Measurement-Based Spectral Deep Scatter Estimation for Photon-Counting CT

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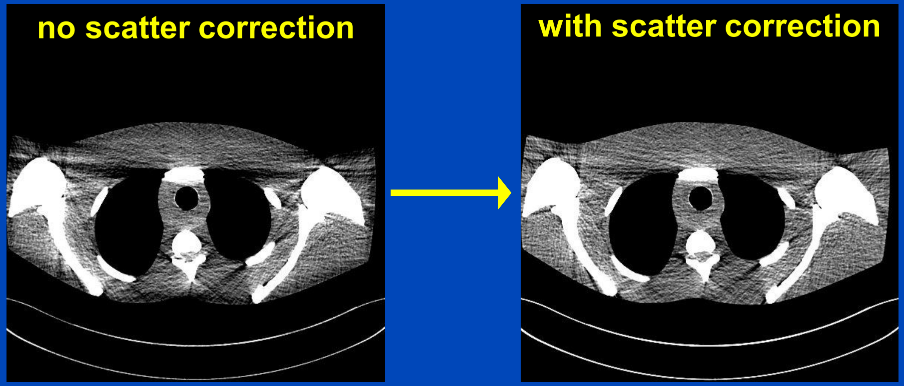
Motivation

- Scatter degrades image quality: loss of contrast, cupping artifacts, streaks and inaccurate quantitative values.
- Accurate scatter estimation is crucial for spectral CT and quantitative imaging tasks.
- Software-based scatter correction methods:

Method	Speed	Accuracy
Analytical models[1]	+ Fast	○ Moderate
Monte Carlo simulations	– Slow	+ High
Deep learning-based[2,3]	+ Fast	+ High (depends on data)



Kernel Qr40f, *C* = 40 HU, *W* = 200 HU

**Deep learning approaches rely on large, realistic datasets.
However, Monte Carlo simulations may not fully reflect system-specific physics.
Using real measured data are alternative and may be the more practical choice for training.**

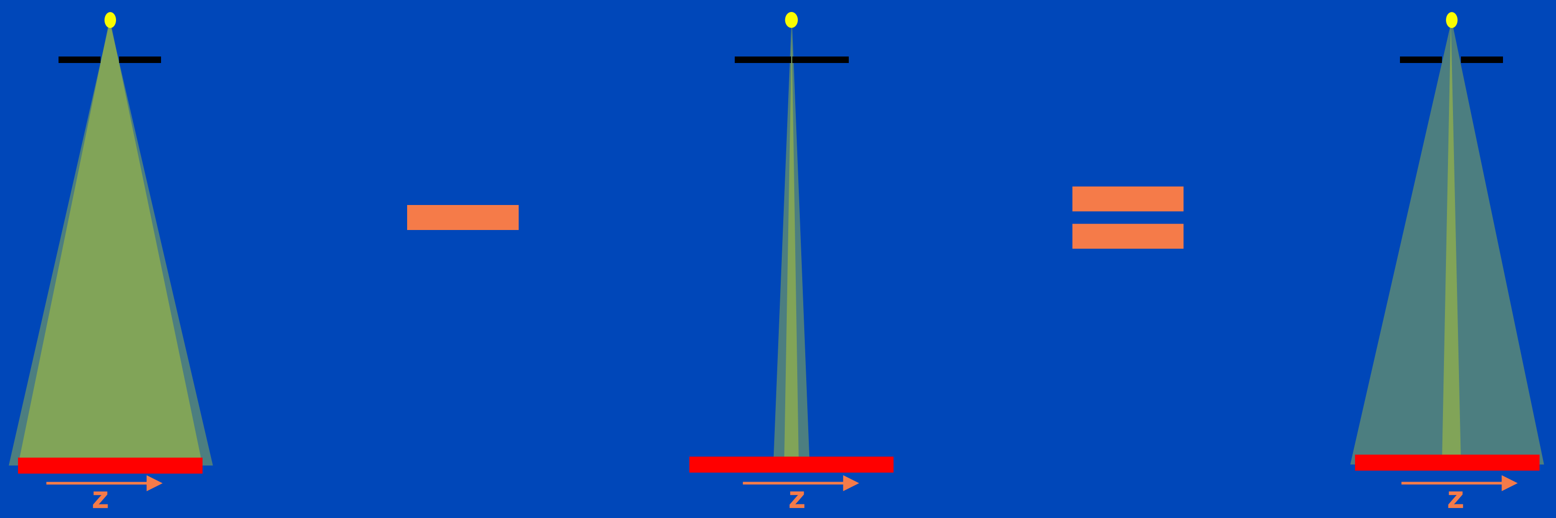
[1]B. Ohnesorge, K. Klingenbeck-Regn et al. “Efficient object scatter correction algorithm for third and fourth generation CT scanners” European Radiology 9, 563–569, March 1999.

