

Systematic Errors in Dimensional X-ray Computed Tomography

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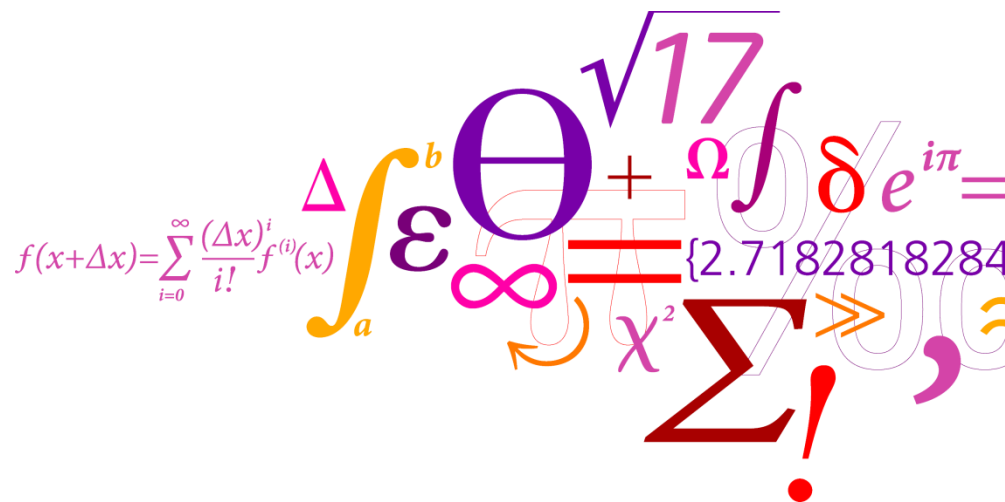
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Systematic Errors in Dimensional X-ray Computed Tomography

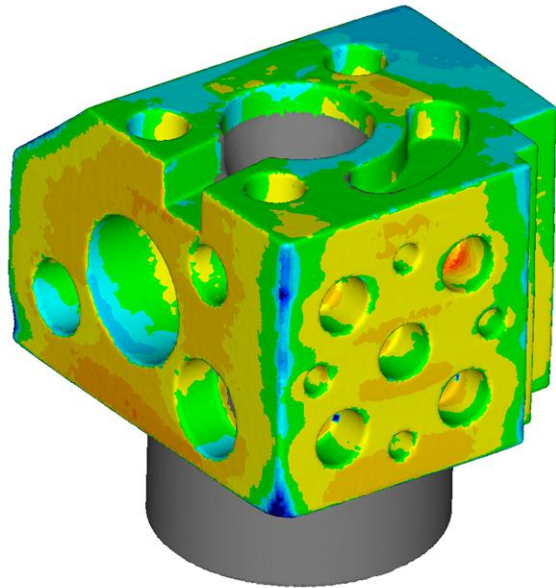
Jochen Hiller

Måletekniske dage
Teknologisk Institut
31.05.2012

DTU Mekanik
Institut for Mekanisk Teknologi



Overview



- Industrial X-ray CT today
- Dimensional CT as a key technology in production metrology
- Errors sources and a good practice in CT scanning
- Conclusions and future works

