Neutron Imaging
Basics + Data Analyis

Michael Schulz

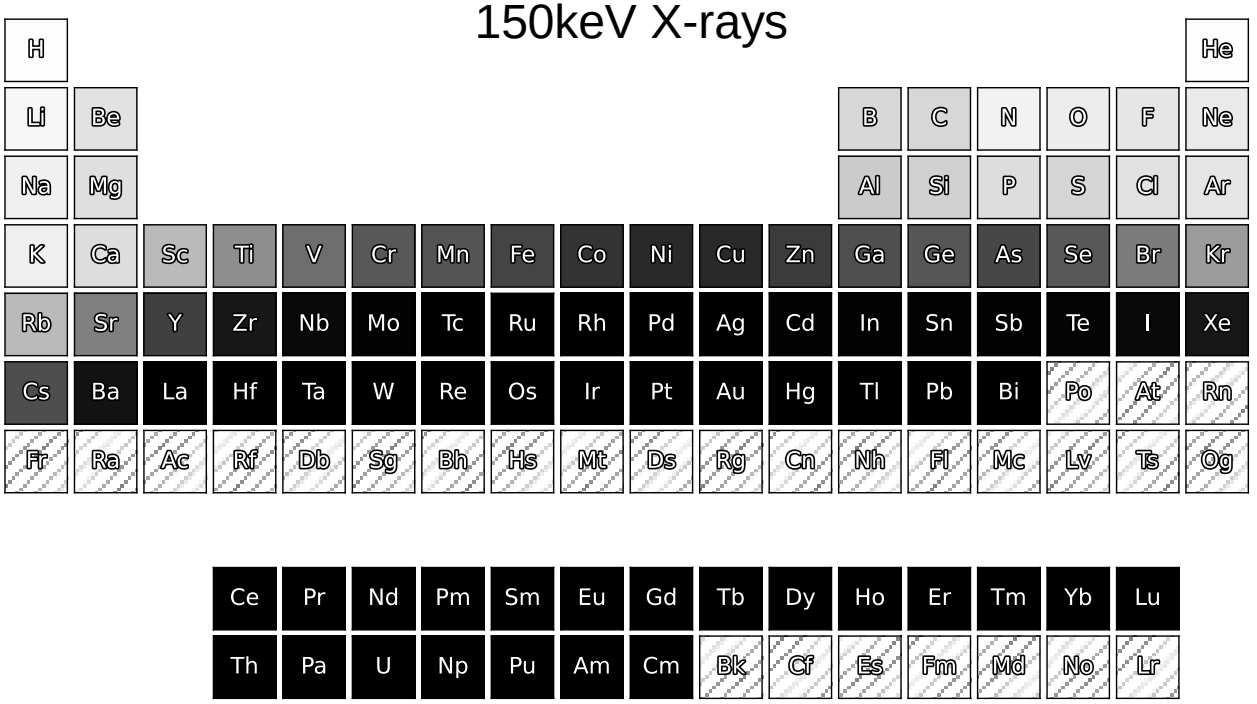
MLZ is a cooperation between:
JÜLICH Forschungszentrum
Helmholtz-Zentrum hereon
Technical University of Munich

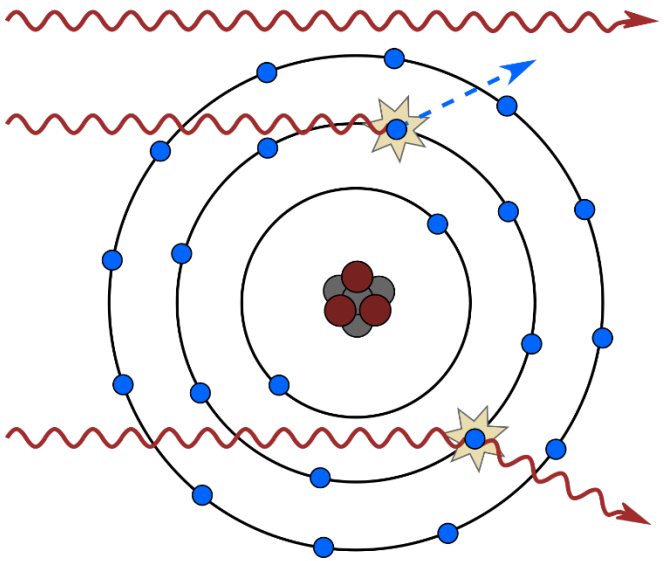
Outline

- Neutrons vs. X-rays
- Pinhole Geometry: Resolution, Intensity, Field of View
- ANTARES as an example instrument
- Neutron Transmission / projections
- Basic data processing steps
- Tomography reconstruction
- Overall data workflow

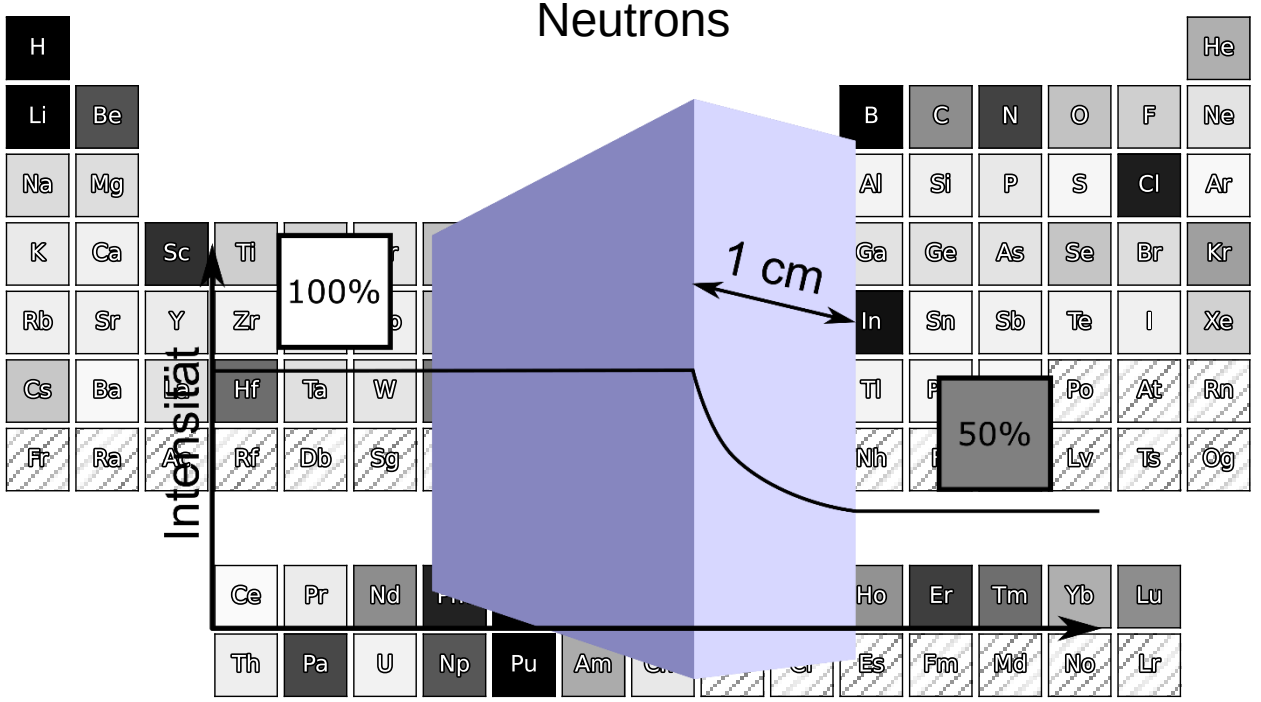
Neutrons vs. X-rays

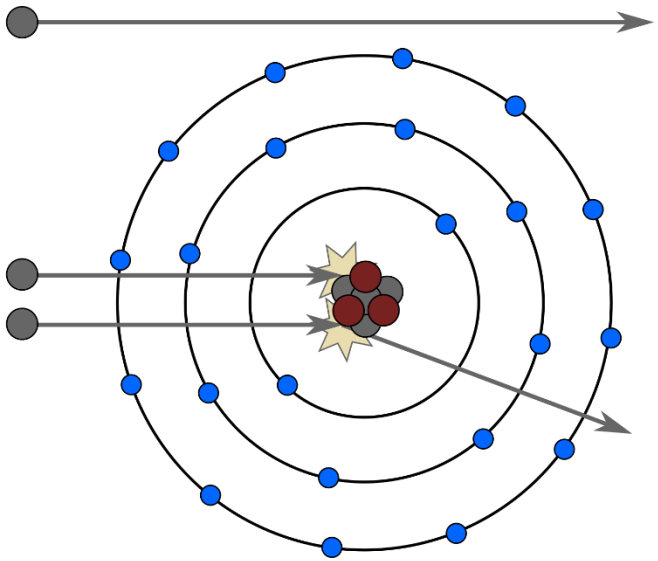
150keV X-rays



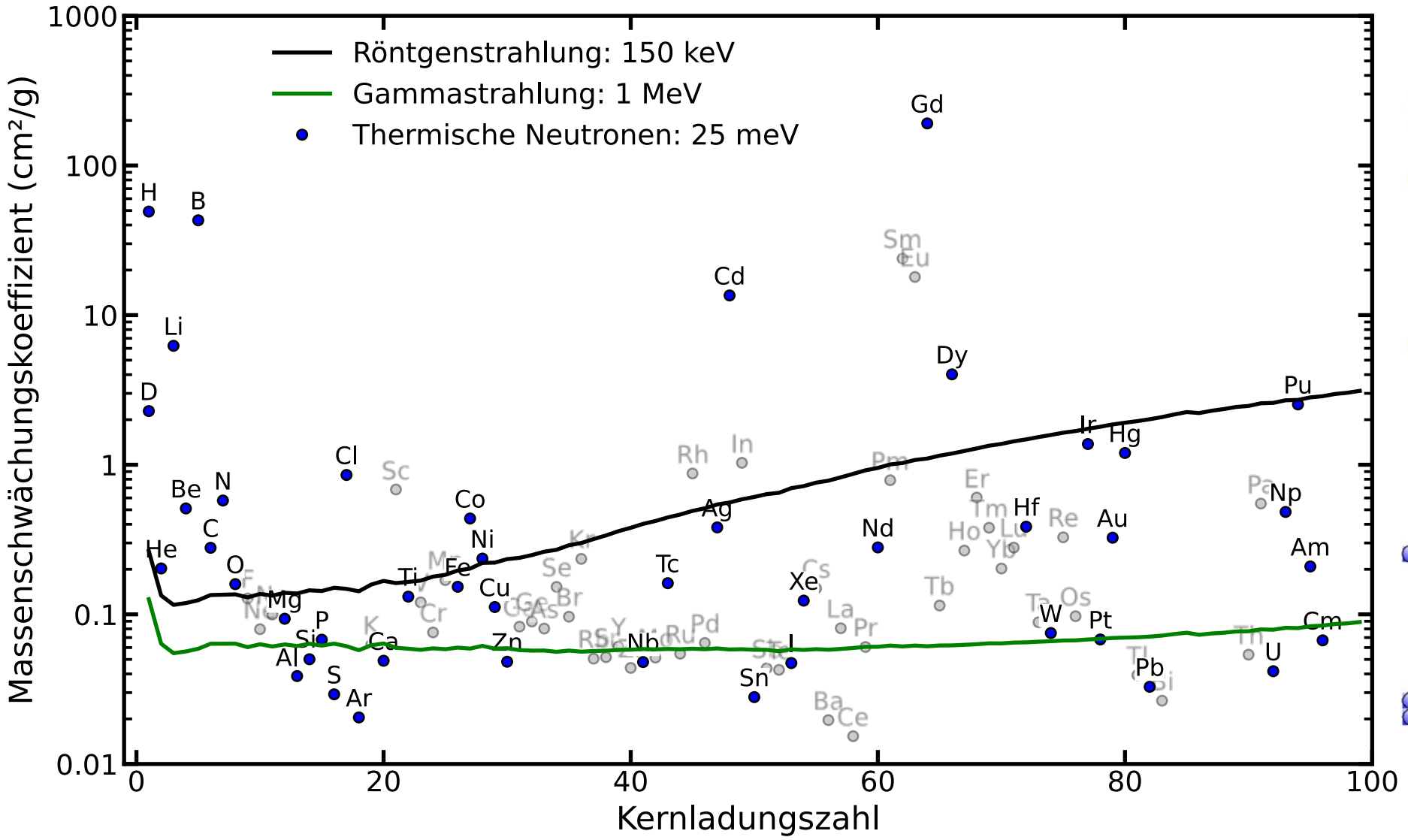


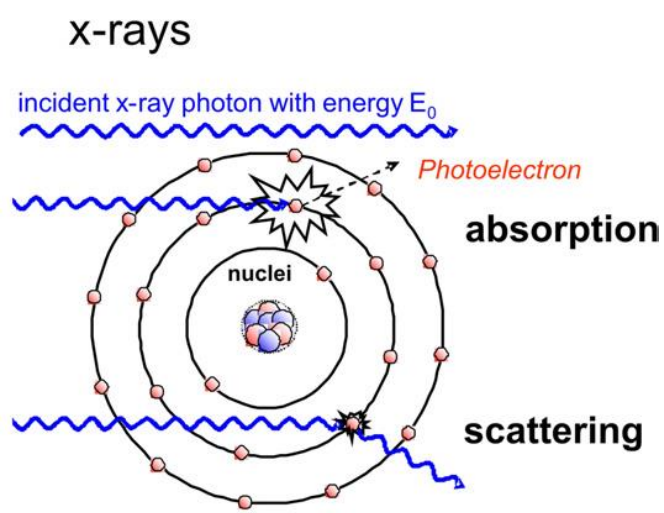
Neutrons

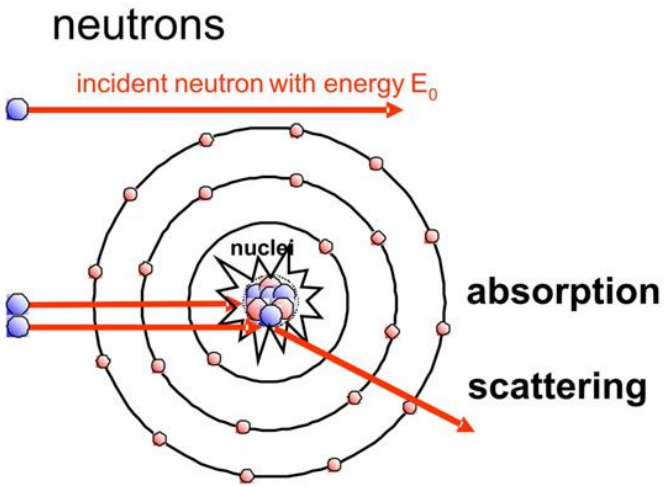




Neutrons vs. X-rays







M.Strobl, J. Phys. D, **42,** 243001 (2009)

