OPPORTUNITIES IN THE USE OF VERY COLD NEUTRONS FOR RADIOGRAPHY TECHNIQUES.

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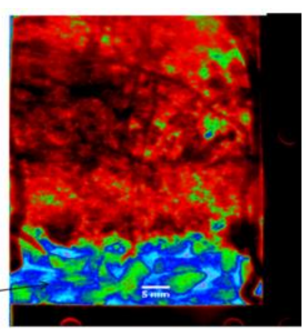
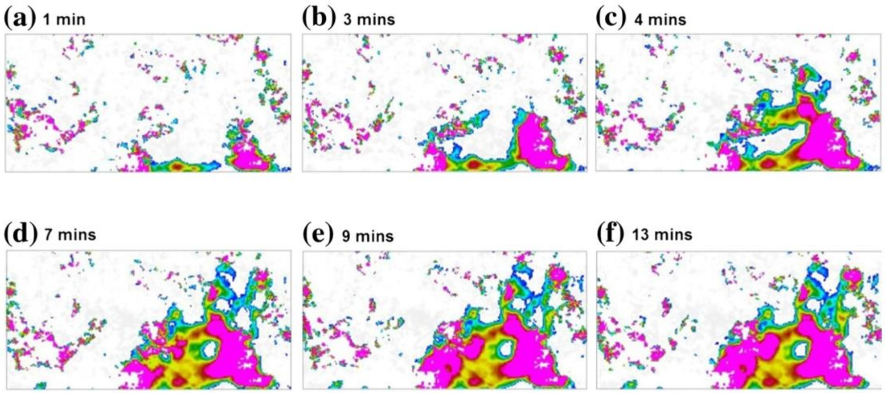
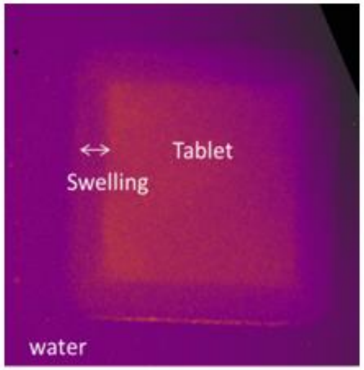
WHAT DO WE AIM AT PROBING ?

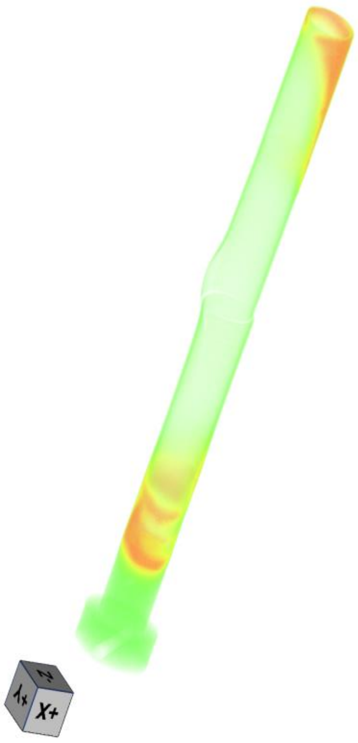
What science ?

- Radio-tomography of microscopic structures (10µm → 200µm)

