Neutron Depolarization Imaging

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AUNIRA Summer School

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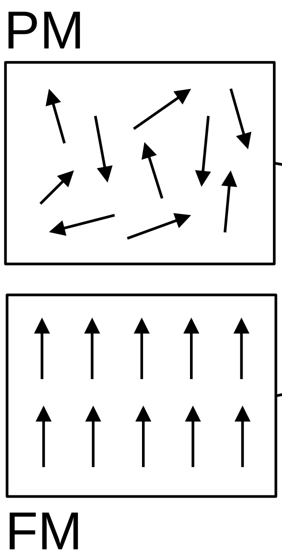
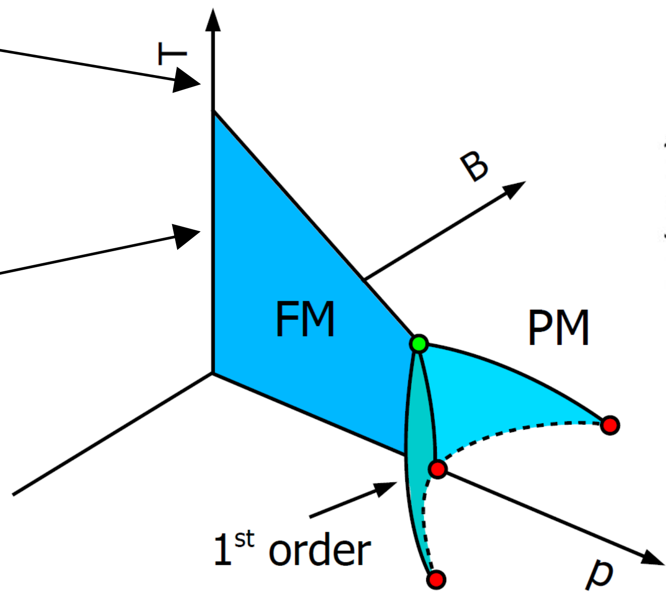
MLZ is a cooperation between:

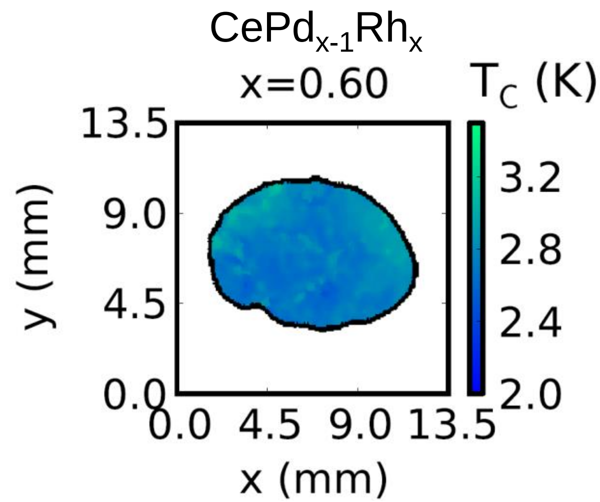
Outline

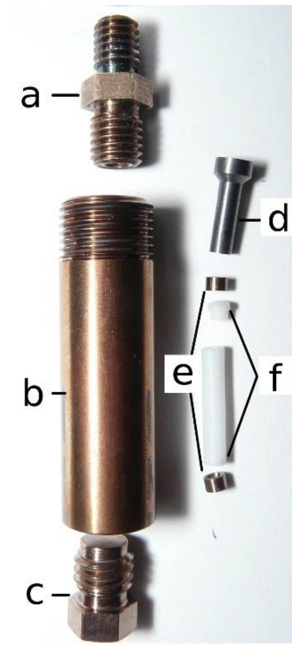
1. Motivation
2. NDI Setup (at ANTARES)
3. Theory of Neutron Depolarization Imaging (NDI)
4. Examples

Phase diagram of a ferromagnet





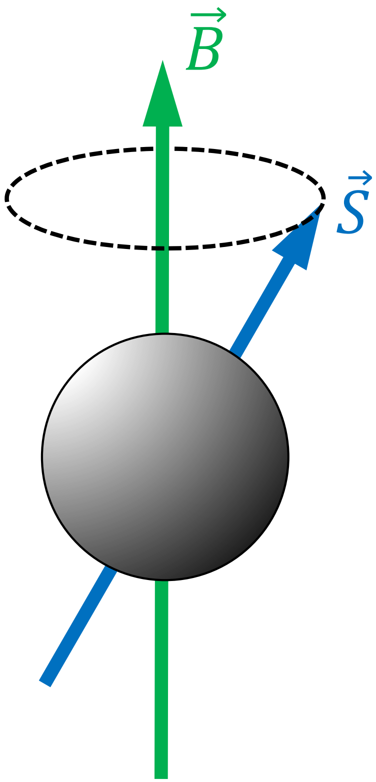


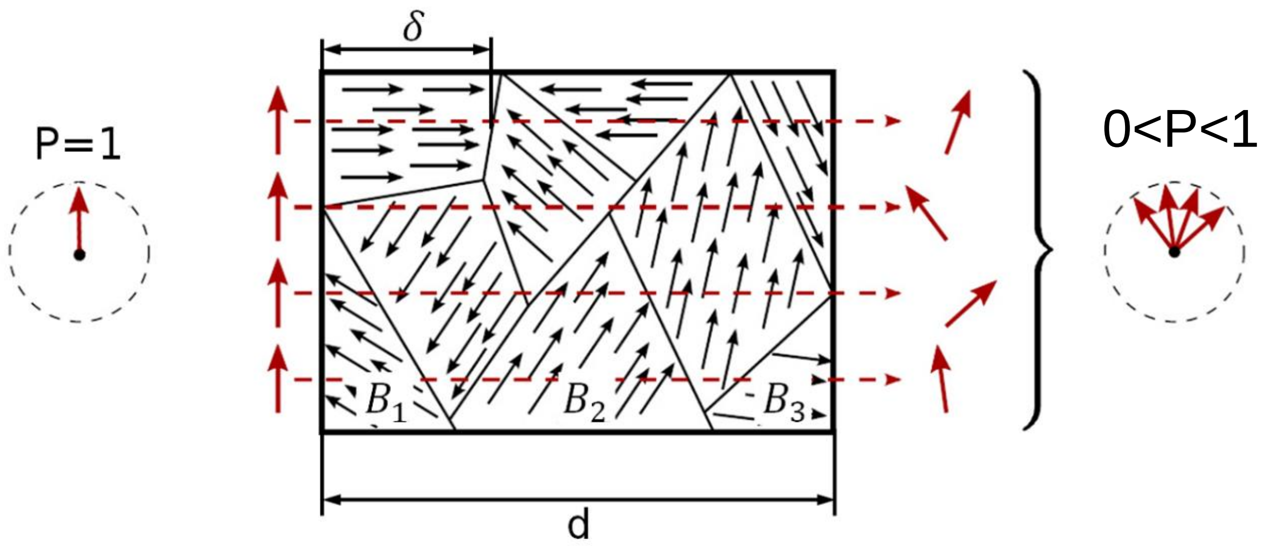


- FM can show complex phase diagrams (T, B, p, …)
- Demanding sample environment necessary
- NDI very suitable for investigation of FM
- Non-destructive and spatially resolved

