# Deep Learning-Based Coronary Artery Motion Estimation and Compensation for Iterative Cardiac CT Reconstructions

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DEUTSCHES
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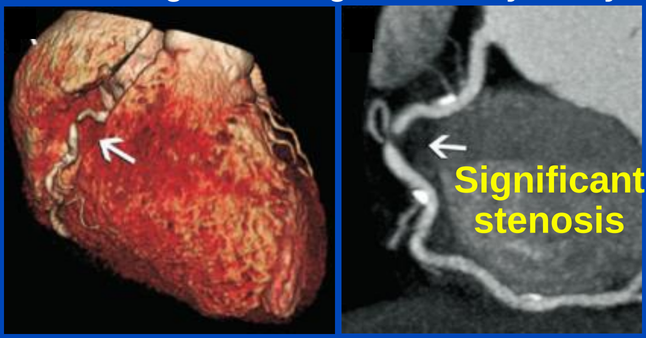
IN DER HELMHOLTZ-GEMEINSCHAFT

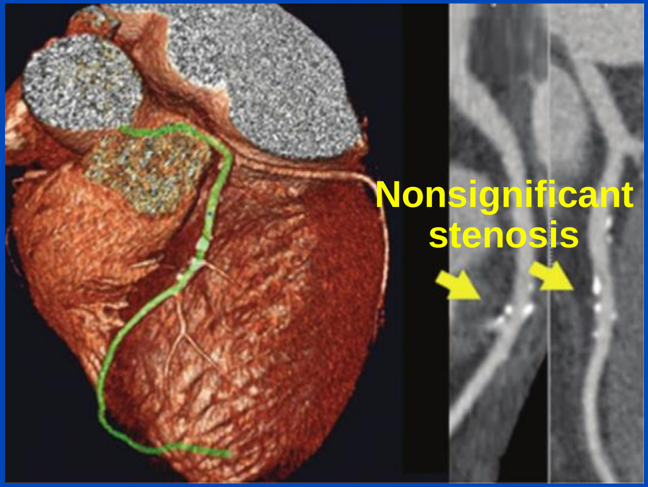
# Motivation

- Cardiac CT imaging is routinely used for the diagnosis of cardiovascular diseases, especially those related to coronary arteries.
- Imaging of coronary arteries places high demands on the spatial and temporal resolution of the CT reconstruction.
- Motion artifacts and image noise may impair the diagnostic value of the CT examination.

CTCA image of the right coronary artery[1]




CTCA image of the left coronary artery[2]




[1] W. B. Meijboom et al., “64-Slice Computed Tomography Coronary Angiography in Patients With High, Intermediate, or Low Pretest Probability of Significant Coronary Artery Disease”, J. Am. Coll. Cardiol. 50 (15): 1469–1475 (2007).
[2] R. Leta et al., “Ruling Out Coronary Artery Disease with Noninvasive Coronary Multidetector CT Angiography before Noncoronary Cardiovascular Surgery”, Heart 258 (2) (2011).

# Motivation

*C* = 0 HU, *W* = 1200 HU

**Motion artifacts**

**High noise levels**

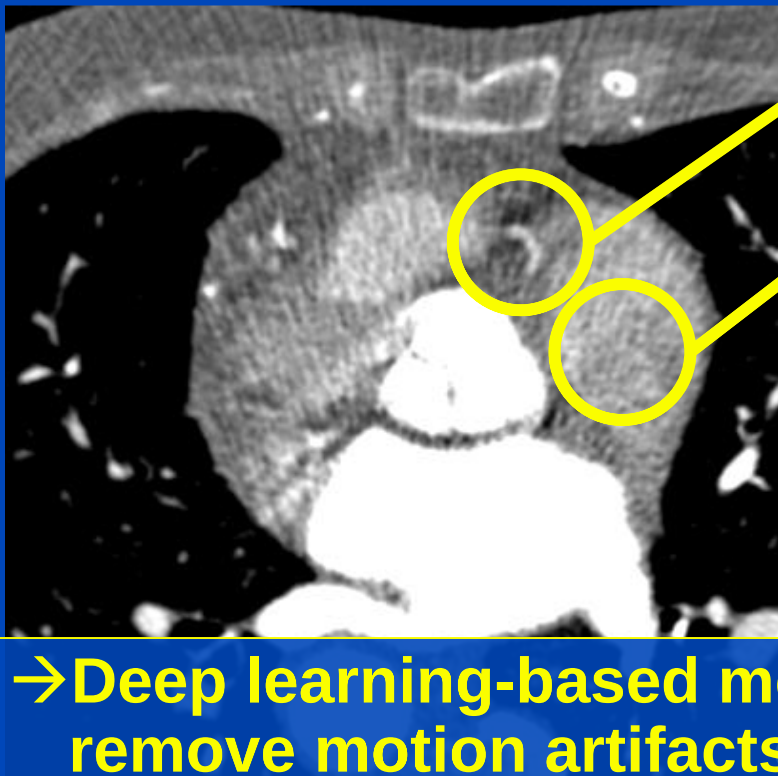
**Table 3: Reason for $FFR_{CT}$ Rejection in the ADVANCE Registry and Clinical Cohort** *

| Reason for Rejection | $FFR_{CT}$ Rejected* ADVANCE Registry ($n$ = 80) | Clinical Cohort ($n$ = 892) |
|---|---|---|
| Inadequate image quality† | | |
| Blooming | 4 (5.0) | 29 (3.0) |
| Clipped structure | 4 (5.0) | 39 (4.3) |
| Motion artifacts | 63 (78.0) | 729 (81.4) |
| Image noise | 2 (2.5) | 198 (22.1) |
| Inappropriate submission | | |
| Stent or previous coronary artery bypass graft present | 5 (6.2) | 116 (13.0) |
| Cardiac hardware present | 2 (2.5) | 29 (3.2) |

