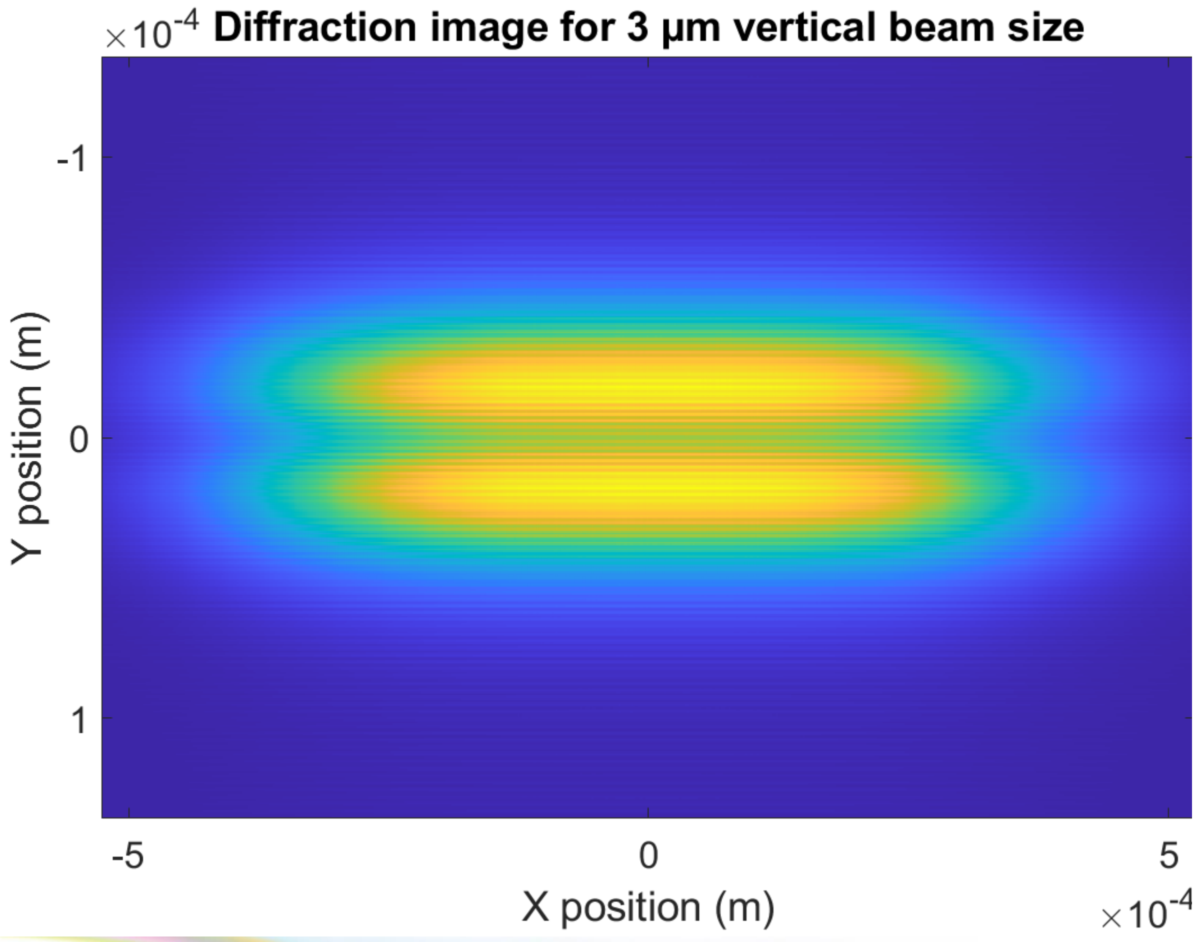
31 µm slit width – 25 keV

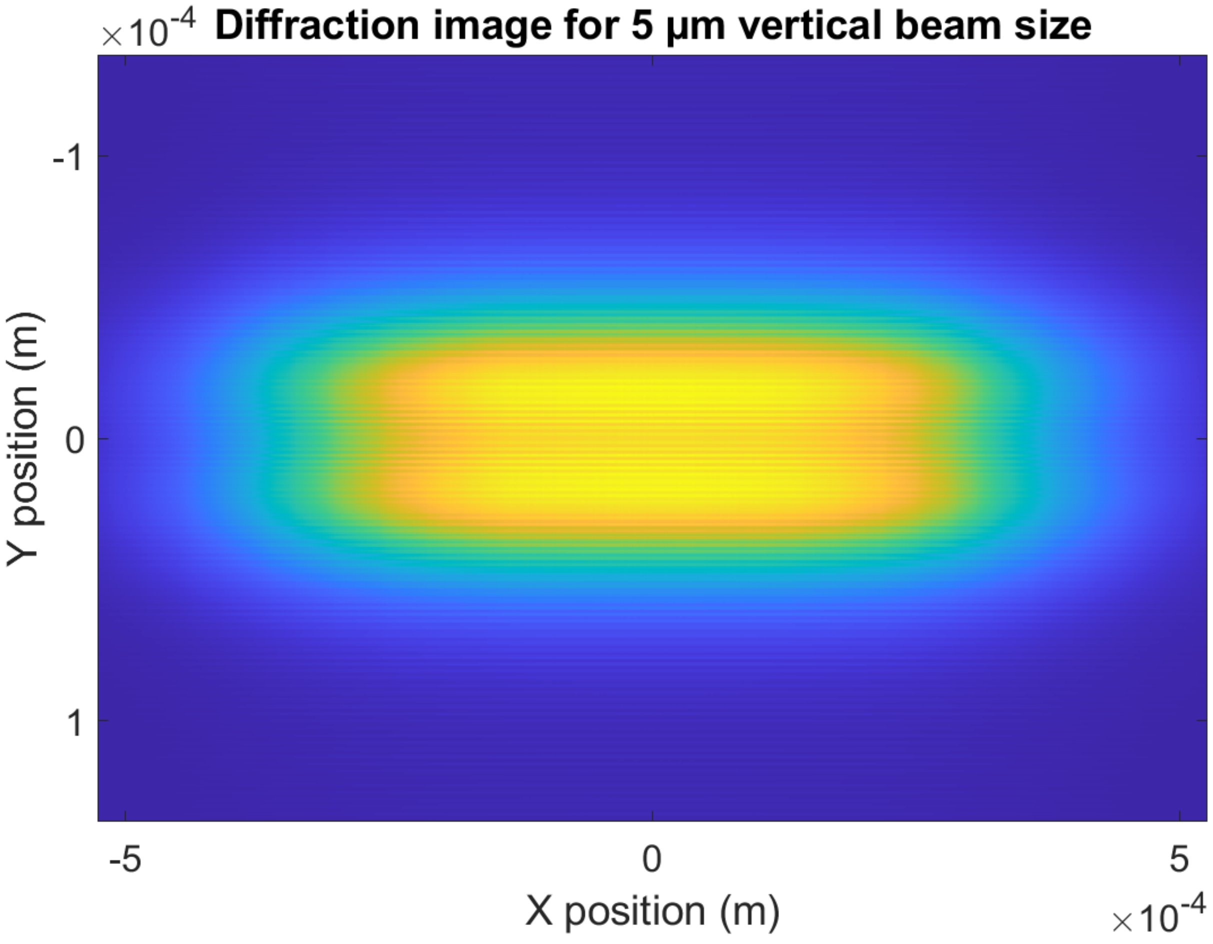


Screen plane

- Calculated PSF expressed by the Fresnel integral and its convolution with Gaussian distributed sources at the screen (scintillator) plane.
- The dip between the lobes appears for beam sizes less than 6 µm.
- From discussions with the Accelerator Physics group 5 µm is challenging to achieve in the current machine.
- Ideally we need settings that can resolve larger beam sizes.

