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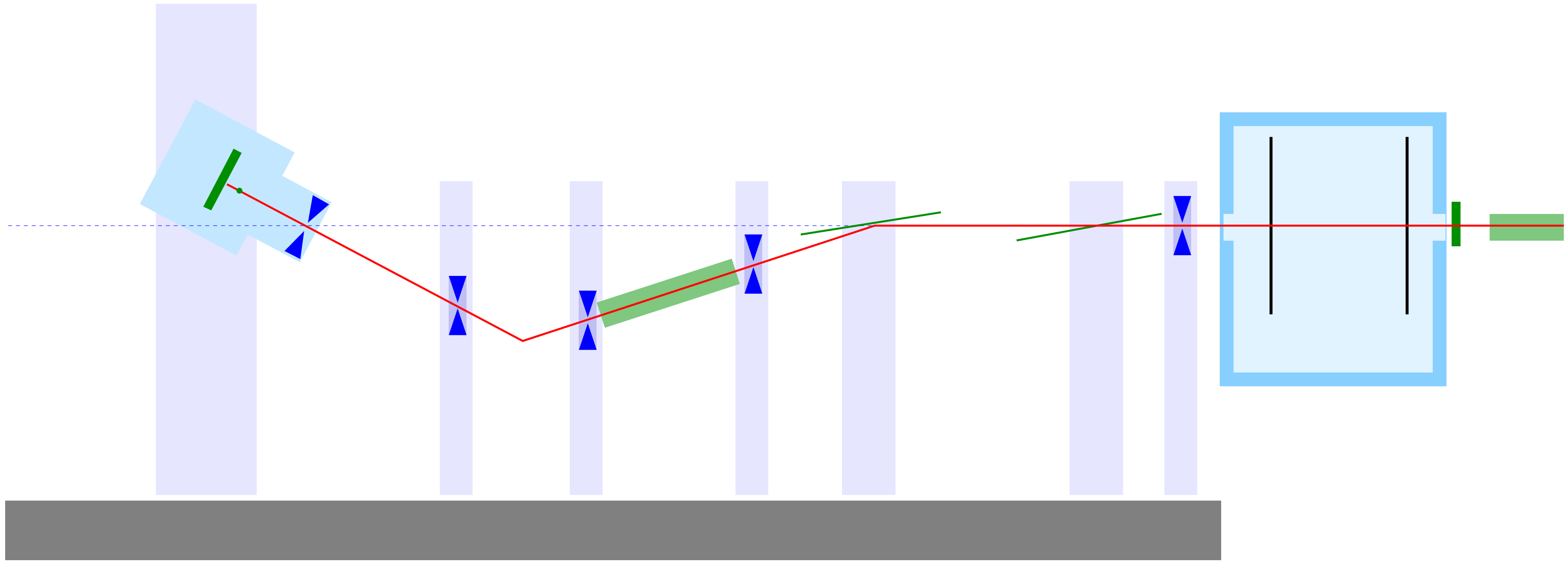
specular reflectomety on small samples using a convergent beam

outline

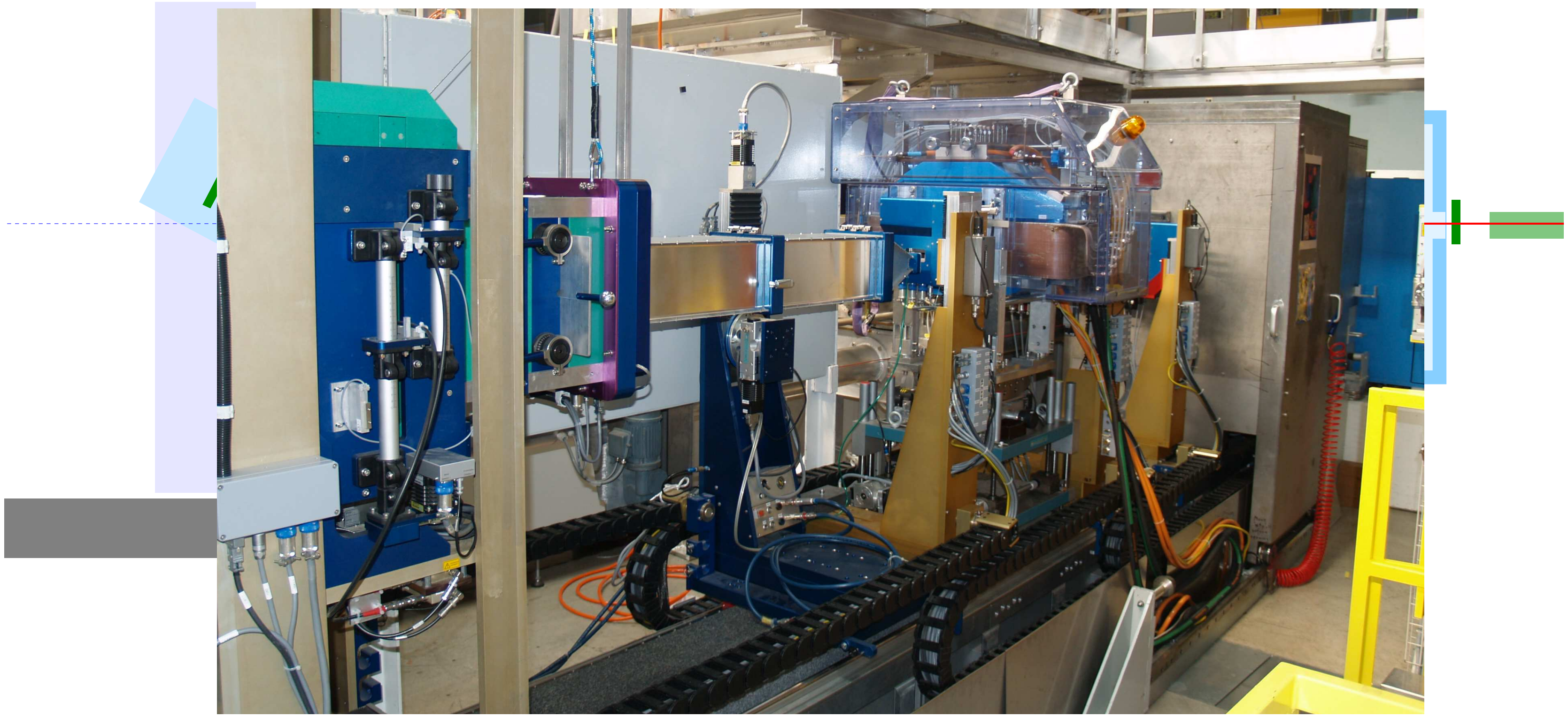
- amor at PSI
- refocus concept
- selene@amor
- design study for a reflectometer

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 $\Rightarrow$ tests of new concepts

allows for liquid surfaces

$\Rightarrow$ 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

$\Rightarrow$ trade more intensity against off-specular scattering

– prism analyser ($\rightarrow$ Bob Cubitt's talk)

spectral analysis of the reflected white beam

– convergent beam (Frédéric Ott)

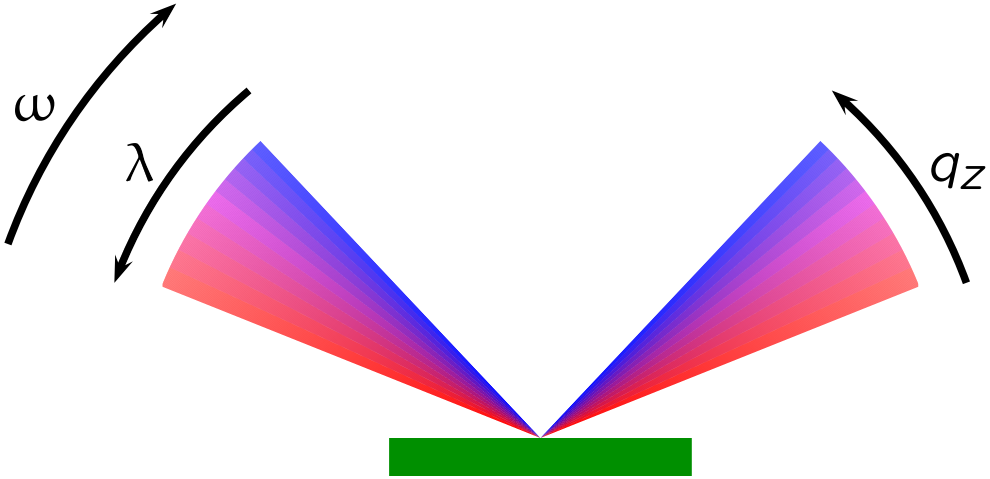
focusing to the sample

- angle/wavelength encoding

convergent beam

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

$\Rightarrow$ broad q_z range

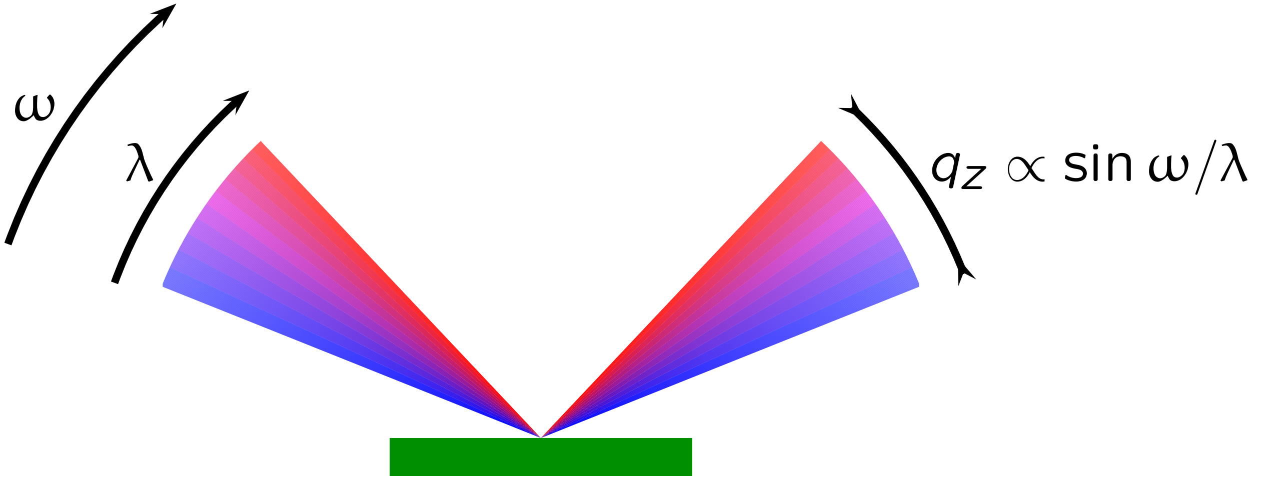


example: $0.5^\circ < \omega < 2^\circ$
$4\,\text{Å} < \lambda < 12\,\text{Å}$ $\Rightarrow 0.01\,\text{Å}^{-1} < q_z < 0.11\,\text{Å}^{-1}$

