Performance of Today's Dual Energy CT and Future Multi Energy CT in Virtual Non Contrast Imaging and in Iodine Quantification

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X-Ray Imaging and Computed Tomography, E025

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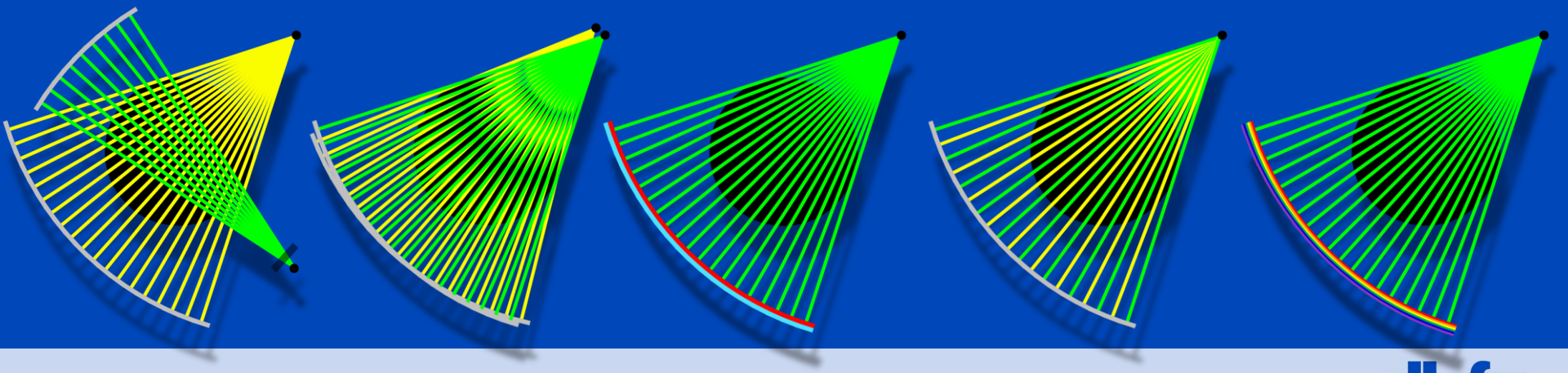
DECT Technology

- **In the clinic:**
  - Multiple scans at different spectra — mid-range
  - Dual source CT (DSCT), generations 2, and 3 — high-end
  - Fast tube voltage switching — high-end
  - Dual layer sandwich detectors — high-end
  - Split filter — mid-range
- **First prototypes:**
  - Photon counting detectors (two or more energy bins) — high-end



Simulations

- Study typical dual energy CT (DECT) application:
  - Material decomposition: virtual non contrast (VNC) and iodine image
- Comparison of:
  - Different DECT techniques with energy integrating (EI) detectors
  - Energy-selective photon counting (PC) detectors
- Statistically optimal material decomposition:
  - Constant contrast due to calibration
  - Constant patient dose in all cases (absorbed energy)
  - Noise minimization = CNRD maximization
- Based on low noise patient data set:
  - Averaged over 8 thin slices
  - Separation into water and iodine
  - Forward projection for material-specific polychromatic sinograms
- DECT image noise:
  - Approximately the same in low and high energy images
  - 100 kV / Sn 140 kV: Low / high 230 mAs / 180 mAs, $\sigma_{low} / \sigma_{high} = 1.13$

For details regarding the material decomposition method see Faby et al., SPIE 2014.

