DHS Applications of PaX Source

Rajiv Gupta, MD, PhD

Neuro and Cardiac Radiology
Massachusetts General Hospital
Harvard Medical School
Boston, MA

Why should DHS Care?

- X-ray phase provides an independent signature:
  - Attenuation: Eff. Z
  - Phase: Eff. ED
- Threats and stream-of-commerce may have different signatures
- MGH/MIT PaX source enables PCI

Overview

What is Phase Contrast Imaging?

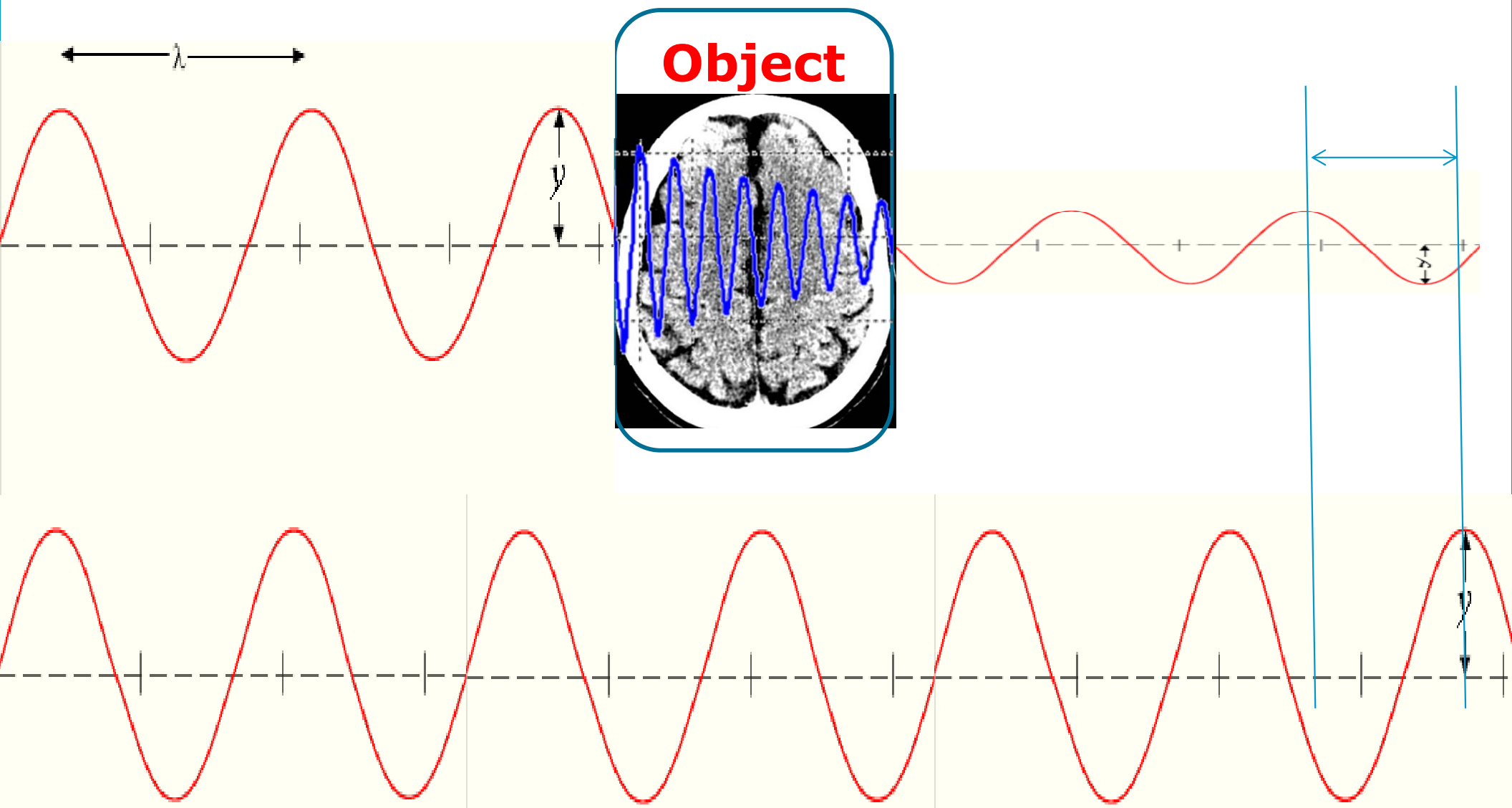
Is there experimental demonstration?

How can we harvest phase?

How can we achieve coherence?

How does PaX do PCI?

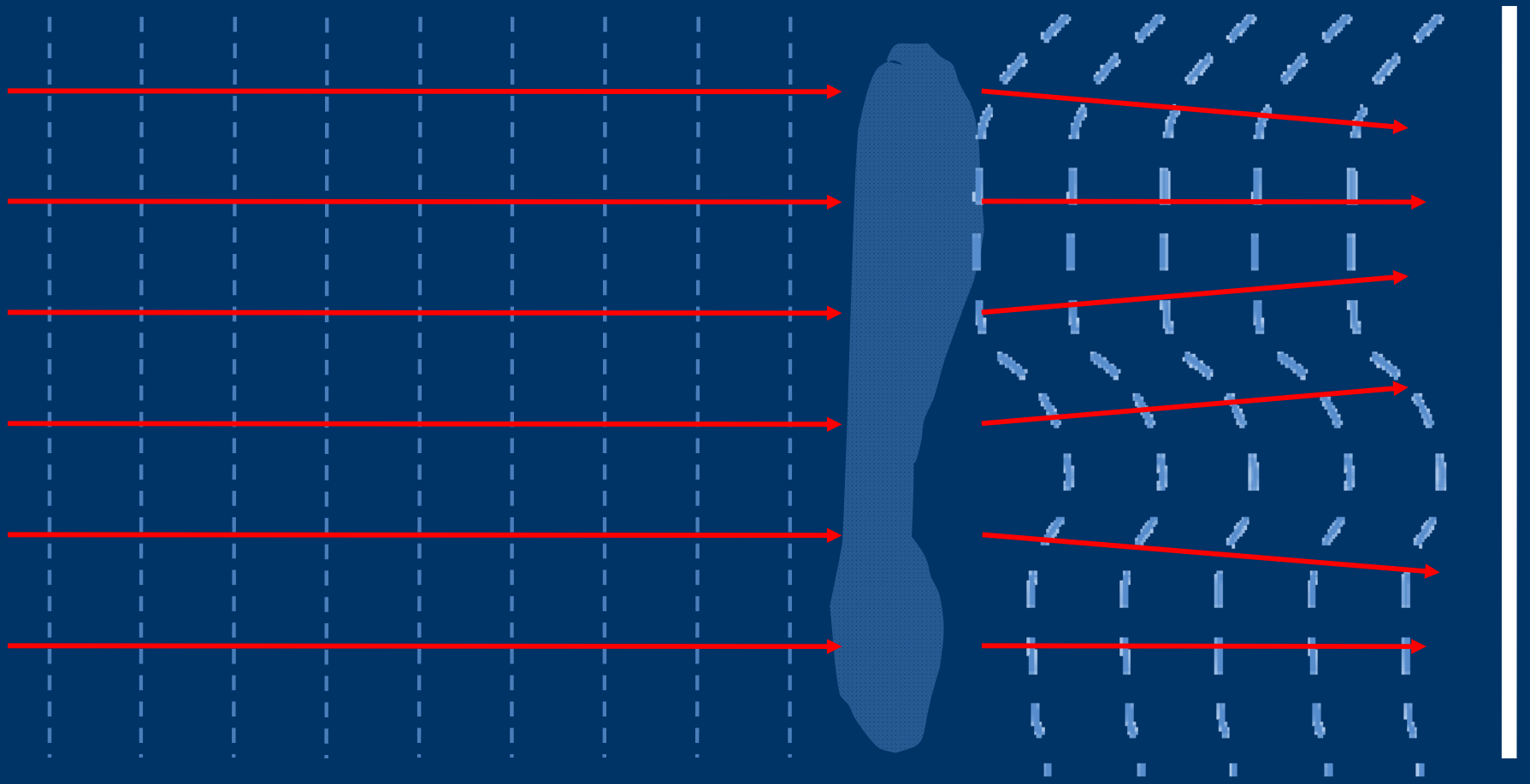
What is Phase Contrast Imaging?



X-rays Wave: Amplitude, frequency, and phase

Phase Effect on Wave front

Complex refractive index: $\eta = 1 - \delta + i\beta$



Contrast Mechanisms

Complex refractive index:

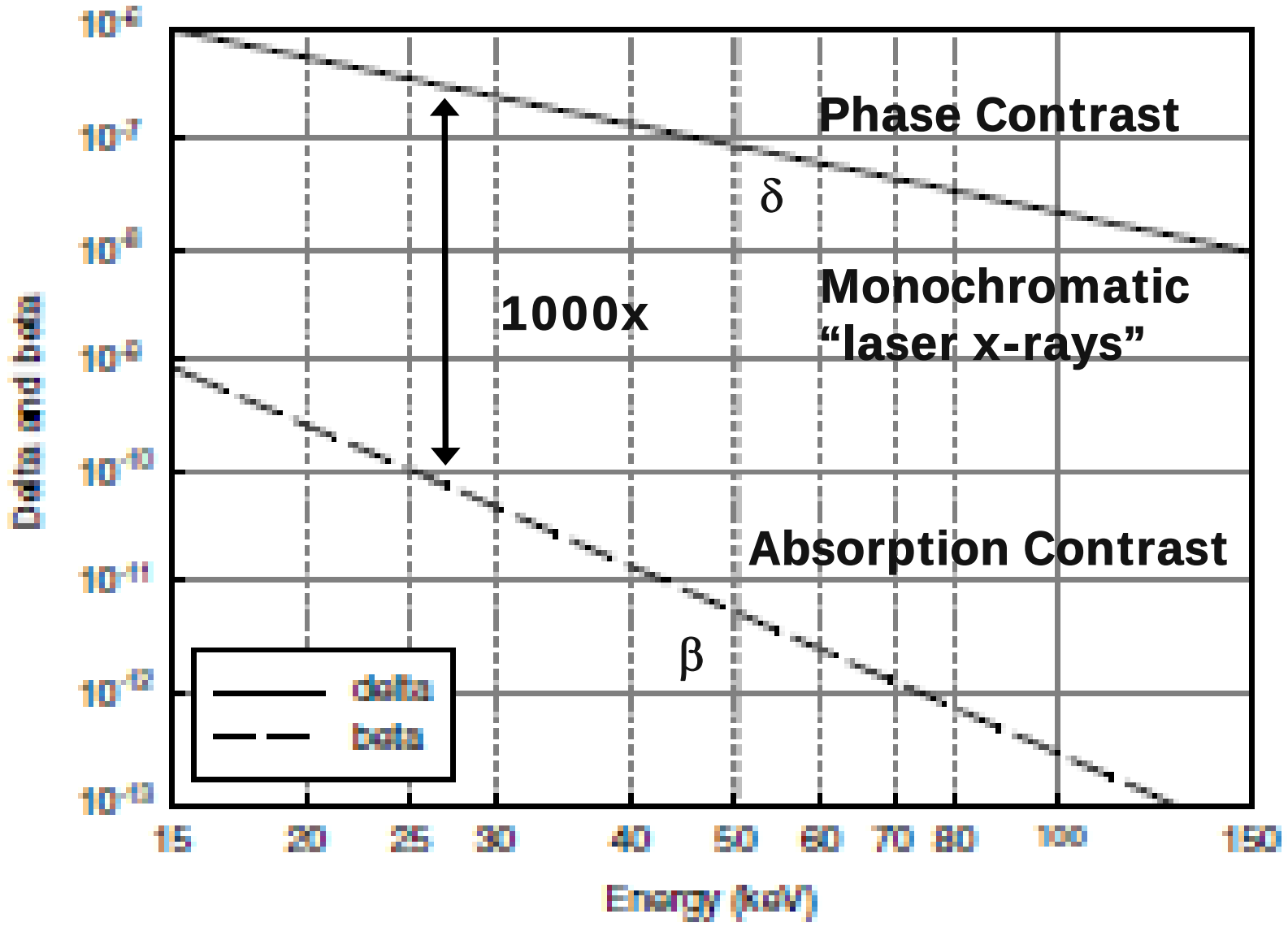
$$\eta = i\beta + (1 - \delta)$$

- Attenuation:
  - Depends on β
  - Path length
  - Photoelectric effect
  - Compton scattering
  - Depends on *Z*
- Phase change:
  - Depends on *δ*
  - Path length
  - Depends on Electron Density

Magnitude of Attenuation and Phase Contrasts

Material	μ (cm^{-1}) at 60keV	Φ (cm^{-1}) at 60keV	Ratio
H2O	0.2061	195.5	949
dH2O	0.2267	215.1	949
Ethenol	0.1582	156.6	990
Glycerin	0.2477	140.7	568
Fat	0.1793	180.7	1008
Liver	0.2174	205.2	944
Sources:			
ICRP (1975)			
Woodard and White (1986)			

Attenuation vs. Phase Contrast



Refractive index of soft tissue

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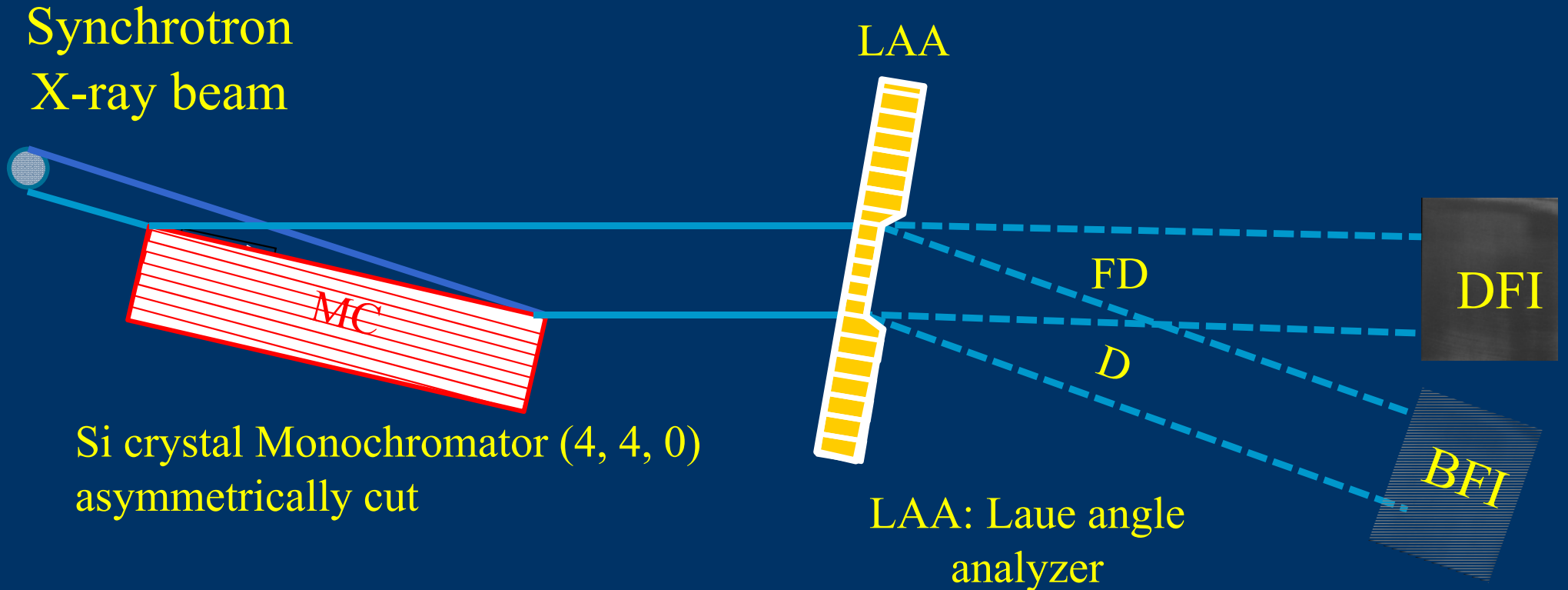
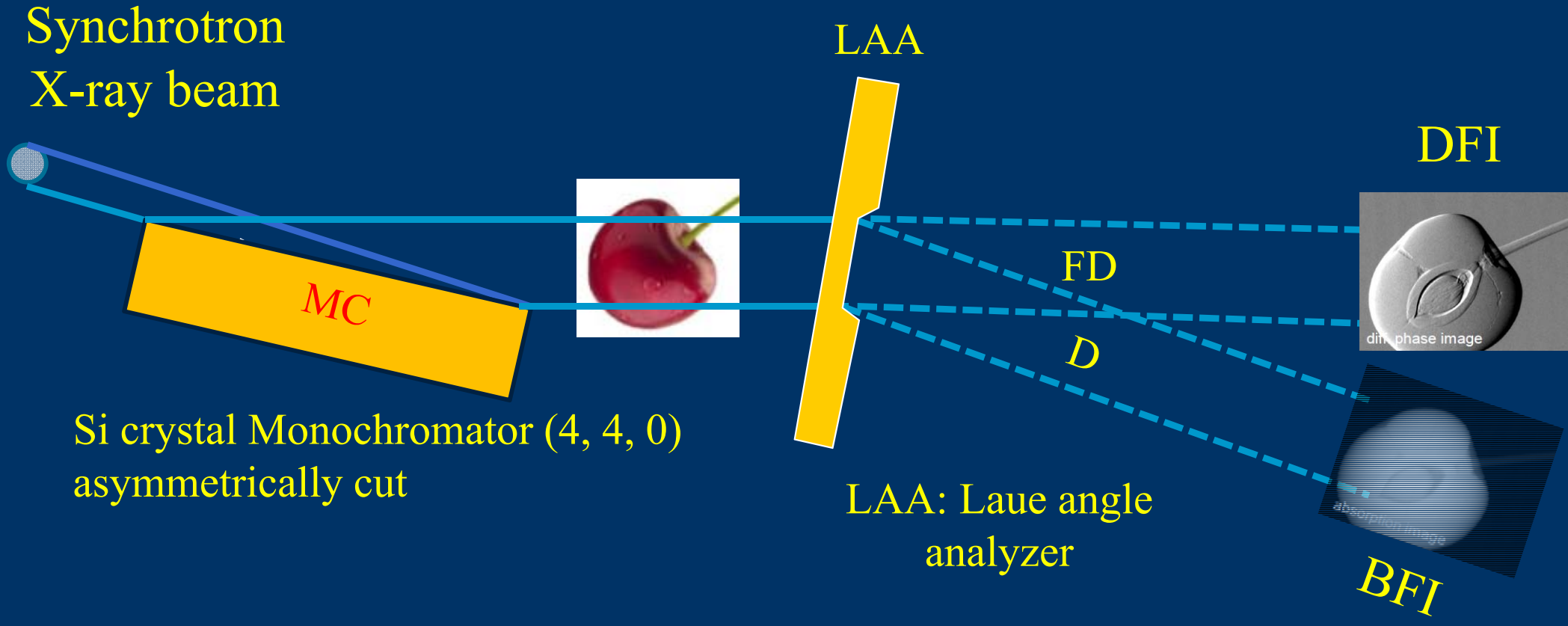
PCI at Photon Factory, KEK Tsukuba

- Beam-line BL-14Cmono
- Vertically polarized 31KeV X-ray beam
- Filed-of-view: 2.5x3cm
- Rotational stage for the specimen

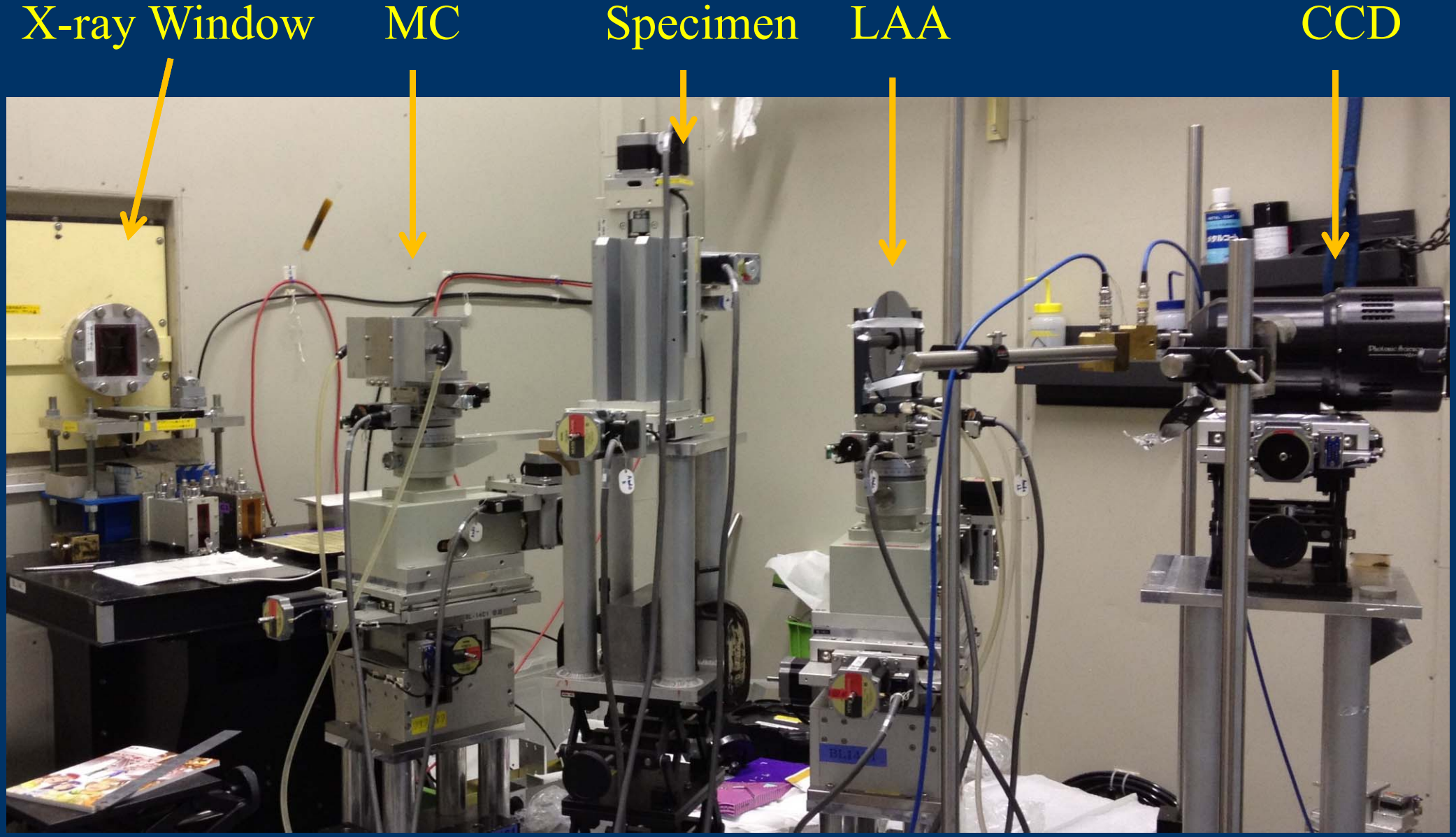
XDFI: X-ray Dark-Field Imaging



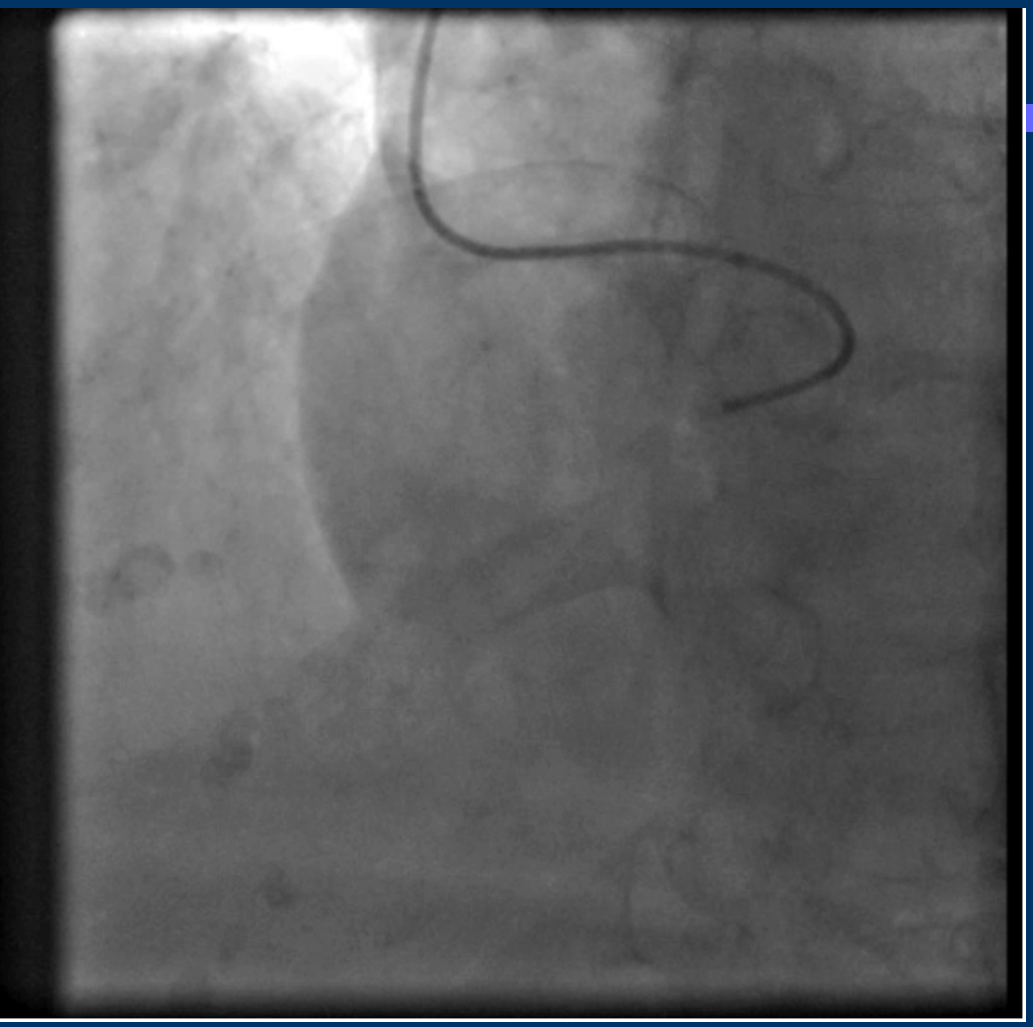
XDFI: X-ray Dark-Field Imaging



Experimental Setup



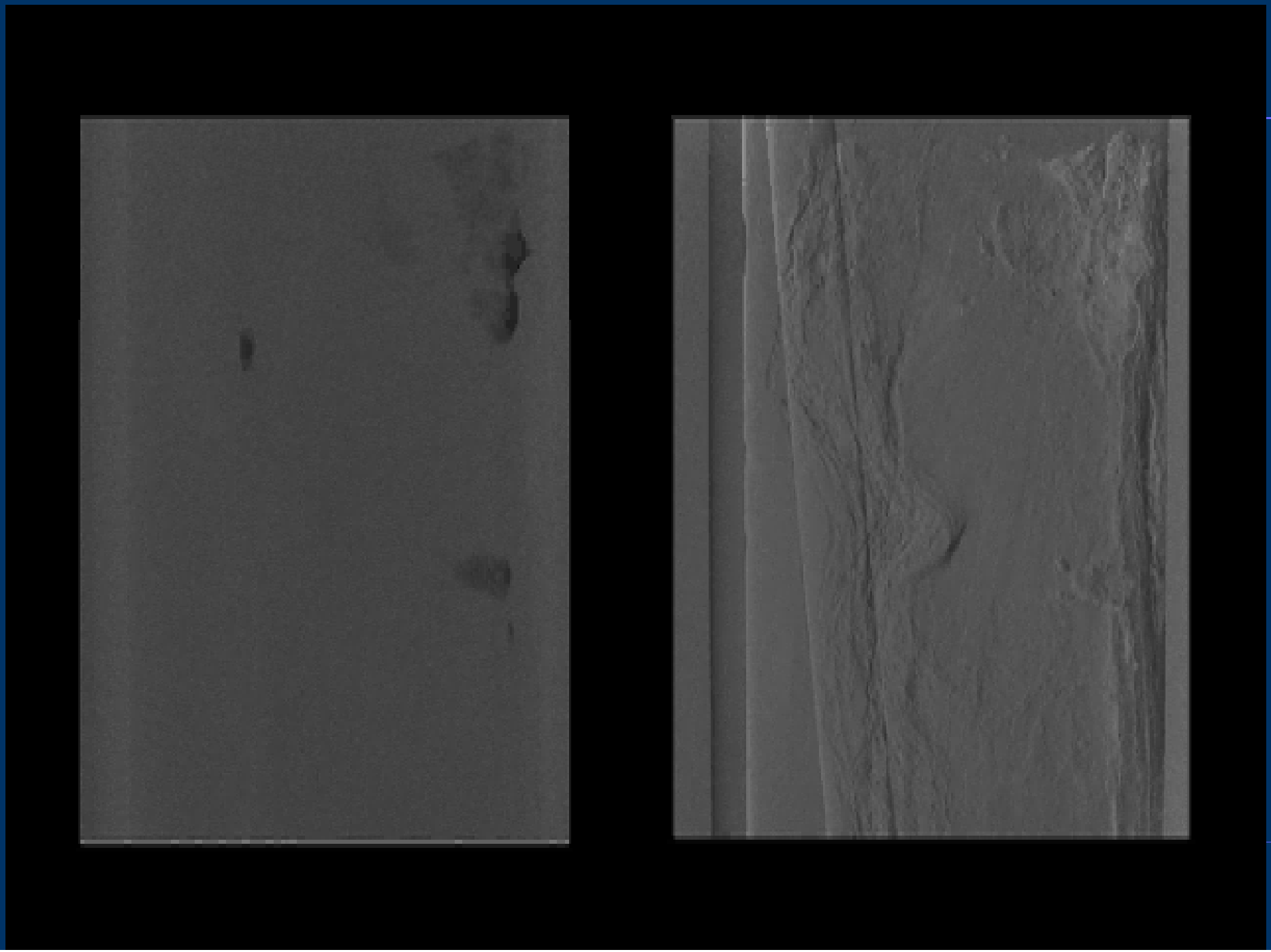
Coronary Plaque Imaging



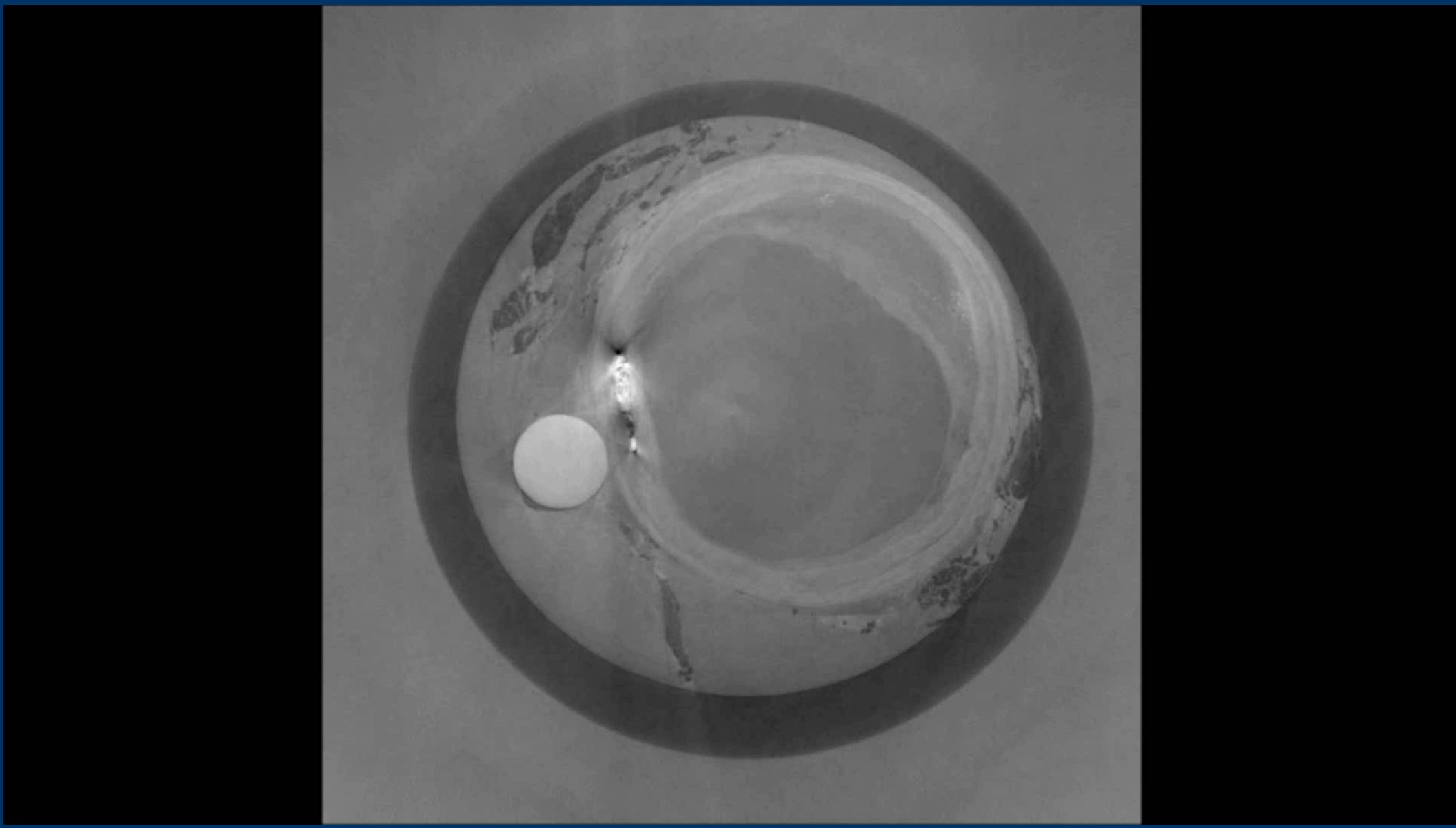
Catheter Angiography:
LAO cranial view

CT Angiography:
LAD, LCX and RCA

Plaque: Absorption and Phase



Plaque: Phase CT



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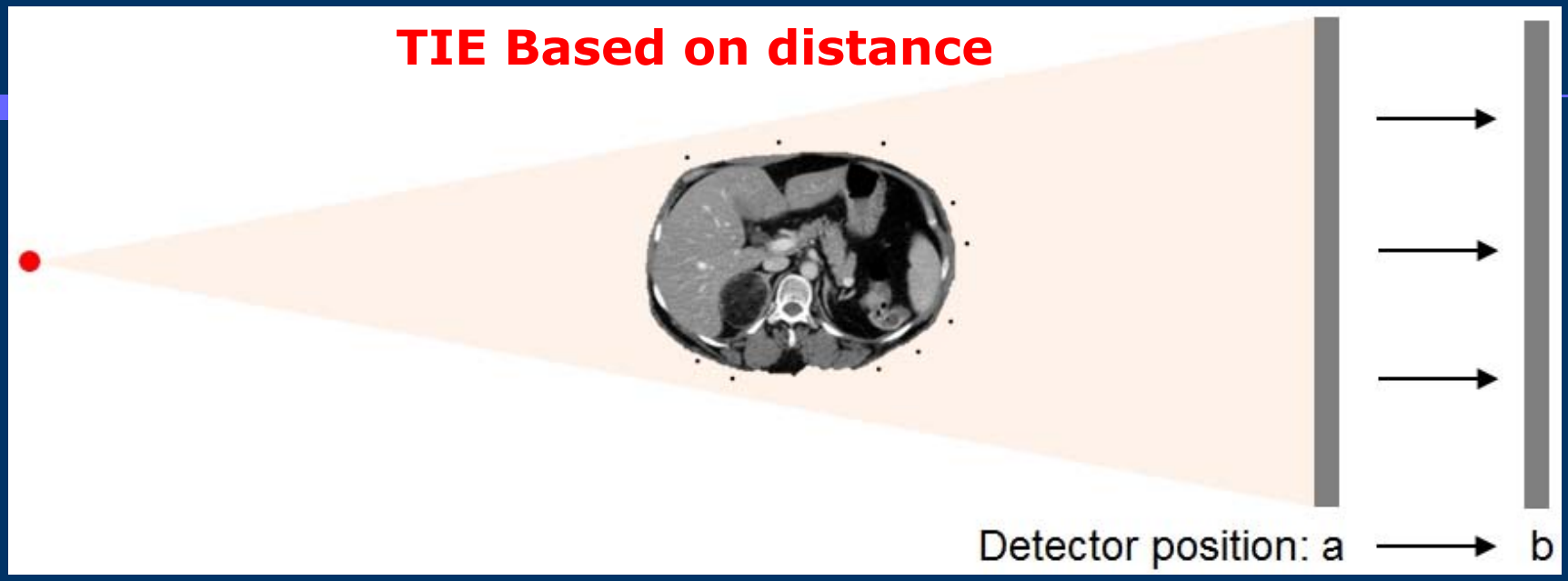
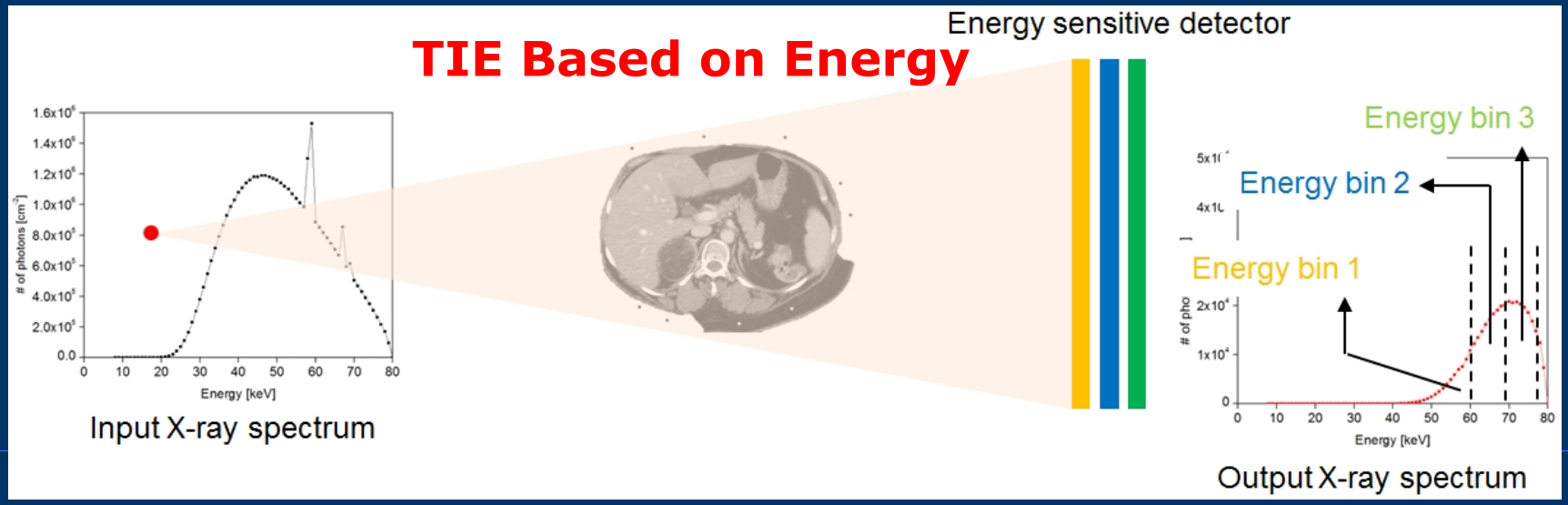
TIE-based PCI imaging





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What is Phase Contrast Imaging?

Experimental demonstration of PCI

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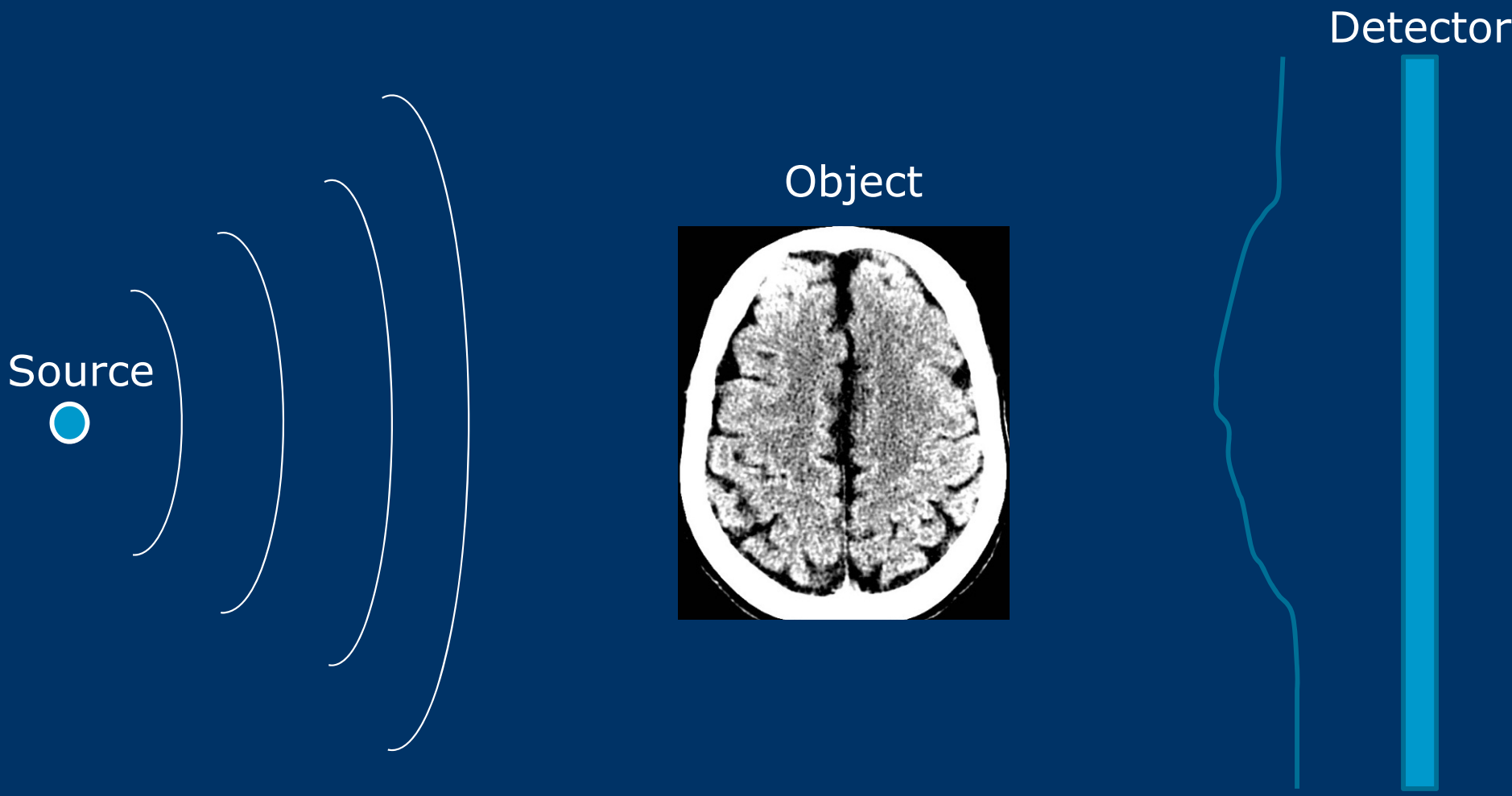
PaX Architecture

MGH/MIT PaX Source: Basic Concept



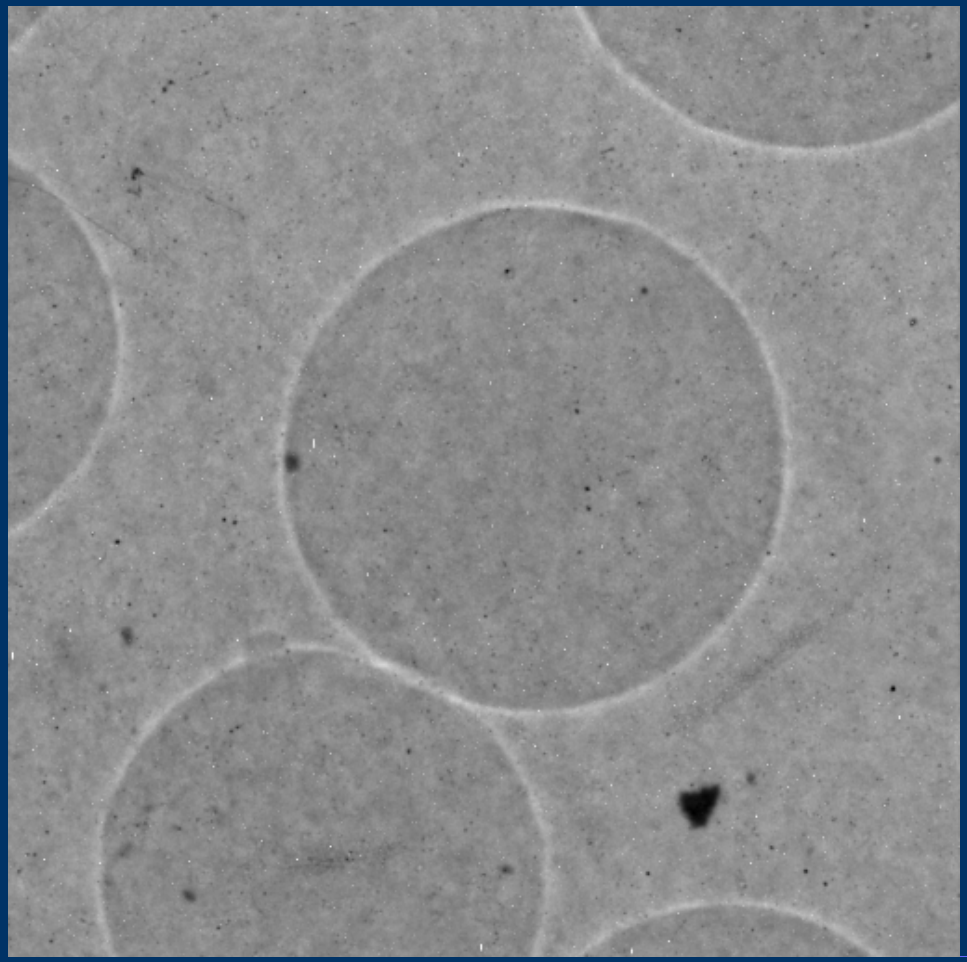
Trick 1: Use ultra-small focal spot size for x-ray

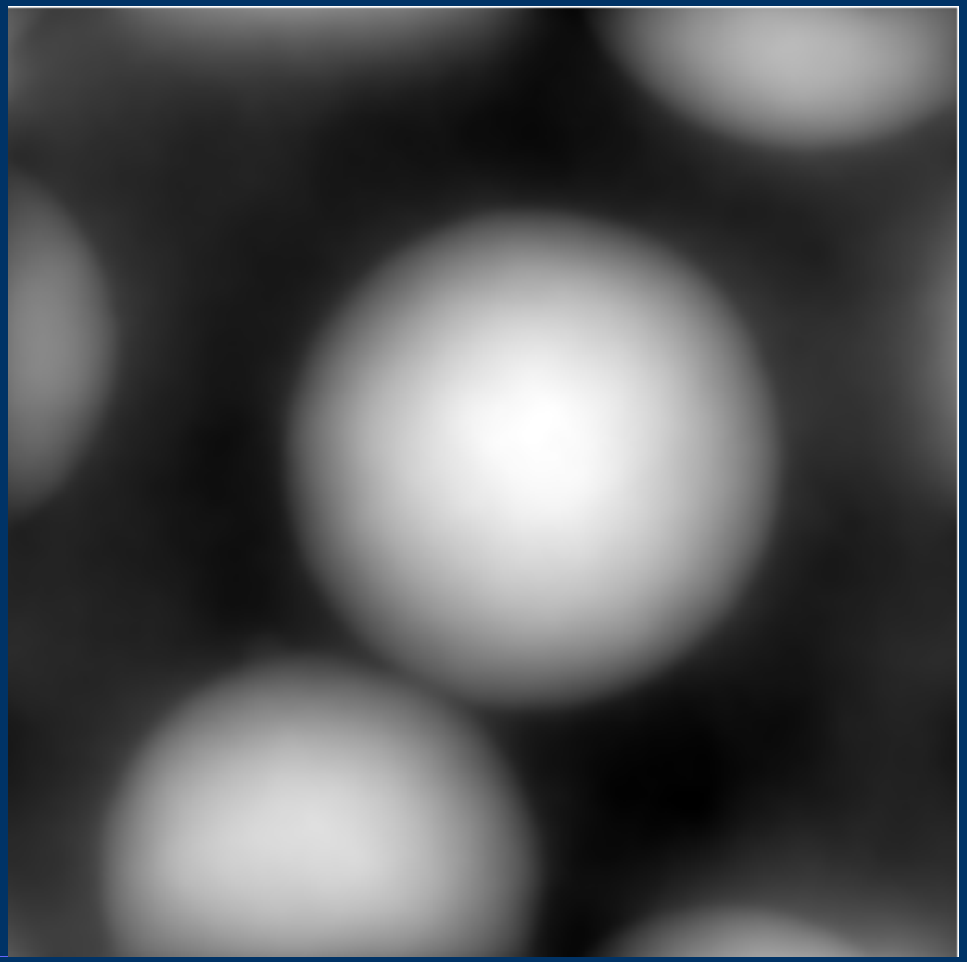
Trick 2: Keep the object far away from the source, and the detector far away from the object

Trick 3: Deduce phase from intensity images

Experimental results

Plastic microspheres (Cospheric, Inc):





Projection image

Reconstructed phase image

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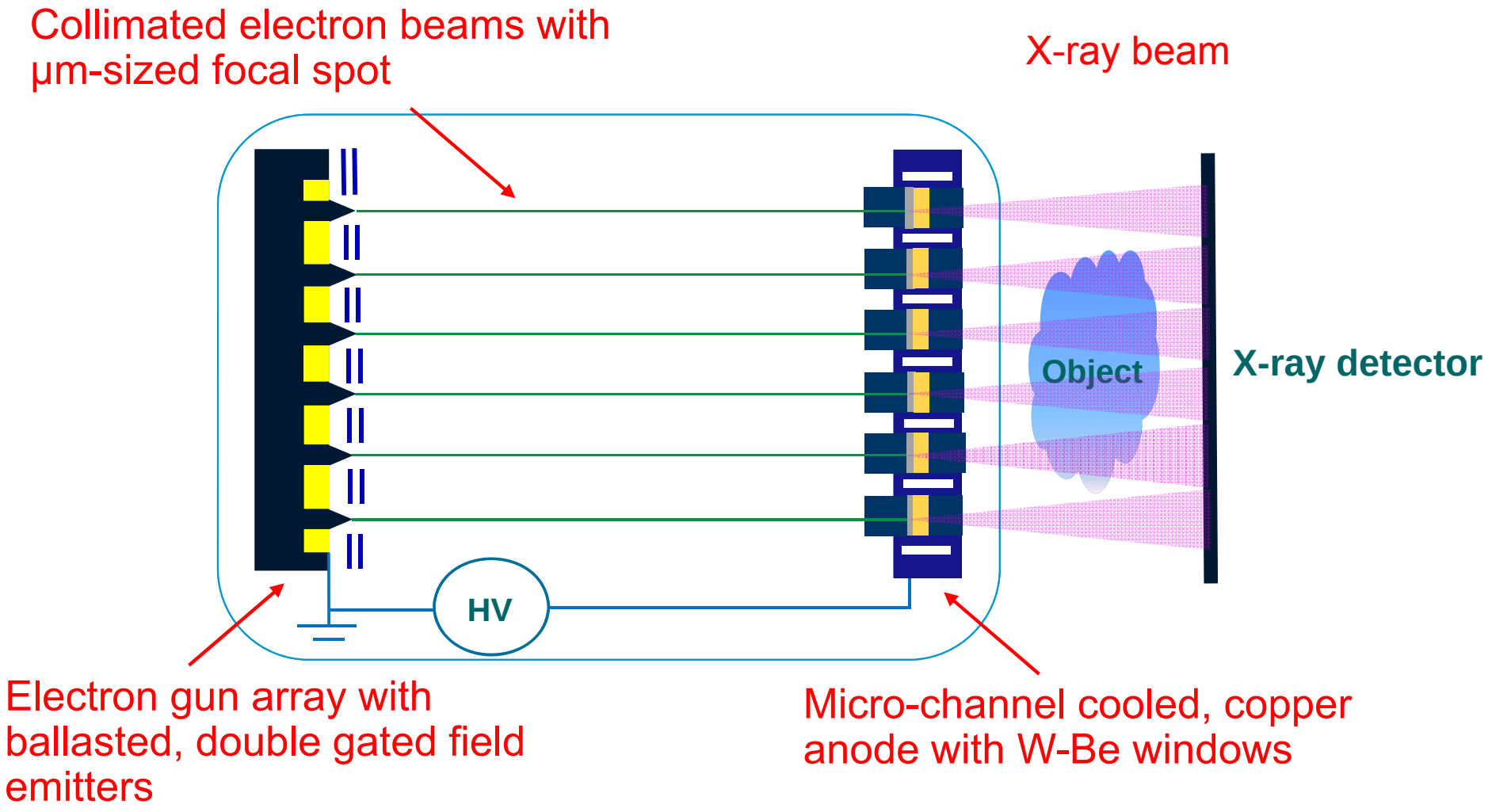
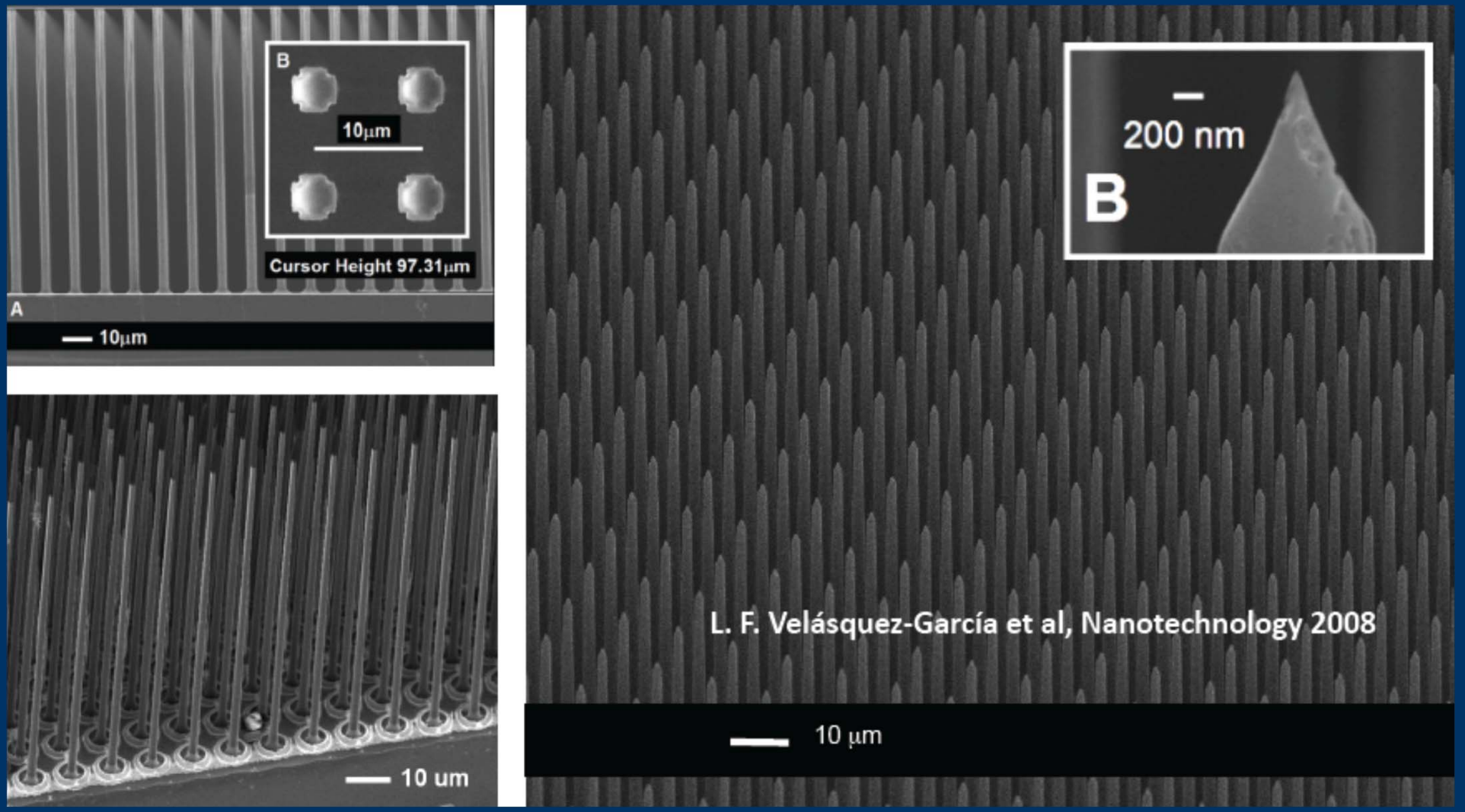
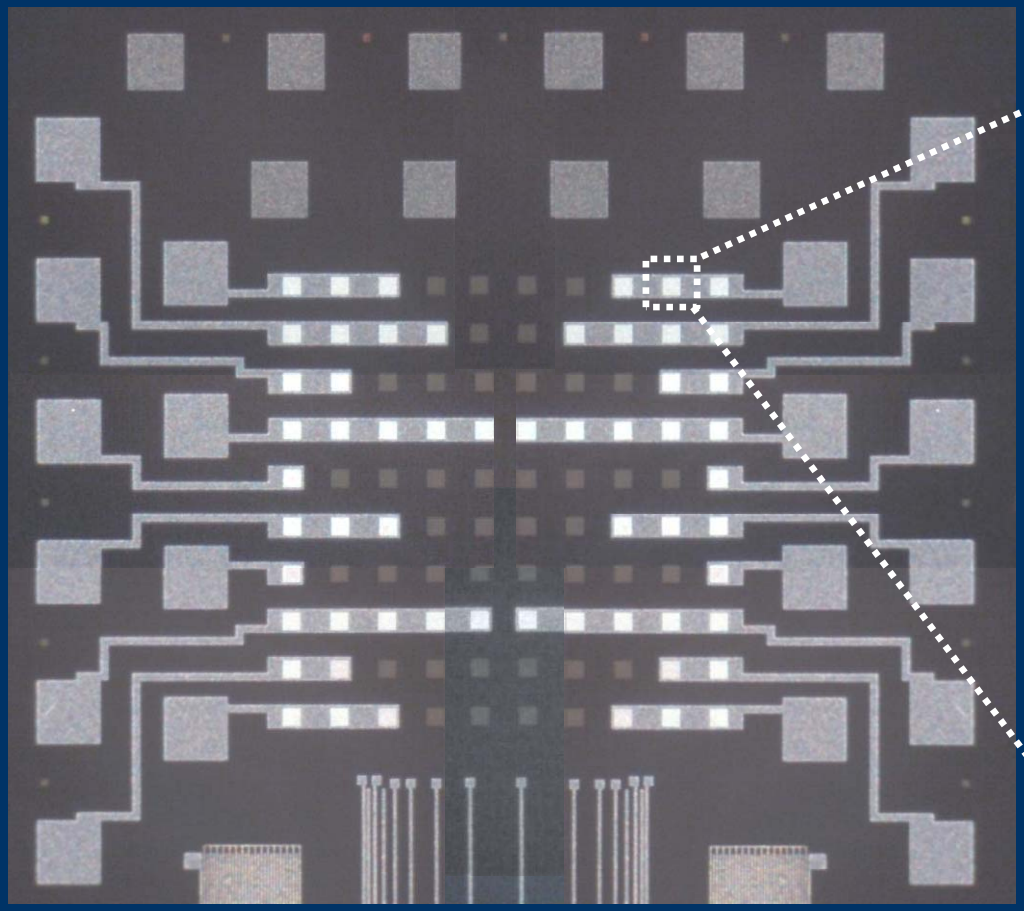
PaX Source – System Architecture



Field-emission Cathode Array

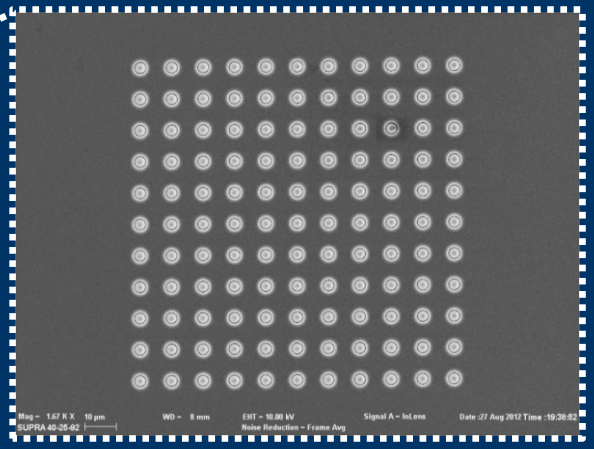


Fabricated Chip Layout

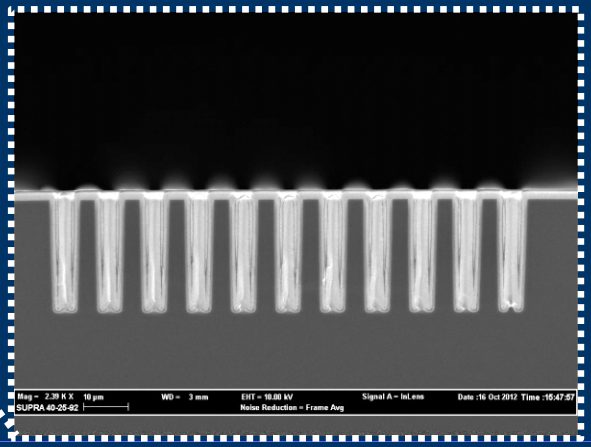


1 mm

11x11 FET array

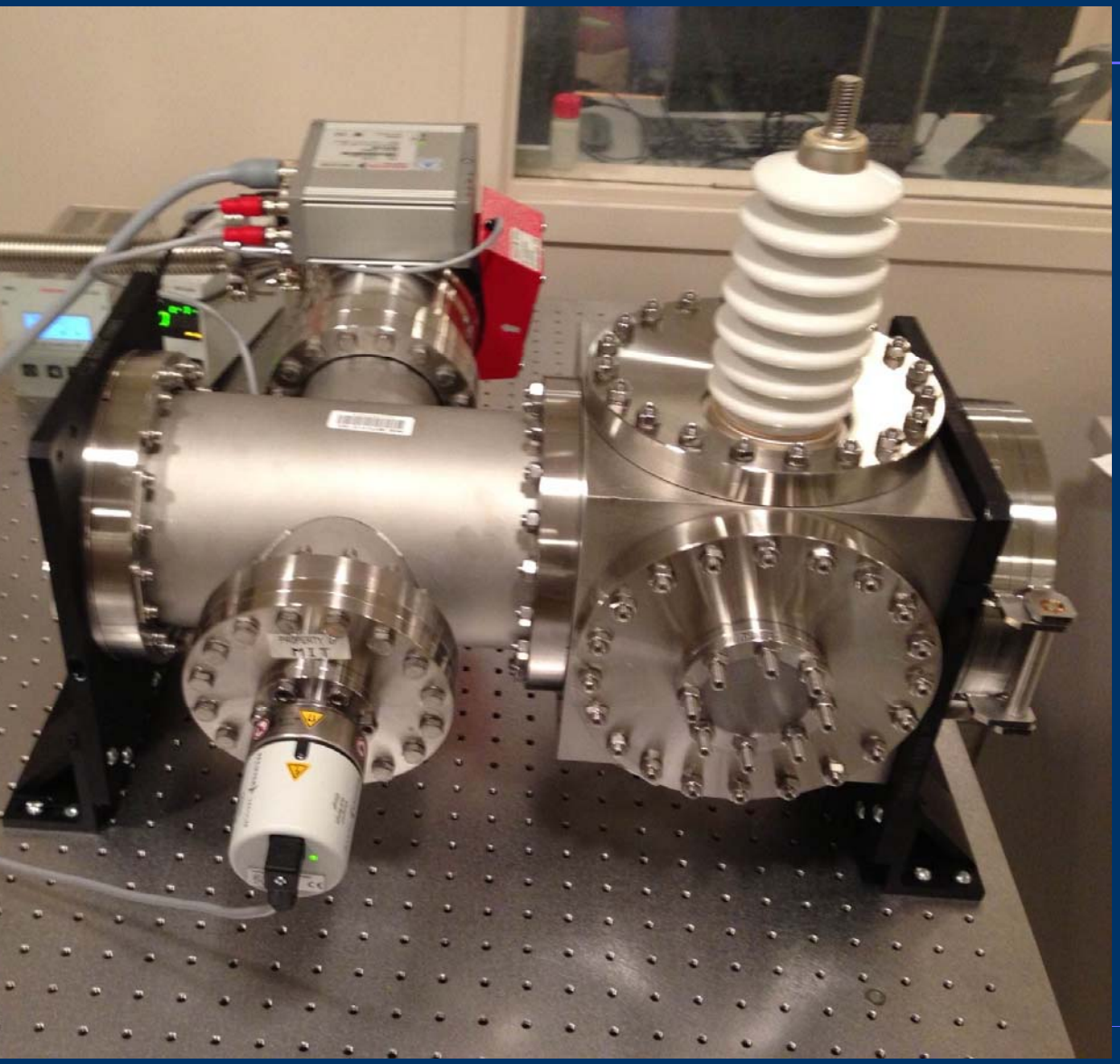


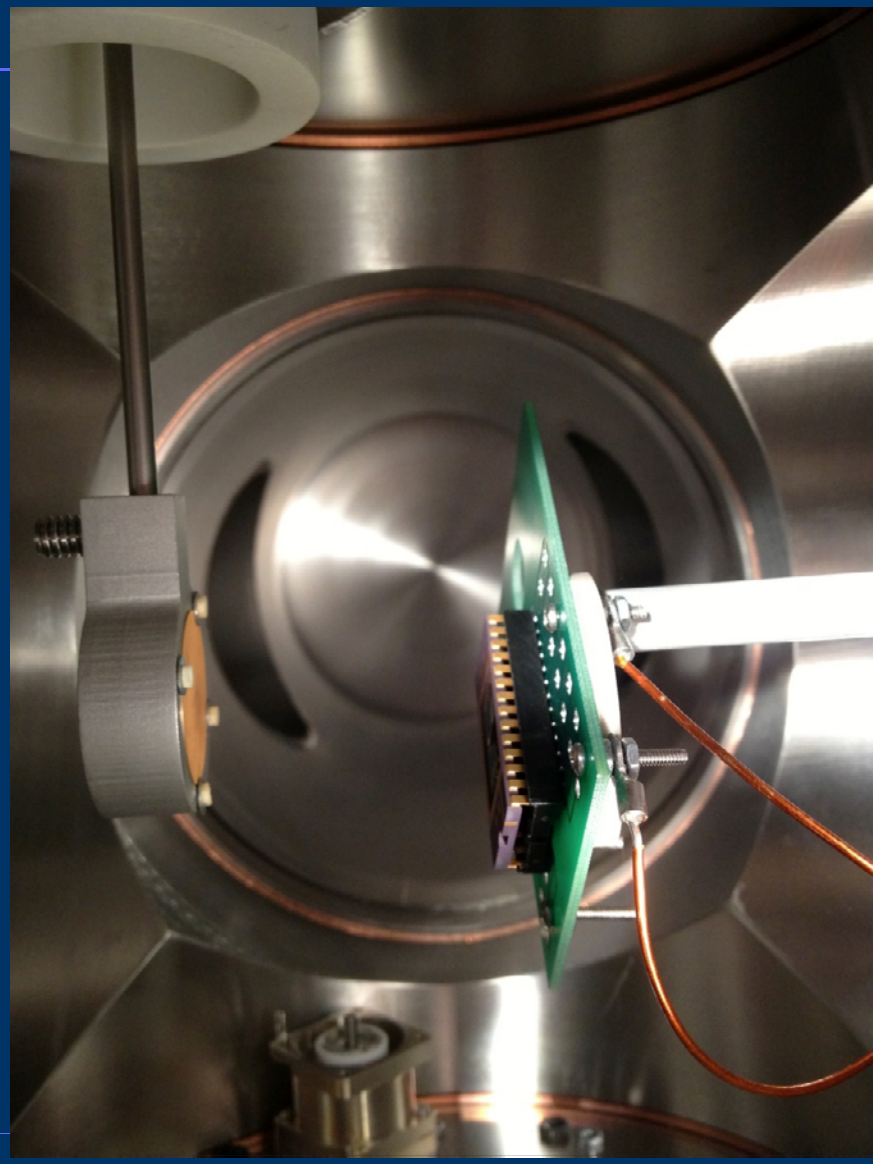
Top view



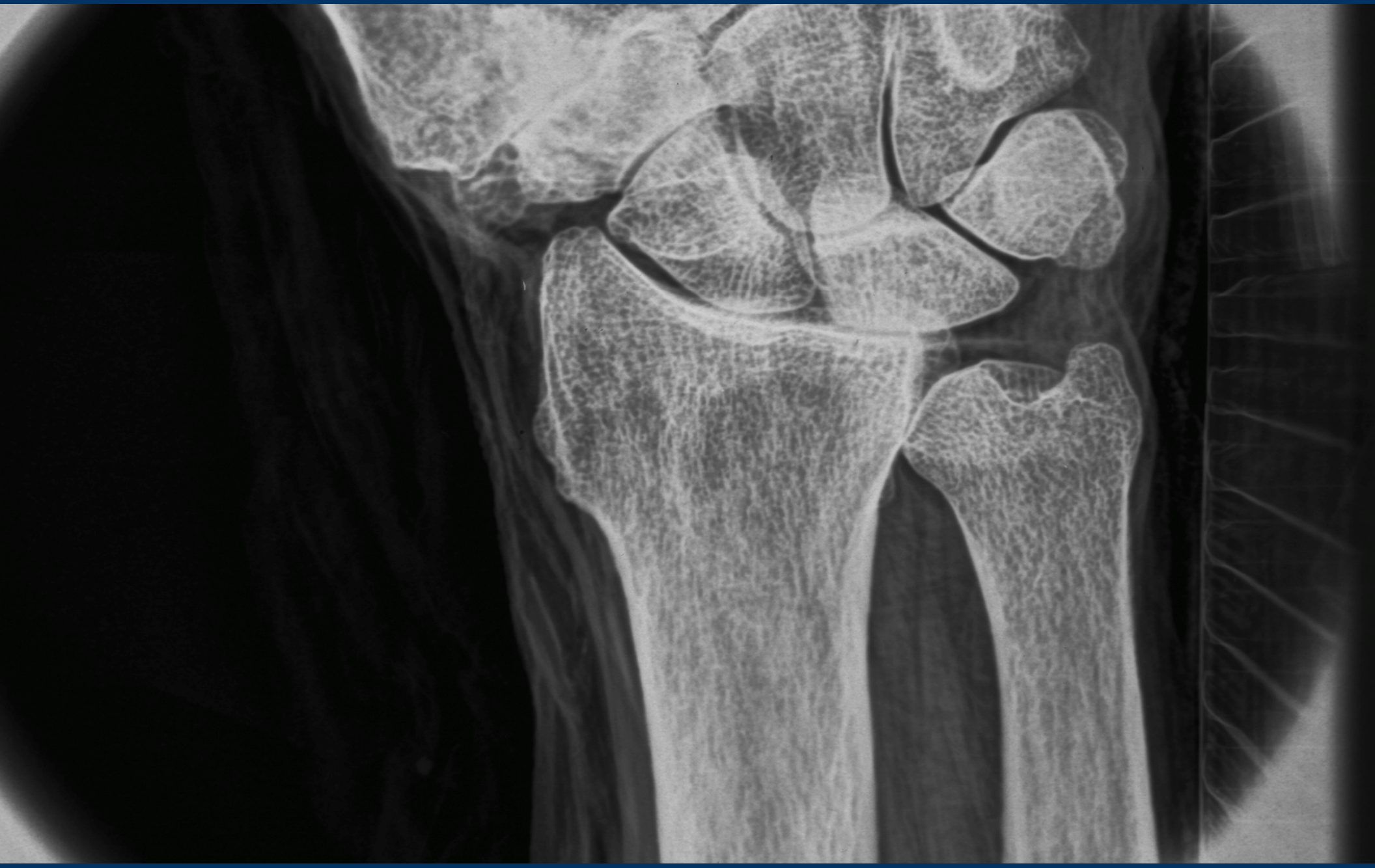
Side view

MGH/MIT PaX Source





First Image: Cadaver Wrist



Summary

- *X-ray phase represents an untapped contrast mechanism that can distinguish materials that look similar on conventional X-ray imaging*
- *There are ways to:*
  - *Make coherent X-rays*
  - *Deduce phase signatures*

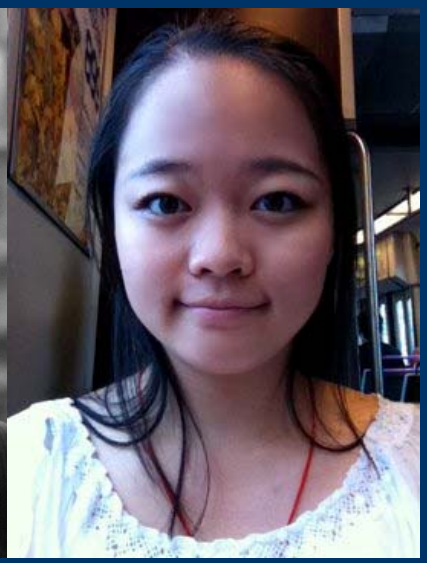
Team

Rajiv Gupta

Yongjin Sung

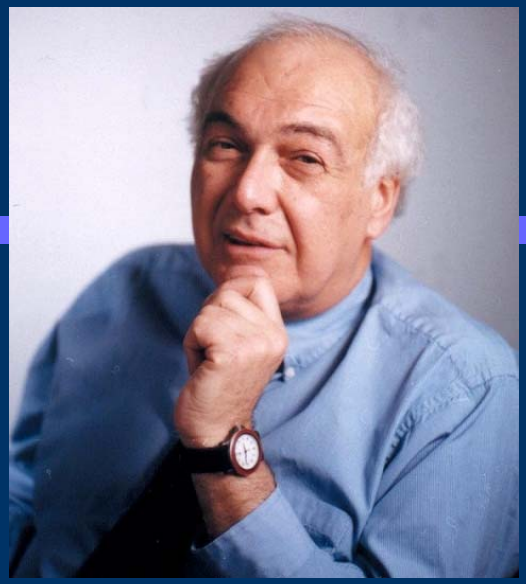
Synho Do

Julien Dinkel



Irene Wang

MIT



Richard Lanza

Luis Velasquez-Garcia

George Barbastathis

Jonah Jacob

SRL

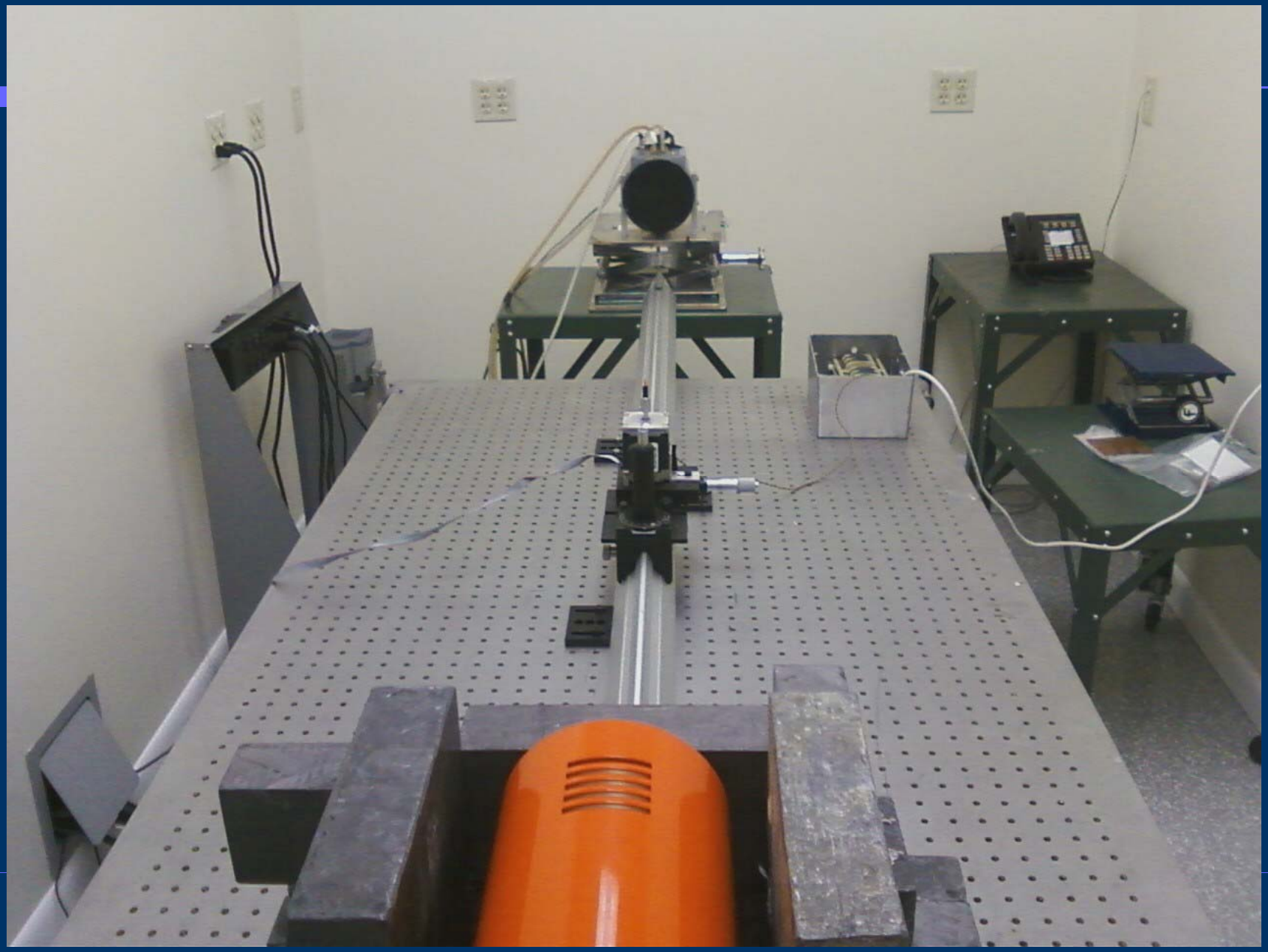
Geoff Campbell

John Pasour

NRL

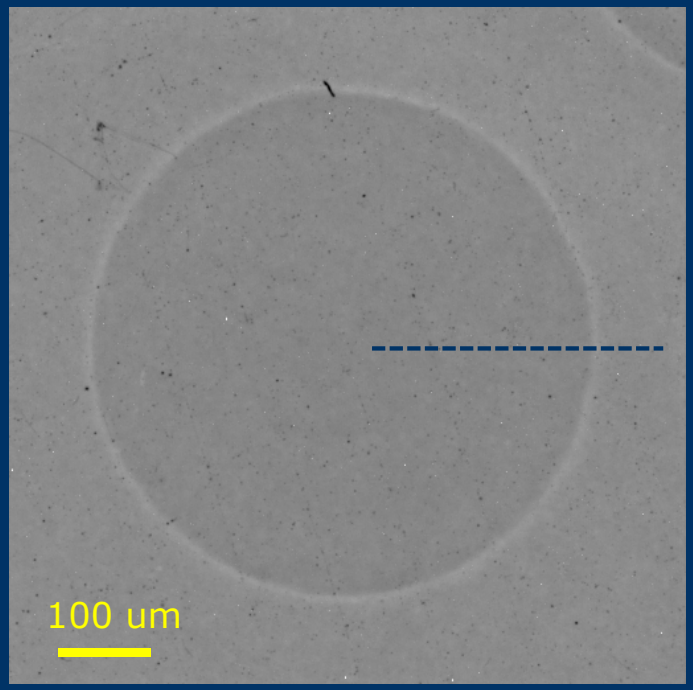
THANK YOU!

Proof that Micro-focus can do PCI

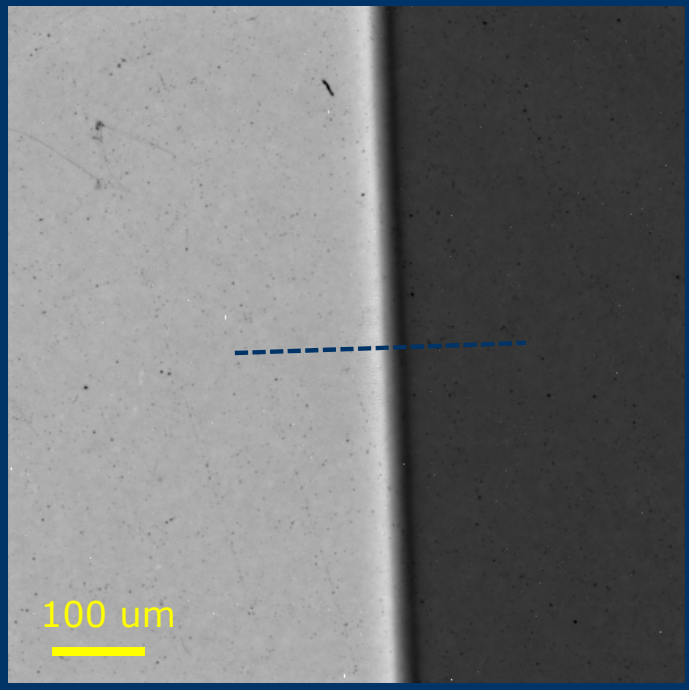


PCI with a micro-focus source

Polyethylene bead (~ 520 micron):
Creates a gradually varying phase



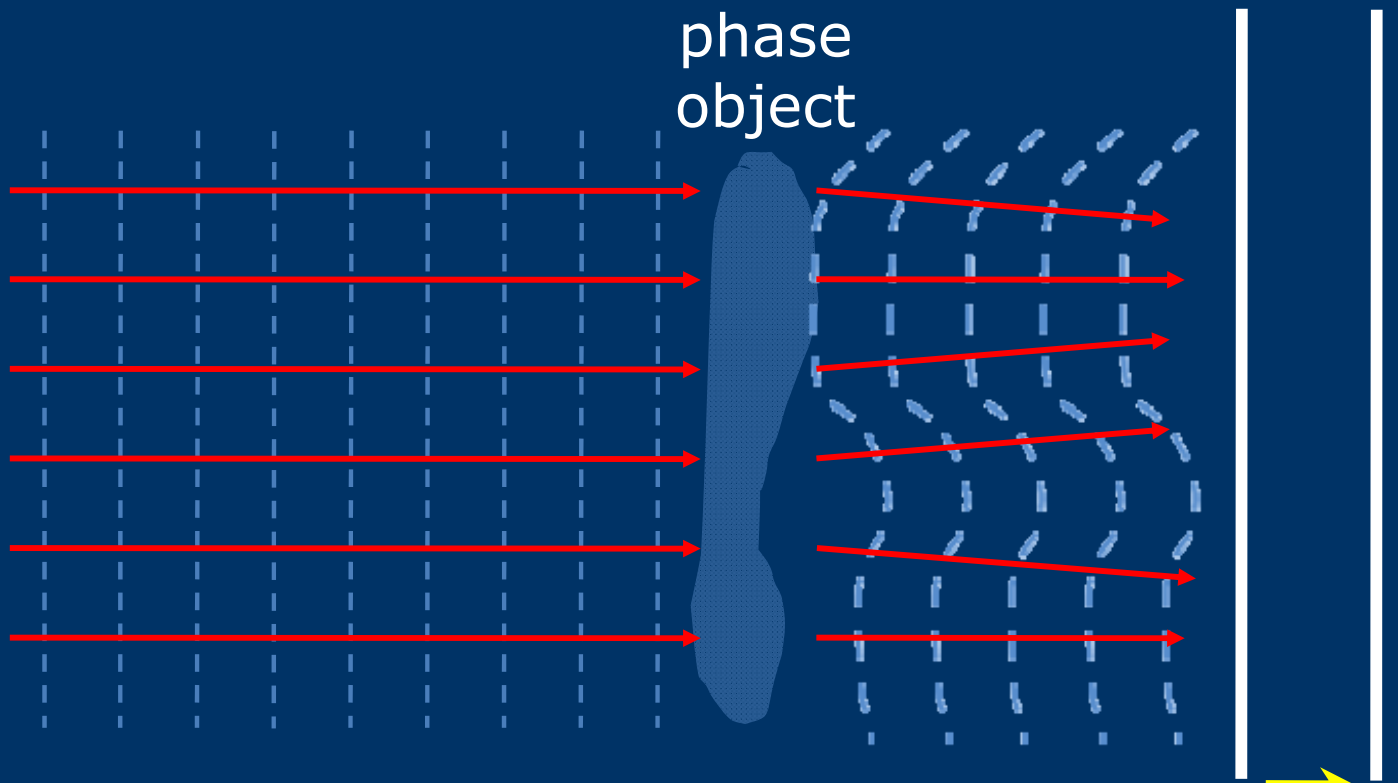
Cover glass (1 mm thick):
Creates a discrete jump in phase



PCI makes the bead and cover glass, which are essentially transparent in attenuation X-rays, visible.

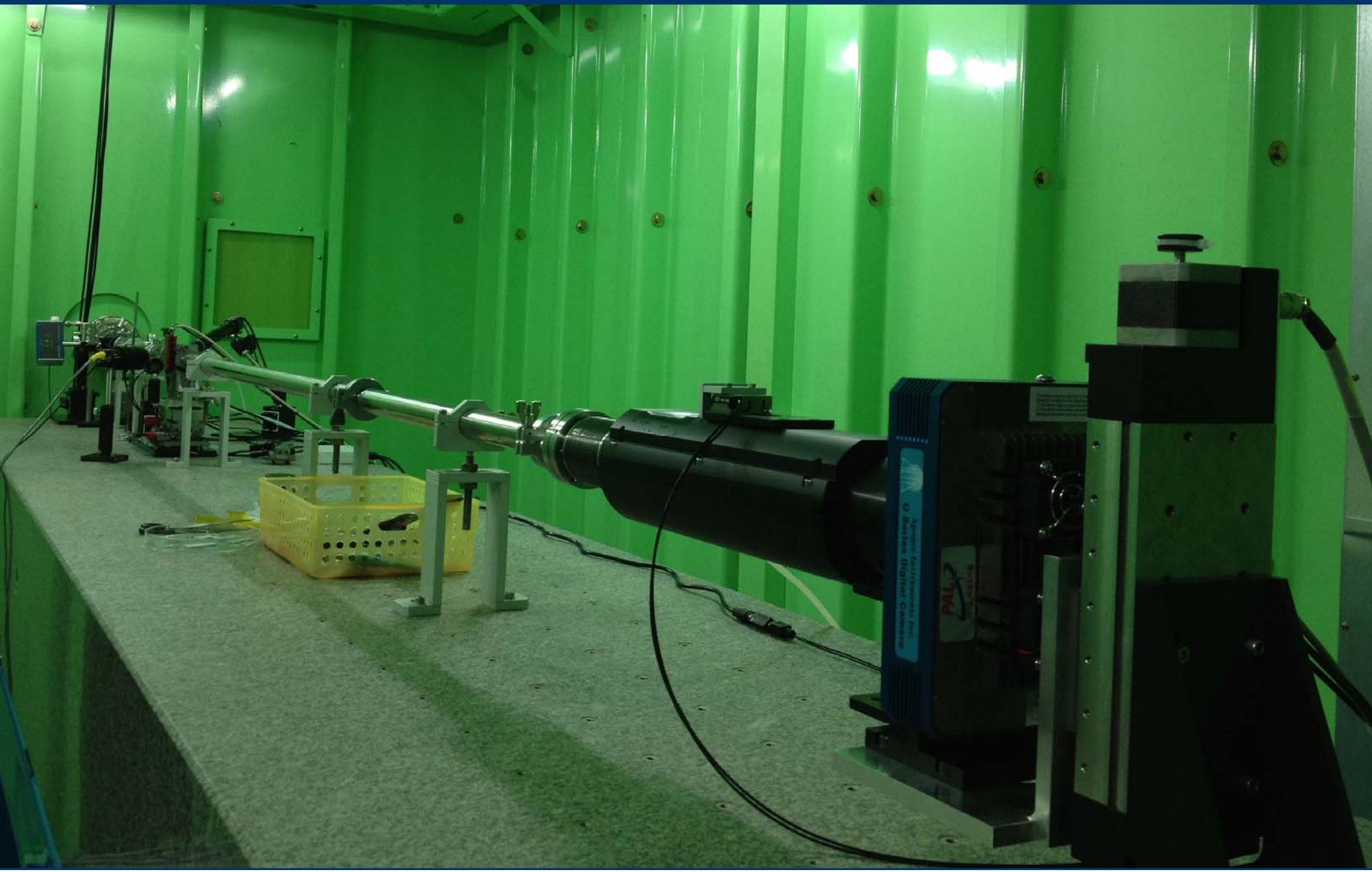
Voltage: 40 kVp; Source-to-sample: 44 cm; Sample-to-detector: 159 cm

How to derive Quantitative Phase Information



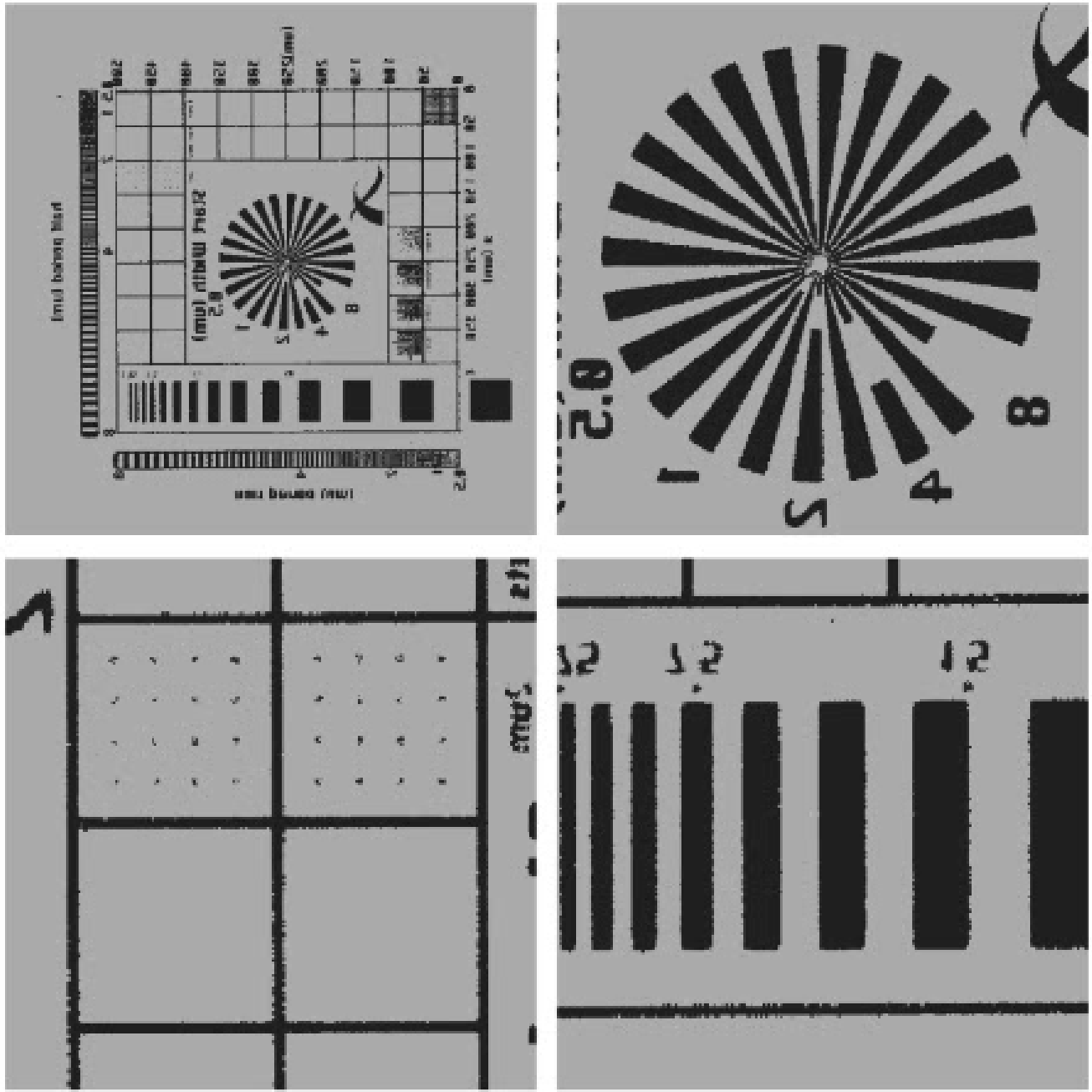
Two intensity measurements
Separated by δz

Pohang Light Source (So Korea)

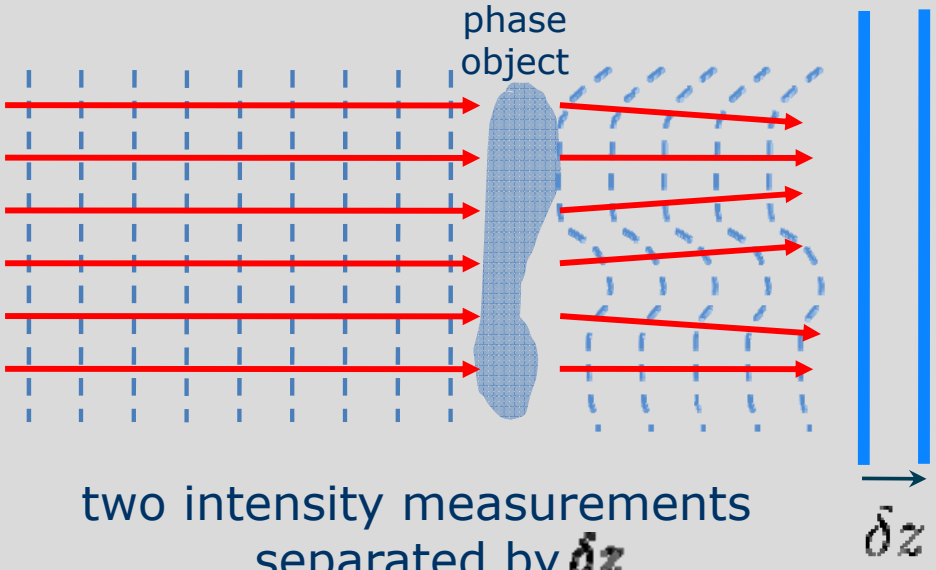


Siemens Phantom at different distances

Z = 0.80 (m)



Transport of Intensity (TIE) Equation



two intensity measurements separated by δz

Continuity Equation for Intensity Transport

I: intensity ϕ: phase

$$\frac{2\pi}{\lambda}\frac{\partial I}{\partial z} = -\nabla_\perp \cdot (I \nabla_\perp \phi)$$

M. Teague, *JOSA* (1983). $\nabla_\perp \equiv \left(\frac{\partial}{\partial x}, \frac{\partial}{\partial y}\right)$

- 'Conservation of intensity'
- Phase recovery from intensity derivative
- Partially coherent illumination