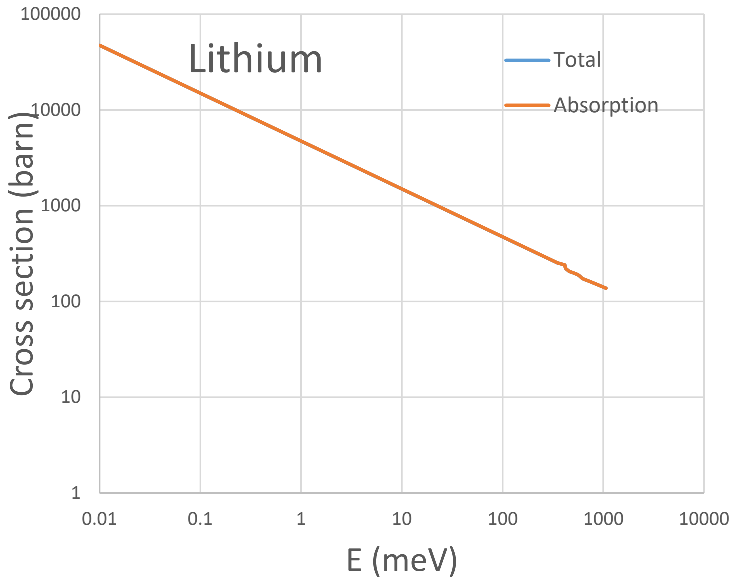


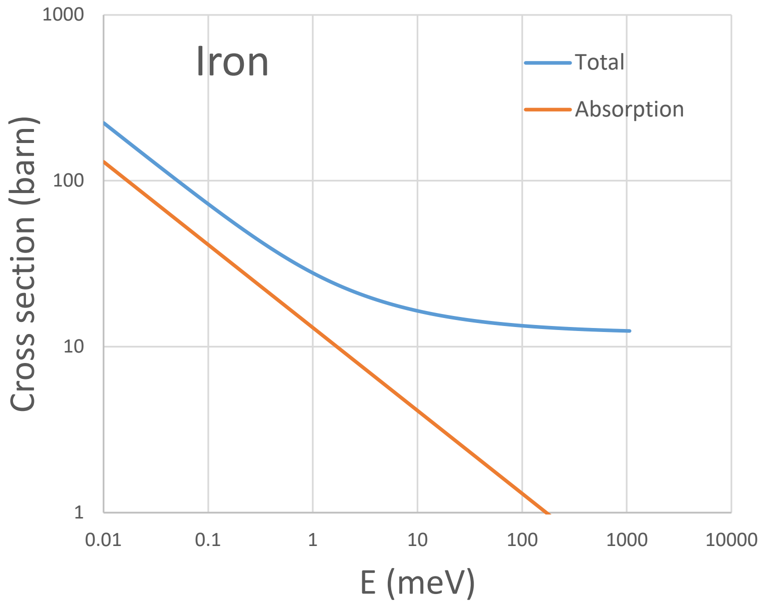


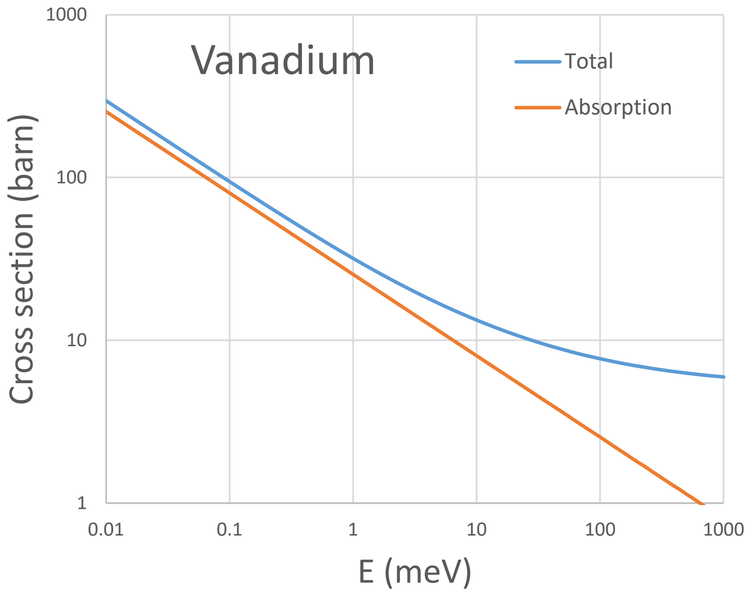


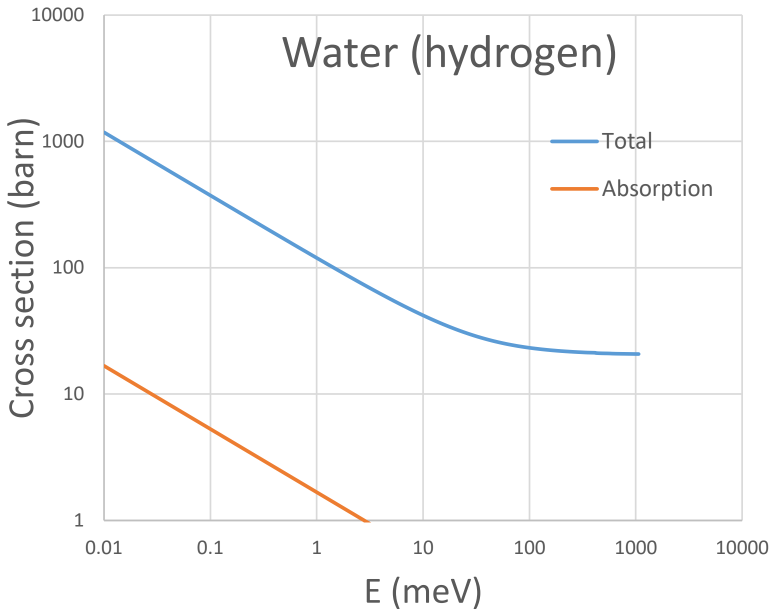


NEUTRON CROSS SECTIONS









SOURCES OF NEUTRON IMAGING CONTRAST

Most of the time incoherent scattering from hydrogenated materials

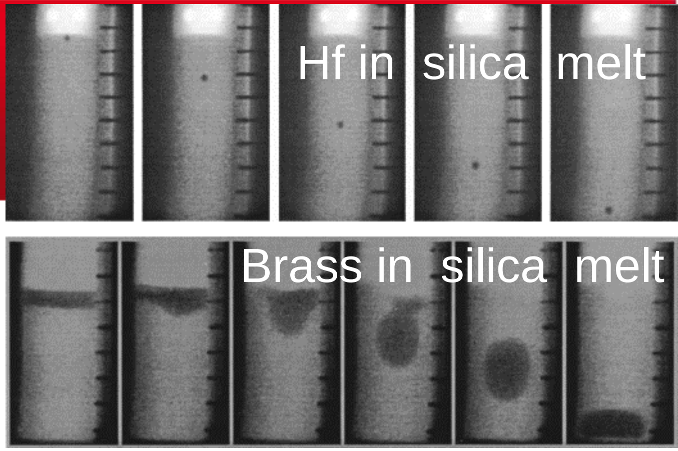
