Motion Vector Field Upsampling for Precise Respiratory Motion Compensation with Cone-Beam CT of the Thorax Region

Sebastian Sauppe[1], Cristopher M. Rank[1],
Marcus Brehm[2], Pascal Paysan[2], Dieter Seghers[2],
and Marc Kachelrieß[1]

[1] German Cancer Research Center (DKFZ), Heidelberg, Germany
[2] Varian Medical Systems Imaging Laboratory, Baden-Dättwil, Switzerland

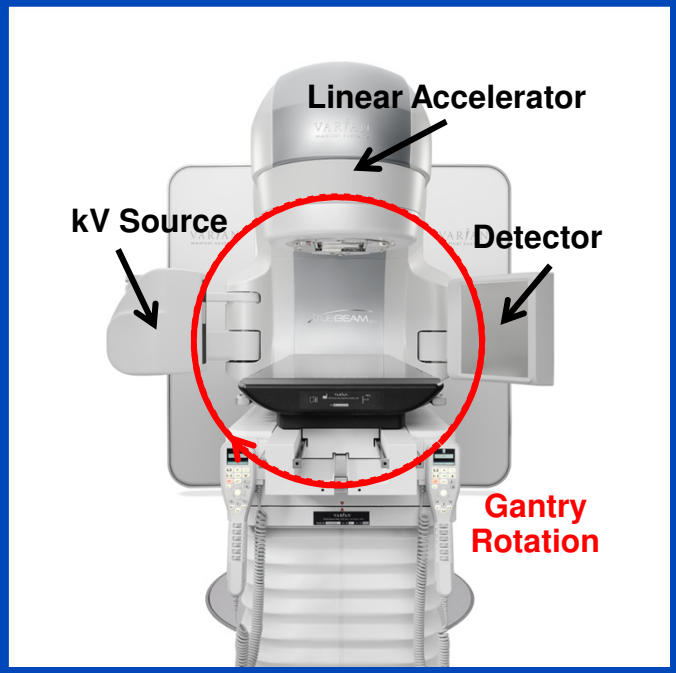
VARIAN medical systems
A partner for life

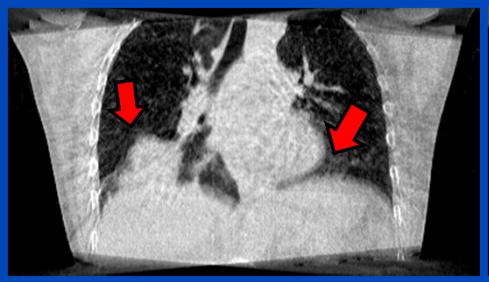
dkfz. DEUTSCHES KREBSFORSCHUNGSZENTRUM IN DER HELMHOLTZ-GEMEINSCHAFT

Slowly Rotating CBCT Devices

- Image-guided radiation therapy (IGRT)
  - Cone-beam CT (CBCT) imaging unit mounted on gantry of a LINAC treatment system
  - Accurate information about patient motion required for radiation therapy
- Slow gantry rotation speed of 6° per second (60 s/360°)
  - Much slower than clinical CT devices
- Breathing about 10 to 30 respiration cycles per minute (and thus per scan)
- Heartbeat about 50 to 80 beats per minute

Account for patient motion!





