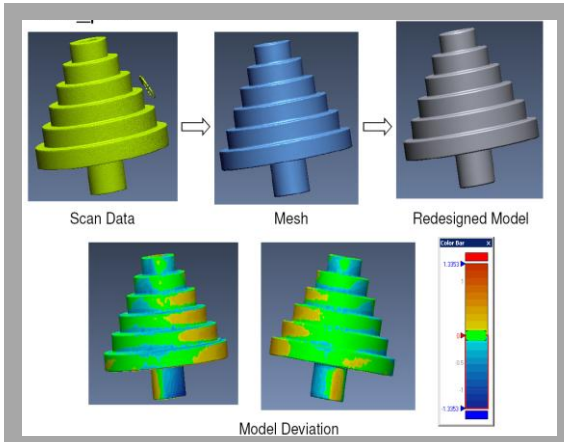
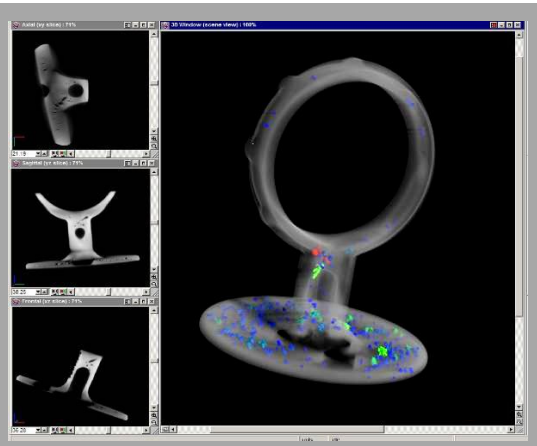
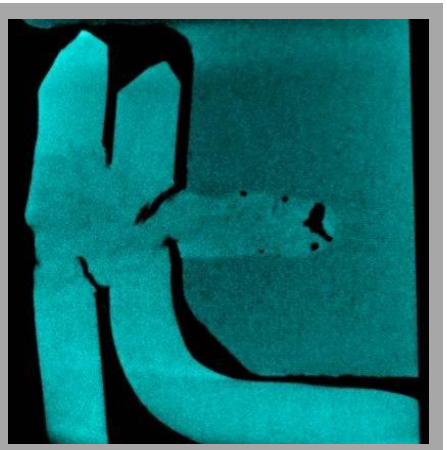
Hochauflösende Röntgen-Computertomographie an der Hochschule Aalen/Institut für Materialforschung



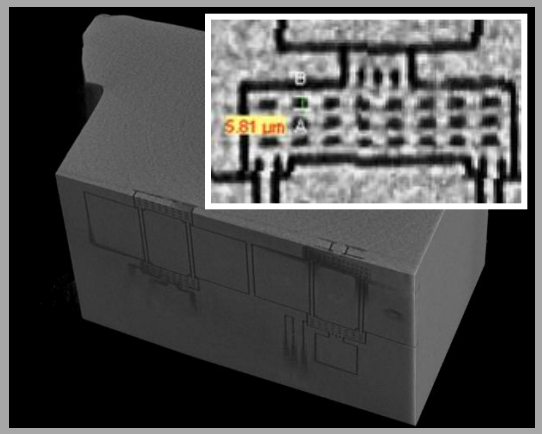
FEM Simulation – Metrologie



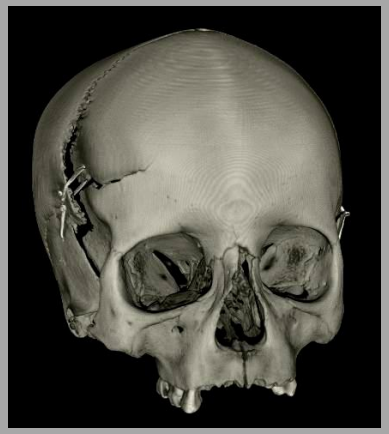
Bauteilprüfung



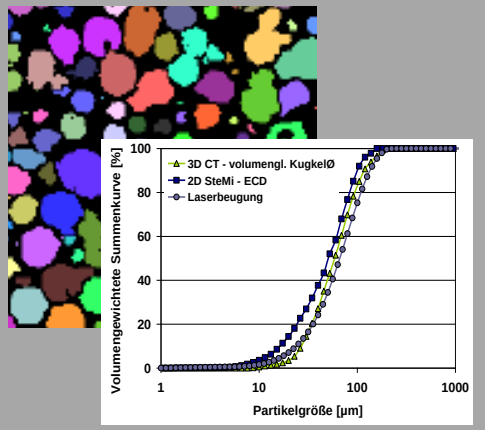
Schadensanalyse



Forschung



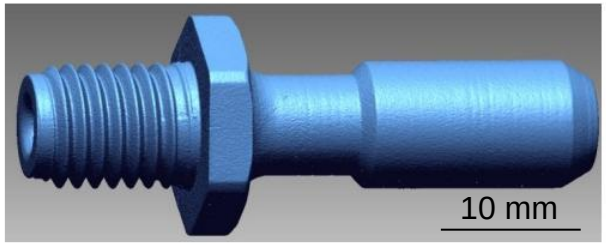
Rapid Prototyping



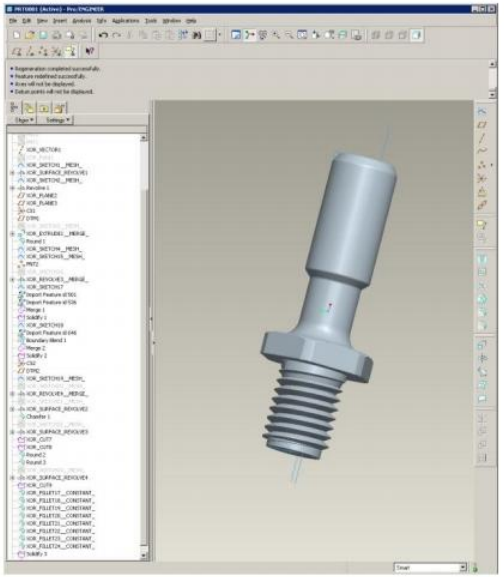
3D-Quantifizierung

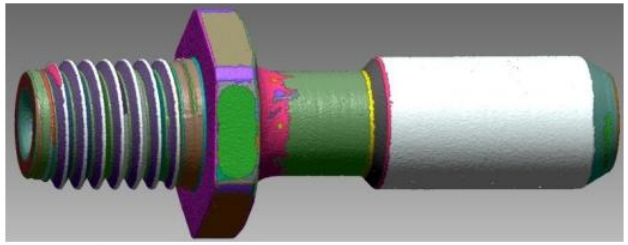
Anwendungsbeispiel µCT und Reverse Engineering

Überdruckventil aus Stahl

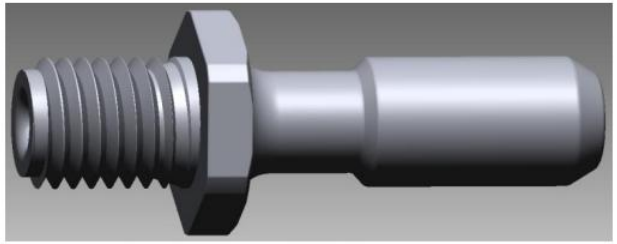


Scan data

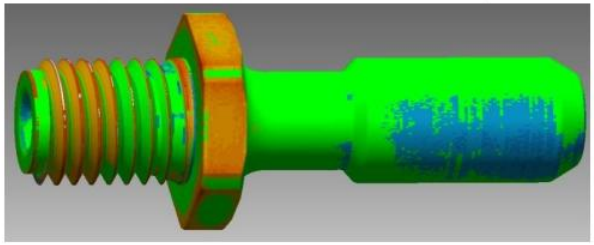




Regions



Featured based solid

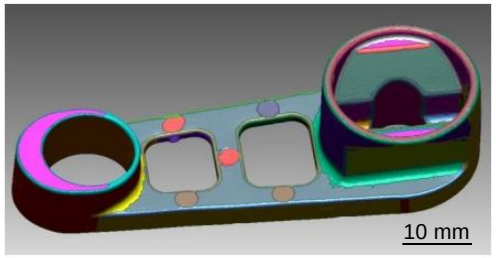


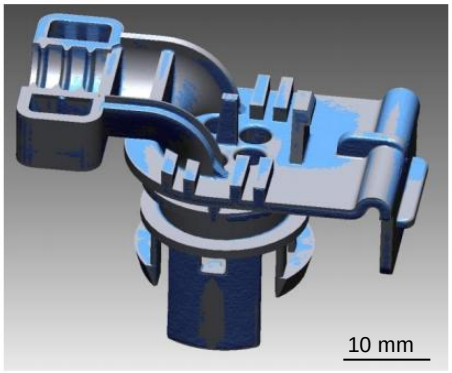
Deviation 0.03

In Zusammenarbeit mit Inneo Solutions GmbH

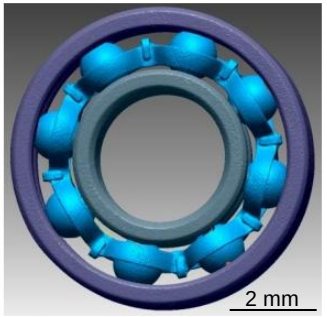
Anwendungsbeispiele µCT und Reverse Engineering

