Systematic Errors in Dimensional

X-ray Computed Tomography

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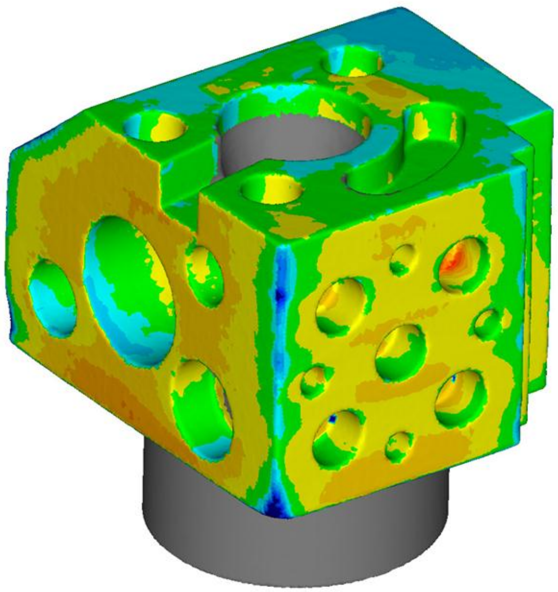
Institut for Mekanisk Teknologi

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


Zeiss

Phoenix

Wenzel

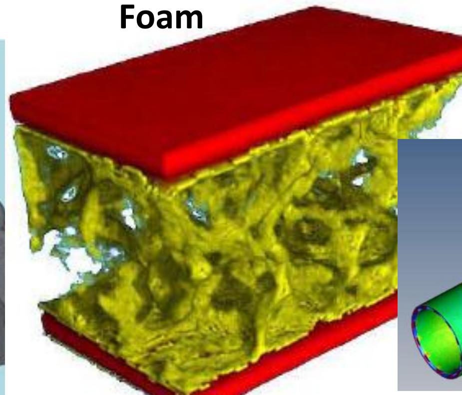
Werth

Skyscan

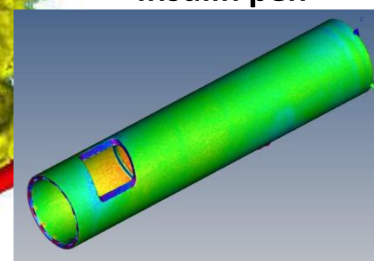
Industrial X-ray CT today

Aluminum casting

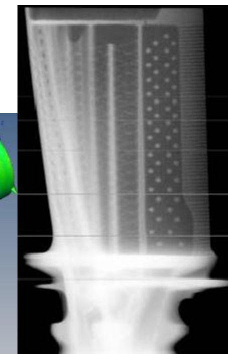
Foam



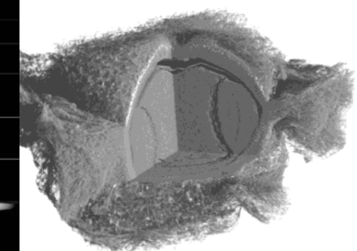
Insulin pen

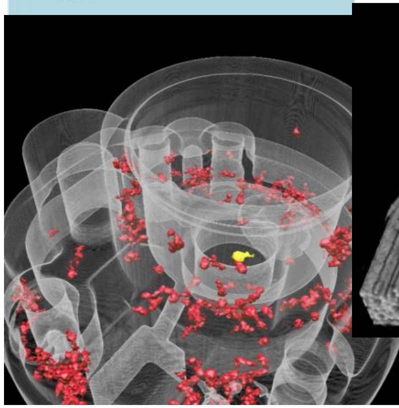


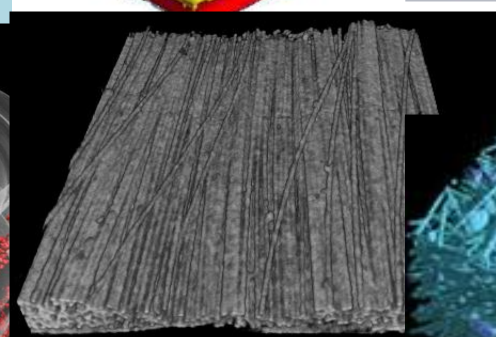
Turbine plate

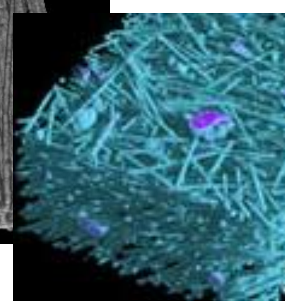


Seed



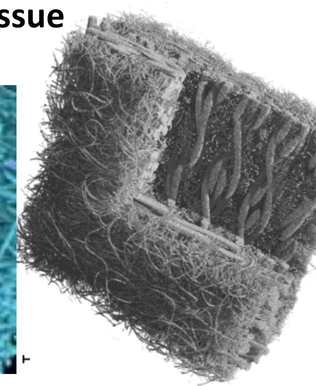




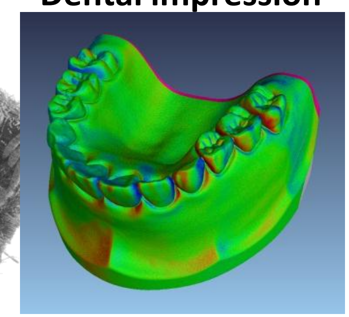


Fiber-composite

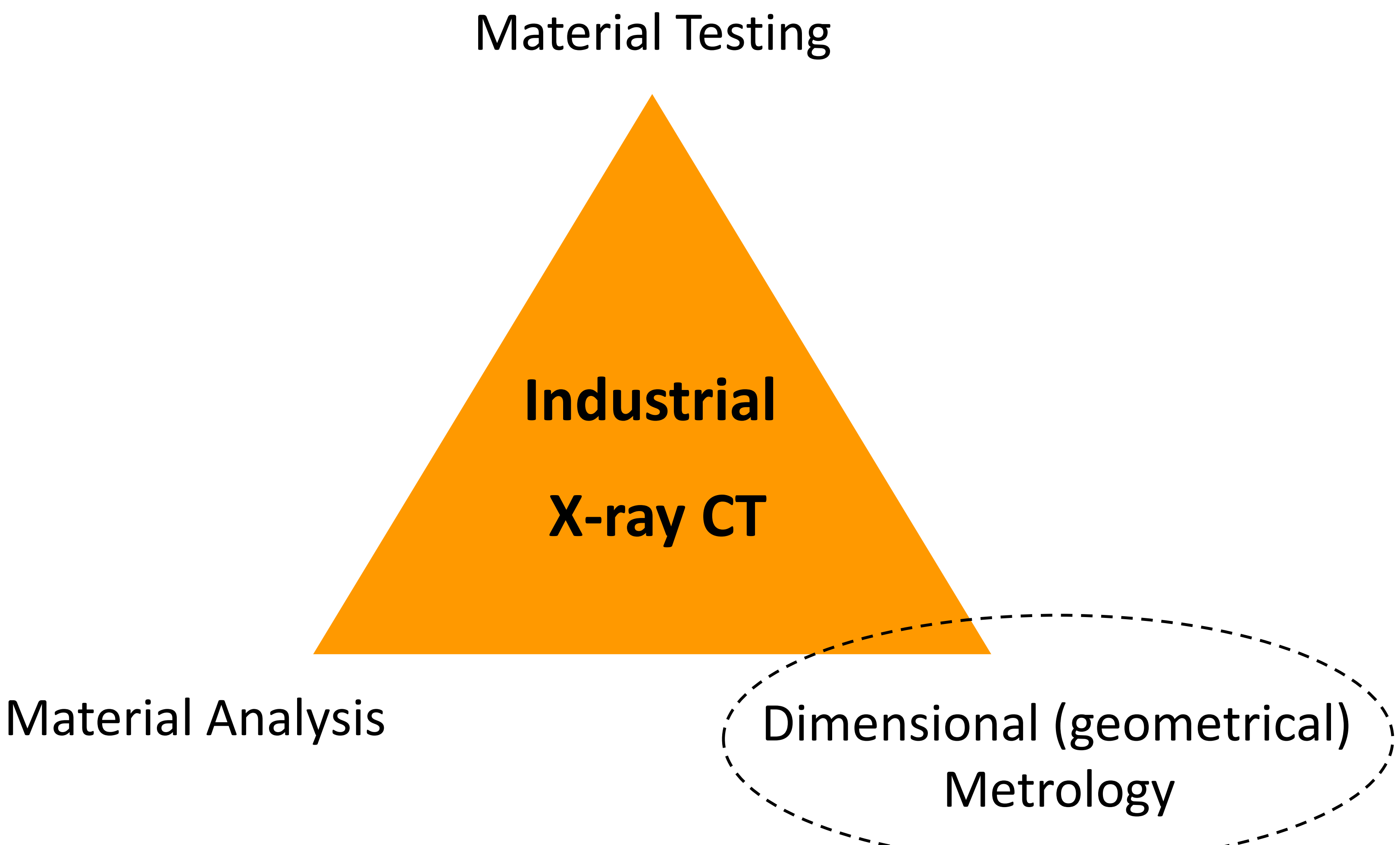
Tissue



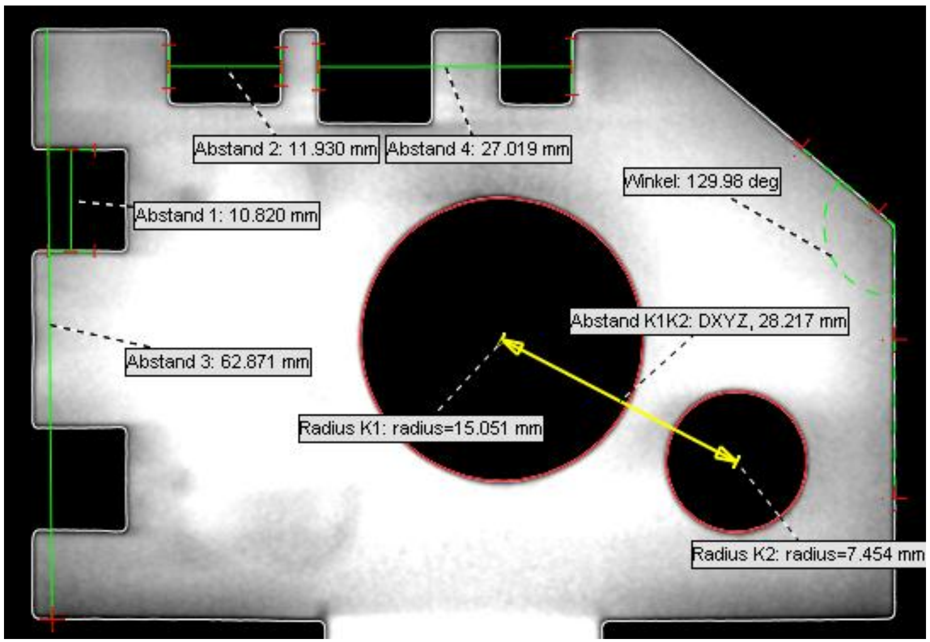
Dental impression



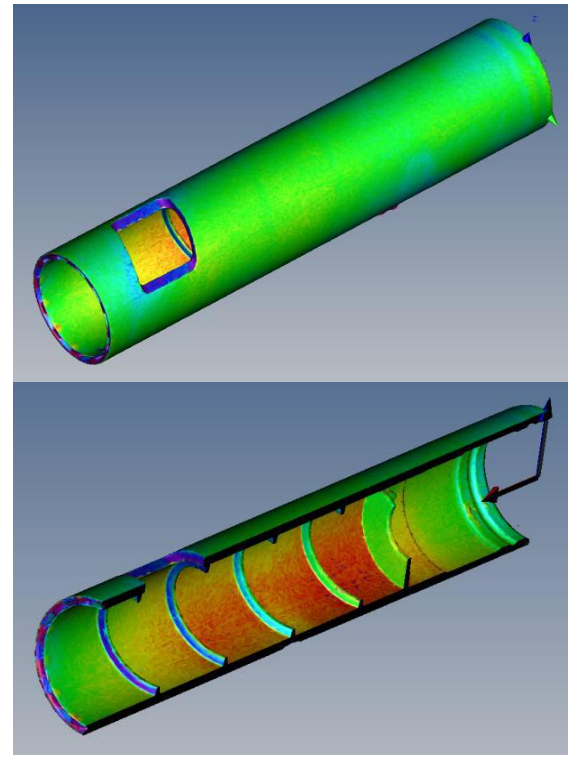
Industrial X-ray CT today



Dimensional CT as a key technology in production metrology

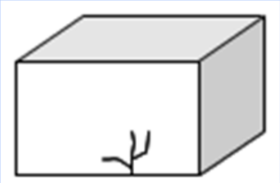
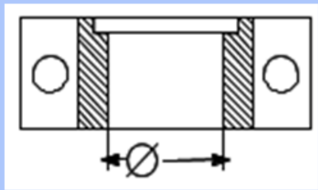


