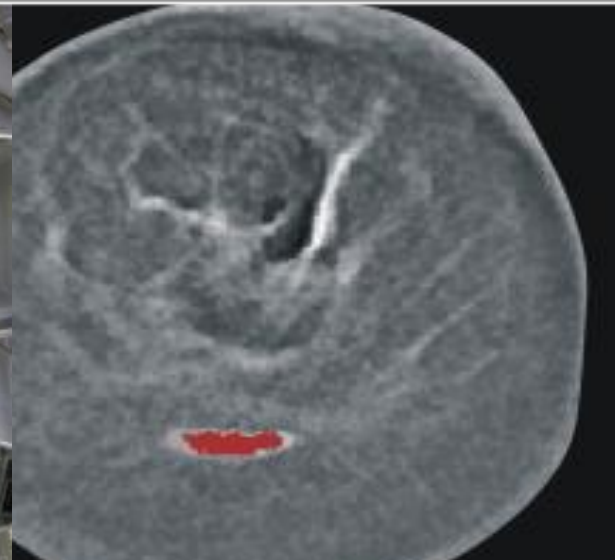


3D Ultrasound Tomography for Breast Cancer Diagnosis

N. V. Rüter, M. Zapf, T. Hopp and H. Gemmeke

INSTITUTE FOR DATA PROCESSING AND ELECTRONICS



Karlsruhe Institute of Technology



Campus South
Technical University



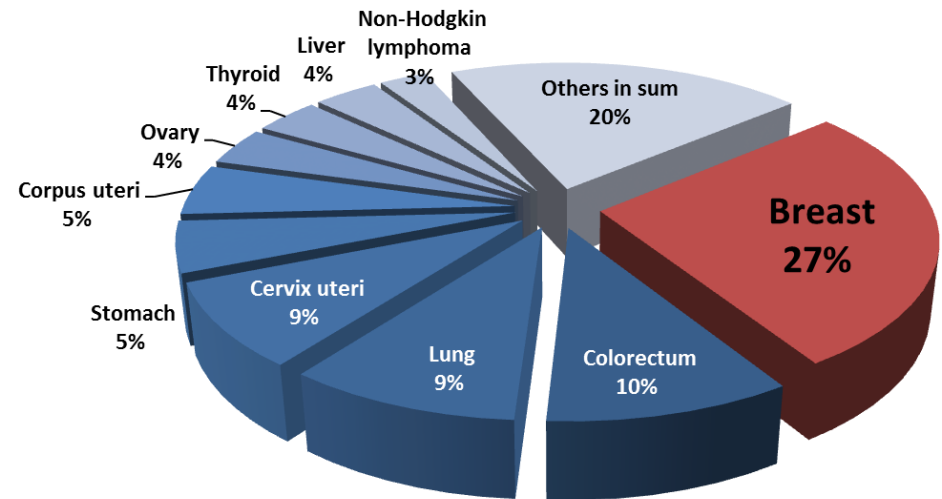
Campus North
Helmholtz Research Center



University of Karlsruhe and Helmholtz Research Center
Karlsruhe

Breast cancer

- Most common cancer of women in western world (every 10th woman)



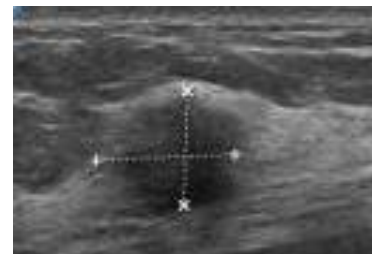
WHO cancer statistics 2012 (GLOBOCAN 2012)

- Challenge: Early diagnosis

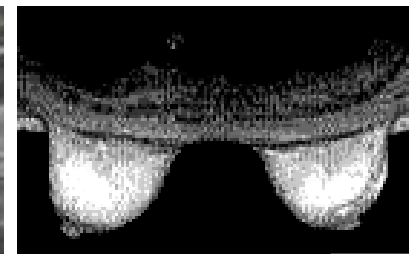


X-ray mammography

Screening



Sonography



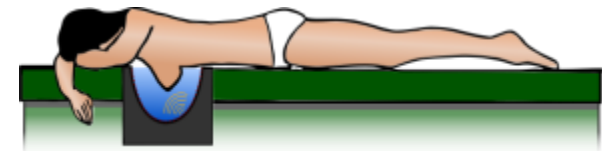
MRI

Symptomatic patients

What is USCT?

Basic idea

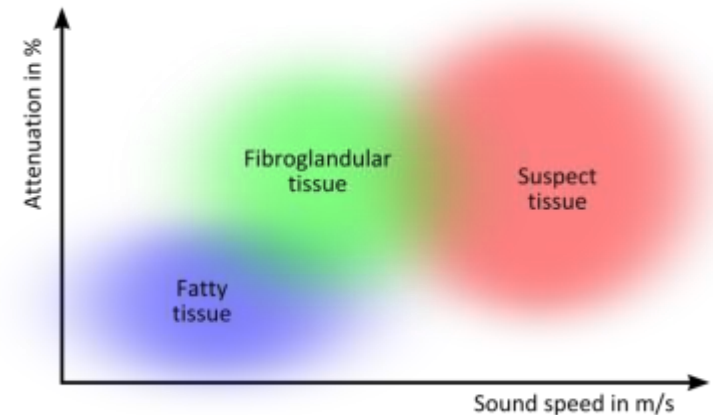
- Surround object with (unfocused) ultrasound transducers in a fixed setup



Breast imaging in fixed setup

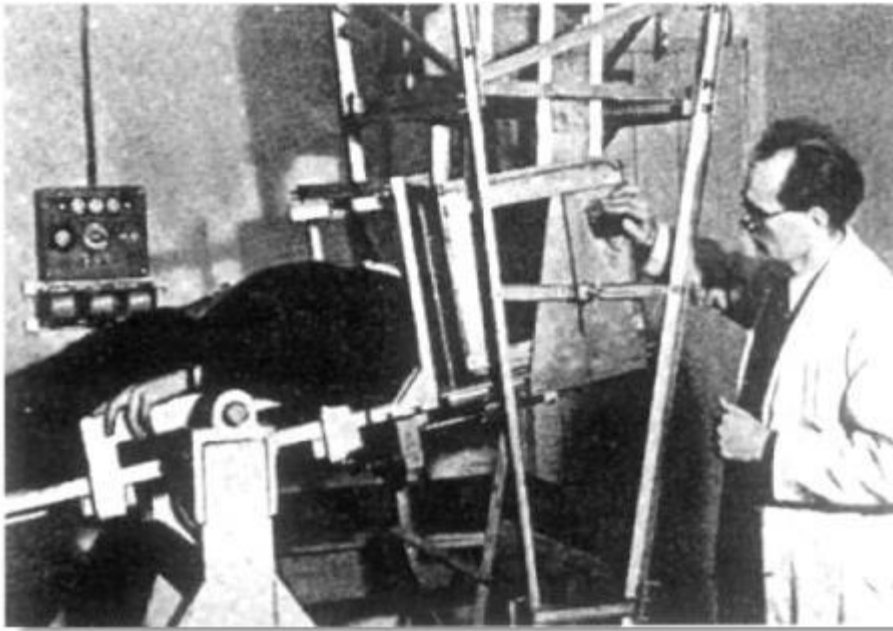
Diagnostic value

- Reproducible 3D images with ultrasound
- Images three modalities concurrently:
 - **Reflection**
High quality “B-scans”
 - **Speed of sound and attenuation**
Quantitative information



Simplified from Greenleaf et al., 1981

The beginnings



First attenuation imaging (Dussik, 1946): Not so successful imaging of brain ventricles



First "USCT" device (Holmes et al., 1954): Slice image of the neck, compounding device

Current state of the art

2D ring systems:

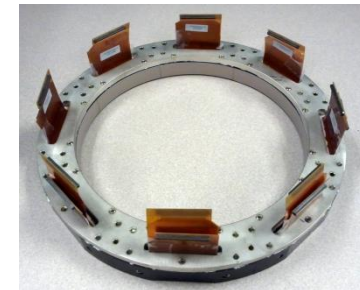
- Kamanos Cancer Institute (Delphinus Medical Technologies)
- University of Southern California (MastoScopia)

2,5D planar array system:

- University of Utah (TechniScan)

Problem:

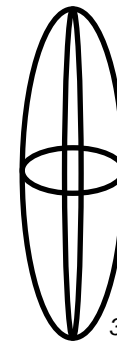
- Anisotropic 3D point spread function



Sonovue



CVUS



3D PSF 2D system



KIT 3D USCT system

3D aperture

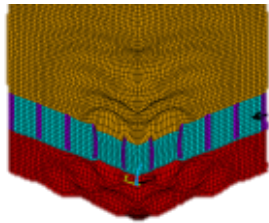


Vision for 3D USCT ...

