Design and Evaluation of a Prototype High-Throughput Micro-CT System for In-Vivo Small Animal Imaging

Jan Kuntz, Carsten Funck, Joscha Maier,
Marc Kachelrieß, and Stefan Sawall

German Cancer Research Center (DKFZ)
Heidelberg, Germany
www.dkfz.de/ct

DEUTSCHES
KREBSFORSCHUNGSZENTRUM
IN DER HELMHOLTZ-GEMEINSCHAFT

Practical Example

- Cooperation with the Division of Molecular Thoracic Oncology of the DKFZ.
- Preclinical development of a new drug to treat highly progressive lung cancer involves 750 mice.
- Five imaging session per animal are required over five weeks.
- I.e., in total 3750 single measurements are required in this study.
- The tumor load, i.e. distribution and size, shall be quantified.
- Hence, phase-correlated data are required to allow for a size quantification in moving structures.

Current Imaging Procedure

Siemens Inveon Micro-CT

10 min	Anesthetize mouse, place a catheter in the tail vein, administer blood pool contrast agent (ExiTron nano 12000).
10 min	Place the animal in the scanner, verify correct placement of pneumatic pillow, perform scout scan.
15 min	Measurement of enough data to allow for a phase-correlated reconstruction.
35 min	per mouse

Current Imaging Procedure

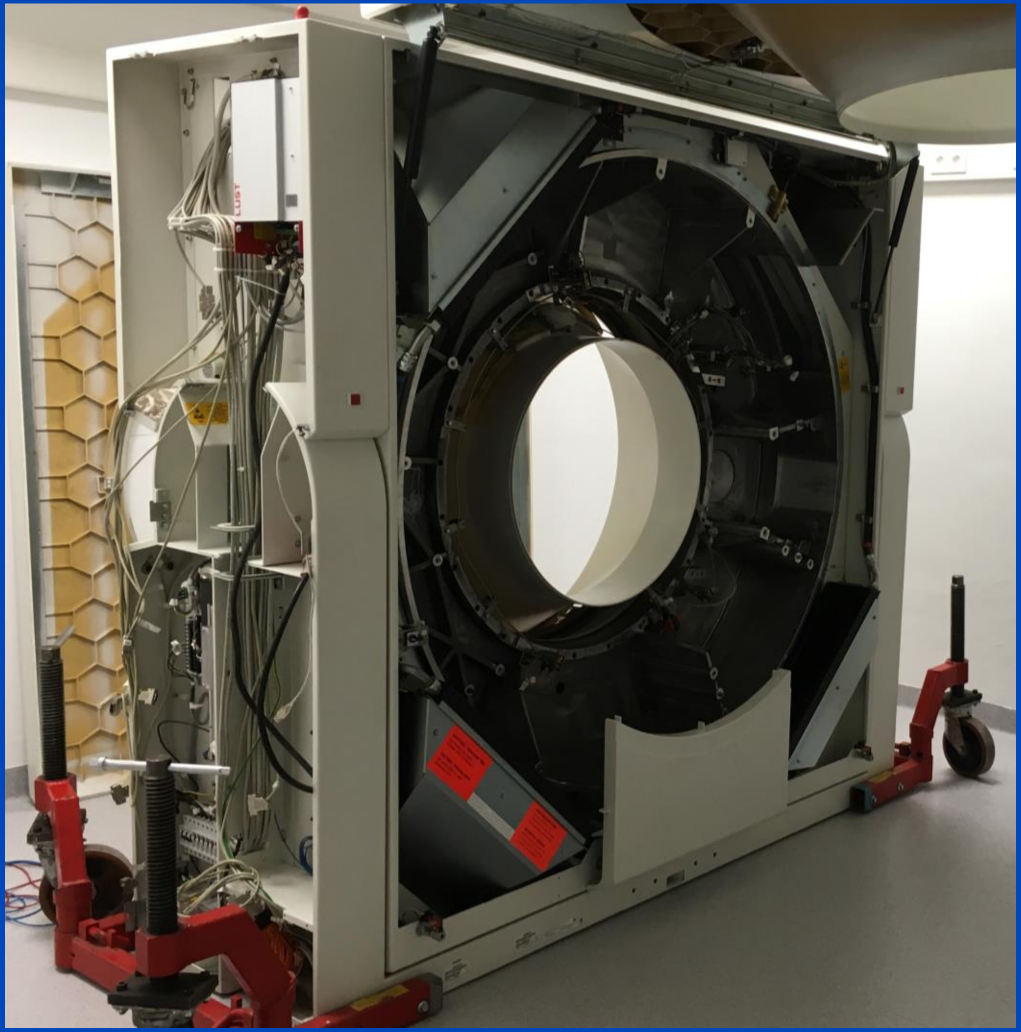
Siemens Inveon Micro-CT

0 min	Anesthetize mouse, place a catheter in the tail vein, administer blood pool contrast agent (ExiTron nano 12000).
10 min	Place the animal in the scanner, verify correct placement of pneumatic pillow, perform scout scan.
15 min	Measurement of enough data to allow for a phase-correlated reconstruction.
25 min	per mouse
93750 min	750×5×25 min, i.e. per cohort of 750 animals with five scans each.

Aim

- Design a novel micro-CT system simultaneously allowing for:
  - short scan times
  - a high spatial resolution
  - a high temporal resolution.
- Equip this micro-CT with state-of-the-art reconstruction methods to reduce radiation dose and allow for longitudinal studies.

Mechanical Framework



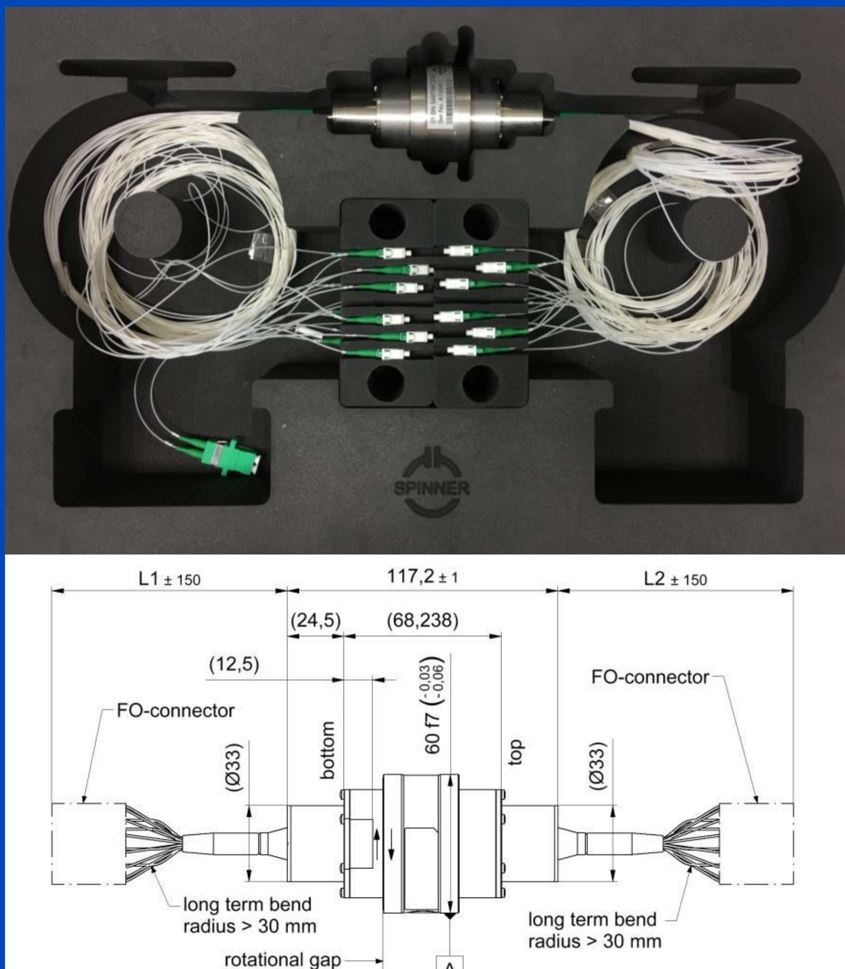
- Siemens Sensation Gantry
- High payload (>500 kg)
- Rotation speed 2 Hz
- High power slip rings
- High quality bearings (large number of installations)

