Magnetic heterostructures as seen by x-rays and neutrons

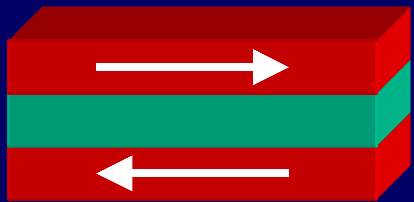
Hartmut Zabel
Experimentalphysik/Festkörperphysik
Ruhr-Universität Bochum, Germany

MMSPN, 7-9 December, 2001, Budapest, Hungary

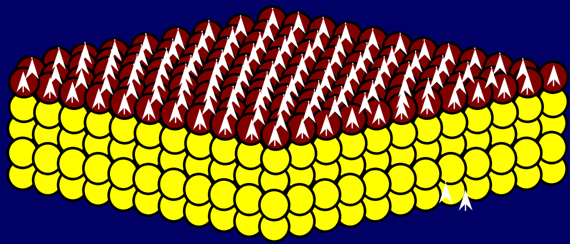
Thin films

for magnetism, electronics, spintronics, superconductivity, optics, corrosion protection...

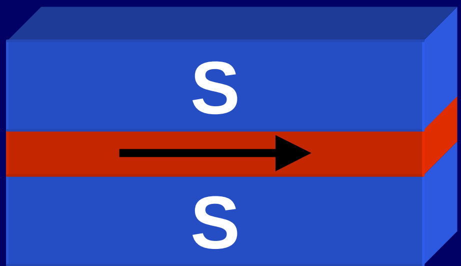
GMR heterostructures



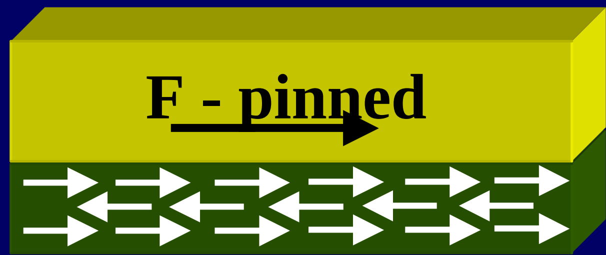
Magnetic films



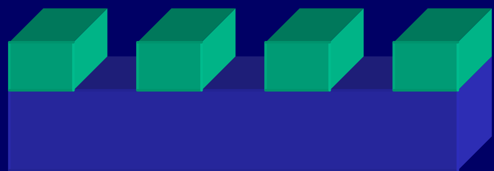
Proximity effects and tunneling



Exchange bias



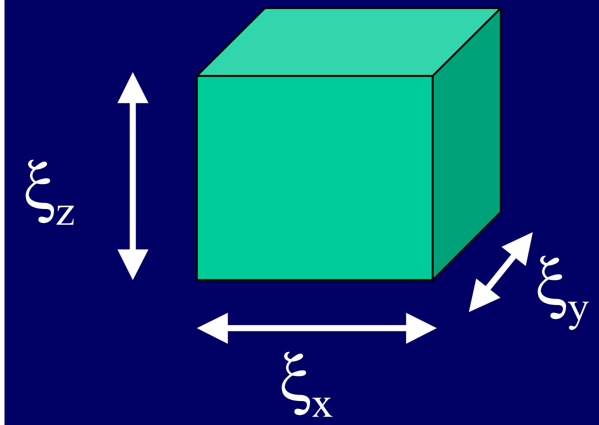
Lateral structures

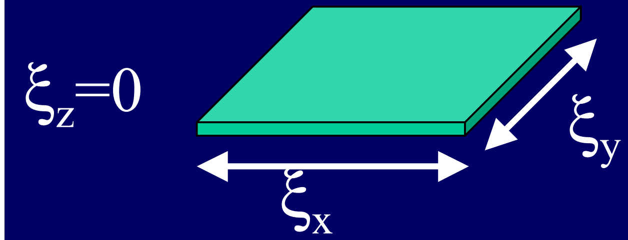


Topics:

- Dimensional scaling of Ho/Y
- Exchange bias of Co/CoO
- Enhancement of interface sensitivity

Scaling behavior
of the critical temperature with thickness:



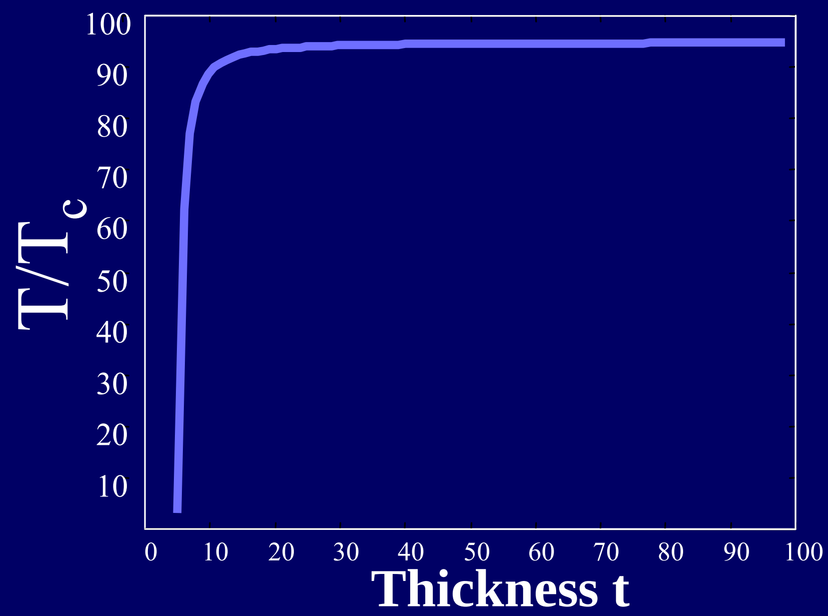


Connection between correlation length and suszeptibility:

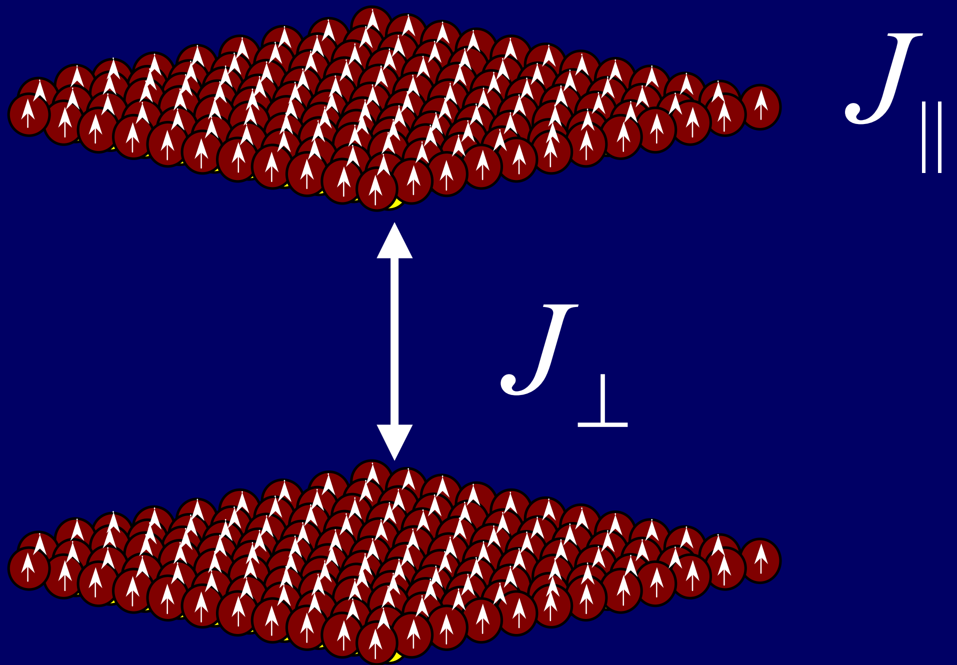
$$\chi_q = \frac{\chi(\pm)}{1+q^2\xi_\pm^2}, \qquad \xi = \xi_0 \left|\varepsilon\right|^{-\nu}, \varepsilon = \frac{T-T_C}{T_C}$$

$$\frac{T_C(\infty)-T_C(t)}{T_C(\infty)} = b \cdot \left(\frac{t}{t_0}\right)^{-\lambda}$$

$\lambda = 1/\nu$



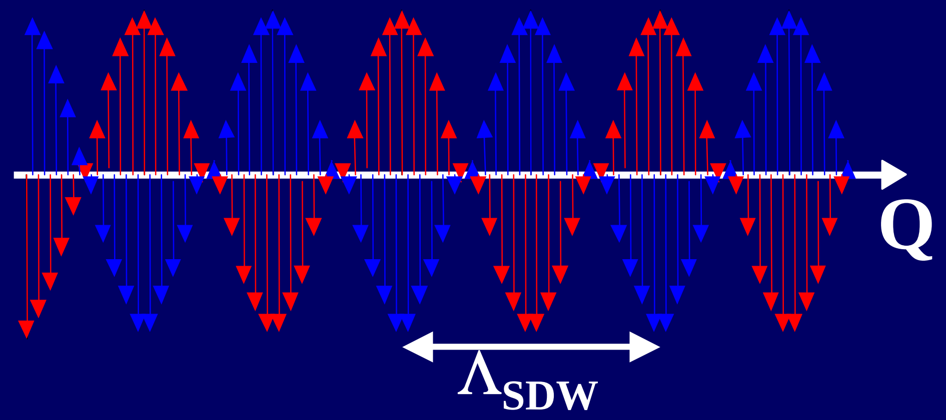
How does coupling affect the critical temperature?



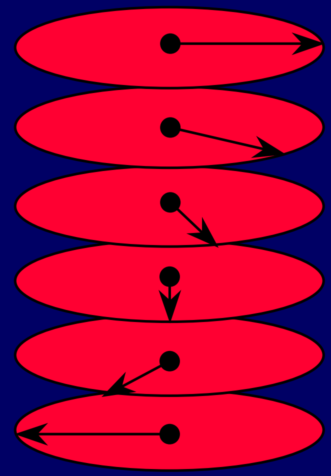
$$k_B T_c = \frac{1}{4} J$$

Scaling behavior of complex spin structures

SDW magnetism in Cr



Spin helix in Ho

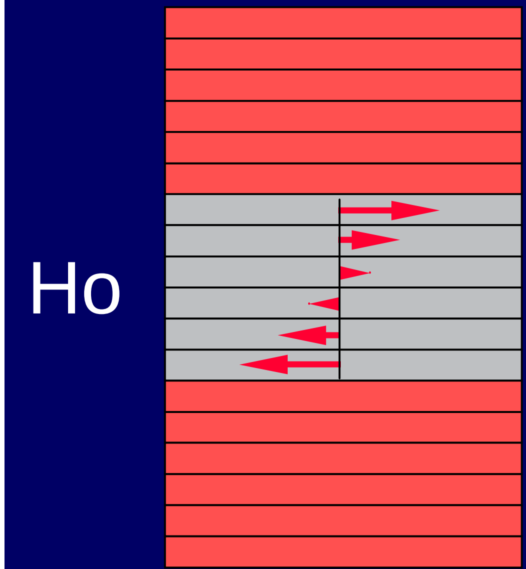


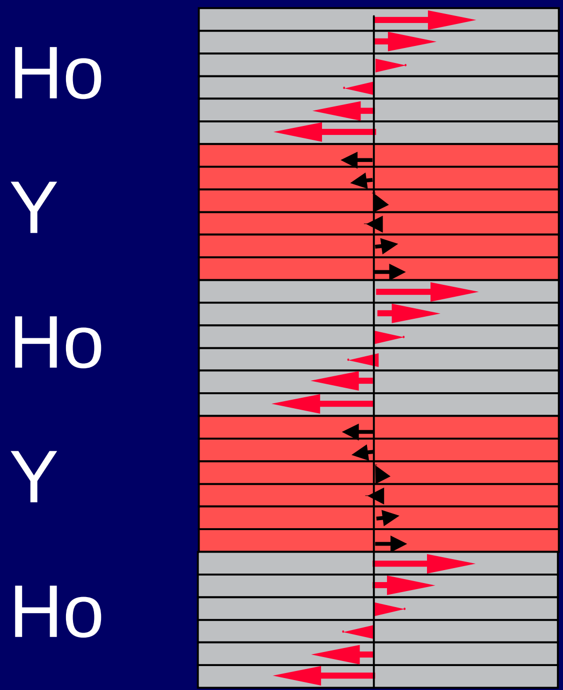
How does the Ho spin structure and the Néel temperature depend on interlayer coupling?

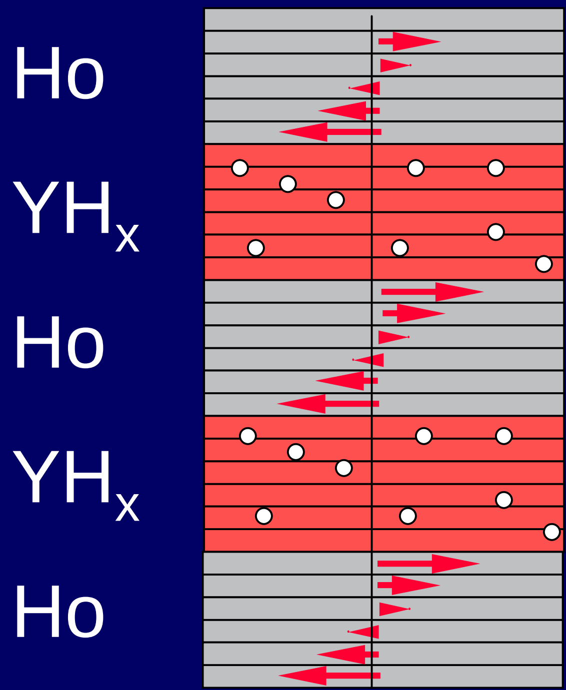
Single film

Coupled superlattice

Breaking the coupling with hydrogen

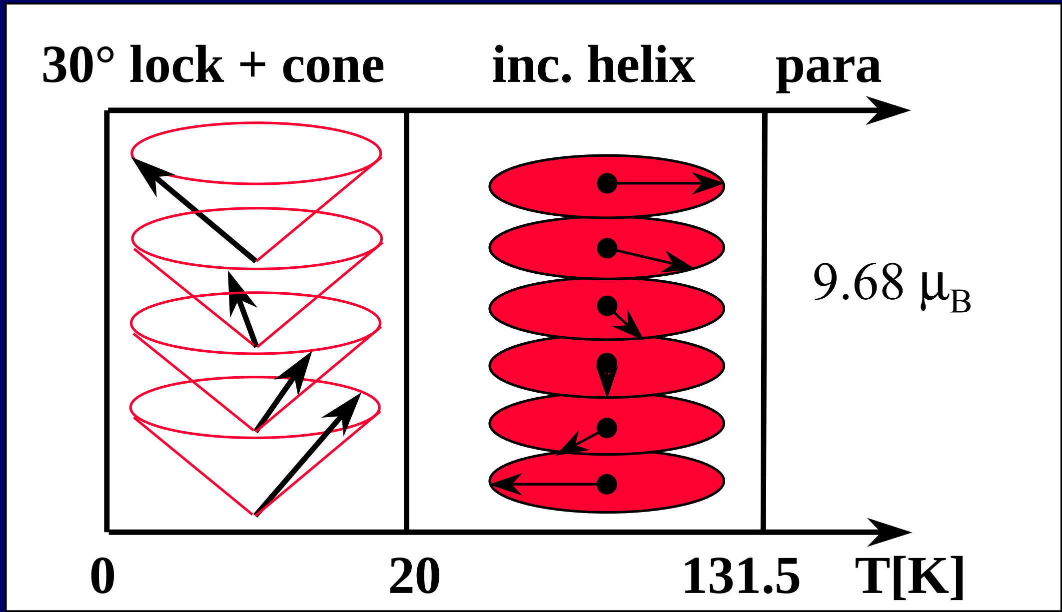






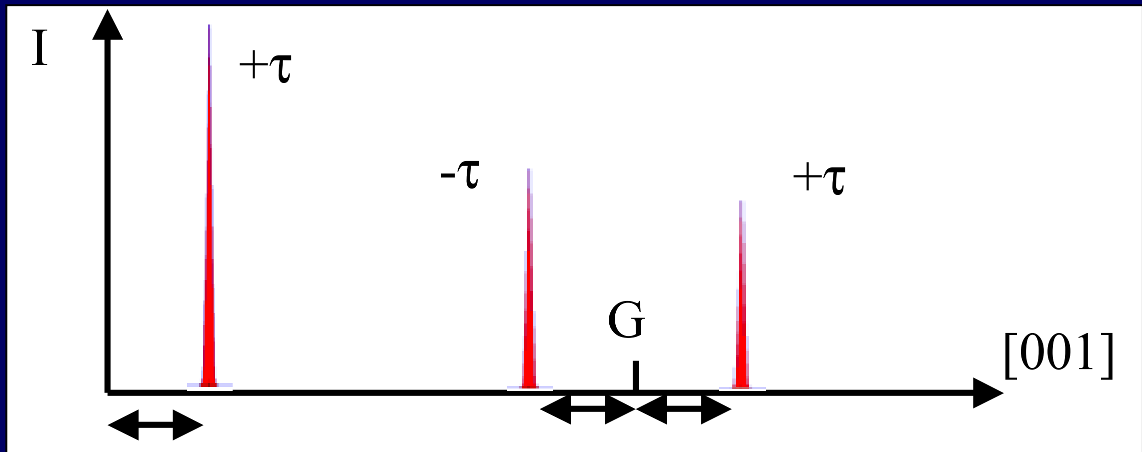
V. Leiner, D. Labergerie, H. Zabel

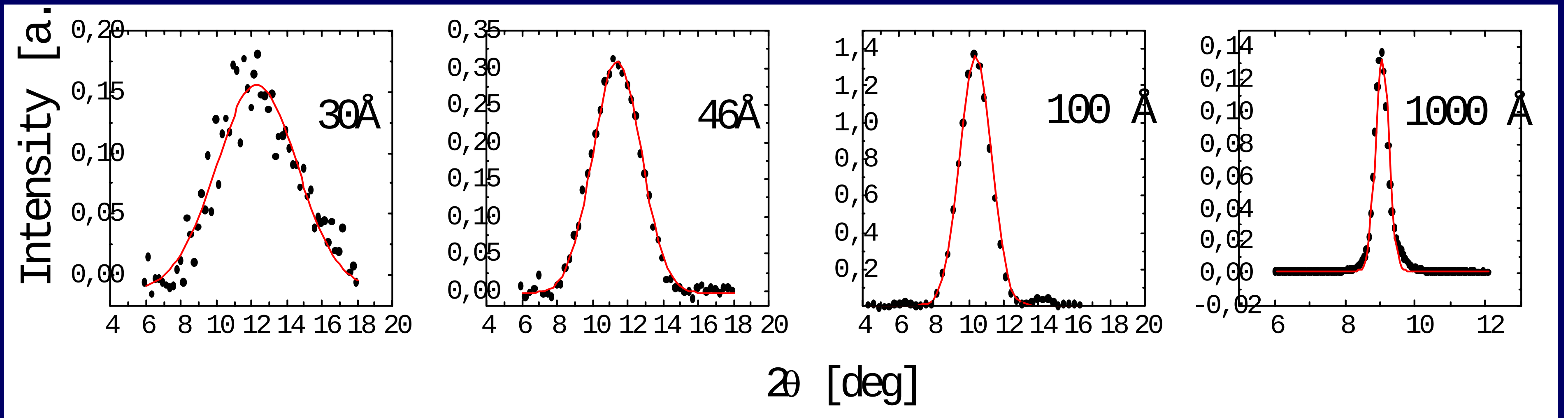
Bulk Holmium Phase Diagram



W.C. Koehler et al.
PR 151 (1966) 414
G.P. Felcher et al.
PRB 13 (1976) 3034
M.J. Pechan and C. Stassis,
JAP 55 (1984) 1900

