

Deep Scatter Estimation (DSE) for Multi-Source Static CT

Andreas Heinkele^{1,2,3}, Julien Erath^{2,3}, Lukas Hennemann^{1,2,3},
Eric Fournié², Johan Sunnegaardh², Christian Hofmann²,
Martin Petersilka², Karl Stierstorfer², and Marc Kachelrieß^{1,3}

¹German Cancer Research Center (DKFZ), Heidelberg, Germany

²Siemens Healthineers, Forchheim, Germany

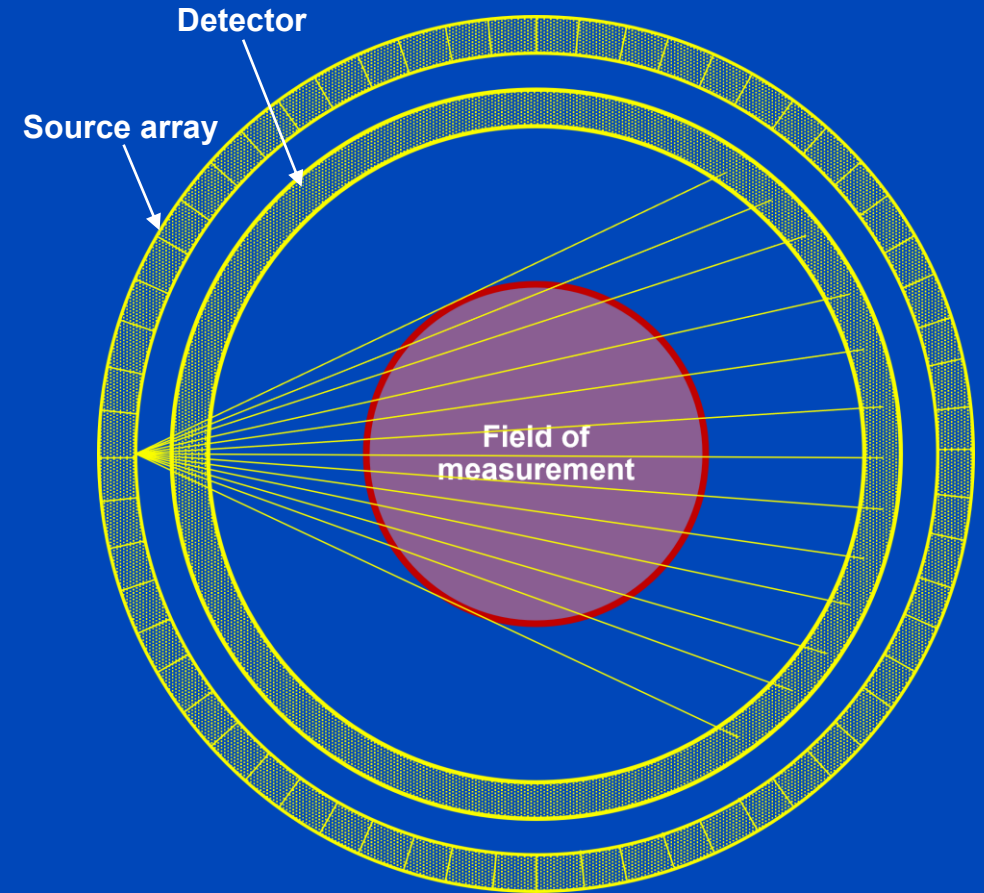
³Ruprecht-Karls-Universität, Heidelberg, Germany

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Construction and Motivation

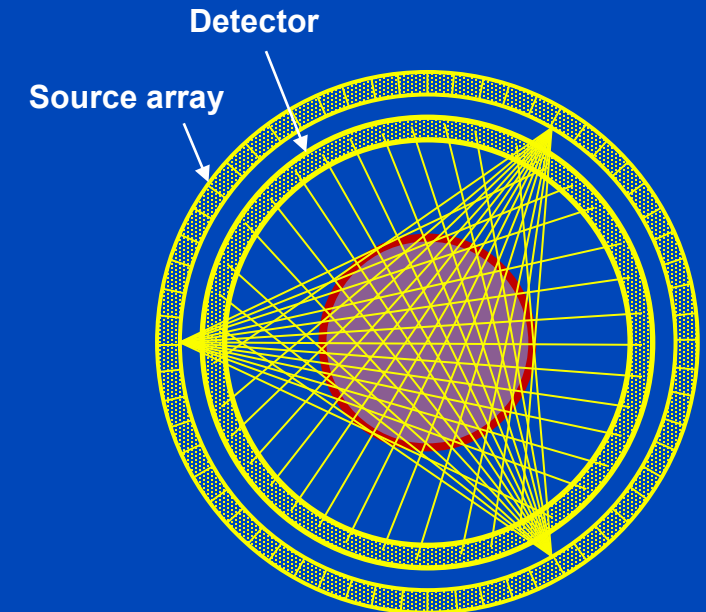
- **No rotating components**
- **Ring source array**
 - Composed of many individual sources
 - Field emission technology possible → more efficient
 - Ability of acquisition with varying tube voltage
 - Ability of shooting multiple sources simultaneously
- **Ring detector**
 - 16 detector rows
 - 12 mm z-coverage in the isocenter

