# Monte-Carlo-Free Deep Scatter Estimation (DSE) for X-Ray CT and CBCT

Julien Erath[1,2,3], Carolin Langner[1], Joscha Maier[1], Eric Fournie [2], Karl Stierstorfer[2], and Marc Kachelrieß[1,3]

[1]German Cancer Research Center (DKFZ), Heidelberg, Germany
[2]Siemens Healthineers, Forchheim, Germany
[3]Ruprecht-Karls-Universität, Heidelberg, Germany

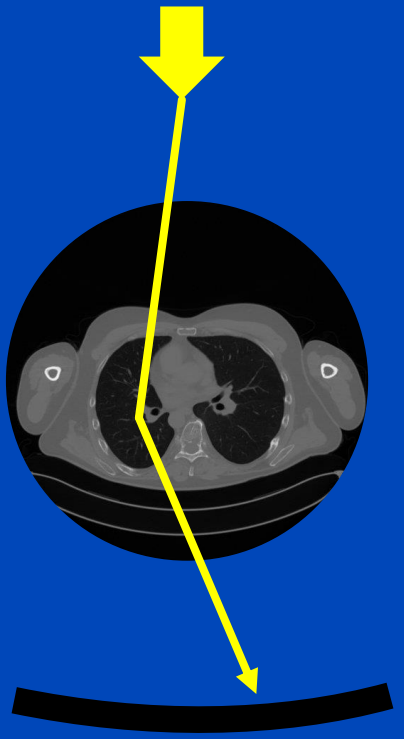
www.dkfz.de/ct

SIEMENS Healthineers

dkfz. DEUTSCHES KREBSFORSCHUNGSZENTRUM IN DER HELMHOLTZ-GEMEINSCHAFT

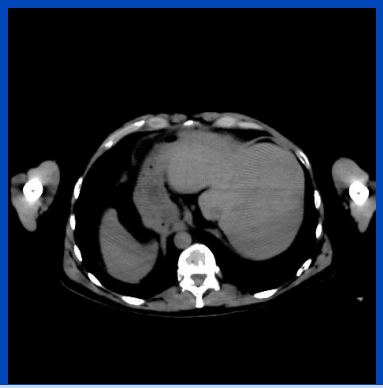
# Motivation

- Scatter degrades image quality in CT
- Correct scatter using Monte Carlo (MC) simulations
  - Very long computation times
  - Prior knowledge (first recon) necessary
  - Has to be adapted to different scanner geometries
- Recently: simulation-based deep scatter estimation (sbDSE) – requires MC in training phase
- Aim: Design phantom to train DSE measurement-based (mbDSE) – no need for MC

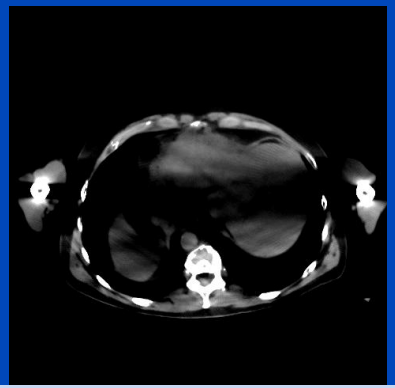


*C* = 40 HU, *W* = 300 HU,
Geometry of Somatom Force
but without anti-scatter grid

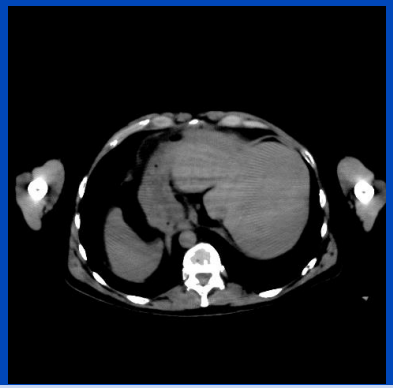
Ground Truth



Effect of Scatter



DSE



J. Maier, M. Kachelrieß et al. Deep scatter estimation (DSE). SPIE 2017 and J. of Nondest. Eval. 37:57, July 2018.
J. Maier, M. Kachelrieß et al. Robustness of DSE. Med. Phys. 46(1):238-249, January 2019.

