3D Material Decomposition Using Synchrotron-Based MicroCT

Motivation

- localize specific materials in sample:
  a) in 3D
  b) non-destructively
  c) quantitatively
  d) submicron resolution

Why?

➢here: localize contrast-enhancing materials in soft-tissue

➢useful in material science, quality assurance, …

Approach

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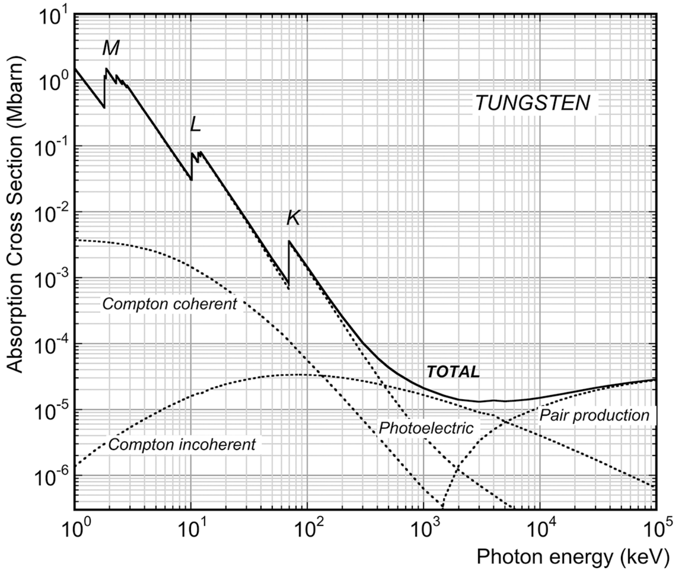
- employ X-rays and their interaction with matter to probe sample
- 3 dominant processes:
  a) Thomson (elastic) scattering
  b) Compton (inelastic) scattering
  c) Photoelectric absorption

- exploit material and energy-dependency of the interaction cross-sections



$$\sigma_T = \frac{8\pi}{3} r_e^2 \cdot Z^2$$

$$\sigma_C = \sigma_{KN}(E) \cdot Z$$

$$\sigma_P \propto \frac{Z^{3\sim 4}}{E^3}$$

Image Formation

- contact-plane: Lambert-Beer-Law

→ integrated attenuation coefficient

$$I(x,y,z) = I_0 \exp[-\int \mu(x,y,z)\,dz]$$

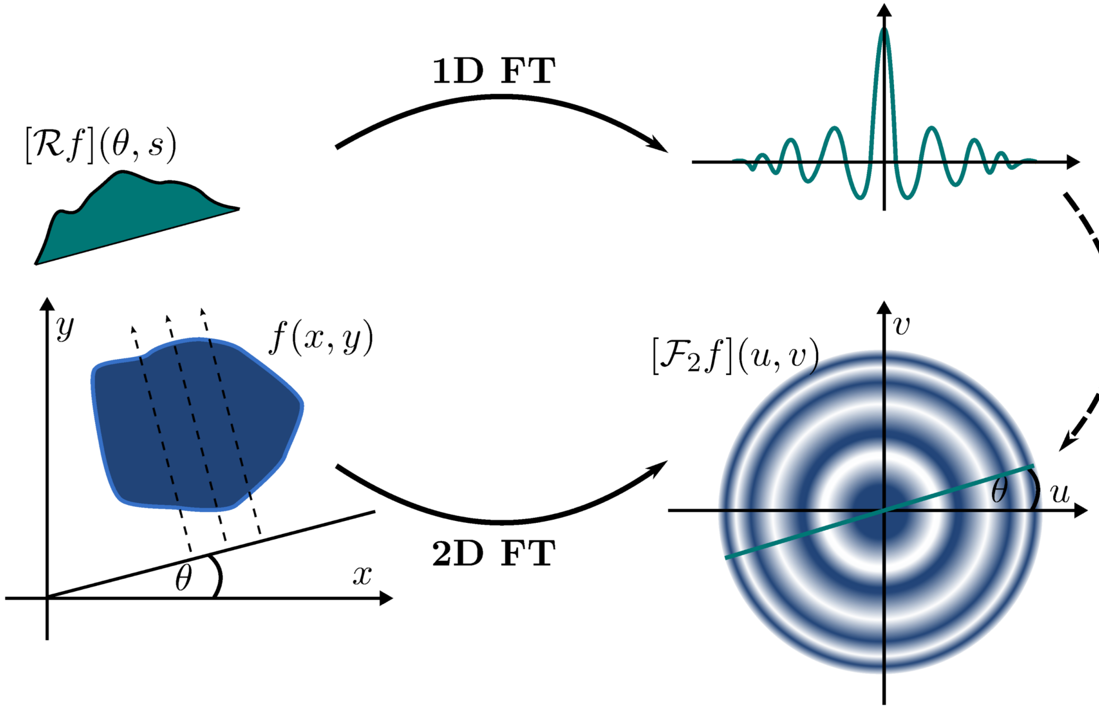
$$\mu(x,y,z) = \frac{\rho_m N_A}{M} \cdot \sigma_a$$

