# TIM

**Traceable in process measurement**
**EMRP project IND 62**

Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin

# Metrology for machine tools: Needs and Expectations

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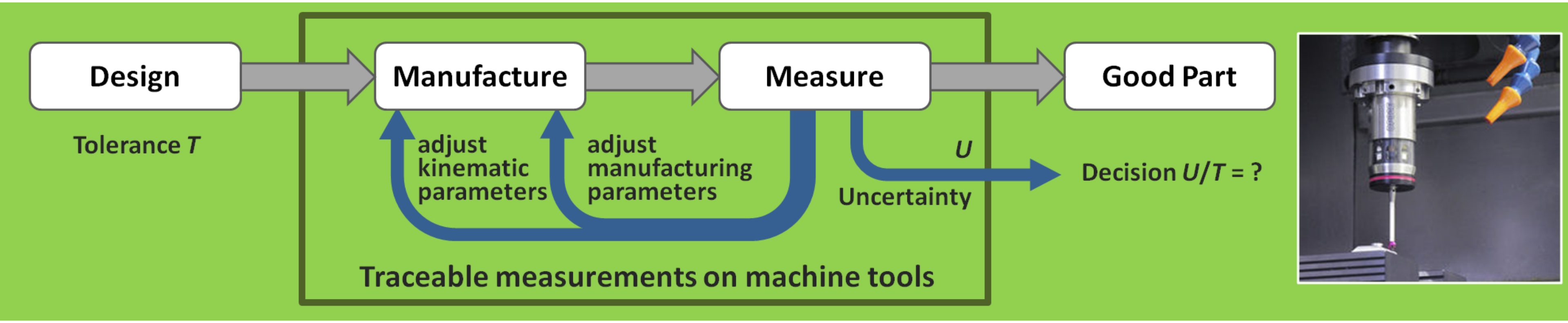
**on behalf of Dr.-Ing. Klaus Wendt (PTB) (TIM project coordinator)**

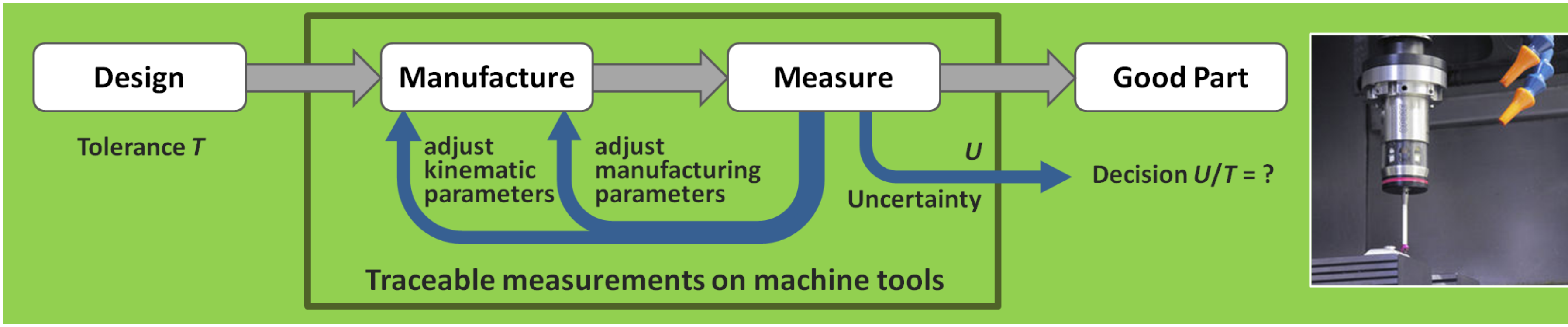
**18th May 2016 at PTB**

# Traceable measurement process
# Concepts for Integration in Machine Tools




Traceable in-process dimensional measurement
(IND 62 TIM)

EURAMET




## *8 Funded Partners*

PTB – Physikalisch-Technische Bundesanstalt Braunschweig und Berlin
Ministerio de Industria, Energía y Turismo – CEM Centro Español de Metrología
CMI – Czech Metrology Institute
LNE – Le progrès, une passion à partager
MIKES
NPL – National Physical Laboratory
METROSERT
MIRS

## *8 Unfunded Partners*

DAIMLER
EMO Orodjarna d.o.o.
gorenje
IK4 TEKNIKER Research Alliance
MAG
RollResearch
Universidad Zaragoza
VEPLAS advanced technologies

## *2 REG Partners*

Aalto University School of Science and Technology
KIT – Karlsruher Institut für Technologie

# Work-Packages (1 to 3 [of 7])

The JRP comprises of seven work-packages, these include:

1) **Framework**
   - Review of standards and in-process metrology
   - Basic guideline describing traceability routes, acceptance and fit-for-purpose tests
2) **Robust measurement standards**
   - Specification, design and manufacturing of 6 material standards
   - Robust against environmental influences and mechanical stress
   - With or without large form deviations
3) **Mobile simulation chamber**
   - Manufacturing of a chamber for simulating the manufacturing and machine tool environmental conditions
     (e.g. temperature, humidity, air circulation, etc.)

# Work-Packages (4 to 7 [of 7] )

The JRP comprises of seven work-packages, these include:

4) **Procedures for ensuring reliable measurements on machine tools**
   - Determination of the ***performance*** and ***task-specific measurement uncertainty*** of machine tools using material artifacts with low / high CTE, little / large form errors

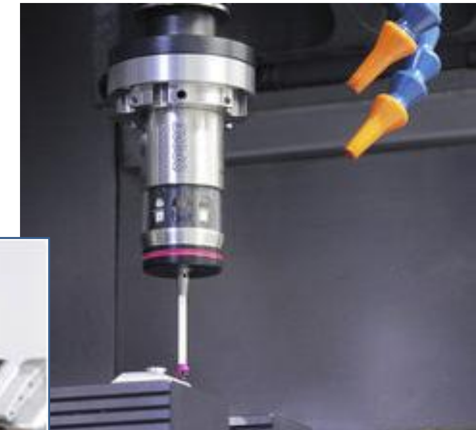
5) **Demonstration and integration focused on end-user needs**

6) **Creating Impact**
   - Dissemination and transfer of the outputs of this JRP to the European machine tool, manufacturing and metrological community

