Formation and ripening of antiferromagnetic domains in a Fe/Cr multilayer

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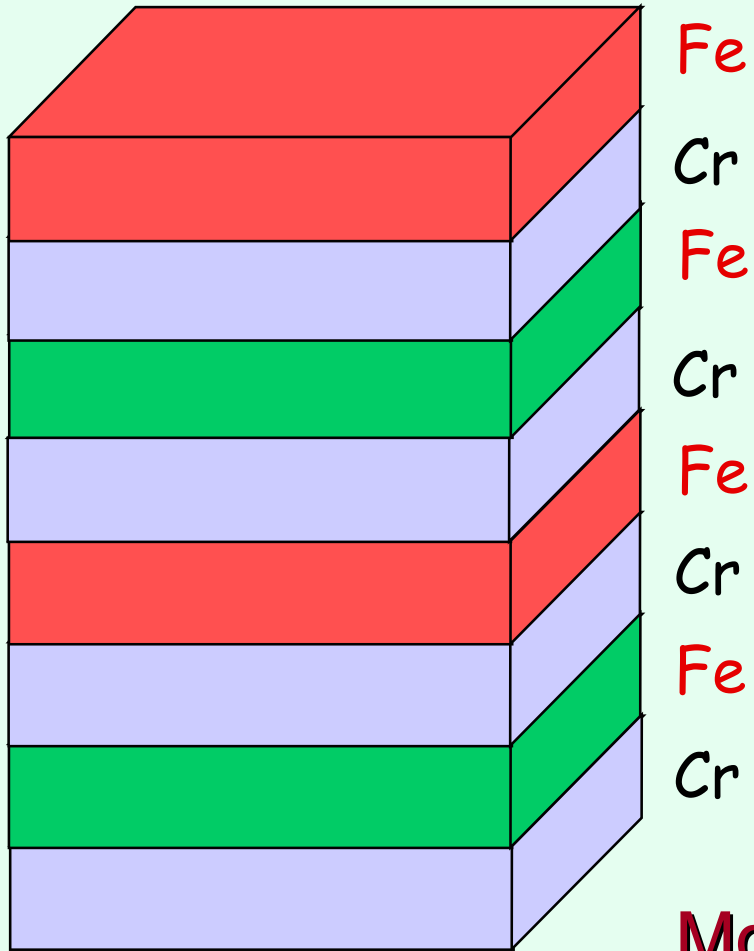
Outline

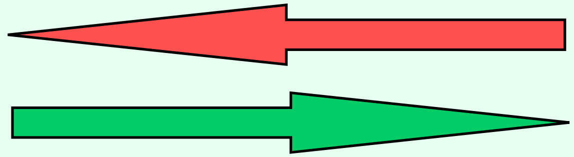
- Introduction: coupled multilayers, magnetic and domain structure, reflectometry
- Native patch-domain formation in antiferromagnetically coupled multilayers
- Spontaneous and irreversible growth of the domain size in decreasing field: the domain ripening

AF coupled multilayers and patch domains

Antiferromagnetically coupled Fe/Cr multilayer



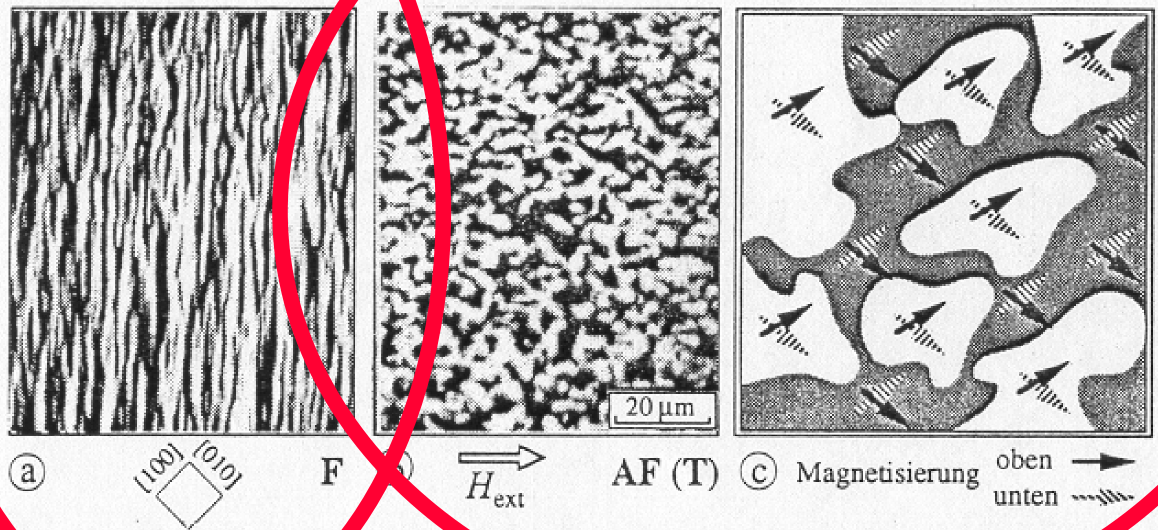
Layer magnetisations:



MgO(001)[^{57}Fe(26Å)/Cr(13Å)]$_{20}$

Domains in a Fe/Cr/Fe trilayer

M. Rührig et al., Phys. Stat. Sol. (a) **125**, 635 (1991).
M. Rührig, Theses, 1993.

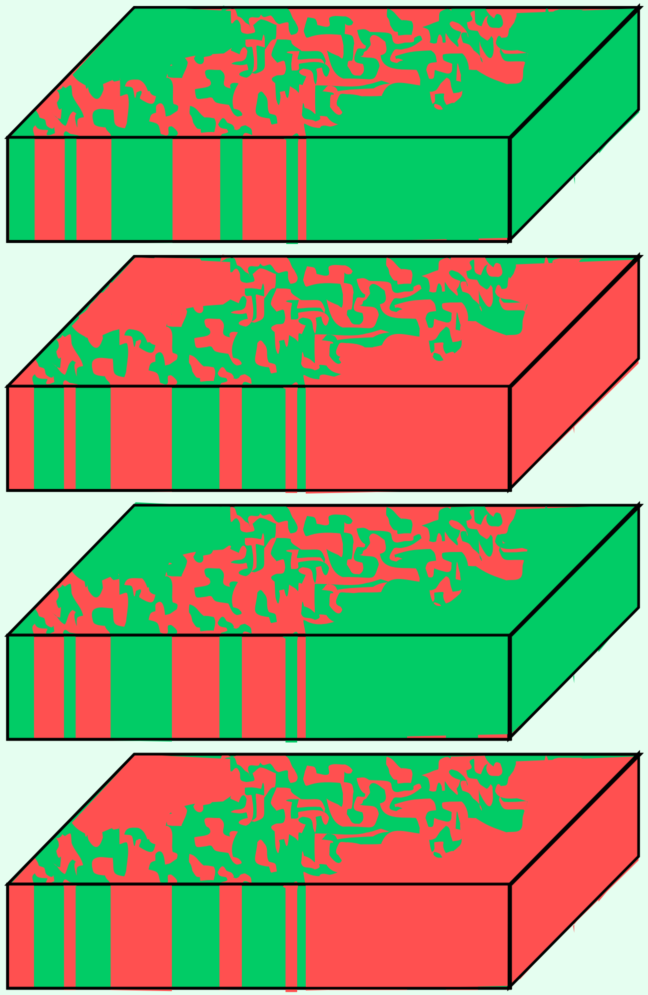


'Ripple' domains

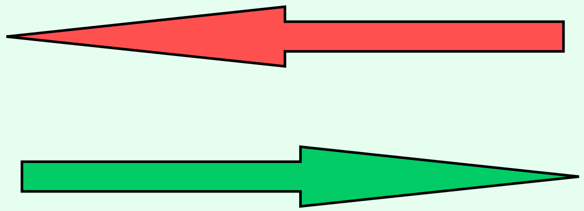
'Patch' domains

Abb. 3.5 Domänenkeimbildung in ferromagnetisch- und antiferromagnetisch gekoppelten Zonen der einkristallinen Keilproben aus der Sättigung in schwerer Richtung kommend. Für *F*-gekoppelte Bereiche findet man wie in Einfachschichten eine ausgeprägte *Ripplebildung*, die in Remanenz zu einem stark anisotropen Domänenmuster führt (ⓐ). Im *AF*-Gebiet dagegen beobachtet man ein isotropes fleckenartiges Keimbildungsmuster (ⓑ), da dort die bevorzugte Antiparallelstellung der Magnetisierung der beiden Schichten eine Kompensation der transversalen Komponente der Magnetisierung bewirkt (ⓒ). Das Fleckenmuster wird auch in den Übergangszonen gefunden (s. unten). (ⓐ und ⓑ aus [3.9])

Patch domains in AF-coupled multilayers



Layer magnetisations:



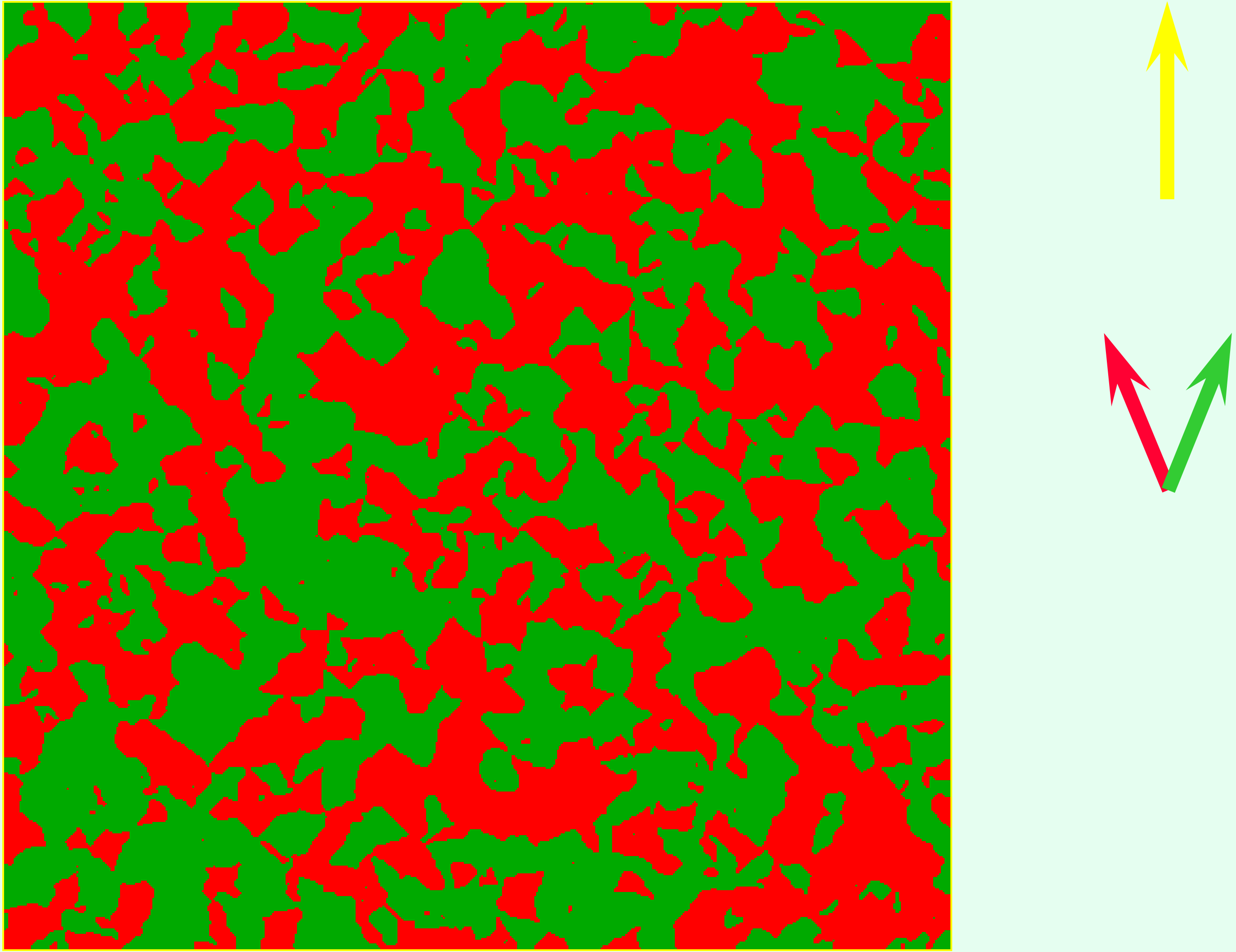
The 'magnetic field lines' are shortcut by the AF structure → the stray field is reduced → no 'ripple' but 'patch' domains are formed.

