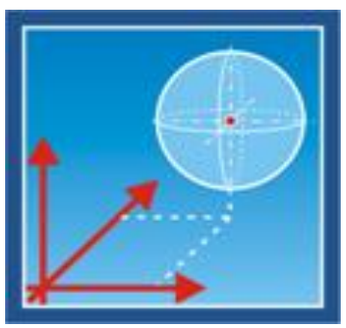
Coordinate metrology using computed tomography systems – an overview of PTB's activities with a focus to standardization

Markus Bartscher, Osamu Sato*, Jens Illemann, Ulrich Neuschaefer-Rube, Frank Härtig

Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin, Germany

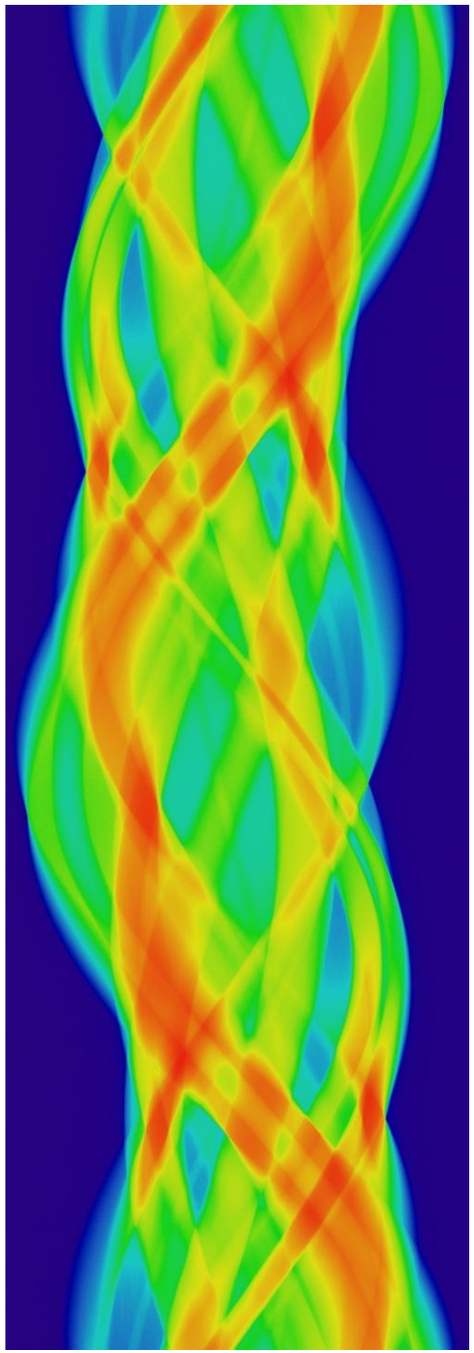
* National Metrology Institute of Japan
National Institute of Advanced Industrial Science and Technology,
Tsukuba, Japan



Industrial CT Scanning
German-Austrian-Danish Workshop

Munich
23-25 October 2013

Content



Standardization for dimensional CT

National standardization

Germany: **VDI/VDE 2630-1.3** (2011-12) **on specifications (acceptance testing)**

International standardization

ISO TC 213 WG 10: Preliminary working item CT has been defined

Task force objective: Create **ISO 10360-11 for CT**

Principles (written form is pending):

1) **CMS (former CMMs) shall be tested as *integrated systems***
(no component testing)

2) **Tests shall include the *dominant error behavior***
New classification for influence quantities (<5%, 5 % ⋯ 15%, > 15%)

3) **Tests shall comprise *local and global performance characteristics***
Test of probing errors for size *PS* and form *PF*
Test of length measurement errors *E*

Recent development & open issues

Open issues & recent developments for ISO work on CT:

Create comparable characteristics

Finalize test design & procedures

Include material influence in tests

Analyse behavior for uni- and bidirectional measurands (length measurements *E)*

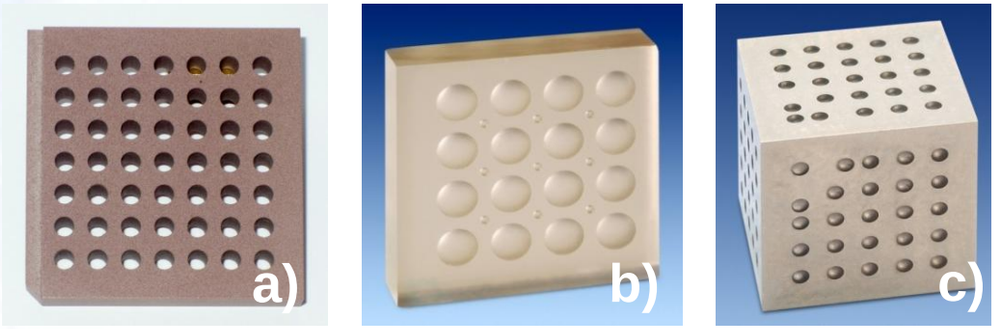
Solve structural resolution testing issue for dimensional measurements

Focus of following presentation and discussion

Material impact on measured lengths

Length measurement error *E* testing

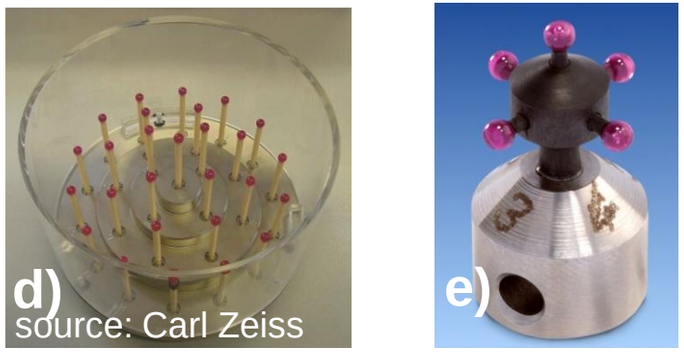
- ***MPE*$_{Em}$ including material influence**; examples, implicit with internal features
  - a: hole plate
  - b: “calotte” plate
  - c: “calotte” cube



Under discussion:

Test with hole plate sufficient to show material influence?

- ***MPE*$_{Ez}$ negligible material influence**
  - d: multiple sphere standards (stylus or probe forest)
  - e: stylus star