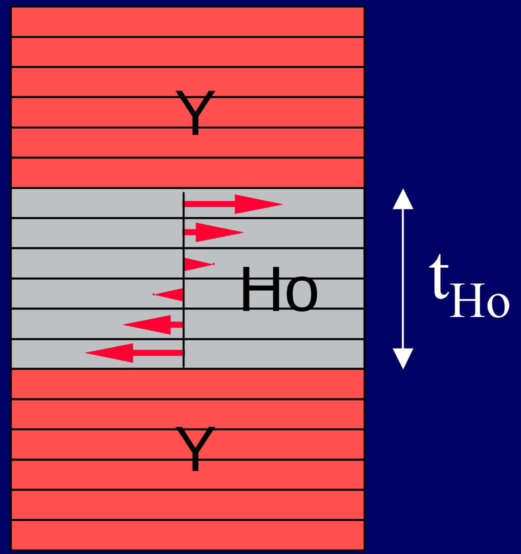
Magnetic peaks from a spin helix are expected at: $\vec{K} = \vec{G} \pm \vec{\tau}$



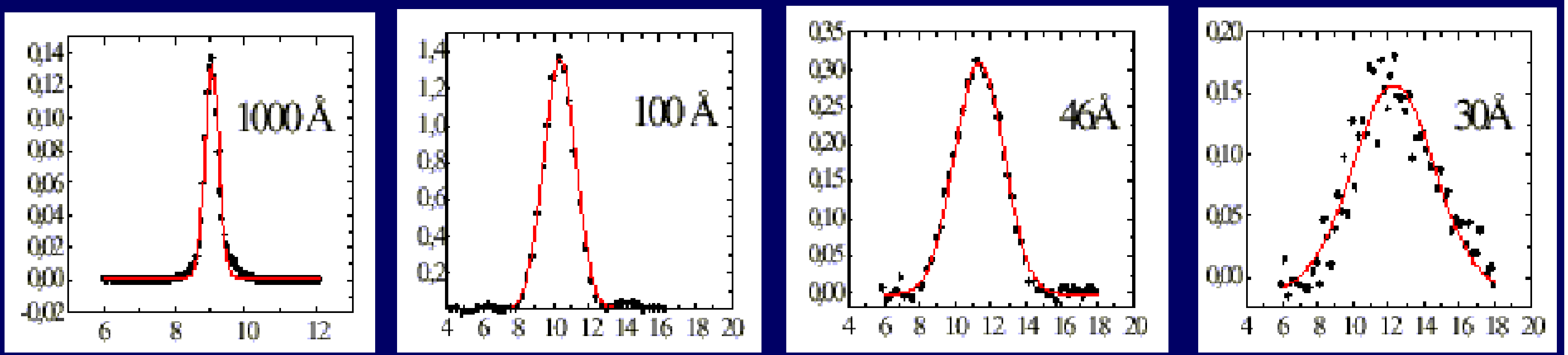


Intensity [a.
0,20
0,15
0,10
0,05
0,00
30Å
4 6 8 10 12 14 16 18 20
0,35
0,30
0,25
0,20
0,15
0,10
0,05
0,00
46Å
4 6 8 10 12 14 16 18 20
1,4
1,2
1,0
0,8
0,6
0,4
0,2
100 Å
4 6 8 10 12 14 16 18 20
0,14
0,12
0,10
0,08
0,06
0,04
0,02
0,00
-0,02
1000 Å
6 8 10 12
2θ [deg]

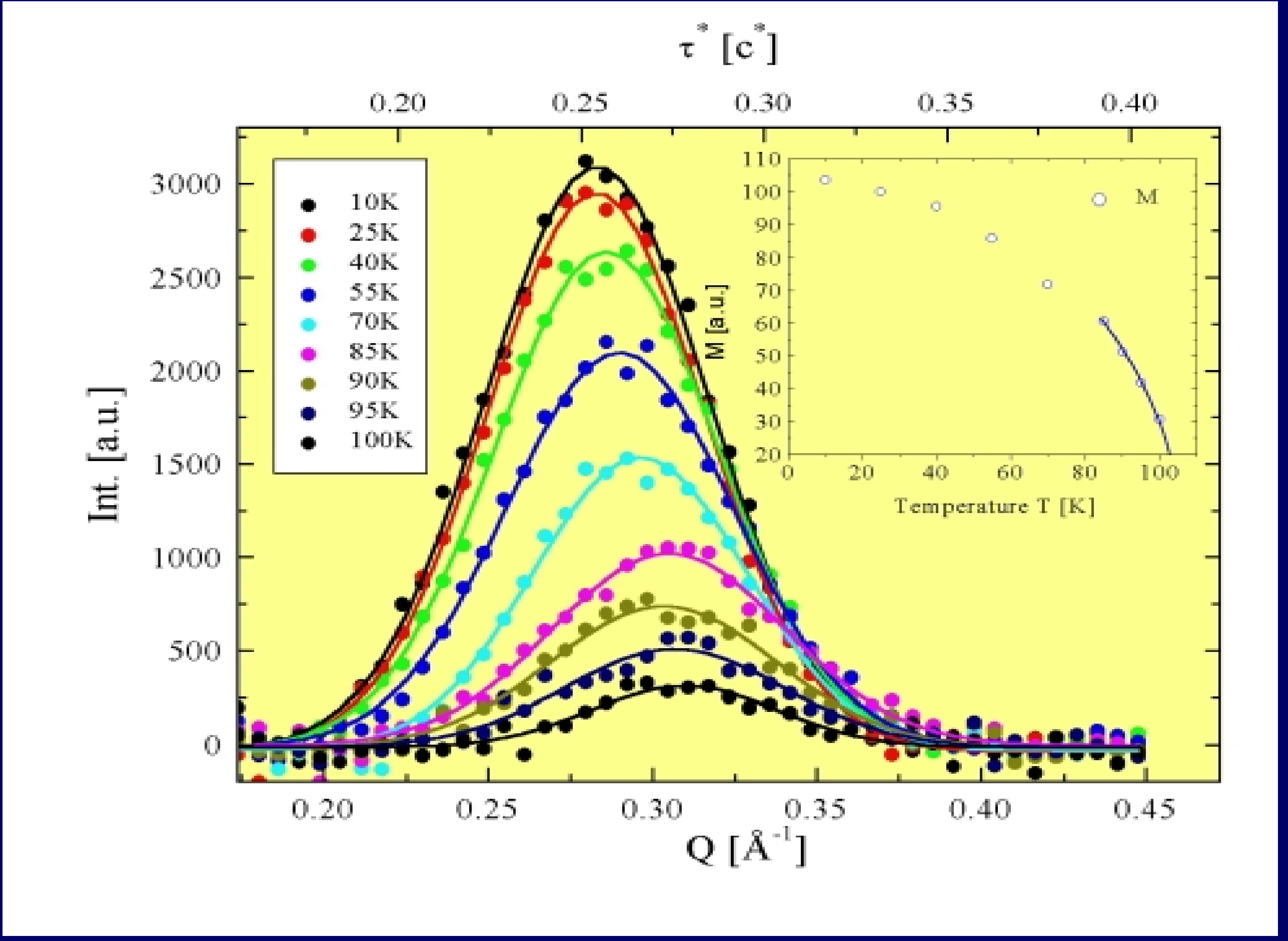
Magnetic signal from single Ho films



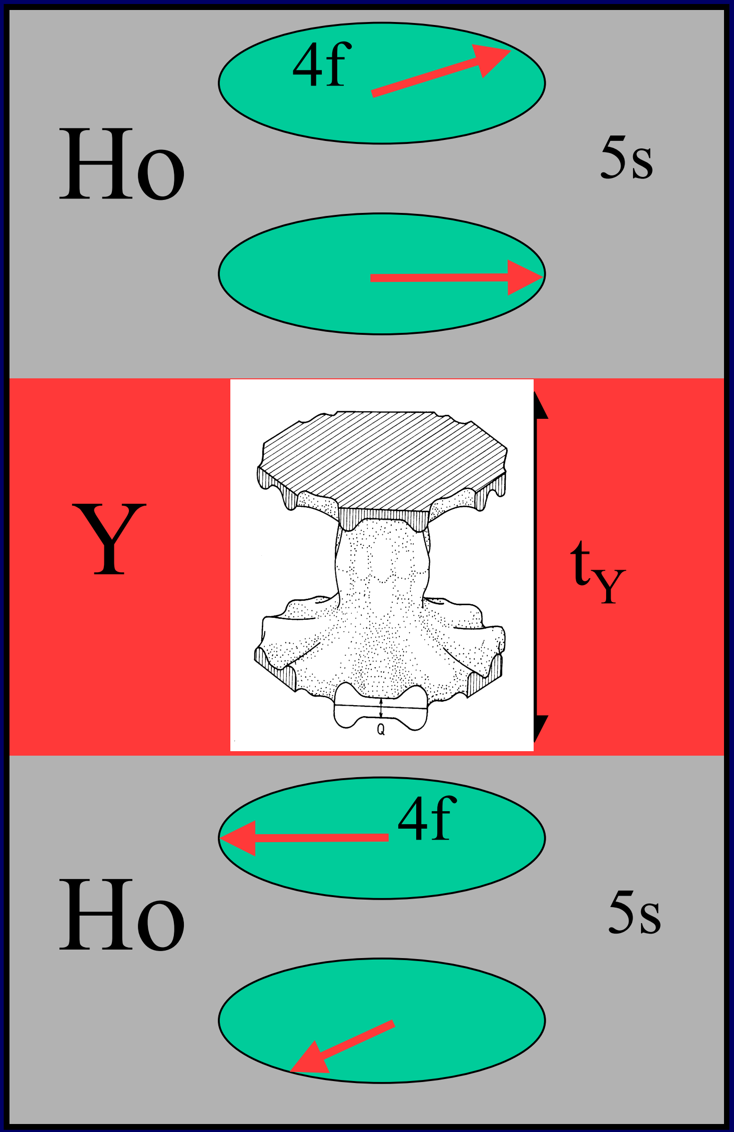
(00.τ) as a function of the Ho thickness t_{HO}



Order parameter for a single 4.6 nm thick Ho-film



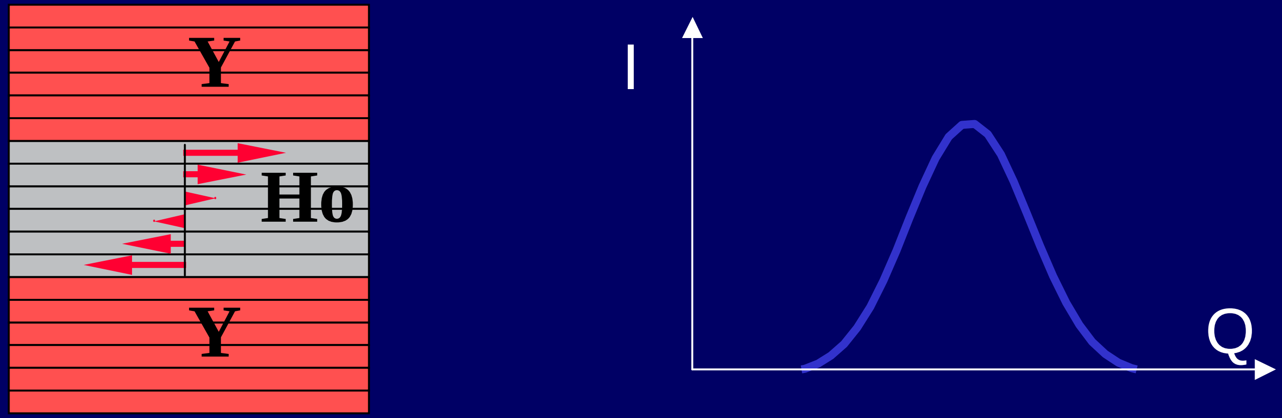
RKKY-type Interactions in Ho/Y Superlattices



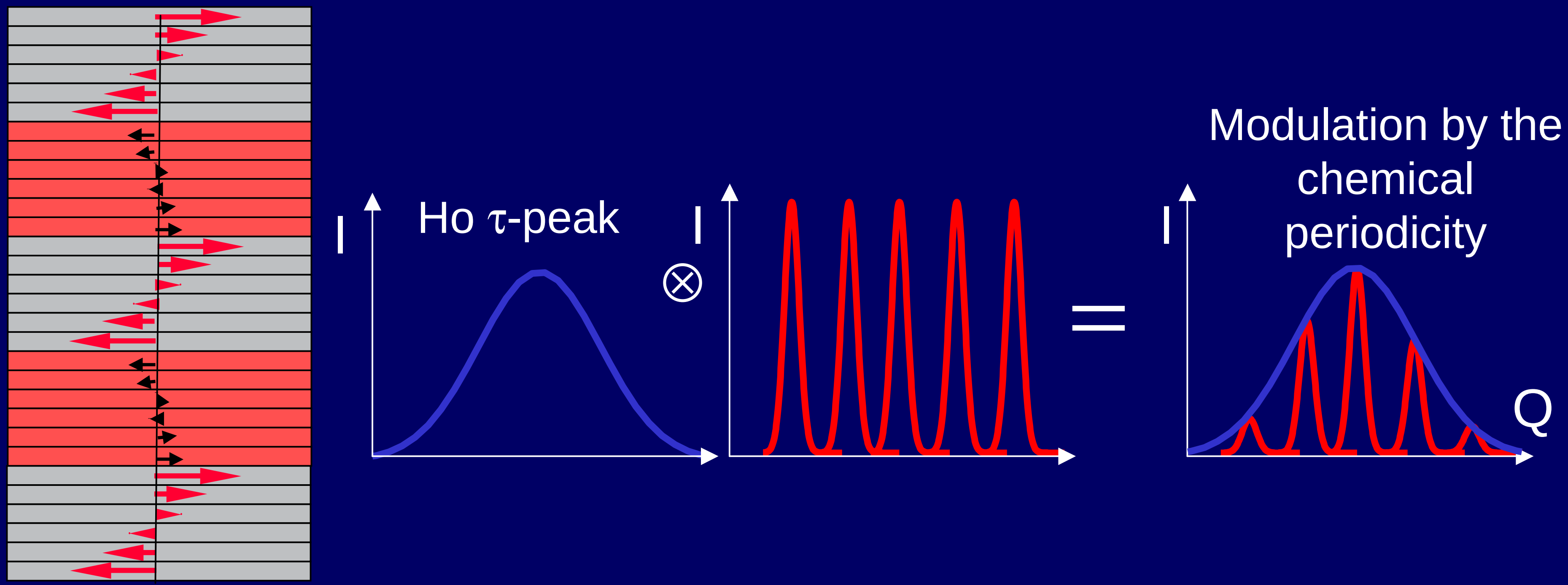
RKKY coupling between localised Ho 4f - moments

