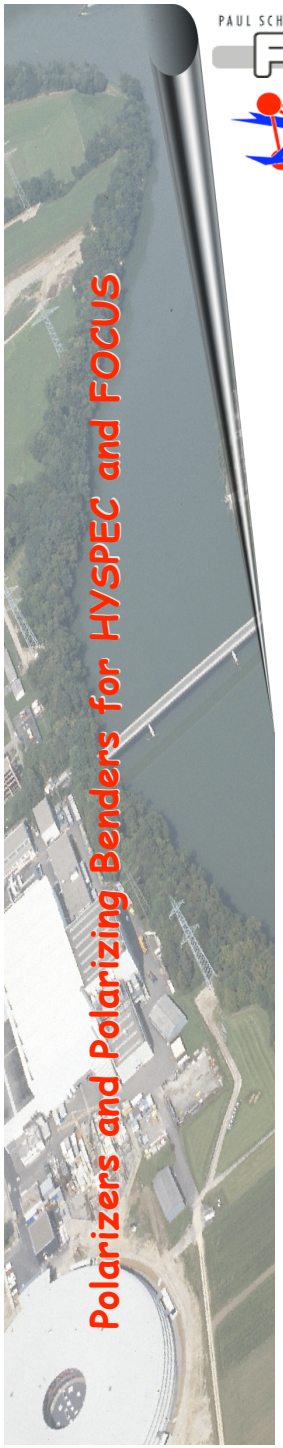


Polarizers and Polarizing Benders for HYSPEC and FOCUS

Jochen Stahn (LNS), Christian Schanzer (LNS)

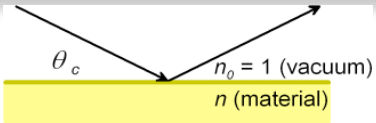
- Polarizers
- Possible Polarizing Analyzers for Wide Angle ToF
- -> Simulations (Uwe Filges)

Peter Allenspach
Head of Laboratory for Developments and Methods (LDM)
Condensed Matter Research with Neutrons and Muons
Paul Scherrer Institute

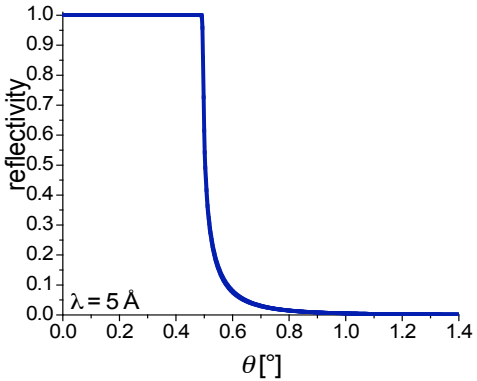
Polarizers

neutron reflection at grazing incidence (< ≈2°)

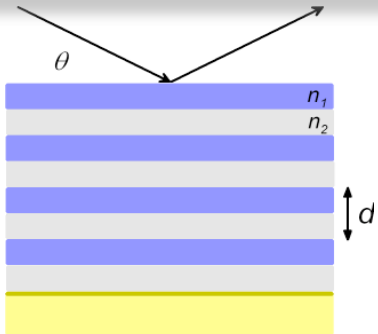
@ smooth surfaces



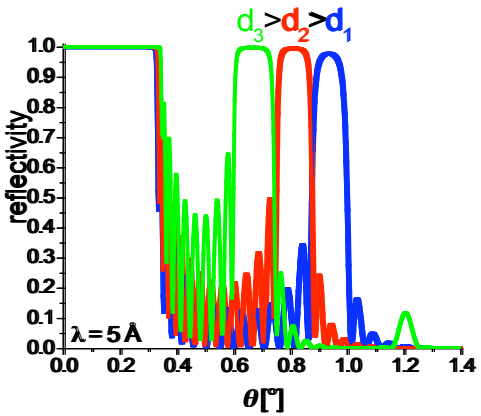
- refractive index $n < 1$
- total external reflection e.g. Ni θ_c = 0.1 °/Å



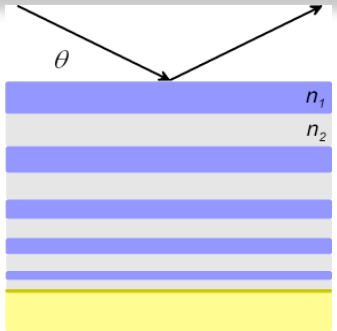
@ multilayer

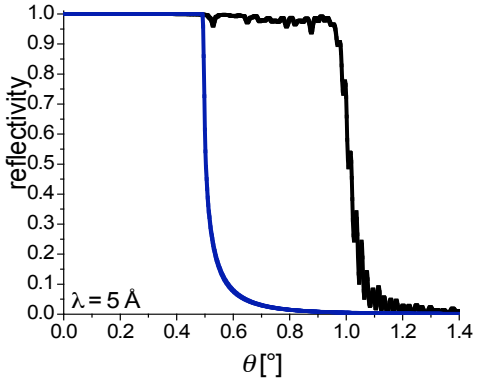


$$\lambda = 2d \sin\theta$$



@ supermirror

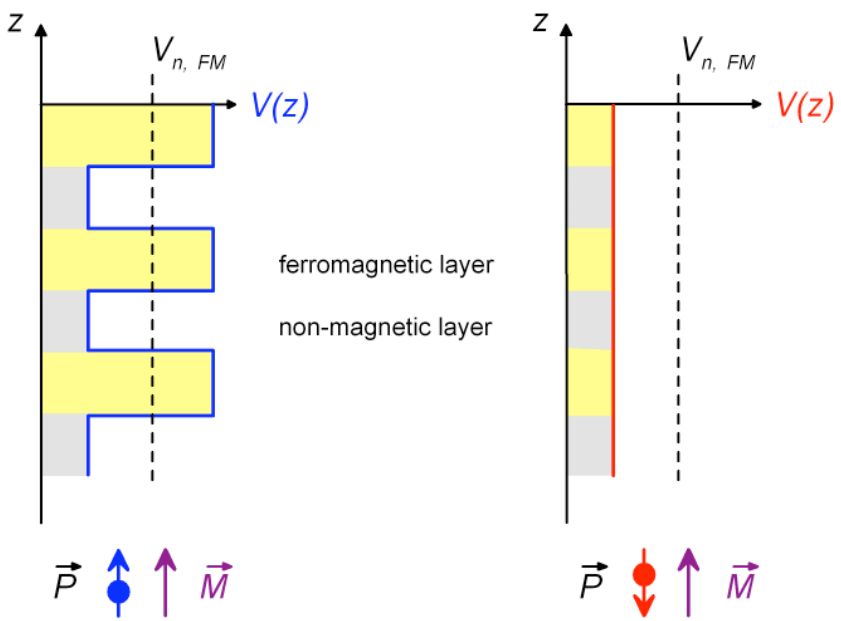




Polarizers

concept of polarizing supermirrors – contrast matching

- ferromagnetic (FM) / non-magnetic (NM) multilayer
- spin dependent interaction of neutron with FM: $(b_n \pm p_m)$
- contrast matching: $(b_{n\ (FM)} - p_{m\ (FM)}) = b_{n\ (NM)}$