SRW Simulations





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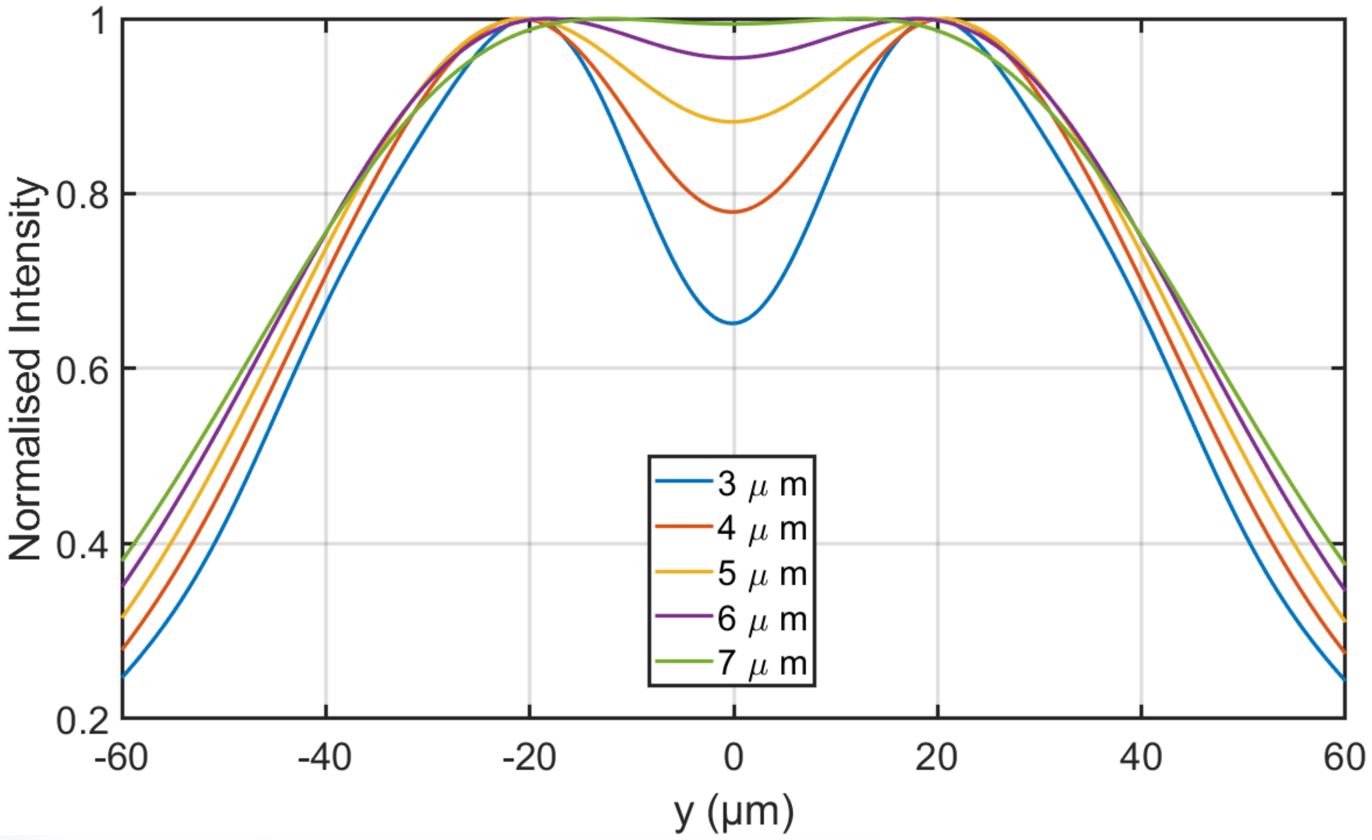
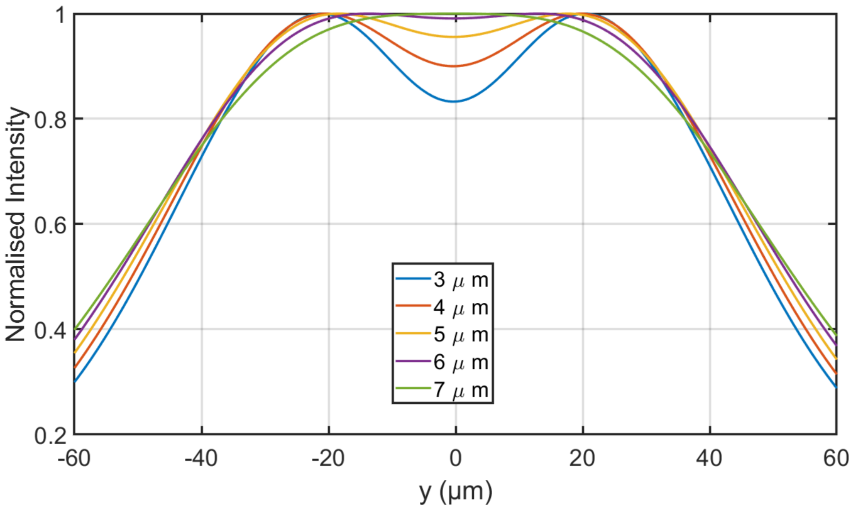
35 µm slit width – 19 keV