The rejection rate was 892 of 10 416 cases submitted

* G. Pontone et al., "Determinants of Rejection Rate for Coronary CT Angiography Fractional Flow Reserve Analysis", *Radiology*, *292*(3), 597–605 (2019)

# Motivation



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→**Deep learning-based motion compensation to remove motion artifacts.**

→**Iterative reconstruction (Siemens ADMIRE) to reduce noise.**

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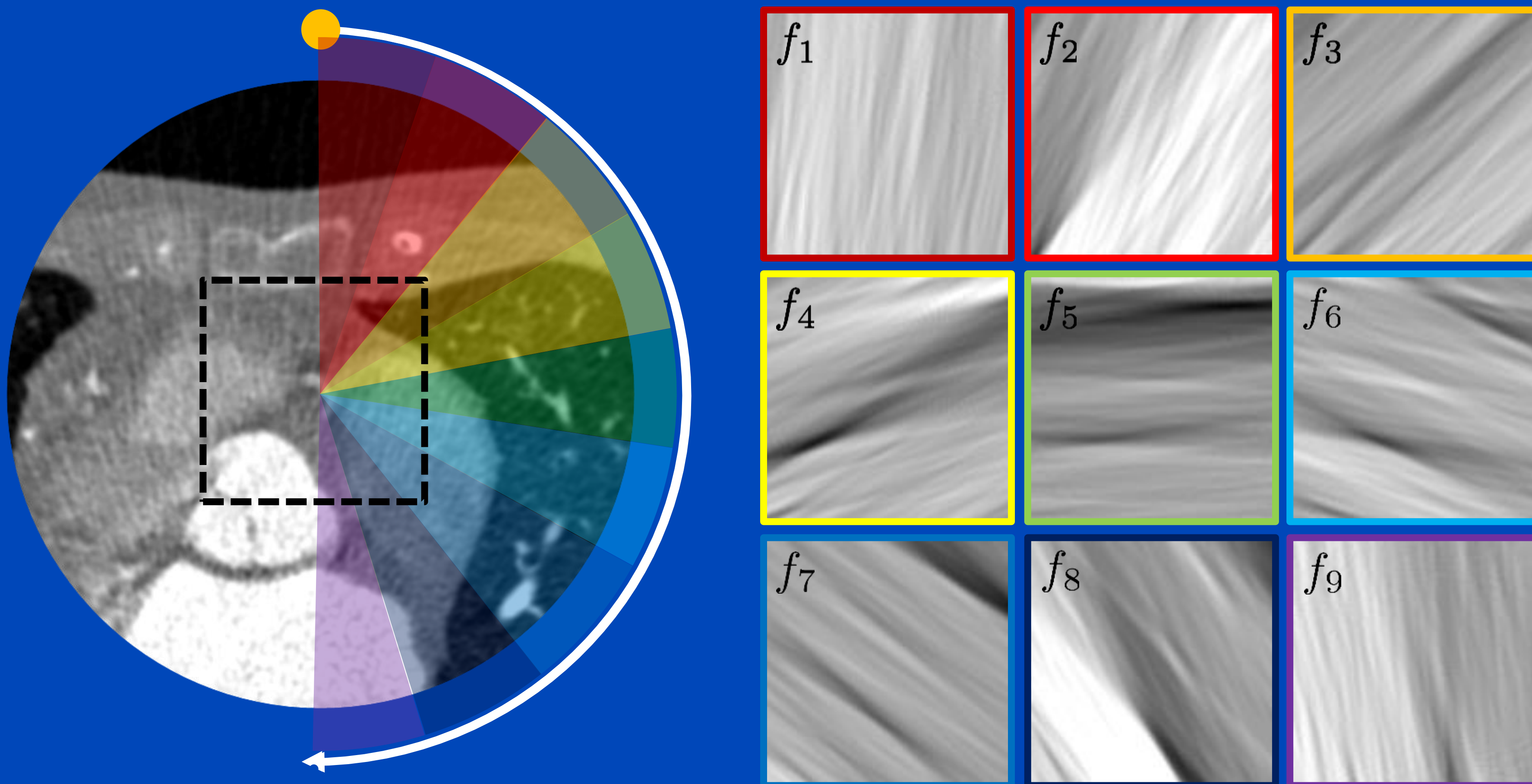
# Partial Angle-Based Motion Compensation (PAMoCo)