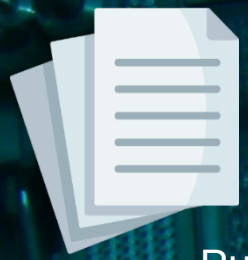
Where do we get neutrons from?

400
Mitarbeiter

28
Instrumente

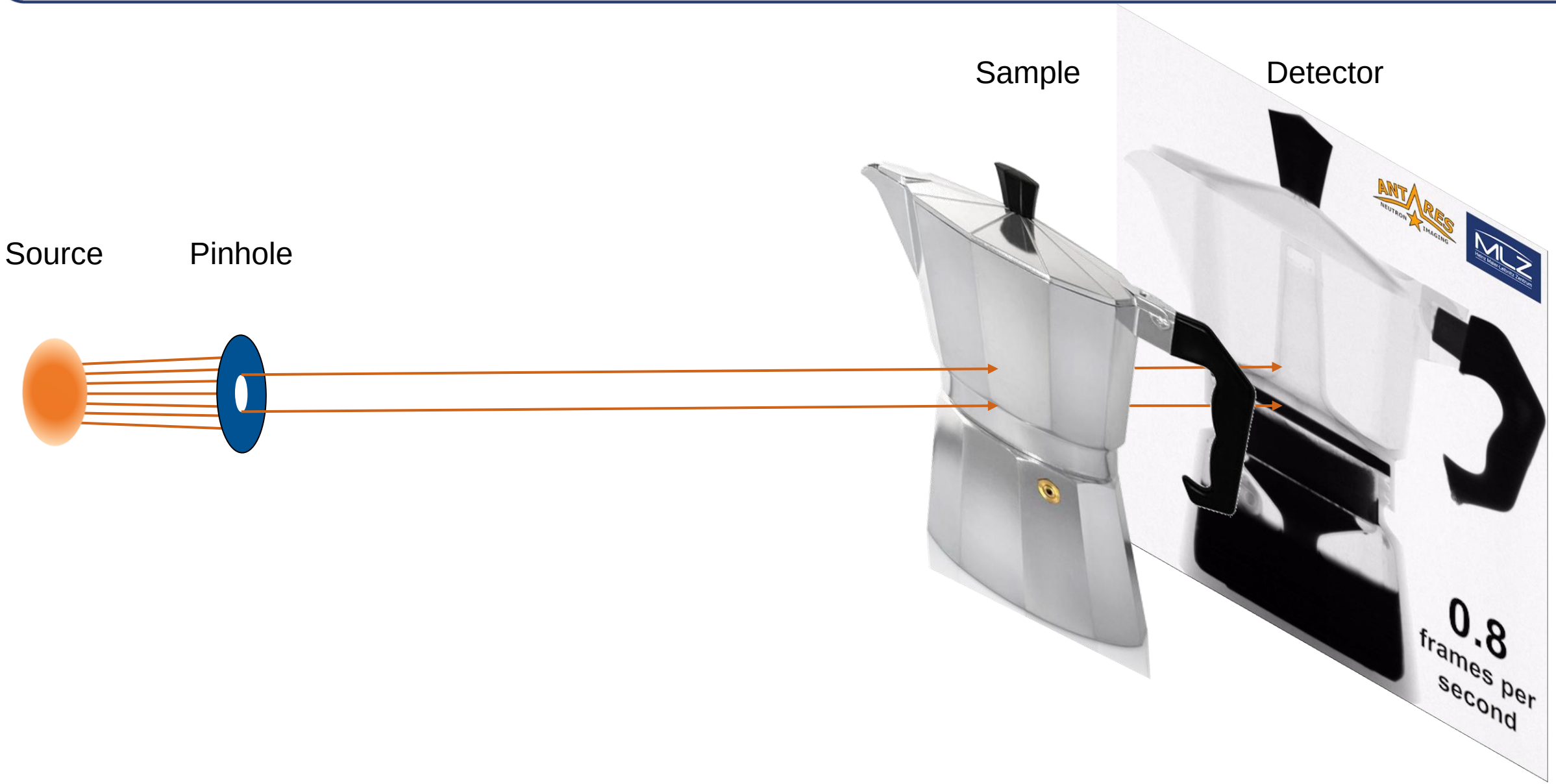
> 1.200
Gastwissenschaftler:innen / Jahr

