Customizing Neutron Beams

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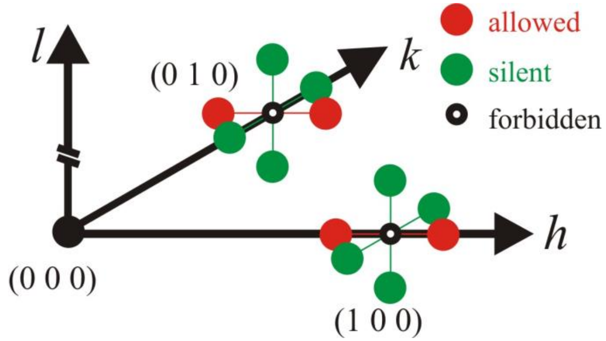
Strongly Correlated Electron Systems

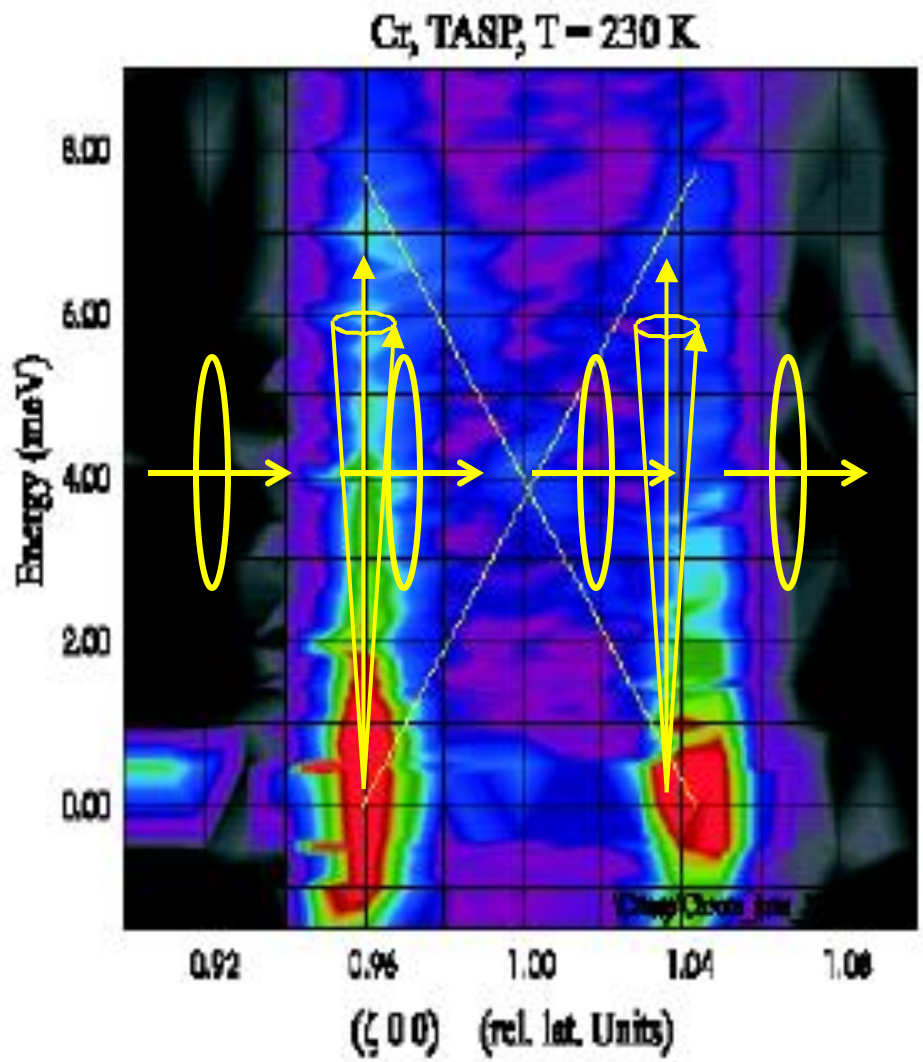
Example: incommensurate Cr



- extremely steep slope:

$$E_{SW} = cq \qquad c = \frac{v_F}{\sqrt{3}}$$

- fine **Q**-resolution
- coarse **E**-resolution



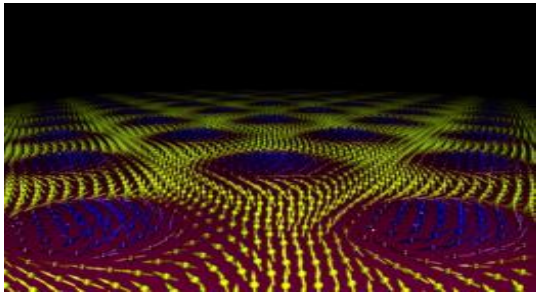
Further examples:

- high T_c superconductors
- strongly correlated electron systems

P. Böni et al., J. Phys.:Condens. Matter **23**, 2011) 254209

Smaller Samples and High Resolution: QPTs

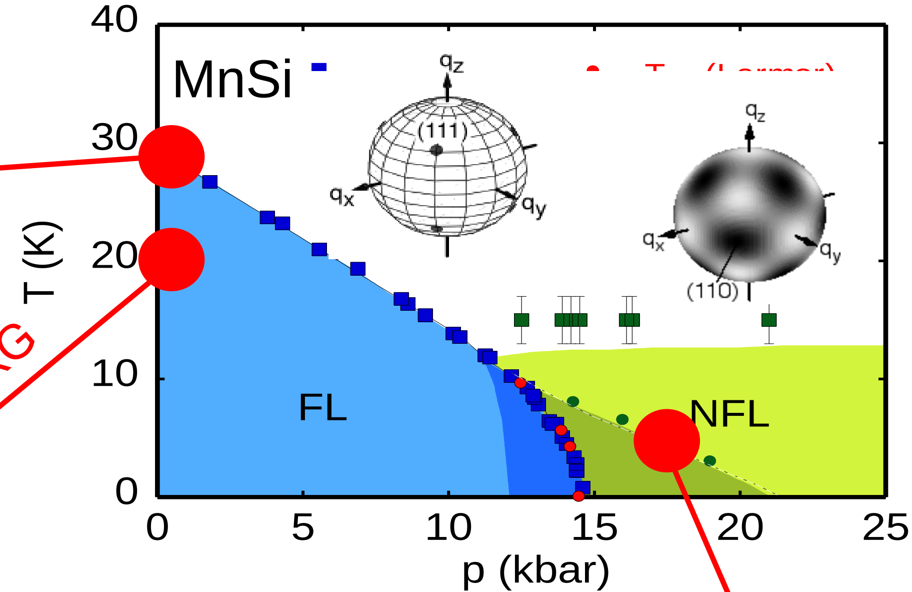
Skyrmions in MnSi



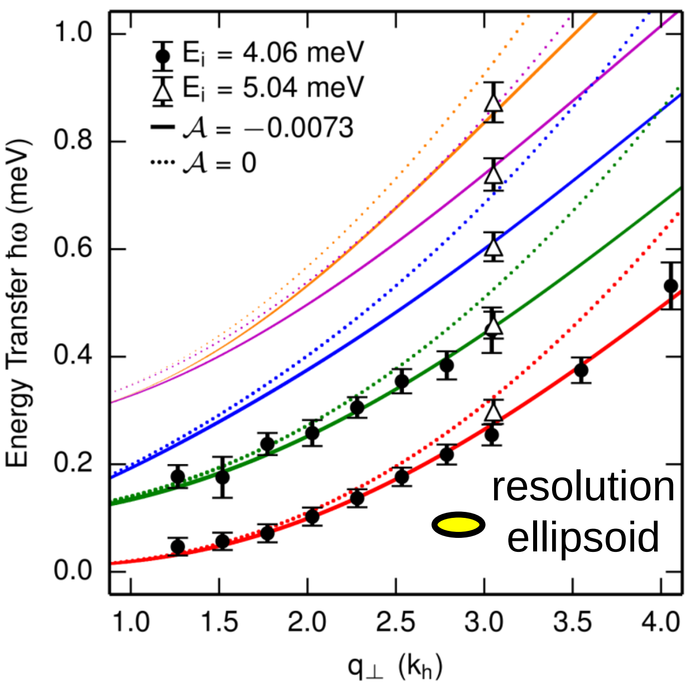
S. Mühlbauer et al., Science **323** (2009) 915

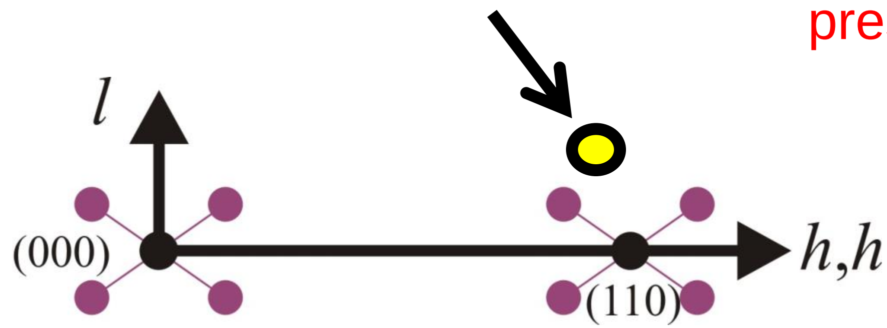
B = 1.8 kG

B = 1 kG



pressure





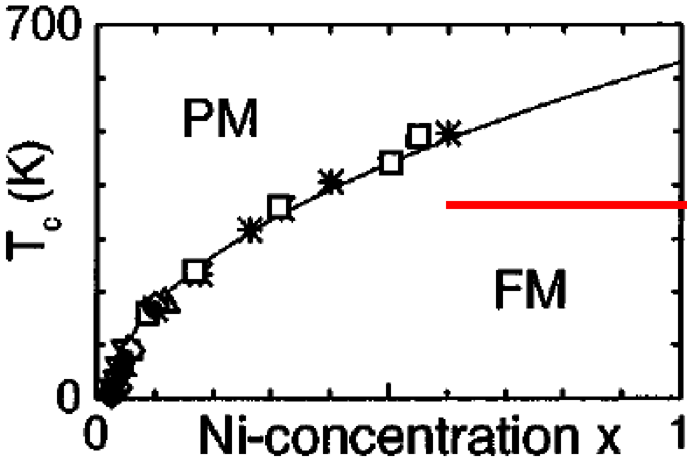
Excellent *Q*- and *E*-resolution required

M. Kugler et al., Phys. Rev. Lett., to be published.

QPT Using Doping ←→ Homogeneity of Samples

$Pd_{1-x}Ni_x$: control parameter: *x*

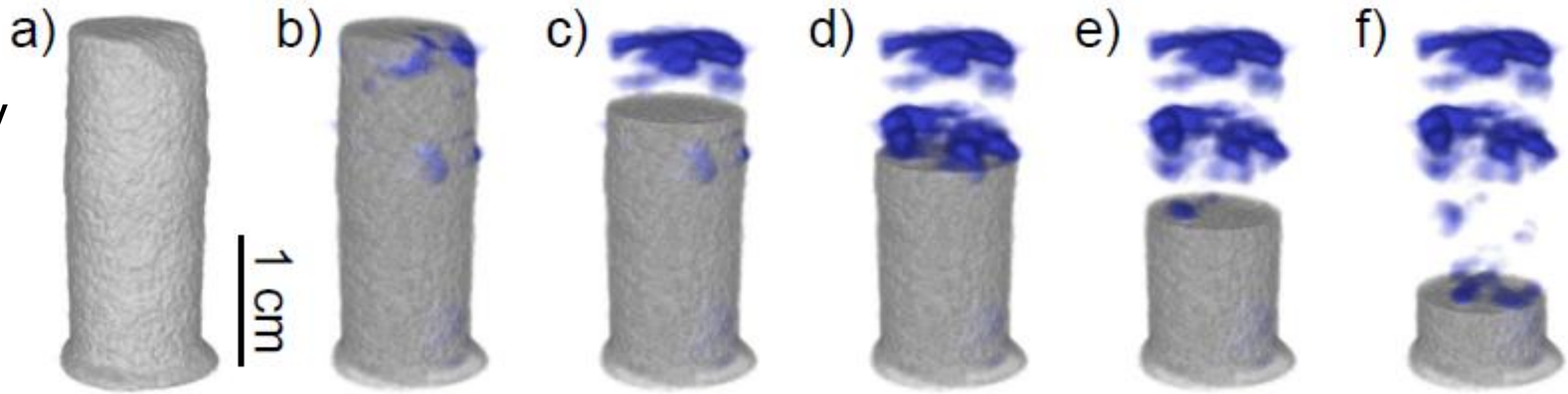
M. Nicklas et al., Phys. Rev. Lett. **82**, 4268 (1999)



QPT?

single crystal:

tomography with polarized neutrons:



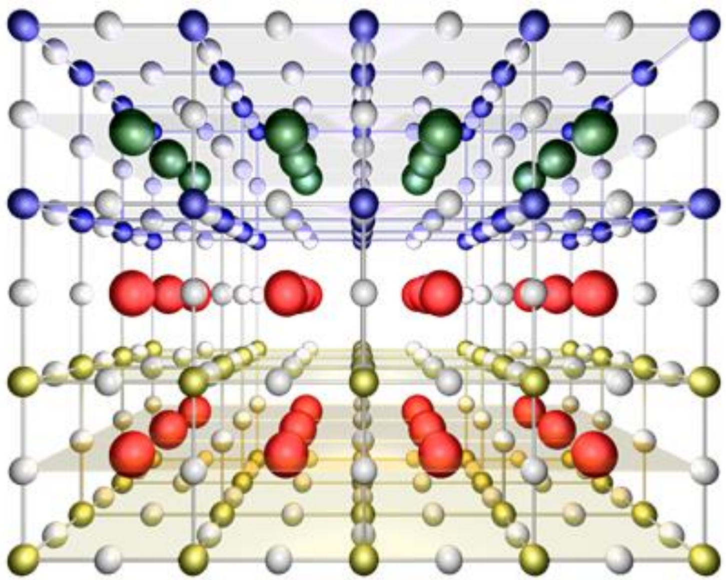
Apply position dependent scattering techniques

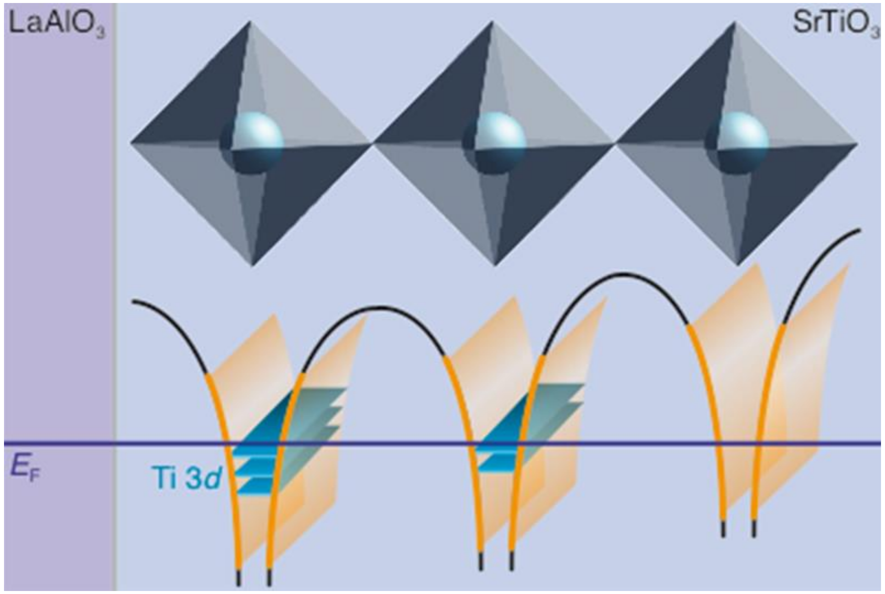
M. Schulz et al., J. Phys: Conf. Series **211**, 012025 (2010)

Heterostructures of Functional Oxides

$SrTiO_3/LaAlO_3$:

- control parameter: number of layers $SrTiO_3$ on $LaAlO_3$





2-D electron liquid at the $LaAlO_3$-$SrTiO_3$ interface: ferrom. / supercond.

monolayer samples → adaption of reflectometry for *in-situ* studies

after J. Mannhart et al., JUM@P´09, Paul Scherrer Institut, 13.10.2009

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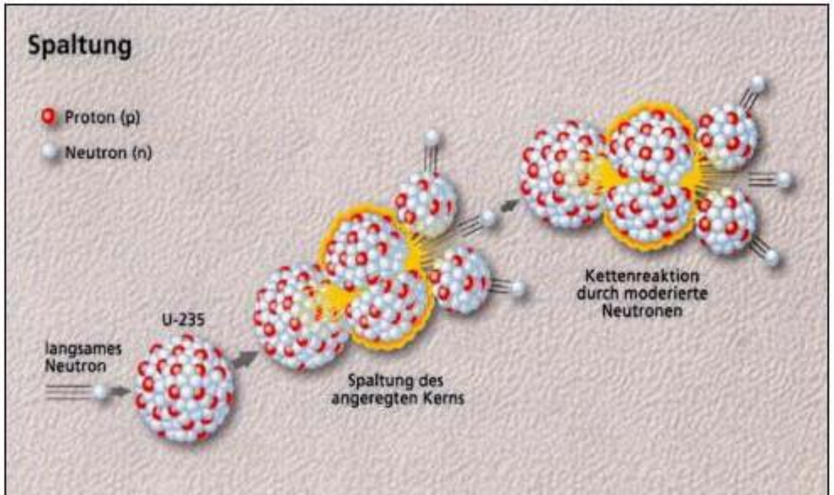
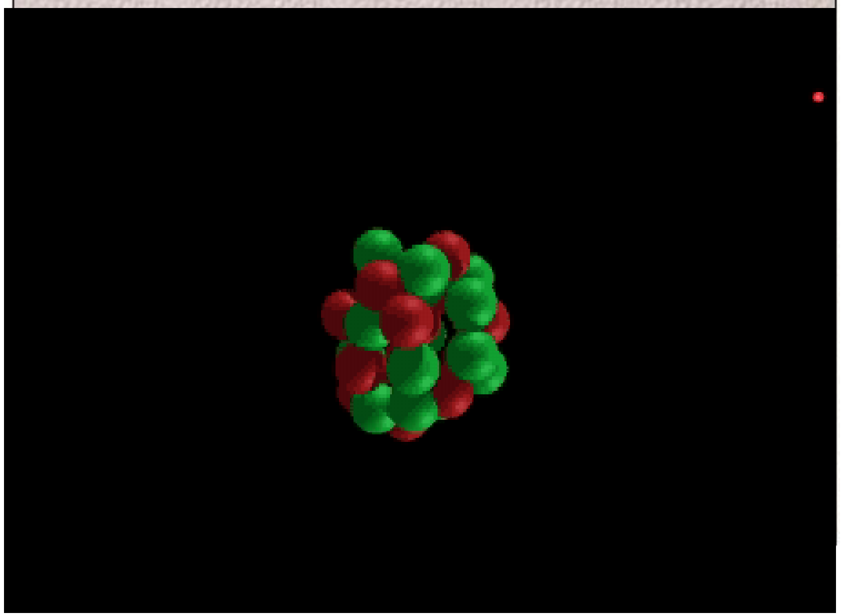
- Introduction
- Supermirrors
- Transport
- Focusing Optics
- Montel Mirrors
- Beam Extraction
- Summary

Production of Neutrons





fission

FRM-II, München

spallation

SINQ, Paul Scherrer Institut

→ ESS in Lund, Sweden

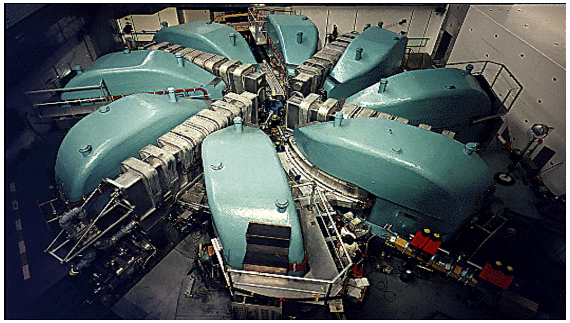
Some Pictures of Neutron Sources

ESS, Sweden

Chalk River, Canada

FRM II, Germany

SINQ, Switzerland

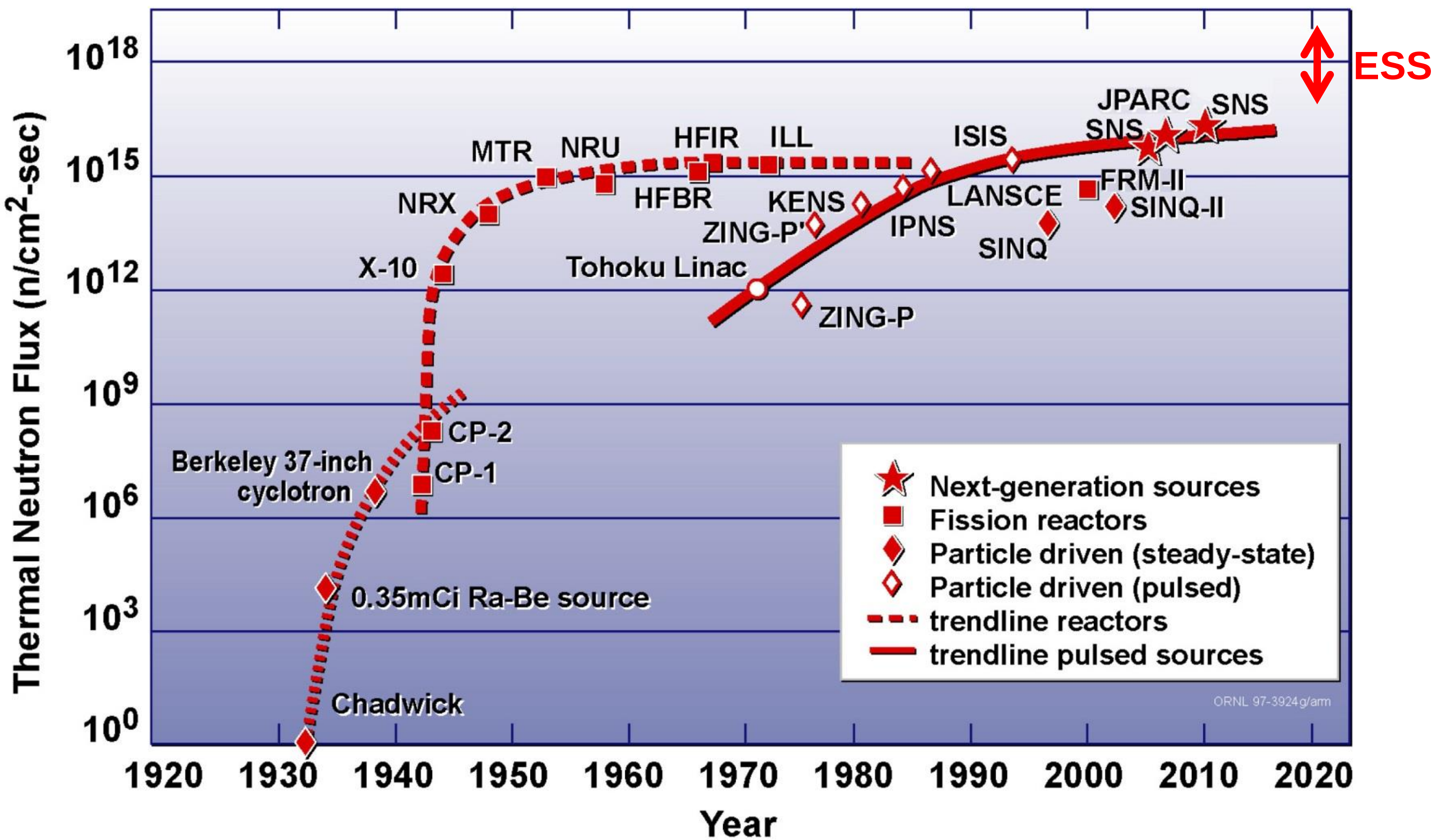


ILL, France

ISIS TS-2, UK

SNS, USA

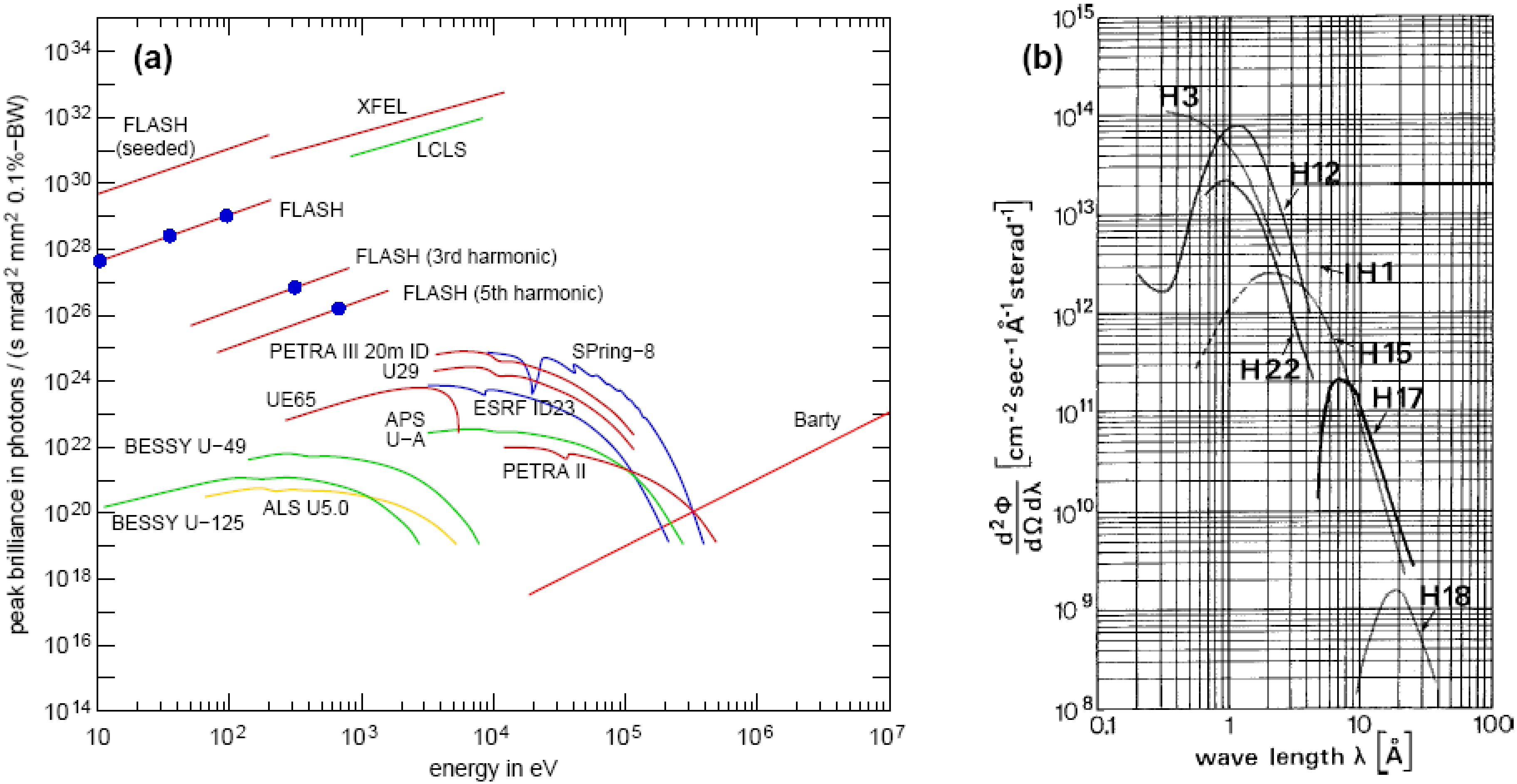
Flux of Neutron Sources



(Updated from *Neutron Scattering*, K. Skold and D. L. Price: eds., Academic Press, 1986)