convergent beam

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

$\Rightarrow$ narrow q_z range

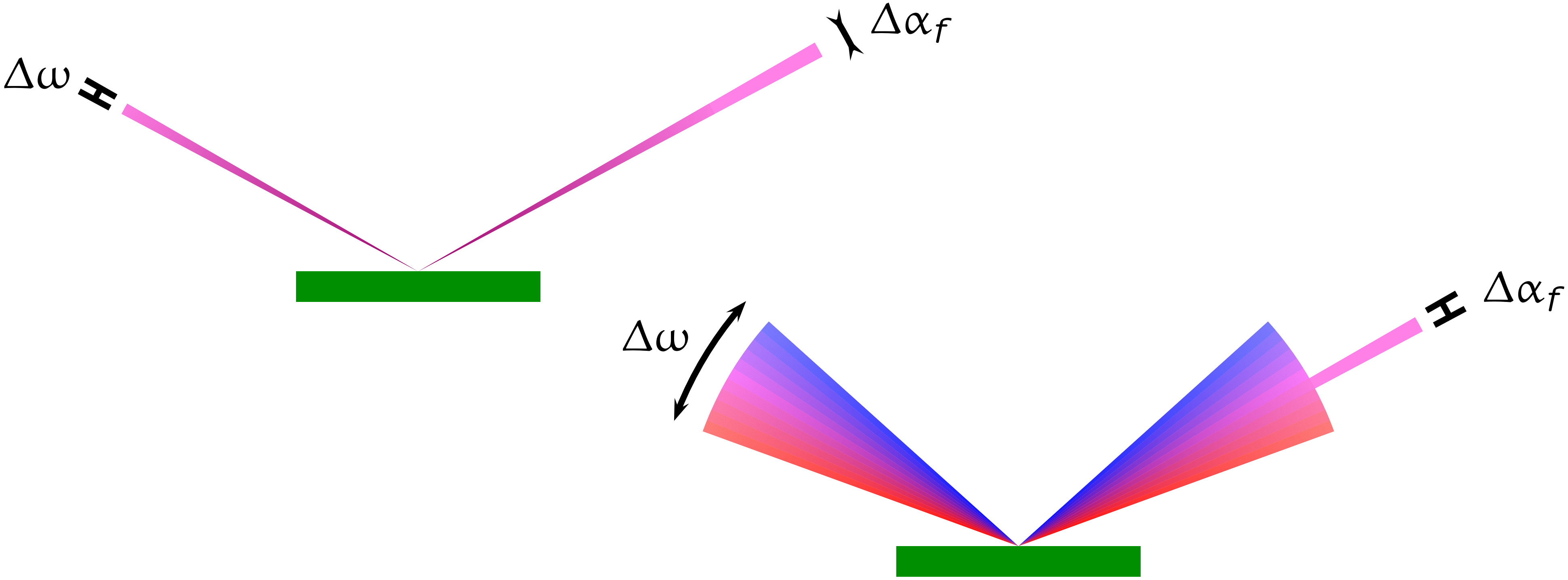


example: $0.5^\circ < \omega < 2^\circ$

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

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
$\left.\begin{array}{l}\text{large}\\ \text{broad}\end{array}\right\}$ encoded

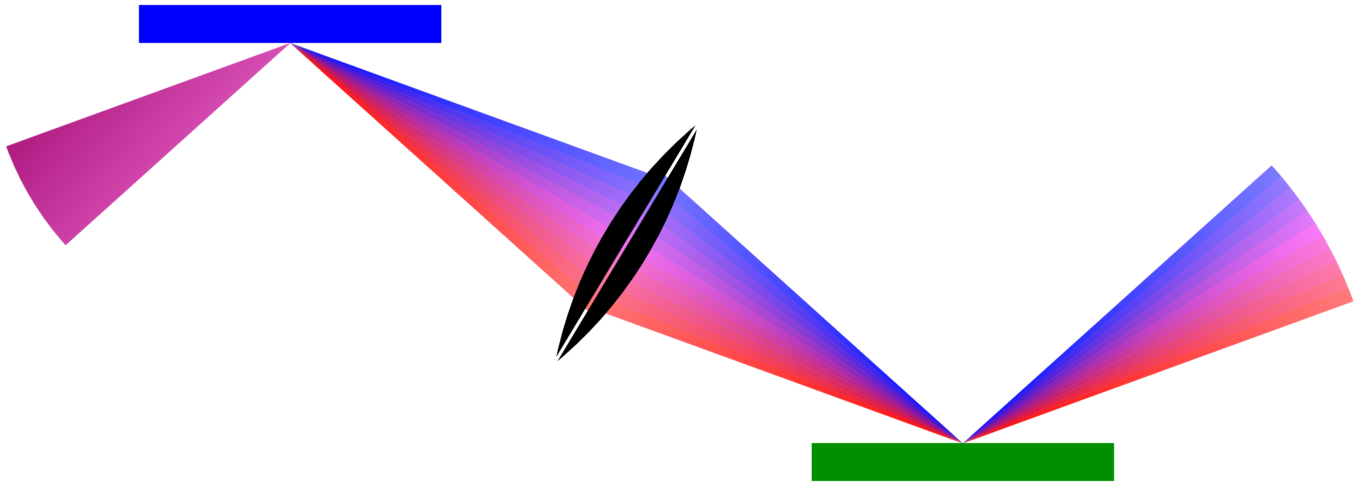
$\Rightarrow$ focusing optics

dispersive monochromator

filtering / beam-profiling far from the sample

convergent beam — how to create it?

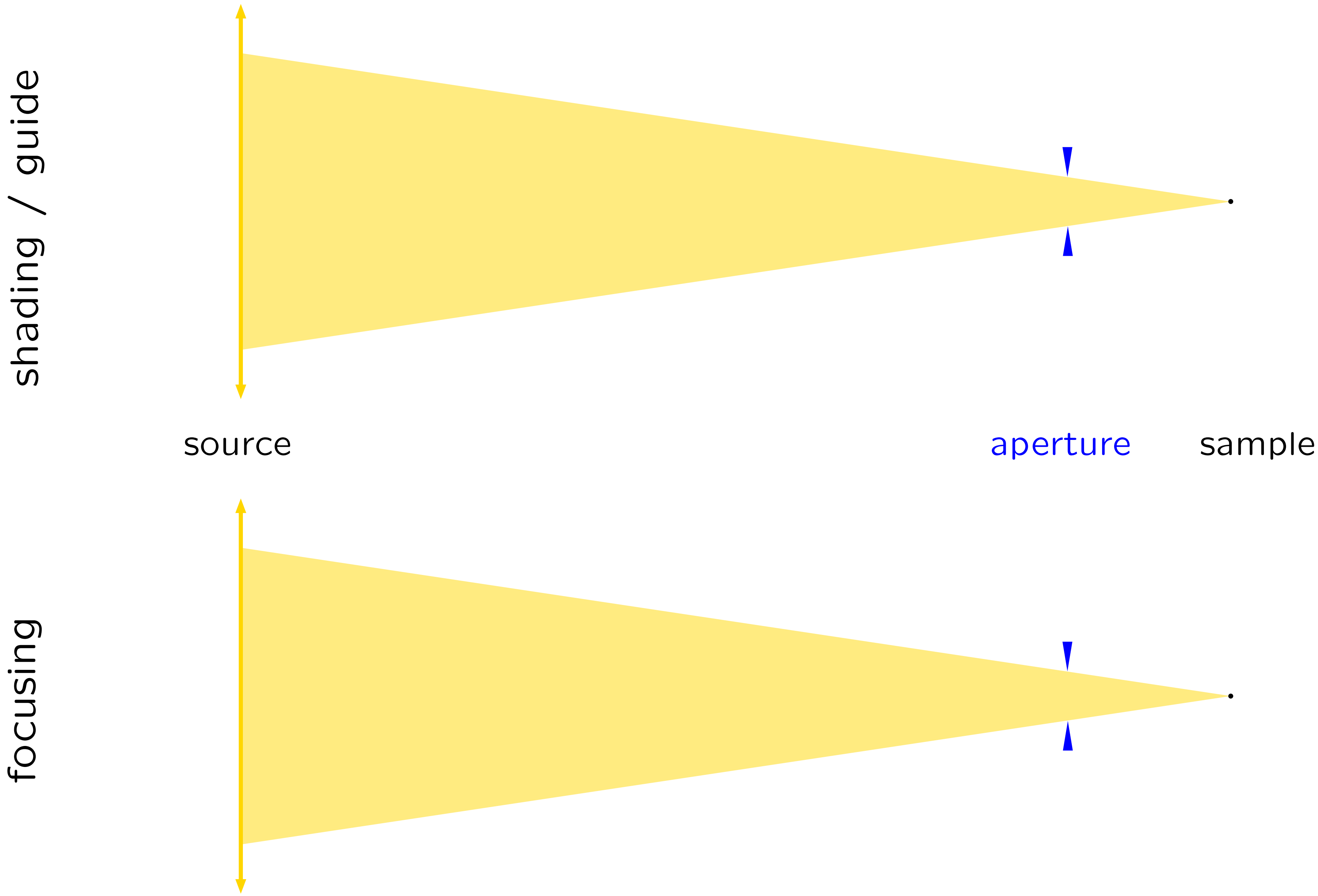
define the beam, starting at the sample
and avoid everything else!



