Threshold-Dependent Dual Energy Performance and Spectral Separation in Whole Body Photon-Counting CT

Stefan Sawall[1,2], Laura Klein[1,2], Carlo Amato[1,2], Katharina Roth[3,4], Eckhard Wehrse[1,2], Joscha Maier[1,2], Heinz-Peter Schlemmer[1,2], Christian H. Ziener[1,2], Sarah Heinze[5], and Marc Kachelrieß[1,2]

[1]German Cancer Research Center (DKFZ), Heidelberg, Germany
[2]Ruprecht-Karls-University of Heidelberg, Heidelberg, Germany
[3]Siemens Healthineers, Forchheim, Germany
[4]Duale Hochschule Baden-Württemberg, Mannheim, Germany
[5]University Hospital Heidelberg, Heidelberg, Germany

DEUTSCHES KREBSFORSCHUNGSZENTRUM IN DER HELMHOLTZ-GEMEINSCHAFT

Aim

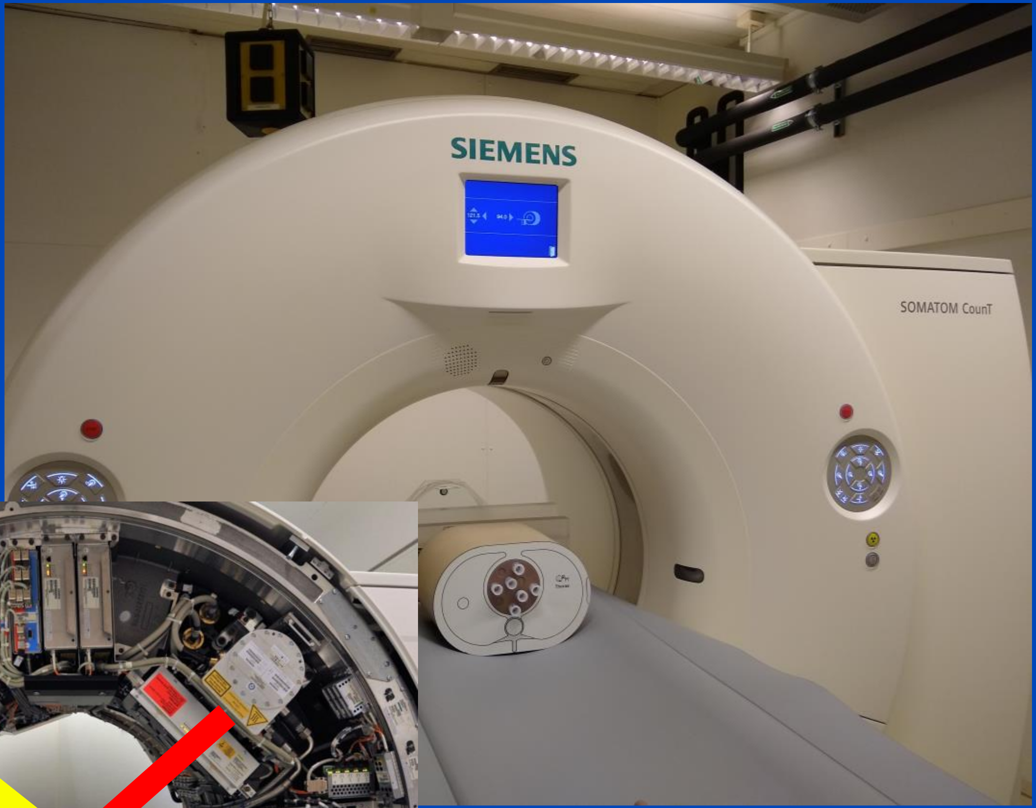
Evaluate the threshold-dependent spectral separation and its consequences on the quality of material images in a whole-body photon-counting (PC) CT compared to a conventional, energy-integrating (EI) dual-source dual energy (DSDE) CT.

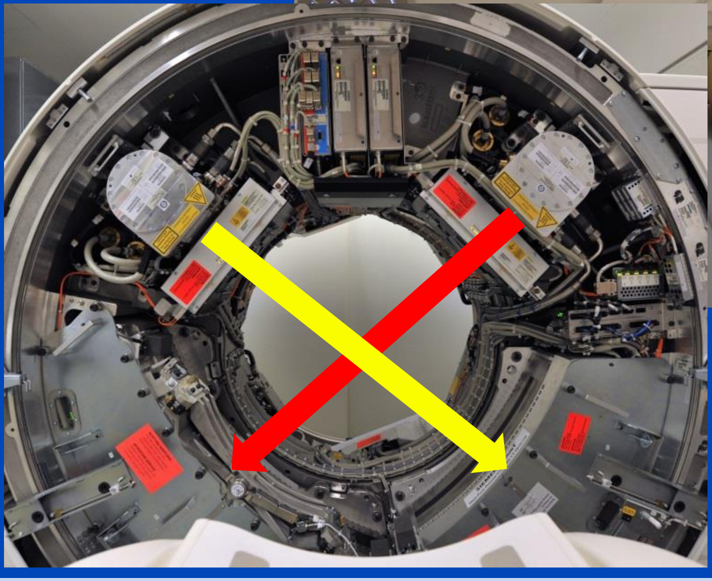
SOMATOM CounT CT @ DKFZ

Gantry from a clinical dual source scanner

A: conventional CT detector (50 cm FOV)

