J. Stahn, M. Radovic, C. Schneider
Paul Scherrer Institut, Switzerland
C. Aruta, R. Arpaia, M. Riaz, U. Scotti di Uccio, F. Miletto Granozio
CNR-SPIN and Dipartimento di Scienze Fisiche Univ. di Napoli *Federico II*, Italy
D. Maccariello, P. Perna
IMDEA-Nanociencia, Madrid, Spain

Magnetic phenomena at LSMO / PCMO interfaces

studied by Polarised Neutron Reflectometry

intro / motivation

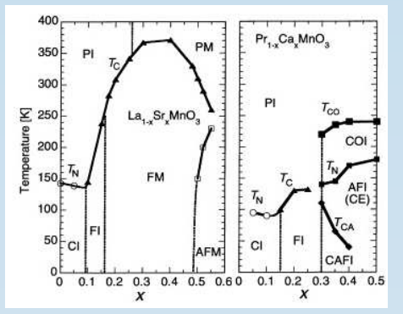
Magnetization at manganite interfaces is an issue of crucial importance, since it determines the degree of spin polarization of the current injected by a manganite electrode into any spintronic device. The presence of a magnetically dead layer has been frequently reported as a result of different experiments, including transport and magnetic properties of ultrathin films, x-ray magnetic dichroism, magneto-optic Kerr effect, tunneling magnetoresistance and photoemission spectroscopy.

For the present research, epitaxial superlattices grown in Naples by means of RHEED assisted pulsed laser deposition (PLD) have been investigated with polarised neutron reflectometry (PNR).

Here we present the results on the multilayer

$$\mathrm{Pr_{0.7}Ca_{0.3}MnO_3} \,/\, [\,\mathrm{La_{2/3}Sr_{1/3}MnO_3} \,/\, \mathrm{Pr_{0.7}Ca_{0.3}MnO_3}\,]_5 \,/\, \mathrm{NdGaO_3}$$

where the ferromagnetic LSMO layers, 5 unit cells thick, are embedded in-between insulating PCMO manganite spacer layers. Within the quite complex $\mathrm{Pr_{1-x}Ca_xMnO_3}$ phase diagram, this composition is at the border between a weak glassy ferromagnet and an antiferromagnet:



Phase diagrams of bulk LSMO and PCMO
taken from Y. Tokura & Y. Tomioka: MMM **200**, 1 (1999).

F: ferromagnet, AF: antiferromagnet, P: paramagnet
I: insulator, M: metal, CO: charge ordered, C: canted

Unlike previous reports suggesting that single LSMO films thinner than about 10 unit cells should not exhibit the ferromagnetic-metallic double exchange state, our 5 unit cells thick LSMO layers separated by PCMO spacing layers showed a record-high Curie temperature and metal-insulator transition temperature.

results

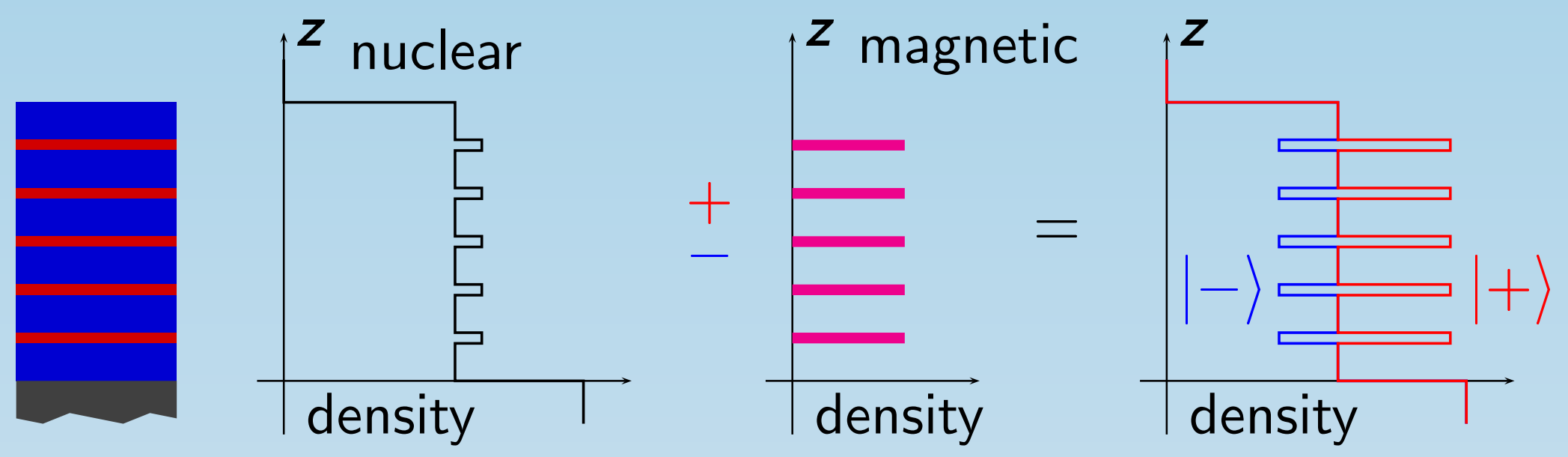
The structural and the magnetic depth profiles of various multilayers have been measured by polarised neutron reflectometry. The main finding of theses experiments is, that no reduced or even suppressed magnetisation is observed within LSMO towards the interface. Instead a magnetic interface layer is formed within PCMO. The size and strength of this layer depend on temperature and external field strength, and eventually also on the cooling regime.

