Fraunhofer Entwicklungszentrum Röntgentechnik

The EZRT is a joint department of the Fraunhofer-Institutes IIS Erlangen and IZFP Saarbrücken/Dresden

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International Workshop on Imaging NDE
April 25 – 28, 2007, Kalpakkam, India

Fraunhofer EZRT @ INDE 2007

Status of Computed Tomography

Fast Inline CT

Automated Defect Recognition and CT

Dimensional Measurement with CT

In cooperation with:
BAM (Dr. Ewert and Dr. Goebbels, Berlin)
PTB (Dr. Bartscher, Braunschweig)

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Dimensional Measurement with CT

Industrial 3D-Metrology with Volume Computed Tomography

Qualitative → Quantitative

CT for industrial 3D-metrology

nominal / actual
geometry
comparison

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Dimensional Measurement with CT

Overview

- Introduction and Motivation
- Dimensional Control: Process Chain
- Measurement Uncertainty in CT
- Simulation-based investigation
- Measurement results

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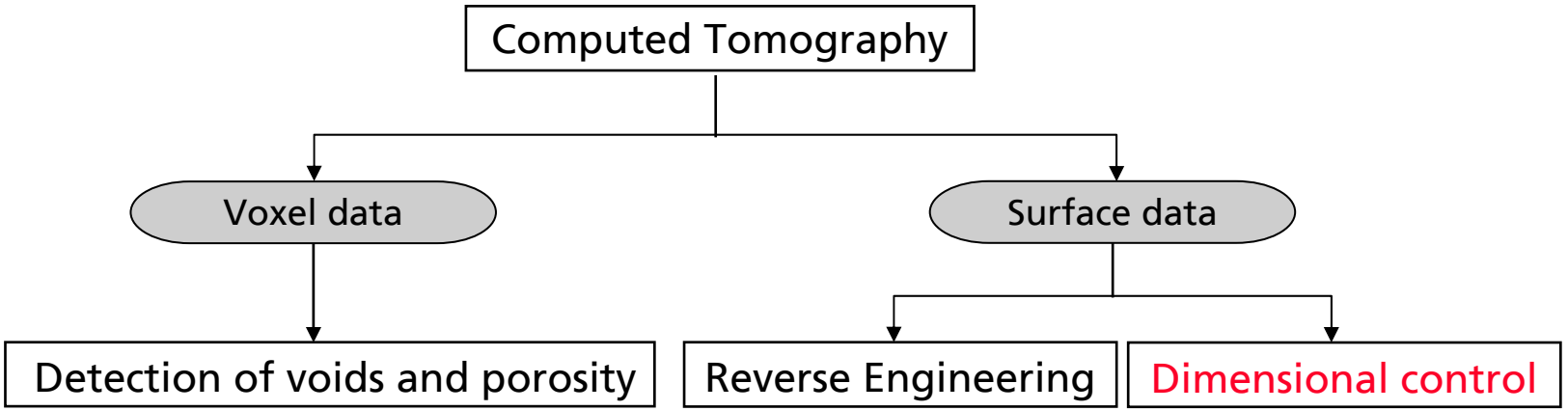
Quality inspection in industrial applications with CT



Advantages
- Non-destructive testing method
- Measuring of complex internal structures

Drawback
- Currently the CT is not yet established as a principle of measurement

Task
- *You must measure the things that are measurable, and make measurable the things that are not.* Galileo Galilei (1564 - 1642)