Animated rotation time = 100 × real rotation time

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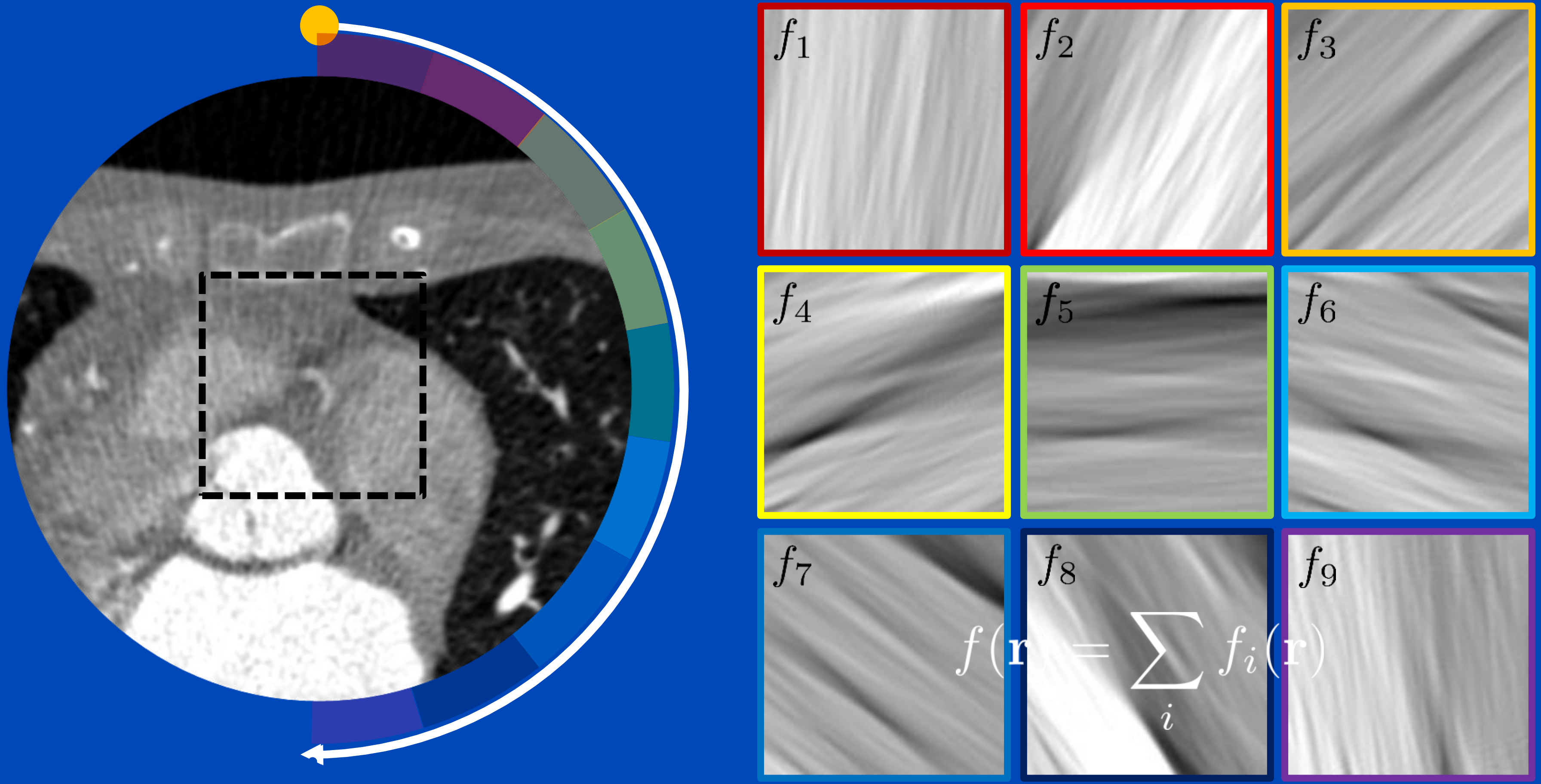

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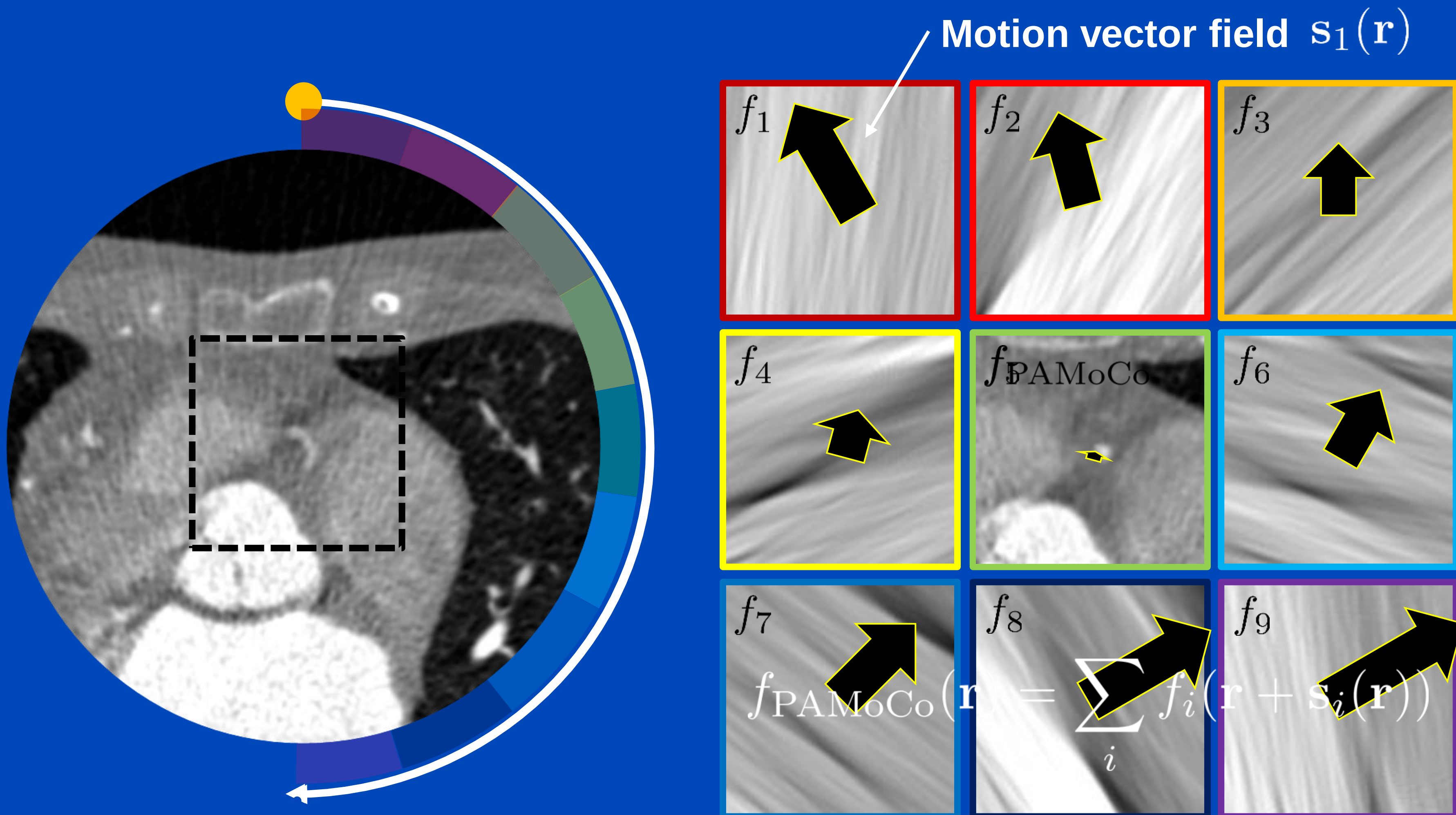


