Spectral Deep Scatter Estimation for Photon-Counting CT

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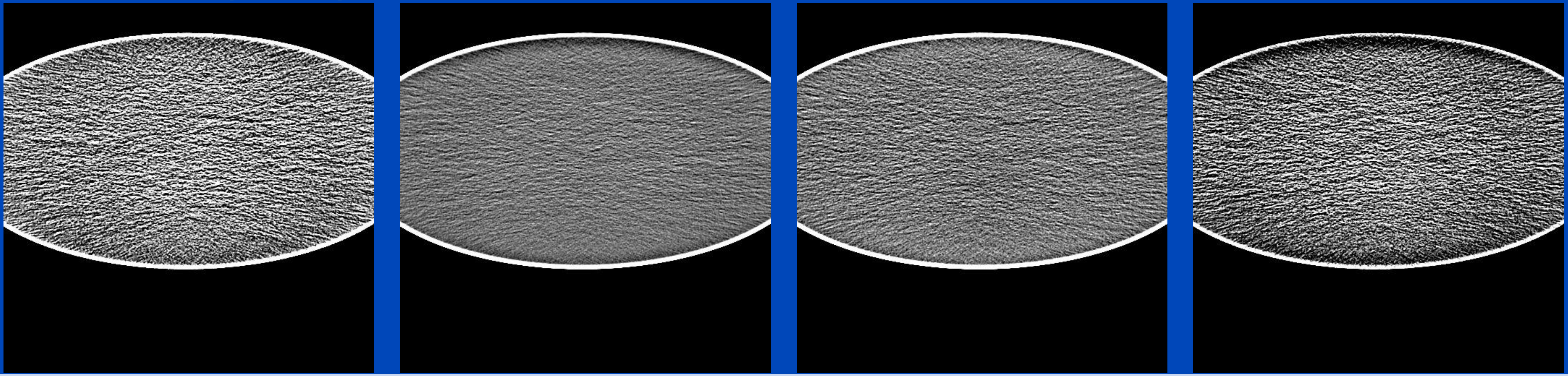
Aim

- To provide a scatter estimation and correction algorithm that is specific to the energy threshold information inherent in clinical photon-counting CT (PCCT) scans.
- Can the spectral properties of the incoming photons provide relevant or advantageous information for scatter estimation, while processing multiple energy thresholds simultaneously?

GT 50 keV VMI without scatter (slit scan) | low energy | high energy | 50 keV VMI with scatter



Reconstructed images C = 0 HU, W = 100 HU

Deep Scatter Estimation (DSE) vs. Spectral DSE

- Deep scatter estimation (DSE) [1,2,3,4,5] outperforms other scatter estimation techniques[1,2,4,5] and shows great potential for cross-scatter correction[4,5] and real-time scatter estimation[1,2,5]
- Approach: one network processing multiple energy thresholds simultaneously (sDSE) vs. networks trained for a single threshold each (DSE)

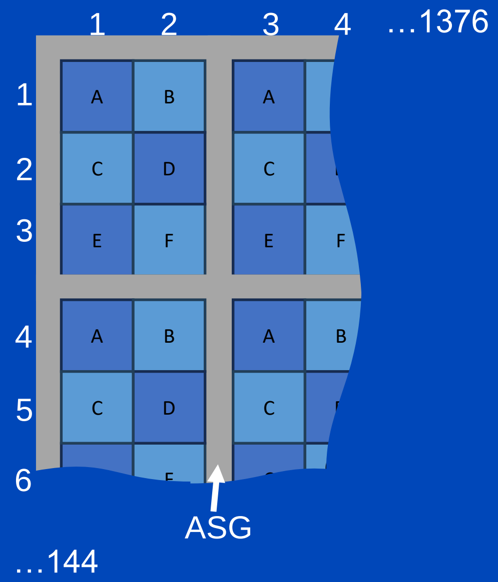
- Training parameters:
  – Input: $$p = -\ln\left(\frac{I_{\text{primary}}}{I_0} + \frac{I_{\text{scatter}}}{I_0}\right)$$
  – Addition of varying noise in projection domain (corresponds to approx. 10 to 100 HU in image domain) during training to further improve robustness
  – Loss function: SPMAPE (scatter-to-primary weighted MAPE)

