Artifacts and Pitfalls in CT

Jan Kuntz

German Cancer Research Center (DKFZ)
Heidelberg, Germany
www.dkfz.de/ct

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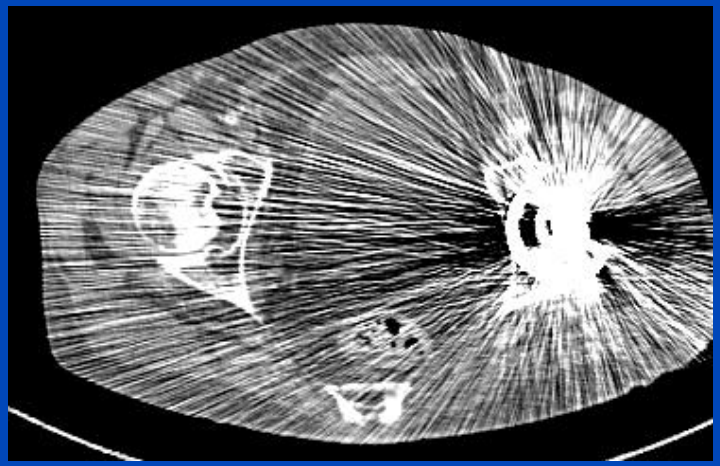
DEUTSCHES
KREBSFORSCHUNGSZENTRUM
IN DER HELMHOLTZ-GEMEINSCHAFT

Definition: Imaging Artifacts

Imaging artifacts are misrepresentations in a resulting image with no real counterpart



Artifacts in Computed Tomography

Relevant artifacts in diagnostic CT

- **Sampling artifacts**
- **Geometric artifacts**
- **Motion artifacts**
- **Metal artifacts**
- **…**

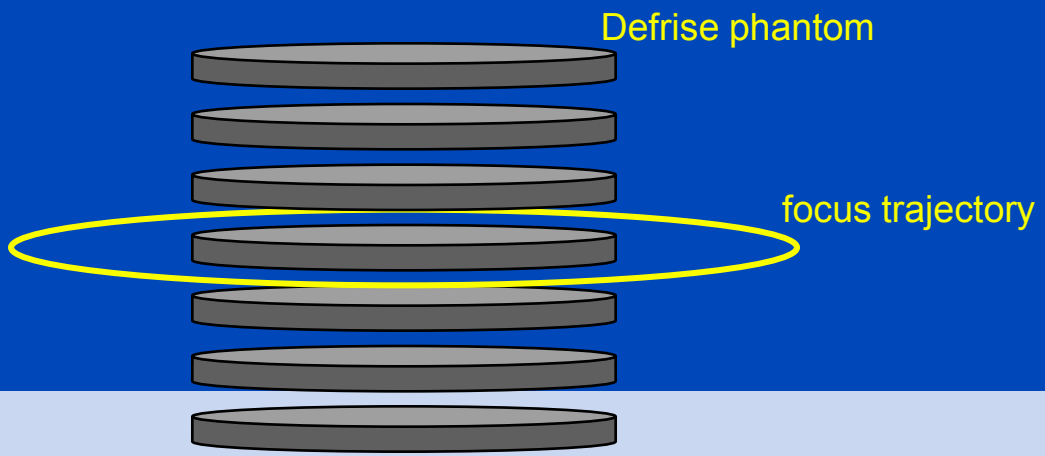
Artifacts with minor relevance for diagnostic CT

- **Come-beam artifacts**
- **Scatter artifacts**

Cone-Beam Artifacts

Cone-angle γ = 6° Cone-angle γ = 14° Cone-angle γ = 28°

These are minimized or avoided using the spiral trajectory and/or iterative image reconstruction.



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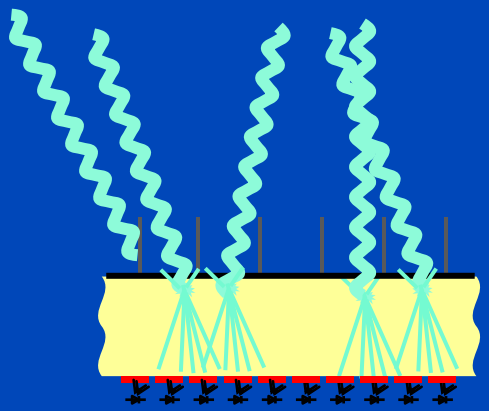
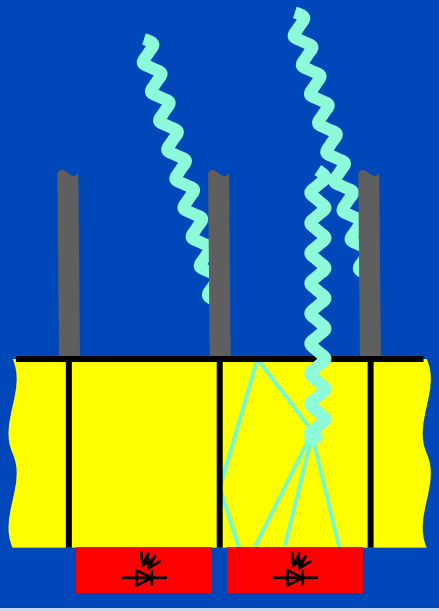
Scatter Artifacts

Cone-Beam CT



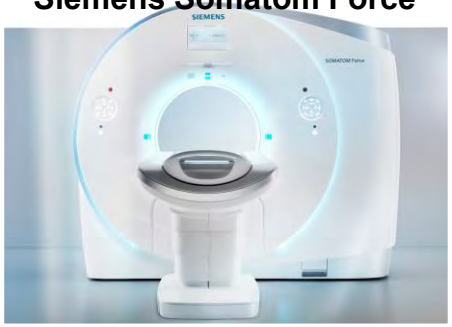
Diagnostic CT



GE Revolution CT

Philips IQon Spectral CT

Siemens Somatom Force



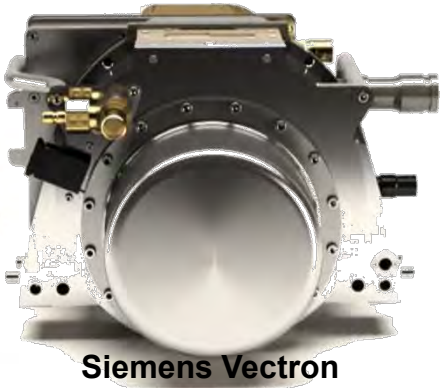
Toshiba Aquilion ONE Vision

In-plane resolution:	0.4 … 0.7 mm
Nominal slice thickness:	S = 0.5 … 1.5 mm
Tube (max. values):	120 kW, 150 kV, 1300 mA
Effective tube current:	mAs_{eff} = 10 mAs … 1000 mAs
Rotation time:	T_{rot} = 0.25 … 0.5 s
Simultaneously acquired slices:	M = 16 … 320
Table increment per rotation:	d = 1 … 183 mm
Scan speed:	up to 73 cm/s
Temporal resolution:	50 … 250 ms

GE Performix HDw

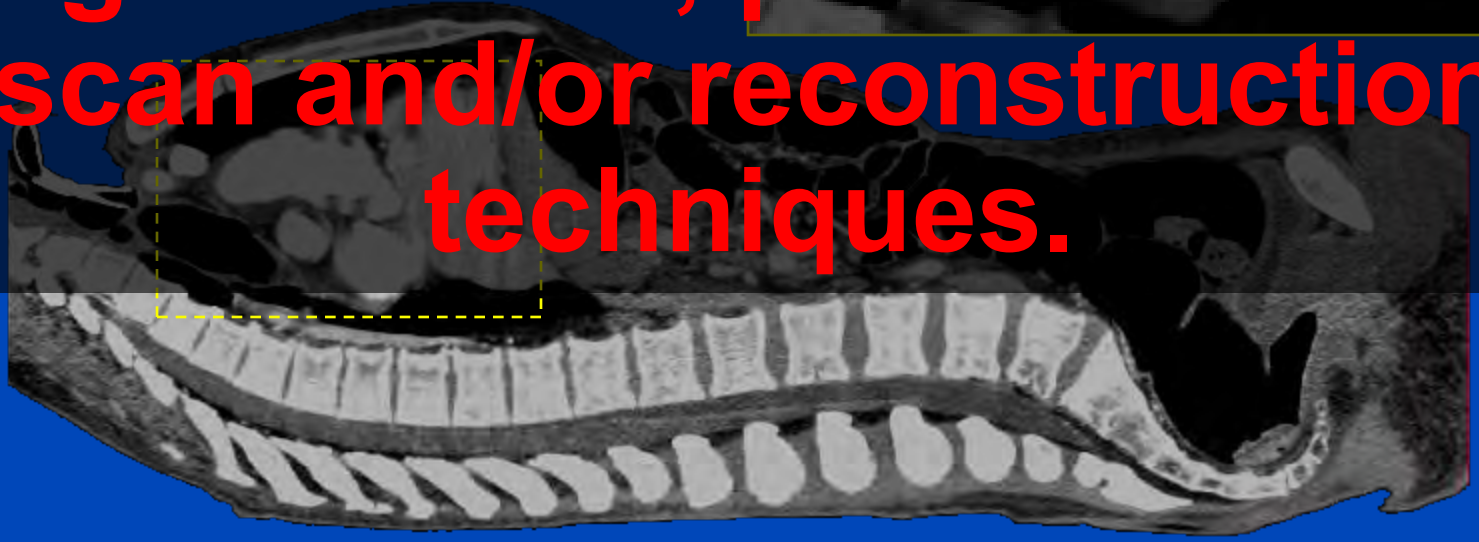
Philips iMRC

Siemens Straton



Siemens Vectron

Motion Artifacts of the Heart



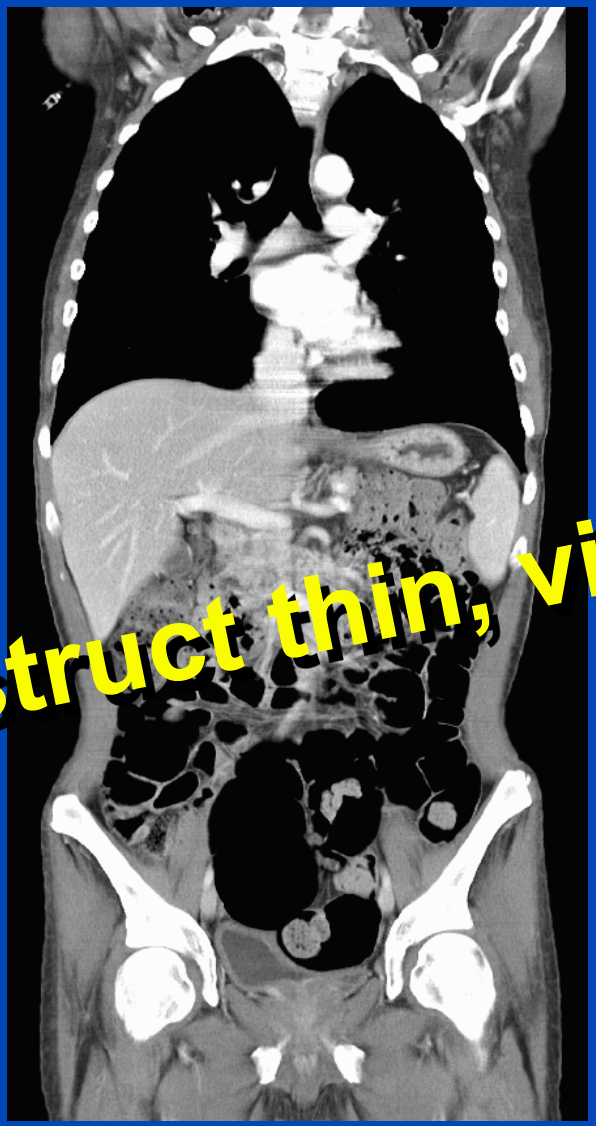
These are minimized or avoided using fast scan, phase-correlated scan and/or reconstruction techniques.

