Types of DECT Acquisitions: Pros and Cons

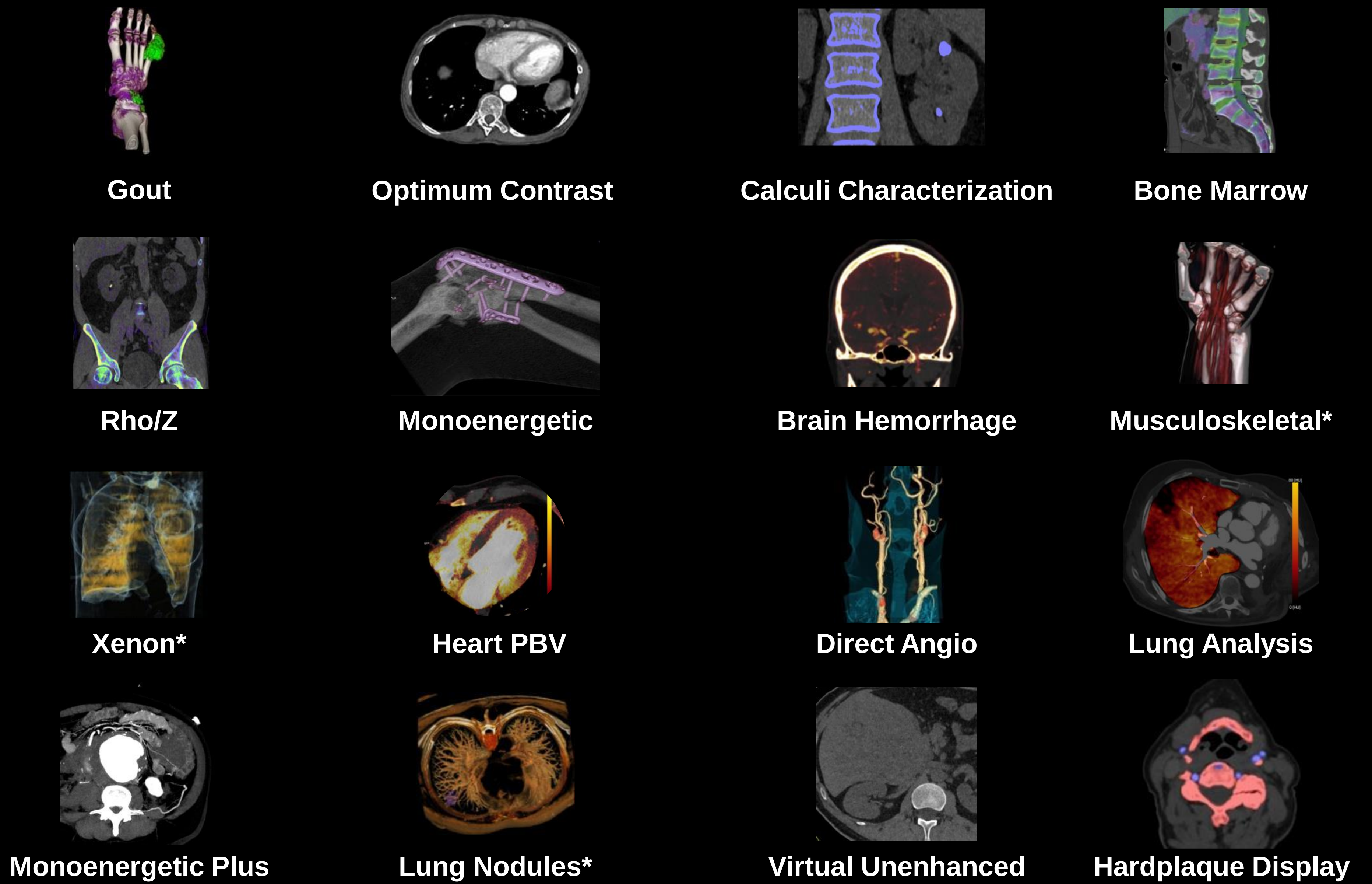
Marc Kachelrieß

German Cancer Research Center (DKFZ)

Heidelberg, Germany

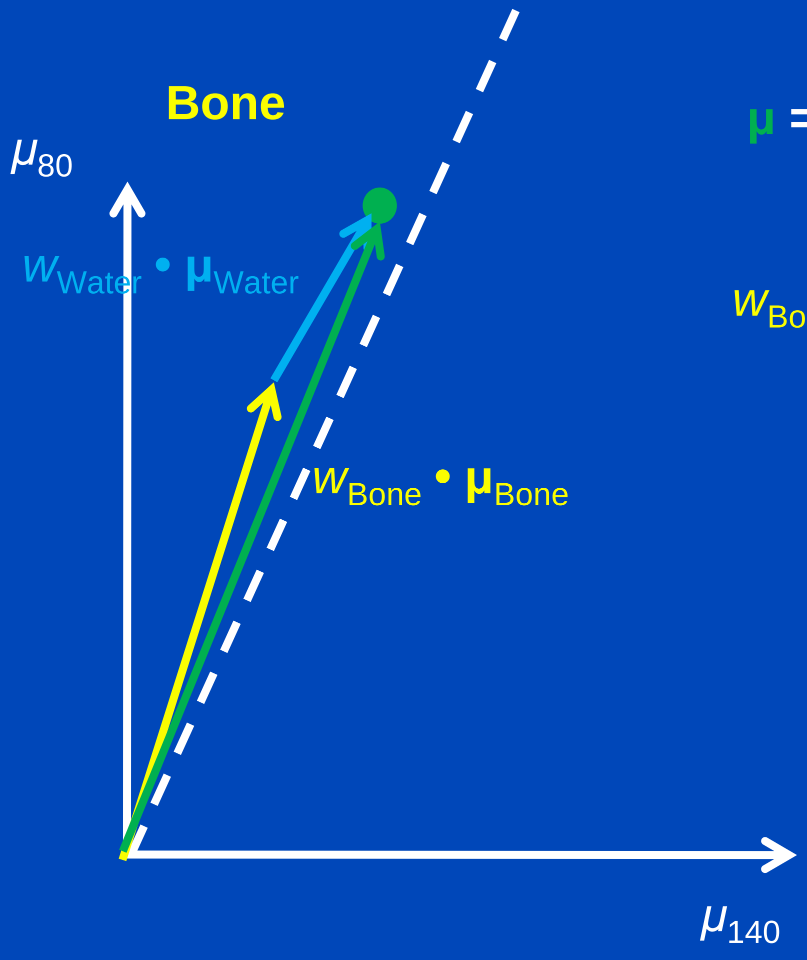
www.dkfz.de/ct

DEUTSCHES KREBSFORSCHUNGSZENTRUM IN DER HELMHOLTZ-GEMEINSCHAFT



Syngo.CT DECT application examples. Virtual unenhanced contains liver VNC, lung analysis contains lung PBV.
Courtesy of Siemens Healthineers, Forchheim, Germany

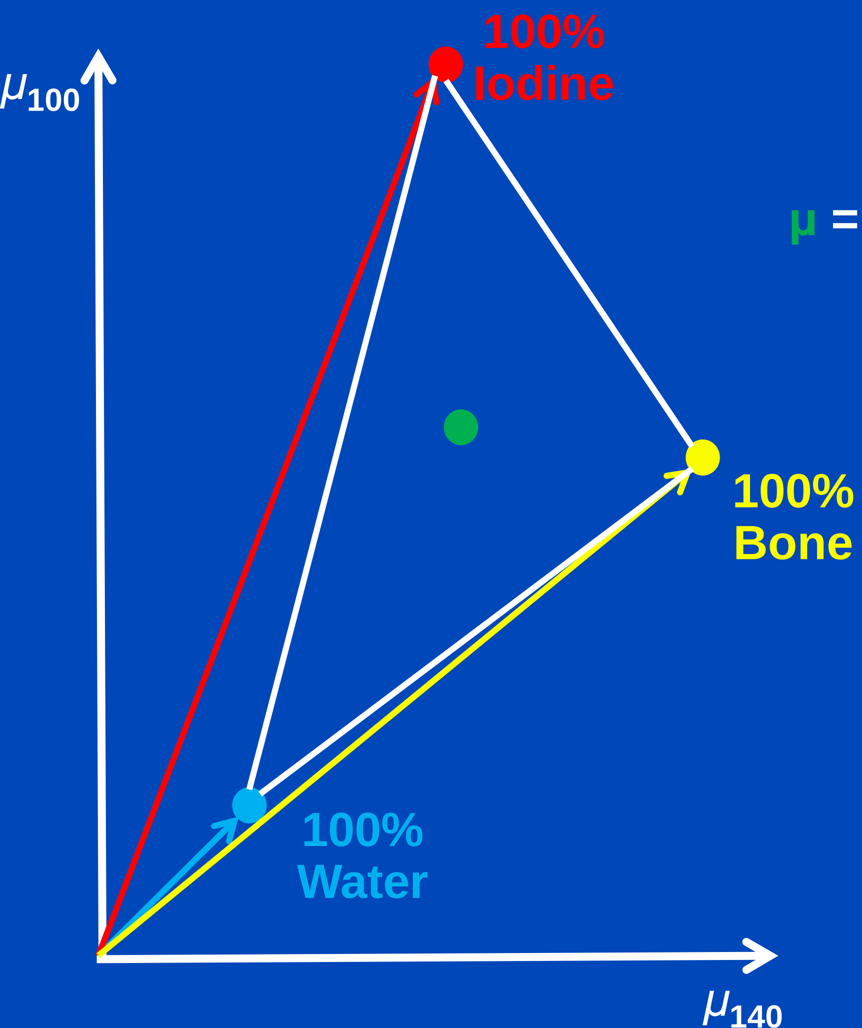
Image-Based Decomposition (2 Materials)



$\mu = w_{Water} \cdot \mu_{Water} + w_{Bone} \cdot \mu_{Bone}$

w_{Bone}, w_{Water}: **water and bone fractions**

Image-Based Decomposition (3 Materials – Requires Assumption)



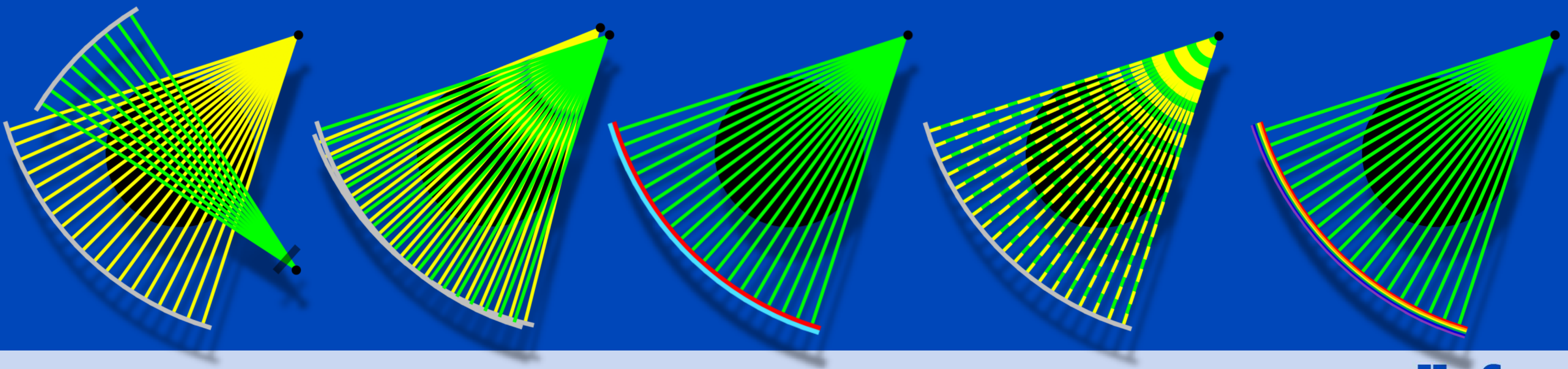
$$\mu = w_{Water} \cdot \mu_{Water} + w_{Bone} \cdot \mu_{Bone} + w_{Iodine} \cdot \mu_{Iodine}$$

$$w_{Water} + w_{Bone} + w_{Iodine} = 1$$

$$w_{Water}, w_{Bone}, w_{Iodine} \geq 0$$

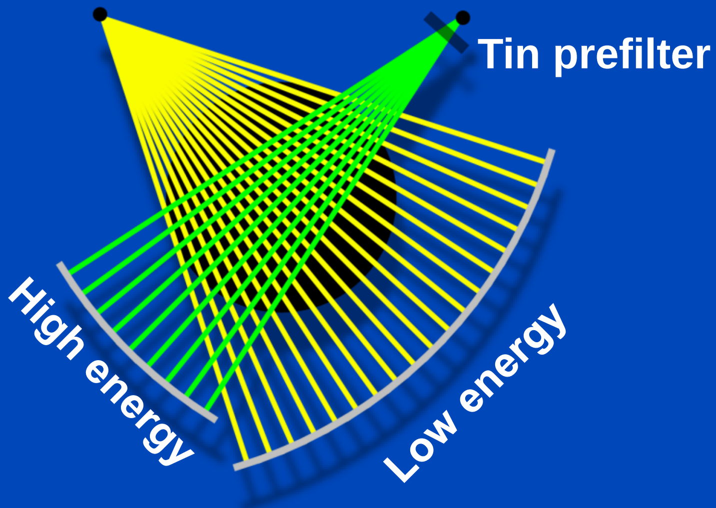
DECT Technology

- 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
  - Photon-counting CT — high-end