→ Mechanical simplification and compact size
→ Acquisition time is not limited by rotation speed but rather by source power
→ Arbitrary acquisition patterns possible



Why Multi-Source Operation?

- Respiratory and cardiac motion may cause artifacts in reconstructed images.
- Multi-source operation may increase temporal resolution^{1,2} and thereby avoid motion artifacts (given that image quality is not impaired by cross-scatter).
- Spectral imaging with different tube voltages is possible.
 - In this work, we focus on single-energy simulations



Challenges in Static CT and Aim

Challenges

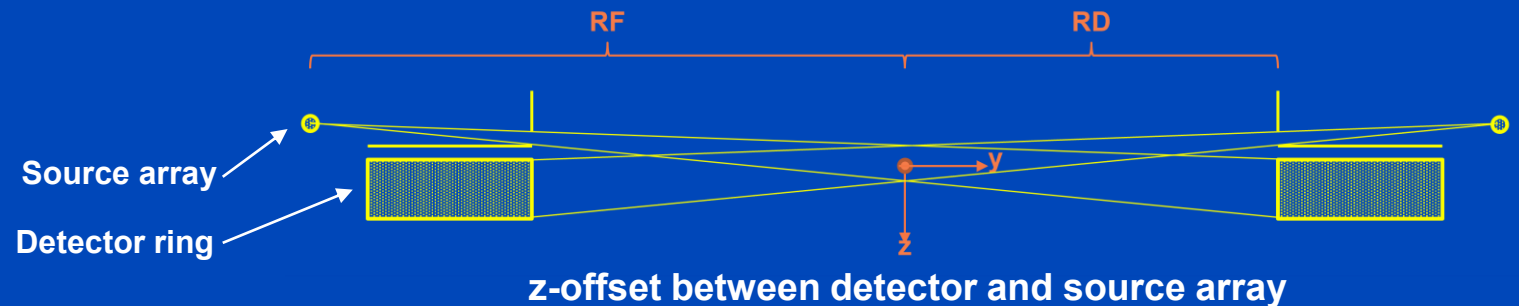
- No hardware-based scatter rejection possible
 - Impairment of image quality due to scatter artifacts
 - Increased image noise due to scatter
- Challenges in reconstruction
 - No exact image reconstruction possible due to longitudinal offset (along z) between source array and detector
- Source and detector ring are expensive



Software-based scatter correction is one of the central challenges in static CT.