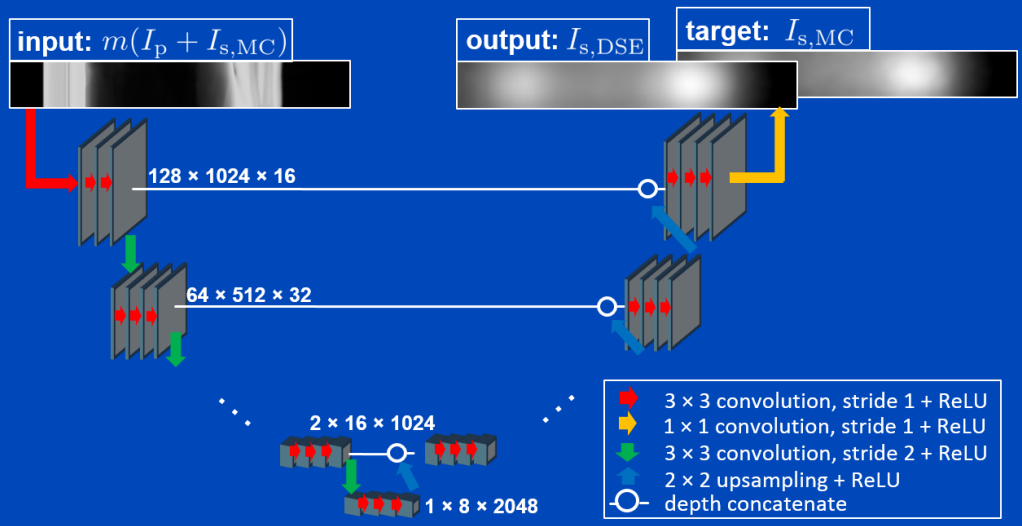
# Deep Scatter Estimation (DSE)

- Use 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 much faster than the Monte Carlo simulation.

Scatter profile from Monte Carlo simulation
Time: 65 s per projection = 14 h per circle scan

Scatter prediction from deep scatter estimation
Time: 14 ms per projection = 10.3 s per circle scan

| DSE - MC |  MAPE = 2.5 %





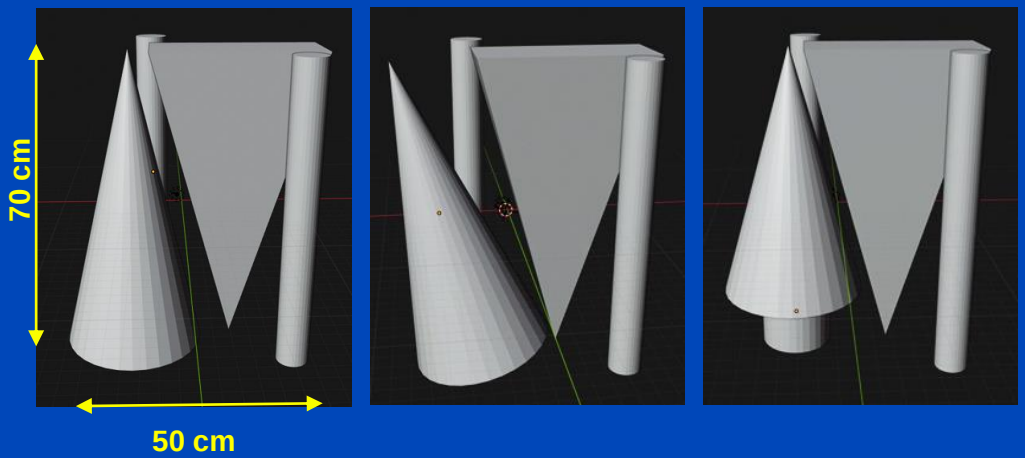
J. Maier, M. Kachelrieß et al. Deep scatter estimation (DSE). SPIE 2017 and J. of Nondest. Eval. 37:57, July 2018.
J. Maier, M. Kachelrieß et al. Robustness of DSE. Med. Phys. 46(1):238-249, January 2019.

