Behnken-Berger-Preis 2021

Real-Time Scatter Estimation for Medical CT using the Deep Scatter Estimation (DSE)

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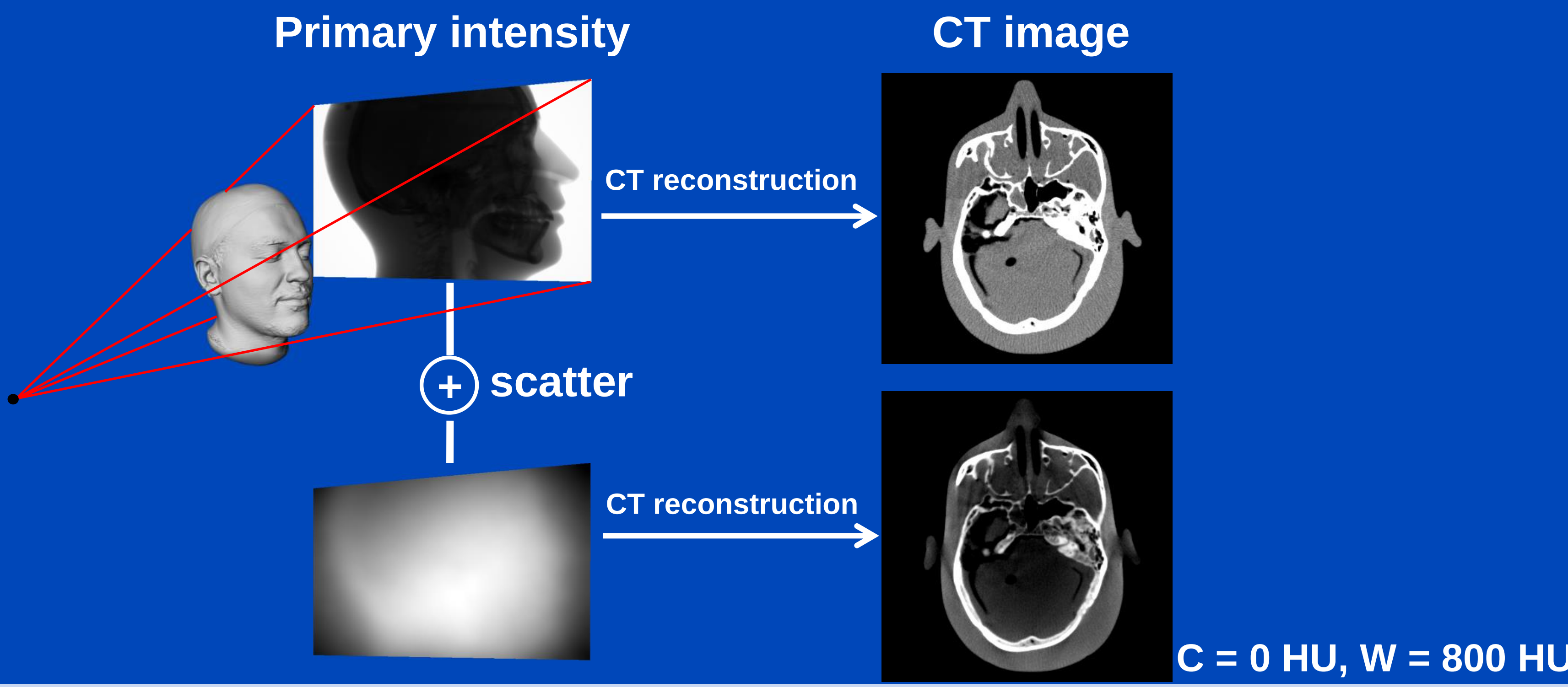
DEUTSCHES KREBSFORSCHUNGSZENTRUM
IN DER HELMHOLTZ-GEMEINSCHAFT

Motivation

- X-ray scatter is a major cause of image quality degradation in CT and CBCT.
- Appropriate scatter correction is crucial to maintain the diagnostic value of the CT examination.



