18 Feb. 2019

# Forward and Cross-Scatter Estimation in Dual Source CT Using the Deep Scatter Estimation (DSE)

**Tim Vöth[1,2], Joscha Maier[1,2] , Julien Erath[1,3] and Marc Kachelrieß[1,2]**

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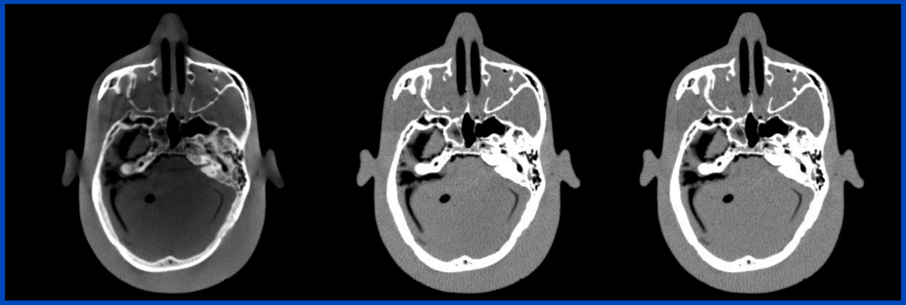
DEUTSCHES KREBSFORSCHUNGSZENTRUM IN DER HELMHOLTZ-GEMEINSCHAFT

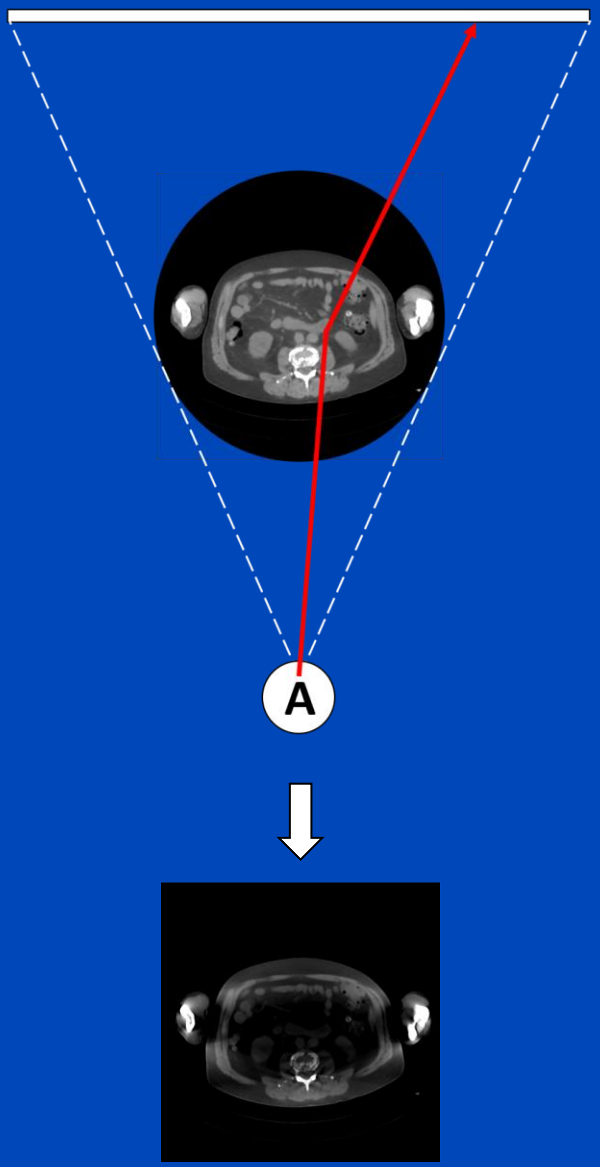
# Overview

- **Scatter degrades image quality**
- **Ideally: correct scatter using Monte Carlo (MC) simulations**
  - **→ very long computation times**
- **Idea of the deep scatter estimation (DSE): train neural network to reproduce MC scatter distributions**
  - **→ fast and highly accurate scatter estimation**
- **Recently: demonstrated outstanding performance of DSE for cone-beam CT[1,2]:**

**Uncorrected** **DSE** **Ground truth**



**C = 0 HU, W = 1000 HU**




[1] Maier, Kachelrieß et al. *Med. Phys.* (2019)
[2] Maier, Kachelrieß et al. *J. Nondestruct. Eval.* (2018)

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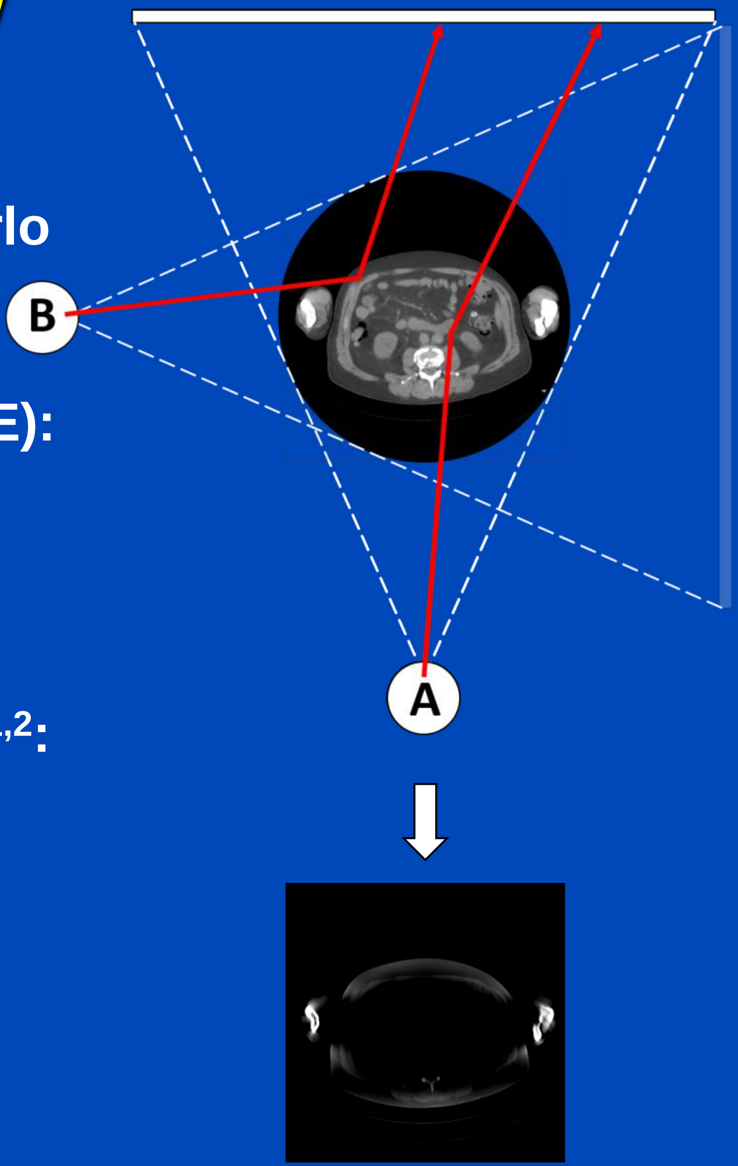
- Recently: demonstrated outstanding performance of DSE for cone-beam CT[1,2]:
- Now: test DSE in a dual source CT
- Challenge: cross-scatter




[1] Maier, Kachelrieß et al. *Med. Phys.* (2019)
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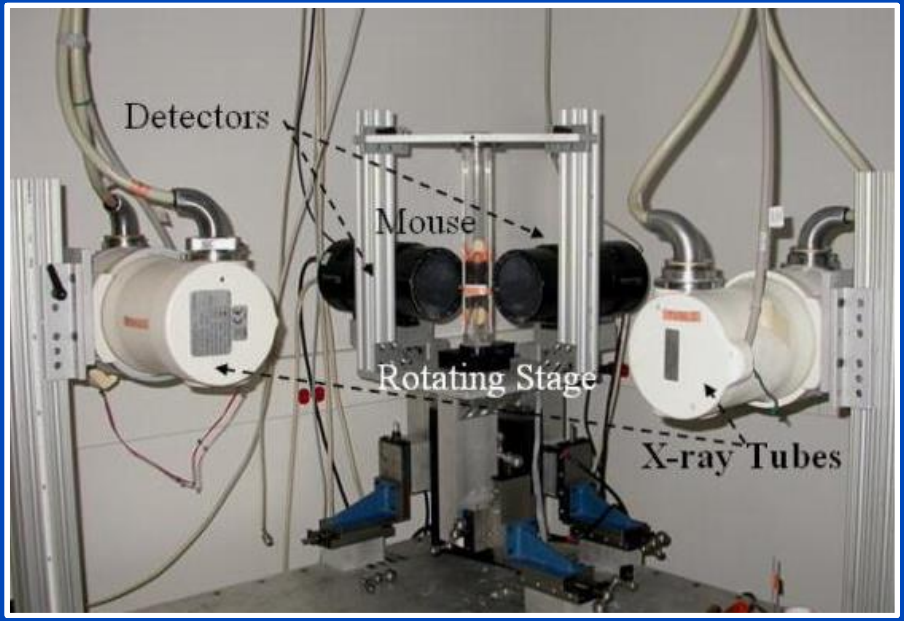
# Why DSCT?