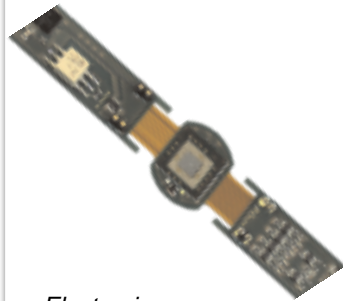
- as harmless as diagnostic ultrasound
- as affordable as X-ray mammography
- as good as MRI

Challenges

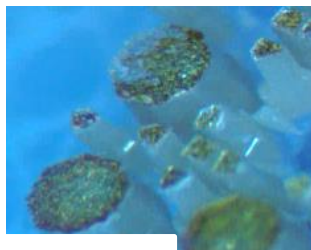
Transducer development



Transducer design



Electronics



Transducer

Parallel data acquisition



Parallel channels

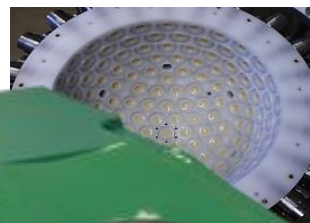


Electronics



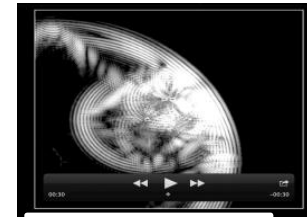
Digital processing

Clinical applicability



Biocompatibility

3D reconstruction



Ultrasound physics



Algorithms



Acceleration

Medical analysis

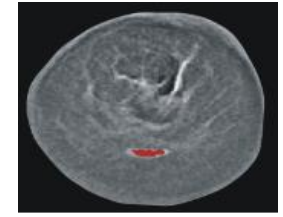
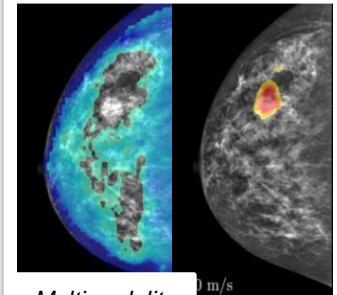


Image fusion



Multimodality



Analysis

How does it work? Ultrasound and soft tissue

- Wave equation for inhomogeneous water like materials:

$$\nabla^2 p(\vec{x}) + k_0^2 \left(\sqrt{\frac{K_0}{\rho_0}} \sqrt{\frac{\rho(\vec{x})}{K(\vec{x})}} + i \frac{\mu(\vec{x})}{k_0} \right)^2 p(\vec{x}) - \frac{1}{\rho(\vec{x})} \nabla \rho(\vec{x}) \nabla p(\vec{x}) = 0$$

- Three physical properties influence wave propagation:

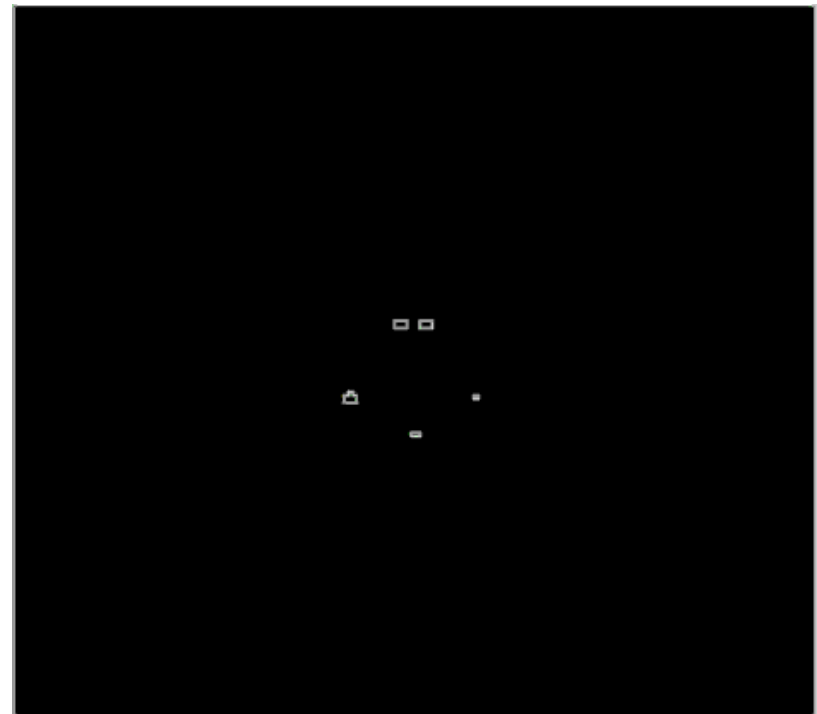
- Density ρ , compressibility K and absorption μ

- Typically reconstructed in USCT:

- qualitative acoustical impedance $Z = \rho c$,

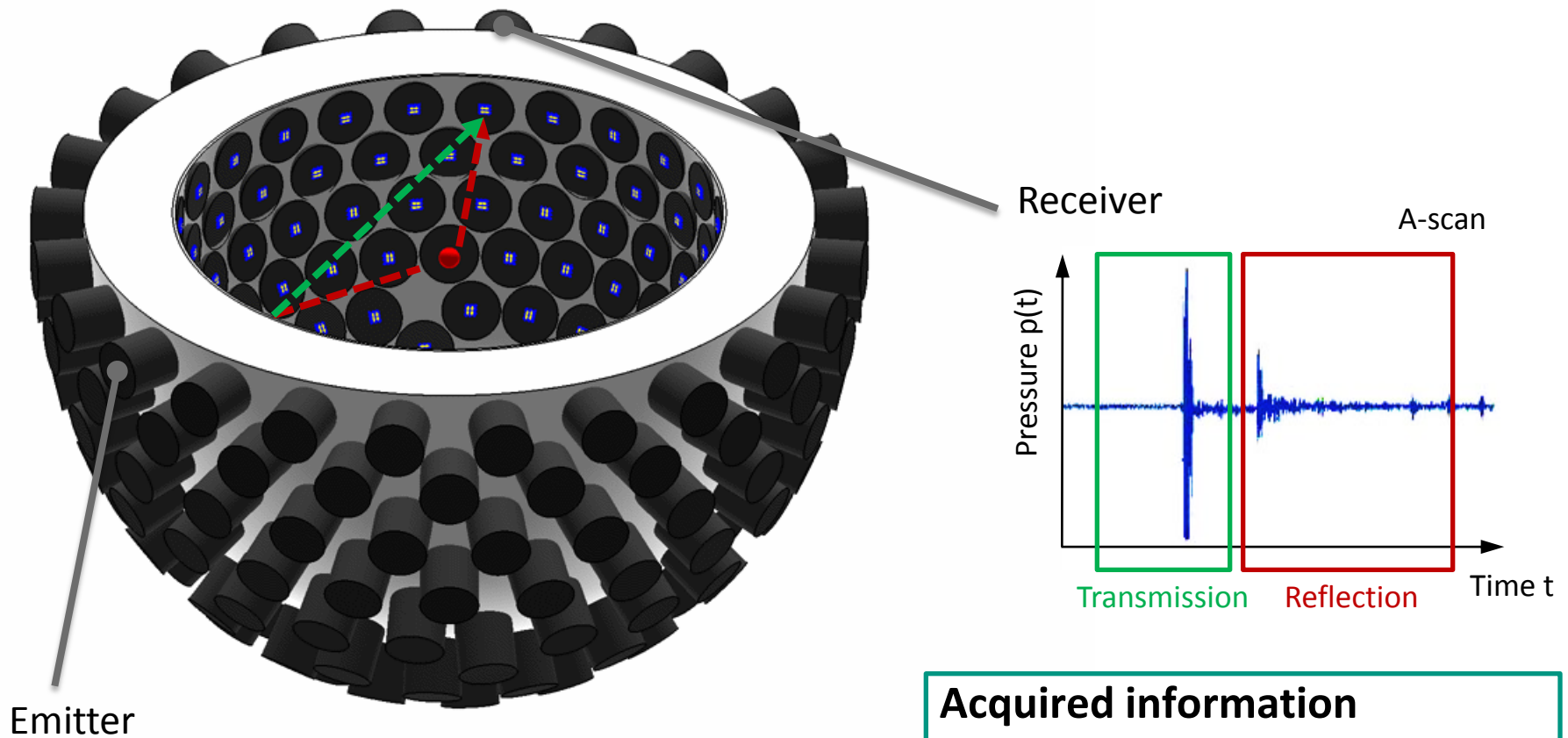
- speed of sound $c = \sqrt{\frac{K}{\rho}}$,

- attenuation $\alpha = \mu + \mu_s$



2D simulation of interaction with point scatterers

How does it work? Data acquisition

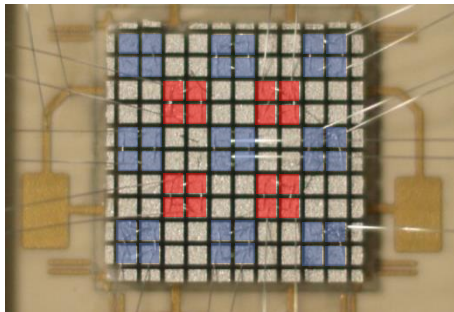


Acquired information

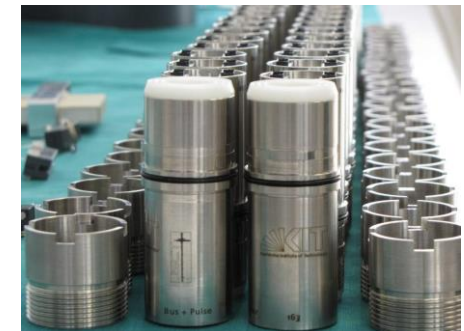
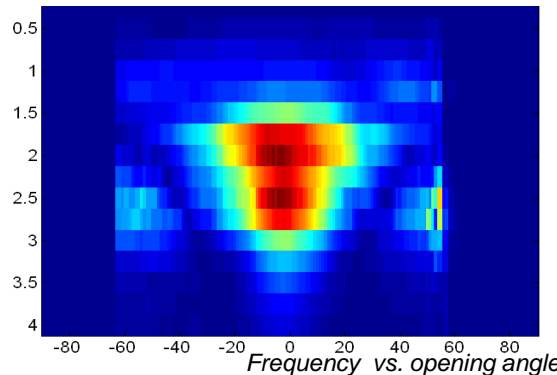
- Sound speed
- Attenuation
- Reflection

Transducer array systems (TAS)

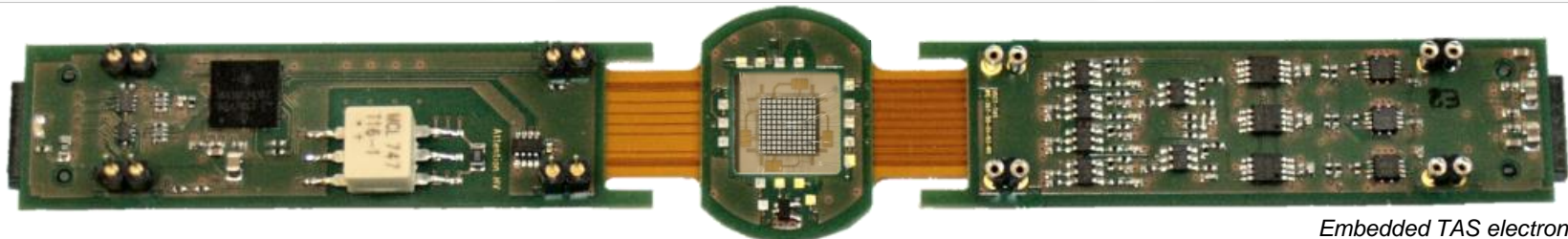
Center frequency (bandwidth)	2.5 MHz (1.5 MHz)
Opening angle	38° at -6dB ($\pm 1.5^\circ$)
Structured Piezo composites	0.64 mm ²
Emitters / receivers per TAS	4 emitters and 9 receivers



Emitters (red) and receivers (blue) per TAS



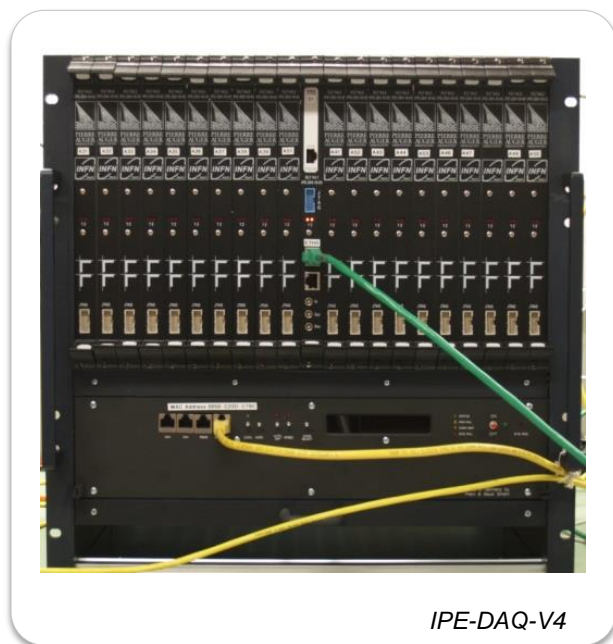
TAS



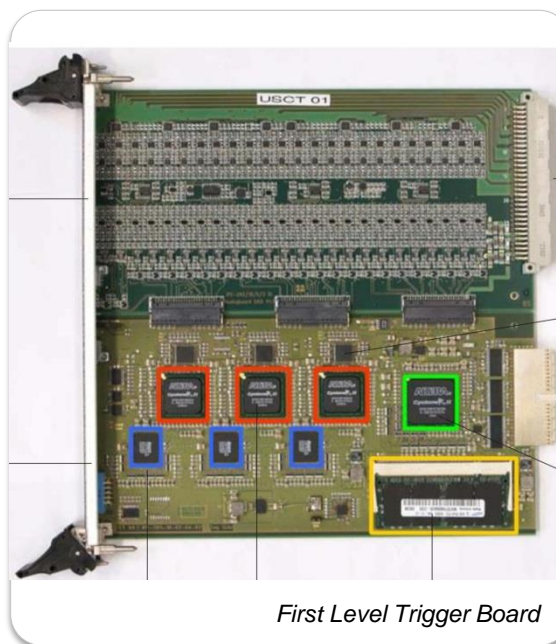
Embedded TAS electronics

Data acquisition system

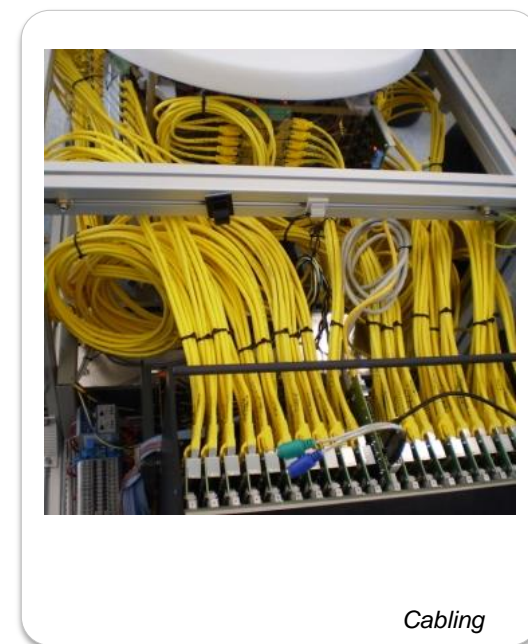
Number channels	480
AD conversion	12 Bit @ 20 MHz
Memory	80 GB
Measurement time	10 s – 6 min



IPE-DAQ-V4



First Level Trigger Board



Cabling

Listen to USCT data

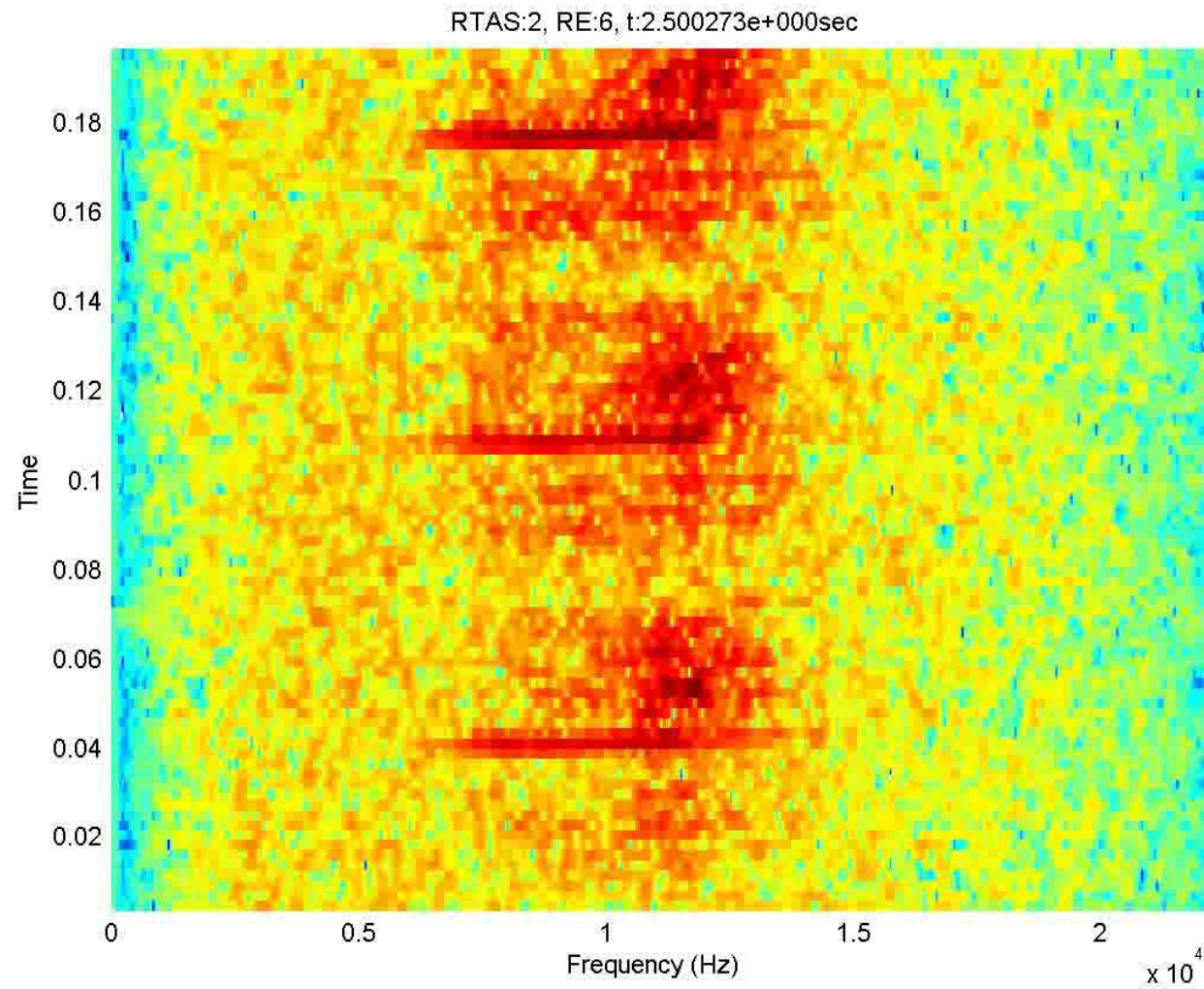
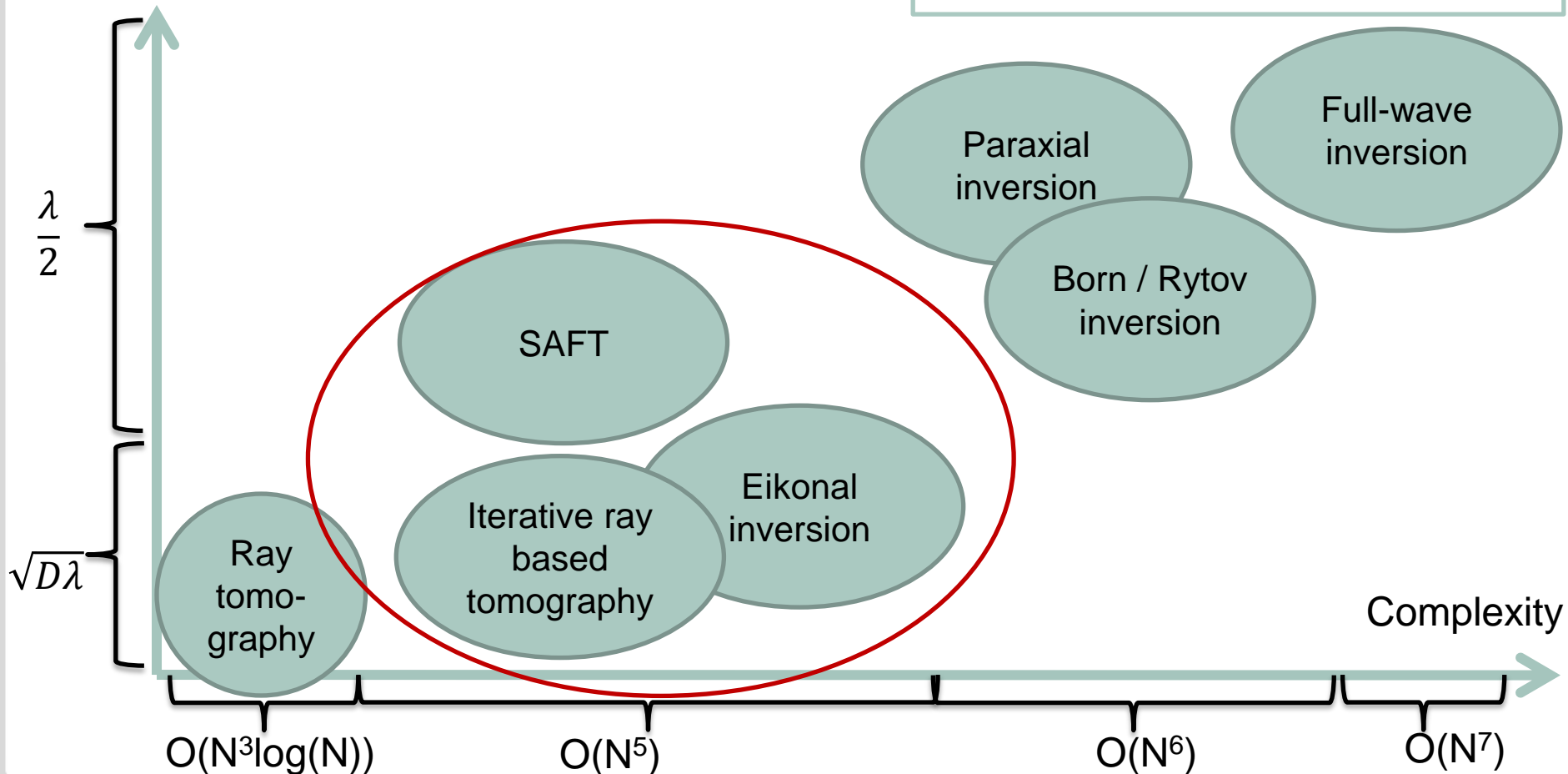


Image reconstruction

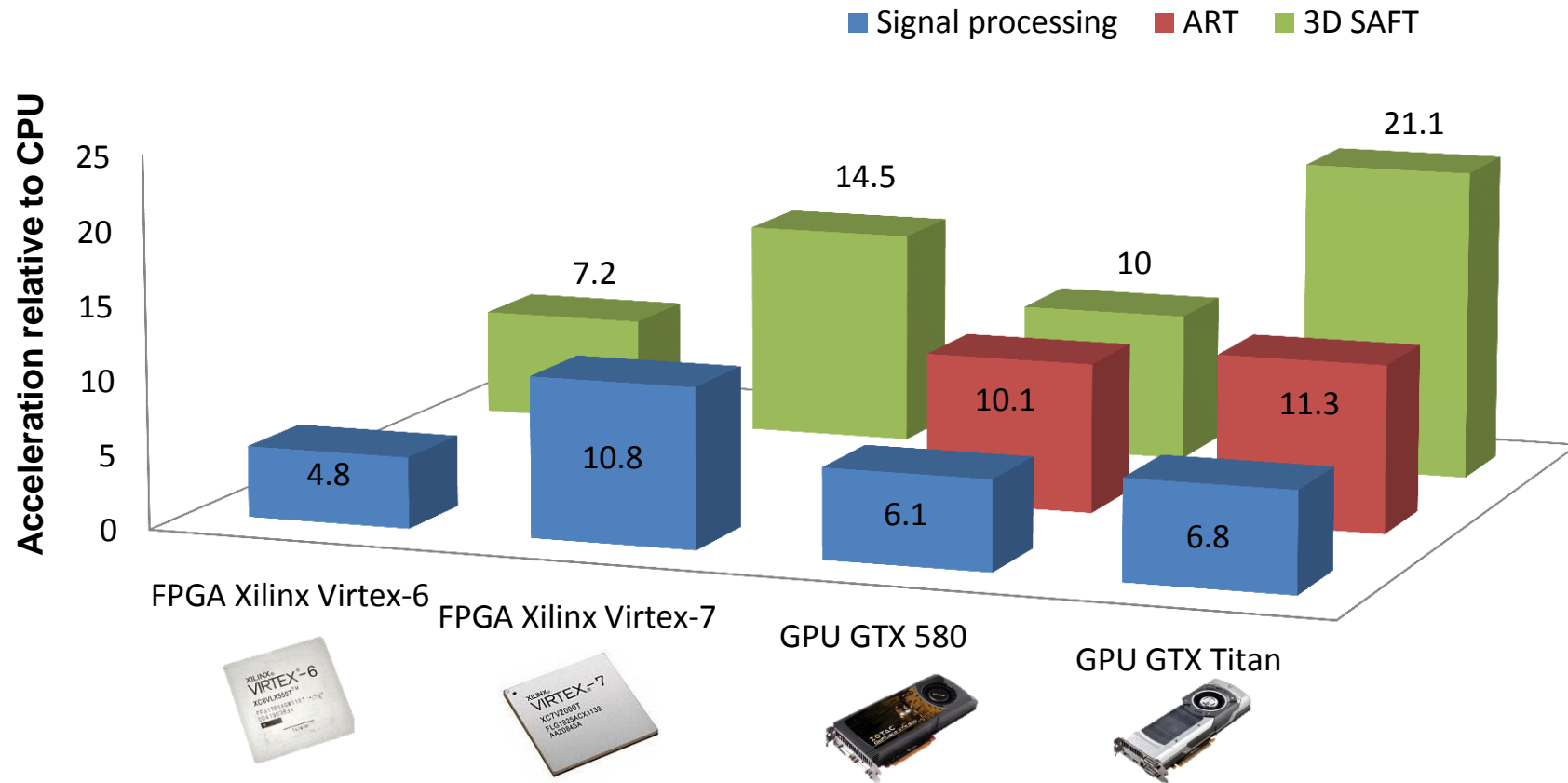
Resolution/accuracy

Example:

$N^3 = 1000^3$ voxels from N^2 A-scans



Acceleration of signal and image processing



GPU server with 8 GPU GTX Titan: 3D SAFT in 16 min

Clinical study Jena



- Universitätsklinikum Jena
(Prof. W. A. Kaiser)

- Aim: Test device in clinical setting
→ prepare larger study

- 10 patients, all with suspicious lesions
 - 2 implants
 - 4 cancers
 - Papilloma, fibroadenoma, mastopathy, cyst

- End of clinical trial: September 2014



Prof. Kaiser in Jena

Patient 1: Healthy

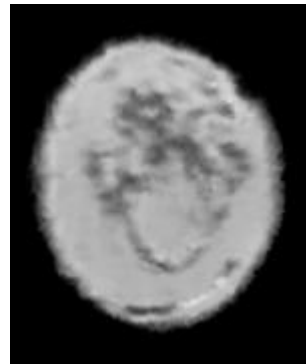


Coronal plane

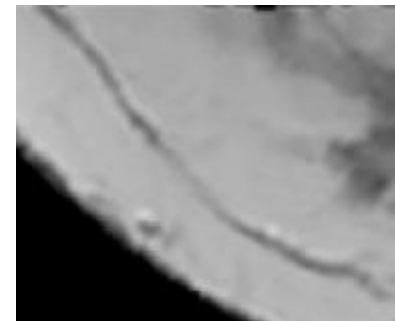


Transversal plane

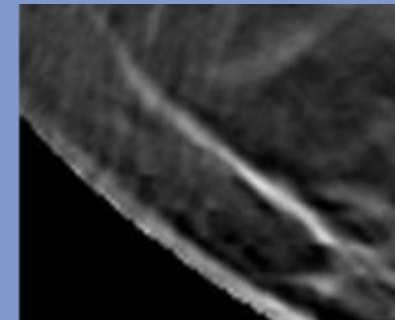
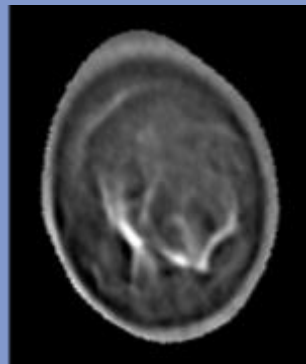
Registered MRI
T1-weighted



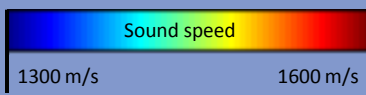
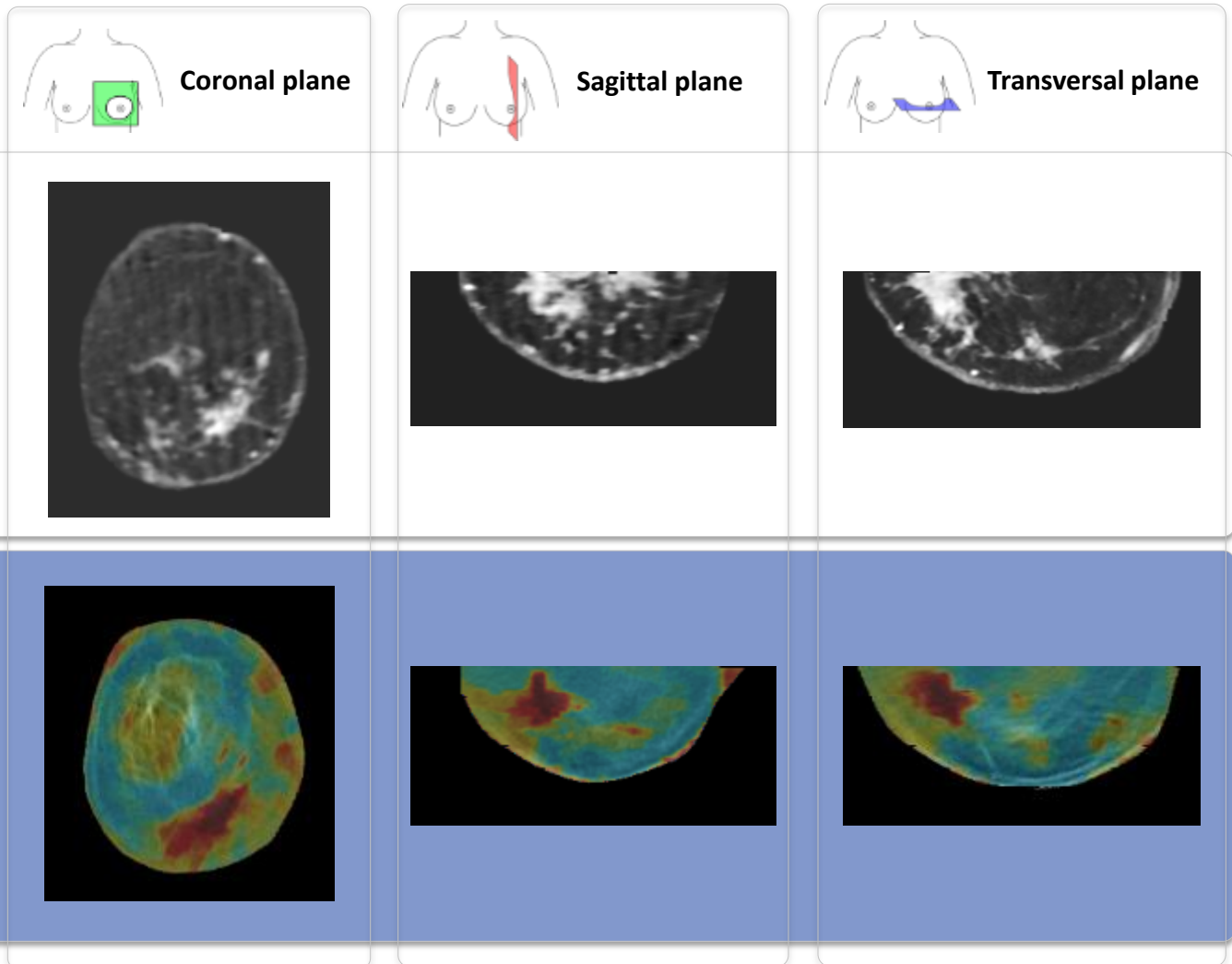
(detail view)



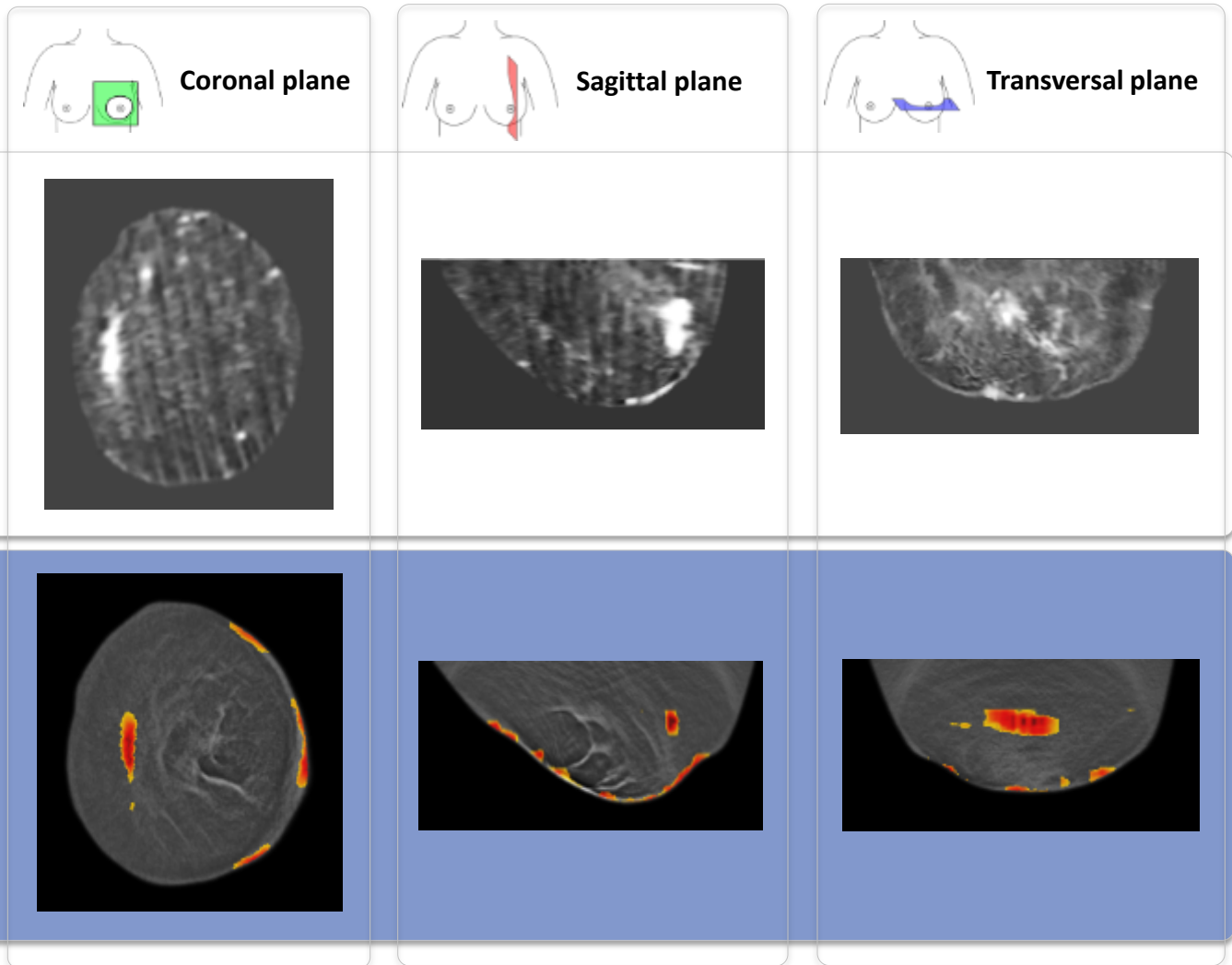
USCT
Reflectivity



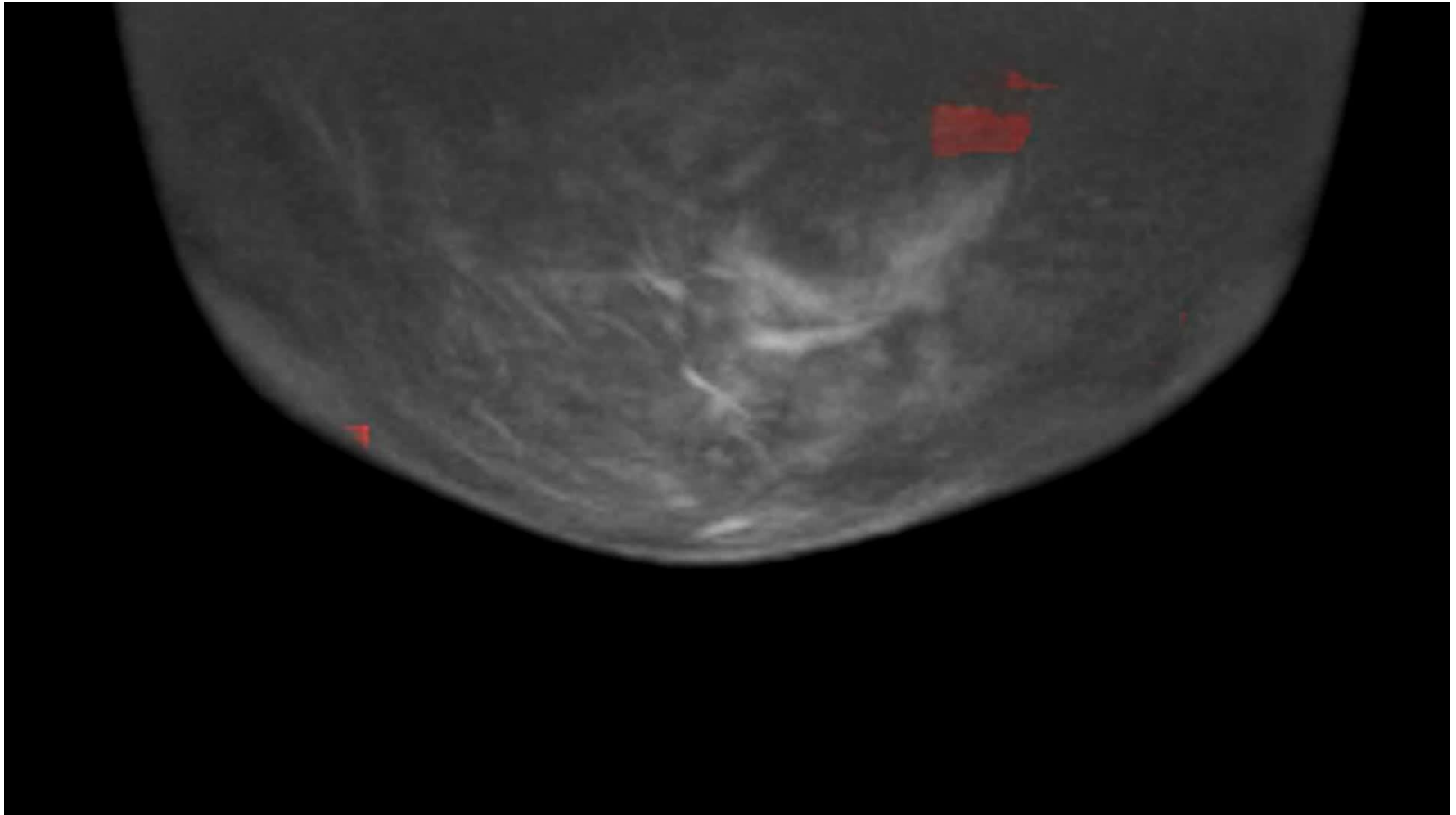
Patient 2: Inflammatory carcinoma



Patient 3: Multicenter carcinoma



3D data



Summary pilot study in Jena

- 3D USCT was applicable in clinical setting (~ 1 patient/h)
- First images very were encouraging
- Speed of sound seem to give best cancer detection

- Mean patient movement: 3 mm
- Breast positioning critical

Major system updates:

- Data acquisition time: 8 min → 6 min
- New patient interface: + 1 cm



USCT in Jena



Image analysis

Clinical study Mannheim

- Universitätsmedizin Mannheim
(Prof. S. Schönberg)
- Aims of study
 - Does USCT give comparable diagnoses to MRI?
 - Analyze different lesion types
- 200 patients
- Start: October 2015

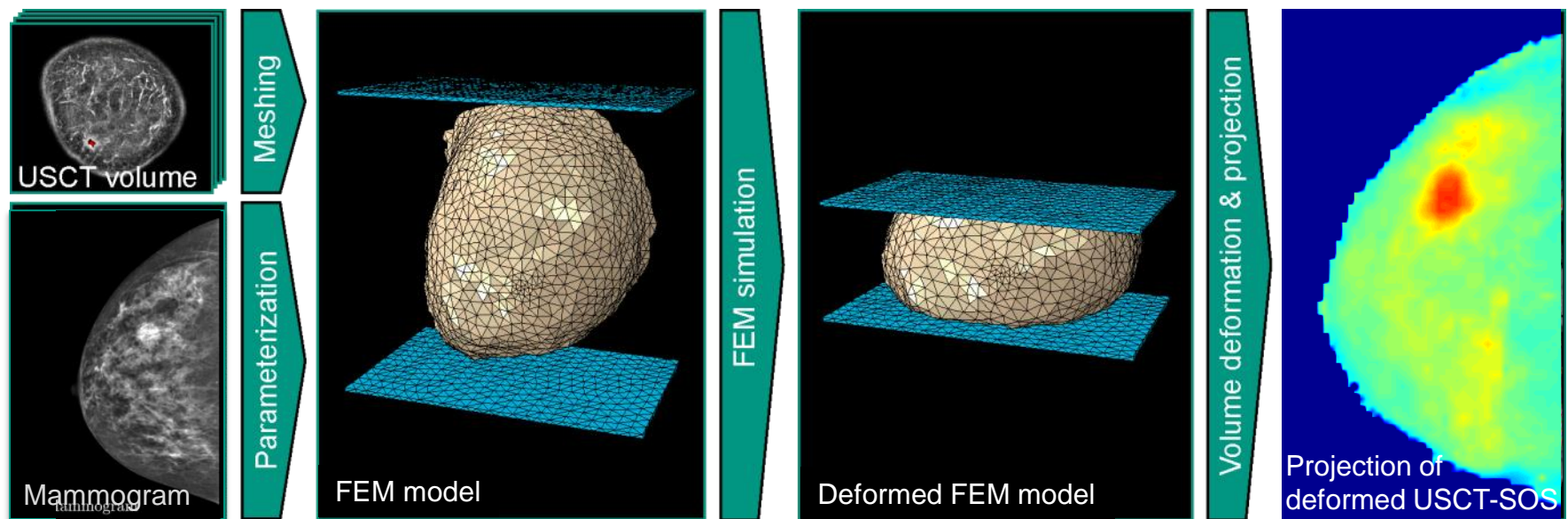


USCT in Mannheim

Multimodal imaging and classification

- Supports comparability of USCT to MRI and X-ray mammography
- Enables automatic analyses

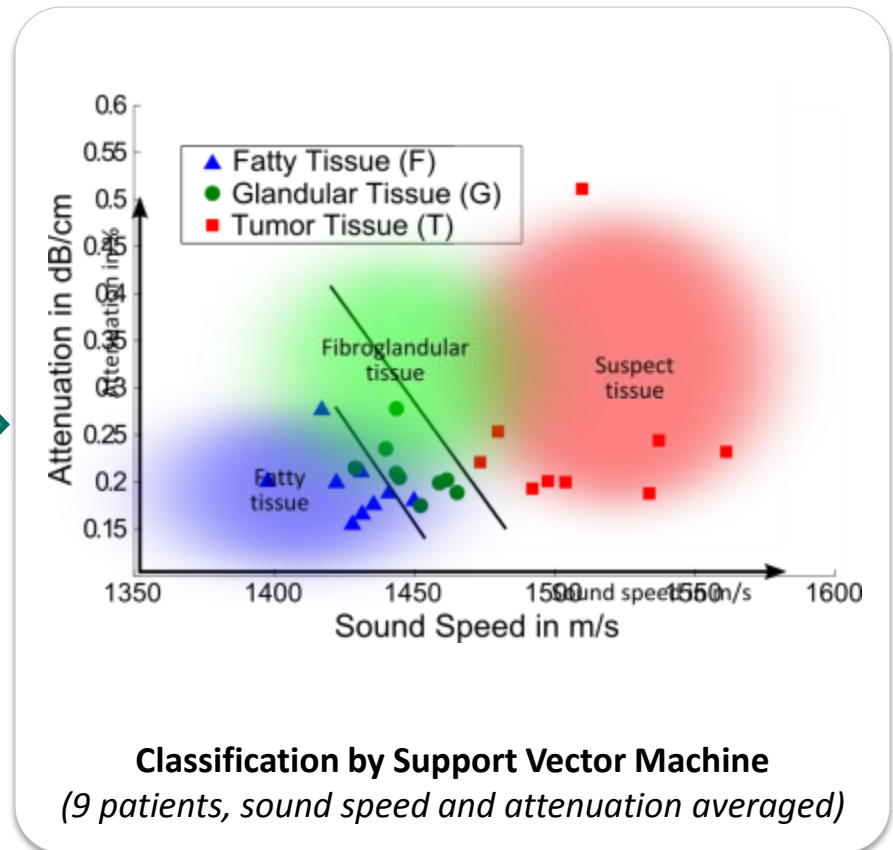
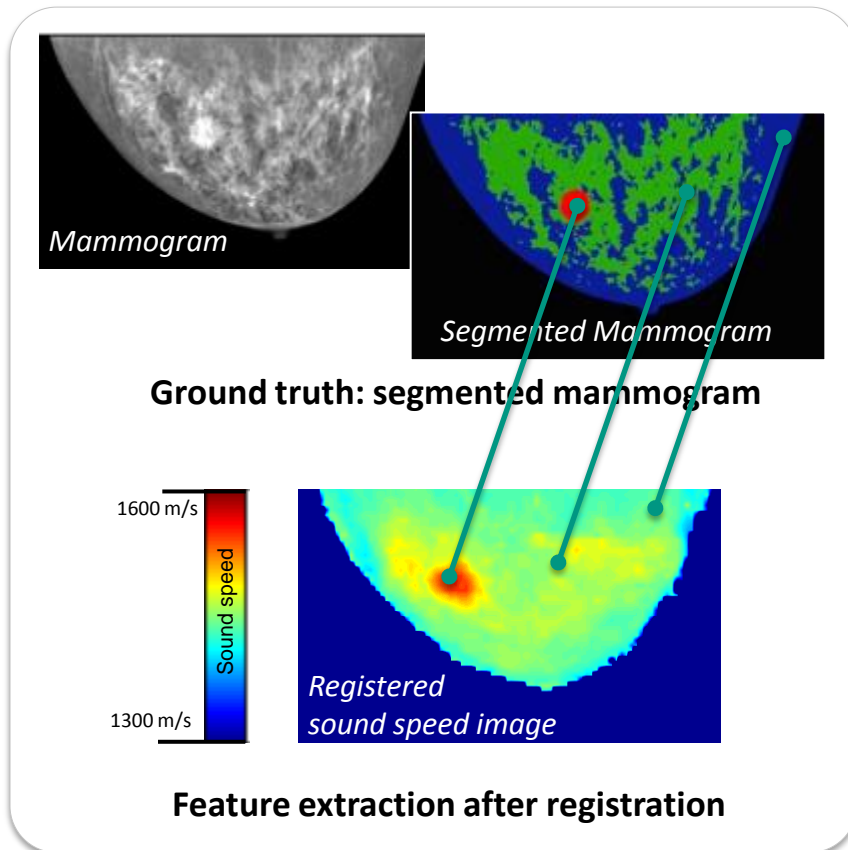
- Example: USCT to X-ray registration



Data from Karmanos Cancer Institute

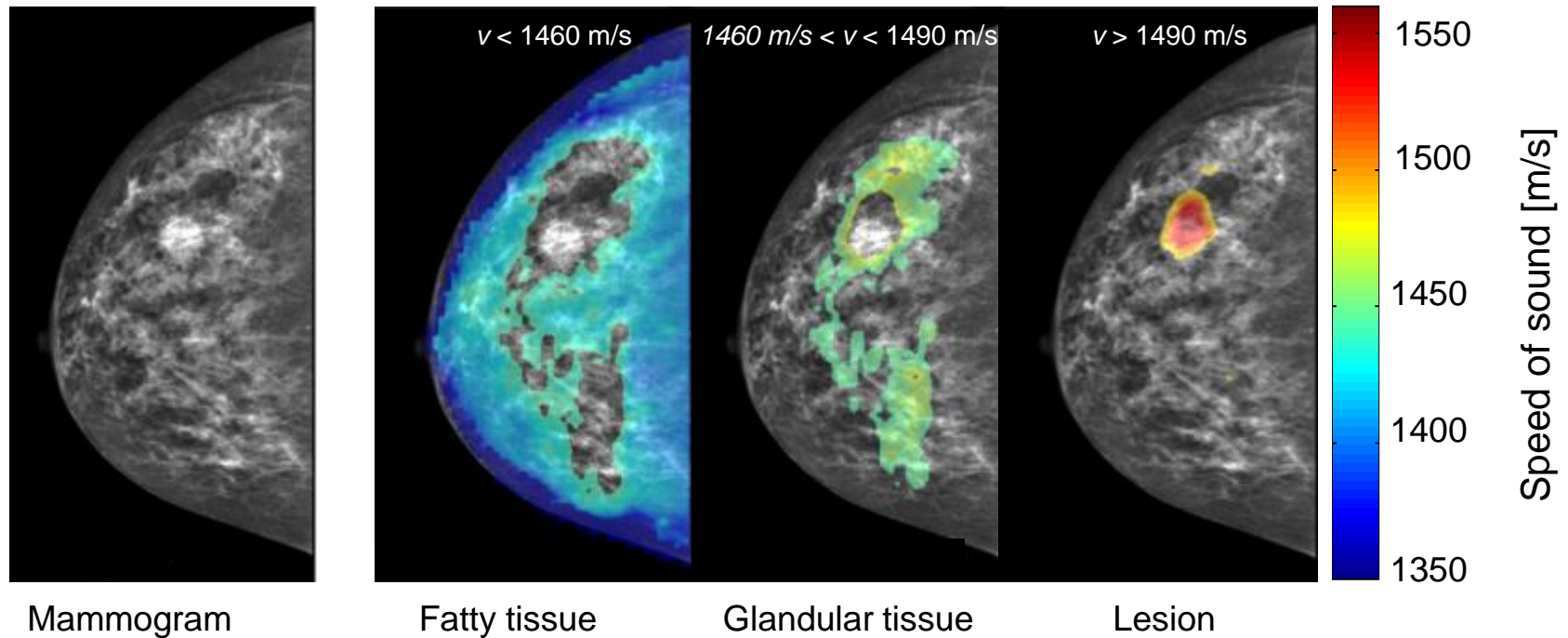
Multimodal imaging and classification

■ Can we reproduce Greenleaf's results?



Data from Karmanos Cancer Institute

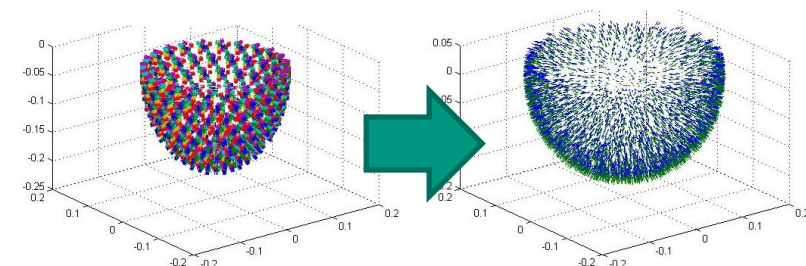
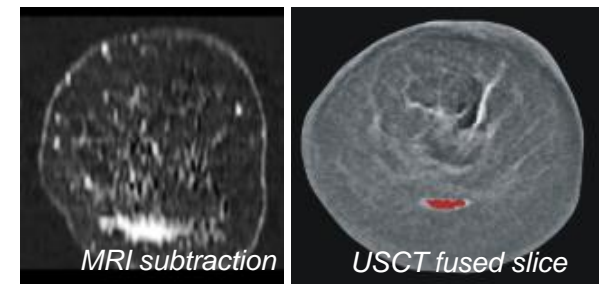
USCT tissue classification in X-ray mammogram



Data from Karmanos Cancer Institute

Summary

- USCT is a new imaging method for at early breast cancer diagnosis
- KIT 3D USCT:
first clinically applicable full 3D USCT
- First pilot study successful,
second study started
- 3D USCT III:
 - Faster DAQ
 - Optimized image quality



Thank you!

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Deutsche Forschungsgemeinschaft (DFG)



3D USCT in Mannheim

- Algorithms / Imaging / Image Processing
N. V. Ruiter, M. Zapf, T. Hopp, W.Y. Tan, H. Gemmeke, et al.
- Hardware acceleration
E. Kretzek, M. Balzer, et al.
- Transducers
M. Zapf, H. Bouquet, et al.
- DAQ and Hardware
D. Tscherniakhovski, A. Menshikov, et al.
- Design and Mechanics
L. Berger, B. Osswald, T. Piller, W. Frank, et al.

Contact: nicole.ruiter@kit.edu