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Local model reconstruction for metal artifact reduction

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Content

- Artifacts in computed tomography
- Metal artifact reduction
  - Projection completion
  - Iterative reconstruction
- Local models
  - Patchwork structure
  - Patchwork reconstruction
- Measurement: hip phantom
  - Acquisition
  - Phantom
  - Results
- Simulation: hip phantom with bone
- Acceleration effect
- Conclusion and future work

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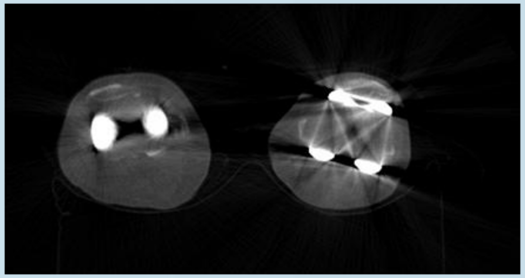
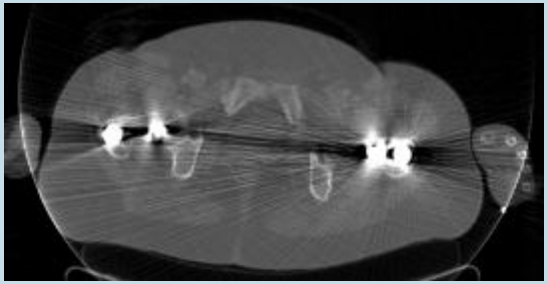
Artifacts in computed tomography (CT)

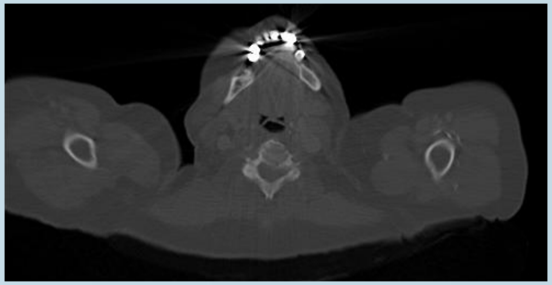
- Important facility for non-destructive imaging
- Metals in the scanned object → severe artifacts
- Artifacts are often due to an incorrect or incomplete modeling of the acquisition
- Most important causes of (metal) artifacts:
  - Beam hardening
  - (Non)-linear partial volume effects
  - Scatter
  - Noise
  - (Motion)



Double knee prosthesis



Hip prostheses



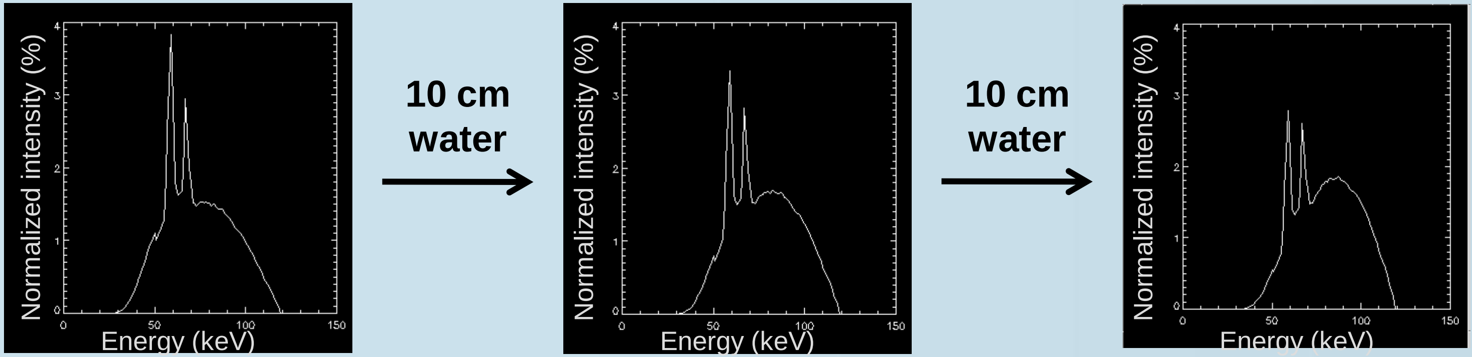
Dental fillings

Artifacts in CT

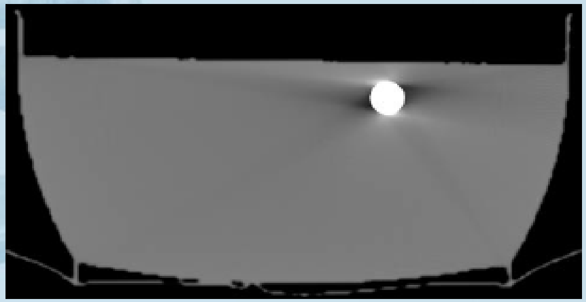
I. Beam hardening

Polychromatic spectrum, beam hardens when going through the object

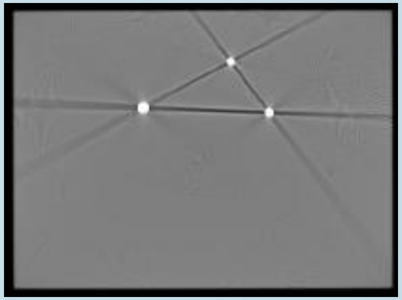
Low energy photons are more likely absorbed



Typical artifact appearance: dark streaks in between metals, dark shades around metals (and cupping)



Iron in water

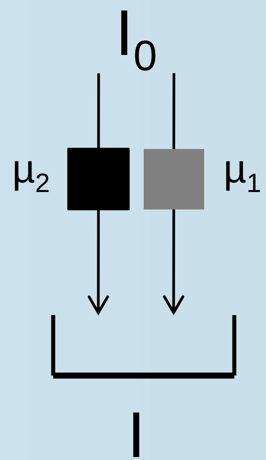


Amalgam in PMMA

Artifacts in CT

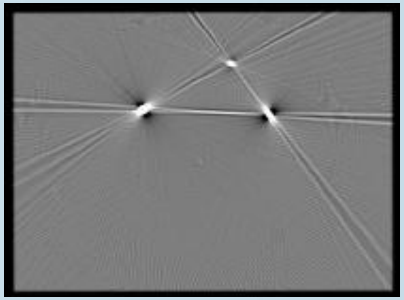
II. (Non)-linear partial volume effects

- Linear: voxels only partly filled with particular substance
- Non-linear: averaging over beam width, focal spot, …



Typical artifact appearance: dark and white streaks connecting edges

Iron in water

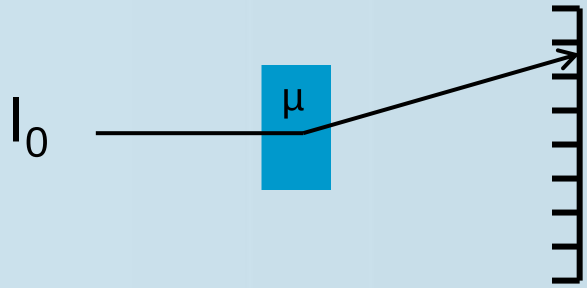


Amalgam in PMMA

Artifacts in CT

III. Scatter

- Compton scatter: deviation form original trajectory
- Scatter grids?



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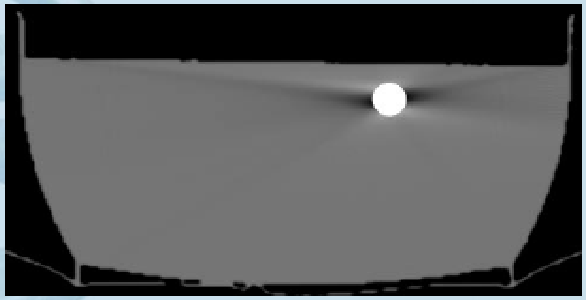

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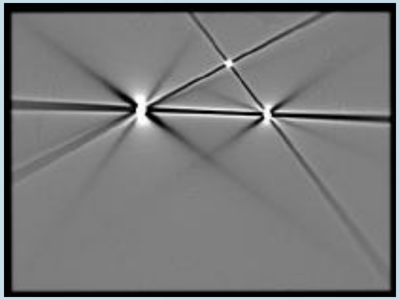


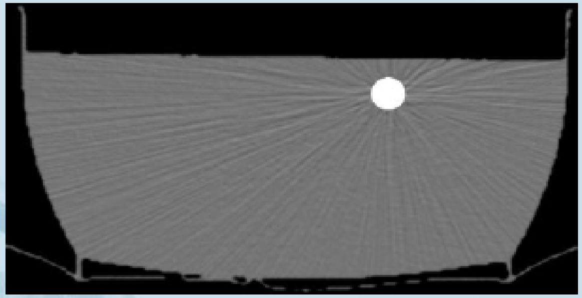
Amalgam in PMMA

Artifacts in CT

IV. Noise

- Quantum nature: Poisson distribution

Typical artifact appearance: streaks around and in between metals



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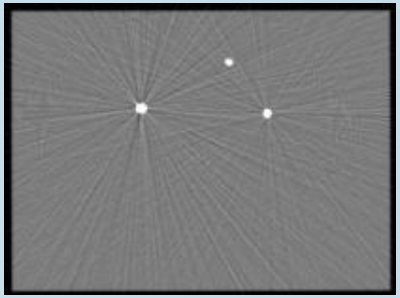

Amalgam in PMMA

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Metal artifact reduction (MAR)

Two important groups of MAR-methods:

<u>Projection completion</u>

<u>Iterative reconstruction</u>

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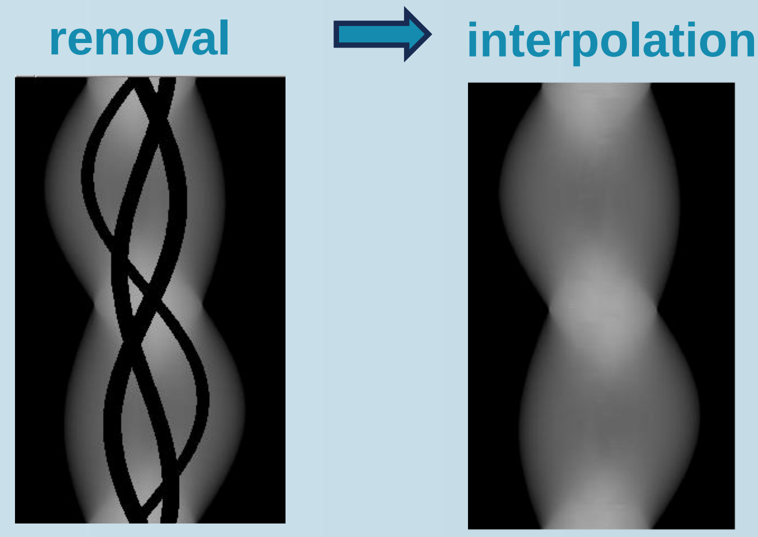
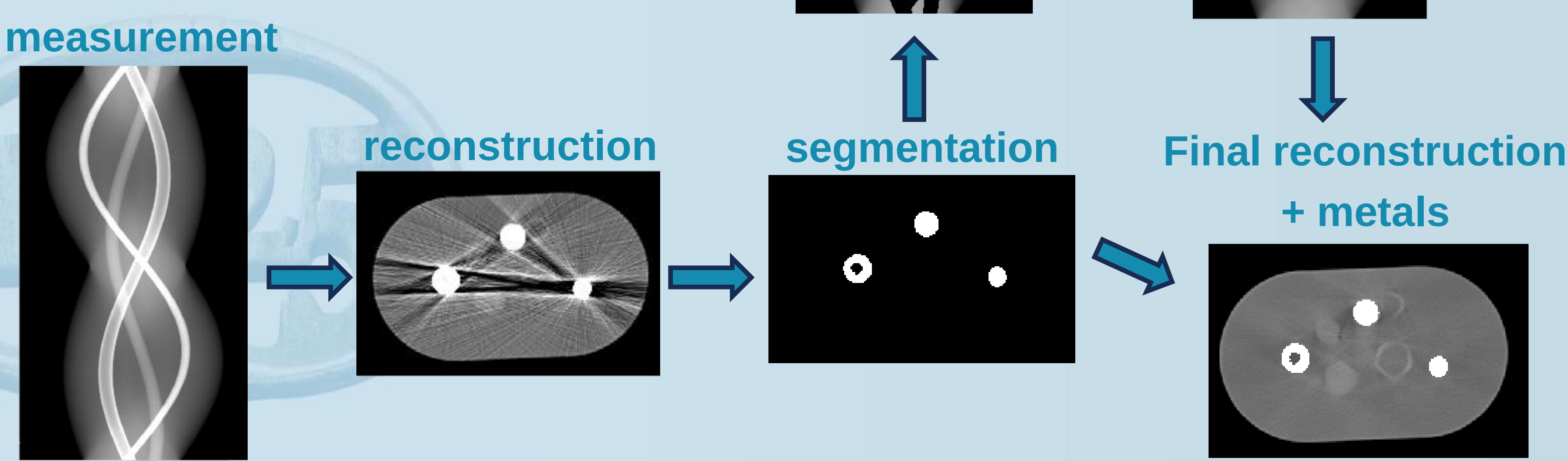
Two important groups of MAR-methods:

Projection completion

→ Metal projections are corrupt

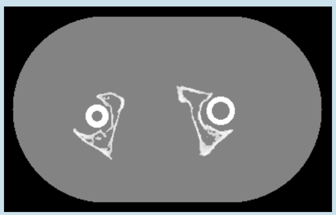
Metal projection are selected, removed and replaced by interpolated projections





Projection completion

- Standard *PC* → linear interpolation
- *PC-NMAR** → linear interpolation with normalisation for intersection lengths of differents tissues
- $FSMAR^* = NMAR^{low} + w_j\, FBP^{high} + (1 - w_j)\, NMAR^{high}$

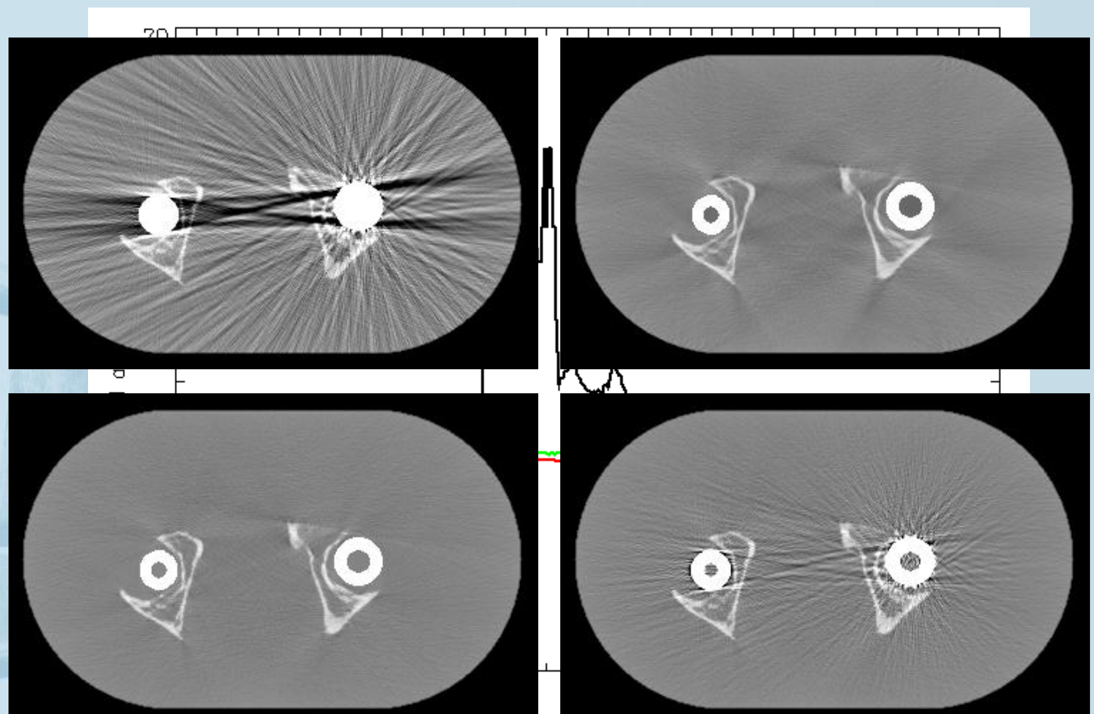


FBP

PC

PC - NMAR

PC - FSMAR



Meyer et al, Med. Phys., (2010 & 2011)

Metal artifact reduction (MAR)

Two important groups of MAR-methods:

Projection completion

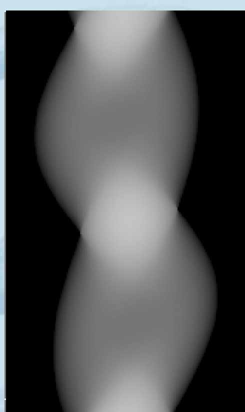
Iterative reconstruction

Metal artifact reduction (MAR)

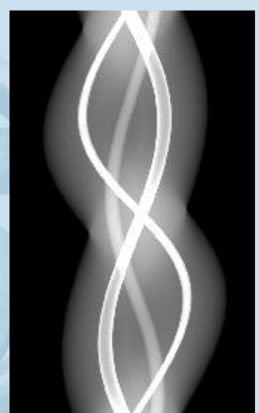
Two important groups of MAR-methods:

Initial estimate

Projection



Measurement

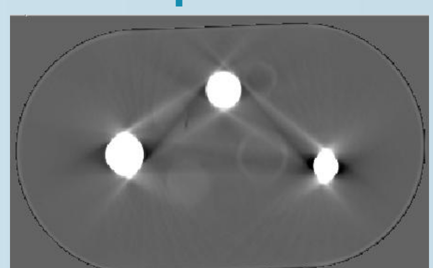


<u>Iterative reconstruction</u>

→ Artifacts are caused by the use of an incorrect/inaccurate acquisition model

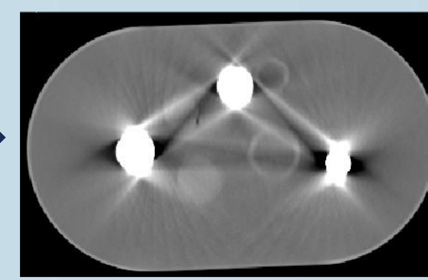
Accurate modeling (e.g. polychromatic)

Update



+

Next estimate



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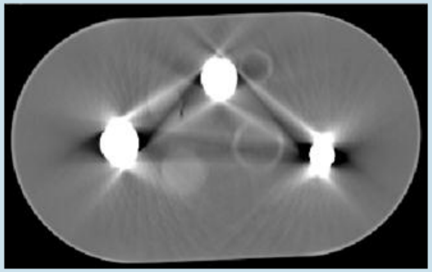
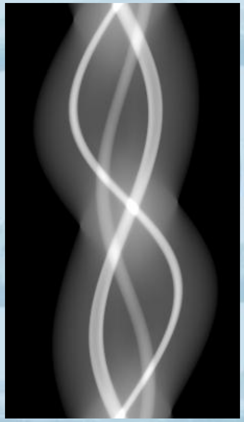
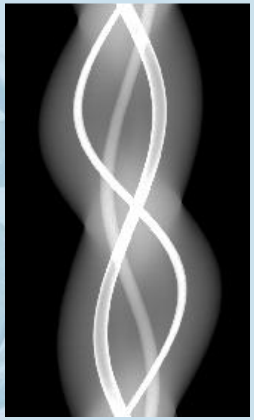
NEW estimate