Measurement of size, form, and position



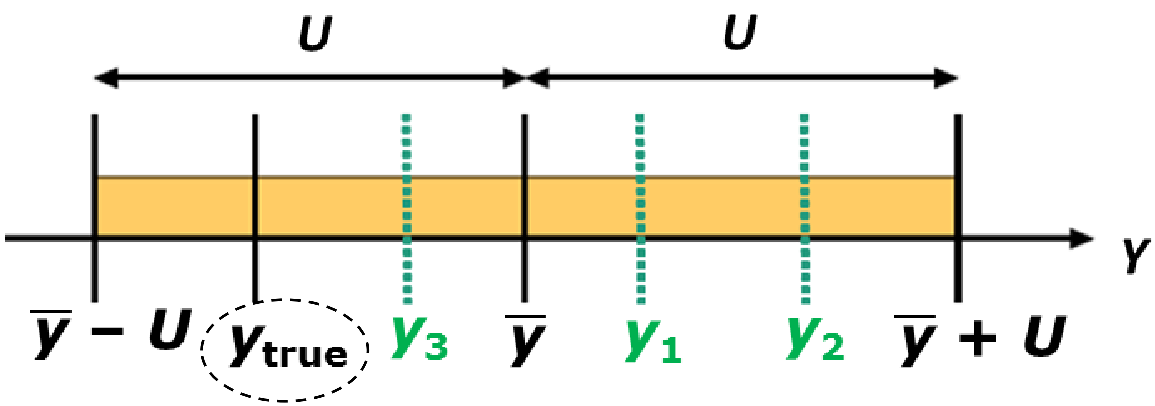
CAD/CT comparison

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*:

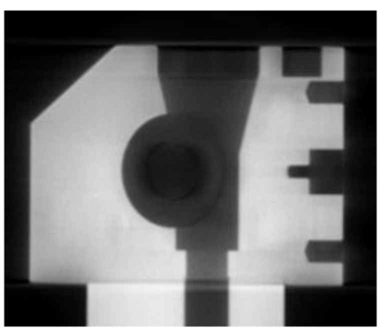


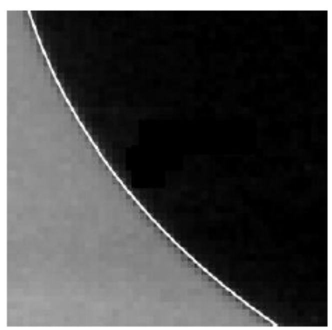
- We will never know the *true* value of a measurement
- Measurement results must be repeatable and reproducible
- What about systematic (effects) errors?

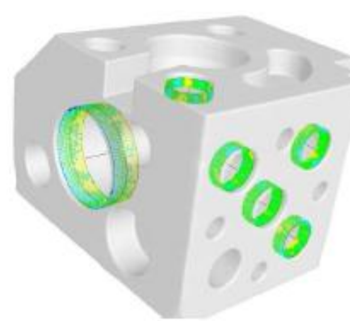
Should be corrected!

Errors sources and good practice in CT scanning

CT	Image processing	Coordinate measurement	Geometrical measurand
Scanning Reconstruction →	**Surface determination** →	**Coordinate measurement in the 3D model** →	**Determination of size, form, and position**







$Ø_1 = 15.24$ mm

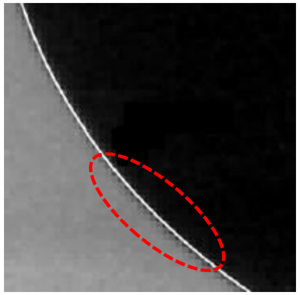
$Ø_2 = 18.87$ mm

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

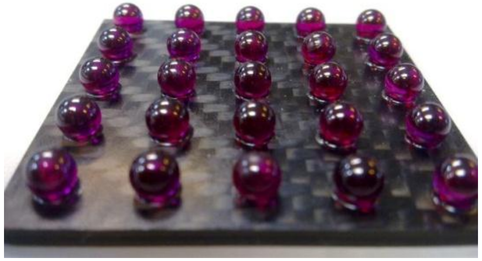


- Metrological data evaluation strategy

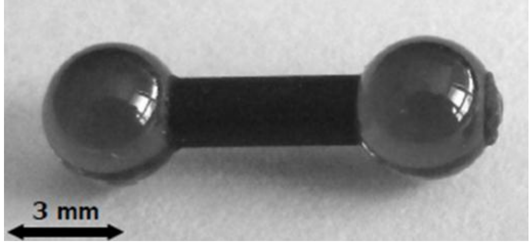
Errors sources and good practice in CT scanning

Can we use calibration artefacts?