- e.g. FeCoV:
  b = (5.97 fm – 5.26 fm) ≈ 0
- vs. Ti: $b_{n\ (NM)}$ = -3.4 fm

↳ reactive sputtering – TiN_x

↳ $b_{n\ (TiN_x)} \approx 0$

Polarizers

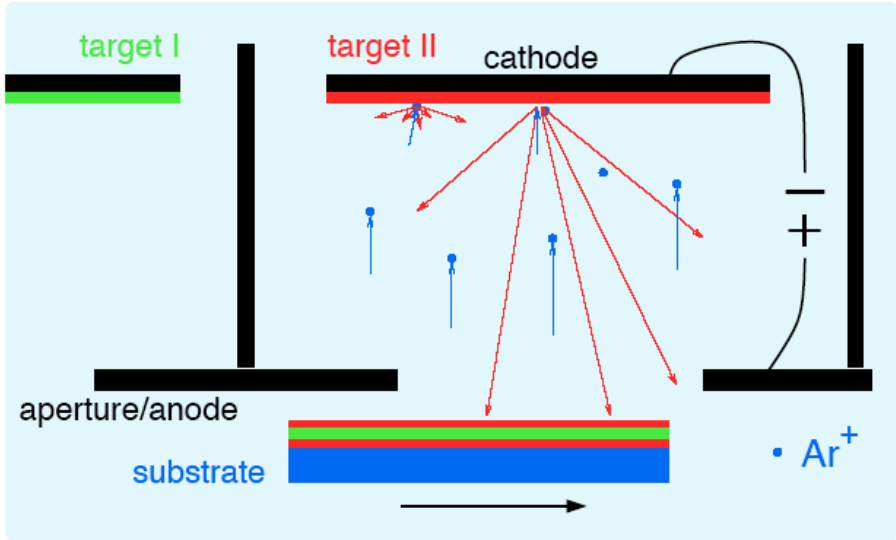
ferromagnetic material: Fe
- might show easy axis of magnetisation
- almost matches Si for $|-\rangle$
- low absorption (required for transmission, less radiation damage)

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

Polarizers

all our multilayers are produced by magnetron sputtering:



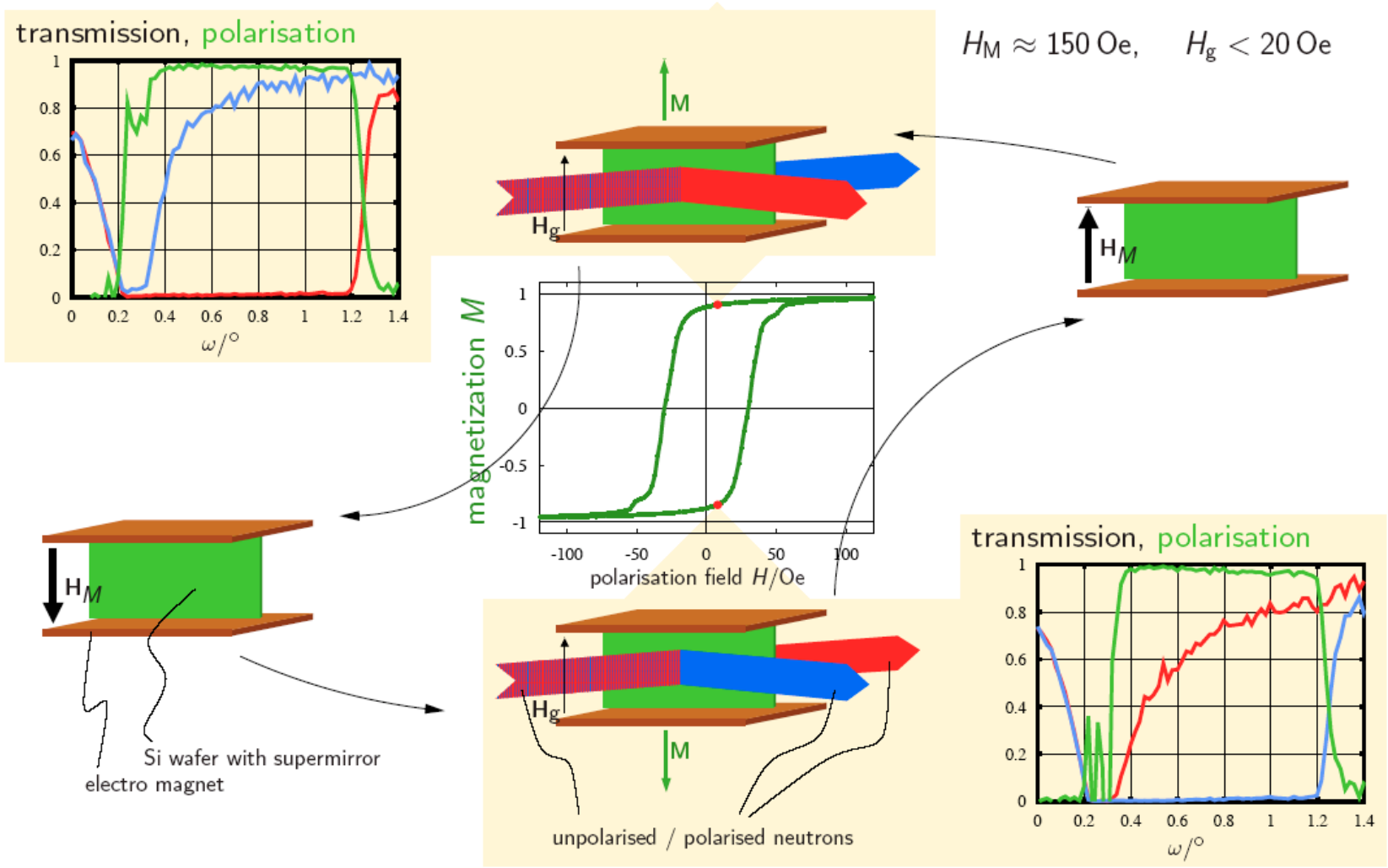
parameters:

- 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)

Polarizers


transmission, polarisation
ω/°
M
Hg
$H_M \approx 150$ Oe, $H_g < 20$ Oe
H_M
magnetization M
polarisation field H/Oe
H_M
Si wafer with supermirror
electro magnet
Hg
M
unpolarised / polarised neutrons
transmission, polarisation
ω/°

Polarizers

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

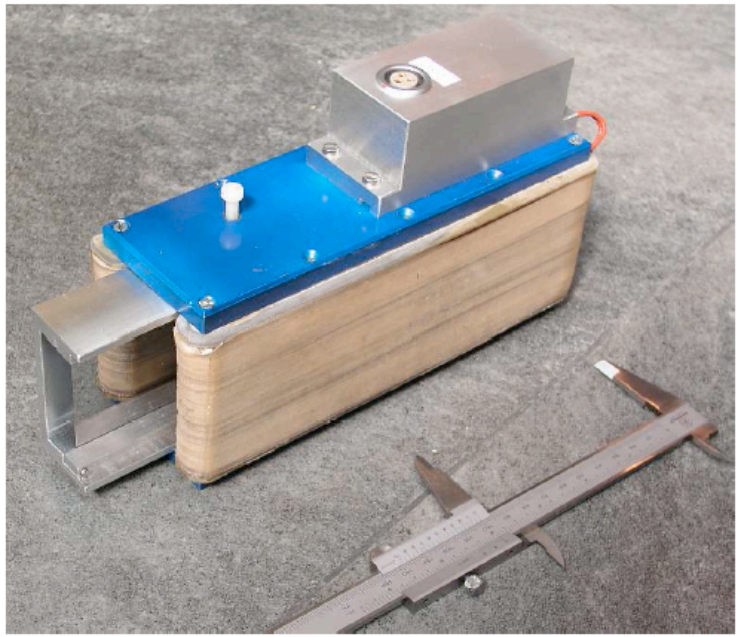
the reactive gases N_2 and O_2 in Si are needed to
- match the potentials for $|-\rangle$
- tailor strain in Fe layers (anisotropic stress), but
- keep the overall stress small

limitations:
- stress limits the number of layers $\Rightarrow m < 3$
- FeSi layer causes 2nd Bragg peak
  $\Rightarrow |-\rangle$ contamination in reflection mode