X-Ray Detector

Dexela 2923

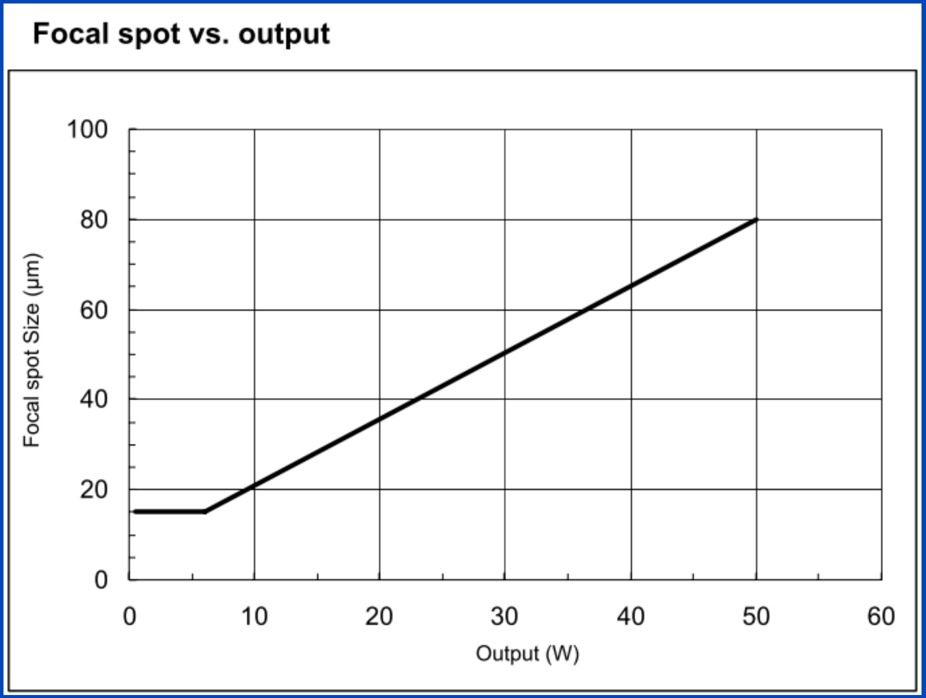
- Based on CMOS technology (crystalline silicon)
- 29 × 23 cm active area
- 3888 × 3072 pixel
- 150 µm CsI scintillator
- 75 × 75 µm² pixel size
- 4×4 / 2×2 / 1×1 binning
- 86 / 70 / 26 Hz frame rate
- About 125 MB/s, 400 MB/s and 600 MB/s of data

Data Transmission via Rotary Joint



- **20 fibres with up to 100 Gbit/s each**

X-Ray Tube
Hamamatsu L10951

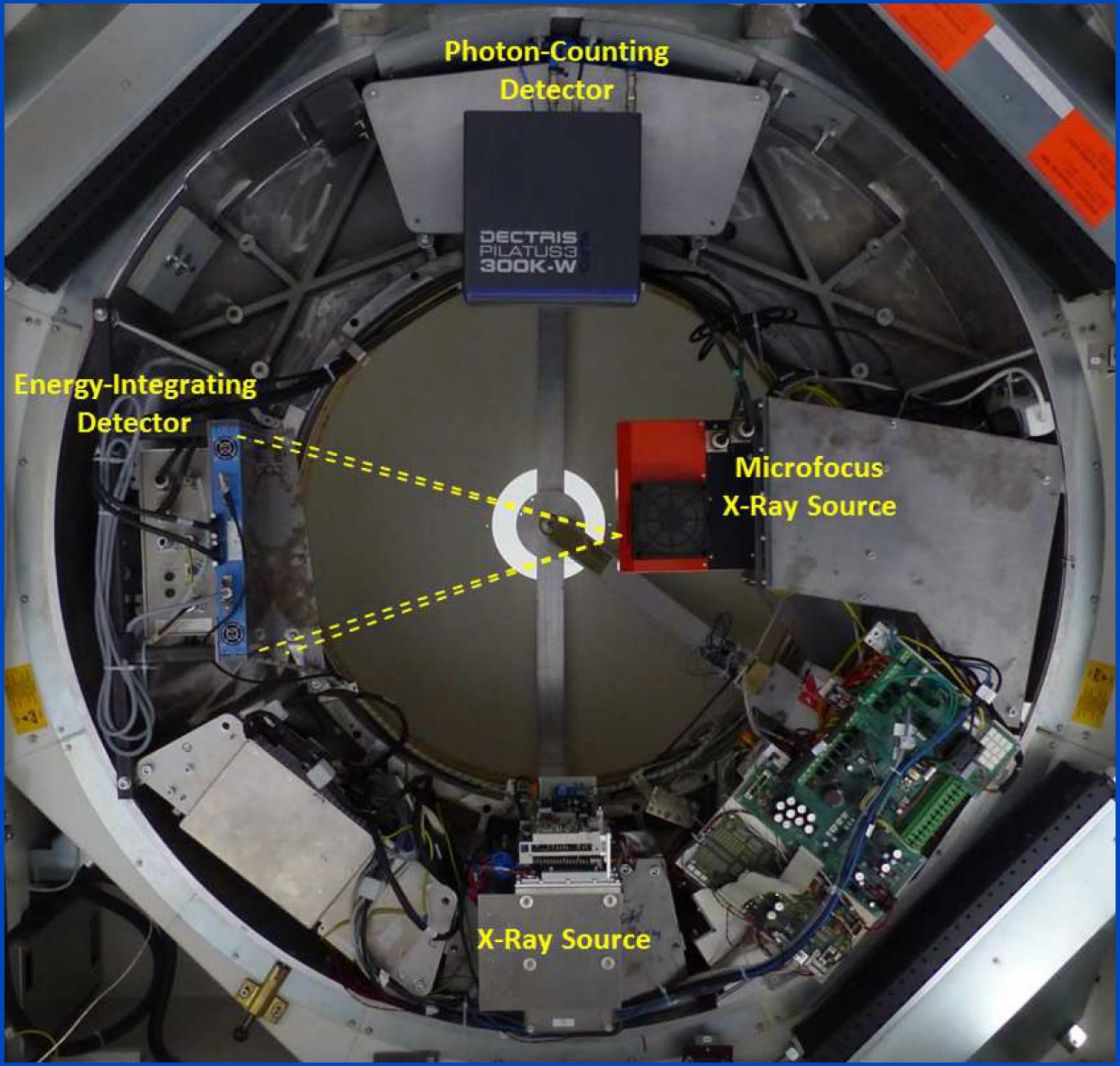


- Fixed transmission anode
- Voltage: 40-110 kV
- Maximal current: 0.8 mA
- Minimal focal spot: 0.015 mm

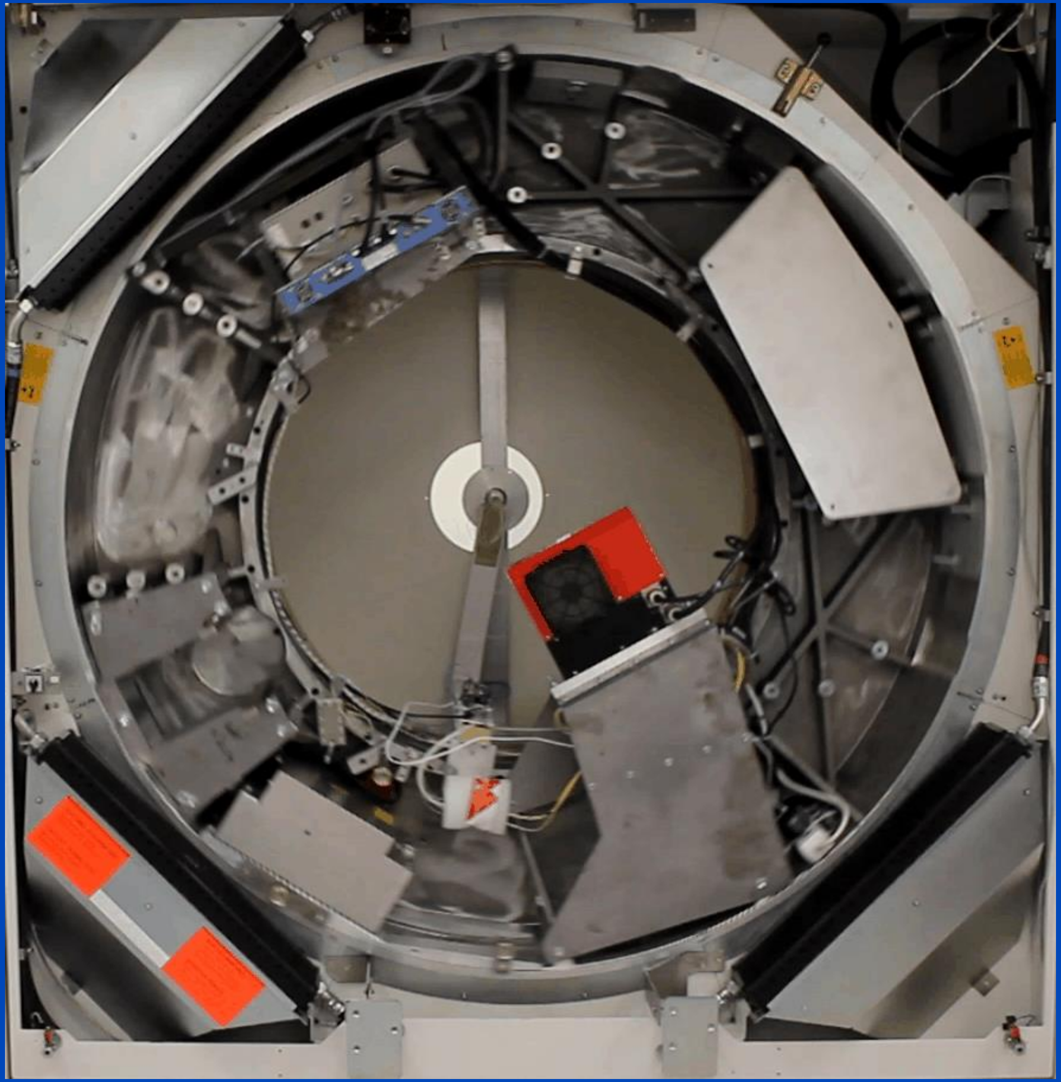
Achievable Spatial Resolution

- The source-isocenter distance is 90 mm and the source-detector distance is 590 mm.
- Assuming 80 µm focal spot size, the following spatial resolutions can be realized in the isocenter:
  - 69 µm in 1×1 binning (26 fps)
  - 71 µm in 2×2 binning (70 fps)
  - 82 µm in 4×4 binning (86 fps)