Diffraction contrast → Bragg edge imaging

SANS scattering – Refraction effects

More exotic → magnetic contrast

Rarely absorption contrast : Lithium – Boron – Gadolinium

ABSORPTION CONTRAST



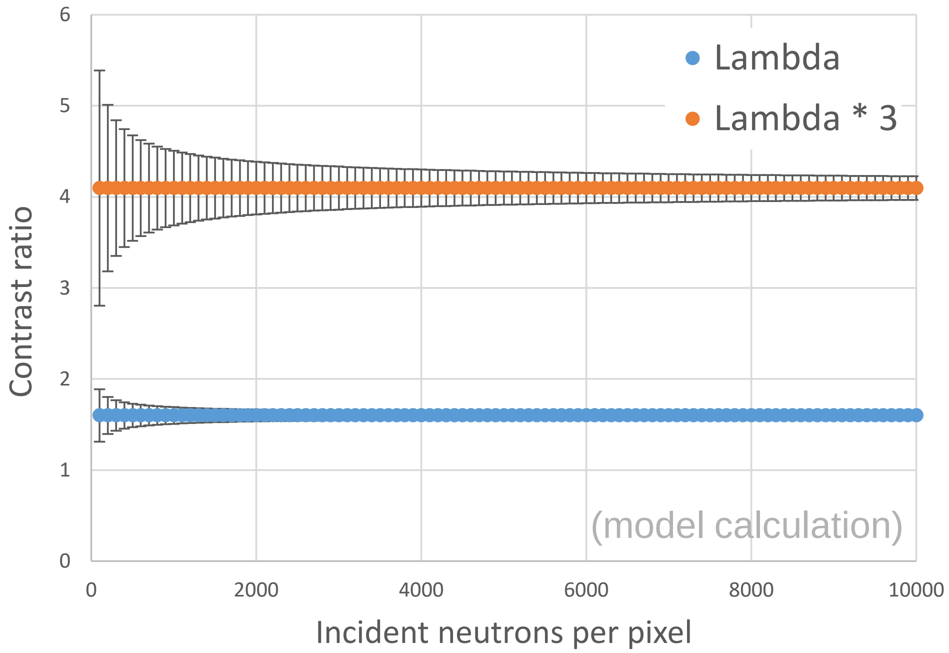
- Lithium in batteries
- Boron in metallic nuclear materials (good homogeneity)
- Gadolinium or Hafnium as a marker

