Laboratory for Neutronen Scattering
ETH Zürich & Paul Scherrer Institute

Jochen Stahn

Antiphase magnetic proximity effect in perovskite superconductor / ferromagnet multilayers

SNI 2006 4.–6. 10. 2006
Universität Hamburg

Laboratory for Neutronen Scattering
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C. Niedermayer
T. Gutberlet
Jochen Stahn

U Fribourg
C. Bernhard, J. Hoppler

FZ Jülich
U. Rücker, E. Kenzinger

Antiphase magnetic proximity effect in perovskite superconductor / ferromagnet multilayers

RU Bochum
M. Wolff

MPI-FKF, Stuttgart
G. Cristiani, HU. Habermeier
J. Chakhalian, B. Keimer

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interfaces and layered systems "new physics" and "spintronics"?

general idea: the close contact of materials with different (alternative) properties might lead to new phenomena

e.g. – interface of $SrTiO_3/LaTiO_3$ (insulators) is metallic

a multilayer reduces the dimension and forces the interaction

coupling phenomena might show up

e.g. – RKKY-interaction

– collosal magnetoresistance

– changed characteristic temperatures

present case: multilayers of a FM with a HTSC (both metals) seem to show an metal/insulator transition in ellipsometry transition for small periods — but stay superconducting / magnetic

so: what happens with the magnetisation and the superconduction order parameter?

essence

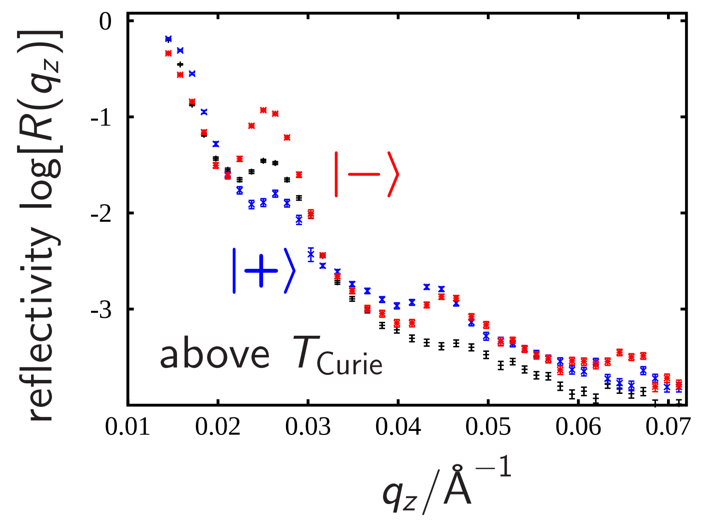
question: What is the magnetic induction (profile) in HTSC / FM multilayers?

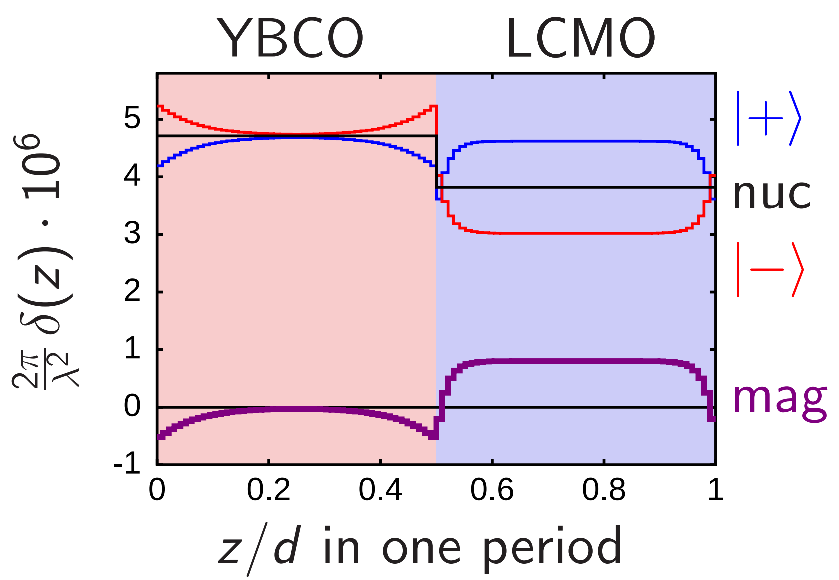
method: polarised neutron reflectometry allows for the determination of $\rho(z)$ and $\mathbf{B}_{\|}(z)$

answers: FM layers magnetised parallel

net magnetic moment in SC at the interfaces, antiparallel to FM magnetisation

SC creates and aligns domain walls in FM





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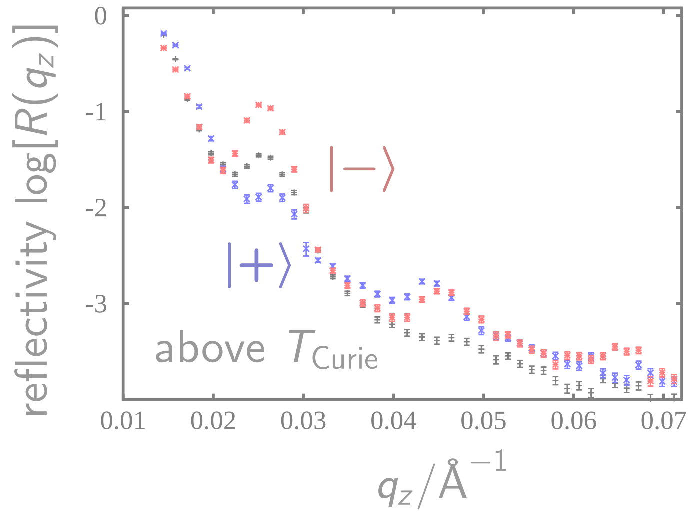
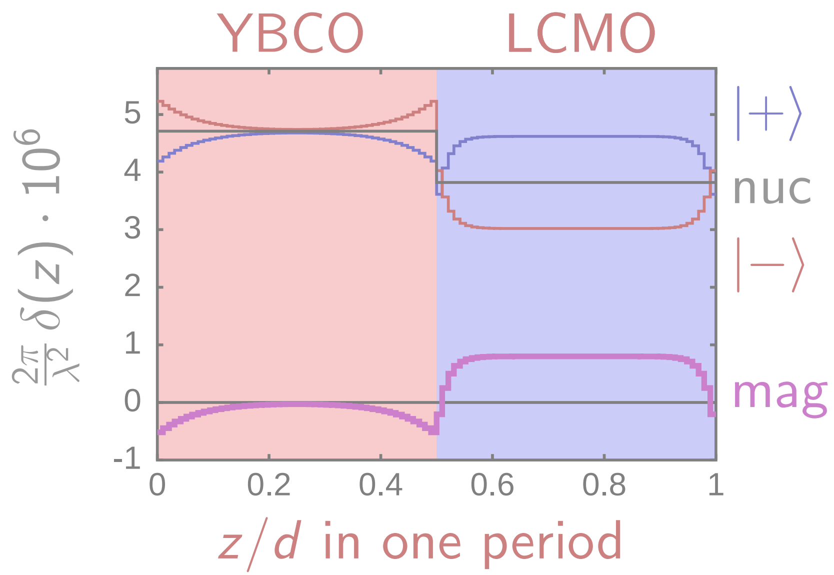
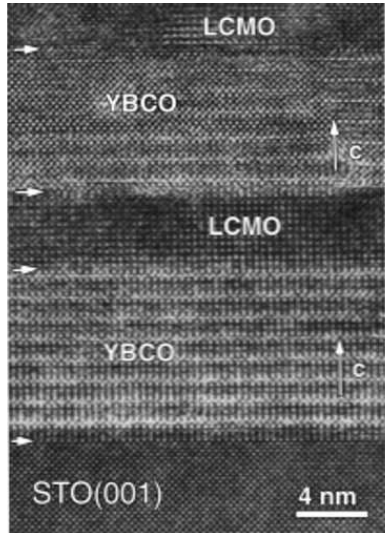


