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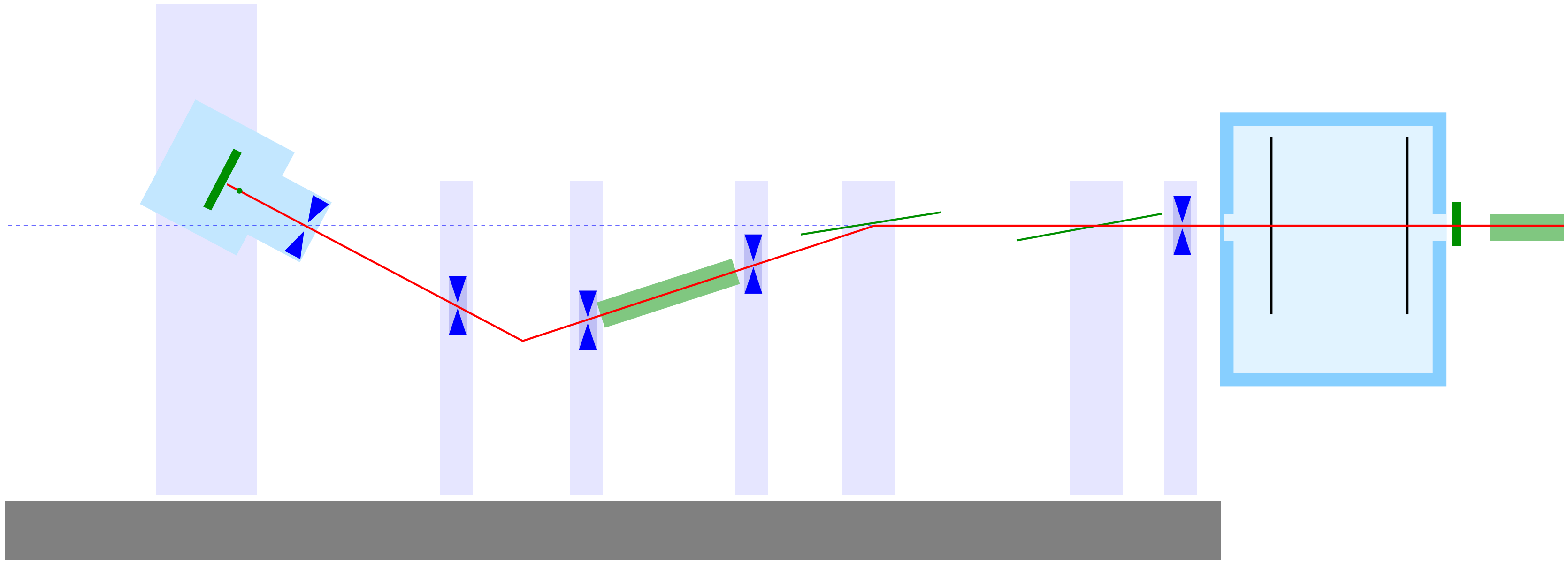
specular reflectomety on small samples using a convergent beam

outline

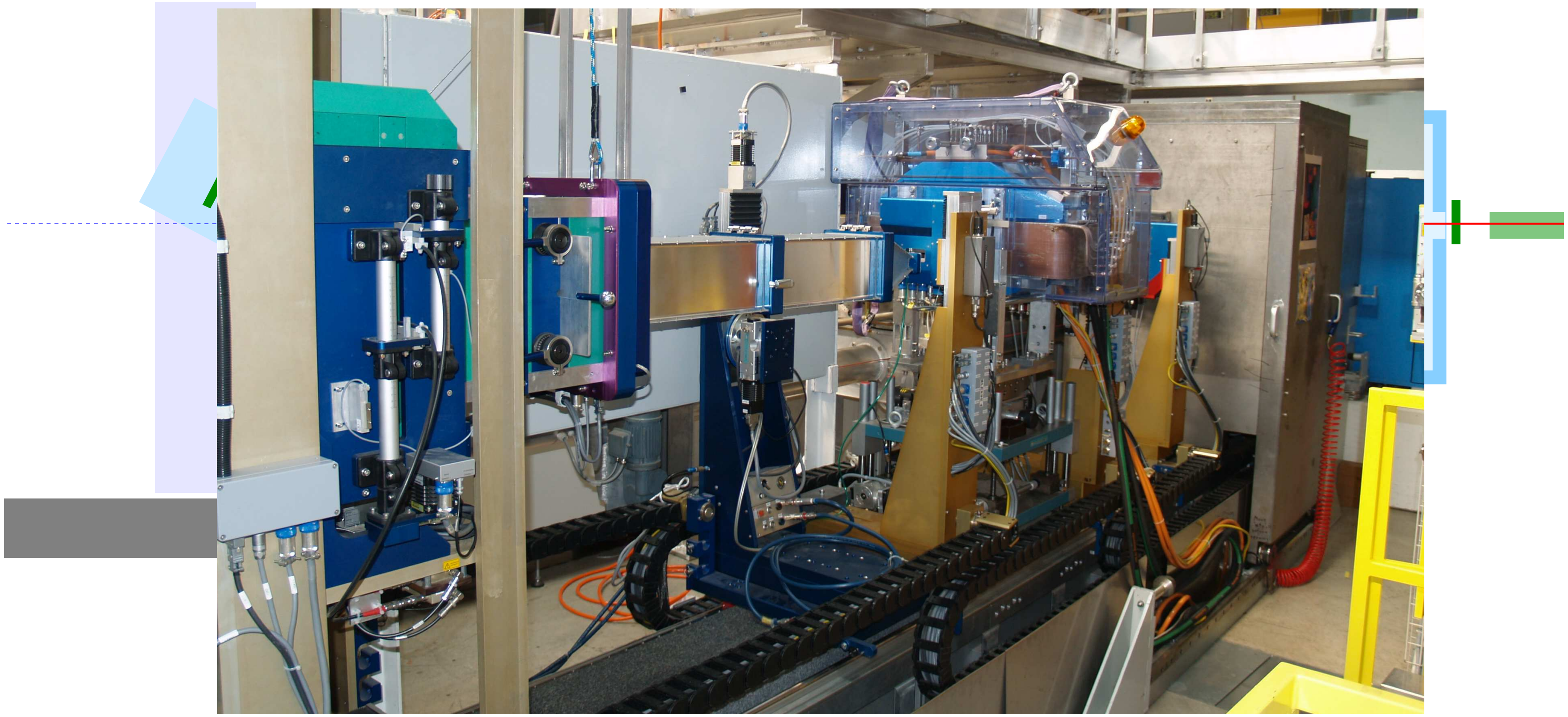
- amor at PSI
- refocus concept
- selene@amor
- design study for a reflectometer

amor – polarised reflectometer in TOF mode



double disk chopper	$\Delta q_z / q_z \approx 7\,\%$
optical bench:	$\approx 9\,\mathrm{m}$ long
	diaphragms frame overlap mirror polariser sample stage area or single detector

amor – polarised reflectometer in TOF mode



highly flexible ⇒ tests of new concepts

allows for liquid surfaces

⇒ can do everything — but nothing really good!

ideas to reduce measurement time for small samples (few mm^2)

- dynamic range: 5 orders of magnitude in a reasonable time, only
- off-specular scattering hardly accessible

⇒ trade more intensity against off-specular scattering

– prism analyser (→ Bob Cubitt's talk)

spectral analysis of the reflected white beam

– convergent beam (Frédéric Ott)

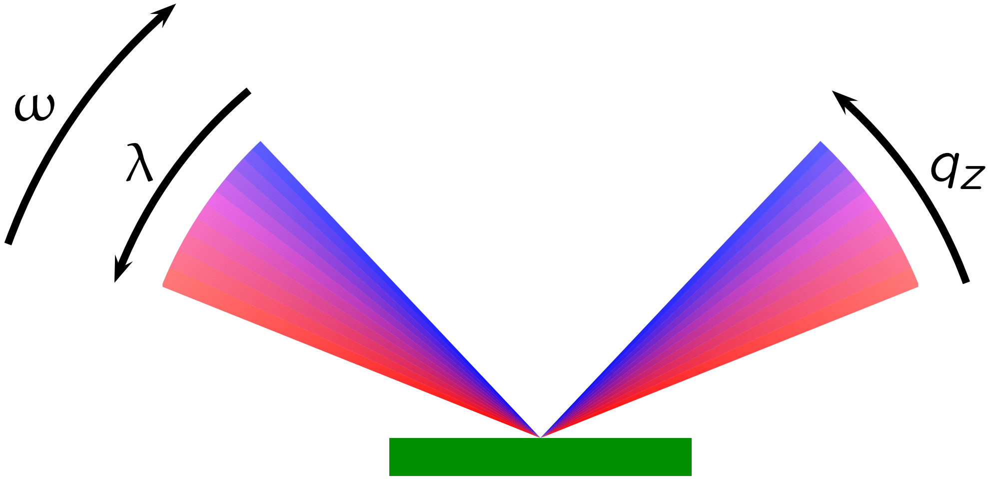
focusing to the sample

- angle/wavelength encoding

convergent beam

- λ/ω encoding of the incomming / reflected beam
- dispersive set-up:

$\Rightarrow$ broad q_z range



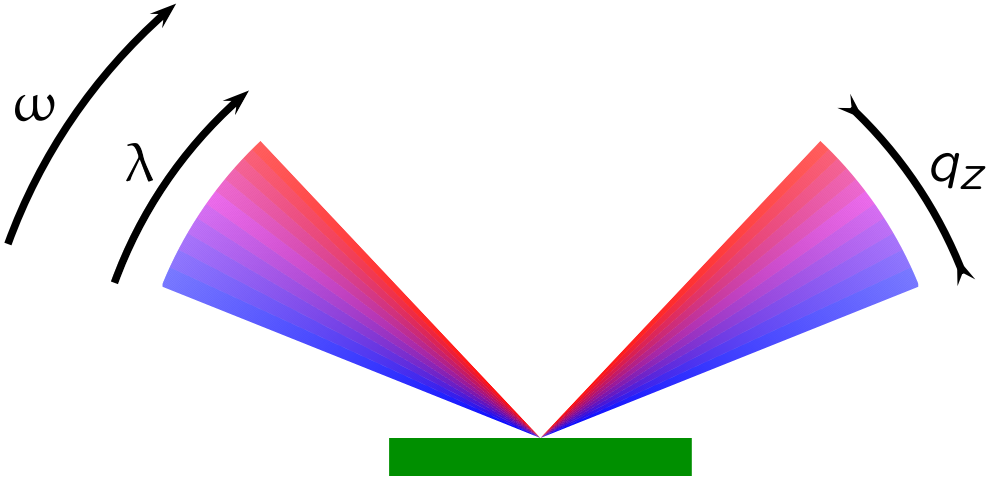
example: $0.5^\circ < \omega < 2^\circ$

$4\,\text{Å} < \lambda < 12\,\text{Å}$ $\Rightarrow 0.01\,\text{Å}^{-1} < q_z < 0.11\,\text{Å}^{-1}$

convergent beam

- λ/ω encoding of the incomming / reflected beam
- weakly dispersive set-up:

$\Rightarrow$ narrow q_z range

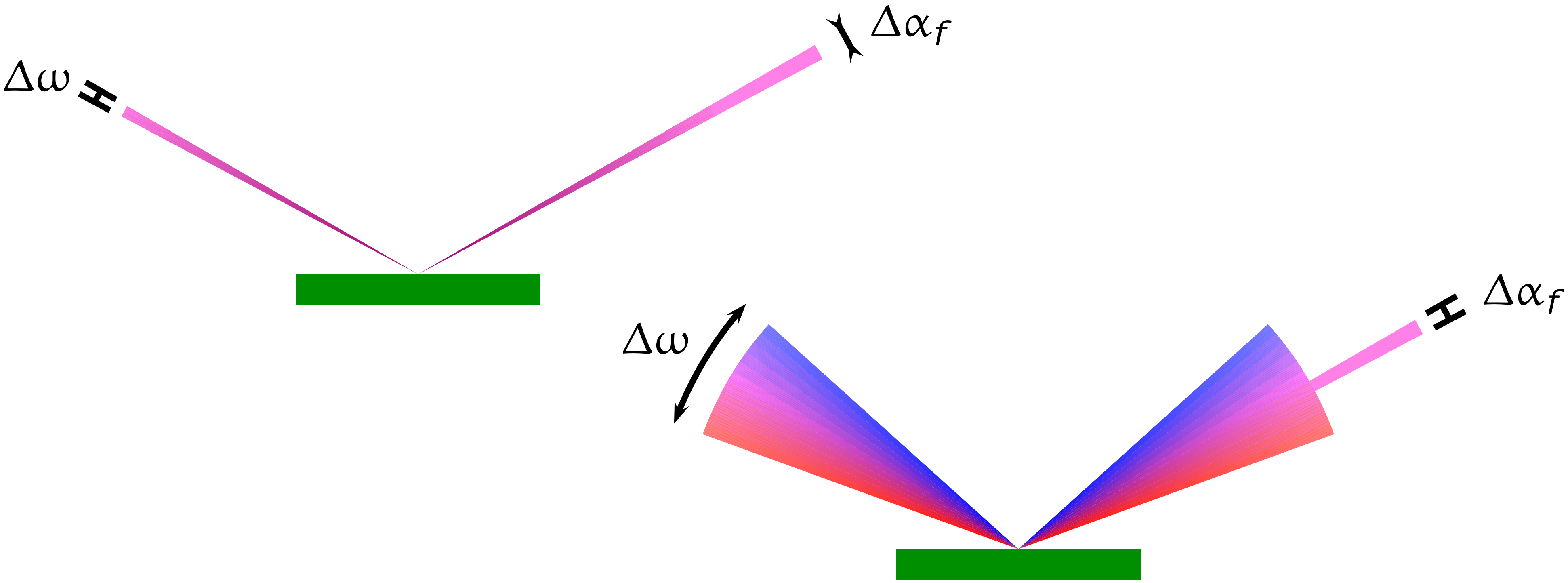


example: $0.5^\circ < \omega < 2^\circ$

$4\,\text{Å} < \lambda < 12\,\text{Å}$ $\Rightarrow 0.03\,\text{Å}^{-1} < q_z < 0.04\,\text{Å}^{-1}$

convergent beam

- resolution defined by detector ($\Delta\alpha_f$)
- gain $\propto \Delta\omega$ e.g. $1.5^\circ/0.05^\circ = 30$



- but: signal per channel $\propto \Delta\alpha_f$

  background per channel $\propto \Delta\alpha_f \cdot \Delta\omega$ $\Rightarrow$ limit at $\approx 10^{-5}$

convergent beam — how to create it?

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

specular reflectometry:
< 1 mm
large } encoded
broad } encoded

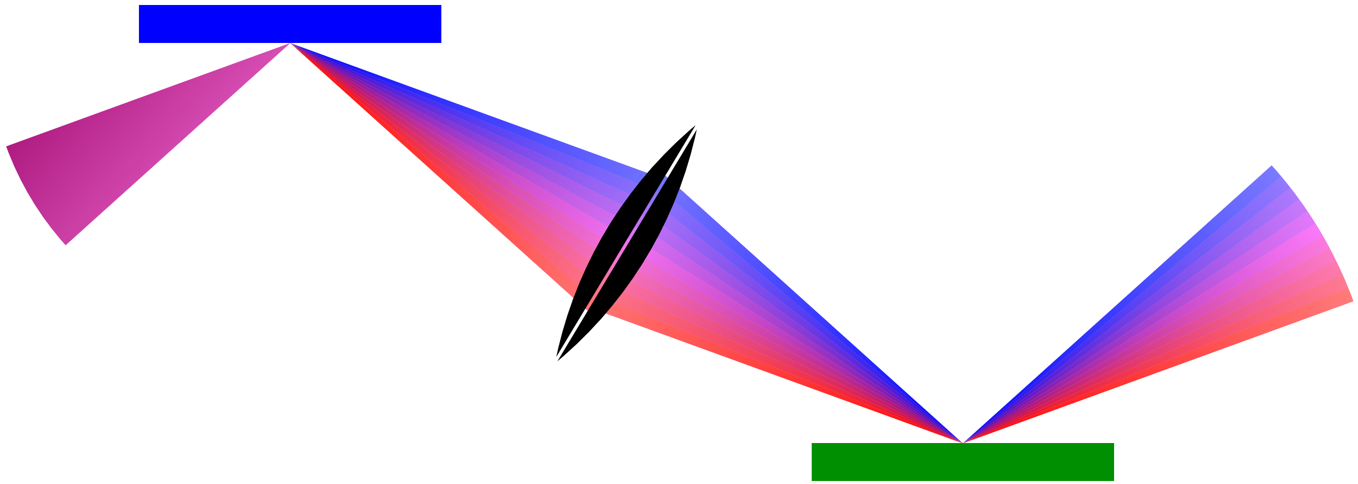
$\Rightarrow$ focusing optics

dispersive monochromator

filtering / beam-profiling far from the sample

convergent beam — how to create it?

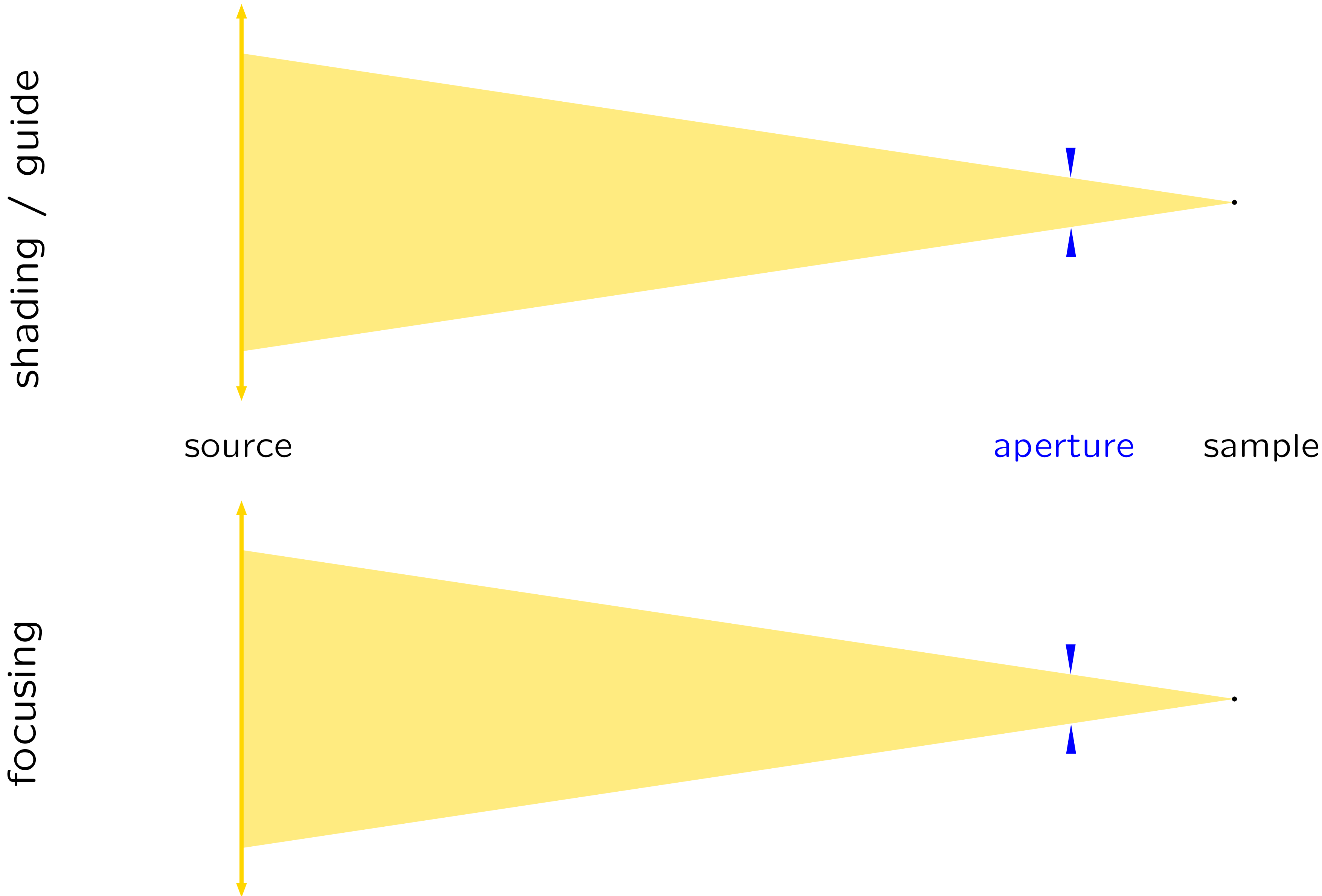
define the beam, starting at the sample
and avoid everything else!



