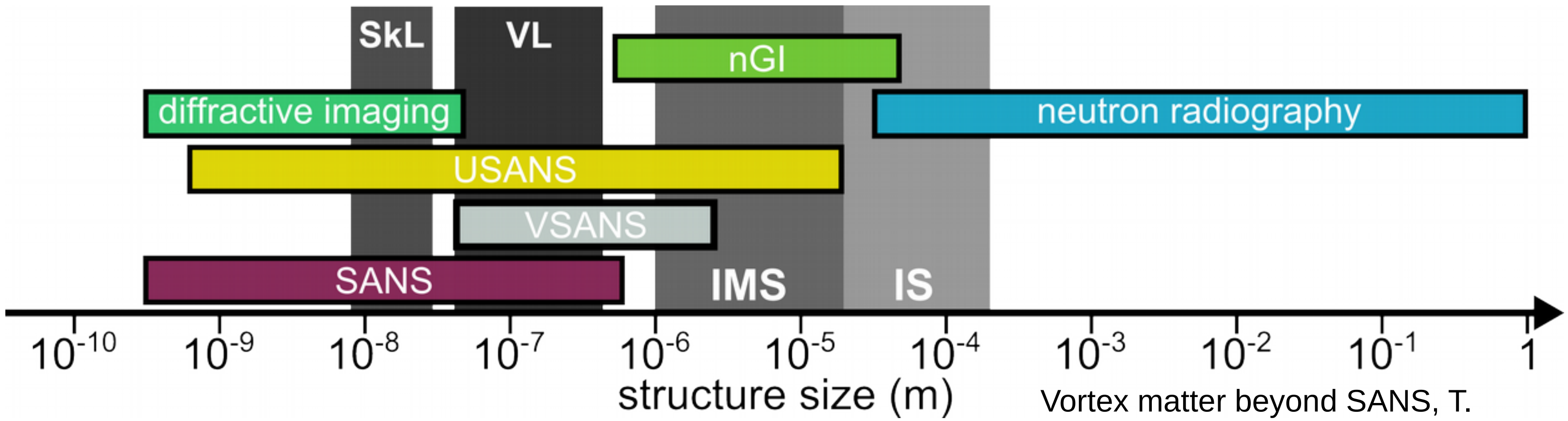
NEUTRON GRATING INTERFEROMETRY I

THEORY AND PRINCIPLES

Tobias Neuwirth

Why neutron grating interferometry?



Vortex matter beyond SANS, T. Reimann, Thesis, 2017

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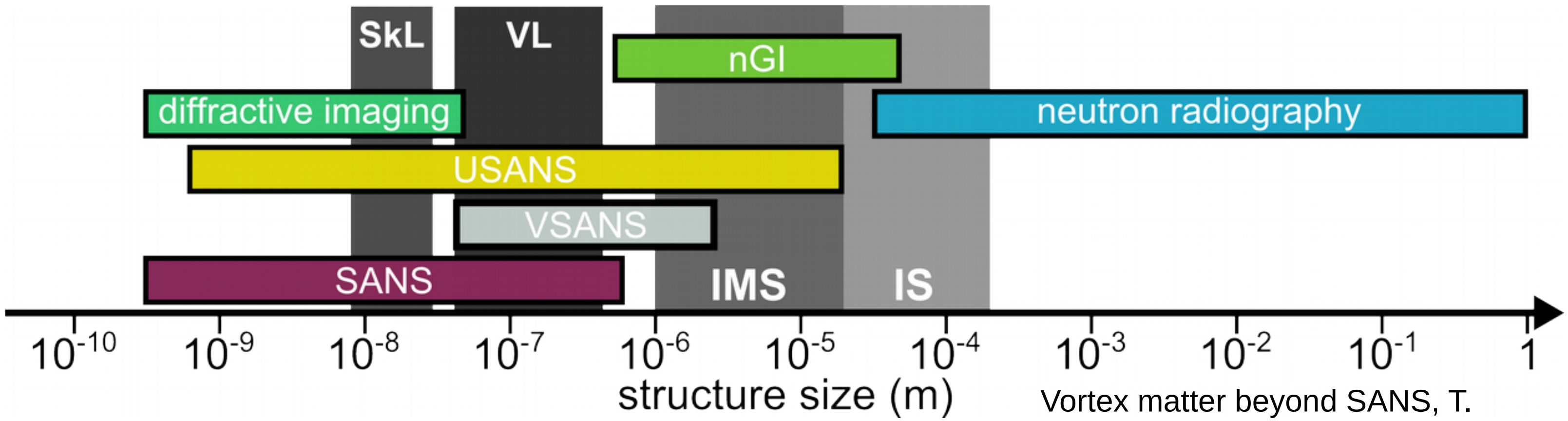

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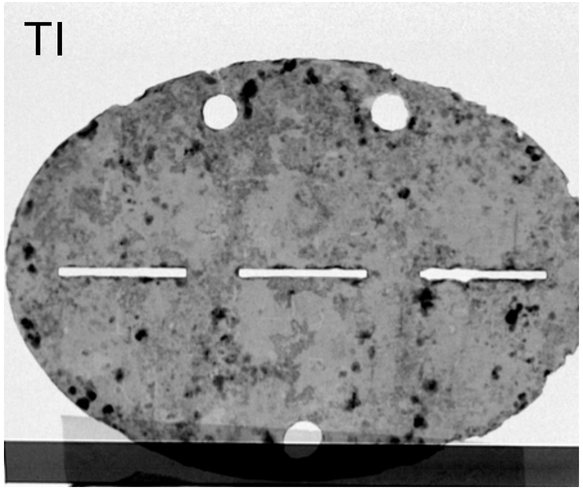

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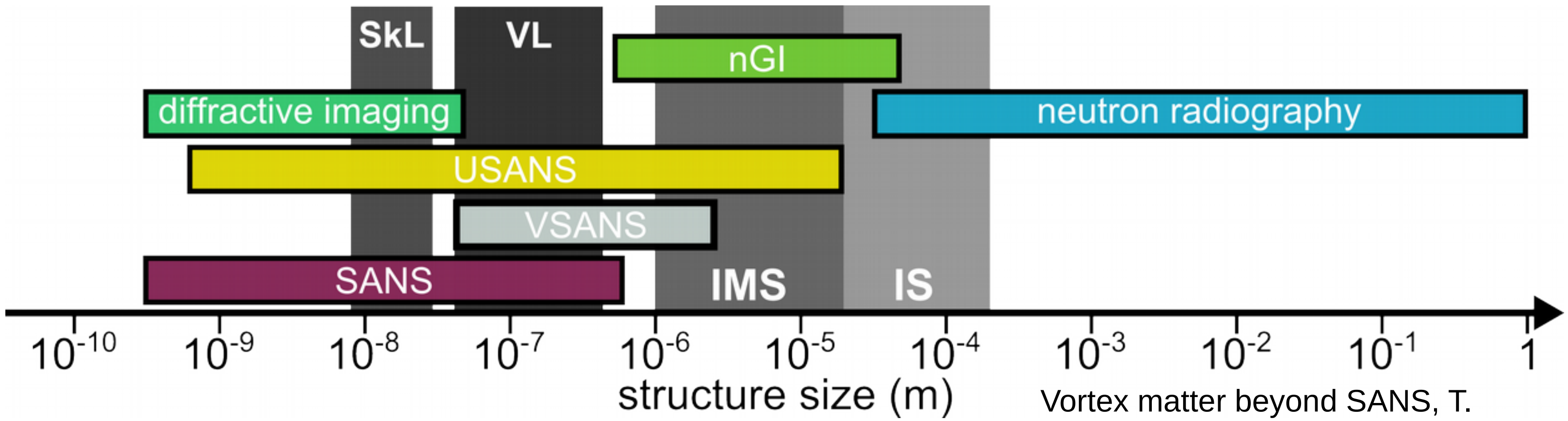

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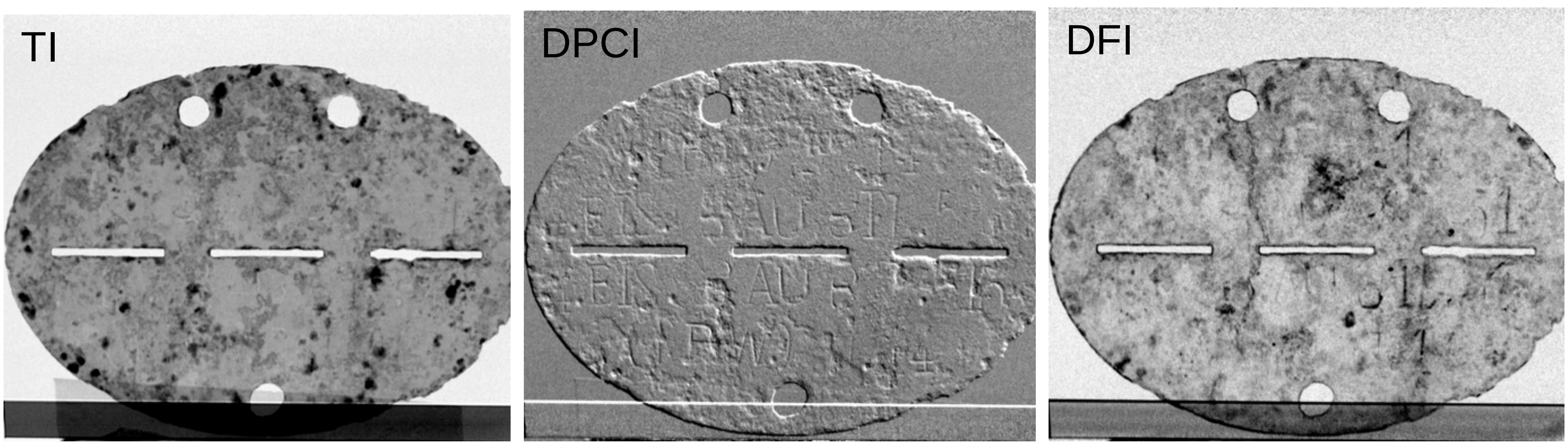
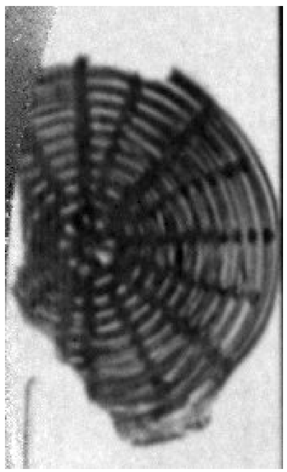


Why neutron grating interferometry?

