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concept for a **reflectometer** using **focusing guides**

Selene

TUM & FRM II seminar

12. 03. 2012, München, Germany

outline

reflectometry

- principle
- examples

slit optics vs. focusing optics

small samples

focusing with elliptic guides

- coma aberration
- operation modes

realisation

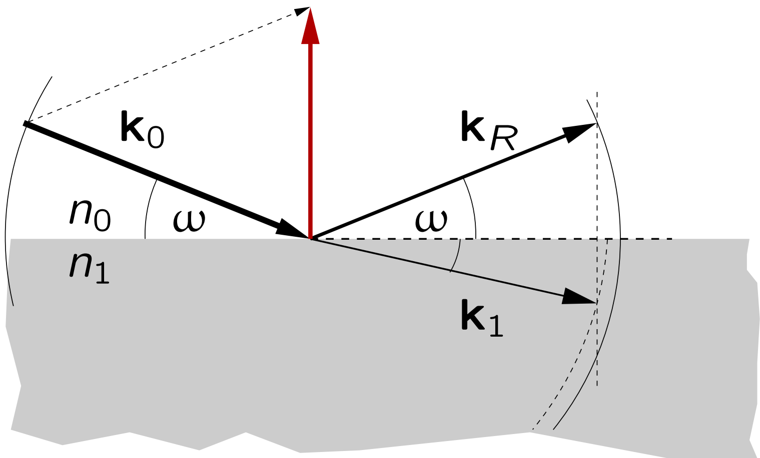
- add-on for Amor $\longrightarrow$ experimental results
- 2D prototype for BOA
- concept for the ESS

reflectometry

reflectometry

analogy to visible light:

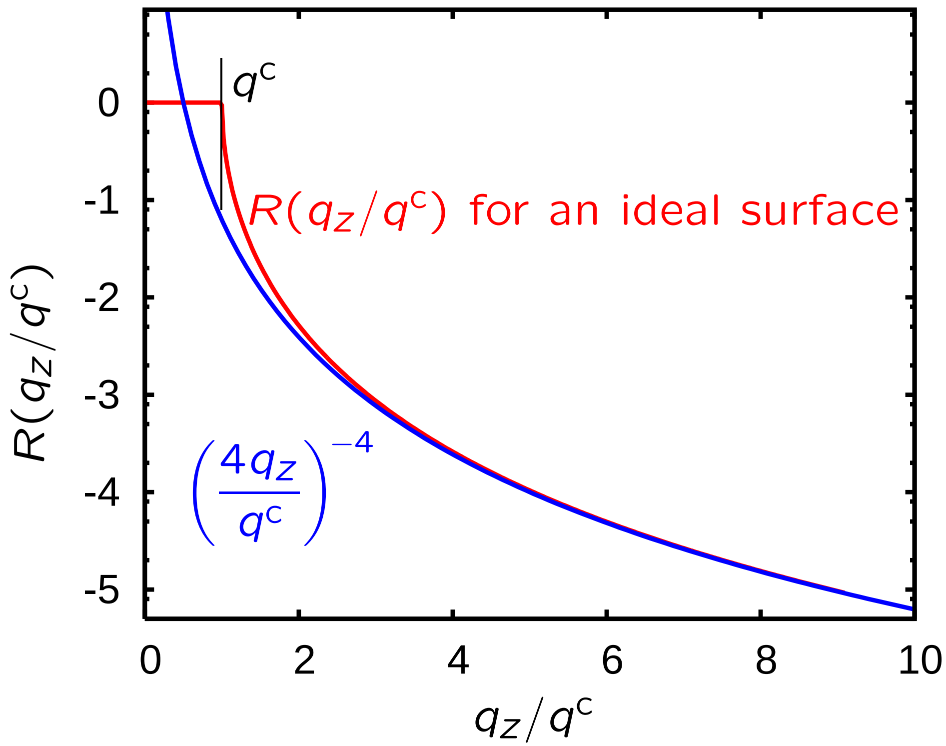
- *flat* surfaces partly reflect light
- some media also transmit light
- parallel interfaces ⇒ interference

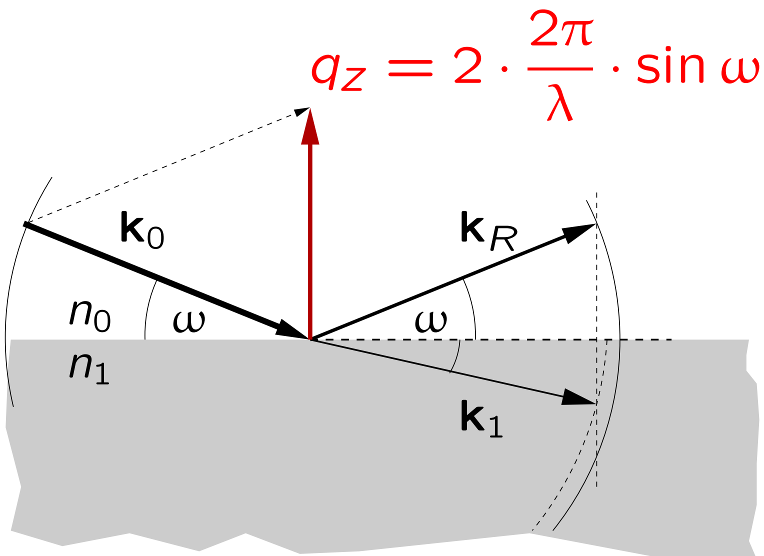


reflectometry

Fresnel reflectivity

- reflectivity of a sharp flat surface
- total external reflection for $q_z < q^c$
- exponential decay of $R(q_z)$ for $q_z > q^c$





neutrons / x-rays:

$\lambda \in \{1 \dots 20\,\text{Å}\}$

$\omega^c < 1^\circ$

reflectometry

reflected intensity of a multilayer

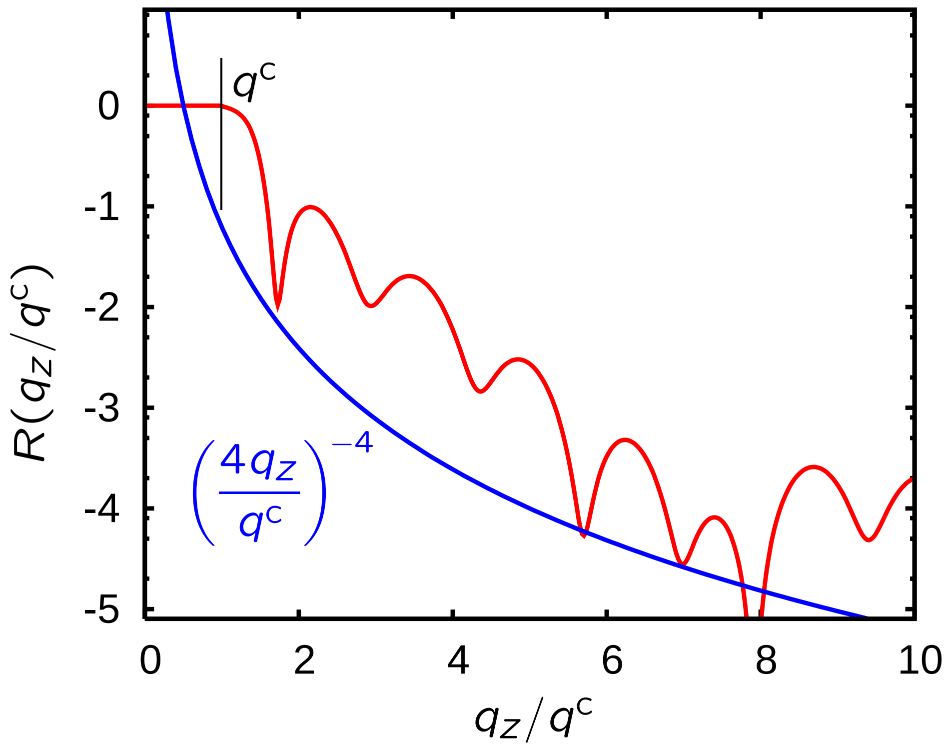
several parallel interfaces:

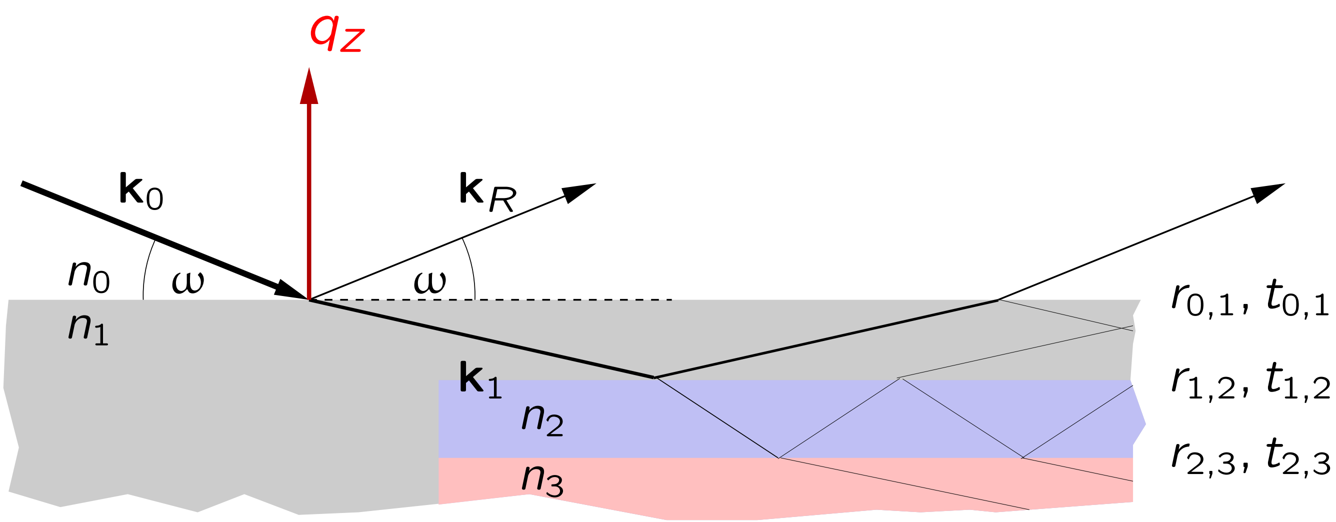
interference of all waves

$\Rightarrow$ complex reflectance

$$r = r(q_z, n_0, n_1, n_2, \ldots, d_1, d_2, \ldots)$$

$$R(q_z) = |r(q_z)|^2$$





d_1 thickness of layer 1

$r_{2,3}$ reflectance of interface 2/3

reflectometry

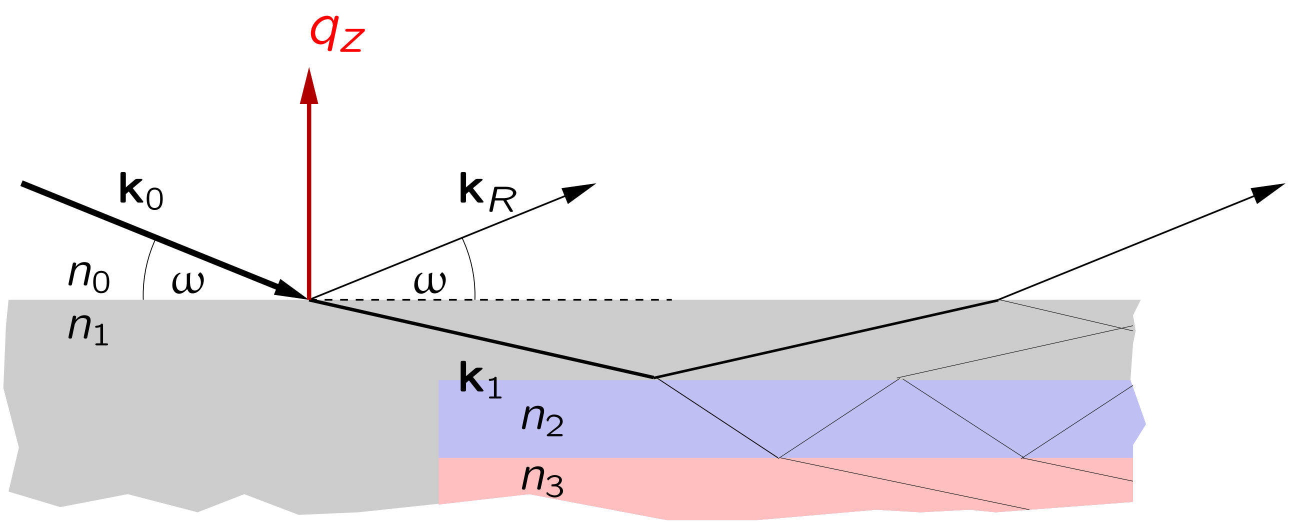
reflected intensity of a multilayer

$$R(q_z) = |r(q_z)|^2$$

$\Rightarrow$ all phase information is lost

$\Rightarrow$ one way road:

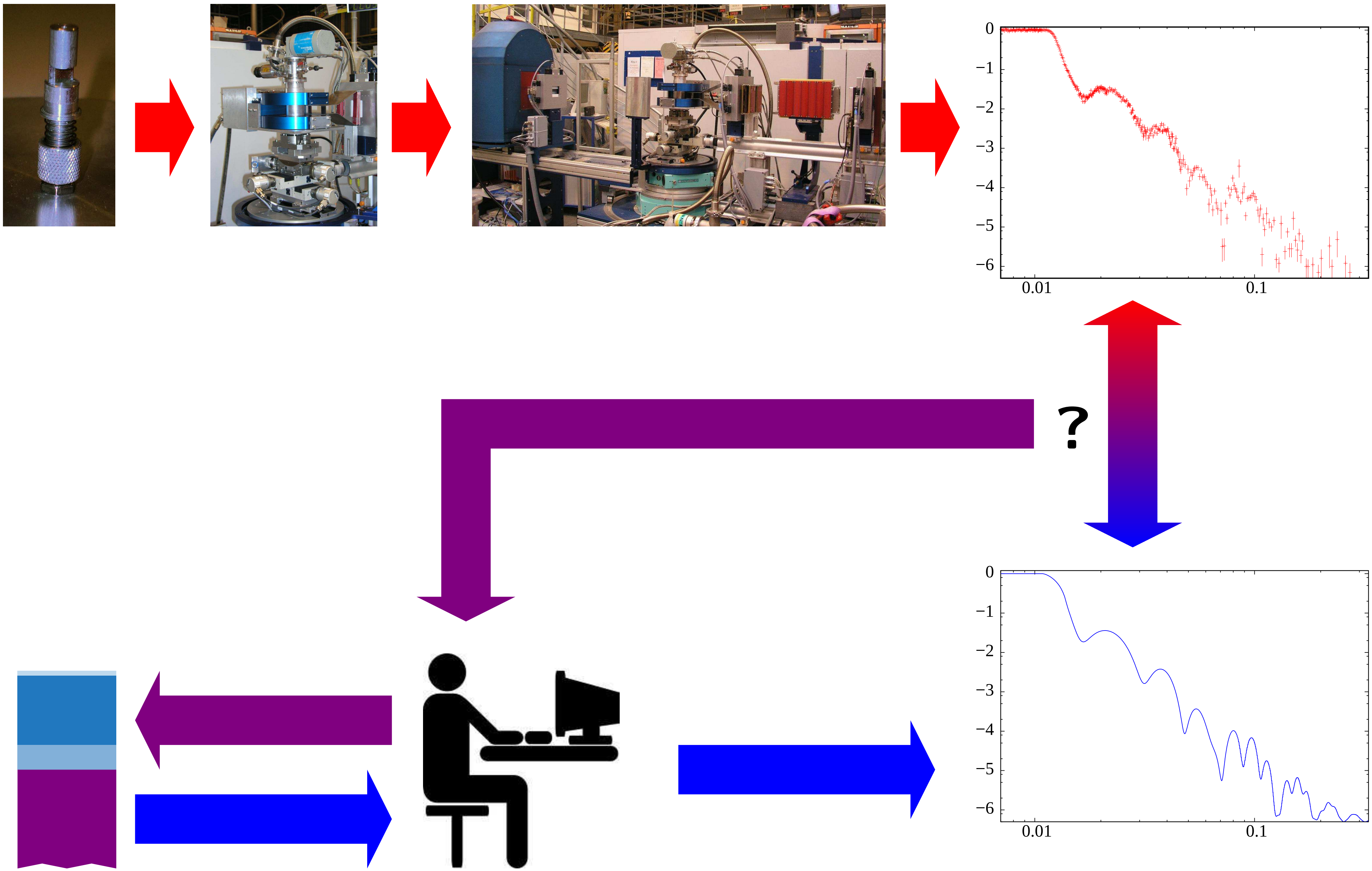
$\Rightarrow$ calculation of $R(q_z)$ using a model
and
comparison to measured curve(s)



real effects
to be taken into account:

– illumination of the sample
– resolution of the set-up
$\Delta\omega$, $\Delta\lambda$
– non-sharp interfaces
– inhomogeneous layers

reflectometry



reflectometry

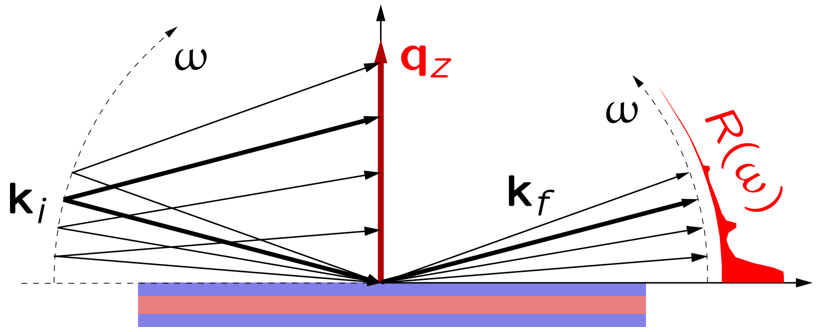
measurement schemes

$$R = R(q_z) = R(\lambda, \omega) \qquad q_z = 4\pi \frac{\sin\omega}{\lambda}$$

angle-dispersive set-up

variation of ω with fixed λ

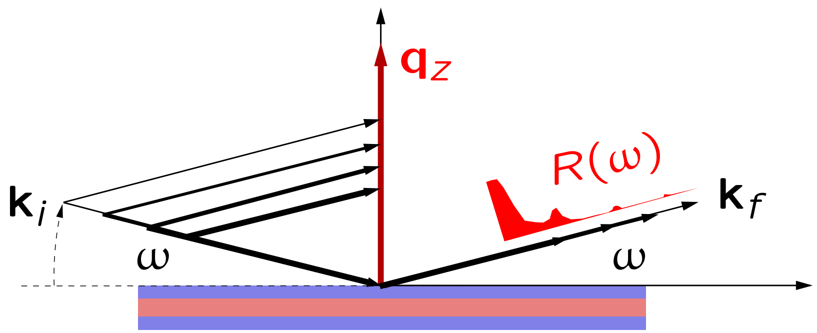
detection under 2ω



energy-dispersive set-up

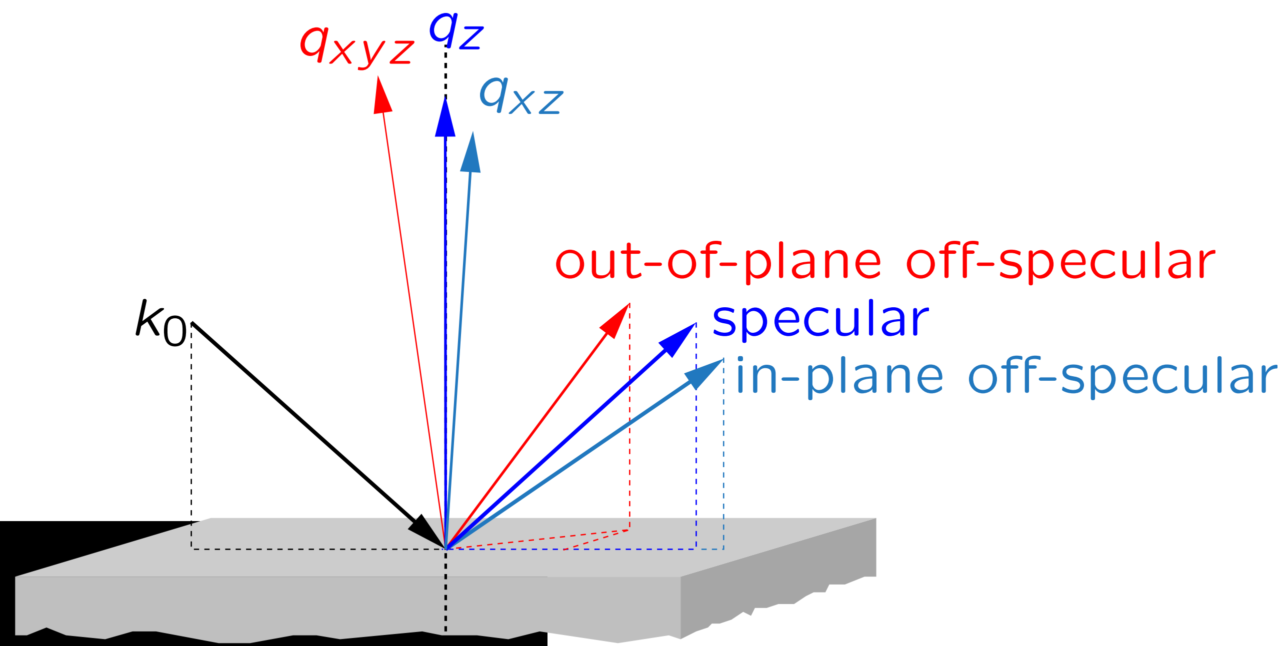
variation of λ with fixed ω

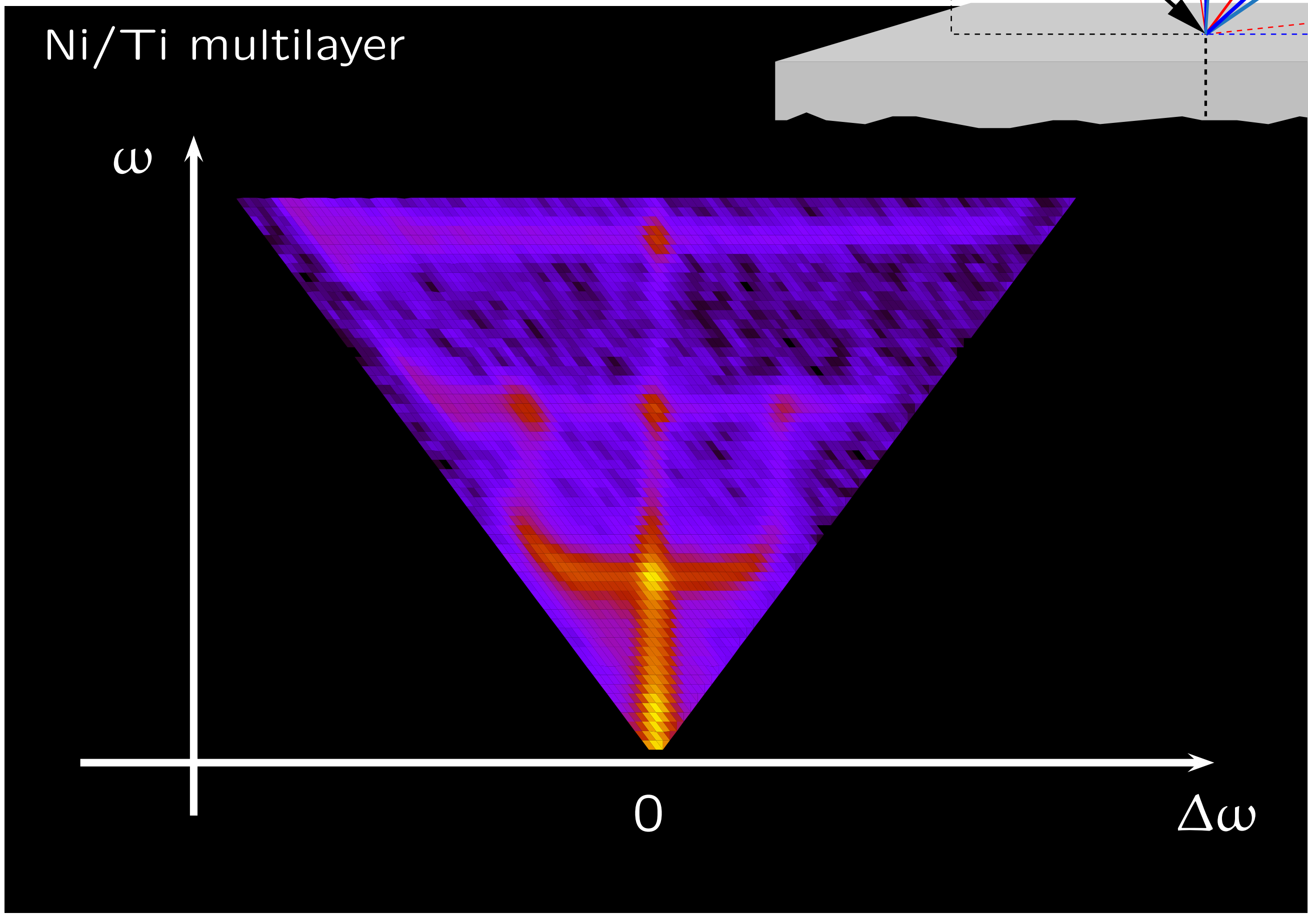
detection via time-of-flight



reflectometry

off-specular scattering





here:

resolution in x: $\approx 0.01^\circ$

resolution in y: $> 1^\circ$

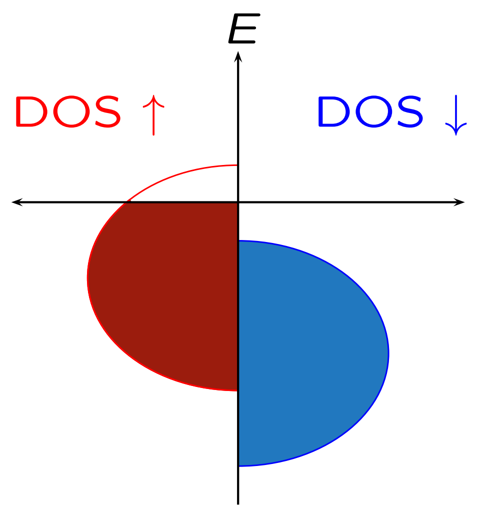
$\Rightarrow$ integration over y

reflectometry

example: perovskite multilayer

$Pr_{0.7}Ca_{0.3}MnO_3$ / [$La_{2/3}Sr_{1/3}MnO_3$ / $Pr_{0.7}Ca_{0.3}MnO_3$]$_5$ / $NdGaO_3$

LSMO is a half-metal



⇒ injection of spin-polarised current expected

→ but not found!

explanation: reduced / suppressed magnetism at interfaces

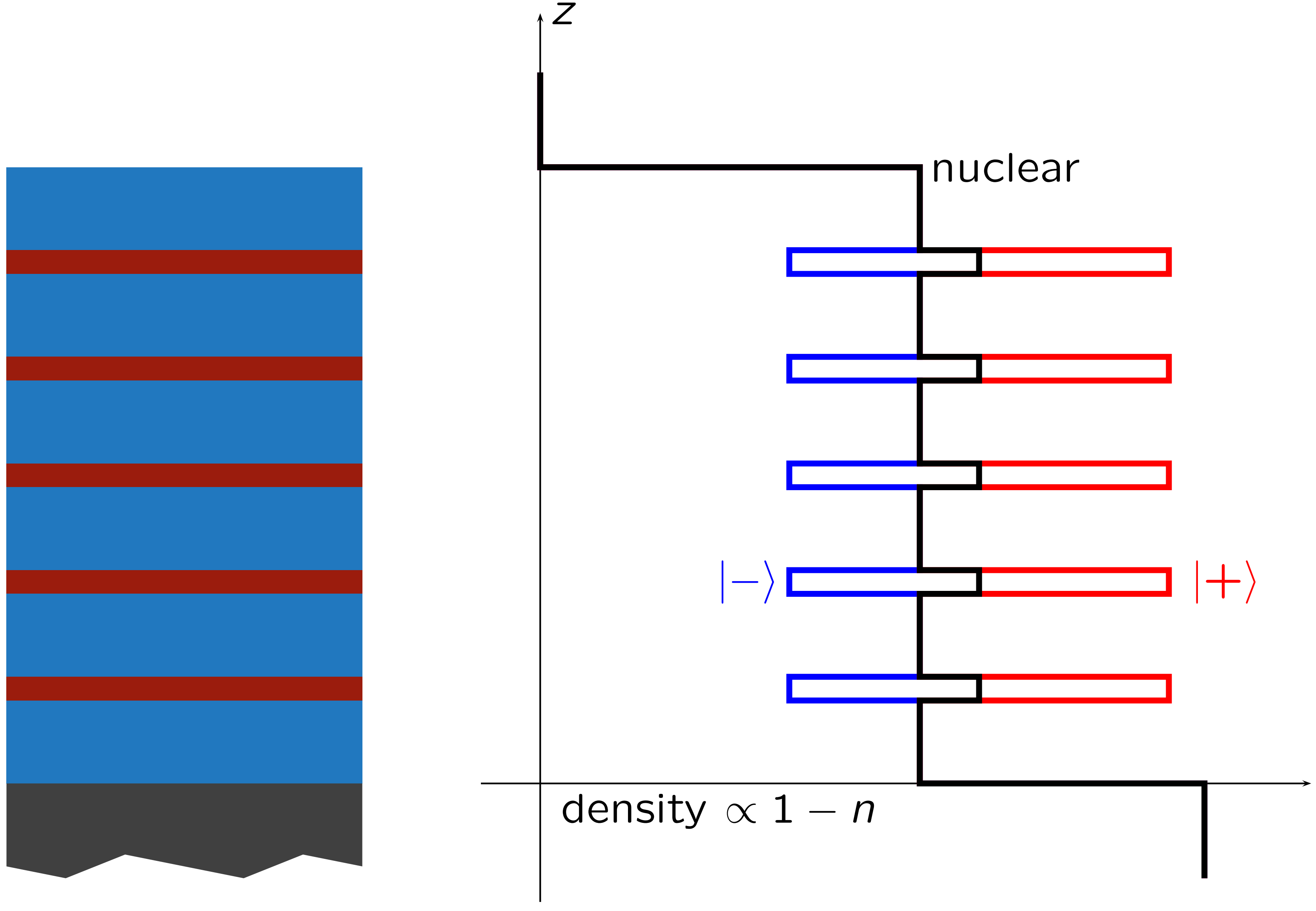
Is that true?

reflectometry

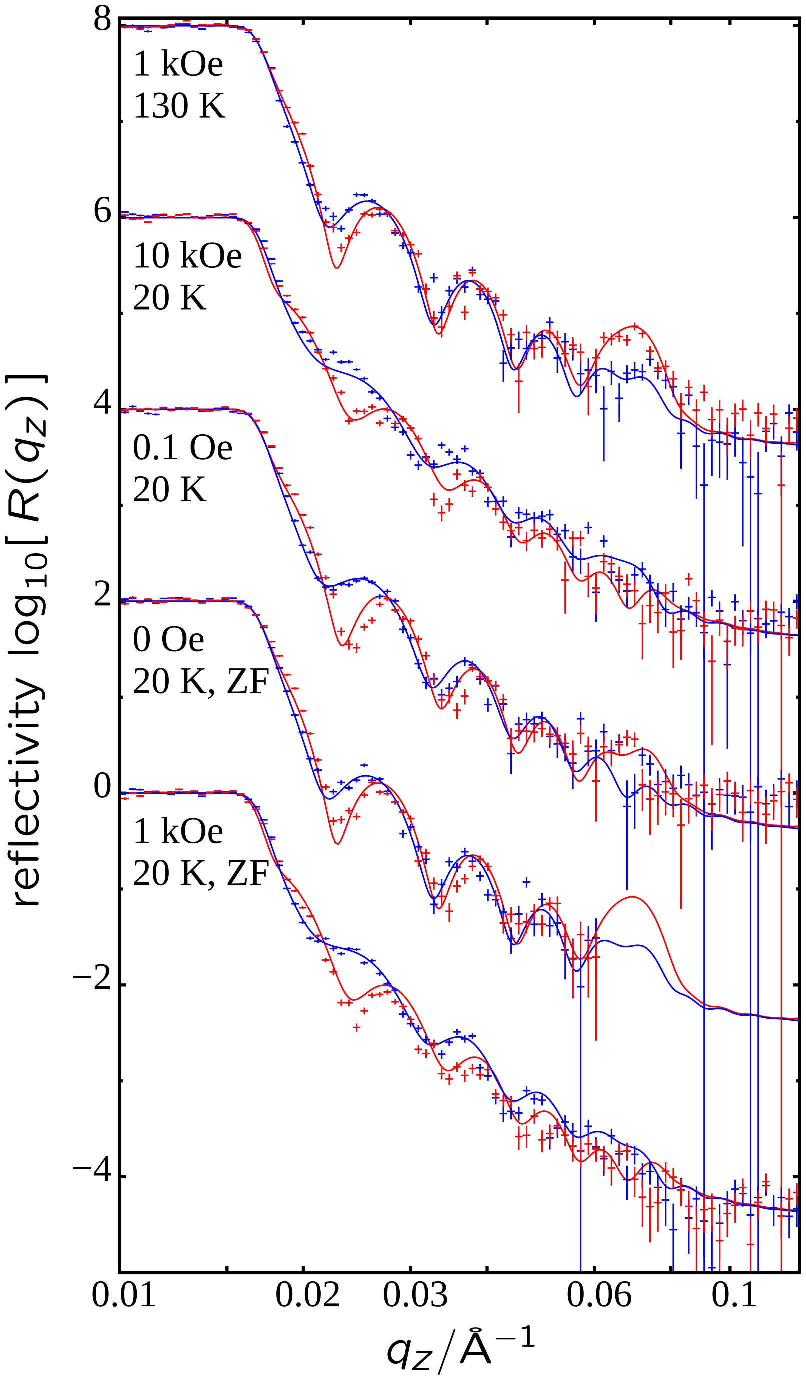
example: perovskite multilayer

by courtesy of C. Aruta and F. Miletto

$Pr_{0.7}Ca_{0.3}MnO_3$ / [$La_{2/3}Sr_{1/3}MnO_3$ / $Pr_{0.7}Ca_{0.3}MnO_3$]$_5$ / $NdGaO_3$



reflectometry



PCMO magnetism:

none

full

interfaces

none

interfaces

findings:

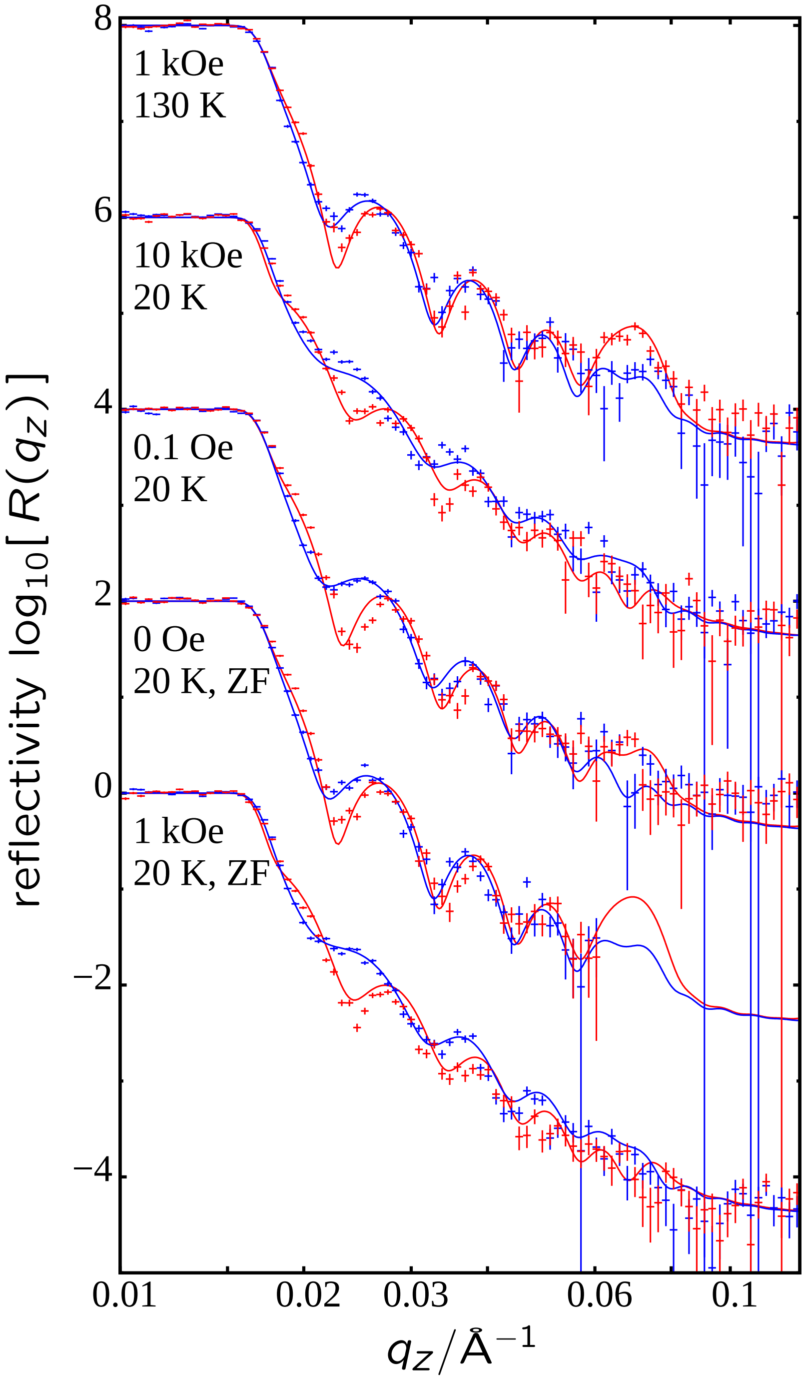
• no reduction of M within LSMO

but

• induced M in PCMO (already above T_{Curie})

to be continued . . .

reflectometry



sample: $5 \times 5\,\text{mm}^2$

$\Downarrow$

counting time per spin state: 12 h!

$\Downarrow$

accurate screening of H
and T not possible

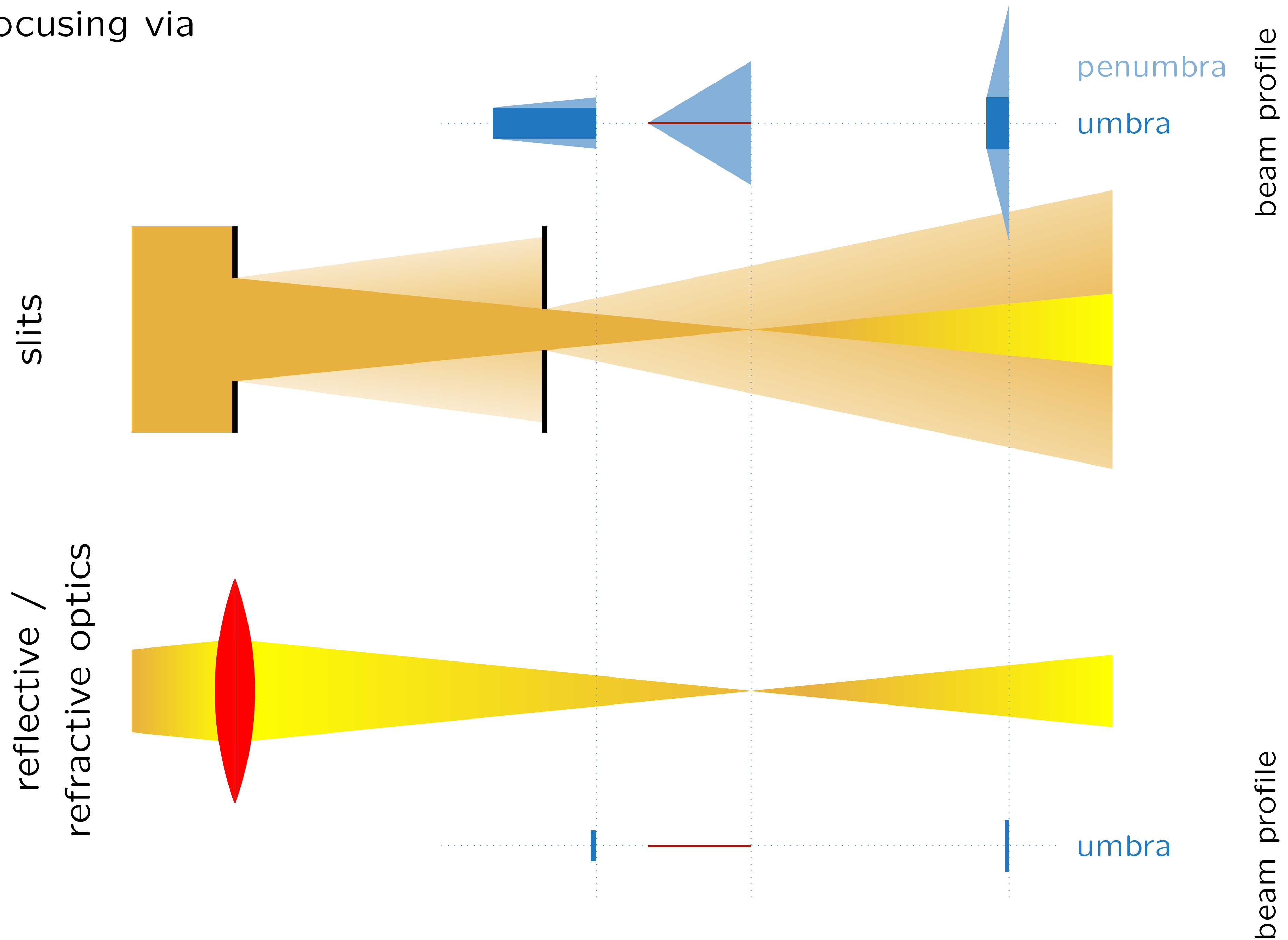
⋮

at the moment!

slit vs. focusing optics

slit vs. focusing optics

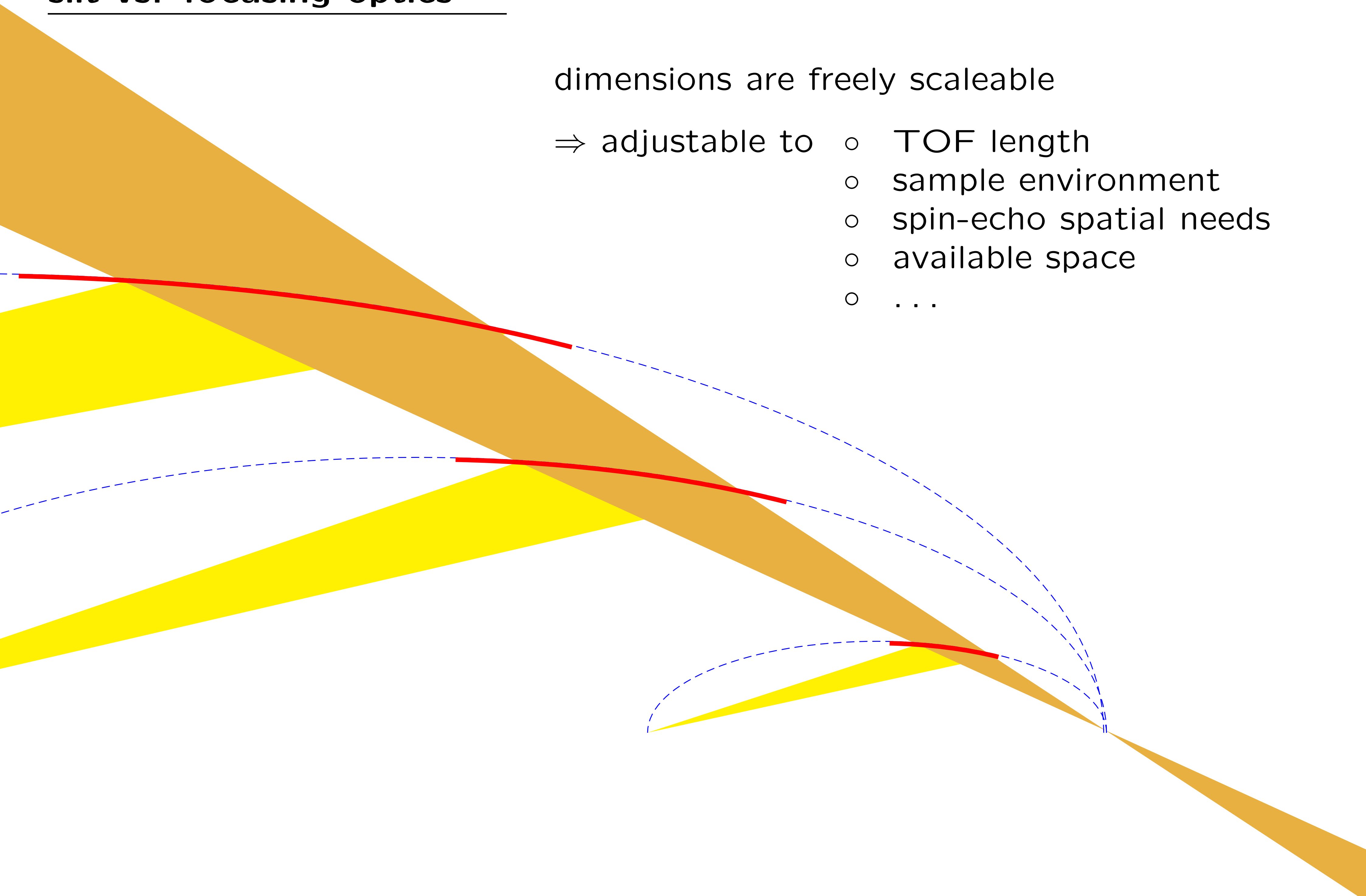
focusing via



slit vs. focusing optics

dimensions are freely scaleable

⇒ adjustable to
- TOF length
- sample environment
- spin-echo spatial needs
- available space
- . . .

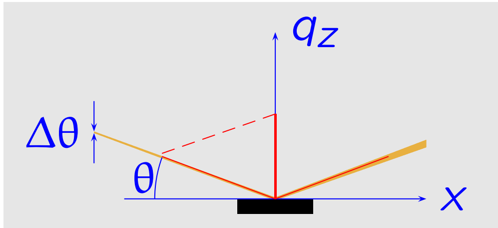


slit vs. focusing optics

focusing for high-flux specular reflectometry

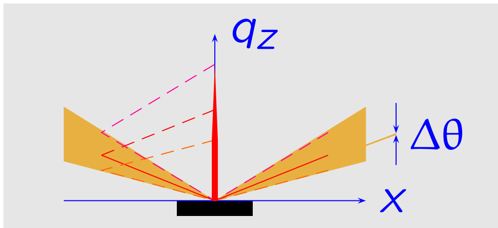
slit-defined beam:

- θ-dispersive, **or**
- λ-dispersive,
- resolution given by Δλ and Δθ



convergent beam:

- θ-dispersive **and**
- λ-dispersive,
- resolution given by Δλ and detector



small samples

small samples

i.e. **samples smaller than the beam**

e.g.
- PLD-grown samples
- latterally structured films
- functional devices
- samples compatible with x-ray or magnetometry environments

projected height < 1 mm!

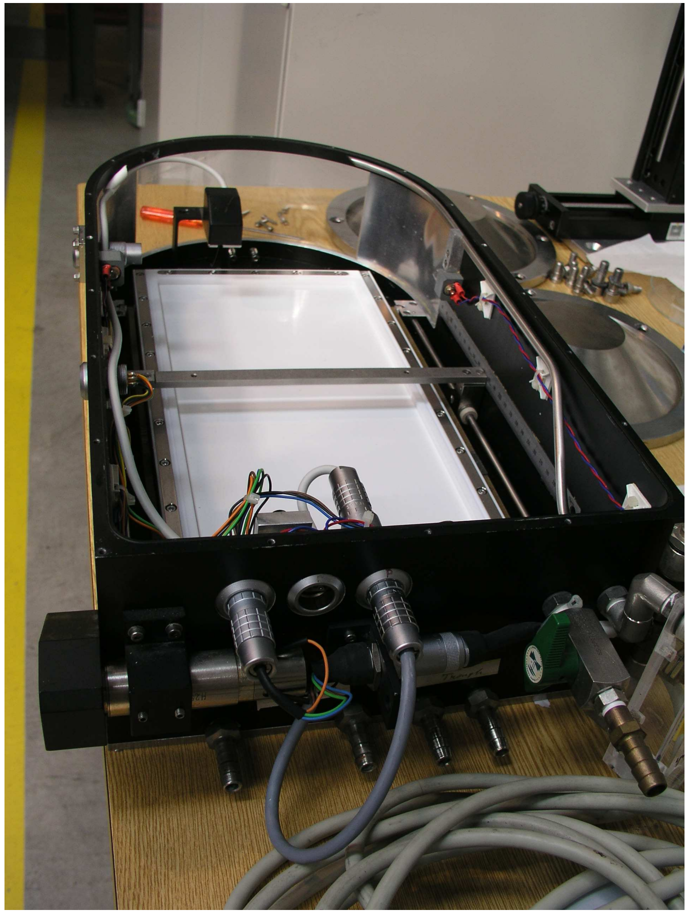
Ni/Ti multilayer on Si, 4×3 mm^2

perovskite multilayer on STO, 5×5 mm^2

small samples

i.e. **illumination of a defined area, only**

e.g.
- inner region within a LB-trough ⟶



- inner region of a solid-liquid cell
- samples with electrical contacts
- partially coated substrates
- bent substrates

footprint < substrate

typical dimensions: $10 \times 10\,\mathrm{mm}^2$ to $20 \times 40\,\mathrm{mm}^2$

small samples

i.e. **latteraly inhomogeneous samples**

e.g.
- structured materials
- samples with (large) domains
- bent surfaces ⟶

footprint ≪ substrate

typical dimensions: $0.1 \times 10\,\mathrm{mm}^2$

⇒ scanning of sample area

focusing with elliptic guides

real focusing!

$\Rightarrow$ pre-image $\longrightarrow$ image

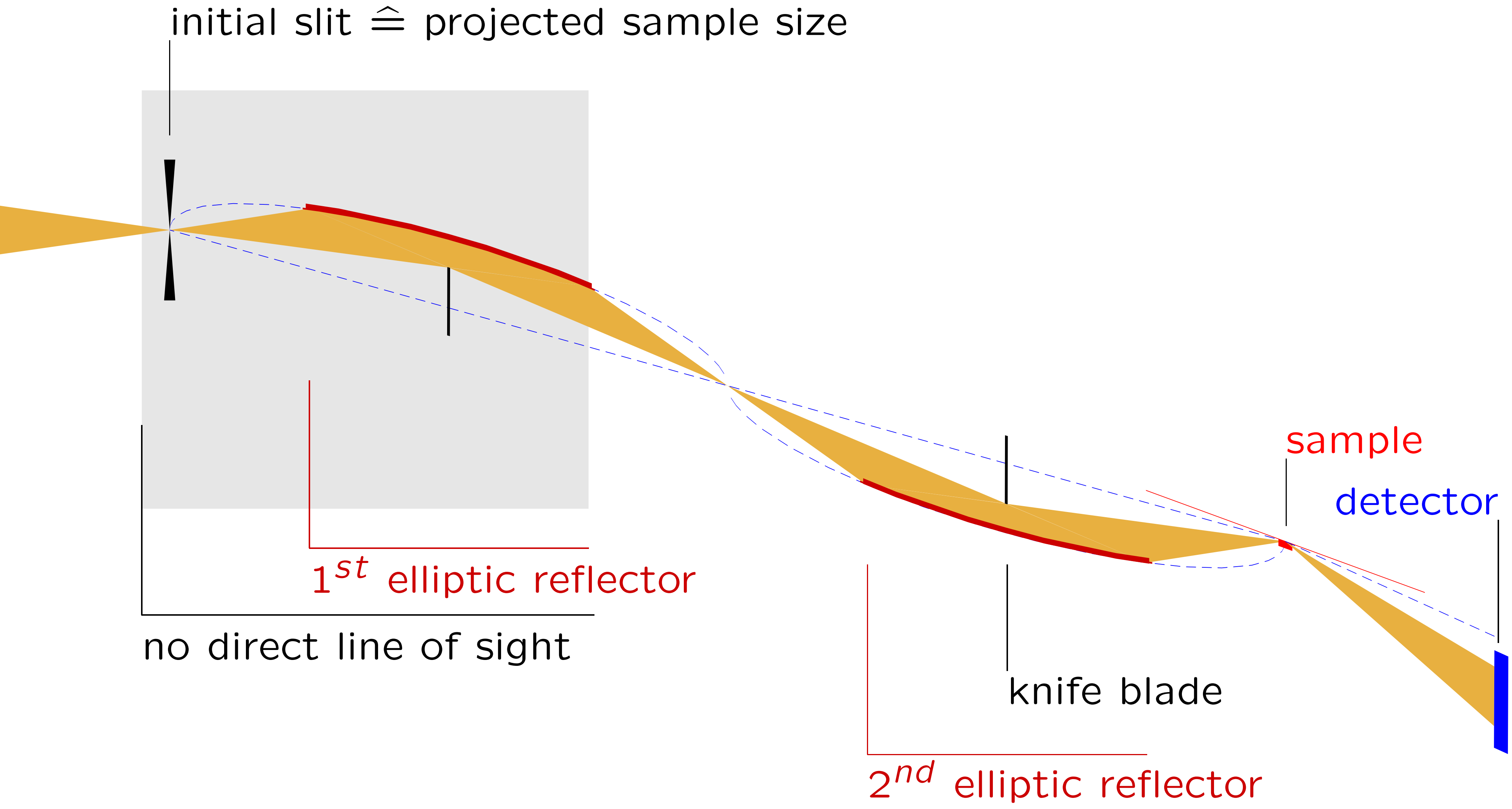
no fancy version of a ballistic guide!

focusing with elliptic guides

generic instrument layout

cut in the scattering plane

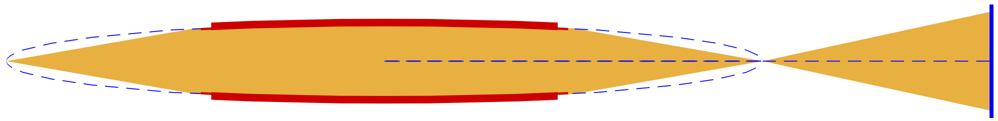
stretched by 10 normal to incident beam



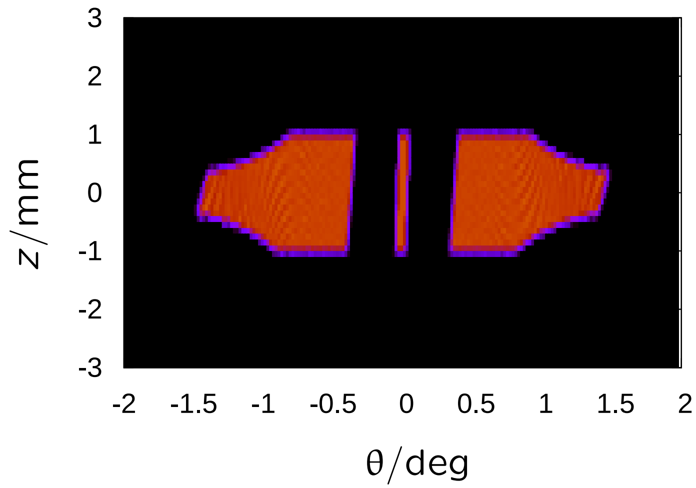
focusing with elliptic guides

why only one branch of an ellipse?