Industrial X-ray CT today

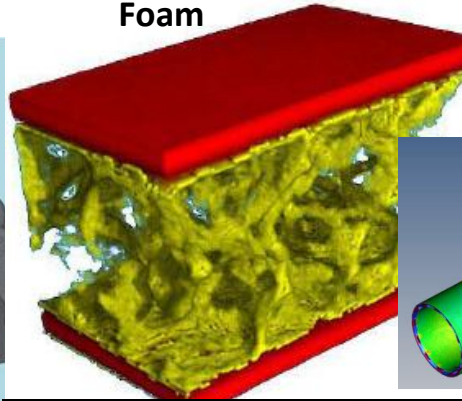


Industrial X-ray CT today

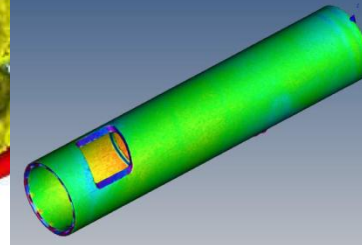
Aluminum casting



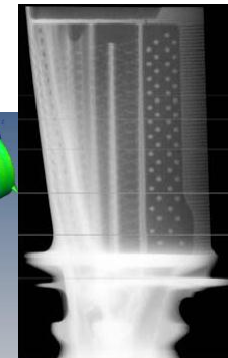
Foam



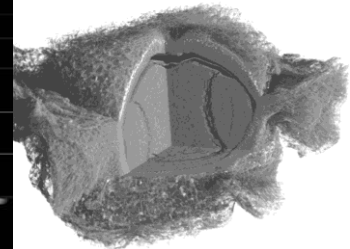
Insulin pen



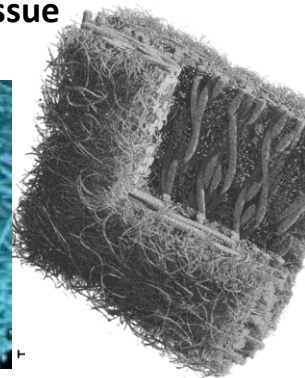
Turbine plate



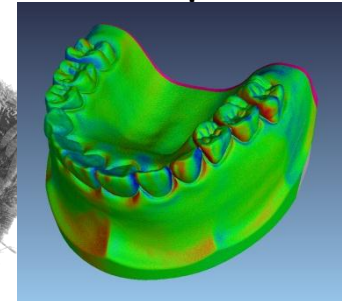
Seed



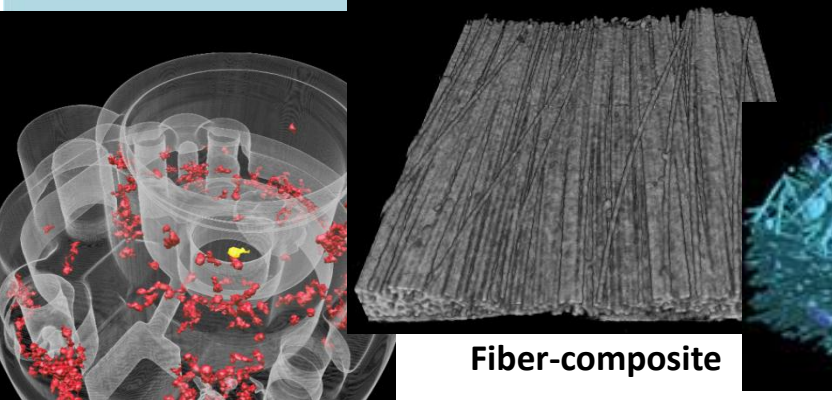
Tissue



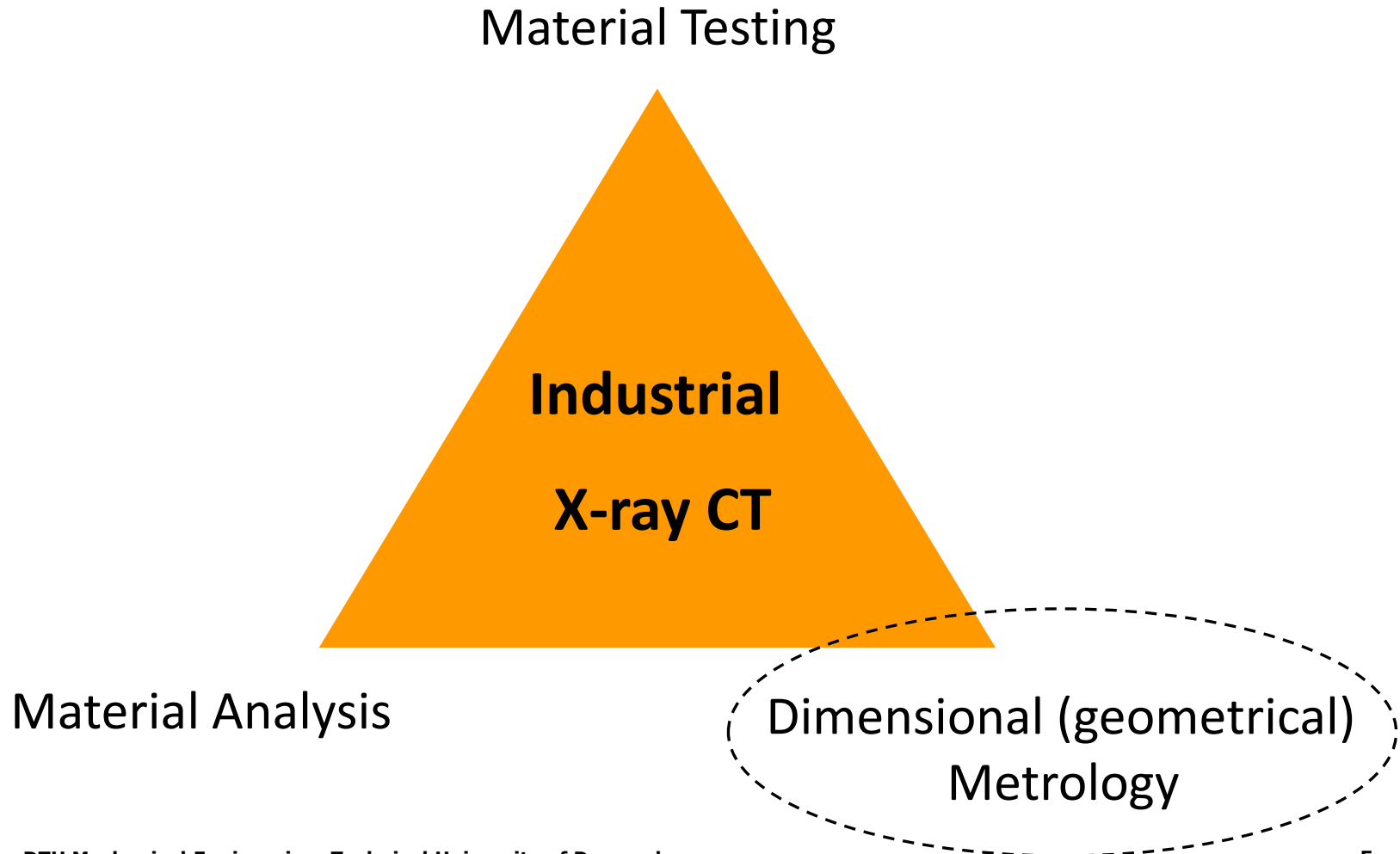
Dental impression



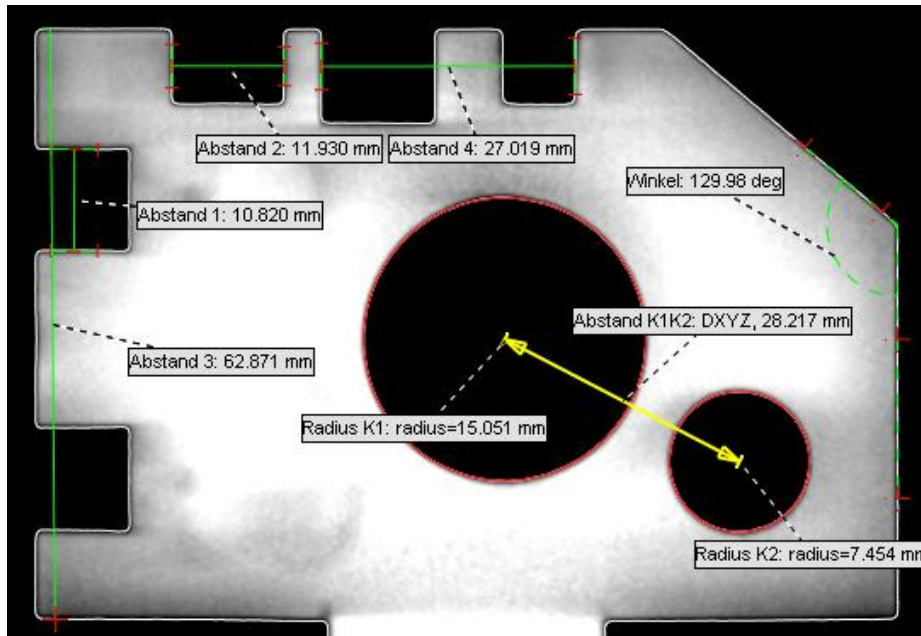
Fiber-composite



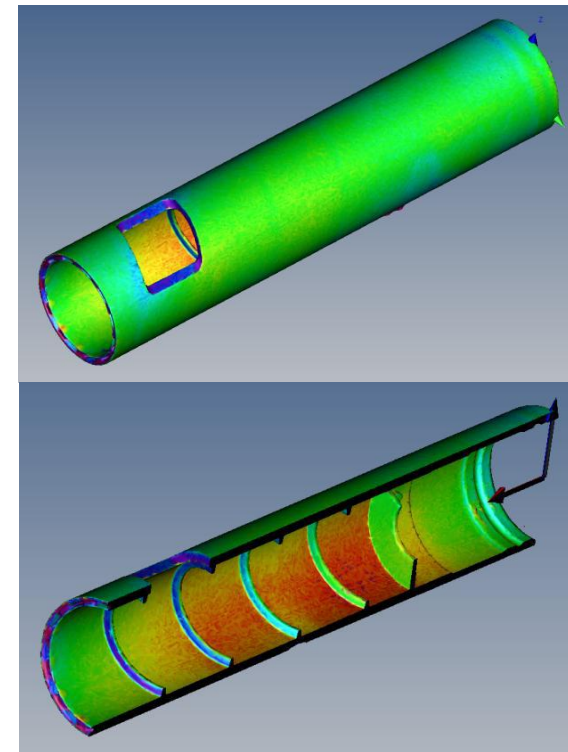
Industrial X-ray CT today



Dimensional CT as a key technology in production metrology


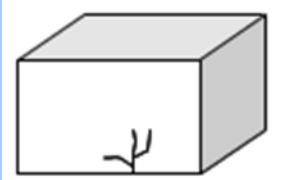
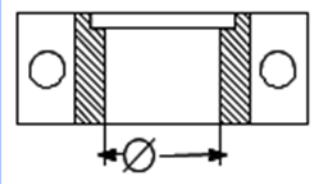


Measurement of size, form, and position



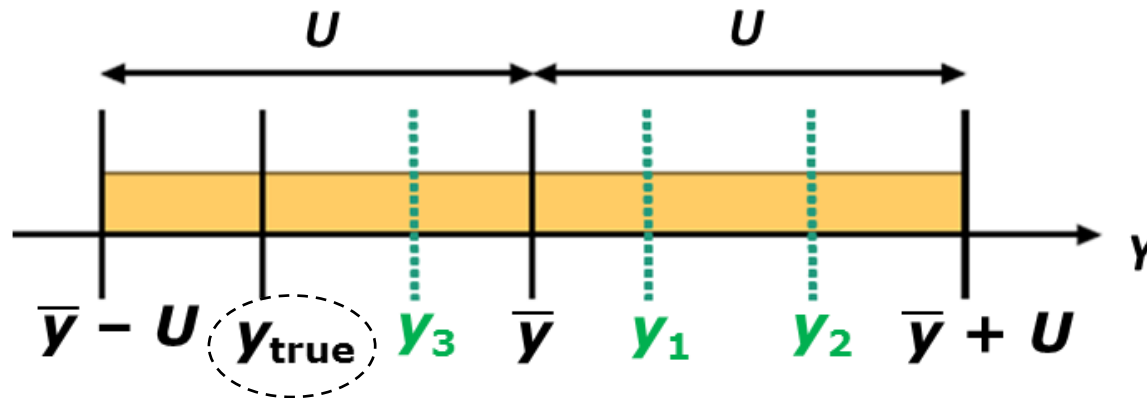
CAD/CT comparison

Dimensional CT as a key technology in production metrology

Application	Material Analysis	Material Testing	Dimensional Metrology
Symbol			
Performance Parameter	Structural Resolution	Failure Detectibility	<div style="border: 2px dashed black; border-radius: 50%; padding: 10px; display: inline-block;"> Measurement Uncertainty </div>

