Jochen Stahn
Laboratorium für Neutronenstreuung
ETH Zürich & Paul Scherrer Institut

A neutron polariser based on magnetically remanent Fe/Si supermirrors

ILL, Grenoble 18. 01. 2006

neutron optics group PSI:

Jochen Stahn
Murat Ay
Christian Schanzer
Jay Padiyath
Michael Horisberger

cooperation partners:

NMI3–JRA3–NO
HMI, TUM, etc.

funding:

NMI3 HII3-CT-2003-505925
MaNEP project 6, Mesot
SNF 200021-101567

outline

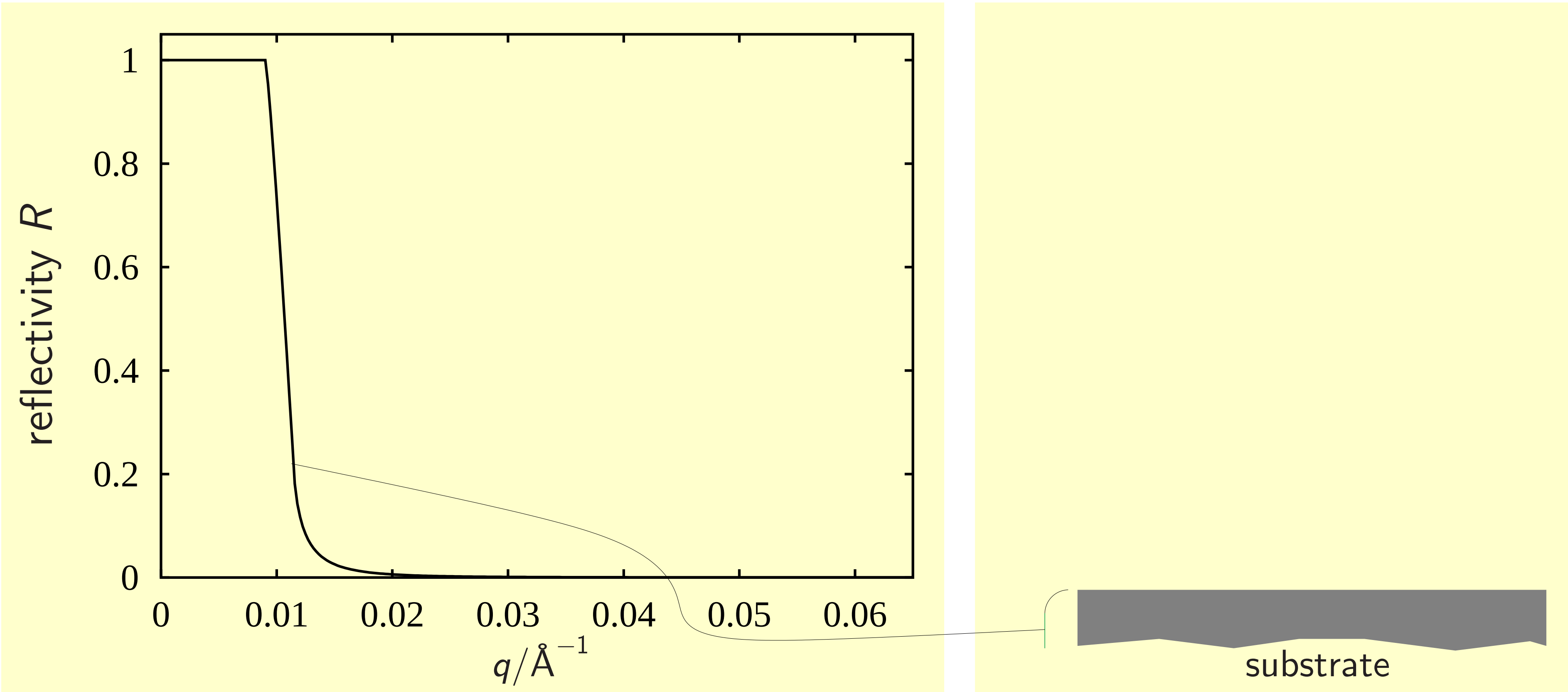
introduction
- multilayer, supermirror

reflectometers at SINQ
- Amor, Morpheus, Narziss

topics of the
neutron optics group at PSI
- supermirrors, interfaces
- focusing devices, polariser

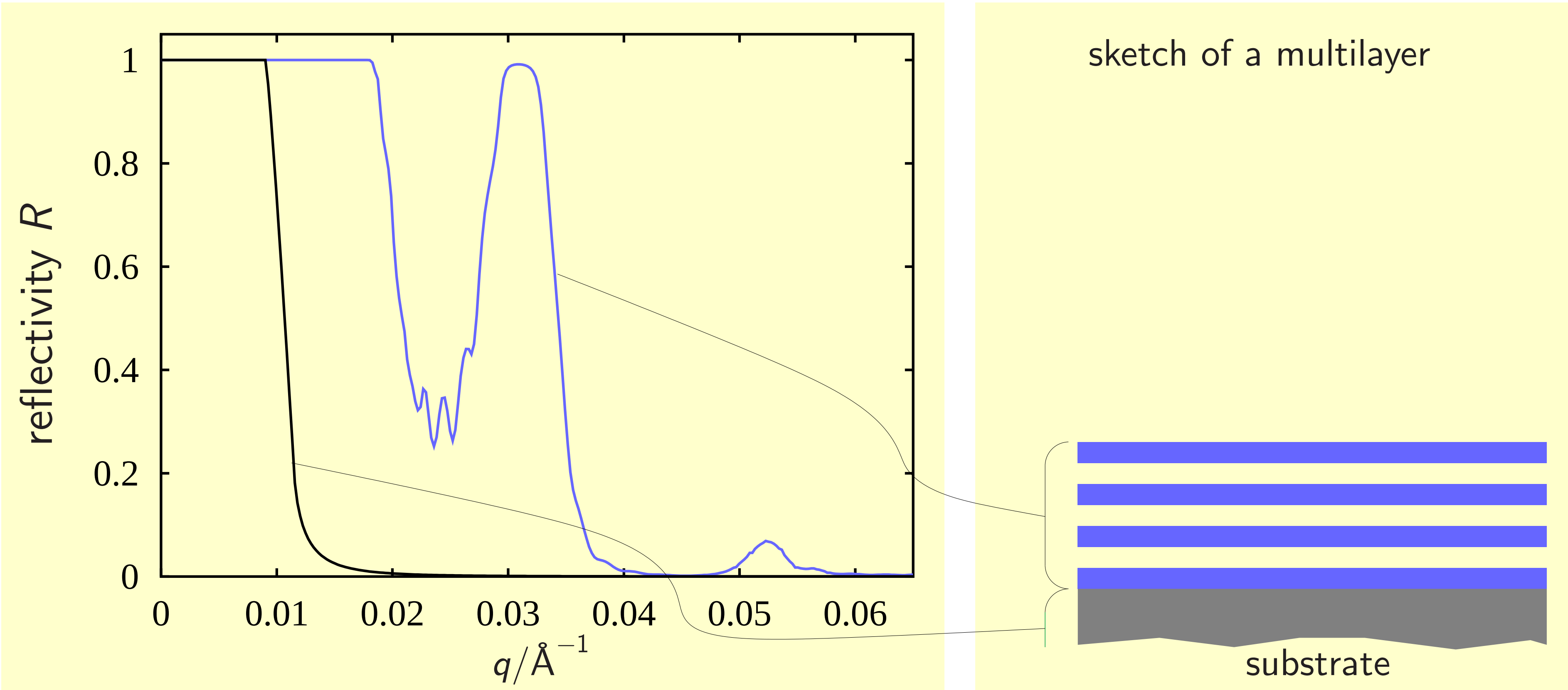
magnetically remanent
neutron polarisers
- principle
- production
- applications

intro supermirror



intro supermirror

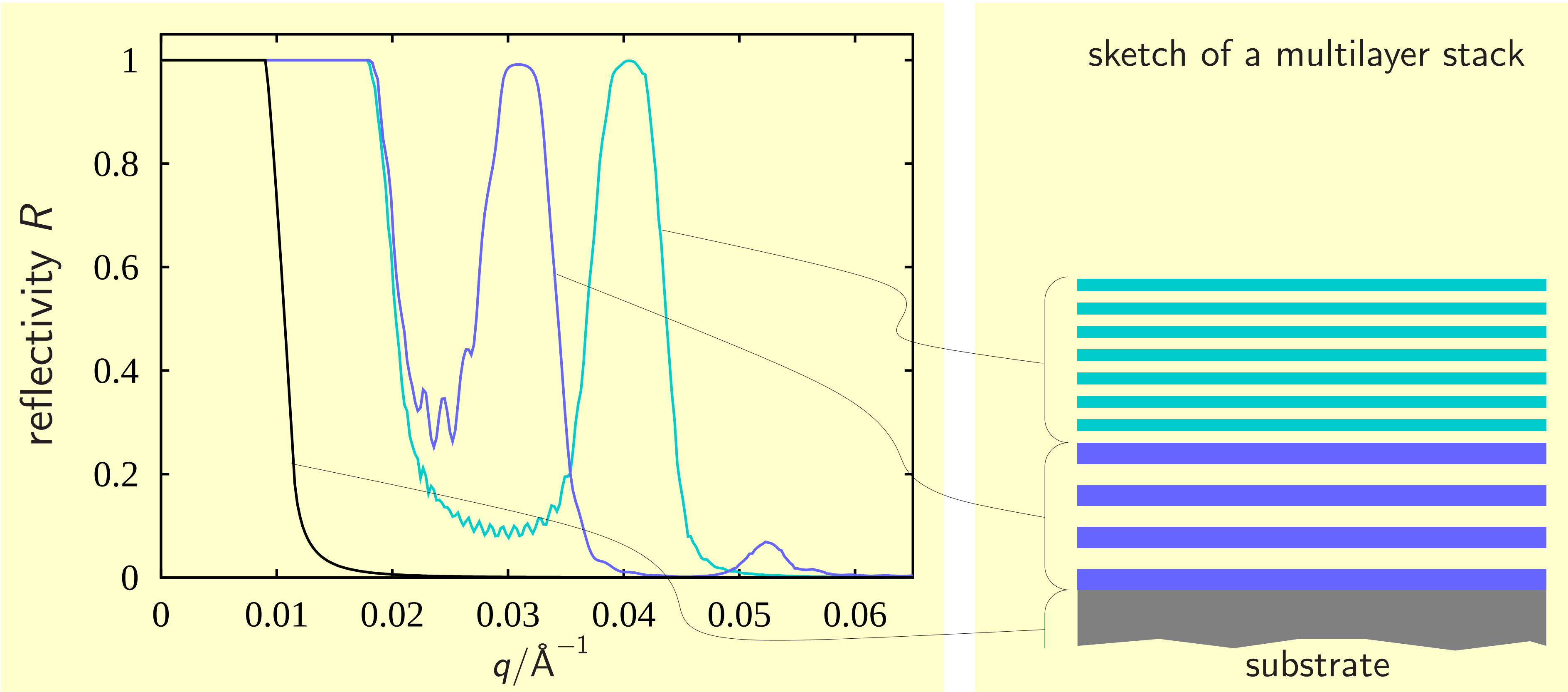
multilayer: causes 'Bragg peaks'



intro supermirror

multilayer: causes 'Bragg peaks'

stack of multilayers: overlapping 'Bragg peaks'