Screen plane

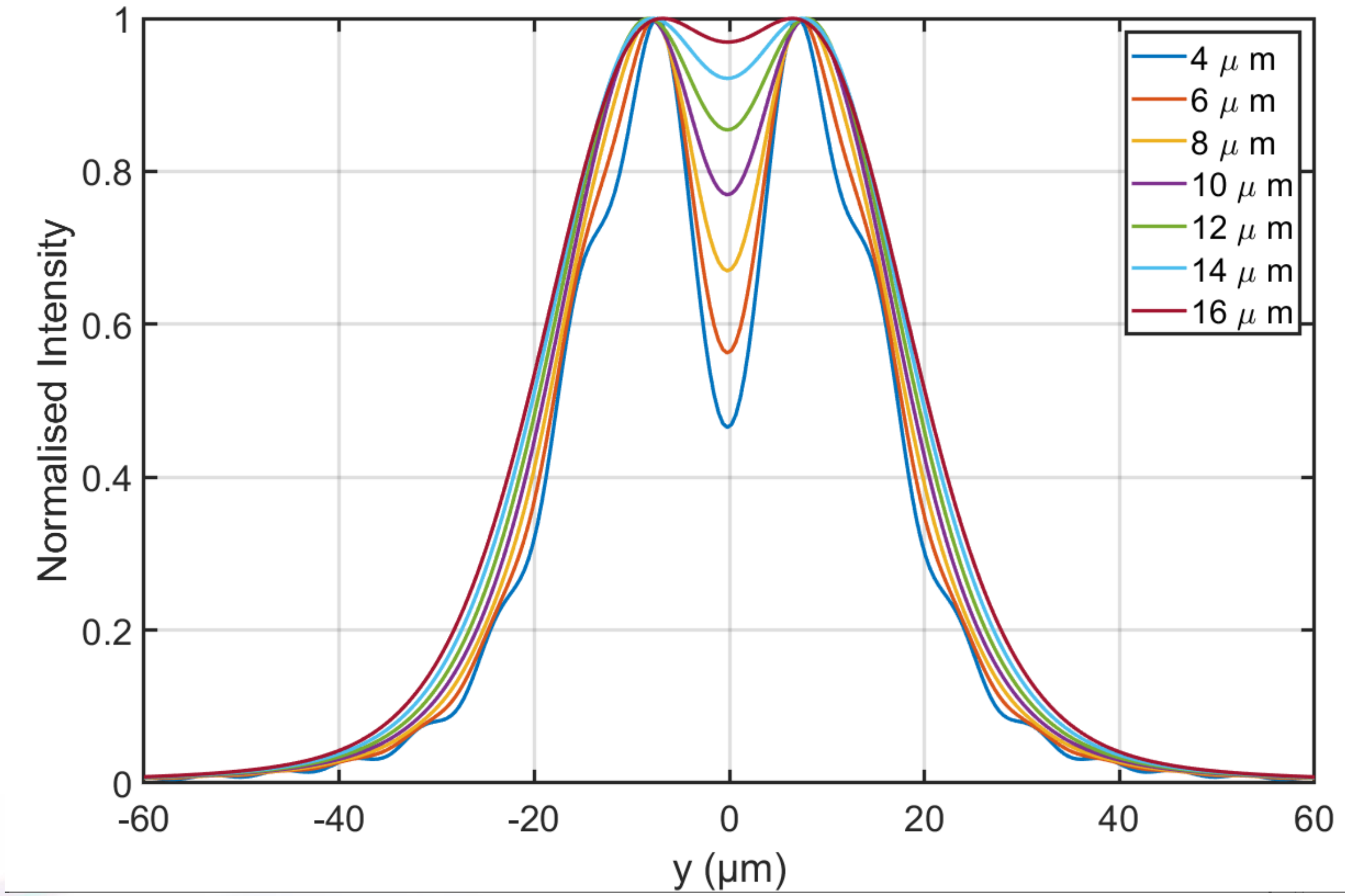
- The dip with these settings is lower.
- From knife-edge measurements the PSF from the scintillator screen, lens and camera is 8 µm.

