Optimal Iodine CNRD in a Whole Body Photon-Counting CT Scanner

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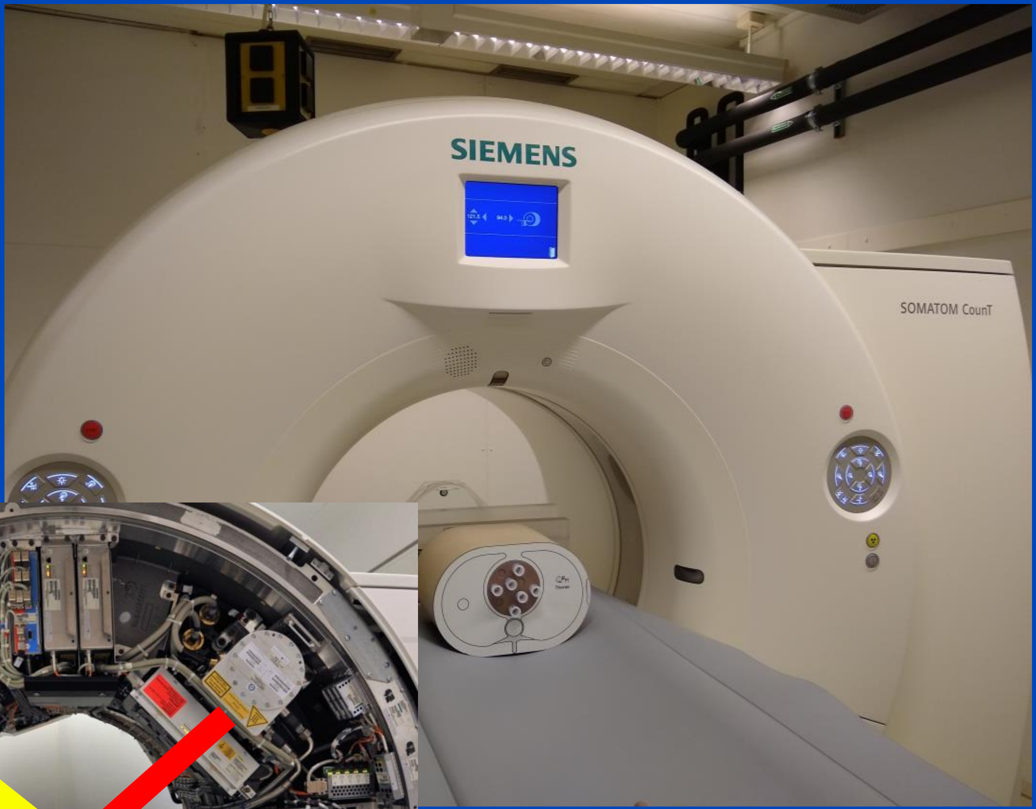
DEUTSCHES KREBSFORSCHUNGSZENTRUM IN DER HELMHOLTZ-GEMEINSCHAFT

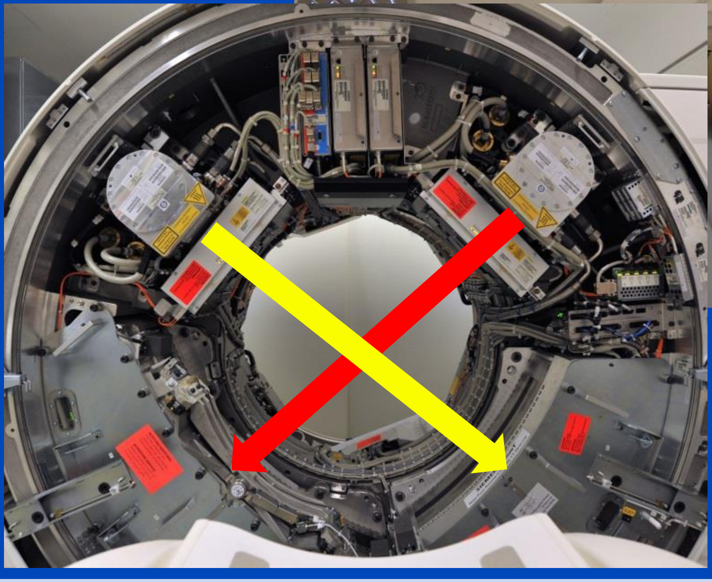
SOMATOM CounT CT @ DKFZ

Gantry from a clinical dual source scanner

A: conventional CT detector (50 cm FOV)

B: Photon counting detector (27.5 cm FOV)