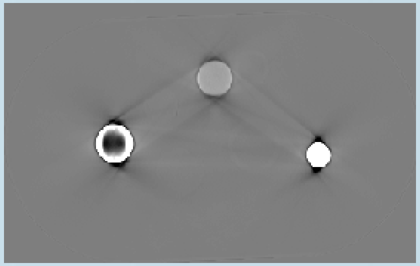
Projection



Measurement

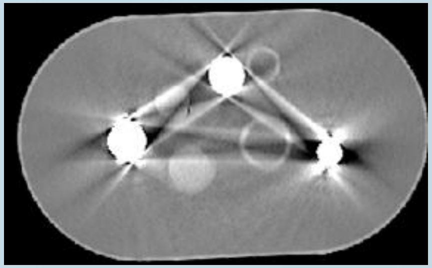


Update



+

Next estimate



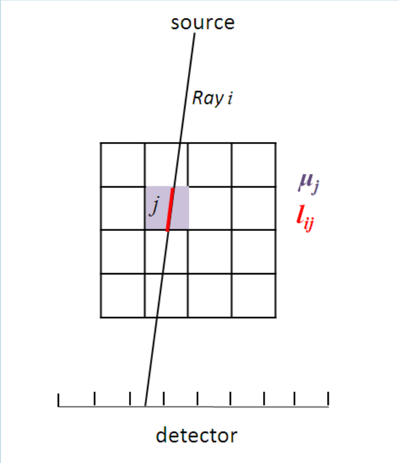
Energy model: MLTR + MLTR-C

- Poisson Likelihood:

$$L = \sum_{i}^{I} \left(y_i \ln \hat{y}_i - \hat{y}_i \right)$$

- Update:

$$\mu_j^{new} = \mu_j^{old} - \frac{\left.\dfrac{\partial L}{\partial \mu_j}\right|_{\vec{\mu}^{old}}}{\sum_h^J \left.\dfrac{\partial^2 L}{\partial \mu_j \partial \mu_h}\right|_{\vec{\mu}^{old}}}$$



- Projection estimate
  - Monochromatic model – MLTR*

$$\hat{y}_i = b_i \exp\left(-\sum_j^J l_{ij} \mu_j \right)$$

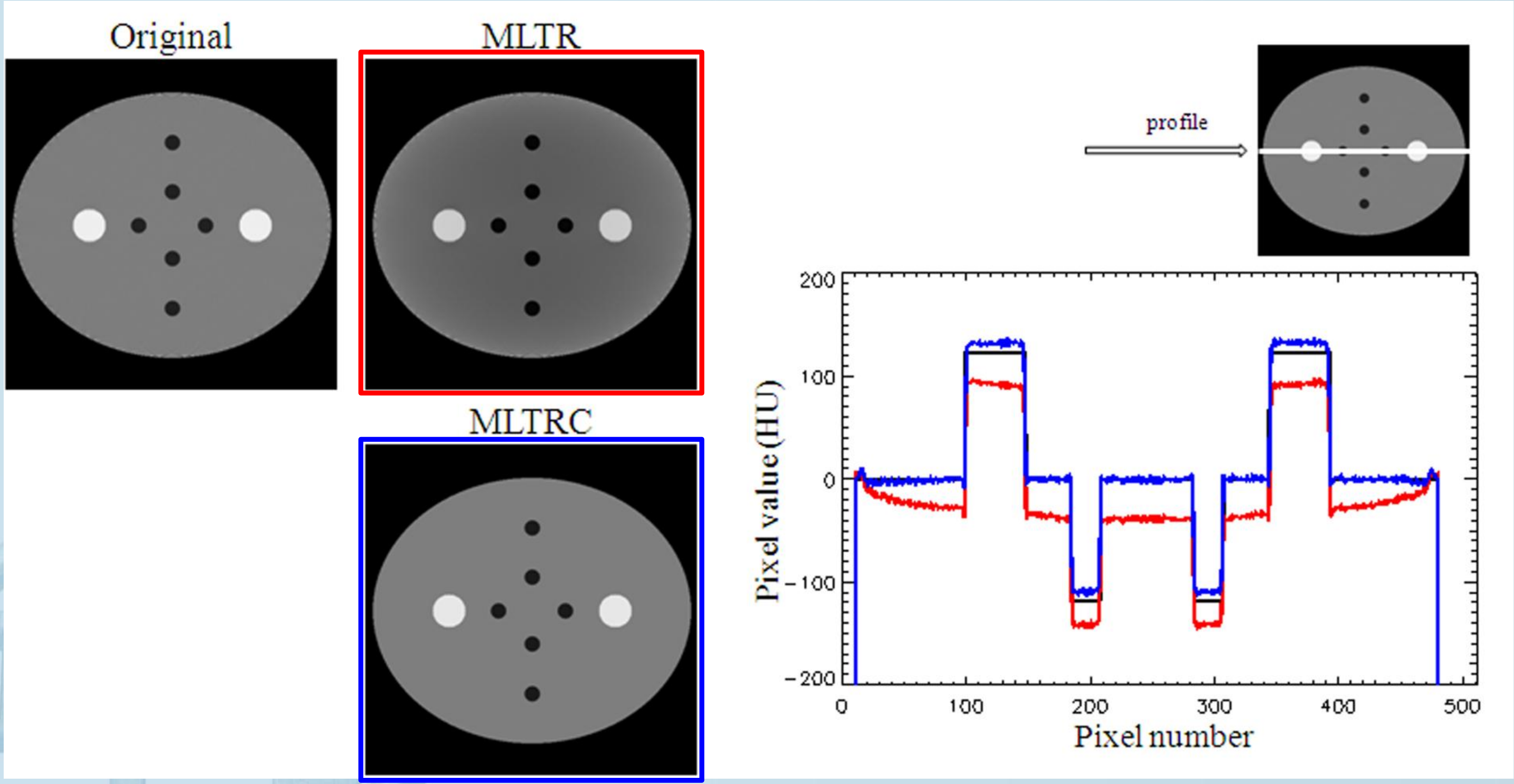
3 (back)projections per iteration

  - Simple polychromatic correction factor – MLTRC

$$\hat{y}_i = \sum_k b_{ik} \exp\left(-P_k \sum_j^J l_{ij} \mu_j \right) \qquad P_k = \frac{\mu_k^{\text{water}}}{\mu_{\text{ref}}^{\text{water}}}$$

*Nuyts et al, Phys. Med. Biol., 1998; 43: 729-737

Energy model: MLTRC

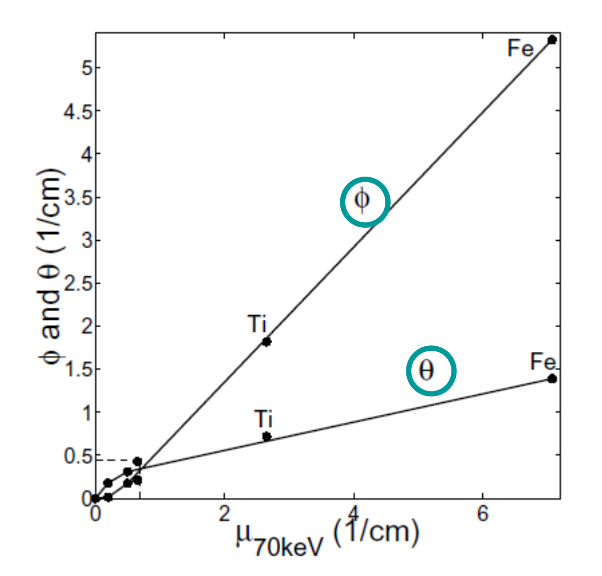


Energy model: IMPACT

- **I**terative **M**aximum **L**ikelihood **P**olychromatic **A**lgorithm for **CT** – **IMPACT***

Projection estimate takes (full) polychromaticity into account:

$$\hat{y}_i = b_i \exp\left(-\sum_j^J l_{ij} \mu_j \right) \Rightarrow \hat{y}_i = \sum_k^K b_{ik} \exp\left(-\sum_j^J l_{ij} \mu_{jk} \right)$$



$$\mu_{jk} = \text{photo-electric} + \text{Compton at energy k}$$

$$\mu_{jk} = \phi_j \cdot \Phi_k + \theta_j \cdot \Theta_k$$

Energy dependence

Material dependence

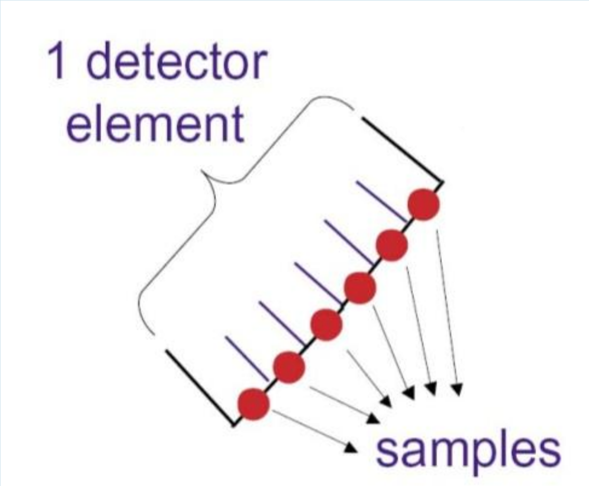
8 (back)projections per iteration

*De Man et al, Trans. Med. Im., 2001; 20 (10): 999-1008

Resolution model

Resolution model:

- Pixel size
- Sampling detector elements



Metal artifact reduction (MAR)

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Two important groups of MAR-methods:

Projection completion

→ Metal projections are corrupt

Metal projection are selected, removed and replaced by interpolated projections

+ Fast (FBP-based)
+ Often artifact free (small and few metals)

- Loss of information (metals and edges)

Iterative reconstruction

→ Artifacts are caused by the use of an incorrect/inaccurate acquisition model

Accurate modeling (e.g. polychromatic)

+ All information is used

-Slow **Local model reconstruction**

-Often not artifact-free

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Local models iterative reconstruction

Hypothesis: sophisticated models only needed in the vicinity of metals

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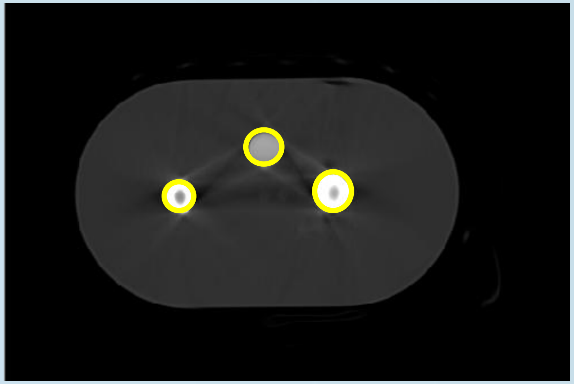
Maximum likelihood iterative reconstruction

Select metal areas = patches: thresholding



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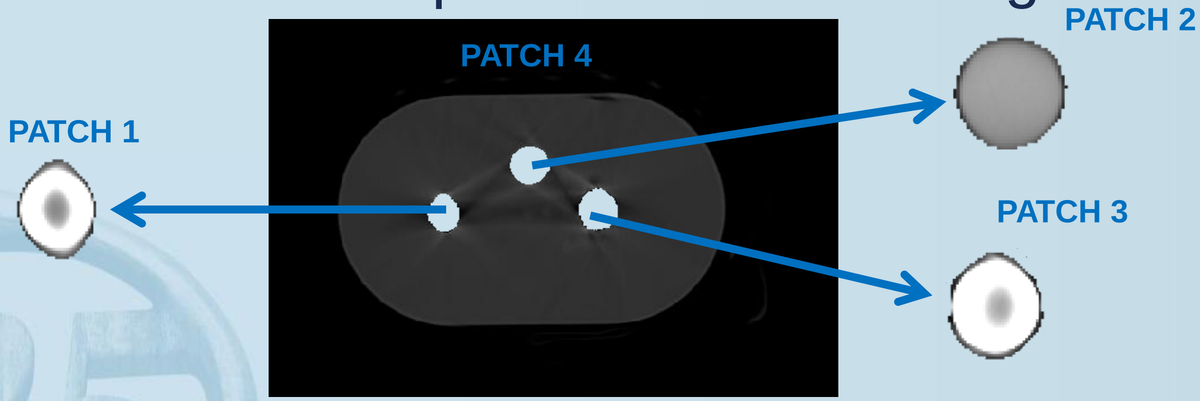
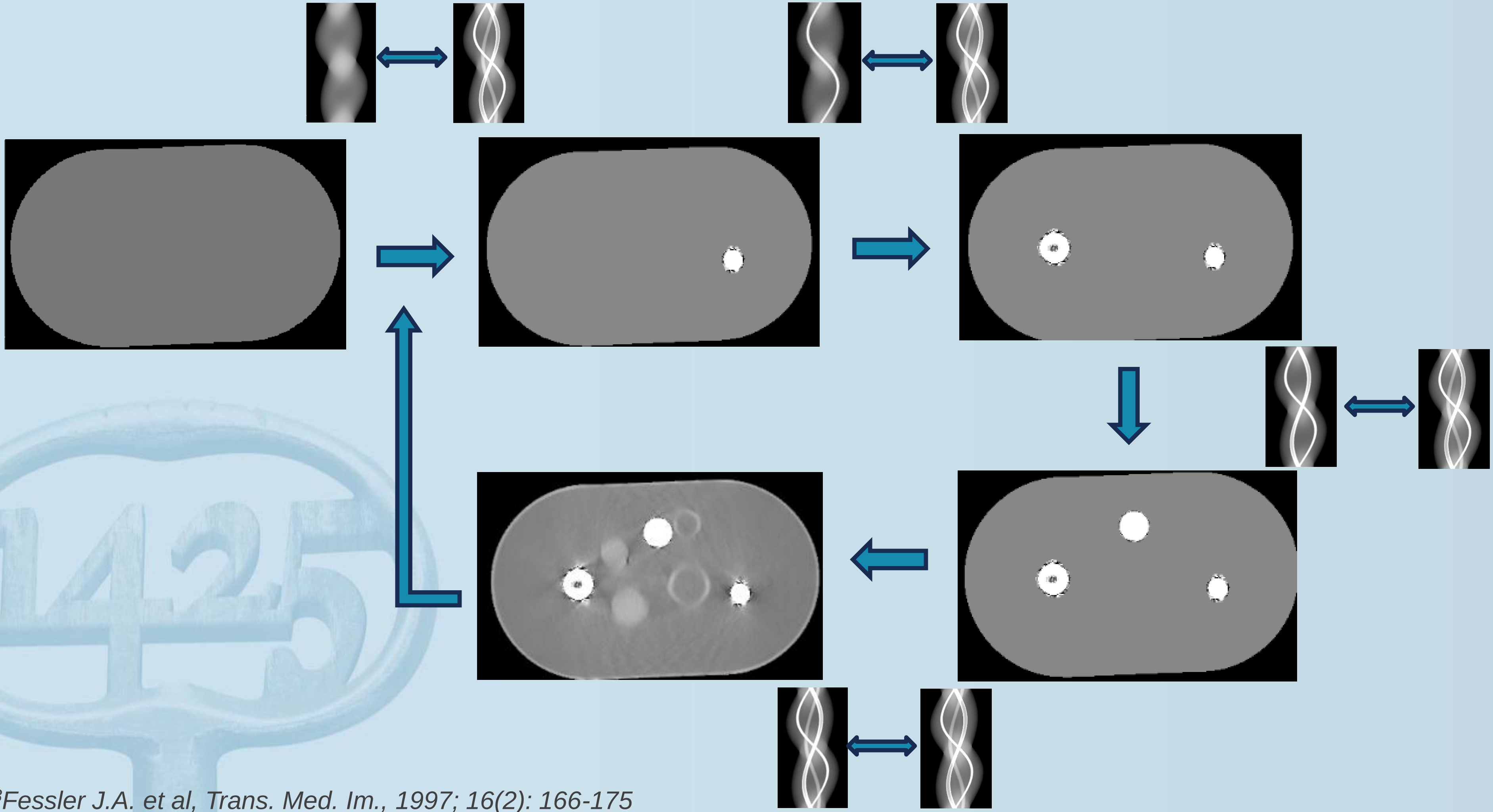


Define model for each patch: energy and resolution

Local models iterative reconstruction

Sequential update of the different patches[3]



[3]Fessler J.A. et al, Trans. Med. Im., 1997; 16(2): 166-175

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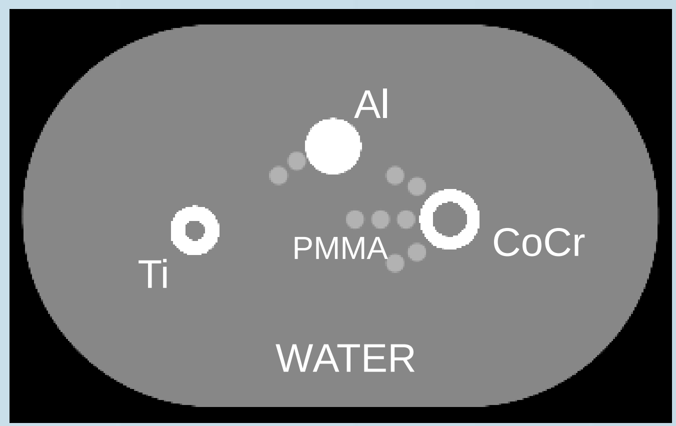
Acquisition

Siemens Sensation 16 (part of Biograph 16 PET/CT)

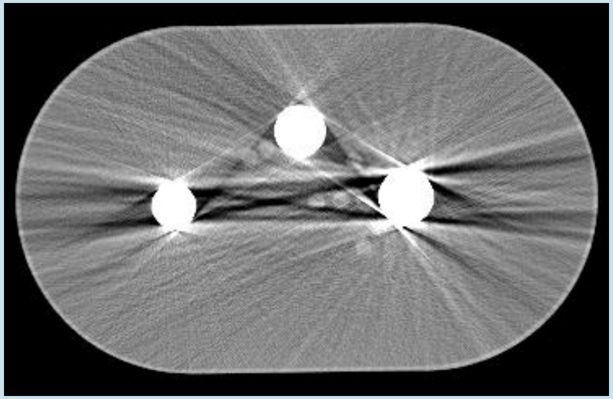
- 120 kV, 300 mA
- 2 x 1.00 mm
- Circular scan, 0.5 s per rotation (no flying focal spot)
- 2D reconstruction of 1 slice