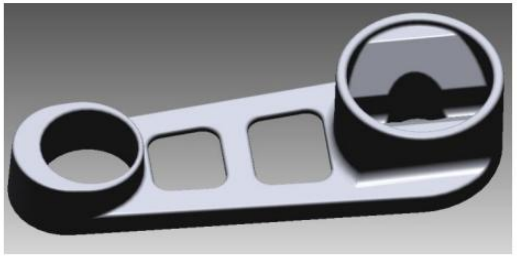
Hebel aus Spritzmetallguss



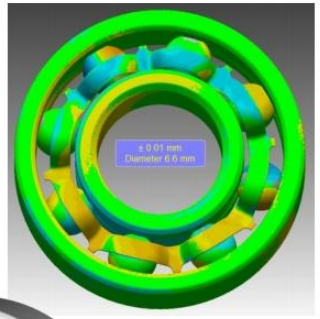


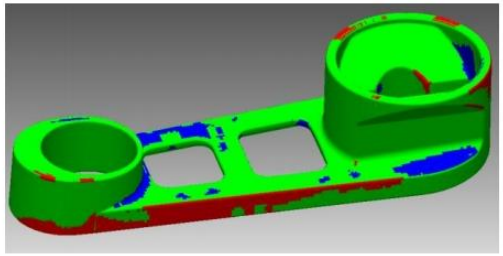
Mikro-Kugellager





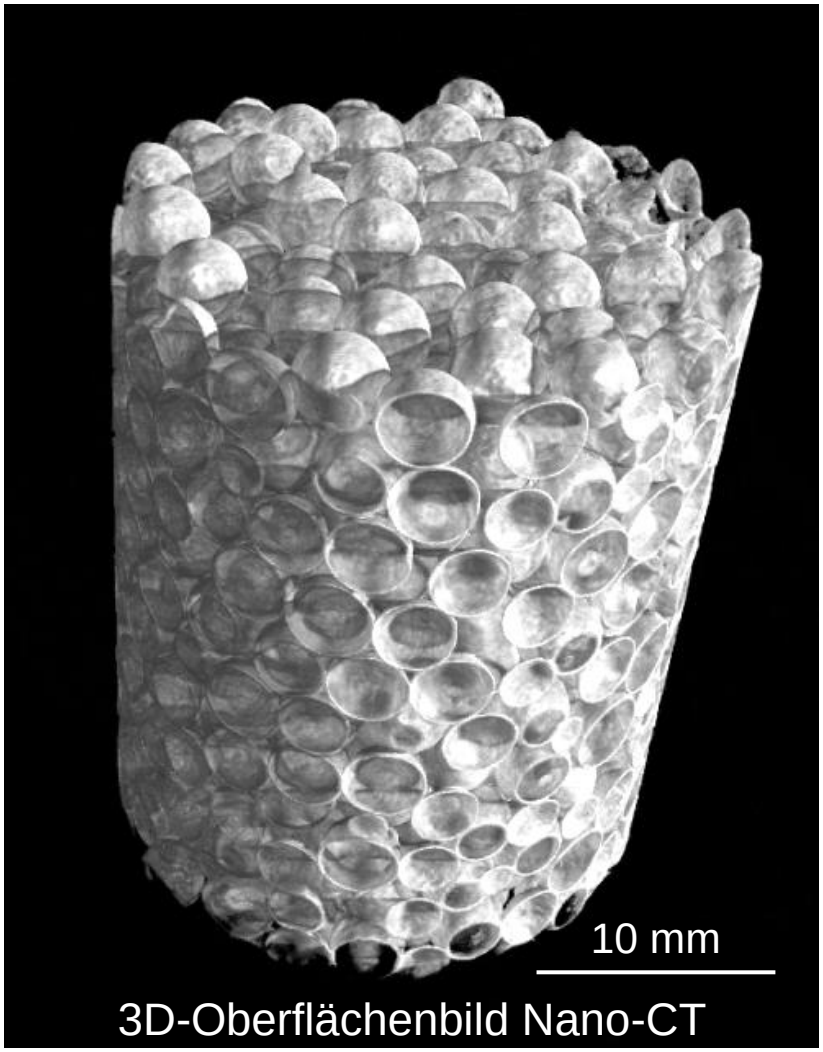
Kunststoffbauteil



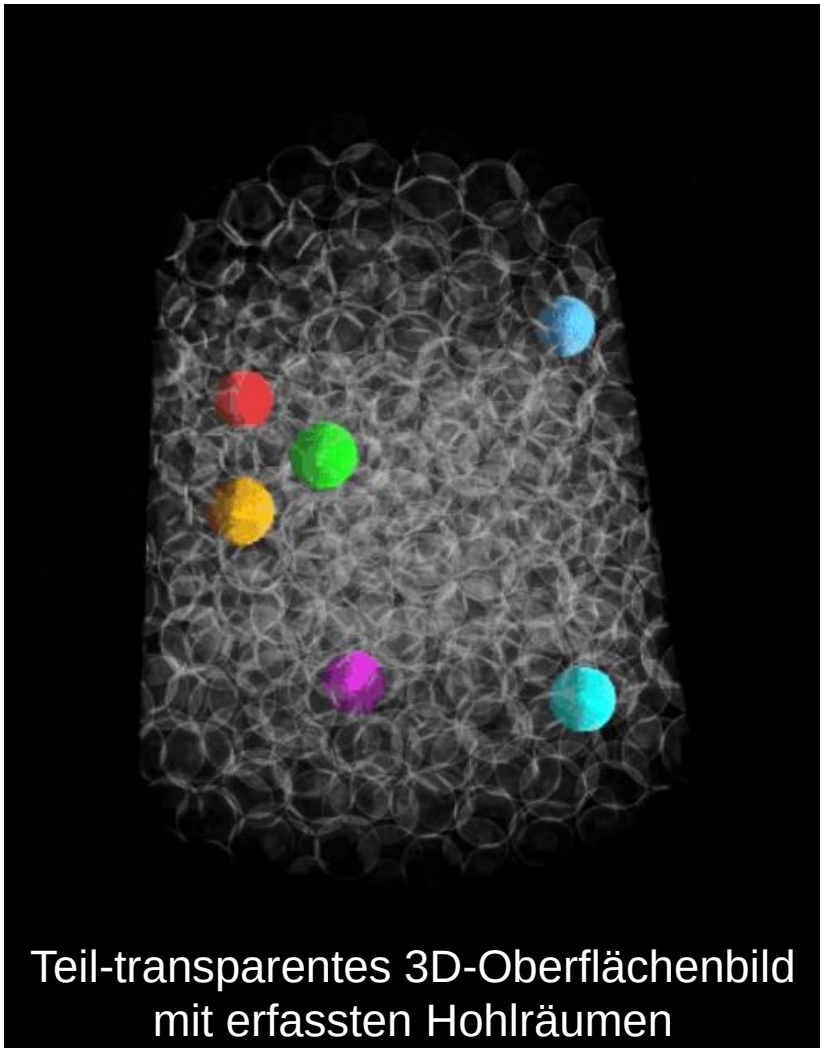


In Zusammenarbeit mit Inneo Solutions GmbH

Hohlkugel Stahl-Werkstoff: Datenbasis für FEM-Simulation der mechanischen Eigenschaften



3D-Oberflächenbild Nano-CT

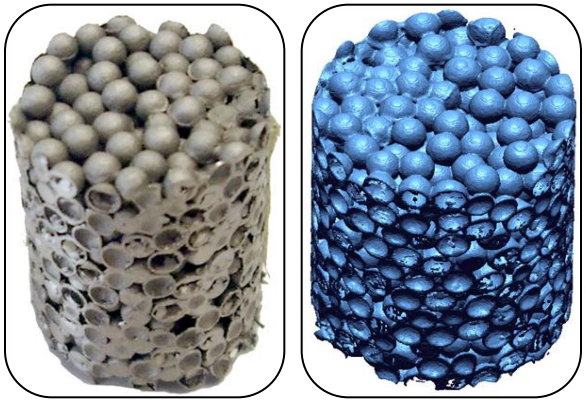


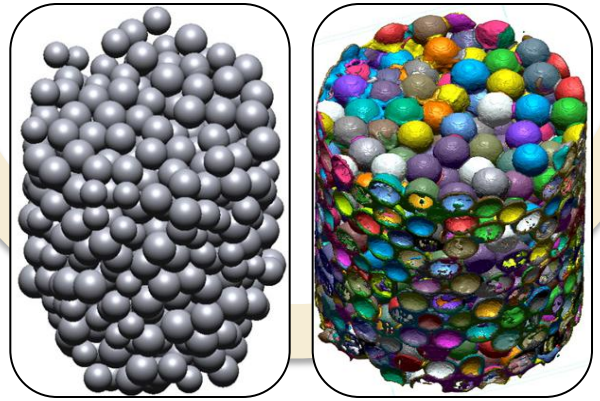
Teil-transparentes 3D-Oberflächenbild mit erfassten Hohlräumen

Hohlkugel Stahl-Werkstoff: Datenbasis für Simulation und Reverse Engineering

Original

Scan Daten

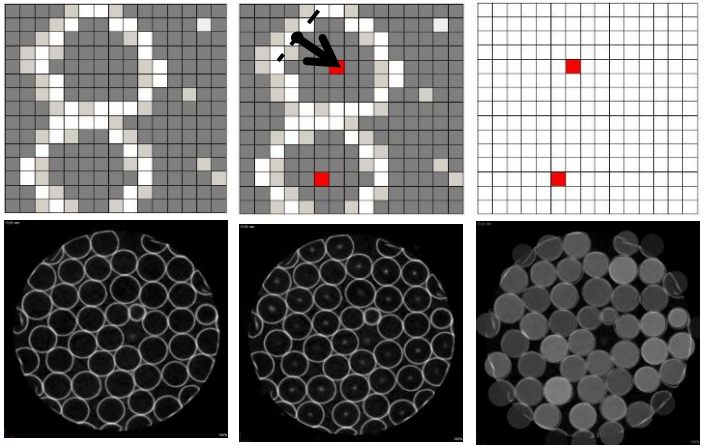




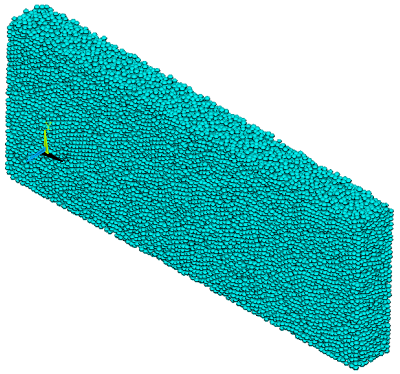
CAD Modell

Lokalisierung

Berechnungsmethode: Akkumulatorprinzip

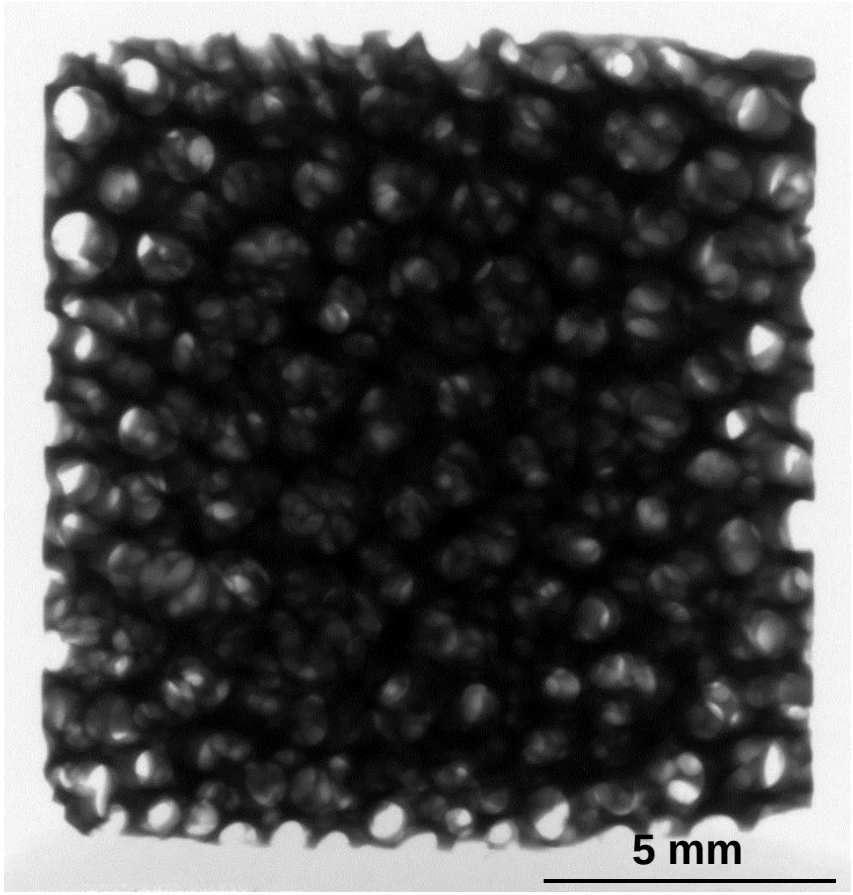


Beispiel:
Platte mit über 40.000 Hohlkugeln

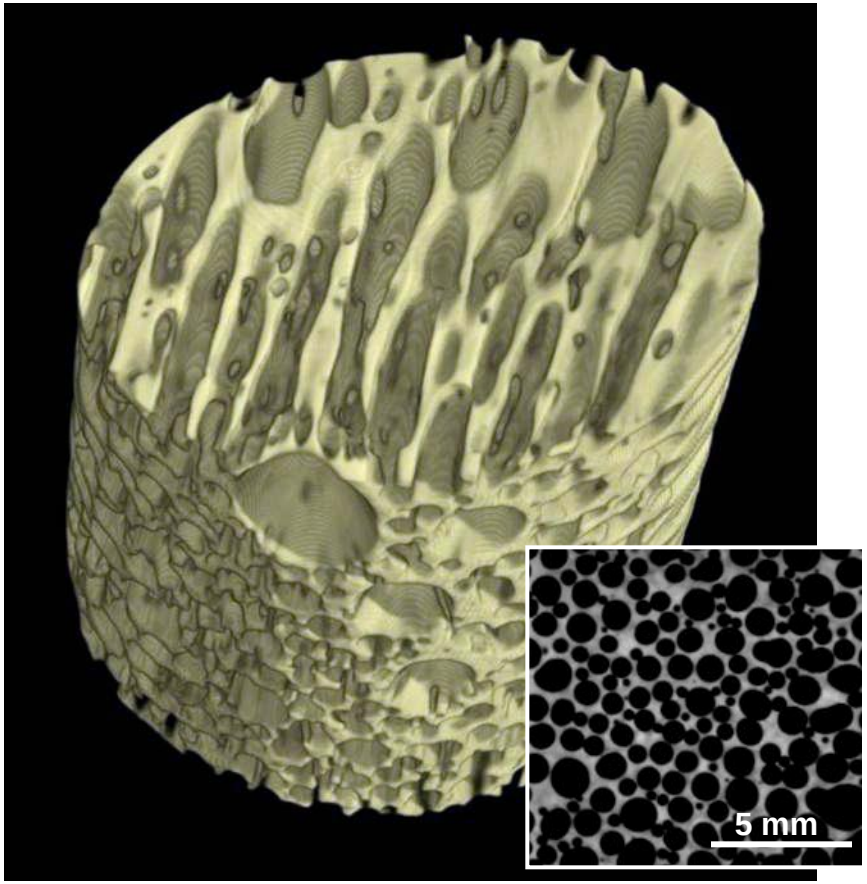


Offen-zelliger Lotus-Type Cu-Werkstoff: Datenbasis für FEM-Simulation der mechanischen Eigenschaften

2D-Röntgenprojektion

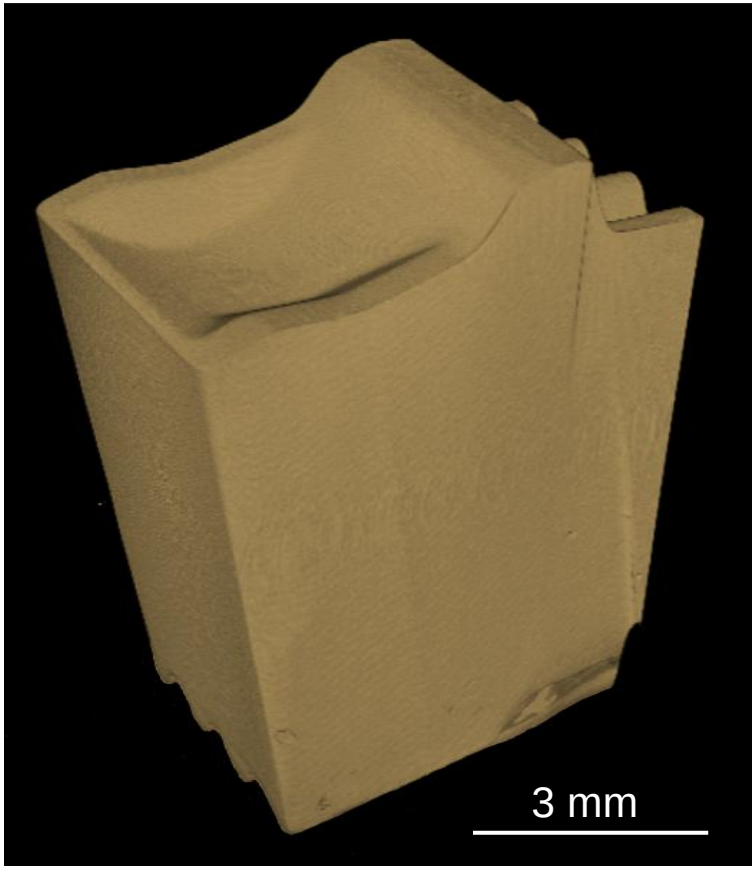


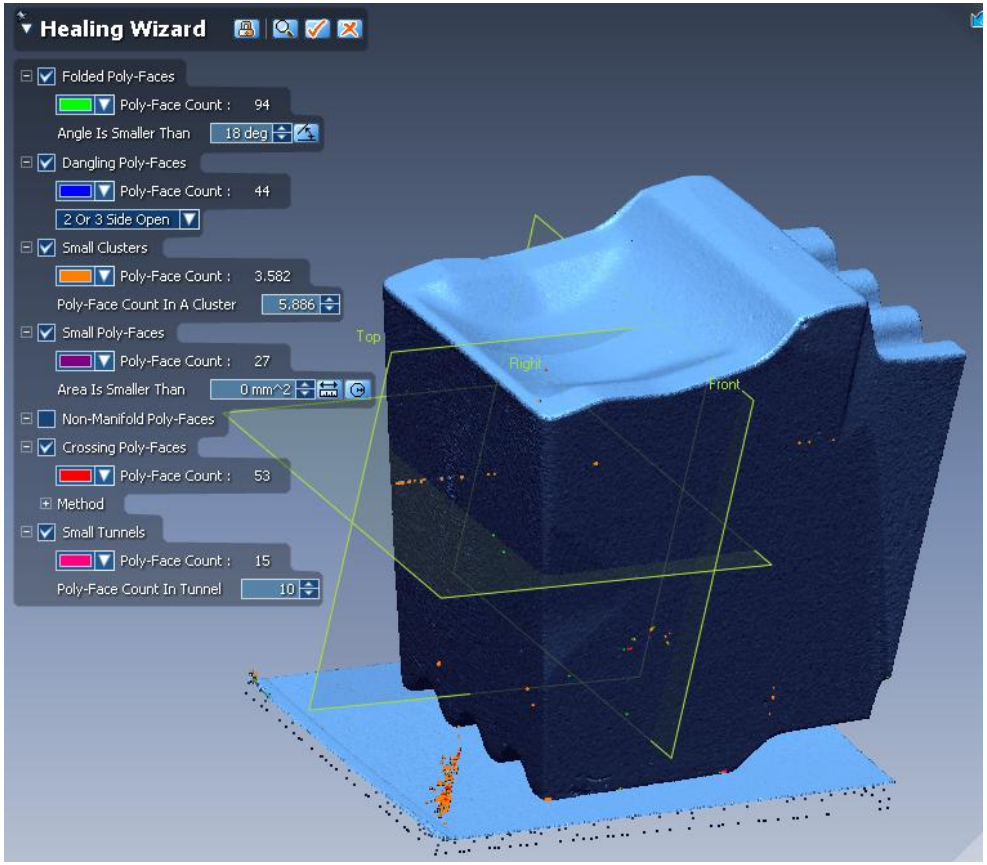
3D-Oberflächendarstellung



- Stark an-isotrope Materialverteilung → dünne Wandstege

Nano-CT einer Hartmetall-Schneide → quantitative Erfassung der komplexen Spanraumgeometrie

