# Synthesizing 4D CBCT Scans from 3D CBCT Phantom Acquisitions

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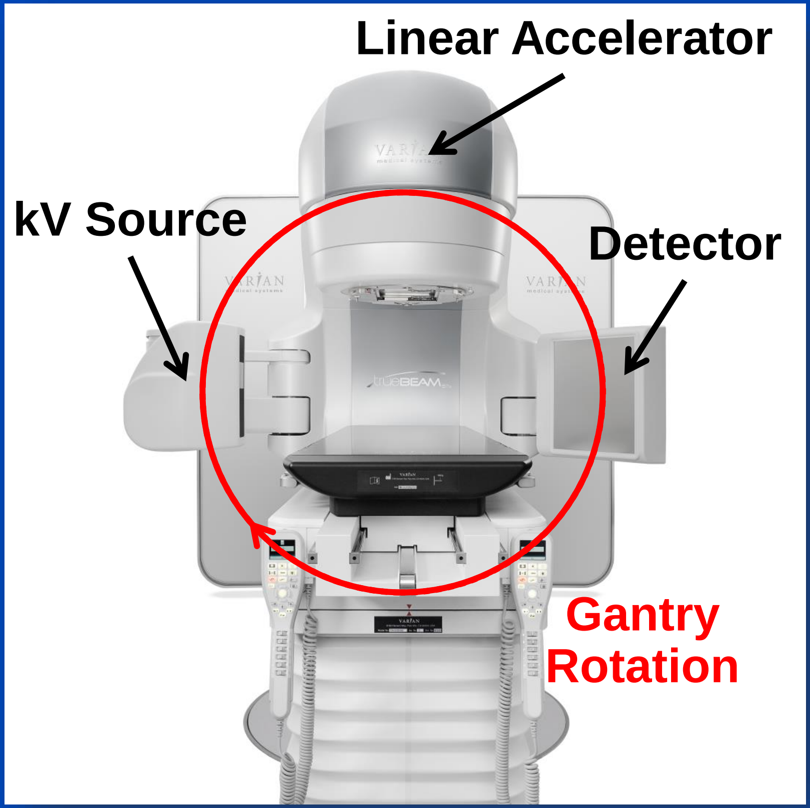