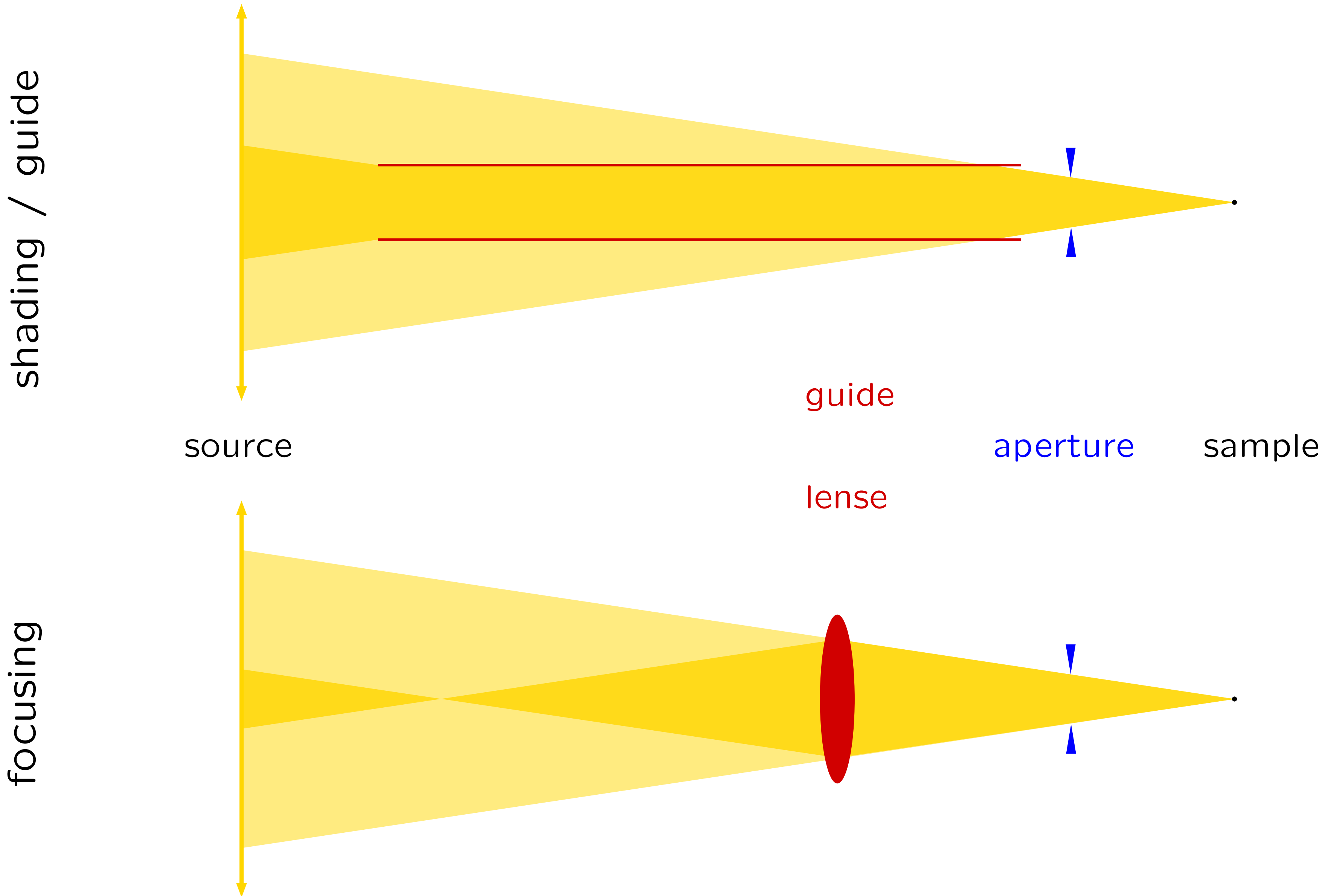
⇒ focusing optics

dispersive monochromator

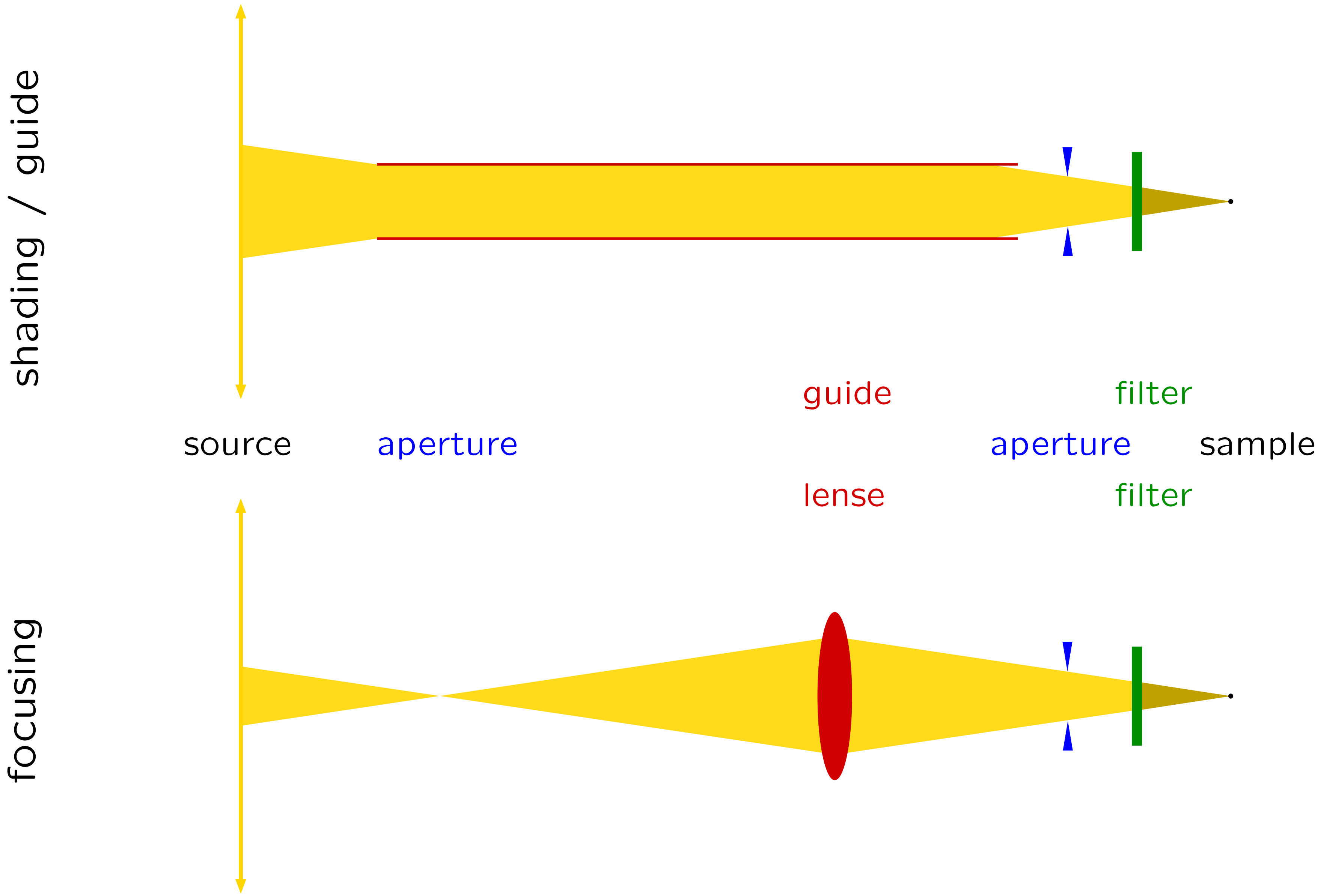
filtering / beam-profiling far from the sample beam defined by • required beam divergence