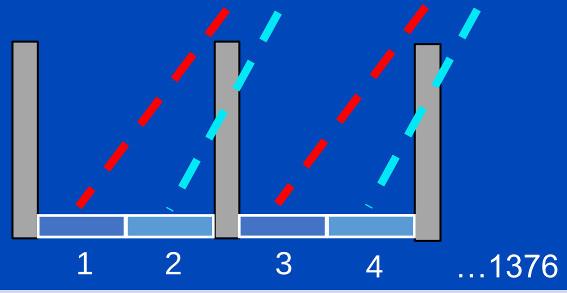
[1] J. Maier, M. Kachelrieß et al. “Deep Scatter Estimation (DSE)“, SPIE 2018 and J. of Nondest. Eval. 37:57, July 2018.
[2] J. Maier, M. Kachelrieß et al. “Robustness of DSE“, Med. Phys. 46(1):238-249, January 2019.
[3] J. Erath, M. Kachelrieß et al. “Monte-Carlo-Free Deep Scatter Estimation (DSE) for 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.

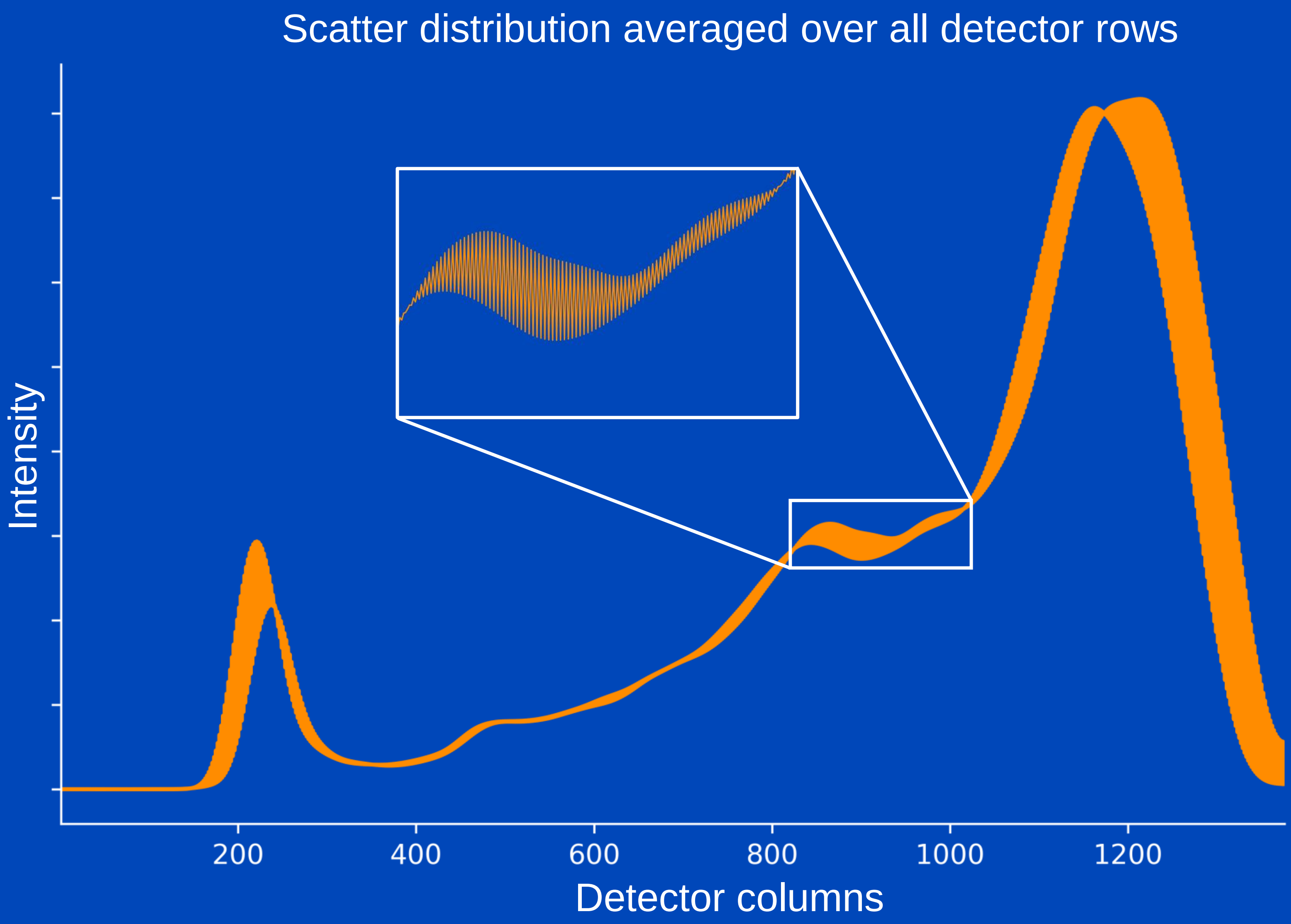
Data Set

- Monte Carlo-simulated data with the geometry of the photon-counting CT scanner NAEOTOM Alpha (Siemens Healthineers)
- 100 different thorax (FORBILD), head (FORBILD) and cylindrical/elliptical 30 cm water phantoms