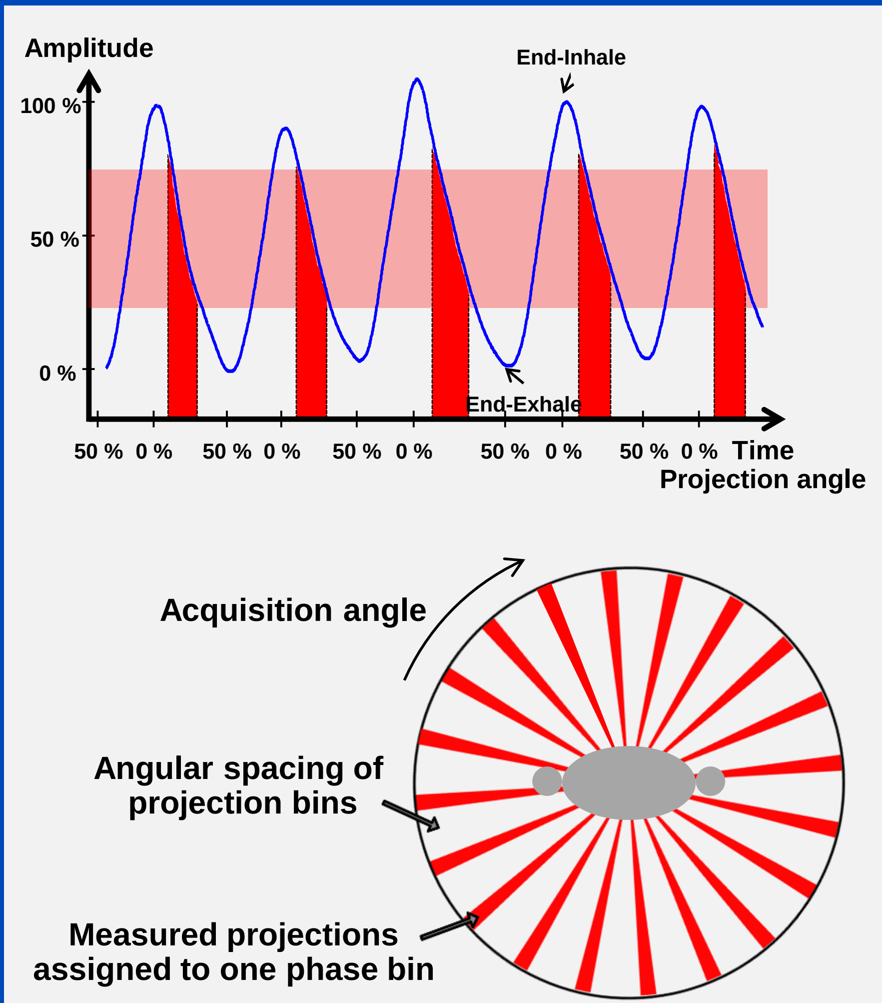
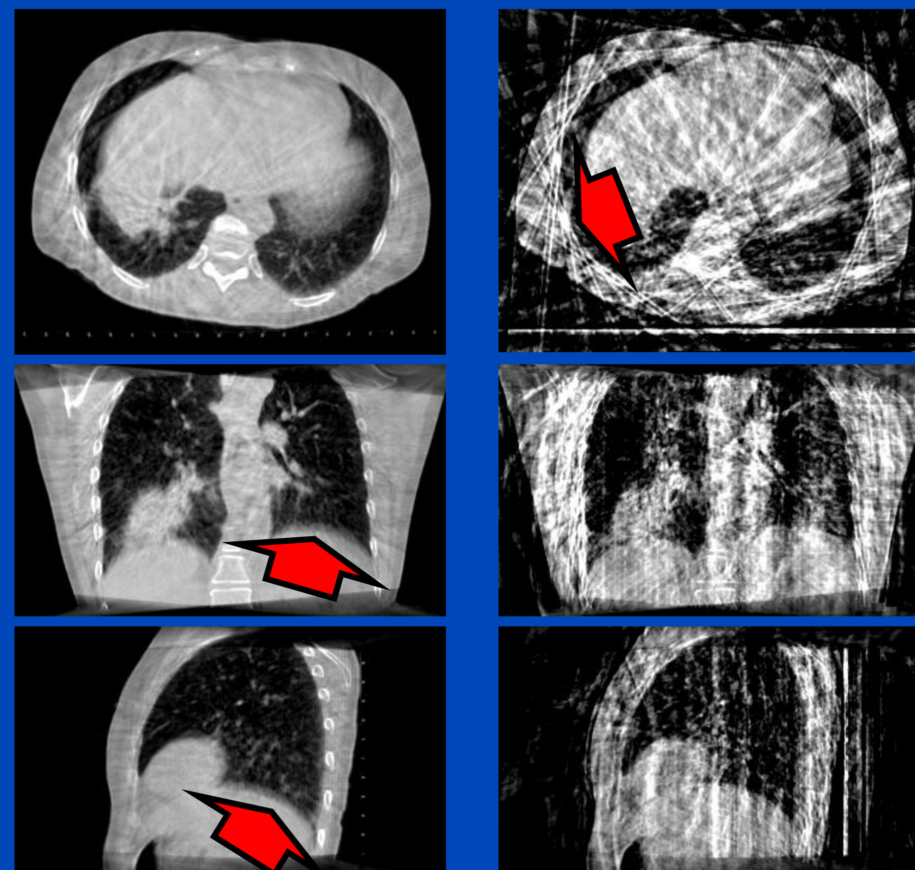
# Cone-Beam CT (CBCT) in Image Guided Radiotherapy