Polarizers

at Morpheus, Narziss (SINQ)

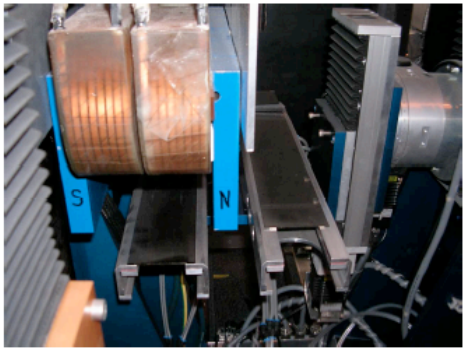
coating	Fe / Si:N:O
	$m = 3$, 599 layers
substrate	Si-wafer, 0.6 mm
mirror size	$200 \times 60\,\mathrm{mm}^2$
magnet size	$200 \times 100 \times 100\,\mathrm{mm}^3$
B_M	200 Oe
B_g	20 Oe
$P_{T,\uparrow\uparrow}$	$> 97\,\%$
$P_{T,\uparrow\downarrow}$	$> 95\,\%$

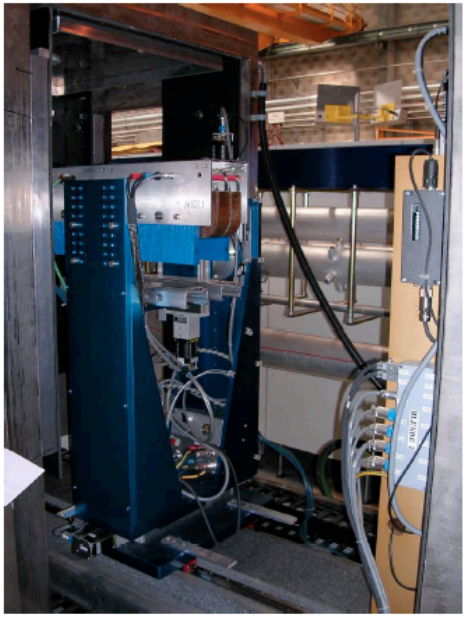


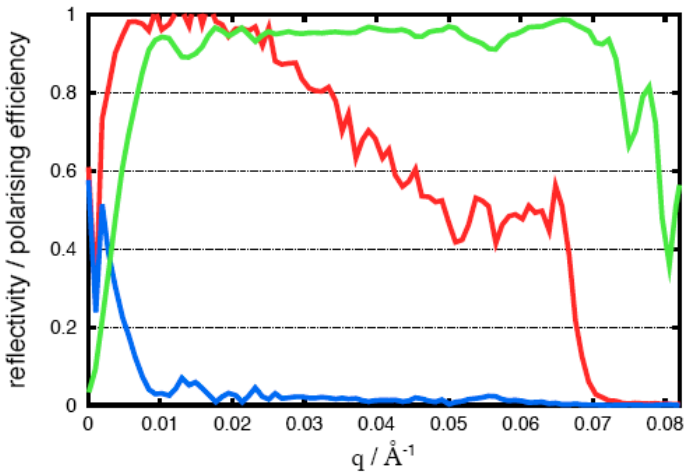
Polarizers

at Amor (SINQ)

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

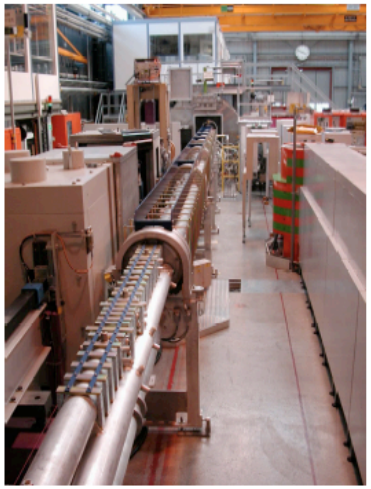


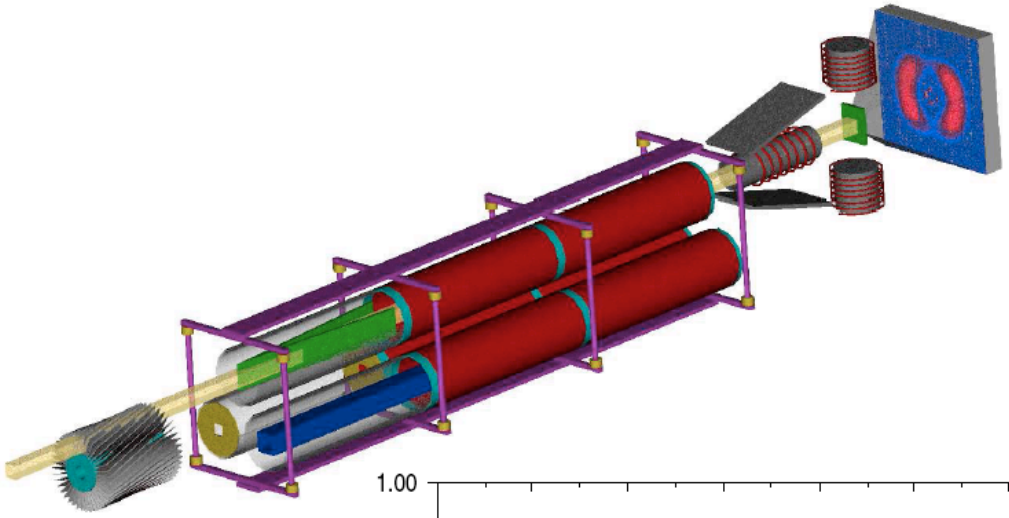




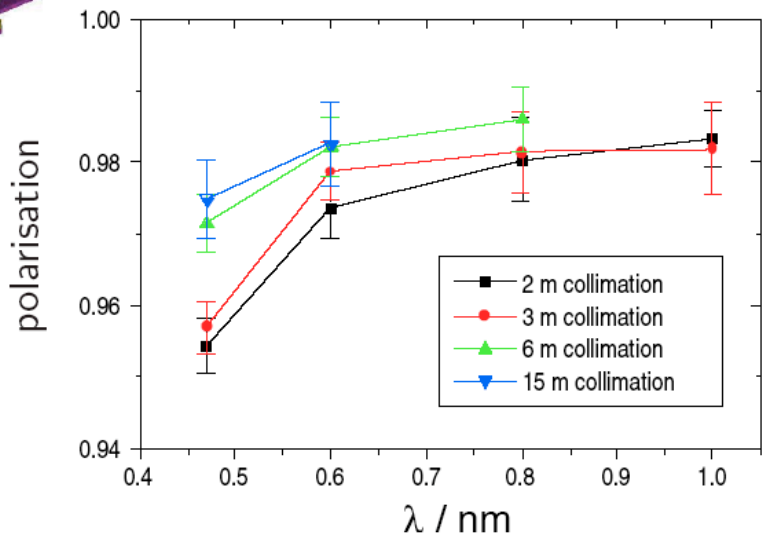
Polarizers

at SANS I (SINQ)