⇒ focusing optics

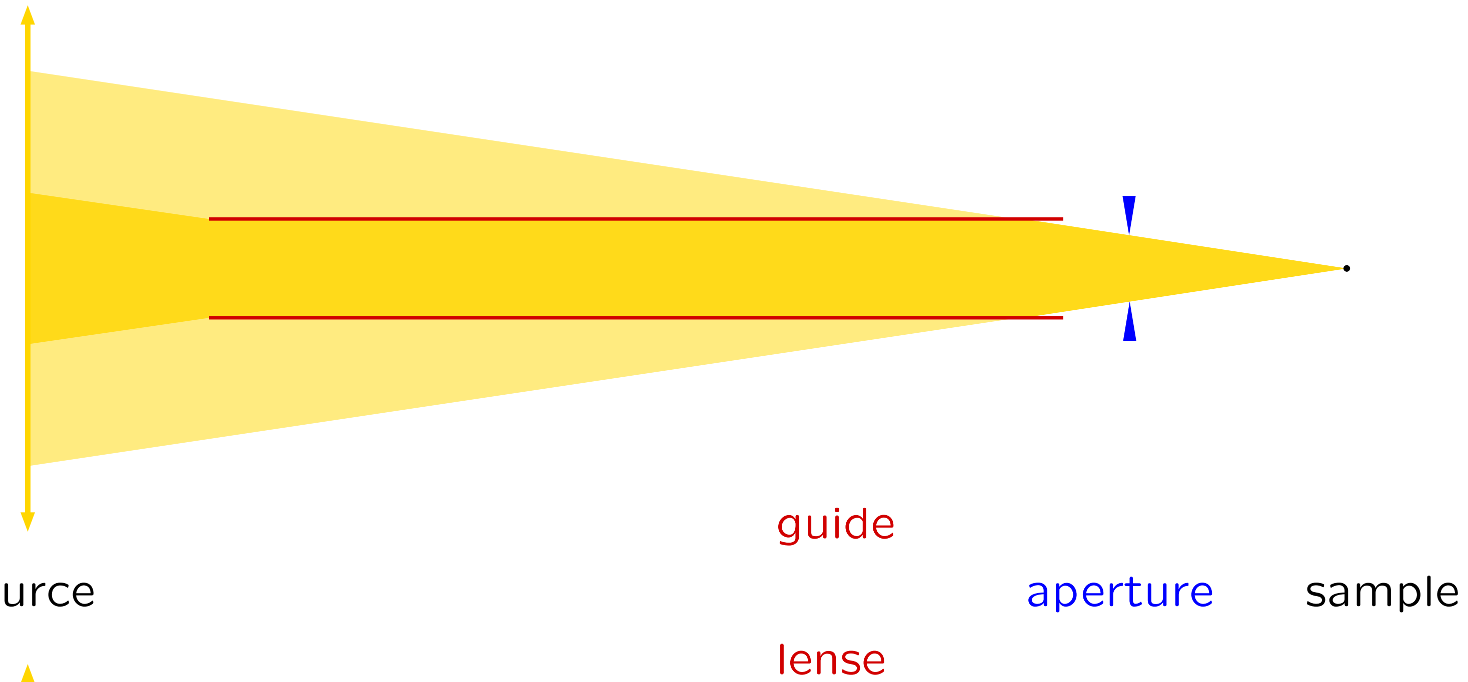
dispersive monochromator

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

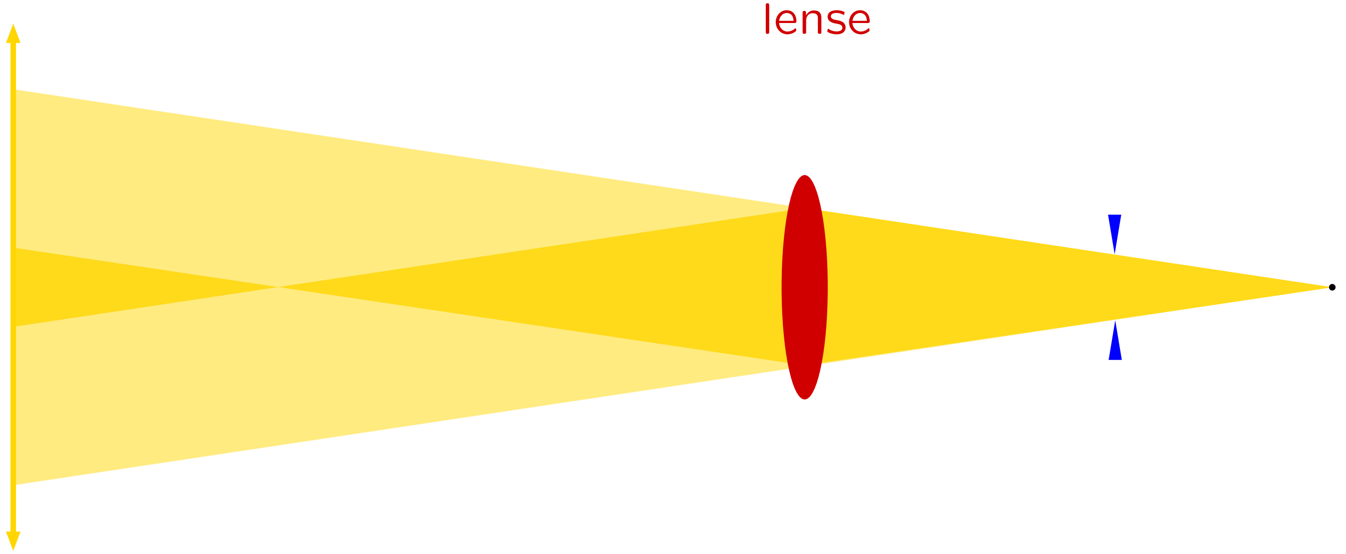


beam defined by • finite source size

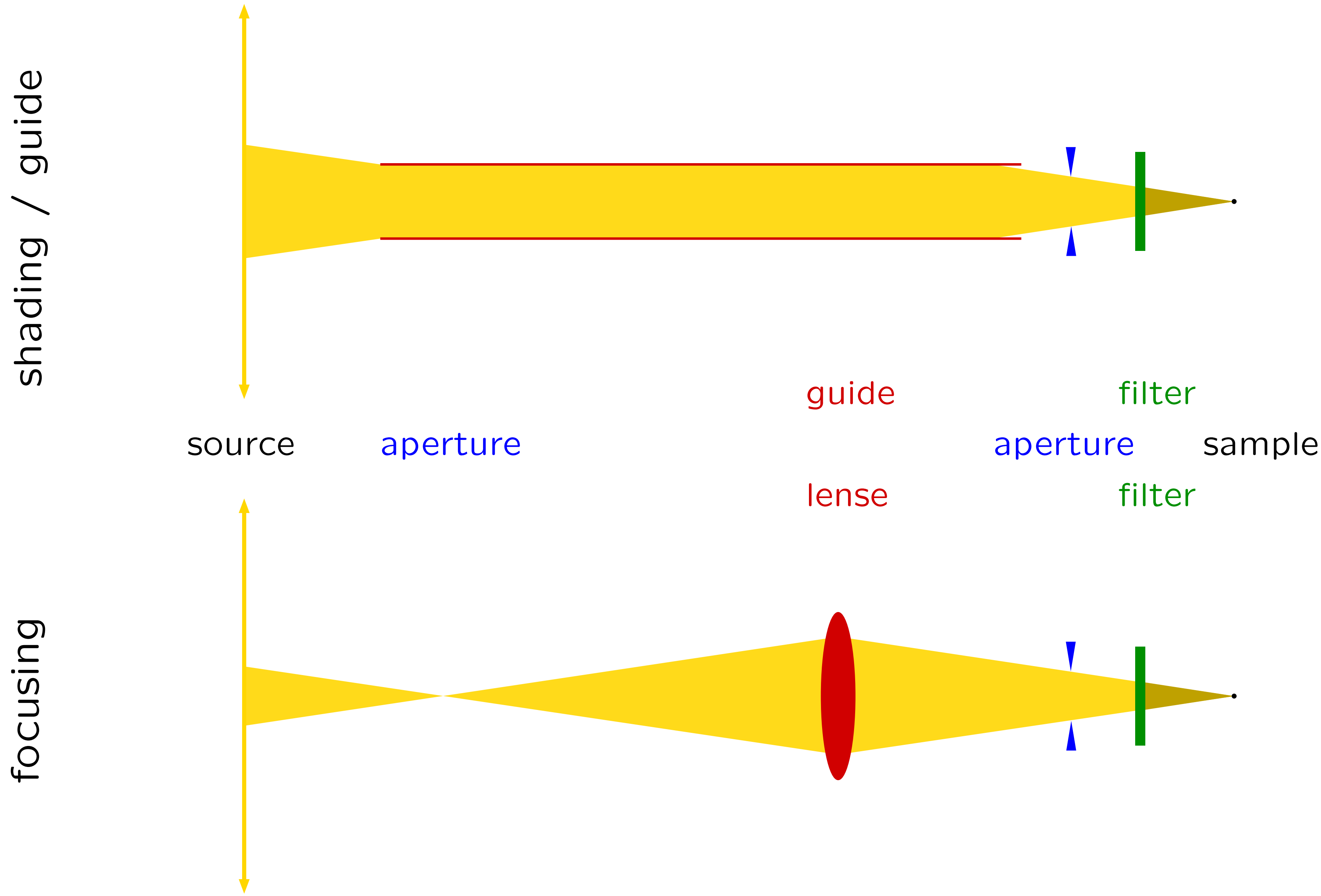