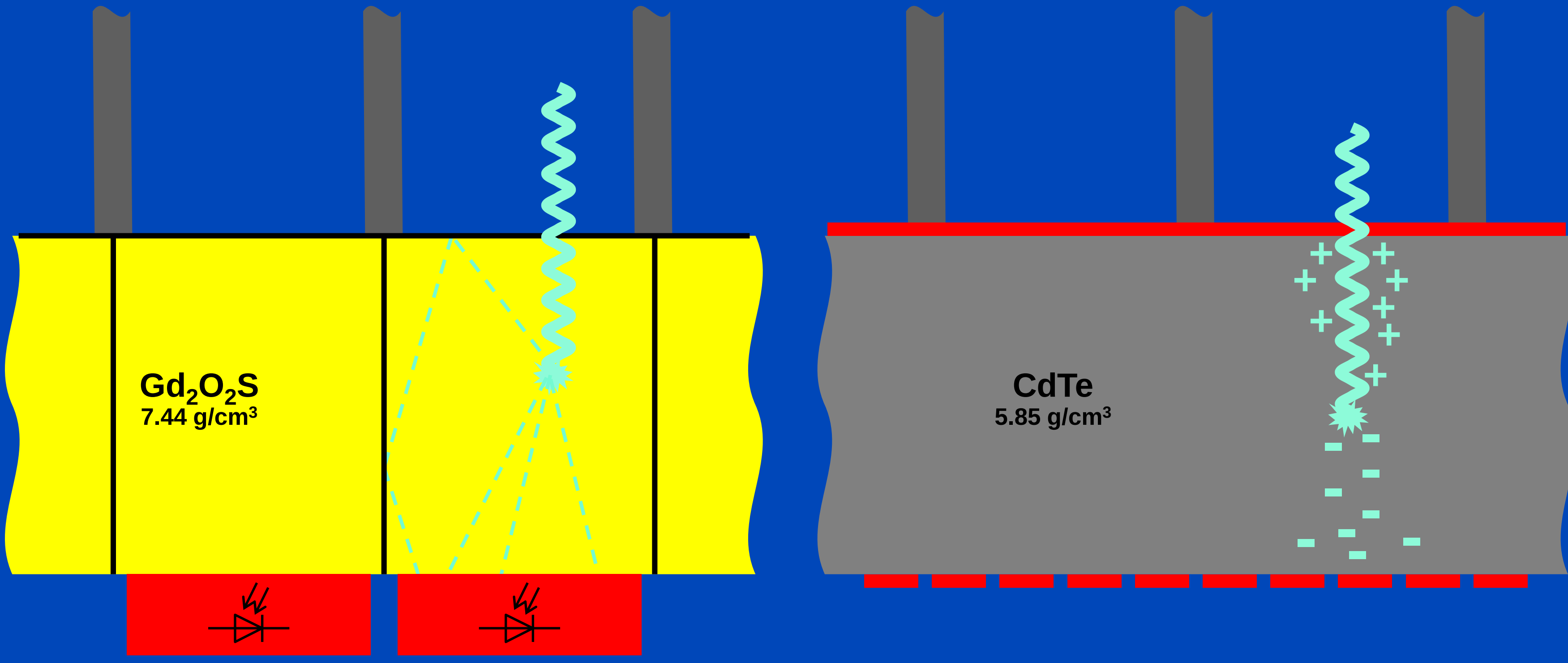




Photon-Counting CT

Counting Single Photons

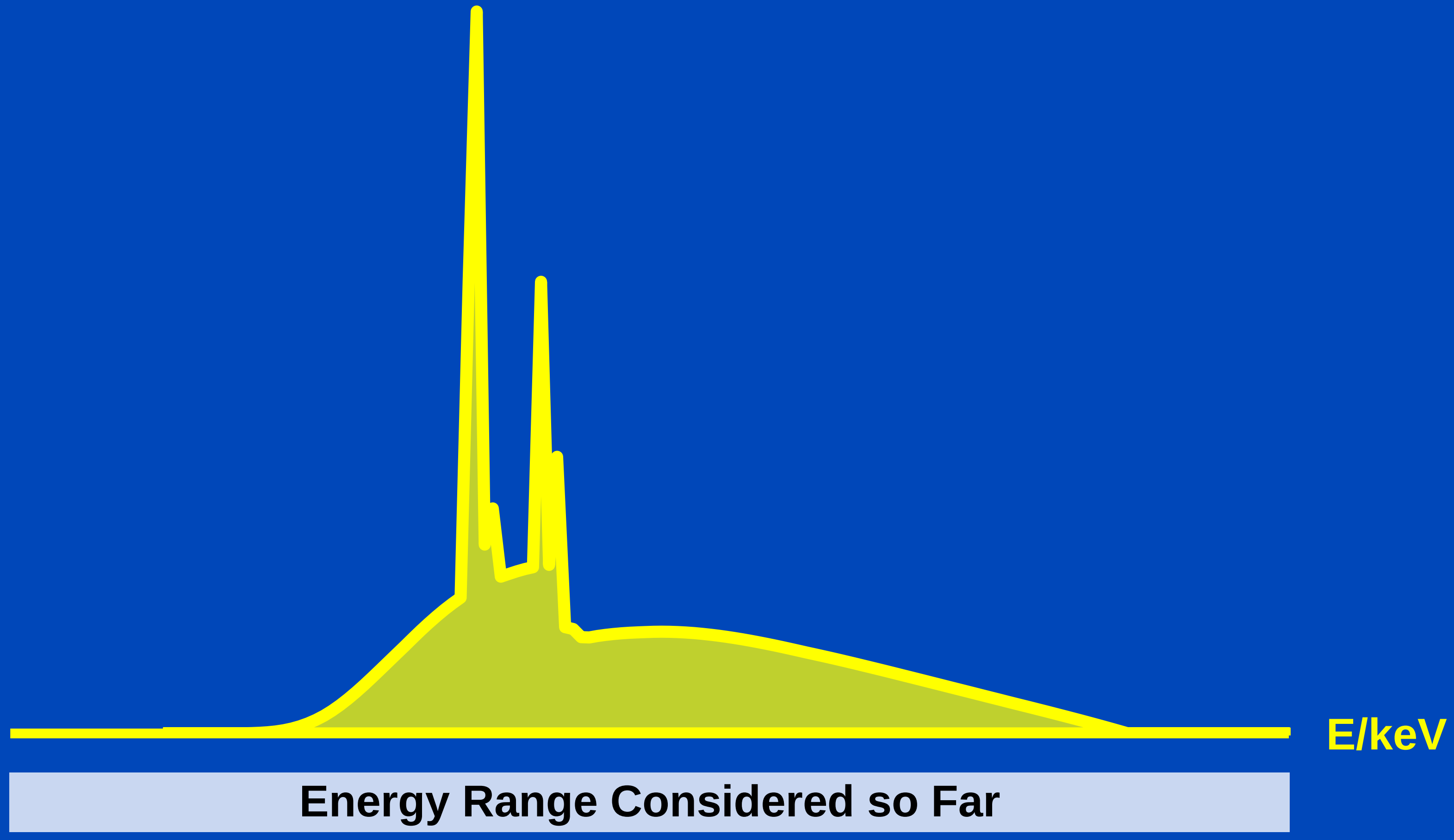
Energy-Integrating (Today) | **Photon-Counting (Future)**



Requirements for CT: up to 10^9 x-ray photon counts per second per mm^2.
Hence, photon counting only achievable for direct converters.

