Iodine in Photon-Counting CT

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Anode angle, and the small pixel effect (SPE)

GENERAL FACTS

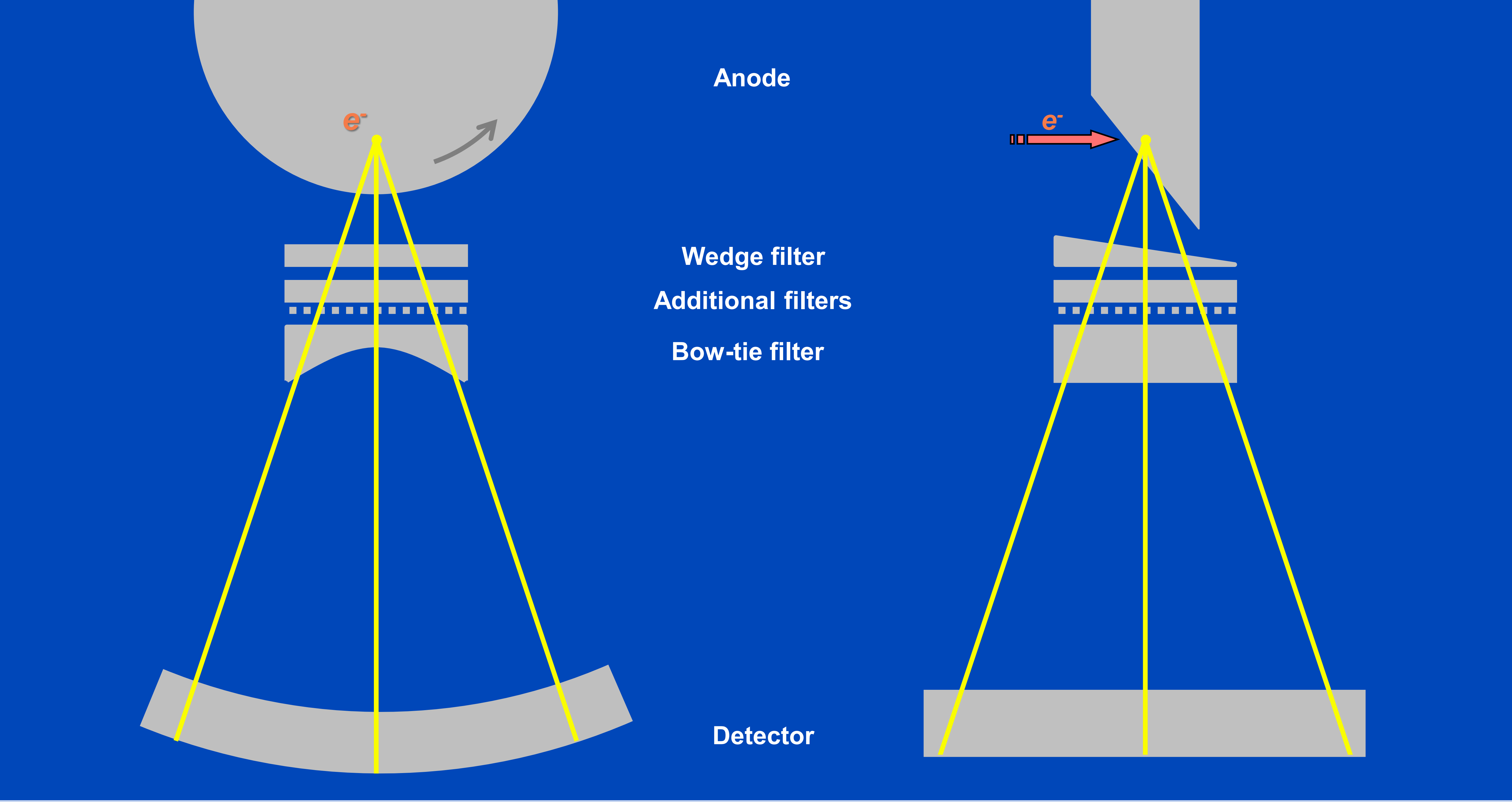


Figure not drawn to scale. Type and order of prefiltration may differ from scanner to scanner.
Depending on the selected protocol filters are changed automatically (e.g. small bowtie for pediatric scans).

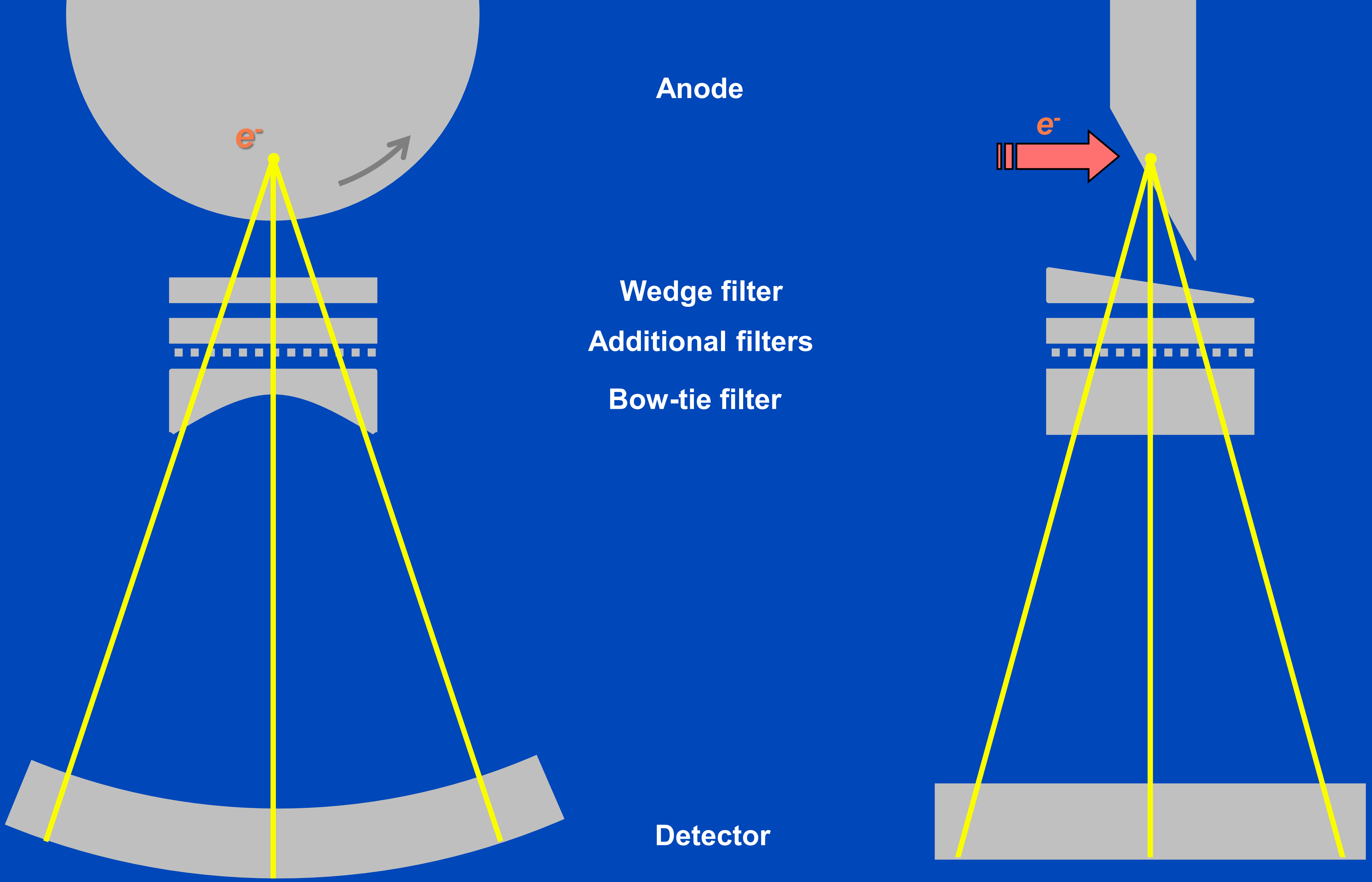
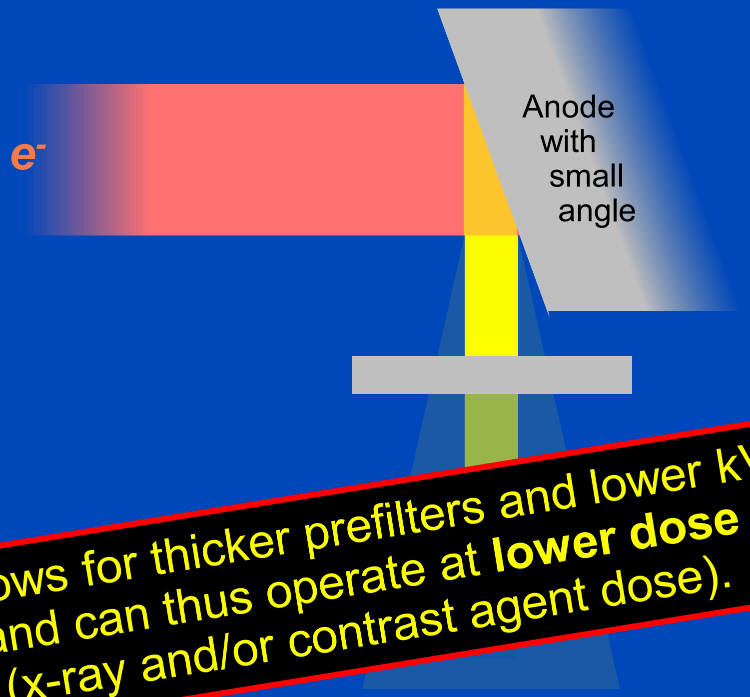


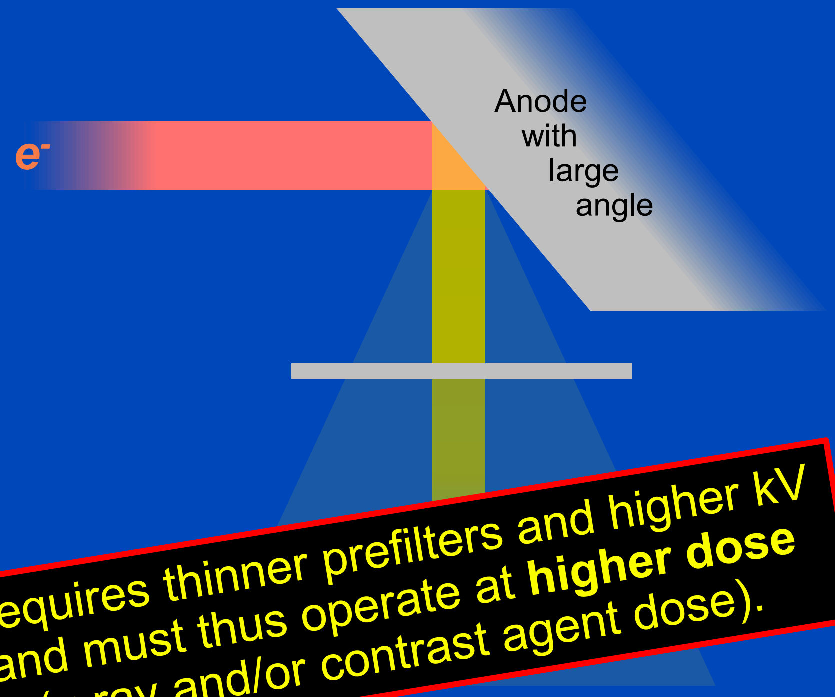
Figure not drawn to scale. Type and order of prefiltration may differ from scanner to scanner.
Depending on the selected protocol filters are changed automatically (e.g. small bowtie for pediatric scans).

Narrow Cone = High Tube Power



Allows for thicker prefilters and lower kV and can thus operate at **lower dose** (x-ray and/or contrast agent dose).

