Systematic Errors in Dimensional X-ray Computed Tomography

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Systematic Errors in Dimensional

X-ray Computed Tomography

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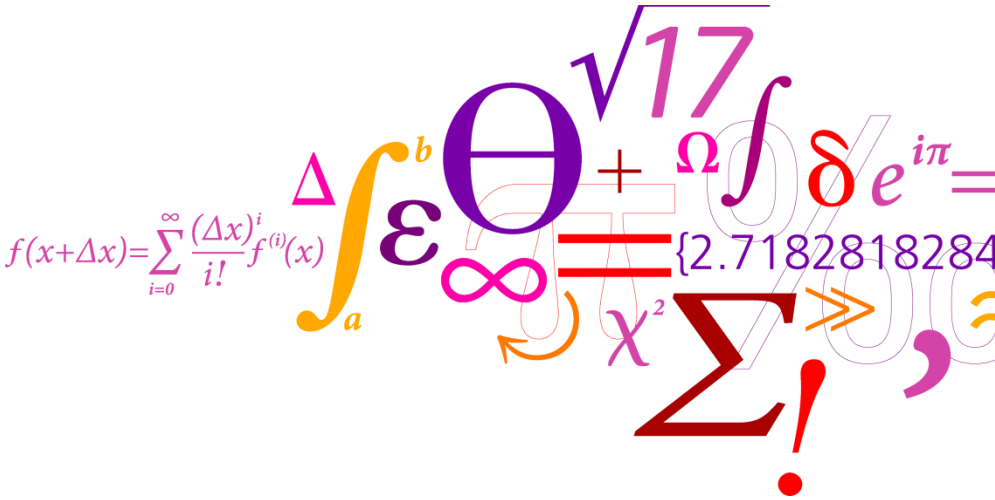
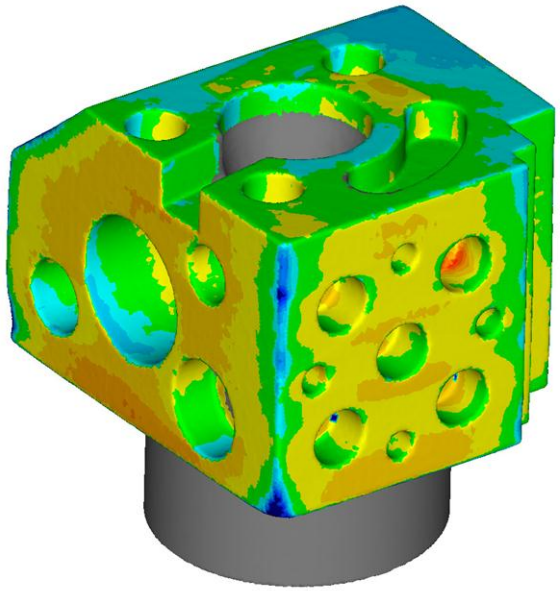
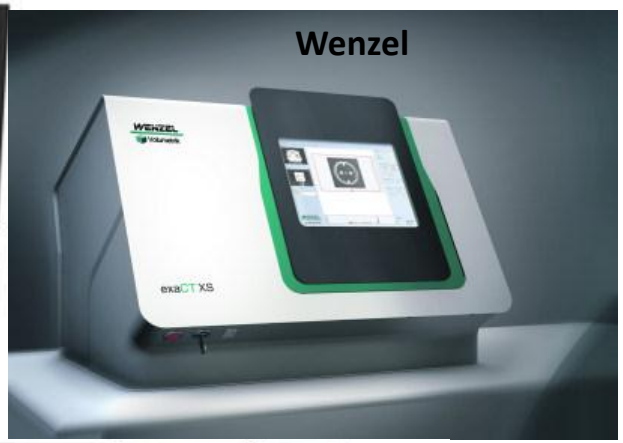