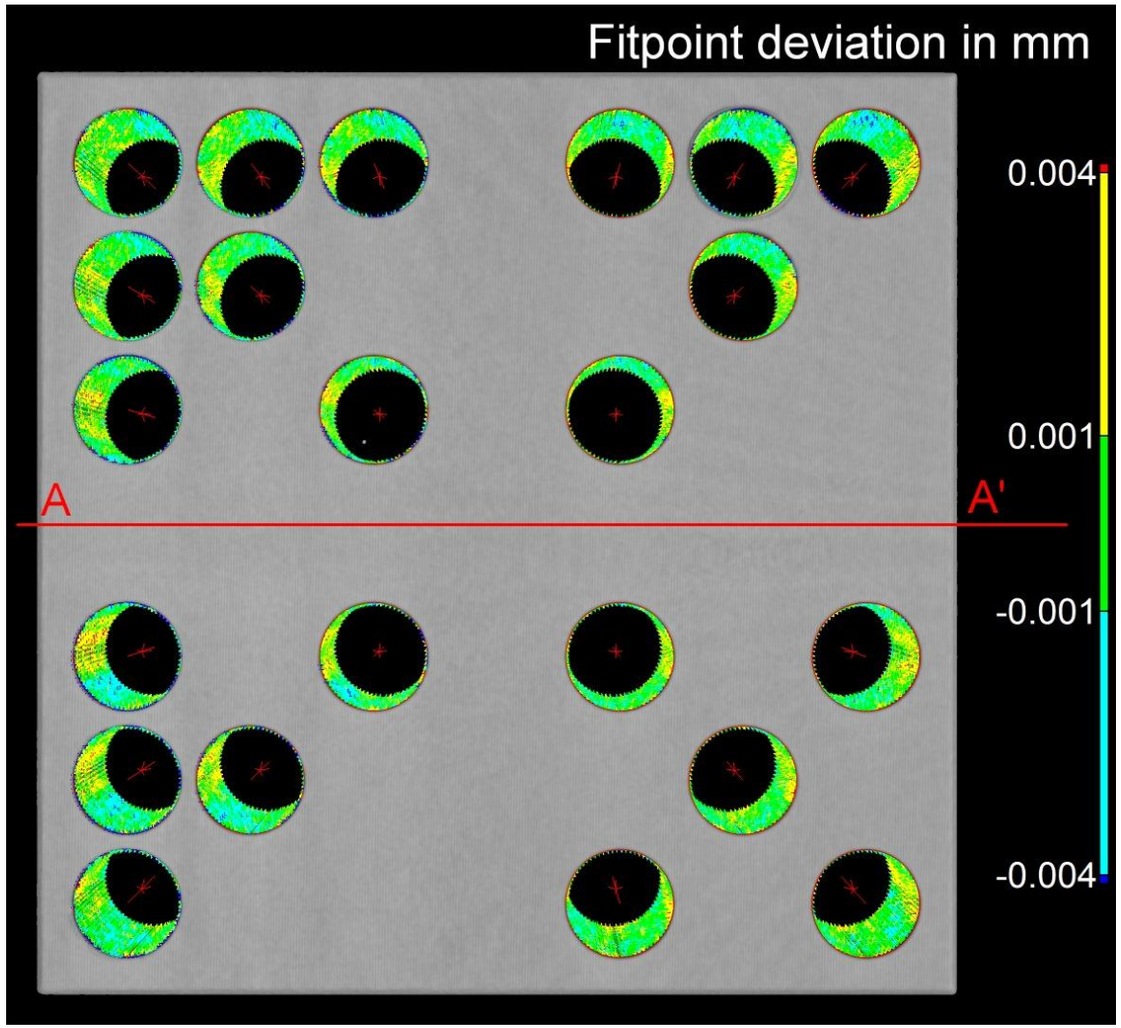


Additional measure-ments for material influence testing required (e.g. step cylinder)

Measurement of hole plate

Hole plate

featuring 4 primitive directions



CT measurement (PTB CT system):

190 kV, 10.3 W, 0.3 mm Cu, 1640 projections

Magnification 4.0 – voxel size $(50.0\ \mu m)^3$

95% form dispersion values of individual cylinder 3.1 µm

Length measurement error analysis

Length measurement testing

Classical approach: bidirectional test

Now: unidirectional test becoming standard (additional bidirectional statement feasible either by measurement or correction)

(approach due to problems of optical sensors and due to ongoing consideration of sensor and mover separation)

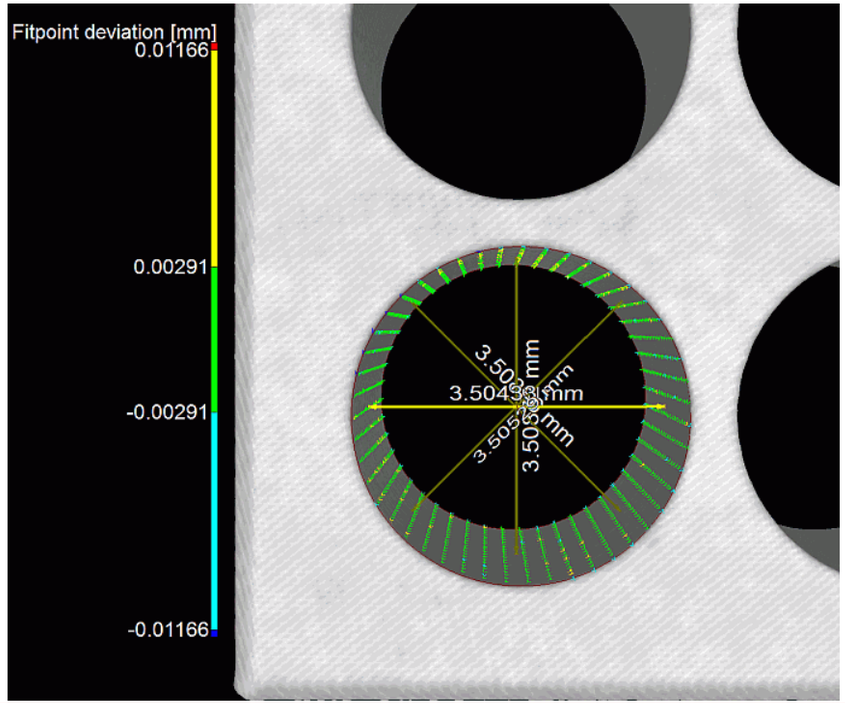
Here:

Unidirectional length measurement errors = Centre distance errors of cylinders

Bidirectional length measurement errors = Centre distance errors of cylinders + correction

Conversion uni- to bidirectional based on VDI/VDE 2630-1.3 and ISO 10360-8:

Add bidirectional measure to unidirectional values
here:
Two-point diameter error of one hole collinear to measurement line



Length measurement error analysis

Test study using hole plate

U = 190 kV, *P* = 10.3 W, 0.3 mm Cu filter, 1640 projections

Magnification: 4.0 (voxel size: 50 μm), fast CT mode (1h 50min), tilted setup

4 verified direction on plate (0°, 90°, 45° and 135°)

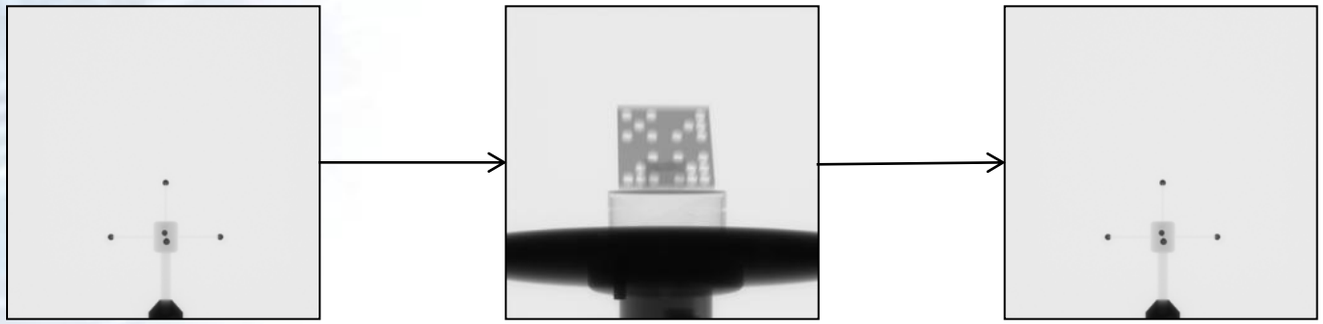
Reconstruction: w/o, with soft and mid beam hardening correction

Quality assurance provisions:

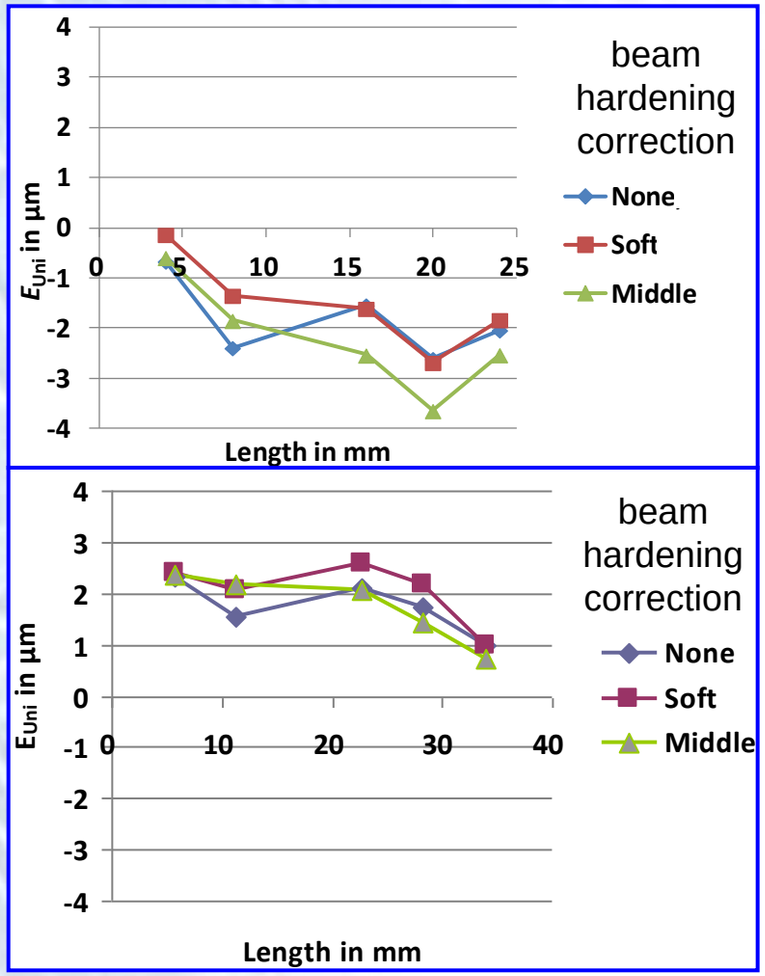
1) Correct residual scaling error before hole plate test