– no structured $I(\theta, z)$



$I(\theta, z)$ map



– one branch can cover $\Delta\theta$

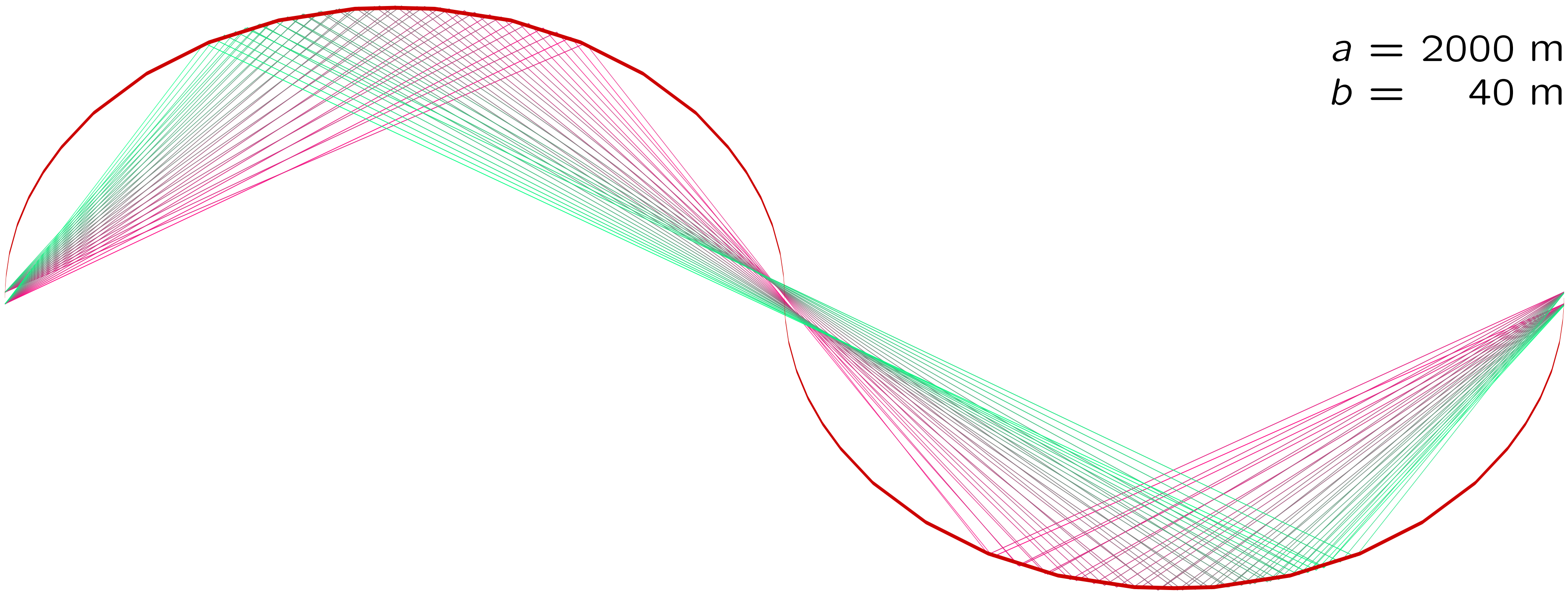
why two subsequent elliptic guides?

– convenent beam manipulation
– guide dimensions not too large

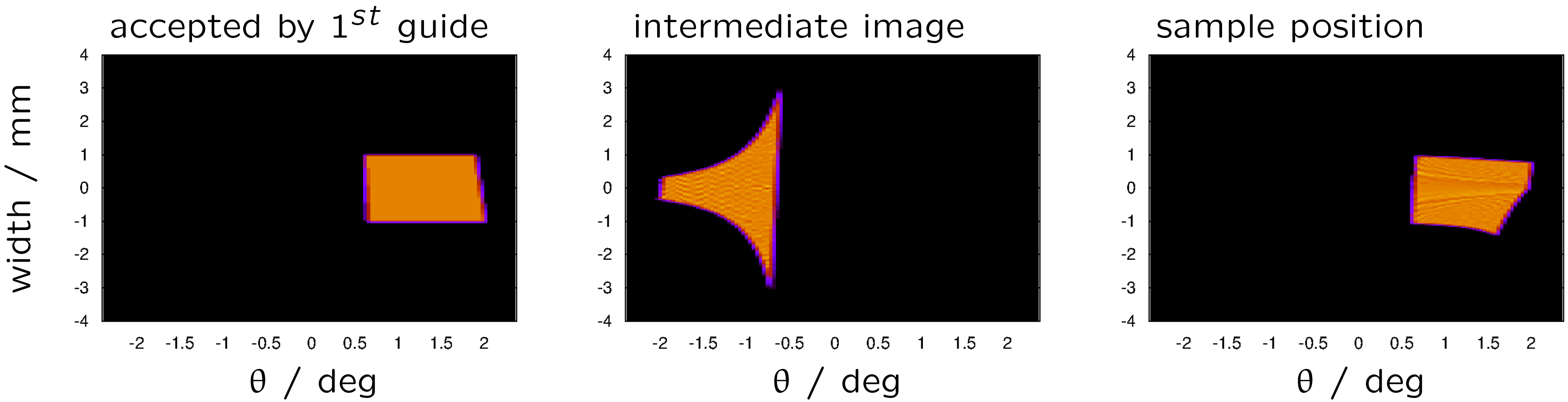
→ correction for coma aberration!

focusing with elliptic guides

coma aberration — and its correction

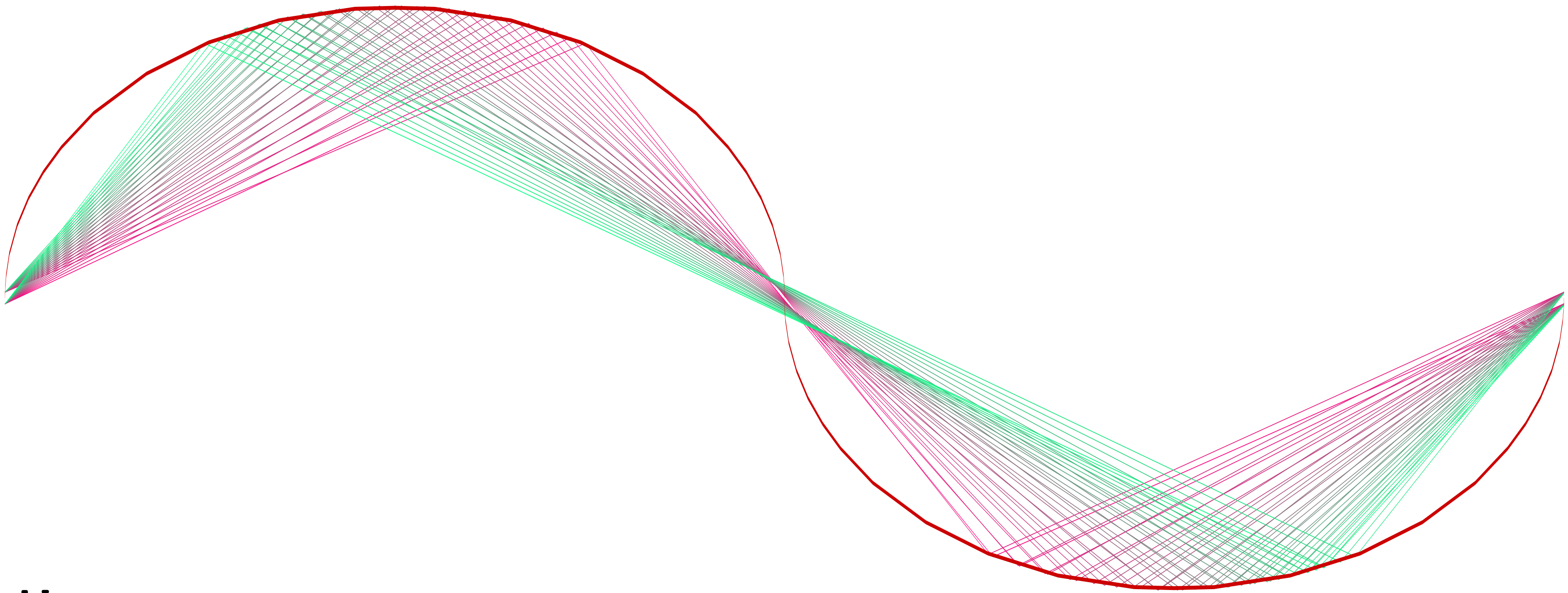


$a = 2000$ mm
$b = 40$ mm



focusing with elliptic guides

coma aberration — and its correction



limitations:

– finite length of the guides

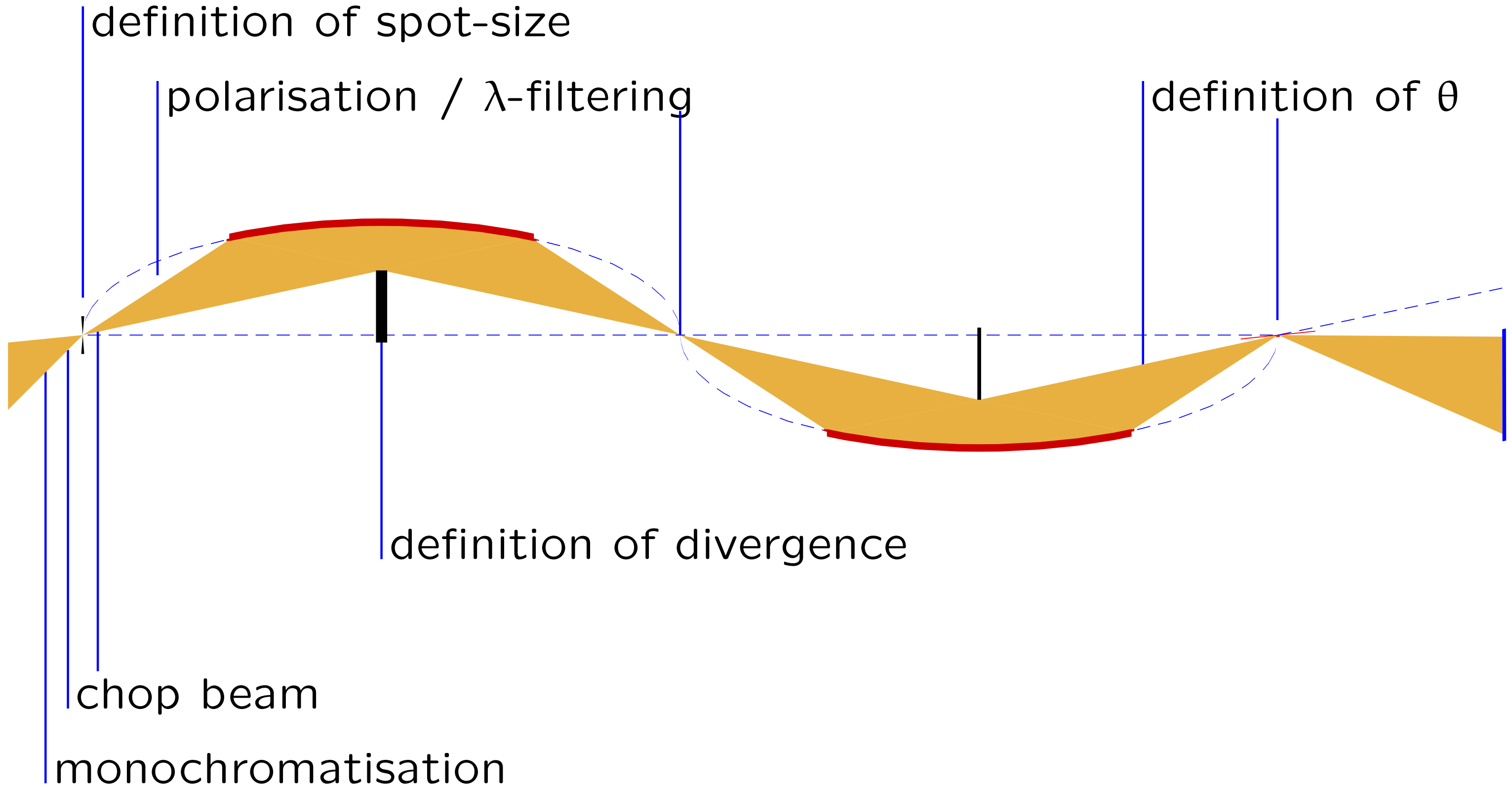
– non-perfect coating

oportunities:

– use aberration to reduce beam spot or divergence at the sample

focusing with elliptic guides

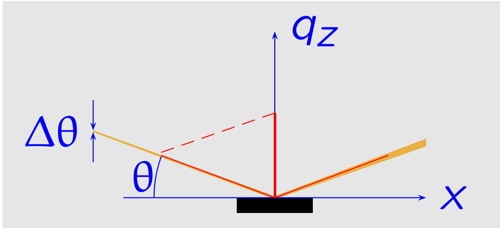
operation modes for TOF: (non-TOF operation is also possible!)