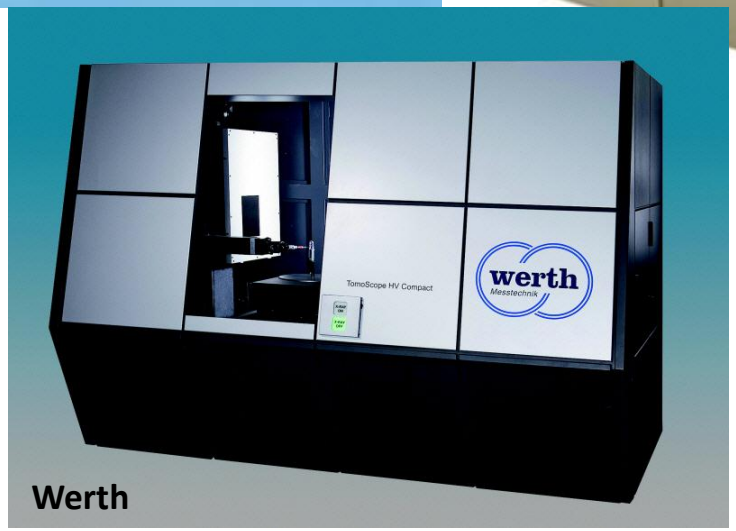
Overview



- 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

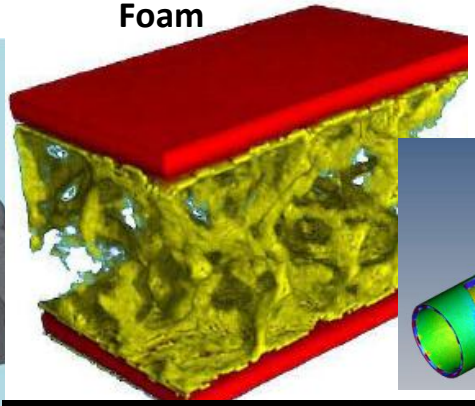




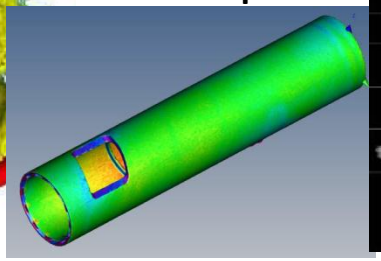
Industrial X-ray CT today

Aluminum casting

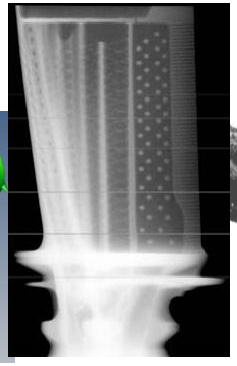
Foam



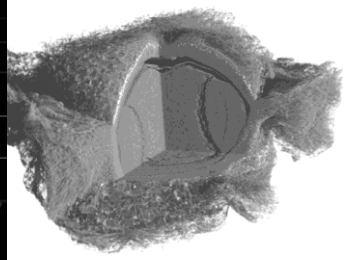
Insulin pen

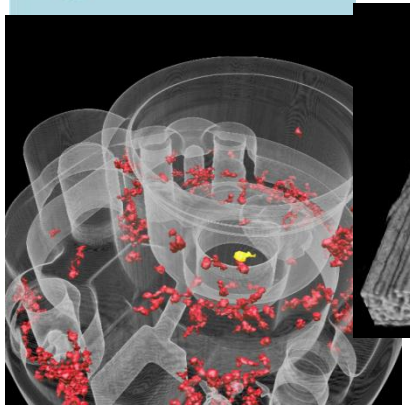


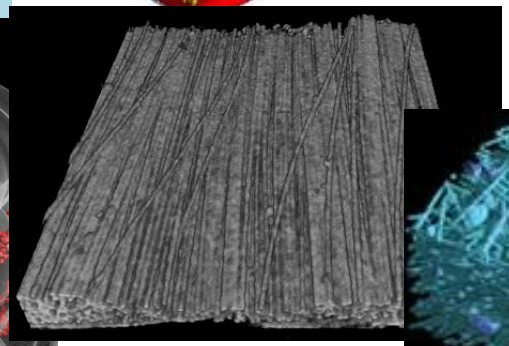
Turbine plate



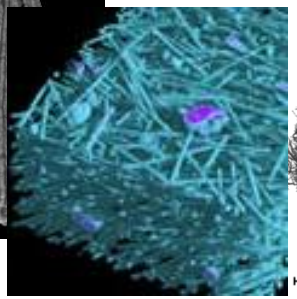
Seed



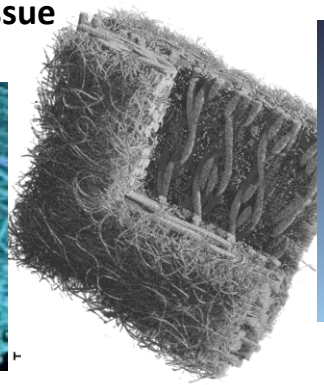




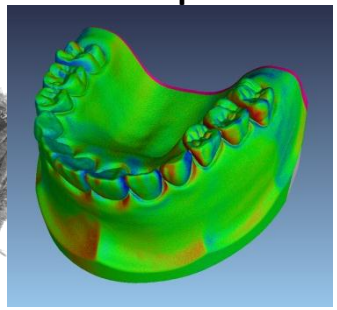
Fiber-composite



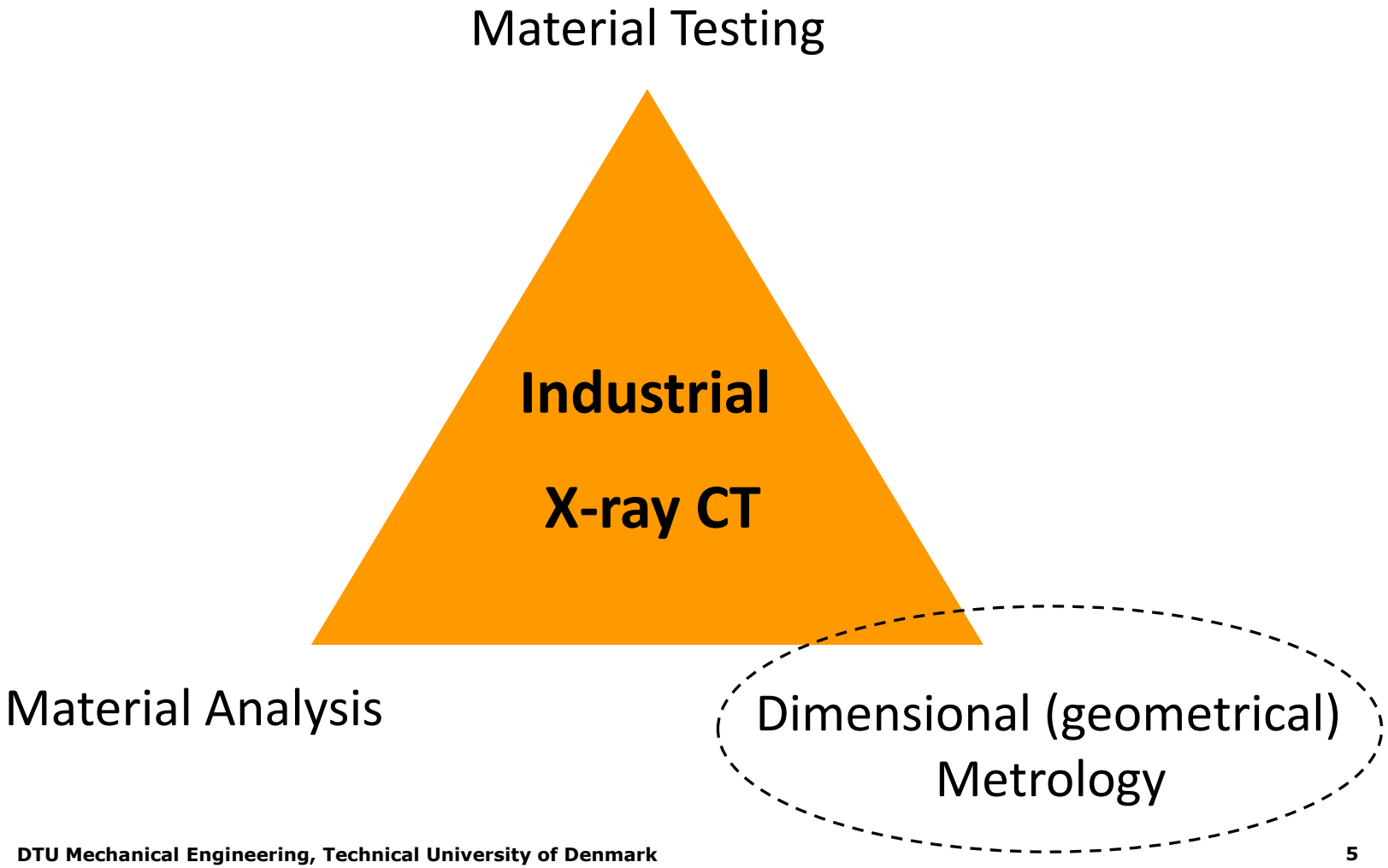
Tissue



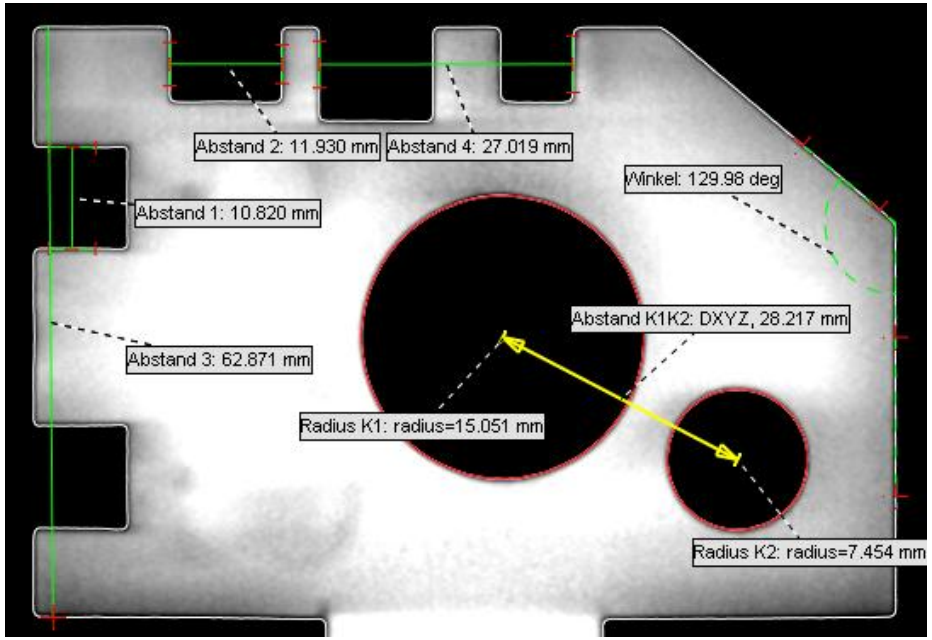
Dental impression



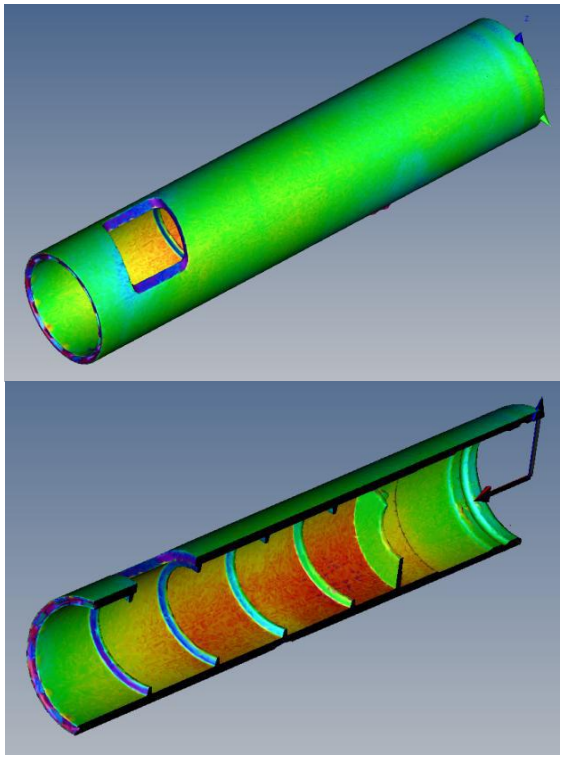
Industrial X-ray CT today



Dimensional CT as a key technology in production metrology

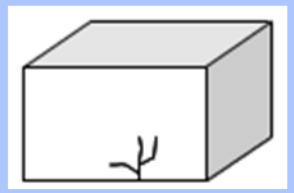
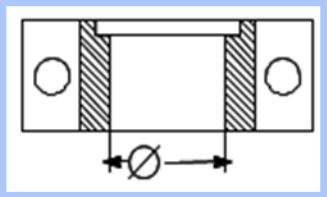


Measurement of size, form, and position



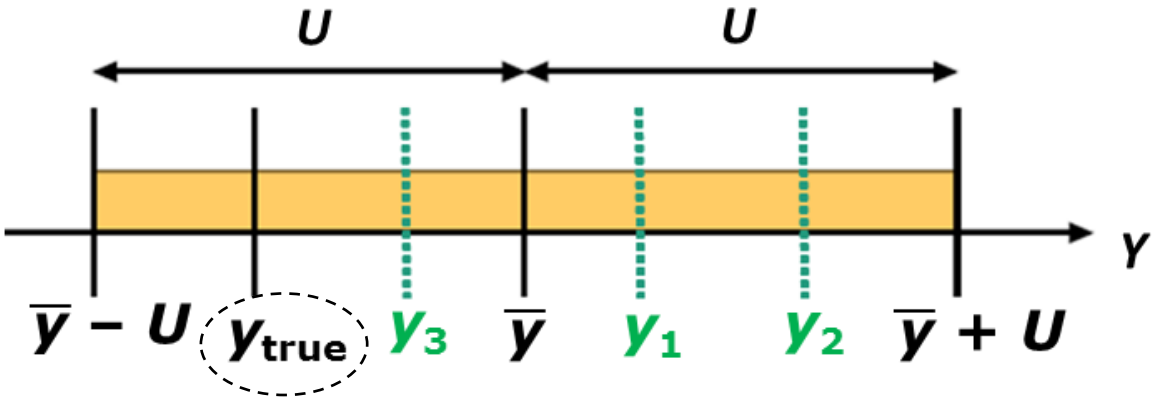
CAD/CT comparison

Dimensional CT as a key technology in production metrology

Application	Material Analysis	Material Testing	Dimensional Metrology
Symbol			
Performance Parameter	Structural Resolution	Failure Detectibilty	Measurement Uncertainty