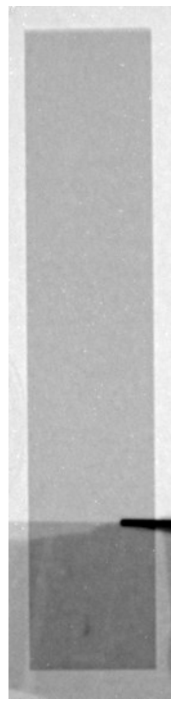
qualitative

TI

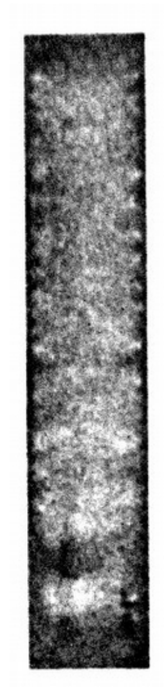
DFI



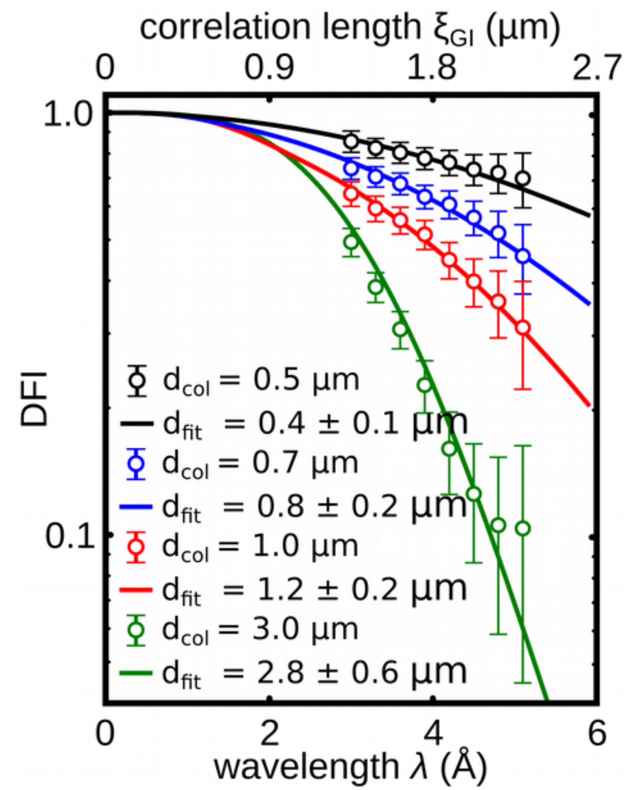
TI



DFI



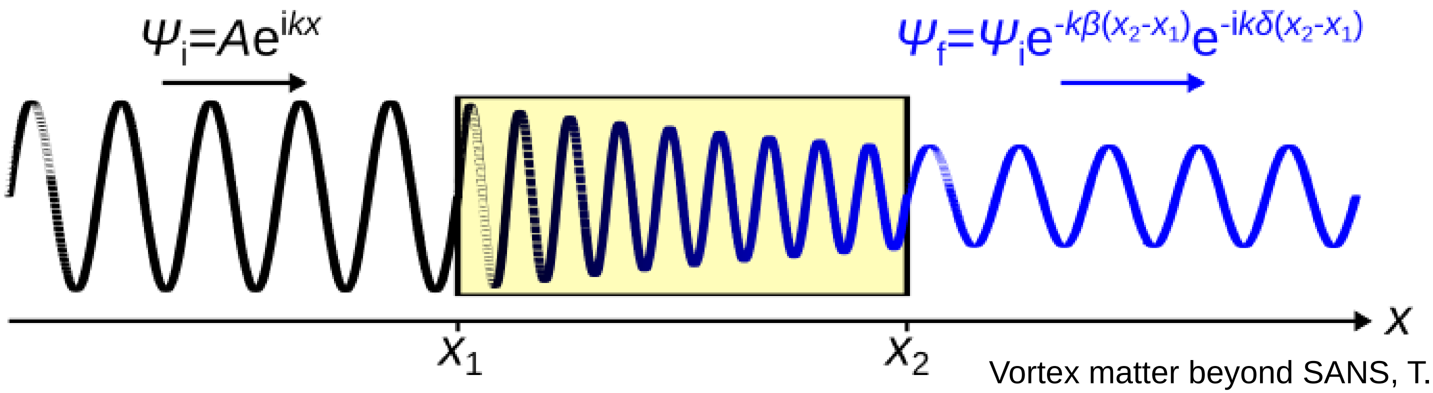
quantitative



Vortex matter beyond SANS, T. Reimann, Thesis, 2017

Outline

- **Interaction of neutrons with matter**
- **Principle of neutron grating interferometry**
- **Construction of an nGI**
- **Summary**



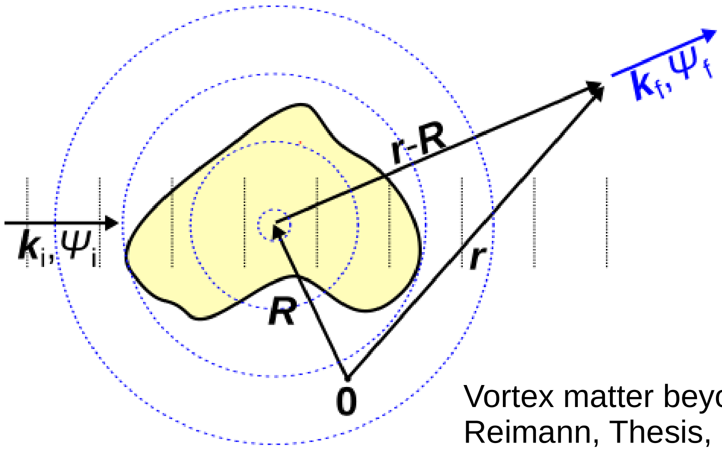
Vortex matter beyond SANS, T. Reimann, Thesis, 2017

Absorption & Refraction

$$T = \frac{I_f}{I_i} = \exp\left[-\left(\sigma_{abs} + \sigma_{inc}\right) N t\right]$$

$$\Delta\Phi = -\lambda N b_c t$$

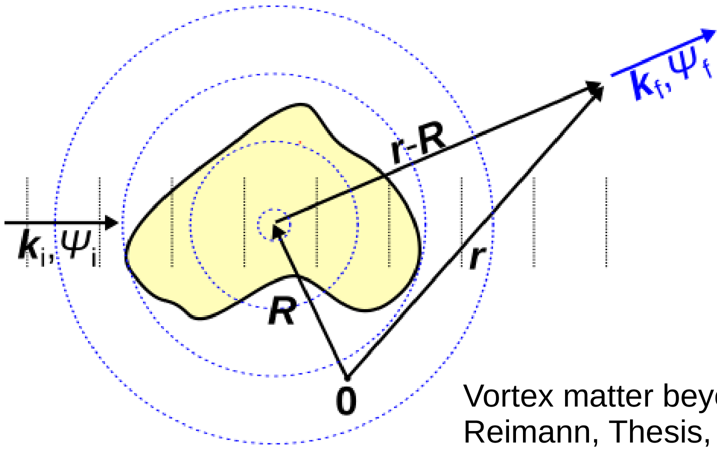
Interaction of neutrons with matter



Vortex matter beyond SANS, T. Reimann, Thesis, 2017

$$\Psi_f(k_f, r) = \exp(i k_i \cdot r) + \exp\frac{(i k_f \cdot r)}{r} f(q)$$

Basic scattering function



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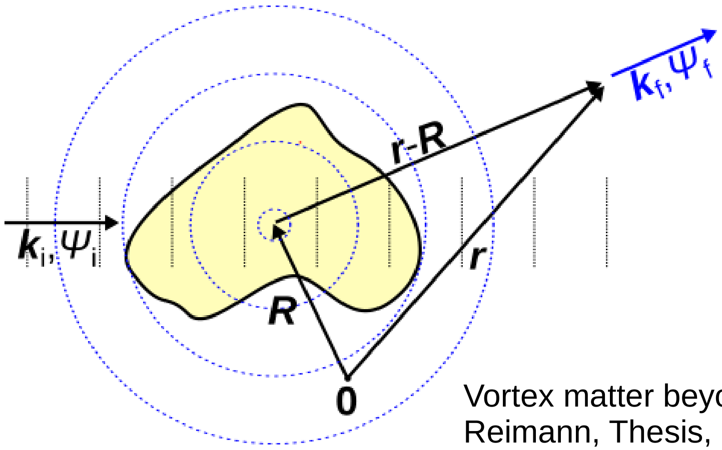
For neutron grating interferometry the scattering we are interested in the scattering under ultra-small-angles (USANS).

Interaction of neutrons with matter



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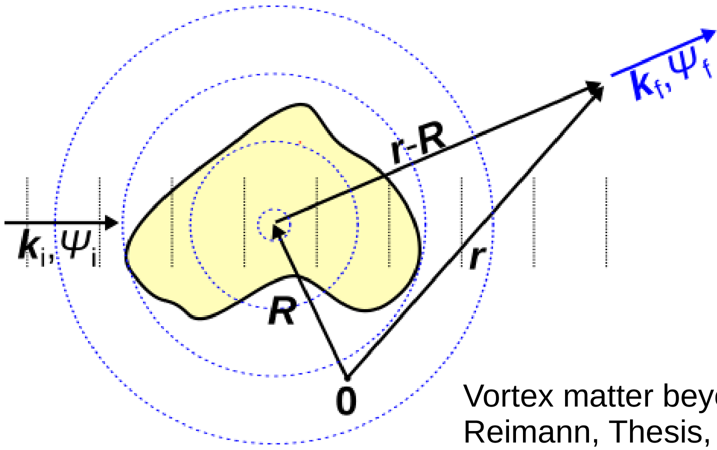
How do we analyse this scattering?



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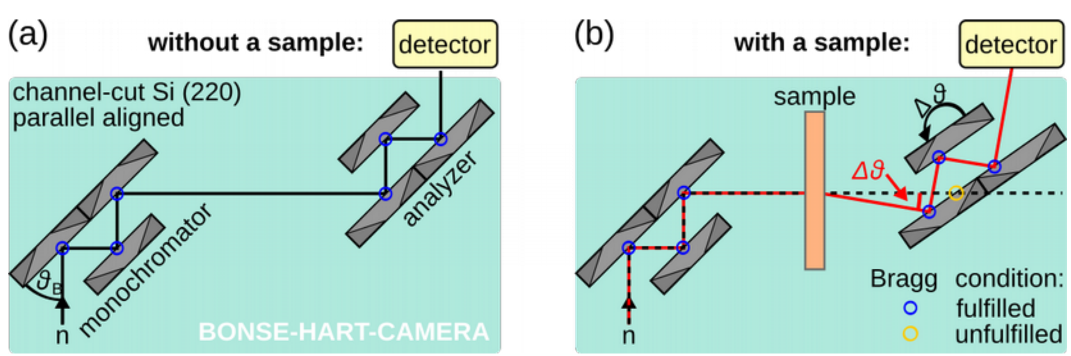

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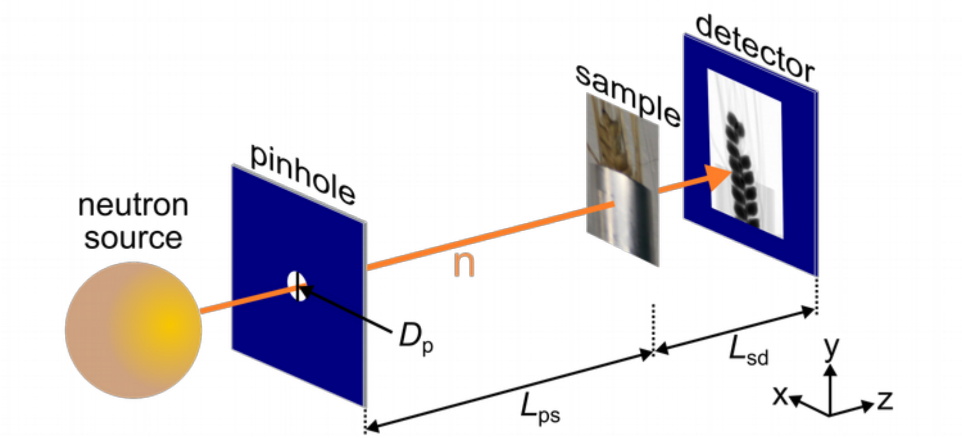
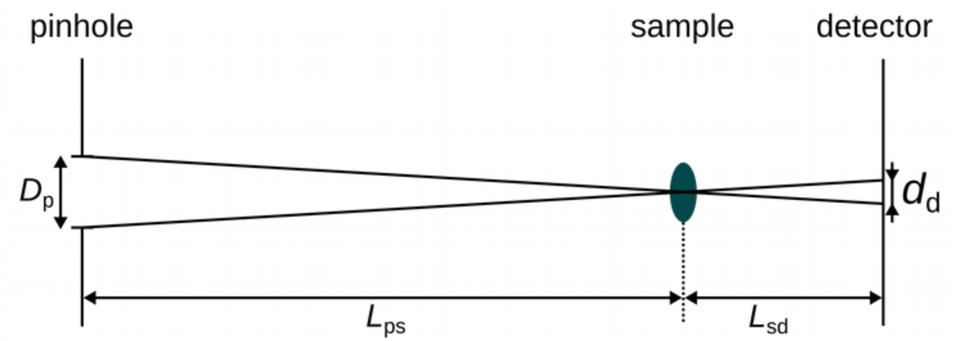
Neutron radiography