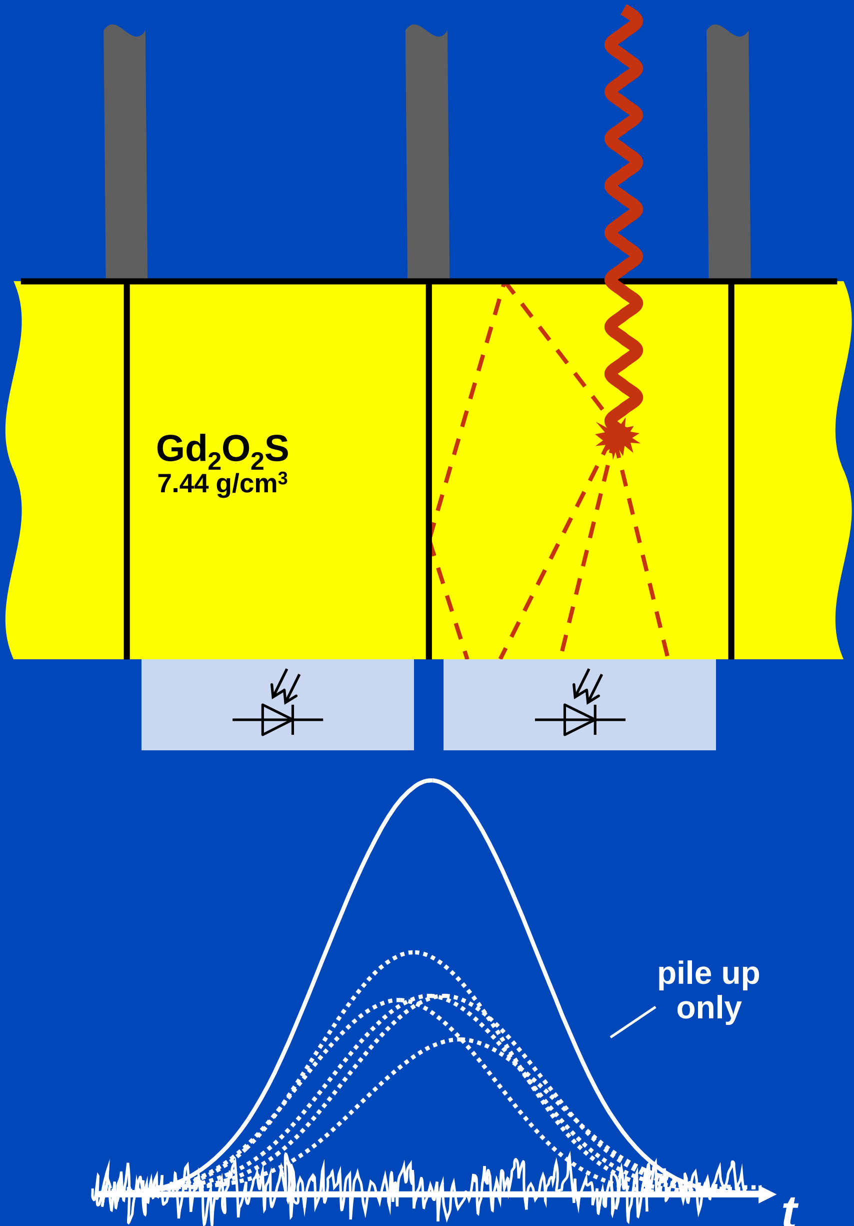
B: Photon counting detector (27.5 cm FOV)