Body phantom with two femoral implants

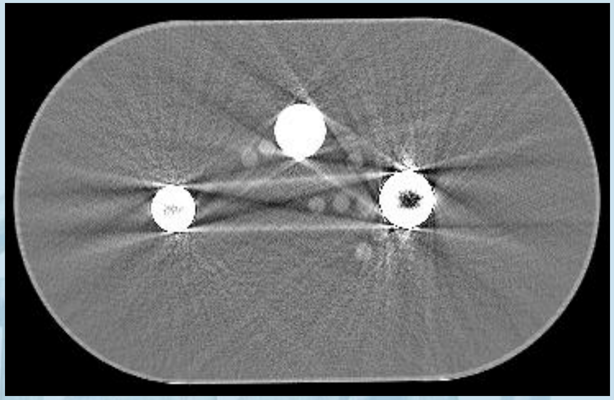


Results: patch update, energy model

FBP



IMPACT



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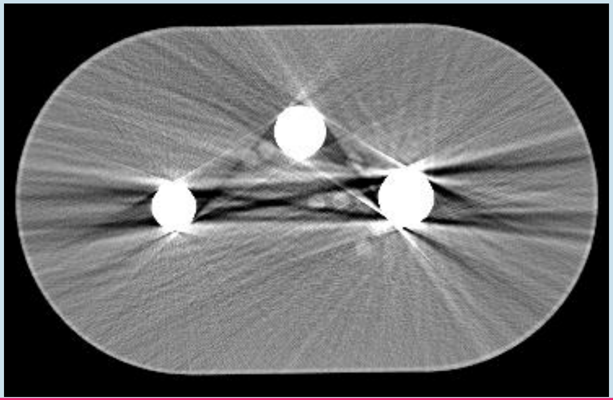

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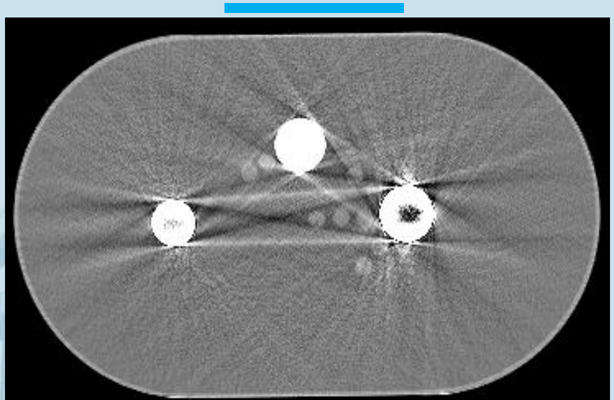
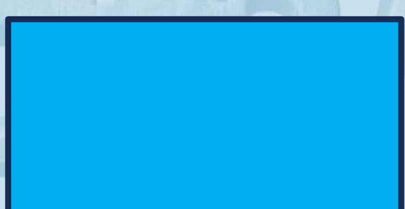
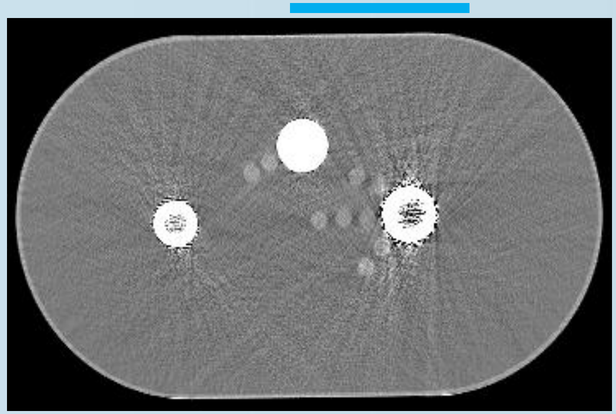
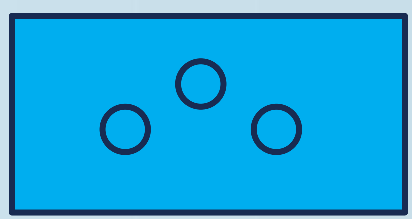




Patched IMPACT





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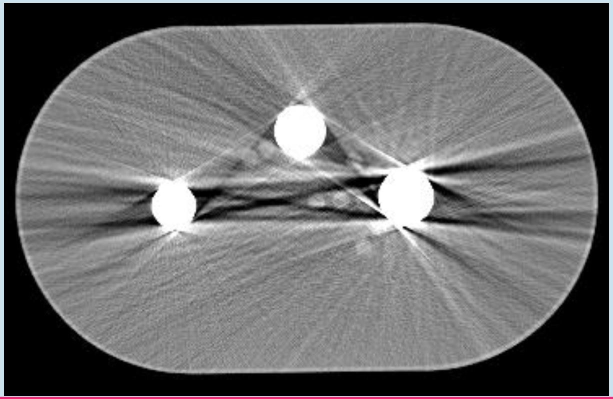

Improved convergence?

$$\mu_j^{new} = \mu_j^{old} - \frac{\left.\frac{\partial L}{\partial \mu_j}\right|_{\vec{\mu}^{old}}}{\sum_h^J \left.\frac{\partial^2 L}{\partial \mu_j \partial \mu_h}\right|_{\vec{\mu}^{old}}}$$

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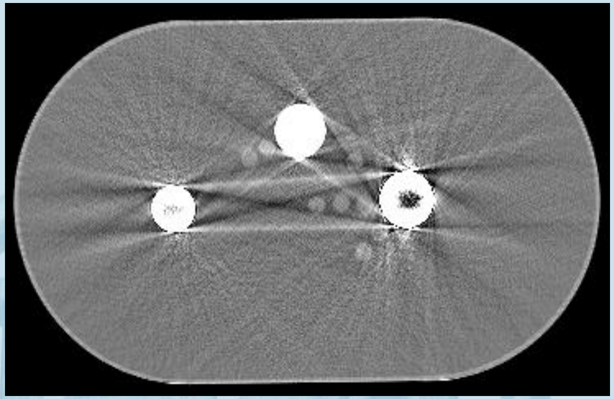

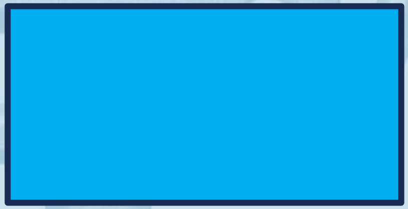

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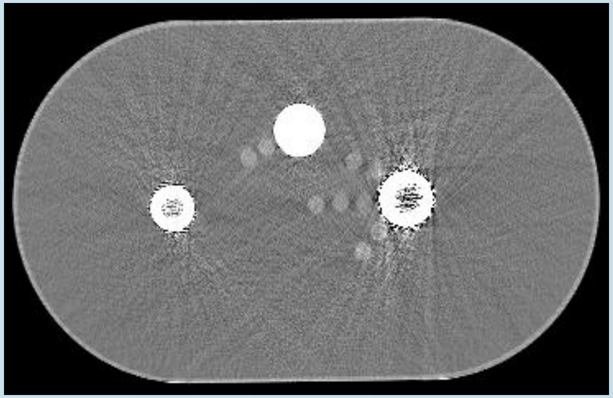

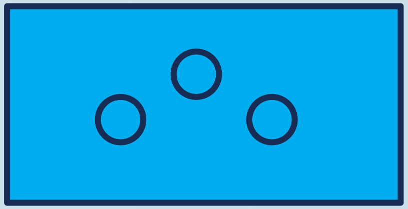

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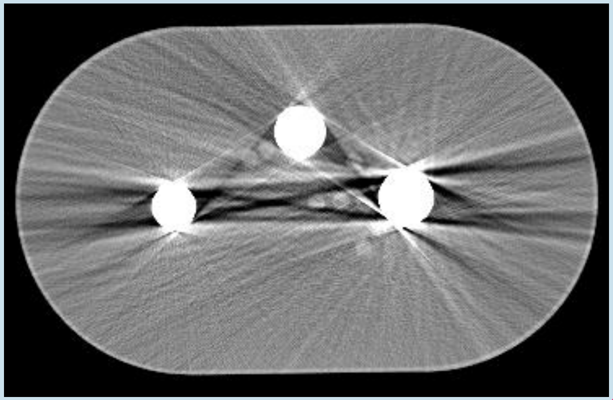

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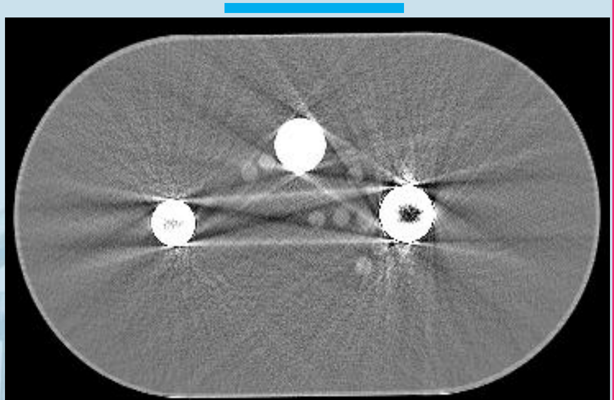

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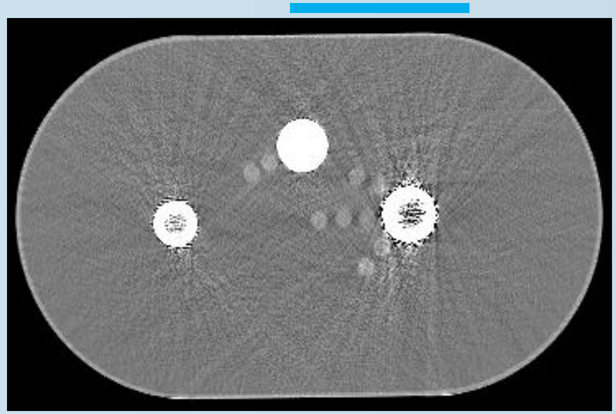
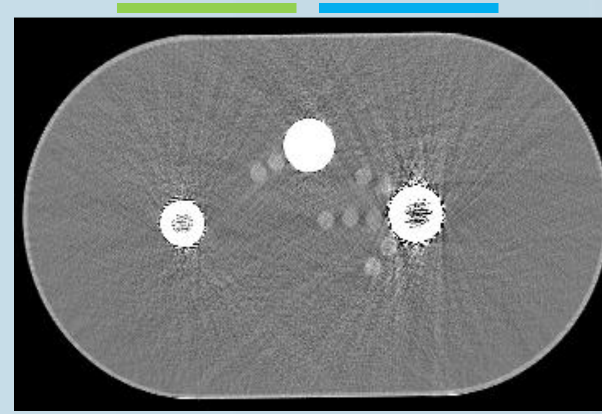
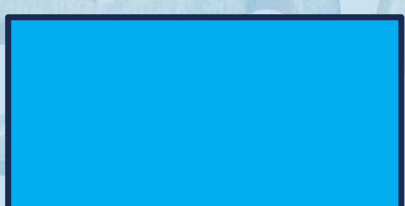
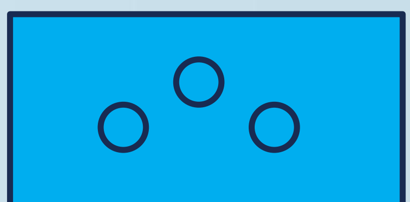
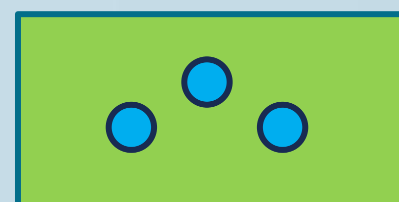