The patch domains

- The domain-size-dependent magnetoresistance noise may be as high as to limit GMR applications → 'tailoring' of the domain structure ('domain engineering') is required.

- The first step towards domain engineering is to understand the formation mechanism of patch domains.

Domain formation on leaving saturation



From saturation to remanence: the domain ripening

- The domain structure in remanence may differ from that of the native domains.
- The domain-wall energy is increasing in decreasing field.
- In order to decrease the surface density of the domain-wall energy, the multilayer spontaneously increases the average size of the patch domains (‘ripening’).
- The spontaneous domain growth is limited by domain-wall pinning (coercivity).

Polarized Neutron Reflectometry (PNR)

Neutron reflectometry: the scattering amplitudes

$$f_{\mathrm{n}} = f_{\mathrm{n}}^{\mathrm{nuc}} + f_{\mathrm{n}}^{\mathrm{mag}}$$

isotope-specific scattering length

$$f_{\mathrm{n}}^{\mathrm{mag}} = \pm b$$

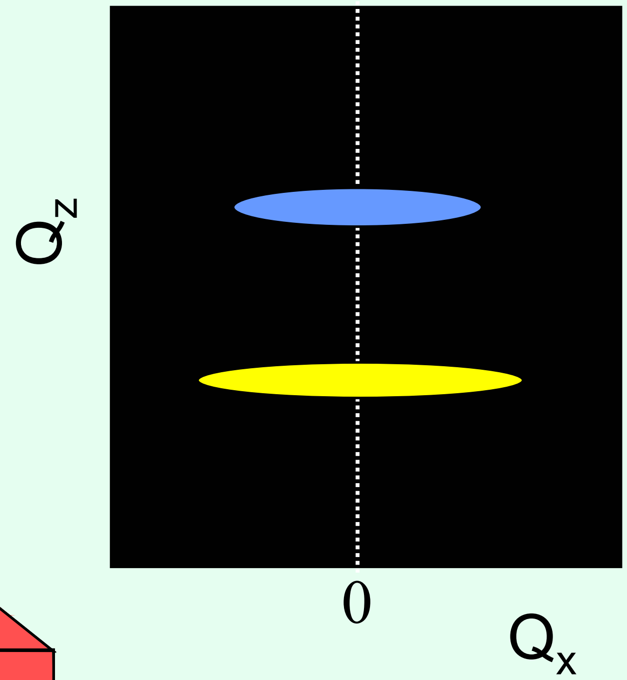
+ for neutron spin parallel to magnetisation