→tomographic reconstruction

$$f(x,y) = \int_0^{\pi} d\theta \;\; \mathcal{F}_S^{-1}\{|S| \cdot \mathcal{F}_S \Re f\}$$

↑

$\mu(x,y)$



Material Decomposition

Max-Planck-Institut für Physik

- use energy dependency to decompose into basis materials *i*

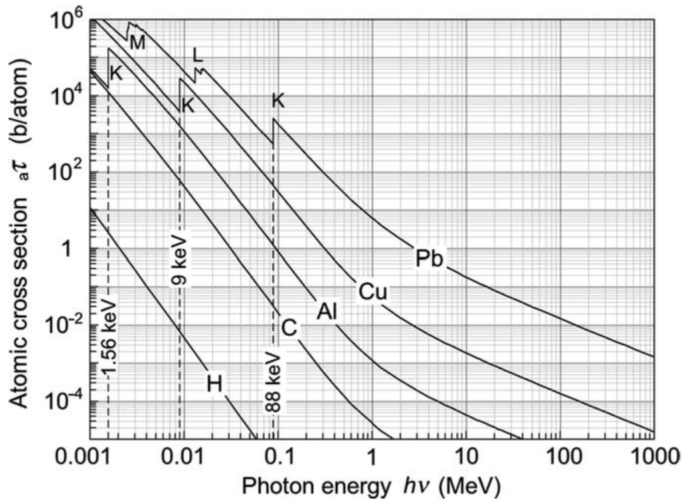
$$\mu(E) = \sum_i^N \mu_i(E) = \sum_i^N \left(\frac{\tilde{\mu}_i(E)}{\rho}\right) \cdot \rho_i$$