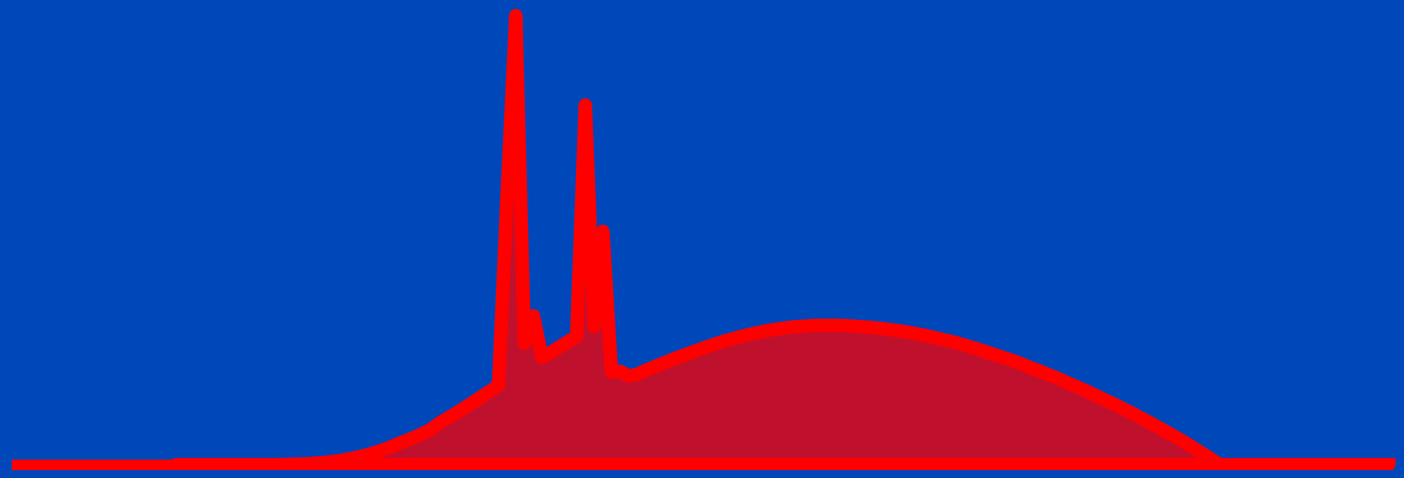
DECT Technology

- DECT approaches in the clinic:
  - Dual source DECT (Siemens)



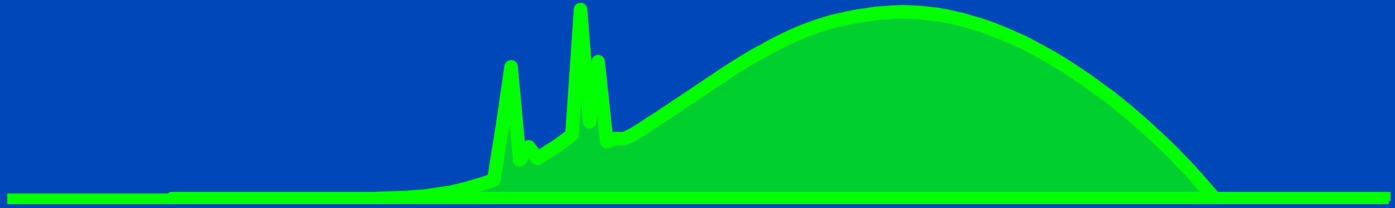
Siemens Somatom Force

Effect of the Prefilter: Without Sn



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

Effect of the Prefilter: With 0.4 mm Sn



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

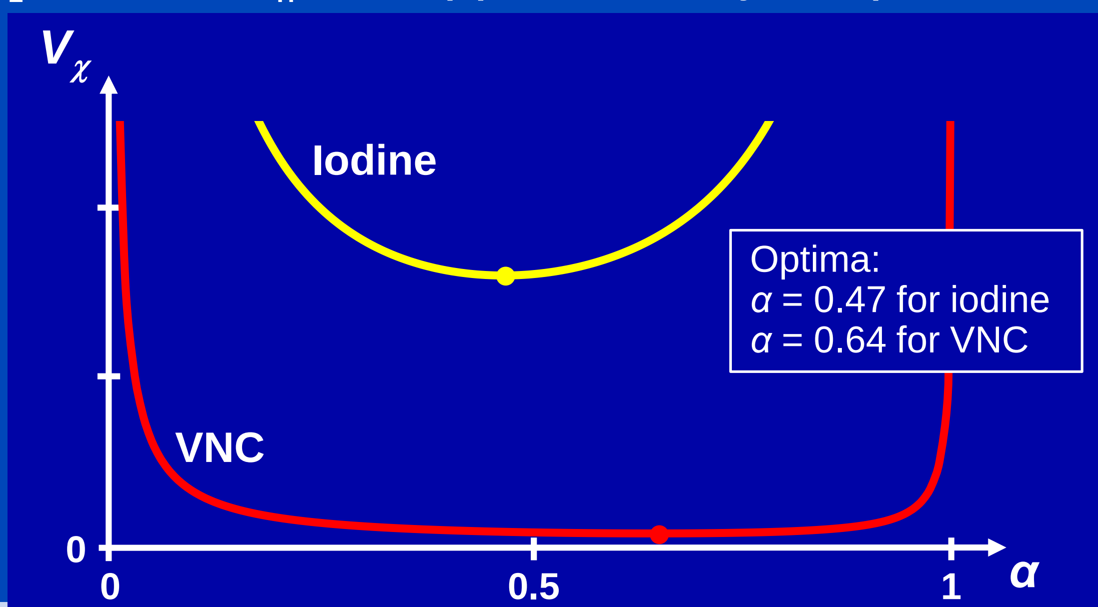
Optimal Dose Distribution

- A linear combination of a low and a high energy image yields

$$V_\chi = w_{\mathrm{L}}^2 V_{\mathrm{L}} + w_{\mathrm{H}}^2 V_{\mathrm{H}} = w_{\mathrm{L}}^2 \frac{k_{\mathrm{L}}}{D_{\mathrm{L}}} + w_{\mathrm{H}}^2 \frac{k_{\mathrm{H}}}{D_{\mathrm{H}}} = w_{\mathrm{L}}^2 \frac{k_{\mathrm{L}}}{(1-\alpha) D_{\mathrm{T}}} + w_{\mathrm{H}}^2 \frac{k_{\mathrm{H}}}{\alpha\, D_{\mathrm{T}}}$$

  with *k* relating the variances *V* to doses *D*, with $D_T = D_L + D_H$, and with α being the relative dose of the high energy image.

- For the Flash dual source 100 kV / Sn 140 kV we have
  - w_L = -0.943509 and w_H = 1.943850 for χ = VNC
  - w_L = 6.468680 and w_H = -6.466740 for χ = Iodine
  - k_L = 1.087 and k_H = 0.826 (up to an arbitrary factor)



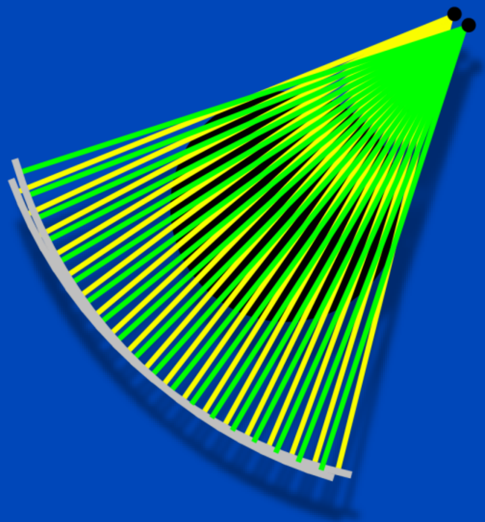
	H_2O	I
Low	1	1+a
High	1	1+b
VNC	1	1

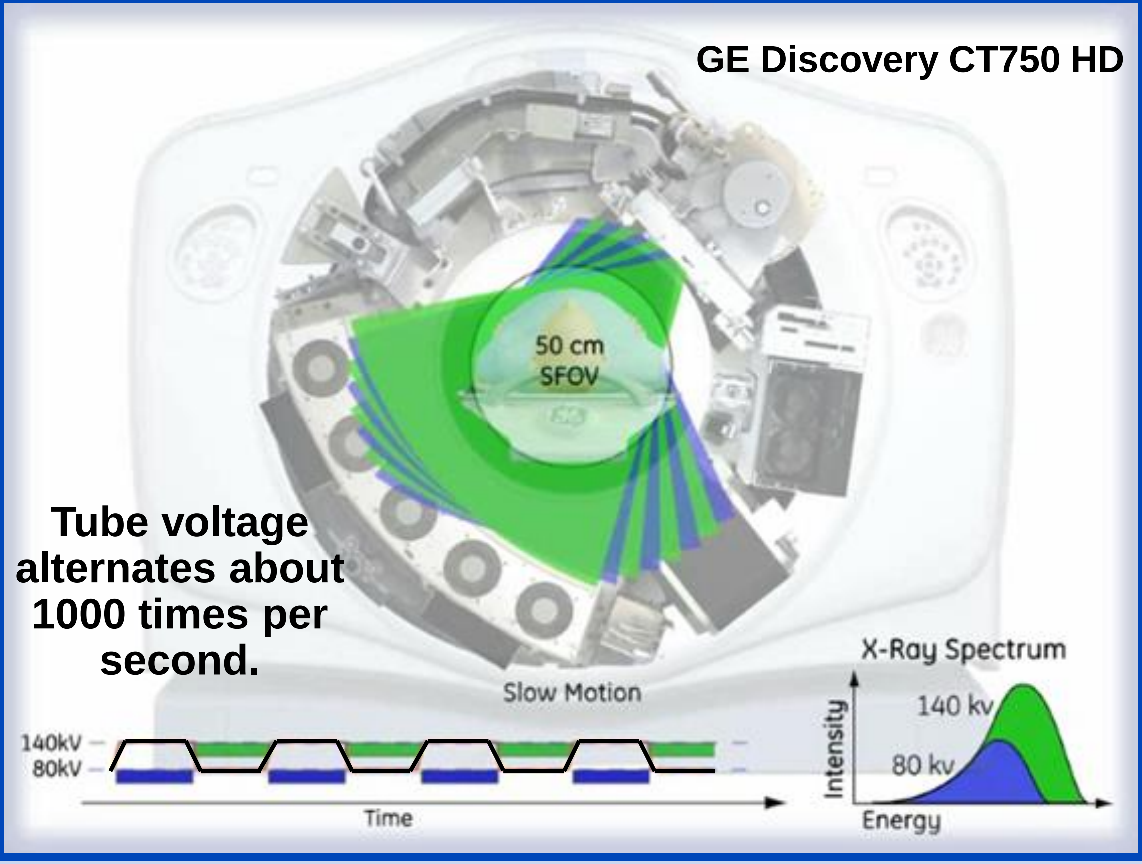
	H_2O	I
Low	1	1+a
High	1	1+b
Iodine	0	(a+b)/2

Here, dose and α refer to the energy absorbed in the patient, and not to mAs or CTDI.

DECT Technology

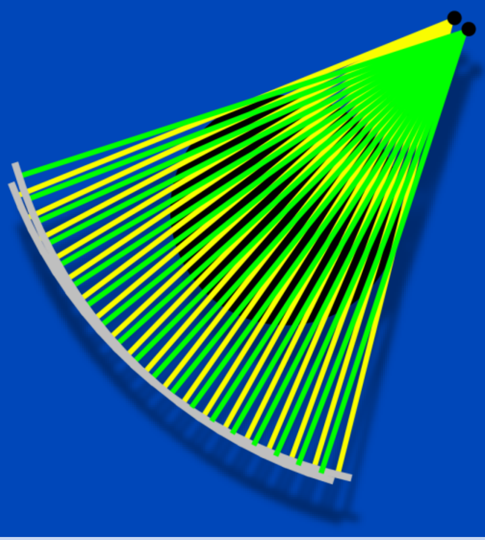
- DECT approaches in the clinic:
  - Dual source DECT (Siemens)
  - Fast tube voltage switching (Canon, GE)