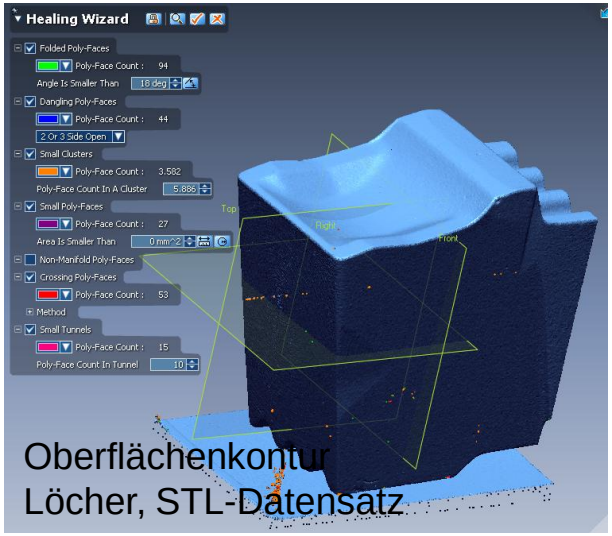




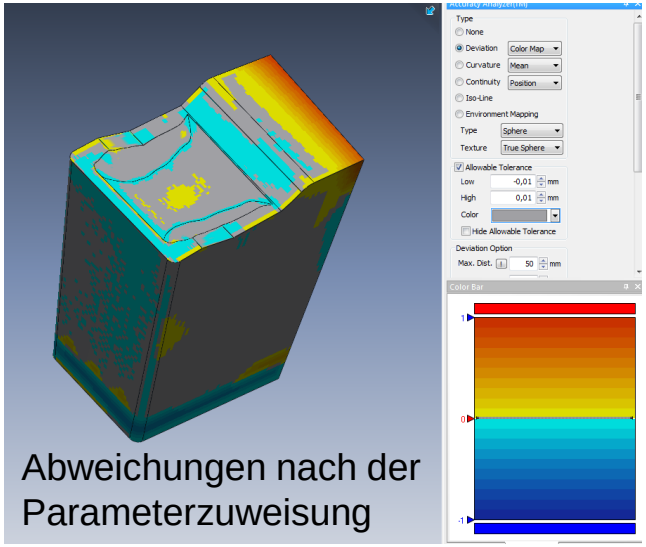
3D-Oberflächenbild aus Nano-CT, Auflösung 5 µm/Voxel

3D-Oberflächendaten aus Nano-CT für Reverse Engineering

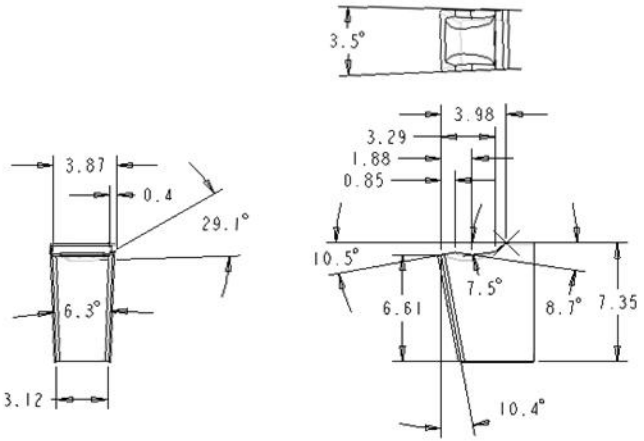
3D-Geometrie: Reverse Engineering von CT-Volumenbilder in voll parametrisierte 3D-CAD Modelle



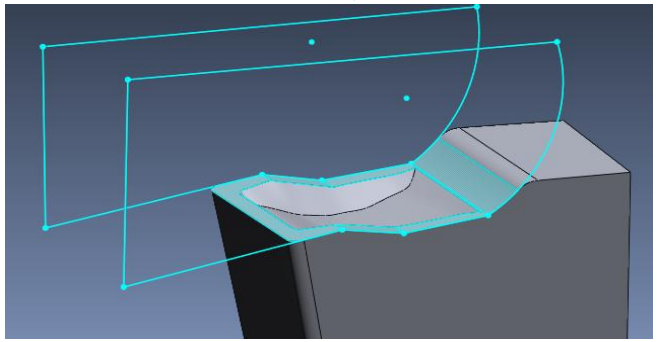
Oberflächenkontur
Löcher, STL-Datensatz



Abweichungen nach der Parameterzuweisung



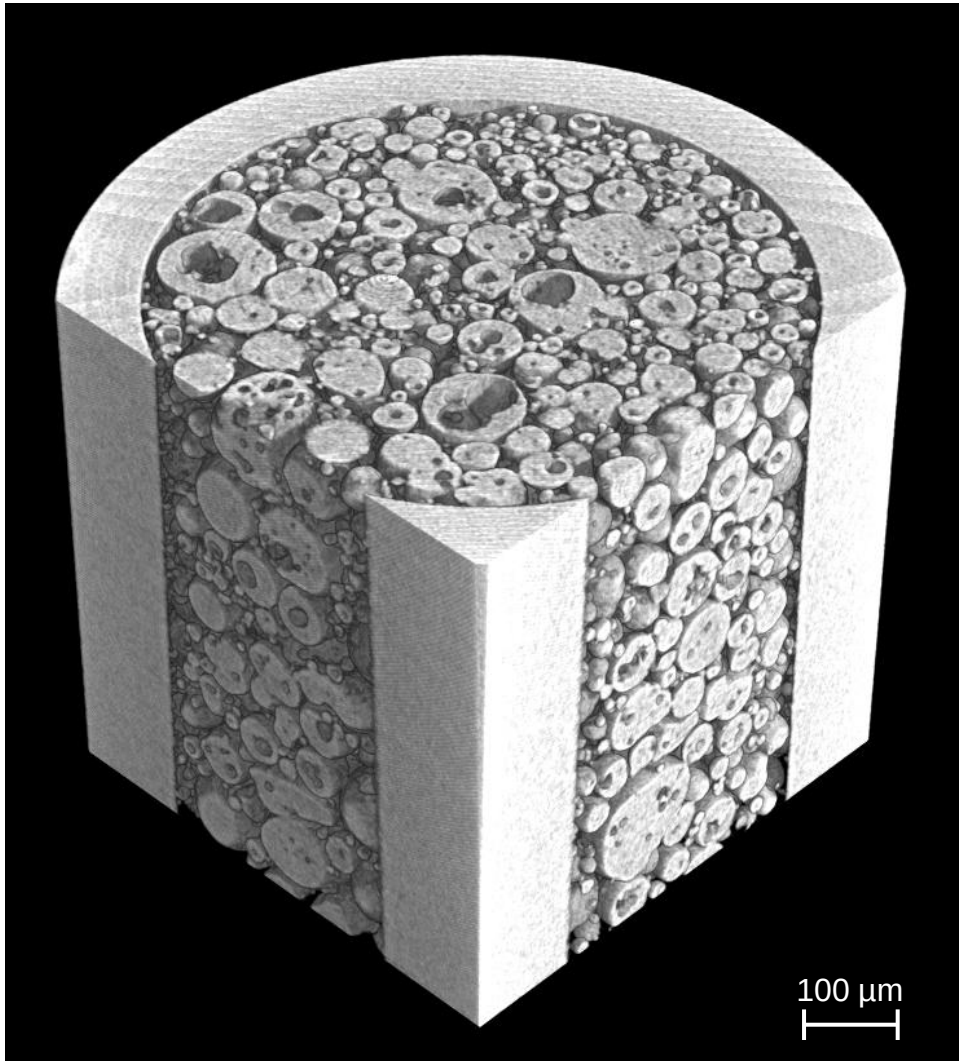
Löcher-Schneide, Fertigungszeichnung



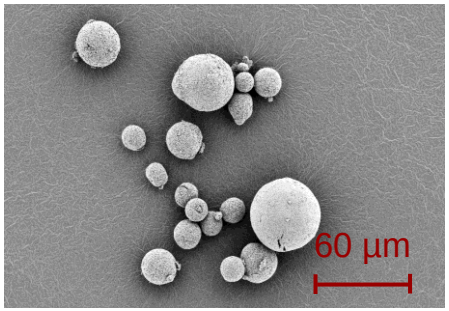
Löcher-Schneide, CAD-Modell

Höchst aufgelöste 3D-Visualisierung von Pulver mittels Nano-CT – Bsp. Aluminiumoxid Sprühgranulate

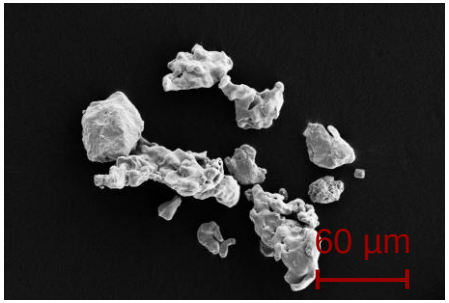
NanoCT an Aluminiumoxid Sprühgranulat



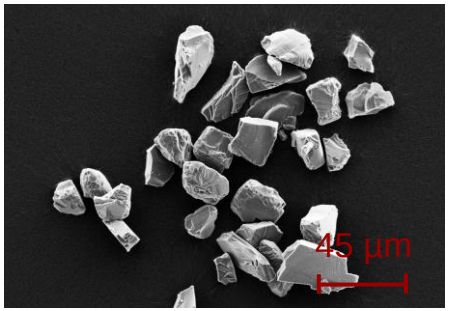
Aluminiumoxid



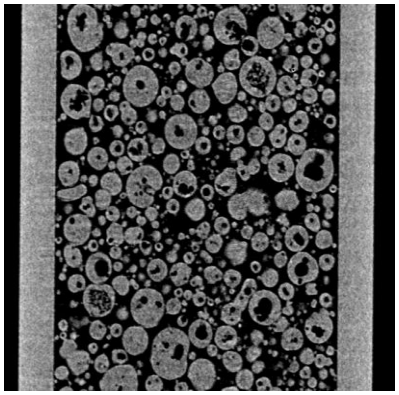
Schwammeisen



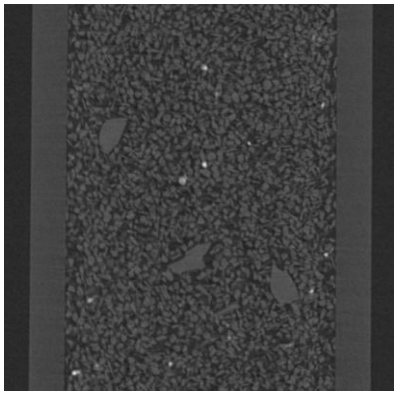
Siliziumcarbid



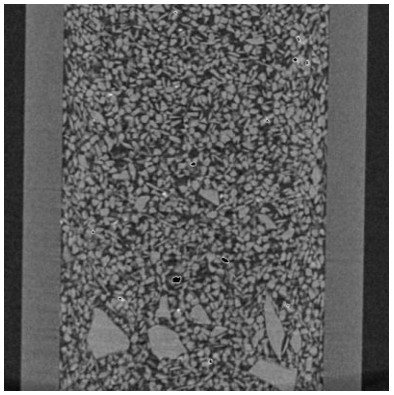
Höchst aufgelöste 3D-Visualisierung von Pulver mittels Nano-CT – unterschiedlichste Werkstoffe und Größen