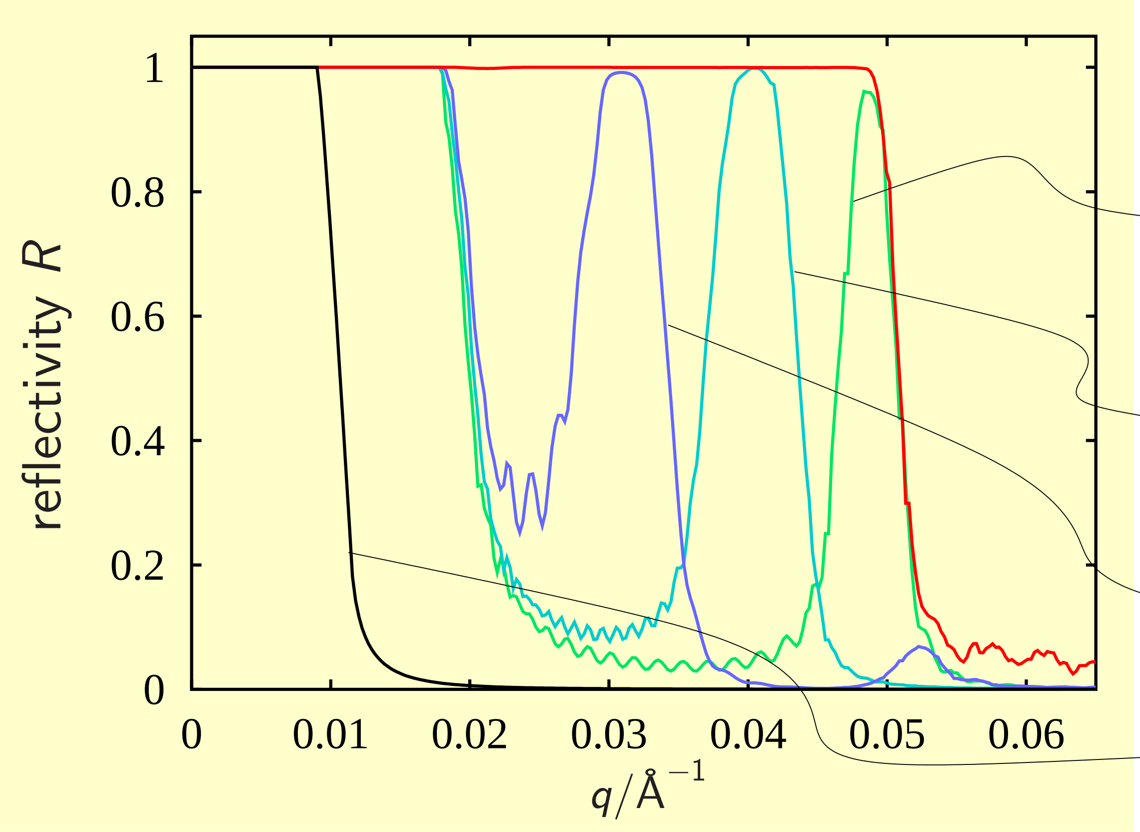


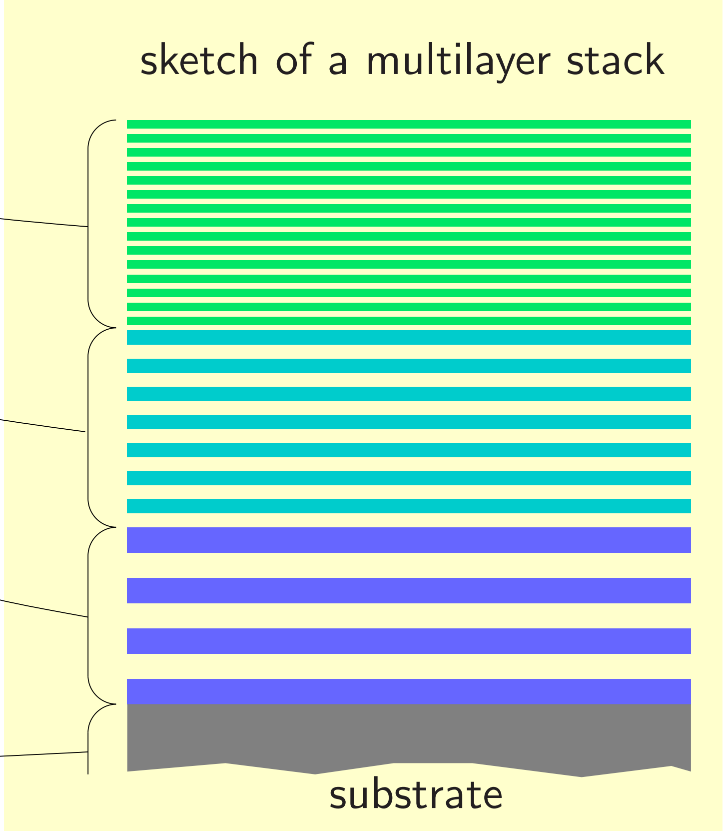
intro **supermirror**

multilayer: causes 'Bragg peaks'

stack of multilayers: overlapping 'Bragg peaks'

supermirror: 'multilayer' with layer-thickness gradient





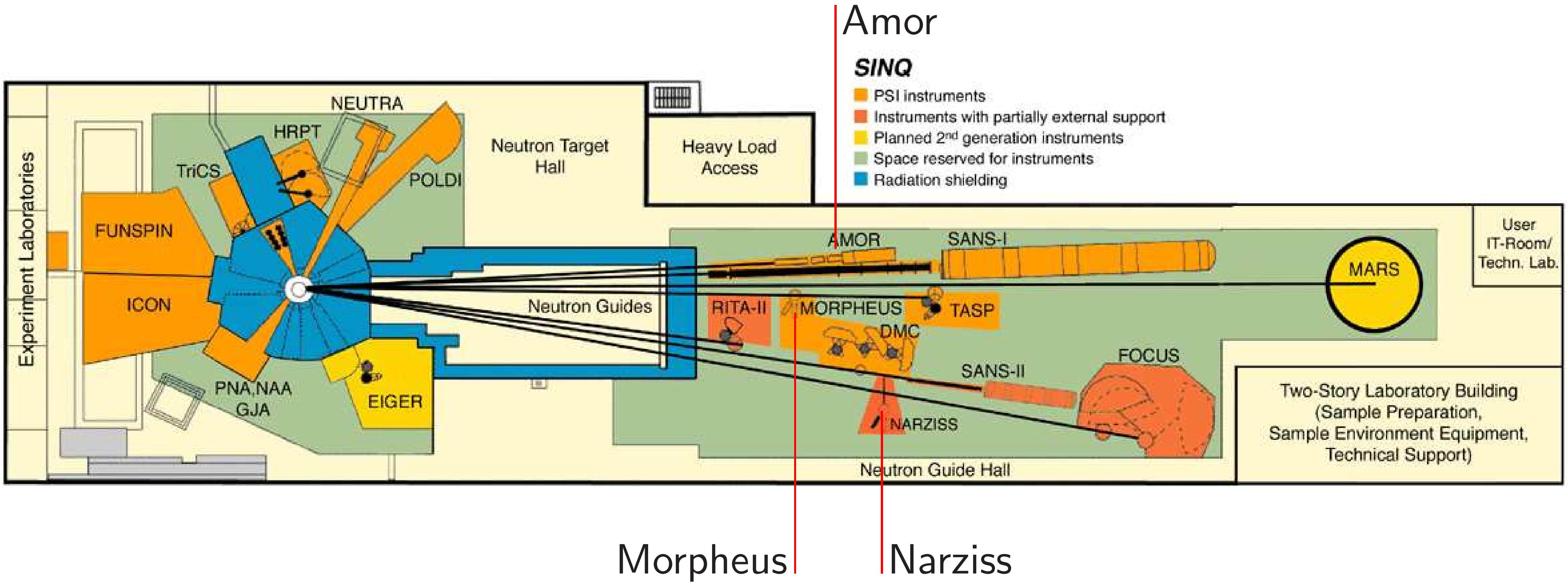
instruments

SINQ: continuous flux spallation source

⇒ combination of the disadvantages of reactor- and spallation sources!

flux: 10^{14} n/cm^{2}s

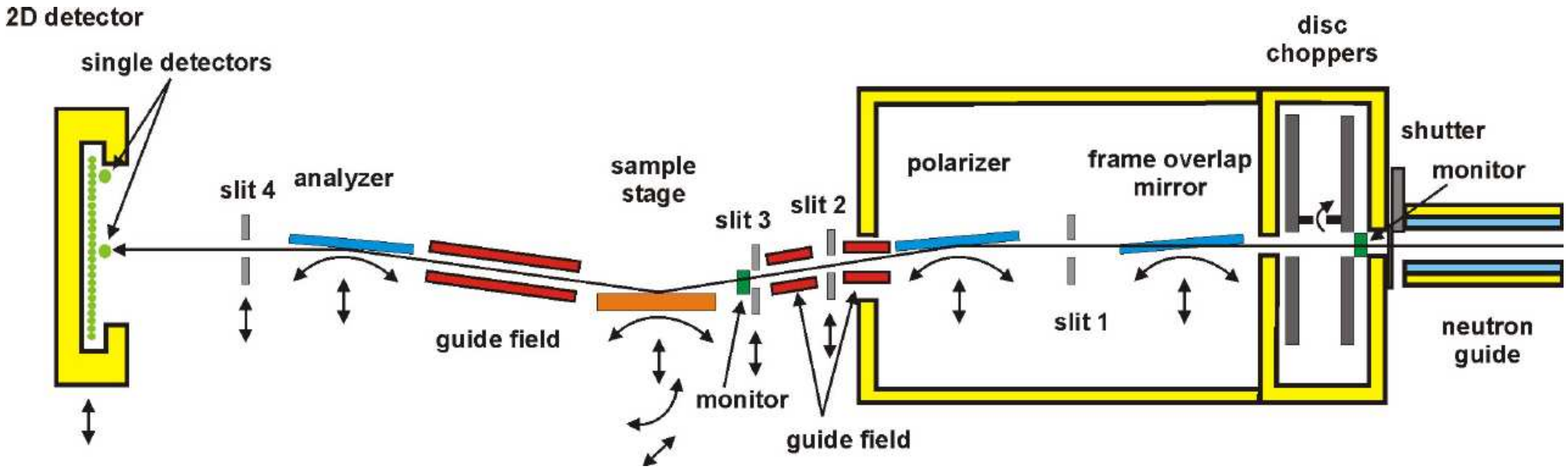
cold source: liquid deuterium



instruments Amor

TOF reflectometer, user instrument

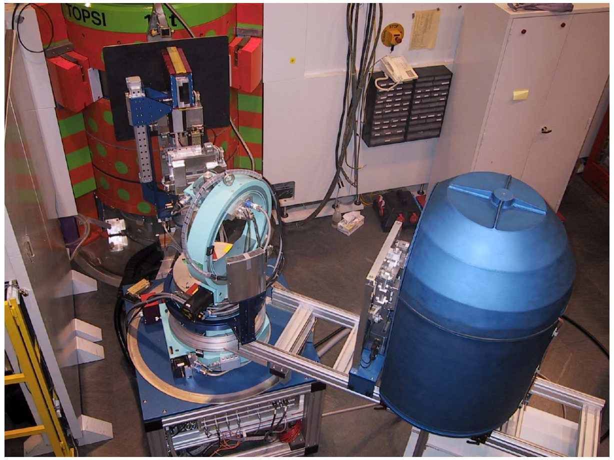
– $0\,\text{Å}^{-1} < q_z < 0.4\,\text{Å}^{-1}$, $\Delta q_z / q_z > 0.5\,\%$
– single counter and area detector
– polarisation option
  (with analysis)