Brilliance of X-ray and Neutron Beams

$$\Psi = \frac{d^2\phi}{d\Omega d\lambda} = \frac{1}{\text{cm}^2\ \text{s BW sterad}}$$

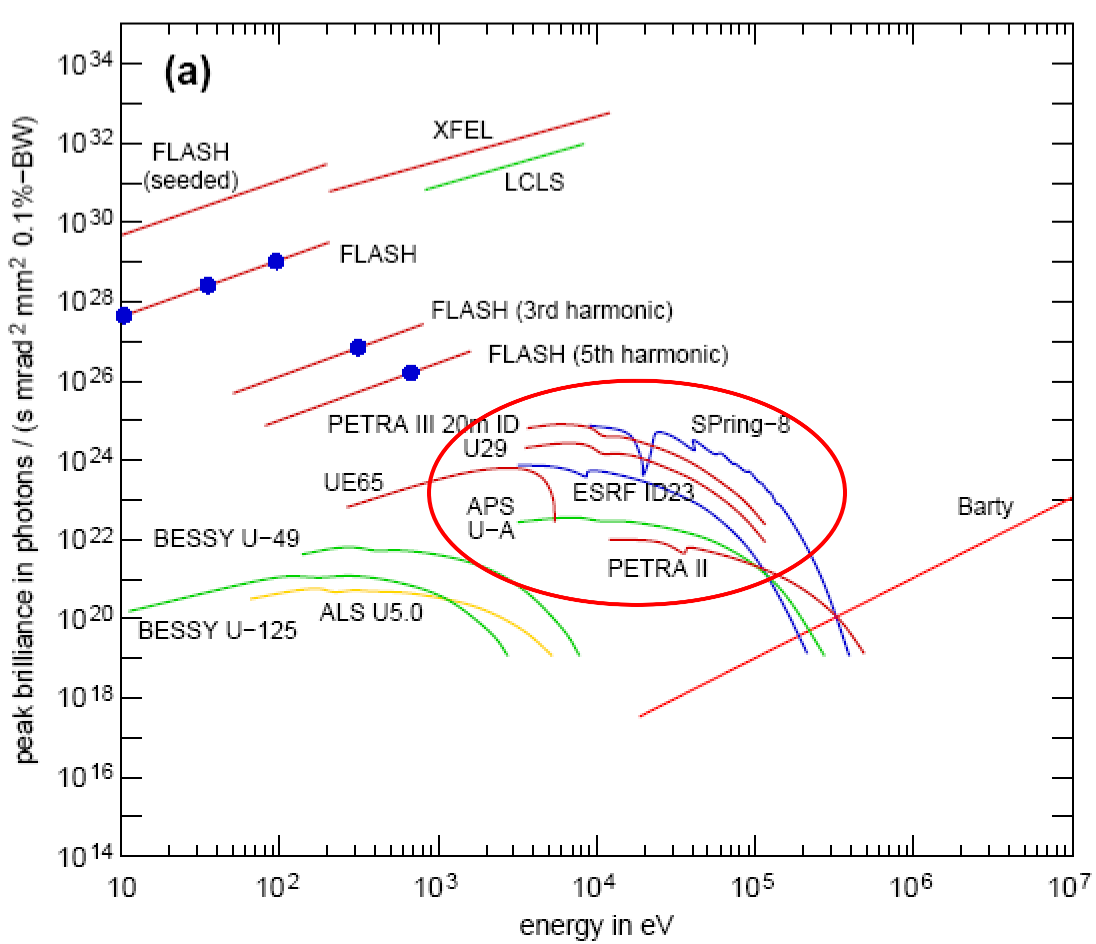


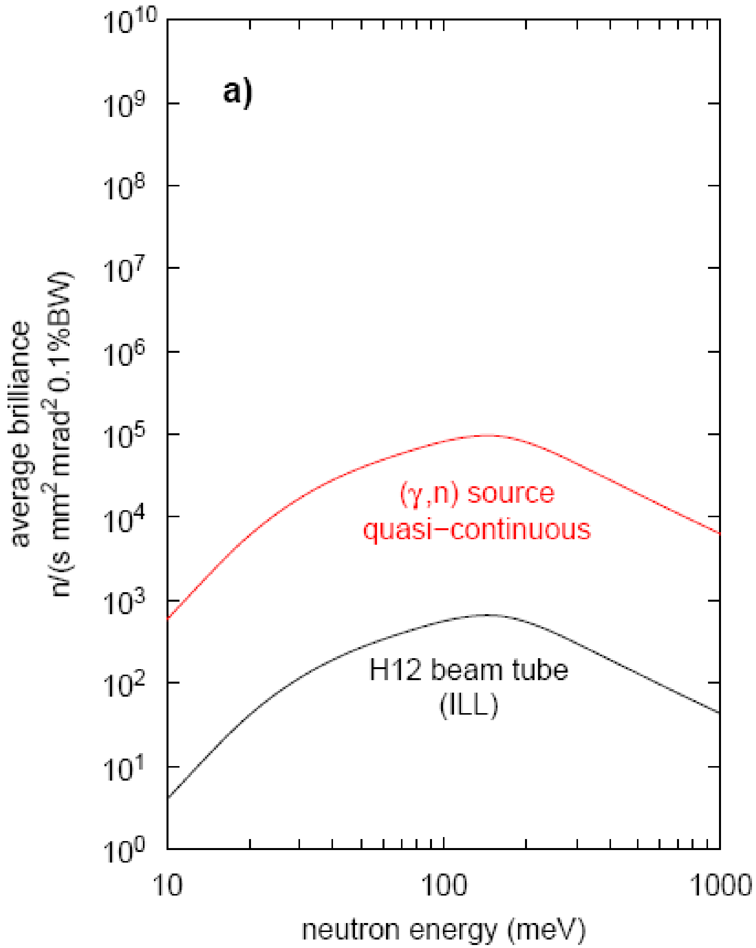
Difficult to compare for non-expert.

D. Habs, M. Gross, P. G. Thirolf, and P. Böni, Appl. Phys. B **103**, 485 (2011)

Brilliance of X-ray and Neutron Beams: Units!

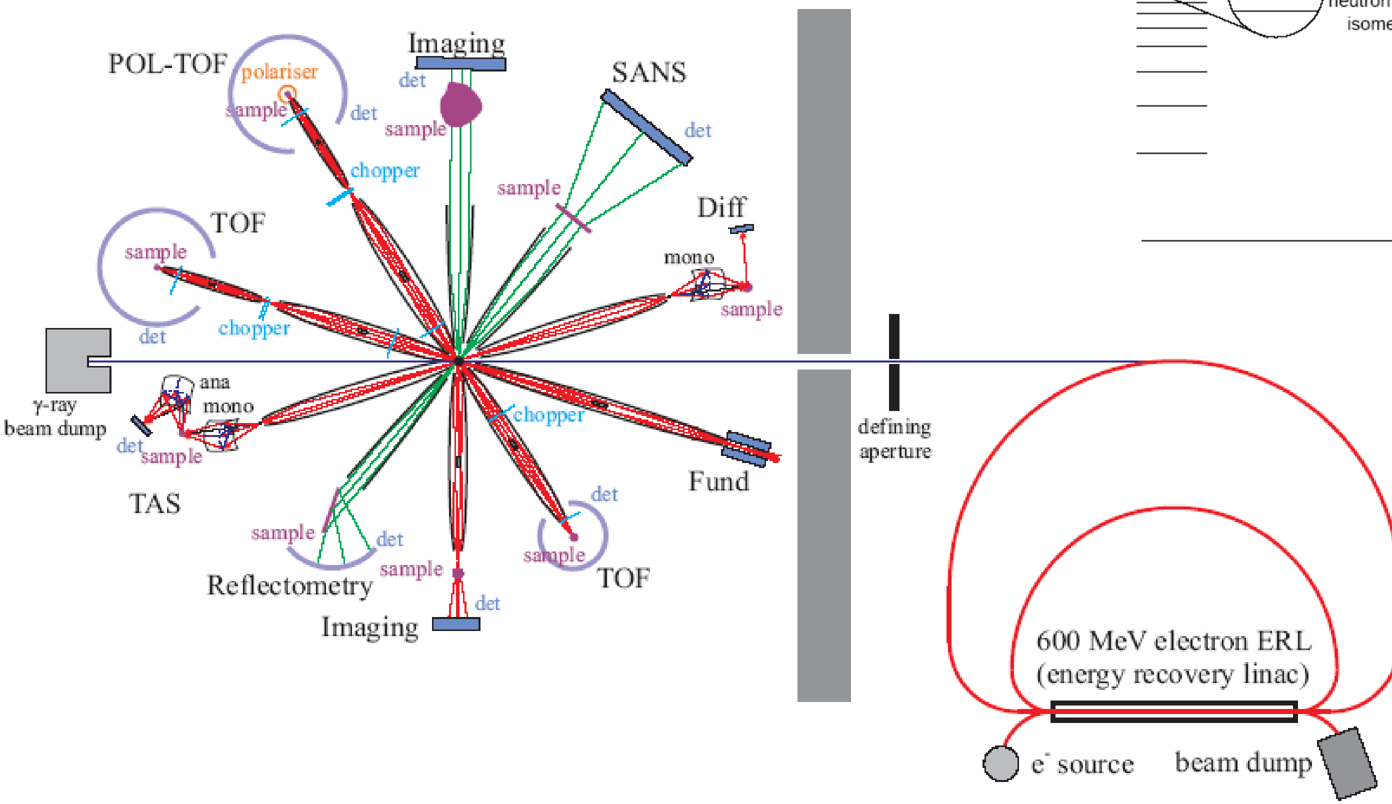
$$\Psi = \frac{d^2\phi}{d\Omega d\lambda} = \frac{\text{neutrons}}{\text{cm}^2 \text{ s Å sterad}}$$

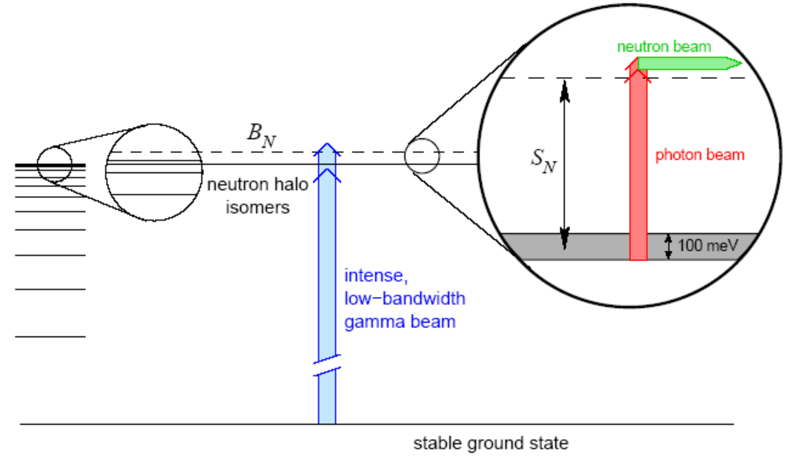


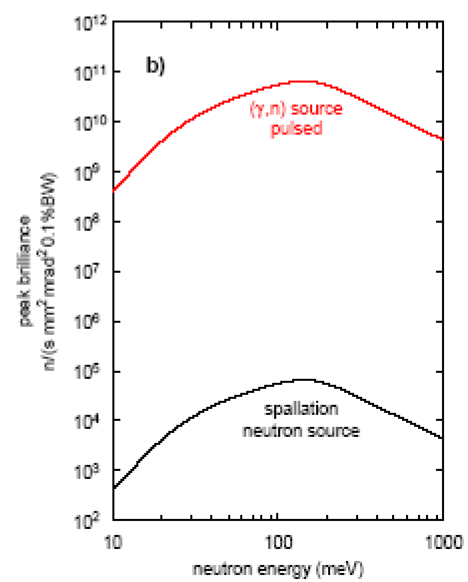


D. Habs, M. Gross, P. G. Thirolf, and P. Böni, Appl. Phys. B **103**, 485 (2011)

Photo-Neutrons from Halo Nuclei?







brilliant neutron source: ø ≅ 0.1 mm

D. Habs, M. Gross, P. G. Thirolf, and P. Böni, Appl. Phys. B **103**, 485 (2011)

Performance of a Source

intensity:

- counts ≈ photons, neutrons, …
- detection may not be 100% efficient

$$I = \frac{\text{counts}}{\text{s}}$$

flux:

$$\phi = \frac{1}{\text{cm}^2\,\text{s}}$$

brilliance:

- Ω: solid angle (sterad)
- λ: wavelength (Å)

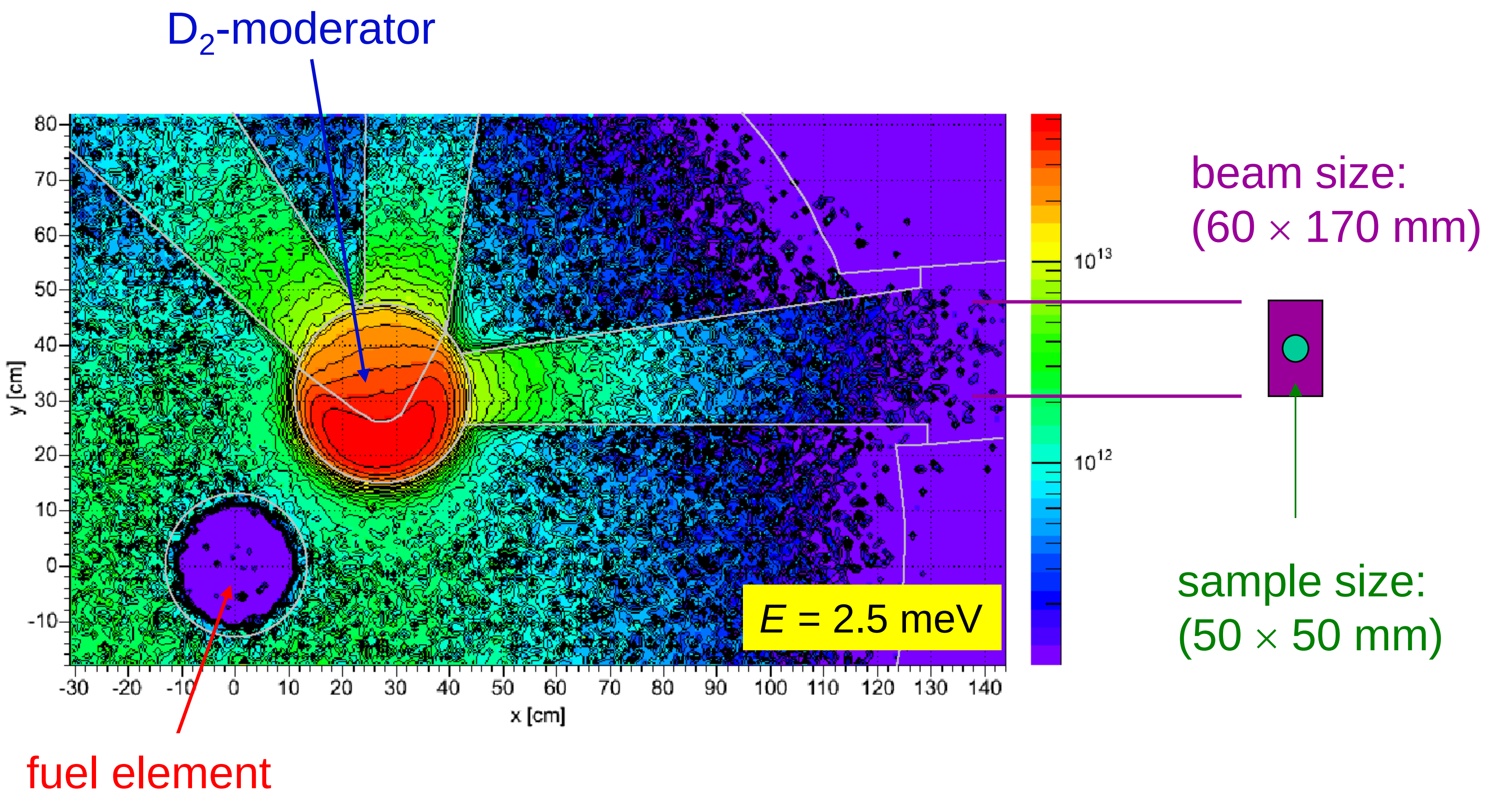
$$\Psi = \frac{d^2\phi}{d\lambda d\Omega} = \frac{1}{\text{cm}^2\,\text{s}\,\text{Å}\,\text{sterad}}$$

The more the better?

Optimization Using Monte-Carlo Simulations (MCNPX)

FRM-II, Garching:

20’000 km/s → 2 km/s → 200 m/s

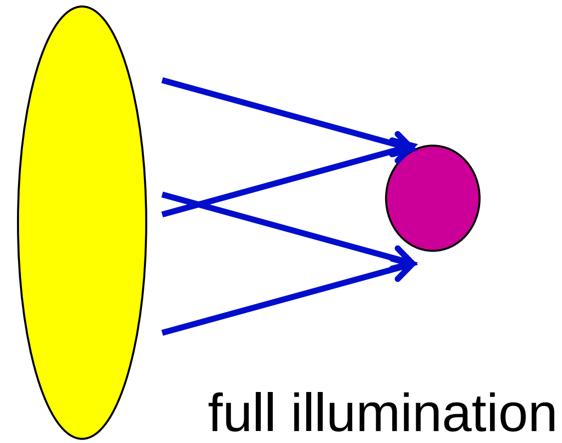


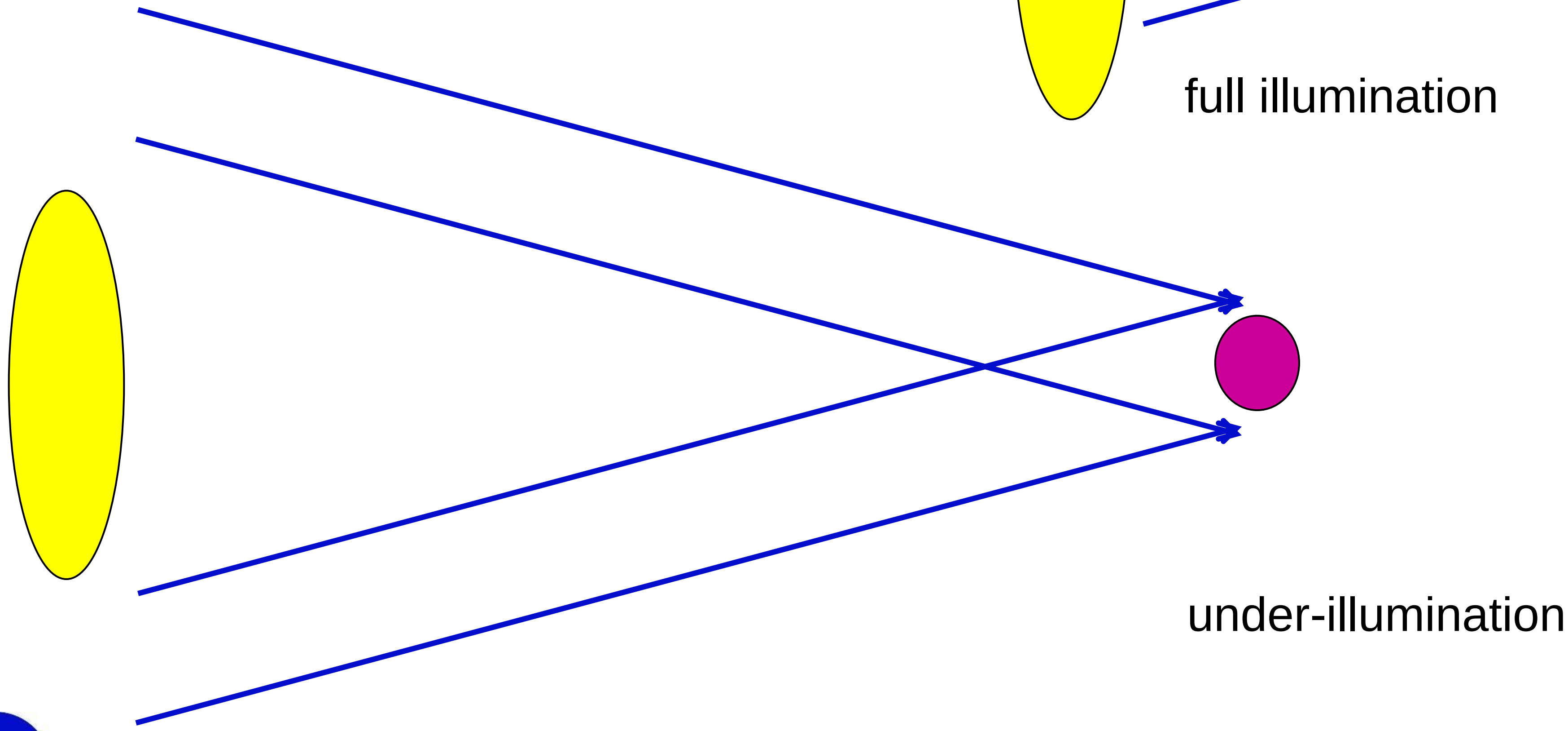
Thesis: F. Grüninger, E21

Illumination of a Sample

Reading a newspaper:

- go close to the light
- choose a bright light

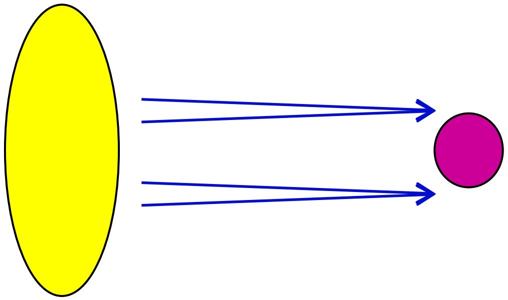


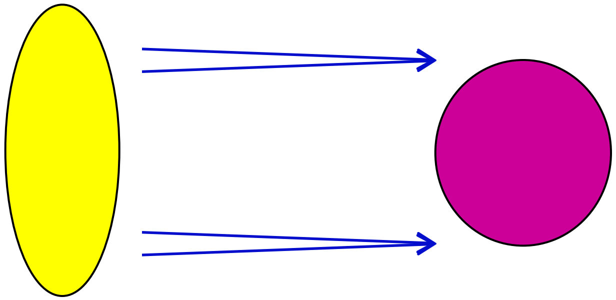


Intensity (neutrons/s) Is Proportional to ...

- **sample size**

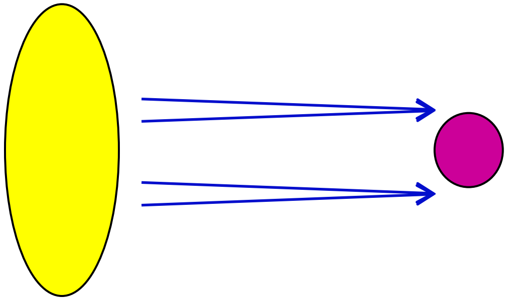
(assumption: large source – full illumination)

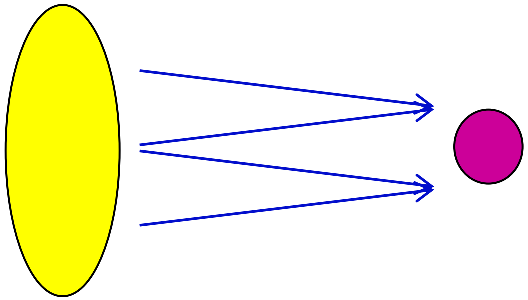




A (cm^2)

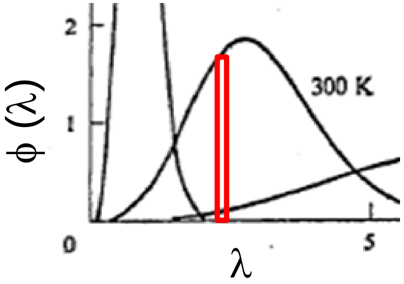
- **solid angle**

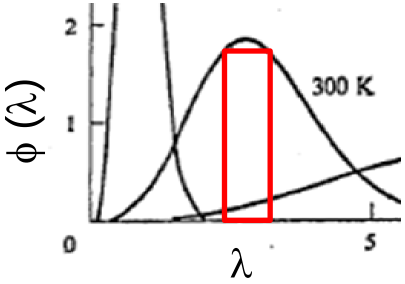




Ω (sterad)

- **band width**





$\Delta\lambda$ (Å^{-1})

What is the Ultimate Intensity at the Sample?