Photon-Counting CT

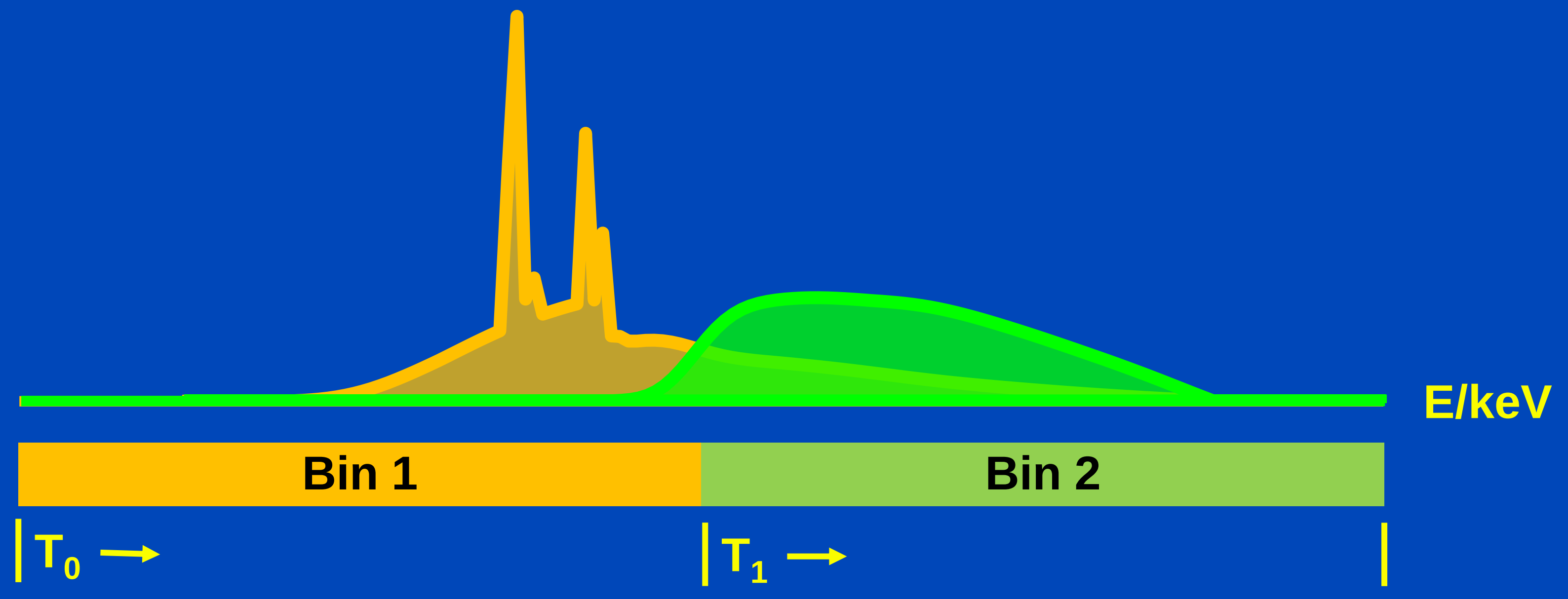
Spectral/Energy Information



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.

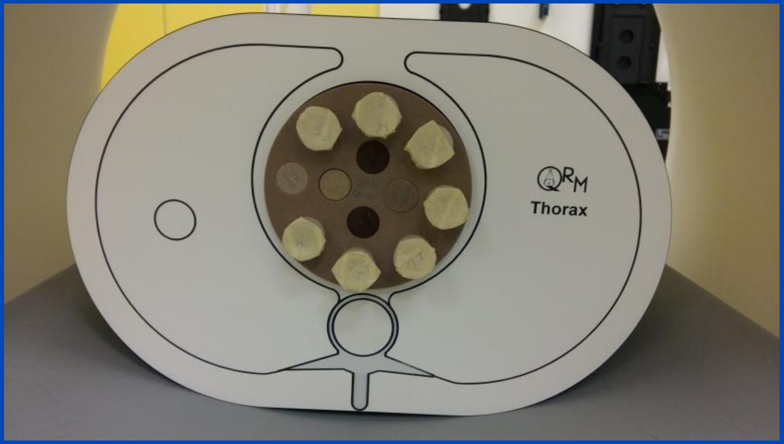
Aim

To evaluate the iodine CNRD improvements obtained using a statistically optimal weighting of photon-counting (PC) data compared to using a conventional energy-integrating (EI) CT detector.