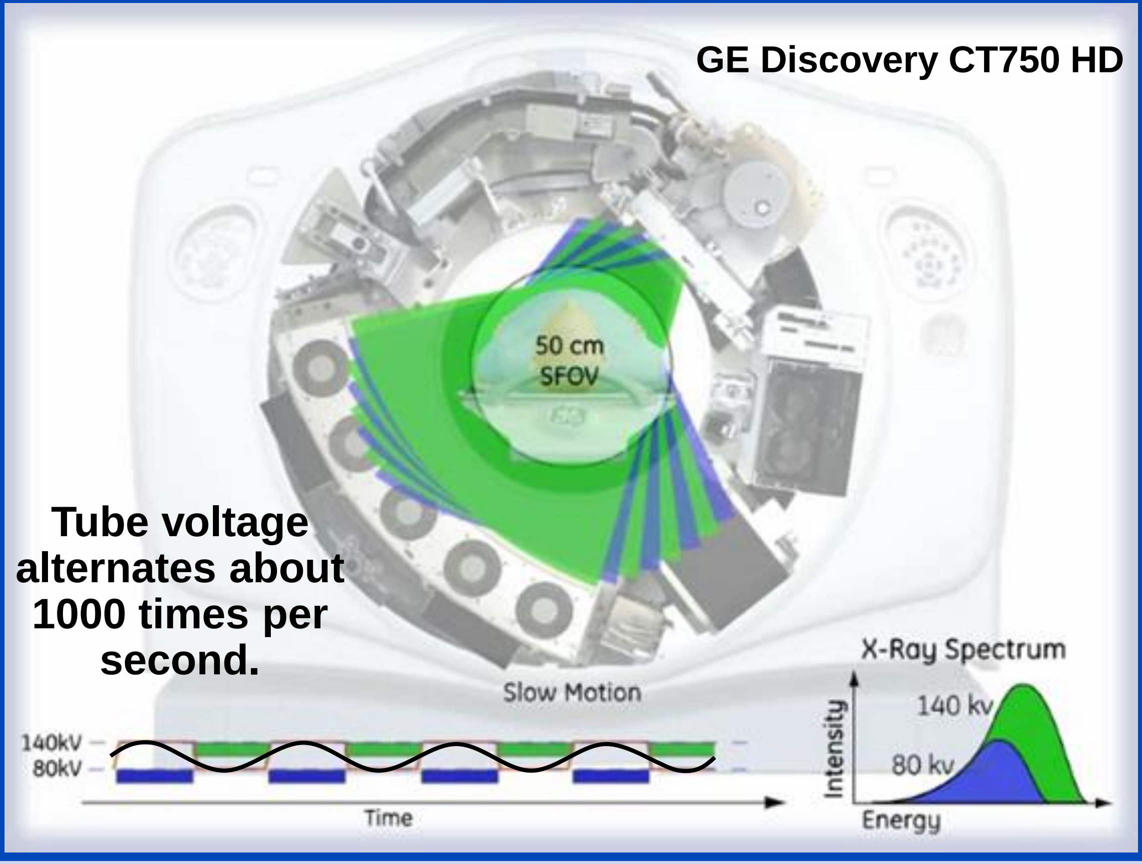




DECT Technology

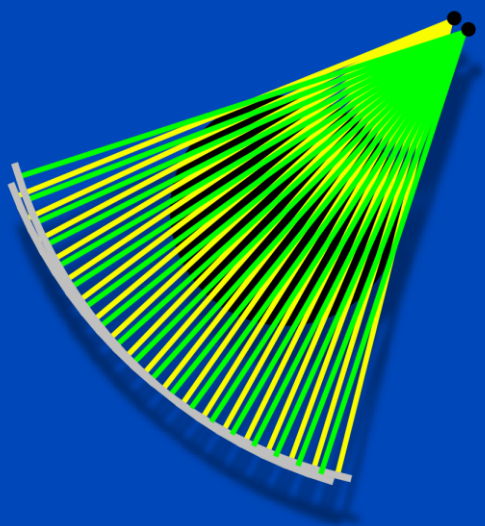
- DECT approaches in the clinic:
  - Dual source DECT (Siemens)
  - Fast tube voltage switching (Canon, GE)

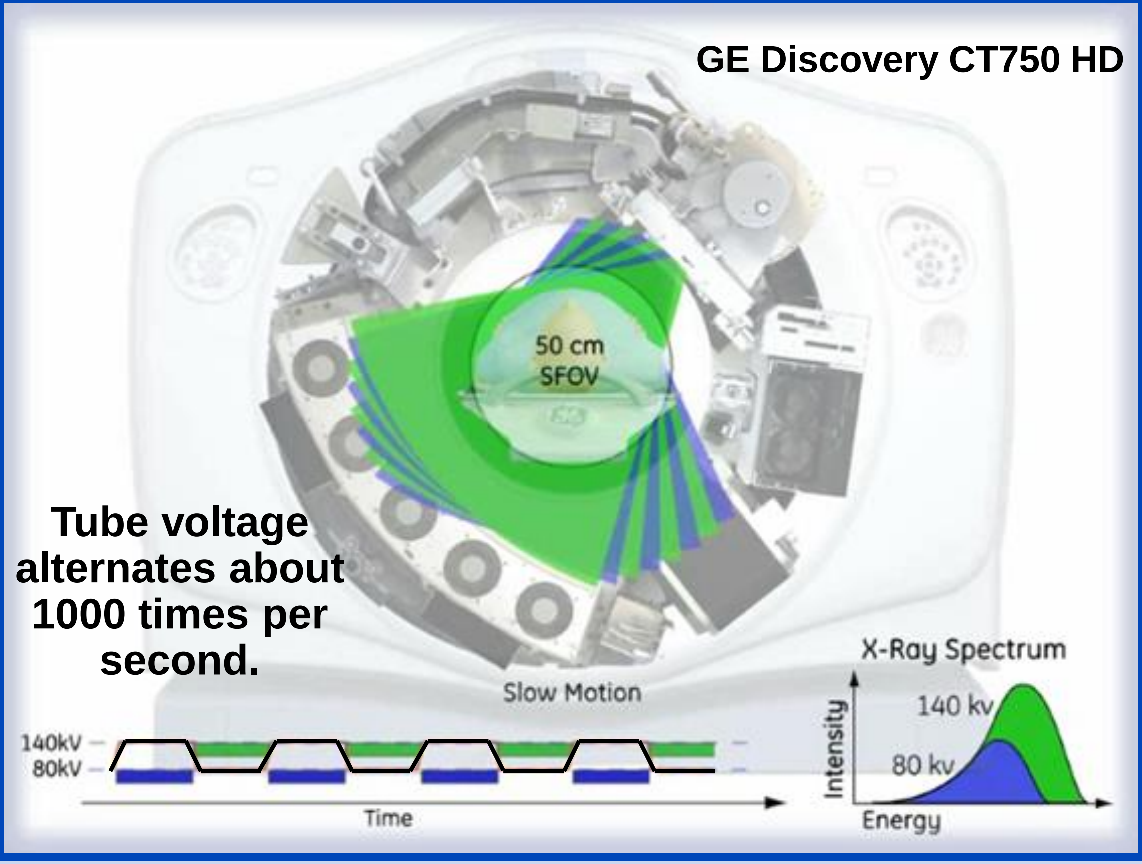




DECT Technology

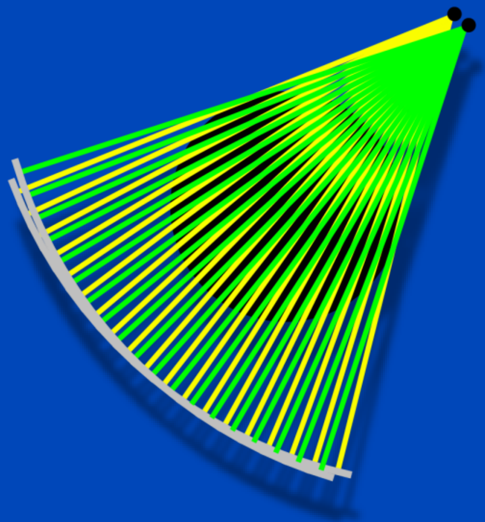
- DECT approaches in the clinic:
  - Dual source DECT (Siemens)
  - Fast tube voltage switching (Canon, GE)

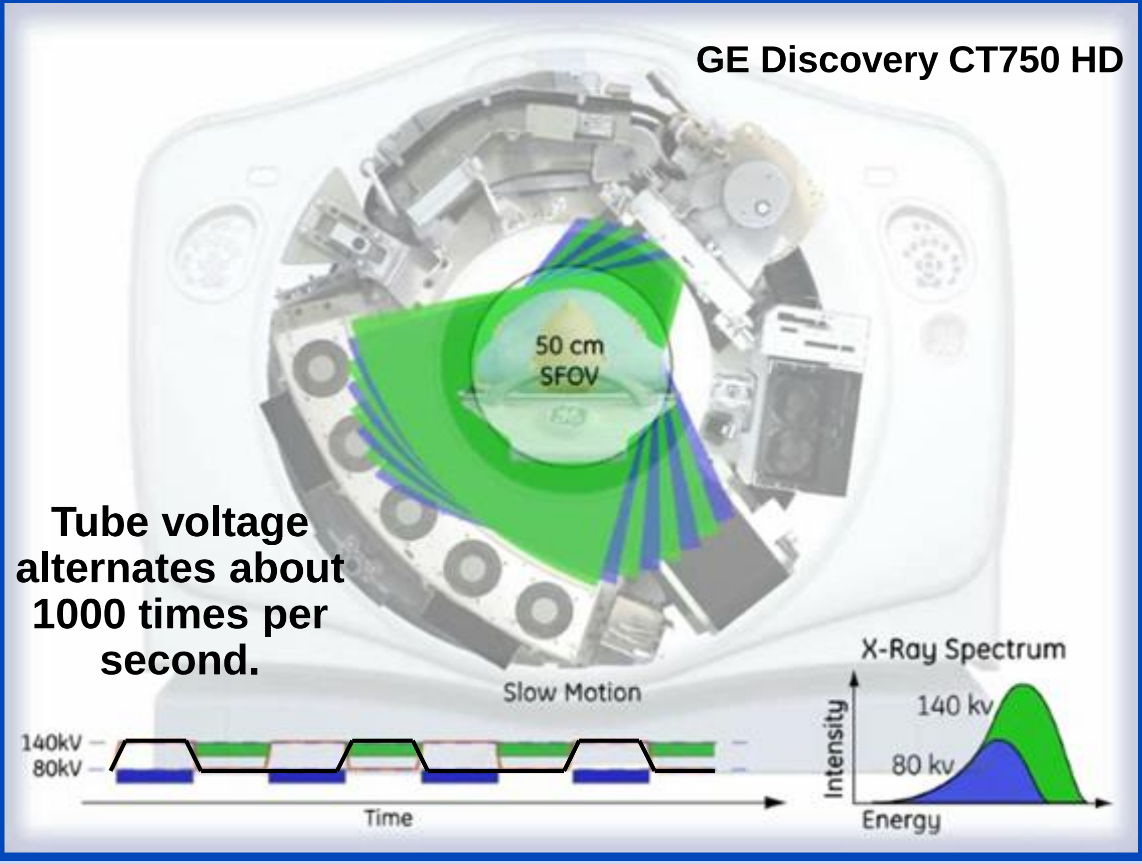




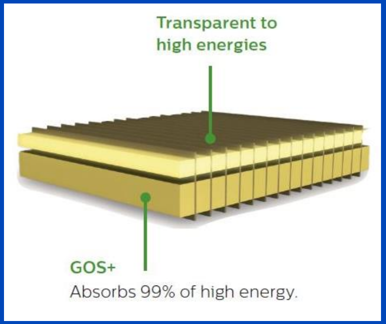
DECT Technology

- DECT approaches in the clinic:
  - Dual source DECT (Siemens)
  - Fast tube voltage switching (Canon, GE)



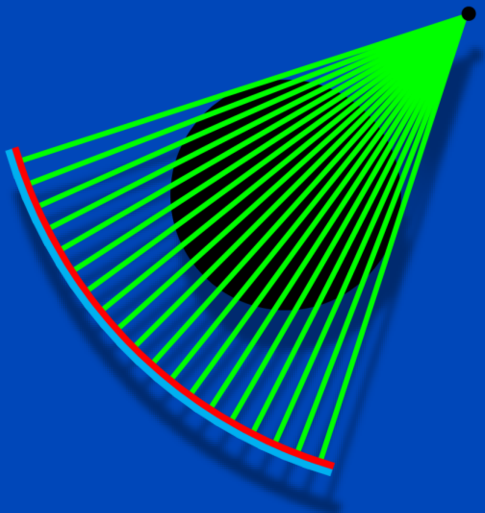


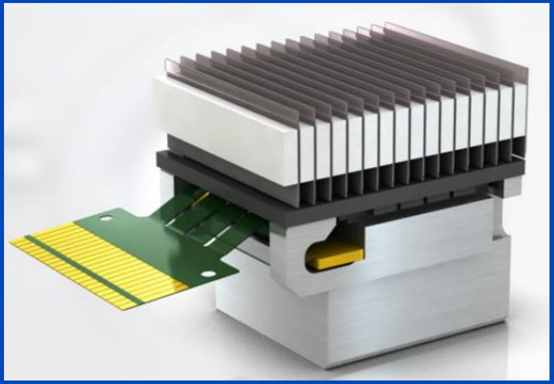
DECT Technology

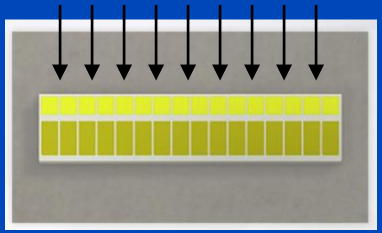


- **DECT approaches in the clinic:**
  - Dual source DECT (Siemens)
  - Fast tube voltage switching (Canon, GE)
  - Dual layer (sandwich) detector (Philips)

Philips IQon



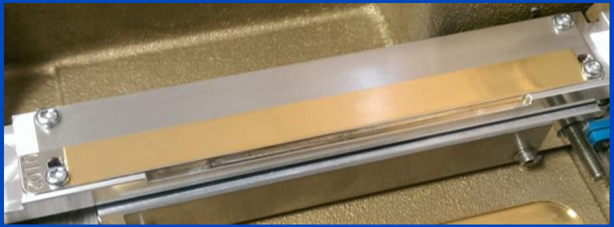




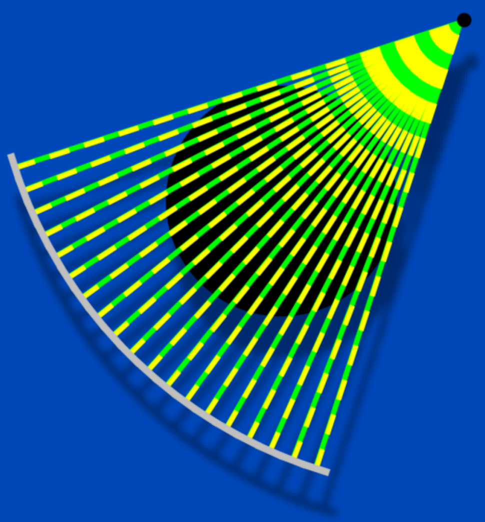
Top layer acts as a prefilter
for the bottom layer.