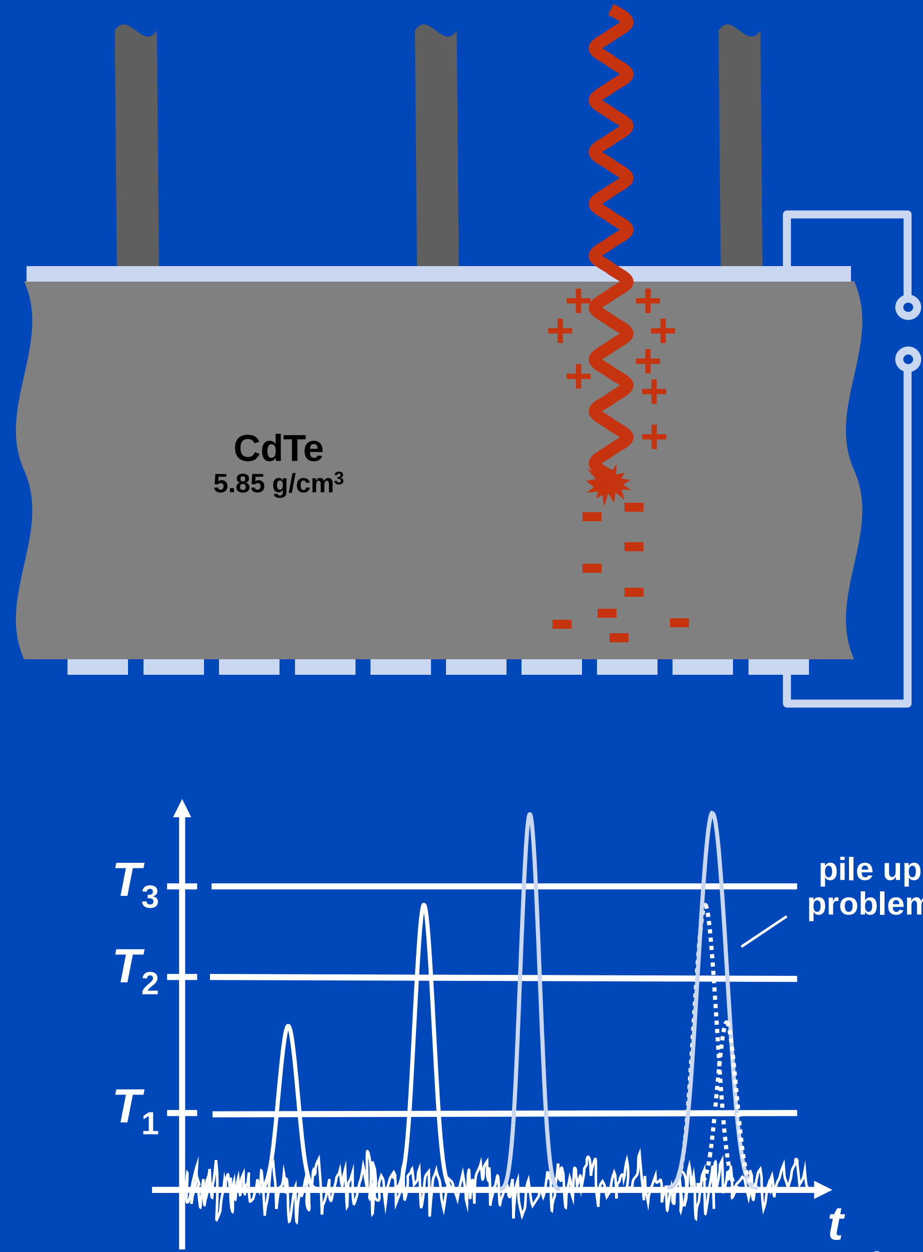


Prototype, not commercially available.

