Optimal Image-Based Material Decomposition With Energy-Selective Detectors in Spectral CT in Comparison to Dual Energy CT (DECT)

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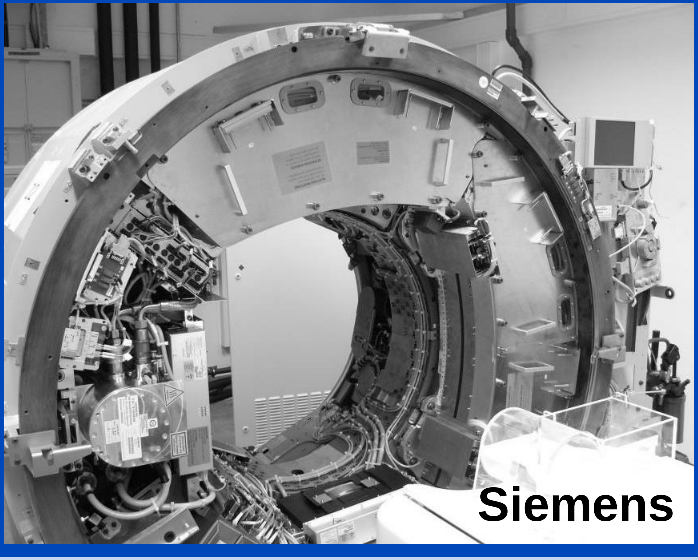
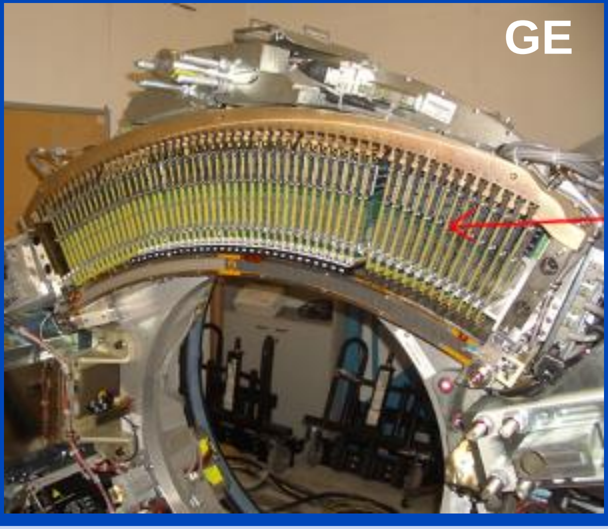
Aims

- Make use of energy data redundancies in spectral CT with photon counting (PC) detectors
- Minimize noise in material images, i.e. reduce patient dose
- Compare to today's dual energy CT (DECT)





Motivation

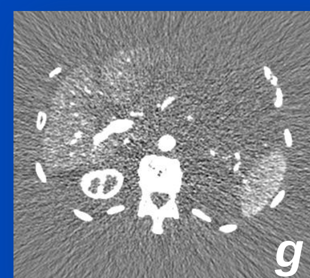
- Clinically only two independent basis materials exist:
  - 1 = water/soft tissue, 2 = bone/iodine
  - 1 = photoelectric effect, 2 = Compton scattering
  - 1 = virtual non-contrast (VNC) image, 2 = iodine map
- Two basis materials, but more than two energy bins → Optimally use additional degrees of freedom!
- Image-based method for this task
  - Narrow energy bins, images show only little beam hardening.
  - Image-based methods are fast.
- Projection-based algorithms available
  - Maximum likelihood approach (Roessl and Proksa, PMB 2007)
  - EMEC + Dose Minimization (Maaß and Kachelrieß, MIC 2011)