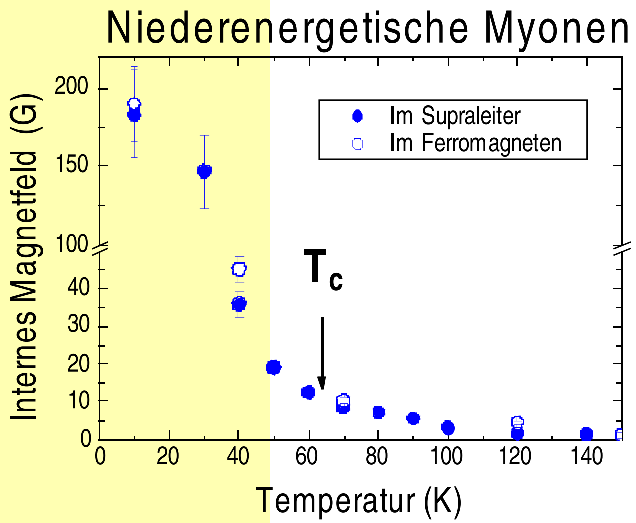


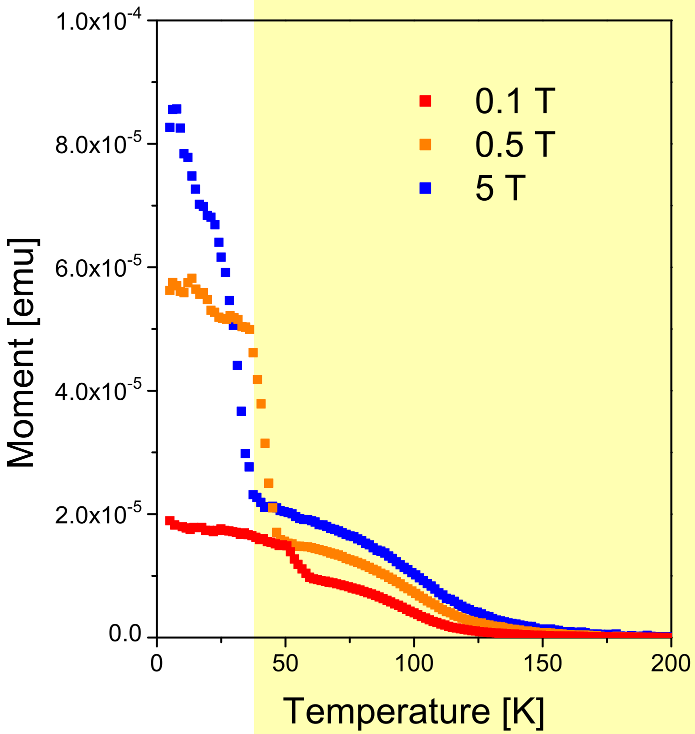
motivation / history:

observation of coexistence of FM and SC in RuSrCuGdO multilayers:
enhanced magnetism below T_c



(spring 2003, μSR and magnetisation measurements at PSI)





$\longrightarrow$ competitive order parameters

questions:

– interaction of FM and SC at the interfaces?

– location of the magnetisation?

– coupling through the layer?

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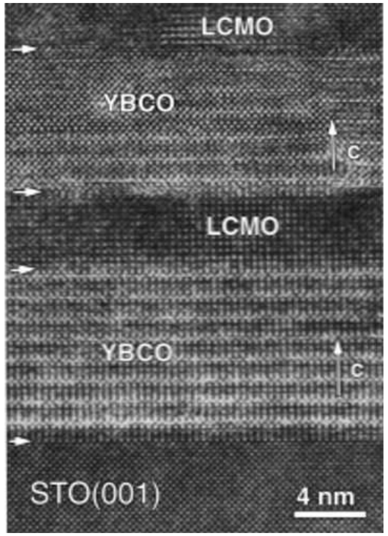

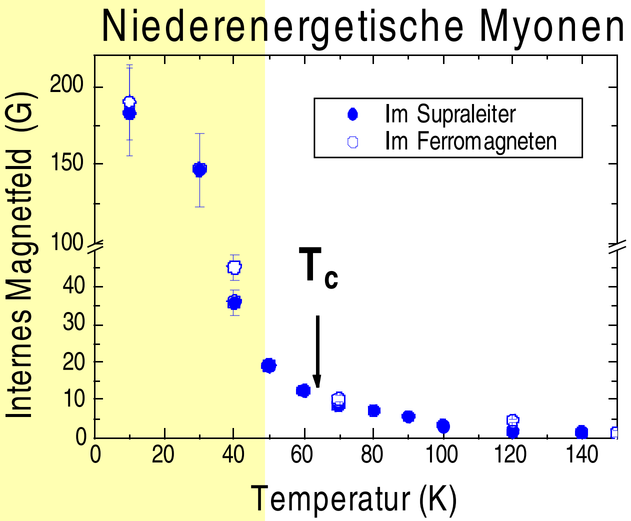

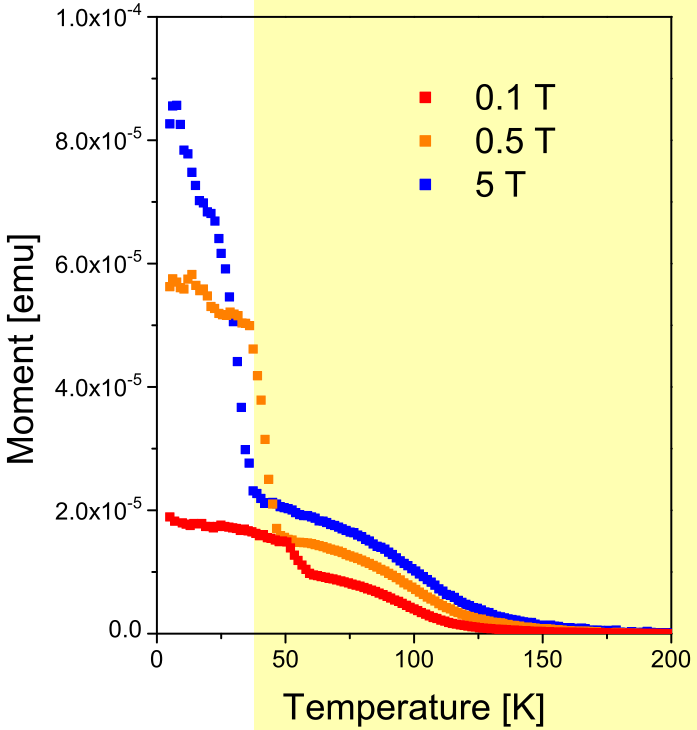

method of choice
(for a neutron scatterer):

neutrons!

in particular *polarised n-reflectometry*

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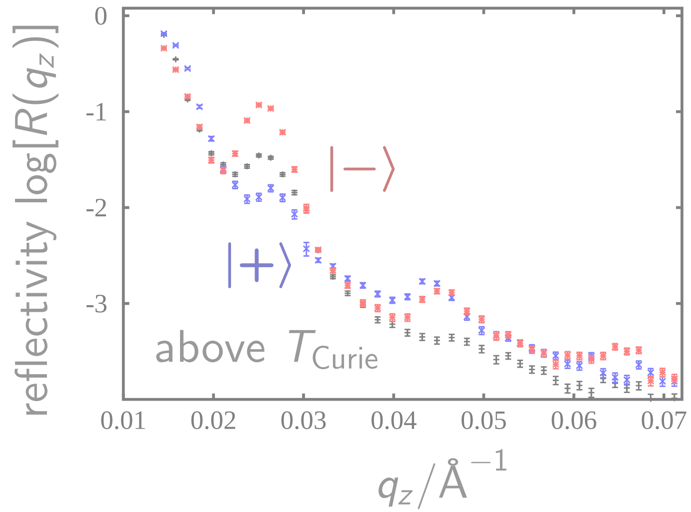
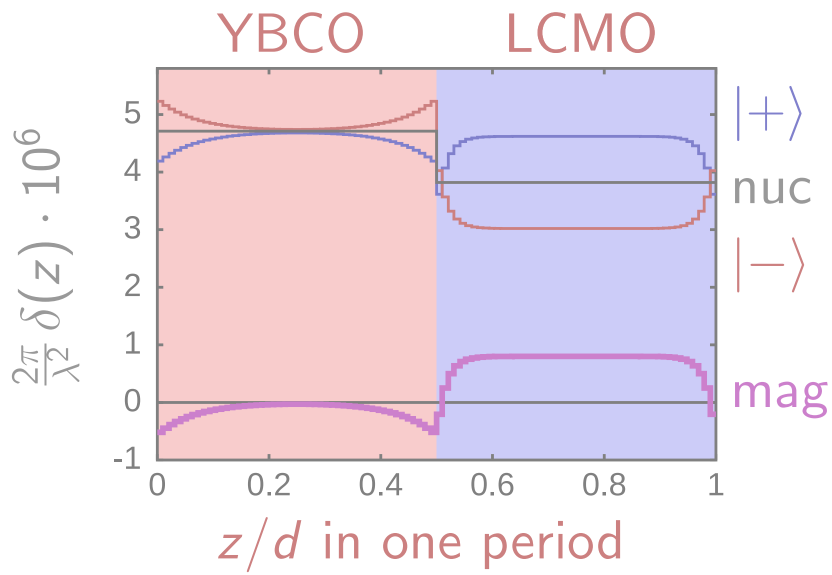