MLTRC + IMPACT









Results: patch update, energy model

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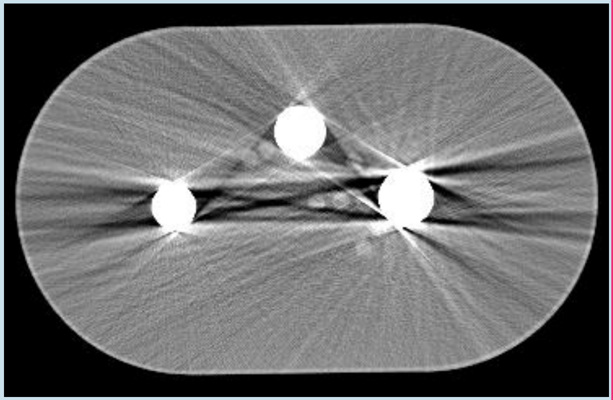
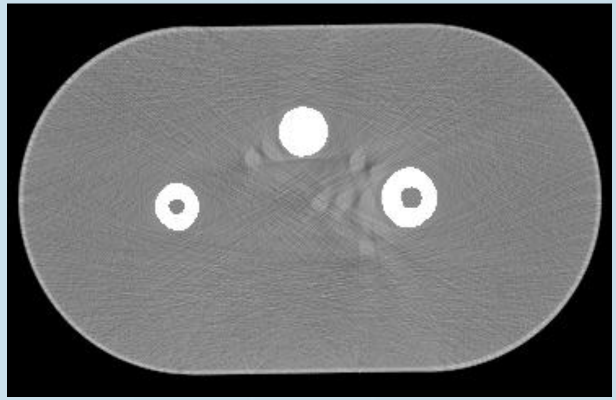
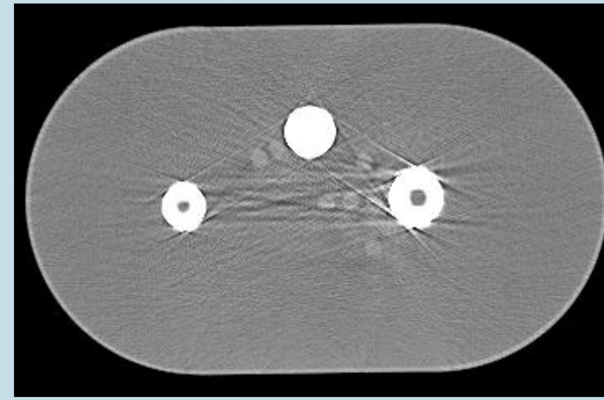


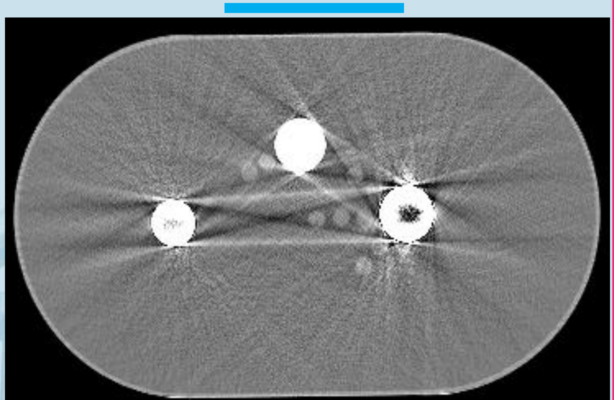
PC - NMAR



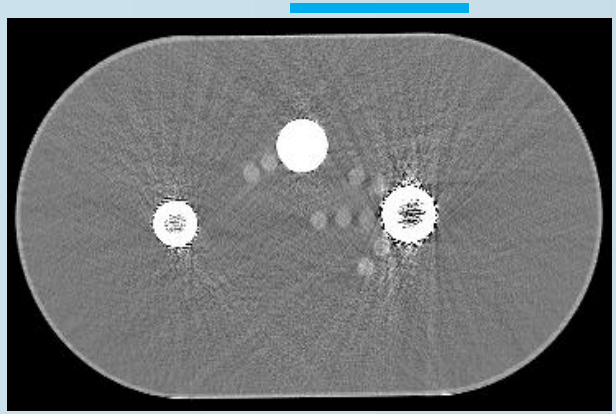
PC-FSMAR



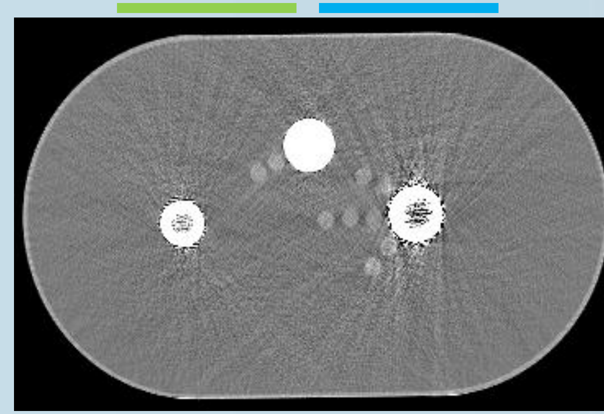
IMPACT

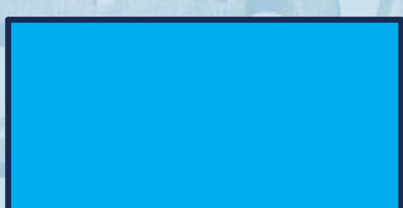


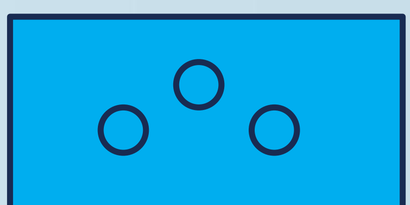
Patched IMPACT

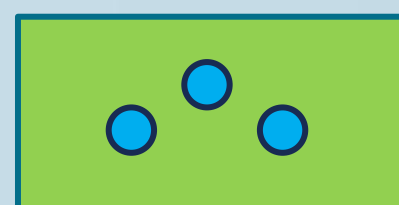


MLTRC + IMPACT

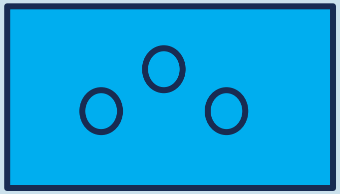








Results: Resolution



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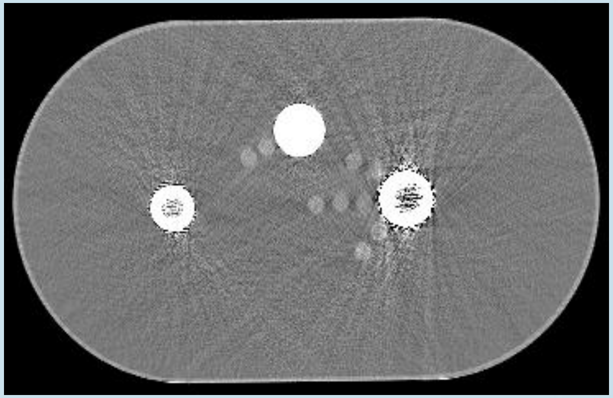
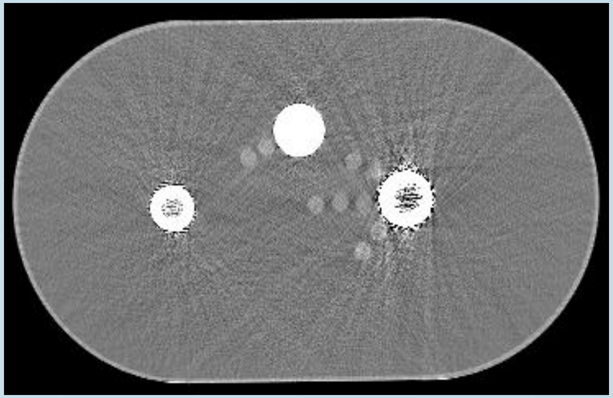
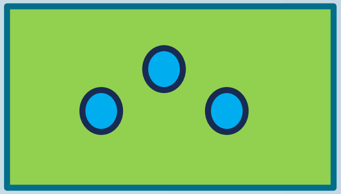
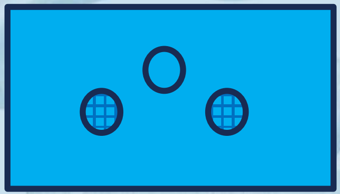