shading / guide



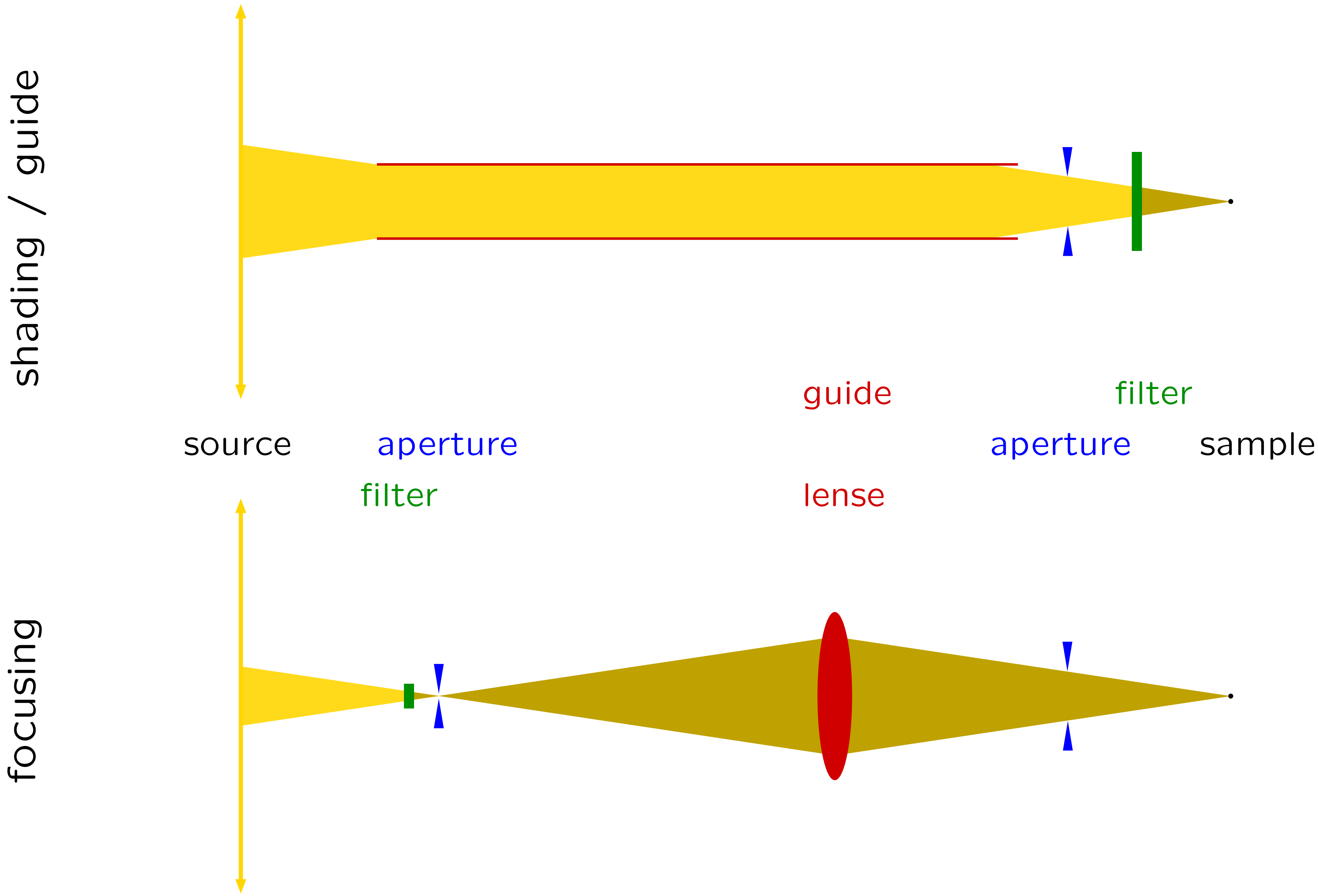
focusing



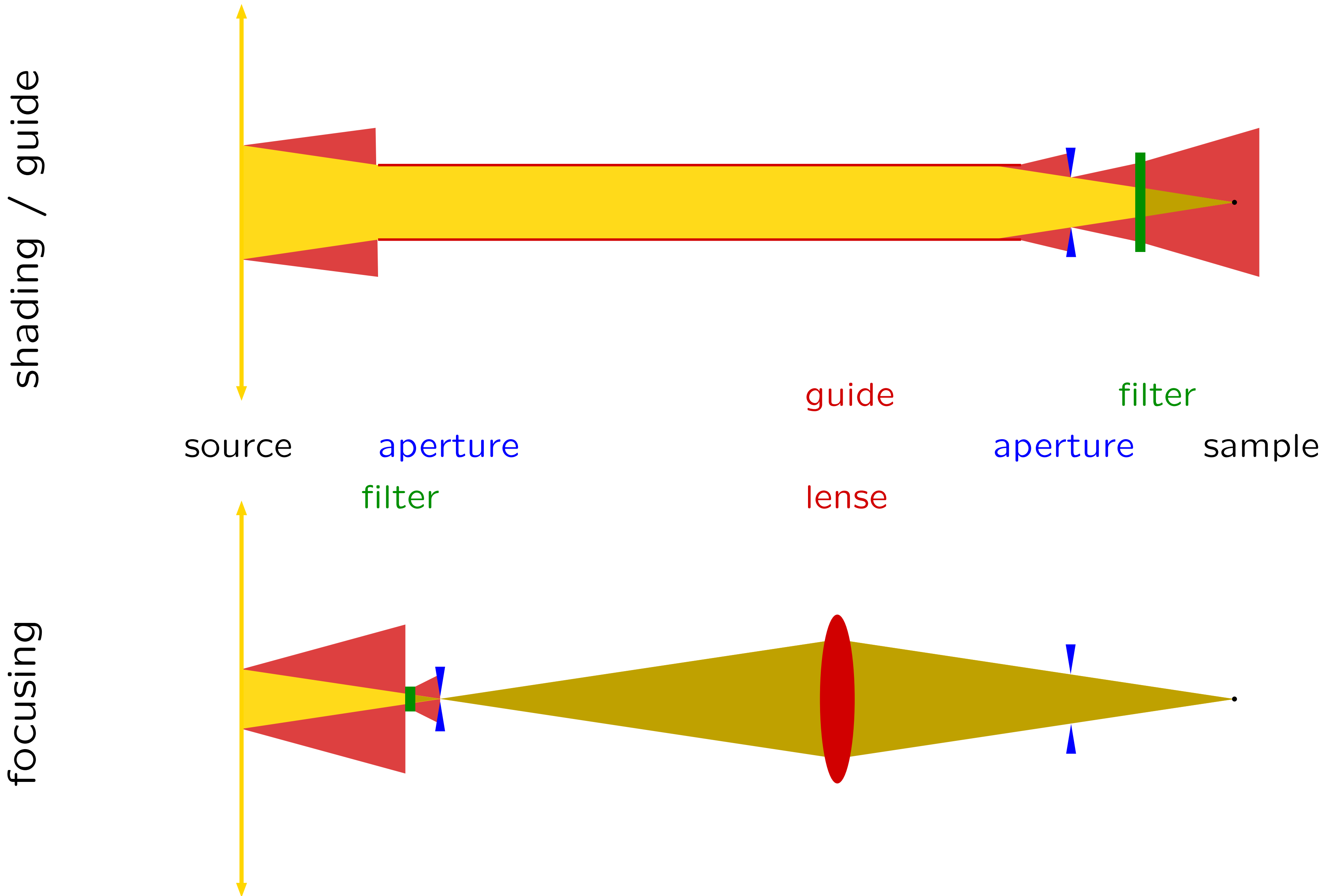
beam defined by • filtering (polarisation / monochromatisation)



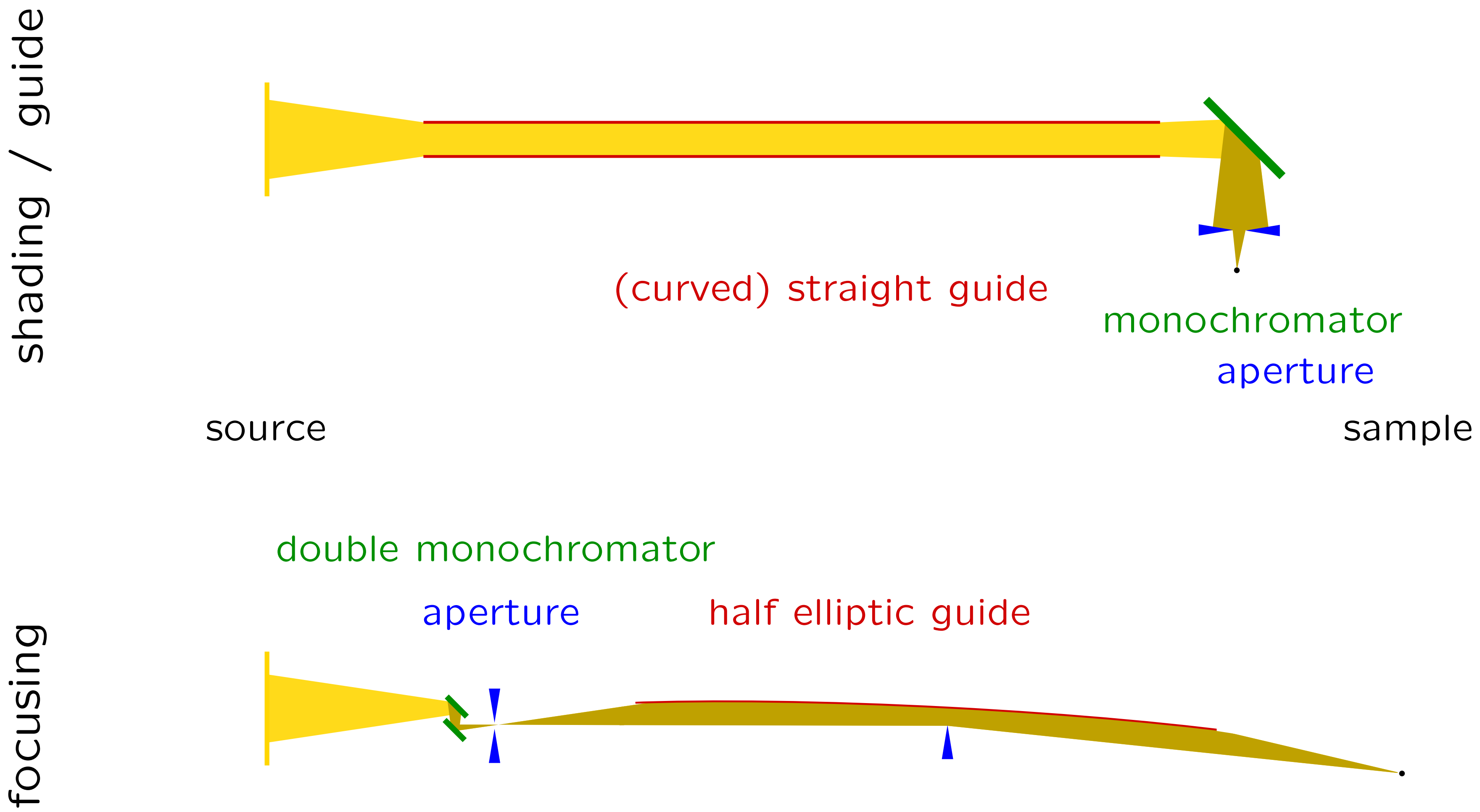
beam defined by • background / radiation issues