Dimensional CT as a key technology in production metrology

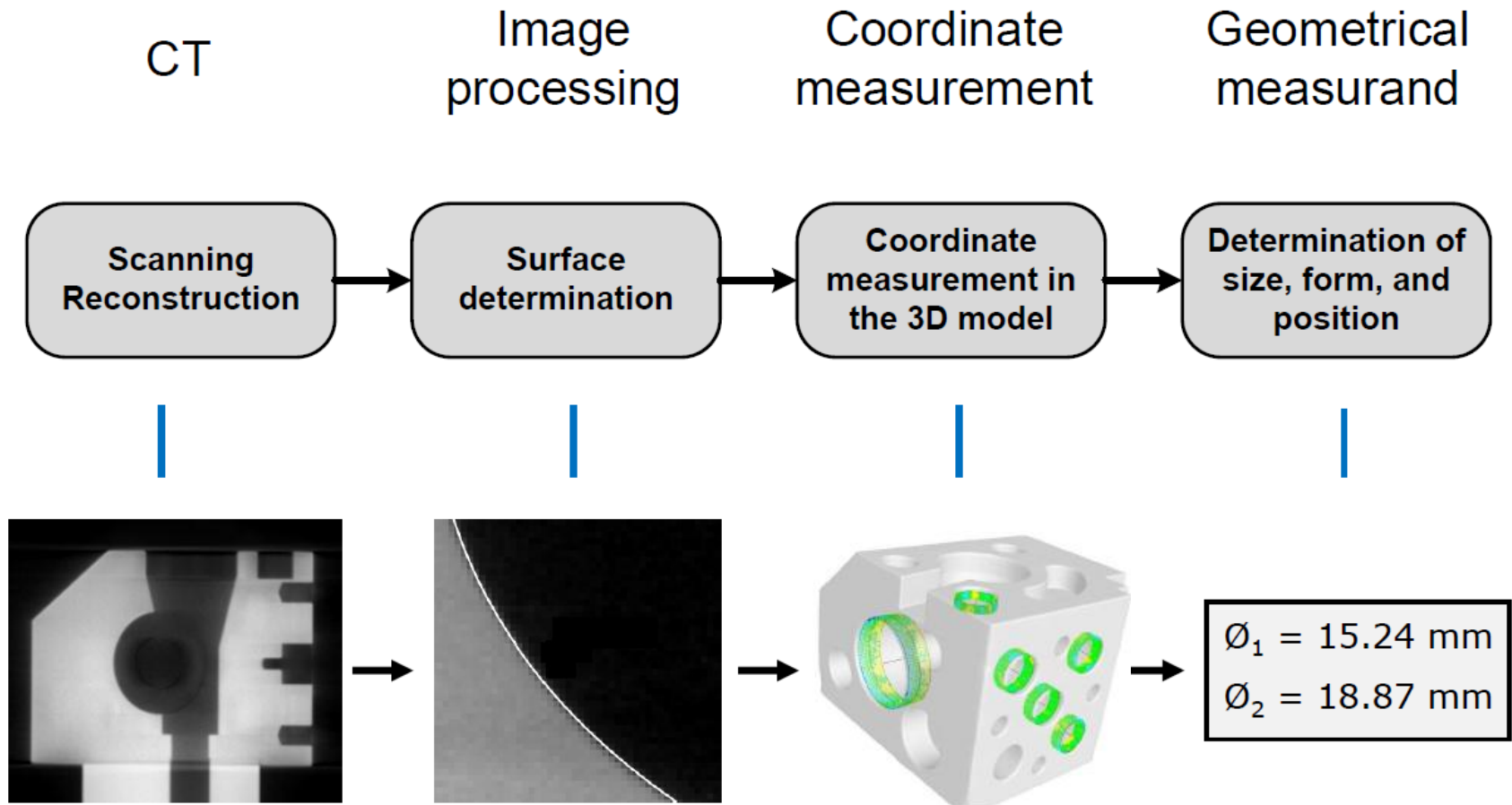
Measurement uncertainty U :



- We will never know the *true* value of a measurement
- Measurement results must be repeatable and reproducible
- What about systematic (effects) errors?

Should be corrected!

Errors sources and good practice in CT scanning

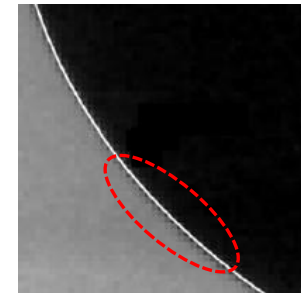


Errors sources and good practice in CT scanning

What are sources of systematic errors?

- Image artefacts
- Scaling (voxel size) error
- CT system limits (image blurring, noise)

**Segmentation and surface
determination errors**

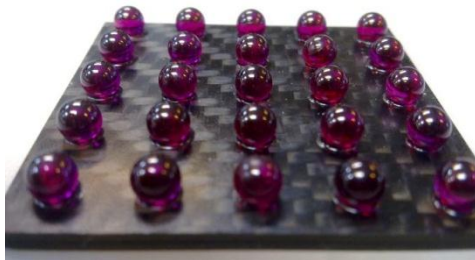


- Metrological data evaluation strategy

Errors sources and good practice in CT scanning

Can we use calibration artefacts?

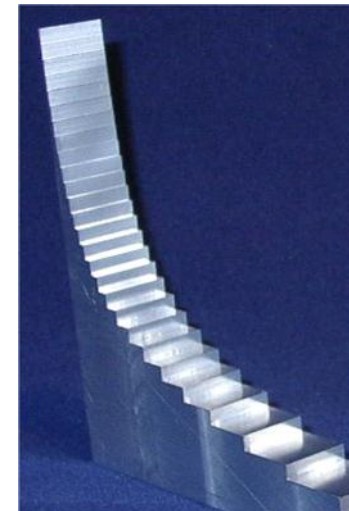
Only for the compensation of effects linked to geometrical scanner misalignment or beam-hardening artefacts



Ball-plate



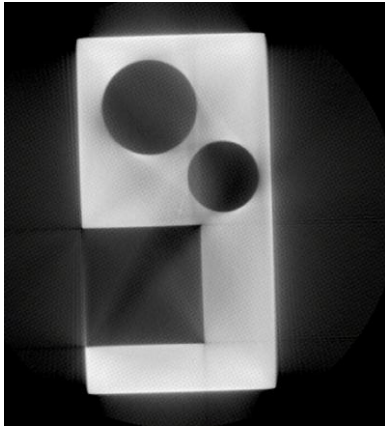
Ball-bar



Step-wedge

- Calibrated masterpieces
- Systematic scanning and evaluation planning to avoid high systematic errors (blunder)

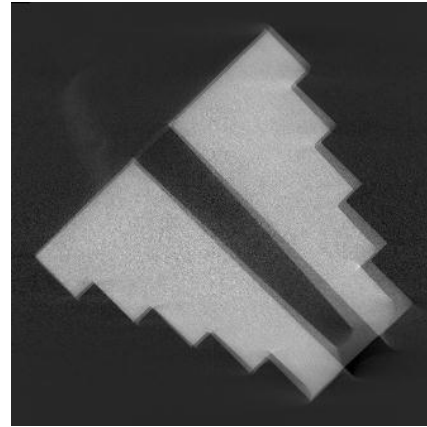
Errors sources and good practice in CT scanning