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

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

example: (Yellow Book of the ILL, p. 8, Fig. 4 (1986))

- port H12 @ ILL: $\Psi = 8{\cdot}10^{13}$ $cm^{-2}s^{-1}$ Å^{-1}sterad^{-1} (λ = 1.2 Å)
- typical sample: $\eta = 0.5$, $A = 1$ mm^2, $\Delta\lambda = 1\%$, divergence: $1^0/4^0$

→ Maximum neutron intensity at sample: $I = 5{\cdot}10^6$ s^{-1}

- experiment feasible?
- intensity not achieved? → technical limitations (SMs) / refurbish beam line

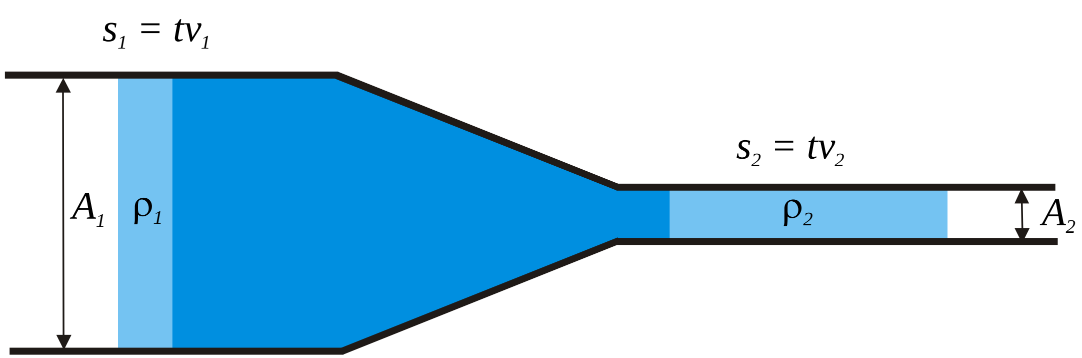
Peter Böni, J. Phys.: Conf. Series **502** (2014) 012047

Theorem of Liouville ←→ Plumbing Heating

water pipes:

- fluid not compressible

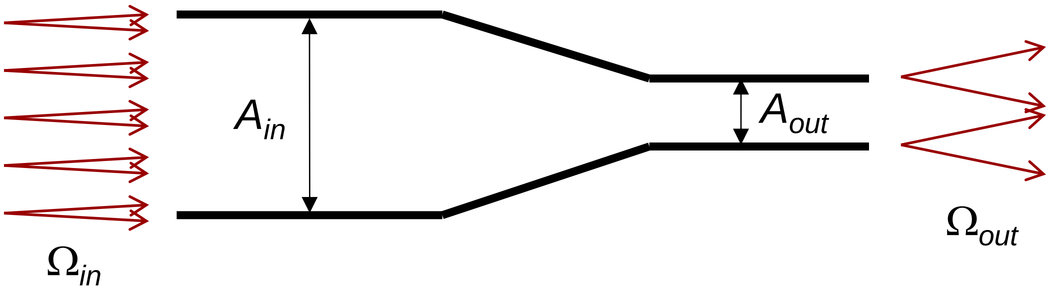
$$A_{in} v_{in} = A_{out} v_{out}$$



neutron transport:

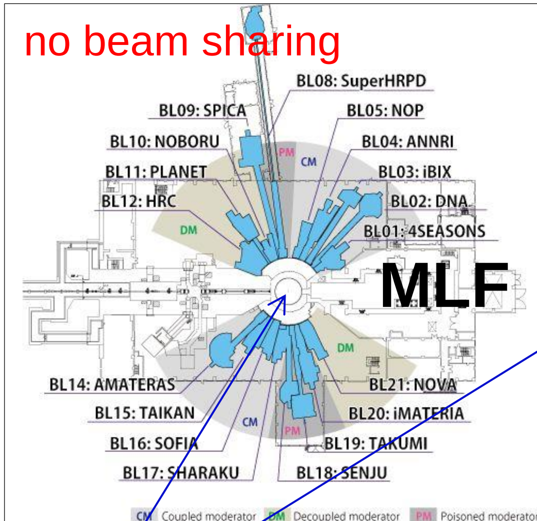
- Liouville: phase space density is constant in time
- neutrons do not change energy

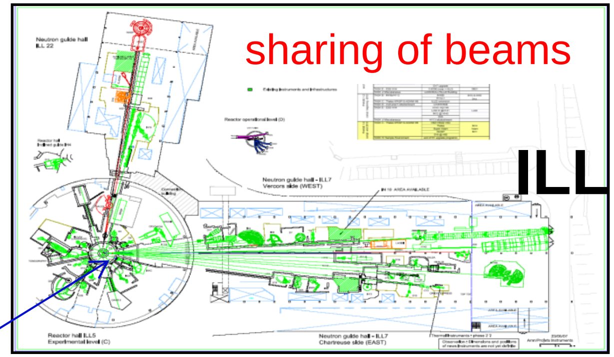
$$A_{in} \Omega_{in} = A_{out} \Omega_{out}$$



We focus the beam by increasing the divergence!

Most Neutron Beams Are not Adapted to Sample





Liouville's theorem:
phase space density:

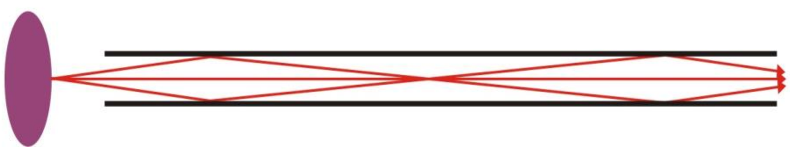
$B = A \times \Omega = \text{const}$

area × solid angle

used neutron beam:

- beam size: 1 cm × 1 cm
- divergence: 2^0 / 2^0

→ $B = 4\ (\text{cm}\ ^0)^2$



extracted neutron beam:

- beam size: 6 cm × 17 cm
- divergence: 1.5^0 / 1.5^0

→ $B = 230\ (\text{cm}\ ^0)^2$

balance: only ~2% of neutrons used!

- irradiation of materials → damage
- expensive shielding
- high background

monochromatization: further reduction (~10^{-4})

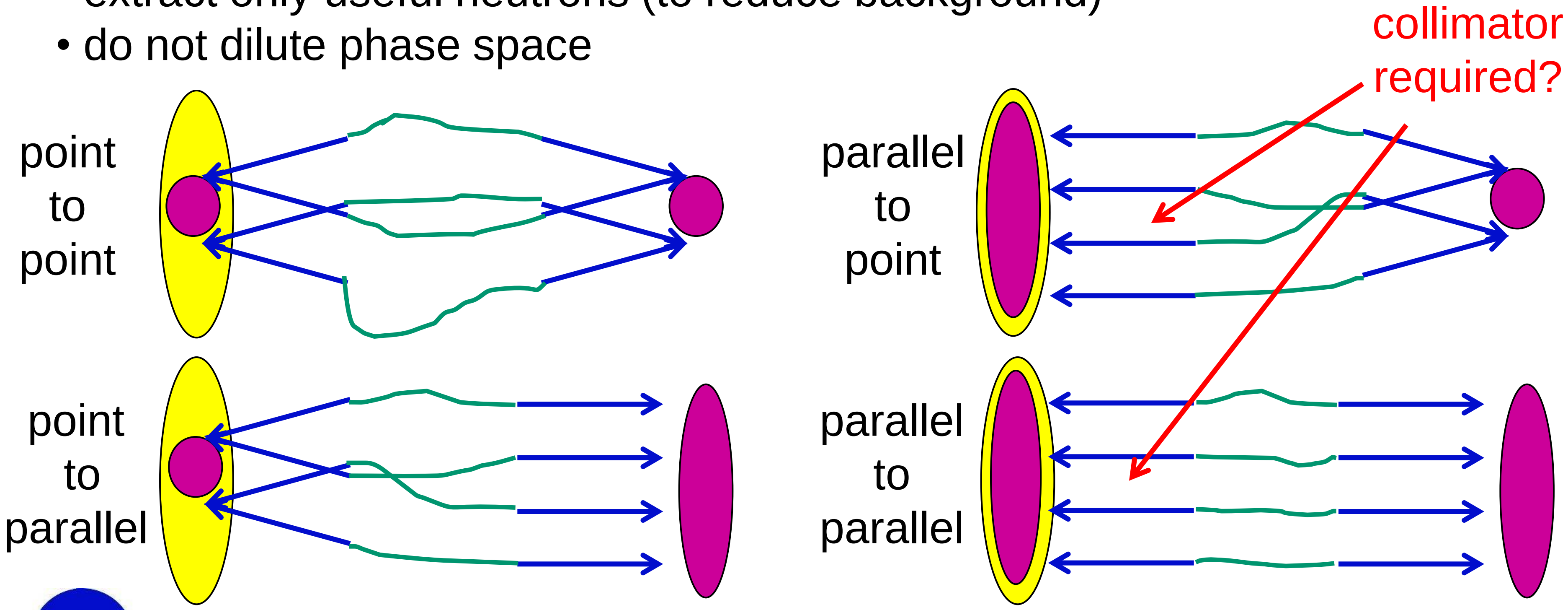
Summary

suggested procedure:

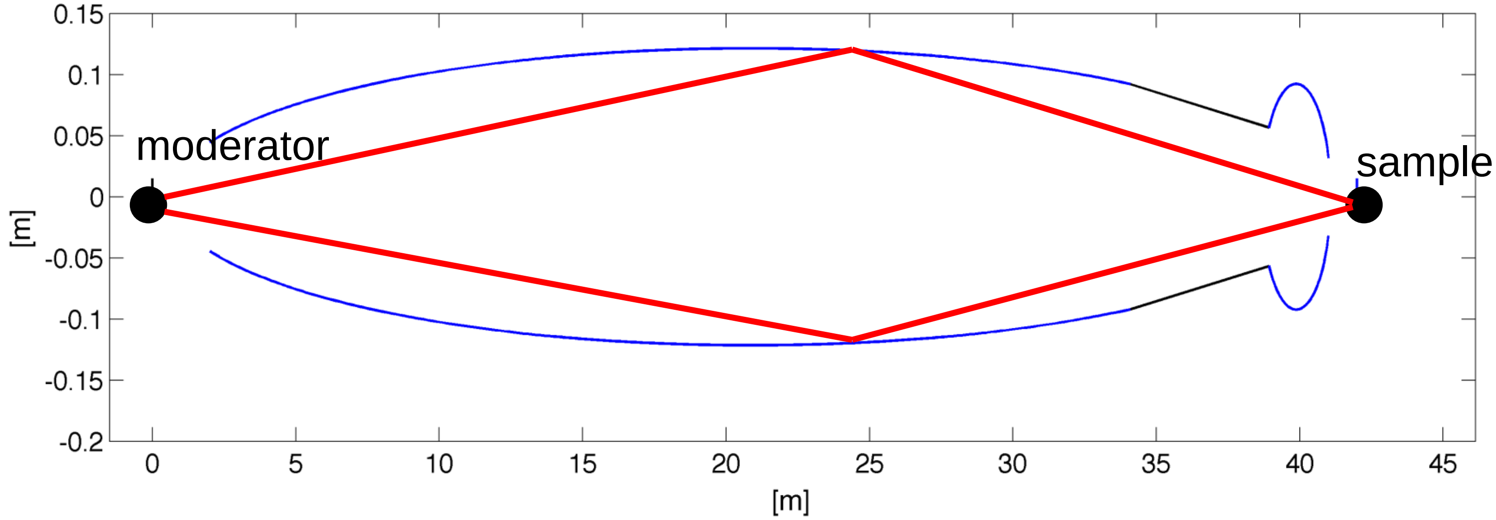
- define task of beam line:
  - sample size
  - divergence
  - band width, etc.

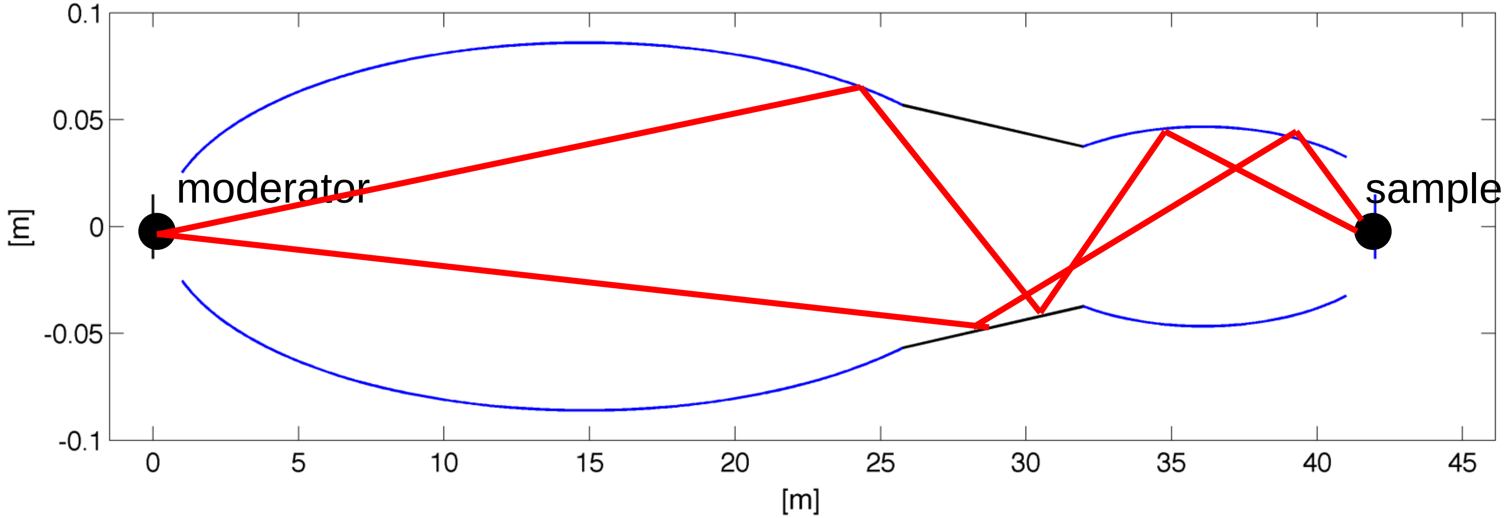
$$I = A \cdot \Delta\lambda \cdot \Omega \cdot \Psi$$

- calculate intensity at sample position (η = 1): experiment feasible?
- extract only useful neutrons (to reduce background)
- do not dilute phase space



The Computer Does it for You





Mads Bertelsen, Niels Bohr Institute, University of Copenhagen, Universitetsparken 5, Denmark

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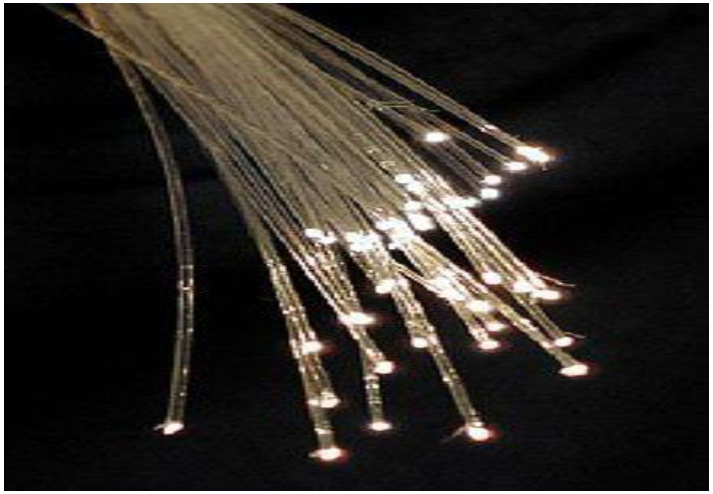
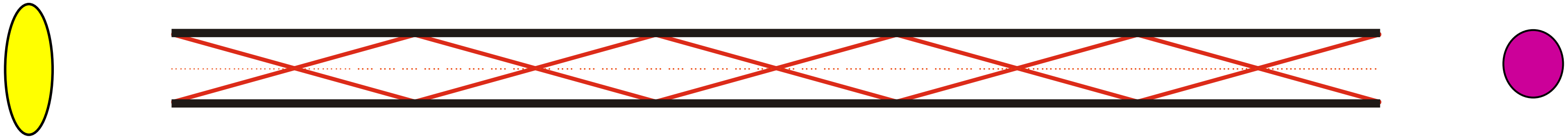
Guide Neutrons ←→ Compare Optical Fibers





moderator **neutron guide** **beam line**

Reflection from Surfaces 1

- interaction neutron – nuclei: $V(\mathbf{r}) = \sum_j b_j \delta(\mathbf{r}_j - \mathbf{r})$
- Schrödinger equation:

$$\frac{\hbar^2}{2m_n}\nabla^2\psi + (E - V(\mathbf{r}))\psi = 0$$

- neutrons in vacuum:
  (outside sample)

$$E_{free} = \frac{\hbar^2}{2m_n}k_i^2$$

- structure factor of sample:

$$F_{\boldsymbol{\tau}} = \sum_j b_j e^{i\boldsymbol{\tau}\cdot\mathbf{d}_n} e^{-W_n}$$

- potential in terms of F_τ:

$$V(\mathbf{r}) = \frac{\hbar^2}{2m_n}\frac{4\pi}{V}\sum_{\boldsymbol{\tau}} F_{\boldsymbol{\tau}} e^{-i\boldsymbol{\tau}\cdot\mathbf{r}}$$

- forward scattering:
  ($\tau = 0$)

$$V_0(\mathbf{r}) = \frac{\hbar^2}{2m_n}\frac{4\pi}{V}F_0 = \frac{\hbar^2}{2m_n}\frac{4\pi}{V}\sum_j b_j = \frac{\hbar^2}{2m_n}\frac{4\pi}{V}N\langle b\rangle = \frac{\hbar^2}{2m_n}4\pi\rho\langle b\rangle$$

Complementarity between Neutron and Synchrotron X-Ray Scattering, Proceedings of the 6th Summer School on Neutron Scattering, edited by A. Furrer (World Scientific, Singapore, 1998), 305-327.

Reflection from Surfaces 2

Repetition:

- potential:
  (ρ = N/V: density)
  (<b>: coherent scattering length)

$$V_0(\mathbf{r}) = \frac{\hbar^2}{2m_n} 4\pi\rho\langle b\rangle$$

- Schrödinger equation:

$$\frac{\hbar^2}{2m_n}\nabla^2\psi + (E - V_0(\mathbf{r}))\psi = 0$$

$$k_i^2 \qquad -k^2 \qquad 4\pi\rho\langle b\rangle$$

- therefore:

$$-k^2 + k_i^2 - 4\pi\rho\langle b\rangle = 0$$

- typically: $4\pi\rho\langle b\rangle < 10^{-4} k_i^2$

$$k_i^2 - k^2 \cong 2k_i(k_i - k)$$

- **index of refraction:**

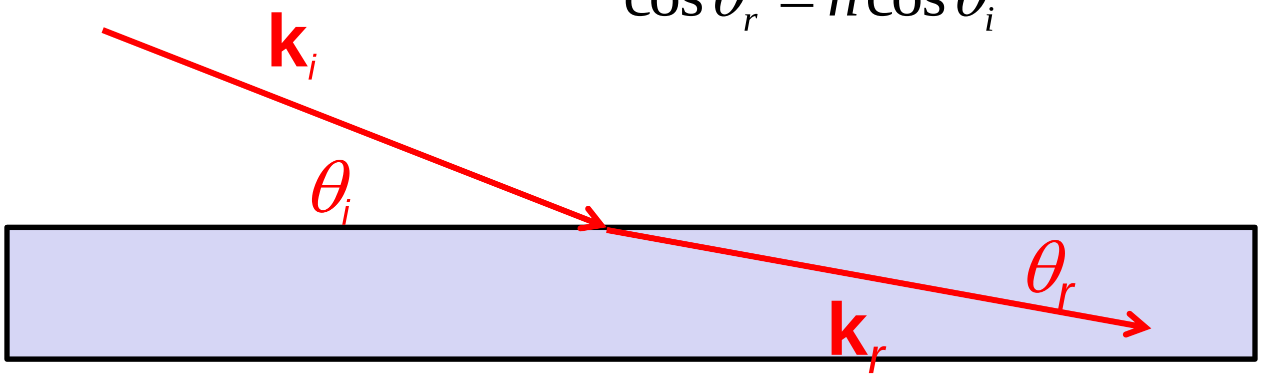
$$n = \frac{k}{k_i} = 1 - \frac{1}{2\pi}\rho\langle b\rangle\lambda^2$$

$$n \propto \lambda^2$$

Compare with Light Optics: Total Reflection

- **Snell's law:**

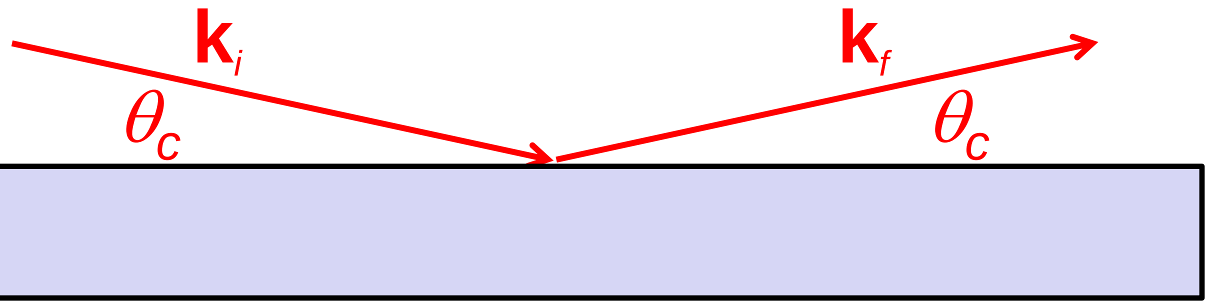
$$\cos\theta_r = n\cos\theta_i$$



- **total reflection:**

$$\cos\theta_c = n$$

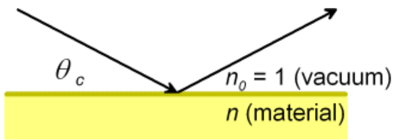
$$\theta_c^{Ni}(^0) = 0.1\lambda(\text{Å})$$



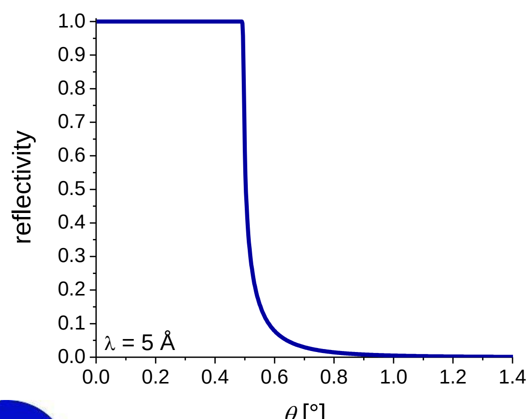
Extend Angle of Total Reflection: Supermirror

(Turchin 1976, Mezei 1976)

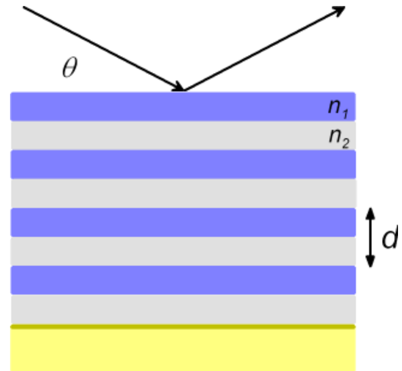
smooth surfaces



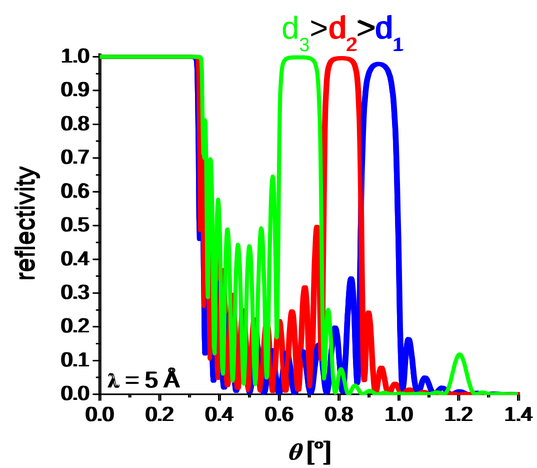
• useful for cold neutrons ($\lambda \cong$ 5 Å)



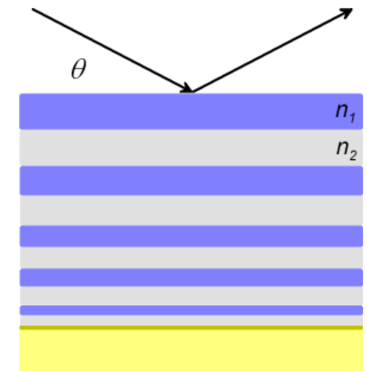
multilayer



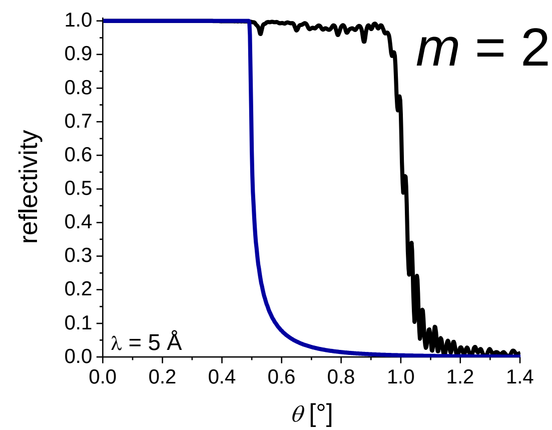
$$\lambda = 2d \sin\theta$$



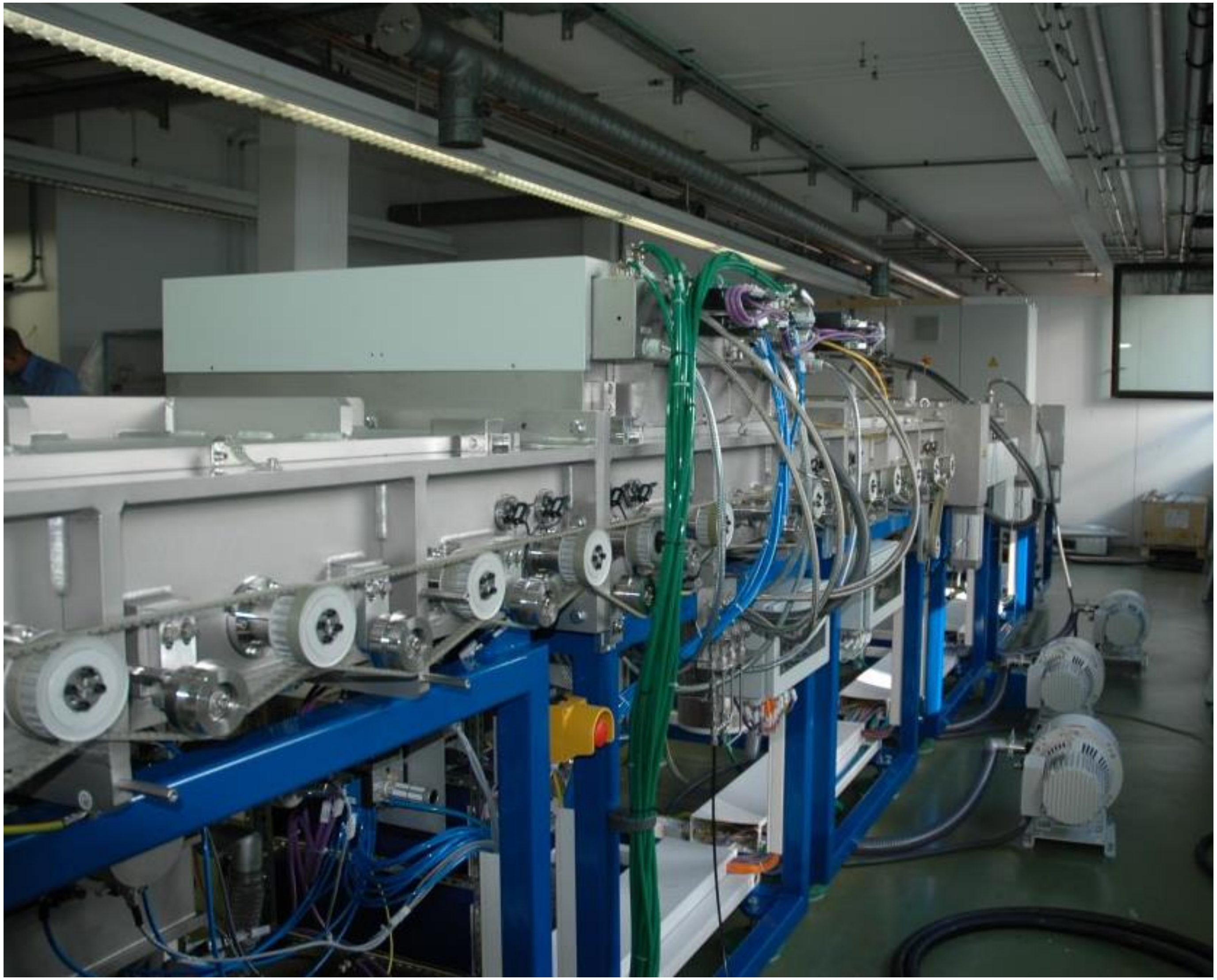
supermirror



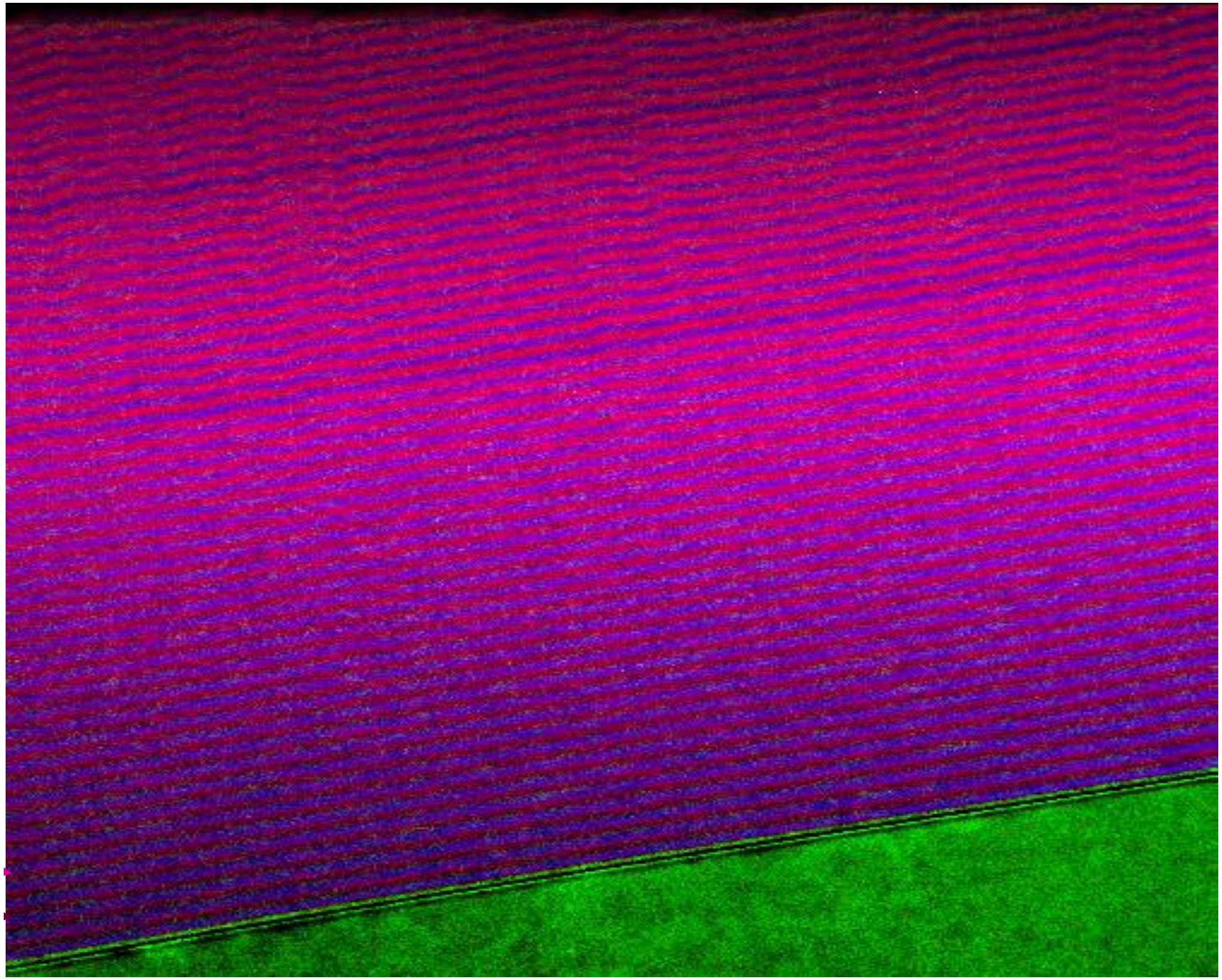
prevailing opinion:
- for cold neutrons only