Schmakat, PhD thesis (2016)

Neutron depolarization due to ferromagnetism



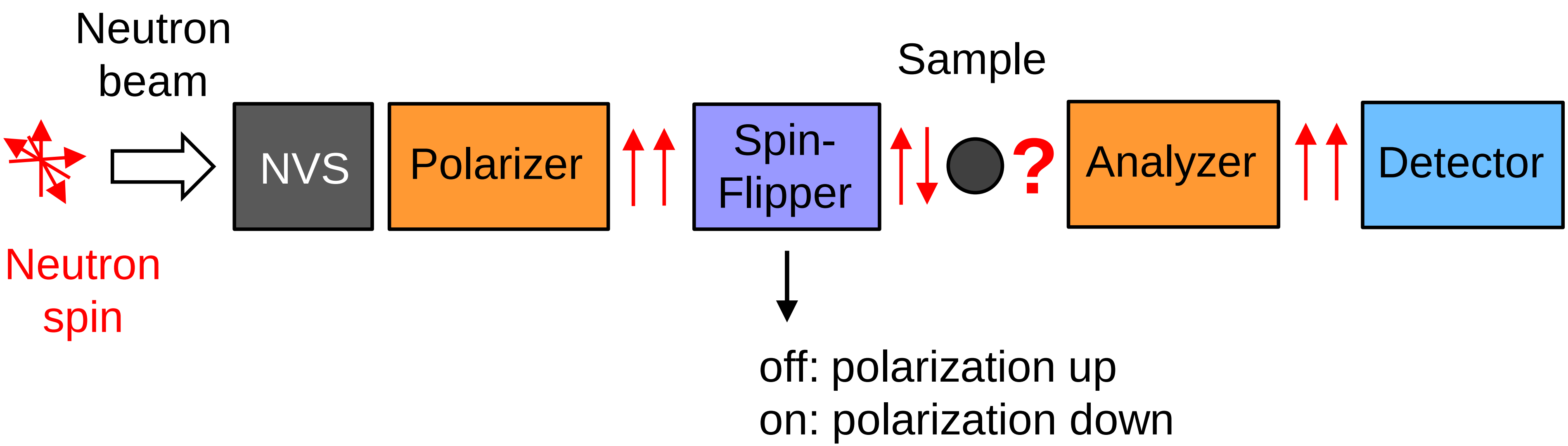


Larmor precession: $\vec{\omega}_L = -\gamma \vec{B}$

spin rotation per domain: $\varphi_L = \omega_L t$

M. Schulz, PhD thesis (2010)

NDI setup



Polarisation: $P = \frac{1}{P_0} \frac{I_\uparrow - I_\downarrow}{I_\uparrow + I_\downarrow}$

Polarizers

3He cell

http://mlz-garching.de/wissenschaft-und-projekte/instrumentservice/neutronenoptik.html

- Absorption cross section of 3He depends on spin direction of the 3He nucleus
- Polarized 3He gas in glass container
- P=80%

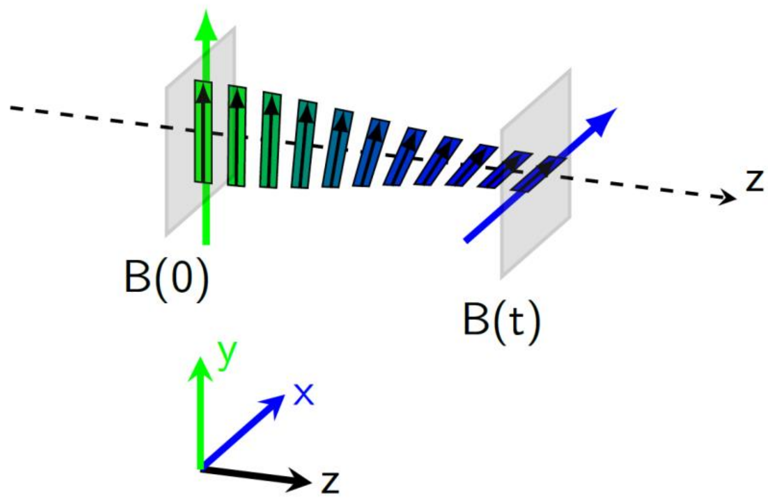
V-cavity

https://www.swissneutronics.ch/index.php?id=190

- Polarizing supermirrors aranged in V-shapes
- One spin direction transmitted, other reflected to the side
- P=80%

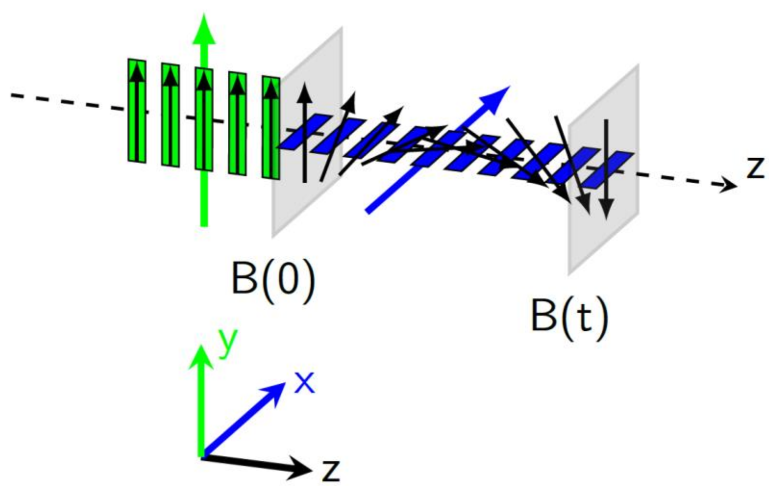
Neutron spins in dynamic magnetic fields