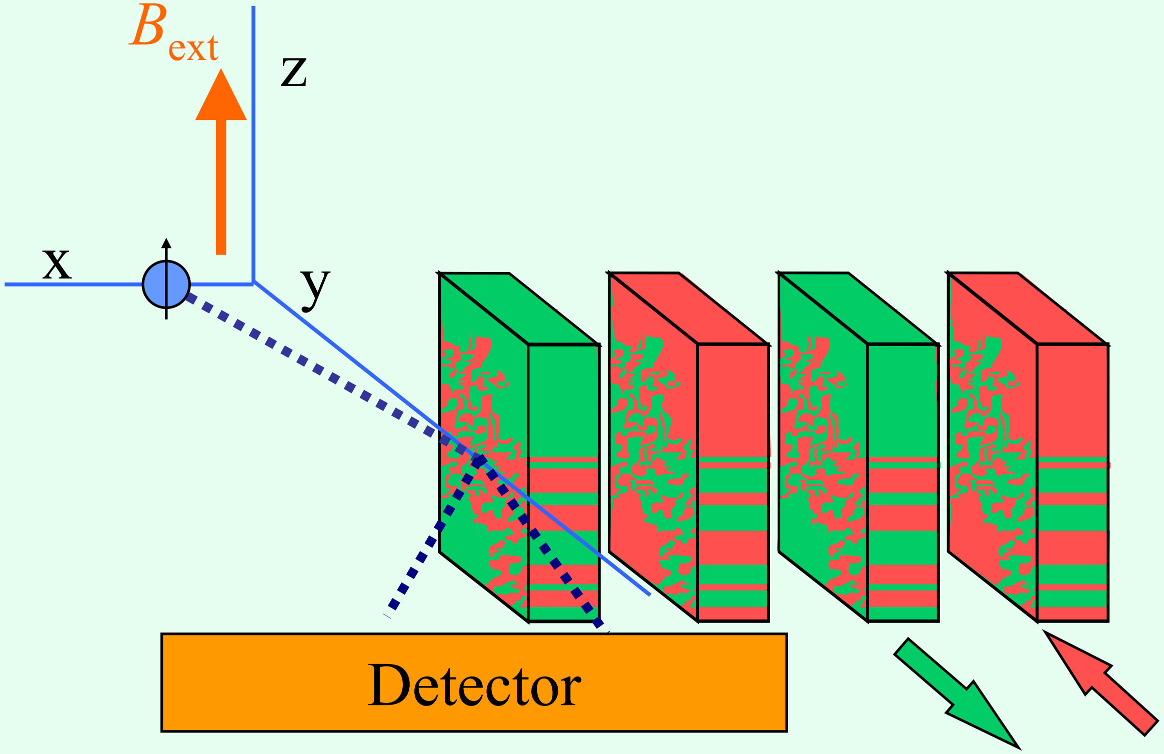
- for neutron spin antiparallel to magnetisation

for neutron spin perpendicular to magnetisation:
spin-flip scattering!

Neutron reflectometry

AF coupling: magnetic doubling of the 'unit cell', appearance of half order reflection peaks





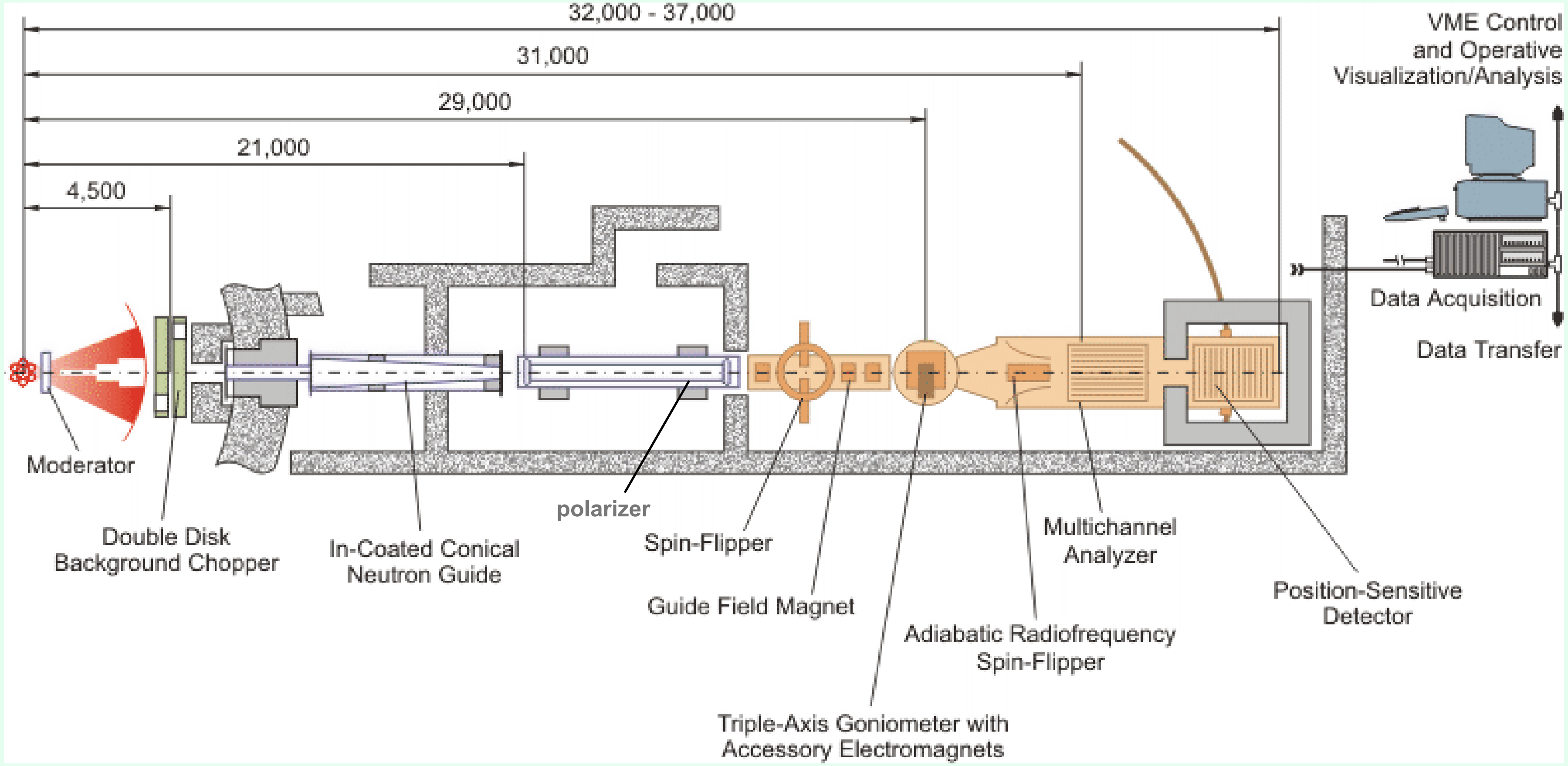
The off-specular scattering width

- The off-specular (diffuse) scattering width around an AF reflection stems only from the magnetic roughness.
- The diffuse scattering width ΔQ_x at an AF reflection is inversely proportional to the correlation length ξ of $\mathbf{M}$:

$$\xi = 1/\Delta Q_x$$

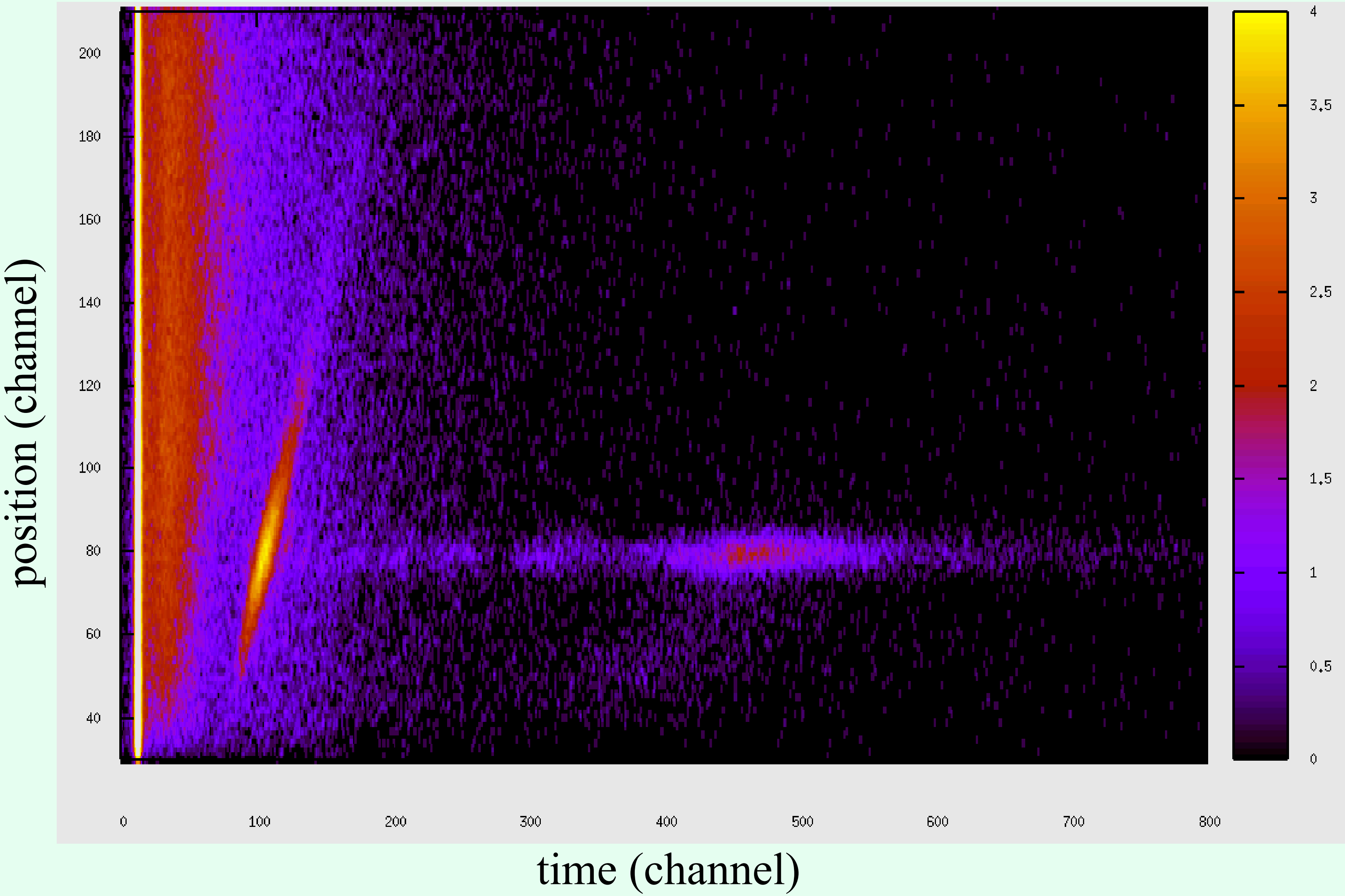
At an AF reflection, ξ is the average domain size!