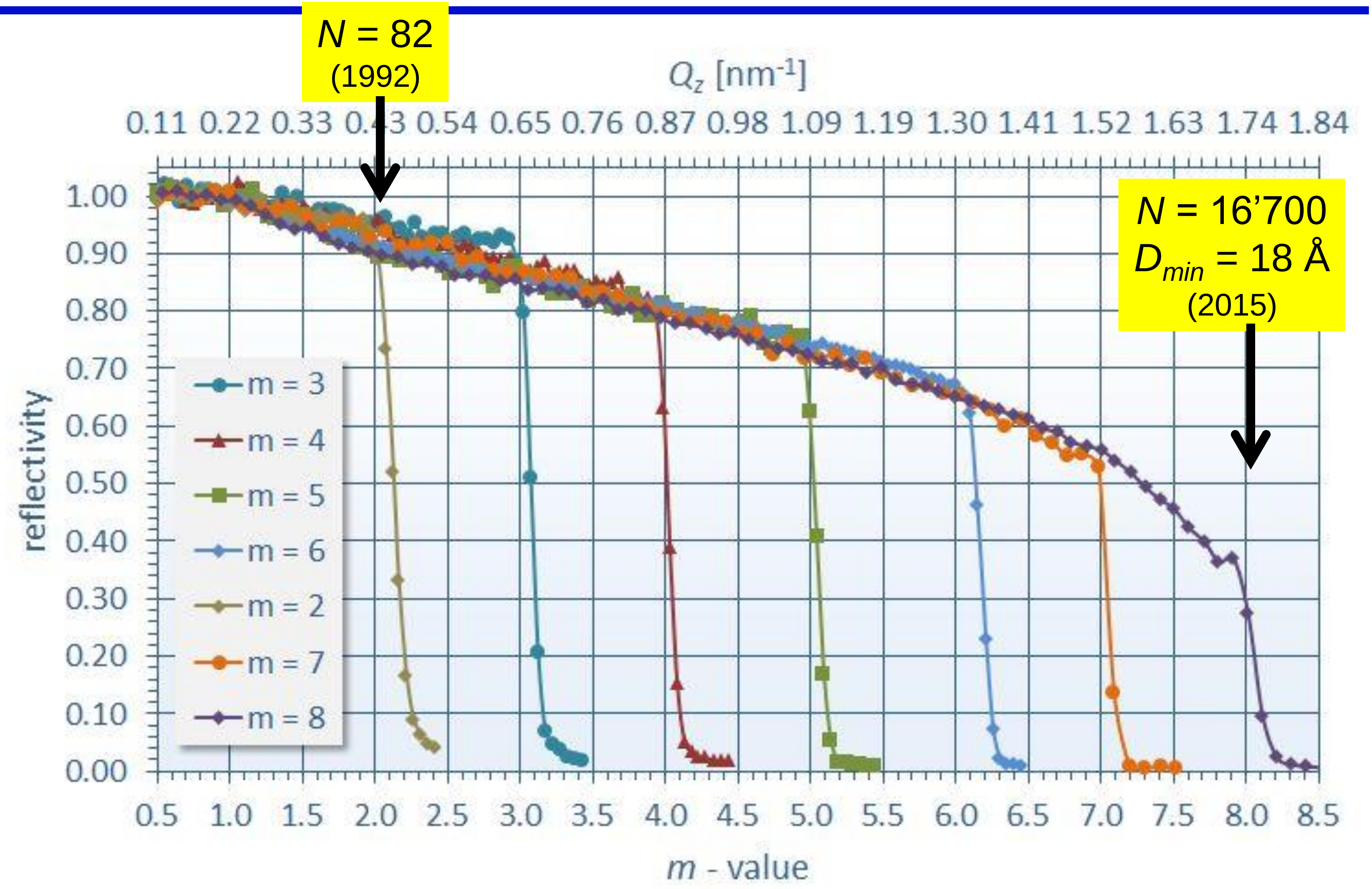
New Coating Processes → Larger θ_c



View by Transmission Electron Microscopy

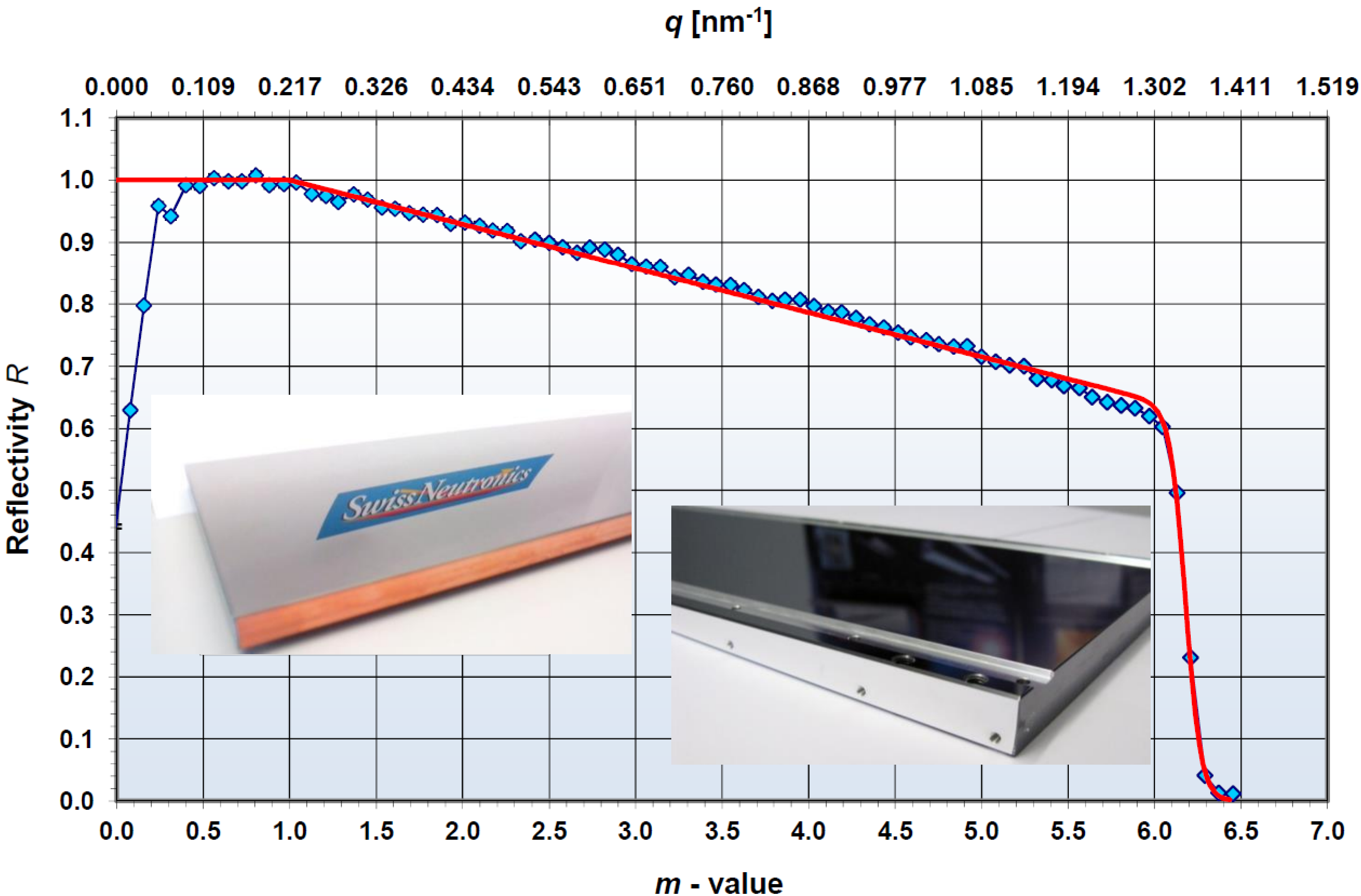


Supermirror: State of the Art



Dr. C. Schanzer, SwissNeutronics

Supermirror on Atomically Smooth Metal Substrates



Modern Supermirrors: large *m*, large *R*

large divergence available:

- extension of critical angles → large divergence α

1 Å

thermal: $\alpha(1\,\text{Å}) \cong 2 \cdot 0.1 \cdot 8 \cdot \lambda = 1.6^0$

0.5 Å

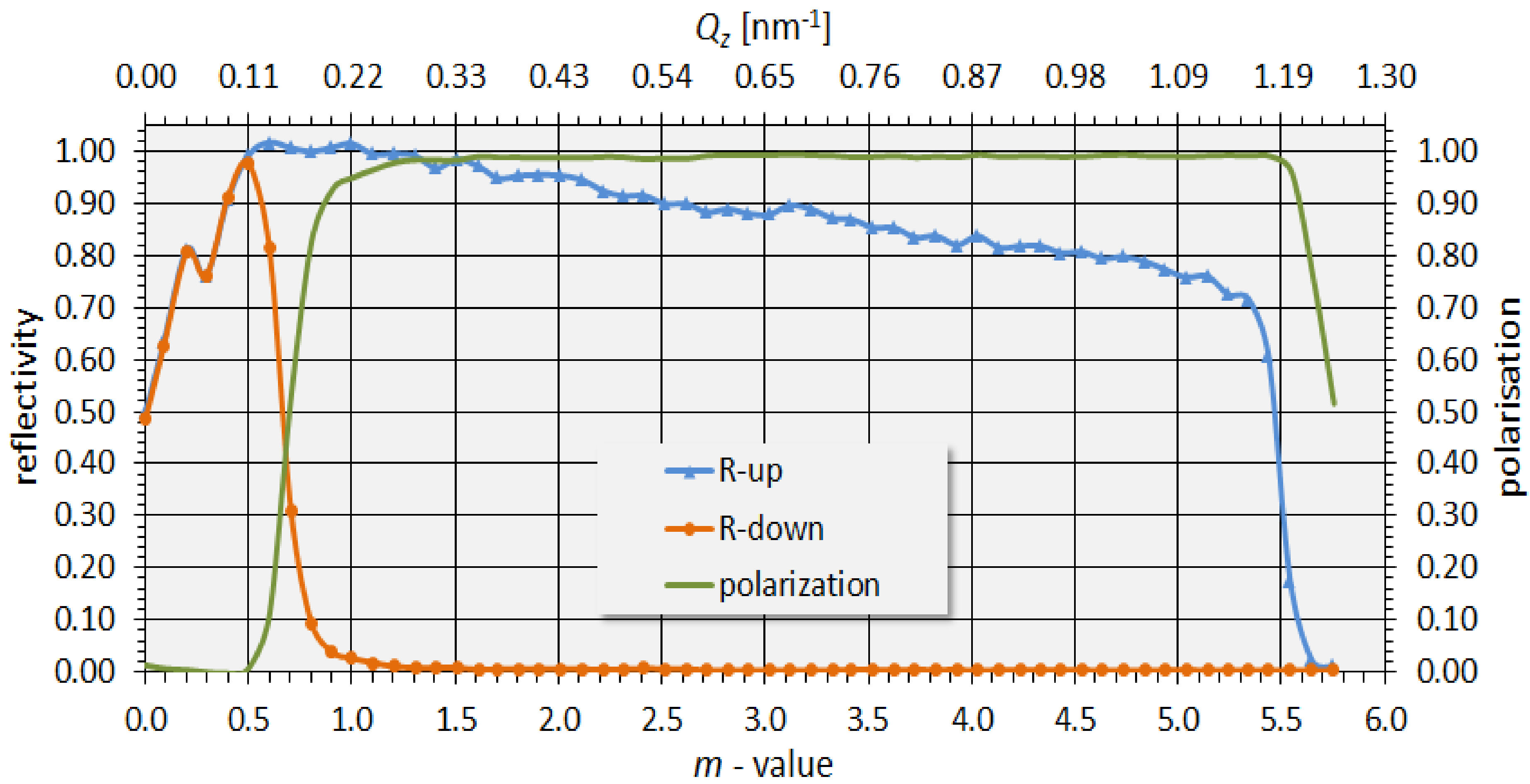
epithermal: $\alpha(0.5\,\text{Å}) \cong 2 \cdot 0.1 \cdot 8 \cdot \lambda = 0.8^0$

- applications for hot (and epithermal?) neutrons possible
  → required for spallation sources!

efficient polarizers: Fe/Si

- maximum θ_c: $m = 5.5$
- $P > 99\%$

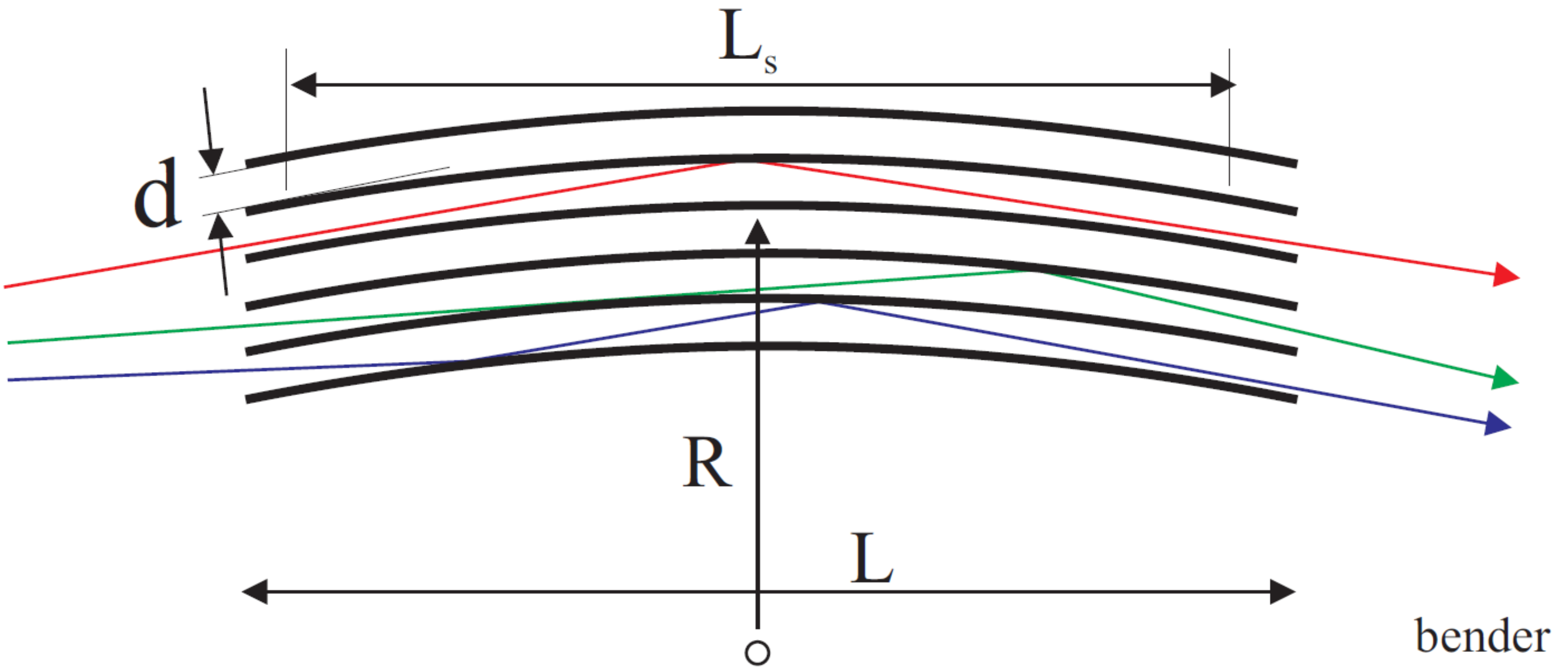
Fe/Si-Supermirror: Reflect and Polarize



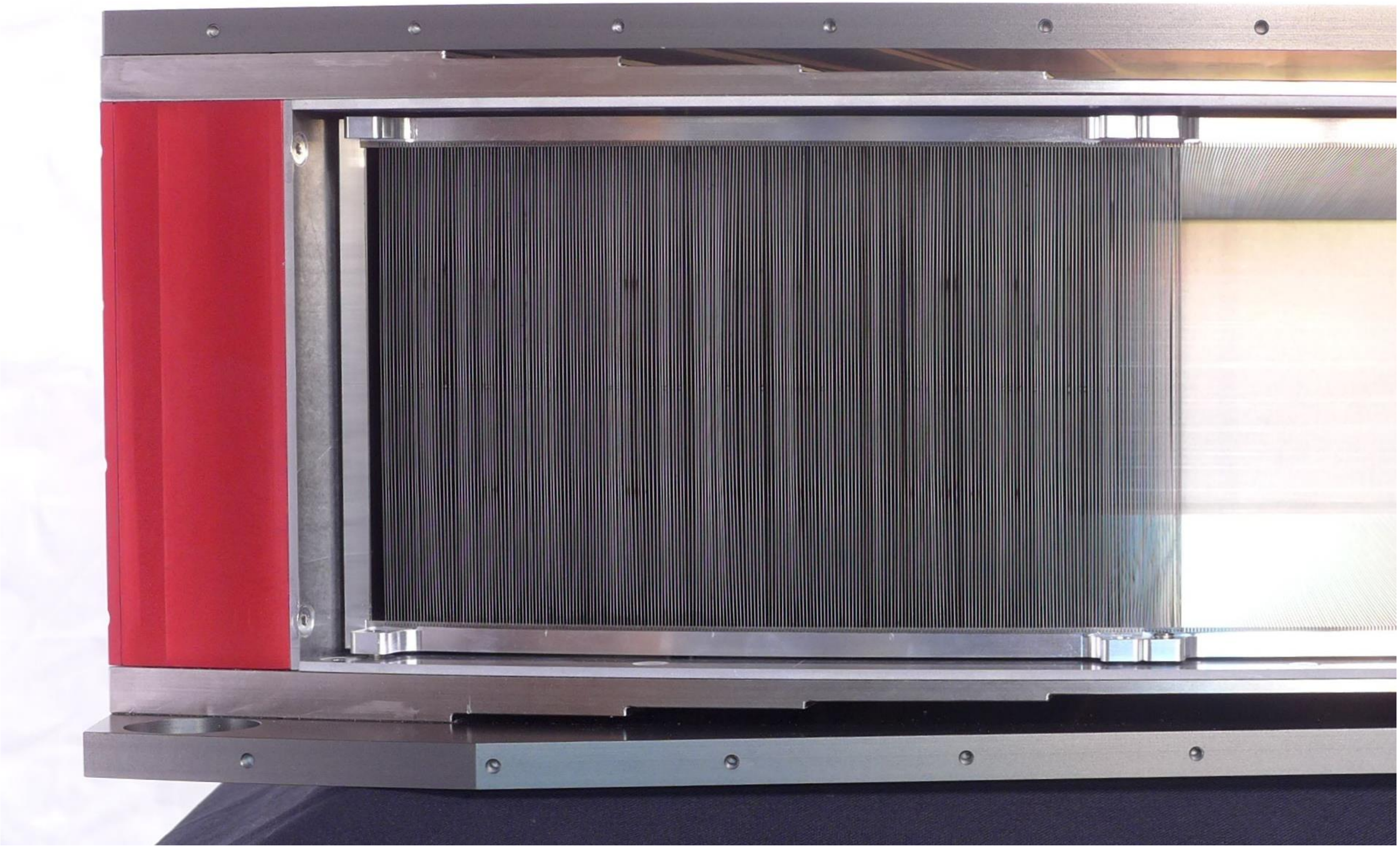
- $m = 5.5$
- $P > 99\%$

Dr. C. Schanzer, SwissNeutronics

Polarizing Bender



Large Area Analyzers



Thermal ToF: POLANO @ J-PARC

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- Montel Mirrors
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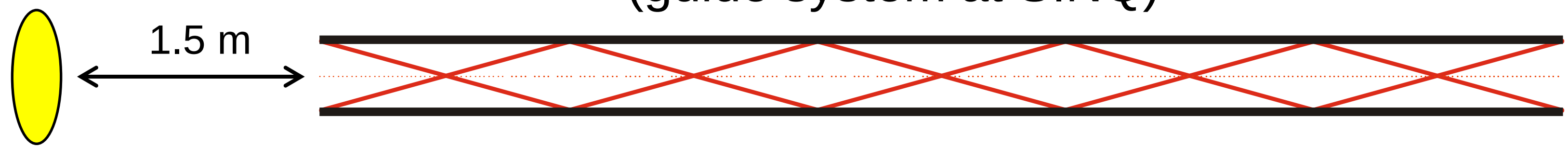
Brilliance Transfer: Standard vs. Elliptic Guides

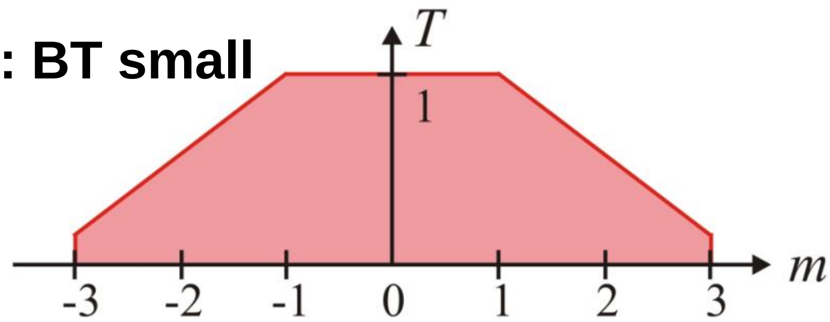
(guide system at SINQ)

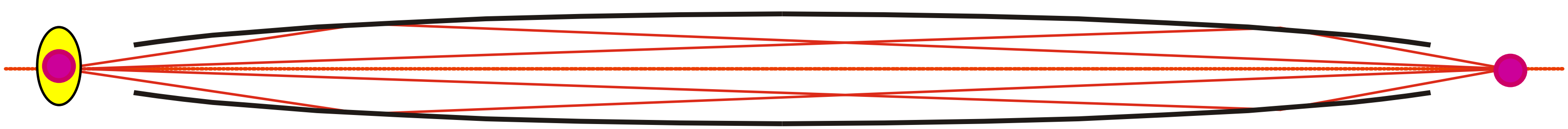


drawbacks:

- non-compact phase space
- illumination losses
- large entrance → large background

***n* >> 1: BT small**

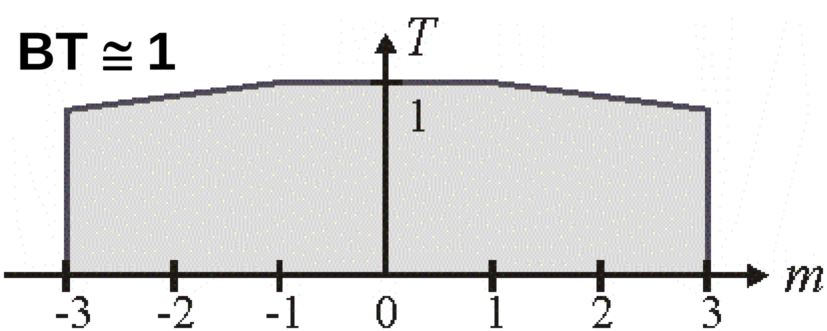




Advantages:

- compact phase space (tails reduced)
- no illumination losses (if …)
- smaller moderator → lower background