Materials & Methods

Phantoms

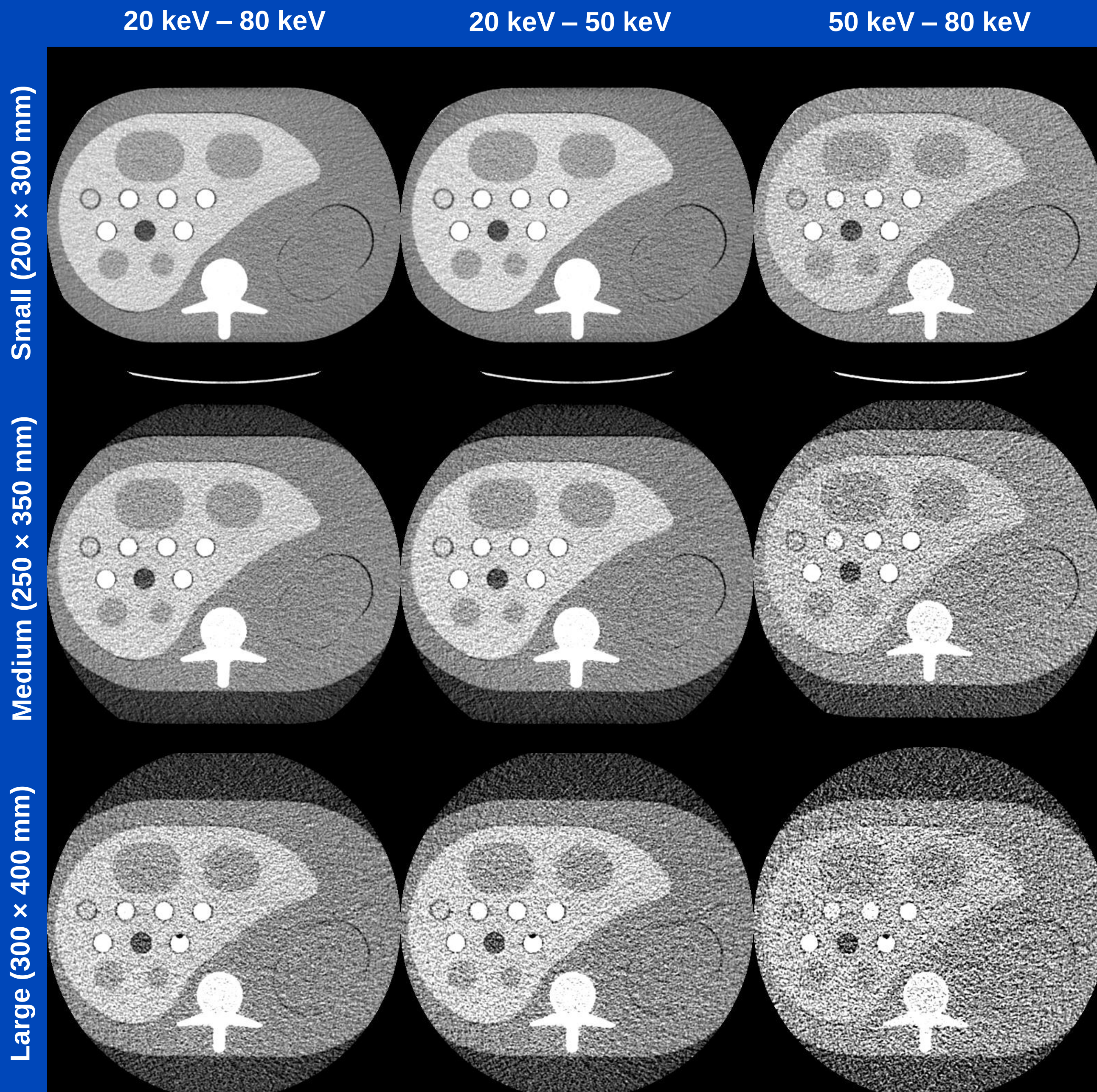
- Anthropomorphic thorax and liver phantom
- Three different phantom sizes
  - Small (200 × 300 mm)
  - Medium (250 × 350 mm)
  - Large (300 × 400 mm)



Materials & Methods

Image Acquisition and Reconstruction

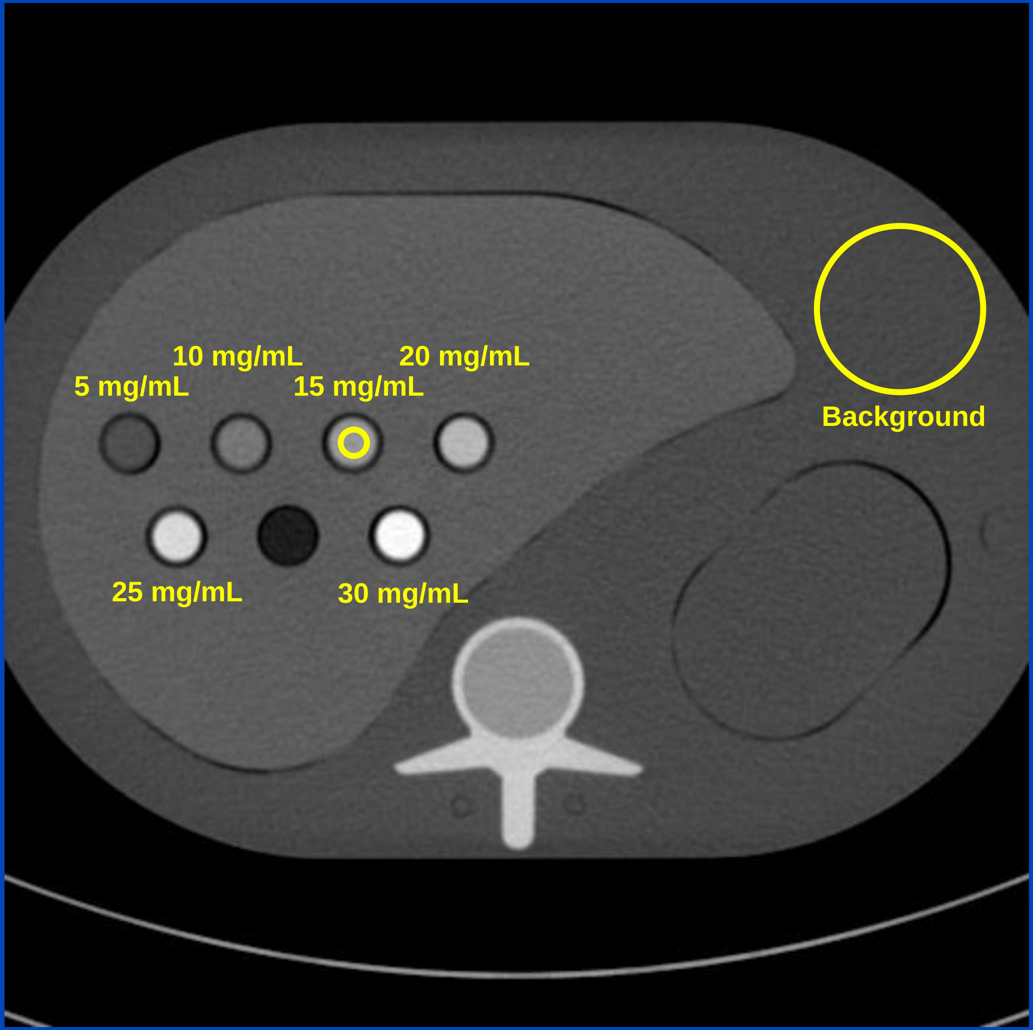
- Images are acquired at different tube voltages:
  - 80 kV at 4.40 mGy ($CTDI_{vol\ 32\ cm}$) using 200 mAs_{eff}
  - 100 kV at 9.20 mGy ($CTDI_{vol\ 32\ cm}$) using 200 mAs_{eff}
  - 120 kV at 15.03 mGy ($CTDI_{vol\ 32\ cm}$) using 200 mAs_{eff}
  - 140 kV at 21.76 mGy ($CTDI_{vol\ 32\ cm}$) using 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 thresholds were fixed at 20 keV and 50 keV, resulting in two bins: [20 keV, 50 keV] and [50 keV, max].