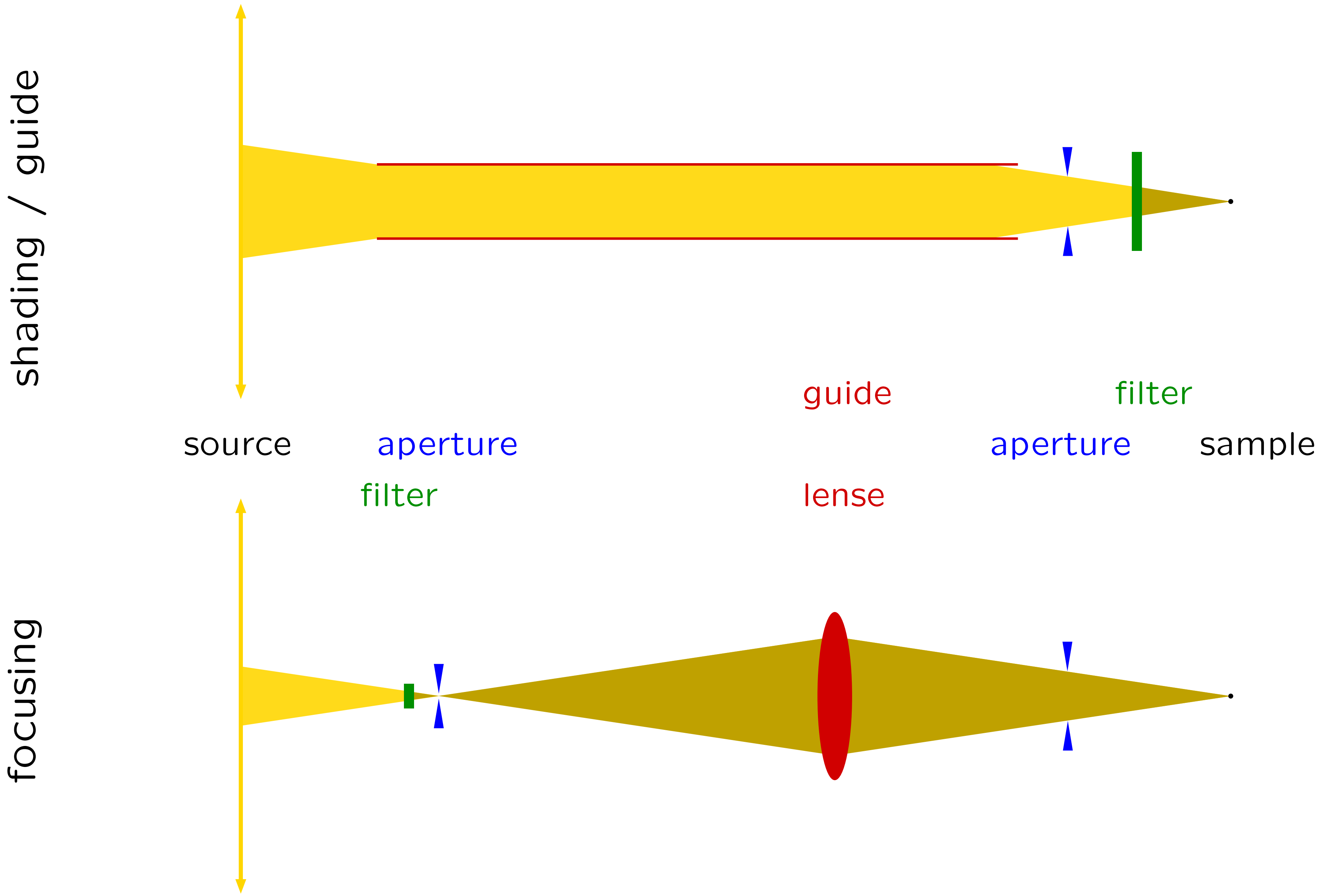
beam defined by • finite source size



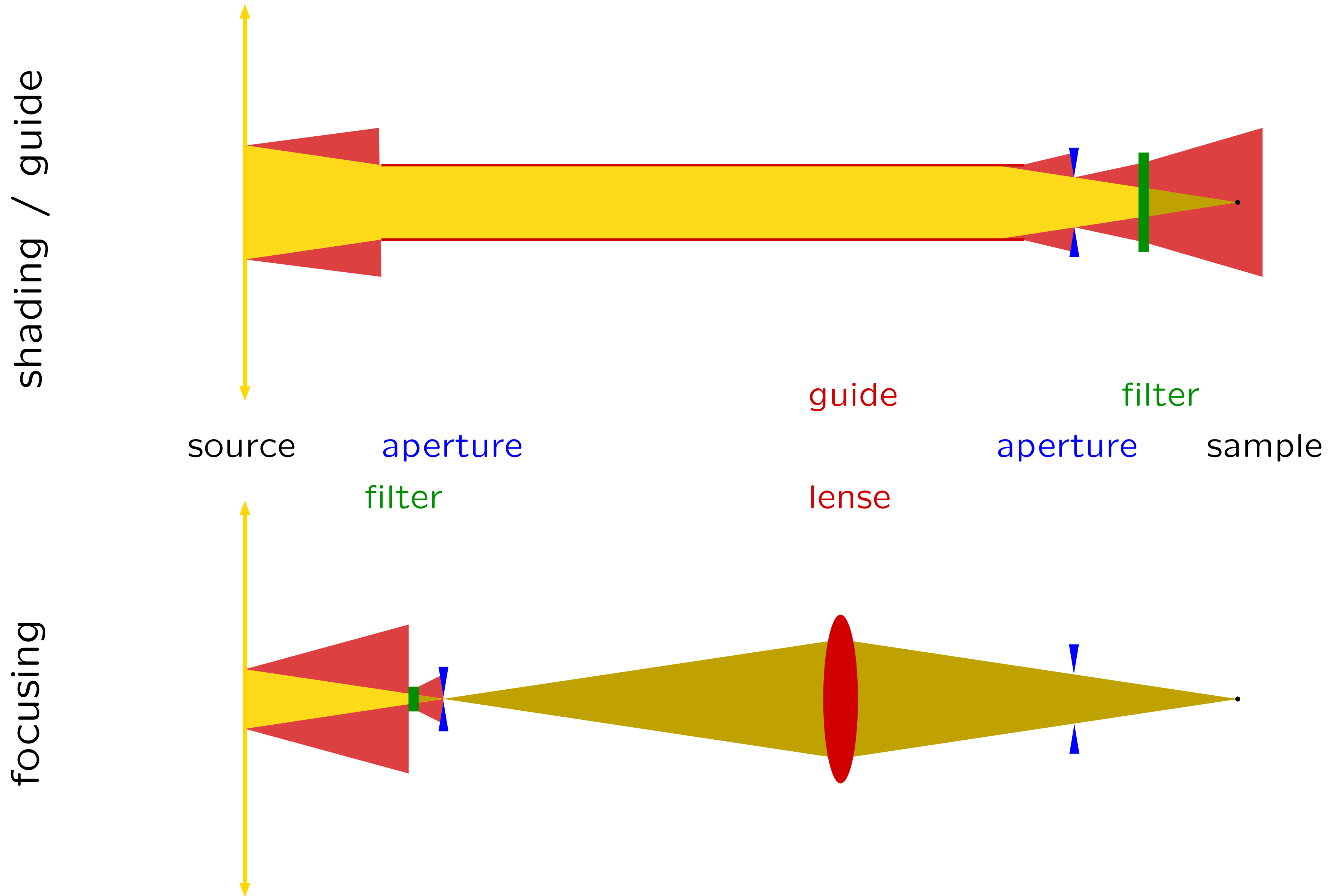
beam defined by • filtering (polarisation / monochromatisation)



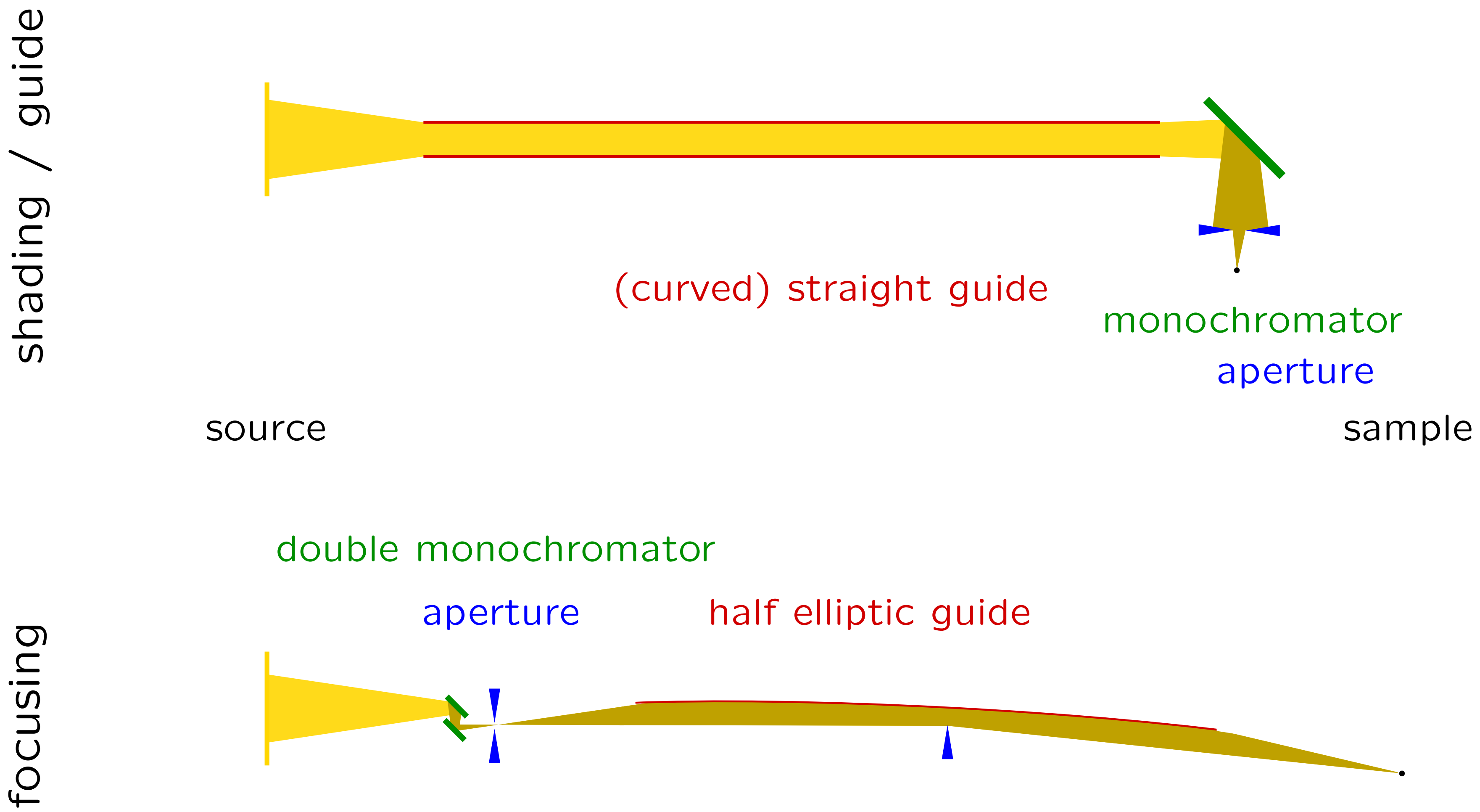
beam defined by • background / radiation issues