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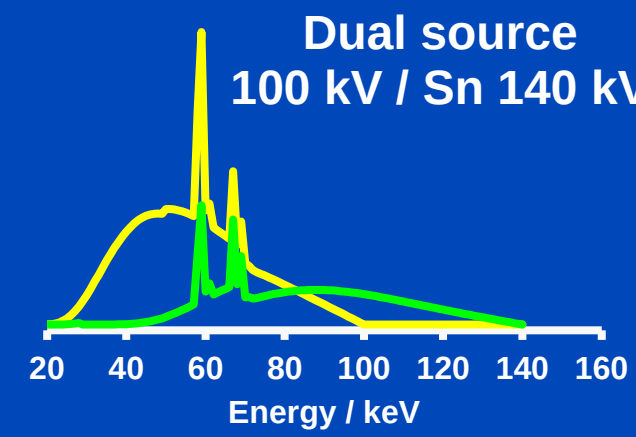
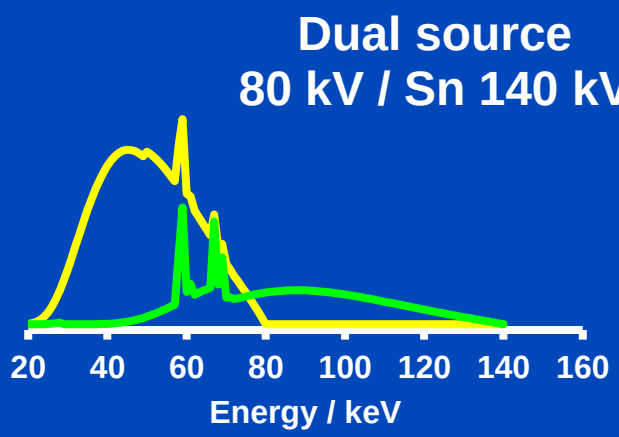
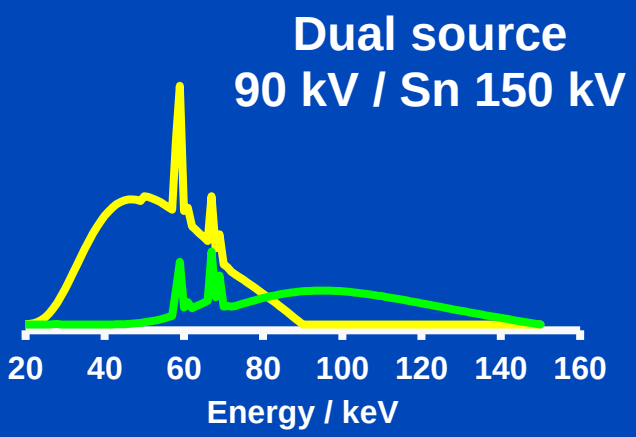
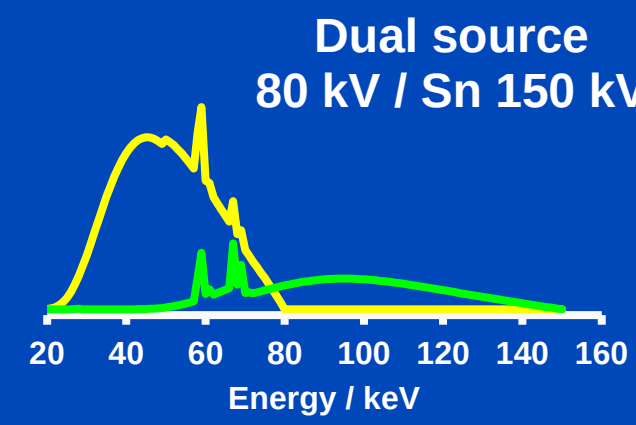
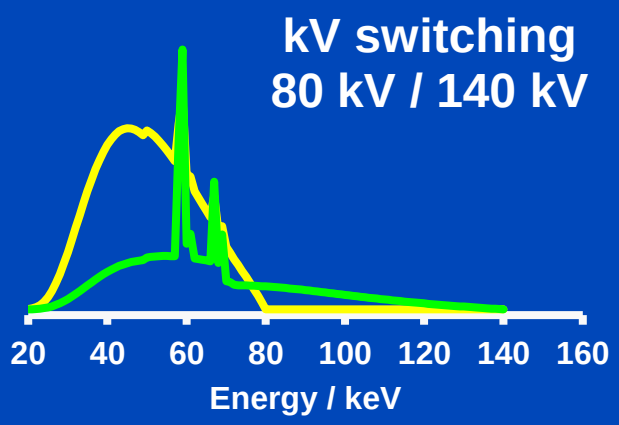
DECT Spectra

