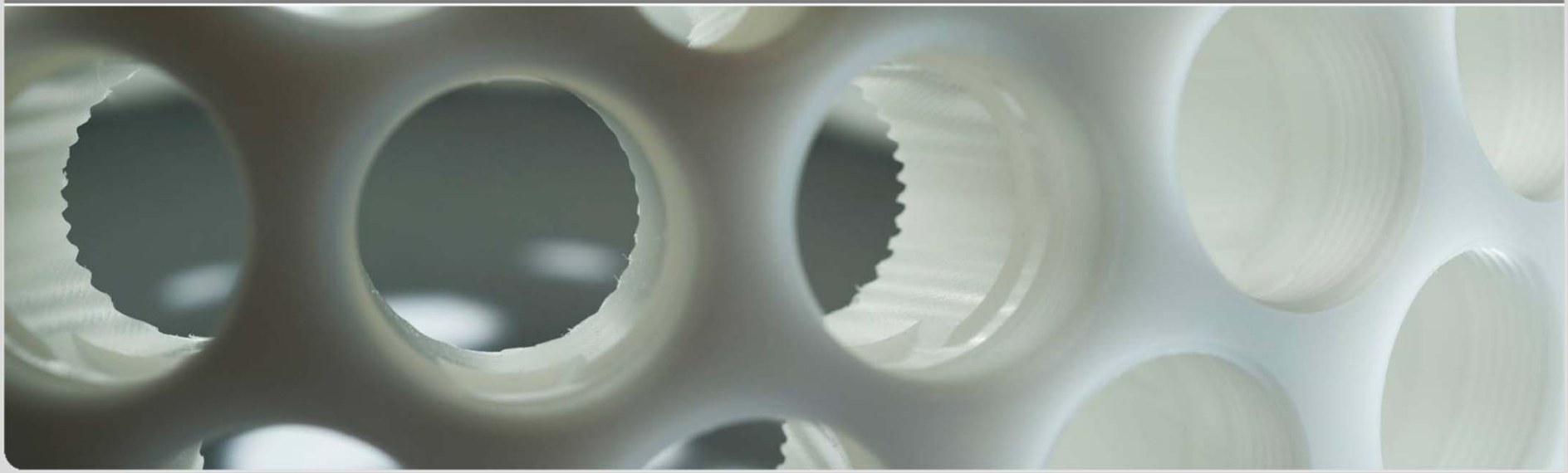
Karlsruhe Institute of Technology

3D USCT at KIT

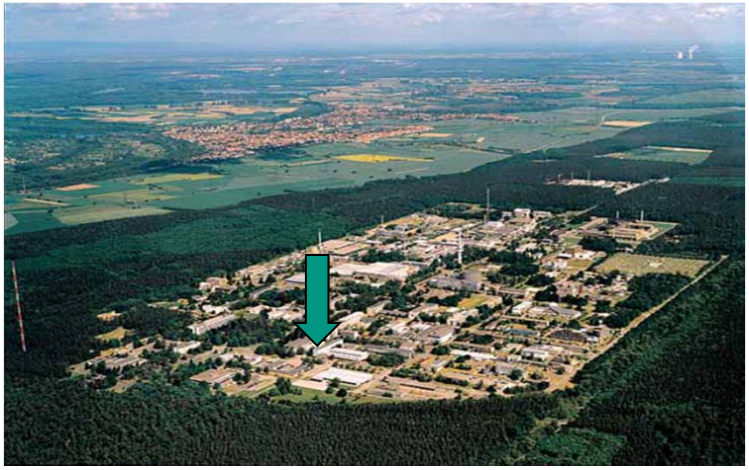
N.V. Ruiter

INSTITUTE OF DATA PROCESSING AND ELECTRONICS



Karlsruhe Institute of Technology

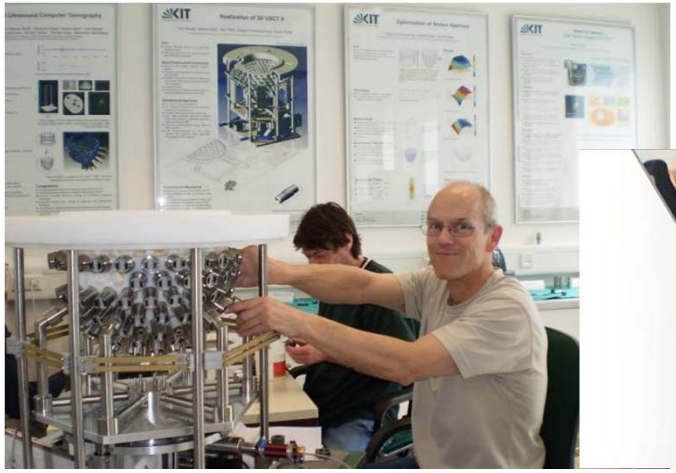
Campus South
Technical University



Campus North
Helmholtz Research Center

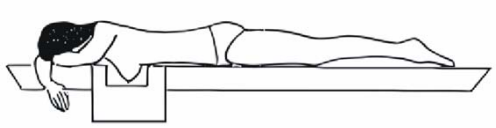
University of Karlsruhe and Helmholtz Research Center Karlsruhe currently joined
8,500 employees, 20,000 students, 364 professors

Institute for Data Processing and Electronics



Ultrasound Computer Tomography