Siemens X.Cite: 0.7 mm Sn (29 keV) and 0.07 mm Au (81 keV)

DECT Technology



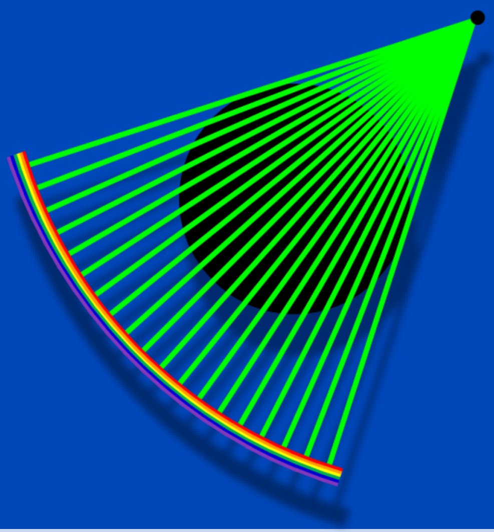
- DECT approaches in the clinic:
  - Dual source DECT (Siemens)
  - Fast tube voltage switching (Canon, GE)
  - Dual layer (sandwich) detector (Philips)
  - Split filter (Siemens)



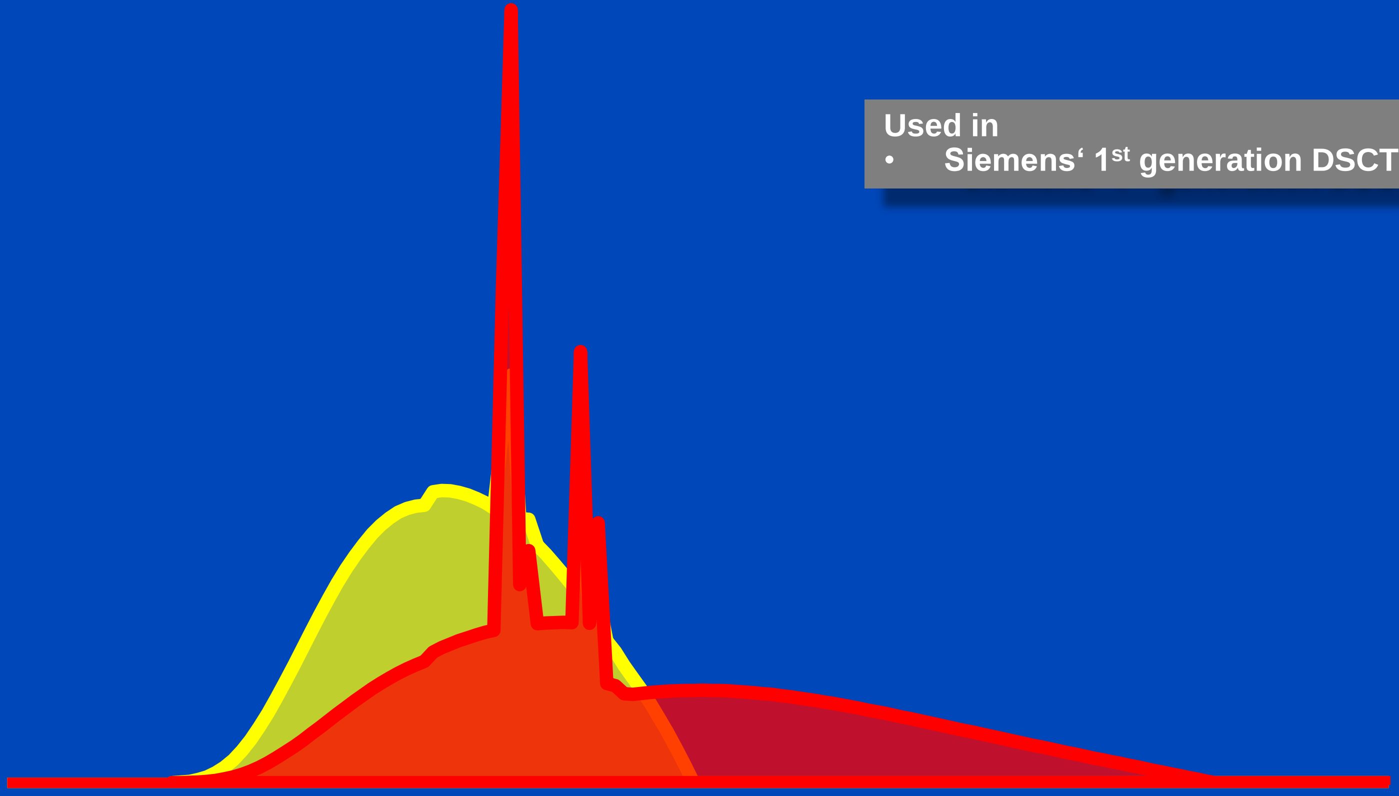
Siemens Definition Edge TwinBeam

DECT Technology

- DECT approaches in the clinic:
  - Dual source DECT (Siemens)
  - Fast tube voltage switching (Canon, GE)
  - Dual layer (sandwich) detector (Philips)
  - Split filter (Siemens)
  - Photon counting detector, multiple energy bins



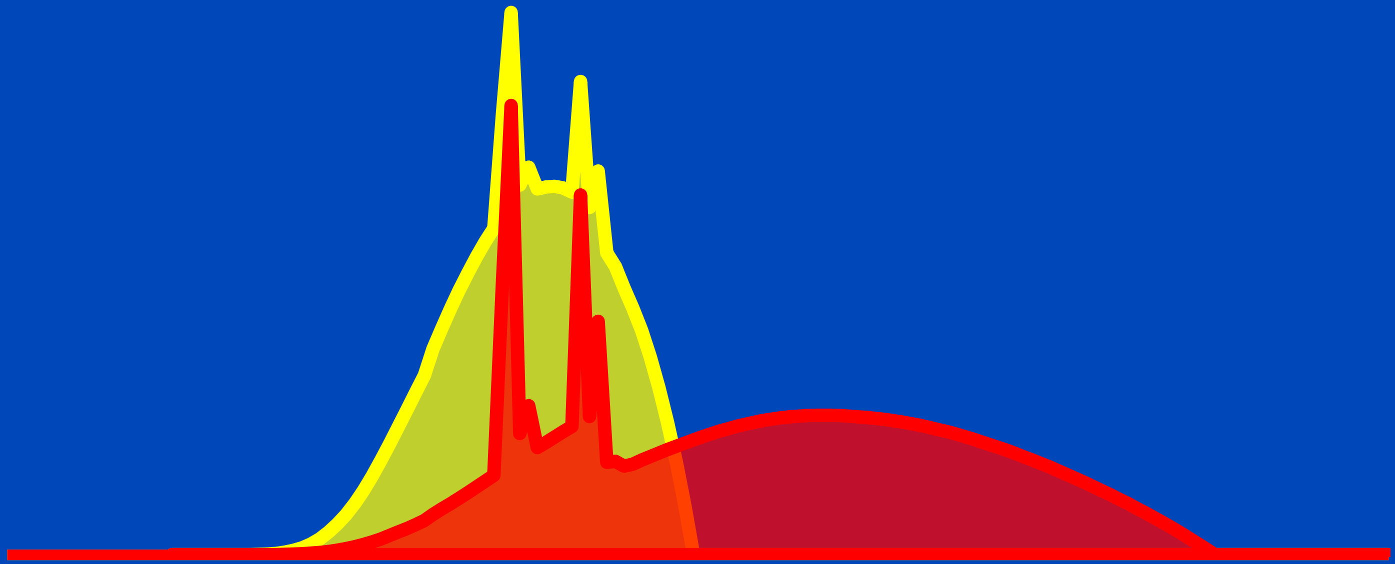
80 kV / 140 kV



Used in
- Siemens‘ 1st generation DSCT

80 kV / 140 kV

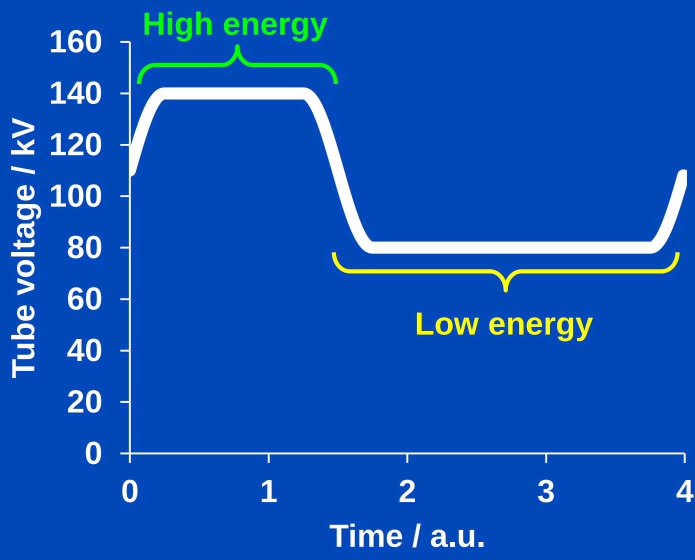
Used in
- Siemens‘ 1st generation DSCT



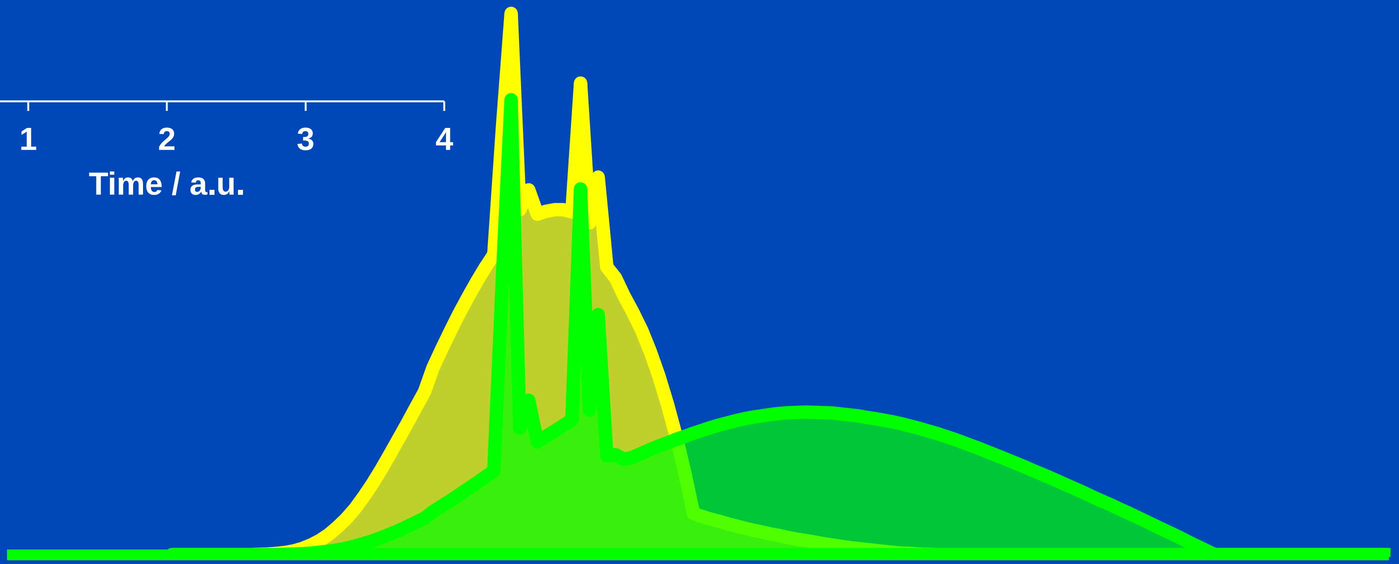
Spectra as seen after having passed a 32 cm water layer.

dkfz.