- Increased temporal resolution
- Dual energy imaging


[1]



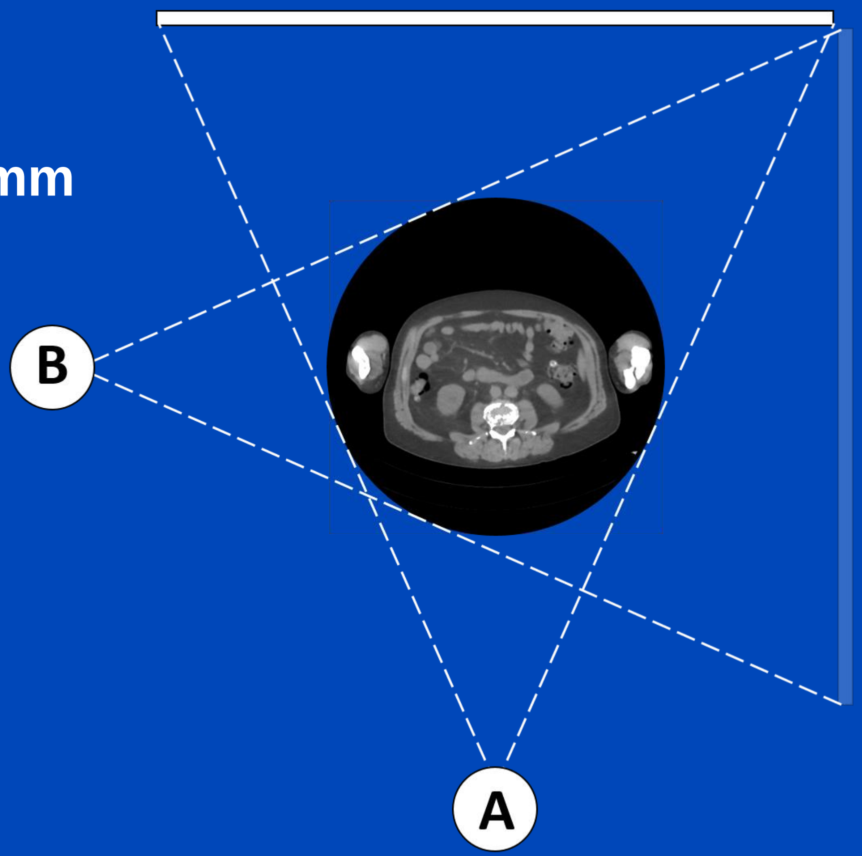

[2]

[1] Siemens Healthcare GmbH, Henkestr. 127, 91052 Erlangen, Germany.
[2] Badea, Piantadosi et al. *Am. J. Physiol. Lung Cell. Mol. Physiol.* (2012)

# Simulated Geometry

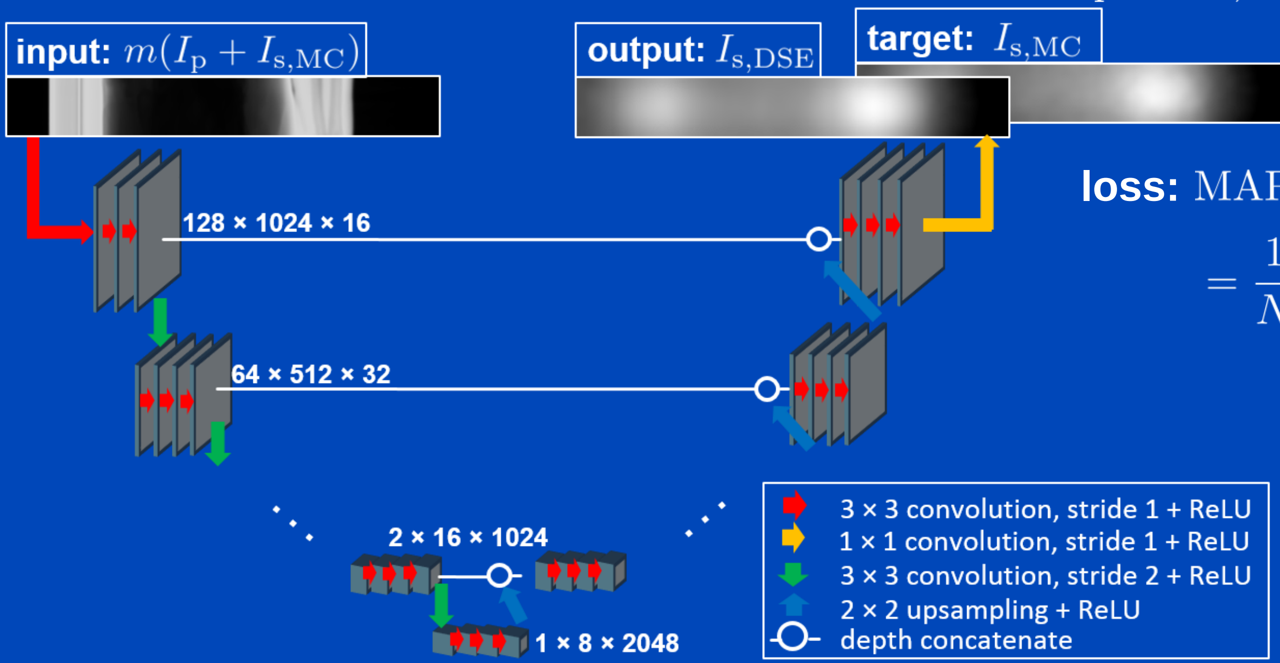
**Simplified geometry:**

- **128 × 1024 pixels, flat detector**
- ***z*-collimation at isocenter C = 70 mm**
- **Two identical sources**
- **Angle between sources = 90°**
- **No anti-scatter grid**



# DSE – Basic Principle

- Train a U-Net-like[1] CNN to estimate total scatter $I_{\mathrm{s,MC}}$ given only (a mapping m of) the total intensity $I_{\mathrm{p}} + I_{\mathrm{s,MC}}$ as input




**loss:** $\mathrm{MAPE}$

$$= \frac{1}{N} \sum \left| \frac{I_{\mathrm{s,MC}} - I_{\mathrm{s,DSE}}}{I_{\mathrm{s,MC}}} \right|$$

[1] Ronneberger, Brox et al. [*MICCAI*] (2015)

dkfz.

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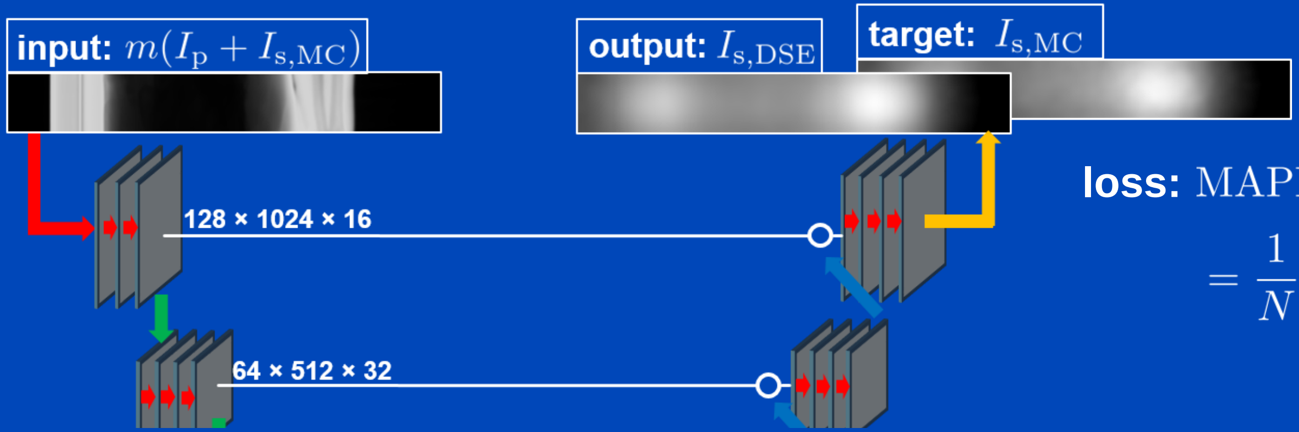


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- **Corrected intensity:**

~~$I_{\mathrm{corrected}} = I_{\mathrm{p}} + I_{\mathrm{s,MC}} - I_{\mathrm{s,DSE}}$~~

- **To prevent overestimation:**

$$I_{\mathrm{corrected}} = \begin{cases} (1 - 0.985) \cdot (I_{\mathrm{p}} + I_{\mathrm{s,MC}}) & \text{if } I_{\mathrm{s,DSE}} > 0.985 \cdot (I_{\mathrm{p}} + I_{\mathrm{s,MC}}) \\ I_{\mathrm{p}} + I_{\mathrm{s,MC}} - I_{\mathrm{s,DSE}} & \text{else} \end{cases}$$