2) Correct residual rotation axis tilt before hole plate test

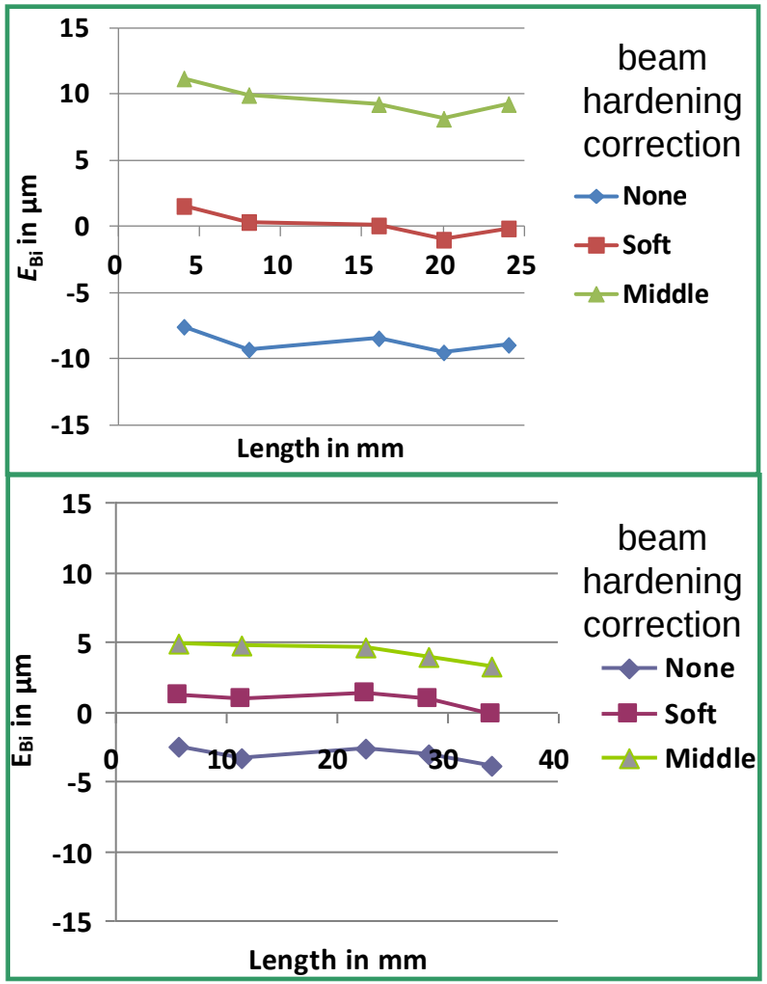
3) Check drift of scaling – if present after hole plate test



Length measurement error analysis



Unidirectional measurement
(centre-to-centre distance)



0° horizontal

-45° diagonal

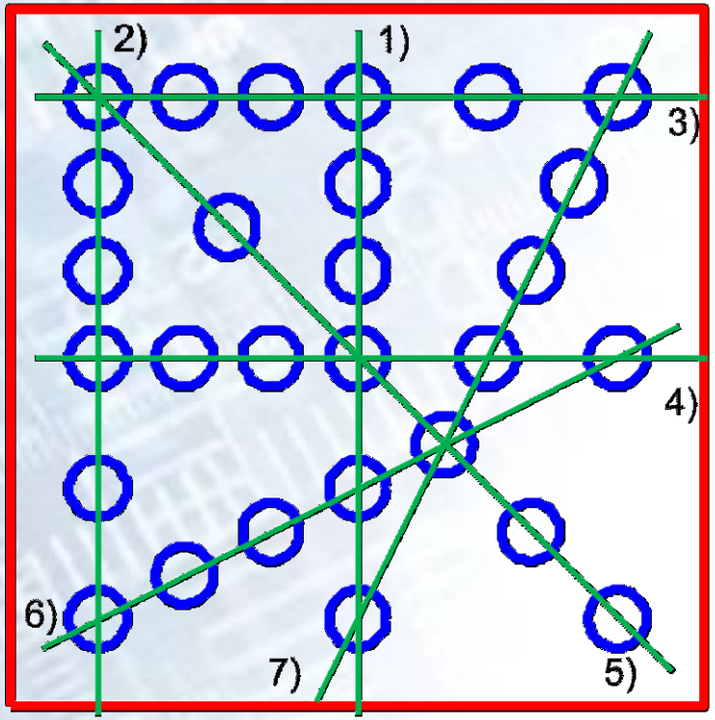
Bidirectional measurement
(centre-to-centre + 2 point diameter error)

Nearly no material impact for unidirectional lengths

Big material influence for bidirectional length measurements!

New hole plate design

New design of hole plate with 28 holes



Advantage of new design:

7 lengths measured in one setting

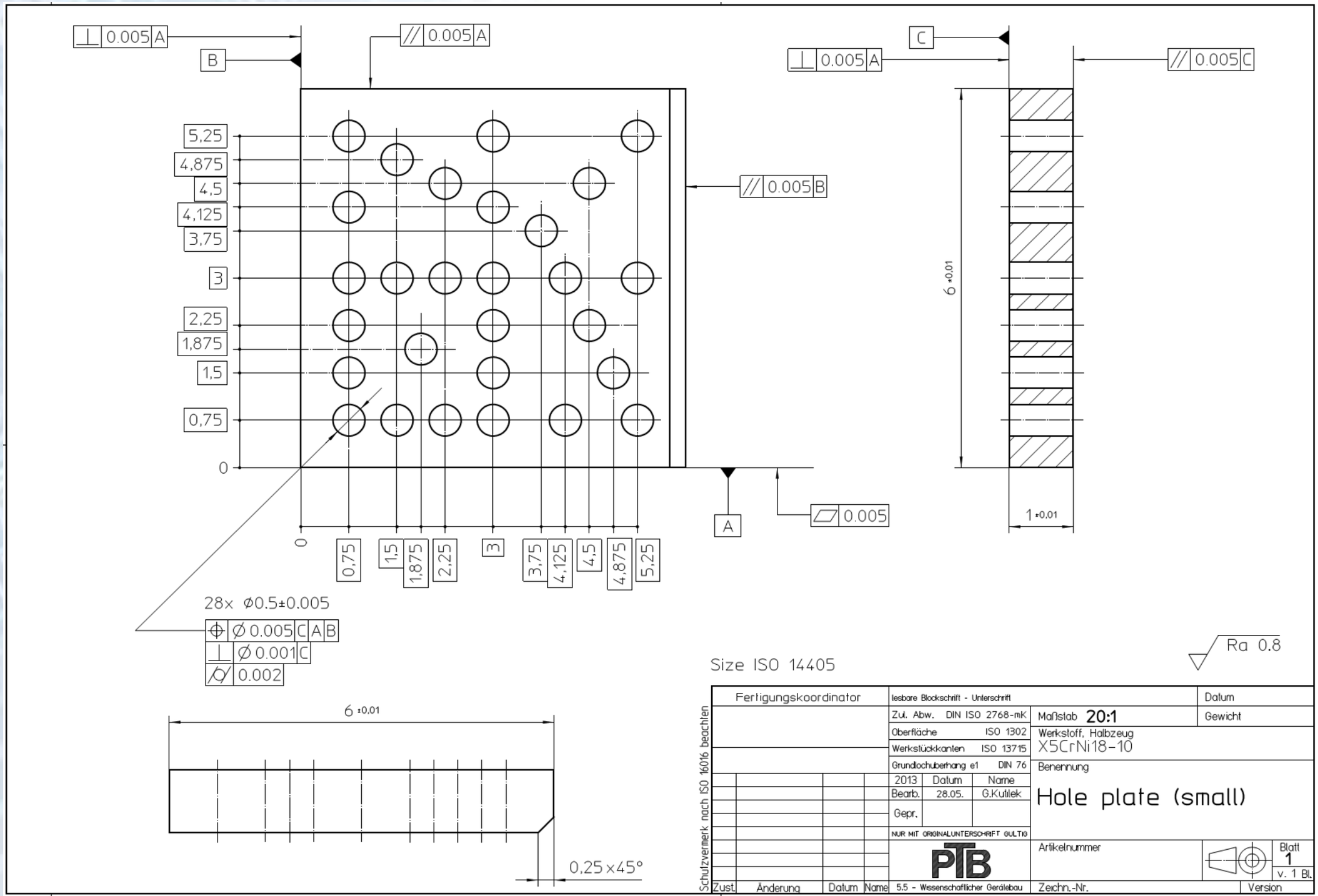
Size considerations for aluminum (low magnification case)