[2]J. Maier, M. Kachelrieß et al. “Deep Scatter Estimation (DSE)“, SPIE 2018 and J. of Nondest. Eval. 37:57, July 2018.

[3]J. Maier, M. Kachelrieß et al. “Robustness of DSE“, Med. Phys. 46(1):238-249, January 2019.

Methodology

- **Performing two scans:**
  - Full collimation, contains scatter and primary intensity
  - Narrow collimation, contains primary intensity as the scatter should be negligible
- **Scatter intensity:**
  - Difference between the intensitys of full and narrow collimated data is used as label
  - Only the data within the primary fan of the narrow collimated scan are used



Full collimation (144 × 0.4 mm):
Primary + scatter

Narrow collimation (6 × 0.4 mm):
Primary only

Difference:
Scatter only

Measurement-Based Training Data Generation

- Naeotom Alpha.Peak (Siemens Healthineers, Forchheim, Germany)
- Several phantoms (water phantoms, multi-energy QA phantoms, and anthropomorphic patient-like phantoms) are used in the data set.
- Automated script that moves the patient table in predefined steps in z-direction
- The table height is chosen randomly around the isocenter.
- Two scans at each position
  - 6 × 0.4 mm = 2.4 mm
  - 144 × 0.4 mm = 57.6 mm
- Default bowtie filter
- Energy thresholds at 20 keV and 65 keV
- 140 kV tube voltage and 100 mAs / rotation

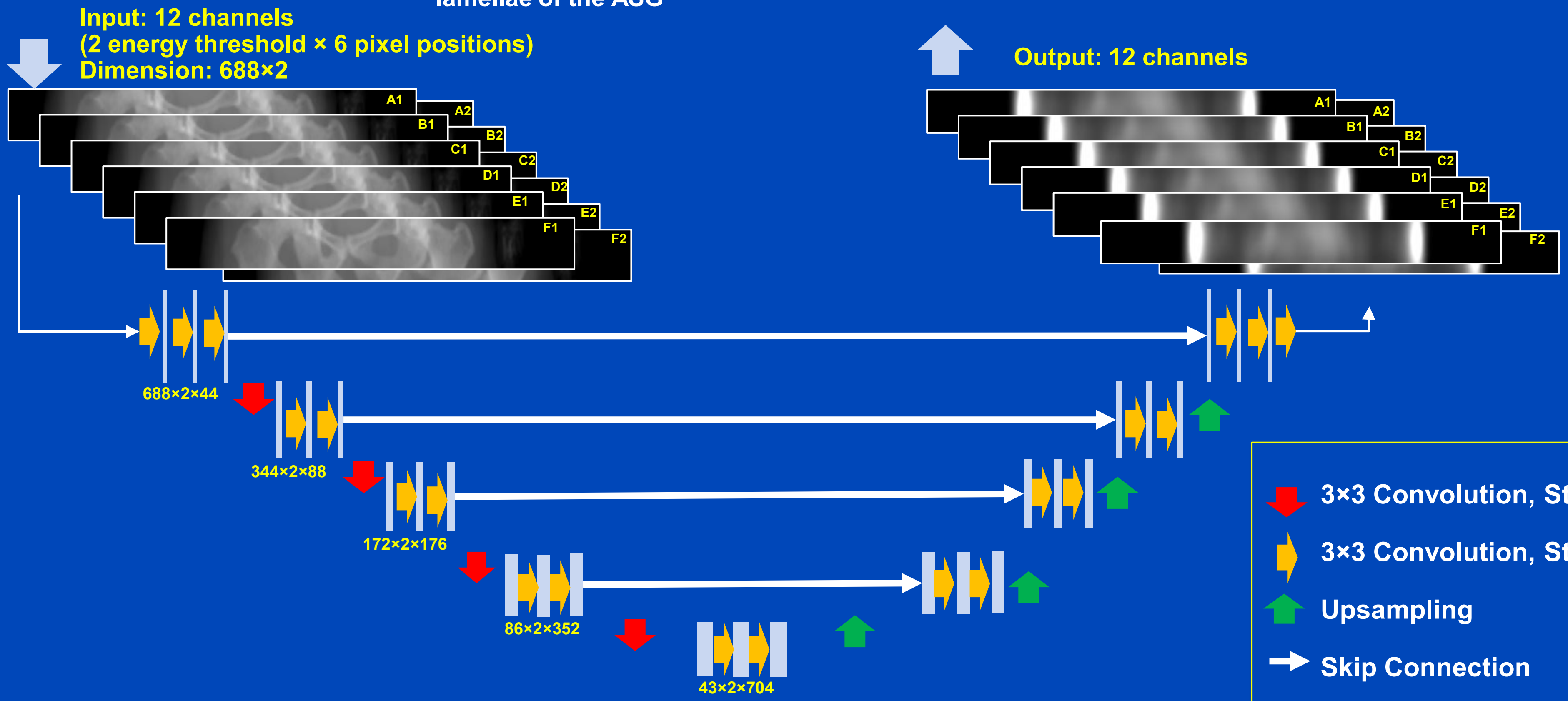
Total data set: 5760 projections
- 36 projections per z-position
- 160 different z-positions