20 keV – 80 keV
20 keV – 50 keV
50 keV – 80 keV
Small (200 × 300 mm)
Medium (250 × 350 mm)
Large (300 × 400 mm)

C/W=0 HU/400 HU

Materials & Methods

Regions of Interest



C/W=180 HU/600 HU

Materials & Methods
CNRD Computations

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

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

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

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

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

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

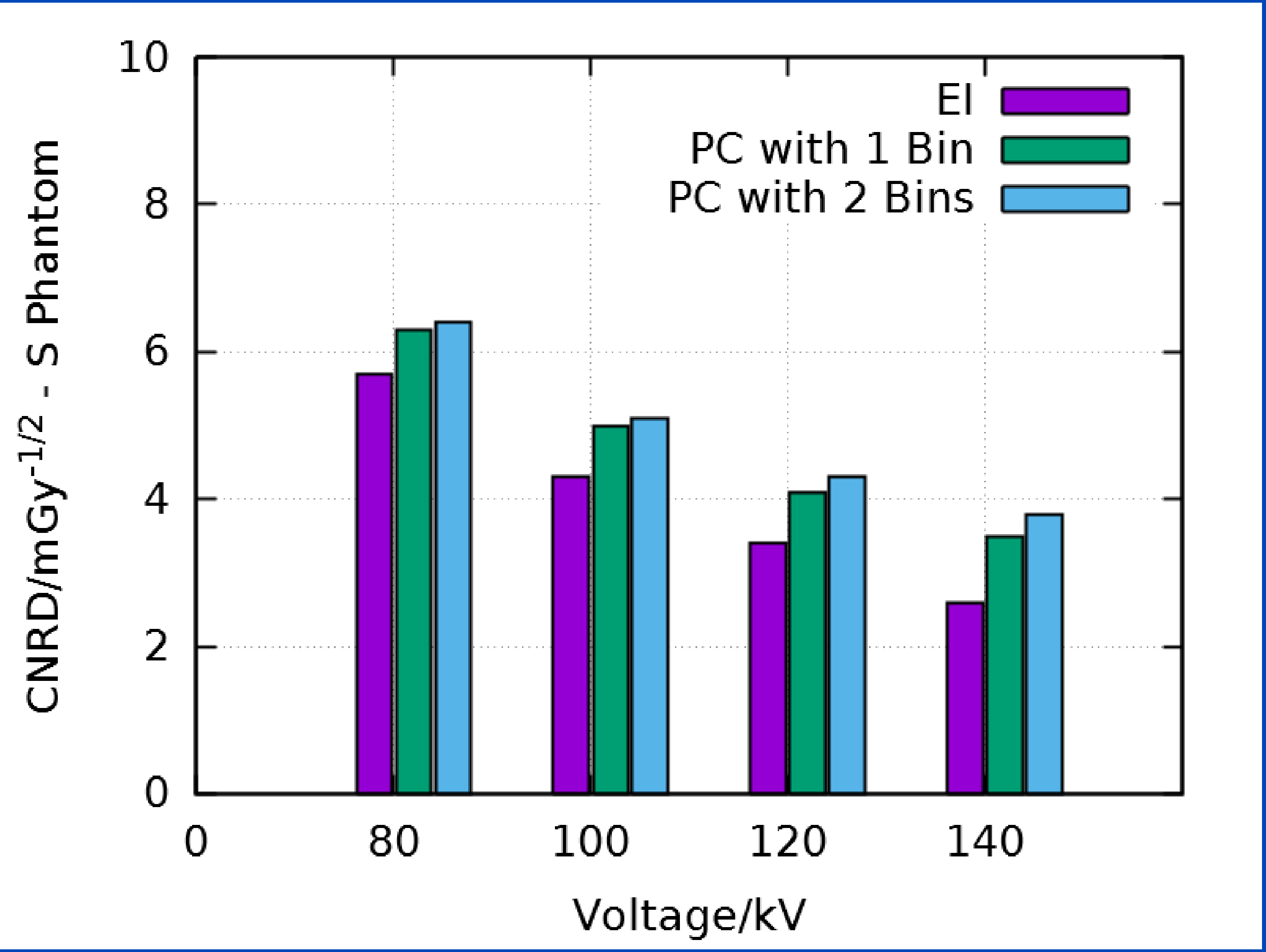
with C_b being the contrast in the respective bin image and V_b being the variance in the ROIs used to compute C_b.