Absorption contrast scales as λ → VCN are a priori better

- One may study thinner samples

But the absorption increases also for the surrounding materials

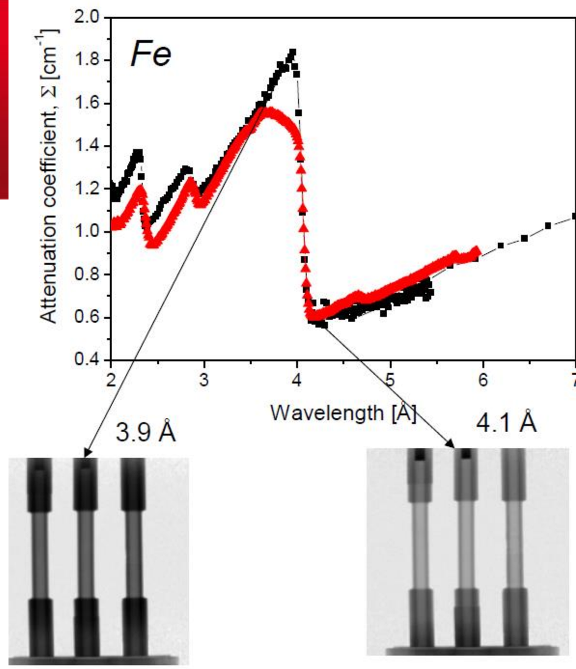
- For some « fixed geometry » problems, long wavelengths may be unsuitable
  → the « sample » is not sufficiently transparent anymore
  - Boron in metallic nuclear elements
  - Lithium in batteries
  - Melts (geophysics)



DIFFRACTION CONTRAST – BRAGG EDGE IMAGING

Bragg edge imaging relies on the diffraction on crystallites in the studied material (Fe, Ni, Cu, Al)

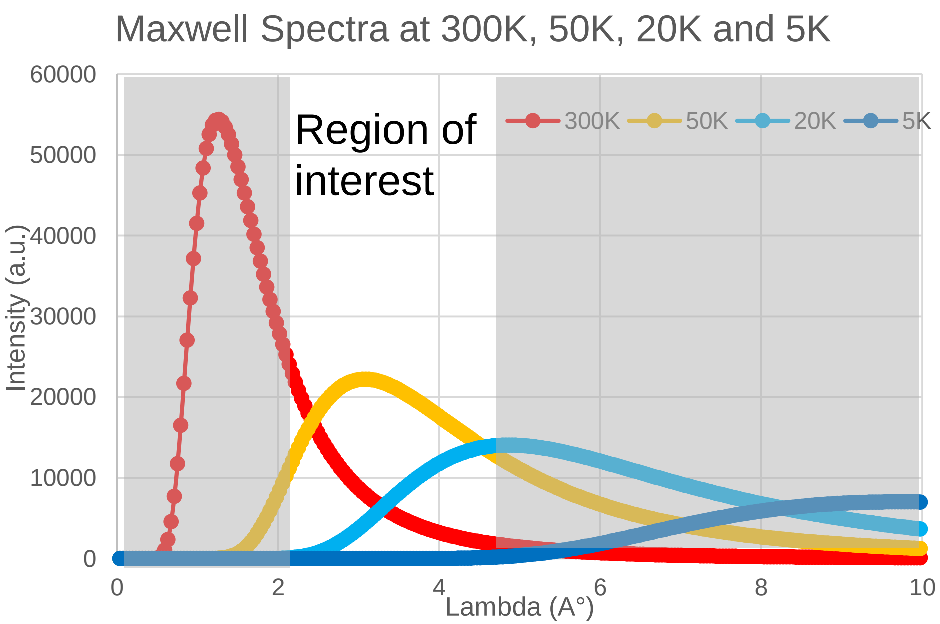
- Wavelengths are scattered only up to 4.2A° (in 3d metals)
- Useful wavelength range { 2A° - 5A° }
  = typical cold neutron spectrum
- It is possible to take advantage of the pulsed structure of ESS
  - The Bragg edge information is obtained « for free »
  - ESS especially suited for such studies