Motion blurring in standard 3D reconstruction

5D* Motion compensation removes almost all motion blurring

VARIAN medical systems

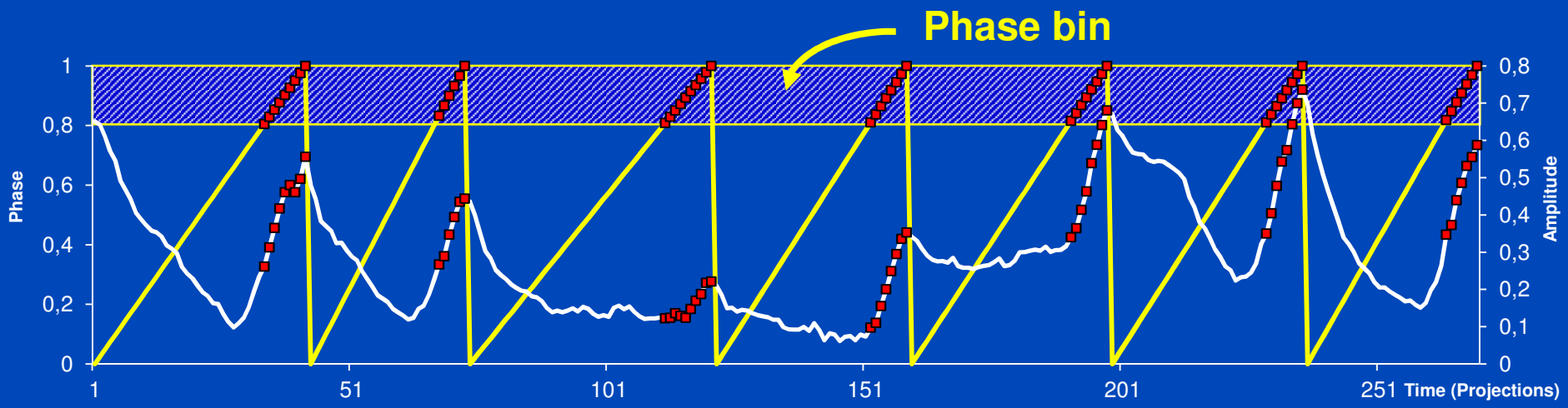
*Brehm, Sawall, Maier, and Kachelrieß, "Cardio-respiratory motion-compensated micro-CT image reconstruction using an artifact model-based motion estimation" Med. Phys. 42(4):1948-1958, 2015.

dkfz.

Aims

- To provide high fidelity motion-compensated (MoCo) respiratory- or cardiac-correlated volumes from CBCT.
- To further increase the temporal resolution by motion vector field (MVF) resampling.
- Use cases for MoCo (in the field of radiation therapy):
  - Accurate patient positioning
  - Reduce irradiation of the heart (organ at risk)
  - Treatment verification
  - Online treatment adaption
  - …

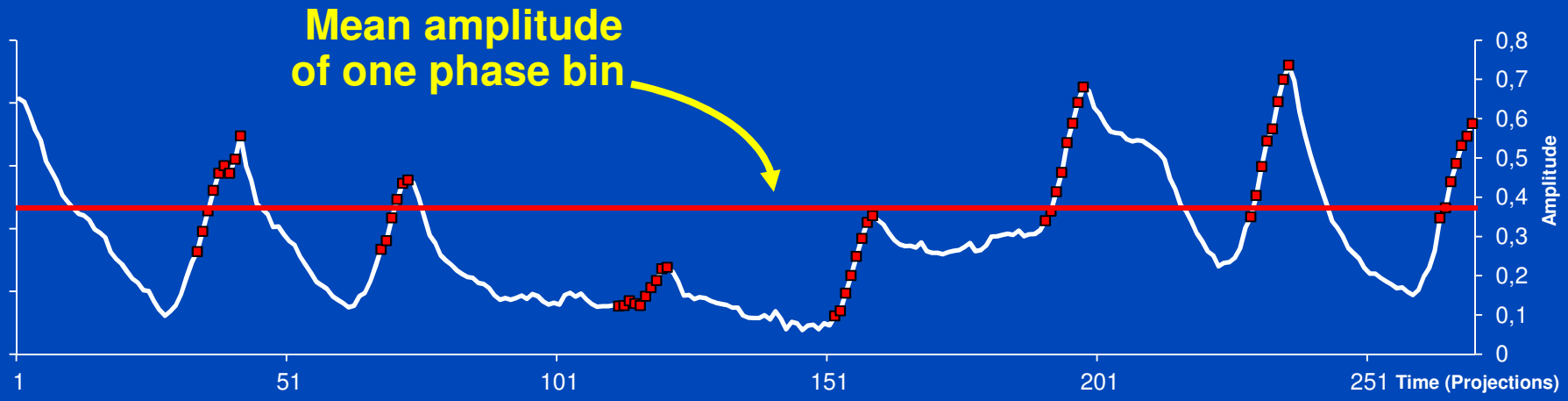
Step 1: Phase Gating



- The white curve shows a respiratory amplitude signal (external monitor)
- The yellow curve shows the dedicated phase signal (modulo 1)
- The red squares are phase-gated projections (phase and amplitude ordinates)

- Phase gating ensures a nearly uniform projection distribution for all phases
- Phase-gated projections may have a strong variation in their respiratory amplitude. This introduces motion blurring even with perfect MVFs.