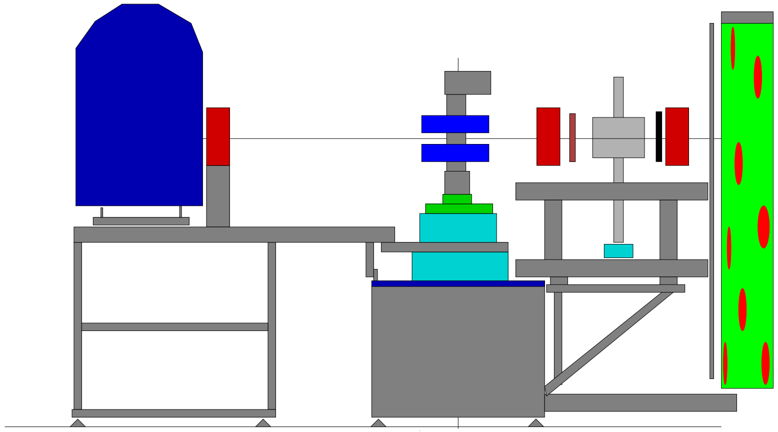


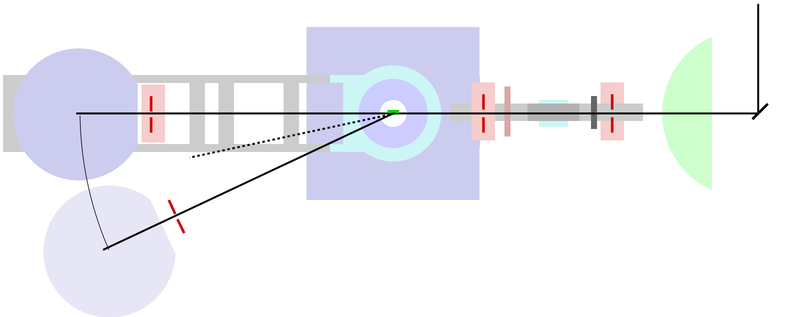
instruments Morpheus

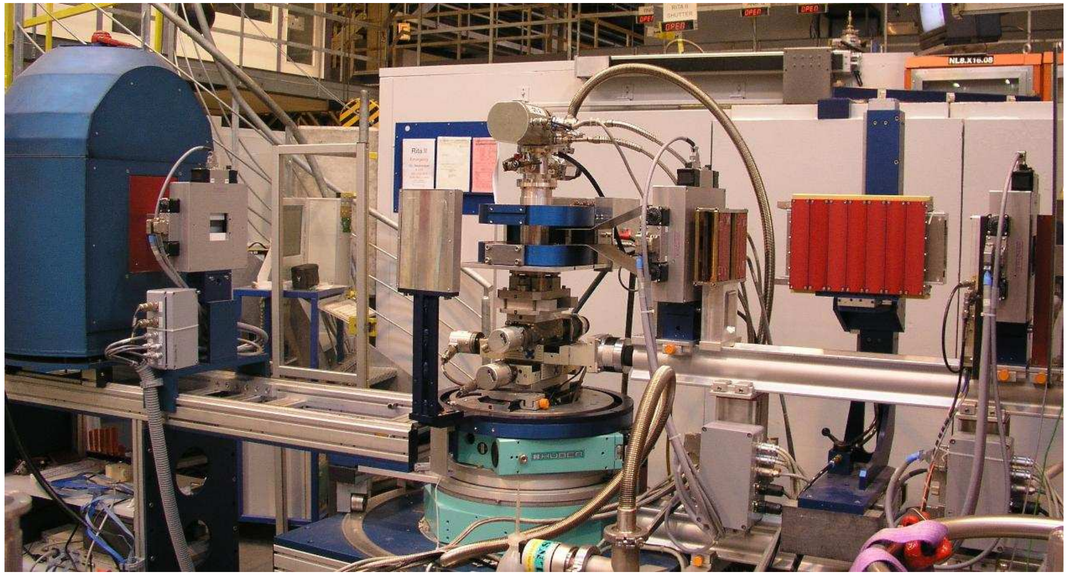
test diffractometer and reflectometer
for in-house research and sample alignments

– angle-dispersive
– $2\,\text{Å} < \lambda < 7\,\text{Å}$,
– single counter and area detector
– all SINQ sample environment ($H < 1\,\text{T}$)
– 4-circle set-up
– polarisation option
(with analysis)









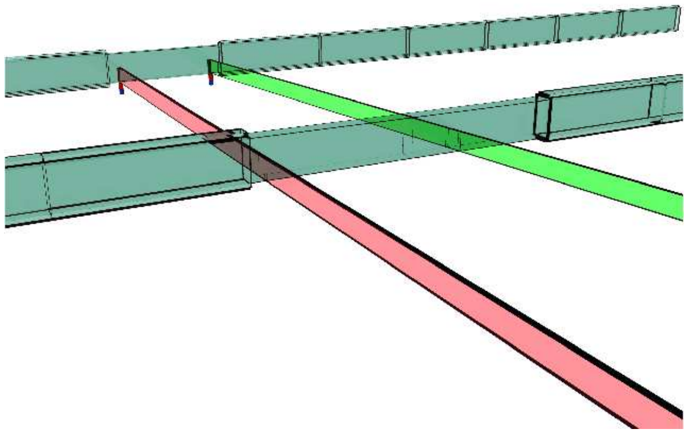
instruments Narziss cooperation with SwissNeutronics

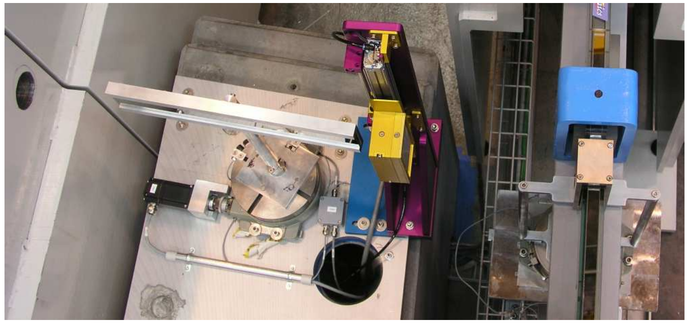
new reflectometer, dedicated to neutron optics research, only.

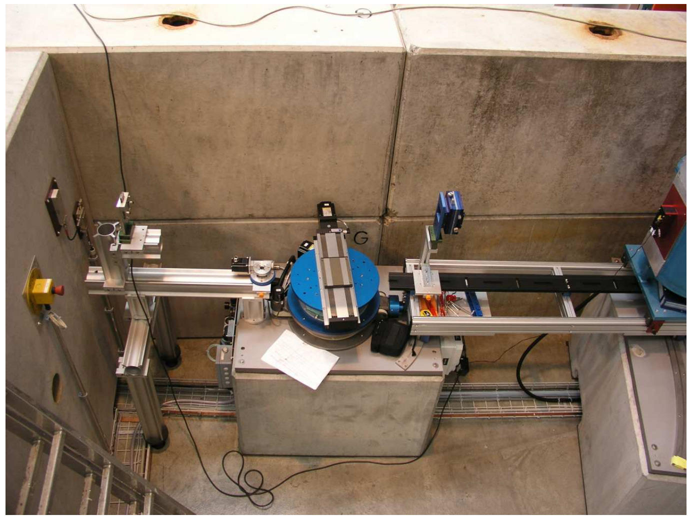
– $\lambda = 5\,\text{Å}$

– polarisation option, with analysis

– sample magnet $-1000\,\text{Oe} < H < 1000\,\text{Oe}$
  $600 \times 150 \times 50\,\text{mm}^3$







topics of the neutron optics group

- high-*m*-sm & band-pass filters
- interface design
- *fundamental* monochromators
- focusing devices
- remanent polarisers

topics **high-m-sm / band pass filter**

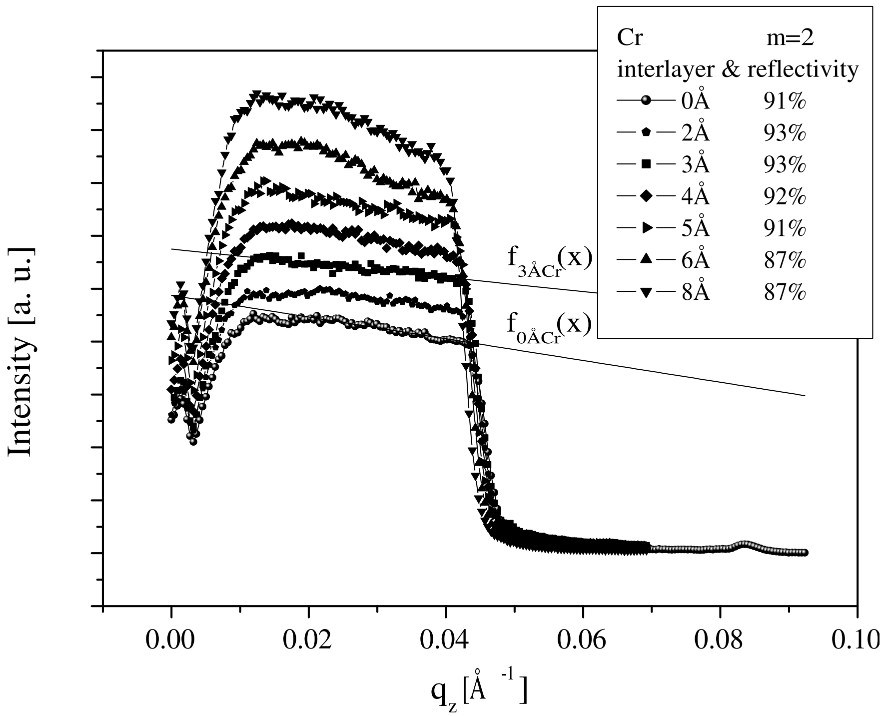
ideas:

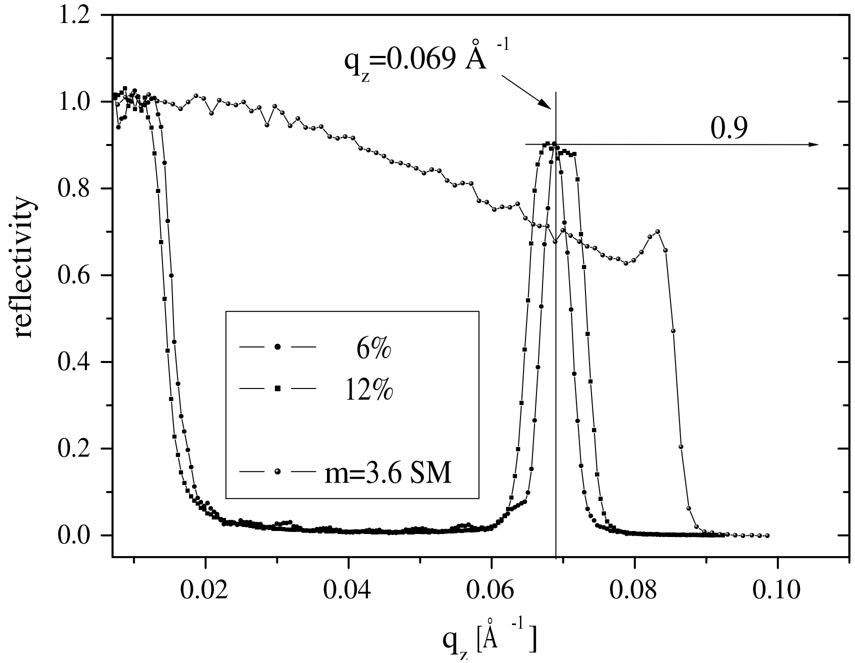
– prevent interdiffusiom by introducing a blocking layer

– flaten the accumulated roughness by substituting some layers by a smoothening material as e.g. Cr

works good for not too many layers!

fails for $m > 2.5$.



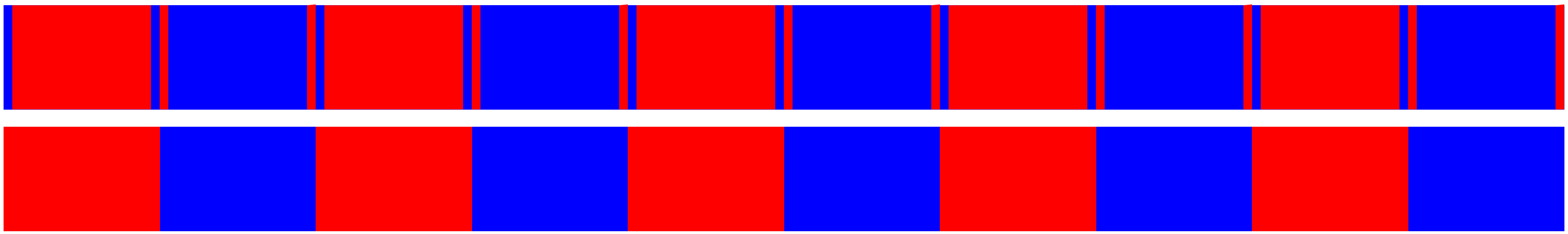


topics **interface design**

non-sharp but laterally homogeneous interfaces

– annealing: interdiffusion
limited by diffusion length, melting
and grain-formation/growth ⇒ roughness

