UNIVERSITÀ DEGLI STUDI DI TRIESTE

Validation of a µCT system simulation with a small-pixel photon-counting spectral detector

26th IWORID, BRATISLAVA, SLOVAKIA

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X-RAY IMAGING IN TRIESTE

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- ELETTRA SYNCHROTRON
- OPTIMATO LAB
- PEPI LAB

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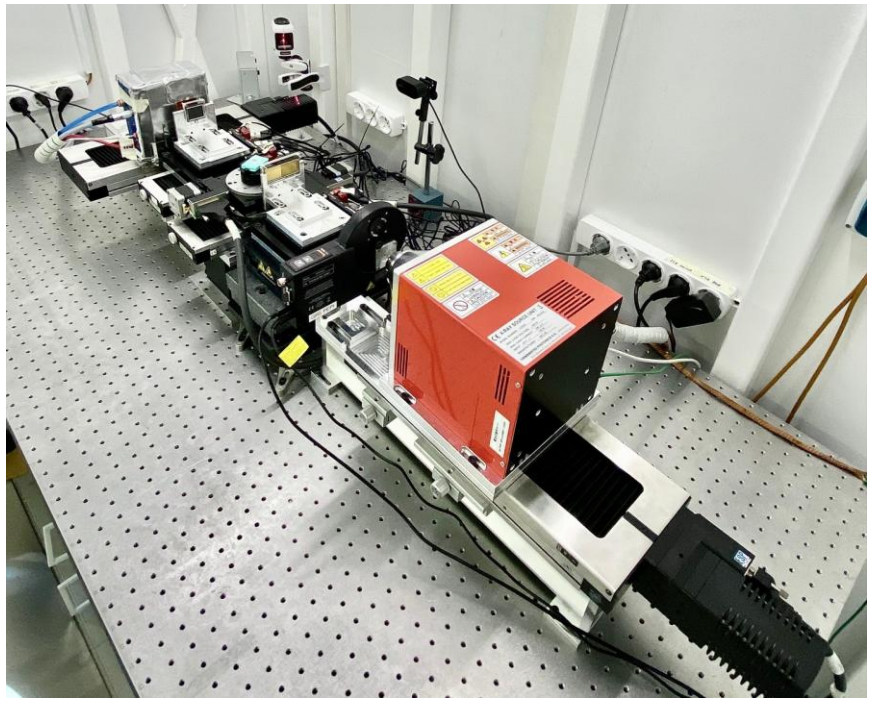
- **PEPI LAB**

PEPI LAB OVERVIEW

Istituto Nazionale di Fisica Nucleare

Photon-counting
Edge-illumination
Phase-contrast
Imaging



- **PEPI LAB** is an X-ray micro-scale imaging tool capable of **phase-contrast imaging** equipped with a **small-pixel spectral detector**

KEYS:

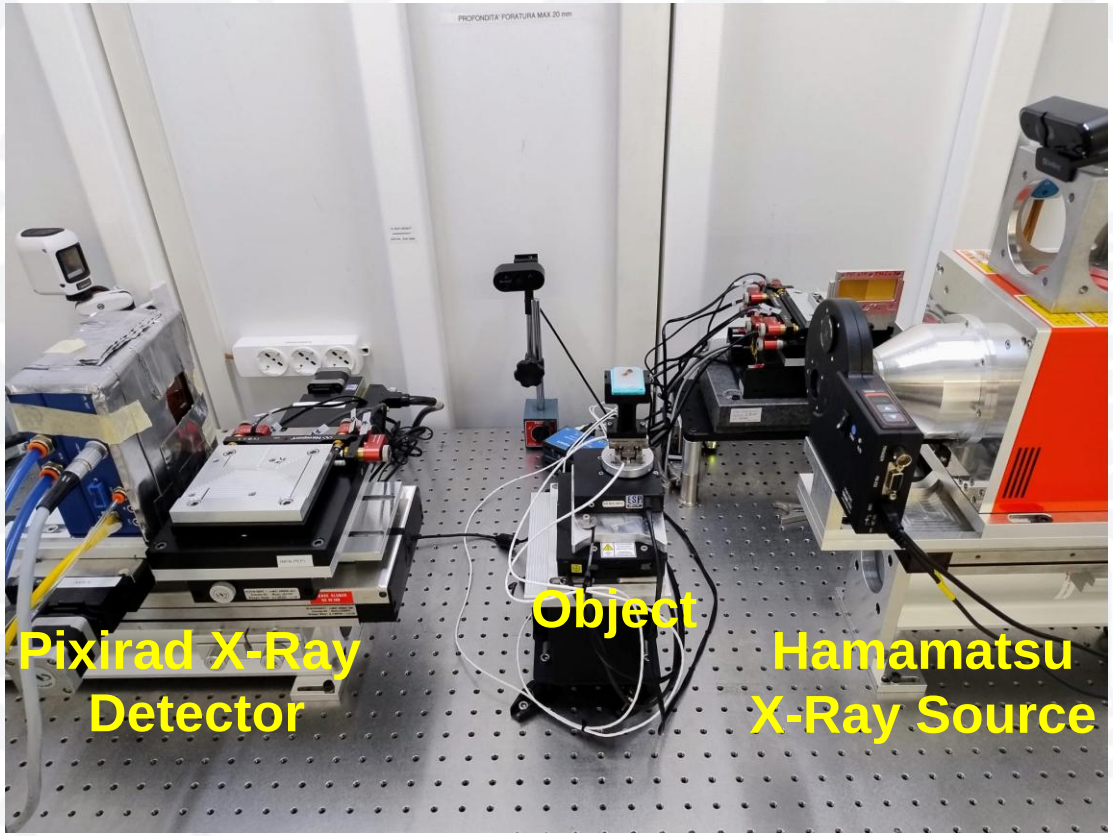
- ***Flexibility**: multiple imaging modalities on a broad energy range (applications from soft tissue to material science)*
- ***Compactness**: overall dimension < 1 m*

APPLICATIONS:

- ***Spectral µCT***
- ***Edge Illumination Spectral Phase-Contrast***
- ***Spectral PBI virtual histology***

PEPI Lab specs – Spectral, propagation-based x-ray µCT

X-ray source *Hamamatsu L10101*	Spectrum	Tungsten, 40 – 100 kVp
	Power	20 W
	Focal spot	5 – 30 µm
Detector *Pixirad PixieIII*	FOV	512 x 402 pixels
	Pixel size	62 µm
	FOV	30.7 x 24.9 mm^2
	Sensor	CdTe
Geometry	Dimension	40 – 135 cm (continuous)
	Magnification	1.3 – 3.8 (continuous)
	Resolution – PSF	15 – 40 µm (PBI)



PEPI Lab – Spectral, propagation-based x-ray µCT

CHALLENGES:

- It is not trivial to know what the best combination of acquisition parameters are for a particular sample.
- Moreover, acquisitions cost a lot in terms of time, sample preparation, equipment use, etc.

PEPI Lab – Spectral, propagation-based x-ray µCT

CHALLENGES:

- It is not trivial to know what the best combination of acquisition parameters are for a particular sample.
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IDEA:

- **We want to know beforehand what image quality we can expect for a given sample**

PEPI Lab – Spectral, propagation-based x-ray µCT

THE VISION:

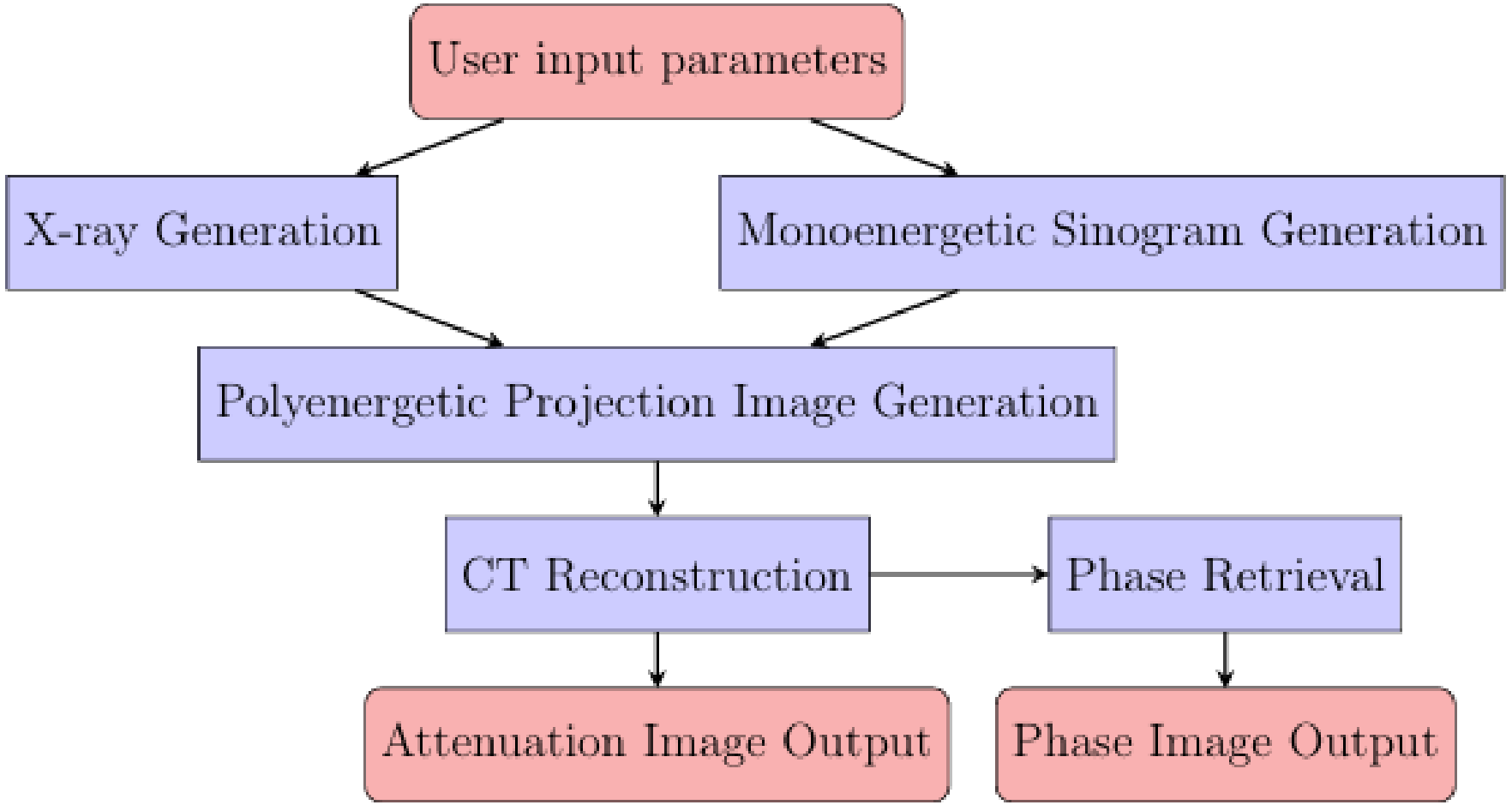
Develop a simulation tool that accurately simulates the spectral, propagation-based X-ray phase-contrast µCT setup at the PEPI Lab:

- Spectral, photon-counting
- Propagation-based X-ray phase-contrast
- µCT

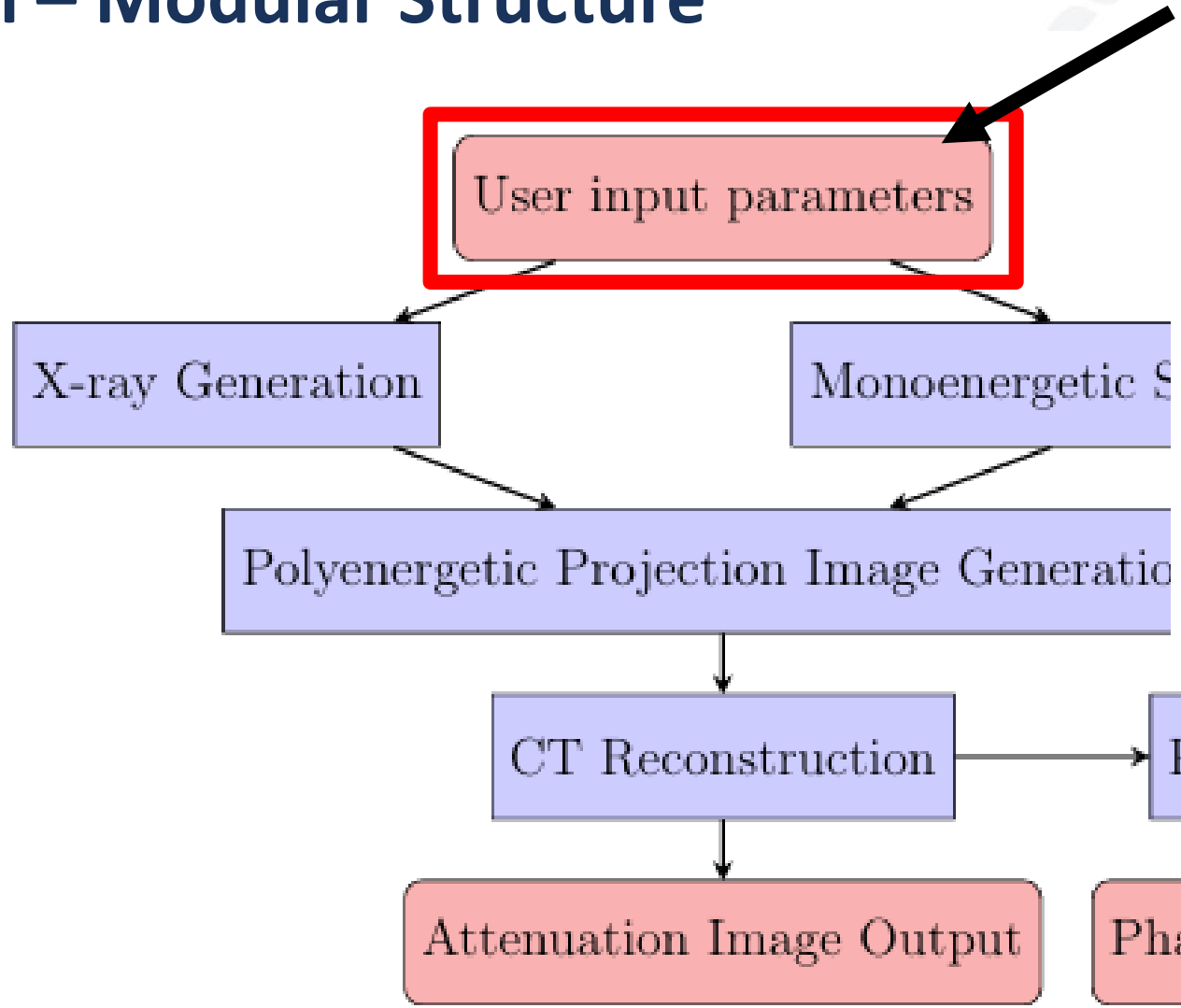
Solution: PEPIsim

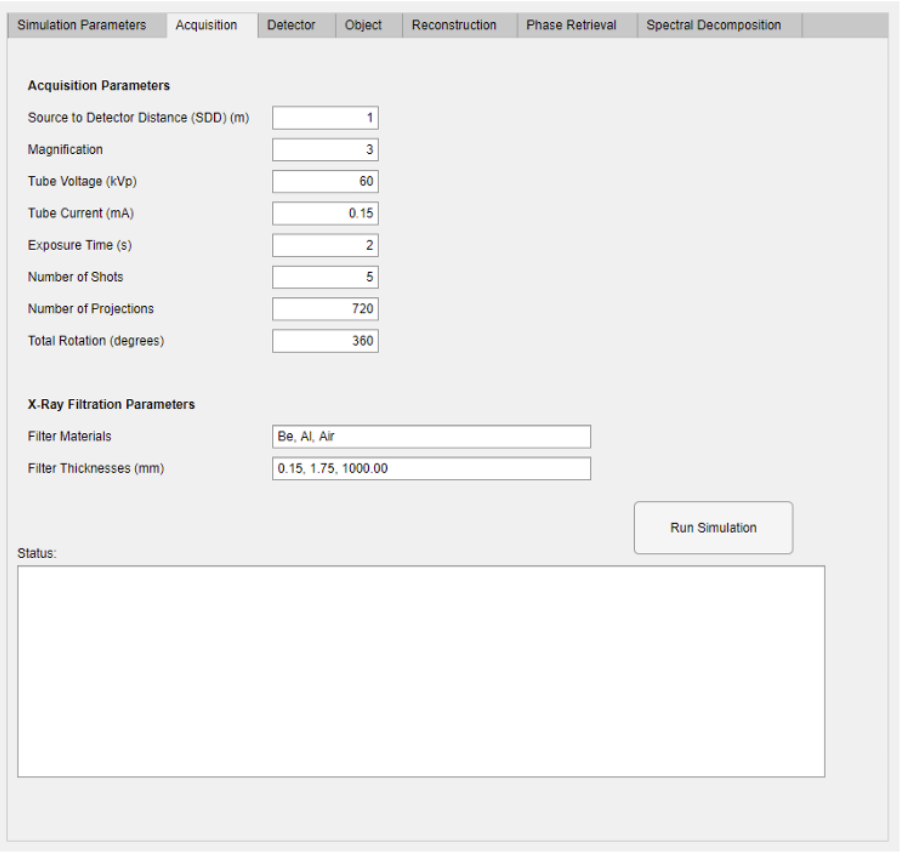
- PEPIsim is a new photon-counting, phase-contrast μCT simulation tool that combines these techniques
- Simulates the entire pipeline from photon-generation to CT reconstruction
- Developed in Matlab with modular structure
  - Can be adapted to other systems
- Features a user-friendly GUI
- Offers a near real-time *fast mode* which simulates the entire pipeline in < 20s