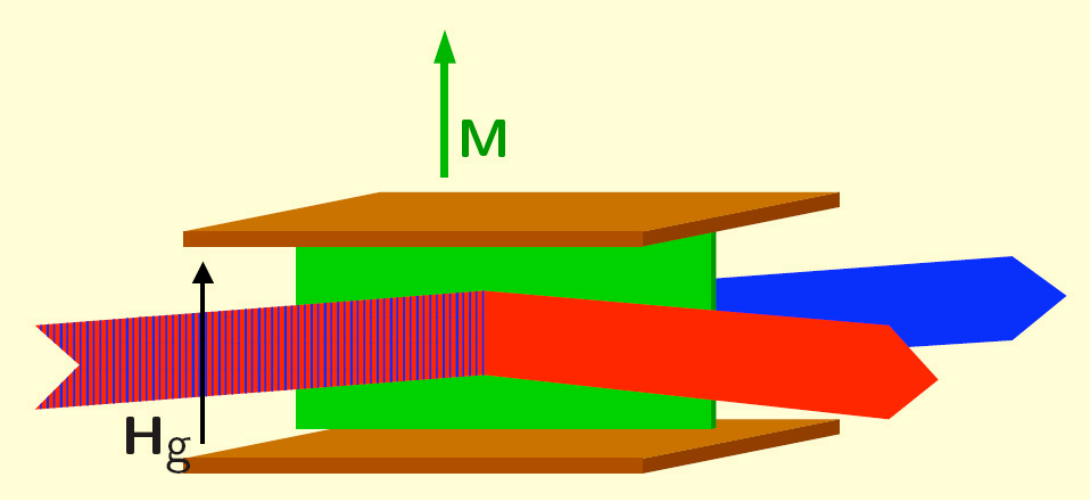


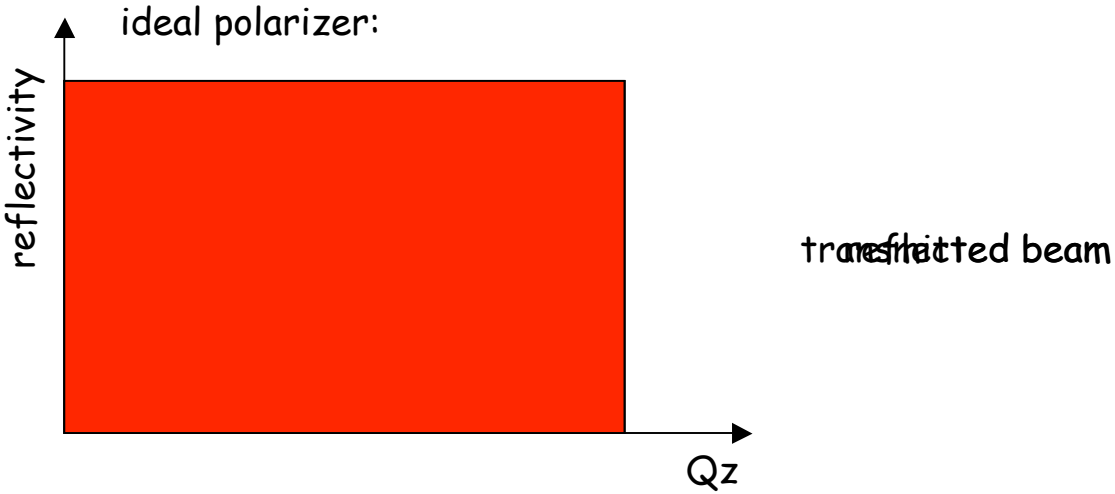


coating	Fe / Si:N:O
	$m = 2.4$, 299 layers
substrate	Si-wafer, 0.6 mm
mirror size	$200 \times 6\,\mathrm{cm}^2$