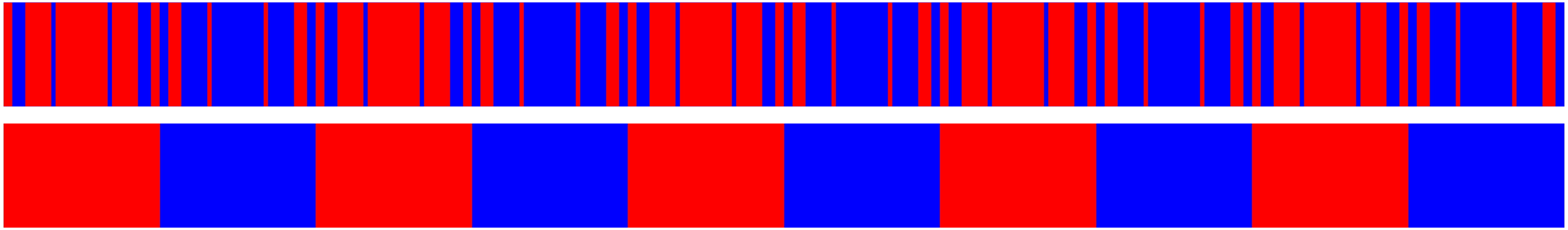
– artificial intermixing:
intermediate films between the layers



topics ***fundamental* monochromator**

extreme limit: sinusoidal profile

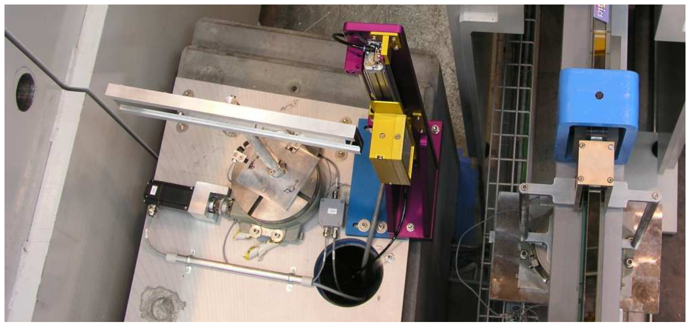
⇒ only fundamental Bragg peak, no higher harmonics

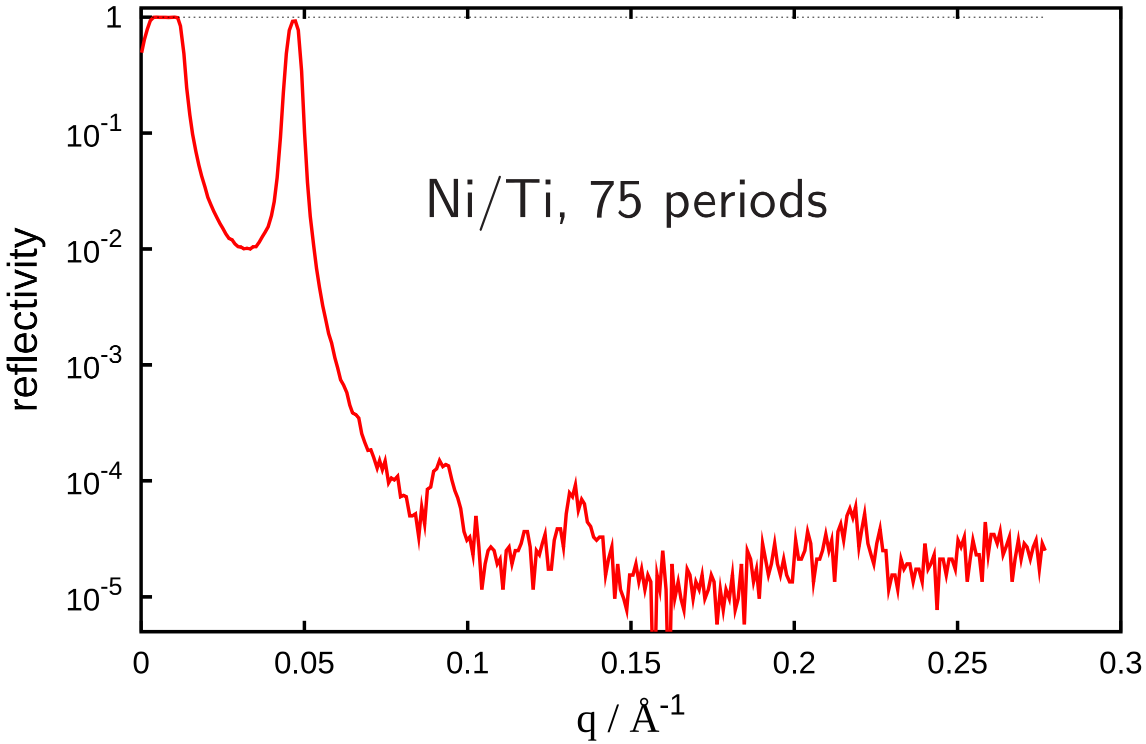


applications:

– monochromator

– wavelength filter
(*e.g.* for Narziss)



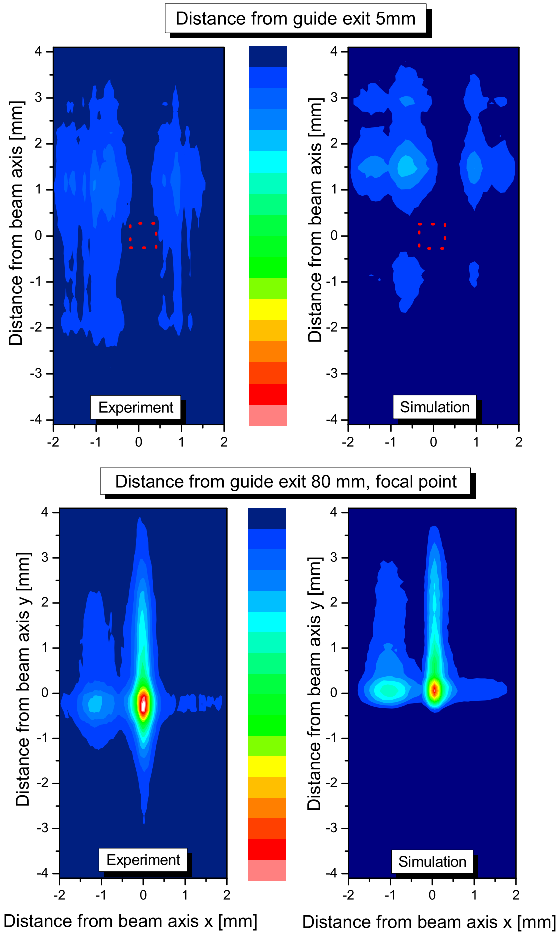


topics focusing devices

bi-elliptic neutron guide

together with TUM

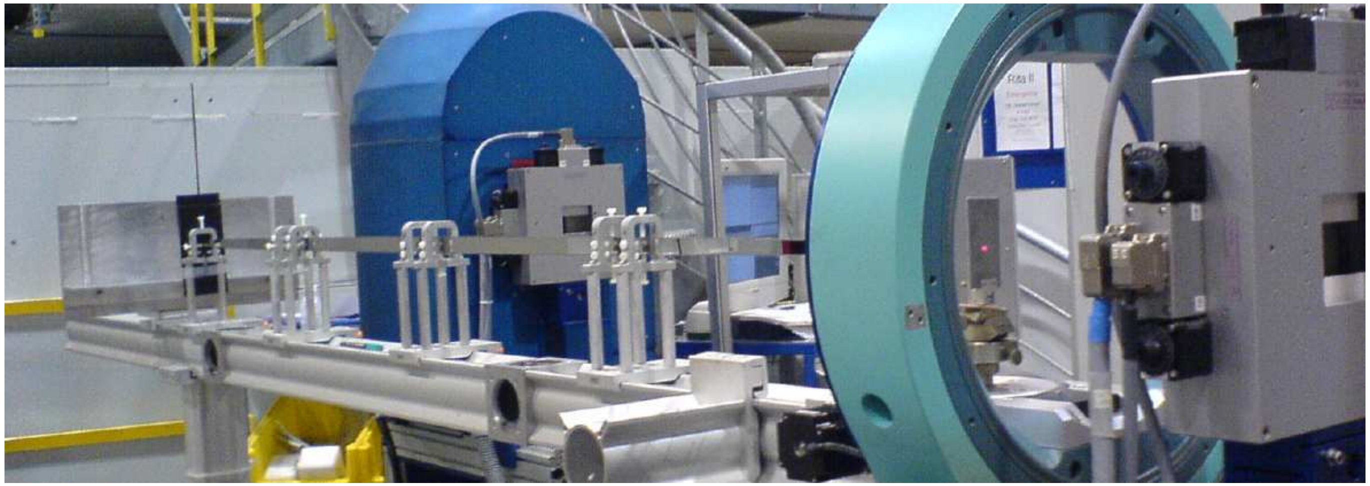
built by SwissNeutronics



1:10 model of a neutron guide.

ideally only 2 reflections from source to image

openings: $4 \times 8\,\mathrm{mm}^2$, length: $2\,\mathrm{m}$

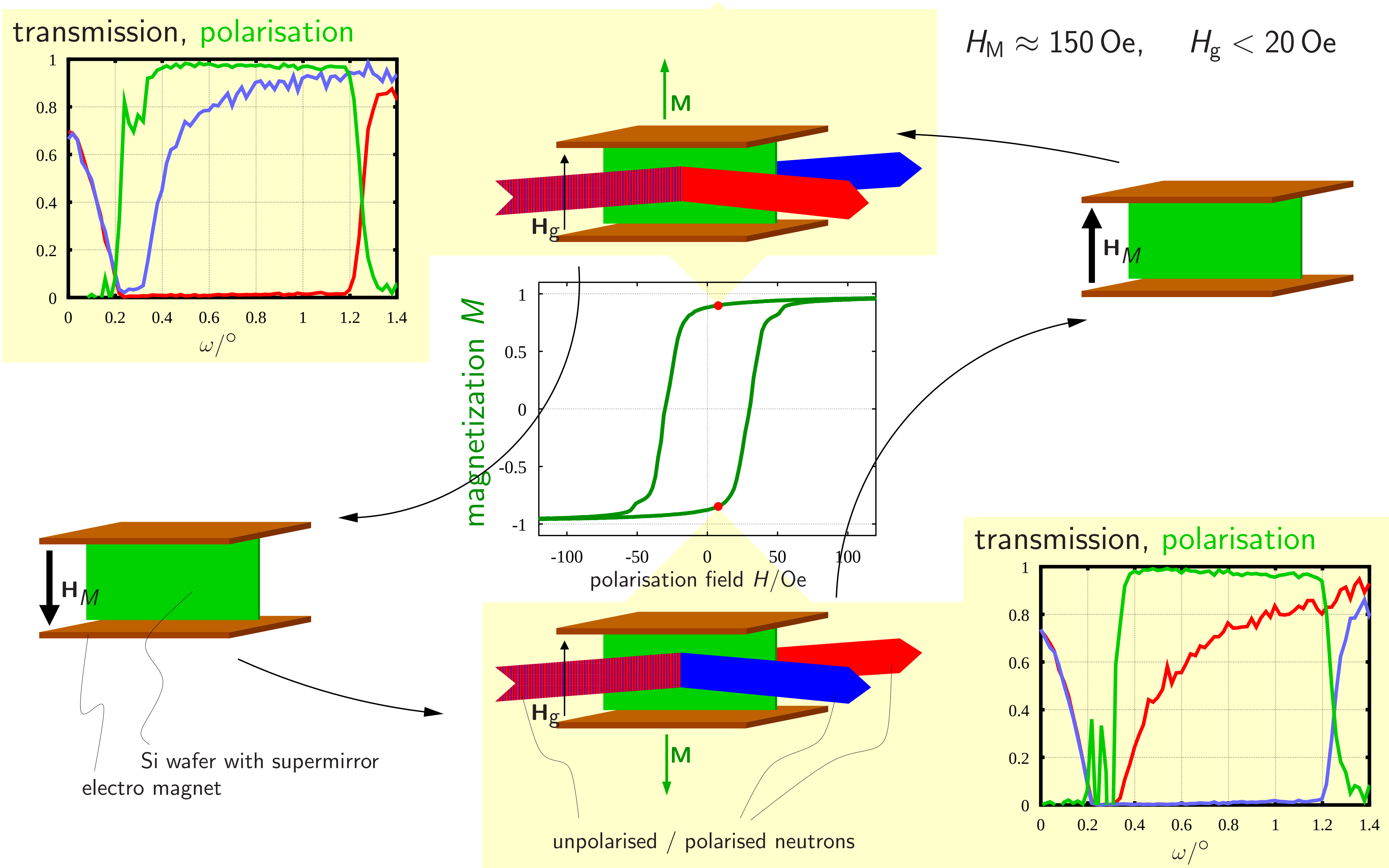


topics remanent polarisers

. . . fills rest of the presentation!