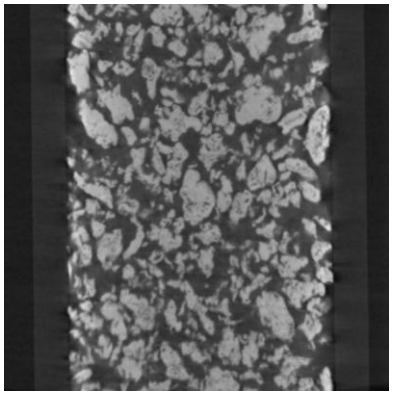
Aluminiumoxid



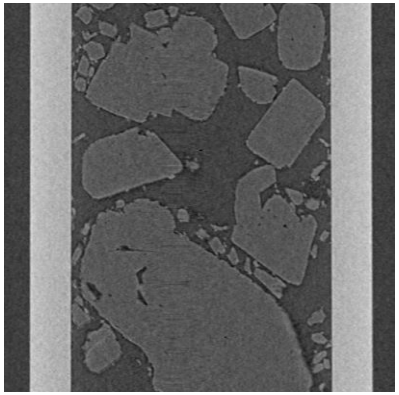
Siliziumcarbid-bimodal



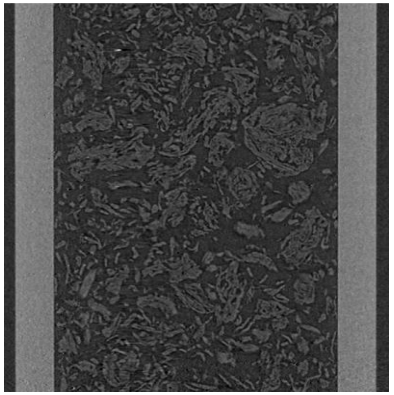
Siliziumcarbid-trimodal



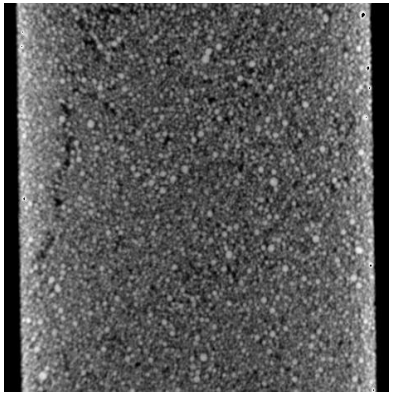
Schwammeisen



Acetylsalicylsäure



Cellulose

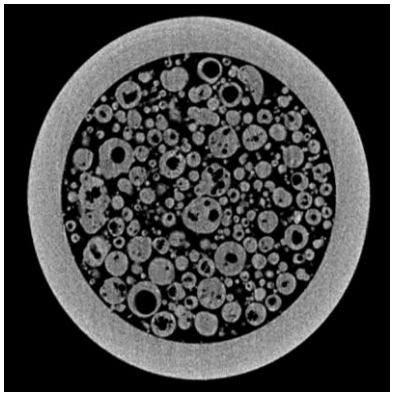


Metal Injection Molding

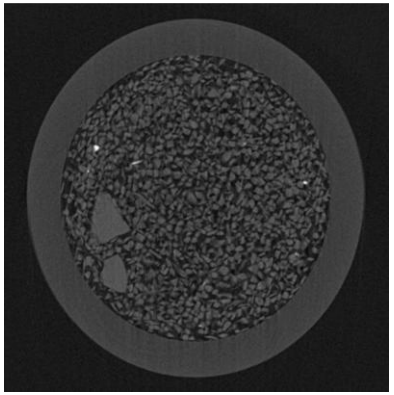
450 µm

ca. 1,6 µm/Voxel

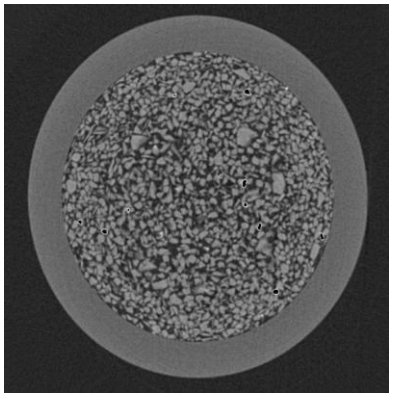
Höchst aufgelöste 3D-Visualisierung von Pulver mittels Nano-CT – unterschiedlichste Werkstoffe und Größen



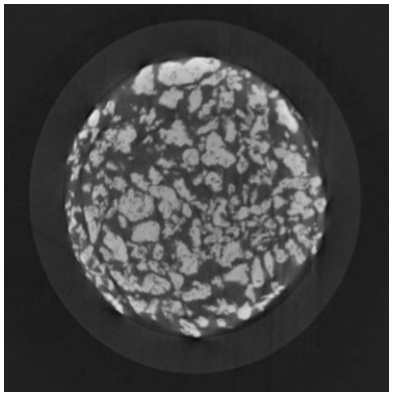
Aluminiumoxid



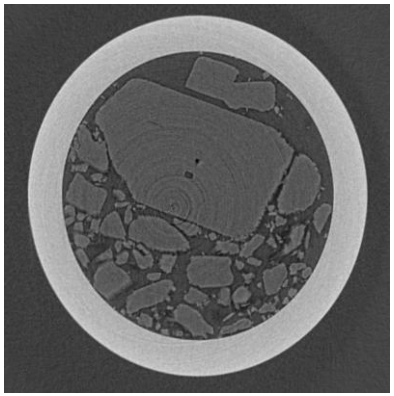
Siliziumcarbid-bimodal



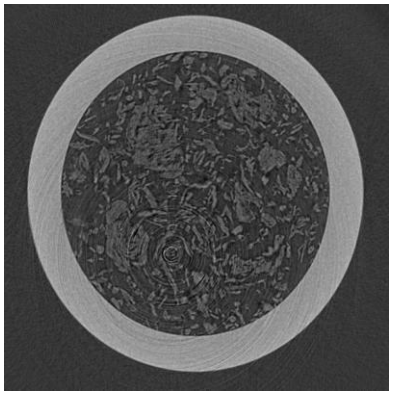
Siliziumcarbid-trimodal



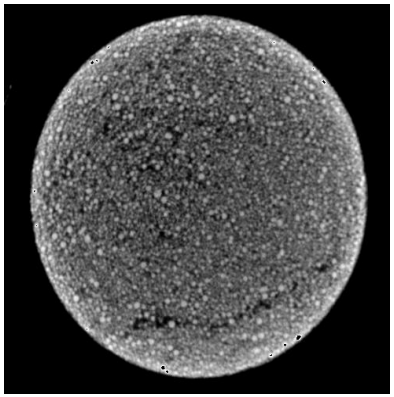
Schwammeisen



Acetylsalicylsäure



Cellulose

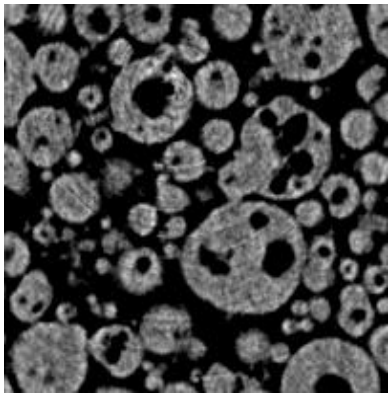


Metal Injection Molding

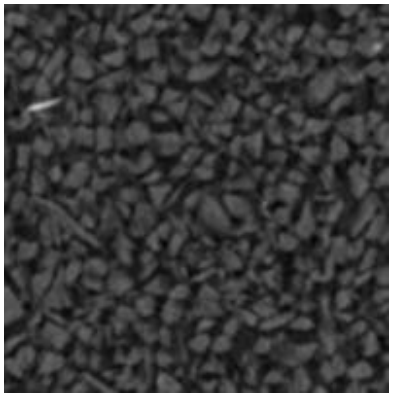
450 µm

ca. 1,6 µm/Voxel

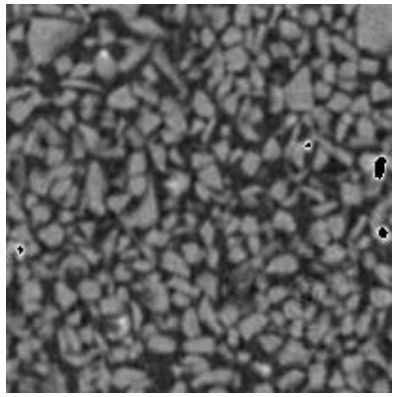
Höchst aufgelöste 3D-Visualisierung von Pulver mittels Nano-CT – unterschiedlichste Werkstoffe und Größen



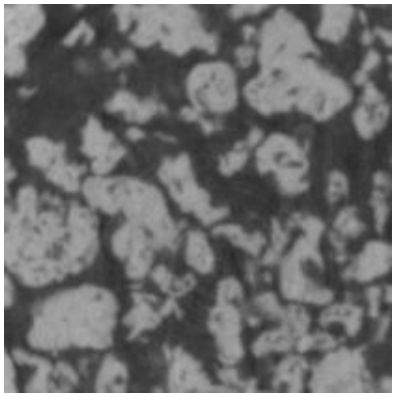
Aluminiumoxid



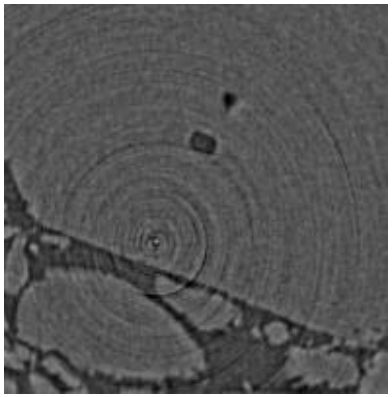
Siliziumcarbid-bimodal



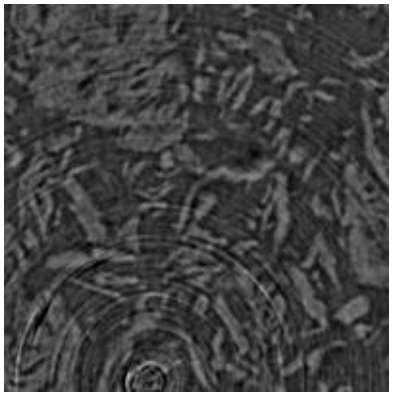
Siliziumcarbid-trimodal



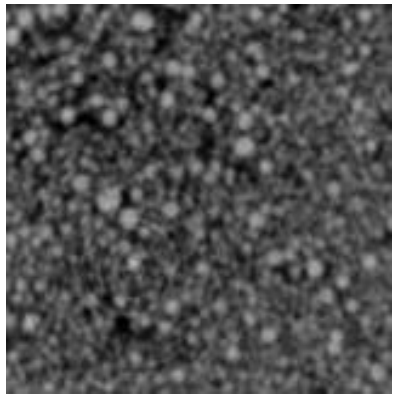
Schwammeisen



Acetylsalicylsäure



Cellulose



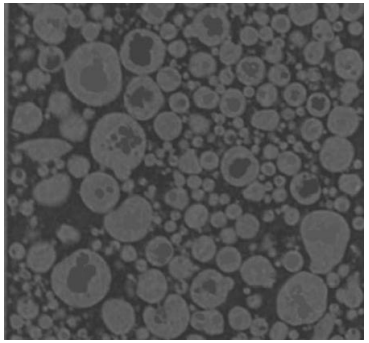
Metal Injection Molding

1400 µm

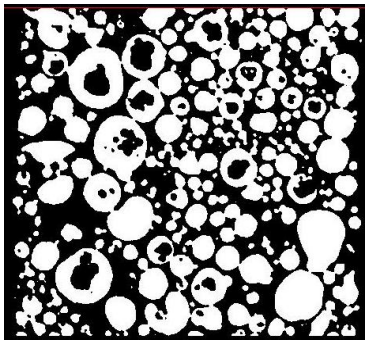
ca. 1,6 µm/Voxel

Quantitative Bestimmung der wahren Partikelgrößen-verteilung mittels 3D-Bildanalyse und Nano-CT

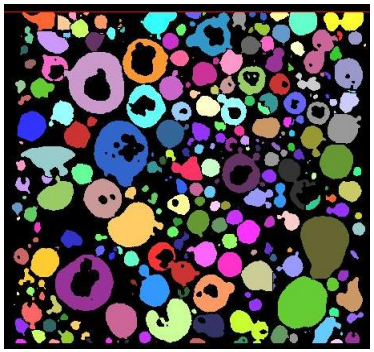
Slice Volumenbild – original

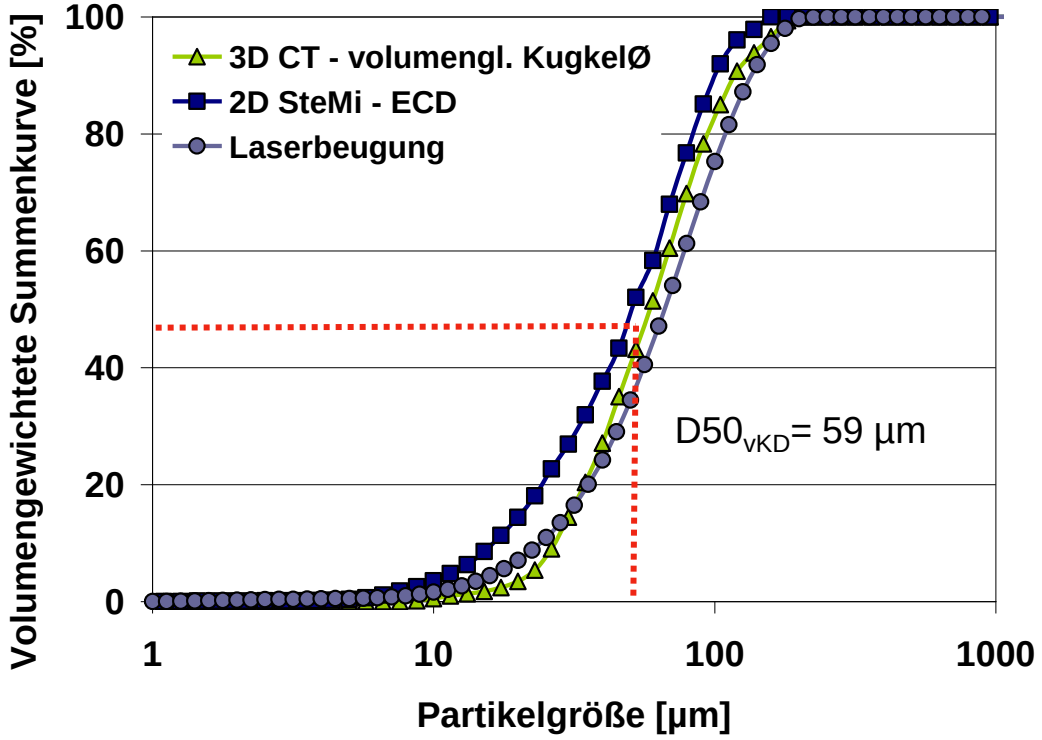


Slice Volumenbild – binarisiert.