Mean Amplitude of Phase Bins

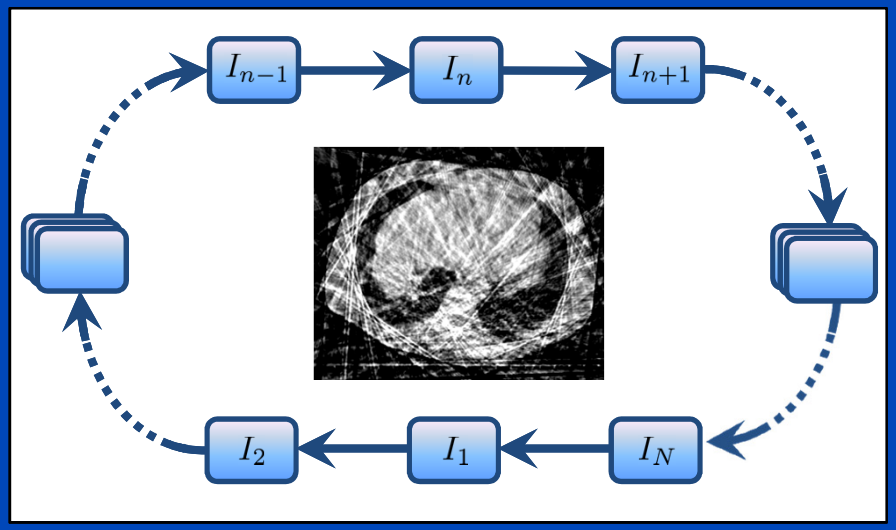


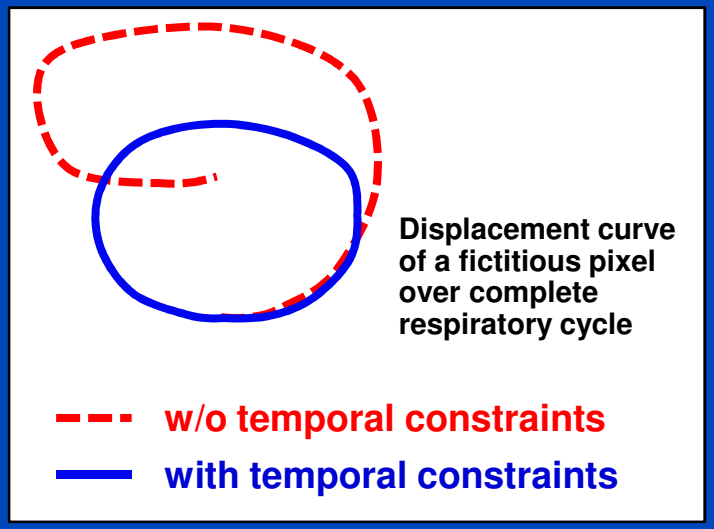
- The white curve shows a respiratory amplitude signal
- The red line represents the average amplitude of all projections in this phase

- Motion estimation is done between adjacent phase bins
- Pragmatic assumption: The MVFs describe the deformation between the mean amplitude of adjacent phase bins

Step 2: a) Motion Estimation
with Cyclic Regularization (cMoCo)