Apply motion vector fields (MVFs) to partial angle reconstructions

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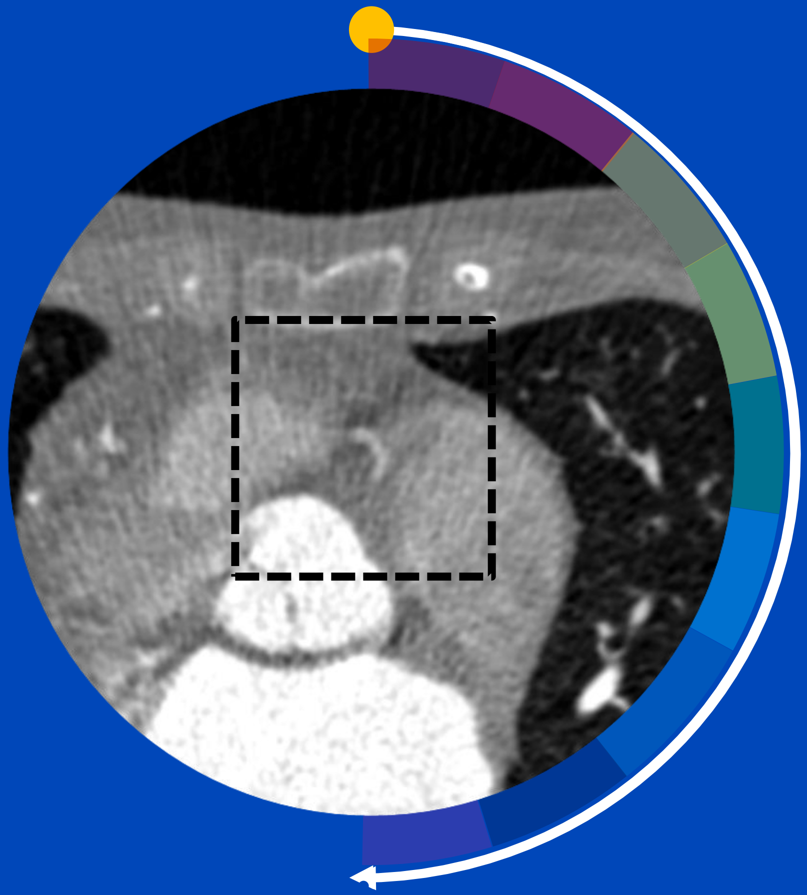


**Prior work:**

[1] S. Kim et al., “Cardiac motion correction based on partial angle reconstructed images in x-ray CT”, Med. Phys. 42 (5): 2560–2571 (2015).

[2] J. Hahn et al., “Motion compensation in the region of the coronary arteries based on partial angle reconstructions from short-scan CT data”, Med. Phys. 44 (11): 5795–5813 (2017).

[3] S. Kim et al., “Cardiac motion correction for helical CT scan with an ordinary pitch”, IEEE TMI 37 (7): 1587–1596 (2018).

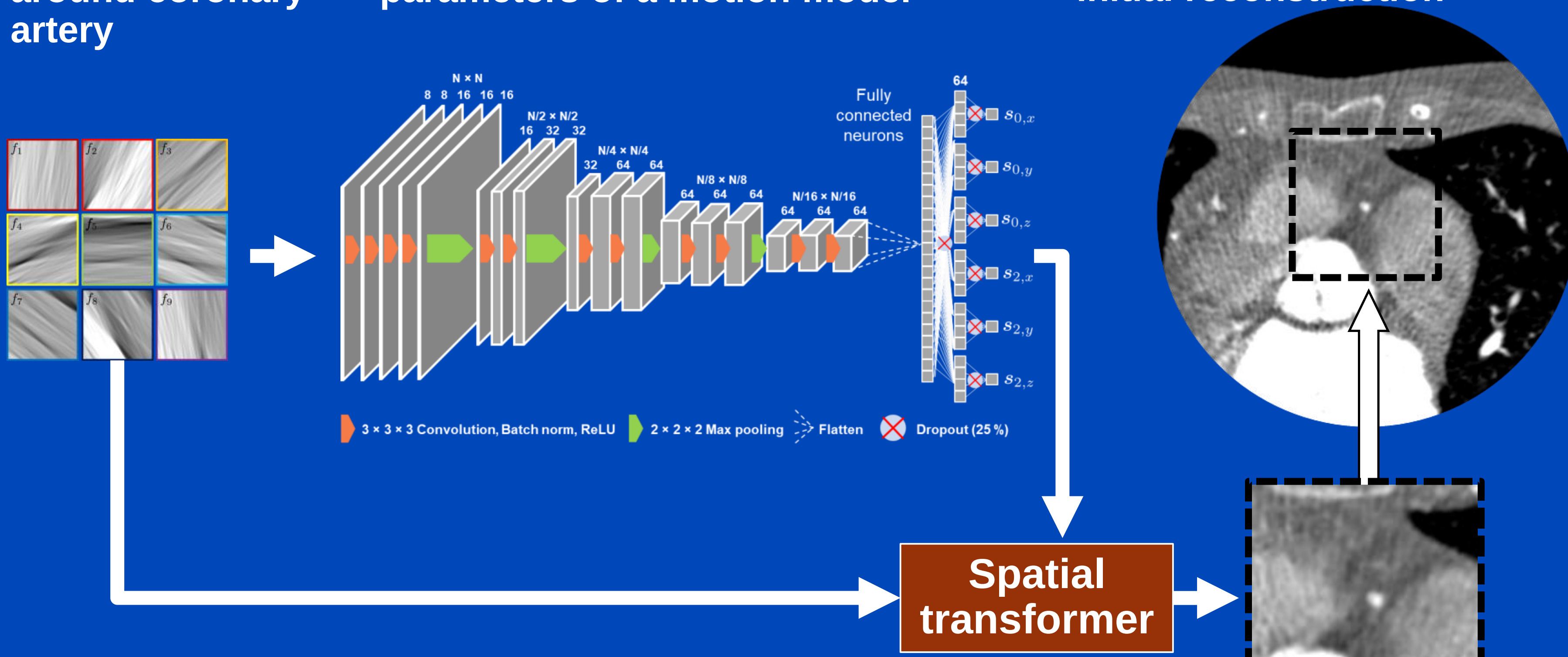
→ Limitation: Challenging / time-consuming optimization