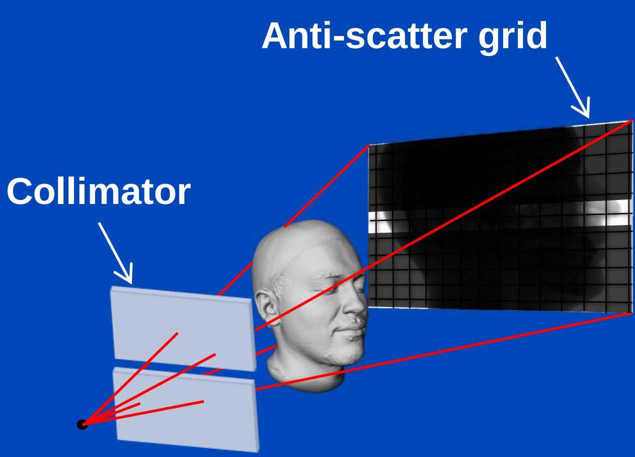
Scatter Correction

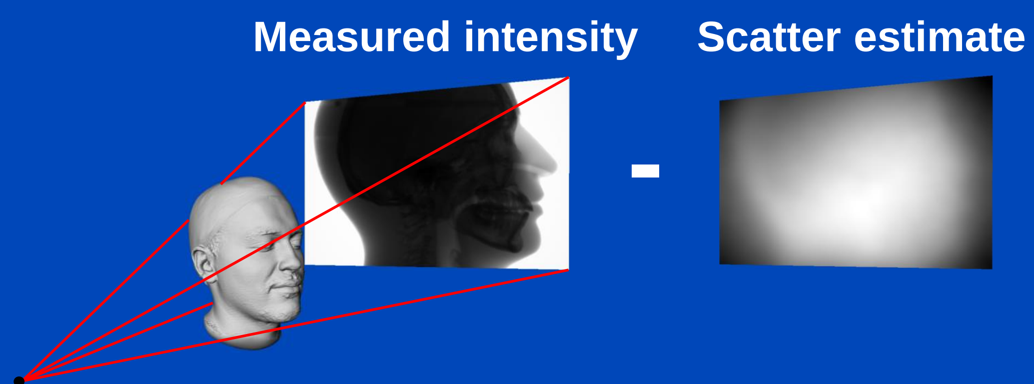
Scatter suppression

- Anti-scatter grids
- Collimators
- …

Scatter estimation

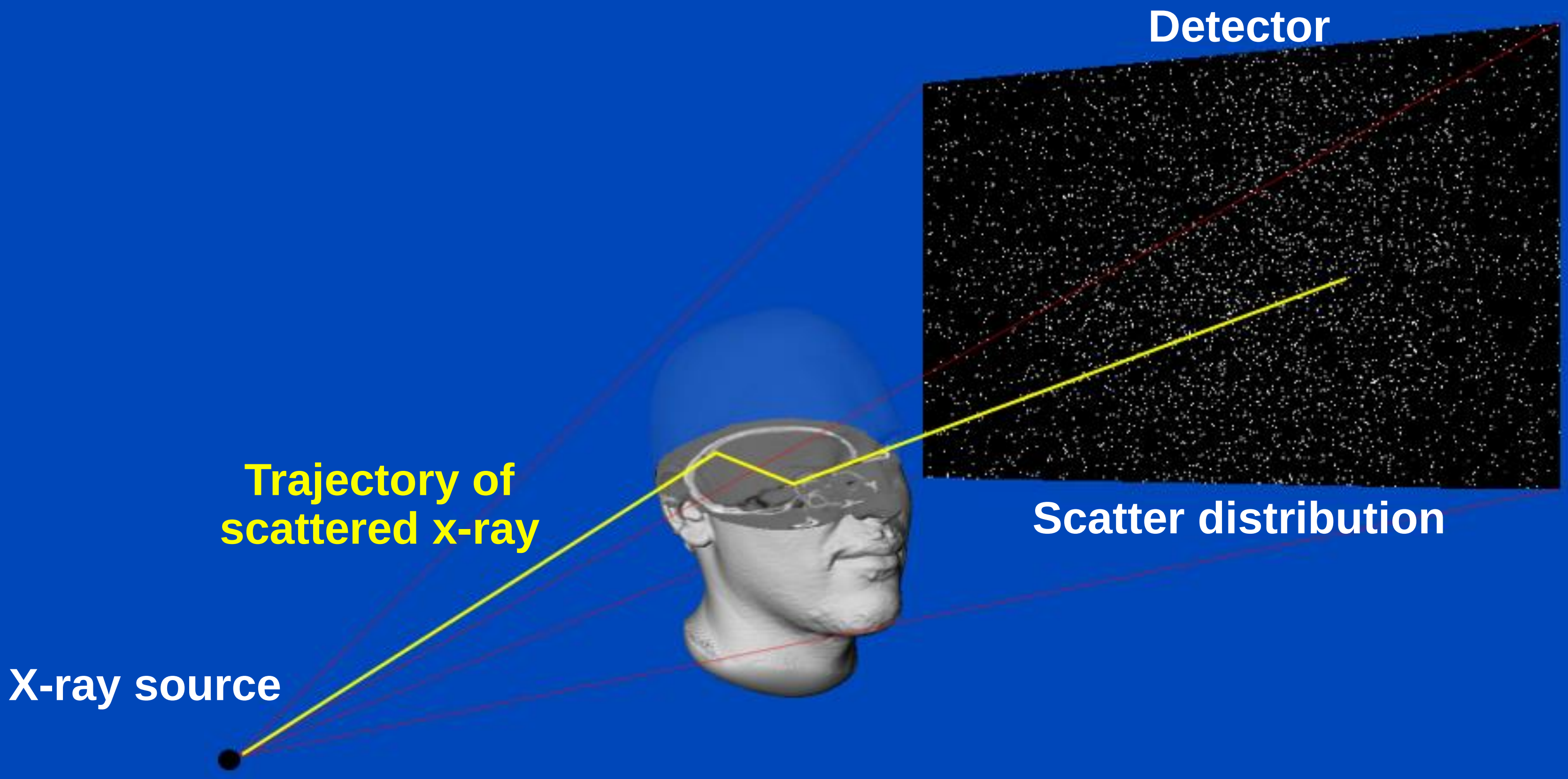
- Monte Carlo simulation
- Kernel-based approaches
- Boltzmann transport
- Primary modulation
- Beam blockers
- …





Monte Carlo Scatter Estimation

- Simulation of individual photon trajectories according to physical interaction probabilities.



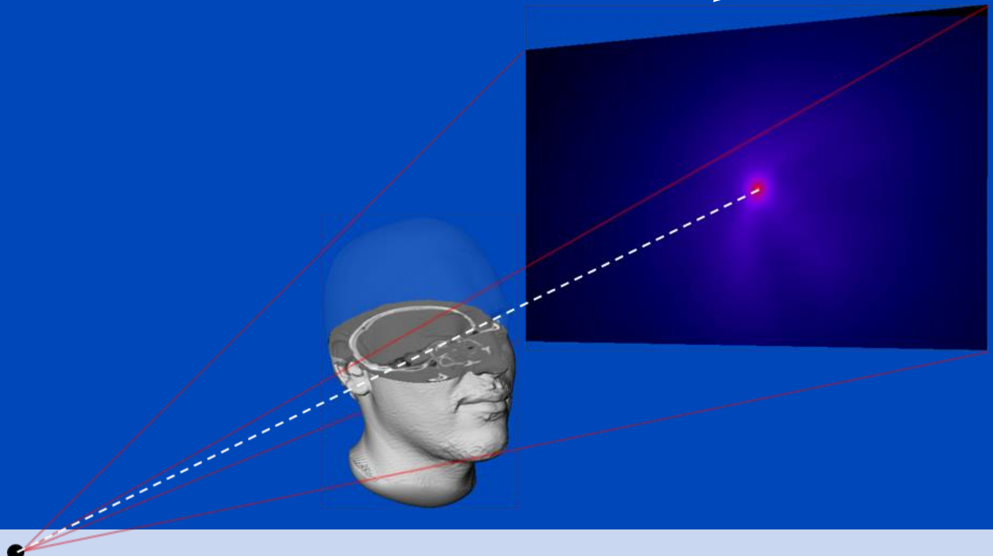
→ Typically too slow to be applied routinely.

