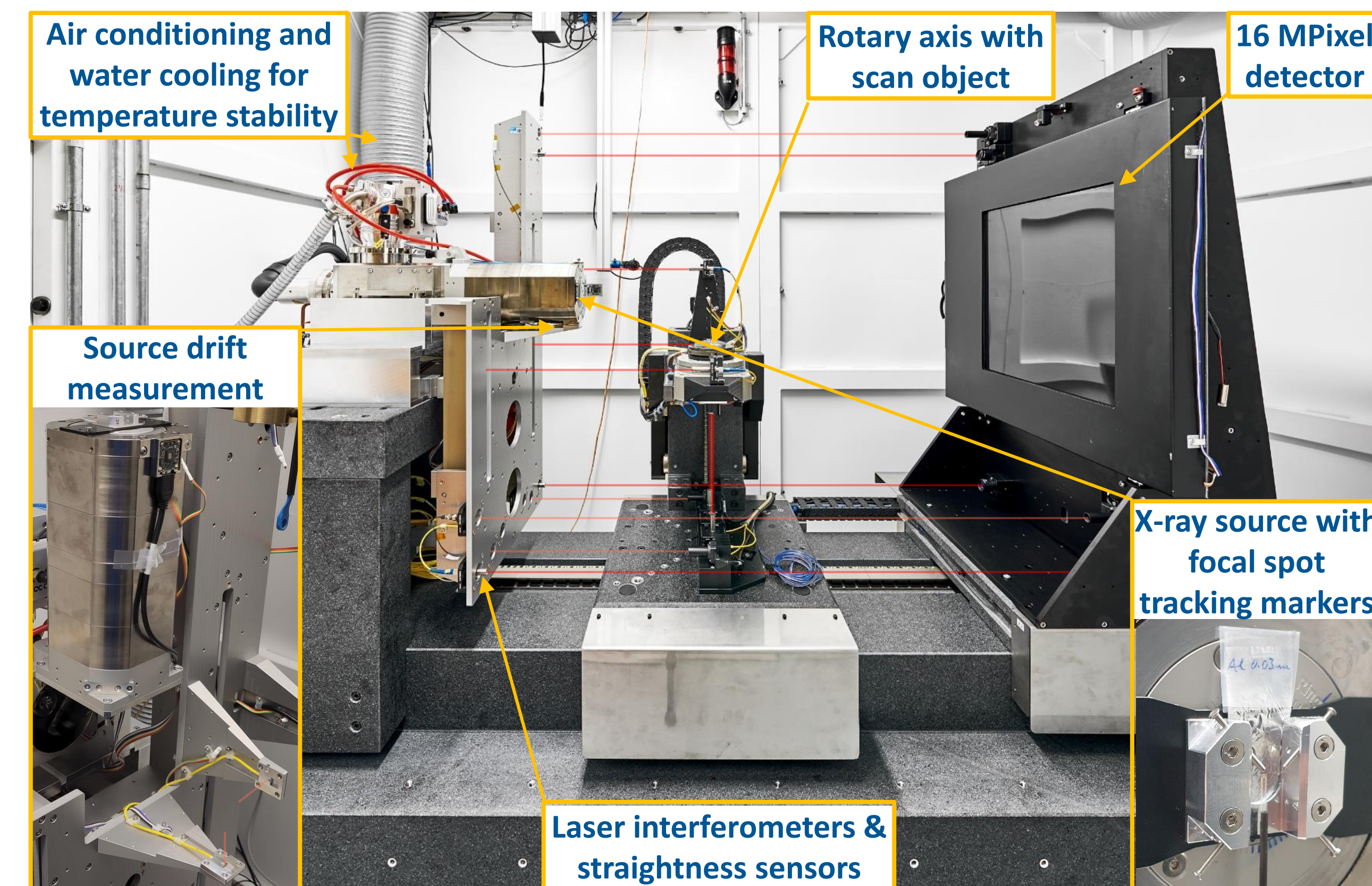


Towards traceable 3D metrology with homogeneous sub-micron accuracy in X-ray computed tomography