Wide Cone = Low Tube Power

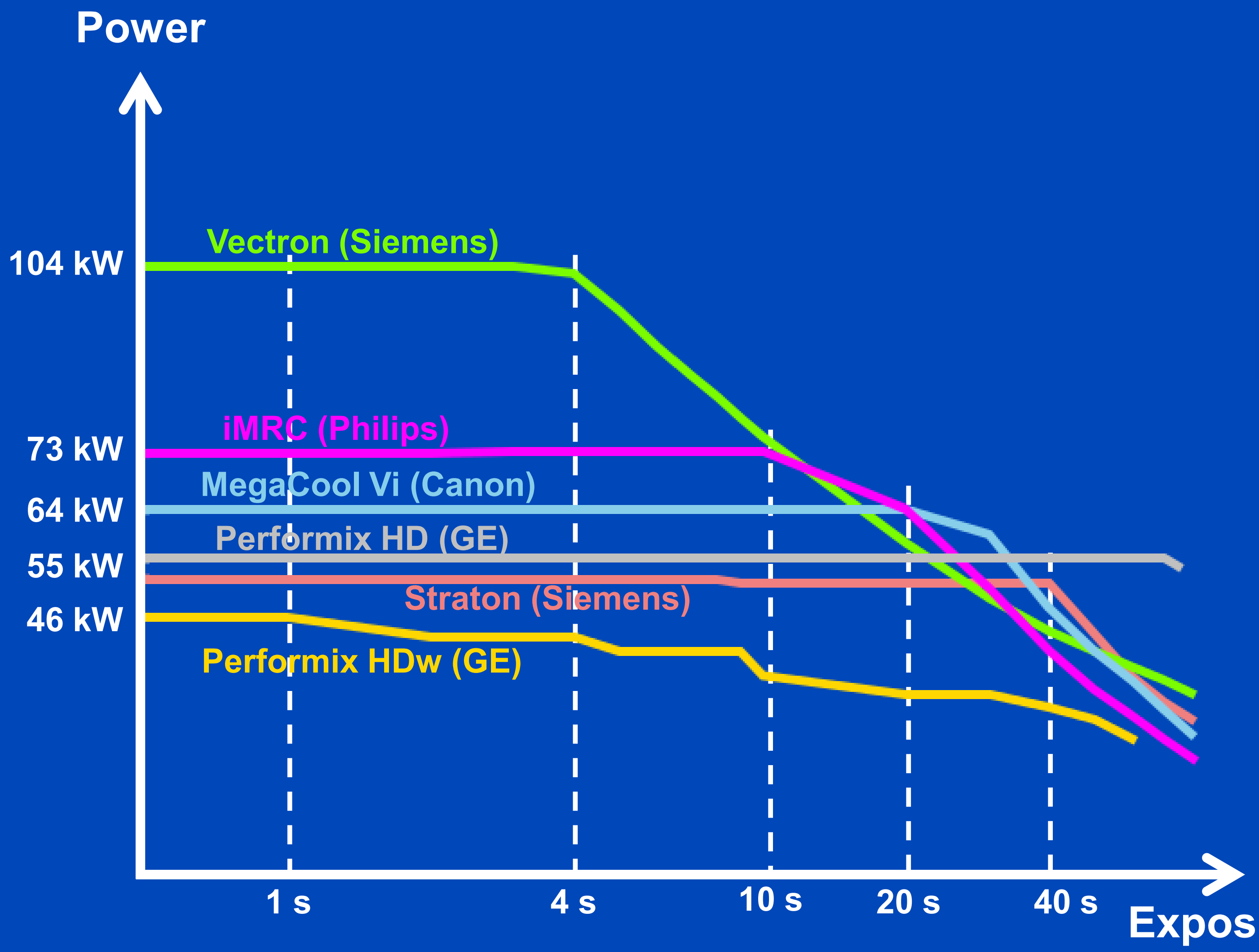


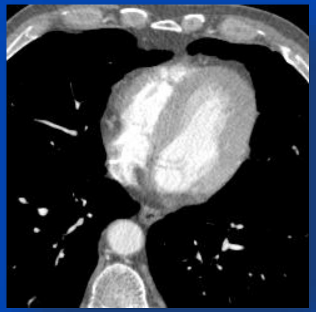
Requires thinner prefilters and higher kV and must thus operate at **higher dose** (x-ray and/or contrast agent dose).

… at the same spatial resolution

Onset of target melting (rule of thumb): 1 W/µm

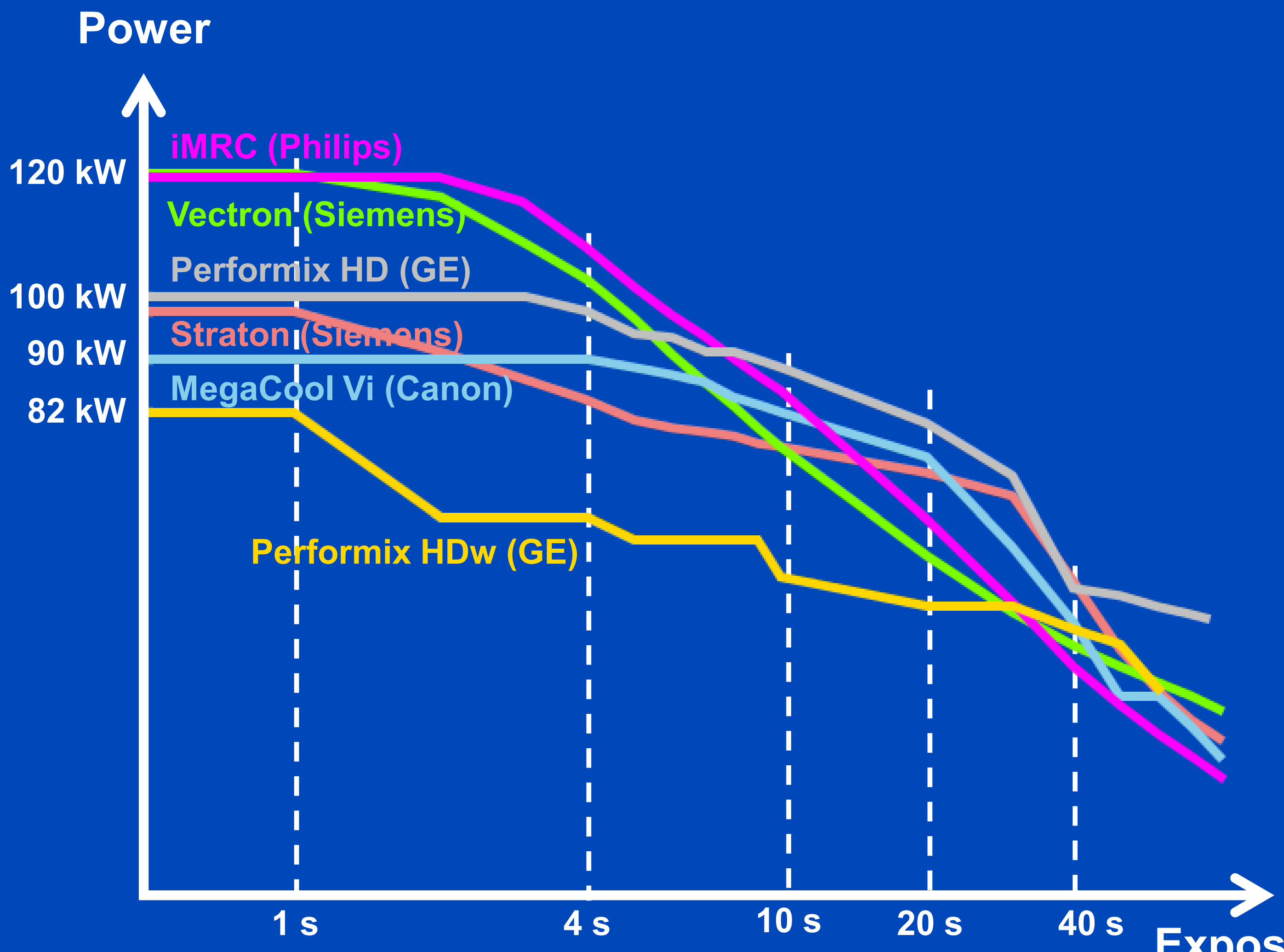
Tube Voltage 80 kV





C = 0 HU, *W* = 700 HU

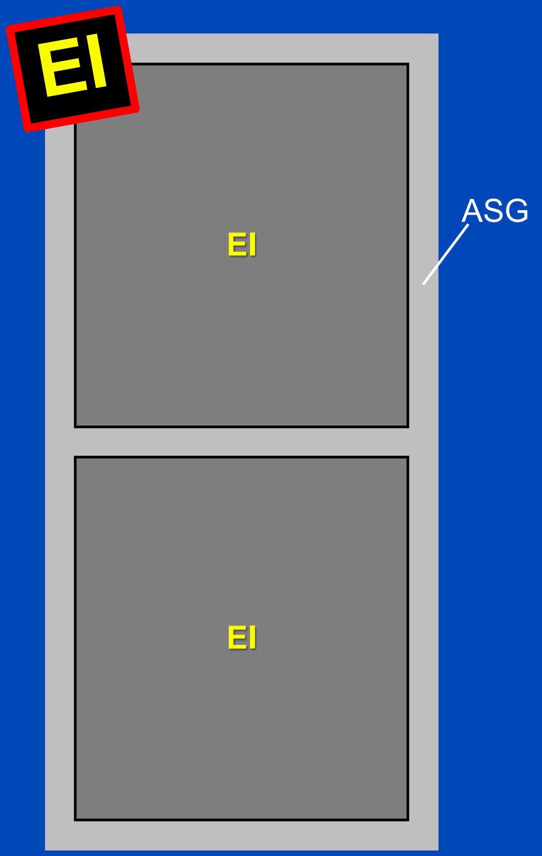
Tube Voltage 120 kV



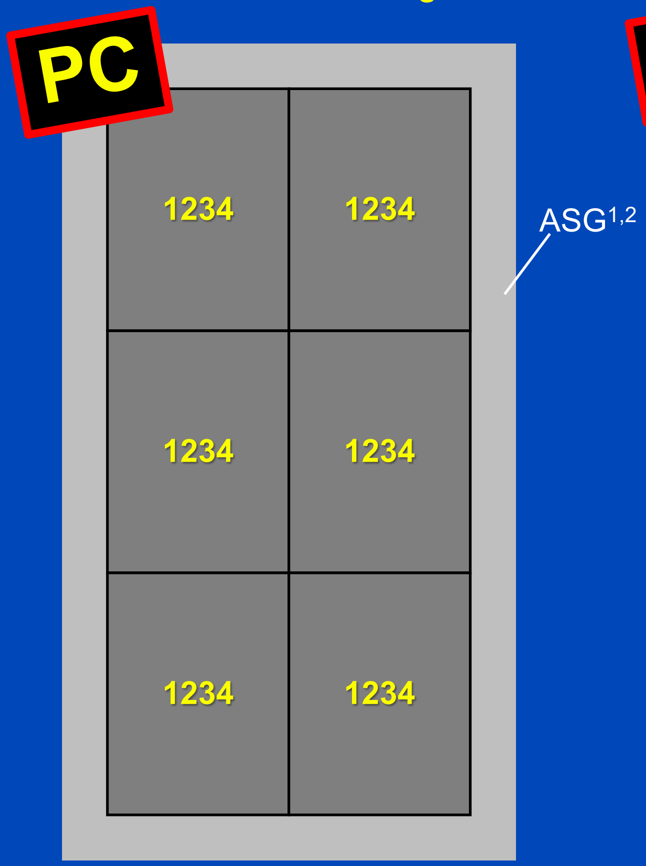
C = 0 HU, W = 700 HU

Detector Pixel Force vs. Alpha

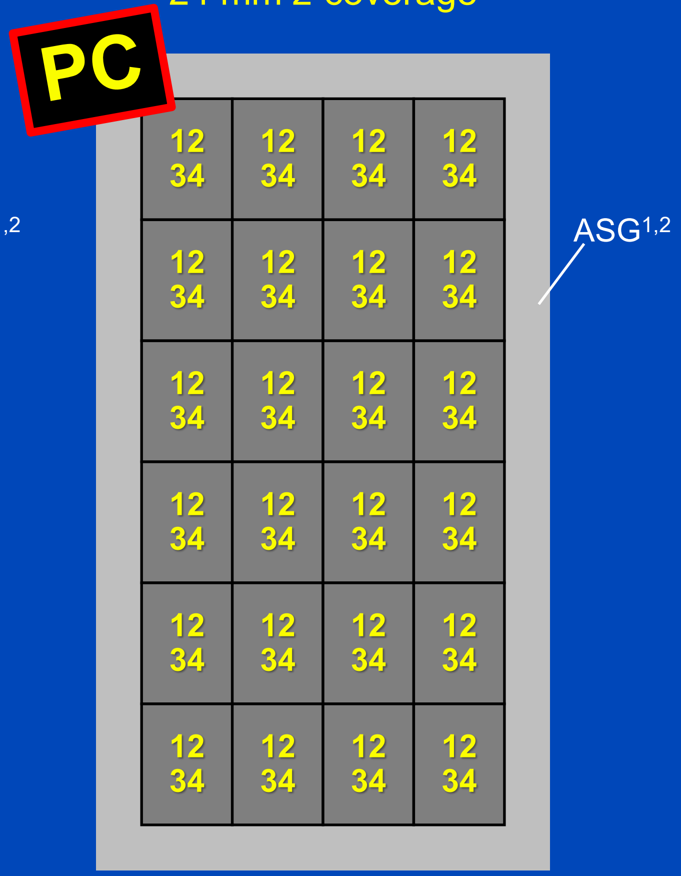
Force
920 × 96 detector pixels
pixel size 0.52 × 0.56 mm at iso
avg. sampling 0.56 × 0.6 mm at iso
57.6 mm z-coverage