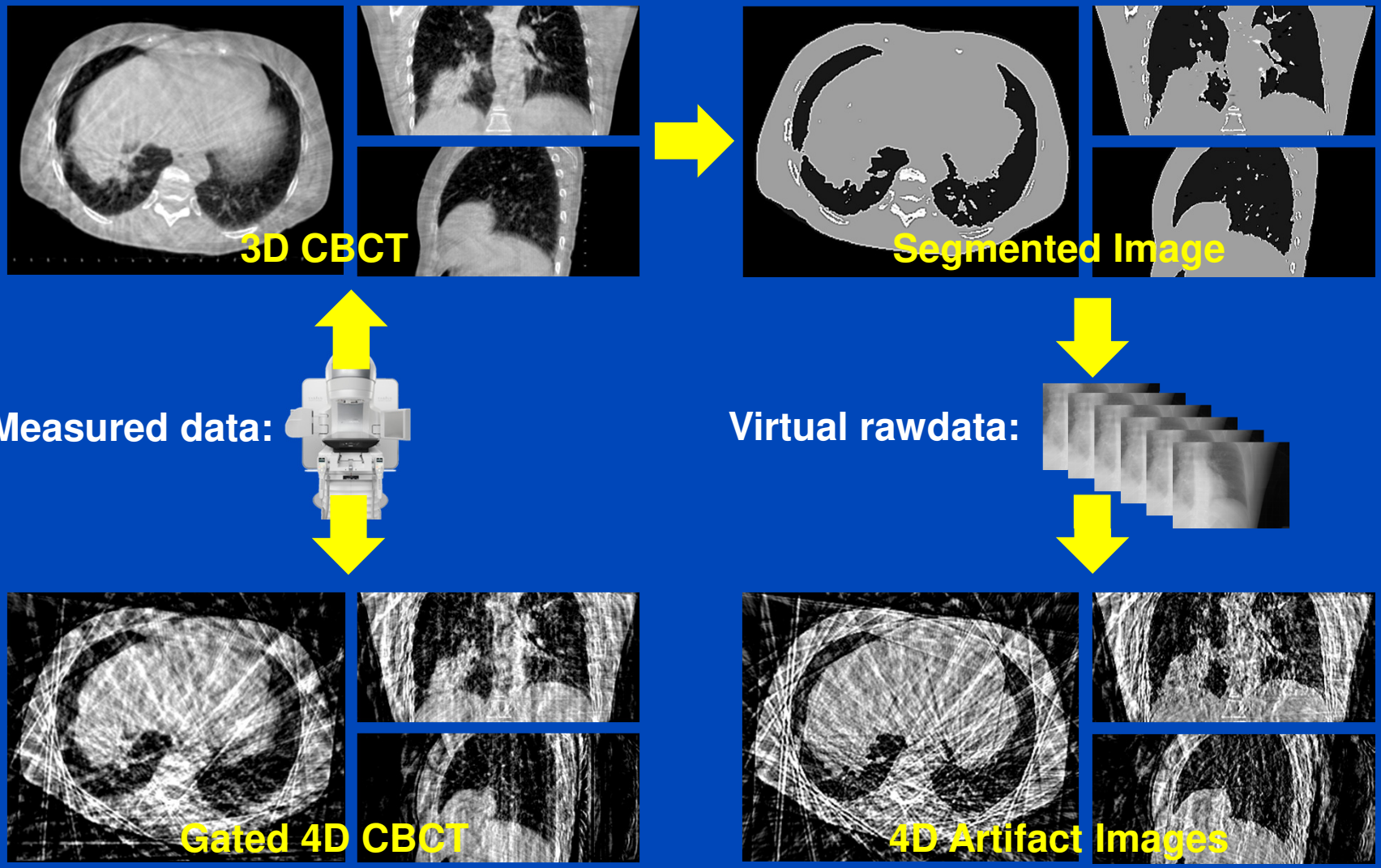
- Motion estimation only between adjacent phases
- Incorporate additional knowledge
  - A priori knowledge of quasi periodic breathing pattern
  - Non-cyclic motion is penalized
  - Error propagation due to concatenation is reduced





Brehm, Paysan, Oelhafen, Kunz, and Kachelrieß, "Self-adapting cyclic registration for motion-compensated cone-beam CT in image-guided radiation therapy," Med. Phys. 39(12), 7603-7618, 2012.