Fully Equipped System



System in Action

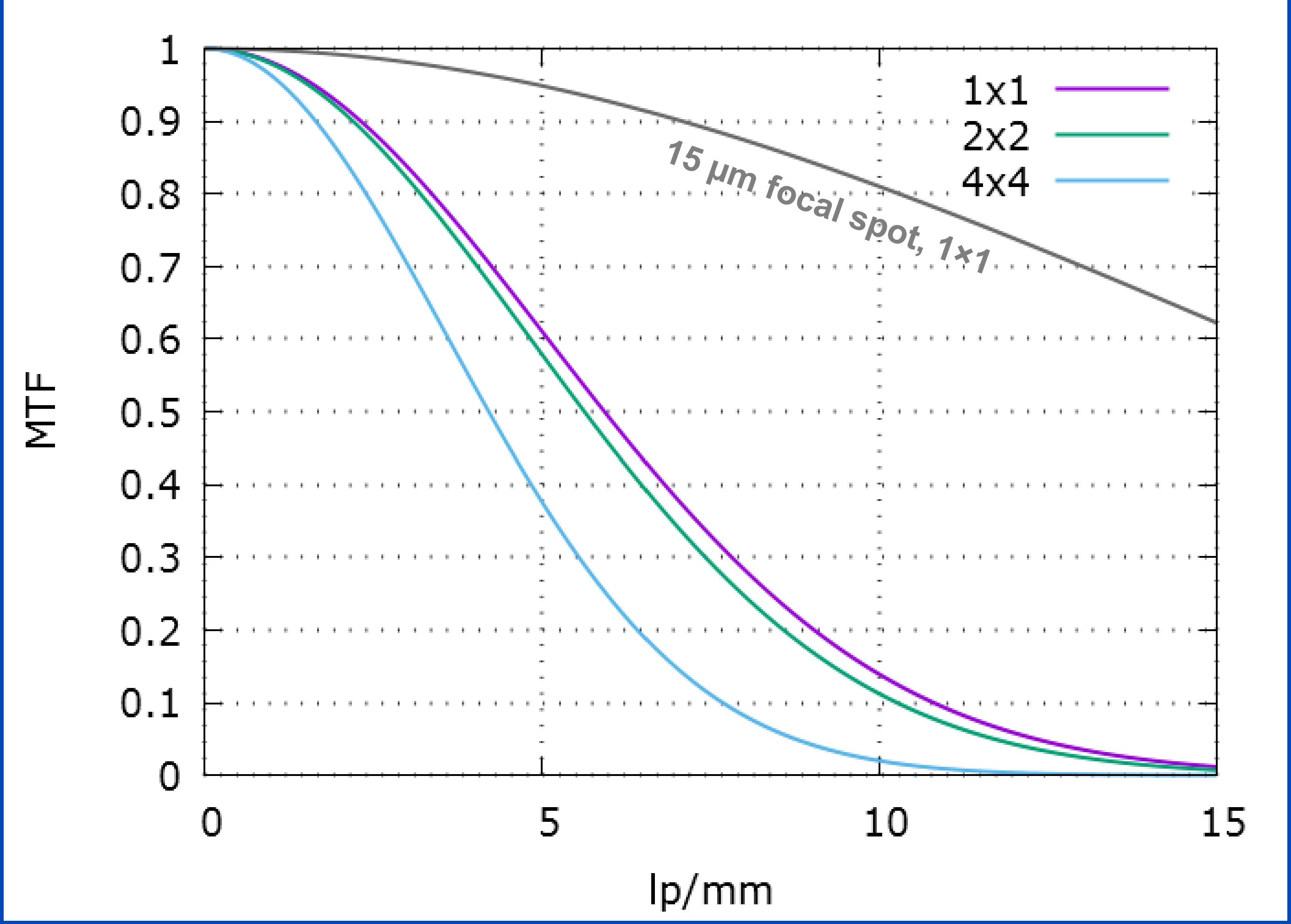


Protocol Definition

- All measurements presented in the following were obtained using a rotation time of 5 s per revolution.
- Data were acquired using a tube voltage of 60 kV and 833 µA, i.e. at 50 W.
- The focal spot size is about 80 µm.
- Measurements are performed over 300 s corresponding to:
  - 7800 projections / 180 GB of data in 1×1 binning
  - 21000 projections / 120 GB of data in 2×2 binning
  - 25800 projections / 37 GB of data in 4×4 binning