Faster Alternative: Kernel-Based Scatter Estimation

$T(p)$

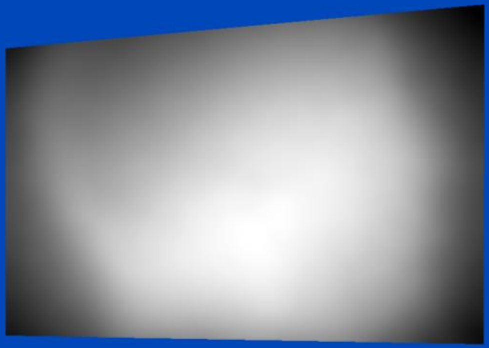
Estimate needle beam scatter kernels as a function of the projection data p

$$I_{\mathrm{s,\ est}}(\boldsymbol{u}) = \int T(p)(\boldsymbol{u}')G(\boldsymbol{u},\boldsymbol{u}',\boldsymbol{c})d\boldsymbol{u}'$$



Estimate mean scatter kernel that maps a function of the projection data p **to scatter distribution**

$$I_{\mathrm{s,\ est}}(\boldsymbol{u}) = T(p)(\boldsymbol{u}) * G(\boldsymbol{u},\boldsymbol{c})$$

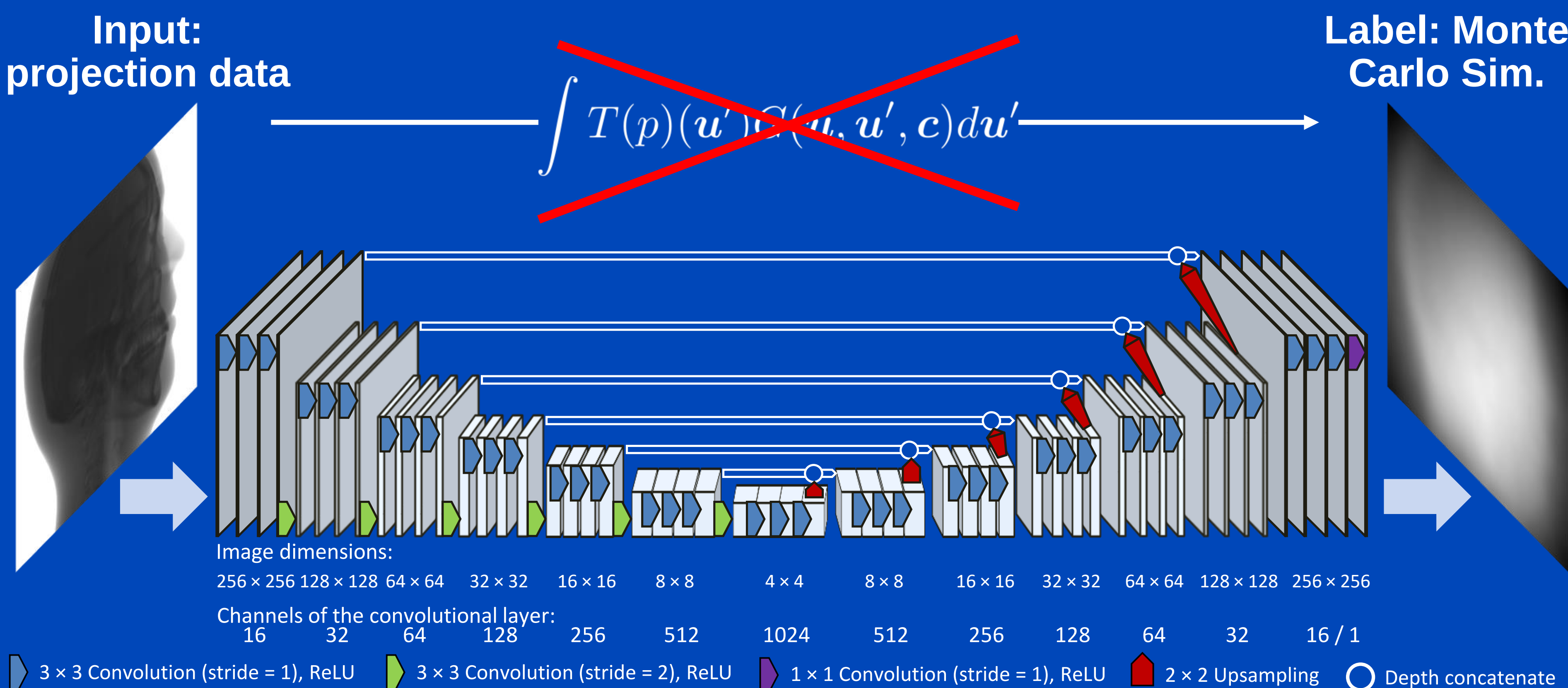


→ Typically far less accurate than Monte Carlo simulations.

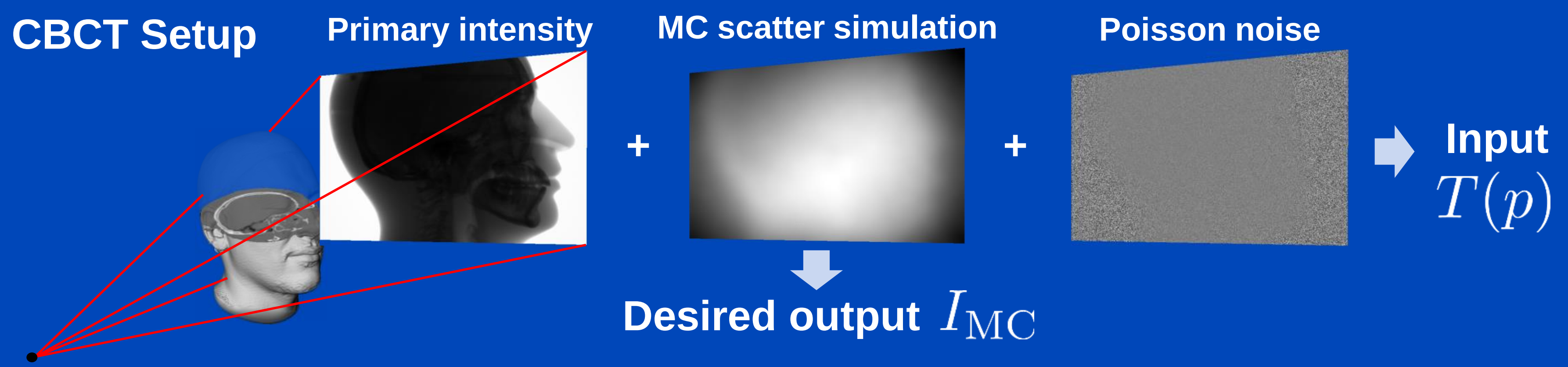
Deep Scatter Estimation (DSE)

Basic Principle

- Use a deep convolutional neural network to estimate scatter as a function of the acquired projection data.



