Strategien zur Dosisoptimierung in der Photonenzählenden Ganzkörper-Computertomographie

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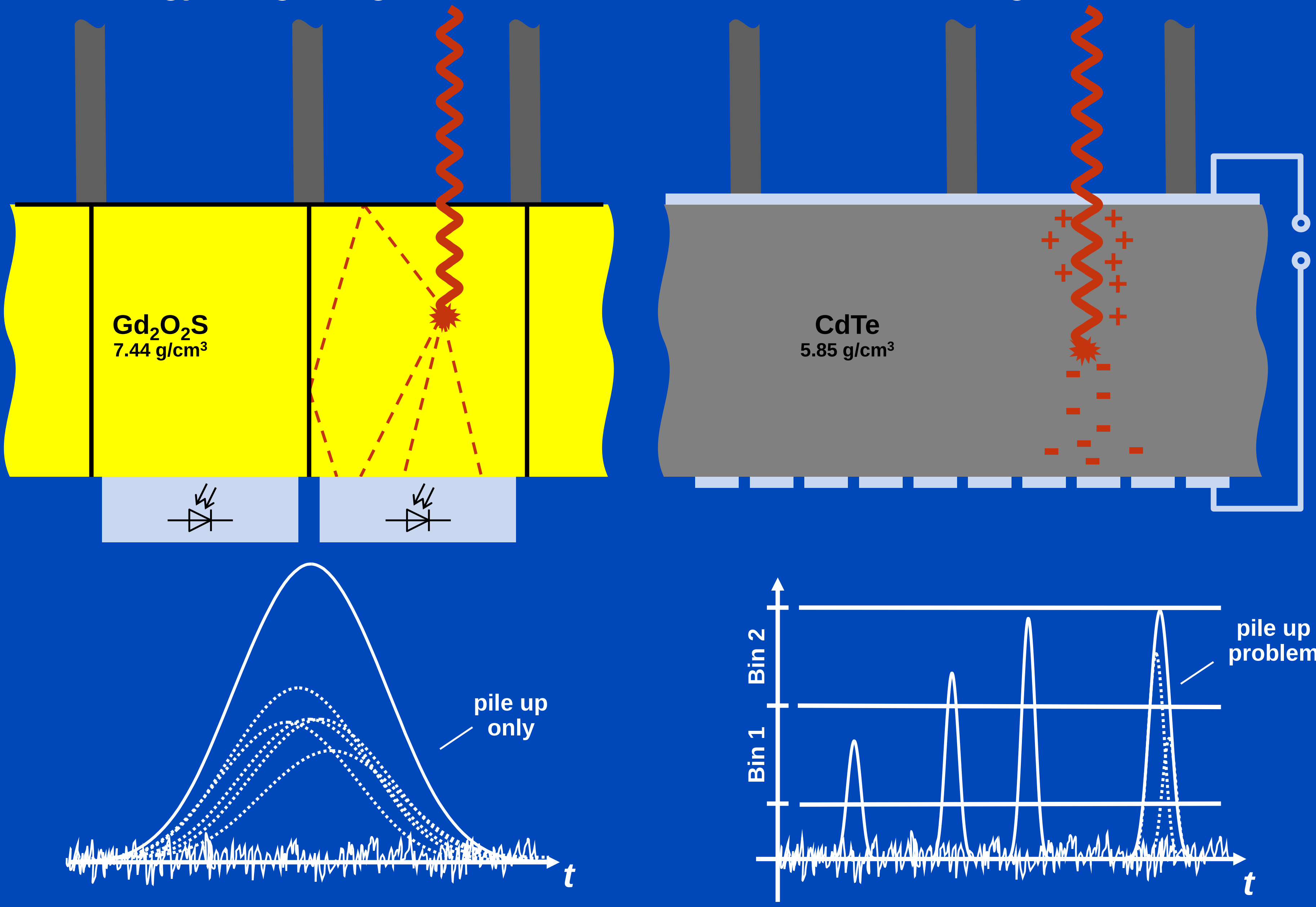
dkfz. DEUTSCHES KREBSFORSCHUNGSZENTRUM IN DER HELMHOLTZ-GEMEINSCHAFT