- Since > 30 years
- Basic idea:
  Surround object with ultrasound transducers in fixed setup

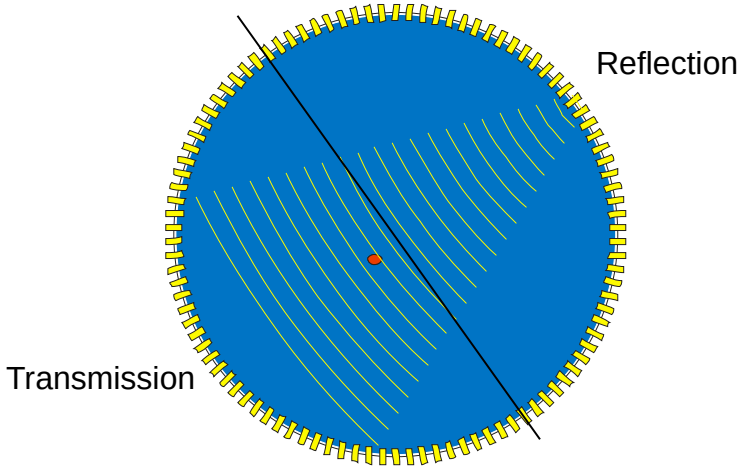


Breast imaging in fixed setup

- Long term goal:
  Early breast cancer diagnosis
- Vision: diagnostics at $\varnothing \leq 5$ mm?
  (Approx. 5% probability for metastases)

3D USCT: Motivation and Basic Concepts

- Many USCT systems use:
  - Surrounding aperture:
    - 3 “modalities” are acquired in one step
  - Unfocussed data acquisition
    - “Post beam forming“:
      Optimal focus in image reconstruction
    - Synthetic aperture focusing technique (SAFT)