X-ray tube voltage in kV	Dimensions of square-shaped hole plate in mm			
	Side	Thickness	Diameter of holes	Material
90	18.0	3.0	1.5	Al
130	30.0	5.0	2.5	
225	48.0	8.0	4.0	
450	66.0	11.0	5.5	
600	77.0	13.0	6.0	

Size considerations for steel (high magnification case)

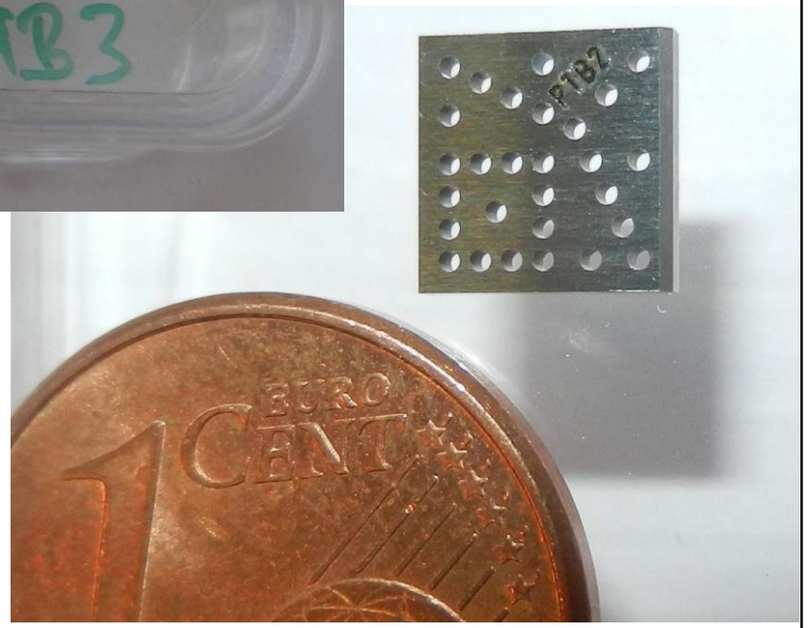
X-ray tube voltage in kV	Dimensions of square-shaped hole plate in mm			
	Side	Thickness	Diameter of holes	Material
90	6.0	1.0	0.5	Fe
130				
225				
450				ZrO_2
600				WC

CAD sketch of steel hole plate



Manufactured steel hole plates

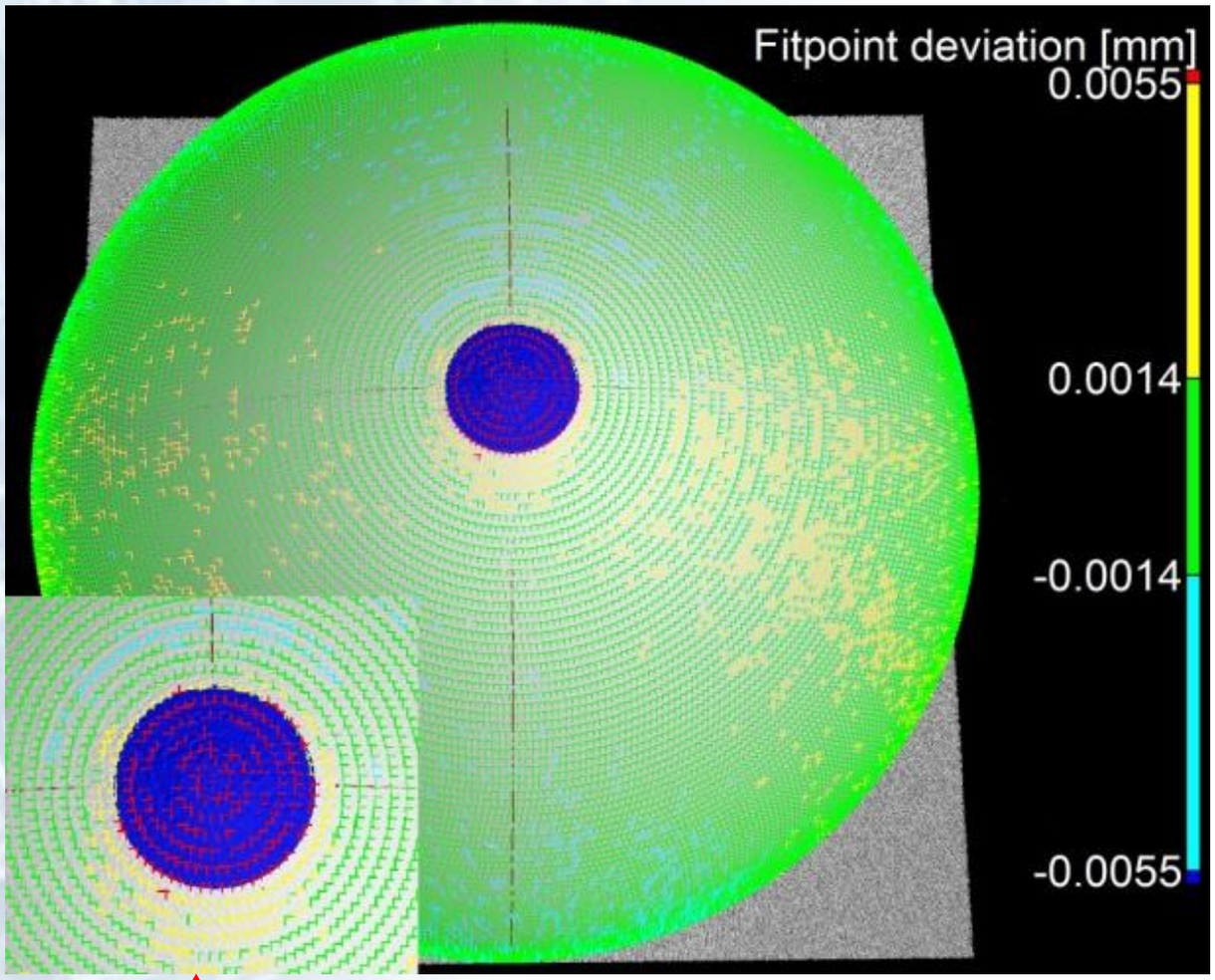
Price for three specimen (industrial manufacturing): 2400 € incl. VAT



Currently ISO test study on material impact on dimensional CT started (results due Feb. 2014). Hole plates are in use here