Courtesy of Prof. D. Penumadu, UTK and N. Kardjilov, HZB

- Colder neutrons are a handicap
  → Bragg edge diffraction is no more possible

- Upside, no need to care about the pulse time structure anymore ☺

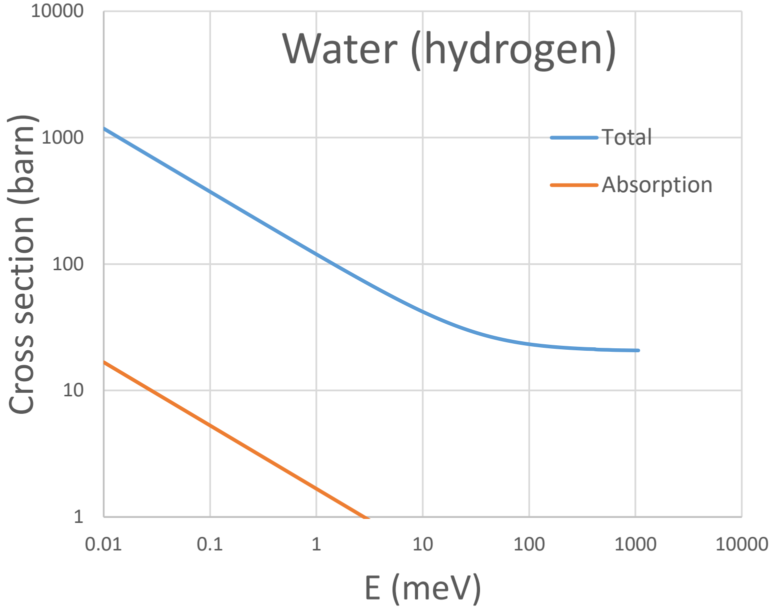


INCOHERENT SCATTERING

Incoherent scattering from hydrogen is one of the most widely used contrast in neutron radiography experiments

- Liquids in porous medium (rocks, concrete, fuel cells, roots, food …)

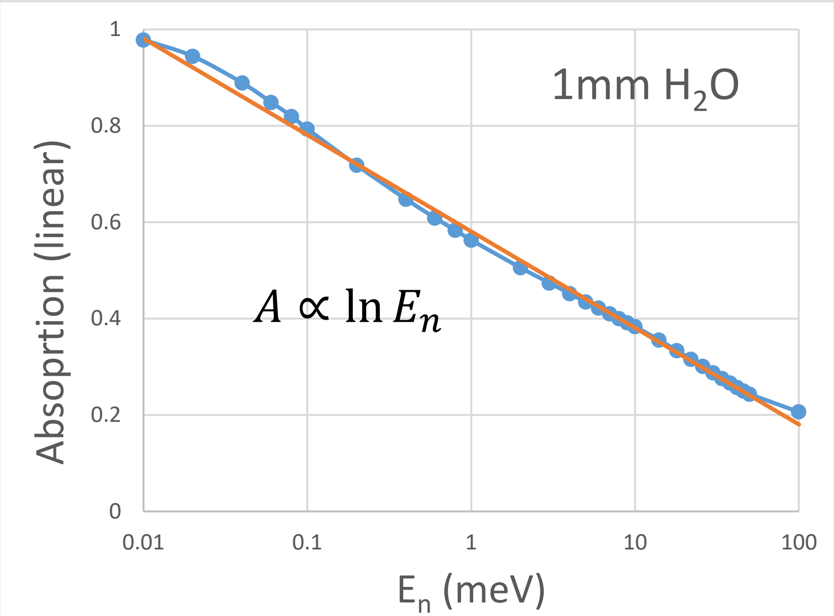
Incoherent scattering (on H) is a strong effect in neutron cross section