# Deep Partial Angle-Based Motion Compensation (Deep PAMoCo)

**PARs centered around coronary artery**

**Neural network to predict parameters of a motion model**

**Reinsertion of patch into initial reconstruction**




**Application of the motion model to the PARs via a spatial transformer[1]**

[1] M. Jaderberg et al., "Spatial transformer networks", NIPS 2015: 2017–2025 (2015).

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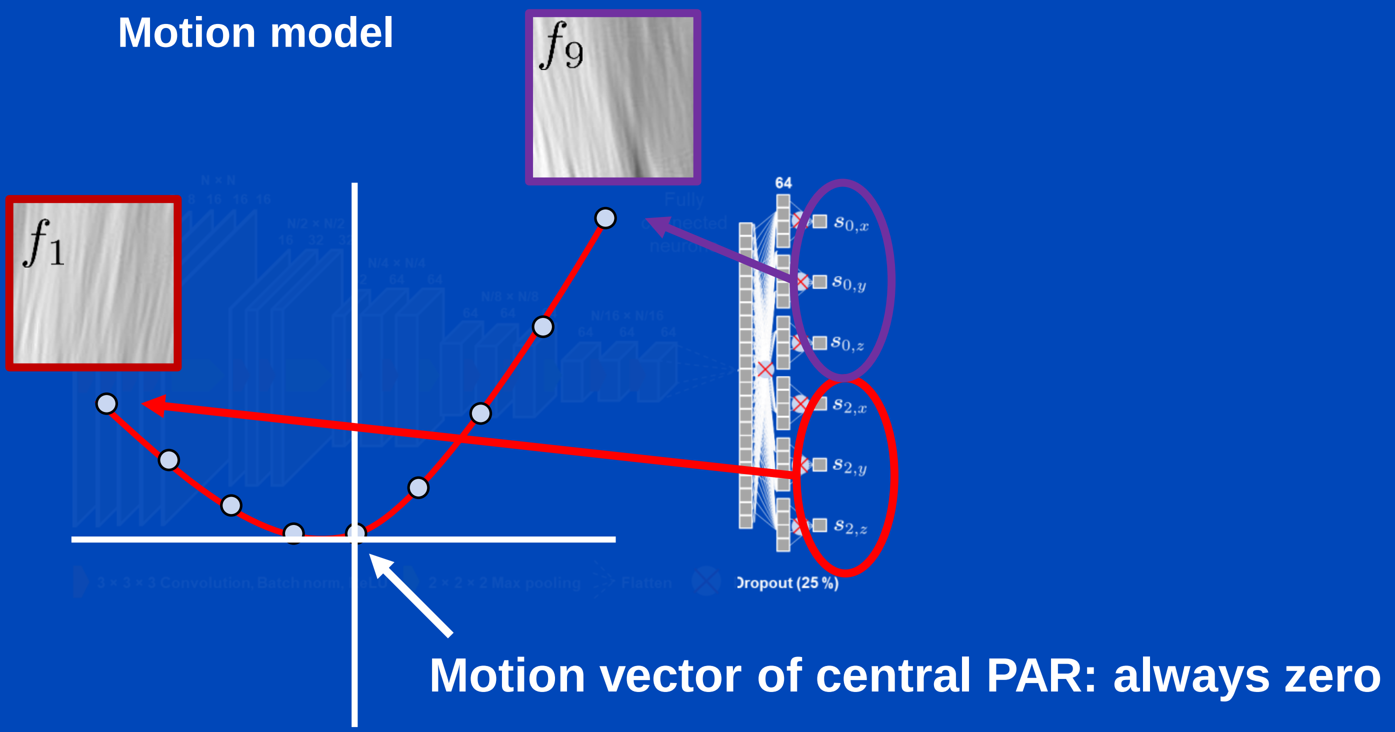