Step 2: b) Motion Estimation
with Artifact-Model-Based Regularization (aMoCo)



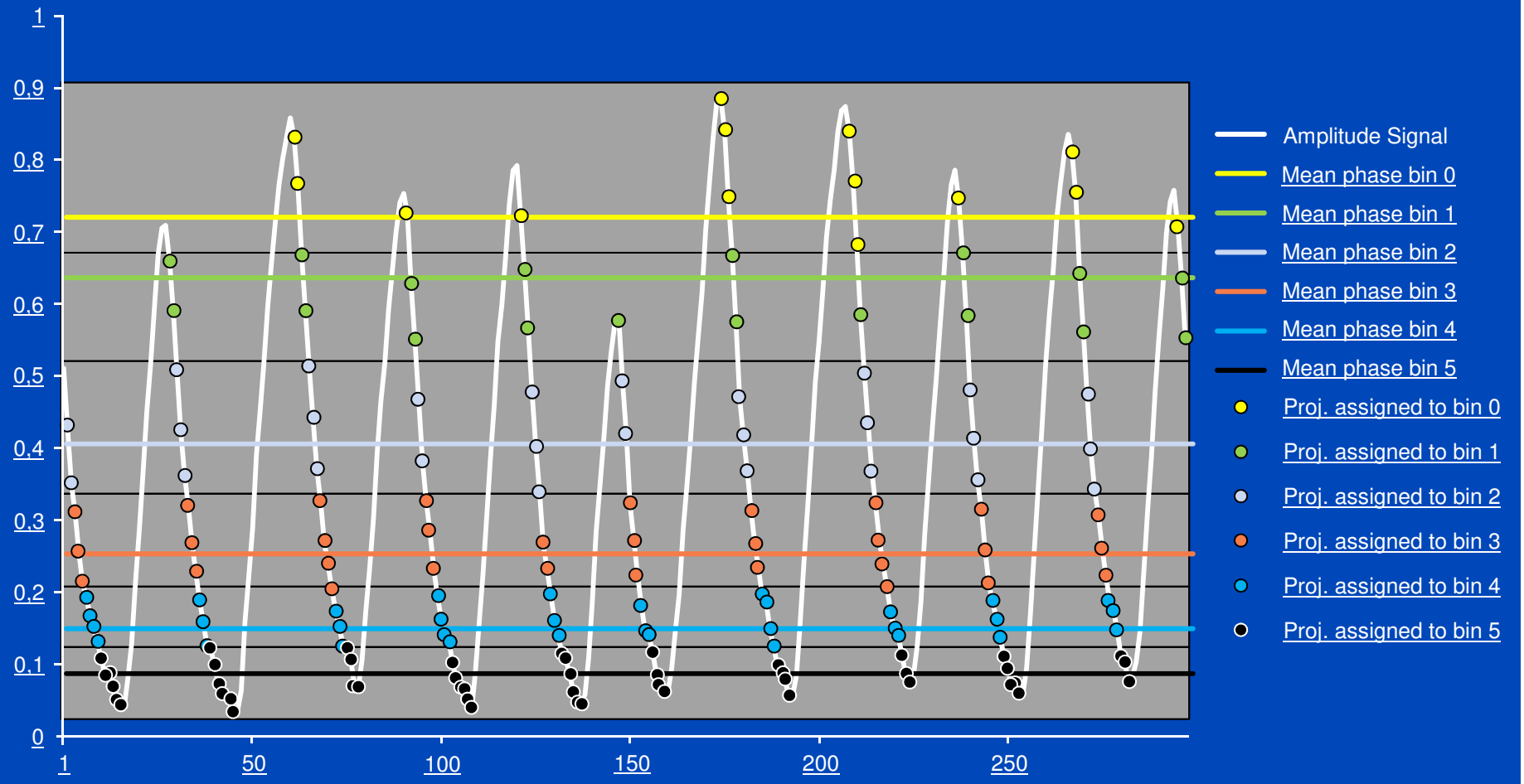
VARIAN medical systems

Brehm, Paysan, Oelhafen, and Kachelrieß, "Artifact-resistant motion estimation with a patient-specific artifact model for motion-compensated cone-beam CT" Med. Phys. 40(10):101913, 2013.

dkfz.

