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study on a focusing, low-background neutron delivery system

approach:

define the beam, starting at the sample, by:
– size at the sample position
– divergence
– wavelength, $\Delta\lambda/\lambda$
and avoid everything else!

small samples (i.e. in the mm^2, mm^3 range)

focusing

low-background

filtering / beam-profiling far from the sample define the beam, starting at the sample

$\Rightarrow$ beam line lay-out

– shading optics

– focusing optics

$\longrightarrow$ aberration

application to a specular reflectometer

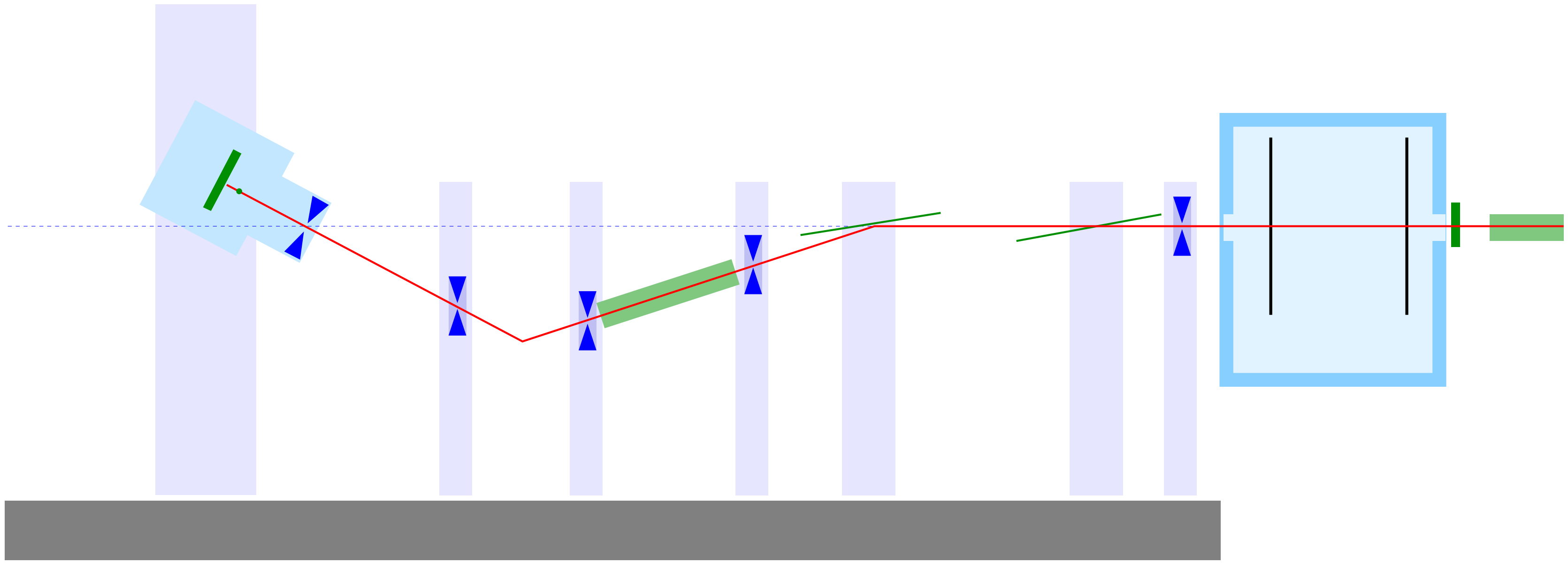
McStas simulations on the performance

extention to diffraction / spectroscopy

next steps

prototype for amor

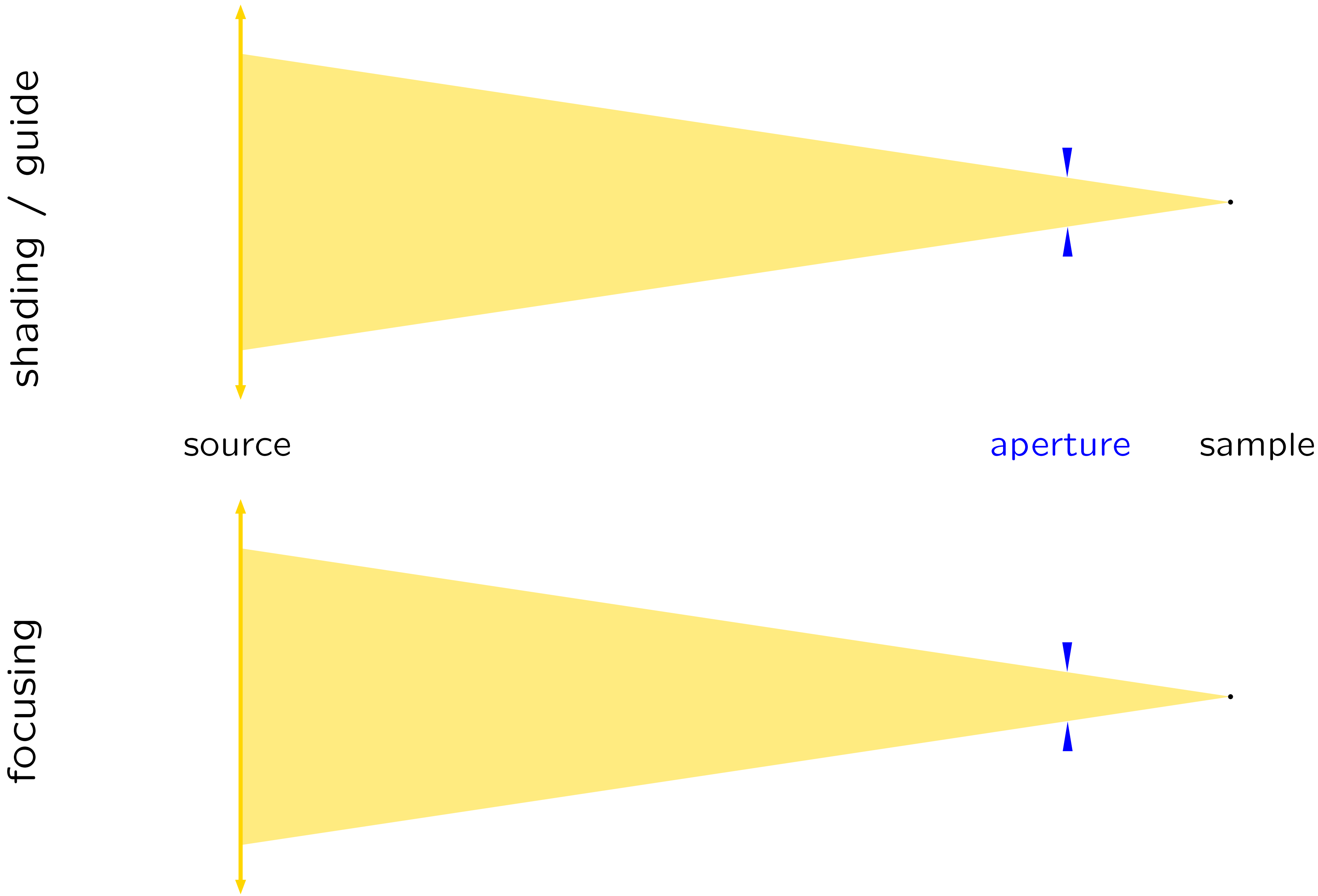
Amor – polarised reflectometer in TOF mode



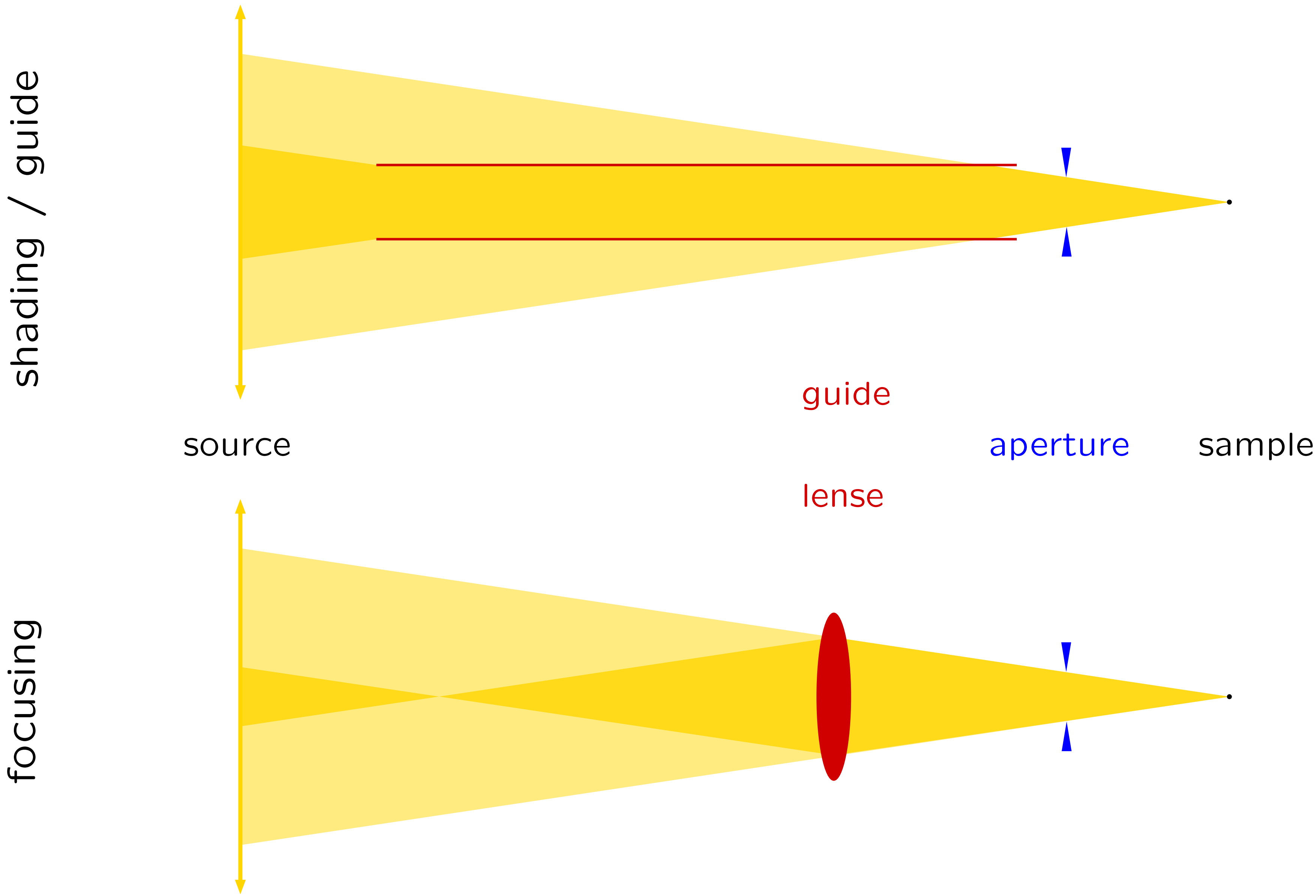
losses between guide ($50 \times 50\,\mathrm{mm}^2$) and sample:

chopper:	96%
first diaphragm:	$> 80\%$
frame overlap filter:	$\approx 5\%$
polariser:	$> 60\%$
sample ($10 \times 10\,\mathrm{mm}^2$):	20%
Π:	$> 99.75\%$

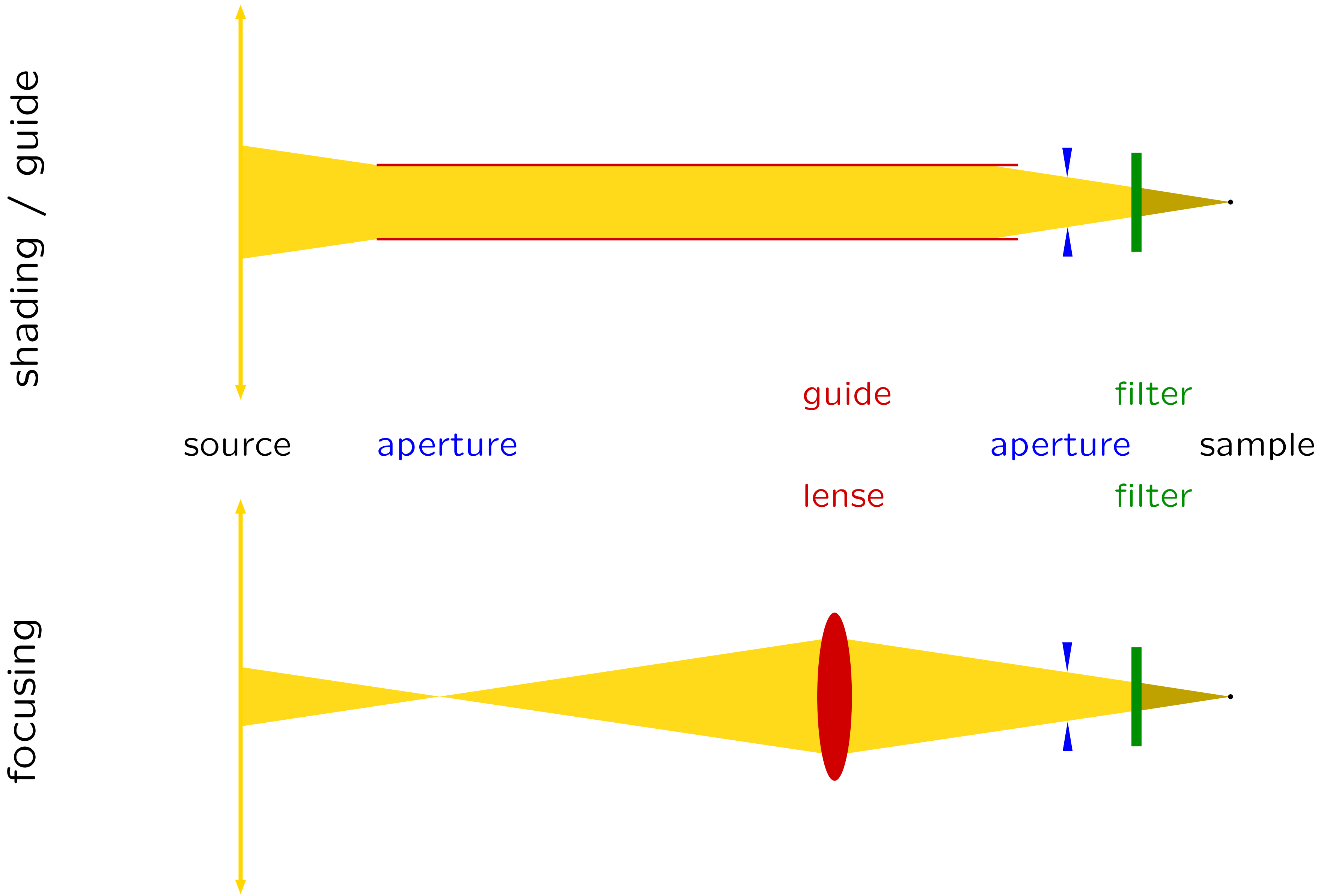
beam defined by • required beam divergence