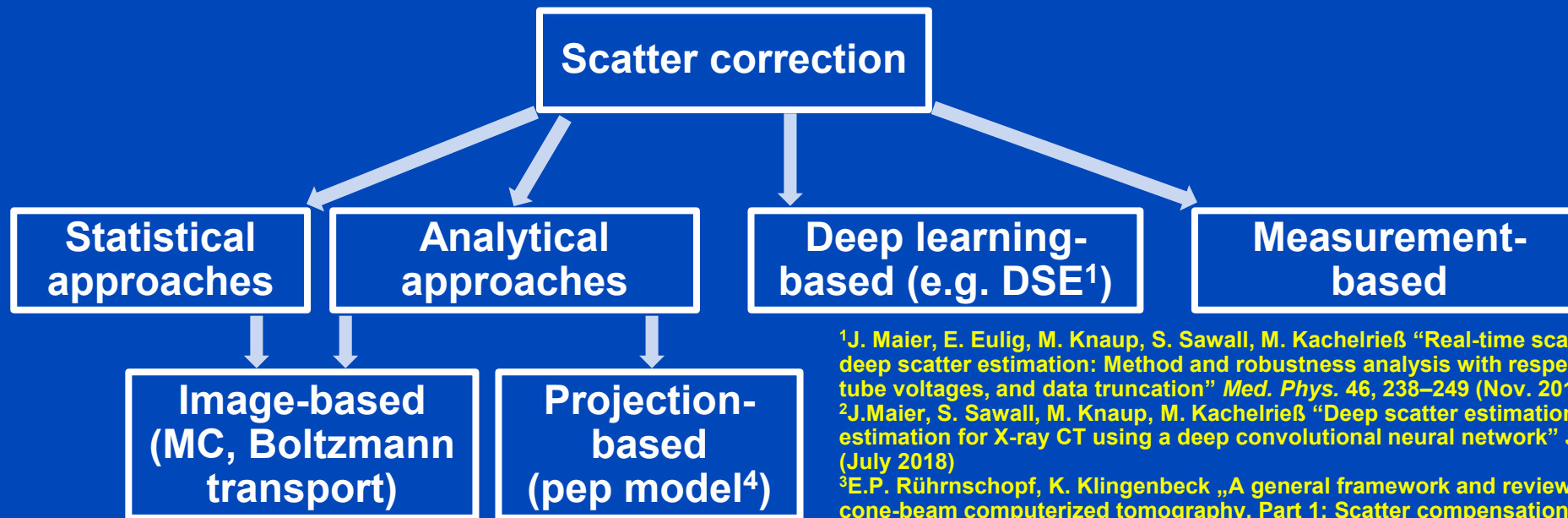
Aim

- Development of a software-based scatter correction method to mitigate scatter artifacts



Software-based Scatter Correction Methods

- The gold standard for scatter estimation is the Monte Carlo (MC) method.
 - High accuracy but computationally expensive and therefore not suitable for clinical application
- In this work, we focus on the deep scatter estimation (DSE)^{1,2}.
 - DSE predicts MC scatter estimates.
 - DSE maintains high accuracy.
 - DSE is computationally less expensive than MC by orders of magnitude
- A summary of scatter correction methods is provided by Rührnschopf and Klingenbeck³.



¹J. Maier, E. Eulig, M. Knaup, S. Sawall, M. Kachelrieß "Real-time scatter estimation for medical CT using the deep scatter estimation: Method and robustness analysis with respect to different anatomies, dose levels, tube voltages, and data truncation" *Med. Phys.* 46, 238–249 (Nov. 2018)

²J. Maier, S. Sawall, M. Knaup, M. Kachelrieß "Deep scatter estimation (DSE): Accurate real-time scatter estimation for X-ray CT using a deep convolutional neural network" *Journal of Nondestructive Evaluation* 37 (July 2018)

³E.P. Rührnschopf, K. Klingenbeck „A general framework and review of scatter correction methods in X-ray cone-beam computerized tomography. Part 1: Scatter compensation approaches“ *Medical Physics* 38, 4296–4311 (June 2011)