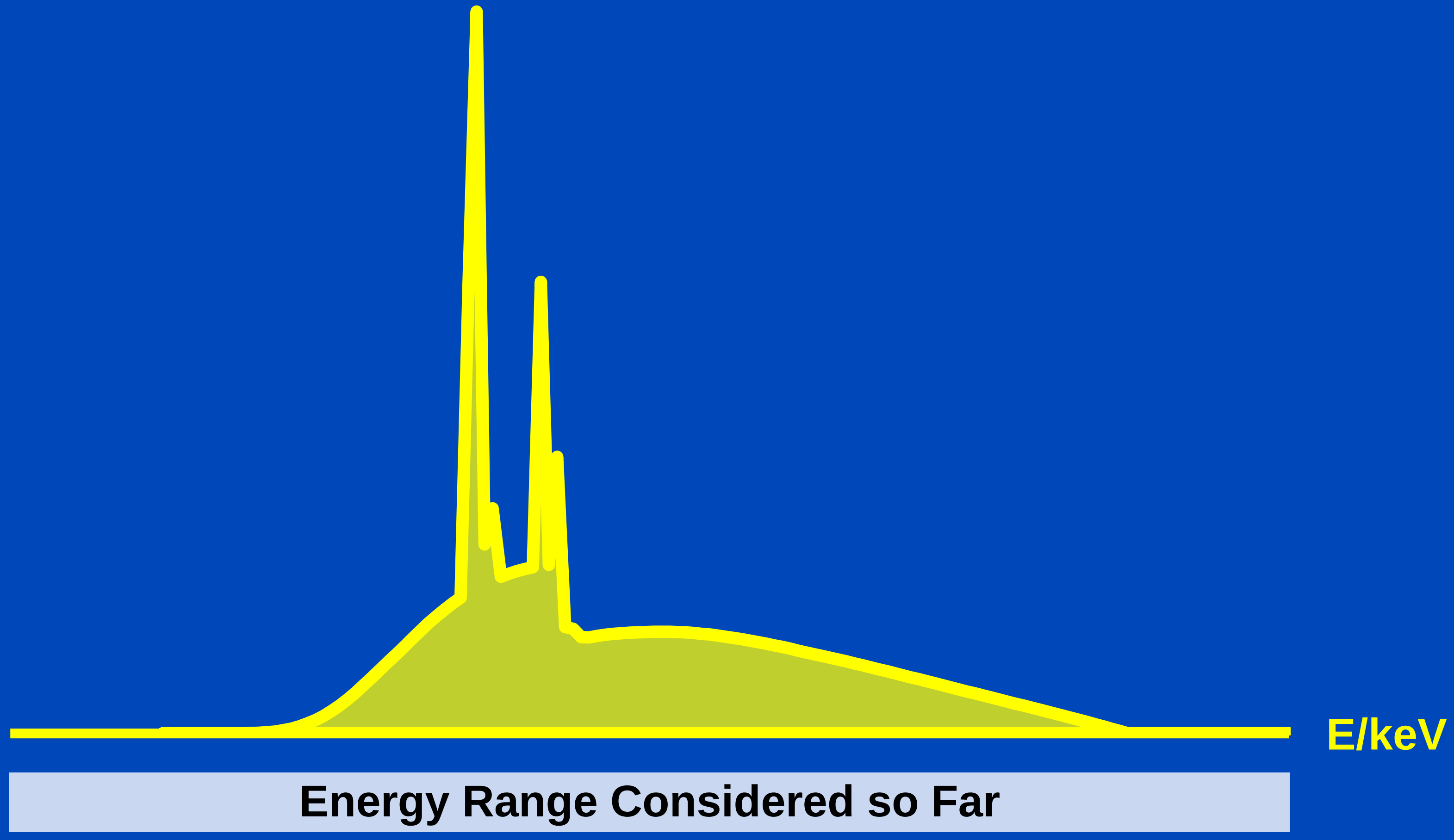
Energy integrating detector

Photon counting detector



Photon-Counting CT

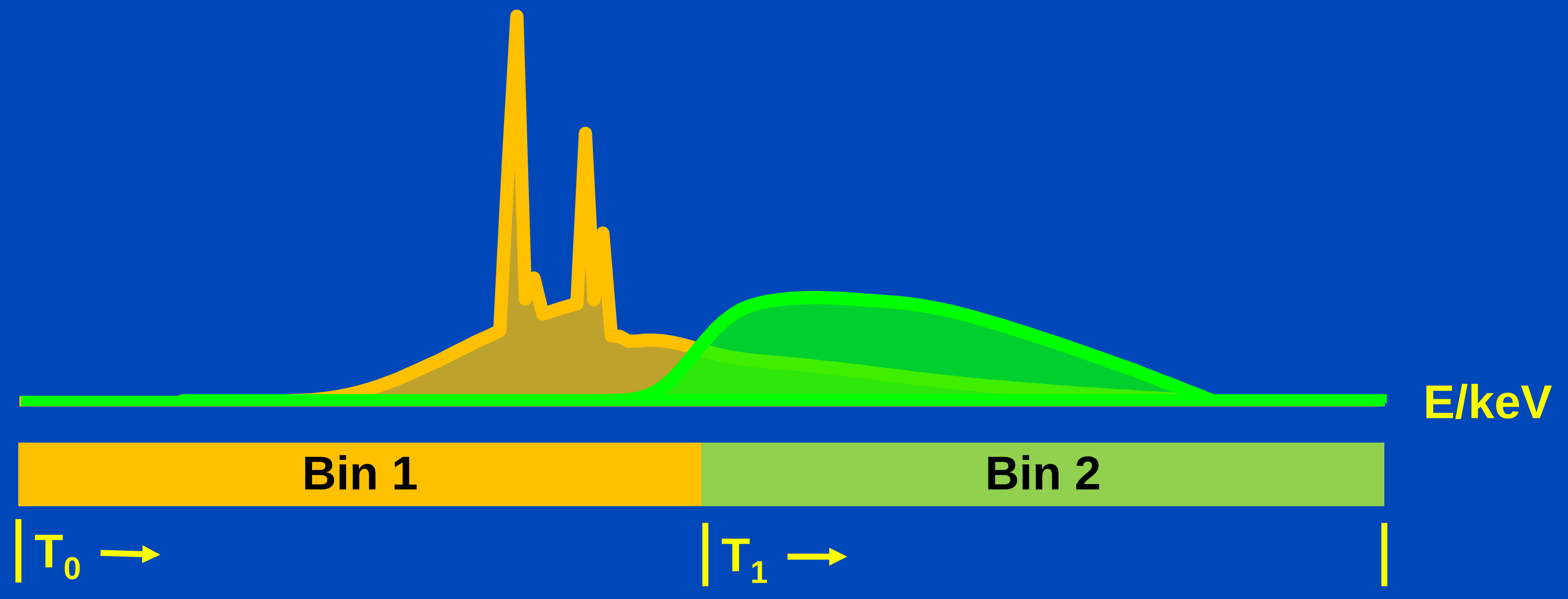
Spectral/Energy Information



140 kV spectrum as seen after having passed a 32 cm water layer.