***Paper, Industrial interaction, Conferences, Workshops***

# Needs

**Manufactured parts are normally measured immediately after machining on the machine tool**

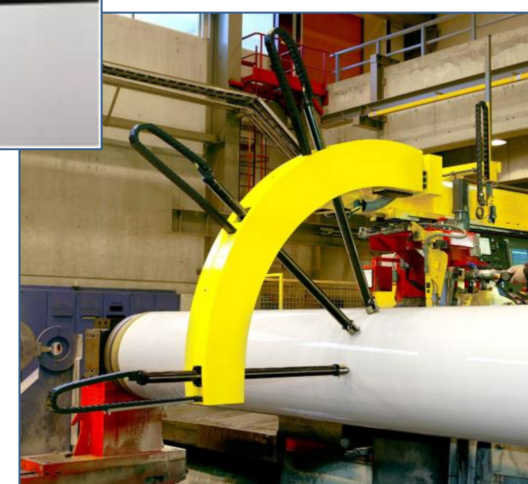


- *by a tactile probing system attached to the tool holder*
- *And possibly separate optical 3D measuring system*

*or* **in-process**

- *Using optical measuring sensors*

**'on-machine' measurements form**
the basis for a definite decision, whether or not the manufactured parts lie *within the specified tolerance*



**go/no-go decision is based on**
*reliable and traceable measurement uncertainties*

# Expectations of TIM project

**TIM is aiming at:**

- ***Evaluating*** *the dimensional metrology* ***capability of CNC*** metal cutting machine-tools such as ~ milling, drilling and grinding machines

  Using various methods and procedures

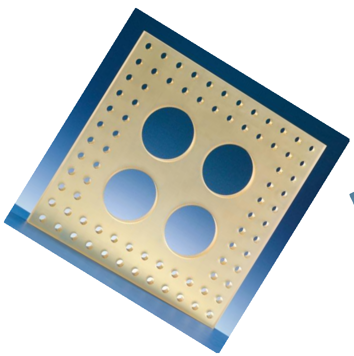
  - To demonstrate the *general measurement capability* ***by comparison*** with calibrated reference artefacts (test lengths)
  - And to determine ***specific uncertainties*** for measuring and inspection tasks

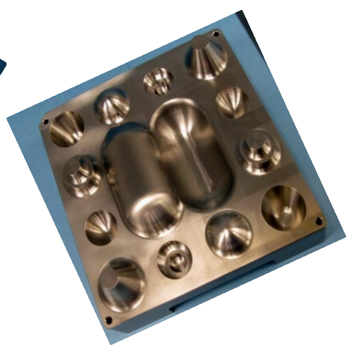
- *To demonstrate effectivity, using practical tests and show the benefits*
  - ***To end users*** and machine tool manufactures
  - Through real measurements of ***standards and calibrated workpieces***
  - And under ***shop floor conditions***

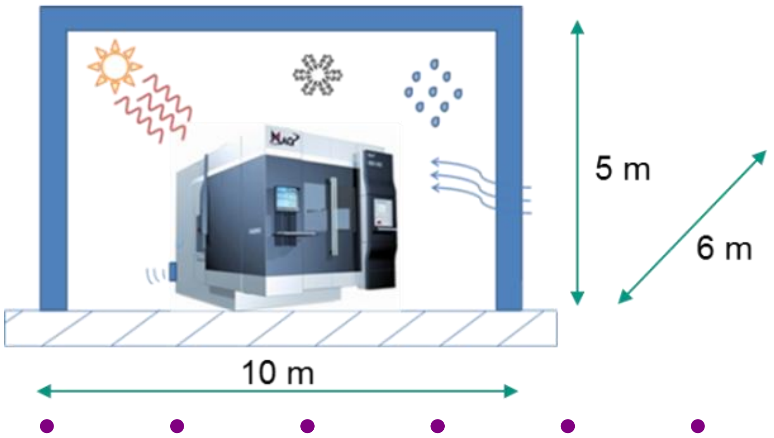
# Mapping of machine tool errors

**TIM is aiming at**

- ***Improving the measuring capability*** of CNC metal cutting machine tool through *correction of geometric and thermally* induced distortions of the machine by:
  - ***Volumetric error mapping*** using general applicable material standards or other techniques such as laser interferometry where required.
  - ***Task-specific error*** mapping using material standards with multiple features.
  - Using a ***climate chamber*** for simulating varying environmental conditions.