Training / Testing of the DSE Network



- Training data: Simulated CBCT projection data (input) and Monte Carlo scatter simulation (label).
- Simulation of different anatomical regions, tube voltages and scan protocols.
- Optimization of the network's trainable parameters:

$$\{w, b\} = \operatorname{argmin} ||DSE(T(p)) - I_{\mathrm{MC}}||_2^2$$

- Testing on independent simulations of different patients.

Reference 1

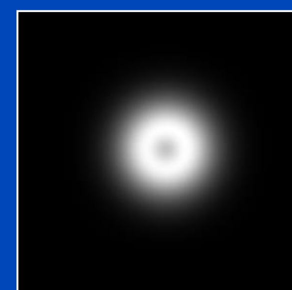
Kernel-based scatter estimation (KSE)

- **Kernel-based scatter estimation[1]:**
  - Estimation of scatter by a convolution of the scatter source term $T(p)$ with a scatter propagation kernel $G(\boldsymbol{u}, \boldsymbol{c})$:

$$I_{\mathrm{s,\ est}}(\boldsymbol{u}) = \underbrace{\left(c_0 \cdot p(\boldsymbol{u}) \cdot e^{-p(\boldsymbol{u})}\right)} * \underbrace{\left(\sum_{\pm} e^{-c_1(\boldsymbol{u}\hat{\boldsymbol{e}}_1 \pm c_2)^2} \cdot \sum_{\pm} e^{-c_3(\boldsymbol{u}\hat{\boldsymbol{e}}_2 \pm c_4)^2}\right)}$$

$T(p)(\boldsymbol{u})$

Open parameters: c_0



$G(\boldsymbol{u}, \boldsymbol{c})$

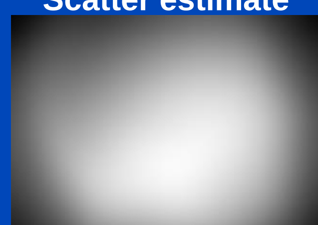
Open parameters: c_1, c_2, c_3, c_4

$$\{c_i\} = \operatorname{argmin} \sum_{n} \sum_{\boldsymbol{u}} \left\| I_{\mathrm{s,\ est}}(n, \boldsymbol{u}, \{c_i\}) - I_{\mathrm{s}}(n, \boldsymbol{u}) \right\|_2^2,$$

Samples of the training data set

Detector coordinate

Scatter estimate



MC scatter simulation

[1] B. Ohnesorge, T. Flohr, K. Klingenbeck-Regn: Efficient object scatter correction algorithm for third and fourth generation CT scanners. Eur. Radiol. 9, 563–569 (1999).

Reference 2

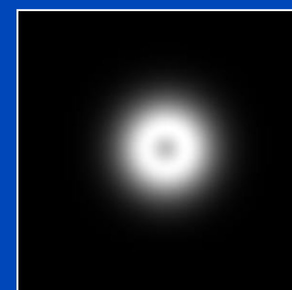
Hybrid scatter estimation (HSE)

- **Hybrid scatter estimation[2] :**
  - **Estimation of scatter by a convolution of the scatter source term $T(p)$ with a scatter propagation kernel $G(\boldsymbol{u},\boldsymbol{c})$:**

$$I_{\text{s, est}}(\boldsymbol{u}) = \underbrace{\left(c_0\cdot p(\boldsymbol{u})\cdot e^{-p(\boldsymbol{u})}\right)} * \underbrace{\left(\sum_{\pm} e^{-c_1(\boldsymbol{u}\hat{\boldsymbol{e}}_1\pm c_2)^2}\cdot\sum_{\pm} e^{-c_3(\boldsymbol{u}\hat{\boldsymbol{e}}_2\pm c_4)^2}\right)}$$

$T(p)(\boldsymbol{u})$

Open parameters: c_0



$G(\boldsymbol{u},\boldsymbol{c})$

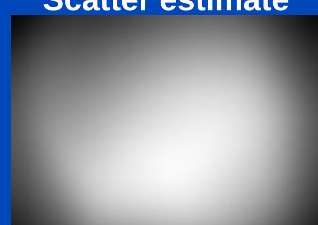
Open parameters: c_1, c_2, c_3, c_4

$$\{c_i\}_n = \operatorname{argmin}\sum_{\boldsymbol{u}} \left\|I_{\text{s, est}}(n,\boldsymbol{u},\{c_i\}) - I_{\text{s}}(n,\boldsymbol{u})\right\|_2^2,$$