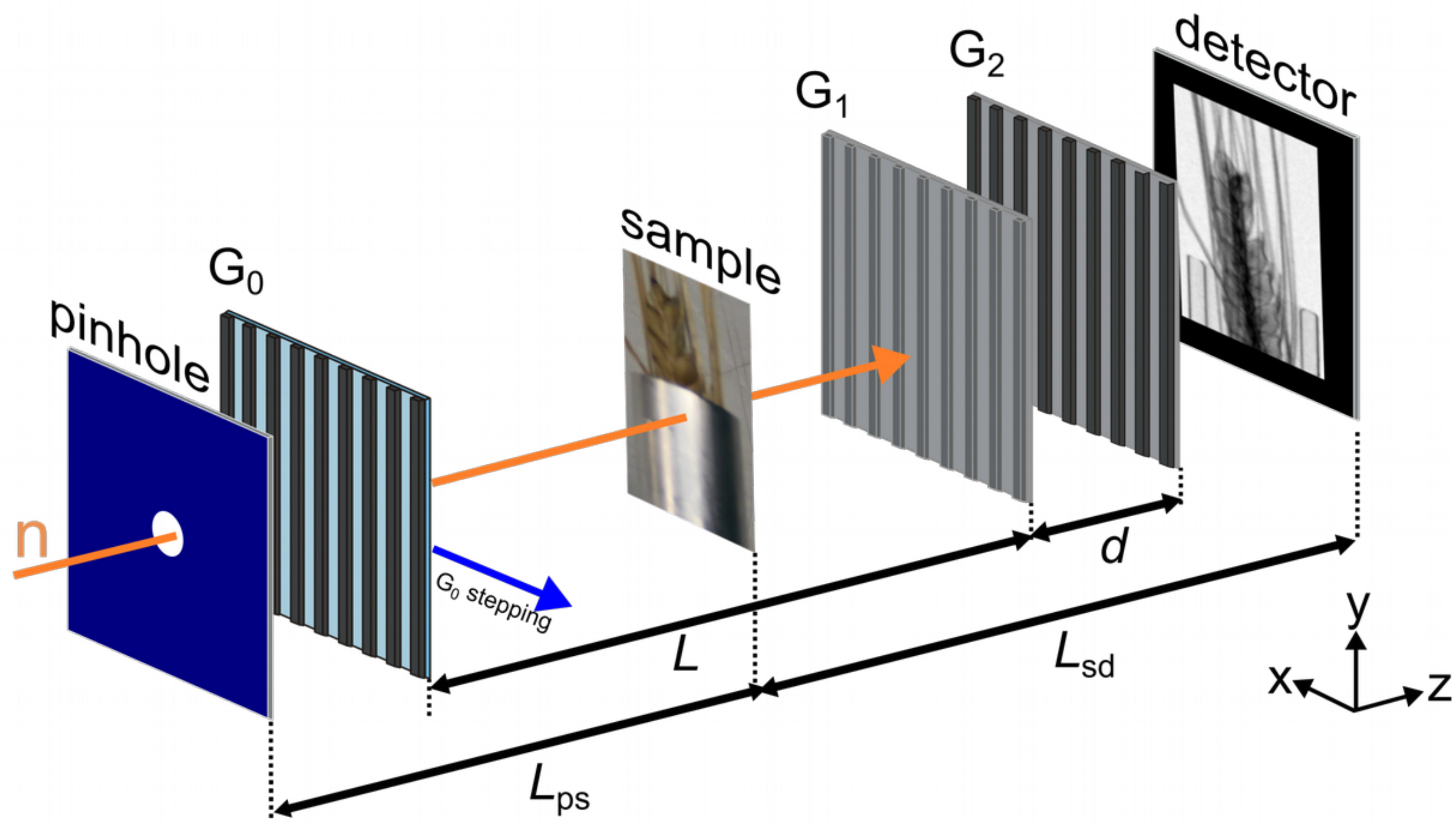
Geometric resolution



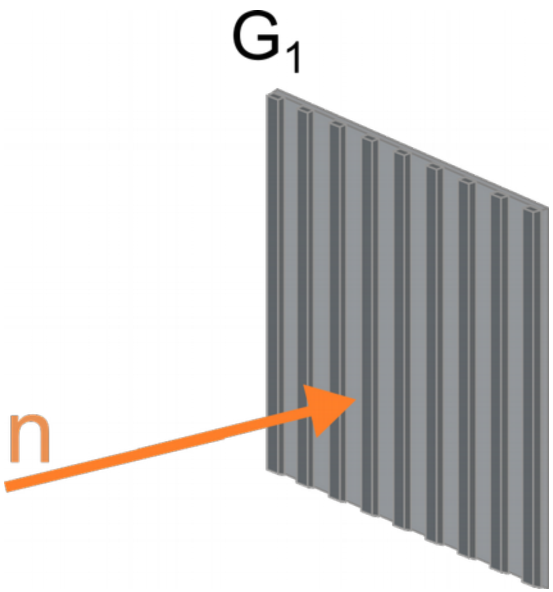
$$d_d = \frac{D_p}{L_{ps}} \cdot L_{sd}$$

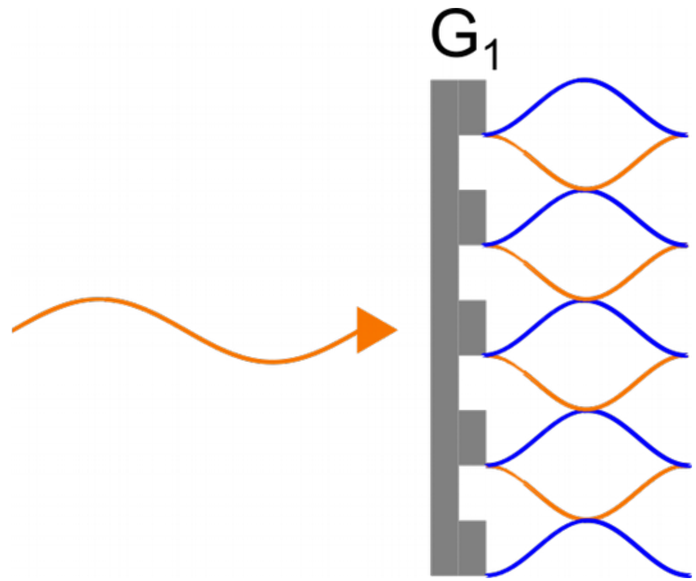
- Analysis of the inner structure of a sample by analysing the absorption
- Resolvable structure size limited by geometric resolution, scintillator thickness and quality of the camera system

Neutron grating interferometer



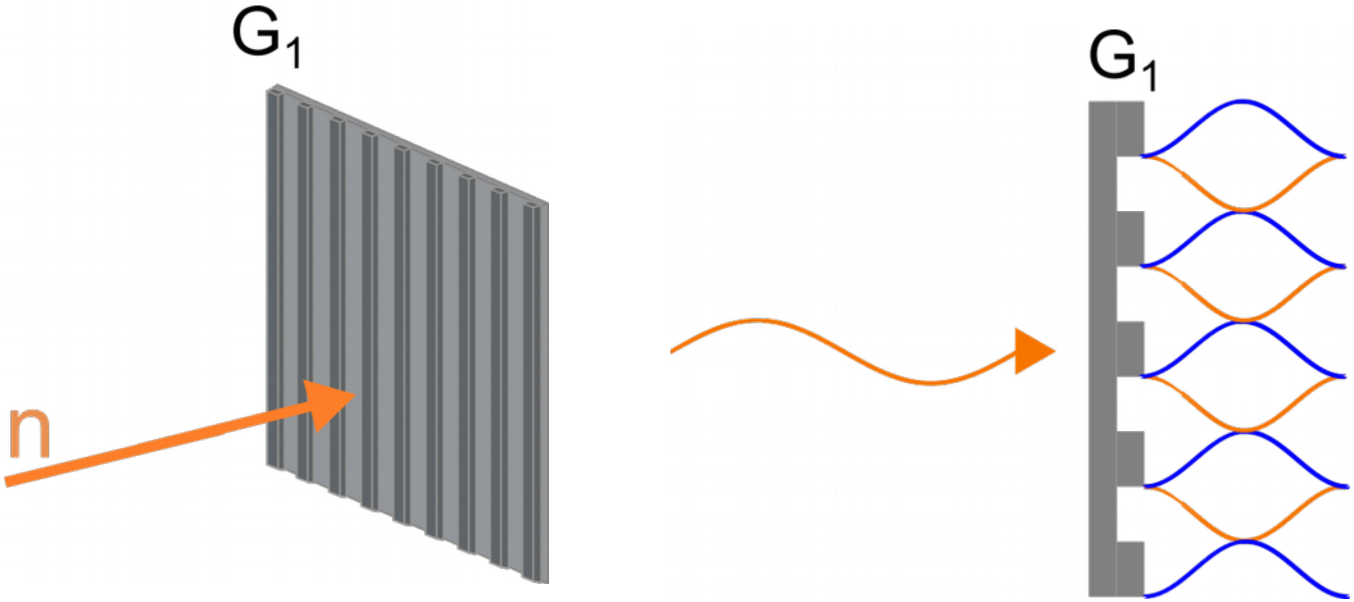
G_1 – splitting the beam





$$\Delta\Phi = -\lambda N b_c t$$

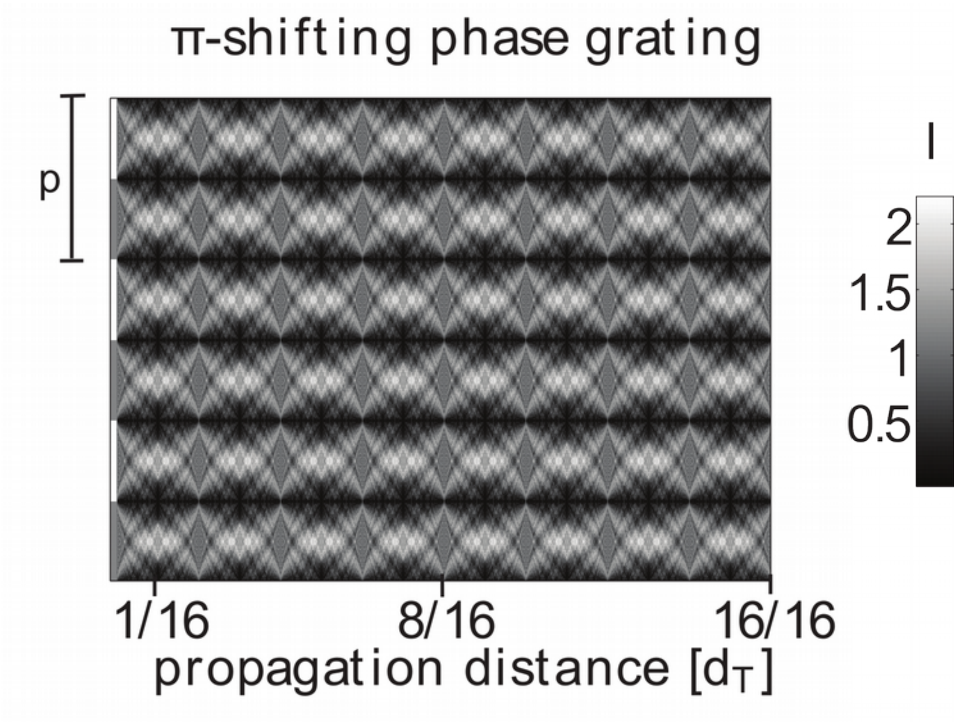
G_1 – splitting the beam



$$\Delta\Phi = -\lambda N b_c t$$

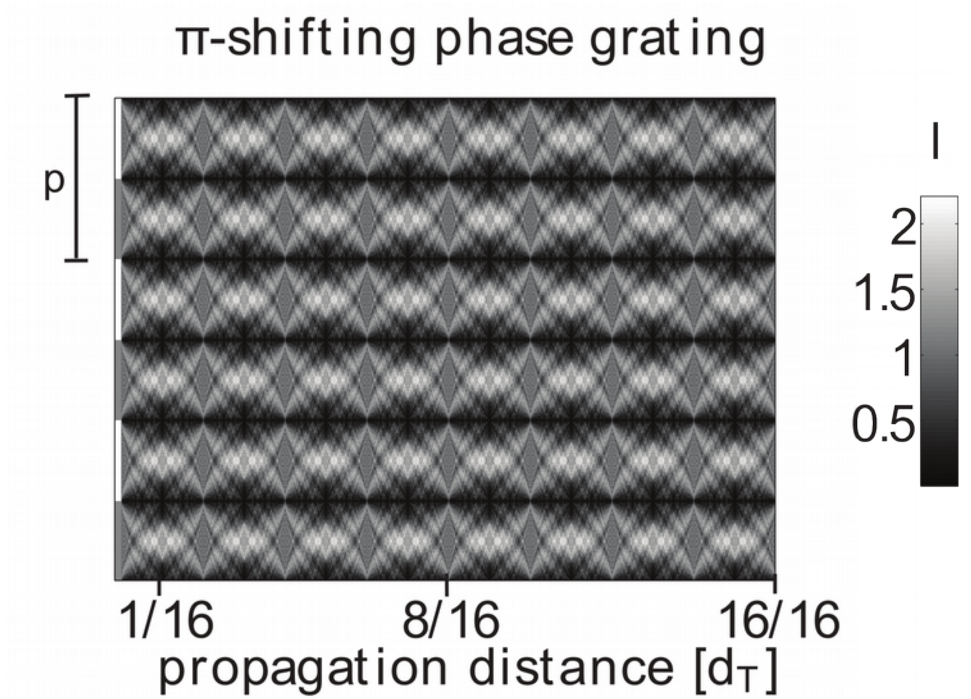
- Phase shift of the neutron when passing through G_1 dependent on the height of the grating and the wavelength of the neutrons
- Period of G_1 used in ANTARES ≈ 8 µm