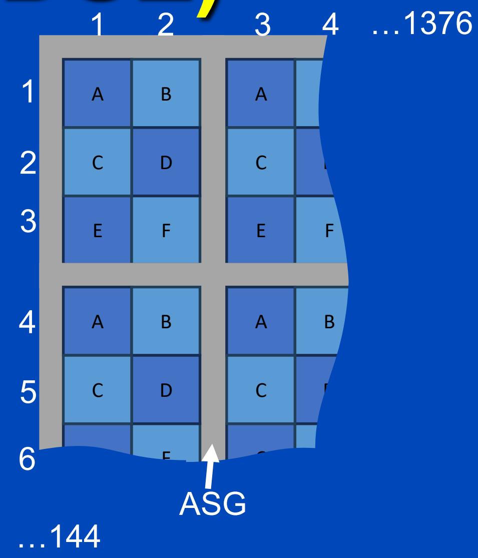
Measurement-Based Spectral DSE (mbsDSE)

Detector dimension 1376×6

Each channel corresponds to a different pixel position between the lamellae of the ASG

merging 6 pixel positions





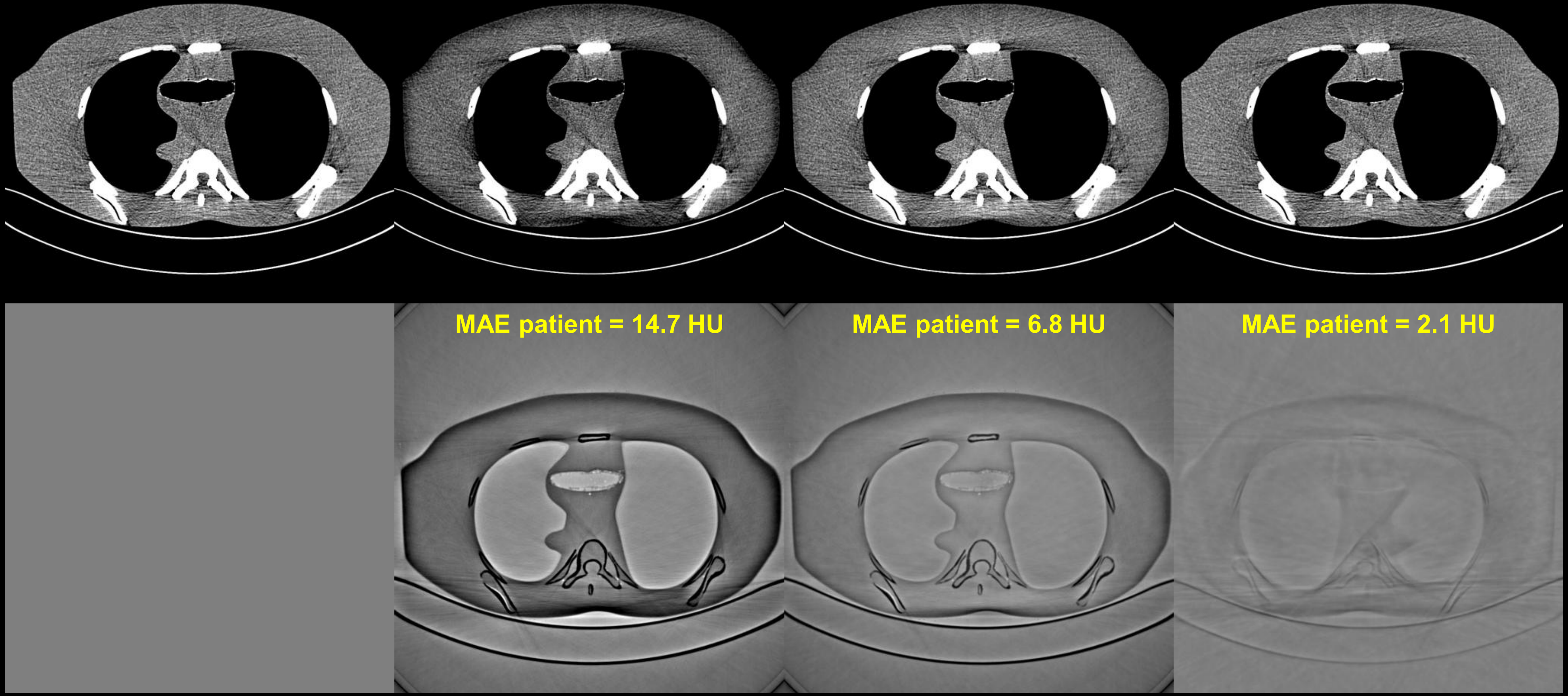
- 3×3 Convolution, Stride 2
- 3×3 Convolution, Stride 1
- Upsampling
- Skip Connection

[1] J. Maier, M. Kachelrieß et al. “Deep Scatter Estimation (DSE)“, SPIE 2018 and J. of Nondest. Eval. 37:57, July 2018.
[2] J. Maier, M. Kachelrieß et al. “Robustness of DSE“, Med. Phys. 46(1):238-249, January 2019.
[3] J. Erath, M. Kachelrieß et al. “Monte-Carlo-Free Deep Scatter Estimation (DSE) for X-Ray CT and CBCT”, RSNA 2019.
[4] J. Erath, T. Vöth, J. Maier, E. Fournié, M. Petersilka, K. Stierstorfer, and M. Kachelrieß, “Deep Scatter Correction in DSCT”, CT Meeting August 2020.
[5] J. Erath, T. Vöth, J. Maier, E. Fournié, M. Petersilka, K. Stierstorfer, and M. Kachelrieß, “Deep Learning-Based Forward and Cross-Scatter Correction in DS CT” Med. Phys. 2021.