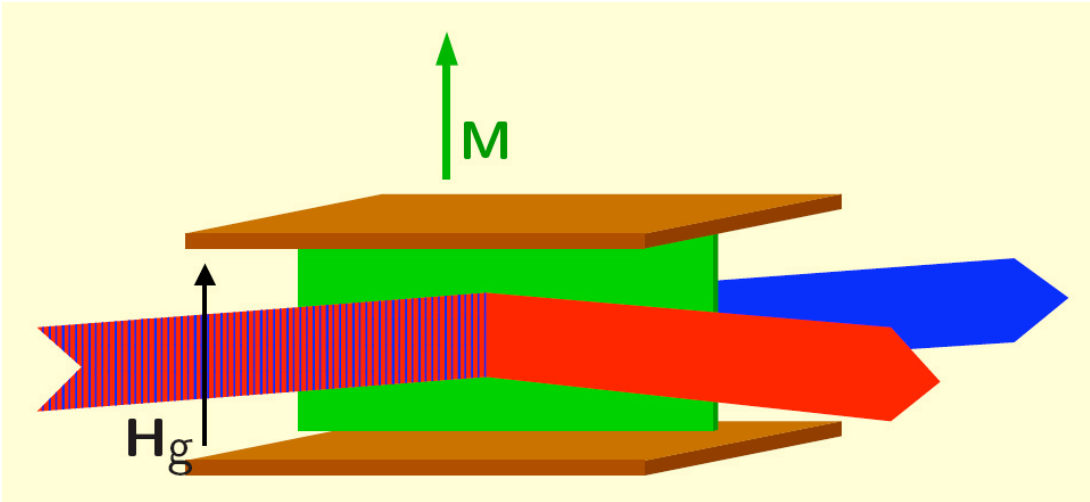


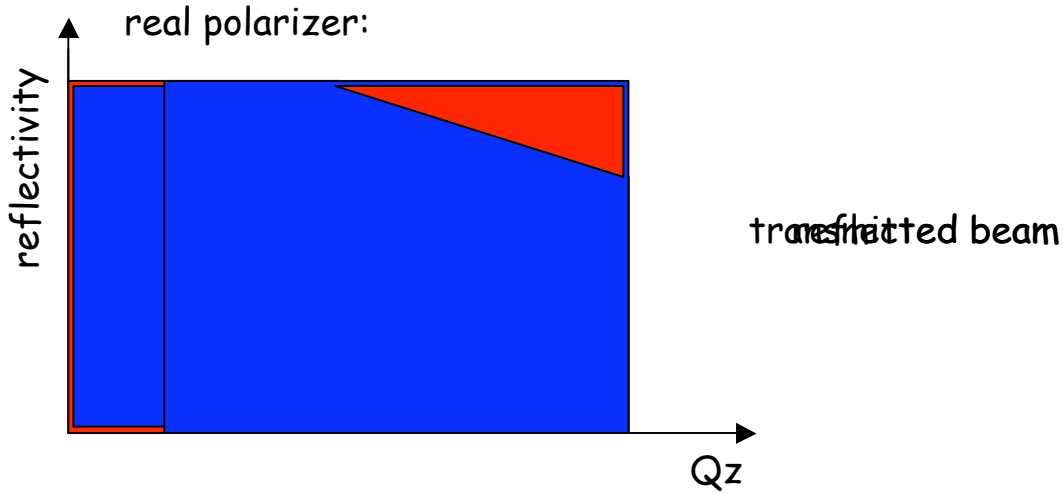
Polarizers





Polarizers

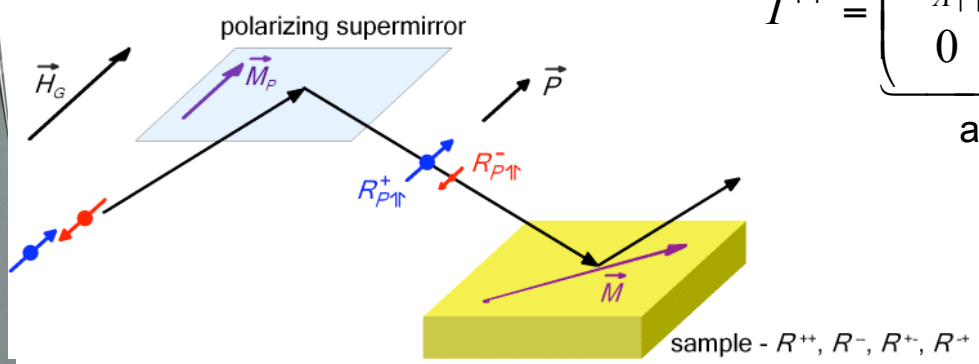




Correction of finite polarization

Experiment

– finite polarization/analysis

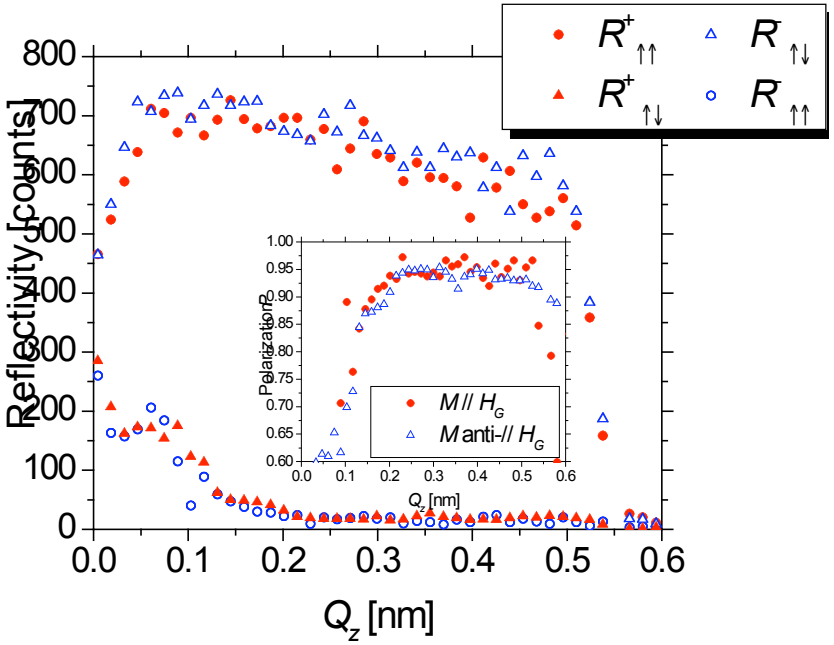


measured intensities: I^{++}, I^{+-}, I^{--}, I^{-+}

$$I^{++} = \underbrace{\begin{pmatrix} R^+_{A\uparrow\uparrow} & 0 \\ 0 & R^-_{A\uparrow\uparrow} \end{pmatrix}}_{\text{analyzer}} \underbrace{\begin{pmatrix} R^{++} & R^{-+} \\ R^{+-} & R^{--} \end{pmatrix}}_{\text{sample}} \underbrace{\begin{pmatrix} R^+_{P\uparrow\uparrow} & 0 \\ 0 & R^-_{P\uparrow\uparrow} \end{pmatrix}}_{\text{polarizer}} \underbrace{\begin{pmatrix} n_+ \\ n_- \end{pmatrix}}_{n_+=n_-=1/2} I_0$$

$$\begin{pmatrix} I^{++} \\ I^{+-} \\ I^{--} \\ I^{-+} \end{pmatrix} = \frac{I_0}{2} \begin{pmatrix} R^+_{A\uparrow\uparrow}R^+_{P\uparrow\uparrow} & R^-_{A\uparrow\uparrow}R^+_{P\uparrow\uparrow} & R^-_{A\uparrow\uparrow}R^-_{P\uparrow\uparrow} & R^+_{A\uparrow\uparrow}R^-_{P\uparrow\uparrow} \\ R^-_{A\uparrow\downarrow}R^+_{P\uparrow\uparrow} & R^+_{A\uparrow\downarrow}R^+_{P\uparrow\uparrow} & R^+_{A\uparrow\downarrow}R^-_{P\uparrow\uparrow} & R^-_{A\uparrow\downarrow}R^-_{P\uparrow\uparrow} \\ R^-_{A\uparrow\downarrow}R^-_{P\uparrow\downarrow} & R^+_{A\uparrow\downarrow}R^-_{P\uparrow\downarrow} & R^+_{A\uparrow\downarrow}R^+_{P\uparrow\downarrow} & R^-_{A\uparrow\downarrow}R^+_{P\uparrow\downarrow} \\ R^+_{A\uparrow\uparrow}R^-_{P\uparrow\downarrow} & R^-_{A\uparrow\uparrow}R^-_{P\uparrow\downarrow} & R^-_{A\uparrow\uparrow}R^+_{P\uparrow\downarrow} & R^+_{A\uparrow\uparrow}R^+_{P\uparrow\downarrow} \end{pmatrix} \begin{pmatrix} R^{++} \\ R^{+-} \\ R^{--} \\ R^{-+} \end{pmatrix}$$

Correction of finite polarization



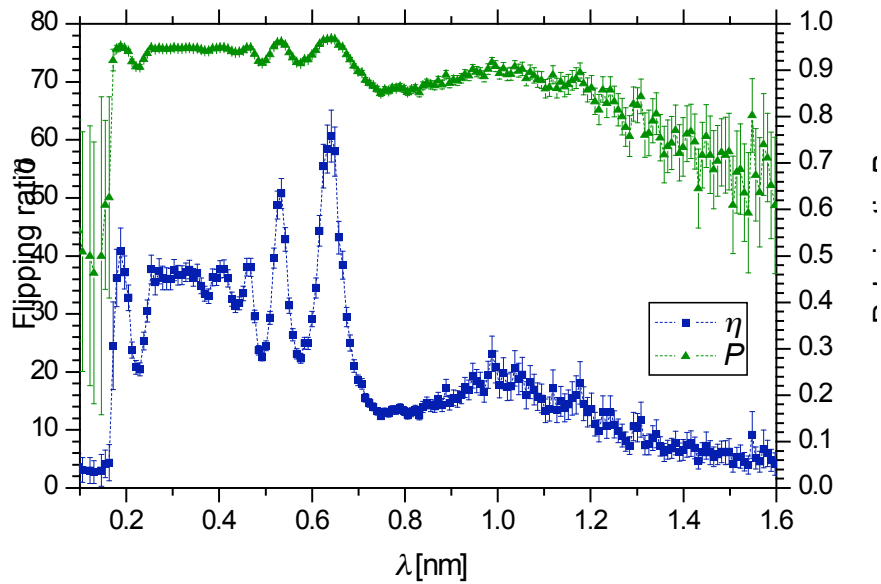
identical and ‚symmetric' properties of polarizer/analyzer:

$$R^+ = R^+_{P\uparrow\uparrow} = R^+_{A\uparrow\uparrow} = R^-_{P\uparrow\downarrow} = R^-_{A\uparrow\downarrow}$$