next steps

– PNR investigation of intermediate T;
– PNR with various cooling regimes and H;
– transport measurements;

measurements & analysis

- Neutrons experience a potential given by the nuclear (isotope) densities and by a magnetic induction **B**:



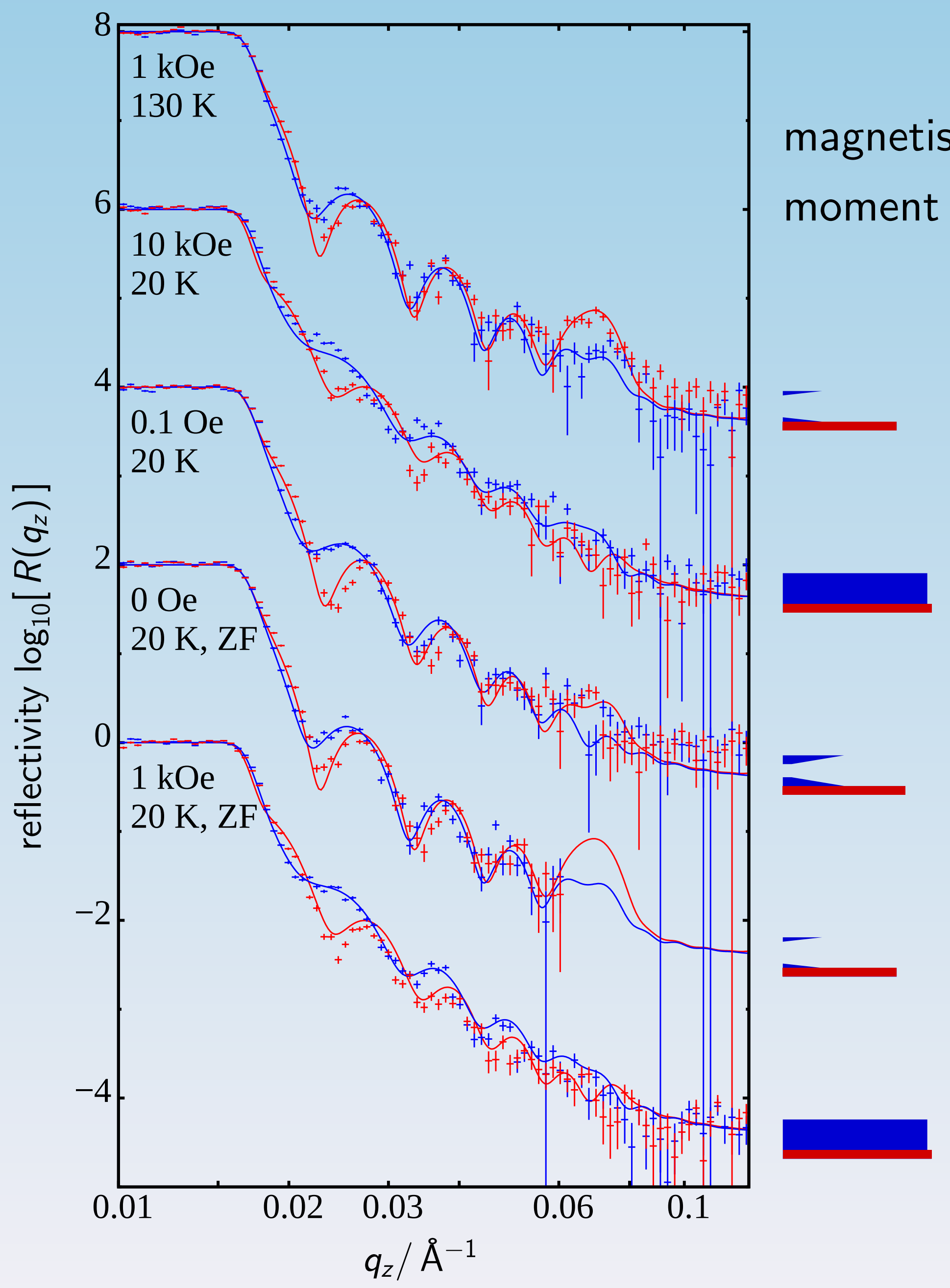
The latter depends on the orientation of **B** relative to the neutron spin.
⇒ spin-polarisation allows to disentangle both contributions.