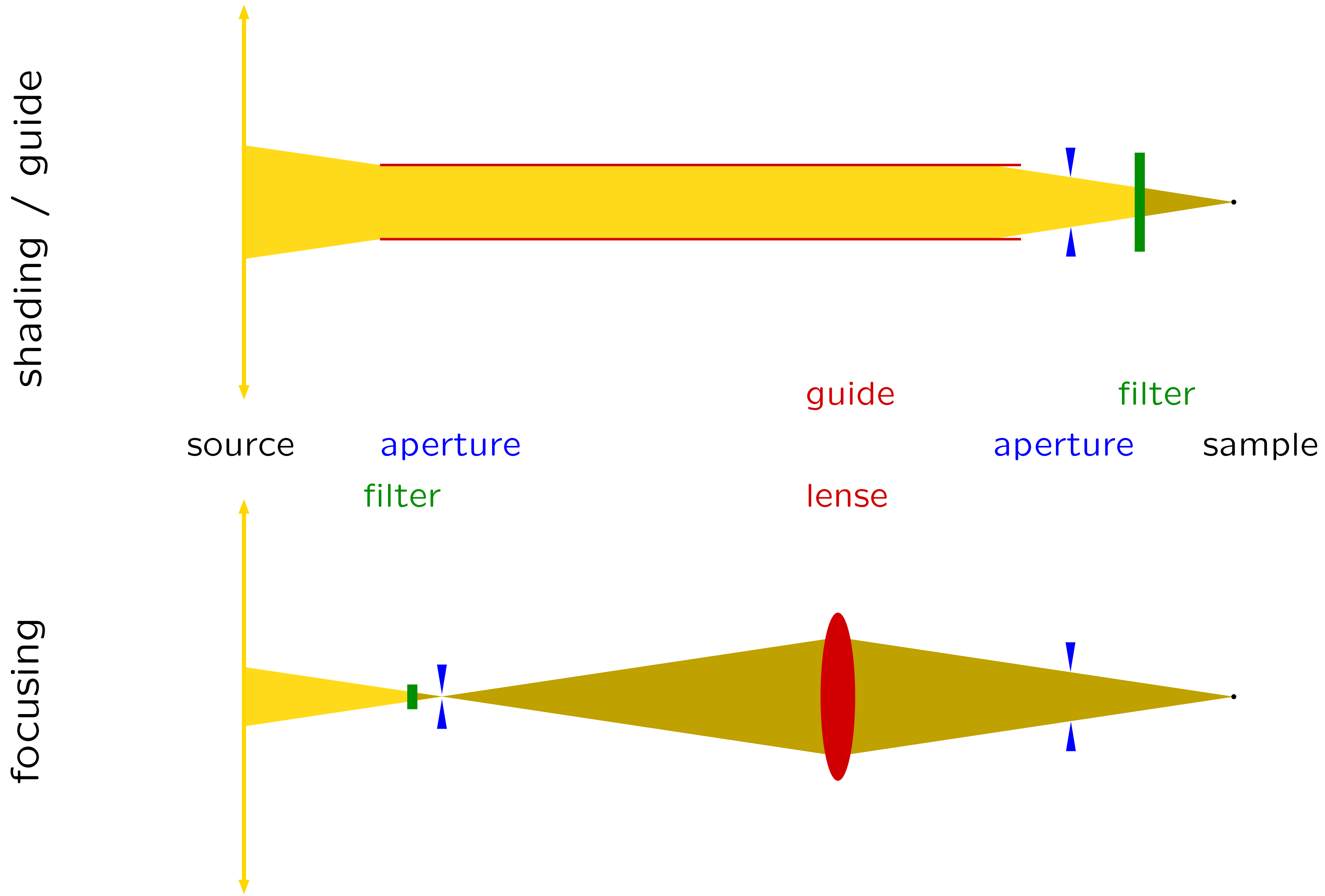
beam defined by • finite source size



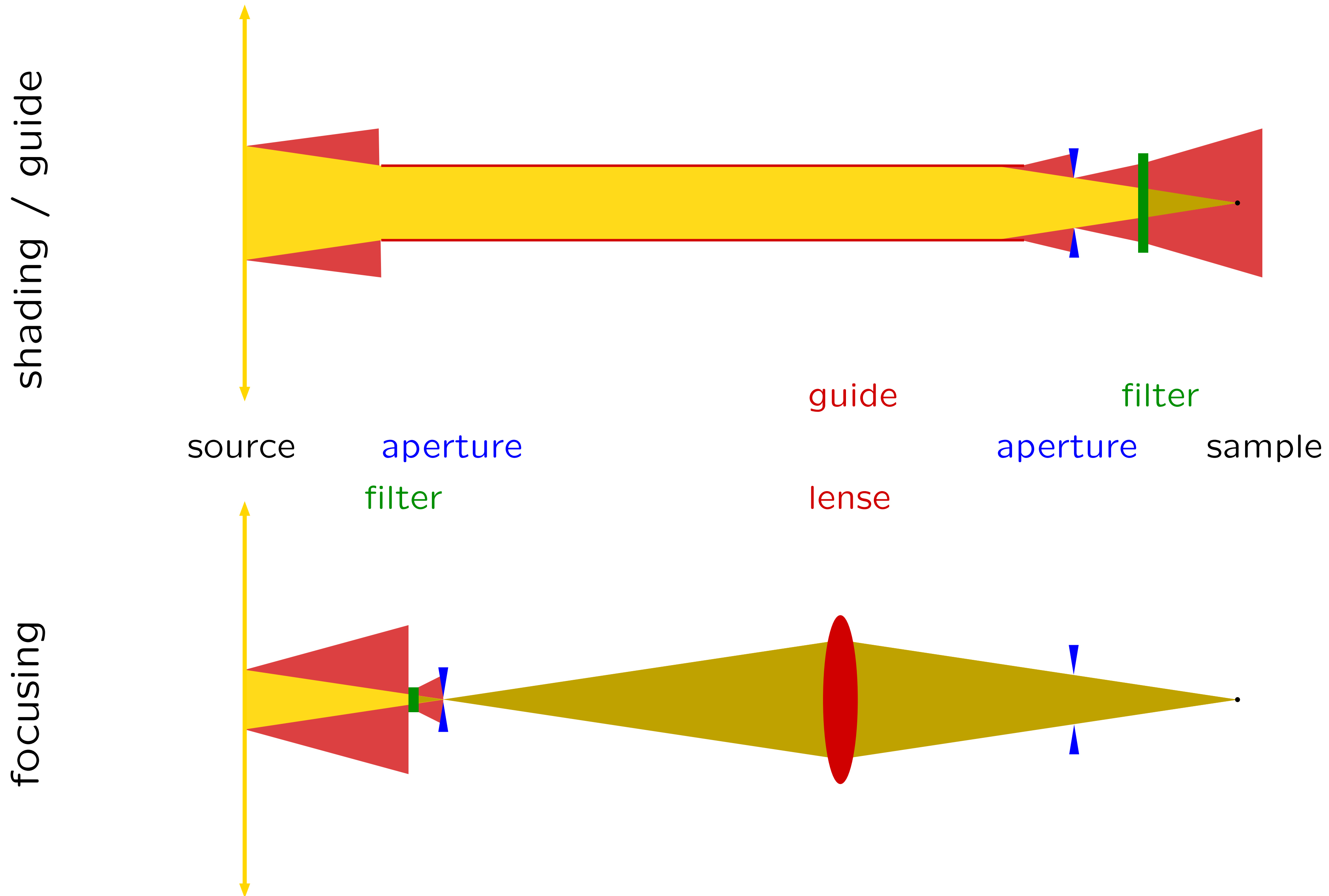
beam defined by • filtering (polarisation / monochromatisation)



beam defined by • background / radiation issues



background / radiation issues



effect of optical elements on the phase space

non-focusing elements: (*shading optics*)

diaphragm	cuts phase space
plain mirror	alters direction, λ filter
(long) guide	", can be seen as diaphragm + translation

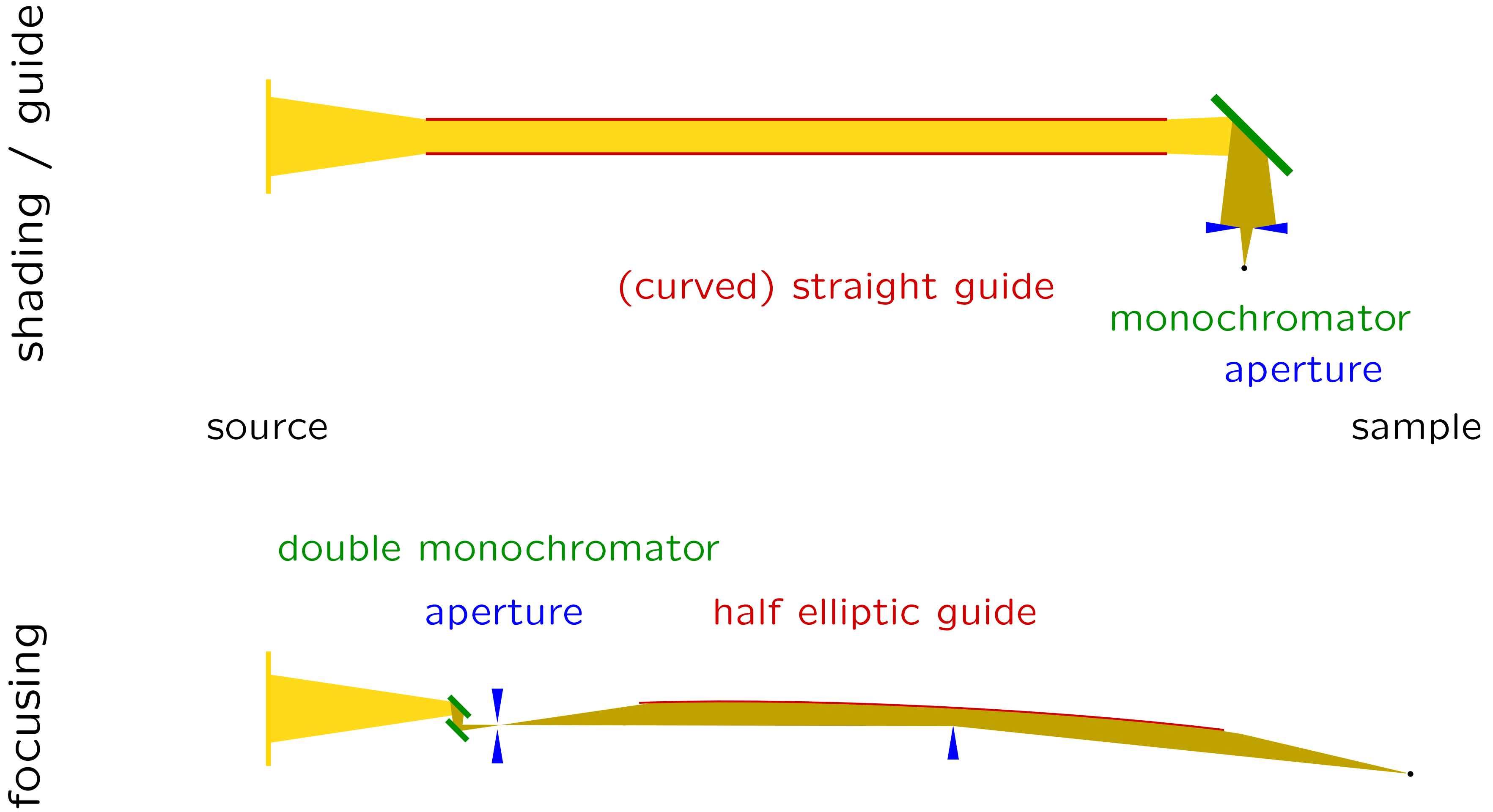
. . . limit and dilute phase space

focusing elements:

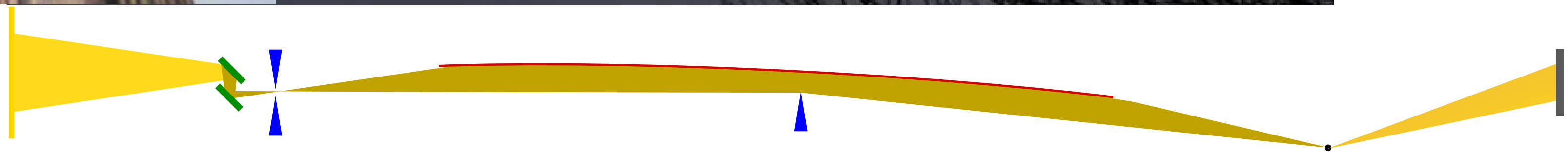
lense	distorts phase space, aberration
bent mirror	", λ filter
focusing guide	", open end $\Rightarrow$ shading + focusing effects

. . . alter and dilute phase space

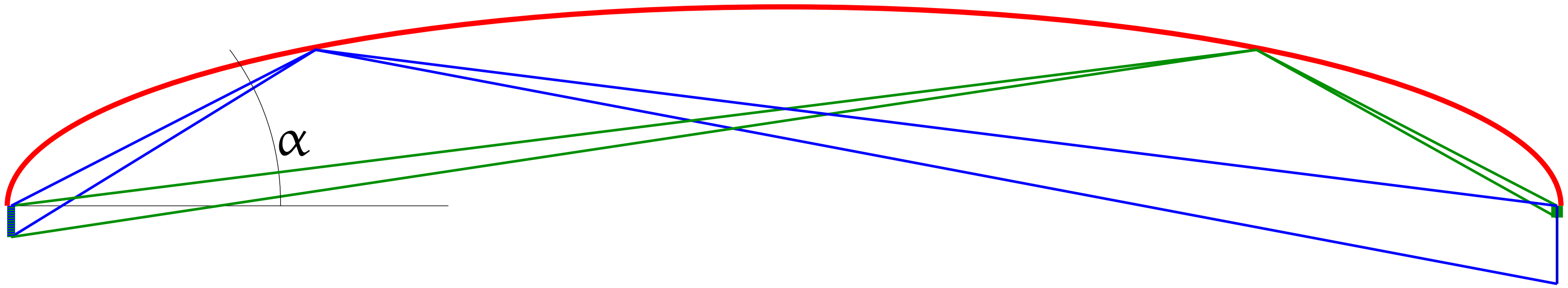
realisation



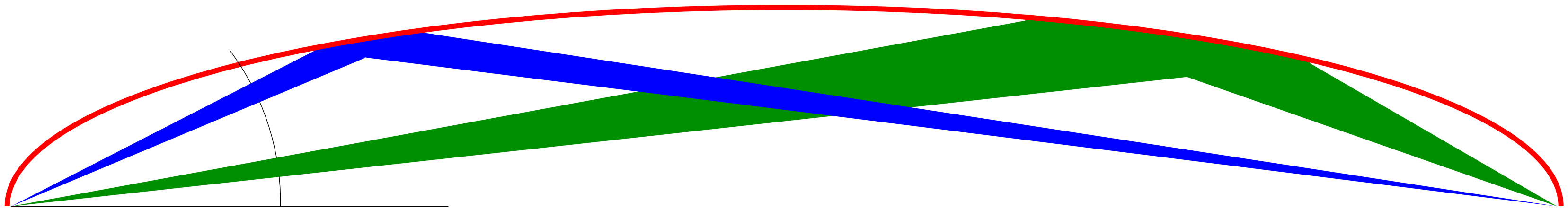

selene
titan goddess of the moon



coma aberration (distortion of the image of an off-axis point source)