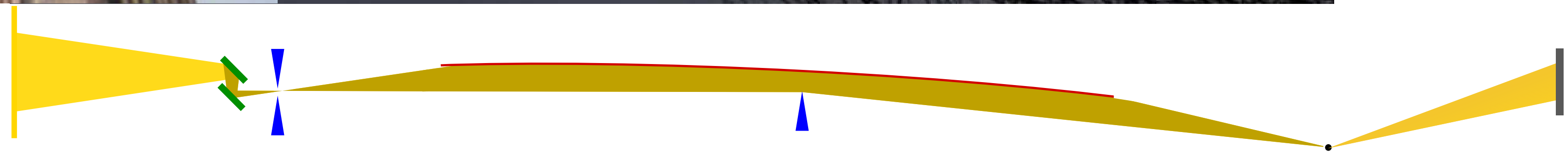
background / radiation issues



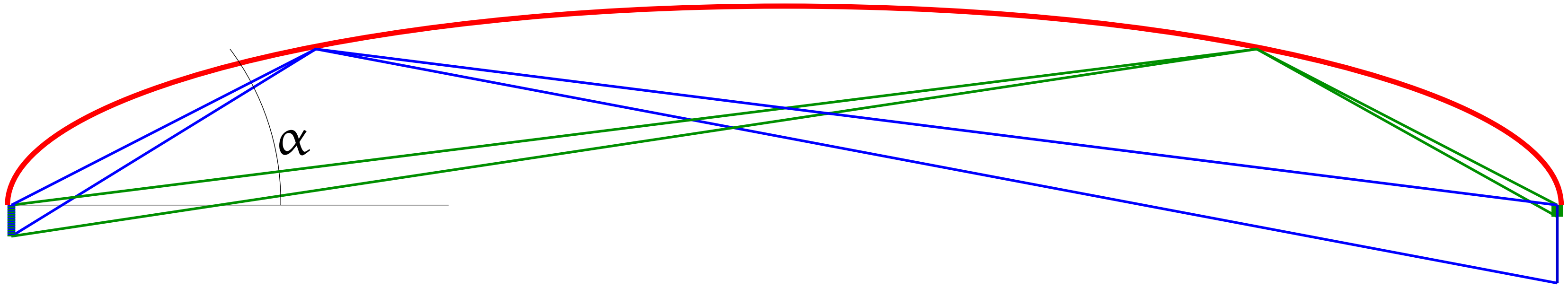
realisation



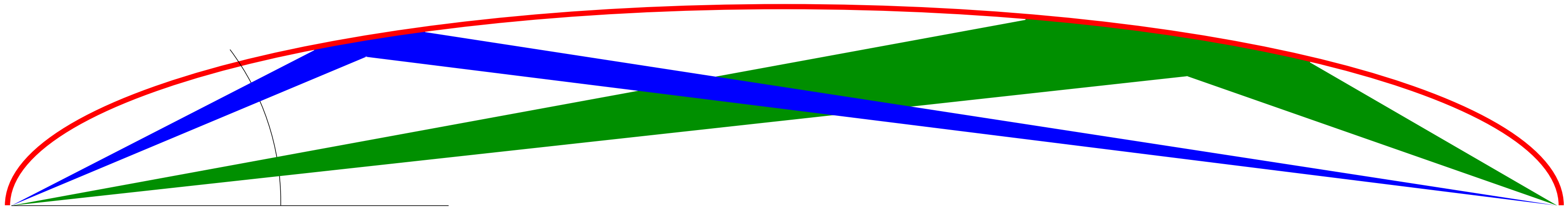
focusing optics — a name



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



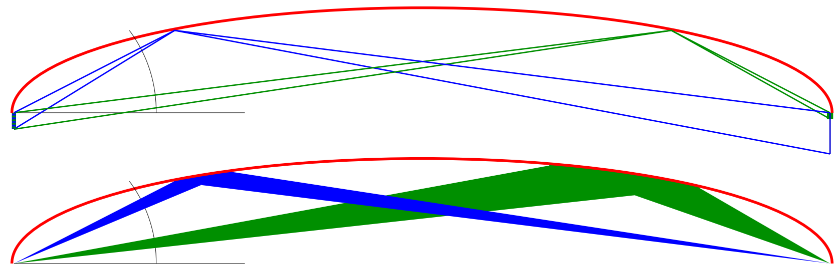
inhomogeneous ilumination



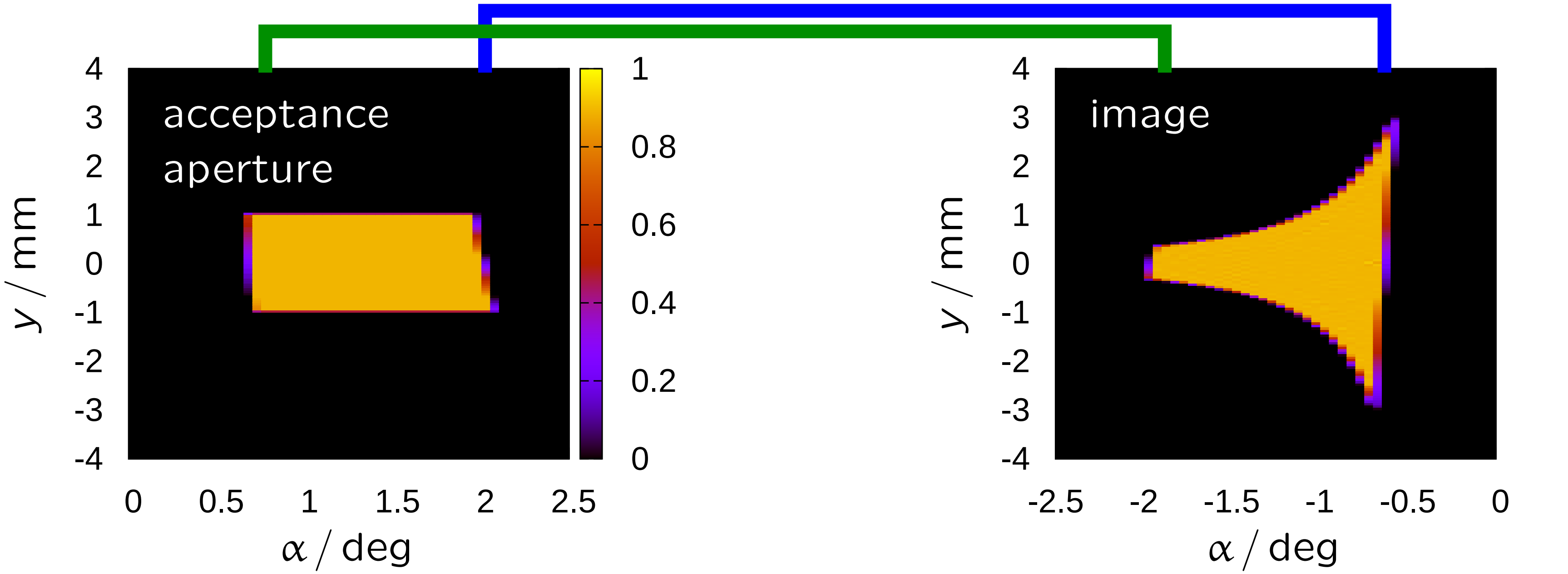
	large α	small α	
coma effect:	amplification	reduction	of preimage (slit)
divergence	low	high	at the sample position
intensity	high	low	”