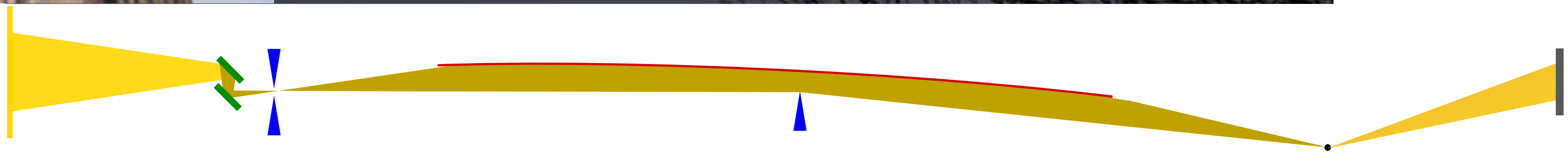
background / radiation issues



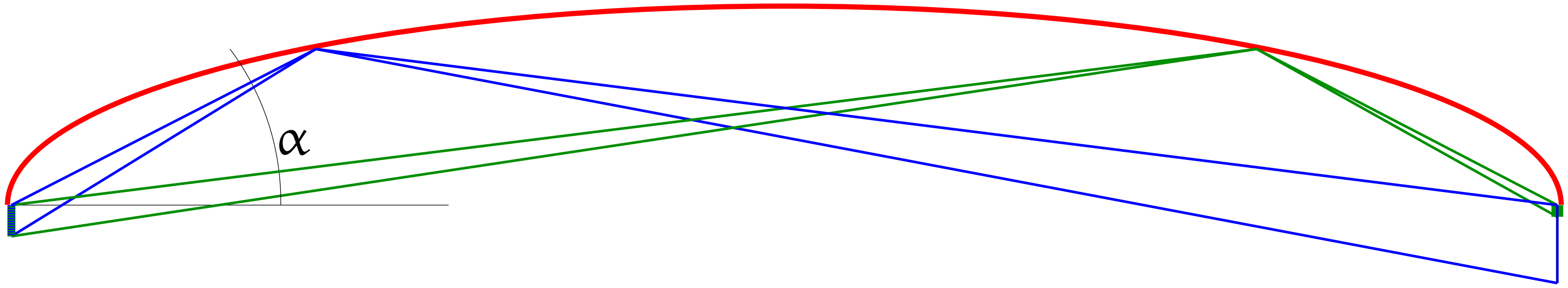
realisation



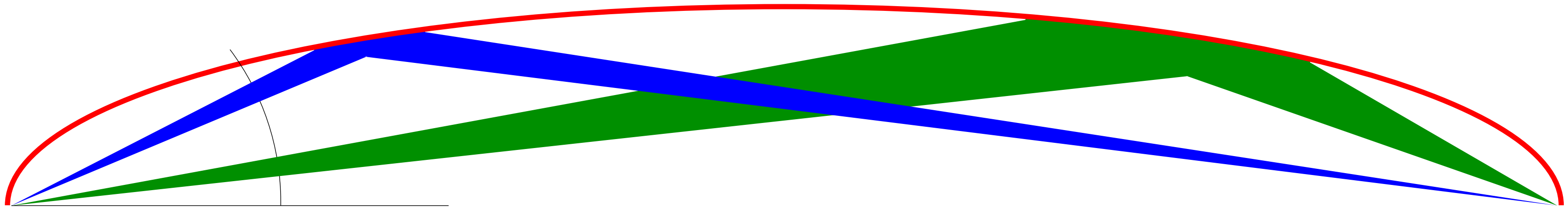

selene
titan goddess of the moon



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



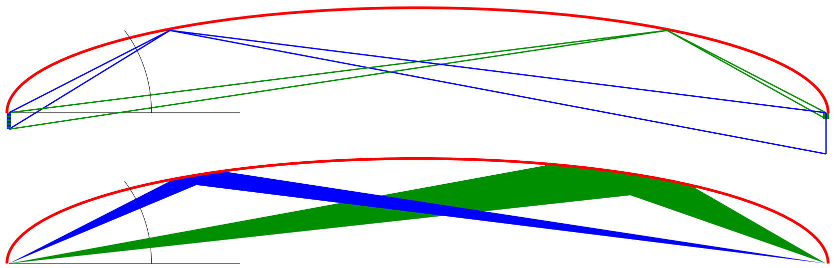
inhomogeneous ilumination



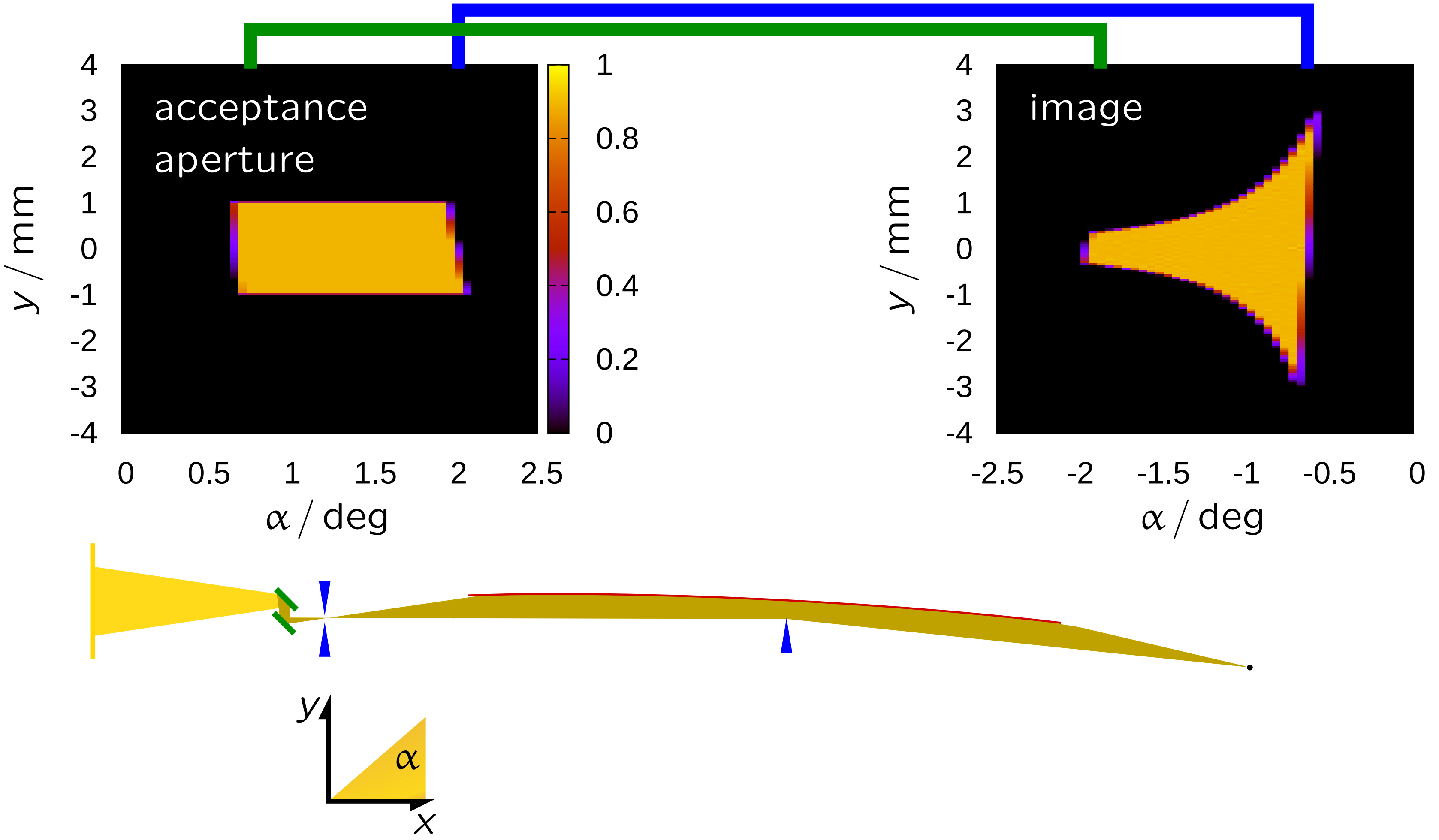
	large α	small α	
coma effect:	amplification	reduction	of preimage (slit)
divergence	low	high	at the sample position
intensity	high	low	"