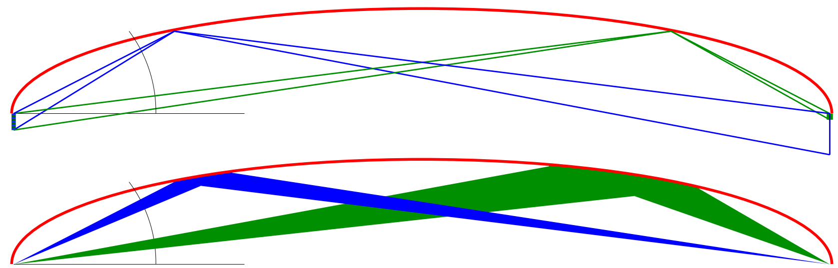


inhomogeneous ilumination



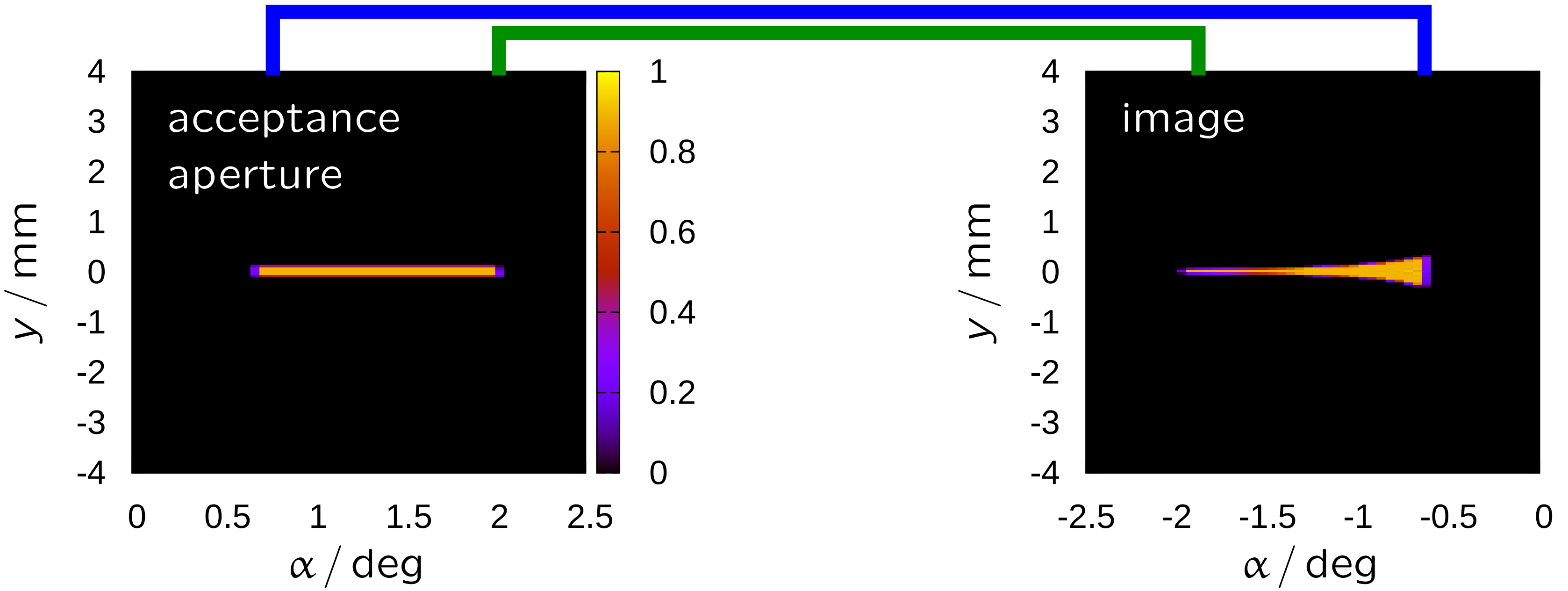
	large α	small α	
coma effect	de-focusing	focusing	of a finite source
divergence	low	high	at the sample position
intensity	high	low	"

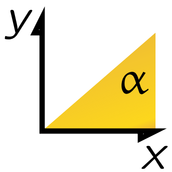
coma aberration



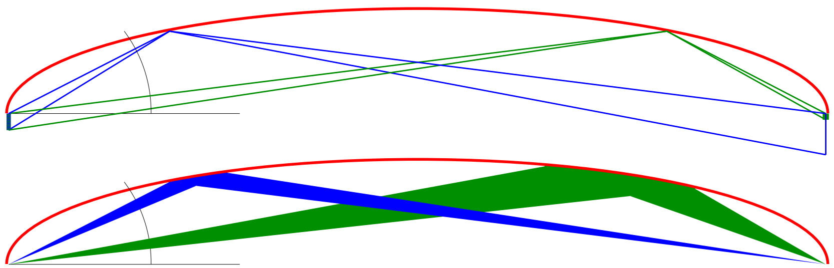
analytic calculations for selene

slit: high emmittance
aperture = 0.2 mm



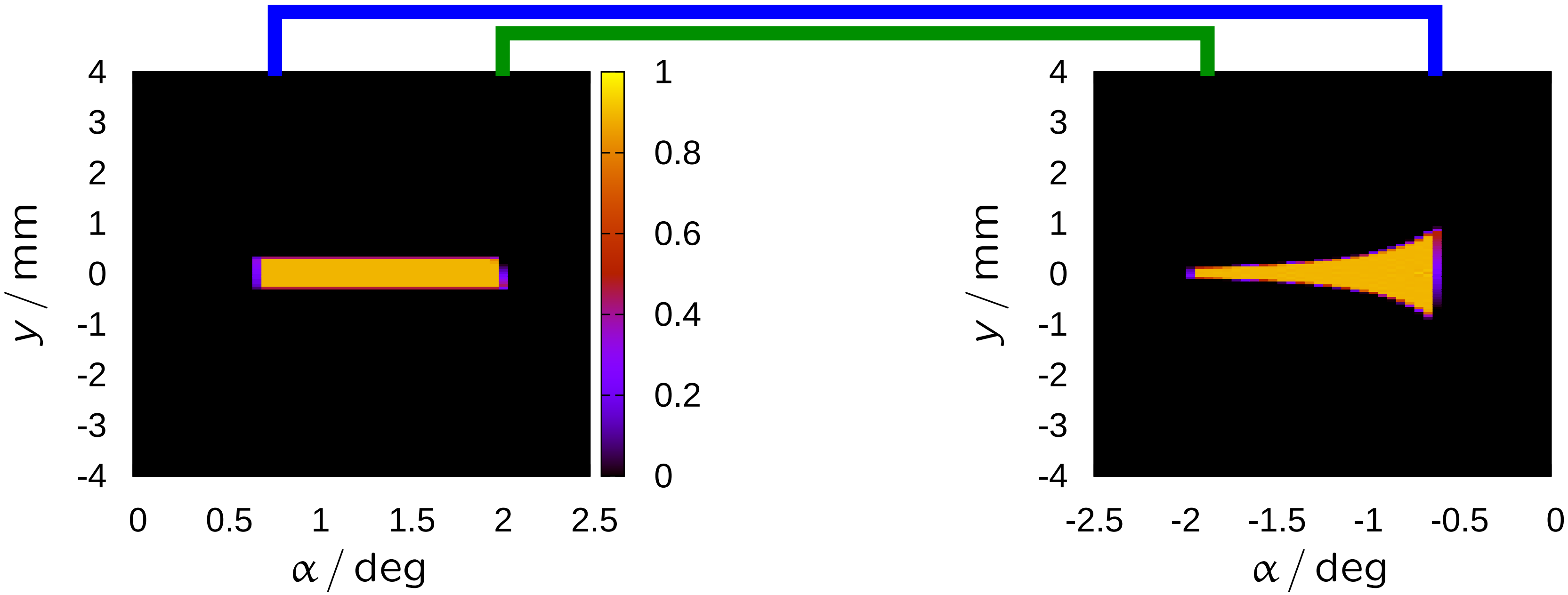


coma aberration

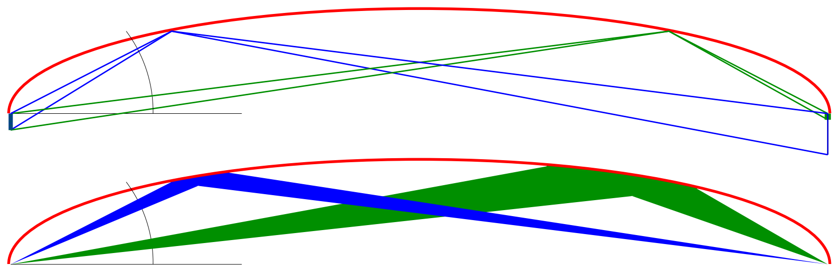


analytic calculations for selene

slit: high emmittance
aperture = 0.6 mm

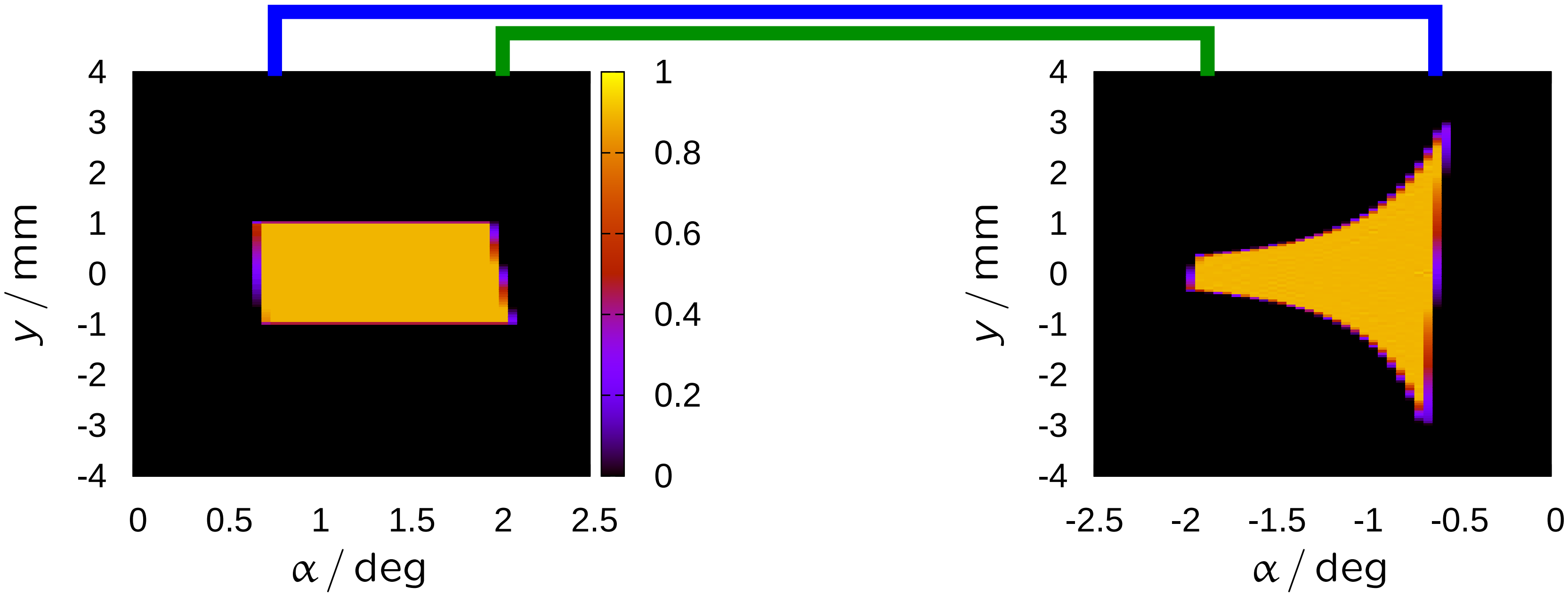


coma aberration



analytic calculations for selene

slit: high emmittance
aperture = 2.0 mm



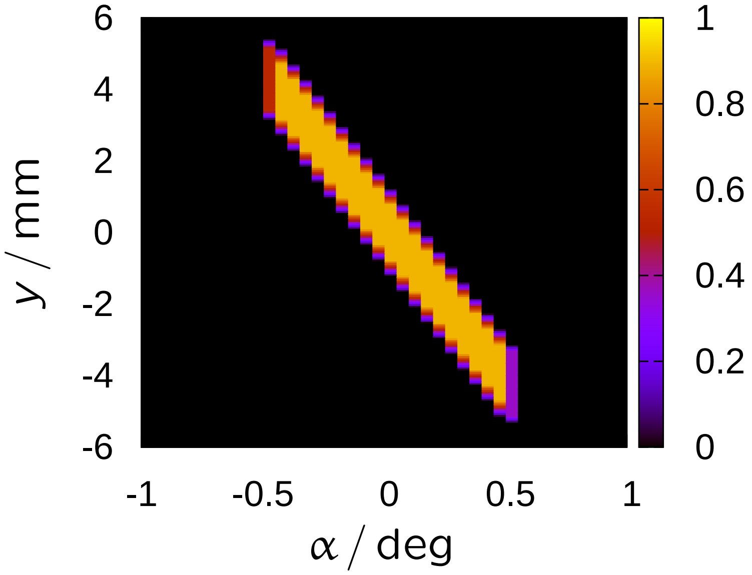
⇒ a *nice* phase space element requires a sample aperture