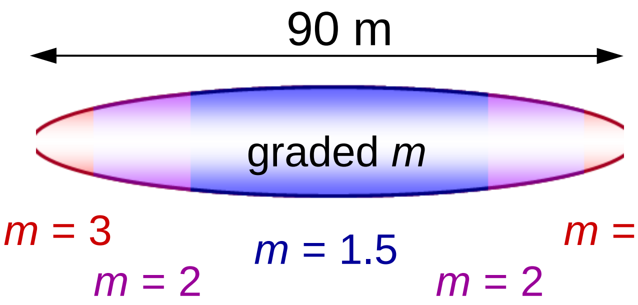
***n* ≅ 2: BT ≅ 1**



C. Schanzer et al., Nucl. Instr. Meth. A **529**, 63 (2004)

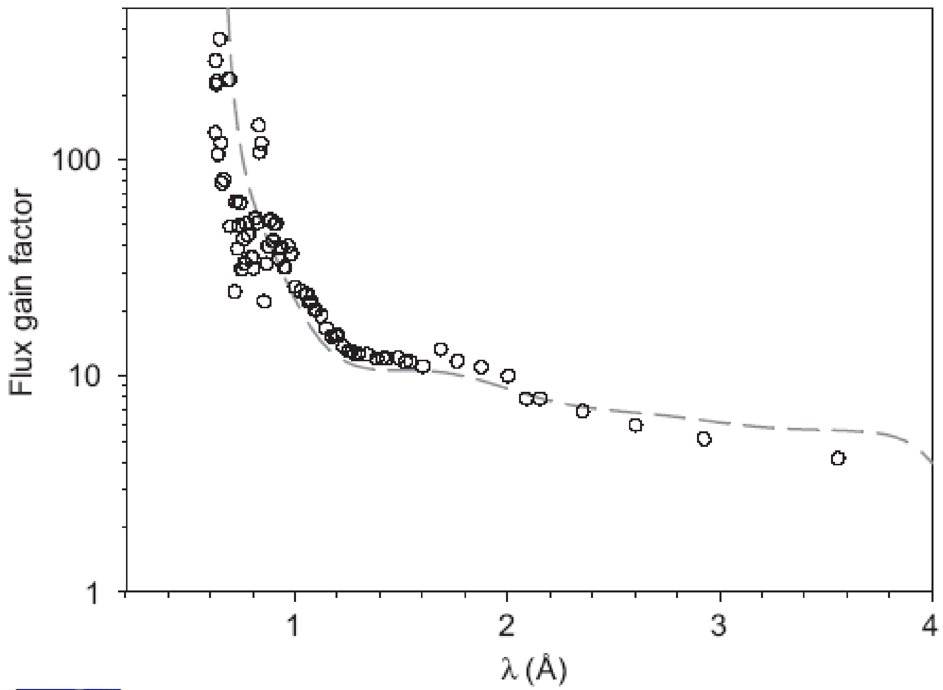
P. Böni, Nucl. Instr. Meth. A **624**, 162 (2010)

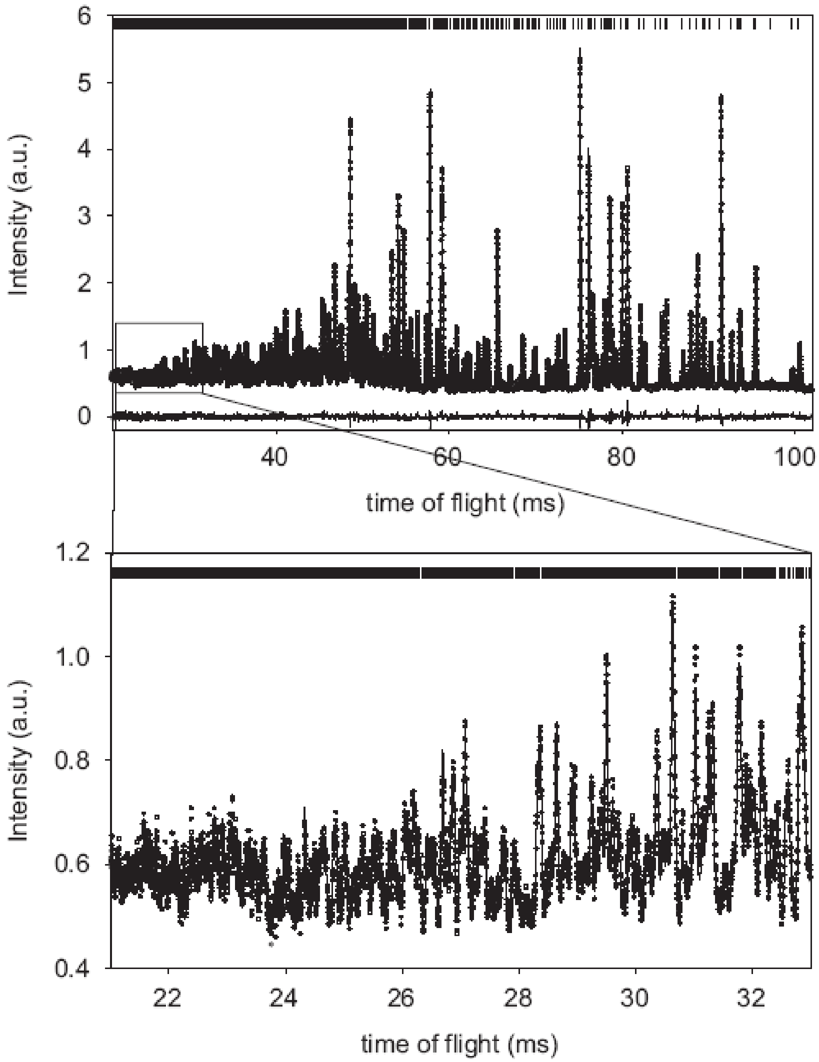
HRPD @ ISIS: Deuterated Benzene C_6D_6



truly curved

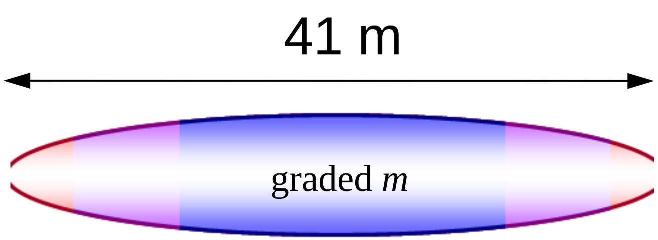
designed: 2006





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

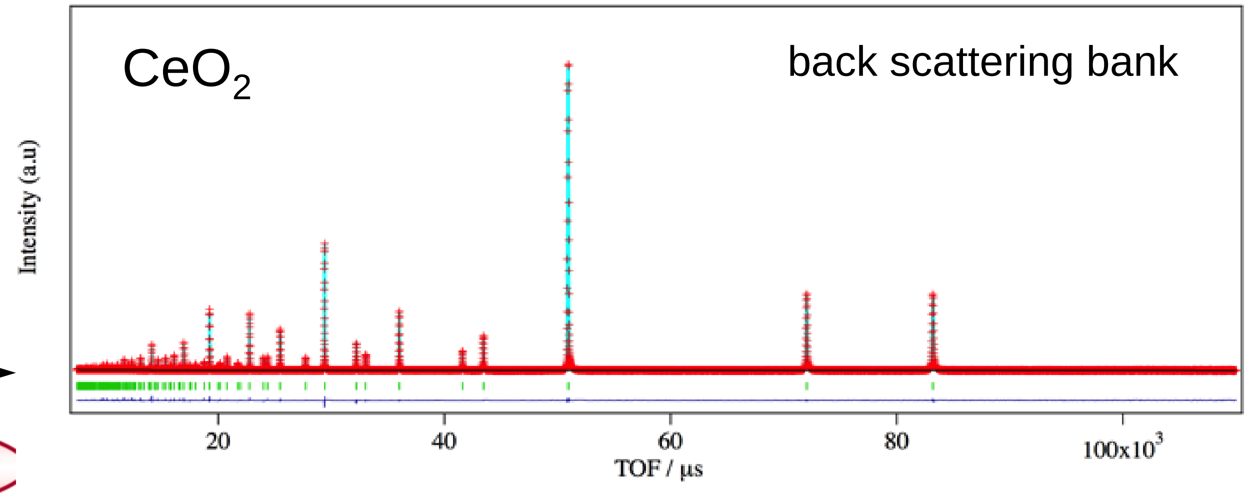
SPICA @ J-PARC: Diffraction from CeO_2

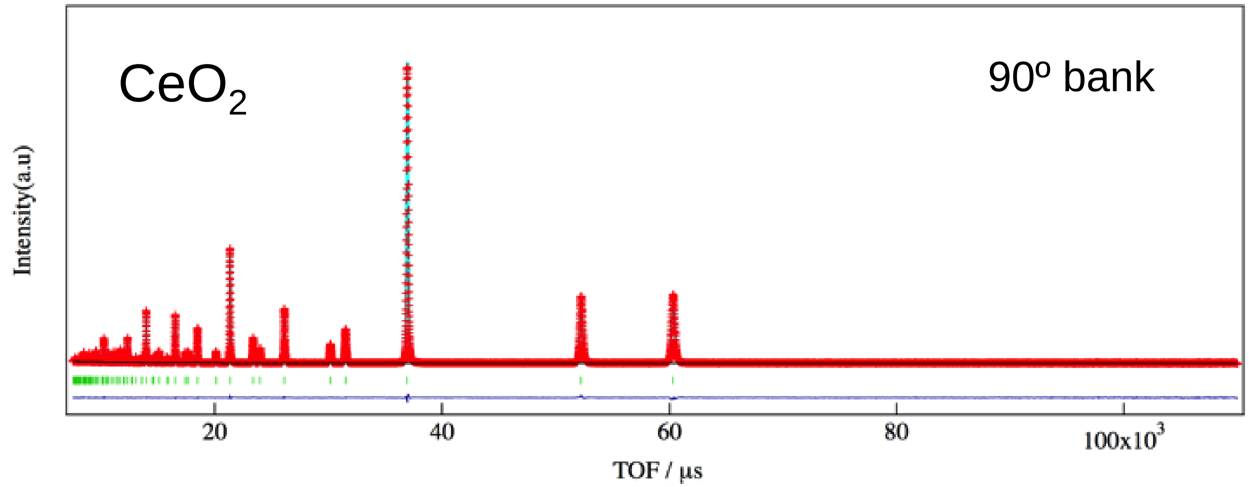


$3.0 \leq m \leq 6.0$

designed 2009

truly curved

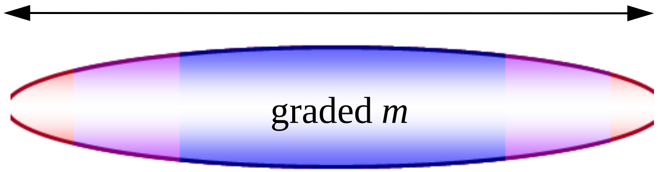




M. Yonemura, K. Mori, T. Kamiyama, T. Fukunaga, S. Torii, M. Nagao, Y. Ishikawa, Y. Onodera, and D.S. Adipranoto, SPICA_Proceeding_20130723v0TK1

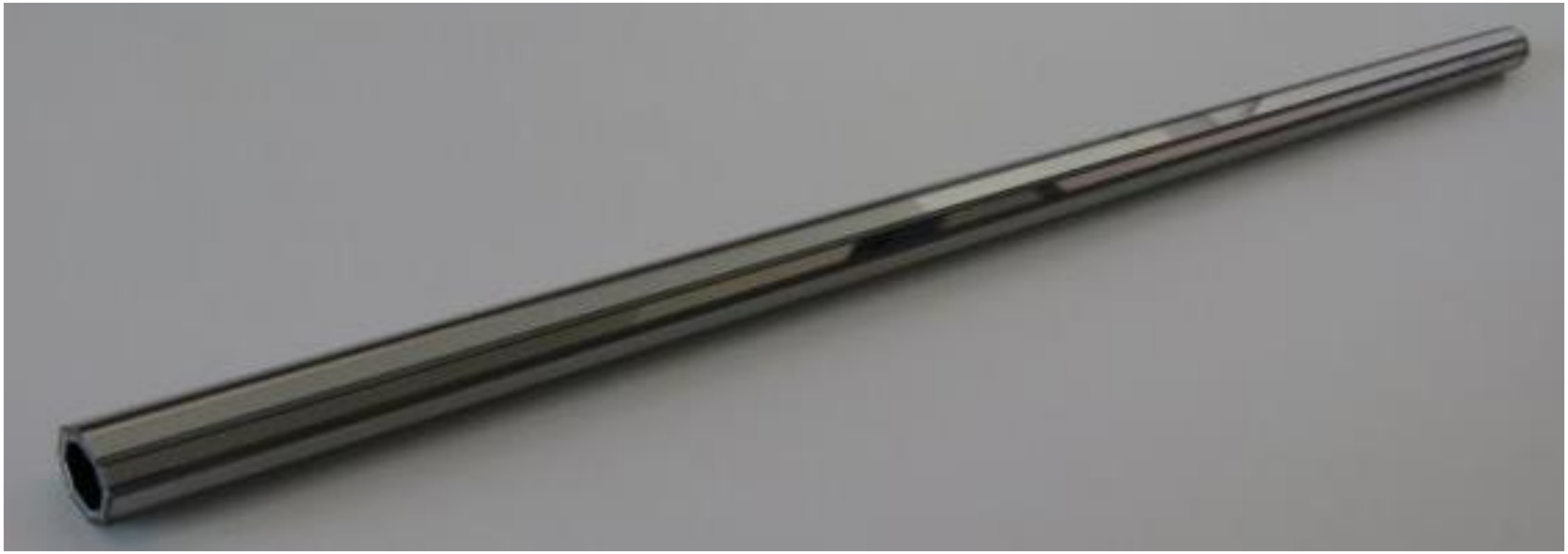
POWTEX @ FRM-II: Octahedral-Elliptic Guide

15 m



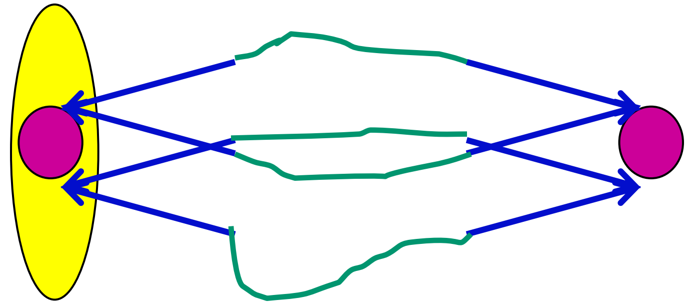
$2.0 \leq m \leq 5.0$

designed 2010

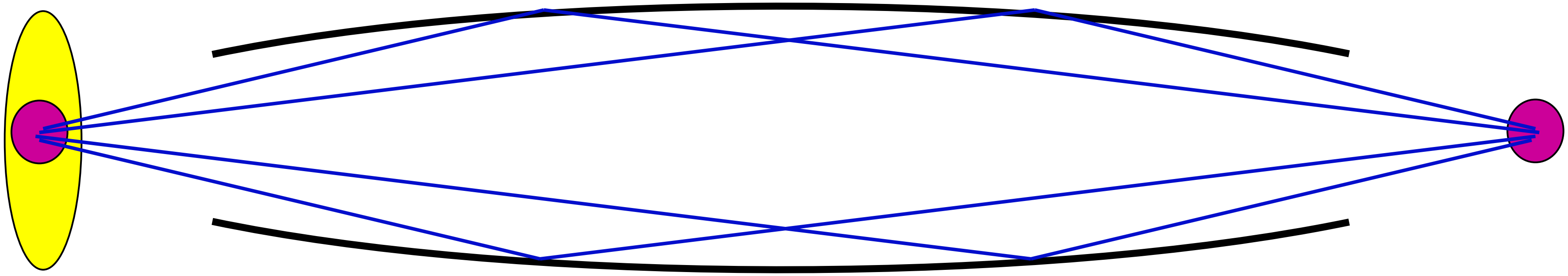


Brilliance Transfer with Elliptic Guides

from the idea:



to the realization:



elliptic guide

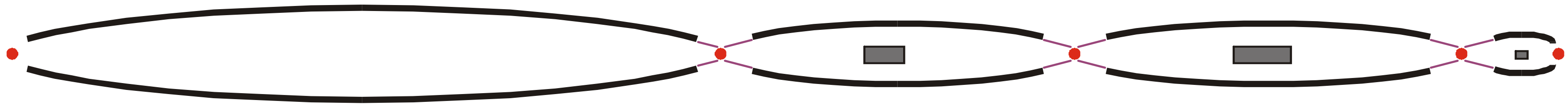
C. Schanzer et al., Nucl. Instr. Meth. A **529**, 63 (2004)

performance:

- brilliance transfer up to 90%: almost all useful neutrons transported
  (K. H. Kleno et al., Nucl. Instr. Meth. A 696, 75 (2012)

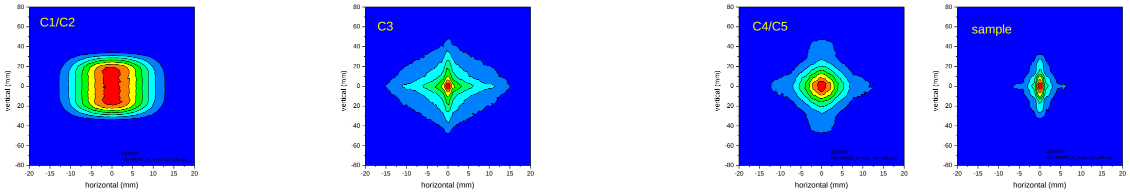
Fooling Around With Elliptic Guides

Reduction of background / equalize path lengths / reduce chopper size:



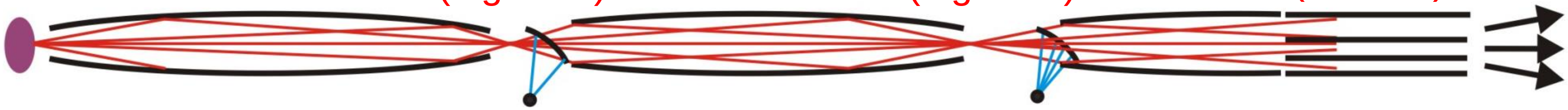
matching of phase space:

- beam size vs. divergence
- flight time is constant

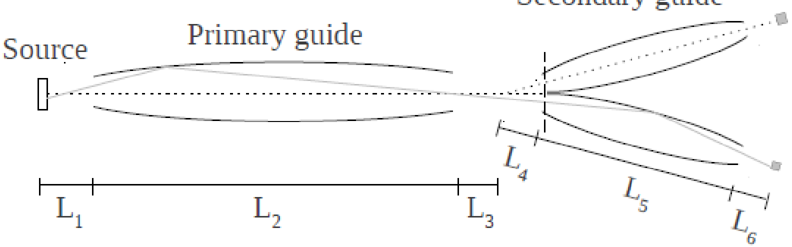


P. Böni, Nuclear Instr. Meth. A **586** (2008) 1

Multiple use of beams:



Neutron guide-split: guide bundle concept for elliptical guides



S. L. Holm, K. Lefmann, K. Andersen et al., Nucl. Instr. Methods **782**, 1 (2015)

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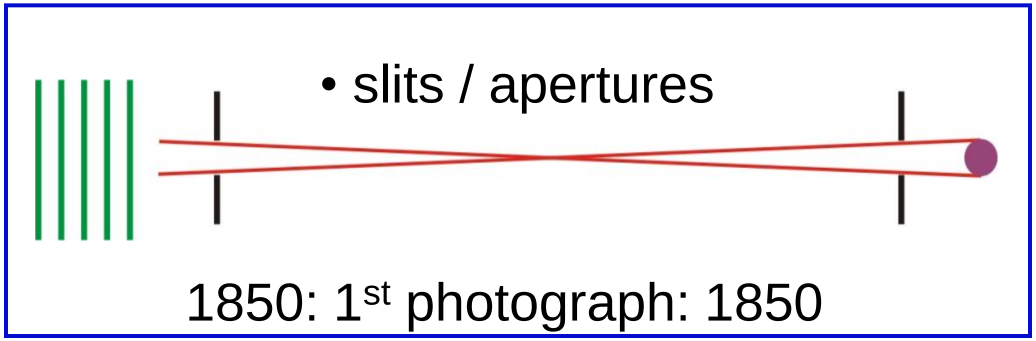
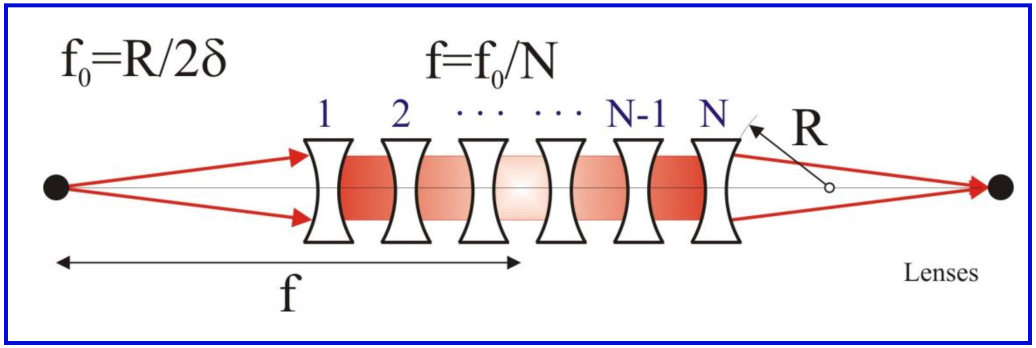
Focused Beams for Small Samples (1 - 30 mm)

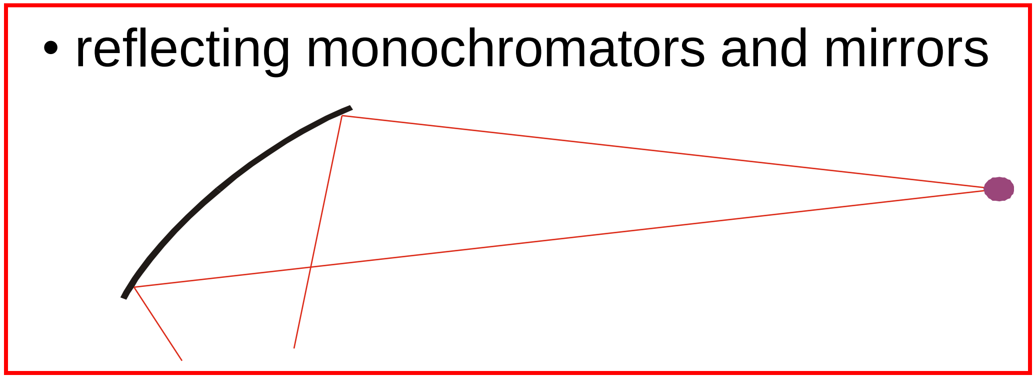
- pin-hole camera:
  (used for neutron scattering)



- lenses (comp. hexapoles):
  (chromatic aberration)
  M. Eskildsen et al., Nature **391**, 563 (1998)



- reflection optics:
  (no chromatic aberration)



Focusing Monochromators

Focusing:

- Bragg reflection from curved monochromators

  (W. Bührer, Nucl. Instr. Meth. A **338**, 44 (1994)
- instead of an explanation: KOMPASS @ FRM-II

specification:

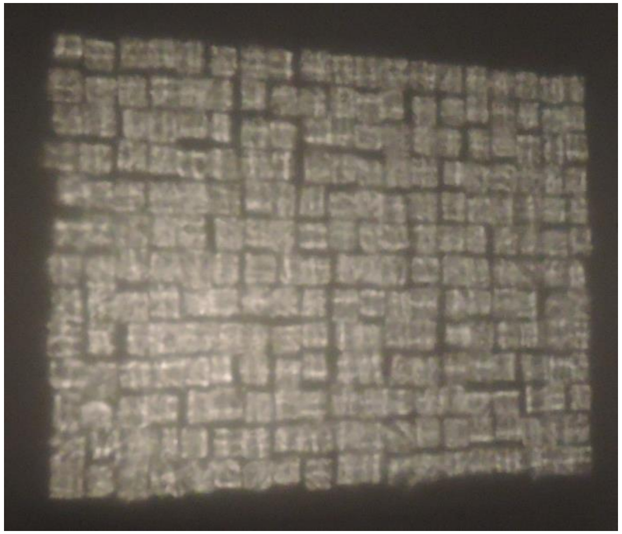
- area: 193× 275 mm^2
- 13 rows
- 19 columns

  → **247 monochromators**
- crystal size:

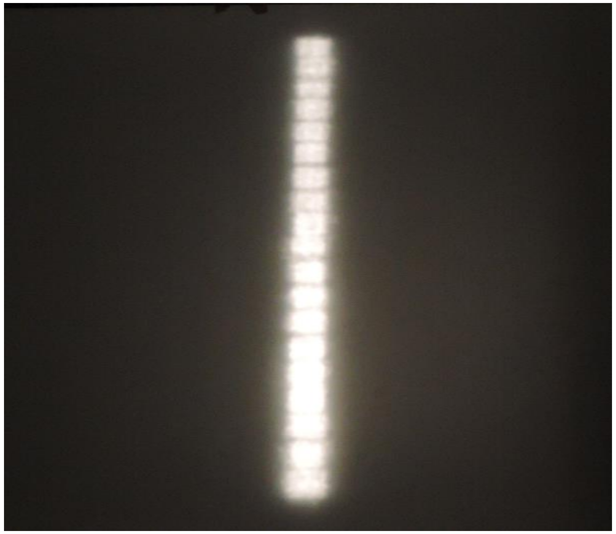
  14 × 14 mm^2

Visualization of Focusing Monochromator

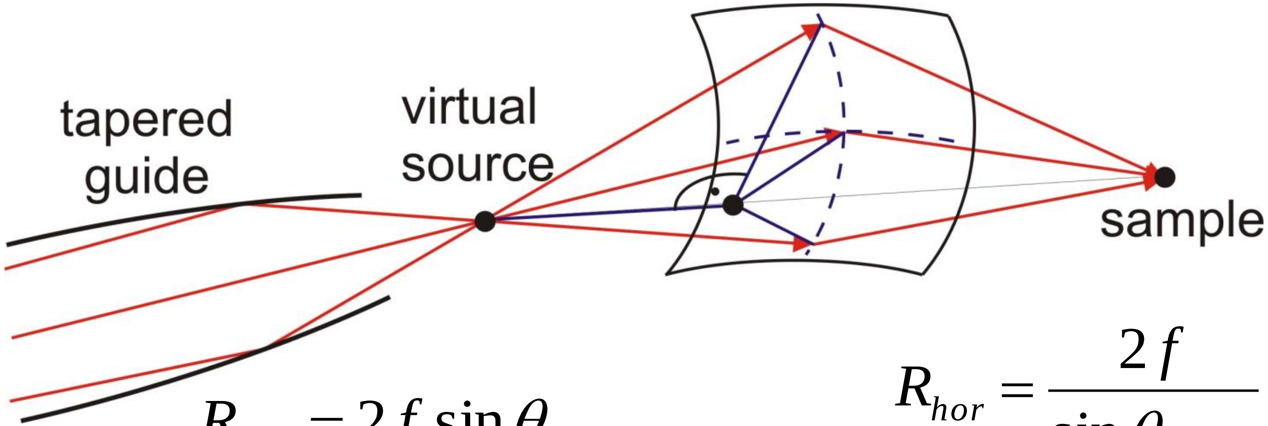
flat



vert./horiz. focusing



doubly foc.