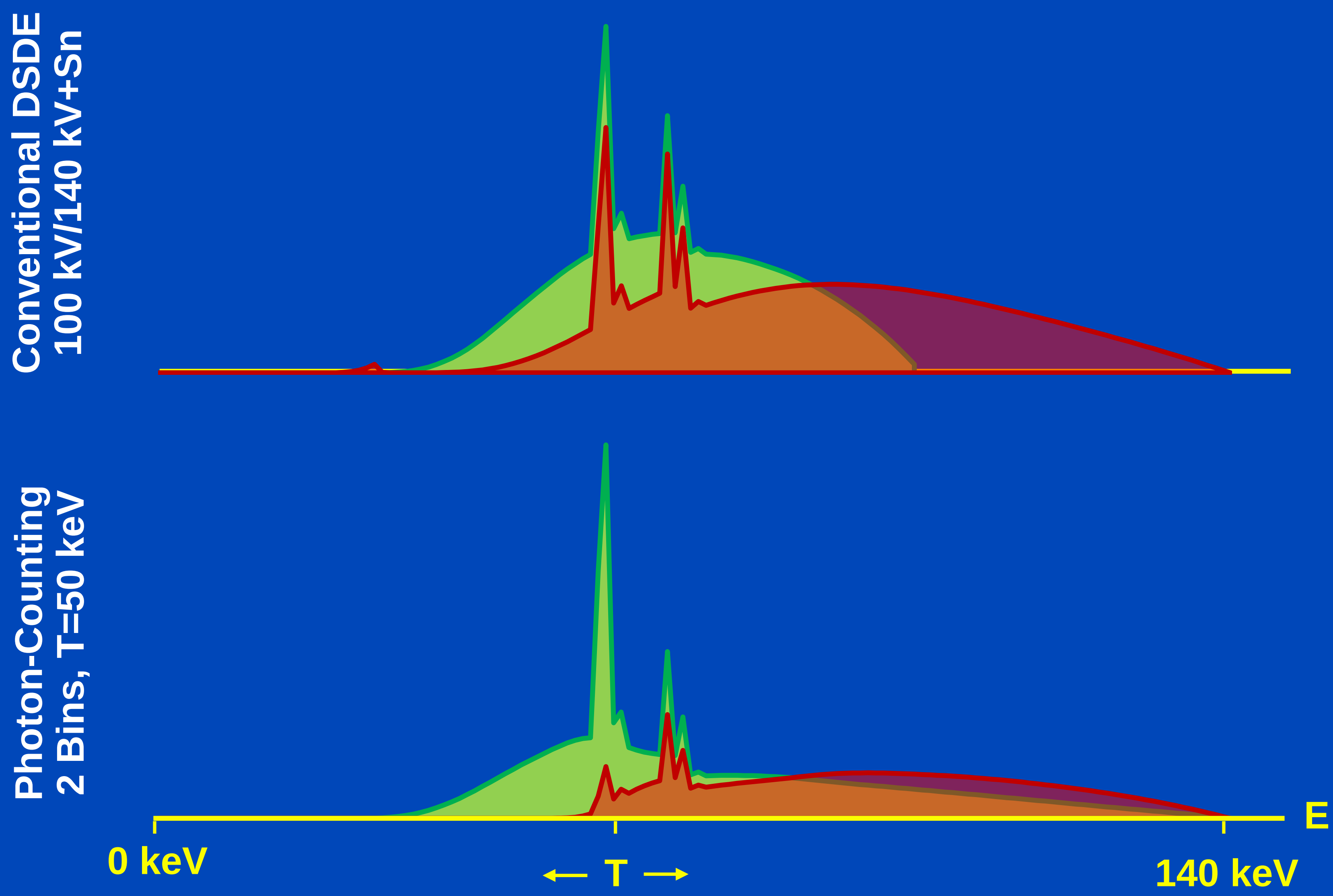
Energy integrating detector



Photon counting detector



Dual Source vs. Photon-Counting



Material Mixtures

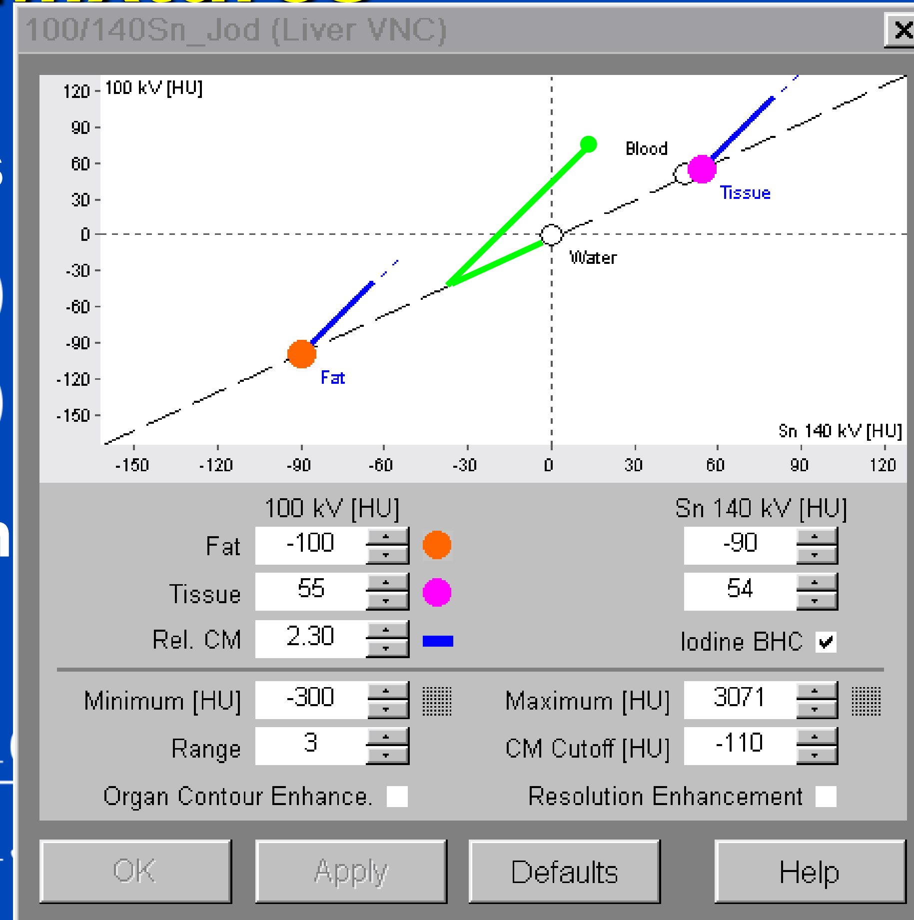
- **Two water-iodine mixtures**

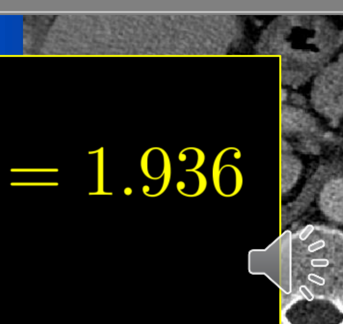
$$CT_1(E) = (1 - w_1)CT_\mathrm{W}(E)$$
$$CT_2(E) = (1 - w_2)CT_\mathrm{W}(E)$$

- **Their relative contrast is in ratio**

$$\frac{CT_1(E_{100\,\mathrm{kV}}) - CT_2(E_{1}}{CT_1(E_{150\,\mathrm{kV}}) - CT_2(E_{1}}$$

- **Hence, it can be used to calibrate DECT**





$$\frac{CT_\mathrm{I}(60\ \mathrm{keV})}{CT_\mathrm{I}(80\ \mathrm{keV})} = \frac{\mu_\mathrm{I}(60\ \mathrm{keV})/\mu_\mathrm{W}(60\ \mathrm{keV}) - 1}{\mu_\mathrm{I}(80\ \mathrm{keV})/\mu_\mathrm{W}(80\ \mathrm{keV}) - 1} = 1.936$$

In monochromatic scans or in rawdata-based preprocessed DECT data!