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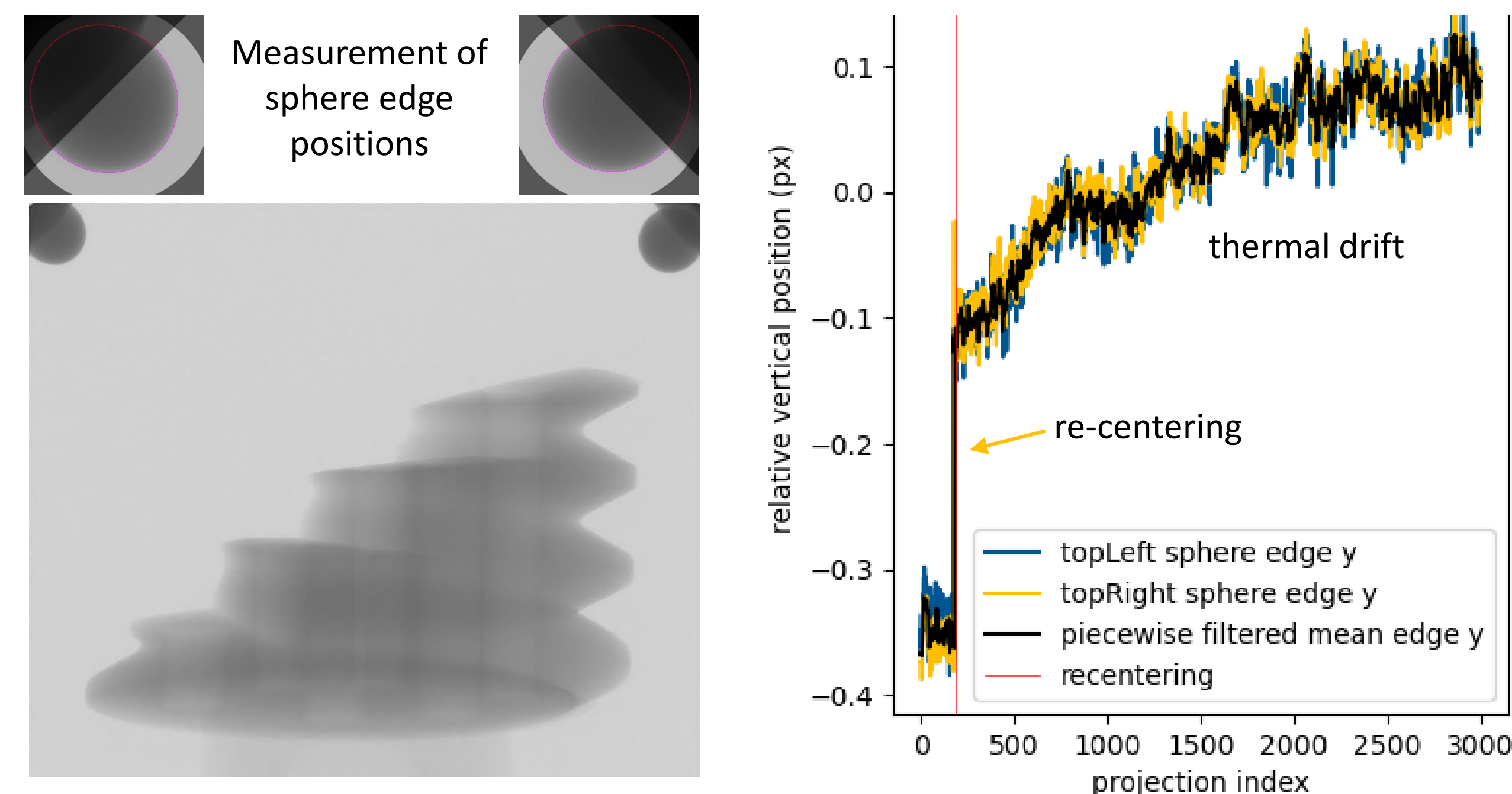
Metas-CT Setup



- Measurement of the rotary axis and detector positions with laser interferometers and straightness sensors using lasers and CMOS image sensors [1]
- Measurement of the position of the X-ray tube head using lasers and CMOS sensors [2]
- Measurement of the position of the X-ray focal spot relative to the tube head using focal spot tracking [3]