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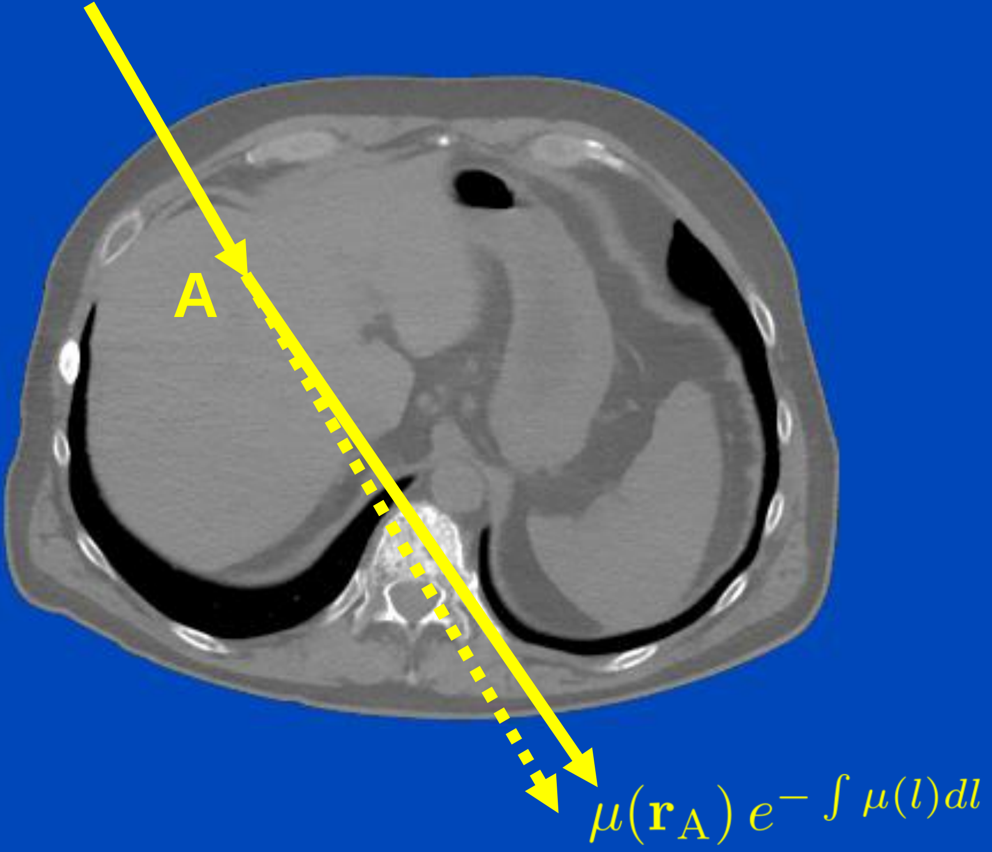
# DSE – Input Mapping

- **Mapping: pep[1] i.e.** $m = p\,e^{-p}$ **with** $p = -\ln(I_\mathrm{p} + I_\mathrm{s,MC})$




[1] **Ohnesorge, Klingenbeck-Regn et al.** ***Eur. Radiol.*** **(1999)**

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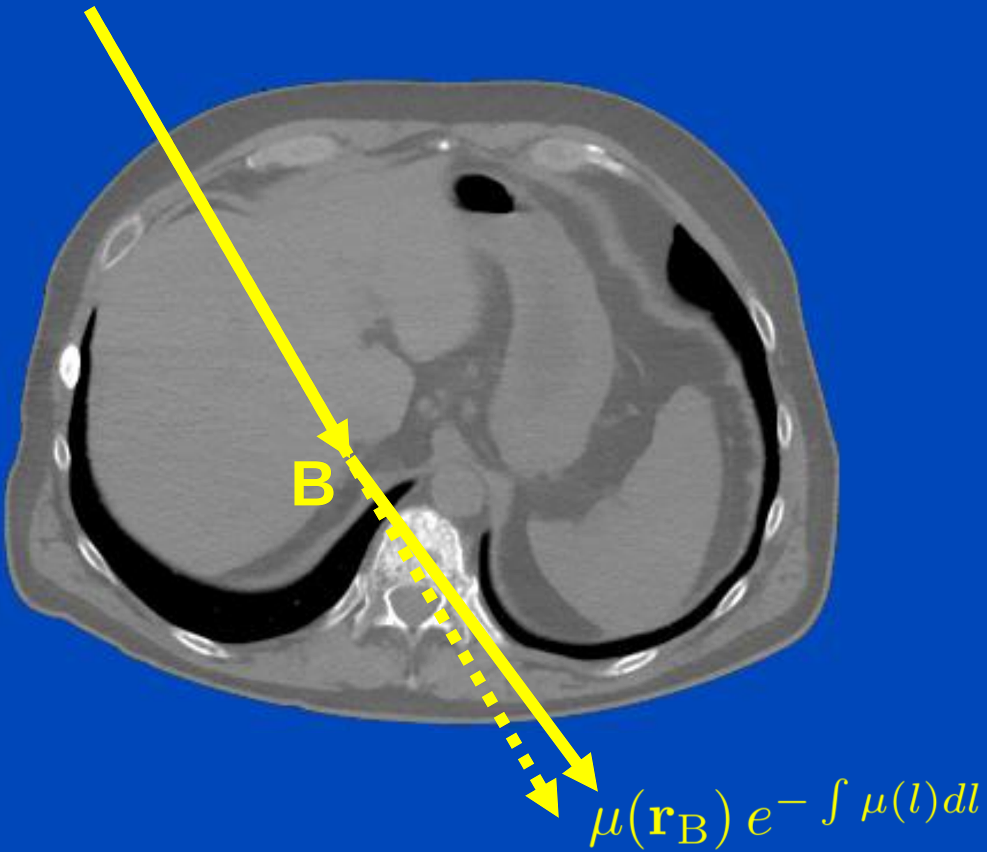


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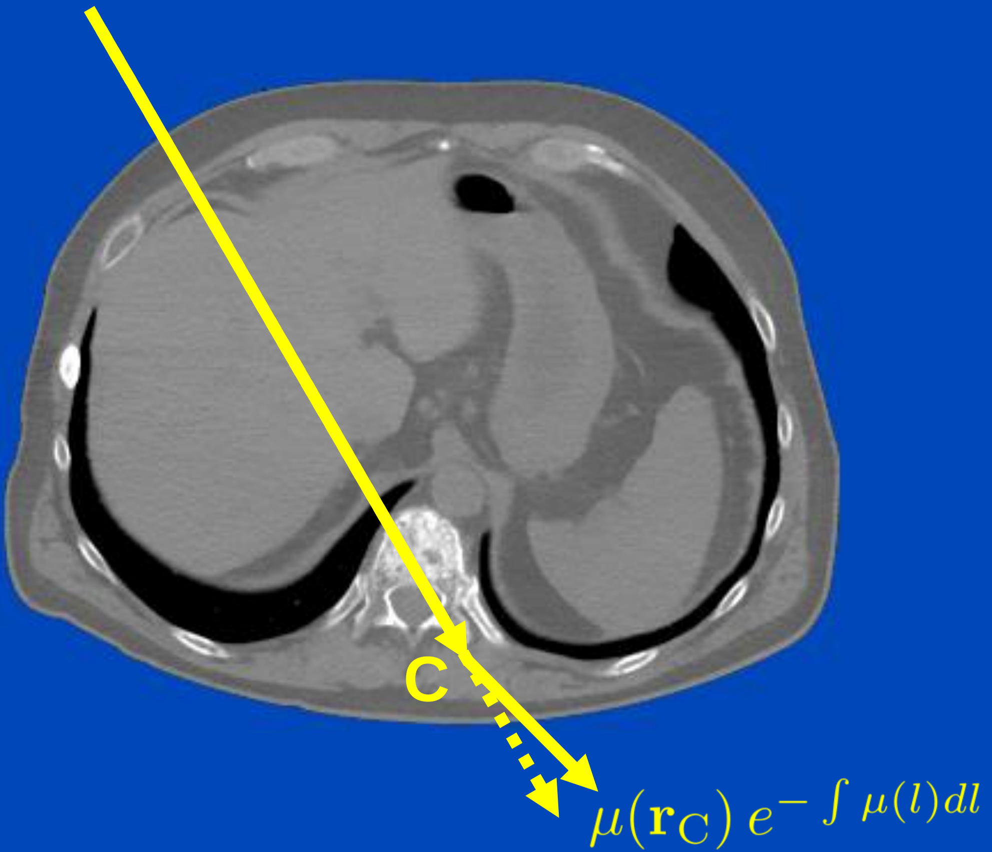


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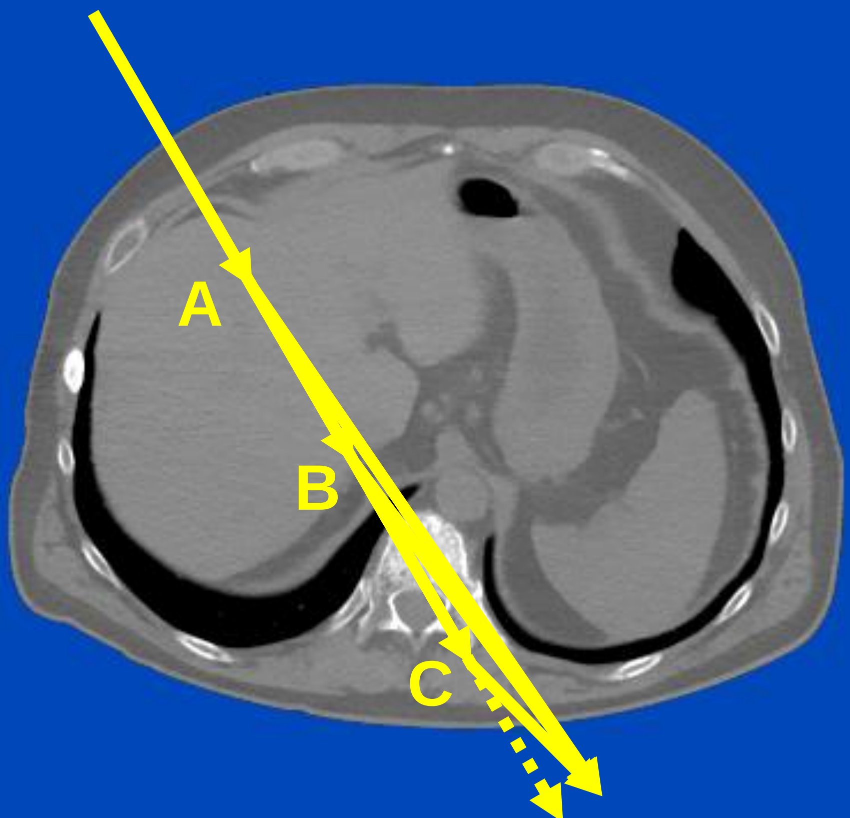


$$(\mu(\mathbf{r}_\mathrm{A}) + \mu(\mathbf{r}_\mathrm{B}) + \mu(\mathbf{r}_\mathrm{C}))\,e^{-\int \mu(l)dl} = \int \mu(l)dl \cdot e^{-\int \mu(l)dl} \approx p\,e^{-p}$$