# 4D CBCT Scan with Retrospective Gating




**Without gating (3D): Motion artifacts** | **With gating (4D): Sparse-view artifacts**



# Motivation & Aim

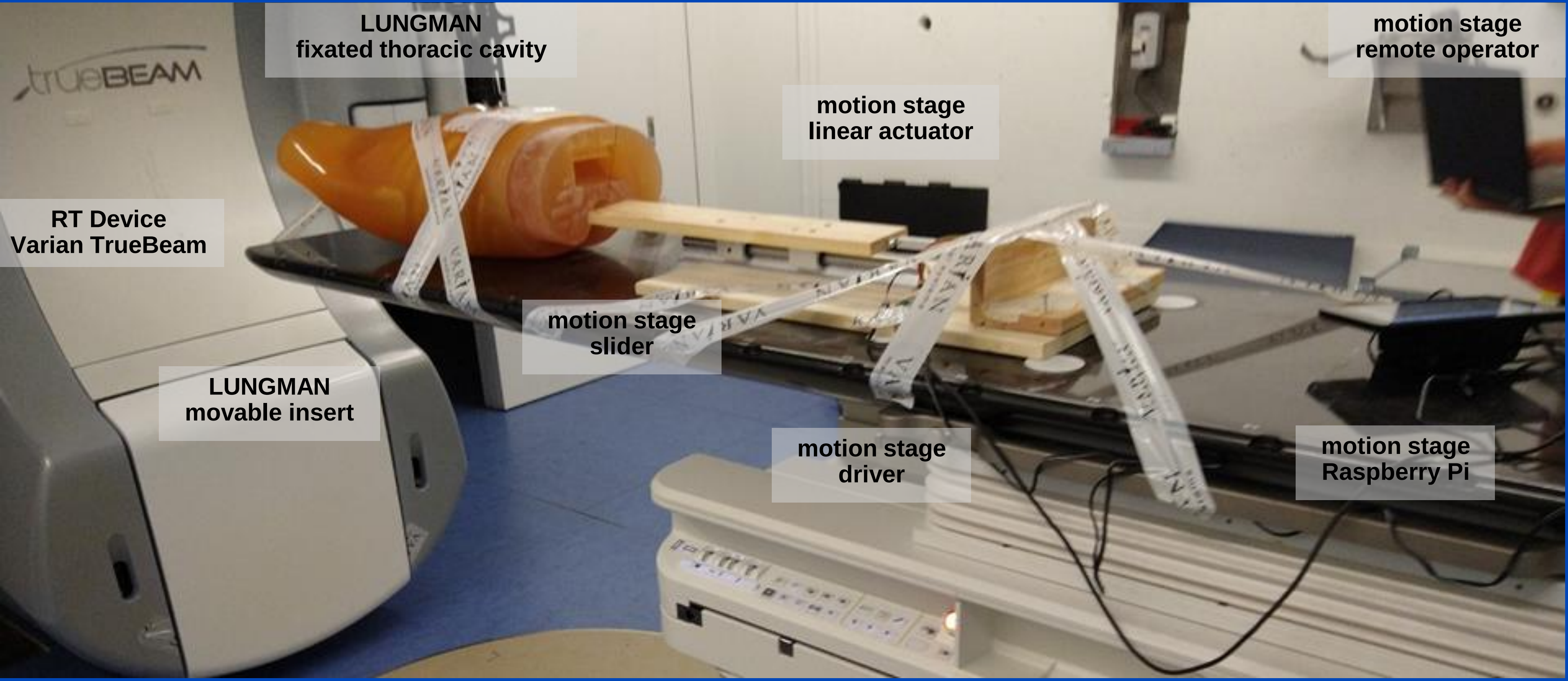
- Motivation: Ground truth in 4D CBCT is hard to get due to the high patient dose involved for artifact-free images.
- Comparing 4D CBCT reconstructions algorithms without a ground truth is cumbersome.
- A measured ground truth is of advantage to compare different scanners or tumor positions.

- Aim: Provide patient-realistic 4D CBCT ground truth without artifacts.