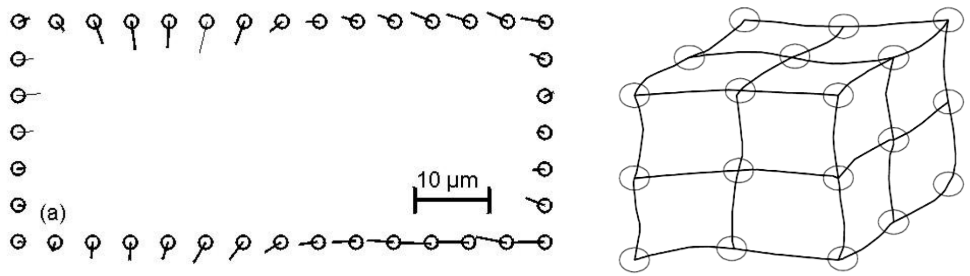




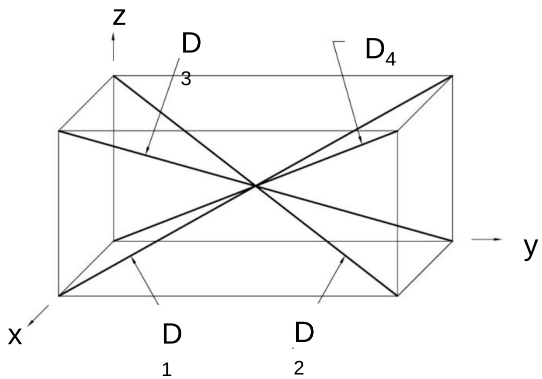


# Methods and procedures for error mapping

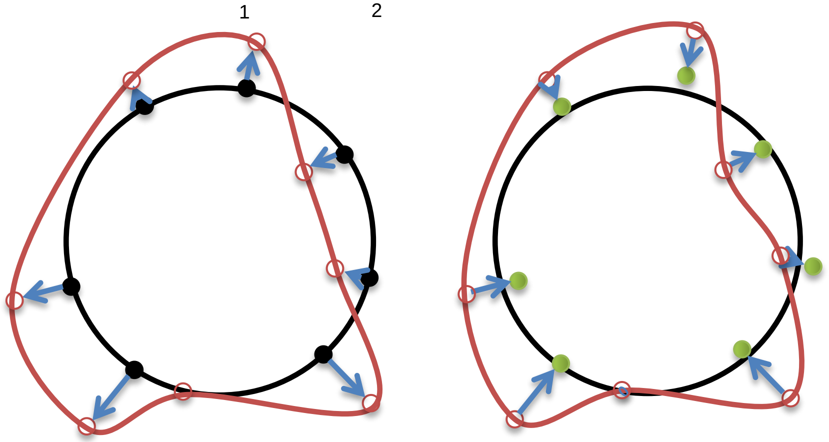
- **Volumetric error mapping**
  Mapping of geometric errors across the entire working volume (generally *requires* a mathematical error model)



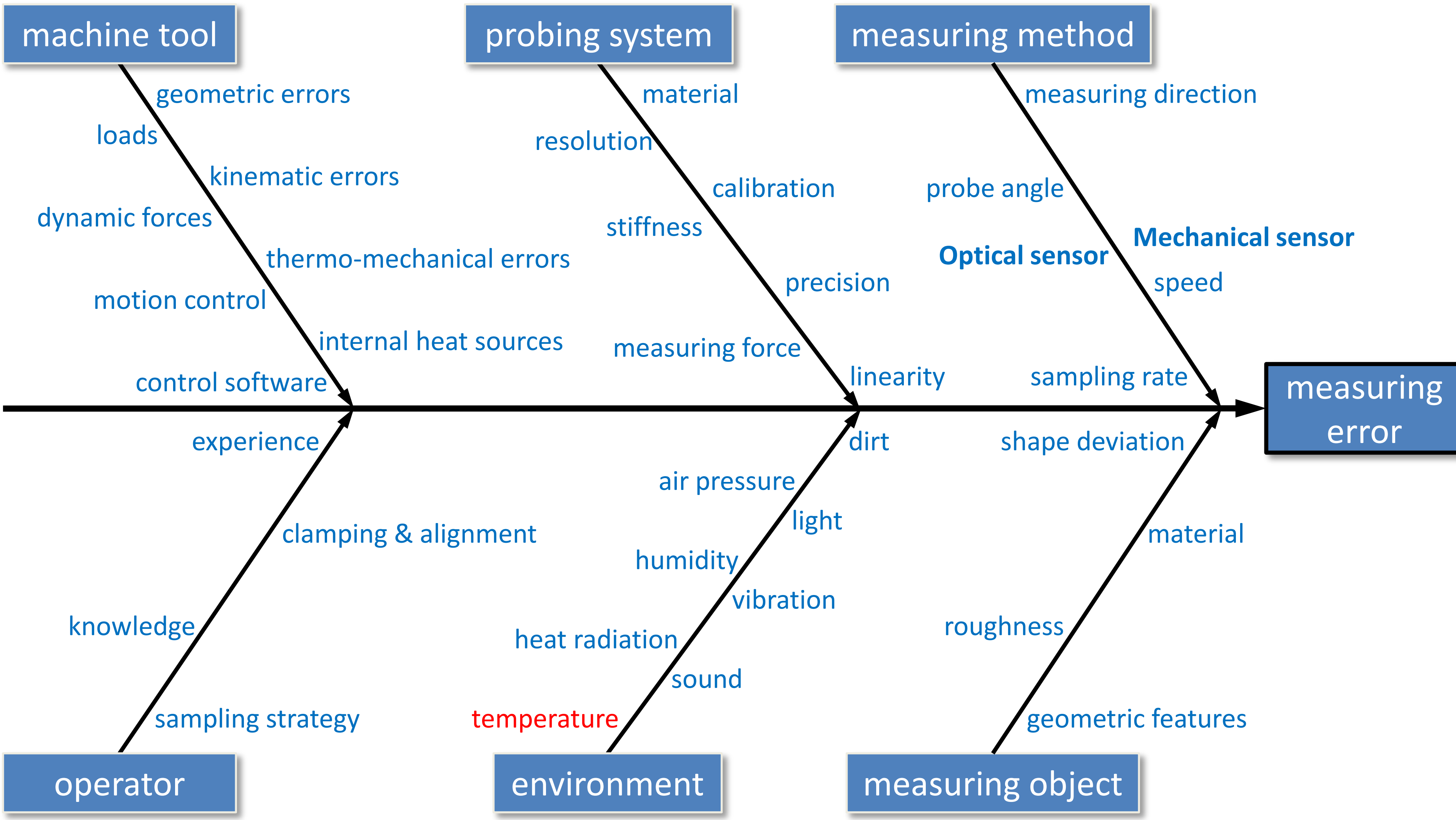

- **Verification of MPE**
  Verification of error compensation and MPE compliance test




- **Task-specific error mapping and correction**
  Determination of size, form and position errors of geometric features (generally *does not require* a mathematical error model)