Spatial Resolution

80 µm Focal Spot



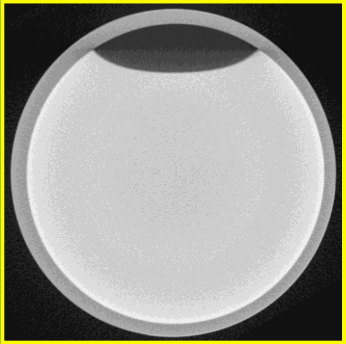
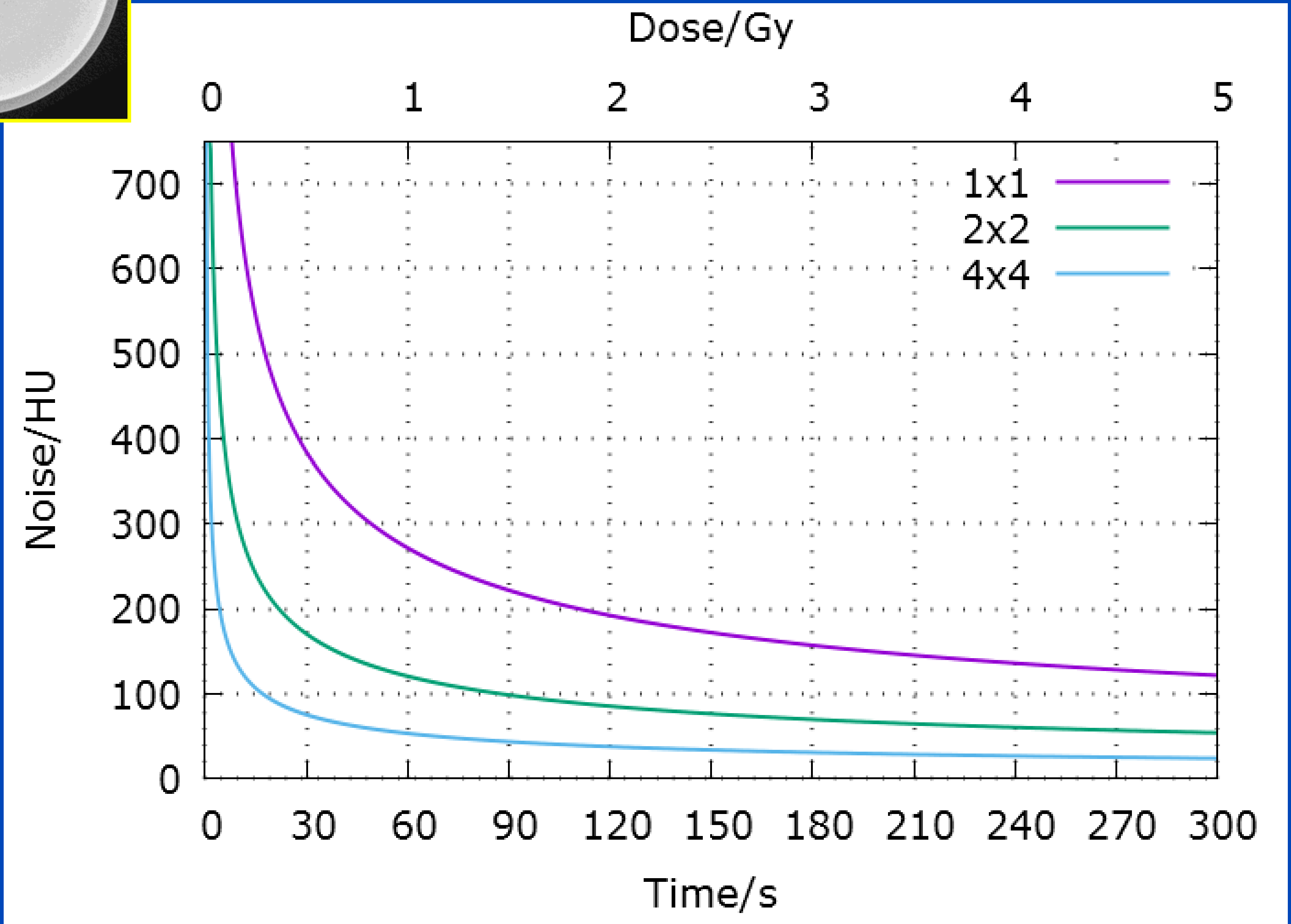
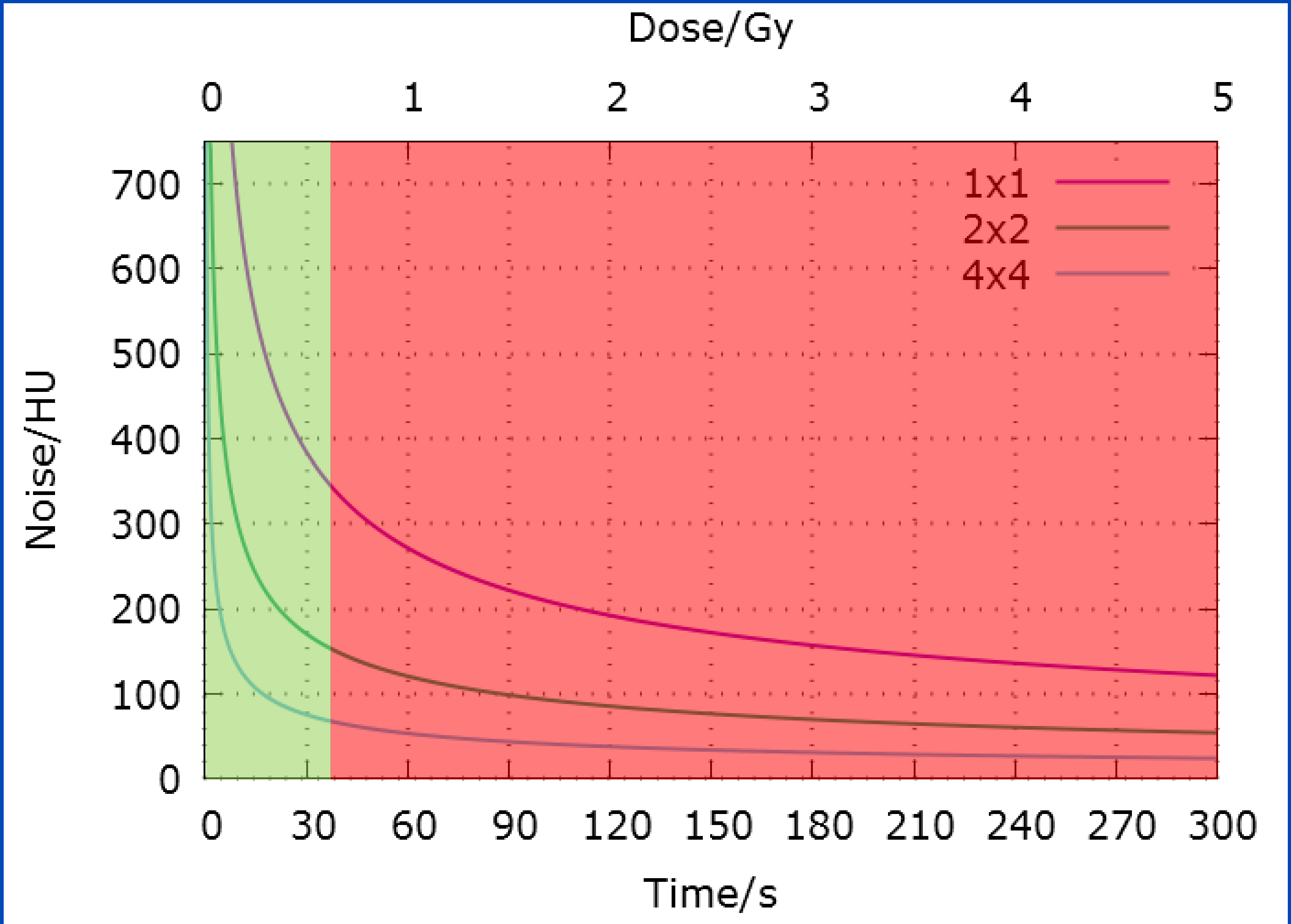


Image Noise

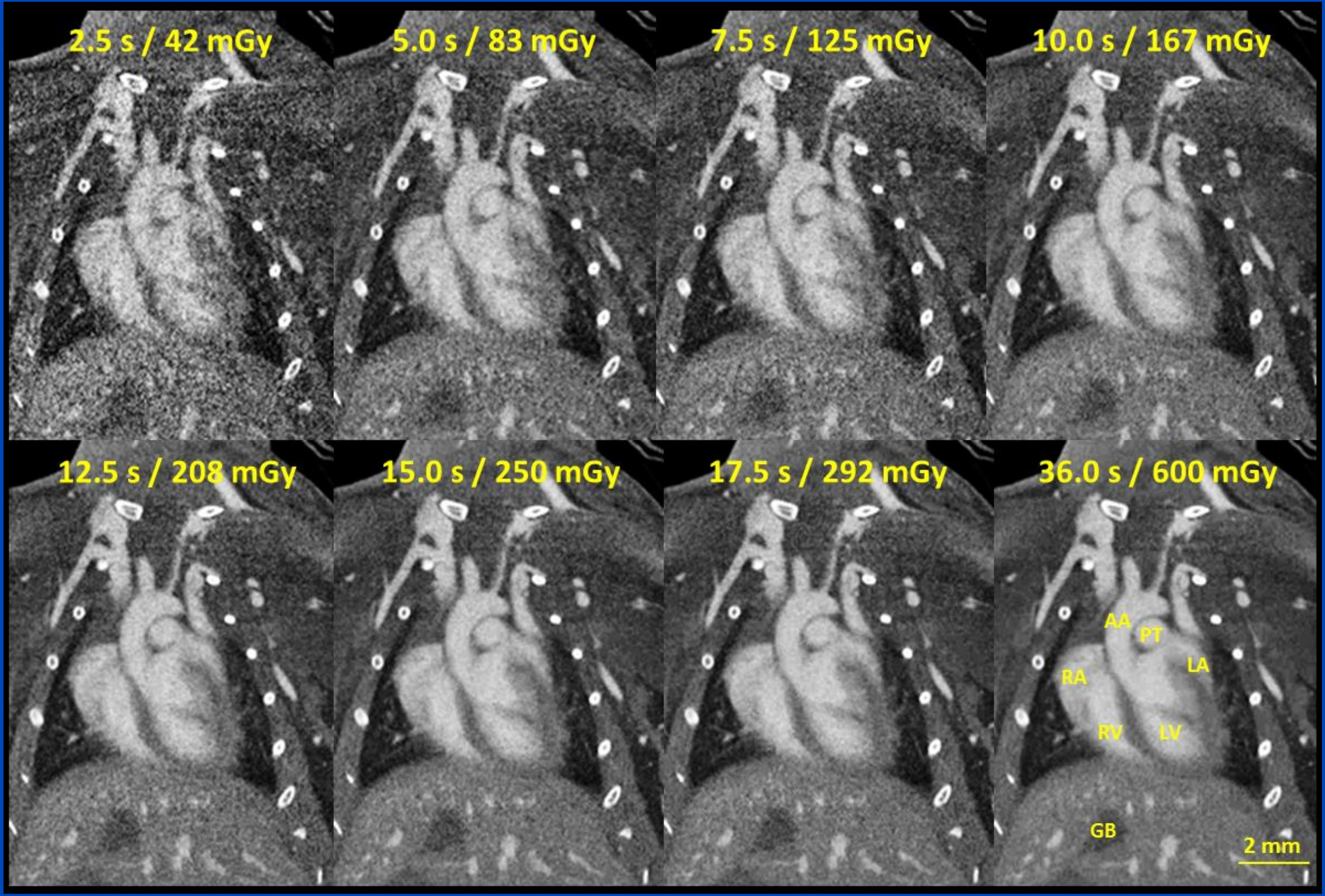

Dose/Gy
0
1
2
3
4
5
700
600
500
400
300
200
100
0
Noise/HU
1x1
2x2
4x4
0
30
60
90
120
150
180
210
240
270
300
Time/s