RKKY-type interlayer coupling mediated by Y conduction electrons

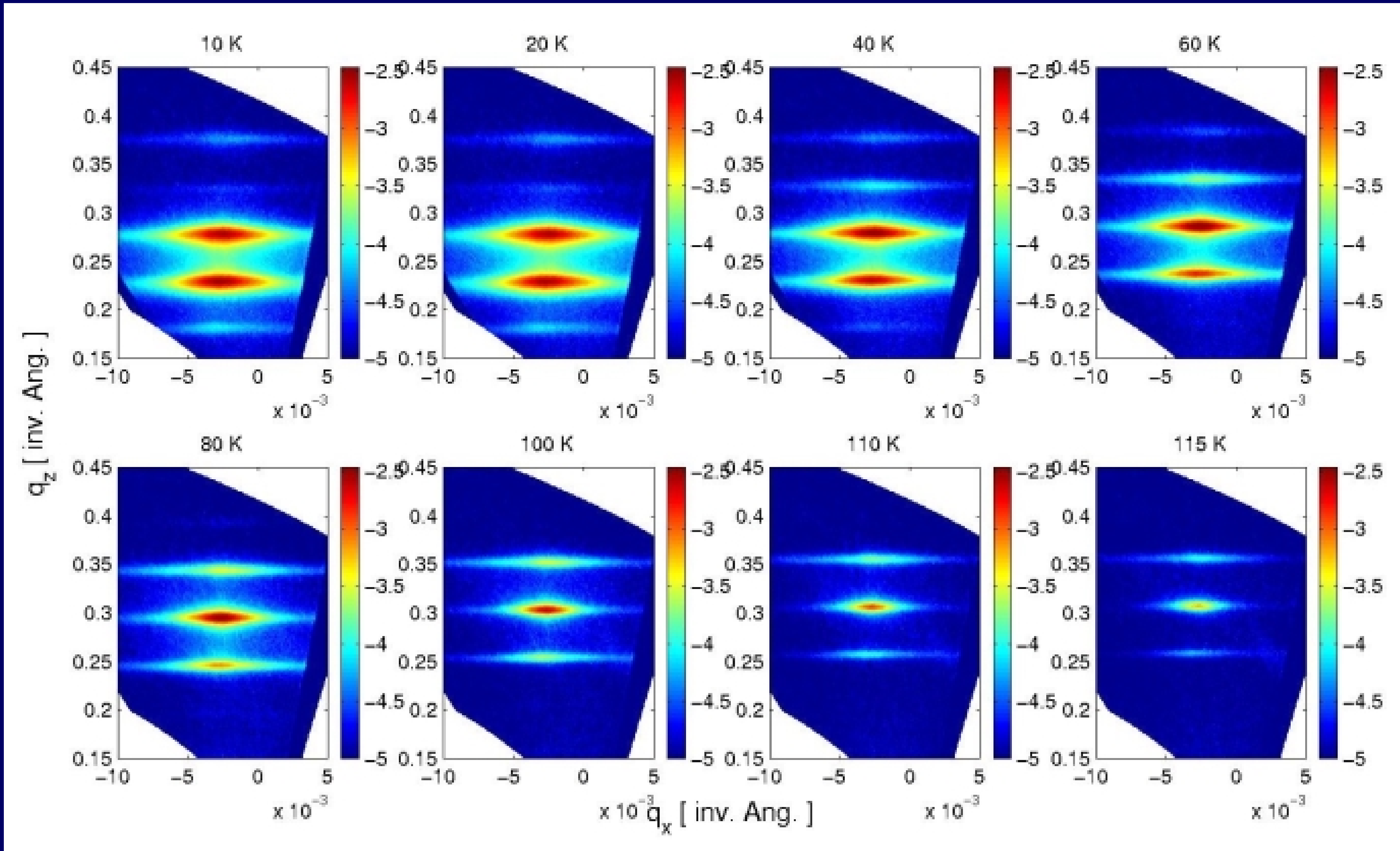
Magnetic τ-peak for a single thin Ho film:



Magnetic τ-peak for a coupled Ho/Y superlattice:

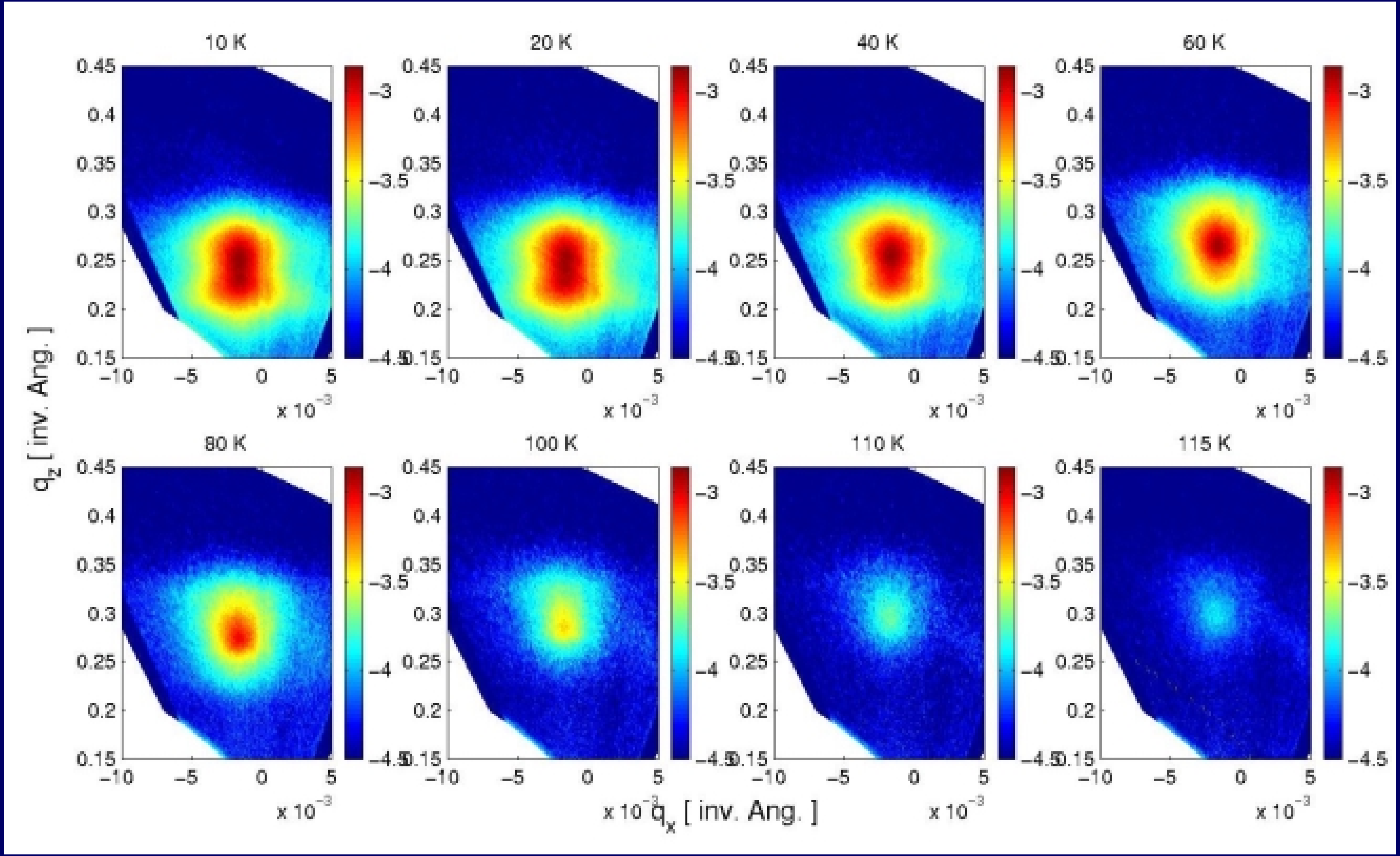


Magnetic Signal from 30 x [77Å Ho/52Å Y]

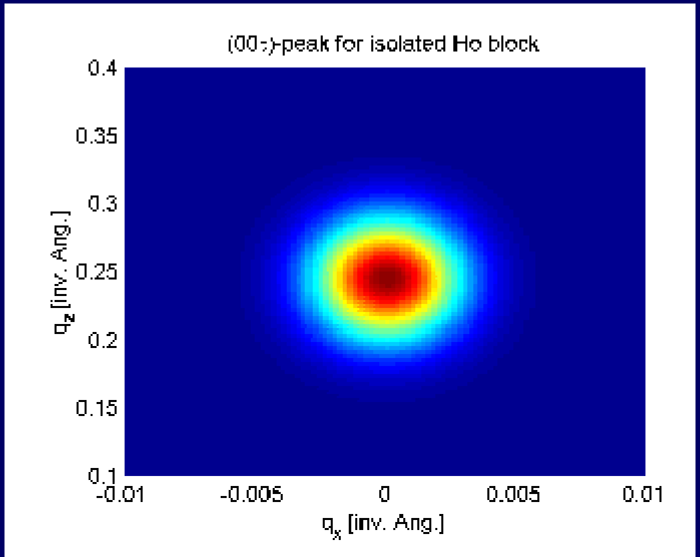


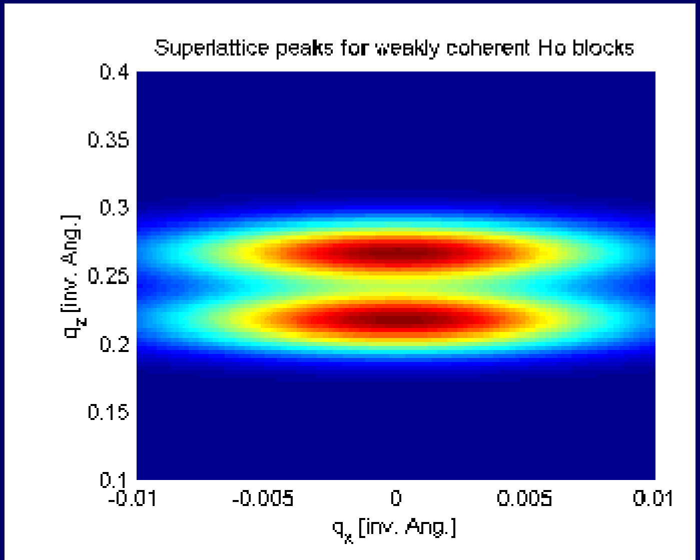
V. Leiner, D. Labergerie, M. Ay, H. Zabel, 2001

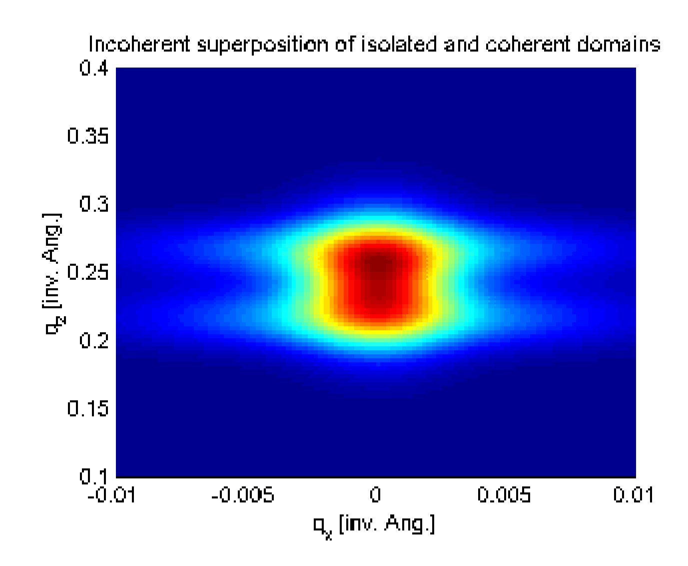
Temperature dependence of the Ho/Y(00.0+τ) peak after hydrogen loading of the Y-spacer



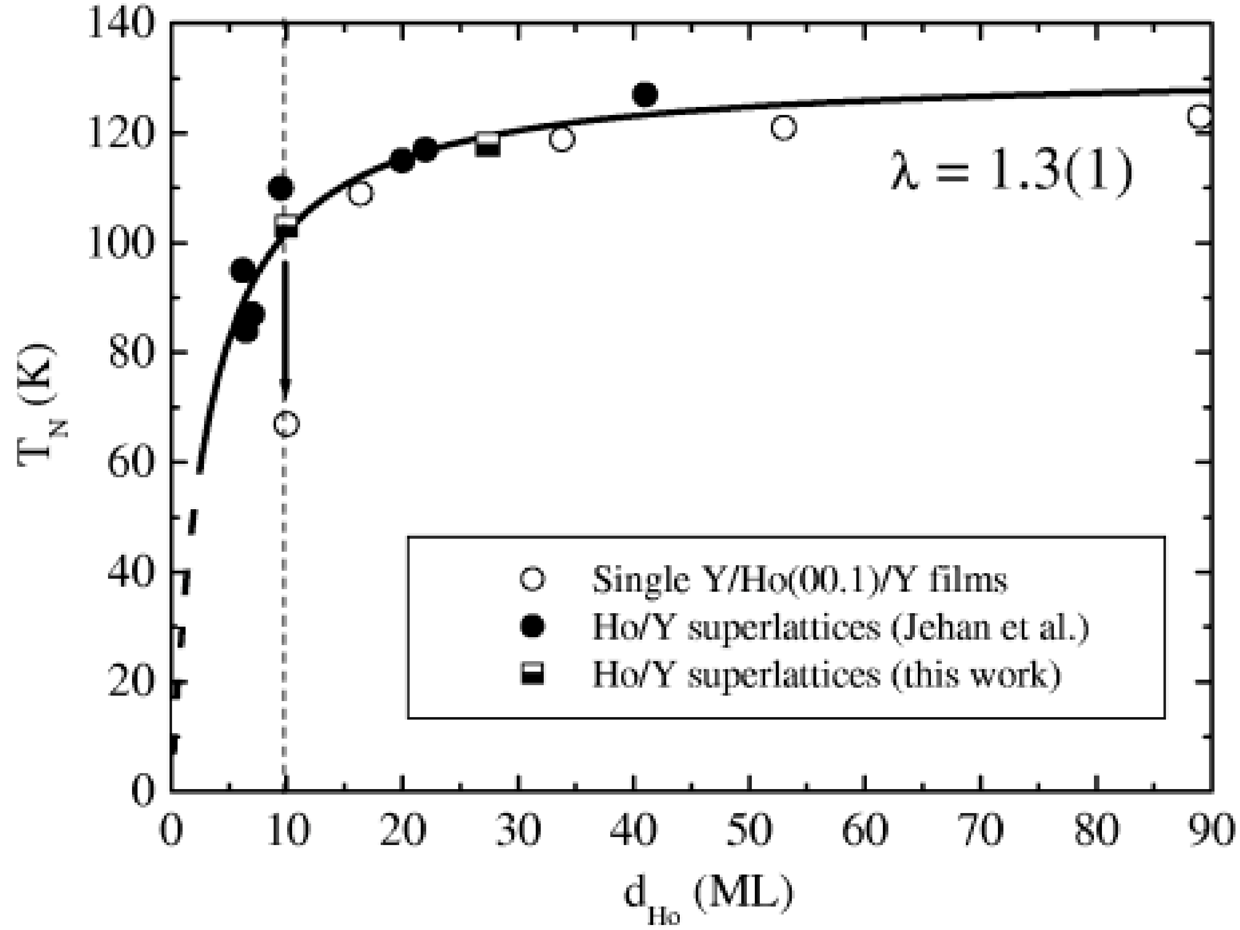
Simulation of τ-peak for uncoupled and weakly coupled Ho-blocks



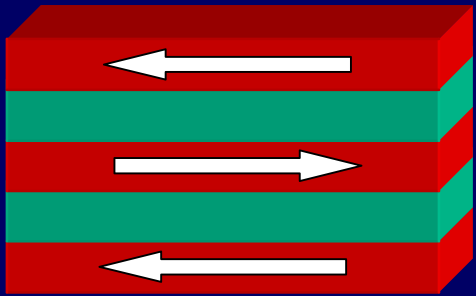


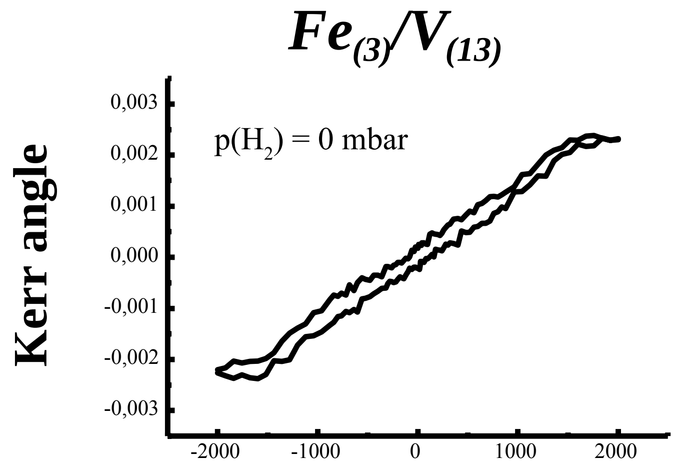


Scaling of the Néel – Temperature



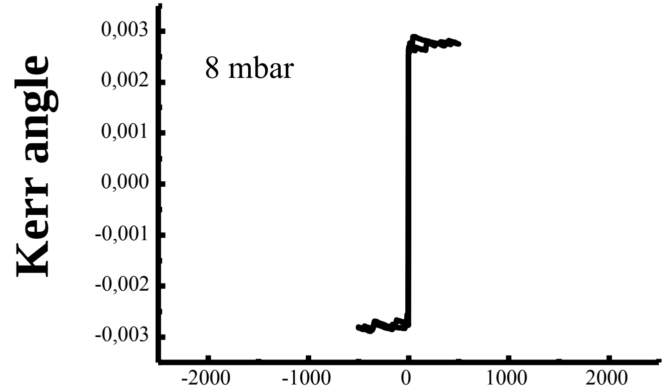
Tunability of the exchange coupling in Fe/V superlattices with hydrogen