> 40
Promotionen / Jahr

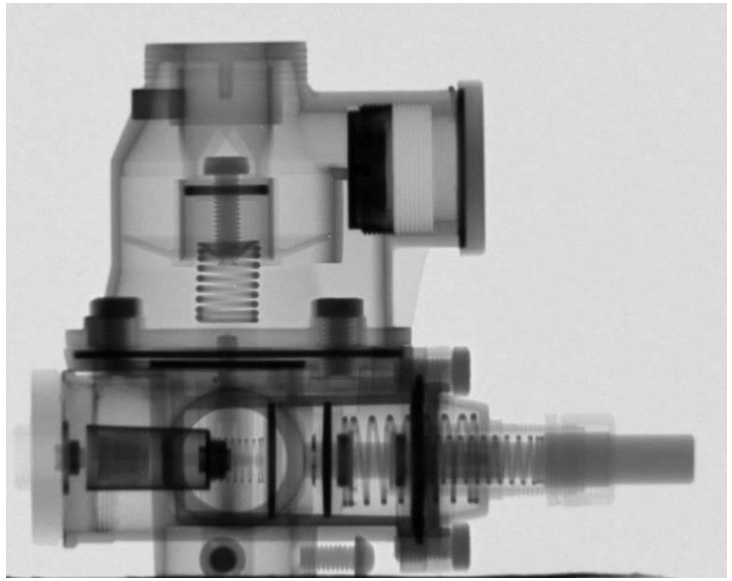


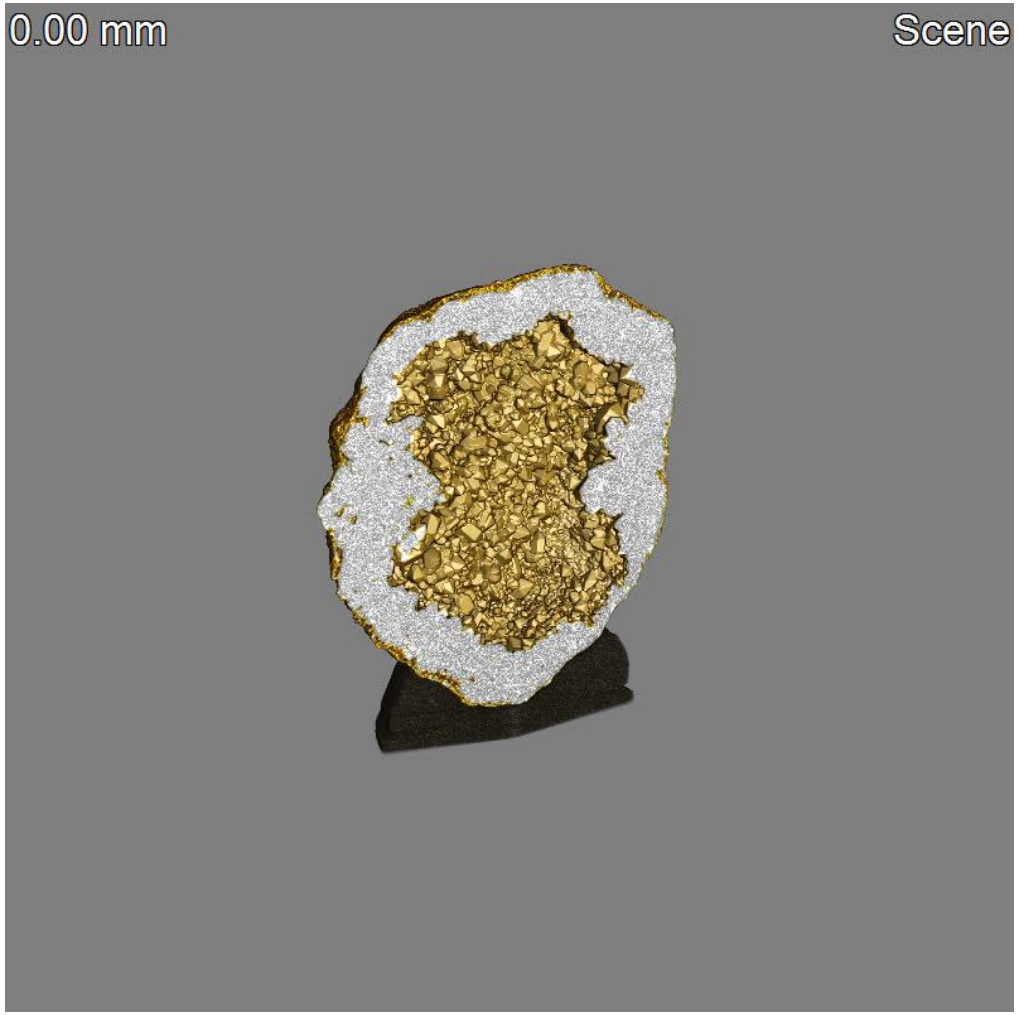
> 300
Publikationen / Jahr

Neutron Imaging Principle

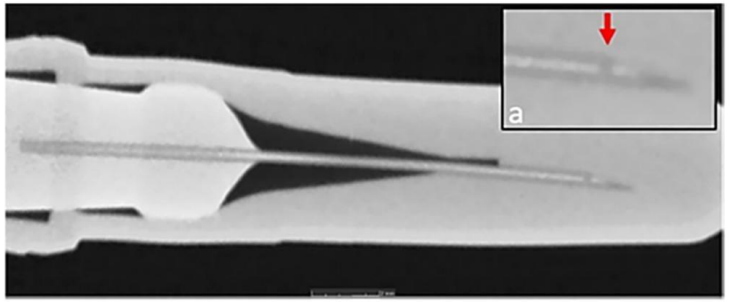


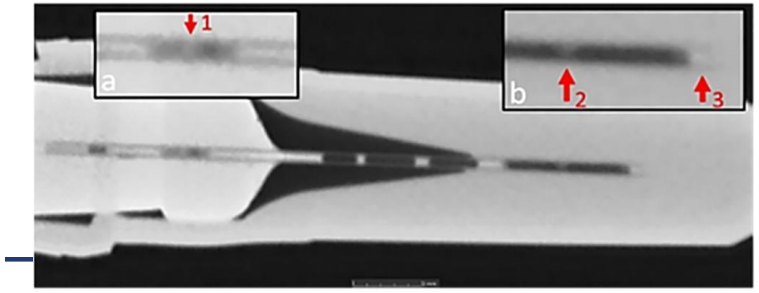
Neutron Imaging - Examples

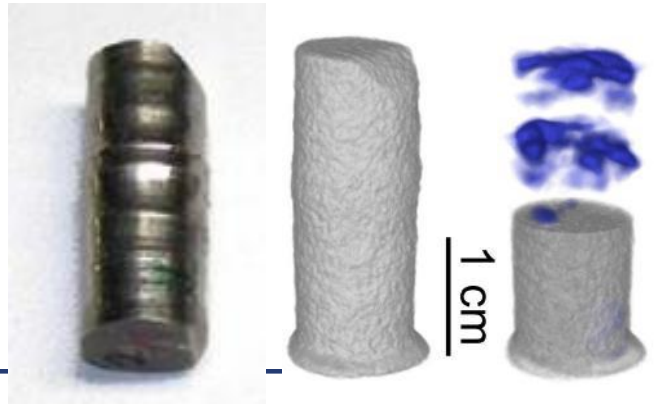




A. Gustschin, et al., J. Imaging **7** (2020) 701001





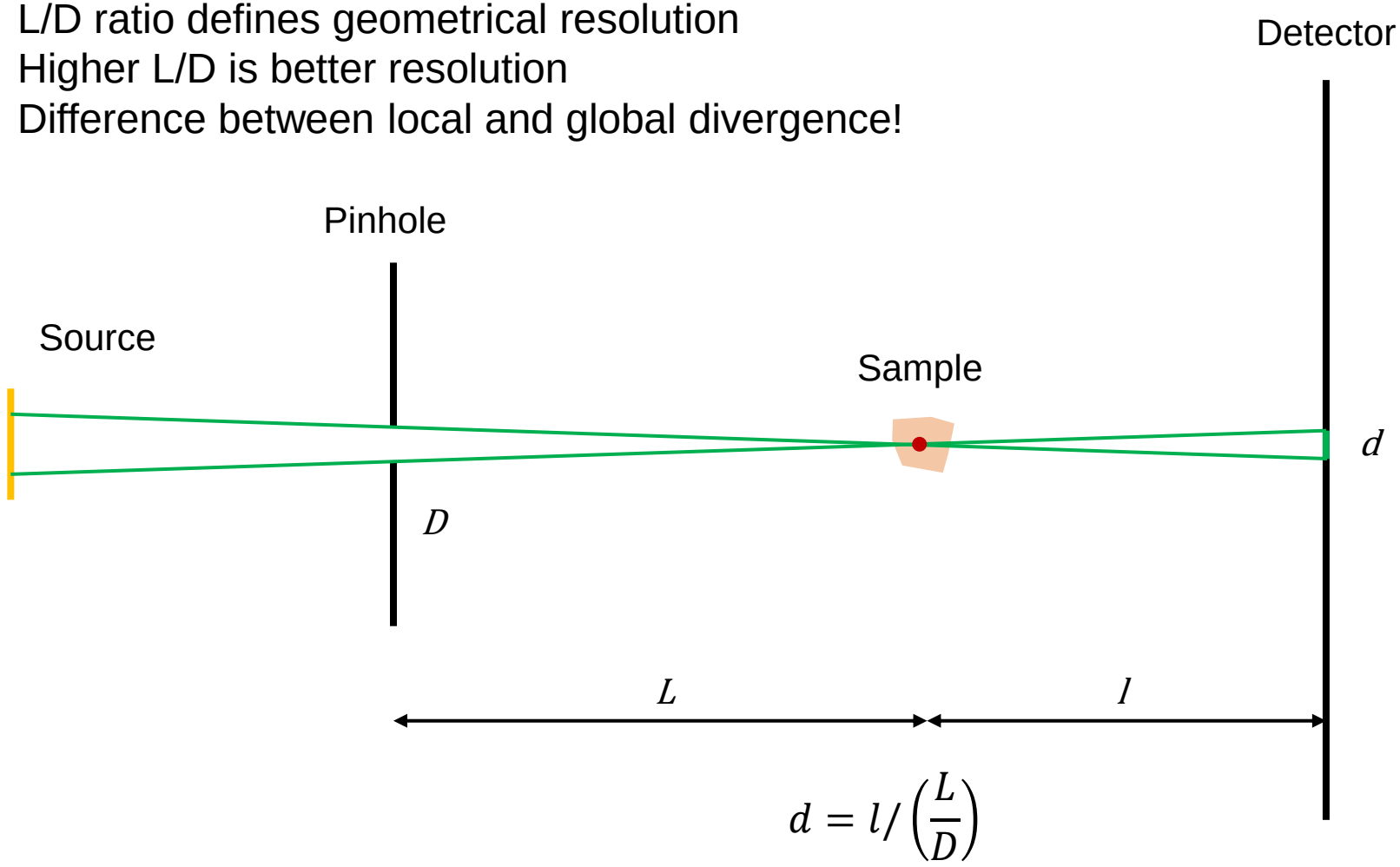


M. Schulz, et al., J. Phys. Conf. **211** (2010) 012025

S. Scheler, et al., E. J. of Pharmaceutics and Biopharmaceutics **176** (2022) 188-198

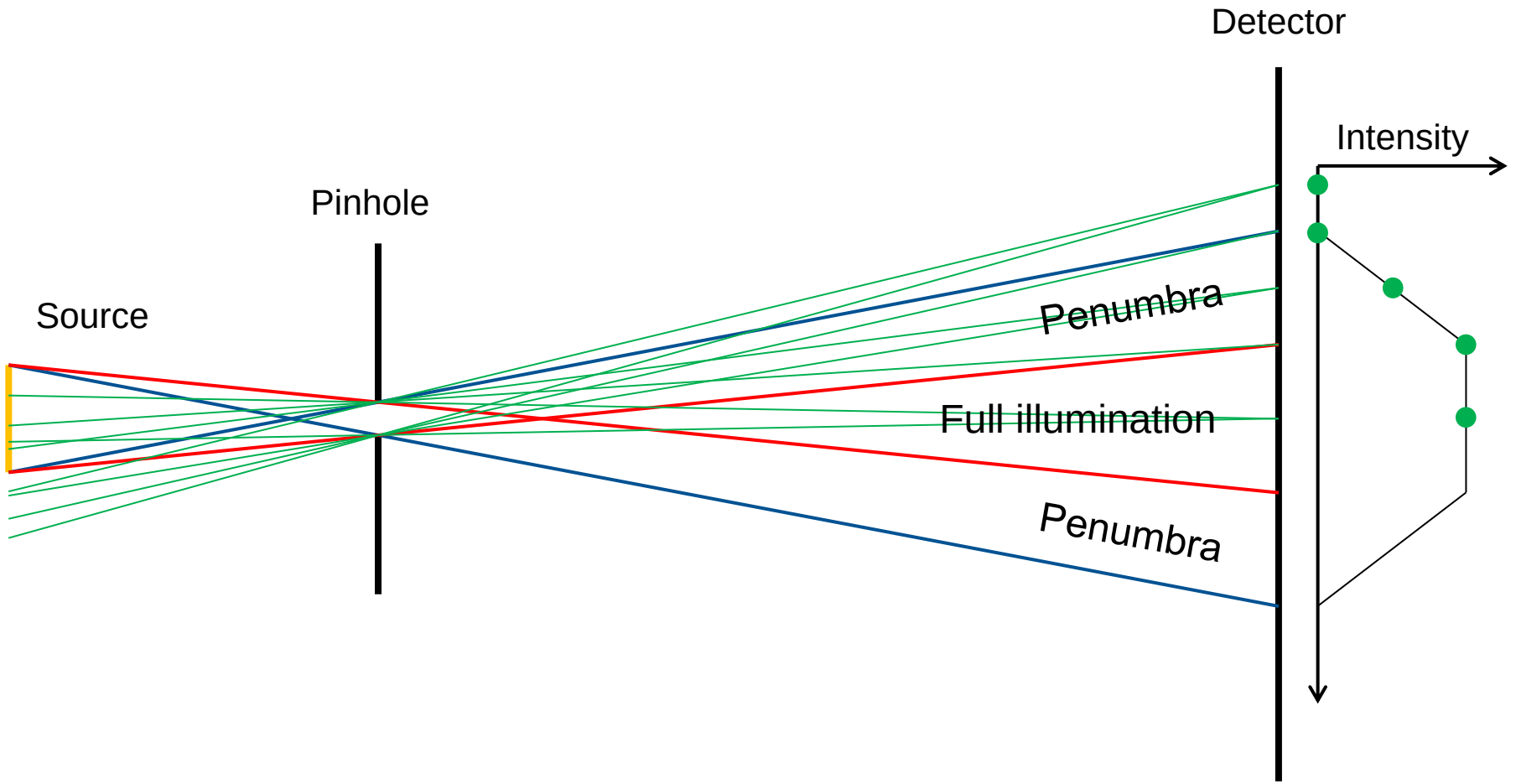
Spatial Resolution

- L/D ratio defines geometrical resolution
- Higher L/D is better resolution
- Difference between local and global divergence!