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# Generation of Training and Test Data

- **Pairs of projections containing** $I_\mathrm{p} + I_\mathrm{s,MC}$ **and** $I_\mathrm{s,MC} = I_\mathrm{s,AA} + I_\mathrm{s,BA}$
  $\rightarrow$ **Simulate CT-scans**

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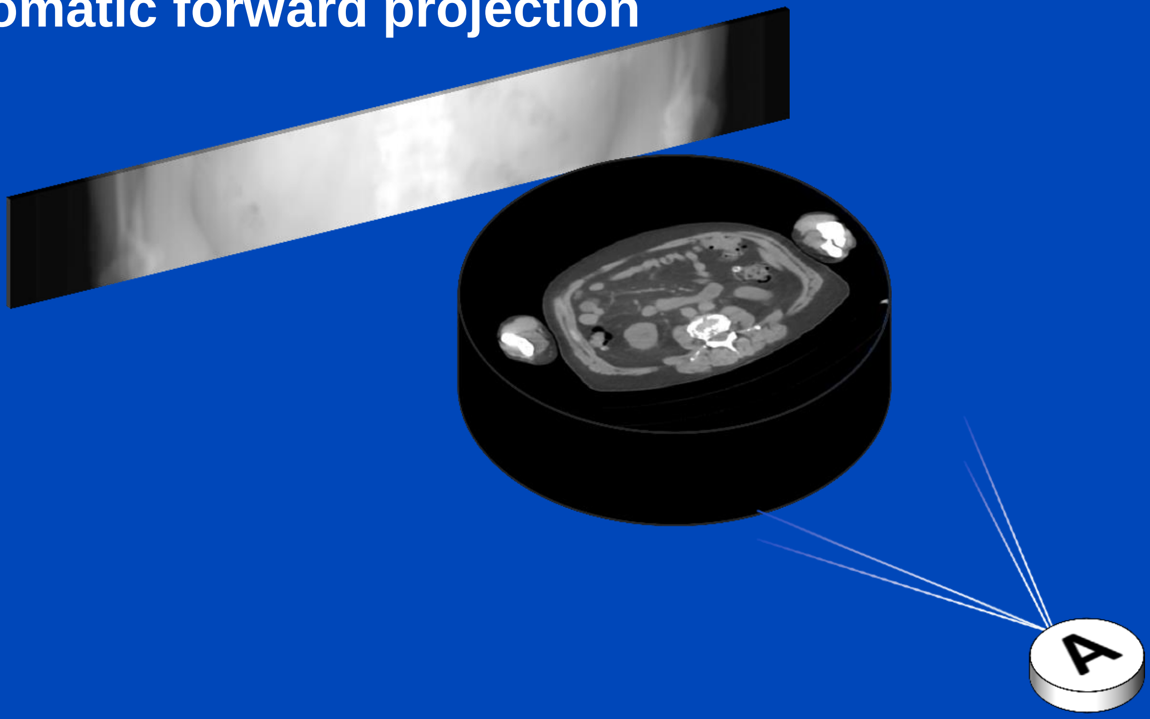
- Simulate $I_\mathrm{p}$ by polychromatic forward projection



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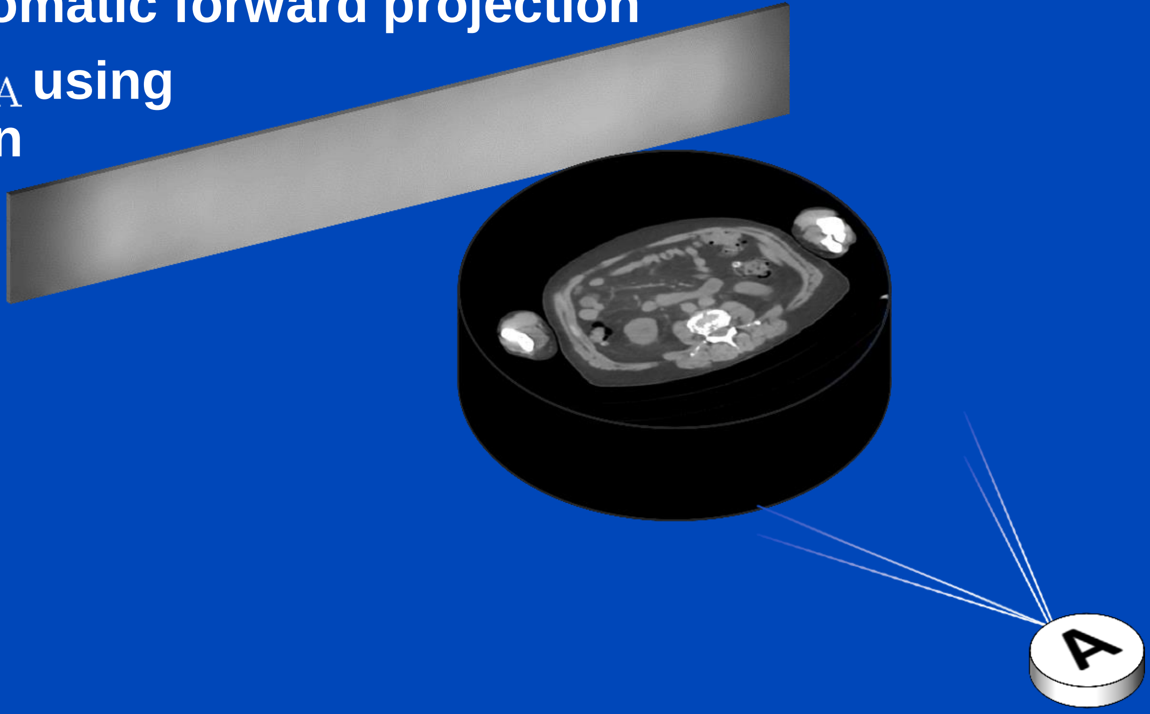


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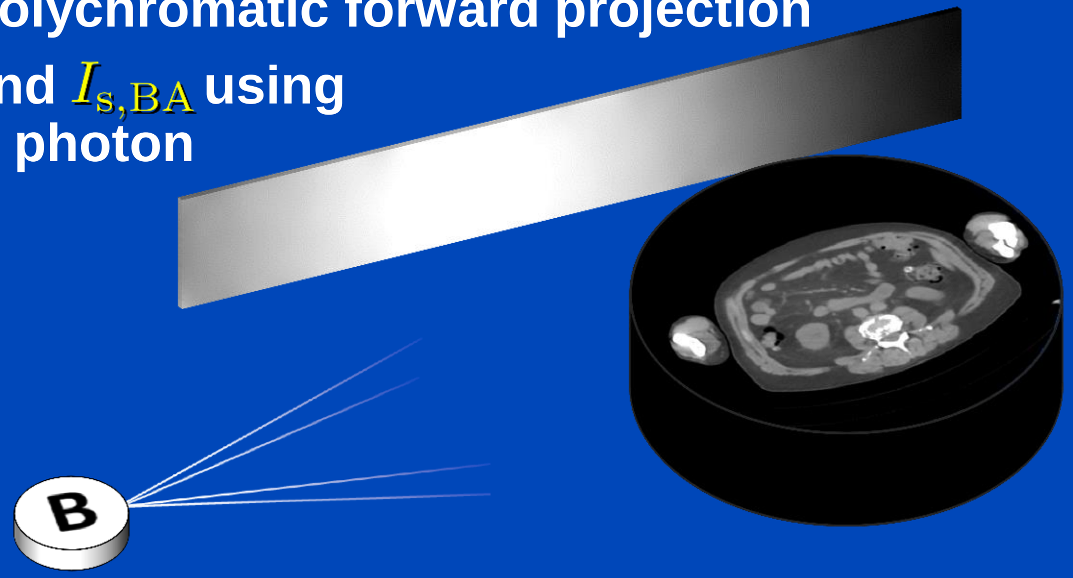