coma aberration

analytic calculations for selene

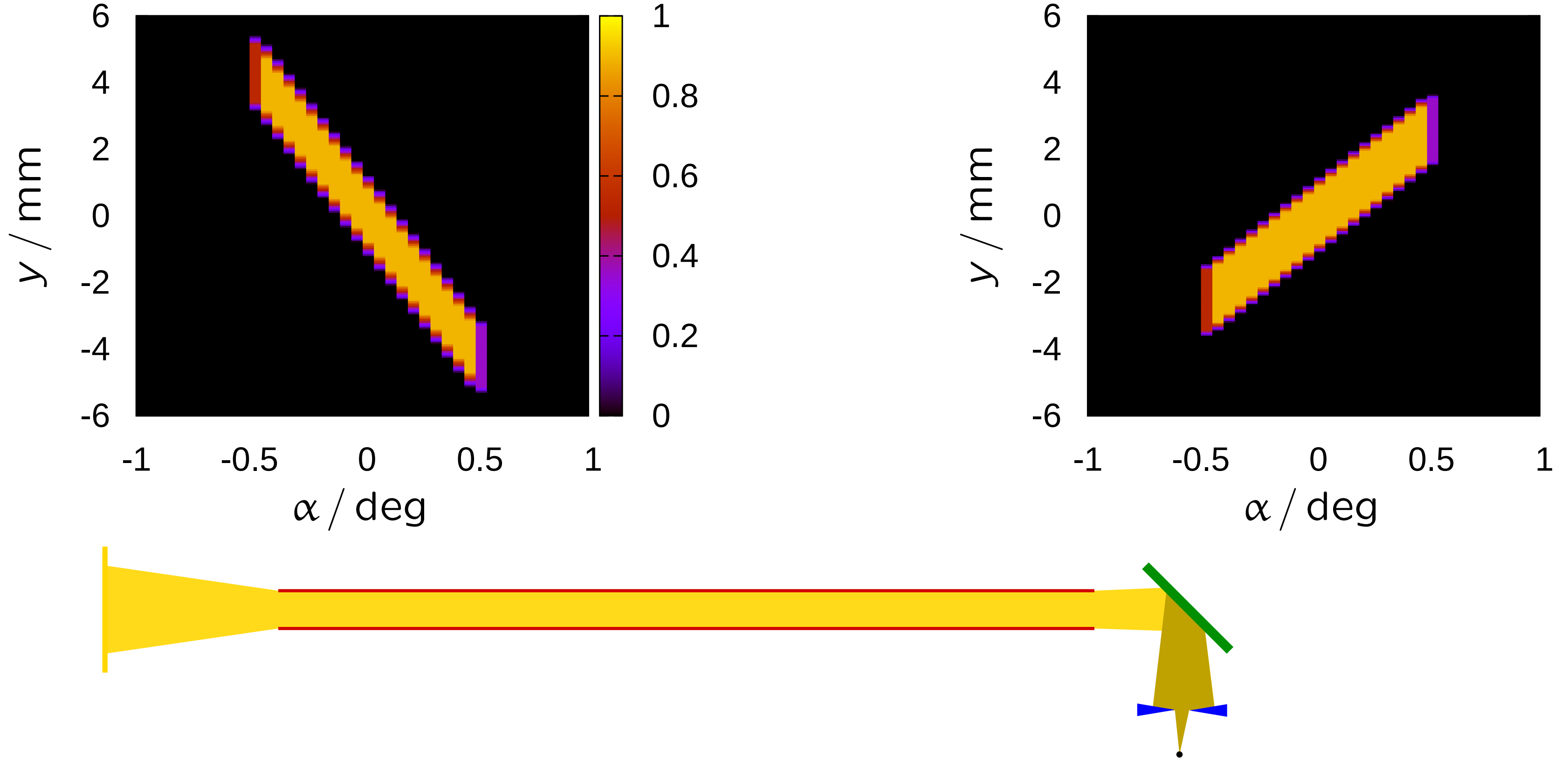


slit: high emmittance
aperture = 2 mm

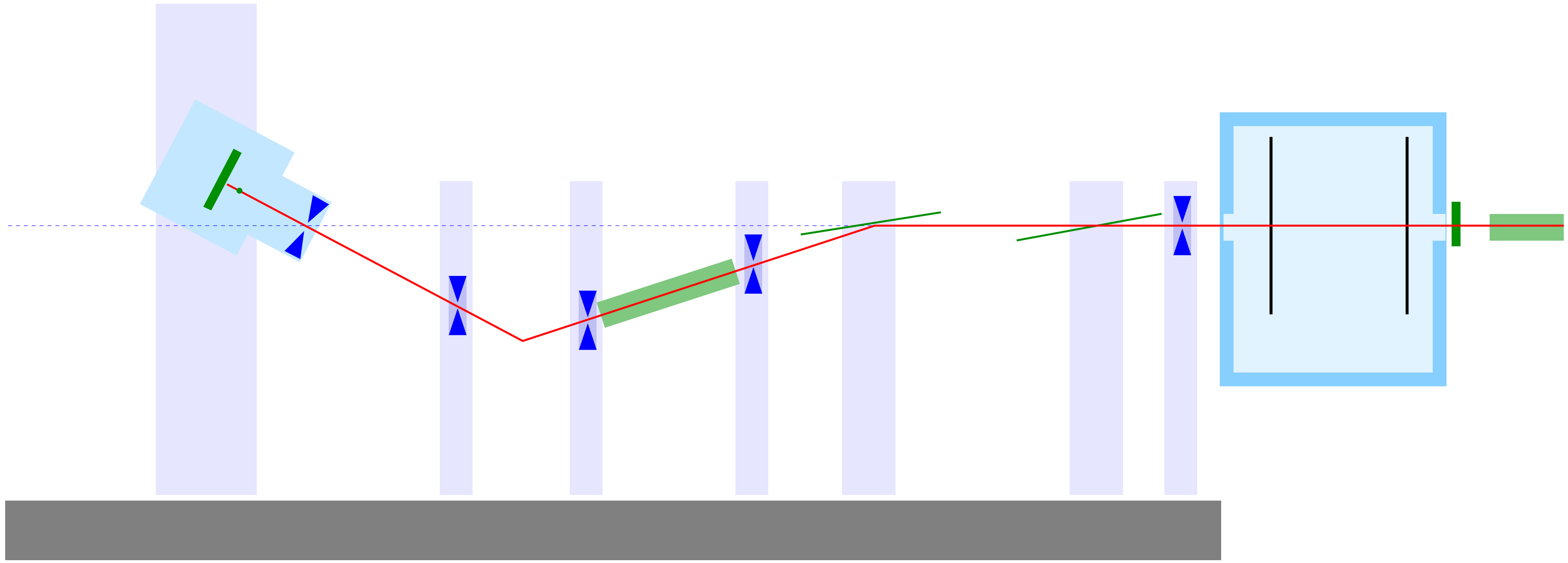


aberration of a staight guide

guide: emmittance $= \pm 0.5^\circ$
slit: aperture $= 2.0\,\mathrm{mm}$



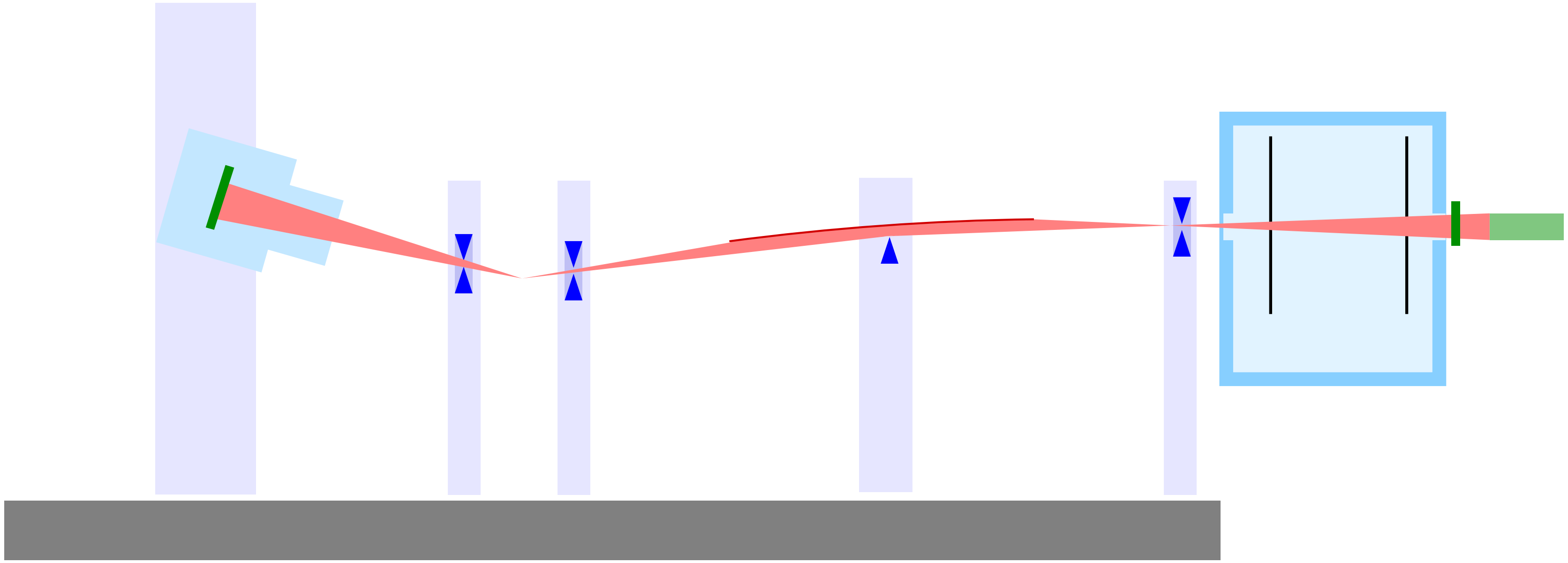
amor – polarised reflectometer in TOF mode



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

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

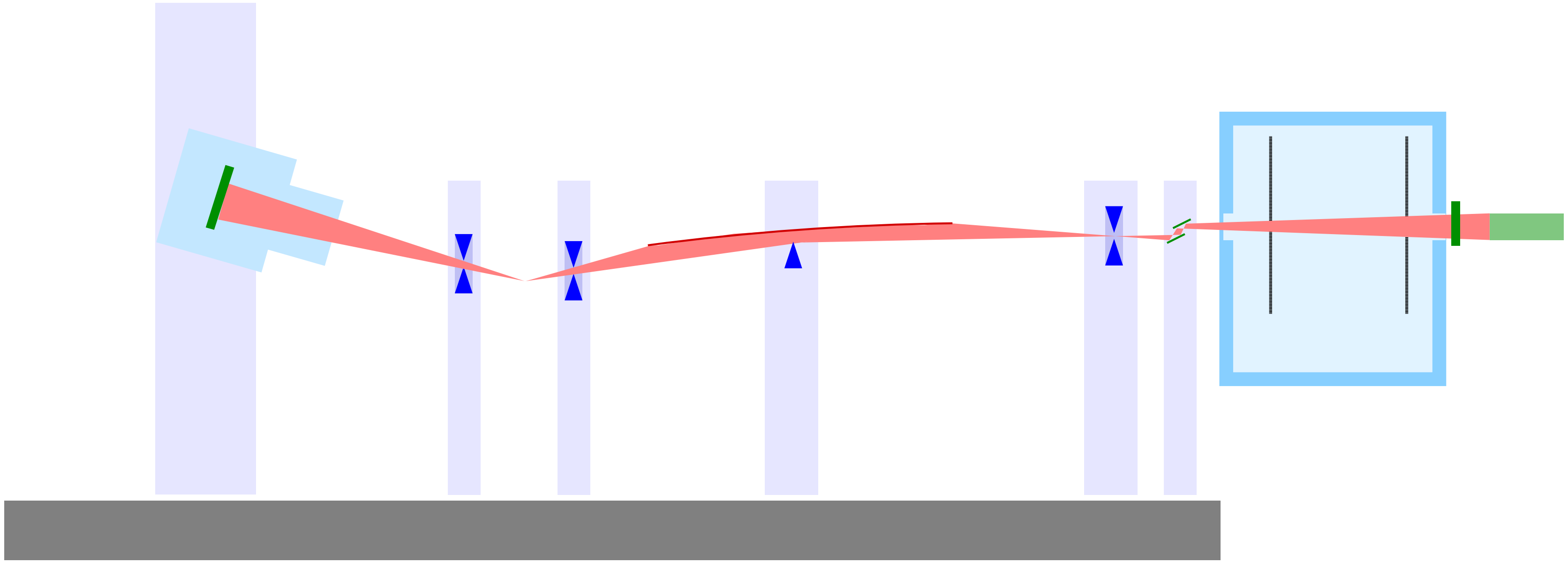
amor with selene in TOF mode



horizontal focusing
gain factor ≈ 6

enables high-intensity specular reflectivity
gain factor ≈ 20

amor with selene in monochromator mode

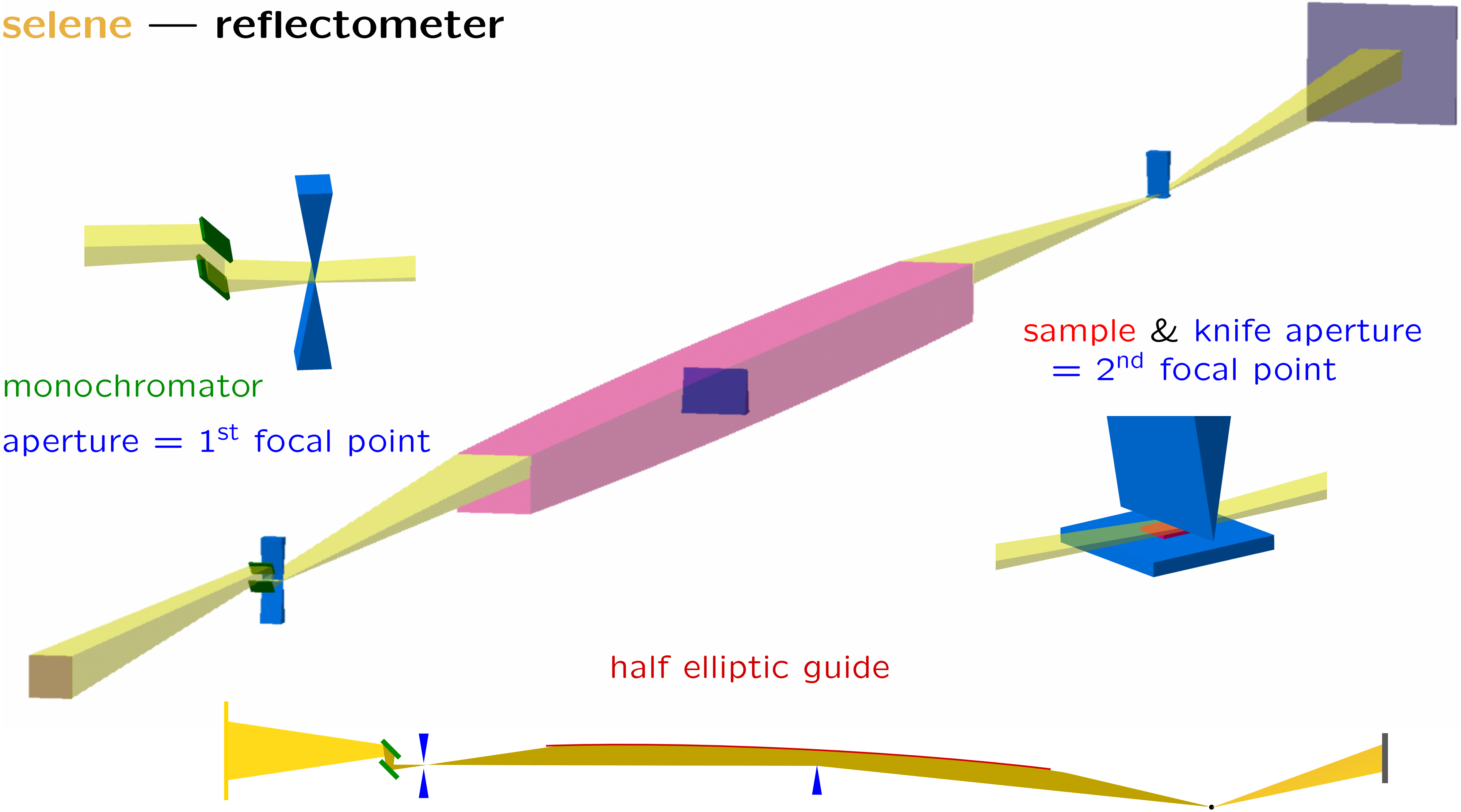


chopper stopped
double monochromator (ml or PG)