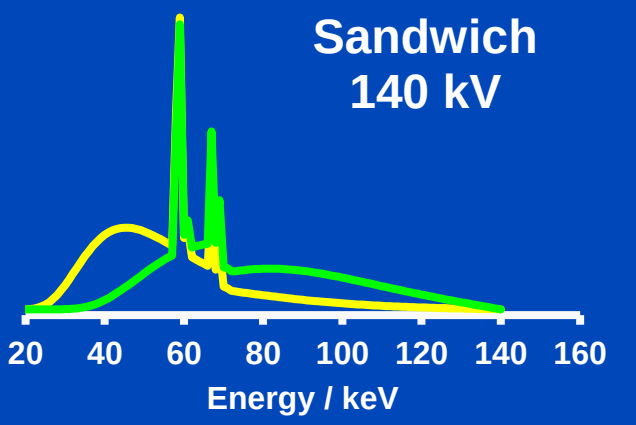






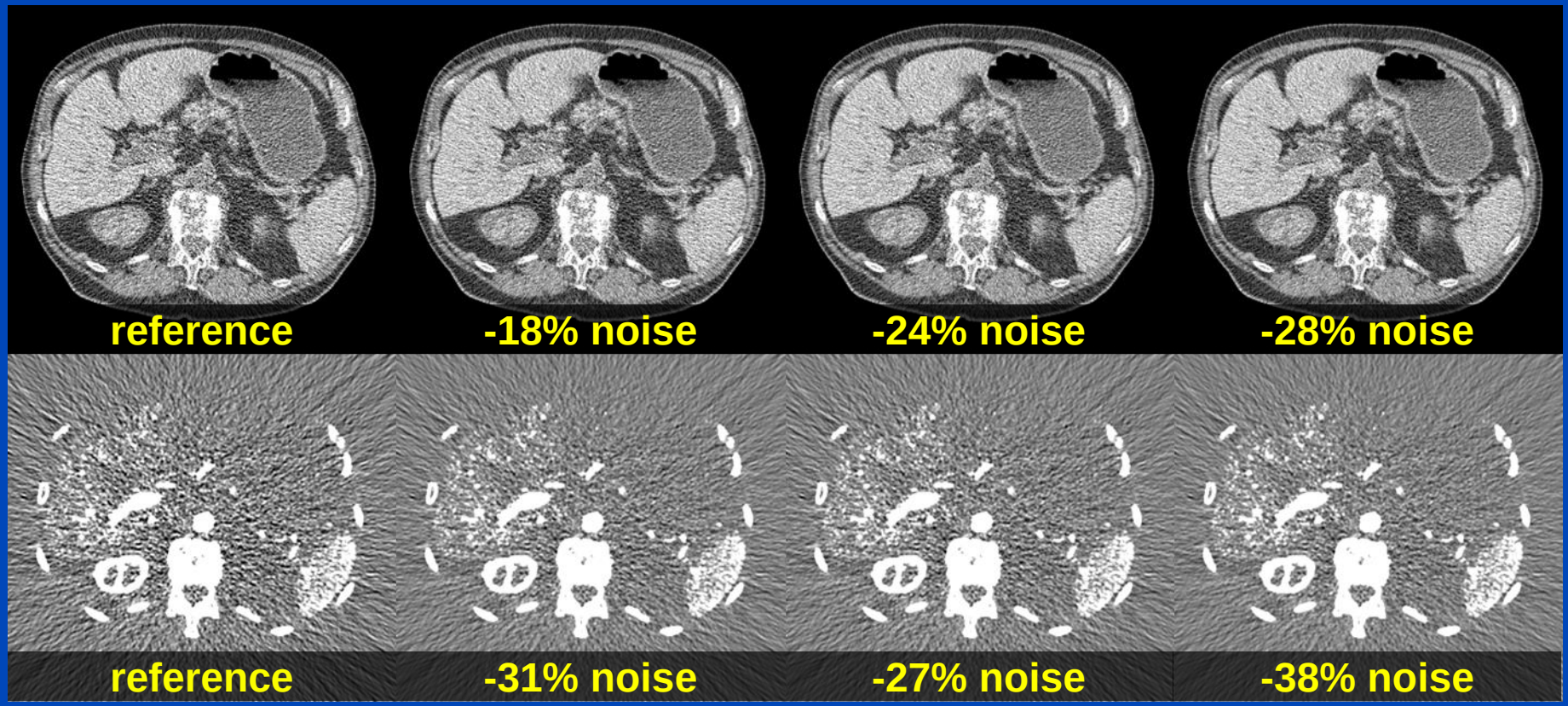






- Overlap between low and high energy spectrum important in image-based material decomposition
- Mutual information in both spectra increase noise in image subtraction

Results – Different DSCT Generations



For details regarding the material decomposition method see Faby et al., SPIE 2014.

Water: *C* = 0 HU / *W* = 400 HU
Iodine: *C* = 0 mg/mL / *W* = 6 mg/mL

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Results – Different DECT Techniques

	DS 100 kV / Sn 140 kV	DS 80 kV / Sn 140 kV	TVS 80 kV / 140 kV	Sandwich 140 kV
VNC	reference	-18% noise	+35% noise	+41% noise
Iodine	reference	-31% noise	+2% noise	+50% noise

For details regarding the material decomposition method see Faby et al., SPIE 2014.