Algorithm Concept

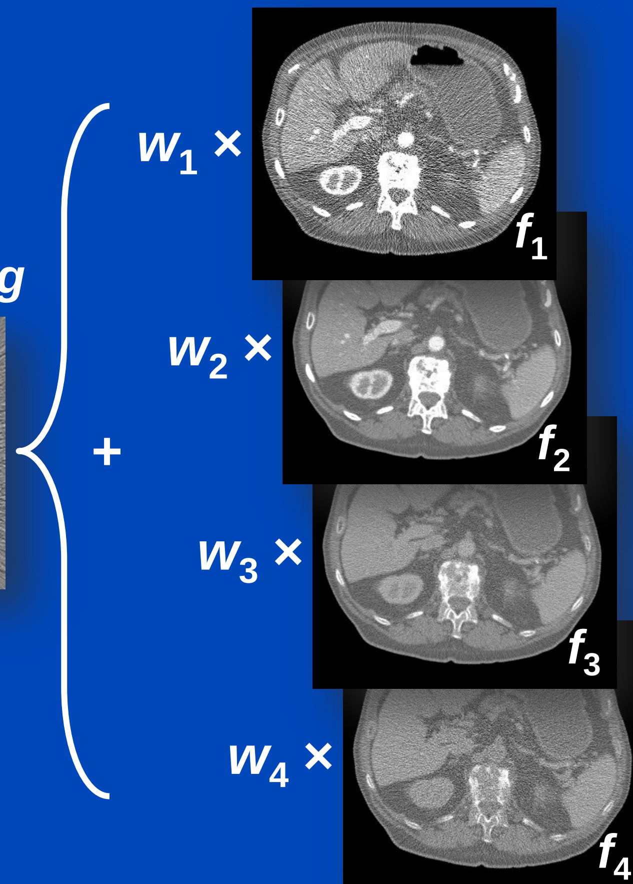
- Linear image weighting
  - Material image *g*
  - Weighting coefficients *w*
  - Energy bin images *f*

$$g = \begin{pmatrix} w_1 \\ \vdots \\ w_B \end{pmatrix} \cdot \begin{pmatrix} f_1 \\ \vdots \\ f_B \end{pmatrix}$$

Material image *g*



Bin images *f*



- Two subsequent steps:
  - Material decomposition calibration
  - Image noise minimization using the additional degrees of freedom

Algorithm

- Material images: E.g. VNC image and iodine map
- Two calibration measurements: water and iodine ROI
- Calibrate weighting coefficients *w*
  - *B* coefficients, but only *M* = 2 calibration equations
  - We solve this in a least squares sense
- SVD finds the solution and the null space

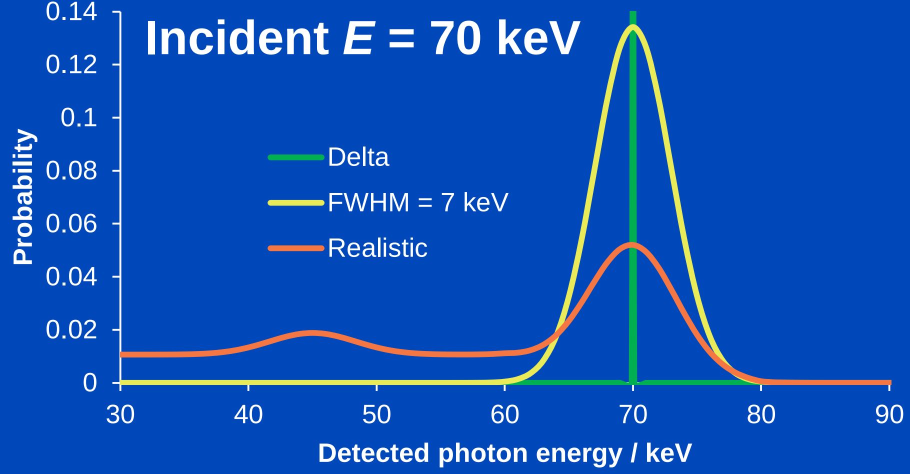
$$\boldsymbol{w}(\alpha_k) = \boldsymbol{w}_0 + \sum_{k=1}^{B-M} \alpha_k \boldsymbol{w}_k \ , \forall\, \alpha_k \in \mathbb{R}$$

- Covariance matrix *C* of all bin images required
- Use error propagation to find minimum noise solution based on null space:

$$\mathrm{Var}\ g = \boldsymbol{w}^{\mathrm{T}} \cdot \boldsymbol{C} \cdot \boldsymbol{w}$$

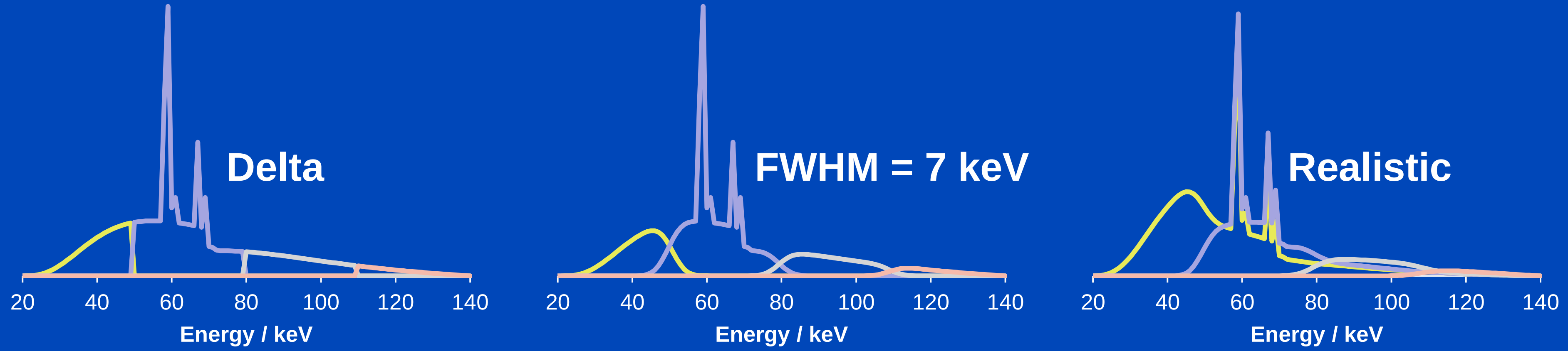
Simulation Spectral CT

- Spectral response:



Energy bins placed equidistantly from 20 keV to 140 keV

- Energy bin spectra for four energy bins:



J. P. Schlomka, E. Roessl, R. Dorscheid, S. Dill, G. Martens, T. Istel, C. Bäumer, C. Herrmann, R. Steadman, G. Zeitler, A. Livne and R. Proksa, "Experimental feasibility of multi-energy photon-counting K-edge imaging in pre-clinical computed tomography," Phys. Med. Biol. 53, 4031-4047, 2008.

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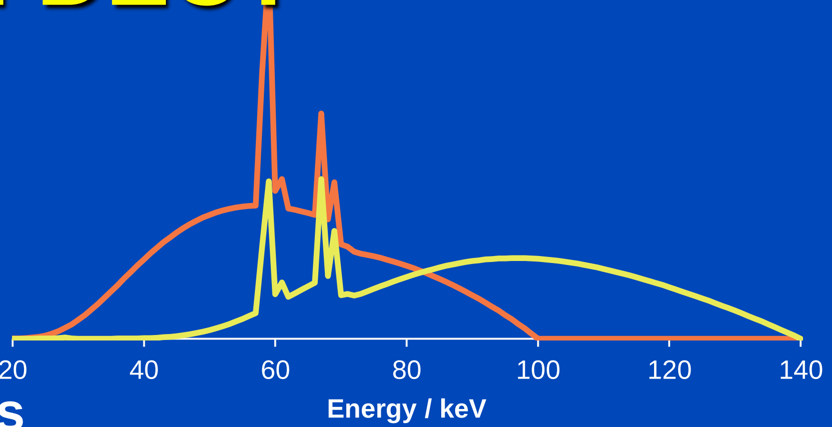
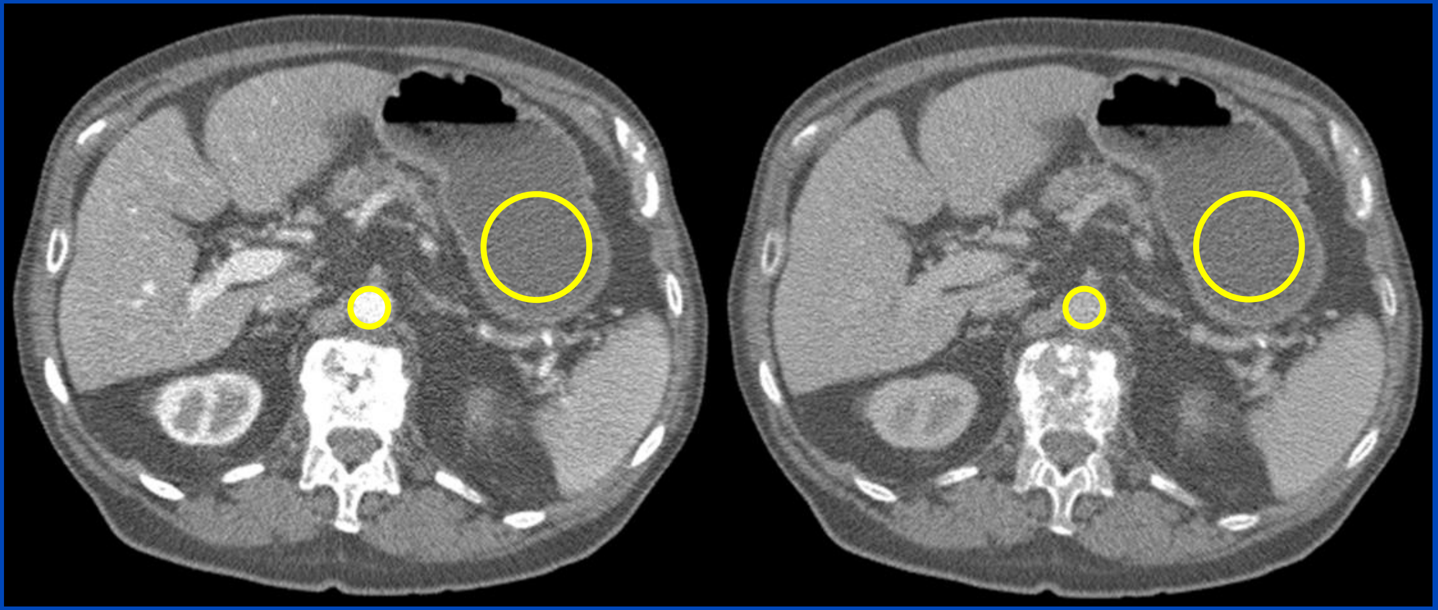
Simulation DECT

- Dual source DECT:
  - 100 kV
  - 140 kV + 0.4 mm Sn
  - Corresponds to two energy bins





100 kV

140 kV Sn

C = 0 HU / *W* = 700 HU

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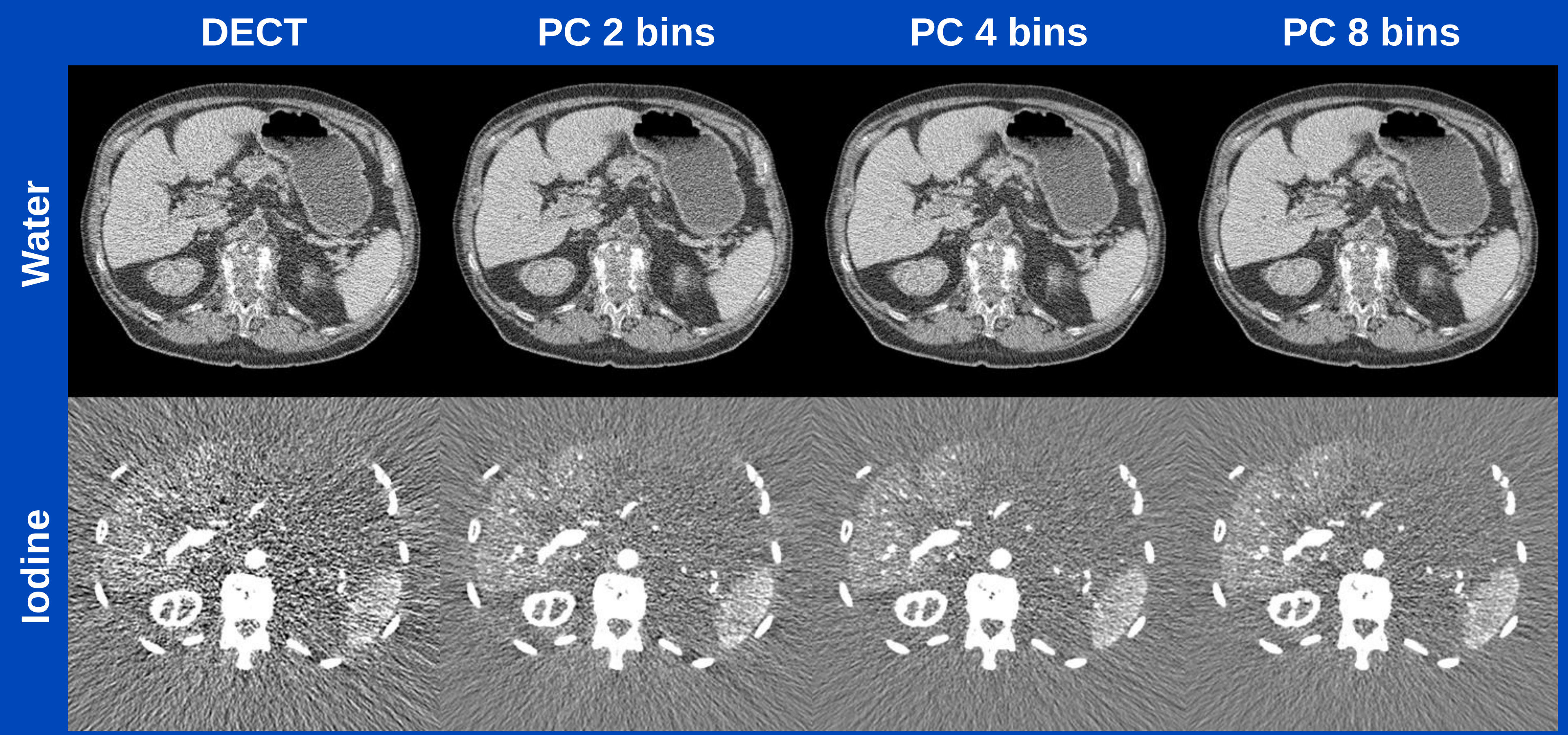
Results – Delta Model



		2 bins	4 bins	8 bins	12 bins
Water	Noise rel. to DECT	-16%	-22%	-27%	-29%
Iodine	Noise rel. to DECT	-37%	-43%	-49%	-52%

$$\frac{\sigma_{\mathrm{PC}}}{\sigma_{\mathrm{DECT}}} - 1$$

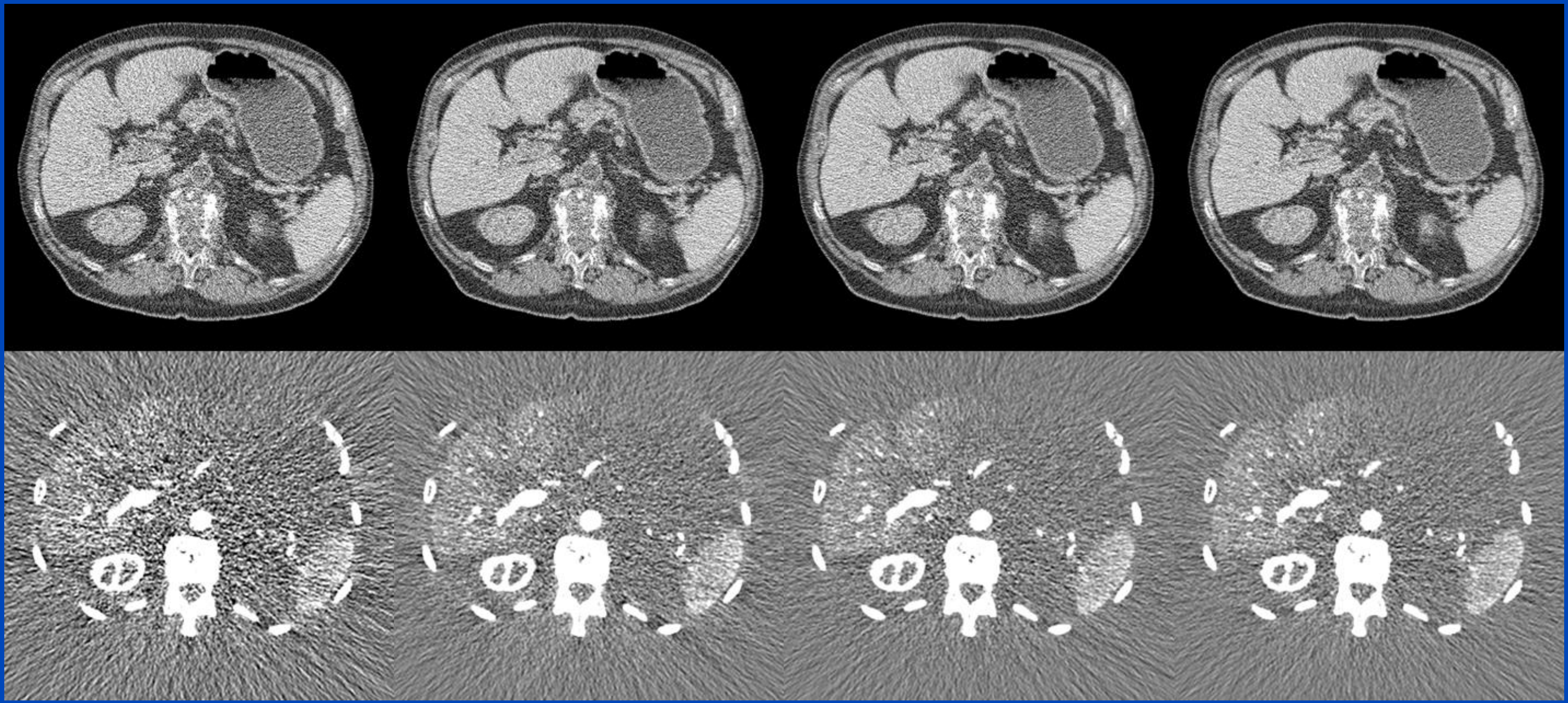
Water: $C = 1$ / $W = 0.4$
Iodine: $C = 0$ / $W = 0.4$

Results – FWHM = 7 keV Model

DECT | PC 2 bins | PC 4 bins | PC 8 bins

Water

Iodine



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Iodine	Noise rel. to DECT	-37%	-43%	-48%	-49%