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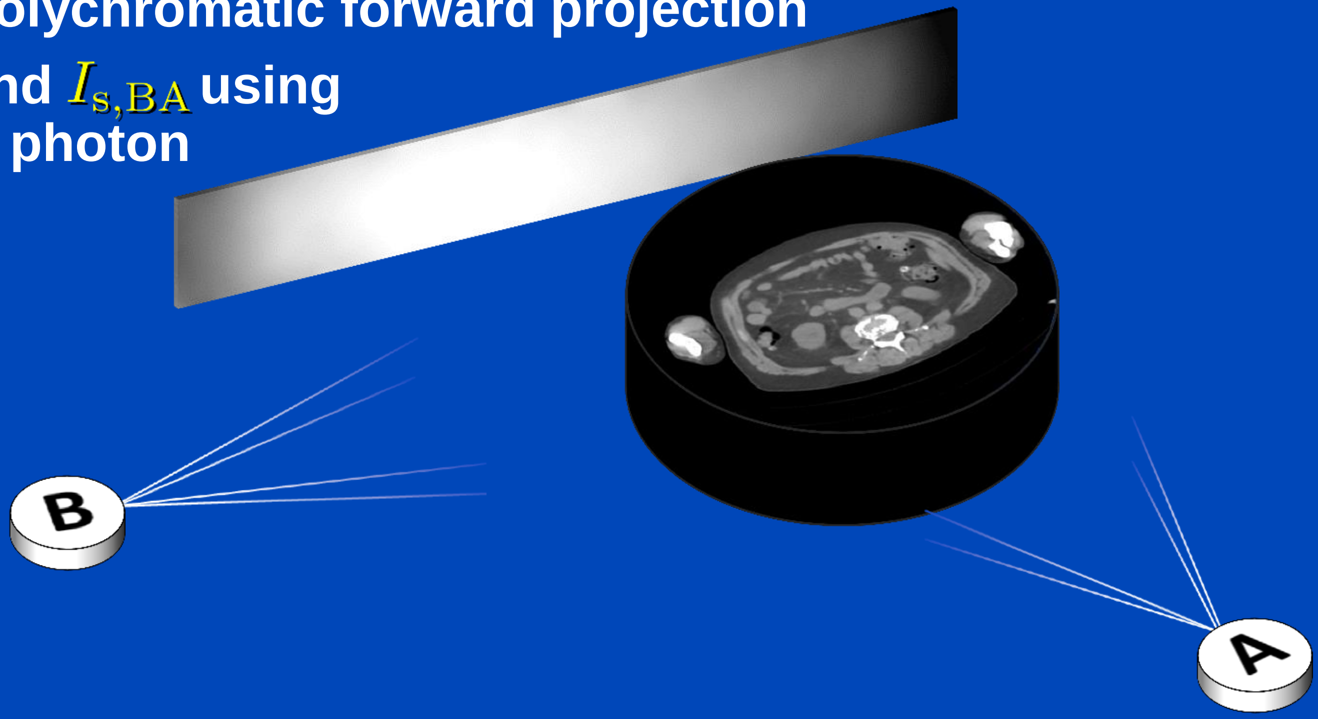


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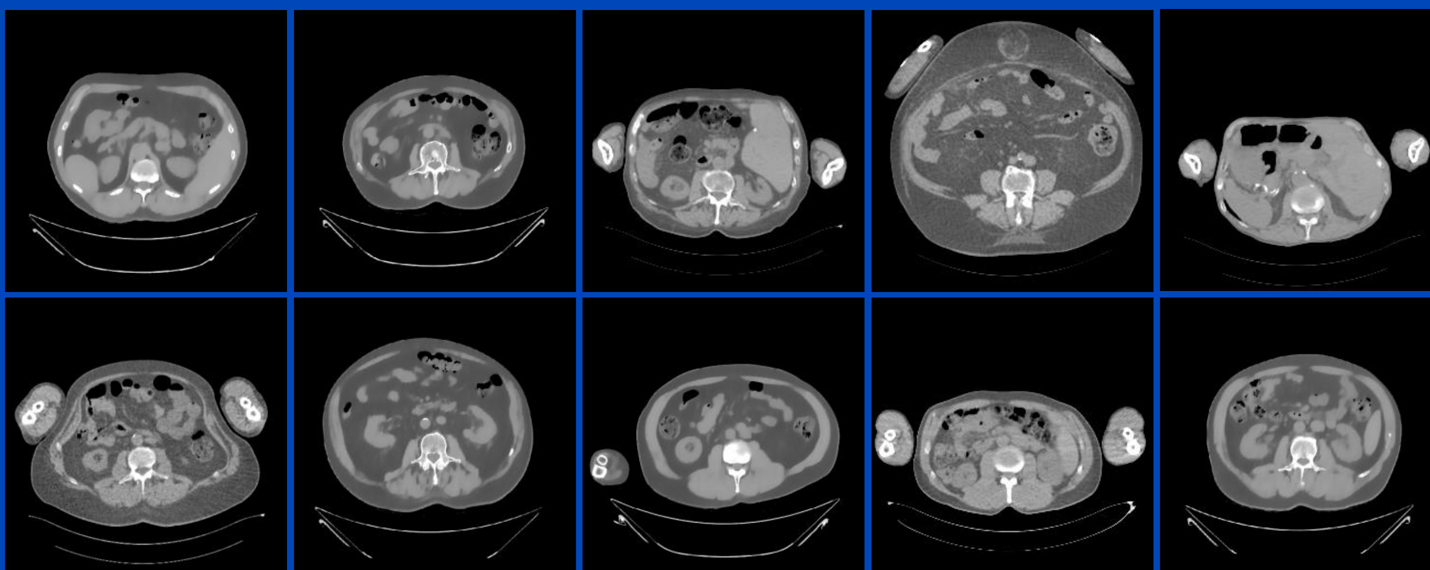
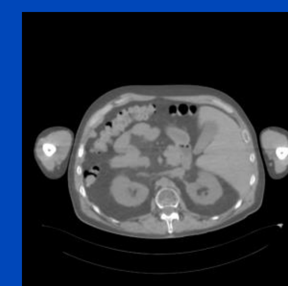
# Generation of Training and Test Data

- Simulate projections at four tube voltages (80 to 140 kV), 13 table positions (pelvis, abdomen, thorax), 36 view angles (0 to 350°) in 11 patients (10 for training, 1 for testing). No data augmentation.

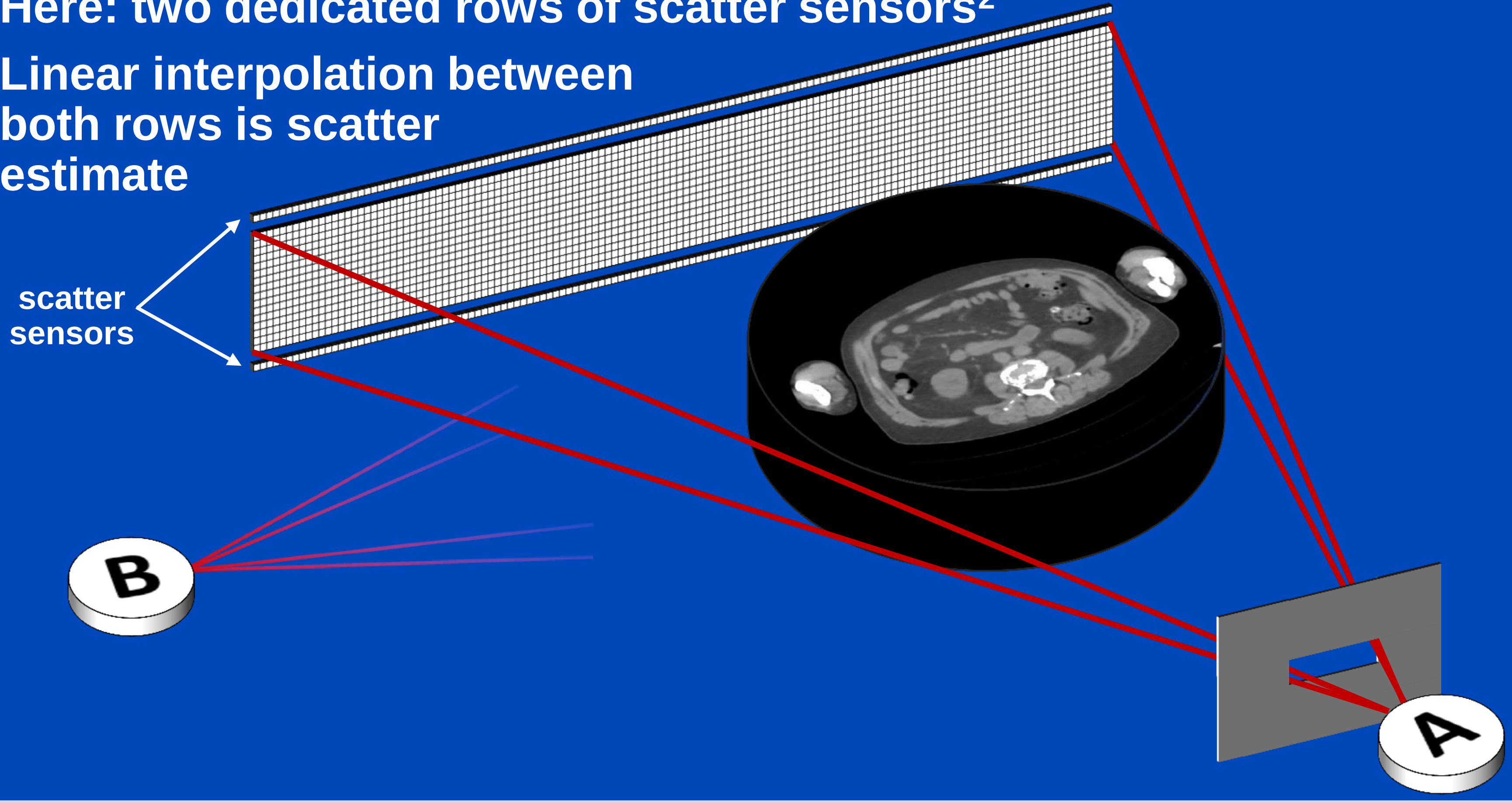




→ 4×13×36×10 = 18720 training projections,
4×13×36×1 = 1872 test projections

# Reference Method

- Idea: measure scatter in the full shadow of the collimator and interpolate to obtain scatter estimate on the main detector[1]
- Here: two dedicated rows of scatter sensors[2]
- Linear interpolation between both rows is scatter estimate