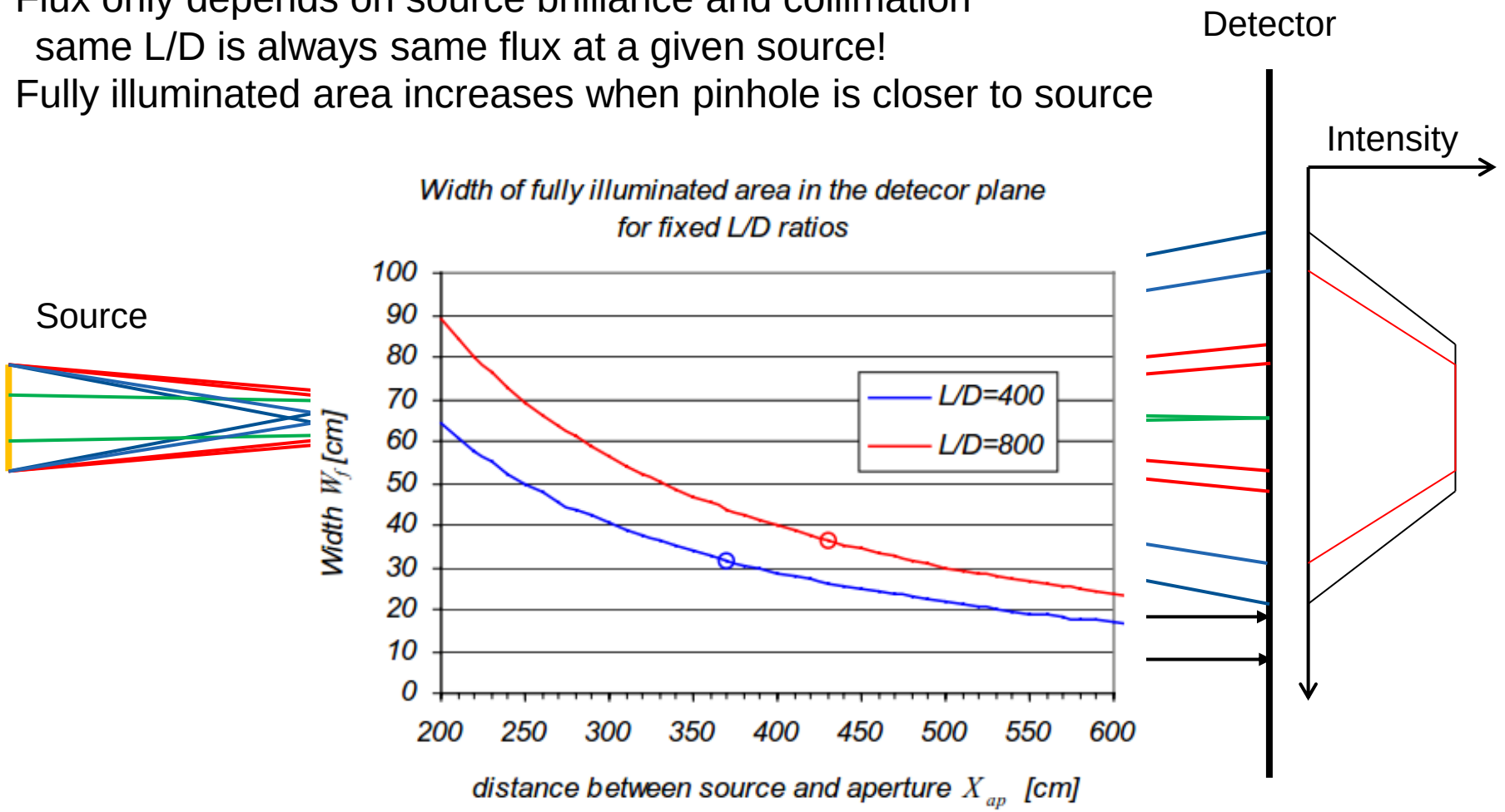
$$d = l / \left(\frac{L}{D}\right)$$

Pinhole camera geometry in detail



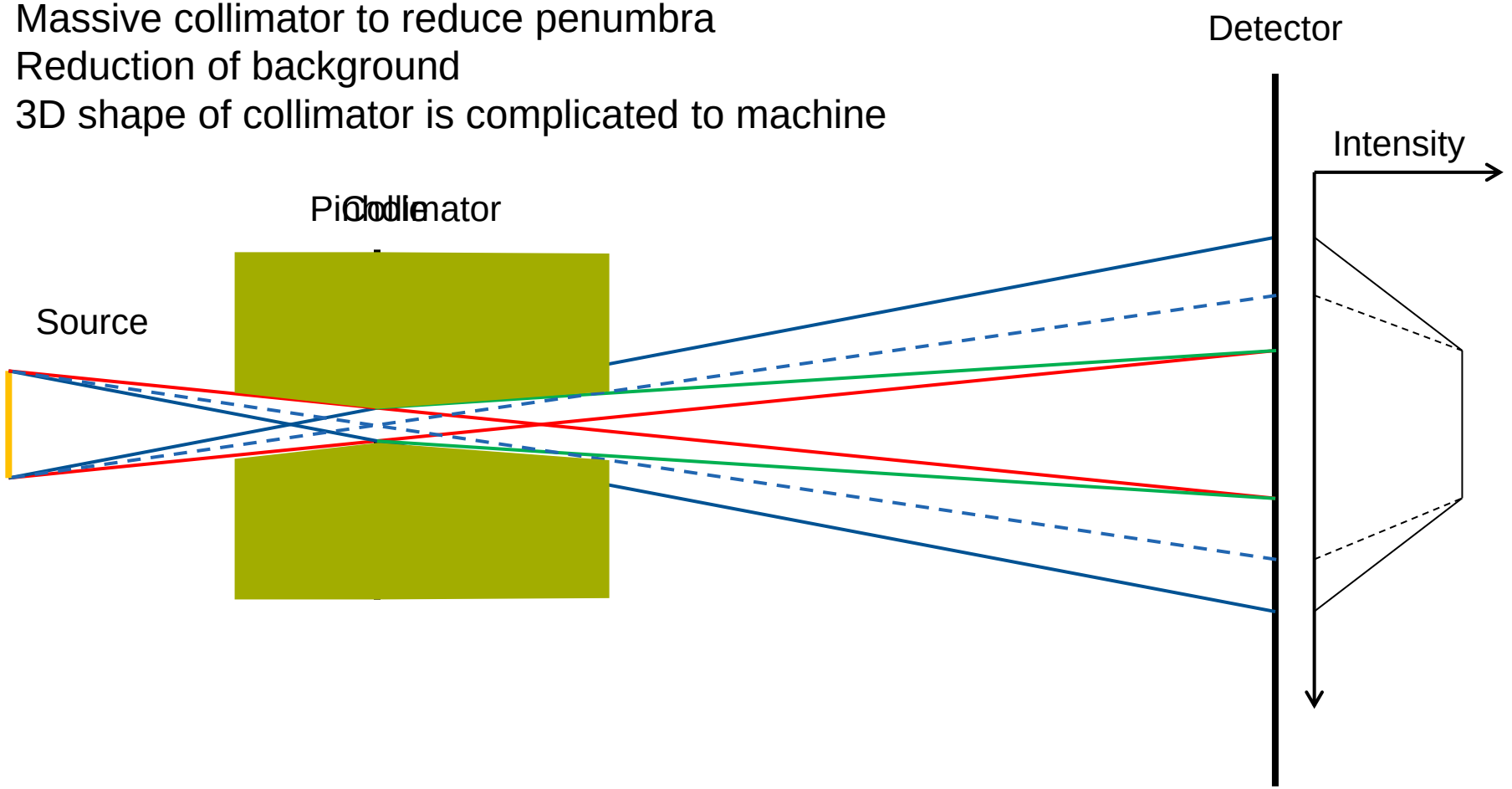
Distance source-pinhole

- Flux only depends on source brilliance and collimation
  same L/D is always same flux at a given source!
- Fully illuminated area increases when pinhole is closer to source

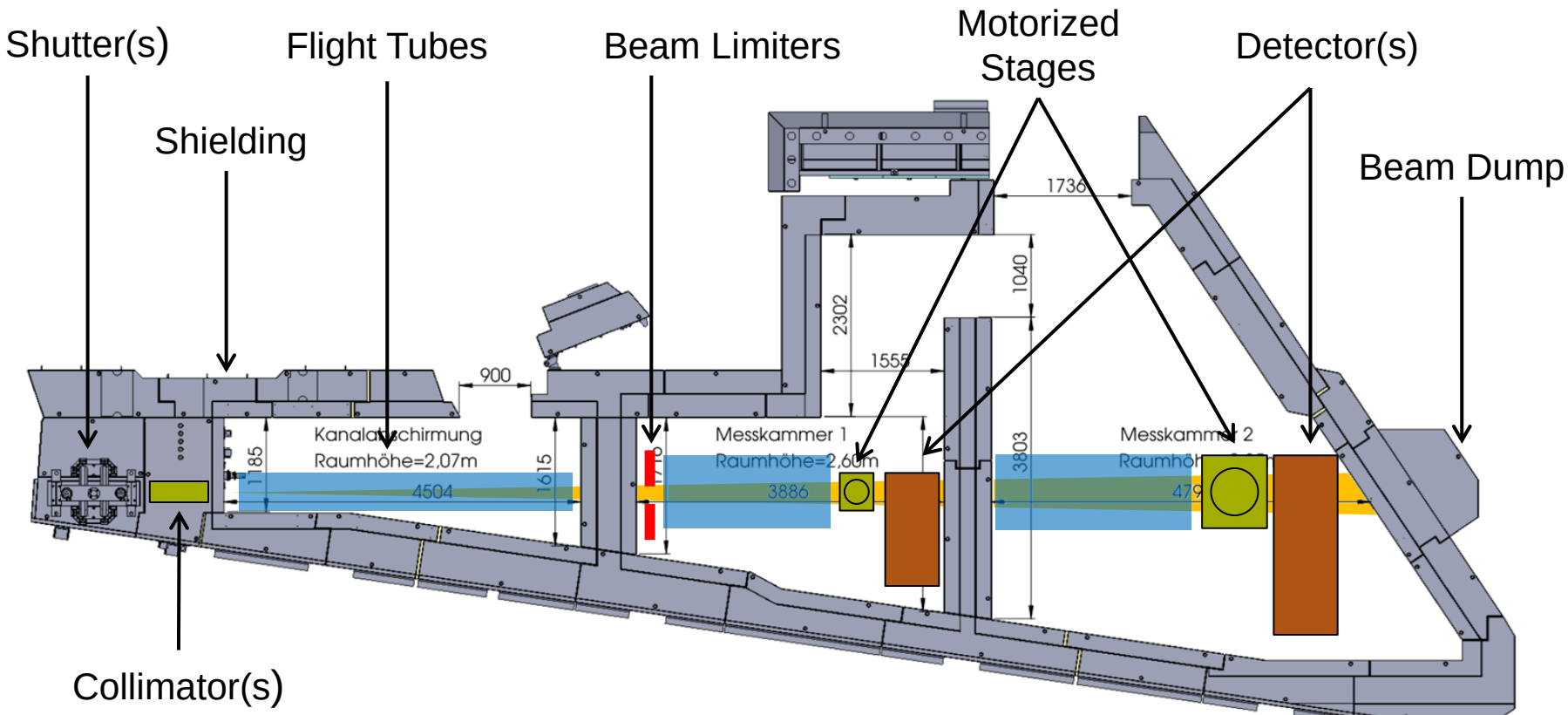


Collimator instead of pinhole

- Massive collimator to reduce penumbra
- Reduction of background
- 3D shape of collimator is complicated to machine



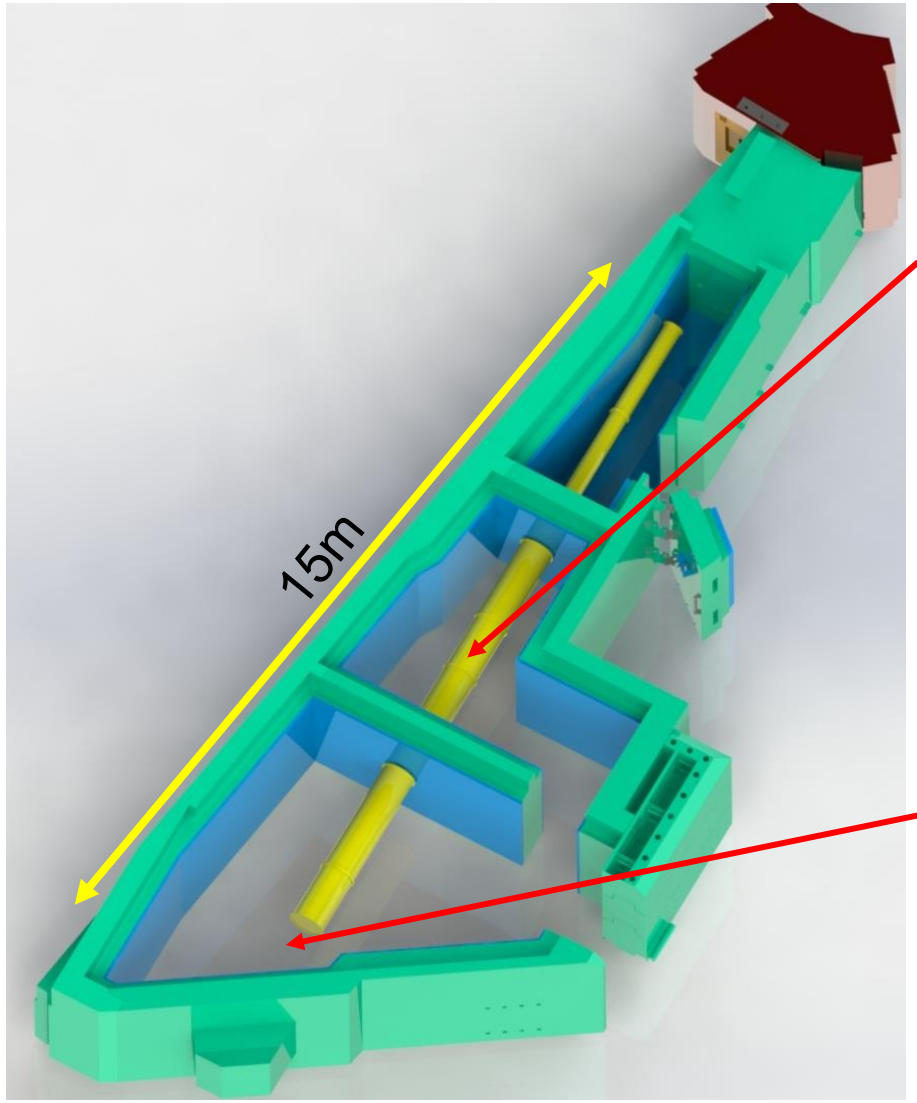
ANTARES – Imaging with cold neutrons

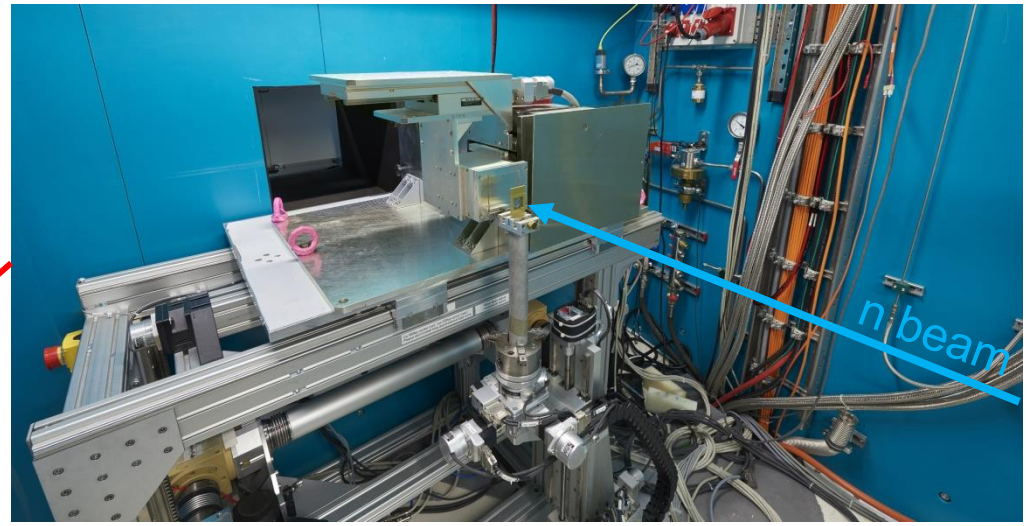


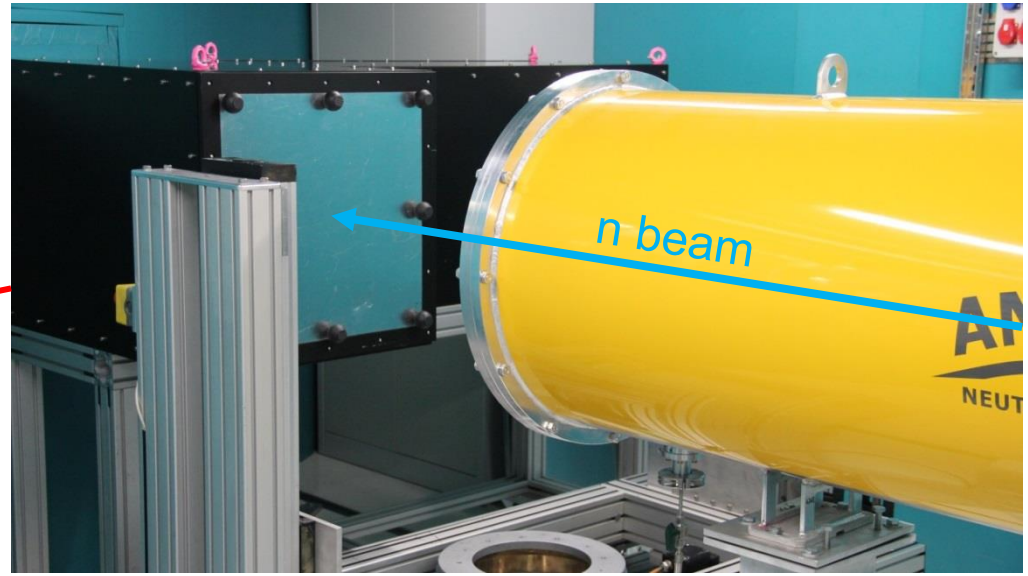
optional:
- Beam Filters
- Monochromator / Selector
- Neutron grating interferometer

plus:
- Access Control
- Media Supply (electricity, gas, water, …)
- IT (network, storage, servers, software, …)