Falschfarben visualisierung

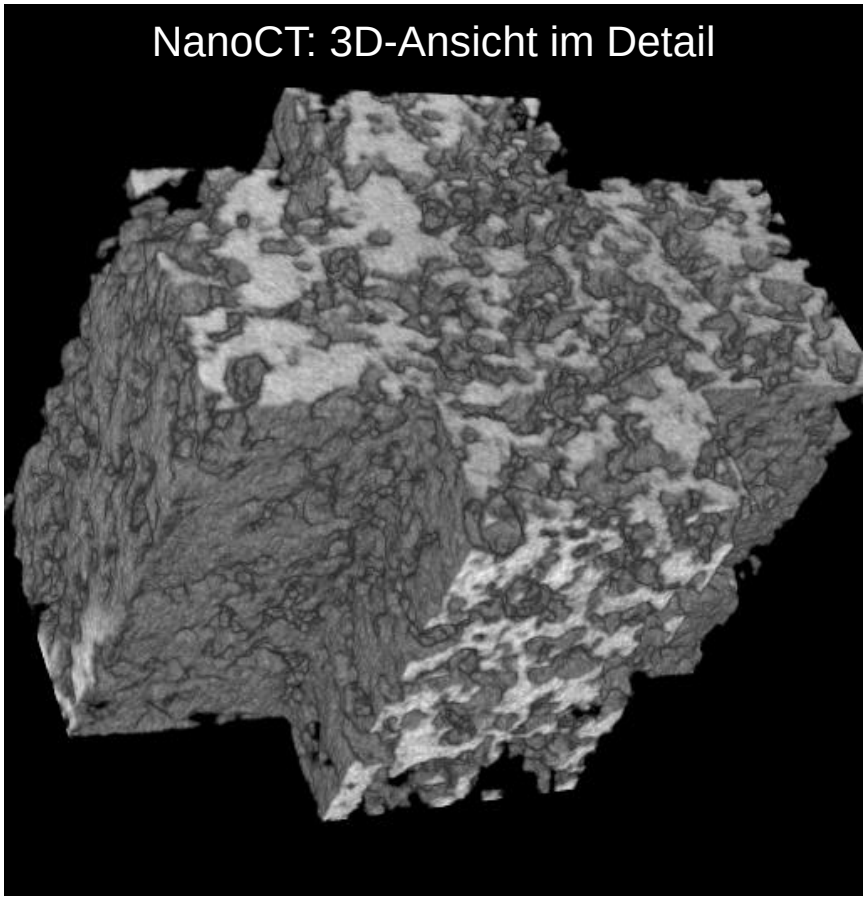


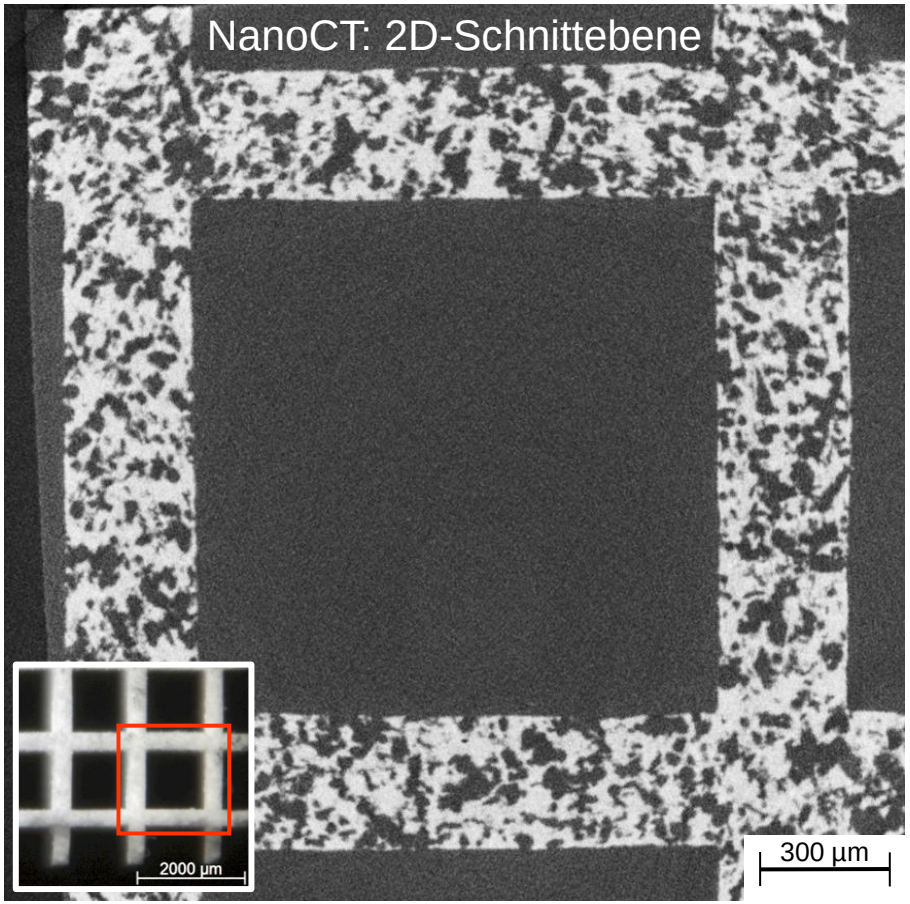


Details CT-Messung Al_2O_3 Sprühgranulat:

- Nano-CT
- Voxelgröße: 1,81 µm
- Ausgewertete Partikel: 2531

nanoCT-Analyse einer Keramik mit stark vernetzen Porenkanälen und bimodaler Größenverteilung

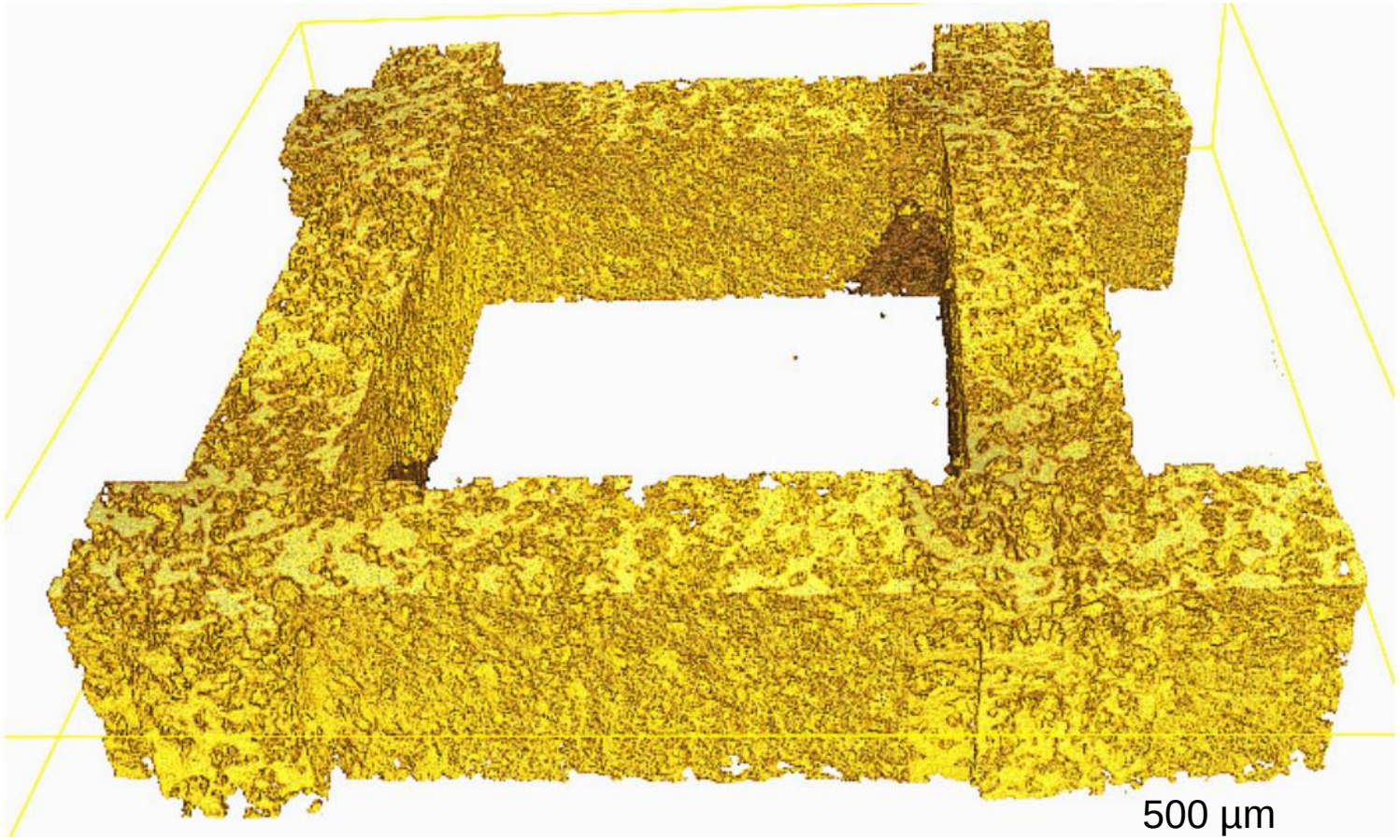




➔ *Charakterisierung und quantitative Beschreibung der Porengrößenverteilung und Permeabilität*

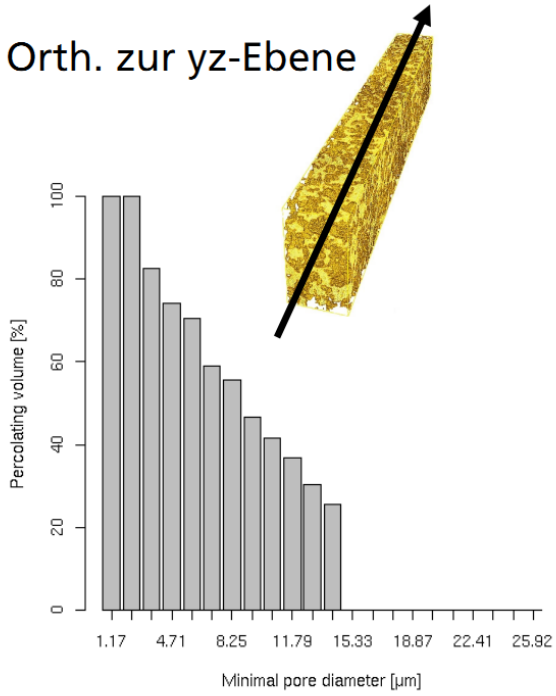
3D-Bildanalyse zur Bestimmung der geometrischen Perkolation offen-poröser Keramikkörper (z.B. Filter)

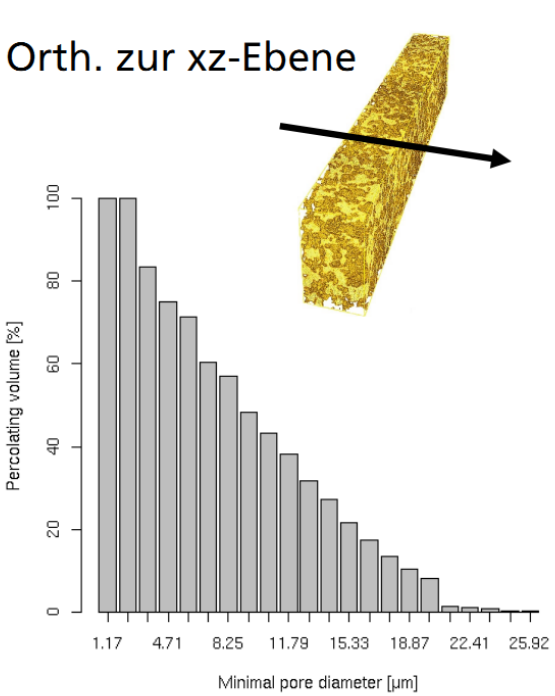
Nano-CT eines offen-porösen keramischen Filters, Auflösung: 1,5 µm/Voxel

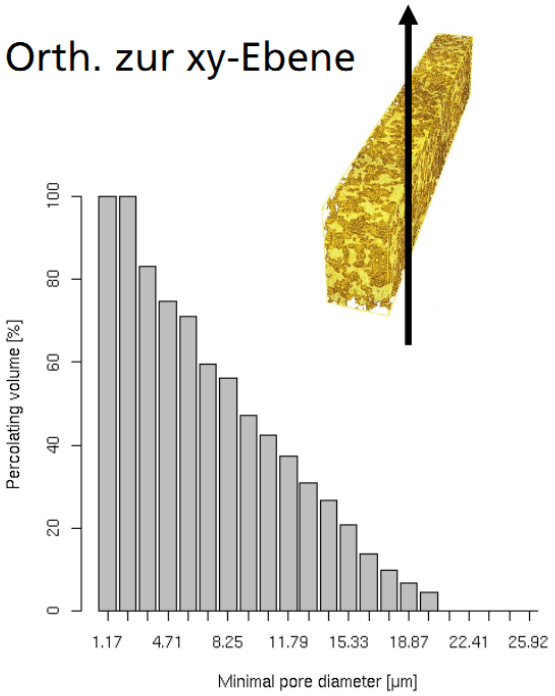


In Zusammenarbeit mit Hochschule Darmstadt, Fraunhofer ITWM

3D-Bildanalyse zur Bestimmung der geometrischen Perkolation offen-poröser Keramikkörper (z.B. Filter)