adiabatic field transition



neutron spin follows the magnetic field

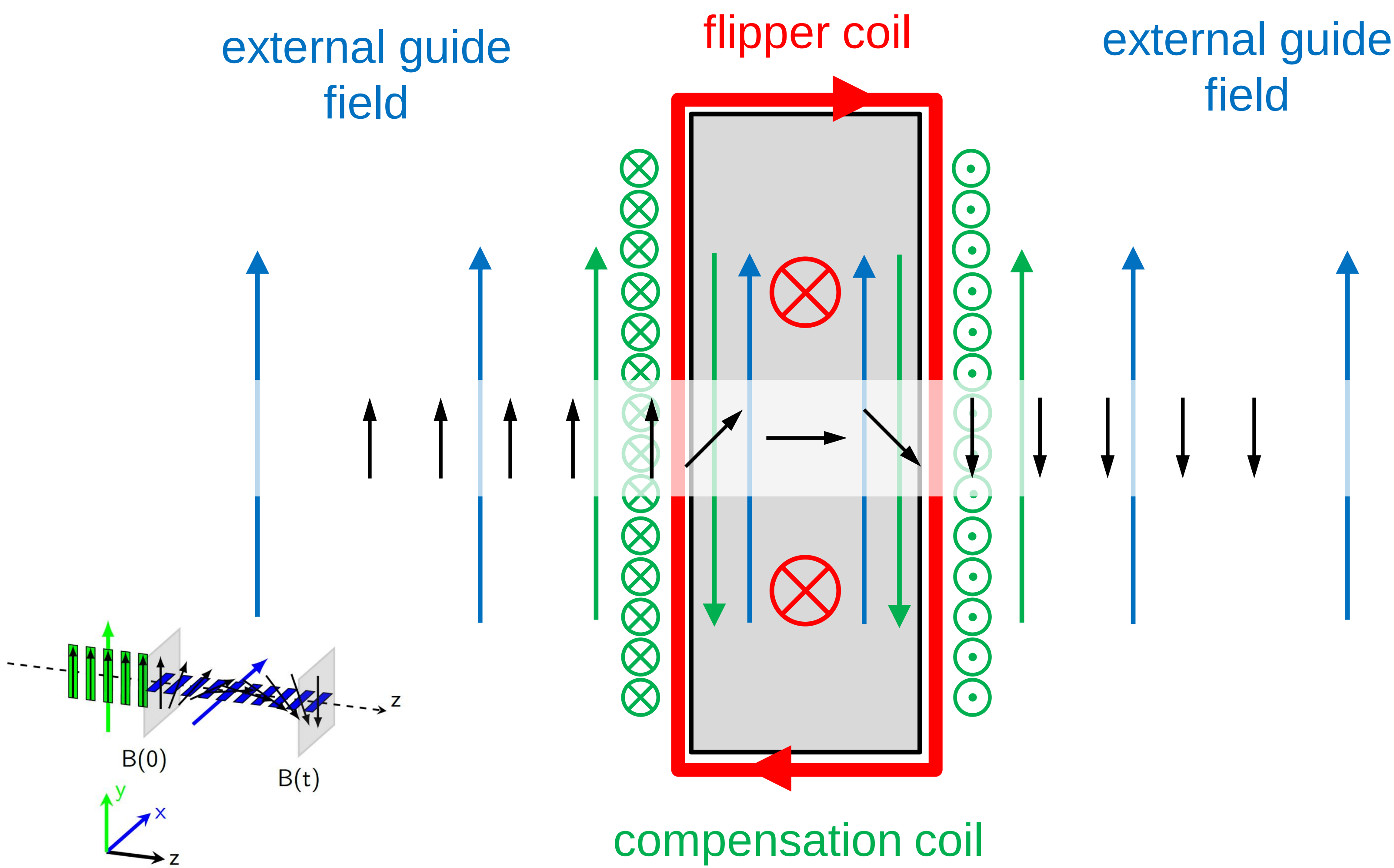
non-adiabatic field transition