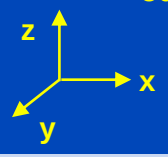
# Measurement-Based DSE

- Design a phantom that is easy to manufacture and to simulate
- Subtract simulated from the measured intensities to obtain scatter
- Train DSE with these data pairs: mbDSE

- Phantom contains a cone, a pyramid and two rods to cover a large range of typical attenuation values, e.g. 0 to 40 cm soft tissue, 0 to 5 cm bone, …
- Phantom is scanned in various configurations

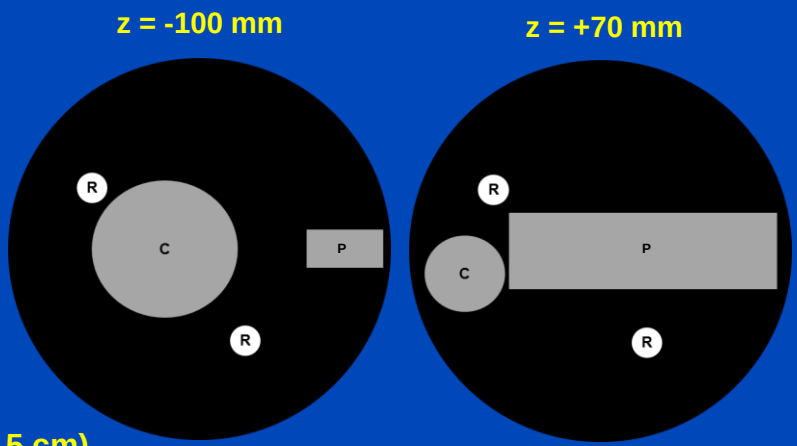
Example configurations obtained by rotations and translations




C = PE cone (diameter from 10 cm to 28 cm)
P = PE pyramid (from 35 cm × 10 cm to 10 cm × 5 cm)
R = Teflon rod (4 cm diameter)

Along *z* we obtain different cross sections:



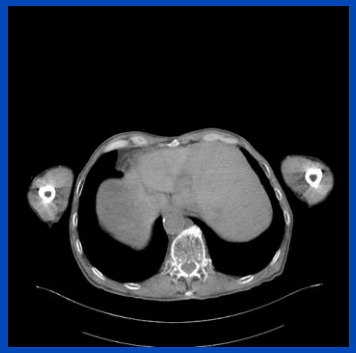
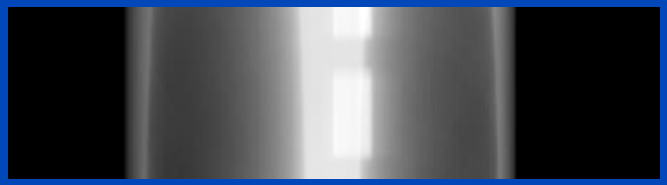
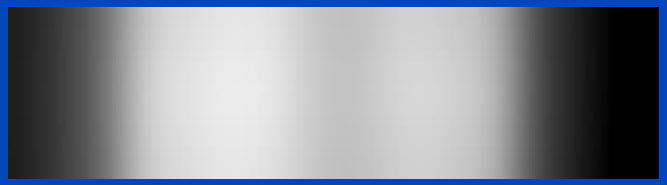
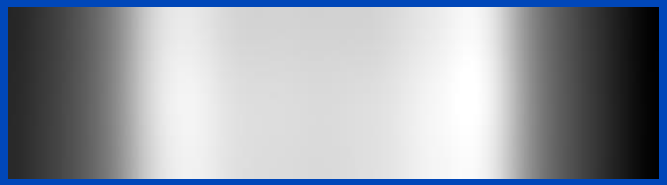
# Generation of Training and Test Data

- **Simulate** $I_{\mathrm{Primary}}$ **by polychromatic forward projection**
- **In ideal condition we can measure:** $I_{\mathrm{Measured}} = I_{\mathrm{Primary}} + I_{\mathrm{Scatter}}$
- **So we obtain:** $I_{\mathrm{Scatter}} = I_{\mathrm{Measured}} - I_{\mathrm{Primary}}$
- **Neural network will get pairs of projection containing:**
  $I_{\mathrm{Primary}} + I_{\mathrm{Scatter}}$ **and** $I_{\mathrm{Scatter}}$

# Disclaimer

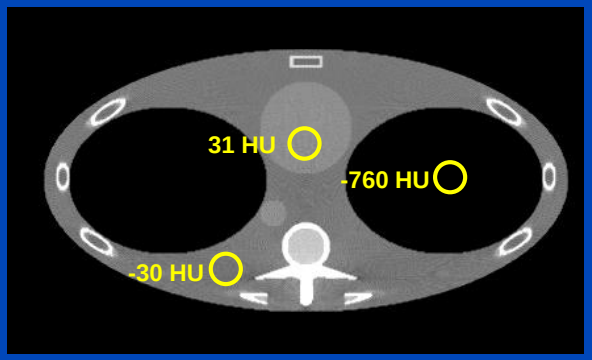
We have not yet manufactured the phantom.
Therefore we simulate the phantom measurements.
The results shown are based on these simulations.