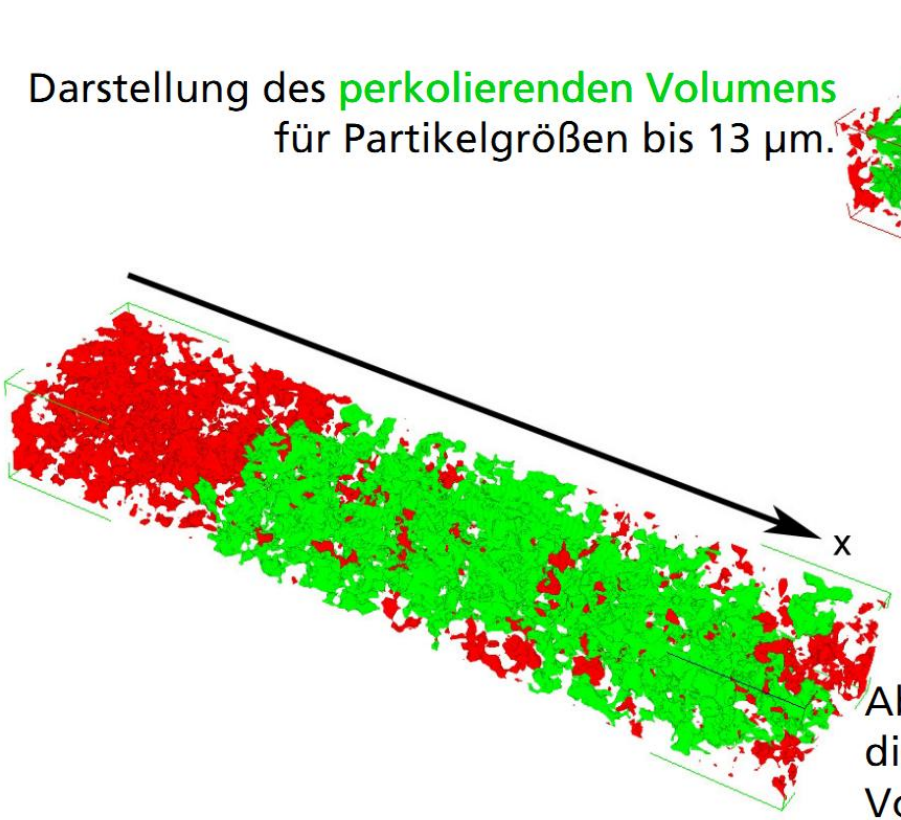
Ausgewerteter Teilbereich aus Gesamtvolumen

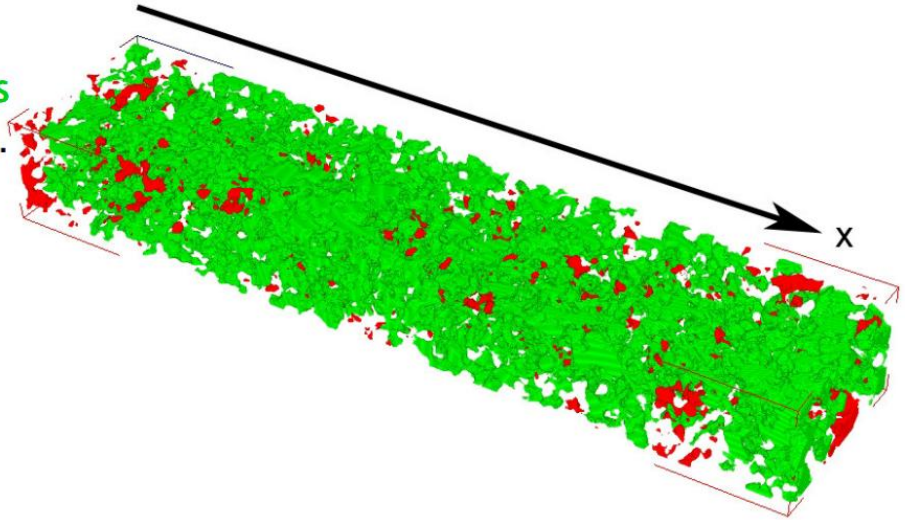
In Zusammenarbeit mit Hochschule Darmstadt, Fraunhofer ITWM

3D-Bildanalyse zur Bestimmung der geometrischen Perkolation offen-poröser Keramikkörper (z.B. Filter)

Perkolierendes Volumen orthogonal zur yz-Ebene

Darstellung des perkolierenden Volumens für Partikelgrößen bis 13 µm.





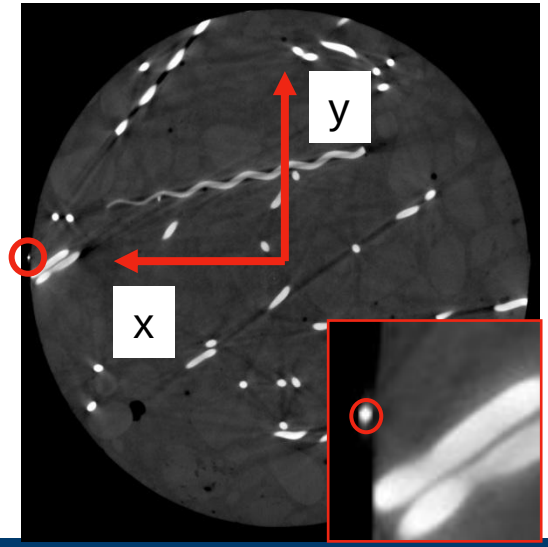
Ab einer Partikelgöße von 15 µm perkoliert die größte Zusammenhangskomponente das Volumen nicht mehr.

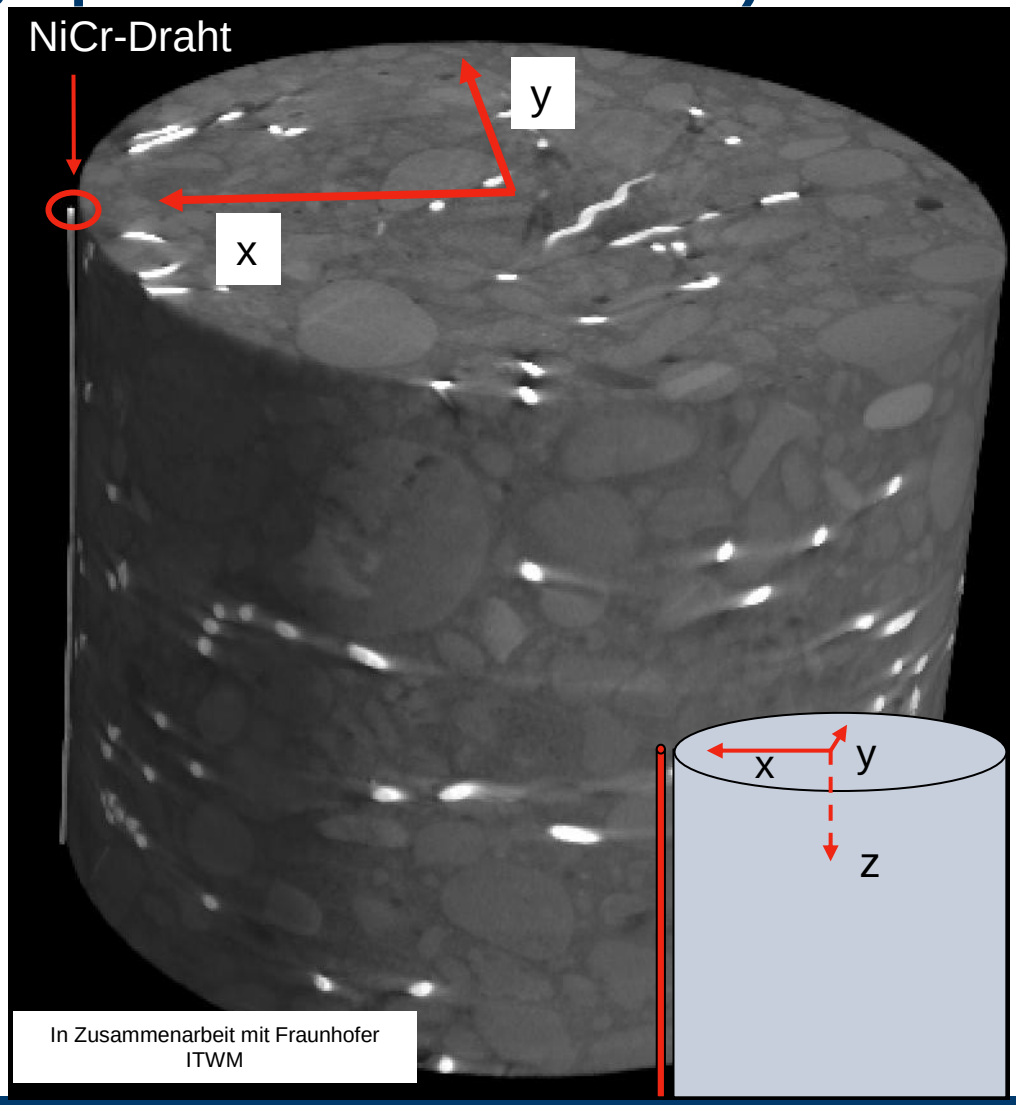
In Zusammenarbeit mit Hochschule Darmstadt, Fraunhofer ITWM

CT-Analyse von stahlfaserverstärktem Hochleistungsbeton (high-performance concrete)

Digitalkamera

CT-Axial Schnitt

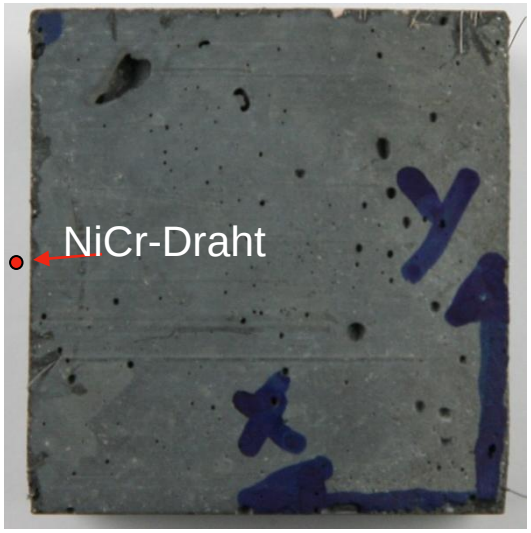




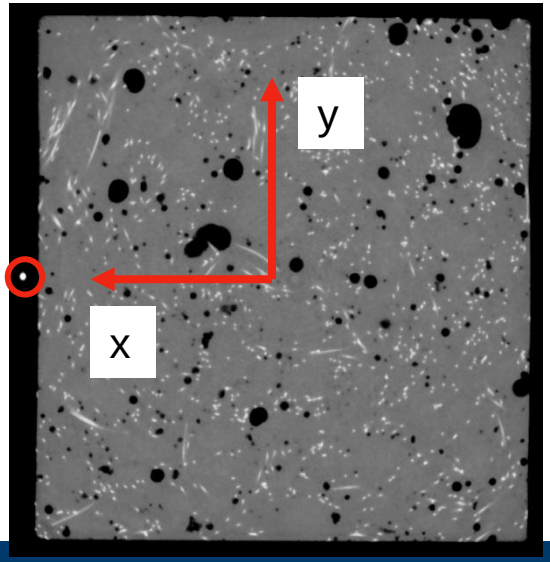
In Zusammenarbeit mit Fraunhofer ITWM

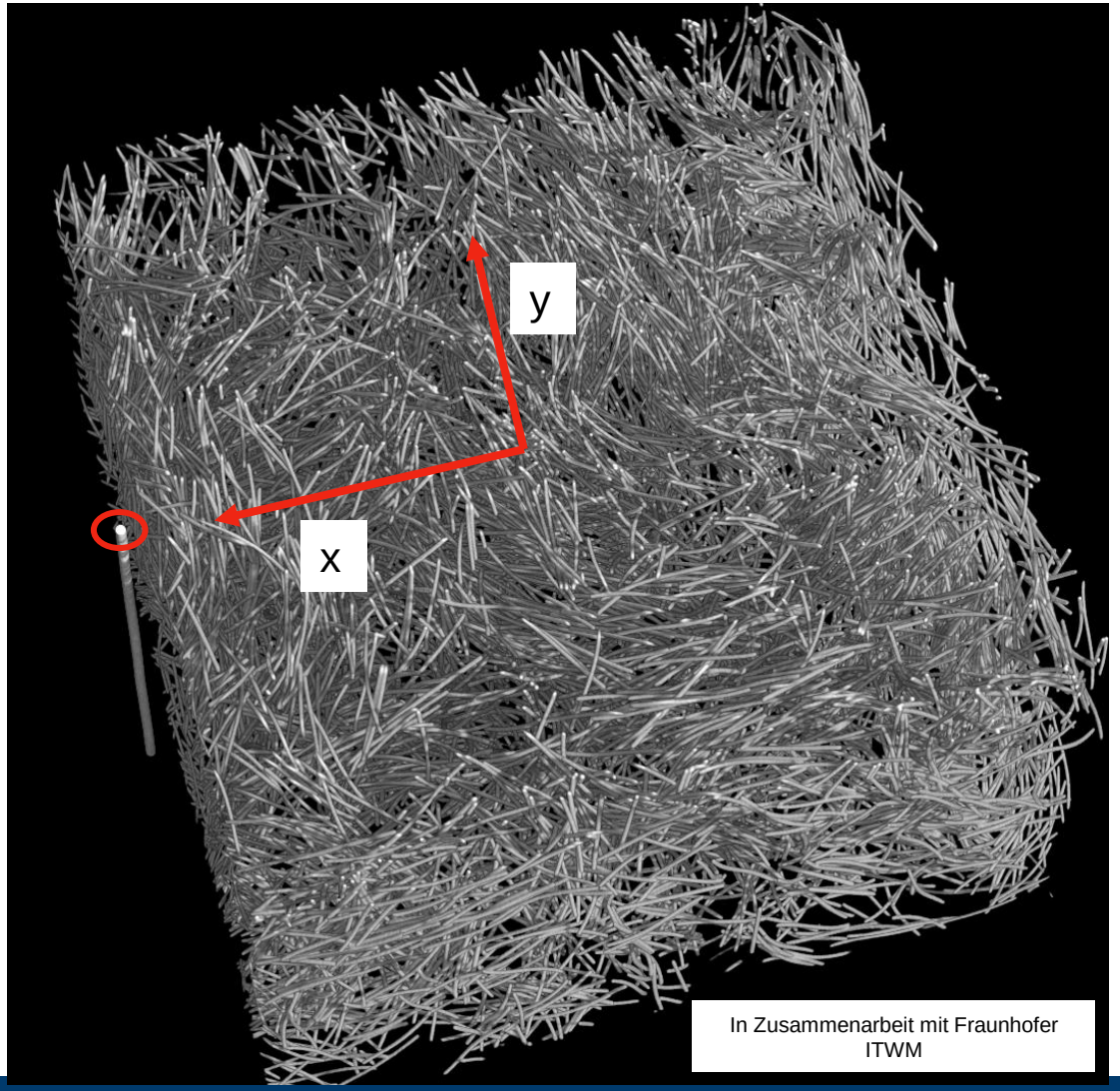
CT-Analyse von stahlfaserverstärktem Hochleistungsbeton (high-performance concrete)