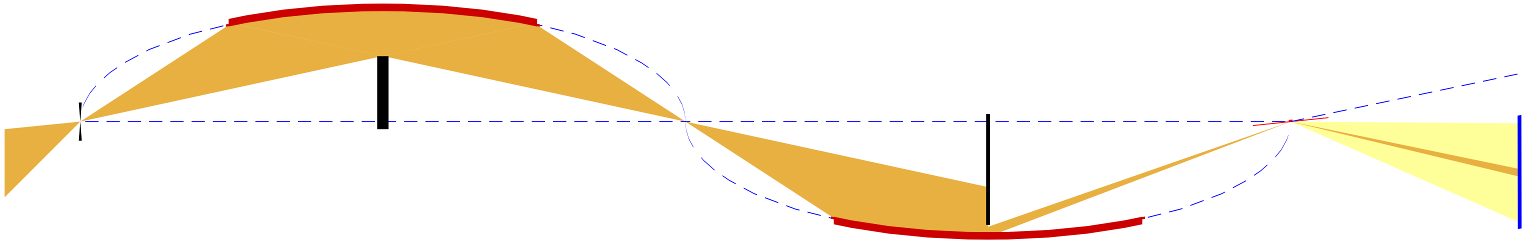


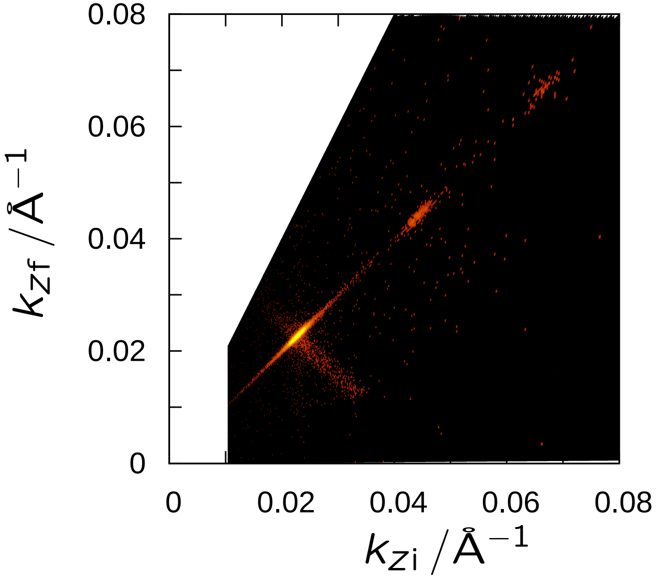
focusing with elliptic guides

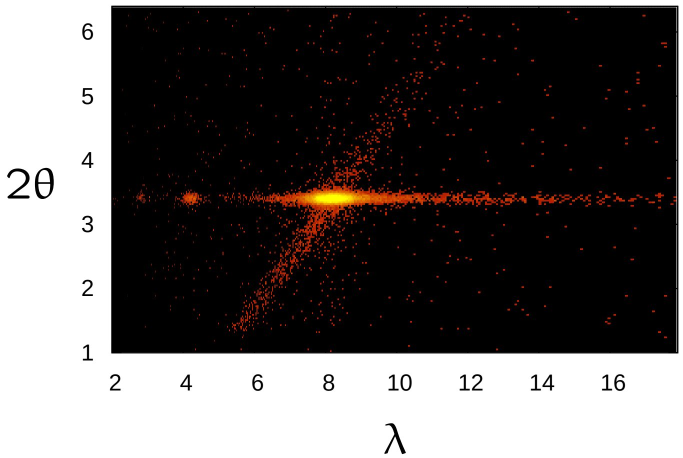
mode: almost conventional

– beam is still convergent
– off-specular measurements are feasible







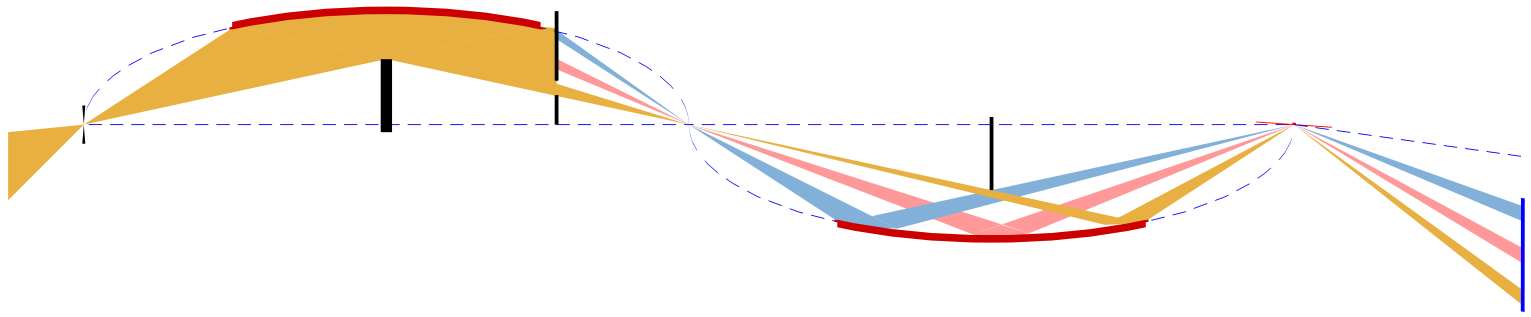


focusing with elliptic guides

mode: wide q-range

– vary θ with fixed sample position

– shift diaphragm (chopper) between pulses



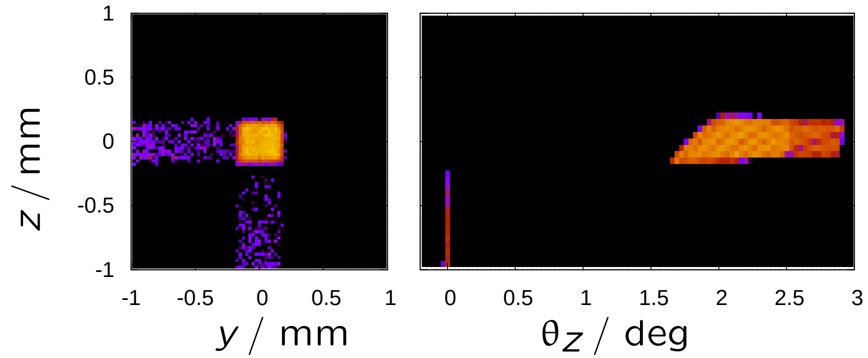
– suited for liquid surfaces

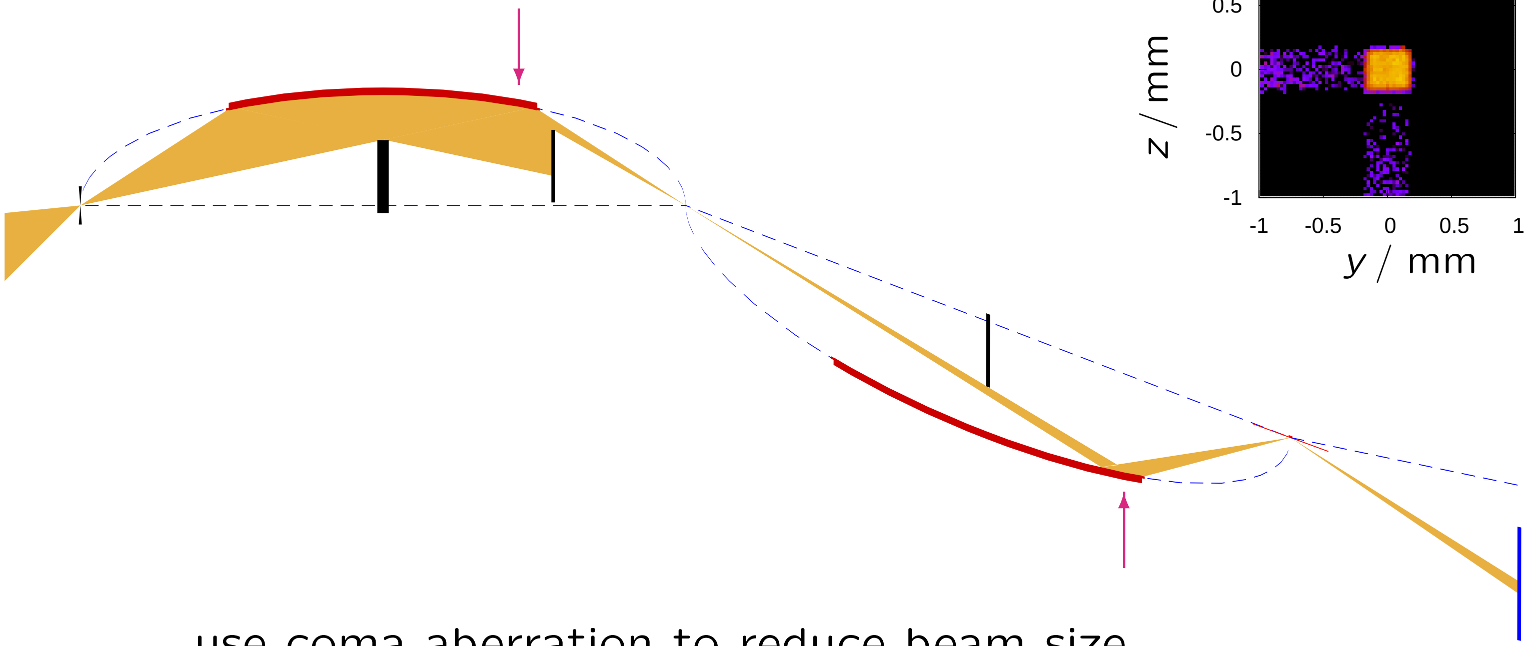
focusing with elliptic guides

mode: small spot size

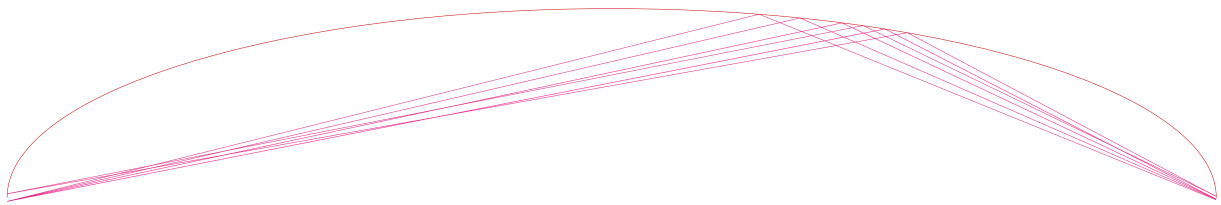
– uses focusing due to coma aberration
– scanning mode possible

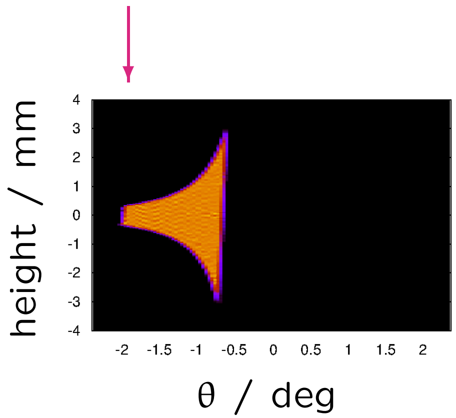
$I(y, z)$ and $I(z, \theta_z)$ at the sample
for a $1 \times 1\,\mathrm{mm}^2$ entrance slit





use coma aberration to reduce beam size

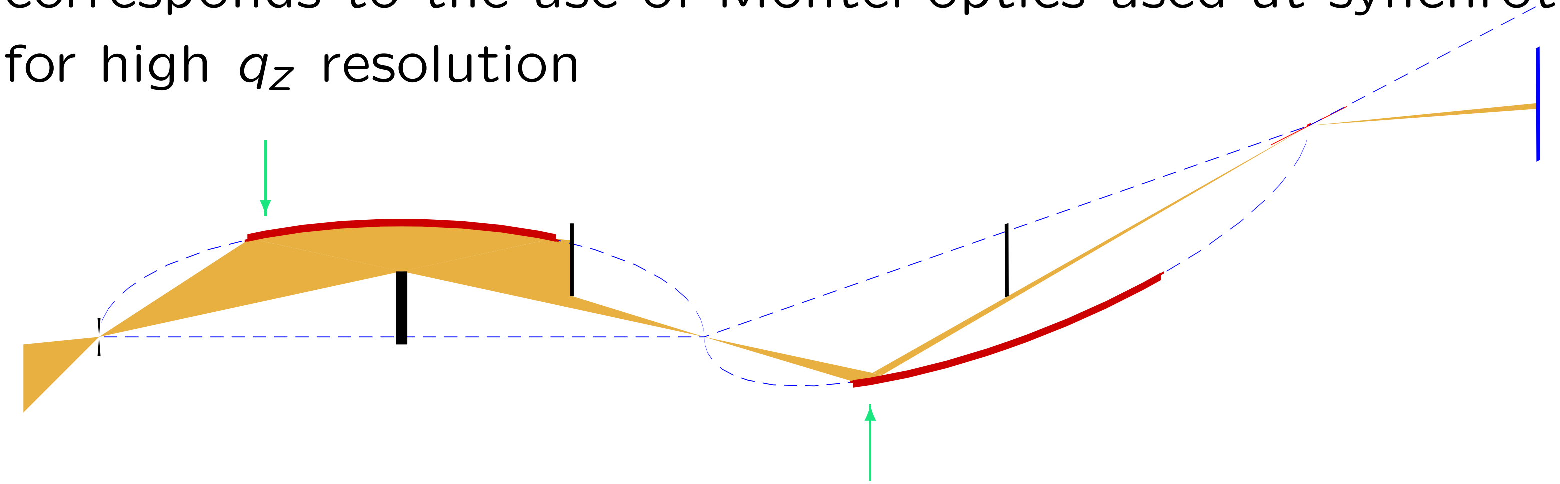




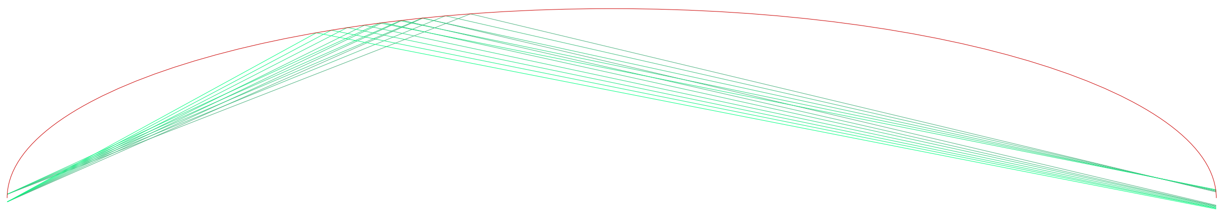
focusing with elliptic guides

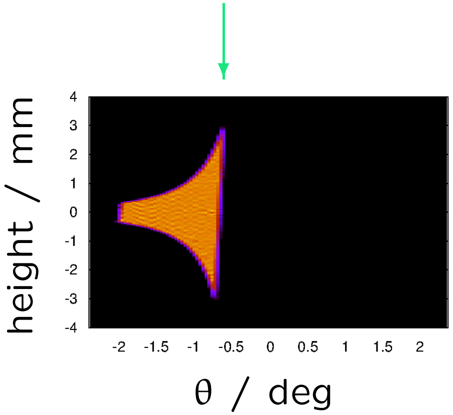
mode: low-divergent beam

– uses defocusing due to coma aberration
– corresponds to the use of Montel optics used at synchrotrons
– for high q_z resolution



use coma aberration to reduce divergence

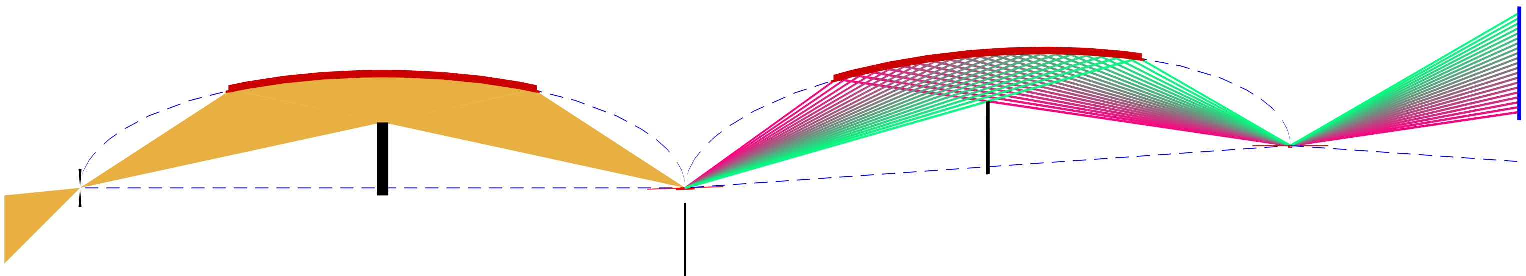




focusing with elliptic guides

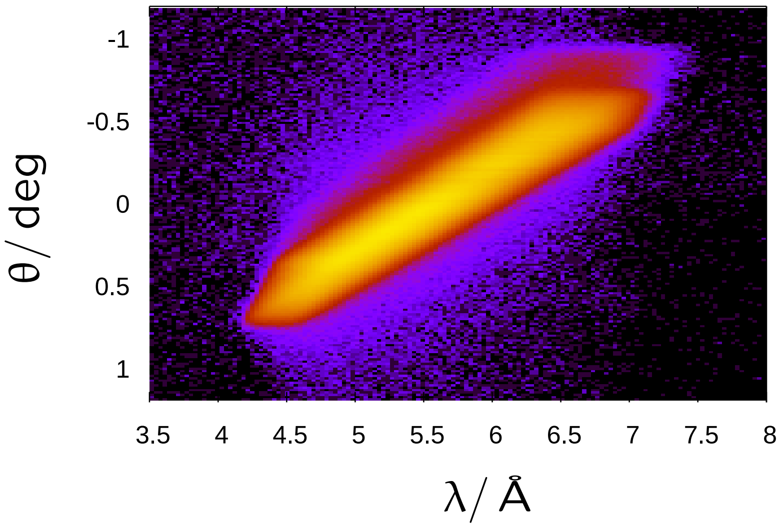
mode: angle/energy encoding

– use a ml-monochromator at the intermediate image
– spectral analysis of the beam: λ / θ encoding



$\log_{10}[I(\lambda,\theta)]$ after ml monochromator

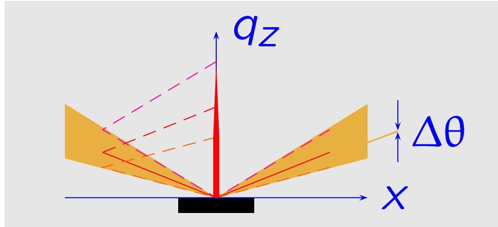
– large λ on small θ
  $\Rightarrow$ wide q_z-range