Standard Display

0,5×0,5×0,5 mm³
C = 50 HU, W = 400 HU

Sliding Thin Slab (STS) Display

0,5×0,5×10 mm³
C = 50 HU, W = 400 HU



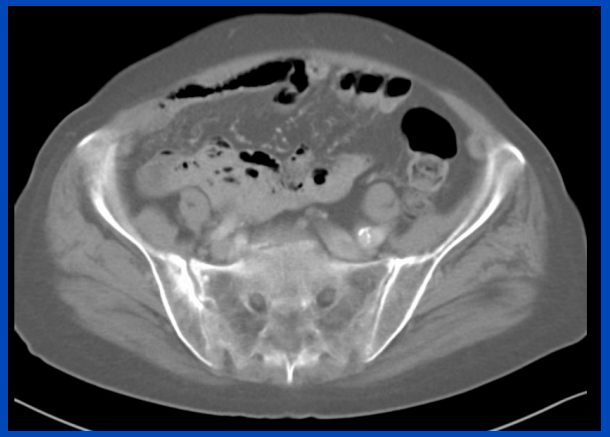
"Reconstruct thin, view thick!"

Linear Partial Volume Effect

S = 1 mm

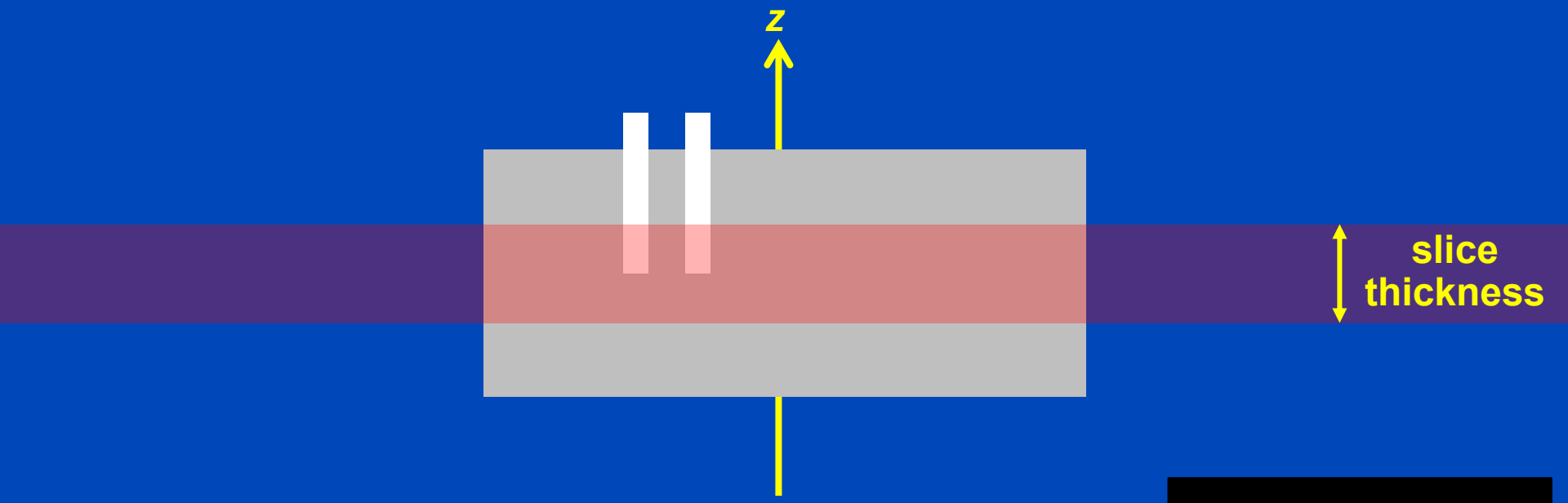
S = 5 mm

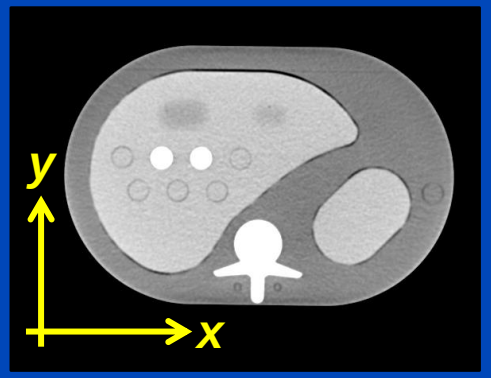
S = 10 mm



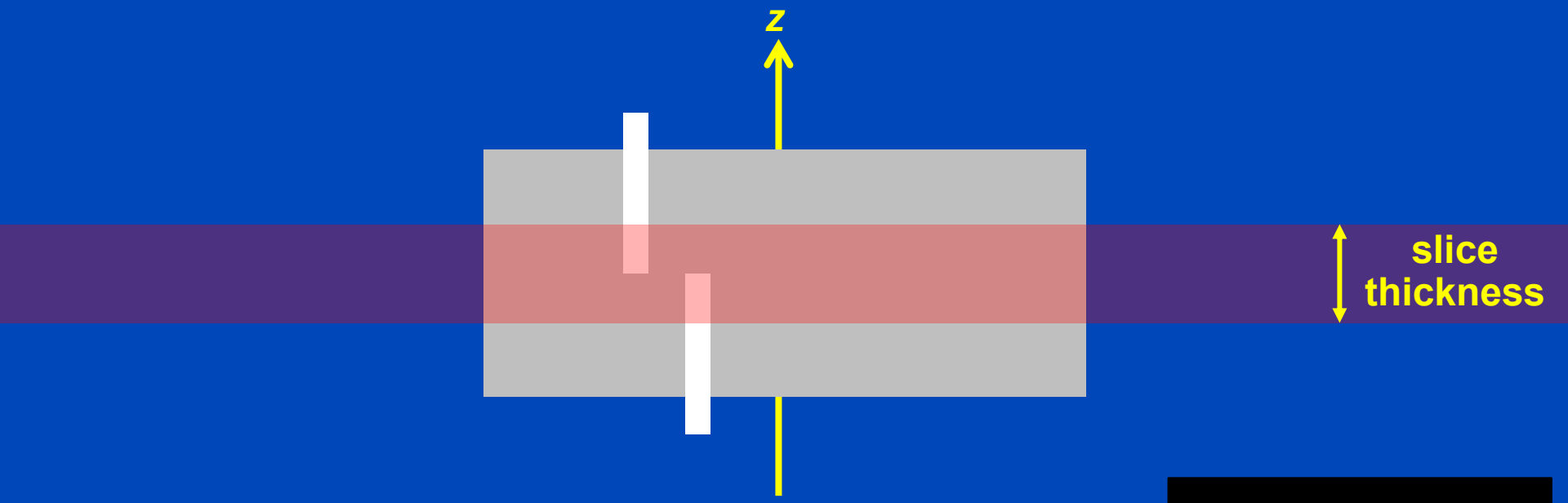
C = 0 HU, *W* = 800 HU

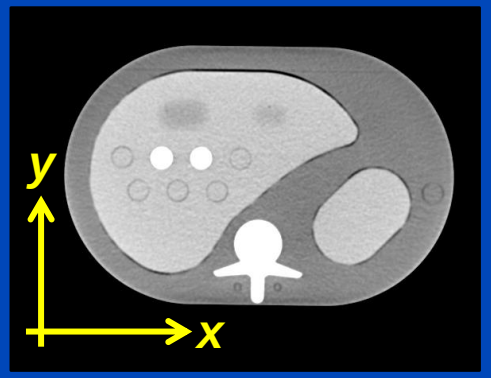
Partial Volume Effect: Experiment





Partial Volume Effect: Experiment



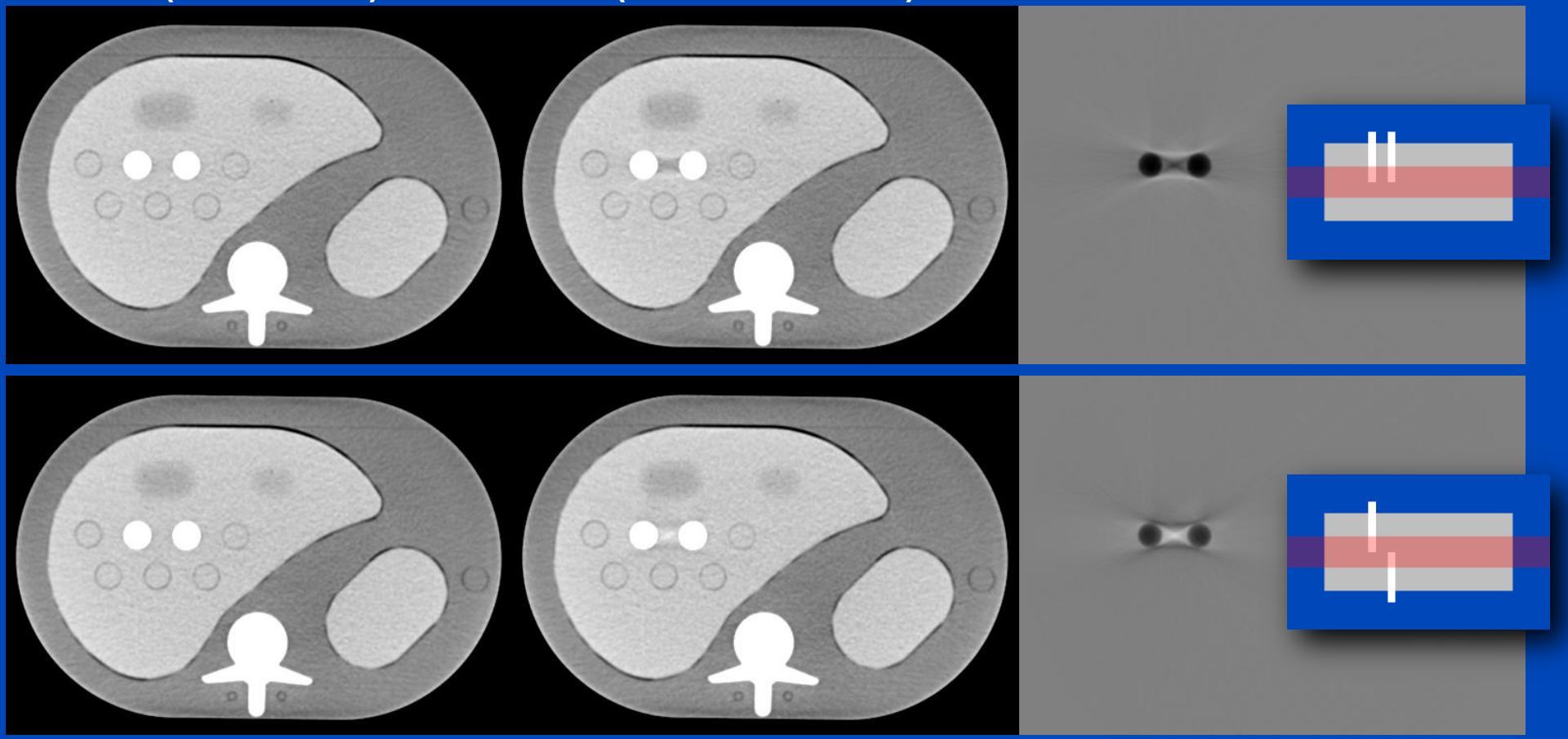


Linear and Non-Linear Partial Volume Effect

Log domain average (linear PVE)

Intensity domain average (non-linear PVE)

Intensity minus log domain average



C = 40 HU, *W* = 200 HU

C = 0 HU, *W* = 100 HU

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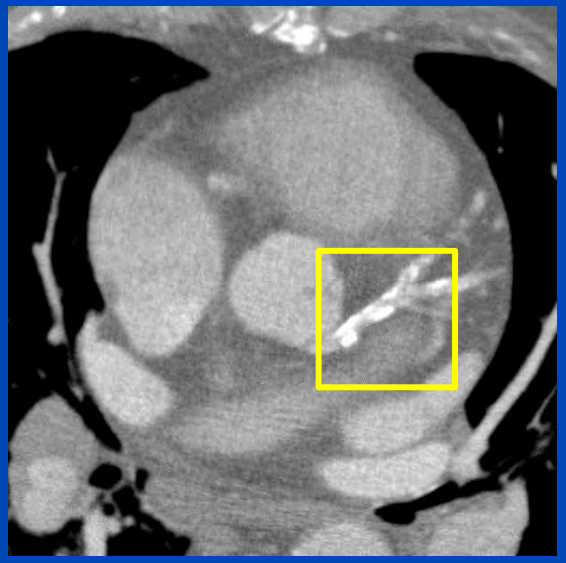
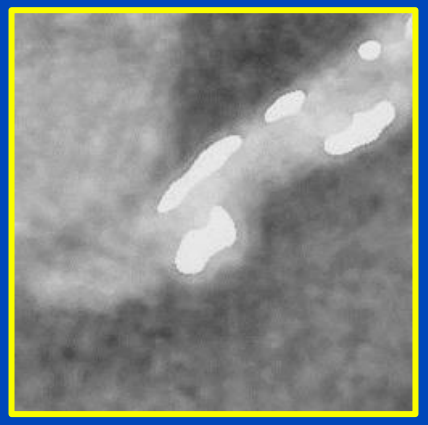
Blooming Artifacts and their Reduction

Cardiac reconstruction



Calcification + Blooming

Estimated calcification



- This shows a dedicated blooming artifact reduction approach based on a discrete tomography reconstruction technique.
- Blooming artifacts are also suppressed by today‘s iterative reconstruction algorithms.