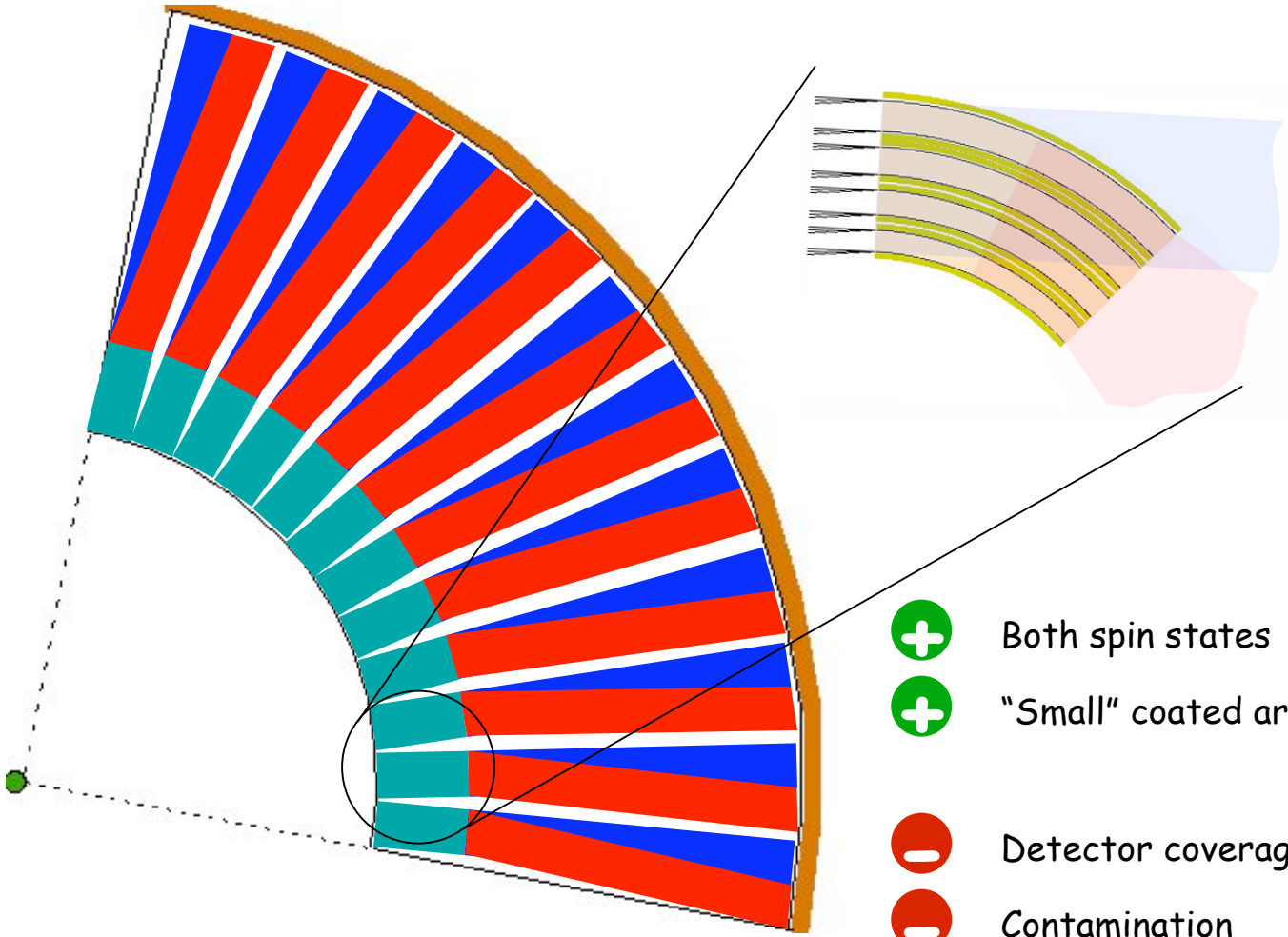
$$R^- = R^-_{P\uparrow\uparrow} = R^-_{A\uparrow\uparrow} = R^+_{P\uparrow\downarrow} = R^+_{A\uparrow\downarrow}$$

flipping ratio: $\eta = \dfrac{R^+}{R^-}$

$$\begin{pmatrix} I^{++} \\ I^{+-} \\ I^{--} \\ I^{-+} \end{pmatrix} = \frac{I_0}{2R^-R^-} \begin{pmatrix} \eta^2 & \eta & 1 & \eta \\ \eta & \eta^2 & \eta & 1 \\ 1 & \eta & \eta^2 & \eta \\ \eta & 1 & \eta & \eta^2 \end{pmatrix} \begin{pmatrix} R^{++} \\ R^{+-} \\ R^{--} \\ R^{-+} \end{pmatrix}$$