Dimensional CT as a key technology in production metrology

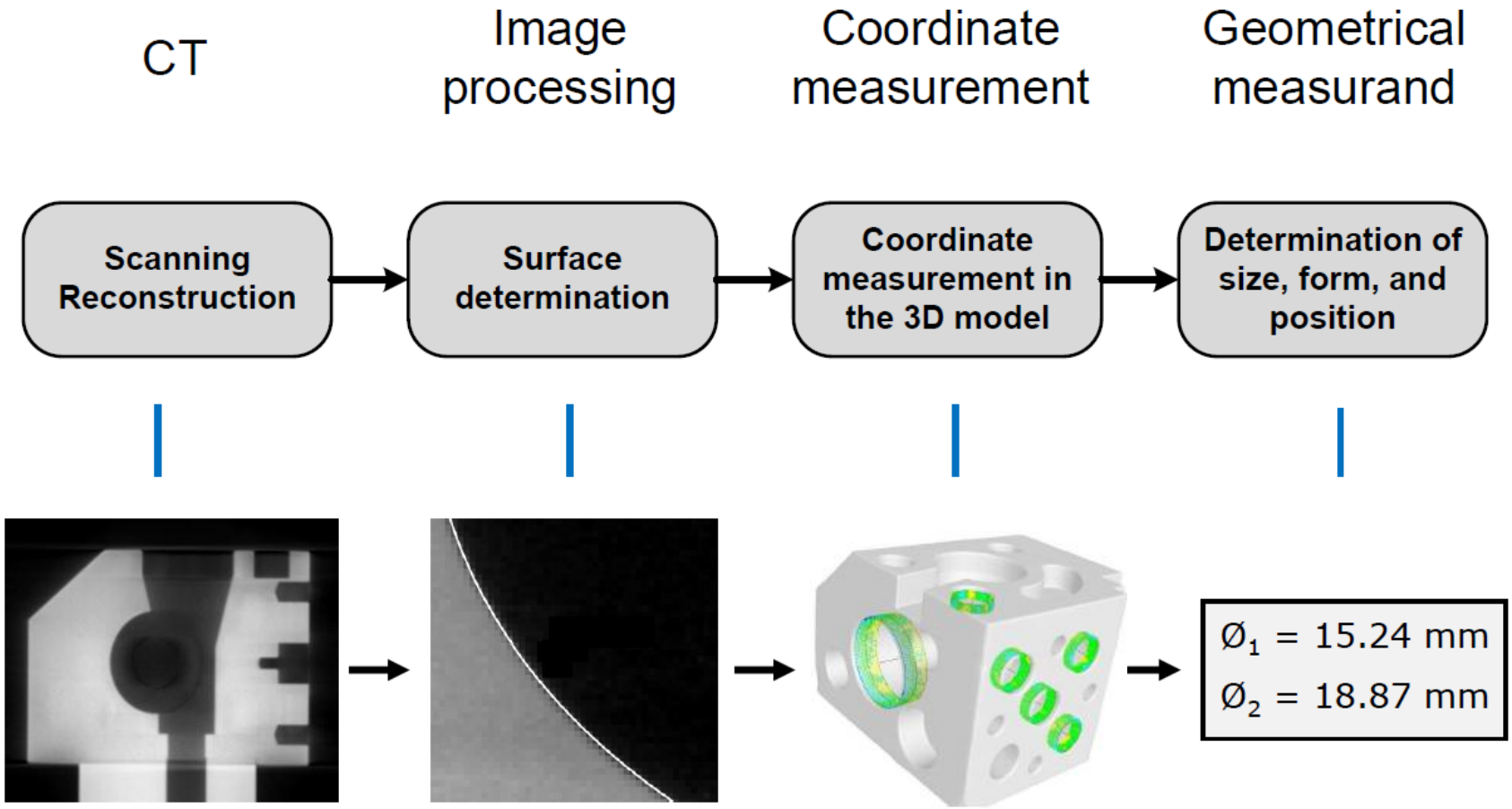
Measurement uncertainty *U*:



- 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

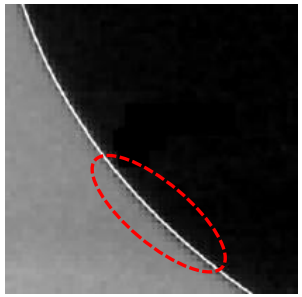


Errors sources and good practice in CT scanning

What are sources of systematic errors?

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

Segmentation and surface determination errors

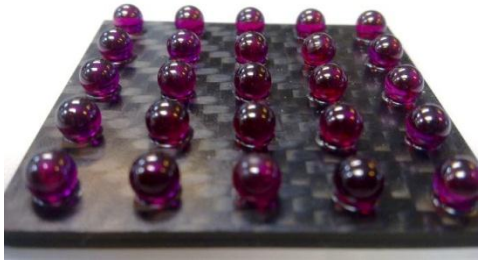


- Metrological data evaluation strategy

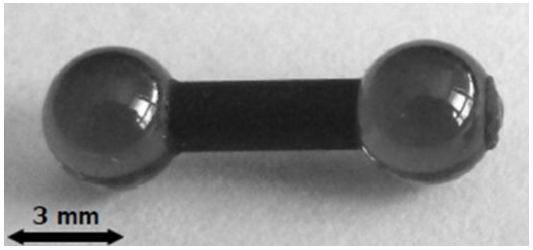
Errors sources and good practice in CT scanning

Can we use calibration artefacts?

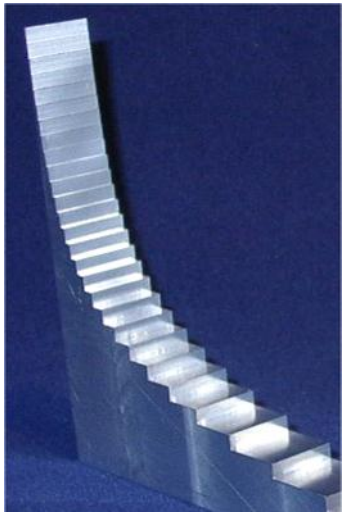
Only for the compensation of effects linked to geometrical scanner misalignment or beam-hardening artefacts



Ball-plate



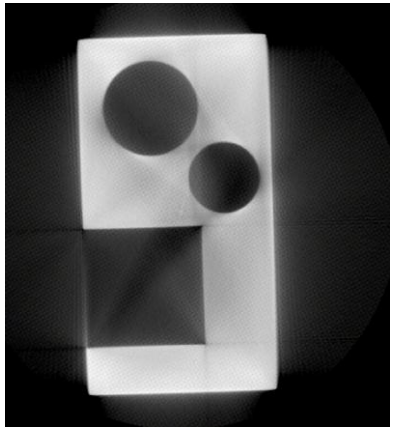
Ball-bar



Step-wedge

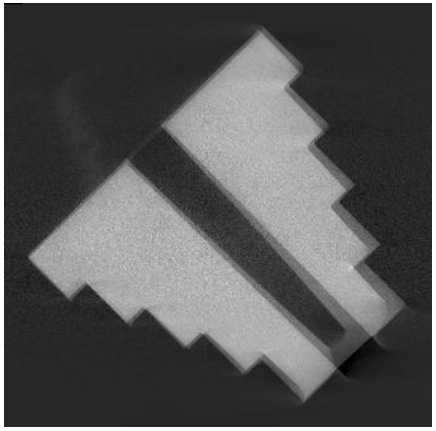
- Calibrated masterpieces
- Systematic scanning and evaluation planning to avoid high systematic errors (blunder)