Practical Example



Scan Time Variation

Healthy Mouse, 4×4 binning

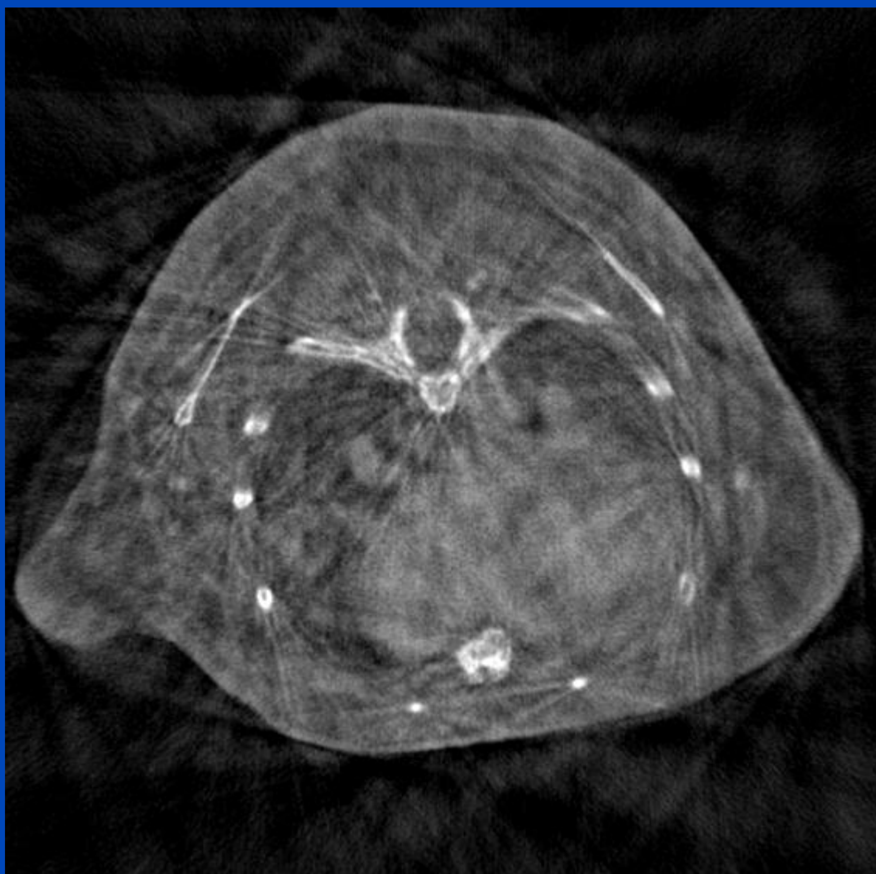


C/W=0 HU/1000 HU

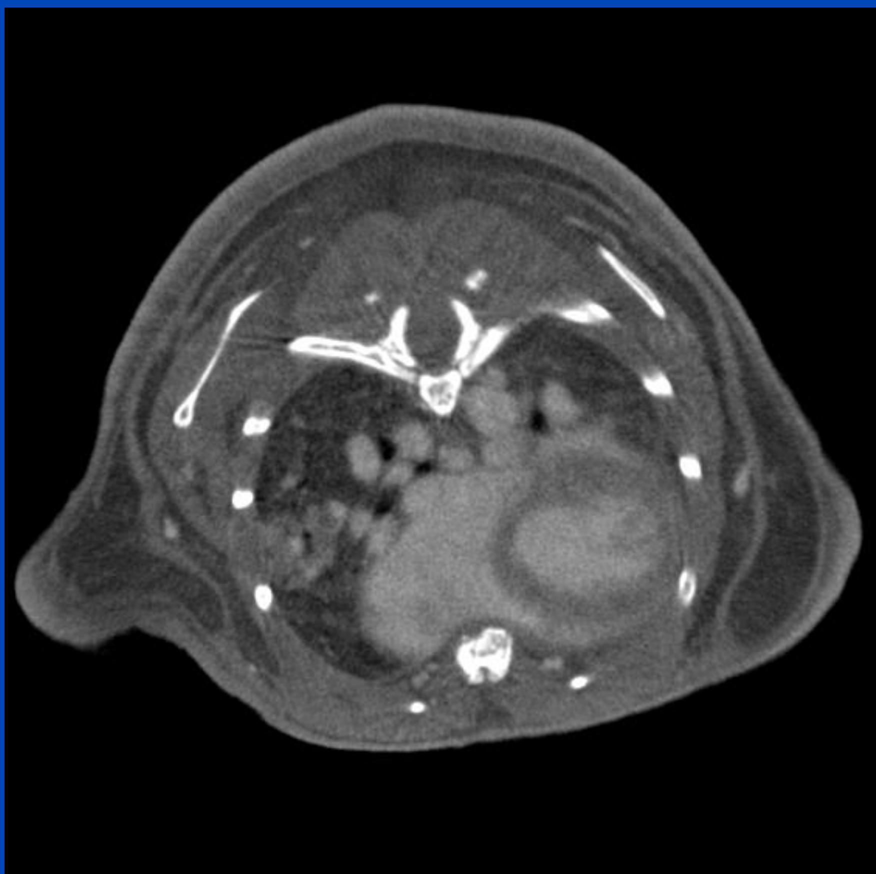
Practical Example

5 respiratory phases, Δr=20 %, 600 mGy

Standard Phase Correlated Reconstruction



Motion Compensation*

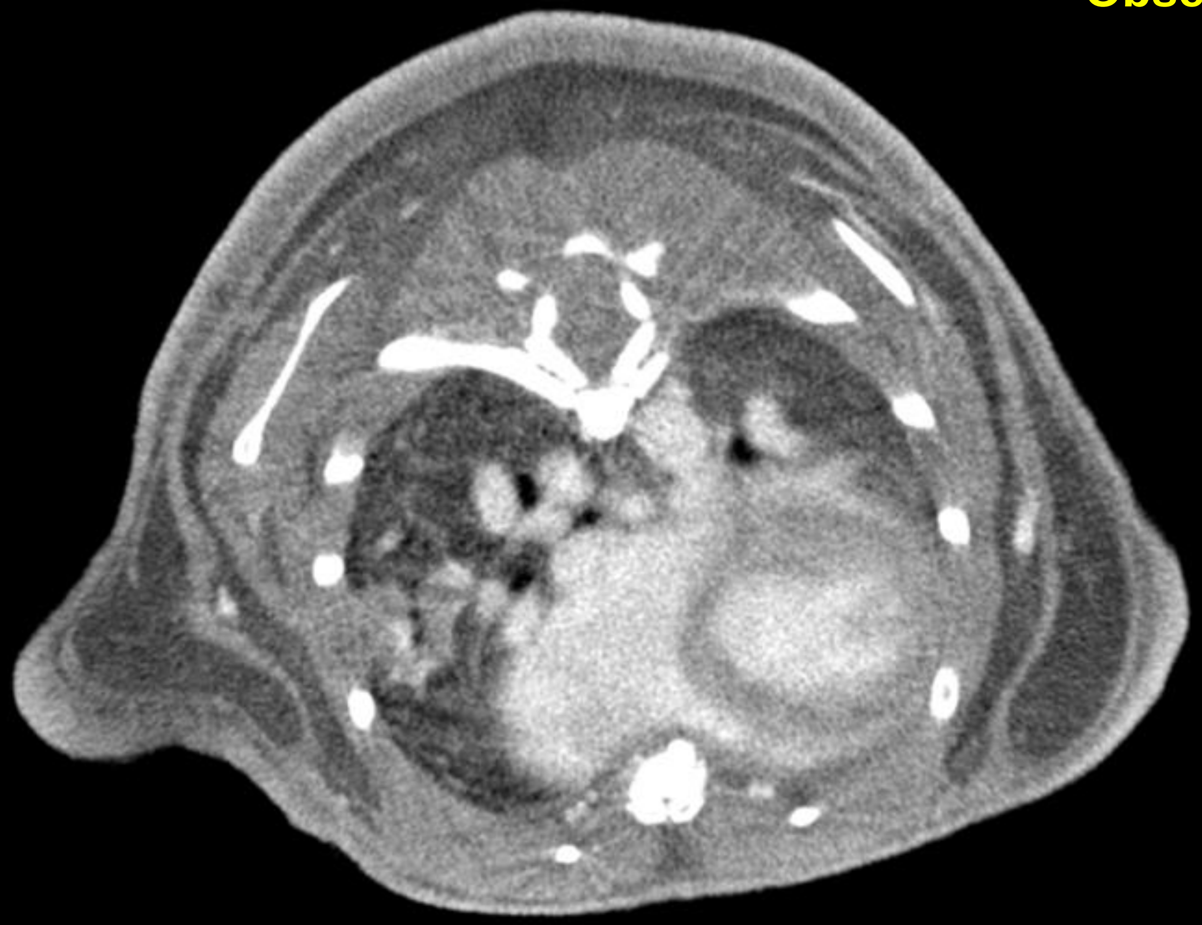


C/W=-100 HU/500 HU

*Brehm, Sawall, Kachelrieß et al. Cardiorespiratory motion-compensated micro-CT image reconstruction using an artifact model-based motion estimation. Med. Phys. 2015.