- A periodic depth-profile leads to Bragg-reflections (at $q_z \approx 0.065\,\text{Å}^{-1}$), the total height of the film to a modulation of the reflected beam.

- nuclear density: low contrast ⇒ no/weak peak

- magnetic density:
  - ○ increased contrast at interfaces (only one material is magnetic)
    ⇒ Bragg-peak increases
  - ○ increase contrast at surface (almost homogeneous **B** in both materials)
    ⇒ oscillations increase
  - ○ interface magnetism (i.e. non-sharp boundaries)
    ⇒ damping of the signal

- quantitative analysis via modeling & simulation



magnetism:
moment per Mn in . . .

LSMO	PCMO
$2.6\,\mu_B$	$0 \to 0.9\,\mu_B$
$3.4\,\mu_B$	$3.3\,\mu_B$
$2.8\,\mu_B$	$0 \to 1.4\,\mu_B$
$2.6\,\mu_B$	$0 \to 0.9\,\mu_B$
$3.4\,\mu_B$	$3.3\,\mu_B$

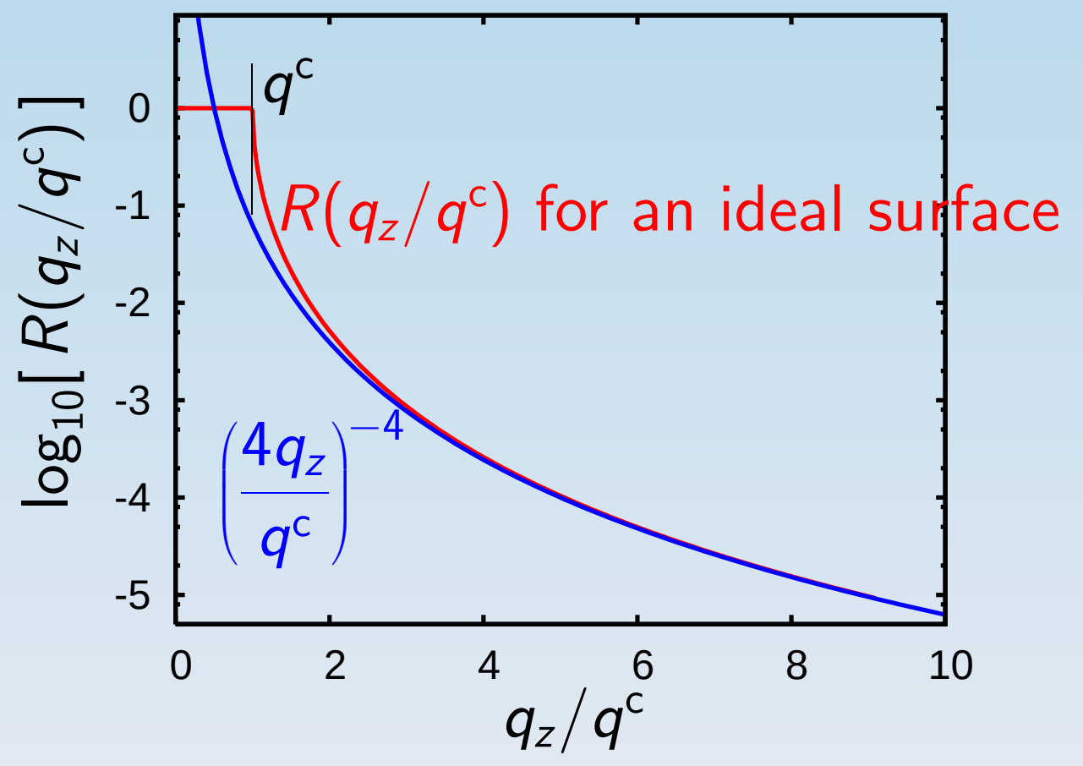
findings:
- no reduction of M within LSMO
- induced M in PCMO