Water: *C* = 0 HU / *W* = 400 HU
Iodine: *C* = 0 mg/mL / *W* = 6 mg/mL

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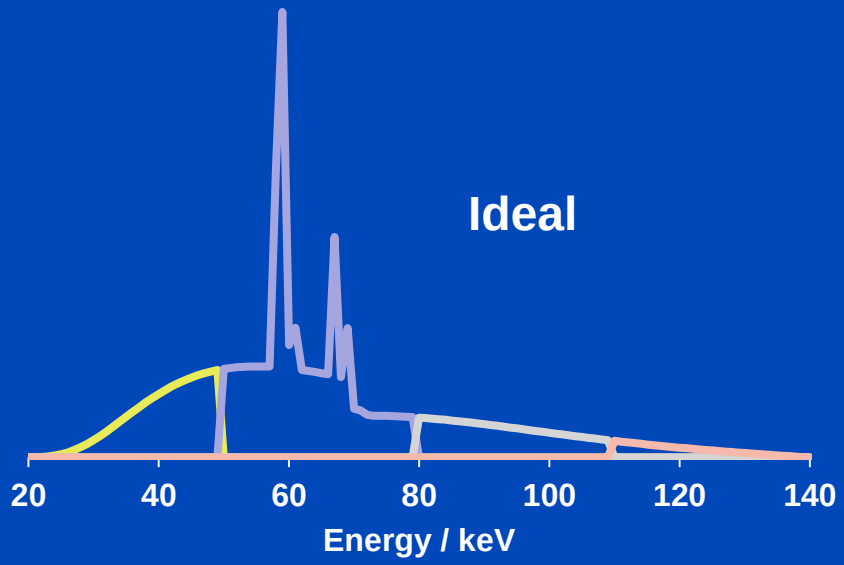
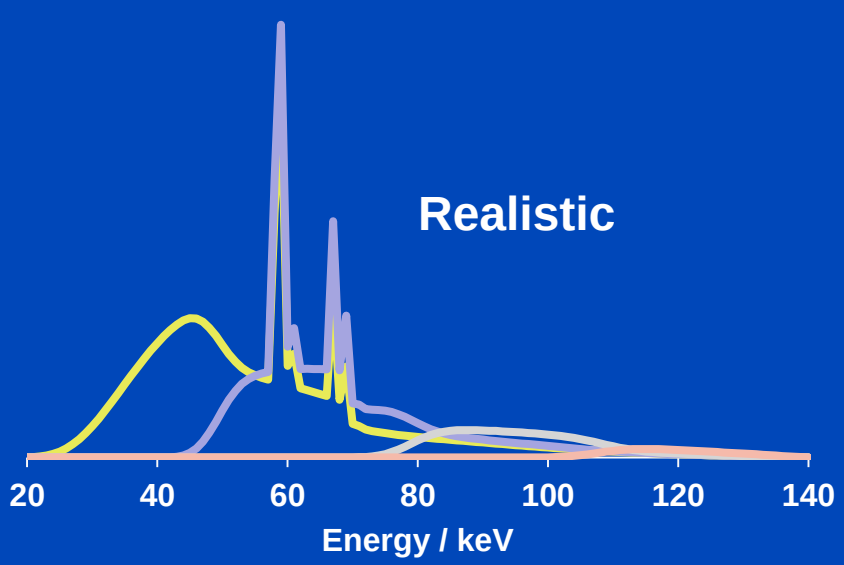
MECT Simulation

- Photon counting detector
- Energy bin spectra for $B = 4$:

Energy bins equidistantly placed from 20 keV to 140 keV.





[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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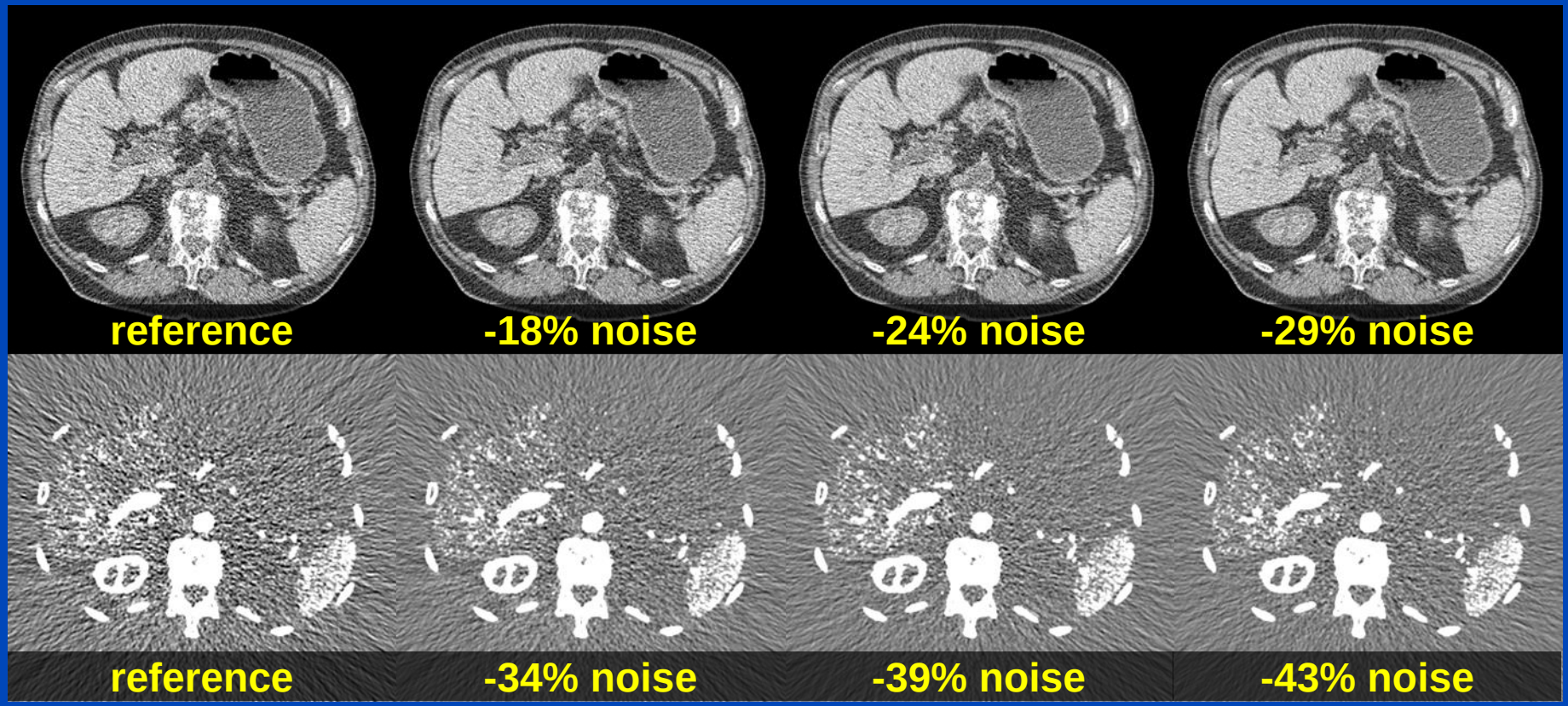
Results – PC (Ideal Model)