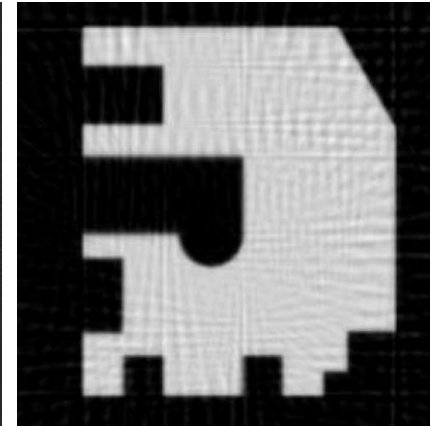
Beam-hardening



Cone-beam



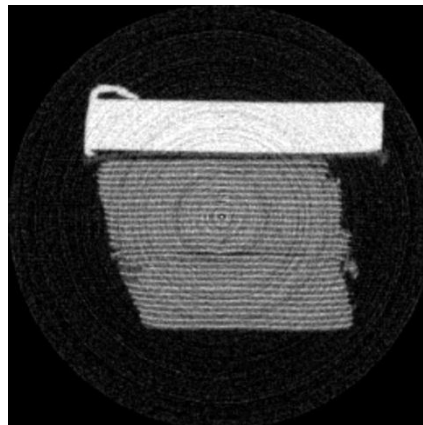
Misalignment



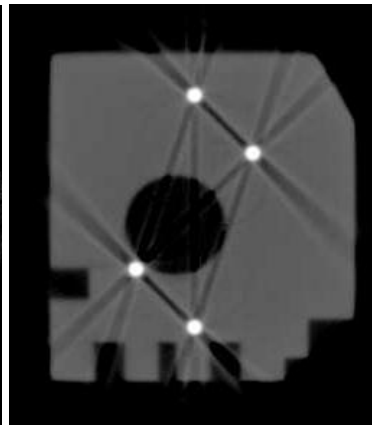
Undersampling



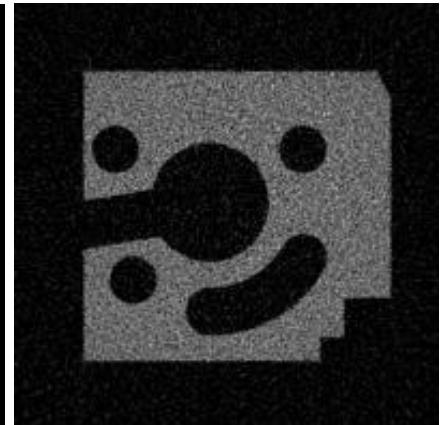
Truncation



Ring artifacts



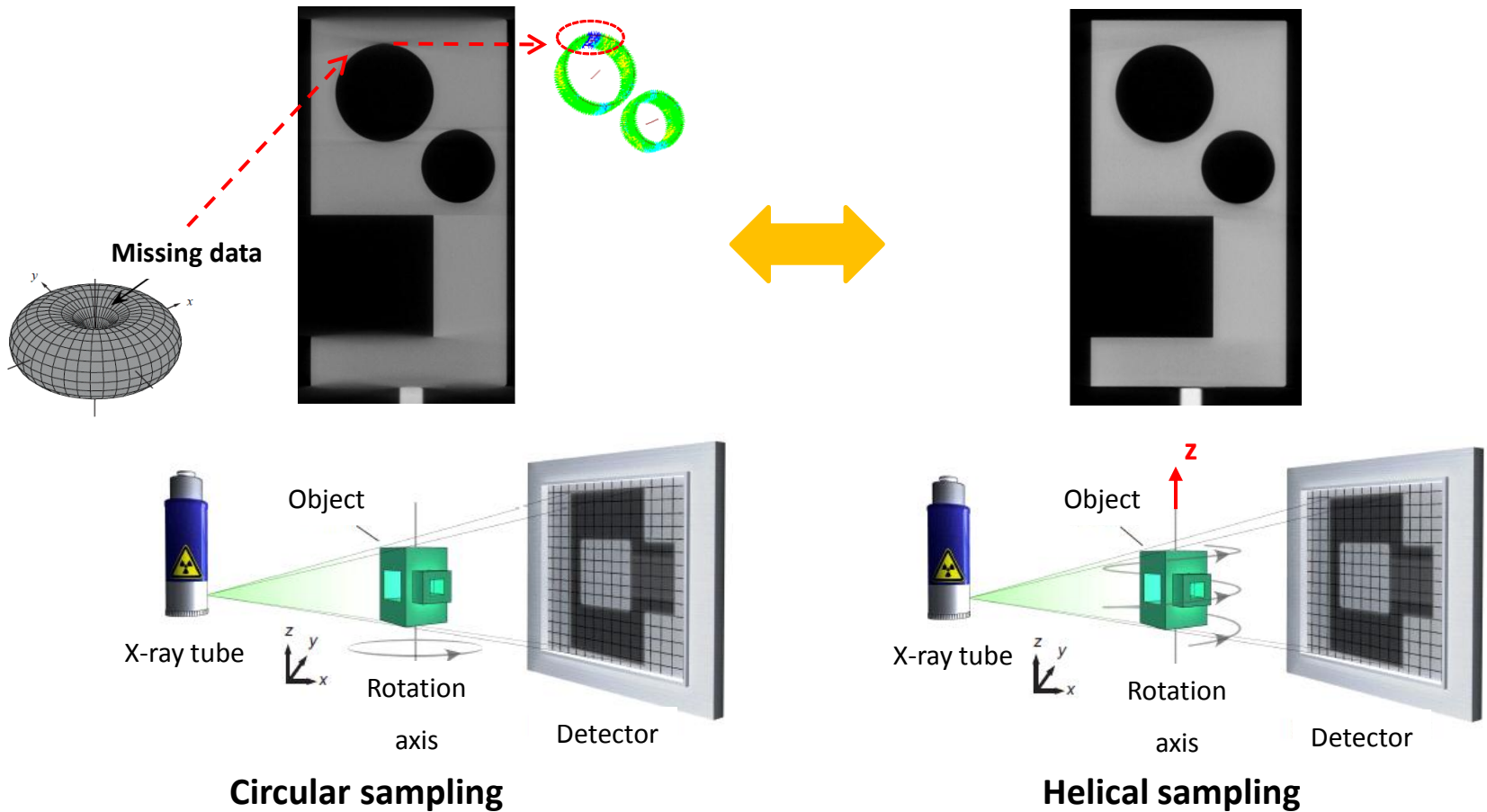
Metal artifacts



Noise artifacts

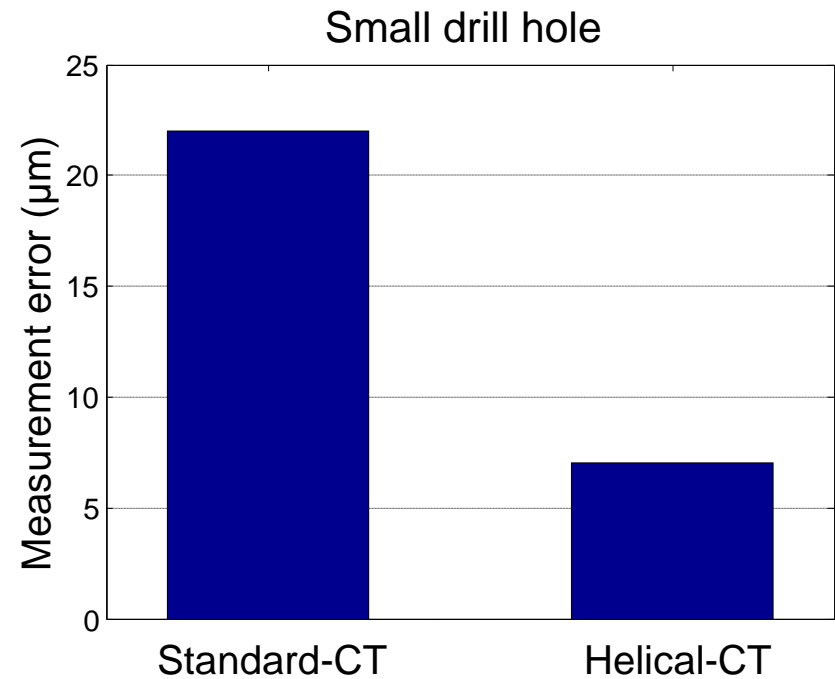
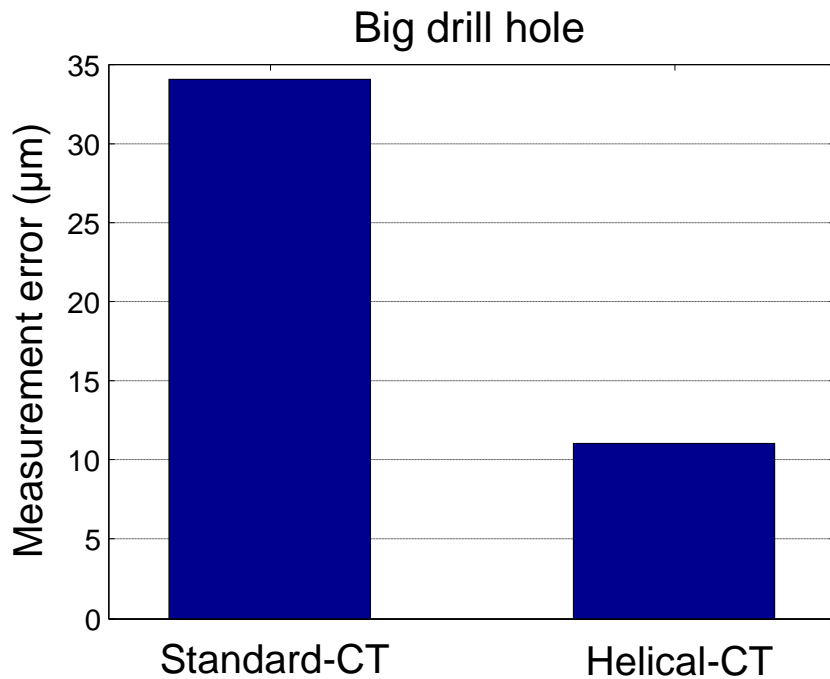
Errors sources and good practice in CT scanning

Cone-beam artefacts:



Errors sources and good practice in CT scanning

Standard vs. helical CT:

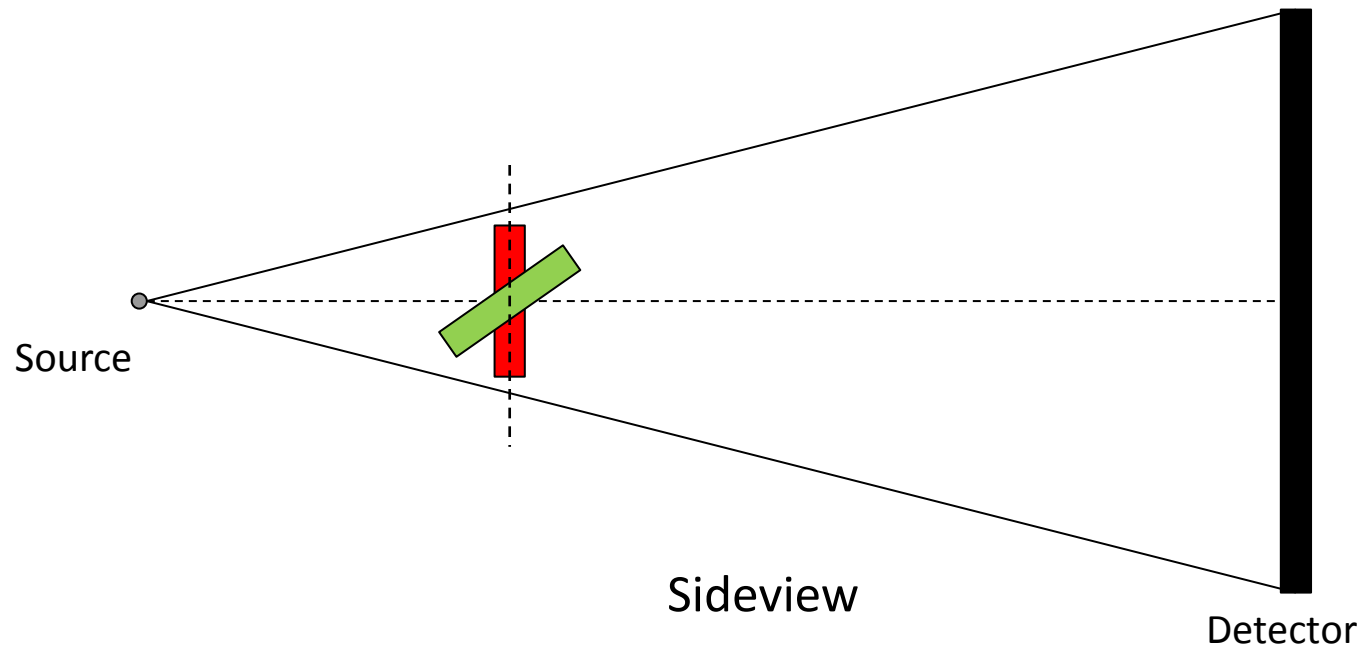


Voxel size: $105,7 \mu\text{m}^3$

Errors sources and good practice in CT scanning

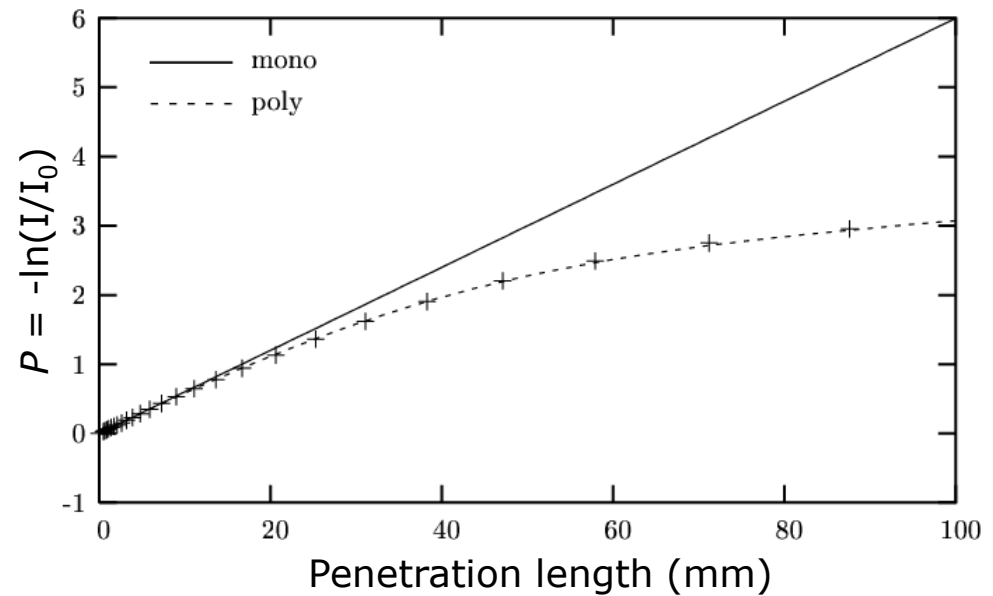
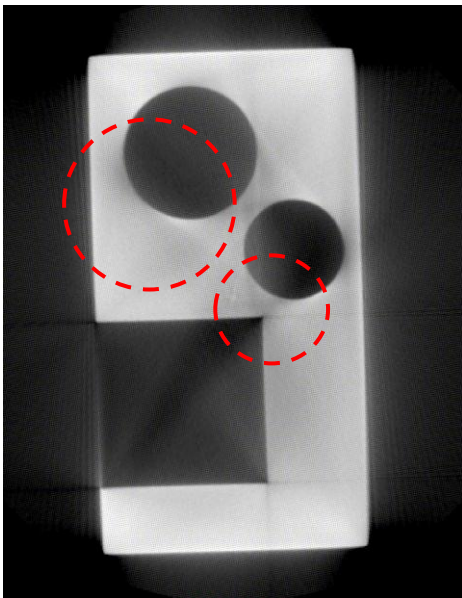
Good practice:

- Tilted position of the workpiece



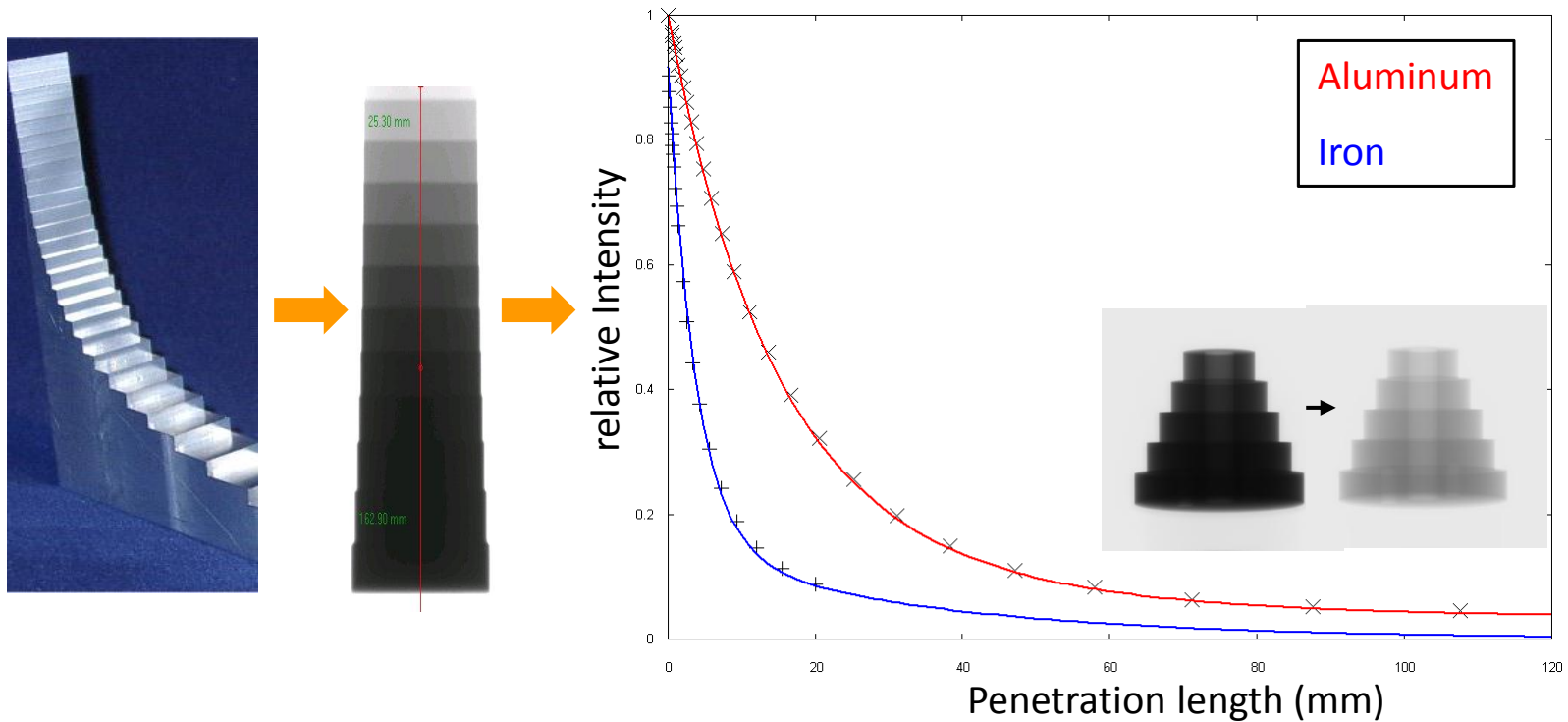
Errors sources and good practice in CT scanning

Beam-hardening:



Errors sources and good practice in CT scanning

Beam-hardening correction:



Step wedge → Radiography → Linerization of projections with inverse function

Errors sources and good practice in CT scanning

DTU beam-hardening correction GUI

LUT Manager

Load LUT

Compute LUT

Load Step Wedge image

Insert calibration values

Compute new LUT

Save LUT

Intensity	Length in mm
0.05	58
0.08	52
0.12	45
0.15	38
0.20	30
0.25	24
0.32	18
0.45	12
0.68	6