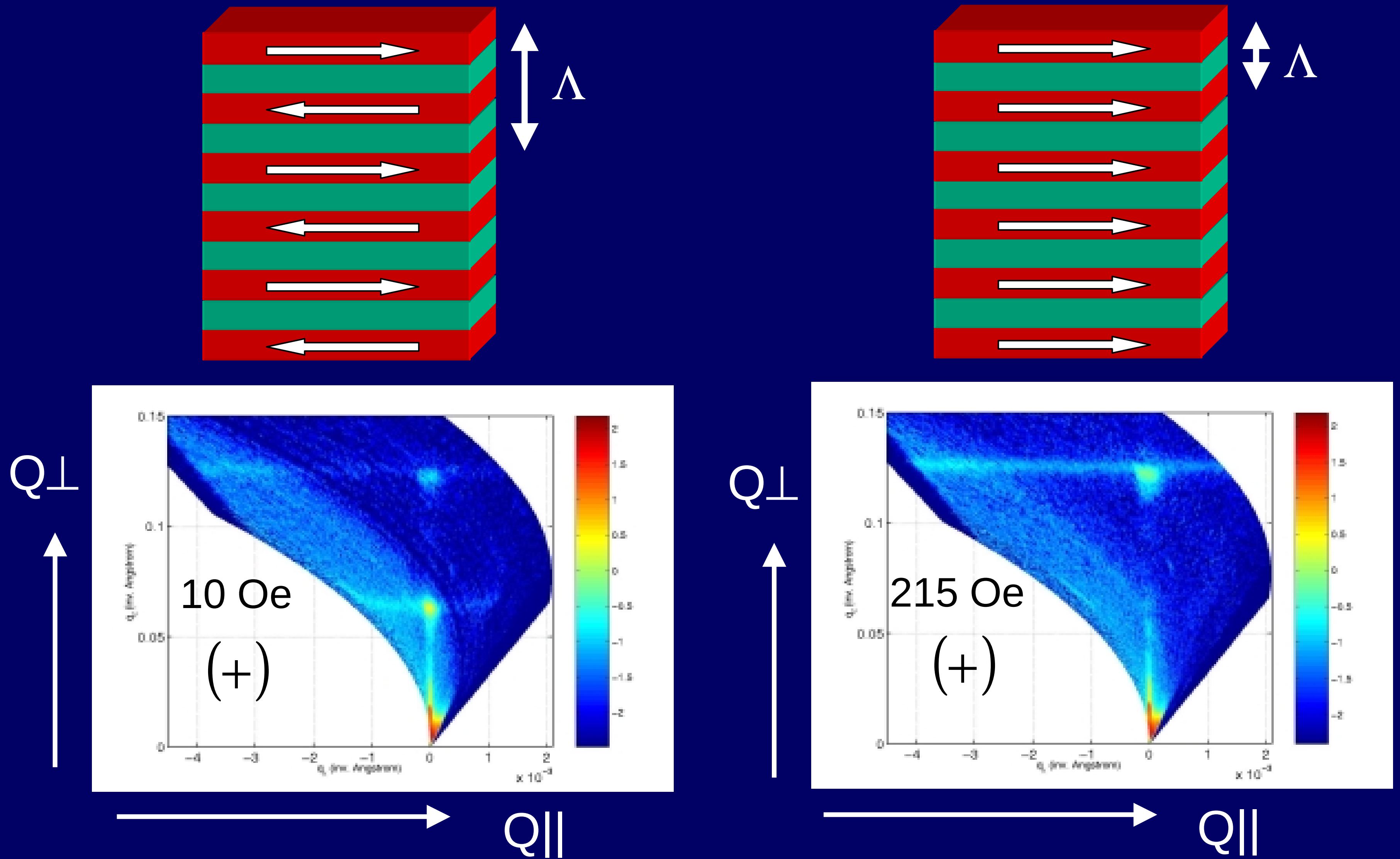
before H-loading

after H-loading < 10 mbar



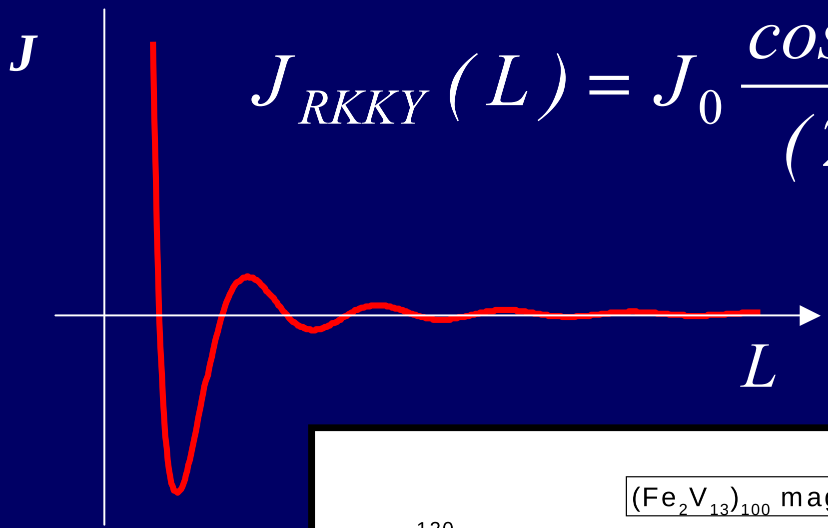
V. Leiner, K. Westerholt, B. Hjörvarsson, H. Zabel, to be published

Exchange Coupling in Fe/Cr Superlattices

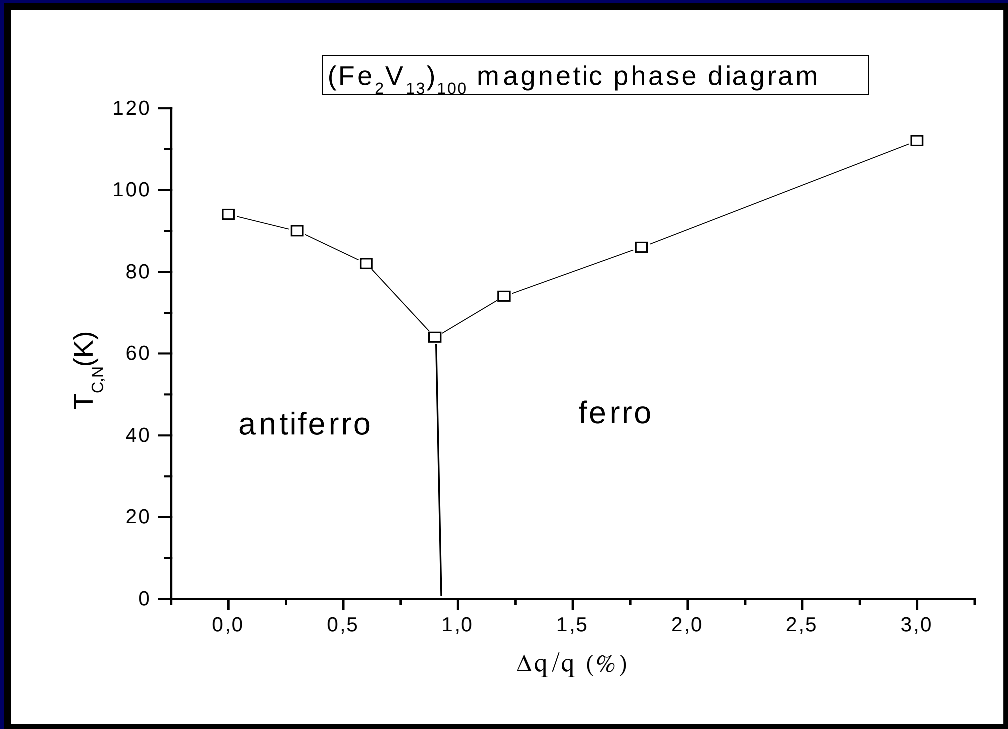


R. Siebrecht, A. Schreyer, H. Zabel, 2000

Crtical temperature as a function of interlayer exchange coupling for Fe 2 ML/VH$_x$ 12 ML



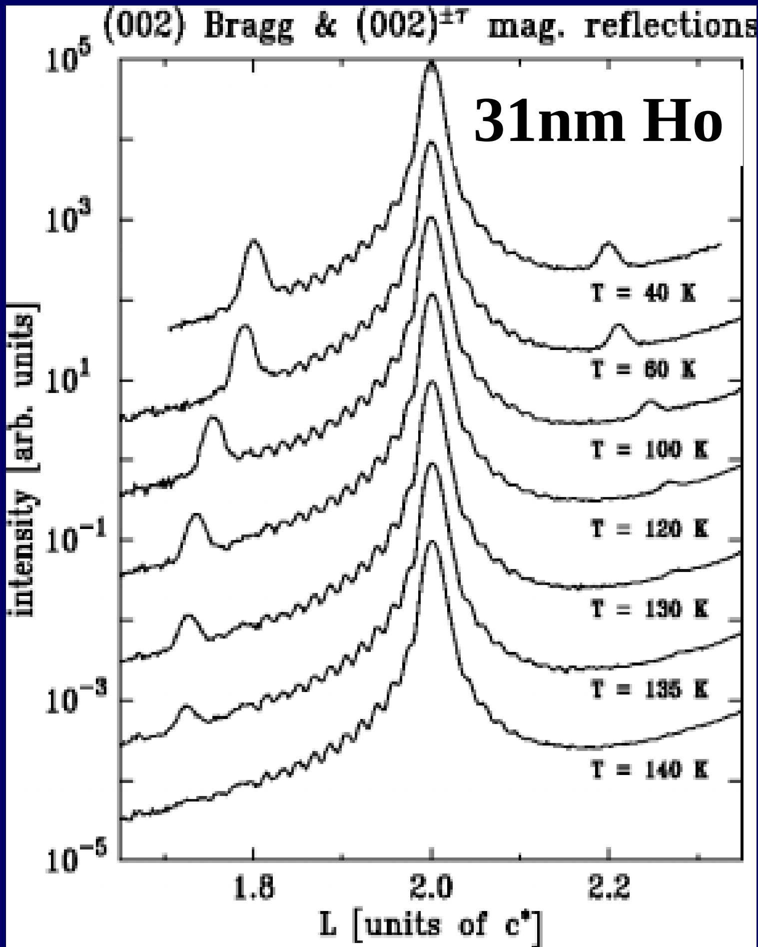
$$J_{RKKY}(L) = J_0 \frac{\cos(2k_F L)}{(2k_F L)^2} \propto \frac{1}{L^2}$$

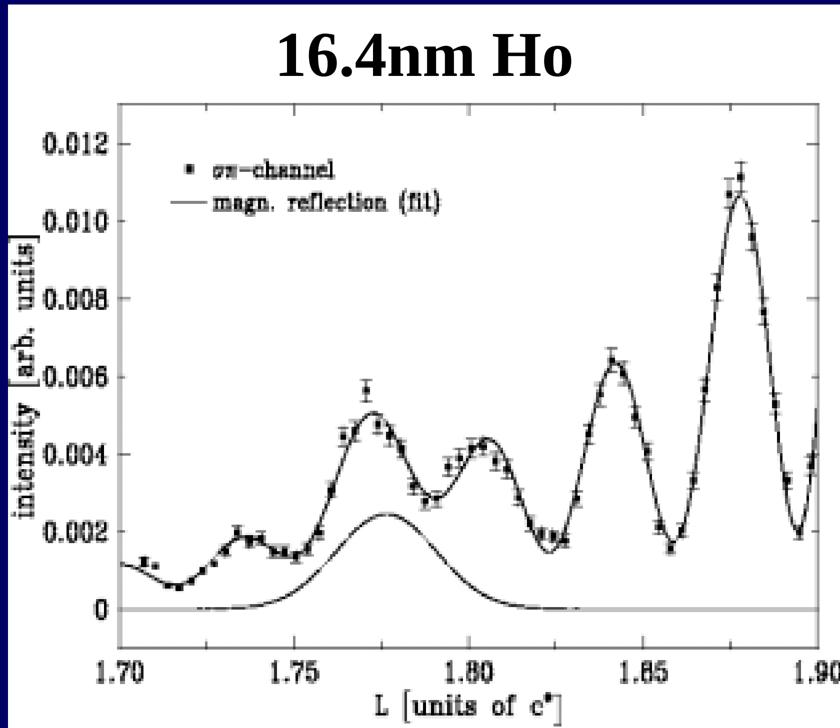


The ADAM Reflectometer at ILL

http://www.ill.fr/YellowBook/ADAM/

Magnetic resonance x-ray scattering of Ho at the L_{III} - absorption edge (8074 eV), sp-channel Troika beam line, ESRF

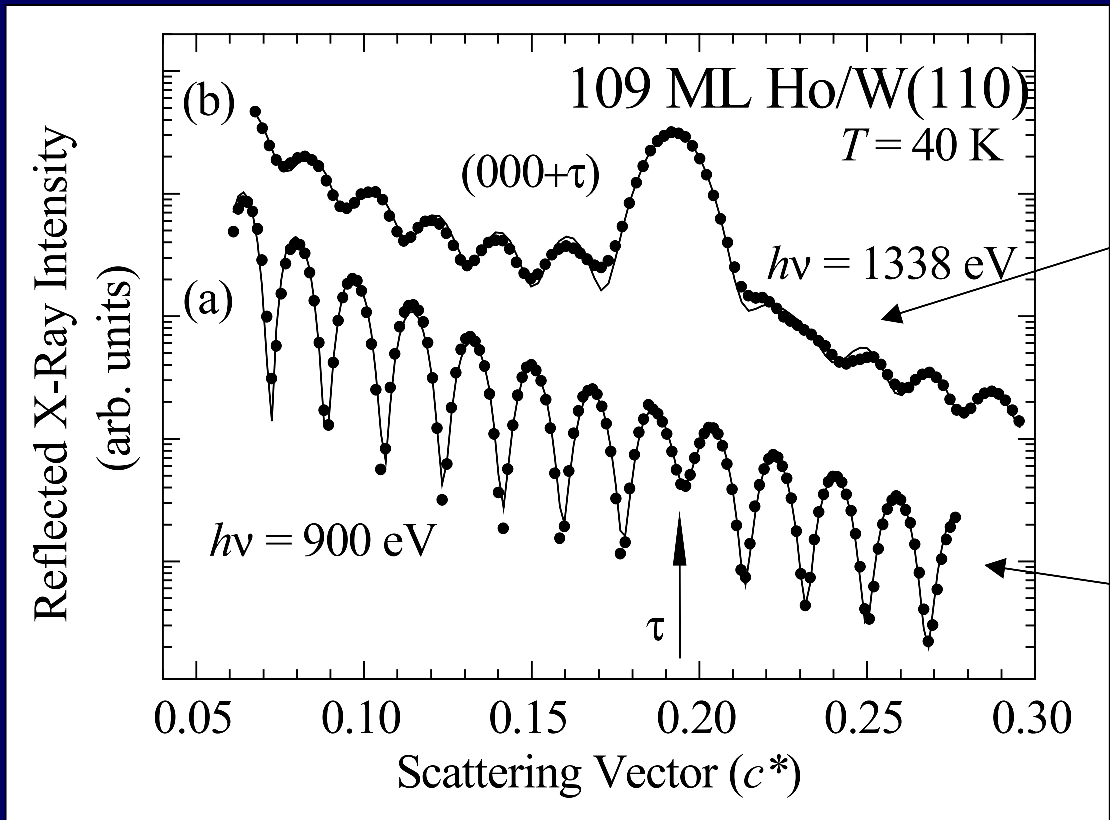




C. Sutter, E. Weschke, R. Meier, C. Schüßler-Langeheine, G. Grübel, D. Abernathy

Resonant enhancement of the magnetic superstructure satellite at the Ho M_V edge

Reflectivity of a 109-ML-thick Ho film (a) well below and (b) in the vicinity of the Ho M_V edge

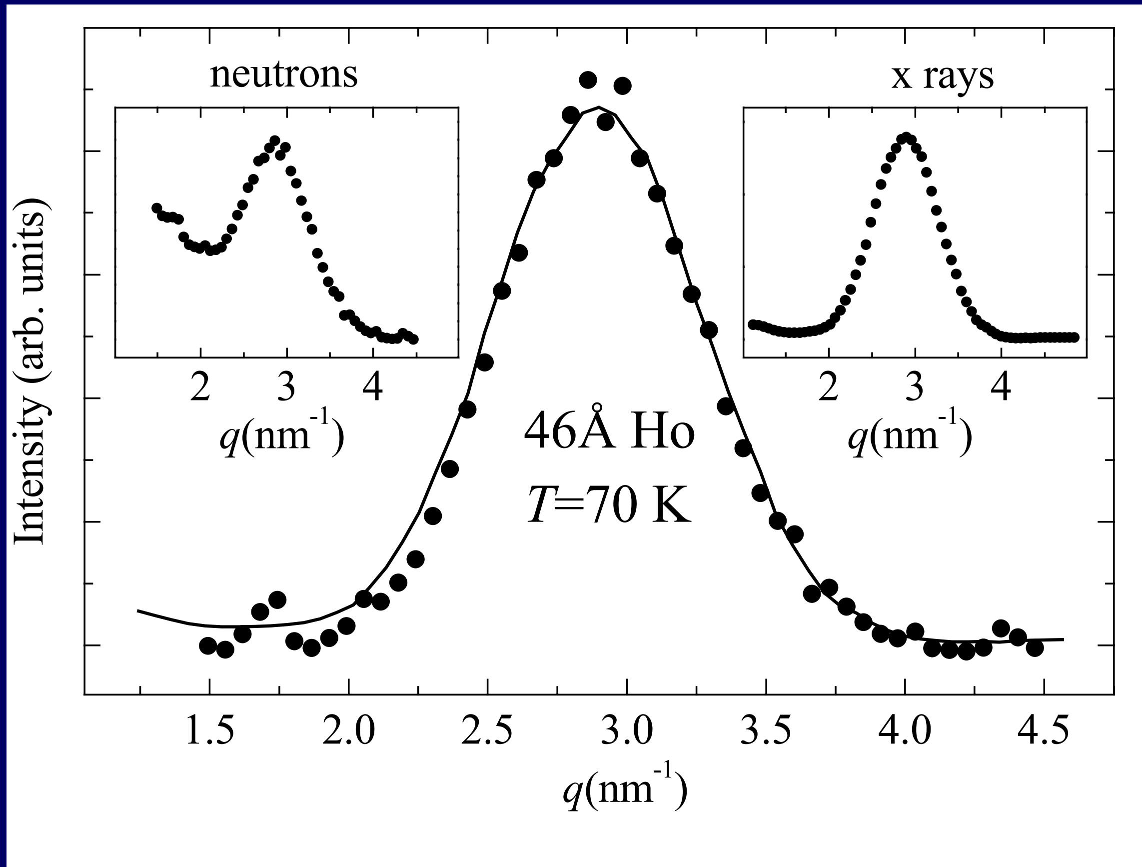


at resonance

below resonance

Resonant enhancement of the magnetic superstructure satellite at the Ho M_V edge, BESSY