Errors sources and good practice in CT scanning

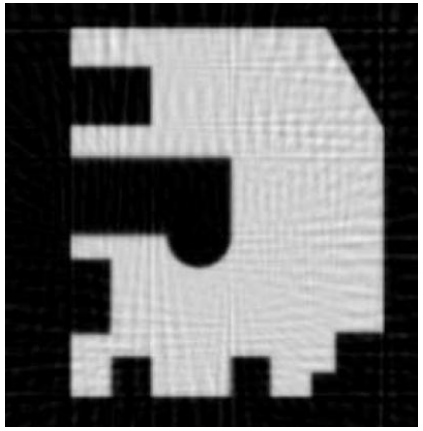


Beam-hardening

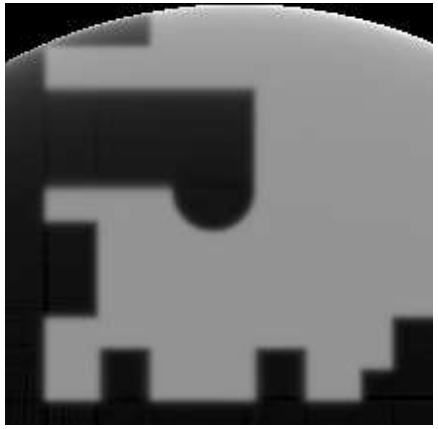
Cone-beam



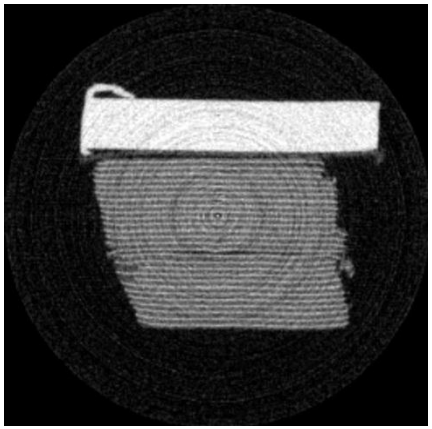
Misalignment



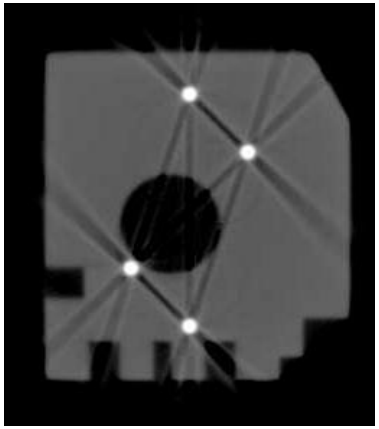
Undersampling



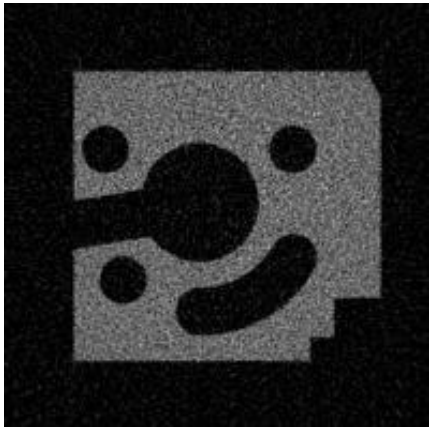
Truncation



Ring artifacts



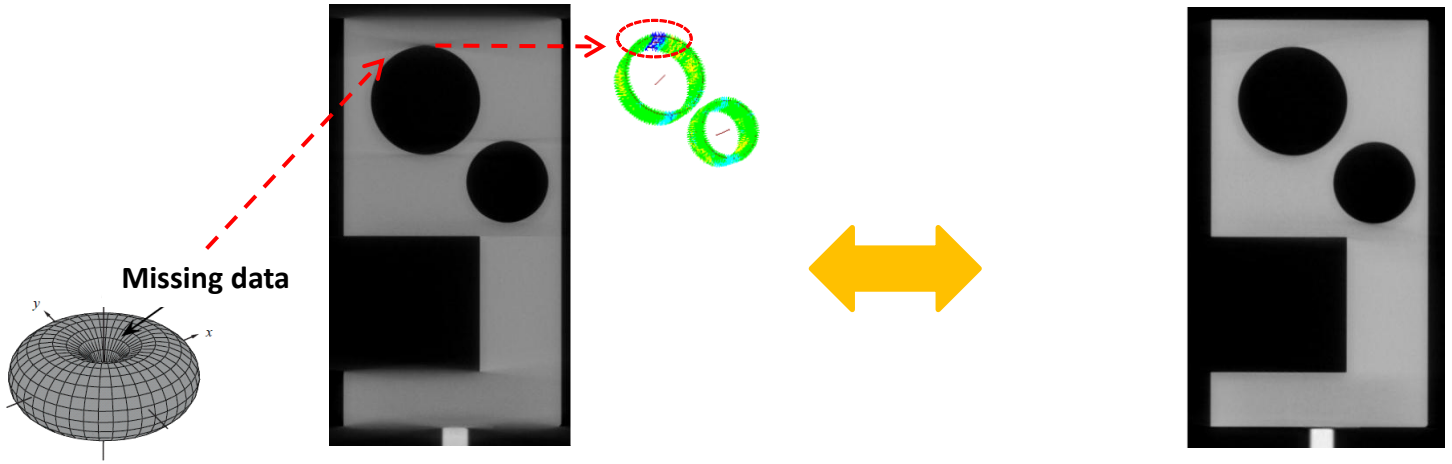
Metal artifacts

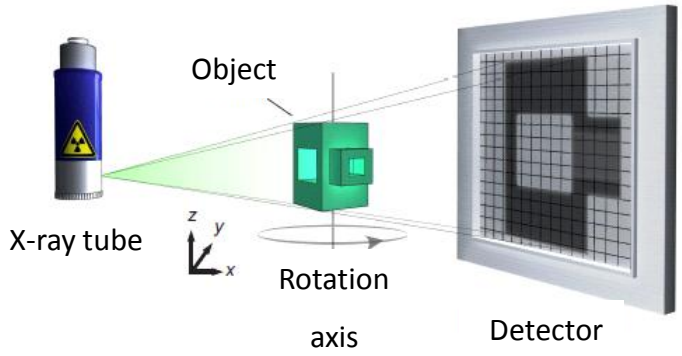


Noise artifacts

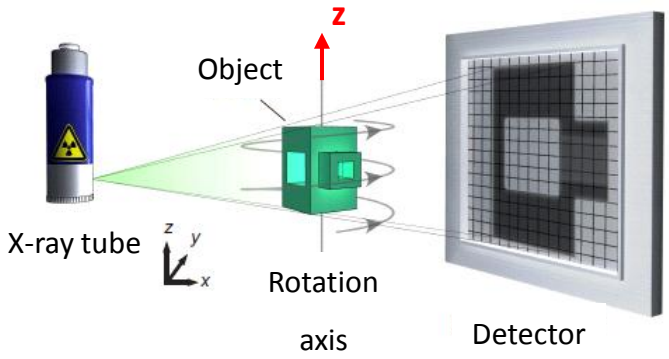
Errors sources and good practice in CT scanning

Cone-beam artefacts:





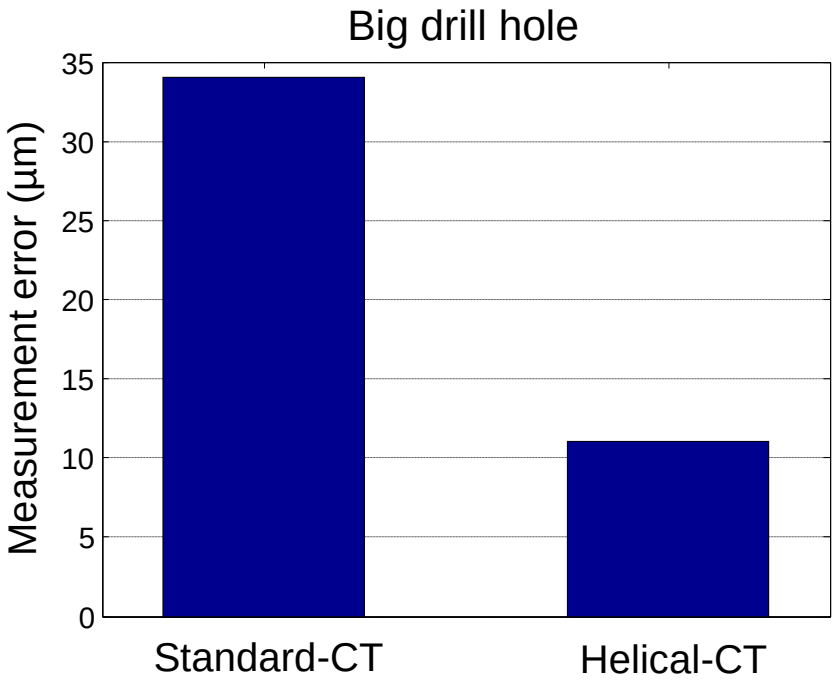
Circular sampling

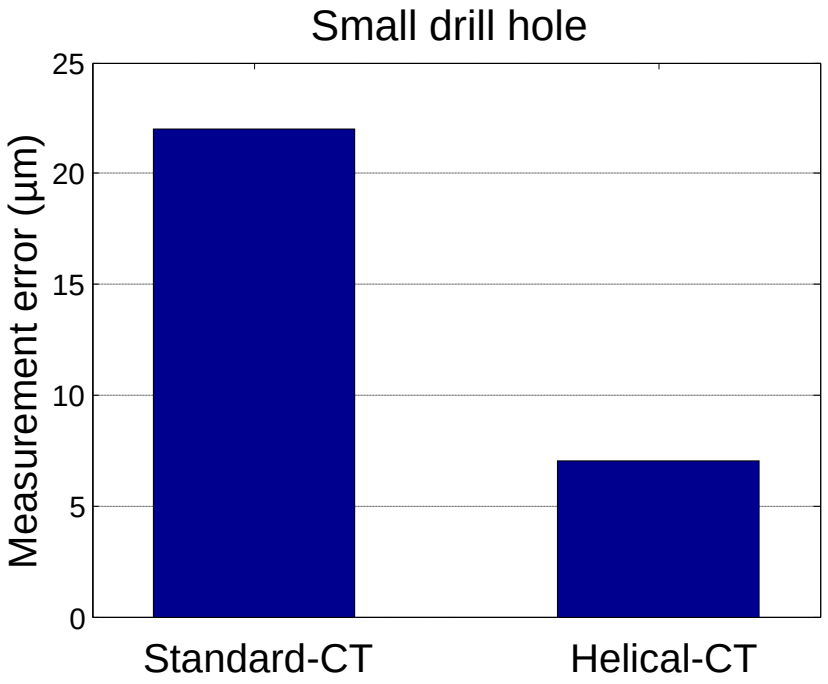


Helical sampling

Errors sources and good practice in CT scanning

Standard vs.helical CT:



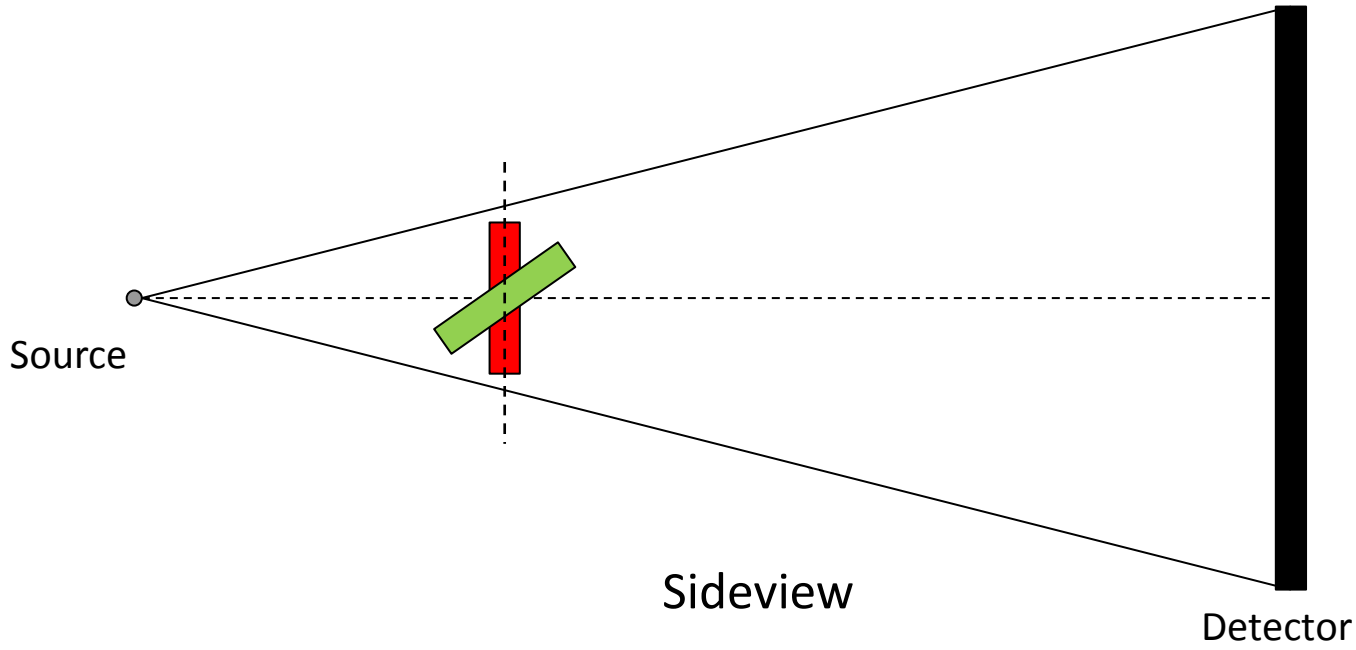


Voxel size: 105,7 μm^3

Errors sources and good practice in CT scanning

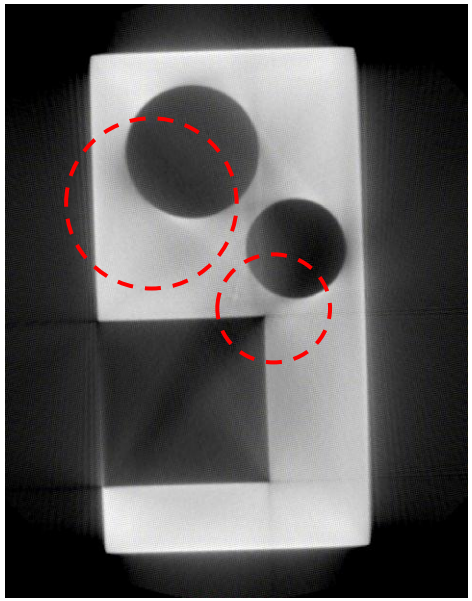
Good practice:

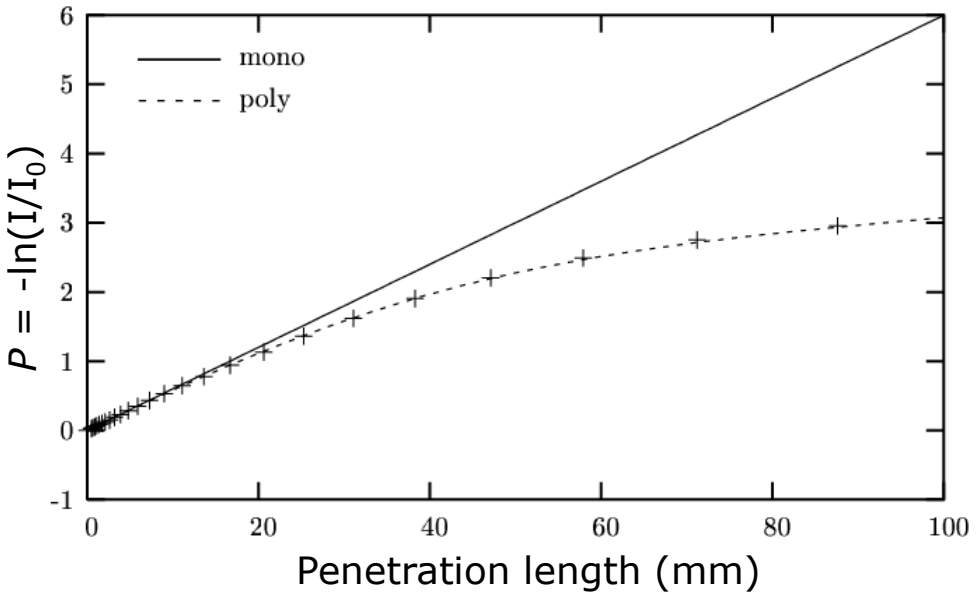
- Tilted position of the workpiece



Errors sources and good practice in CT scanning

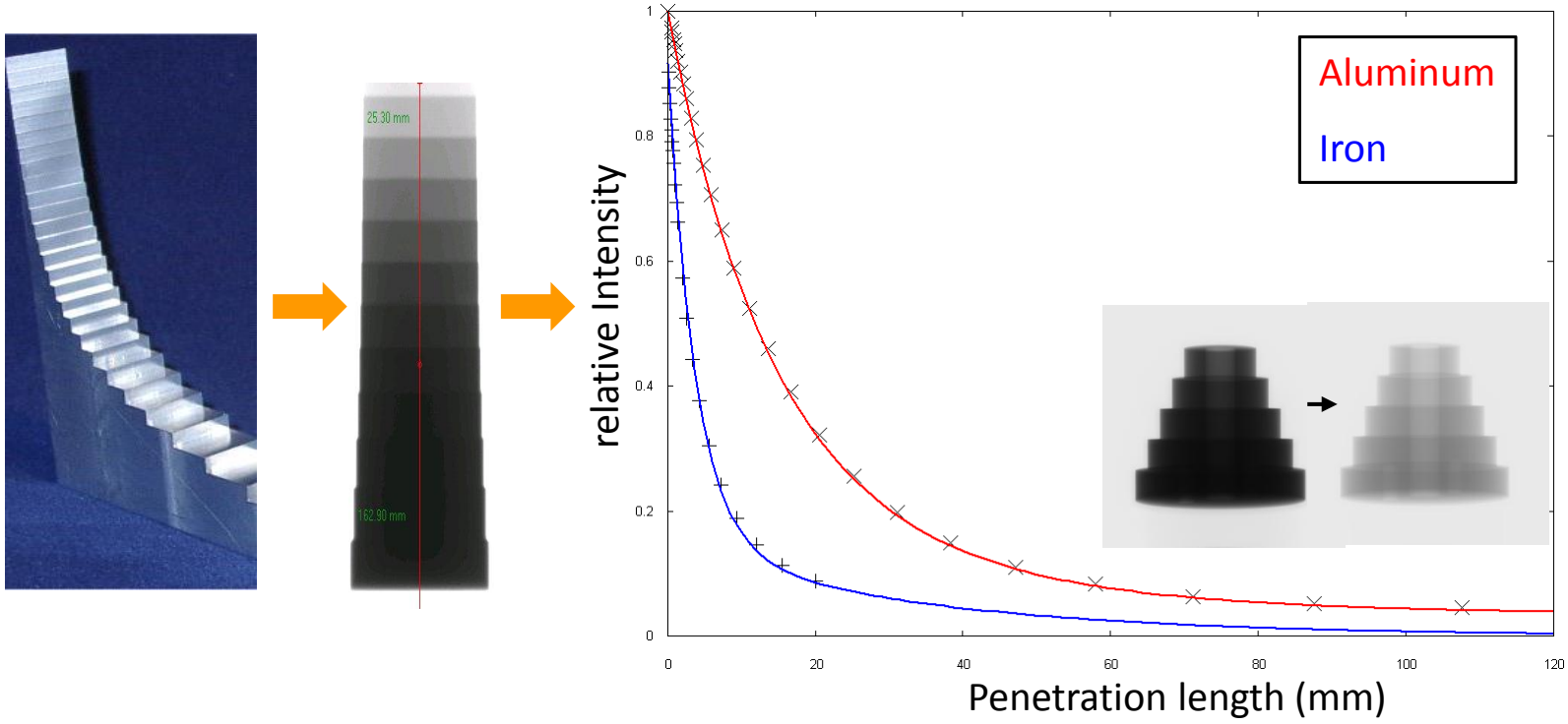
Beam-hardening:





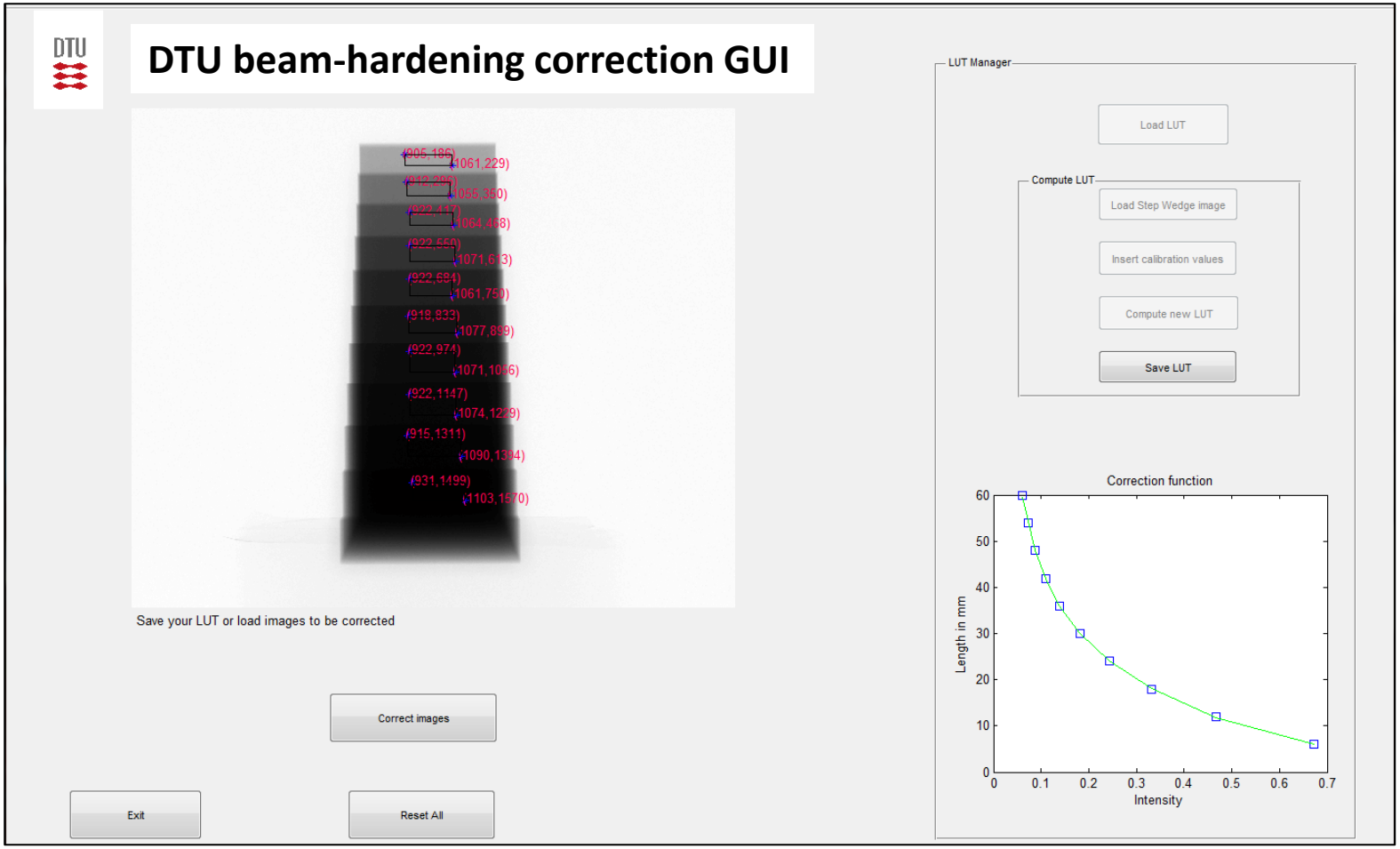
Errors sources and good practice in CT scanning

Beam-hardening correction:



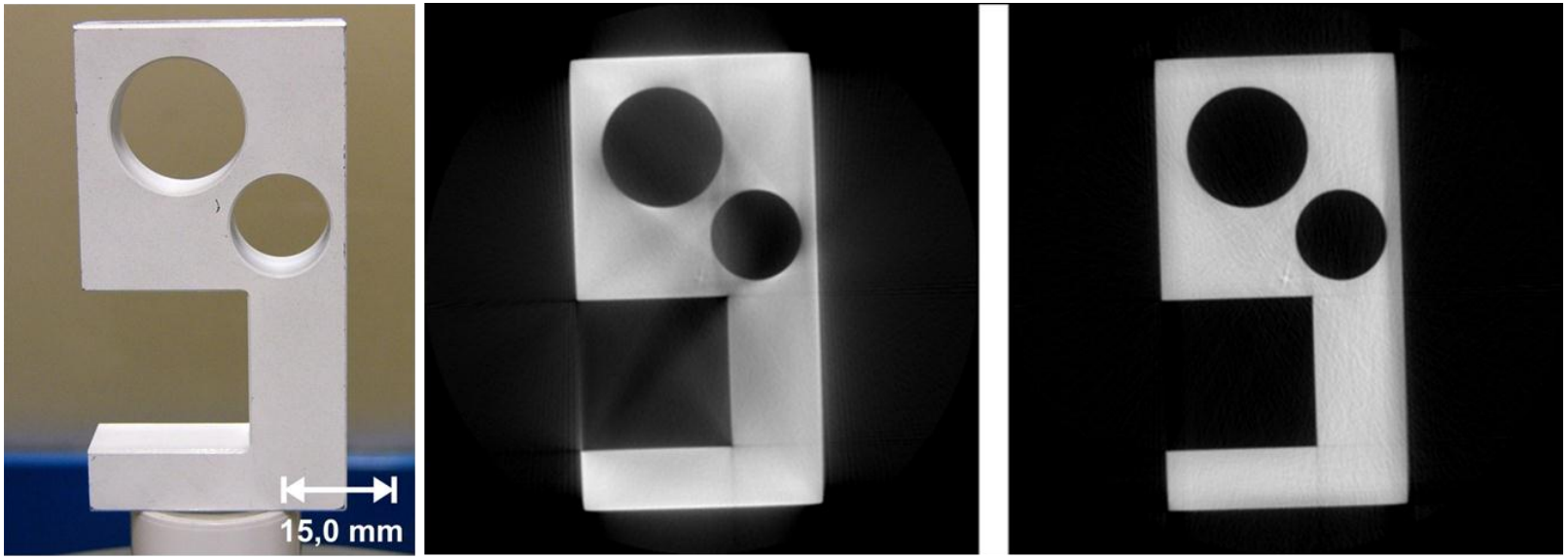
Step wedge → Radiography → Linerization of projections with inverse function

Errors sources and good practice in CT scanning



Errors sources and good practice in CT scanning

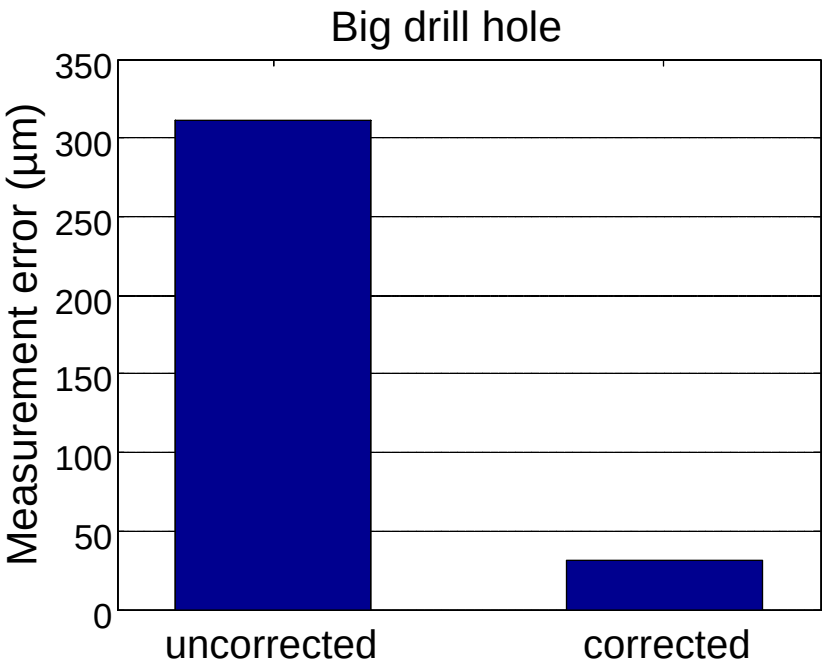
Beam-hardening correction:

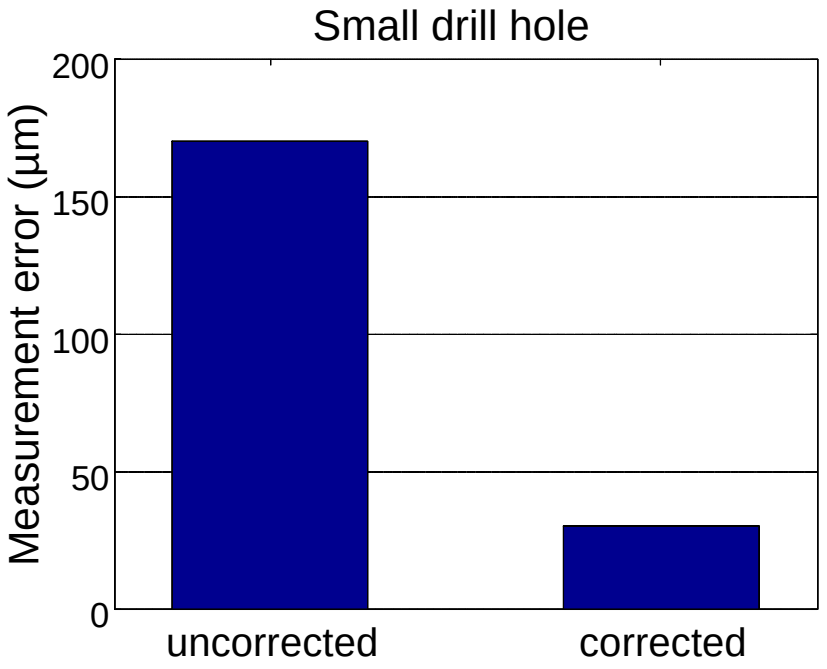


Object (Al) uncorrected corrected

Errors sources and good practice in CT scanning

Beam-hardening correction:



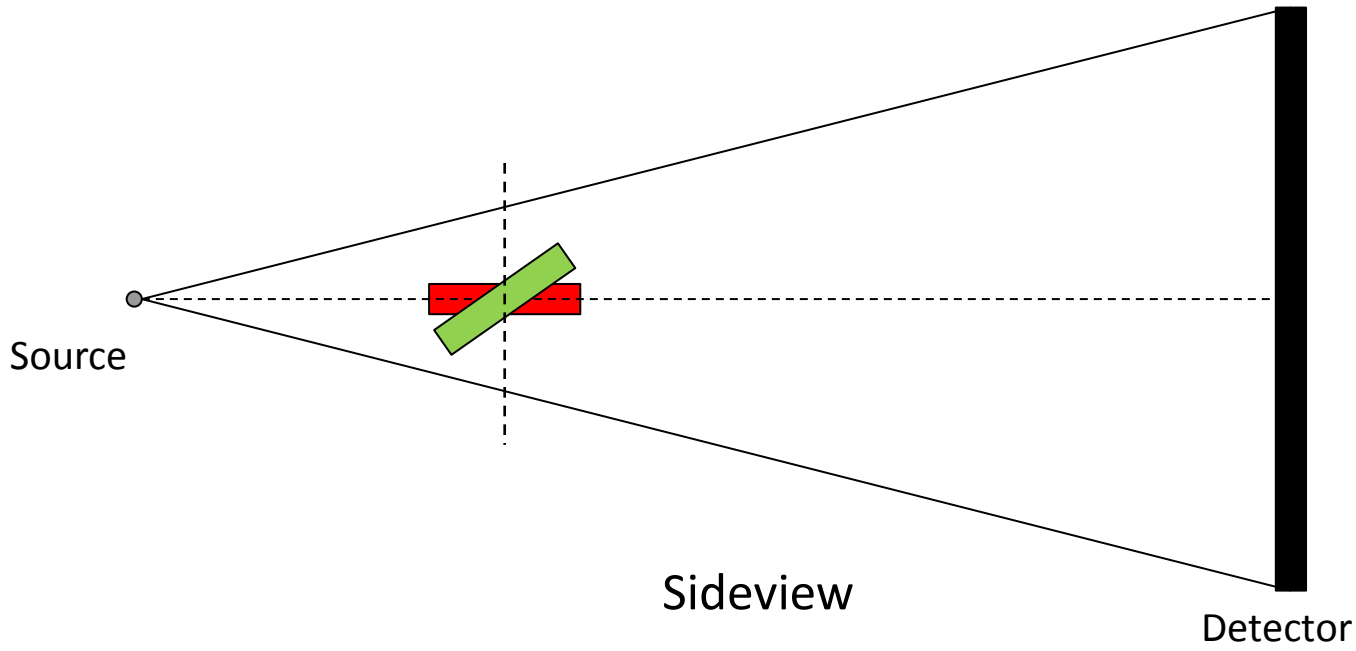


Voxel size: (156,7 × 156,7 × 179,3) μm^3

Errors sources and good practice in CT scanning

Good practice:

- Tilted position of the workpiece

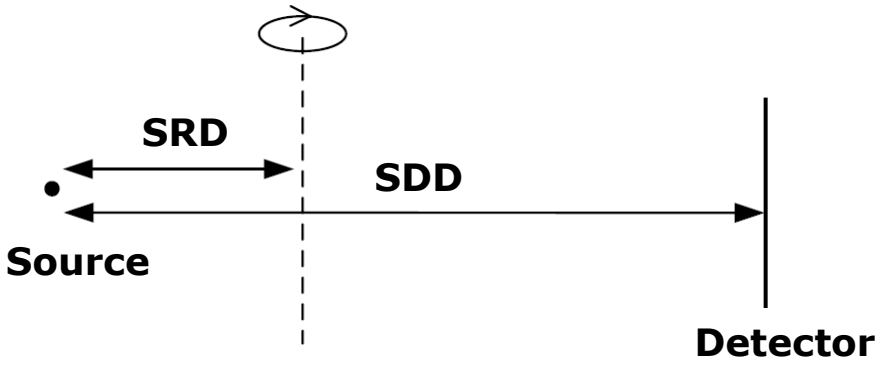


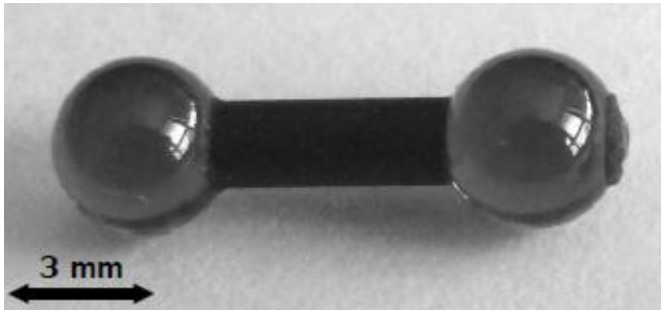
- Using a prefilter

Errors sources and good practice in CT scanning

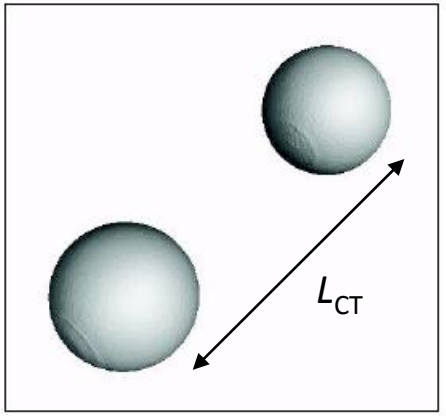
m = SDD/SRD

$v = a/m$





Calibrated length: 8,7678 mm

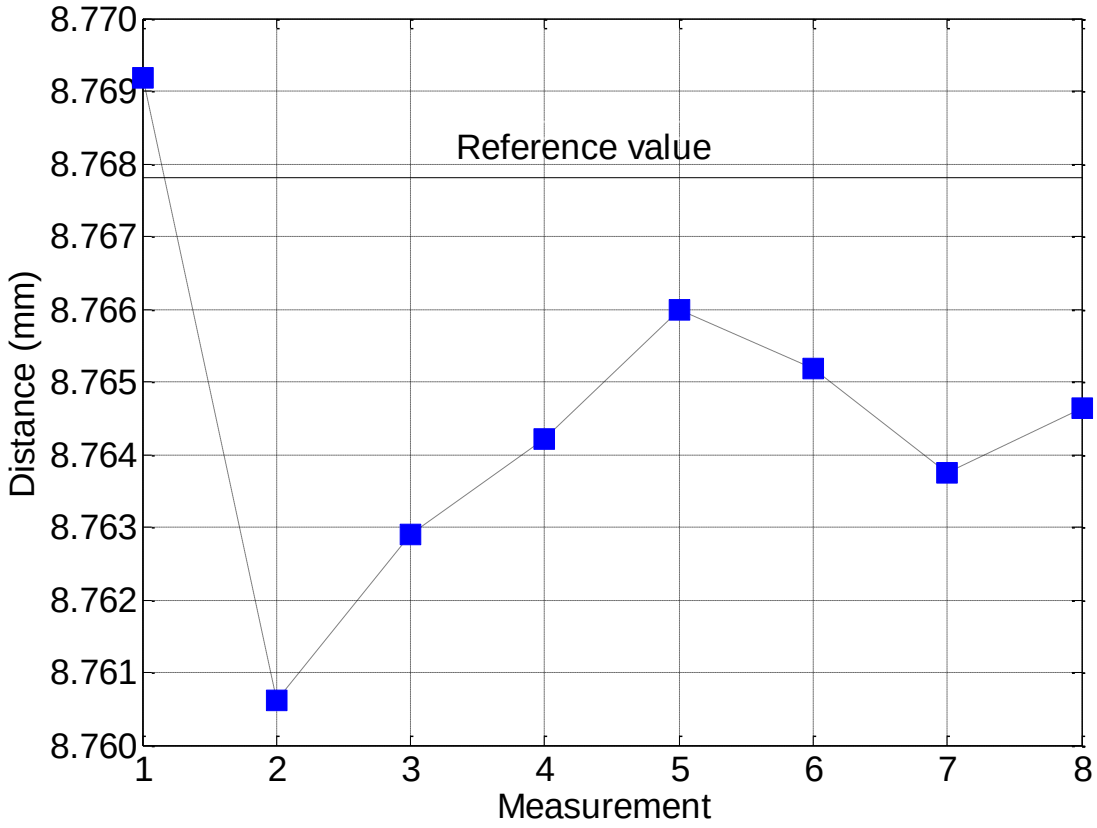


v = 30 µm, Δv = 1 µm

l = 1,5 mm

Error: Δl = 50 µm

Errors sources and good practice in CT scanning



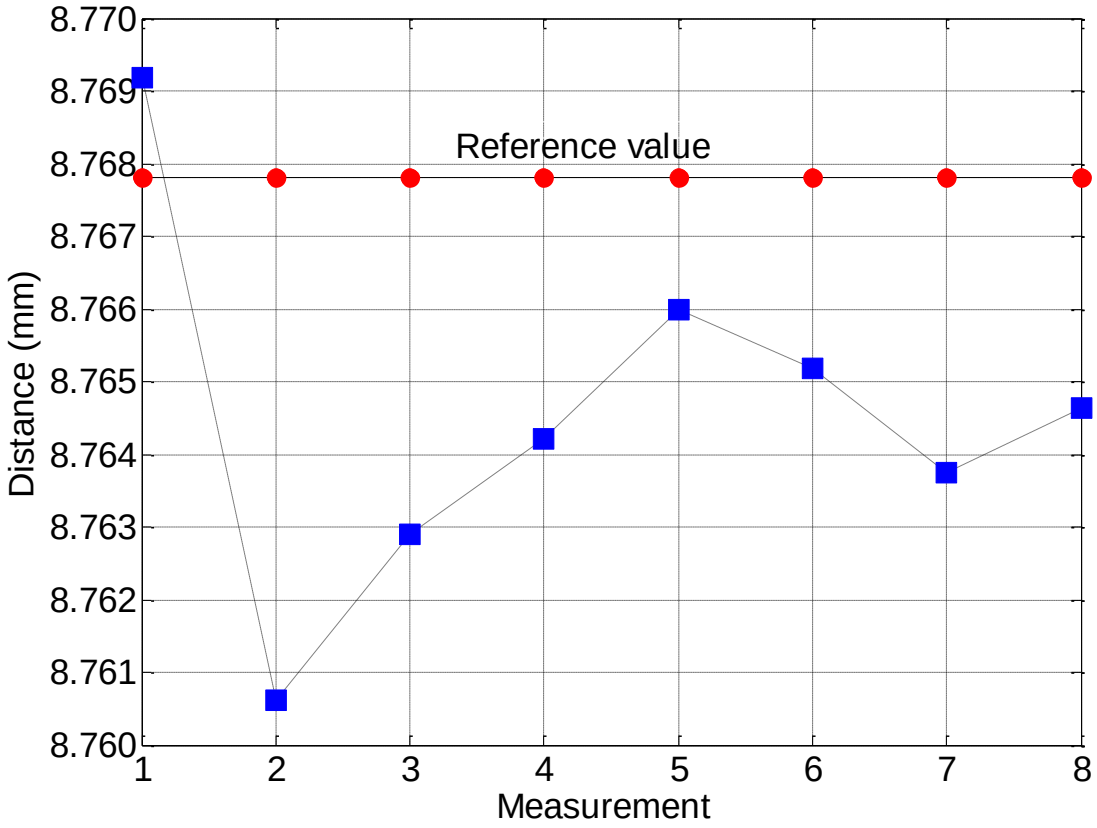
Variations are caused by inaccuracies of the SRD measurement (manipulator)

+

Focus drift during scanning due to tube temperature changes

superimposed

Errors sources and good practice in CT scanning



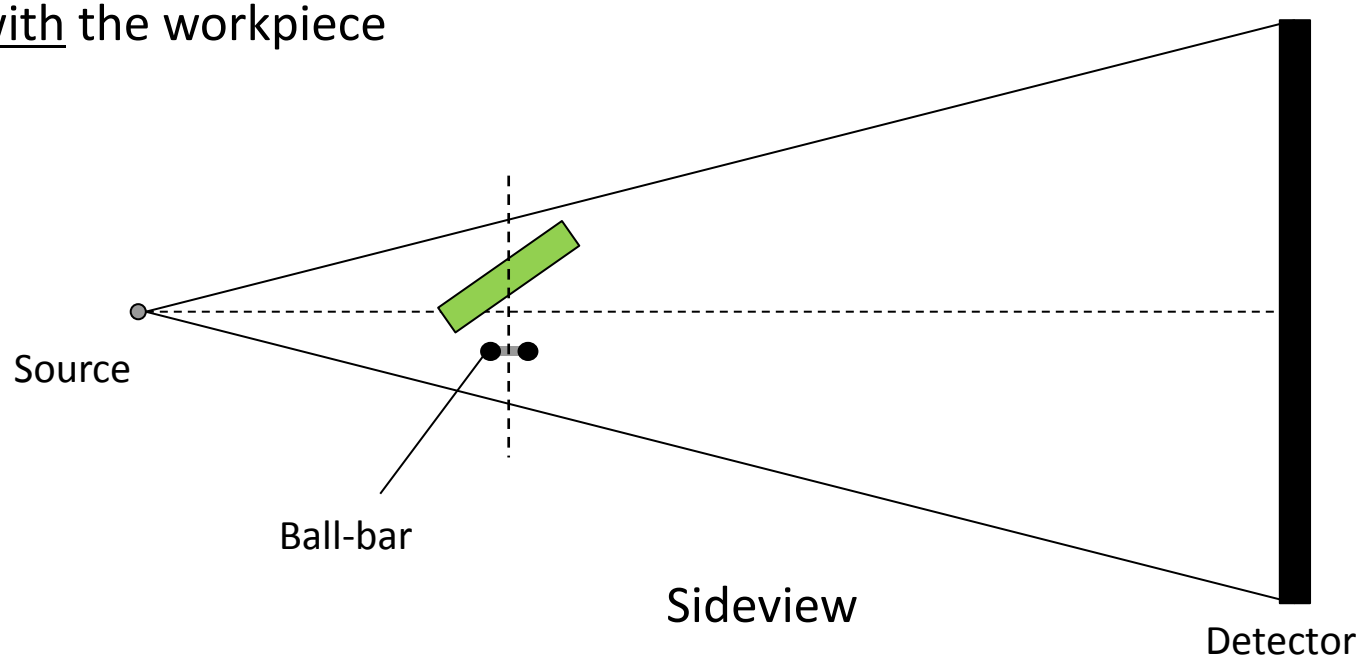
Voxel size rescaling:

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

Errors sources and good practice in CT scanning

Good practice:

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

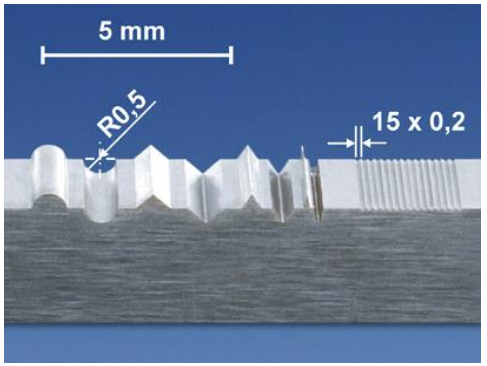


Focus drift differs from scan to scan!

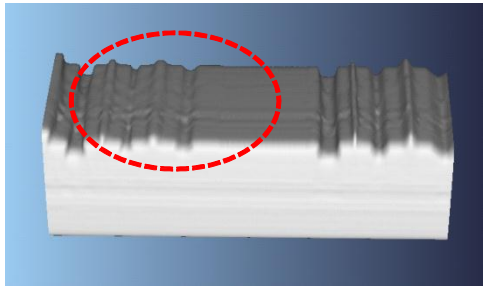
Errors sources and good practice in CT scanning

Image unsharpness

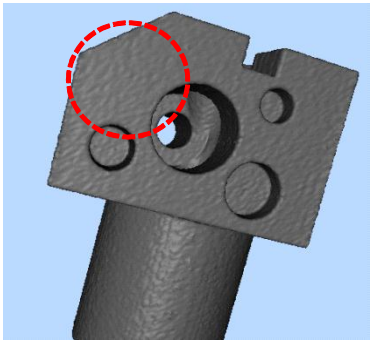
Object



CT



Noise

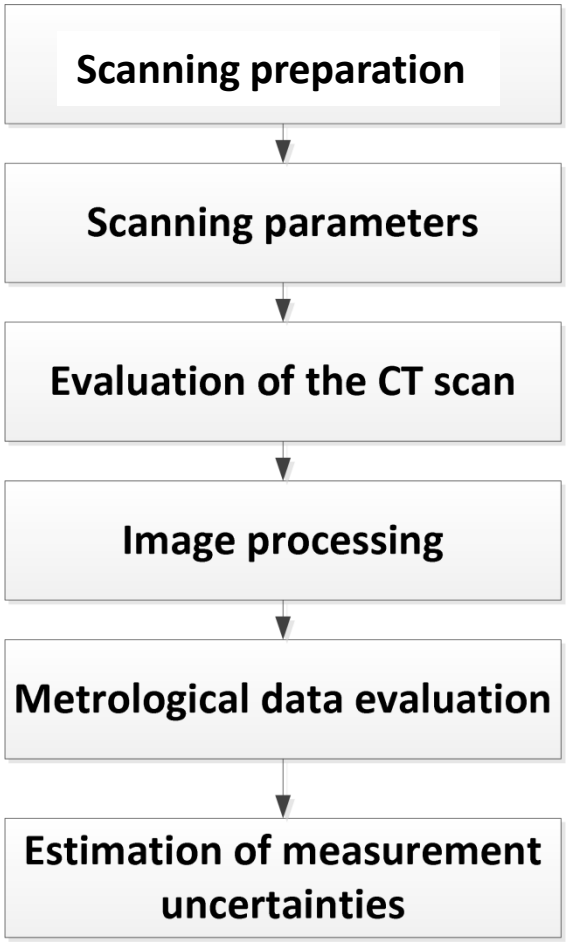


Depending on object, scanning parameters, system hard- and software

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!