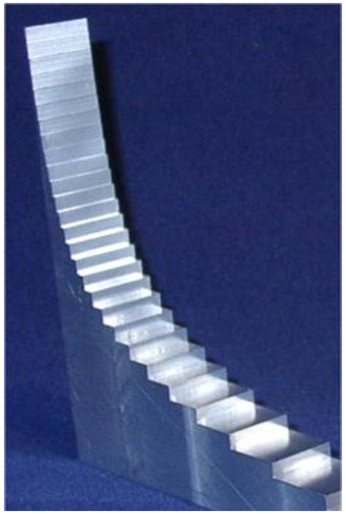
Only for the compensation of effects linked to geometrical scanner misalignment or beam-hardening artefacts



Ball-plate



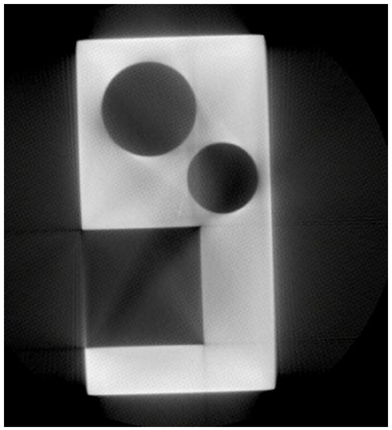
Ball-bar



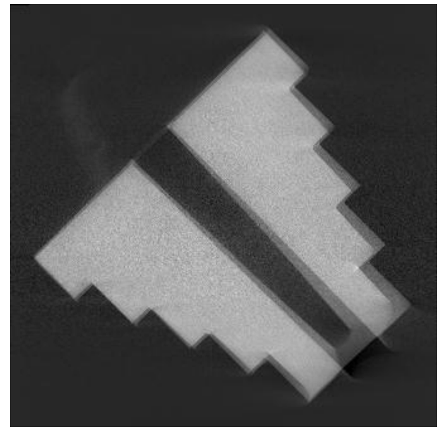
Step-wedge

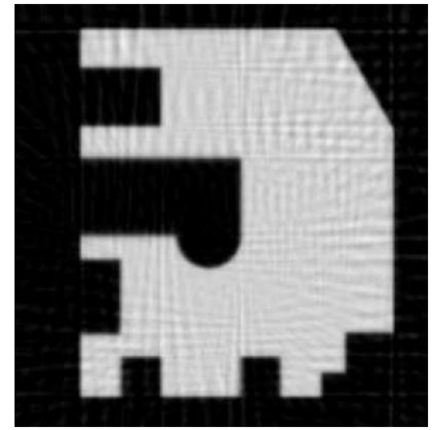
- Calibrated masterpieces
- Systematic scanning and evaluation planning to avoid high systematic errors (blunder)

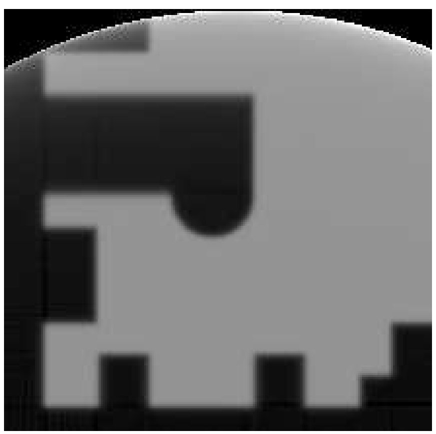
Errors sources and good practice in CT scanning

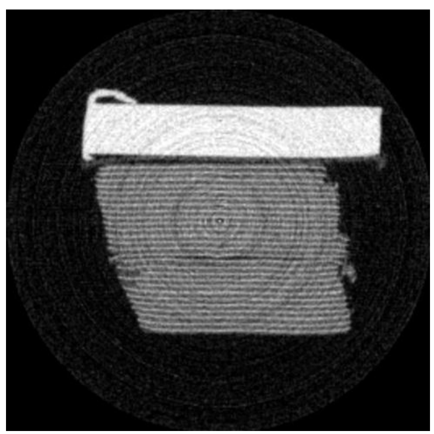

Beam-hardening

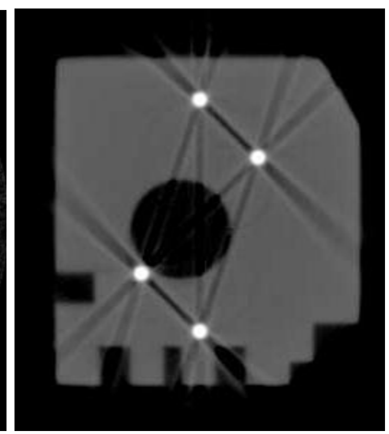

Cone-beam

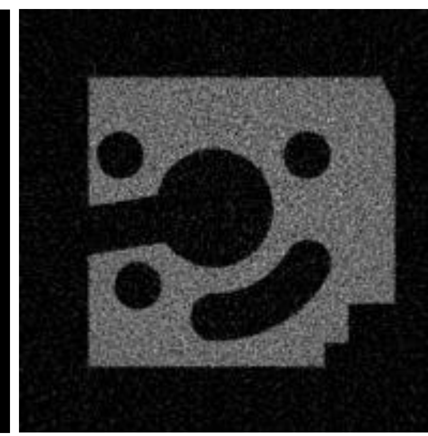

Misalignment


Undersampling


Truncation

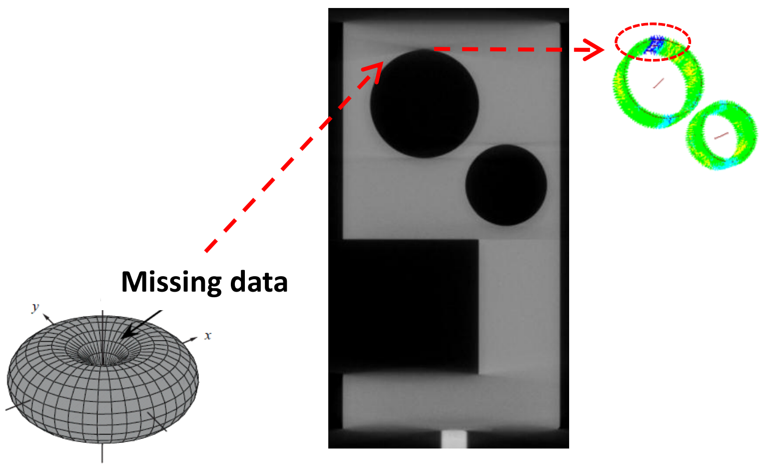

Ring artifacts

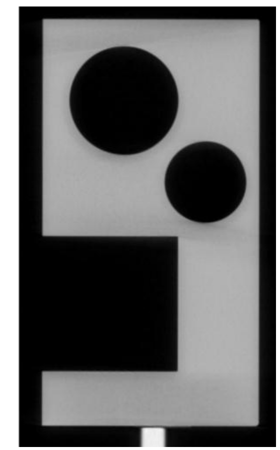

Metal artifacts

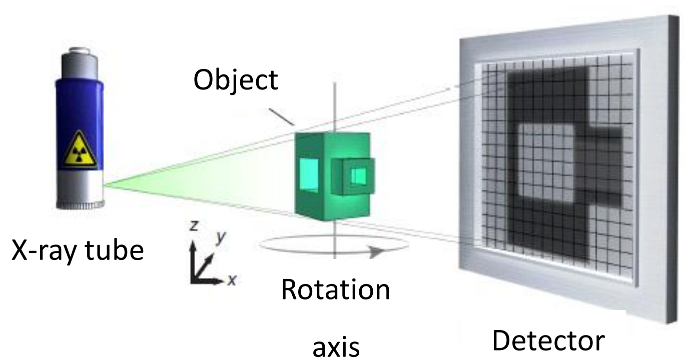

Noise artifacts

Errors sources and good practice in CT scanning

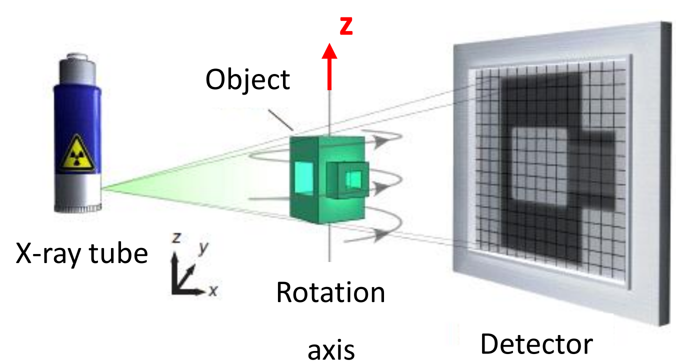
Cone-beam artefacts:







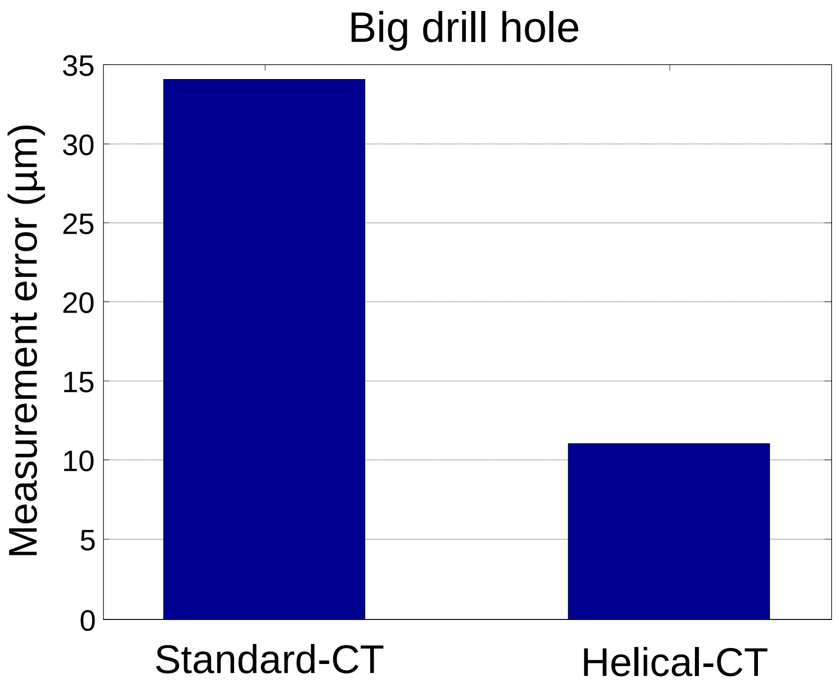
Circular sampling

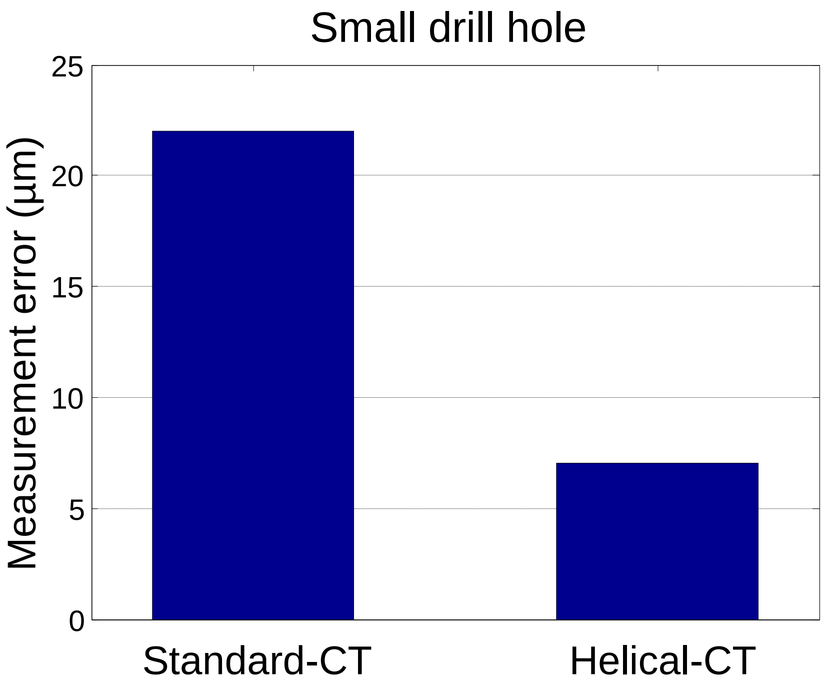


Helical sampling

Errors sources and good practice in CT scanning

Standard vs.helical CT:



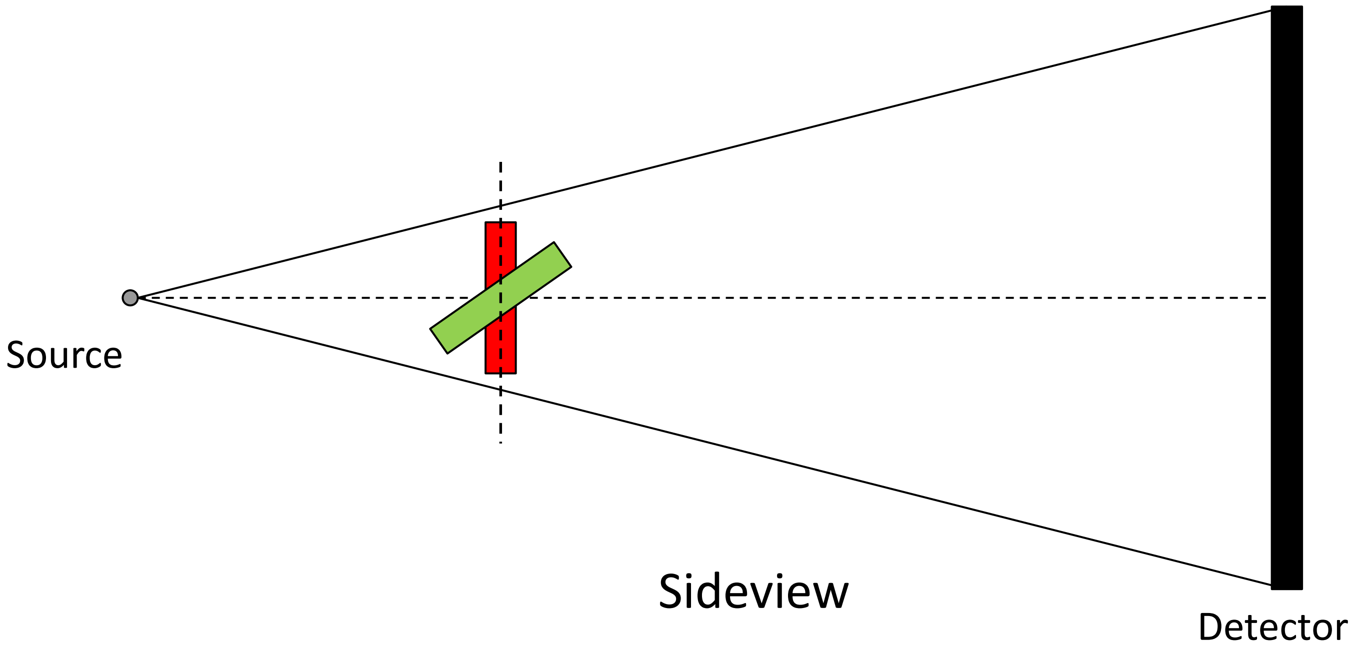


Voxel size: 105,7 μm^3

Errors sources and good practice in CT scanning

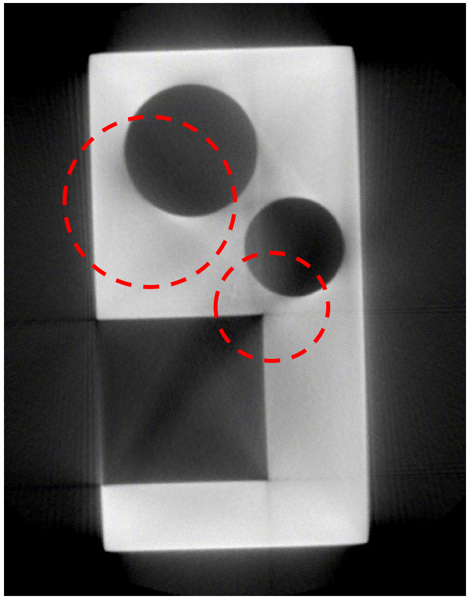
Good practice:

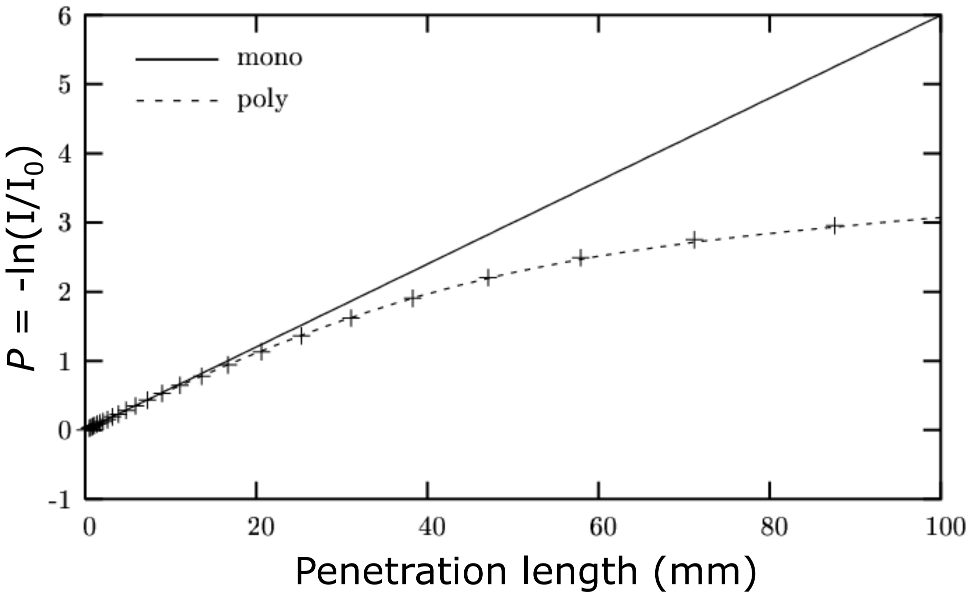
- Tilted position of the workpiece



Errors sources and good practice in CT scanning

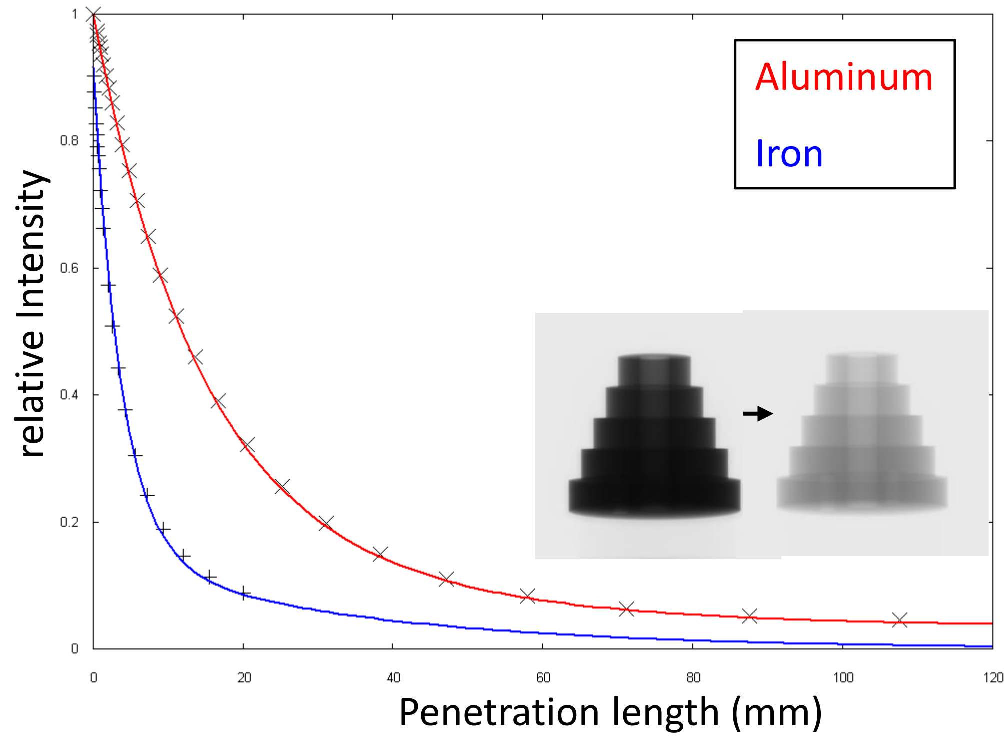
Beam-hardening:





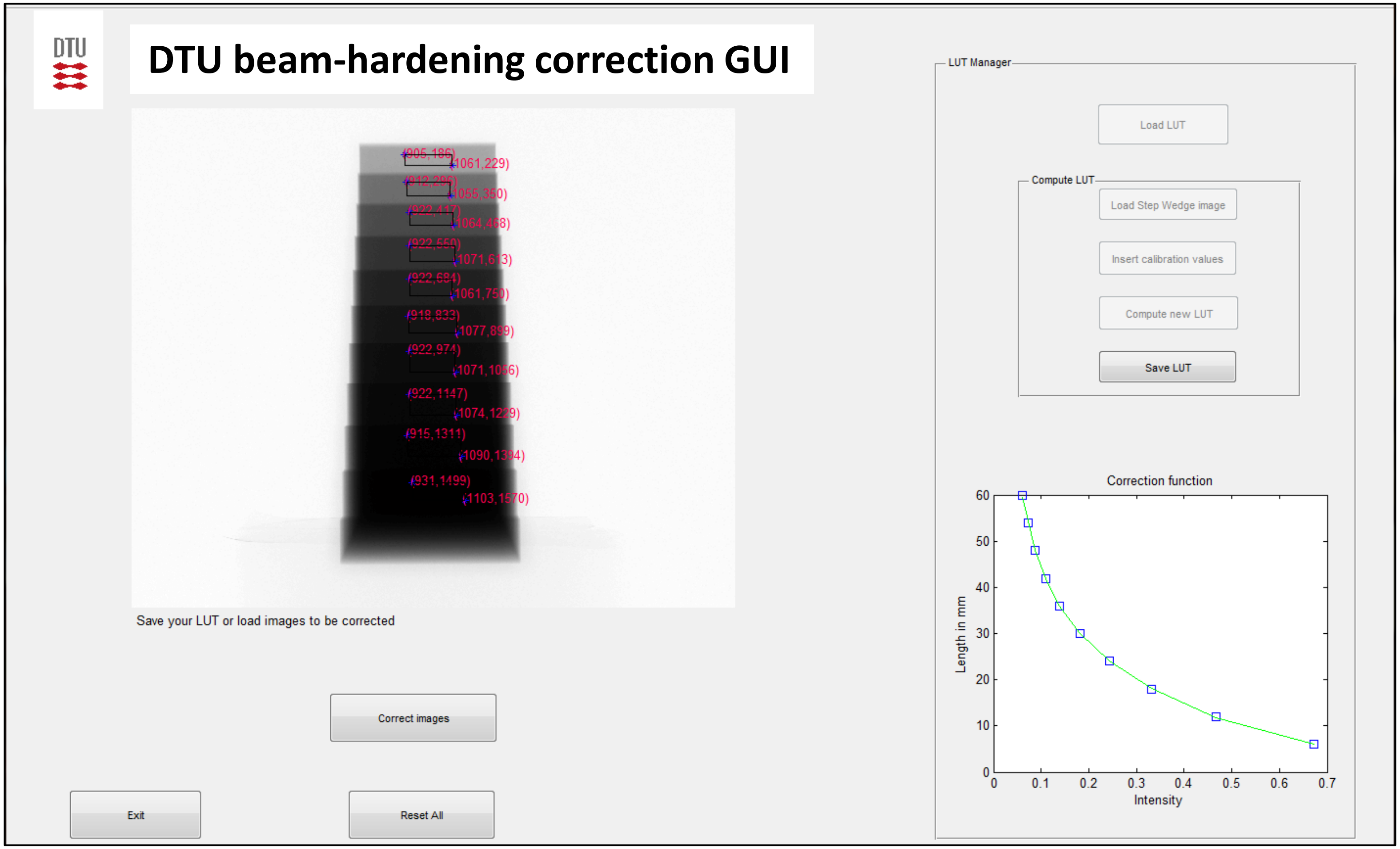
Errors sources and good practice in CT scanning