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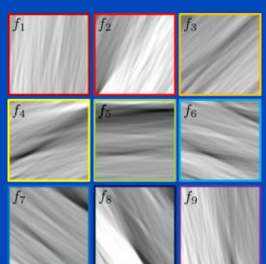
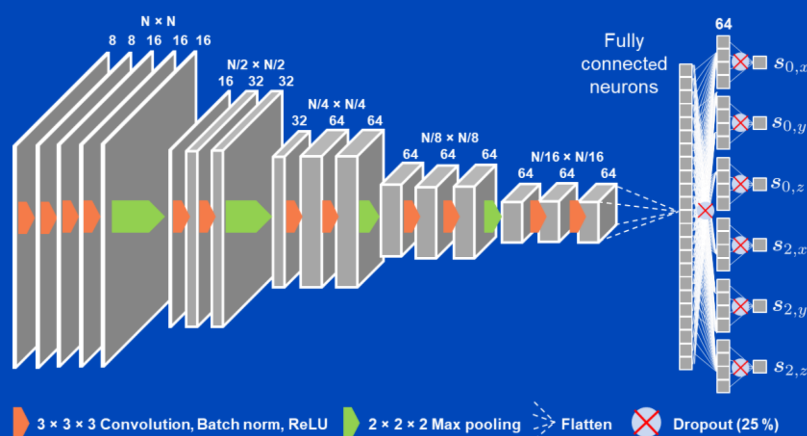
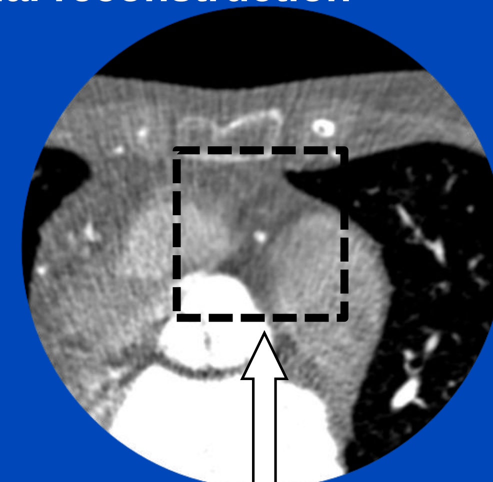


Neural network to predict parameters of a motion model




Reinsertion of patch into initial reconstruction



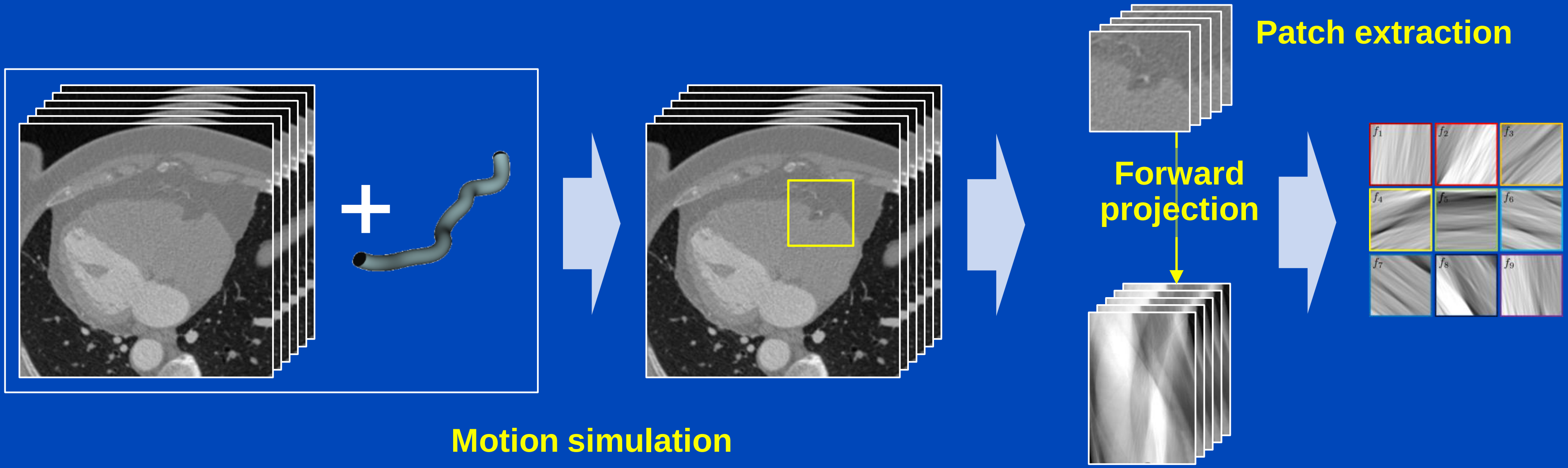
**Spatial transformer**

Application of the motion model to the PARs via a spatial transformer[1]


[1] M. Jaderberg et al., "Spatial transformer networks", NIPS 2015: 2017–2025 (2015).

# Training Data Generation

- Removal of coronary arteries from real CT reconstructions.
- Insertion of artificial coronary arteries with different shape, size, and contrast.
- Simulation of CT scans with coronary artery motion.