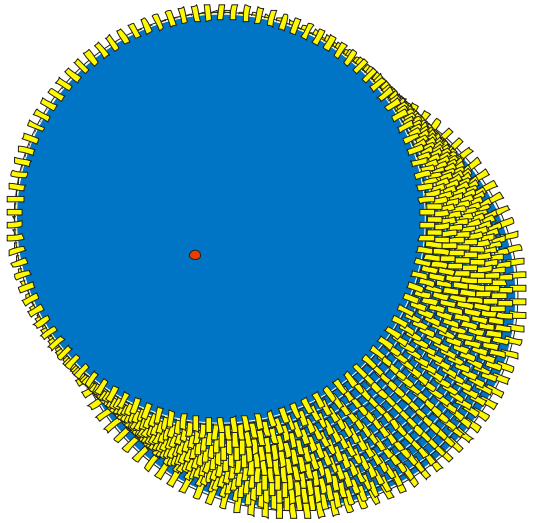


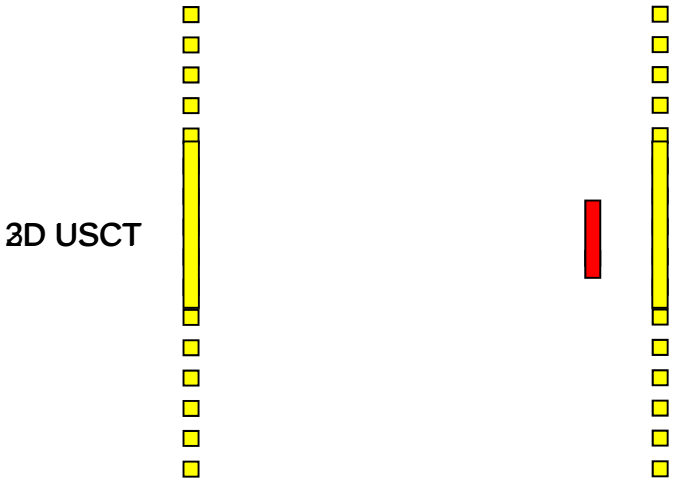
- Usually “hybrid approaches”:
  2D SAFT, focused in elevation on emission and reception