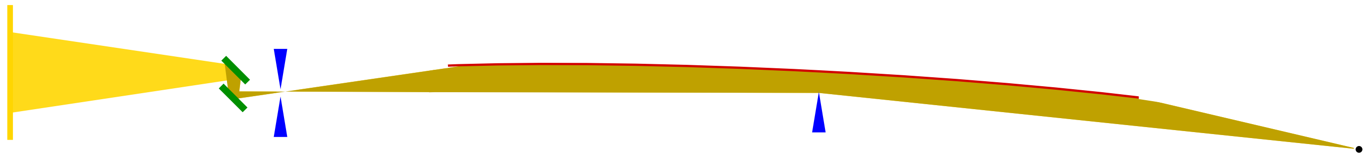
coma aberration

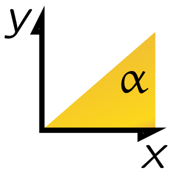
analytic calculations for selene



slit: high emmittance
aperture = 2 mm



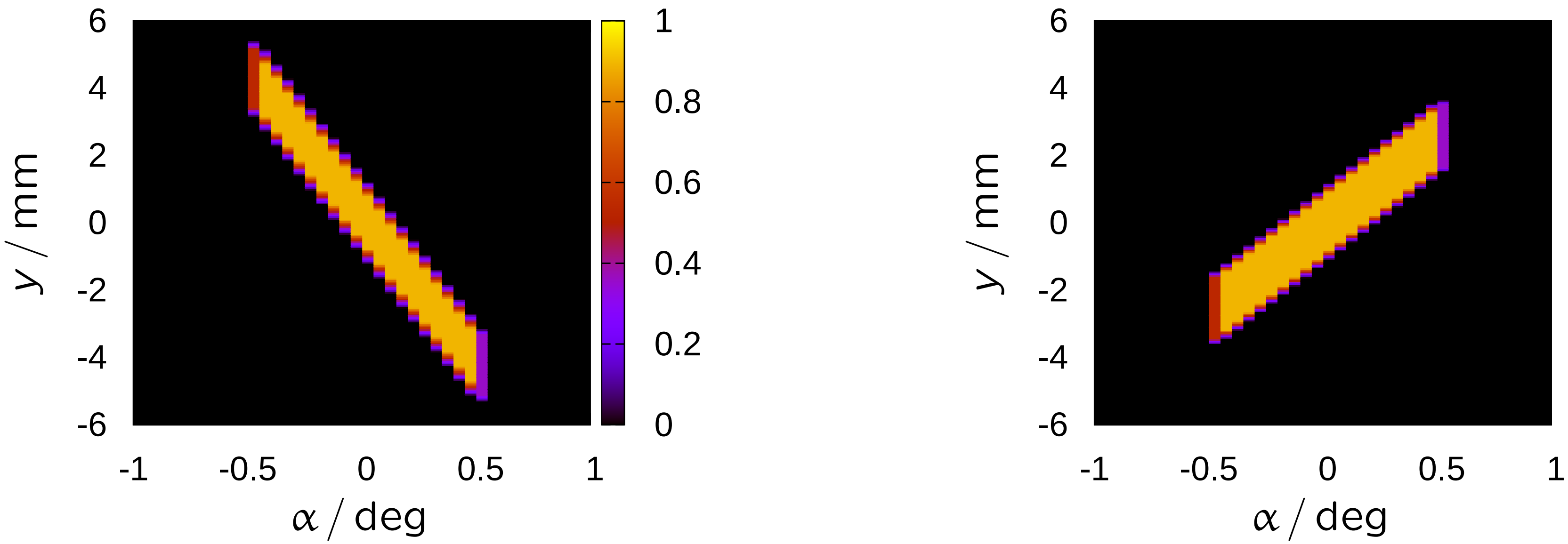




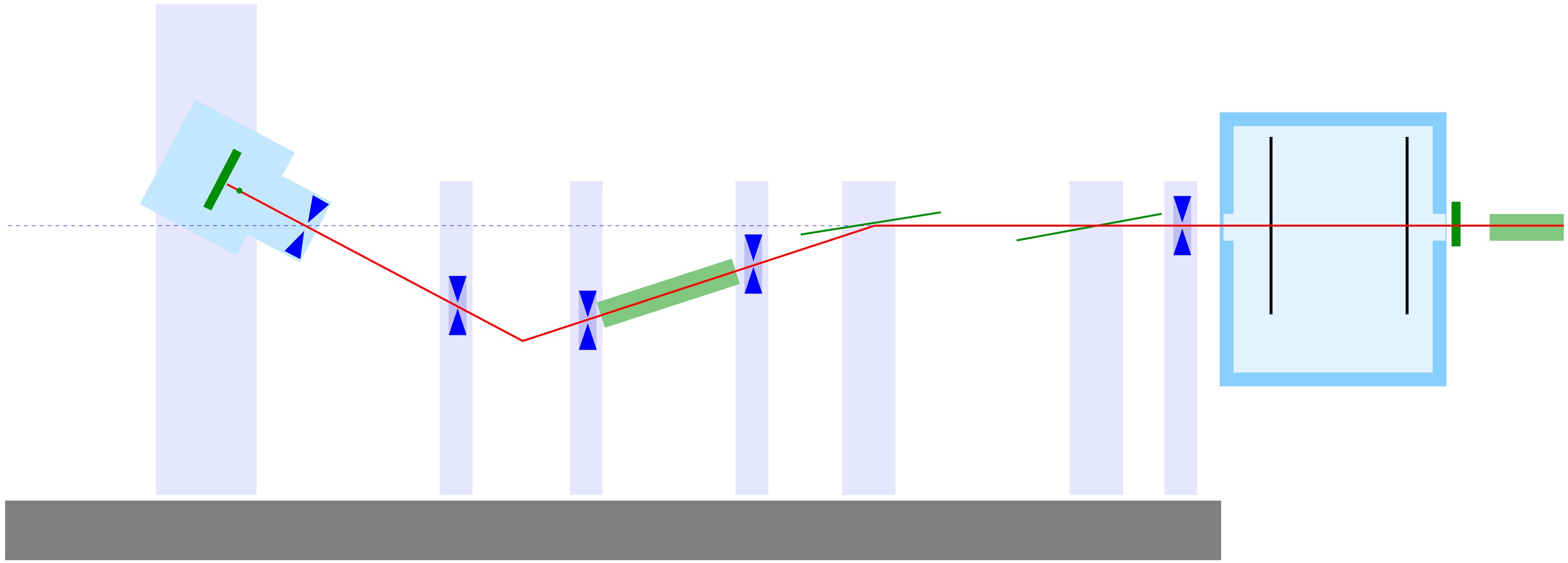
aberration of a staight guide

guide: emmittance $= \pm 0.5^\circ$

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



amor – polarised reflectometer in TOF mode

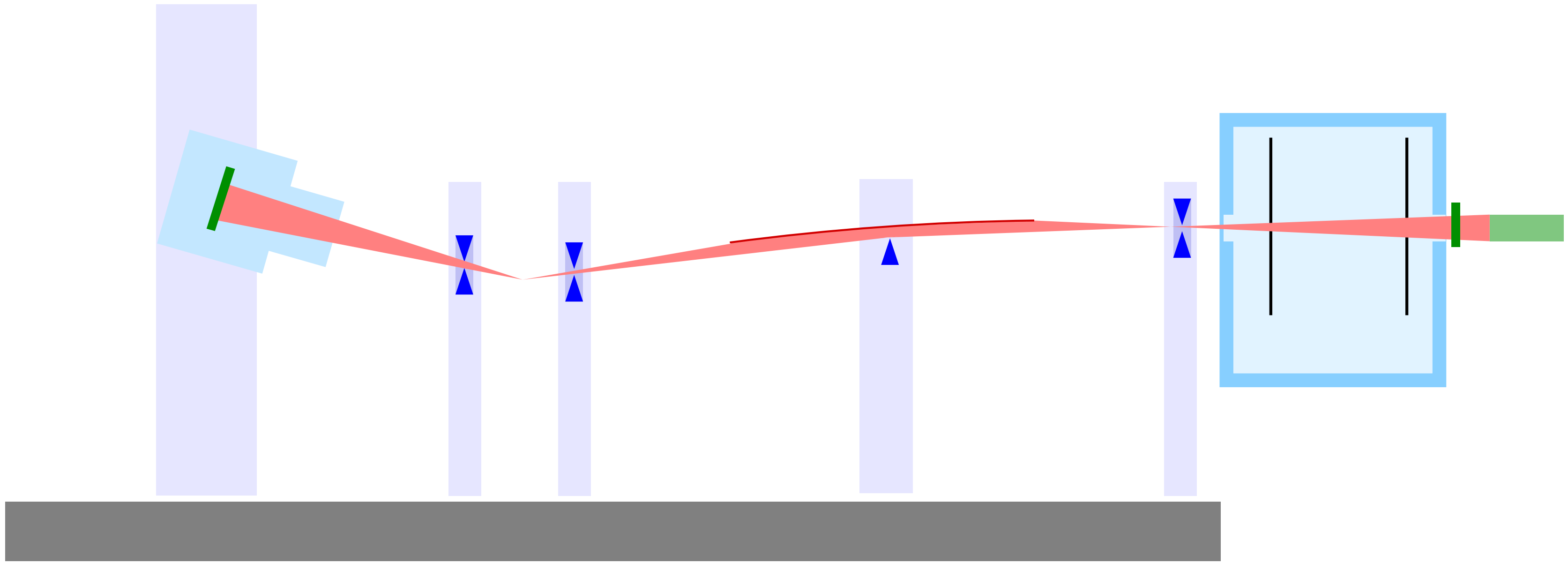


losses between guide ($50 \times 50\,\mathrm{mm}^2$) and sample:

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

use more flux
&
avoid the rest

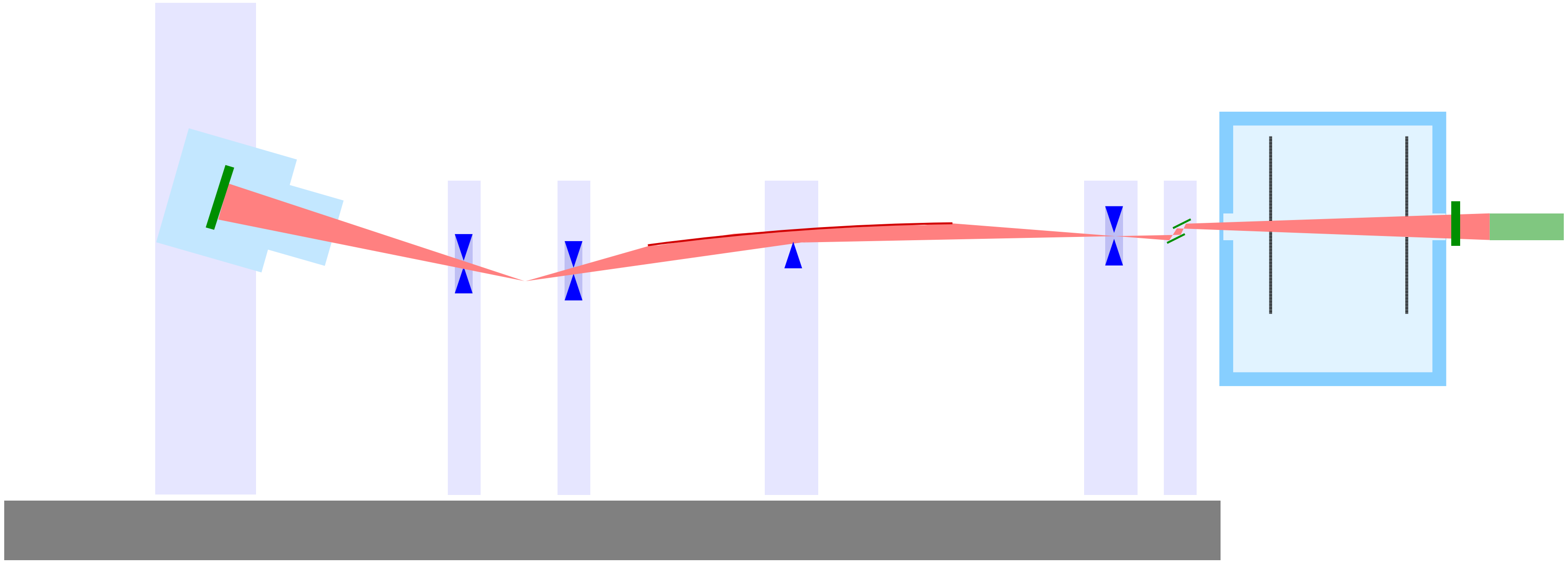
amor with selene in TOF mode



horizontal focusing
gain factor ≈ 6

enables high-intensity specular reflectivity
gain factor ≈ 20

amor with selene in monochromator mode

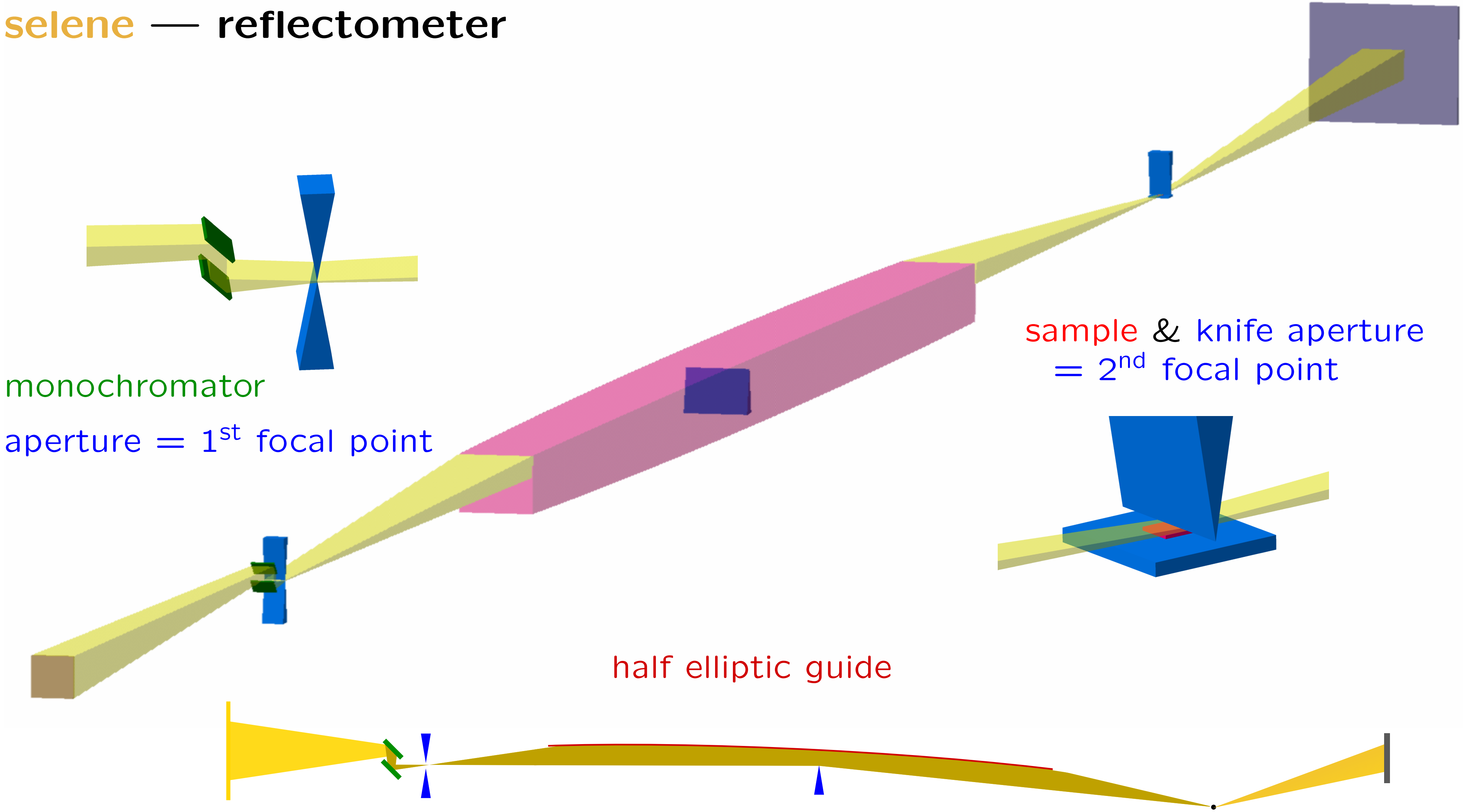


chopper stopped
double monochromator (ml or PG)