- The resulting CNR is

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

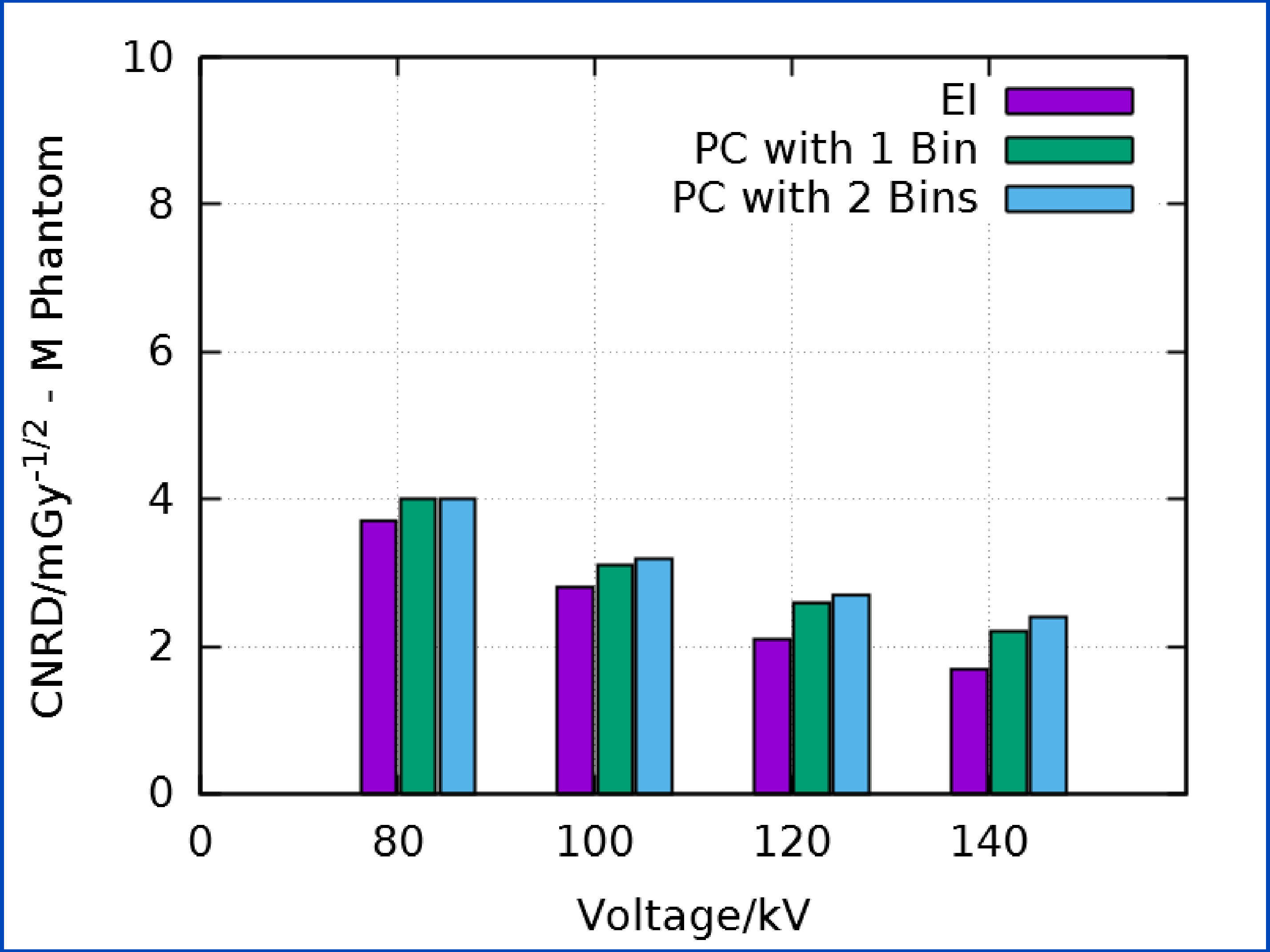
Results

CNRD – Small Phantom



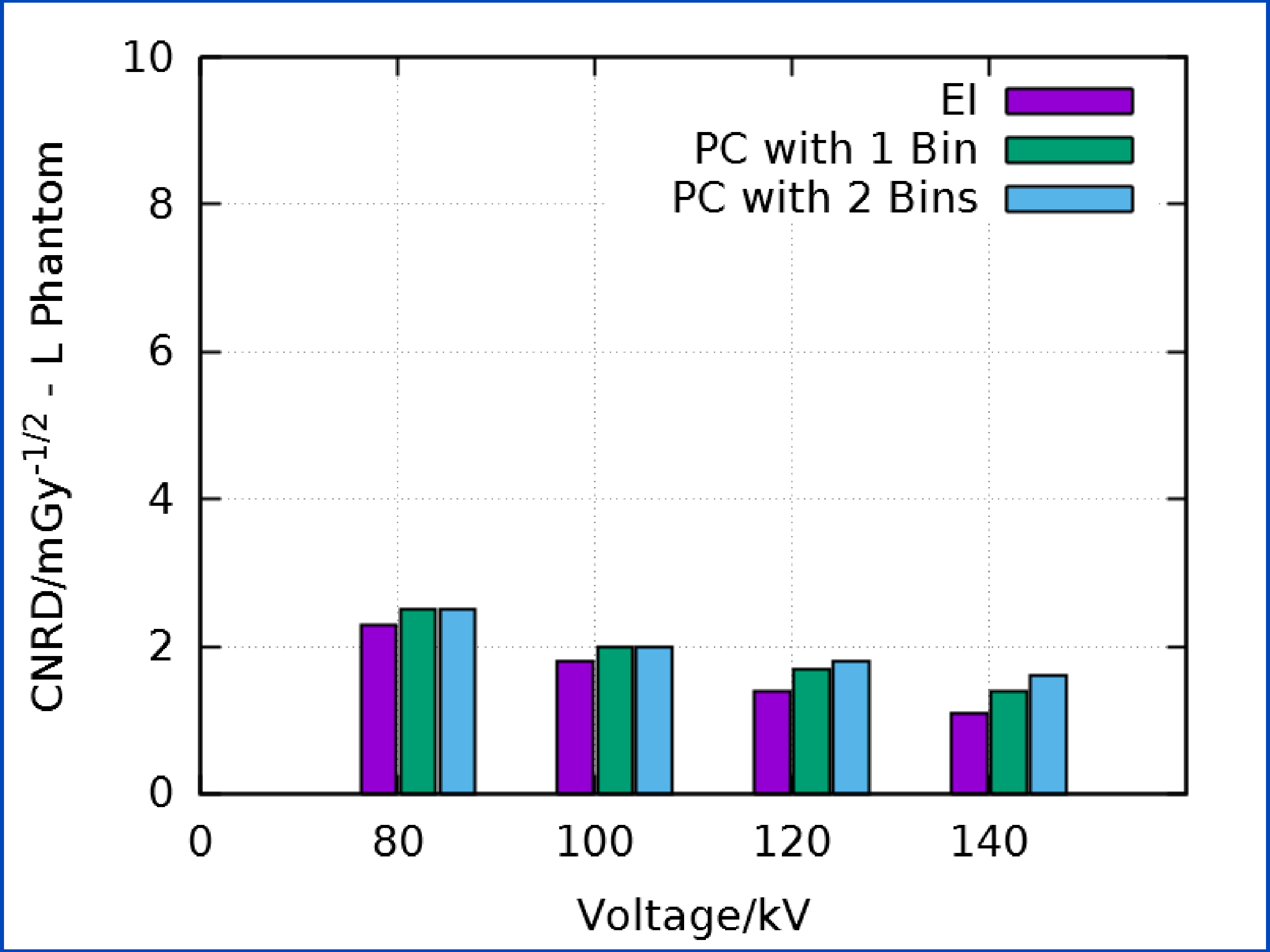
Results

CNRD – Medium Phantom



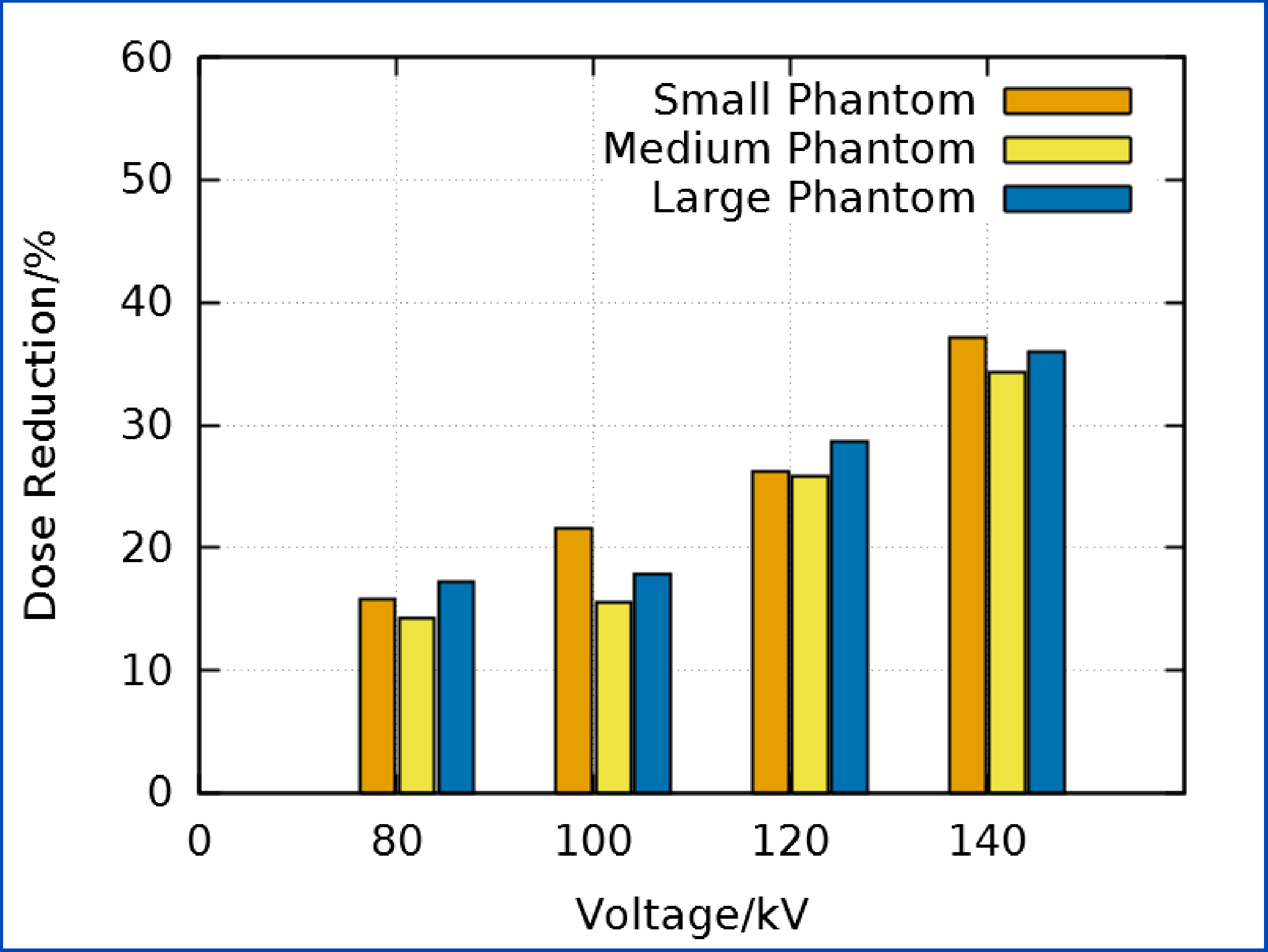
Results

CNRD – Large Phantom



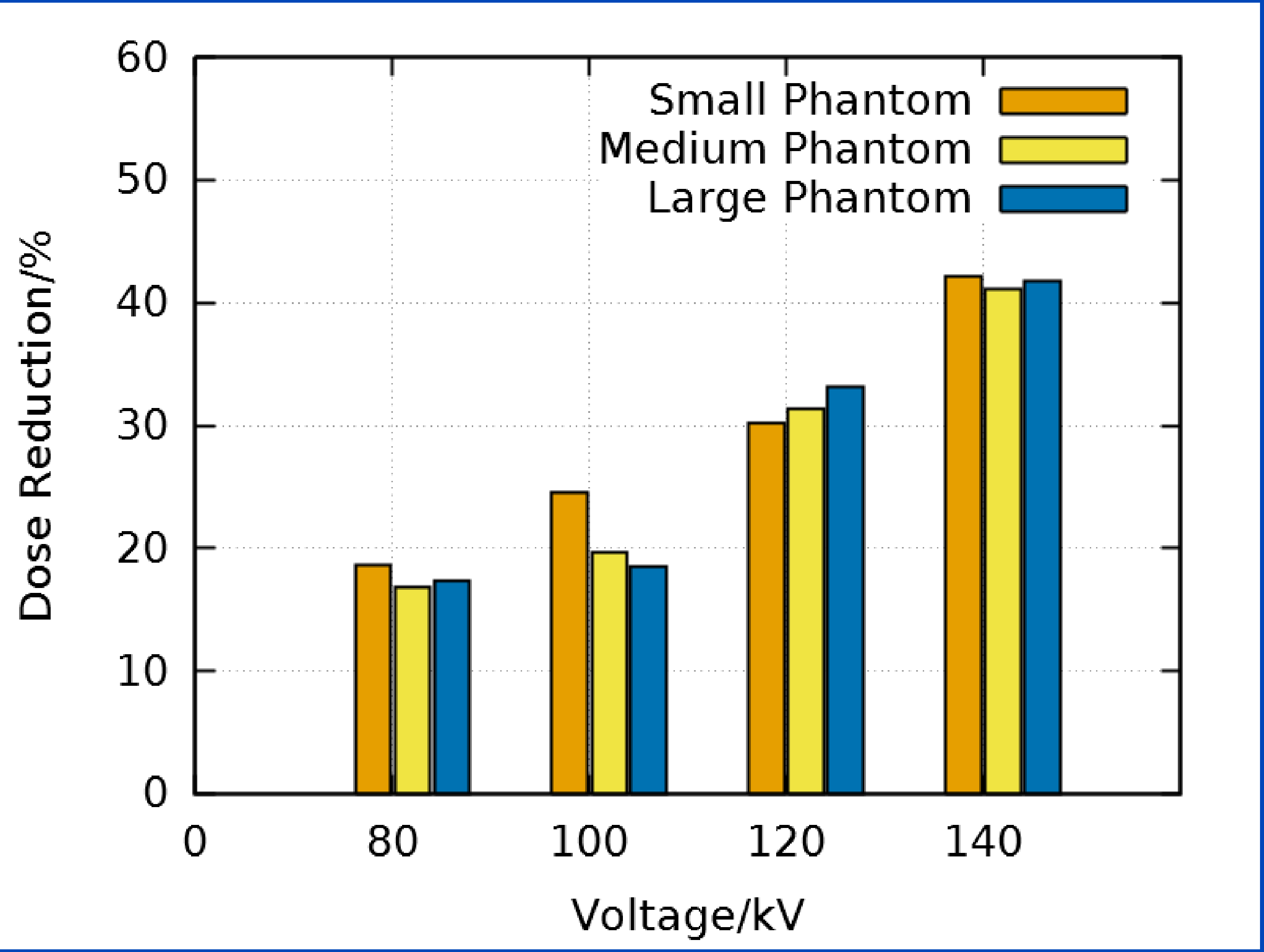
PC with 1 Bin vs. EI

Potential Dose Reduction



PC with 2 Bins vs. EI

Potential Dose Reduction



PC with 1 Bin vs. EI

… in Numbers

Tube Voltage /kV	Small	Medium	Large	Average over all Phantoms
Relative CNRD Improvement				
80	9.0%	7.9%	9.9%	**8.9**%
100	12.9%	8.8%	10.4%	**10.7**%
120	16.4%	16.1%	18.3%	**16.9**%
140	26.0%	23.4%	25.0%	**24.8**%
Potential Dose Reduction				
80	15.8%	14.2%	17.2%	**15.7**%
100	21.6%	15.6%	17.9%	**18.4**%
120	26.2%	25.8%	28.6%	**26.9**%