# Results

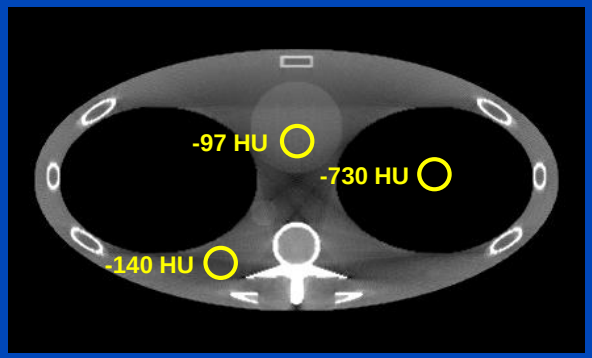
| | Thorax phantom | Patient |
|---|---|---|
| Ground truth images: |  |  |
| Input to neural network: Primary + Scatter |  |  |
| MC scatter (GT) |  |  |
| mbDSE estimation |  |  |

# Results: Thorax Phantom

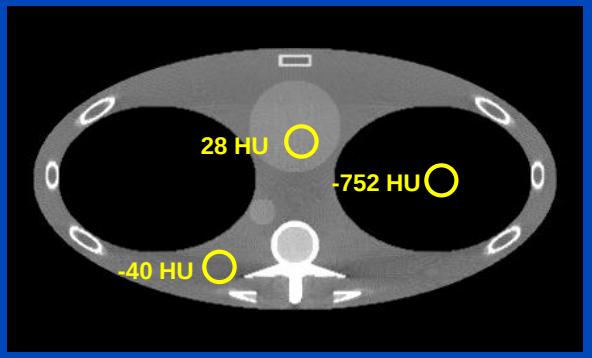
**Ground truth (no scatter)**



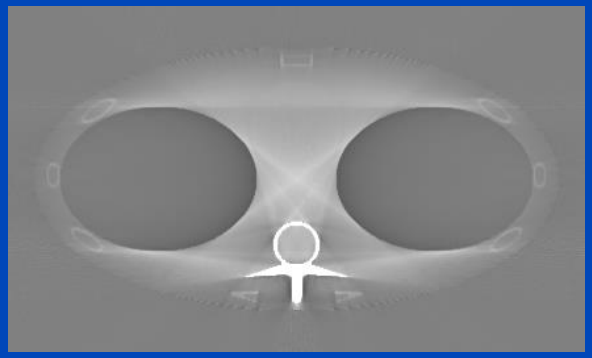

**Uncorrected (with scatter)**




**mbDSE-corrected**




**Difference reconstruction to ground truth**

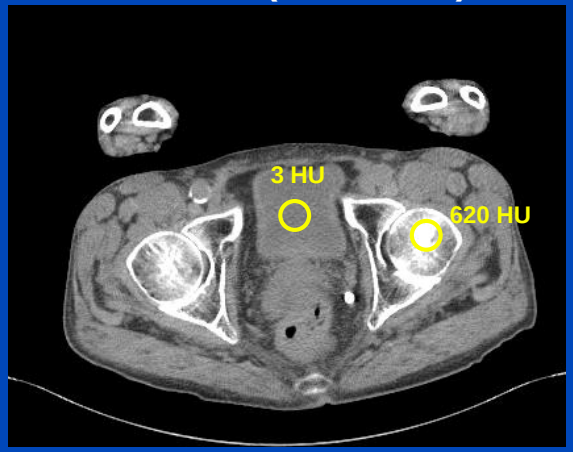


**MAE: 52 HU**

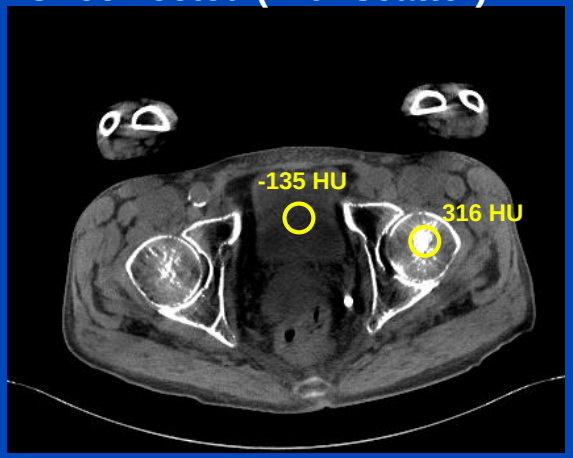
**MAE: 5 HU**

# Results: Patient Example 1

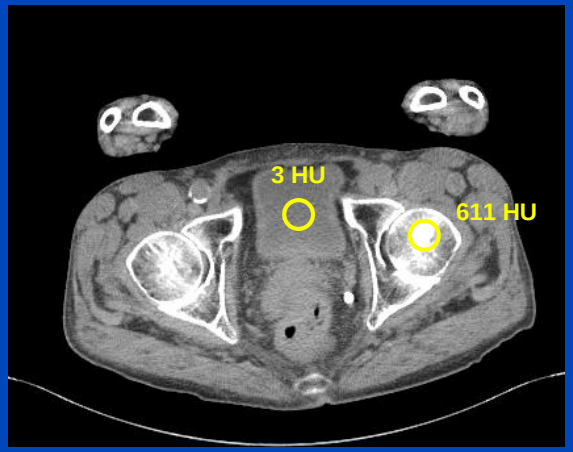
Ground truth (no scatter)



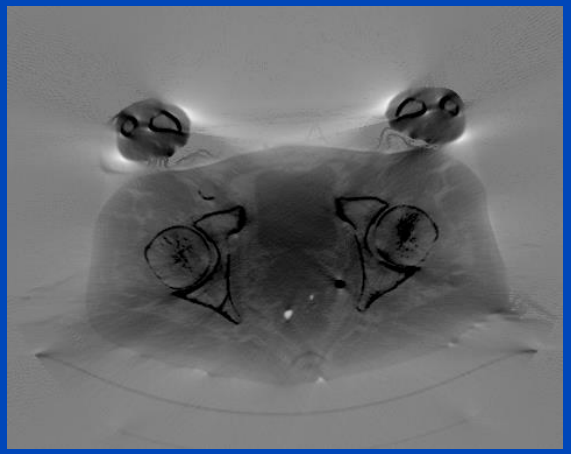

Uncorrected (with scatter)