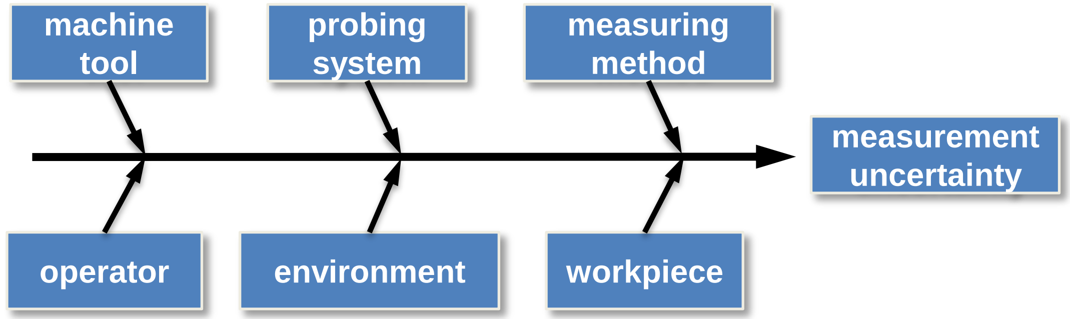


# Sources of measuring errors

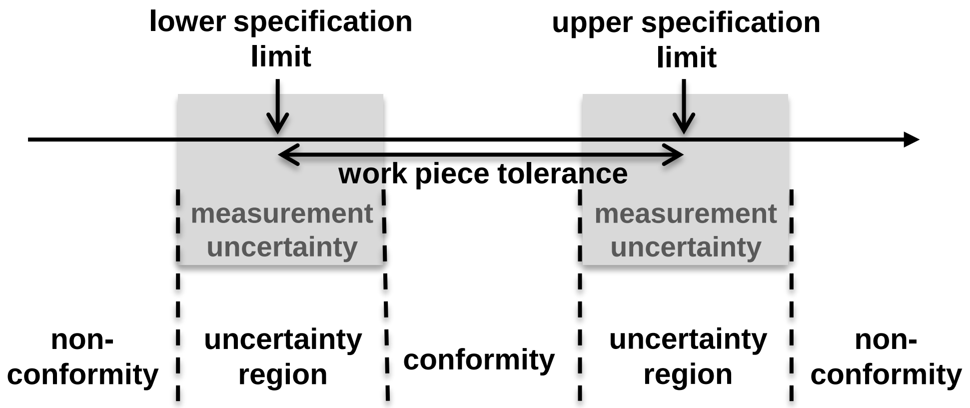


# Methods and procedures

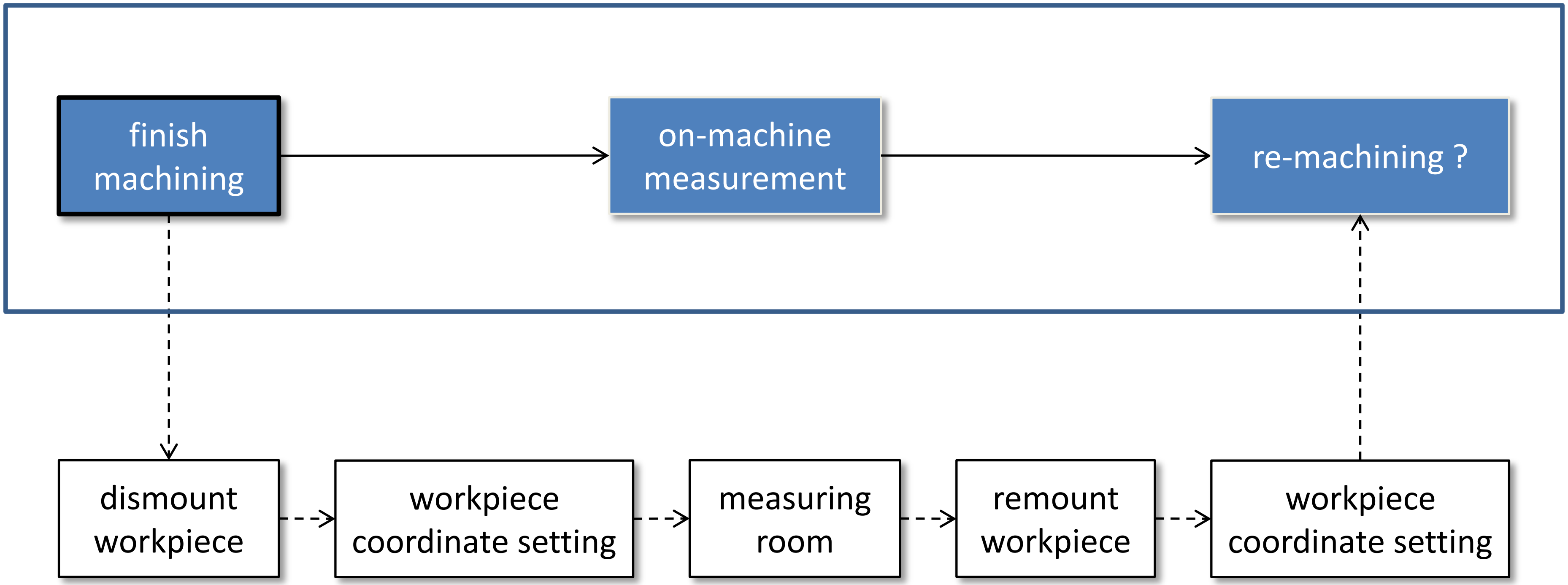
- **Task-specific measurement uncertainty**
  Determination of measurement uncertainty for shape and form measurements / typical geometric features




- **Fitness-for-purpose**
  Assessment of the capability of a machine tool to measure geometric features with sufficient small accuracy compared to the permissible manufacturing tolerance



# On-machine measurements

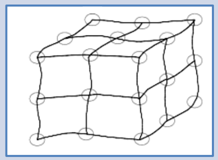
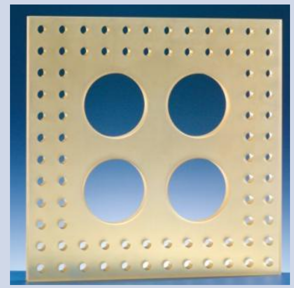
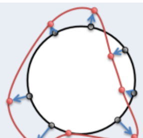
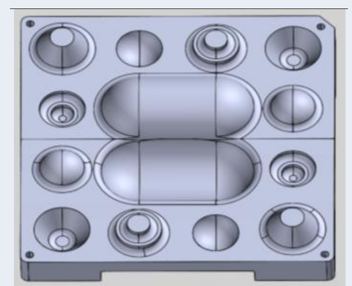
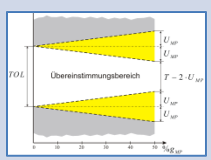



**Benefit:** Shortened measurement duration
reduction of energy costs (no expensive air-conditioning)

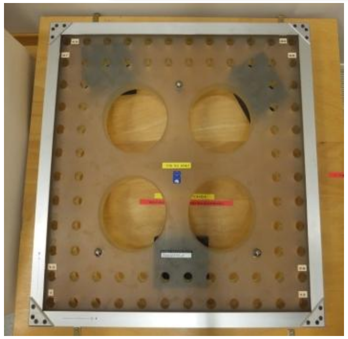
**Challenge:** Measurement under shop floor conditions
complex determination of measurement uncertainty