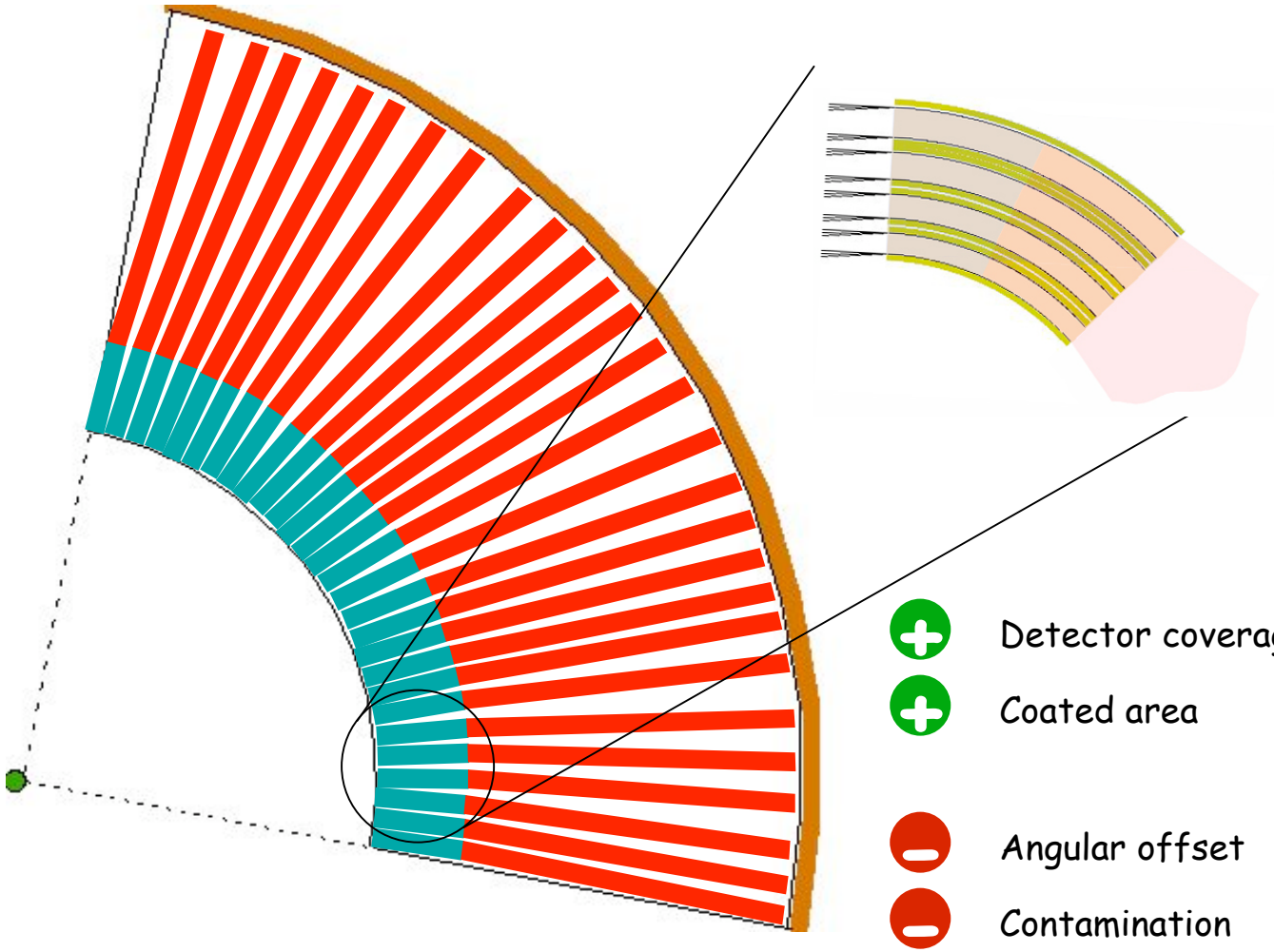


Possible polarizing analyzers



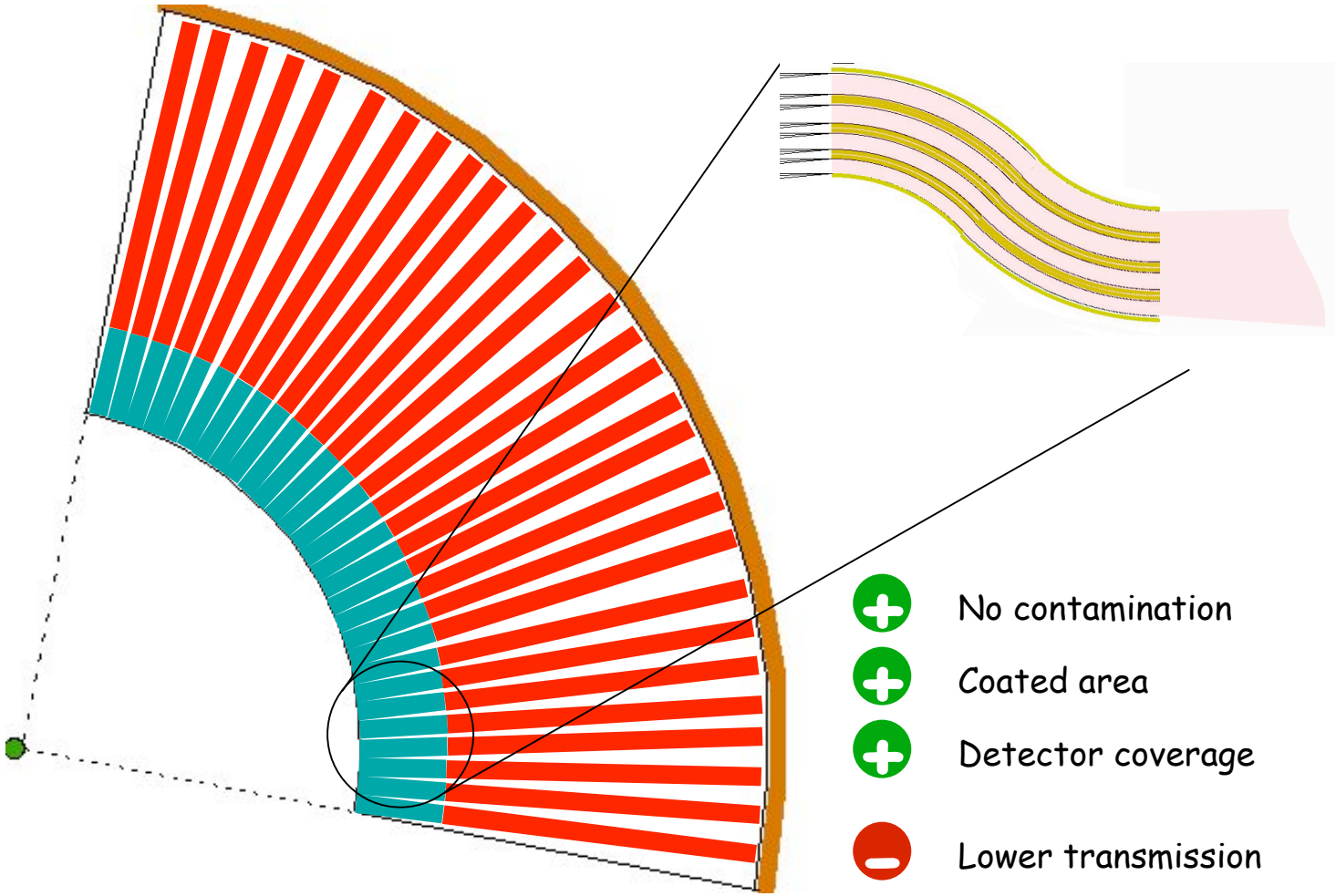
- + Both spin states
- + "Small" coated area
- − Detector coverage
- − Contamination

