FRIEDRICH-ALEXANDER
UNIVERSITÄT
ERLANGEN-NÜRNBERG
FACULTY OF ENGINEERING

Polychromatic Reconstruction for Talbot-Lau X-ray Tomography

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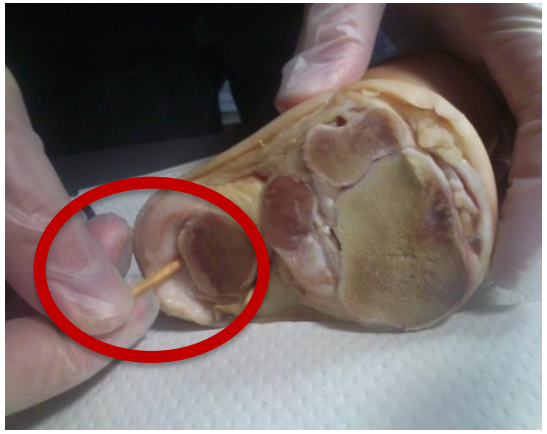
PATTERN
RECOGNITION
LAB

ERLANGEN CENTRE
FOR ASTROPARTICLE
PHYSICS

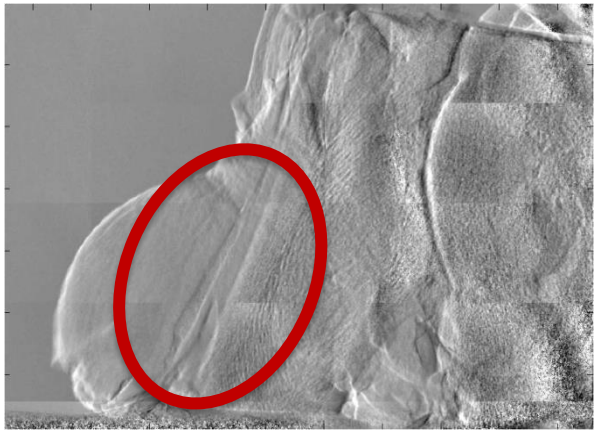
Wooden splinter in pig foot

J. Rieger *et al.*: “Optimization procedure for a Talbot-Lau x-ray phase-contrast imaging system”, 2017.

Absorption



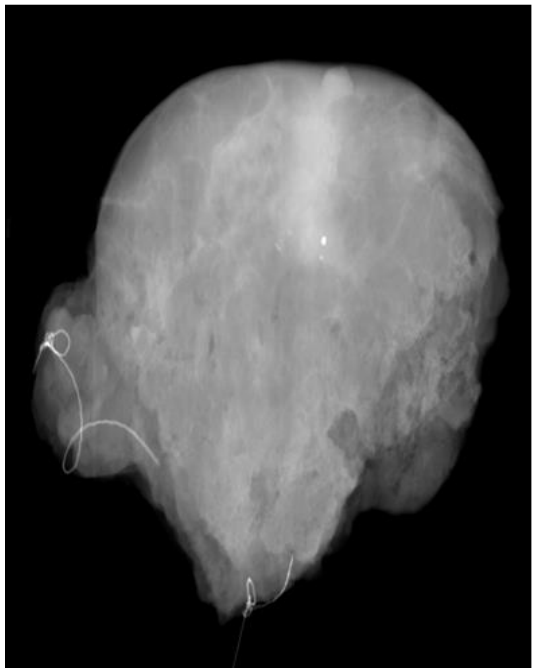
Optical image



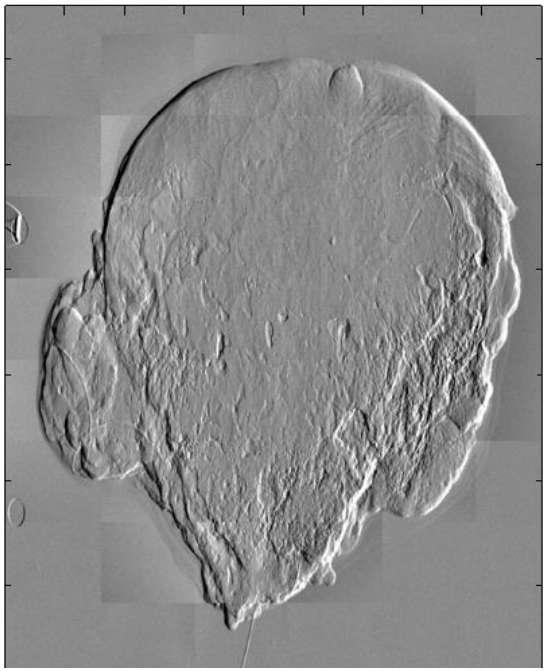
Diff. Phase

Dark-Field

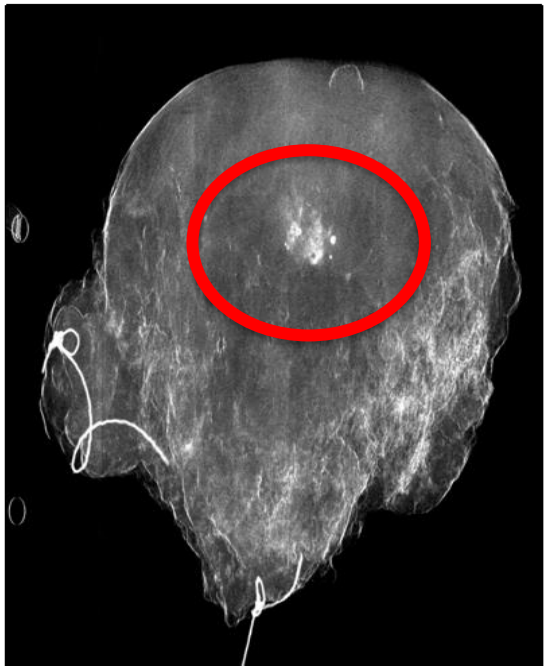
Mammography: micrometer-sized calcifications



Absorption



Diff. Phase



Dark-Field

T. Michel *et al.*: “On a dark-field signal generated by micrometer-sized calcifications in phase-contrast mammography”, 2013.

Human knee

F. Horn *et al.*: “High-energy x-ray grating-based phase-contrast radiography of human anatomy ”, 2016.

Absorption

Diff. Phase

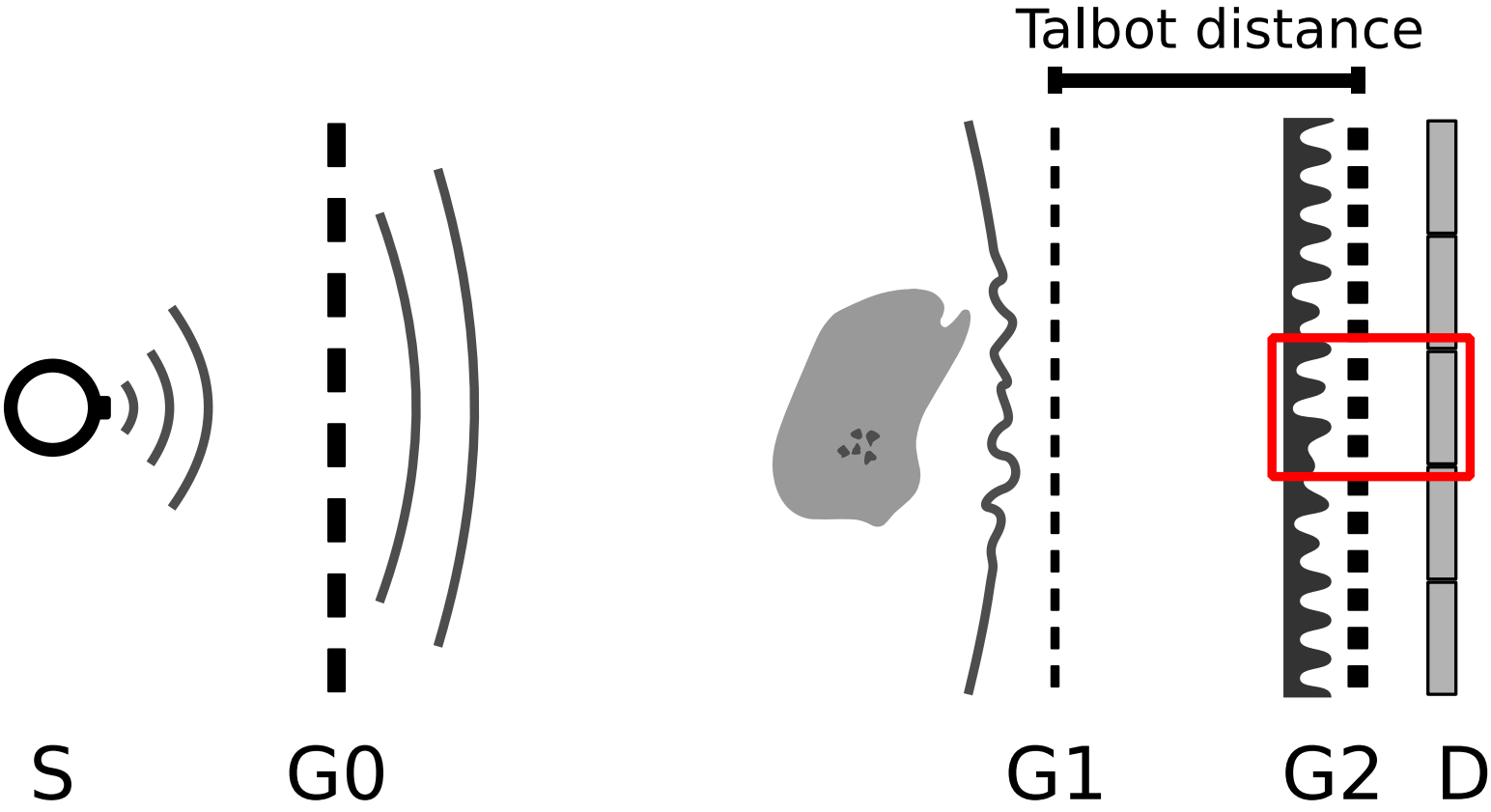
Dark-Field

Human knee

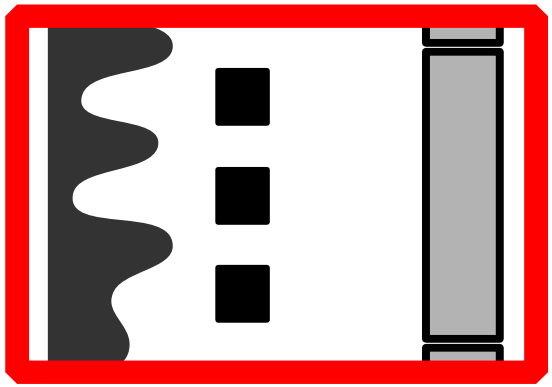
F. Horn *et al.*: “High-energy x-ray grating-based phase-contrast radiography of human anatomy ”, 2016.

Absorption | Diff. Phase | Dark-Field

Talbot-Lau X-ray Imaging



Phase stepping



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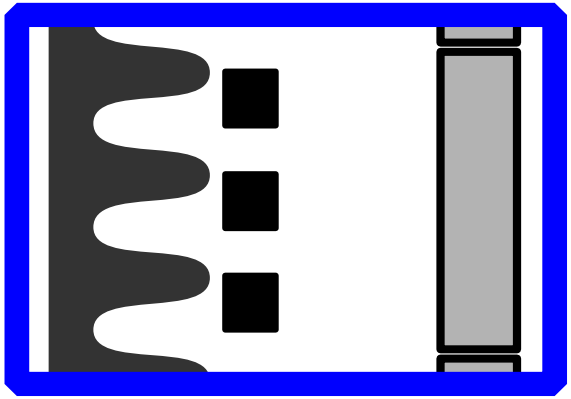

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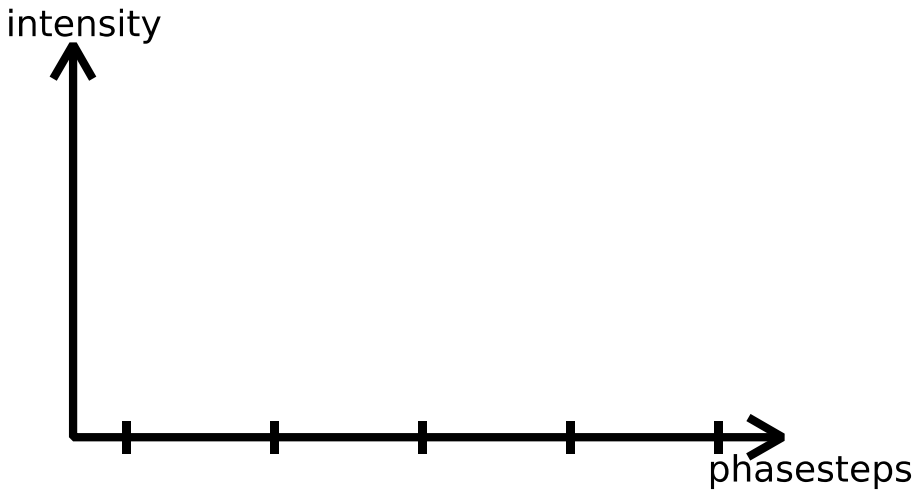
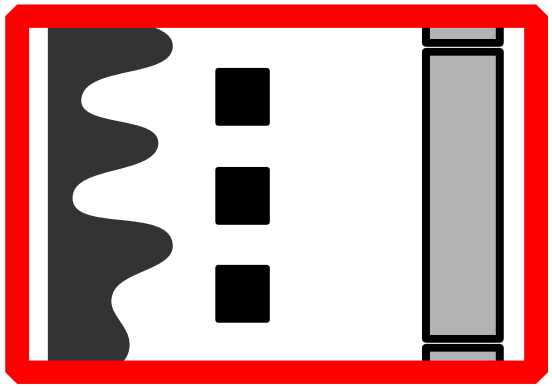


Phase stepping



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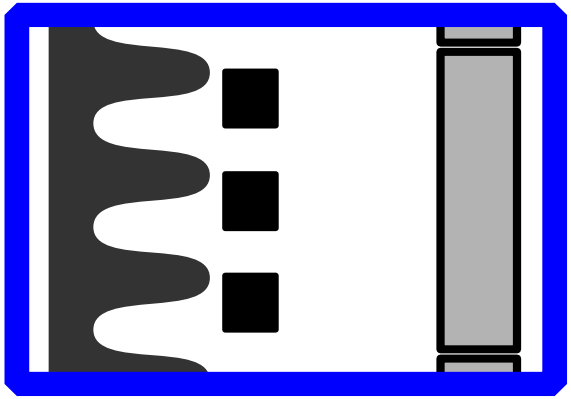

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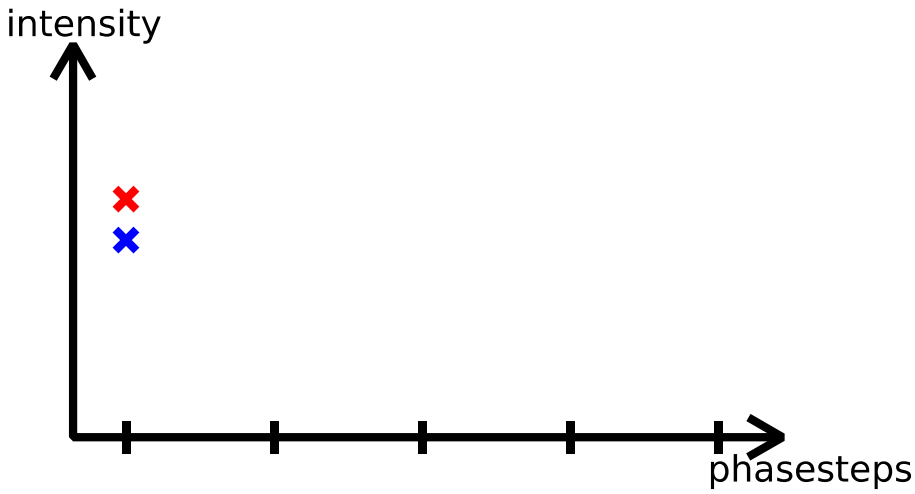
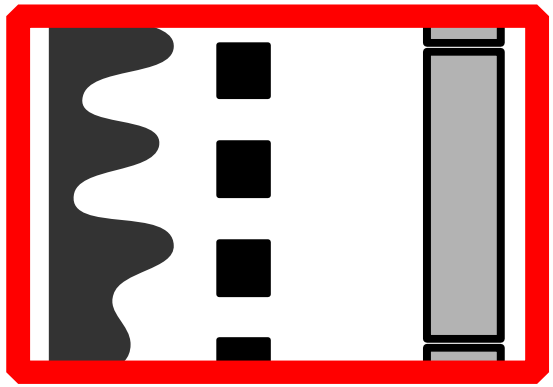


Phase stepping



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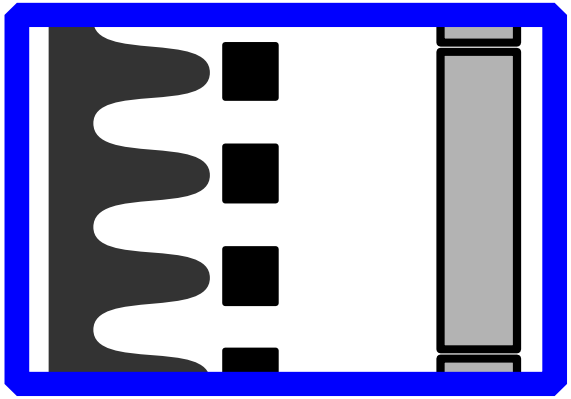

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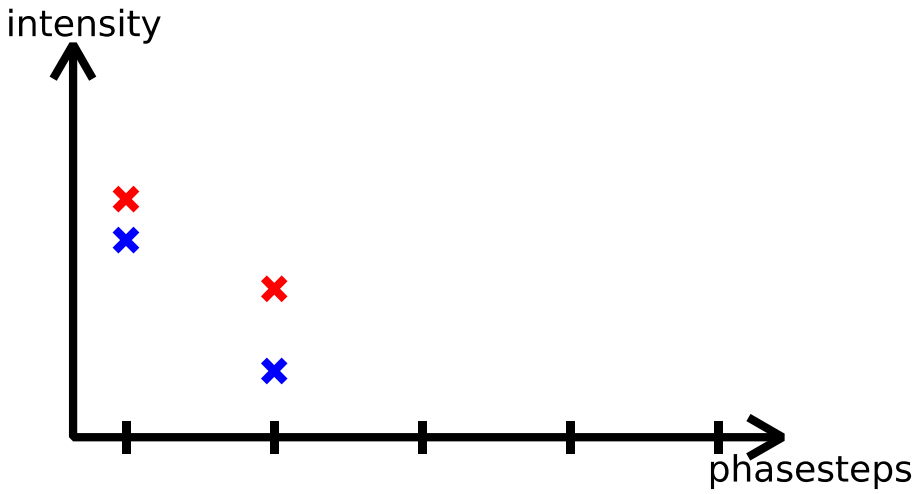
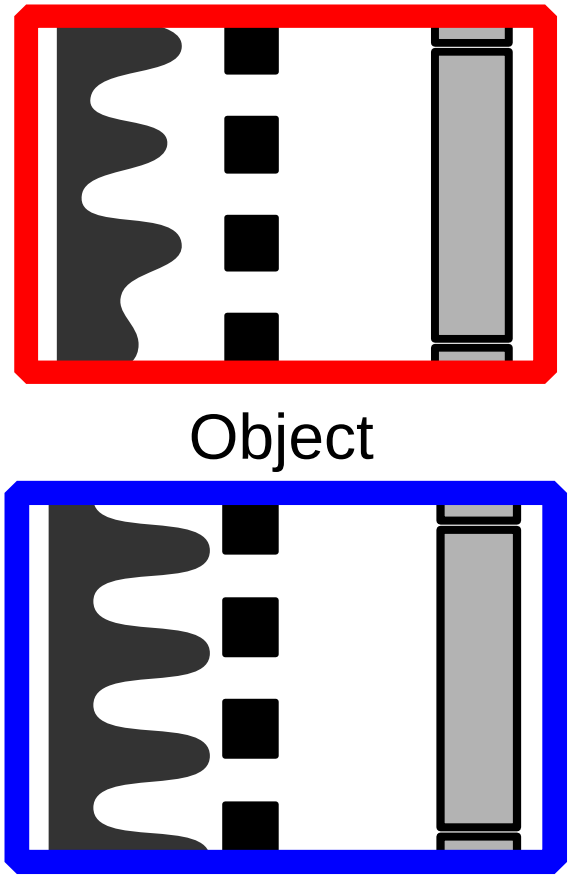
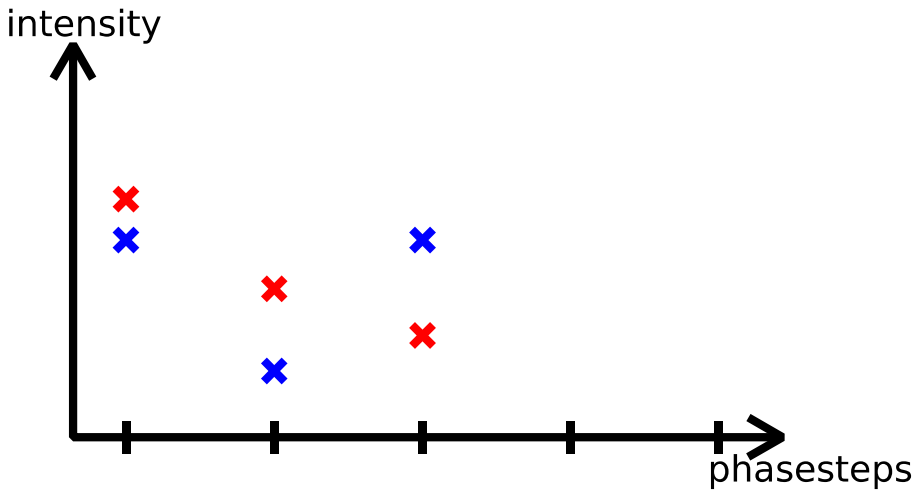
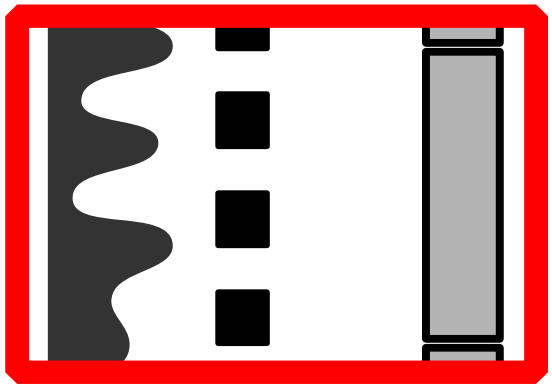


Phase stepping





Phase stepping



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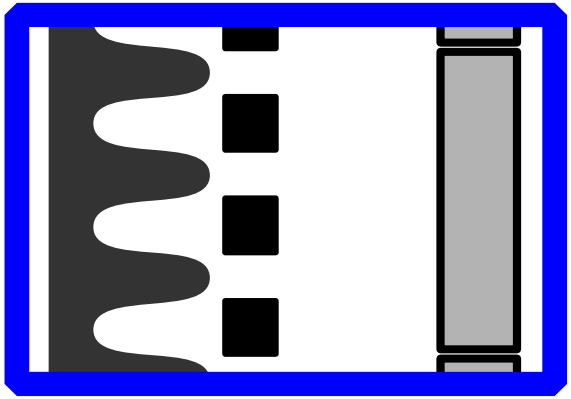

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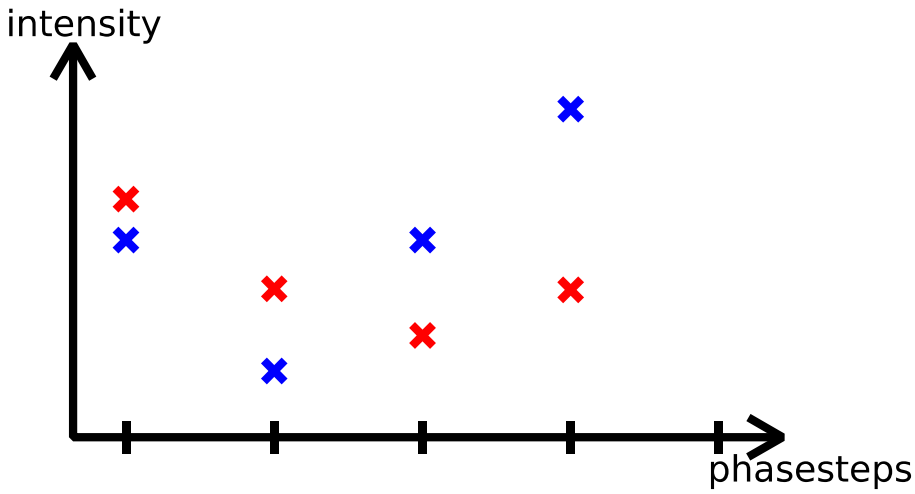

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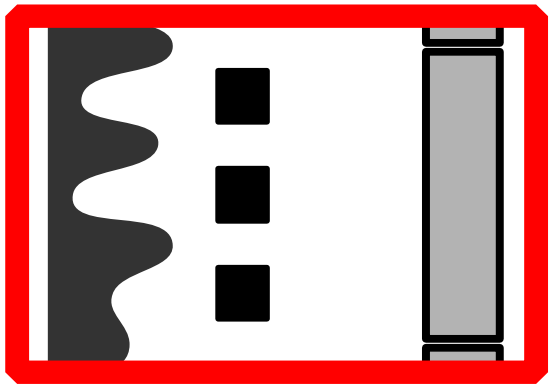

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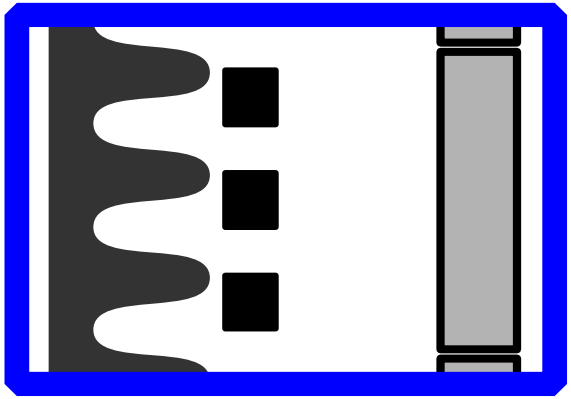

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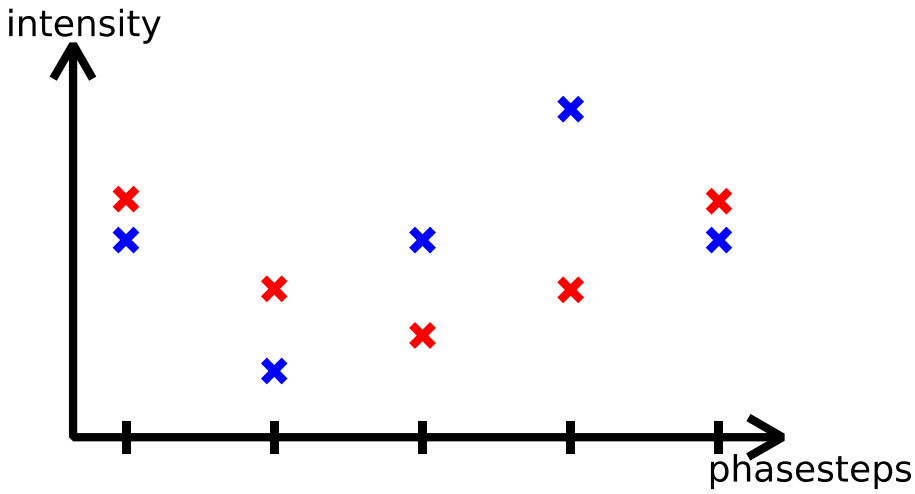
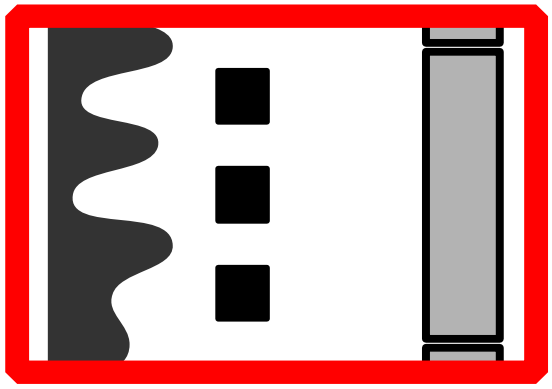


Parameter fitting



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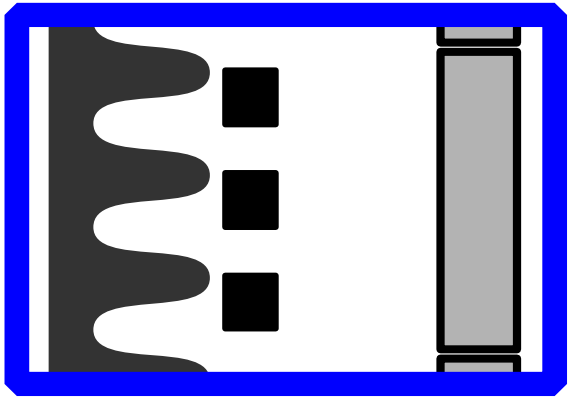

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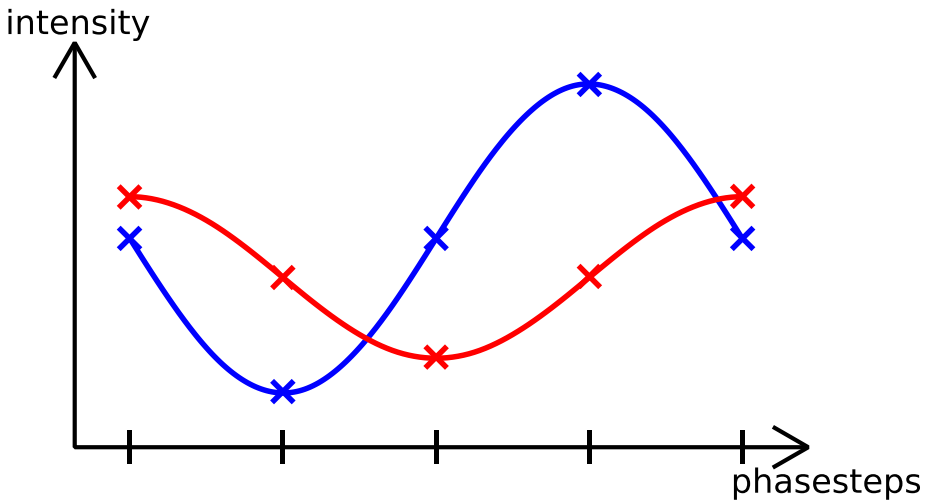

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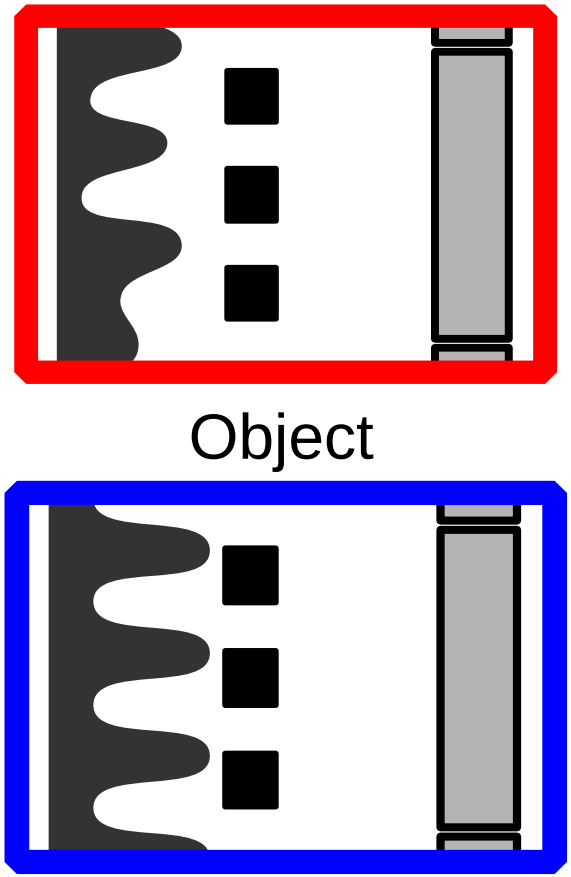
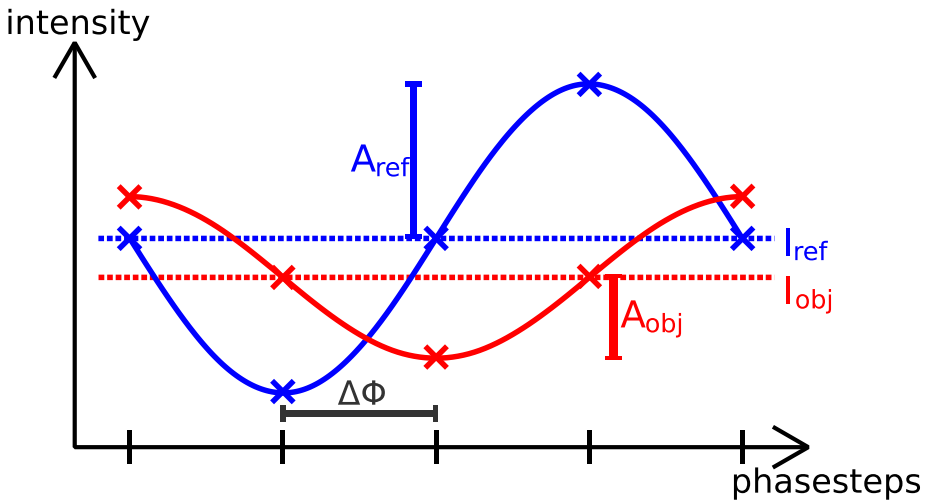




Information retrieval

Attenuation

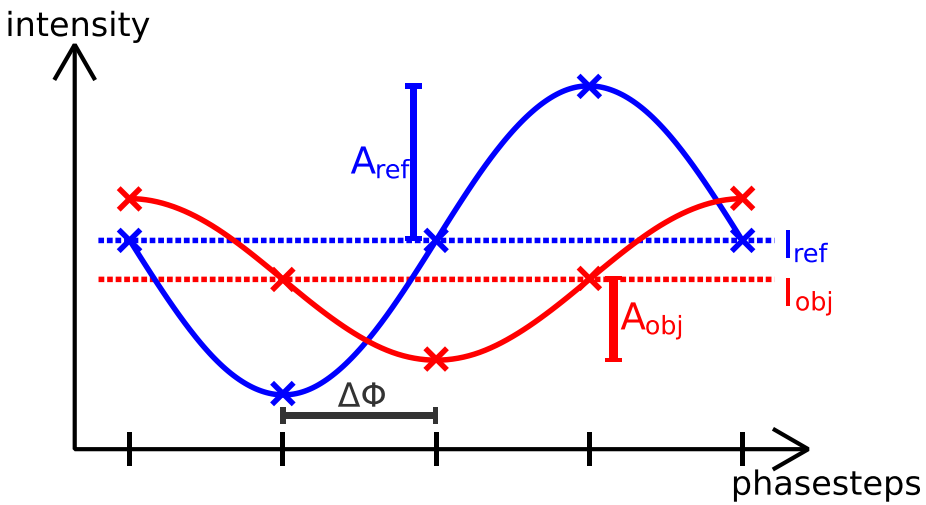
$$T = \frac{I_{obj}}{I_{ref}}$$

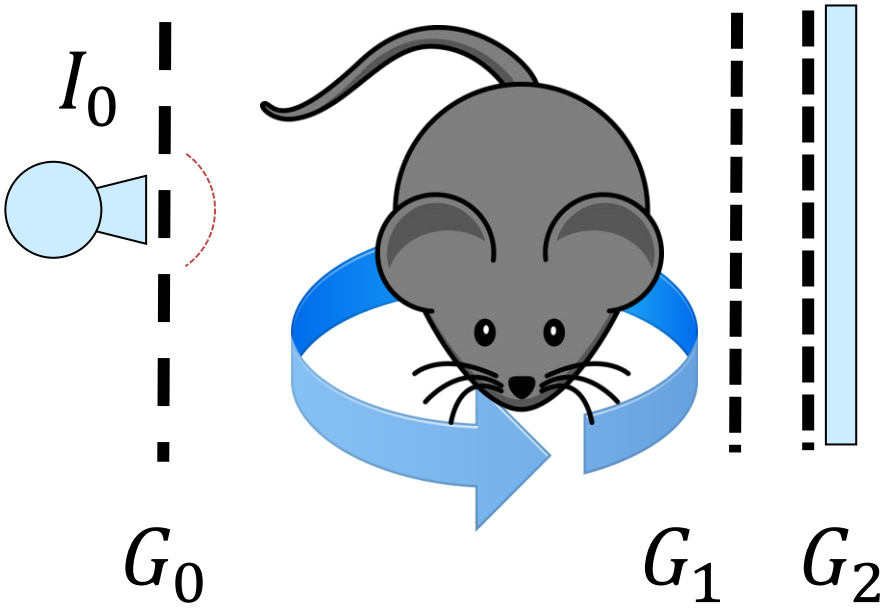
Differential phase

$$\Delta\Phi = \Phi_{ref} - \Phi_{obj}$$

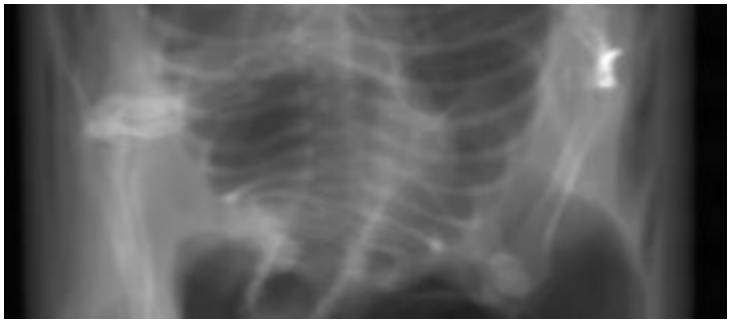
Dark-field

$$D = \frac{V_{obj}}{V_{ref}} = \frac{A_{obj}}{I_{obj}} \cdot \frac{I_{ref}}{A_{ref}}$$

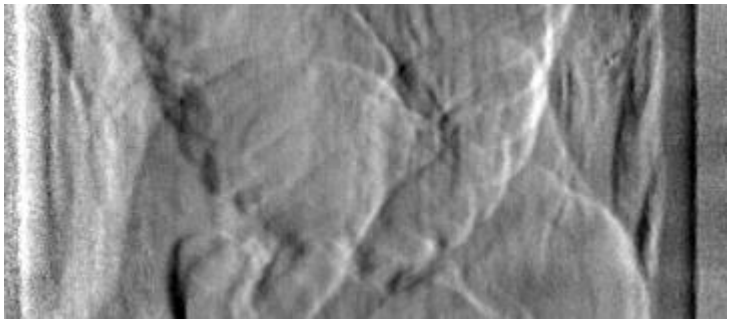




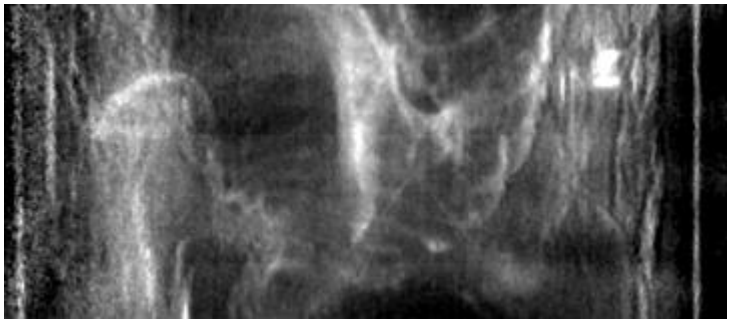
Attenuation



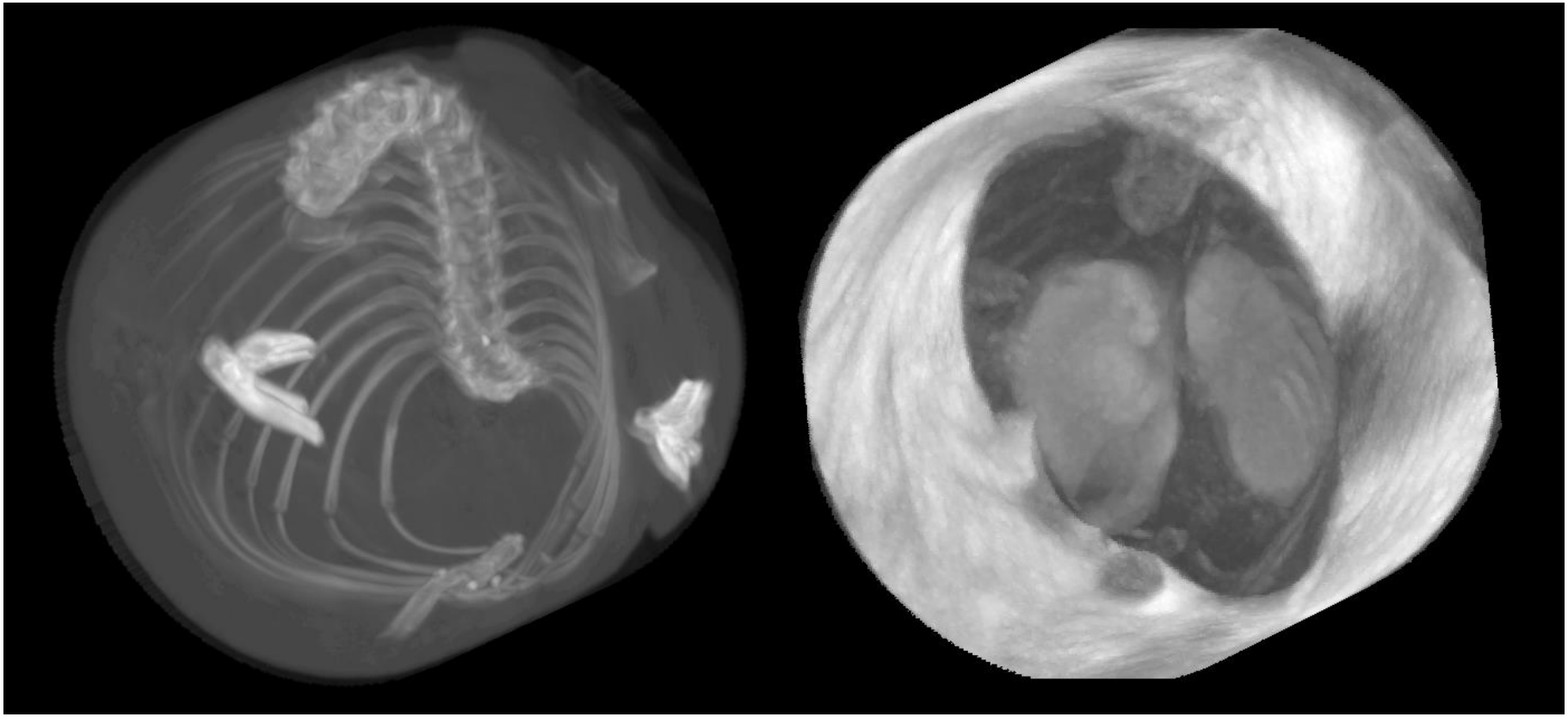
Differential Phase



Dark-field



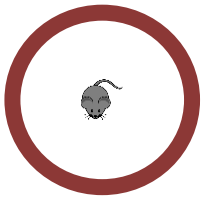
Attenuation Scatter



Polychromatic imaging of larger objects

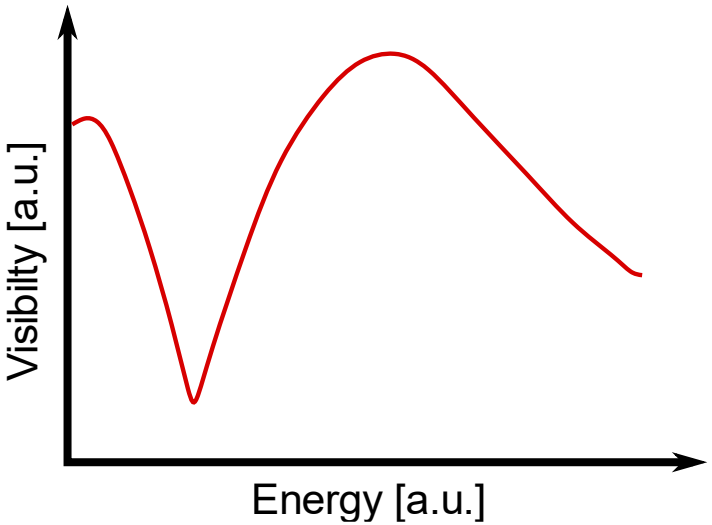
- Beam hardening leads to artifacts in attenuation CT
  - Cupping and streak artifacts
  - Reason: energy dependent attenuation coefficients

- Talbot-Lau interferometry
  - Energy dependent refraction and scattering
  - Other energy dependencies:
    - reference phase
    - reference visibility

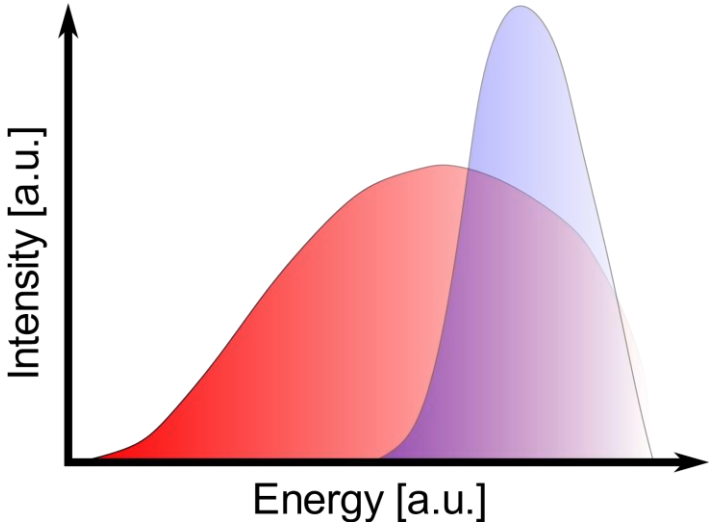


Dark-field due to beam hardening

- Visibility V: Energy dependent contrast
- Dark-field Image: Loss of visibility due to object scattering
- BUT: Can be due to beam hardening



Energy dependent contrast



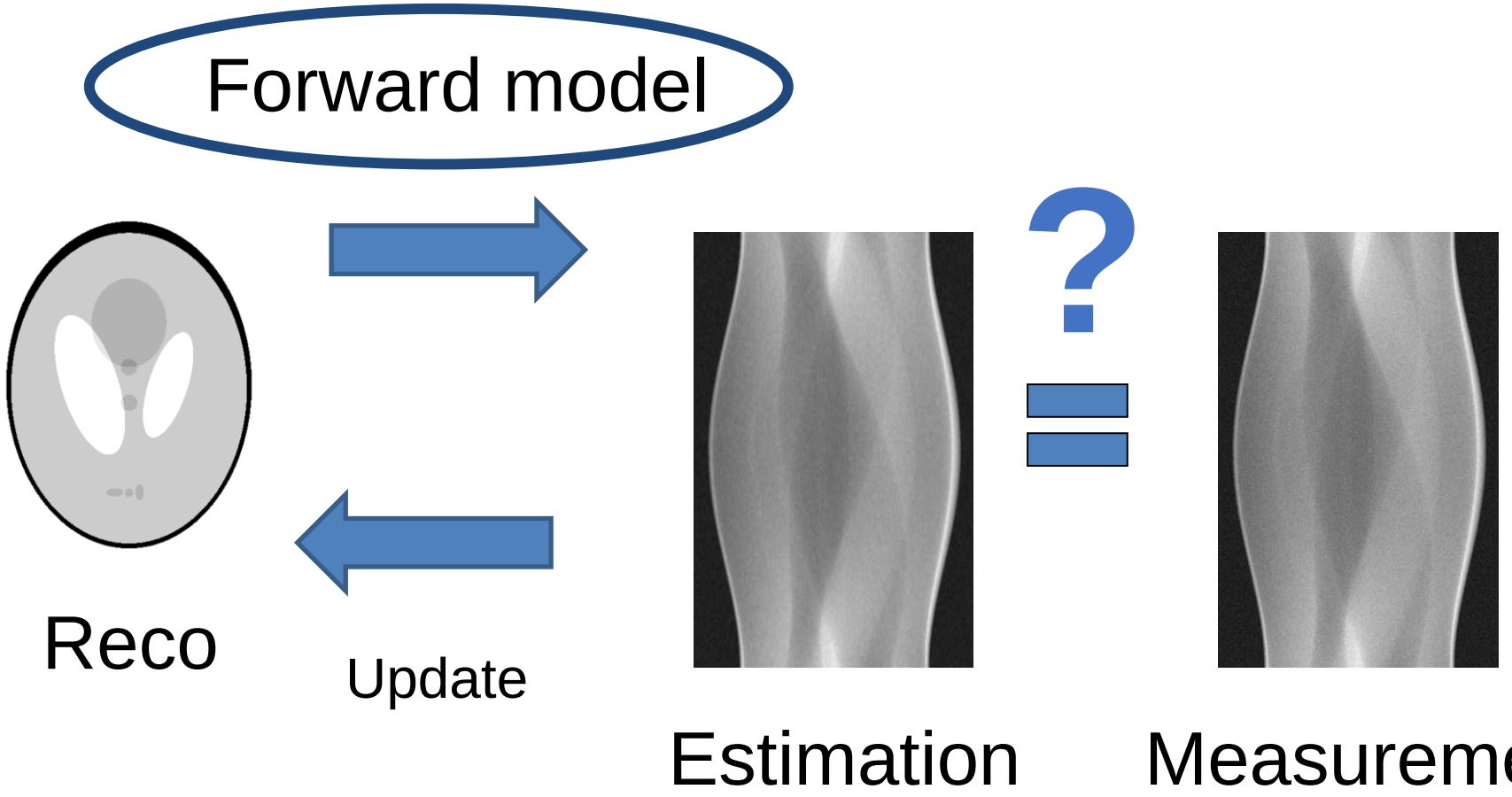
X-ray Spectrum w/ and w/o beam hardening

Polychromatic Model for Iterative Reconstruction

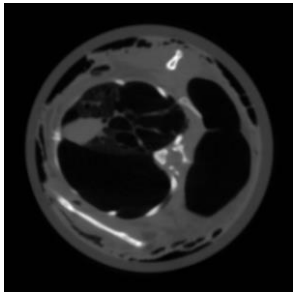
- Iterative reconstruction beneficial for Talbot/Lau imaging
  - Implicit modelling of noise
  - Allows flexible acquisitions
  - Avoids phase retrieval which can lead to complex noise statistics

- This work: polychromatic forward model for statistical iterative reconstruction

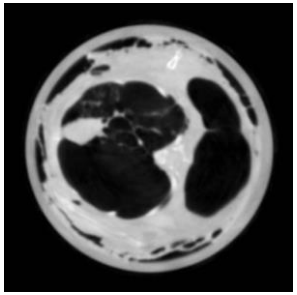
Iterative reconstruction



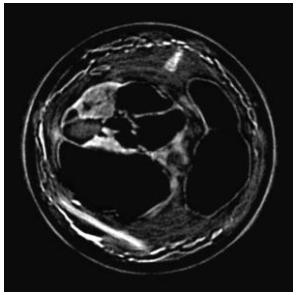
Attenuation



Refractive decrement



Scatter



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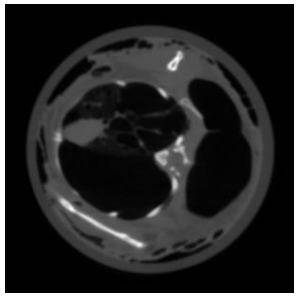
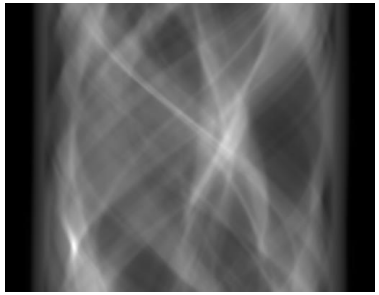
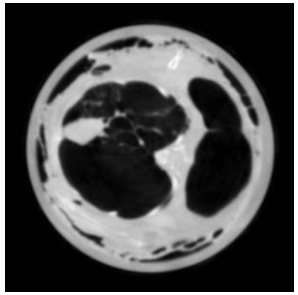


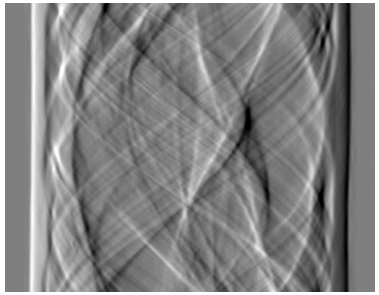
Transmission



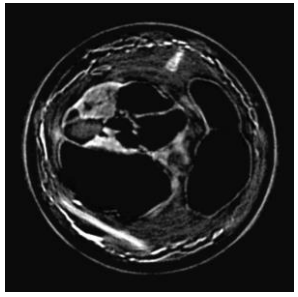
Refractive decrement



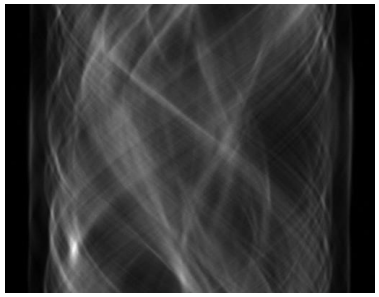
Diff. phase



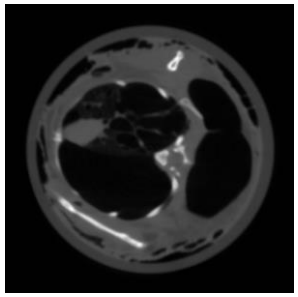
Scatter



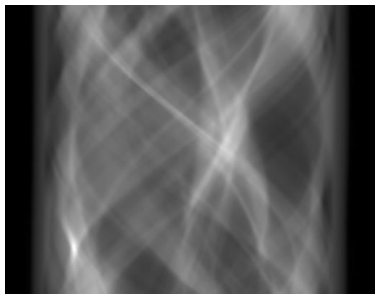
Dark-field



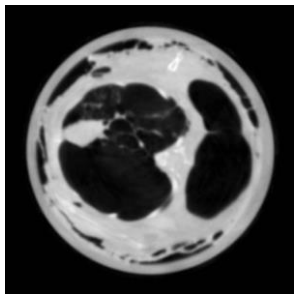
Attenuation



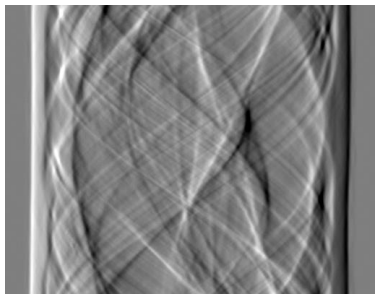
Transmission



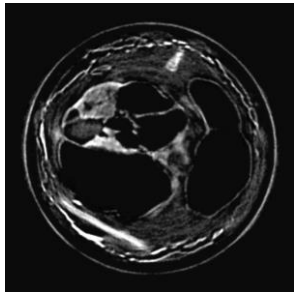
Refractive decrement



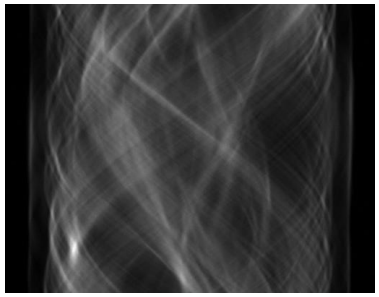
Diff. phase



Scatter

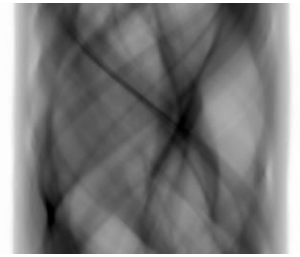


Dark-field

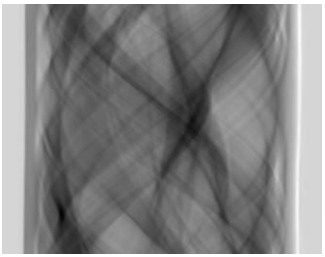


REFERENCE

Phase Step 1

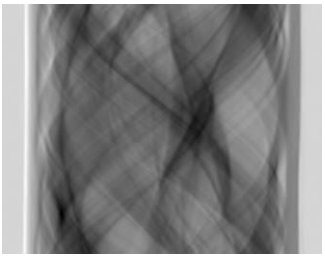


Phase Step 2



Phase Step 3

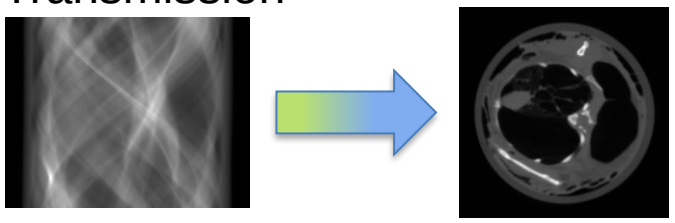
Phase Step 4



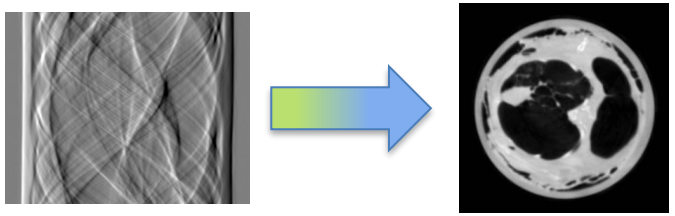
Conventional CT vs. Talbot Lau CT

Sinogram data

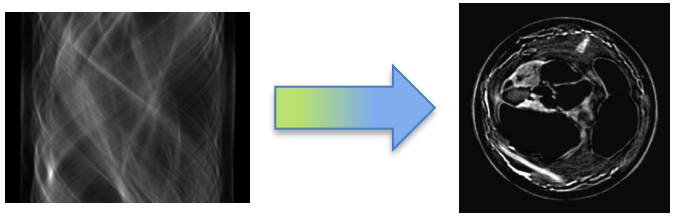
Transmission



Diff. phase



Dark-field



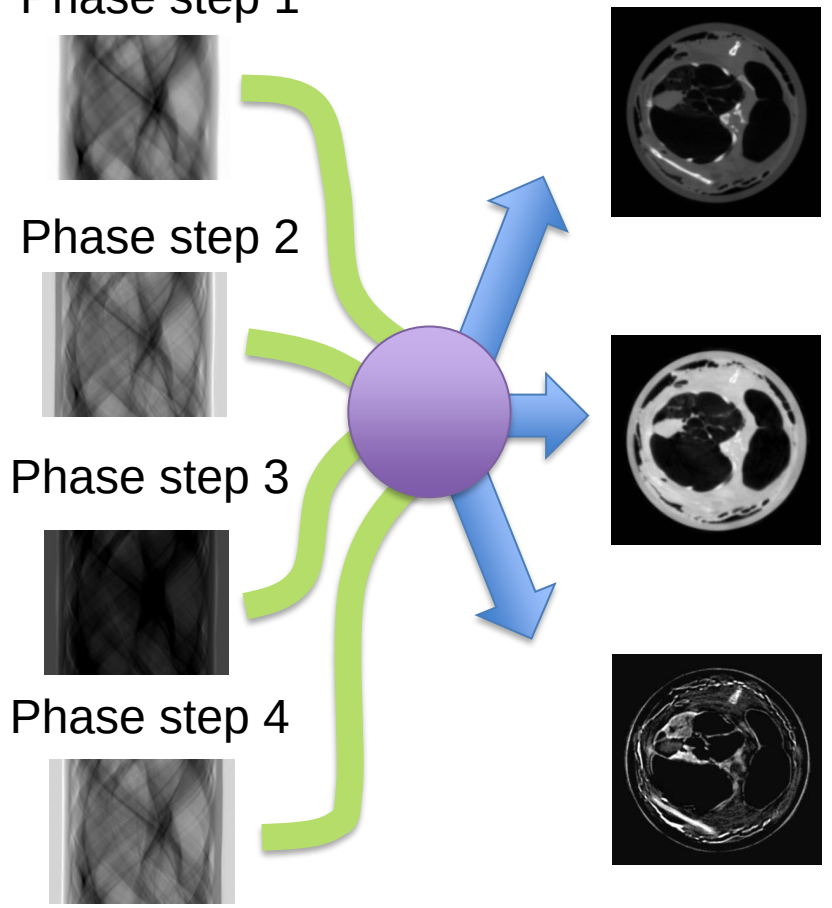
Phase stepping data

Phase step 1

Phase step 2

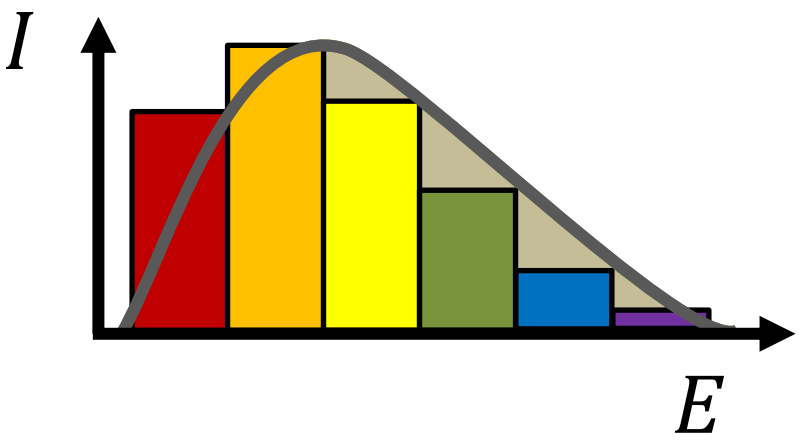
Phase step 3

Phase step 4



From monochromatic to polychromatic

Polychromatic Forward Model

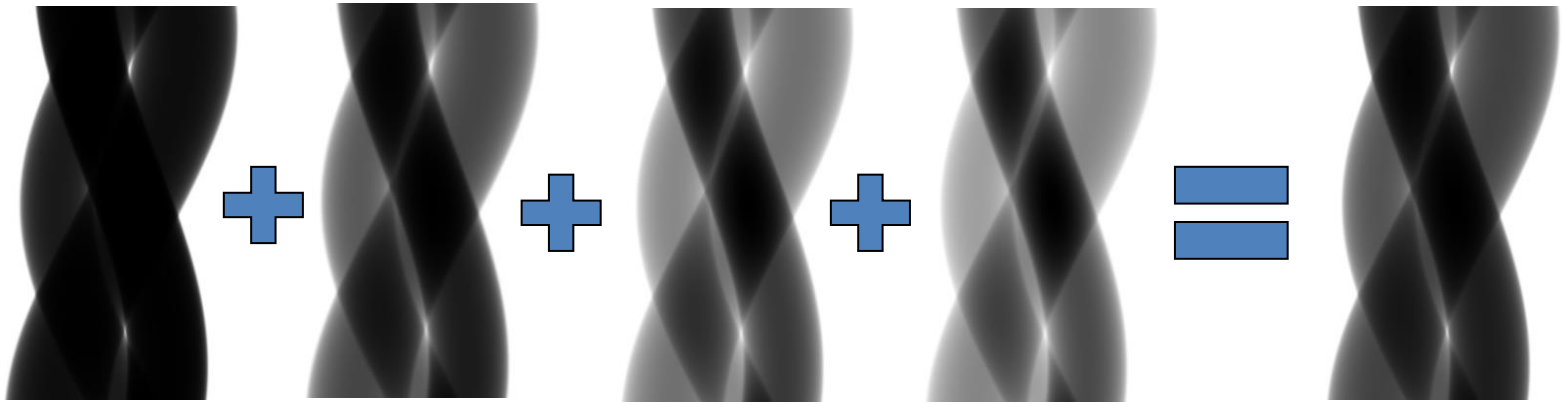


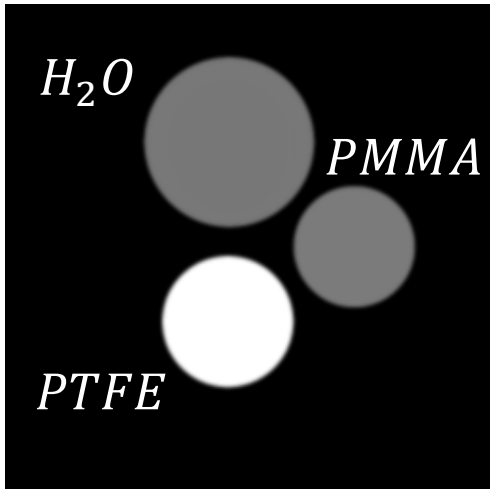
$$\mu(E) = \mu(E_0) \cdot \left(\frac{E}{E_0}\right)^{C_\mu \approx -3}$$

$$\delta(E) = \delta(E_0) \cdot \left(\frac{E}{E_0}\right)^{C_\delta = -2}$$

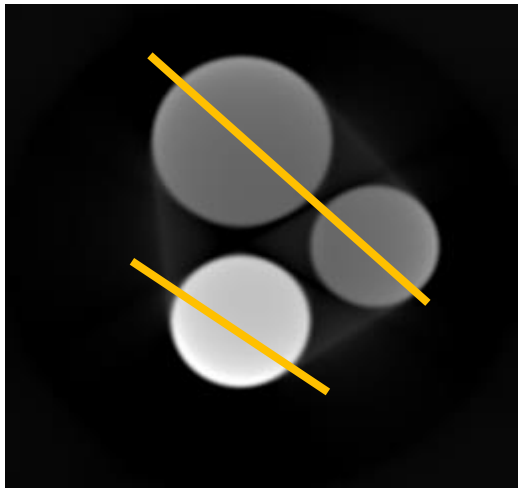
$$\sigma(E) = \sigma(E_0) \cdot \left(\frac{E}{E_0}\right)^{C_{\sigma \approx -3}}$$

15 keV 20 keV ... 60 keV Polychromatic



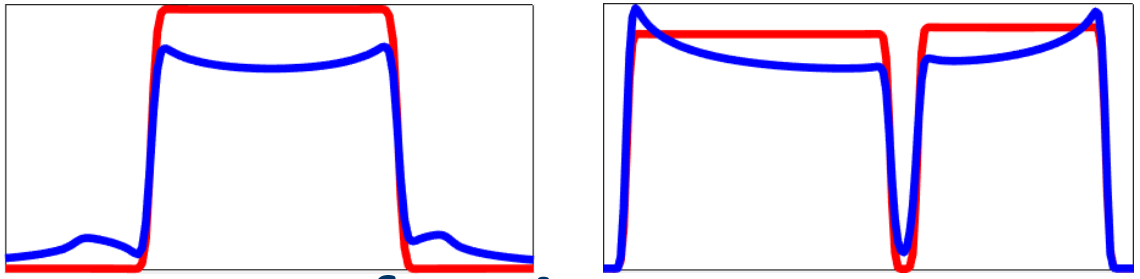


Filtered back projection of attenuation

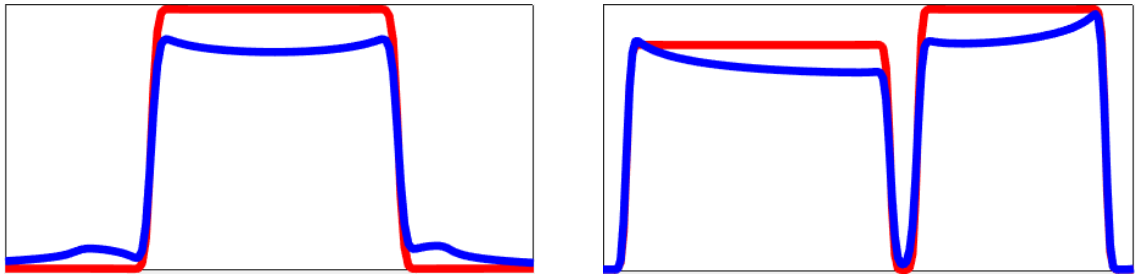


Ground Truth — Simulation

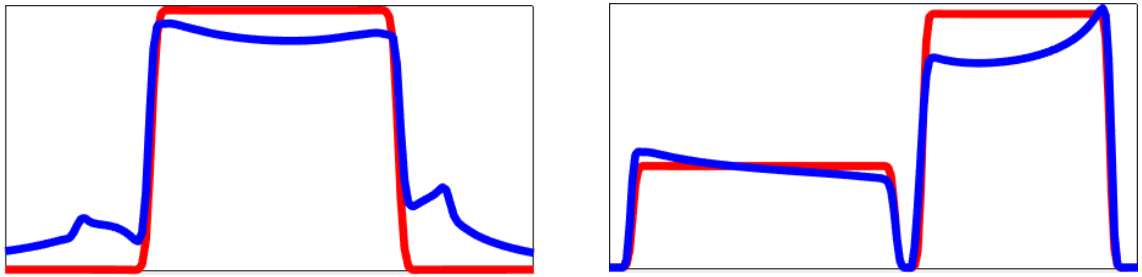
Attenuation

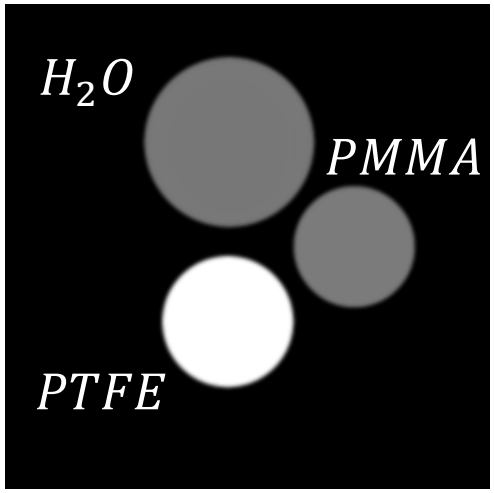


Refractive Decrement

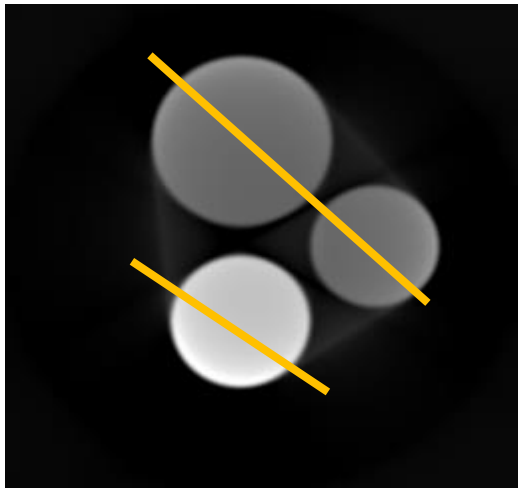


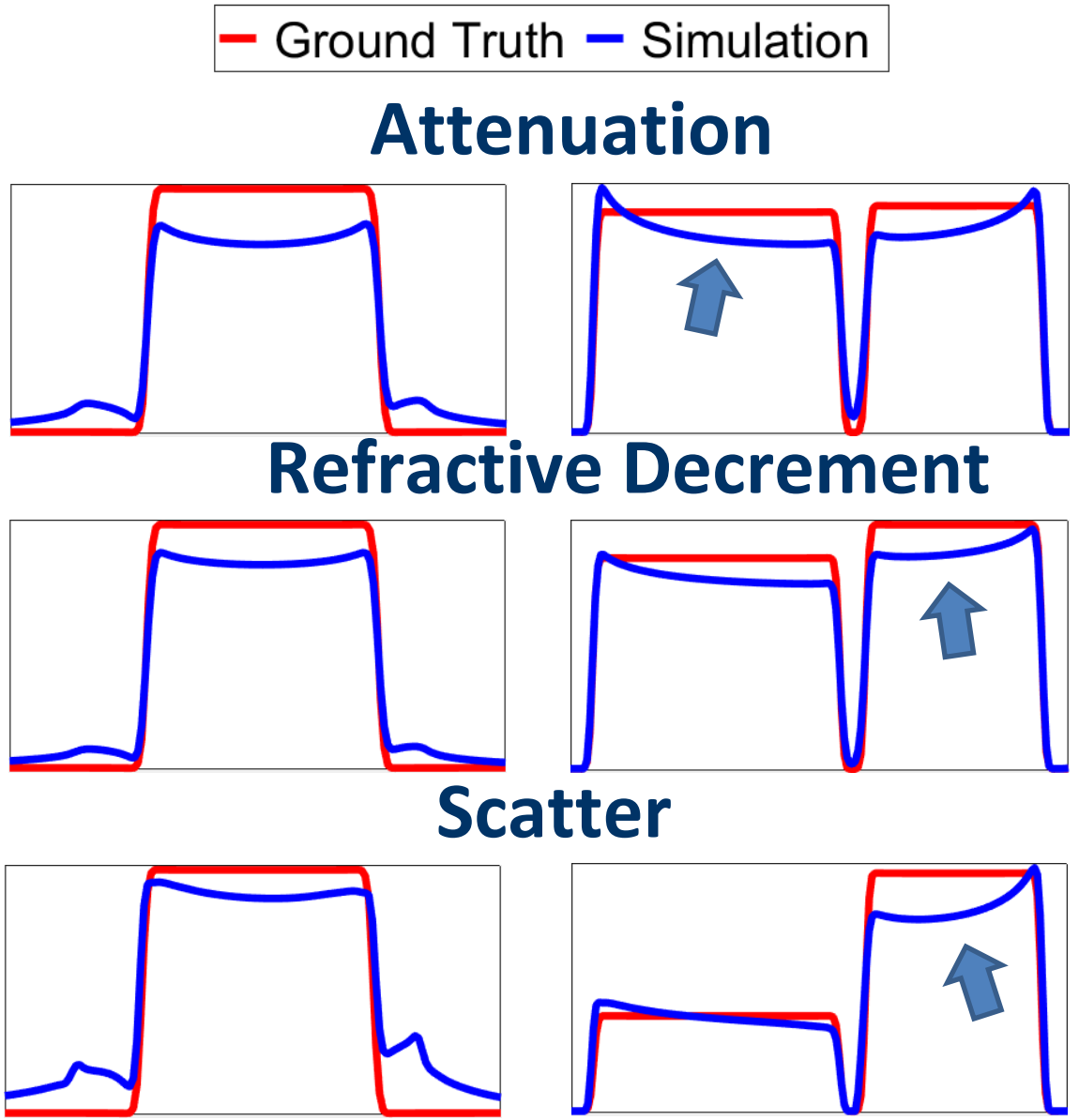
Scatter

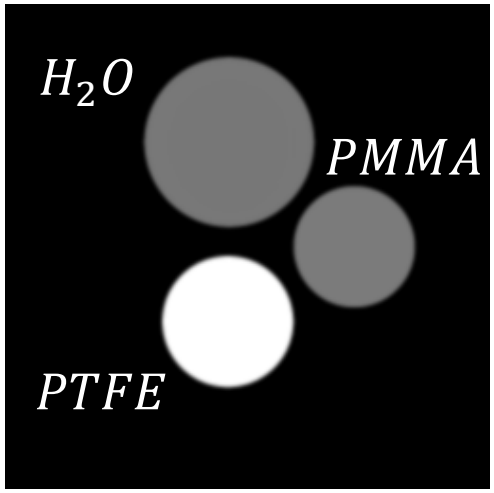




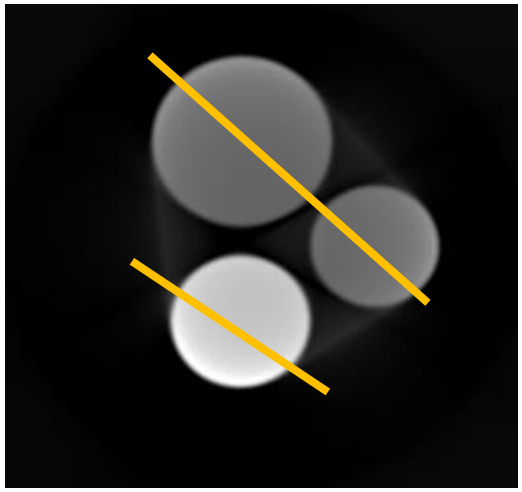
Filtered back projection of attenuation

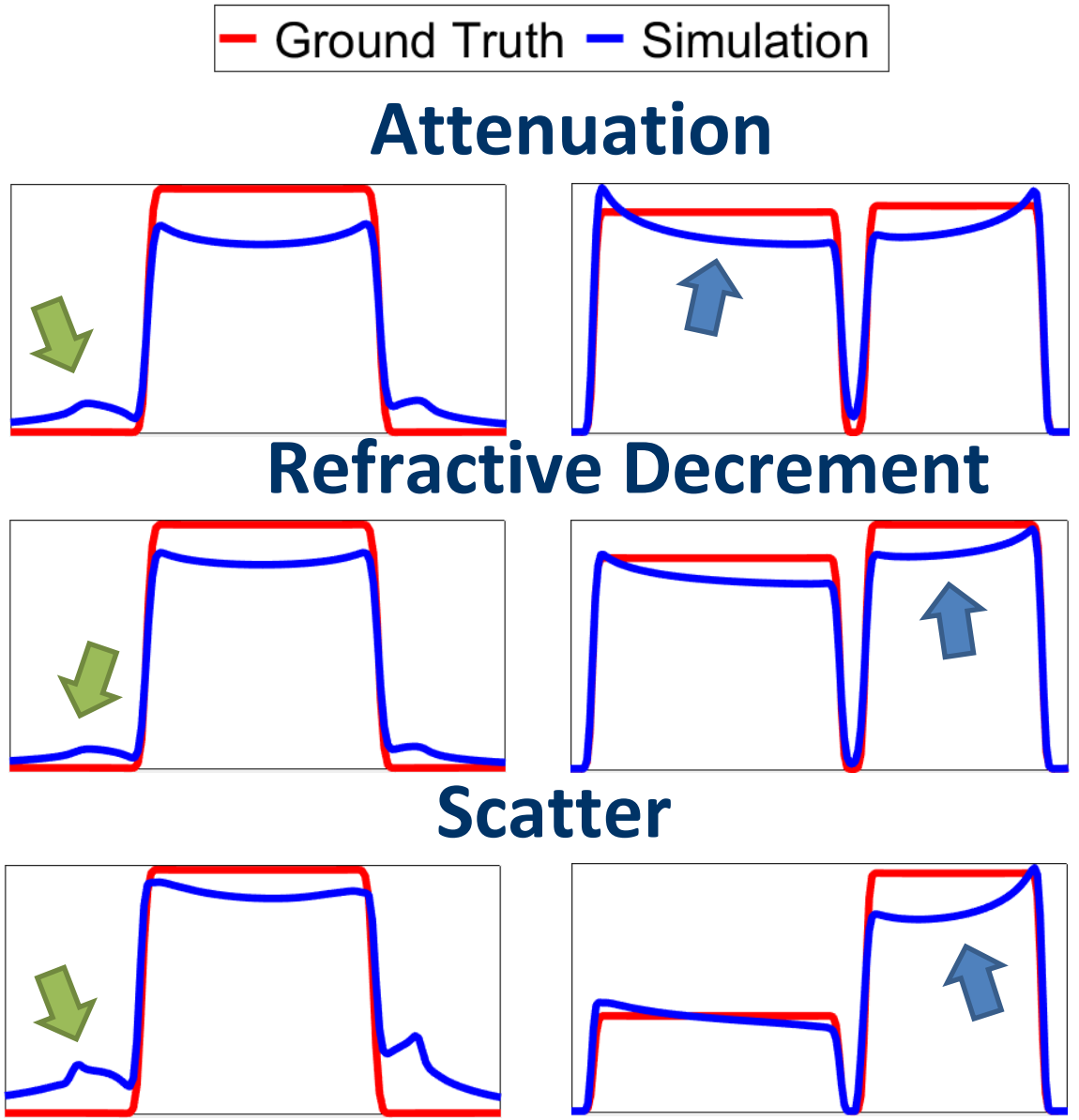


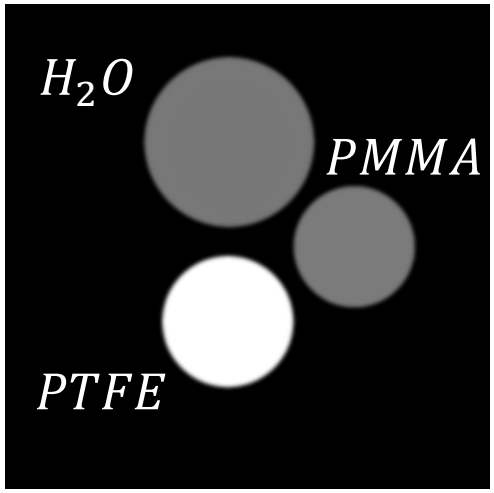




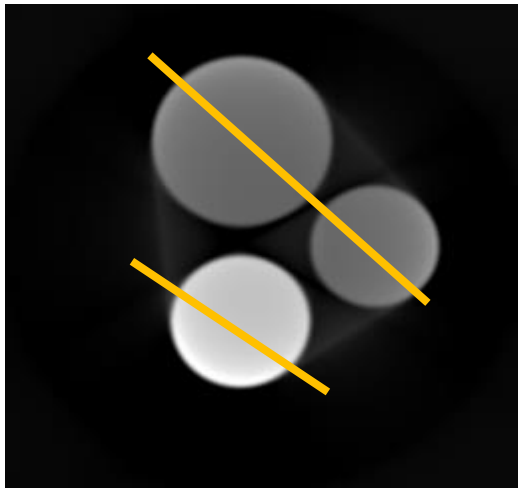
Filtered back projection of attenuation