polarised neutron reflectometry

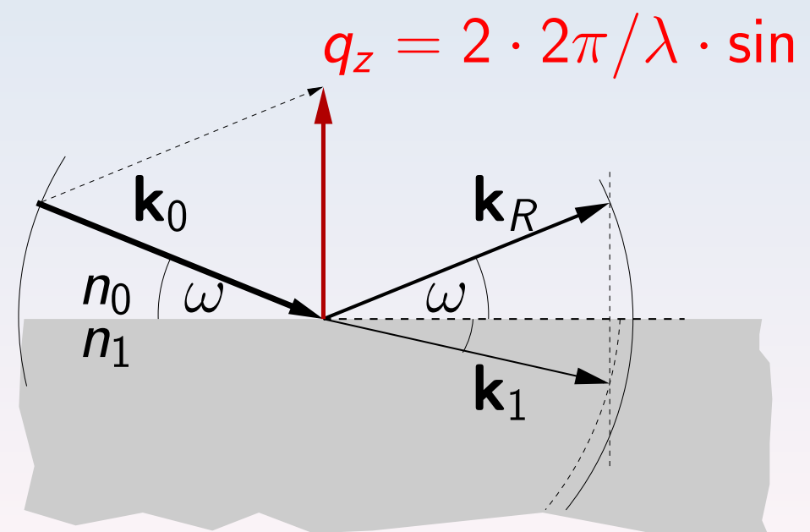
light-reflectometry
(no lab conditions)

○ transmitted light is refracted
○ flat surfaces reflect
○ parallel interfaces lead to interference

Fresnel reflectivity
- reflectivity of a sharp flat surface
- total external reflection for $q_z < q^c$
- exponential decay of $R(q_z)$ for $q_z > q^c$