# Materials

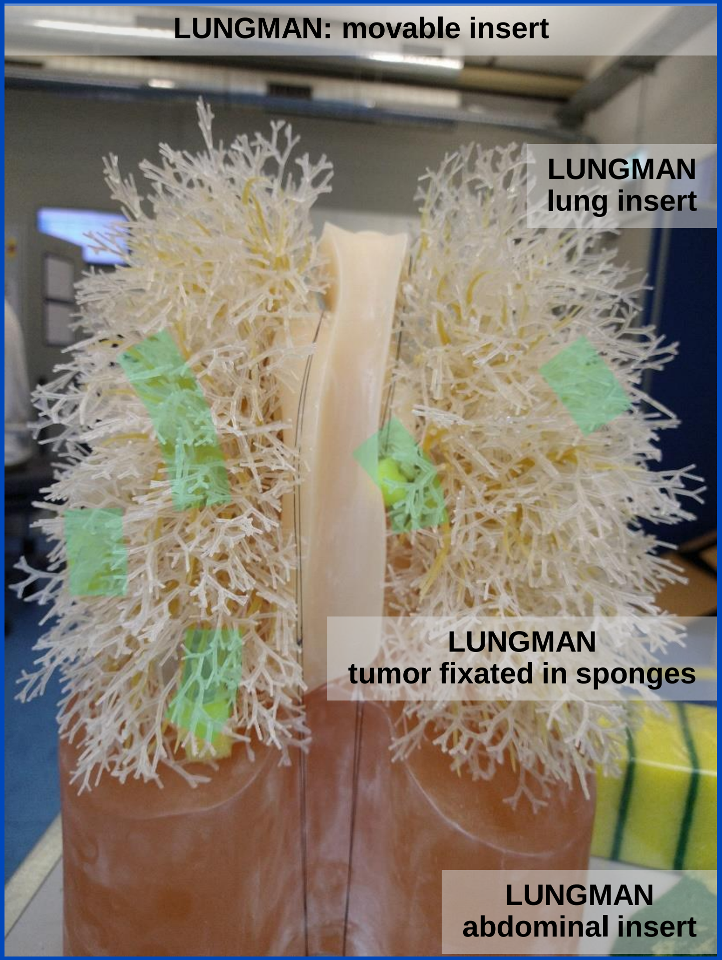
- Perform several consecutive scans with a LUNGMAN phantom at different penetration depths of the abdomen/lung block.
- 51 stop-motion measurements every 1 mm for 50 mm.
- Tube voltages 100 kV & 125 kV

# Experimental Setup




- **LUNGMAN outer cavity fixated on patient's couch**
- **Penetration depths of LUNGMAN inner cavity can be controlled with a linear actuator on a simple motion stage, controllable from the control room. During the scan, the phantom is not moving.**

# LUNGMAN Inner Cavity Setup




- LUNGMAN inner cavity consisting of abdomen and lung insert.
- 3D printed tumors from the LIDC-IDRI dataset provide realistic tumor shapes.
- Gold markers inserted for a metal artifact study.



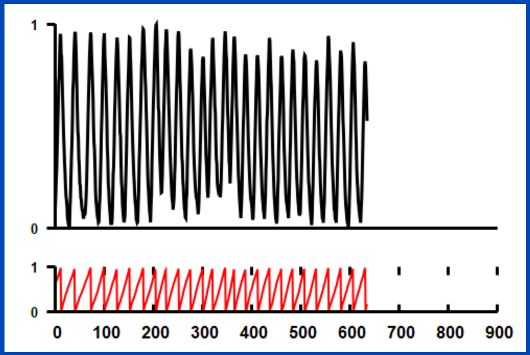
Data From LIDC-IDRI [Data set]. , L. P. Clarke et al., The Cancer Imaging Archive, 2015.

# 4D CBCT Synthesizing Method

- We start with a real (or a simulated) amplitude signal from a CBCT acquisition.