Material Decomposition

- **Assume CT images with air = 0 and water = 1**
- **Mix image:** $f_\alpha = (1-\alpha) f_\mathrm{L} + \alpha f_\mathrm{H}$ α to minimize noise
- **Water image:** $f_\mathrm{W} = (1-\beta) f_\mathrm{L} + \beta f_\mathrm{H}$ $\beta = \frac{\mathrm{RelCM}}{\mathrm{RelCM}-1} > 1$
- **Iodine overlay:** $f_\mathrm{I} = \gamma (f_\mathrm{L} - f_\mathrm{H})$ γ such that $f_\mathrm{W} + f_\mathrm{I} = f_\alpha$
- **Noise in the water image is:**

$$\mathrm{Var}\, f_\mathrm{W} = (1-\beta)^2 \mathrm{Var}\, f_\mathrm{L} + \beta^2 \mathrm{Var}\, f_\mathrm{H}$$

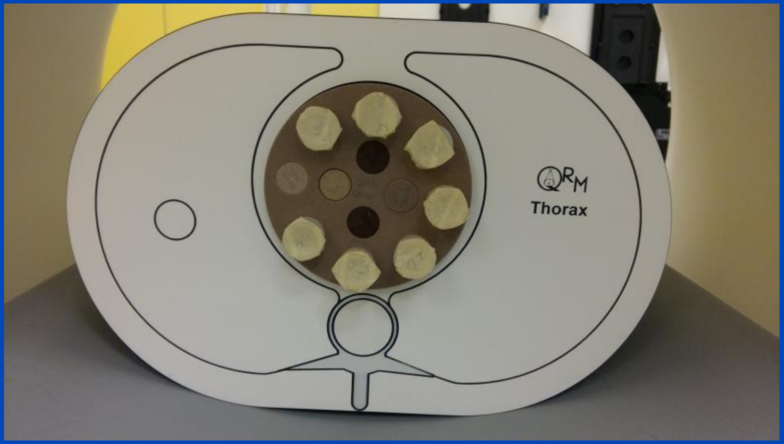
- **The dependency on RelCM is:**

$$\frac{\partial \mathrm{Var}\, f_\mathrm{W}}{\partial \mathrm{RelCM}} = -2 \frac{\mathrm{Var}\, f_L + \mathrm{RelCM} \cdot \mathrm{Var}\, f_H}{(\mathrm{RelCM}-1)^3} < 0$$

- **The higher RelCM the lower the noise in the resulting images if Var f_L and Var f_H would be constant.**

Materials & Methods
Phantoms

- Anthropomorphic thorax and liver phantom
- Three different phantom sizes
  - Small (200 × 300 mm)
  - Medium (250 × 350 mm)
  - Large (300 × 400 mm)
- Equipped with iodine inserts.