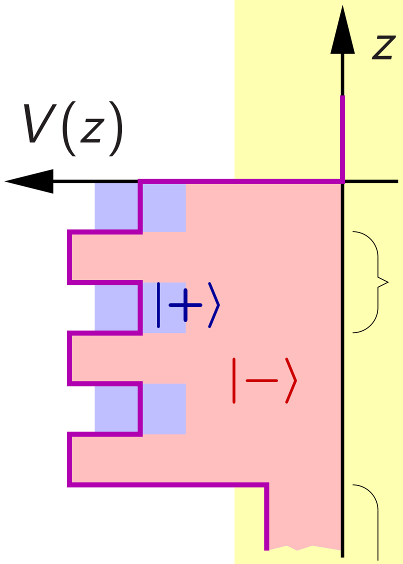
reflectometry

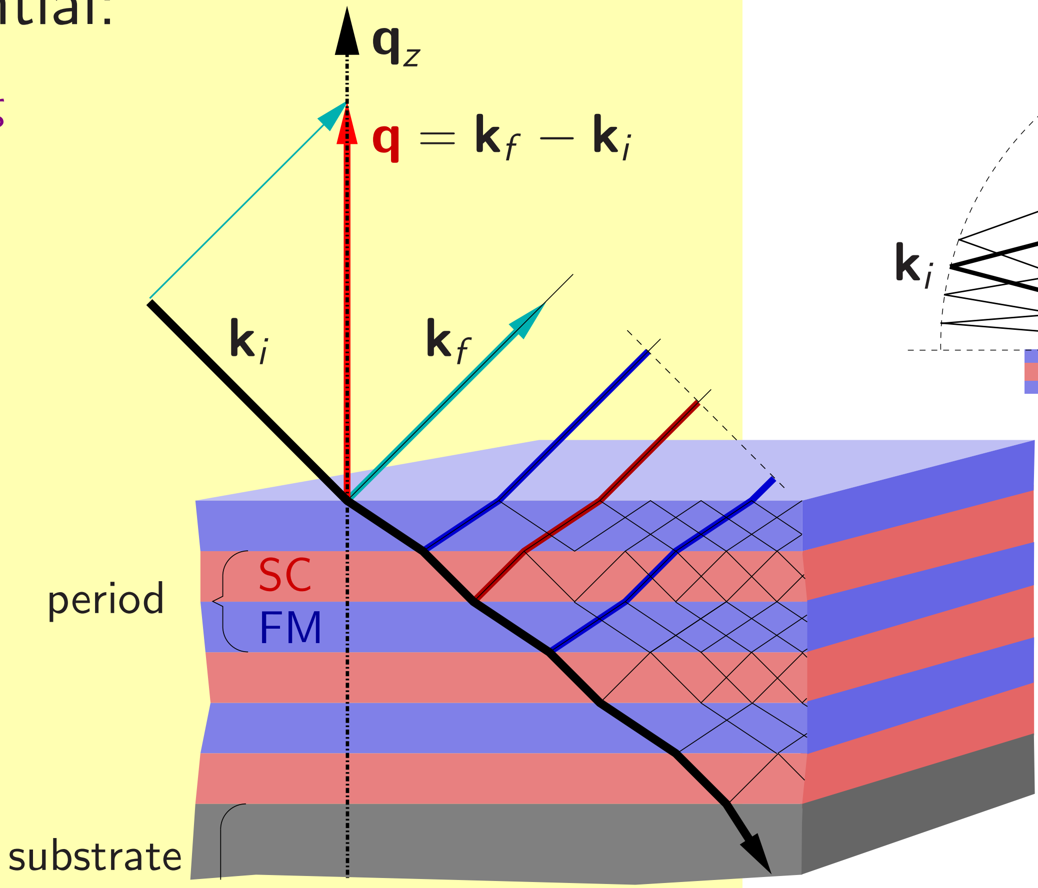
interference of beams reflected from parallel interfaces

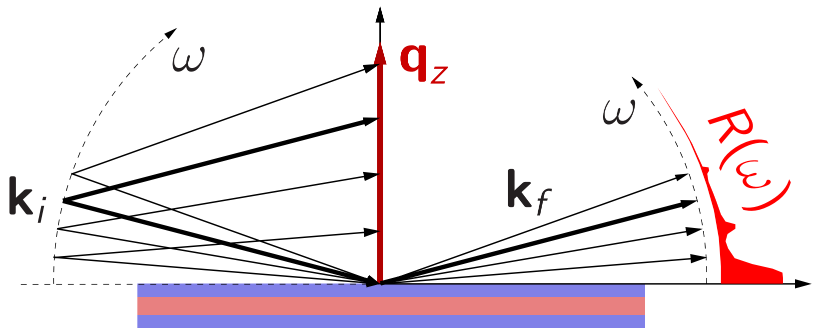
periodic structure $\Rightarrow$ Bragg-condition for constructive interference

scattering potential:

$$V = V_{\text{nuc}} \pm V_{\text{mag}}$$
$$= V_{\text{nuc}} + \boldsymbol{\mu}\mathbf{B}_{\parallel}$$