Practical Example

5 respiratory phases, r=10%, Δr=20 %, 600 mGy

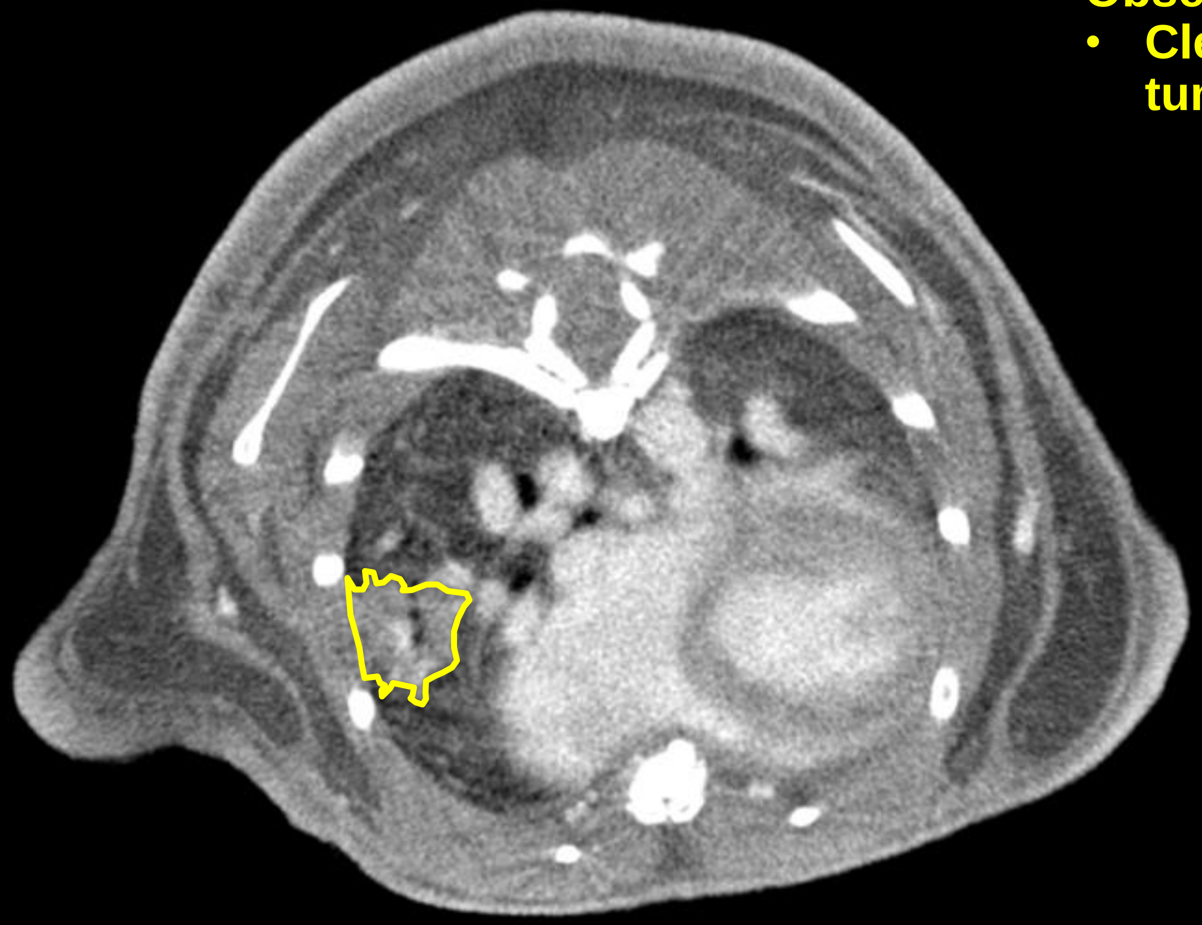


Observations:

C/W=200 HU/500 HU

Practical Example

5 respiratory phases, r=10%, Δr=20 %, 600 mGy

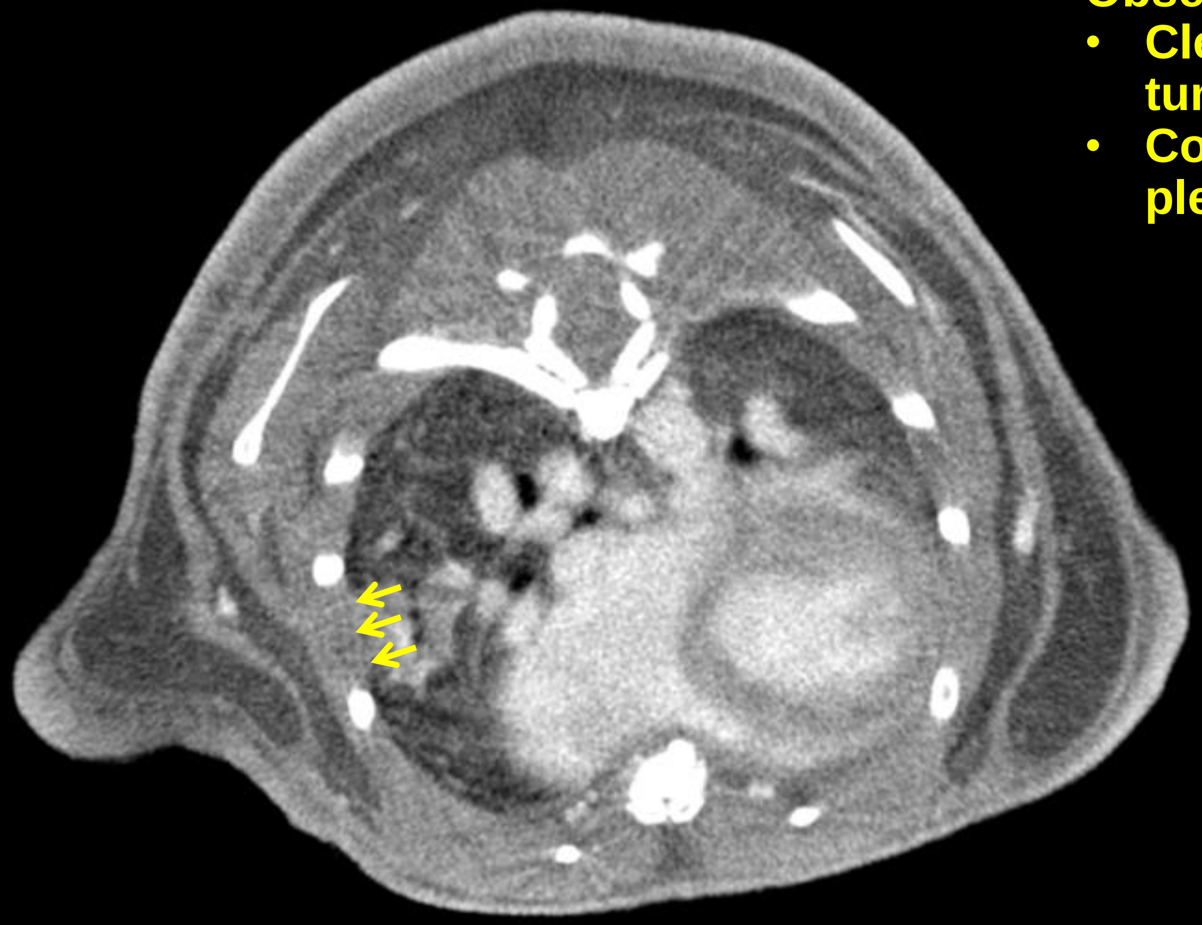


Observations:
- **Clearly defined tumor outline**

C/W=200 HU/500 HU

Practical Example

5 respiratory phases, r=10%, Δr=20 %, 600 mGy

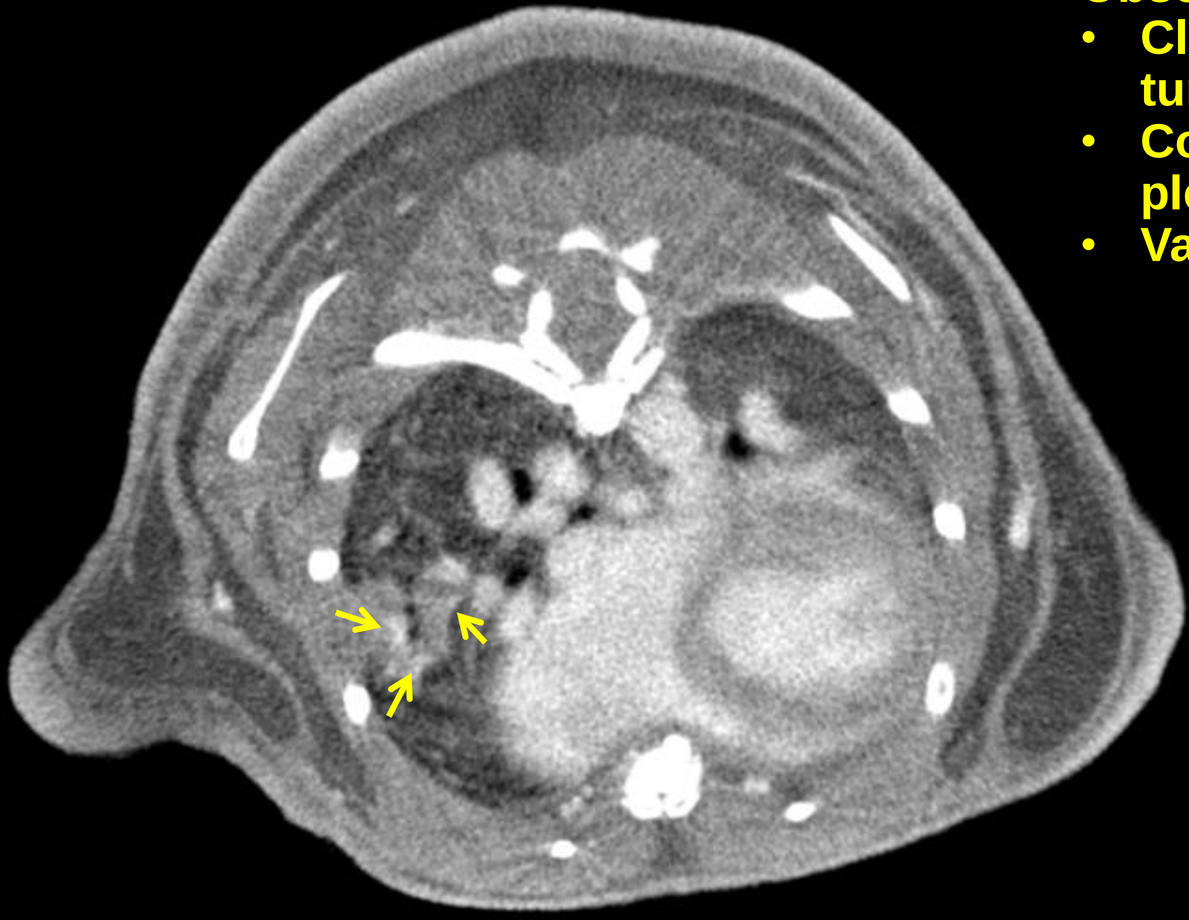


Observations:
- **Clearly defined tumor outline**
- **Connection to pleural gap**

C/W=200 HU/500 HU

Practical Example

5 respiratory phases, r=10%, Δr=20 %, 600 mGy

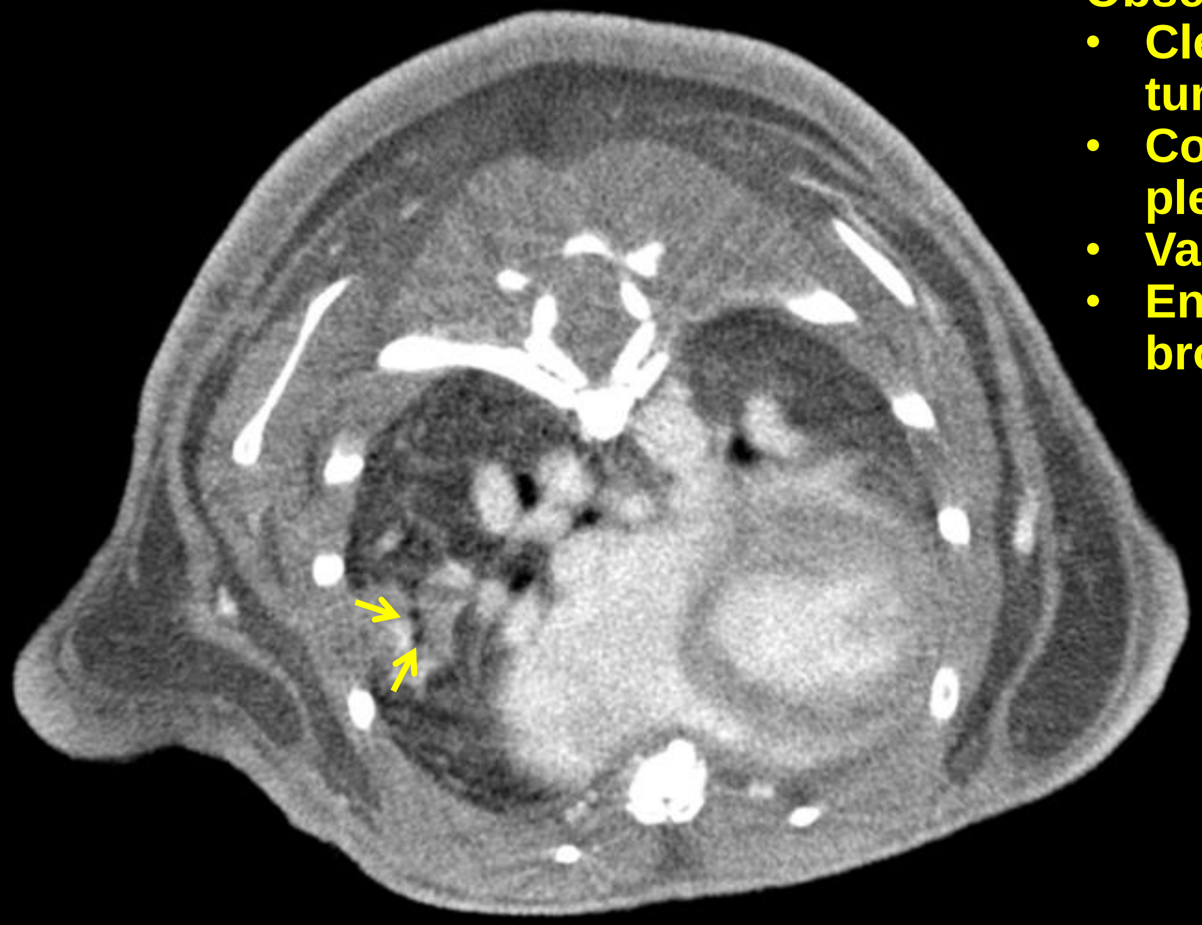


Observations:
- **Clearly defined tumor outline**
- **Connection to pleural gap**
- **Vascularization**

C/W=200 HU/500 HU

Practical Example

5 respiratory phases, r=10%, Δr=20 %, 600 mGy



Observations:

- **Clearly defined tumor outline**
- **Connection to pleural gap**
- **Vascularization**
- **Enclosing of bronchioli**

C/W=200 HU/500 HU

Practical Example

5 respiratory phases, r=10%, Δr=20 %, 600 mGy

Observations:
- Clearly defined tumor outline
- Connection to pleural gap
- Vascularization
- Enclosing of bronchioli
- Dilated right ventricle

C/W=200 HU/500 HU

New Imaging Procedure

Proposed Micro-CT

0 min	Anesthetize mouse, place a catheter in the tail vein, administer blood pool contrast agent (ExiTron nano 12000).
1 min*	Place the animal in the scanner, verify correct placement of pneumatic pillow, perform scout scan.
<1 min	Measurement of enough data to allow for a phase-correlated reconstruction.
2 min	per mouse
7500 min (93750 min)	per cohort of 750 animals with five scans each

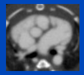
*Hahn and Kachelrieß. Fully automatic intrinsic respiratory and cardiac gating of cone-beam CT scans of the thorax region. Session T4.
*Kuntz et al. Fully automated intrinsic respiratory and cardiac gating for small animal CT. Phys. Med. Biol. 2010.