  - Different phantom sizes (uniformly distributed scaling from 0.7 to 1.3) and positions (uniformly distributed from -5 cm to 5 cm) in field-of-measurement were simulated, with one projection simulated every 5°.
  - This resulted in 72 projections per 360° scan, which corresponds to a total number of data pairs (primary and scatter) of 7200.
  - Training, validation and test spilt is 70% / 20% / 10%
- Simulation of a coarse anti-scatter grid (ASG) with detector dimensions of 1376 × 144 pixels
- Four different energy thresholds 20 keV, 55 keV, 70 keV and 90 keV (values available at the scanner) for 140 kV tube voltage.

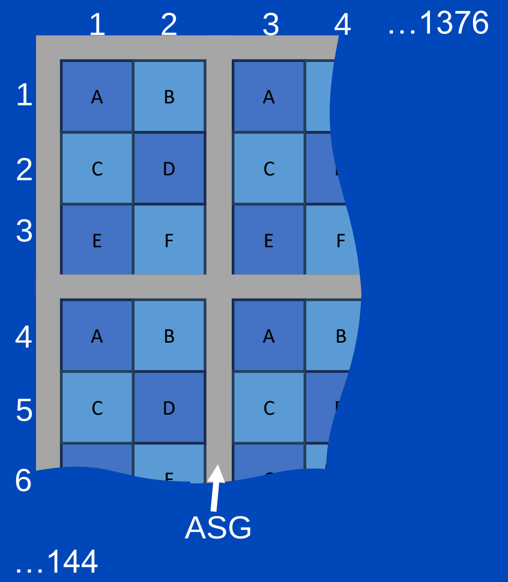
Scatter for Coarse Anti-Scatter Grid (ASG)

