Neutron Optics for focussing and imaging
WP 5, DK-CH
(work in progress since September)

Stefan Othmar Poulsen
NEXMAP
DTU Physics
Technical University of Denmark (DTU)

In collaboration with
H. F. Poulsen (a), P. Bentley (b), U. Filges (c), and A. Snigirev (d)

(a) DTU Fysik Institut for Fysik

(b) EUROPEAN SPALLATION SOURCE

(c) PAUL SCHERRER INSTITUT PSI

(d) ESRF

DANCHIP

Background: X-rays

X-rays: A. Snigirev *et al.* CRL for X-rays: *Nature* **384**, 49 - 51 (1996).

Status:

Synchrotrons: Most used optics for ESRF !

Transmission X-ray Microscopy

Advantages:

- Cheap
- Very adaptable: wide energy range and wide range of focal spots
- Highly reproducible: Can be inserted and removed rapidly
- Supports various types of microscopy

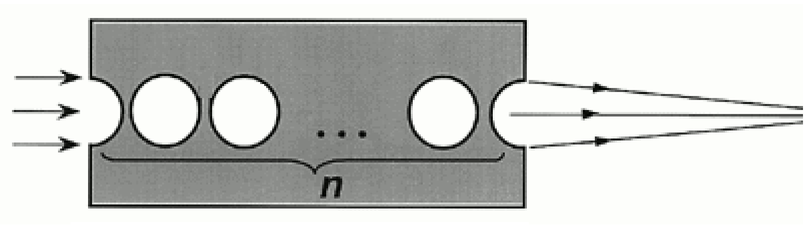
Neutrons: M.R. Eskildsen *et al.* CRL for neutrons: Nature **391**, 563-566 (1998)

Disadvantages

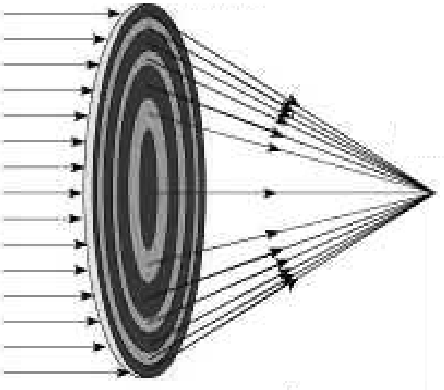
- Less efficient
- Compatibility with time-of-flight?

Existing lens technology

1. Refractive lenses
   Compound refractive lens



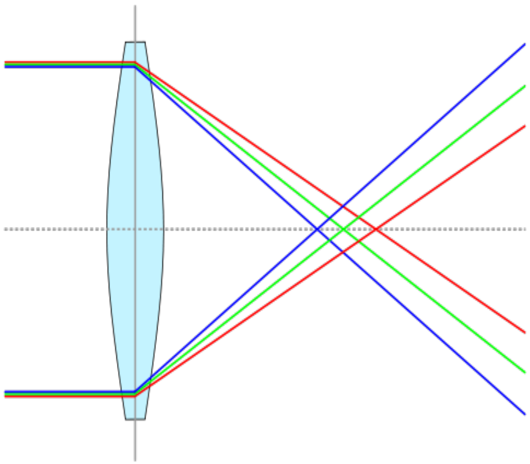
2. Diffractive lenses
   (Fresnel) zone plate



3. Reflective lenses
   Bent supermirror lens

Extension to TOF, pink beam, white beam:

Chromatic abberation:



CRL: $\Delta f / f = -2 \Delta\lambda/\lambda$

ZP: $\Delta f / f = -\Delta\lambda/\lambda$

Mono. synchrotron X-rays: $\Delta\lambda/\lambda \approx 0.001$
Mono. (e.g. SANS) neutrons: $\Delta\lambda/\lambda \approx 0.1$

Variations of order $\Delta\lambda/\lambda$

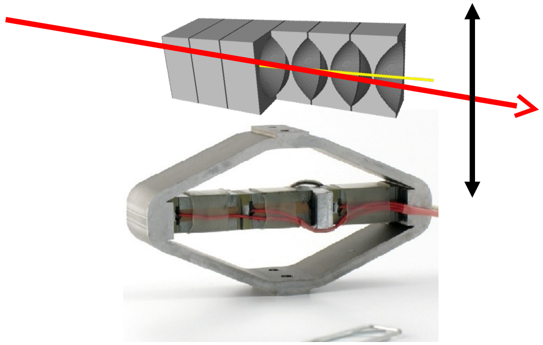
Visible light: Materials with different dispersion are combined

Not possible for neutrons!