Samples of the test data set

Detector coordinate

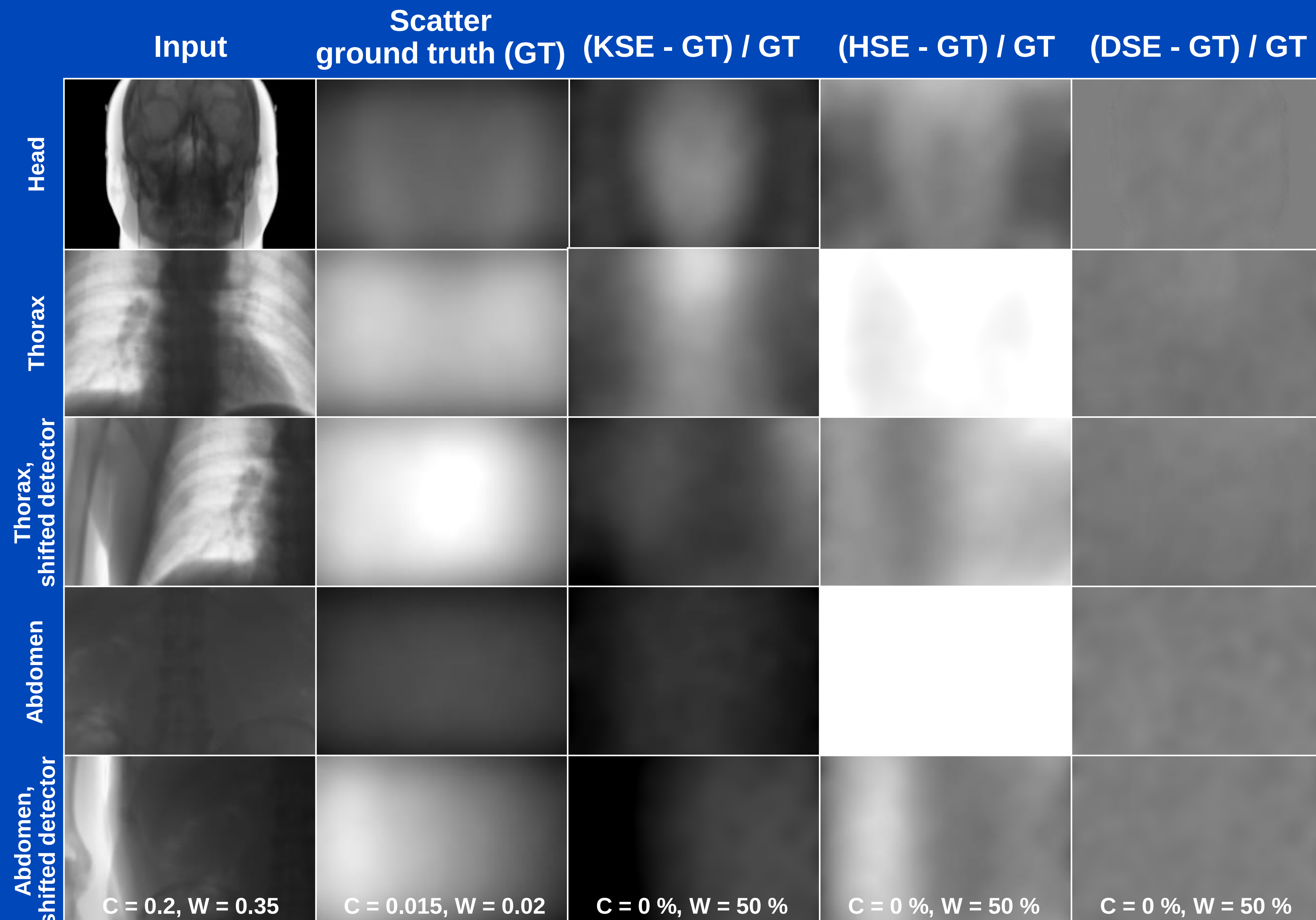
Scatter estimate



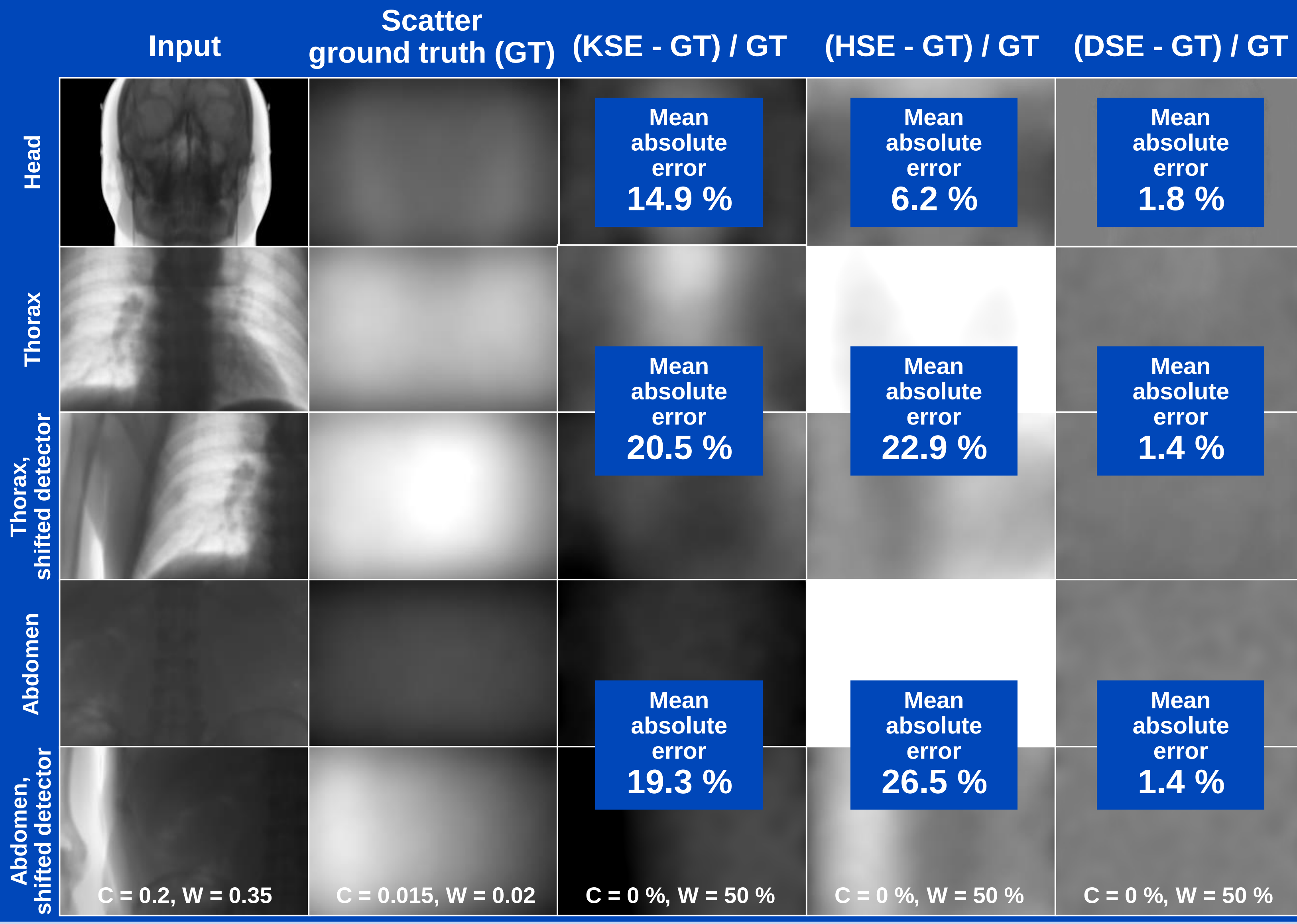
Coarse MC simulation

[2] M. Baer, M. Kachelrieß: Hybrid scatter correction for CT imaging. Phys. Med. Biol. 57, 6849–6867 (2012).