PEPIsim – Modular Structure

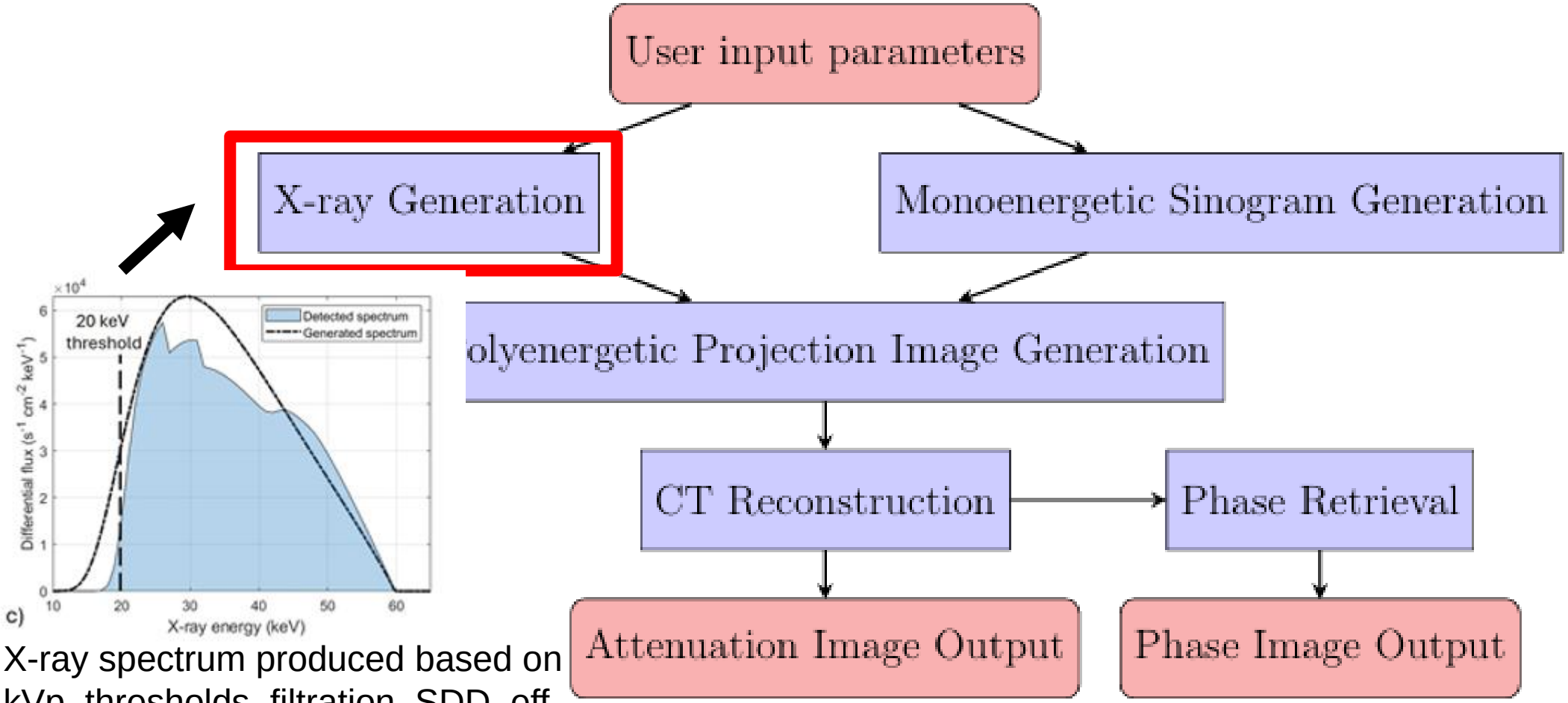


PEPIsim – Modular Structure



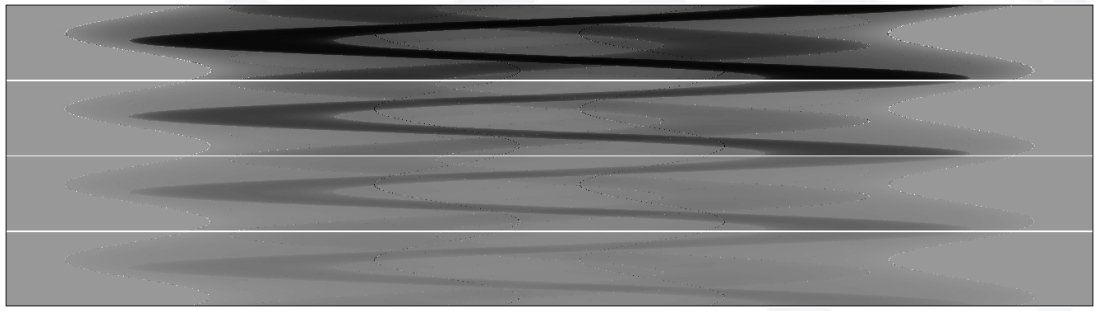


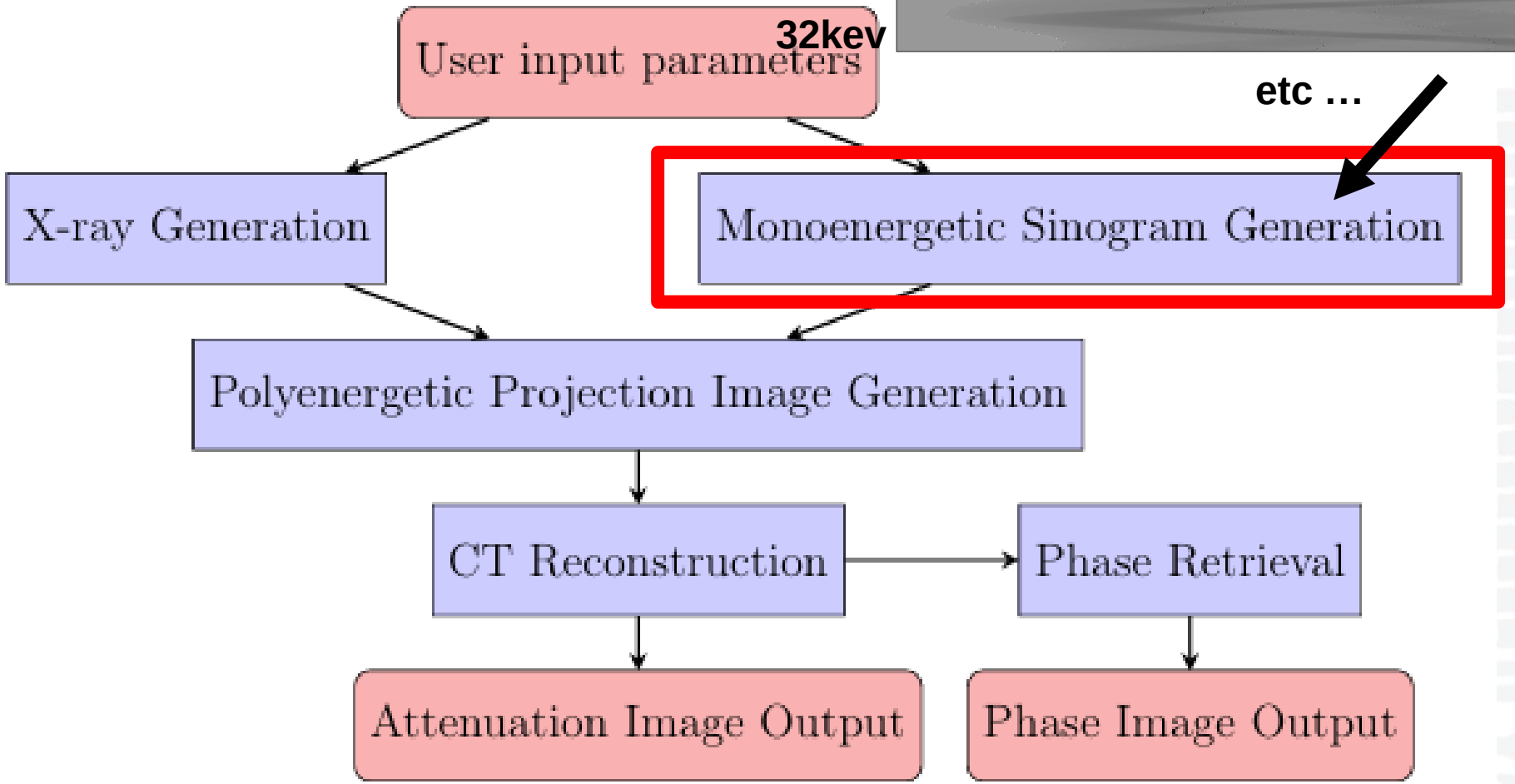
PEPIsim – Modular Structure



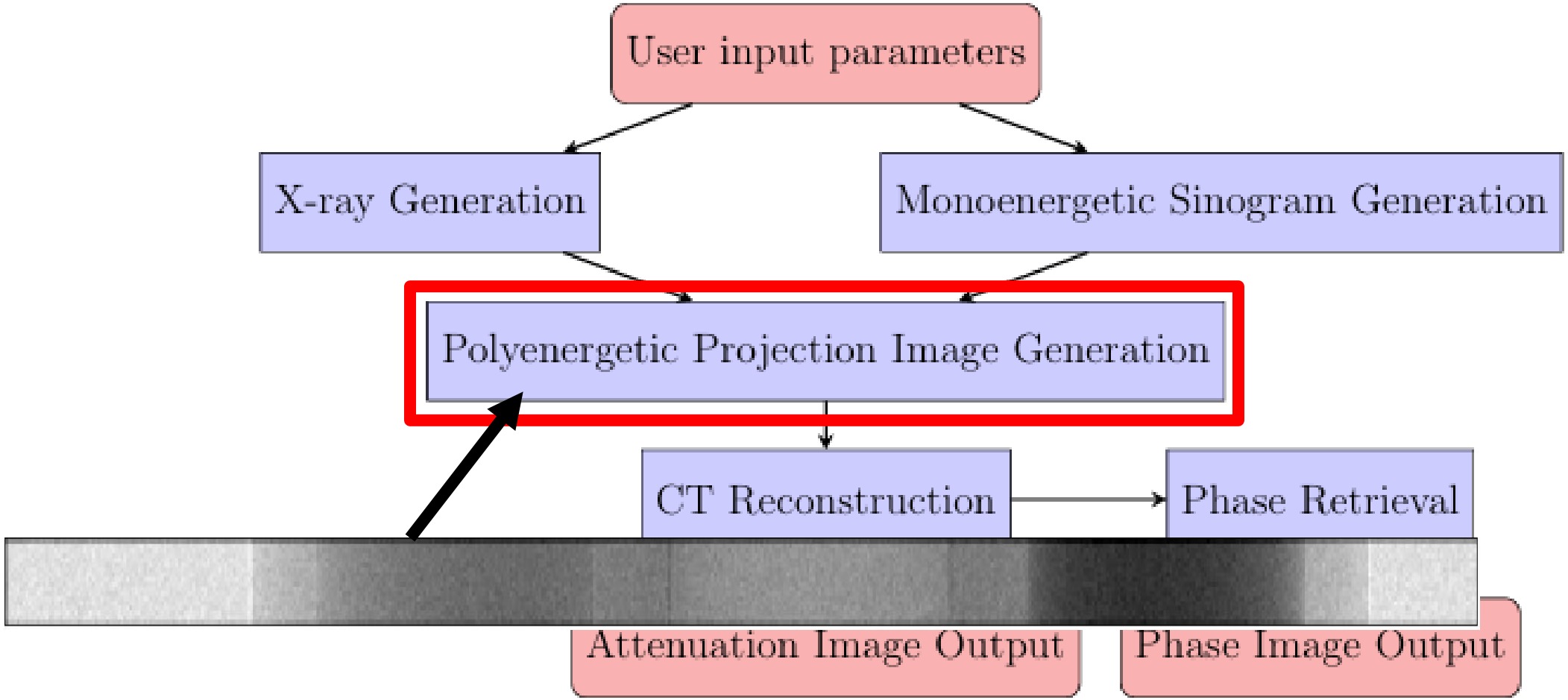
X-ray spectrum produced based on kVp, thresholds, filtration, SDD, eff pixel size