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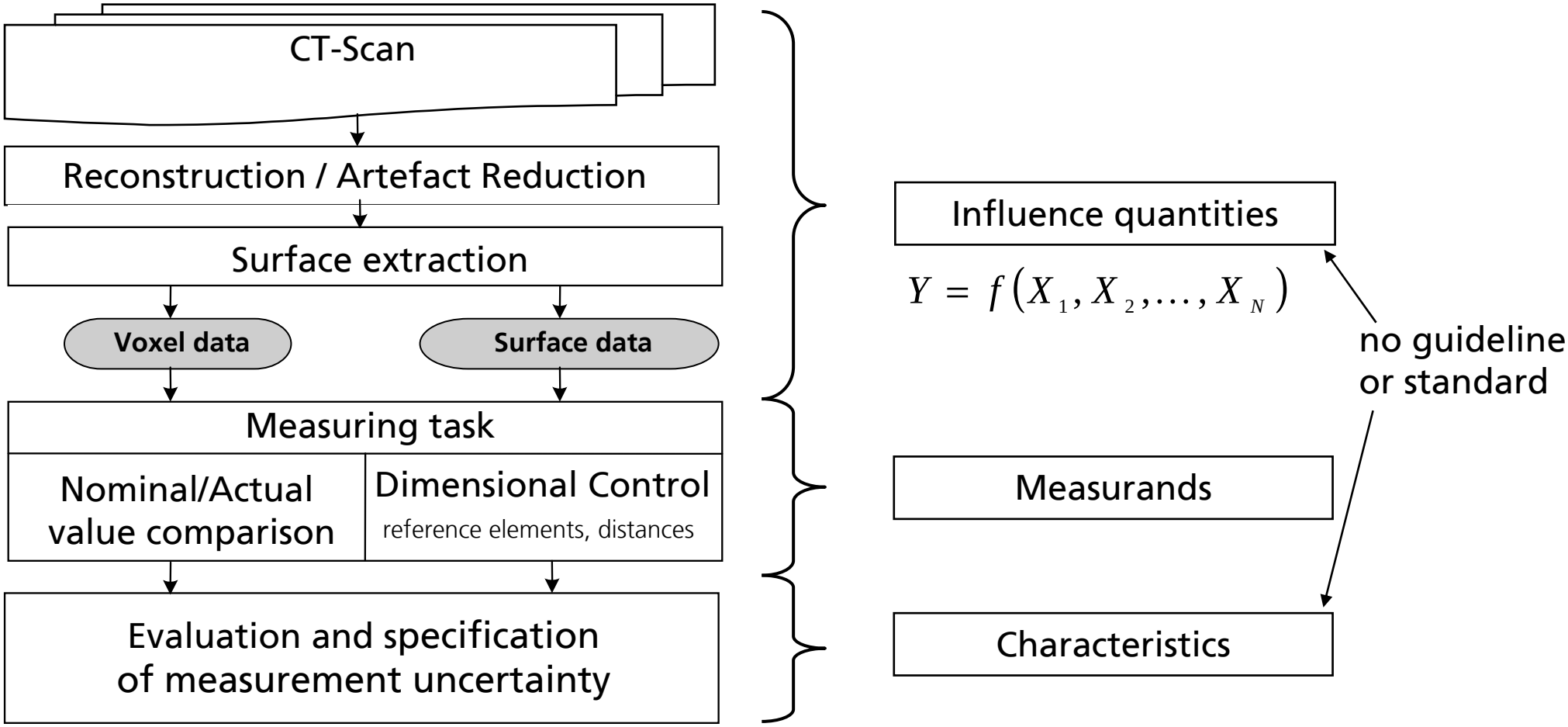
Dimensional Measurements - Procedure



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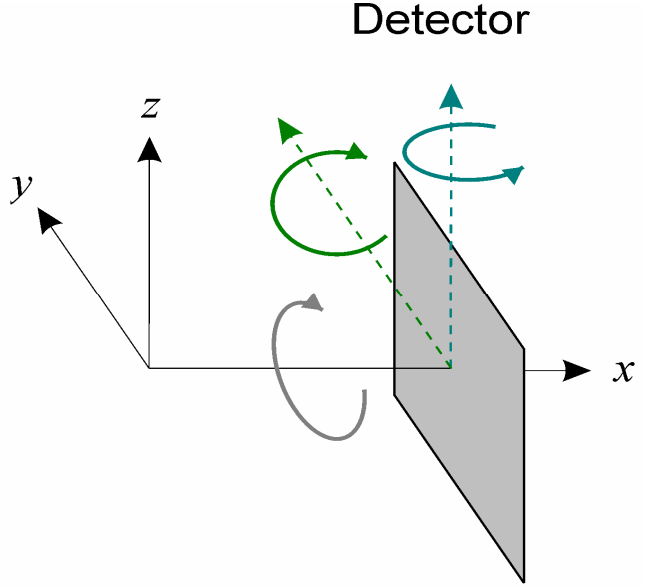
Dimensional Measurement with CT