relative amplitude signal

| phase signal



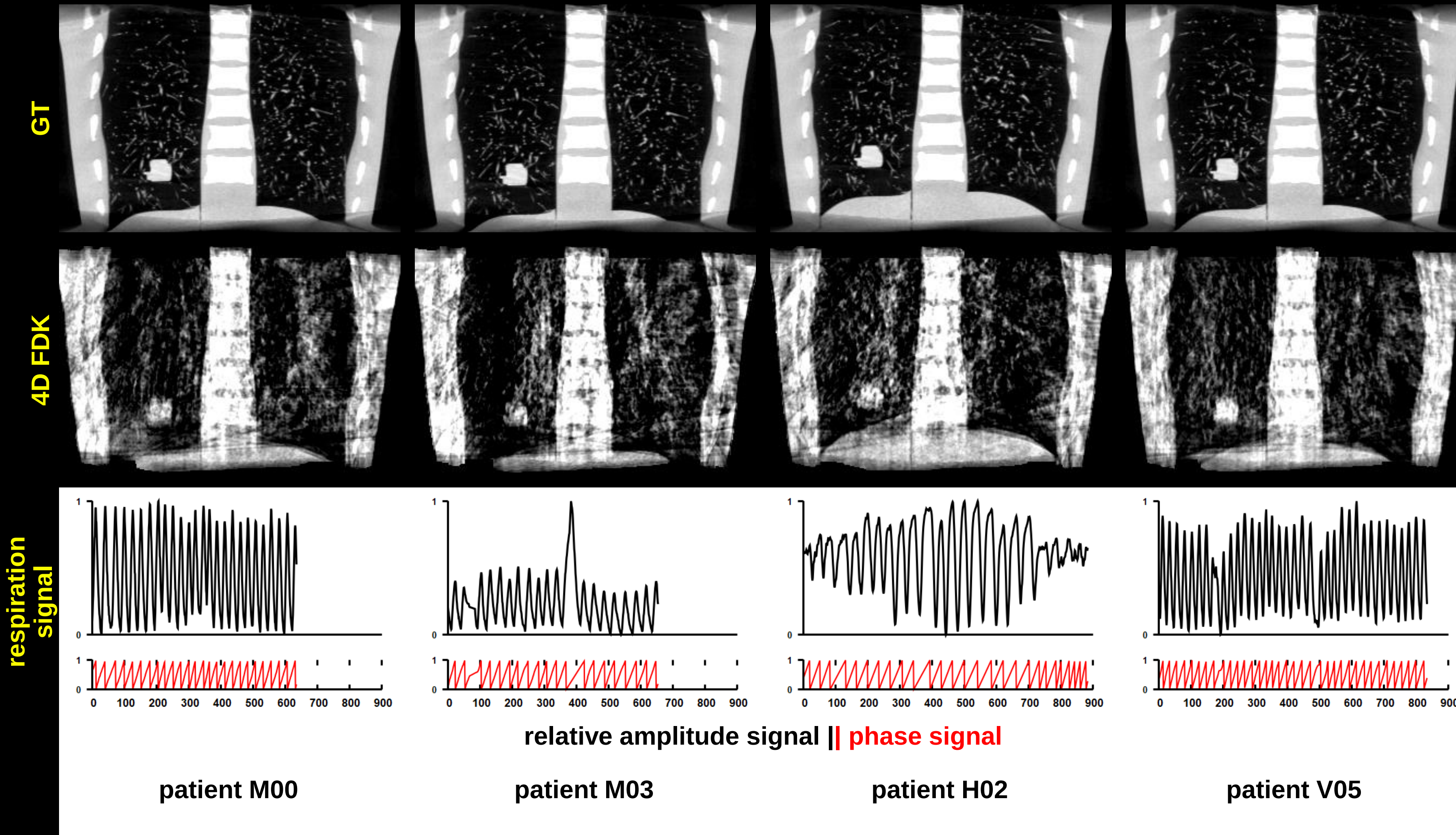

- For each projection angle, we find the amplitude of the respiration and correlate it to the measured 3D scans.
- From that given scan, we select the projection closest to the projection angle.
- Repeat this for all projections in the original signal.

# Reconstruction Methods

- The reconstruction size is 512×512×210 voxel at 1×1×1 mm³.
- The 3D images are reconstructed with FDK[1].
- The 4D images are gated according to their phase signal and the respiration bins are reconstructed with FDK, 20 overlapping phases of 10% phase width.
- The motion-compensated images are reconstructed by two MoCo algorithms: acMoCo[2,3] and acacMoCo[4].