Photon-Counting CT

Spectral/Energy Information



140 kV spectra as seen after having passed a 32 cm water layer.

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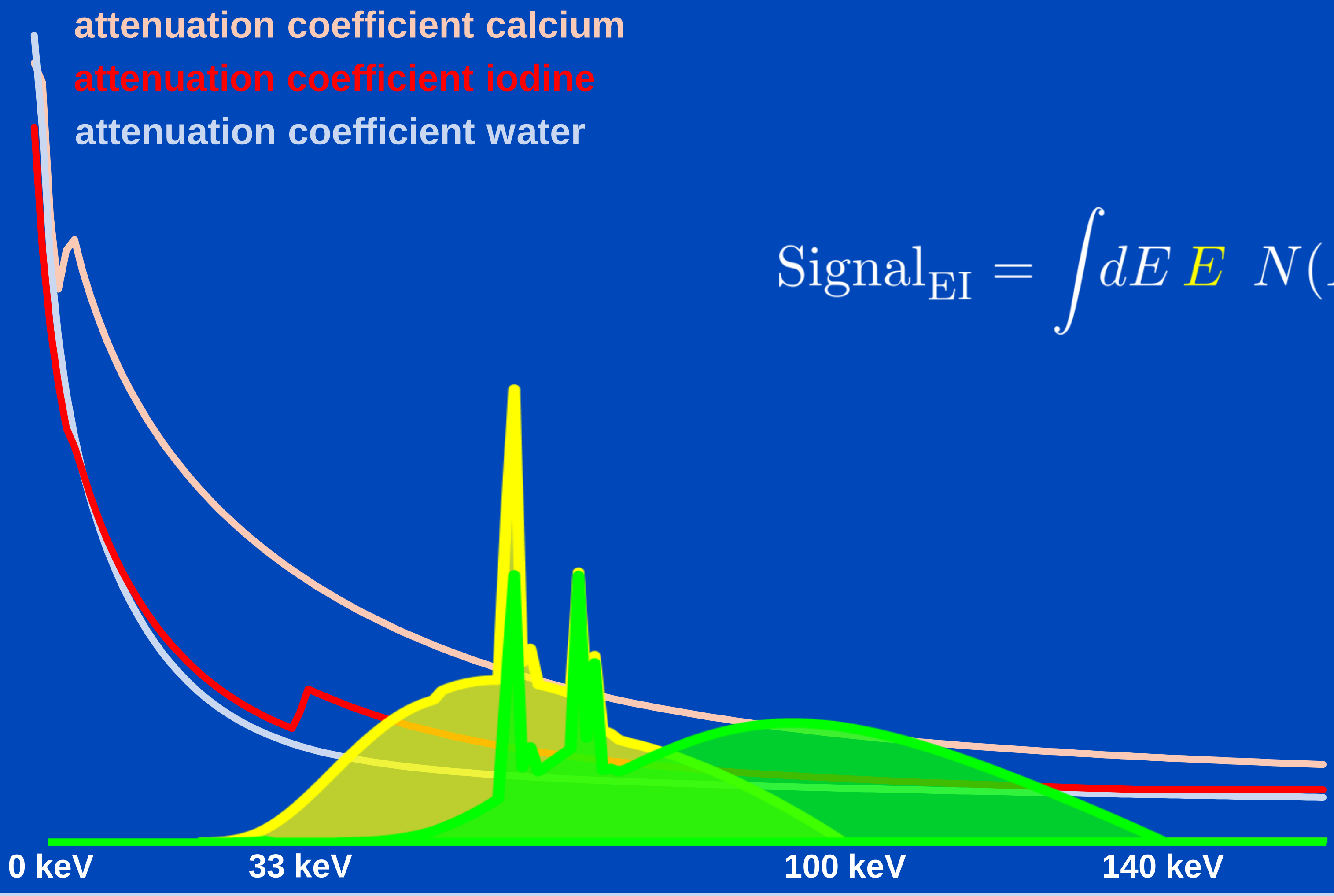
Energy Integrating
(Detected Spectra at 100 kV and 140 kV)



$$\text{Signal}_{\text{EI}} = \int dE\, E\;\; N(E)$$

Spectra as seen after having passed a 32 cm water layer.