layer thickness ratio 1:1 $\Rightarrow$ extinction of even Bragg-peaks

reflectometry tailored samples

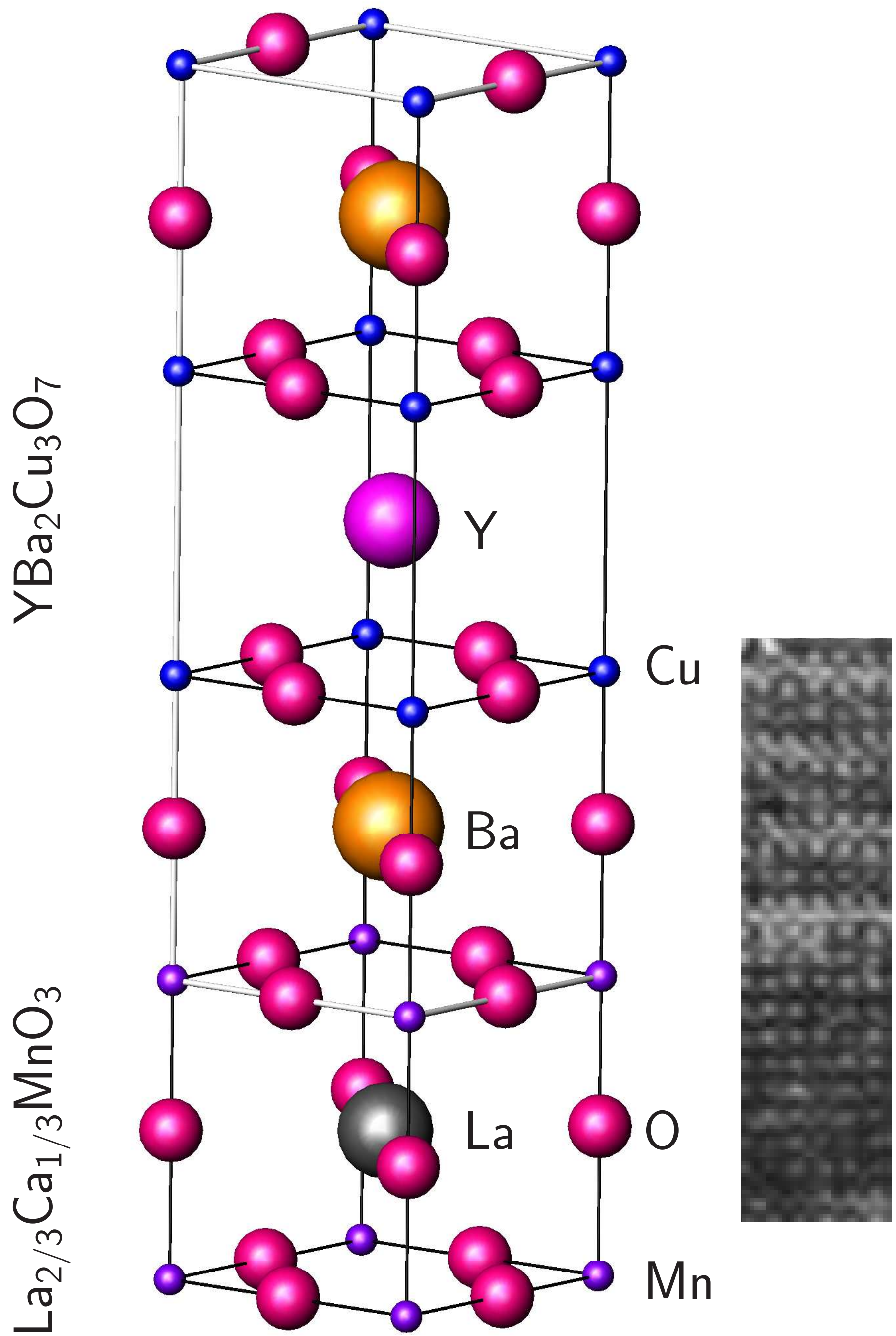
materials:	HTSC	YBCO	$YBa_2Cu_3O_7$
		YPBCO	$Y_{0.6}Pr_{0.4}Ba_2Cu_3O_7$
	FM	LCMO	$La_{2/3}Ca_{1/3}MnO_3$
	substr.	STO	$SrTiO_4$

size: $10 \times 10\,\mathrm{mm}^2$, $5 \times 5\,\mathrm{mm}^2$

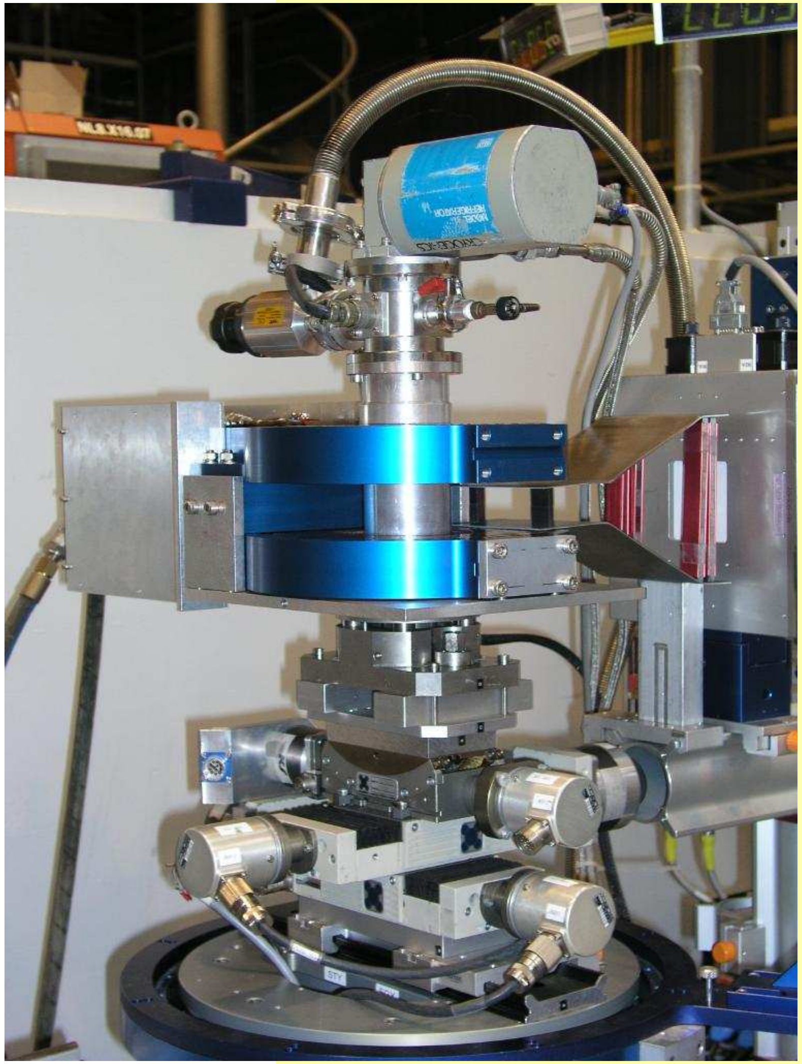
produced: by *P*ulsed *L*aser *D*eposition

period: 200 Å to 500 Å
5 to 16 periods

ratios: 1 : 1 and 1 : 2
to cause extinction



reflectometry sample environment (at SINQ):



sample holder

closed cycle refrigerator
$8\,\mathrm{K} < T < 300\,\mathrm{K}$

Helmholtz coils
$H \leq 1000\,\mathrm{Oe}$
vol: $40 \times 40 \times 40\,\mathrm{mm}^3$

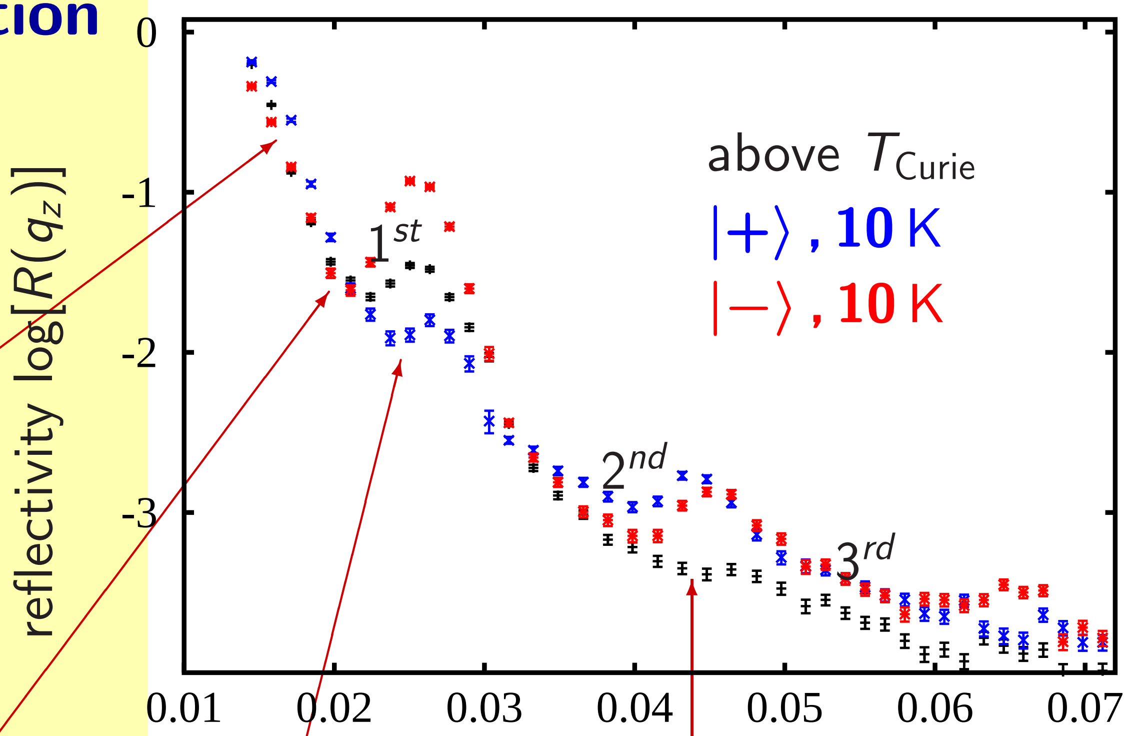
translation stages for alignment

ω-rotation stage

instruments: Morpheus & ANOR, SINQ; ADAM, ILL; and HADAS, FZ Jülich

reflectometry **direct interpretation**

$\mathbf{H} = 100\,\mathrm{Oe}$
field cooled
$T = 10, 300\,\mathrm{K}$



splitting of the edge of total reflection
⇒ changed potential of the surface

no half-order Bragg-peak
⇒ parallel alignment of **B** in the FM layers

intensity variation of the 1^{st} Bragg-peak
⇒ changed potential in the FM layers
$B_{\parallel}$ can be determined

appearance of a 2^{nd} order Bragg-peak
⇒ $B_{\parallel}(z)$ and $V_{\mathrm{nuc}}(z)$ have different symmetry