G_1 – splitting the beam



$$d_n = \frac{n}{16} d_T = n \frac{p_1^2}{8\lambda}$$

G_1 – splitting the beam

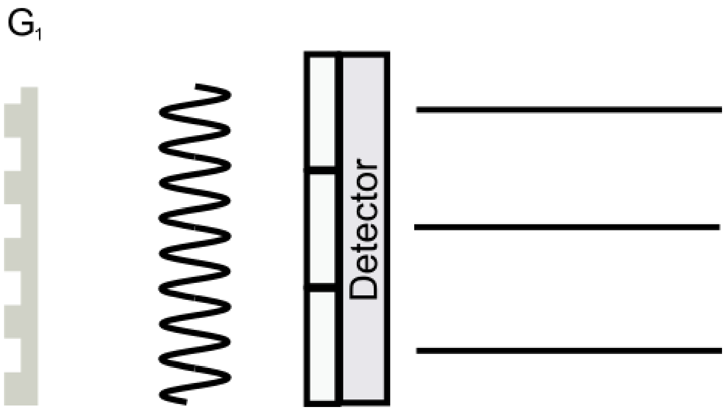


Contributions to the characterization of grating-based x-ray phase-contrast imaging, M. Chabior, Thesis, 2011

$$d_n = \frac{n}{16} d_T = n \frac{p_1^2}{8\lambda}$$

- Generation of a Talbot-carpet after G_1
  - Odd fractional Talbot distances result in a intensity modulation
  - Even fractional Talbot distances result in a phase modulation
- Intensity modulation has half the period of $G_1 \approx 4$ µm

G2 - analysing the intensity modulation



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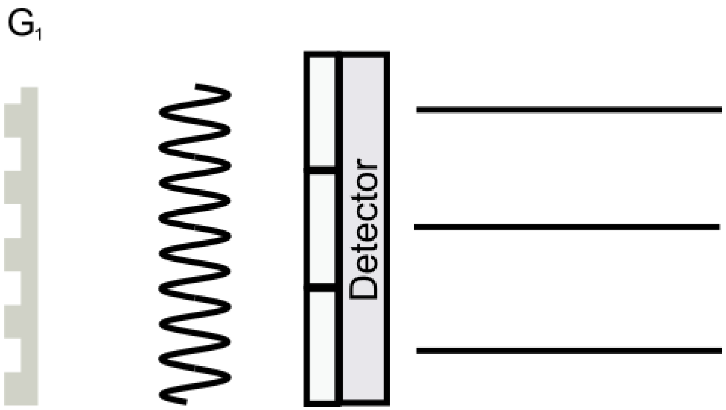
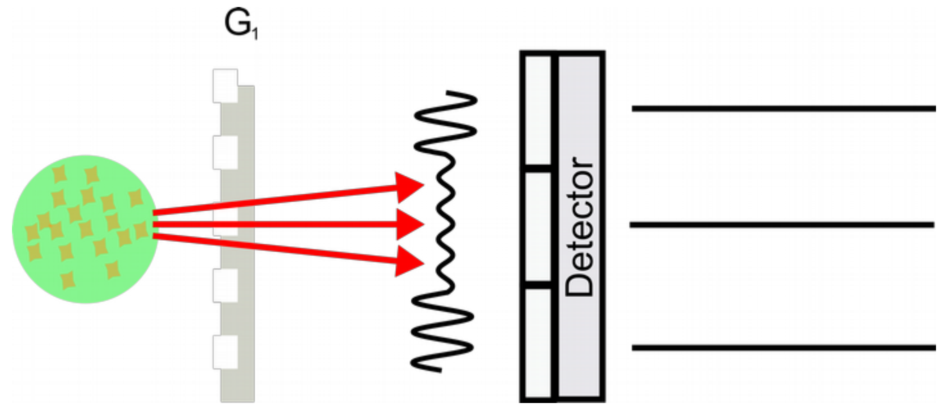
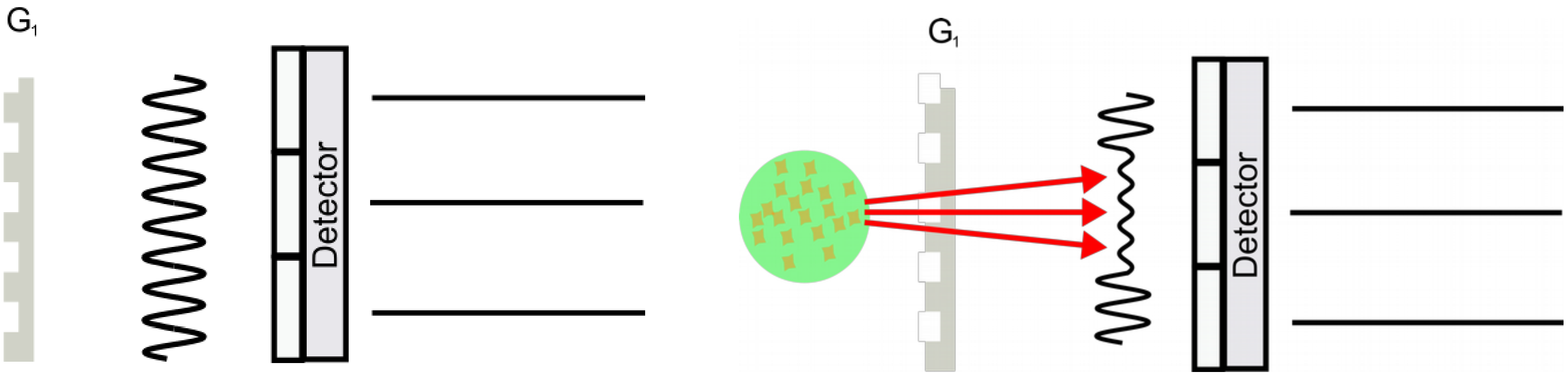


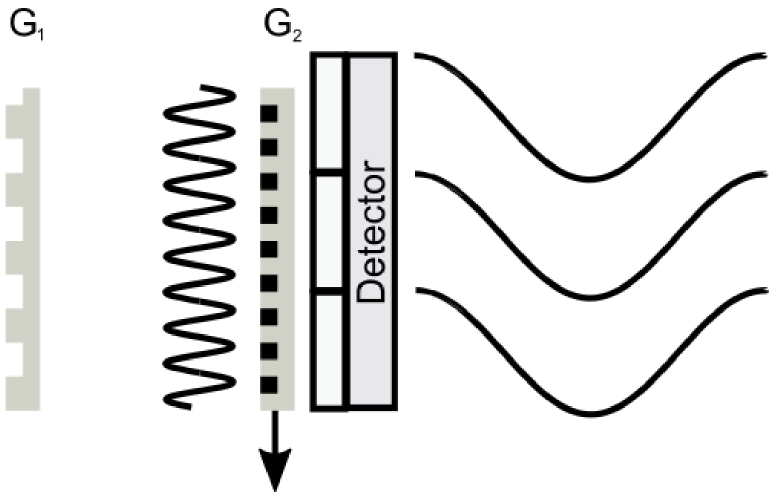


G2 - analysing the intensity modulation



- Intensity modulation generated by G_1 cannot be resolved with standard imaging detectors

G2 - analysing the intensity modulation



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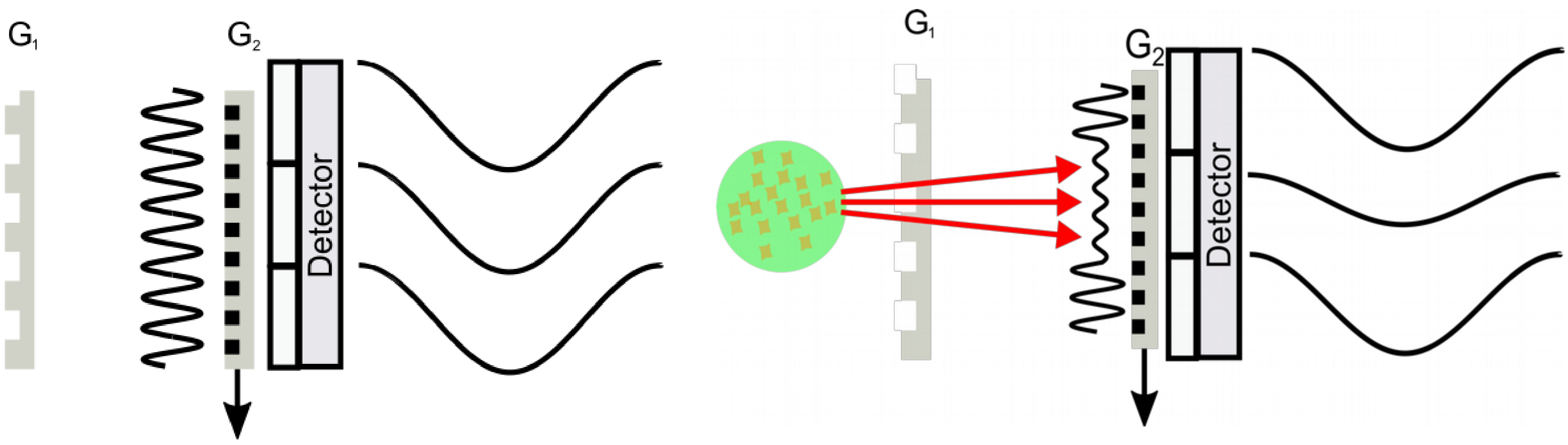

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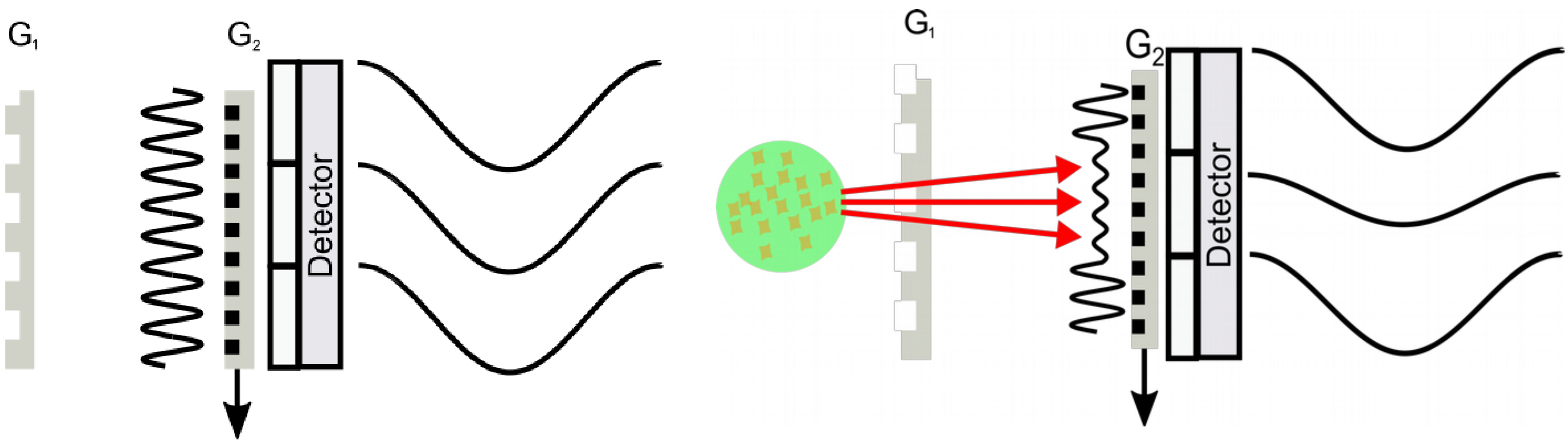
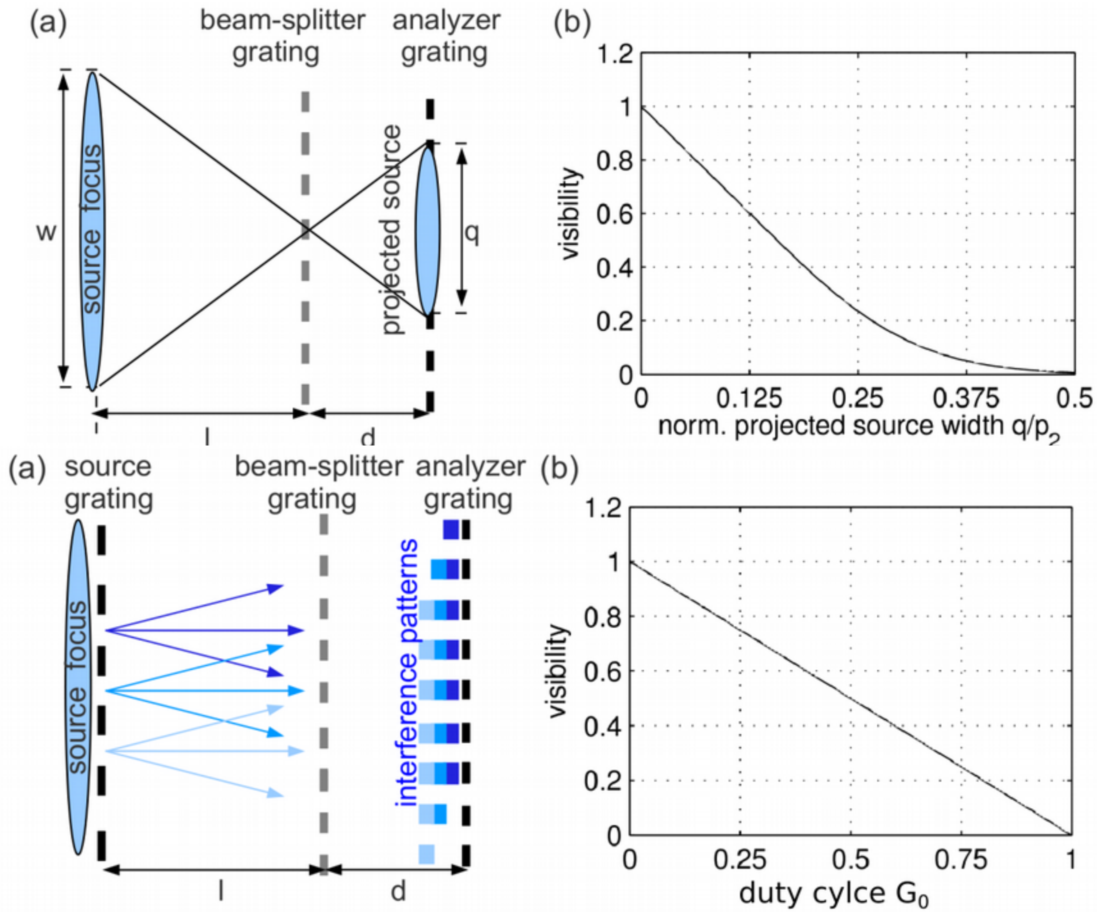