3D USCT: Motivation and Basic Concepts II

- Surround object in 3D
- 3D unfocussed transducers

- Advantages:
  - Optimal focus in 3D
  - Fast data acquisition possible

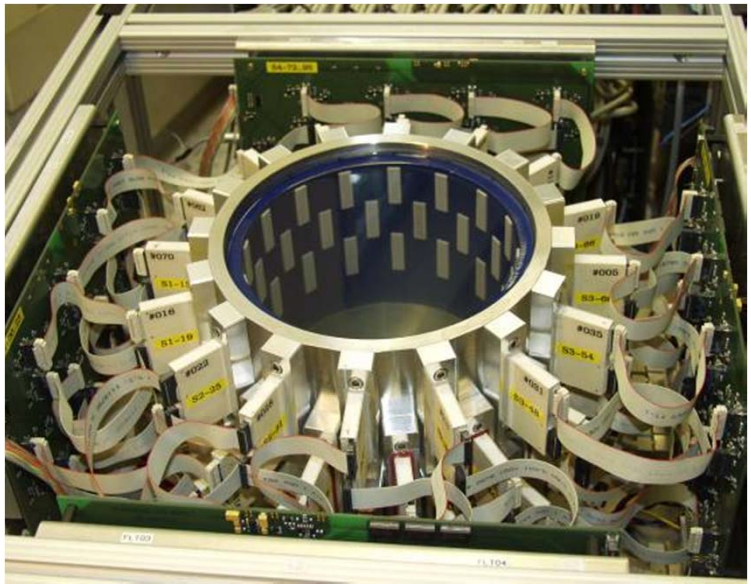


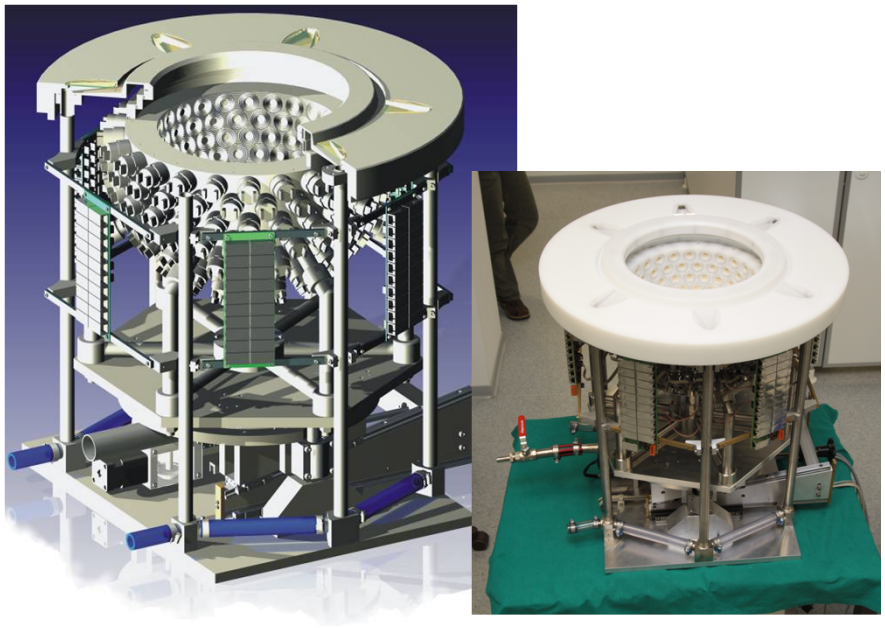


3D USCT: Challenges

Challenges	*Solution strategies 3D USCT Generation I and II*
Nyquist > 100 000 transducers	„Sparse Aperture“ approach with 6 x 2 000 transducer positions (Accept artifacts and suppress)
Cheap, reproducible unfocussed transducers	In house designed transducers, automatic batch fabrication, dedicated channels, integrated amplification
3D aperture?	Feasible cylinder aperture and optimized semi-ellipsoidal aperture
Large amount of data at high data rates	Powerful DAQ Hardware and dedicated powerful DAQ Hardware
Demanding image reconstruction	Signal and image processing in Grid and in Hardware

Currently: “In-between Systems”





- 3D USCT I
  - Cylindrical aperture
  - 1920 transducers (12 000 pos.)
  - 3.5 million A-Scans ~ 20 GB
  - Proof of concept with static phantoms
- 3D USCT II
  - Optimized semi-ellipsoidal aperture
  - Rotation and translation
  - Powerful DAQ hardware: 6 s - 2 min
  - Imaging of living tissue

Image Reconstruction at KIT

- 3D SAFT in spatial domain
  - Critical: Phase aberration correction
  - Grating lobe suppression
  - Projection kernel optimized:
    ~200 MVoxel/s

$$f(\vec{x}) = \sum_{(i,k)} T(A_{(i,k)}(\frac{\left\|\vec{x}_i - \vec{x}\right\| + \left\|\vec{x} - \vec{x}_k\right\|}{\hat{c}(\vec{x}_i, \vec{x}_k, \vec{x})}))$$

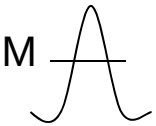
f: image
T: preprocessing
A: A-scan
c: speed of sound
i: number of emitter
k: number of receiver

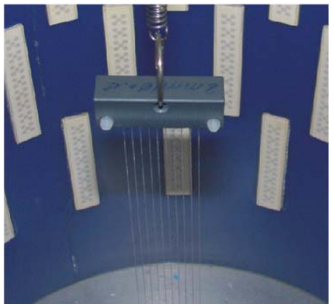
- Transmission tomography
  - Speed of sound and attenuation volumes
  - 3D USCT I:
    FDK Algorithm (cone beam CT)
  - 3D USCT II:
    Geometry independent methods, ART or pseudo polar Fourier with compressive sampling

SAFT Results with 3D USCT I

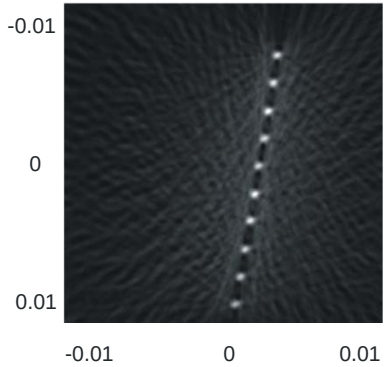
10 **nylon threads**,
Ø 0.2 mm

$$\mathrm{SDNR} = \frac{\mu_{\mathrm{FG}} - \mu_{\mathrm{BG}}}{\sigma_{\mathrm{BG}}} > 5$$