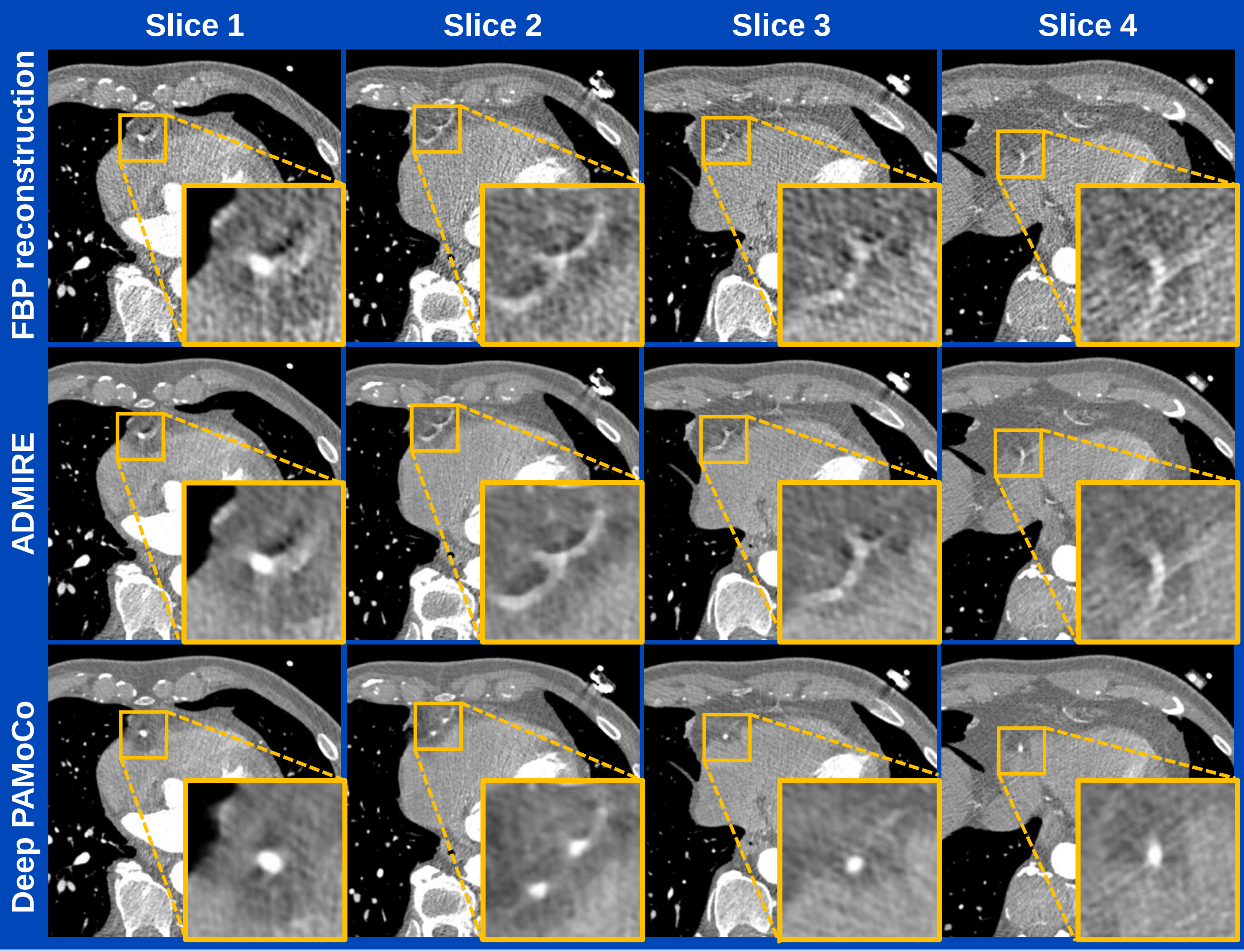


# Training & Evaluation

- Training for 100 epochs
  - 100,000 training samples
  - 80 % training data and 20 % validation data
  - Loss in image domain: MSE between prediction and ideal (no motion) CT reconstruction
  - Adam Optimizer
- Application to Siemens Somatom AS measurements.
- Reconstruction using FBP and an iterative reconstruction algorithm (ADMIRE).

# Results

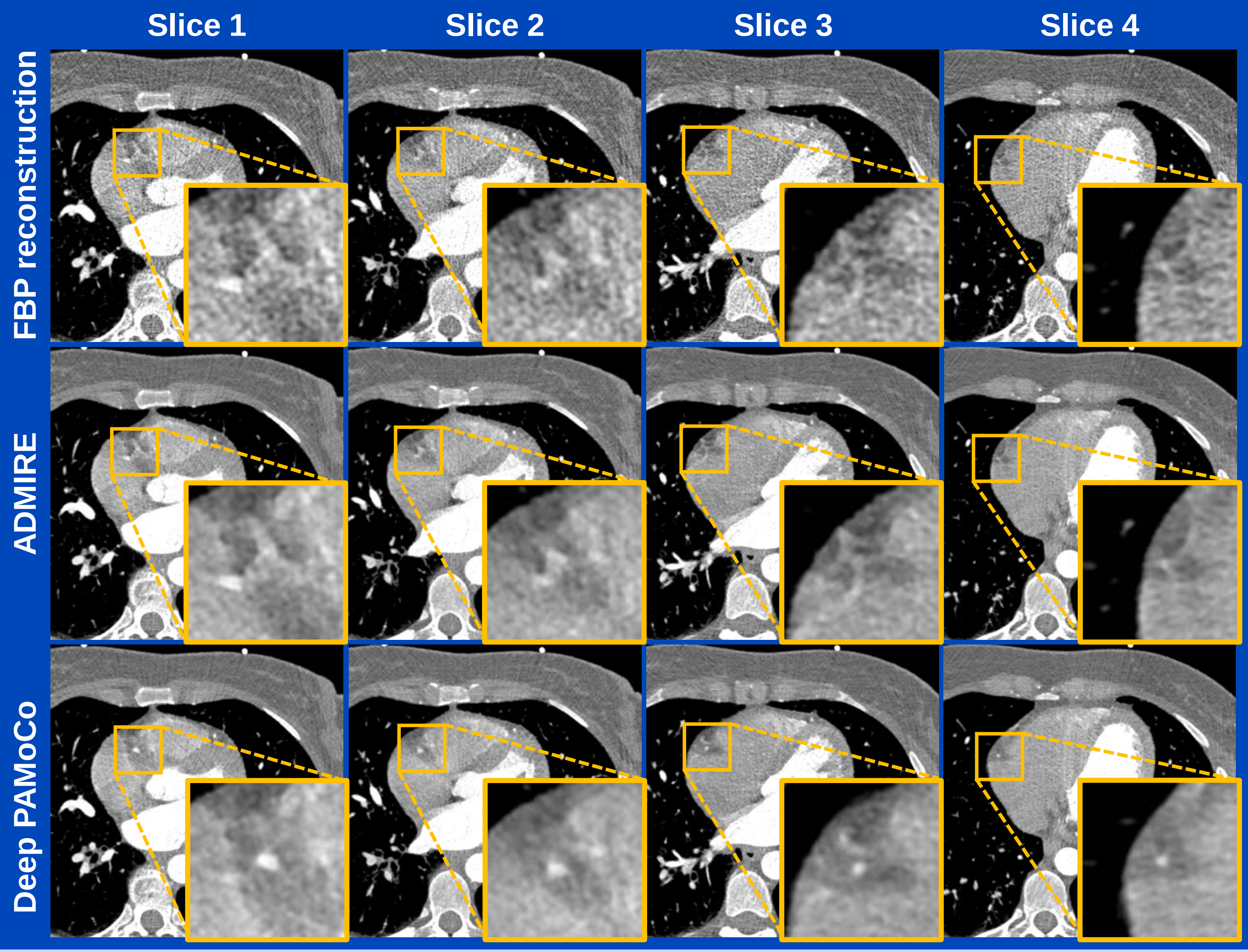
## Measurements at a Siemens Somatom AS, patient 1