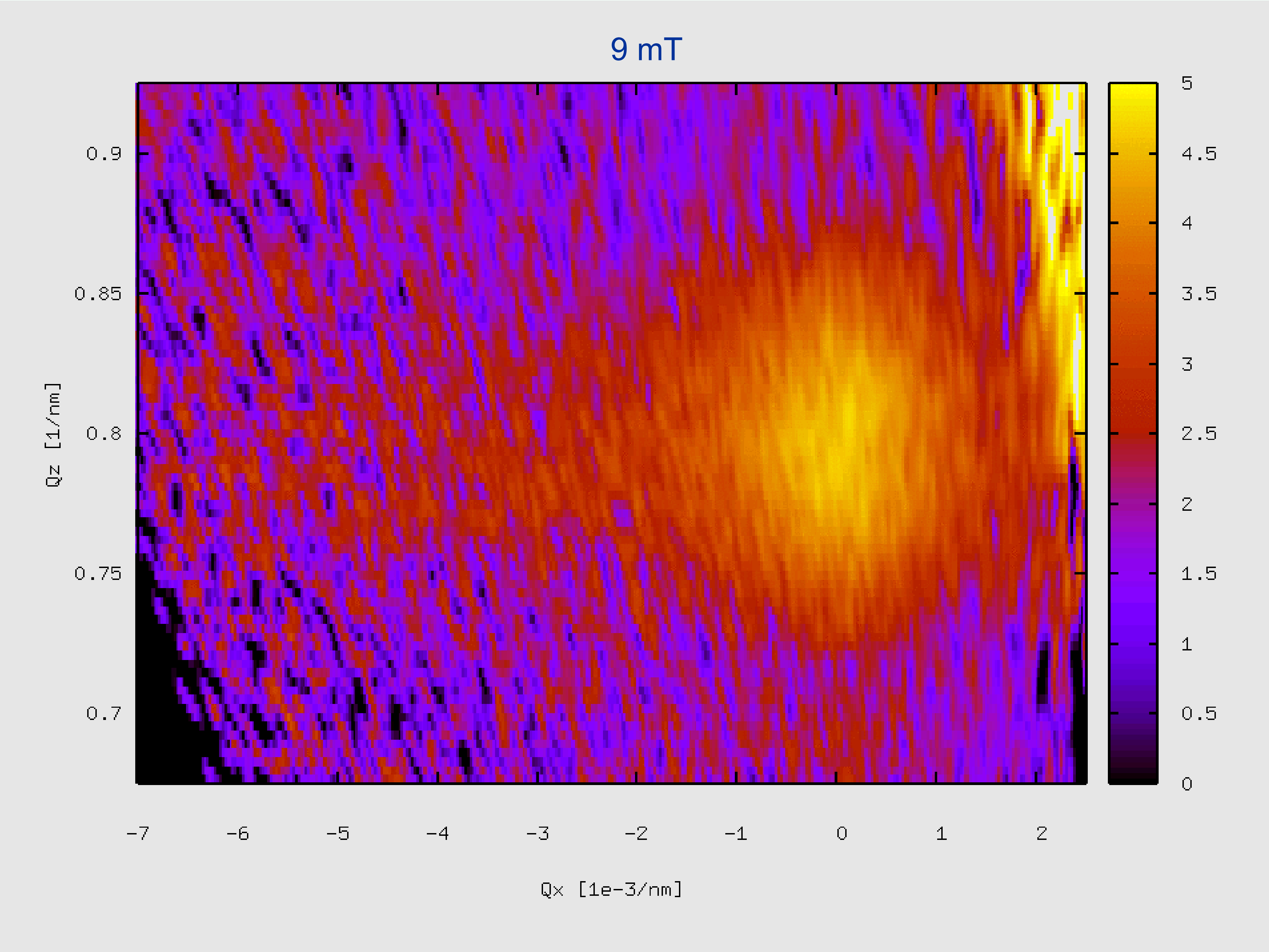
Arrangement of the PNR experiments



http://nfdfn.jinr.ru/ibr2.html

Raw data

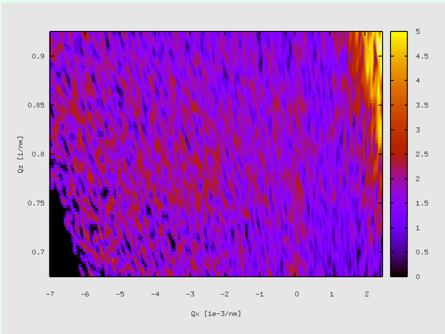

position (channel)
200
180
160
140
120
100
80
60
40
0
100
200
300
400
500
600
700
800
time (channel)
4
3,5
3
2,5
2
1,5
1
0,5
0


9 mT
Qz [1/nm]
0.9
0.85
0.8
0.75
0.7
-7
-6
-5
-4
-3
-2
-1
0
1
2
Qx [1e-3/nm]
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0