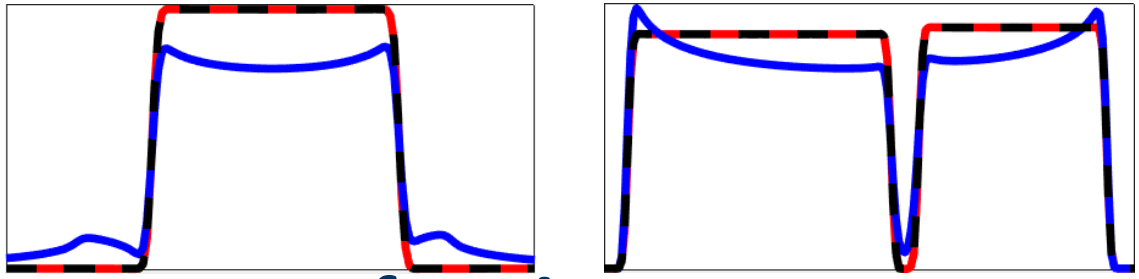


Filtered back projection of attenuation

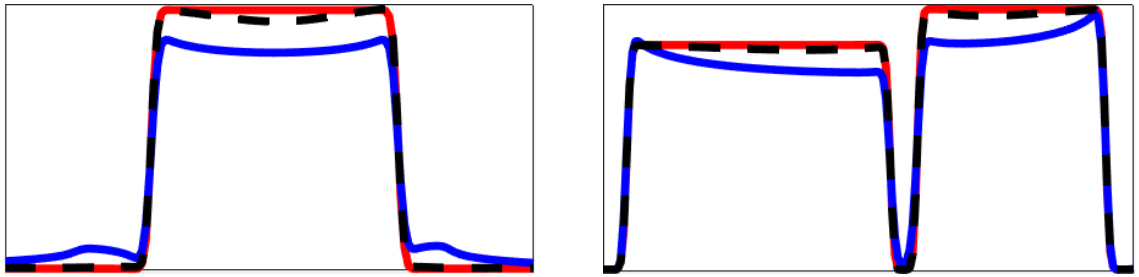


Ground Truth — Simulation — Reconstruction

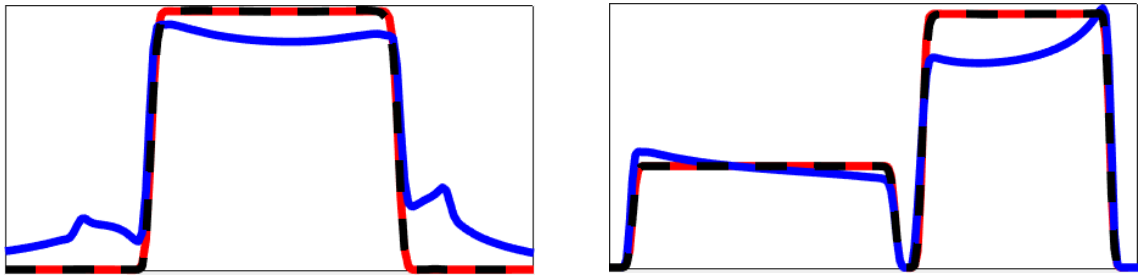
Attenuation



Refractive Decrement



Scatter



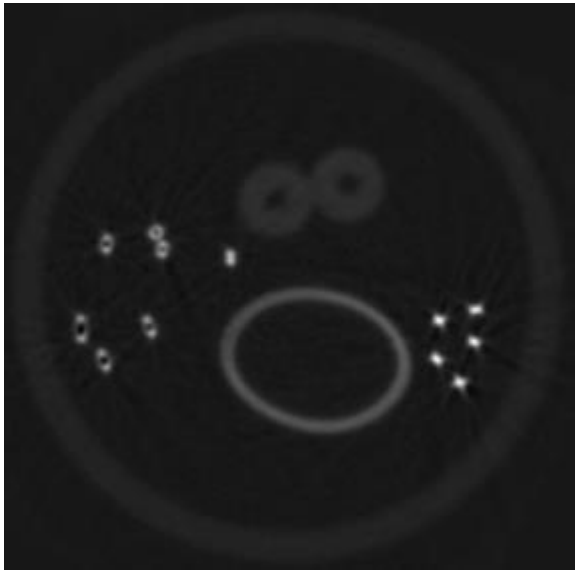
Conclusion

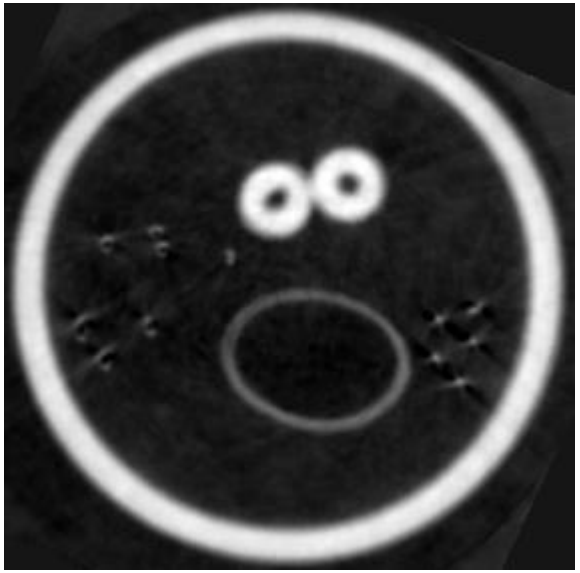
- Polychromatic **artifacts** in grating-based X-ray imaging
- **Polychromatic** forward model
- Iterative reconstruction **removes** artifacts

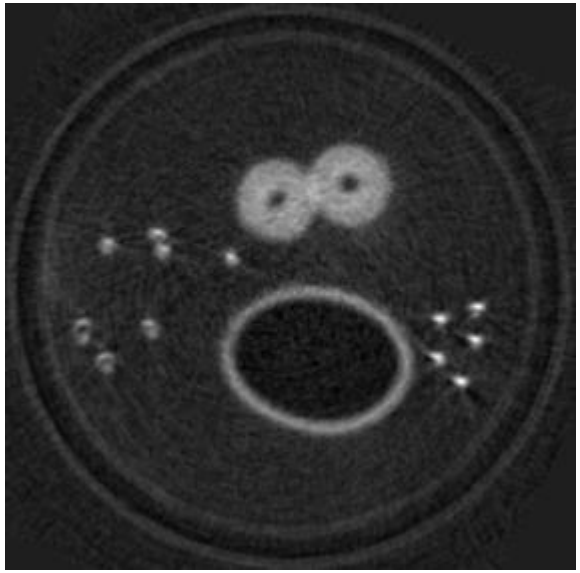
Future work

- Evaluation on **real data**
- **Efficient** implementation of algorithm

Thank you







Attenuation Phase Scatter