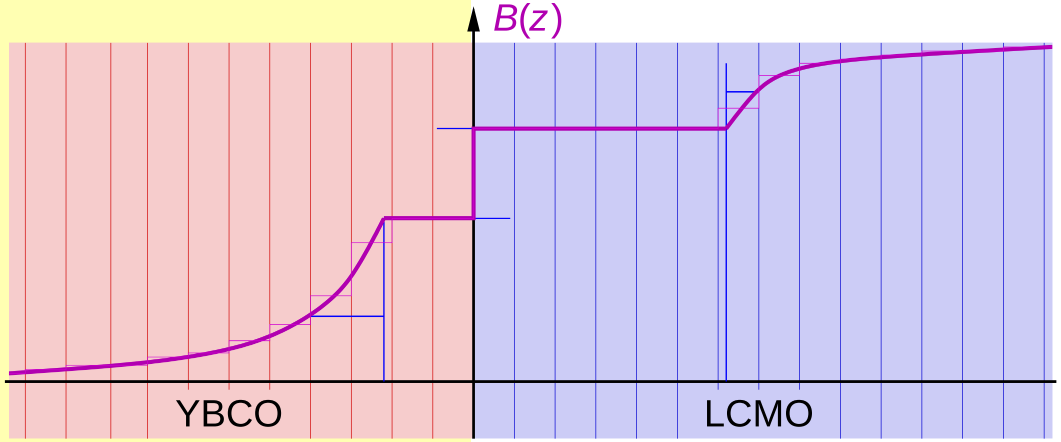
simulations performed with EDXR by Petr Mikulík (no fitting)

bilayer structure has been broken down to some 100 sublayers to pay respect to $\mathbf{B}(z)$.

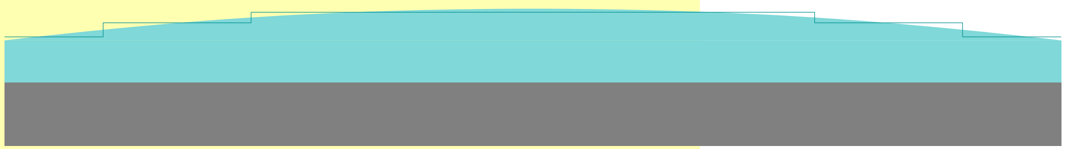
analytic expressions for $B(z)$:

cosh-functions

off-sets with constant B



decrease of layer thickness towards the borders taken into account

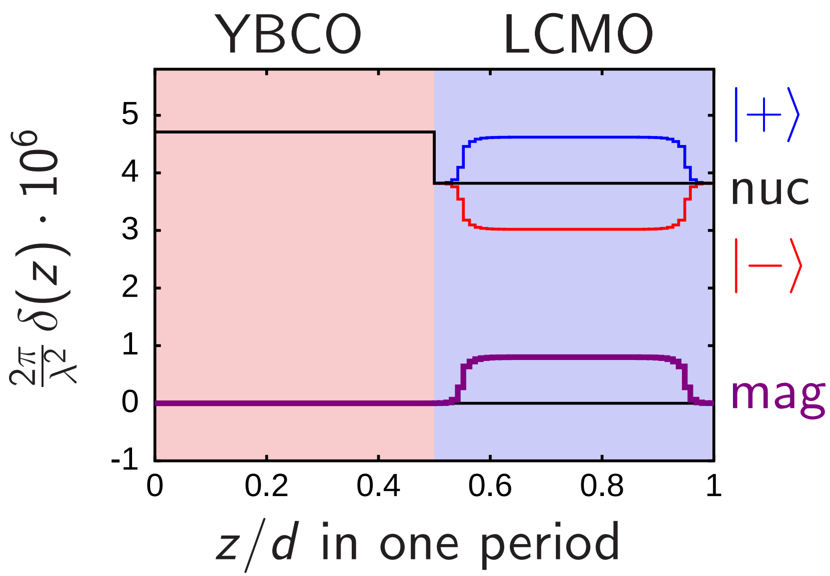


reflectometry **simulations**

PNR at RT and below T_{Curie} and T_c exclude *all* models besides

AFM-region within LCMO

charge-injection from YBCO leads to a doping of LCMO and thus to an AFM ground state