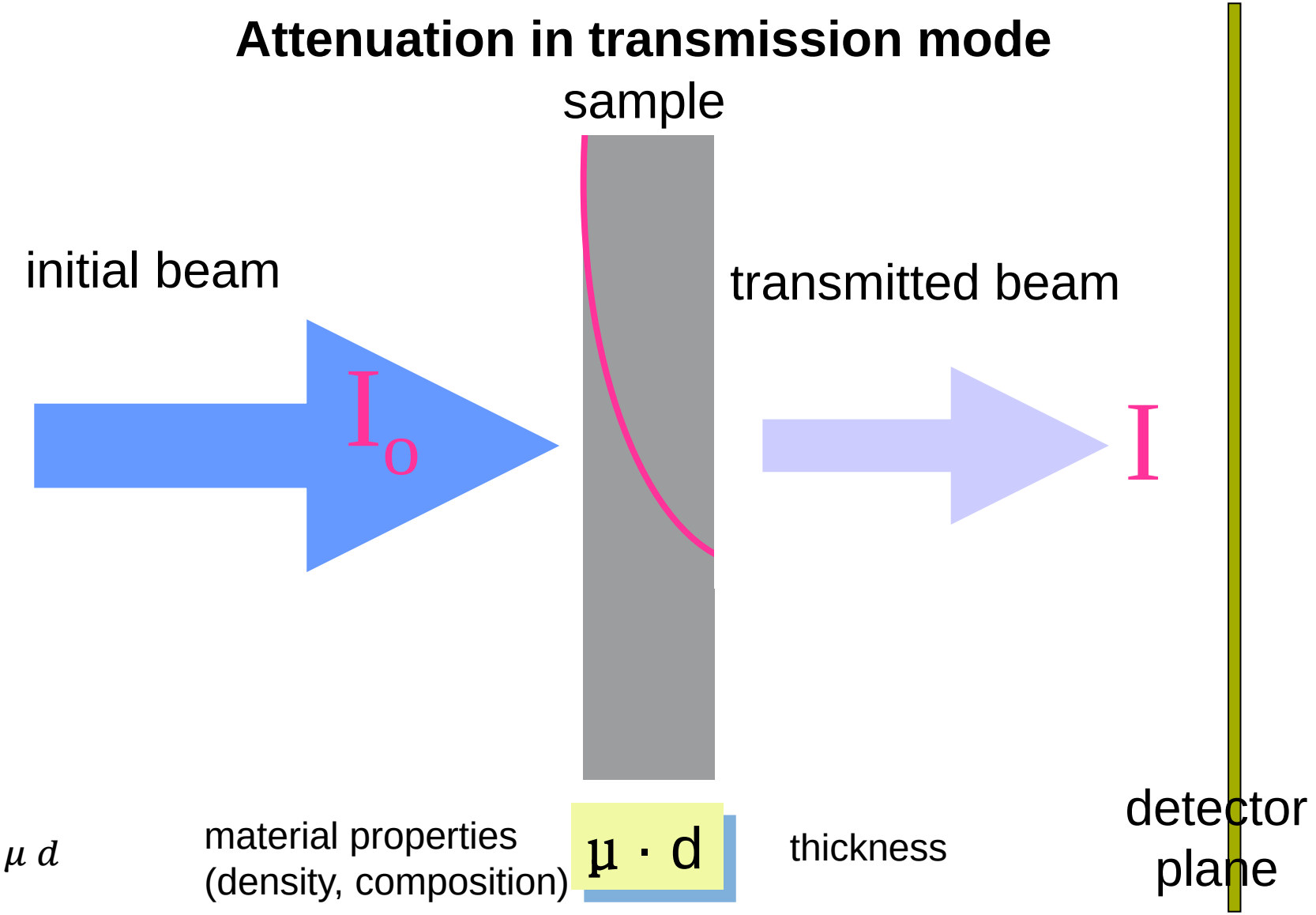
ANTARES – cold neutrons







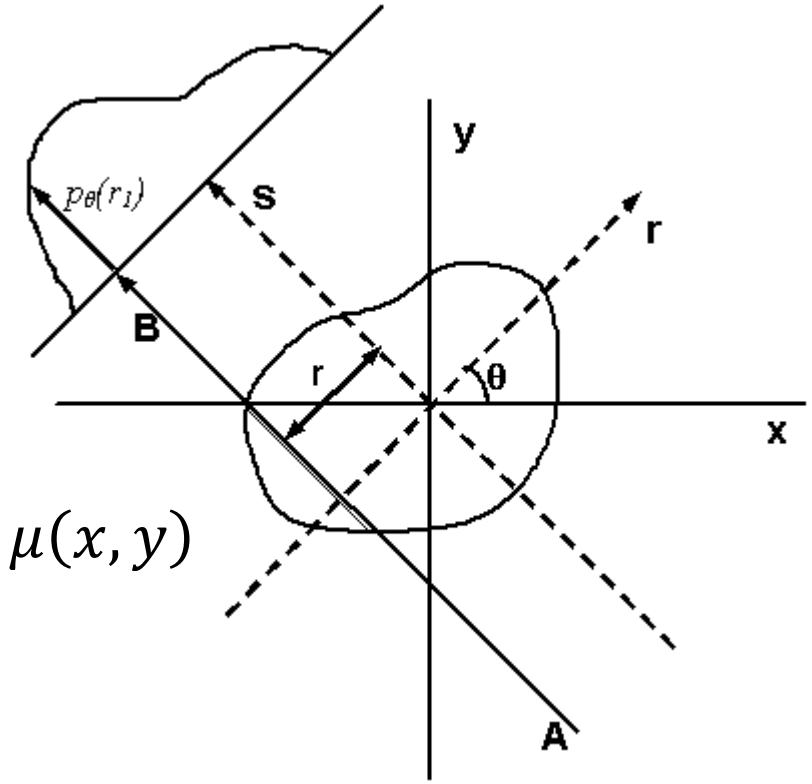
Attenuation in transmission mode



$$T = \frac{I}{I_0} = e^{-\mu\, d}$$

material properties (density, composition) μ · d thickness

Neutron transmission – more general



$$T = \frac{I}{I_0} = e^{-\int \mu(x,y)ds} = e^{-\int \sigma(x,y)\cdot N(x,y)ds}$$

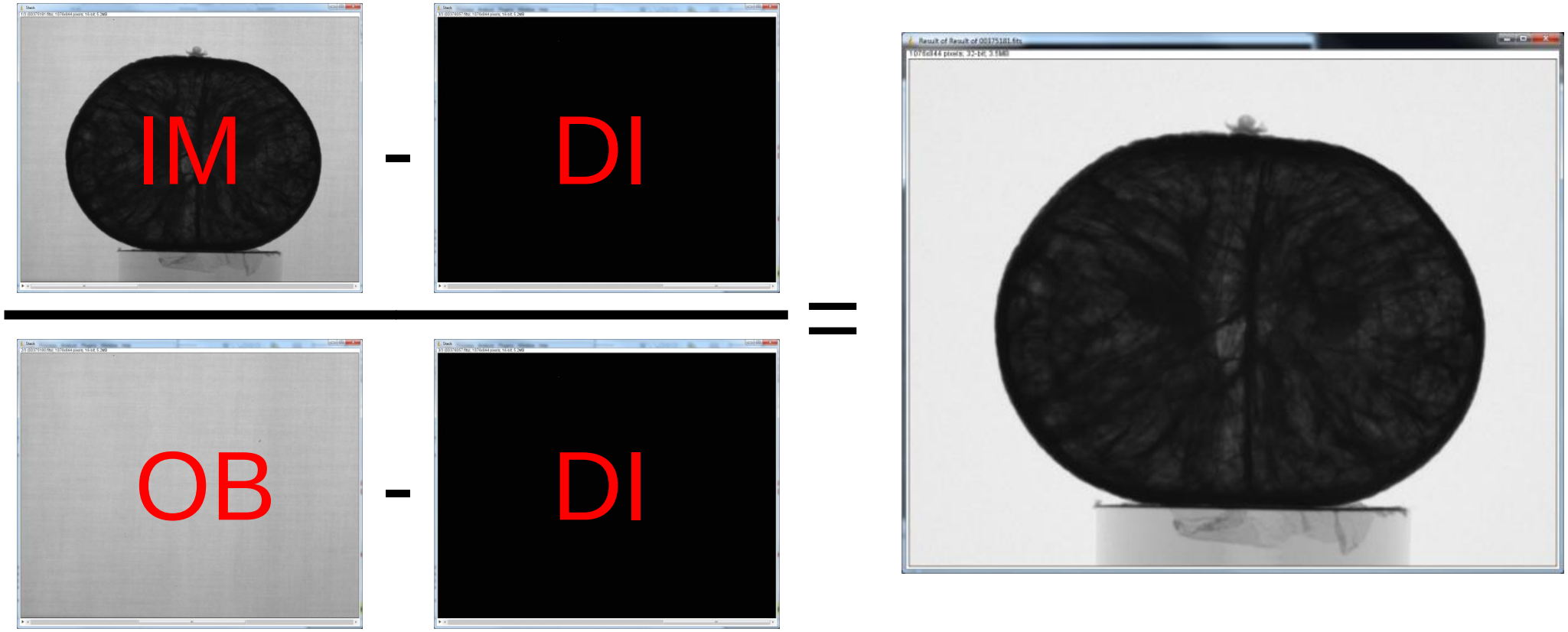
$$p_\theta(r) = \ln\left(\frac{I}{I_0}\right) = -\int \mu(x,y)ds$$

https://en.wikipedia.org/wiki/Tomographic_reconstruction

Data processing - normalization

- Image data requires pixelwise treatment
- „Open Beam Image“ contains structure introduced by beam, scintillator, optics, camera, …
- „Dark Image“ contains offset of detector electronics, high-energy background, …

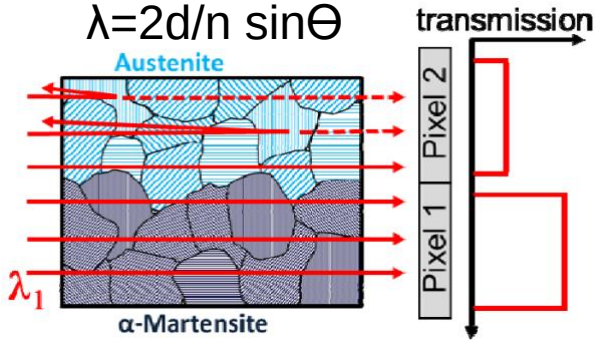
$$T = I/I_0 = \frac{IM - DI}{OB - DI} =$$