Extension to TOF, pink beam, white beam:

Three solutions investigated:

1. Mechanical transfocator



Piezo: CEDRAT Tech.
Range: ~1 mm
Time: ~2 ms

2. Magnetic transfocator

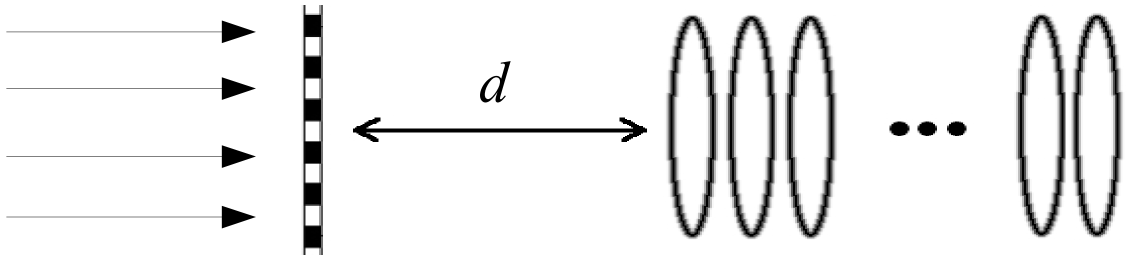
Make lenses of ferrite: material for fast switching

→ Polarization at the same time*

*: K. C. Littrell et al. *Rev. Sci. Instr.* (2007) **78**, 035101

Extension to TOF, pink beam, white beam:

3. (Passive) combination of ZP and CRL:



ZP focusses, CRL defocusses

d=0 ⇒ $$\frac{\Delta f}{f} = \left(\frac{\Delta \lambda}{\lambda}\right)^2$$

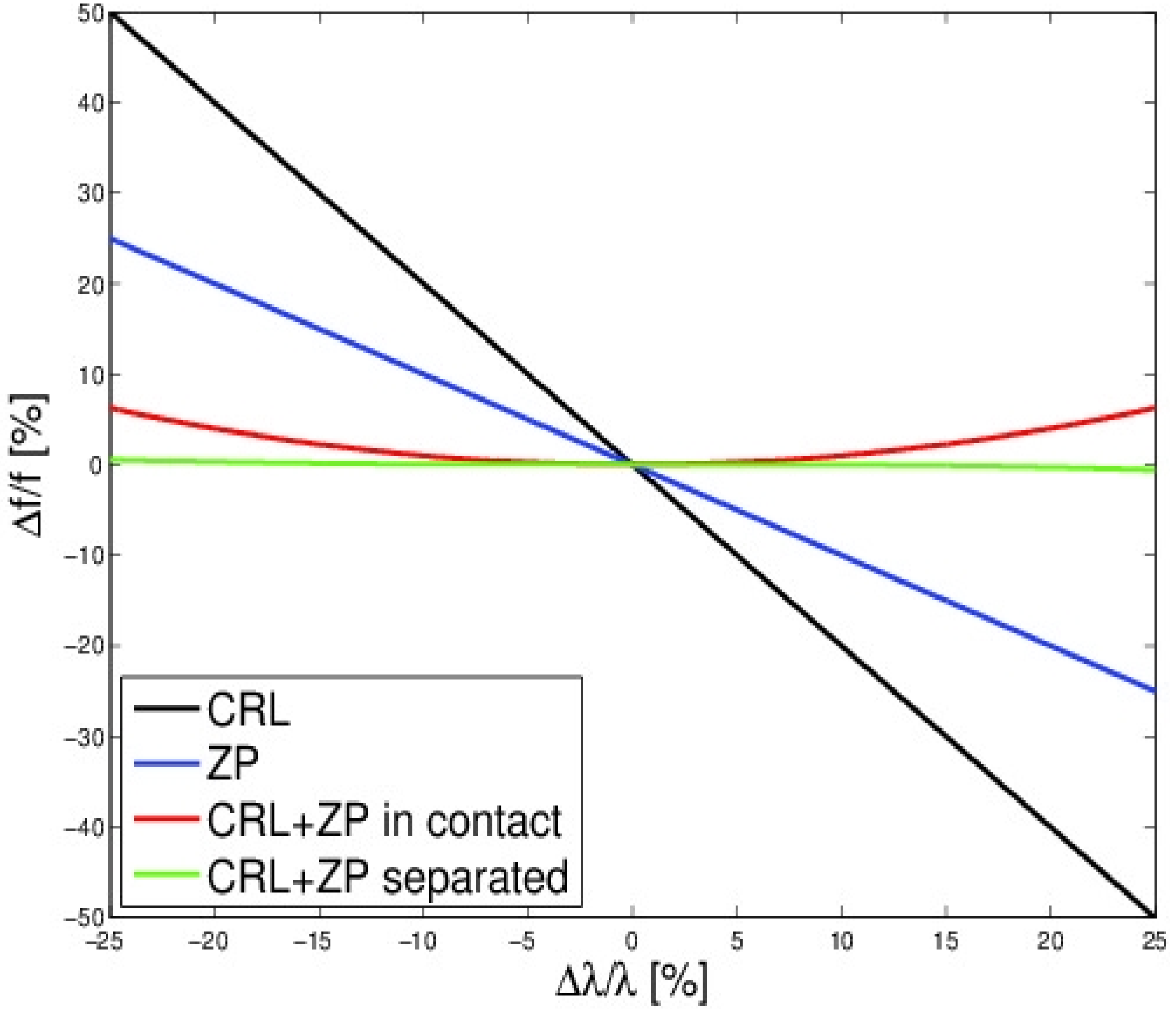
d>0 ⇒ $$\frac{\Delta f}{f} = \frac{-3}{8}\left(\frac{\Delta \lambda}{\lambda}\right)^3$$