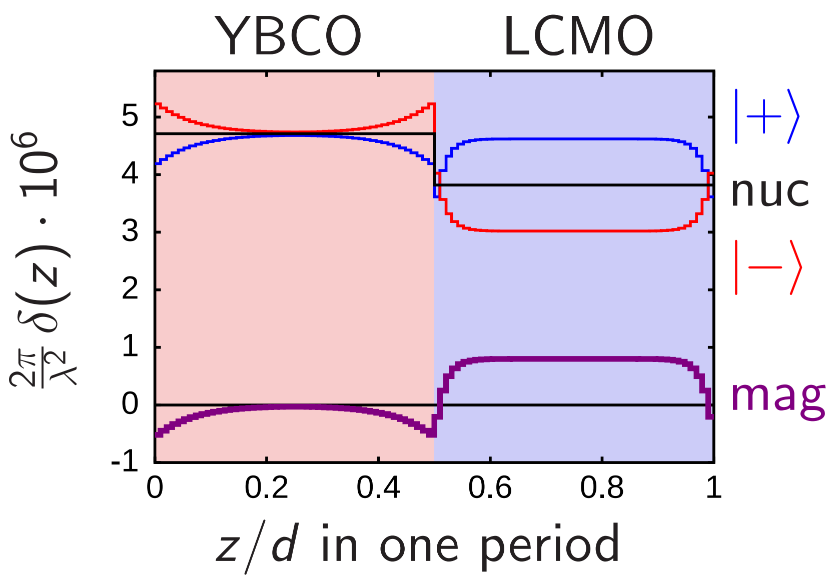
antiphase magnetic proximity effect

AF coupling of Mn and Cu moments through oxygen

or

Cooper pairs penetrate into LCMO and are *polarised*

$\Rightarrow$ antiparallel magnetisation in YBCO



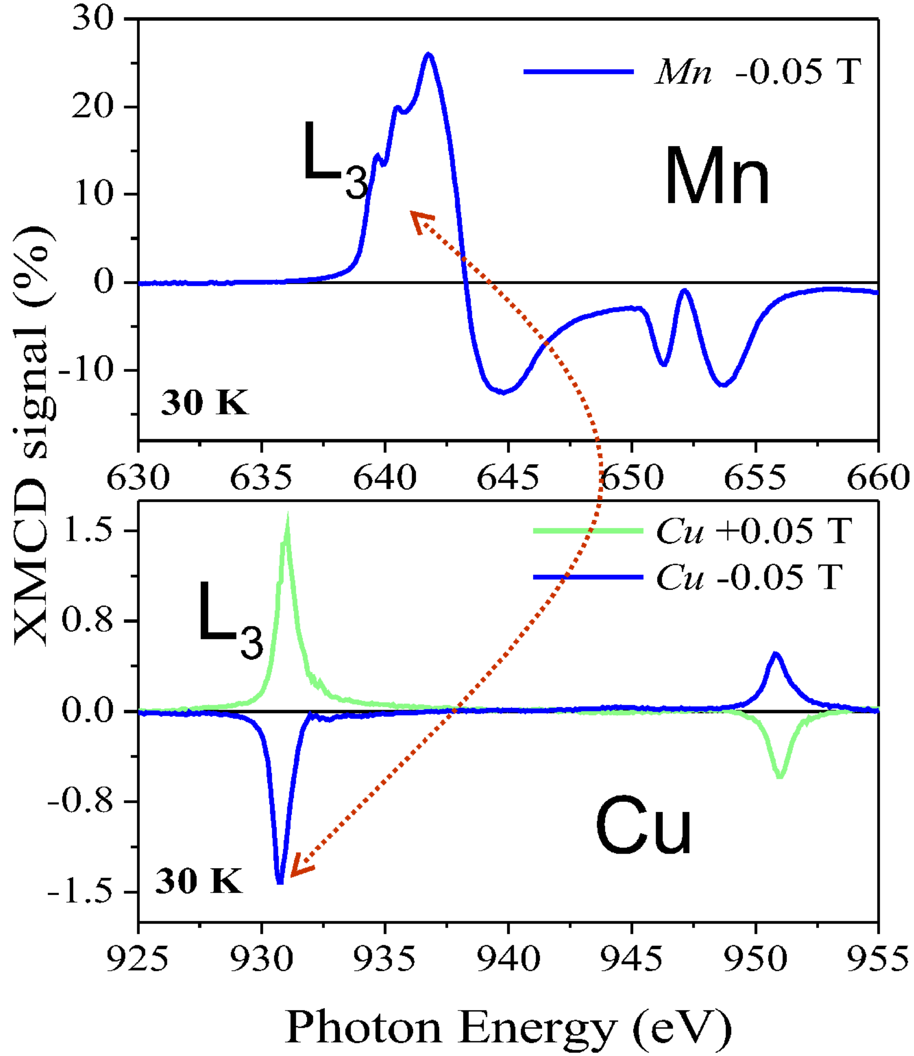
X-ray magnetic circular dichroism:

measurements by J. Chakhalian and B. Keimer, Stuttgart performed at APS, Chicago.

– magnetic moment on Cu detected

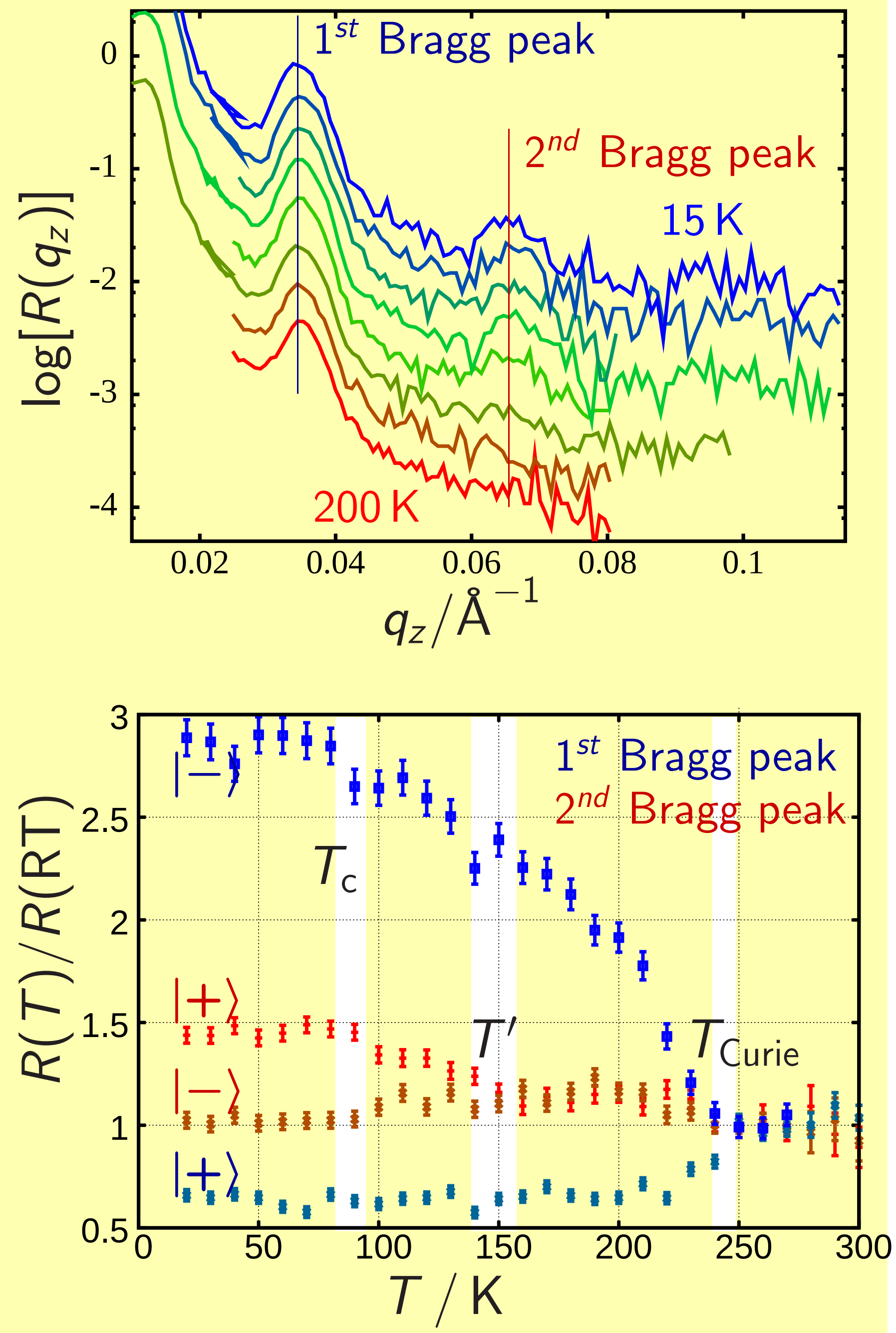
– it is antiparallel to the moment on Mn

⇒ antiphase proximity effect is strongly supported!



graph taken from a talk by J. Chakhalian given at the Summer School on Interfaces of Oxides, Stuttgart, July 2005