Schutzvermerk nach ISO 16016 beachten	Fertigungskoordinator			lesbare Blockschrift - Unterschrift		Datum	
				Zul. Abw. DIN ISO 2768-mK	Maßstab 20:1	Gewicht	
				Oberfläche ISO 1302	Werkstoff, Halbzeug X5CrNi18-10		
				Werkstückkanten ISO 13715			
				Grundlochüberhang e1 DIN 76	Benennung Hole plate (small)		
				2013 Datum Name			
				Bearb. 28.05. G.Kutilek			
				Gepr.			
				NUR MIT ORIGINALUNTERSCHRIFT GÜLTIG			
				PTB	Artikelnummer		Blatt 1 v. 1 Bl.
Zust.	Änderung	Datum	Name	5.5 - Wissenschaftlicher Gerätebau	Zeichn.-Nr.		Version

Probing error testing



Magnified pole region

8 mm ruby test sphere measurement off central plane (90kV, 3.6W, no filter, voxel size $[8.2\ \mu m]^3$)

→ Artefact at one pole region! (further away from centre)

Size is e.g. 0.6% of hemisphere area

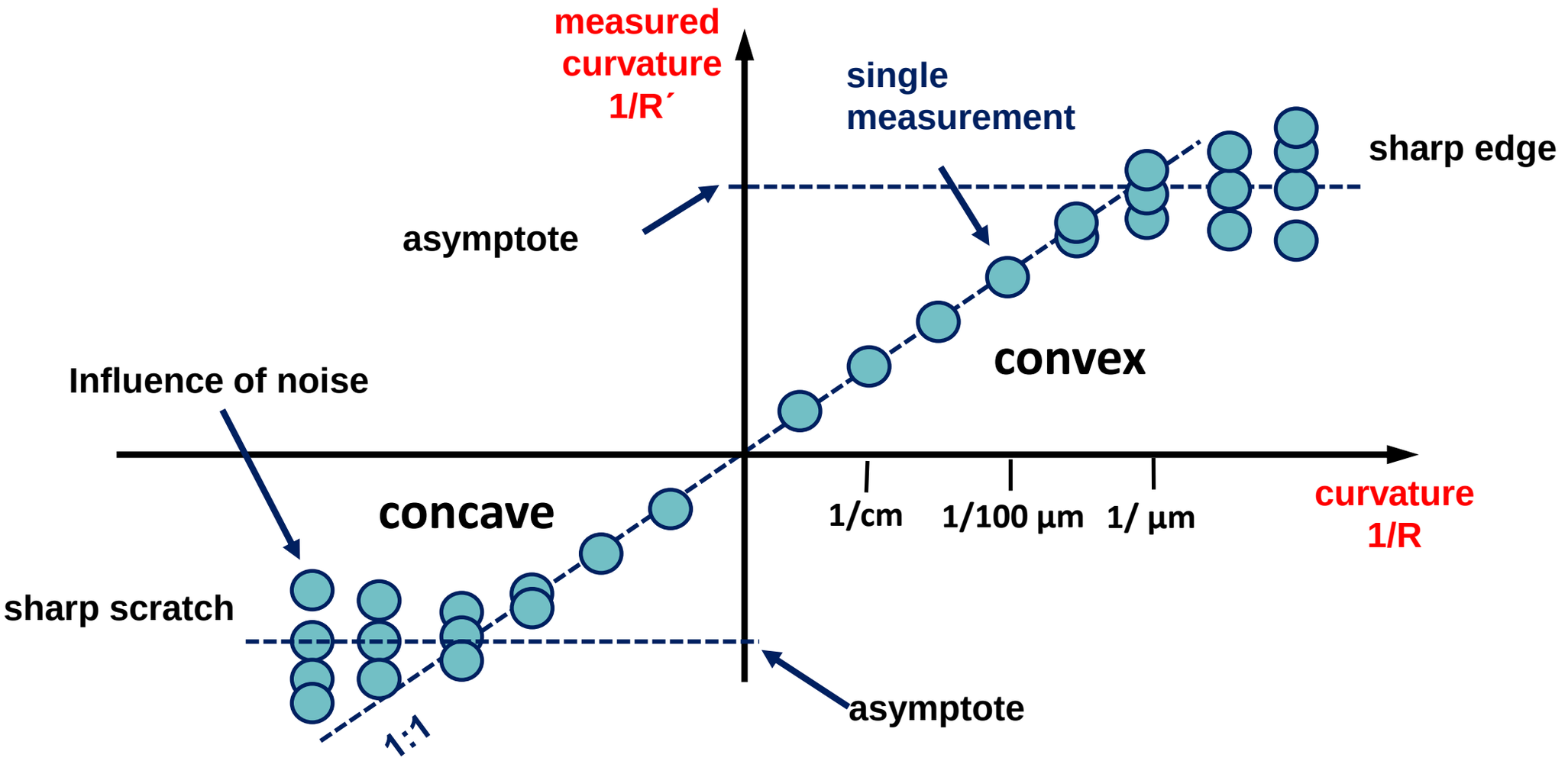
→ $P_{Form.Sph.D95\%}$ probing dispersion error excludes this effect!

Test criteria shall be adapted as this effect is realistic also for real`s life parts and shall be included in dimensional CT testing

Structural resolution

Property of CMS described by curvature transfer

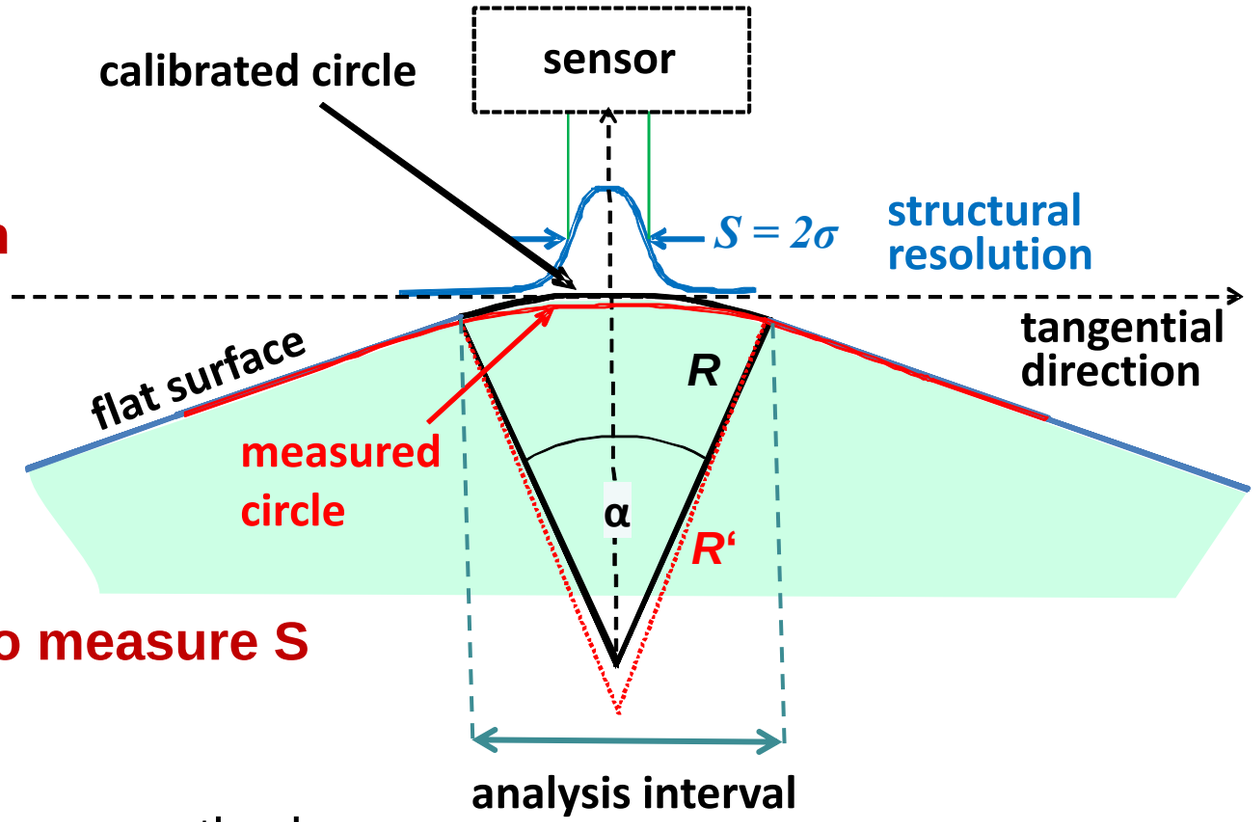
Presentation for one direction:



Approach

The sensor system locally **convolves** the coordinate values in tangential direction. The edge will be flattened

The kernel is assumed a **Gaussian with a full width *S***. This size **defines the structural resolution**



The **ratio of measured radius** of the arc **and calibrated value enables to measure S**

The radii are determined by **a least-squares** method.