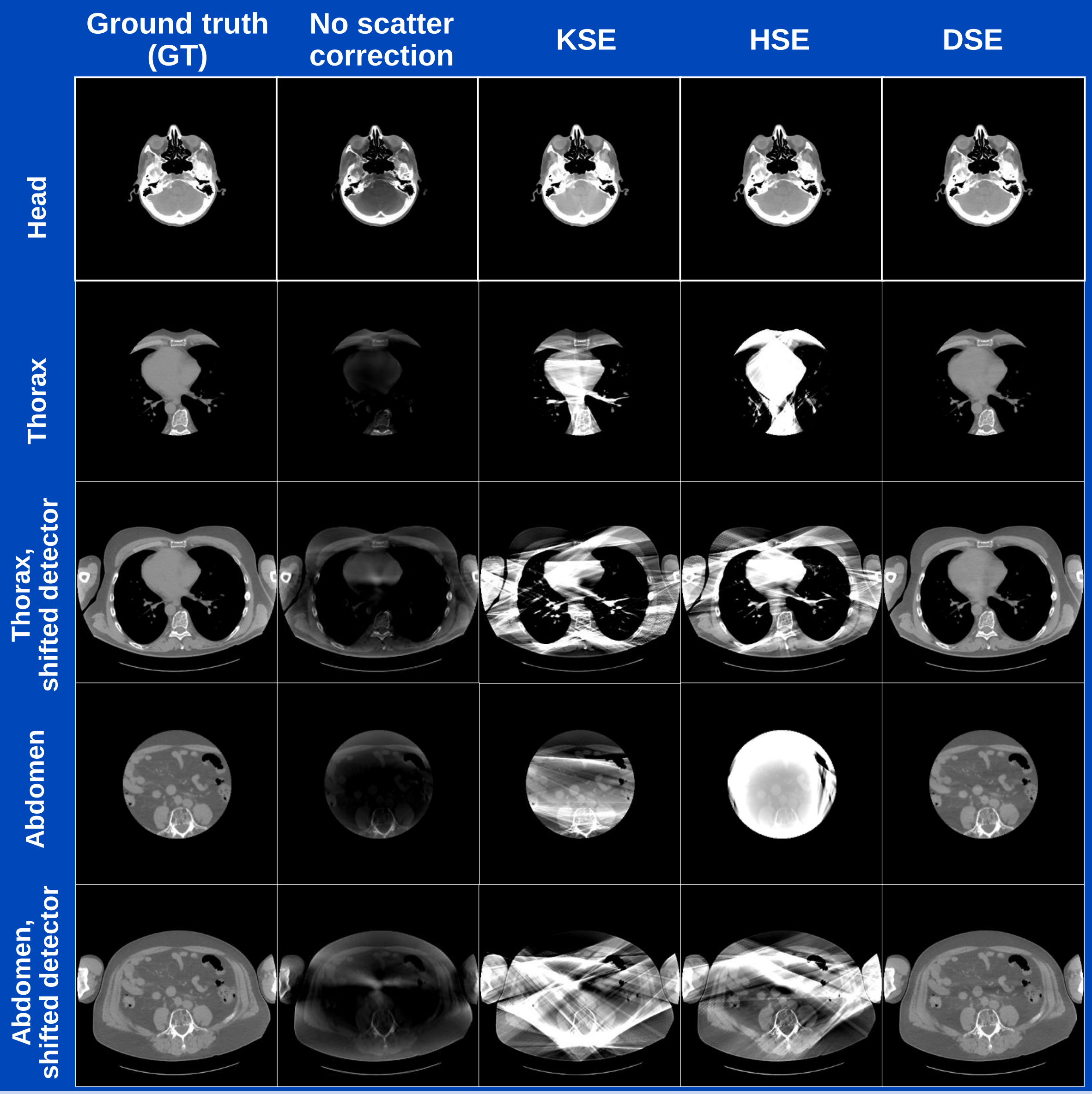
Results – Scatter Estimates



Results – Scatter Estimates



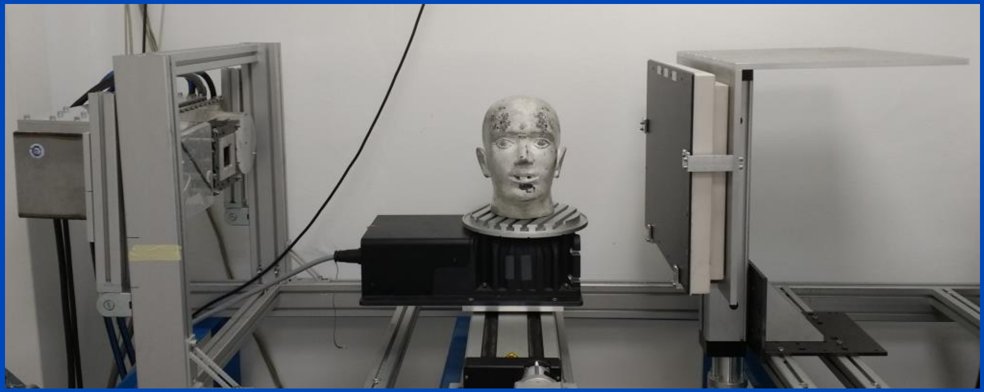
Results – CT Reconstructions



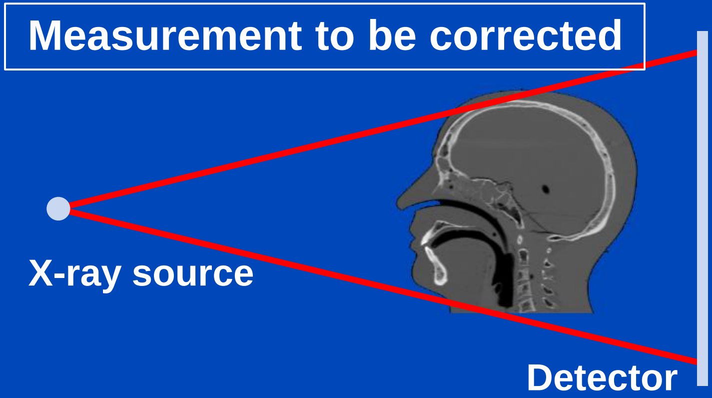
C = 0 HU, W = 700 HU