PEPIsim – Modular Structure





PEPIsim – Modular Structure



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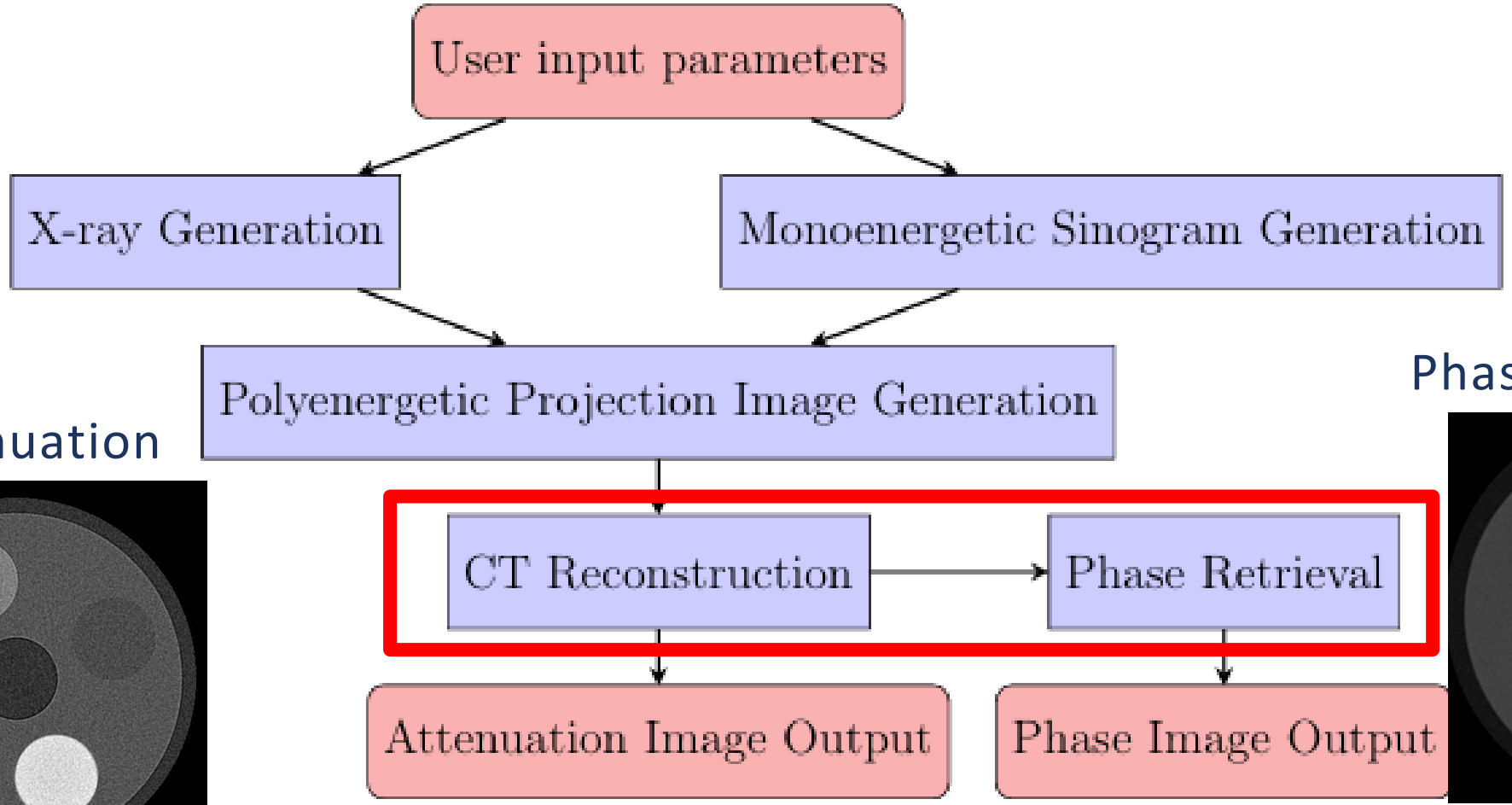
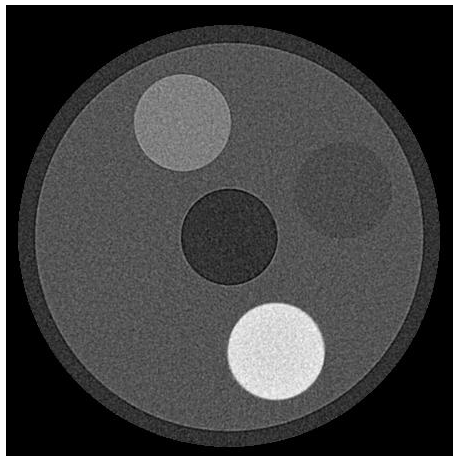
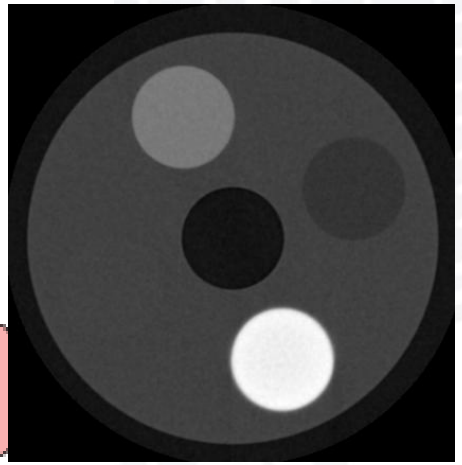


Attenuation



Phase-Retrieved



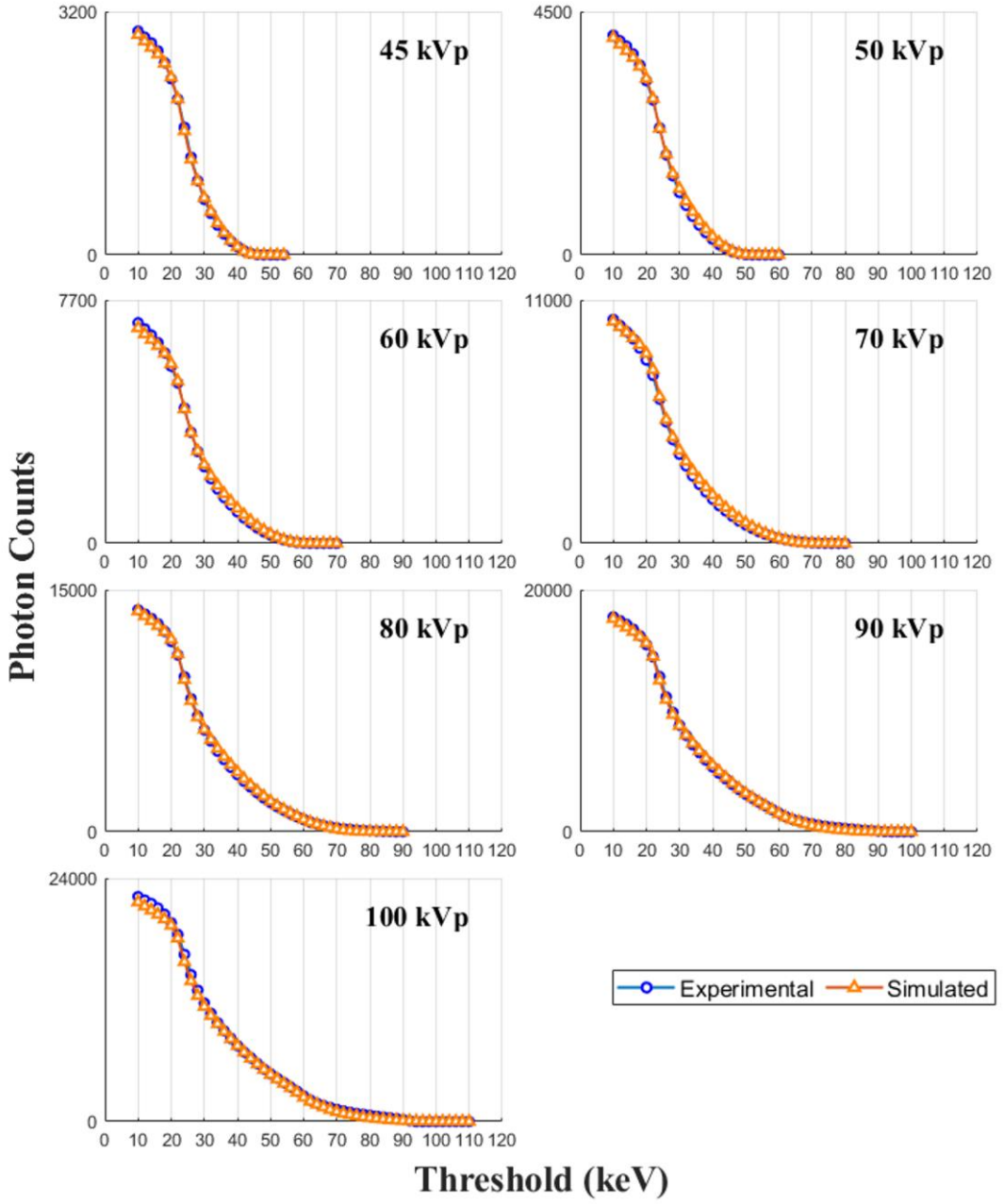
PEPIsim – Experimental Validation

- System Spectral Response Validation

- Imaging Validation – PEPIsim simulated µCT reconstructions compared against experimental µCT reconstructions for agreement in:
  - Attenuation value
  - Attenuation image SNR
  - Phase retrieved image SNR
  - Phase-induced edge-enhancement visibility