same flux, but different q_z-range

polarising ml possible

selene — reflectometer



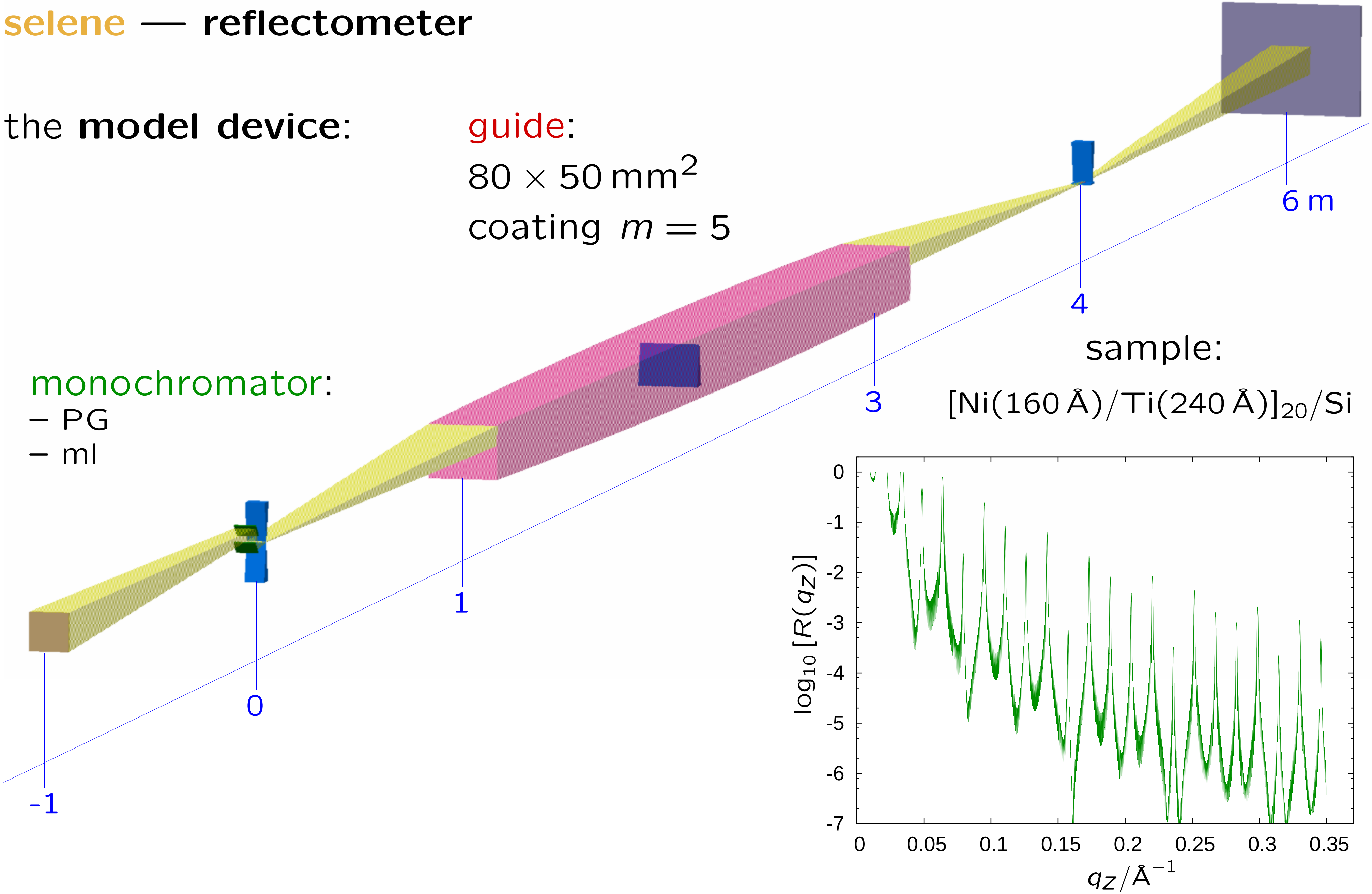
selene — reflectometer

the **model device**:

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

monochromator:
– PG
– ml

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



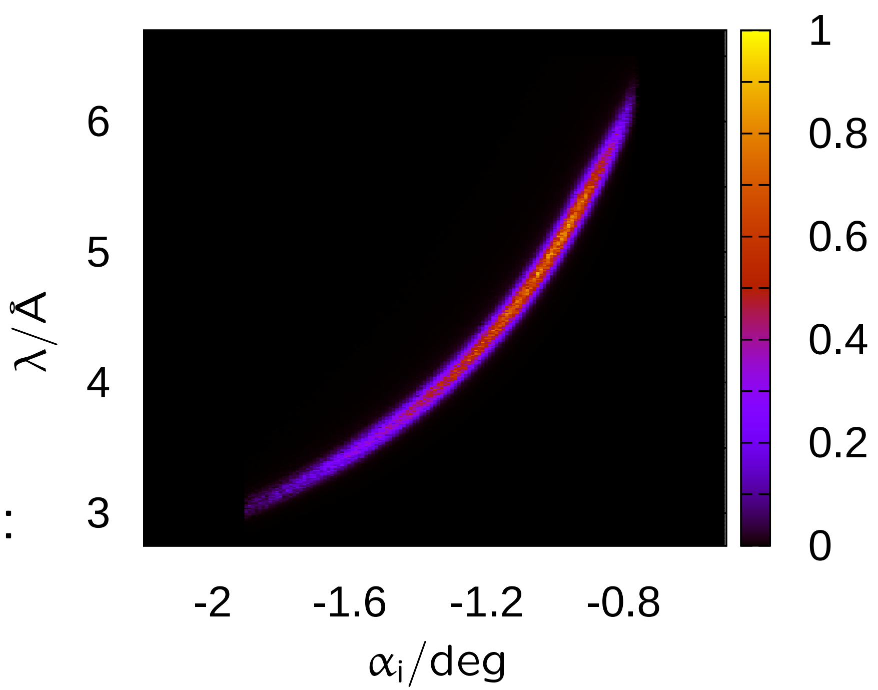
McStas simulations for selene — **reflectometer**
using a double **ml monochromator** ($m = 3$)

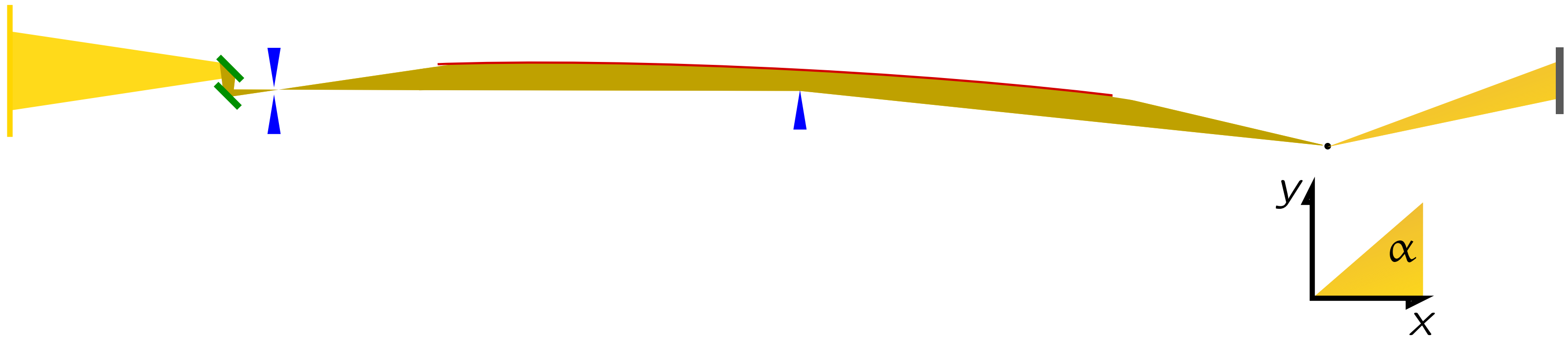
incident angle on the ml: $0 \ldots 2^\circ$

with $\lambda \propto \sin \alpha_\mathrm{i}$

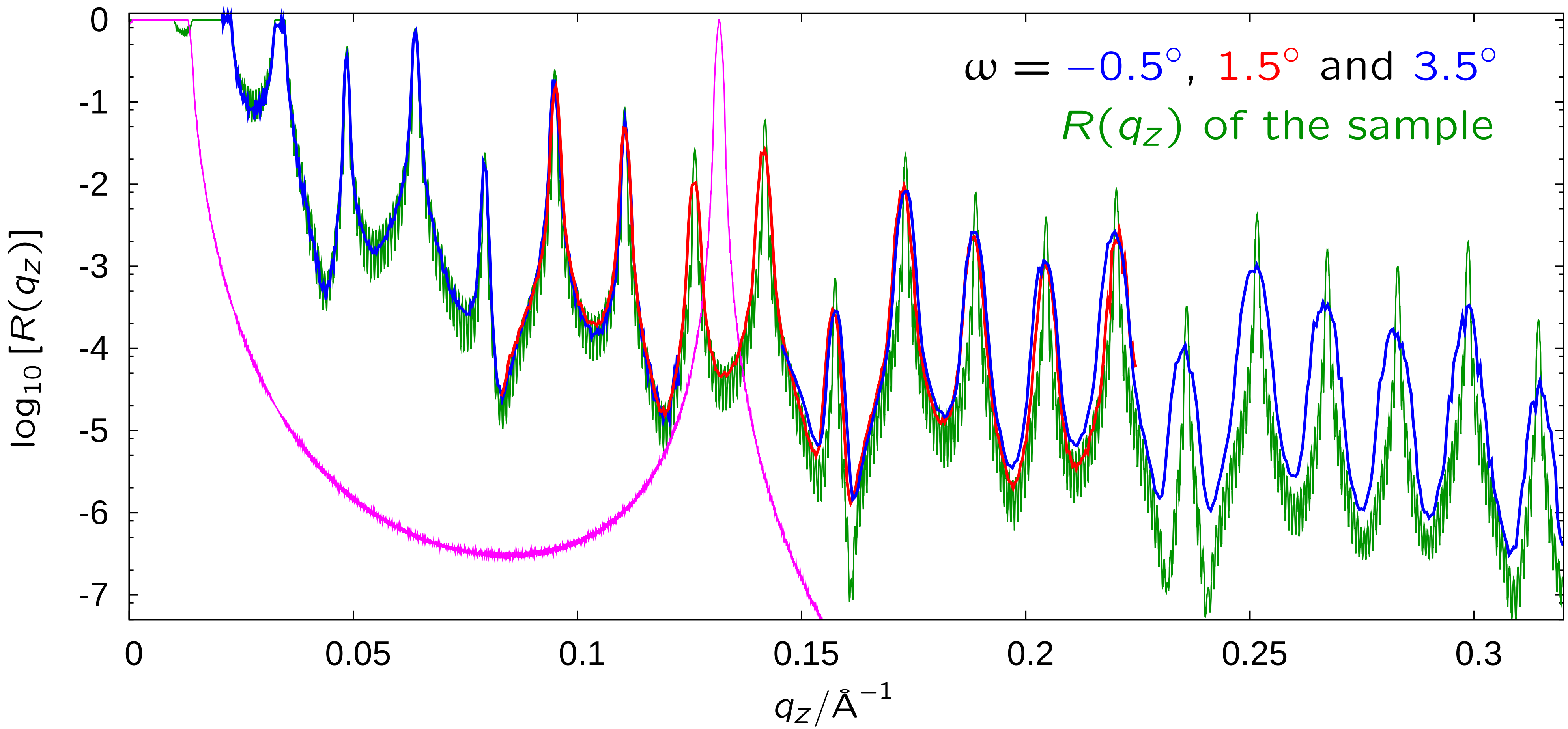
acceptance of the guide:
$\Delta\alpha = 1.3^\circ$