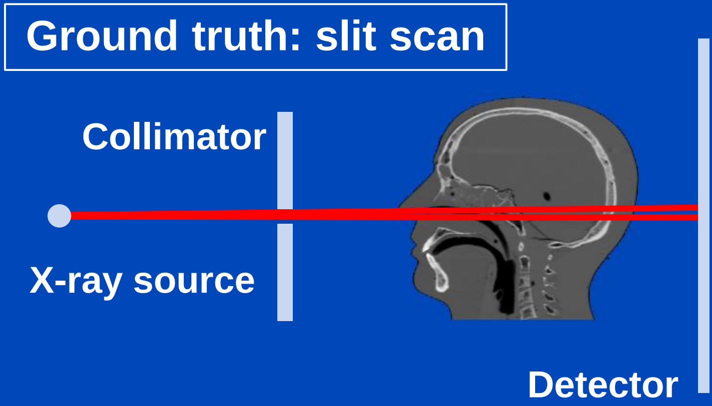
Application to Measured Data

DKFZ table-top CT

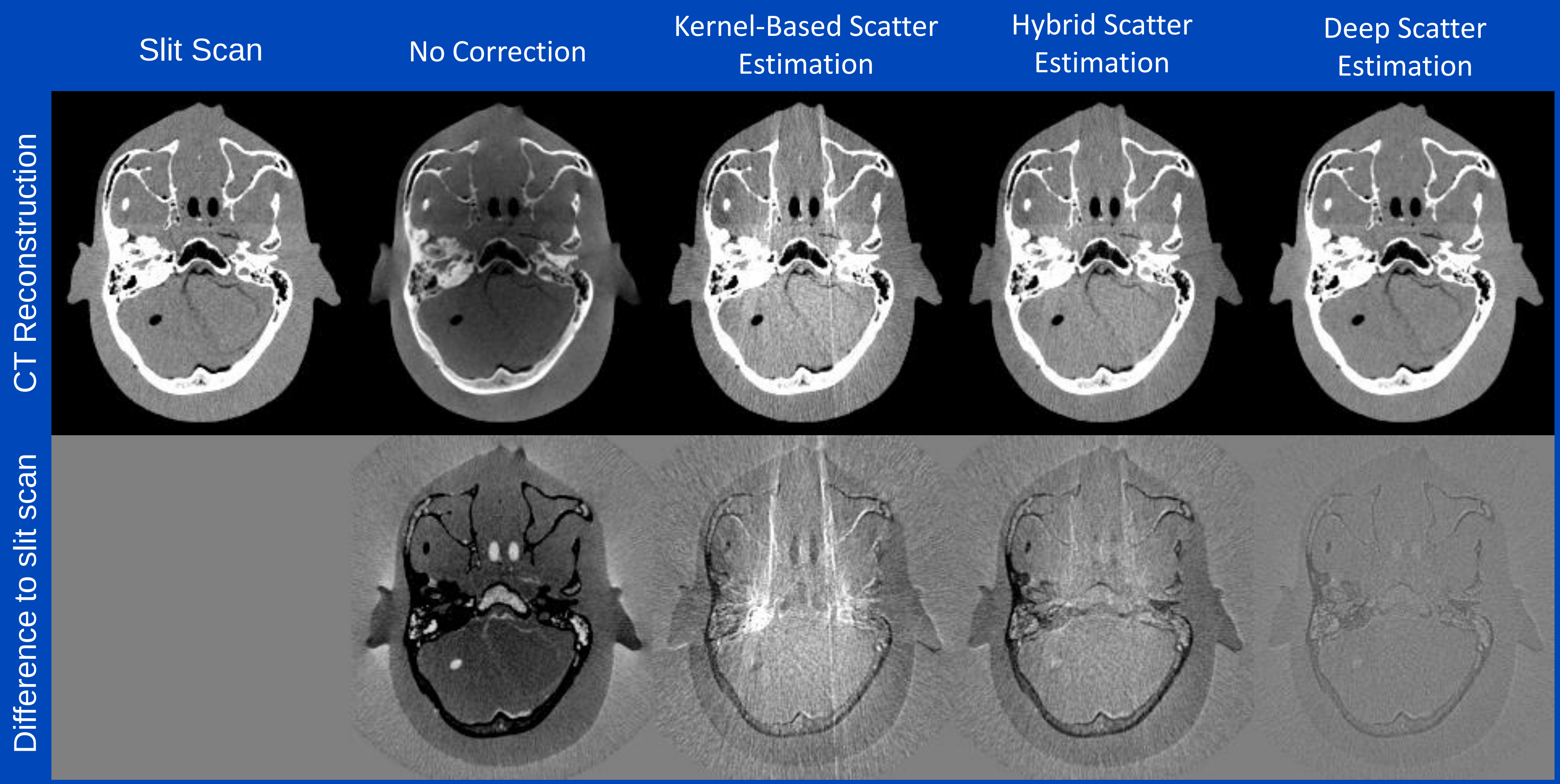


- Measurement of a head phantom at our in-house table-top CT.
- Slit scan measurement serves as ground truth.