Extension to TOF, pink beam, white beam:

- Chromatic spread for CRL and ZP is substantial

- A CRL and ZP in contact is much better

- A CRL and a ZP distanced is even better



Experimental investigation of CRL + ZP combination:

is being pursued (at BOA beamline at SINQ)

<u>Production/purchase of CRL</u>:

Table 1 Candidate elements for CRLs

Element/isotope	b_c/σ_a (fm^{-1})
O	310
C	19
Be†	10
Pb*	8.0
F†	5.8
Zr*	5.3
Pb*	3.1
Bi†	2.5
H*†	2.1
Zr*	1.6
Mg†	0.86
Mo*	0.85
Mo*	0.68
Sr*	0.43
N*†	0.34
Tl*†	0.24

Be:
- Used for X-rays
- A. Snigirev?

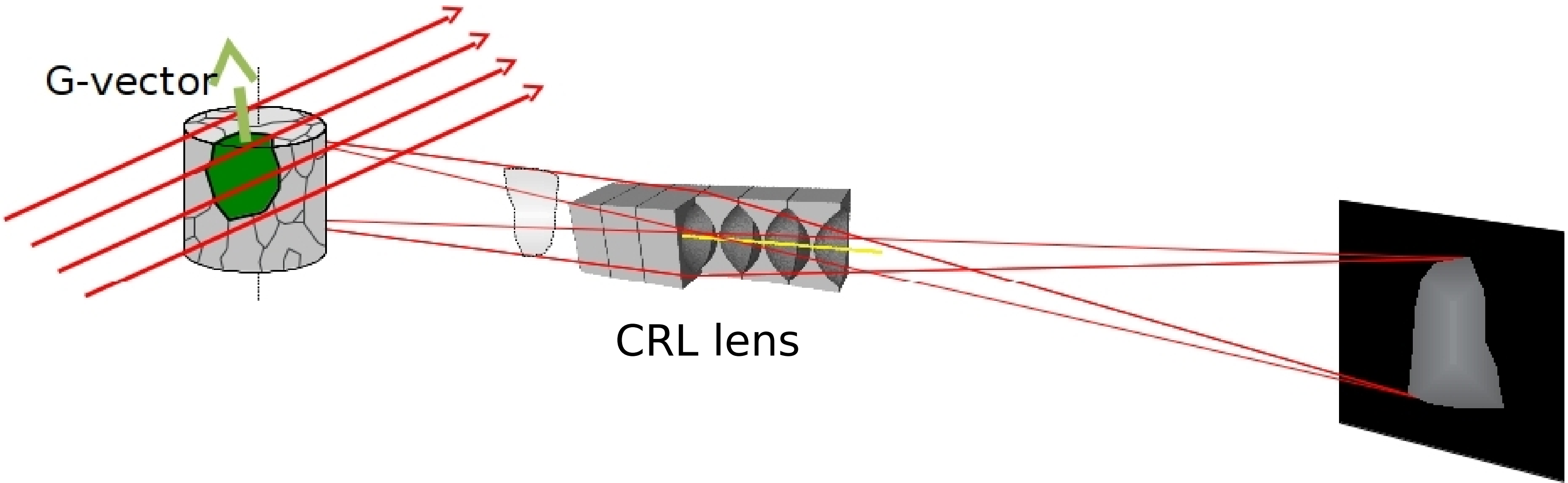
MgF2:
- Used for light
- Commercially available