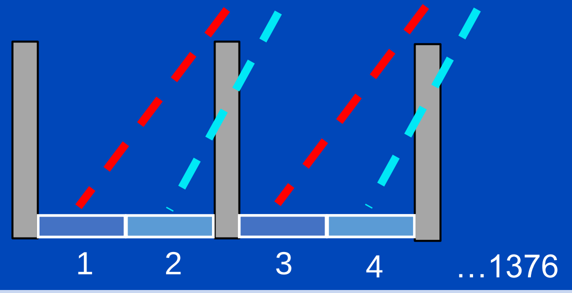


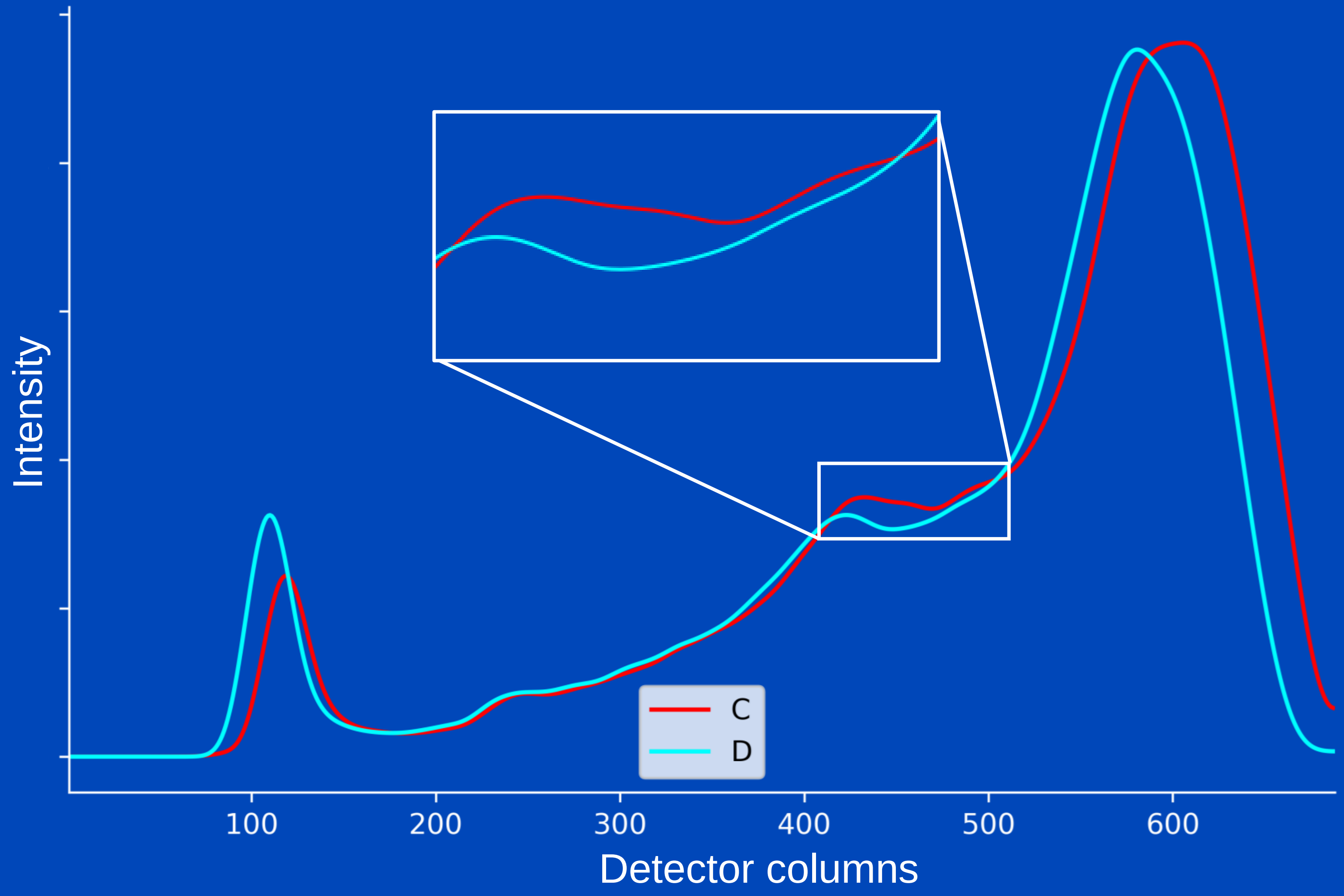




Scatter for Coarse ASG





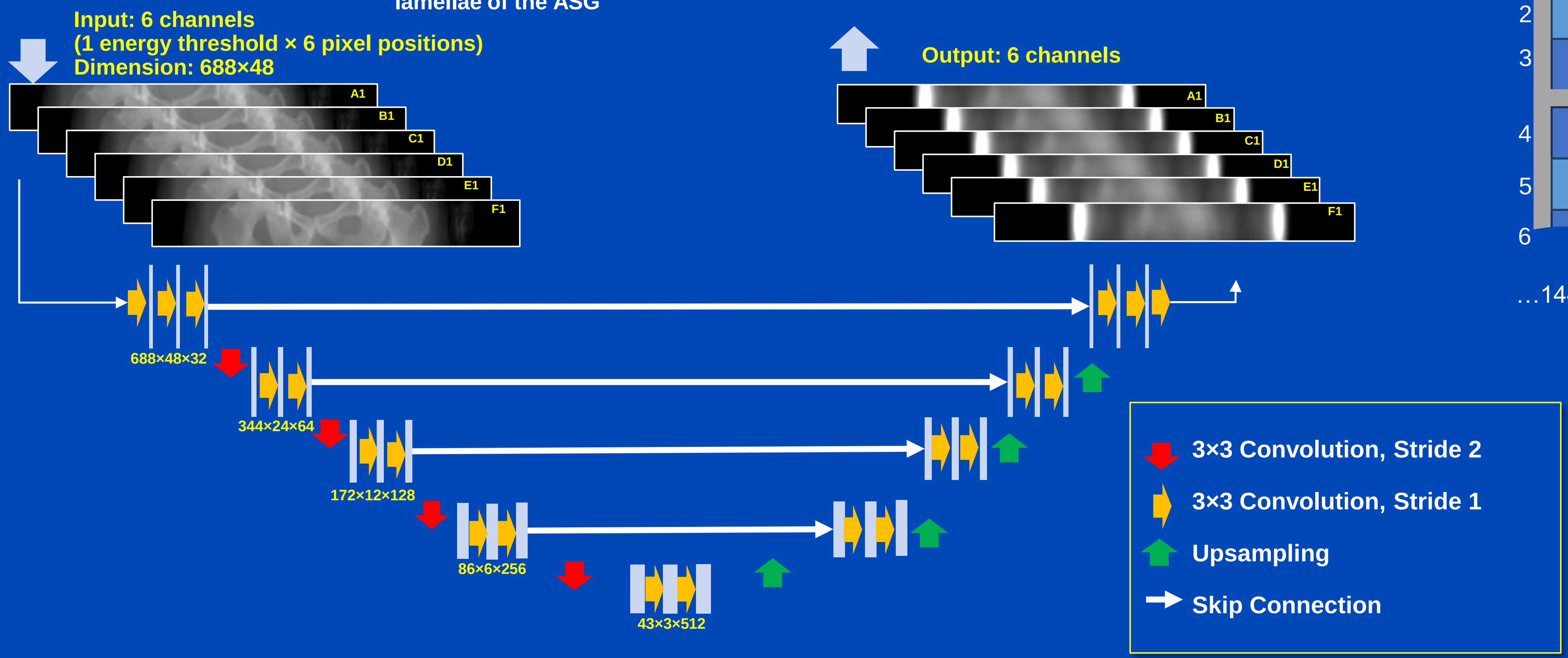