**Target accuracy: 5 µm/m**

# Procedures for determining measuring errors

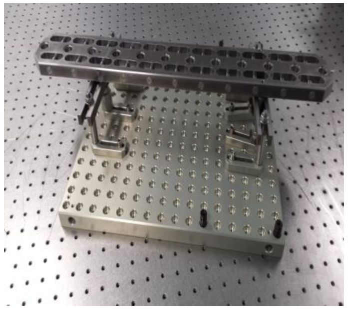
| procedure | material standards | error sources |
|---|---|---|
| Volumetric error mapping verification of MPE  |  | geometric, thermo-mechanical |
| Task-specific error mapping task-specific measurement uncertainty  |  | + dynamic forces<br>+ motion control<br>+ control software |
| Fitness-of-purpose  |  Source: eμmetron | ++ loads<br>++ heat |

# Manufactured material standards

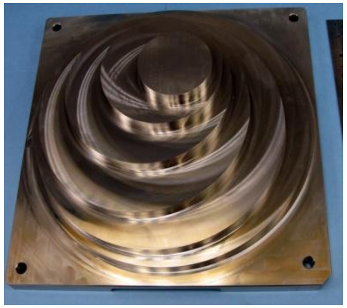


PTB: Hole plate

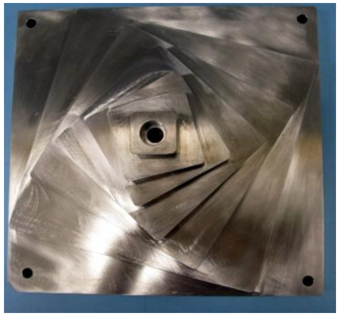
UM: Ball bar



LNE: Hole bar

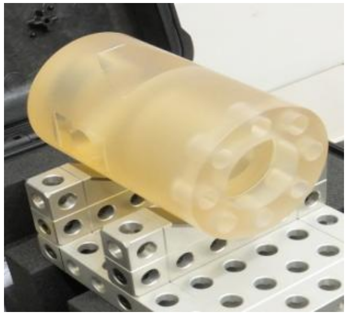


NPL: Eccentric cylinders

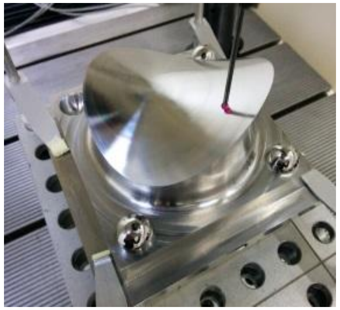


NPL: Rotating squares

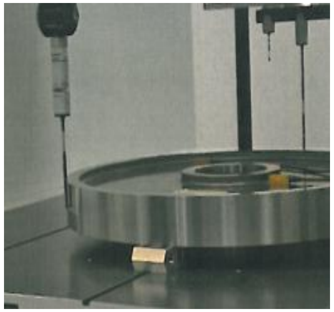
NPL: Prismatic geometries



PTB: Multi-feature check



CMI: Hyperbolic paraboloid



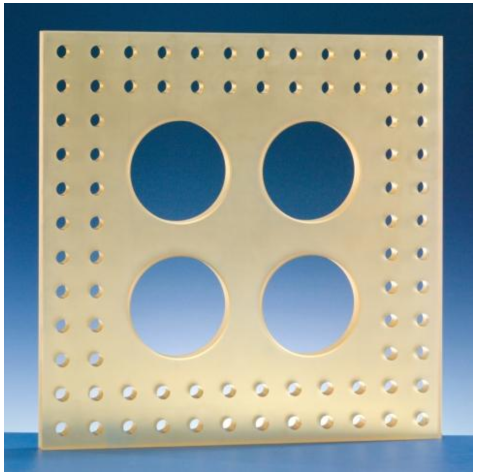
VTT: 3x Roundness Disks

# Procedure for mapping geometric errors

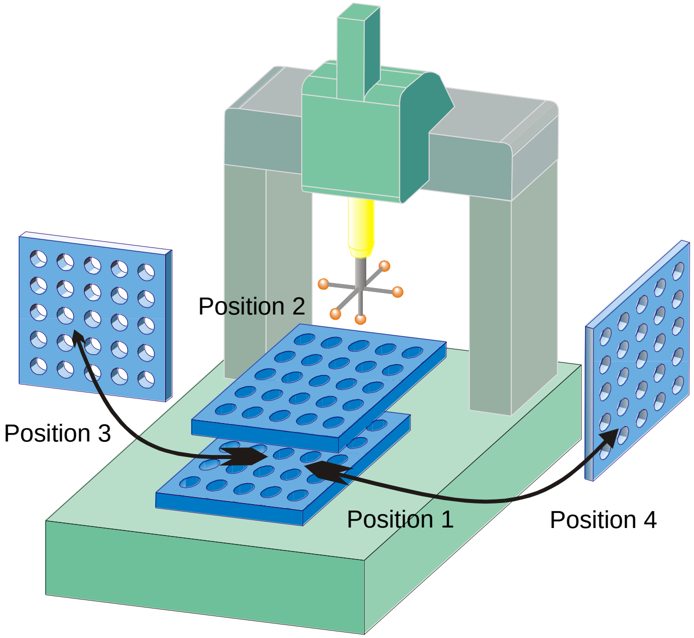
## Linear axes:

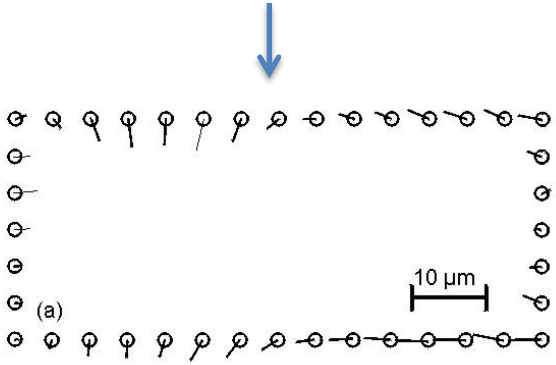
- *Uncorrected machine tool*
  mapping of systematic machine errors based on measurements of a thermo-invariant reference artefact in four or more positions