80 kV / 140 kV Sinrect kV-Switching



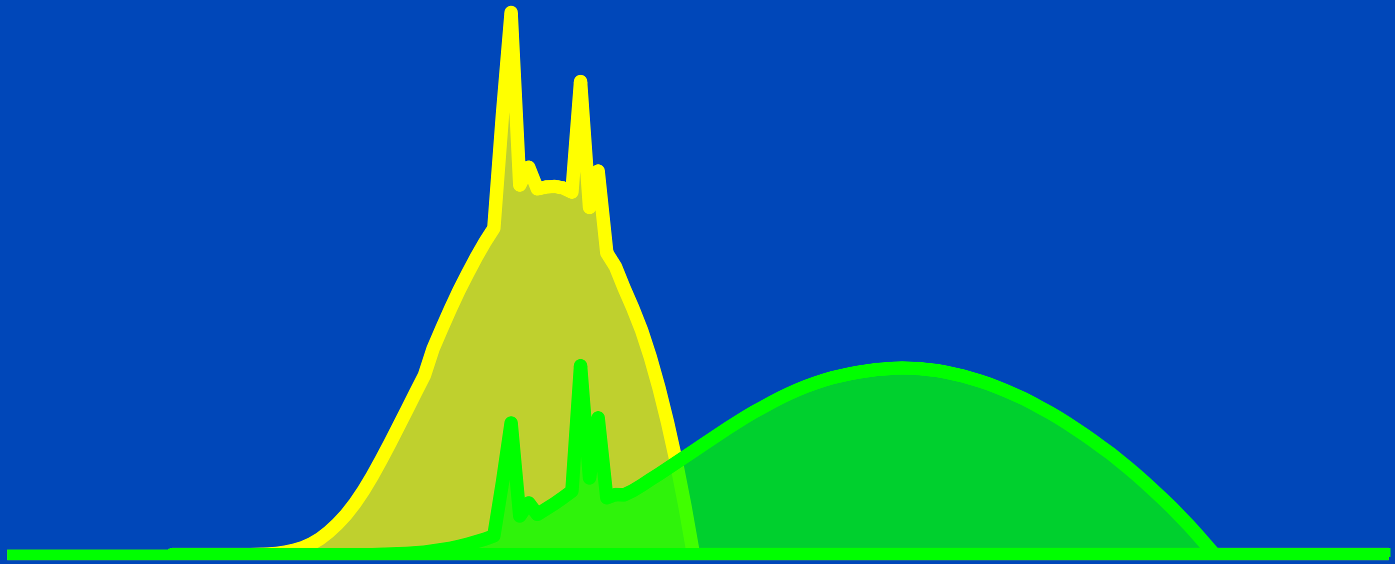
Used in
- GE‘s fast tube voltage switching CT



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

80 kV / 140 kV $Sn_{0.4\ mm}$

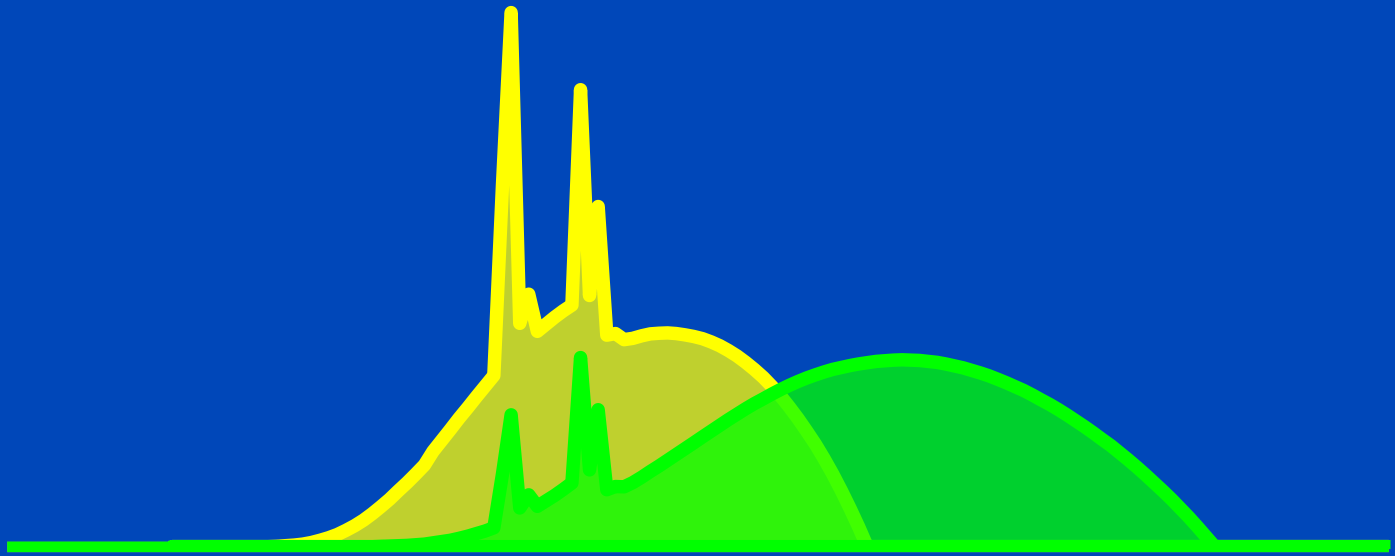
Used in
- Siemens‘ 2nd generation DSCT



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

100 kV / 140 kV $Sn_{0.4\ mm}$

Used in
- Siemens‘ 2nd generation DSCT



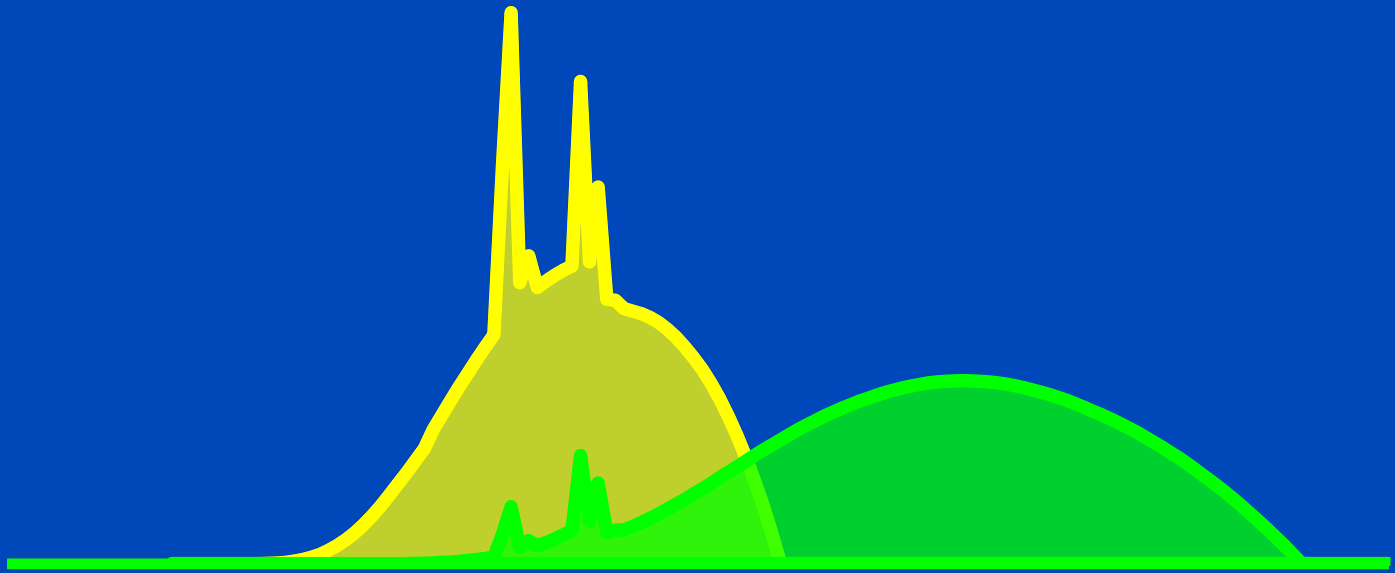
Spectra as seen after having passed a 32 cm water layer.

dkfz.