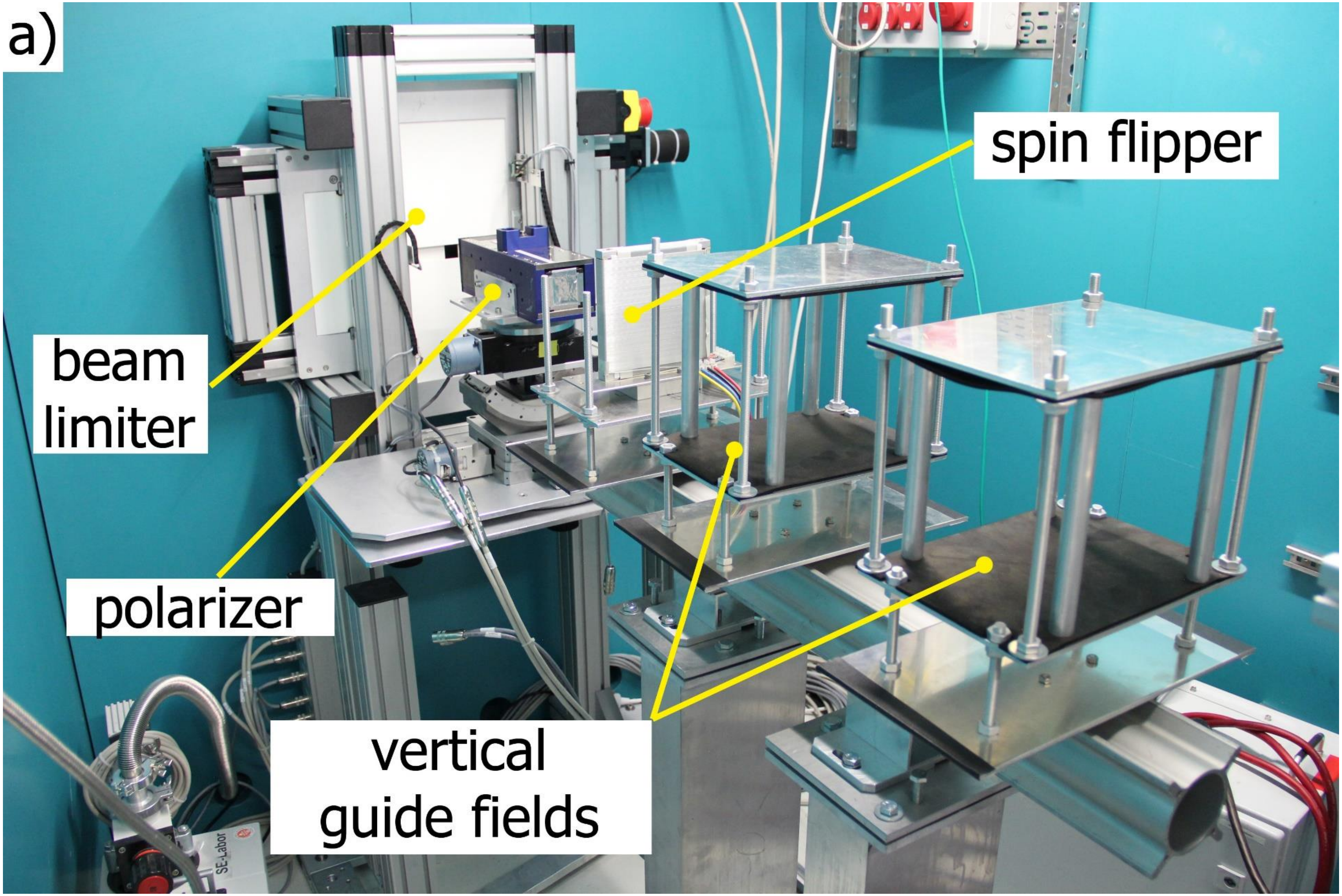


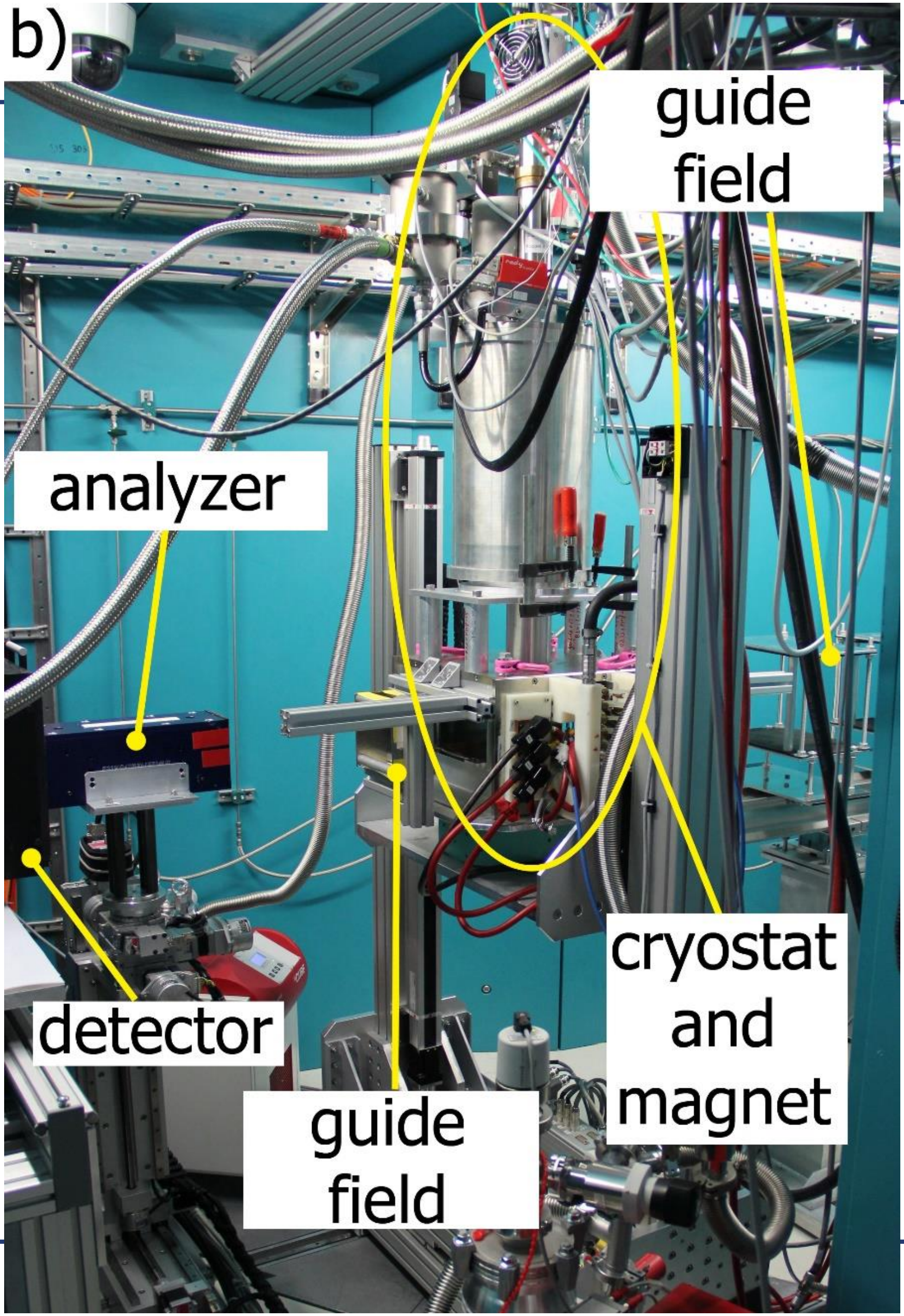
neutron spin starts precessing around the magnetic field