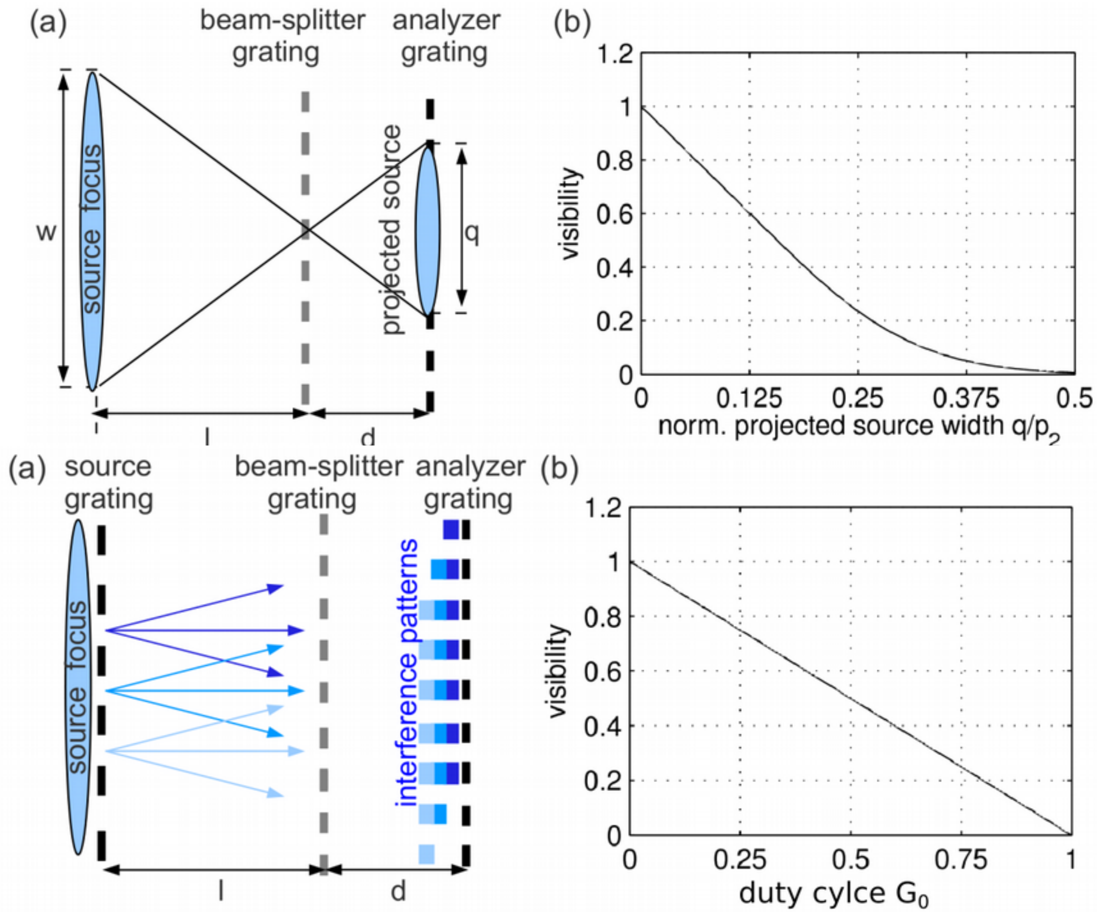
- By using an absorption grating (G_2), with the same period as the interference pattern, the pattern can be analysed
- Period of G_2 used in ANTARES ≈ 4 µm

G0 – providing spatial coherence



Contributions to the characterization of grating-based x-ray phase-contrast imaging, M. Chabior, Thesis, 2011

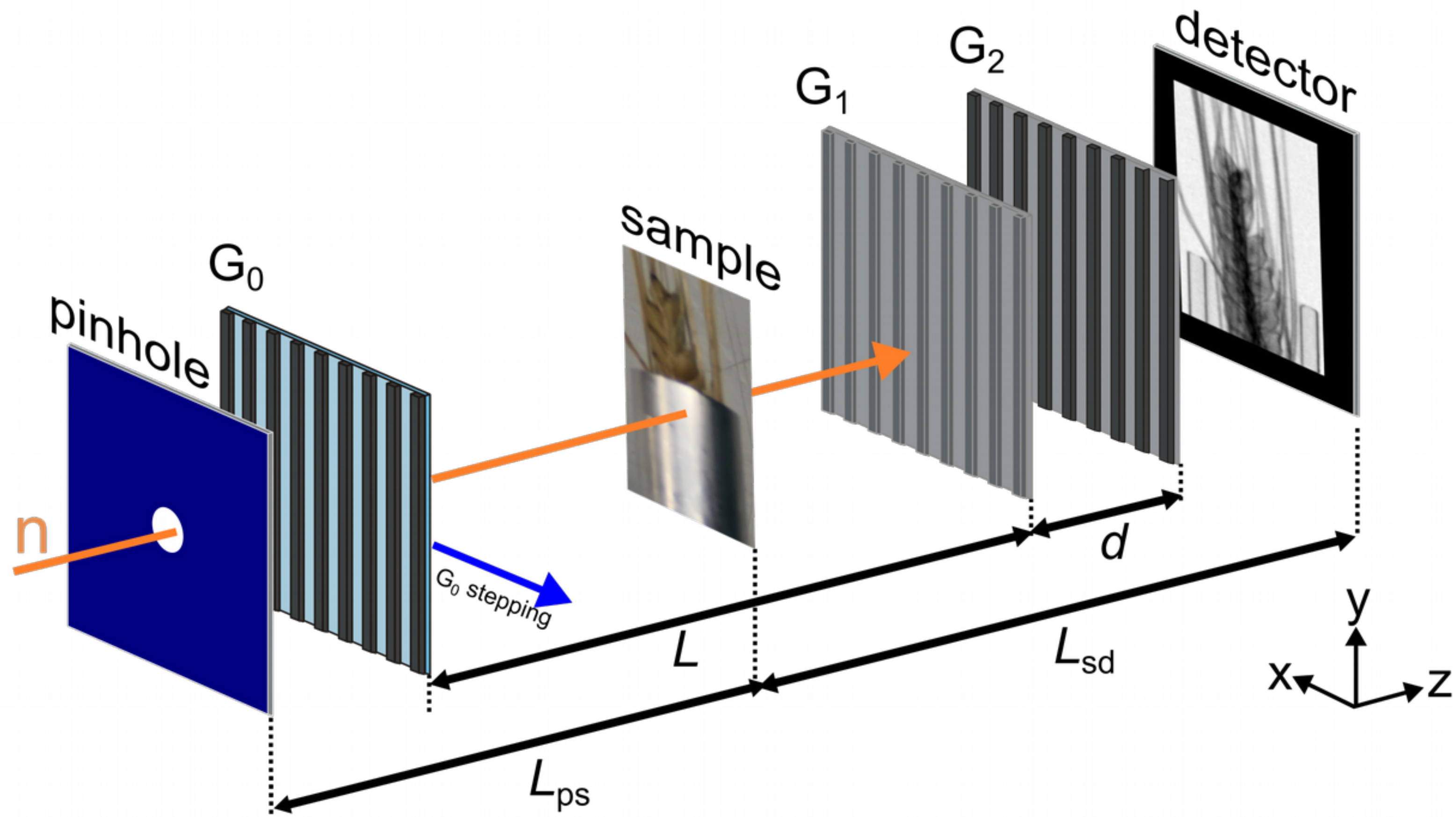
G0 – providing spatial coherence



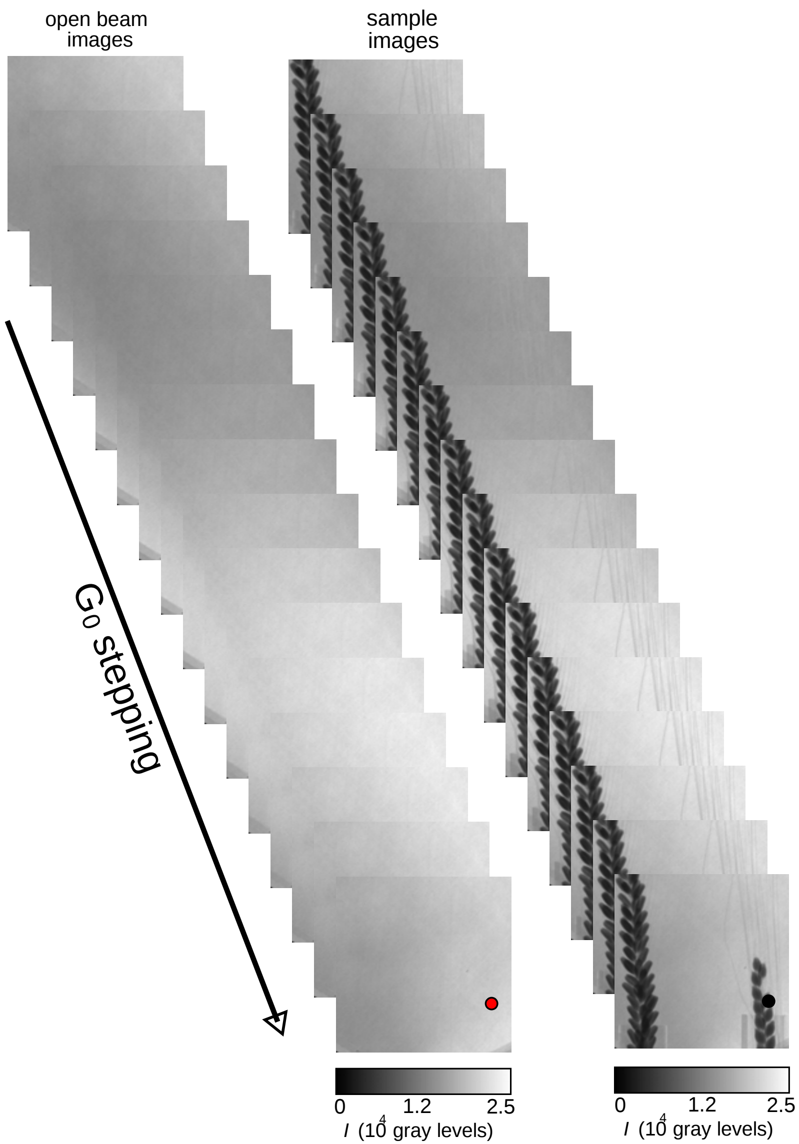
Contributions to the characterization of grating-based x-ray phase-contrast imaging, M. Chabior, Thesis, 2011