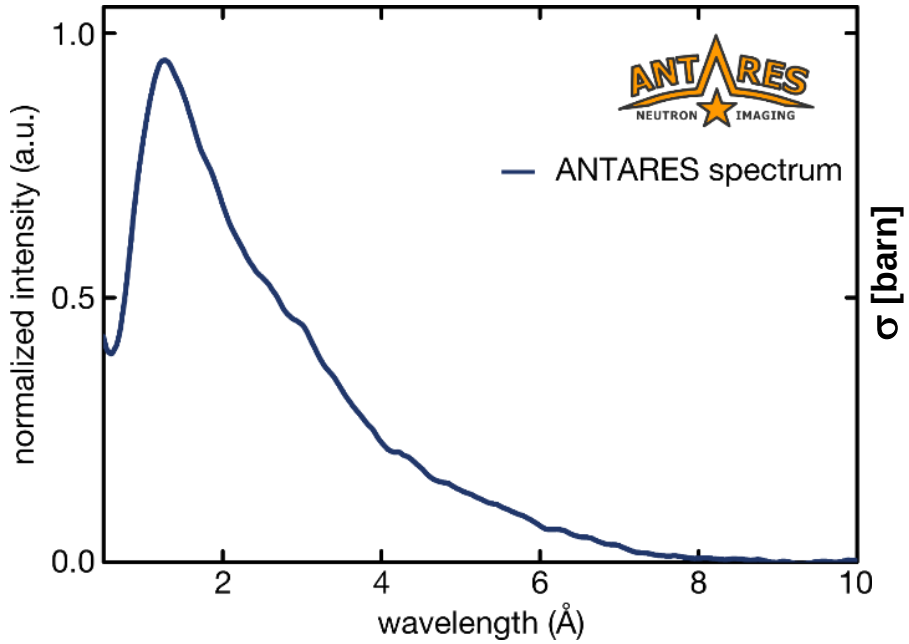


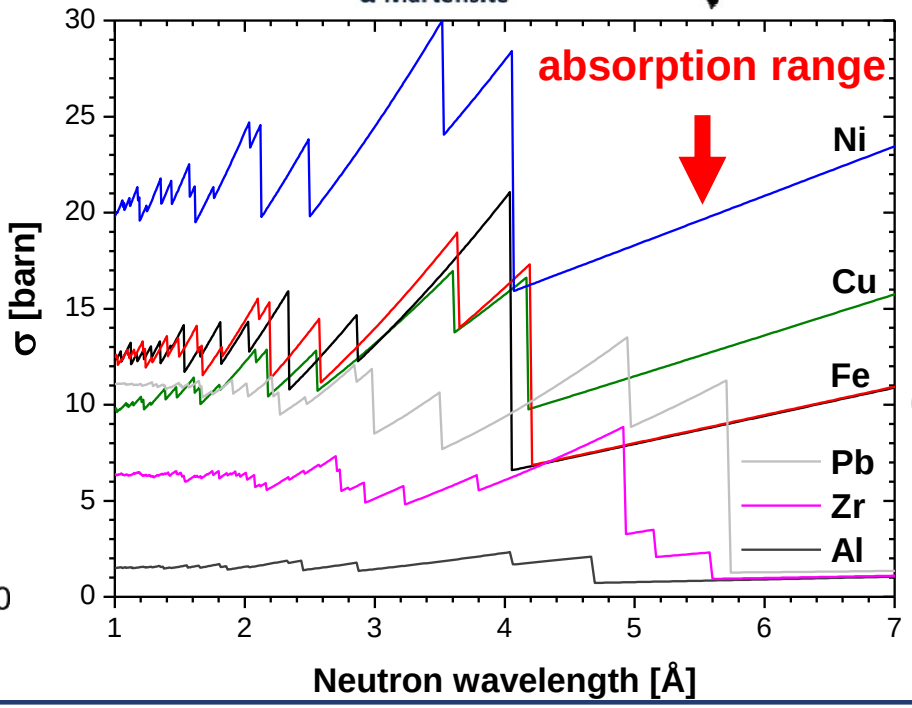
Influence of the neutron spectrum

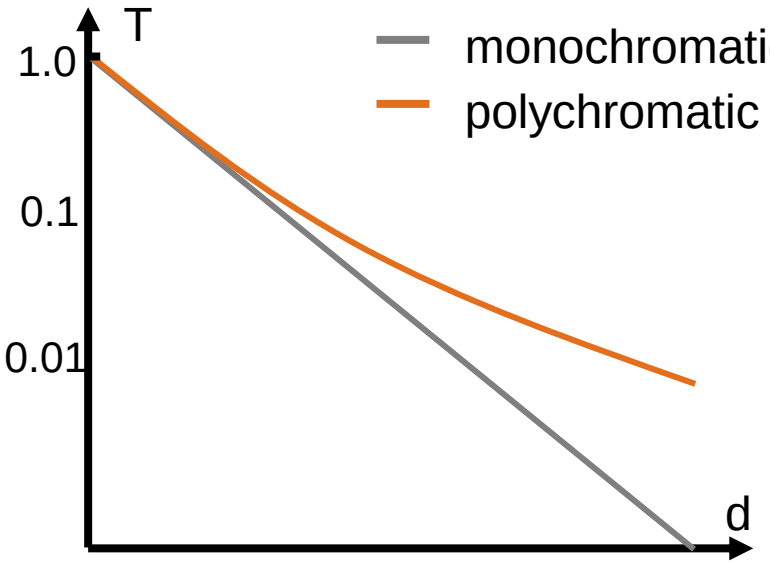
- Cold, thermal, hot, (fission) sources
- General 1/v law
- Plus Bragg edges
- Beam Hardening effects

$$T(\lambda) = \frac{I}{I_0} = e^{-\int \mu(x,y,\lambda)ds} = e^{-\int \sigma(x,y,\lambda)\cdot N(x,y)ds}$$