Digitalkamera



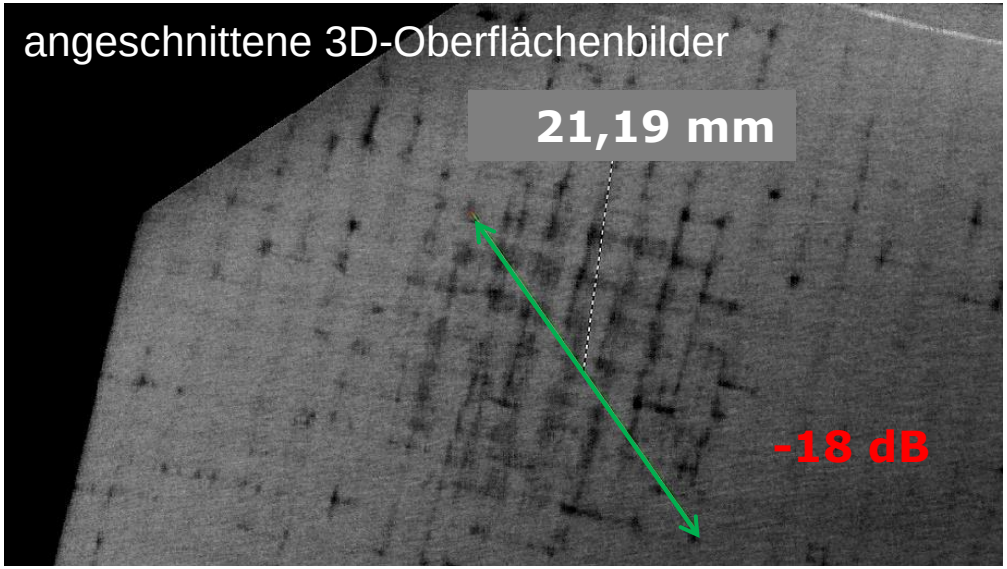
CT-Axial Schnitt

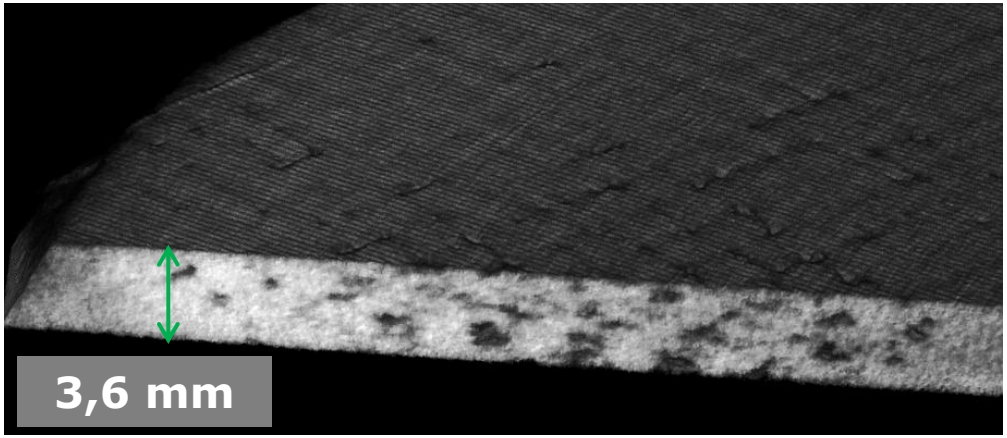


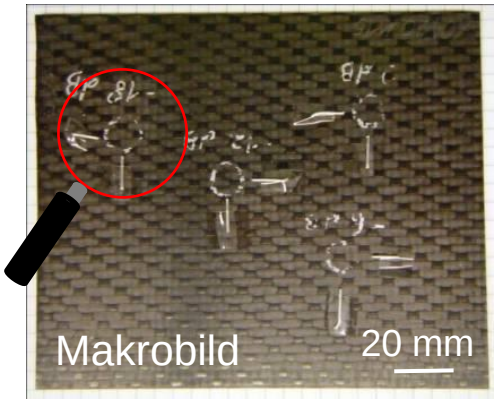


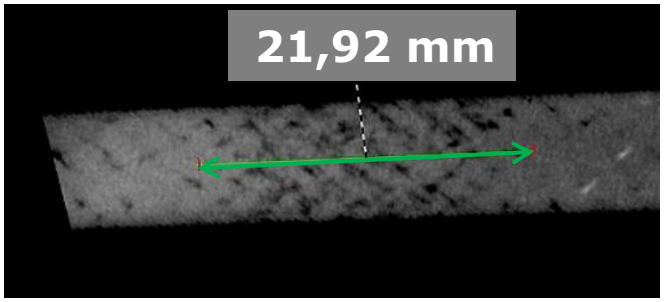
In Zusammenarbeit mit Fraunhofer ITWM

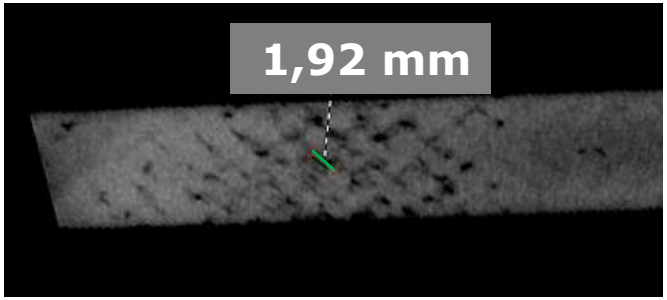
Visualisierung der Porosität eines gewobenen CFK Bauteils mittles µCT



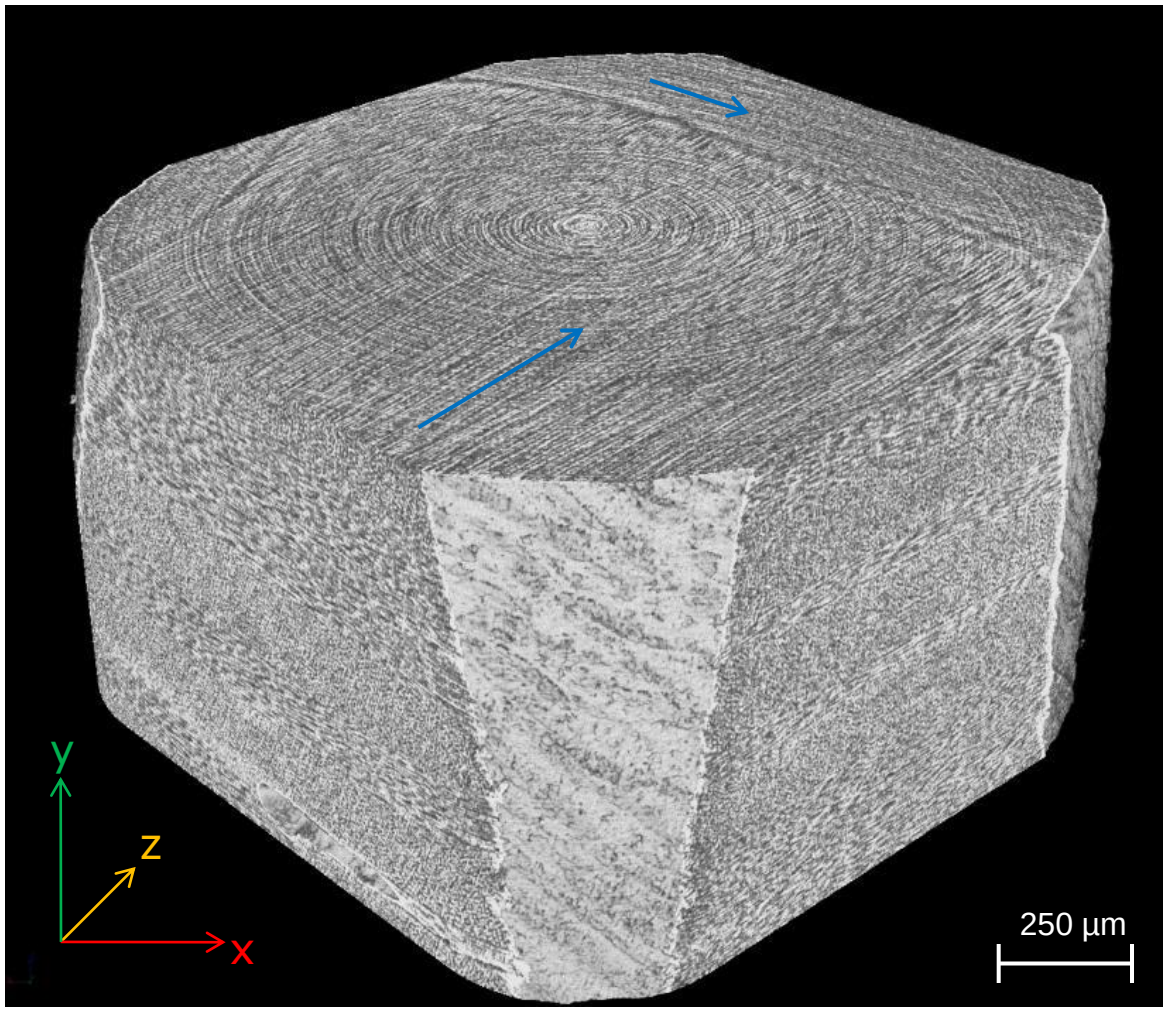








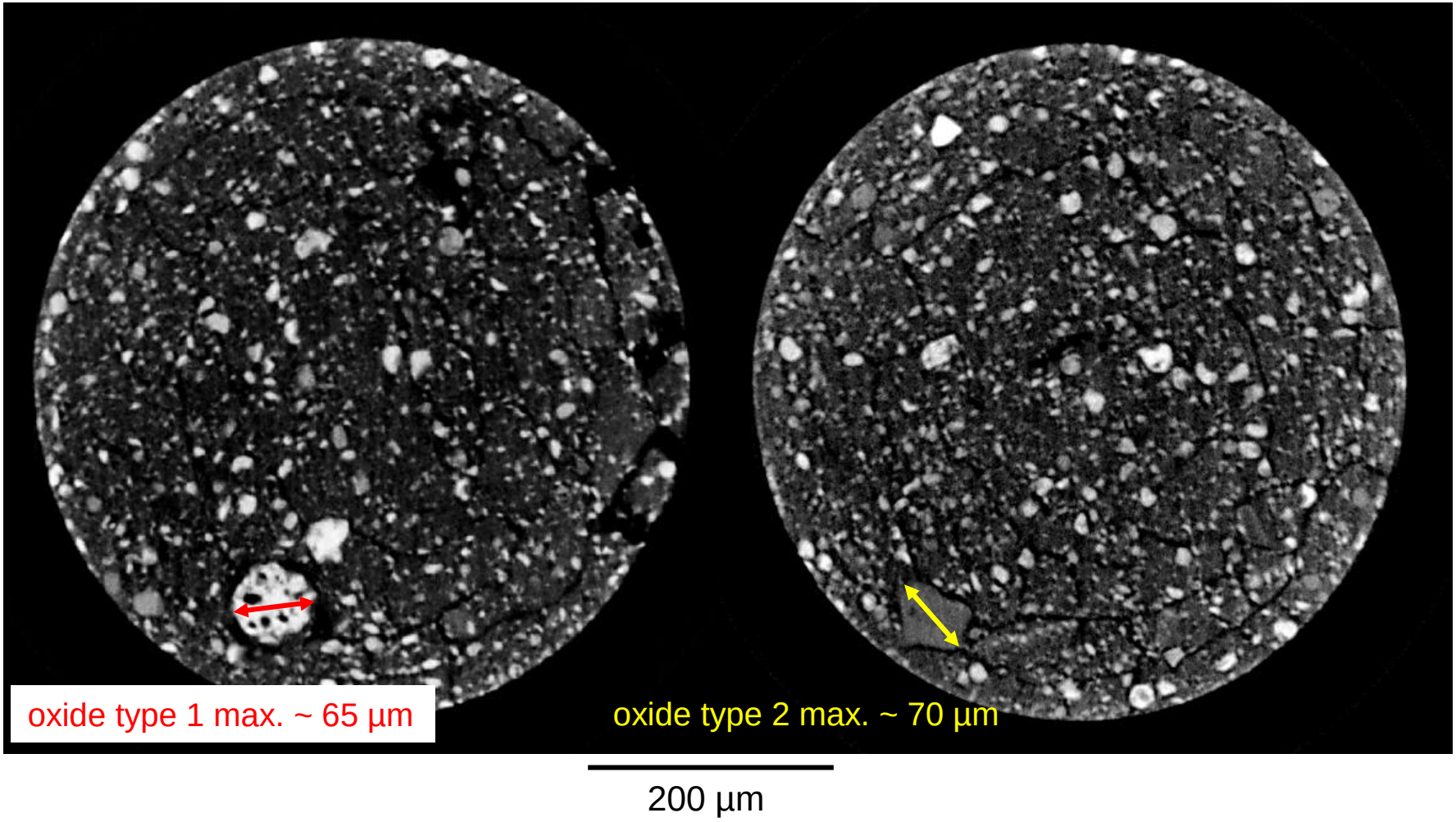
Höchst aufgelöste Visualisierung von Faserorientierung und Schichtaufbau eines gewobenen CFK Bauteils mittels Nano-CT