Consider only data in the **region of interest** interval

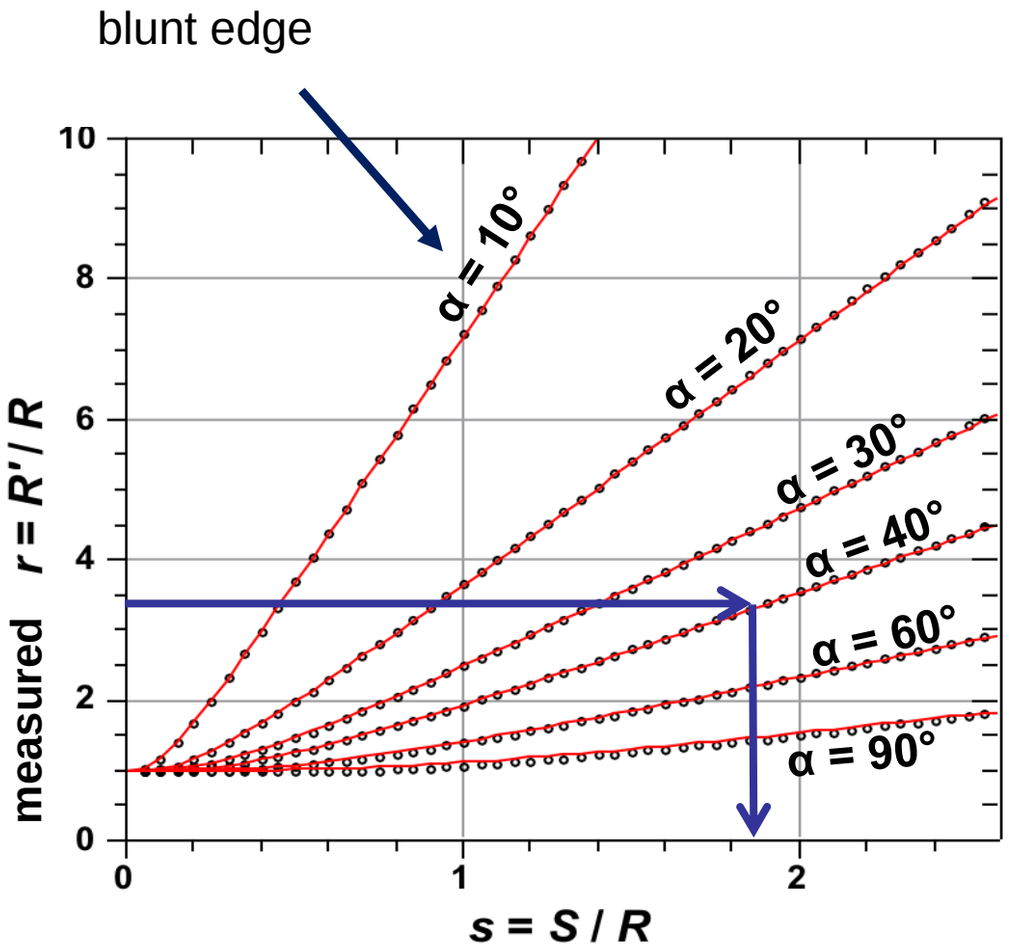
$$[\ -\sin(\alpha/2)\cdot R,\ +\sin(\alpha/2)\cdot R\ ]$$

using the known **arc opening angle** and known **radius**

Evaluation

Structural resolution *S* deduced from ratio of measured radius *R´* and calibrated radius *R*

Result of simulations:



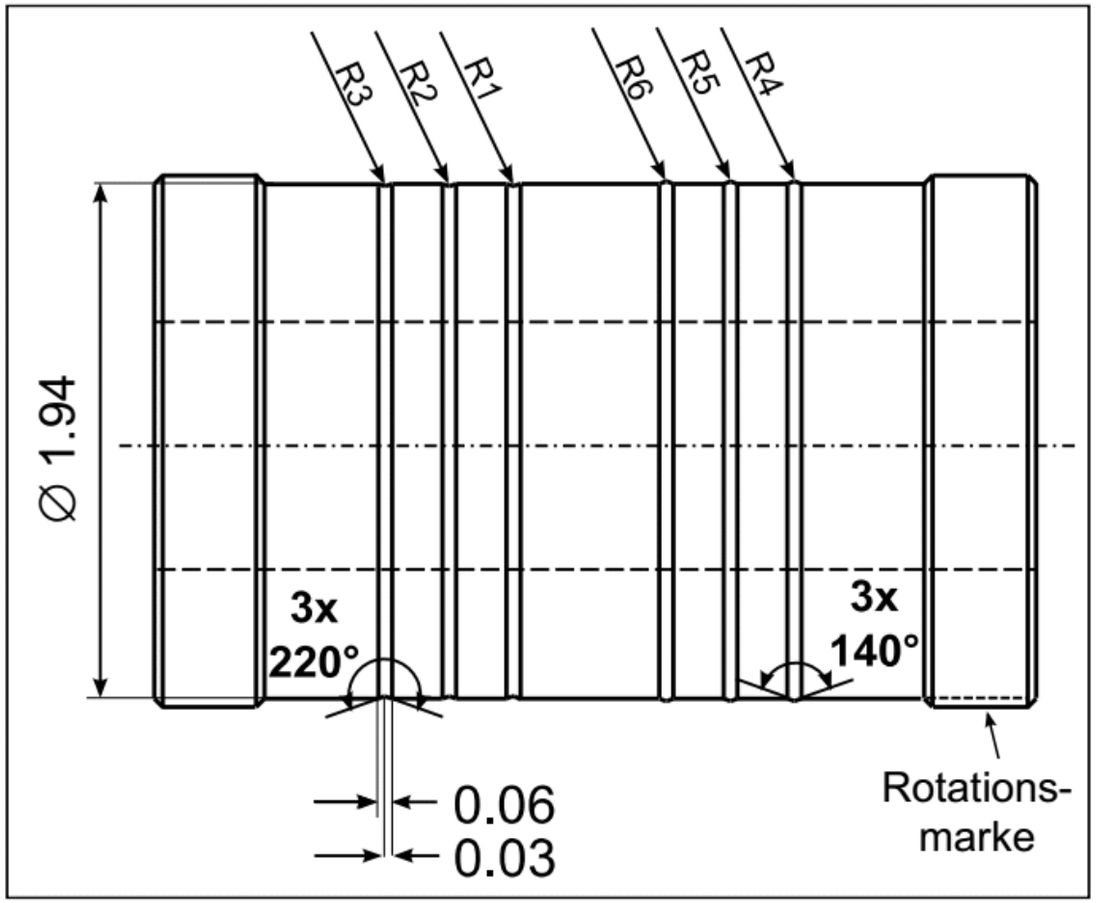
Analytic description (implicit equation!)

$$r = \frac{R'}{R} = \frac{1}{erf\left(\frac{\tan(\alpha/2)}{(S/R)/\sqrt{2}}\right)}$$