- G0 needed to keep a reasonable compromise between flux and visibility
- Constructive overlap of the interference patterns

Neutron grating interferometer



Performing measurements



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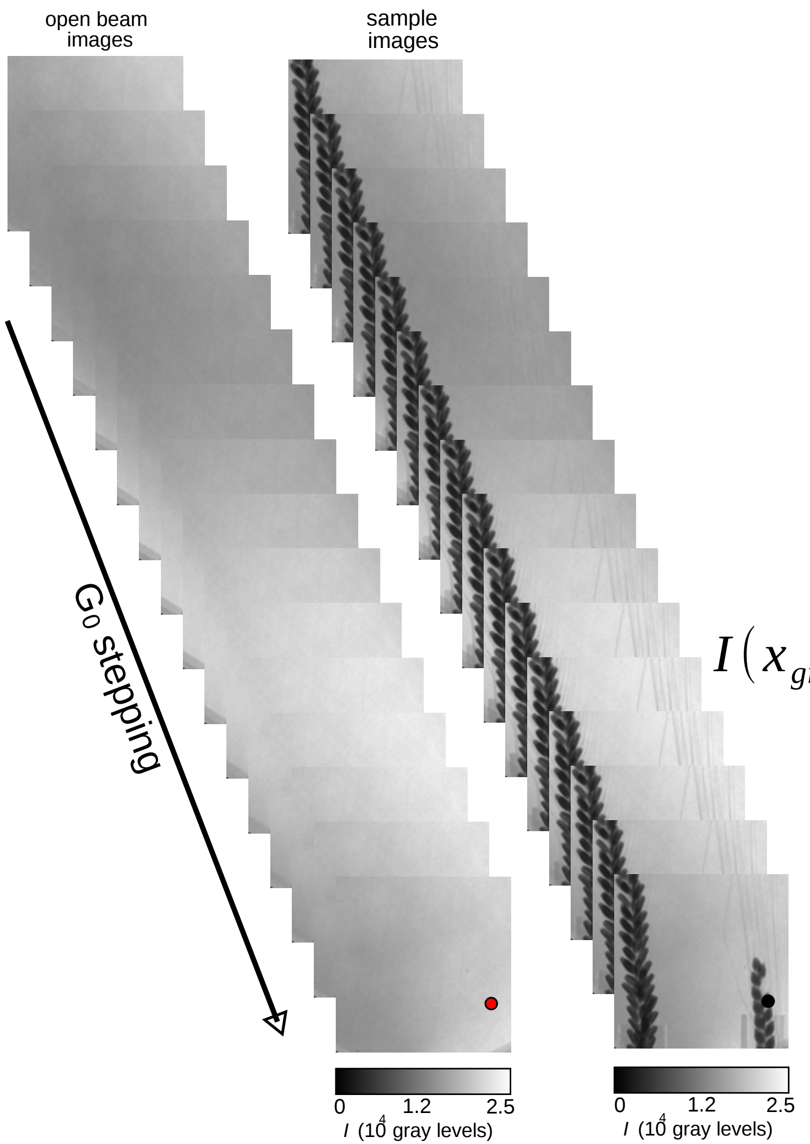
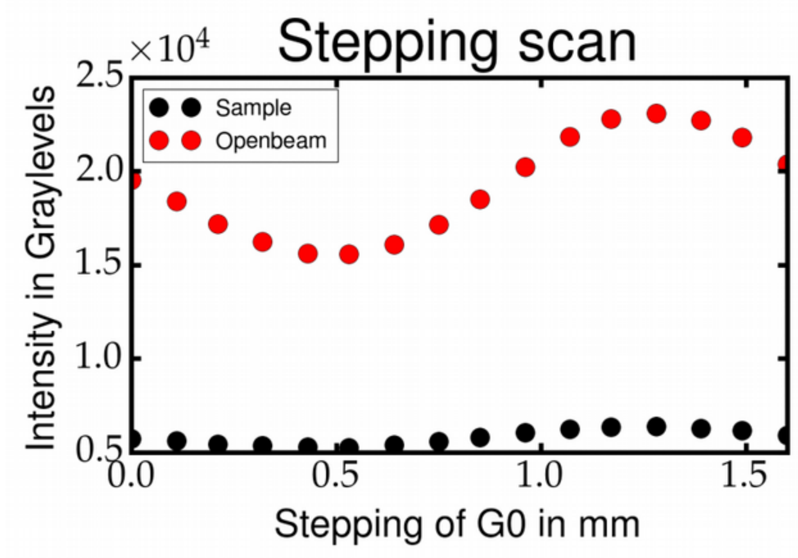
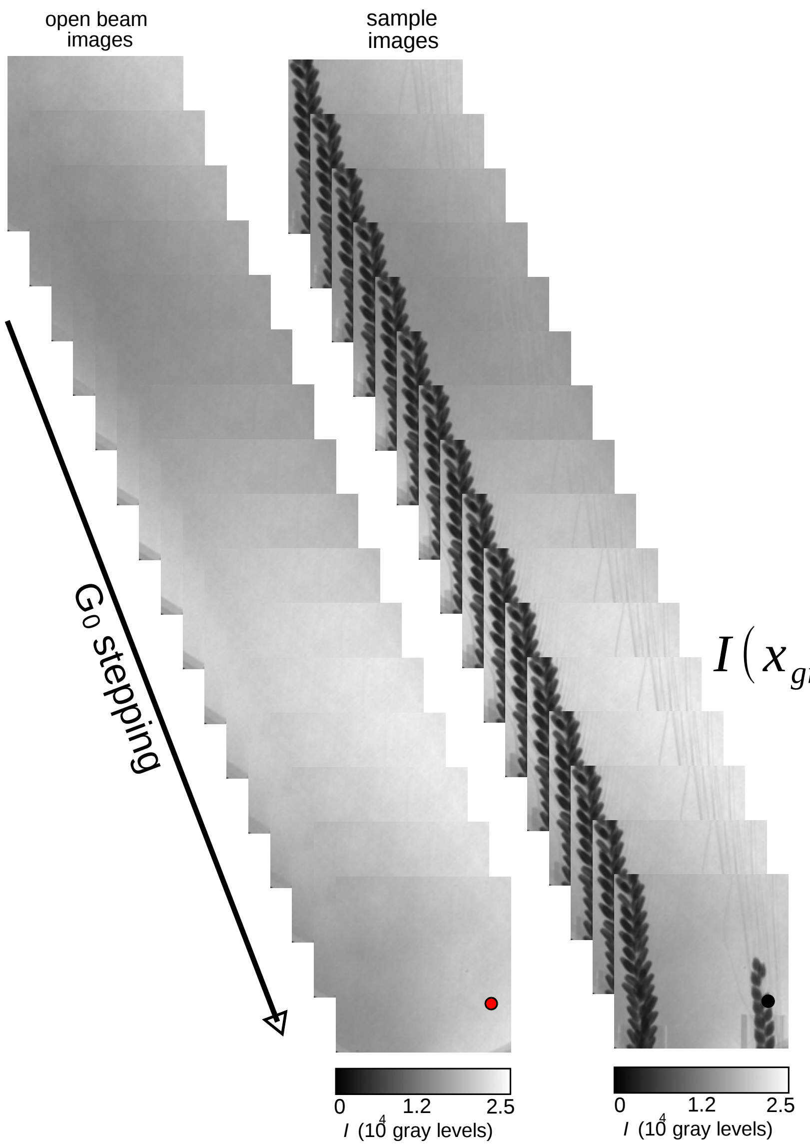
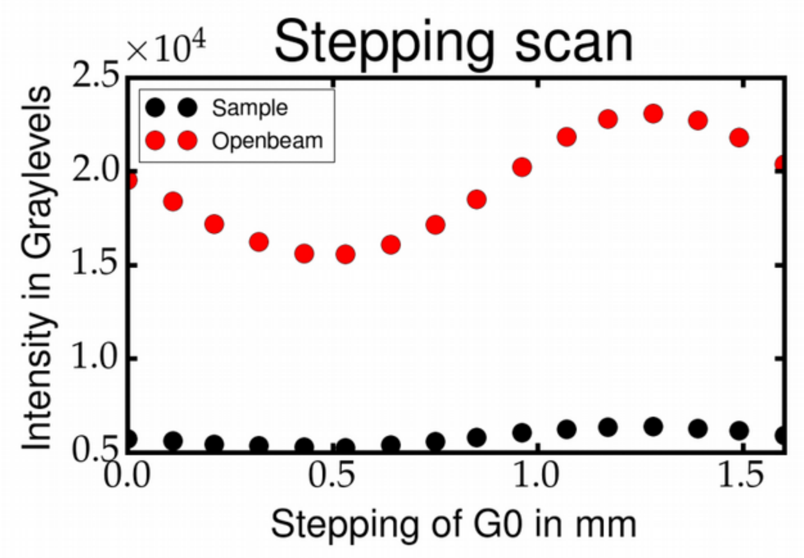




$$I(x_{gi}, m, n) = a_0(m,n) + a_1(m,n)\cos\left(\frac{2\pi x_{gi}}{p_i} - \varphi(m,n)\right)$$

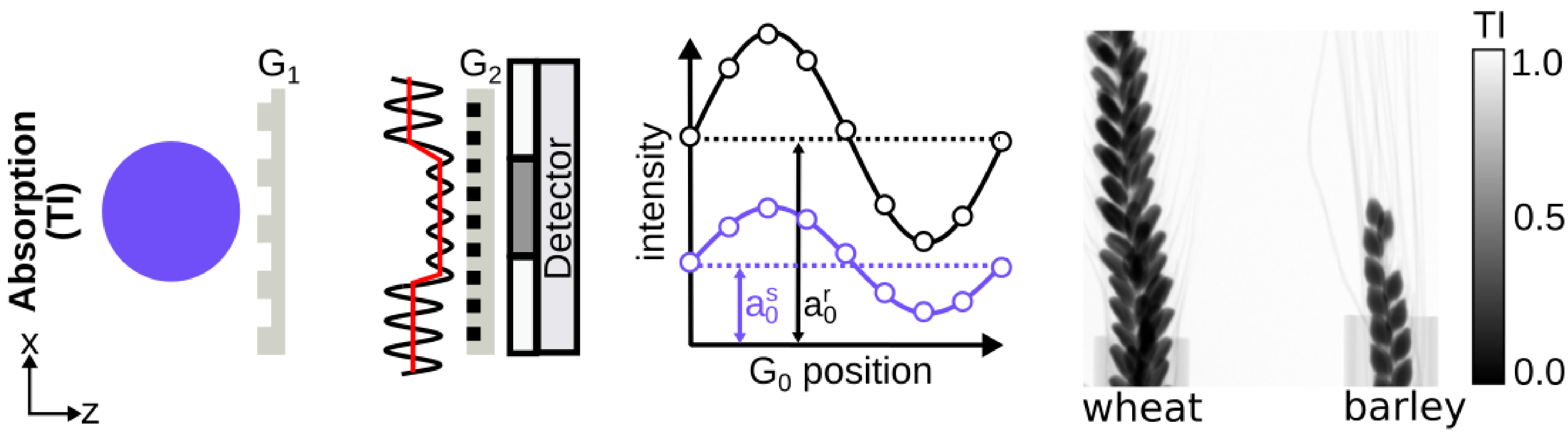




$$I(x_{gi}, m, n) = a_0(m,n) + a_1(m,n)\cos\left(\frac{2\pi x_{gi}}{p_i} - \varphi(m,n)\right)$$