90 kV / 150 kV $Sn_{0.6\ mm}$

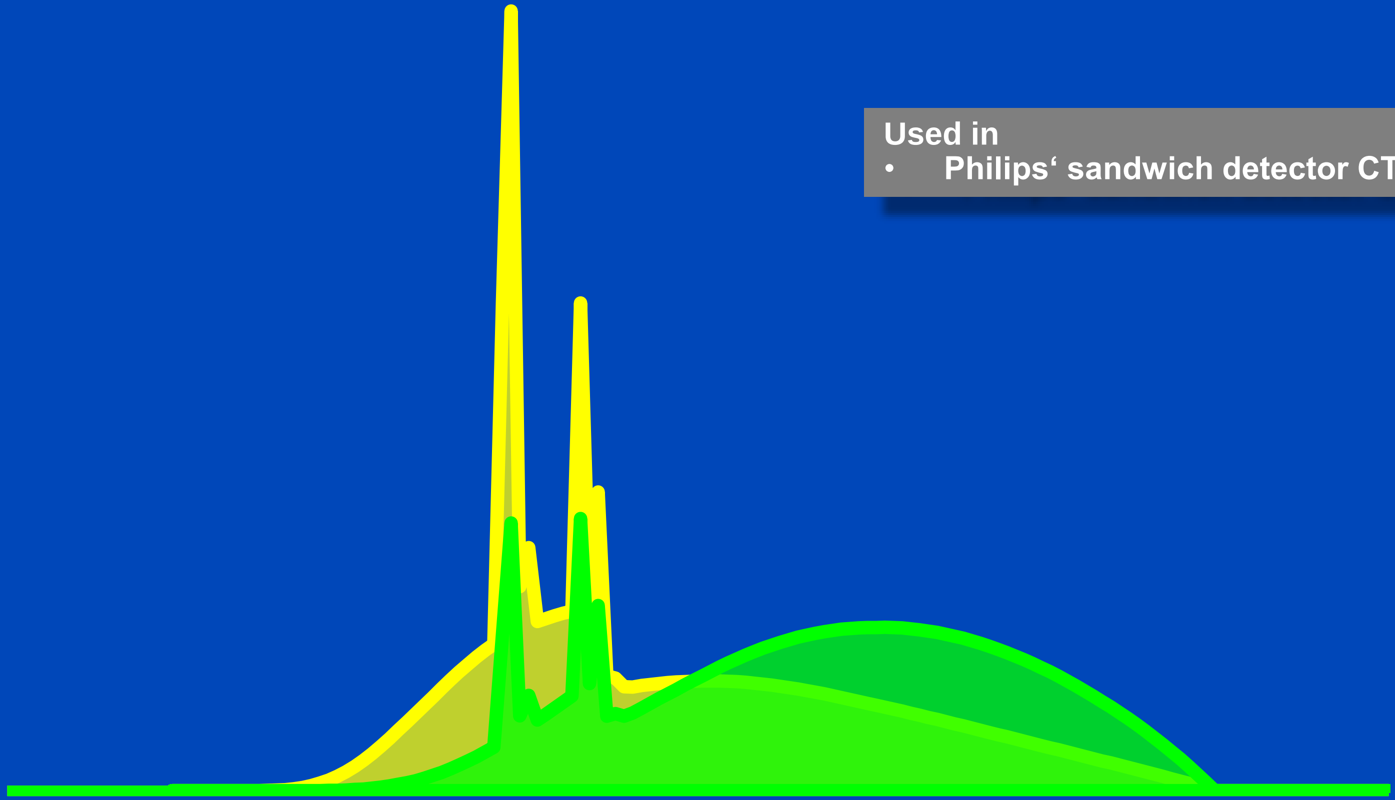
Used in

- **Siemens' 3rd generation DSCT**



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

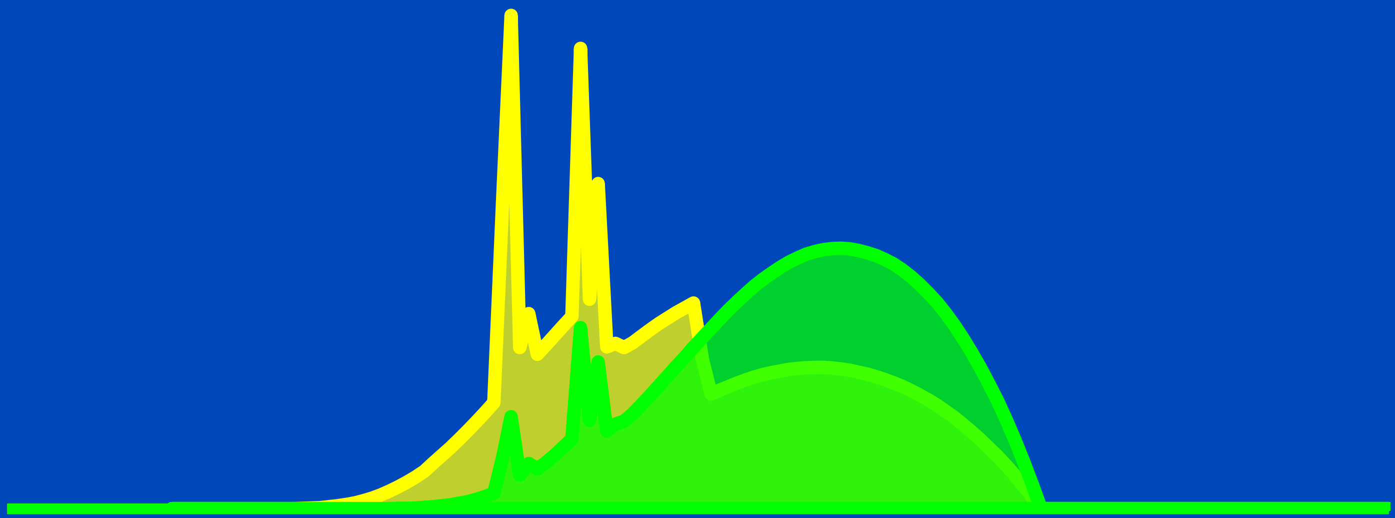
140 kV YAG / GOS



Used in
- Philips‘ sandwich detector CT

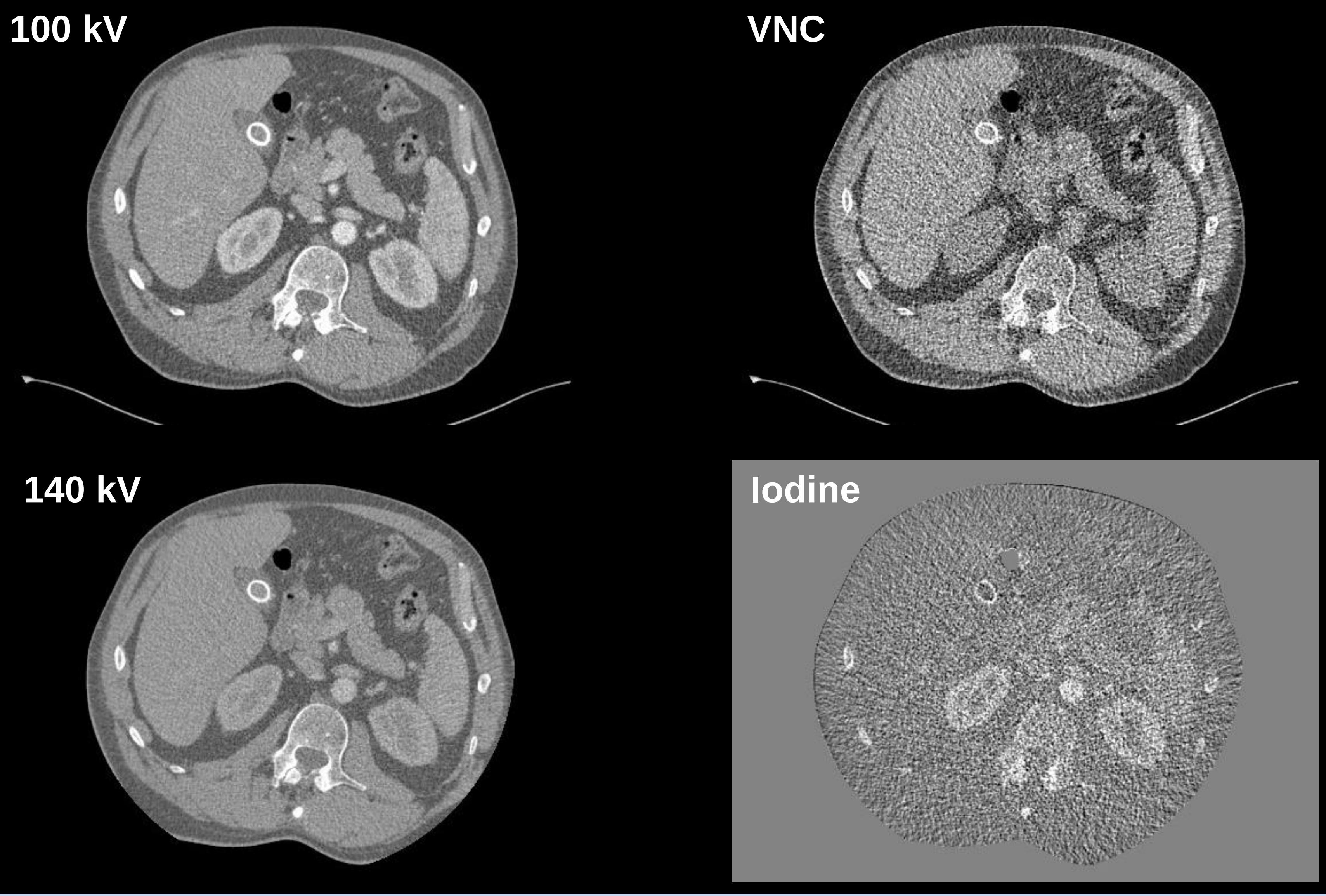
Split filter 120 kV (Au+Sn)

Used in
- Siemens‘ split filter DSCT



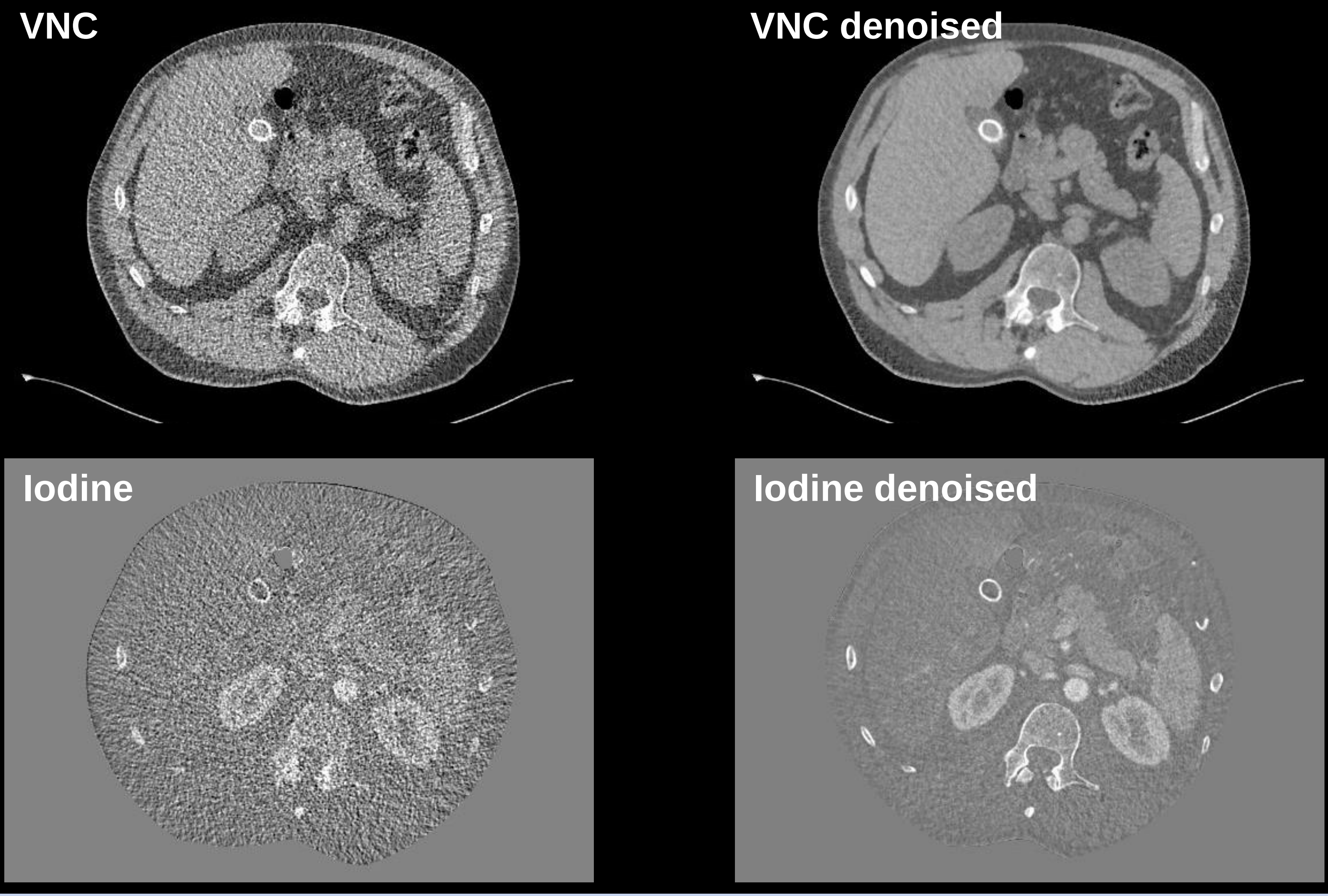
Spectra as seen after having passed a 32 cm water layer.

Decomposition Increases Noise



C = 0 HU, W = 700 HU

Denoising is Mandatory!



Simple Denoising Example

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

- **Denoised images:**

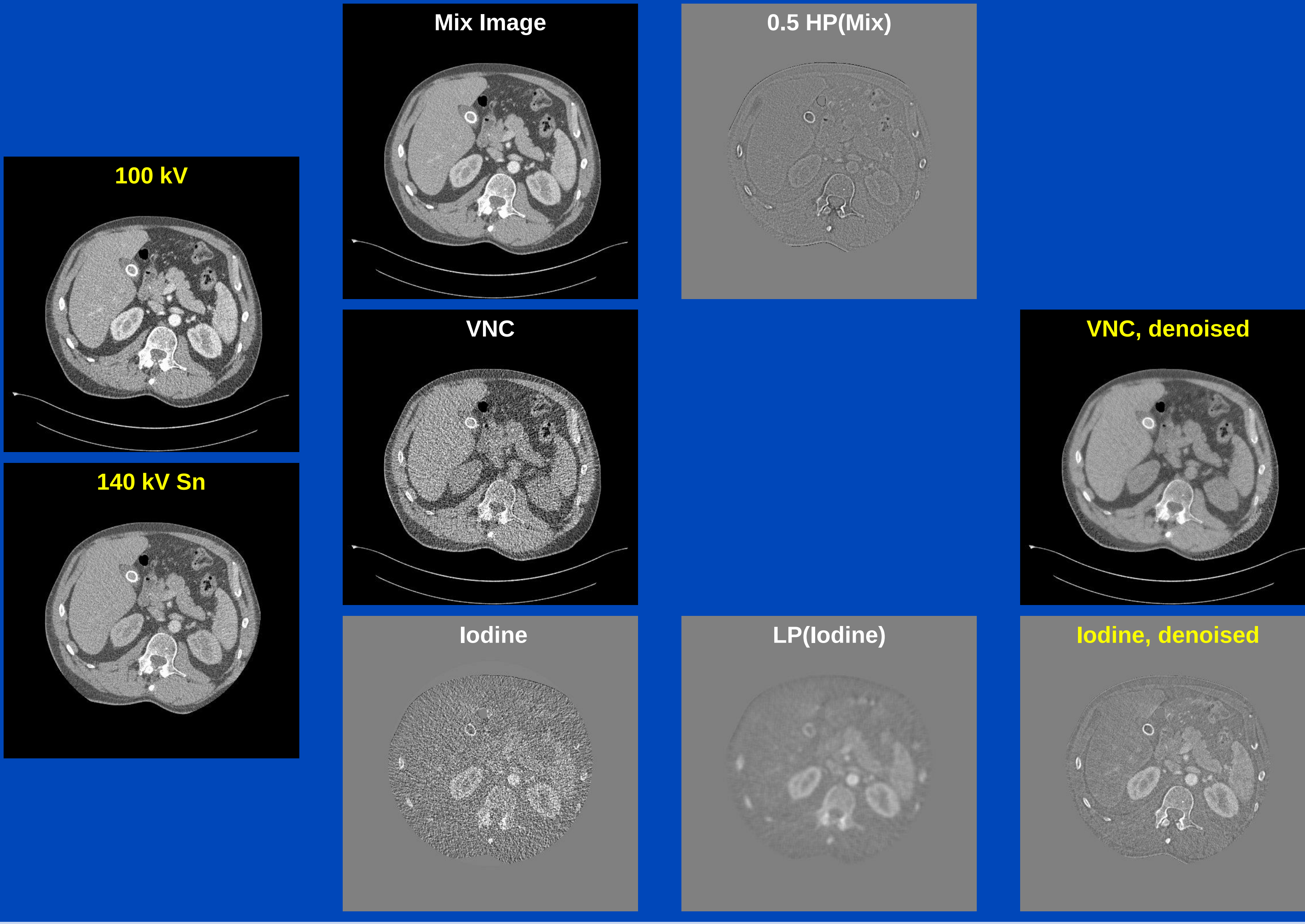
$$\hat{f}_\mathrm{I} = \mathrm{LP}(f_\mathrm{I}) + 0.5\,\mathrm{HP}(f_\alpha)$$

$$\hat{f}_\mathrm{W} = f_\alpha - \hat{f}_\mathrm{I}$$

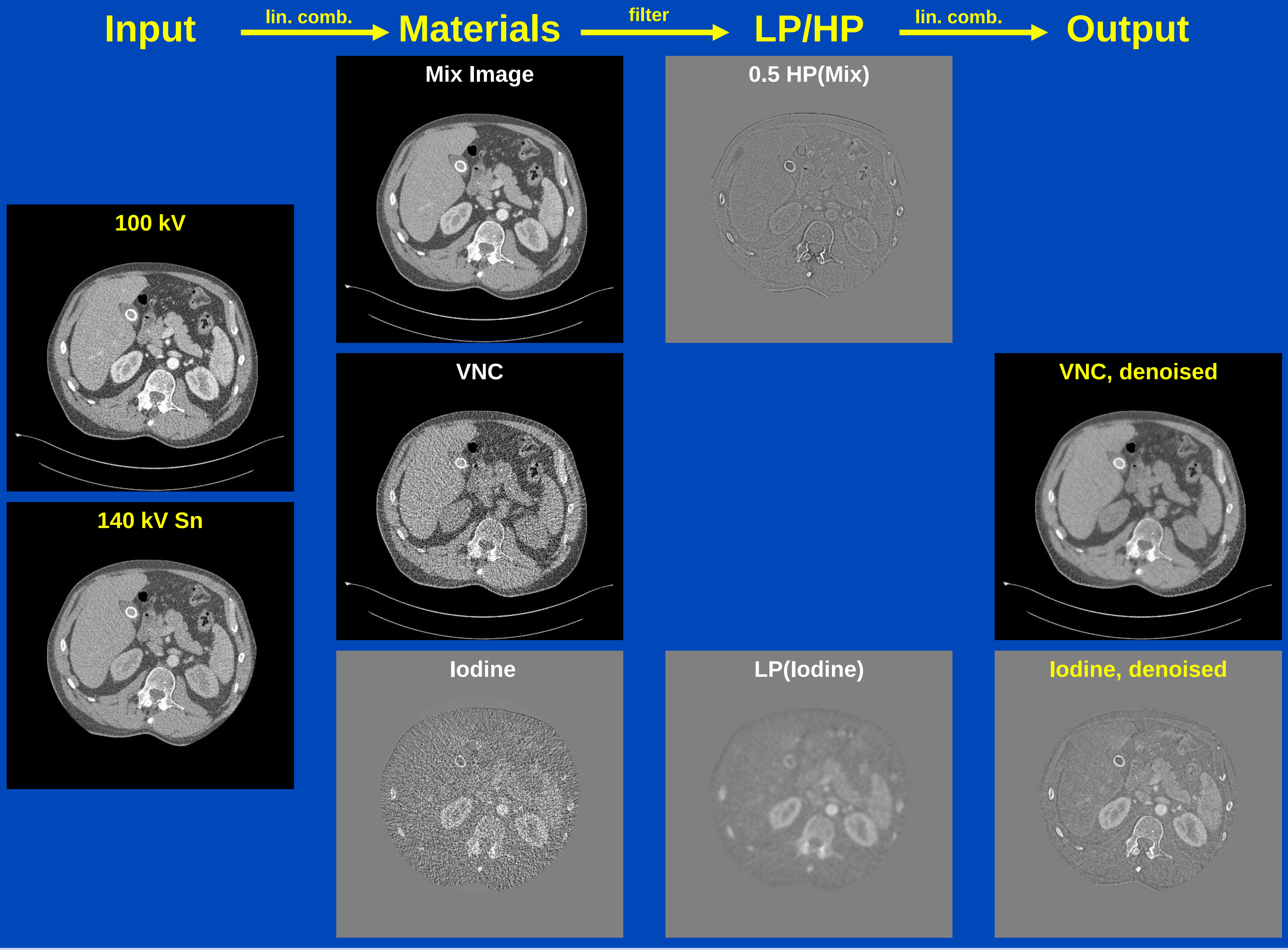
  - **Low pass LP = (1 2 2 2 2 2 1) / 12, for example (pixel size dependent)**
  - **High pass HP = 1- LP**

*Macovski et al. "Measurement-Dependent Filtering: A Novel Approach to Improved SNR" IEEE TMI MI-2(3): 122-127, 1983

dkfz.