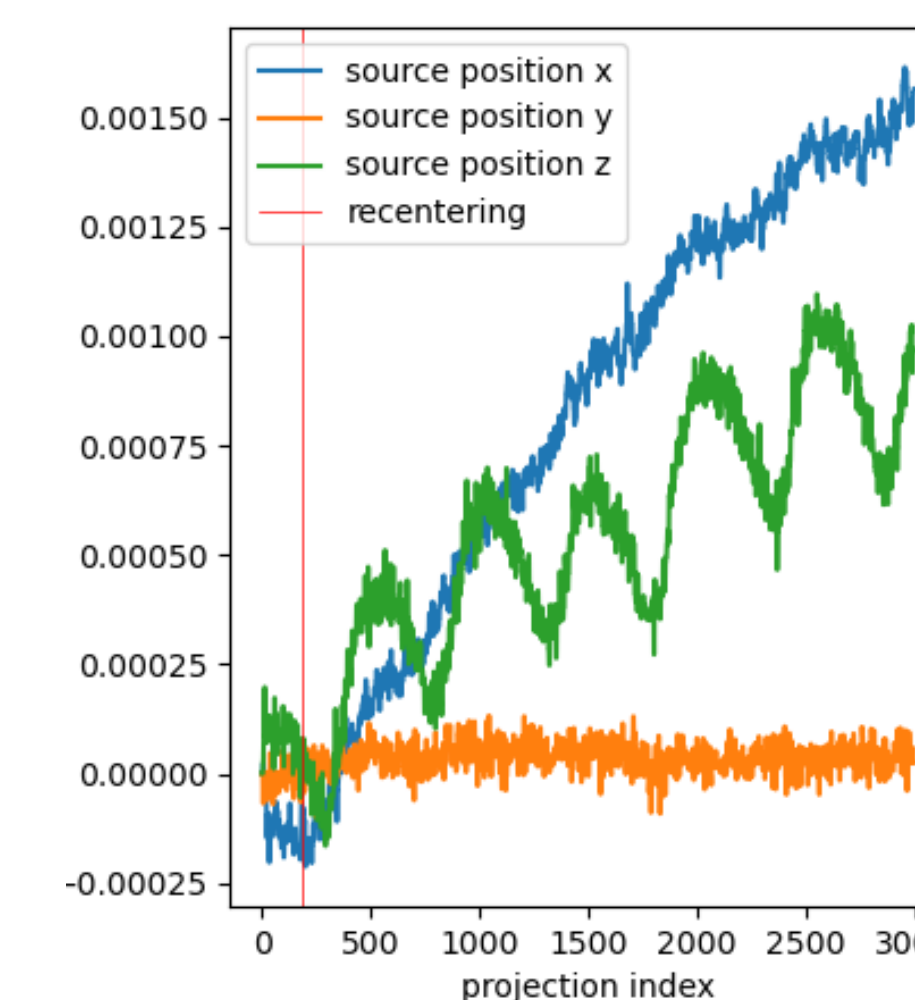
Focal spot tracking

- Steel spheres mounted on screws attached to the X-ray tube can be placed in the image corners
- Movements of the focal spot relative to the X-ray tube are reflected in a position change of the projected spheres in the radiographs
- Fitting the sphere edge positions during image processing allows calculating the lateral movements of the focal spot.