CT Reconstructions of Measured Data



C = 0 HU, W = 1000 HU

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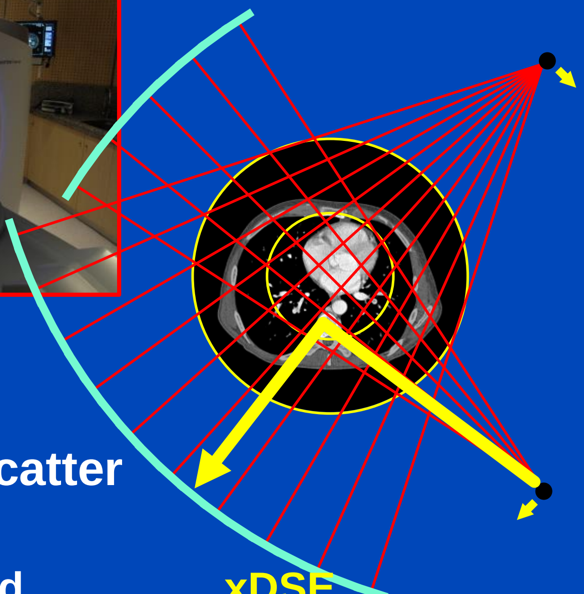
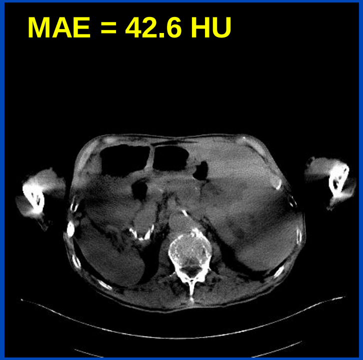
Further DSE Applications

Single- and dual-source CT

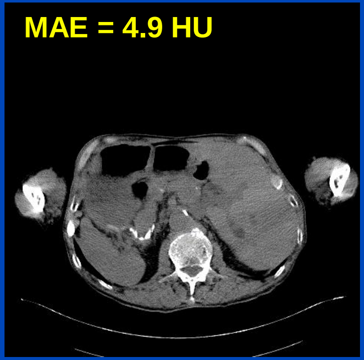


Cross scatter

Uncorrected

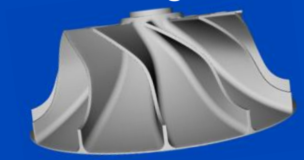


xDSE

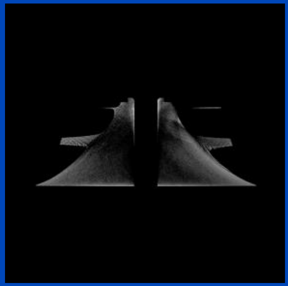


Industrial CT

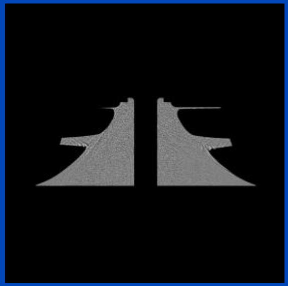
Sample: turbo charger



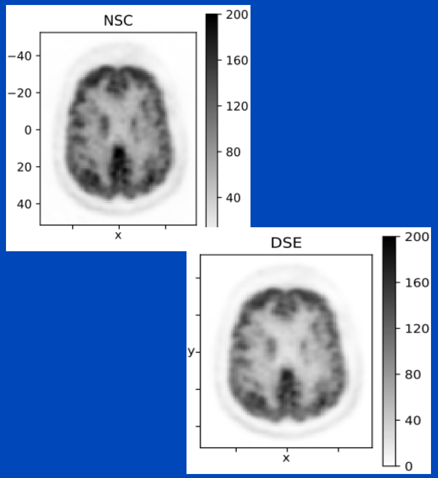
Uncorrected



DSE



PET Imaging



Collaborations:

DSE Publications

DOI: 10.1109/NSSMIC.2018.8824594 • Corpus ID: 201848248

Deep Scatter Estimation in PET: Fast Scatter Correction Using a Convolutional Neural Netw

Yannick Berker, J. Maier, M. Kachelriess • Published 2018 • Mathematics •
2018 IEEE Nuclear Science Symposium and Medical Imaging Conference Proceedings (NSS/MIC)

01-09-2018 | Issue 3/2018 OPEN ACCESS

Deep Scatter Estimation (DSE): Accurate Real-Time Scatter Estimation for X-Ray CT Using a Deep Convolutional Neural Network

Journal of Nondestructive Evaluation

Journal: Journal of Nondestructive Evaluation > Issue 3/2018

Authors: Joscha Maier, Stefan Sawall, Michael Knaup, Marc Kachelrieß

MEDICAL PHYSICS

The International Journal of Medical Physics Research and Practice

Research Article

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

Joscha Maier, Elias Eulig, Tim Vöth, Michael Knaup, Jan Ku...

...PHYSICS

...nal Journal of Medical Physics Research and Practice

RESEARCH ARTICLE | Open Access

Deep learning-based forward and cross-scatter correction in dual-source CT

Julien Erath, Tim Vöth, Joscha Maier, Eric Fournié, Martin Petersilka, Karl Stierstorf...

1 March 2019

Forward and cross-scatter estimation in dual source CT using the deep scatter estimation (DSE)

Tim Vöth, Joscha Maier, Julien Erath, Marc Kachelrieß

Affiliations +

...Imaging 2019: Physics of Medical Imaging; 109480P (20...

9 March 2018

Deep scatter estimation (DSE): feasibility of using a deep convolutional neural network for real-time x-ray scatter prediction in cone-beam CT

Joscha Maier, Yannick Berker, Stefan Sawall, Marc Kachelrieß

Author Affiliations +

...0573, Medical Imaging 2018: Physics of Medical Imaging; 105731L (2018)

.../12.2292919

...naging, 2018, Houston, Texas, United States

The 6th International Conference on Image Formation in X-Ray Computed Tomography

Deep Learning-Based Cross-Scatter Correction for Clinical CT

Julien Erath, Tim Vöth, Joscha Maier, Eric Fournié, Karl Stierstorfer, Martin Petersilka, and Marc Kachelrieß

Citations (as of 09/13/2021): 107

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Conclusions

- DSE needs about 3 ms per CT and 10 ms per CBCT projection.
- DSE is a fast and accurate alternative to MC simulations.
- DSE outperforms kernel-based approaches in terms of accuracy and speed.
- Facts:
  - DSE can estimate scatter from a single (!) x-ray image.
  - DSE generalizes to all anatomical regions.
  - DSE works for geometries and beam qualities differing from training.
  - DSE may outperform MC even though DSE is trained with MC.
- DSE is not restricted to reproducing MC scatter estimates.
- DSE can rather be trained with any other scatter estimate, including those based on measurements.

Thank You!

BEHNKEN-BERGER STIFTUNG

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.