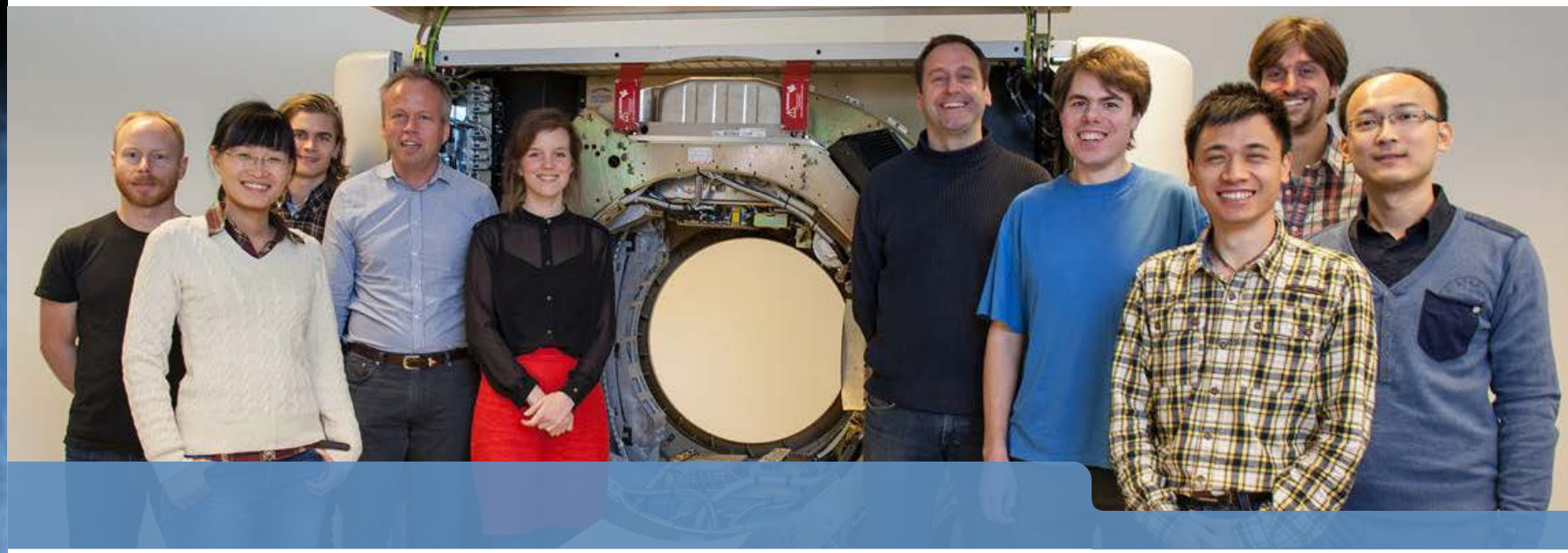
The Art of Experiment, Berkeley, CA , May 2-3, 2014



"Photon Counting Medical X-ray Imaging from Mammography to CT"

Mats Danielsson
KTH – Royal Institute of Technology, Stockholm, Sweden

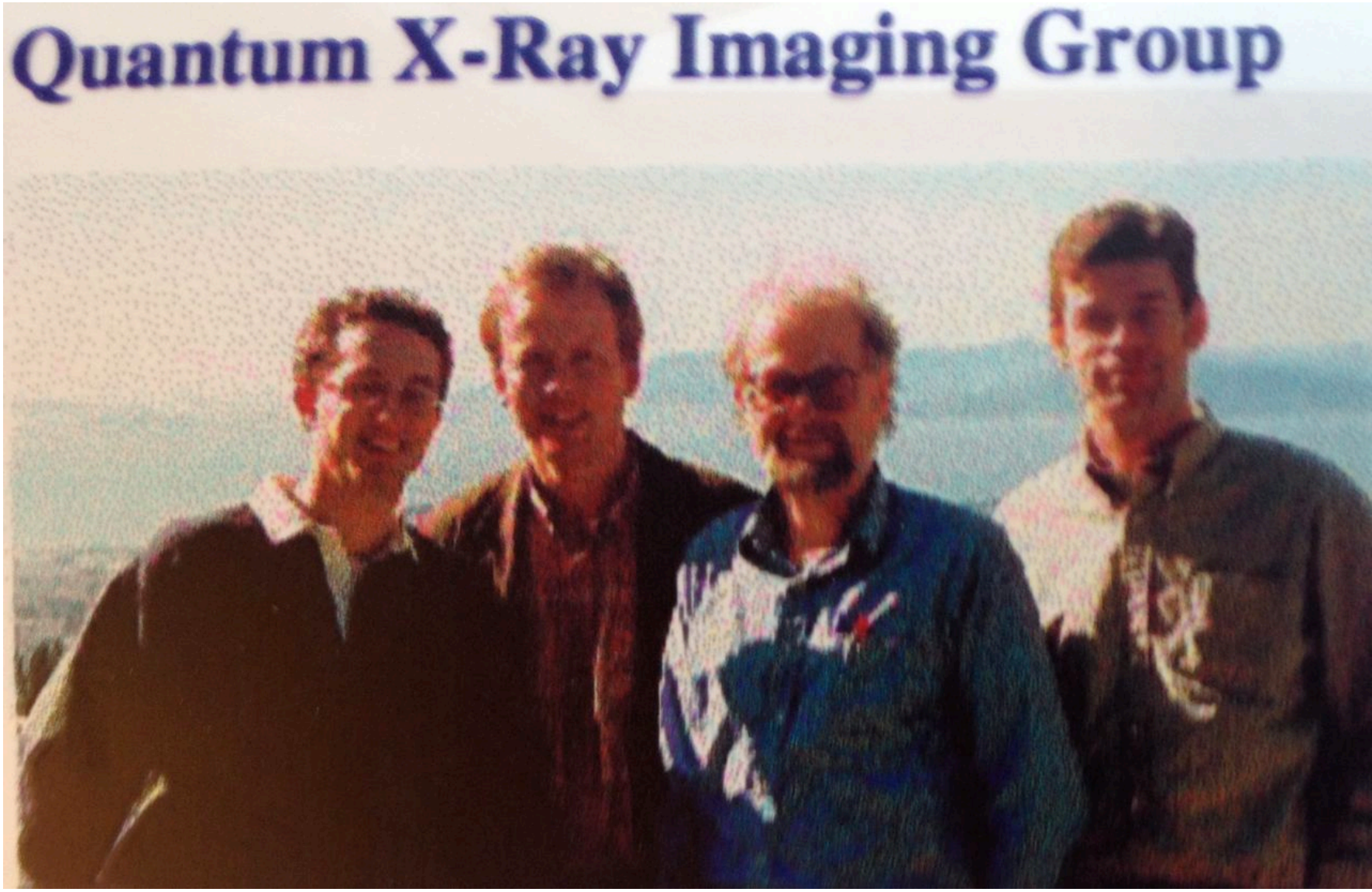
Sponsors for the Project

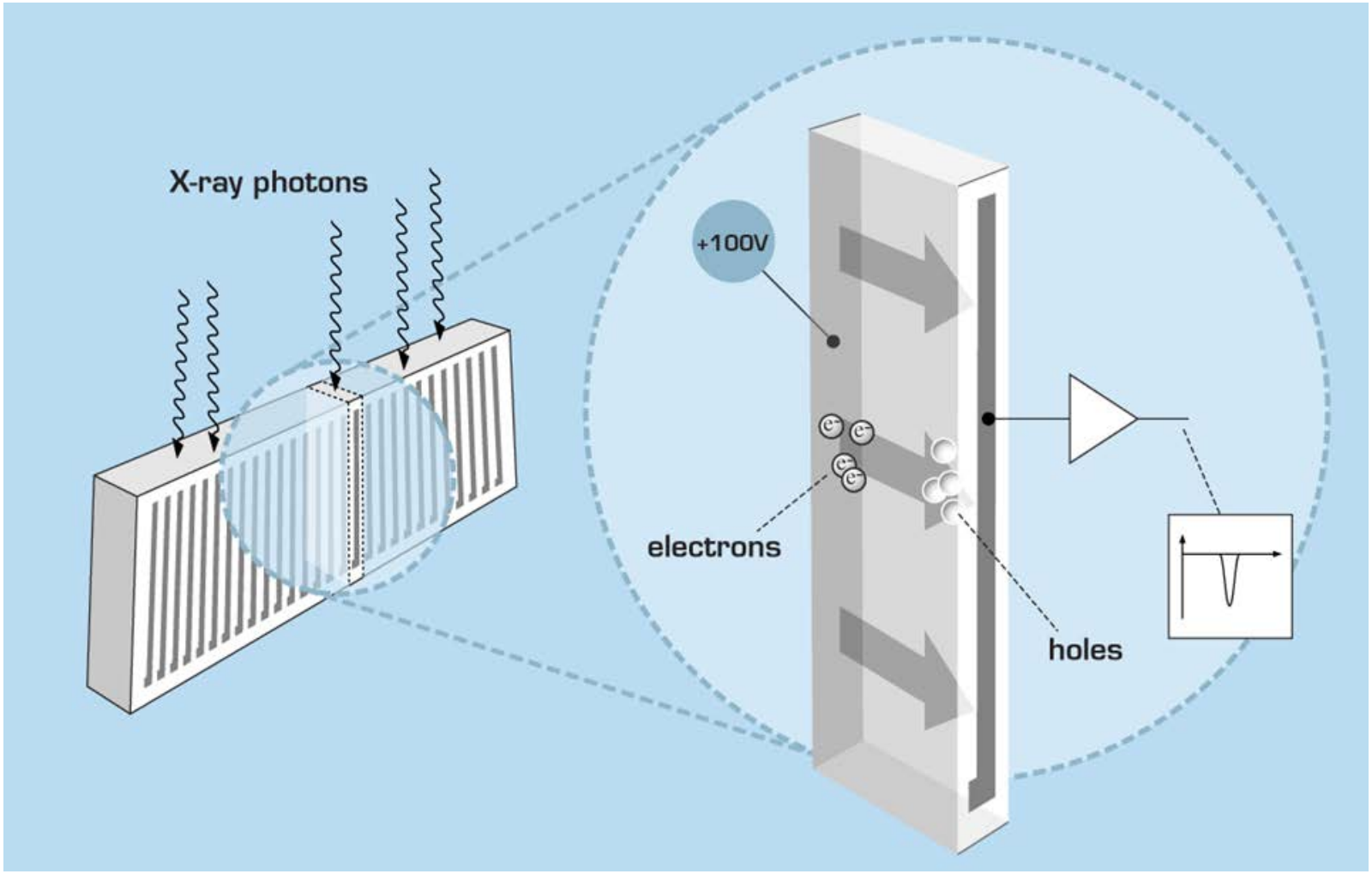
The Erling-Persson Family Foundation

H&M

CT Gantry

PHILIPS


Quantum X-Ray Imaging Group


X-ray photons
+100V
electrons
holes

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Clinical Applications

Chest Radiography

Bone Densiometry

Computed Tomography

Mammography

Angiography

Mammography

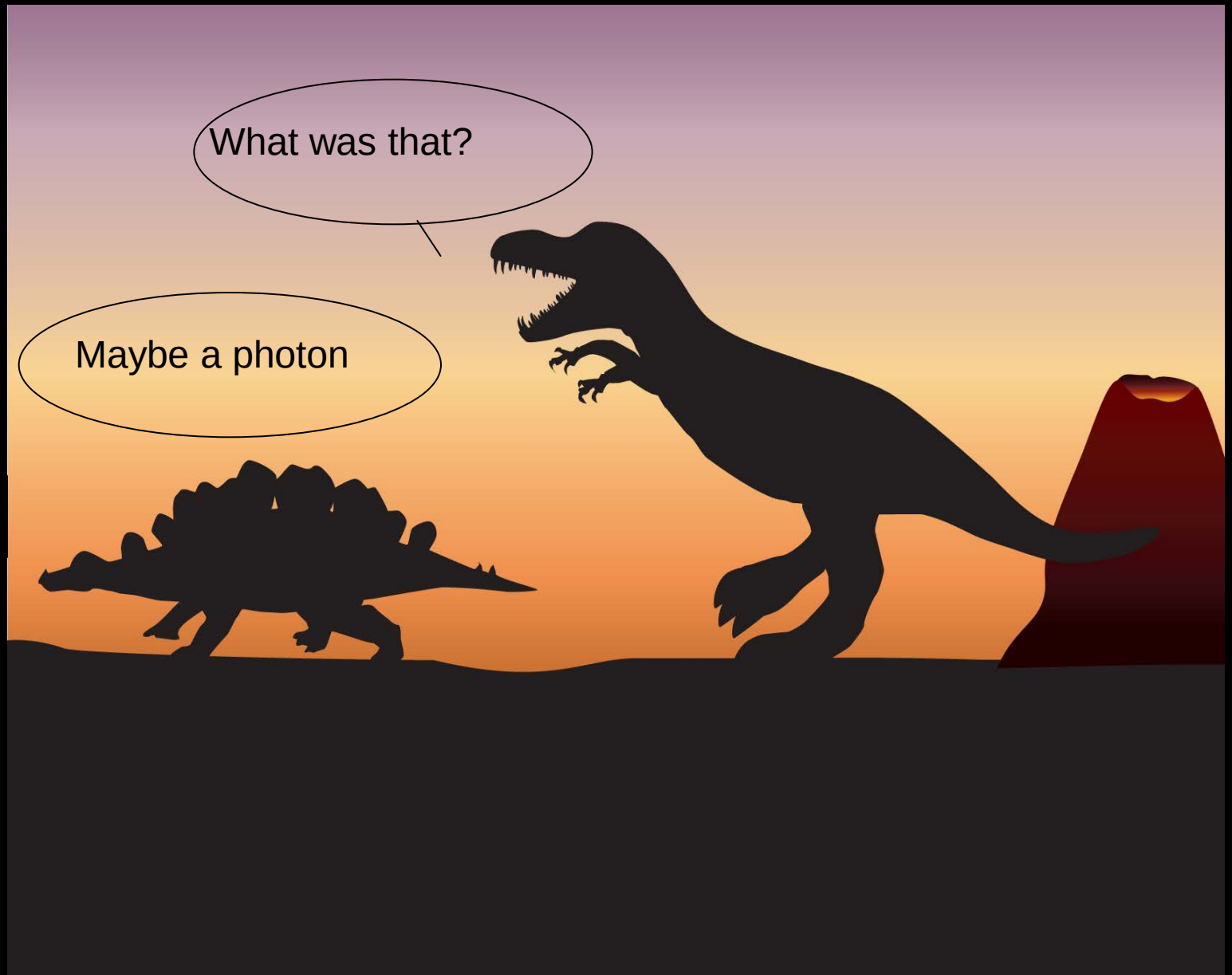
Digital Subtraction Radiography

Other Applications

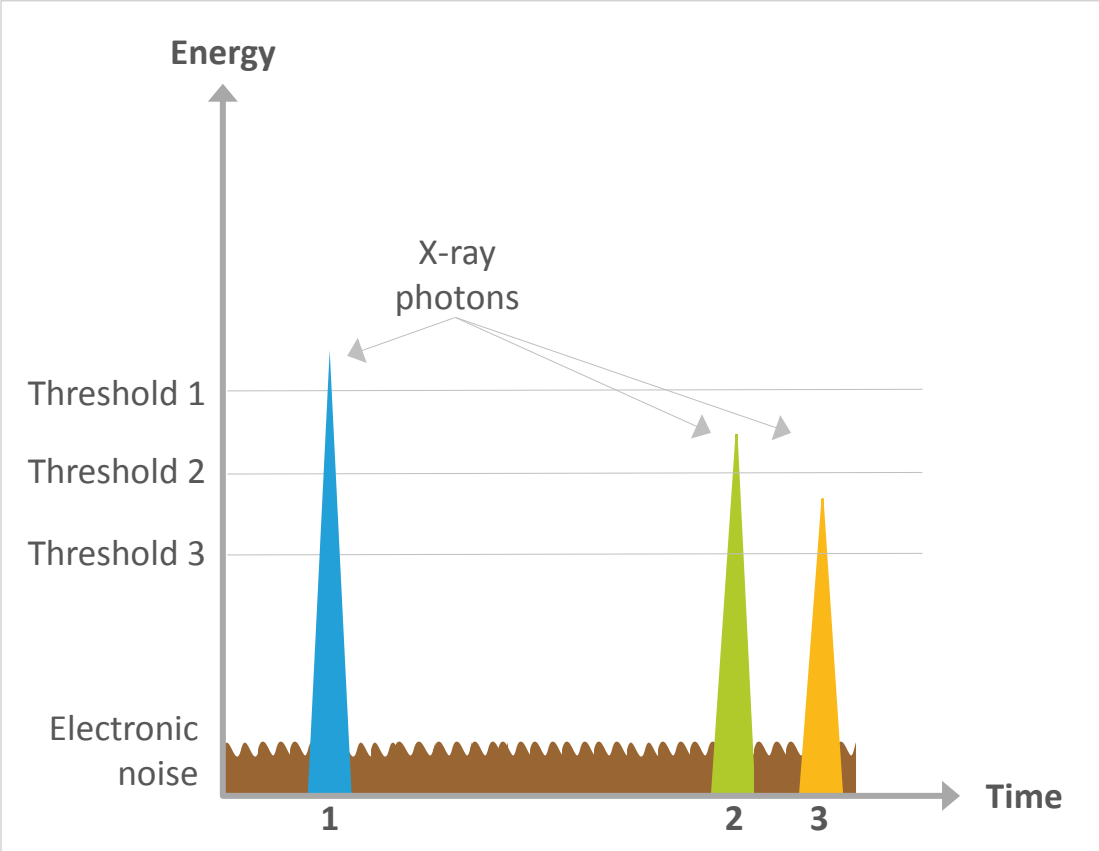
Non Destructive

Testing Airport Security

Who Counted Photons First?



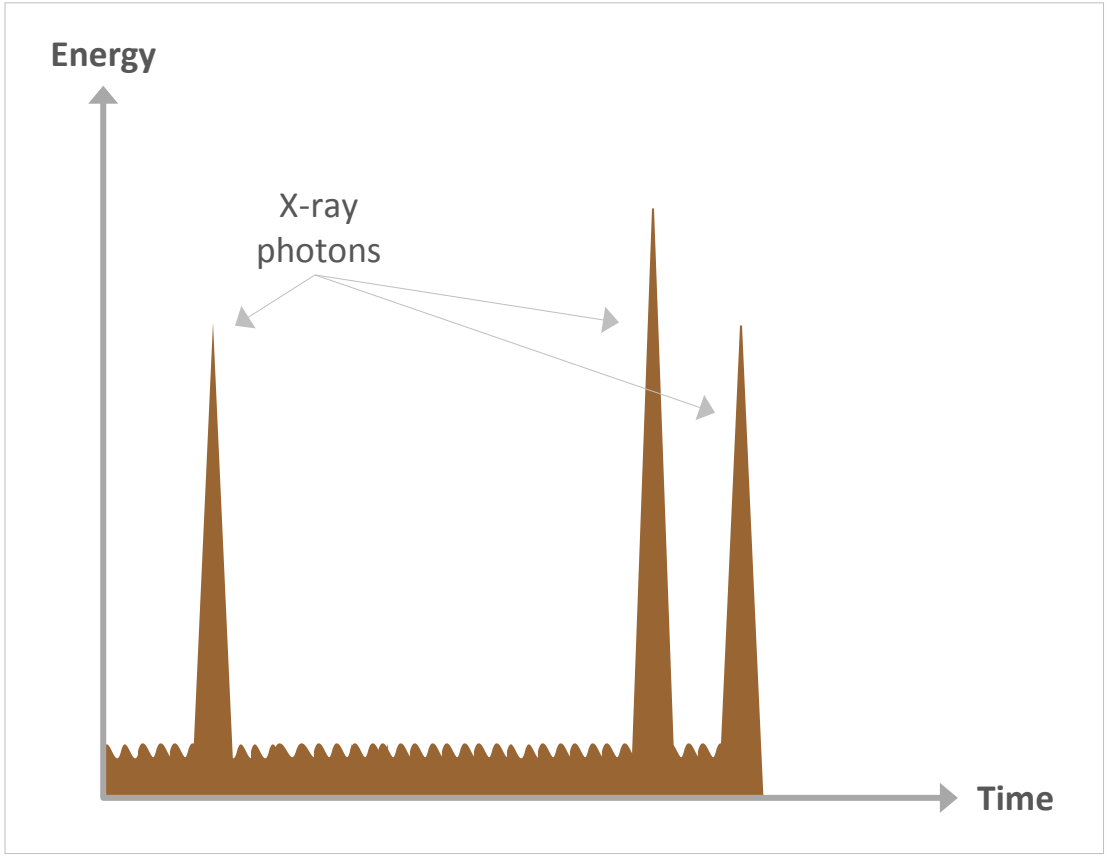
To Count Photons – What does it mean?



Result

- Number of X-rays
- Pulse height give the energy for each X-ray
- No electronic noise

Integrating Current: Today's praxis in X-ray Imaging



Result

- Area of
- Indirect estimate of number of photons

Photon Counting or Integrating – Two Ways of Eating the Smorgasbord

The normal way (one dish at a time)

Mix everything before you eat and try to guess the ingredients

Example of Clinical use Today: Mammography

Adaptation to mammography

Shorter detectors

Smaller pixels - higher resolution?

Possibility of adjusting the scan speed for differences in breast thickness

Basic approach of using silicon strip detectors wirebonded to ASICs stays the same

U.S. PHS office of Women's Health: New Frontiers in Image-Guided Breast Cancer Diagnosis and Treatment. Site Visit to Berkeley Lab, Feb. 27, 1997

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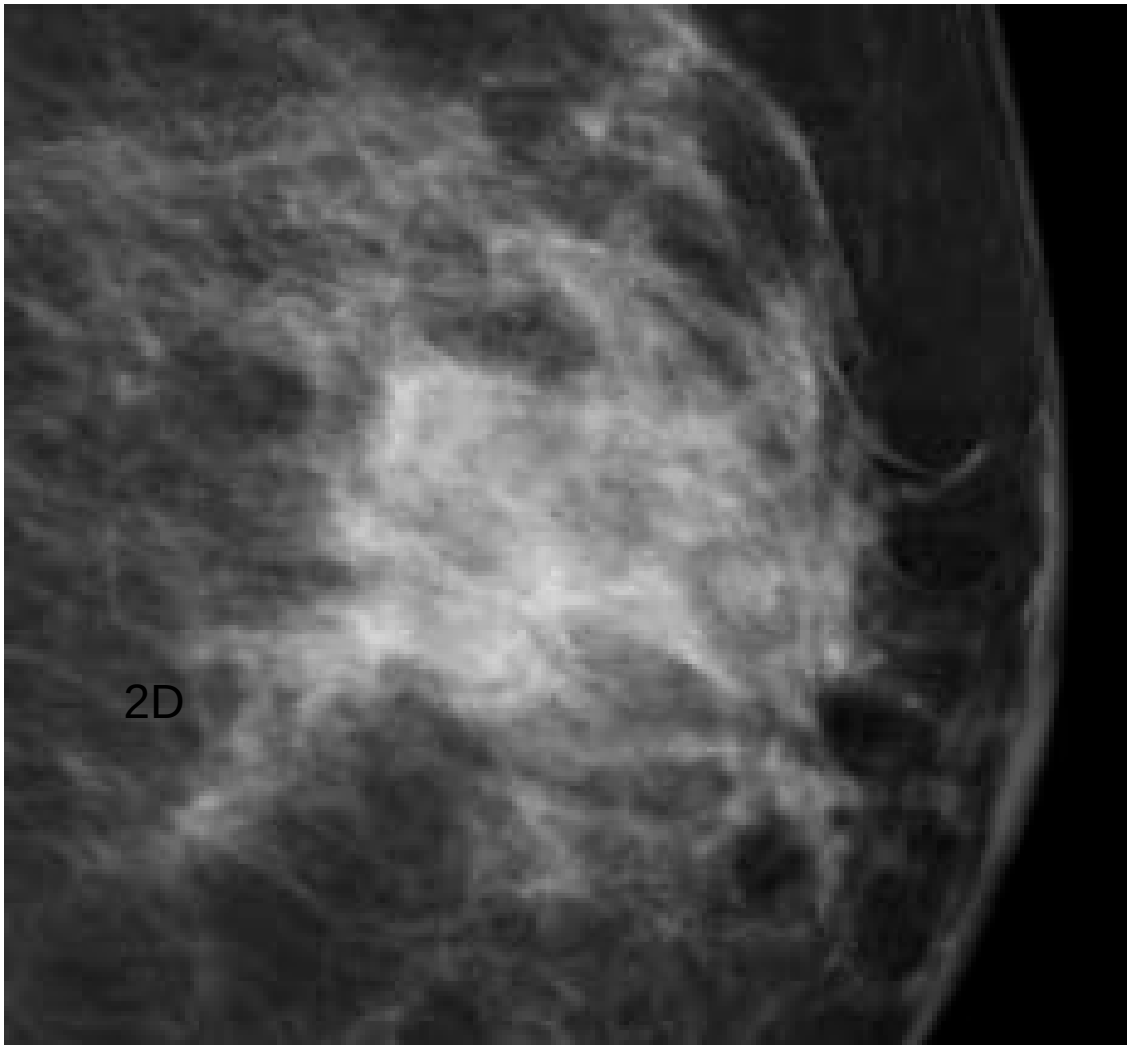
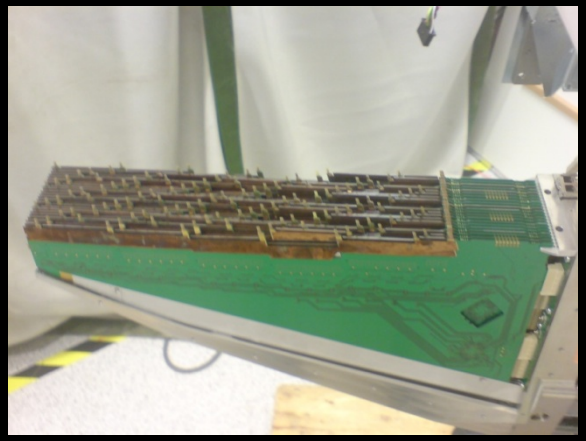
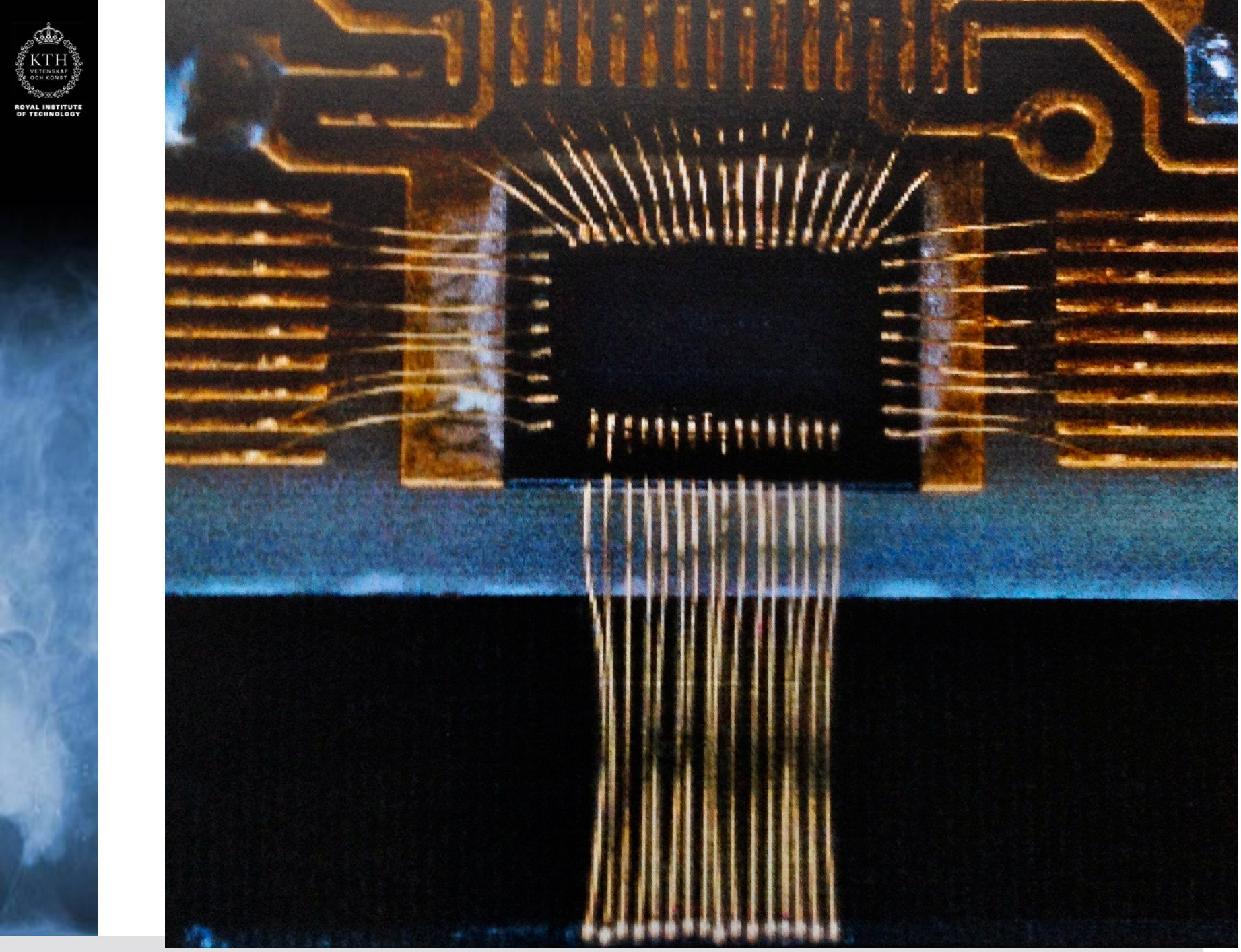
Photon Counting Mammography

Spiculated mass



Crystalline Silicon Detector





60 kV and Al filter
0
5
10
15
20
25
30
35
mm
0
5
10
15

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Scanning slot approach

Advantages:

Scatter rejection (reduced dose to patient)

Possibility to adjust scan speed to tissue transmission

Facilitates calibration

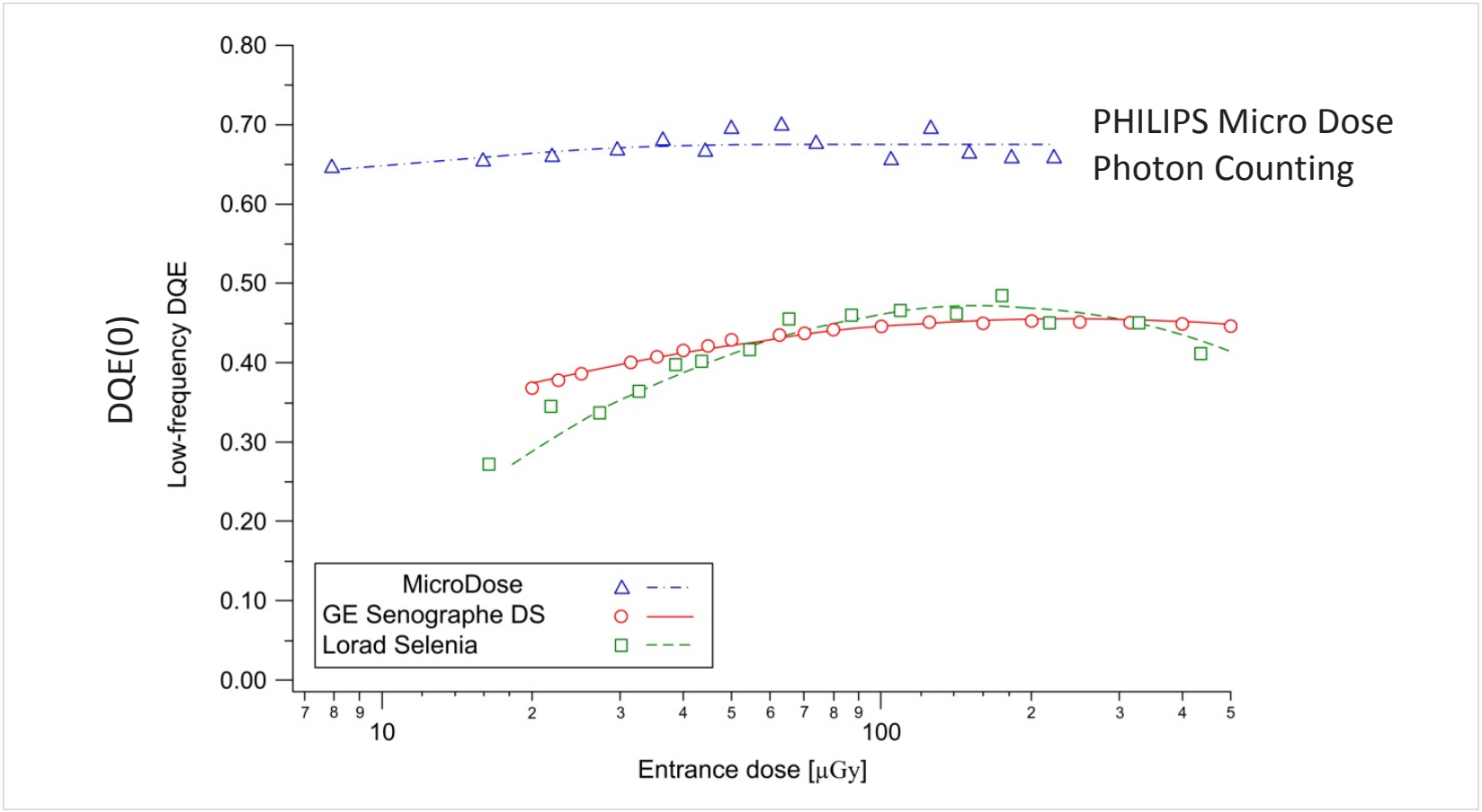
Drawbacks:

Mechanical scanning mechanism needed

Longer image acquisition time (around 10 s)

Higher load of X-ray tube, movements during scan would distort image

DQE at Zero Spatial Frequency

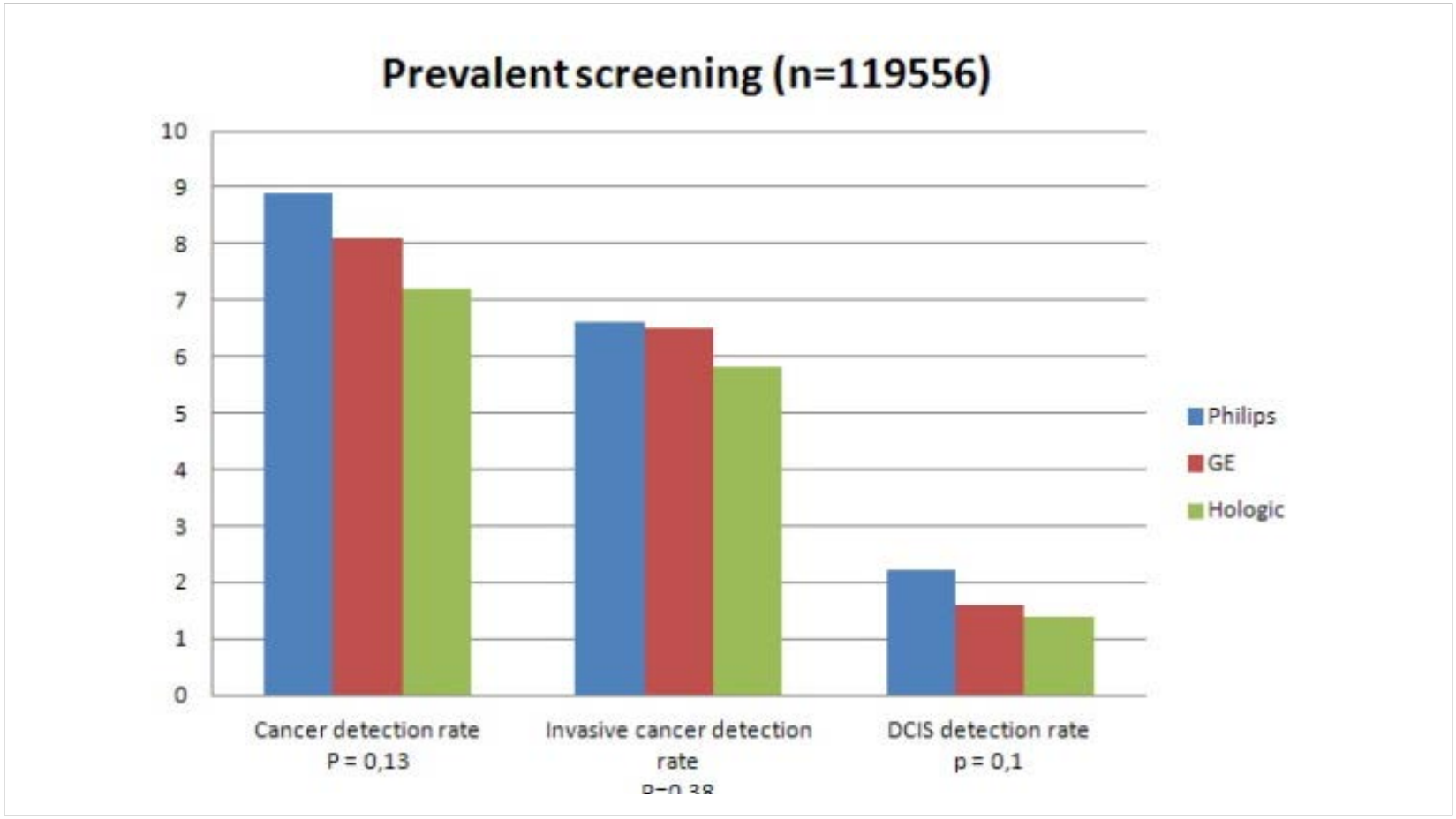


Monnin et al. Med. Phys., vol. 34 (3), pp. 906-914, 2007

Clinical Example: Experience from Breast Check, the Irish Breast Screening Program

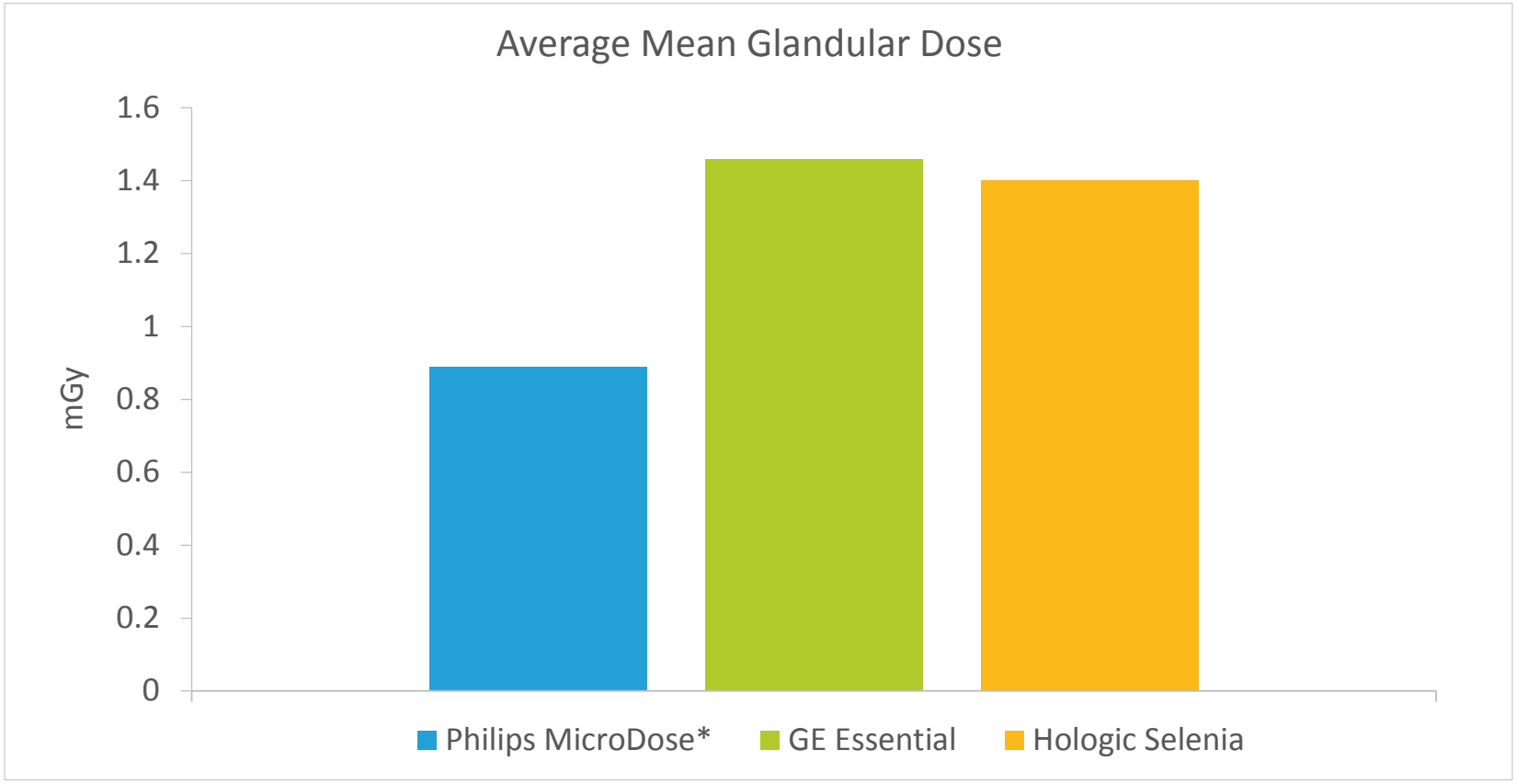
- 4 static & 16 mobile screening units
- Equipment:
  - 11 CsI scintillator
  - 10 a-Se
  - 7 Photon counting

Ireland Breast Screening Program Cancer Detection Rates



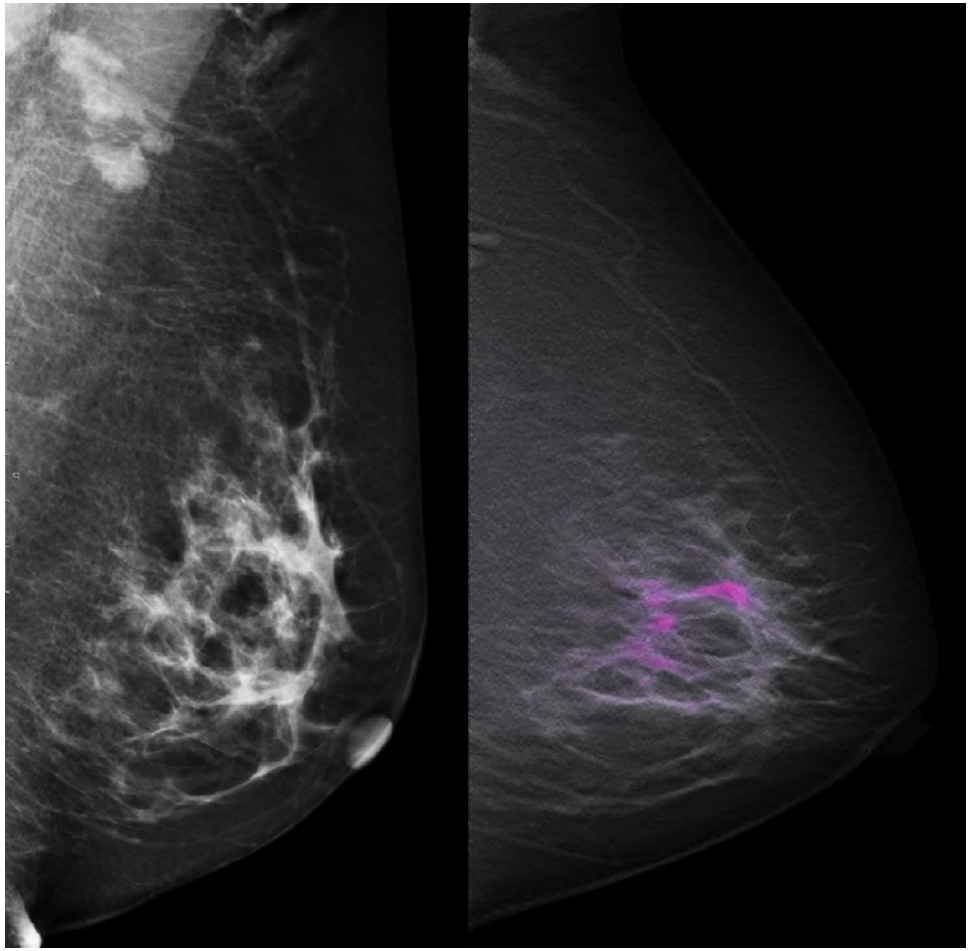
Mccullagh et al. The British Institute of Radiology (2011), doi: 10.1259/bjr/29747759

Ireland Breast Screening Program Radiation Dose



P Baldelli et. al., "Comprehensive Dose Survey Of Breast Screening In Ireland", Radiation Protection Dosimetry , Vol. 145, No. 1, pp. 52–60, 2010

Visualization of Iodine Contrast Agent



Courtesy Dr. Felix Diekmann

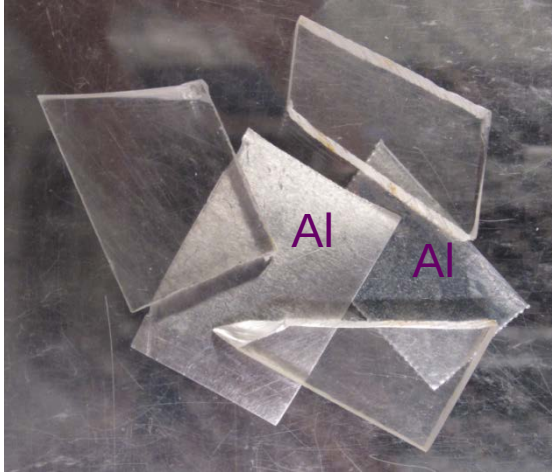
- 35 mm invasive lobular carcinoma
- Difficult to detect in 2D
- Difficult to detect in tomosynthesis
- Energy subtraction – clear improvement in this case

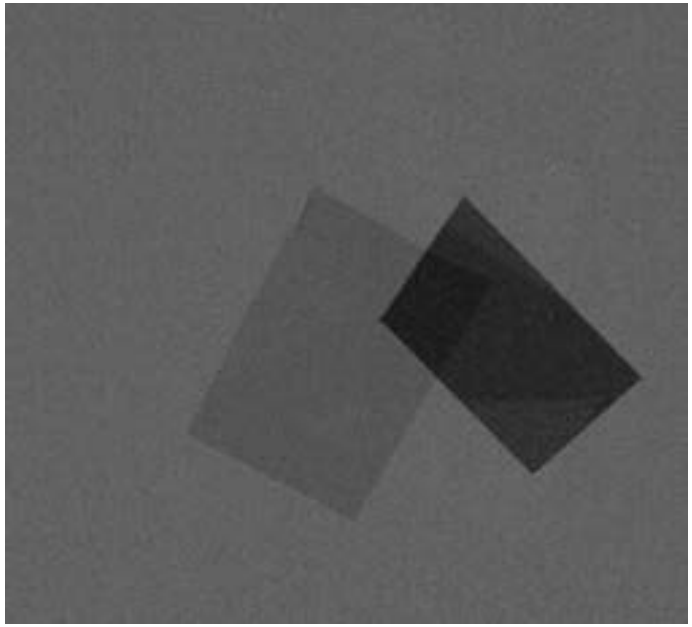
Differentiation of Cysts from Cancer

On the photo you can tell what is what…
Acrylic
Acrylic
Aluminum
Aluminum
Acrylic

But on the X-ray image, can you tell what is what?

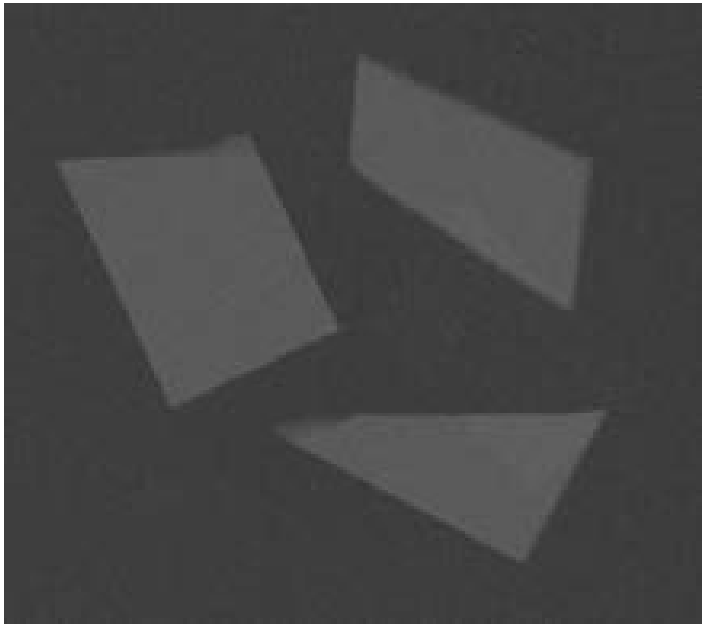
On photon counting spectral you can!





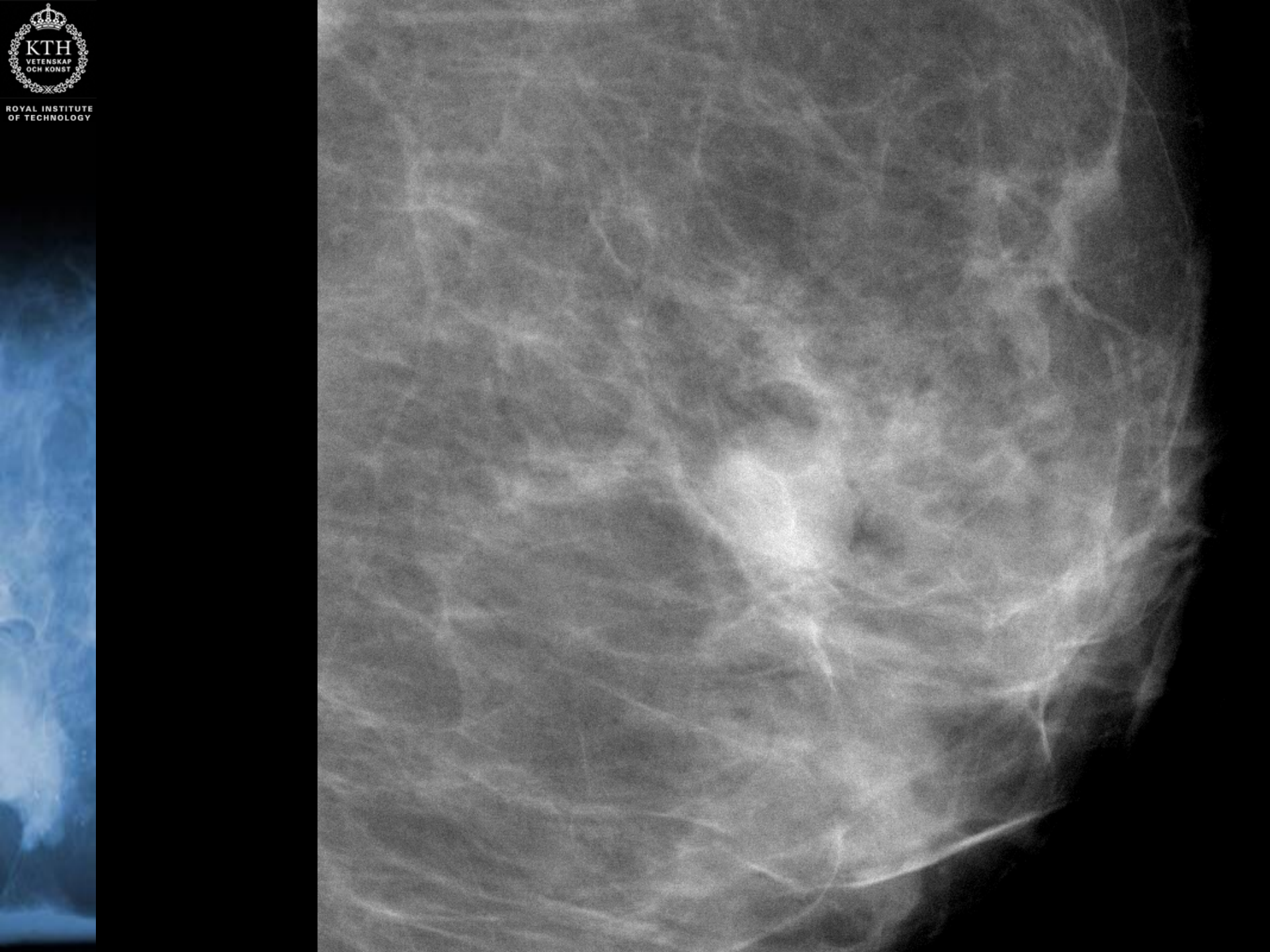
Spectral image of Aluminium

All acrylic removed



Spectral image of acrylic

Aluminum removed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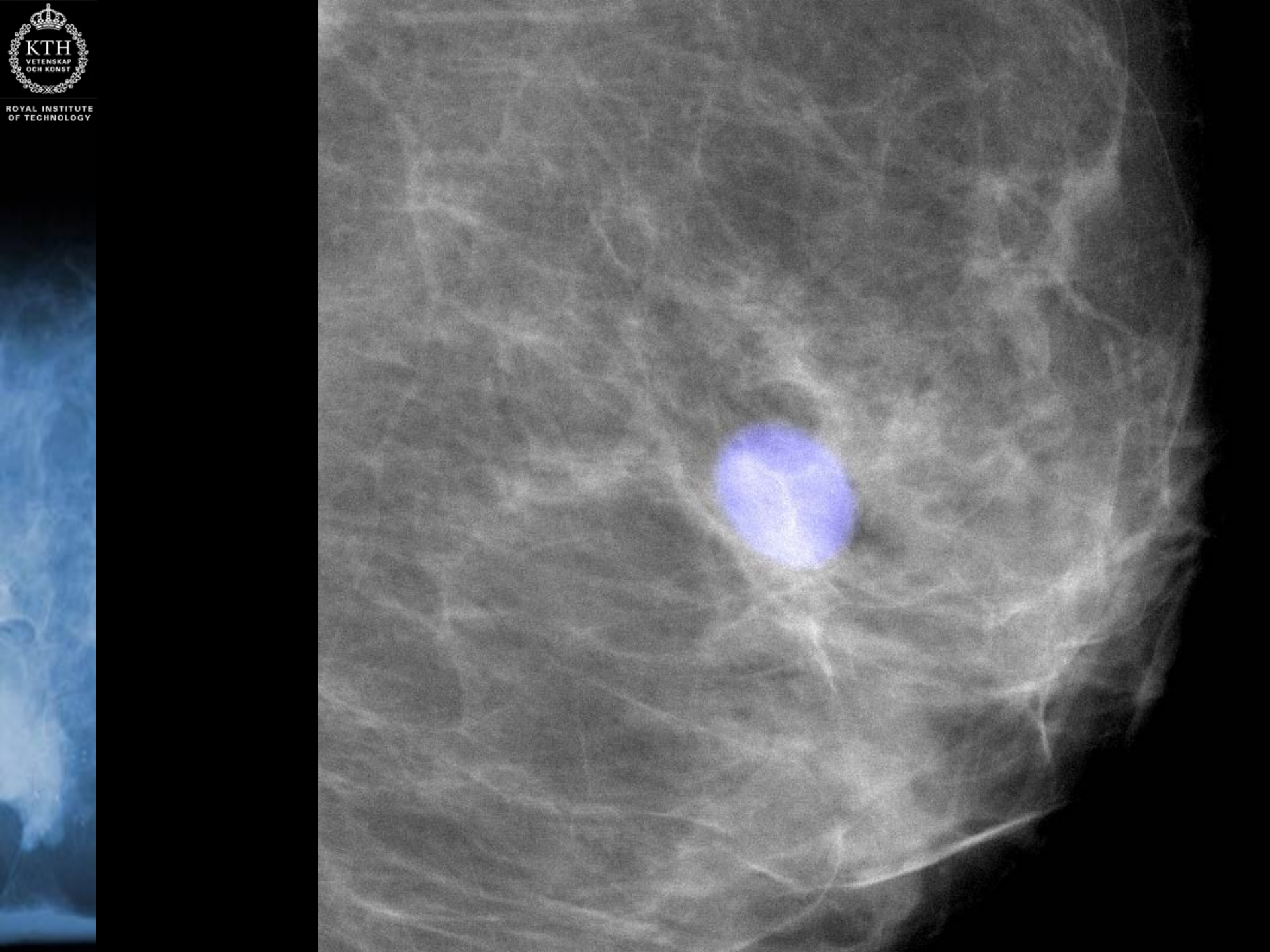
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Measuring breast tissue attenuation

Björn Cederström, Erik Fredenberg

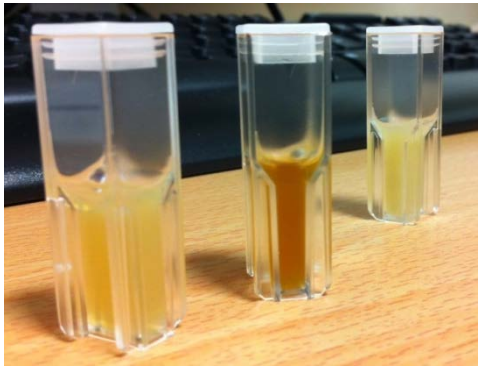
Philips, Solna, Sweden

Matthew G. Wallis, Paula Willsher,

Cambridge Breast Unit and NIHR Cambridge Biomed. Research Centre, U.K.

David R. Dance, Kenneth C. Young,

NCCPM, Royal Surrey County Hospital, U.K.

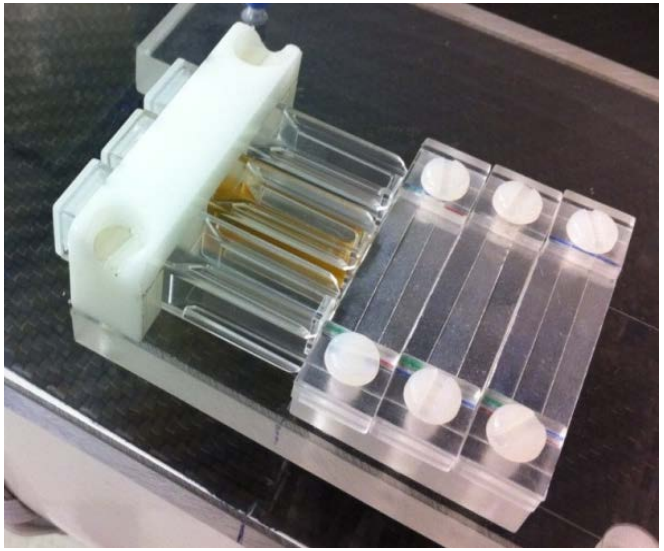


Setup:

- cyst samples in 1-cm cuvettes
- PMMA + Al step wedge

Method:

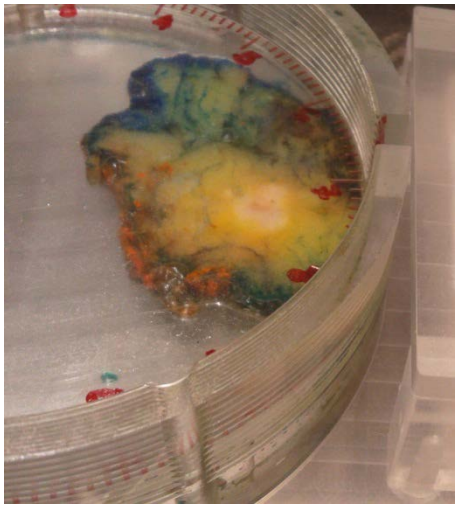
- Map cyst fluid directly into (PMMA, Al)-space

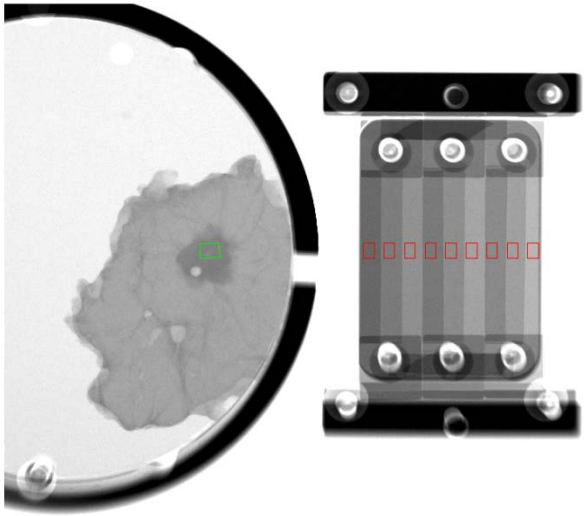


E. Fredenberg et al. "Measurement of breast-tissue x-ray attenuation by spectral mammography: first results on cyst fluid", Phys. Med. Biol. 58 (2013) 8609–8620

Measurement of solid tumor attenuation

- Published data on tumor composition/attenuation scarce
- Different experimental condition
- Use same setup as for cyst fluid
- Tailored sample holder

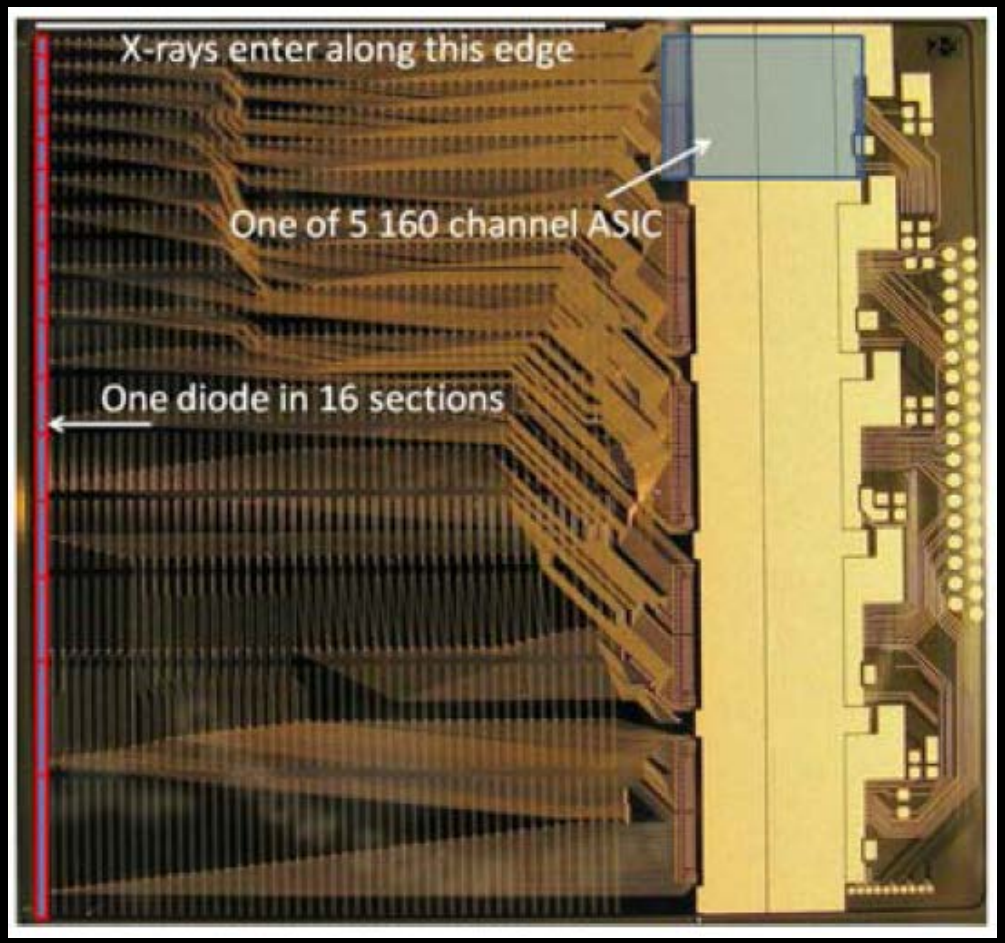




Clinical use in the Future: Computed Tomography

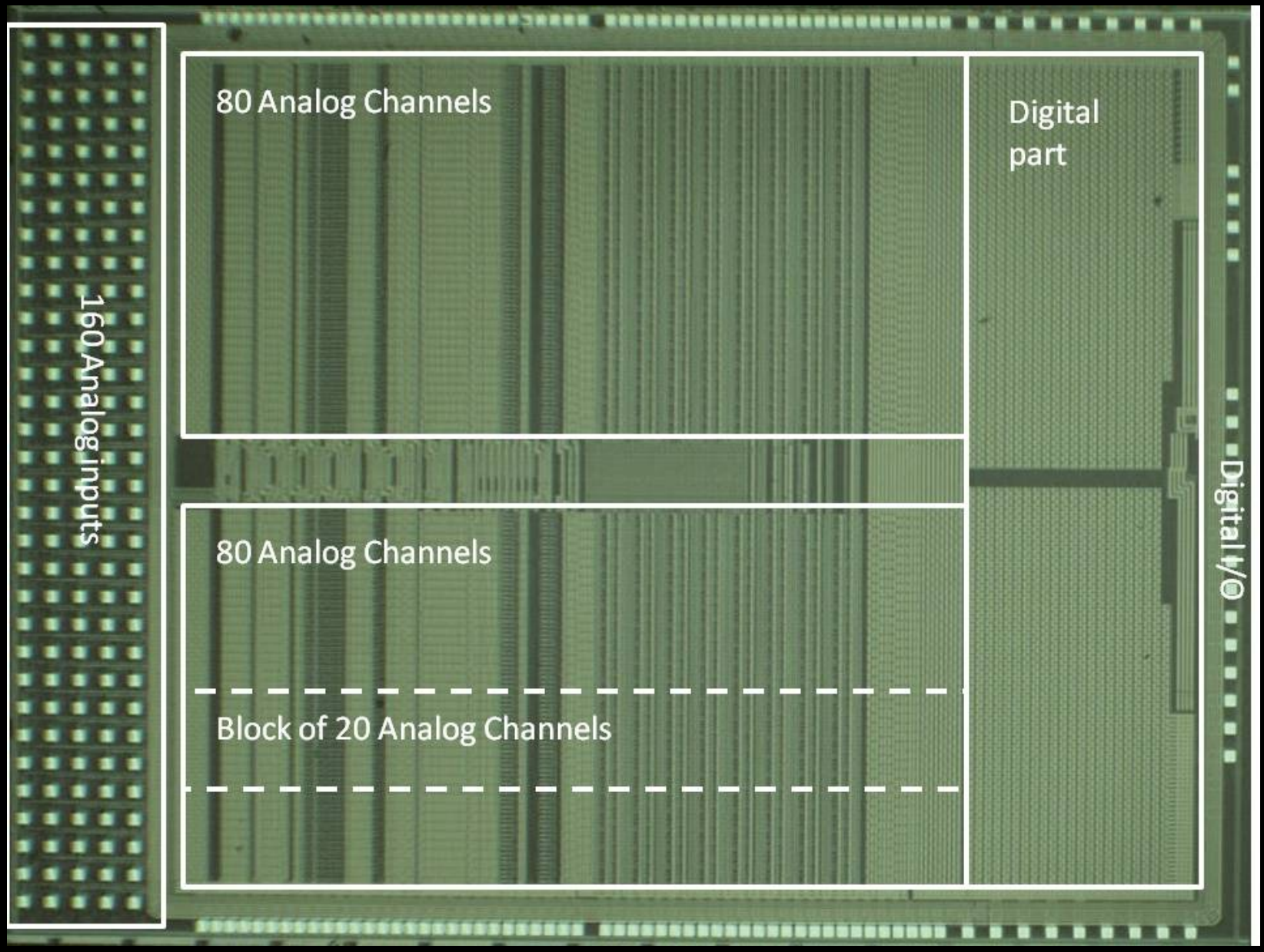
PHILIPS

Overview of detector



- Detector element size: 0.4 × 0.5 mm^2
- Depth segmentation:
  16 segments along incident direction
- 8 thresholds for each channel

ASIC – Developed for Silicon Spectral CT



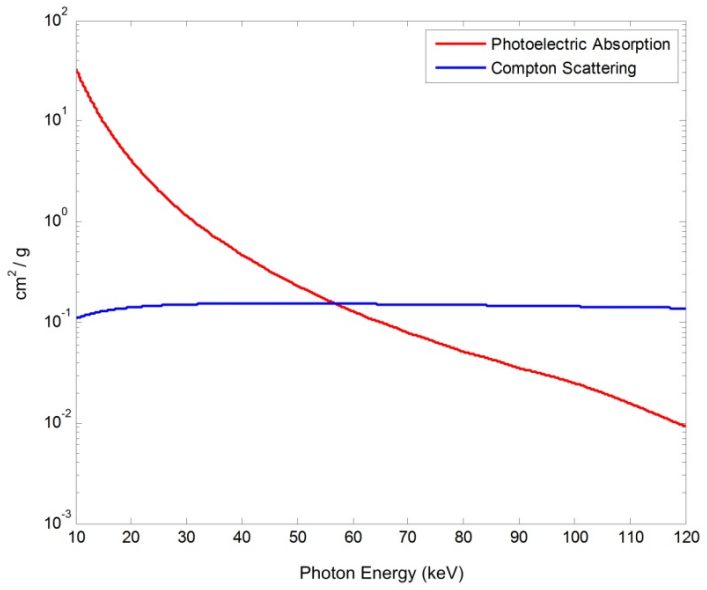
Detector Materials

Detector Materials for Spectral Photon Counting

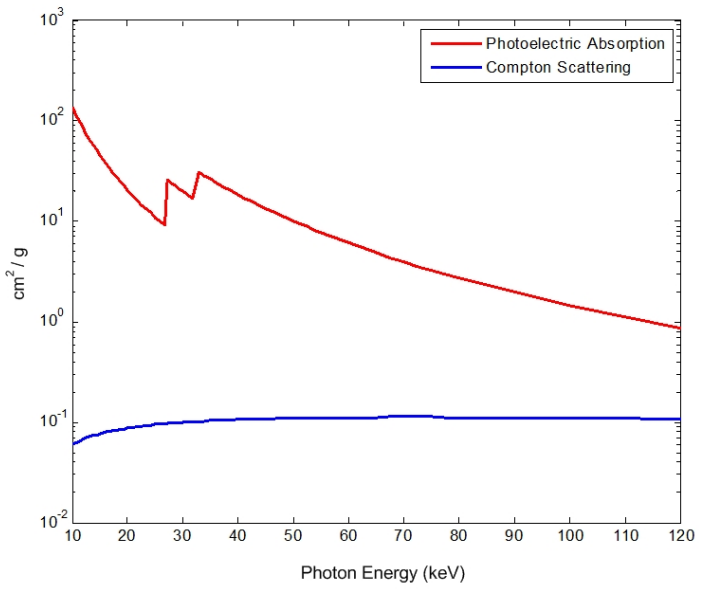
Material	Signal (20 keV X-ray)	Fano-factor	Speed (ns)	70% Absorption Depth (mm)	
				20 keV	100 keV
Silicon	5500	0.1	10	1	28
Gas (Krypton)	770	0.2	10	12	900 (Xe 200)
CdTe/CZT	2000	0.1	10	0.1	1.3

Compton Scattering versus Photo-effect

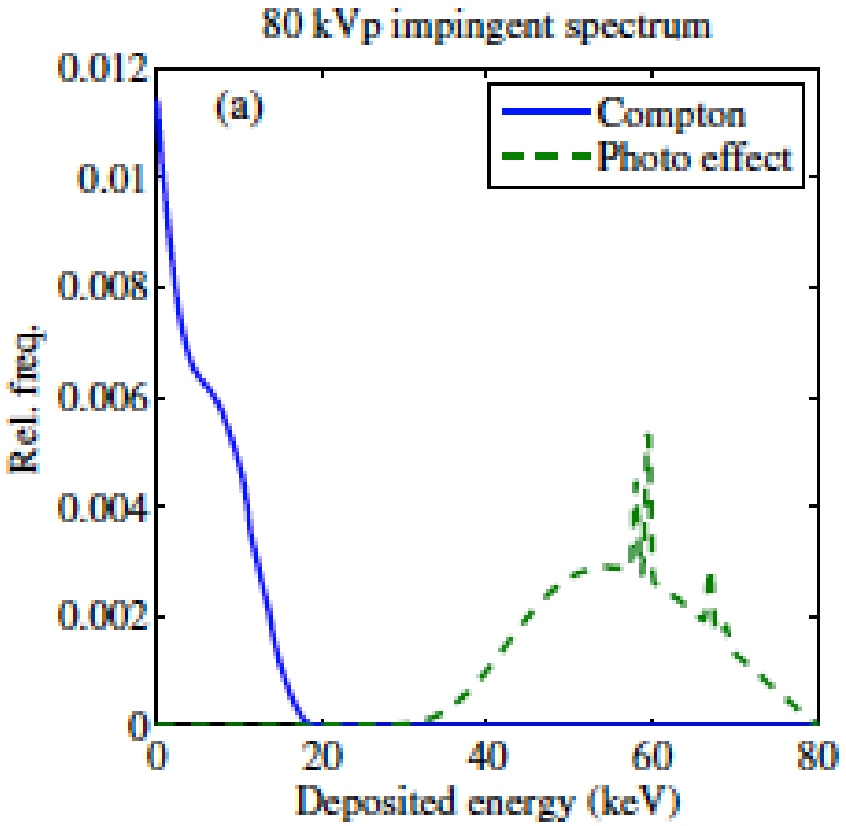
Silicon

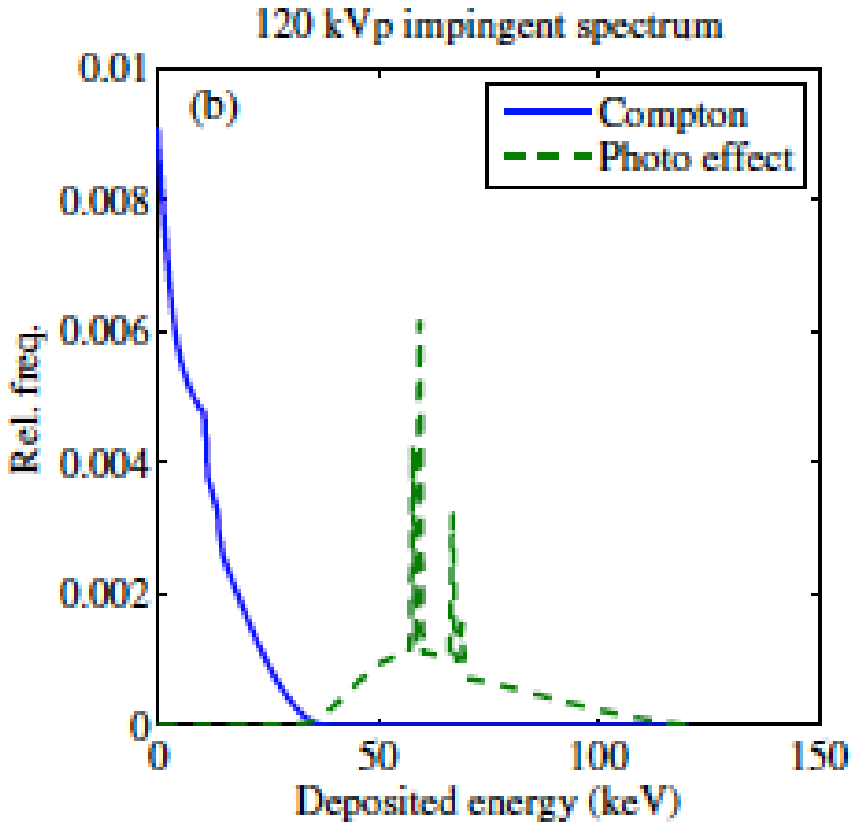


CdZnTe



Compton scattering?

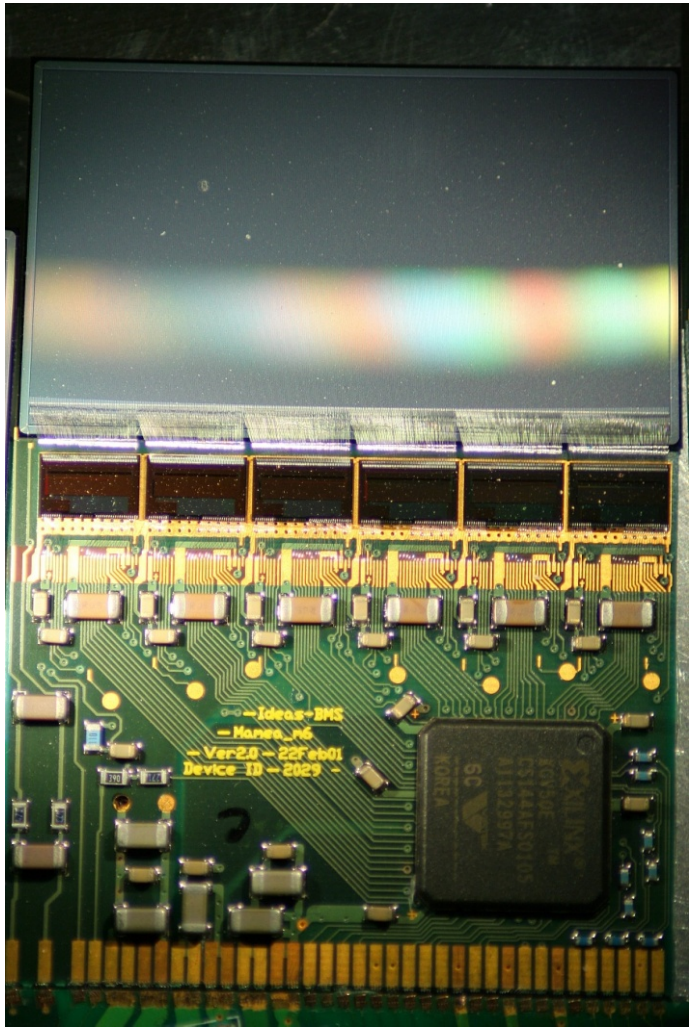




H Bornefalk and M Danielsson, “Photon-counting spectral computed tomography using silicon strip detectors: A feasibility study,” Phys. Med. Biol., vol. 55, no. 7, pp. 1999–2022, Apr. 2010

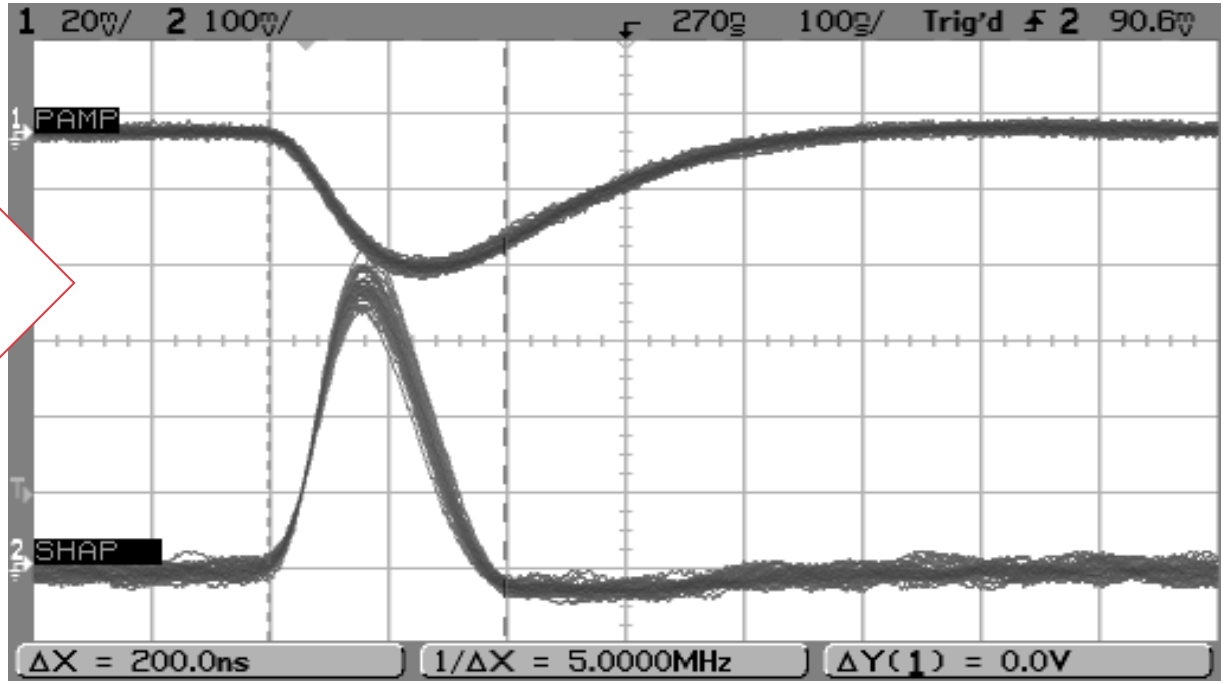
Front-end Electronics -very similar to high energy physics

- Fast
- Small Signals
- Low noise
- Massive parallel processing
- Small channel to channel variation
- Low power
- Temperature stable
- Digital readout not inducing noise



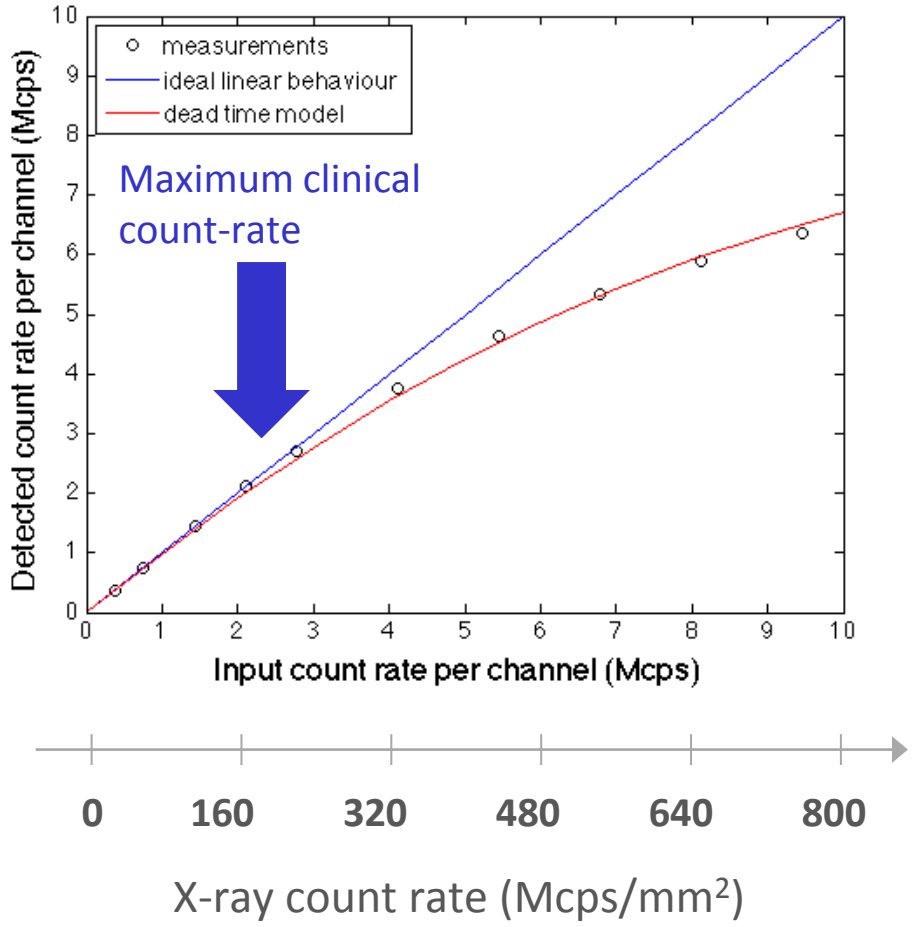
Electronics for Photon Counting

Oscilloscope Screen-dump



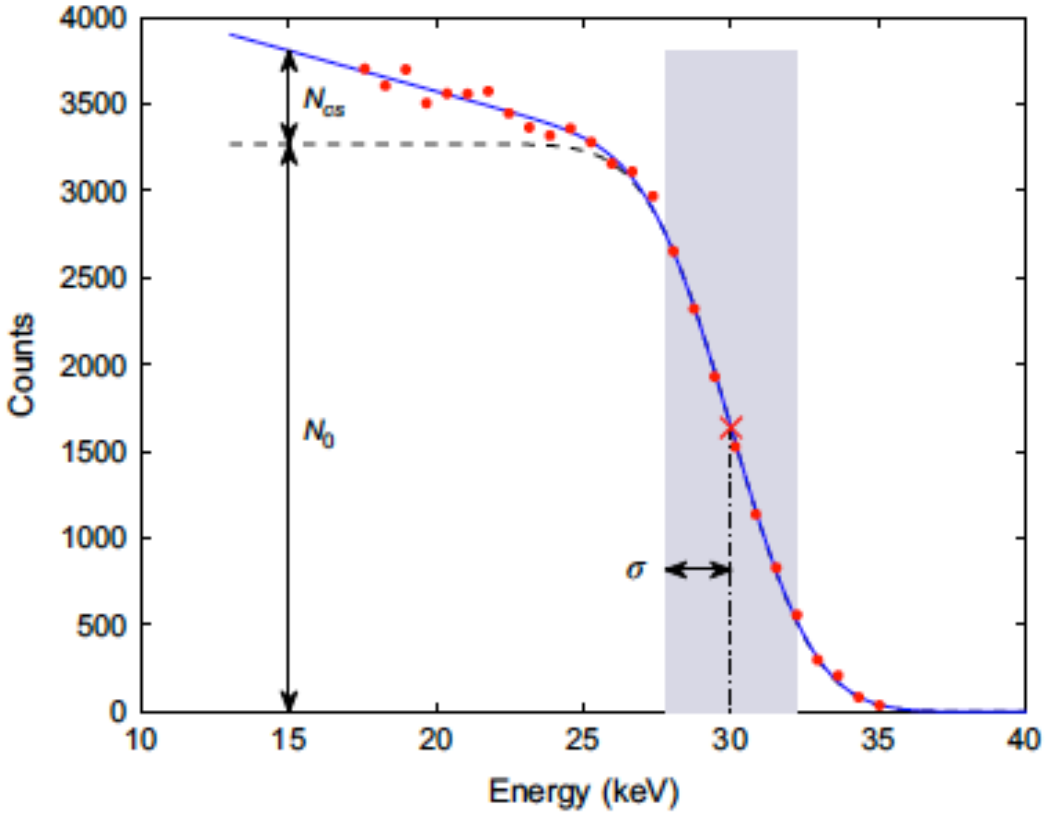
Problems:
Pile-up and charge sharing

Are we fast enough?



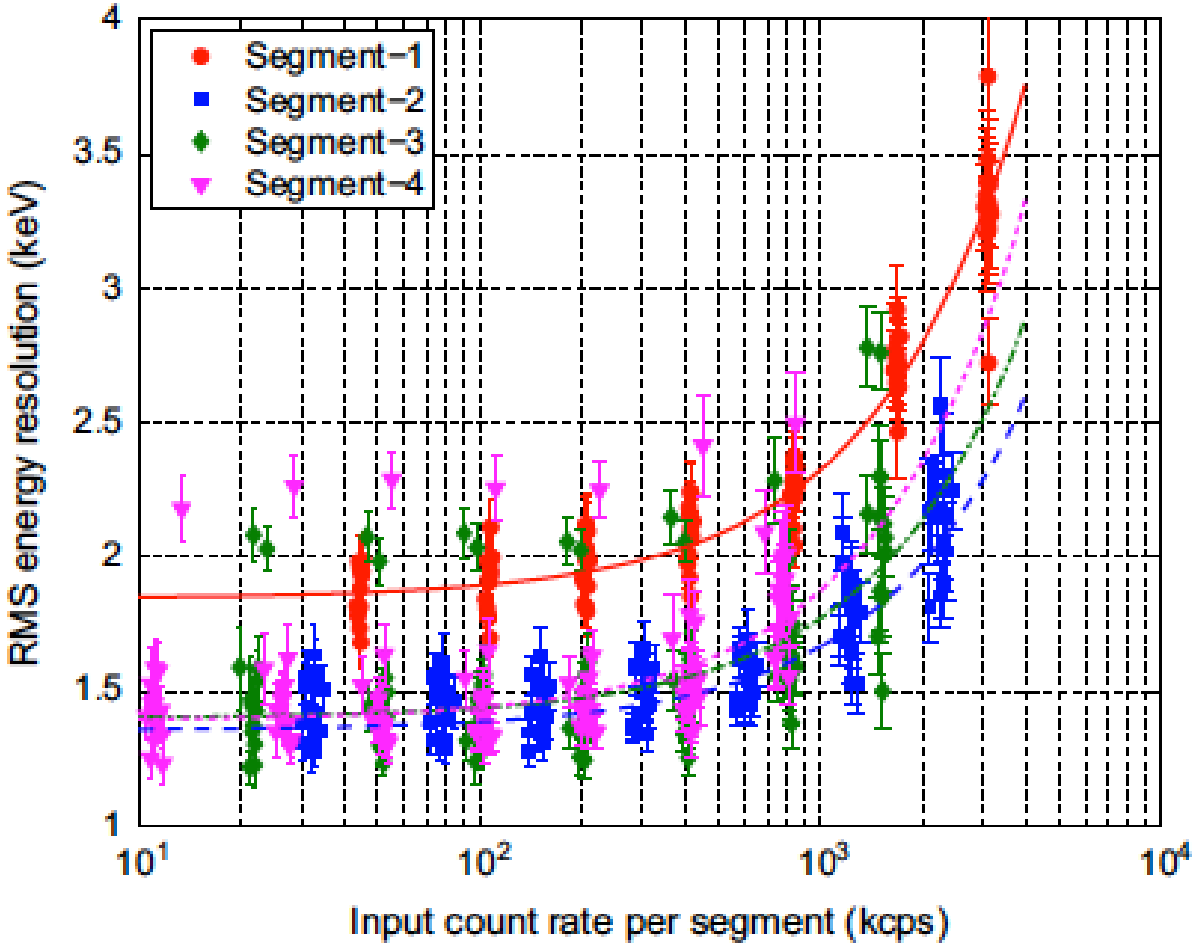
- 120 kVp polychromatic x-ray spectrum
- 33 ns deadtime per x-ray detection
- Linear relation up to 200 Mcps/mm^2

Measurement of Energy Resolution - Example



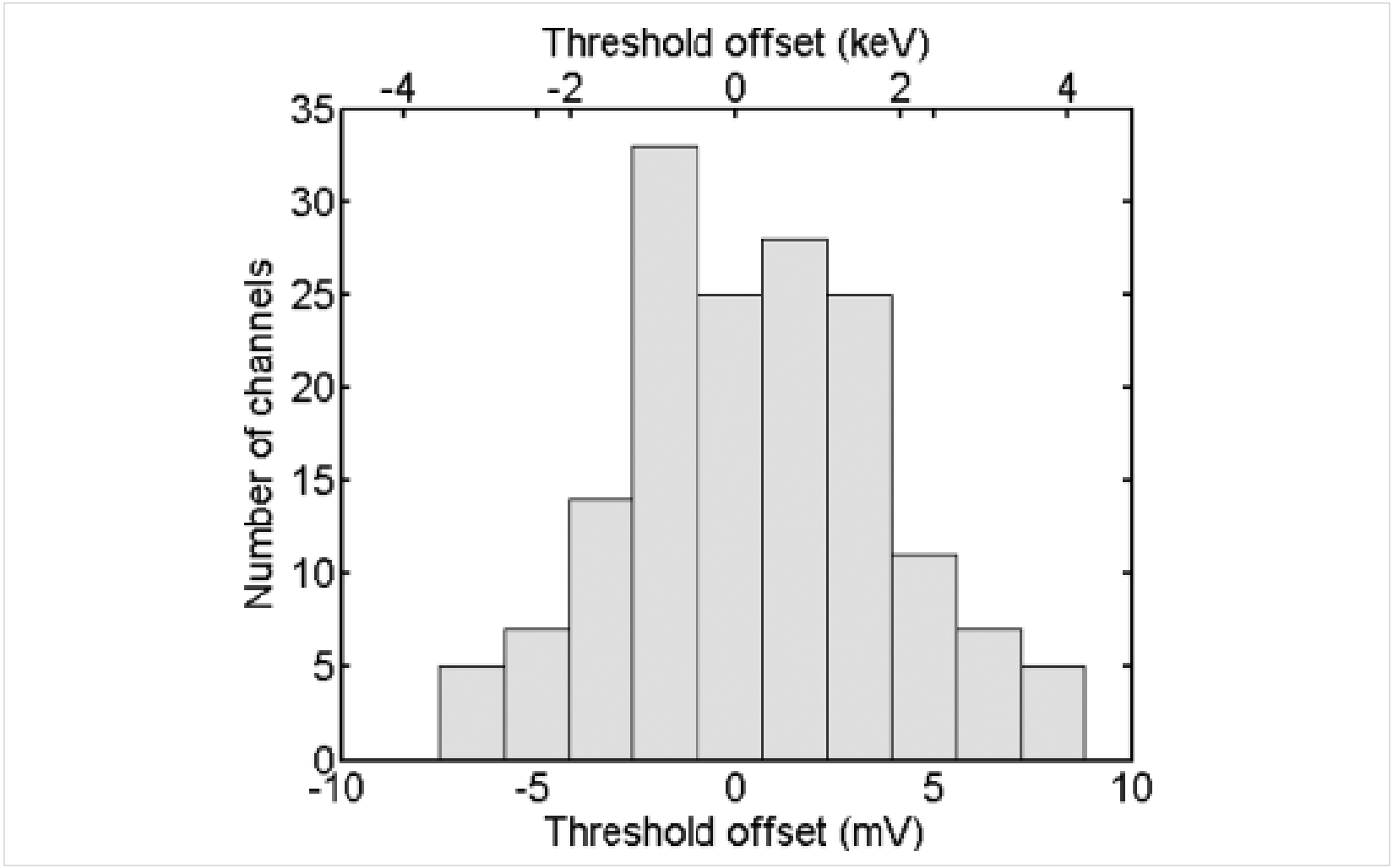
$$f(x;\mu,\sigma,\mathrm{A},\mathrm{B}) = \frac{1}{2}\mathrm{erfc}\left(\frac{x-\mu}{\sqrt{2}\sigma}\right)(A(x-\mu)+B)$$

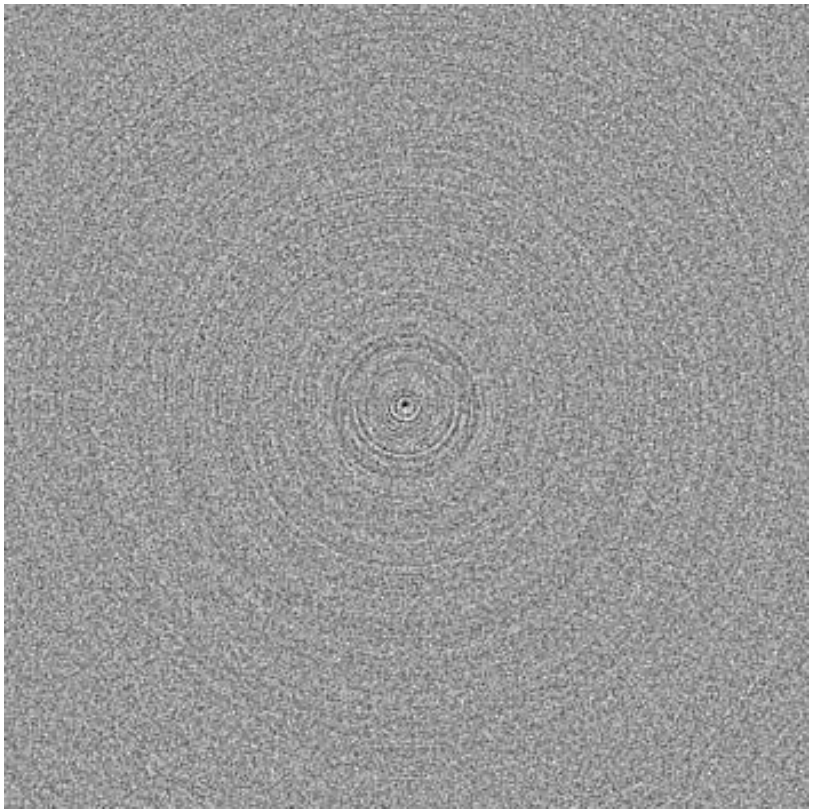
Measurement of Energy Resolution - Example

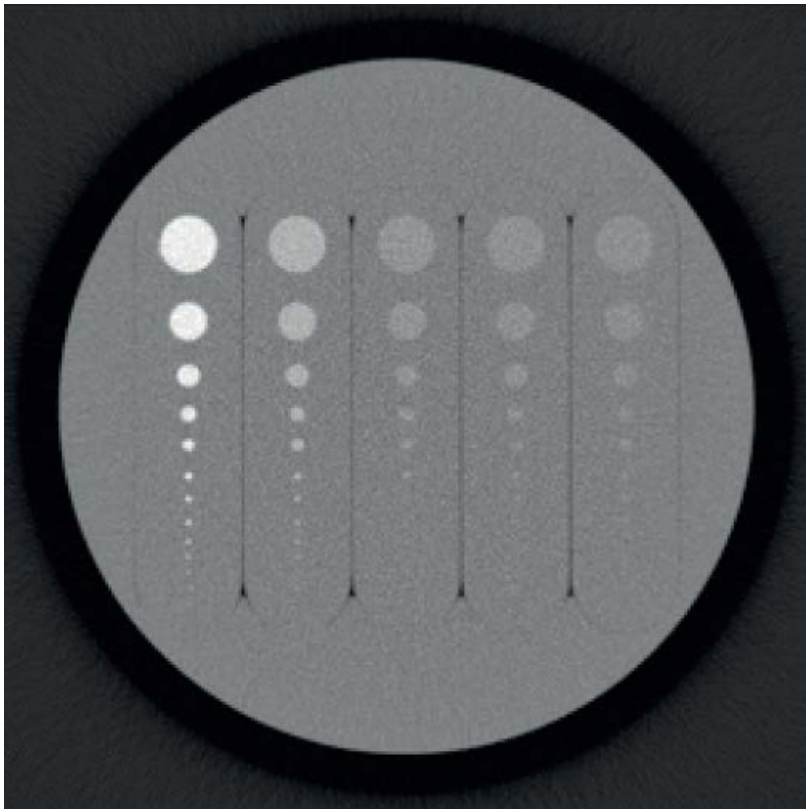


Normalization

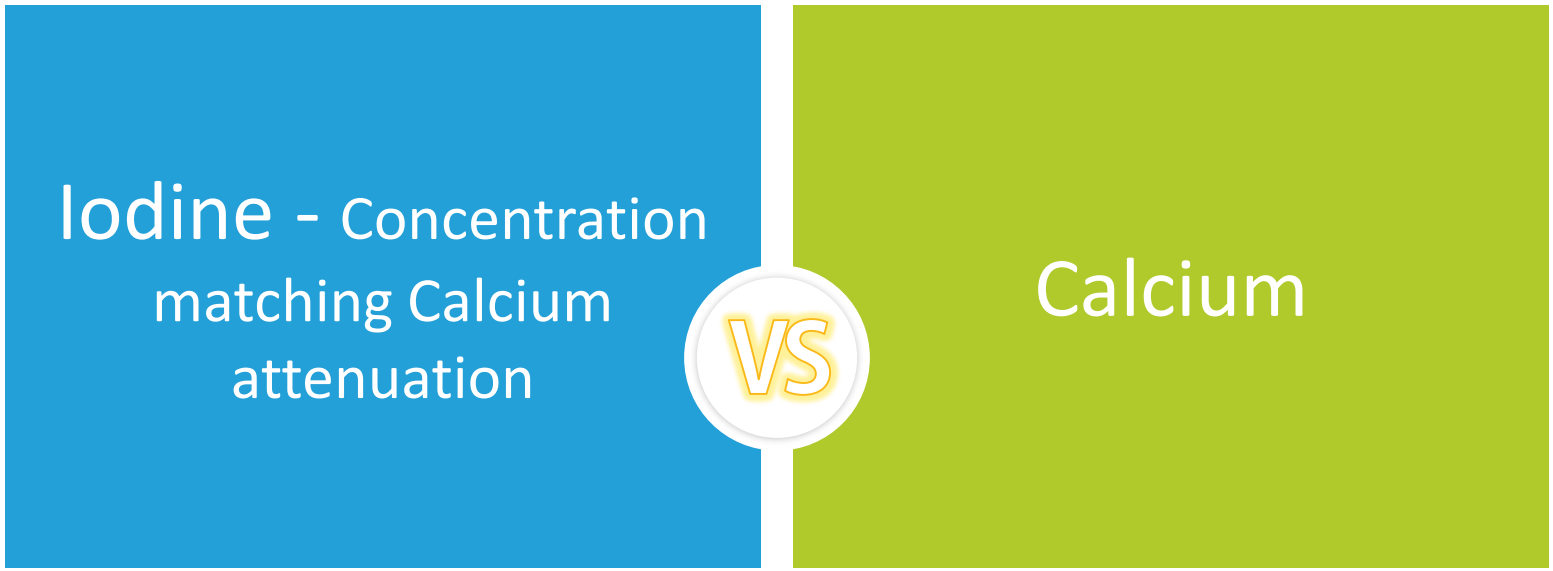
Threshold off-set



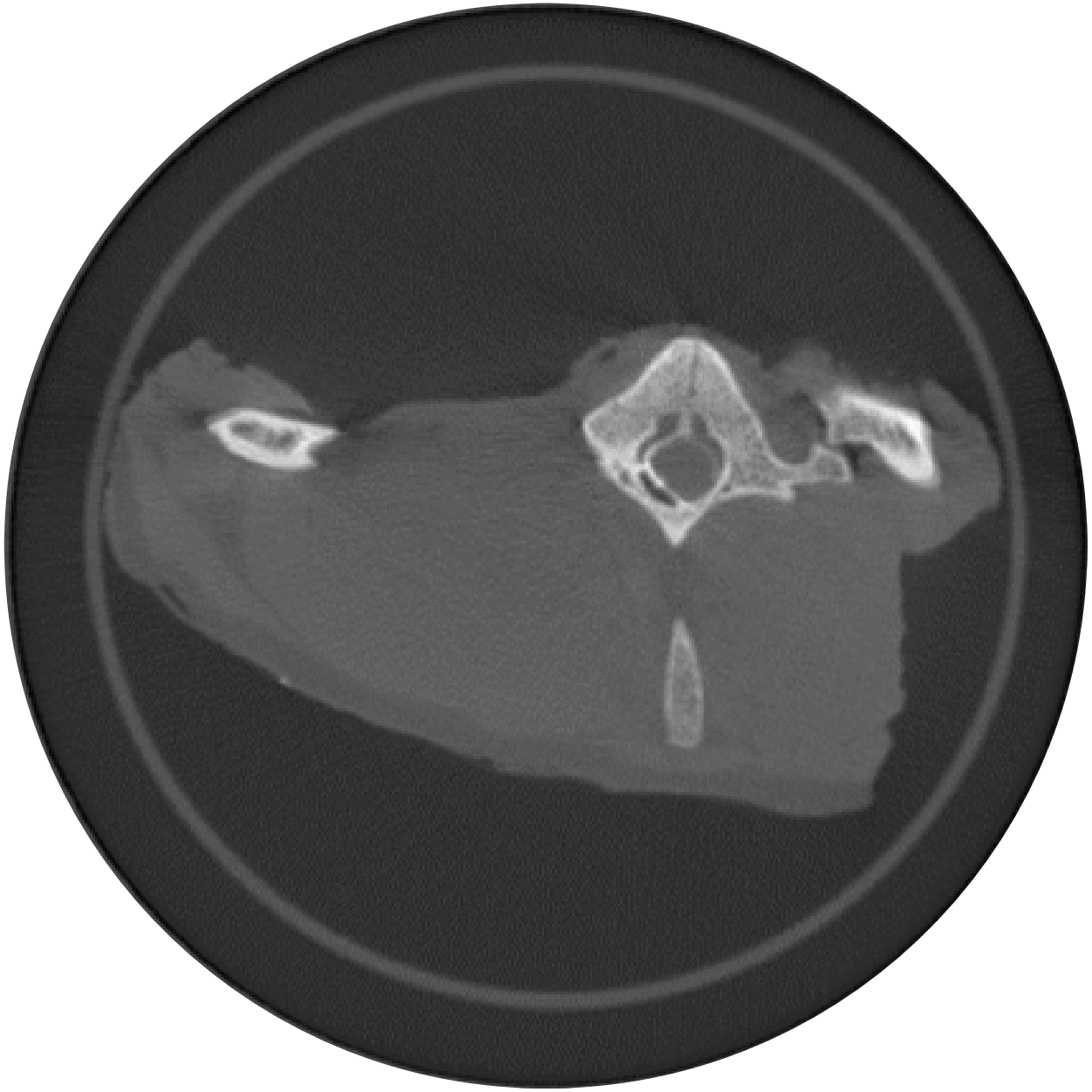


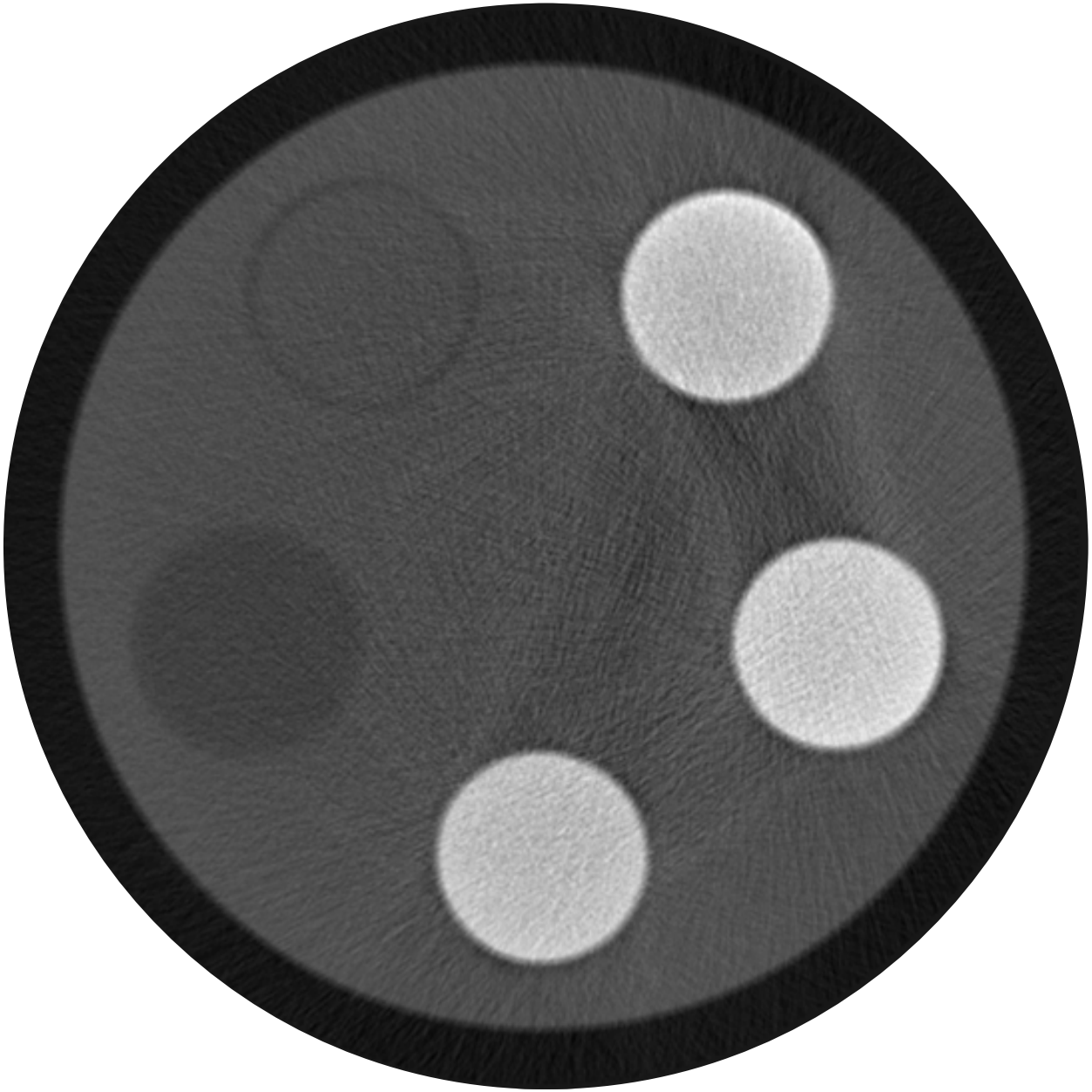


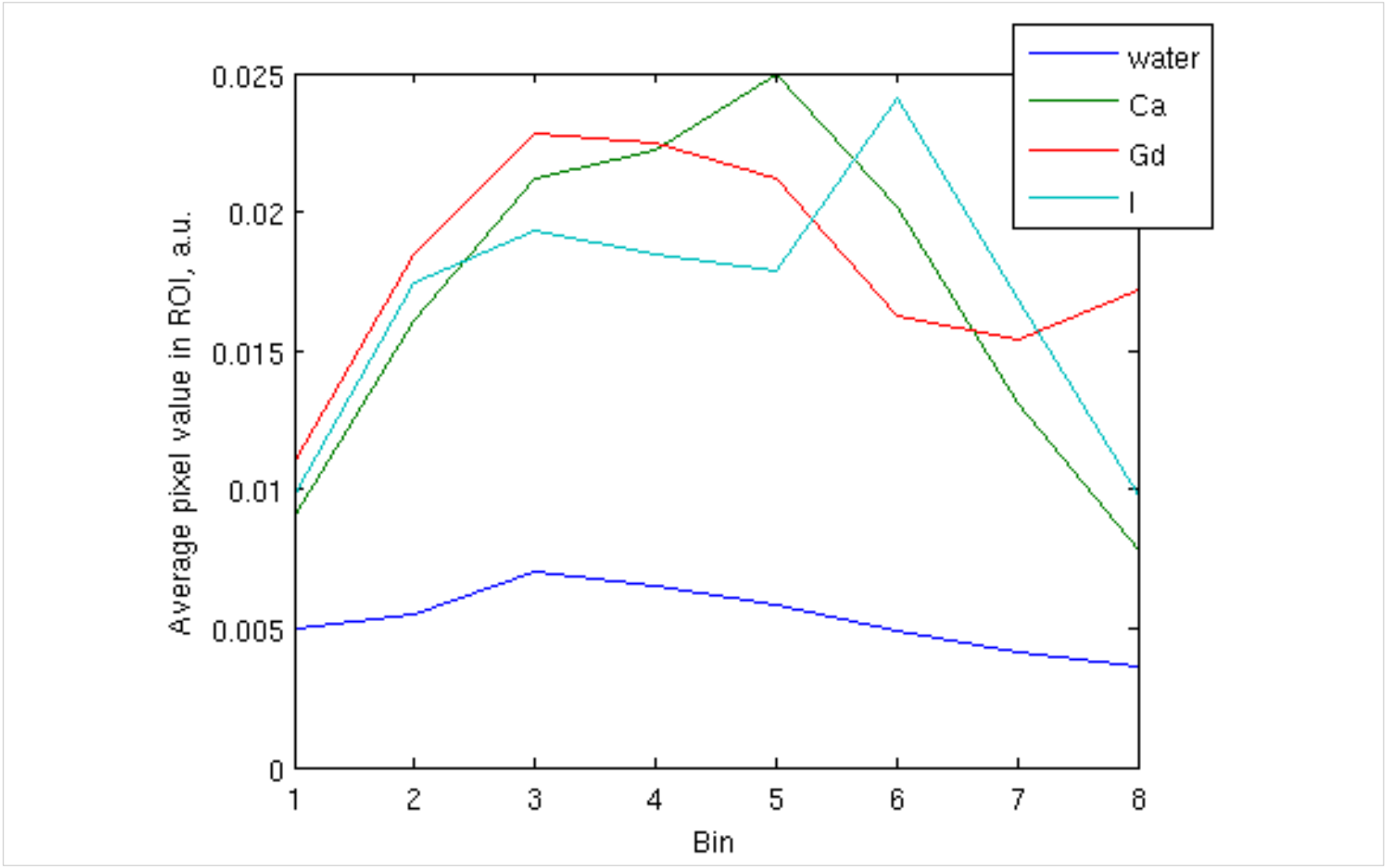
Clinical Benefit Example: Bone versus Iodine

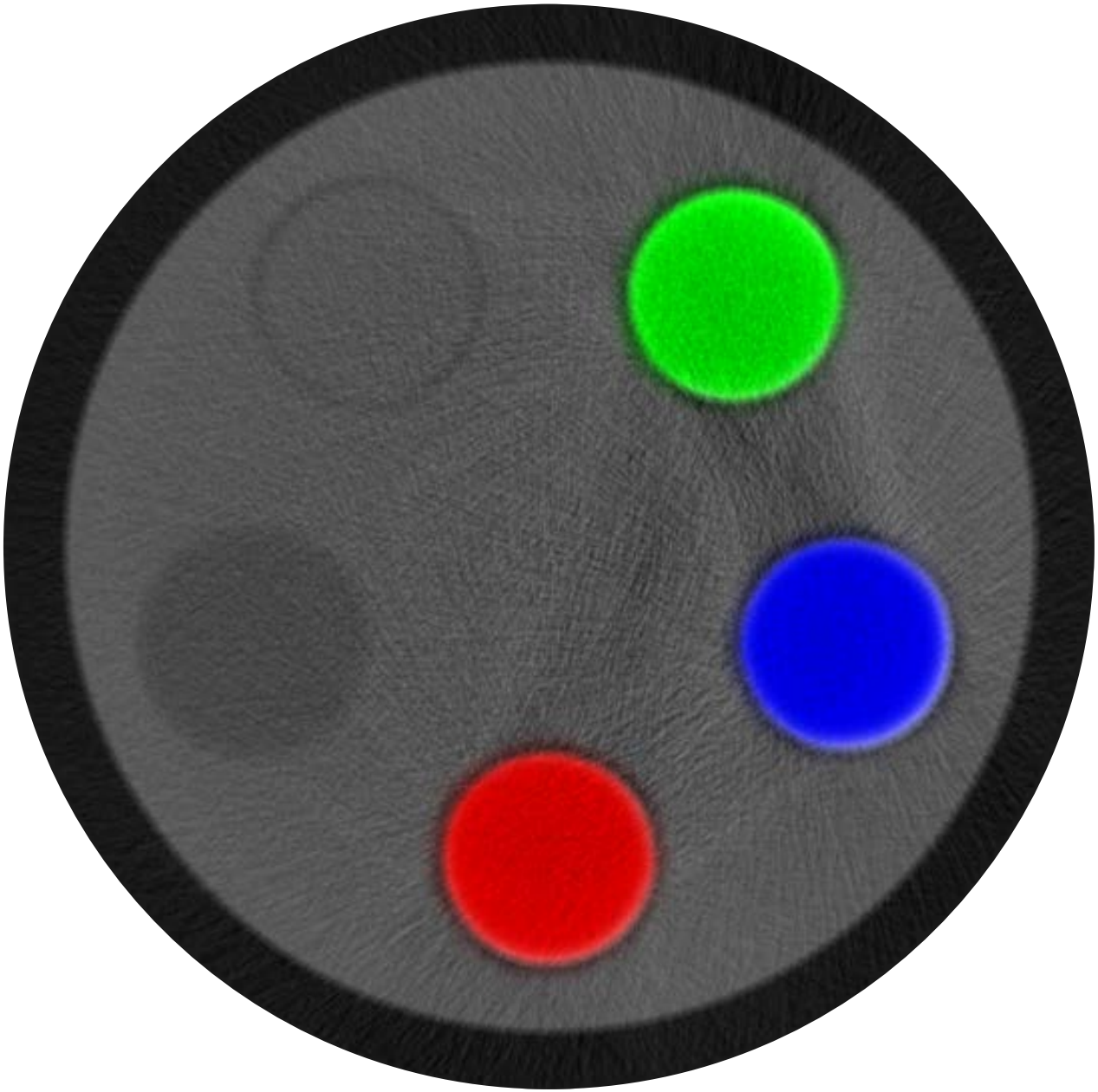


Voxels with different materials can appear the same in image



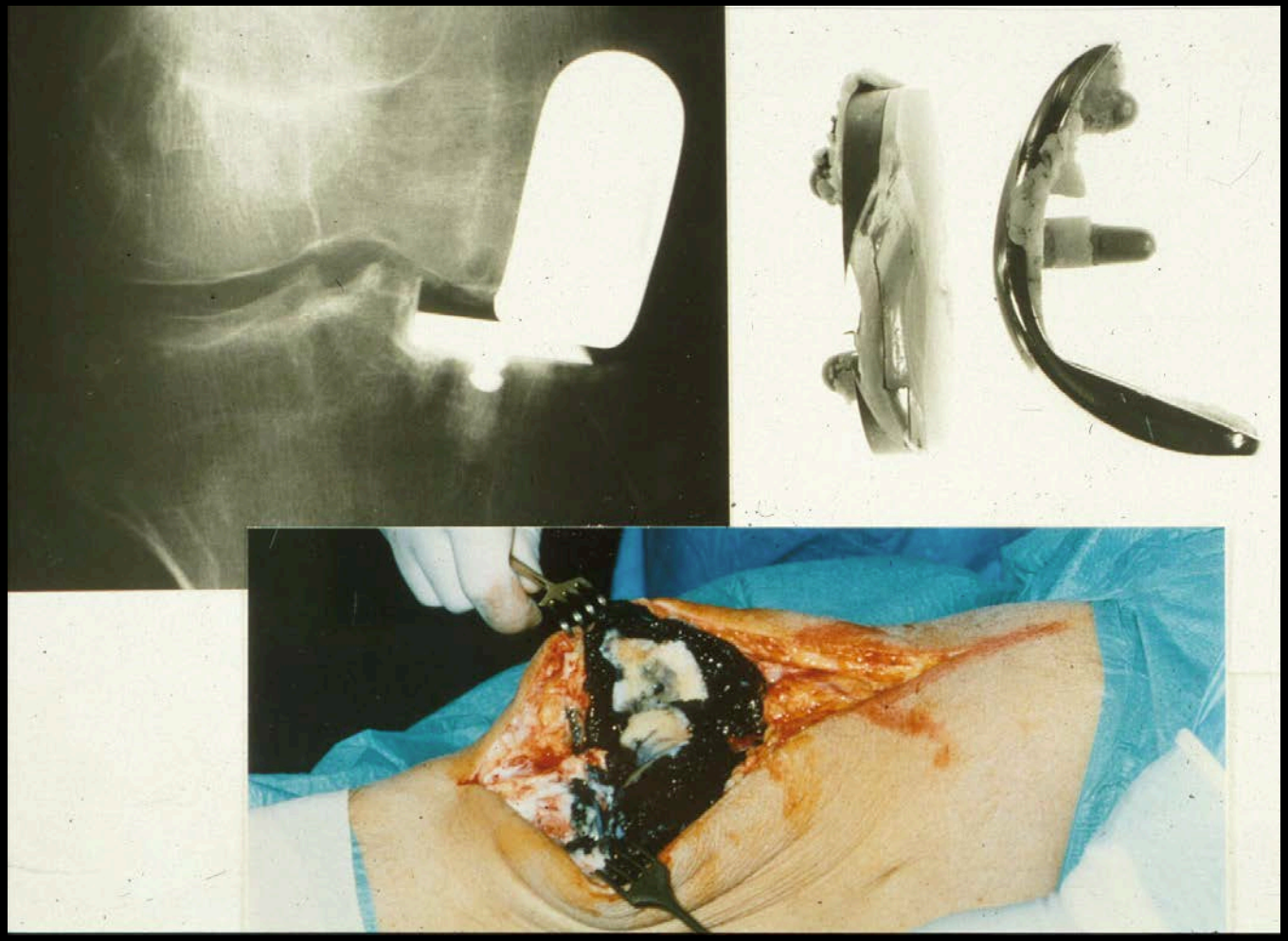



water
Ca
Gd
I
0.025
0.02
0.015
0.01
0.005
0
Average pixel value in ROI, a.u.
1
2
3
4
5
6
7
8
Bin

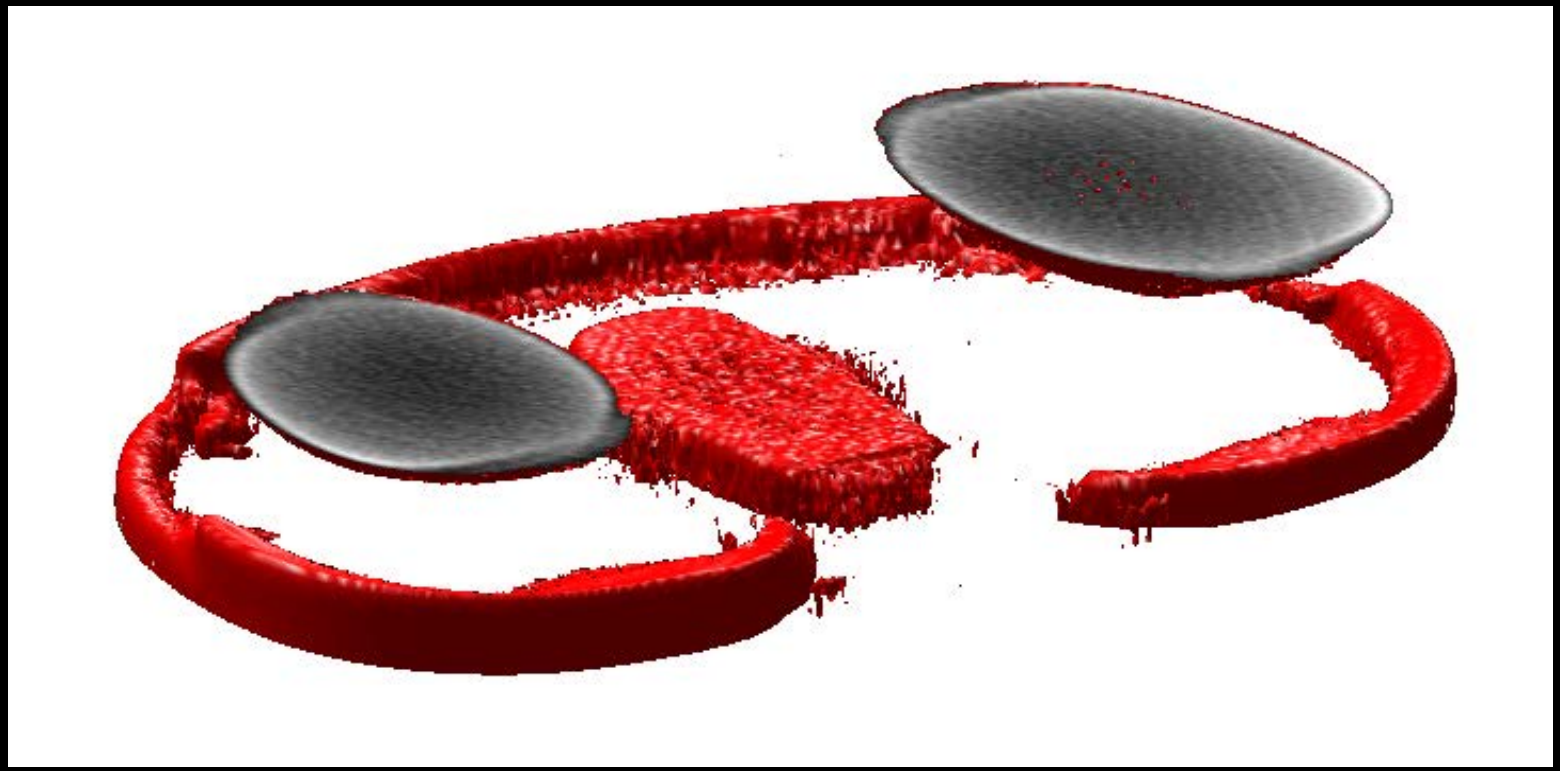


Wear in Knee Replacements

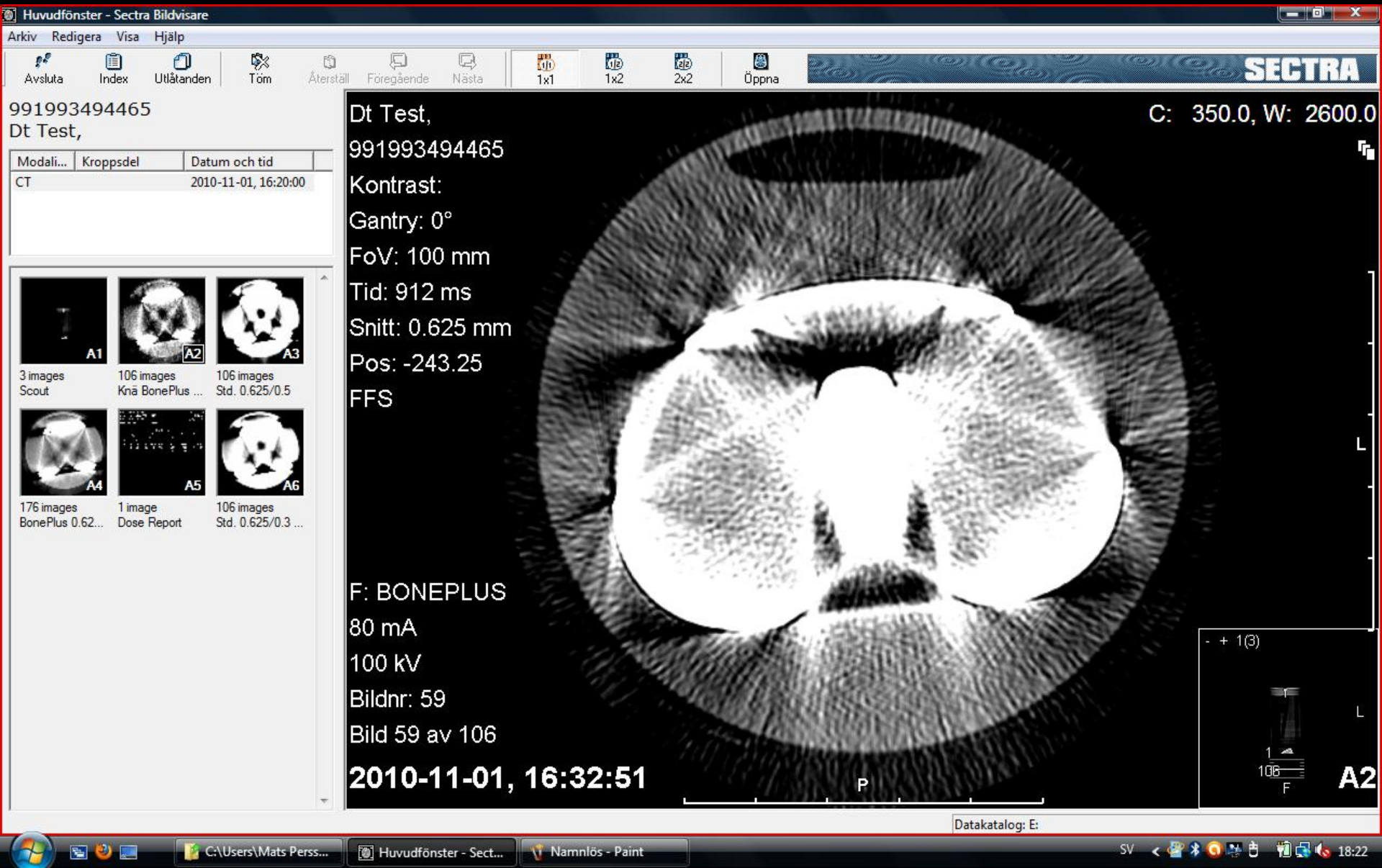
Image Courtesy of Dr L. Wiedenhielm, Karolinska Hospital, Stockholm Hospital



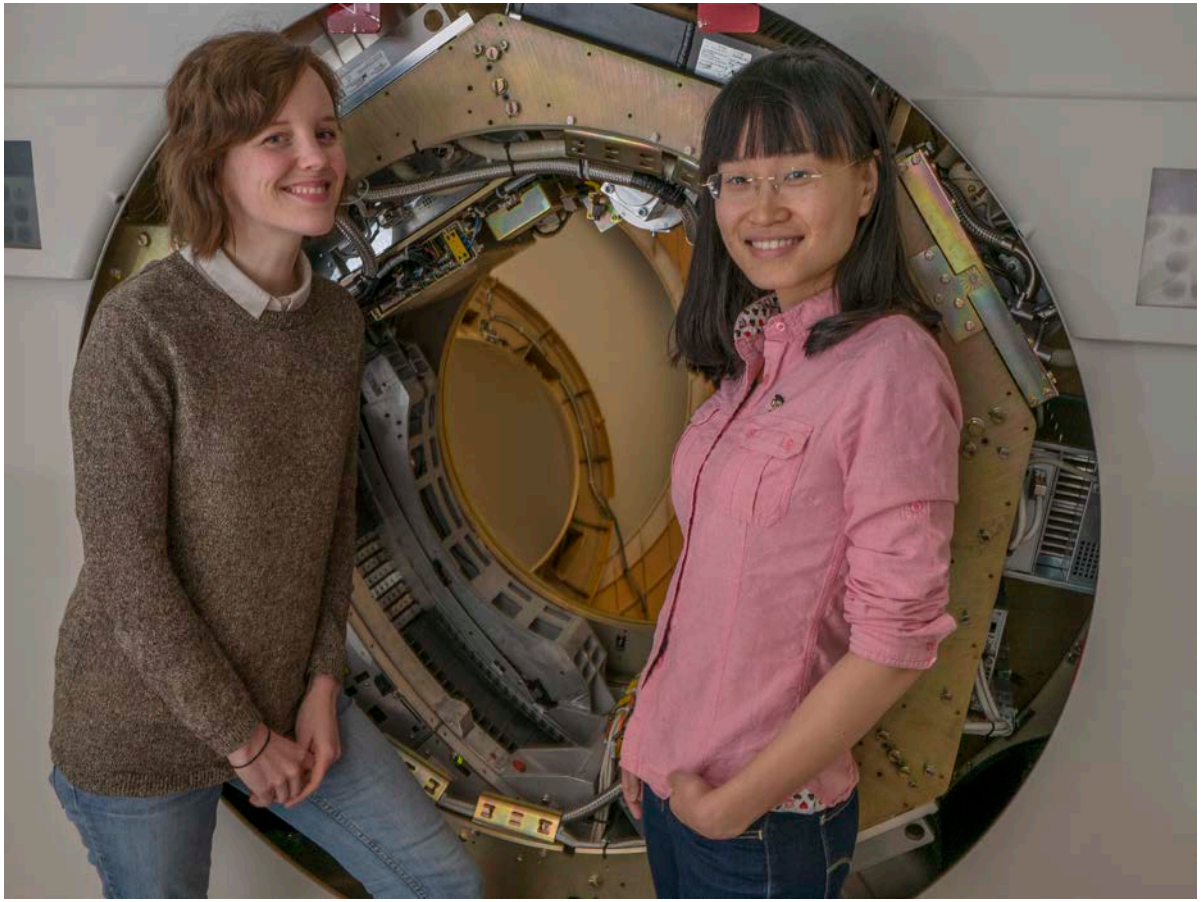
Silicon CT segmented image



State-of-the-art Karolinska Hospital



Clinical trial focusing on stroke planned for 2015



Project Background

Patent for the idea granted to David Nygren 1995

During the last 6 months:

A flexible personal computer based data acquisition system has been developed

The 16 channel ASIC has been fabricated and tested to work according to our specifications

Detectors have been manufactured and dark currents have been measured to be in the order of 10 pA as expected

The ASIC has been wirebonded to the detector and signals obtained from radioactive source

Currently everything is ready for mounting in the X-ray cabinet and we will very soon scan our first images.

The project has been supported by the physics division by about $40k/year

U.S. PHS office of Women's Health: New Frontiers in Image-Guided Breast Cancer Diagnosis and Treatment, Site Visit to Berkeley Lab, Feb. 27, 1997

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Clinical Applications

Chest Radiography

Bone Densiometry

Computed Tomography

Mammography

Angiography

Mammography

Digital Subtraction Radiography

Other Applications

Non Destructive

Testing Airport Security

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