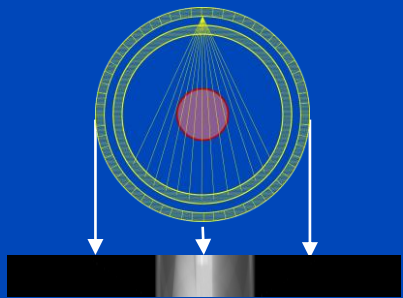
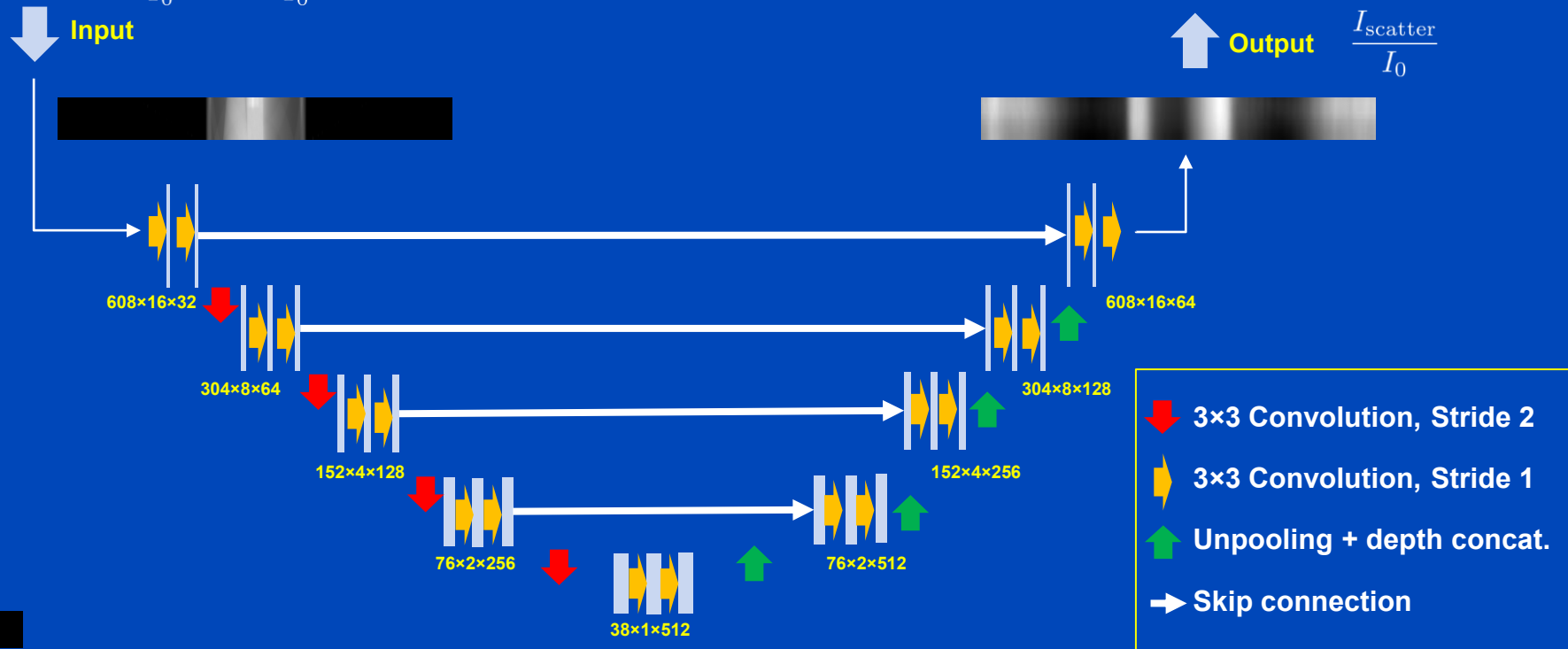
⁴B. Ohnesorge, T. Flohr, K. Klingenbeck-Regn "Efficient object scatter correction algorithm for third and fourth generation CT scanners" *European Radiology* 9, 563–569 (March 1999)

DSE (Deep Scatter Estimation) Architecture

- DSE¹ uses a deep convolutional neural network to estimate scatter using the acquired projection data as input.
- Train the network to predict Monte Carlo scatter estimates based on the acquired projection data.
- DSE outperforms other scatter estimation techniques.
- DSE is faster than Monte Carlo simulations by orders of magnitude.

Input dimension:
608×16
Input mapping:

$$p = -\ln\left(\frac{I_{\text{primary}}}{I_0} + \frac{I_{\text{scatter}}}{I_0}\right)$$