$$\frac{\sigma_{\mathrm{PC}}}{\sigma_{\mathrm{DECT}}} - 1$$

Water: $C = 1$ / $W = 0.4$
Iodine: $C = 0$ / $W = 0.4$

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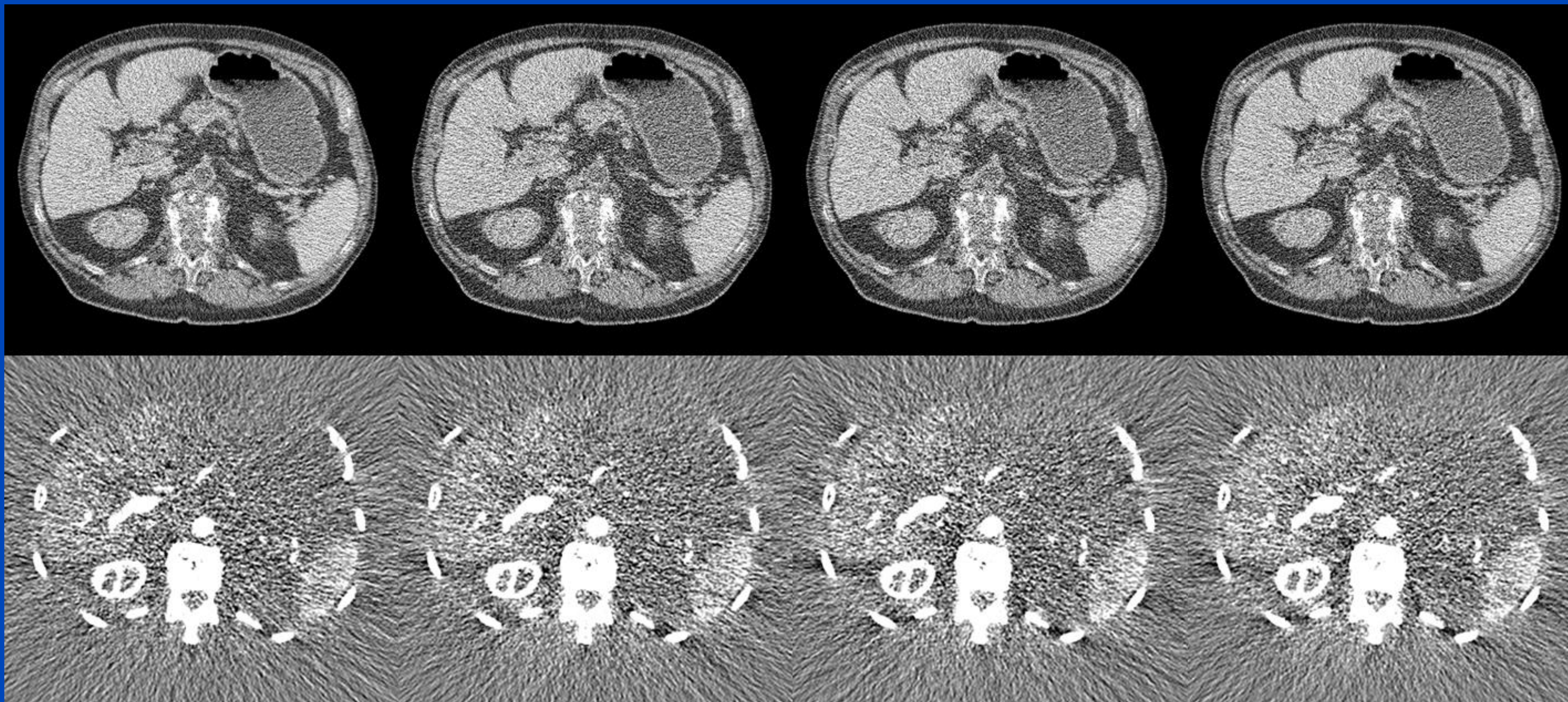
Results – Realistic Model

DECT | PC 2 bins | PC 4 bins | PC 8 bins

Water

Iodine



		2 bins	4 bins	8 bins	12 bins
Water	Noise rel. to DECT	+27%	+23%	+15%	+15%
Iodine	Noise rel. to DECT	+6%	+2%	-6%	-6%

$$\frac{\sigma_{\mathrm{PC}}}{\sigma_{\mathrm{DECT}}} - 1$$

Water: $C = 1$ / $W = 0.4$
Iodine: $C = 0$ / $W = 0.4$

Conclusions

- Ideal energy response:
  - PC detector with two bins is already better than DECT.
- Realistic energy response:
  - Low energy tail of realistic model impairs PC performance.
  - DECT is performing better than PC detector.
- Good performance of image noise minimization step:
  - More than 10% additional noise reduction (8 vs. 2 bins)
  - Corresponds to more than 18% dose reduction

Thank You!

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This presentation will soon be available at www.dkfz.de/ct.