Beam-hardening correction:



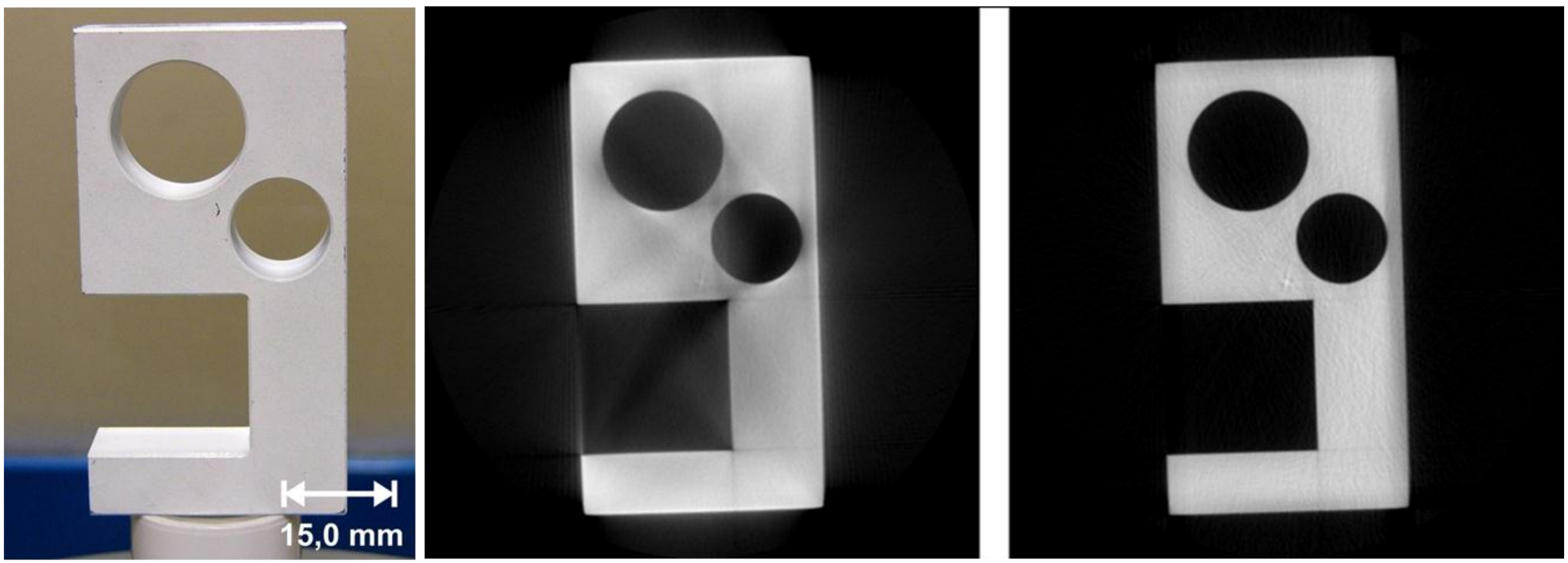
Step wedge → Radiography → Linerization of projections with inverse function

Errors sources and good practice in CT scanning



Errors sources and good practice in CT scanning

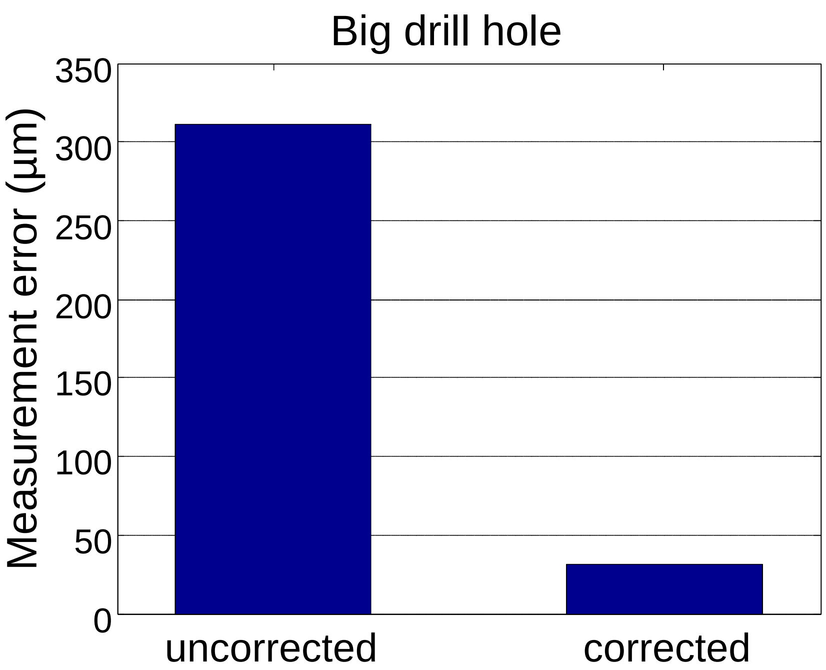
Beam-hardening correction:

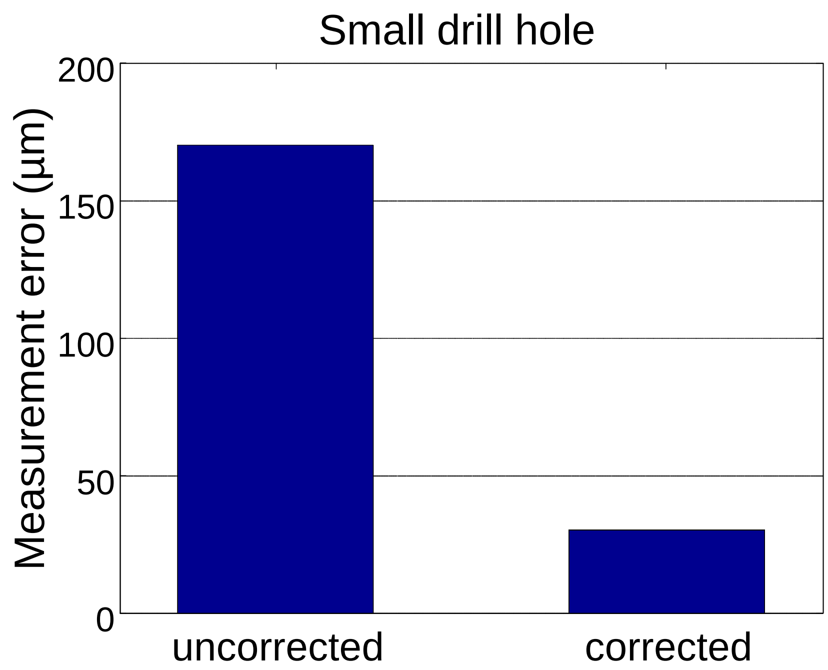


Object (Al) uncorrected corrected

Errors sources and good practice in CT scanning

Beam-hardening correction:



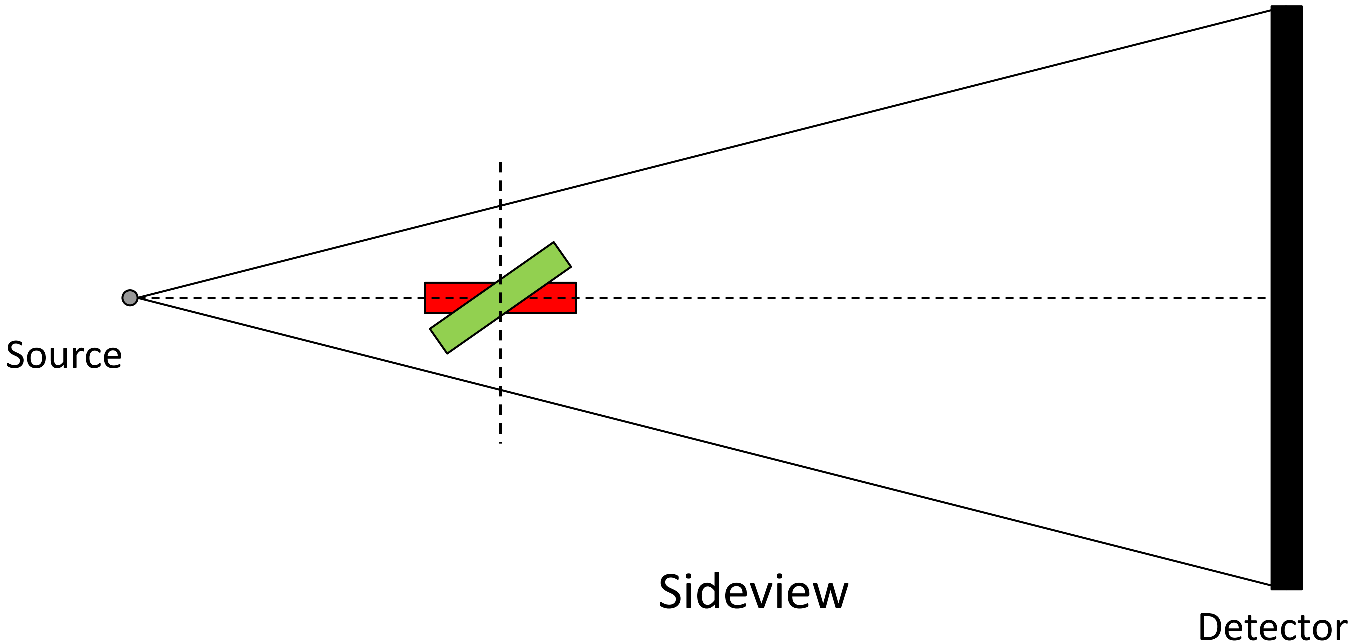


Voxel size: (156,7 × 156,7 × 179,3) μm^3

Errors sources and good practice in CT scanning

Good practice:

- Tilted position of the workpiece

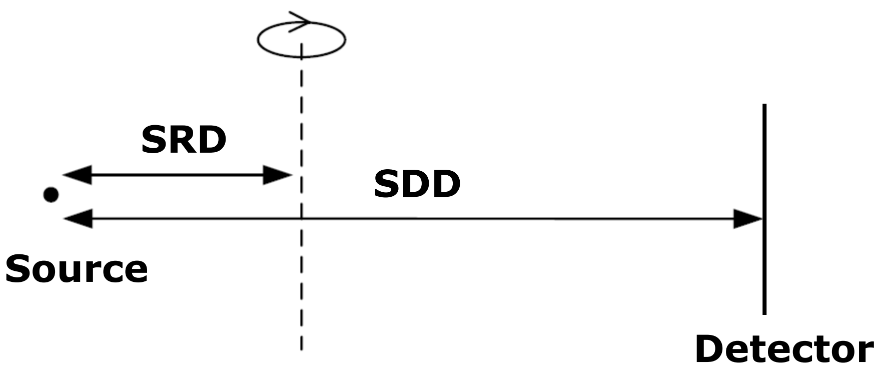


- Using a prefilter

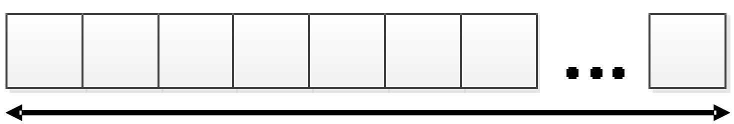
Errors sources and good practice in CT scanning

m = SDD/SRD

$v = a/m$



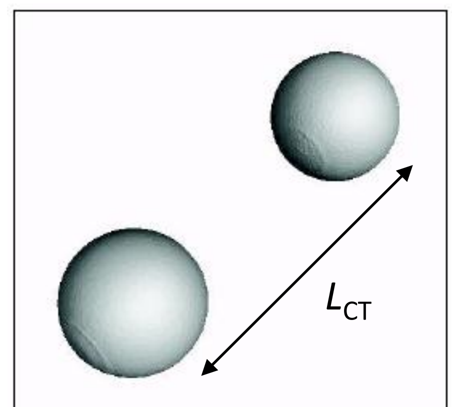
v = 30 µm, Δv = 1 µm



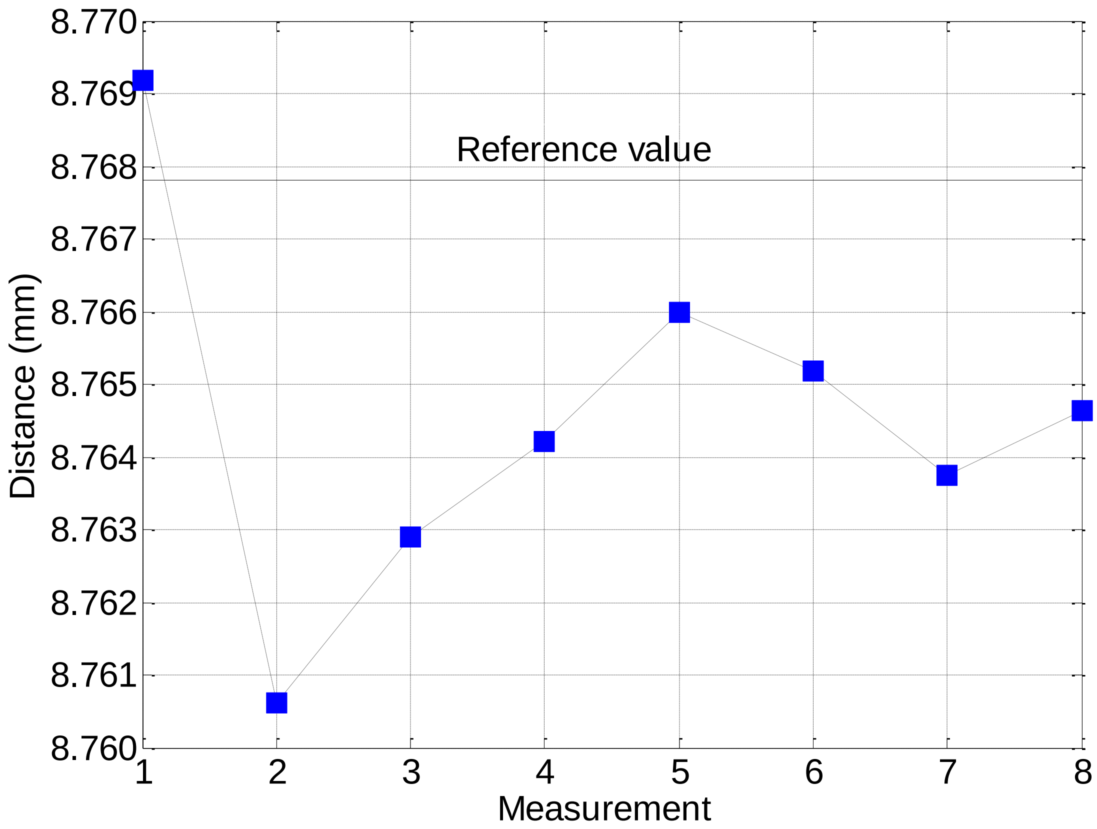
l = 1,5 mm

Error: Δl = 50 µm

Calibrated length: 8,7678 mm



Errors sources and good practice in CT scanning



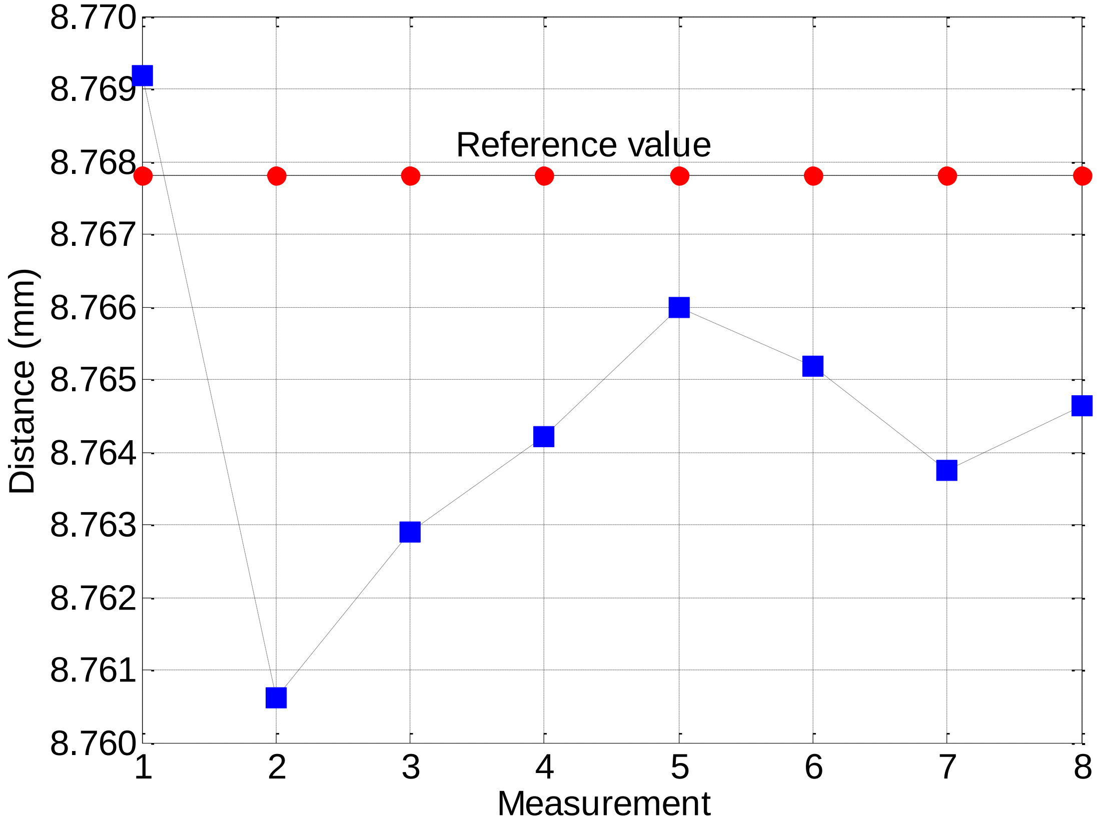
Variations are caused by inaccuracies of the SRD measurement (manipulator)