[1] Siewerdsen, Jaffray et al. *Med. Phys.* (2006)
[2] Petersilka, Flohr et al. *Med. Phys.* (2010)

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# Results

pep

MC scatter (GT)

Measurement-based

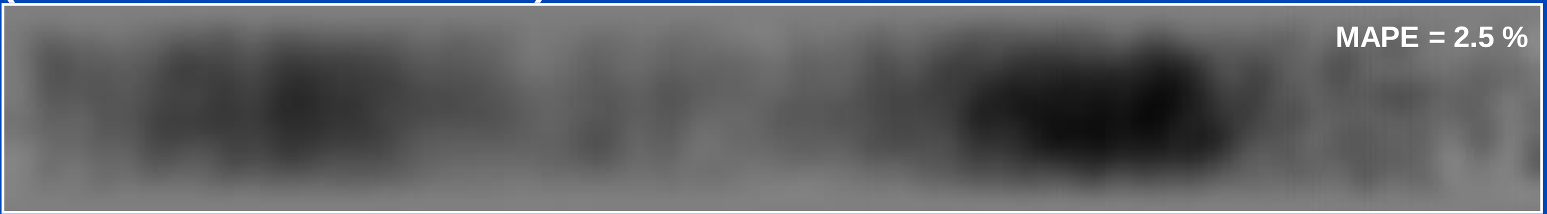

DSE

# Results

pep

MC scatter (GT)

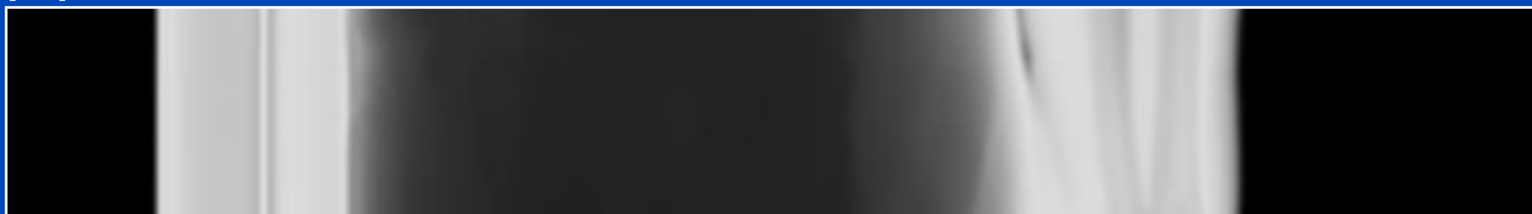
(Measurement-based – GT) / GT




(DSE – GT) / GT

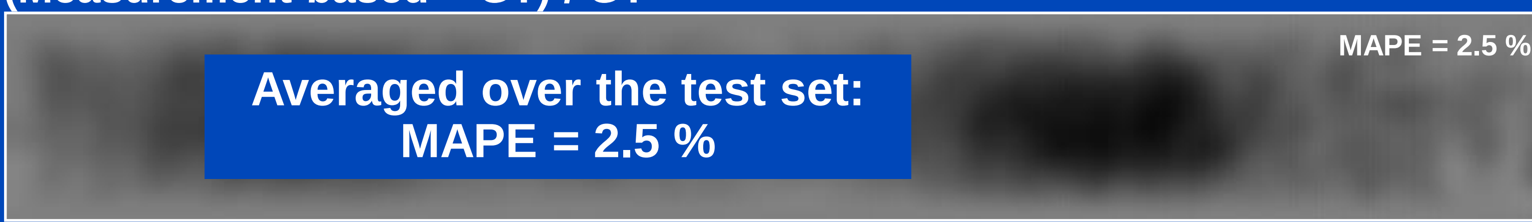
# Results

pep



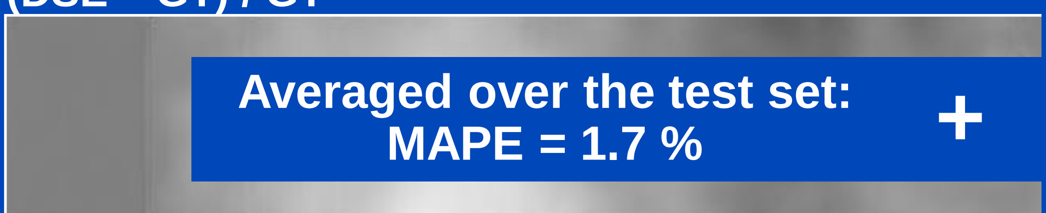
MC scatter (GT)