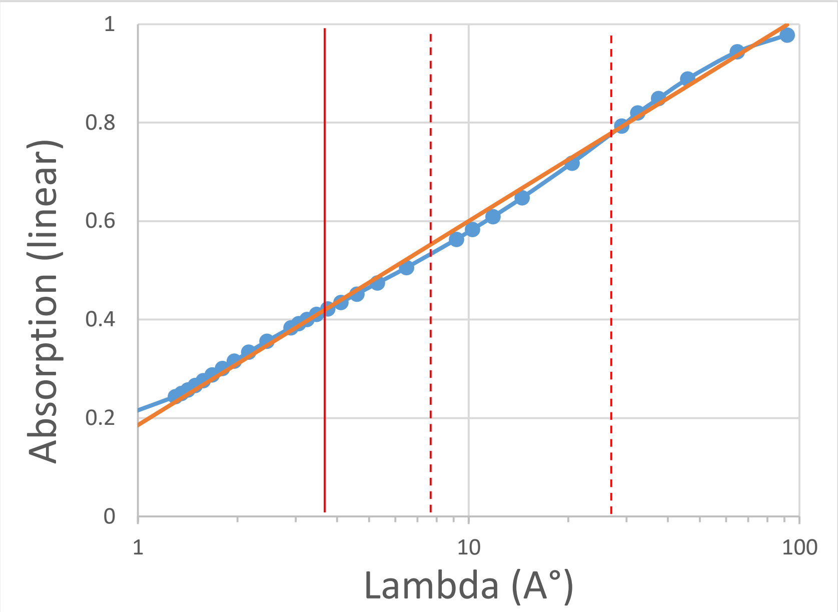


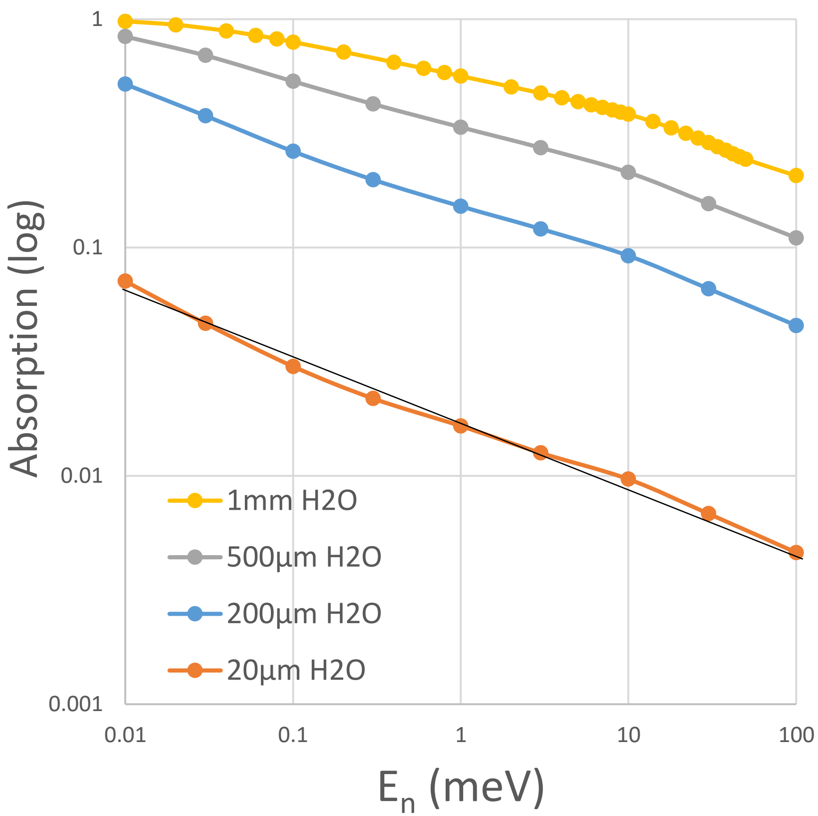
But it is a complex process

- Most often it is a multiple scattering process
- It leads to inelasticity
- The wavelength dependance is non trivial

ABSORPTION OF WATER VS E_N







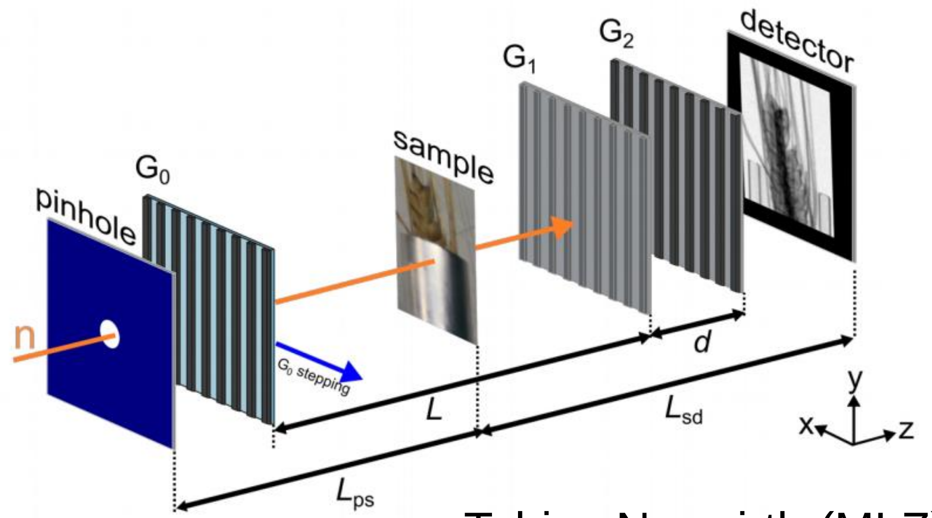
Very cold neutrons are useful for very small contrasts

SANS and refraction as a source of contrast

Neutron grating interferometry is probably easier to implement

- Phase gratings and absorption gratings are easier to build for long wavelengths
- SANS and refraction effects are higher for long wavelengths
  → better contrast expected