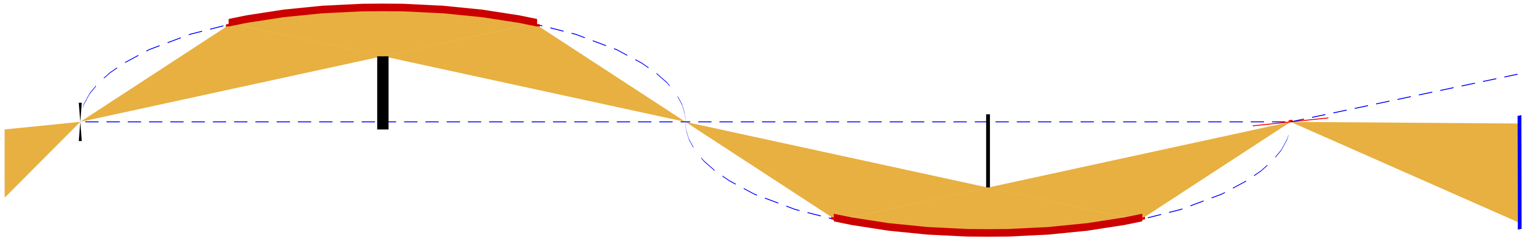


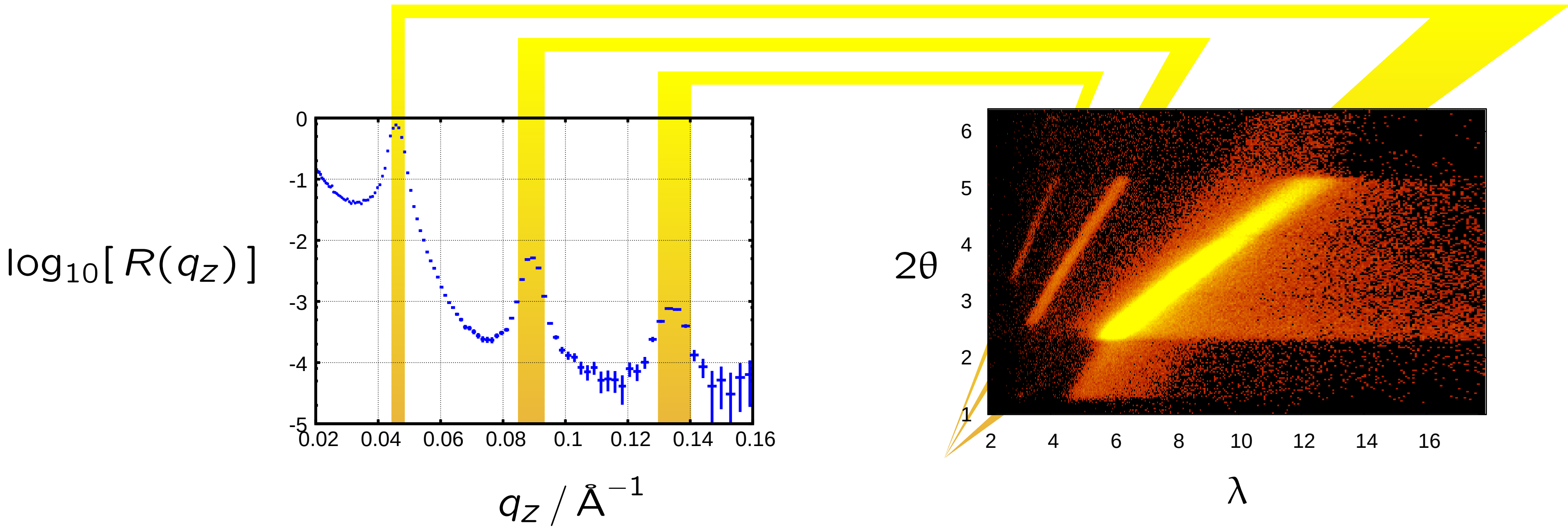
focusing with elliptic guides

mode: high-intensity specular reflectivity

– energy- and angle-dispersive ⇒ gain > 10
– for fast scanning $(T, \mathbf{H}, \mathbf{E} \ldots)$
– or if off-specular scattering is no *problem*

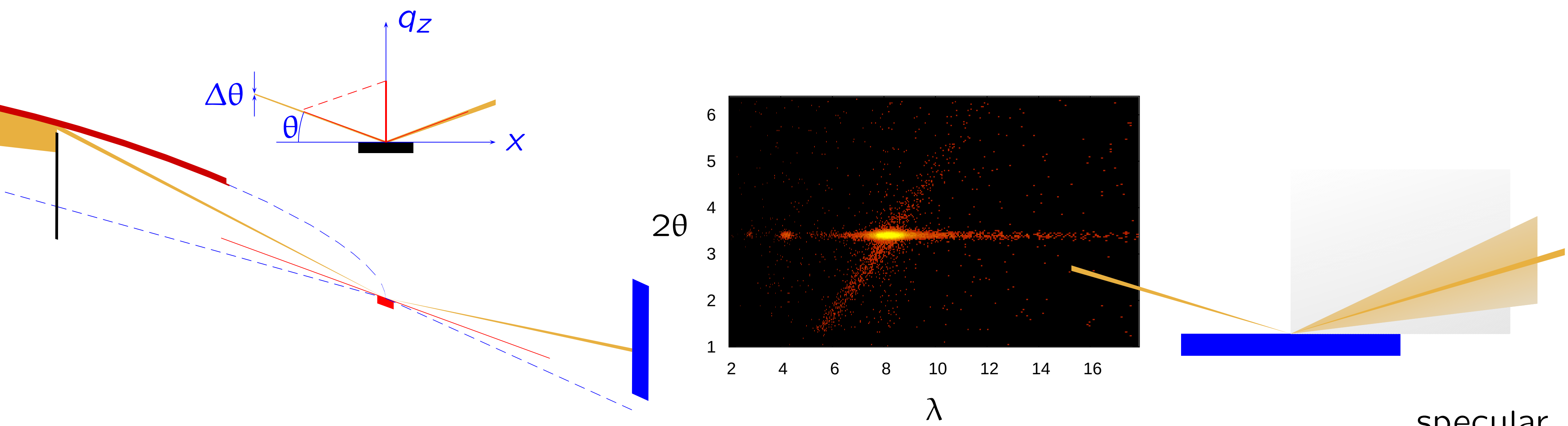


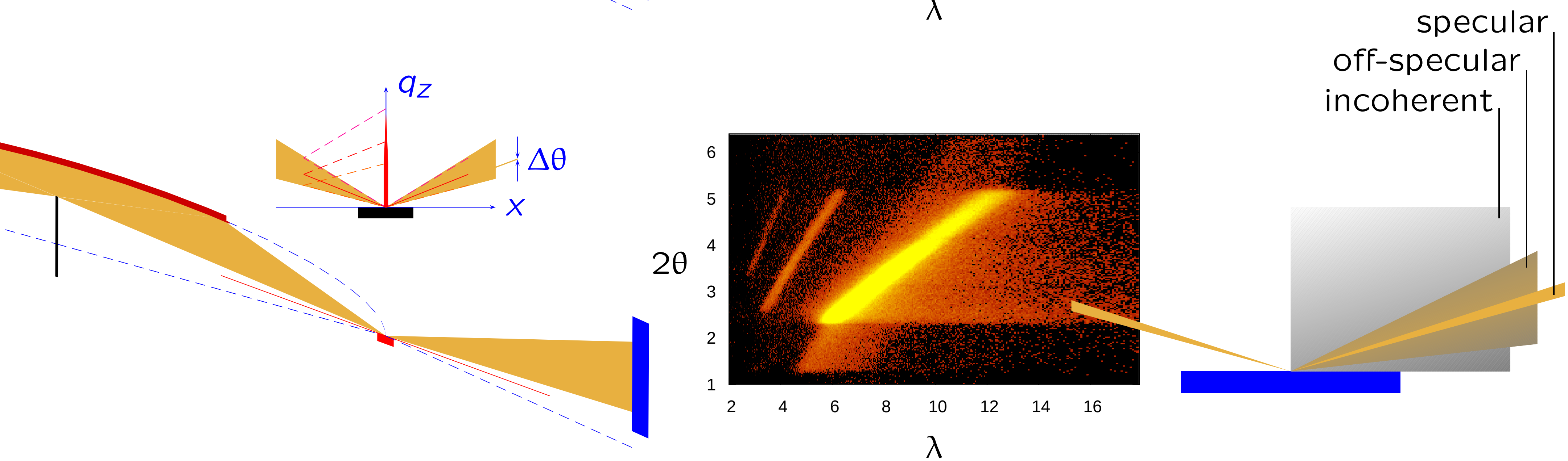




focusing with elliptic guides

high-intensity specular reflectivity vs. allmost conventional





realisation

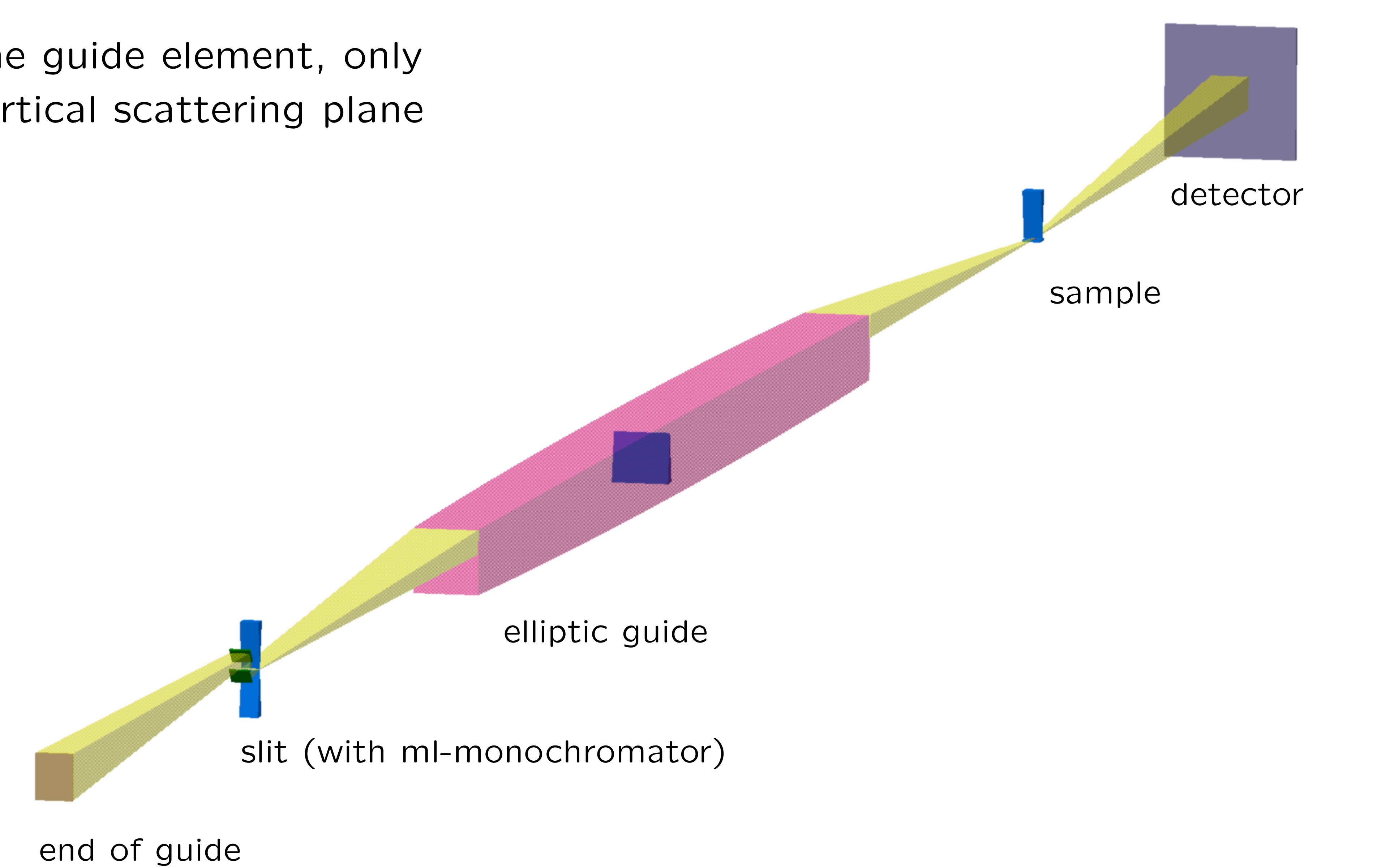
add-on for Amor

prototype on BOA

concept for the ESS

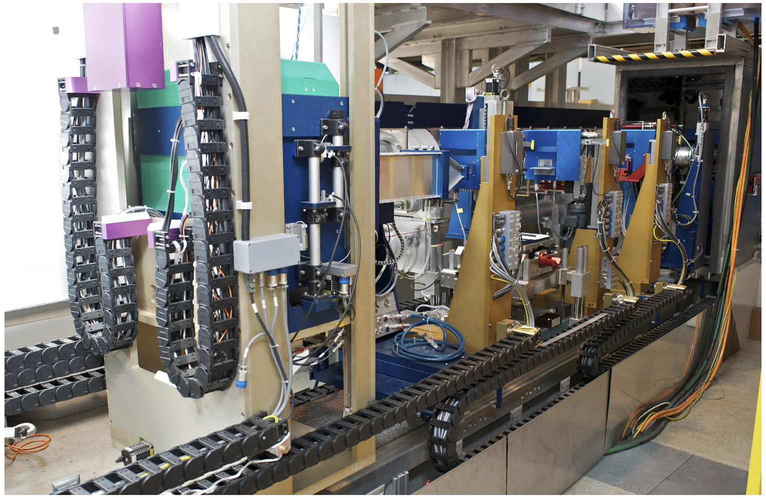
realisation: add-on for Amor

one guide element, only
vertical scattering plane



realisation: add-on for Amor

Amor, conventional TOF set-up



8 m granite block

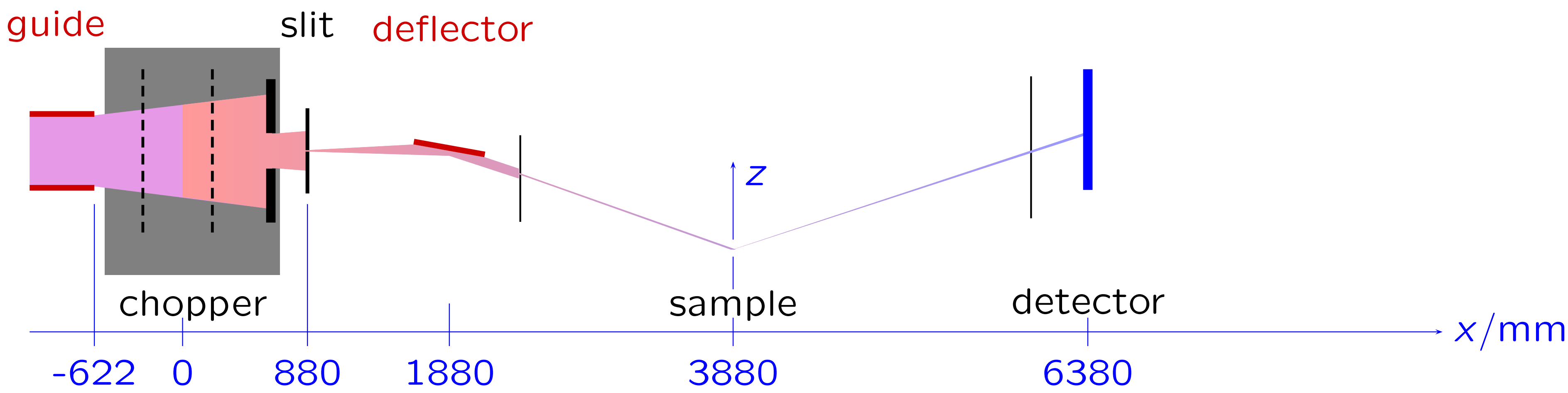
maximum length chopper to detector = 10 m

$2\theta \in [-3^\circ, 12^\circ]$

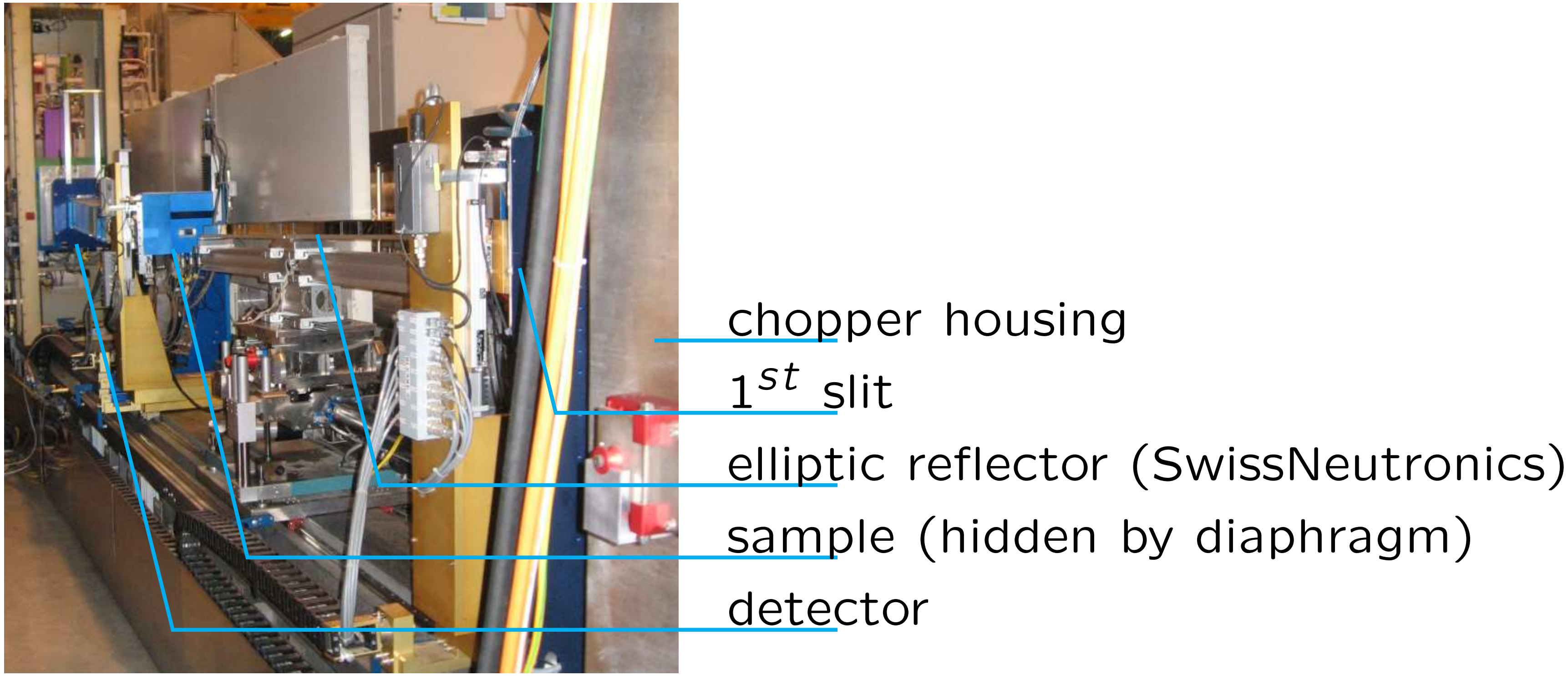
$\lambda \in [2\,\text{Å}, 18\,\text{Å}]$