(Measurement-based – GT) / GT




Averaged over the test set:
MAPE = 2.5 %

(DSE – GT) / GT

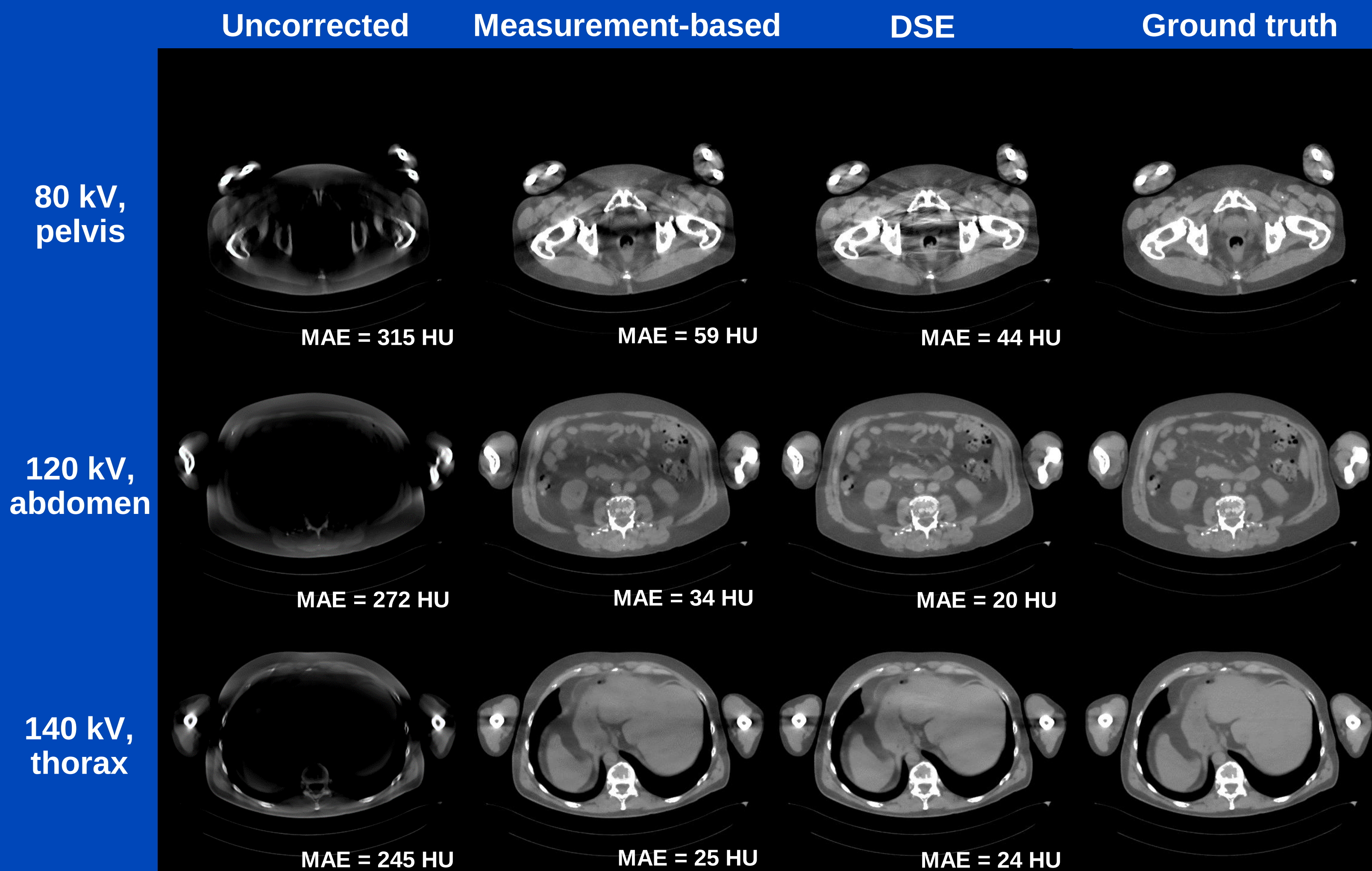


Averaged over the test set:
MAPE = 1.7 %

+

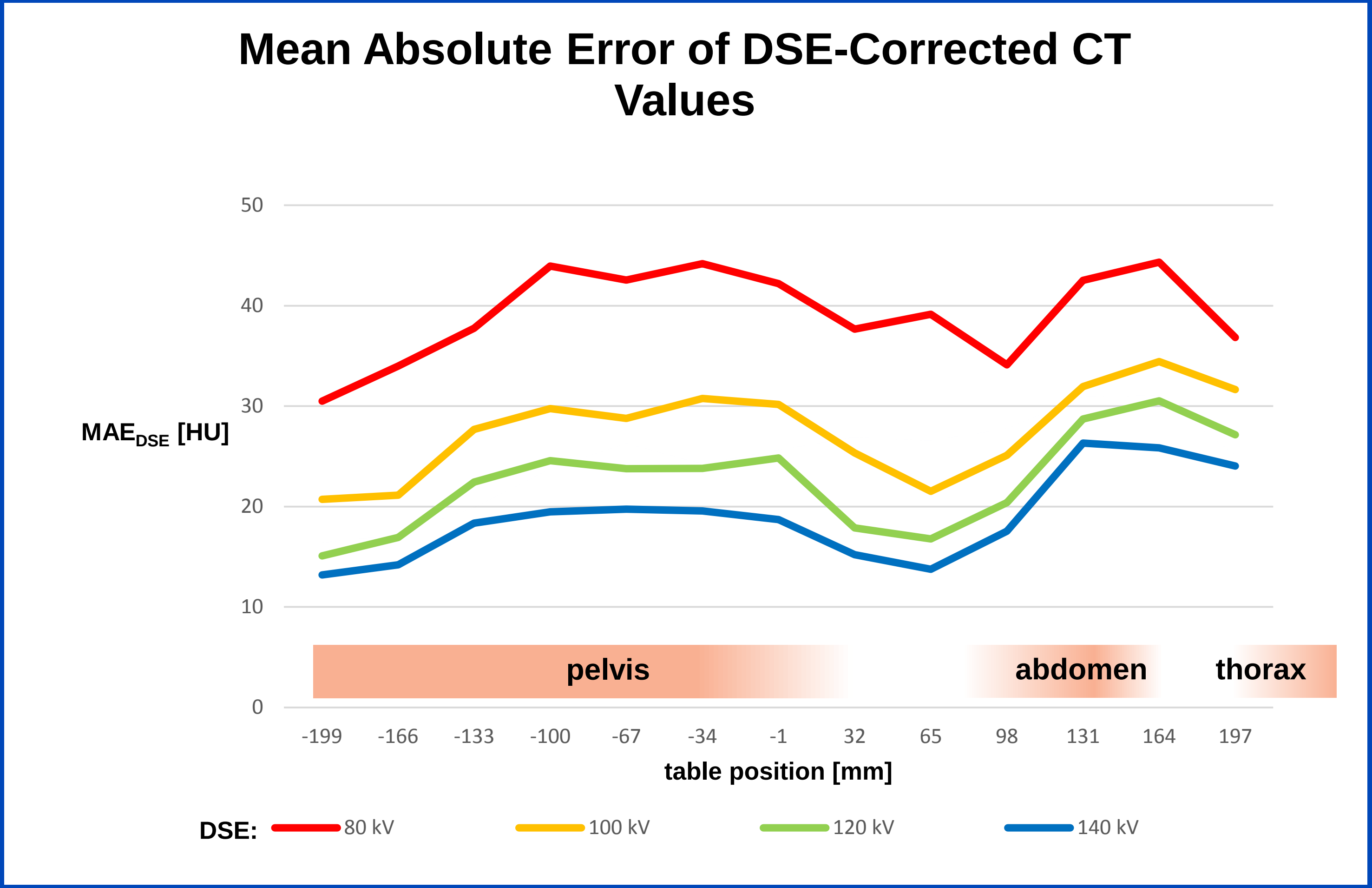
DSE: 12 ms per projection
(= 8.6 s per circle scan)
MC: 88 s per projection
(= 18 h per circle scan)

# Results




All images: C = 0 HU, W = 700 HU

# Analysis of Results



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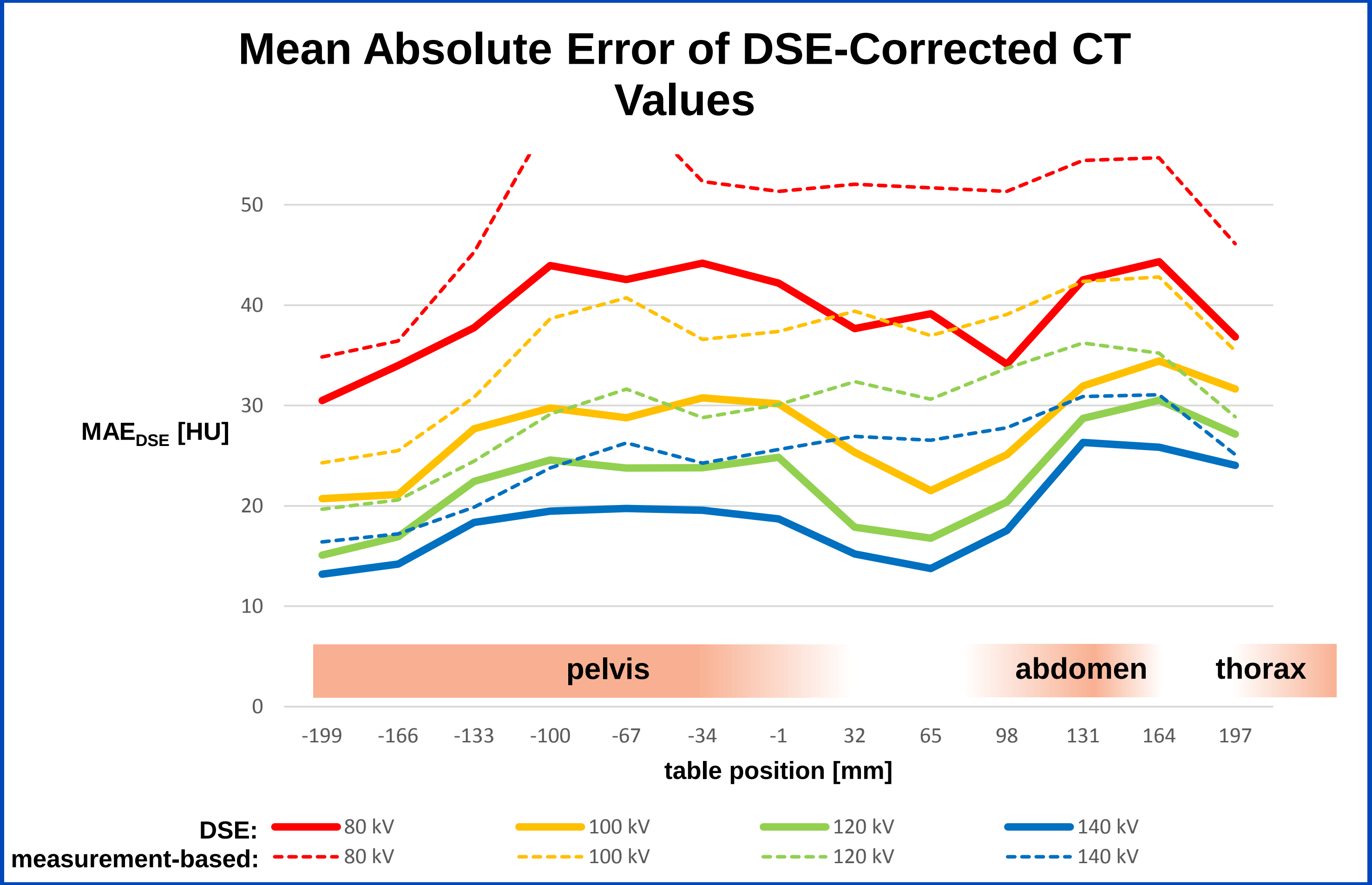
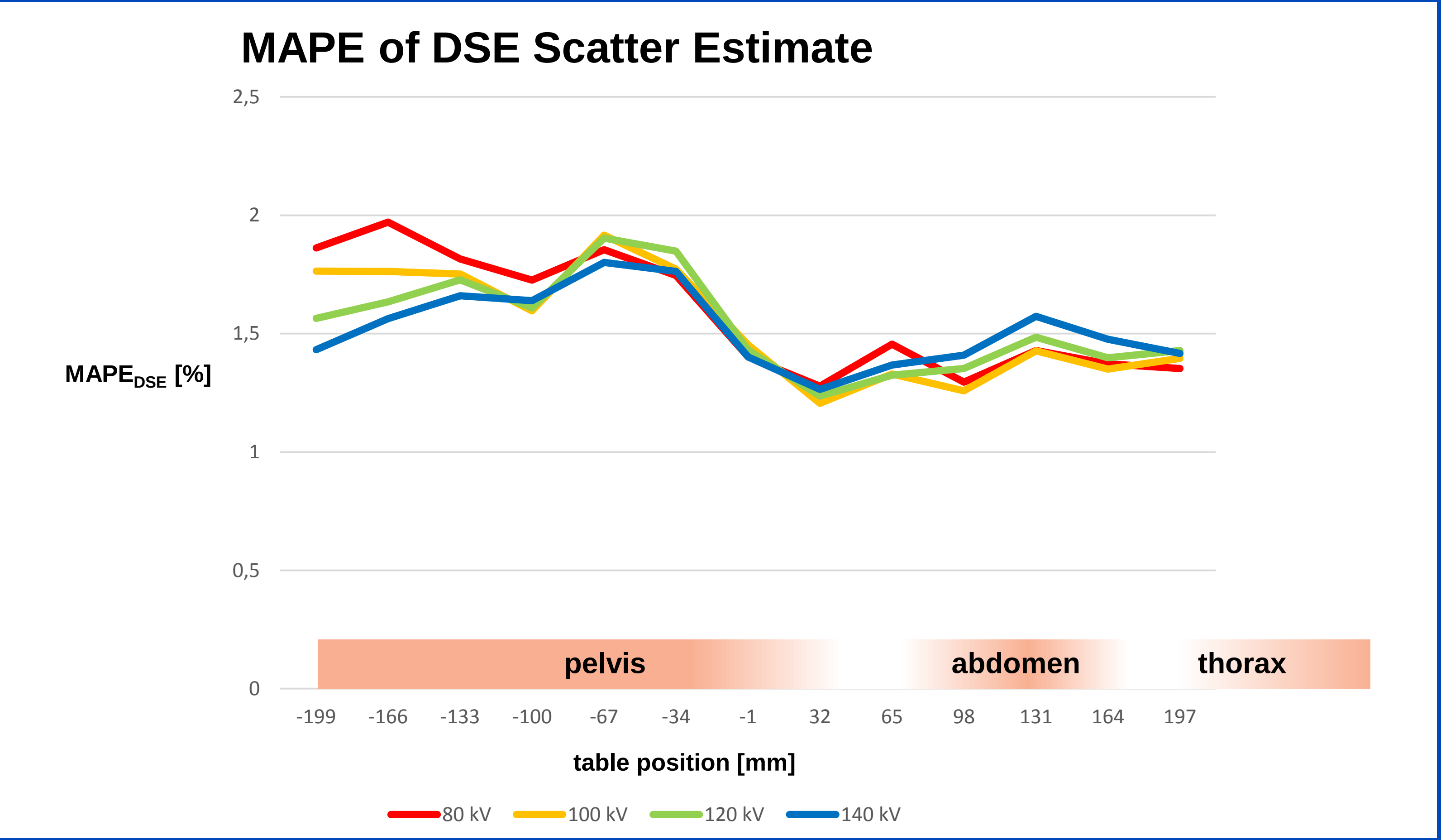