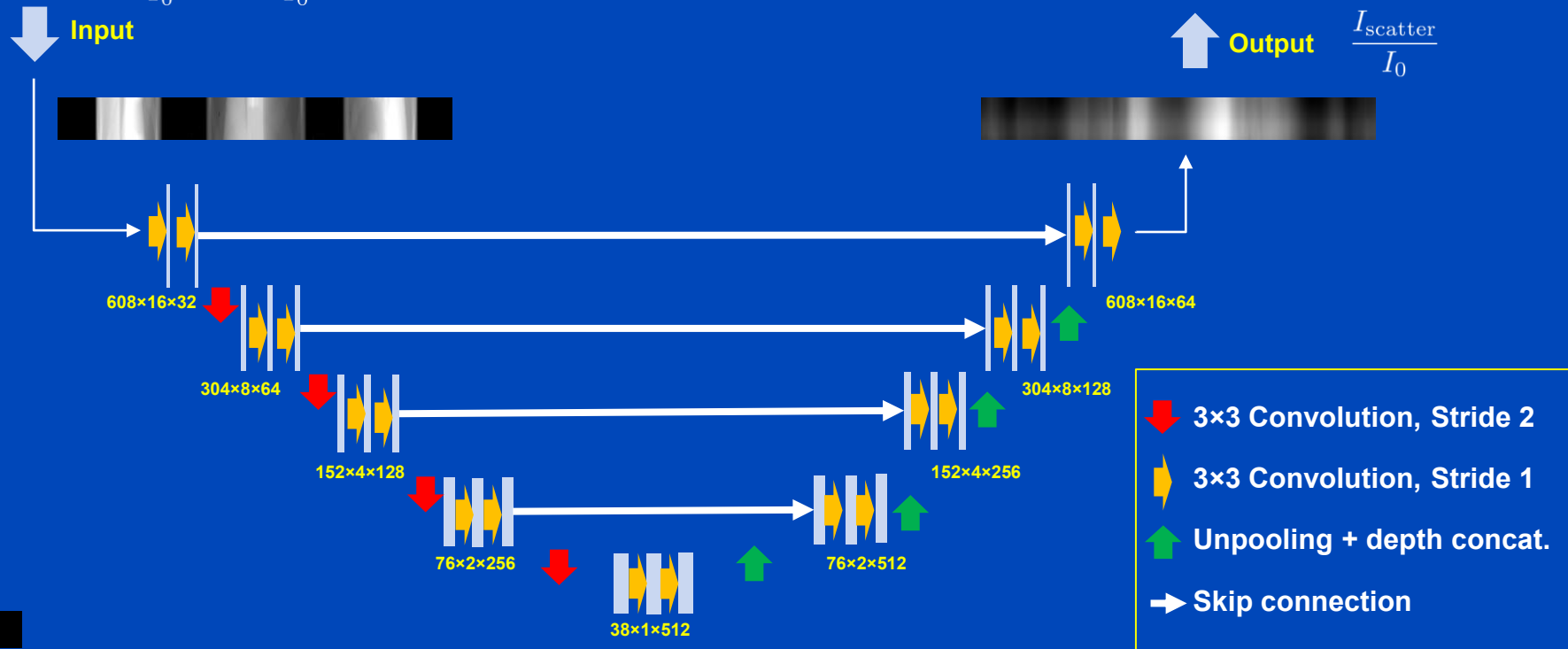


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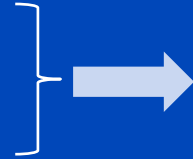
$$p = -\ln\left(\frac{I_{\text{primary}}}{I_0} + \frac{I_{\text{scatter}}}{I_0}\right)$$



Monte Carlo Simulations

- Training dataset consists of:

- 50 water phantoms
- 50 ellipse phantoms
- 100 thorax phantoms



Phantoms differ from each other by simulating with:

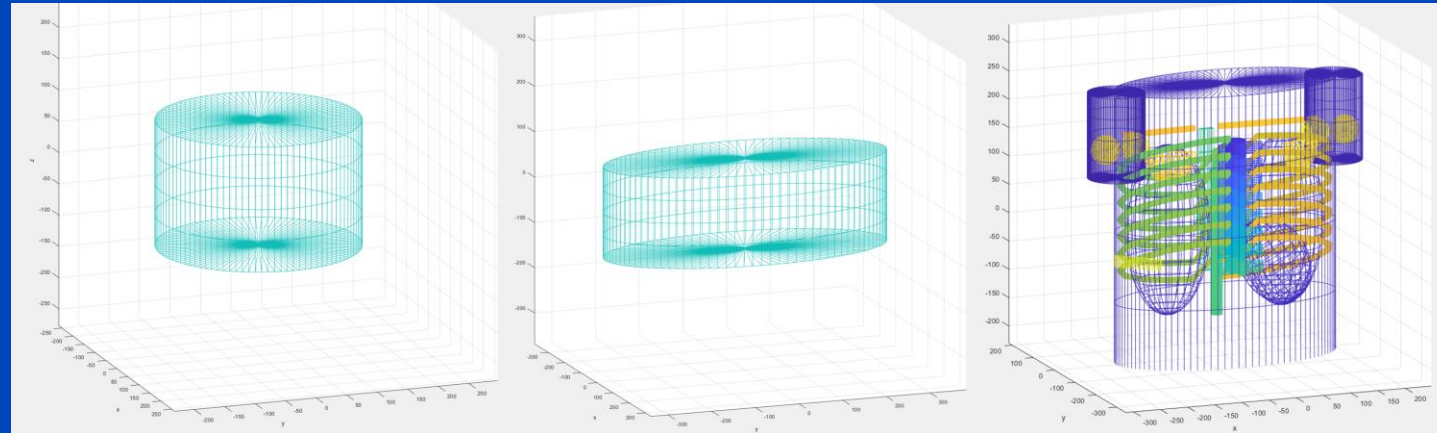
- Random size
- Random lateral shift up to 8 cm in x and y direction
- Random longitudinal shift (thorax)

- Angular steps of 5° simulated.

- 72 projections per phantom

- Train / validation split 90:10

→ A total of 200 phantoms simulated for training / validation (14400 projections).
→ For testing, additional phantoms were simulated (FORBILD head and XCAT phantoms).