P. Schmakat, PhD thesis (2016)

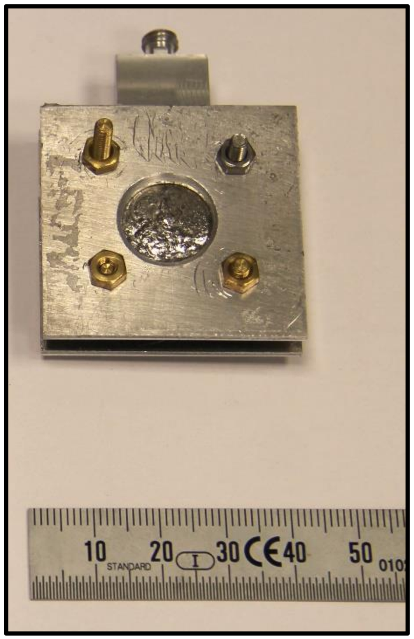
Mezei spin flipper

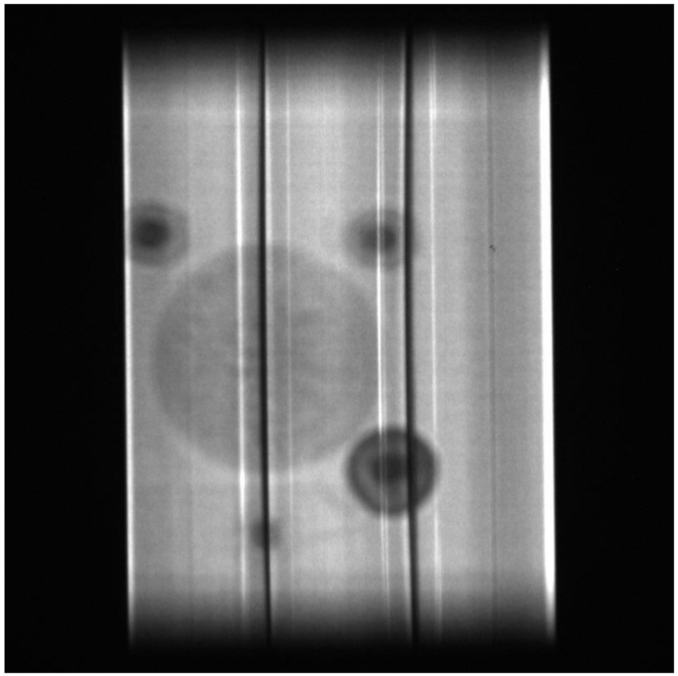



a)
spin flipper
beam limiter
polarizer
vertical guide fields
SE-Labor

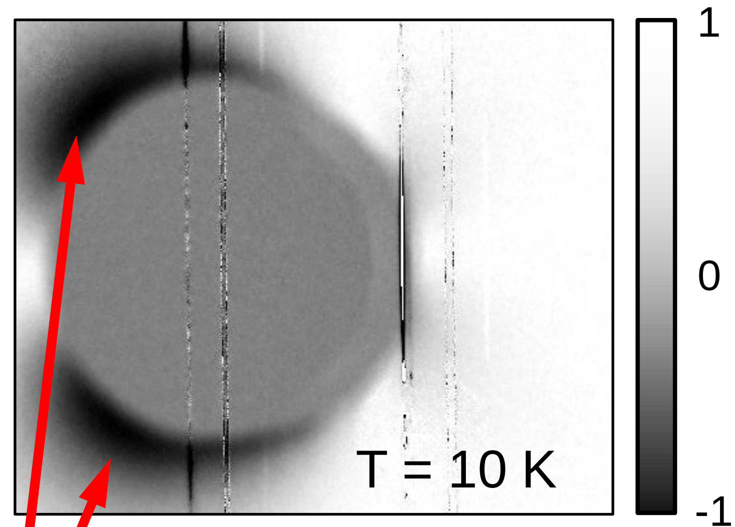

b)
guide field
analyzer
detector
guide field
cryostat and magnet

NDI measurements on UGe_2 (T_C = 52.6 K)





neutron radiography of the UGe_2 sample



stray fields

Normalized polarization image of the UGe_2 sample

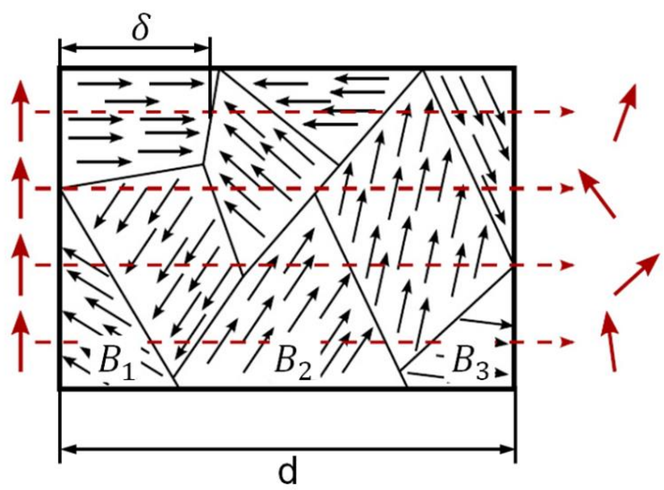
Seifert, Haslbeck, Janoschek, to be published

Theory of neutron depolarization

Developed by Halpern and Holstein (1941)

Ansatz: $$P = P_0 \left[\left\langle \frac{B_{\parallel}^2}{B^2} \right\rangle_B + \left\langle \frac{B_{\perp}^2}{B^2} \right\rangle_B \left\langle \cos\left(\gamma B \frac{\delta}{v}\right) \right\rangle_\delta \right]^N$$

δ	average domain size
N=d/δ	average number of domains
d	sample length



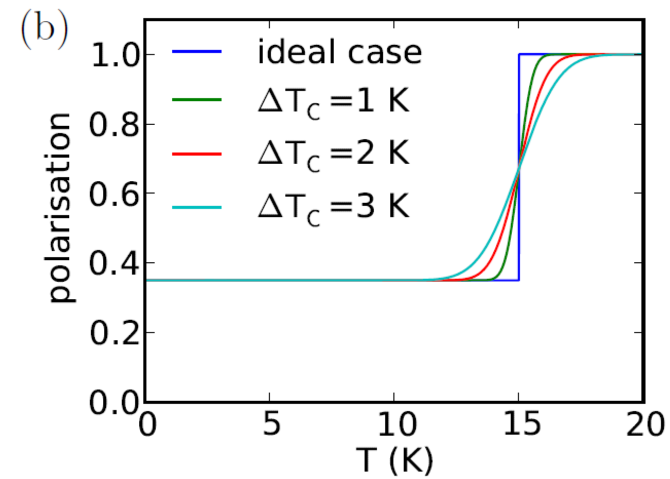
Assumptions:

- Isotropic domain orientation
- Infinitely small domain walls

Theory of neutron depolarization

Large Larmor angle per domain ($\varphi_L > 2\pi$):

$$P = \left(\frac{1}{3}\right)^N P_0$$

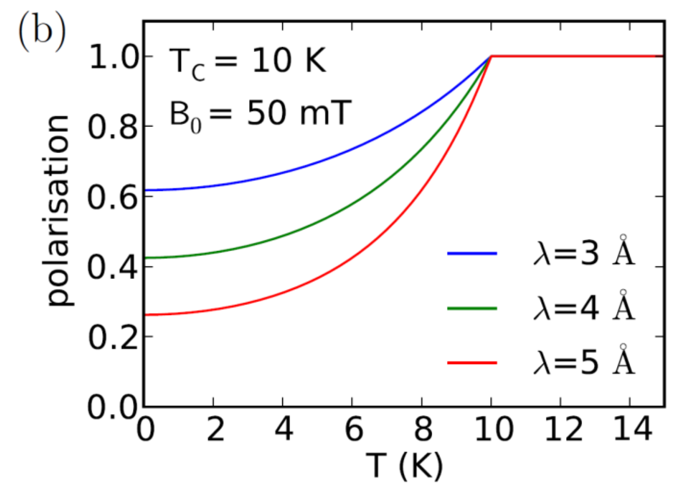


Small Larmor angle per domain ($\varphi_L \ll 2\pi$):

$$P = P_0 \exp\left(-\frac{1}{3}\gamma^2 B^2 d \frac{\delta}{v^2}\right)$$

Temperature dependence:

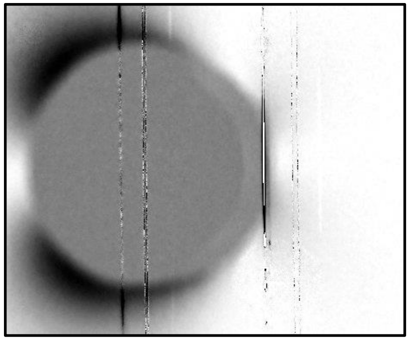
$$B^2(T) = \mu_0^2 M^2(T) = \mu_0^2 M_0^2 \left(\frac{T-T_C}{T_C}\right)^{1/\beta}$$