Step 3: Defining the Amplitude Bins

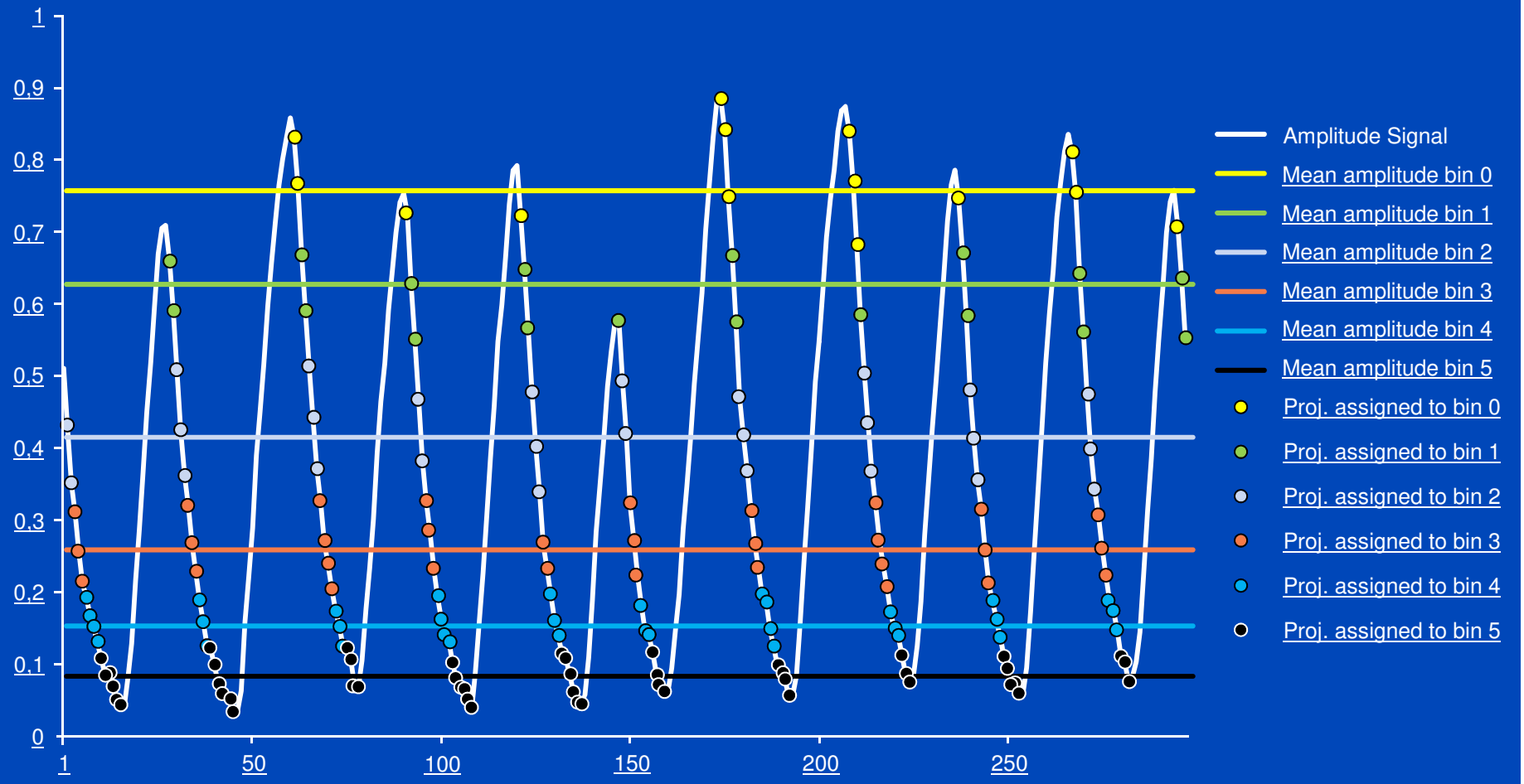
(exhale period shown, R=10, K=1)



VARIAN medical systems

dkfz.