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



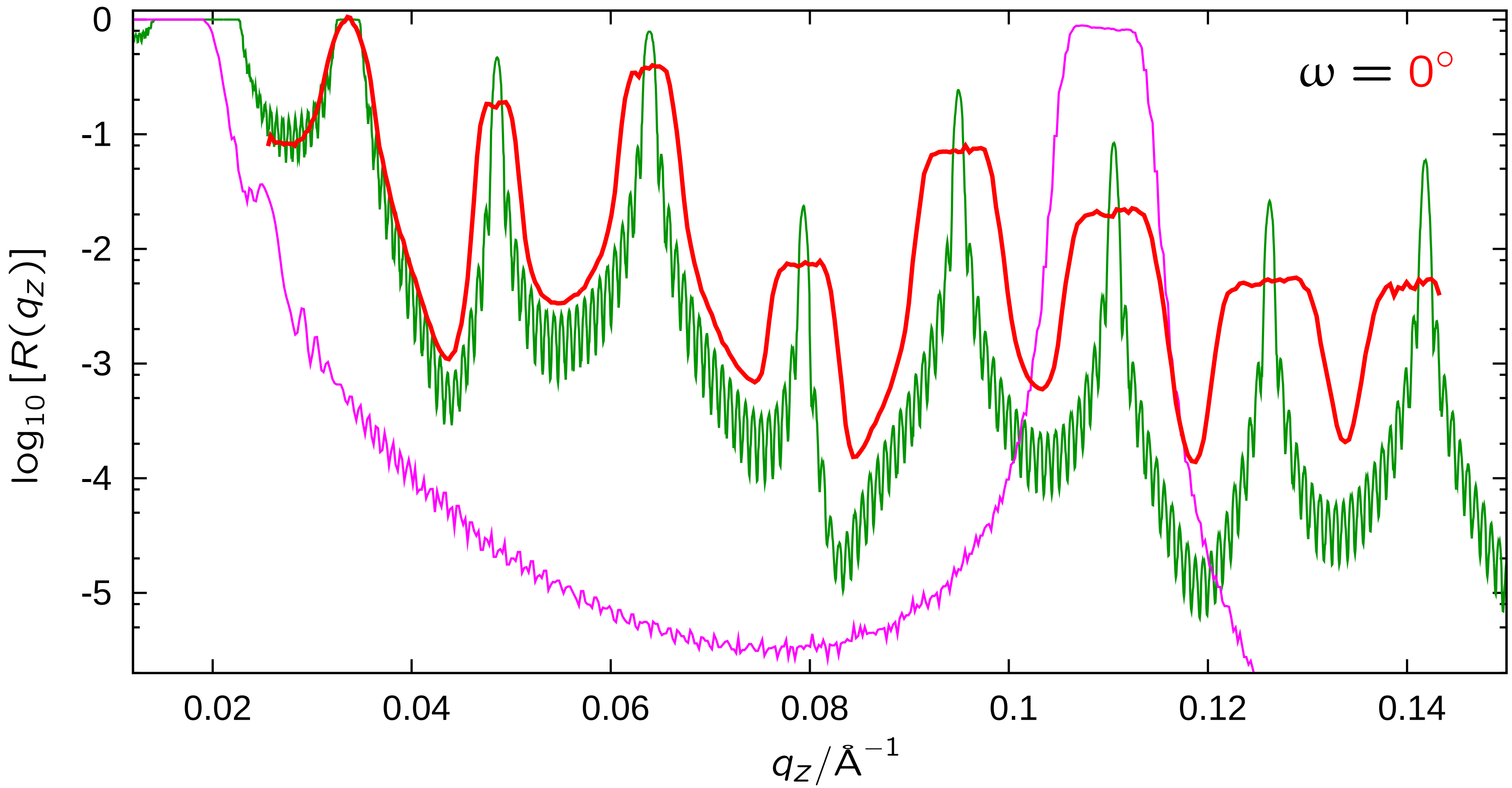


McStas simulations for selene — **reflectometer**
using a double ml monochromator $m = 6$, $\Delta q_z/q_z \approx 1\%$

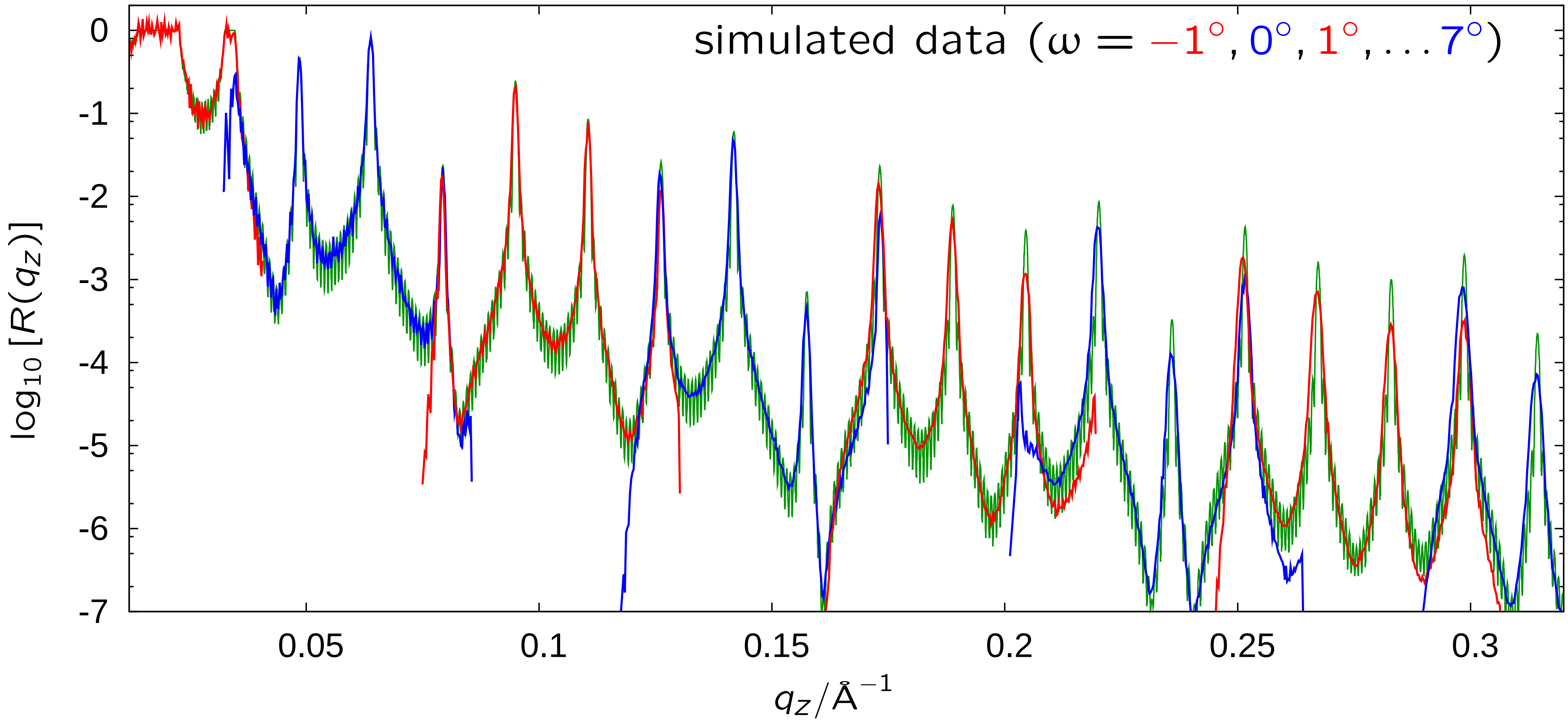


no off-specular scattering included, yet

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



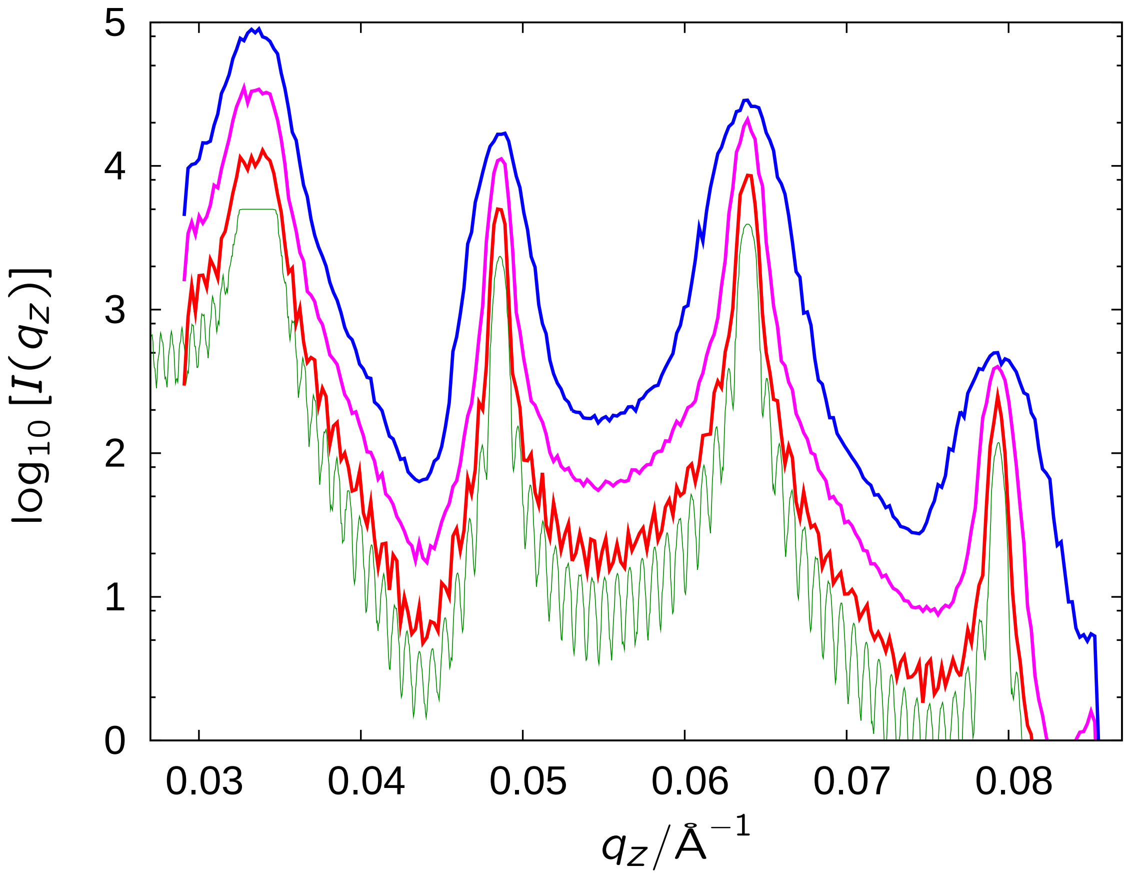
McStas simulations for selene — **reflectometer**
using a double **PG monochromator** ($\Delta\alpha = 0.16^\circ$)



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



selene reflectometer — resumee

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

allows for high-intensity reflectometry:

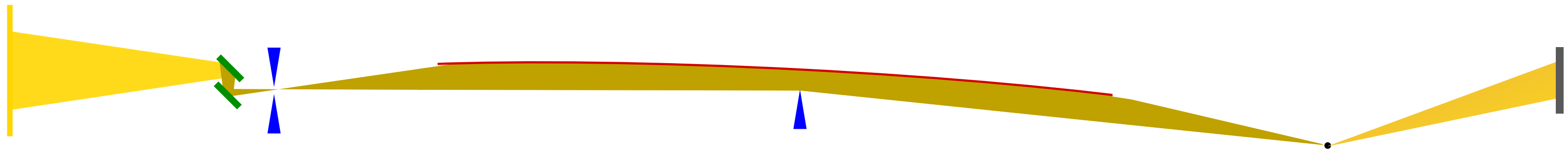
– ml monochromator: q_z-range e.g. 0.01 to 0.1 $Å^{-1}$

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

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

⇒ off-specular measurements are possible

⇒ a diaphragm-scan results in a q_z-scan



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

applies for

– source
– filter
– guide
...

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

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for the McStas programmig and simulation work

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F. Ott
for the ReFOCUS concept — which triggered this work

P. Böni, U. Stuhr and C. Niedermayer
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YOU