Save your LUT or load images to be corrected

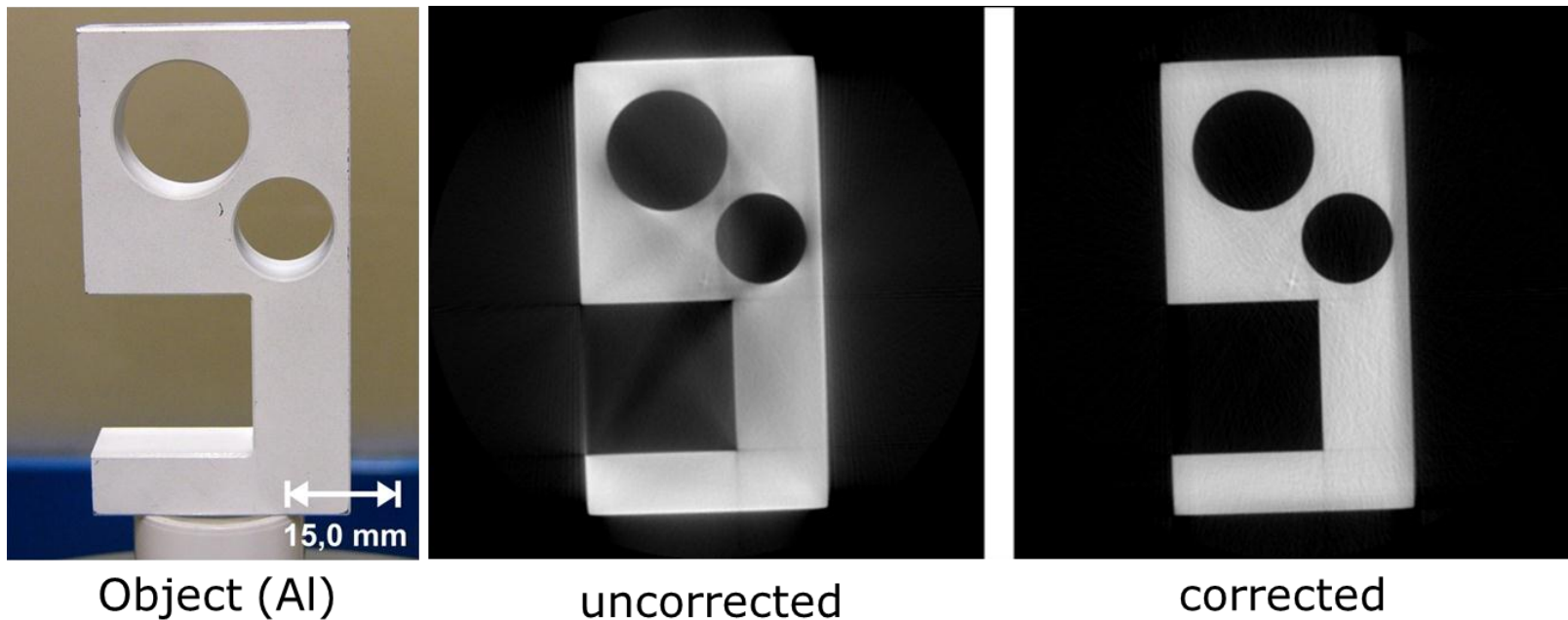
Correct images

Exit

Reset All

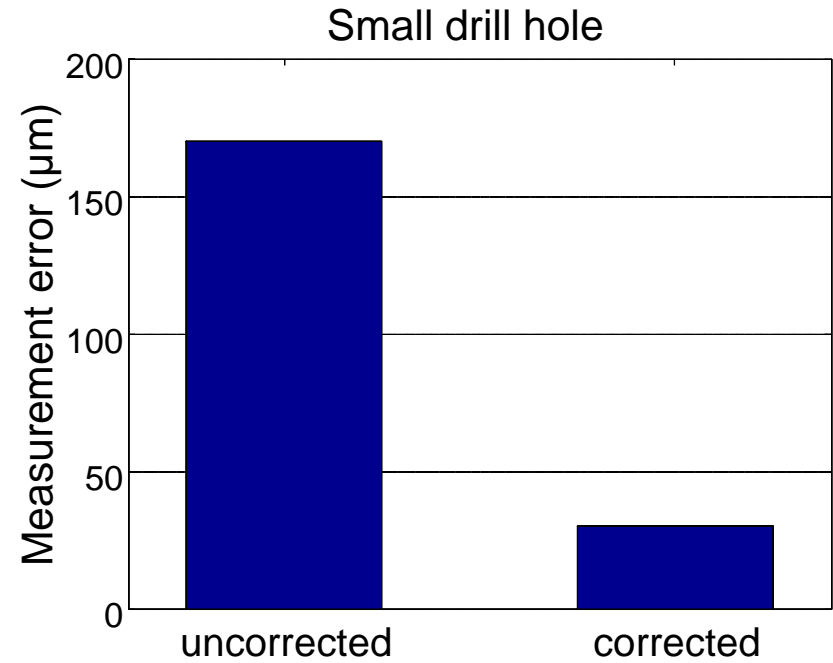
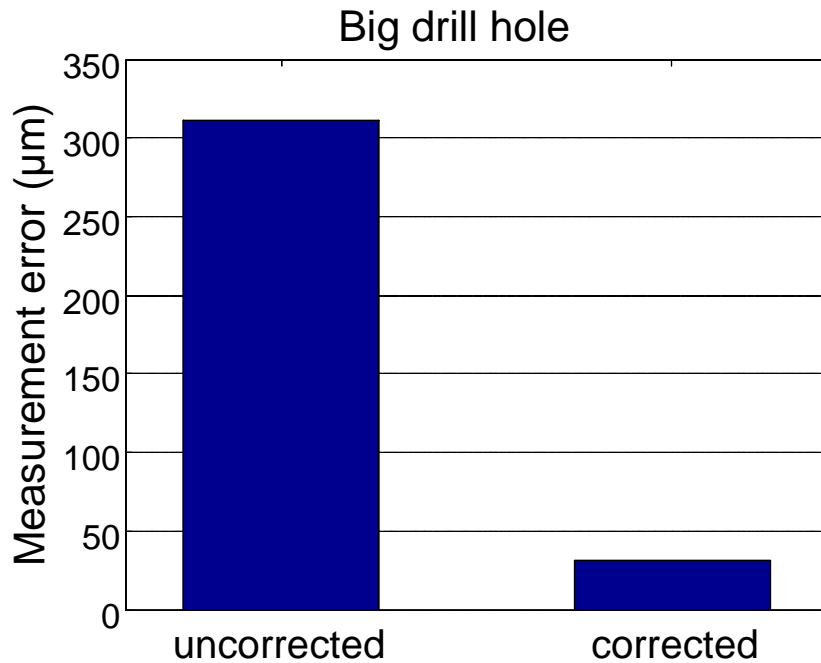
Errors sources and good practice in CT scanning

Beam-hardening correction:



Errors sources and good practice in CT scanning

Beam-hardening correction:

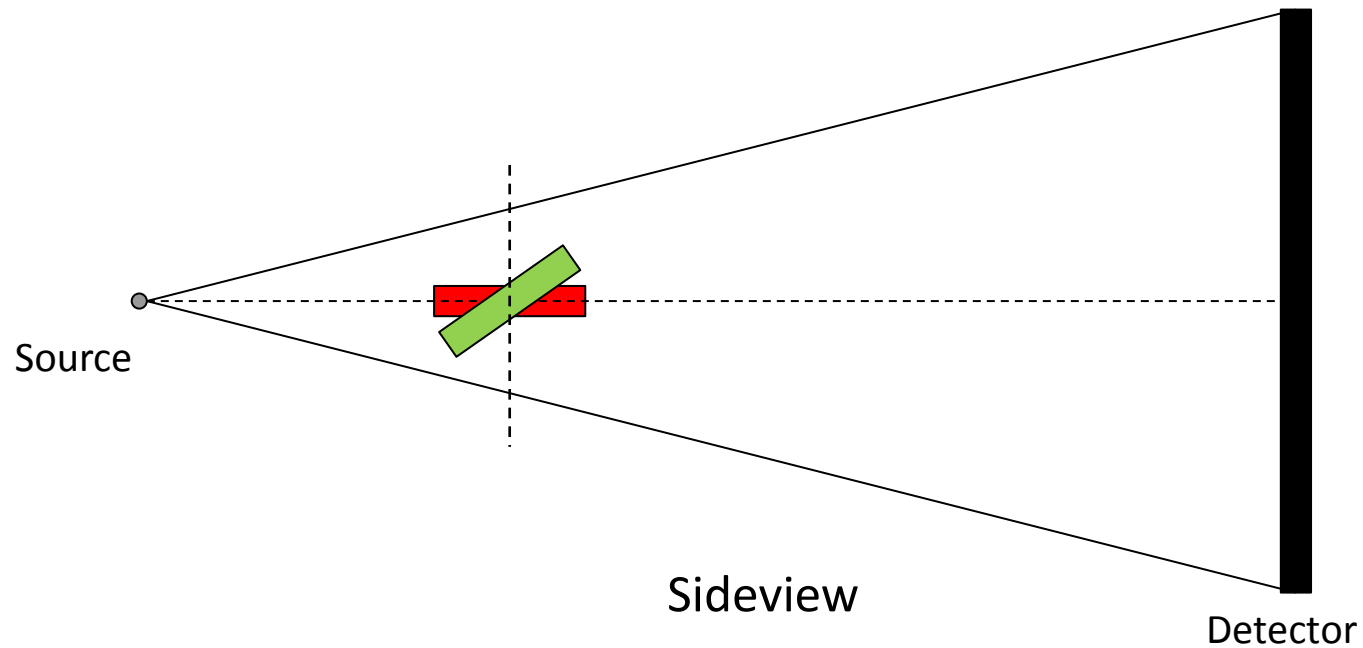


Voxel size: $(156,7 \times 156,7 \times 179,3) \mu\text{m}^3$

Errors sources and good practice in CT scanning

Good practice:

- Tilted position of the workpiece

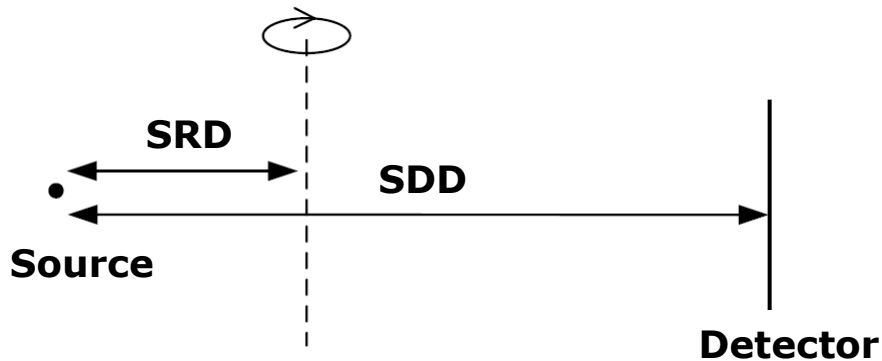


- Using a prefilter

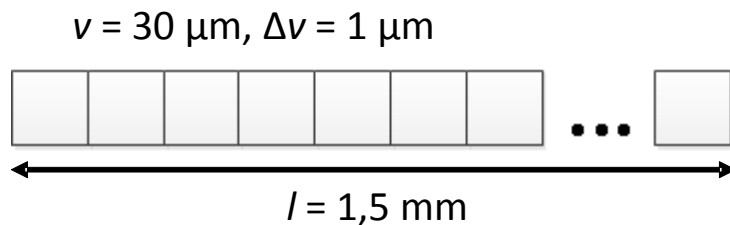
Errors sources and good practice in CT scanning

$$m = \text{SDD} / \text{SRD}$$

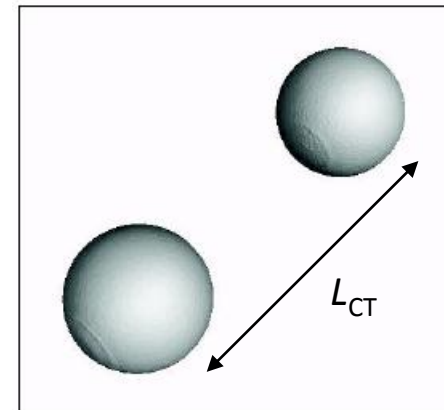
$$v = a / m$$



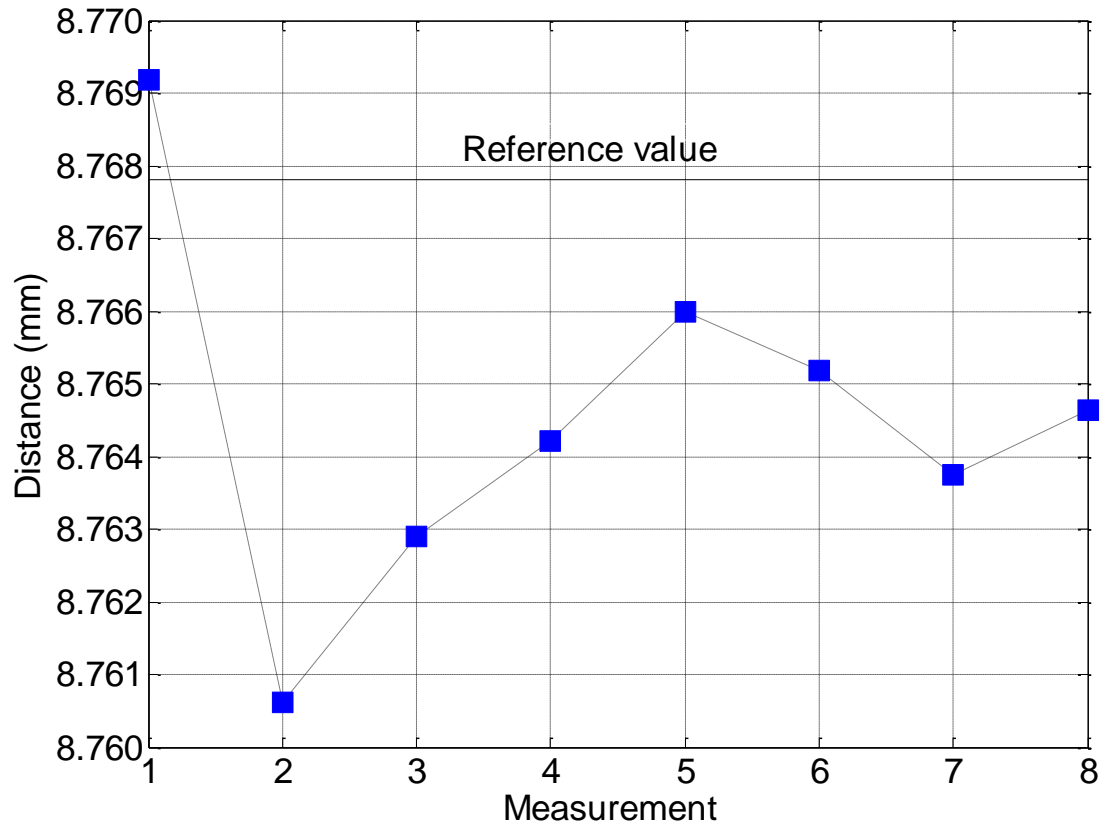
Calibrated length: 8,7678 mm



Error: $\Delta l = 50 \mu\text{m}$



Errors sources and good practice in CT scanning



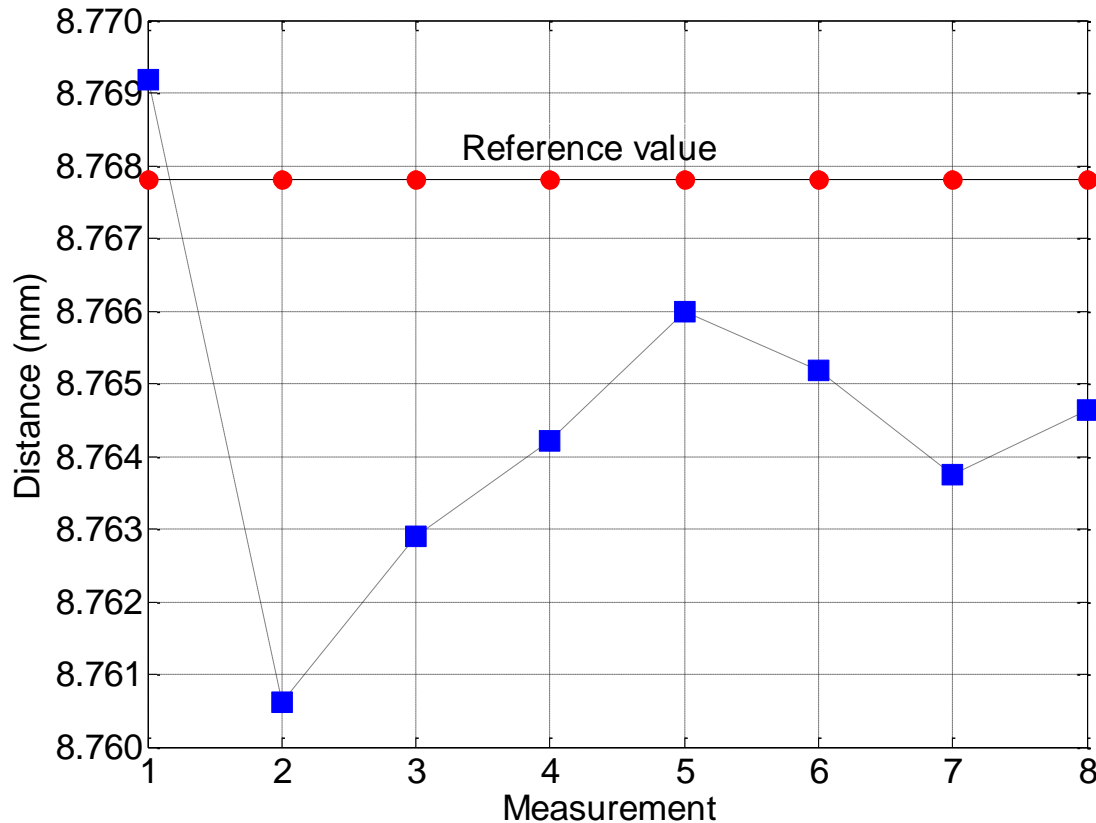
Variations are caused by inaccuracies of the SRD measurement (manipulator)