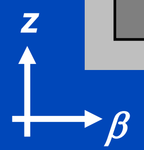


Alpha (Std, Quantum Plus)
1376 × 144 macro pixels
pixel size 0.3 × 0.352 mm at iso
avg. sampling 0.344 × 0.4 mm at iso
57.6 mm z-coverage



Alpha (UHR, QuantumHD)
2752 × 120 pixels
pixel size 0.151 × 0.176 mm at iso
avg. sampling 0.172 × 0.2 mm at iso
24 mm z-coverage



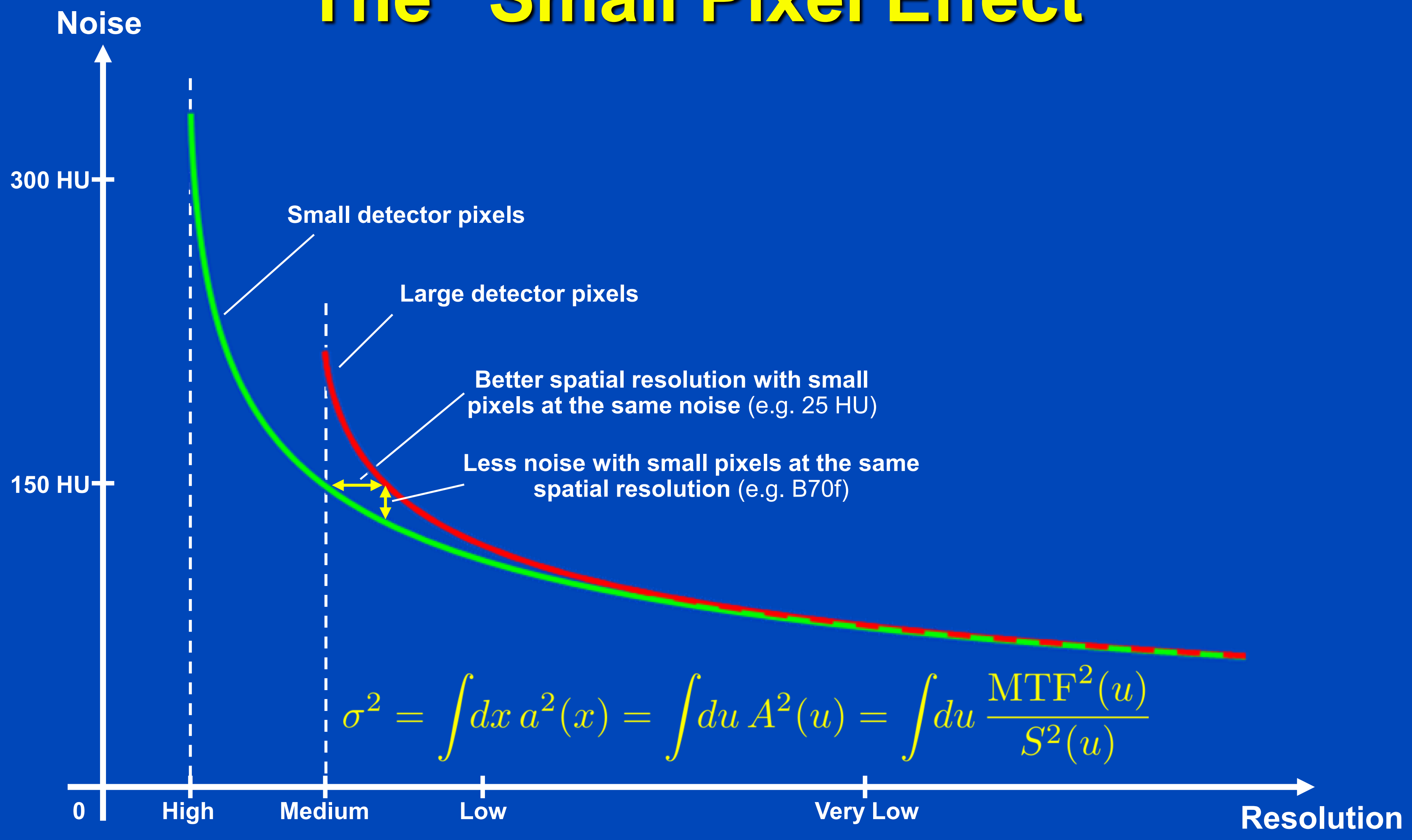


Focus sizes (Vectron): 0.181×0.226 mm, 0.271×0.7316 mm, 0.362×0.497 mm at iso
which are 0.4×0.5 mm, 0.6×0.7 mm, 0.8×1.1 mm at focal spot

[1]J. Ferda et al. Computed tomography with a full FOV photon-counting detector in a clinical setting, the first experience. European Journal of Radiology 137:109614, 2021
[2]Rajendran et al. Full field-of-view, high-resolution, photon-counting detector CT: technical assessment and initial patient experience. Phys. Med. Biol. 66:205019, 2021

dkfz.

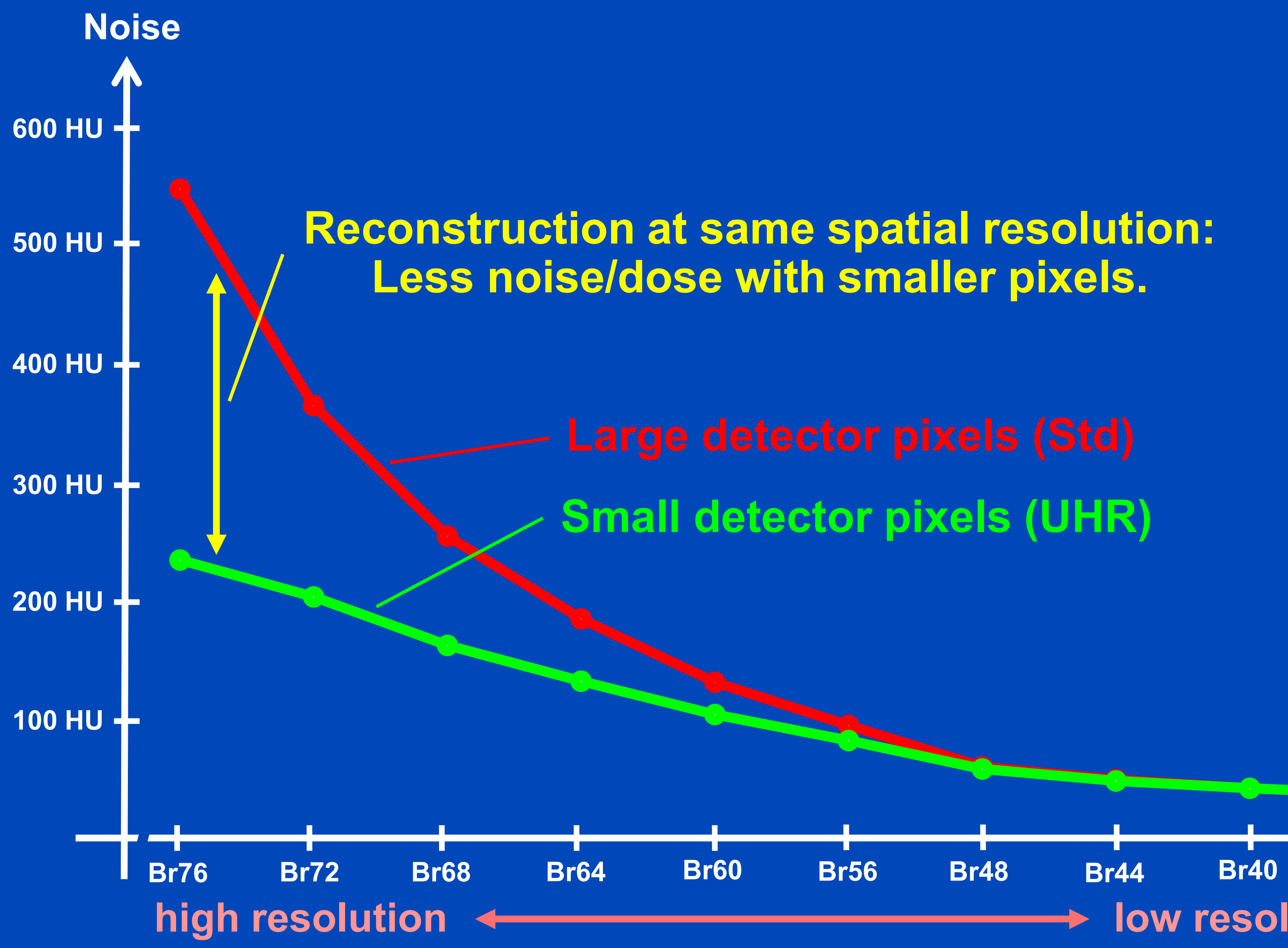
The “Small Pixel Effect”

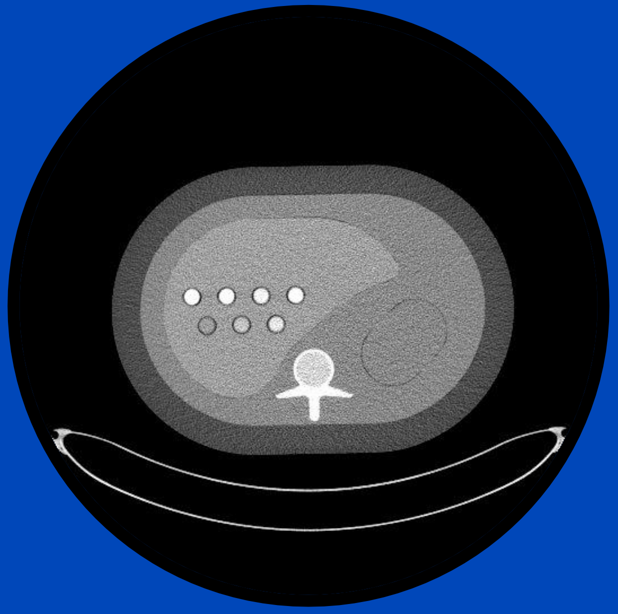


$$\sigma^2 = \int dx\, a^2(x) = \int du\, A^2(u) = \int du\, \frac{\mathrm{MTF}^2(u)}{S^2(u)}$$