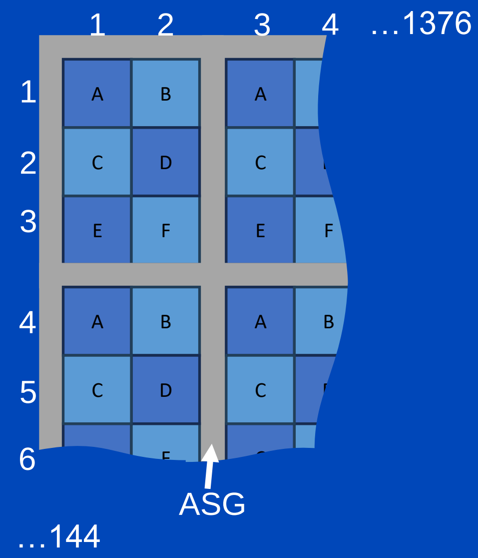
UNet Architecture DSE

Detector dimension 1376×144

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

merging 6 pixel positions





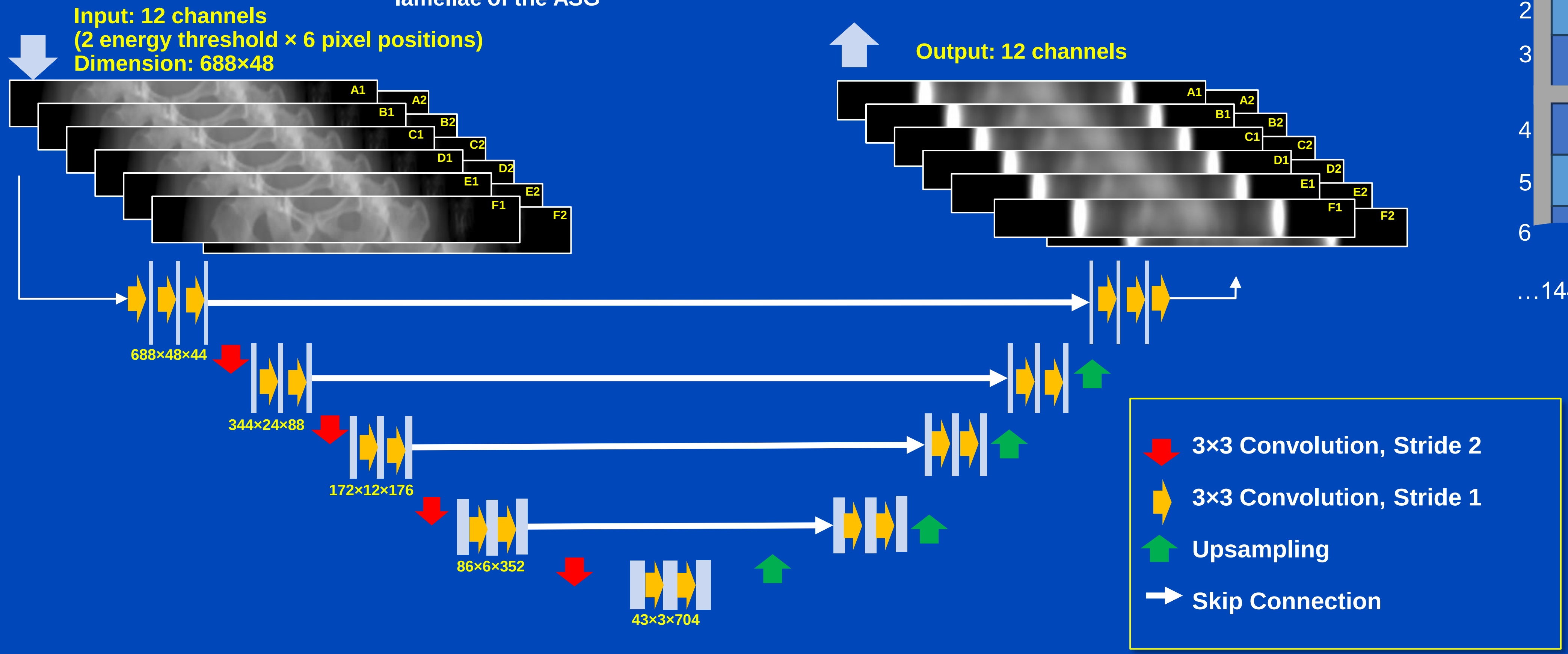
- Number of network parameters: 8,631,724
  → Total number: 4 × 8,631,724