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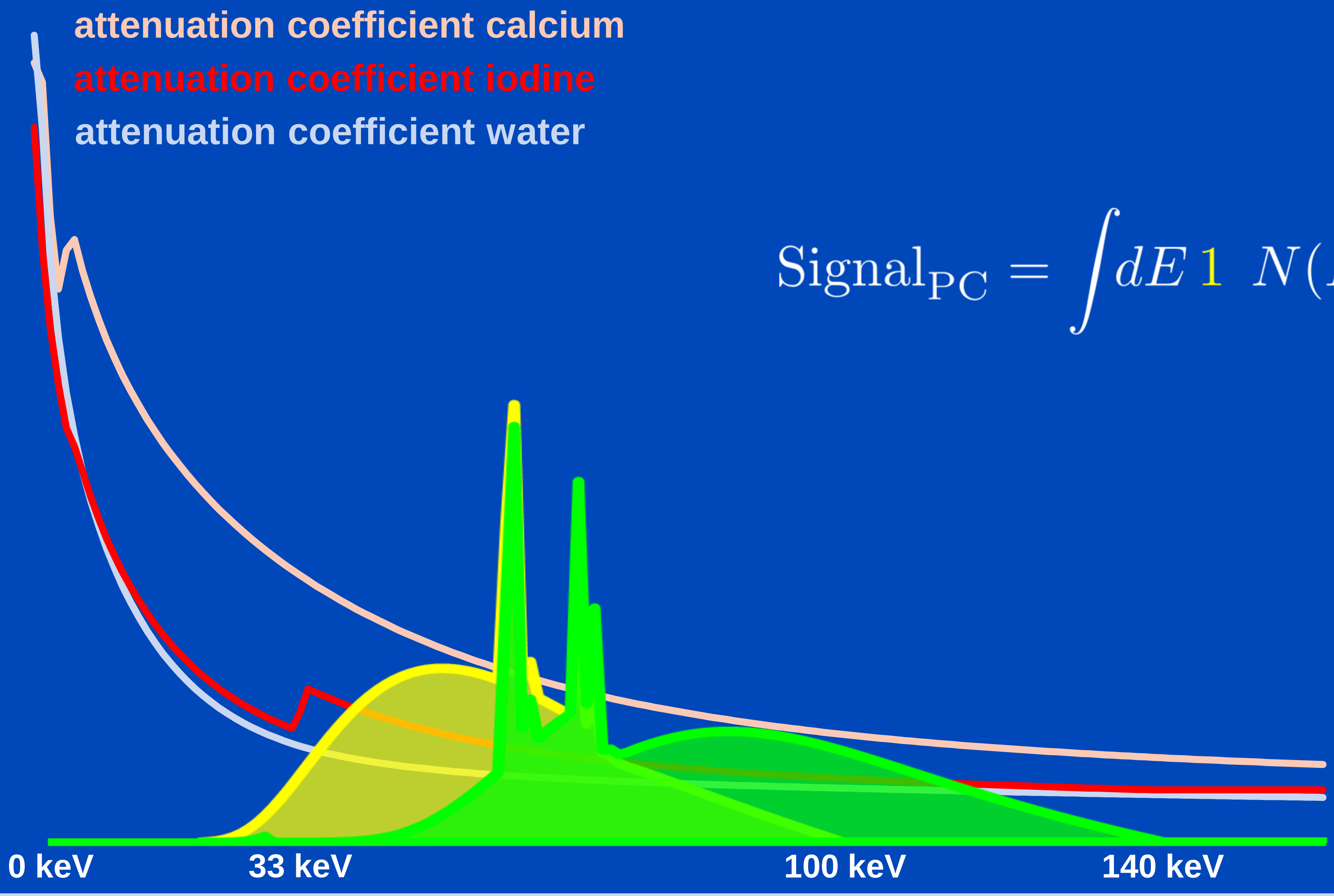
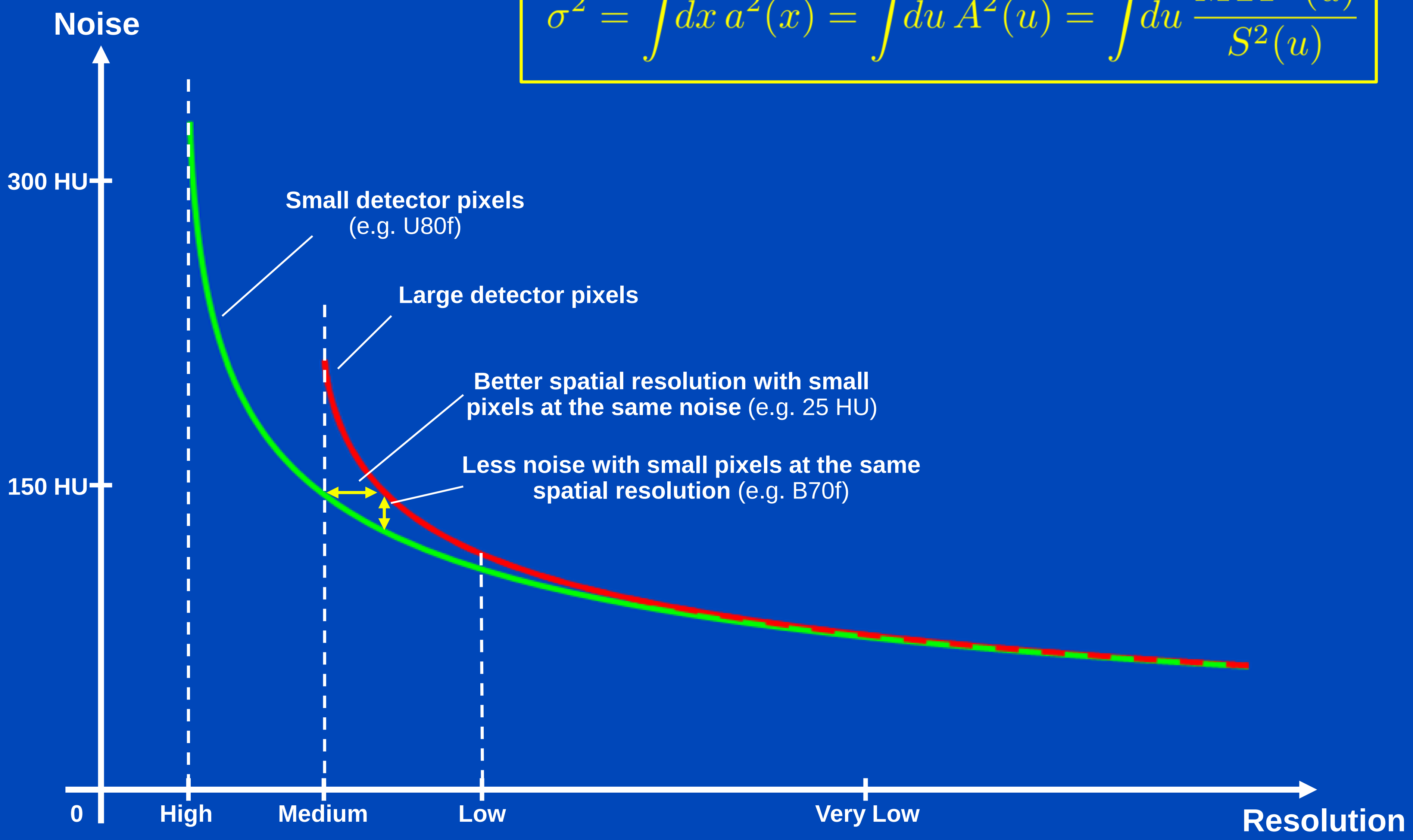
Photon Counting
(Detected Spectra at 100 kV and 140 kV)



$$\text{Signal}_{\text{PC}} = \int dE \, 1 \; N(E)$$

Spectra as seen after having passed a 32 cm water layer.

$$\sigma^2 = \int dx\, a^2(x) = \int du\, A^2(u) = \int du\, \frac{\mathrm{MTF}^2(u)}{S^2(u)}$$



Aim

To make use of the advantages of PC detectors, especially for examinations including contrast media:

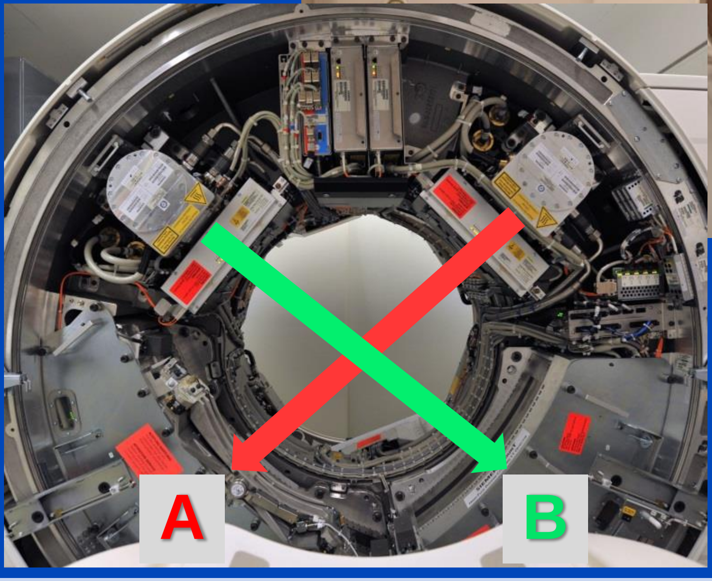
- **Higher iodine contrast**
- **Energy bin weighting (improved iodine CNR)**
- **Smaller pixels, therefore lower noise at conventional resolution**

CounT CT System at the DKFZ

Gantry from a clinical dual source scanner

A: conventional CT detector
(50.0 cm FOV)

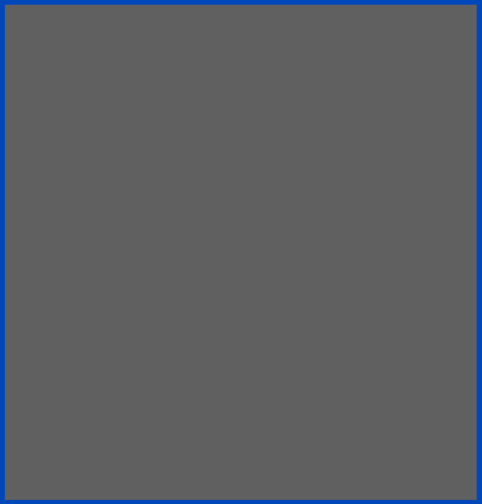
B: Photon counting detector
(27.5 cm FOV)



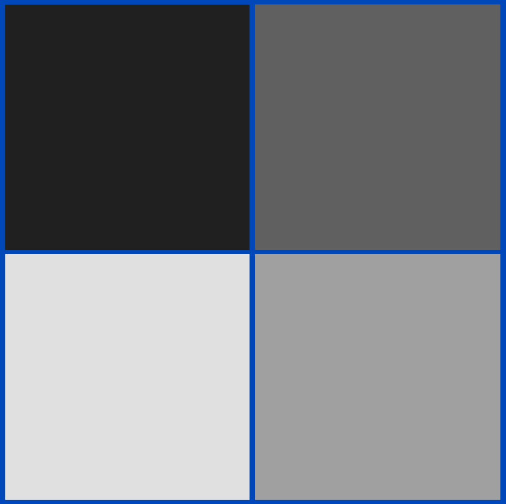
Readout Modes of the CounT

EI detector
0.60 mm pixel size

PC-Macro Mode
0.50 mm pixel size

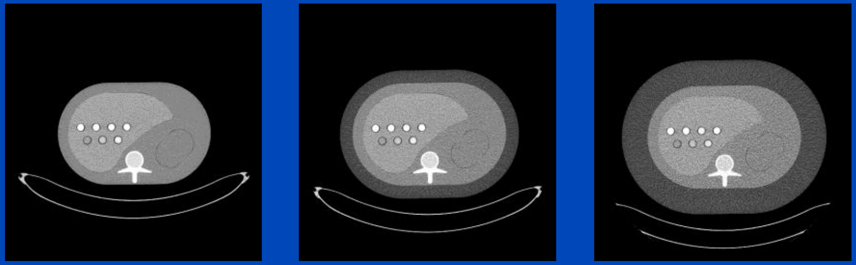


PC-UHR Mode
0.25 mm pixel size



Materials and Methods

- Abdomen phantoms of three different sizes (S, M, L) with iodine inserts of different concentrations
  - Small: 20 cm × 30 cm
  - Medium: 25 cm × 35 cm
  - Large: 30 cm × 40 cm



- Post-mortem angiography
- Tube voltages: 80 kV, 100 kV, 120 kV, and 140 kV
- Effective tube current of 200 mAs
- Collimation:
  - UHR: Acq. 64 × 0.25 mm
  - Macro: Acq. 32 × 0.50 mm
  - EID: Acq. 32 × 0.60 mm
- Reconstruction with D40f kernel

C = 20 HU, *W* = 600 HU

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Materials & Methods

CNRD Computations

- The contrast-to-noise ratio (CNR) could be used as a figure of merit:

$$\mathrm{CNR} = \frac{\mathrm{Contrast}}{\mathrm{Noise}} = \frac{|\mu_{\mathrm{ROI\ 1}} - \mu_{\mathrm{ROI\ 2}}|}{\sqrt{\sigma^2_{\mathrm{ROI\ 1}} + \sigma^2_{\mathrm{ROI\ 2}}}}$$

- To account for different tube voltages and different dose levels we rather use the dose-normalized CNR (CNRD):

$$\mathrm{CNRD} = \frac{\mathrm{Contrast}}{\mathrm{Noise} \cdot \sqrt{\mathrm{Dose}}} = \frac{\mathrm{CNR}}{\sqrt{\mathrm{Dose}}}$$

- The potential x-ray dose reduction can be calculated by

$$\mathrm{Dose\ Reduction} = 1 - \frac{\mathrm{CNRD}^2_{\mathrm{Ref}}}{\mathrm{CNRD}^2_{\mathrm{PC}}}$$

Materials & Methods

CNRD Optimization – Bin Combination

- To optimize CNR in case of two bins, we use an inverse variance weighting.
- In particular, weights for bin b are given as

$$w_b \propto \frac{C_b}{V_b}$$

with C_b being the contrast in the respective bin image and V_b being the variance in the ROIs used to compute C_b.

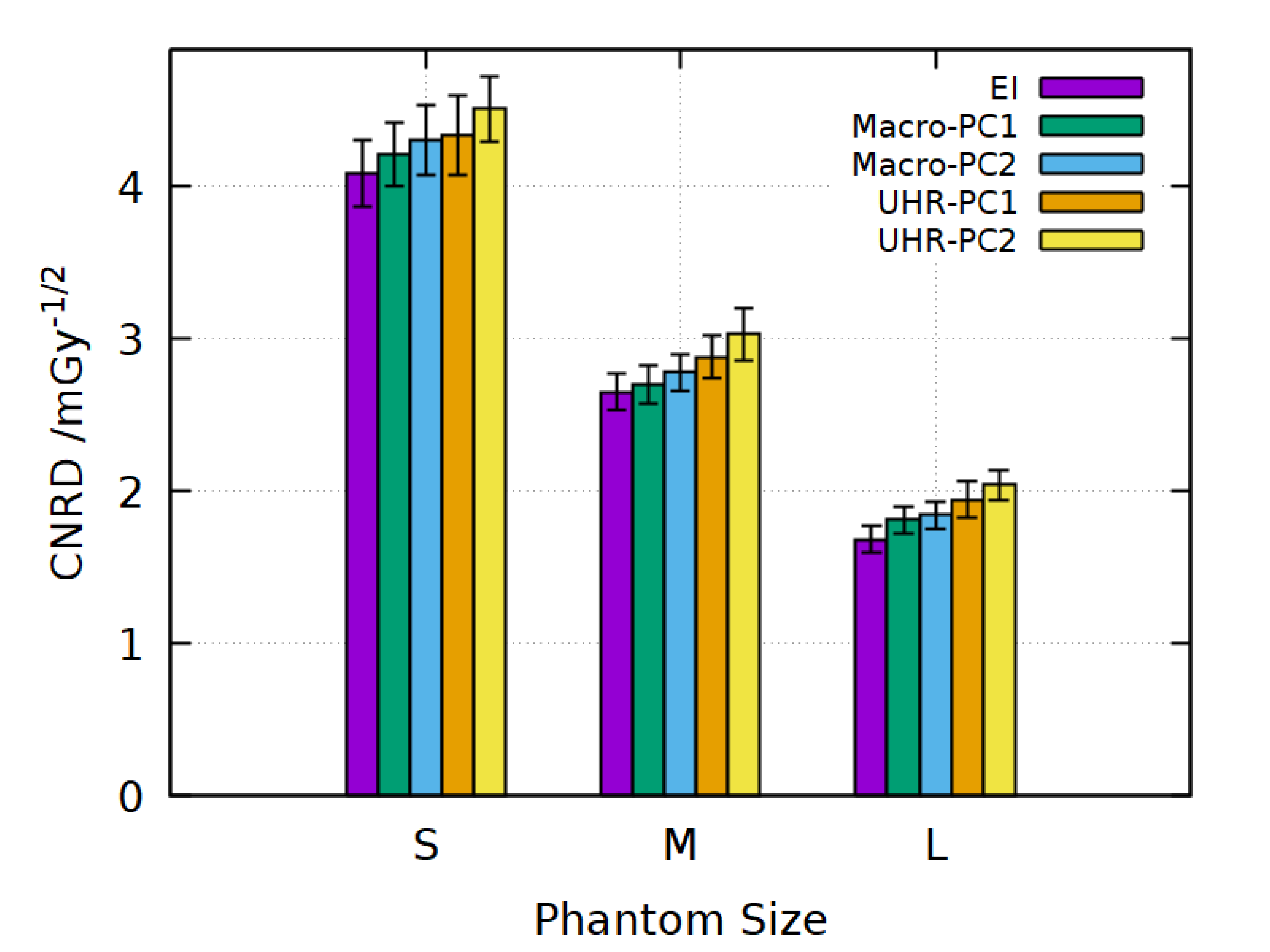
- The resulting CNR is

$$\mathrm{CNR}^2 = \frac{\left(\sum_b w_b \, C_b\right)^2}{\sum_b w_b^2 V_b}$$

Materials & Methods

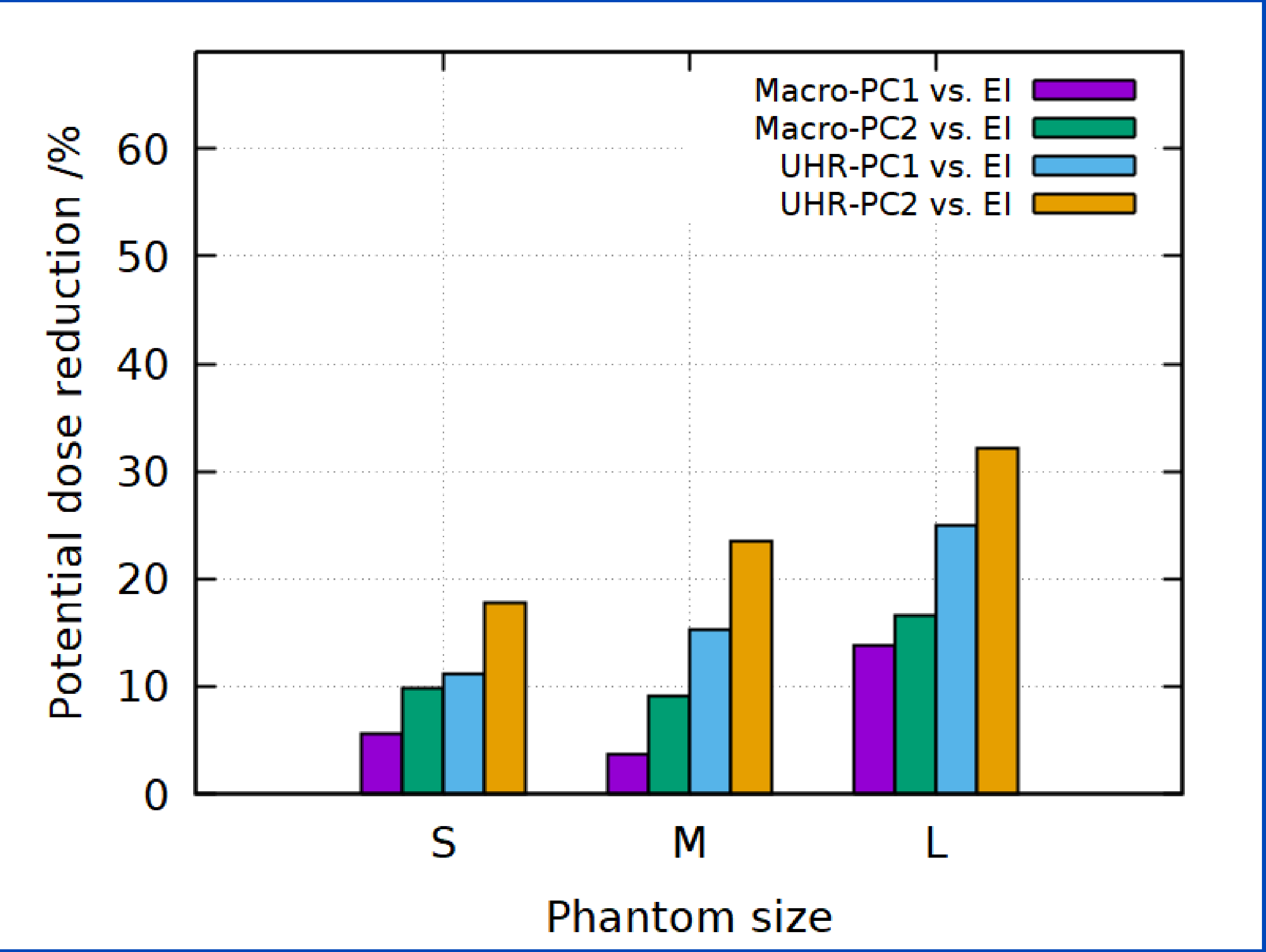
- **Investigation of different protocols:**
  - **EI:** standard EI acquisition
  - **Macro-PC1:** PC detector, similar pixel size as EI
  - **Macro-PC2:** PC detector, similar pixel size as EI, energy bin weighting
  - **UHR-PC1:** PC detector, small pixels
  - **UHR-PC2:** PC detector, small pixels, energy bin weighting

Results at 80 kV



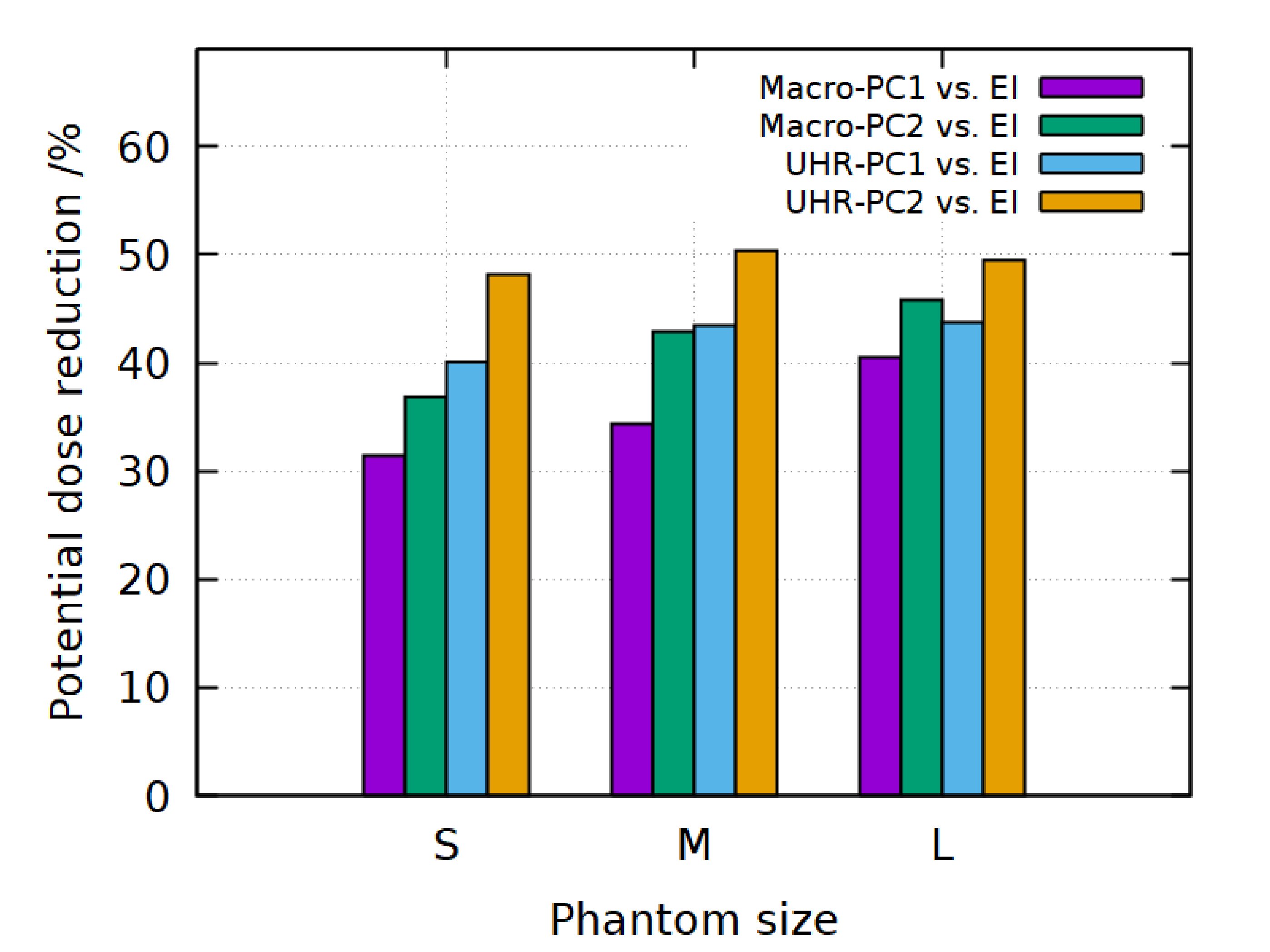
Error bars indicate the errors when analyzing 15 different slices of the same contrast.

Results at 80 kV



Error bars indicate the errors when analyzing 15 different slices of the same contrast.

Results at 140 kV



Error bars indicate the errors when analyzing 15 different slices of the same contrast.

Head Scan

EI
140 kV / 200 mAs
22.16 mGy
CNRD = 4.31

UHR-PC2
140 kV / 200 mAs
24.17 mGy
CNRD = 6.46
CNRD Improvement of 50 %

UHR-PC2
140 kV / 100 mAs
12.08 mGy
CNRD = 4.78

Head Scan

EI	UHR-PC2	UHR-PC2
140 kV / 200 mAs	140 kV / 200 mAs	140 kV / 100 mAs
22.16 mGy	24.17 mGy	12.08 mGy
CNRD = 4.31	CNRD = 6.46	CNRD = 4.78
		45% lower dose

Conclusions

- PC CT offers many advantages over EI CT to improve scan protocols for various medical indications.
- For applications with contrast media, advantages include higher iodine contrast, bin weighting due to the intrinsic acquisition of spectral data, and noise reduction at conventional resolution due to small pixels.
- Depending on the scan parameters, a dose reduction up to 50 % can be expected with the implementation of PC CT scanners in clinical practice.

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.