- *mass* attenuation coefficients tabulated

→retrieve densities

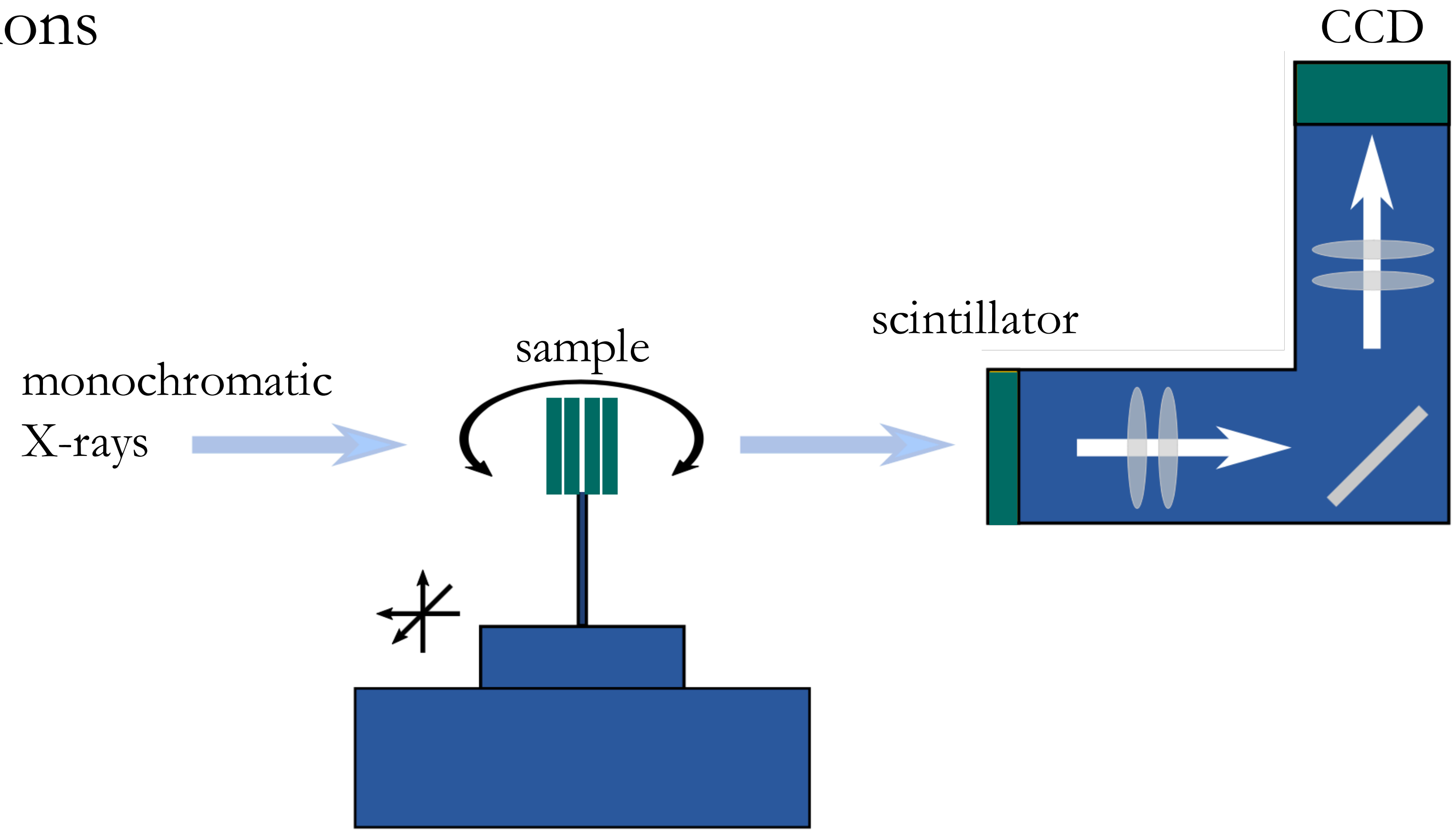
$$\begin{pmatrix} \rho_1 \\ \vdots \\ \rho_N \end{pmatrix} = \begin{pmatrix} \left(\frac{\tilde{\mu}_1(E_1)}{\rho}\right) & \dots & \left(\frac{\tilde{\mu}_N(E_1)}{\rho}\right) \\ \vdots & \ddots & \vdots \\ \left(\frac{\tilde{\mu}_1(E_N)}{\rho}\right) & \dots & \left(\frac{\tilde{\mu}_N(E_N)}{\rho}\right) \end{pmatrix}^{-1} \begin{pmatrix} \mu(E_1) \\ \vdots \\ \mu(E_N) \end{pmatrix}$$

requirement: linear independence !



