

Photon-counting CT with edge-on silicon

Mats Danielsson

Kungliga Tekniska Högskolan, Stockholm, Sweden

23rd International Workshop for Radiation Imaging Detectors

June 29, 2022 Riva del Garda, Italy

Acknowledgements

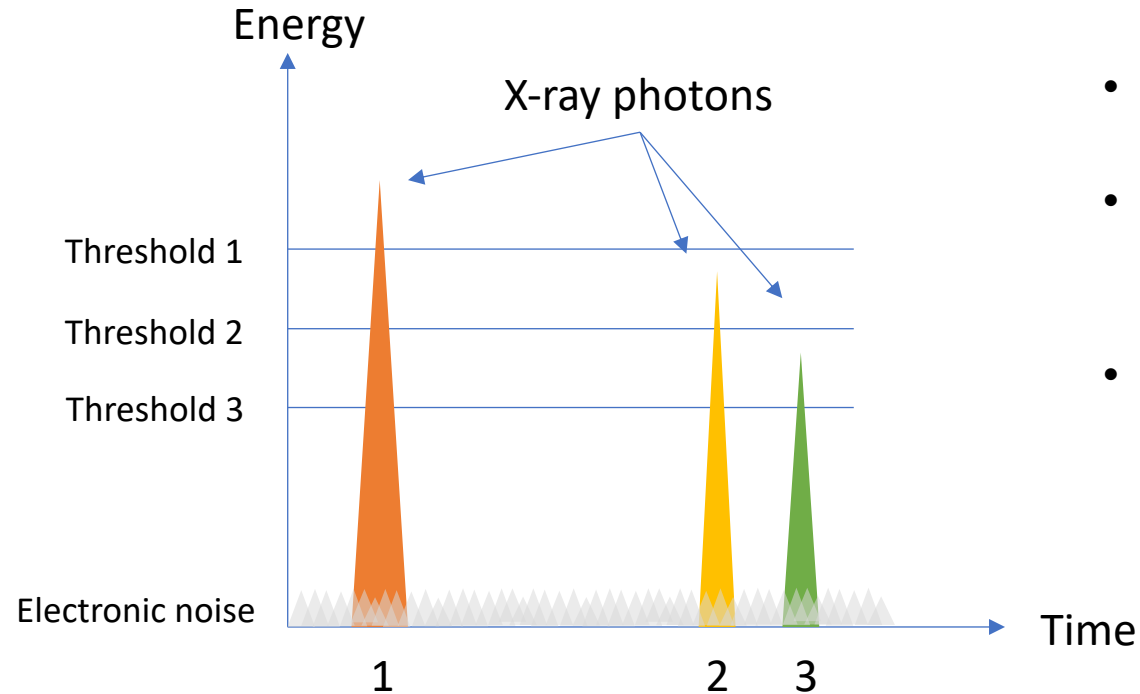
Mats Persson

Christel Sundberg

Disclosures

Consulting agreement with GE Healthcare

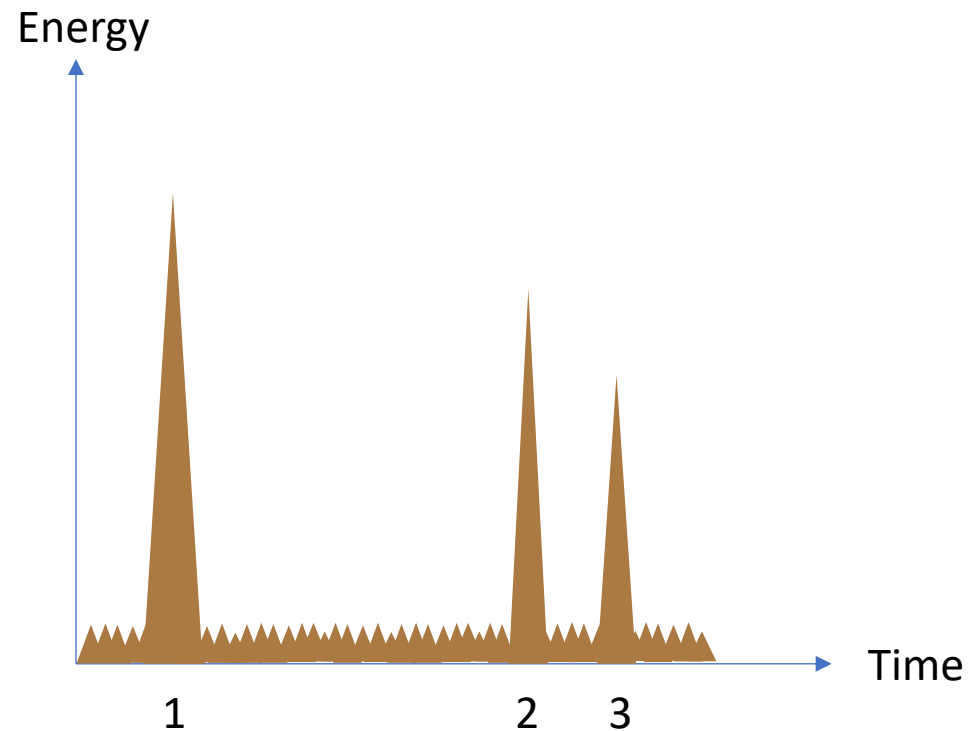
To Count Photons – What does it mean?




Result

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

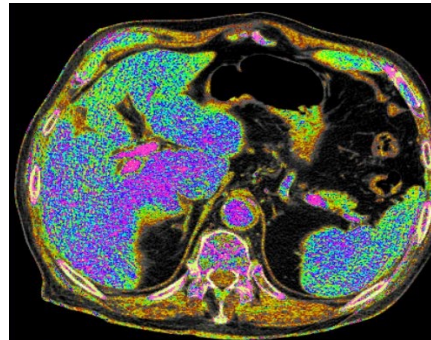
Integrating Current – Today's praxis in X-ray Imaging



Result

- Area of 
- Indirect estimate of number of photons

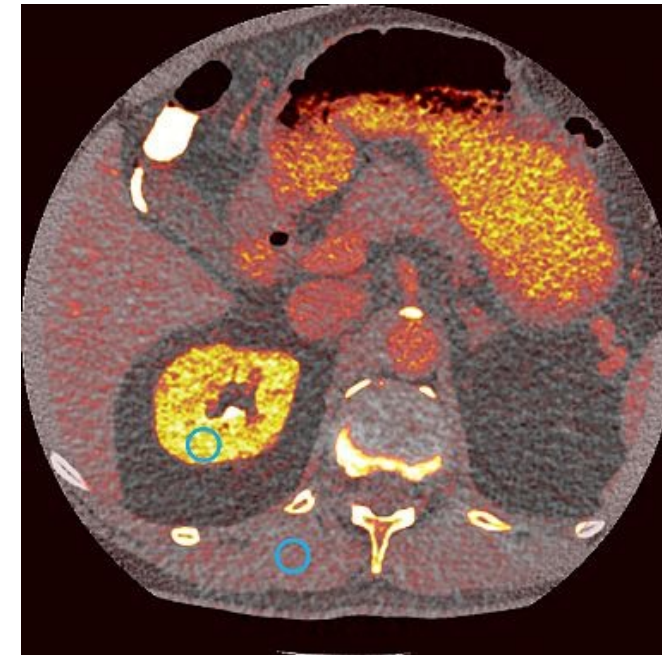
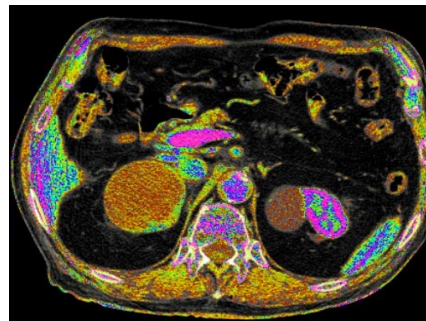
Clinical Photon Counting CT



Z-map*
images



MCI-70 keV



*Color-mapping according to tissue atomic number

Diagnostic Imaging 25 (7) 2009

NIH press release Feb 24 2016

For Immediate Release: September 30, 2021

FDA Clears First Major Imaging Device Advancement for Computed Tomography in Nearly a Decade

“Computed tomography is an important medical imaging tool that can aid in diagnosing disease, trauma or abnormality; planning and guiding interventional or therapeutic procedures; and monitoring the effectiveness of certain therapies,” said Laurel Burk, Ph.D., assistant director of the Diagnostic X-ray Systems Team in the FDA’s Center for Devices and Radiological Health. “Today’s action represents the first major new technology for computed tomography imaging in nearly a decade and underscores the FDA’s efforts to encourage innovation in areas of scientific and diagnostic progress.”

HEALTH AND SCIENCE

GE health unit buys Swedish start-up Prismatic Sensors, bolstering key medical imaging business

PUBLISHED FRI, NOV 20 2020-12:01 AM EST | UPDATED FRI, NOV 20 2020-7:01 AM EST



Berkeley Lovelace Jr.
@BERKELEYJR

SHARE    

KEY POINTS

- GE Healthcare said the start-up's technology offers sharper images with fewer doses of radiation to patients.
- It has the potential to be a "substantial step forward" in detecting cancer, heart disorders and other diseases, the company said, declining to disclose the terms of the deal.
- The acquisition fits within GE Healthcare's mission to help medical workers deliver more precise diagnoses and detect diseases earlier.

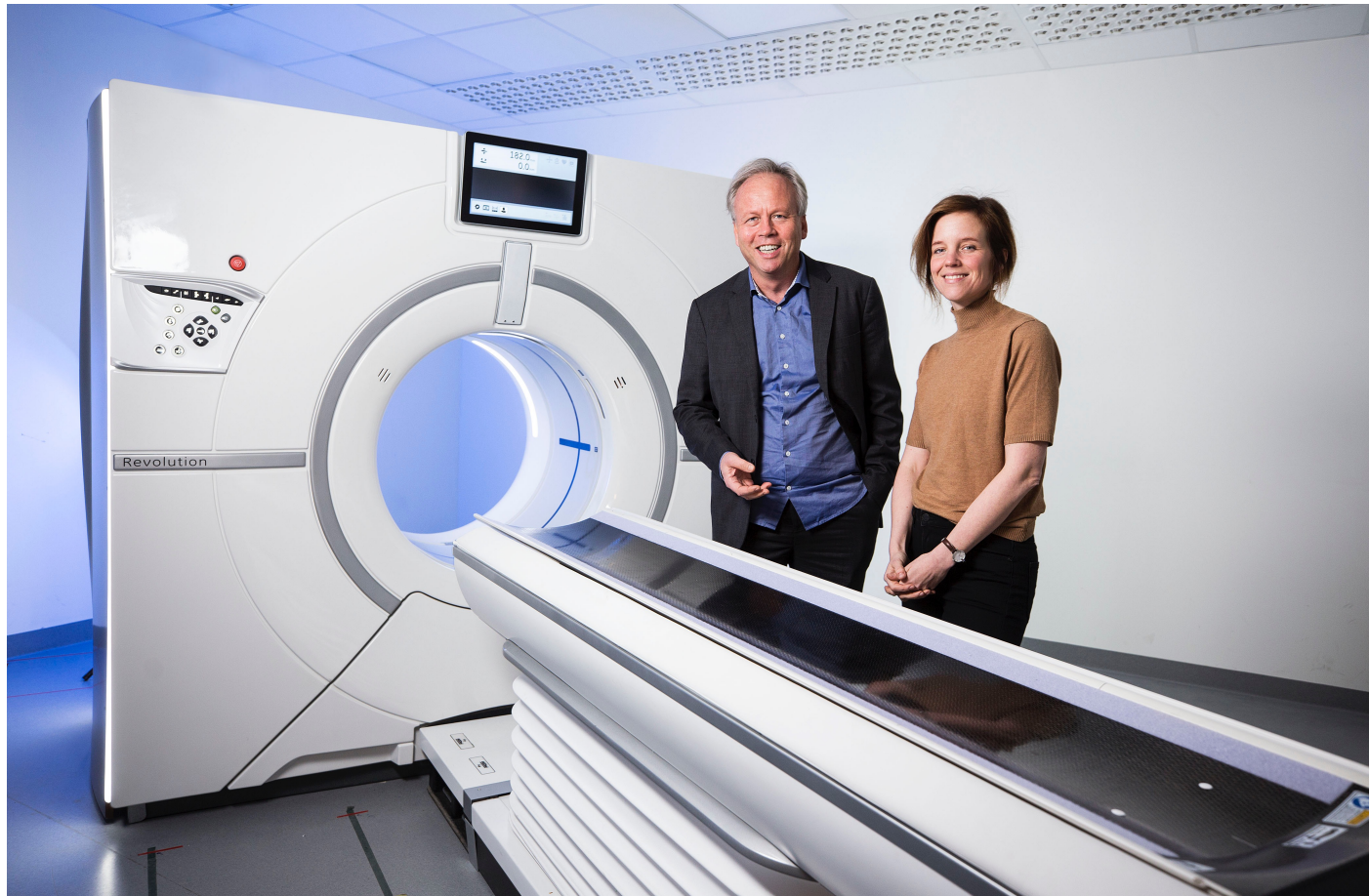


Larry Culp, CEO, General Electric
Scott Mlyn / CNBC

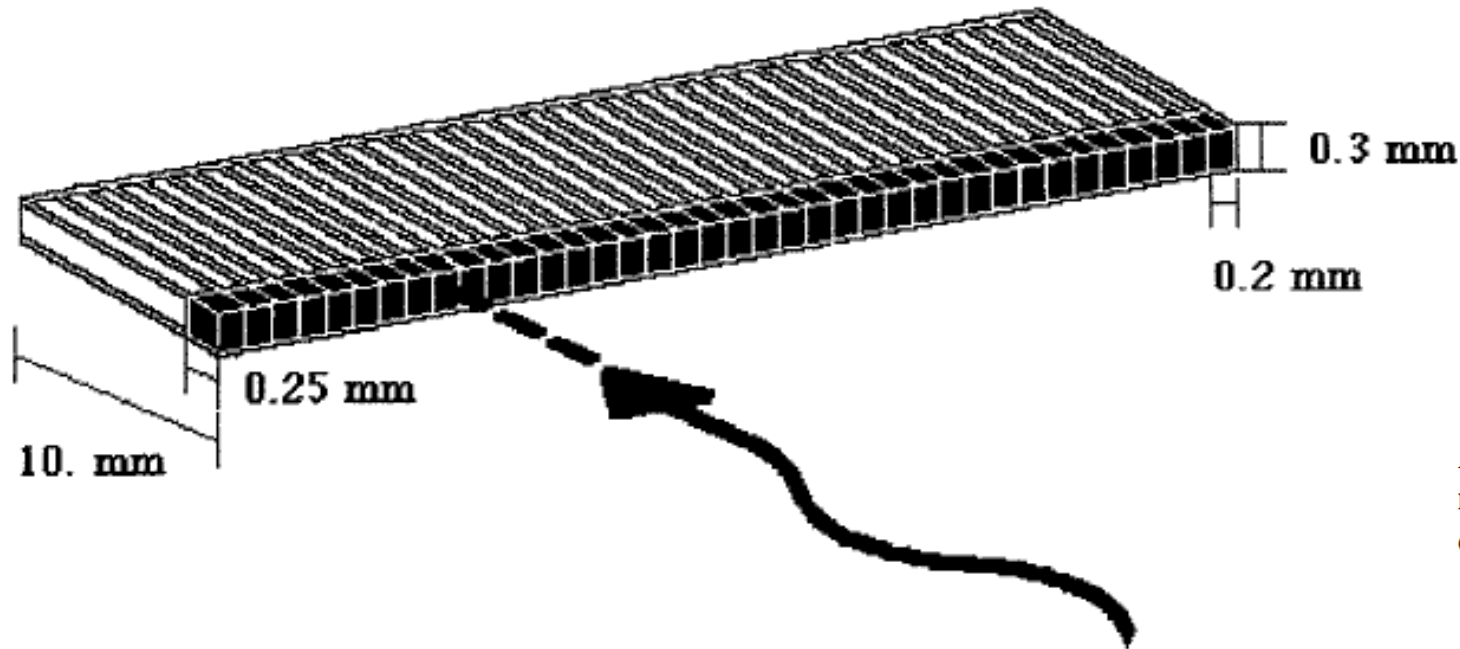
GE Healthcare announced Friday it is acquiring Swedish start-up Prismatic Sensors AB, bolstering its key medical imaging business.

Prismatic Sensors AB was founded in 2012 as a spin-off from KTH Royal Institute of Technology in Stockholm, Sweden. It makes detectors for CT imaging.

Photon-counting Integration in the Revolution Platform



Some history of edge-on Silicon..



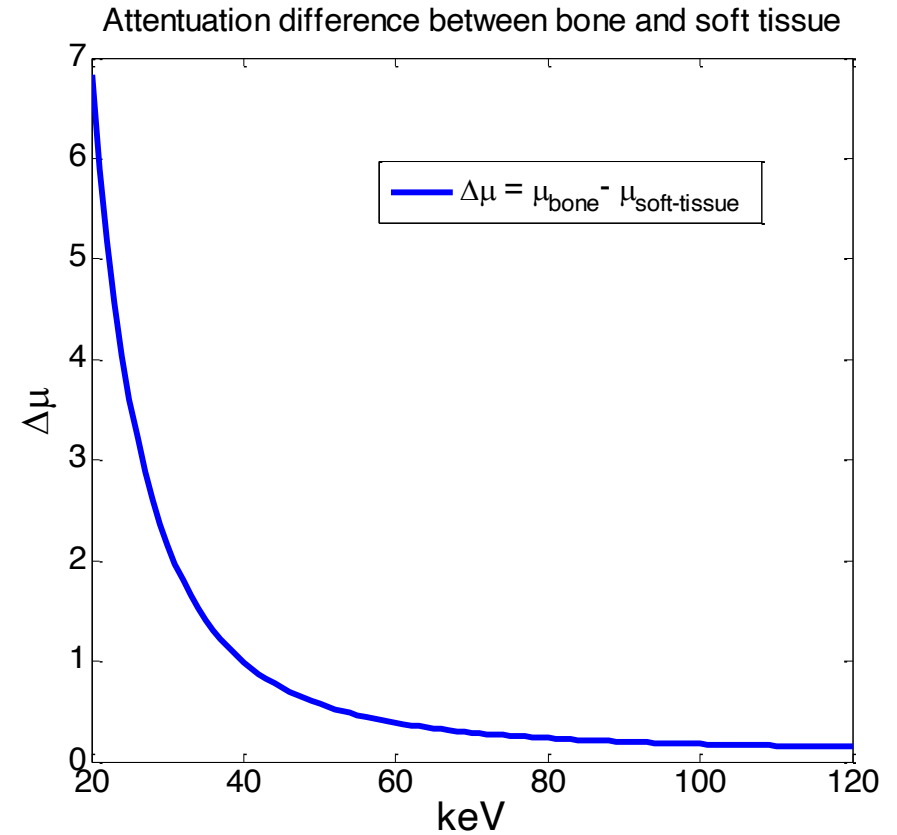
A linear array silicon pixel detector: images of a mammographic test object and evaluation of delivered doses

F Arfelli††, V Bonvicini†, A Bravin†§, G Cantatore†§, E Castelli†§, L Dalla Palma||, M Di Michiel†§, R Longo†§¶, A Olivio†§, S Pani††, D Pontoni††, P Poropat†§, M Prest†§, A Rashevsky†, G Tromba†† and A Vacchi†

† Istituto Nazionale di Fisica Nucleare, Sezione di Trieste, via Valerio 2, 34127 Trieste, Italy
 ‡ Società Sincrotrone, Basovizza, 34012 Trieste, Italy
 § Dipartimento di Fisica dell'Università di Trieste, via Valerio 2, 34127 Trieste, Italy
 || Istituto di Radiologia dell'Università di Trieste, Ospedale di Cattinara, Strada di Fiume, 34100 Trieste, Italy

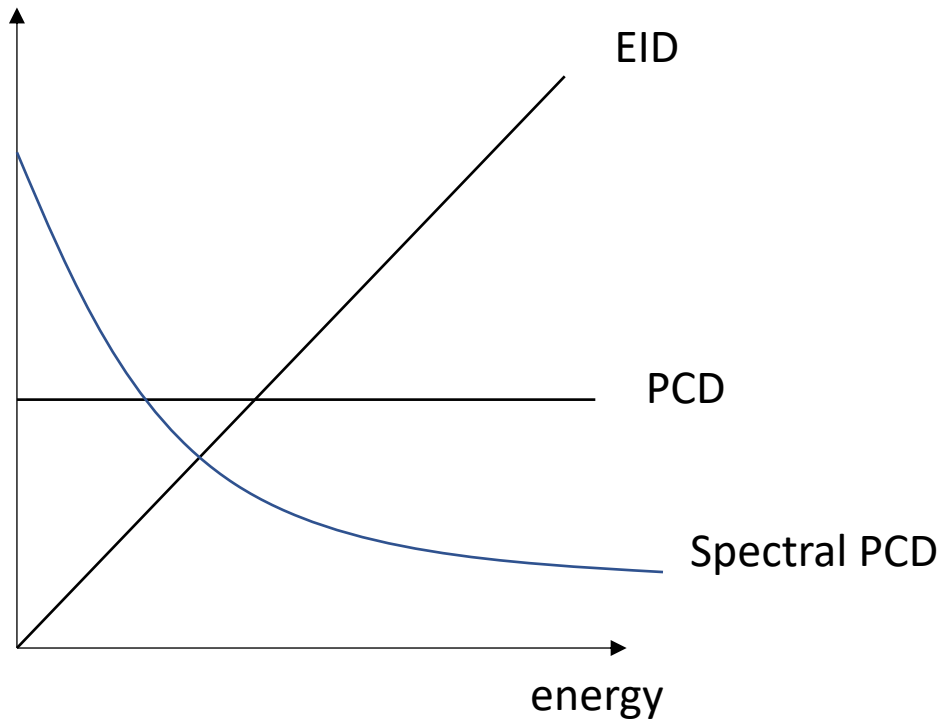
Optimizing the image contrast

- Contrast is higher for low-energy x-rays
- Energy integrating detectors give more weight to high-energy photons
- A spectral PCD with multiple energy bins makes it possible to add more weight to the lower energy range, thus increasing the contrast

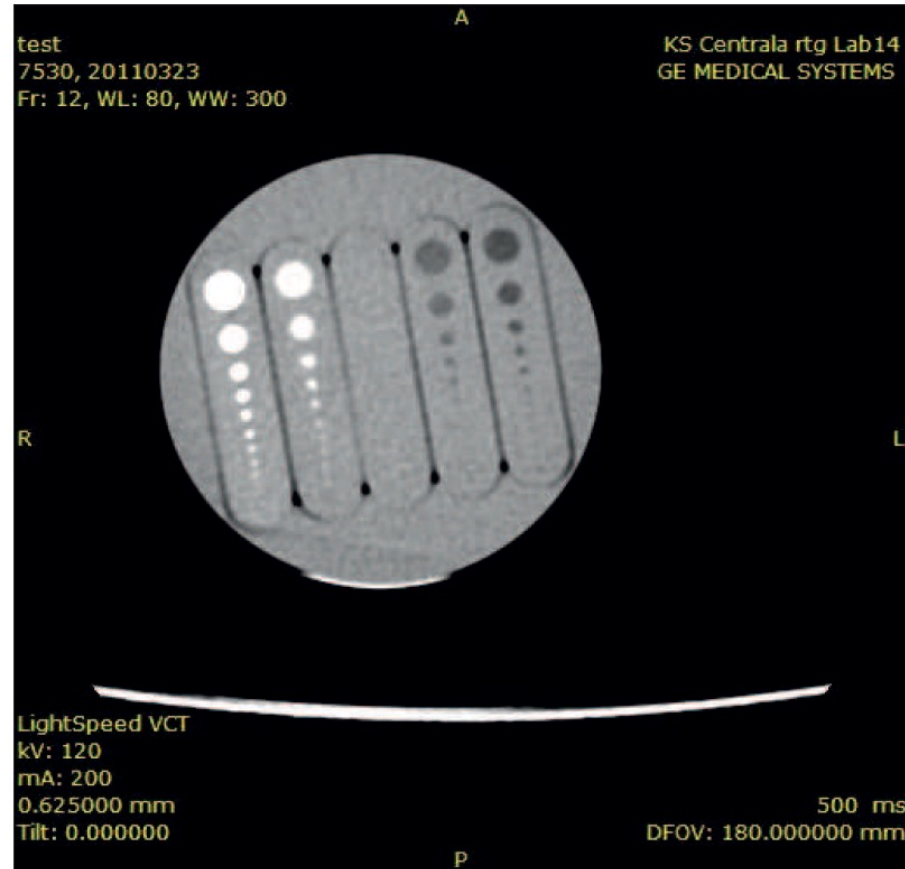


Weighting of photons

weight



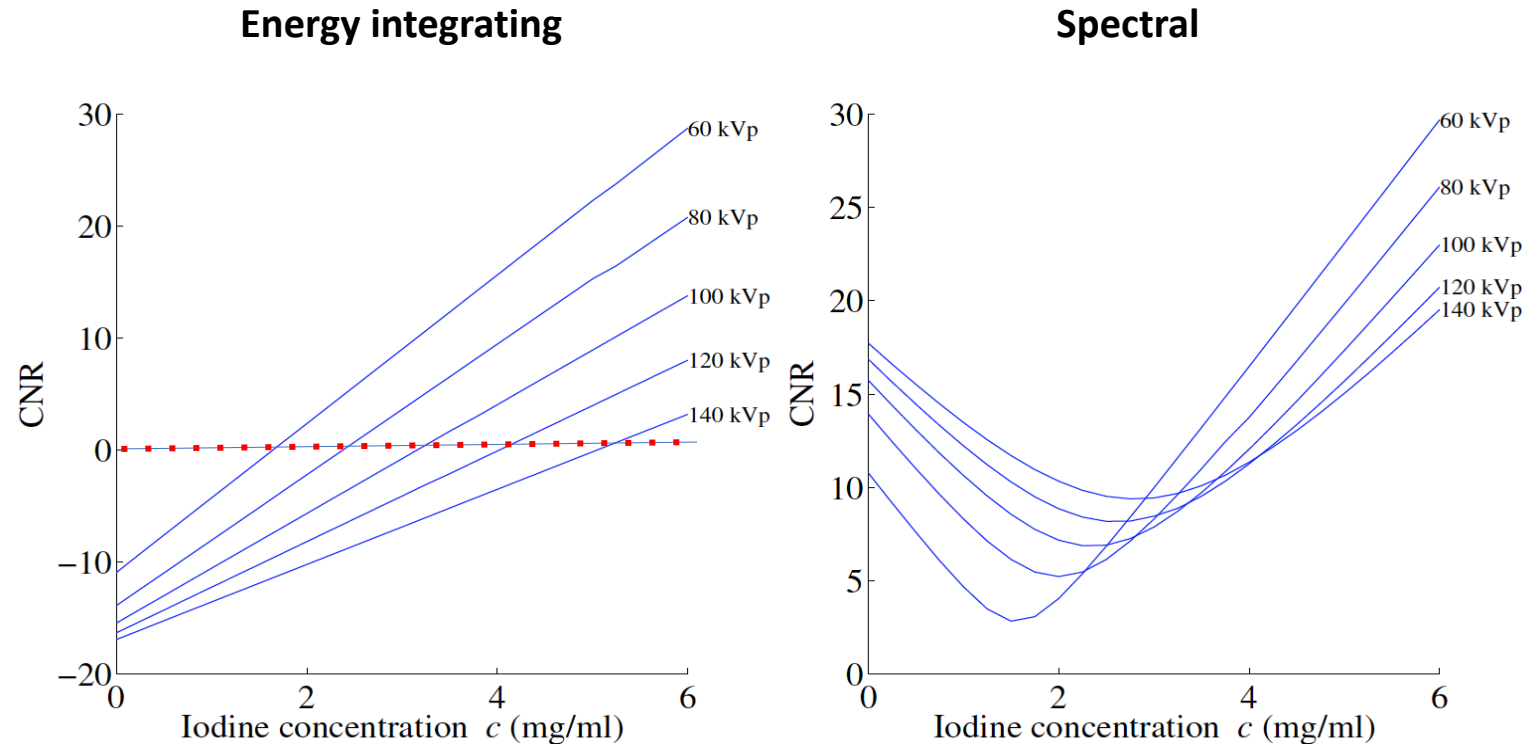
Contrast cancellation



“Eliminated Risk of iodine contrast cancellation with multi-bin spectral CT”, Phys. Med. Biol. 58 (2013) N201N209

Contrast cancellation

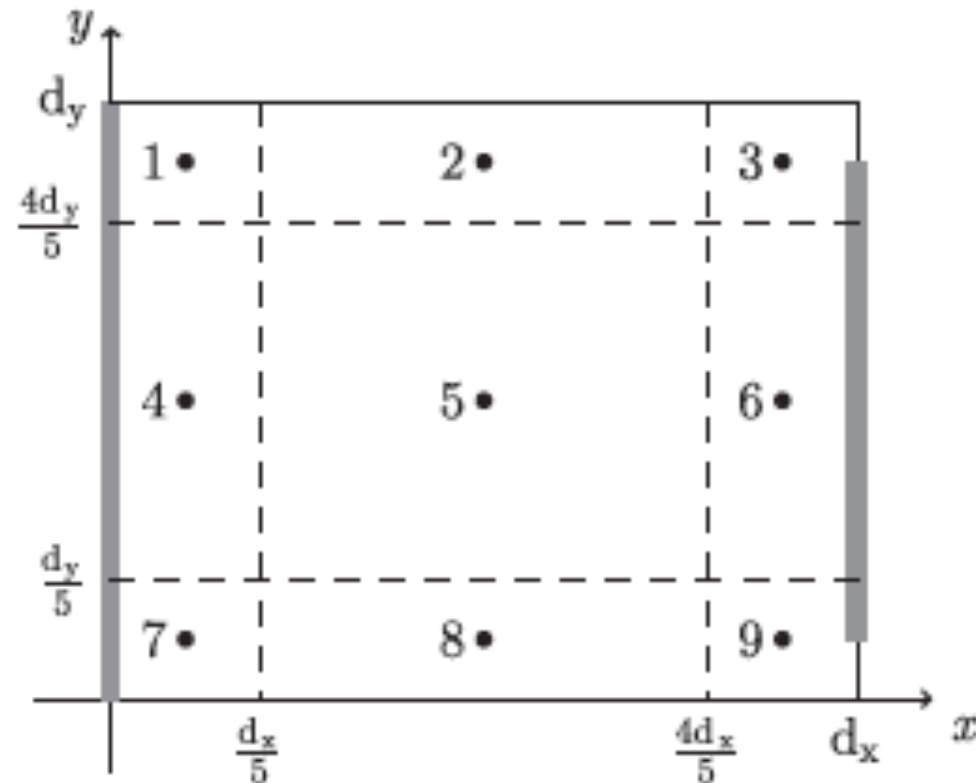
- For energy integrating systems, iodine contrast cancellation occurs for some concentration.
- For PCDs optimal contrast by material basis decomposition or energy weighting prevents contrast cancellation from occurring.

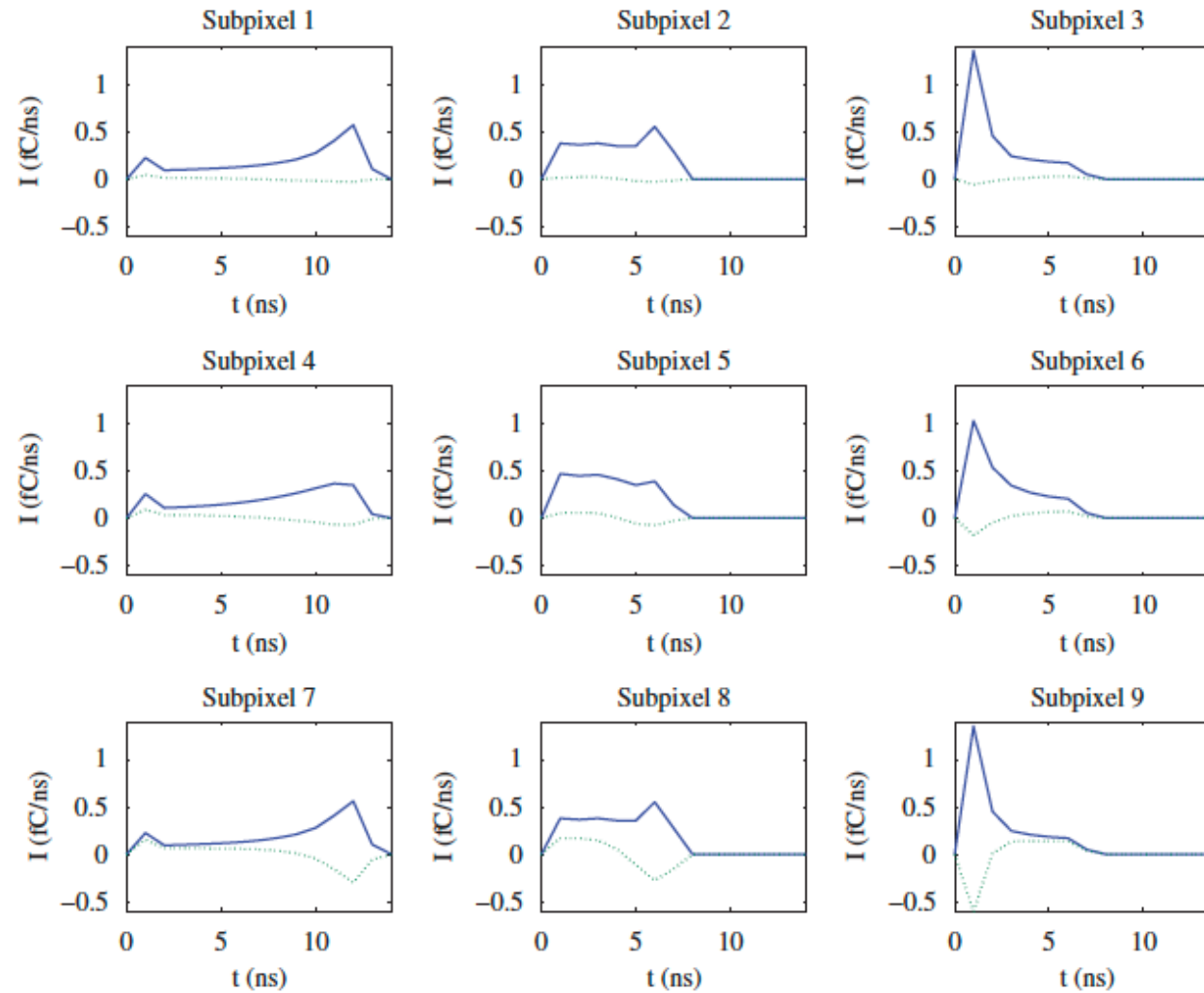


“Eliminated Risk of iodine contrast cancellation with multi-bin spectral CT”,
 Phys. Med. Biol. 58 (2013) N201N209

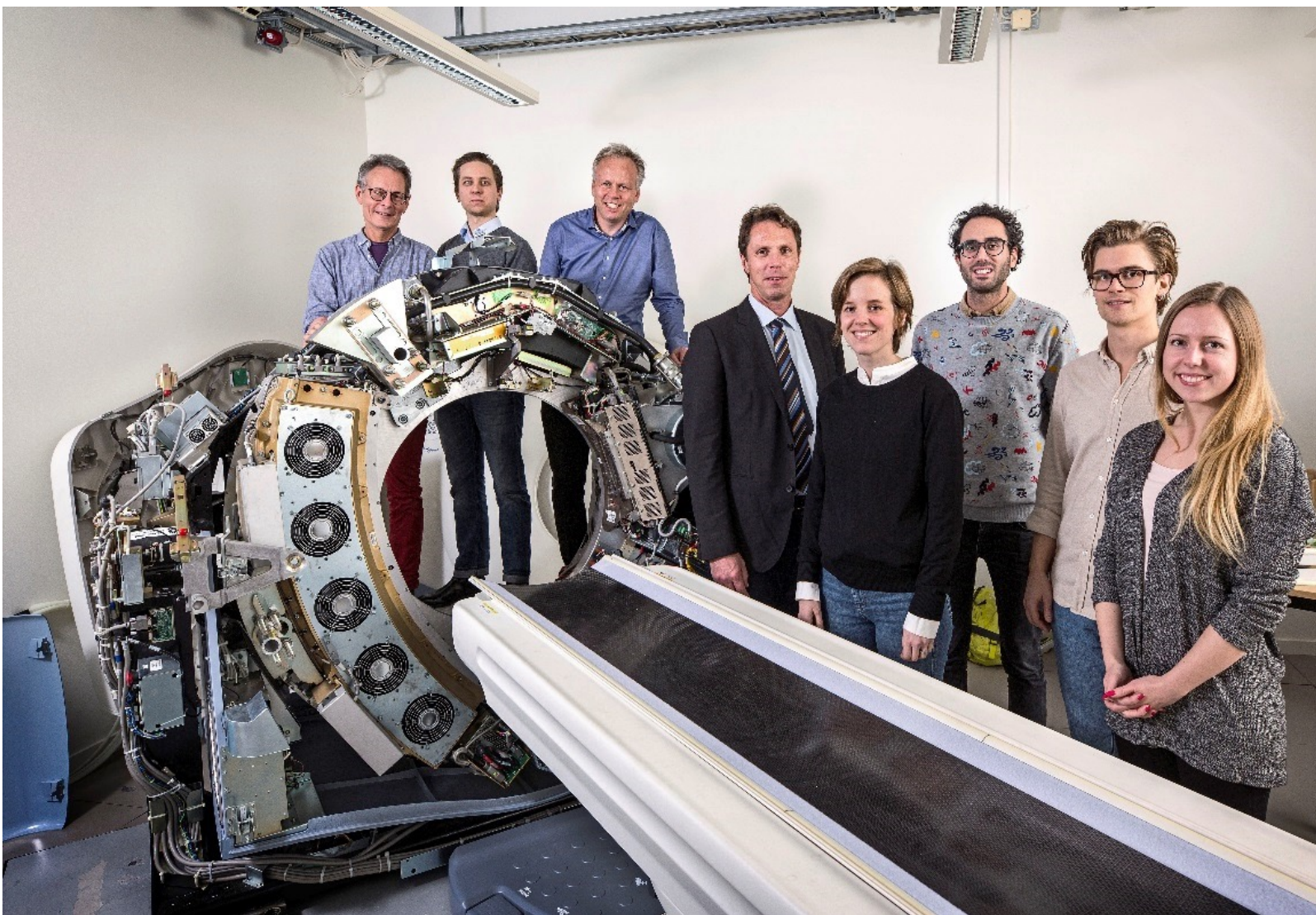
Design considerations to overcome cross talk in a photon counting silicon strip detector for computed tomography

Hans Bornefalk^{a,*}, Cheng Xu^a, Christer Svensson^b, Mats Danielsson^a





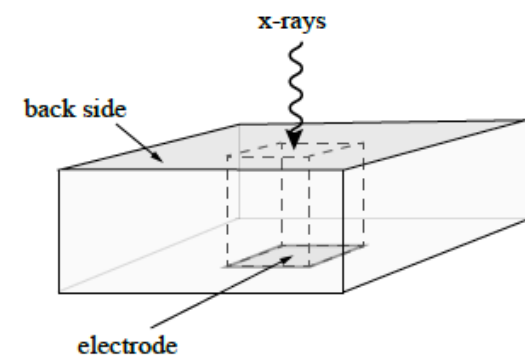
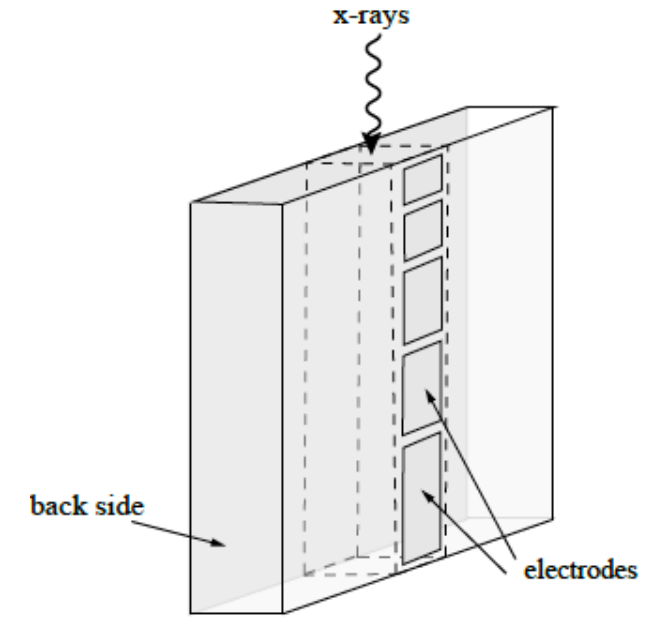
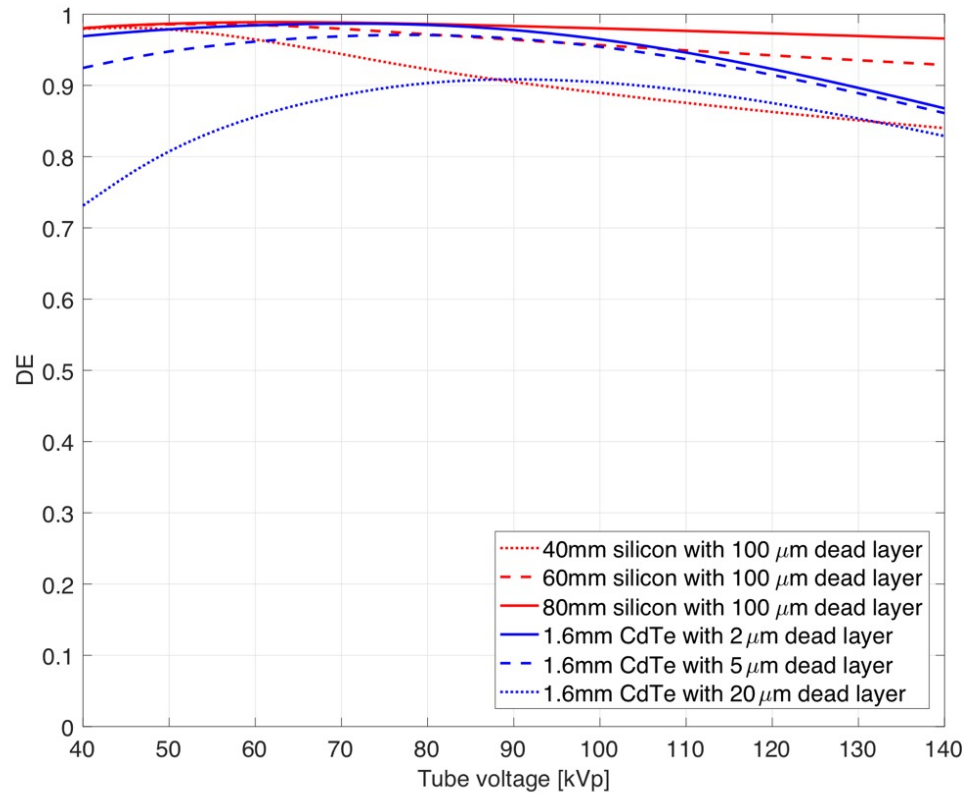
MedTechLabs



Four Physics Questions for a CT Detector Material

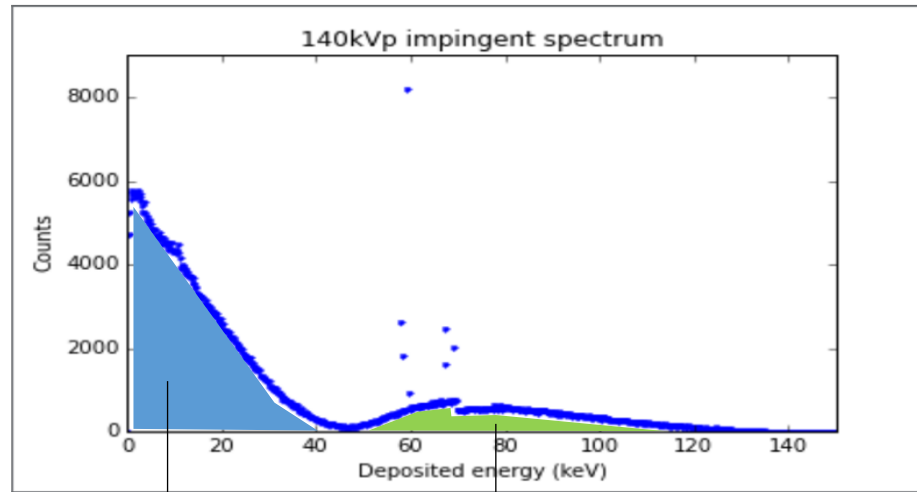
1. X-ray Detection Efficiency?
 2. Scattering/Charge sharing?
 3. Spatial resolution?
 4. Count-rate?
 5. Dose Efficiency?
-

Deep Silicon versus Cadmium-based Detection Efficiency



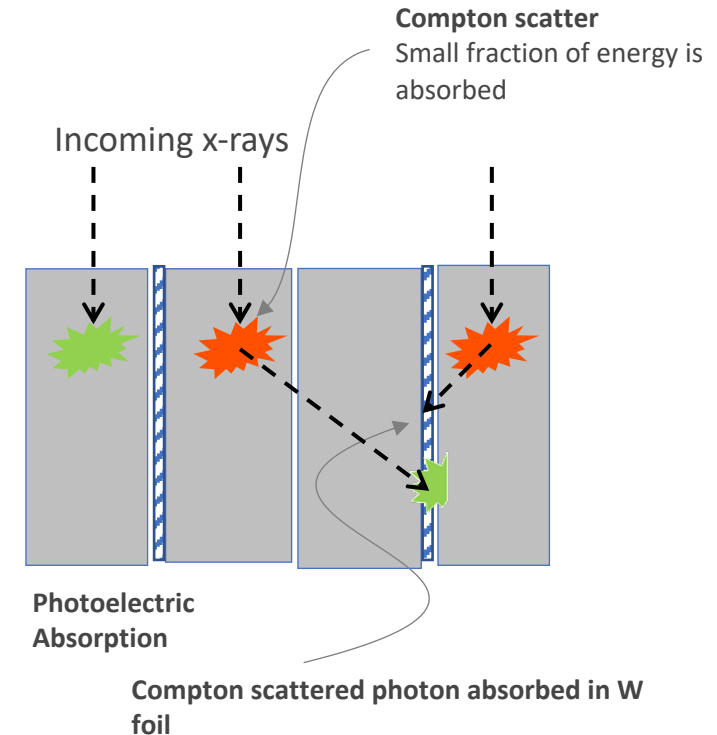
X-rays Scatter in Detector

- In silicon the low atomic number means that Compton scattered photons dominate over K-fluorescence
- Compton interactions are separated from the photoelectric interactions in energy, and the photons will be counted
- Intersecting W foils stop the scattered photon and work as a general anti-scatter collimator

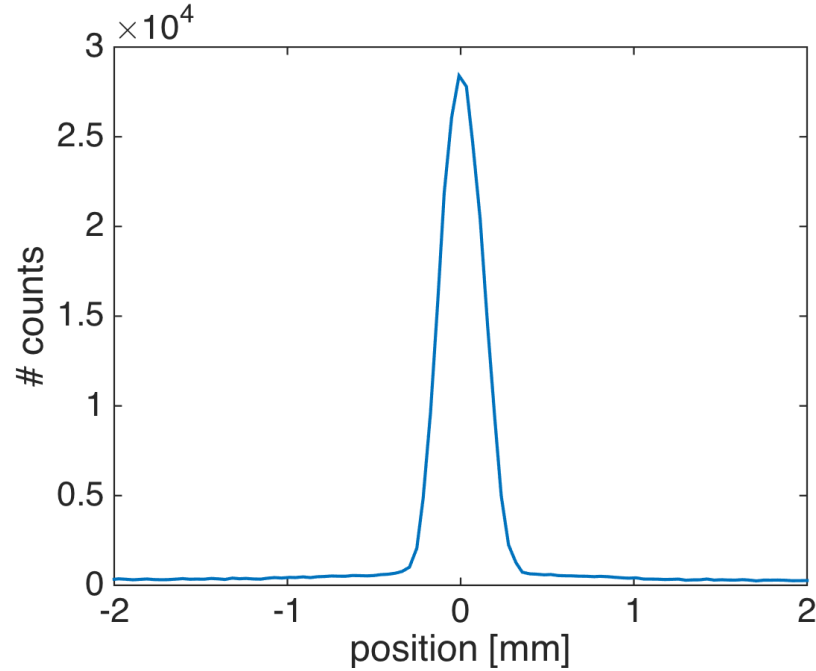


Photoelectric absorption
Very high energy resolution

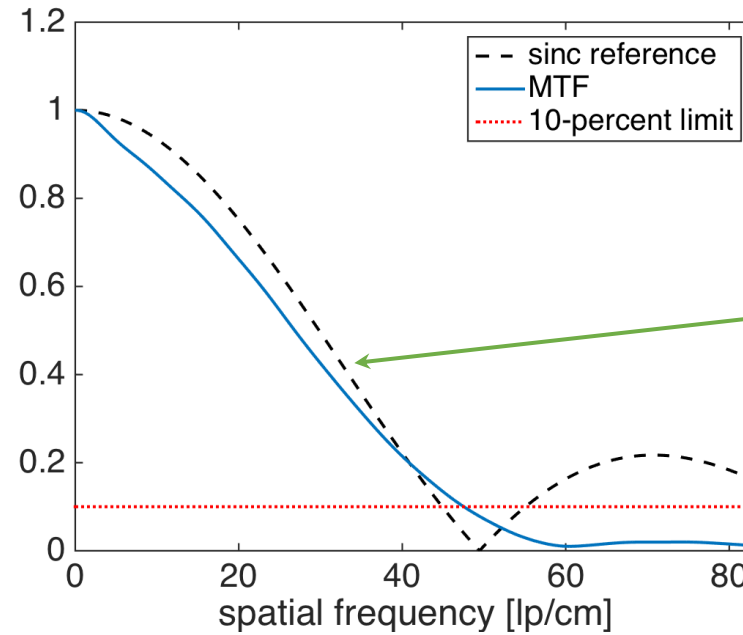
Compton scatter
Photon counting, lower energy resolution



Example of Measured Modulation Transfer Function for Deep Silicon at 140 kVp



Line Spread Function

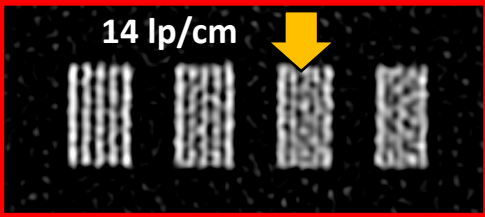
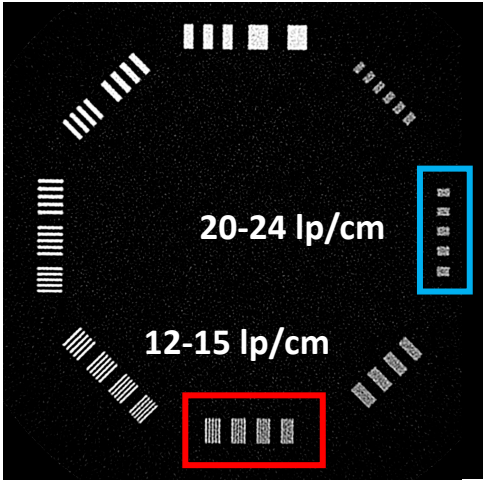


MTF = 10% at 48 lp/cm

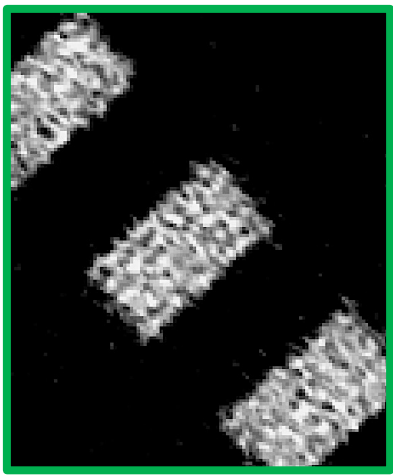
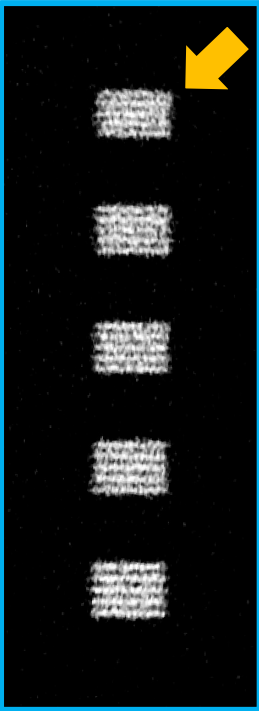
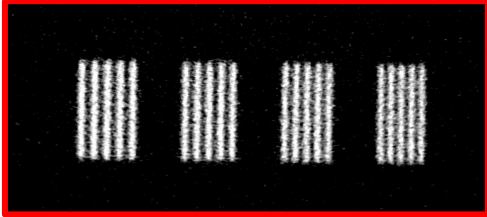
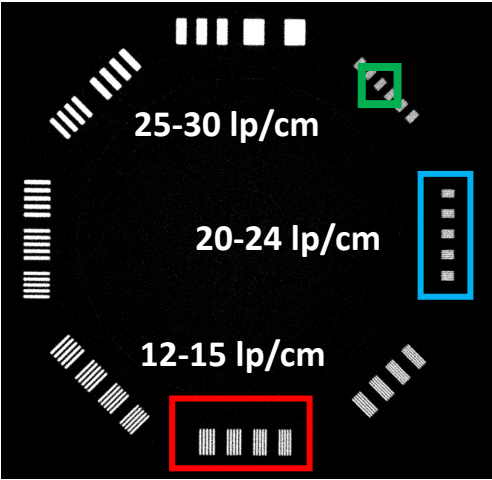
Conclusion:
 Negligible
 impact
 of scattered
 radiation on
 spatial
 resolution

Upplösning jämförelse

Dagens teknik



Fotonräknande spektrala kiselsensorer



CATPHAN 700, CTP714
The Phantom Laboratory

Avbildning av inneröra

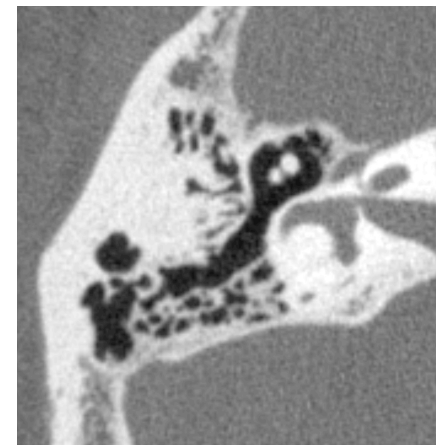
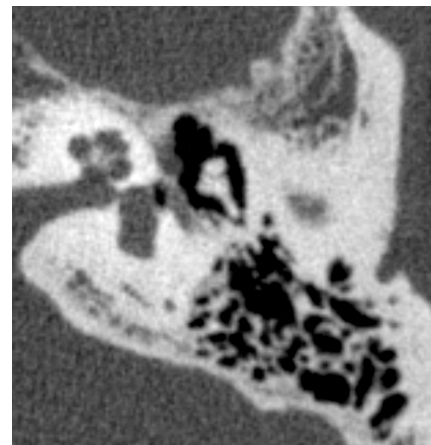
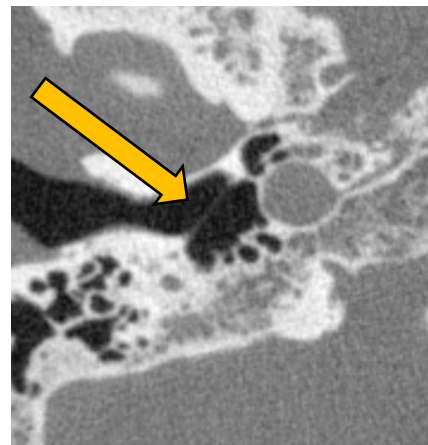
Dagens Teknik

67keV mono
1.2mm focal spot
0.625mm slice
360mA



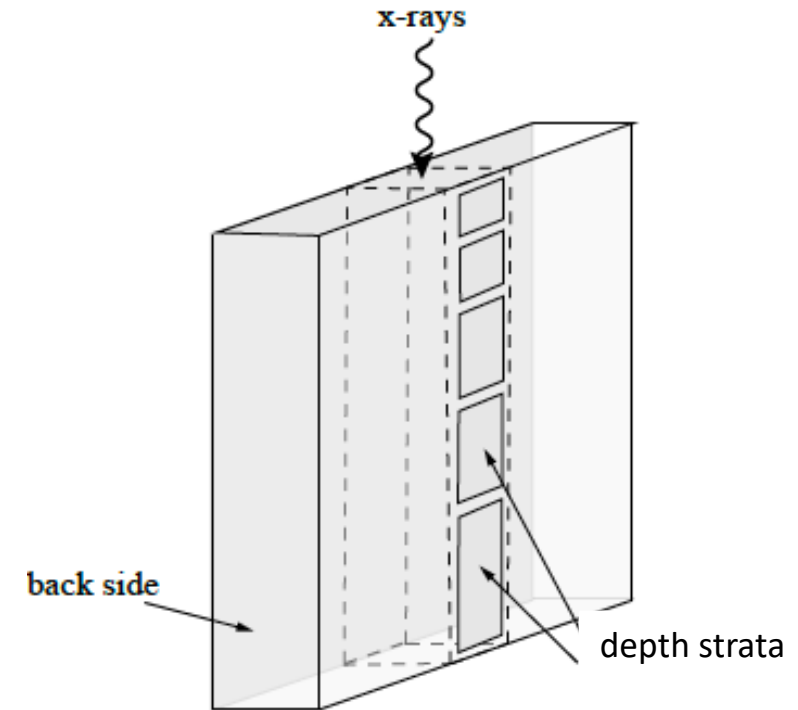
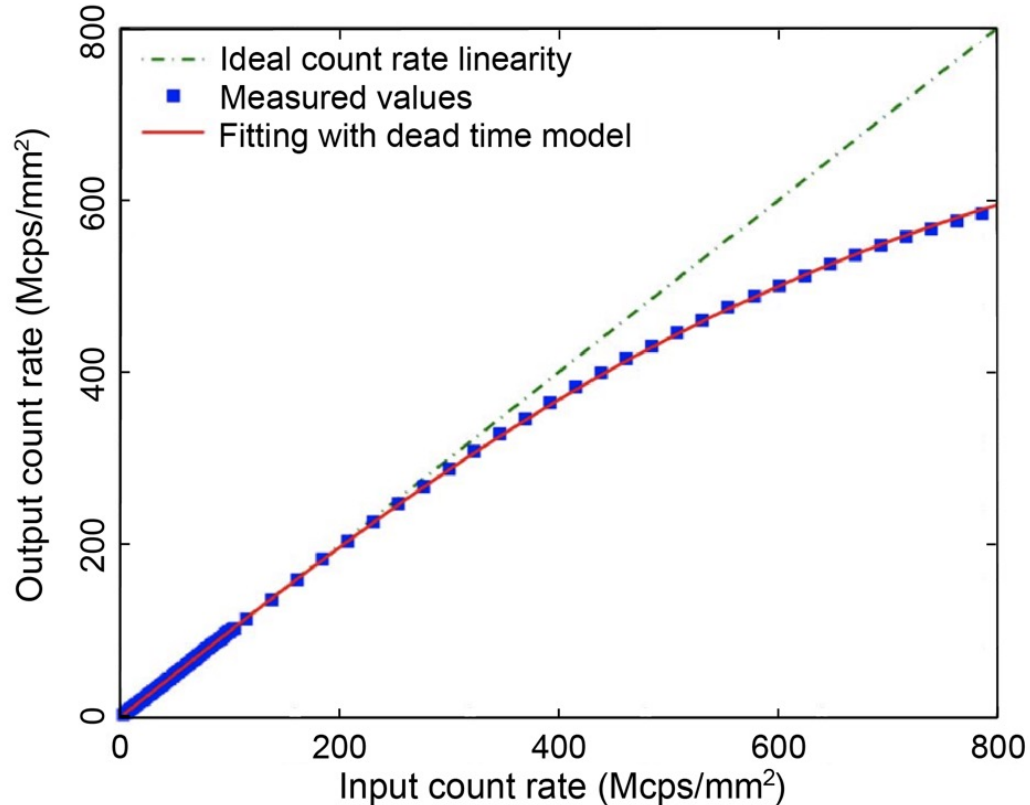
Fotonräknande spektrala kiselsensorer

67keV mono
0.6mm focal spot
0.312mm slice
200mA
120kVp

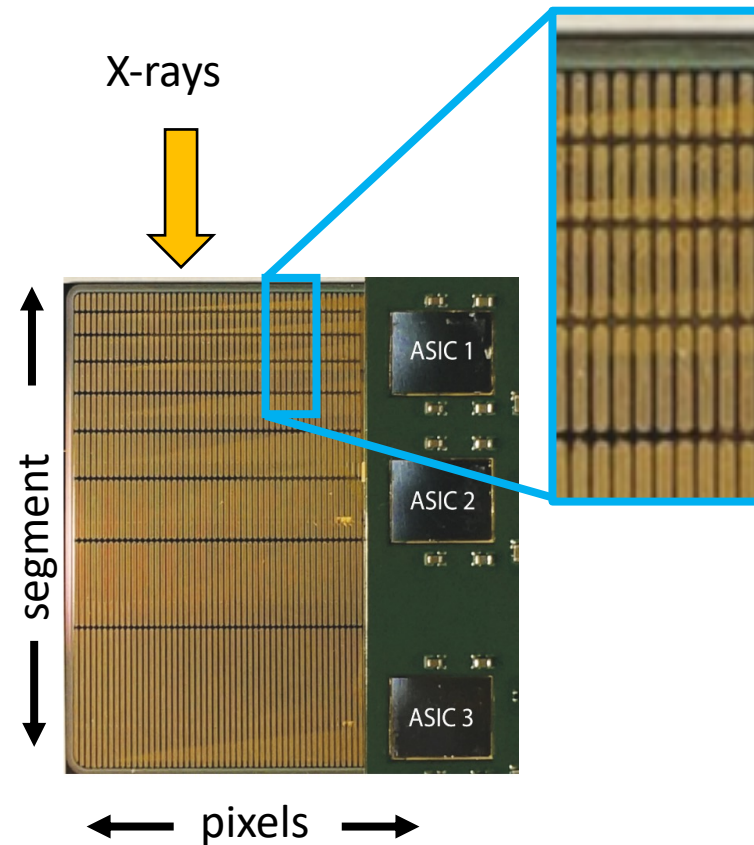


Negligible Pile-up Loss for Silicon at Clinically Relevant Count Rates

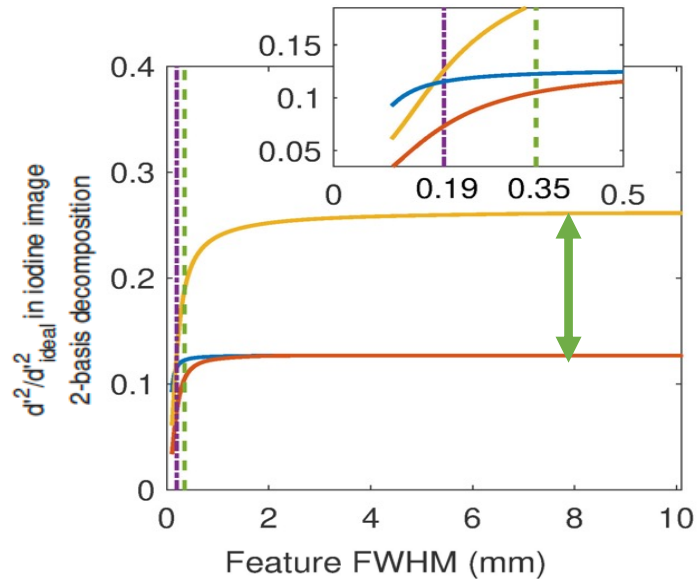
Edge-on Silicon has fast charge collection and enable depth strata to reduce the count rate



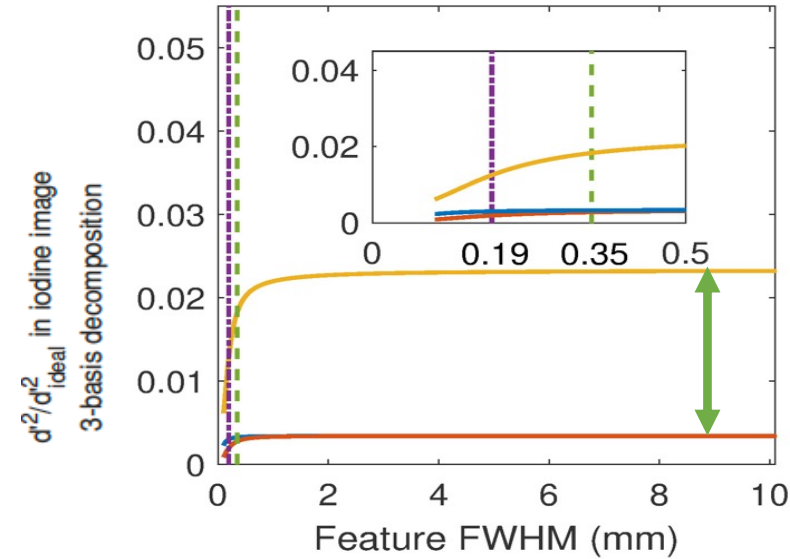
Detector prototype



Dose Efficiency Comparison for 2 and 3 Material Separation (120 kV)



> 2 dose advantage
for silicon



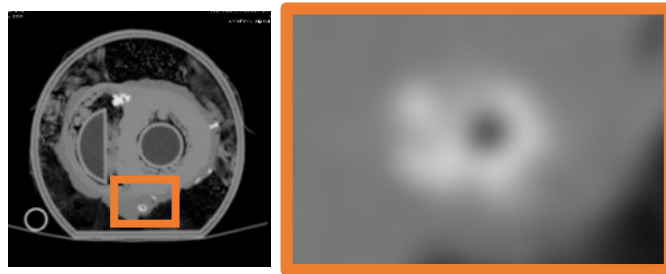
> 5 dose advantage
for silicon

- 60 mm Si, 0.5×0.5 mm² pixels with W foils
- 1.6 mm CdTe, 0.225×0.225 mm² pixels
- 1.6 mm CdTe, 0.45×0.45 mm² macro-pixels
- Resolution limit, 0.4 mm focal spot
- Resolution limit, 0.7 mm focal spot

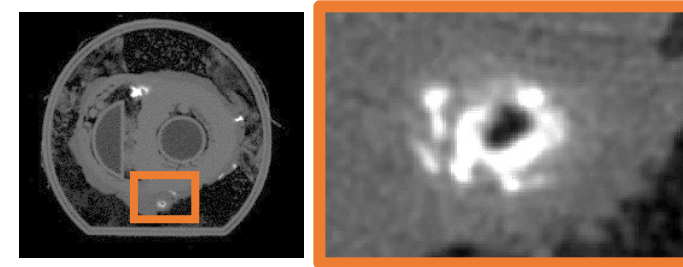
Imaging of coronary arteries in cadaver heart

State-of-the-art

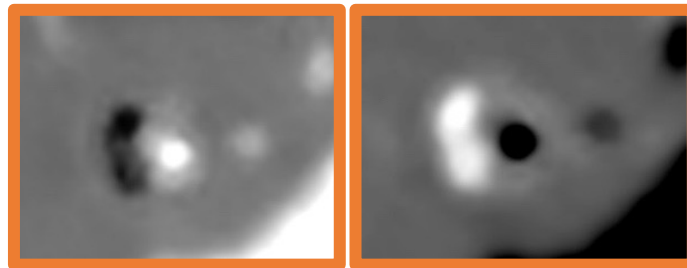
Mono-energy



Photon-counting edge-on silicon

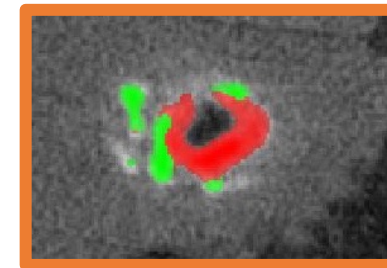


Iodine/Calcium
Reconstruction



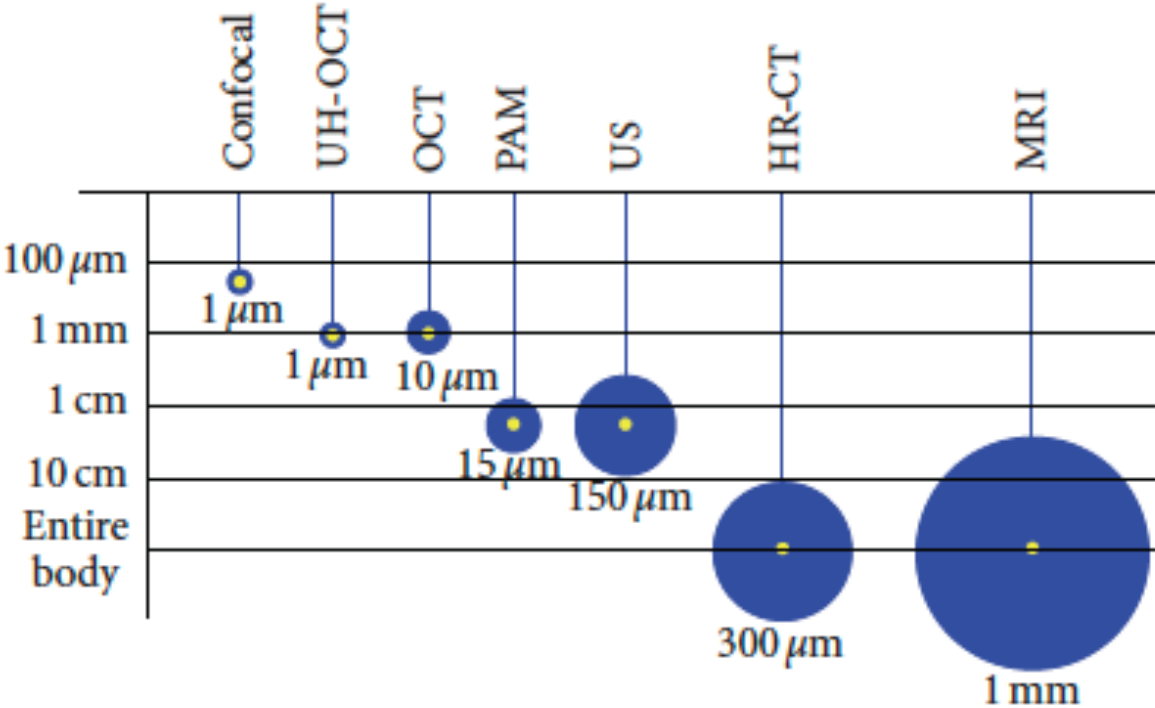
Iodine
(Calcium)

Calcium
(Iodine)