High-Throughput Micro-CT

High-Throughput Cardiac Micro-CT

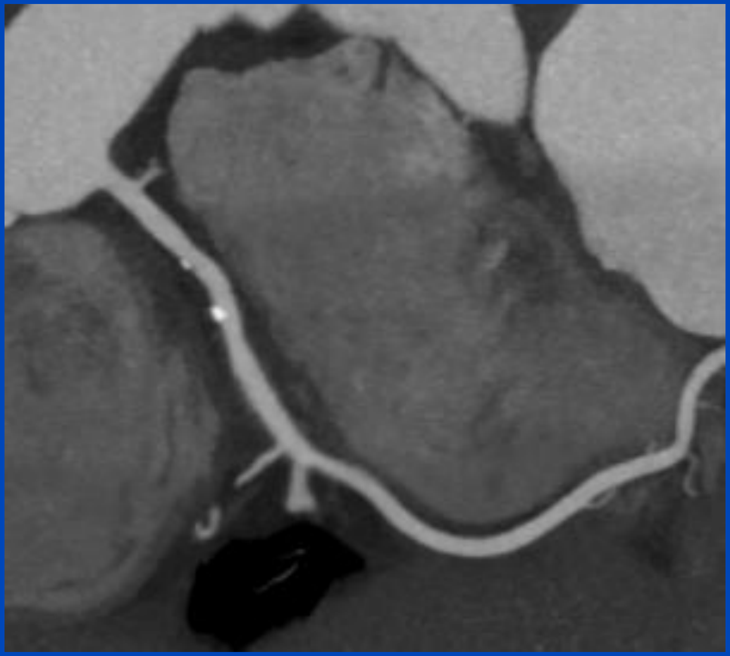
Cardiac Micro-CT

Mouse in a Standard Micro-CT



C/W=400 HU/1400 HU

Human in Clinical CT

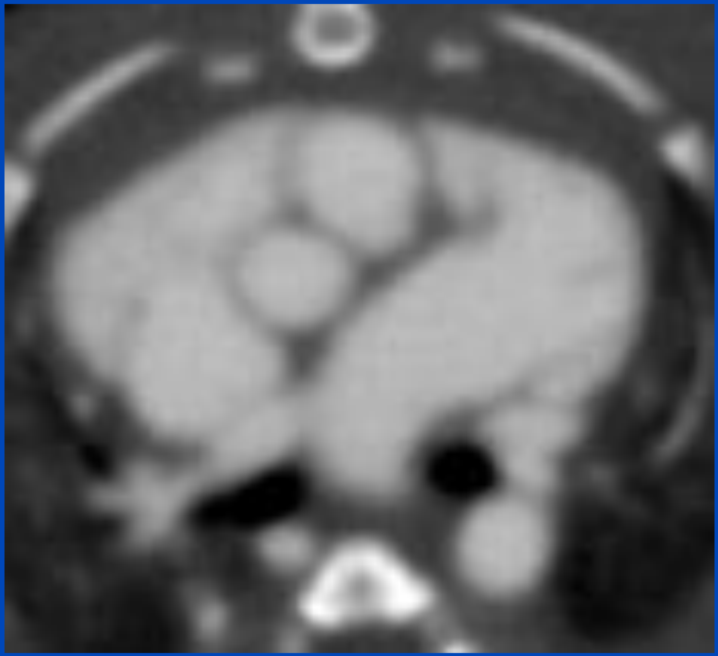


C/W=200 HU/600 HU

Clinical data courtesy of Stephan Achenbach.

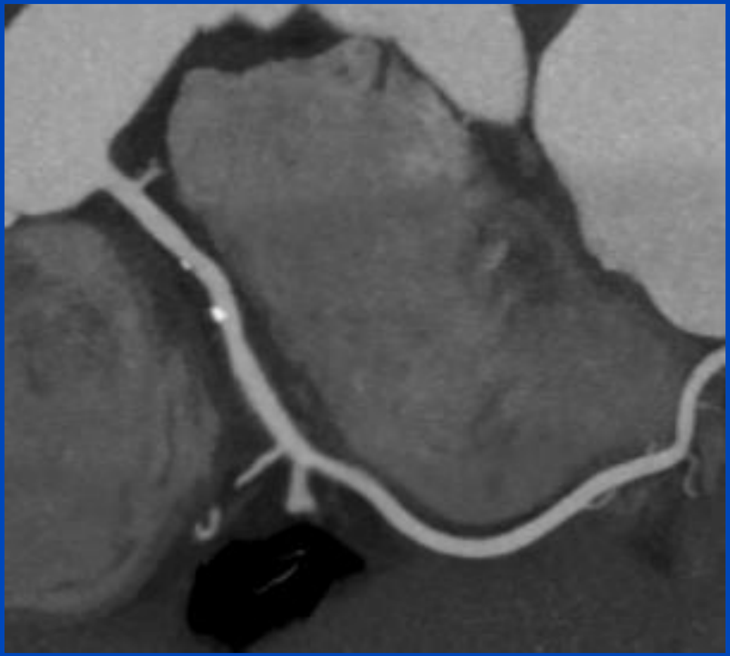
Cardiac Micro-CT

Mouse in a Standard Micro-CT



C/W=400 HU/1400 HU

Human in Clinical CT

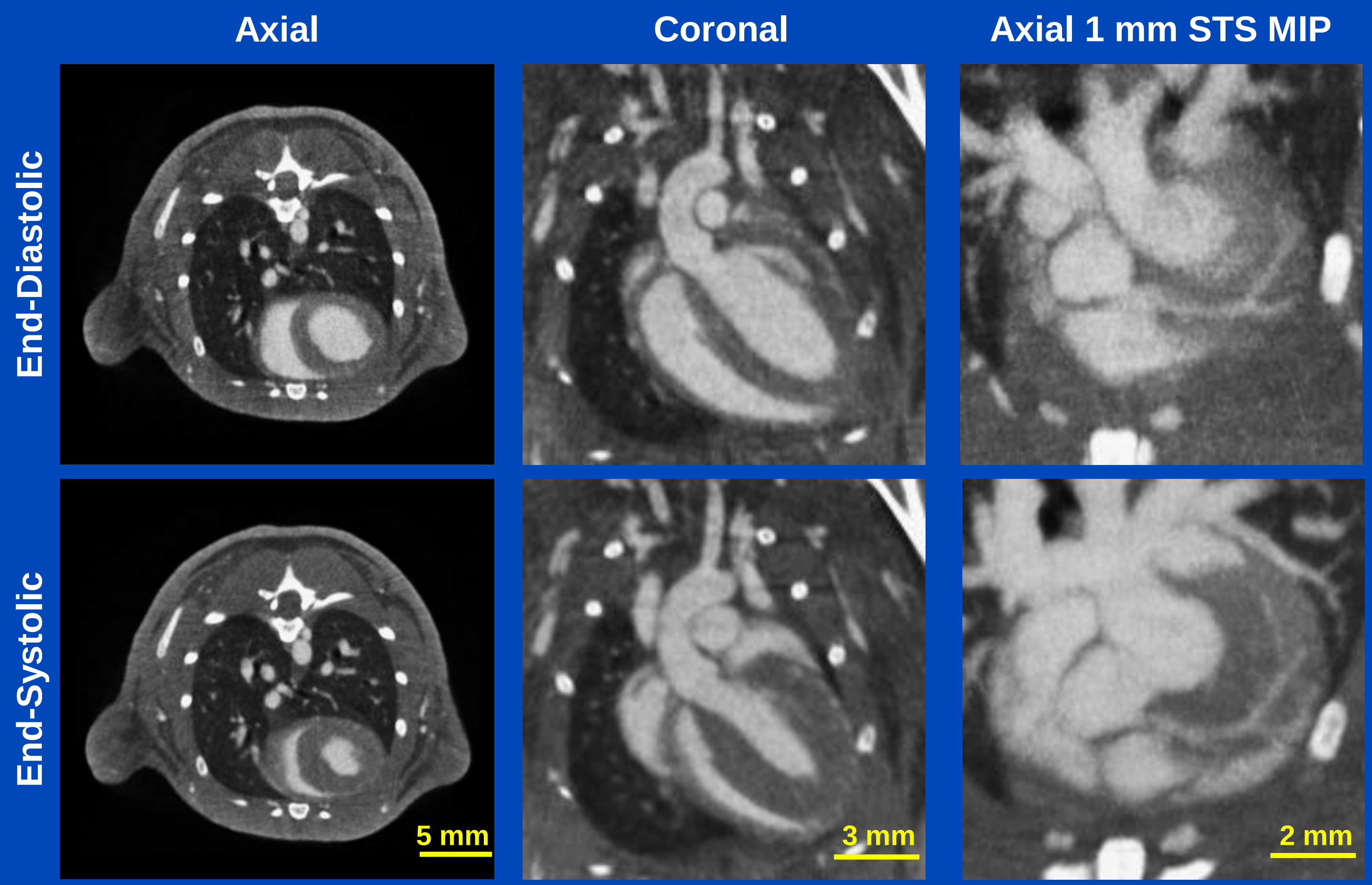


C/W=200 HU/600 HU

Clinical data courtesy of Stephan Achenbach.

Coronary Micro-CT

4 respiratory phases, Δr=25 %, 10 cardiac phases, Δc=10 %



C/W=0 HU/500 HU

Summary

- We designed a novel high-throughput micro-CT.
- The system allows for in-vivo small animal imaging with high temporal and high spatial resolution.
- The short scan times of 1 minute or less allow for the imaging of large cohorts.
- Radiation dose is reduced using sophisticated iterative reconstruction and motion compensation methods.
- The system allows for the visualization of coronary arteries in-vivo.
- Future steps will involve the integration of a photon-counting detector.

Thank You!

This presentation will soon be available at www.dkfz.de/ct.

This study was supported by the Deutsche Forschungsgemeinschaft (DFG) under grant SA 2771/1-1.

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

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