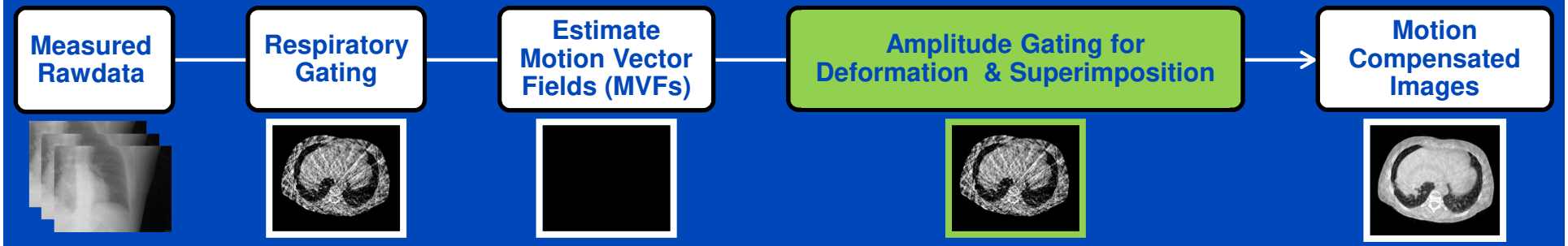
Step 4: Recalculation of the Mean Amplitues

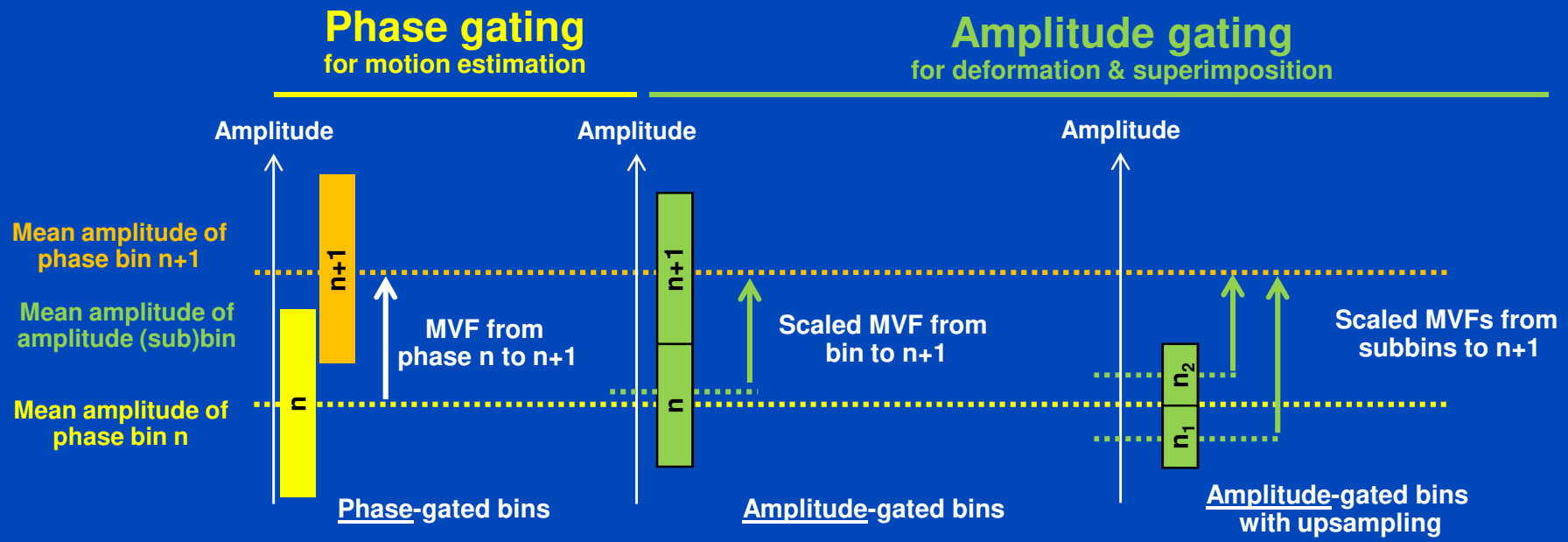


VARIAN medical systems

dkfz.