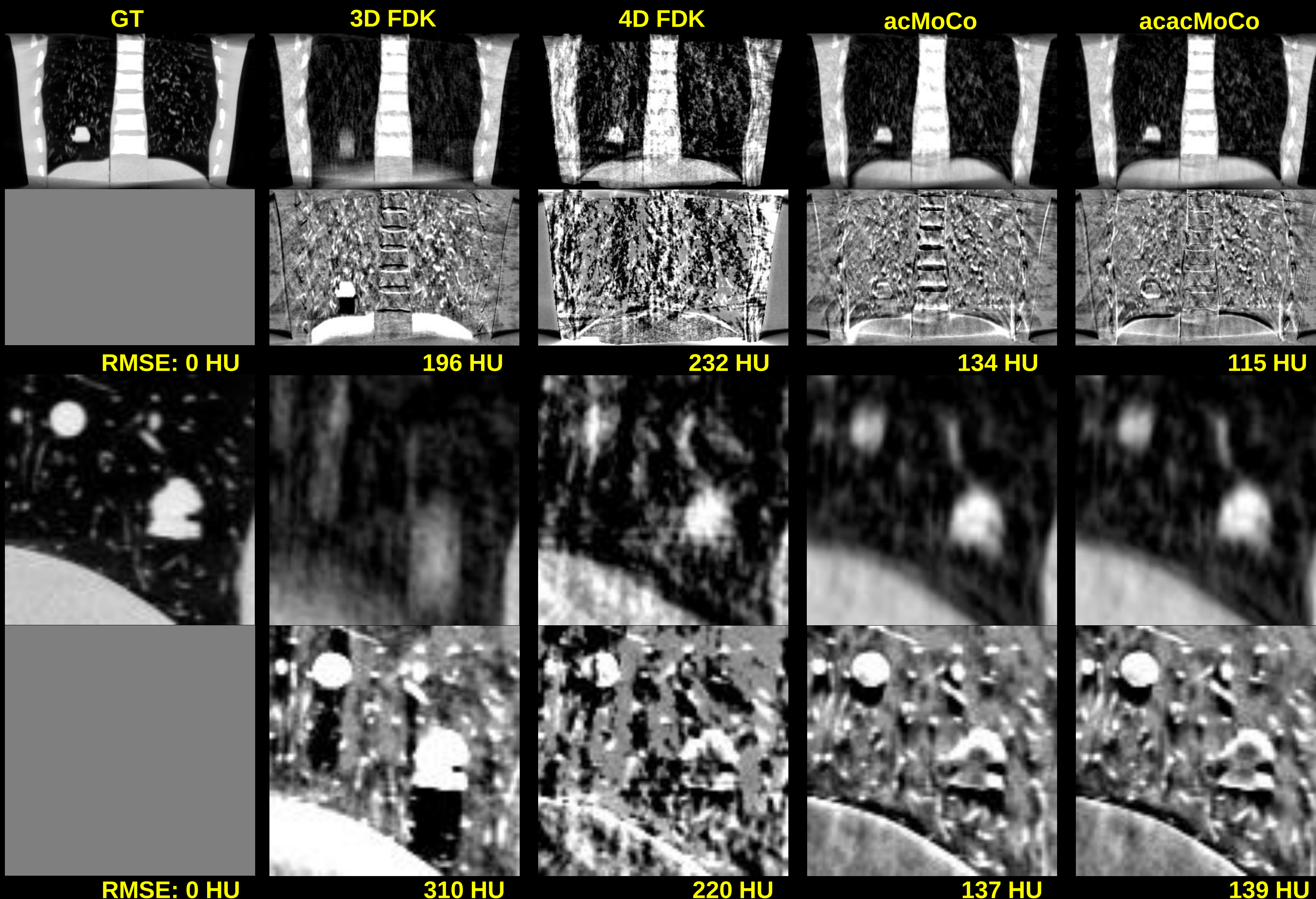
[1] L. Feldkamp, L. Davis und J. Kress, „Practical Cone–Beam Algorithm," Journal of the Optical Society of America, 1(6), 1984.
[2] M. Brehm, and M. Kachelrieß, „Self–Adapting Cyclic Registration for Motion–Compensated Cone–Beam CT in Image–Guided Radiation Therapy," Med. Phys., 39(12), 2012.
[3] M. Brehm and M. Kachelrieß, „Artifact–Resistant Motion Estimation with a Patient–Specific Artifact Model for Motion–Compensated Cone–Beam CT," Med. Phys., 40(10), 2013.
[4] M. Susenburger and M. Kachelrieß, „4D–Segmentation-Based Anatomy-Constrained Motion–Compensated Reconstruction of On–Board4D CBCT Scans," CT Meeting 2020.

# 4D CBCT Synthesis
# Different Patient Respiration Signals




Images: $C$ = -250 HU, $W$ = 1400 HU

# Tumor Shape Recovery




Images: $C$ = -250 HU, $W$ = 1400 HU    Differences: $C$ = 0 HU, $W$ = 600 HU

# Conclusions & Limitations

- 4D CBCT synthesis from consecutive 3D scans is suitable for the comparison of 4D reconstruction algorithms.
- The LUNGMAN anatomy is restricted to one specific phantom.
- Motion can only be analyzed in superior-inferior direction.
- Further, the setup is suitable for different scanners and the results can easily be repeated.
- The LUNGMAN phantom as such is often available in many clinics.

# Thank You!

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Job opportunities through DKFZ's international PhD or Postdoctoral Fellowship programs (marc.kachelriess@dkfz.de).