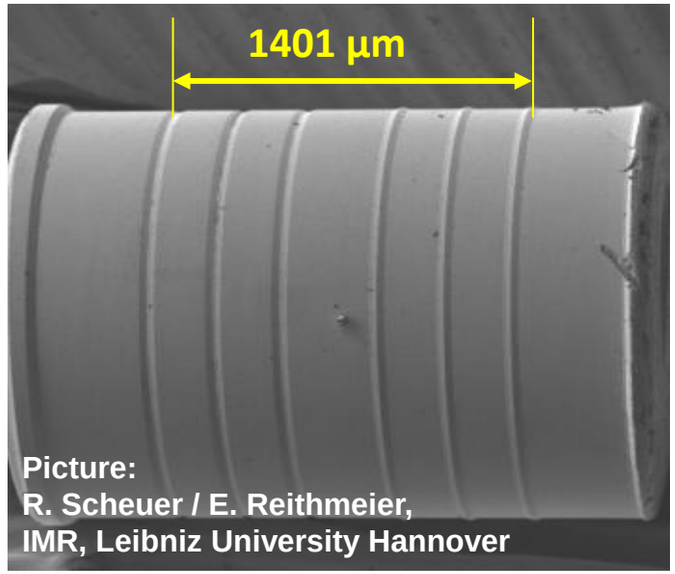
Parametric approximation (also implicit)

$$r \cong 1 + l \cdot e^{-1{,}06/l}, \quad l = \frac{0{,}628 \cdot (S/R)}{\tan(\alpha/2)}$$

Reference standard



REM images of reference standard



Mounted reference standard

Selected radii: 1 µm – 5 µm (nominal)

Manufacturing:

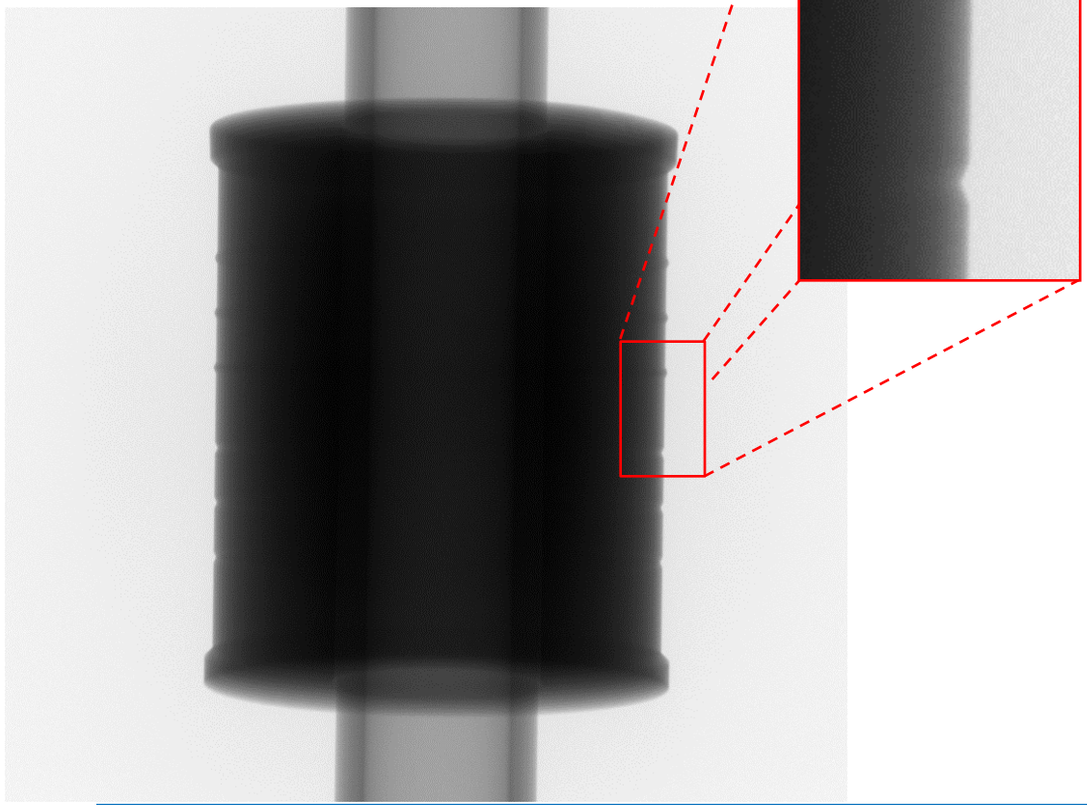
Diamond turned amorphous Ni-P on copper
(PTB scientific instrumentation department)

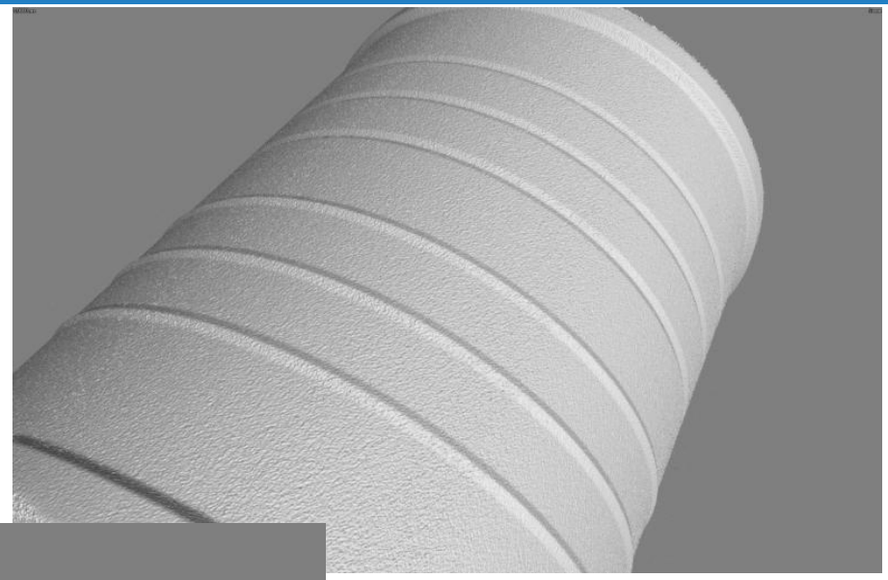
Application to CT

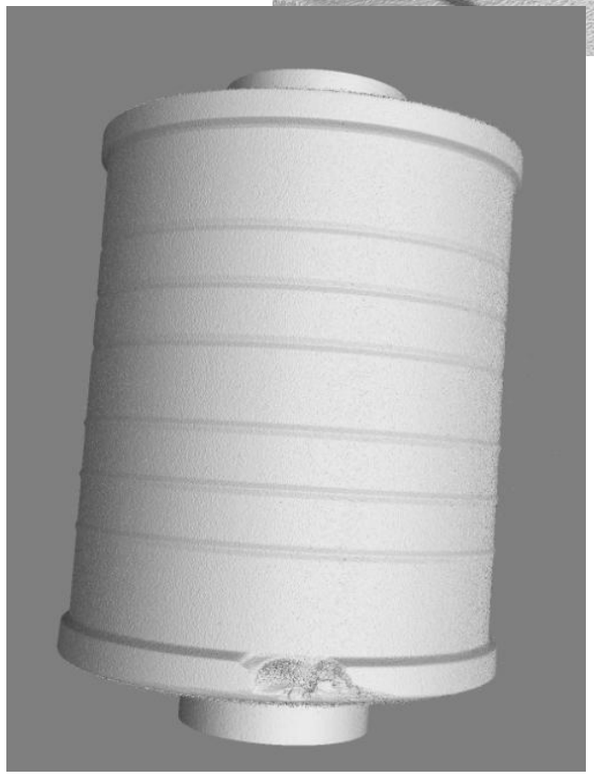
CT measurement using

– Nikon XT 255 ST

– VG Studio Max 2.2







Parameters:

U = 150 kV

P = 1.95 W

no filter

Mag. 120

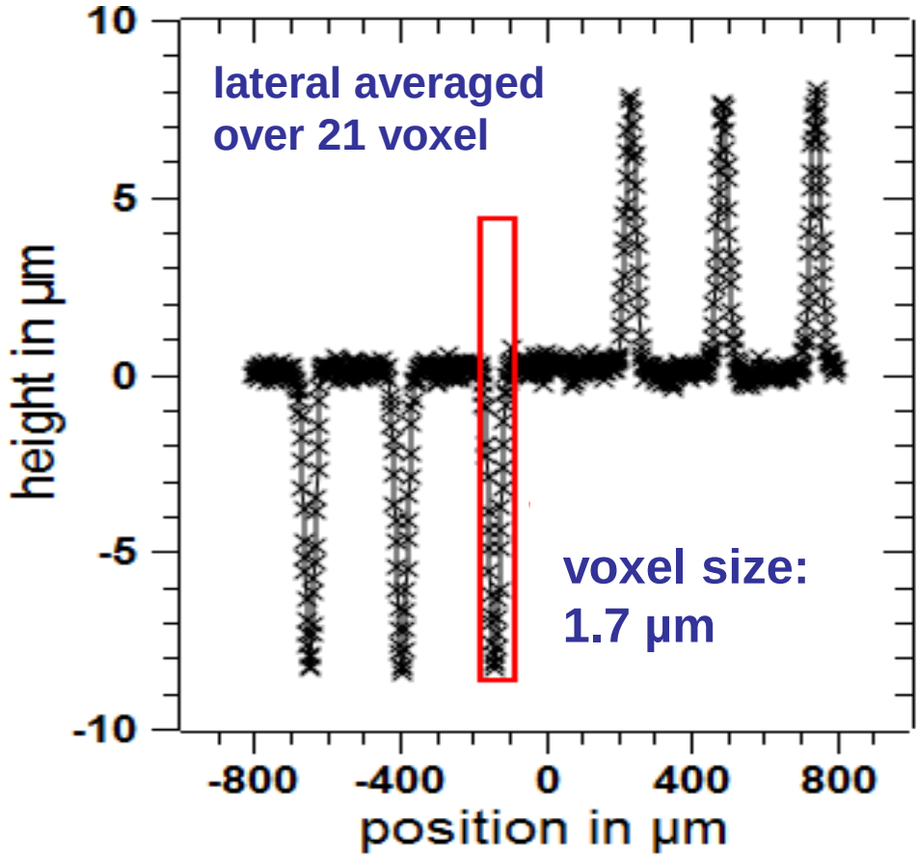
1.67 µm voxel size

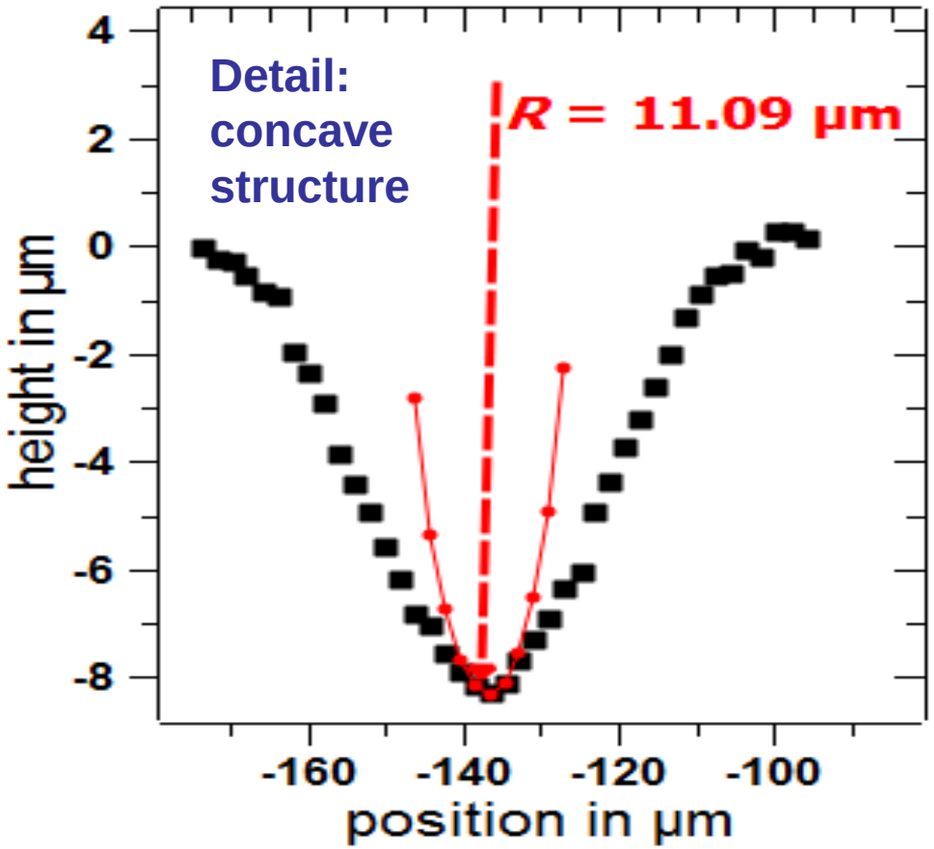
1500 projections

3h20 min measured

adaptive surface determination

Reference standard





Calibration data R — **azimuthal measurements** — **median value**

in µm		1	2	3	4	5	p_{20}	p_{50}	p_{80}	S
R1	**6.72**	6.27	8.19	9.46	11.09	14.48	7.23	**9.46**	12.78	**4.22**
R2	**4.50**	5.08	7.84	9.78	12.79	14.66	6.46	**9.78**	13.72	**5.20**

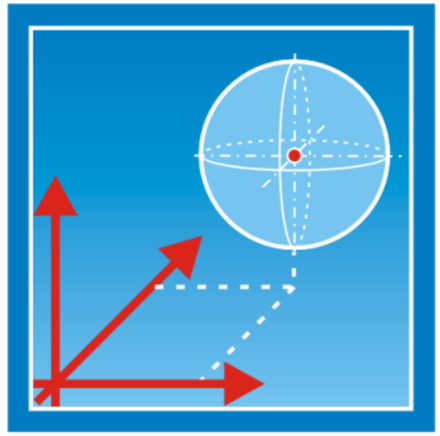
Result:
Structural resolution
S ≈ 4,7 µm
≈ 2,35 · voxel size

Summary

- **Standardization of dimensional CT** started in 2004 in Germany (VDI/VDE 2630 series)
  Today ISO TC 213 WG 10 is working on future ISO 10360-CT.
  Due to the complexity of CT **open issues** exist — esp. for standardization:
  Material influence, test design & data analysis and
  structural resolution for dimensional measurements

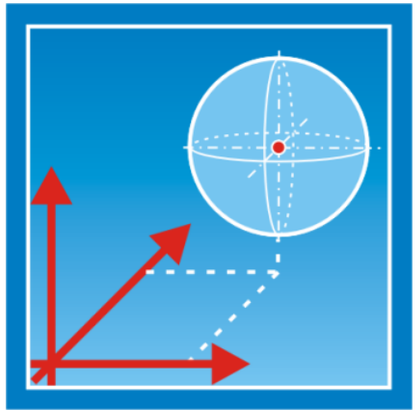
- Measurements and **a new standard design for hole plates** have been presented showing the ability to assess length measurement errors and material impact.
  Bidirectional error statements appear still necessary for *E* testing of CT

- **Structural resolution testing** is a necessary add-on to tests of length measurement & probing errors. New approach has been presented which appears applicable also to CT.
  Further work has to be done to create comparability to other sensors
  and to detail testing conditions as e.g. lateral averaging



Thank you for your attention!

Contact:
markus.bartscher@ptb.de



The authors thank for their contribution:

Dr. I. Schmidt, Werth Messtechnik, Germany
for providing a calibrated hole plate

S. Verhülsdonk, Dr. R. Meeß, PTB, Germany
for manufacturing the new resolution standard

T. Dziomba, PTB, Germany
for AFM measurements of the new resolution standard

Dr. M. Krystek, PTB, Germany
for assistance with analytical solution of *S*

Recent addendum:

We offer jobs to Early Stage Researchers (ESR) @ PTB:

EU Project INTERAQCT (see www.interaqct.eu)

(EU mobility criteria are of importance!
Total number of positions: 13 ESR + 2 ER)

MARIE CURIE ACTIONS

FP7-PEOPLE-2013-ITN
Grant No.: 607817