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Iodine: *C* = 0 mg/mL / *W* = 6 mg/mL

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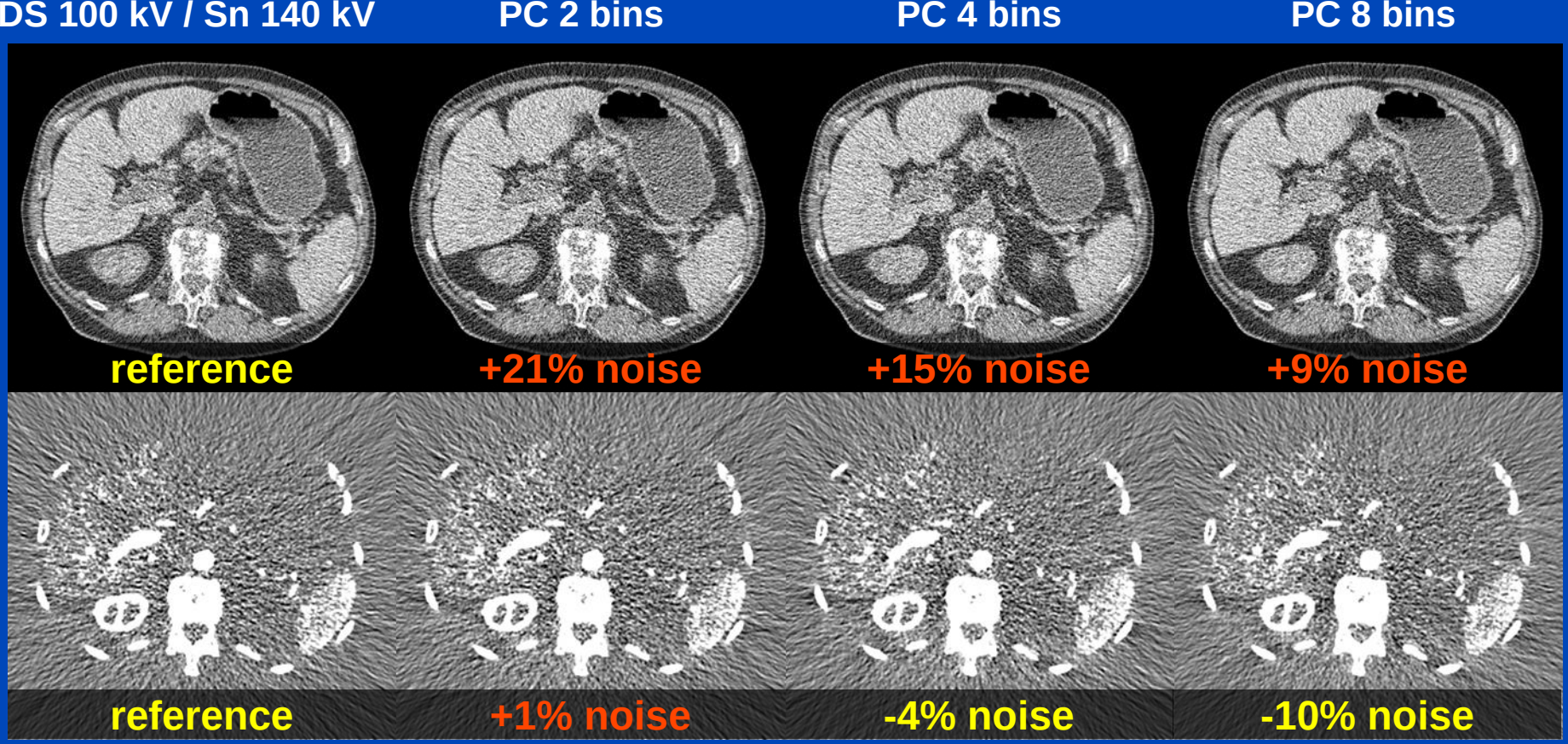
Results – PC (Realistic Model)



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Water: *C* = 0 HU / *W* = 400 HU
Iodine: *C* = 0 mg/mL / *W* = 6 mg/mL