<u>Production of ZP</u>:
- Lithographic process
- Ni on Si is excellent
- In talks with DANCHIP

DANCHIP

Modified from M.R. Eskildsen *et al.* Nature **391**, 563-566 (1998)

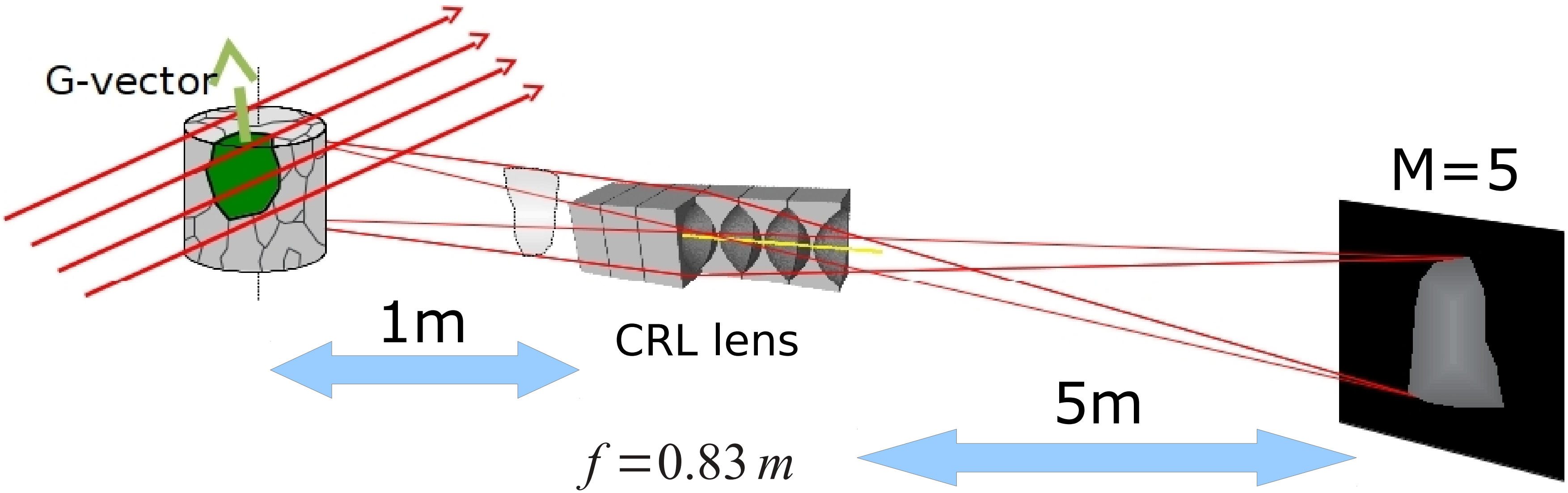
Example: neutron dark field microscope



- Lenses work best at long wavelengths
- Flux is highest at short wavelengths

Compromise: $2\theta \approx 160^{\circ}$

Example: neutron dark field microscope