remanent polariser application principle

$H_M \approx 150$ Oe, $H_g < 20$ Oe



remanent polariser material

ferromagnetic material: Fe

– might show easy axis of magnetisation

– almost matches Si for $|-\rangle$

– low absorption (required for transmission, less radiation damage)

spacer material: Si

– low potential

– matches the substrate (for transmission)

– low absorption

– can be influenced (potential and stress) by reactive sputtering

but

– rather low contrast for $|+\rangle$

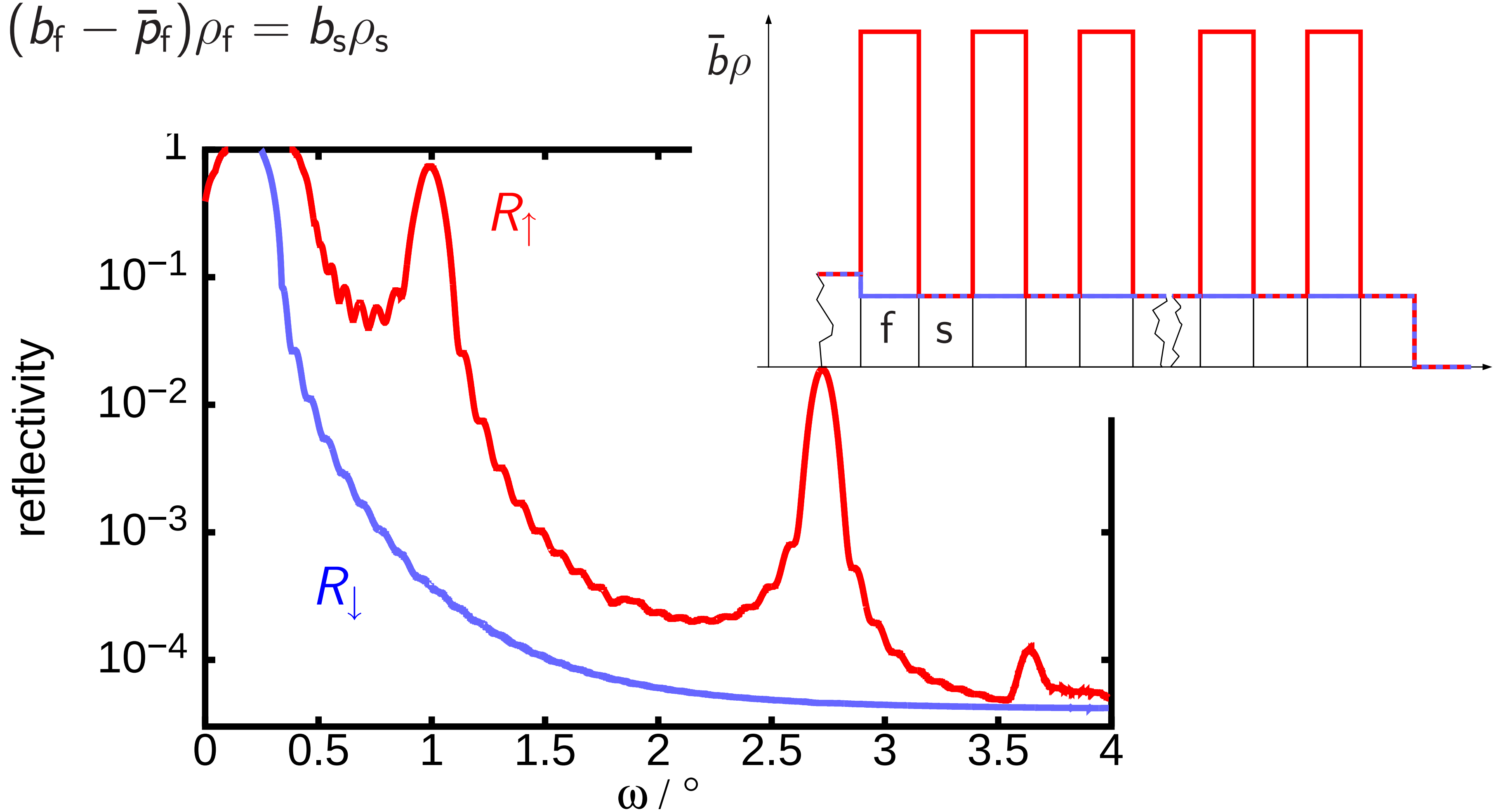
$\Rightarrow$ larger number of layers reqired

– total reflection for low q

remanent polariser ideal ml

$$(\bar{b}_f + \bar{p}_f)\rho_f \gg \bar{b}_s\rho_s, \quad \bar{p}_s = 0, \quad \text{ferromagnet, spacer}$$

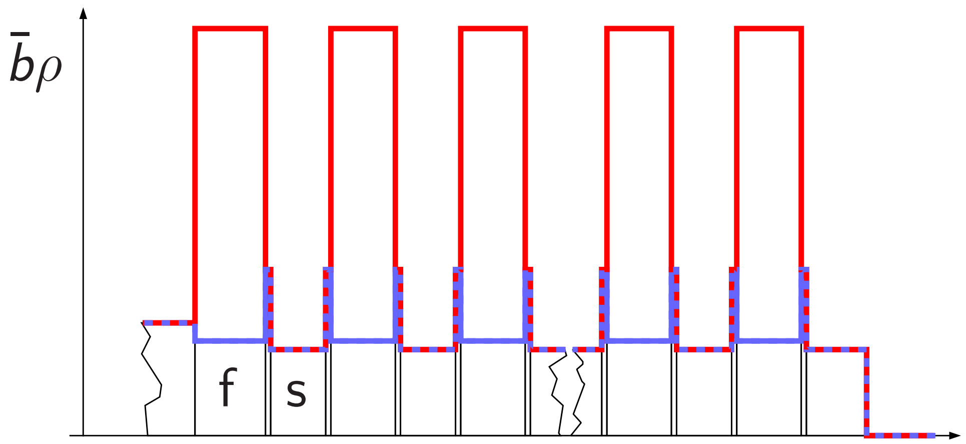
$$(\bar{b}_f - \bar{p}_f)\rho_f = \bar{b}_s\rho_s$$

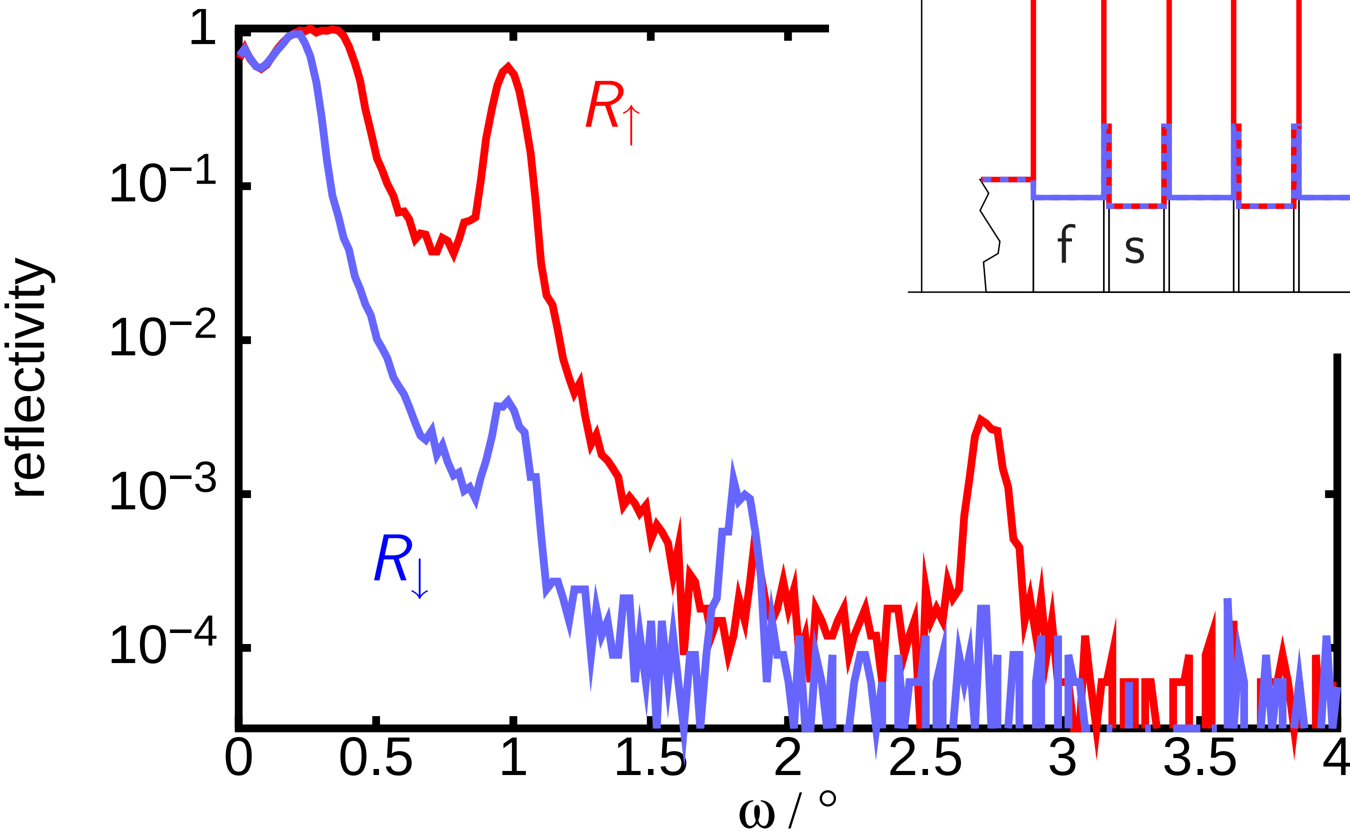


remanent polariser real ml: Fe/Si:N:O

$$(\bar{b}_f + \bar{p}_f)\rho_f \gg \bar{b}_s\rho_s, \quad \bar{p}_s = 0, \quad \text{ferromagnet}, \quad \text{spacer}$$

$$(\bar{b}_f - \bar{p}_f)\rho_f \approx \bar{b}_s\rho_s$$





interdiffusion

⇒ mag. dead layers

⇒ 2nd order peak

remanent polariser   magnetic properties

anisotropic in-plane stress

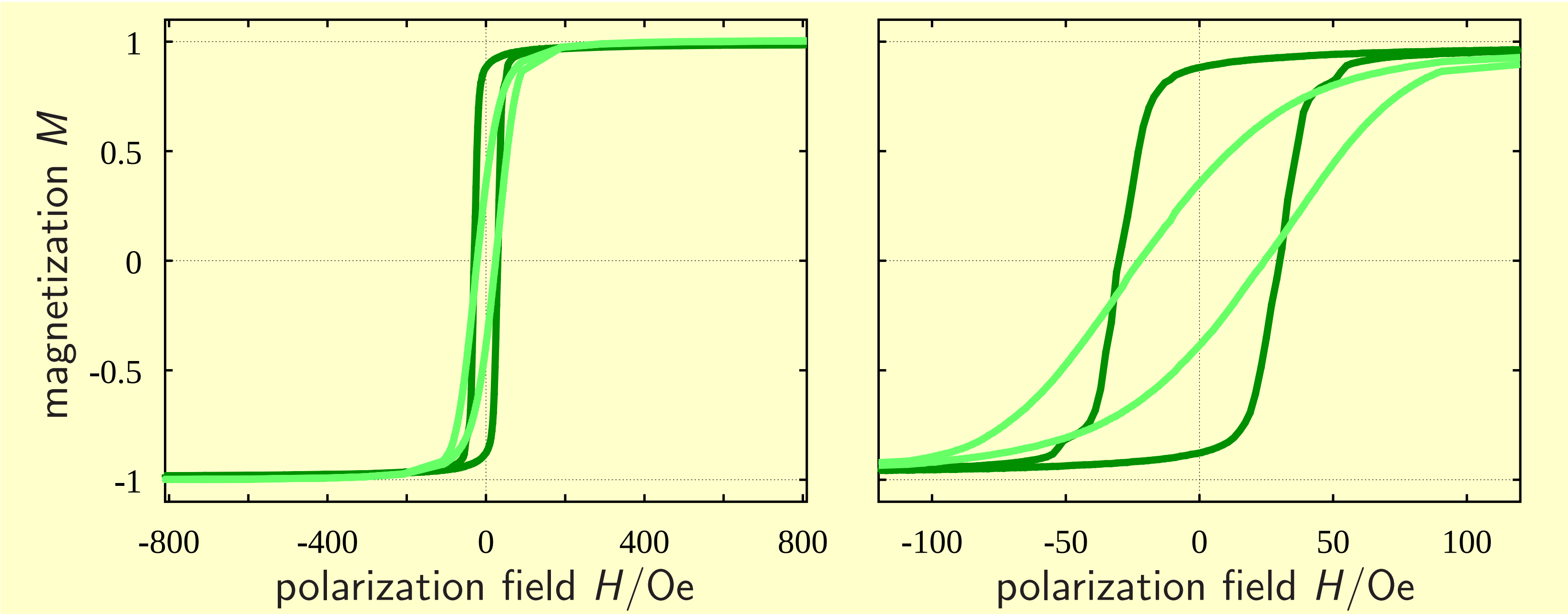
causes anisotropic magnetic properties (magnetostriction)

reason: shape of sputter target and aperture (ca. $100 \times 400\,\mathrm{mm}^2$)