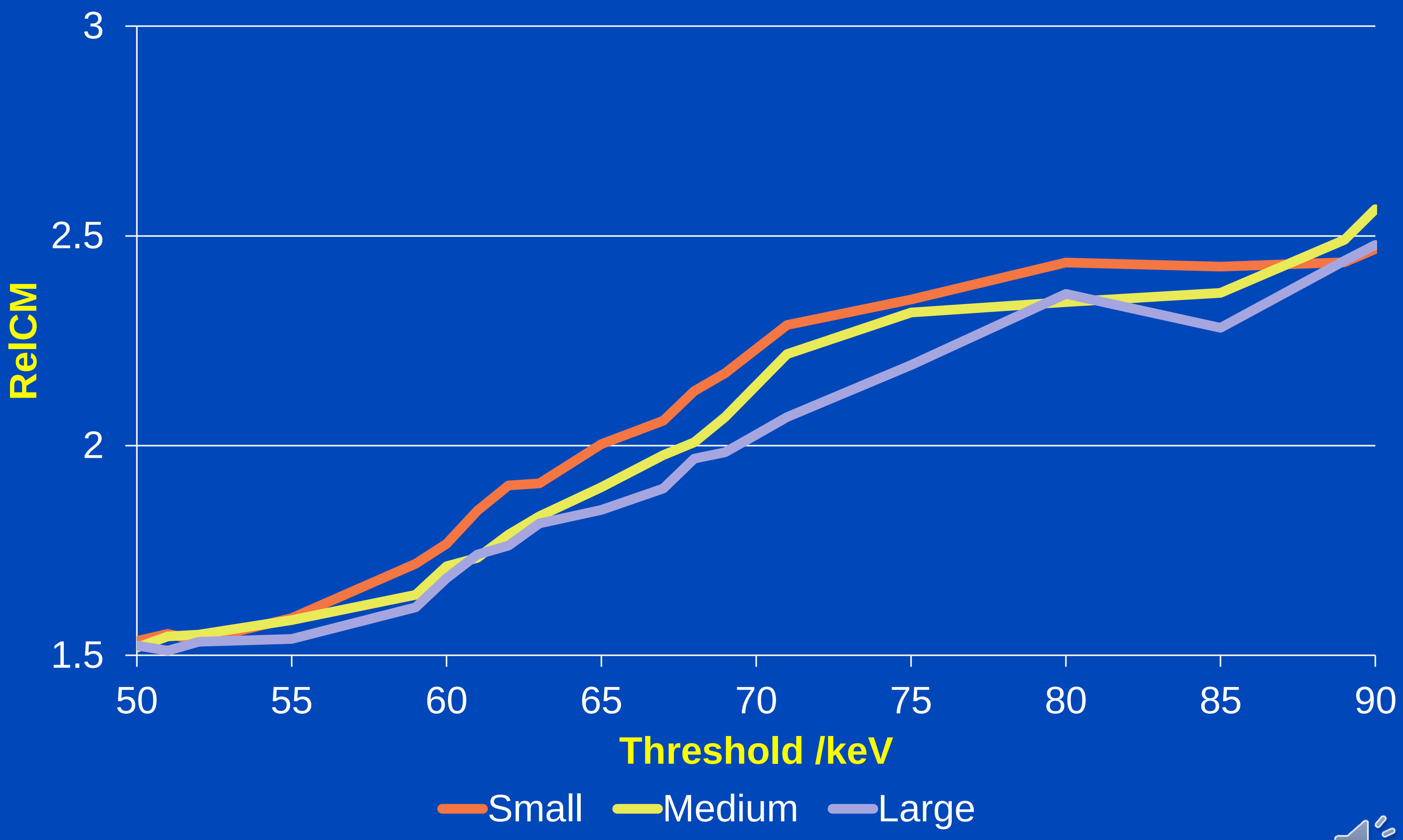
Materials & Methods

Image Acquisition and Reconstruction

- Images are acquired at different tube voltages:
  - 80 kV at 4.40 mGy ($CTDI_{vol\ 32\ cm}$) using 200 mAs_{eff}
  - 100 kV at 9.20 mGy ($CTDI_{vol\ 32\ cm}$) using 200 mAs_{eff}
  - 120 kV at 15.03 mGy ($CTDI_{vol\ 32\ cm}$) using 200 mAs_{eff}
  - 140 kV at 21.76 mGy ($CTDI_{vol\ 32\ cm}$) using 200 mAs_{eff}
- Pitch in all acquisitions was 0.6.
- Collimation for EI (32×0.6 mm) and PC (32×0.5 mm) was matched as close as possible, i.e. geometric efficiency is 80% vs. 82%.
- The threshold is varied between 50 keV and 90 keV in steps of 2 keV.
- Reference measurements were performed using the SOMATOM Flash.