SYSTEM SPECTRAL RESPONSE VALIDATION

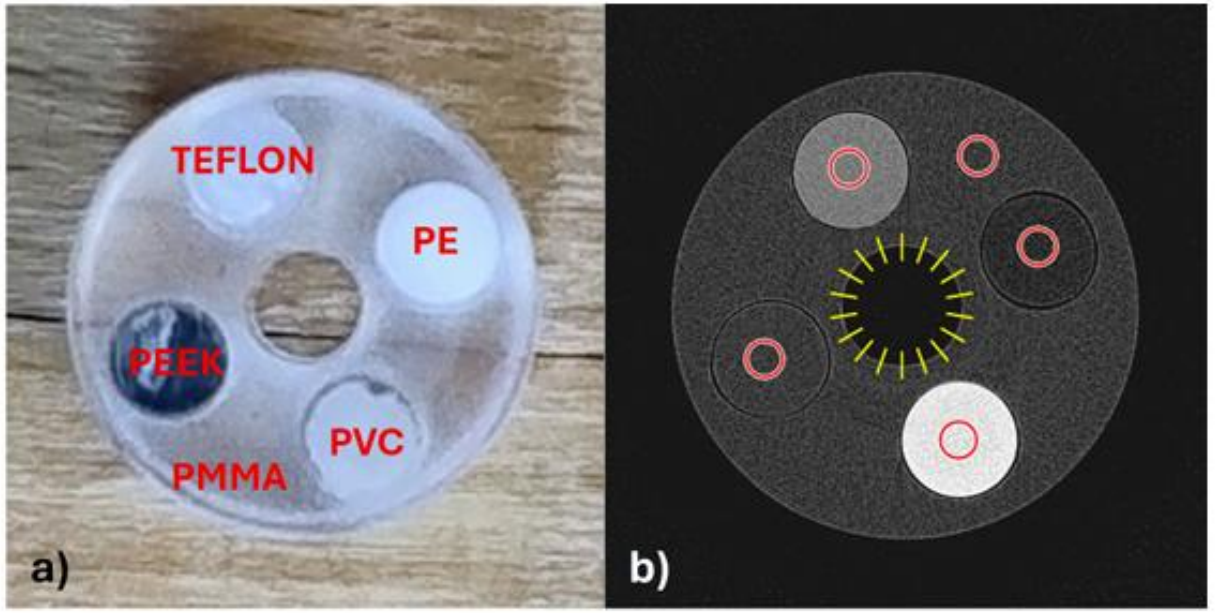
- A **detector threshold scan** validated the detector energy response and X-ray spectrum models
- Compared photon counts in flat field images
- **0.6% NRMSE** between the PEPIsim images and experimental images

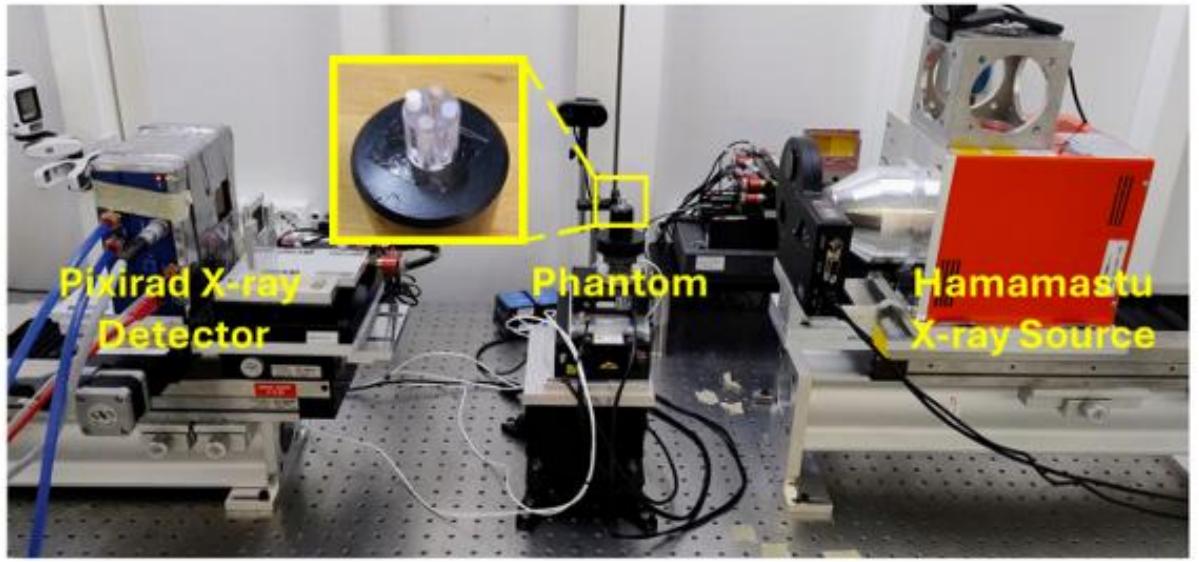


IMAGING VALIDATION

Validation analysis has been completed across different values of:

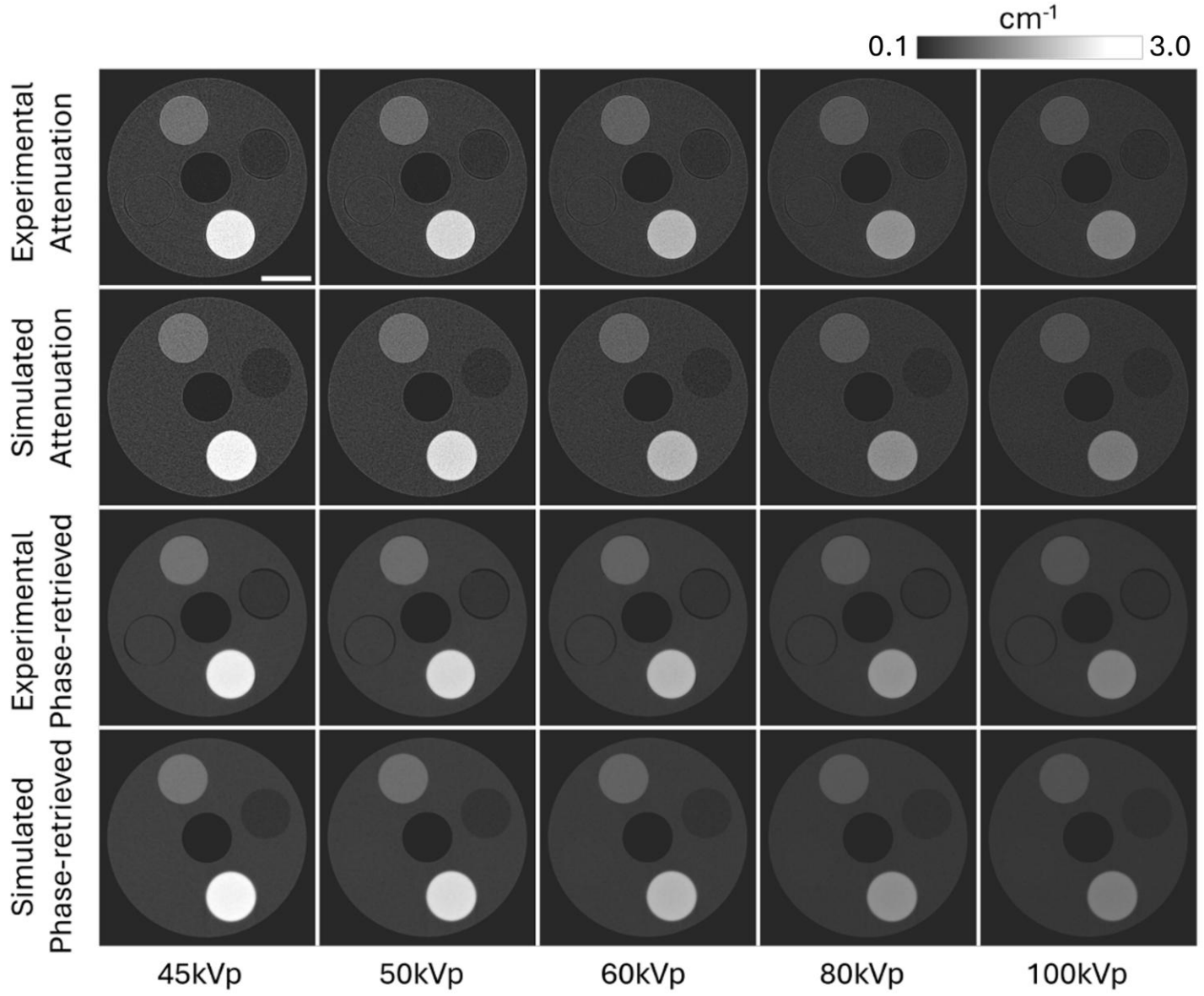
- kVp (45-100kVp)
- Magnification (1.3x – 3.7x)
- Source-Detector Distance (40cm-133cm)





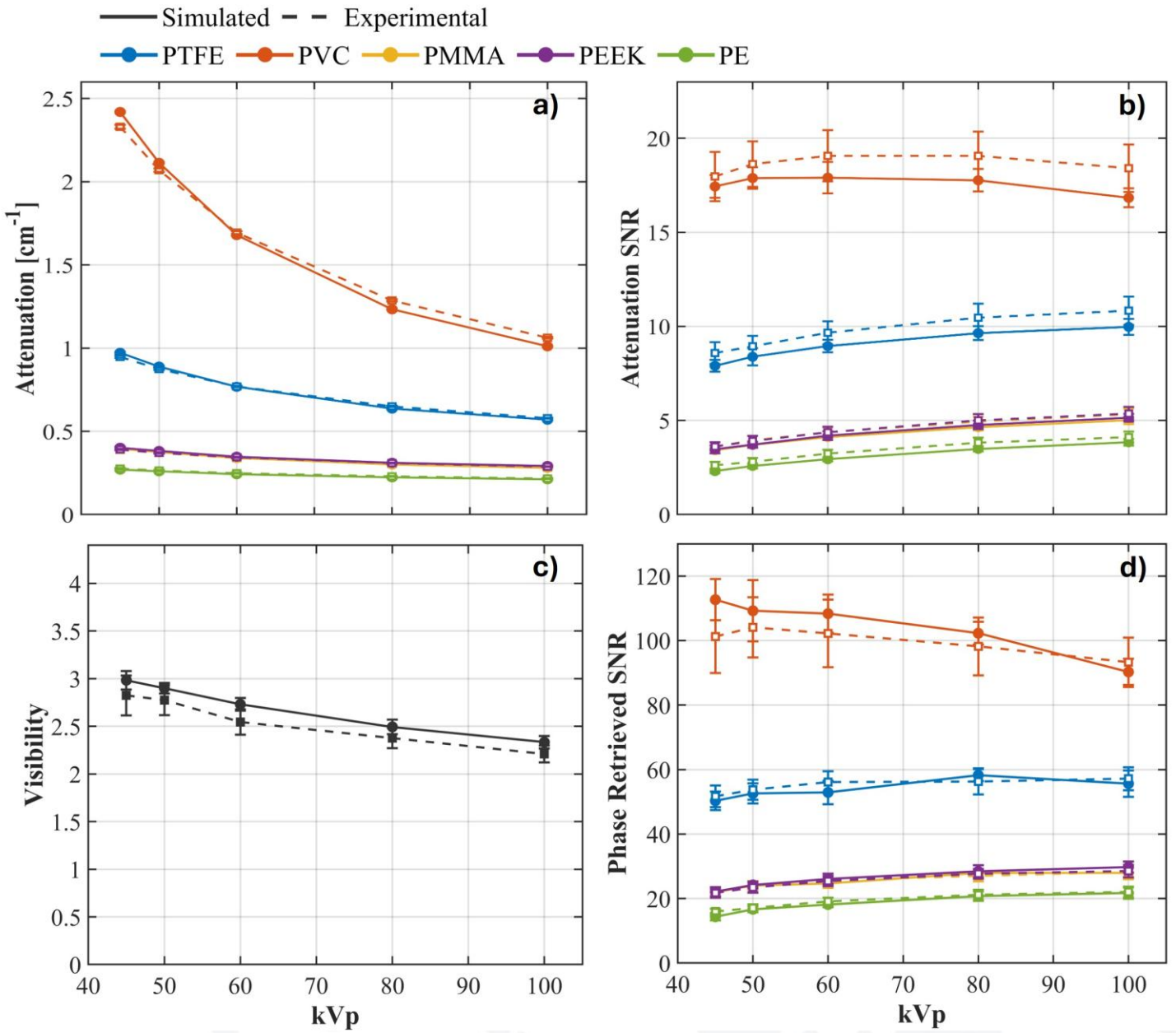
IMAGING VALIDATION KVP

- Good qualitative agreement
- Lower contrast at high kVp, but also lower noise



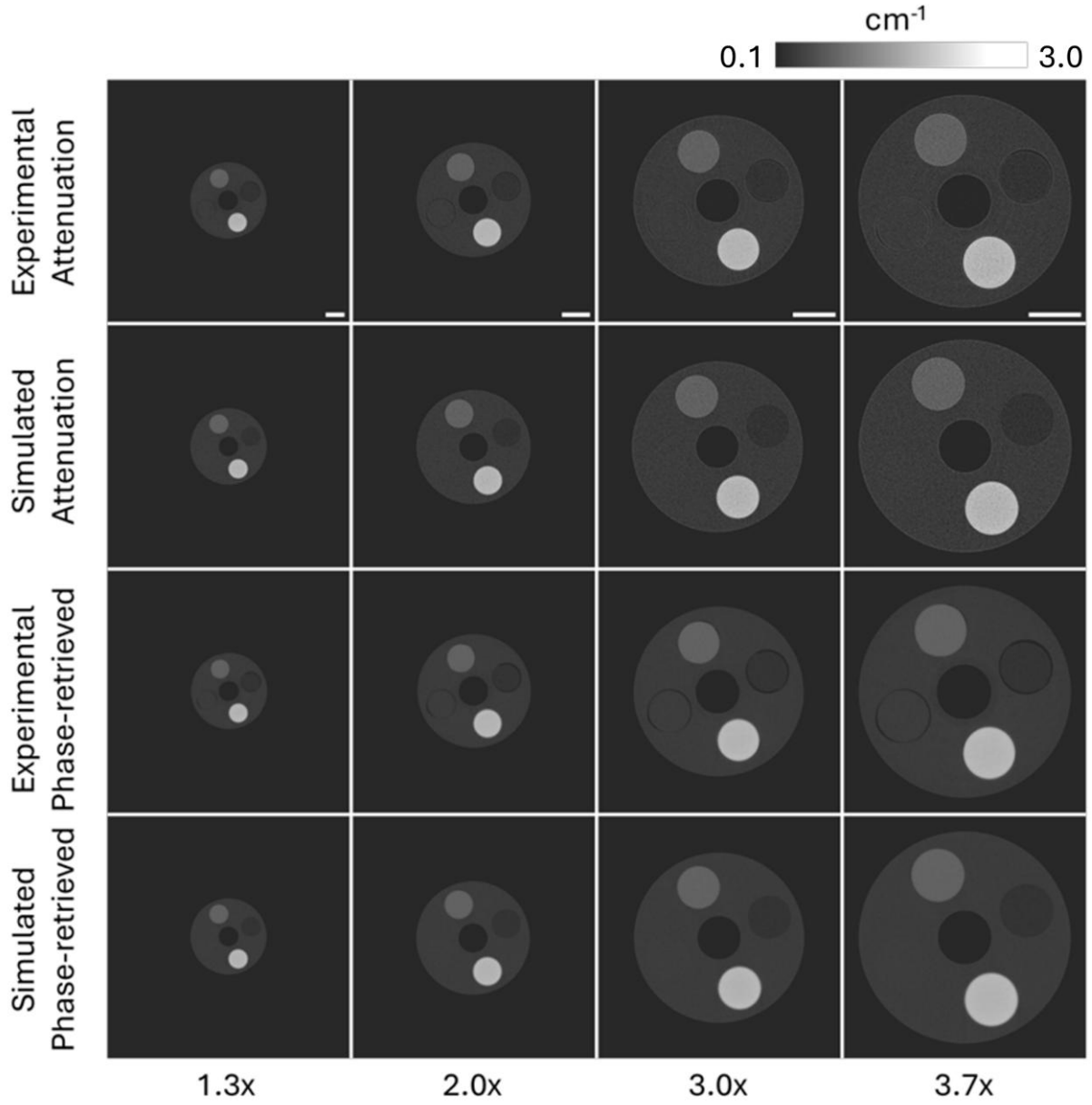
IMAGING VALIDATION KVP

- 1.6% rel error attenuation values
- 6.4% rel error attenuation SNR
- 3.7% rel error phase SNR
- 5.6% rel error fringes



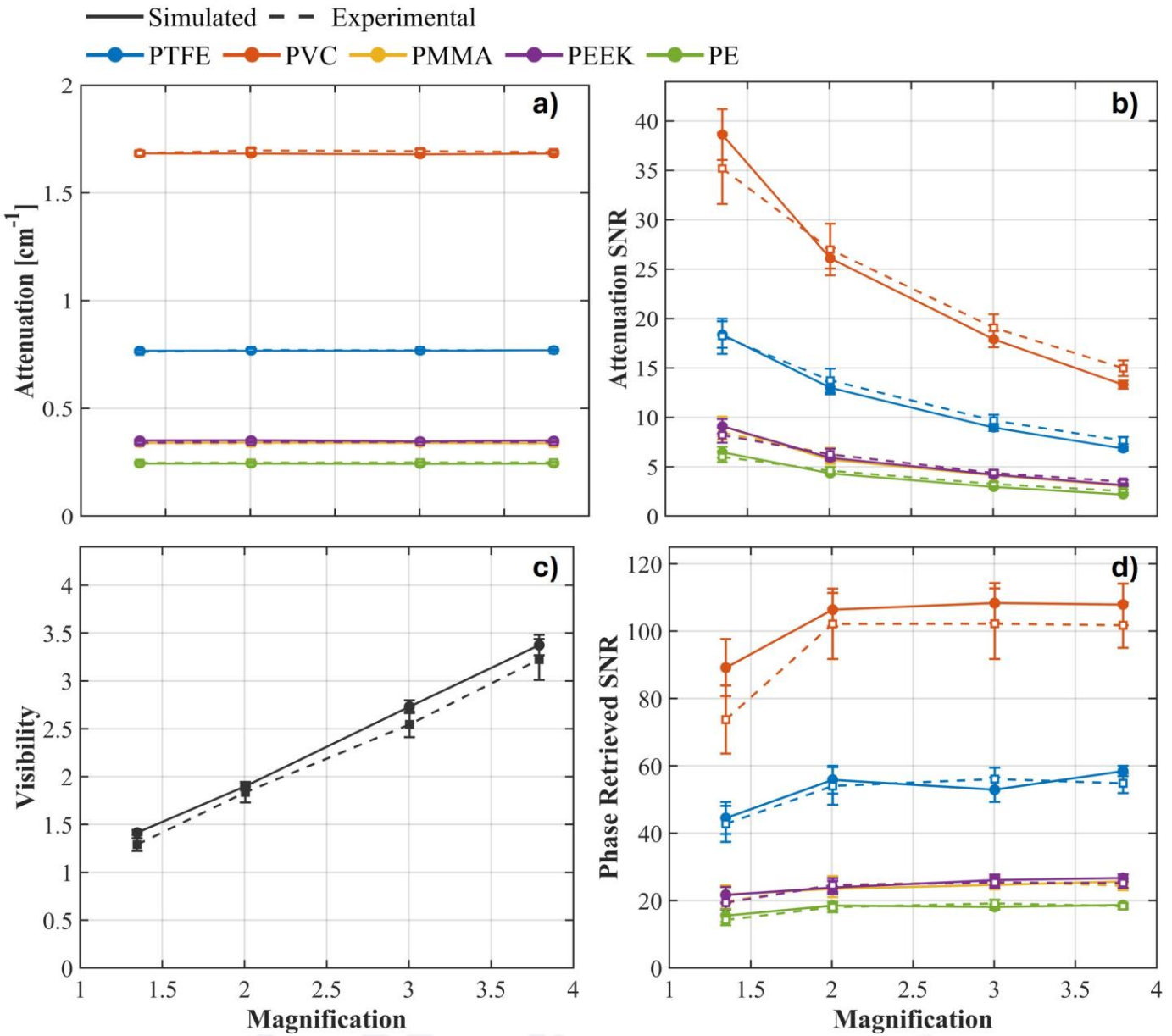
IMAGING VALIDATION MAGNIFICATION

- Good qualitative agreement
- More noise at large magnification
- More fringe visibility at large magnification



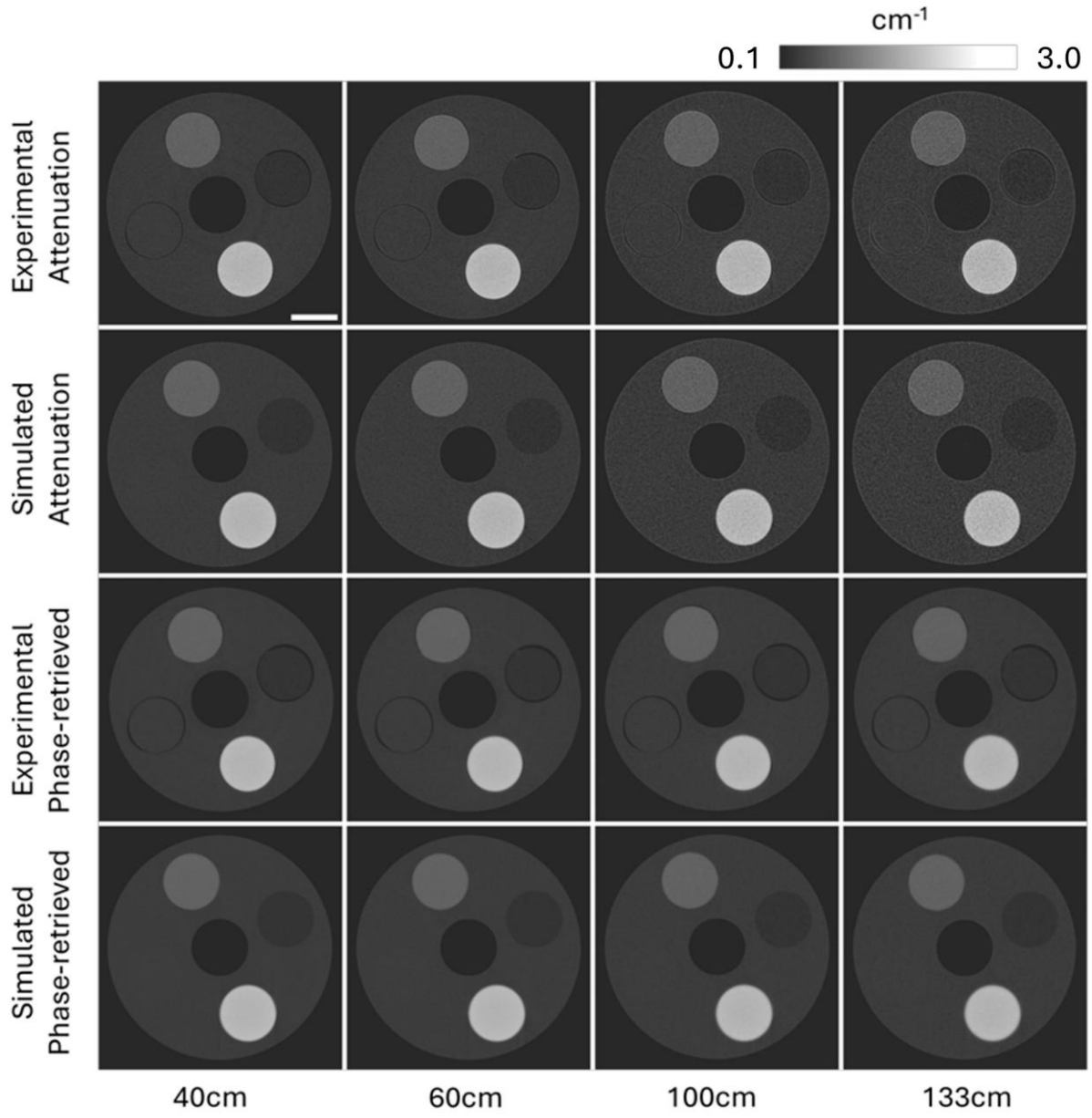
IMAGING VALIDATION MAGNIFICATION

- 1.1% rel error attenuation values
- 7.8% rel error attenuation SNR
- 6.1% rel error phase SNR
- 6.3% rel error fringes



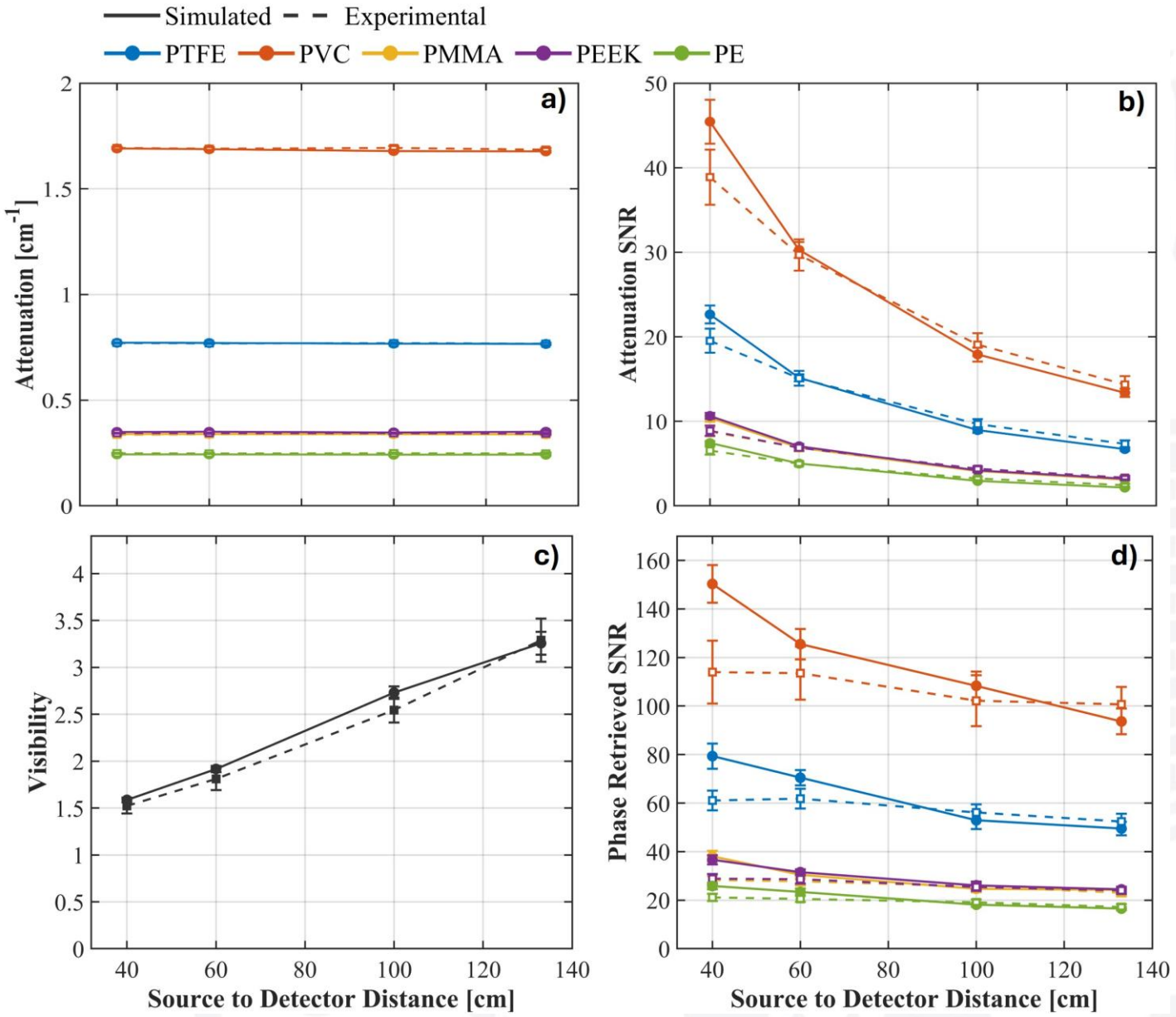
IMAGING VALIDATION SOURCE-DETECTOR DISTANCE

- Good qualitative agreement
- More noise at large distance
- More fringe visibility at large distance



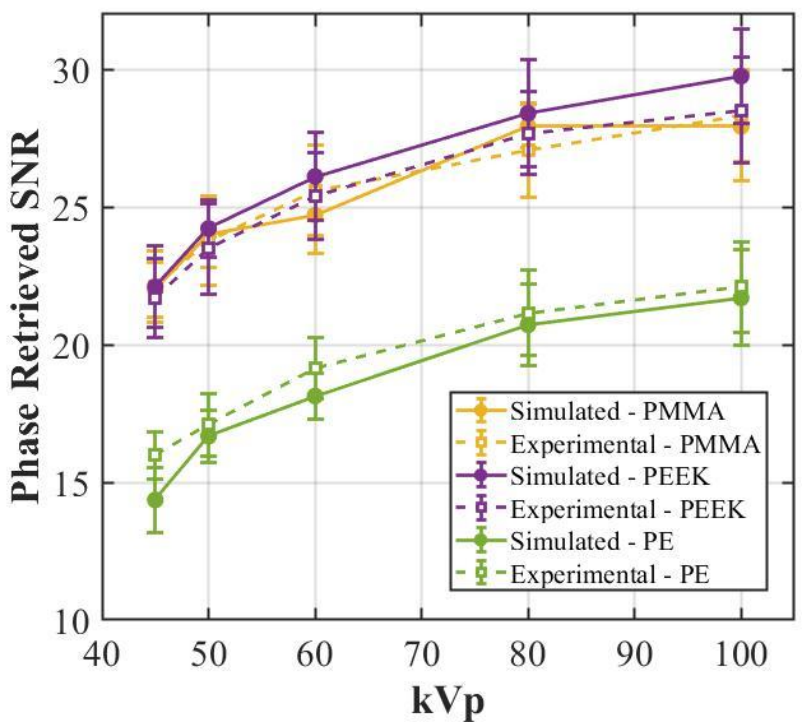
IMAGING VALIDATION SOURCE-DETECTOR DISTANCE

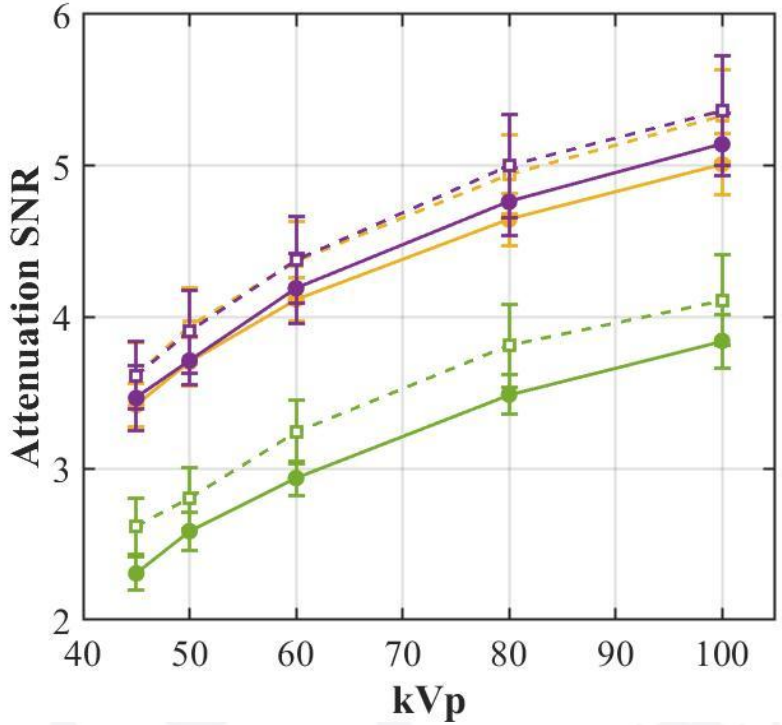
- 1.0% rel error attenuation values
- 5.1% rel error attenuation SNR (excluding 40cm)
- 6.9% rel error phase SNR (excluding 40cm)
- 4.6% rel error fringes



LOW-CONTRAST SNR

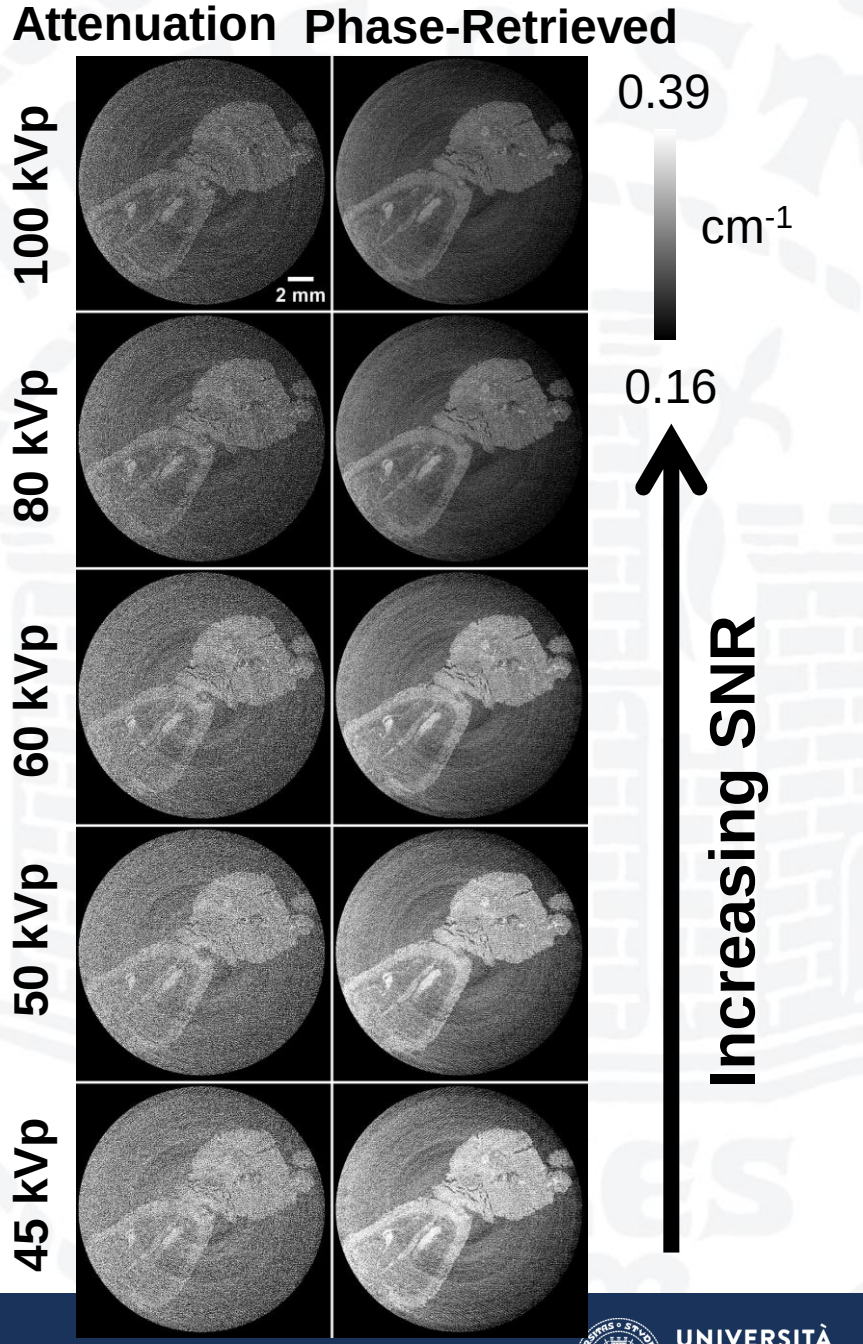
- One of the key applications for **PEPIsim** is in **the optimization of acquisition parameters** for different micro-CT samples
- An initial PEPIsim optimization reveals that **low-contrast SNR improves with higher x-ray tube voltages (kVp)** for constant x-ray tube power





BIOLOGICAL SAMPLE OPTIMIZATION

- A micro-CT of a **pedunculated polyp with adenocarcinoma**
- SNR was found to **improve by 30%** when using higher kVp values (80, 100) compared to lower kVp values (45,50,60)
- This result is **important for micro-CT parameter selection** with low-contrast samples – it is contrary to traditional parameter selection where low kVp values are naively employed to improve intrinsic contrast



SUMMARY

- PEPIsim is a new simulation tool for X-ray phase-contrast micro-CT using small-pixel (<100μm), photon-counting (spectral) detectors
- PEPIsim has been validated for both the accuracy of its spectral response and its image quality across various metrics
- PEPIsim will be employed to develop optimized imaging protocols for different types of samples

THANK YOU!

Andrew Coathup (University of Trieste, INFN Trieste)

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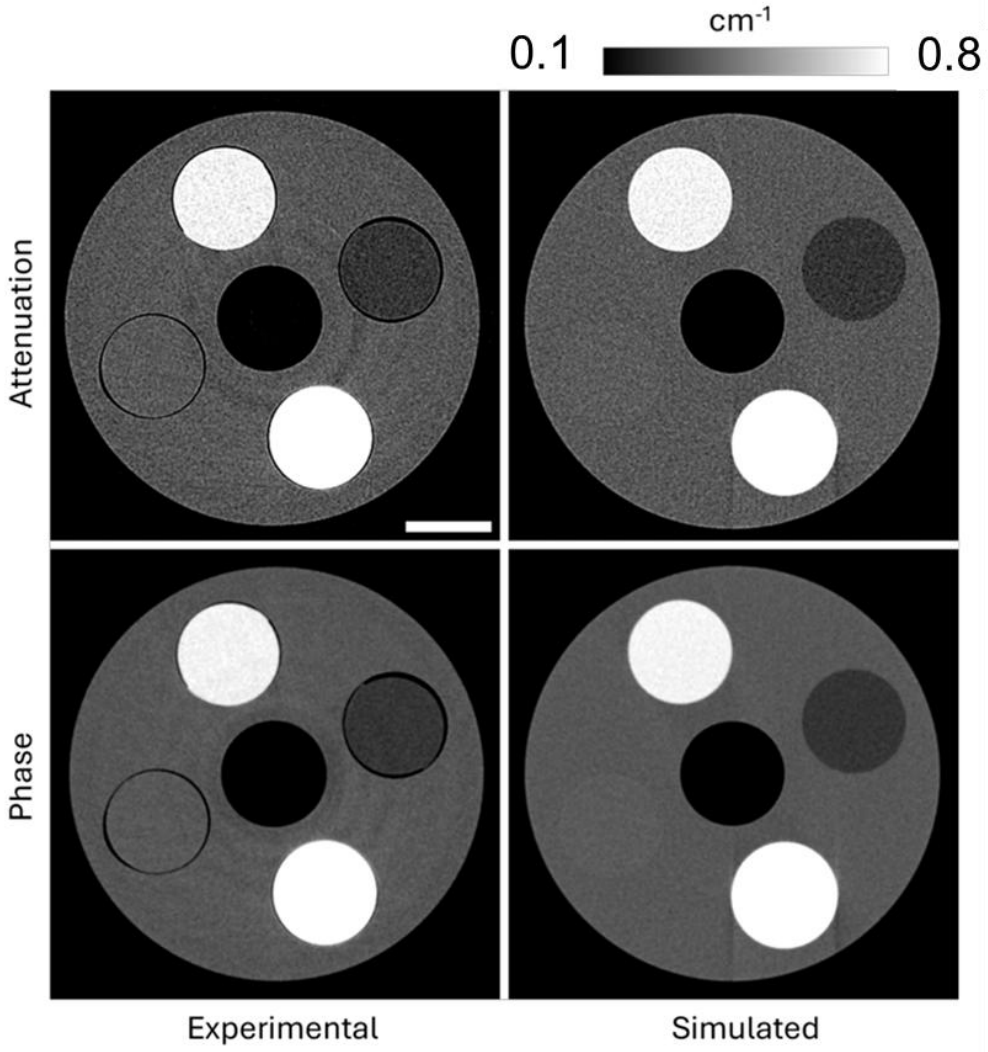
Simone Velardita (INFN Ferrara)

Angelo Taibi (INFN Ferrara, University of Ferrara)

Luca Brombal (University of Trieste, INFN Trieste)


cm-1
0.1
0.8
Attenuation
Phase
Experimental
Simulated