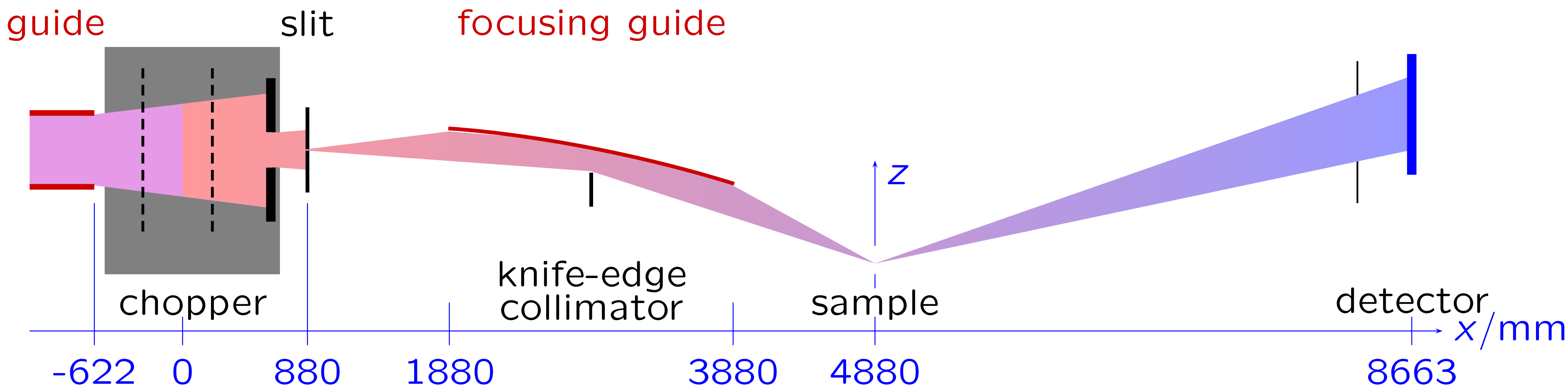
vertical scattering plane

detectors: ^{3}He single and area ($180 \times 180\,\text{mm}^2$)



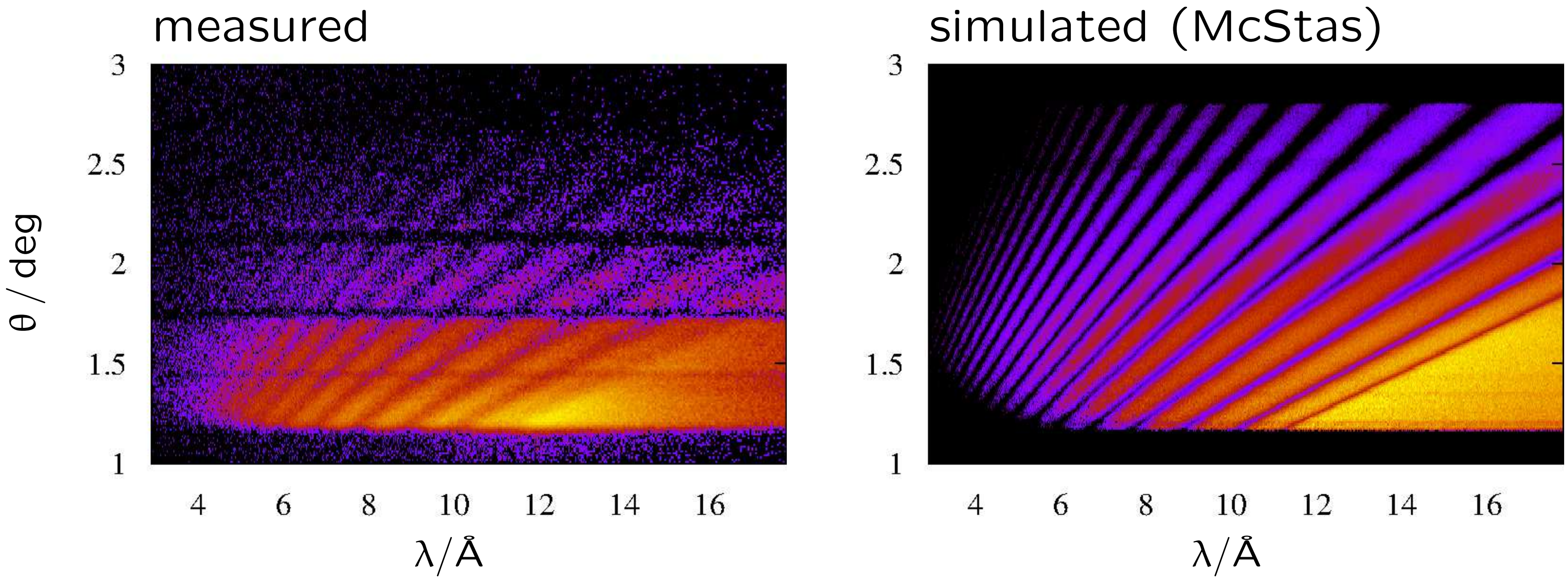
realisation: add-on for Amor

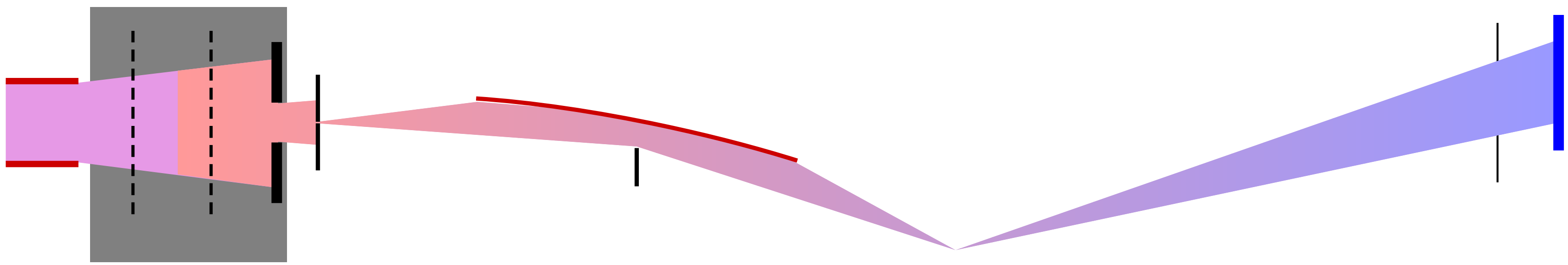




realisation: add-on for Amor

measurements: 1000 Å Ni film on glass, $9 \times 9\,\mathrm{mm}^2$





realisation: add-on for Amor

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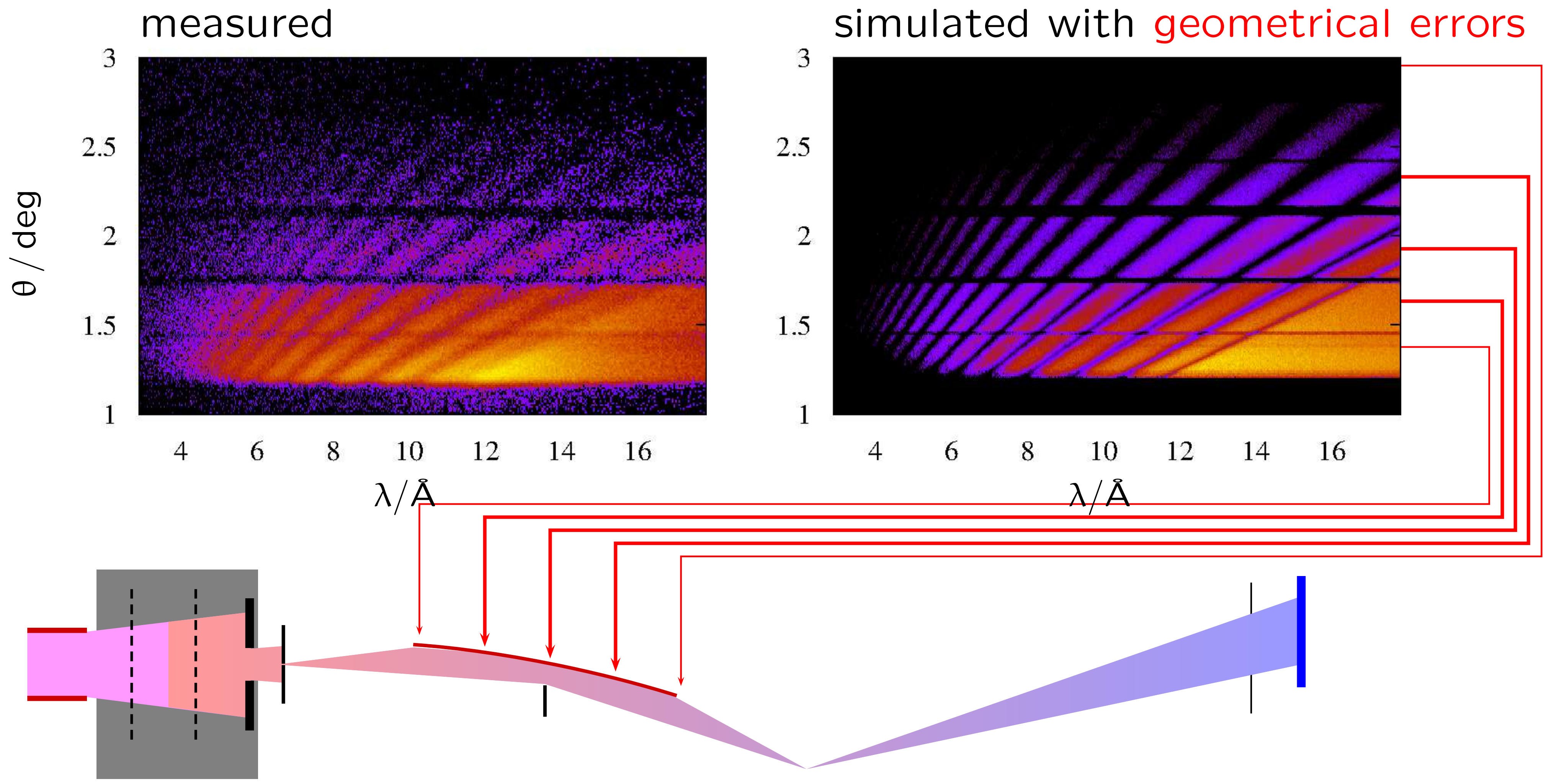
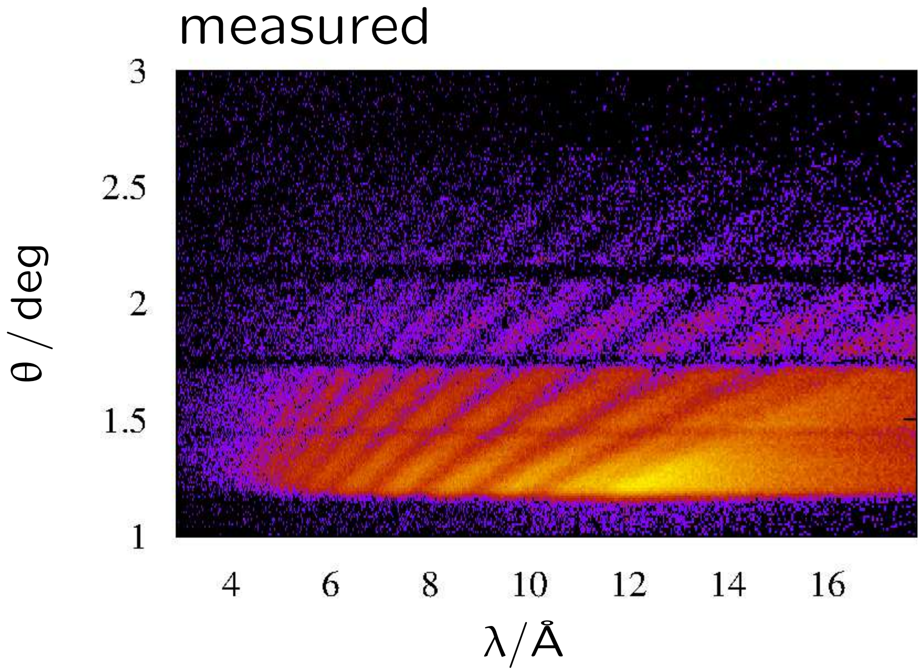
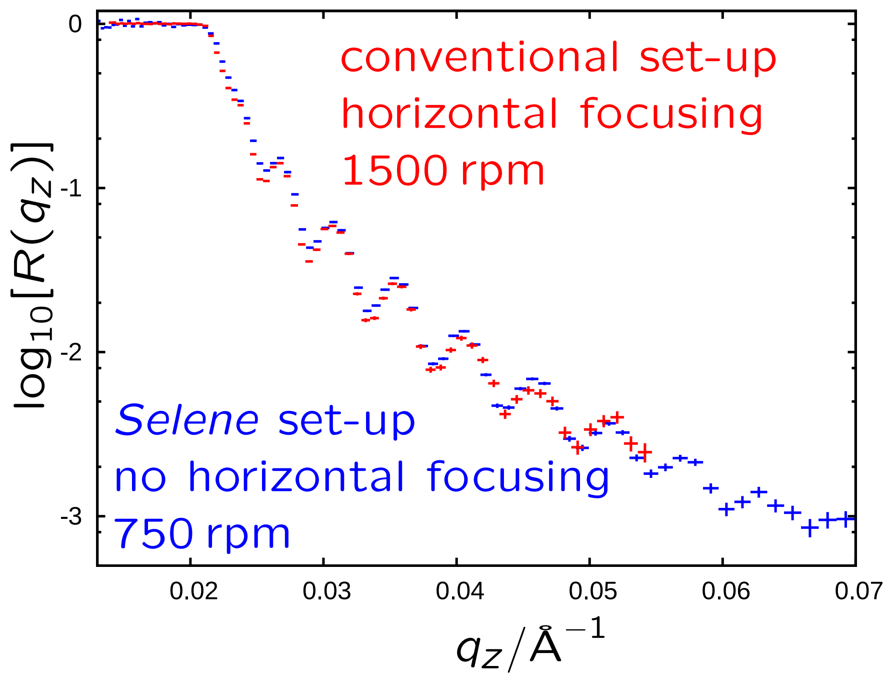


4 guide elements à 500 mm

realisation: add-on for Amor

measurements: 1000 Å Ni film on glass, $9 \times 9\,\mathrm{mm}^2$





measurement time:

conventional	5 h
Selene	45 min
gain-factor	6.7

realisation: add-on for Amor

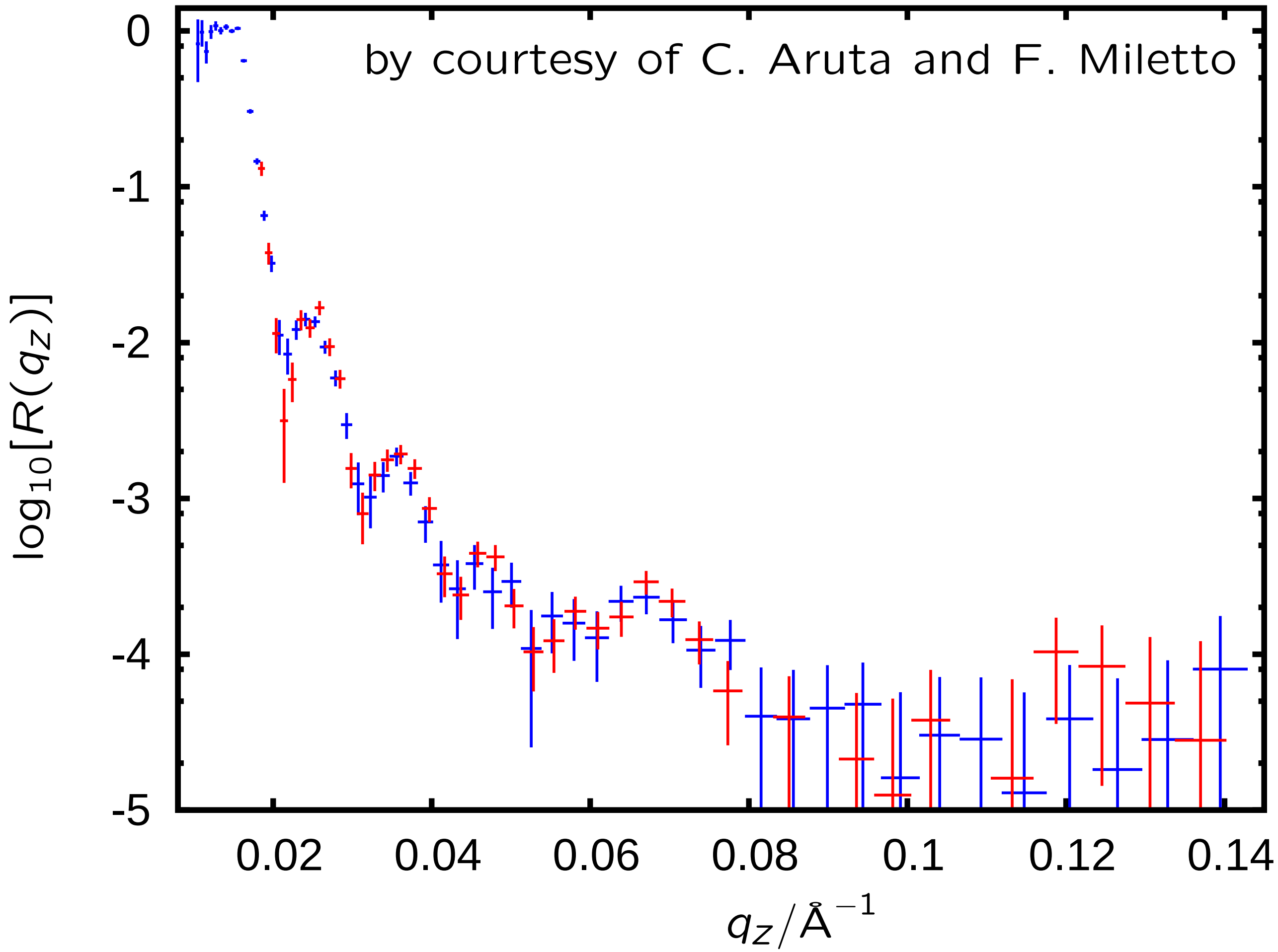
$[La_{2/3}Sr_{1/3}MnO_3 / SrTiO_3]_4 / NGO$ $5 \times 5\,mm^2$