$\Rightarrow$ spread of angle of incidence of sputtered atoms is anisotropic

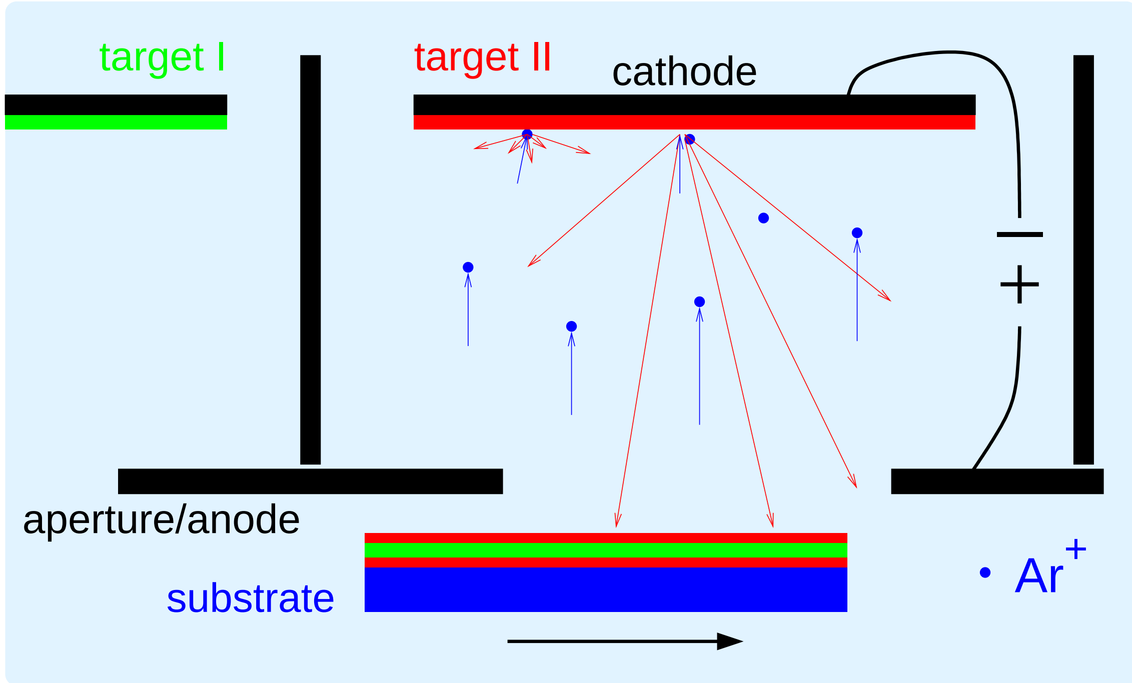
$\Rightarrow$ growth and thus strain formation is effected

$\Rightarrow$ easy axis of magnetisation requires strained filmes!



remanent polariser production

all our multilayers are produced by magnetron sputtering:



parameters:

- power
- velocity
- Ar gas pressure
- reactive gases (O_2, N_2)
- apertures

properties of the films:

- contrast (matching)
- stress minimisation (stable films)
- anisotropic stress (to get an easy axis of magnetisation)
- interface quality (roughness, interdiffusion)

remanent polariser sputter plant

sputter-plant: Leybold Z600

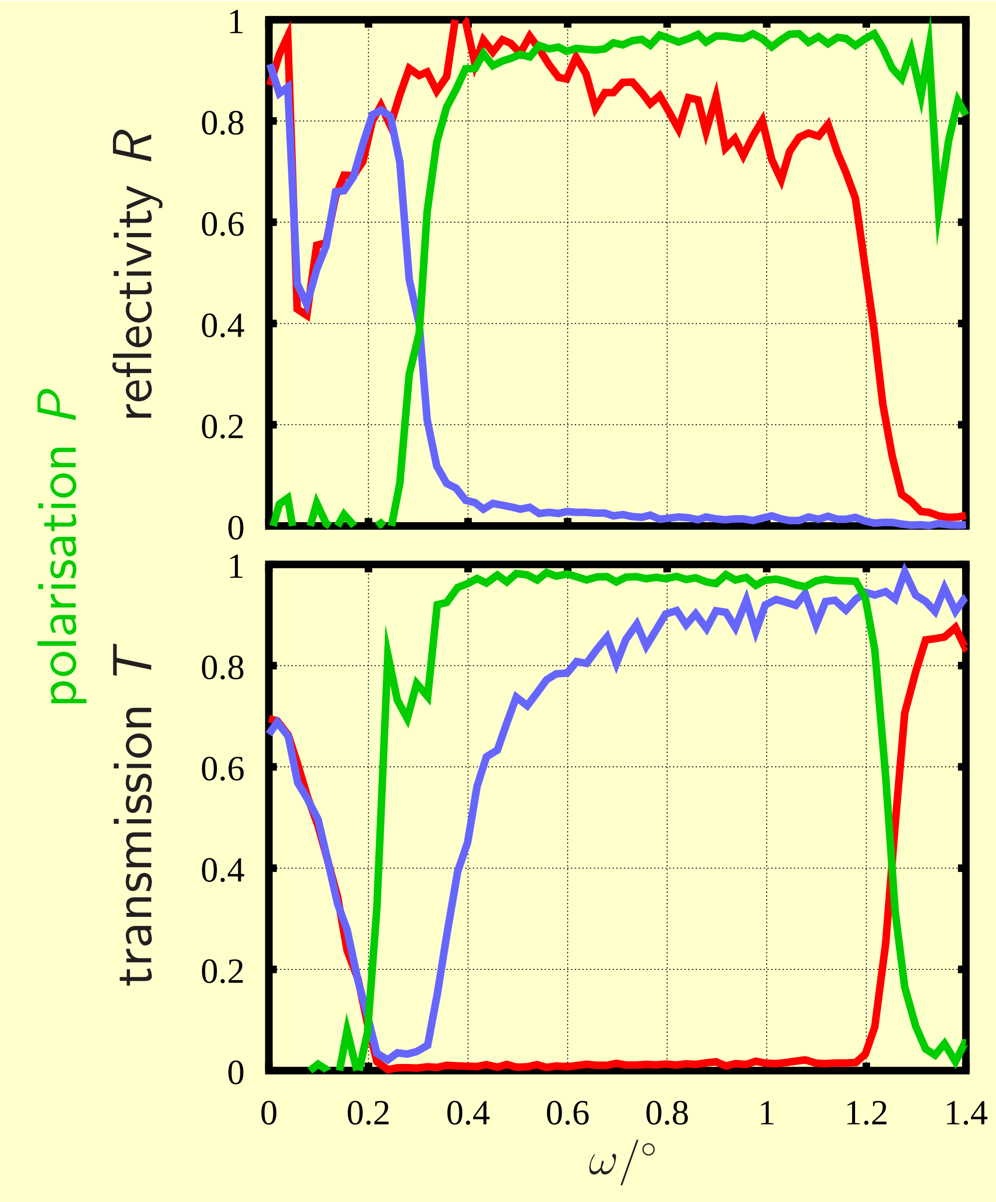
– cleaning of the substrates
  by glow discharge
– 3 cathods
– 1+3 gas inlets per cathod

aperture used to increase the anisotropy
and thus the remanence

consequences:

– unstable discharge
– lower deposition rate
– no influence on the magnetic properties

remanent polariser performance

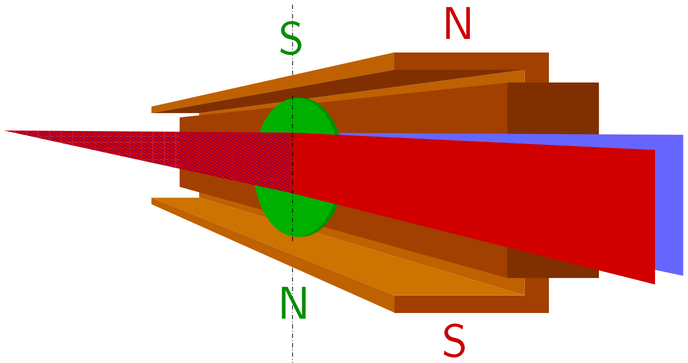


$\mathbf{M} \upuparrows \mathbf{H}_g$

(magnetisation parallel to the guide field)

$H_g = 15\,\mathrm{Oe}$

$\lambda = 4.74\,\text{Å}$



R: $P = 90\,\% - 97\,\%$

T: $P = 96\,\% - 99\,\%$

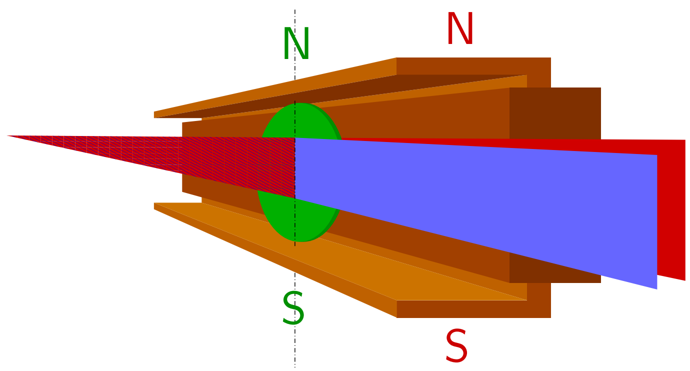
remanent polariser performance

$\mathbf{M} \upharpoonleft\!\downharpoonright \mathbf{H}_g$

(magnetisation antiparallel to the guide field)