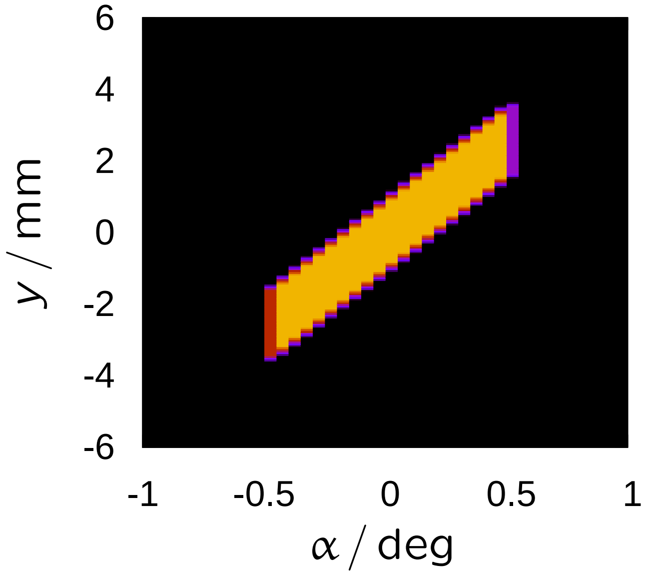
coma aberration

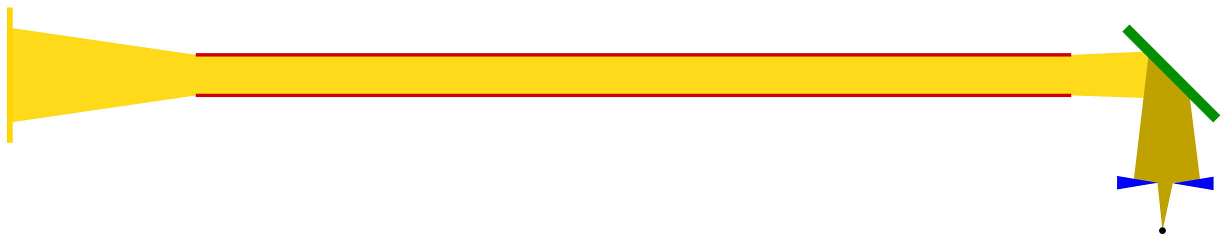
comparison to a straight guide / diaphragm set-up

guide: emmittance $= \pm 0.5°$

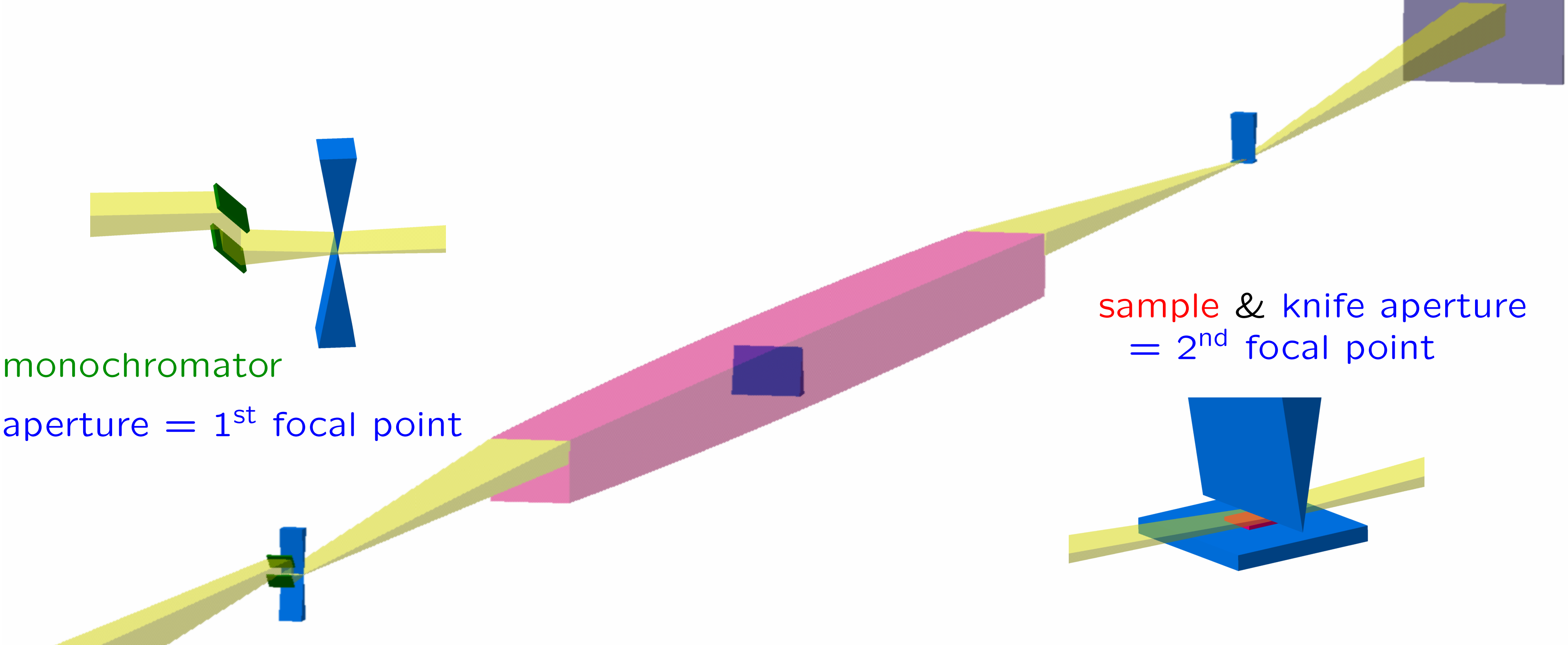
slit: aperture $= 2.0\,\text{mm}$

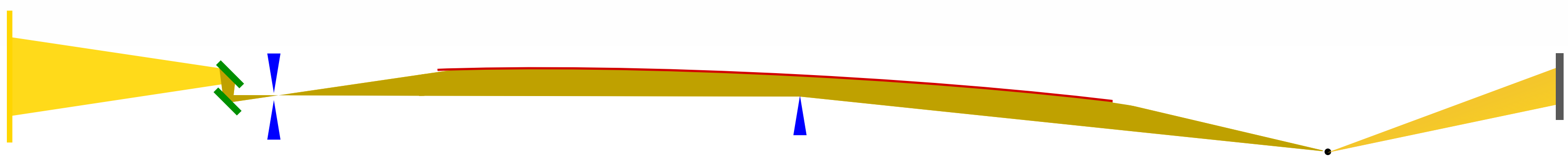






McStas simulations for selene — **reflectometer**





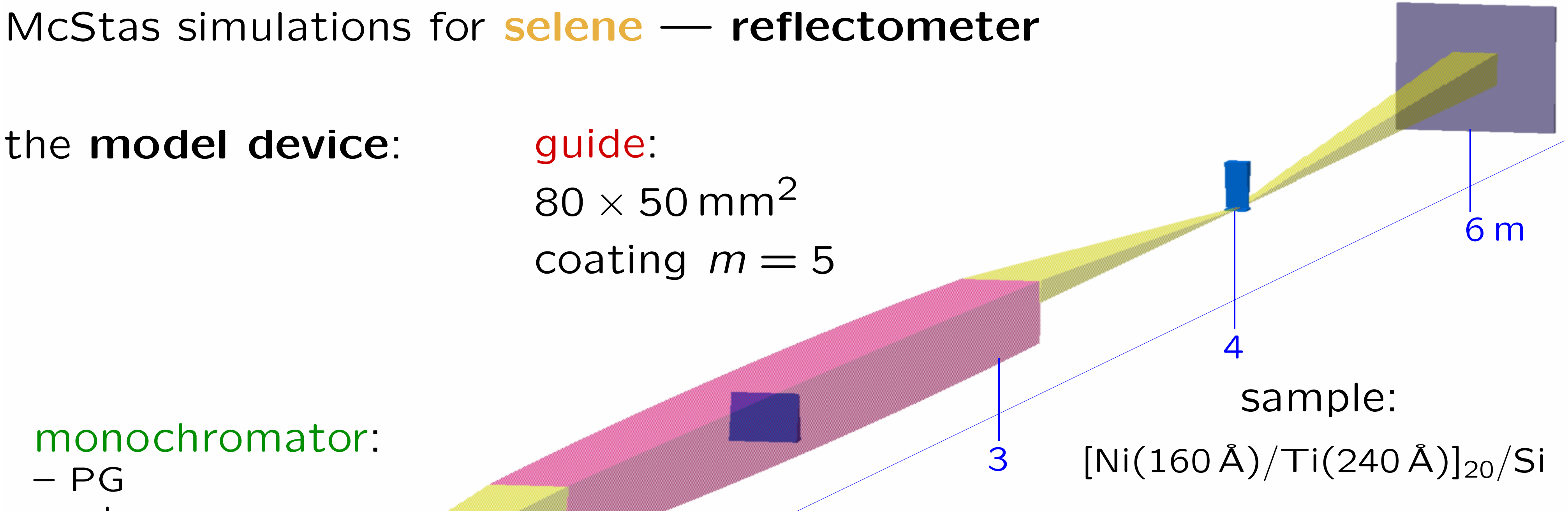
McStas simulations for selene — reflectometer

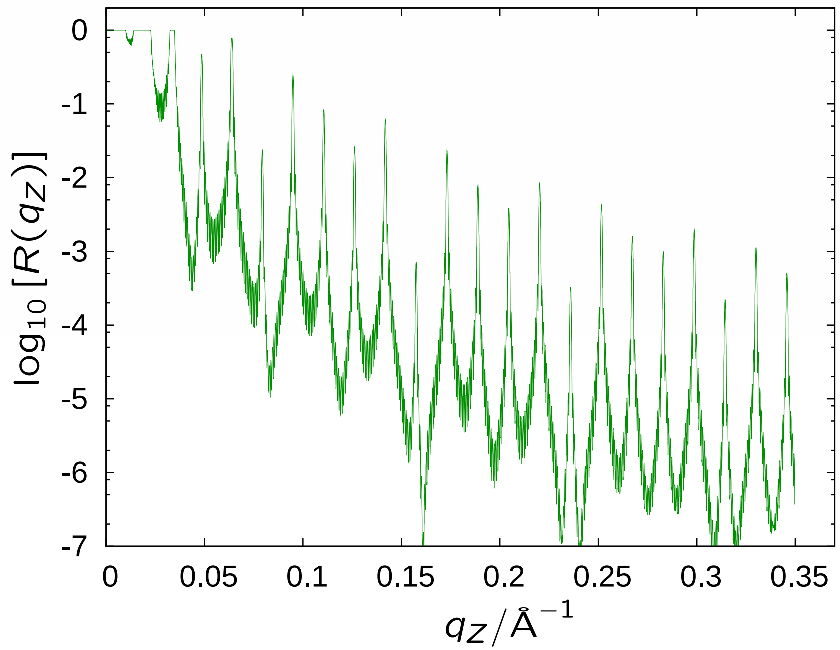
the **model device**:

guide:
$80 \times 50\,\text{mm}^2$
coating $m = 5$

monochromator:
– PG
– ml

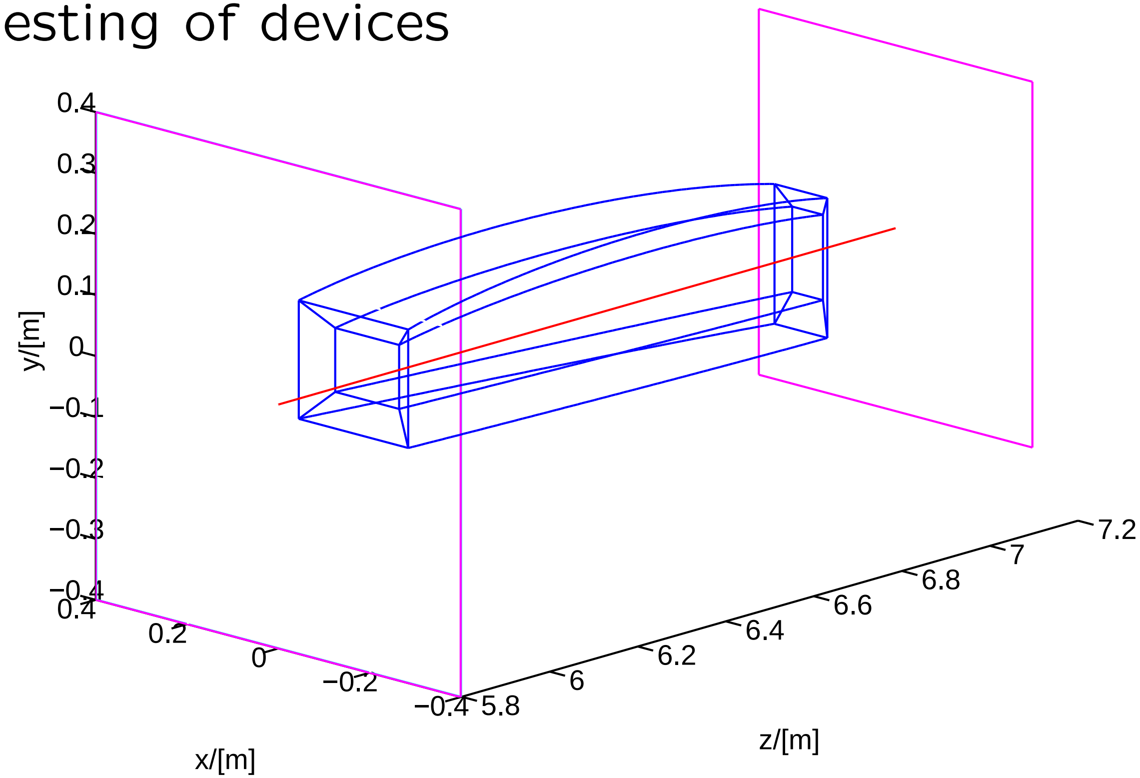
sample:
[Ni(160 Å)/Ti(240 Å)]$_{20}$/Si





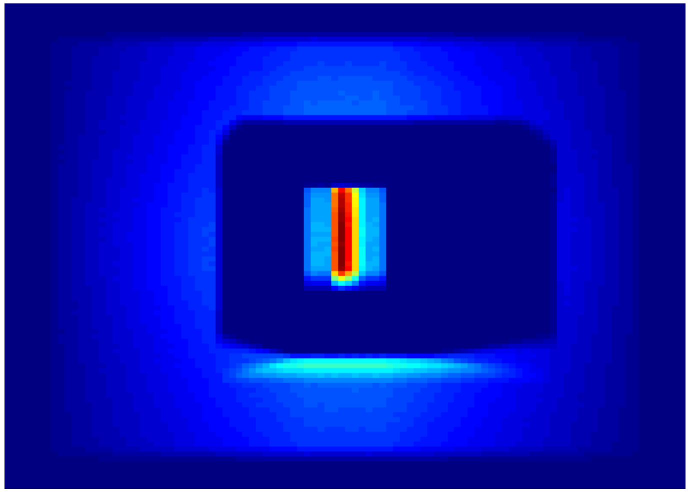
new **McStas component**

– true curvature
– all surfaces with individual properties
– individual shapes
– neutrons can pass by
– nesting of devices

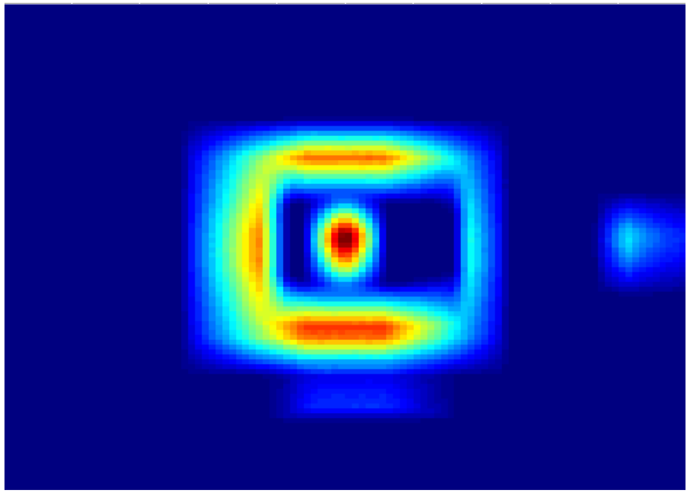


to come:

– off-specular reflectivity



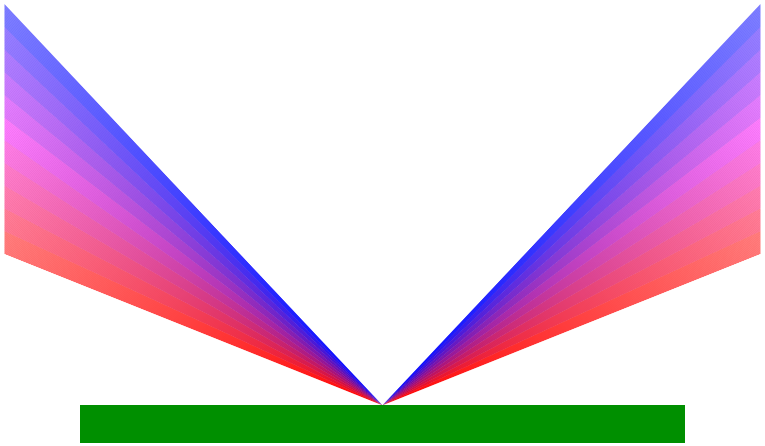
position monitor



divergence monitor

high-intensity specular relectomter – principle

incoming beam with known λ/α_i relation



detection of I vs. α_f

conversion to

$$q_z = 4\pi \frac{\sin\alpha_f}{\lambda}$$

gain:

$\Delta\alpha_i = 1.4^\circ$ compared to $\Delta\alpha/\alpha = 7\%$ gives a gain factor 20

but:

off-specular scattering leads to background

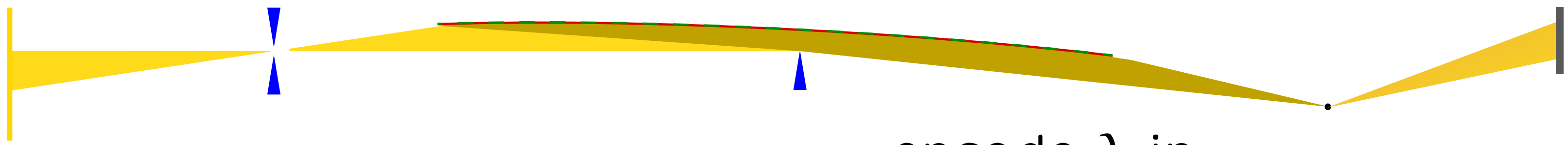
$\Rightarrow$ method is limited to 5 orders of magnitude

high-intensity specular relectomter – implementation

ReFOCUS concept by F. Ott

the elliptic guide
has a (graded)
monochromating coating

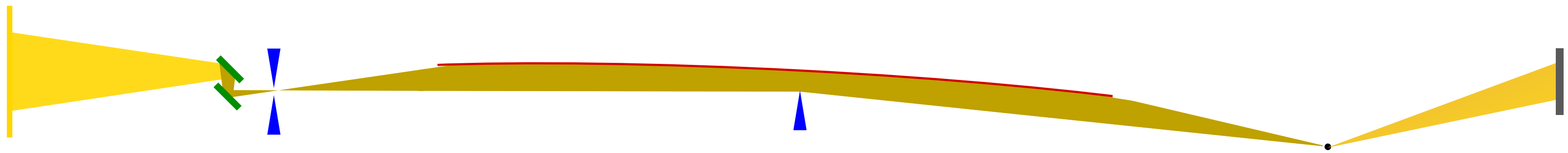
ReFOCUS



encode λ in α_i

resolve $q_z(\lambda, \alpha_i)$ with
an area detector

selene



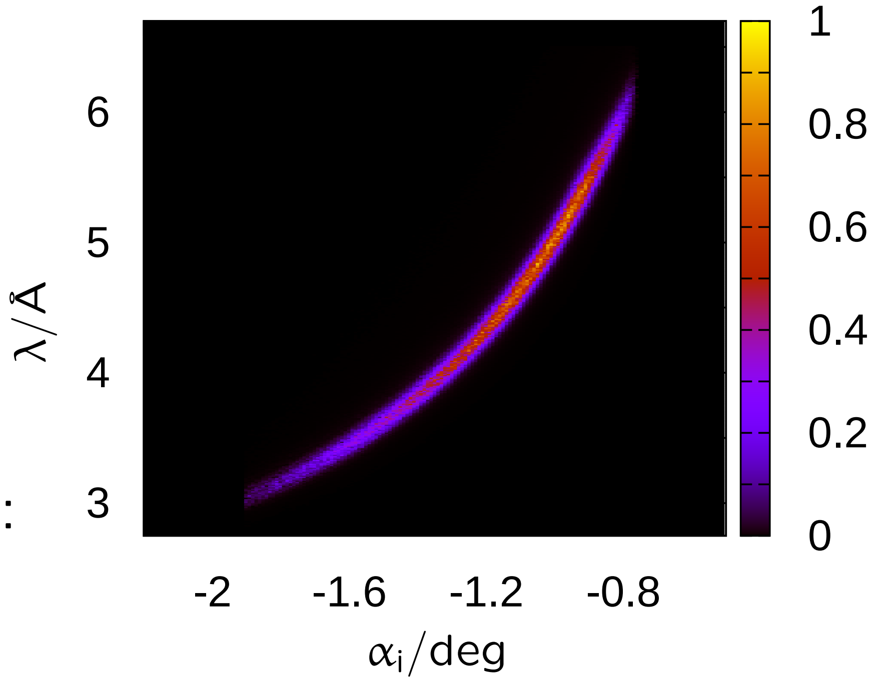
McStas simulations for selene — **reflectometer**
using a double **ml monochromator** ($m = 3$)

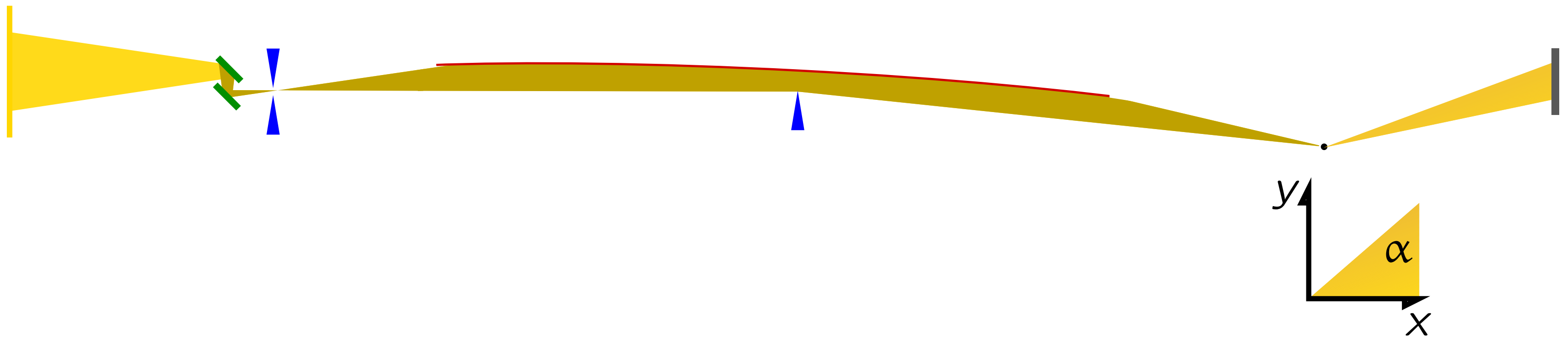
incident angle on the ml: $0 \ldots 2^\circ$

with $\lambda \propto \sin \alpha_i$

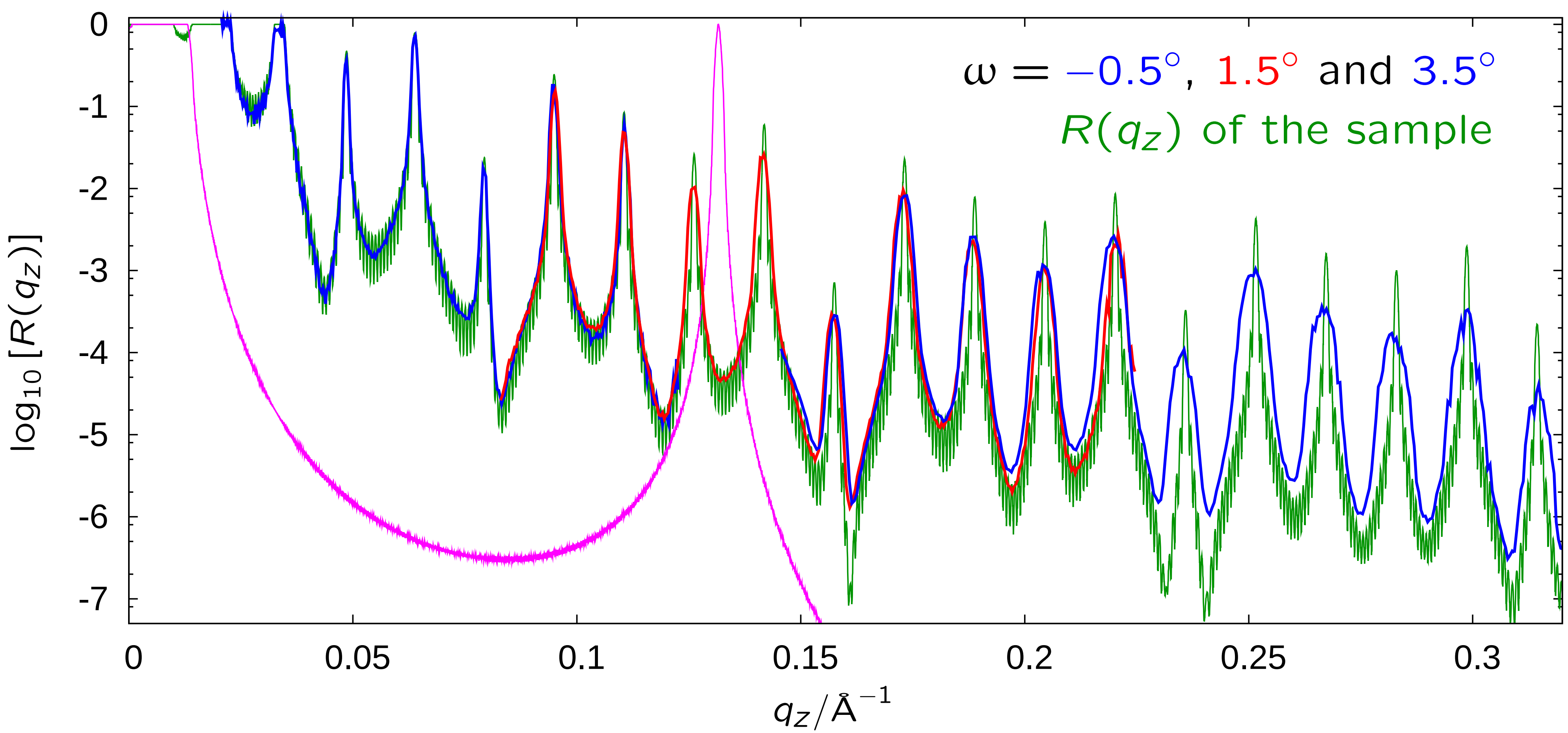
acceptance of the guide:
$\Delta\alpha = 1.3^\circ$

$\Rightarrow \lambda$ vs. α_i at sample poaition:



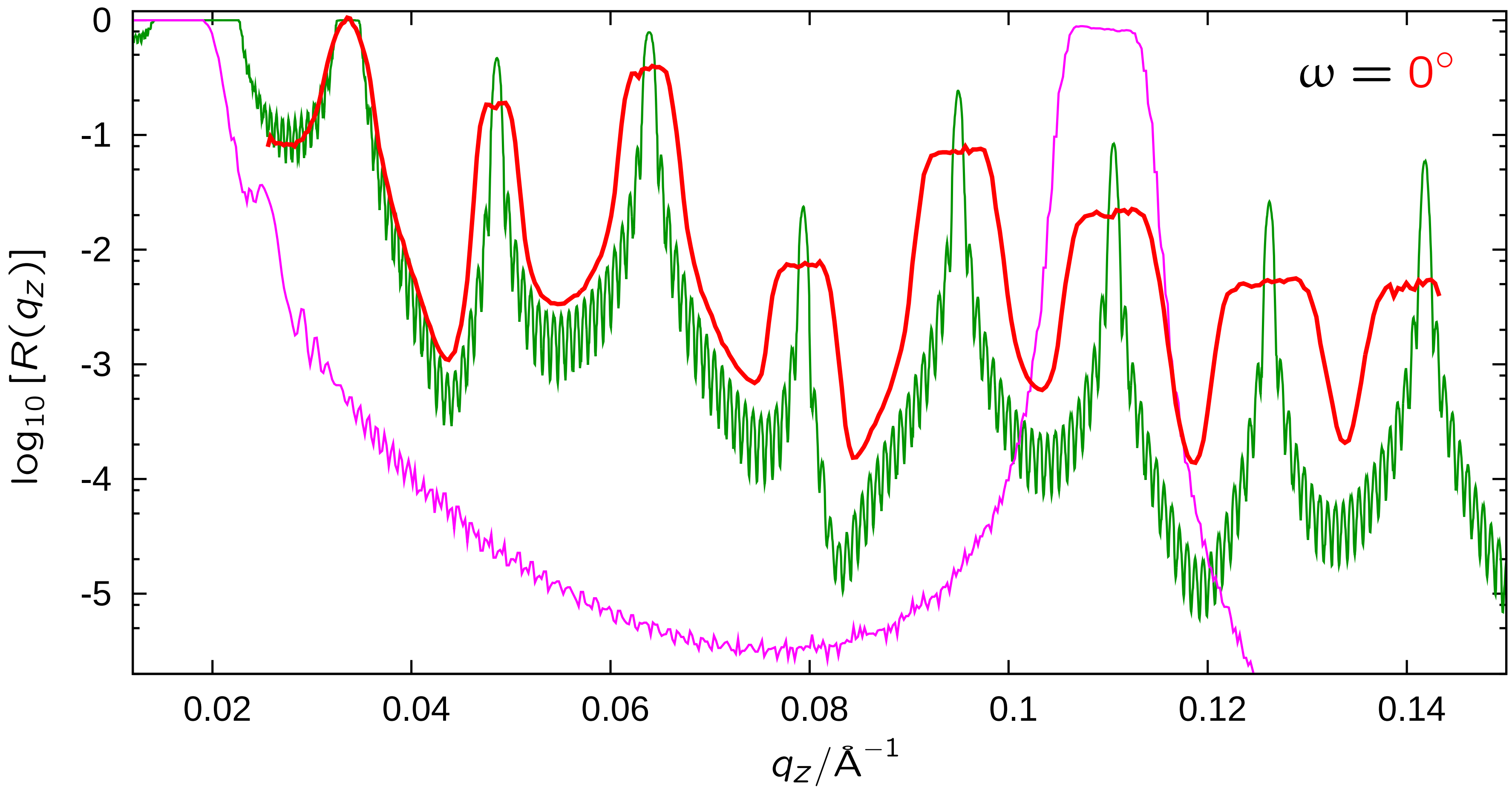


McStas simulations for selene — **reflectometer**
using a double ml monochromator $m = 6$, $\Delta q_z/q_z \approx 1\%$