Experiment

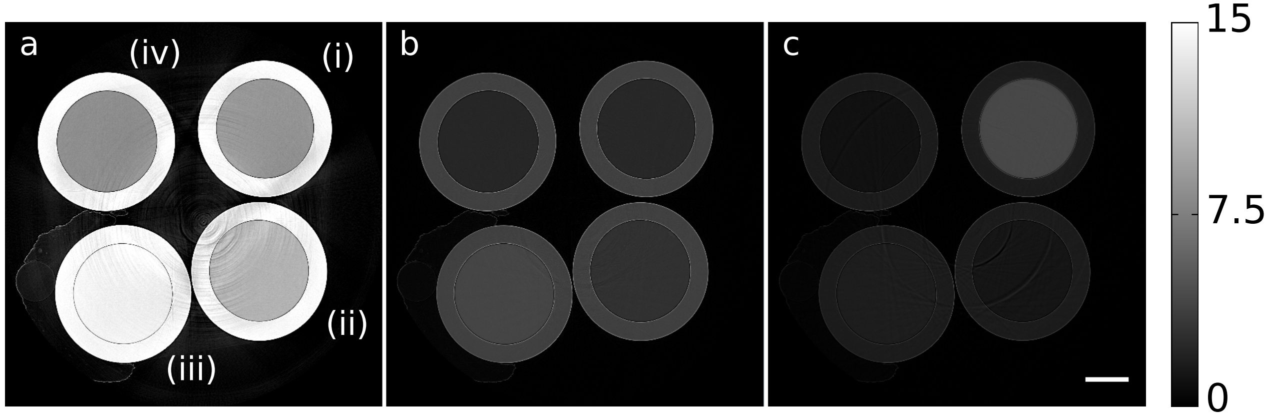
- P05 beamline at DESY
- phantom: glass capillaries filled with different solutions
- feasibility test:
  - simple geometry
  - known densities
  - “low” resolution



Results: Phantom

- beam energies: 15, 25, 35 keV
- iodine (top right): K-edge at 33.2 keV

reconstructed attenuation coefficients [cm^{-1}]



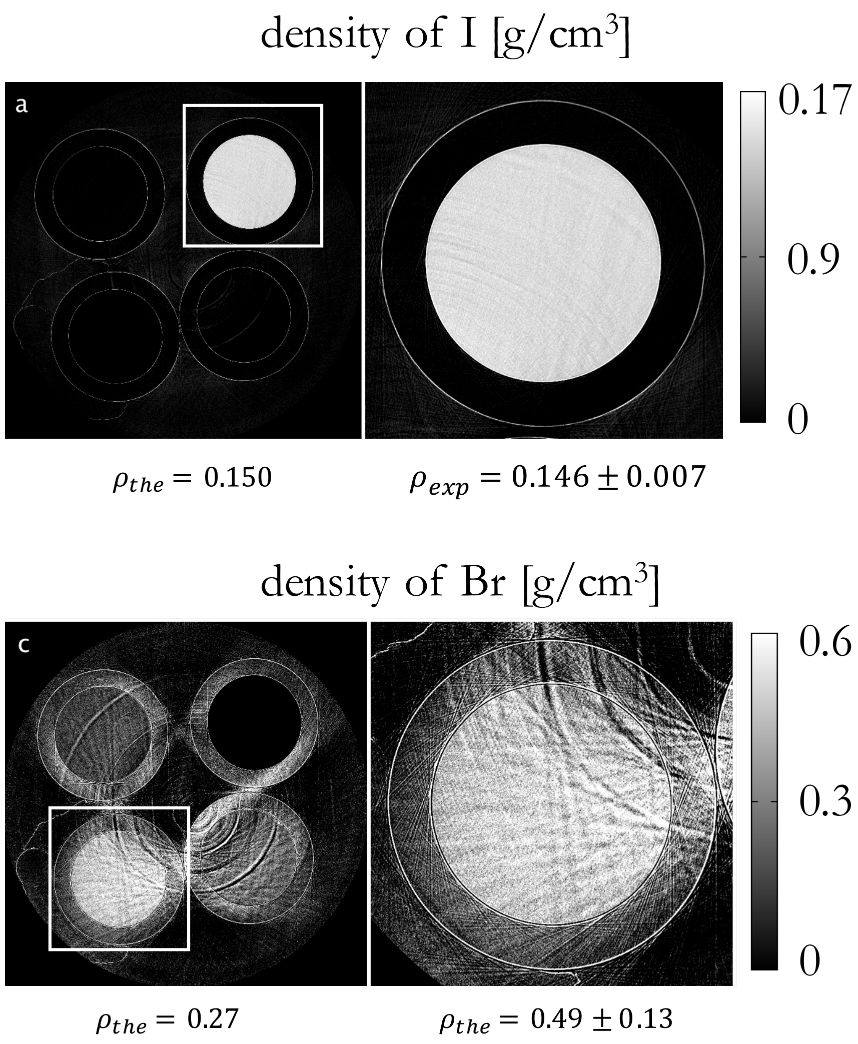
15 keV 25 keV 35 keV

Results: Phantom

- decomposition into basis materials:
  a) glass
  b) water
  c) respective contrast agent

- artifacts:
  - beam starvation
  - moving beam feature

→ use only 2 energies



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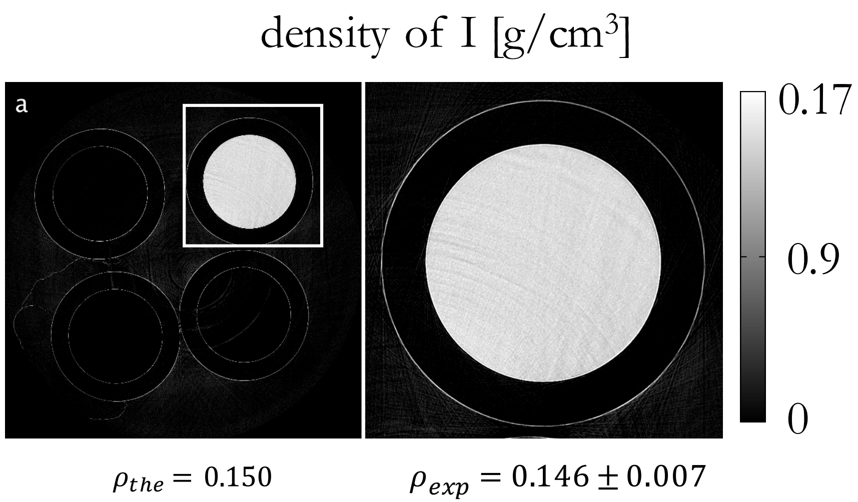
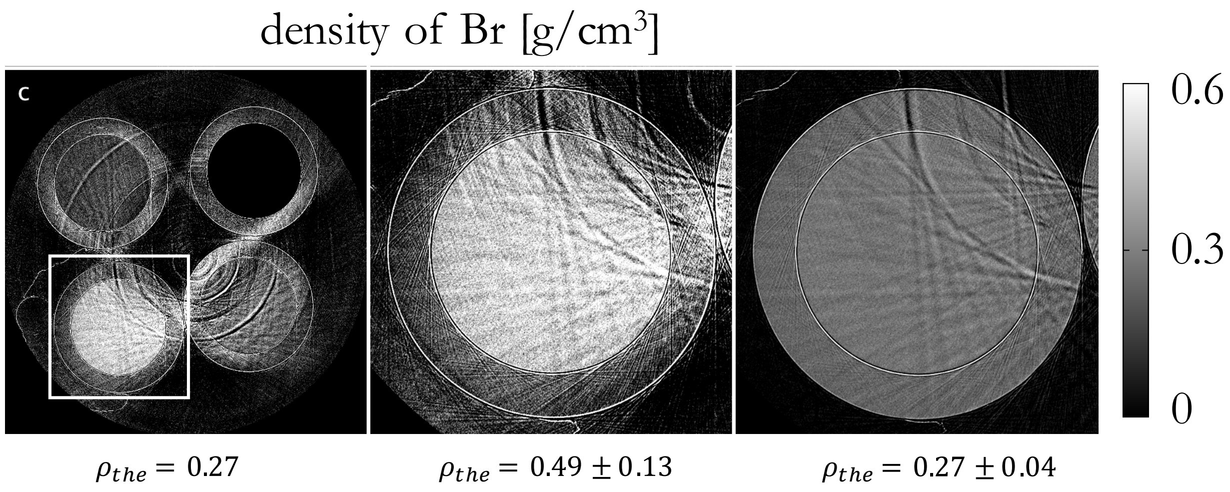
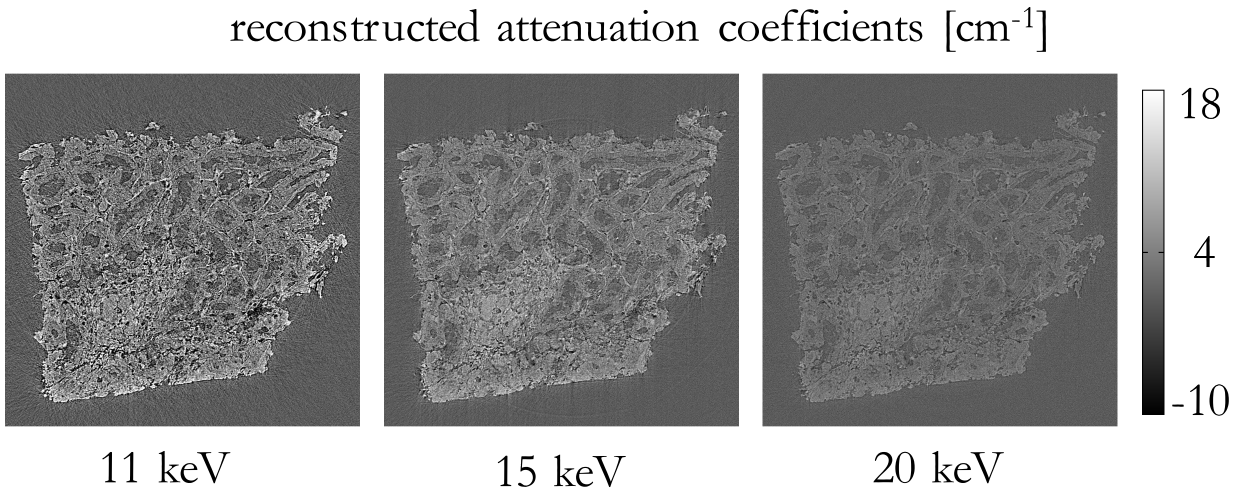




Results: Soft-Tissue

- additional difficulties:
    a) marginal attenuation
    b) no reference
    c) higher resolution (!)
    → spatial registration
    → **phase effects**



$$I(x,y,z=d) \approx I(x,y,z=0) - \frac{d\lambda}{2\pi}\nabla_{\perp}\cdot\left[I(x,y,z=0)\nabla_{\perp}\phi(x,y,z=0)\right]$$

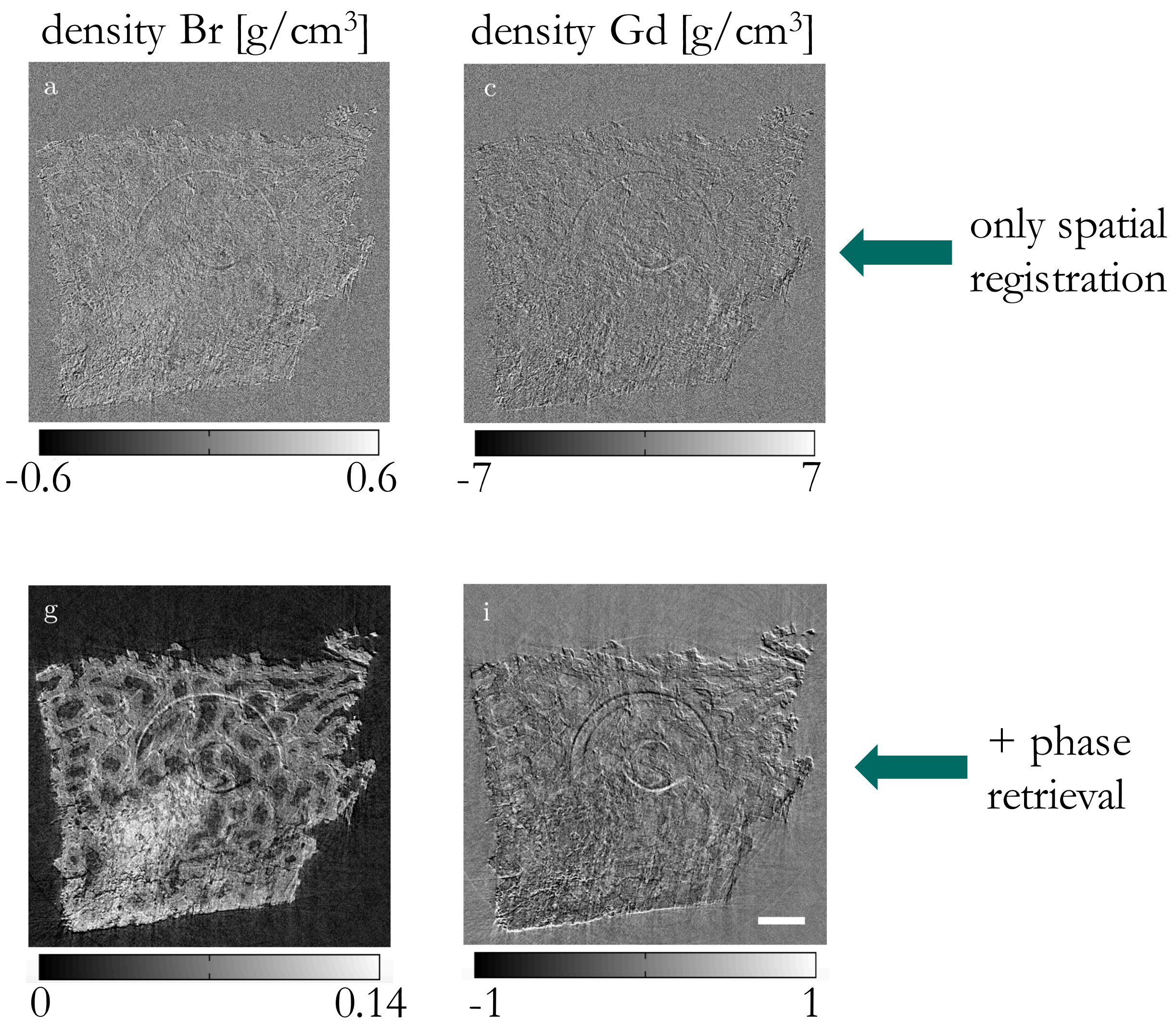
Results: Soft-Tissue

- poor signal-noise ratio

- phase-retrieval (Paganin) to reduce fringes

- large error in $\mu(x, y)$
- similar energy-dependency

→ large anti-correlated errors in $\rho_i(x, y)$



More Recently

- CRESST: search for dark matter using cryogenic crystal detectors
  - data analysis of data taken in Gran Sasso laboratory: trying to identify potential dark matter candidates

- BELLE-II: look for matter-antimatter asymmetries, development of pixel detector:
  - statistical analysis for quality assurance

Thank You!