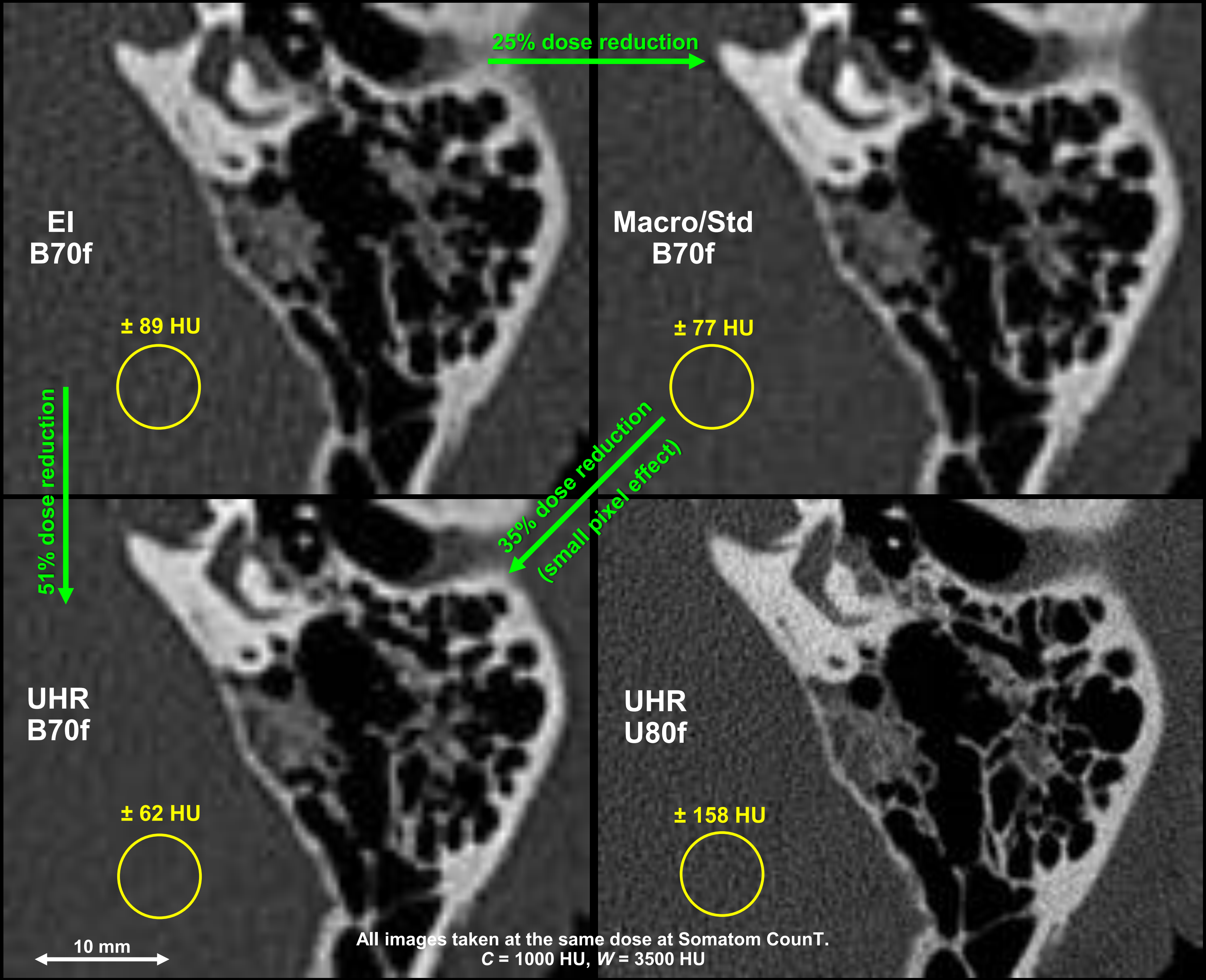
Small Pixel Effect at Naeotom Alpha

Medium Phantom, 4 mGy $CTDI_{32}$

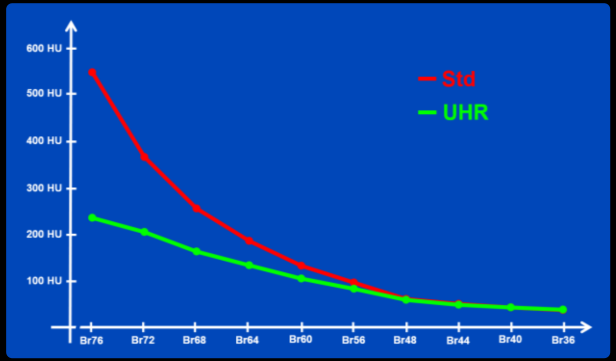




To disable the longitudinal small pixel effect, we reconstructed rather thick slices (1 mm thickness).



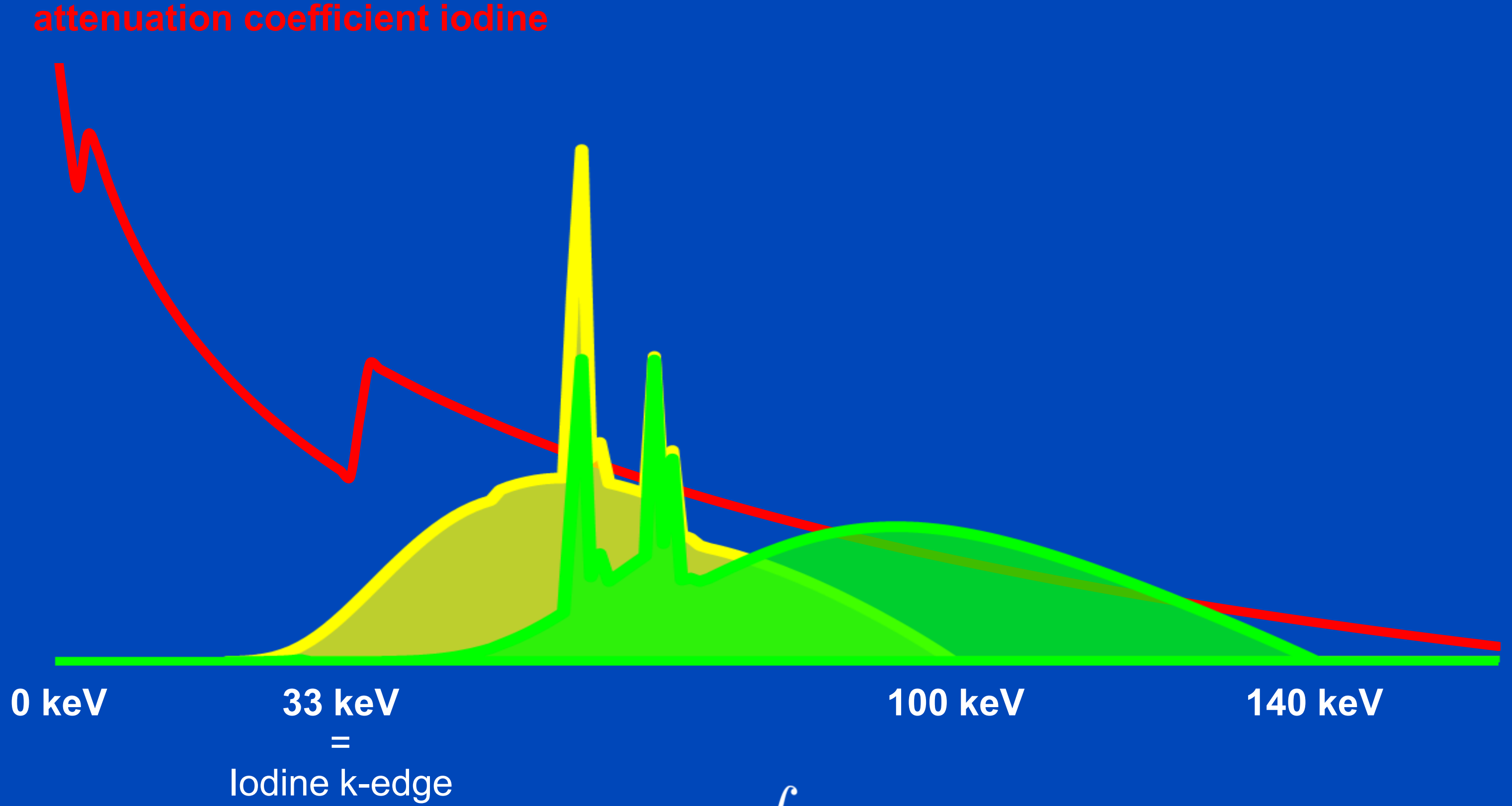
All images taken at the same dose at Somatom CounT.
C = 1000 HU, W = 3500 HU



PCCT without spectral processing

CONVENTIONAL IODINE

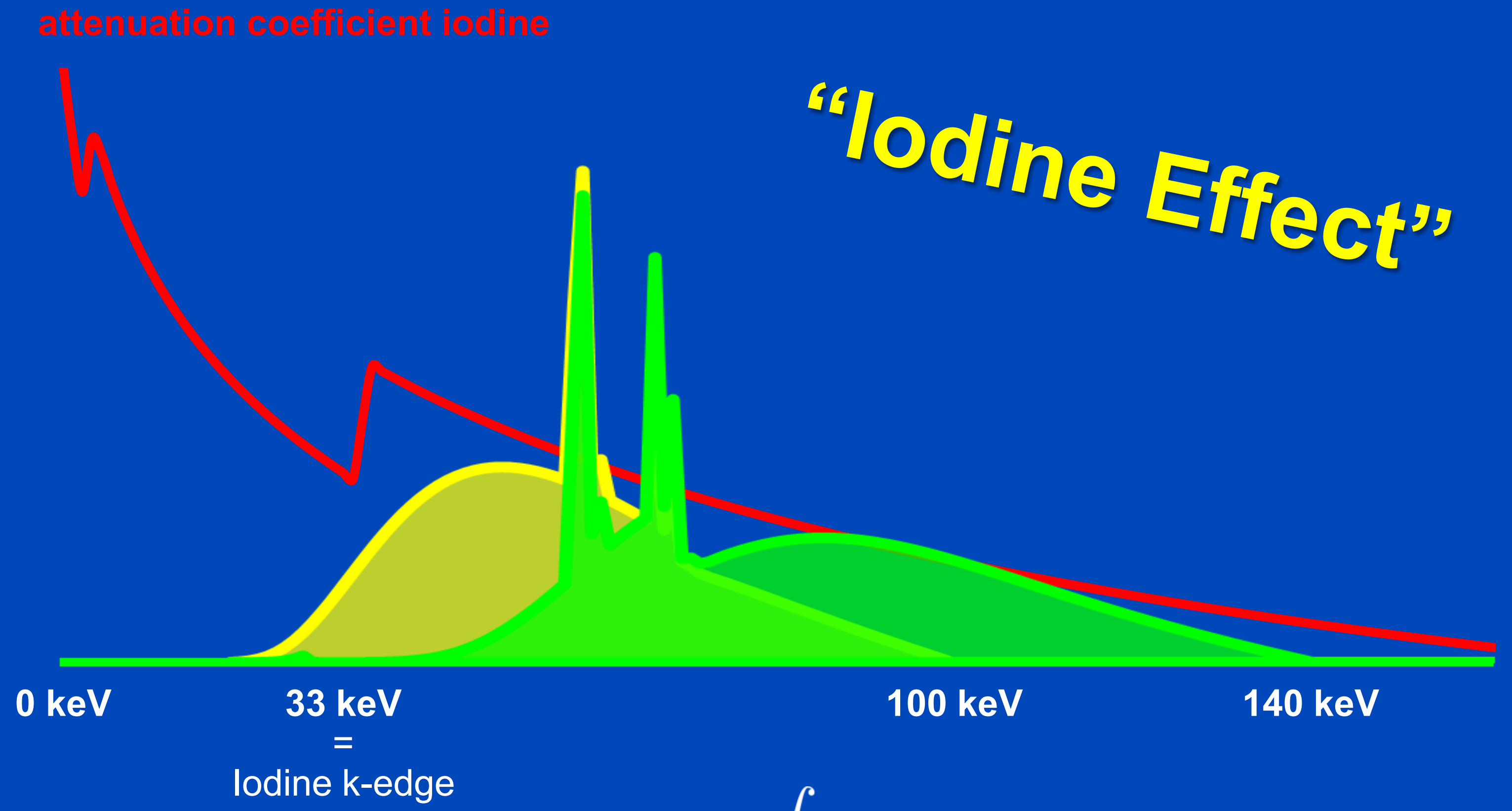
Energy-Integrating
(Detected Spectra at 100 kV and 140 kV)



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

100 kV and 140 kV EI spectra as seen after having passed 32 cm of water.