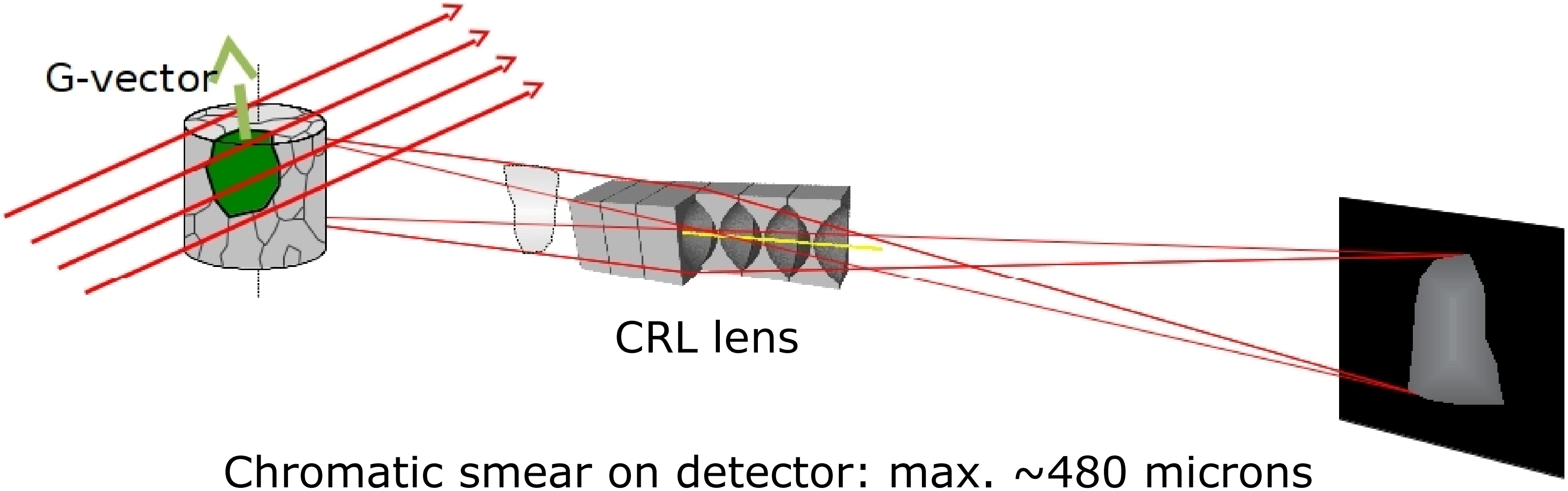
$$f = 0.83\,m$$

bcc iron, a=2.87Å, d=100 microns

$\lambda = 5.5\,\AA$ and $\Delta\lambda/\lambda \approx 0.01$ ➡ $\Phi \approx 4.4\,s^{-1}$

Be lenses, d=0.8 cm ➡ N = 96

Example: neutron dark field microscope



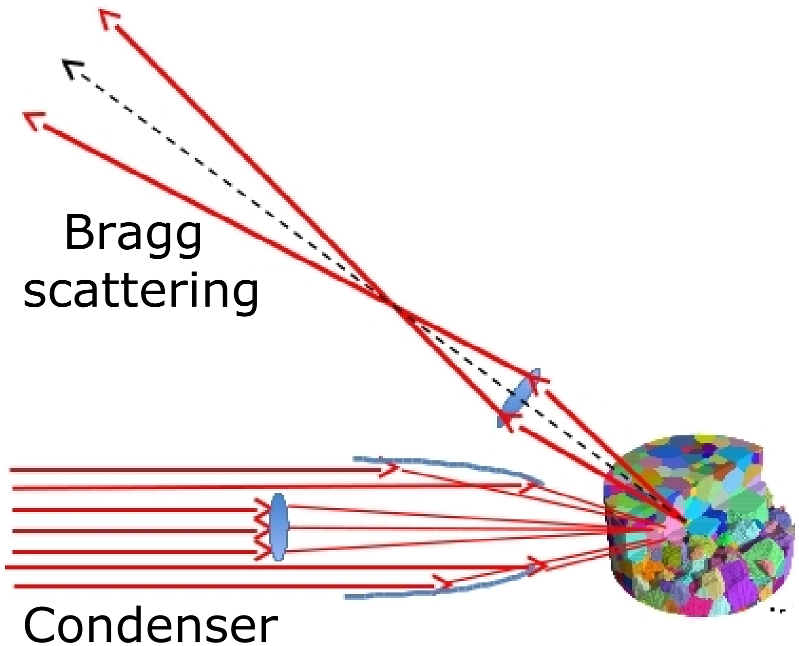
Chromatic smear on detector: max. ~480 microns
=”= in sample space: max. ~ 100 microns