Influence quantities in CT

Definition: Quantity that is not the measurand but that affects the result of the measurement



Influence quantities

X-ray tube
- voltage, current
- prefiltration

Environment
- temperature
- fouling

Detector
- exposure time
- linearity

Axes
- orthogonality
- run out radially

Object
- material
- artefacts

Data evaluation
- reconstruction
- surface extraction

Scan parameter
- angular sampling
- integration time

Operator
- operating error
- method

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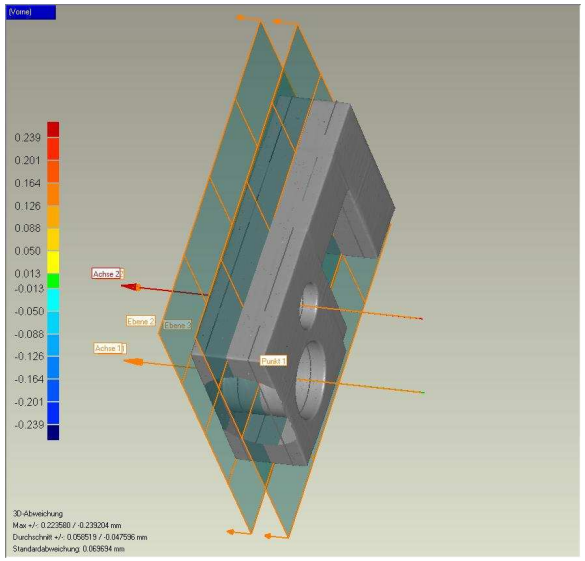
Influence quantities and measurands in CT

Measurands in CT

Definition: Particular quantity subject to measurement



Measurands

Nominal/Actual value comparison

- shrinkage
- shape distortion

Reference element fitting

- probing error
- error of indication for size measurement
- wall thickness analysis

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Characteristics in CT

Definition

Well defined quantifiable number representing an important property of the object thereby allowing to characterizing and optimizing the whole object

Examples: Length, diameter, distance

No measurement result is perfect!

But measurement results

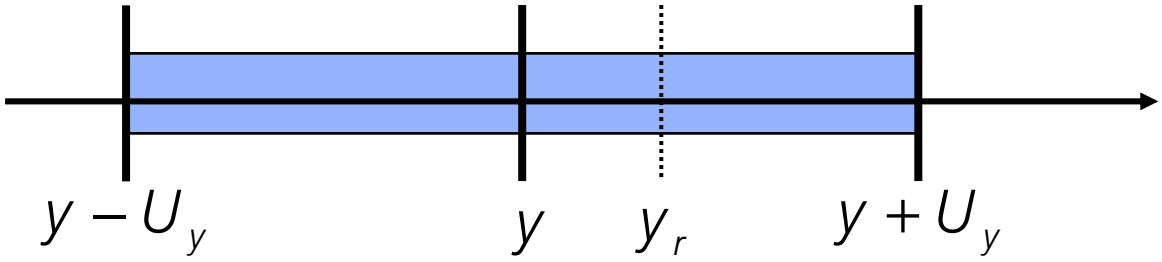
- are important for final inspections of products
- affect the production process

Quality feature of a measurement is the **measurement uncertainty**!

Definition Measurement Uncertainty

Measurement uncertainty (VIM)

A parameter associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the measurand.



Specification of result

measurement result = measured value $\pm$ measurement uncertainty

Symbols: $Y = y \pm U_y$

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Evaluation of the measurement uncertainty

according to the Guide to the Expression of Uncertainity in Measurement, 1995

- worldwide standard for consistent evaluation of measurement uncertainty,
- methodically step-by-step procedure,
- practical and versatile modelling concept,
- based on a solid theoretical foundation

GUM was developed by cooperation of international organizations:

CT specific problems

- Many components influencing the measurement quantity
- Indirect data evaluation is done by various algorithms
- Measurement uncertainty depends strongly on the measurement task and the measurand
- Artefacts reduce image quality

→ **Set up of a model equation for CT measurement procedure is very difficult or nearly impossible.**