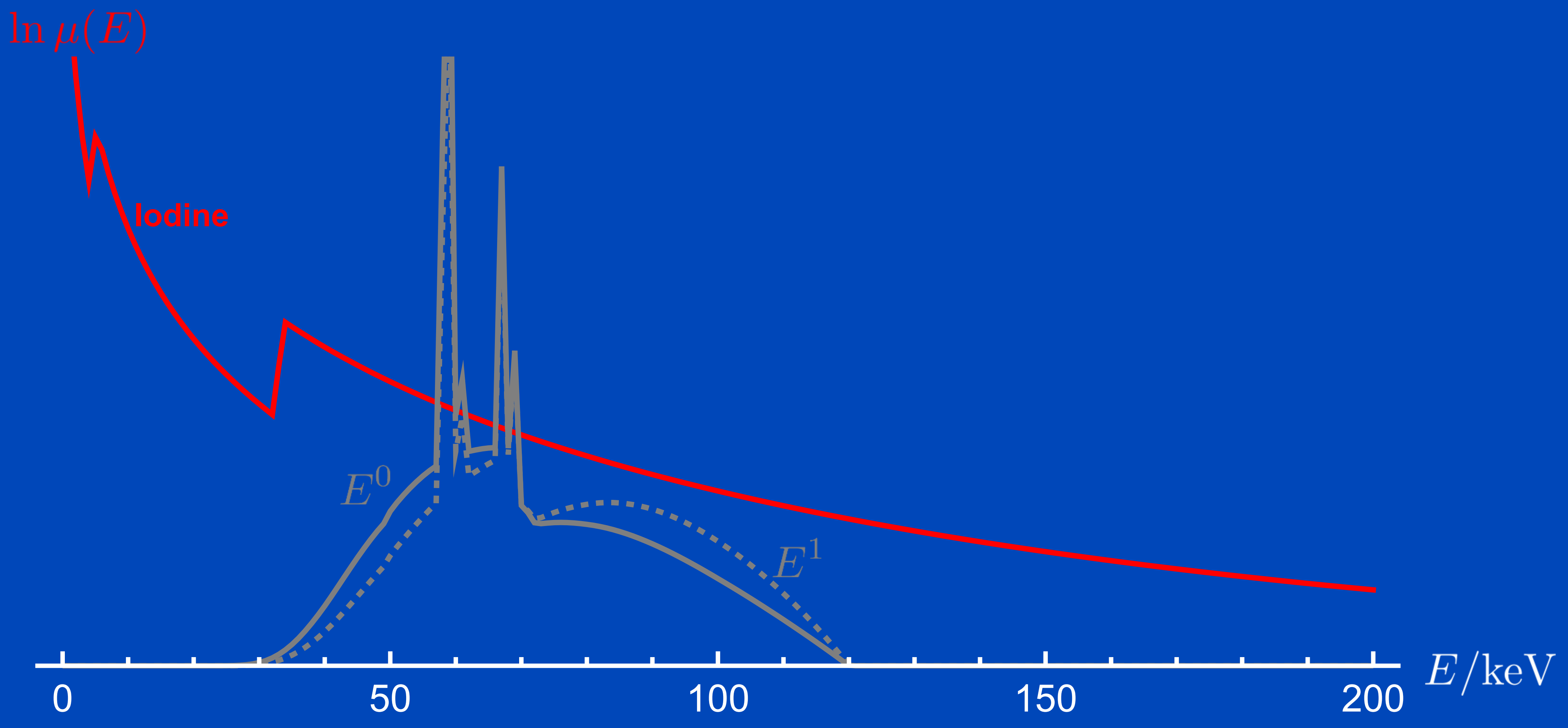
Photon-Counting
(Detected Spectra at 100 kV and 140 kV)



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

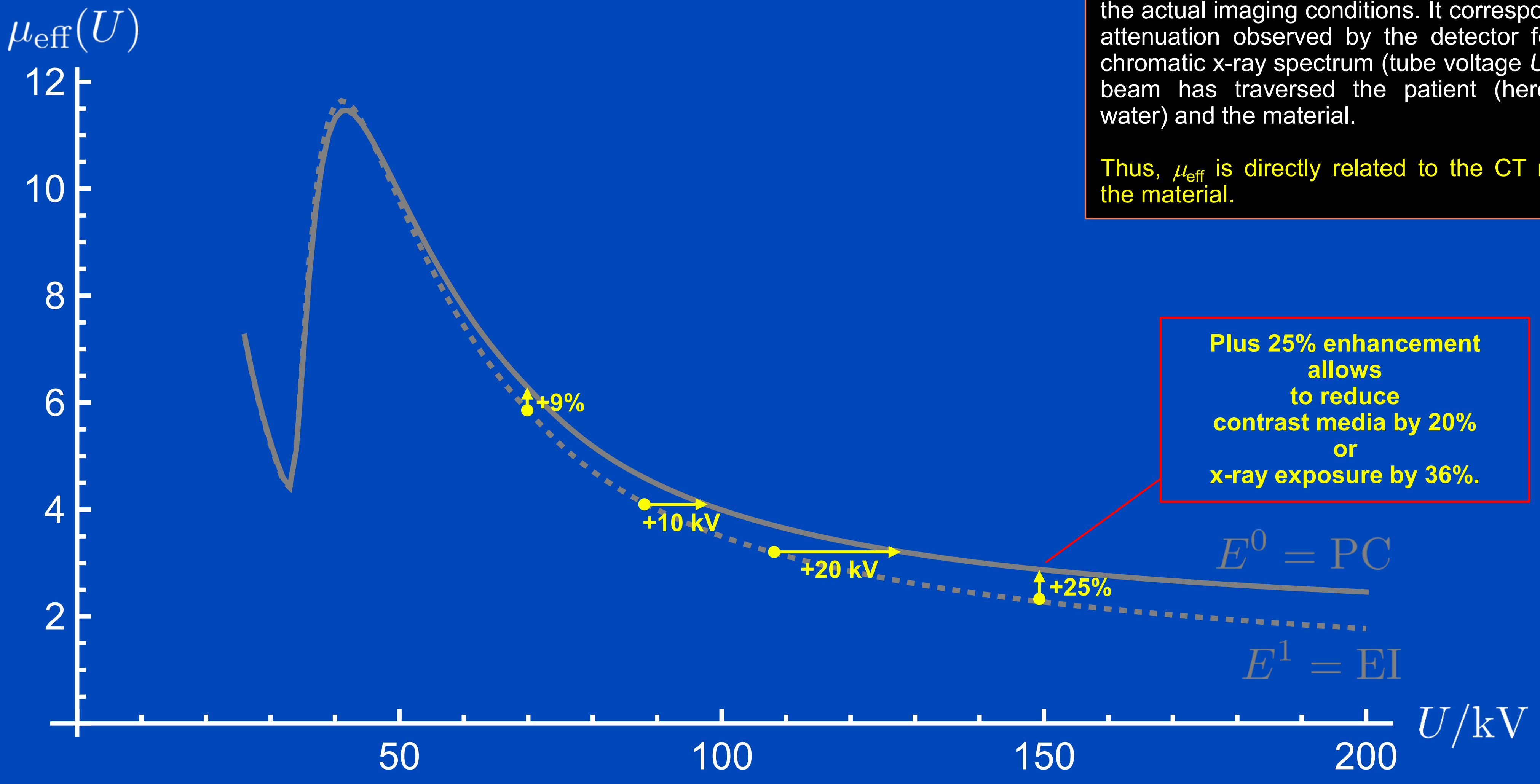
100 kV and 140 kV PC spectra (one bin) as seen after having passed 32 cm of water.

Iodine Effect



Detected 120 kV spectra without (E^0 = PC) and with (E^1 = EI) energy weighting.

Iodine Effect



For those unfamiliar with μ_{eff}

The effective attenuation coefficient, μ_{eff}, describes the attenuation of a material (here: iodine) under the actual imaging conditions. It corresponds to the attenuation observed by the detector for a polychromatic x-ray spectrum (tube voltage *U*) after the beam has traversed the patient (here: 16 cm water) and the material.

Thus, μ_{eff} is directly related to the CT number of the material.

Iodine μ_{eff} wrt 16 cm water layer without and with energy weighting.

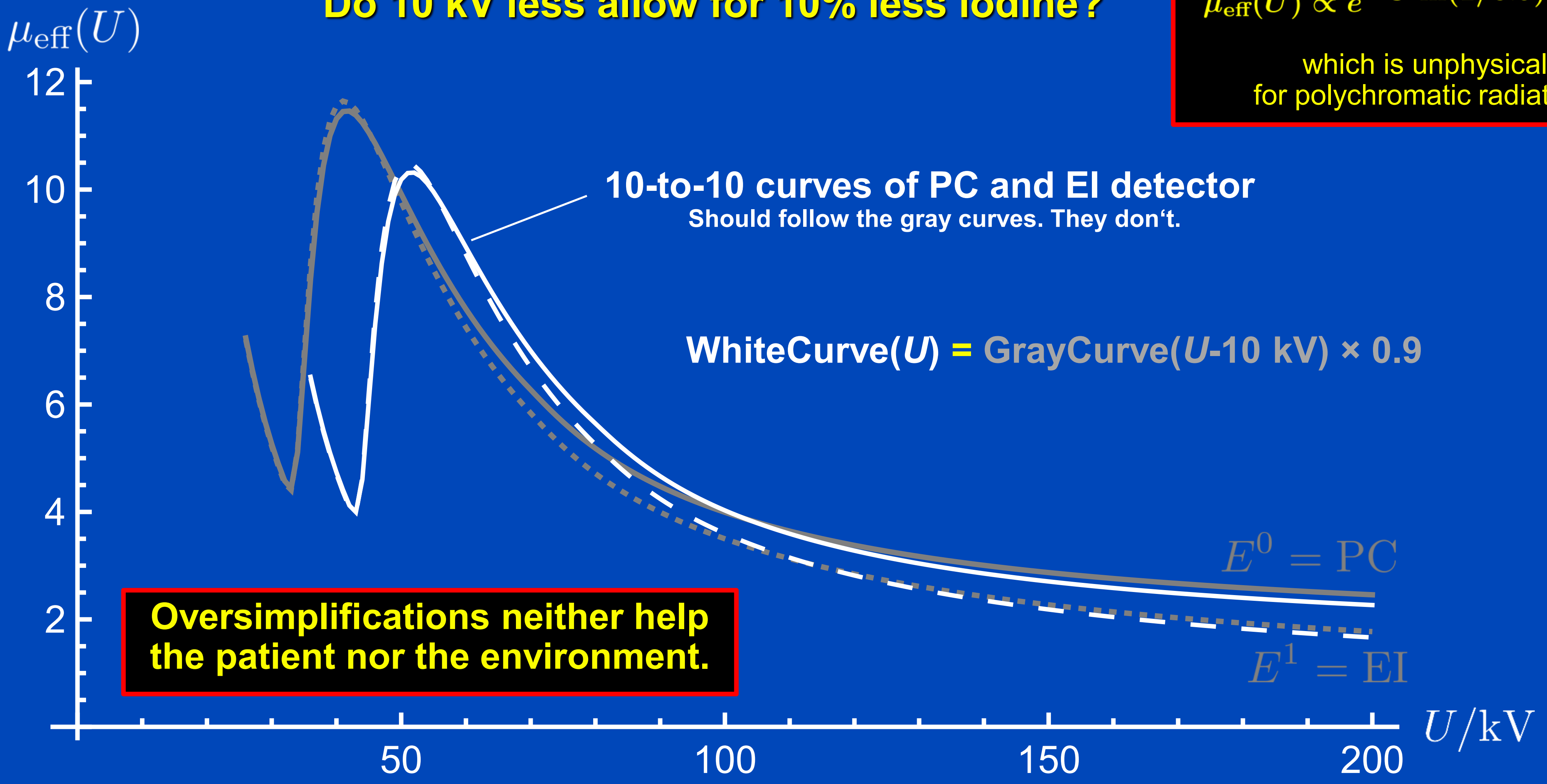
Strange “10-to-10 Rule”[1]

Do 10 kV less allow for 10% less iodine?