Could be reduced / eliminated by an achromatic lens

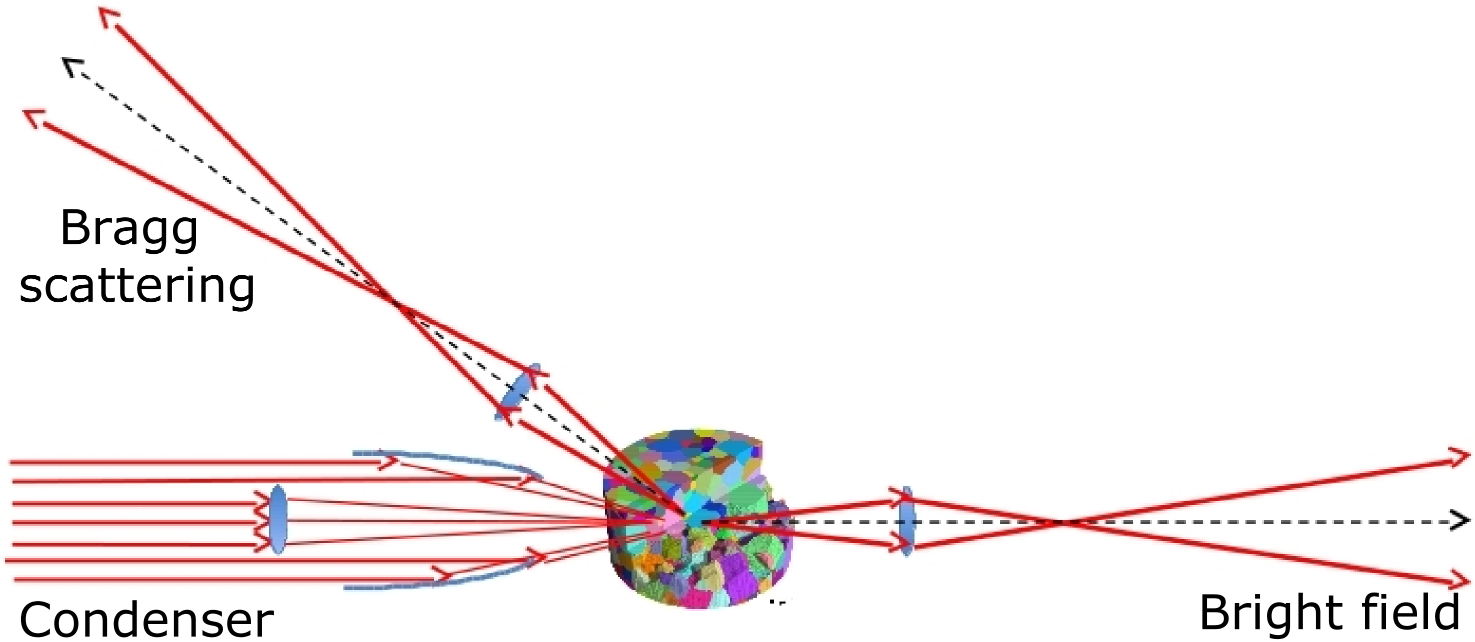
Crystallography, strain, etc. with very high resolution

(This is work in progress!)