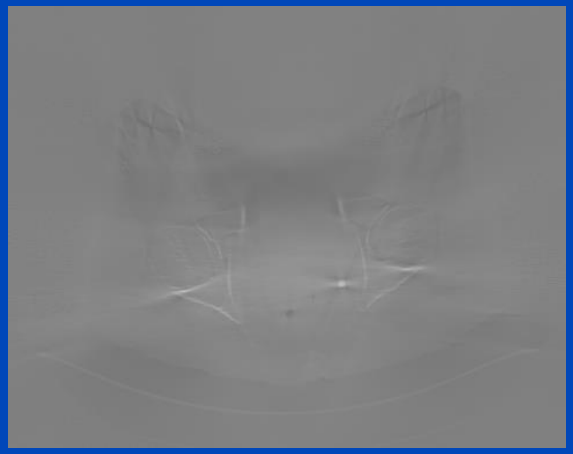

mbDSE-corrected




Difference Reconstruction to Ground Truth



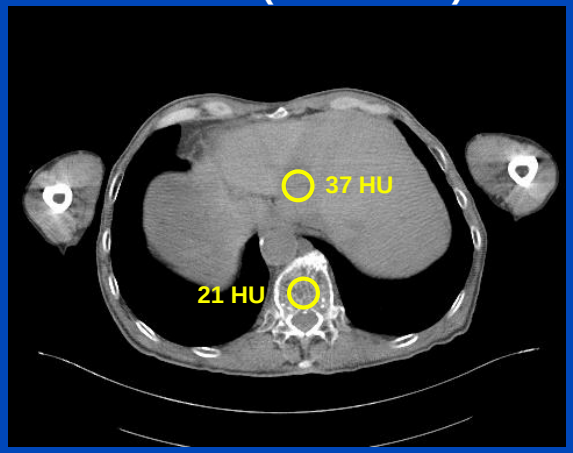
MAE: 82 HU



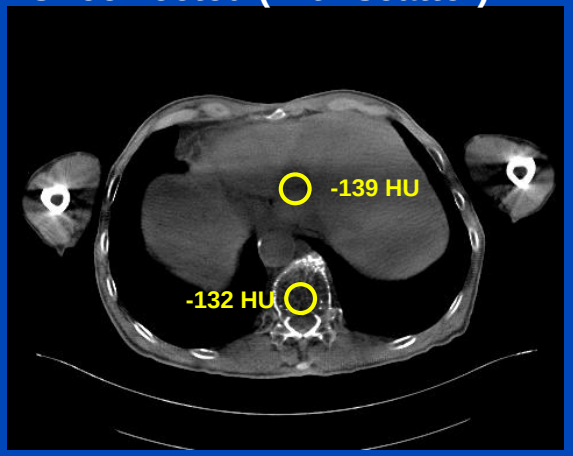
MAE: 9 HU

# Results: Patient Example 2

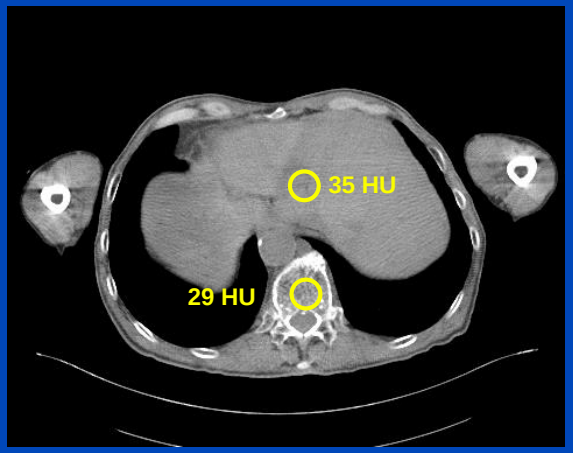
Ground truth (no scatter)



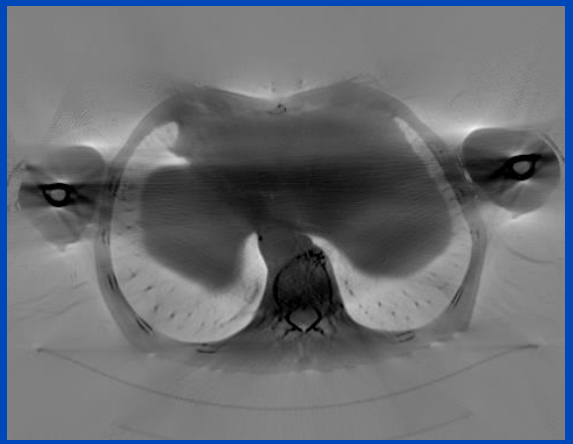

Uncorrected (with scatter)