Mathematically,
that “10-to-10 rule” implies

$$\mu_{\mathrm{eff}}(U) \propto e^{-U \ln(1/0.9)/10\ \mathrm{kV}}$$

which is unphysical
for polychromatic radiation.



Oversimplifications neither help the patient nor the environment.

```
Lowering from  80 to  70 kV increases contrast by 24%. This allows to reduce iodine by 19%.
Lowering from 120 to 110 kV increases contrast by 10%. This allows to reduce iodine by  9%.
Lowering from 150 to 140 kV increases contrast by  7%. This allows to reduce iodine by  6%.
```

[1]Martens et al. Tailoring Contrast Media Protocols to Varying Tube Voltages: The 10-to-10 Rule. Invest Radiol 55(10):673-676, Oct. 2020

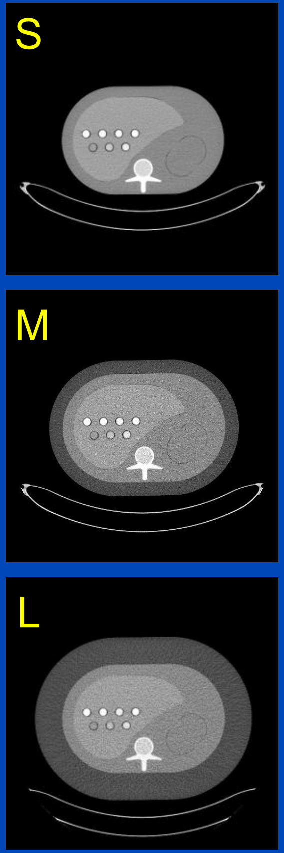
X-Ray Dose Reduction of B70f

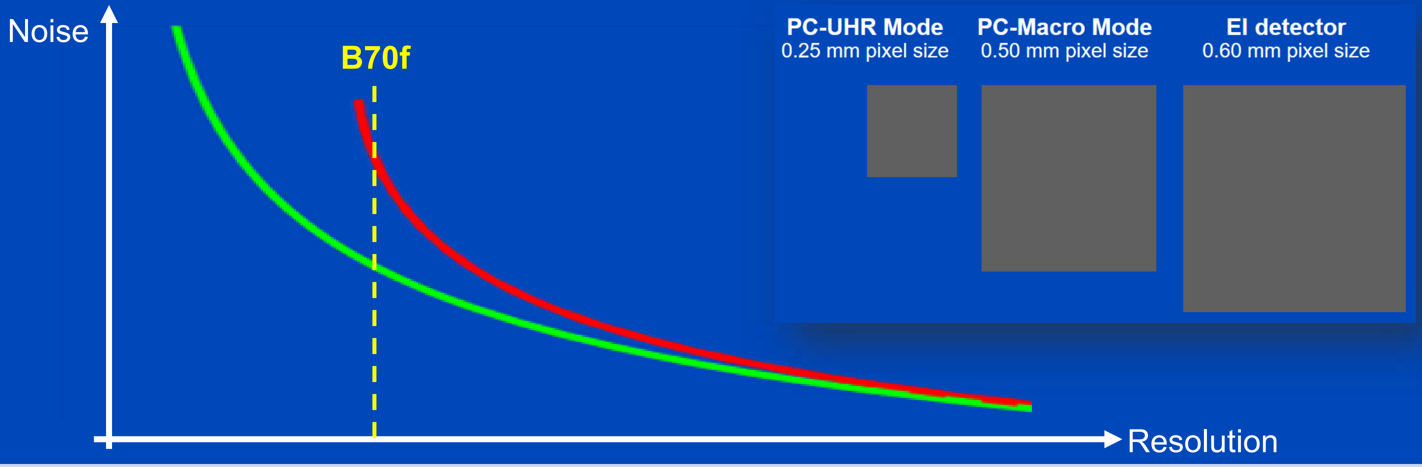
PC vs. PC
("small pixel effect only")

UHR vs. Macro	80 kV	100 kV	120 kV	140 kV
S	**23%** ± 12%	**34%** ± 10%	**35%** ± 11%	**25%** ± 10%
M	**32%** ± 10%	**32%** ± 8%	**35%** ± 8%	**34%** ± 9%
L	**35%** ± 10%	**29%** ± 15%	**27%** ± 9%	**31%** ± 11%

PC vs. EI
("small pixel effect"
and "iodine effect")

UHR vs. EI	80 kV	100 kV	120 kV	140 kV
S	**33%** ± 9%	**52%** ± 5%	**57%** ± 7%	**57%** ± 6%
M	**41%** ± 8%	**47%** ± 7%	**60%** ± 6%	**62%** ± 4%
L	**48%** ± 8%	**43%** ± 10%	**54%** ± 6%	**63%** ± 5%





Klein, Kachelrieß, Sawall et al. Invest. Radiol. 55(2), Feb 2020

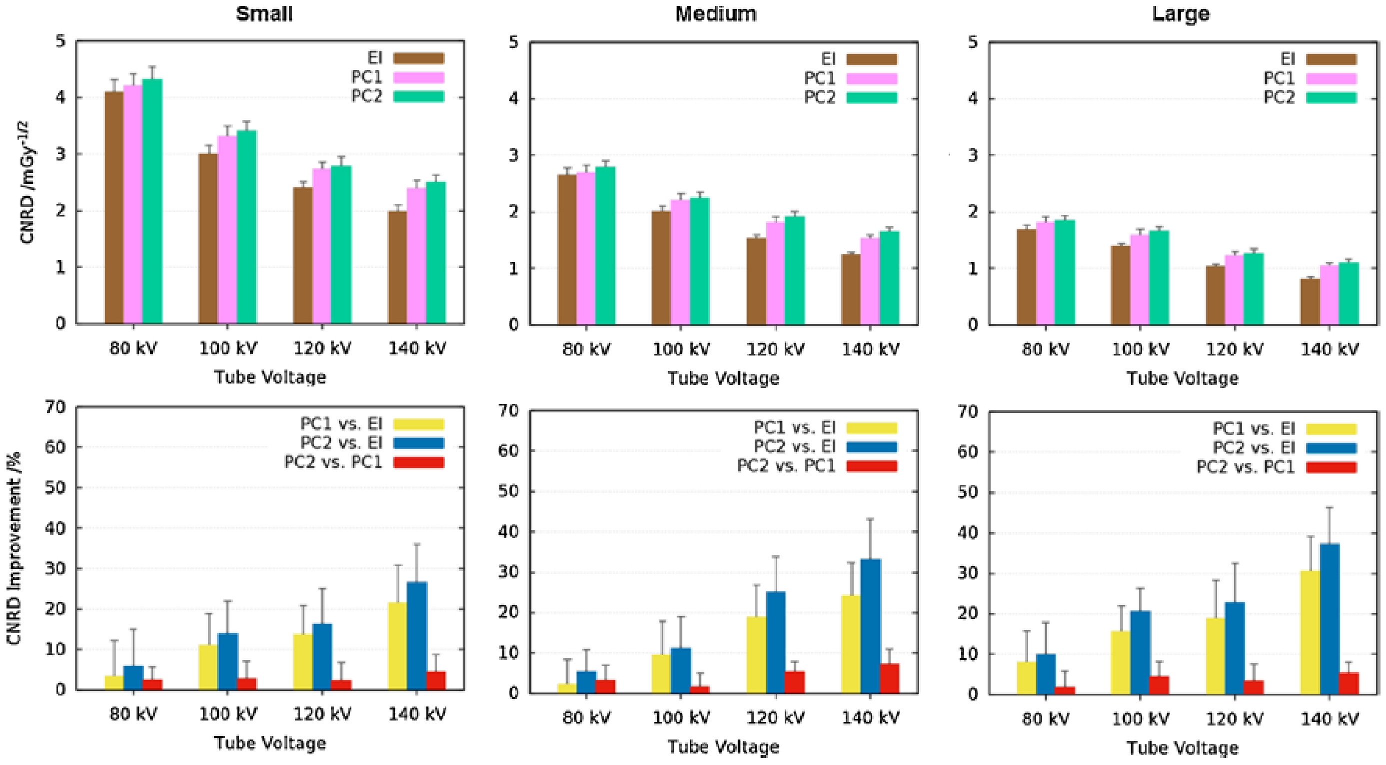


Fig. 3. Exemplary CNRD values measured in semi-anthropomorphic phantoms of different sizes (top) and the resulting CNRD improvement and contrast media reduction potential (bottom).

Table 1
CNRD improvement and contrast media reduction potential, respectively, among all considered scan protocols for all tube voltages and all phantom sizes.

	Tube Voltage	Small	Medium	Large
PC1 vs. EI	80 kV	**3.3 ± 8.8 %**	2.3 ± 6.1 %	8.1 ± 7.6 %
	100 kV	**10.9 ± 8.0 %**	**9.4 ± 8.5 %**	15.6 ± 6.2 %
	120 kV	13.8 ± 7.1 %	**18.8 ± 8.1 %**	**18.8 ± 9.4 %**
	140 kV	21.5 ± 9.4 %	24.1 ± 8.3 %	**30.5 ± 8.6 %**
PC2 vs. EI	80 kV	**5.8 ± 9.1 %**	5.6 ± 5.4 %	10.0 ± 7.9 %
	100 kV	**13.8 ± 8.1 %**	**11.1 ± 7.8 %**	20.6 ± 5.9 %
	120 kV	16.4 ± 8.6 %	**25.0 ± 8.8 %**	**22.7 ± 9.9 %**
	140 kV	26.7 ± 9.4 %	33.2 ± 9.8 %	**37.3 ± 9.0 %**
PC2 vs. PC1	80 kV	**2.4 ± 3.3 %**	3.1 ± 3.9 %	1.8 ± 3.9 %
	100 kV	**2.7 ± 4.4 %**	**1.7 ± 3.4 %**	4.5 ± 3.7 %
	120 kV	2.3 ± 4.5 %	**5.3 ± 2.6 %**	**3.4 ± 4.3 %**
	140 kV	4.4 ± 4.3 %	7.4 ± 3.5 %	**5.3 ± 2.8 %**

Virtual monoenergetic imaging (VMI)

SPECTRALLY PROCESSED IODINE

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journal homepage: www.elsevier.com/locate/ejrad

ELSEVIER

PCD-CT enables contrast media reduction in abdominal imaging compared to an individualized kV-adapted contrast media injection protocol on EID-CT

Eva J.I. Hoeijmakers[a,b,1,*], Lion Stammen[a,b,1], Joachim E. Wildberger[a,b], Nienke G. Eijsvoogel[a], Johanna M. Hersbach[a], Joey C.J.G. Pernot[a], Thomas G. Flohr[a,c], Bibi Martens[a,d,2], Cécile R.L.P.N. Jeukens[a,2]

Hoeijmakers et al., 2024:

A reduction of 20% iodine was observed for PCCT.

Dabli et al. European Radiology Experimental (2025) 9:36
https://doi.org/10.1186/s41747-025-00573-2

European Radiology EXPERIMENTAL

ORIGINAL ARTICLE Open Access

Photon-counting *versus* energy-integrating CT of abdomen-pelvis: a phantom study on the potential for reducing iodine contrast media

Djamel Dabli[1*], Maxime Pastor[1], Sebastian Faby[2], Julien Erath[2], Cédric Croisille[2], Fabricio Pereira[3], Jean-Paul Beregi[1] and Joël Greffier[1]

Dabli et al., 2025:

Iodine reductions of up to 49% were observed.
(49% at 40 keV VMI)

Popp et al. European Radiology (2025) 35:4635–4648
https://doi.org/10.1007/s00330-025-11409-3

European Radiology

CONTRAST MEDIA Open Access

Potential of photon-counting detector CT technology for contrast medium reduction in portal venous phase thoracoabdominal CT

Daniel Popp[1,2], Martin Siedlecki[1], Lena Friedrich[1], Mark Haerting[1], Christian Scheurig-Muenkler[1], Florian Schwarz[3,4], Thomas Kroencke[1,5*], Stefanie Bette[1] and Josua A. Decker[1]

Popp et al., 2025:

120 mL EICT are equivalent to 100 mL PCCT.