Neutron grating interferometer

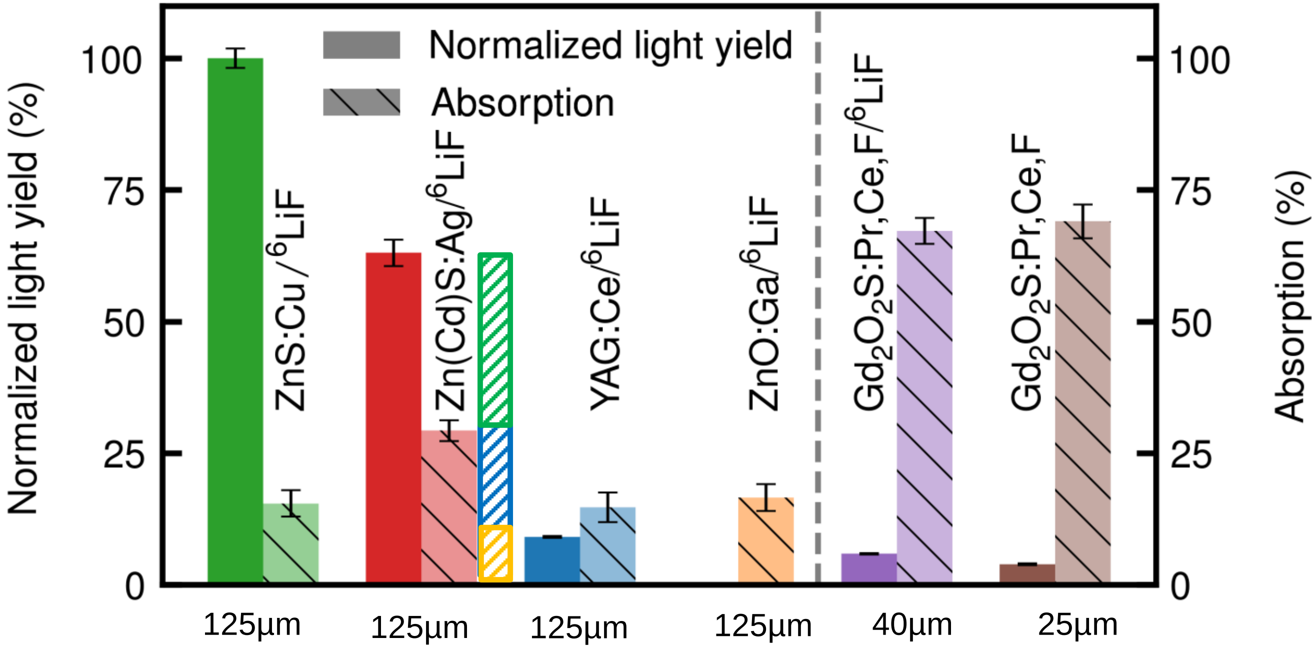


Tobias Neuwirth (MLZ)

INSTRUMENTAL GAINS

The detection efficiency increases as ~λ (actually $1- e^{-a\lambda}$) providing a direct efficiency gain

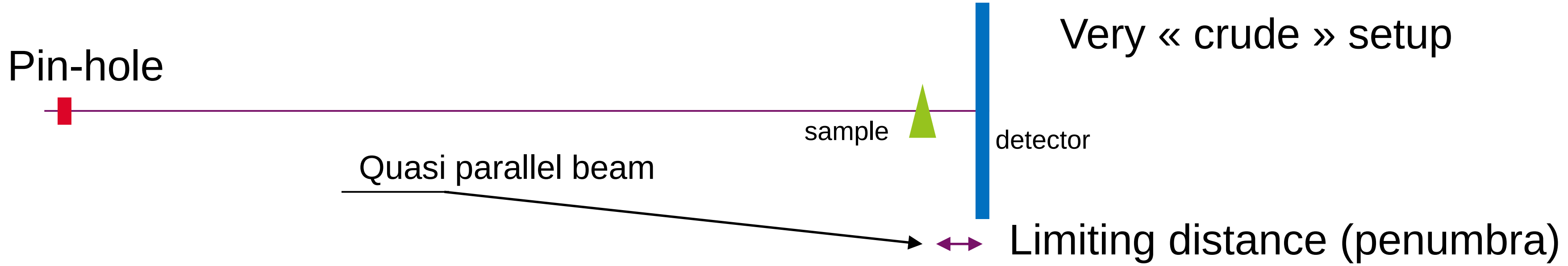
- The gain is higher if it avoids using Gadox