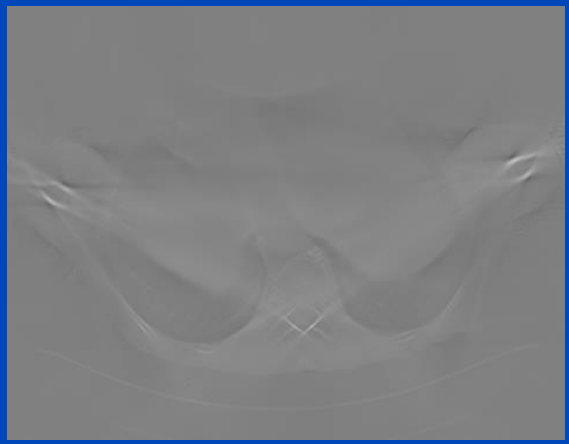

mbDSE-corrected




Difference Reconstruction to Ground Truth



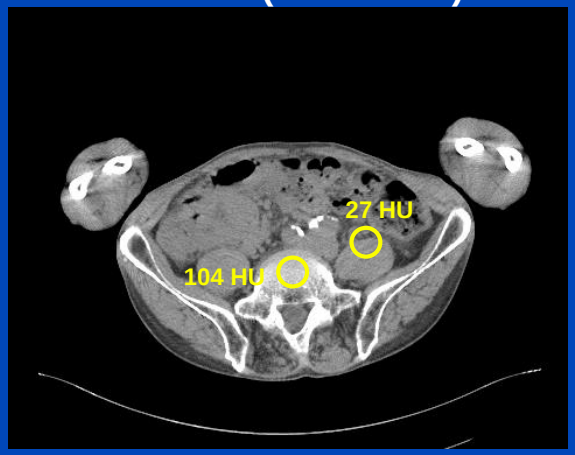
MAE: 80 HU



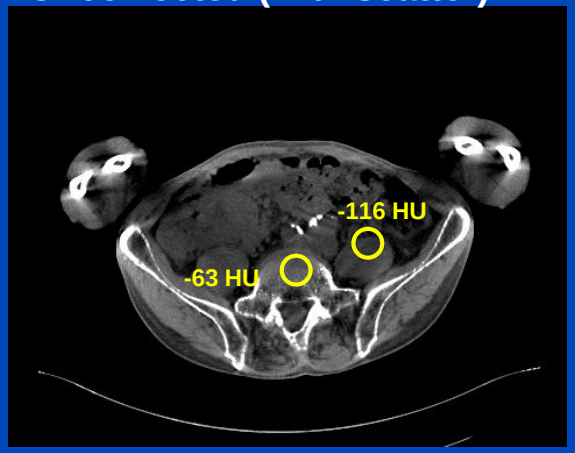
MAE: 12 HU

# Results: Patient Example 3

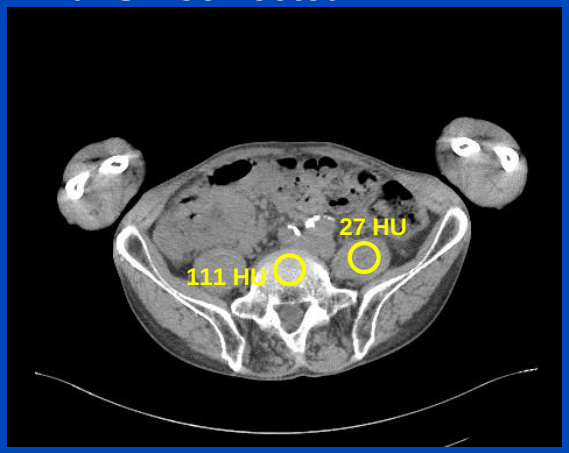
Ground truth (no scatter)



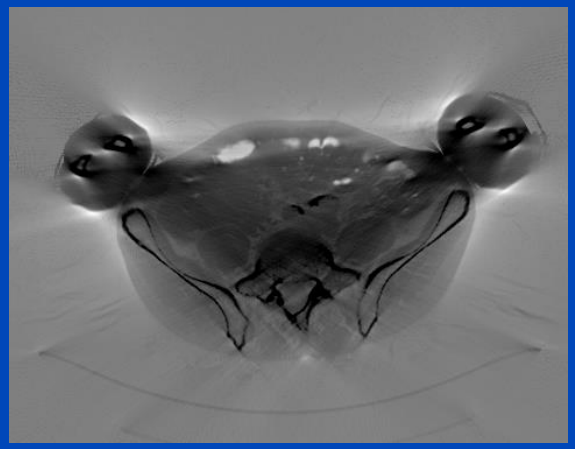

Uncorrected (with scatter)



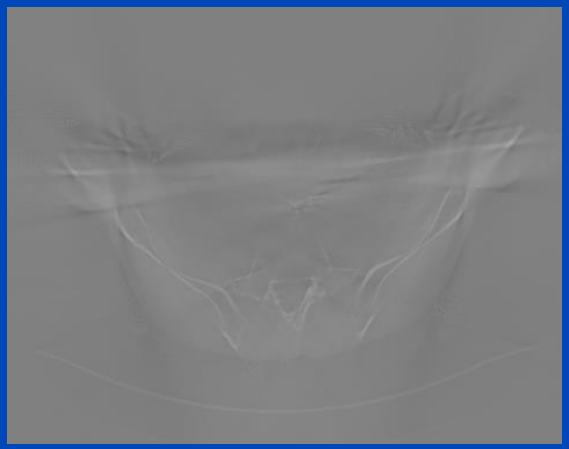

mbDSE-corrected




Difference Reconstruction to Ground Truth



MAE: 90 HU



MAE: 8 HU

# Summary and Outlook

- DSE can be trained with measured phantom data to estimate forward scatter of unseen patients.
- mbDSE is able to accurately estimate scatter in clinical CT.
- Limitations:
  - Currently, mbDSE was only evaluated in a simulation study.
  - Many configurations of the phantom are needed.
- Future work:
  - Develop a phantom where a single configuration is sufficient for mbDSE.
  - Manufacture this phantom and use real measurements for mbDSE training.

# Thank You!

The 6th International Conference on

**Image Formation in X-Ray Computed Tomography**

August 3 - August 7 • 2020 • Regensburg • Germany • www.ct-meeting.org


Conference Chair: **Marc Kachelrieß**, German Cancer Research Center (DKFZ), Heidelberg, Germany

**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.**