C = 0 HU, *W* = 500 HU for the low, high and VNC images. *C* = 0 mg/mL, *W* = 27.6 mg/mL for the iodine images.



C = 0 HU, *W* = 500 HU for the low, high and VNC images. *C* = 0 mg/mL, *W* = 27.6 mg/mL for the iodine images.

Why is Subtraction Potentially Better?

(in case of no motion)

- W = soft tissue (water) signal, X = iodine signal
- Assume same noise N, e.g. 50 HU, in both measurements M_1 and M_2
  - Var M_1 = Var M_2 = N^2 regardless of whether iodine is present or not
- DECT
  - Measurement 1 (high kV): $M_1 = W + 0.25\,X$
  - Measurement 2 (low kV): $M_2 = W + 0.5\,X$
  - Estimated iodine: $4\,(M_2 - M_1)$ Variance = 16 (Var M_2 + Var M_1) = 32 N^2
  - Estimated soft tissue: $2\,M_1 - M_2$ Variance = 4 Var M_1 + Var M_2 = 5 N^2
- **Subtraction**
  - Measurement 1 (native): $M_1 = W$
  - Measurement 2 (enhanced): $M_2 = W + 0.5\,X$
  - Estimated iodine: $2\,(M_2 - M_1)$ Variance = 4 (Var M_2 + Var M_1) = 8 N^2
  - Estimated soft tissue: M_1 Variance = Var M_1 = N^2

**VNC and iodine noise (standard deviation)
in DECT is about twice as high as in subtraction imaging.**

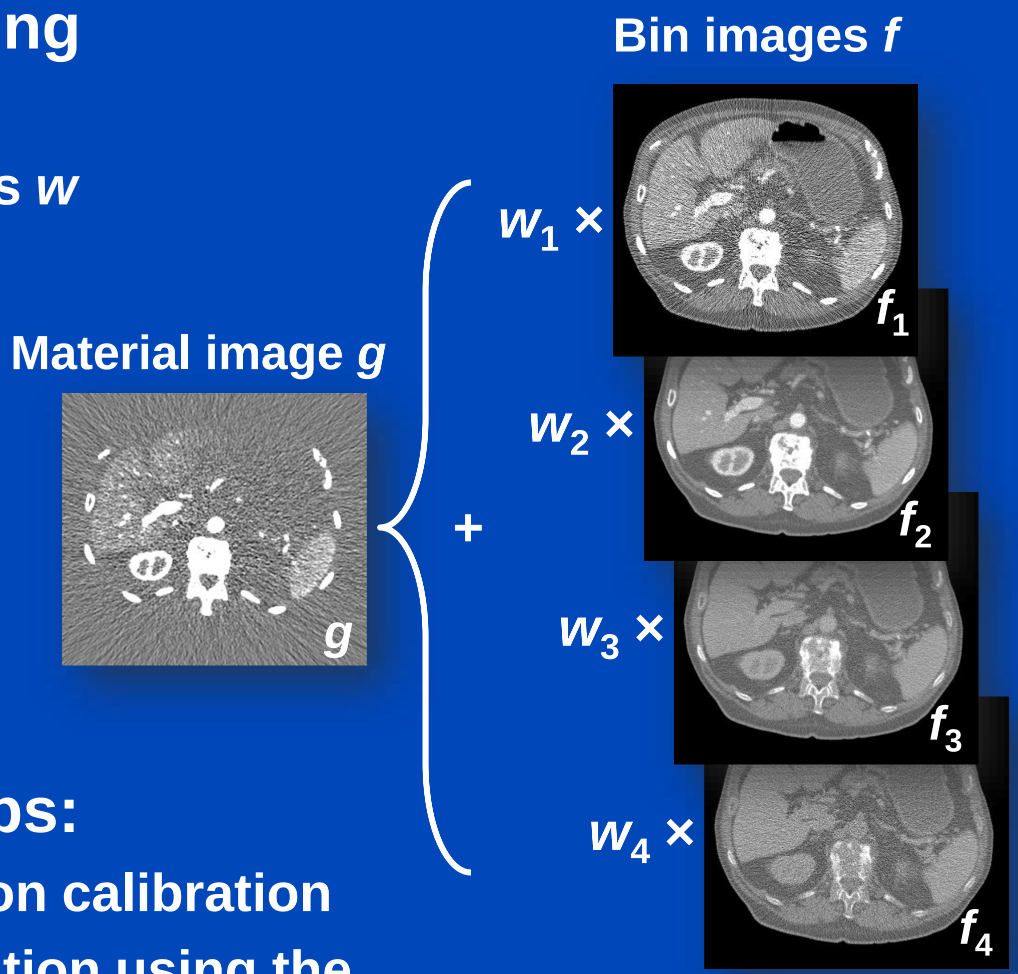
This simple example assumes iodine to contribute half as much to the gray value for the high kV scan as for the low kV scan. Dose is assumed to be the same in both scenarios.

Which Hardware Technology is Best?

Algorithm Concept

- **Linear image weighting**
  - **Material image *g***
  - **Weighting coefficients *w***
  - **Energy bin images *f***

$$g = \begin{pmatrix}-16.5\\+81.8\\-79.7\\-44.9\end{pmatrix}\cdot\begin{pmatrix}f_1\\f_2\\f_3\\f_4\end{pmatrix}$$



- **Two subsequent steps:**
  - **Material decomposition calibration**
  - **Image noise minimization using the $K = B - M$ degrees of freedom**

Faby and Kachelrieß, MedPhys 42(7):4349-4366, July 2015.

Material Decomposition Calibration

- **Example for *M* = 2: water and iodine**
- ***N* = 2 calibration measurements using ROIs**
- **Determine weighting coefficients *w***
  - ***M×B* coefficients, but *M×N* equations**

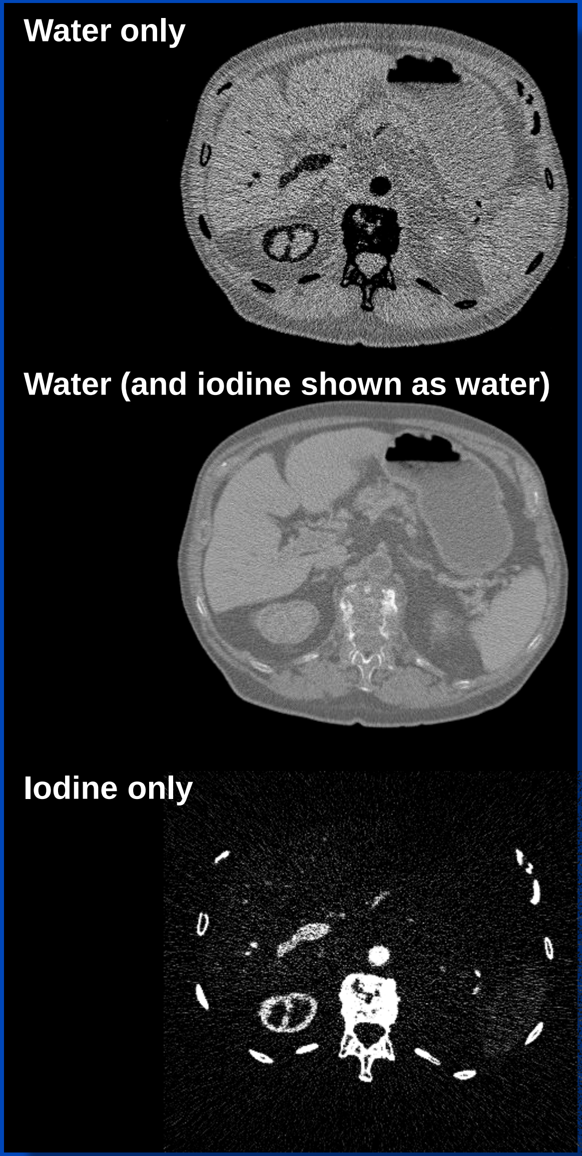
**Water calibration
(maps water ROI values to target values):**

$$\begin{pmatrix}\text{W-Image}\\\text{I-Image}\end{pmatrix}=\begin{pmatrix}1\\0\end{pmatrix}=\begin{pmatrix}w_{\mathrm{W},1}\dots w_{\mathrm{W},B}\\w_{\mathrm{I},1}\dots w_{\mathrm{I},B}\end{pmatrix}\cdot\begin{pmatrix}f_{\mathrm{W},1}\\\vdots\\f_{\mathrm{W},B}\end{pmatrix}$$

**Iodine calibration
(maps iodine ROI values to target values):**

$$\begin{pmatrix}\text{W-Image}\\\text{I-Image}\end{pmatrix}=\begin{pmatrix}1\\1\end{pmatrix}=\begin{pmatrix}w_{\mathrm{W},1}\dots w_{\mathrm{W},B}\\w_{\mathrm{I},1}\dots w_{\mathrm{I},B}\end{pmatrix}\cdot\begin{pmatrix}f_{\mathrm{I},1}\\\vdots\\f_{\mathrm{I},B}\end{pmatrix}$$

- **This is the case studied in the following simulations**



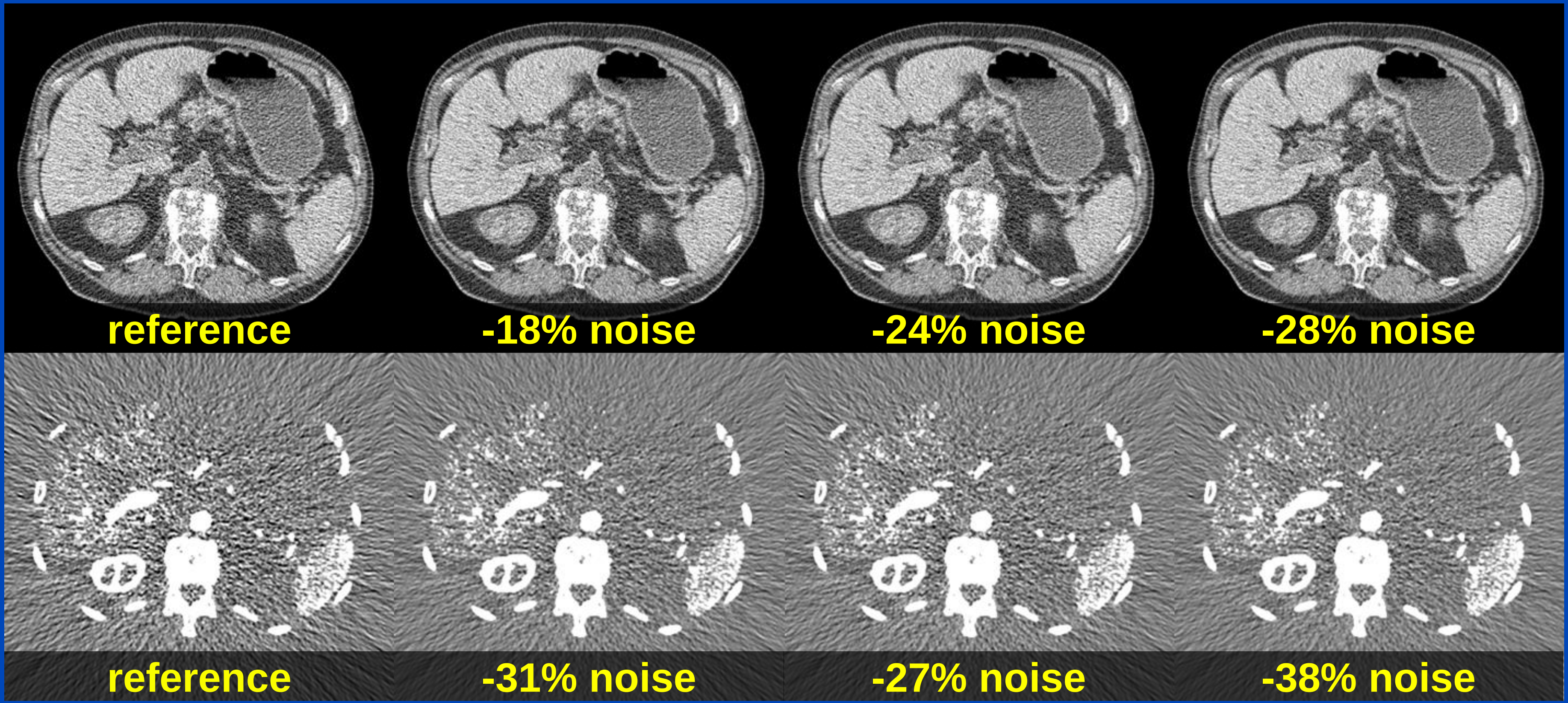
Results – Different DSCT Generations

2nd generation DSCT | **3rd generation DSCT**

DS 100 kV / Sn 140 kV | DS 80 kV / Sn 140 kV | DS 90 kV / Sn 150 kV | DS 80 kV / Sn 150 kV