Stammen et al. European Radiology (2026) 36:3206–3215
https://doi.org/10.1007/s00330-025-12054-6

European Radiology

COMPUTED TOMOGRAPHY Open Access

Reducing contrast media dosage for pulmonary embolism CTPA in PCD-CT: a comparative study of EID-CT and PCD-CT in the era of individualized protocolling

Lion Stammen[1,2*], Eva J. I. Hoeijmakers[1,2], Thomas G. Flohr[1,3], Hester A. Gietema[1,4], Janneke Vandewall[1], Joachim E. Wildberger[1,2], Cécile R. L. P. N. Jeukens[1] and Bibi Martens[1,4]

Stammen et al., 2026:

PCCT reduced iodine by 27% and CTDI by 24%.

40 keV

Siemens Naeotom Alpha
120 kV, 211 mAs
5.2 mGy $CTDI_{32}$
260 mGy*cm DLP
3.9 mSv D_{eff}
Br30 kernel
Mono+

C = 60 HU, *W* = 360 HU

60 keV

Siemens Naeotom Alpha
120 kV, 211 mAs
5.2 mGy $CTDI_{32}$
260 mGy*cm DLP
3.9 mSv D_{eff}
Br30 kernel
Mono+

C = 60 HU, W = 360 HU

80 keV

Siemens Naeotom Alpha
120 kV, 211 mAs
5.2 mGy $CTDI_{32}$
260 mGy*cm DLP
3.9 mSv D_{eff}
Br30 kernel
Mono+

C = 60 HU, W = 360 HU

100 keV

Siemens Naeotom Alpha
120 kV, 211 mAs
5.2 mGy $CTDI_{32}$
260 mGy*cm DLP
3.9 mSv D_{eff}
Br30 kernel
Mono+

C = 60 HU, W = 360 HU

120 keV

Siemens Naeotom Alpha
120 kV, 211 mAs
5.2 mGy $CTDI_{32}$
260 mGy*cm DLP
3.9 mSv D_{eff}
Br30 kernel
Mono+

C = 60 HU, *W* = 360 HU

140 keV

Siemens Naeotom Alpha
120 kV, 211 mAs
5.2 mGy $CTDI_{32}$
260 mGy*cm DLP
3.9 mSv D_{eff}
Br30 kernel
Mono+

C = 60 HU, W = 360 HU

160 keV

Siemens Naeotom Alpha
120 kV, 211 mAs
5.2 mGy CTDI_{32}
260 mGy*cm DLP
3.9 mSv D_{eff}
Br30 kernel
Mono+

C = 60 HU, W = 360 HU

dkfz.

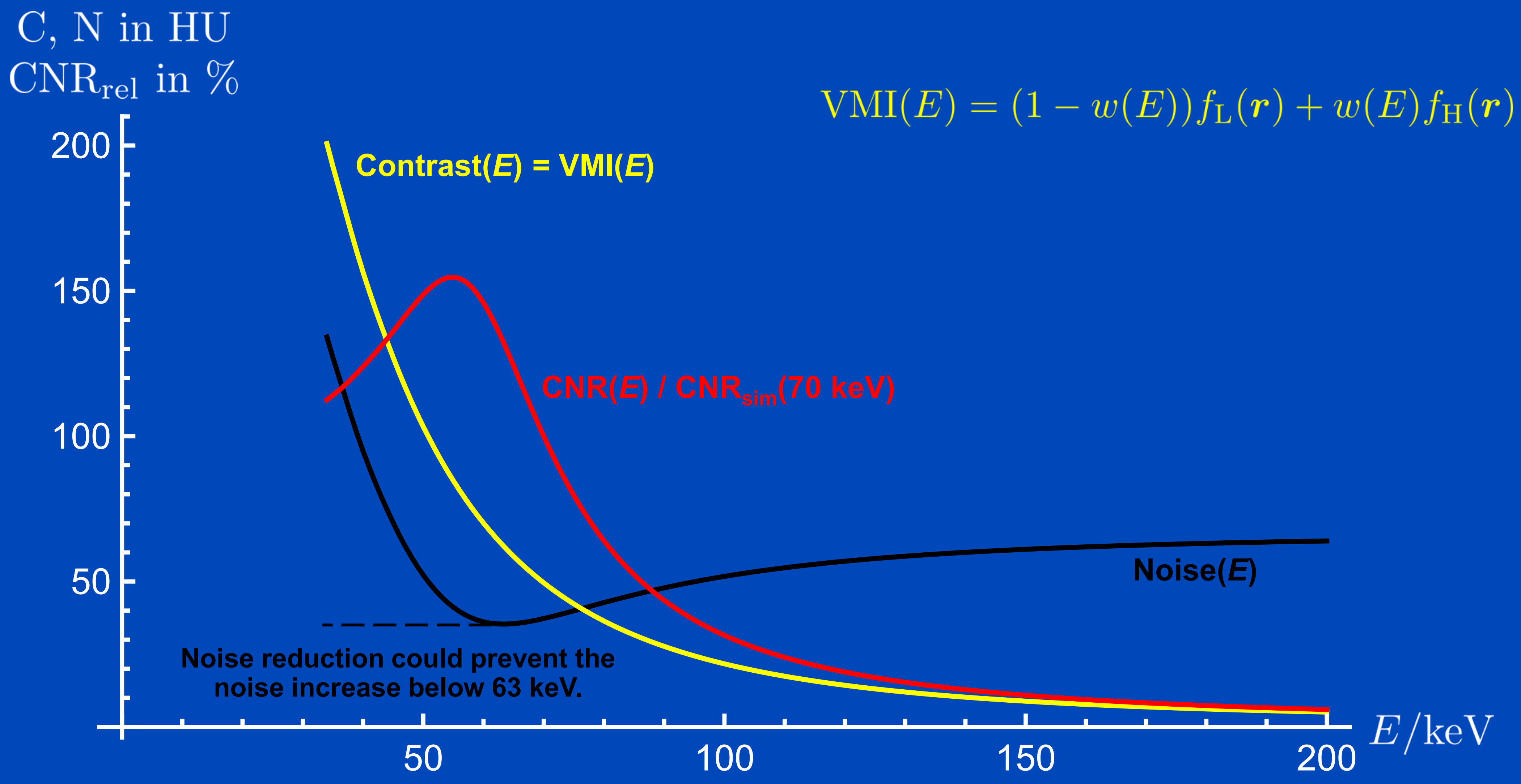
180 keV

Siemens Naeotom Alpha
120 kV, 211 mAs
5.2 mGy $CTDI_{32}$
260 mGy*cm DLP
3.9 mSv D_{eff}
Br30 kernel
Mono+

C = 60 HU, W = 360 HU

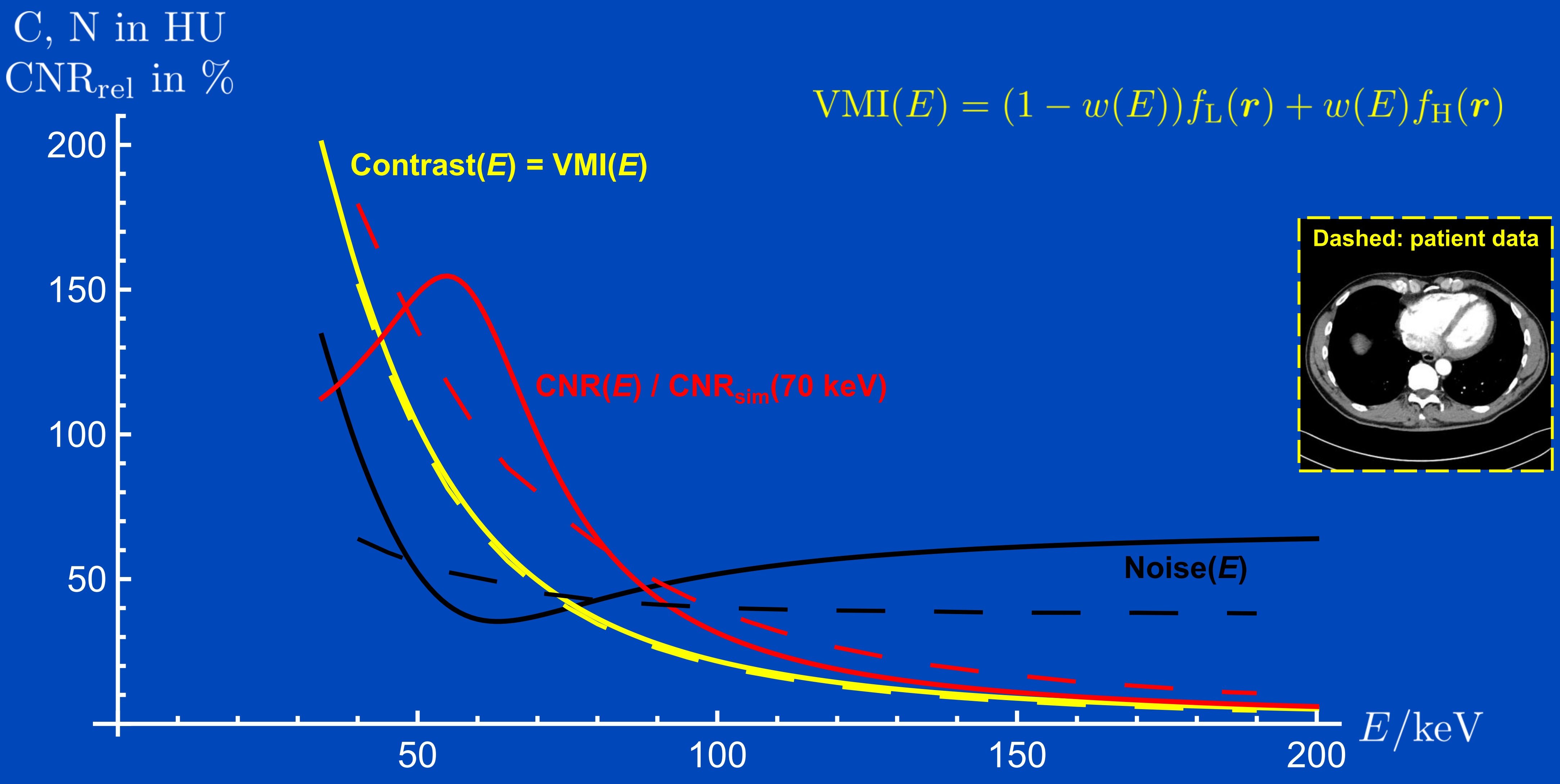
VMI's Iodine Contrast, Noise, CNR

Assuming no noise reduction



VMI demonstration based on 70 and 150 kV simulations of a 16 cm water phantom with 50 HU noise in f_L and f_H.