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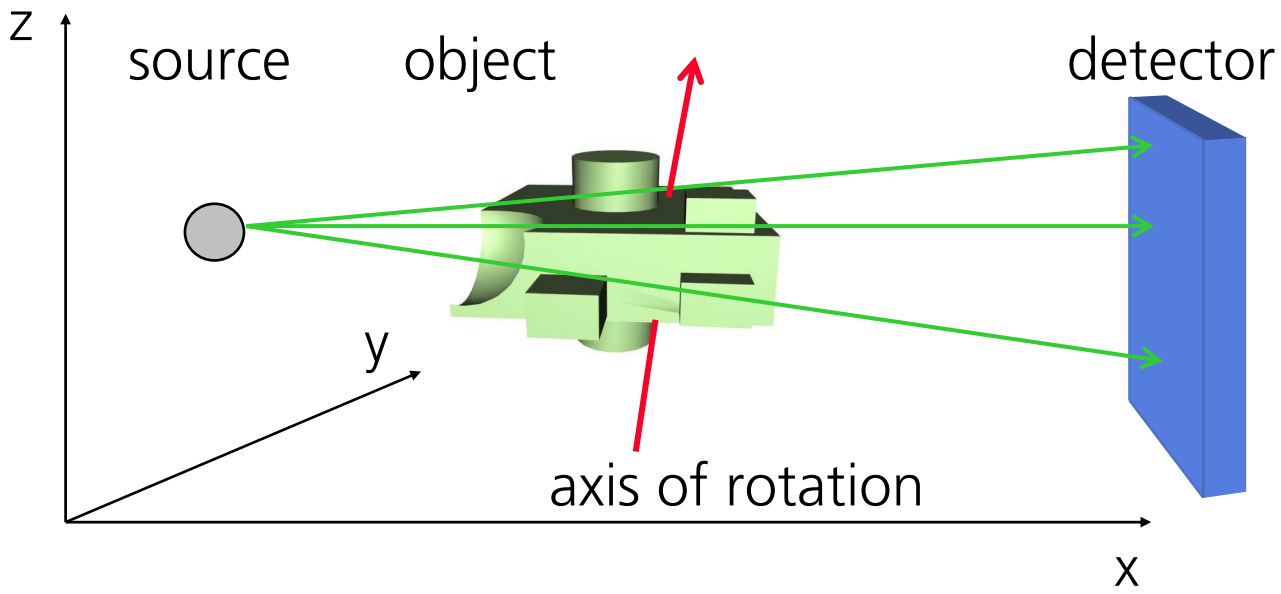
Why simulation?

- Systematic examinations of the influences
- Influences can be activated separately e.g. „on-/off“ switching of quantum noise, scattering, beam hardening…
- No limitations imposed by availabilities of test objects or CT-systems
- Exact reproducibility of conditions and results
- Scheduled for next version of GUM



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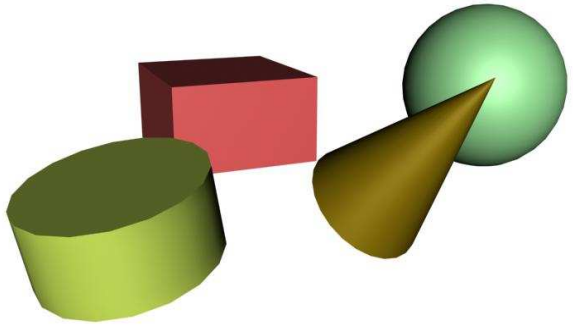
Xlab: CT Simulation Tool