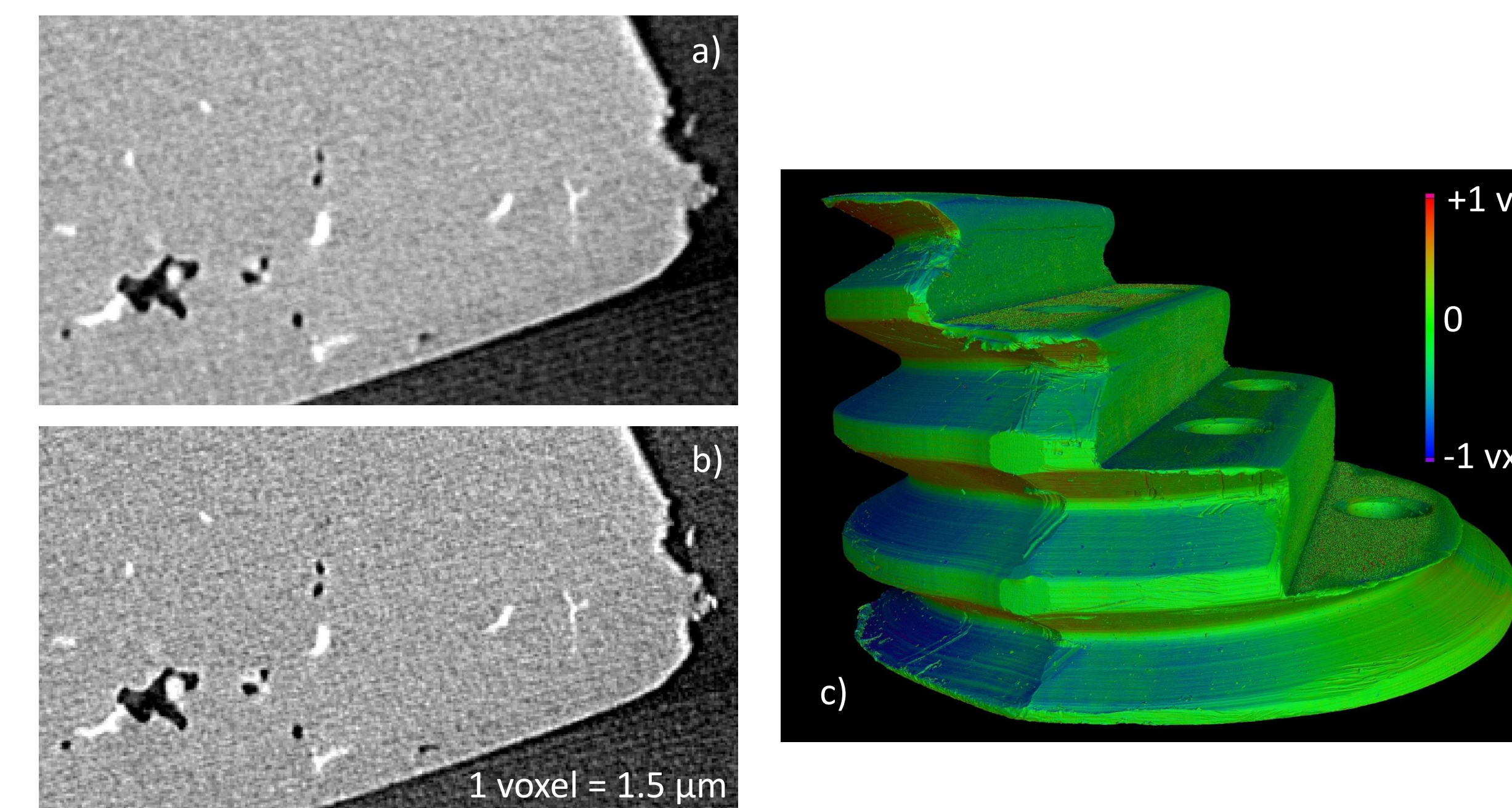
X-ray source drift measurement

- The X-ray source head has a tendency of continuously expanding along the beam direction during a scan (blue)
- The vertical position of the source head shows an oscillatory drift, possibly due to varying power dissipation of the turbo pump caused by intermittent operation of the pre-vacuum pump (green)
- The lateral source movement is negligible (orange)



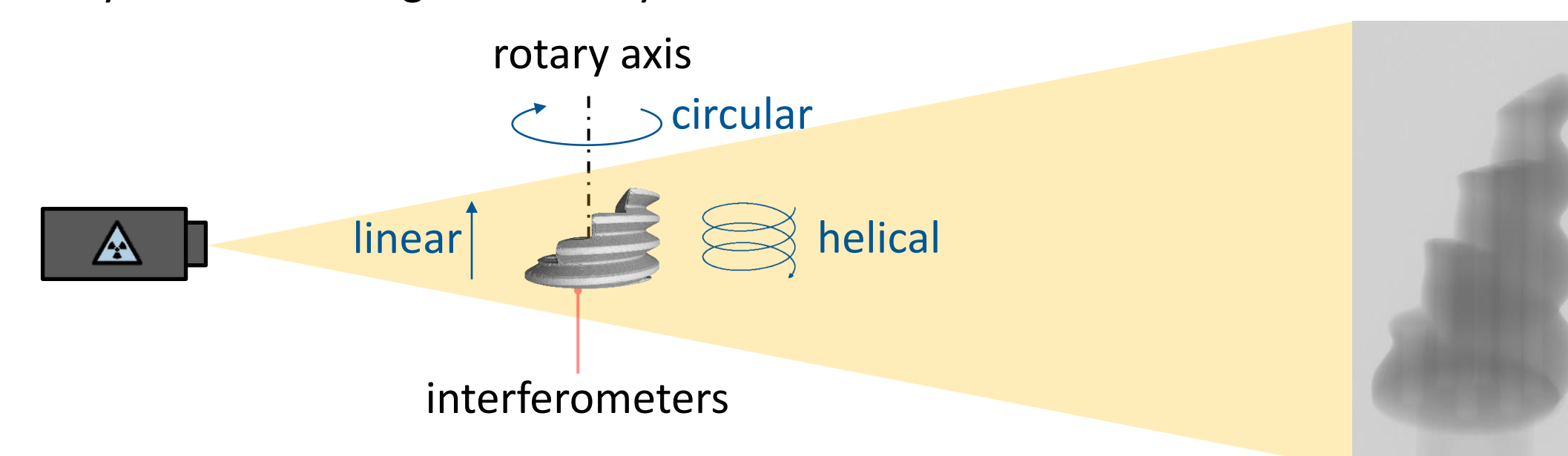
Circular trajectory with/without tube and focal spot tracking