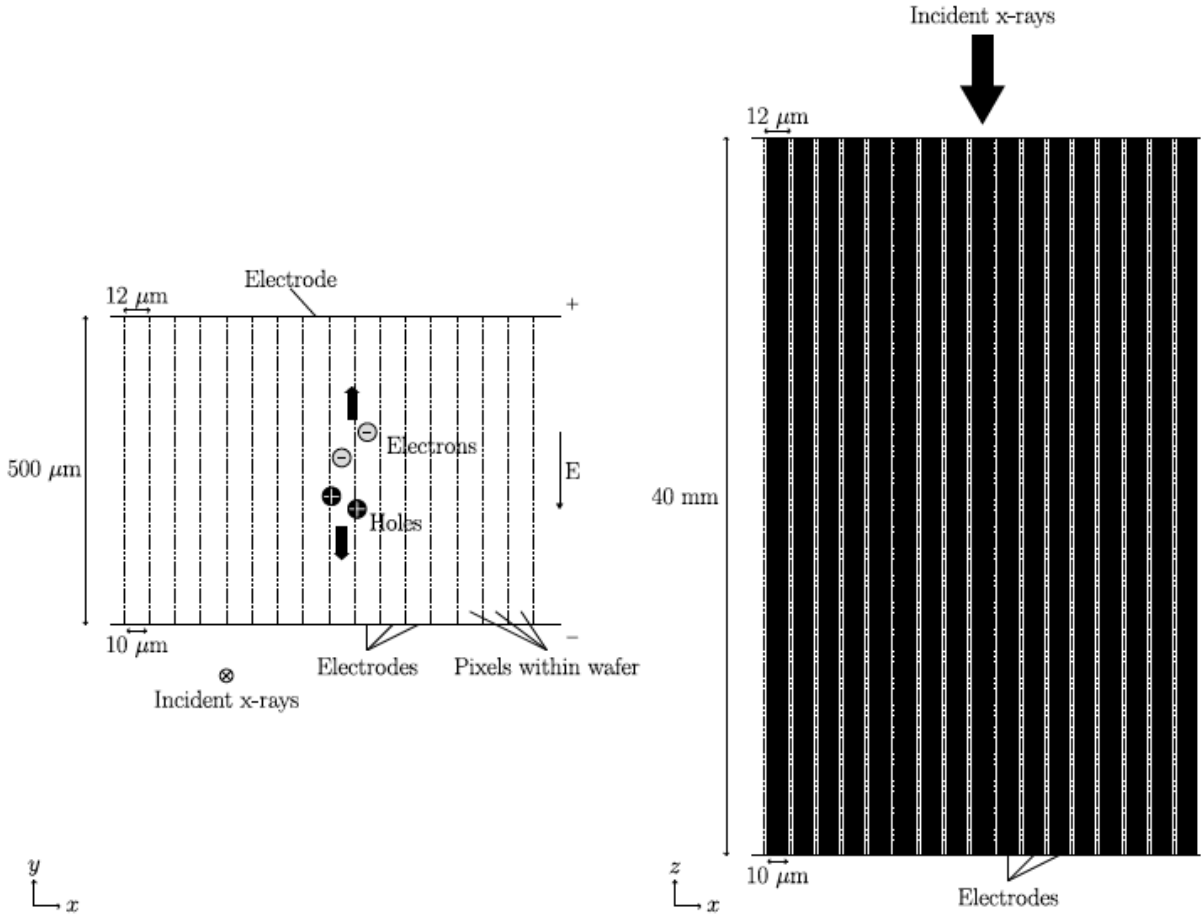


Iodine (red) and Calcium (green)

Spatial Resolution for Different Techniques



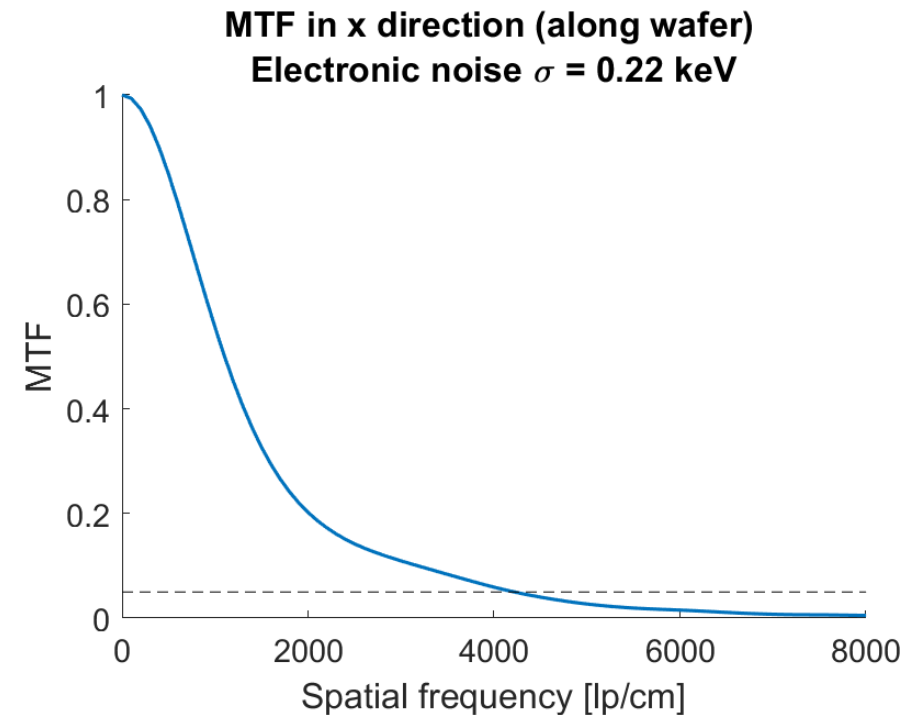
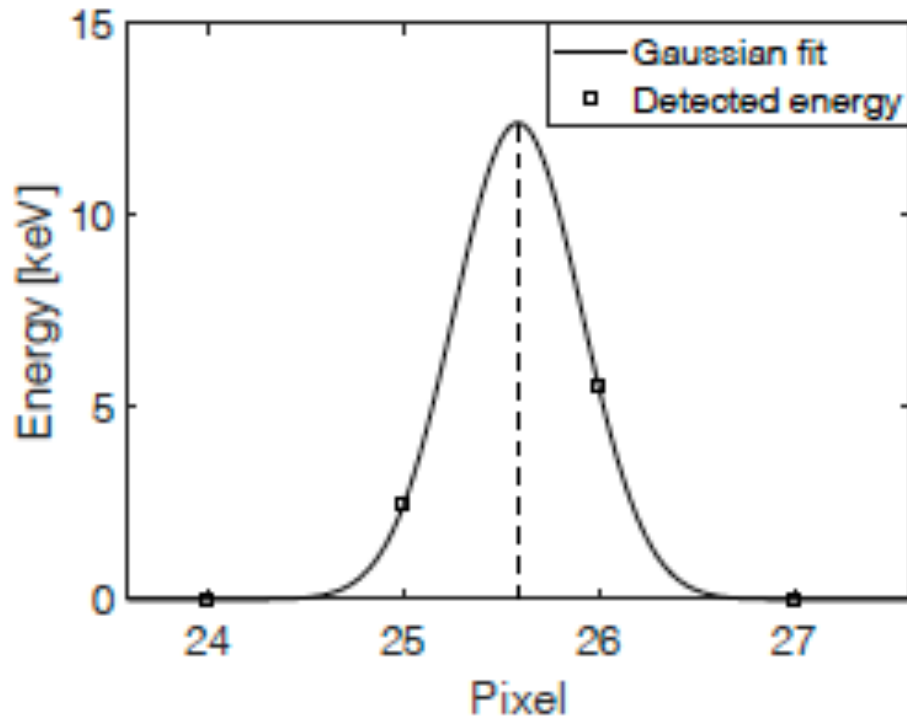
Detector lay-out for future high resolution “Deep Silicon”



Proceedings from SPIE Physics of Medical Imaging, 6-19 February 2020, Houston, Texas, USA

1 μm Spatial Resolution in Silicon Photon-Counting CT Detectors by Measuring Charge Diffusion

Christel Sundberg^a, Mats Persson^a, J Jacob Wikner^b, and Mats Danielsson^a



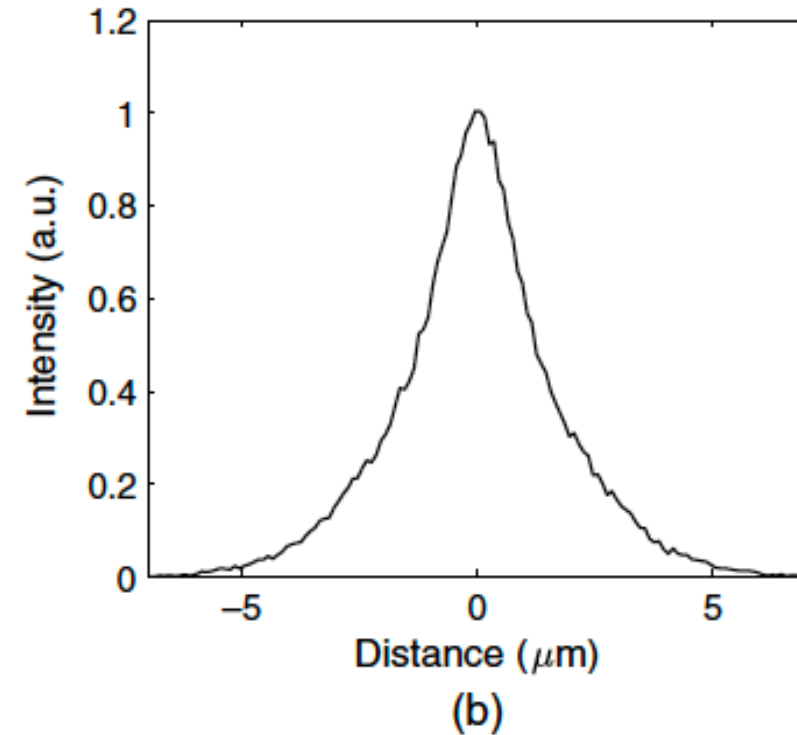
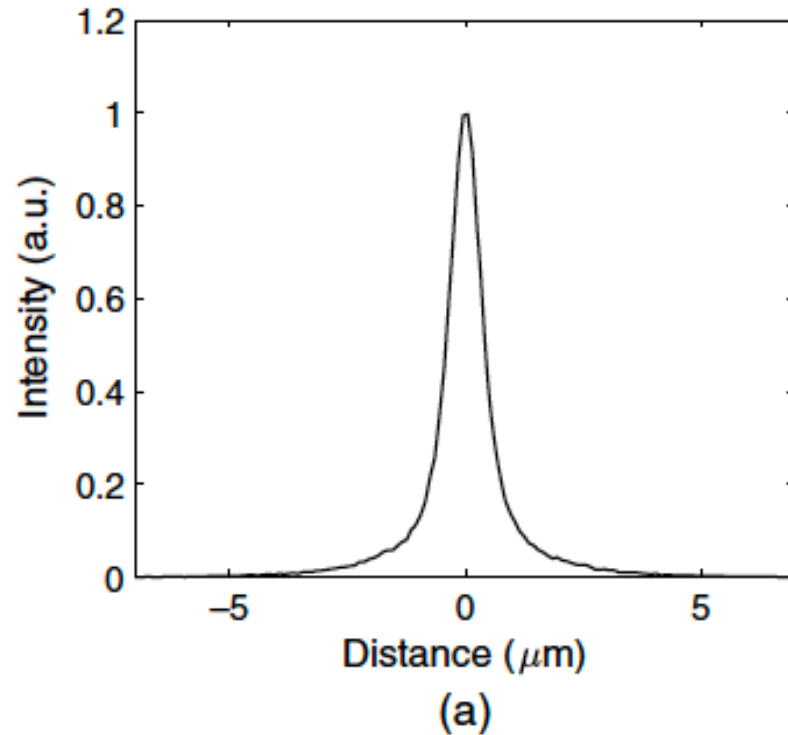


Fig. 7 PSF of the detector and the proposed method of interaction position estimation in the x direction. (a) Ideal data with no electronic noise or lowest threshold. (b) Electronic noise and a lowest threshold of 0.88 keV included.

Discussion

- Deep Silicon is entering the clinic for photon-counting CT
 - Robust to very high count-rates
 - Combination of high energy resolution and high spatial resolution very powerful
 - Available in large volumes
 - The development has only started
-