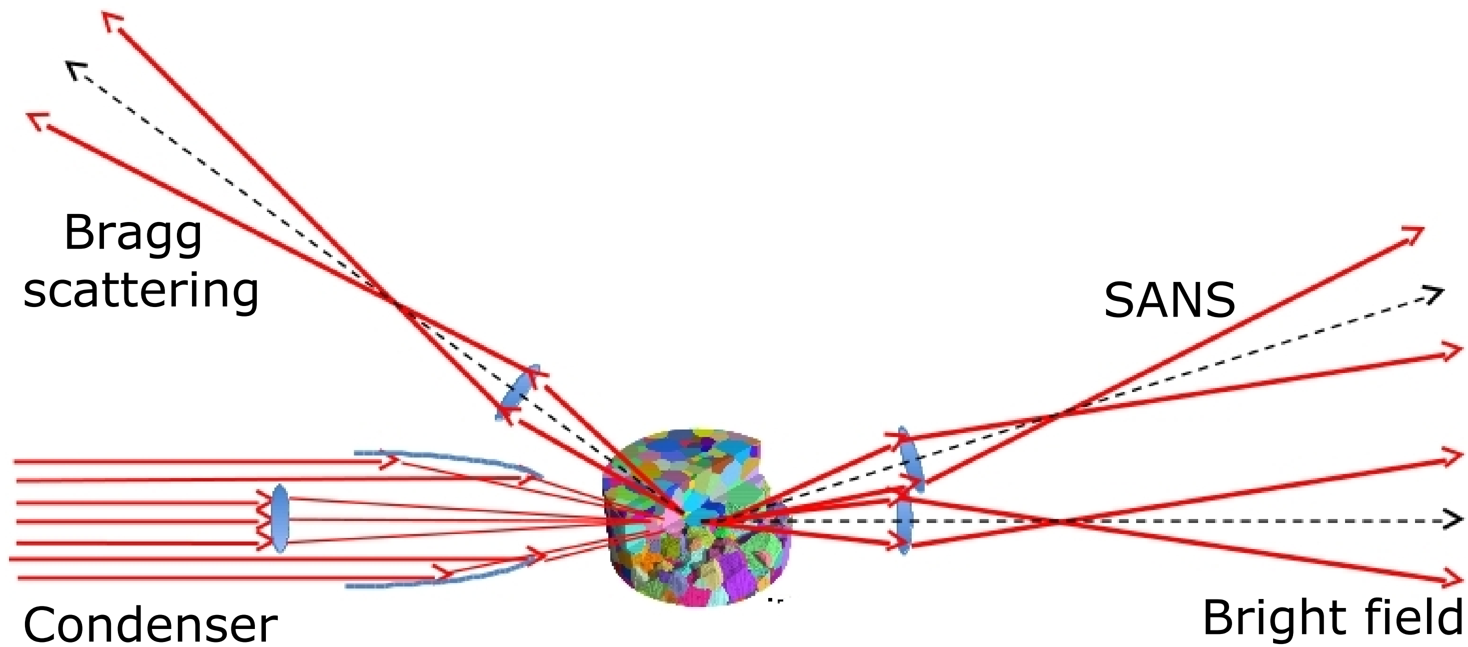
Neutron microscopy



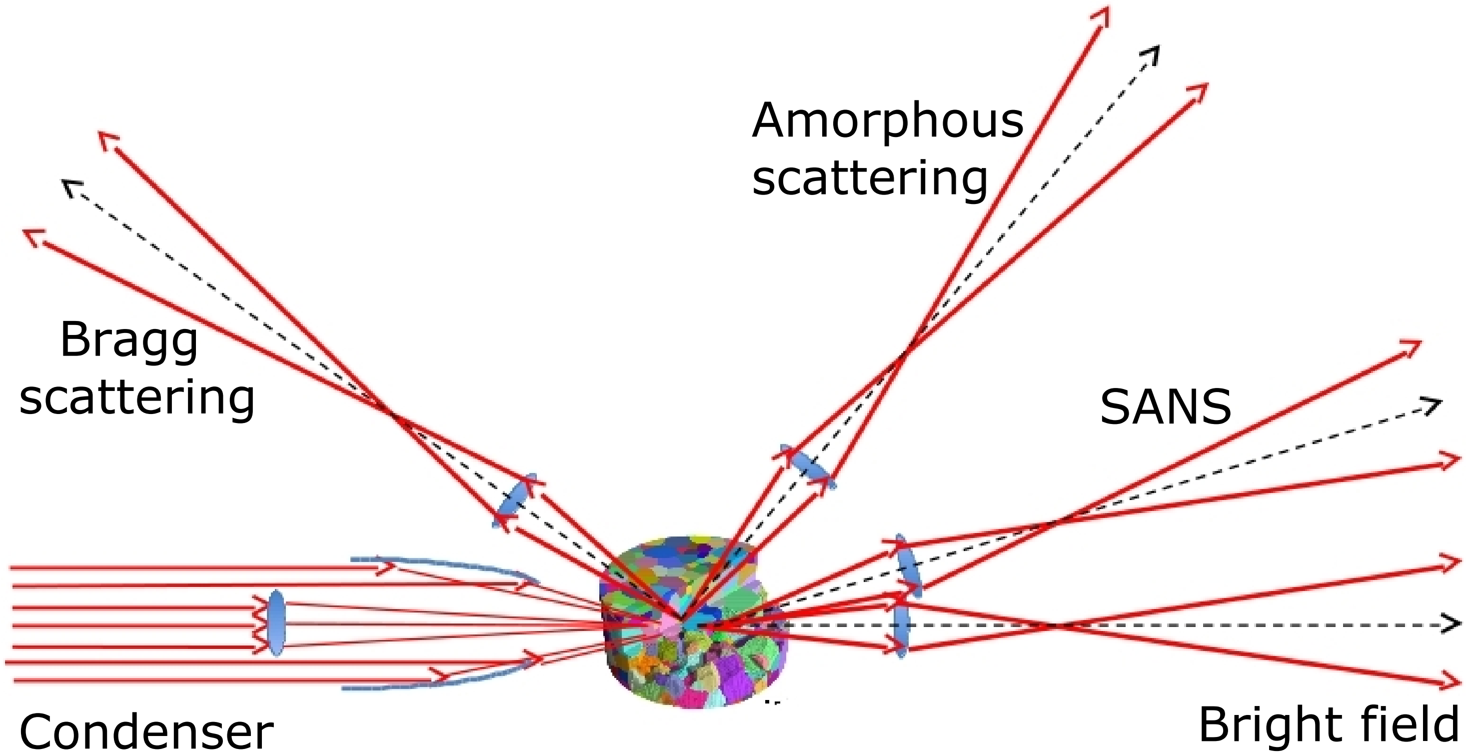
Neutron microscopy