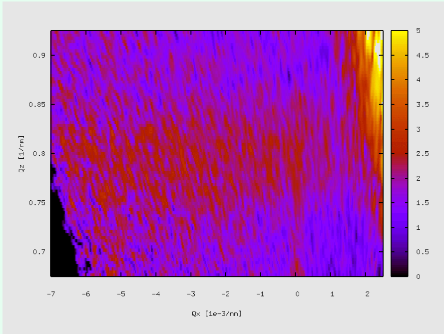
Domain ripening as seen by PNR

Domain ripening: off-specular PNR, easy axis

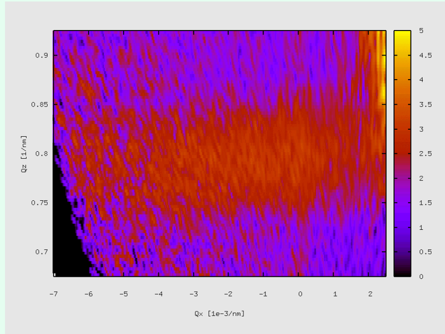
Q_z



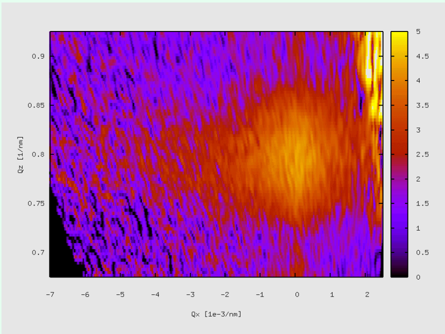
600 mT



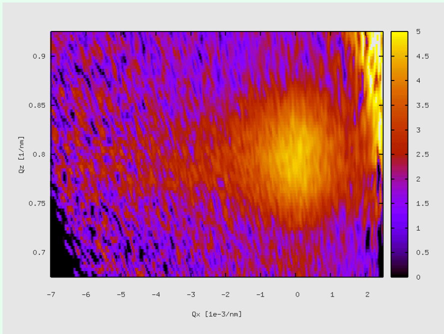
450 mT



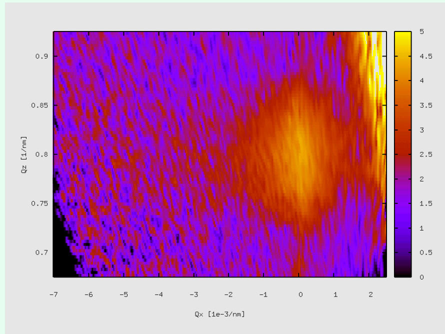
300 mT



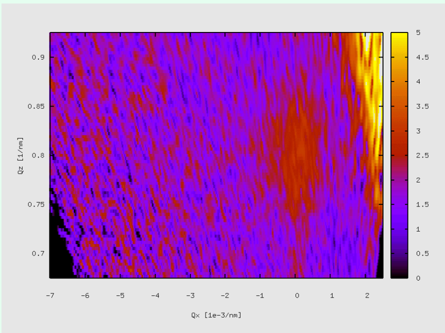
150 mT



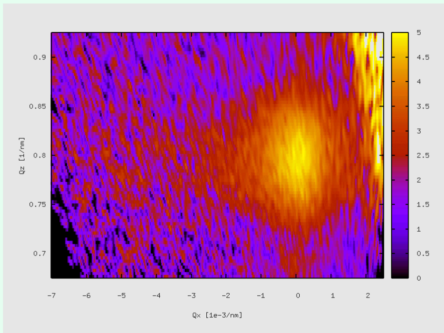
9 mT



300 mT



600 mT



9 mT

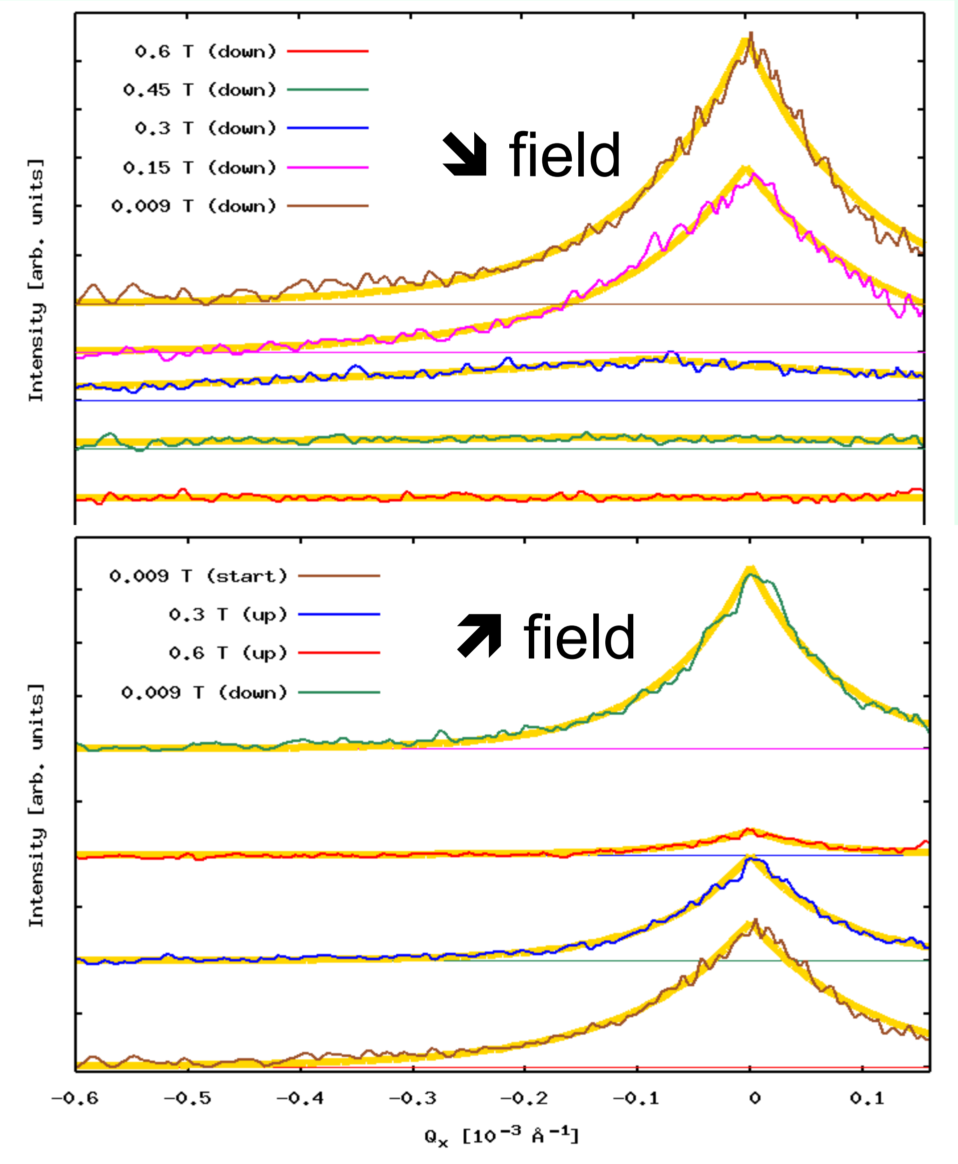
$MgO(001)[^{57}Fe(26Å)/Cr(13Å)]_{20}$

+ → - scattering

JINR Dubna, REMUR

Q_x

Domain ripening: PNR (Q_z-integrated)