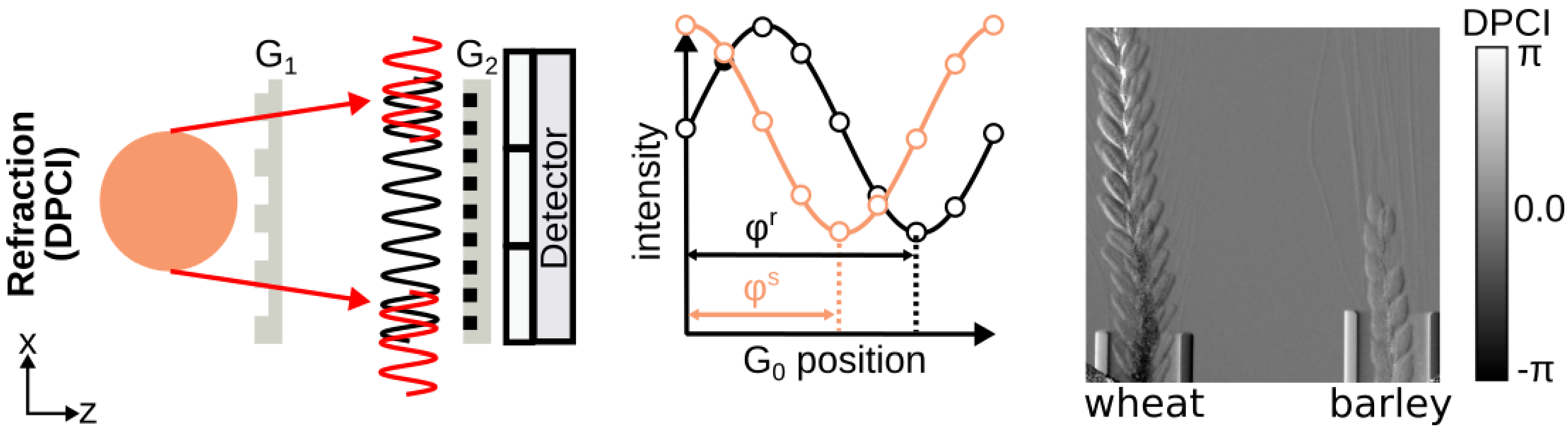
- Movement of any of the three gratings generates an intensity oscillation in every pixel
- Analysis of the oscillation and comparison between open beam and sample allows to obtain information about the sample

Transmission



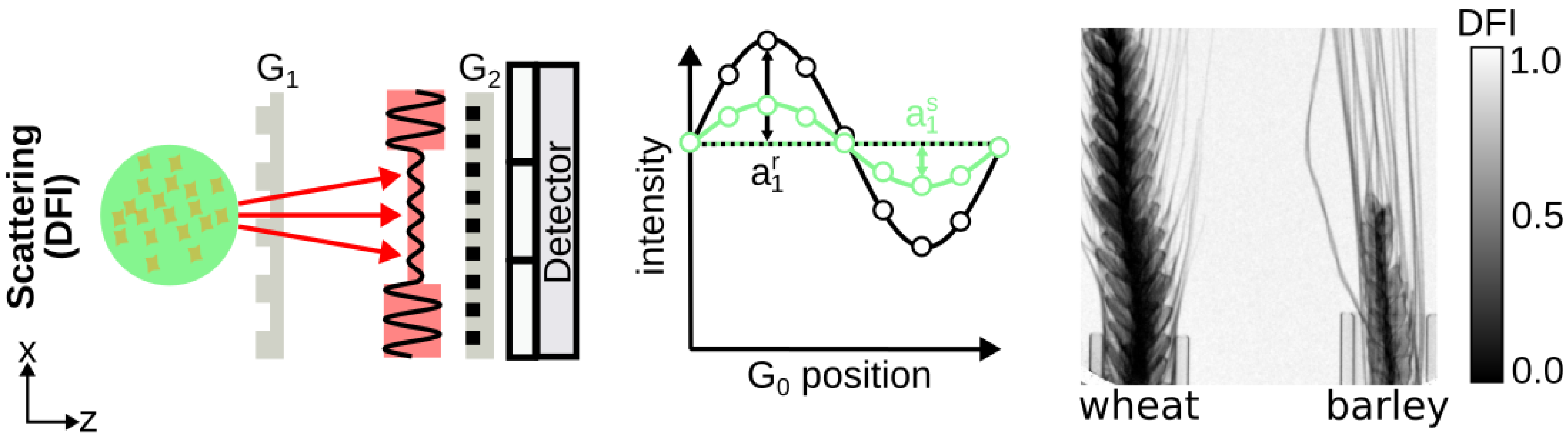
$$TI = \frac{a_0^s}{a_0^r}$$

- Transmission image (TI) is equal to the image of monochromatic radiography



$$DPCI = \varphi^{s} - \varphi^{r}$$

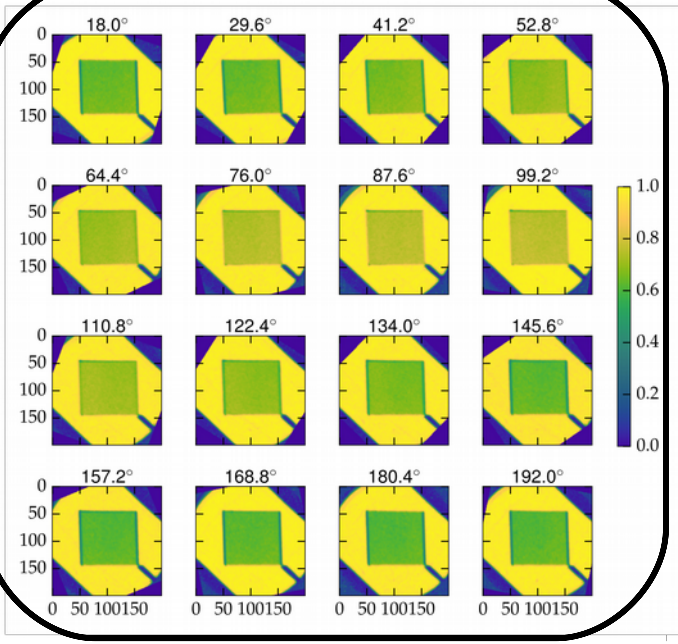
- DPCI maps the gradient of the neutron phase introduced by the sample
- Only sensitive perpendicular to the grating lines
- Currently rarely used in nGI as it delivers no additional information

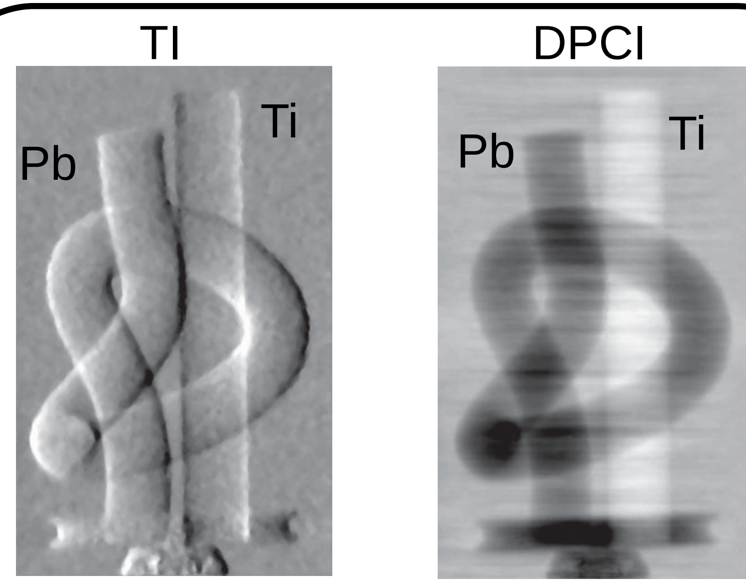


$$DFI = \frac{V^s}{V^r} = \frac{a_1^s \cdot a_0^r}{a_0^s \cdot a_1^r}$$

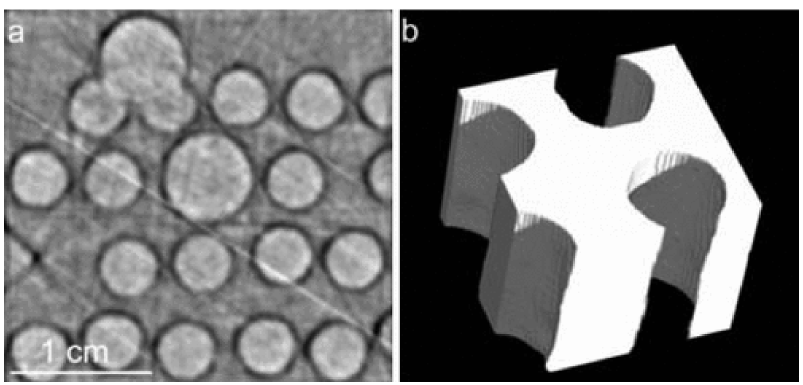
- DFI maps areas containing structures in the range of 100 nm to 15 µm
- Contrast is generated by USANS destroying the interference pattern
- Also sensitive to scattering off magnetic structures

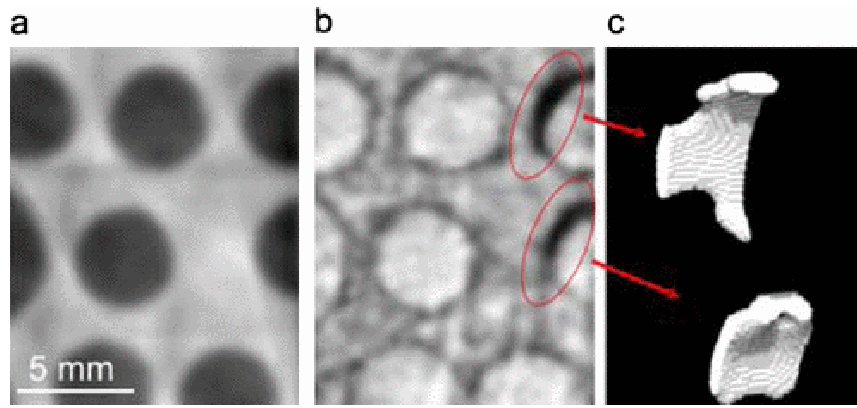
Examples for nGI measurements





Neutron Phase Imaging and Tomography, F. Pfeiffer et al, Physical Review Letters, 2006





Neutron Dark-Field Tomography, M.Strobl et al, Physical Review Letters, 2008

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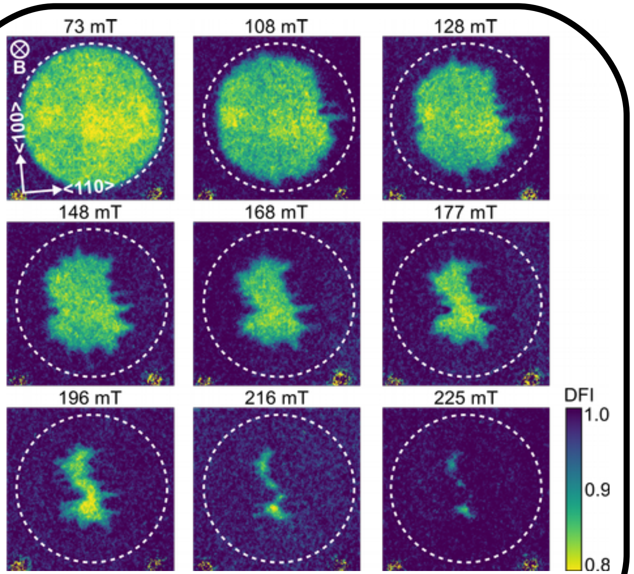