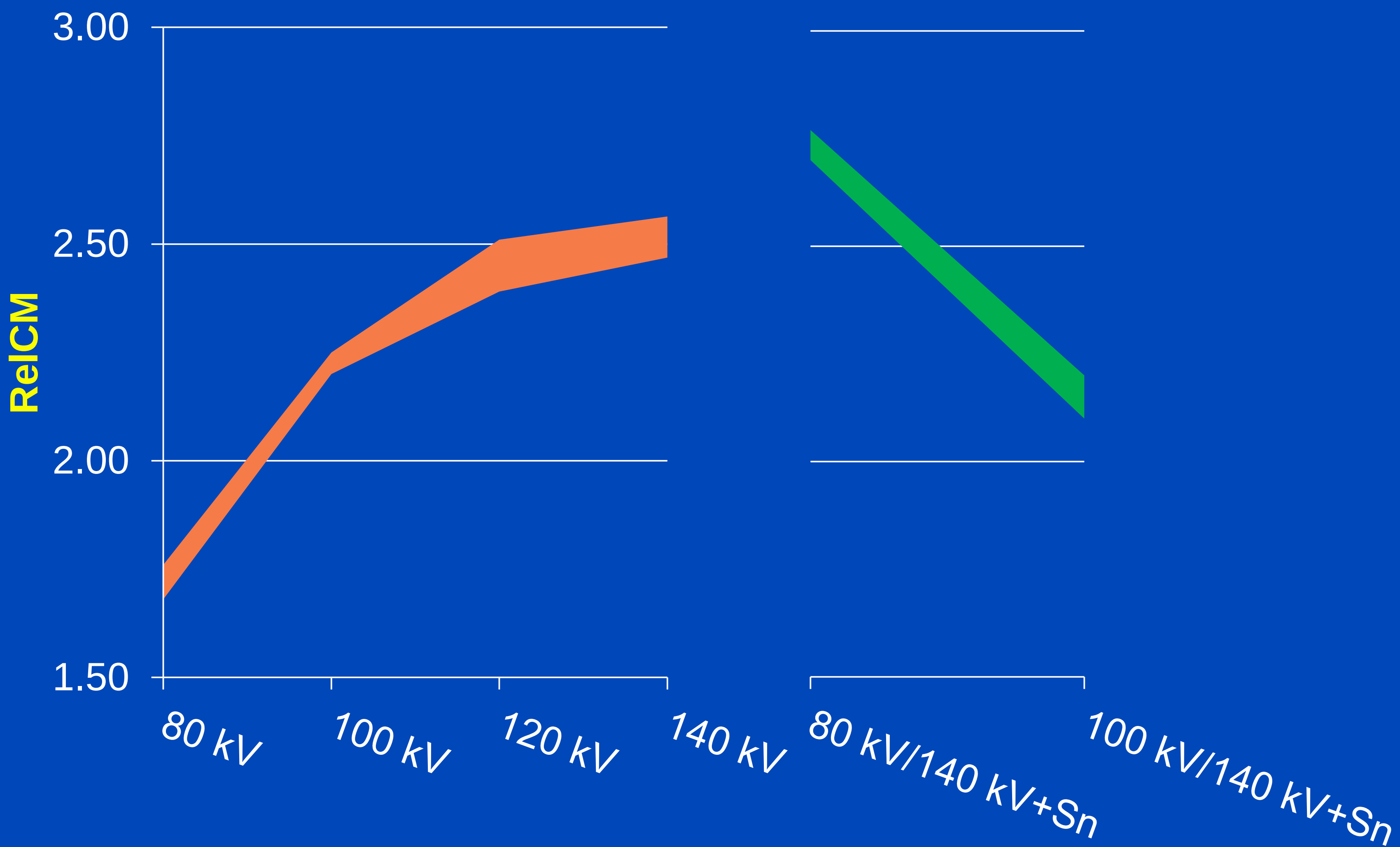
RelCM as Function of Threshold

140 kV, All Phantom Sizes



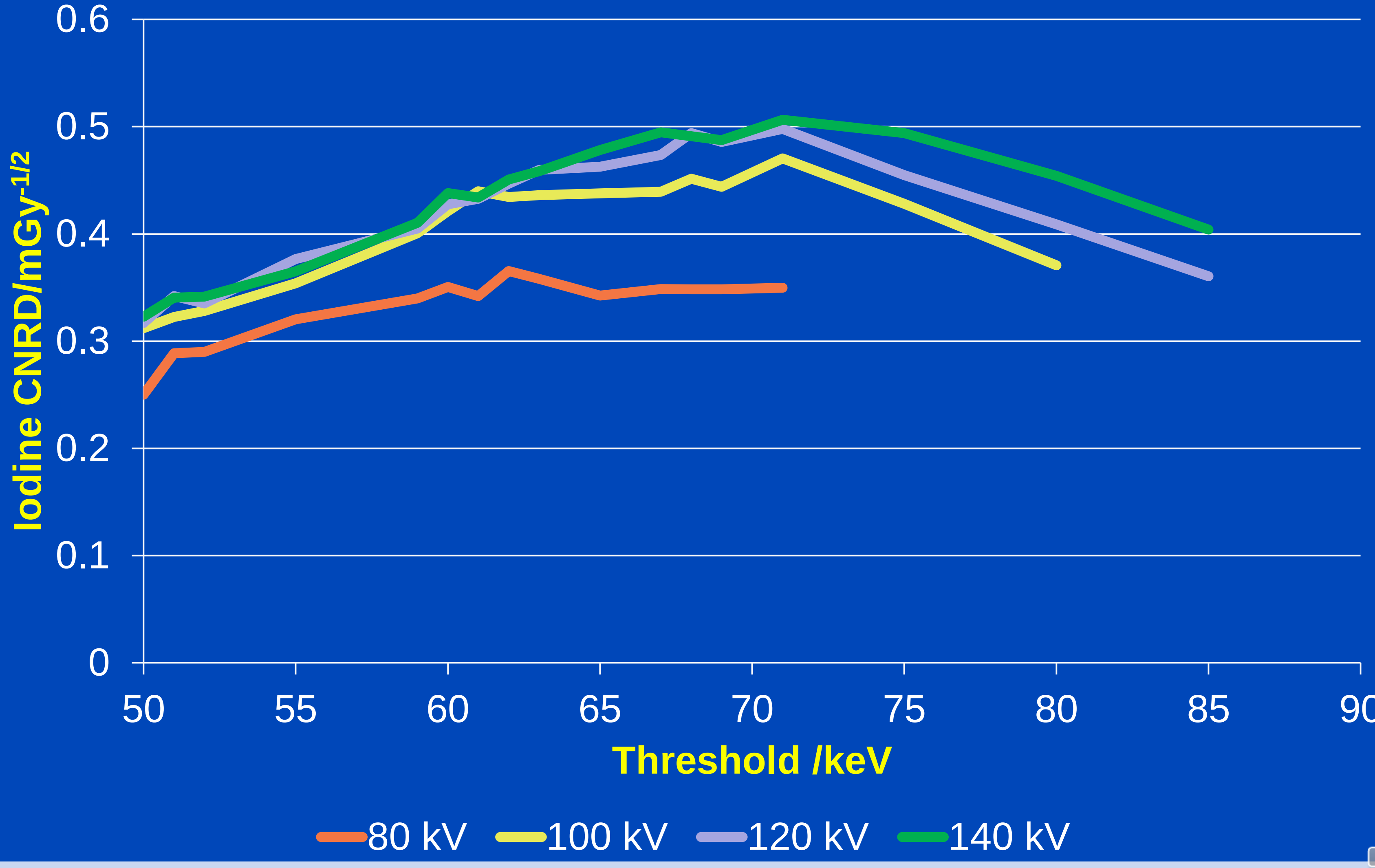
Best RelCM

Min-Max Over All Phantom Sizes



Iodine Map CNRD

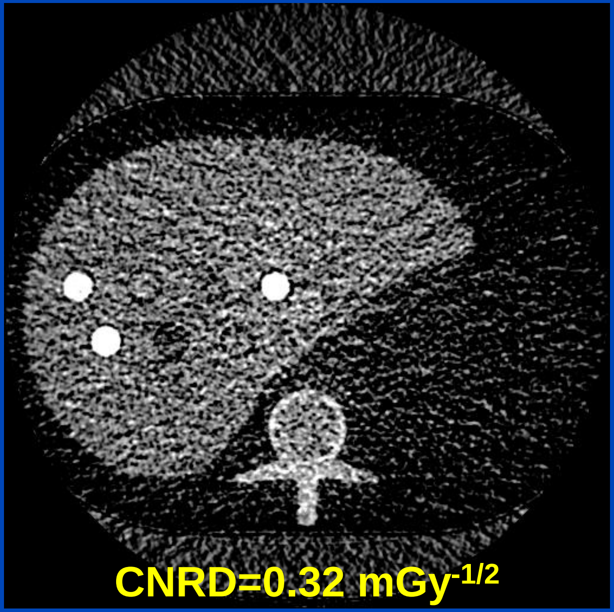
Small Phantom



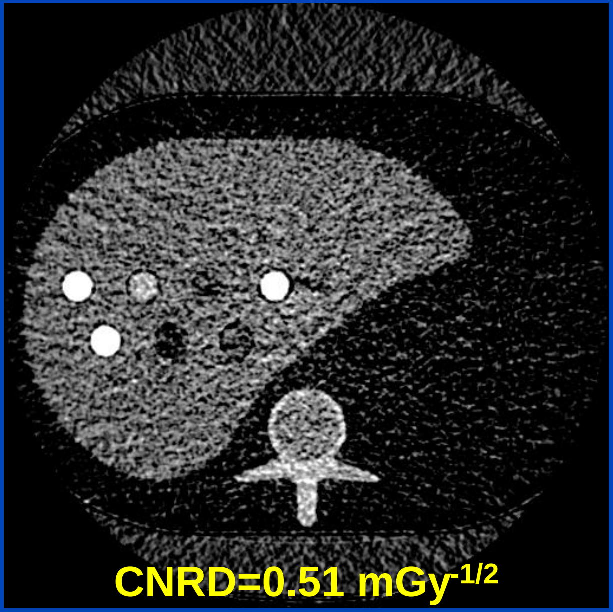
Iodine Map CNRD

140 kV, Small Phantom

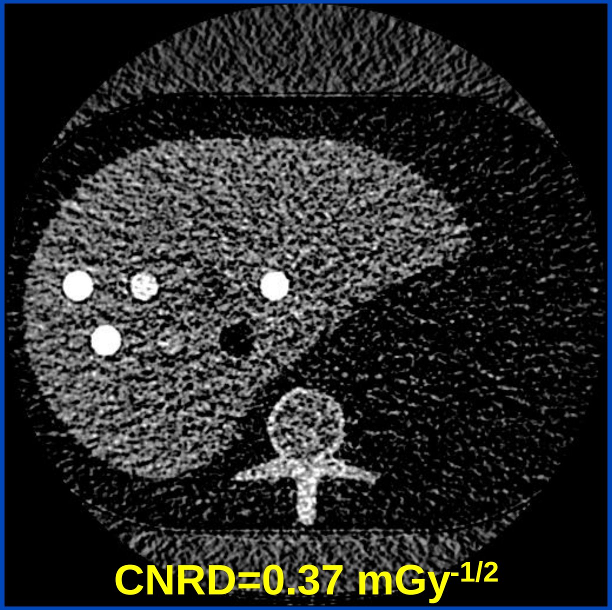
T=50 keV



T=71 keV



T=90 keV



C/W=7.5 mg/mL / 15.0 mg/mL

Summary & Conclusion

- RelCM does not significantly change with phantom size, similar to conventional CT*.
- RelCM in the photon-counting CT is similar to a conventional dual-source CT.
- However, it only requires a single source and a single detector and theoretically allows for rawdata-based dual-energy processing.
- The threshold settings introduce an additional degree of freedom.
- The thresholds should be chosen according to tube voltage and to patient size, e.g. given an acquired topogram.

*Krauss et al. The importance of spectral separation: an assessment of dual-energy spectral separation for quantitative ability and dose efficiency. Invest Radiol, 50(2):114-118, 2015.

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Thank You!

This presentation will soon be available at www.dkfz.de/ct.
Job opportunities through DKFZ's international Fellowship programs (marc.kachelriess@dkfz.de).
Parts of the reconstruction software were provided by RayConStruct® GmbH, Nürnberg, Germany.