- Example data of an aluminium test object ($\varnothing$ 5 mm) shows a clear improvement of detail sharpness with reconstruction using source drift and spot tracking information (b) over conventional reconstruction assuming ideal circular trajectory (a) at 1.5 μ m voxel (vx) size.
- In addition to sharpness improvement, a comparison of the determined object surfaces shows dimensional deviations due to changes in the projective geometry during the scan.



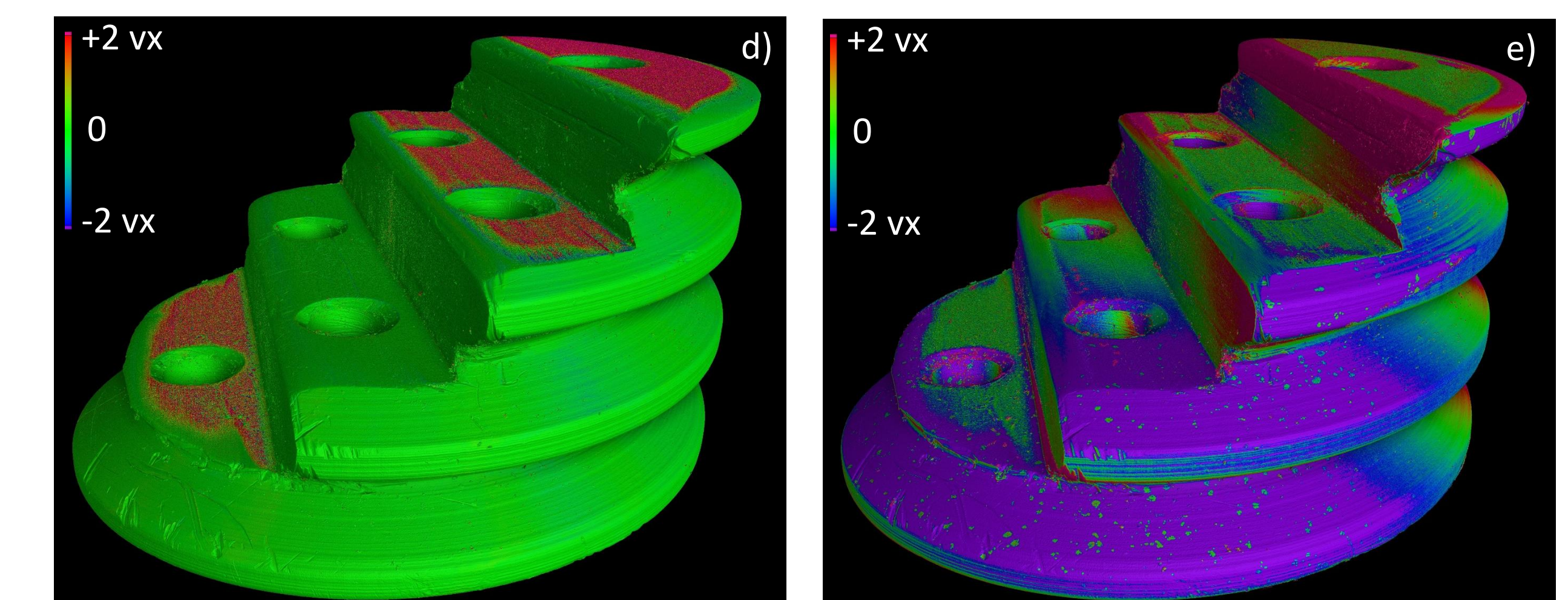
Metrological scan trajectories

- Measurement of the CT system geometry is incorporated in the volume reconstruction for every projection
- Using a flexible open source reconstruction framework enables flexible scan trajectories consisting of circular and linear movements with a transparent reconstruction workflow [4,5]
- Adding linear displacements to circular scans greatly improves vertical image sharpness and requires recording fewer extra projections than a full helical scan
- Interferometric tracking of the vertical object position ensures precise reconstruction geometry without adding uncertainty due to vertical movement