Generation of X-ray projections of virtual objects by simulation



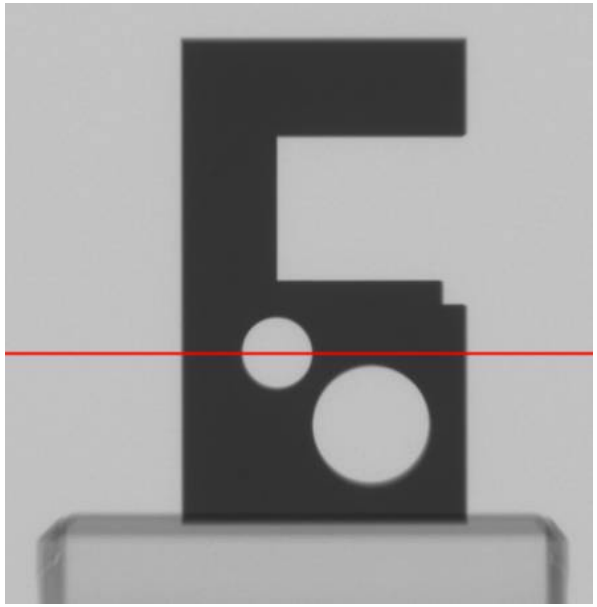
Realization as

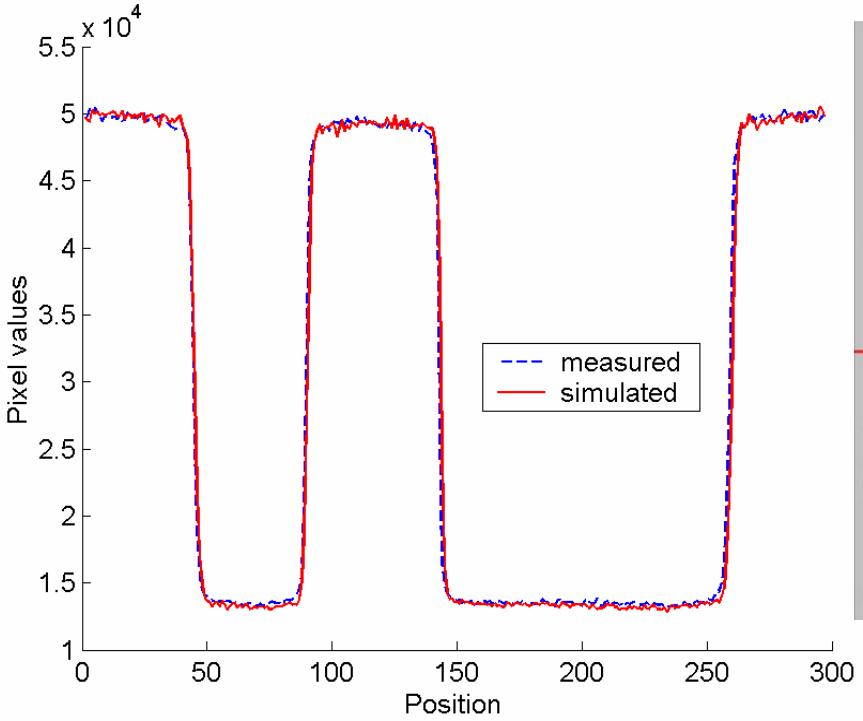
- analytical tool,
- ray-based implementation,
- C++ library („XLab“)

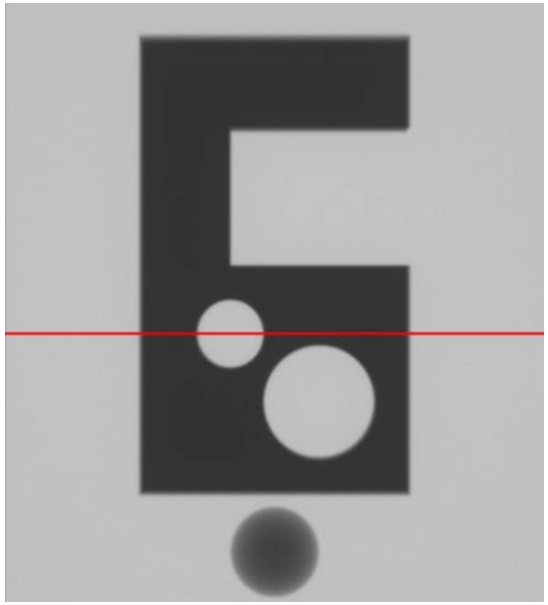
Features

- Multi-material objects
  (defined by a composition of primitive geometric objects)
- Quantum noise
- Radiation scattering (LBSA model)
- Pre-filtration (beam hardening)
- Detector blurring

Comparison of Simulated and Measured Projections







measured projection
at tube voltage of 180 kV

simulated projection
polychromatic at 180 kV

source-detector distance: 100 cm
source-object distance: 70 cm
detector resolution: 512 x 512