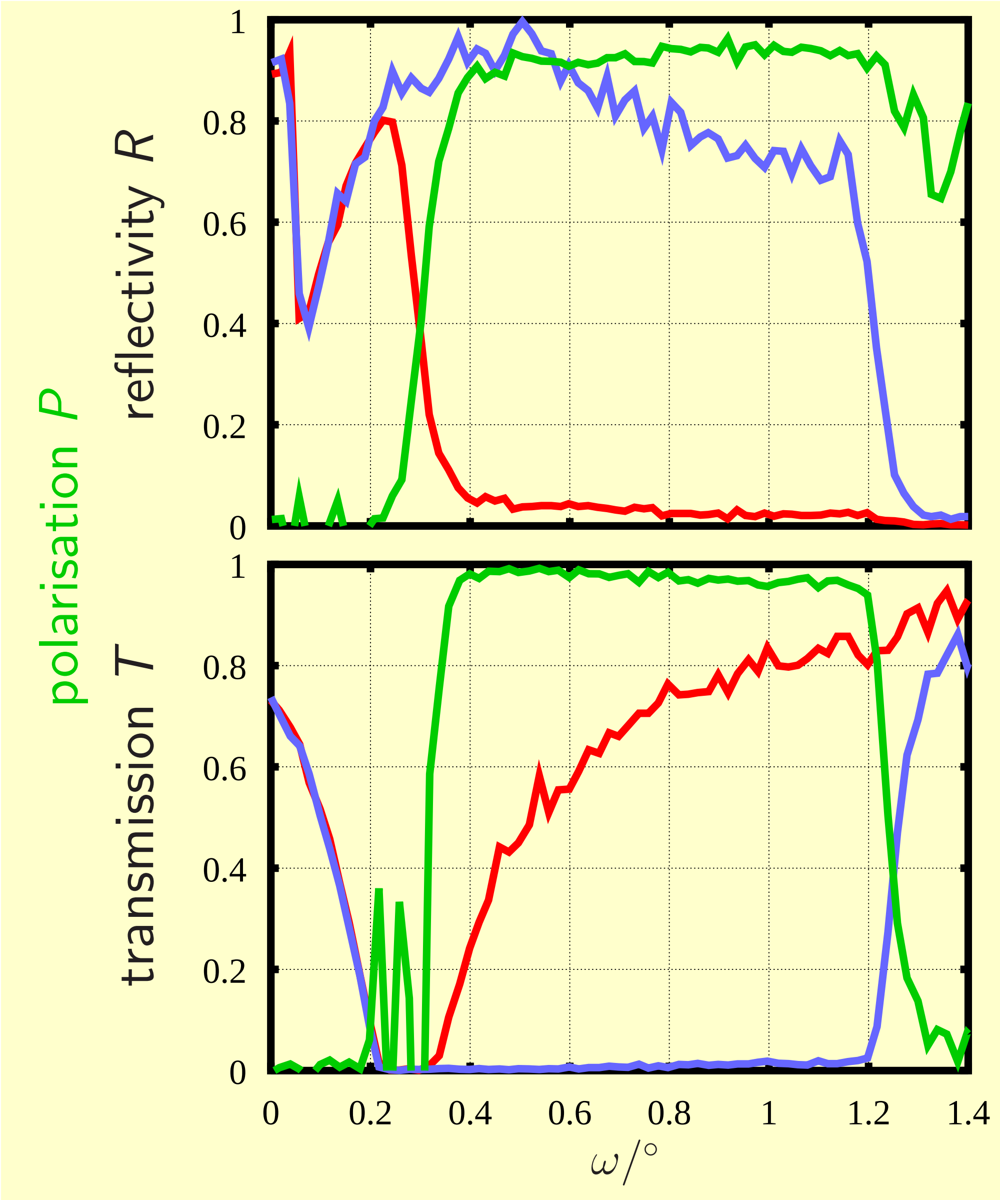
$H_g = 15\,\mathrm{Oe}$

$\lambda = 4.74\,\text{Å}$



R: $P = 90\,\% - 96\,\%$

T: $P = 96\,\% - 99\,\%$

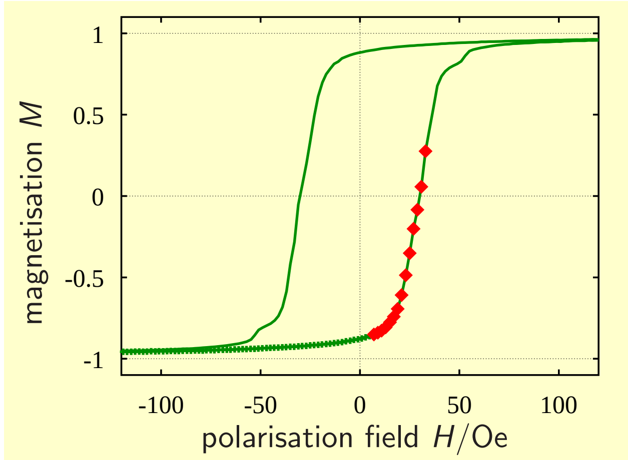


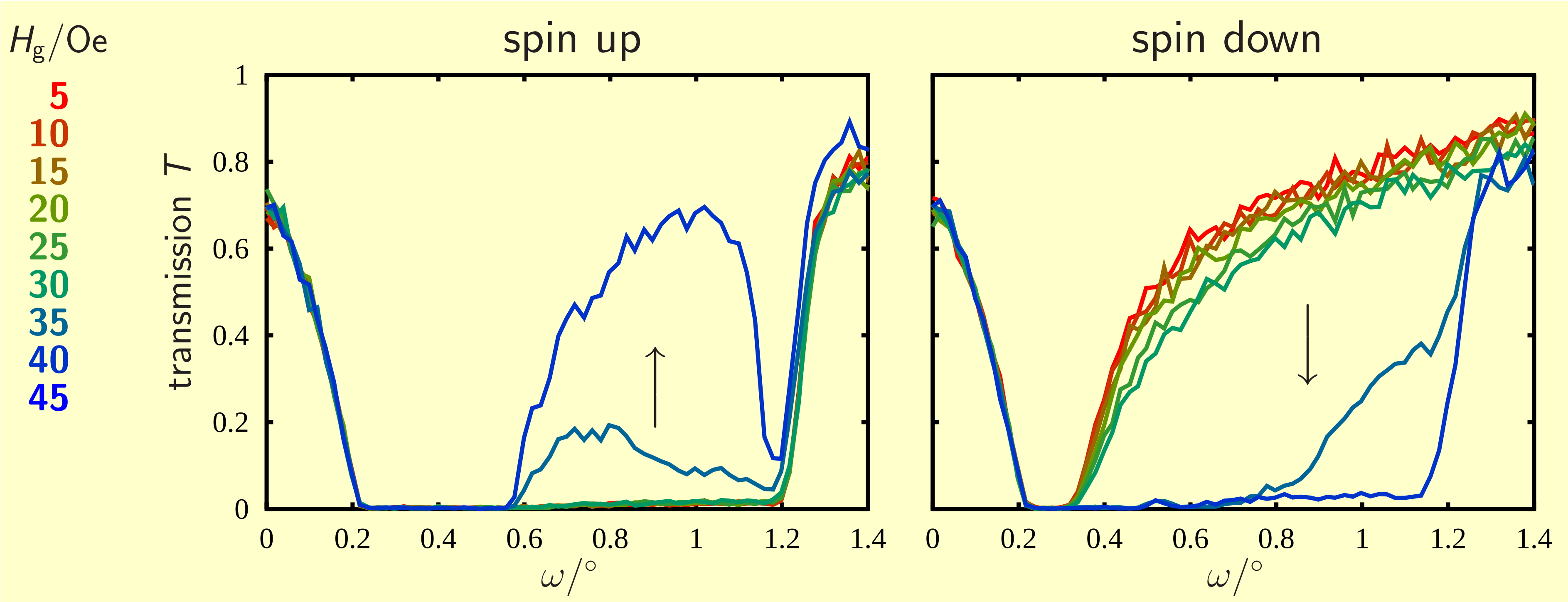
remanent polariser H_c vs. layer thickness

saturation in $H = -700\,\mathrm{Oe}$

transmission measured in guide fields

$$H_\mathrm{g} = +5 \ldots + 45\,\mathrm{Oe}$$





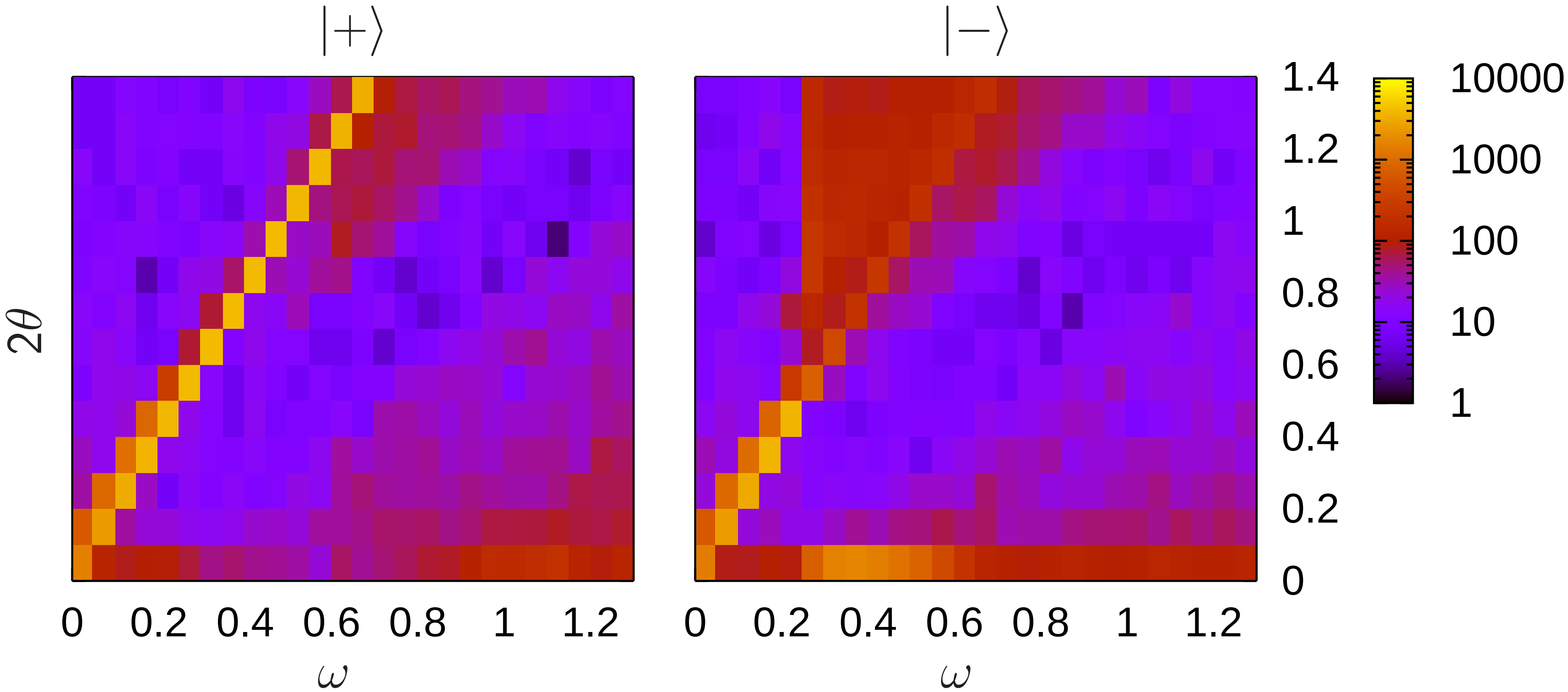
remanent polariser **off-specular scattering**

polarised beam, no spin analysis

Fe/Si:N:O sm, $m = 2.4$

assymetric off-specular signal

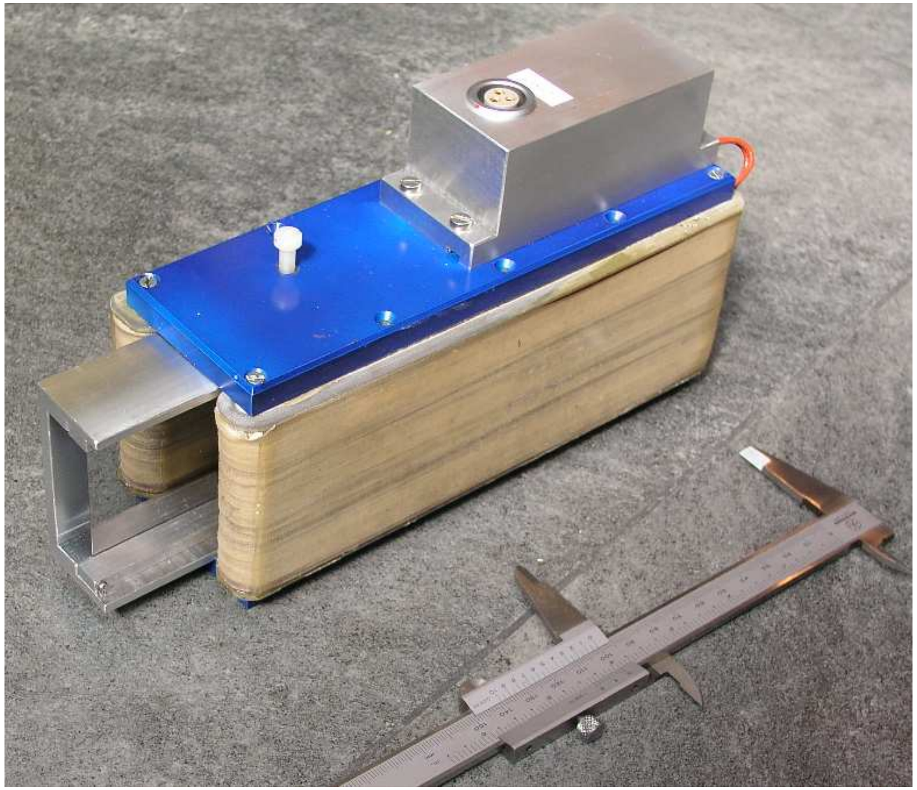
$\Rightarrow$ weak spin-flip scattering



remanent polariser **applications: analyser**

at Morpheus, Narziss (SINQ)