$$R_{vert} = 2f \sin\theta_{Bragg}$$

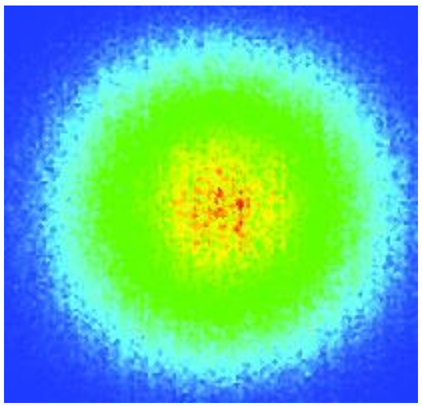
$$R_{hor} = \frac{2f}{\sin\theta_{Bragg}}$$

For movie see: https://www.youtube.com/watch?v=6GeoT1mztzQ

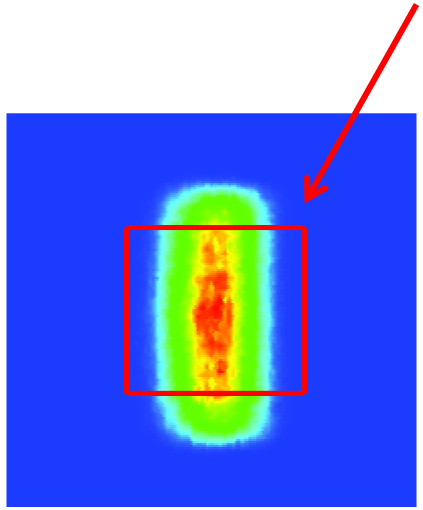
Limits of Focusing Monochromator

Example: PANDA @ FRM-II

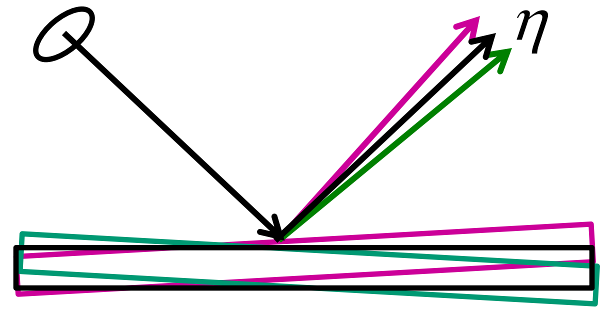
- crystal size: 20 × 20 mm^2
- mosaic: η = 0.5^0

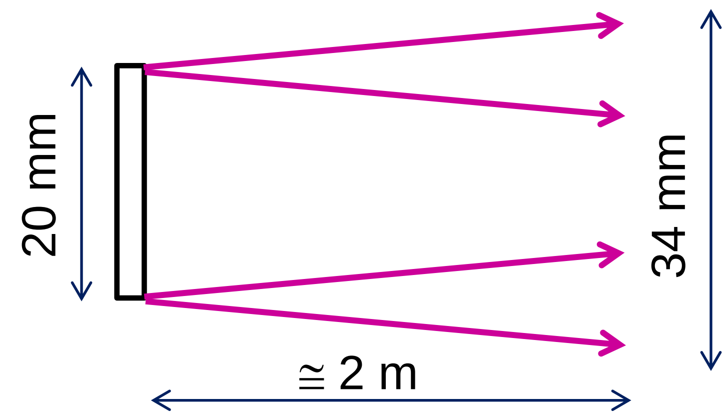


optimum



fwhm: 34 × 34 mm^2 divergence: 2^0 × 5^0





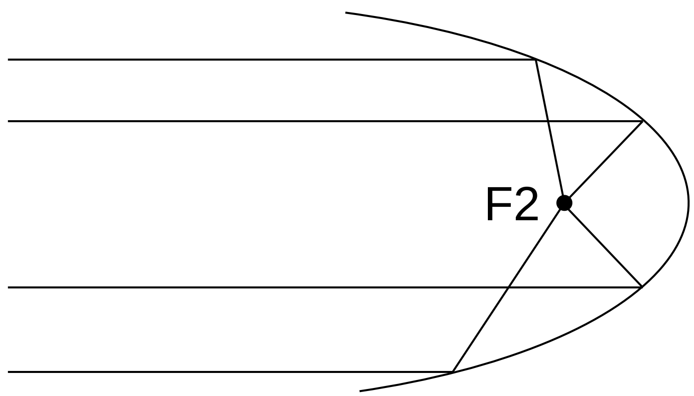
Drawbacks:

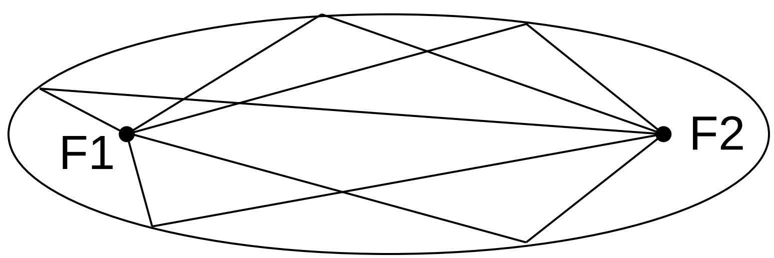
- beam still very large
- edges diffuse: slits/collimation required

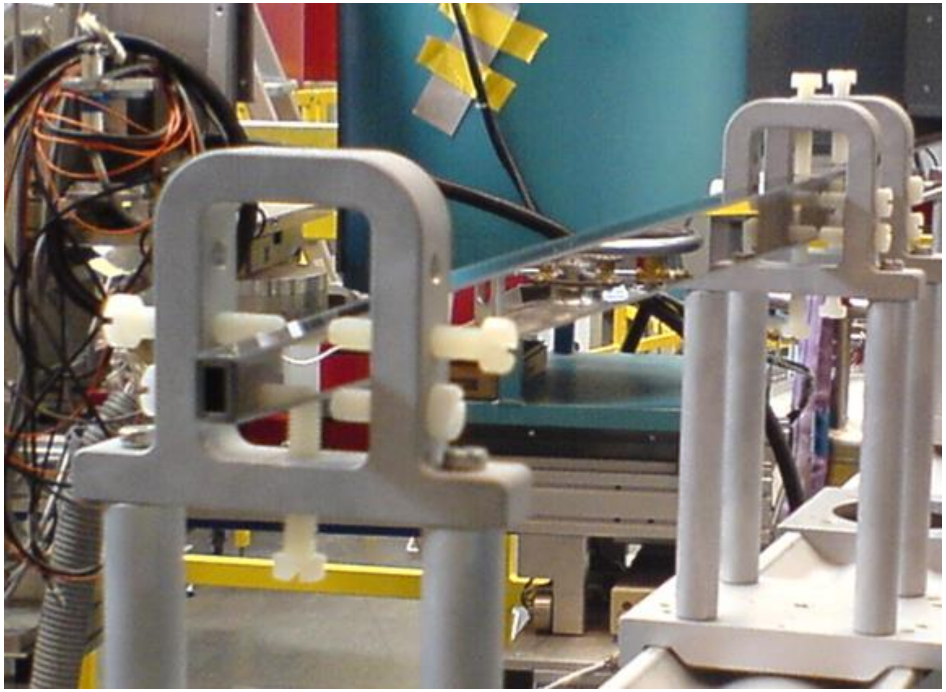
Focusing Guides

Given:

- beam line positioned at a conventional (straight) guide
- define beam size and divergence at sample → $I = \eta \cdot A \cdot \Delta\lambda \cdot \Omega \cdot \Psi$
- design: parabolic / elliptic





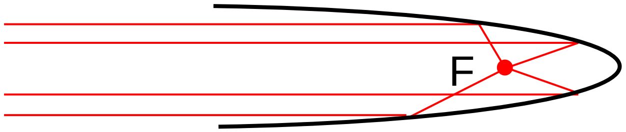


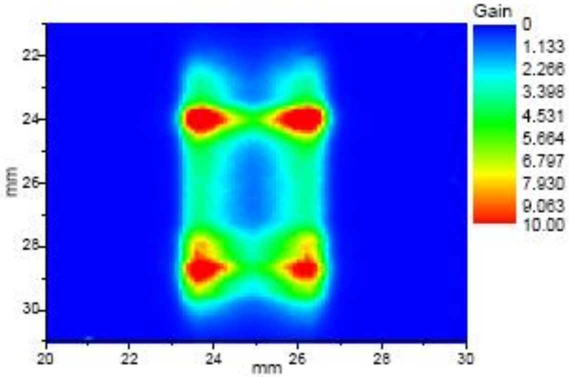
set-up @ MORPHEUS @ SINQ

In collaboration with J. Stahn, PSI

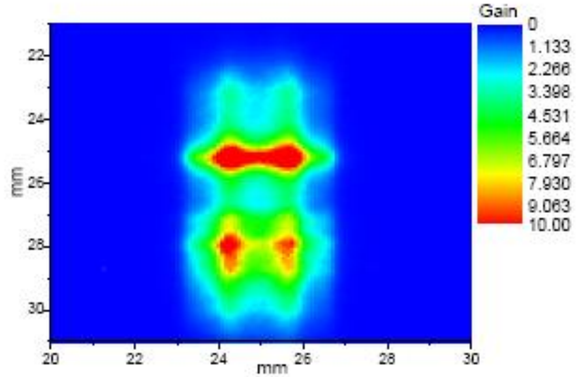
Parabolic Focusing at 3 Å

Wavelength: 3 Å

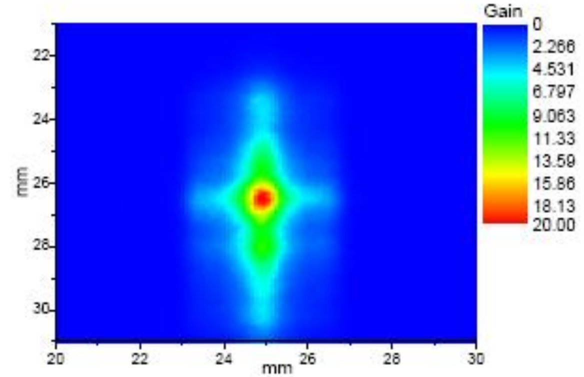




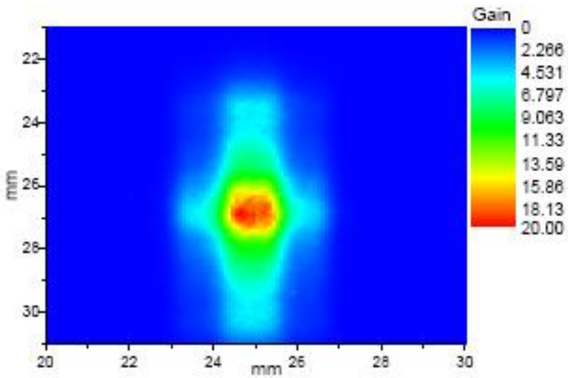
Distance: 0 mm



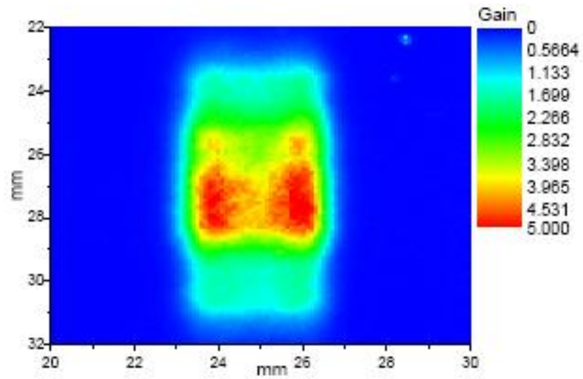
40 mm



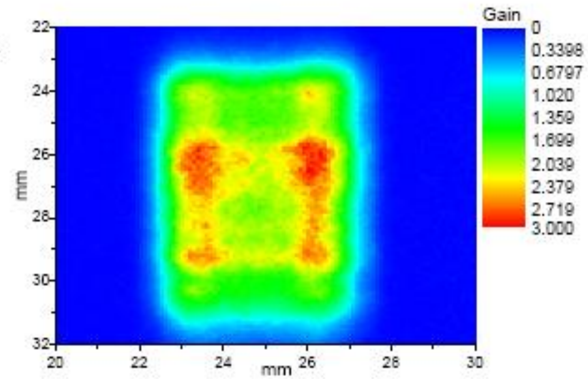
80 mm



Distance: 100 mm



150 mm

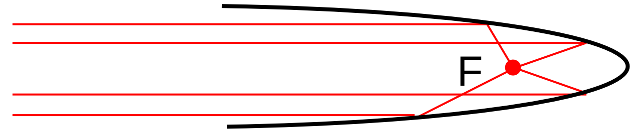


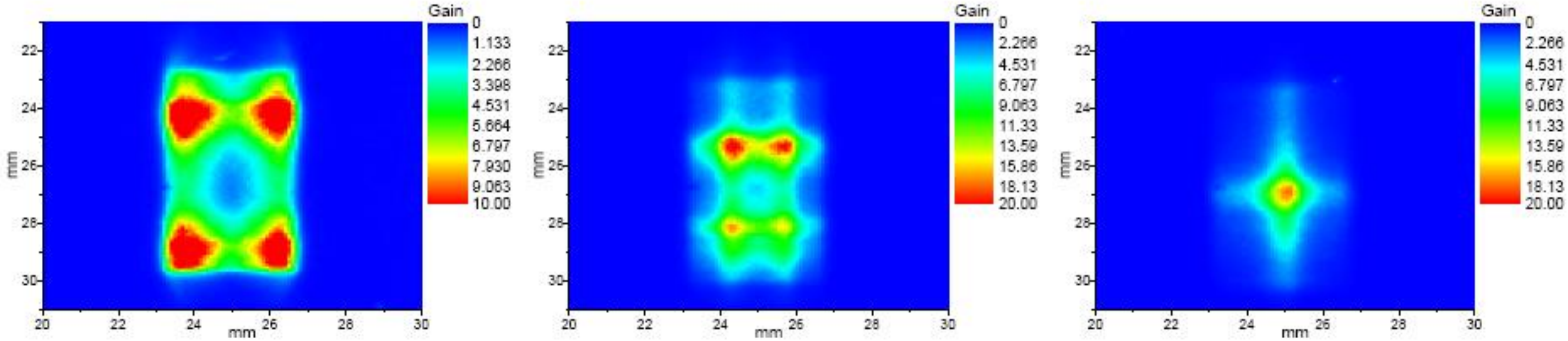
200 mm

N. Kardjilov et al., Nucl. Instr. Meth. A **542**, 248 (2005)

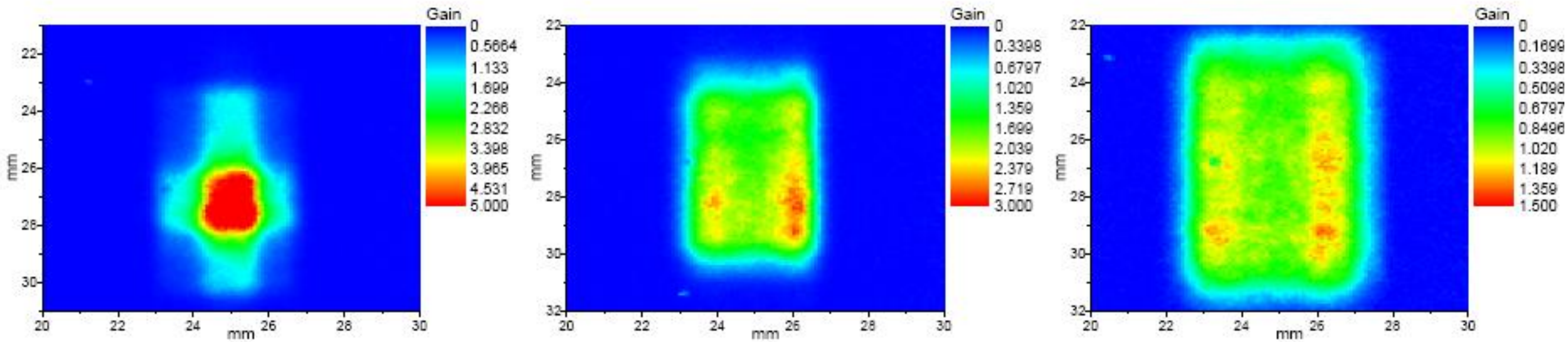
Parabolic Focusing at 3 Å

Wavelength: 6 Å





Distance: 0 mm 40 mm 80 mm

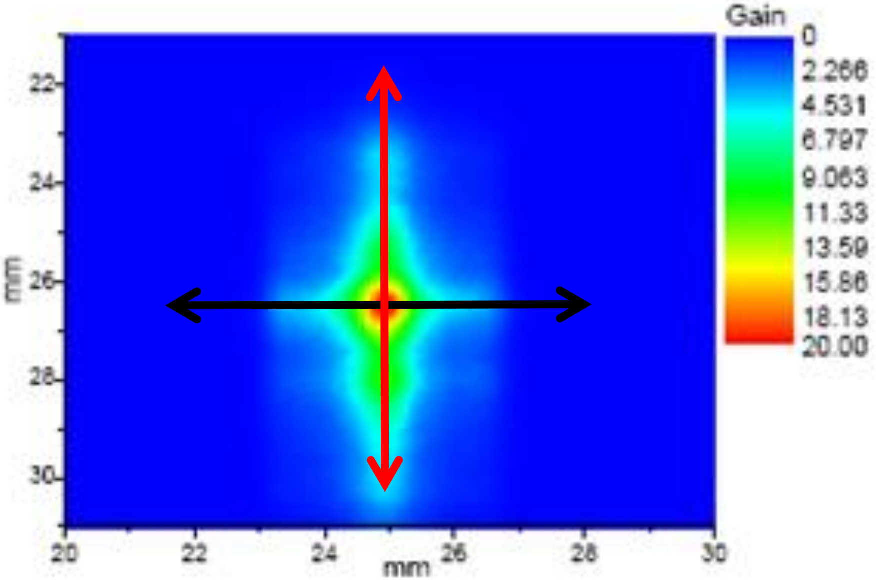


Distance: 100 mm 150 mm 200 mm

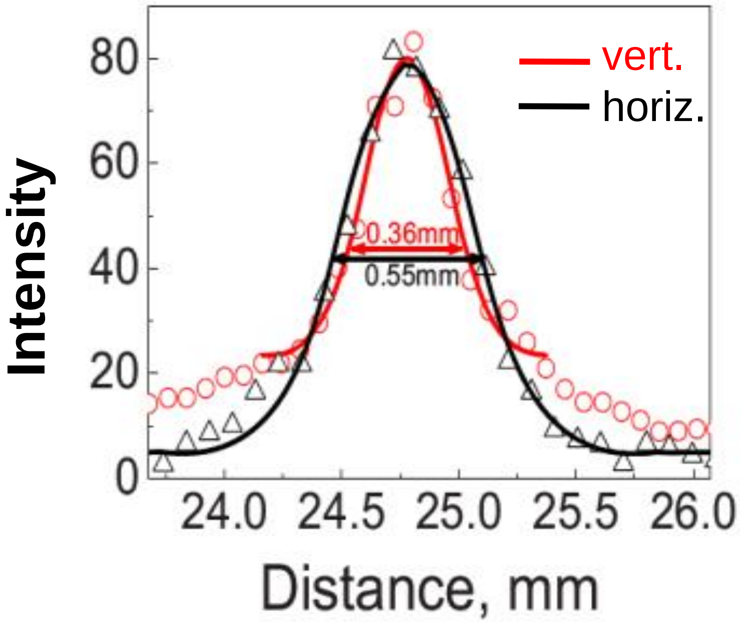
N. Kardjilov et al., Nucl. Instr. Meth. A **542**, 248 (2005)

Beam Size for Parabolic Focusing

spatial distribution of intensity:



width of beam:

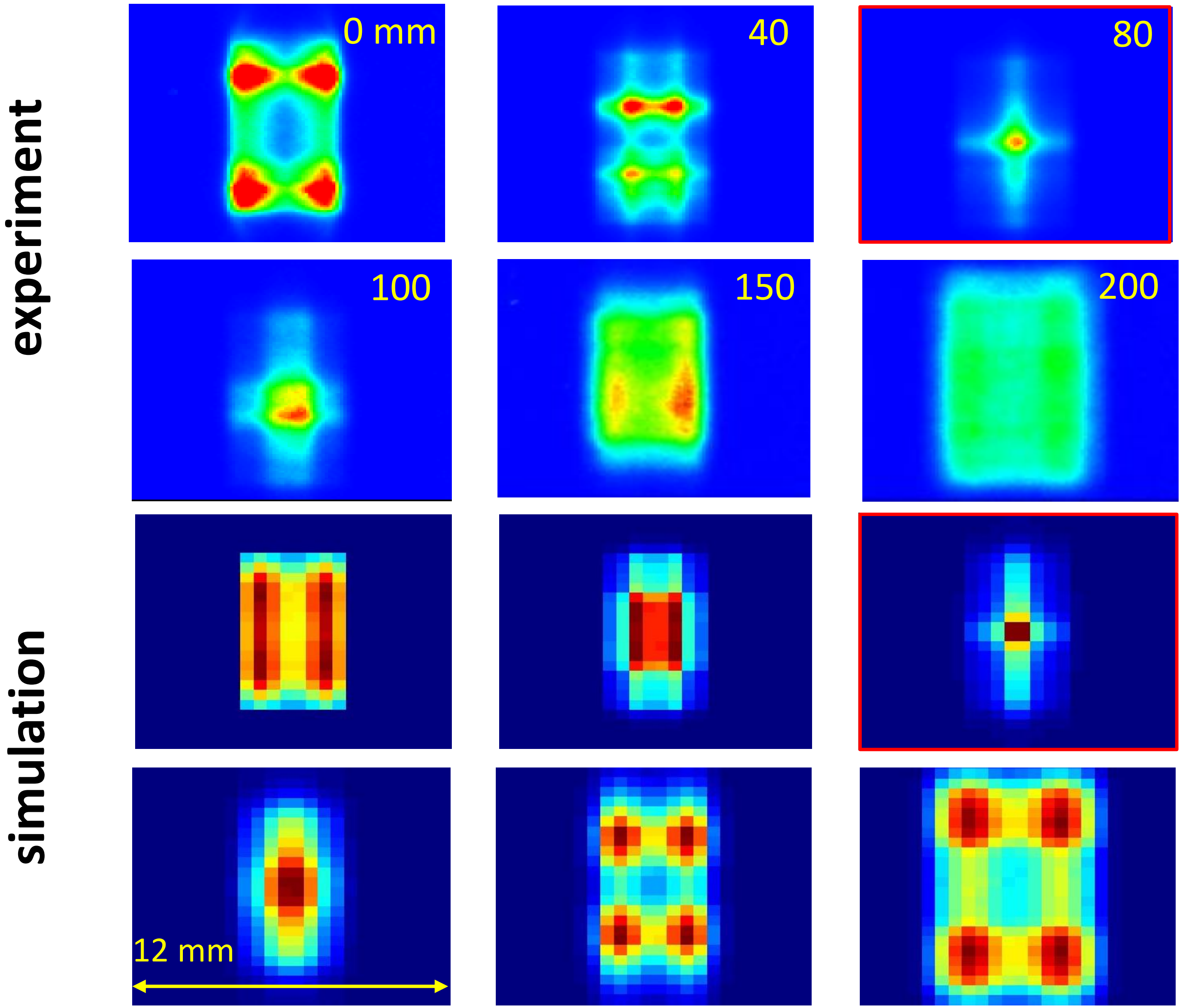


→ remove wings by masking direct beam

result: sub-millimeter beam size

N. Kardjilov et al., Nucl. Instr. Meth. A **542**, 248 (2005)

Experiment versus Monte Carlo



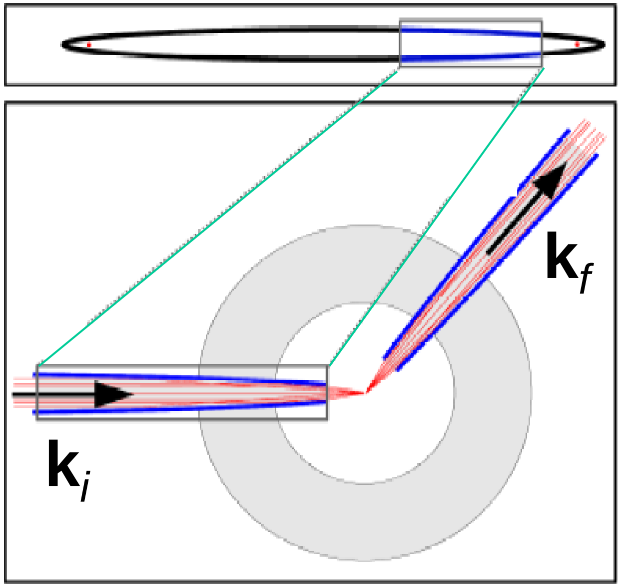
Focusing tube:

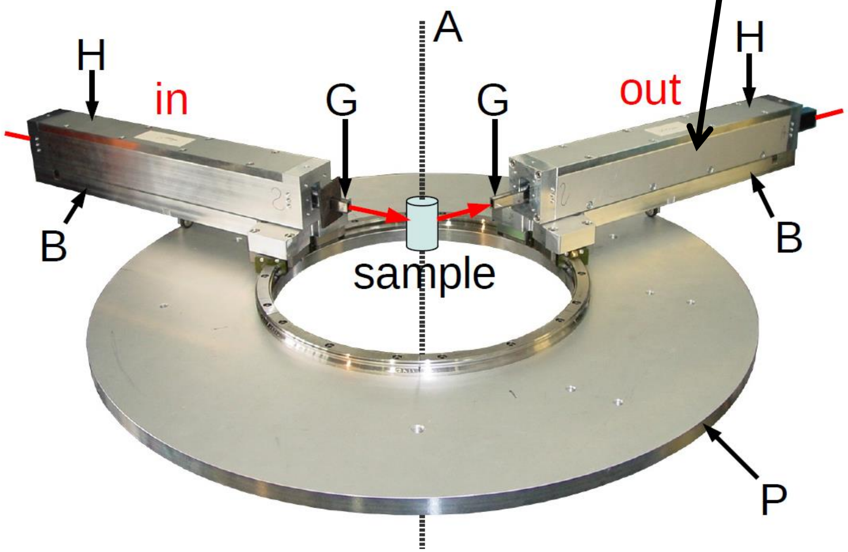
- L = 500 mm
- W_{in} = 10.6 mm
- H_{in} = 21.2 mm
- W_{out} = 4.0 mm
- H_{out} = 8.0 mm
- f = 80 mm
- m = 3
- R = 73%

Set-up:

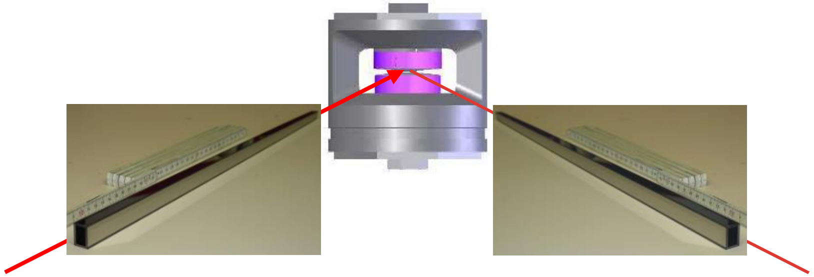
- λ = 4 Å
- hor. div.: 15’
- vert. div.: 60’