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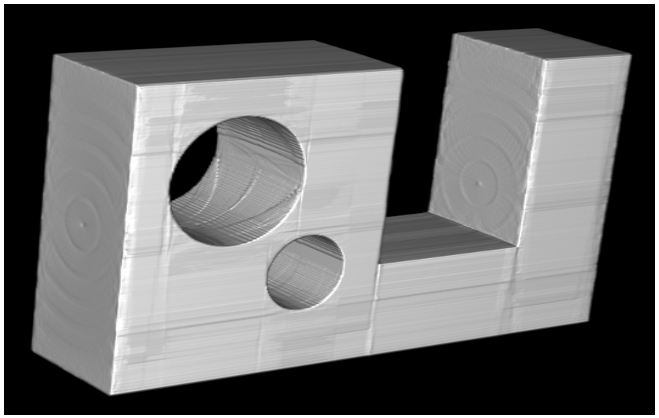
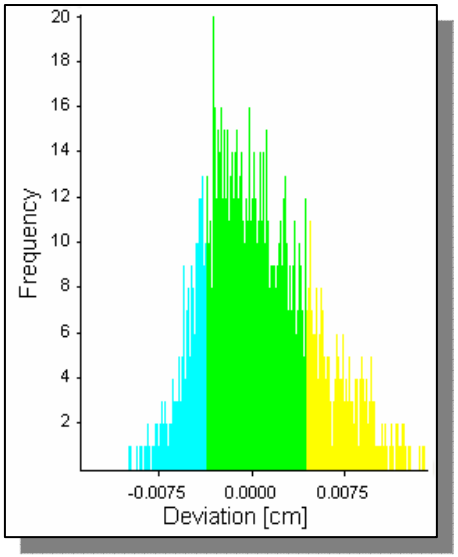
Characteristics: 4-sigma value

Error of measurement

- Fit of ten reference elements (8 planes, 2 cylinders)
- calculate fit point deviation histogram (VG Studio)
- calculate mean of the 4-sigma values over all of the ten geometry fits



Test object (aluminum alloy)



Three test scenarios

- influence of pre-filtration,
- misalignment of scanning geometry and
- quantum noise

pixel size:	400 x 400 µm
voxel size:	270 x 270 x 270 µm
angular steps:	400

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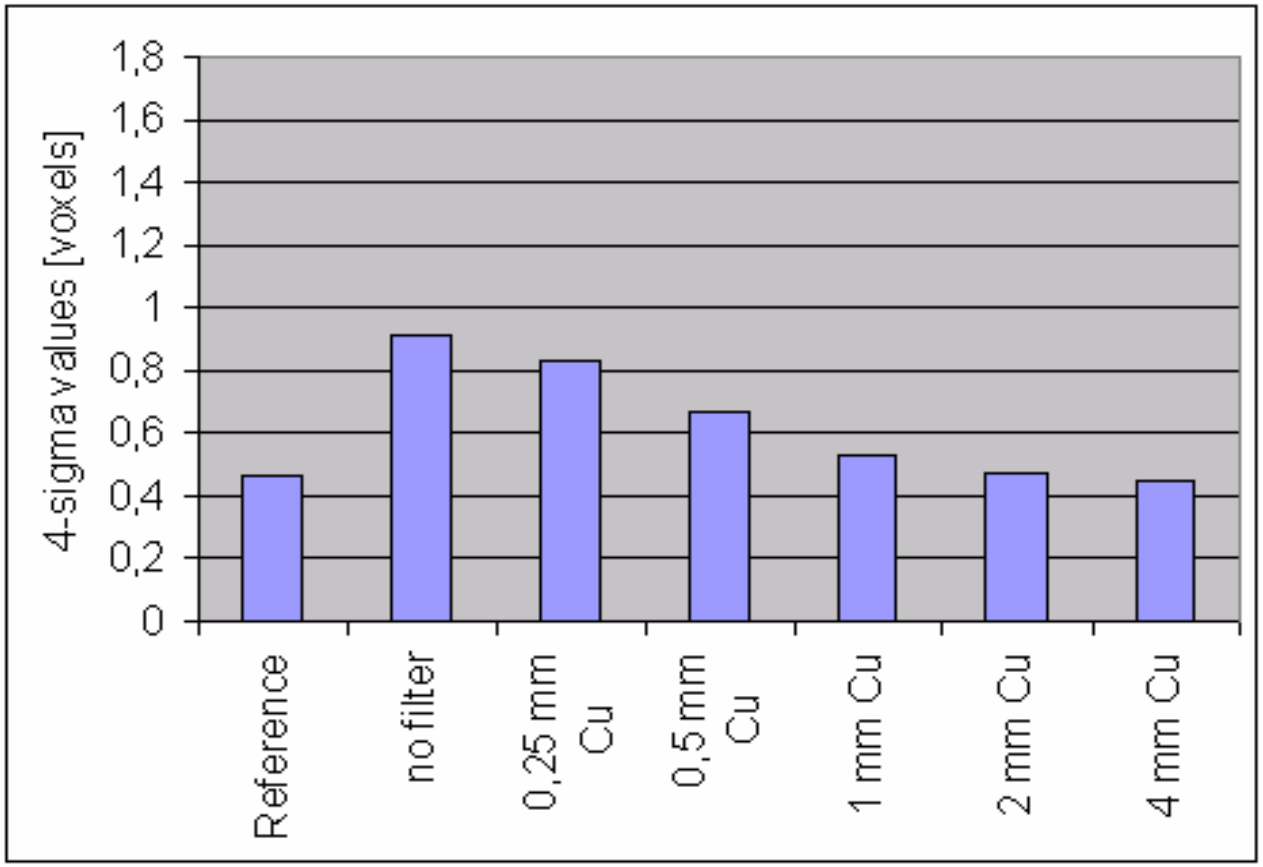
Influence quantity – Pre-filtration