After convolution with the PSF from knife edge measurements:



Camera plane

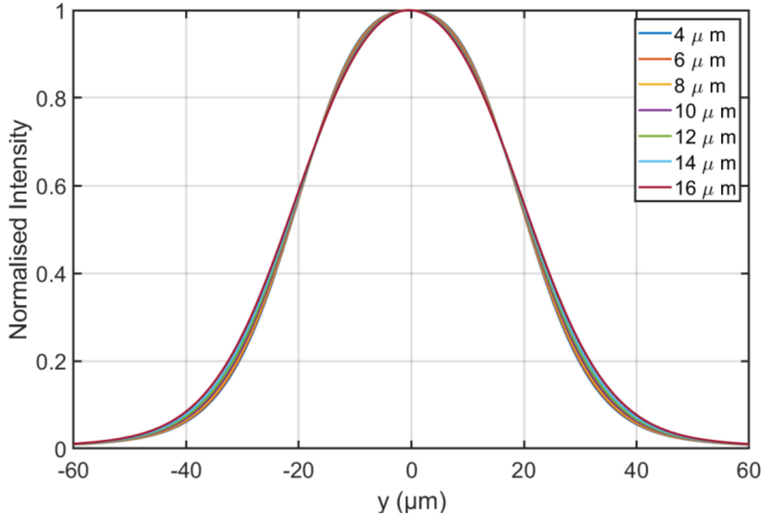
Different Distance Settings



Screen plane

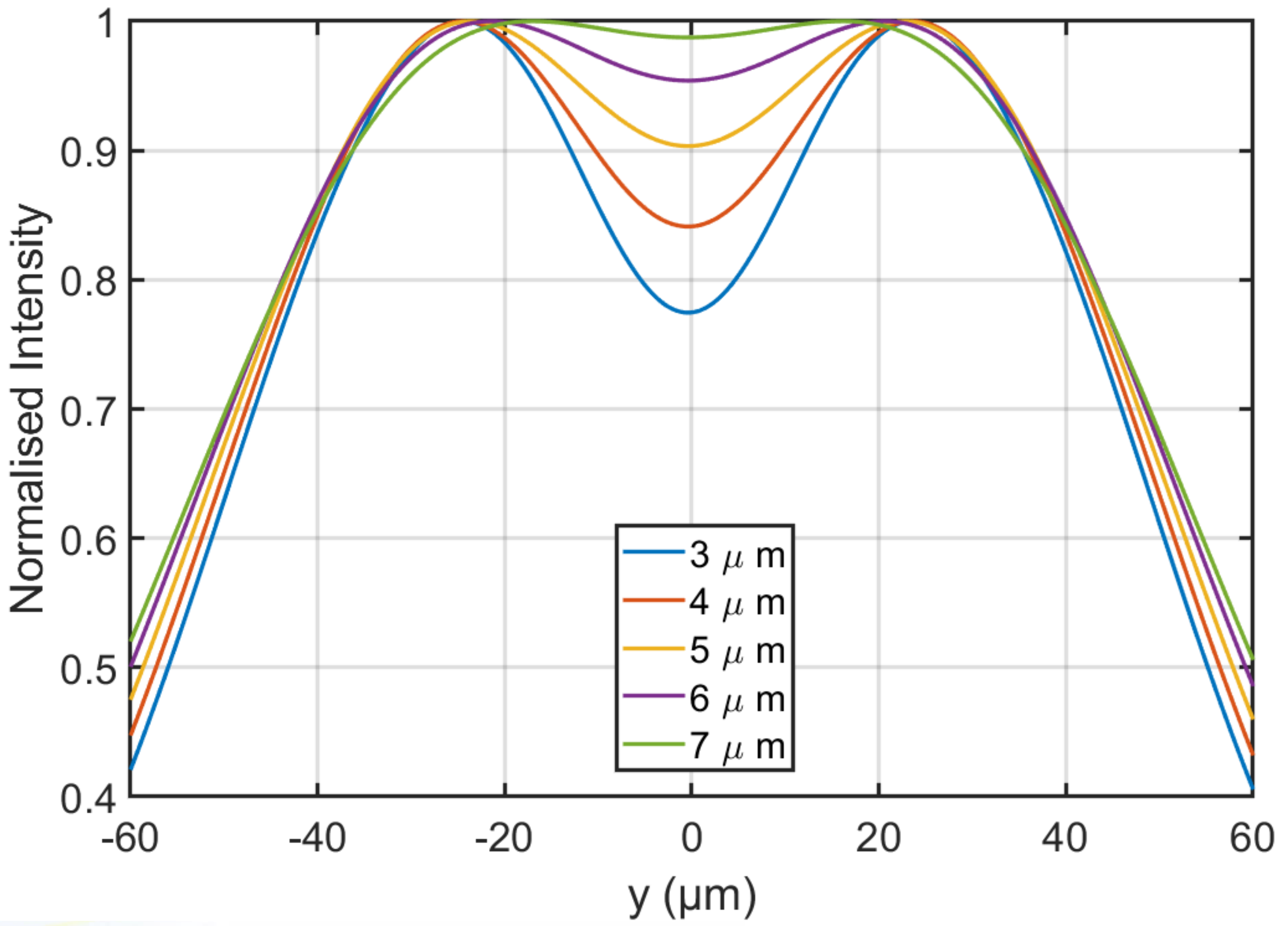
- 35 µm slit width – 19 keV
- L = 9.8 m and R = 3.7 m
- Better resolution for a large range of vertical beam sizes.

After convolution with the PSF from knife edge measurements:



Camera plane

Square Apertures



Camera plane

- Slit wider than 35 μm is not available.
- Test the performance of a square aperture for measurements in the vertical plane.
- 40 μm square aperture and 15 keV X-ray beam.
- Results in the camera plane (already convoluted with PSF from knife edge measurements)
- Most promising results to be tested experimentally.

Conclusions

- The energy range for these measurements in case of Diamond is 15 keV – 35 keV.
- We need a large slit or aperture (35 μm to 40 μm) and working in the lower energies of our spectrum as this gives better sensitivity for larger beam sizes.
- In lower energies we have lower flux due to bending magnet spectrum. Experiment could be challenging.
- Bringing the apertures closer to the screen does not improve the systems resolution.
- Measurements are needed to verify these results.
- Any suggestions welcome!

diamond

References

- (Henke et al. 1993): B.L. Henke, E.M. Gullikson, and J.C. Davis. *X-ray interactions: photoabsorption, scattering, transmission, and reflection at E=50-30000 eV, Z=1-92*, Atomic Data and Nuclear Data Tables Vol. **54** (no.2), 181-342 (July 1993).
- (Masaki et al., 2015) : Masaki, M., Takano, S., Takao, M., & Shimosaki, Y. (2015). X-ray Fresnel diffractometry for ultralow emittance diagnostics of next generation synchrotron light sources. *Phys. Rev. ST Accel. Beams, 18*(4), 042802. https://doi.org/10.1103/PhysRevSTAB.18.042802

Pinhole Camera Resolution

$$A_{opt} = \sqrt{\sqrt{3}\,\frac{(\lambda d D)}{D+d}} \quad ; \quad \sigma_{min} = \sqrt{\frac{\lambda d}{2\sqrt{3}}\,\frac{D+d}{D}}$$

Source size measurement options for low-emittance light sources, N. Samadi et al., Phys. Rev. Accel. Beams **23**, 024801
ESRF-EBS Technical Report, http://www.esrf.eu/about/upgrade

Considering E = 23 keV	d [m]	D [m]	M=D/d	A_o [µm]	$\sigma_{source,min}$ [µm]	$\sigma_{screen,min}$ [µm]
DLS1	4.0	10.0	2.5	16.3	9.3	23.3
D1: Long	2.7	13.3	4.9	14.5	7.1	34.8
D1: Standard	2.7	13.3	4.9	14.5	7.1	34.8
D4	3.0	12.5	4.2	15.0	7.6	31.9

Smallest beam size expected for nominal beam = 8 µm (D4 total horiz size)

Analytical estimations somewhat pessimistic given experience on Diamond-I.
With measurement of the total PSF and deconvolution, 6µm electron beam size has been measured on Diamond-I (Cyrille Thomas et al., Phys. Rev. ST Accel. Beams **13**, 022805).
With improvements (thin scintillator, matched pinhole aperture size) possibly reach 5µm.
Measurements below 5µm are challenging.