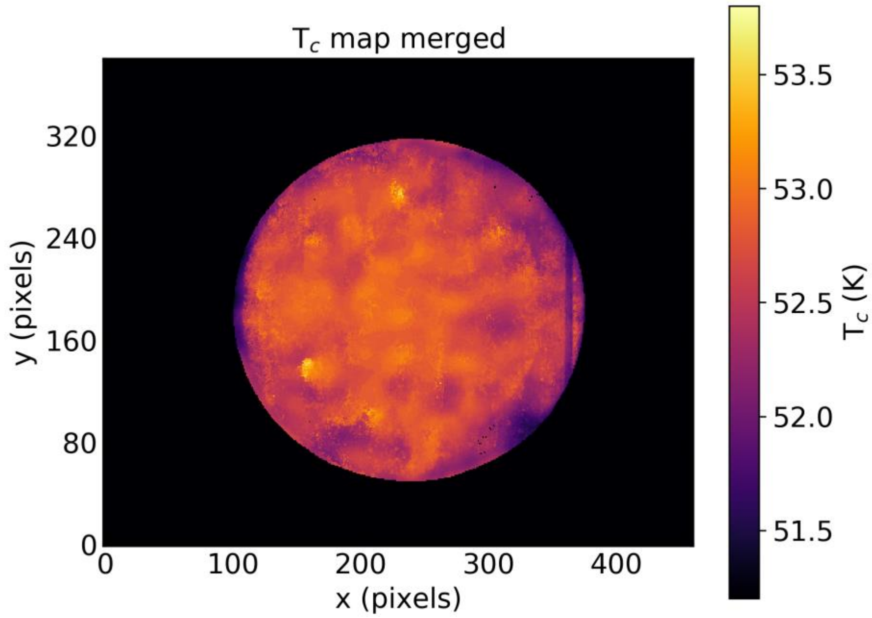


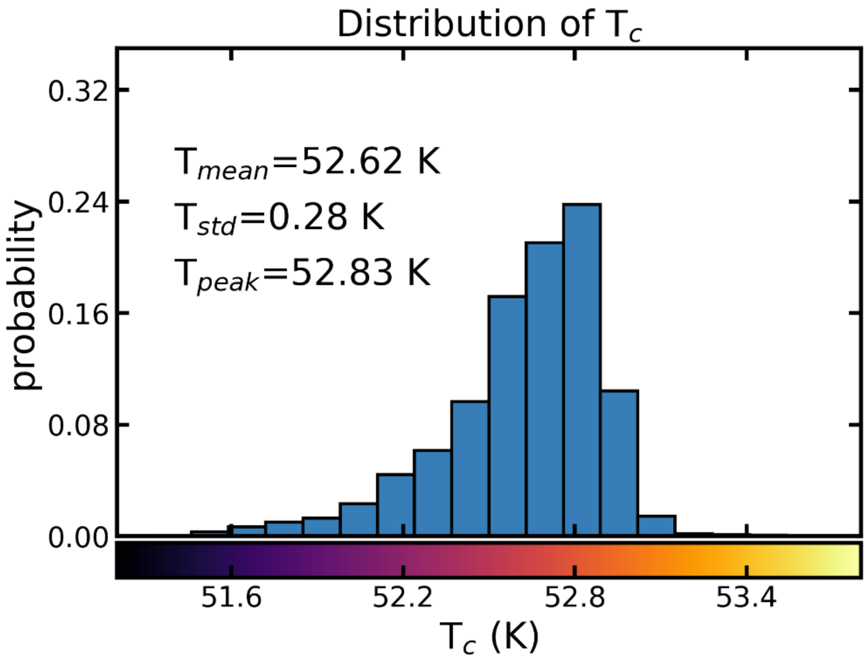
O. Halpern et al., PR 59, 960 (1941)
S. Mitsuda et al., PRB 45, 9788 (1992)
P. Schmakat, PhD thesis (2016)

UGe_2 evaluation

- Calculate normalized polarization images
- Pixelwise fit of depolarization function to data
- Plot fit parameters as a function of (x,y)