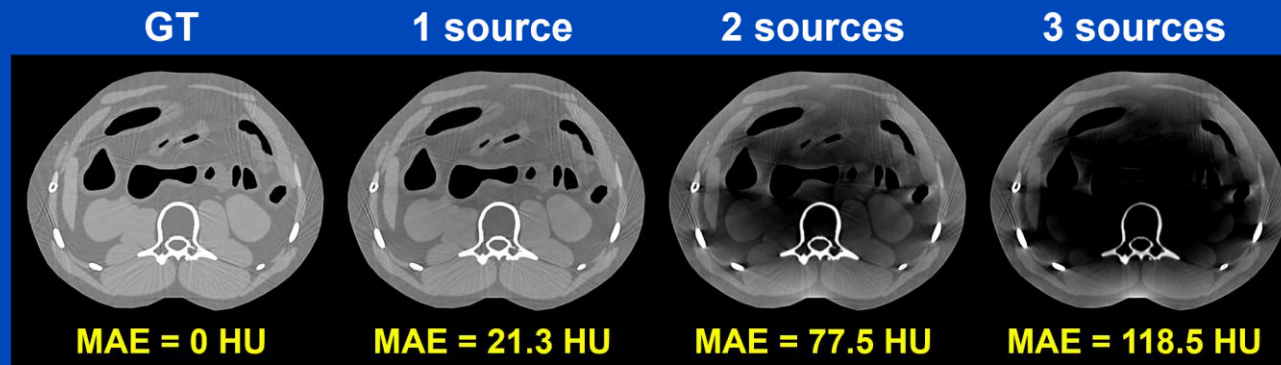
Surface representation of training phantoms

Results

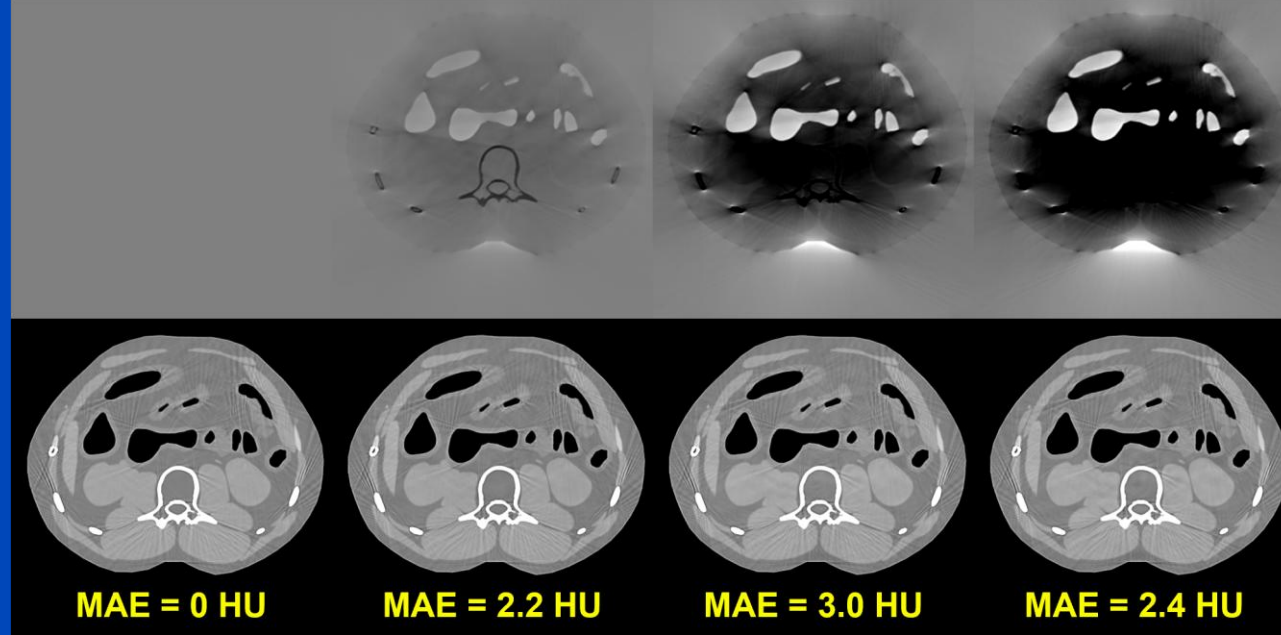
Multi-Source Scatter Correction

- The ground truth (GT) corresponds to a scenario without scatter (e.g. 3rd generation scanner with very effective ASG).
- Multi-source operation results in a strong increase in scatter artifacts.
- DSE performs very well even for multi-source operation.