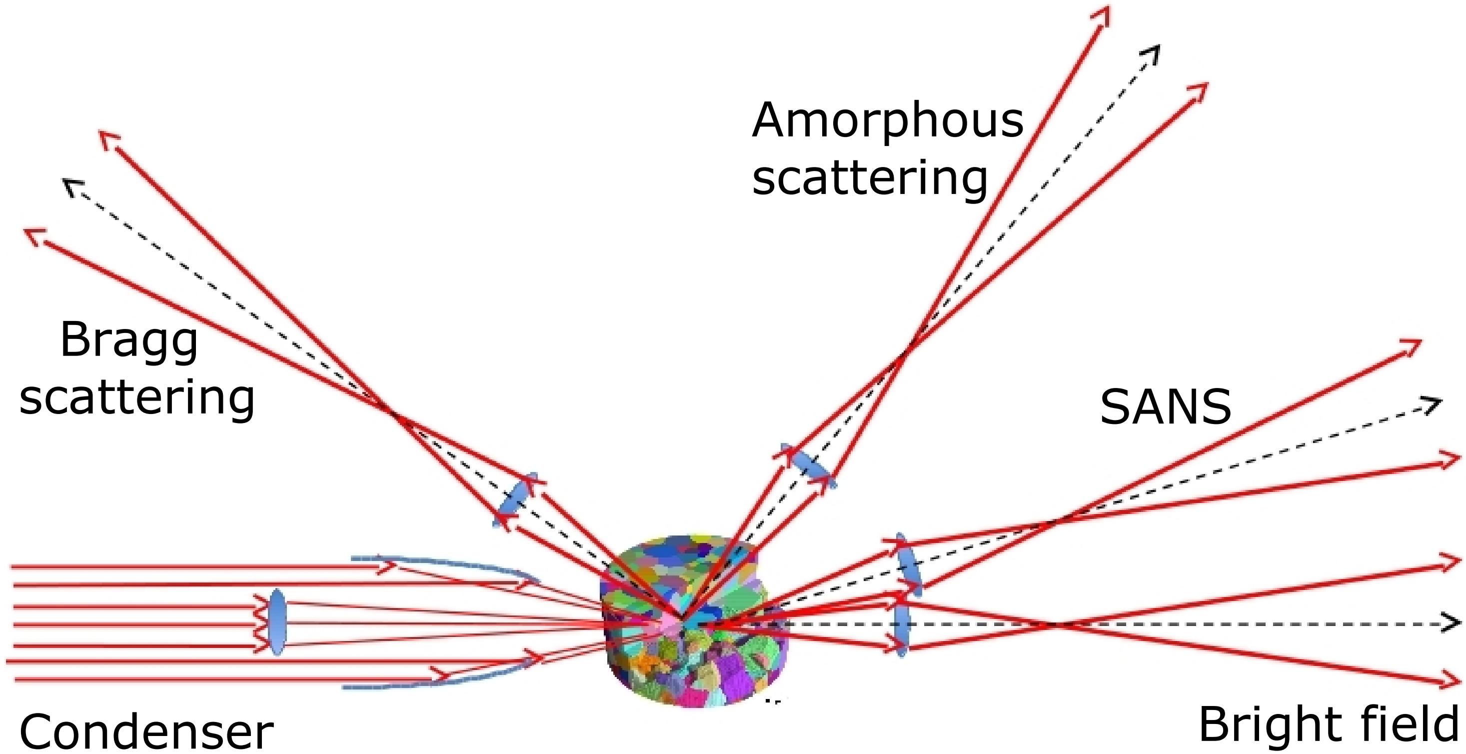
Neutron microscopy



Neutron microscopy



Neutron microscopy



4π coverage with objectives
Microscopy in all of rec. space