(00.0 +τ) peak of a single 4.6 nm thick Ho(00.1) film

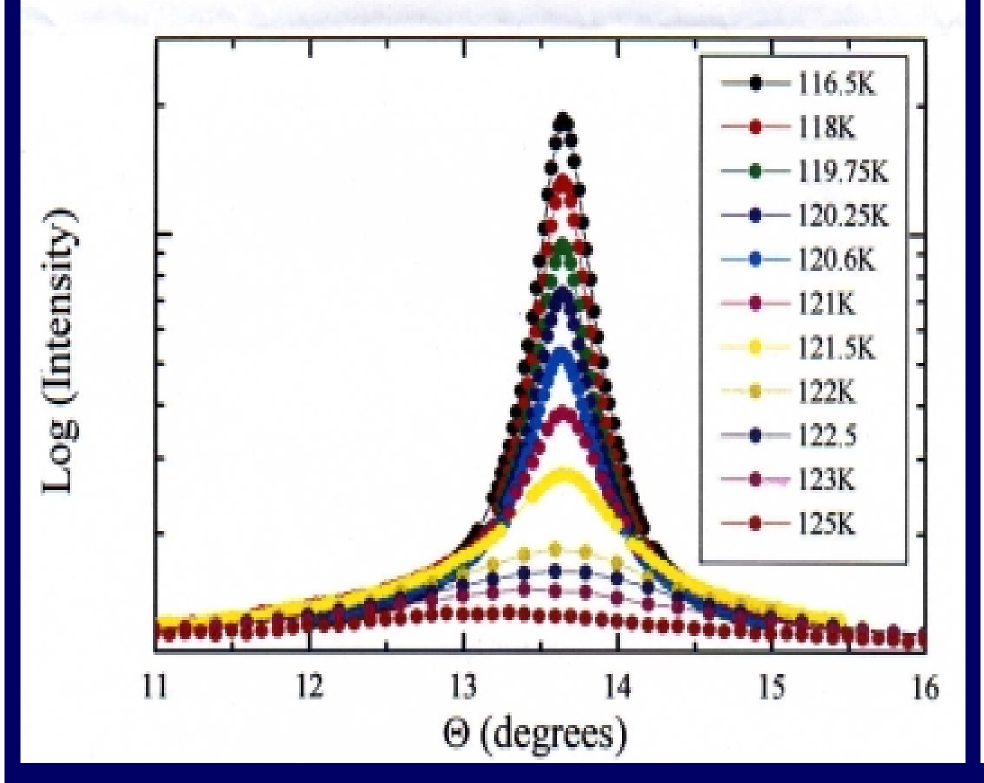


E. Weschke, C. Schüßler-Langeheine, A. Yu. Grigoriev, H. Ott, G. Kaindl, V. Leiner and H. Zabel, to be published

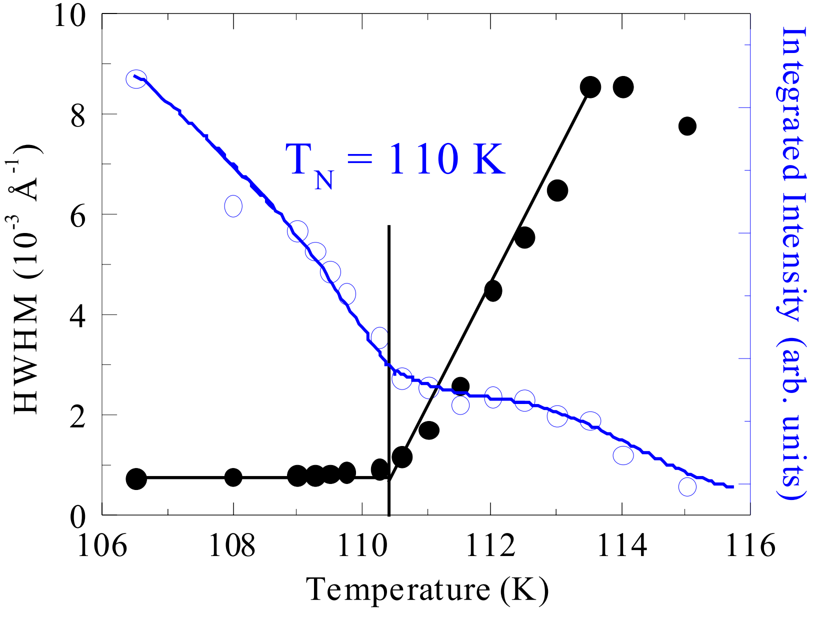
Critical scattering from a 4.6 nm thick Ho film

XRMD results, BESSY

Short range order diffuse scattering

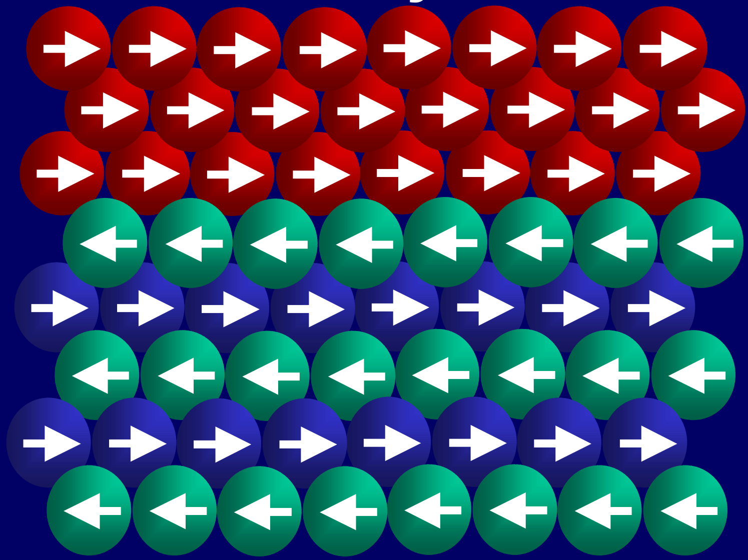


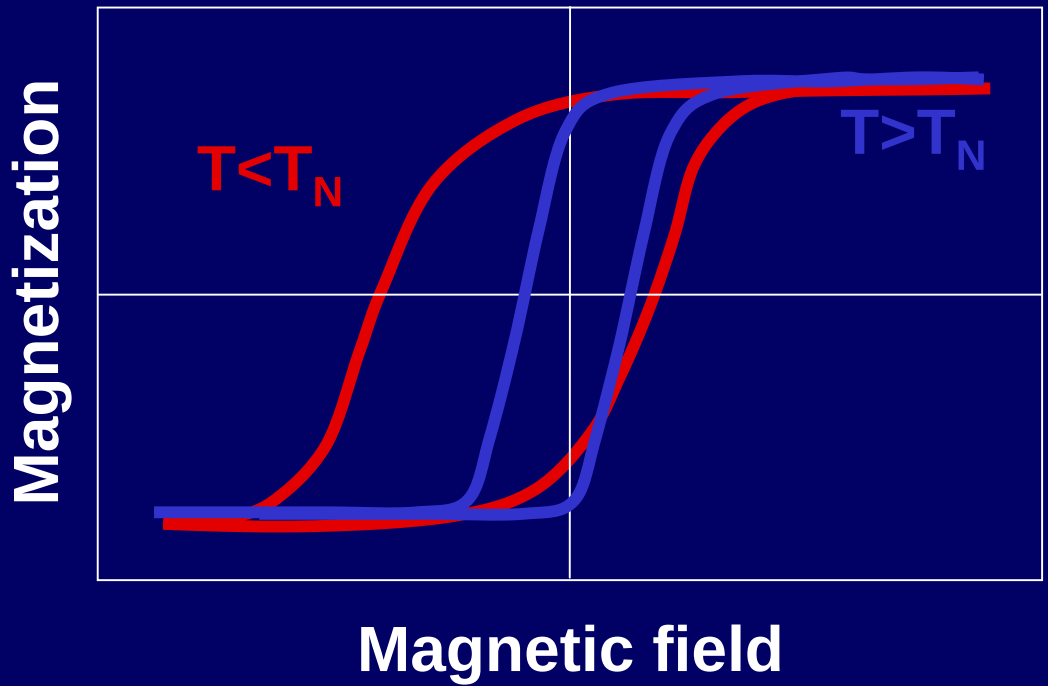
Order parameter and inverse correlation length



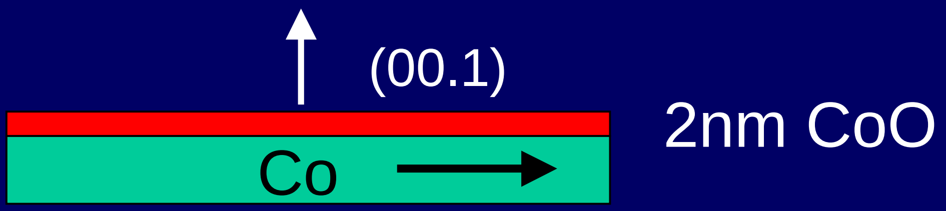
E. Weschke, C. Schüßler-Langeheine, A. Yu. Grigoriev, H. Ott, G. Kaindl, V. Leiner and H. Zabel, to be published

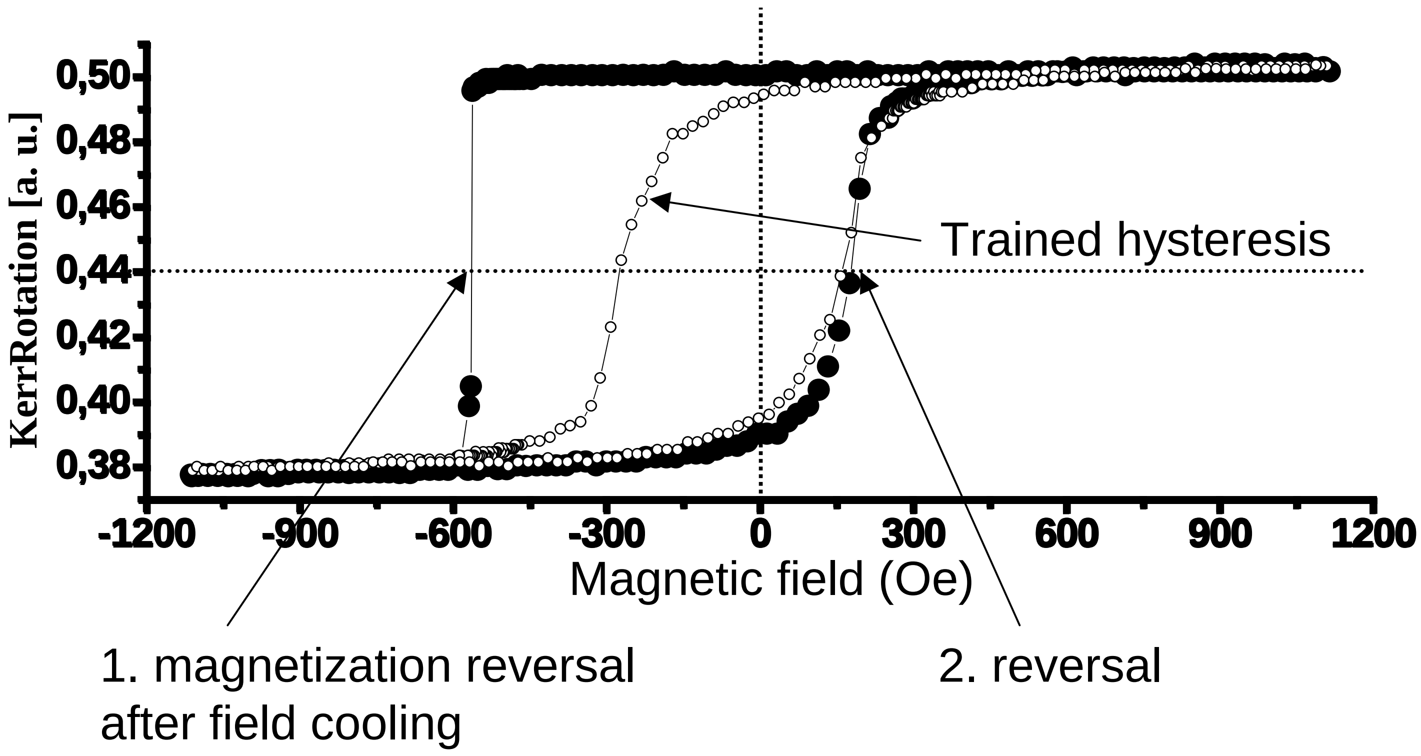
Exchange bias





MOKE measurements of a CoO/Co bilayer

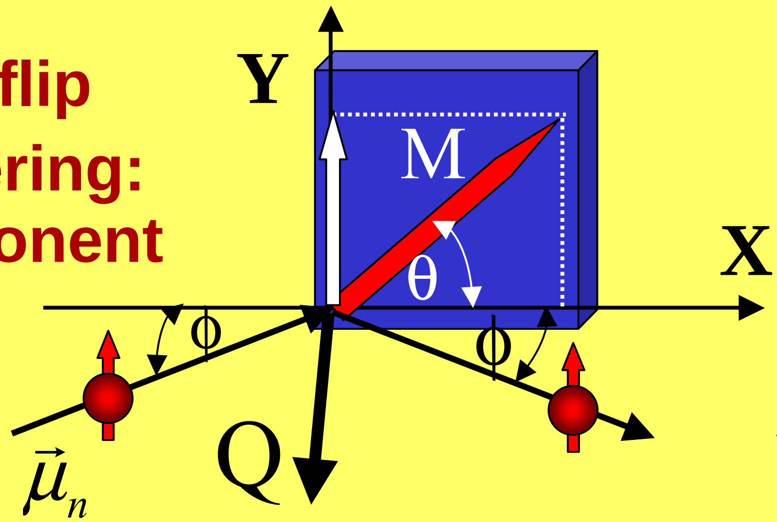


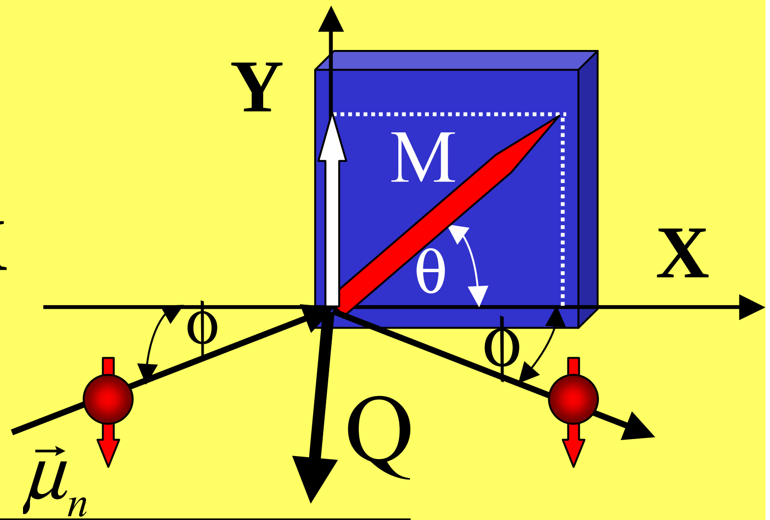


F. Radu, M. Etzkorn, T. Schmitte, R. Siebrecht, V. Leiner, K. Westerholt, H. Zabel

Polarized neutron reflectivity

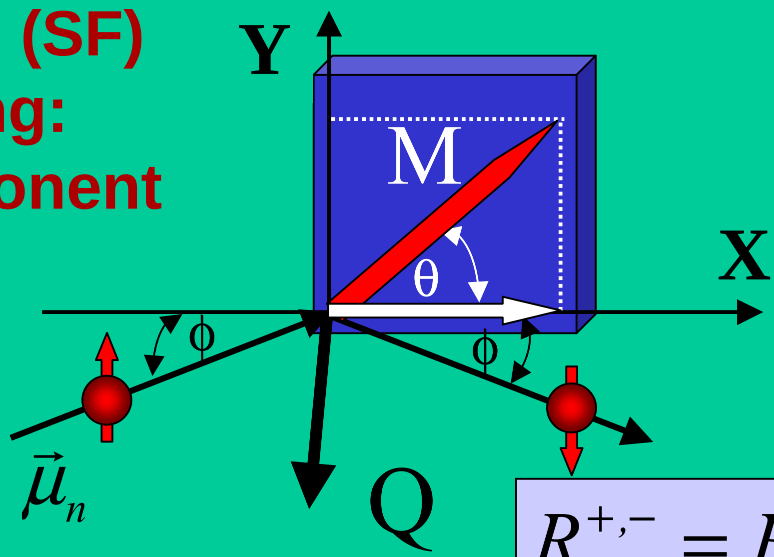
1. Non-spin flip (NSF) scattering: the Y-component