Switching
From Phase to Amplitude Binning



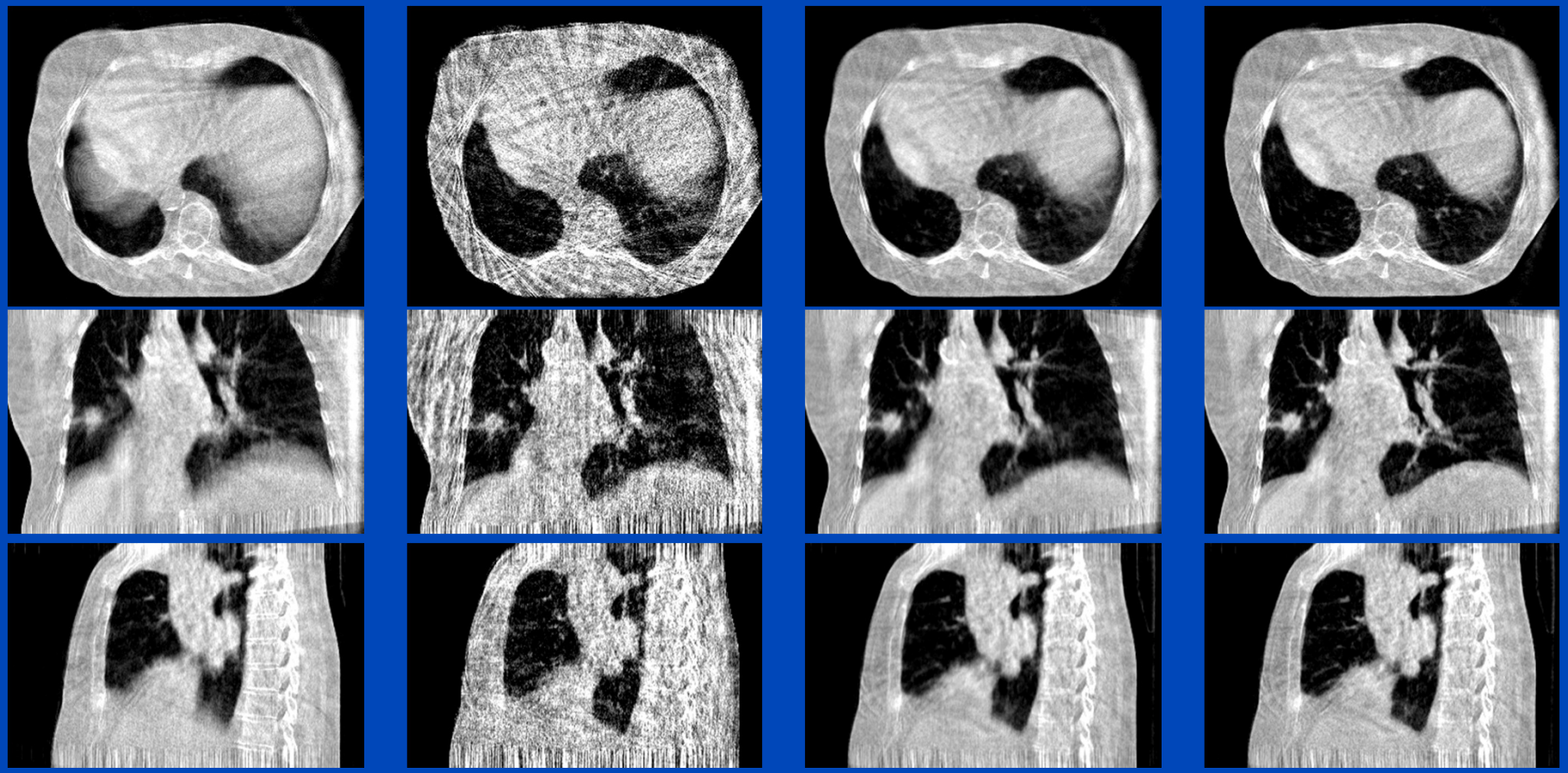


VARIAN medical systems

dkfz.

Patient Data

Motion Compensation R=10, 20% Bin Width
Scan Velocity 2 °/s with 7 fps, 13 rpm



VARIAN medical systems

C = -100, W = 1200 HU
playback speed 30 rpm

dkfz.

Summary

- MVF estimation and thus MoCo image reconstruction can be significantly improved by MVF phase-to-amplitude resampling.
- Motion blurring was reduced in all motion bins.

Thank You!

- This study was supported by Varian Medical Systems.

- 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 Marc Kachelrieß (marc.kachelriess@dkfz.de).

- Parts of the reconstruction software were provided by RayConStruct® GmbH, Nürnberg, Germany.