Possible polarizing analyzers



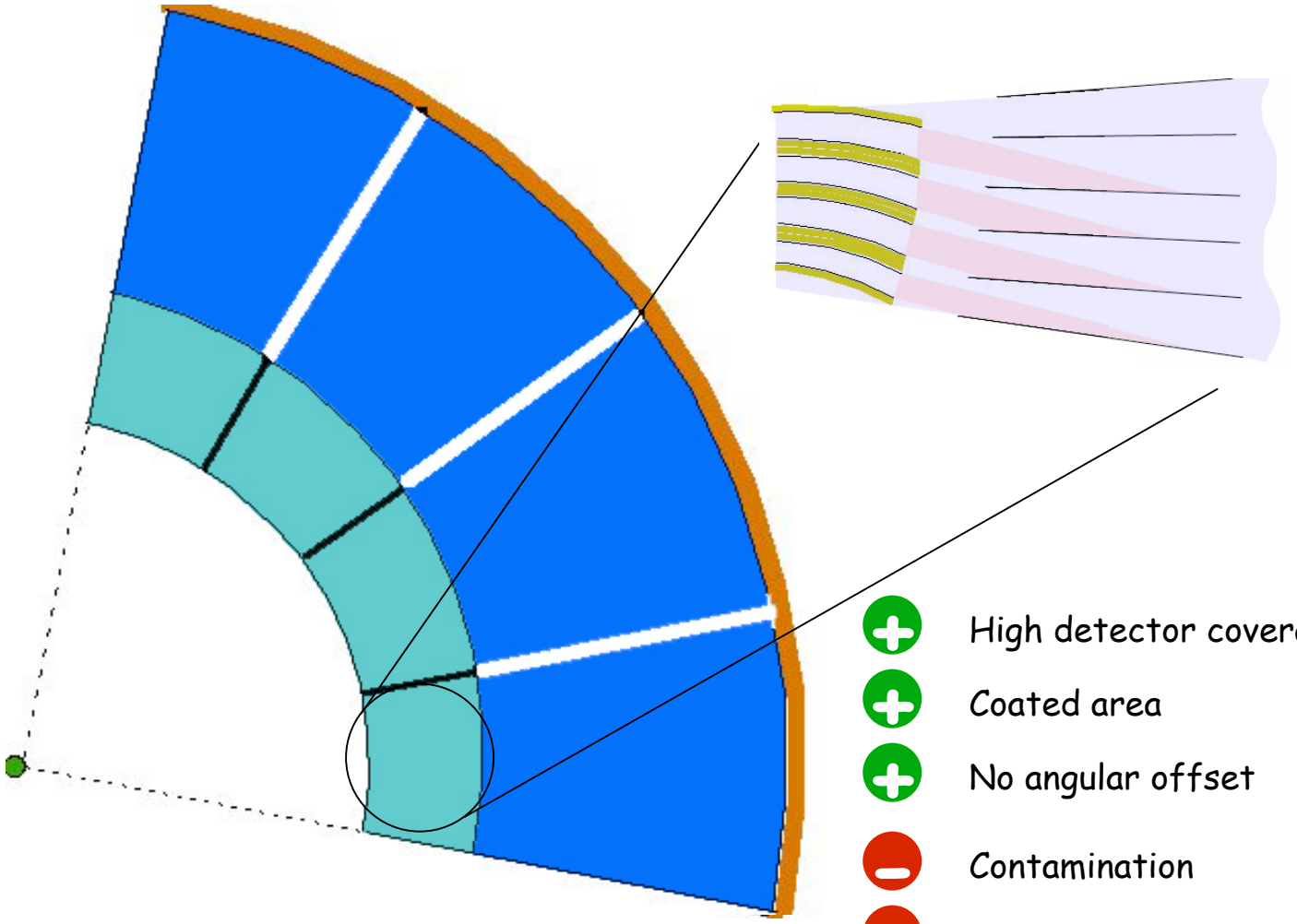
- Detector coverage
- Coated area
- Angular offset
- Contamination

Possible polarizing analyzers



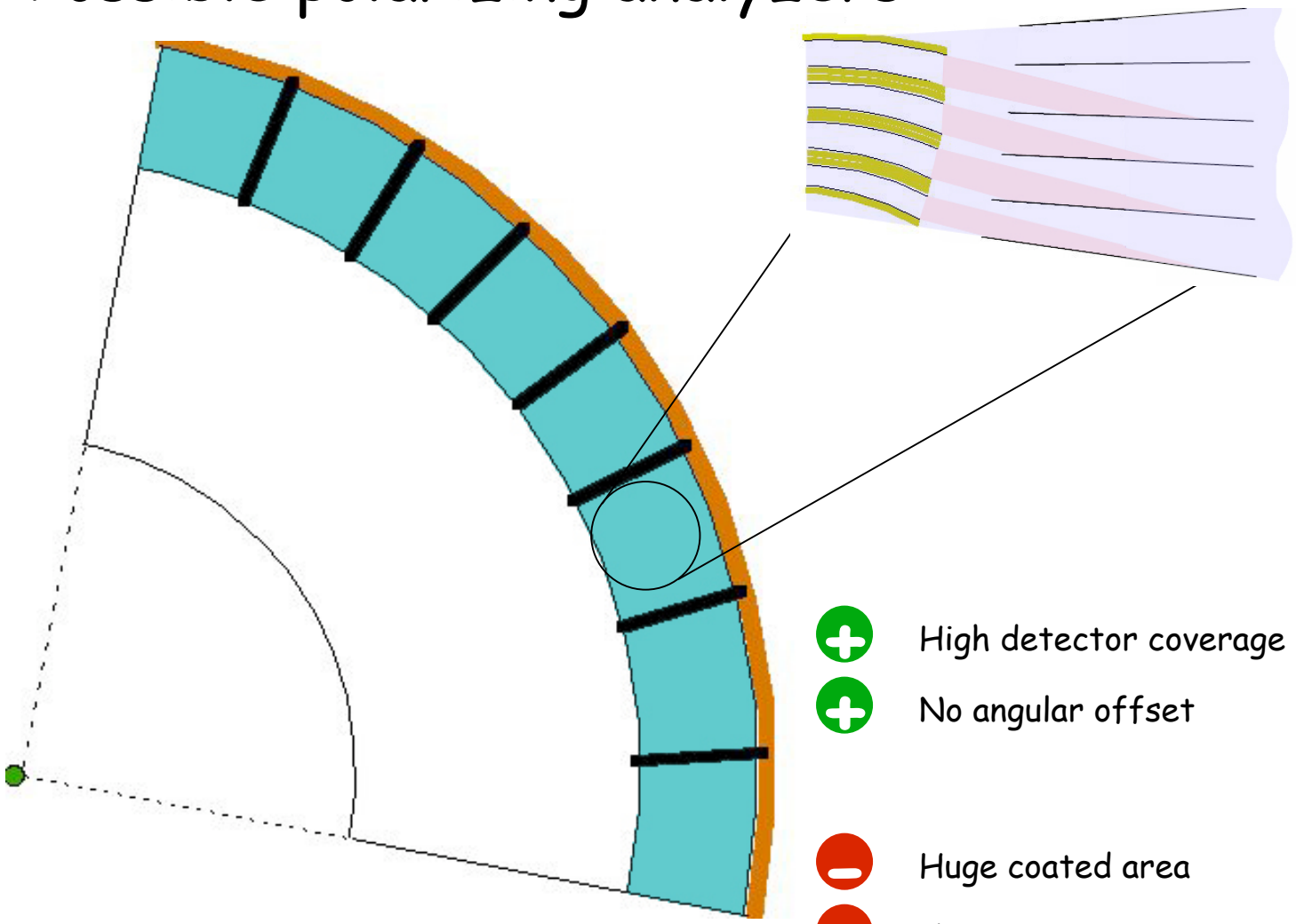
- No contamination
- Coated area
- Detector coverage
- Lower transmission

Possible polarizing analyzers



- High detector coverage
- Coated area
- No angular offset
- Contamination
- Technology

Possible polarizing analyzers



- ➕ High detector coverage
- ➕ No angular offset
- ➖ Huge coated area
- ➖ Contamination

Simulations

-> Uwe Filges (tomorrow morning)