- Copper pre-filtration with thickness: 0 – 4 mm
- 200 kV (reference case: monoenergetic)
- Polychromatic source, without quantum noise and scattering



Mean 4-sigma-value

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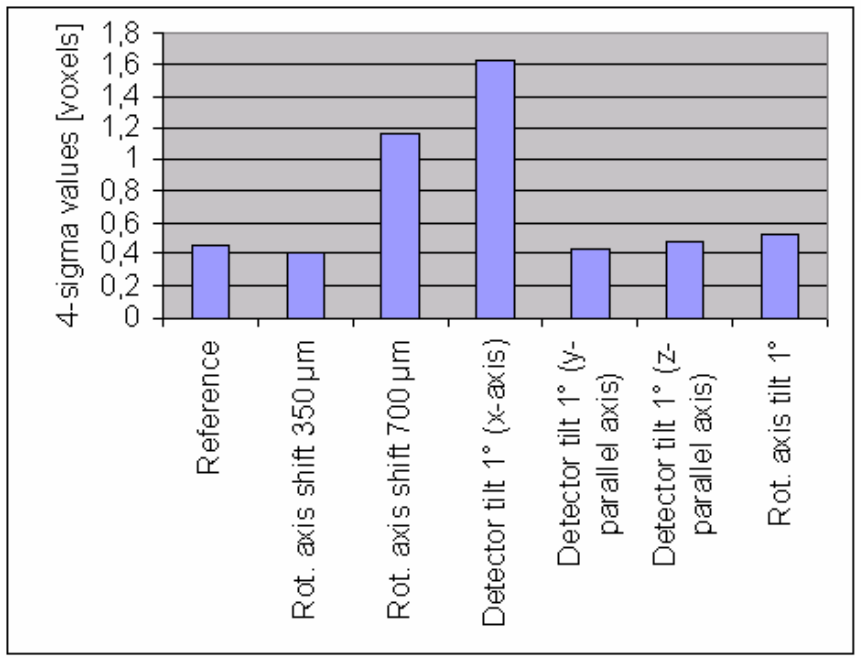
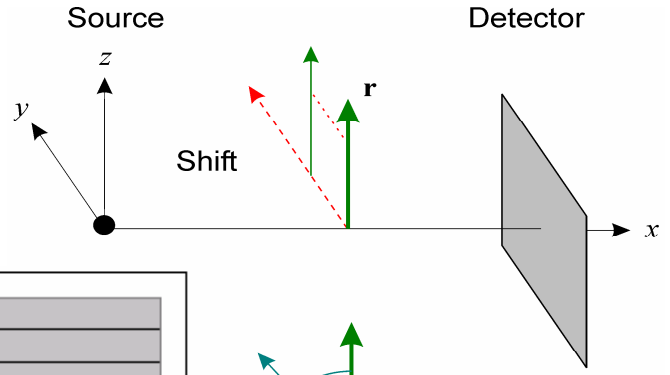
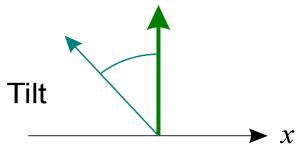
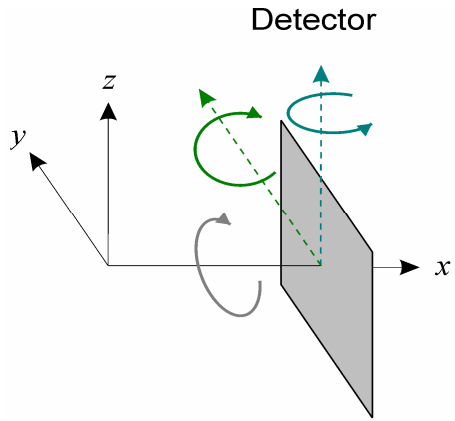
Influence quantity – Misalignment