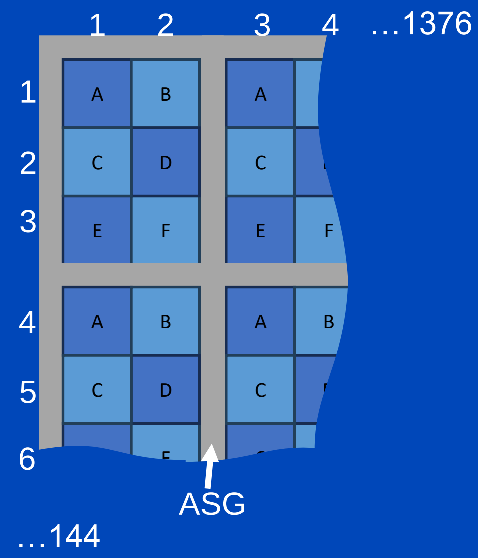
UNet Architecture sDSE2

Detector dimension 1376×144

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

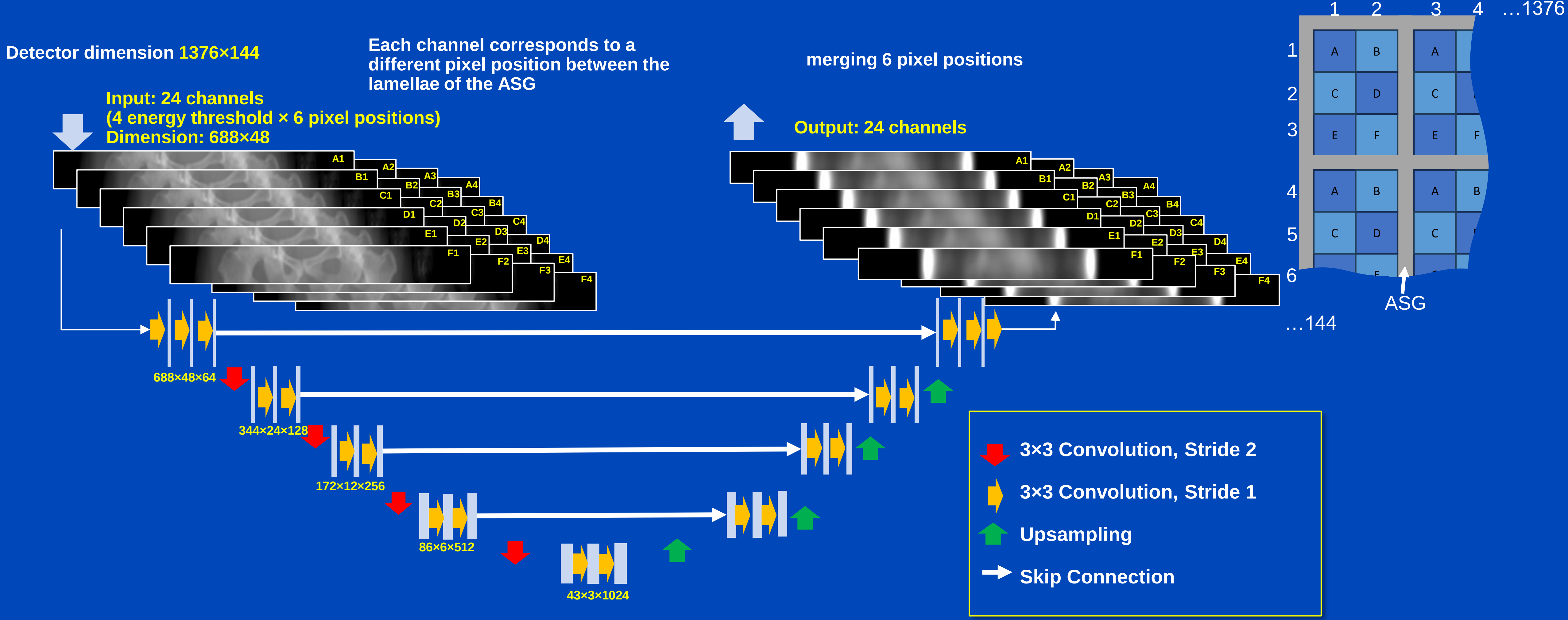
merging 6 pixel positions





- Number of network parameters: 16,316,524
  → Total number: 2 × 16,316,524

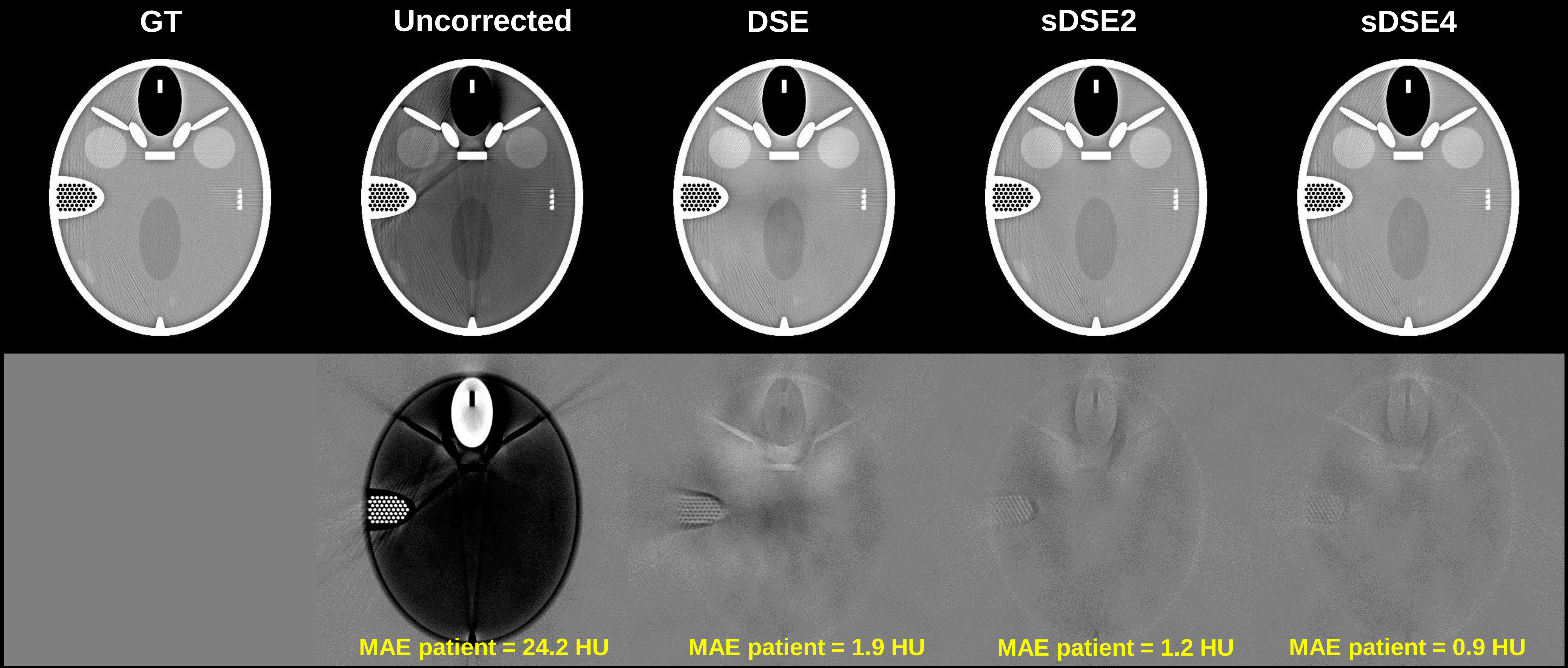
UNet Architecture sDSE4



- Number of parameters: 34,528,496
  → Total number: 1 × 34,528,496

RESULTS

Reconstructions VMI 50 keV



Reconstructed images *C* = 40 HU, *W* = 80 HU
Difference images *C* = 0 HU, *W* = 50 HU

Conclusions

- In all applications tested here, sDSE leads to an improved image quality compared to DSE. Especially in spectral applications, such as VMI.
- With the sDSE4 algorithm the MAE for VMI 50 keV is reduced from about 21 HU to 1 HU on average. DSE is able to reduce the MAE to 1.9 HU, while sDSE2 leads to an image error of 1.2 HU.
- Using the spectral information inherent in PCCT improves forward scatter estimation, compared to conventional DSE.
- As soon as more than one threshold is used for scatter correction, the performance of DSE can be improved.
- Next step: apply sDSE to measurements

- Limitations:
  - Simulation study only
  - No real clinical CT data have yet been used.

Thank You!

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