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Overview Results

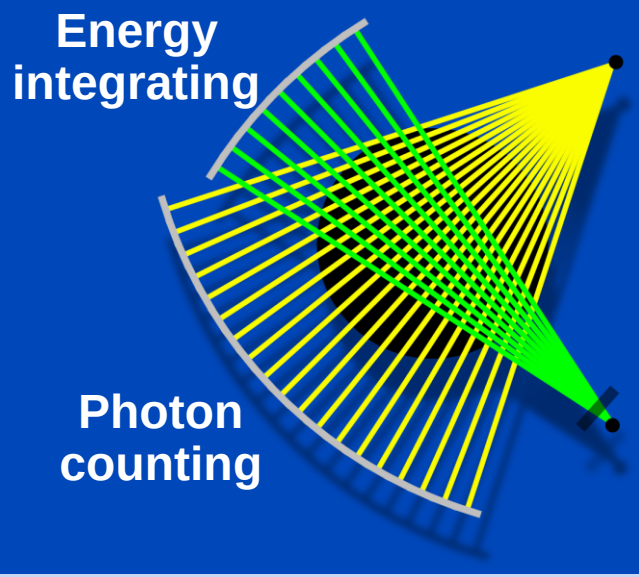
		Water-equivalent image		Iodine map	
		Noise	Dose	Noise	Dose
DS 100 kV / Sn 140 kV	2nd g.	0%	0%	0%	0%
DS 80 kV / Sn 140 kV	2nd g.	-18%	-32%	-31%	-53%
DS 90 kV / Sn 150 kV	3rd g.	-24%	-42%	-27%	-47%
DS 80 kV / Sn 150 kV	3rd g.	-28%	-48%	-38%	-62%
kV switching 80 kV / 140 kV		+35%	+83%	+2%	+4%
Sandwich 140 kV		+41%	+98%	+50%	+125%
PC Ideal 140 kV 2 bins		-18%	-33%	-34%	-56%
PC Ideal 140 kV 4 bins		-24%	-43%	-39%	-62%
PC Ideal 140 kV 8 bins		-29%	-49%	-43%	-68%
PC Realistic 140 kV 2 bins		+21%	+46%	+1%	+2%
PC Realistic 140 kV 4 bins		+15%	+32%	-4%	-8%
PC Realistic 140 kV 8 bins		+9%	+18%	-10%	-19%

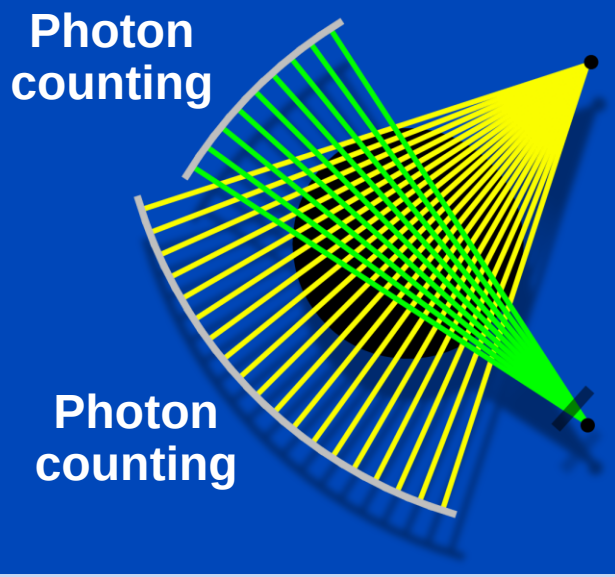
Overview Results

		Water-equivalent image		Iodine map	
		Noise	Dose	Noise	Dose
DS 100 kV / Sn 140 kV	2nd g.	+31%	+71%	+38%	+90%
DS 80 kV / Sn 140 kV	2nd g.	+8%	+16%	-6%	-11%
DS 90 kV / Sn 150 kV	3rd g.	0%	0%	0%	0%
DS 80 kV / Sn 150 kV	3rd g.	-6%	-11%	-15%	-28%
kV switching 80 kV / 140 kV		+77%	+213%	+40%	+97%
Sandwich 140 kV		+84%	+239%	+107%	+327%
PC Ideal 140 kV 2 bins		+7%	+15%	-9%	-17%
PC Ideal 140 kV 4 bins		-1%	-2%	-15%	-29%
PC Ideal 140 kV 8 bins		-7%	-13%	-22%	-39%
PC Realistic 140 kV 2 bins		+58%	+149%	+39%	+95%
PC Realistic 140 kV 4 bins		+50%	+126%	+32%	+75%
PC Realistic 140 kV 8 bins		+42%	+101%	+24%	+54%