Uncorrected

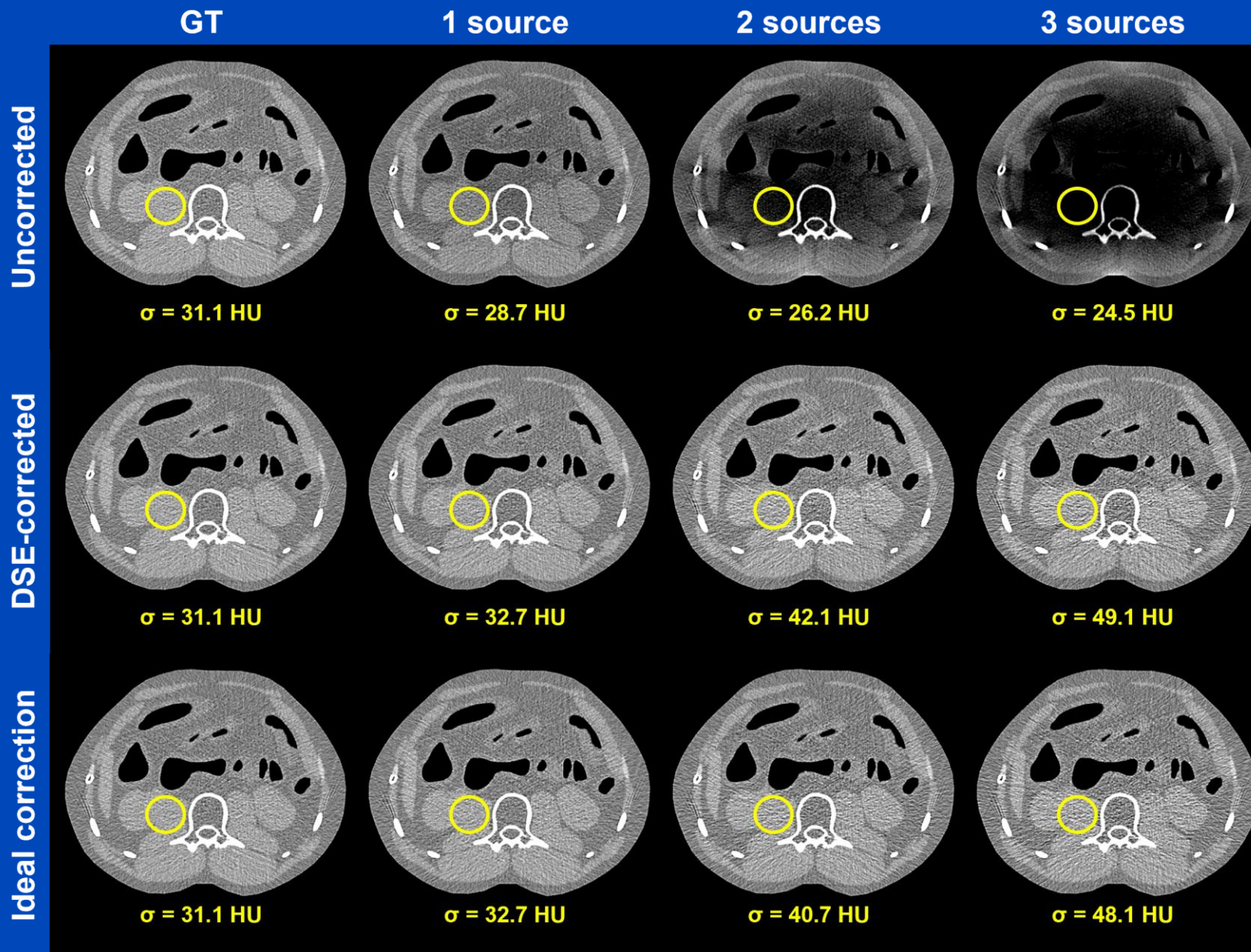


DSE-corrected



C = 0 HU, W = 300 HU

Multi-Source Noise

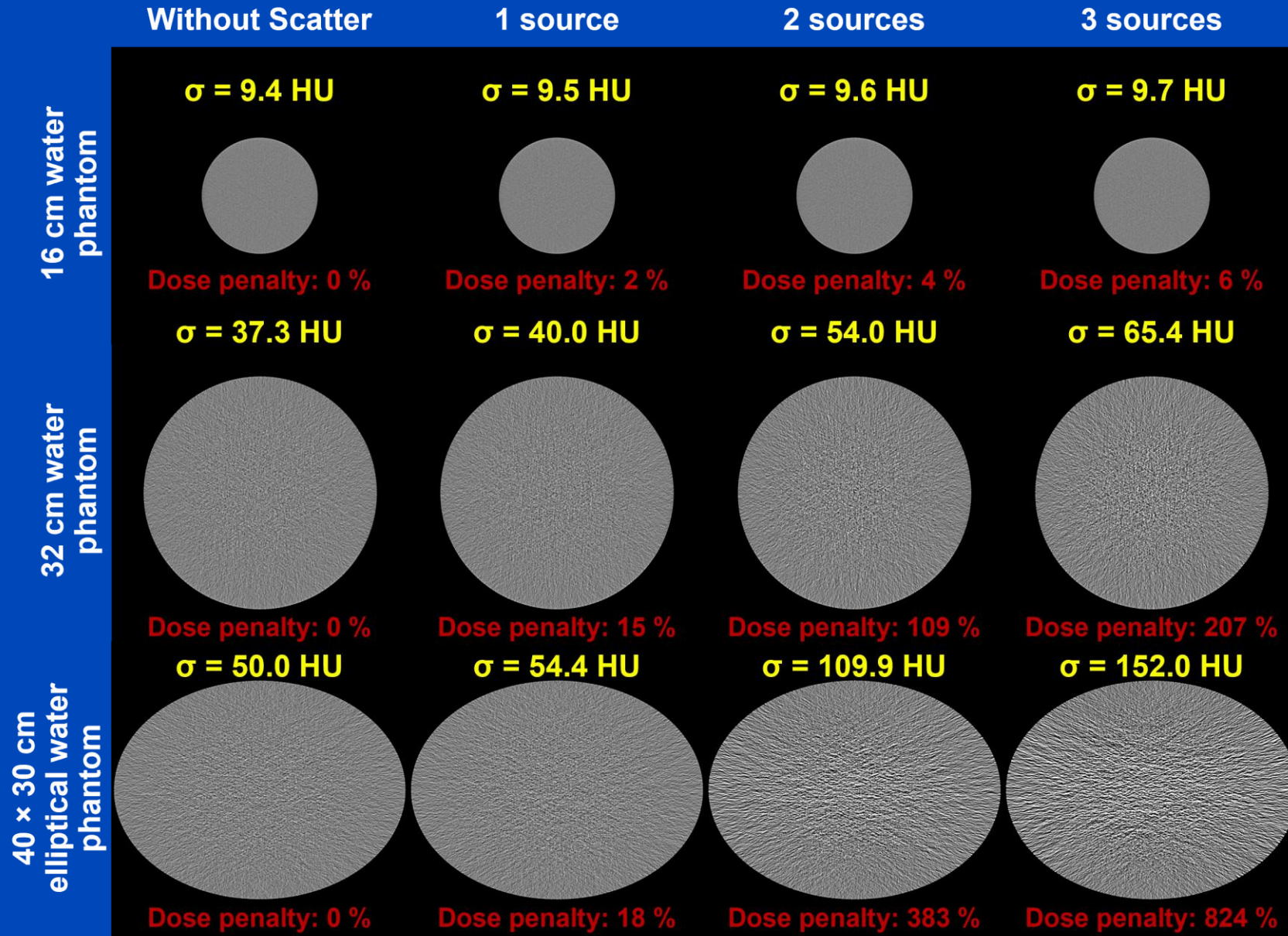


The **ideal correction** is a correction with the MC estimates that were based on the GT image.

This is different from a MC correction where the MC estimates would be based on the uncorrected image.

$C = 0$ HU, $W = 300$ HU

Multi-Source Noise



C = 0 HU, W = 500 HU

Conclusions and Limitation

Conclusions

- DSE can effectively correct scatter artifacts for static CT even with multi-source operation.
- DSE generalizes well to phantoms that were not contained in the training dataset such as head or abdomen phantoms.
- DSE cannot correct for the increased image noise.
- The noise increase depends on factors such as phantom size or region within the object.
- For larger objects, multi-source operations may result in a waste of dose, with no advantages regarding temporal resolution.
- For small objects, multi-source operation may effectively improve temporal resolution.

Limitation

- This work is simulation-based, we did not correct any physical measurements.

Thank You!

- This study was supported by Siemens Healthineers AG.
- This presentation will soon be available at www.dkfz.de/ct.
- Job opportunities through DKFZ's international PhD or Postdoctoral Fellowship programs (marc.kachelriess@dkfz.de).