- *Corrected machine tool*
  mapping of remaining machine errors for determining the achievable accuracy

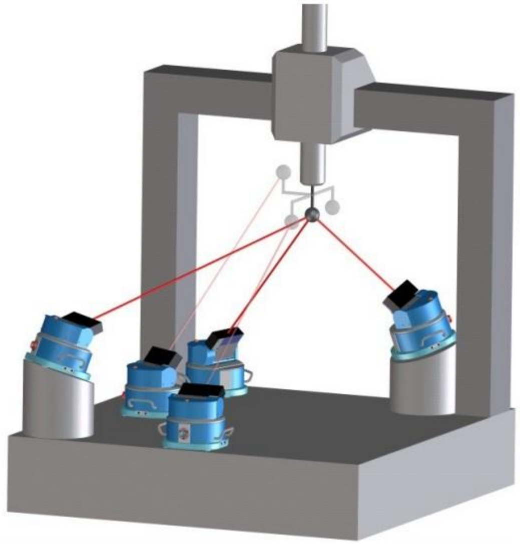


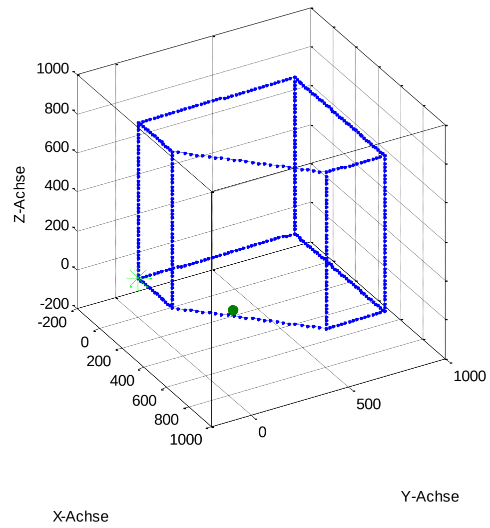
PTB: Hole plate



# Alternatively, mapping using Laser Interferometry



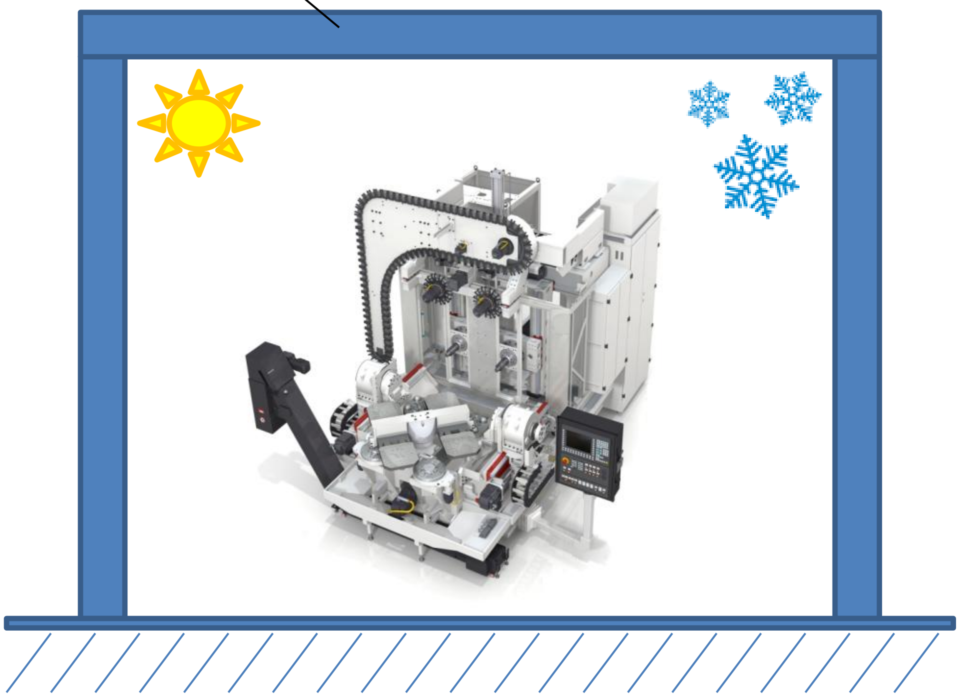


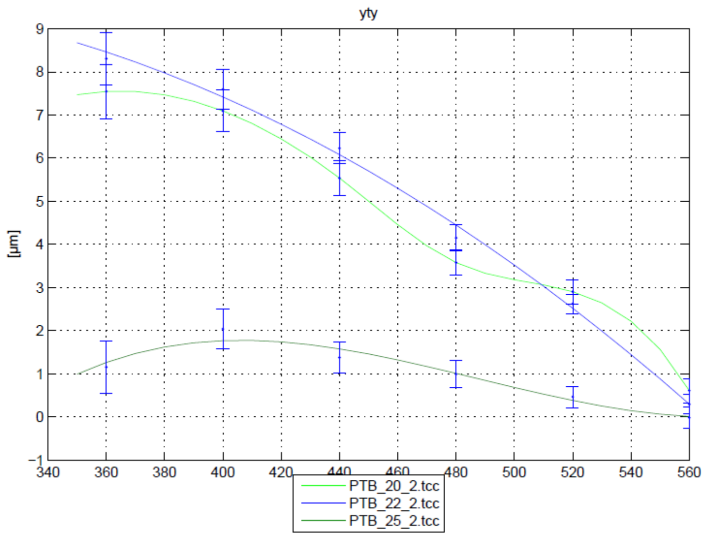

```
G01 G90 X800.0000
Y0.0000 Z0.0000
//(Point 1 of 929)
G04 X1.0
G01 G90 X780.0000
Y0.0000 Z0.0000
//(Point 2 of 929)
G04 X1.0
G01 G90 X760.0000
Y0.0000 Z0.0000
//(Point 3 of 929)
G04 X1.0
G01 G90 X740.0000
Y0.0000 Z0.0000
//(Point 4 of 929)
G04 X1.0
...
```