C = 0 HU, *W* = 1000 HU

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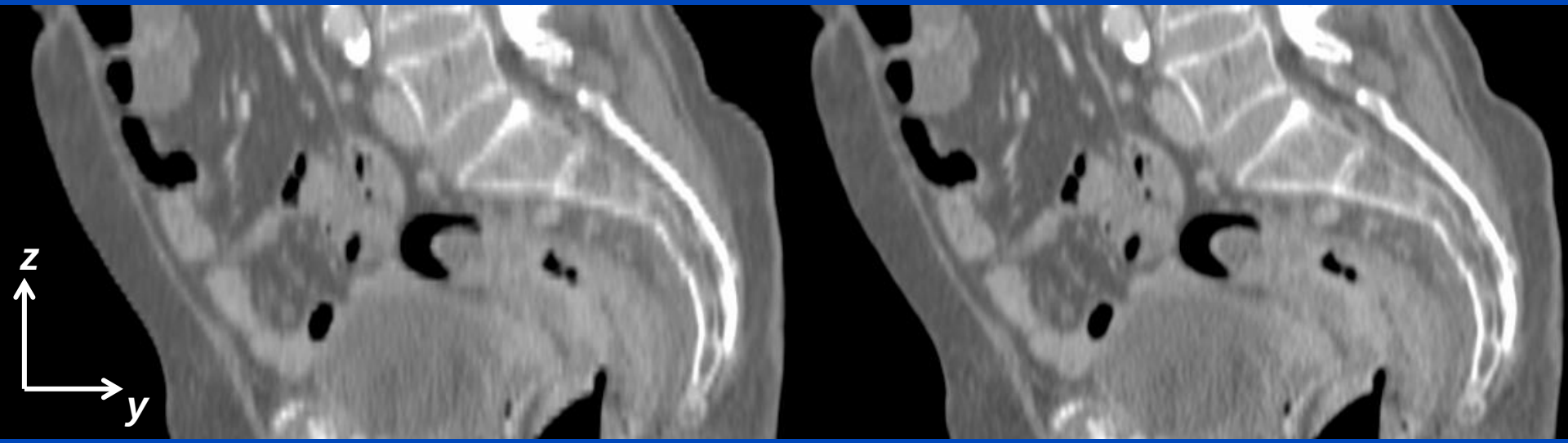
Sampling Artifacts and their Removal

S_{eff} = 3 mm, *RI* = 3 mm

S_{eff} = 3 mm, *RI* = 1 mm



Always perform Overlapping Recons!

C = 0 HU, *W* = 800 HU

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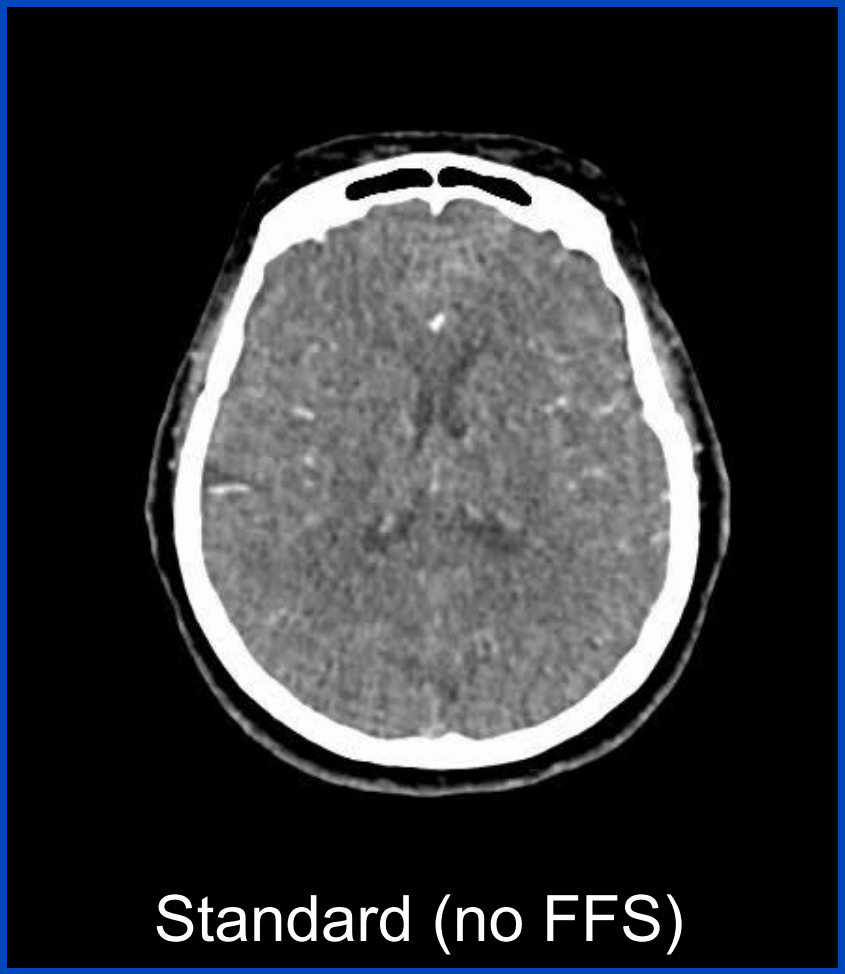
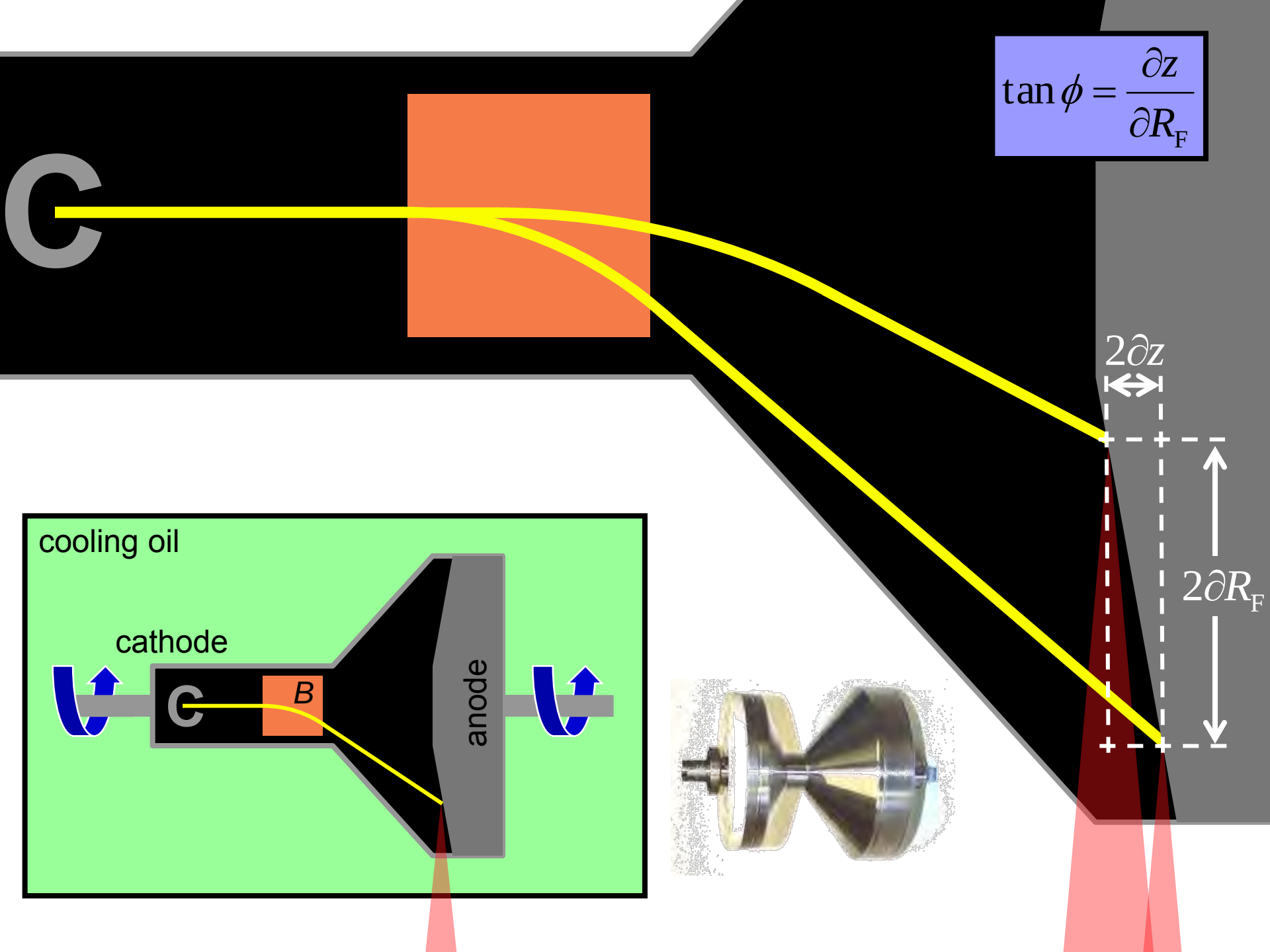
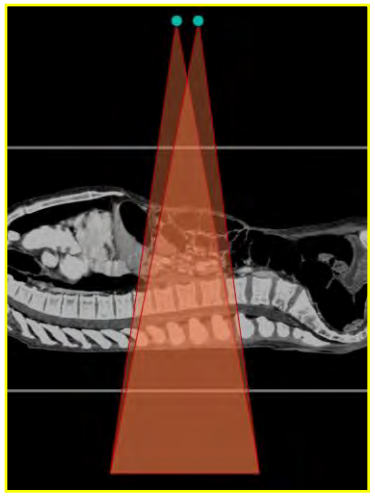
Windmill Artifacts and their Removal



ASSR reconstruction, p = 1.0, (C = 0 HU, W = 200 HU)

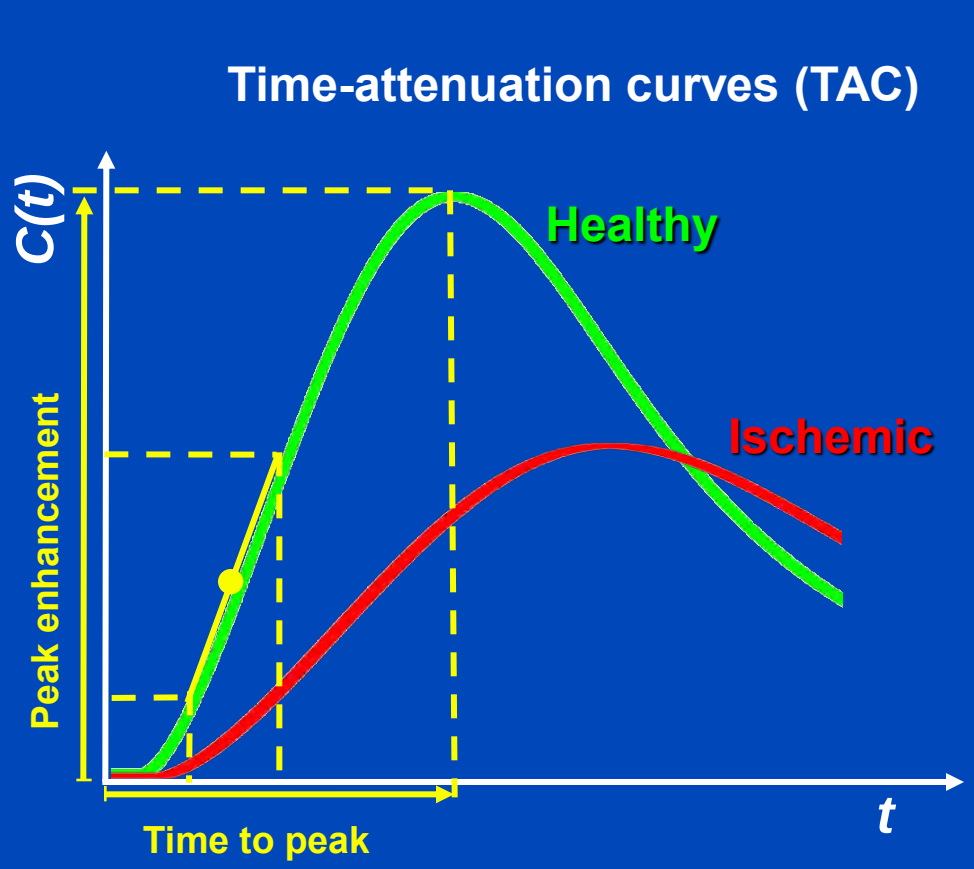

$\tan\phi = \frac{\partial z}{\partial R_F}$
C
$2\partial z$
$2\partial R_F$
cooling oil
cathode
C
B
anode

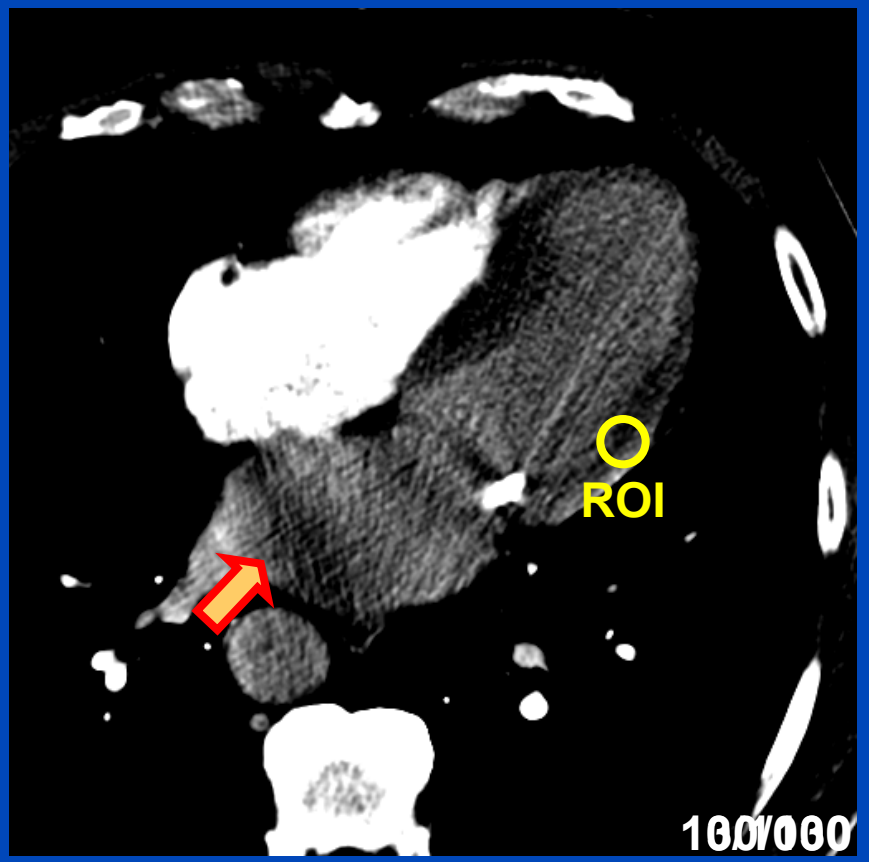
zFFS



$$\partial z = \frac{1}{4}\Delta b \frac{R_F}{R_D}$$

BH: Perfusion Analysis in CT





Beam hardening artifacts cause an underestimation of the CT-values leading to incorrect perfusion parameters!

Beam Hardening

- **Measurement**

$$q = -\ln \int dE\, w(E) e^{-\int dL\, \mu(\boldsymbol{r}, E)}$$

- **Single material approximation:** $\mu(\boldsymbol{r}, E) = f_1(\boldsymbol{r})\psi_1(E)$

$$q = -\ln \int dE\, w(E) e^{-p_1 \psi_1(E)}$$

→ cupping artifacts, first order BH artifacts → cupping correction (water precorrection)

- **Two material case:** $\mu(\boldsymbol{r}, E) = f_1(\boldsymbol{r})\psi_1(E) + f_2(\boldsymbol{r})\psi_2(E)$

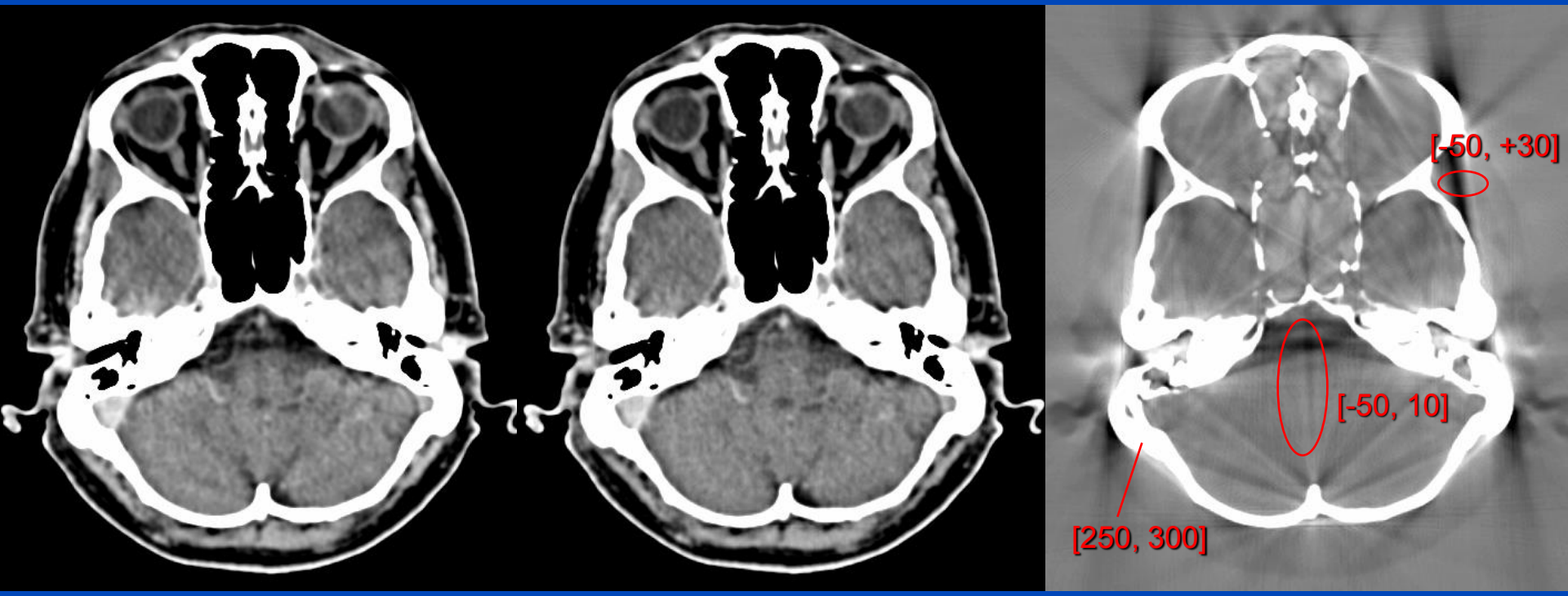
$$q = -\ln \int dE\, w(E) e^{-p_1 \psi_1(E) - p_2 \psi_2(E)}$$

→ banding artifacts, higher order BH artifacts → higher order BH correction

Patient Data

Spiral 4-Slice CT Scan at 120 kV

Original Image | BHC Image | Original minus BHC



(*C* = 40 HU, *W* = 150 HU)

(*C* = 0 HU, *W* = 100 HU)

Red values indicate the range of CT-values within the corresponding ROI in HU

M. Kachelrieß, and W.A. Kalender, "Improving PET/CT attenuation correction with iterative CT beam hardening correction," IEEE Medical Imaging Conference Program, M04-5, October 2005.

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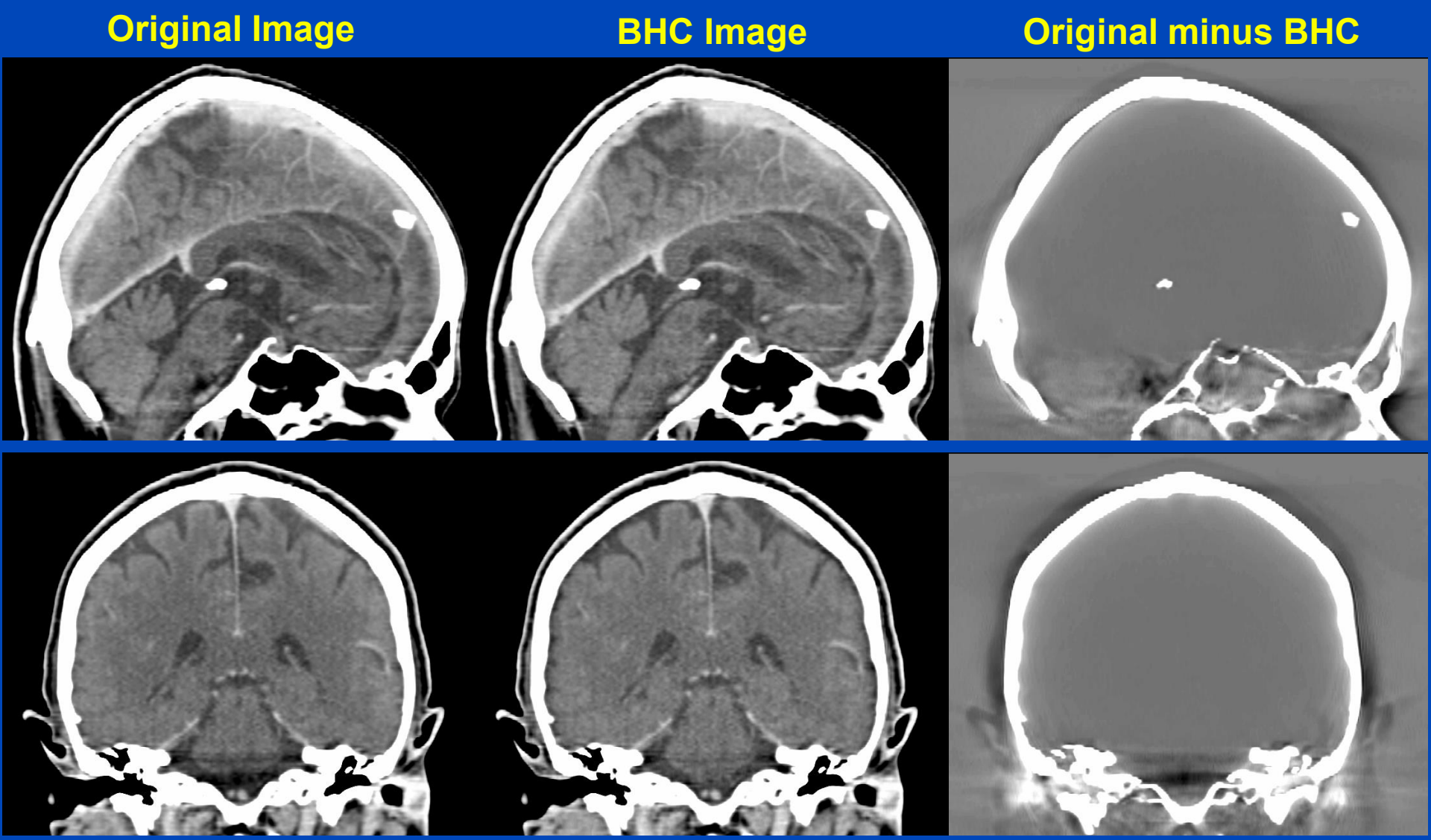

M. Kachelrieß, and W.A. Kalender, "Improving PET/CT attenuation correction with iterative CT beam hardening correction," IEEE Medical Imaging Conference Program, M04-5, October 2005.

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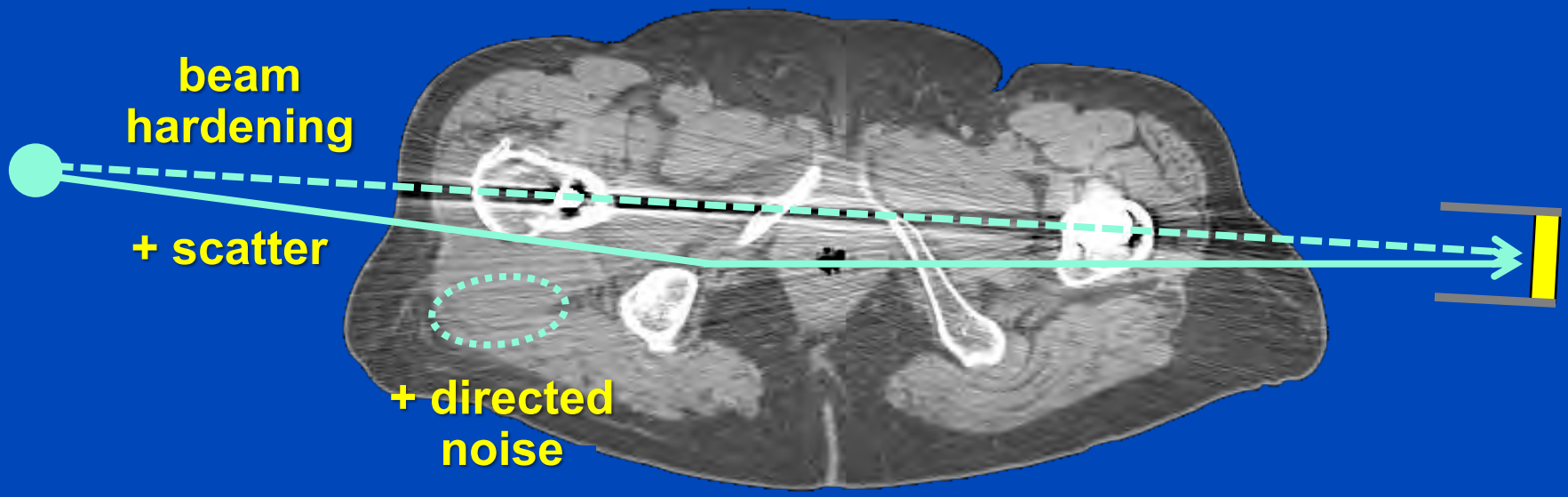
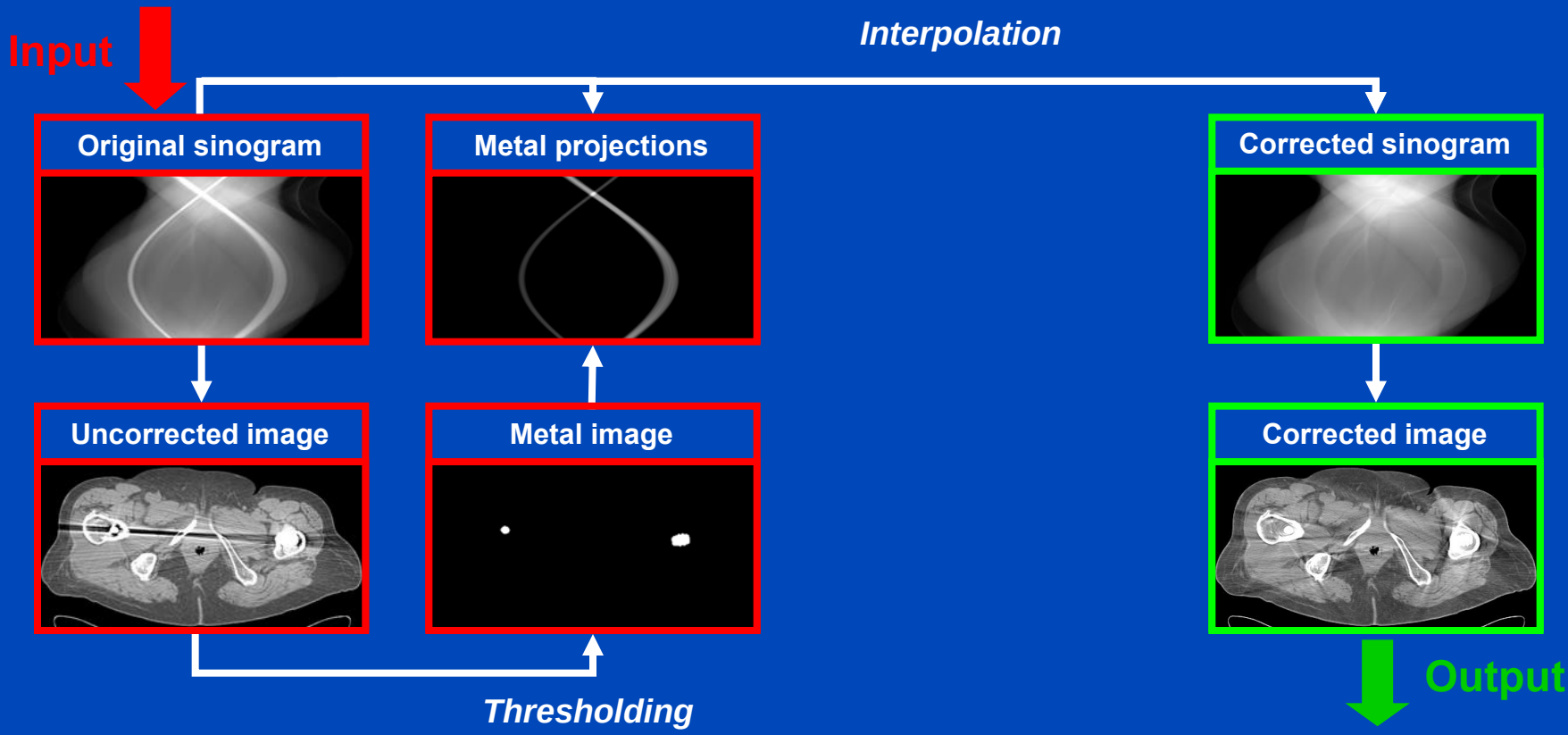
Metal artifacts are



+ increased susceptibility to sampling artifacts and motion.

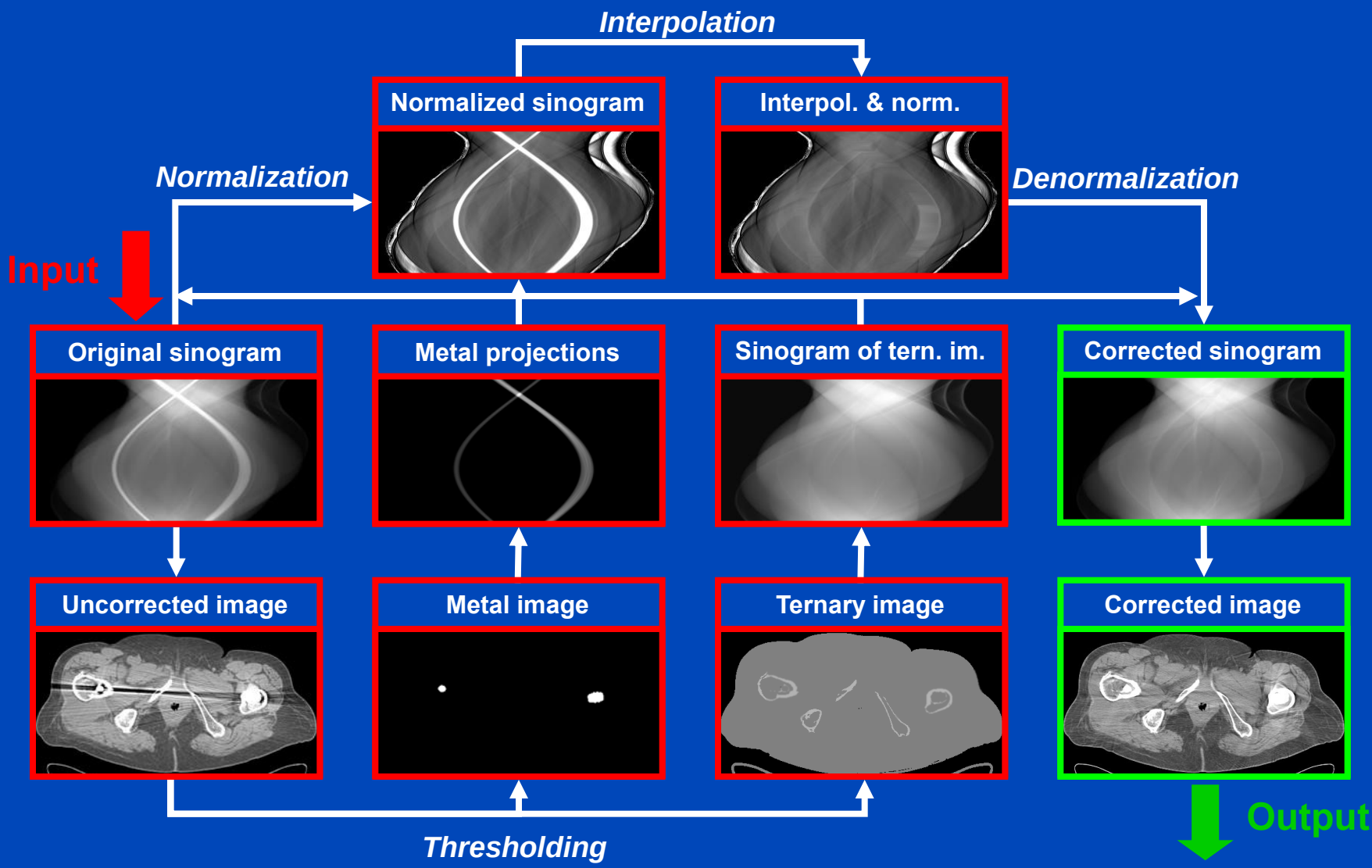
Linear Interpolation MAR (LIMAR)



W. A. Kalender, R. Hebel, and J. Ebersberger, "Reduction of CT artifacts caused by metallic implants," Radiology 164(2): 576–577, 1987.

dkfz.

Normalized MAR (NMAR)



Meyer, Raupach, Lell, Schmidt, and Kachelrieß, "Normalized metal artifact reduction (NMAR) in computed tomography", Med. Phys. 37(10):5482-5493, 2012.

dkfz.

Results and Comparison: Patient Data

Uncorrected

LIMAR

NMAR

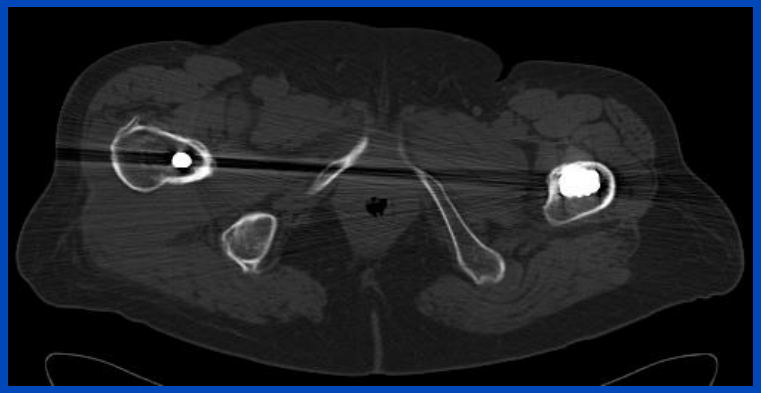
Patient with hip implants, Sensation 16, 140 kV, (*C* = 0 HU, *W* = 500 HU)

Meyer, Raupach, Lell, Schmidt, and Kachelrieß, "Normalized metal artifact reduction (NMAR) in computed tomography", Med. Phys. 37(10):5482-5493, 2012.

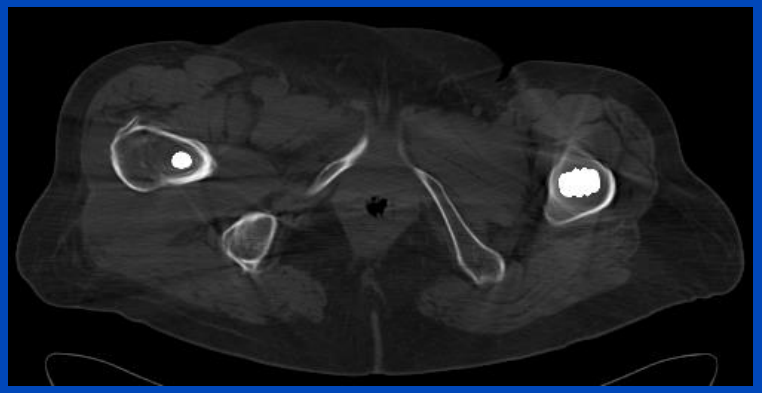
dkfz.

Results and Comparison: Patient Data

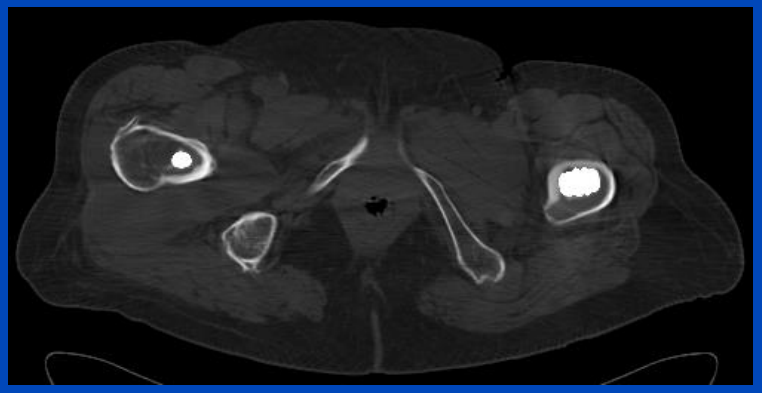
Uncorrected



LIMAR



NMAR



Patient with hip implants, Sensation 16, 140 kV, (*C* = 500 HU, *W* = 1500 HU)

Meyer, Raupach, Lell, Schmidt, and Kachelrieß, "Normalized metal artifact reduction (NMAR) in computed tomography", Med. Phys. 37(10):5482-5493, 2012.

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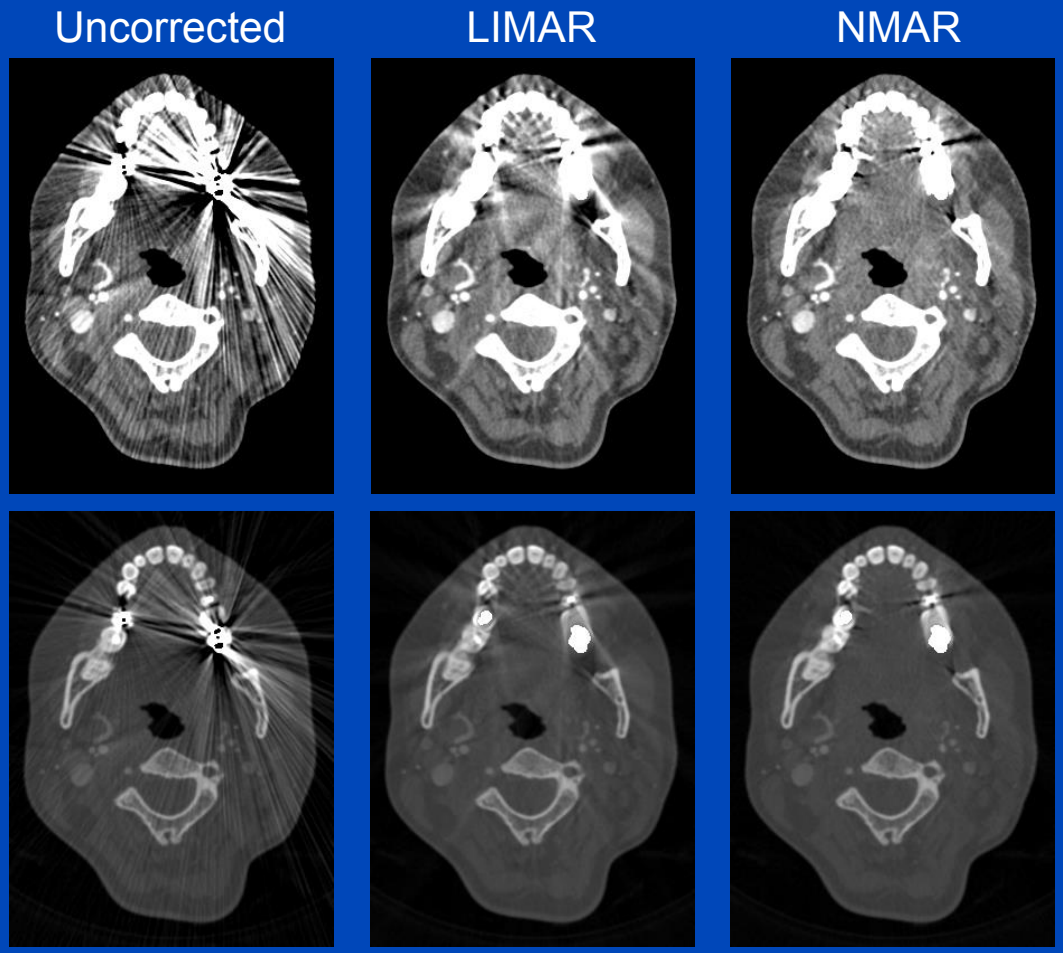
Results and Comparison: Patient Data



Patient dental fillings, slice 110, Somatom Definition Flash, pitch 0.9.
Top row: (*C* = 100 HU, *W* = 750 HU). Bottom row: (*C* = 1000 HU, *W* = 4000 HU)

Meyer, Raupach, Lell, Schmidt, and Kachelrieß, "Normalized metal artifact reduction (NMAR) in computed tomography", Med. Phys. 37(10):5482-5493, 2012.

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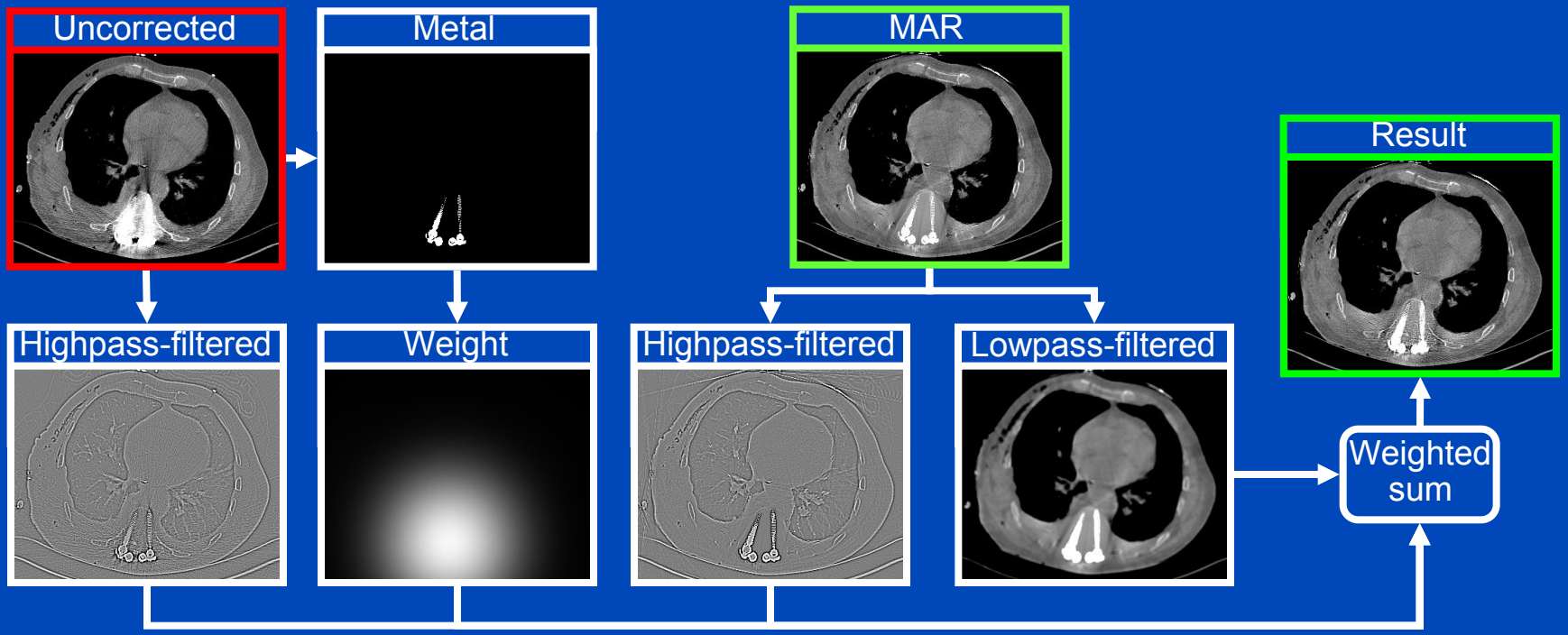
FSMAR: Scheme



Meyer, Raupach, Lell, Schmidt, and Kachelrieß, "Frequency split metal artifact reduction (FSMAR) in computed tomography", Med. Phys. 39(4):1904-1916, 2012.

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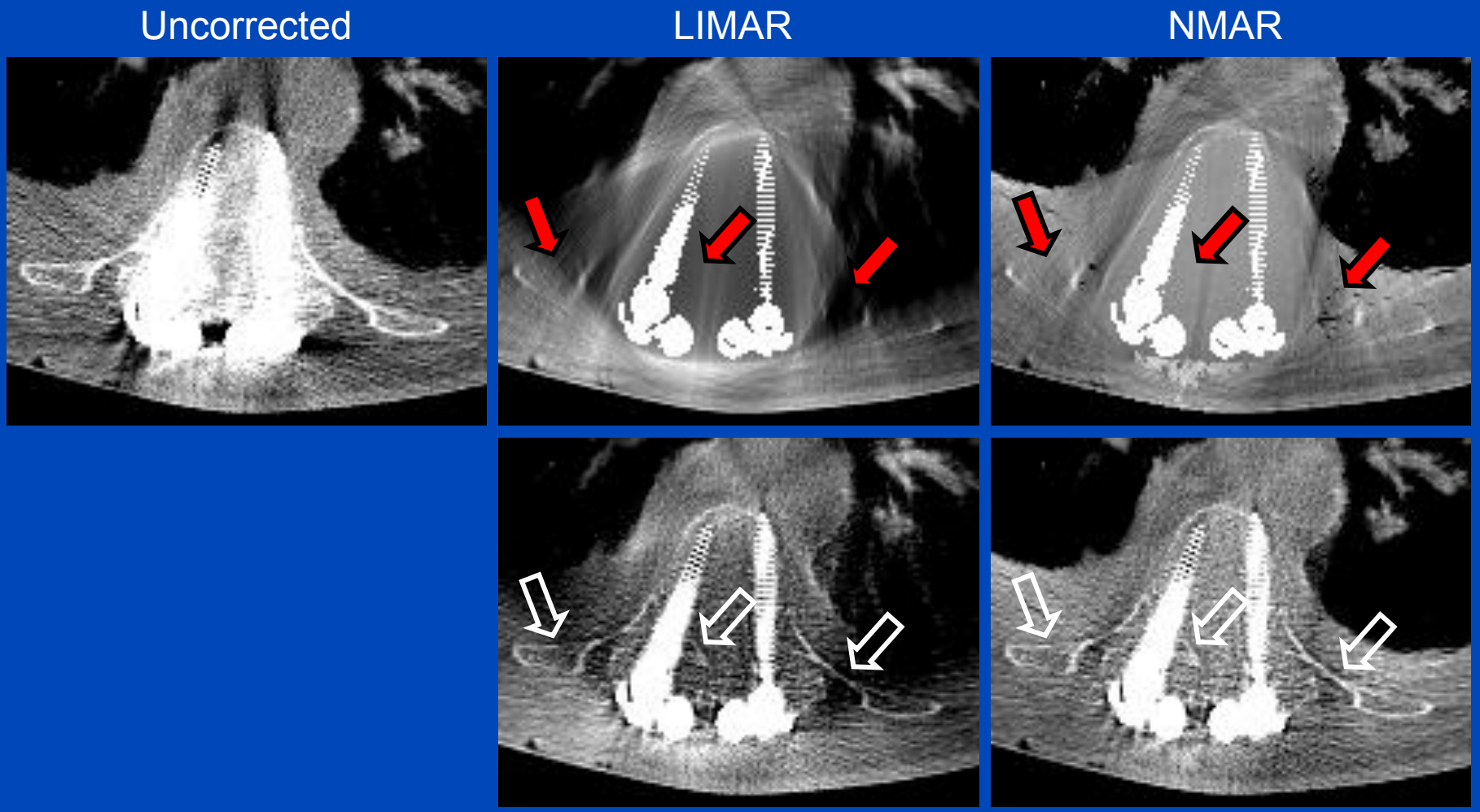
FSMAR: Results



Patient with spine fixation, Somatom Definition, (C=100/W=1000).

Meyer, Raupach, Lell, Schmidt, and Kachelrieß, "Frequency split metal artifact reduction (FSMAR) in computed tomography", Med. Phys. 39(4):1904-1916, 2012.

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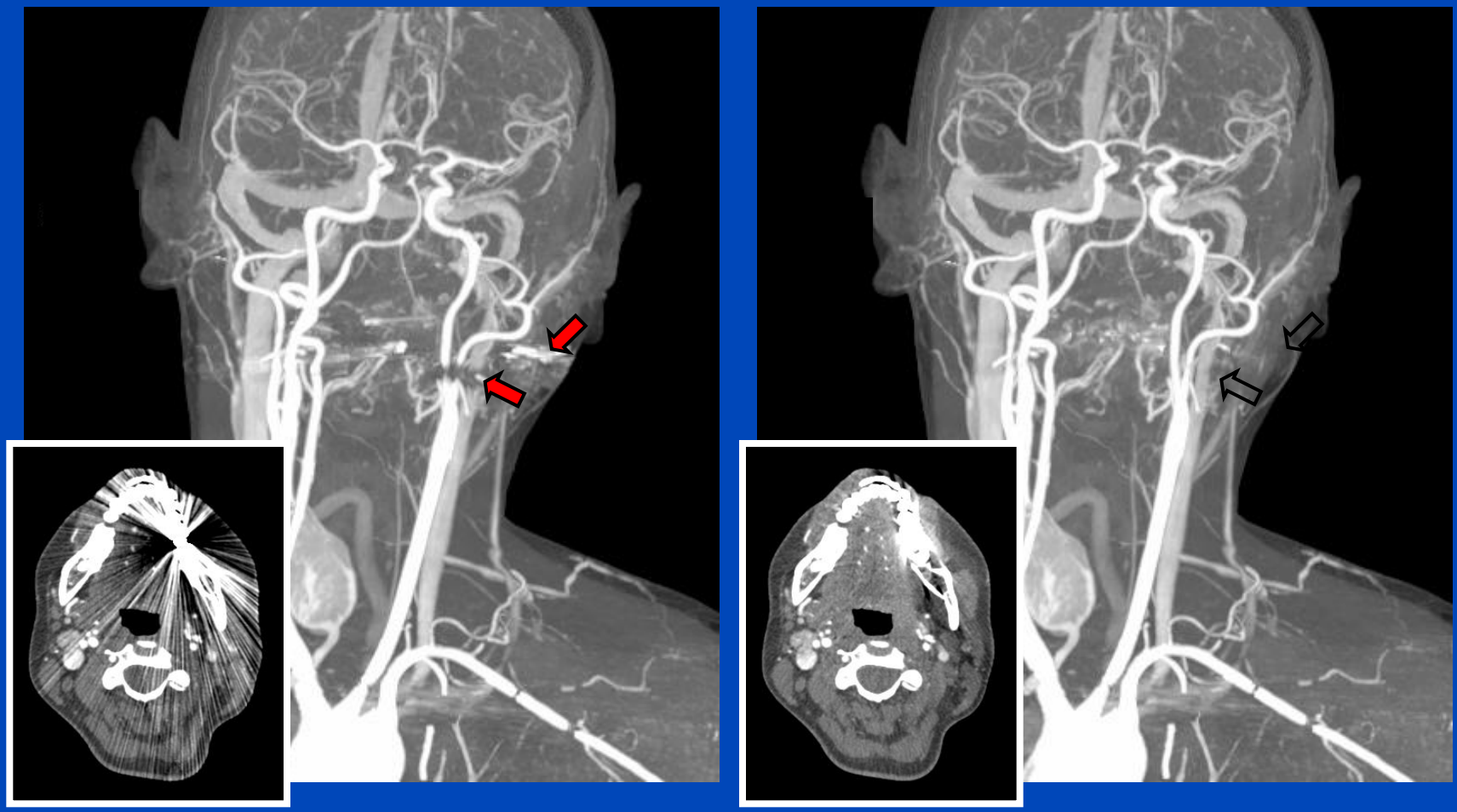
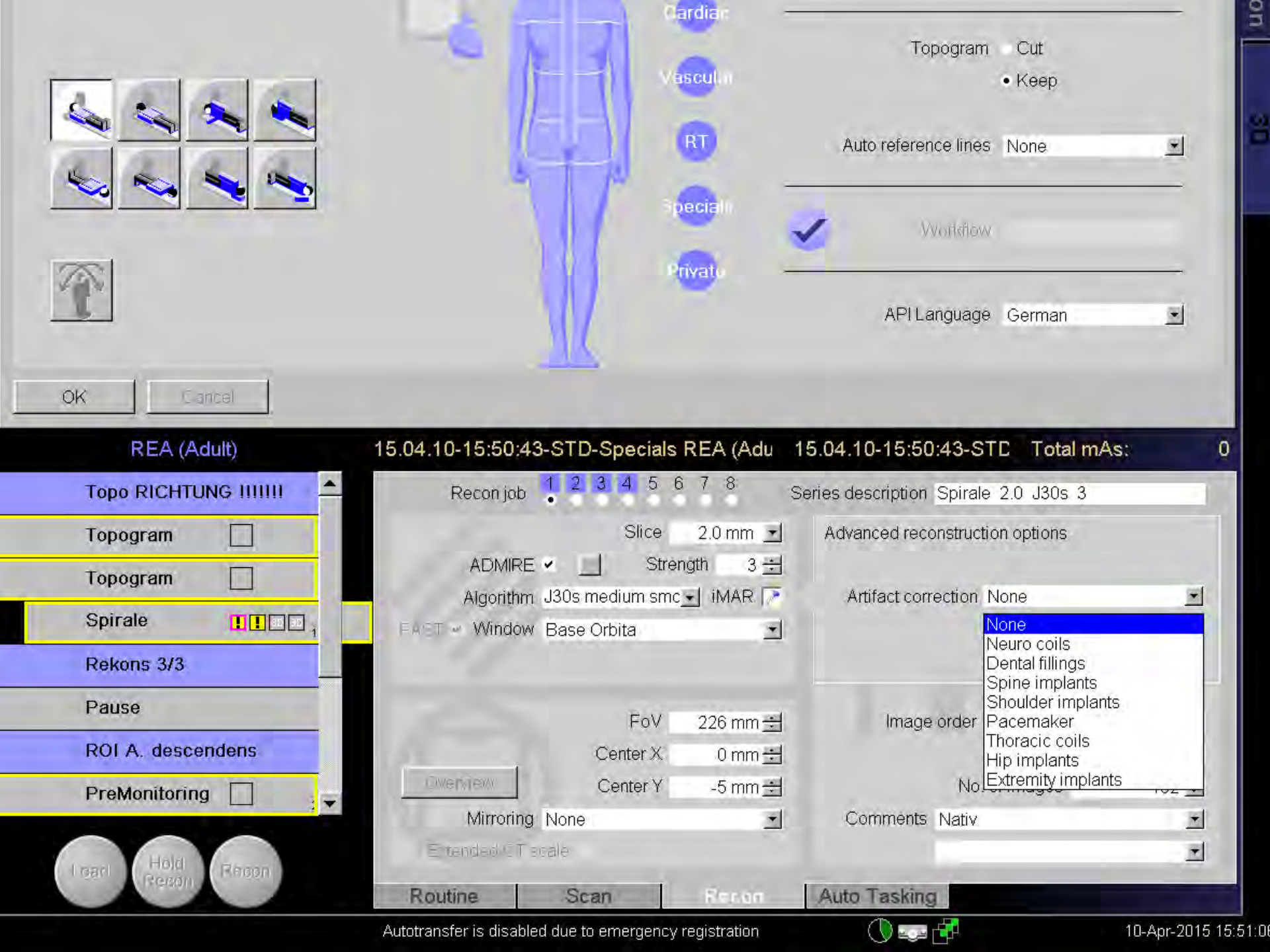
NMAR: Results

Uncorrected

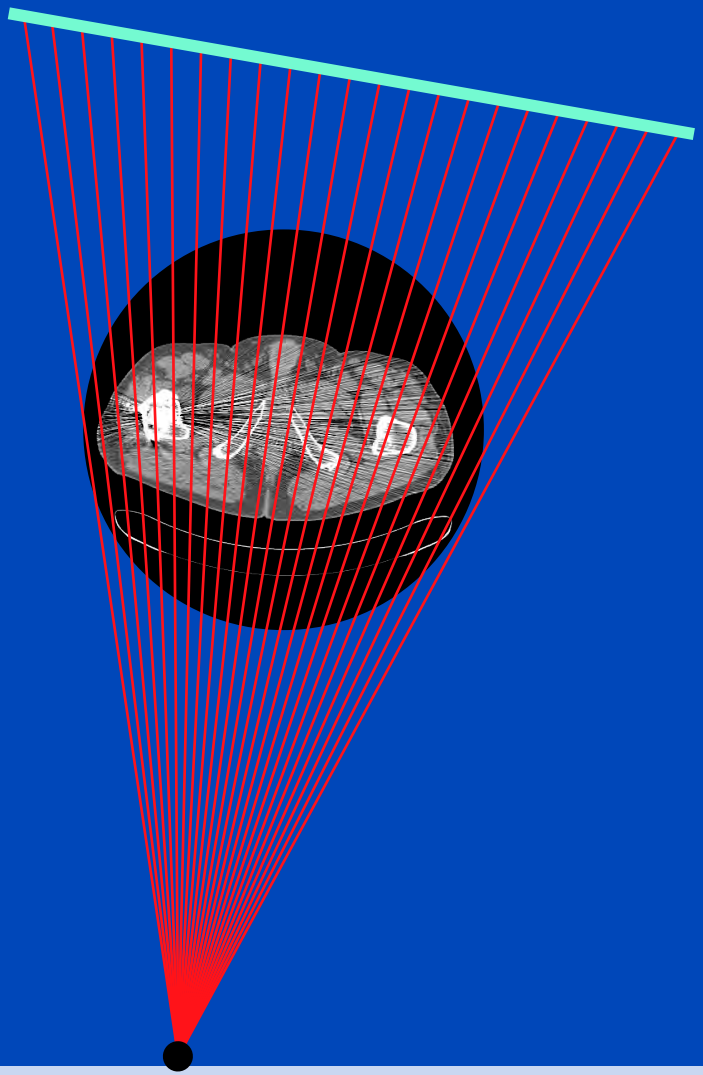
NMAR



Bone removal (with scanner software), (C=40/W=500).

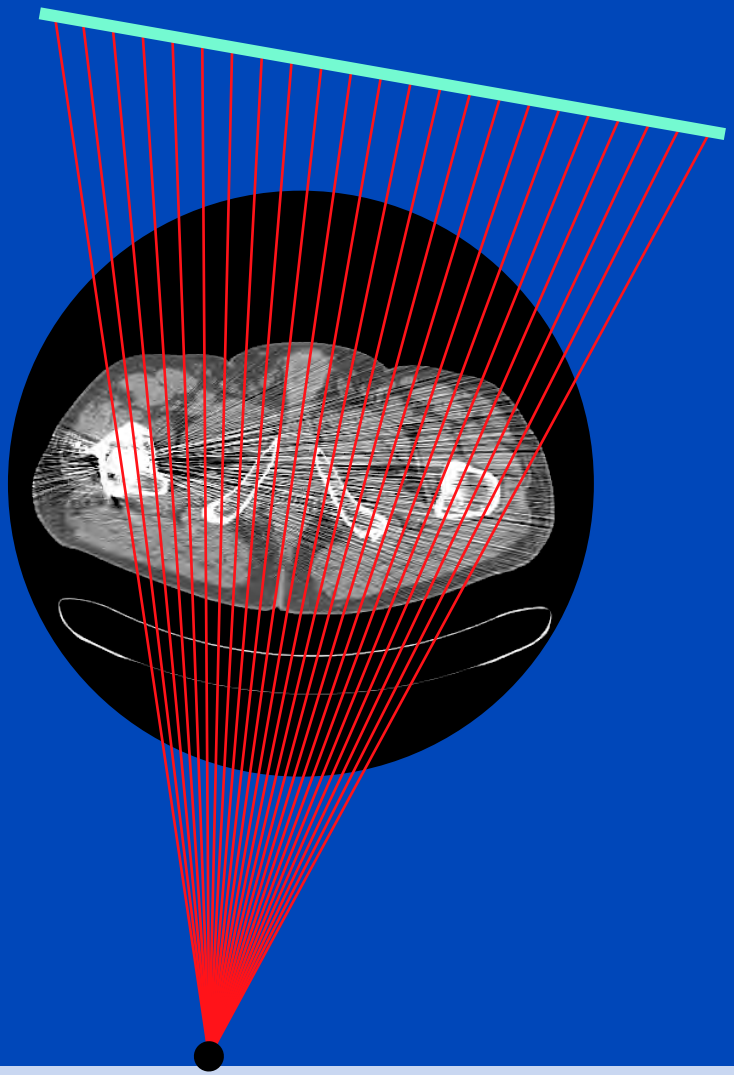

Cardiac
Vascular
RT
Specials
Private
Topogram Cut
Keep
Auto reference lines None
Workflow
API Language German
OK
Cancel
REA (Adult)
15.04.10-15:50:43-STD-Specials REA (Adu
15.04.10-15:50:43-STD
Total mAs: 0
Topo RICHTUNG !!!!!!
Topogram
Topogram
Spirale
Rekons 3/3
Pause
ROI A. descendens
PreMonitoring
Load
Hold Recon
Recon
Recon job 1 2 3 4 5 6 7 8
Series description Spirale 2.0 J30s 3
Slice 2.0 mm
ADMIRE
Strength 3
Algorithm J30s medium smc
iMAR
FAST
Window Base Orbita
Advanced reconstruction options
Artifact correction None
None
Neuro coils
Dental fillings
Spine implants
Shoulder implants
Pacemaker
Thoracic coils
Hip implants
Extremity implants
FoV 226 mm
Center X 0 mm
Center Y -5 mm
Overview
Image order
Mirroring None
Comments Nativ
Extended CT scale
Routine
Scan
Recon
Auto Tasking
Autotransfer is disabled due to emergency registration
10-Apr-2015 15:51:0

Truncation Artifacts



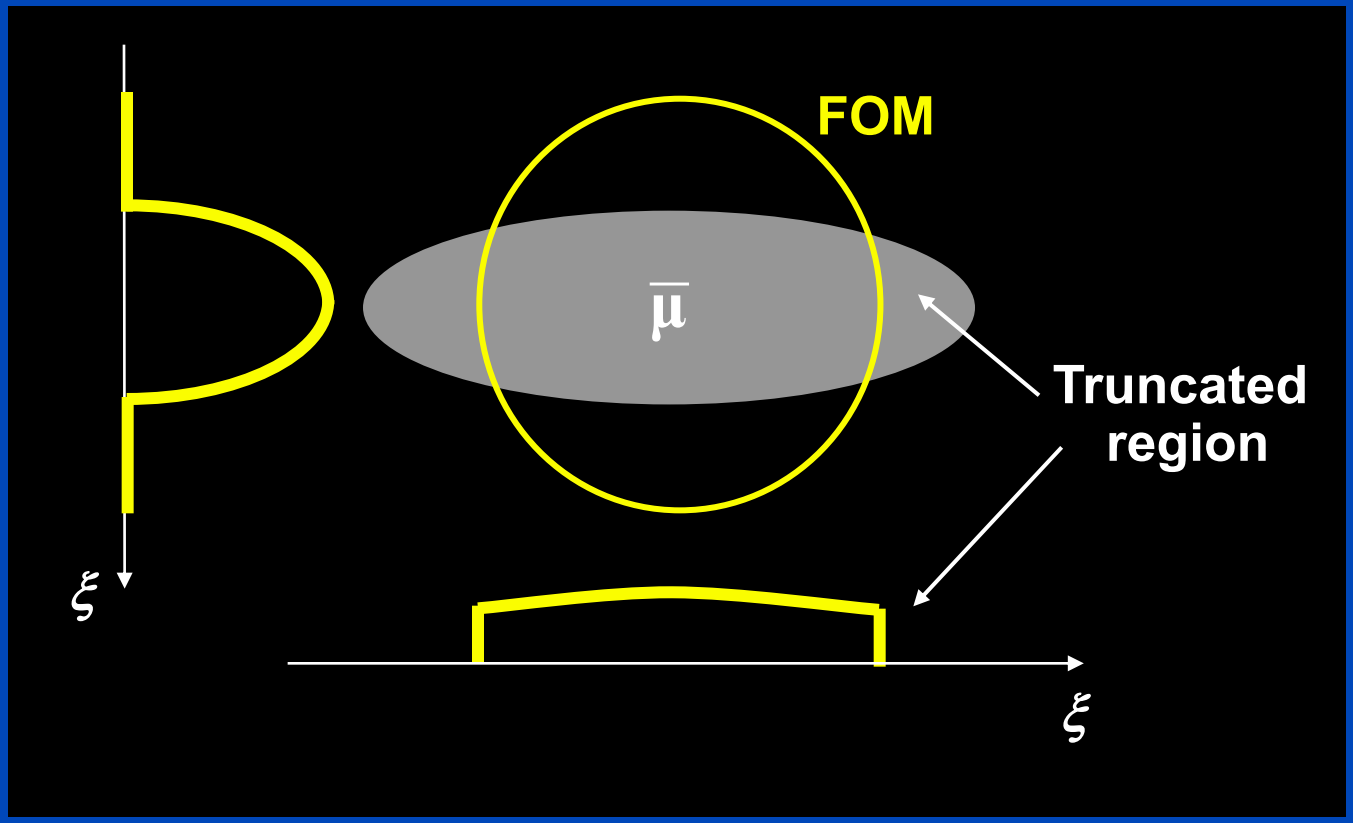
Sinogram, Rawdata

Truncation Artifacts

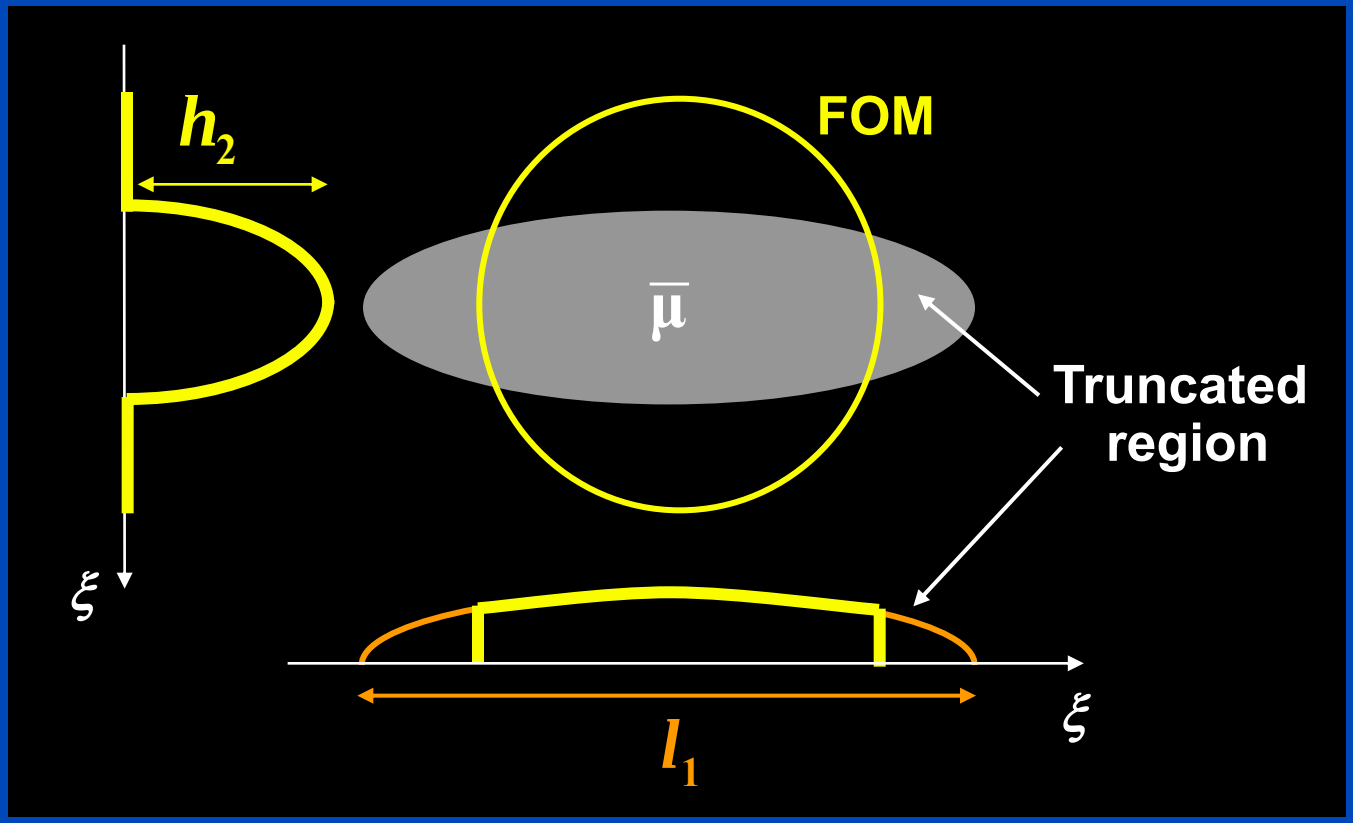


Sinogram, Rawdata

Adaptive Detruncation Method (ADT)



Adaptive Detruncation Method (ADT)



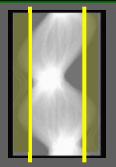
Data consistency

$$l_1 = h_2/\bar{\mu}$$
$$A_1 = A_2$$

Smooth extrapolation

$$\sqrt{a\xi^2 + b\xi + c}$$

Example :
2 × 100 suppressed columns

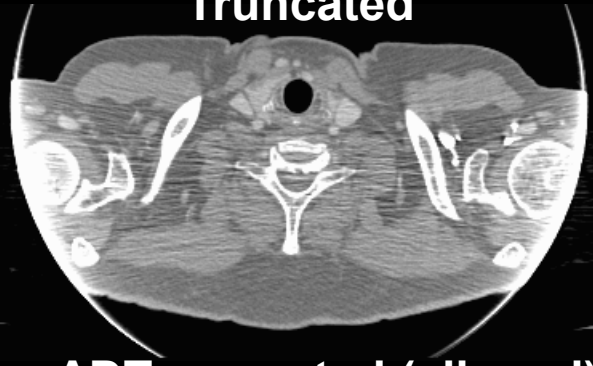


Original

(0 / 1000)

Truncated

(0 / 1000)



ADT corrected

(0 / 1000)

ADT corrected (clipped)

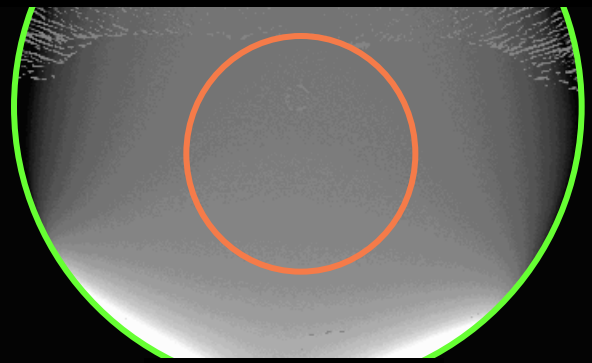
(0 / 1000)

M = – 1.8 HU, σ = 8.6 HU

M = – 0.8 HU, σ = 1.1 HU

Original – Corrected (clipped)

(0 / 50)



Thank You!

This presentation will soon be available at www.dkfz.de/ct.
Parts of the reconstruction software were provided by
RayConStruct® GmbH, Nürnberg, Germany.

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