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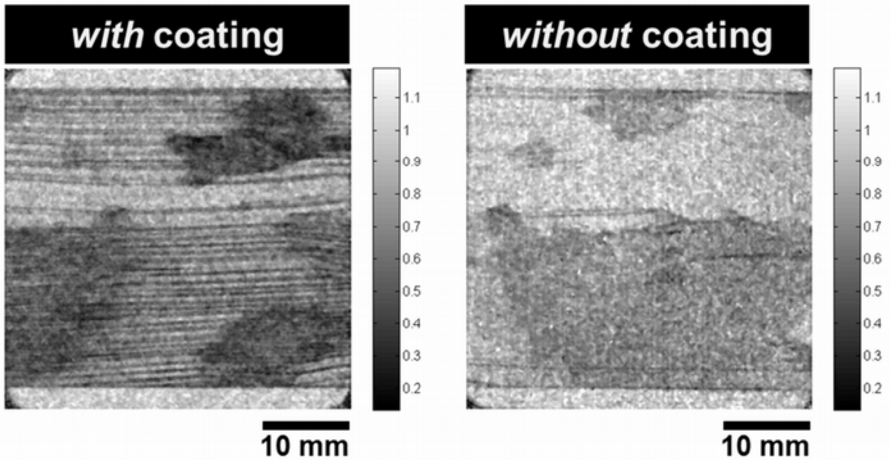
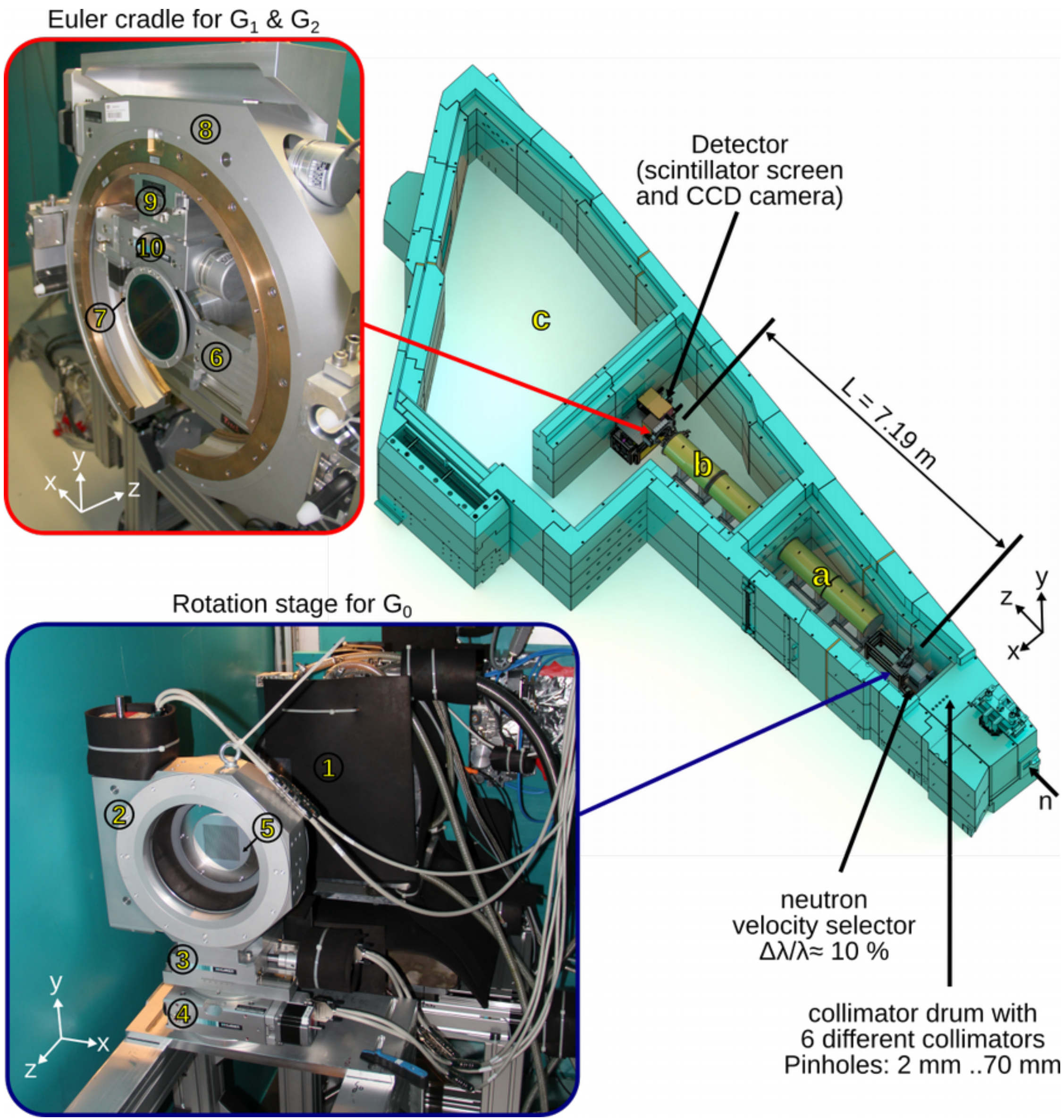
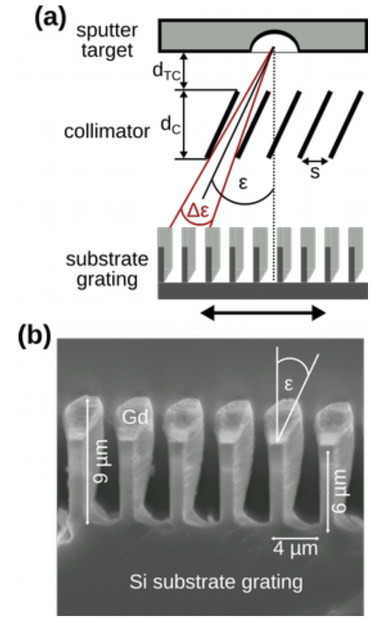
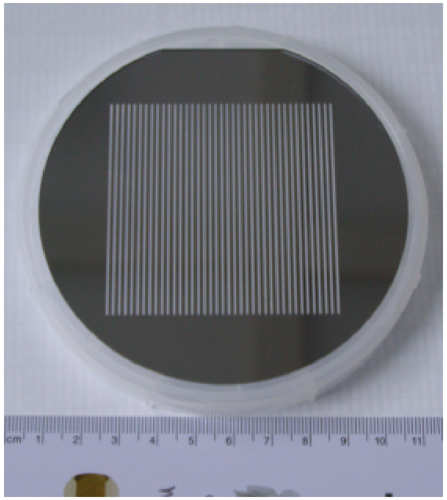


Determination of Bulk Magnetic Volume Properties by Neutron Dark-Field Imaging, Ch. Grünzweig et al, 10 WCNR, 2014

Construction of an nGI







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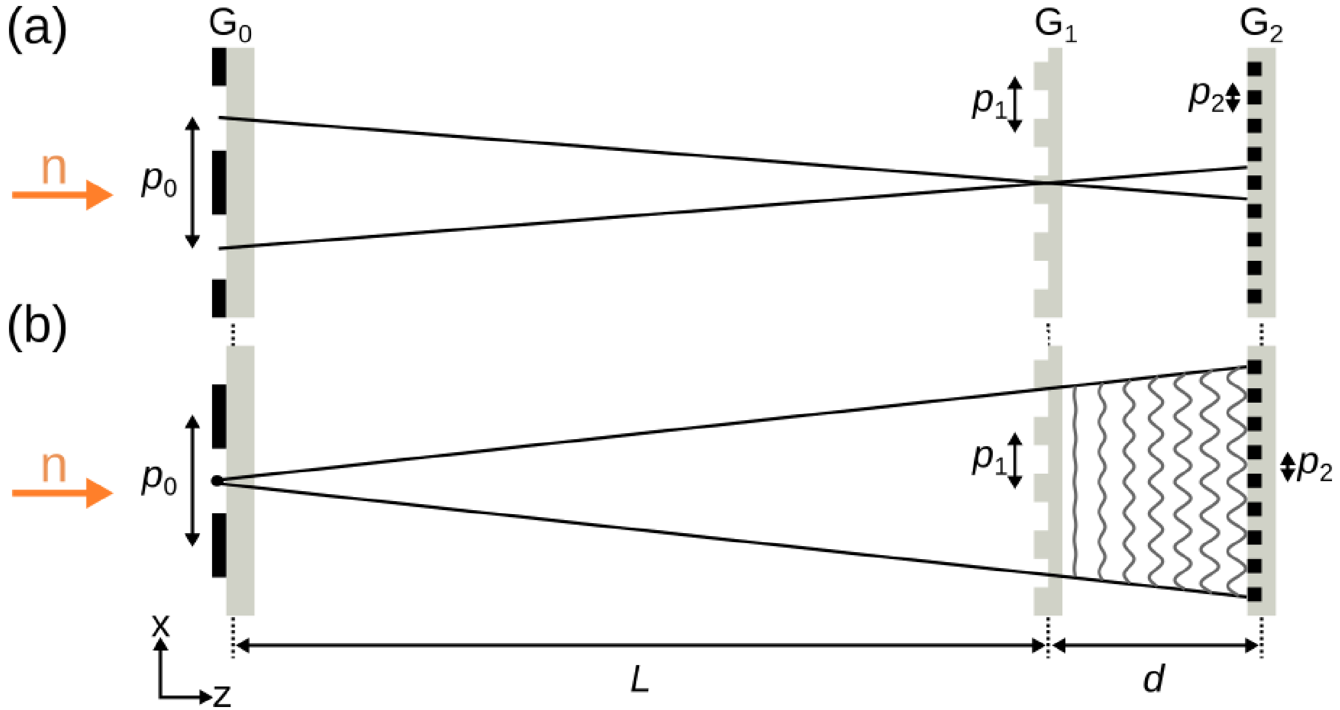
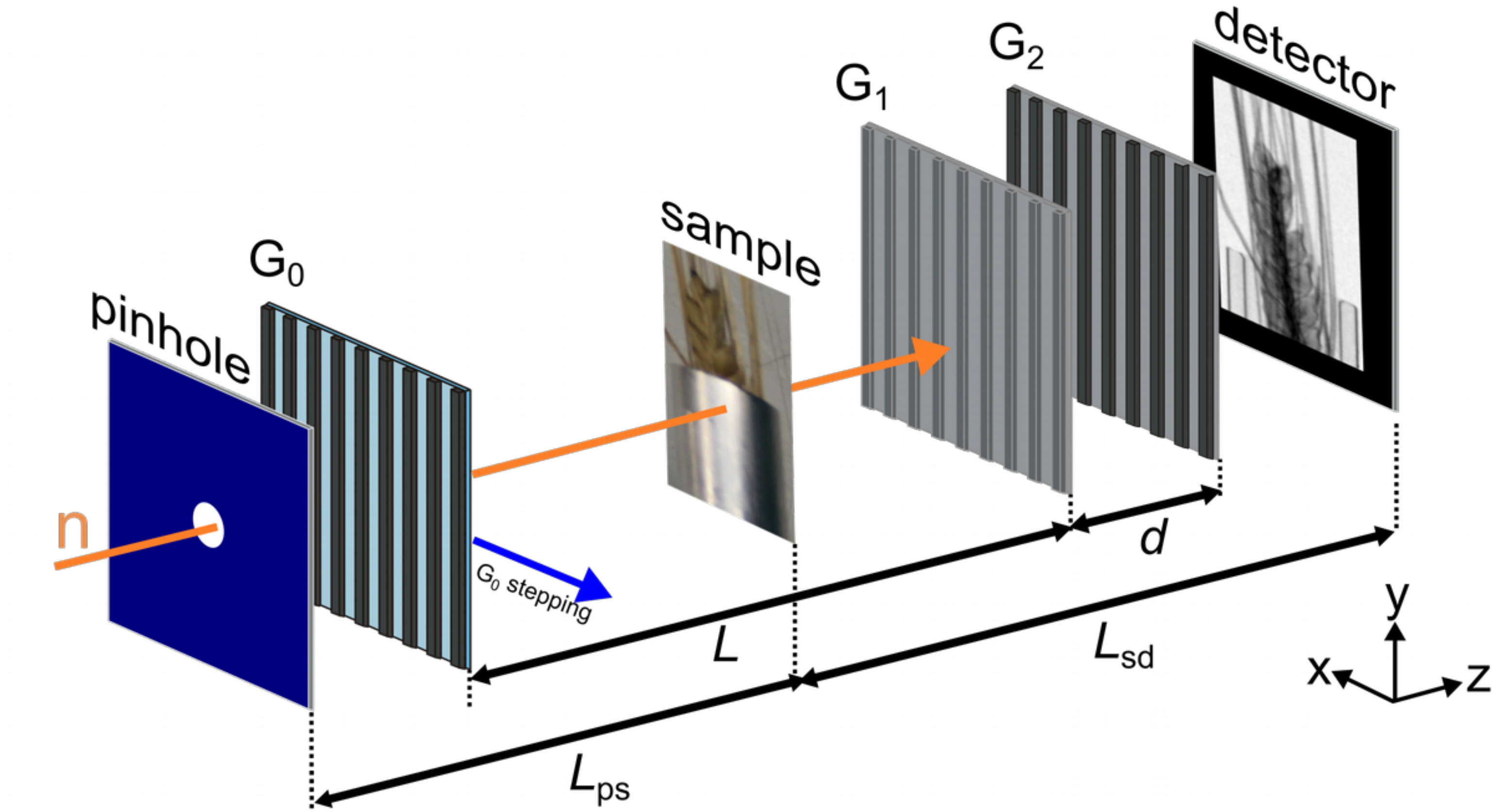


$$p_0 \frac{d}{L} = p_2$$

$$\frac{d}{L} = \left(\frac{2 p_2}{p_1} - 1 \right) = const.$$

- Strong geometric constraints imposed by the nGI
- Change of one component leads to a change in the whole setup
- Correlation length defined by these geometric constraints
- Positioning of the gratings key to good results

Summary



- nGI (DFI) allows to look at USANS in samples, with which structures in the range of 100 nm to 15 µm can be probed
- Magnetic structures can also be resolved by this, as neutrons scatter on the domain walls
- Compared to normal USANS lower q-range, but allows for spatial resolution

Danke!

Thank you for your attention!

Questions?