*C* = 0 HU, *W* = 1200 HU

# Results

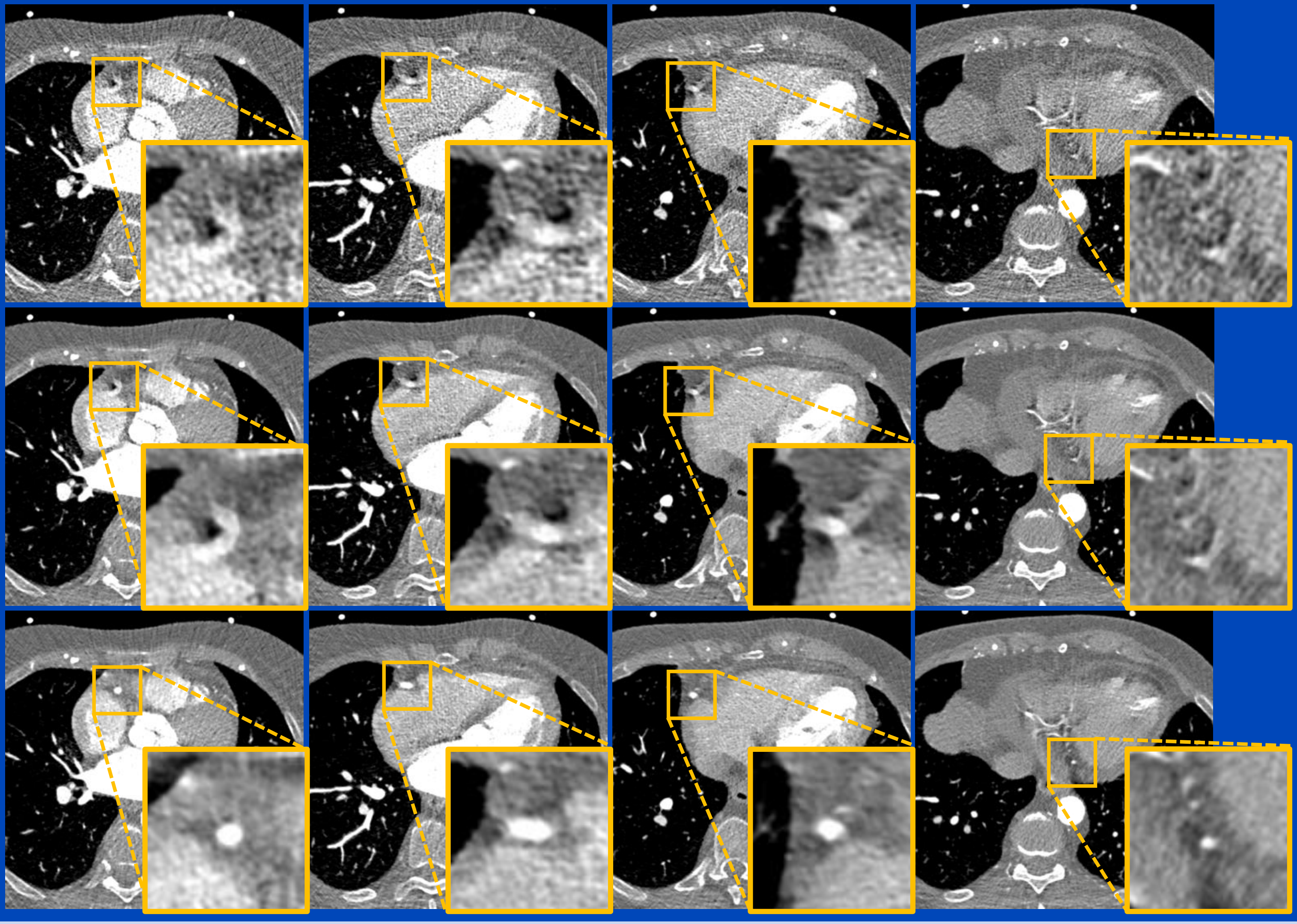
## Measurements at a Siemens Somatom AS, patient 2




$C$ = 0 HU, $W$ = 1200 HU

# Results

## Measurements at a Siemens Somatom AS, patient 3




*C* = 0 HU, *W* = 1400 HU

# Conclusions

- Deep PAMoCo enables an end-to-end training of coronary artery motion compensation using a deep neural network.
- Deep PAMoCo provides a fast (~10 s per cardiac CT scan) and efficient approach to reduce motion artifacts.
- Deep PAMoCo in combination with an iterative reconstruction may help to further improve the diagnosis of coronary artery diseases even if the corresponding CT scans are corrupted by strong motion artifacts and high noise levels.

# Thank You!

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.