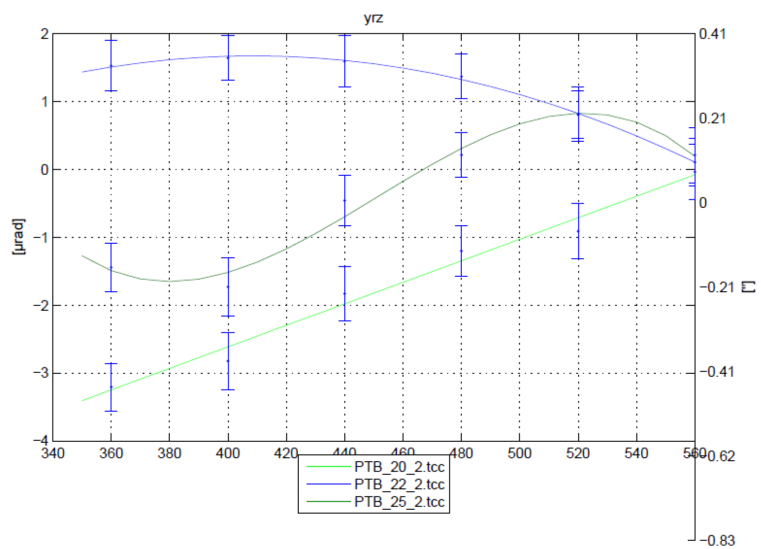
- Determination of volumetric errors via ***multilateration*** with the help, for example using ***self-tracking laser interferometers*** each in conjunction with a special ***gimbal type reference optics***.
- Suitable for **both linear and rotational axes**
- Such a system could ***generates CNC code*** for the machine tool
- And in principle could ***generate a correction table*** for a machine tool controller.

# Temperature dependency of volumetric errors

*Climate chamber*

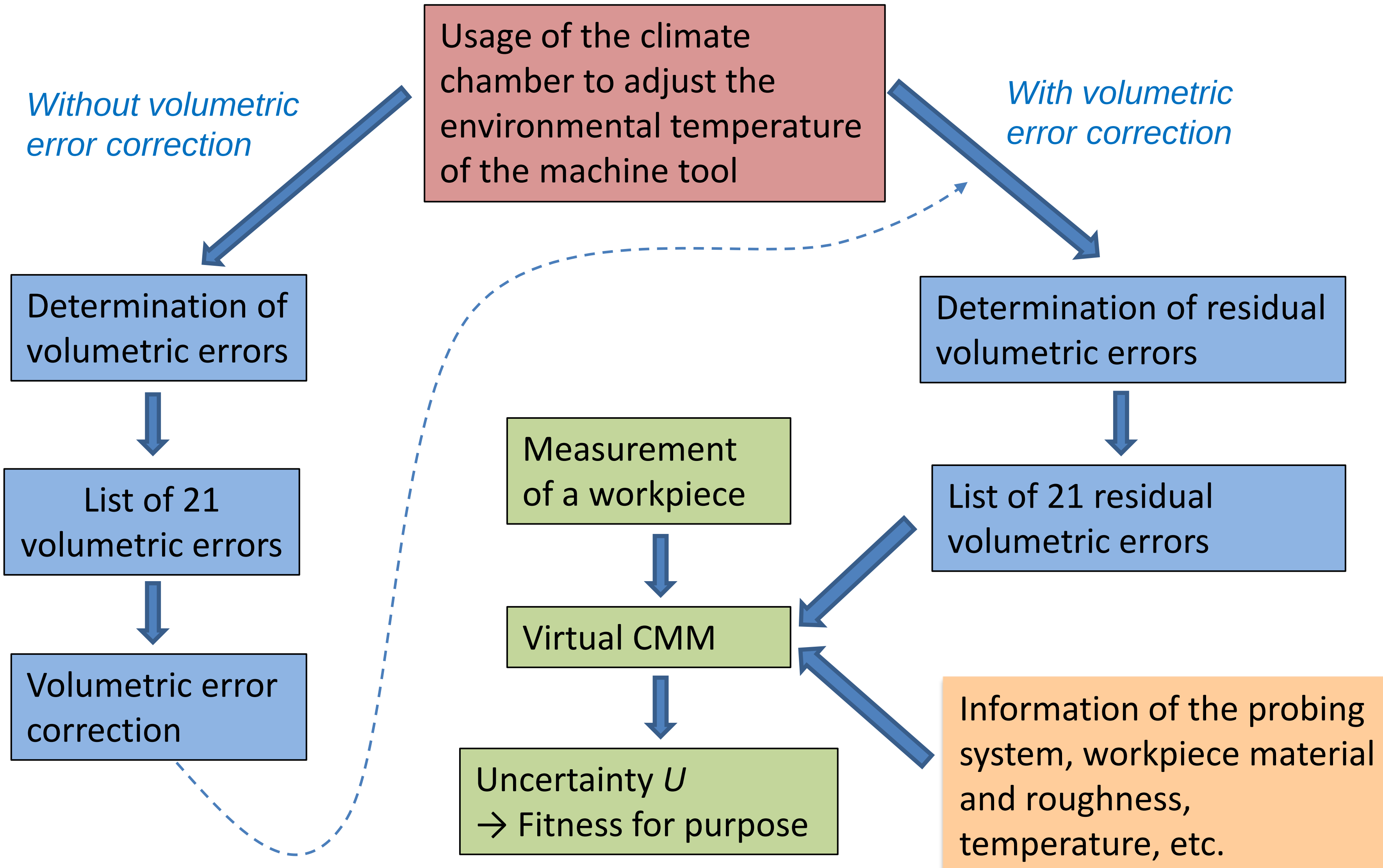




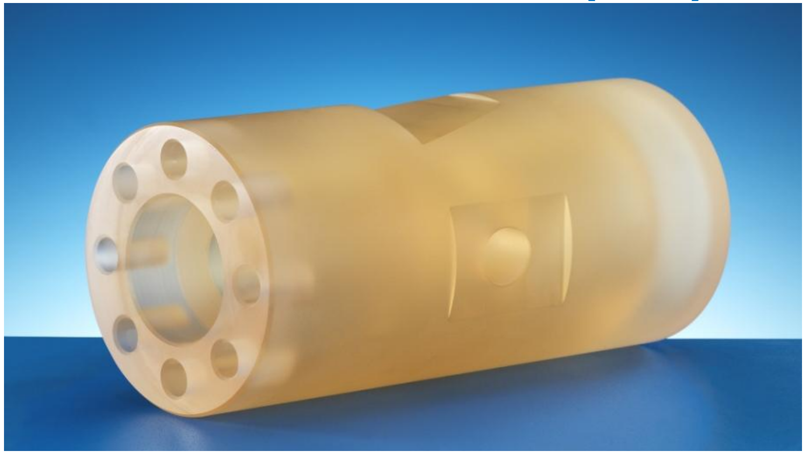

*Determination of volumetric errors at different temperatures:*
*T = 15°C, 20°C,…,35°C*