PC/EI and PC/PC DSCT Concepts

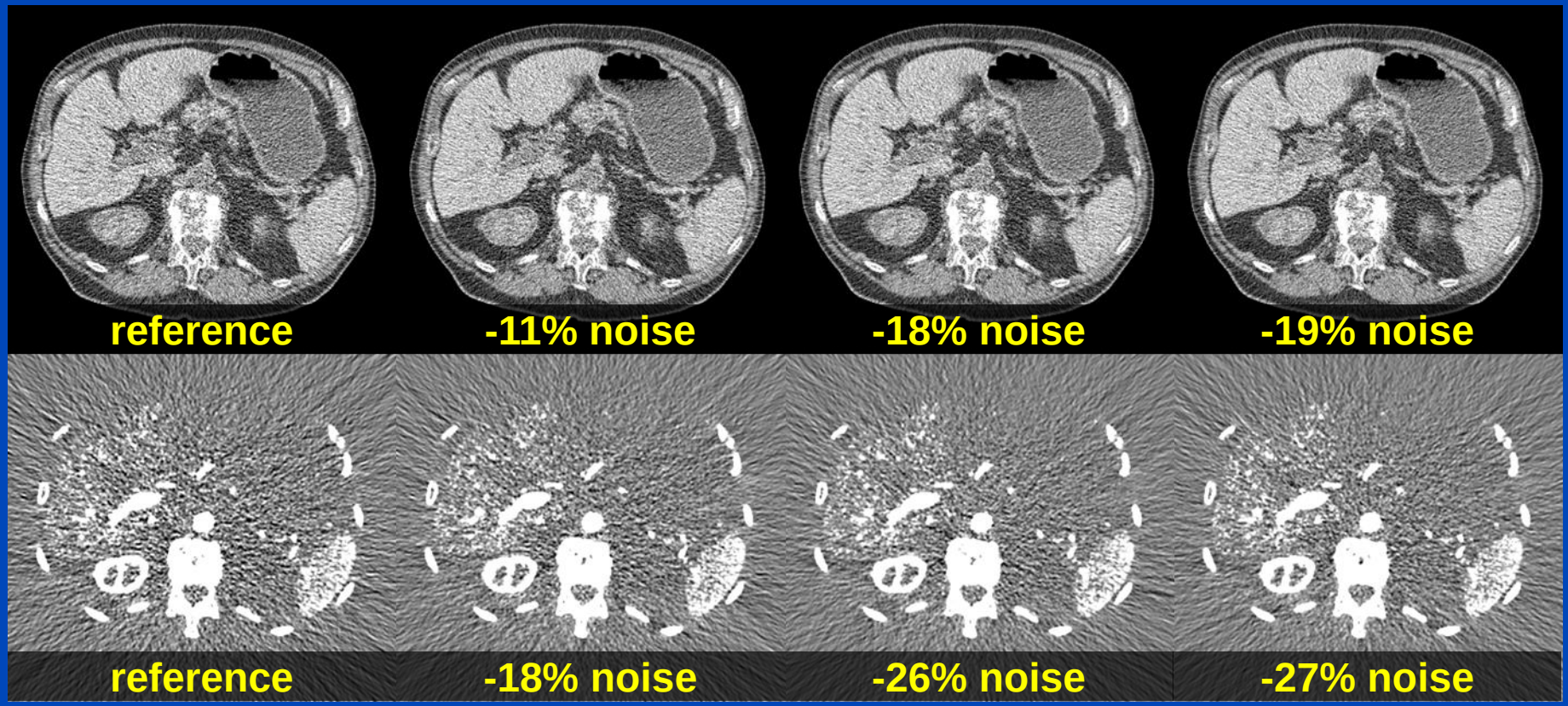
- Improve PC detector performance using DSCT
- Replace low spectrum EI detector by PC detector
- Replace both EI detectors by PC detectors





Results – PC/EI (Realistic PC Model)

PC 100 kV / EI Sn 140 kV



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Water: *C* = 0 HU / *W* = 400 HU
Iodine: *C* = 0 mg/mL / *W* = 6 mg/mL