– no focusing in sample plane

– TOF mode, $\lambda \in [2 \ldots 18$ Å]

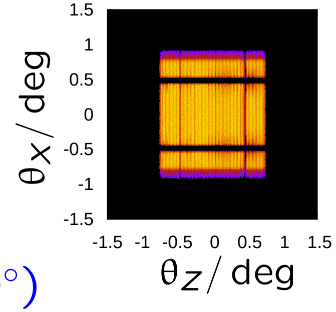
– measurement time:

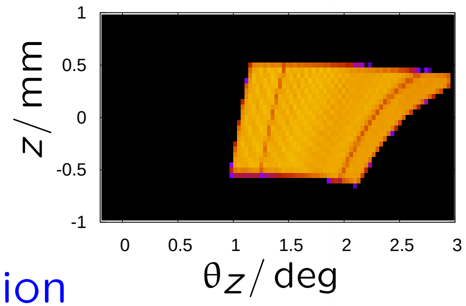
conventional	6.5 h
Selene	45 min
gain-factor	8.3

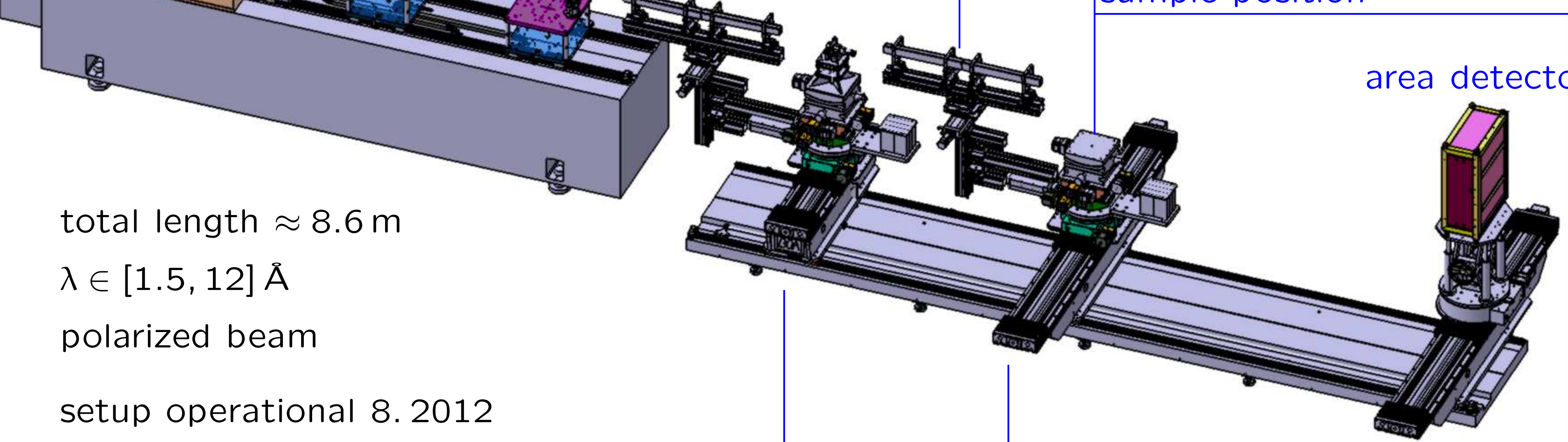


realisation: prototype on BOA

BOA is a test beam line at SINQ, PSI







total length $\approx 8.6\,\mathrm{m}$

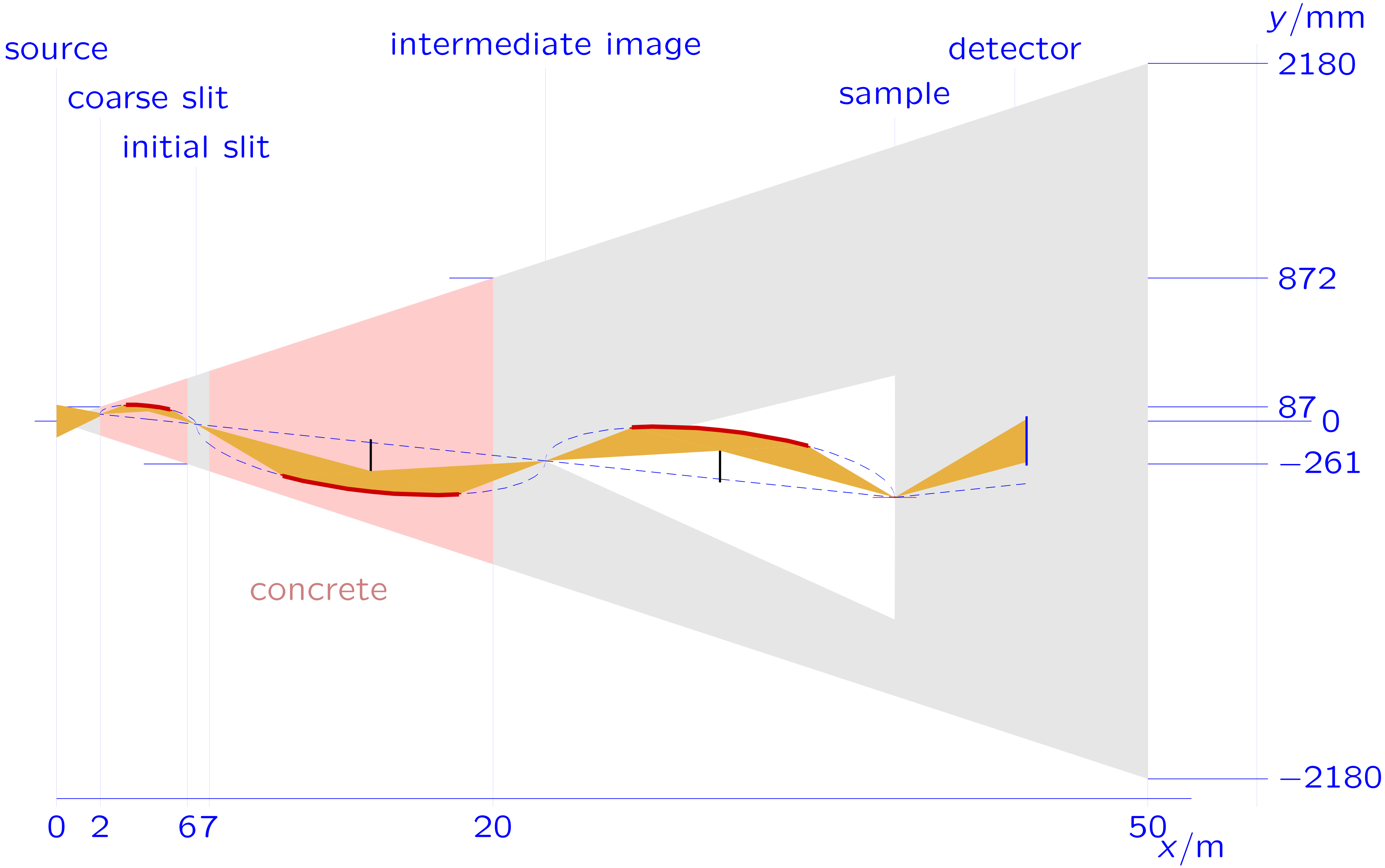
$\lambda \in [1.5, 12]\,\text{Å}$

polarized beam

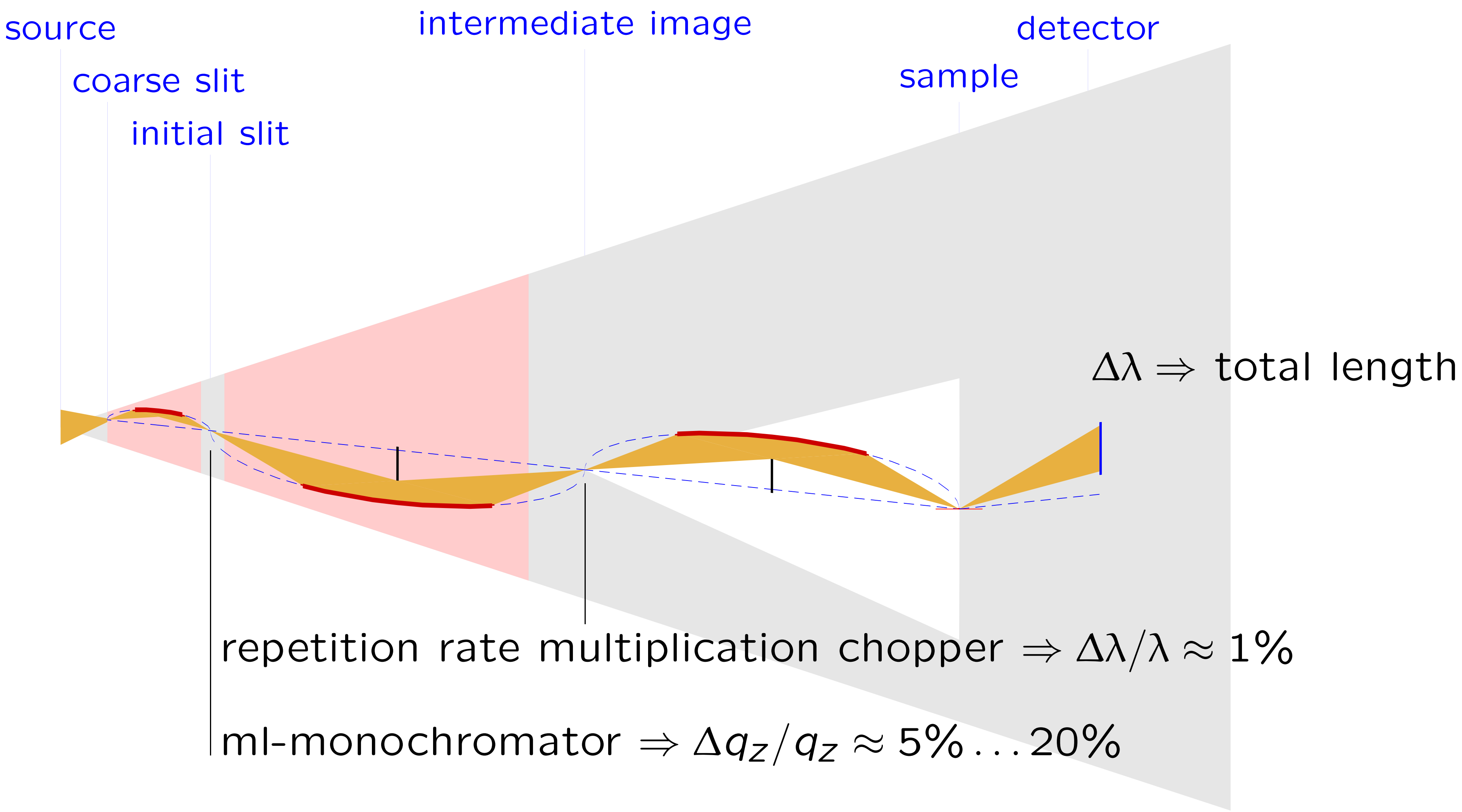
setup operational 8. 2012

realisation: concept for the ESS

schematic lay-out of the reflectometer for tiny samples



realisation: concept for the ESS

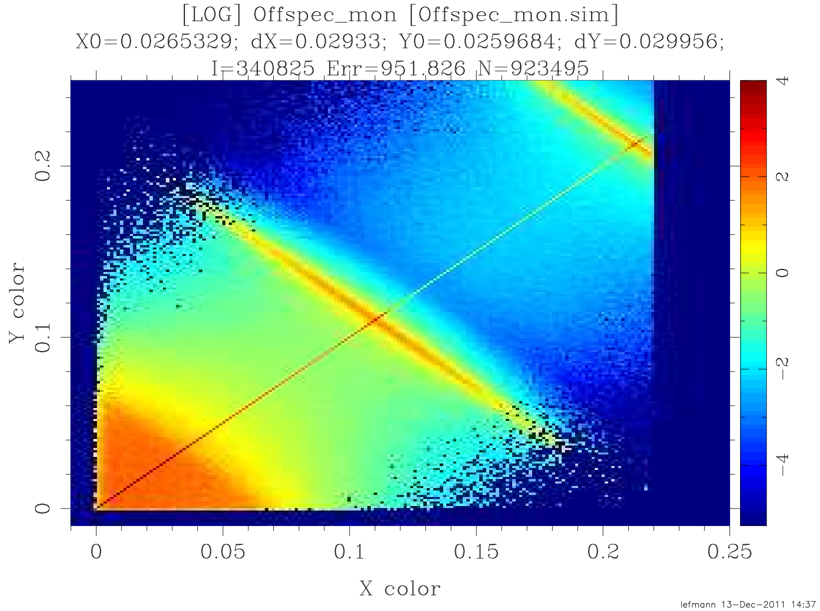


final remarks

critical points

- accuracy of guides
  - how to assemble the 0.5 m units without errors
- alignment of guides
- scattering at focal points
  - from diaphragms / choppers
  - off-specular form mirrors

first simulation with off-specular scattering with McStas (K. Leffman, 12. 2011)



- influence of gravity
  - will be simulated within the next months

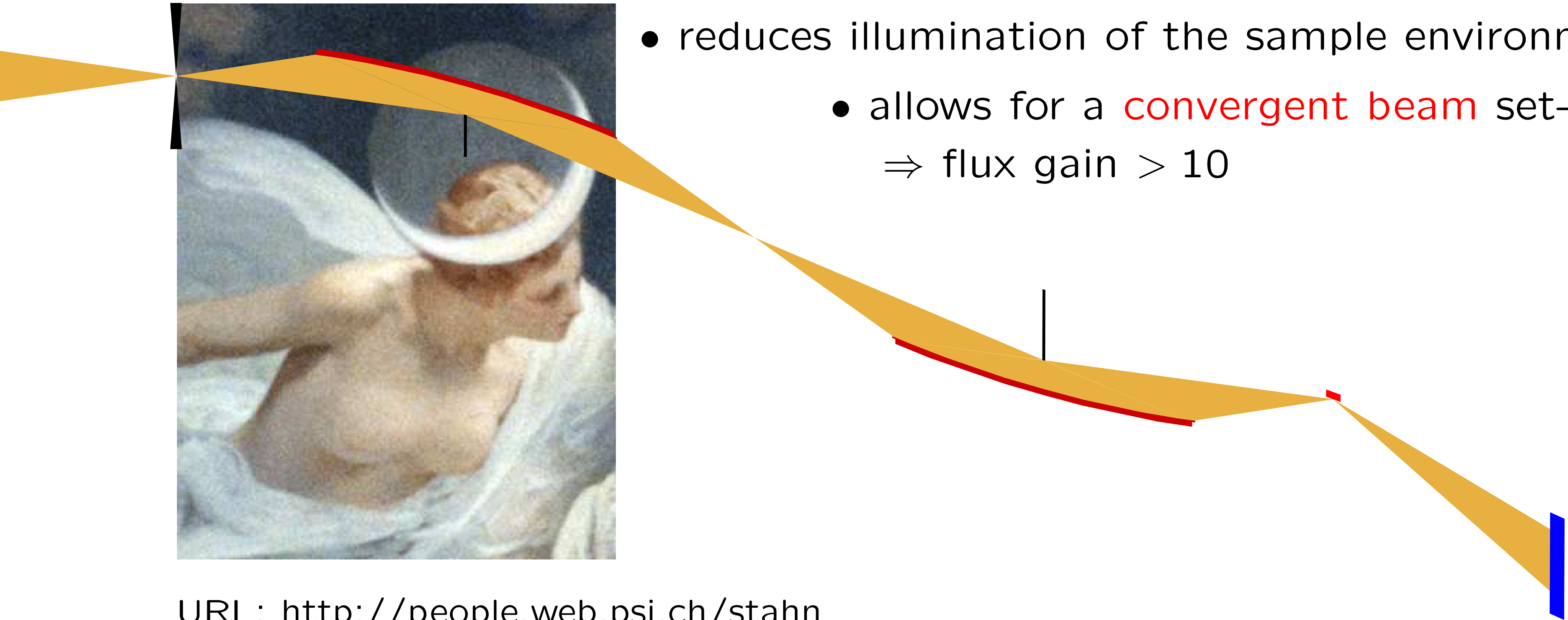
thanks to

Tobias Panzner Uwe Filges	McStas simulations, experiments, BOA
Dieter Graf	construction
Marcel Schild	electronics
SwissNeutronics	elliptic guide development
Marité Cardenas Anette Vickery	experiments
Hanna Wacklin Bob Cubitt Peter Böni Uwe Stuhr Frederic Ott Thomas Krist	discussions

Selene is a guide concept

which . . .

- prevents direct line of sight
- reduces radiation in the guide
- allows for convenient beam manipulation
- reduces illumination of the sample environment
- allows for a convergent beam set-up
  $\Rightarrow$ flux gain > 10



URL: http://people.web.psi.ch/stahn
J. Stahn, *et al.* N.I.M. A **634**, S12 (2011)
J. Stahn, *et al.* Eur. Phys. J. Appl. Phys., doi:10.1051/epjap/2012110295