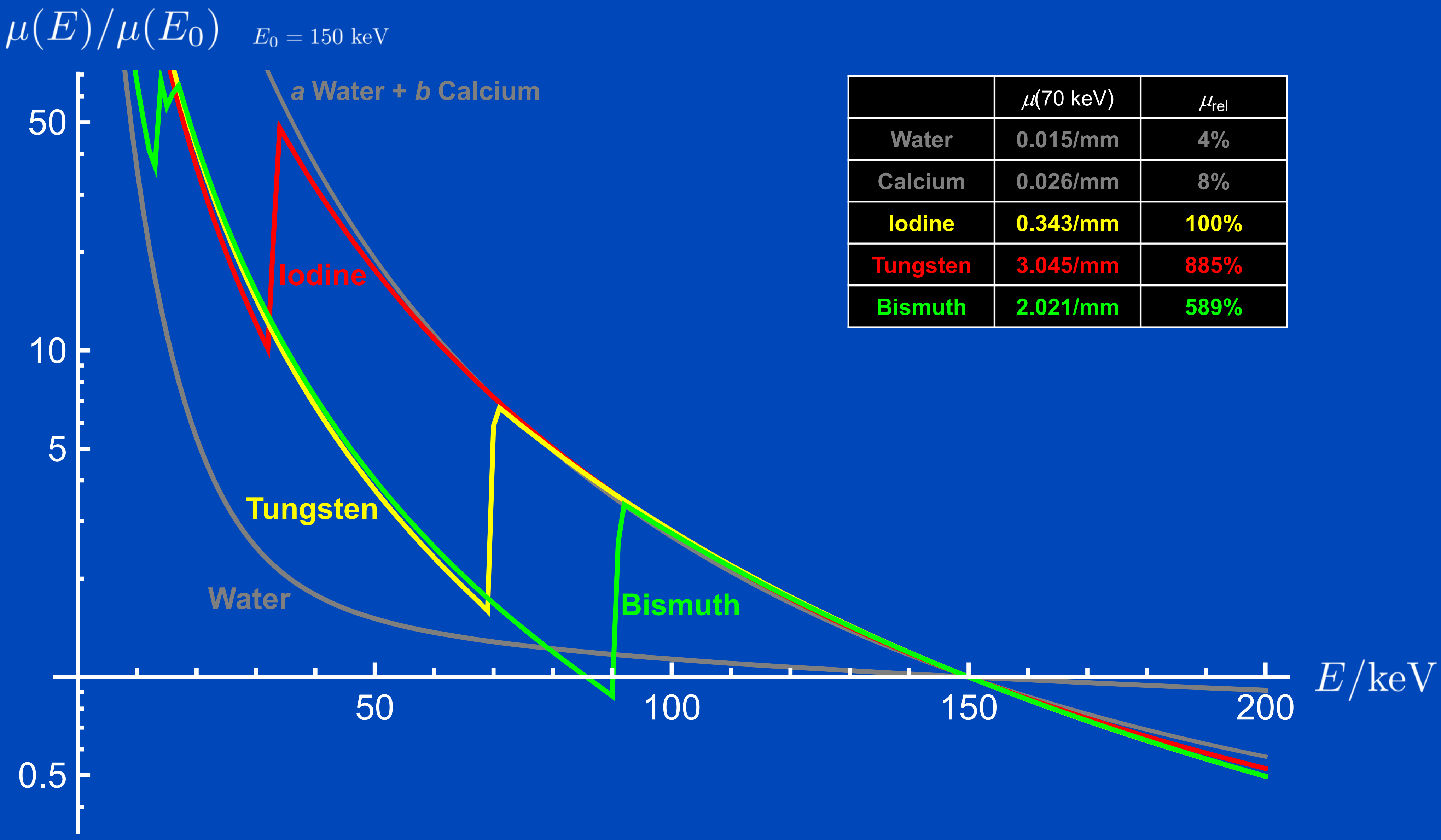
VMI's Iodine Contrast, Noise, CNR



70 and 150 kV simulations (solid) and patient measurements on Naeotom Alpha (dashed).

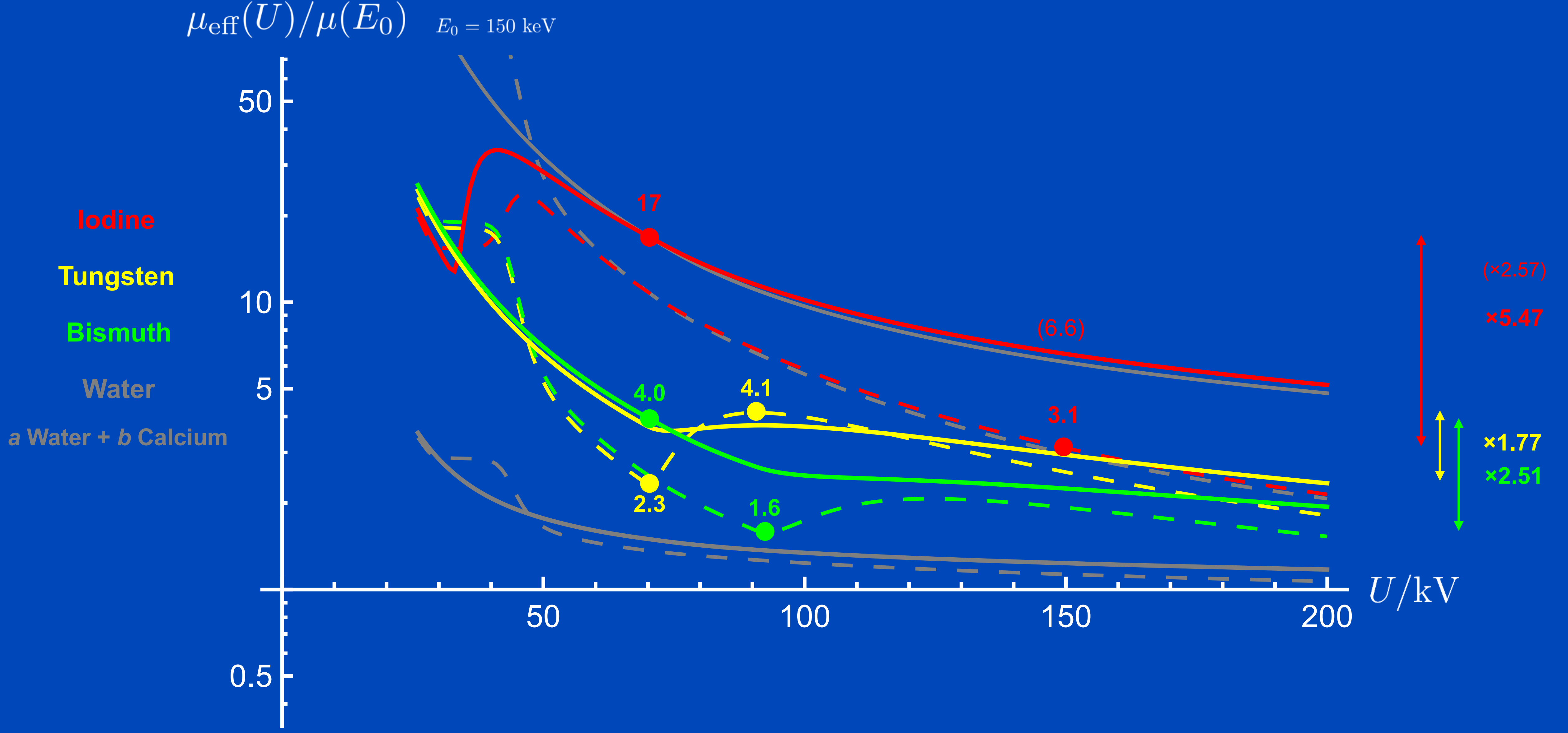
Shaken, not stirred

OTHER CONTRAST AGENTS?

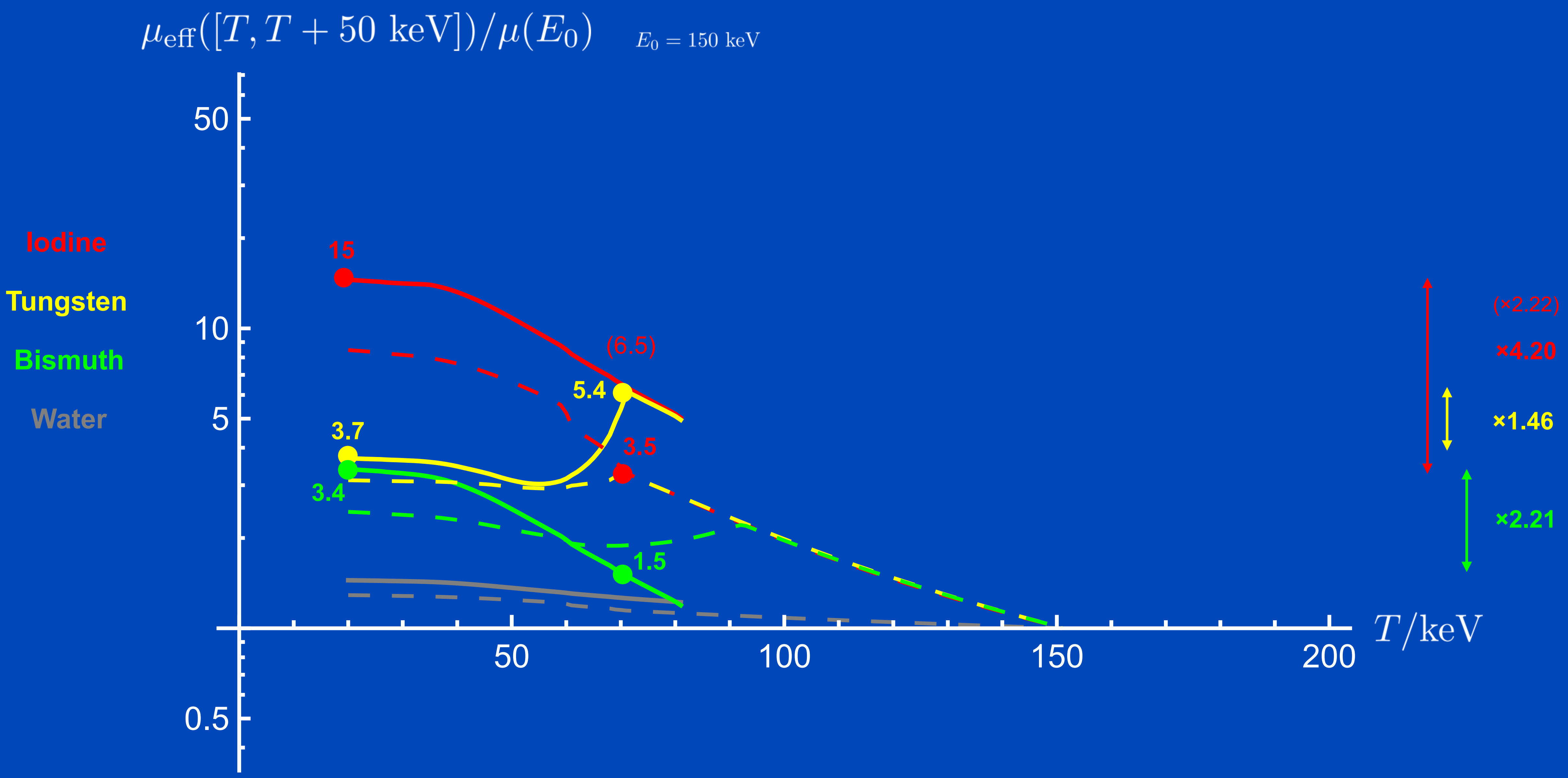


	μ(70 keV)	μ_{rel}
Water	0.015/mm	4%
Calcium	0.026/mm	8%
Iodine	0.343/mm	100%
Tungsten	3.045/mm	885%
Bismuth	2.021/mm	589%

Parameters *a* and *b* chosen such that the calcium-water mixtures is very similar to iodine.



Effective attenuation wrt 16 cm water layer and typical EI detector. Dashed curves are with 0.6 mm tin filter.



Effective attenuation wrt 16 cm water layer and typical PC detector. Solid: 80 kV. Dashed: 150 kV.

Summary

- Due to several effects PCCT is far more dose-efficient than EICT
  - The small pixel effect
  - The iodine effect
  - No electronic noise
  - VMI provides further contrast enhancement
- The increased dose efficiency yields better images or may be traded in for dose or contrast media reduction.
- 10% less contrast agent must be compensated by a 23% increase in x-ray exposure[1].
- Contrast agents other than iodine do not exist and may not make sense.

[1]Due to $1/0.9^2 = 1.23$.

dkfz.

Thank You!

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

Job opportunities through marc.kachelriess@dkfz.de or through DKFZ’s international PhD or Postdoctoral Fellowship programs.

Parts of the reconstruction software were provided by RayConStruct® GmbH, Nürnberg, Germany.