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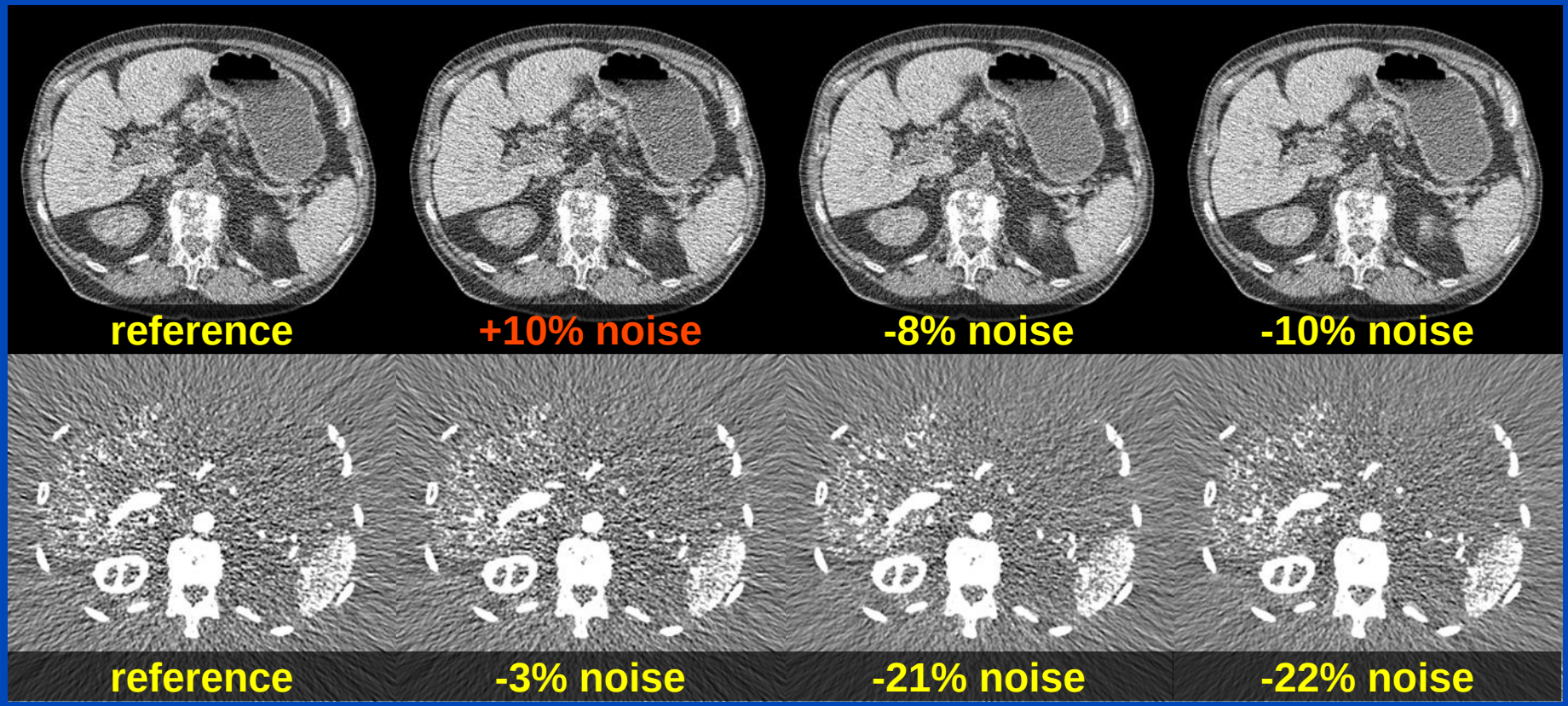
Results – PC/PC (Realistic PC Model)

PC 100 kV / PC Sn 140 kV



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Overview Results

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PC Realistic 140 kV 4 bins	+15%	+32%	-4%	-8%
PC Realistic 140 kV 8 bins	+9%	+18%	-10%	-19%
PC 100 kV / EI Sn 140 kV 1 bin	-11%	-20%	-18%	-33%
PC 100 kV / EI Sn 140 kV 2 bins	-18%	-33%	-26%	-45%
PC 100 kV / EI Sn 140 kV 4 bins	-19%	-35%	-27%	-47%
PC 100 kV / PC Sn 140 kV 1 bin	+10%	+21%	-3%	-6%
PC 100 kV / PC Sn 140 kV 2 bins	-8%	-16%	-21%	-38%
PC 100 kV / PC Sn 140 kV 4 bins	-10%	-18%	-22%	-40%

Overview Results

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PC 90 kV / EI Sn 150 kV 1 bin	-5%	-10%	-13%	-24%
PC 90 kV / EI Sn 150 kV 2 bins	-9%	-17%	-17%	-30%
PC 90 kV / EI Sn 150 kV 4 bins	-10%	-19%	-17%	-32%
PC 90 kV / PC Sn 150 kV 1 bin	+10%	+21%	-2%	-4%
PC 90 kV / PC Sn 150 kV 2 bins	+2%	+5%	-10%	-19%
PC 90 kV / PC Sn 150 kV 4 bins	+1%	+3%	-11%	-21%

Conclusion

- **Comparison of today's DECT approaches**
  - **Dual source CT performs best, having the most flexibility**
  - **Fast kV switching performs a bit worse than DS DECT at 100 kV / Sn 140 kV**
  - **Sandwich detector's performance suffers from spectral overlap**
- **Novel photon counting detector technology studied**
  - **Very promising results and great patient dose saving possibilities in case of ideal detector: Up to 70% (iodine image) for 8 energy bins compared to DS DECT at 100 kV / Sn 140 kV**
  - **Undesired detector effects result in worse performance than today's gold standard (DS DECT at 100 kV / Sn 140 kV)**
  - **Dual source CT with photon counting detectors improves performance**
    → Interesting future technology

Thank You!

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

This work was supported by the Deutsche Forschungsgemeinschaft (DFG) under grant KA 1678/5-1 and LE 2763/1, and by the German Government, Bundesministerium für Bildung und Forschung (01EX1012B, Spitzencluster Medical Valley).

The reconstruction software was provided by RayConStruct® GmbH, Nürnberg, Germany.