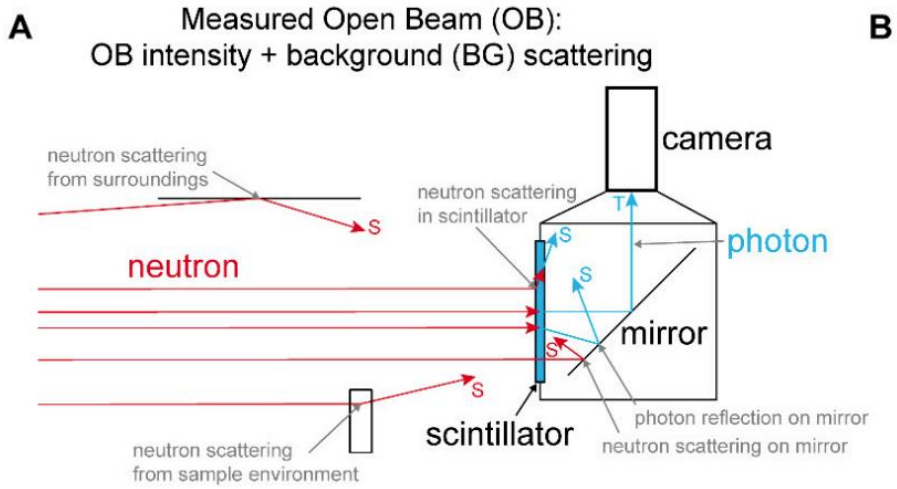


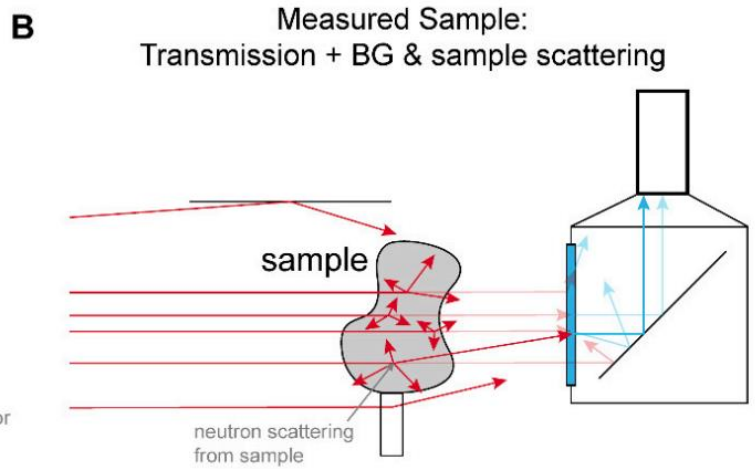


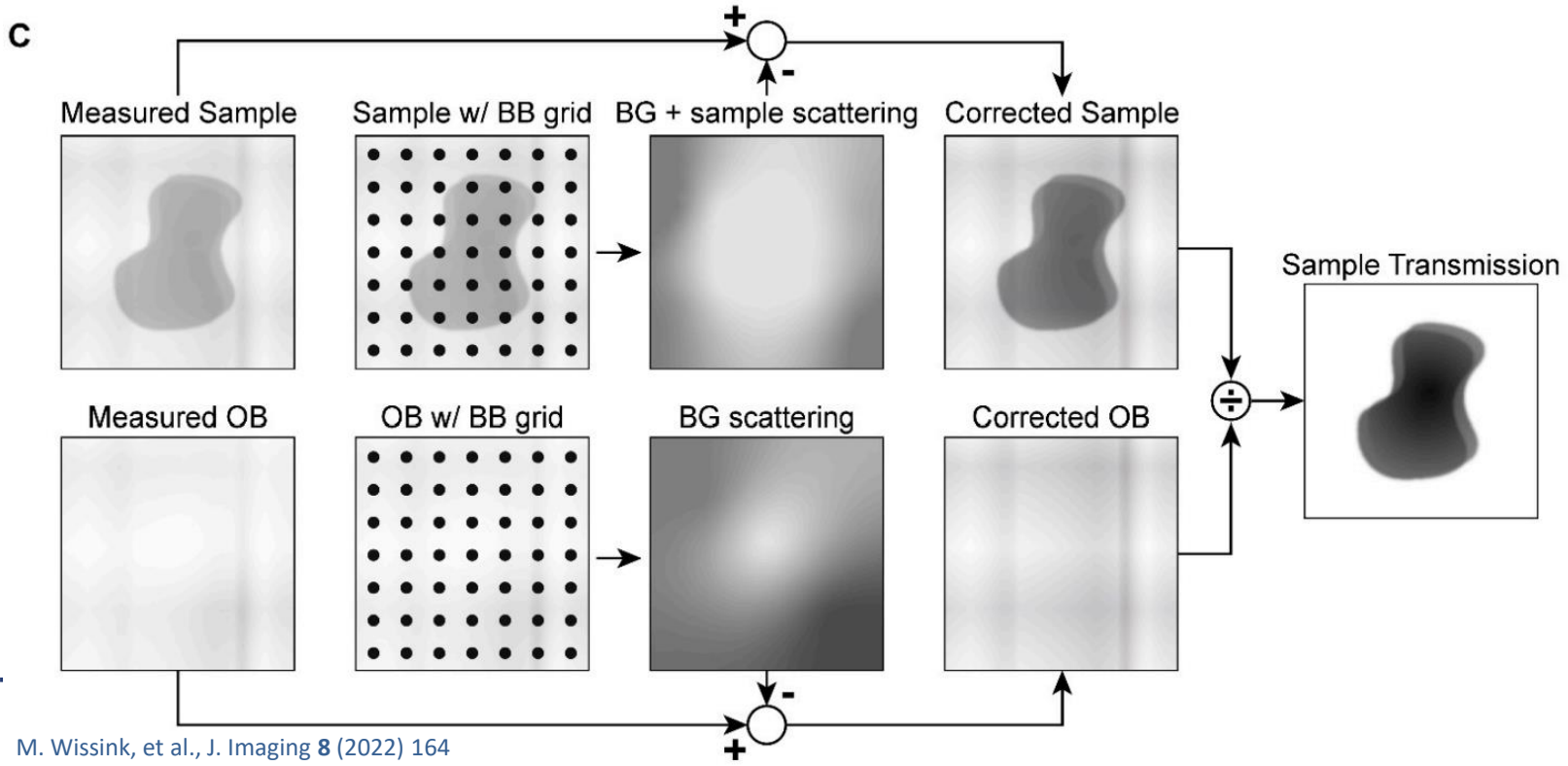




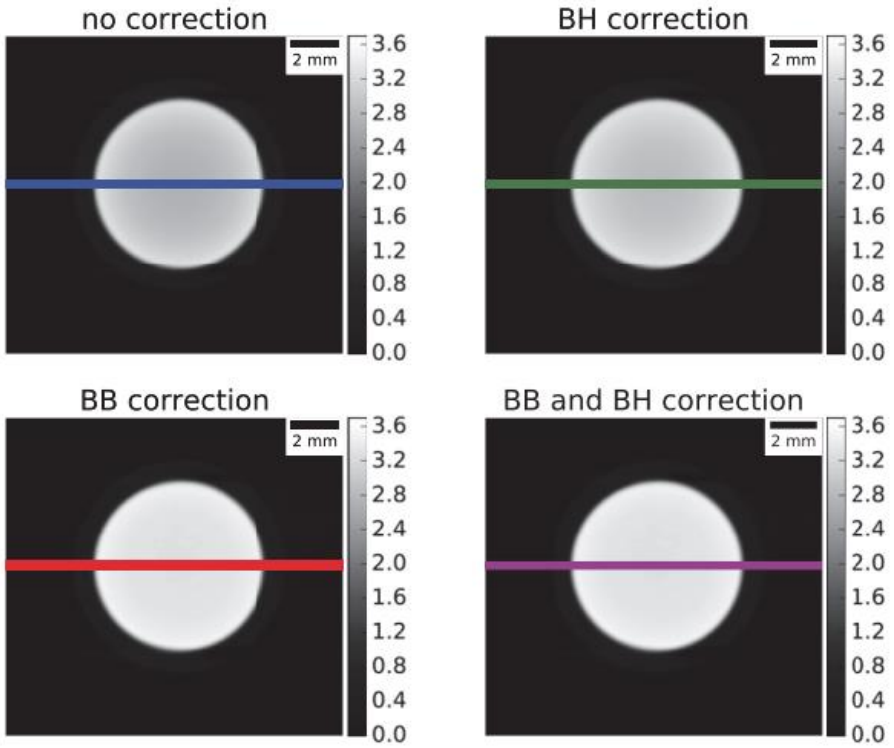
Scattering effects



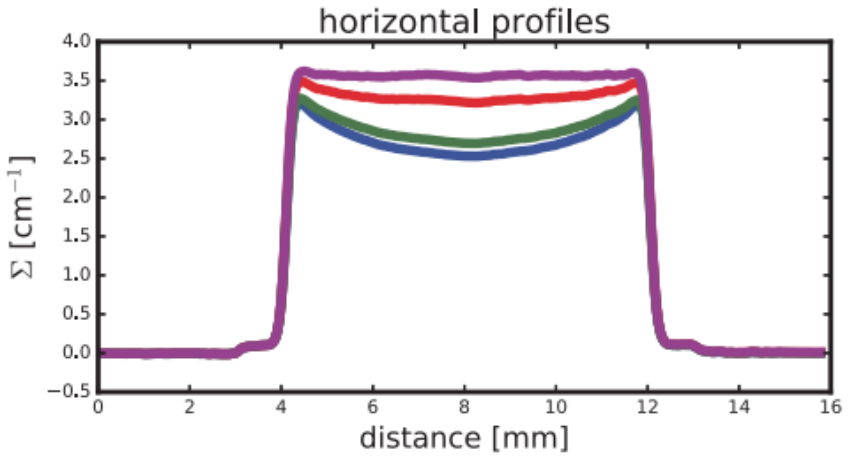




M. Wissink, et al., J. Imaging **8** (2022) 164

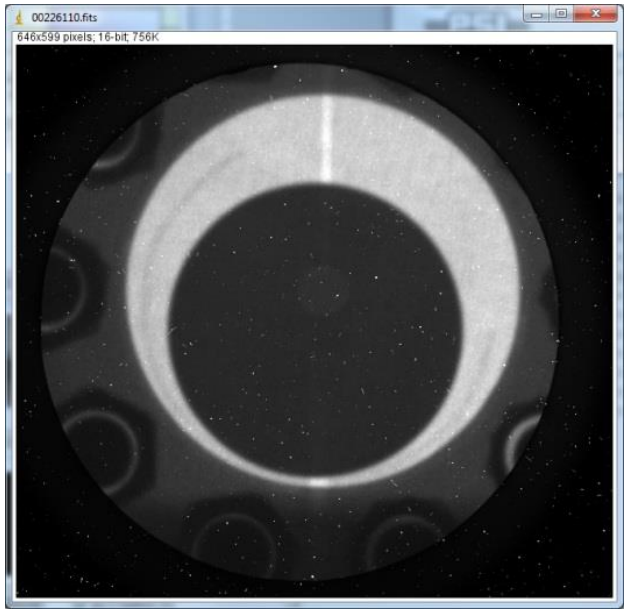


C. Carminati, et al., PLoS ONE **14** (2019) 0210300

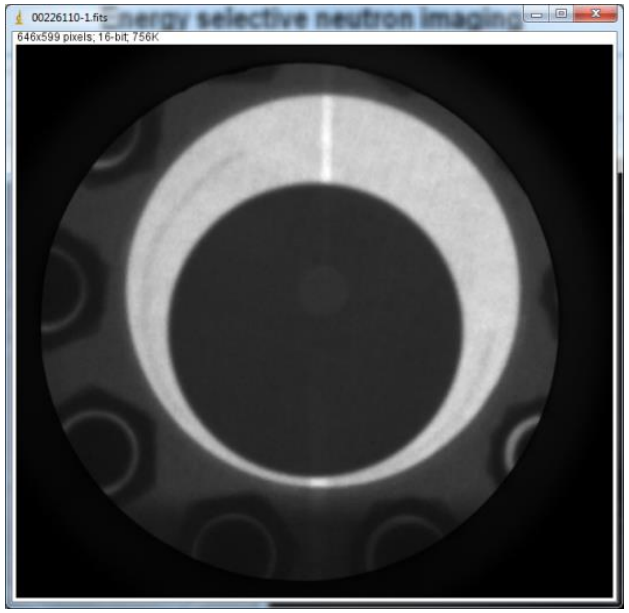


Data processing – gamma spot removal

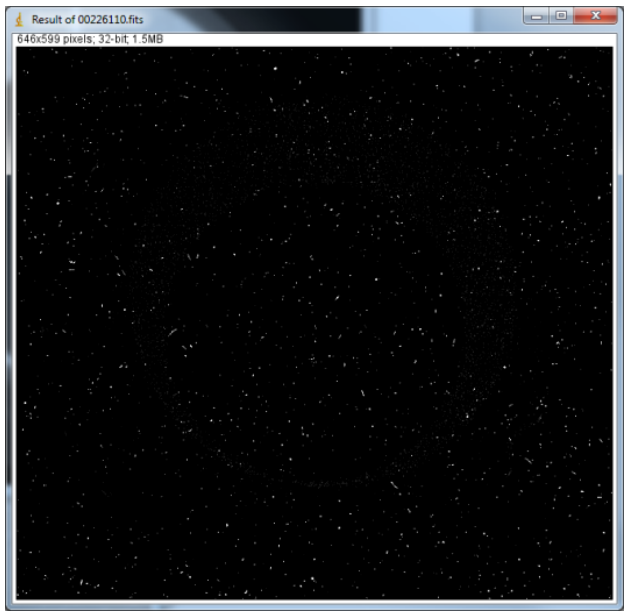
- Gammas directly hitting the CCD produce sharp, bright spots
- Can be removed by different filters (Median, Gauss, Search & Replace filters, …)
- Goal: remove as many spots as possible but no object structure
- Check by subtracting filtered from original image



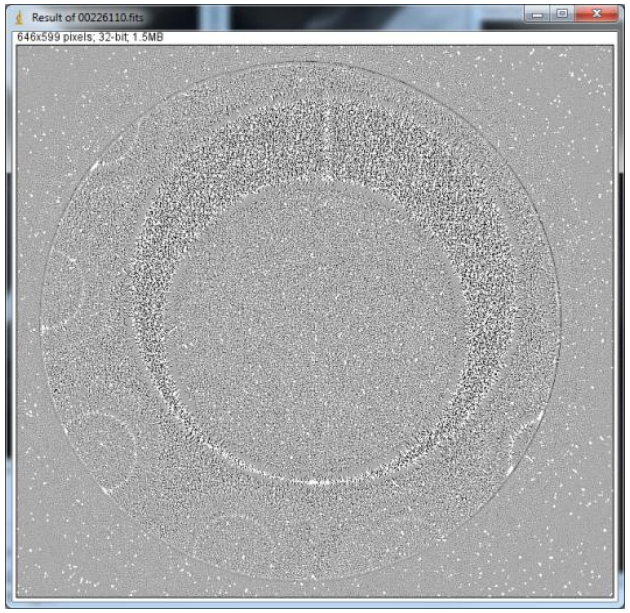
original



filtered



difference



difference - filter too strong!

tli

Foto von Accuray auf Unsplash

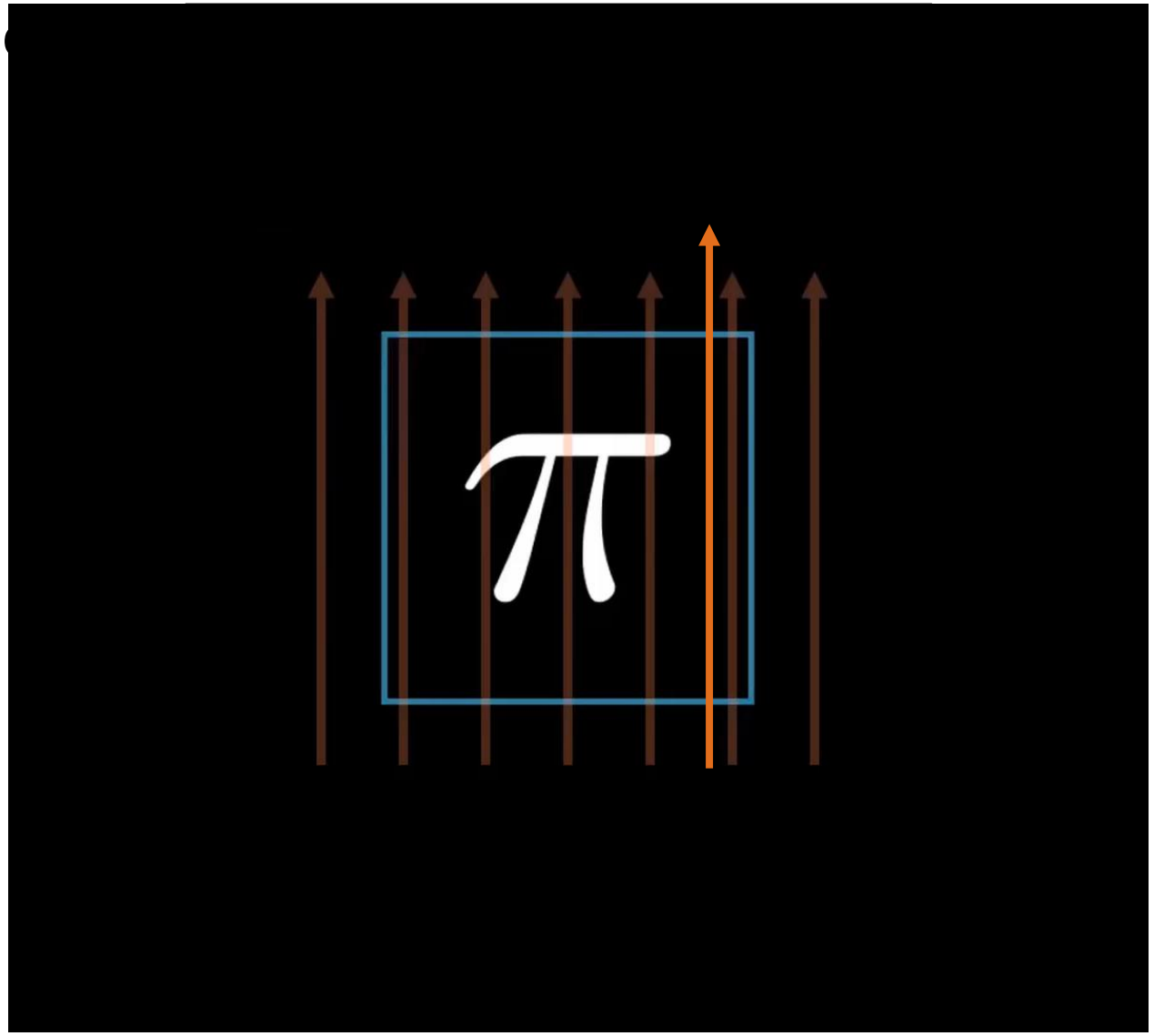


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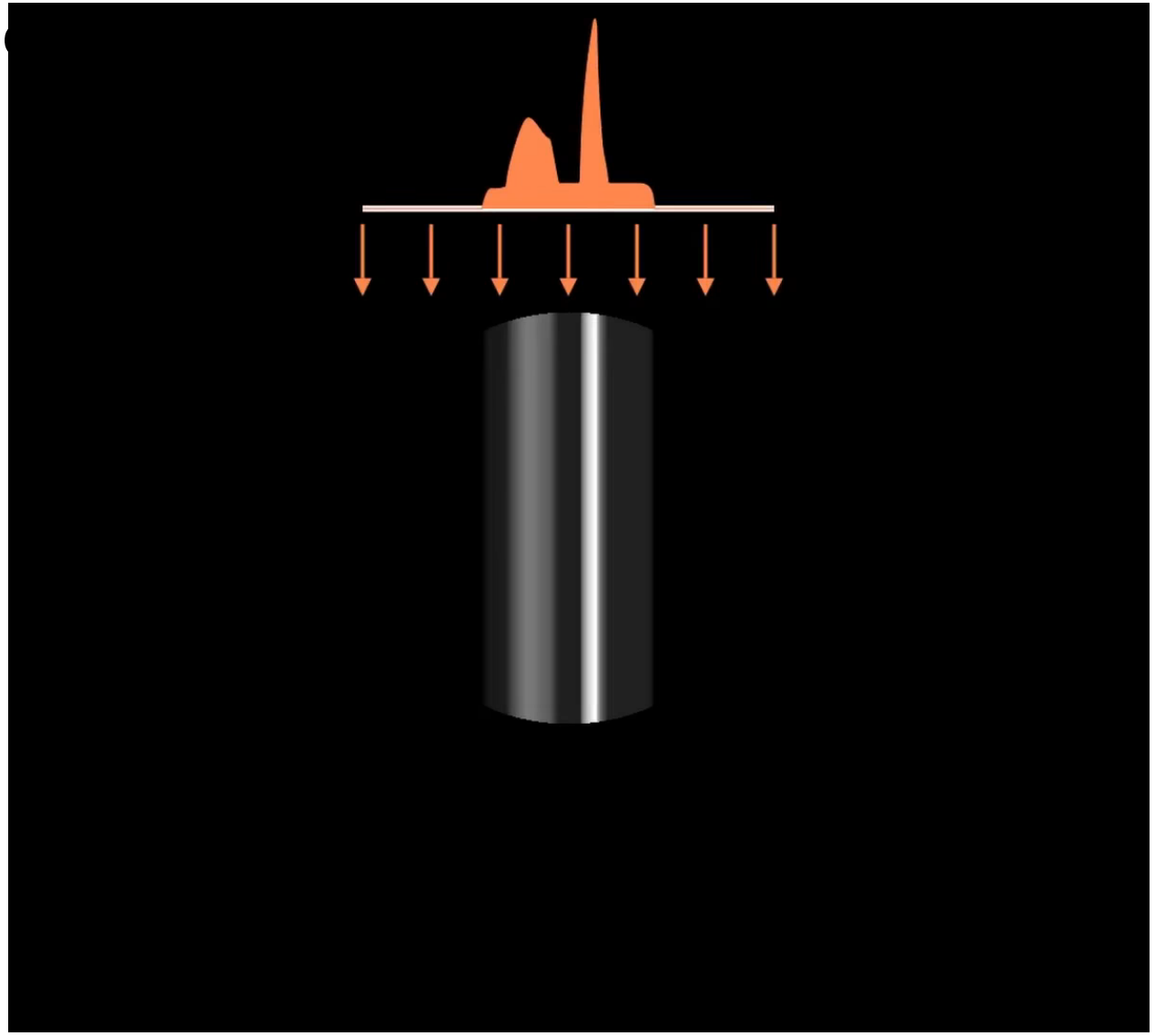
Foto von Accuray auf Unsplash