RESULTS

Low Energy Threshold Image

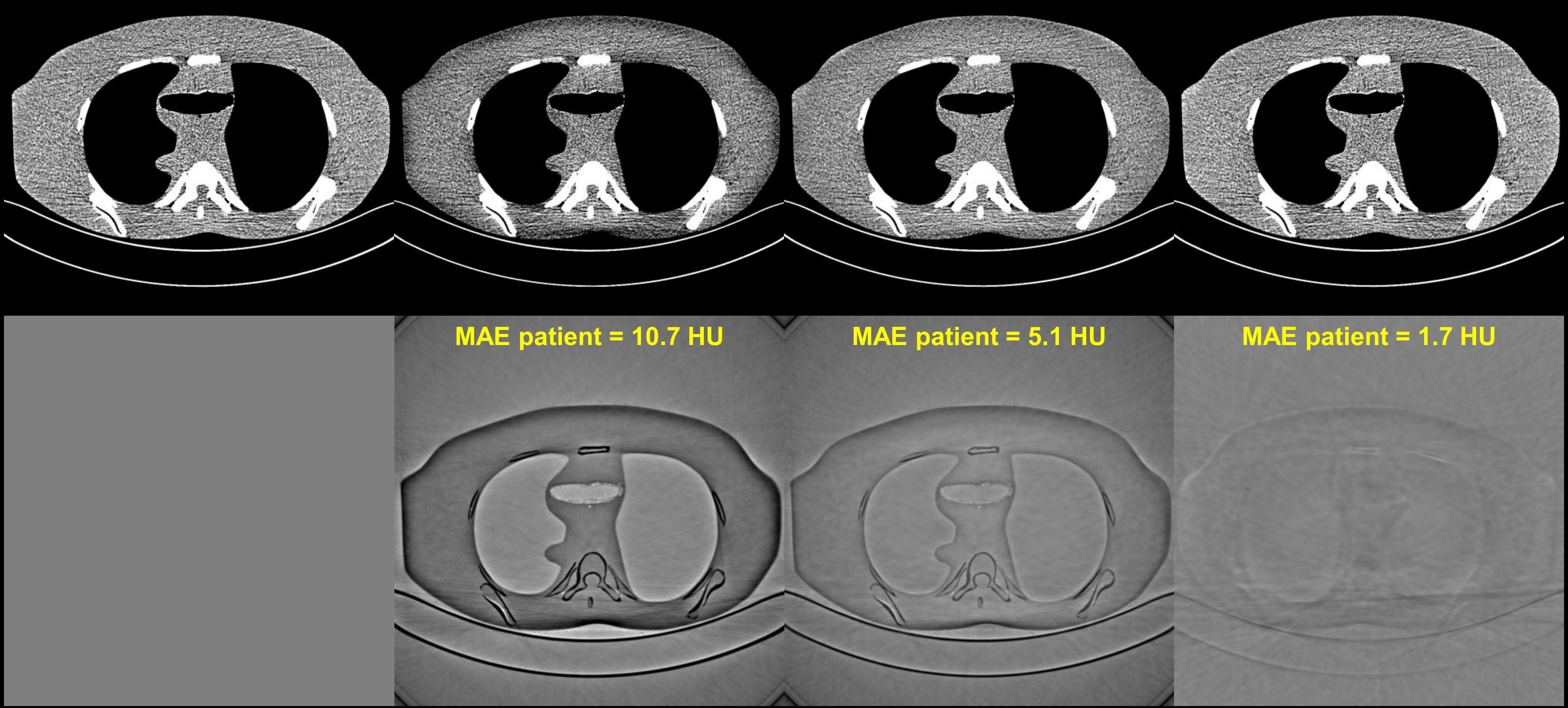
ground truth | uncorrected | analytical model | mbsDSE



DSE was only applied to the innermost 6 detector rows and the images shown are reconstructions from these rows
Kernel Qr40f, reconstructed images *C* = 60 HU, *W* = 120 HU
difference images *C* = 0 HU, *W* = 100 HU