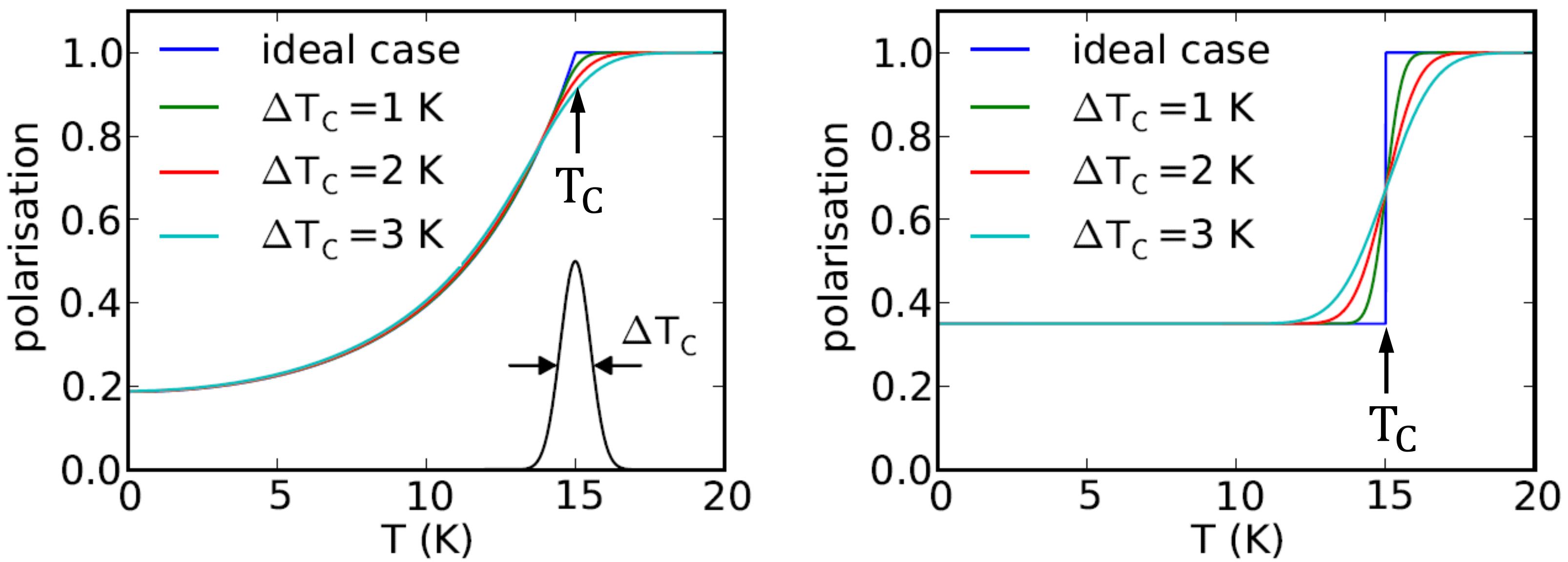




Seifert, Haslbeck, Janoschek, to be published

Broadening due to a T_C distribution

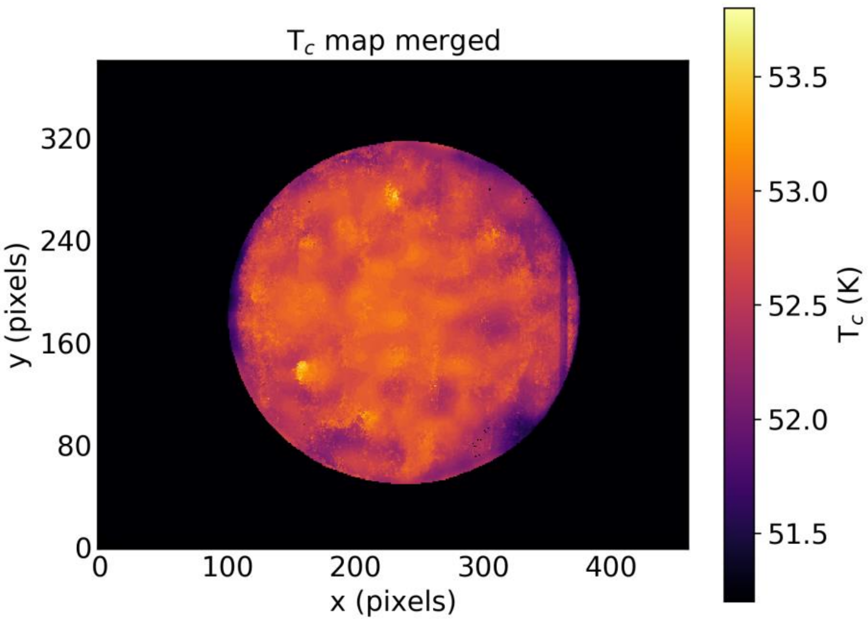
$\varphi_L \ll 2\pi$ $\qquad\qquad$ $\varphi_L > 2\pi$