T dependence of $R(q_z)$



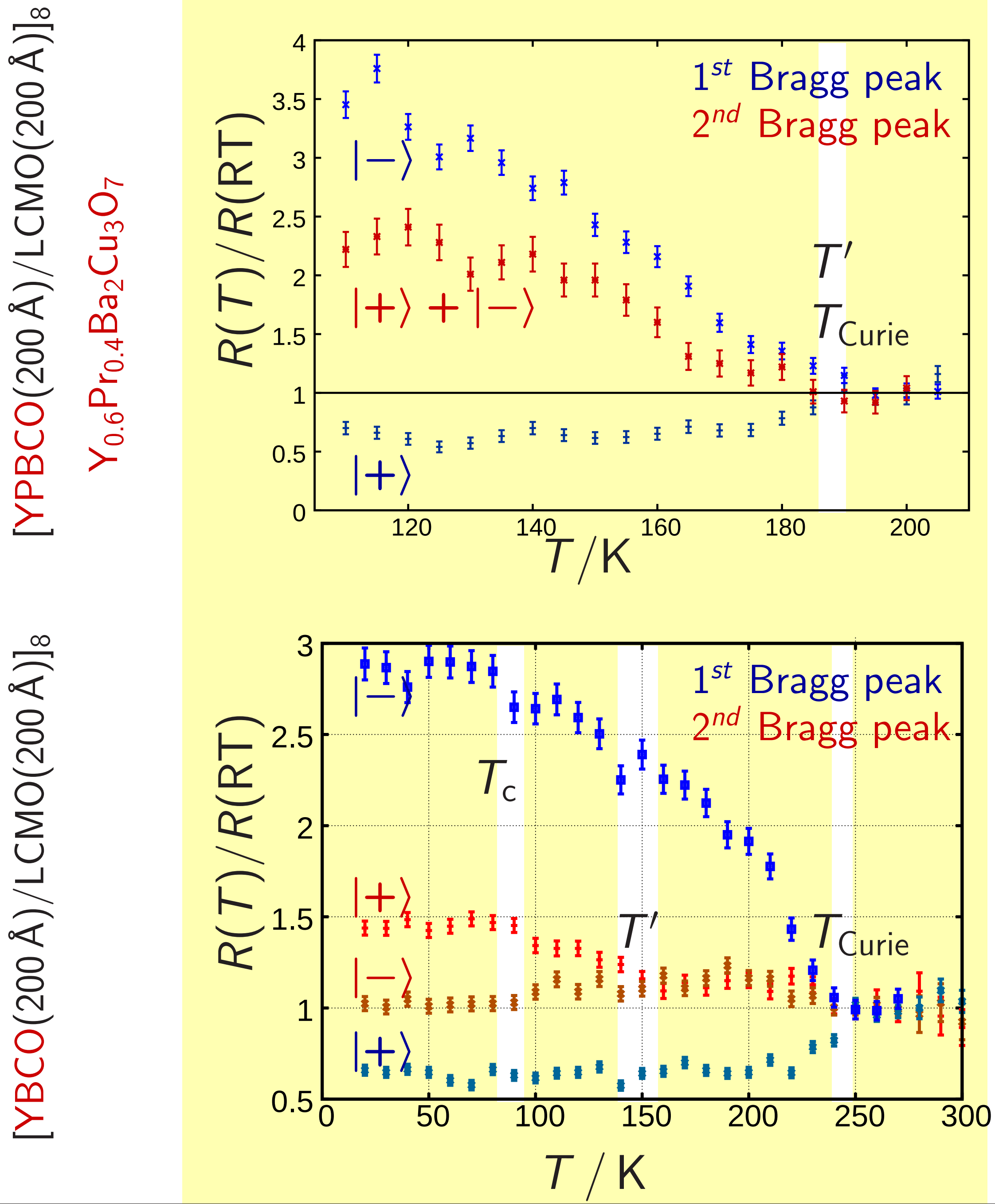
[YBCO(200 Å)/LCMO(200 Å)]$_8$

T_{Curie} (160 $\longrightarrow$ 270 K)
onset of FM: changed contrast

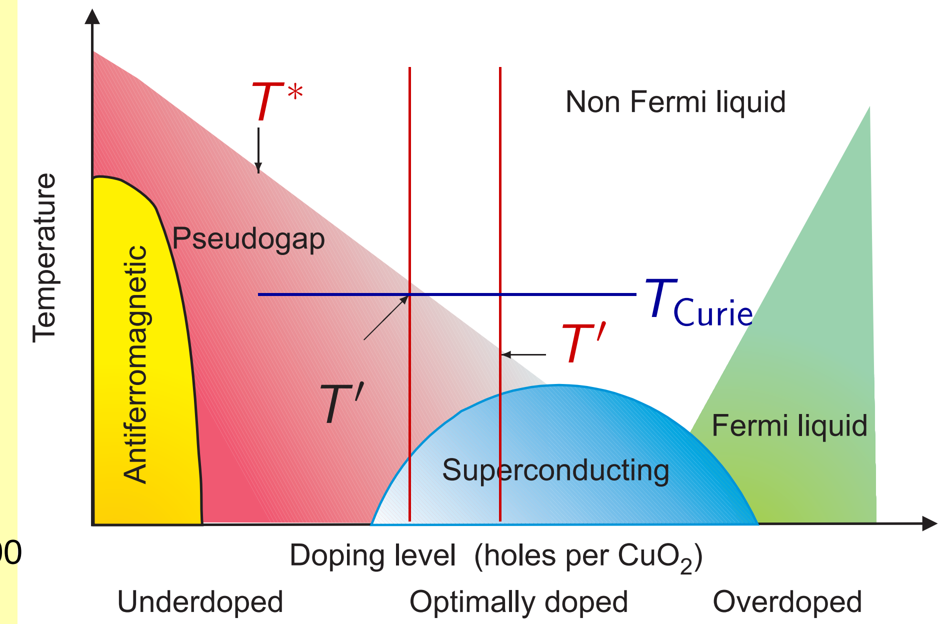
T' ($\approx$ 140 K)
formation of 2$^{\mathrm{nd}}$ peaks
$B(z)$ and $V_{\mathrm{nuc}}(z)$ differ

T_{c} (60 $\longrightarrow$ 90 K)
onset of SC

T dependence of $R(q_z)$



$T' \approx T^*$ varies with doping!



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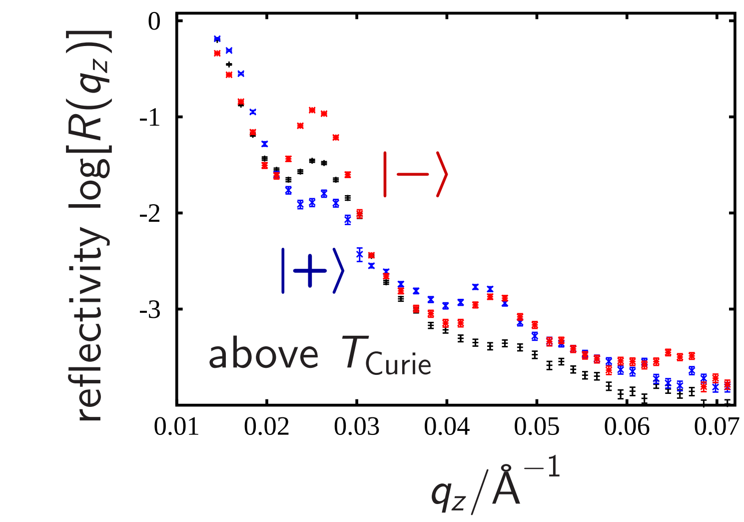
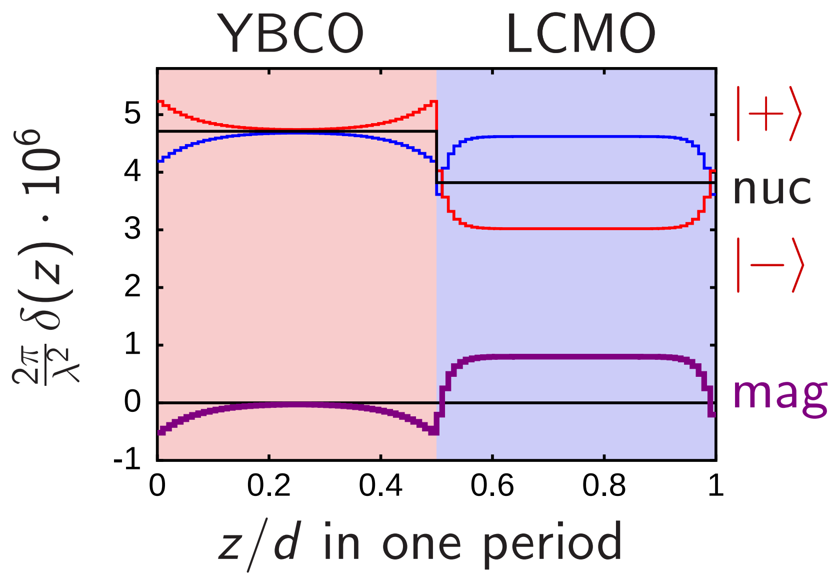
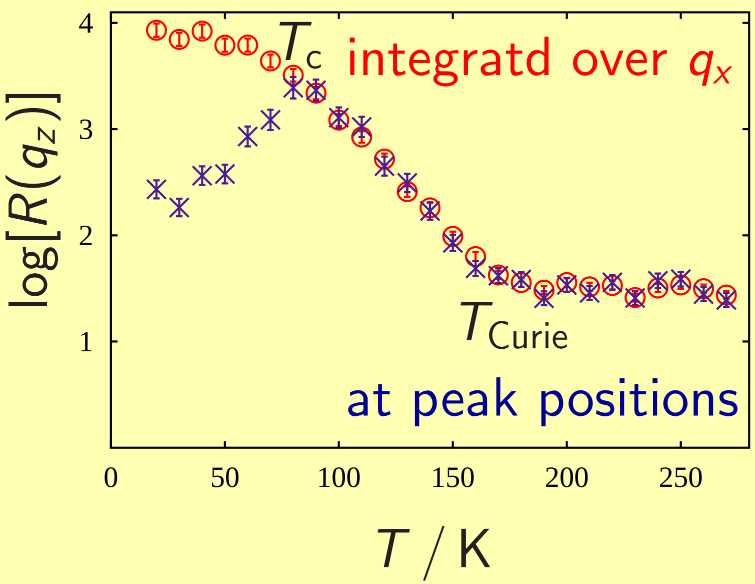


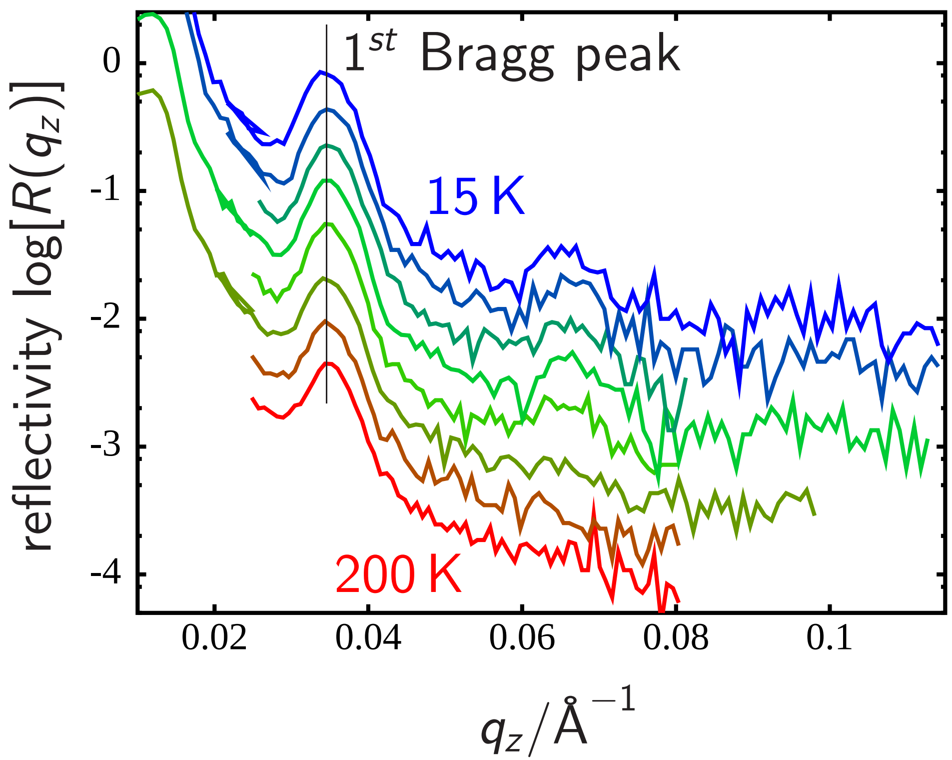


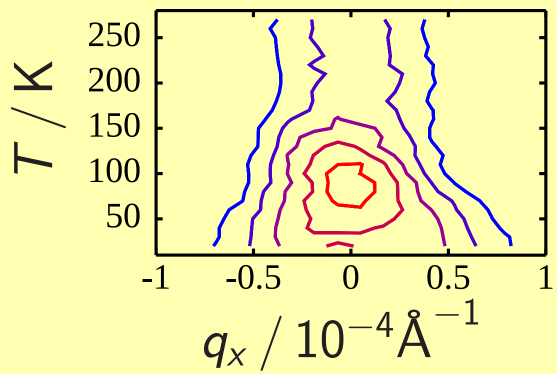
off-specular scattering **ω-scans**

non-polarised, various T

sample: $[YBCO(100\,Å)/LCMO(100\,Å)]_7$

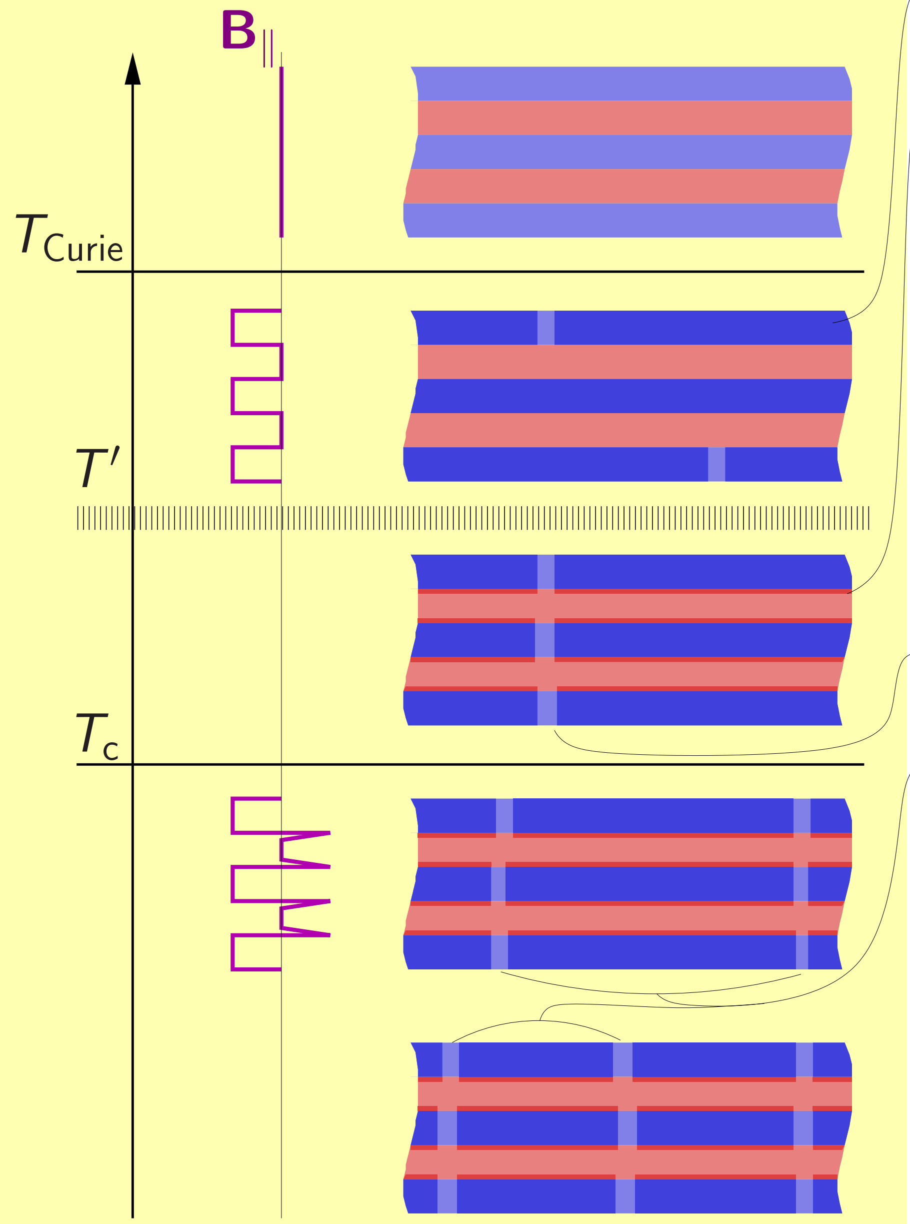






magnetic domains shrink below T_c
from $10\,\mu m$ to $5\,\mu m$ when cooling

conclusion:



- all LCMO layers are magnetised parallel
- interface effect of $\mathbf{B}(z)$ of the order of 10 Å is measured at $T_{\mathrm{c}} < T' \approx 140\,\mathrm{K} < T_{\mathrm{Curie}}$

– *magnetic dead layer* or *antiphase proximity effect*

- simultaneous appearance of Bragg-sheets

– vertical correlation of magnetic domains

- increase of off-specular scattering below T_{c}

– shrinking of magnetic domains / characteristic lengthscale

- correlation of domain size with $T < T_{\mathrm{c}}$ and XMCD measurements support the *antiphase proximity effect*

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