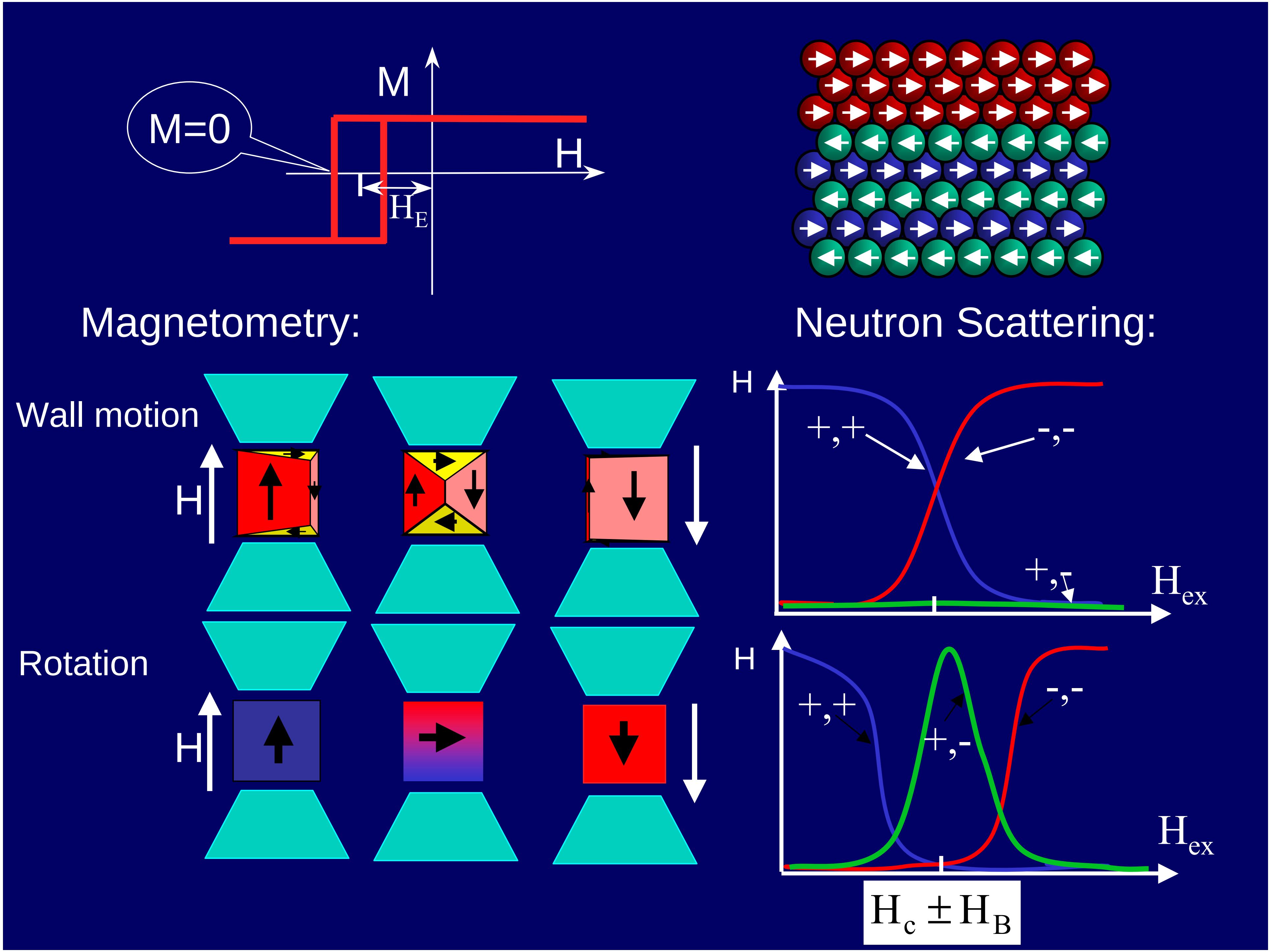


$$R^{+,+} - R^{-,-} = 2p_m \sin(\theta) \propto 2M_Y$$

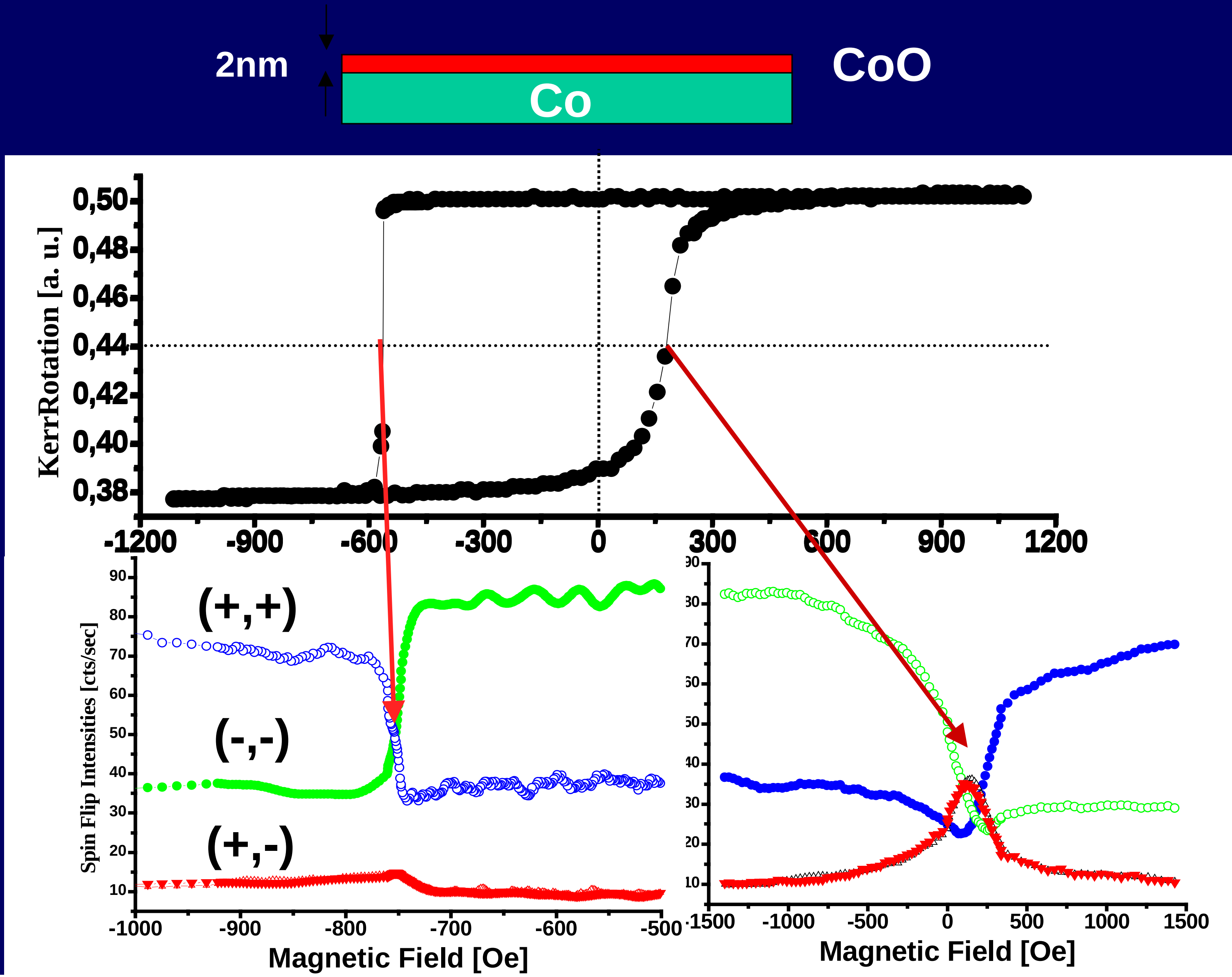
2. Spin-Flip (SF) Scattering: the X-component



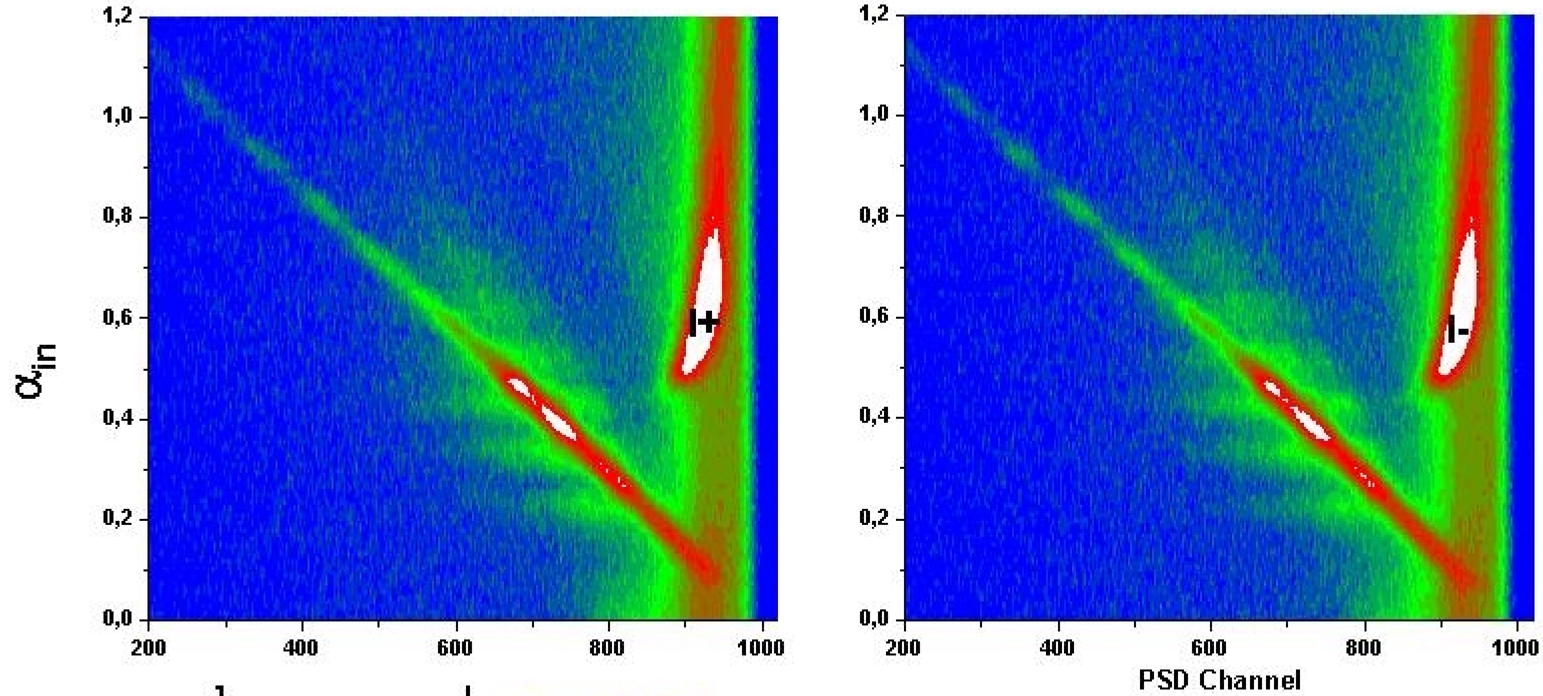
$$R^{+,-} = R^{+,-} = p_m \cos(\theta) \propto M_x$$

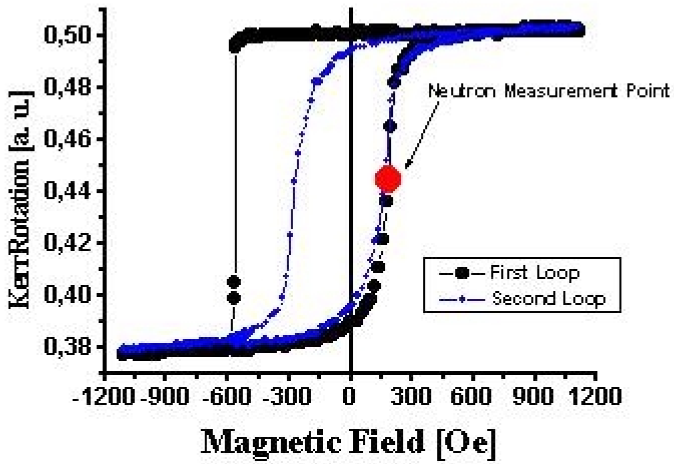

M=0
M
H
H_E
Magnetometry:
Neutron Scattering:
Wall motion
Rotation
H
H
H
+,+
-,-
+,-
H_{ex}
H
+,+
-,-
+,-
H_{ex}
$H_c \pm H_B$

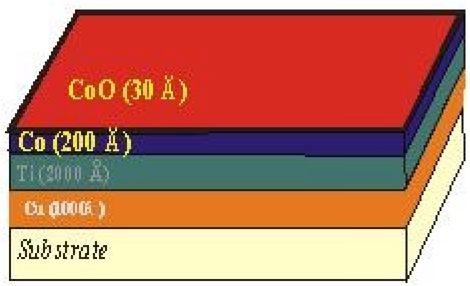
PNR results from a CoO/Co bilayer



Off-specular scattering from magnetic domains in Co/CoO exchange bias system

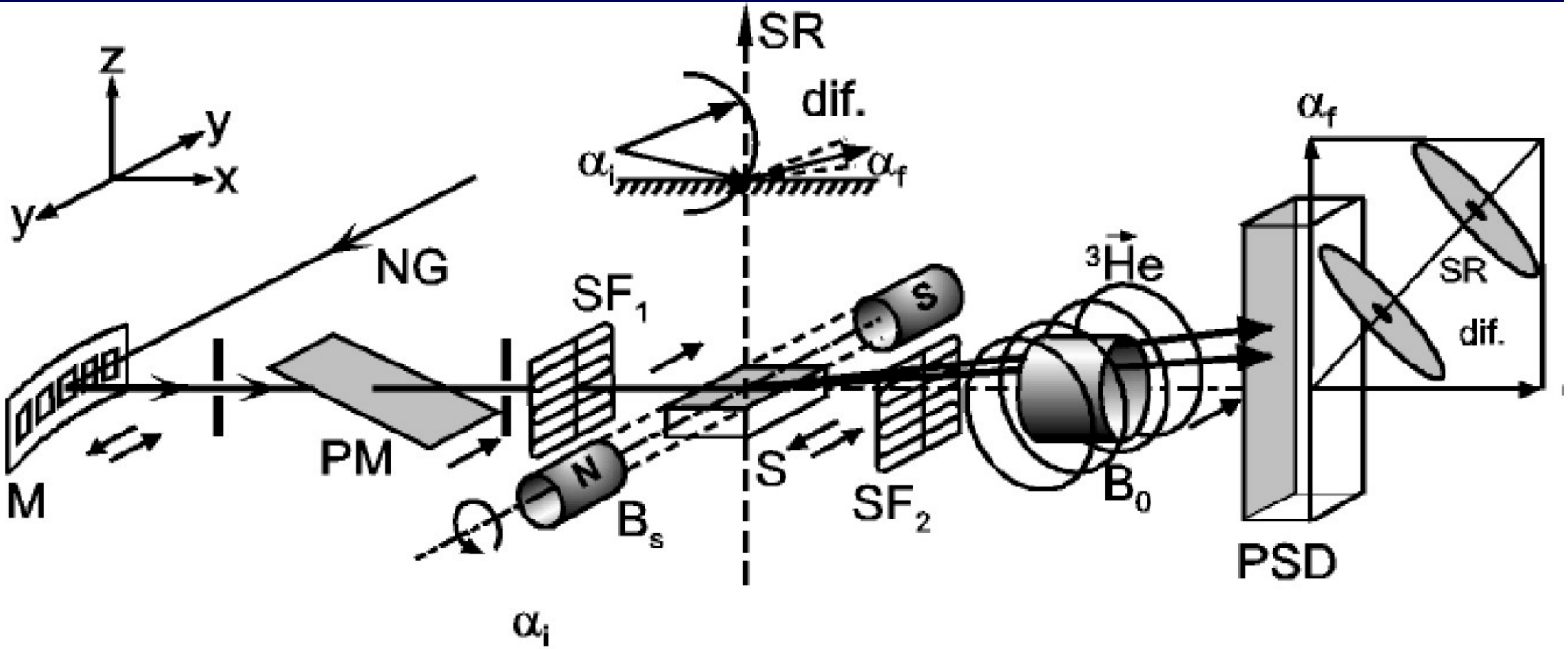






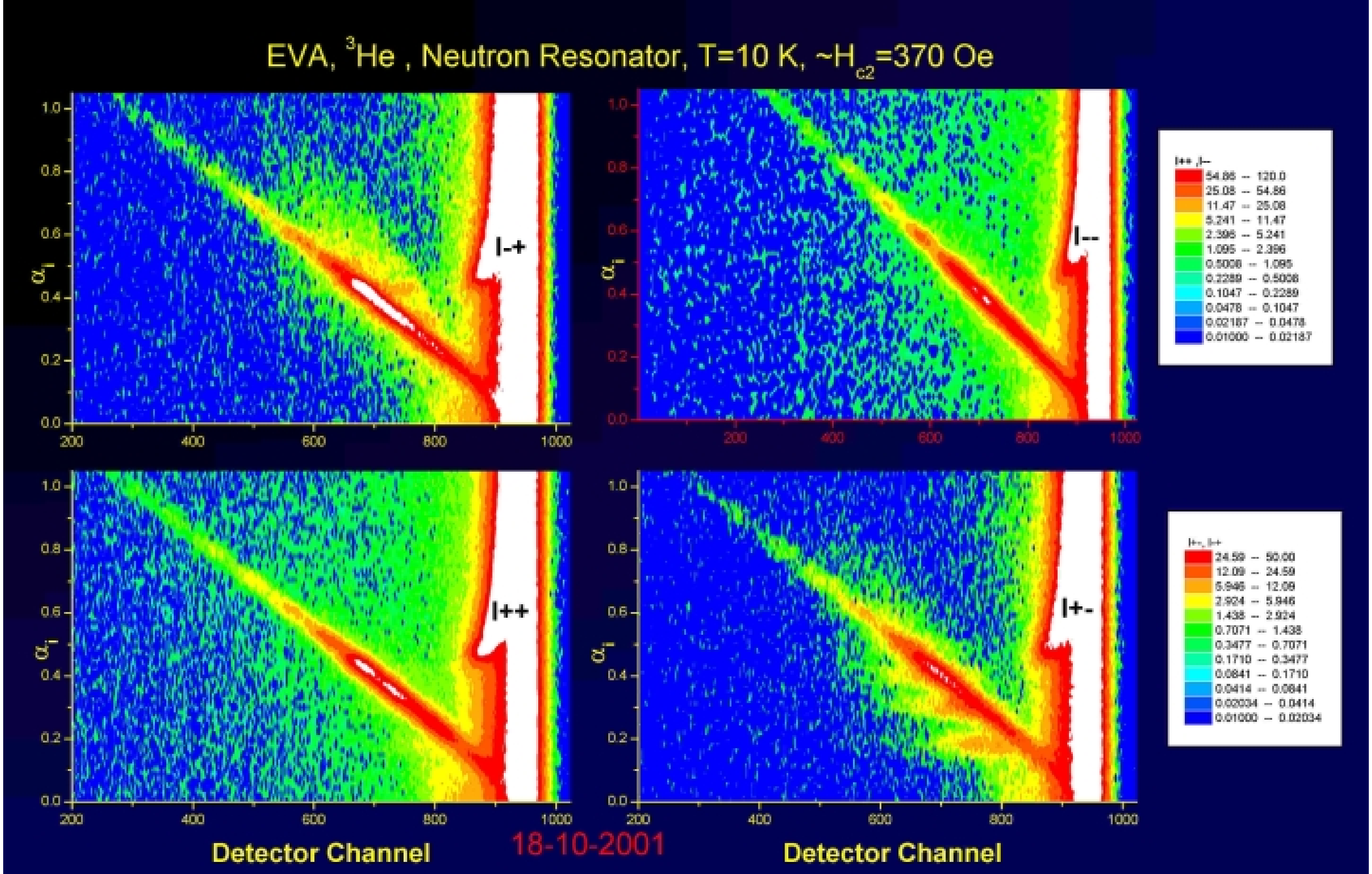
F. Radu, A. Vorobiev, J. Major, H. Humblot, K. Westerholt, H. Zabel, *Phys. Rev. B, 2002, in preparation*