+

Focus drift during scanning due to tube temperature changes

superimposed

Errors sources and good practice in CT scanning



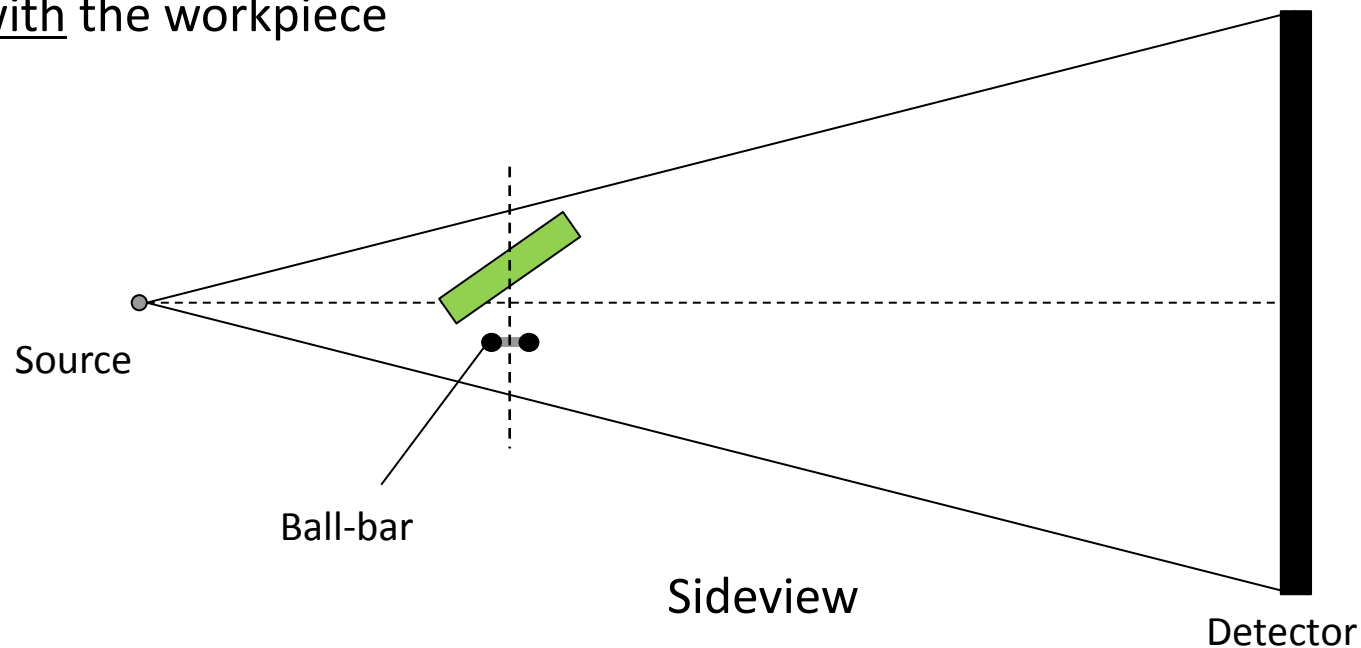
Voxel size rescaling:

$$\tilde{v} = v \cdot \frac{L_{\text{ref}}}{L_{\text{CT}}}$$

Errors sources and good practice in CT scanning

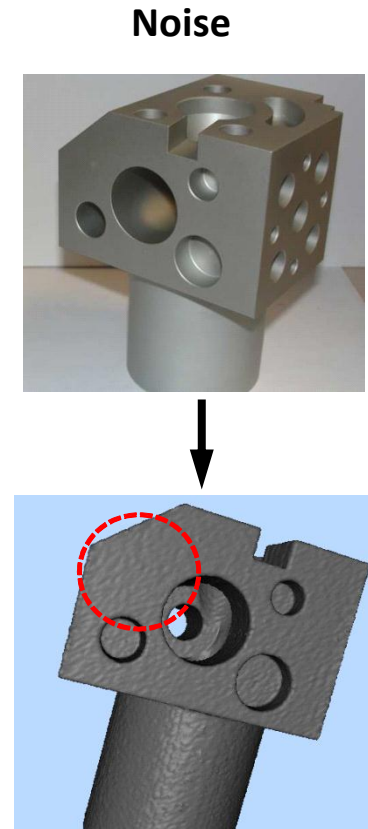
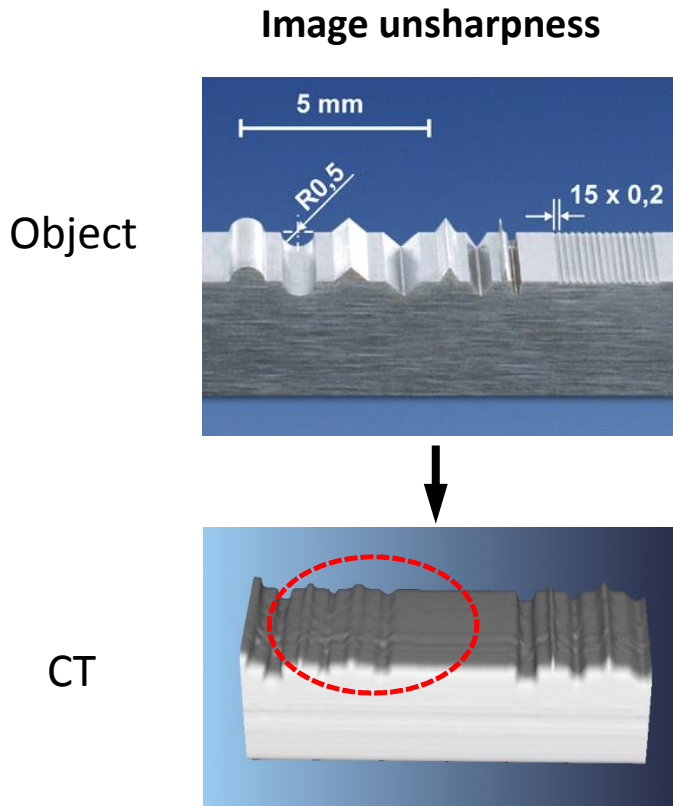
Good practice:

- In particular at high magnifications: Ball-bar must be scanned together with the workpiece



Focus drift differs from scan to scan!

Errors sources and good practice in CT scanning

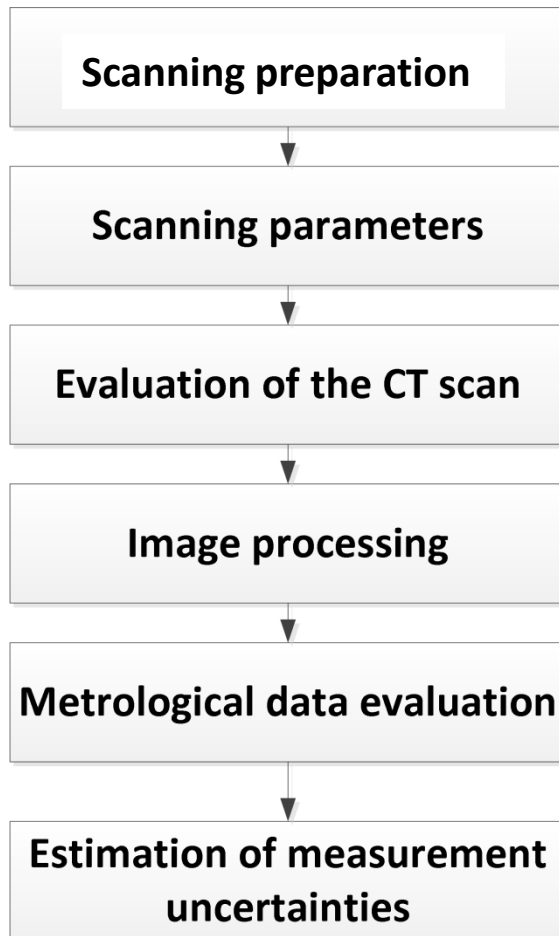


Depending on object, scanning parameters, system hard- and software

Conclusions and future works

- CT as a powerful and flexible tool in production metrology
- Variety of error sources and influence quantities in CT metrology
- Possibilities to reduce systematic errors (effects)
- Importance of a consistent procedure in CT scanning planning

Conclusions and future works



- Material, shape, penetration lengths
- Fixture, positioning, orientation
- Tube voltage, current, prefilter, detector settings
- Evaluation of detector images → histogram analysis
- Image quality (artefacts, sharpness, noise)
- Voxel histogram analysis, threshold tests
- Surface quality inspection
- Alignment
- Measurement strategy (elements, points, methods)
- Reference data available, repeated measurements

Invitation to Conference on

**“Industrial Applications of CT Scanning –
Possibilities & Challenges in the Manufacturing Industry”**

June 12, 2012, 10:00-16:30

DTU, Building 101, meeting room 1

2800 Kgs. Lyngby, Denmark

Thank you very much!