MLTRC + IMPACT

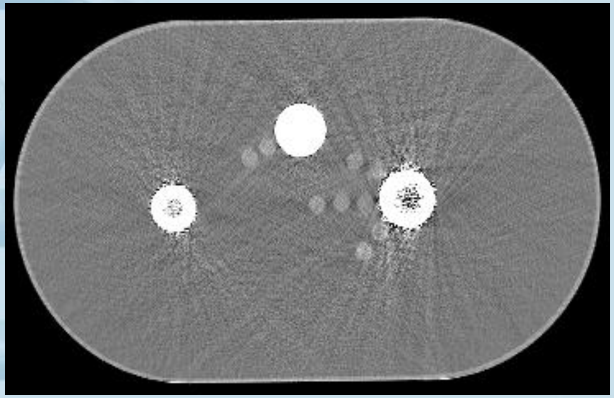






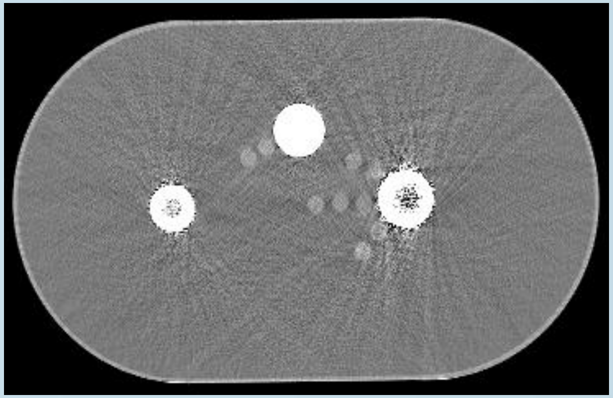
Patched IMPACT

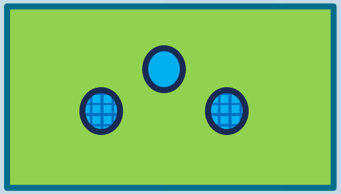
Increased res. for implant-patches



MLTRC + IMPACT

Increased res. for implant-patches





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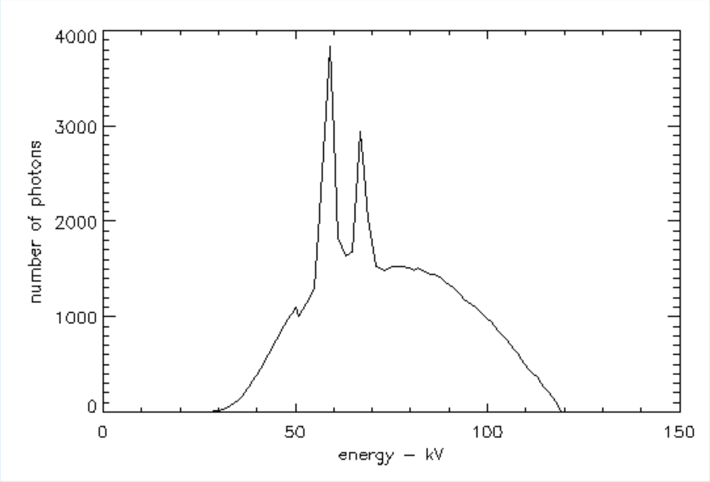
Simulation with bone

Simulation of Siemens Sensation 16

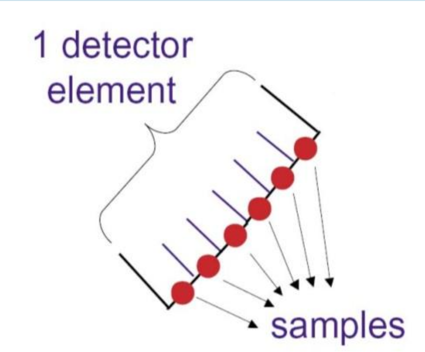
- Polychromatic spectrum - 120 kV
- 2D circular scan (no flying focal spot)

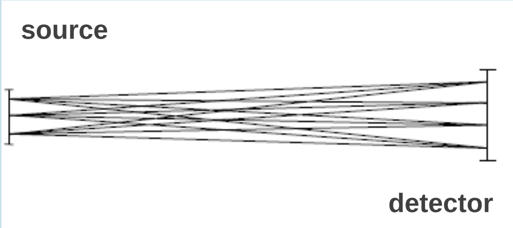


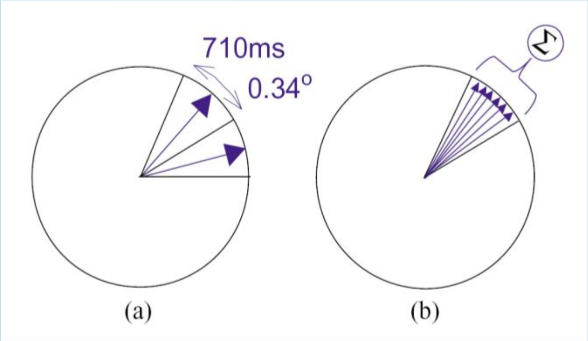
Simulation with bone

Simulation of Siemens Sensation 16

- Polychromatic spectrum - 120 kV
- 2D circular scan (no flying focal spot)
- Subsampled pixels, views, source and detector elements





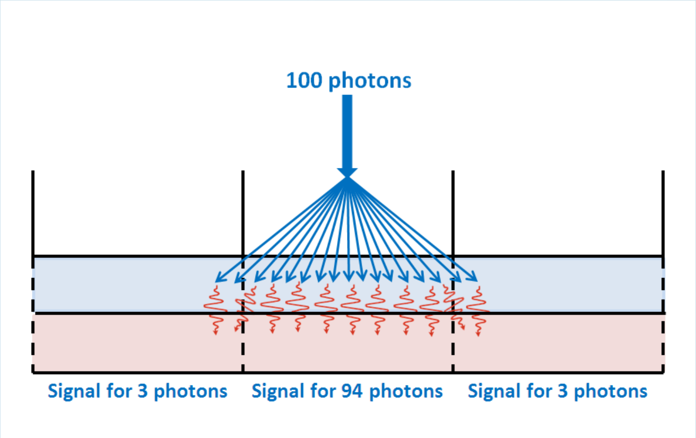


Figures: PhD Thesis Bruno De Man 2001

Simulation with bone

Simulation of Siemens Sensation 16

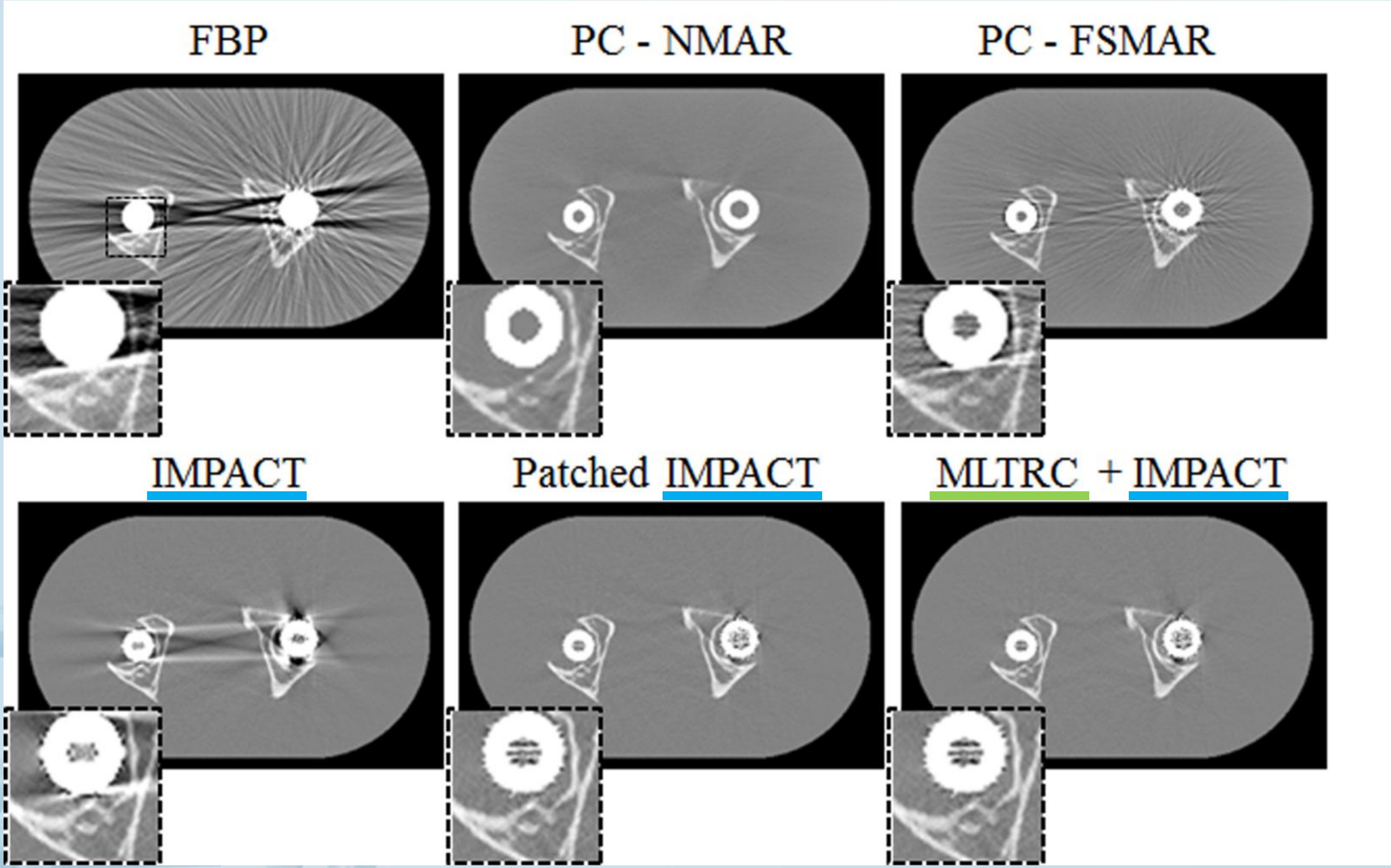
- Polychromatic spectrum - 120 kV
- 2D circular scan (no flying focal spot)
- Subsampled pixels, views, source and detector elements
- Cross talk + afterglow

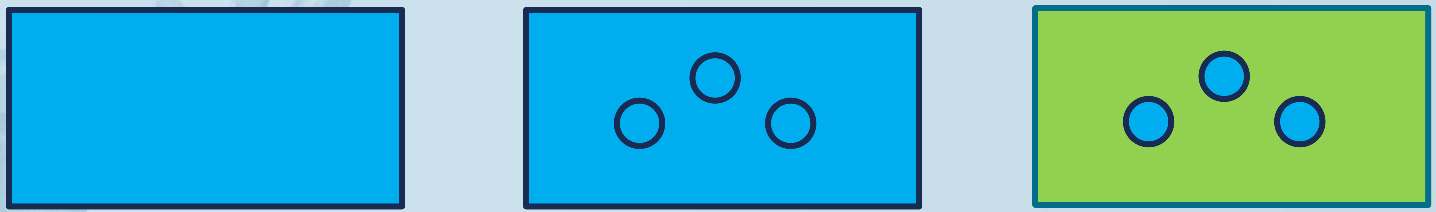


Body phantom with two femoral implants

& realistic bone structure

Simulation with bone





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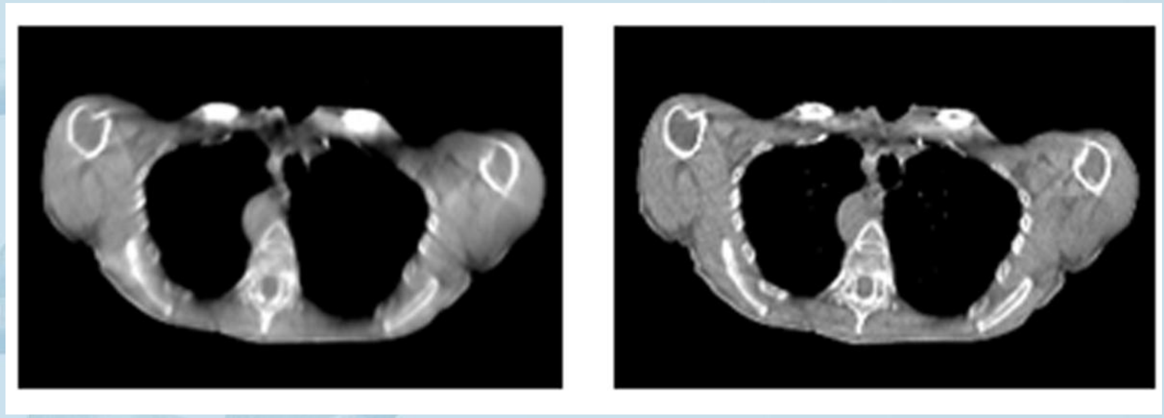
Acceleration

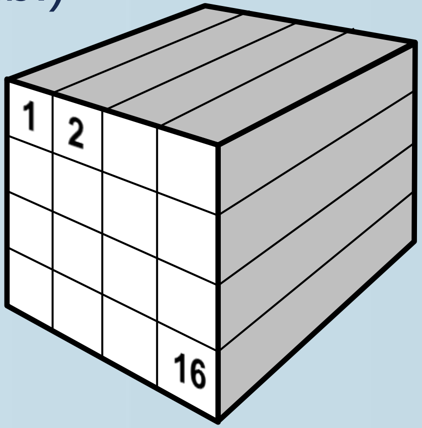
Improved convergence?

$$\mu_j^{new} = \mu_j^{old} - \frac{\left.\frac{\partial L}{\partial \mu_j}\right|_{\vec{\mu}^{old}}}{\sum_{h}^{J} \left.\frac{\partial^2 L}{\partial \mu_j \partial \mu_h}\right|_{\vec{\mu}^{old}}}$$

Patient CT data – low dose whole body: (3 it., 40 sub.)



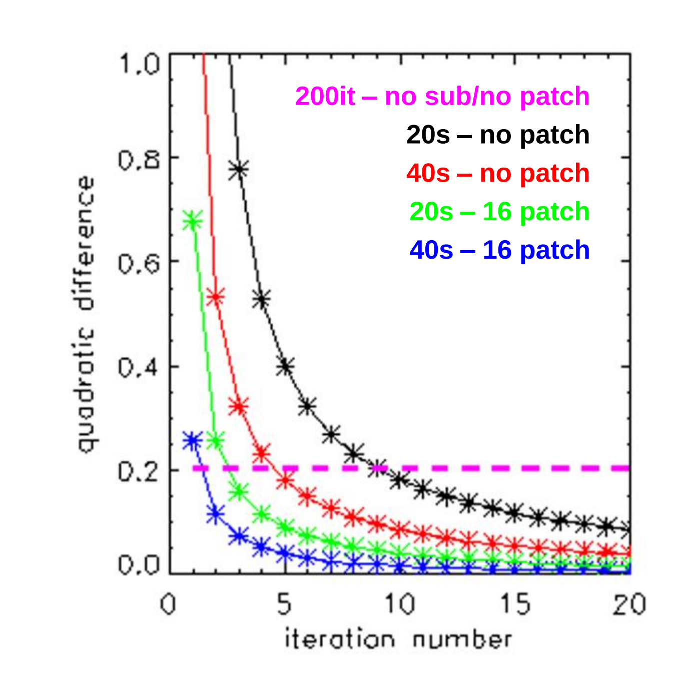
MLTR **16 patches**

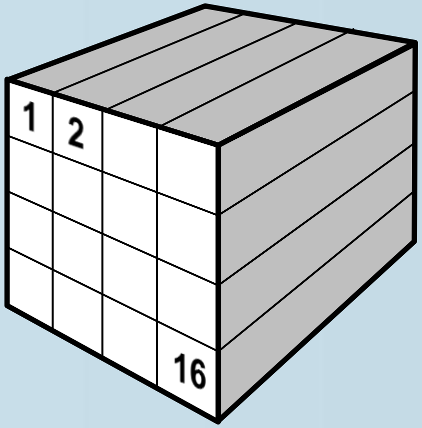


Acceleration

Improved convergence?

$$\mu_j^{new} = \mu_j^{old} - \frac{\left.\frac{\partial L}{\partial \mu_j}\right|_{\vec{\mu}^{old}}}{\sum_h^J \left.\frac{\partial^2 L}{\partial \mu_j \partial \mu_h}\right|_{\vec{\mu}^{old}}}$$





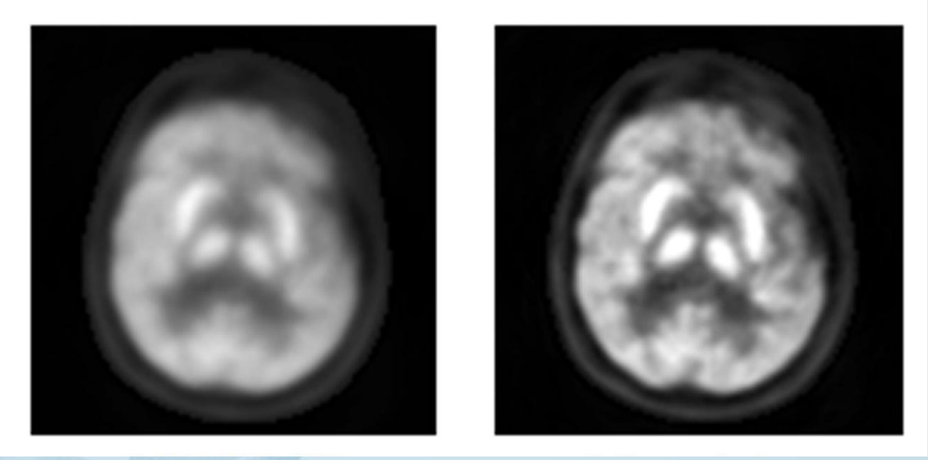
Accerated by √nrpatch

Acceleration

Improved convergence?

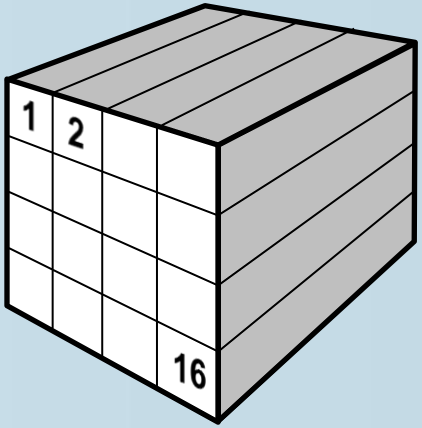
$$\lambda_j^{new} = \lambda_j^{old} - \frac{\left.\dfrac{\partial L}{\partial \lambda_j}\right|_{\vec{\lambda}^{old}}}{\displaystyle\sum_h^J \left.\frac{\partial^2 L}{\partial \lambda_j \partial \lambda_h}\right|_{\vec{\lambda}^{old}}}$$

Patient FDG PET data – (3 it., 10 sub.)



NEGML*

16 patches



*Nuyts et al., J Nucl Med, 2002; 43: 1054-1062

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Conclusion

- Local model reconstruction without losing image quality
- Improved convergence due to sequential update
- Less deformations ↔ projection completion
- Acceleration effect (efficient memory usage)

- Applicable to other modalities and other methods
- Introduction of priors: can also be patched

Future work

- Spiral CT: patient data
  - (Axial) partial volume effect
  - Scatter
  - Motion

Thank you! Questions?