EVA-Neutron Reflectometer at the ILL with a ^{3}He polarisation analyser:



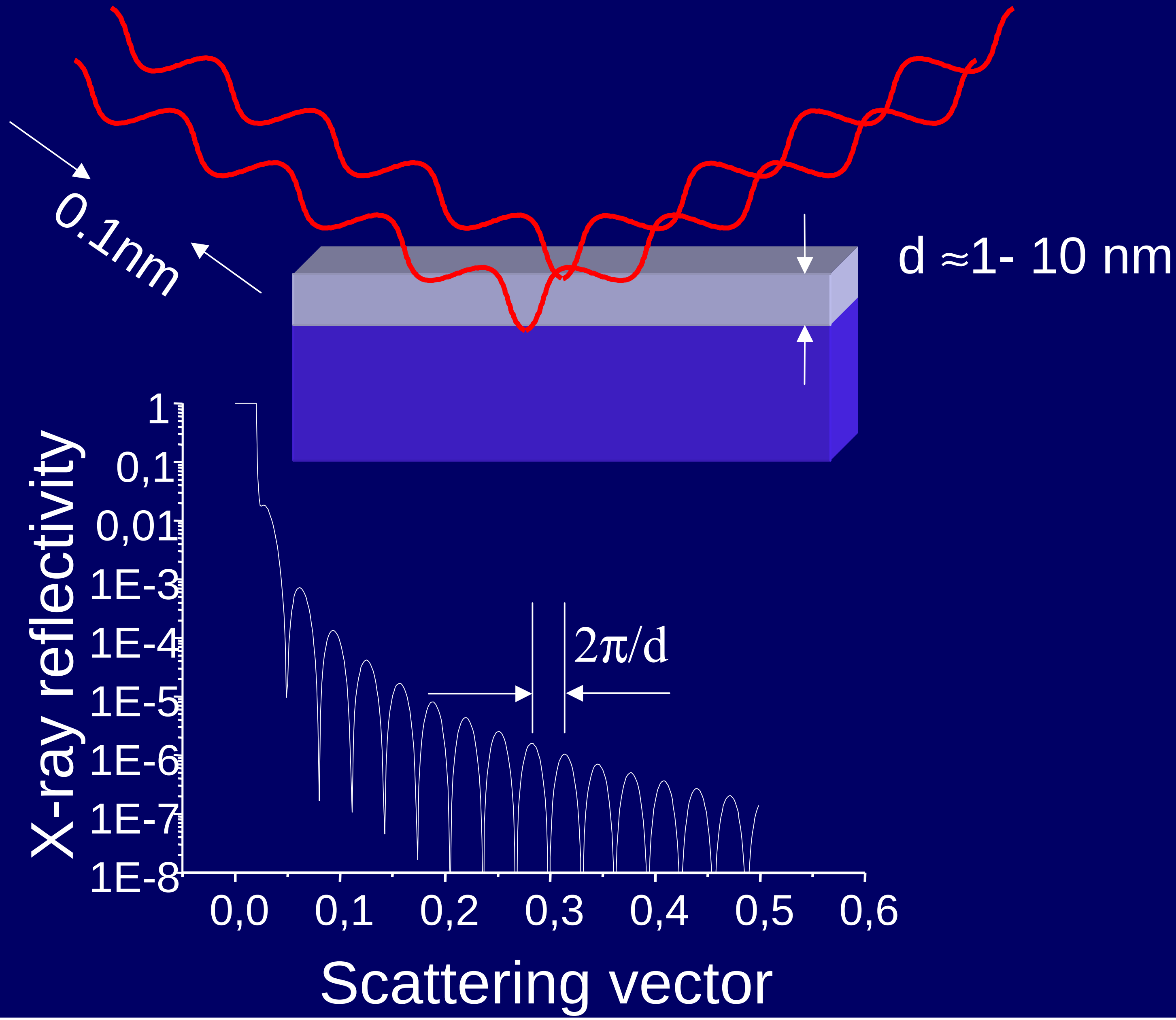
B. Nickel A. Rühm, W. Donner, J. Major, H. Dosch, A. Schreyer, H. Zabel, and H. Humblot, Rev. Sci. Instr. **72,** 163 (2001)

Diffuse scattering from Co/CoO bilayer



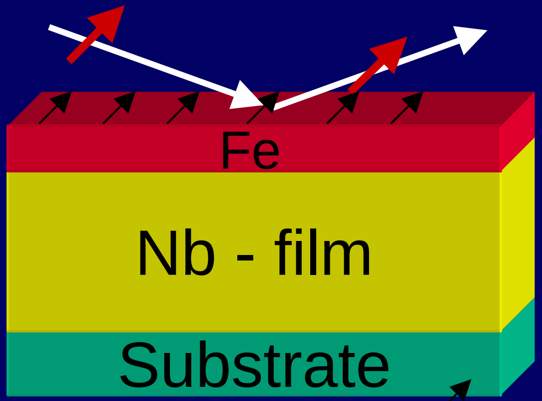
F. Radu, A. Vorobiev, J. Major, H. Humblot, K. Westerholt, H. Zabel

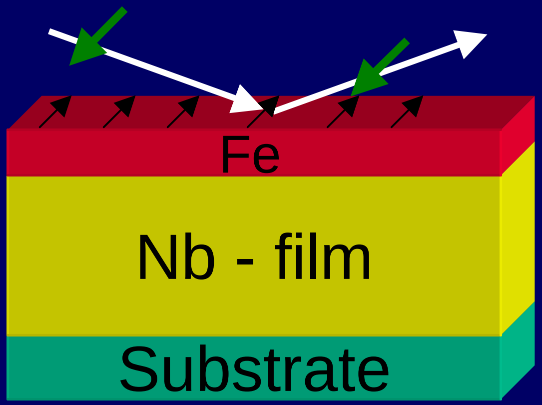
Enhancement of interface sensitivity

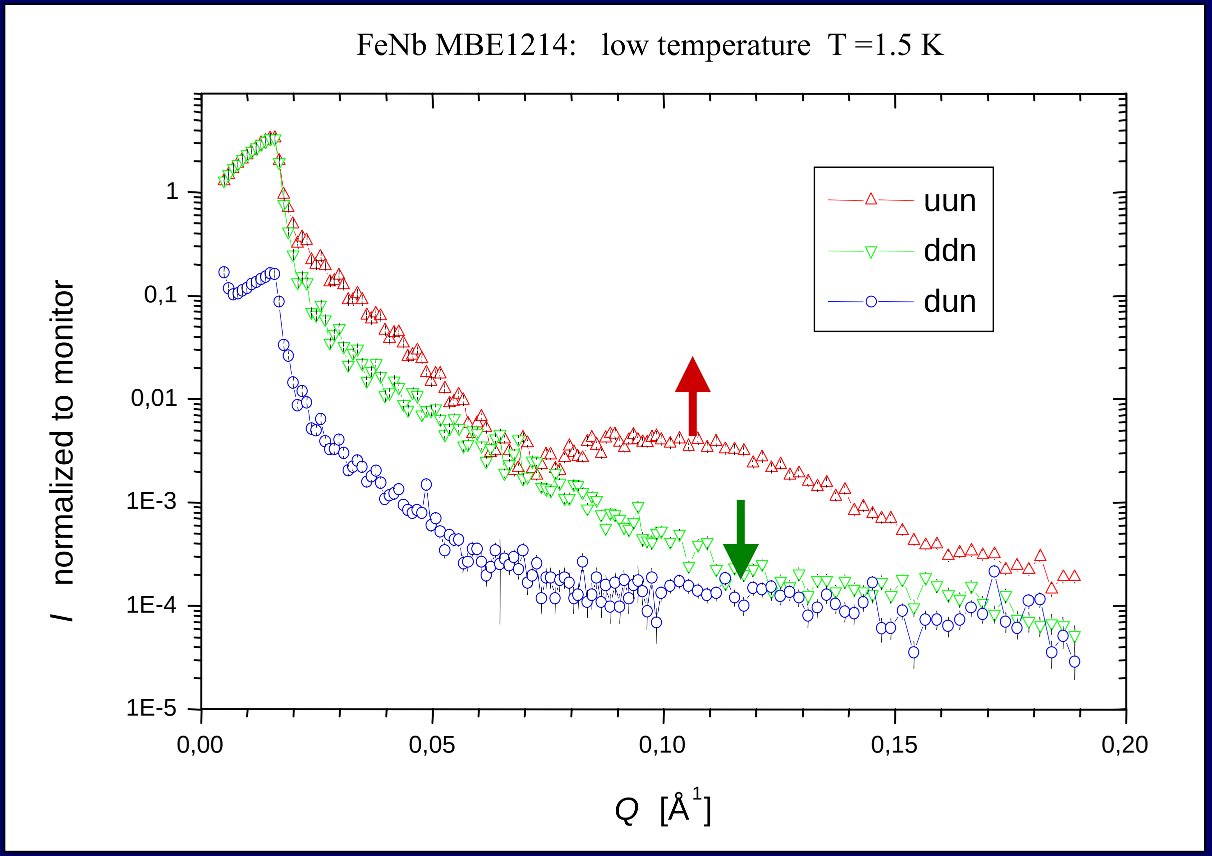


PNR of 2 nm Fe/ 150 nm Nb on sapphire

ADAM neutron reflectometer, ILL

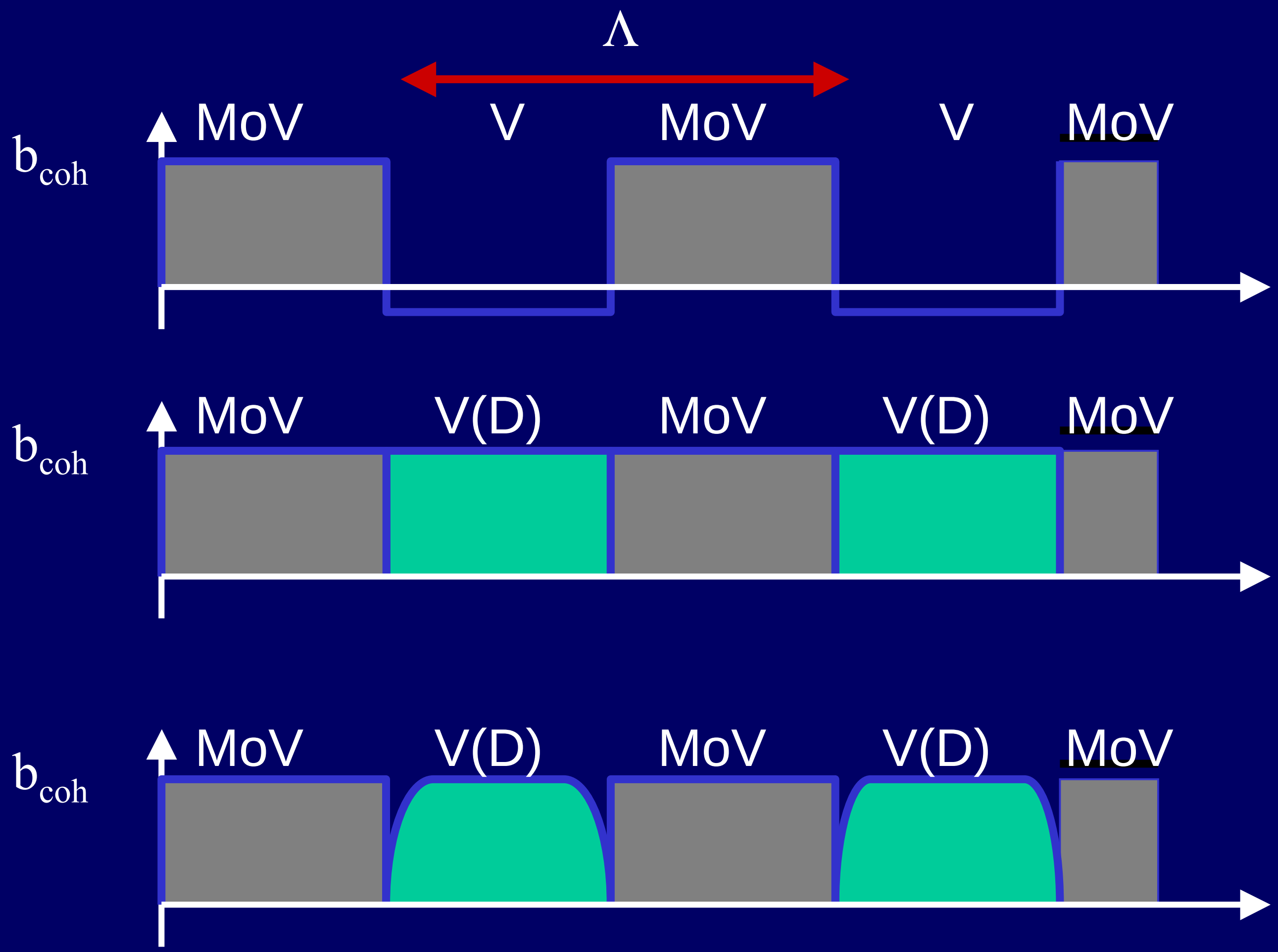






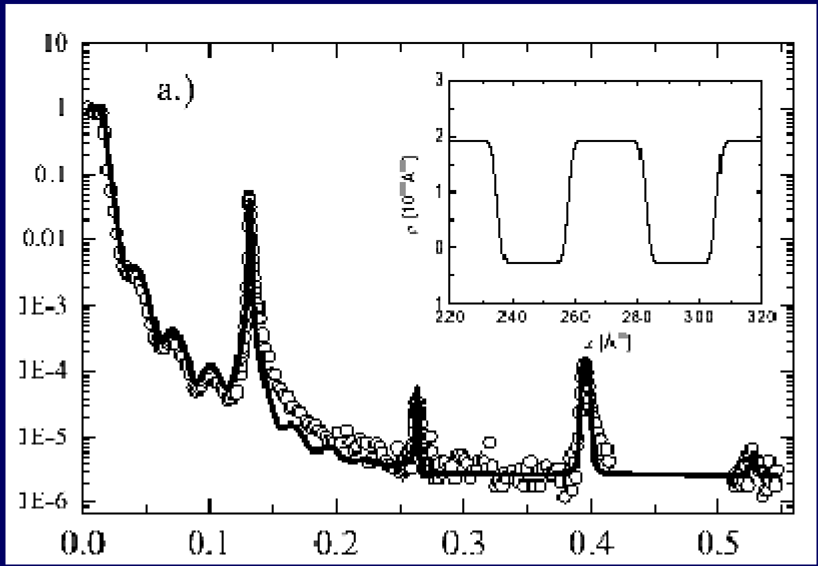
K. Theis-Bröhl, R. Siebrecht, H. Zabel, 2001