T. Neuwirth, J of Imaging (2020)

OPTICS FOR RADIOGRAPHY

Currently → neutron radiography uses a pin-hole geometry



- Spatial resolution proportionnal to L/D (10µm requires L/D = 1000 and SD < 10mm)
- Sample – detector distance is a strongly limiting factor
  - sample environment very challenging at high resolutions (< few 10µm)

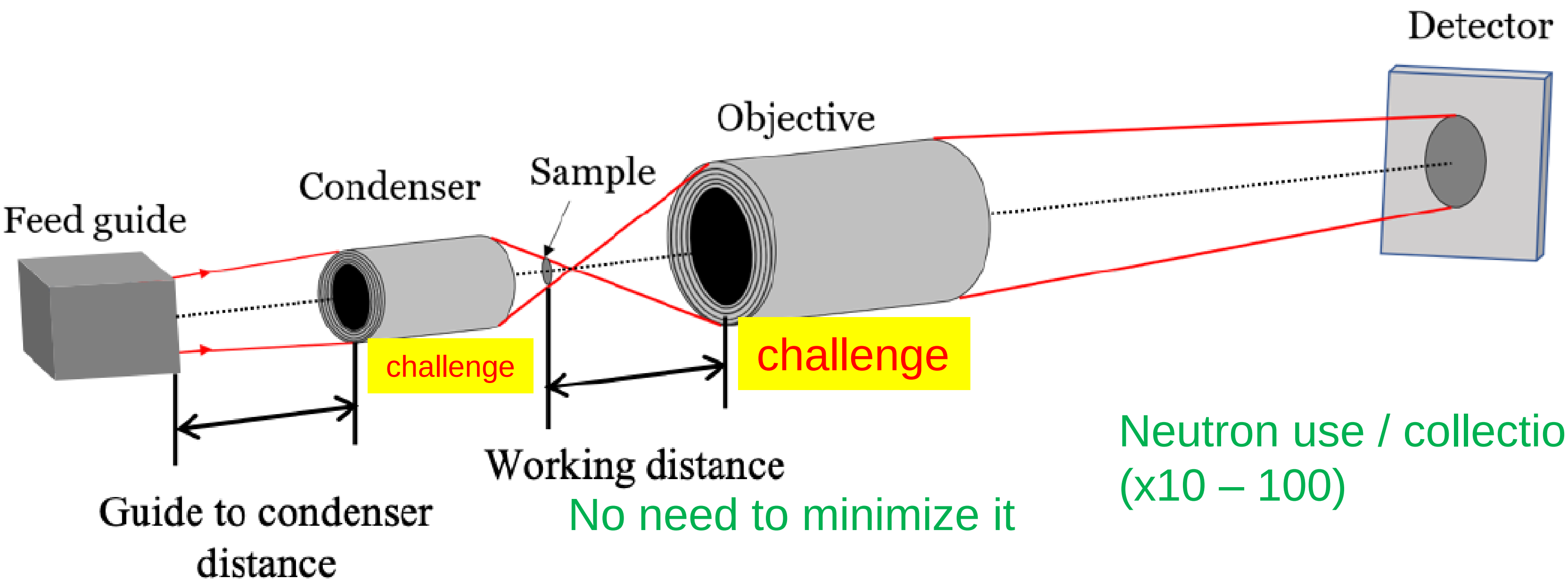
Using proper optics could significanly enhance the performances

- Neutron optics is challenging
- Inefficient + costly
- Reflective optics efficiency scales as λ (the total reflection angles is prop. to λ)

- For imaging, high quality **2D** optics is required

WOLTER OPTICS PROPOSAL
(M. ABIR ET AL , J OF IMAGING 2020, MIT - NIST)

More classical optical setup



No need to minimize it

Neutron use / collection
(x10 – 100)

Optics solid angle scales as λ^2

CONCLUSION

Longer wavelengths would provide

- a increased sensitivity, prop. λ or ln(λ)
- a better detection efficiency, prop. λ

Bragg edge imaging is no more possible if spectrum beyond cold neutrons

- no use left for pulsed beam structure

Phase contrast imaging becomes more efficient

Advanced optics is more efficient

- Wolter optics still needs to be demonstrated in « production »

Optimistic view

- Wolter optics + detection efficiency scales as λ^3 + gain in contrast
- Beware of gravity !

VCN are worth the effort (though not suitable for all problems)