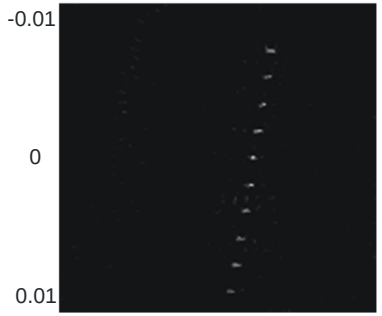
FWHM  ~ 0.2 mm



Adapted matched filter with Chirp:
SDNR 11.0
FWHM 0.62 mm

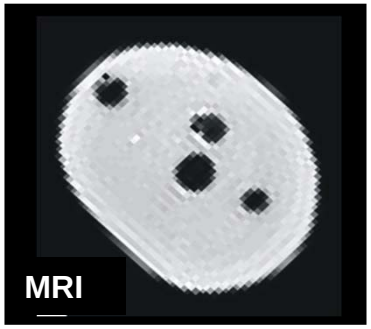


„SAFT 2“
SDNR 35.9
FWHM 0.24 mm

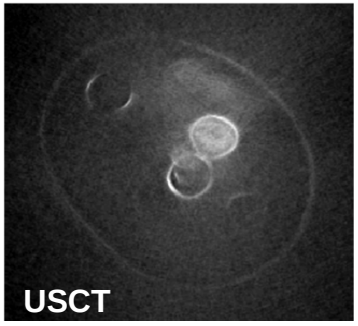


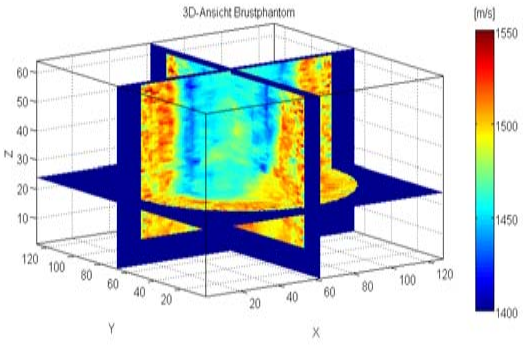
1 cm

Clinical breast phantom



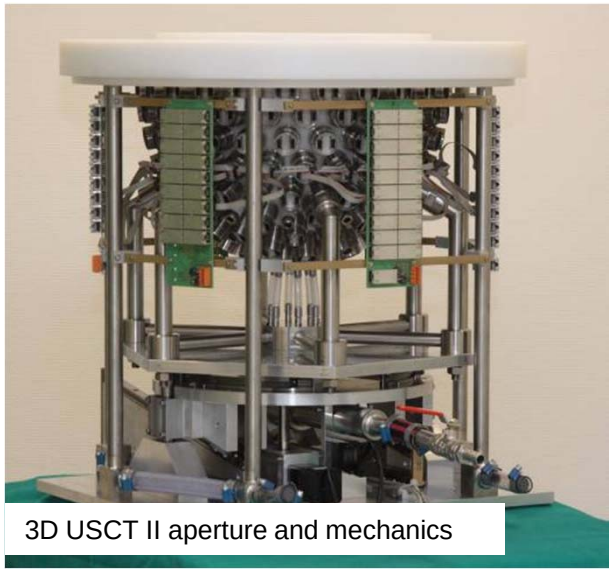
MRI slice with “cyst” and “cancer” mimicking lesions