VNC

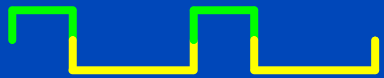
Iodine

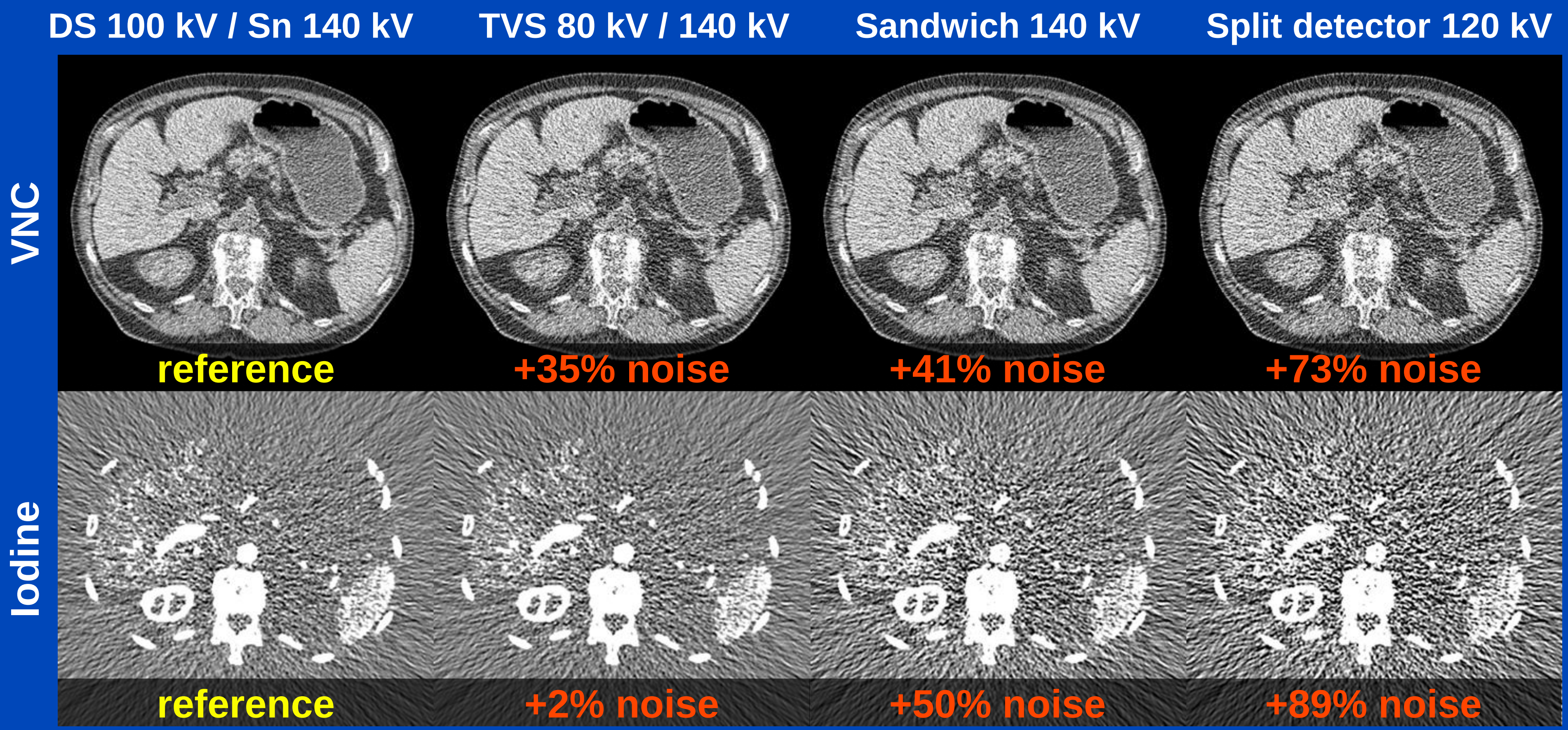


Faby and Kachelrieß, MedPhys 42(7):4349-4366, July 2015.

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

Results – Different DECT Techniques



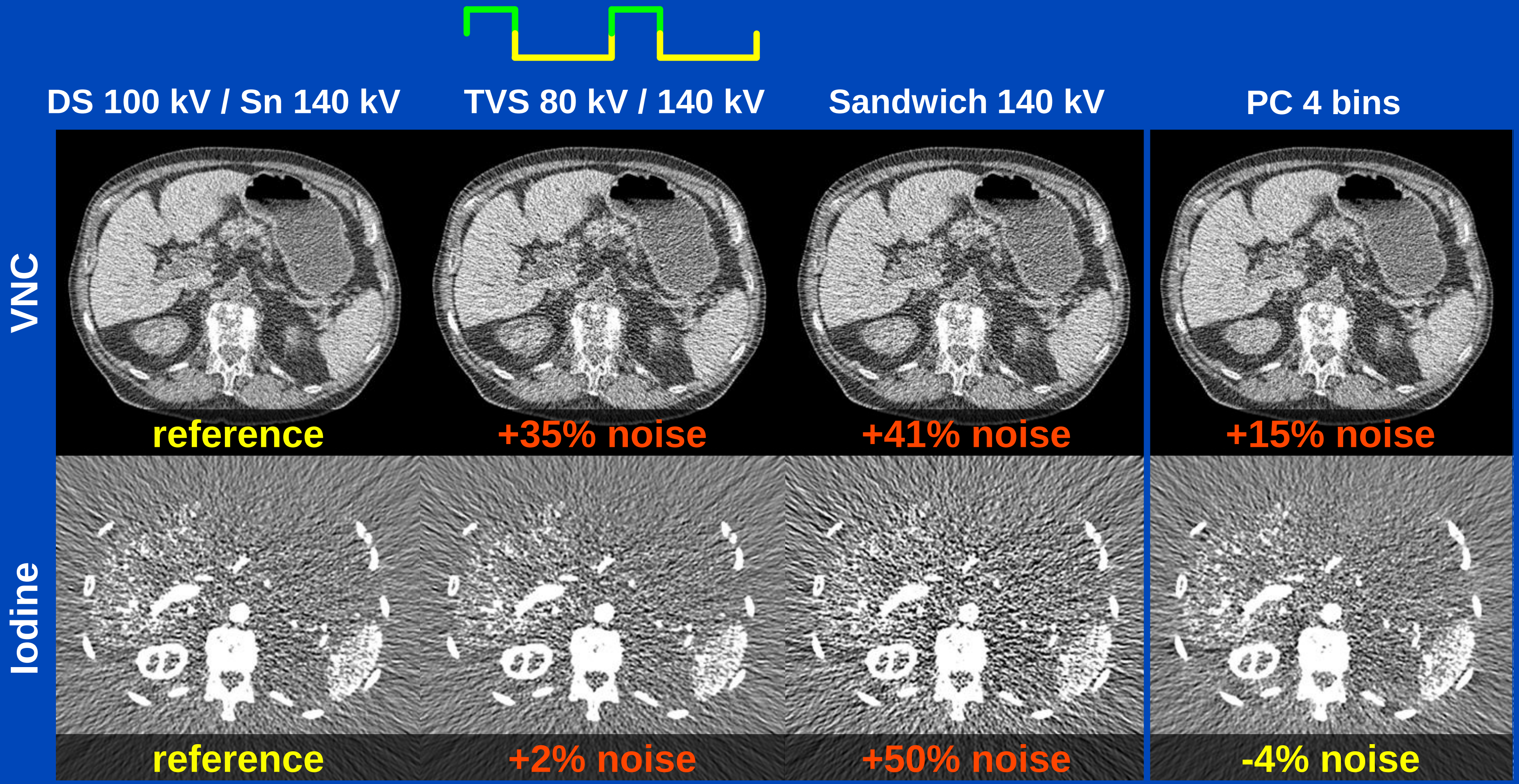


Faby and Kachelrieß, MedPhys 42(7):4349-4366, July 2015.

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

dkfz.

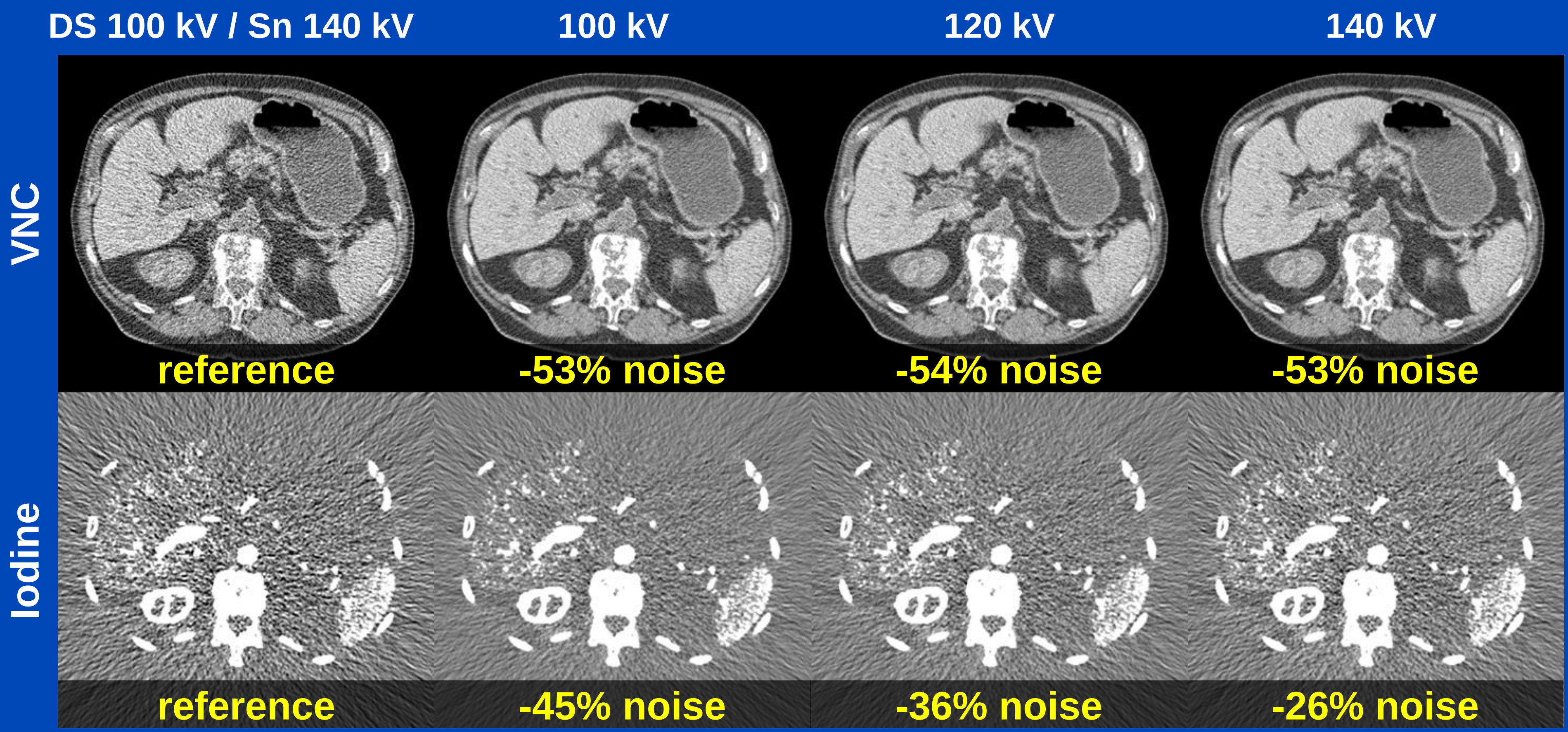
Results – Different DECT Techniques



Faby and Kachelrieß, MedPhys 42(7):4349-4366, July 2015.

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

Results – Subtraction Technique



Summary

- DSCT (with prefilter)
  - Best spectral separation and thus best CNRD
  - Potentially higher costs
- Fast tube voltage switching
  - Rather low cost
  - Low spectral separation
- Sandwich detector
  - Complicated detector
  - Always on demand
  - Very low spectral separation
- PCCT
  - New, and thus expensive, detector technology
  - Good spectral separation
  - Always on demand

Thank you!

Job opportunities through DKFZ's international Fellowship programs (marc.kachelriess@dkfz.de).
Parts of the reconstruction software were provided by RayConStruct® GmbH, Nürnberg, Germany.