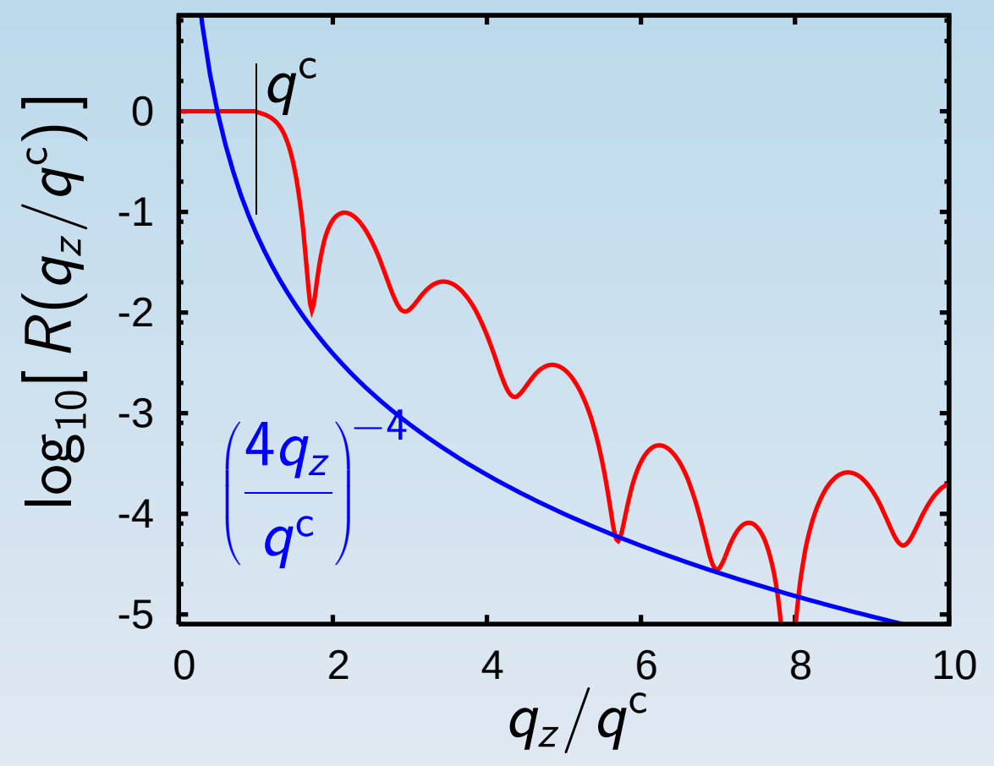


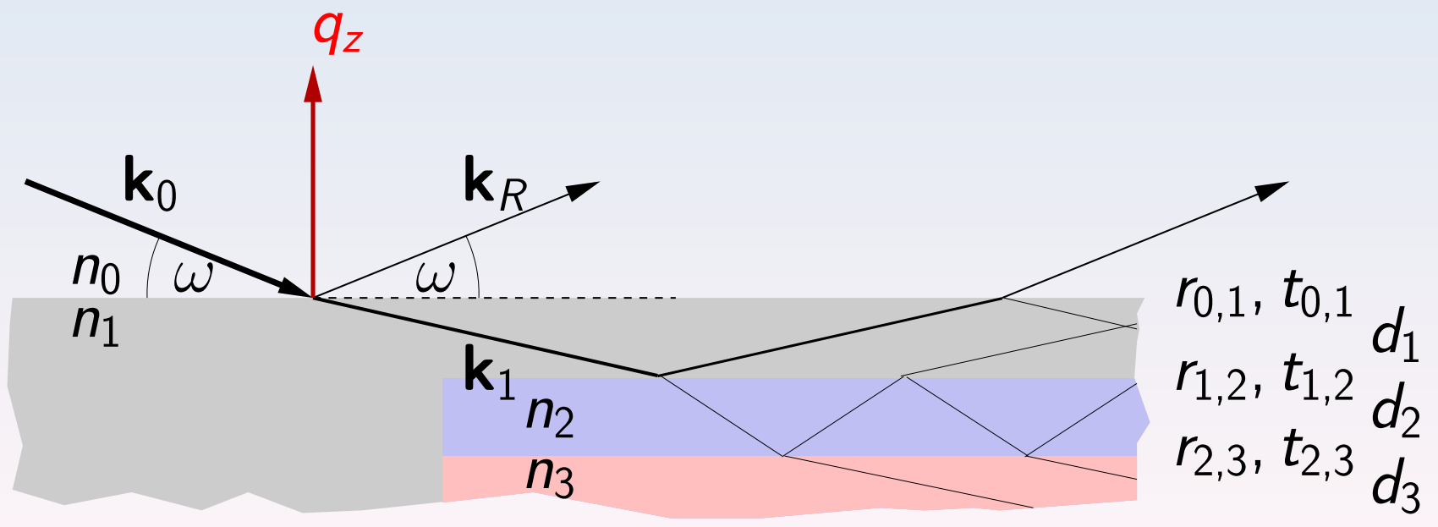
$q_z = 2 \cdot 2\pi/\lambda \cdot \sin\omega$



reflected intensity of a multilayer
- interference of all waves

$$\begin{aligned} r &= r(q_z, n_0, n_1, n_2, \ldots, d_1, d_2, \ldots) \\ R(q_z) &= |r(q_z)|^2 \end{aligned}$$

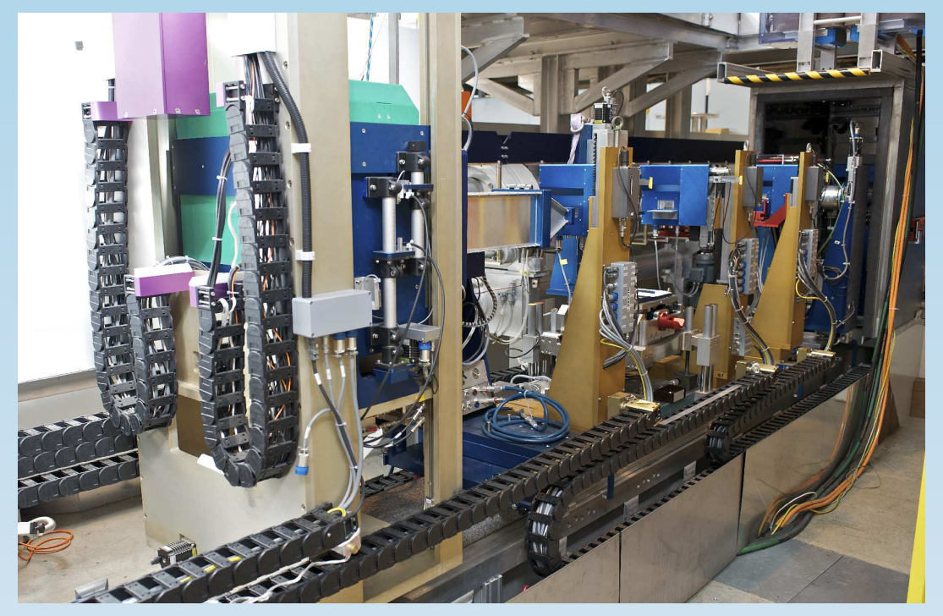




d_1 thickness of layer 1
$r_{2,3}$ reflectance of interface 2/3

neutrons / x-rays:
$\lambda \in \{1 \ldots 20\,\text{Å}\}$
$\omega^c < 1^\circ$

neutron reflectometer *Amor* at PSI, Switzerland.



energy-dispersive set-up

variation of λ with fixed ω
detection via time-of-flight