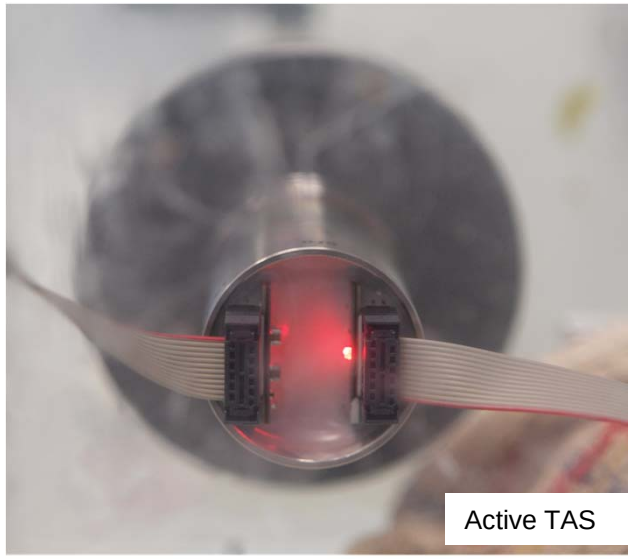


1 cm

Current Status 3D USCT II

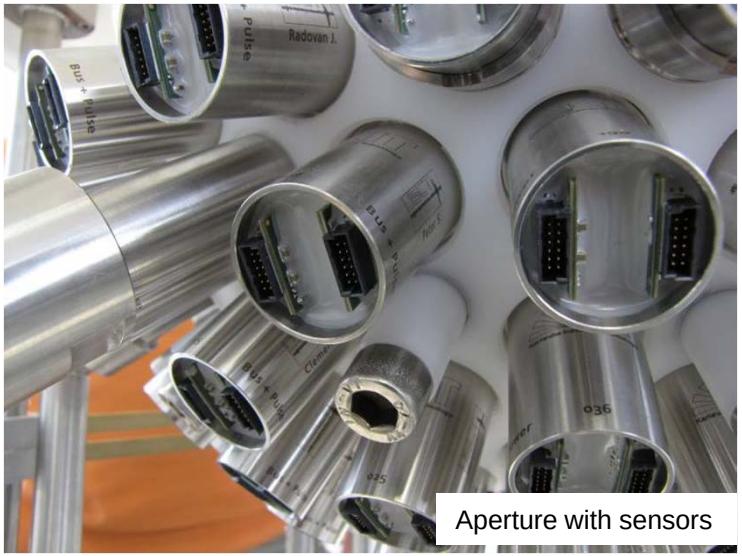


3D USCT II aperture and mechanics



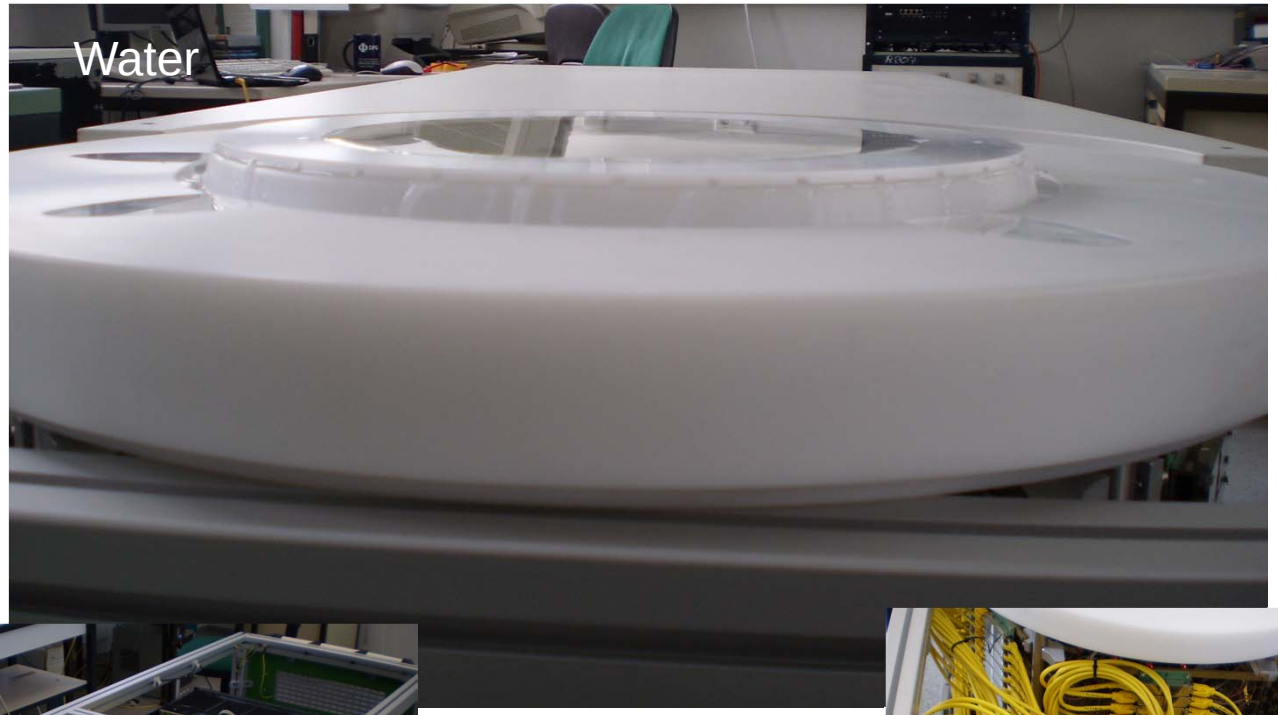
Active TAS

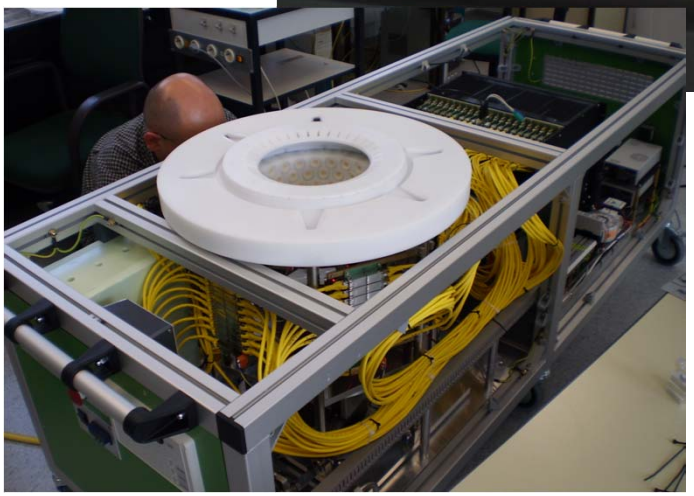
Finshed TAS



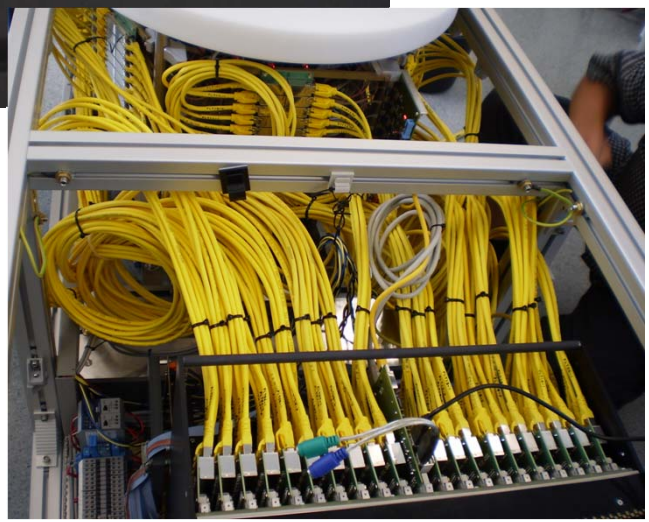
Aperture with sensors

Current Status USCT II





Wiring complete



Conclusion

- 3D USCT I
  - Feasible, if sparse aperture can be accepted
  - Sub-millimeter resolution possible
  - Acceptable contrast
- 3D USCT Generation II:
  - Aperture optimization: Semi-ellipsoidal aperture
  - New DAQ: DAQ time ~ 2 min
- Next step: Imaging living tissue

Patient bed

Thank you!

Karlsruhe Institute of Technology

Algorithms and Imaging
N. V. Ruiter, M. Zapf, R. Dapp, T. Hopp, H. Gemmeke, et. al.

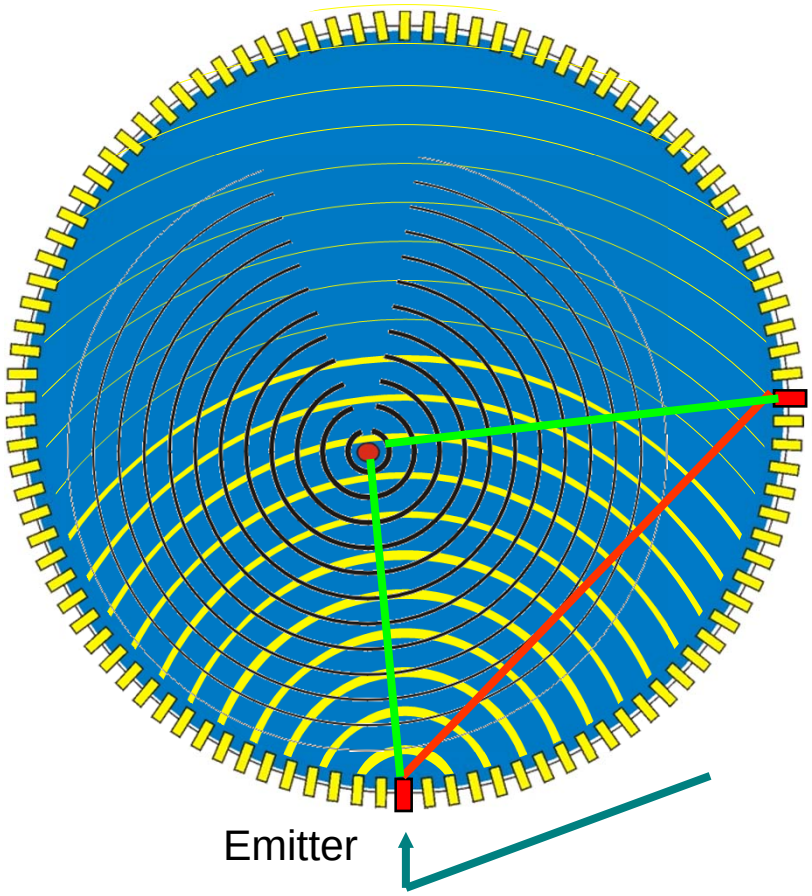
Grid Computing and HW Acceleration
M. Hardt, R. Stotzka, M. Birk, M. Balzer, et. al.

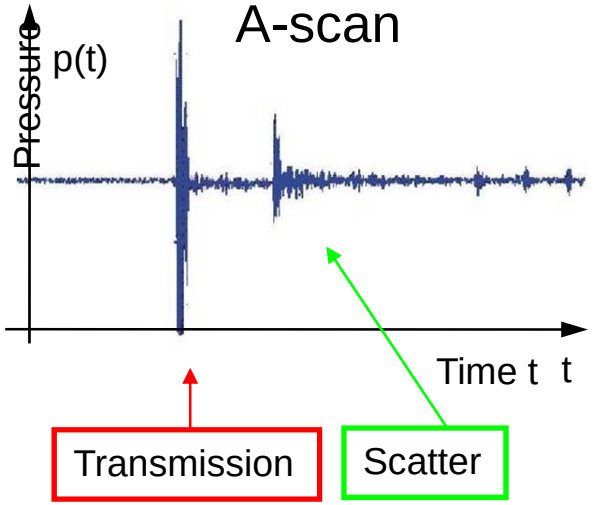
Sensors
G. Göbel, B. Kohout, et. al.

DAQ und Hardware
D. Tsherniakhovski, S. Menshikov, et. al.

Design and Mechanics
L. Berger, B. Osswald, T. Piller, W. Frank, et. al.

Feature: „Image one, get two free“





- Reconstruction of
  - Reflectivity
  - Speed of sound
  - Attenuation