- Tilt of detector by 1° rotations around its center
- Shift of rotation axis towards y-direction by 350 µm and 700 µm
- Tilt of rotation axis out of its z-parallel position
- Reference case: ideal geometric alignment
- Monoenergetic source, without quantum noise and scattering









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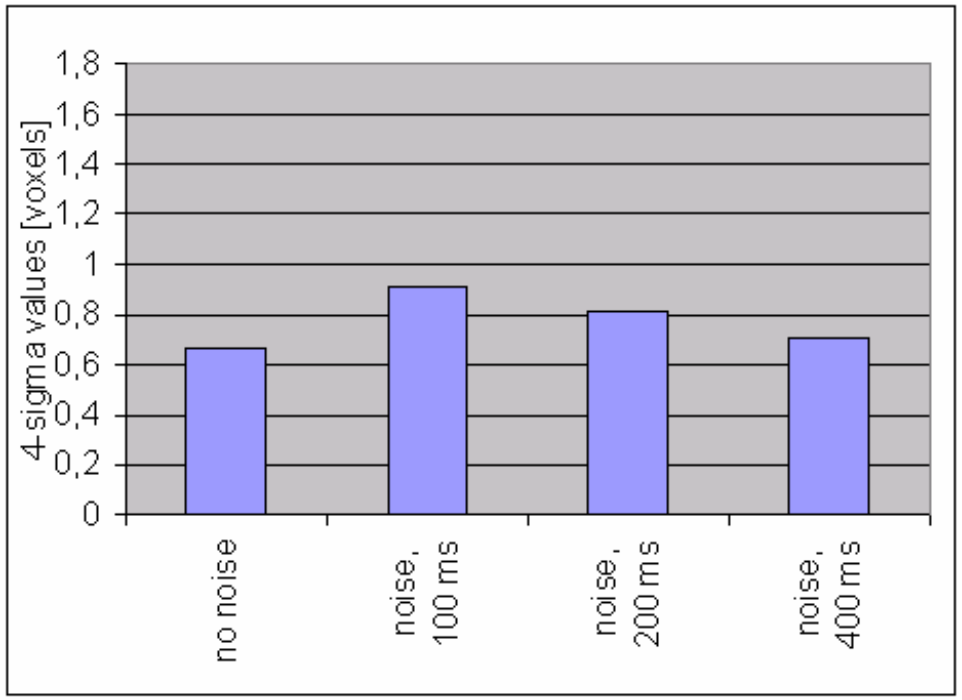
Influence quantity – Quantum Noise

- Detector exposure time: 100 ms, 200 ms and 400ms
- 200 kV, 100 µA, 0.5 mm copper pre-filtration
- Reference case: without quantum noise
- Polychromatic source, without scattering



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Summary

- CT is a tool for dimensional measurements
- Influence quantities can be identified with simulation tool XLab
- Selection of measurement results
- Most critical parameters are
  beam hardening and
  the detector tilt around the x-axis

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