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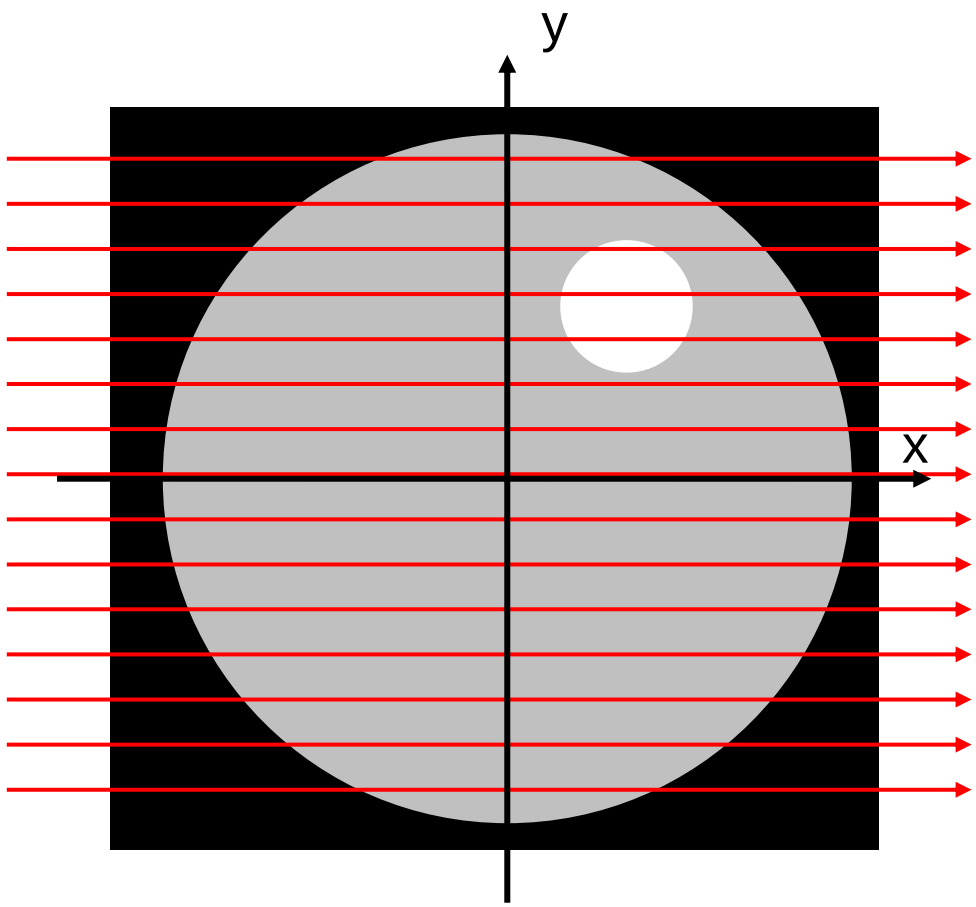
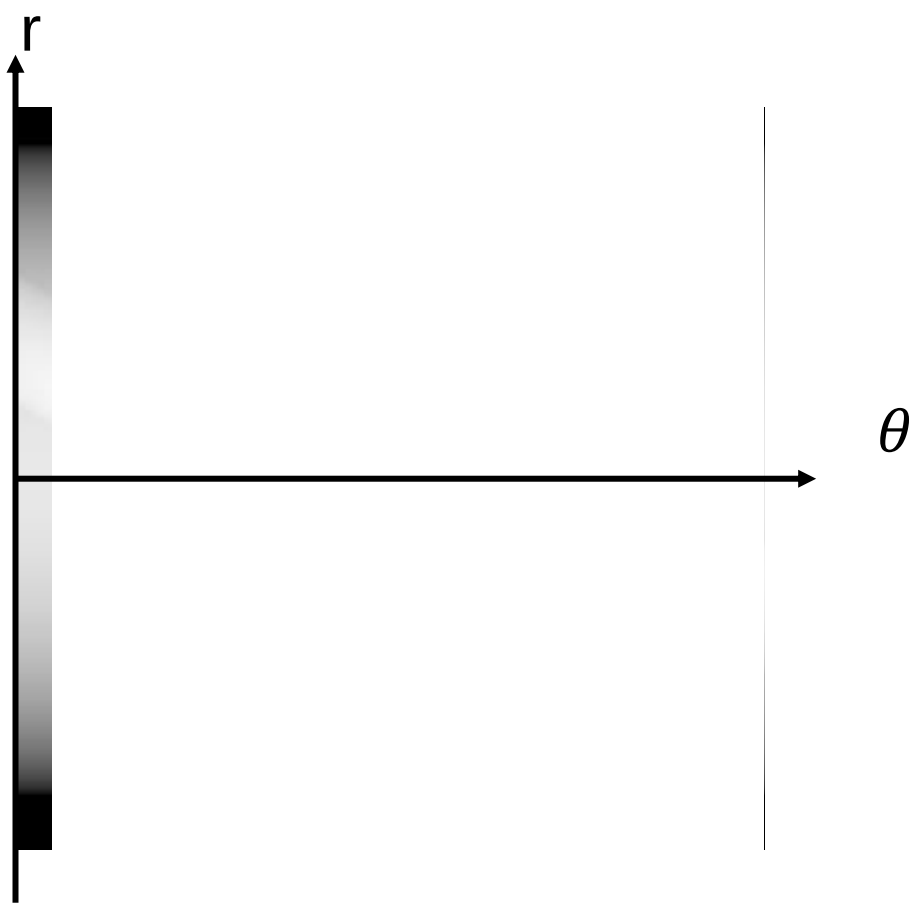
Tomography – acquisition scheme





$$p_\theta(r) = \ln\left(\frac{I}{I_0}\right) = -\int \mu(x,y)ds$$

projection

sinogram

Basic data workflow in neutron imaging – 2D

Raw Data
- Acquired by instrument software
- Enriched with metadata

Spot Filtering
- Clean gamma spots from images

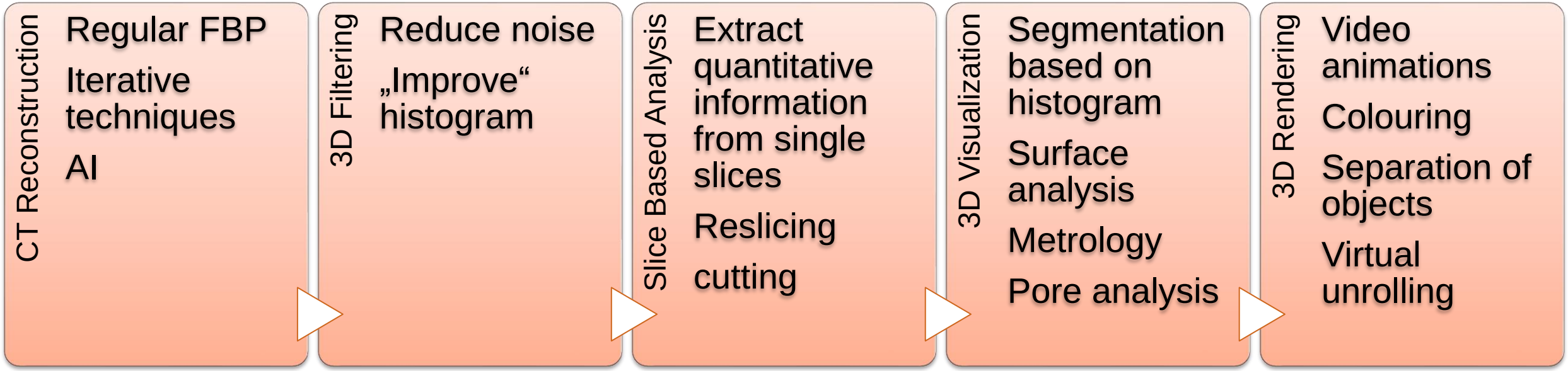
Median (pixelwise)
- E.g. 5 images of same condition
- Also good to remove remaining gamma spots

Normalization
- Correct for open beam and dark image
- Black body correction

2D Analysis
- Reference to initial image
- 2D Filtering
- Transmission measurement

- ImageJ / Fiji
- MuhRec / KIPtool
- Python scripts
- …

Basic data workflow in neutron imaging – 3D



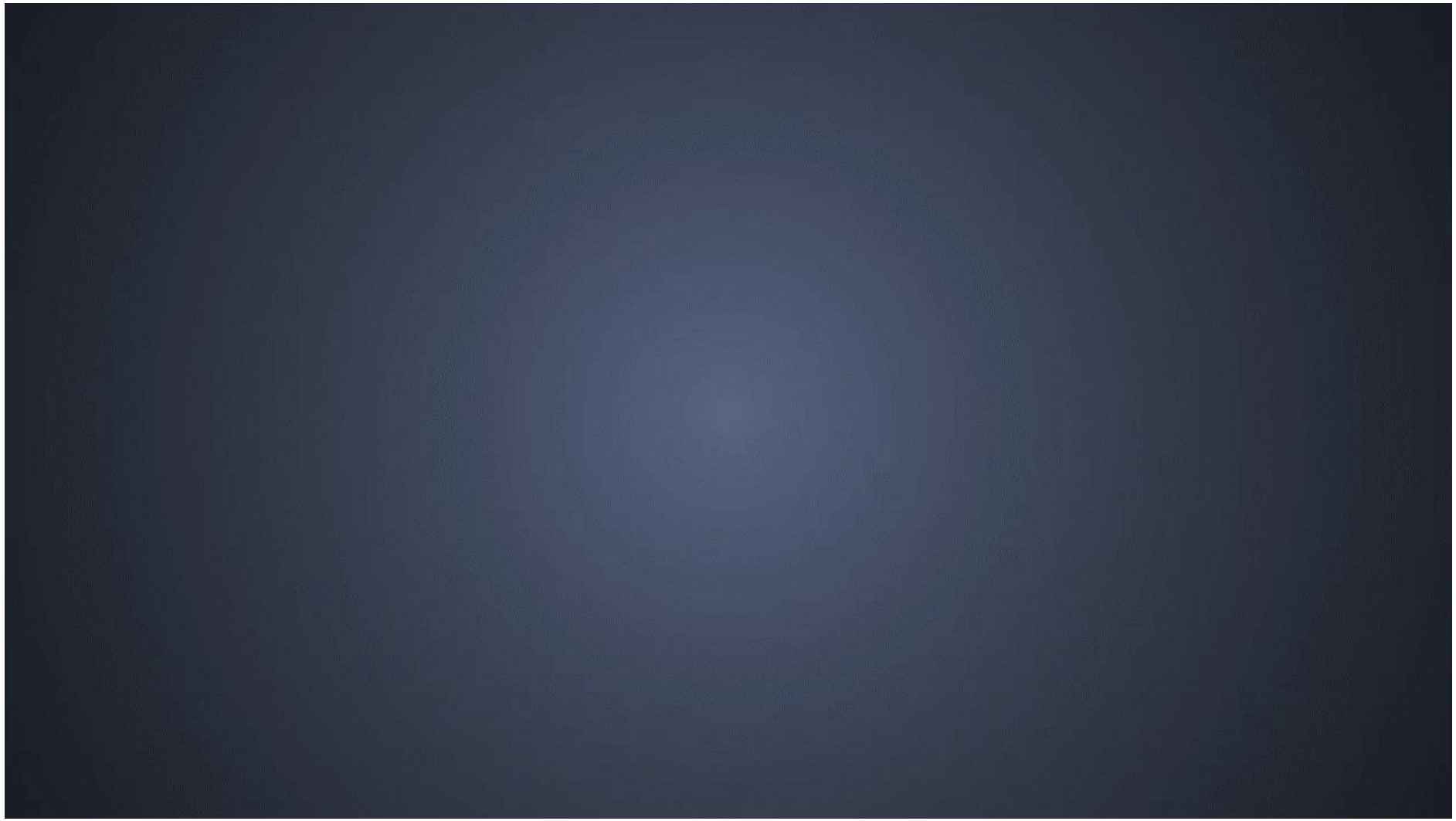
- MuhRec
- Python (tomopy)
- ImageJ / Fiji
- …

- KIPTool
- Python (tomopy)
- ImageJ / Fiji

- ImageJ / Fiji

- VGStudio Max
- Avizo
- Dragonfly (free academic use)

The „holy grail“ – A beautiful animation



Thank You!