140	37.1%	34.3%	36.0%	**35.8**%

PC with 2 Bins vs. EI

… in Numbers

Tube Voltage /kV	Small	Medium	Large	Average over all Phantoms
Relative CNRD Improvement				
80	10.9%	9.6%	10.0%	**10.2%**
100	15.2%	11.6%	10.7%	**12.5%**
120	19.7%	20.6%	22.3%	**20.9%**
140	31.4%	30.3%	31.0%	**30.9%**
Potential Dose Reduction				
80	18.6%	16.8%	17.4%	**17.6%**
100	24.6%	19.7%	18.5%	**20.9%**
120	30.2%	31.3%	33.2%	**31.6%**
140	42.1%	41.1%	41.7%	**41.6%**

Summary & Conclusion

- A combination of intrinsically acquired bin data results in an Iodine-CNRD improvement of up to 30% compared to EI.
- This translates to a potential dose reduction of up to 40%.
- A combination of bins results in an additional CNRD improvement of up to 11% compared to PC with 1 bin.

Photon-Counting Is Now!

- Higher spatial resolution due to
  - smaller pixels
  - lower cross-talk between pixels
- Lower dose/noise due to
  - energy bin weighting
  - no electronic noise
  - Swank factor = 1
  - smaller pixels
- Spectral information on demand
  - single energy
  - dual energy
  - multiple energy
  - virtual monochromatic
  - K-edge imaging
  - …

Summary & Conclusion

- A combination of intrinsically acquired bin data results in an Iodine-CNRD improvement of up to 30% compared to EI.
- This translates to a potential dose reduction of up to 40%.
- A combination of bins results in an additional CNRD improvement of up to 11% compared to PC with 1 bin.

You cannot go wrong with photon-counting as patients of all sizes benefit from the favorable properties in terms of CNRD, noise and dose.

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.