High Energy Threshold Image

ground truth | uncorrected | analytical model | mbsDSE



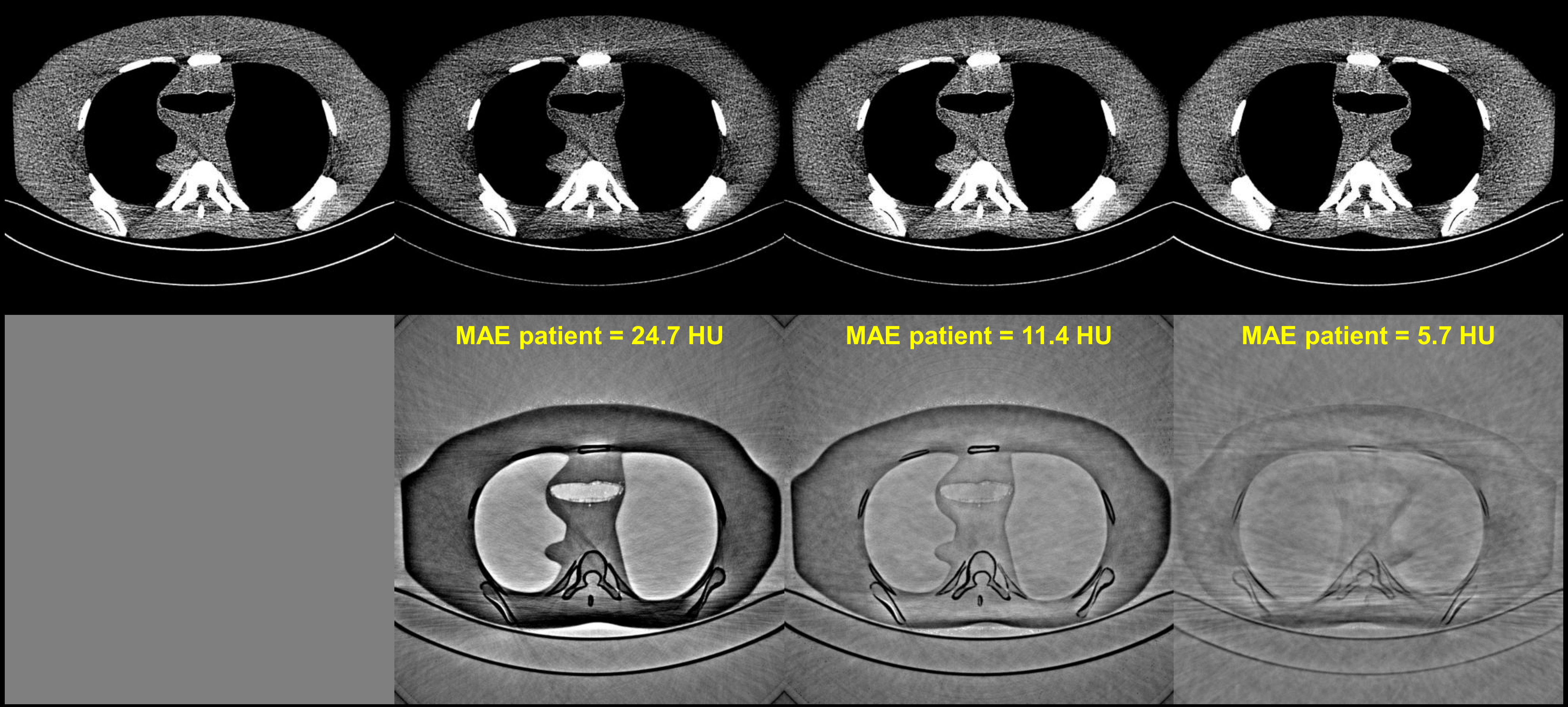
DSE was only applied to the innermost 6 detector rows and the images shown are reconstructions from these rows

Kernel Qr40f, reconstructed images C = 60 HU, W = 120 HU

difference images C = 0 HU, W = 100 HU

VMI 50 keV Image

ground truth | uncorrected | analytical model | mbsDSE



DSE was only applied to the innermost 6 detector rows and the images shown are reconstructions from these rows
Kernel Qr40f, reconstructed images C = 40 HU, W = 200 HU
difference images C = 0 HU, W = 100 HU

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Conclusions & Outlook

- Conclusions
  - mbsDSE achieves substantially stronger MAE reductions (77 to 86%) compared to the analytical model (52 to 54 %) across low energy, high energy, and spectral data for the test phantom.
  - The largest gains appear in low energy threshold data (86% reduction).
- Outlook
  - mbDSE is not limited to PCCT but can also be used for EICT.
  - A measurement-based trained cross-scatter DSE should also be possible.
  - In the future, multiple scans should be used to scan the entire detector and thus obtain a label for the complete detector size.
  - The influence of iodine on mbsDSE performance has not yet been investigated, but will be addressed in future work.

Thank You!

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

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