same flux, but different q_z-range

polarising ml possible

selene — reflectometer



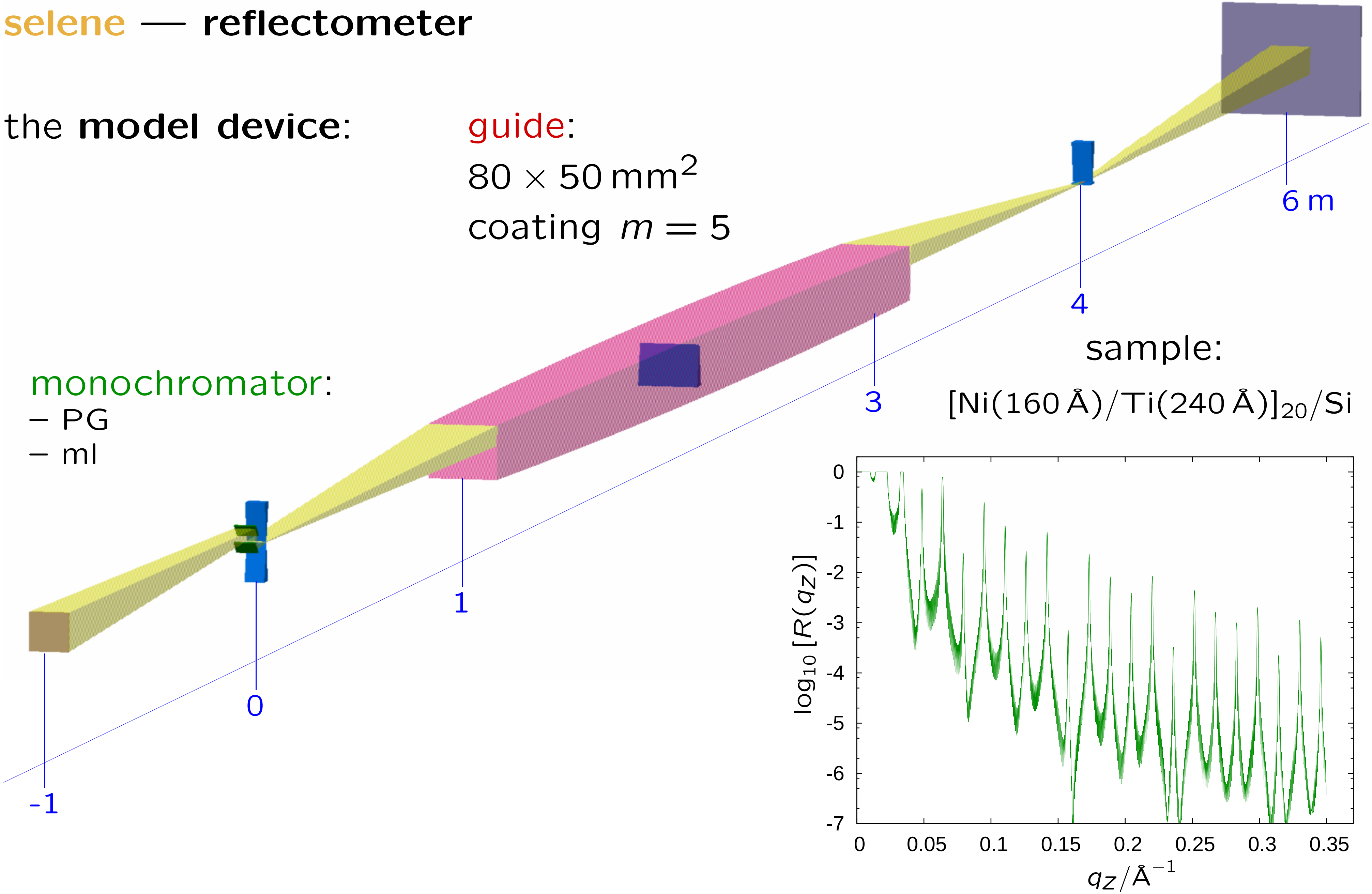
selene — reflectometer

the **model device**:

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

monochromator:
– PG
– ml

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



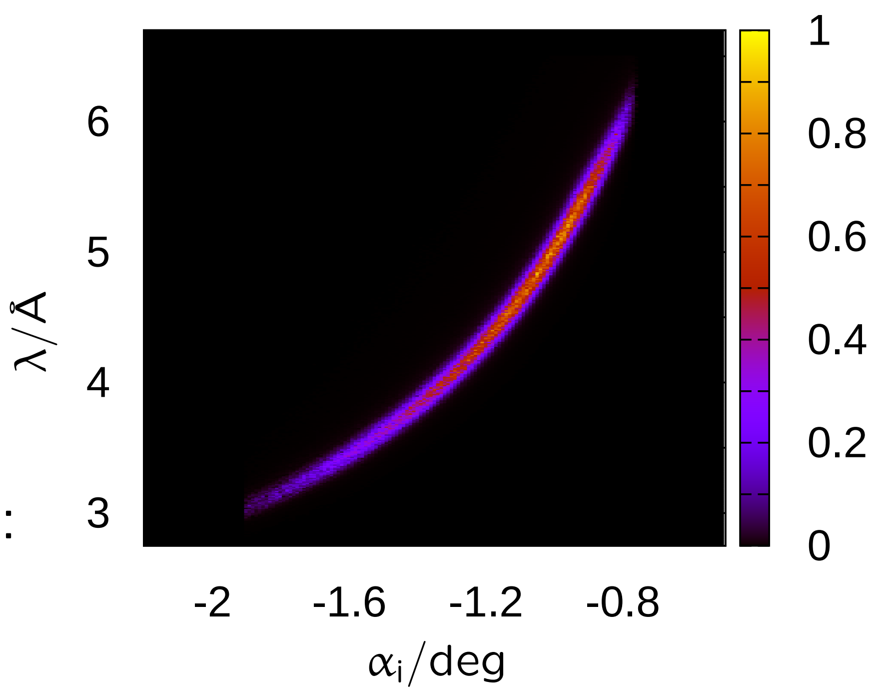
McStas simulations for selene — **reflectometer**
using a double **ml monochromator** $(m = 3)$

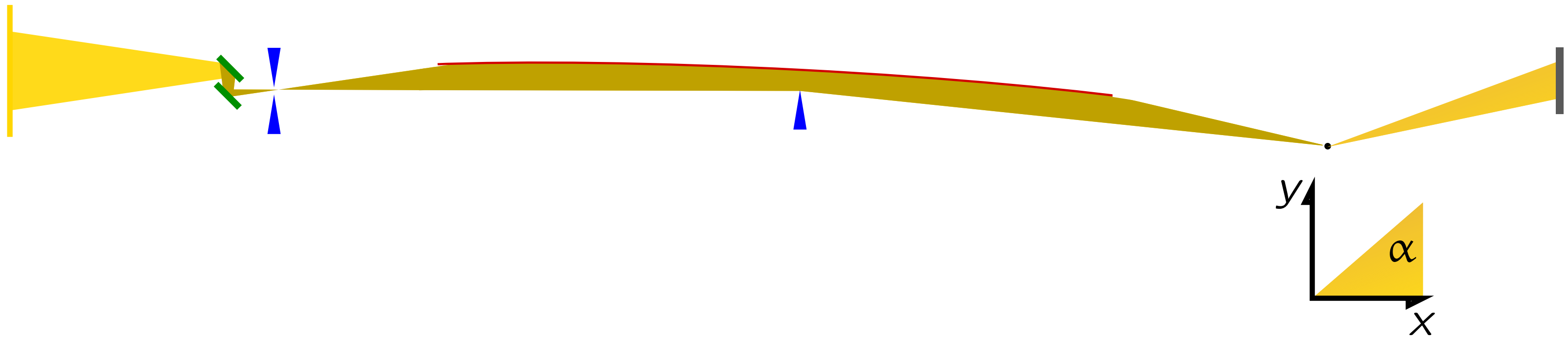
incident angle on the ml: $0 \ldots 2^{\circ}$

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

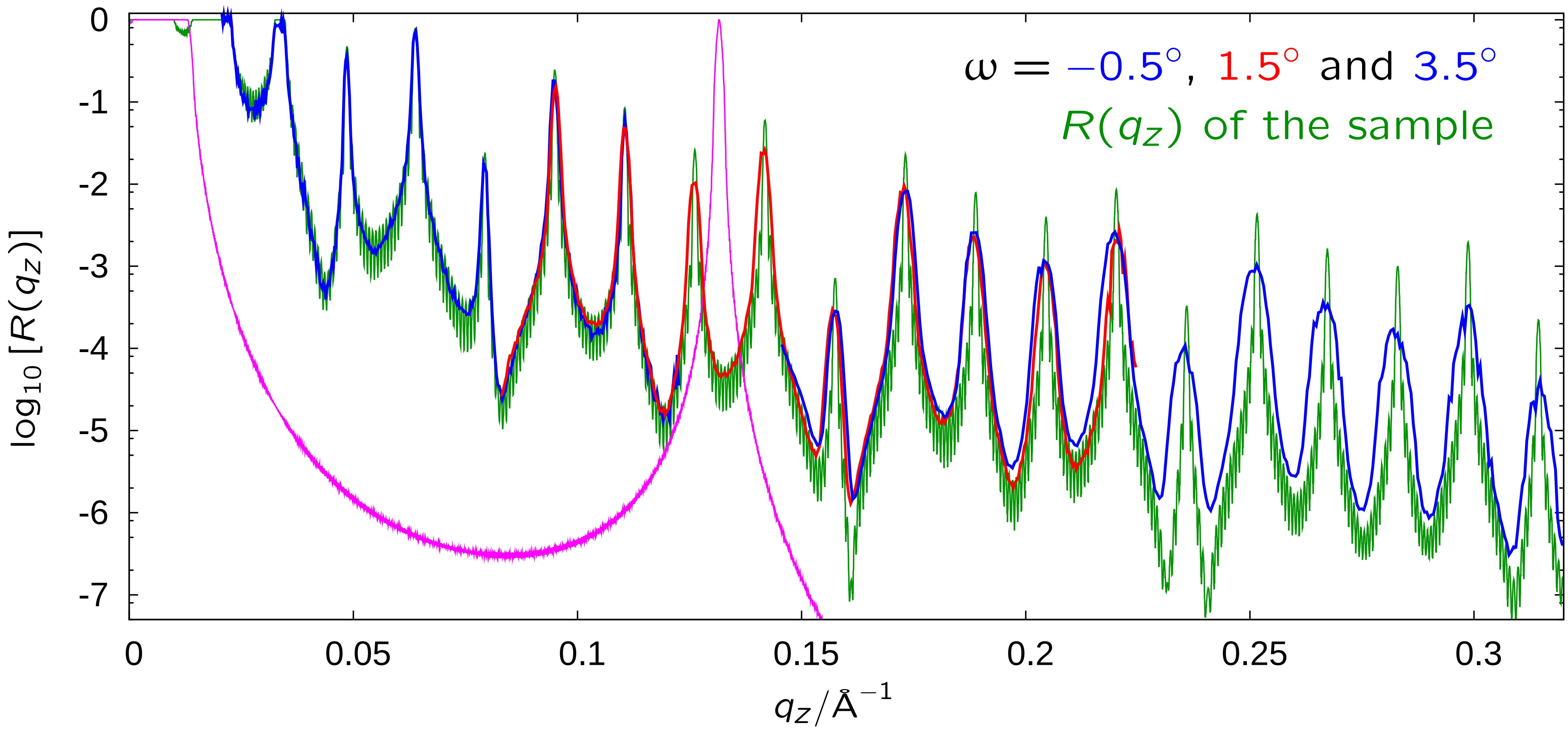
acceptance of the guide:
$\Delta\alpha = 1.3^{\circ}$