Focusing Set-Up Using Parabolic Guides





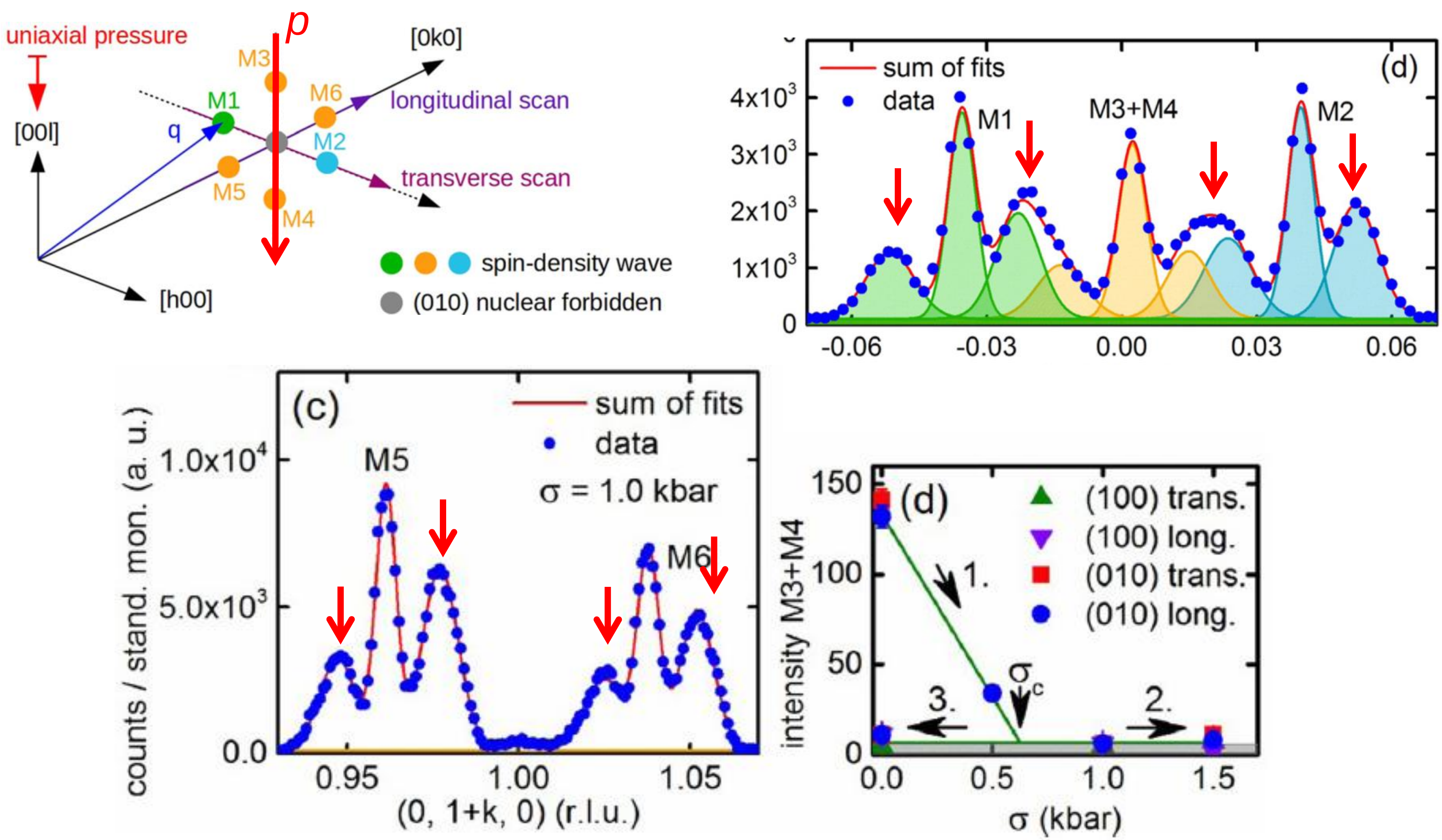
→ focusing before
and
→ defocusing after sample



Implementation at existing beam lines possible

T. Adams et al., Appl. Phys. Lett. **105** (2014) 123505

Domain Population in Cr under Uniaxial Stress



technology: *G* = 4

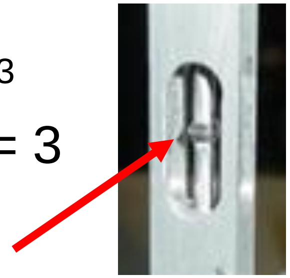
science: investigate tri-critical point

T. Adams et al., Appl. Phys. Lett. **105** (2014) 123505

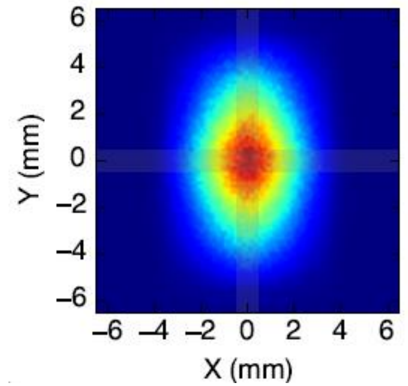
Focusing and Inelastic Neutron Scattering

Phonons in Pb

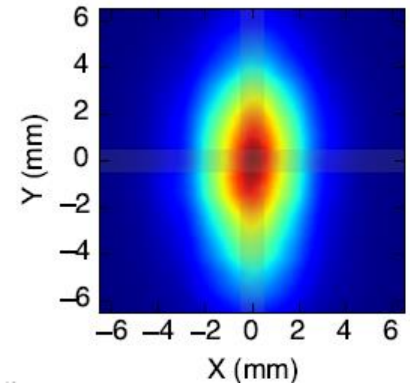
- sample: 2×2×2 mm³
- focusing guides: *m* = 3



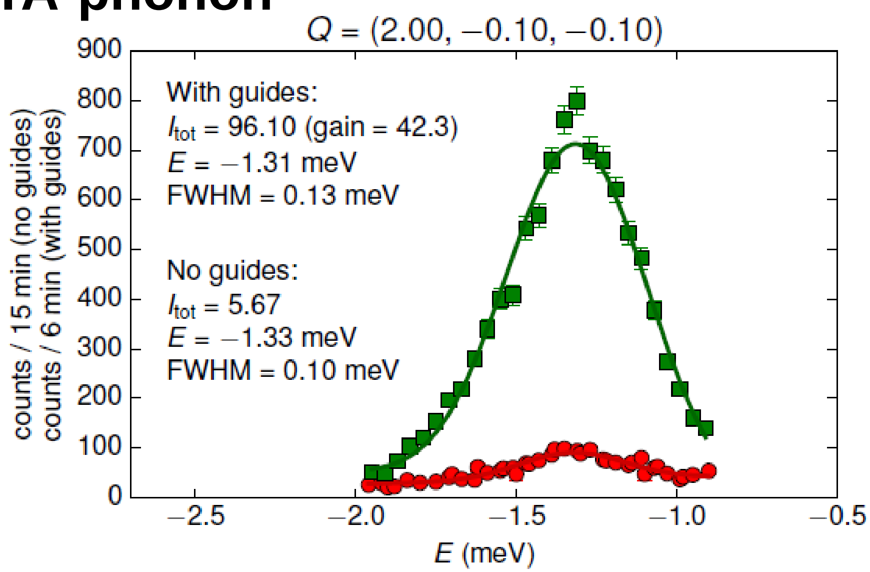
McStas simulation



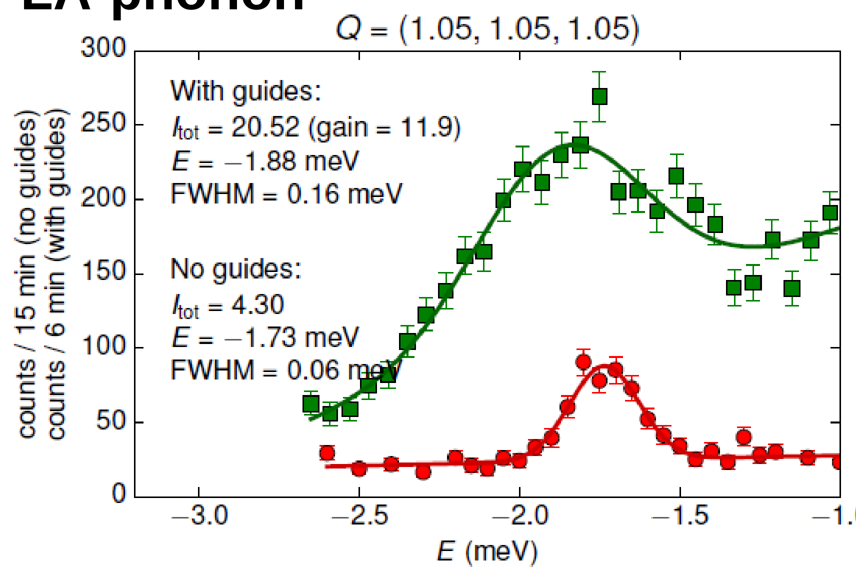
Measurement



TA-phonon



LA-phonon

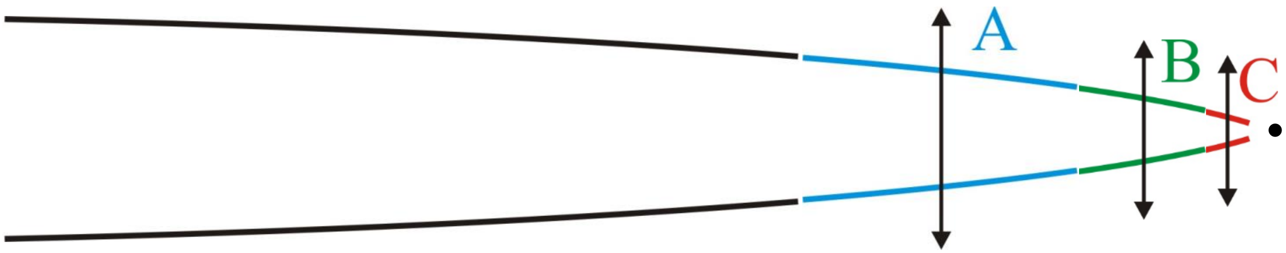


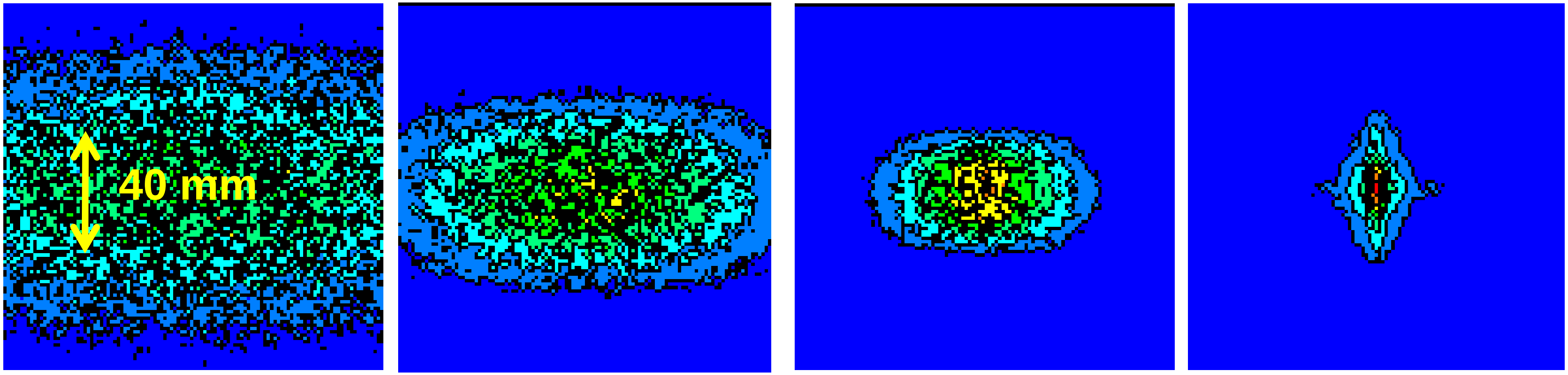
technology: *G* = 42 (pred. 2003)%

science: investigation of QPTs, etc.

G. Brandl et al., manuscipt

Focusing: Adaption of Beam Size





f_{out} = 1.2 m f_{out} = 0.5 m f_{out} = 0.2 m f_{out} = 0.1 m

P. Böni, Nucl. Instr. and Meth. A **586**, 1 (2008)

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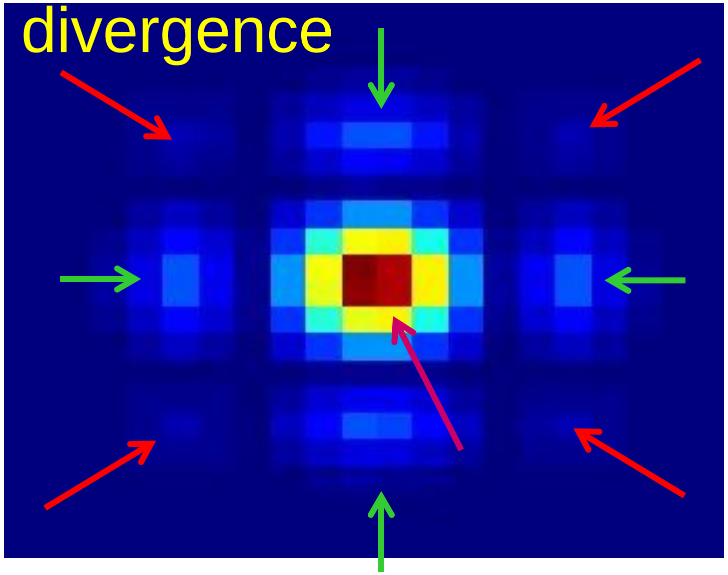
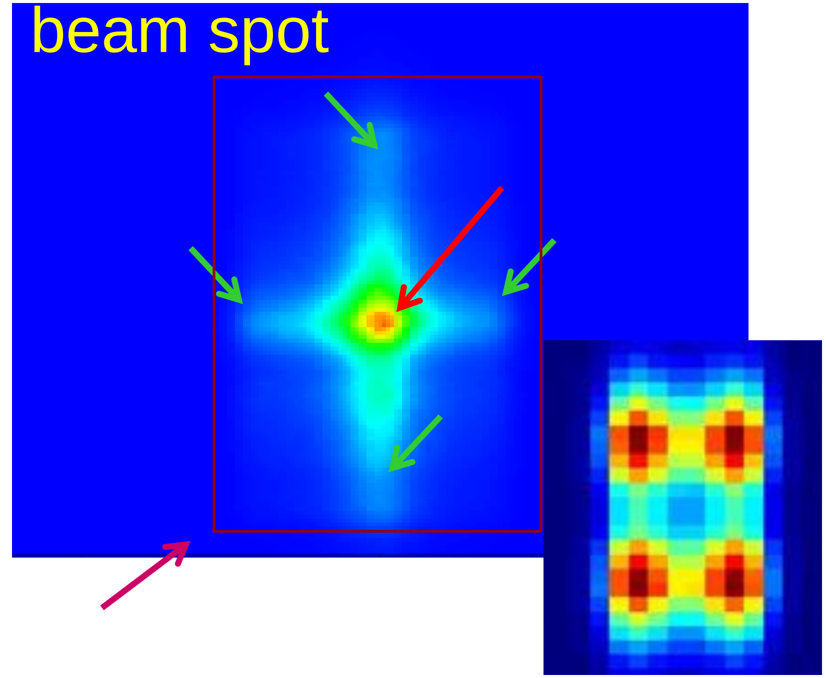
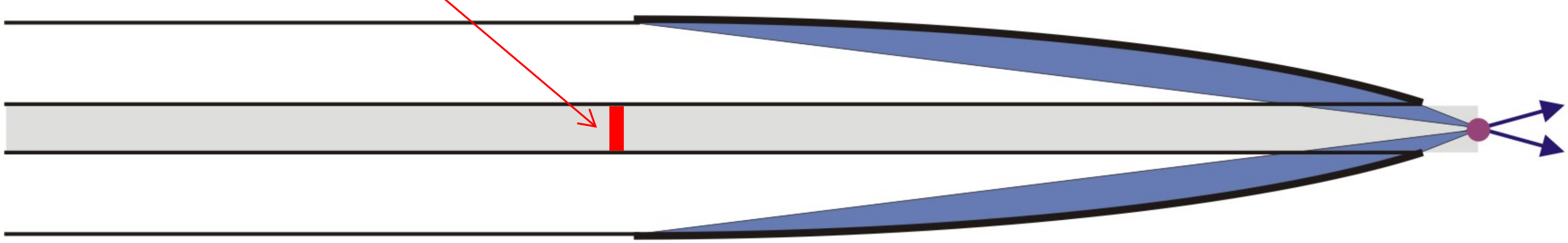
Divergence Is Inhomogeneous

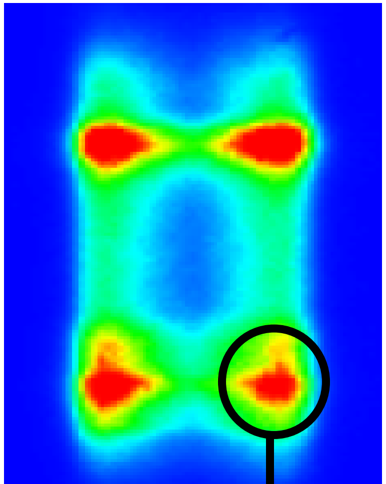


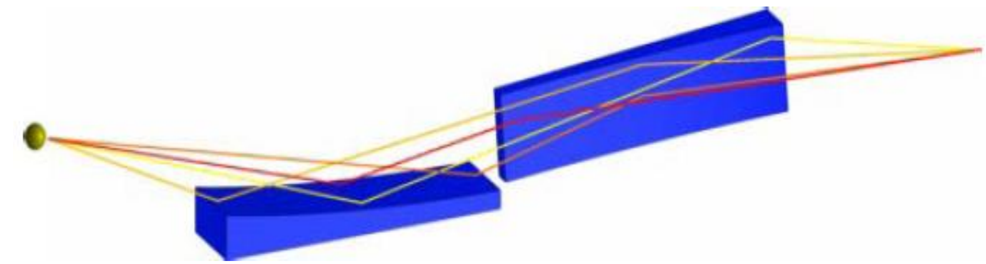




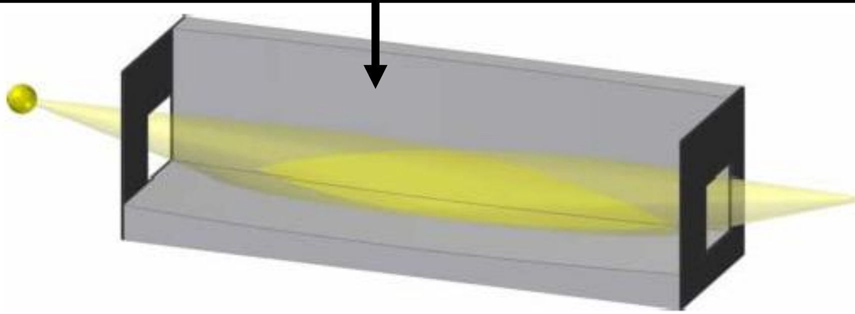
- long guide → more homogeneous divergence
- mask direct beam: wings reduced

Guides → Montel Optics





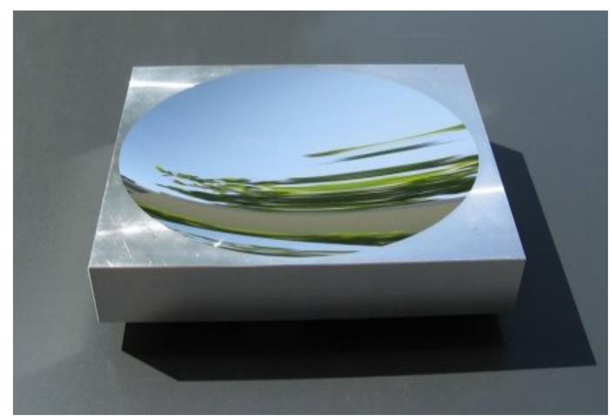
Kirkpatrick-Baez (1948)
(x-ray optics)



Montel optics for x-rays (1957)

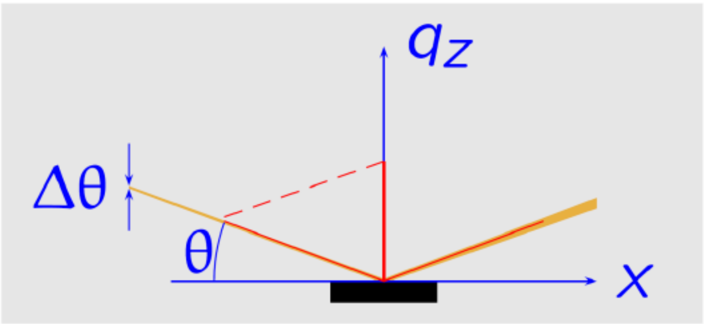
see also: G. Ice et al., J. Appl. Cryst. **42**, 1004 (2009)

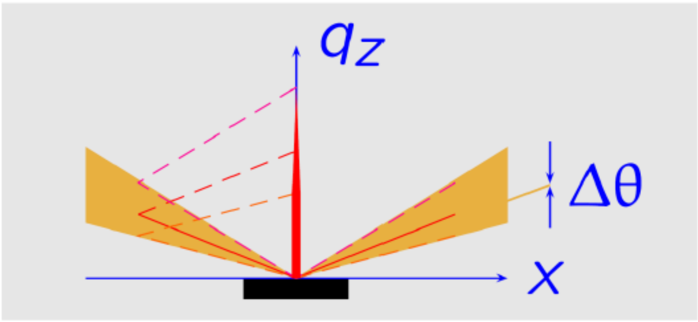
next step:



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

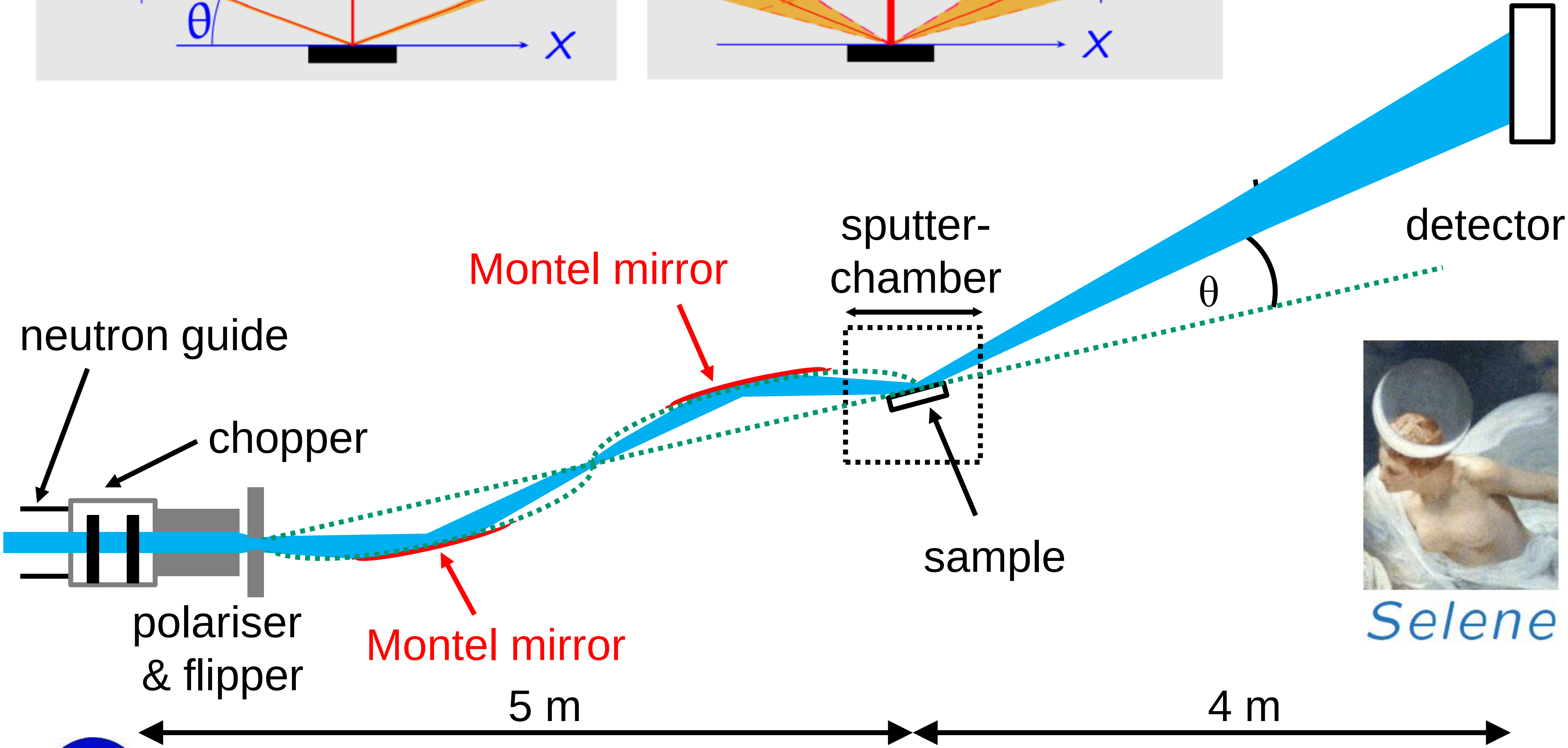
Montel Mirrors for Reflectometry: AMOR @ SINQ





Idea:

J. Stahn, PSI

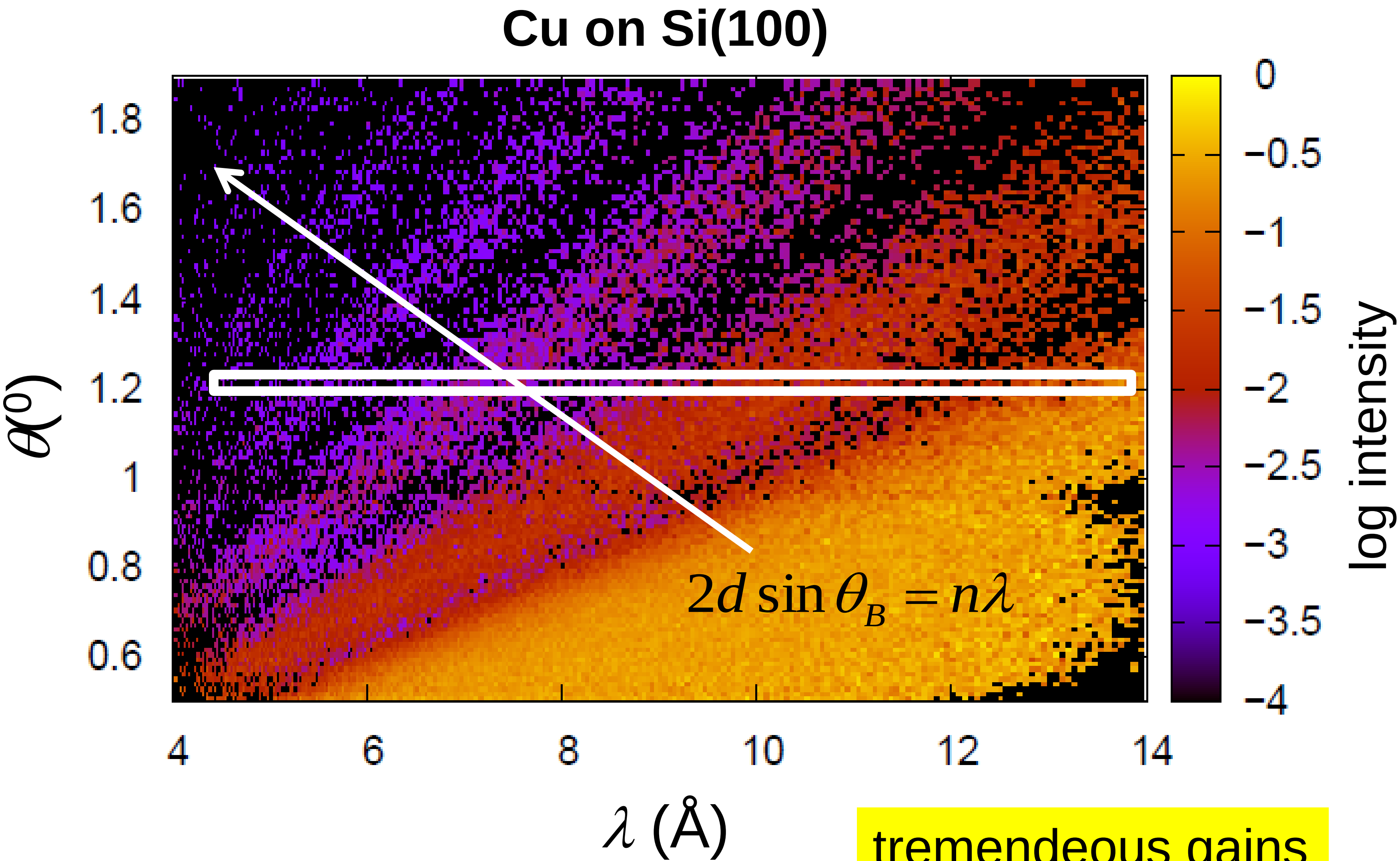


Selene

J. Stahn, T. Panzner, U. Filges, C. Marcelot, and P. Böni, Nucl. Instrum. Methods A **634**, S12-S16 (2011)

Installation of *In-situ* Chamber on AMOR

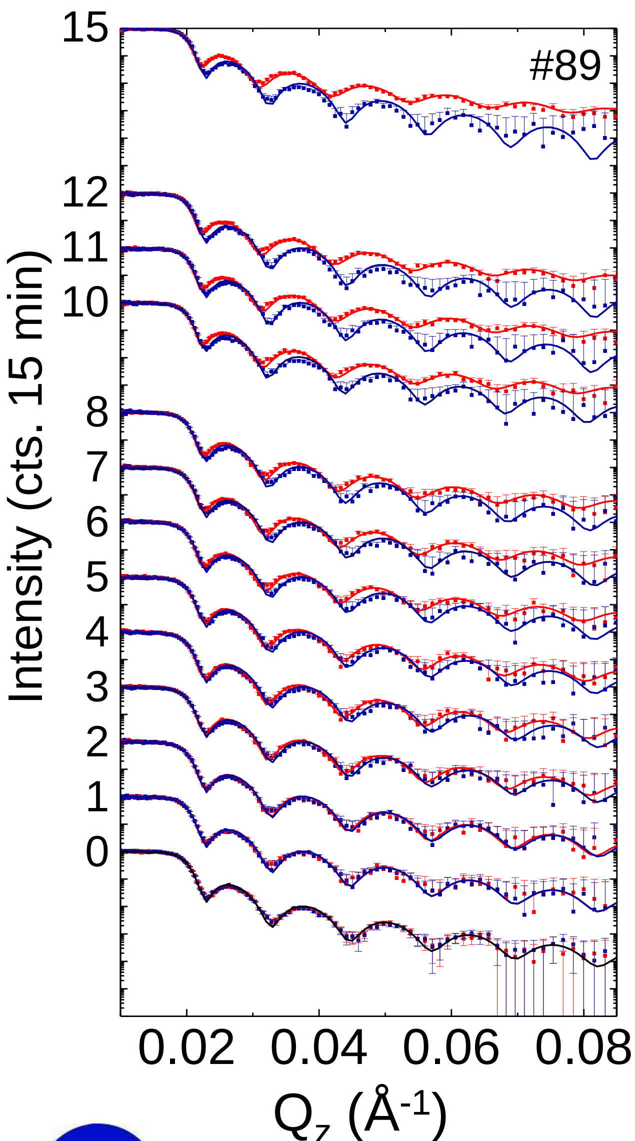
Results: SELENE @ AMOR



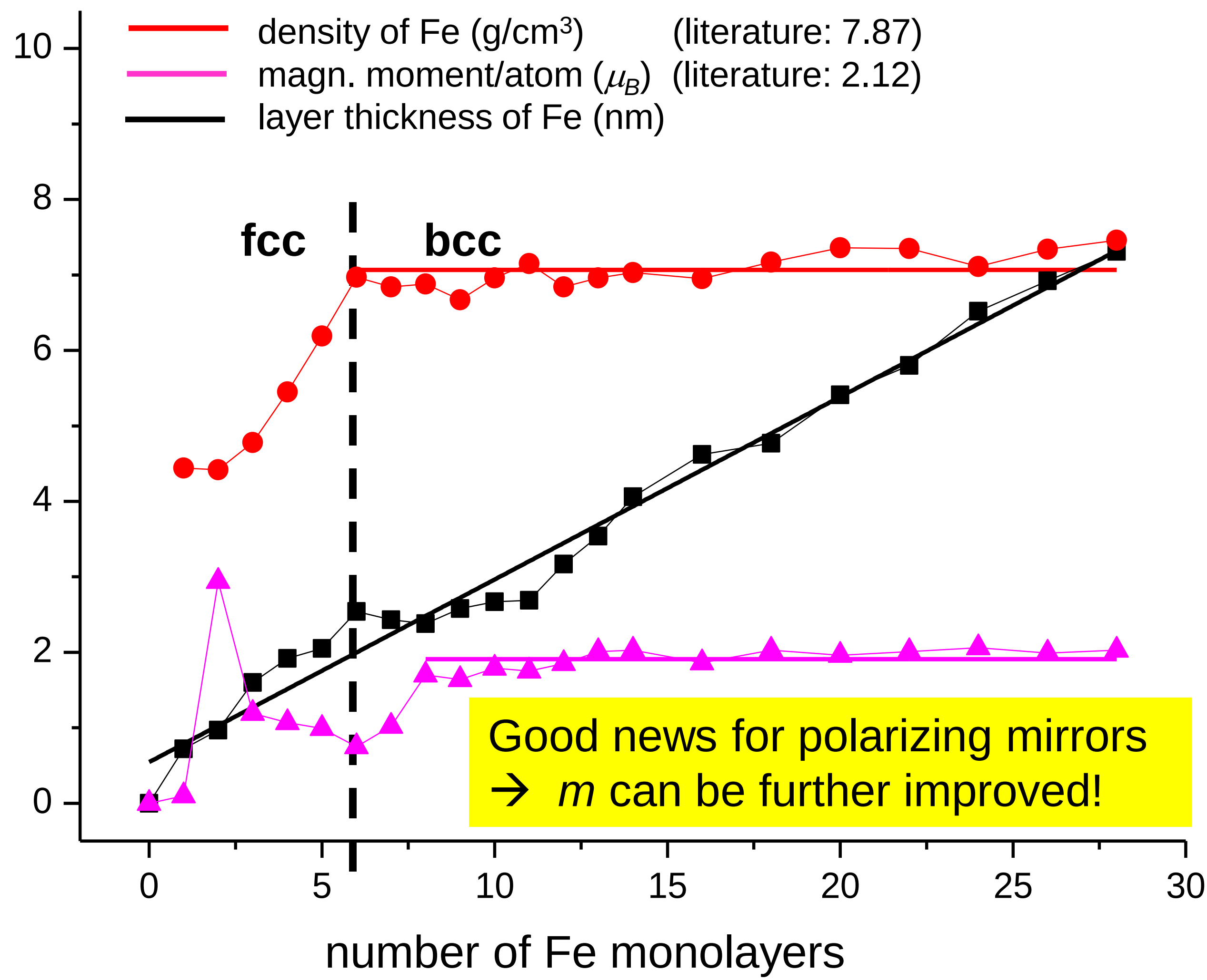
tremendeous gains

B. Wiedemann, Dr. W. Kreuzpaintner, J. Stahn, PB et al. 2014

Modern Optics + *in-situ* Coating Facility



monocrystalline Fe on Cu/Si



Good news for polarizing mirrors
→ *m* can be further improved!

B. Wiedemann, Dr. W. Kreuzpaintner, J. Stahn, PB et al. 2014

Prospects with ESS (→ 2019)

Book keeping:

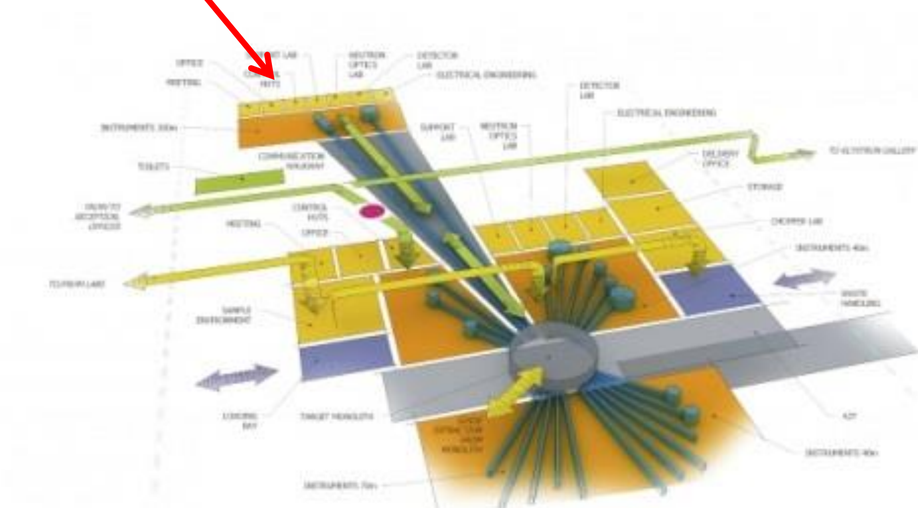
- gain in brilliance: > 100
- longer mirrors:
  - incr. of illum. area: > 10
  - divergence: > 4
- free of charge: extended *Q*-range

→ **gain factor > 4000**

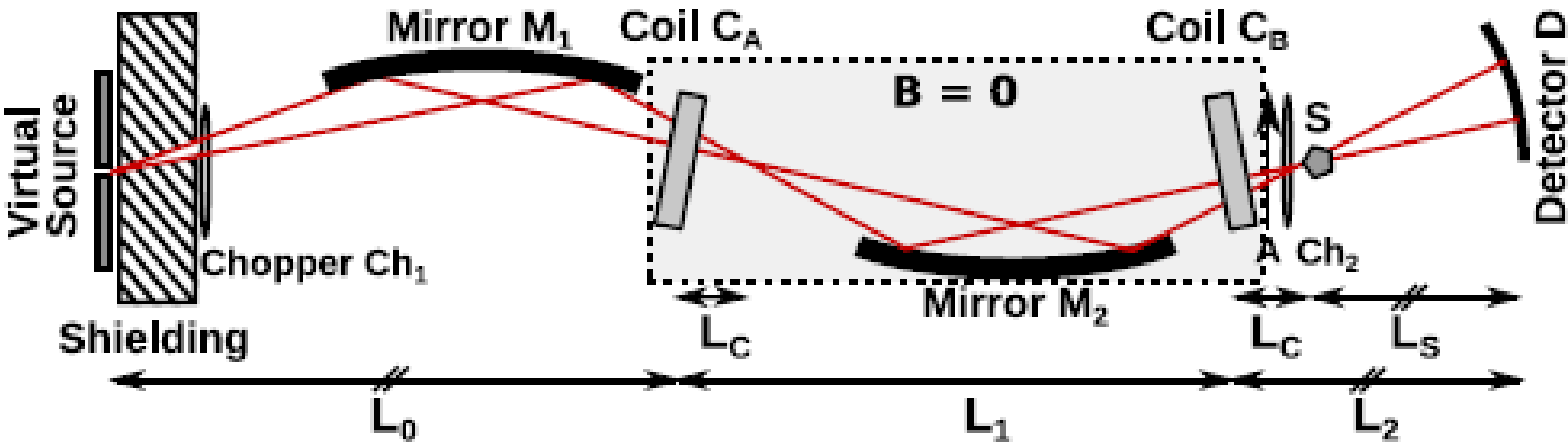
gain in measurement time:

- SELENE @ PSI:
  $T \cong 1$ hour/scan
- ESTIA @ ESS:
  $T < 1$ second

→ ***in-situ* measurements in real time**



Other Implementations of Montel Optics: MIEZE



Possibly too advanced to be accepted by community

→ chance for existing facilities

T. Weber et al., Nucl. Instr. and Meth. **A** 713, 71 (2013)

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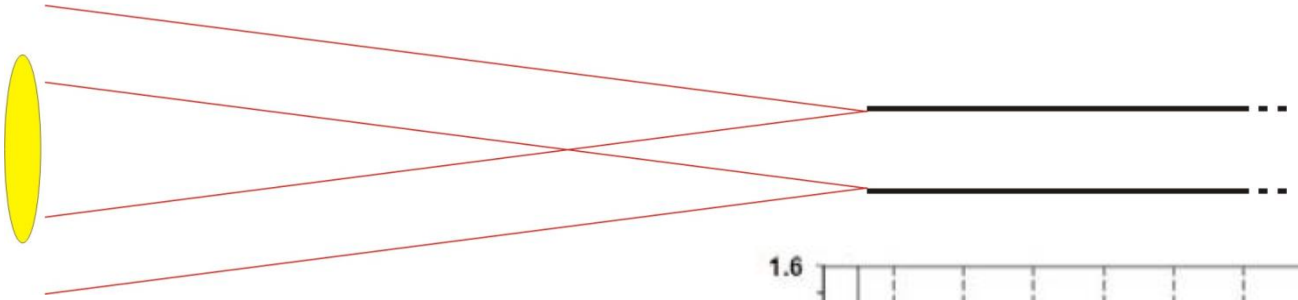
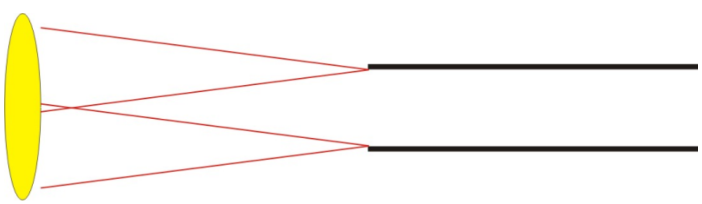
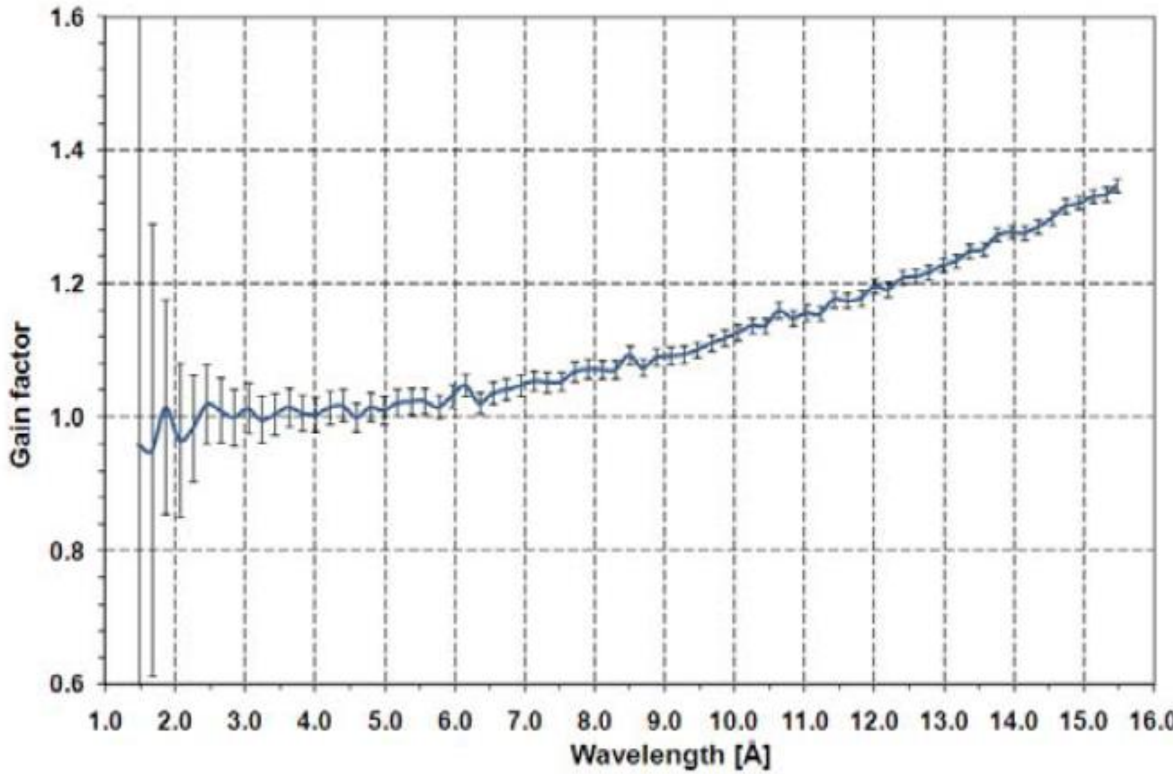
Illumination Losses

under illumination → loss of intensity, moderator too small



go close to moderator





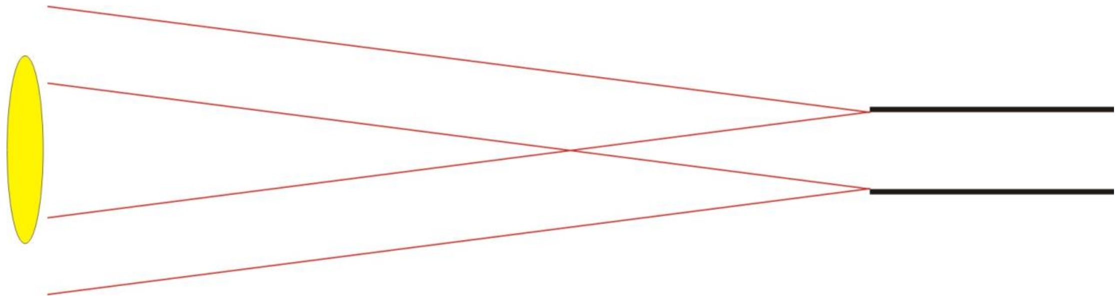
Example: NL1 @ FRM II

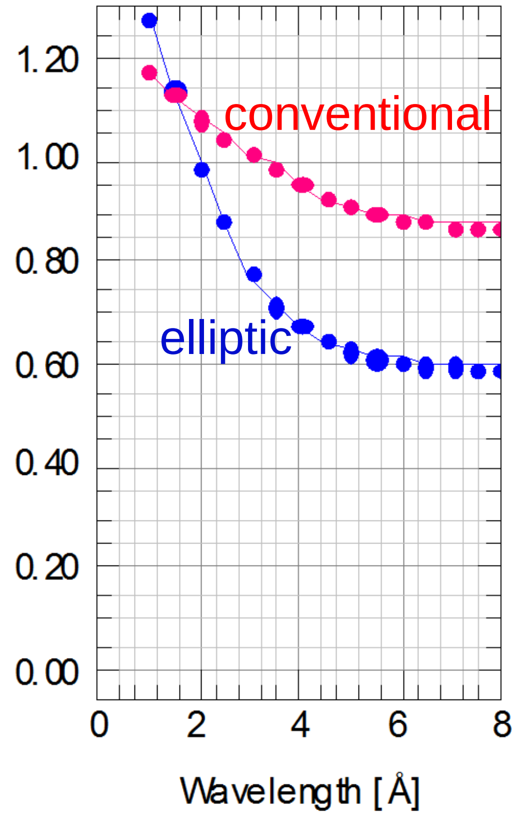
- 30% gain (2 m → 0.1 m)

C. Schanzer et al., J. Phys.: Conf. Series **251** (2009) 012082

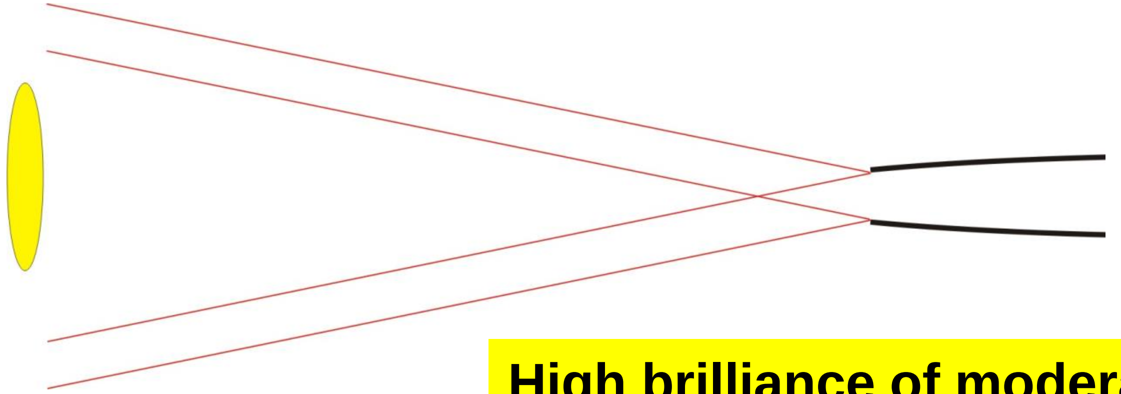
Small Source (example: Pancake Moderator @ ESS)

Straight guide: under-illumination





Elliptic/parabolic guides: even worse!

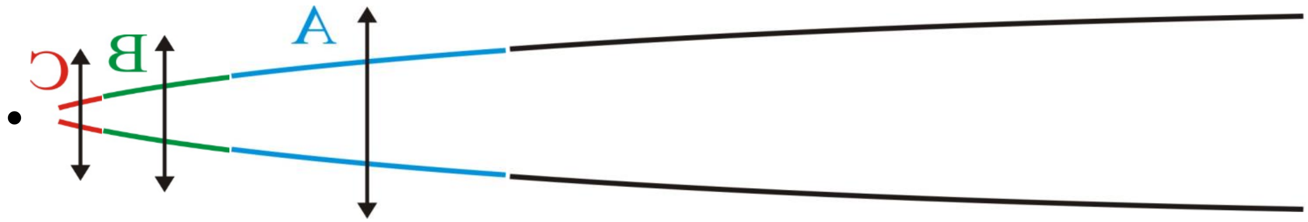


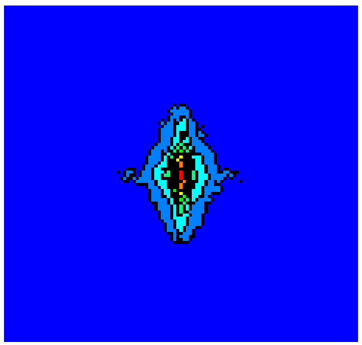
High brilliance of moderator is useful, if:

- guide is extended close to moderator
- **this condition may not be fulfilled at ESS**

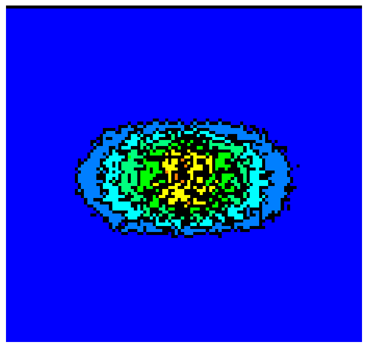
Alternative Solutions

Guides:

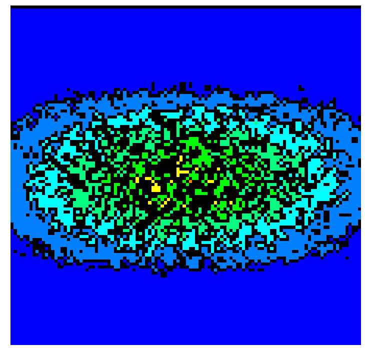




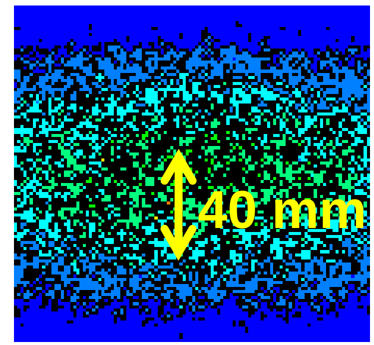
f_{out} = 0.1 m



f_{out} = 0.2 m

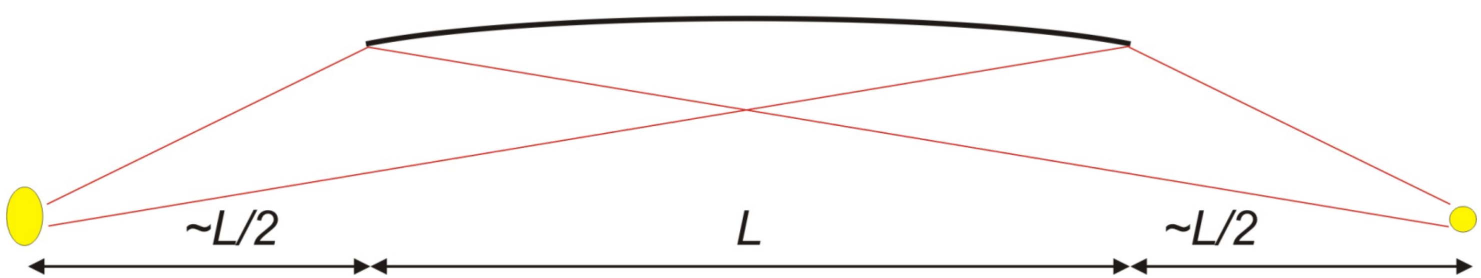


f_{out} = 0.5 m



f_{out} = 1.2 m

Montel Mirrors:



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Summary: Scientific Opportunities

- investigation of small samples facilitated:
  - novel materials
  - extreme conditions
  - quantum phase transition
- investigation of heterostructures
- in-situ / real time experiments

Summary: Technical

Flux considerations:

- maximum possible intensity (is anticipated experiment possible?)

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

$\eta \cong 1$: brilliance transfer
(efficiency of transport)

- consider Liouville‘s theorem

Existing sources:

- new opportunities in beam optics
- „local“ upgrades of instruments possible (cheap and effective)

New sources:

- move guide entraces close to moderator: not realized so far
- extract only useful neutrons

Do not Use Monte-Carlo, Use First Your Brain

Acknowledgment

- T. Adams (TUM)
- G. Brandl (JCNS)
- **U. Filges (PSI)**
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- N. Kardjilov (HZB)
- J. Mannhart (MPI)
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- C. Pfleiderer (TUM)
- K. Hradil (TU Vienna)
- B. Roessli (PSI)
- **C. Schanzer (SwissNeutronics**)
- A. Schmehl (AU, now Zeiss)
- M. Schneider (SwissNeutronics)
- **J. Stahn (PSI)**
- T. Weber (TUM/FRM II)
- etc. (did I forget somebody?