Correlation length:

$$\xi = 1/\Delta Q_x$$

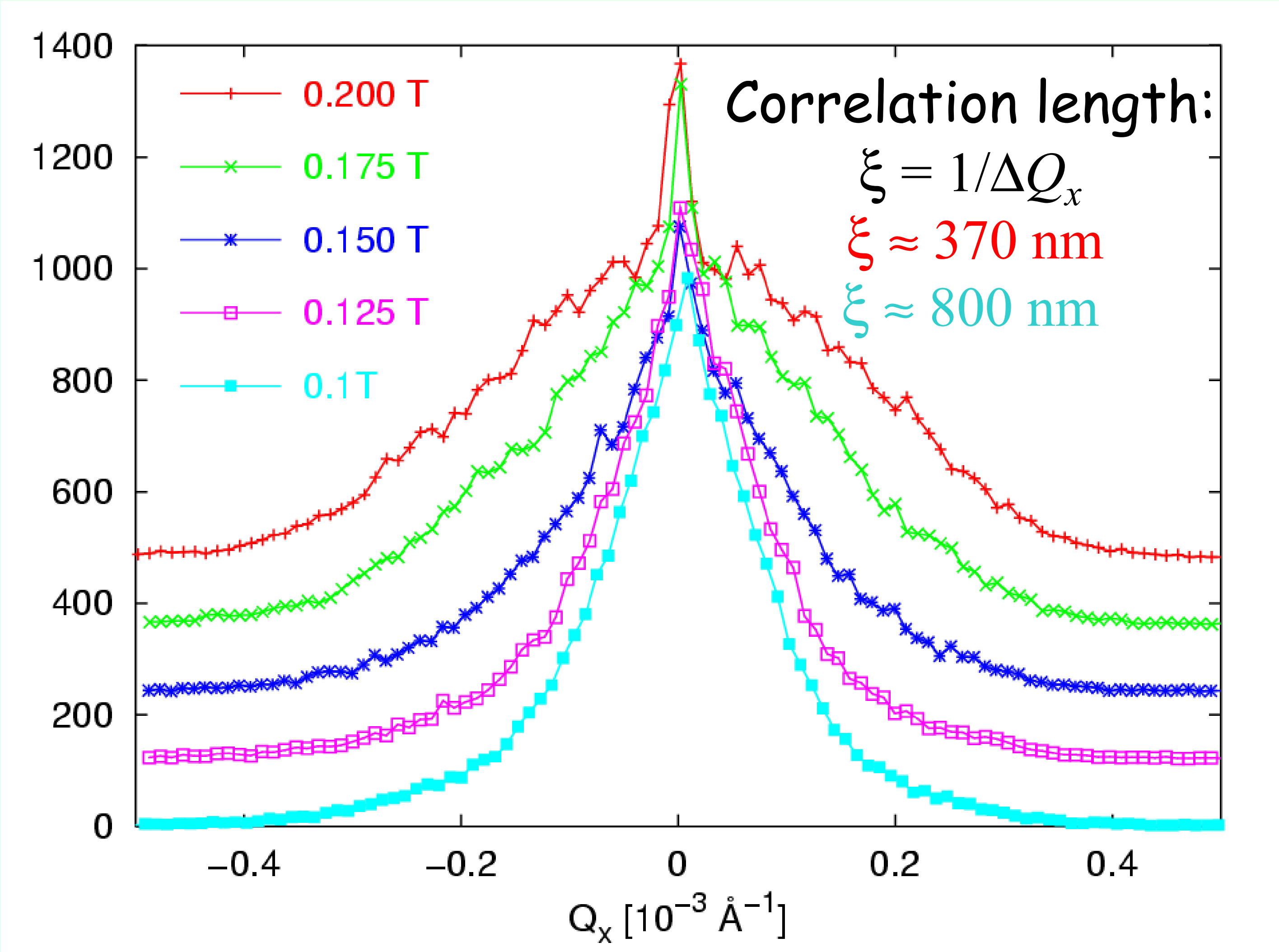
$\xi \approx 370$ nm

$\xi \approx 800$ nm

➔Domain ripening is an irreversible process: the domain size does not appear to change on later increasing or decreasing the field.

Domain ripening: off-specular SMR

MgO(001)[^{57}Fe(26Å)/Cr(13Å)]$_{20}$
2Θ @ AF reflection, hard axis



ESRF
ID18

Conclusions

- The native domains do not change their shape and size from saturation down to 200 mT (evidence from SMR measurements).
- The native domain size is 370 nm.
- Between 300 and remanence, ripening of the domains takes place (SMR evidence: 200-100 mT). The domain size increases to 800 nm.
- The domain ripening is irreversible, as long as the domain structure is not erased by saturating the multilayer.