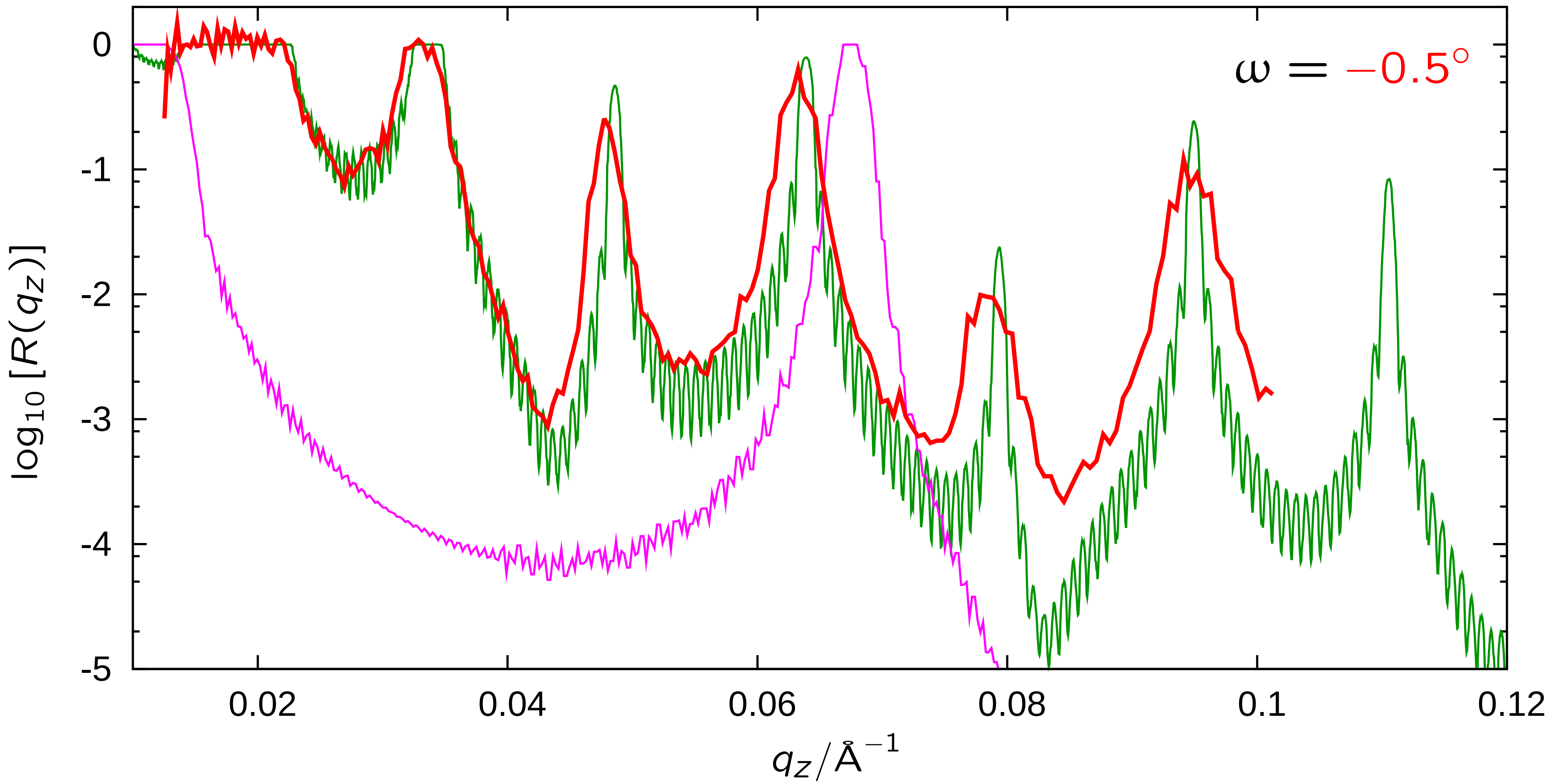


no off-specular scattering included, yet

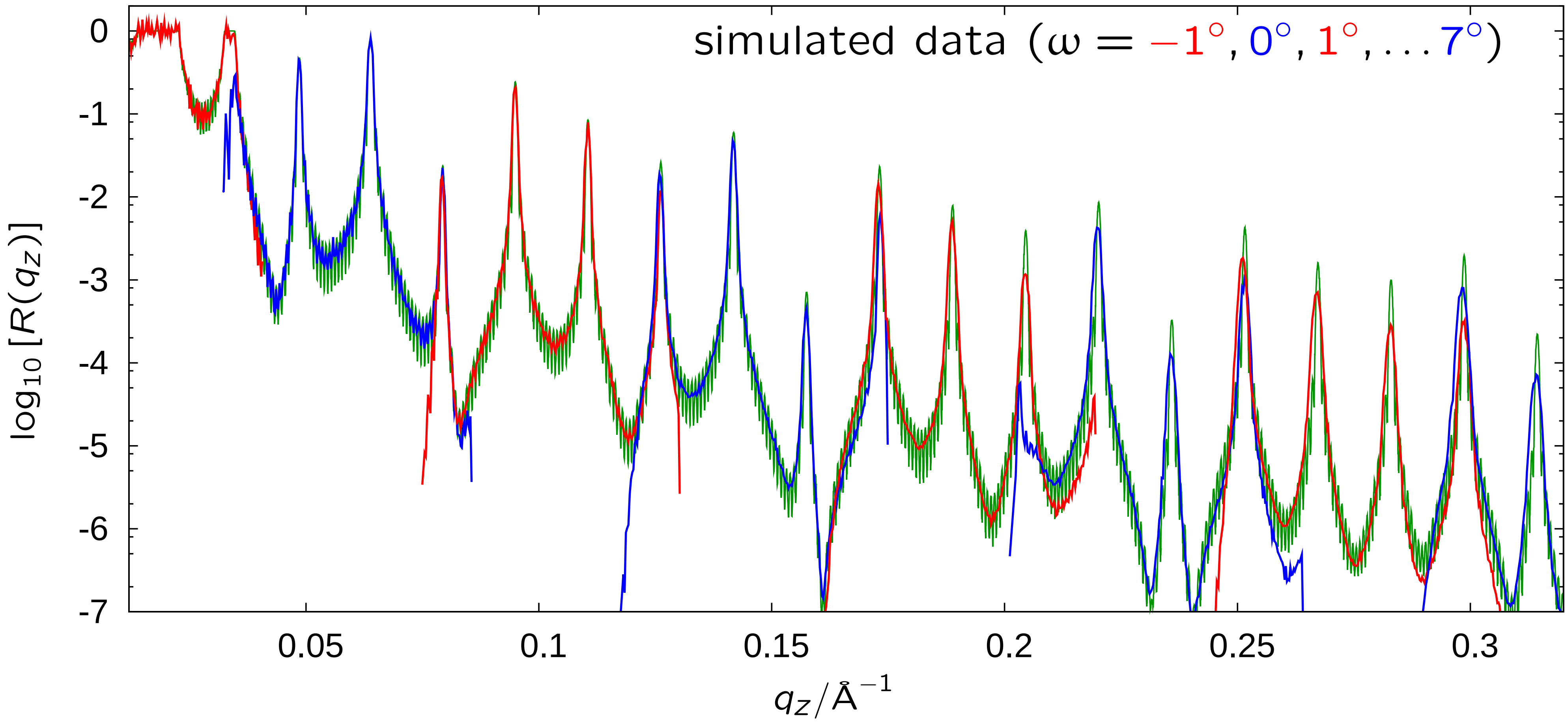
McStas simulations for selene — **reflectometer**
using a double ml monochromator $m = 5$, $\Delta q_z / q_z = 7\%$



McStas simulations for selene — **reflectometer**
using a double ml monochromator $m = 3$, $\Delta q_z / q_z \approx 4\%$



McStas simulations for selene — **reflectometer**
using a double **PG monochromator** ($\Delta\alpha = 0.16°$)

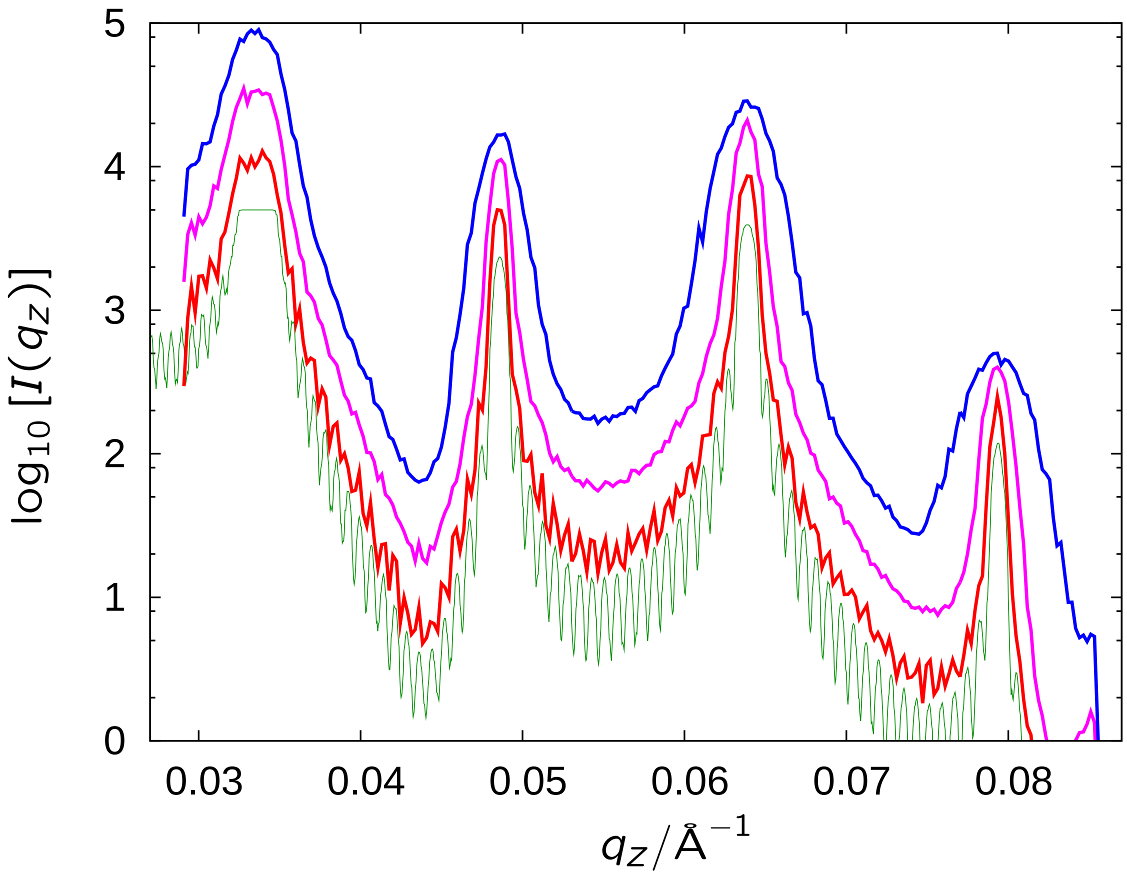


no illumination correction applied yet

McStas simulations for selene — **reflectometer**
using a double **PG monochromator**

comparison: **mosaicity** of PG

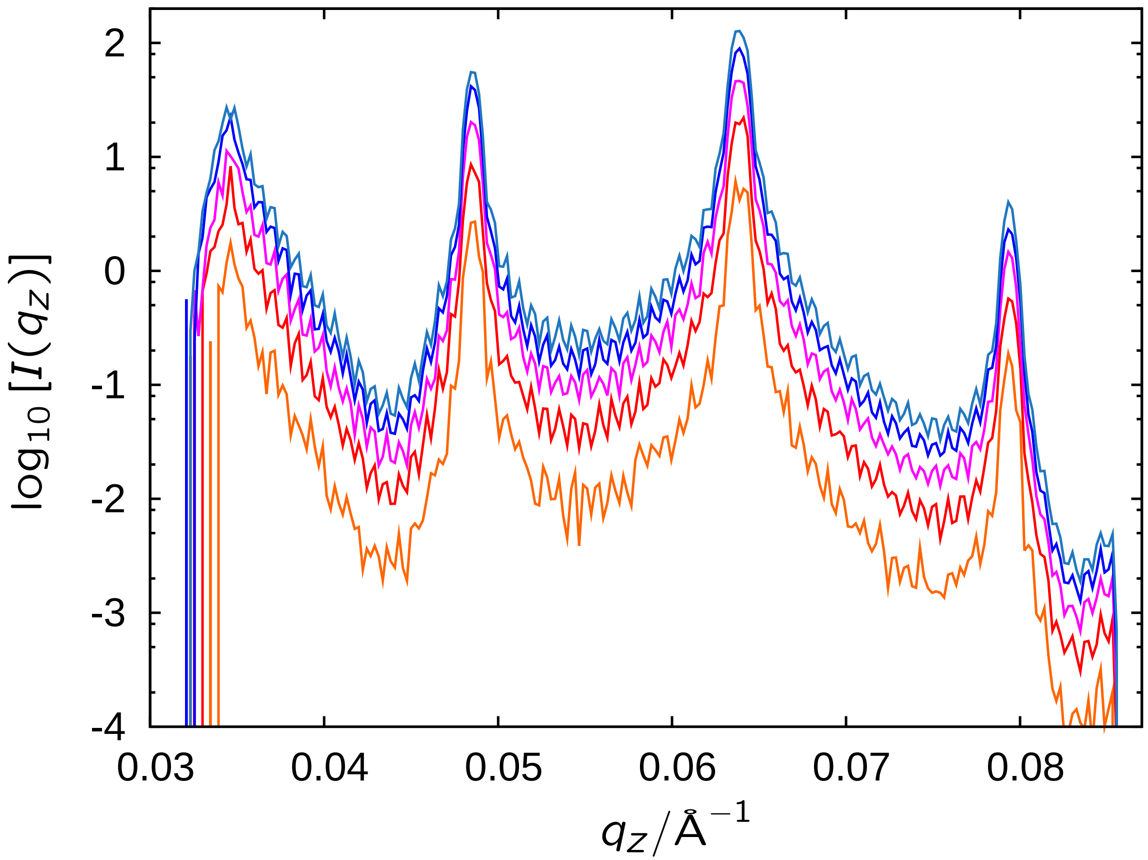
1.40°
0.50°
0.16°
sample



McStas simulations for selene — **reflectometer**
using a double **PG monochromator** ($\Delta\alpha = 0.16°$)

comparison: **sample sizes**

$10 \times 10\,\mathrm{mm}^2$
$8 \times 8\,\mathrm{mm}^2$
$6 \times 6\,\mathrm{mm}^2$
$4 \times 4\,\mathrm{mm}^2$
$2 \times 2\,\mathrm{mm}^2$



reflectometer – resumee

maximum flux on the sample fo a given $\Delta\alpha_i$

allows for high-intensity reflectometry:

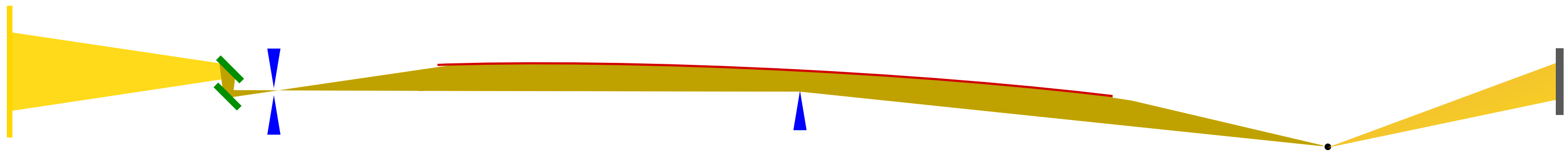
– ml monochromator: q_z-range e.g. 0.01 to 0.1 Å^{-1}

– PG monochromator: q_z-range $\propto \Delta\alpha_i$

reduction of $\Delta\alpha_i$ leads to a *conventional* angle-dispersive reflectometer

$\Rightarrow$ off-specular measurements are possible

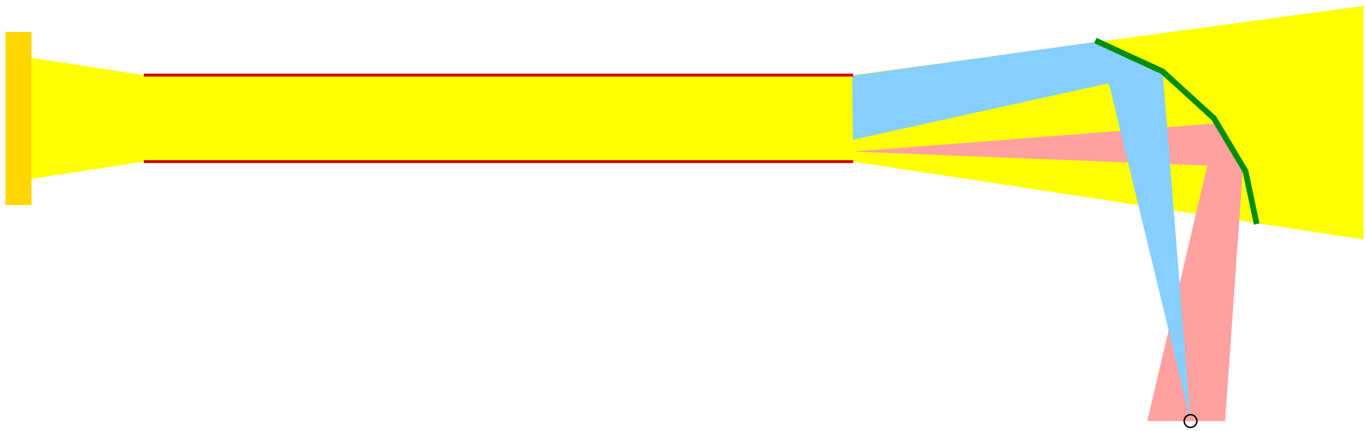
$\Rightarrow$ a diaphragm-scan results in a q_z-scan



some thoughts on focusing monochromators

typical set-up:

source – guide – monochromator – sample



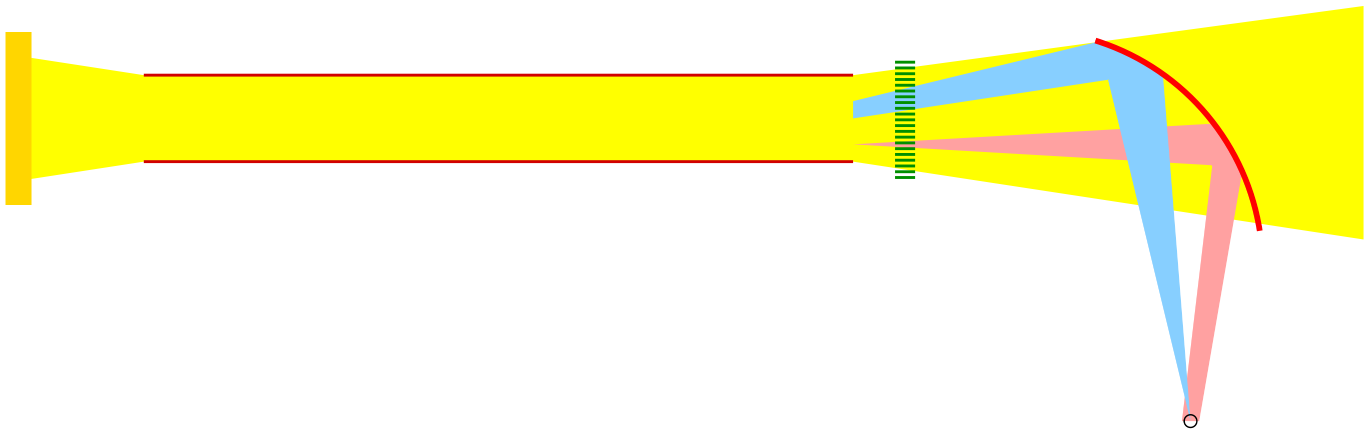
monochromator: array of flat crystals (mirrors)

⇒ divergence is transported

some thoughts on focusing monochromators

modified set-up:

source – guide – **monochromator + lense** – sample



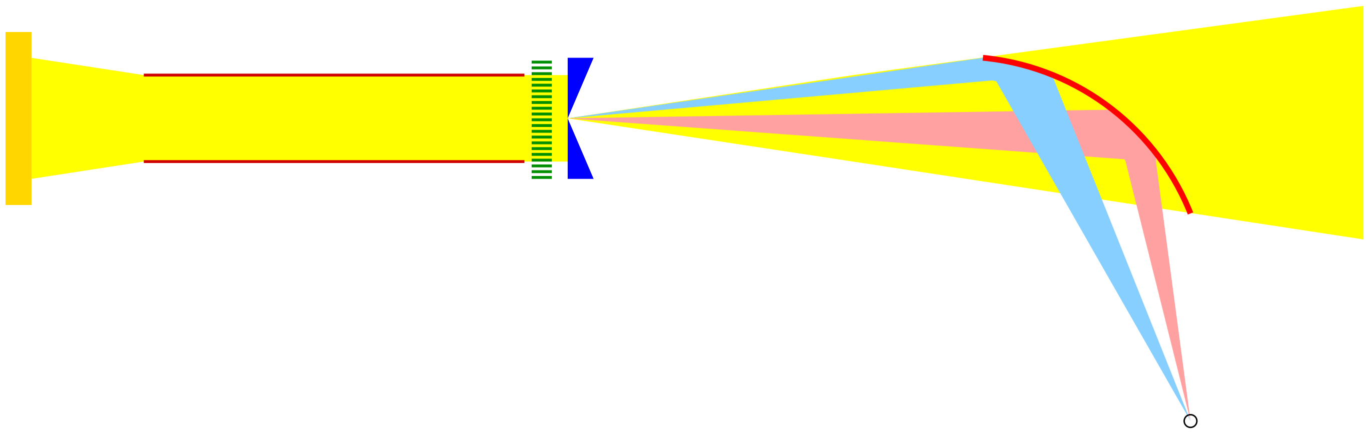
lense: mirror with continuous curvature

⇒ divergence is transformed to convergence

some thoughts on focusing monochromators

modified set-up:

source – **short guide** – monochromator – **aperture** – lense – sample



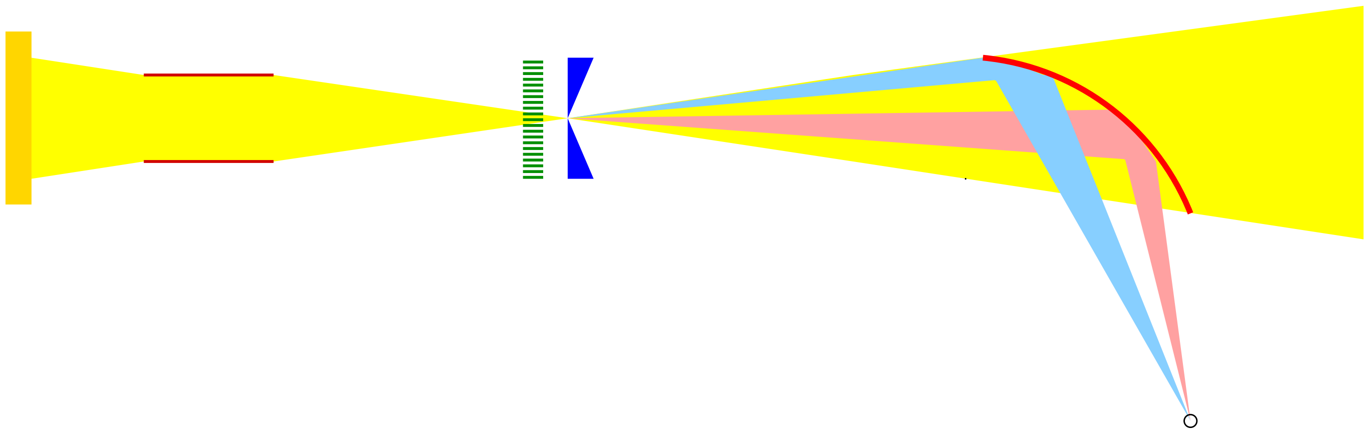
aperture: reduces un-wanted flux

⇒ reduced background

some thoughts on focusing monochromators

modified set-up:

source – short guide – monochromator – aperture – lense – sample



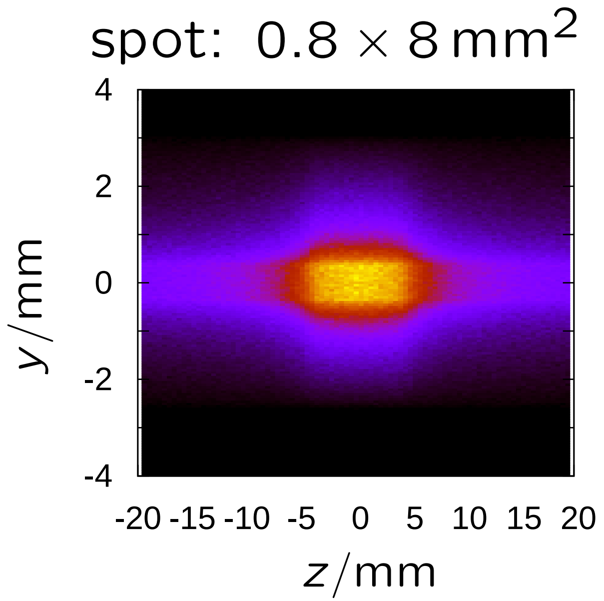
guide: reduced to the necessary length

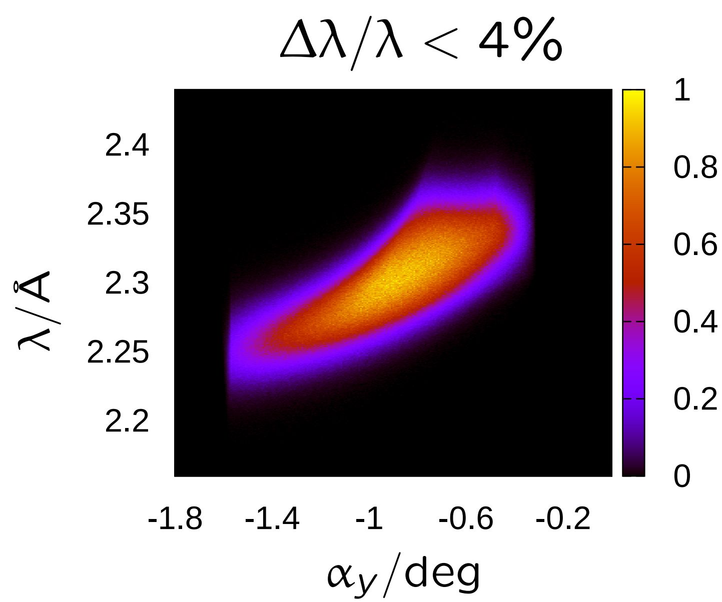
⇒ **selene**-type set-up

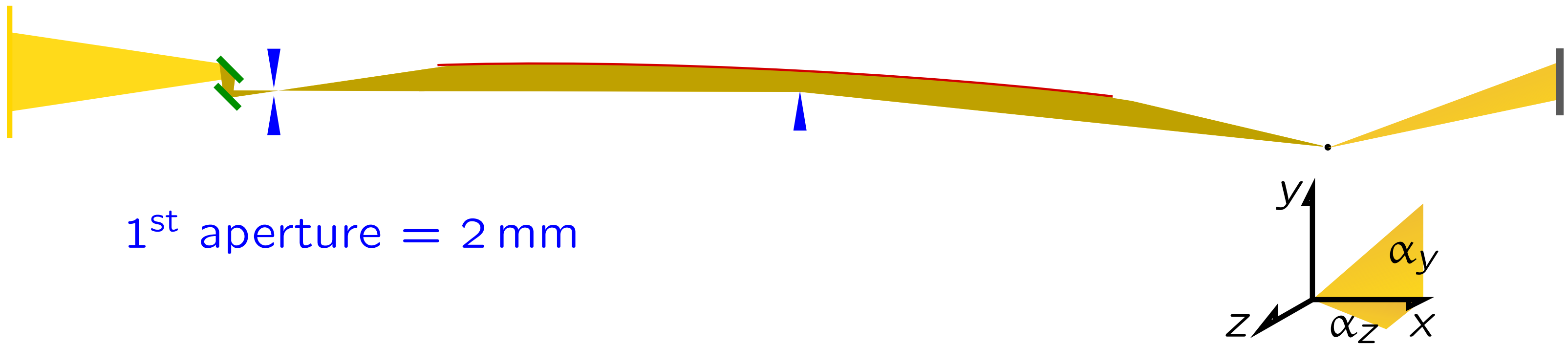
– double monochromator needed
○ same usable intensity on the sample
\+ strongly reduced background
\+ fix sample position

McStas simulations for selene
— **diffractometer**

using a double **PG monochromator**
($\Delta\alpha = 0.5^\circ$)



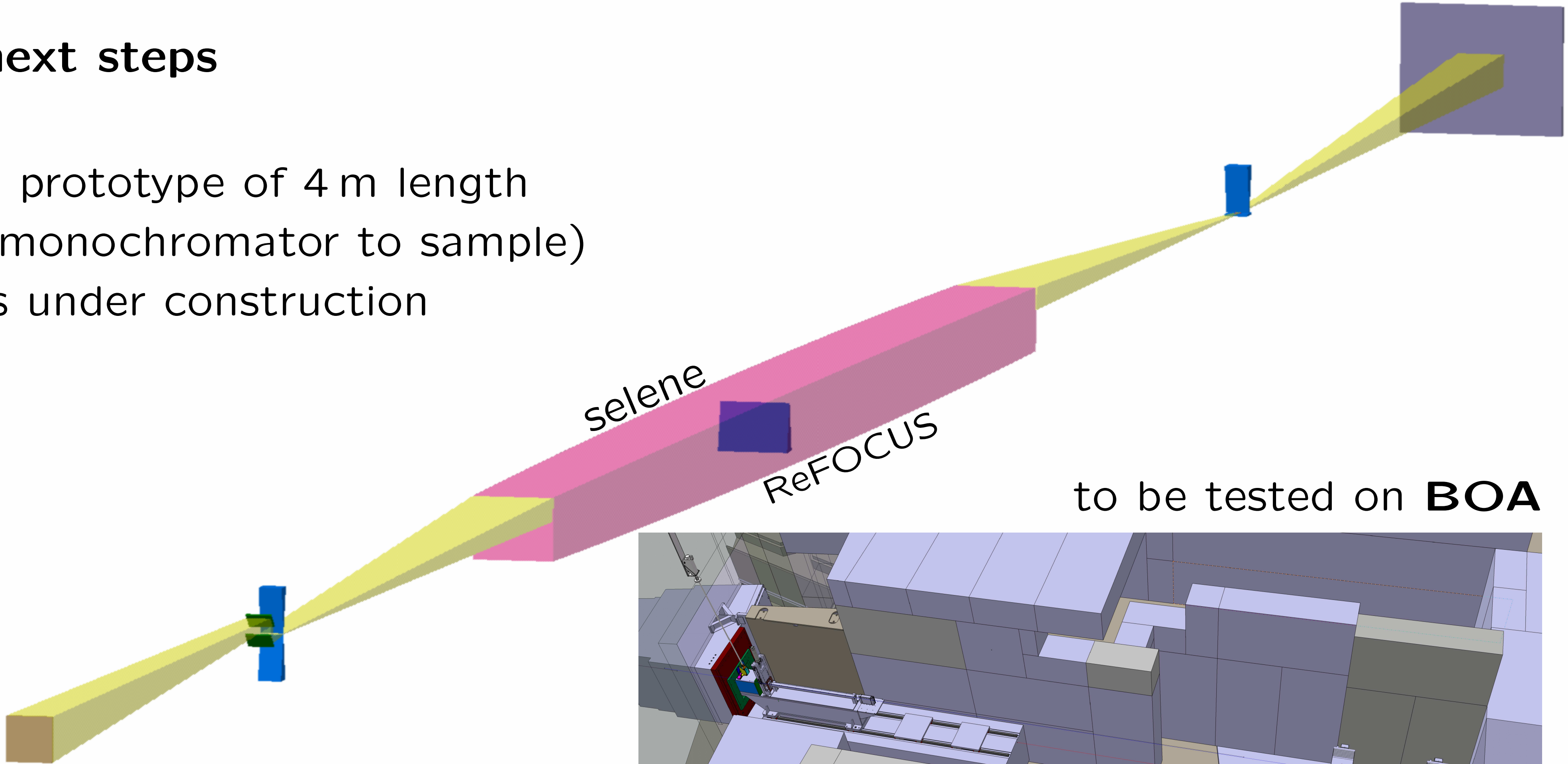




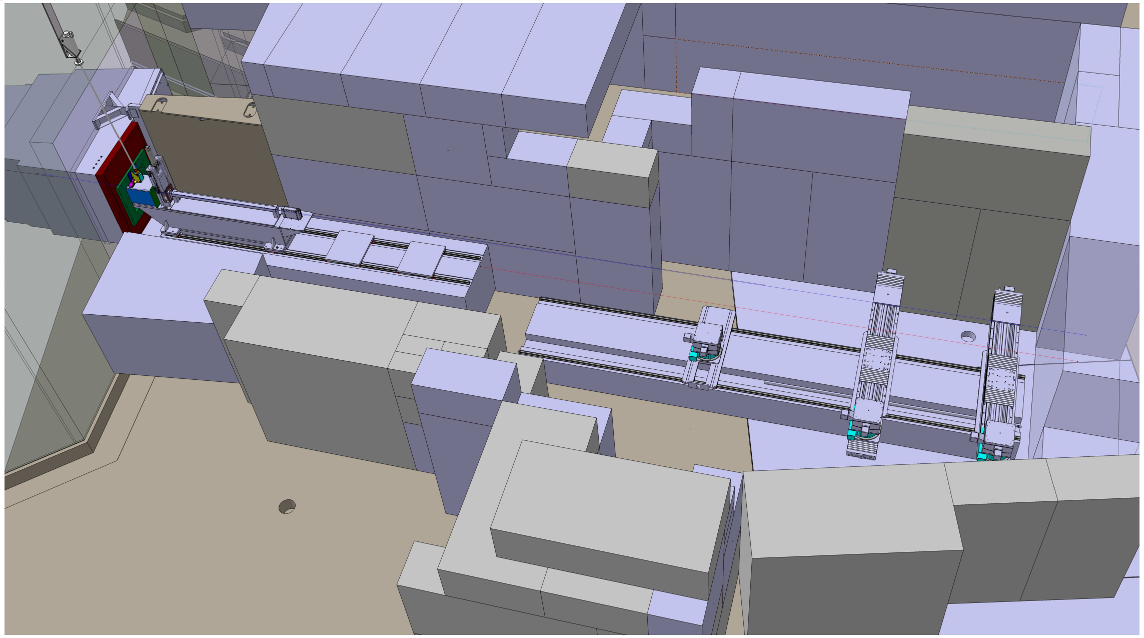
1^{st} aperture $= 2\,\mathrm{mm}$

next steps

a prototype of 4 m length
(monochromator to sample)
is under construction

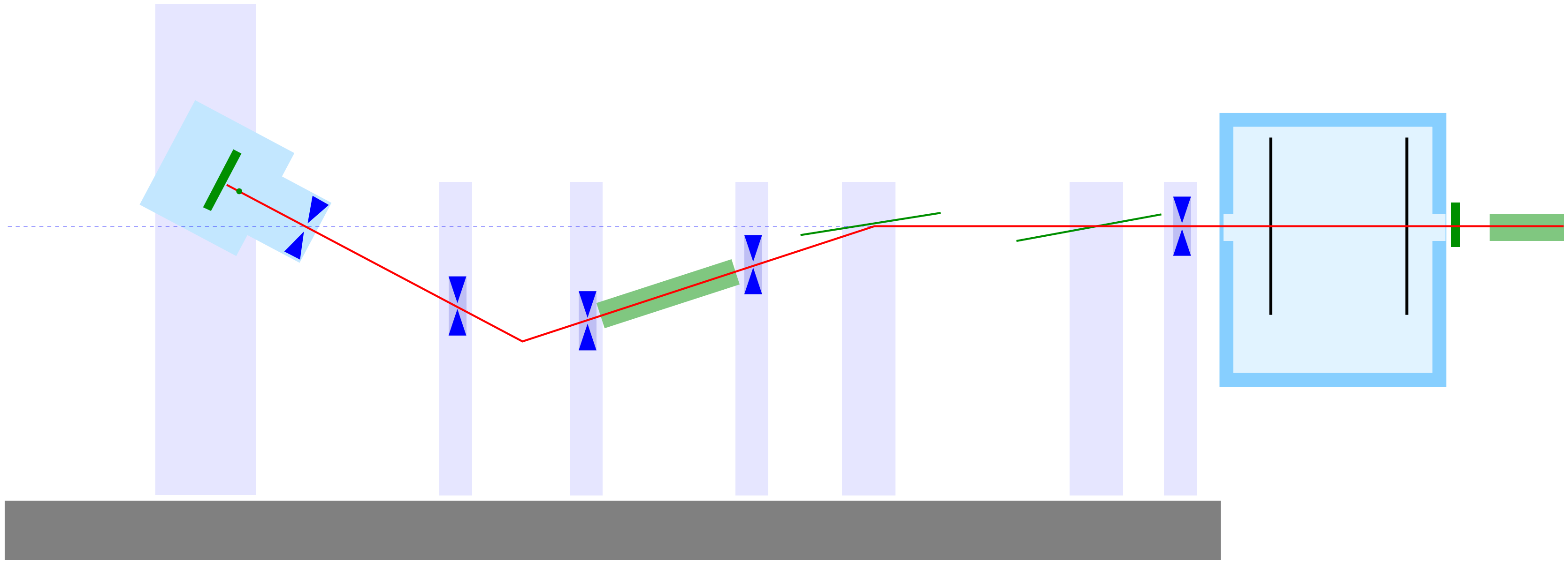


to be tested on **BOA**

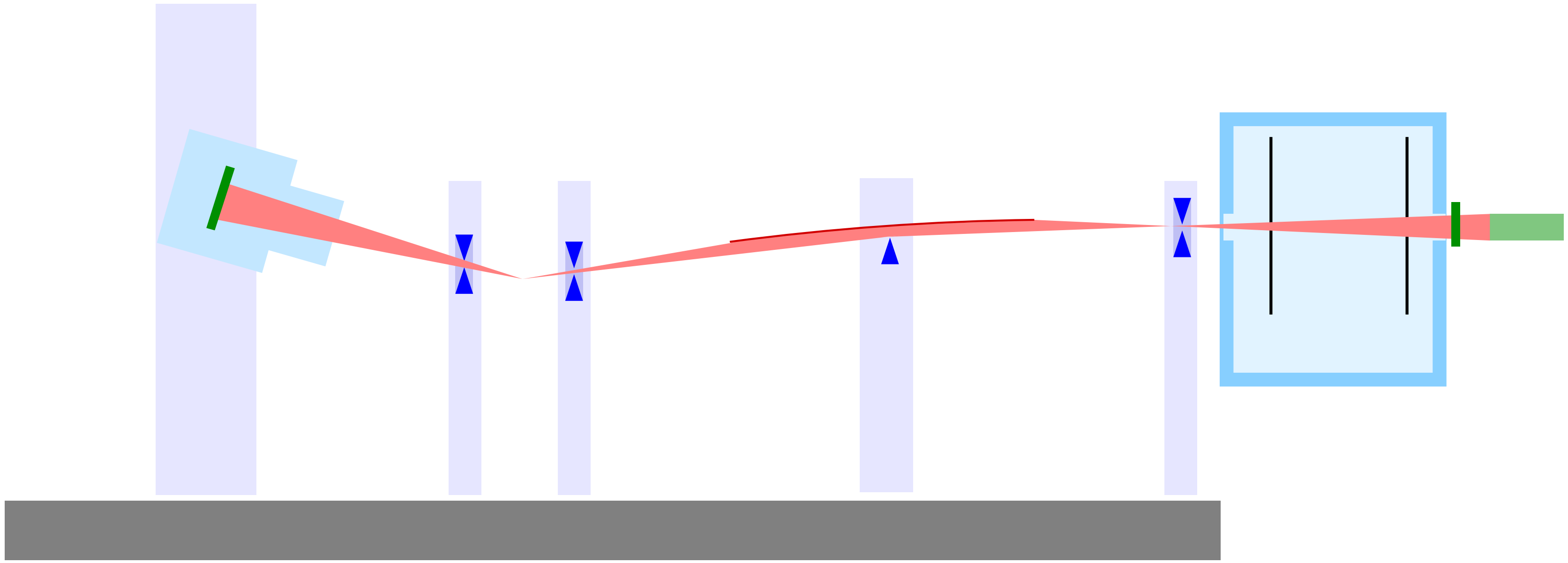


to be used on AMOR

Amor – polarised reflectometer in TOF mode



Amor with selene in TOF mode



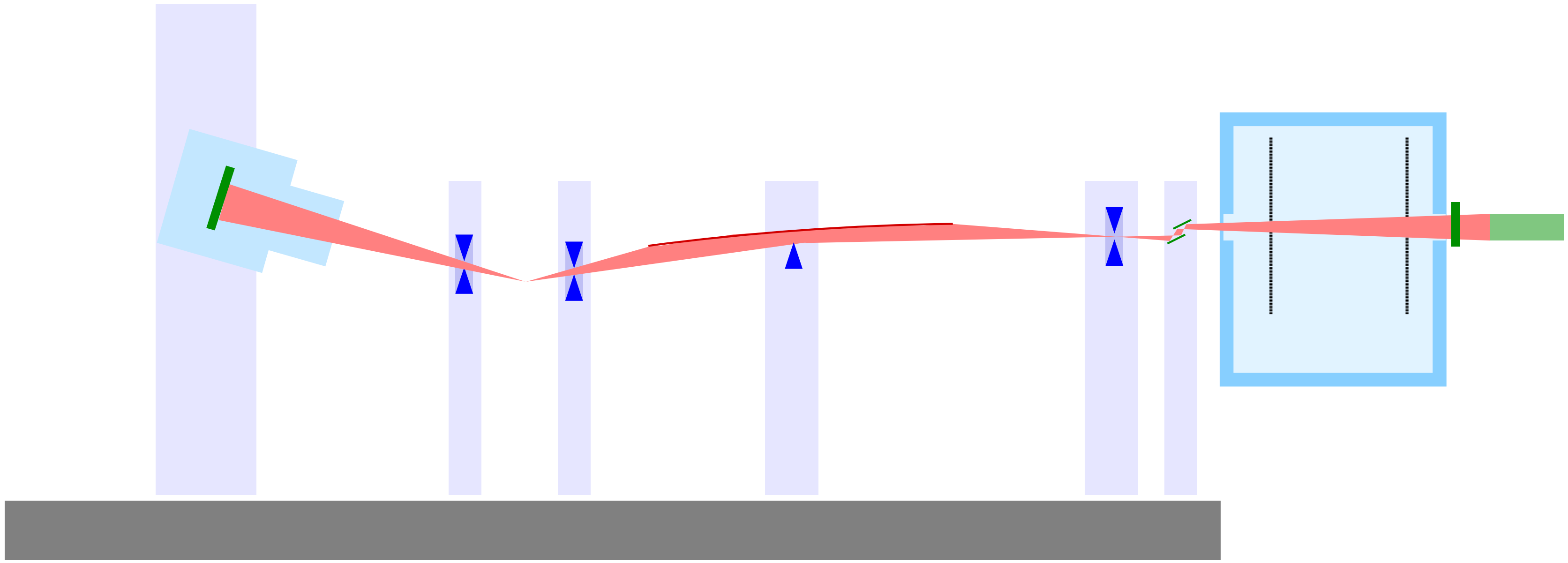
horizontal focusing

gain factor ≈ 6

enables high-intensity specular reflectivity

gain factor ≈ 20

Amor with selene in monochromator mode



chopper stopped
double monochromator (ml or PG)

same flux, but different q_z-range

polarising ml possible

replacement of the guide of e.g. RITA II, SINQ

– old insert / first part of the straight guide can be reused

– monochromator in the 1^{st} part of guide bunker

– guide ends within guide bunker

⇒ fixed sample position

⇒ large 2θ-range accessible

filter first:

+ reduction of radiation entering the guide to $< 1\%$
+ reduced n-background: saves shielding material
+ reduced radiation level: saves life!

∘ no gain in flux!

– mechanical parts close to source

focusing guide:

+ reduces illumination of sample sourroundings
+ no direct view to source
+ allows for small monochromators . . .

∘ no gain in flux!

+ allows for q_z/α_i encoding

– (coma) aberration
– does not work for *large* samples

thanks to

T. Panzner and U. Filges

for the McStas programmig and simulation work

C. Marcelot and L. Holitzner

for support in the test and design process

F. Ott

for the ReFOCUS concept — which triggered this work

P. Böni, U. Stuhr and C. Niedermayer

for long discussions

nmi3, MaNEP, SNF and SwissNeutronics

for financial and technical support

YOU