→ **DSE is always better than the measurement-based approach, but does not require any additional hardware**

# Why is the Error in the CT-Values depending on the tube voltage?

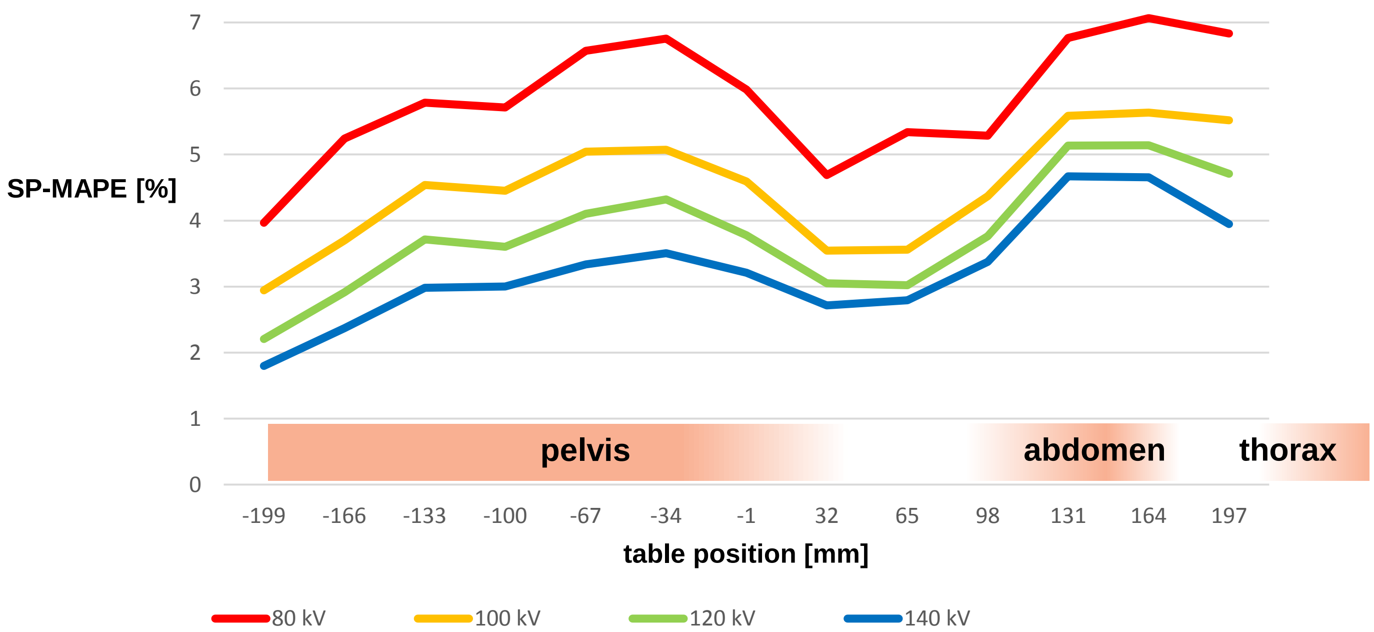



→ The MAPE in the projections can not explain it

# Why is the Error in the CT-Values depending on the tube voltage?

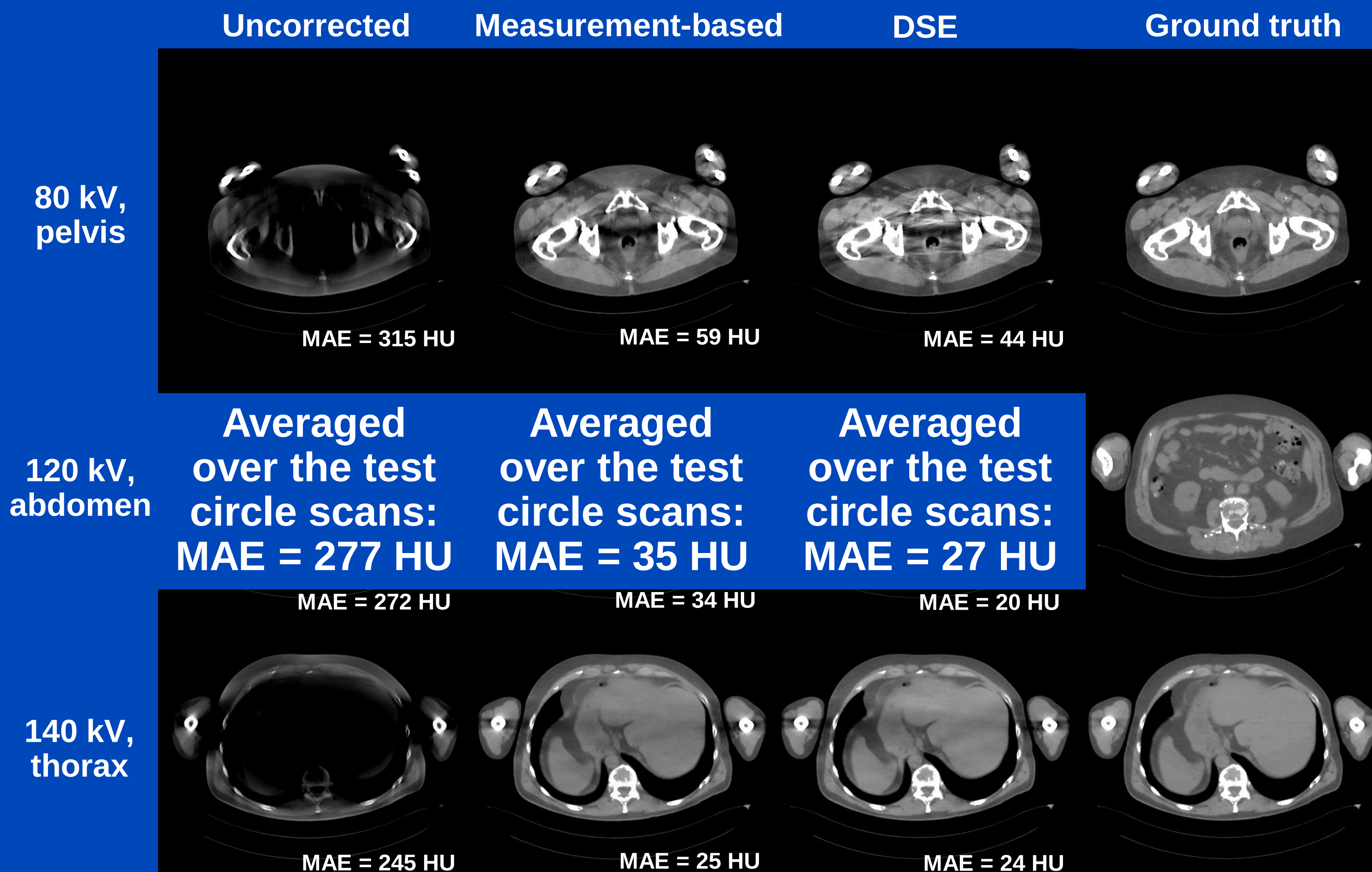
**SP-MAPE of DSE scatter estimates averaged over all projections in a circle scan**

$$\mathrm{SP-MAPE} = \frac{1}{N}\sum \frac{|I_{\mathrm{s,MC}} - I_{\mathrm{s,DSE}}|}{I_{\mathrm{s,MC}}} \cdot \frac{I_{\mathrm{s,MC}}}{I_{\mathrm{p}}} = \frac{1}{N}\sum \frac{|I_{\mathrm{s,MC}} - I_{\mathrm{s,DSE}}|}{I_{\mathrm{p}}}$$




→ **Tube voltage-dependency of the scatter-to-primary ratio seen in the error of the CT-Values after scatter correction**

# Results




All images: C = 0 HU, W = 700 HU

# Conclusions and Outlook

- This study demonstrated the feasibility of DSE in a DSCT
- DSE estimates total scatter in a DSCT with high accuracy (MAPE = 1.7 %)
- Future work:
  - optimization for clinical application
  - leverage information of adjacent projections

# Thank You!


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

**Job opportunities through DKFZ's international PhD or Postdoctoral Fellowship programs (www.dkfz.de), or directly through Prof. Dr. Marc Kachelrieß (marc.kachelriess@dkfz.de).**

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

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