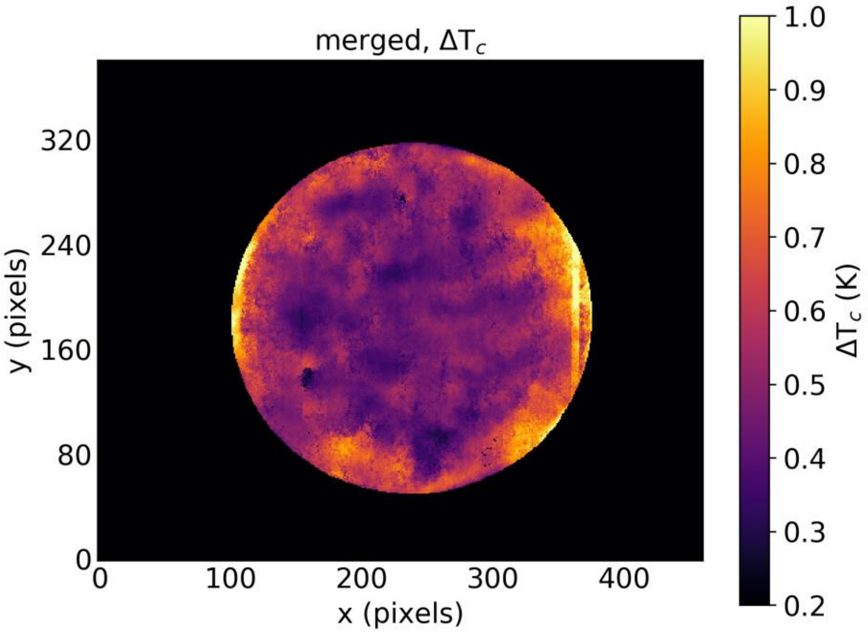


T_C distribution smears sharp features out

P. Schmakat, PhD thesis (2016)

T_C map and Gaussian width



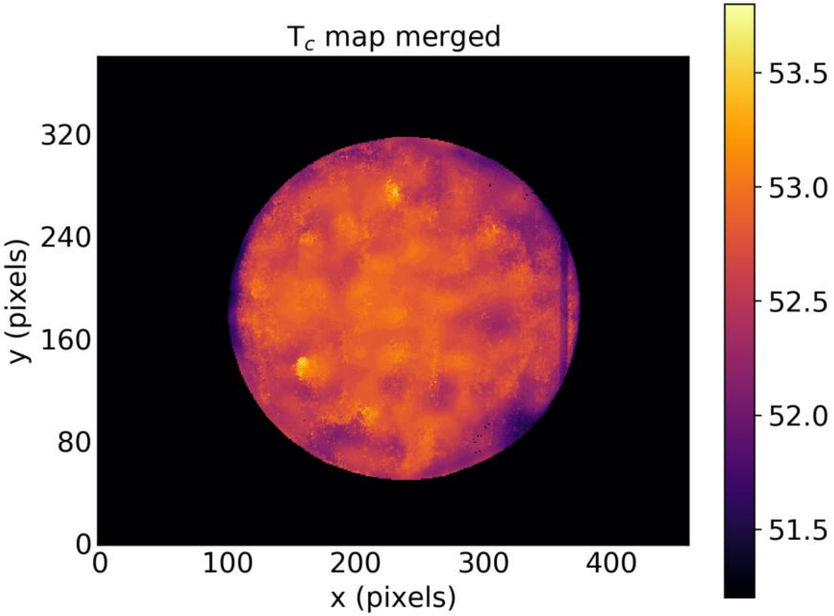


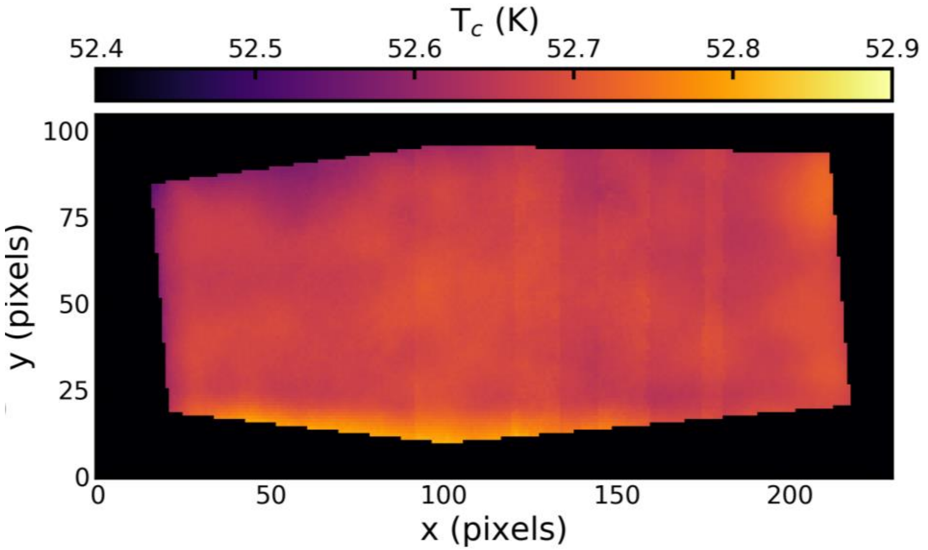
Curie temperature T_C

Width of gaussian distribution

Seifert, Haslbeck, Janoschek, to be published

Comparison of different samples



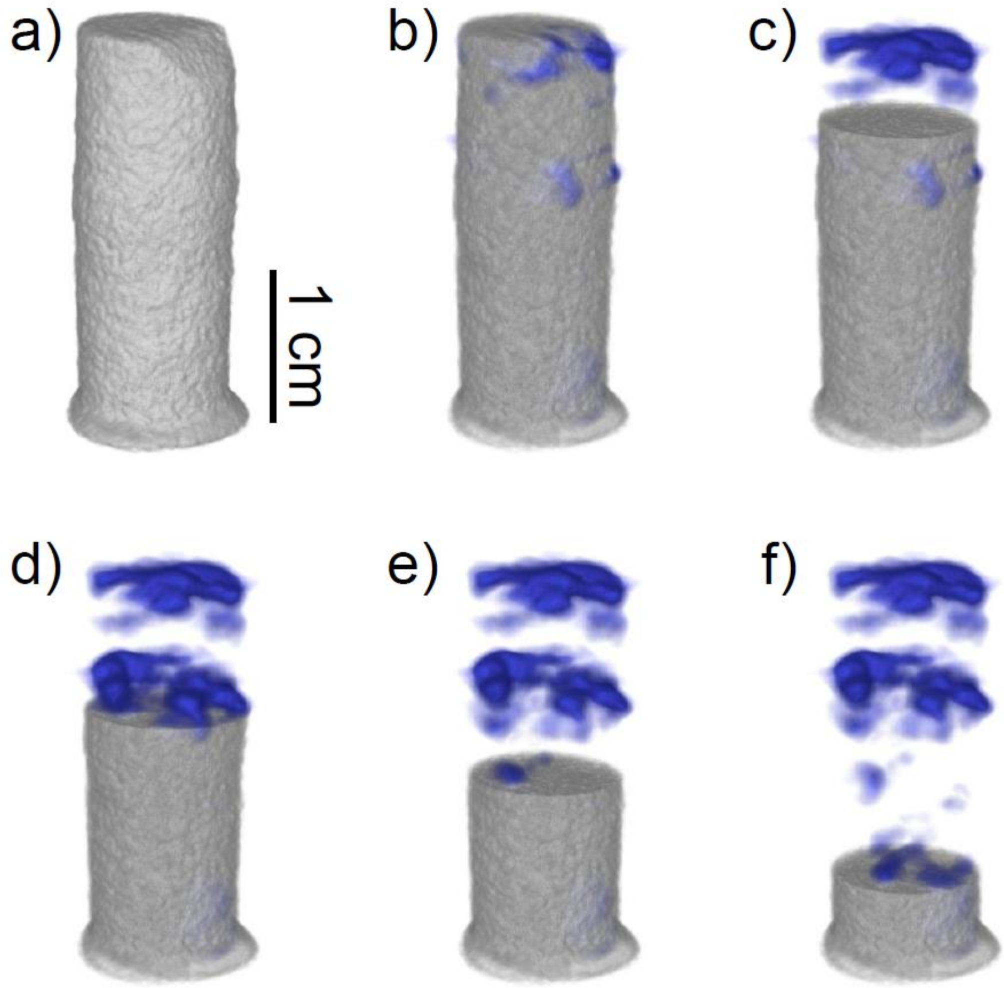


polycrystalline UGe_2 sample

single crystalline UGe_2 sample

Seifert, Haslbeck, Janoschek, to be published

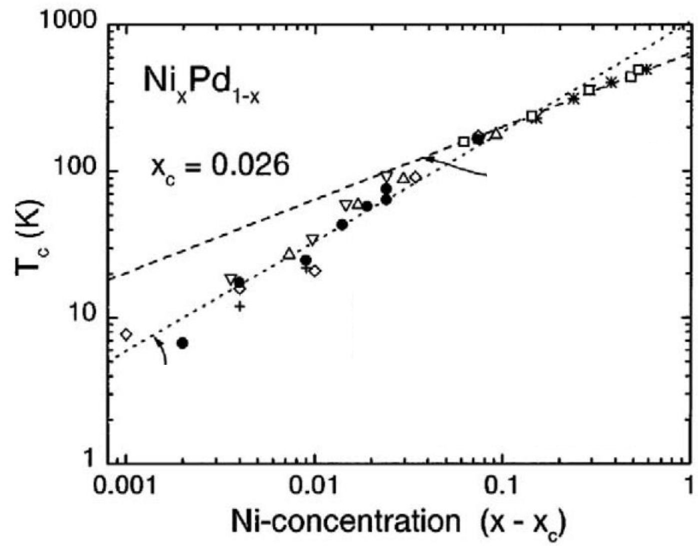
Neutron Depolarization Tomography



Schulz, PhD thesis (2010)

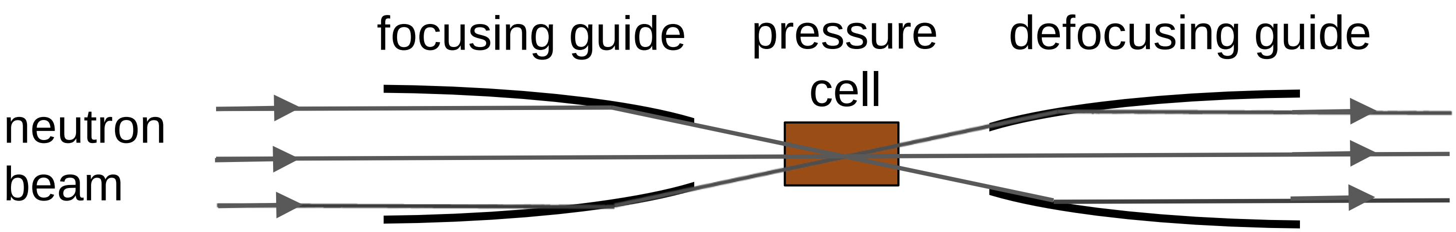
Depolarization tomography of a $Pd_{1-x}Ni_x$ crystal (x=2.67%)

Ni concentration influences T_C



Conclusion

- Depolarization can be used for investigation of ferromagnetism
- NDI gives spatial information about magnetic properties
- Variations of the setup enable the investigation up to 10 GPa



P. Jorba (2017)

Thank you for your attention!