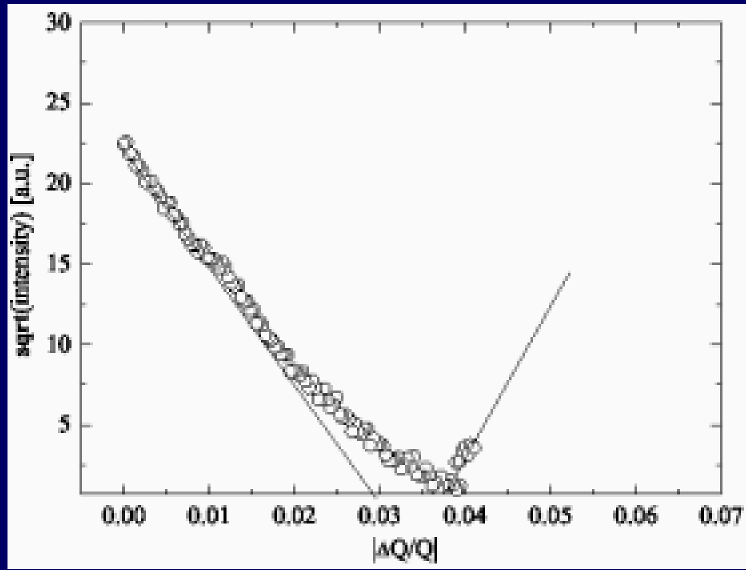
Contrast matching for enhancing interface sensitivity



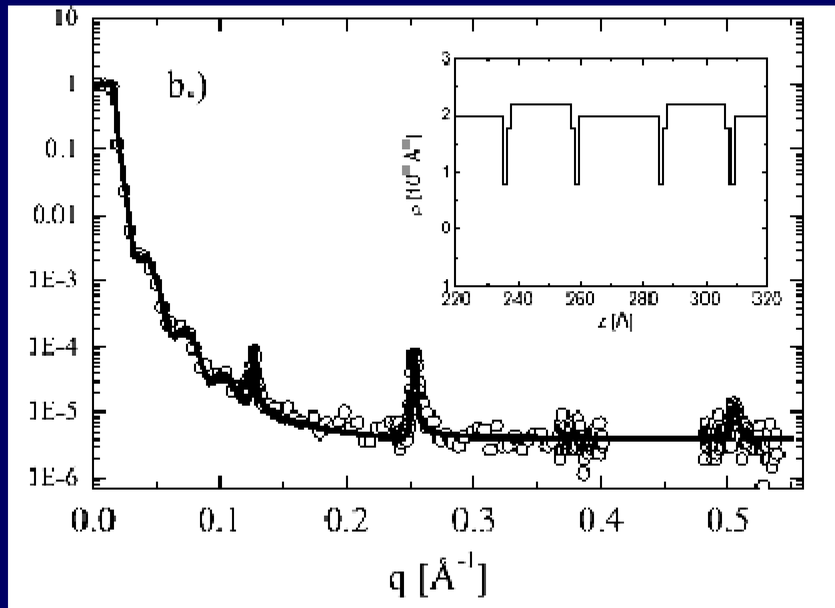
V. Leiner, B. Hjörvarsson, J. Birch, H. Zabel, submitted

Vanishing of 1. order peak by D- loading of V- layers:

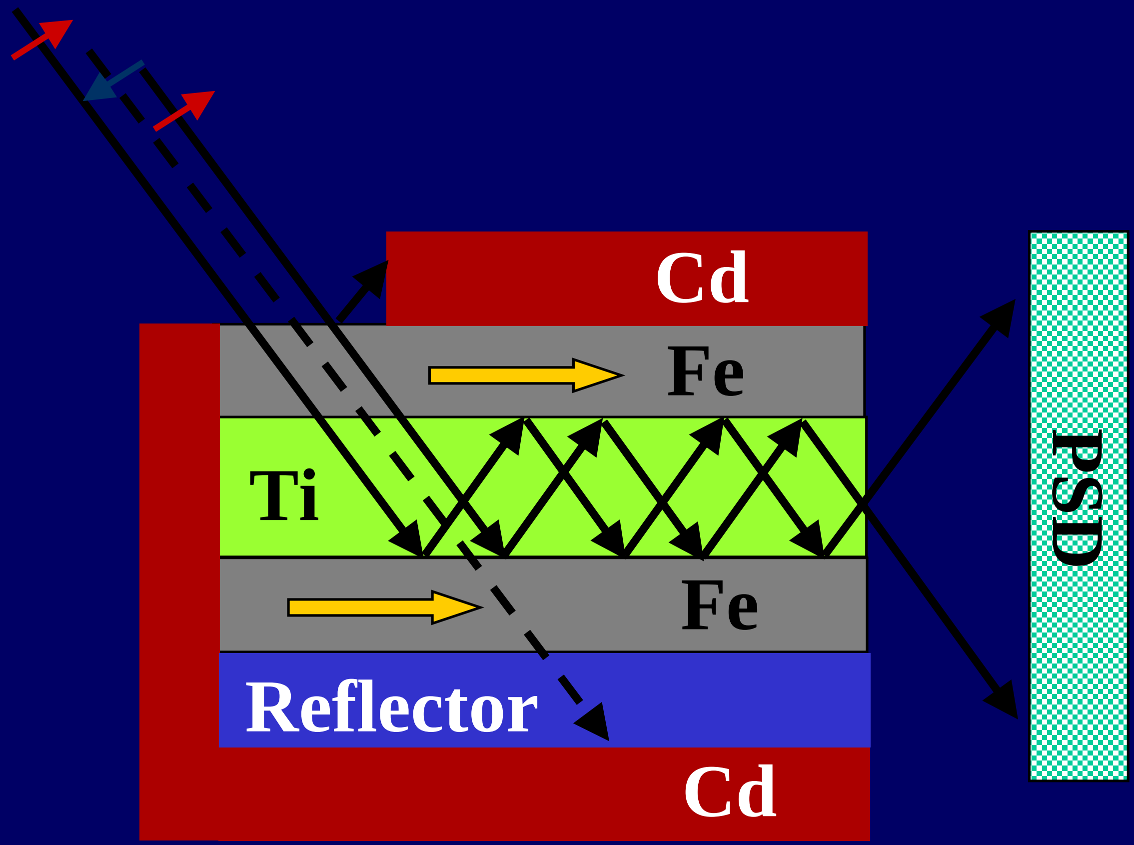




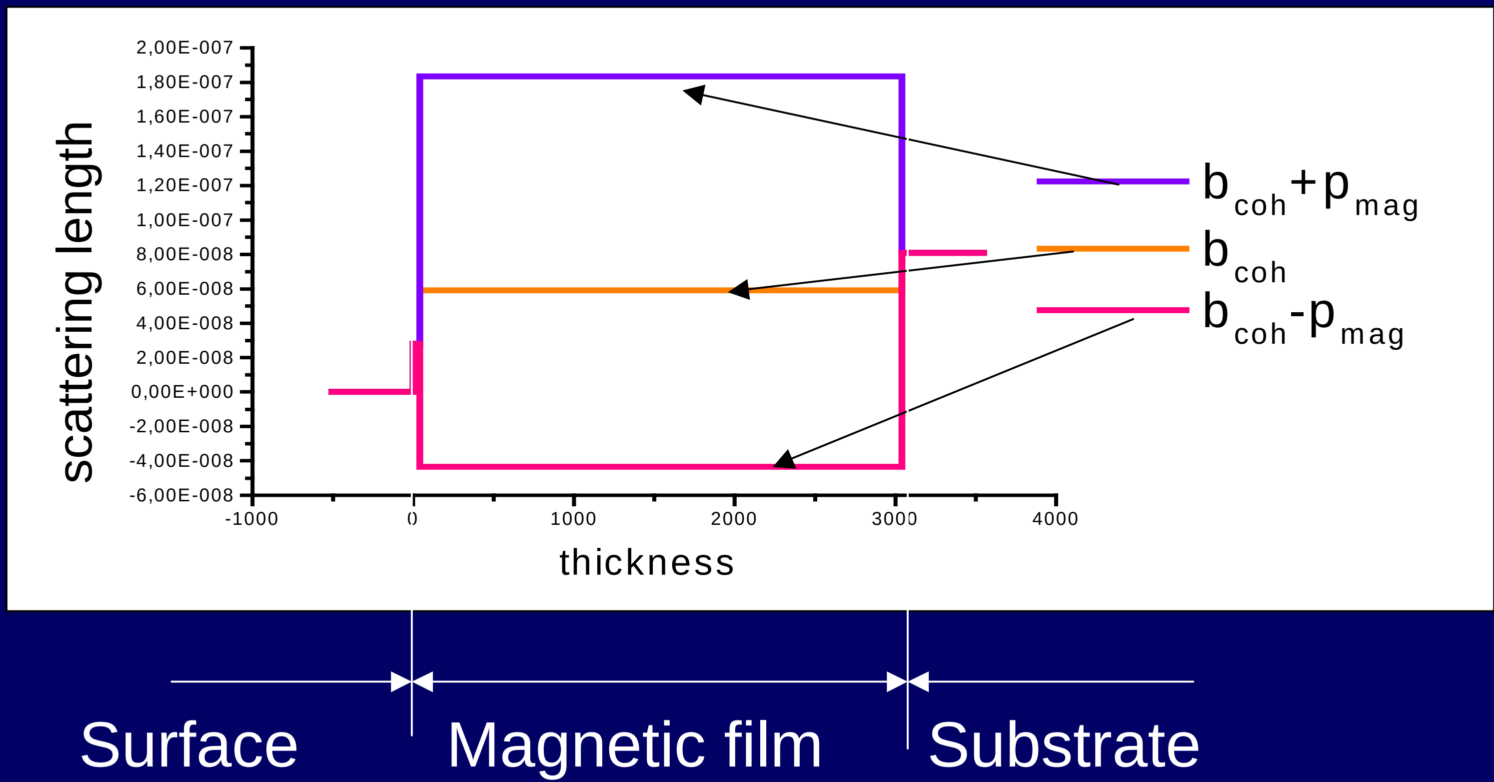
After deuterium loading



Neutron wave guide (resonator) with polarized neutrons

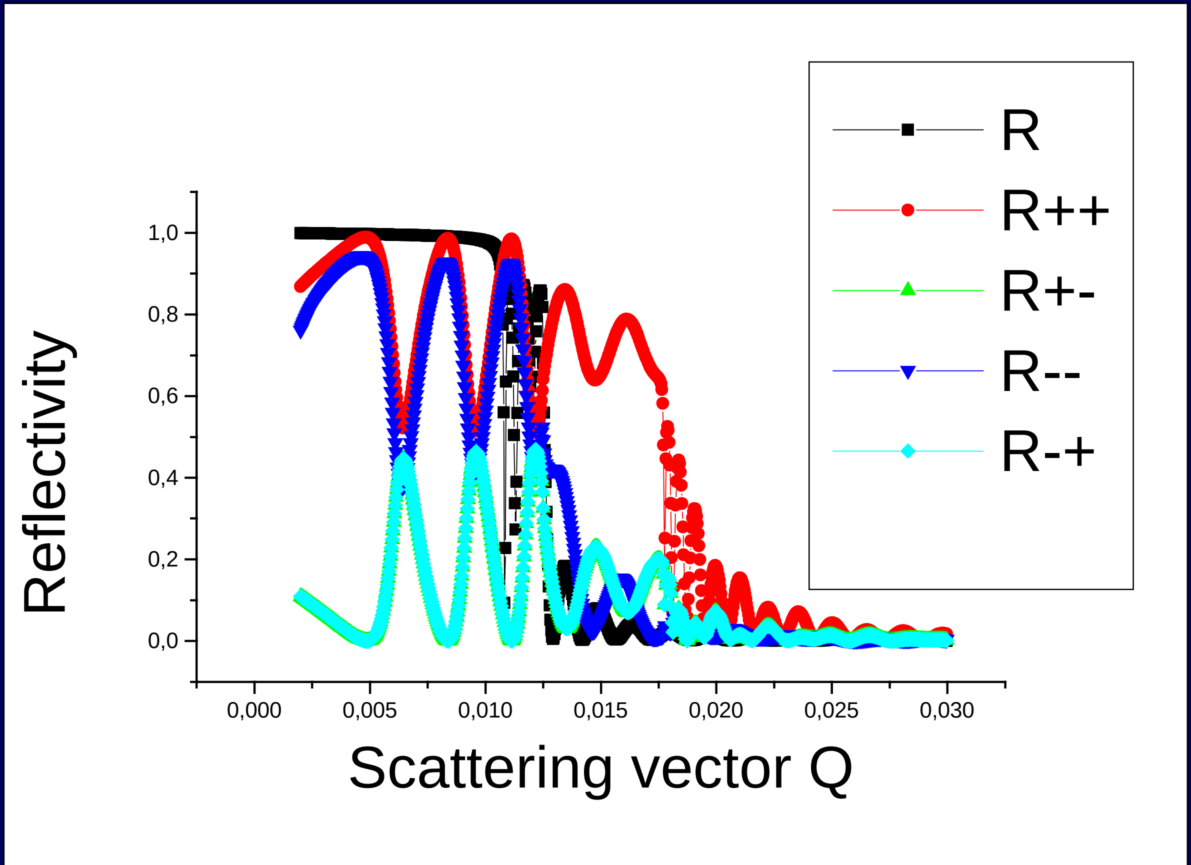


V.K. Ignatovich, F. Radu, V.L. Aksenov, Yu.V.Nikitenko,
Yu. M. Gledenov, P.V. Sedyshev
Frank Laboratory, Dubna

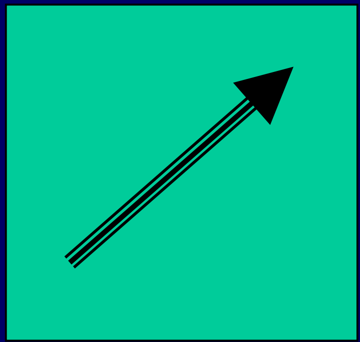

scattering length
thickness
2,00E-007
1,80E-007
1,60E-007
1,40E-007
1,20E-007
1,00E-007
8,00E-008
6,00E-008
4,00E-008
2,00E-008
0,00E+000
-2,00E-008
-4,00E-008
-6,00E-008
-1000
0
1000
2000
3000
4000
$b_{coh}+p_{mag}$
b_{coh}
$b_{coh}-p_{mag}$
Surface
Magnetic film
Substrate

Florin Radu

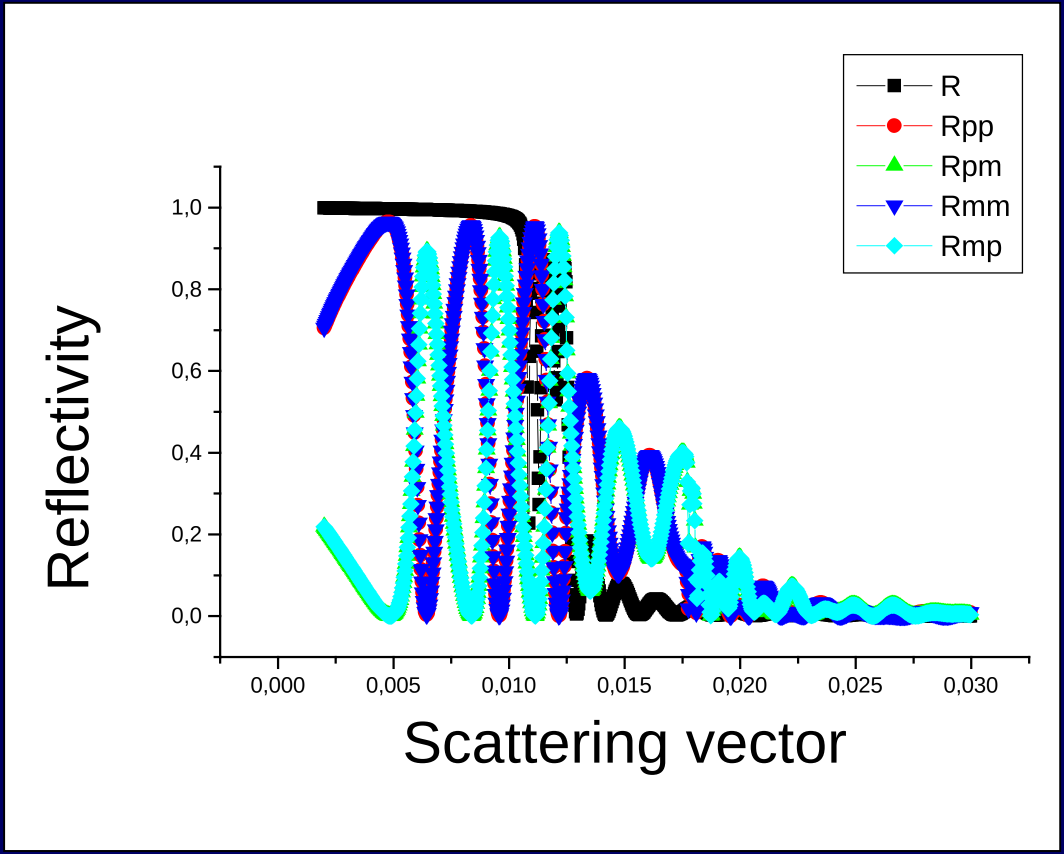
Resonances below the critical edge of total reflection



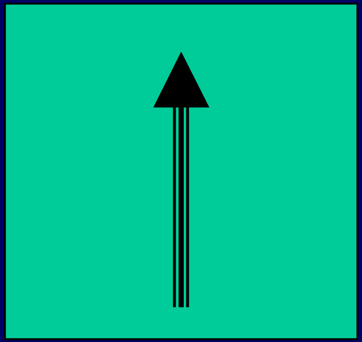
Magnetization vector 45°



Resonances below the critical edge of total reflection



Magnetization vector 0°



Summary

- Neutrons reveal the spin structure and exchange coupling in magnetic superlattices
- Neutrons can distinguish between wall motion and rotation during magnetization reversal
- Resonant magnetic x-ray scattering provides element selective information on magnetic hysteresis and spin structures
- Interface sensitivity can be enhanced by resonant techniques and/or clever design of the sample

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