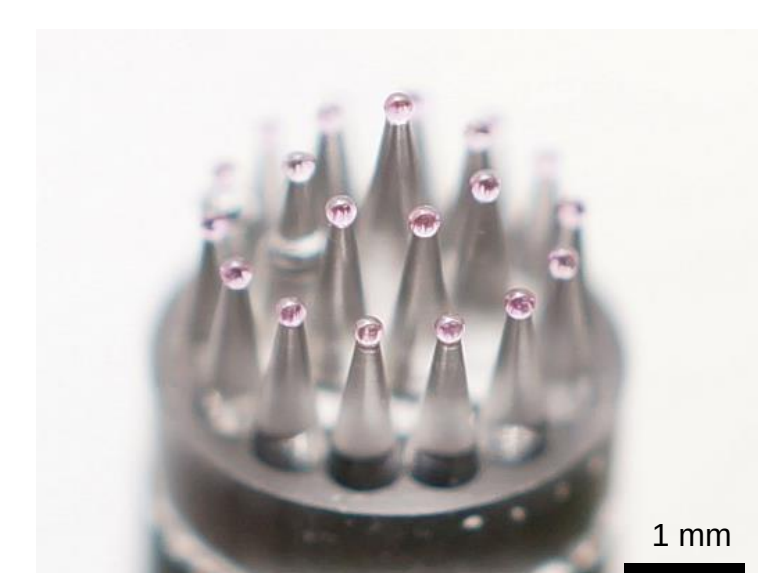
Comparison of circular, circle + lines and helical trajectories

- For comparison, a $\varnothing$ 5 mm Aluminium test object was scanned and reconstructed with a voxel (vx) size of 1.5 μ m with three different scan trajectories (source object distance 10.5 mm, source detector distance 700 mm, 40 x 40 cm detector):
 - Circular 360°, 3000 projections
 - Circular 360°, 3000 projections + 6 x 3.2 mm vertical displacement, offset by 60°, 145 projections each (3870 projections in total)
 - Helical 720°, 4000 projections with 7.4 mm vertical displacement
- Except for correcting strong well-known Feldkamp artifacts on horizontal planes, the circle + lines scan is in very good agreement with the circular scan (d)
- The helical scan trajectory (e) fails to produce metrologically valuable results at a similar number of projections as the circle + lines scan and would require a considerably longer scan time to produce results with comparable quality.



Traceability

- Magnification calibration using a multi-sphere standard which is traceably calibrated in-house on a tactile CMM with 80 nm uncertainty (Metas- μ CMM).
- Constant measurement of the CT system geometry with laser interferometers preserves magnification calibration.



Conclusion

- X-ray computed tomography (CT) can reliably achieve sub-micron accuracy for small parts in a unique metrological setup [1]
- Incorporating the precisely measured complete CT system geometry in volume reconstruction compensates instabilities and enables flexible scan trajectories, improving both the level and uniformity of image sharpness
- Uniform image quality is an important step towards truly traceable 3D metrology in X-ray CT to meet the future demands of advanced manufacturing techniques.

References

- (1) Bircher B A *et al* (2020) METAS-CT: metrological x-ray computed tomography at sub-micrometre precision. The 20th EUSPEN Int. Conf. pp 281–4
- (2) Bircher B A *et al* (2020) X-ray source tracking to compensate focal spot drifts for dimensional CT measurements. 10th Conf. on Industrial Computed Tomography (Wels, Austria)
- (3) Vavřík D *et al* (2016) Correction of the X-ray tube spot movement as a tool for improvement of the micro-tomography quality. J. Instrum. 11 C01029
- (4) Biguri A *et al* (2016) TIGRE: a MATLAB-GPU toolbox for CBCT image reconstruction. Biomed. Phys. Eng. Express 2 055010
- (5) Katsevich A (2004) Image reconstruction for the circle and line trajectory. Phys. Med. Biol. 49 5059-5072