+

Focus drift during scanning due to tube temperature changes

superimposed

Errors sources and good practice in CT scanning



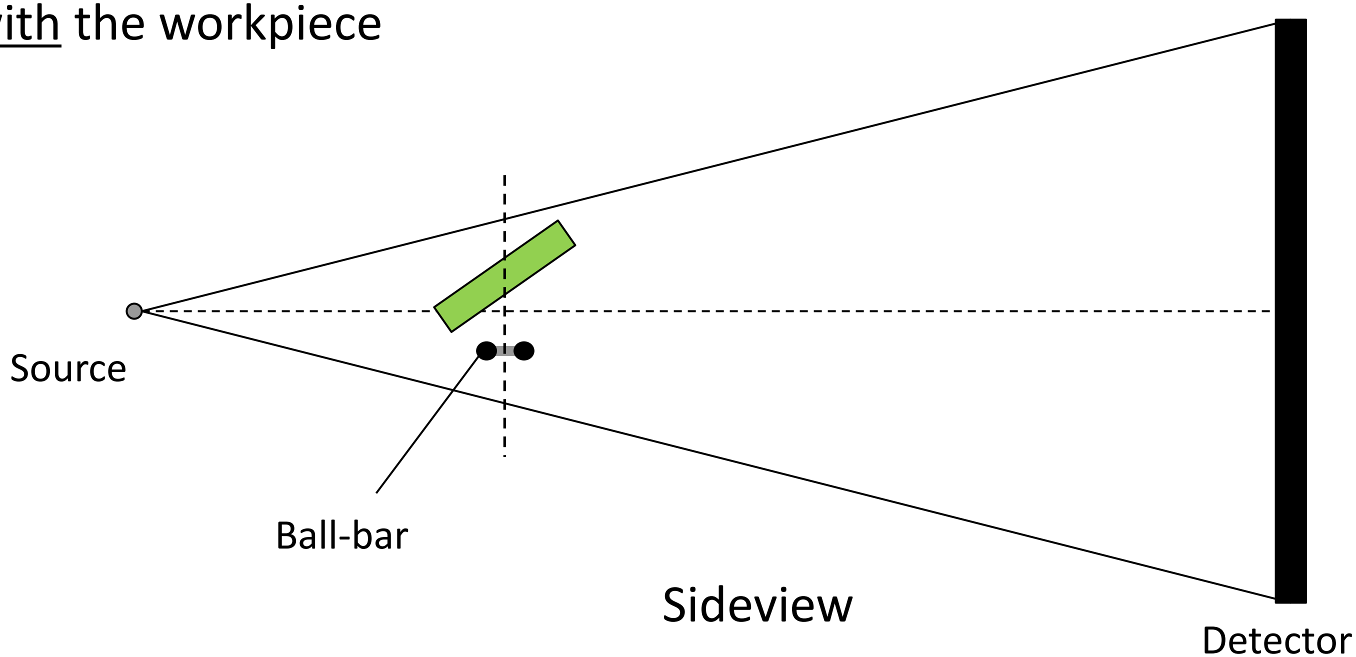
Voxel size rescaling:

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

Errors sources and good practice in CT scanning

Good practice:

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

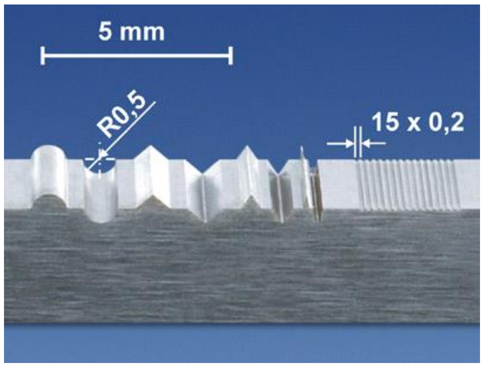


Focus drift differs from scan to scan!

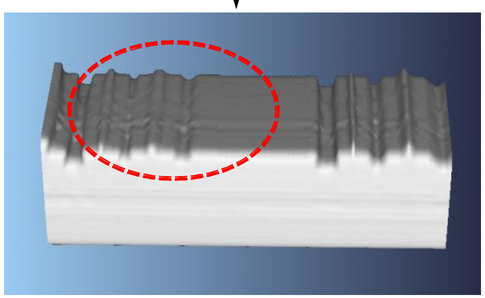
Errors sources and good practice in CT scanning

Image unsharpness

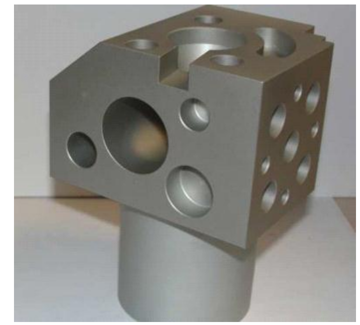
Object

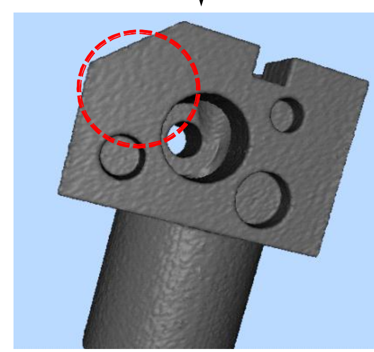


CT



Noise



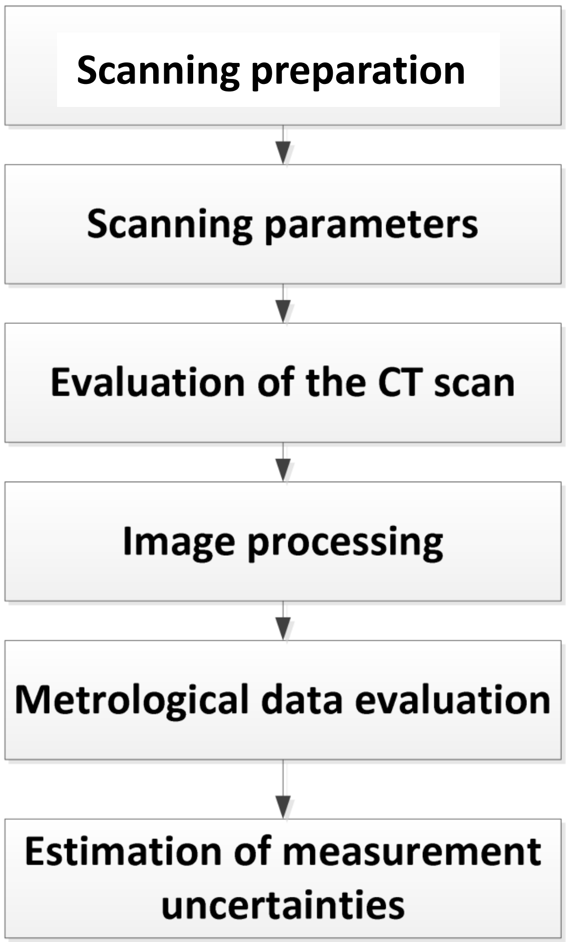


Depending on object, scanning parameters, system hard- and software

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!