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



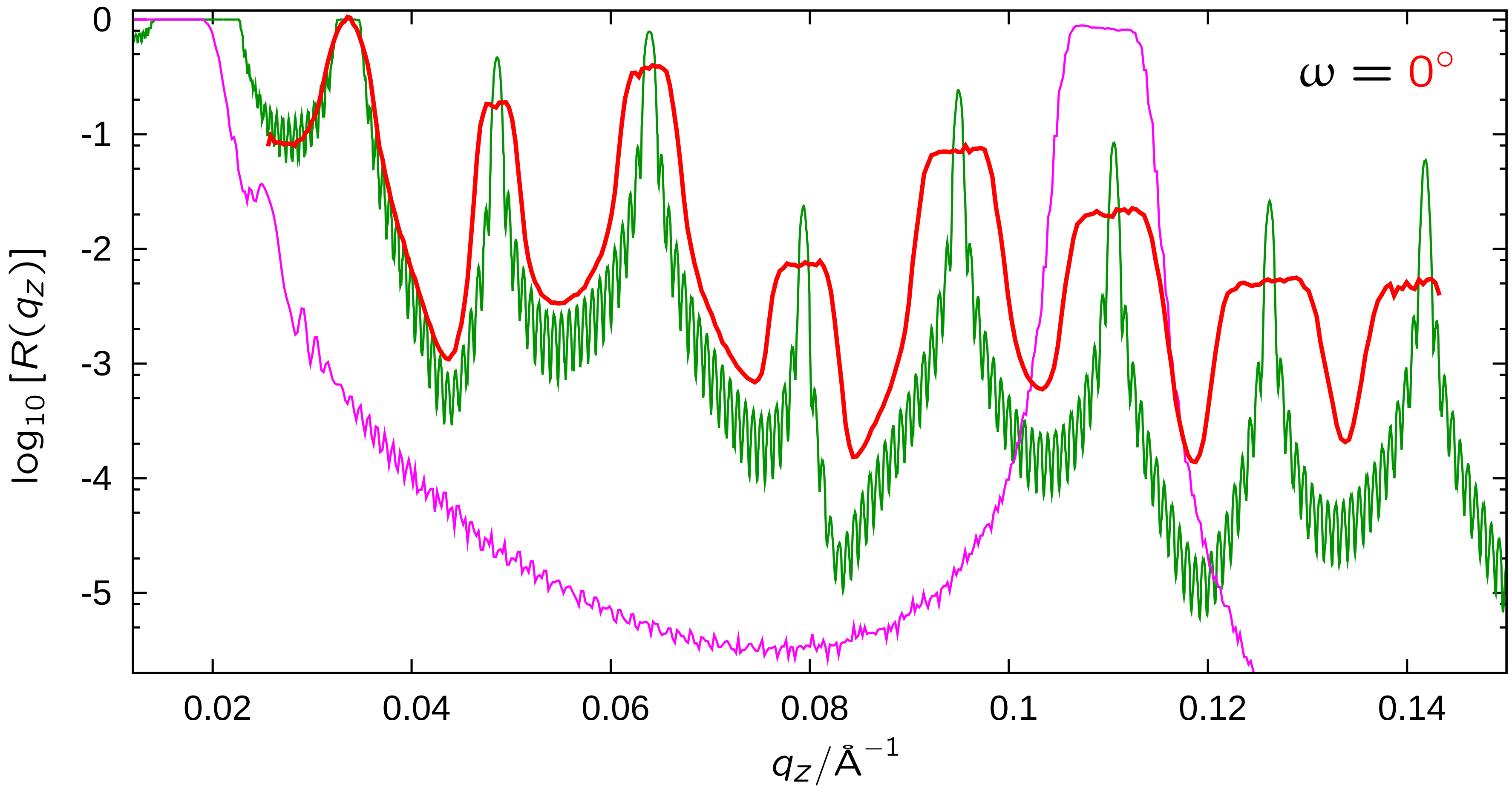


McStas simulations for selene — **reflectometer**
using a double ml monochromator $m = 6$, $\Delta q_z/q_z \approx 1\%$

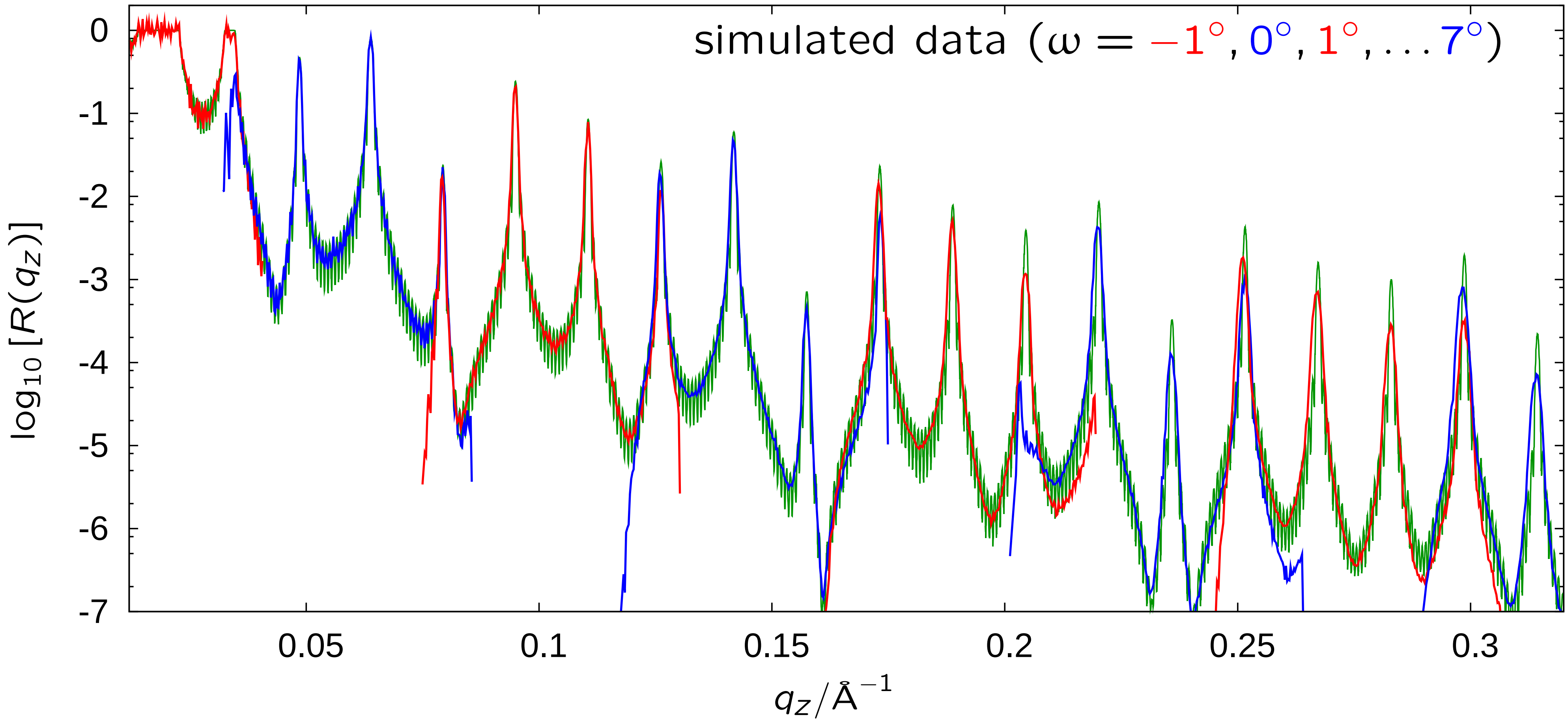


no off-specular scattering included, yet

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** ($\Delta\alpha = 0.16°$)

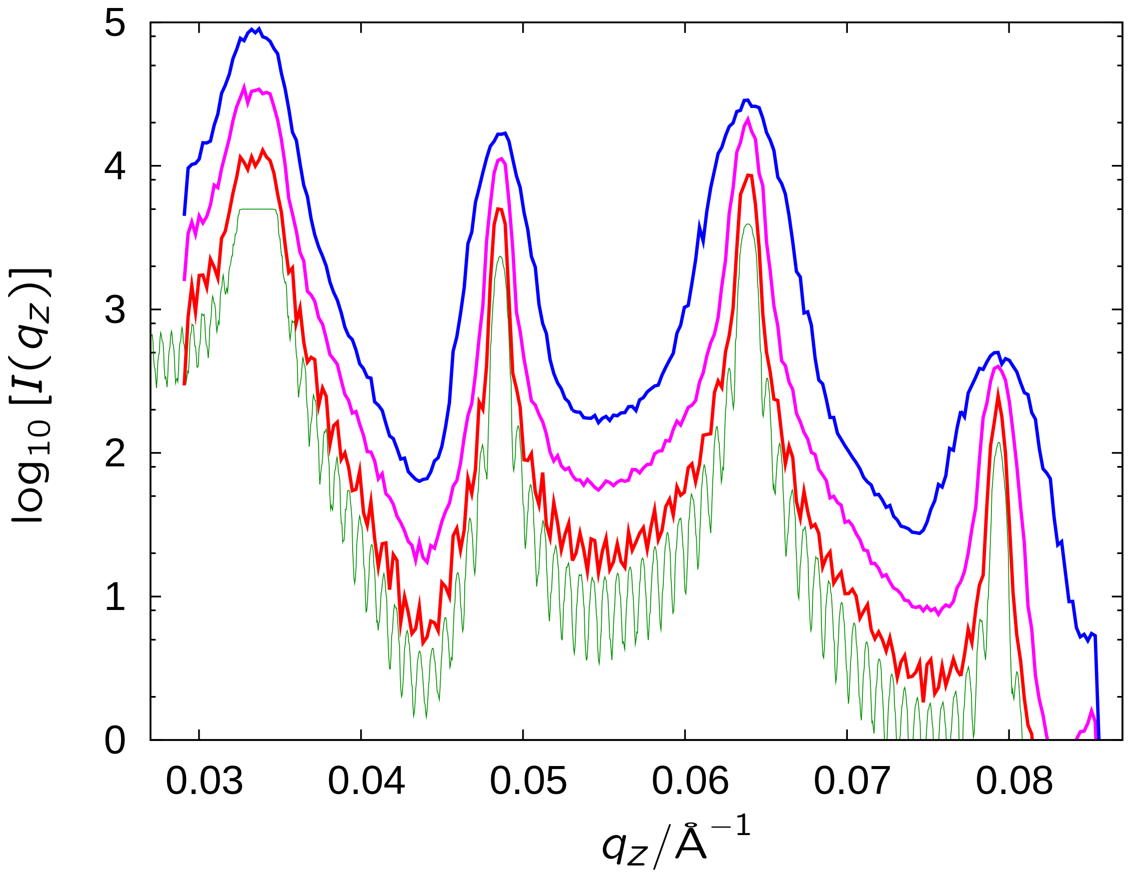


no illumination correction applied yet

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:

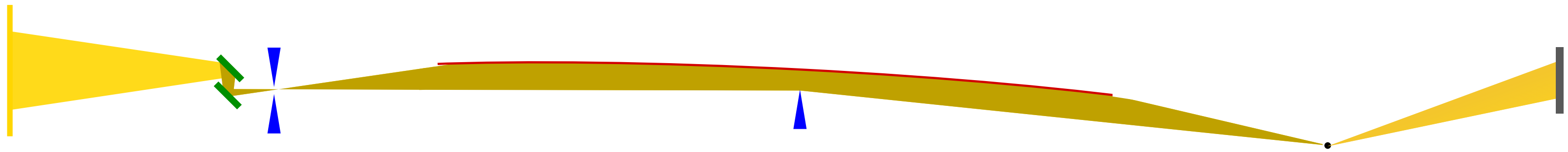
– ml monochromator: q_z-range e.g. 0.01 to 0.1 Å^{-1}

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

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

$\Rightarrow$ off-specular measurements are possible

$\Rightarrow$ 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

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