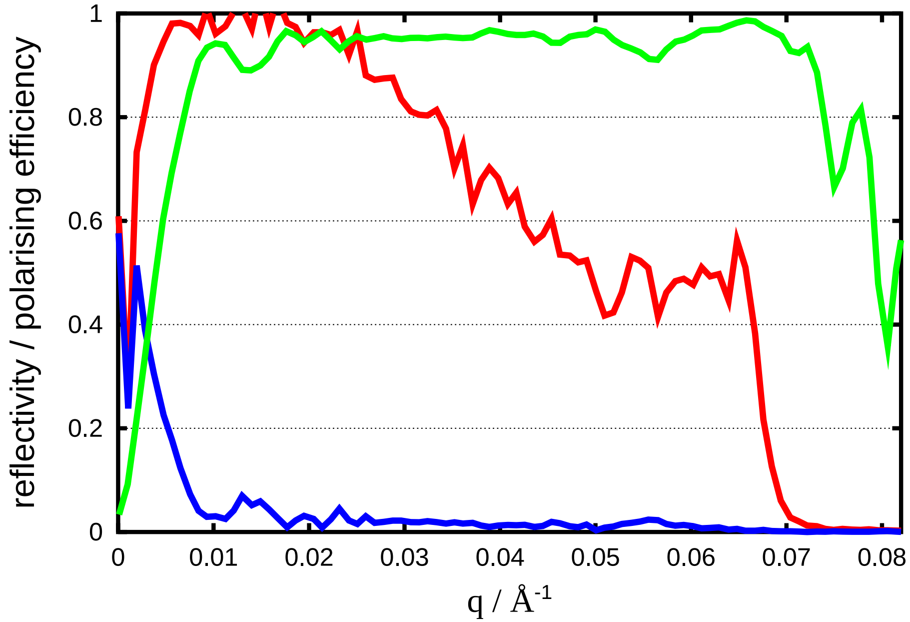
coating	Fe / Si:N:O
	$m = 3$, 599 layers
substrate	Si-wafer, 0.6 mm
mirror size	$200 \times 60\,\mathrm{mm}^2$
magnet size	$200 \times 100 \times 100\,\mathrm{mm}^3$
B_M	200 Oe
B_g	20 Oe
$P_{\mathrm{T},\upuparrows}$	$> 97\,\%$
$P_{\mathrm{T},\updownarrows}$	$> 95\,\%$

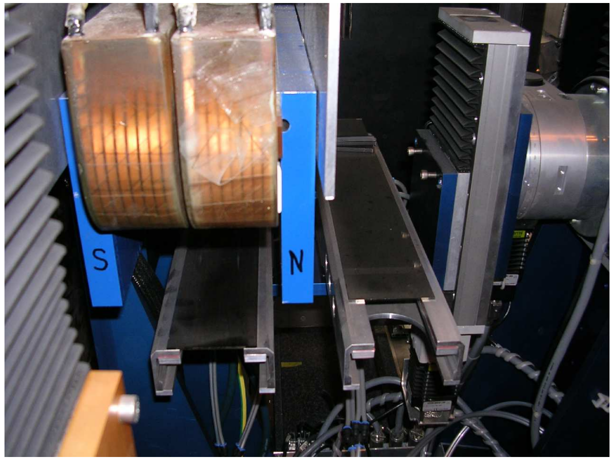


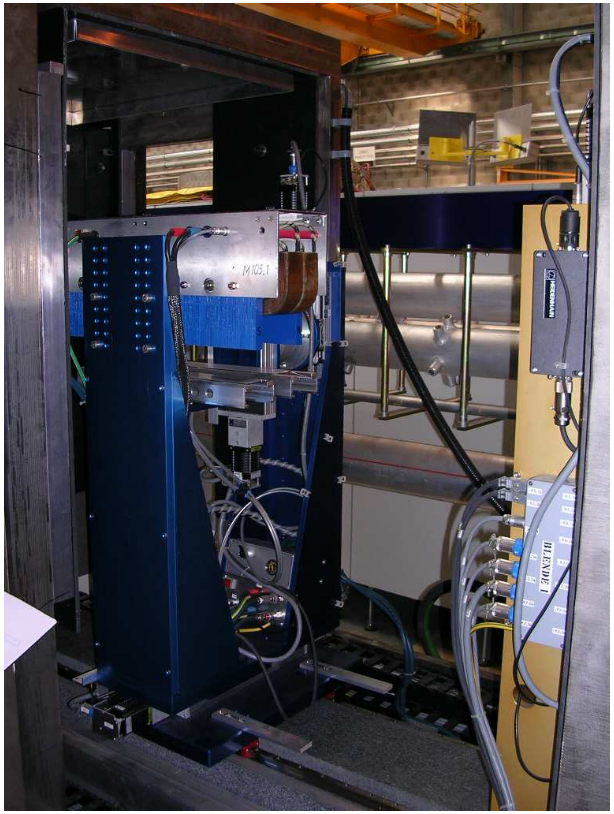
remanent polariser — applications: switchable polariser

at Amor (SINQ)

- FeCoV/TiN on glas
- operated in reflection mode
- saturation fields: ±400 Oe
- guide field: +20 Oe

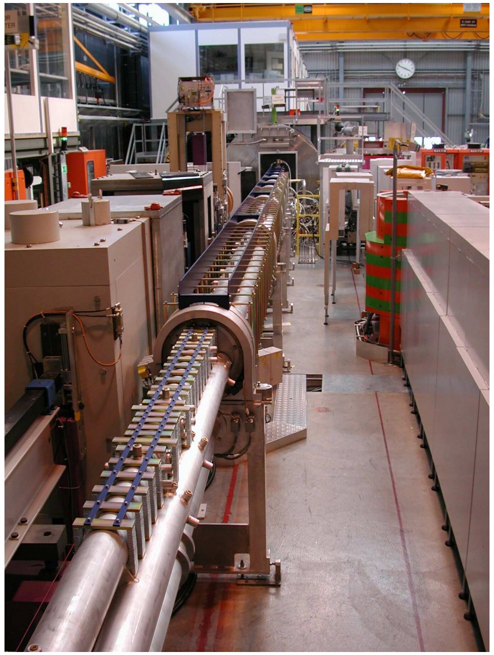


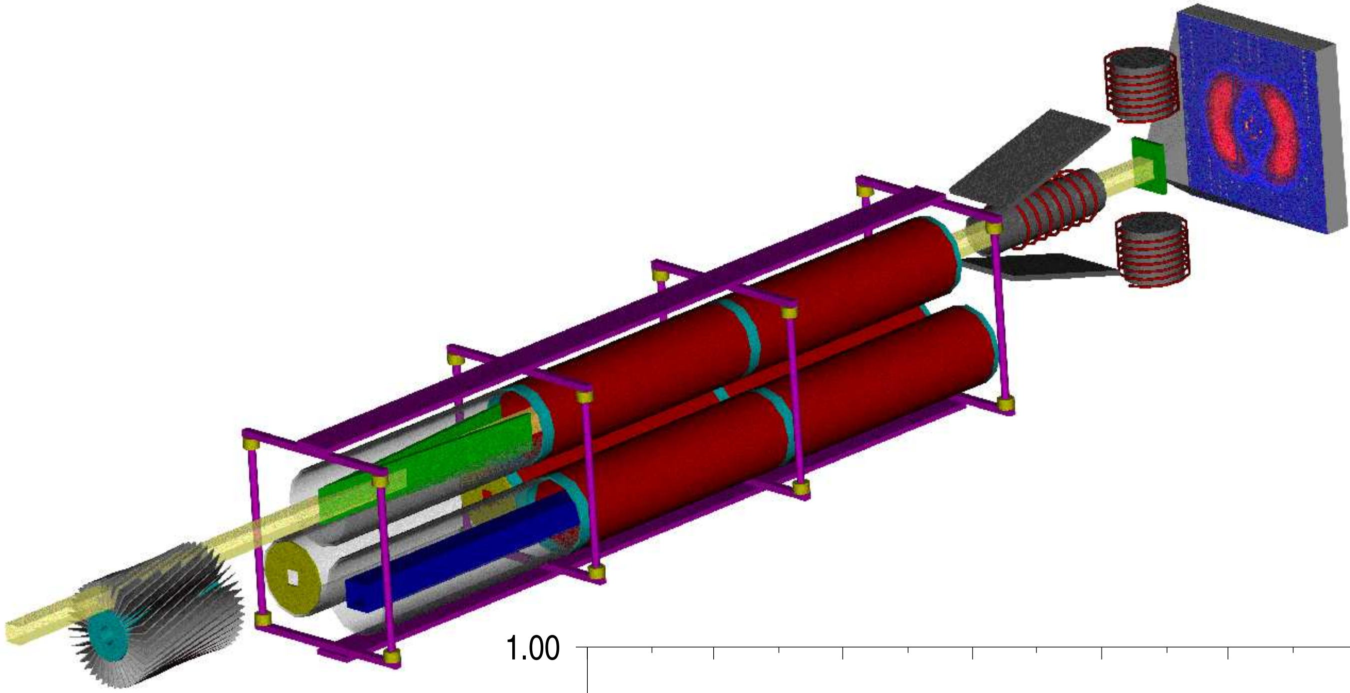




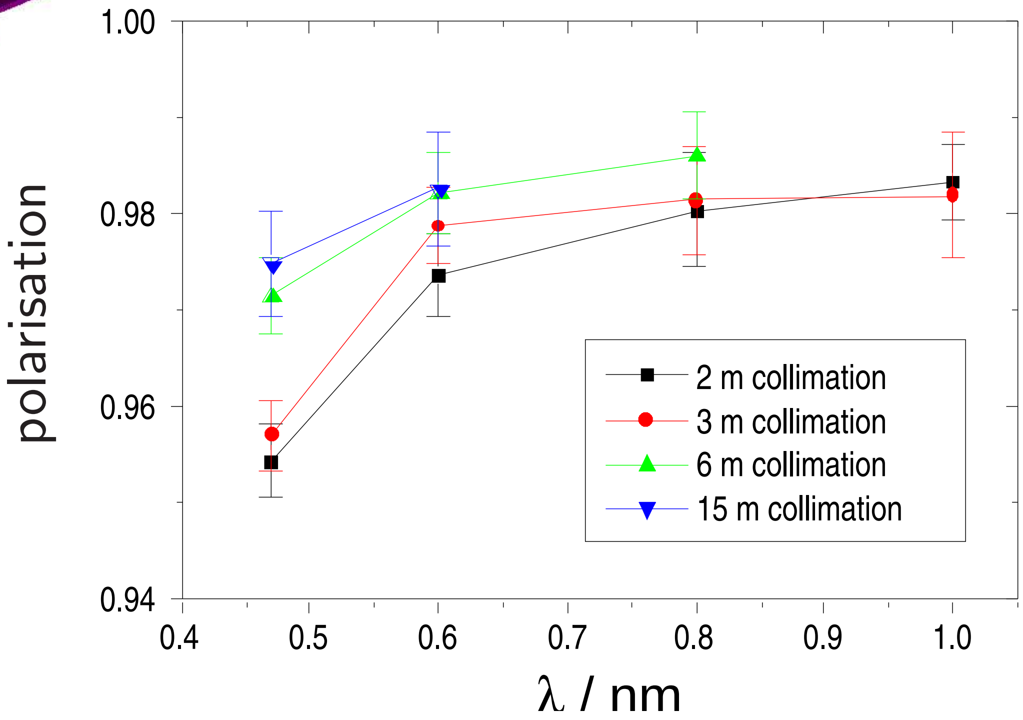
remanent polariser **applications: white beam polariser**

at SANS I (SINQ)





coating	Fe / Si:N:O
	$m = 2.4$, 299 layers
substrate	Si-wafer, 0.6 mm
mirror size	$200 \times 6\,\text{cm}^2$



conclusion:

we produced supermirrors with Fe and Si:N:O which

– polarise neutrons ($P > 95\,\%$ to $P = 99\,\%$)

– can be operated in transmission and reflection mode

– show a magnetic remanence

– thus need guide fields of 20 Oe, only

– can be operated antiparallel to the guide field

the reactive gases N_2 and O_2 in Si are needed to

– match the potentials for $|-\rangle$

– tailor strain in Fe layers (anisotropic stress), but

– keep the overall stress small

limitations:

– stress limits the number of layers $\Rightarrow m < 3$

– FeSi layer causes 2nd Bragg peak
$\Rightarrow |-\rangle$ contamination in reflection mode

THE END