# Volumetric error mapping



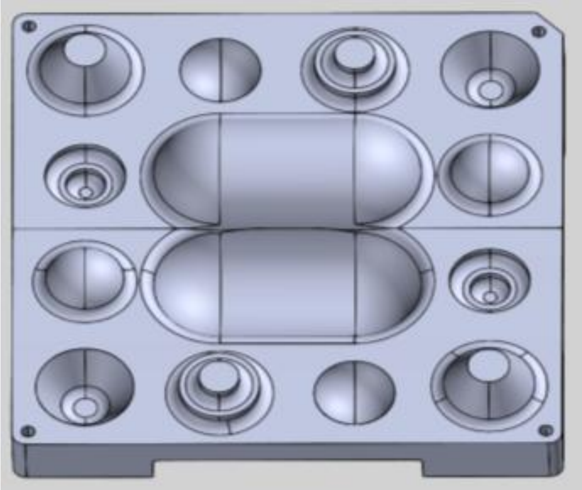
# Task-specific error mapping

## Traceability for tactile measurements (PTB)



- close to zero thermal expansion (made from Zerodur®)
- specifications:
  - form errors< 1 µm
  - roughness < 0.2 µm
  - position and size of features will be calibrated on CMM
- measurement tasks:
  - hole
  - flat surface
  - coaxially

## Traceability for optical measurements (NPL)



- Prismatic artefact
- Extremely low coefficient of thermal expansion (made from Invar)
- specifications:
  - plated surface
  - form errors < 5 µm
  - position and size of features will be calibrated on CMM, accuracy~ 2 µm

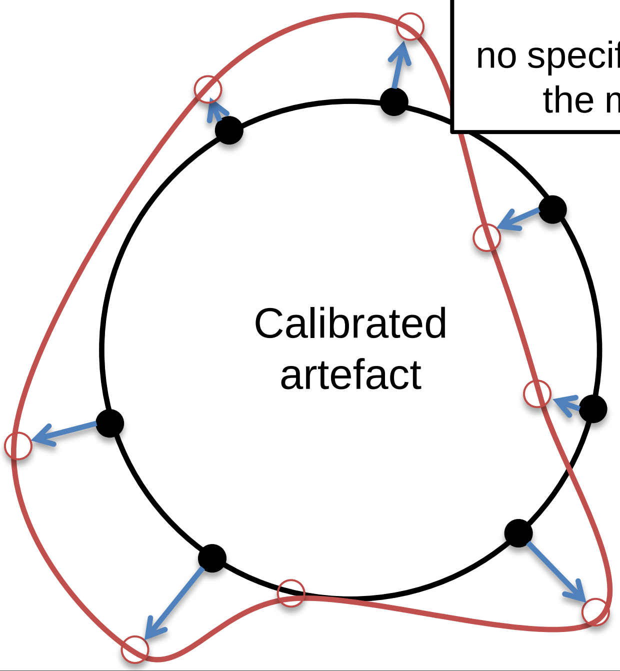
# Task-specific error compensation – concept

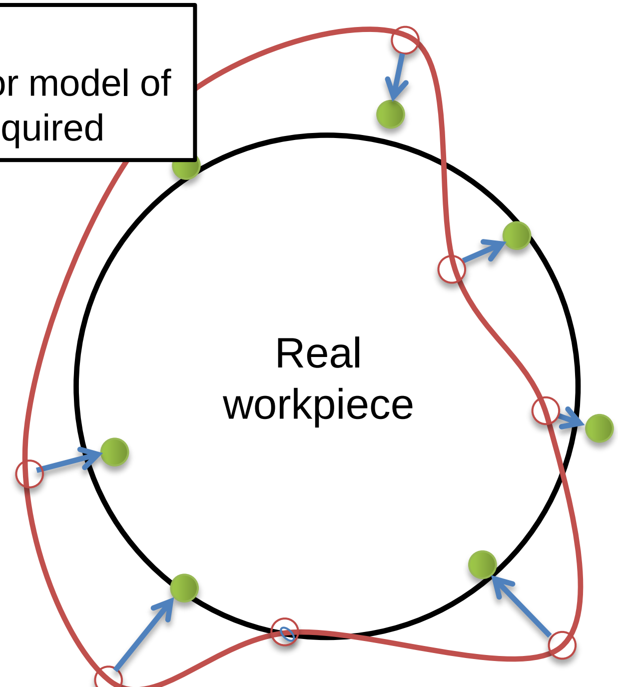
## Approach:

- acquire local error vectors by measuring a calibrated artefact (e.g. Zerodur® Multi-Feature-Check, Prismatic artefact or a workpiece replica)

- measure real workpiece using tactile or optical probe
- use the local error vector to correct the points measured point by point
- evaluation of the corrected points

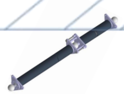
**Advantage**
no specific geometric error model of the machine tool is required



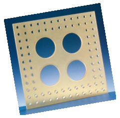



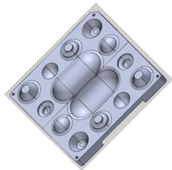
# Final outcome of the TIM project

- Provision of portable ***environmental simulation chamber***



- various high accurate, ***thermo-invariant material standards***





- **Industrial trails** using Machine tool in Chamber with standards
- Five Good Practice Guides for
  1. Checking the ***overall measurement performance***
  2. ***Assessing the fitness-for-purpose*** of on-machine measurements
  3. Verification of ***area-scanning*** metrology systems on machine tools
  4. **Mapping task-specific** measurement errors using ***multi purpose material standards***
  5. Measuring roundness on roller machines and determining the associated uncertainty

# Questions…?: