From focusing monochromators to nested mirror optics

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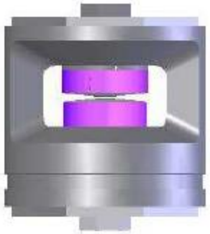
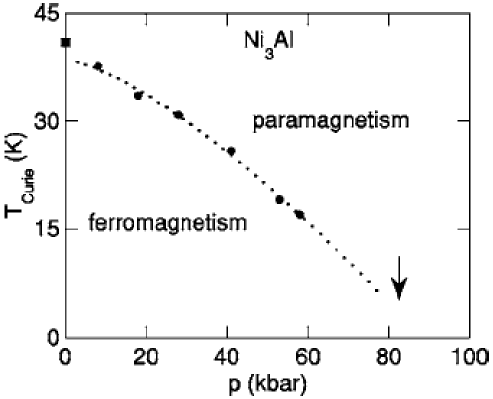
Towards Small Samples and Extreme Environment

Ni_3Al: weak itinerant ferromagnet

- pressure $p > 60$ kbar
  → QPT?

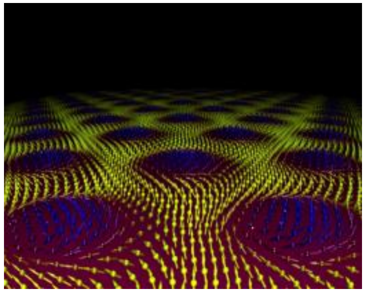




high pressure:
→ small volumes

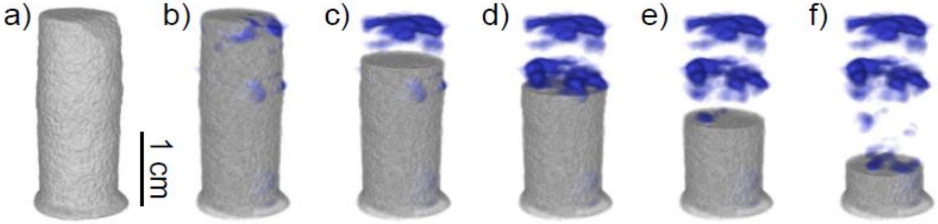
MnSi: helical ferromagnet

- $B = 180$ mT: skyrmions



high magnetic fields:
→ large devices

tomography with polarized neutrons:

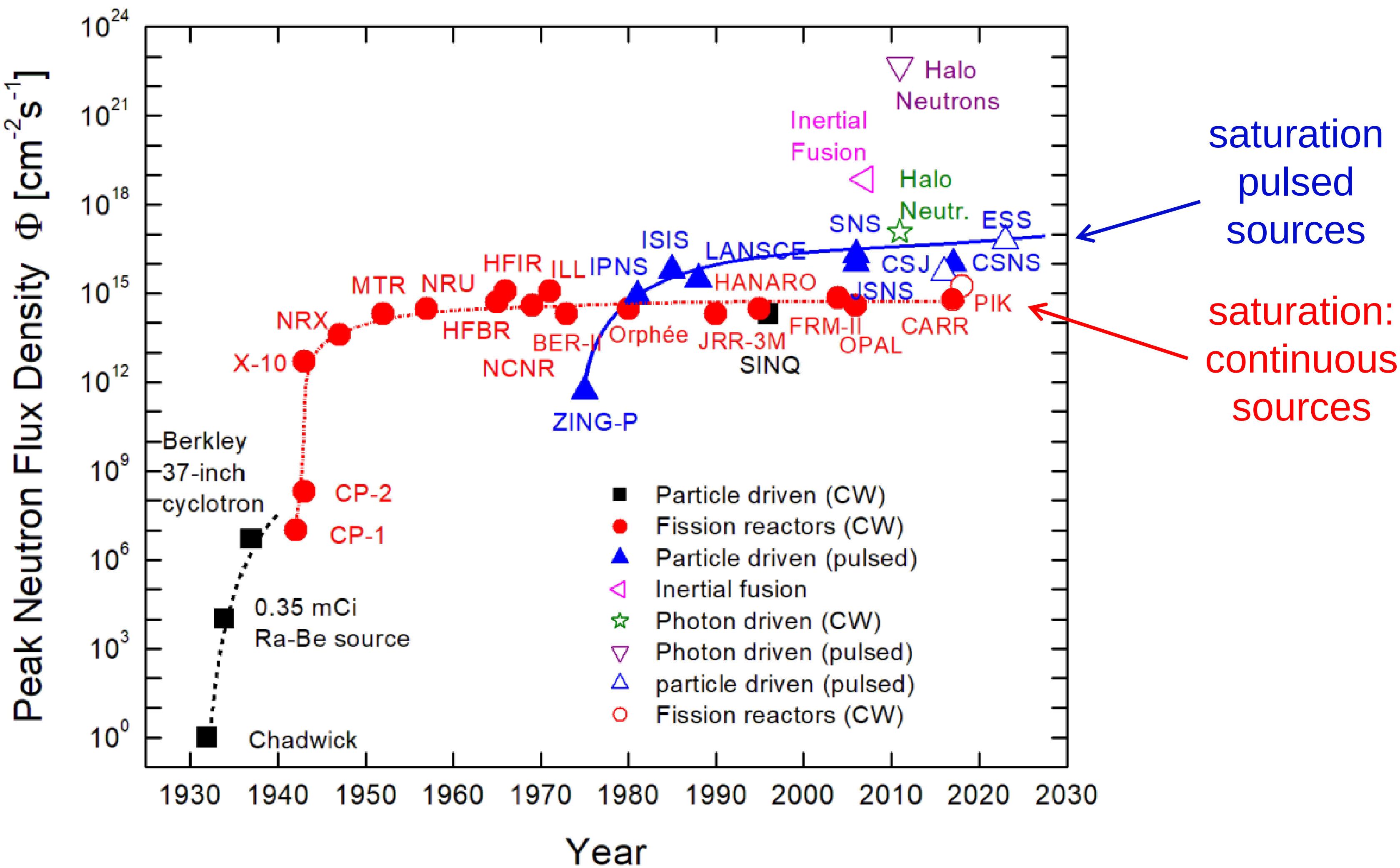


M. Schulz et al., J. Phys: Conf. Series **211**, 012025 (2010)

Homogeneous regions of sample very small

Content

Saturation of the Flux Density



How can we improve the signal from the sample? Moderators, neutron optics!

P. Böni and W. Petry, ``Neutron Science with Highly Brilliant Beams'', in `Applications of Laser-Driven Particle Acceleration', edited by P. Bolton, K. Parodi, and J. Schreiber, CRC-Press Taylor & Francis, 2018, Boca Raton, FL, USA; https://www.crcpress.com/Applications-of-Laser-driven-Particle-Acceleration/Bolton-Parodi-Schreiber/p/book/9781498766418

Liouville's Theorem: Ultimate Intensity at Sample

$$I = \eta \cdot A \cdot \Delta\lambda \cdot \Omega \cdot \Psi$$

- I: intensity (s^{-1})
- η: transport efficiency (.) (maximum: $\eta = 1$)
- A: area (cm^2)
- $\Delta\lambda$: wavelength band (Å)
- Ω: solid angle (sterad)
- Ψ: brilliance ($cm^{-2}s^{-1}$ Å^{-1}sterad^{-1})

Example:

- beam port H12 @ ILL: $\Psi = 8 \cdot 10^{13}$ $cm^{-2}s^{-1}$ Å^{-1} sterad^{-1} ($\lambda = 1.2$ Å)
- typical sample: $\eta = 1$, $A = 1$ mm^2, $\Delta\lambda = 1\%$, divergence: $1^0/4^0$

→ neutron intensity at sample: $I = 0.98 \cdot 10^7$ s^{-1}

- clue for feasibility of experiment
- intensity not achieved? → re-design beam line → technical limitations (SMs)

Content

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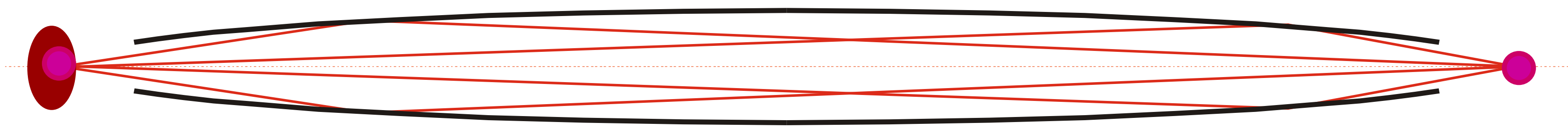
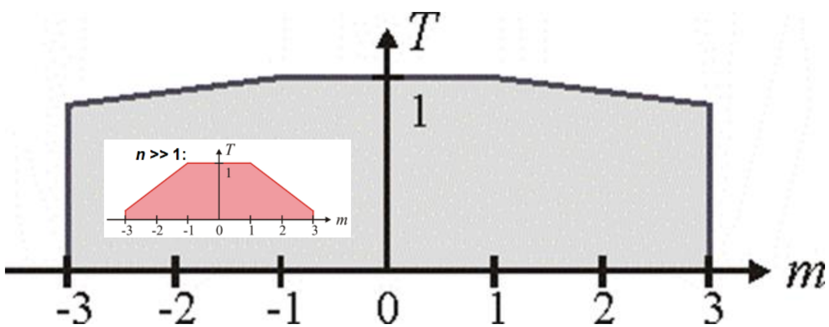
Transport of Neutrons: Elliptic Guides

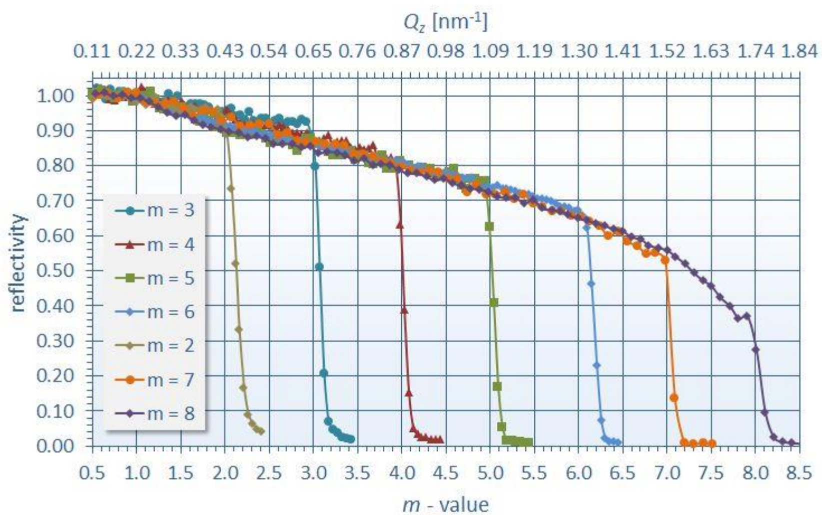
Point to point "imaging" of source:



- typically 2 reflections: $T \cong R^2$ → **B** $\cong 1$
- compact phase space (no tails)
- (small?) illumination losses
- lower background:
  → reduce size of moderator



P. Böni, Nucl. Instr. Meth. A **624**, 162 (2010)



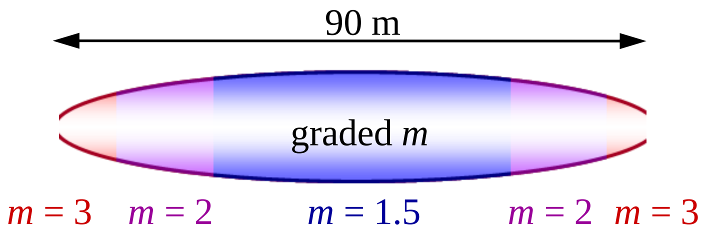
θ_c (^{0}) = 0.099 $m\ \lambda$ (Å):

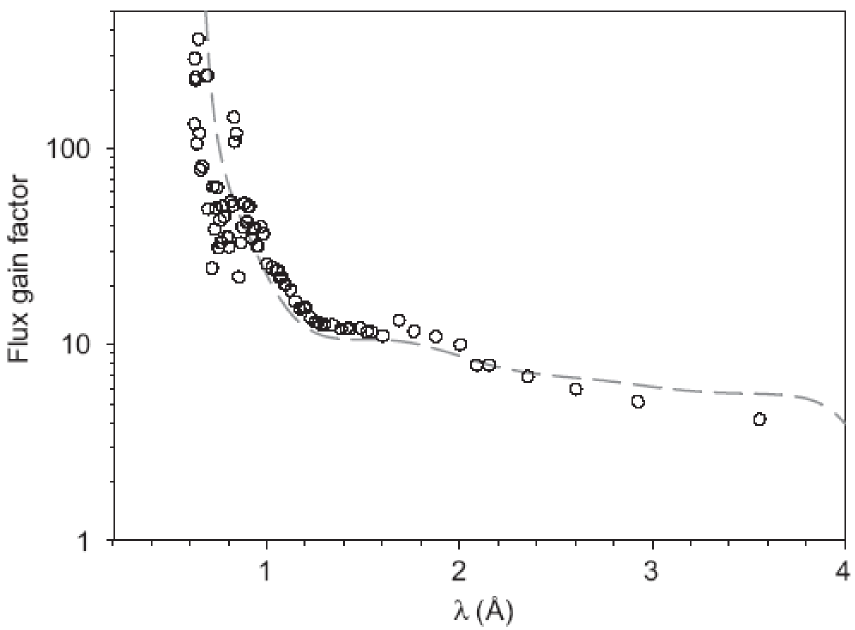
→ example: λ = 1 Å, θ_c = 0.8^0

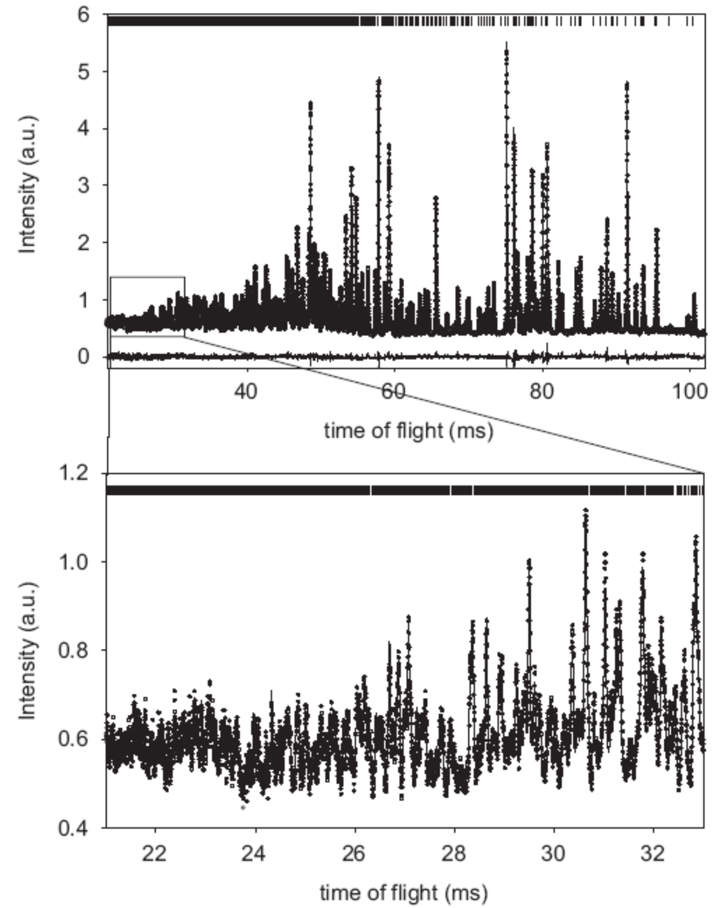
→ **divergence at 1 Å: 1.6^0**

Realization: HRPD @ ISIS: Benzene C_6D_6

graded coating







Gain: 10 - 100

R. M. Ibberson, Nucl. Instr. and Meth. A **600**, 47 (2009)

Content

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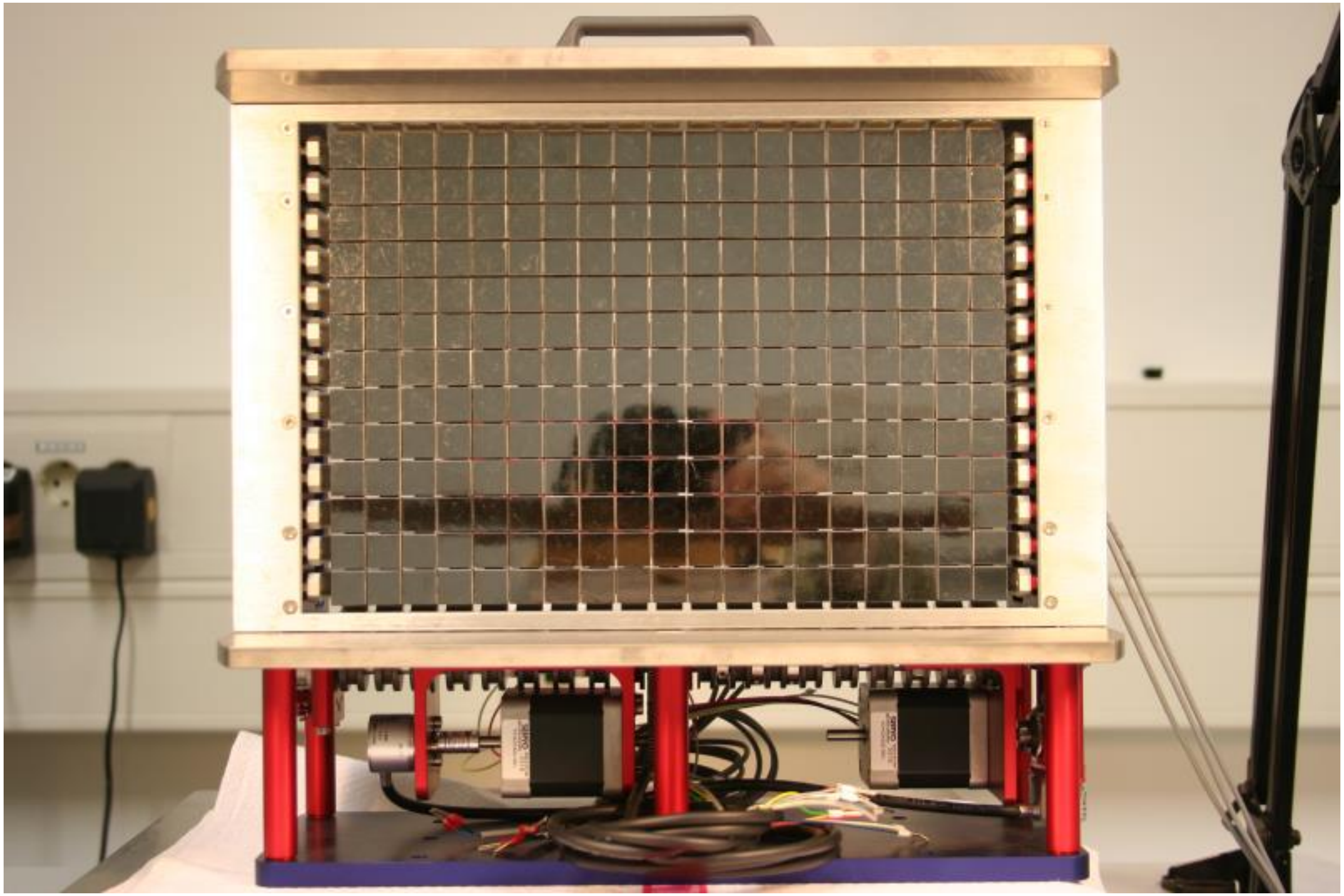
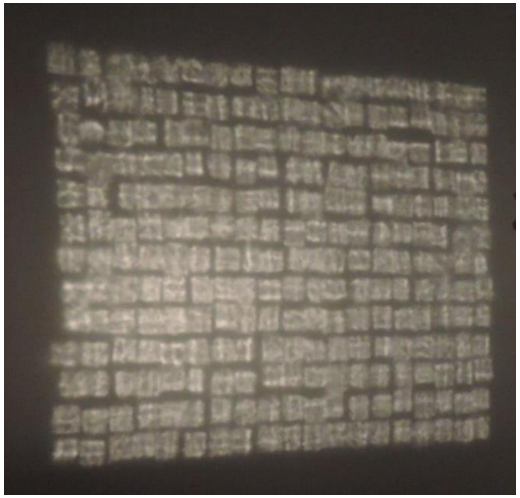
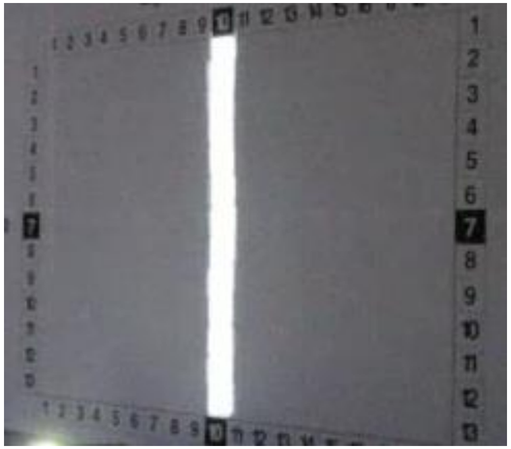
Doubly Focusing Monochromator at KOMPASS



Design of monochromator: 13 rows / 19 columns → **gain: 247**

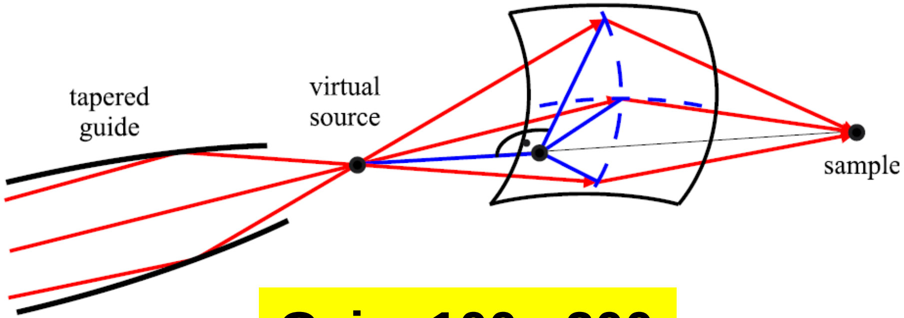
Focusing Properties of KOMPASS Monochromator



D. Gorkov, PB, M. Braden

Focusing scheme: polarizing parabolic guide
combined with focusing mono



Gain: 100 - 200

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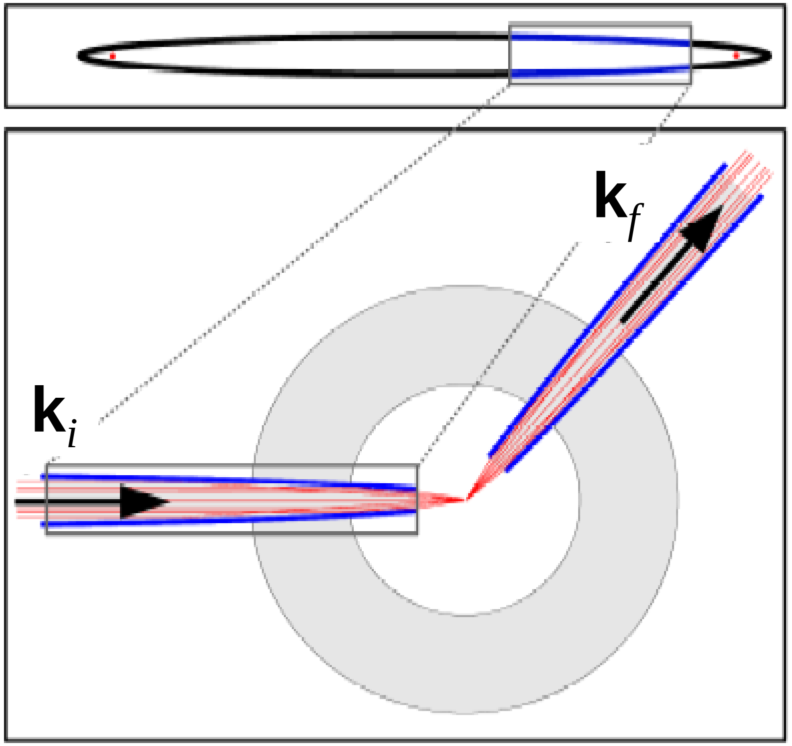
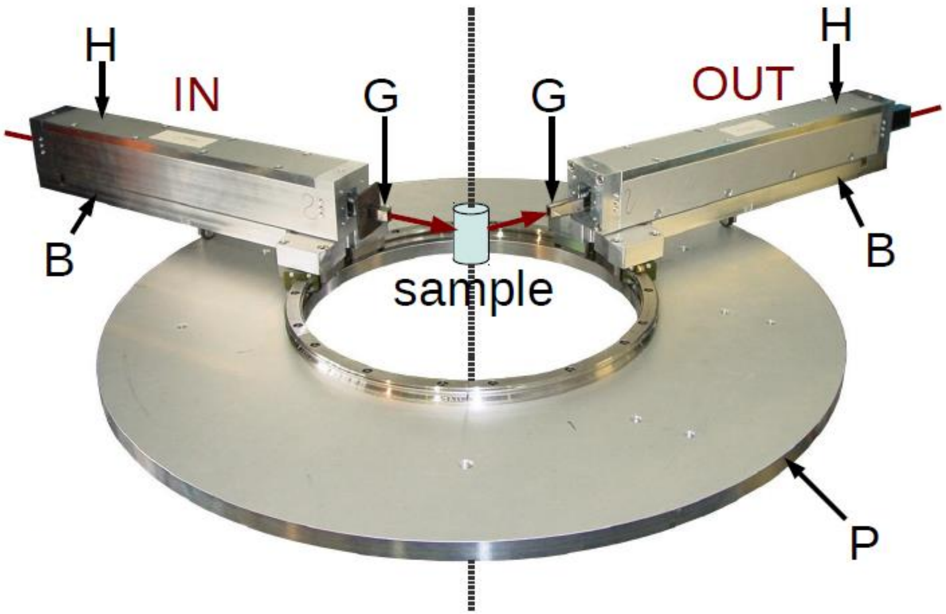
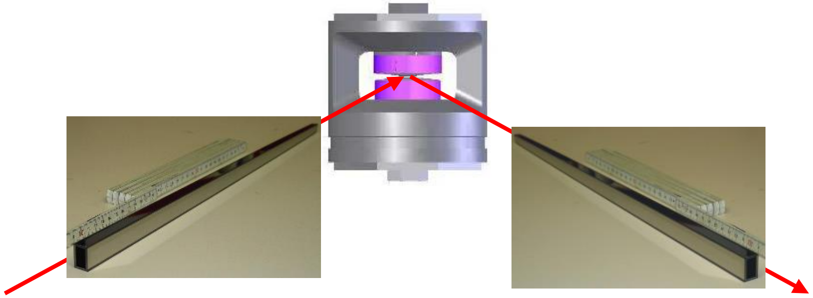
Small Samples: Use of Focusing Elliptic Guides





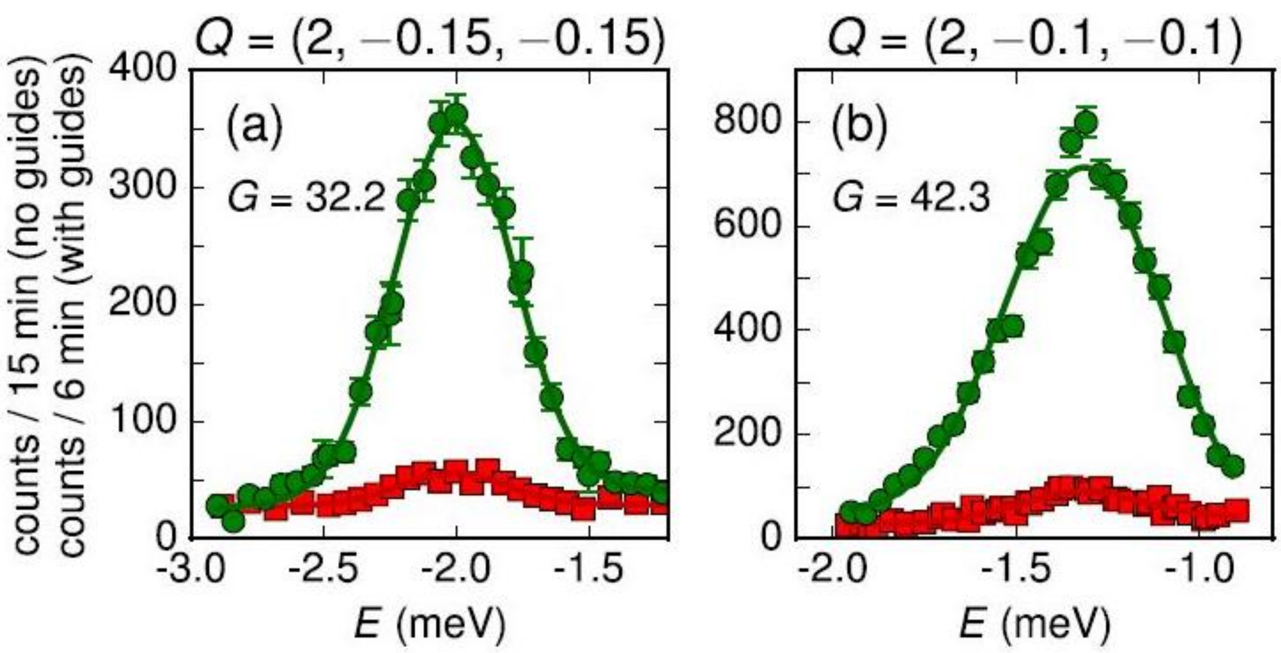
MIRA @ FRM II

→ focusing before
and
→ defocusing after sample



T. Adams et al., Applied Physics Letters **105**, 123505 (2014); http://dx.doi.org/10.1063/1.4896295

Focusing Setup: TA Phonons in Lead



Discussion:

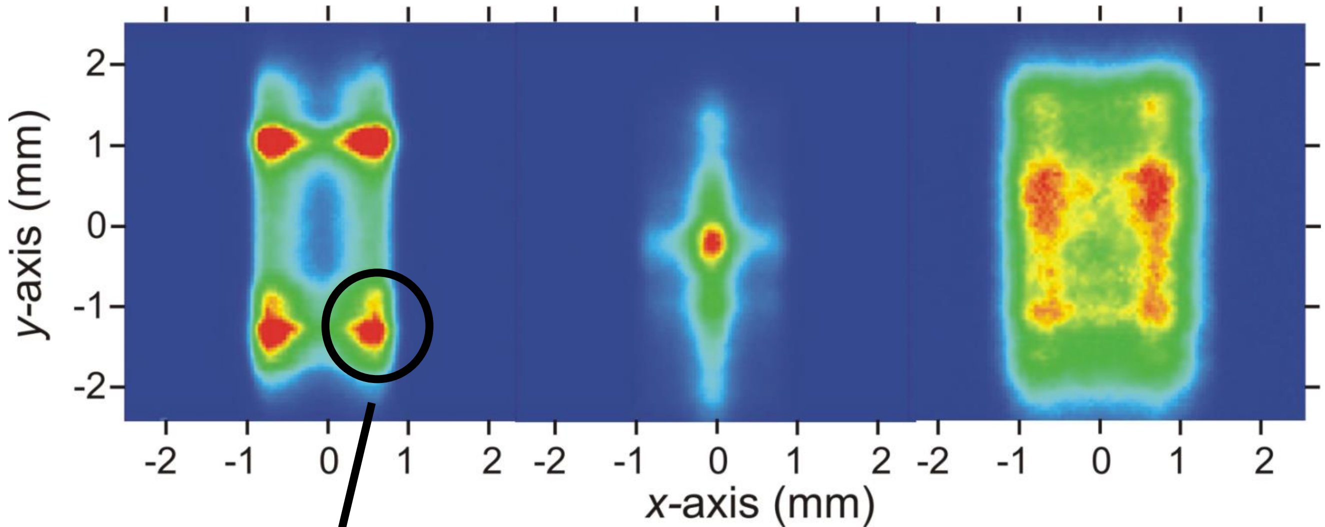
- large gains: $G_{TA} \cong 30 - 40$
- divergent beam does not spoil Q_y resolution
- can be installed at almost any beamline

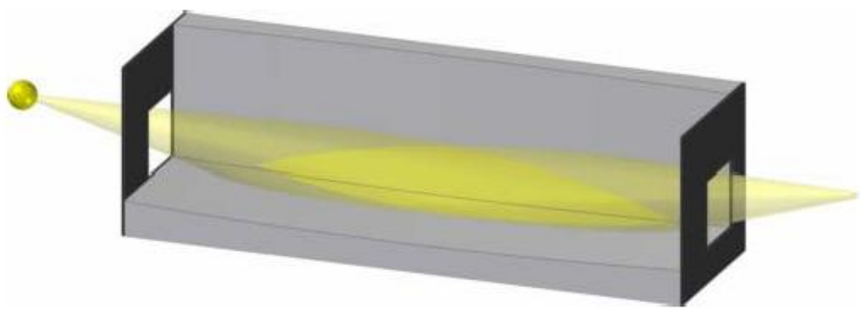
($V_{sample} = 2 \times 2.5 \times 2.5$ mm^3)

Gain: $G_{TA} \cong 30 - 40$

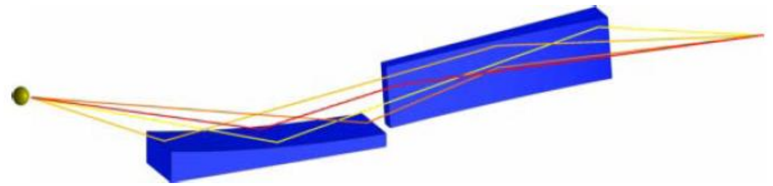
G. Brandl et al., Applied Physics Letters **107**, 253505 (2015); http://dx.doi.org/10.1063/1.4938503

Improve Homogeneity of Beam (Divergence)





Montel optics (1957)



Kirkpatrick-Baez (1948)

(x-ray optics)

G. Ice et al., J. Appl. Cryst. **42**, 1004 (2009) (SNAP @ SNS)

http://x-ray-optics.eu/index.php@option=com_content@view=article&i...

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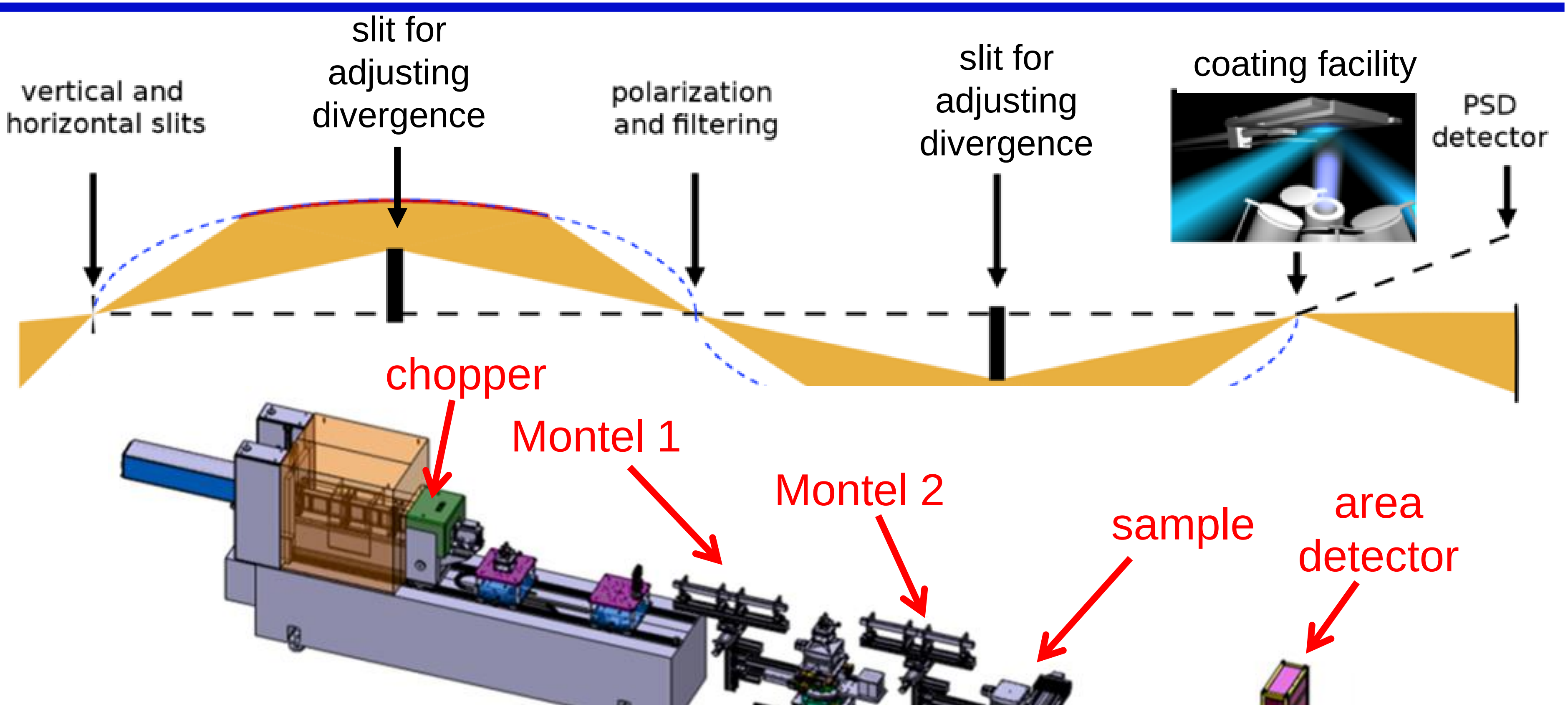
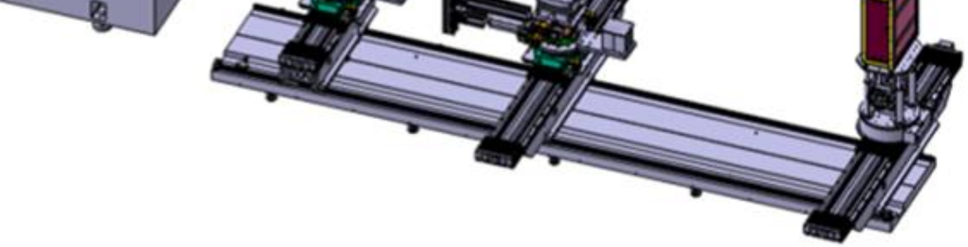
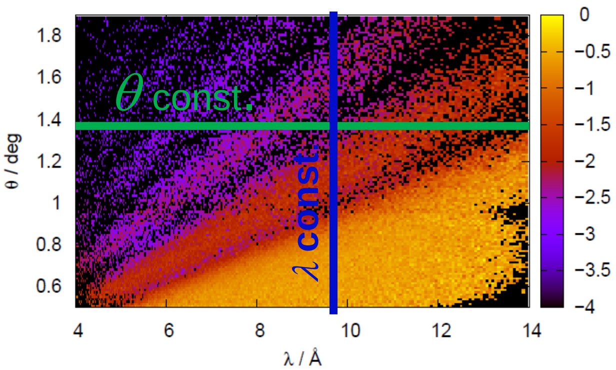
SINQ (PSI): Selene at AMOR



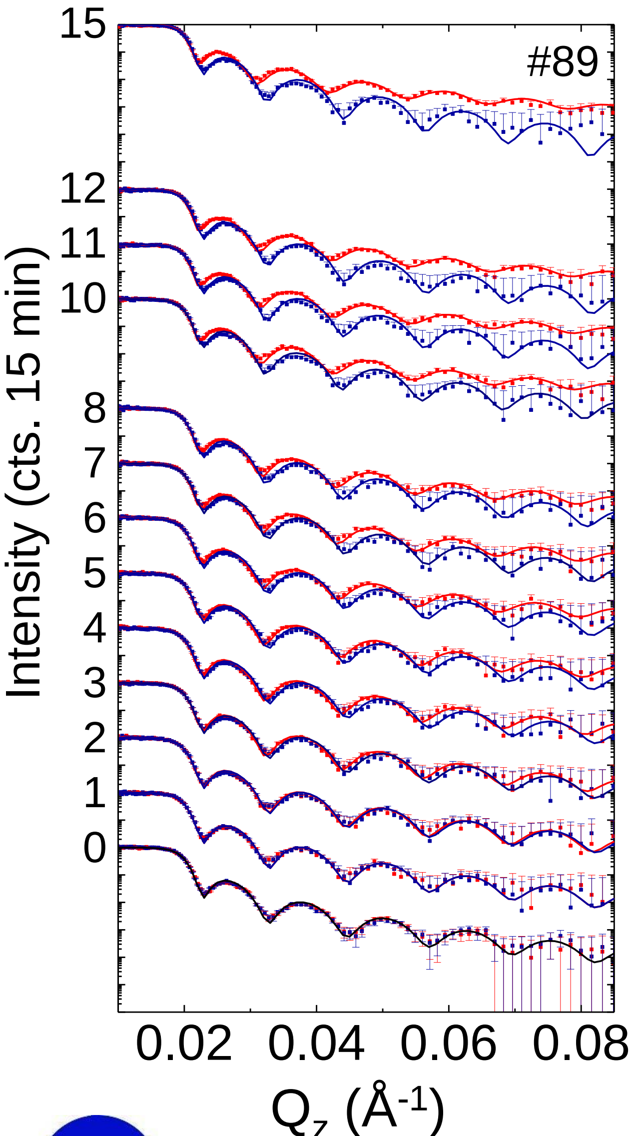




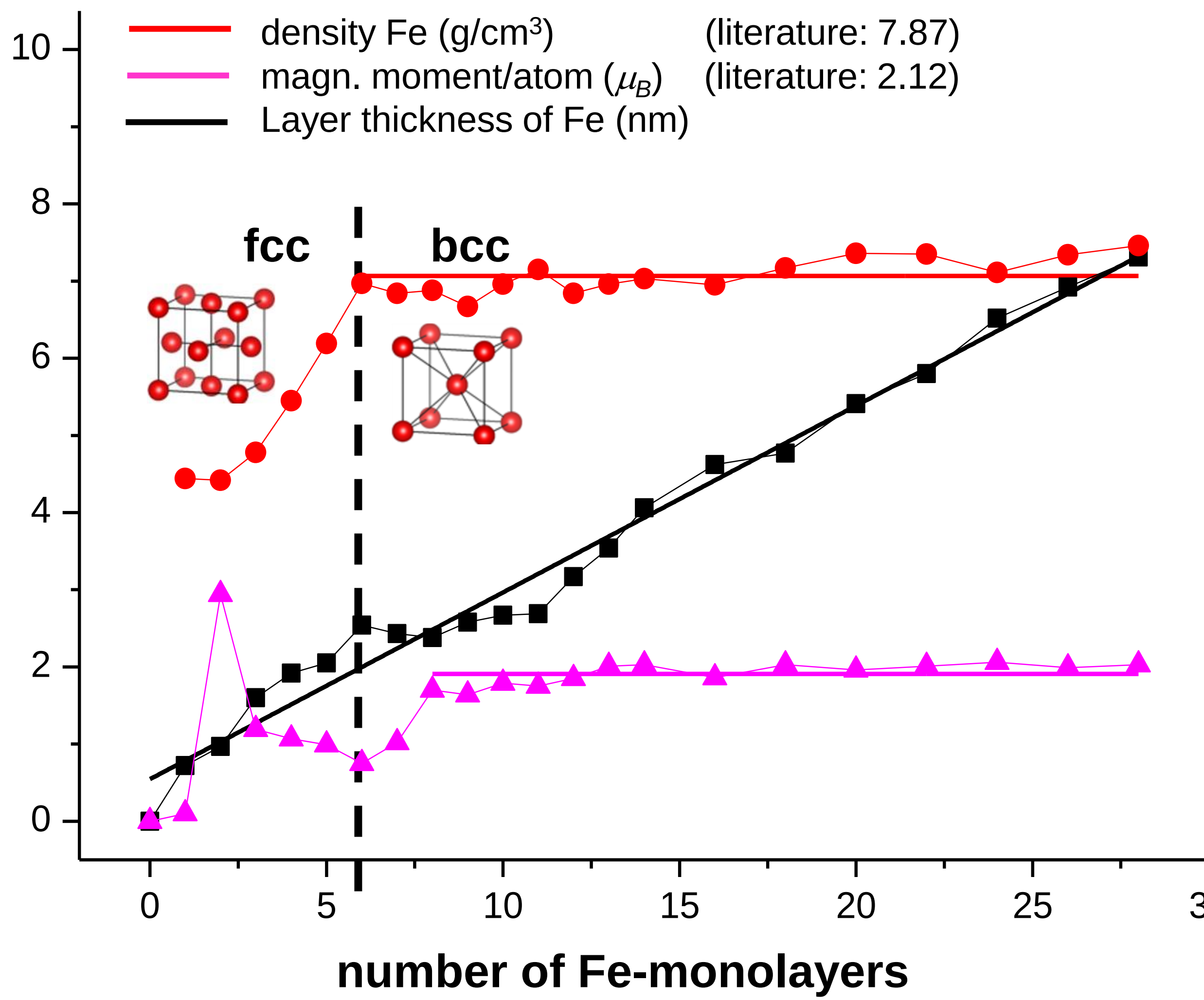
See presentation by J. Stahn, 03-Mar-2023, 14:30 – 15:00

J. Stahn et al, Eur. Phys. J. Appl. Phys. **58**, 11001 (2012)

Selene Combined with + *in-situ* Coating Technology



monocrystalline Fe on Cu/Si



W. Kreuzpaintner et al., Phys. Rev. Appl. **7**, 054004 (2017) https://doi.org/10.1103/PhysRevApplied.7.054004

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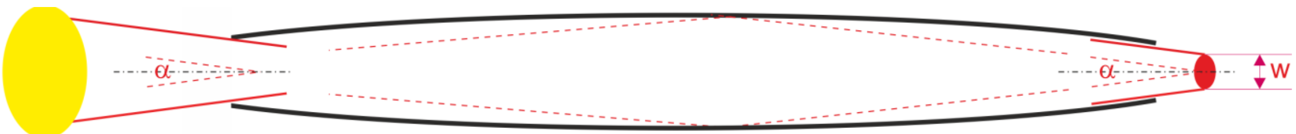
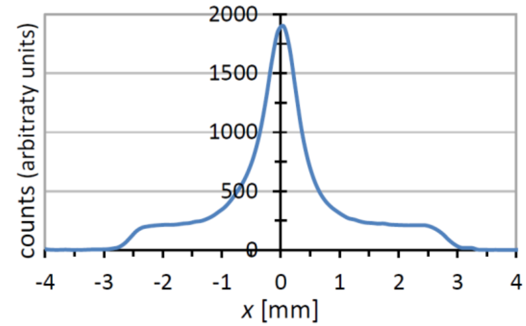
Blurring of Beams by Elliptic Guides

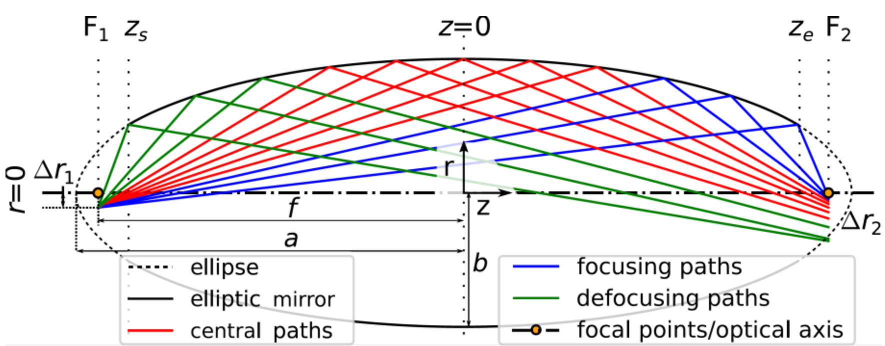
beam profile at sample position:





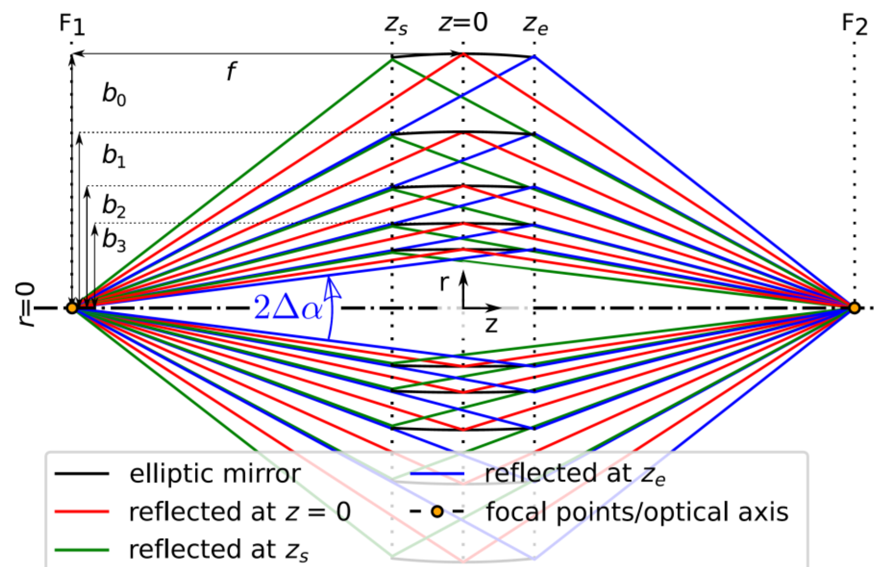
→ blurring due to non-reflected neutrons

geometrical aberrations:



$$\Delta r_2(z) = \left(\frac{f-z}{f+z}\right)\Delta r_1$$

→ off-axis neutrons produce coma

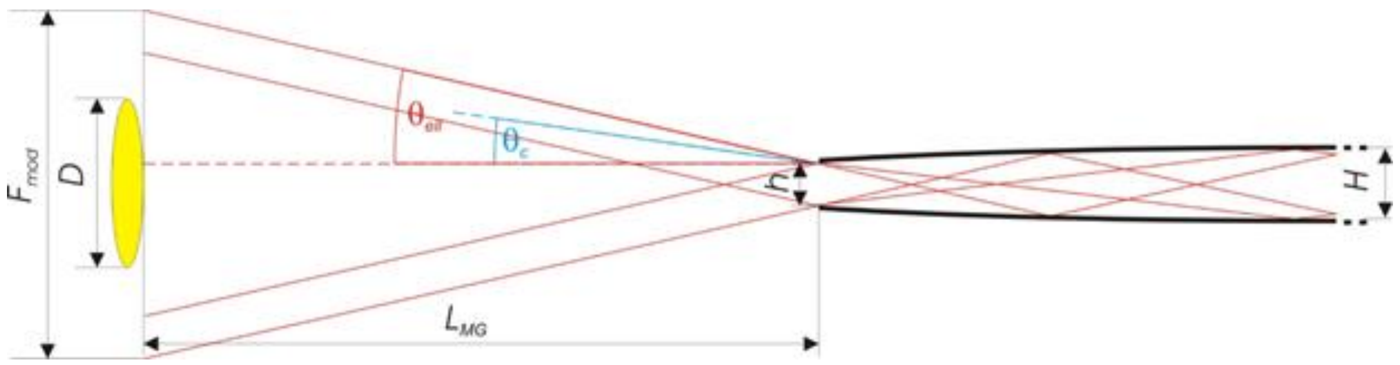


→ image neutron beam using of nested mirror optics

Christoph Herb, Oliver Zimmer, Robert Georgii, and Peter Böni, Nucl. Instrum. Meth. A **1040**, 1671564 (1-18) 2022.

Footprint of Guides: Extraction of Neutrons

Footprint:



$$F_{mod} > h + 2L_{MG}\theta_c = h + 2L_{MG}mc\lambda \qquad (c = 0.00173\ \text{rad/Å})$$

Example (ESS):

- h = 30 mm
- L_{MG} = 2000 mm
- m = 4
- λ = 3 Å

→ F_{MOD} > 30 mm + 83 mm = 113 mm

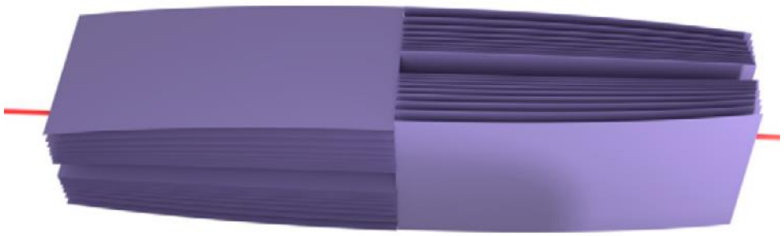
large compared with high-brill. moderators

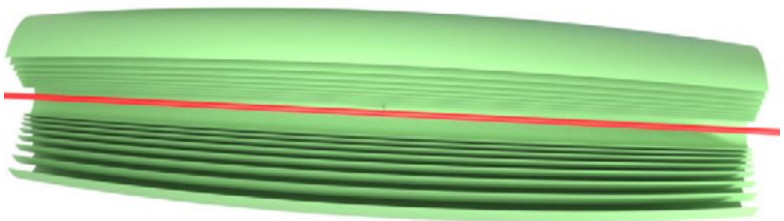
move entrance of guide close to moderator

For m = 2: footprint is still 73 mm.

Nested Mirror Optics

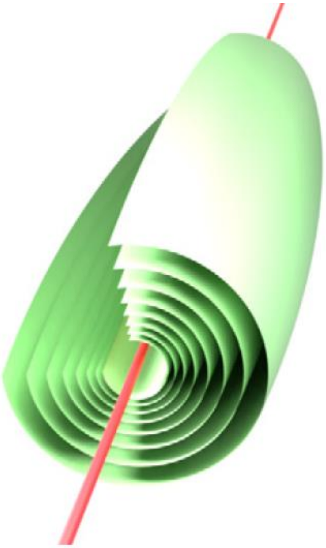
double-planar



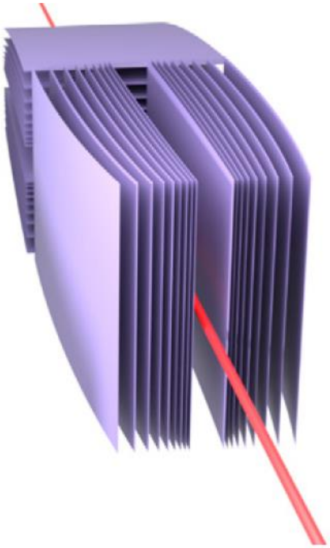


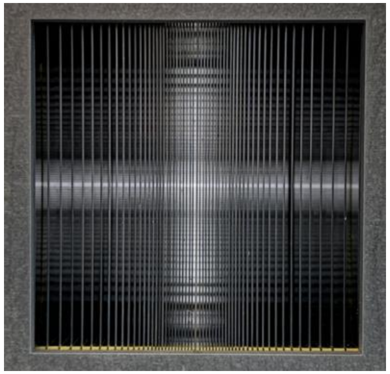
toroidal

toroidal



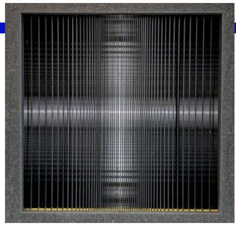
double-planar

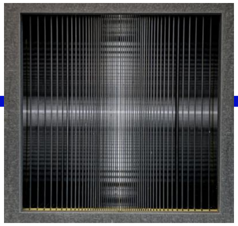




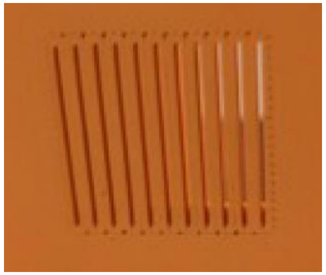
See also presentations by:
- R. Wagner, 02-Mar-2023, 14:30 – 15:00
- B. Khaykovich, 03.-Mar-2023, 16:30 – 17:00

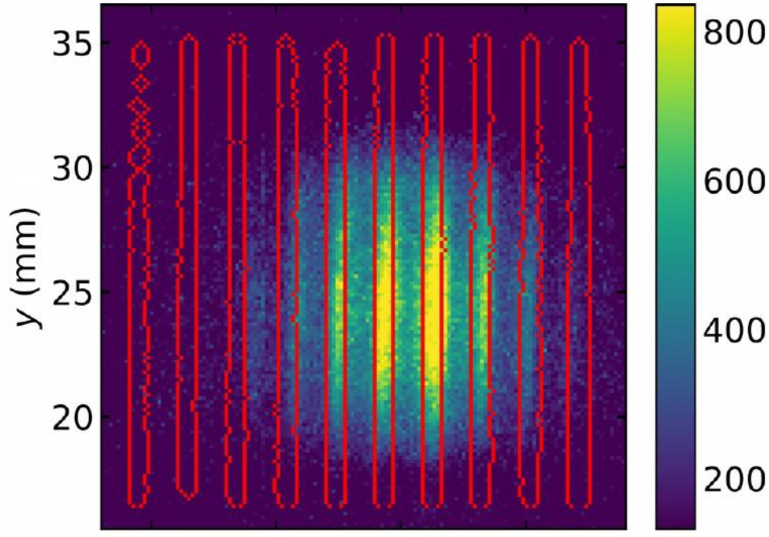
Technical Realization of NMOs

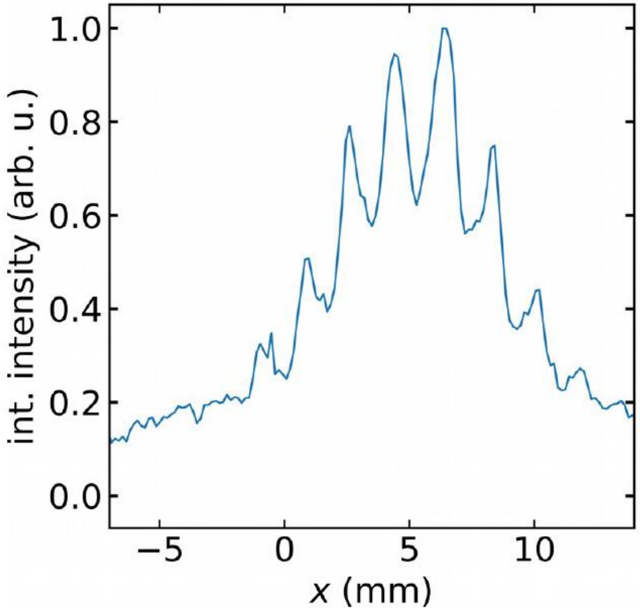




Imaging of a 1D Grid (BOA, Matteo Busi)

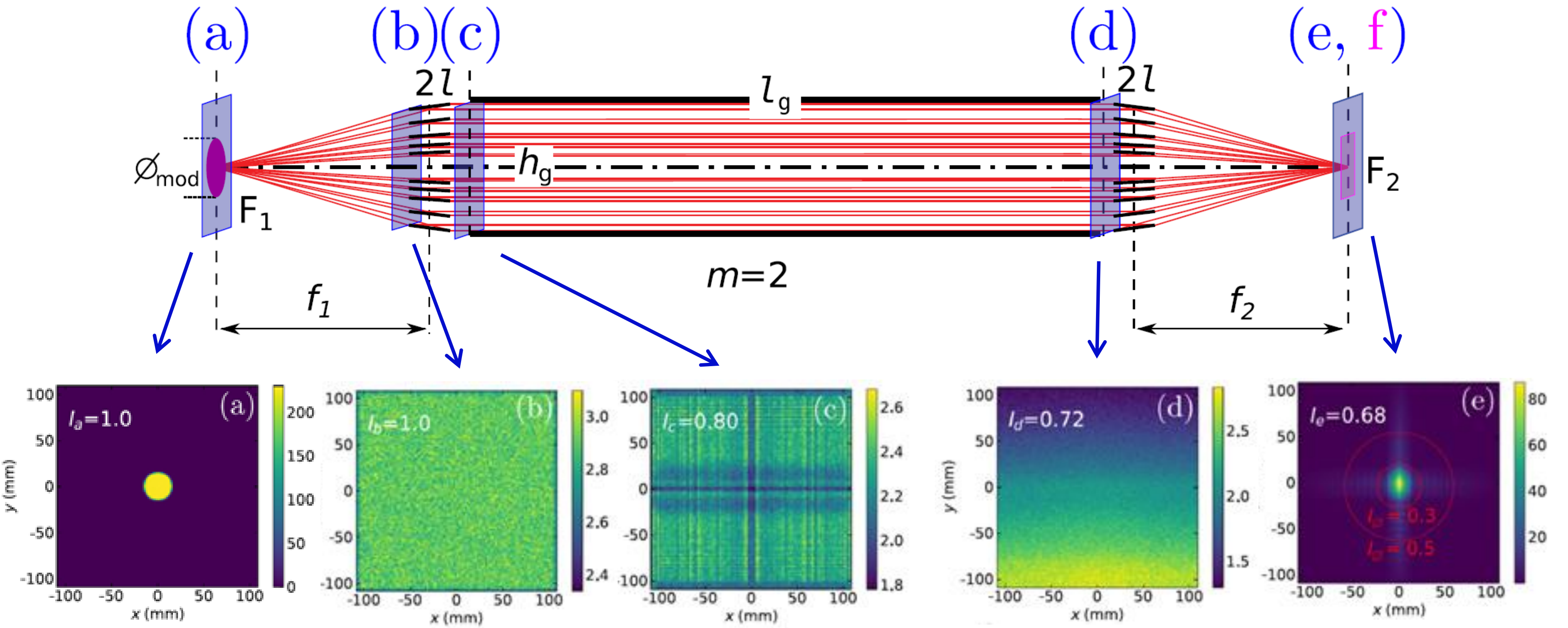




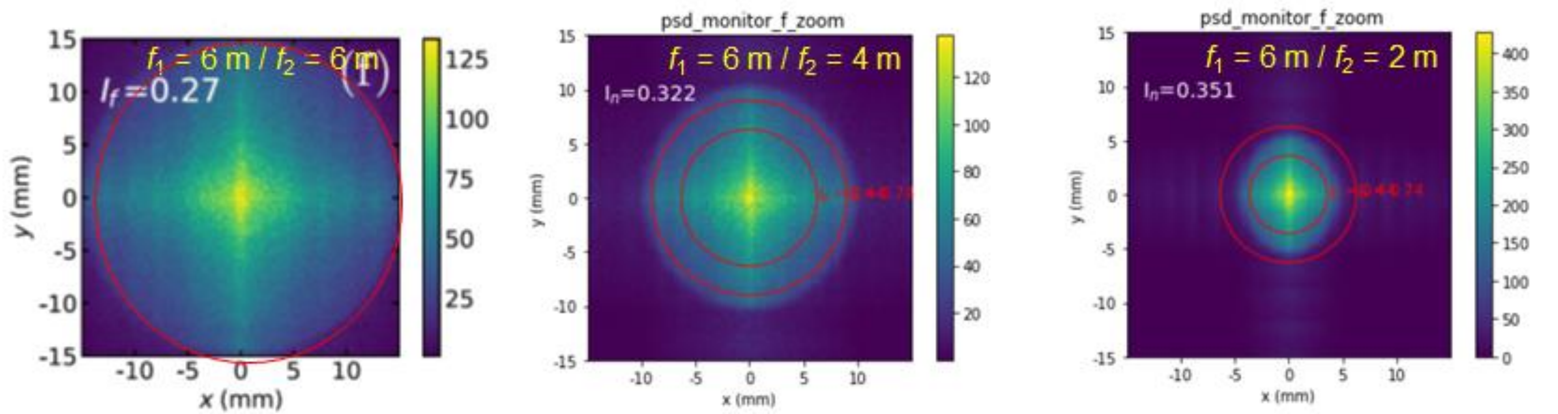


Christoph Herb et al., Nucl. Instrum. Meth. A **1040**, 1671564 (1-18) 2022.

Application: Transport of Neutrons Using NMOs

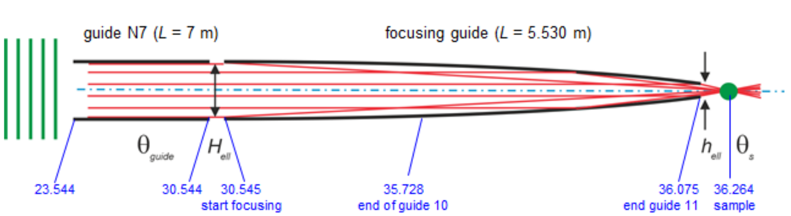


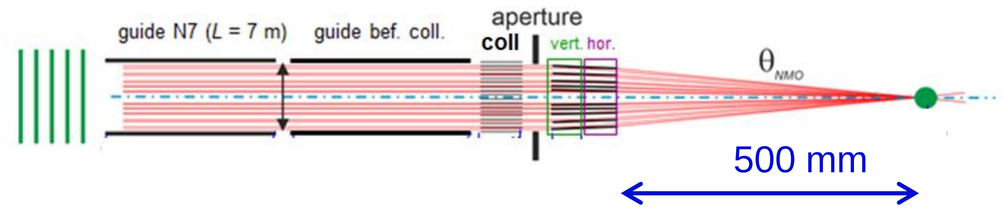
focusing of beam at sample:



Christoph Herb et al., Nucl. Instrum. Meth. A **1040**, 1671564 (1-18) 2022.

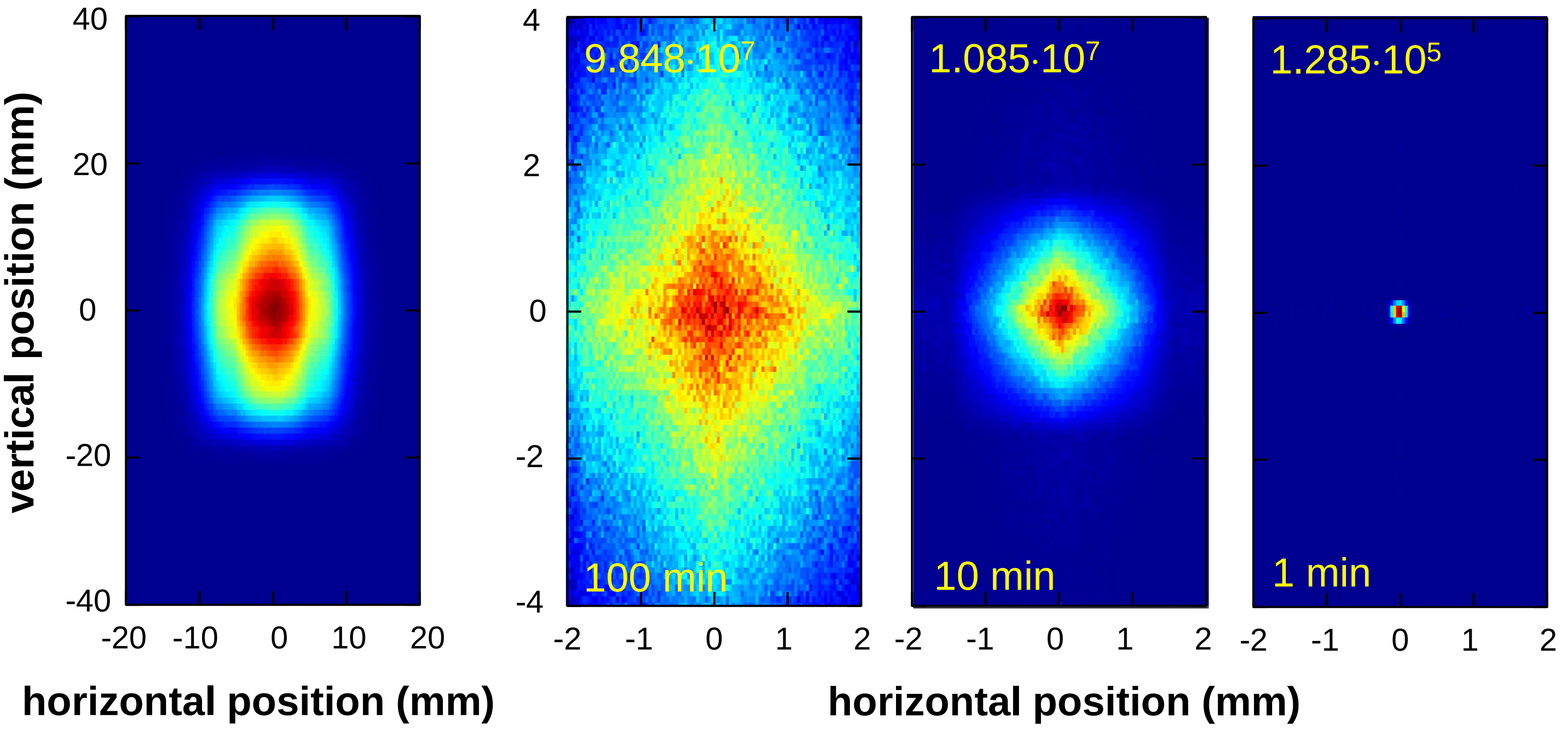
Application: Focusing and Selection of Phase Space





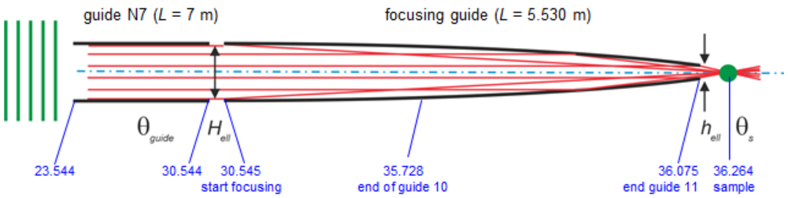
focusing guide

nested mirror optis (NMO)

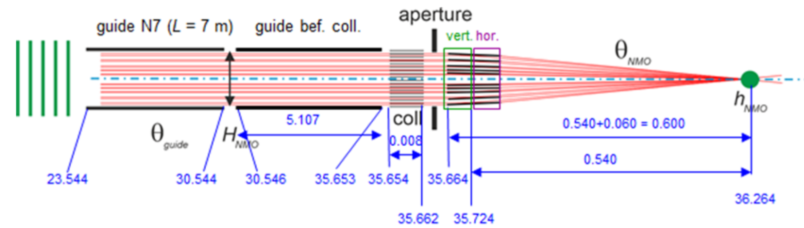


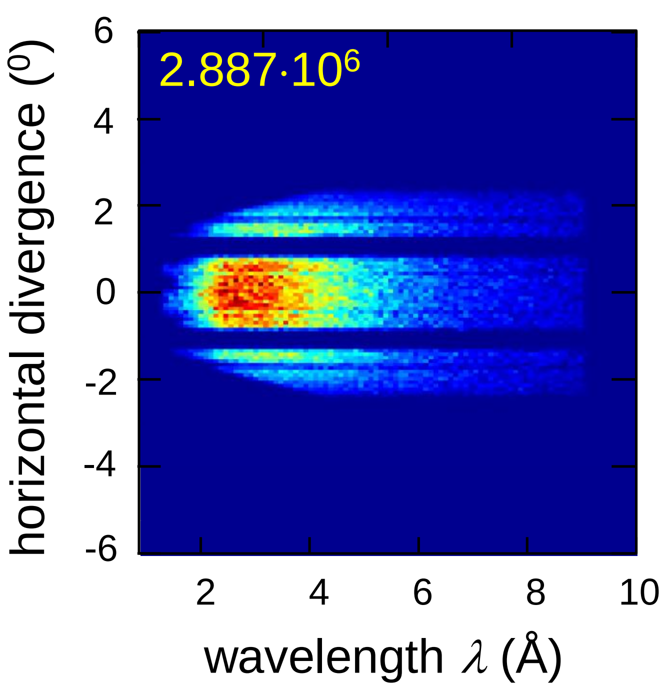
Adjust Horizontal Divergence of Beam at Sample

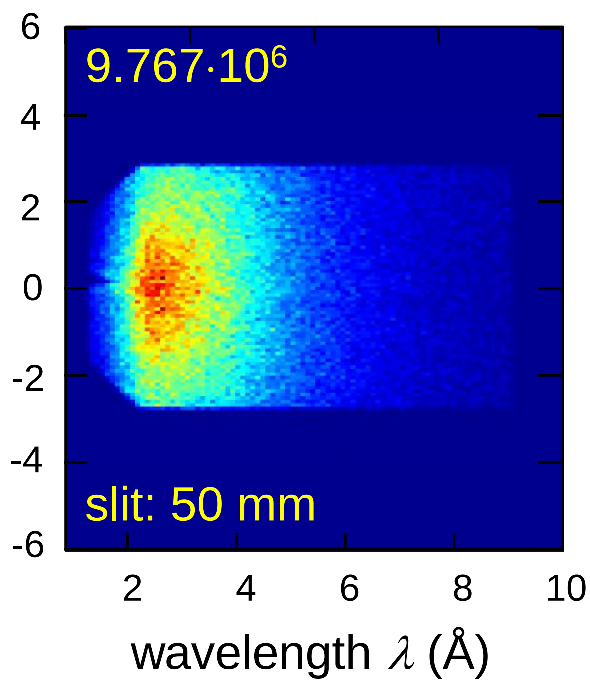
focusing guide

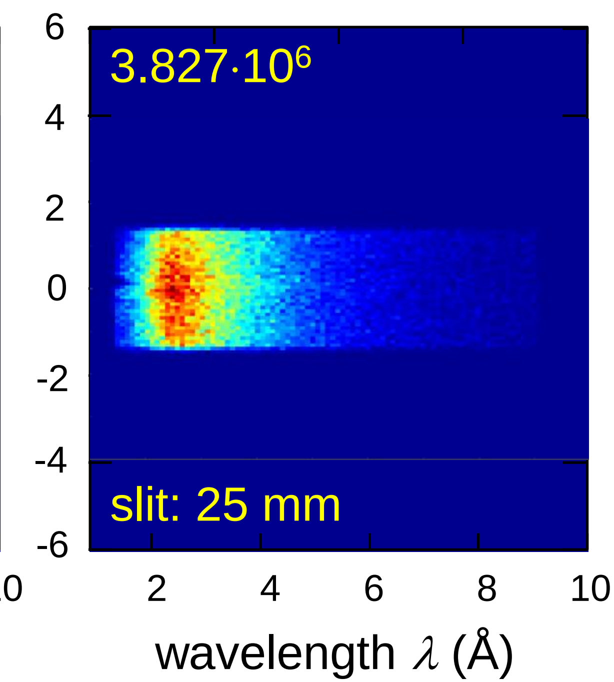


nested mirror optic



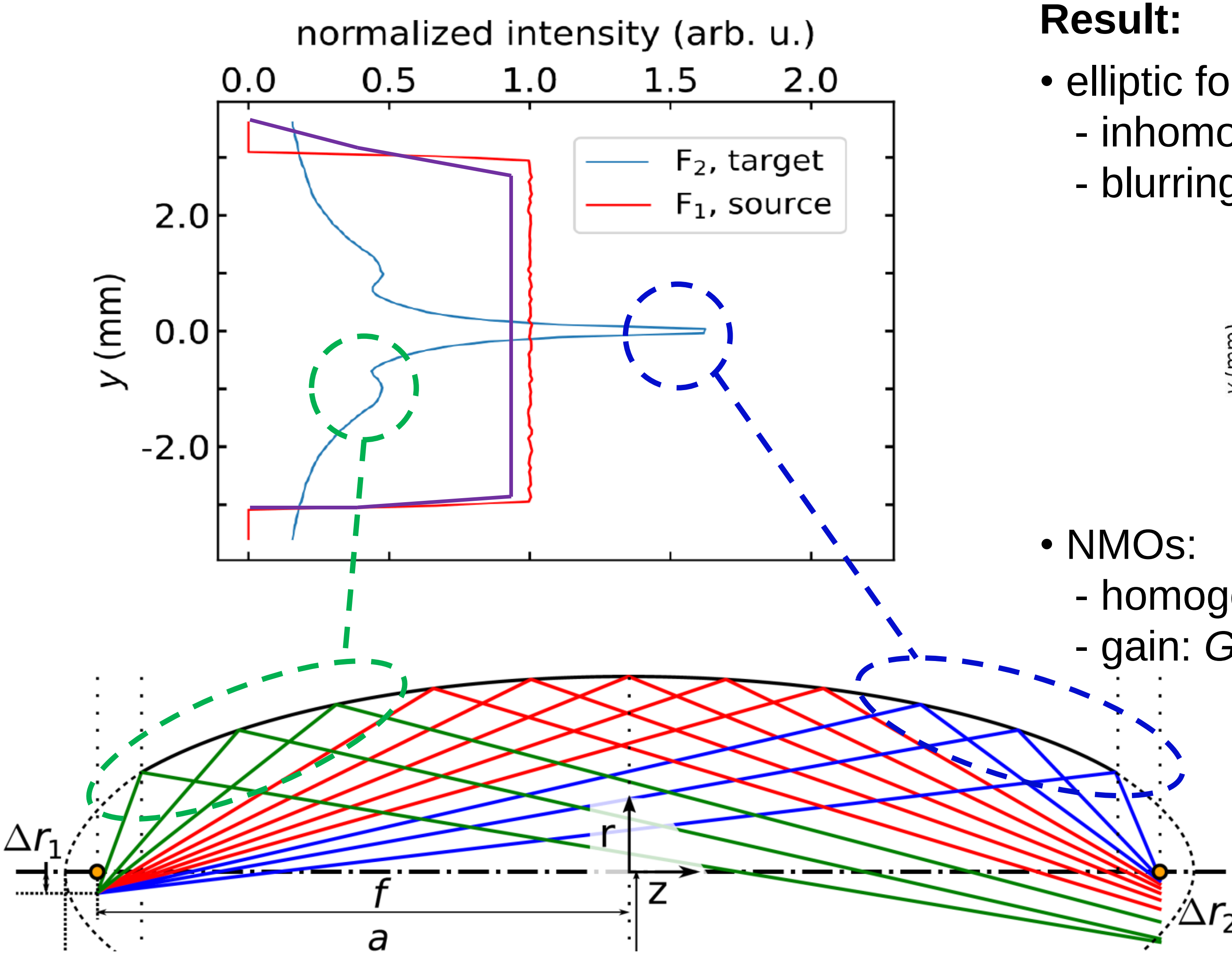






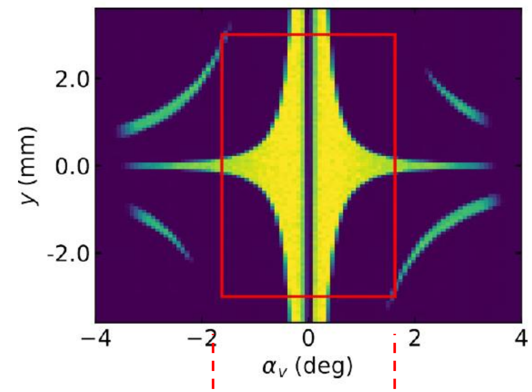
NMOs allow definition of the phase space at the sample position.

Phase Space: Elliptic vs. NMO

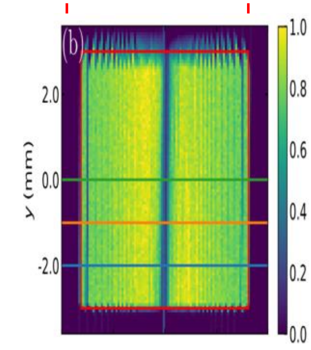


Result:

- elliptic focusing:
  - inhomogeneous beam at samp
  - blurring



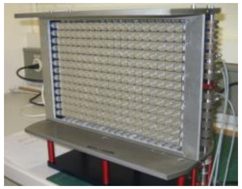
- NMOs:
  - homogeneous beam at sample
  - gain: $G \cong 2$

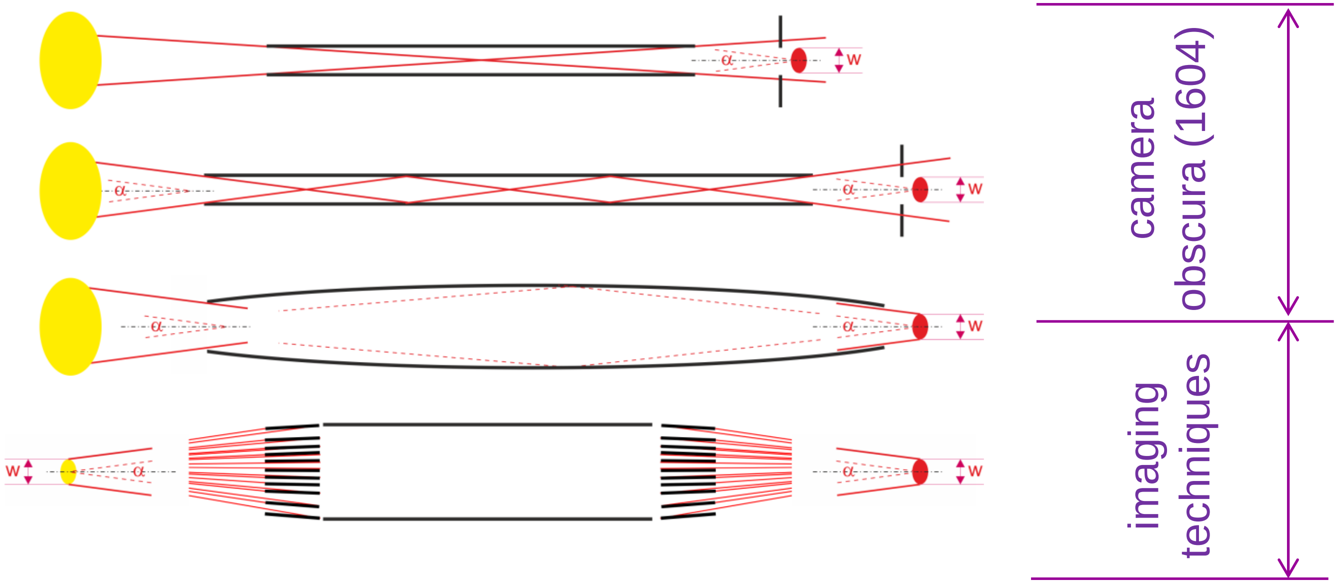


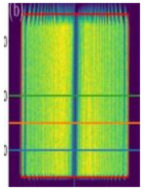
Christoph Herb et al., Nucl. Instrum. Meth. A **1040**, 1671564 (1-18) 2022.

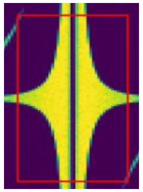
Summary

Developments in neutron beam optics:









Advantages of nested mirror optics :

- compact / simple alignment (similarly as a lens in visible light optics)
- selection of phase space far away from sample
- no chromatic aberration / low sensitivity to gravitation
- excellent sample-/system size ratio   (compare Selene)
- low background
- reduction of irradiation damage (far away from moderator)
- design of beam lines is simplified

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NEUTRONS FOR SOCIETY

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