Online image guidance in particle therapy with spectral X-ray imaging

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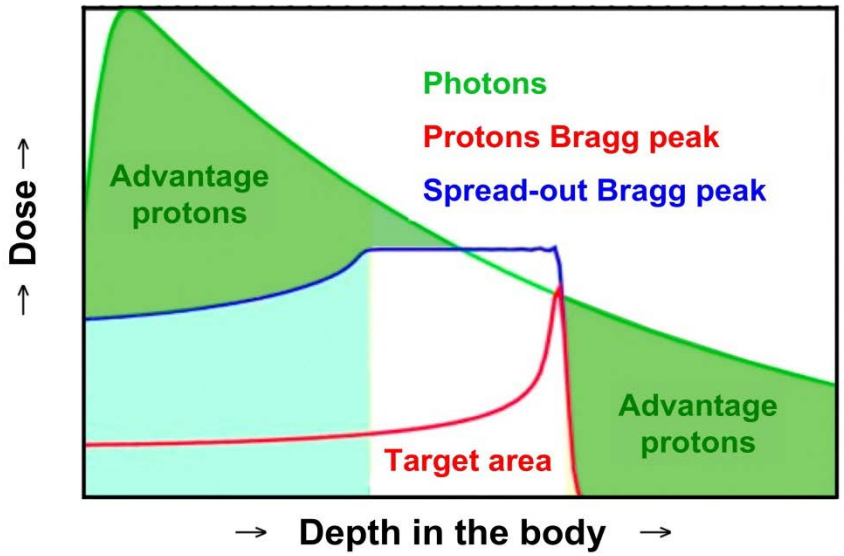
ATTRACT-NL, Amsterdam, The Netherlands, February 9, 2017

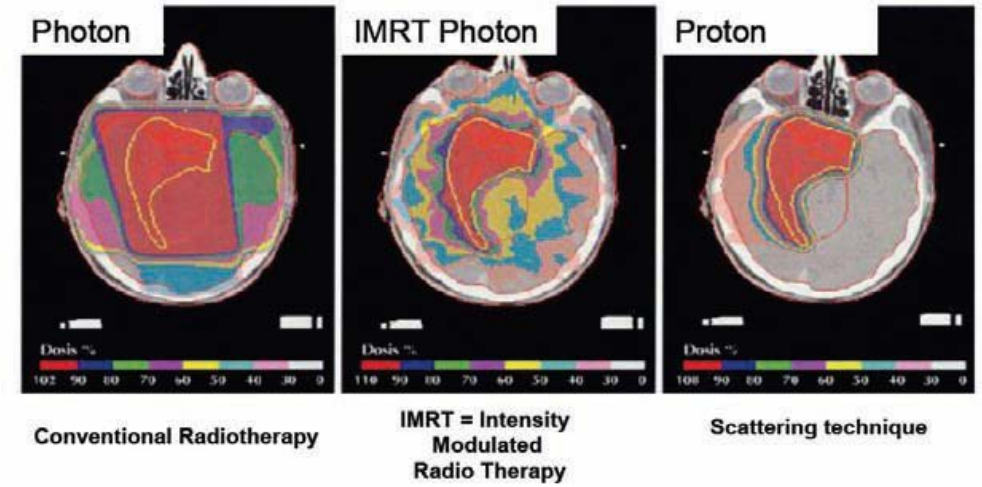
HollandPTC

Holland Particle Therapy Centre (HollandPTC)

- First Dutch proton therapy centre under construction
- First patients in 2017 (initial capacity 600 patients / year)
- Strong (inter)national collaboration on PT-related research

Proton therapy: the promise…

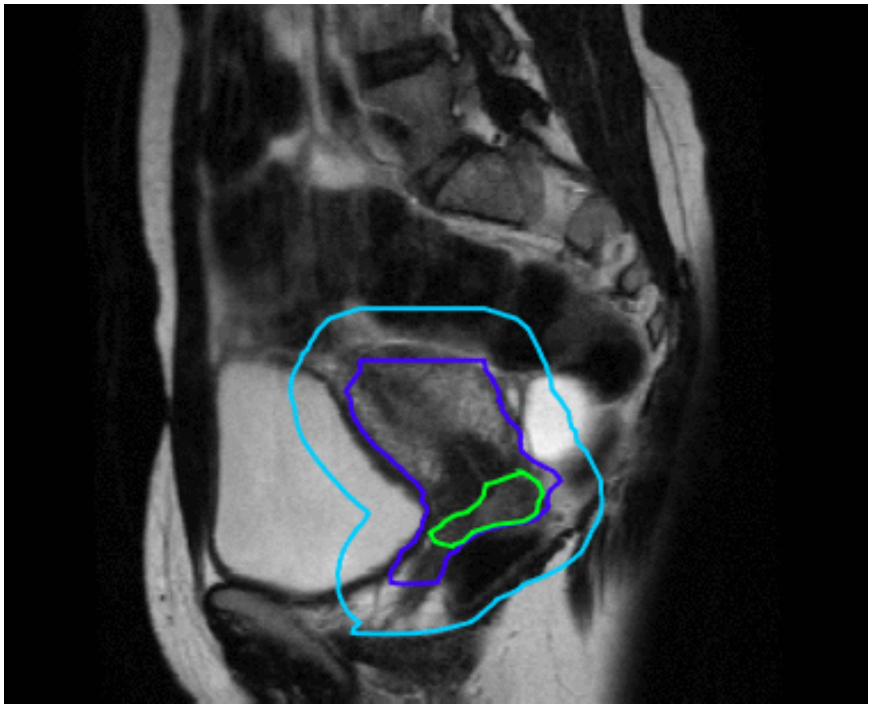




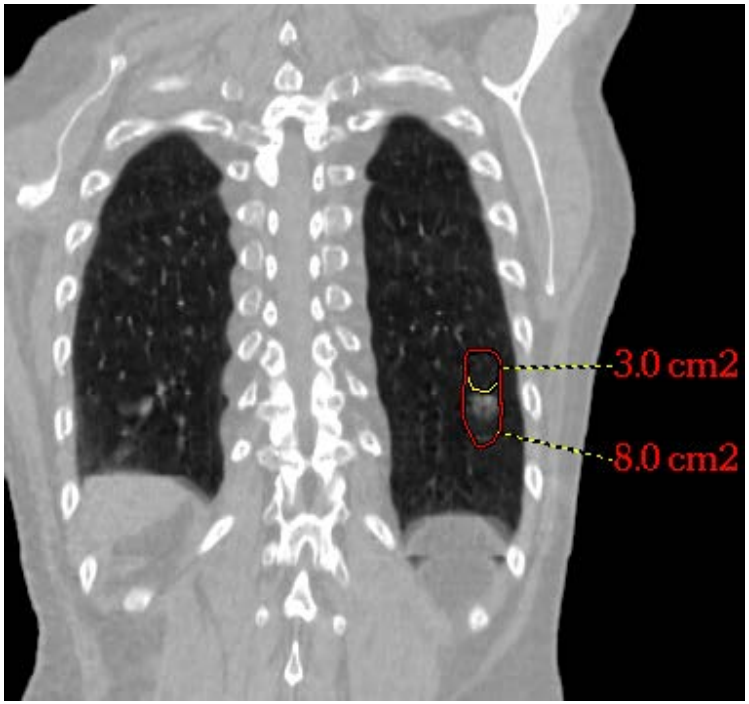
Highly localized dose deposition (Bragg peak) in principle enables more precise dose delivery than photons

… and the problem

MRI

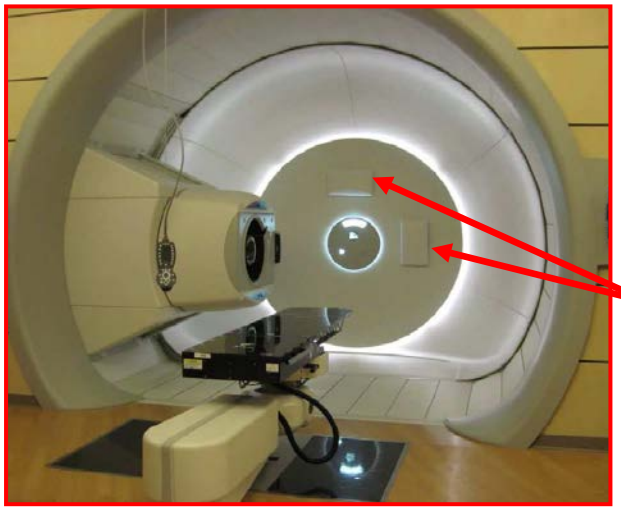


4D-CT



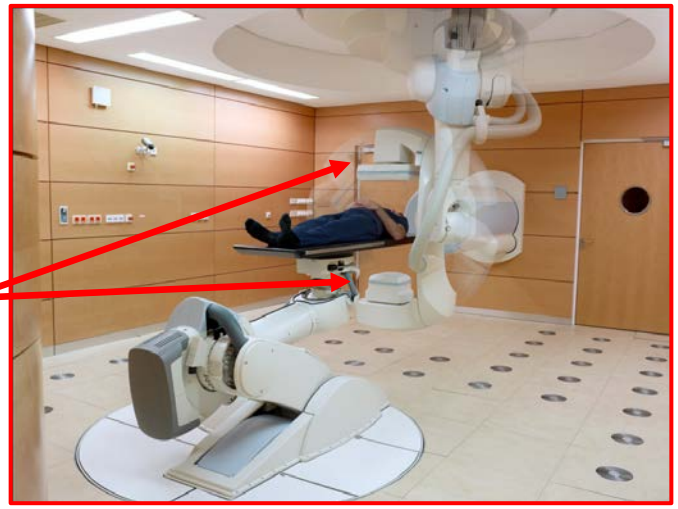
Examples of inter-fraction (left) and intra-fraction (right) target motion

Image guided particle therapy

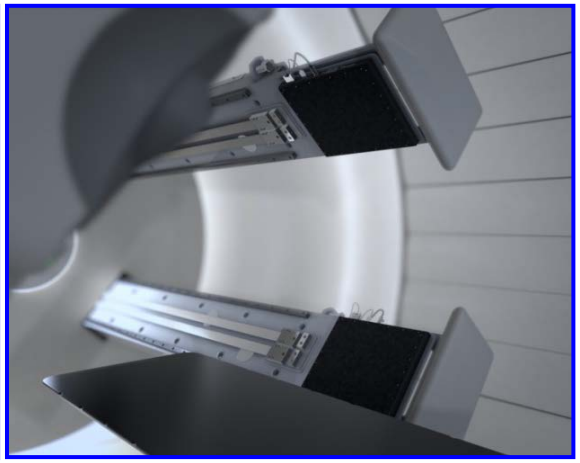


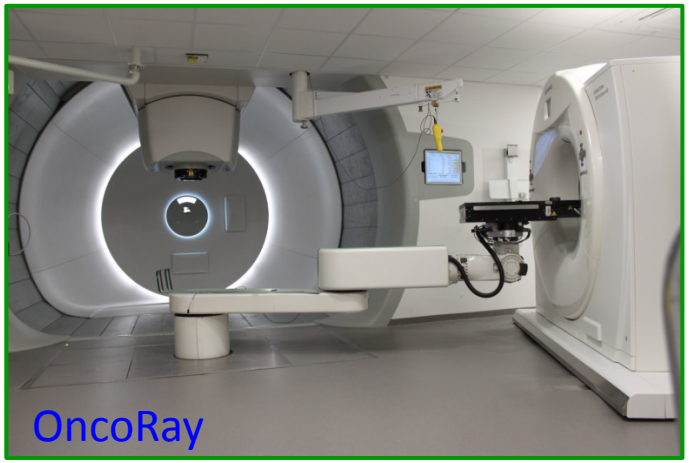
The state of the art (2014)

Orthogonal planar X-ray imaging



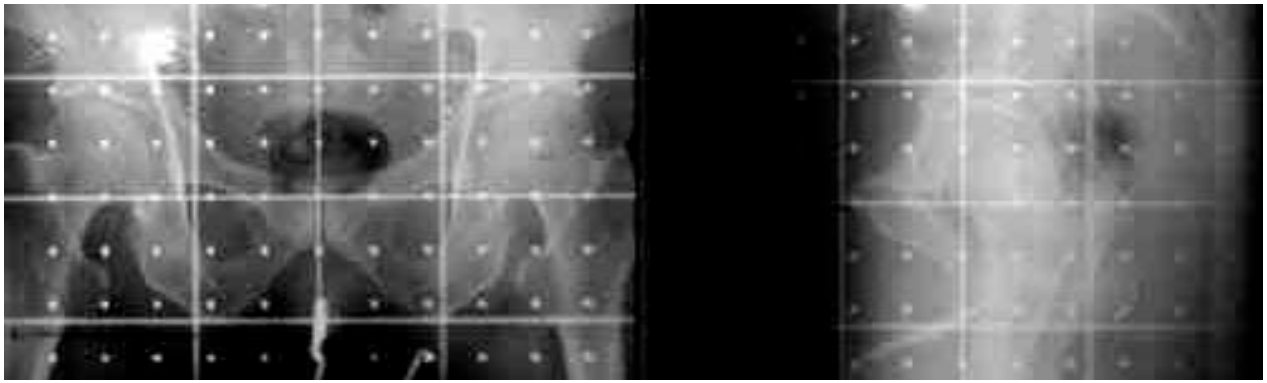
Things start to improve (2014): → CBCT in gantry → in-room CT



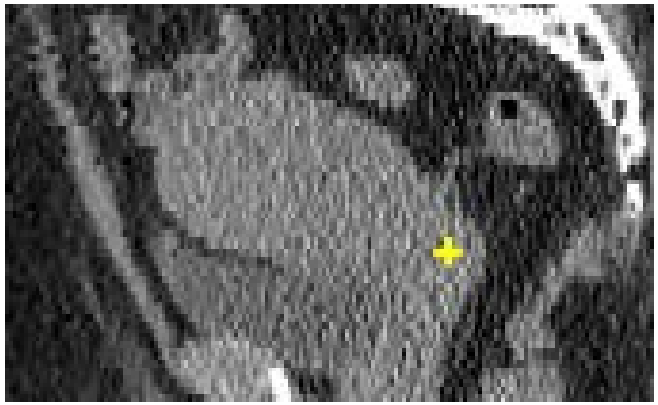


Courtesy: W. Enghardt, Oncoray

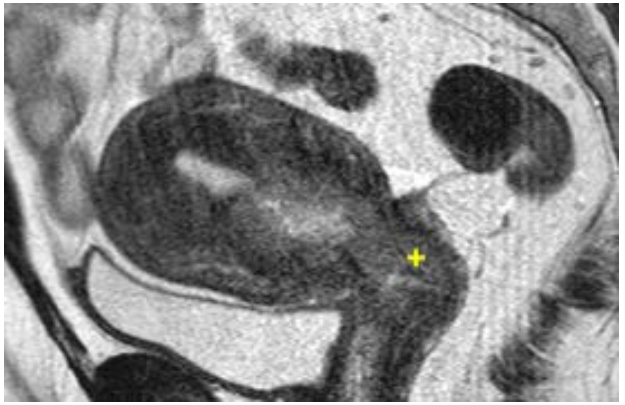
Image quality of current isocentric solutions



Orthogonal planar X-ray imaging



Cone beam CT

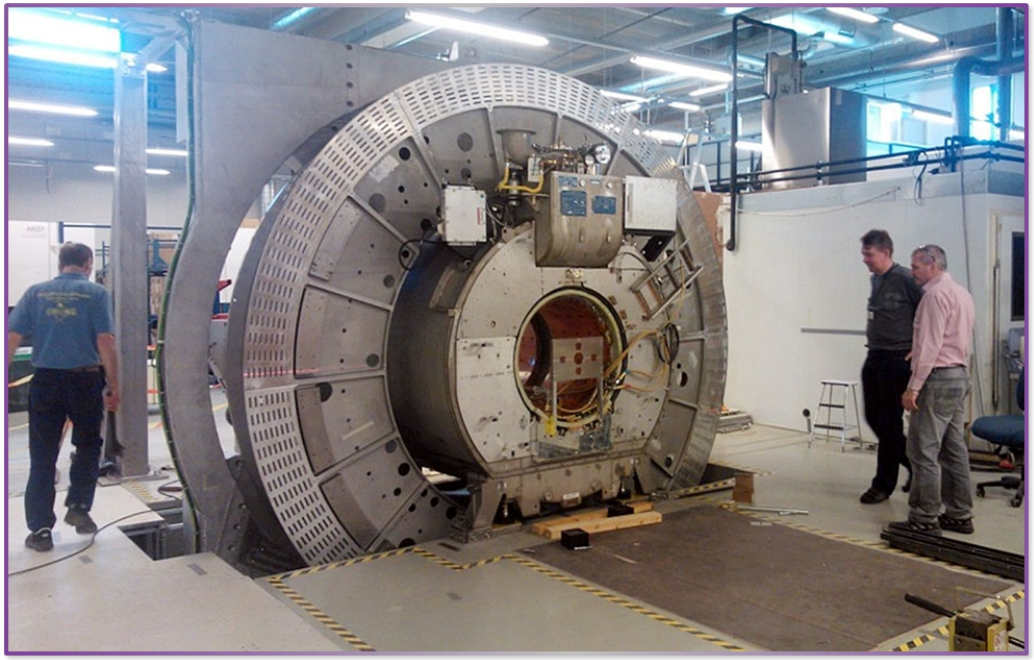


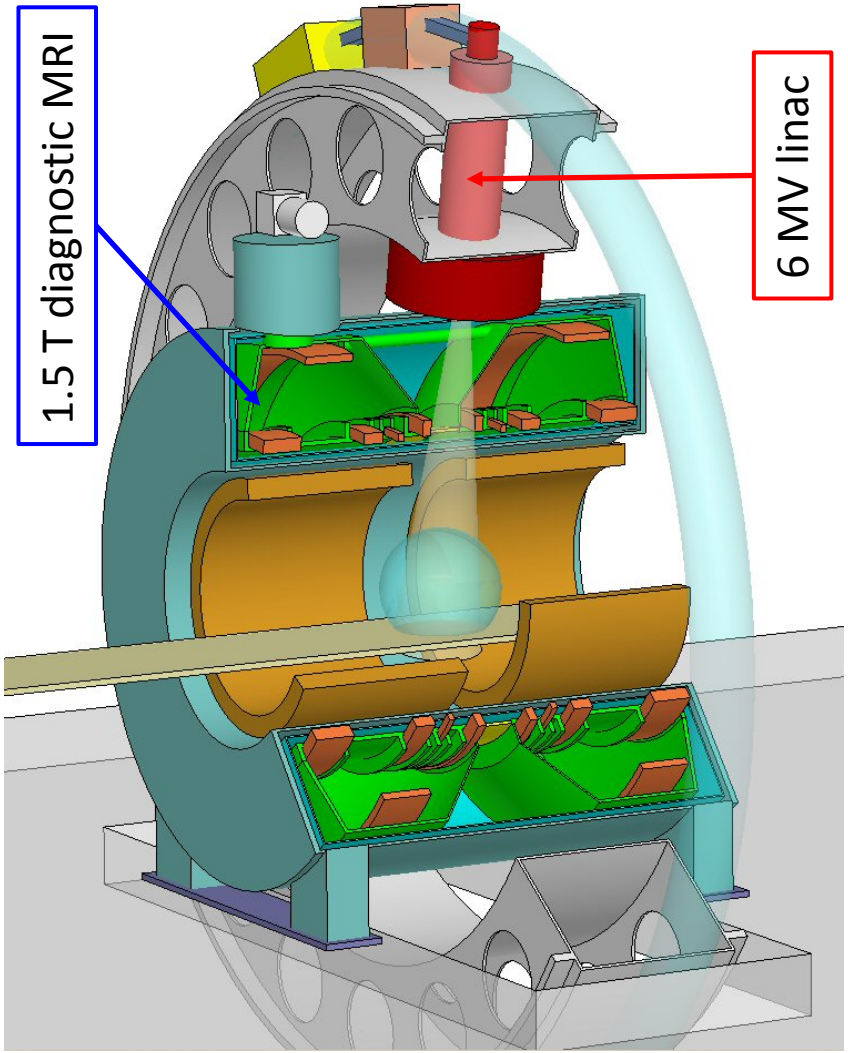
MRI

Online MR guidance: the MRI-Linac

University Medical Center, Utrecht, NL
Philips Research, Hamburg, GER
Elekta Oncology Systems, Crawley, UK
RaySearch Laboratories, Stockholm, S

Apr. 5, 2014: Start of 1st clinical installation
At University Medical Center, Utrecht, NL



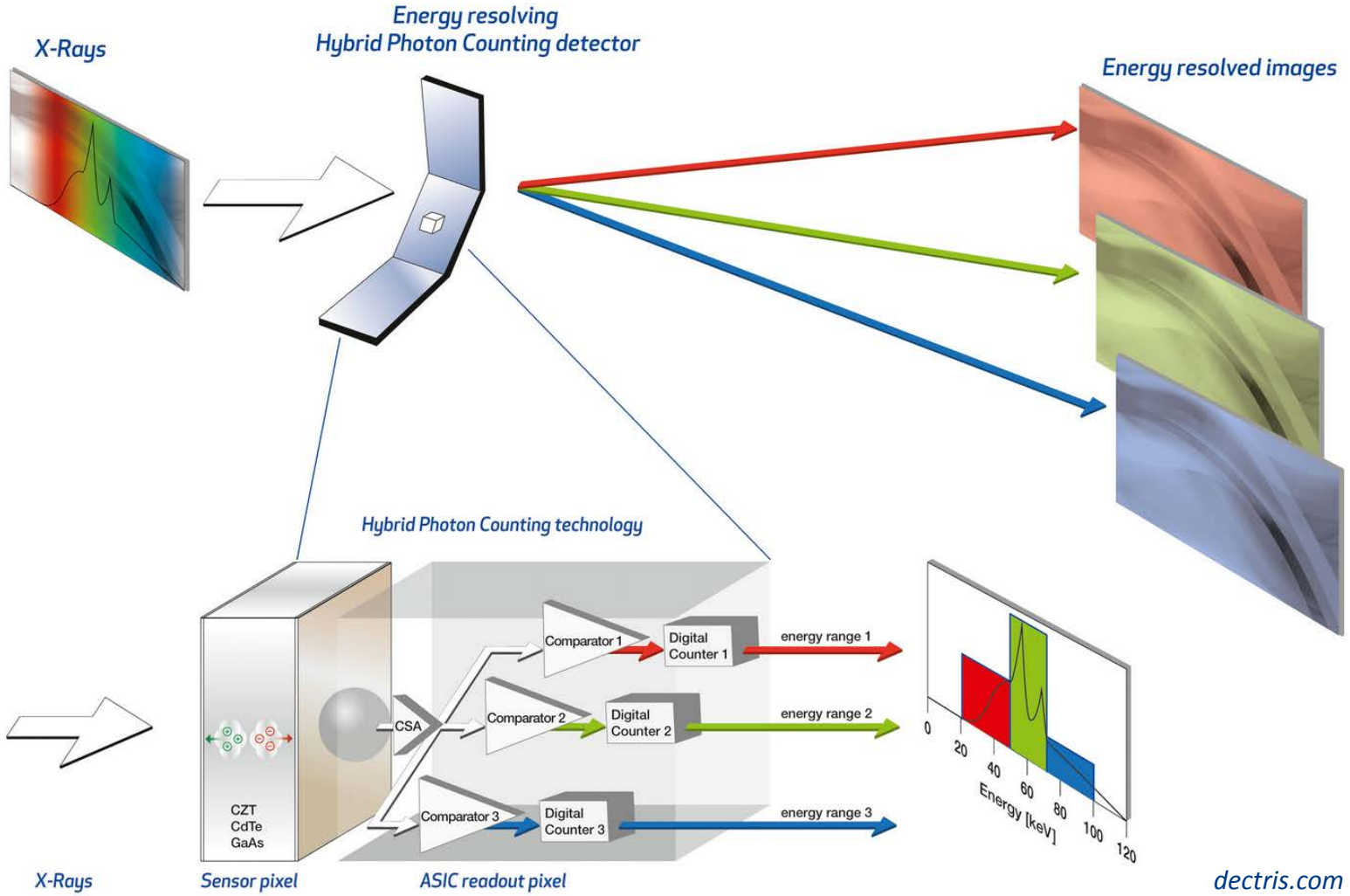


B.W.Raaymakers et al.: PMB 54 (2009); N229, PMB 56 (2011) N207. Courtesy: J. Lagendijk

Current isocentric imaging solutions

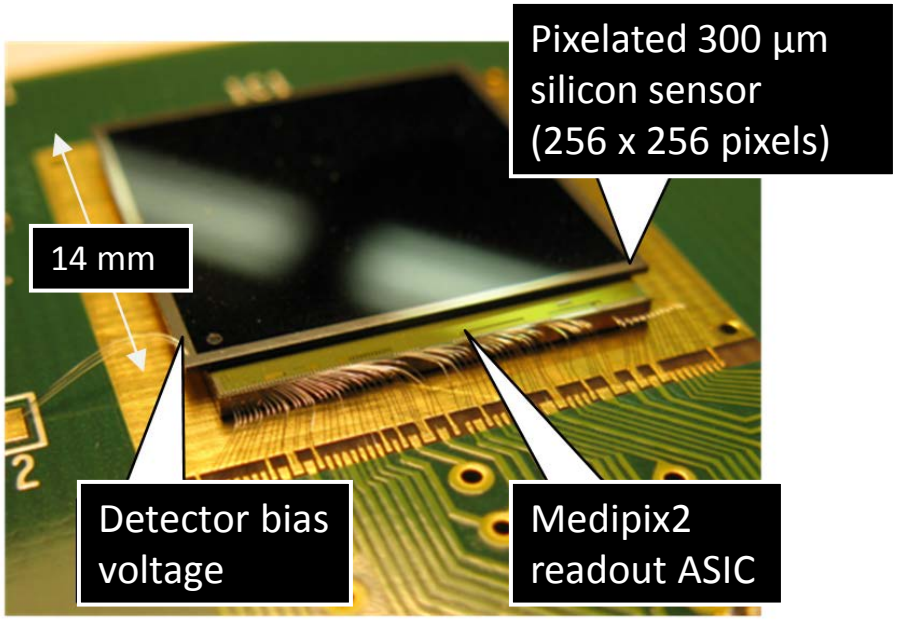
Modality	Soft-tissue contrast	Scan time	Isocentric integration	Patient setup
Orthogonal X-rays	None	4D imaging feasible	Easy	Flexible
Cone beam CT	Poor	~1 minute	Easy	Flexible
In-room CT	Fair	~1 minute	Not isocentric	Flexible
Isocentric MRI	Good	4D imaging feasible	Tough	Limited

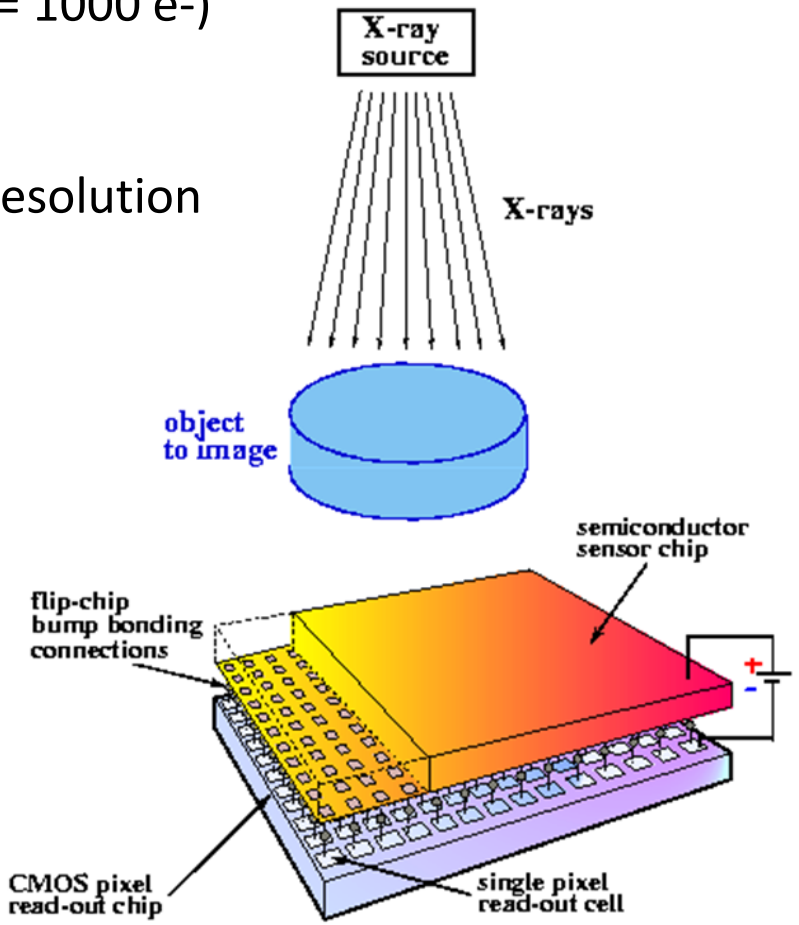
Spectral X-ray imaging



Hybrid pixel detectors

- Photon counting principle (E > 4 keV = 1000 e-)
- Large dynamic range
- Optimise ASIC and sensor separately
- Charge summing to improve energy resolution

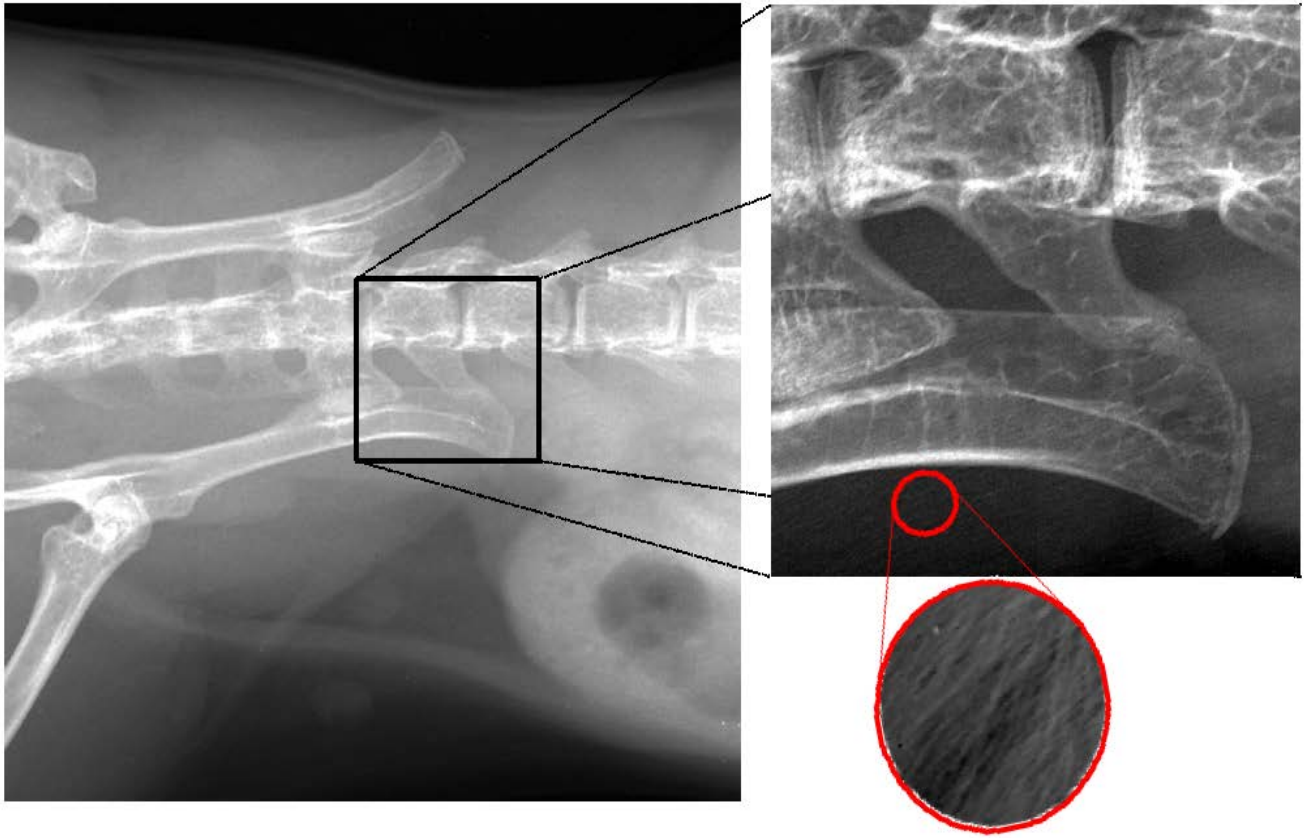




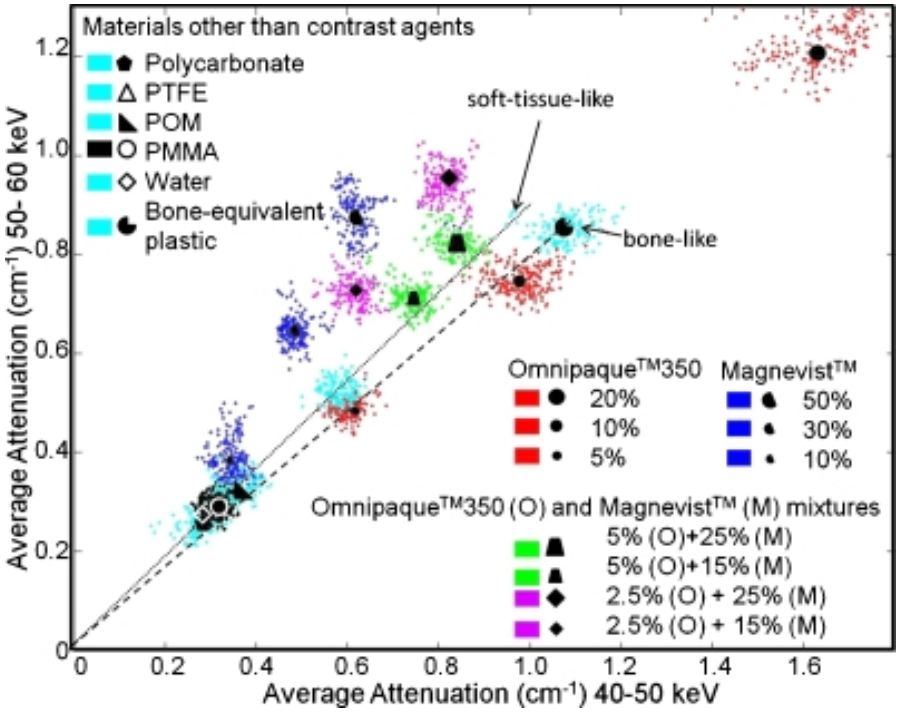
X-ray radiograph

Mouse pelvis and surrounding soft tissue structures

- High contrast of images taken by Medipix
- Even fur is seen at the side of mouse's body



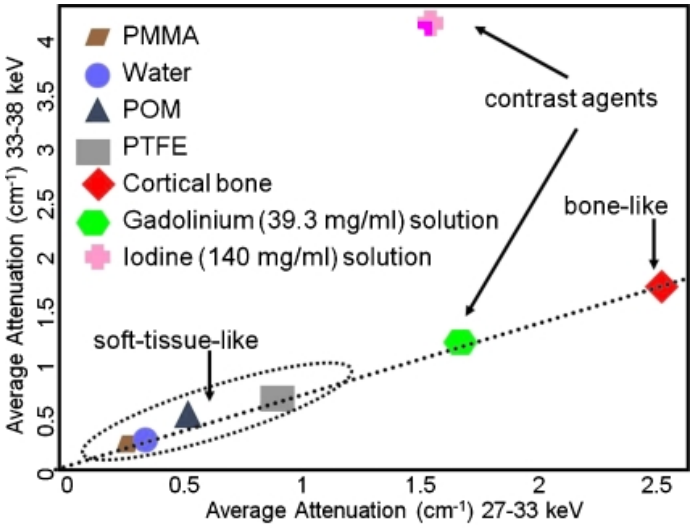
Spectral X-ray imaging

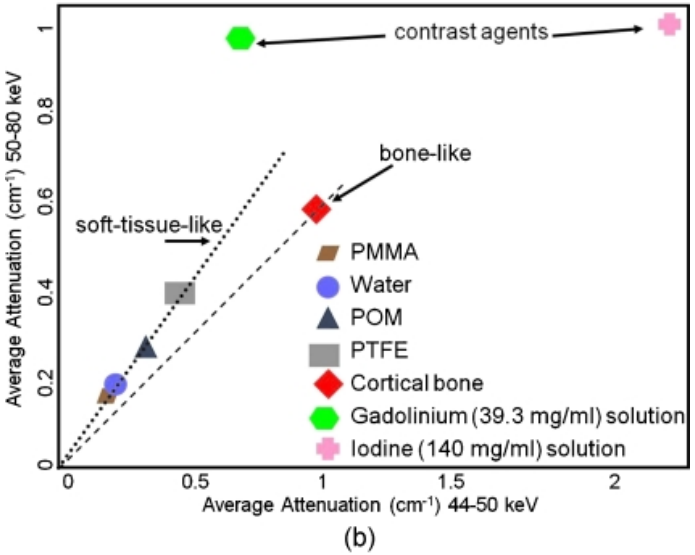


Linear attenuation scatter plots for 40–50 (horizontal axis) and 50–60 keV (vertical axis) windows from physical experiments.

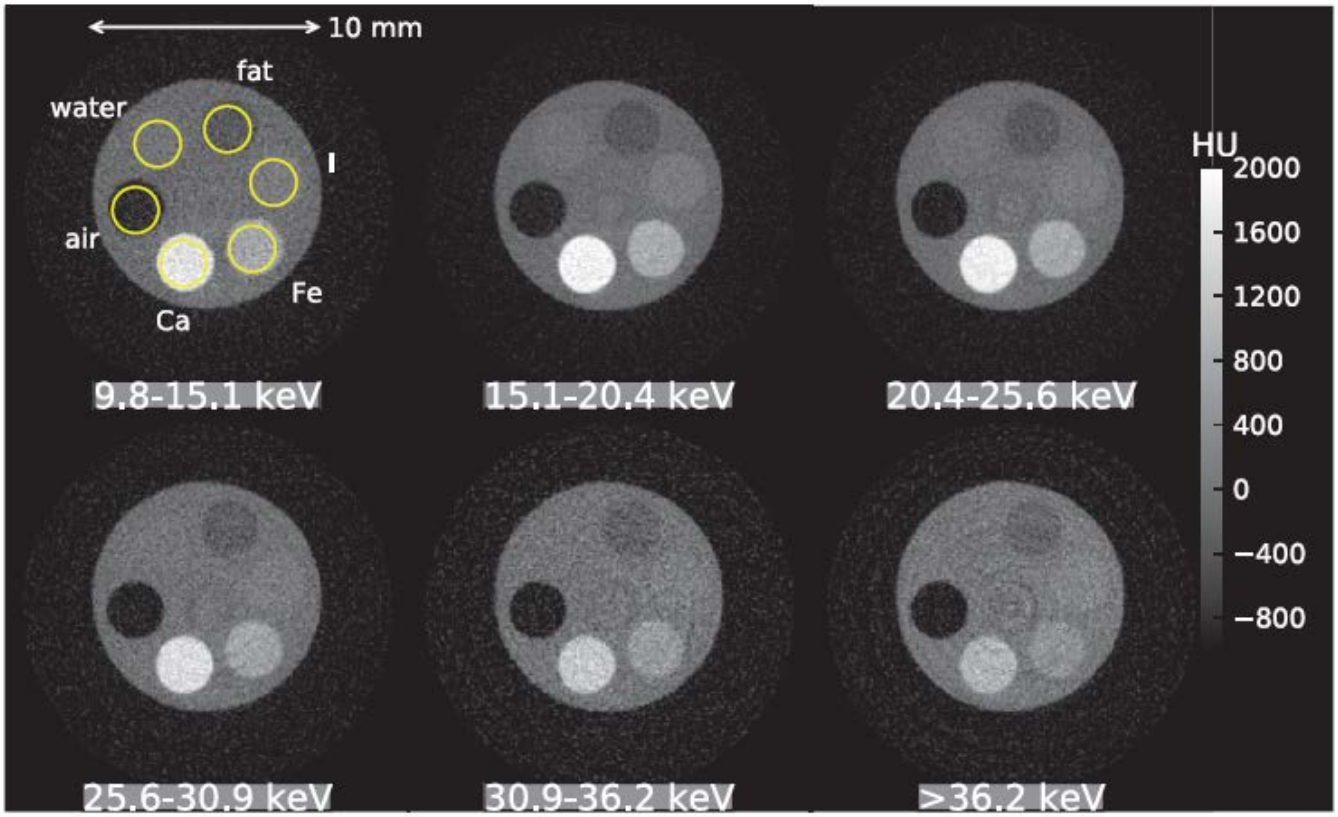
Wang et al, Med Phys 38, 1534–1546, 2011.

Theoretically calculated linear attenuations of different materials for different energy ranges





Spectral X-ray CT



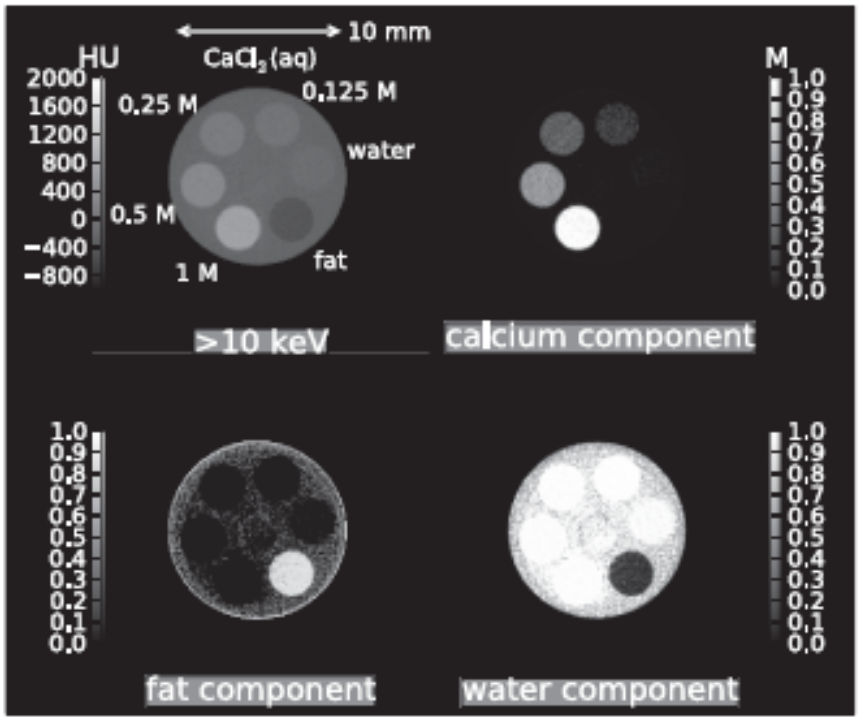
Multispectral CT reconstructions of a perspex phantom containing 2 mol l^{-1} calcium chloride, 0.4 mol l^{-1} ferric nitrate, 0.01 mol l^{-1} iodine, fat surrogate (sunflower oil), water, and air.

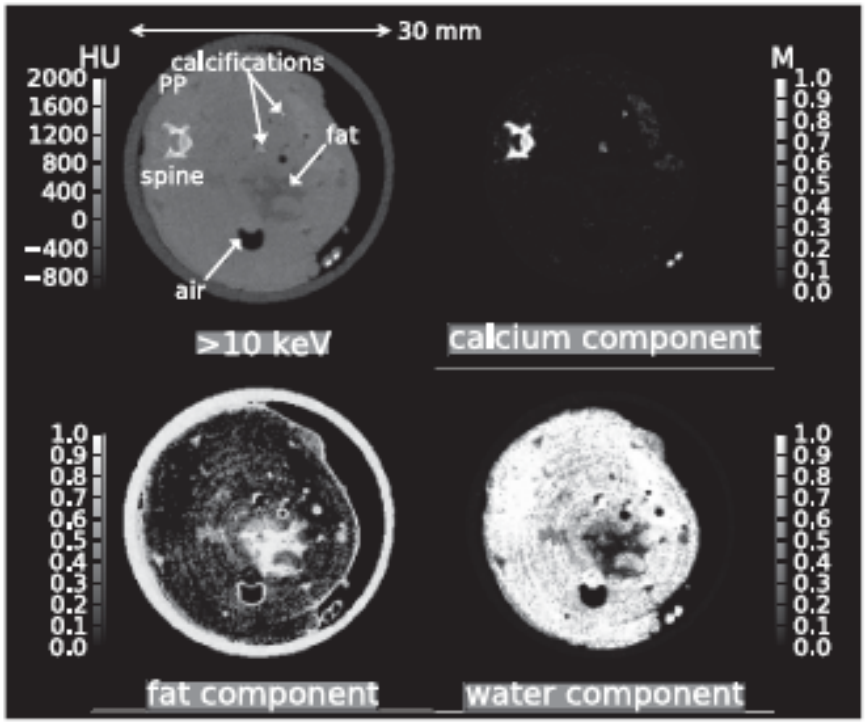
JP Ronaldson et al, Toward quantifying the composition of soft tissues by spectral CT with Medipix3, Med Phys 39, 6847-57, 2012.

Spectral X-ray CT

Spectral CT image of the calcium chloride phantom and material component images for calcium, fat, and water obtained from the analysis of multispectral data.

Spectral CT image of a transgenic mouse and material component images for calcium, fat, and water obtained from the analysis of multispectral data.





JP Ronaldson et al, Toward quantifying the composition of soft tissues by spectral CT with Medipix3, Med Phys 39, 6847-57, 2012.

Challenges posed by the application

Human subjects

- High X-ray energy (~100 keV)
- Low dose

Soft tissue contrast

- High energy resolution

4D imaging

- High frame rate
- Minimal noise

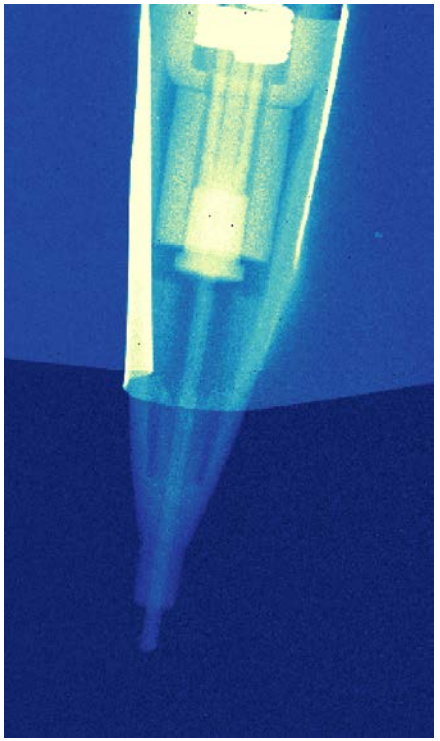
Isocentric integration

- Compactness

Spectral Smurf

Challenges in ASIC design

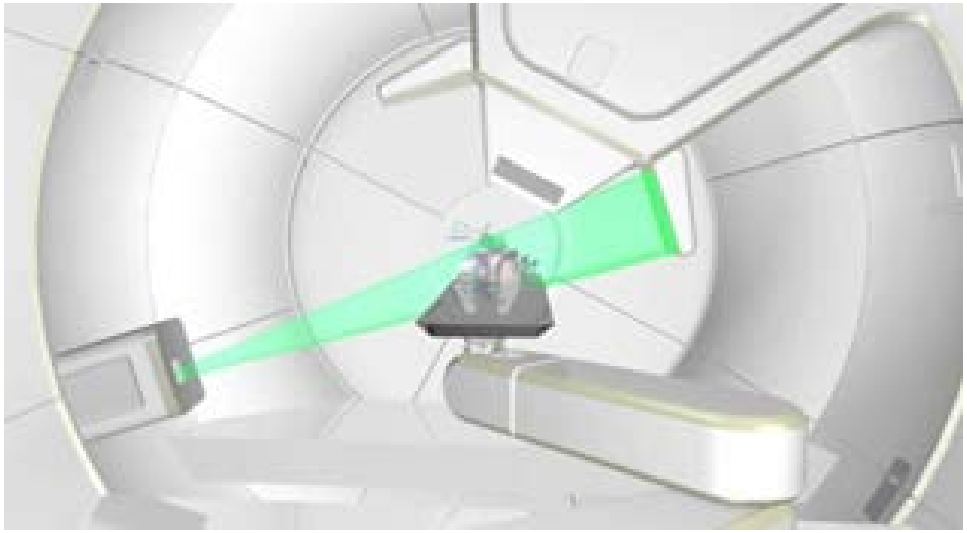
Pencil

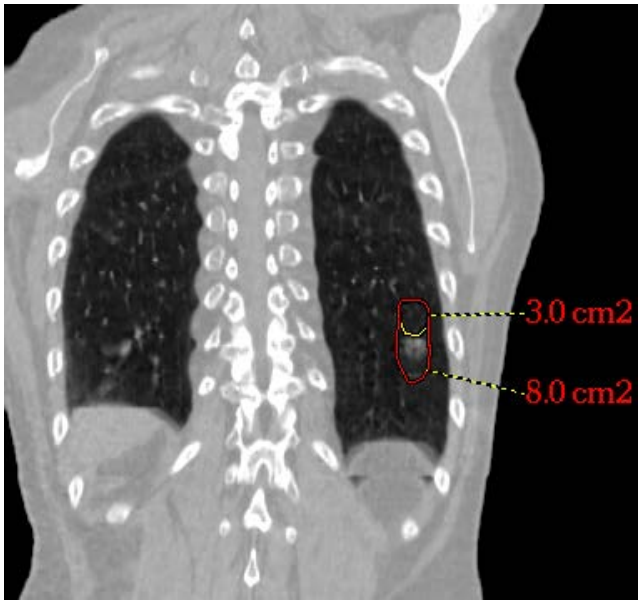


Photon counting hybrid pixel detectors

- Pixel size 50-100 µm
- High photon flux (~10^9/mm^2)
- High frame rate (~10/s)
- Charge summing
- 4-side buttable

Isocentric spectral X-rays: Wishes and dreams





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