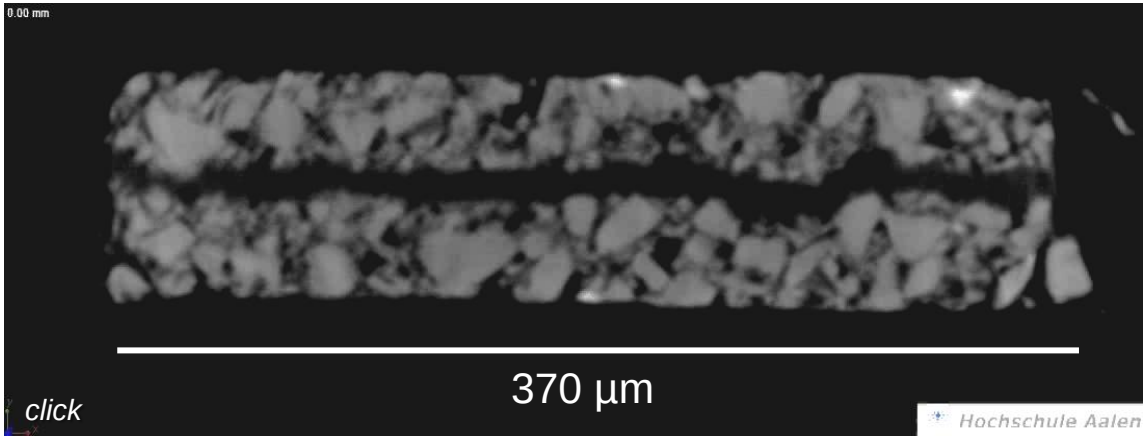
Detailausschnitt:
Kohlenstofffasern

Angeschnittenes 3D-Oberflächenbild Nano-CT mit 1,1 µm Voxelgröße

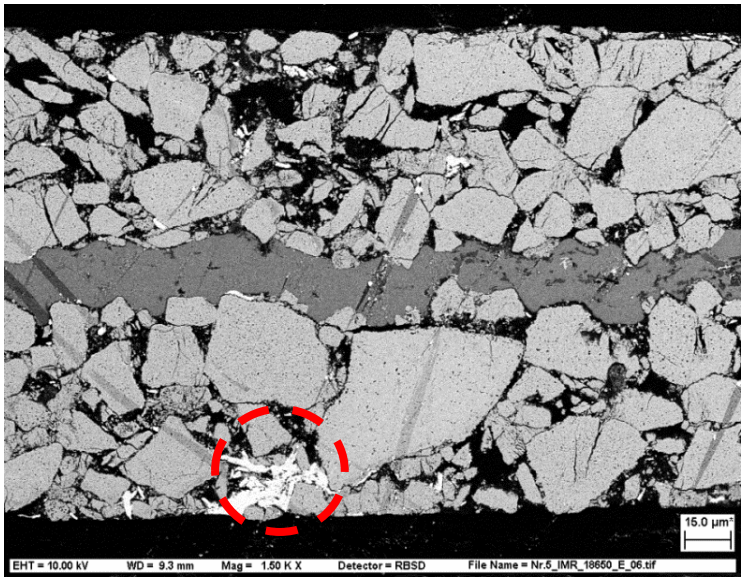
Raw material of cathode active material with mixed oxides and tendencies of agglomeration

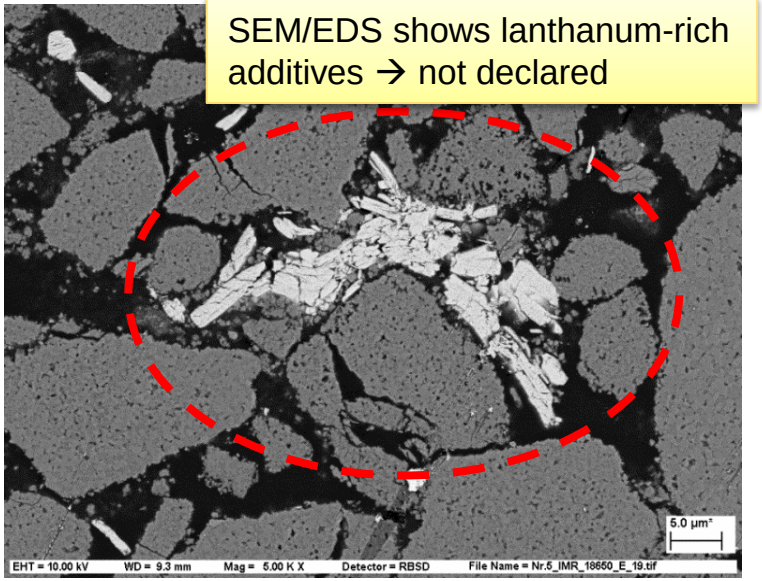


High resolution CT of cathode foil of no-name Lithium ion battery → Discrepancies to data sheet



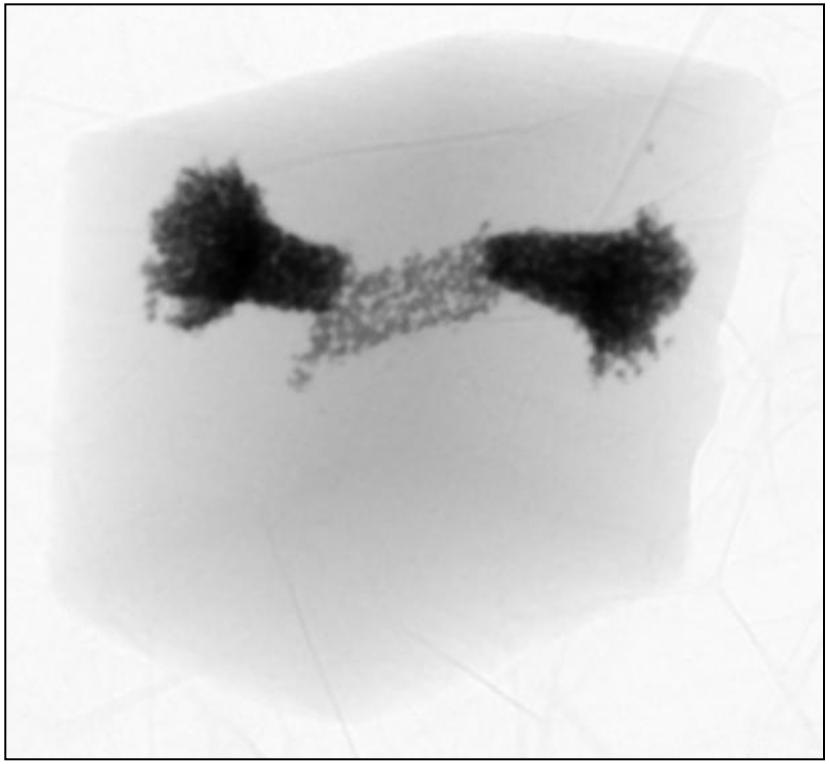
4 µm/voxel



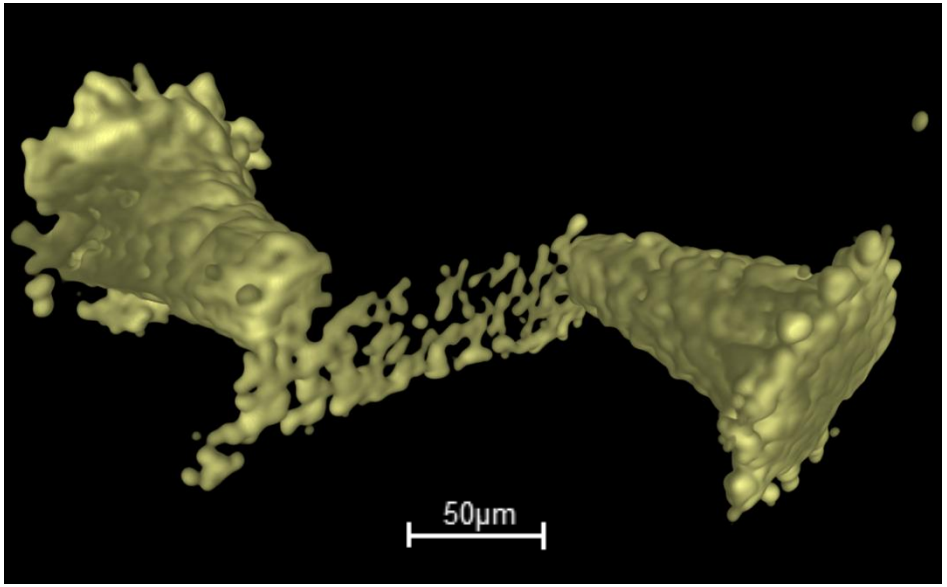


SEM/EDS shows lanthanum-rich additives → not declared

Anwendungsbeispiel Medizintechnik: Visualisierung Mikrochipstrukturen für bionische Applikationen



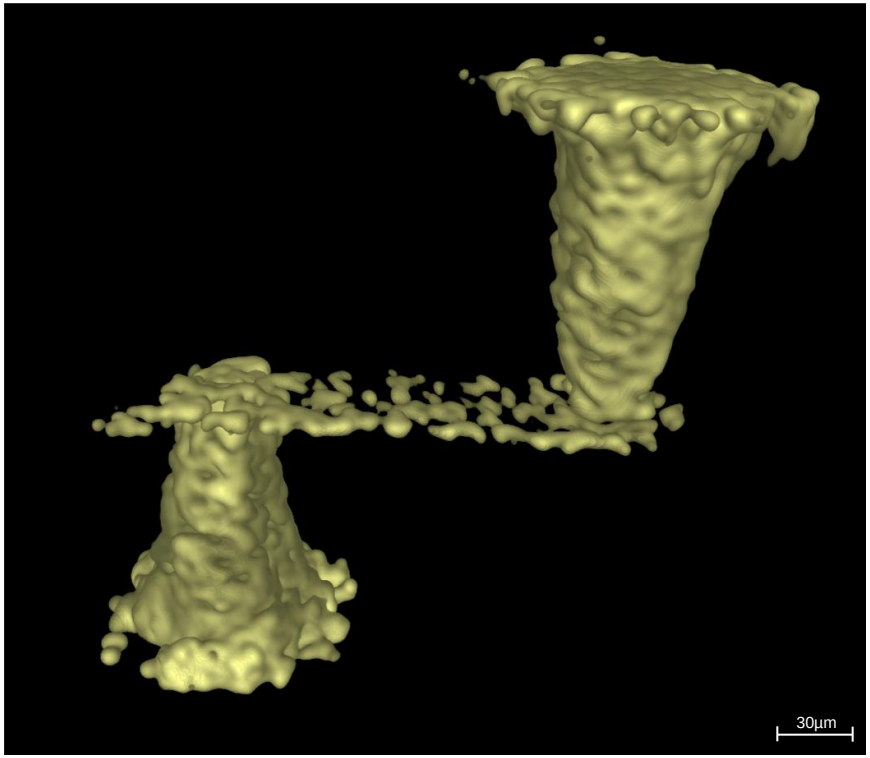
2D-Röntgenprojektion mit Nano-CT
mit 0,5 µm/Voxel Auflösung



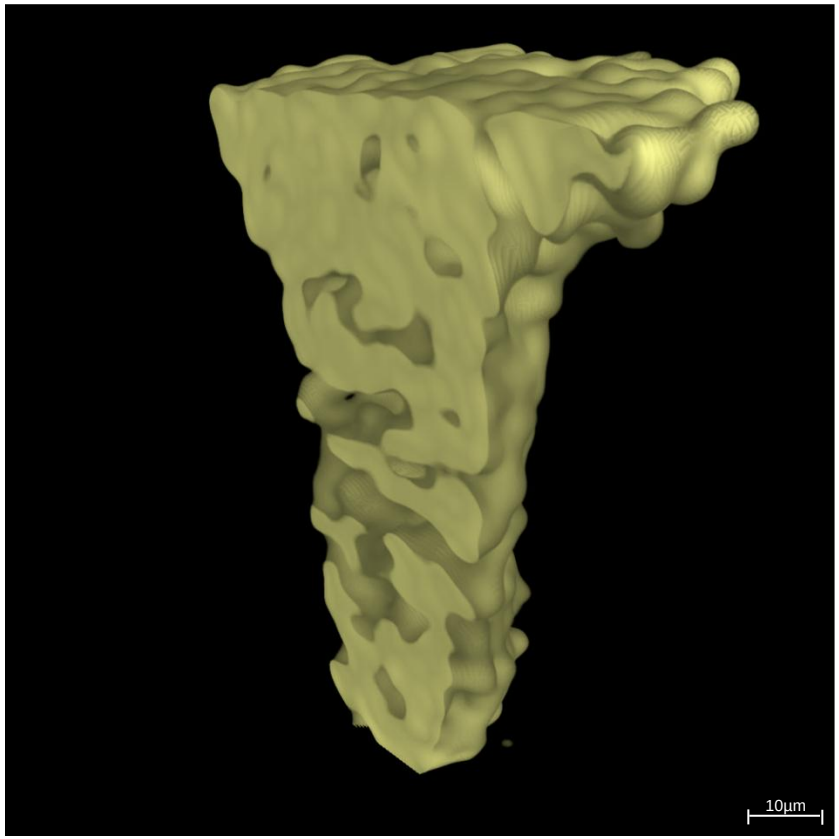
Rekonstruiertes 3D-Bild des Platin Anteils

In Zusammenarbeit mit University of New South Wales,
Graduate School of Biomedical Engineering, Australien

Anwendungsbeispiel Medizintechnik: Visualisierung Mikrochipstrukturen für bionische Applikationen



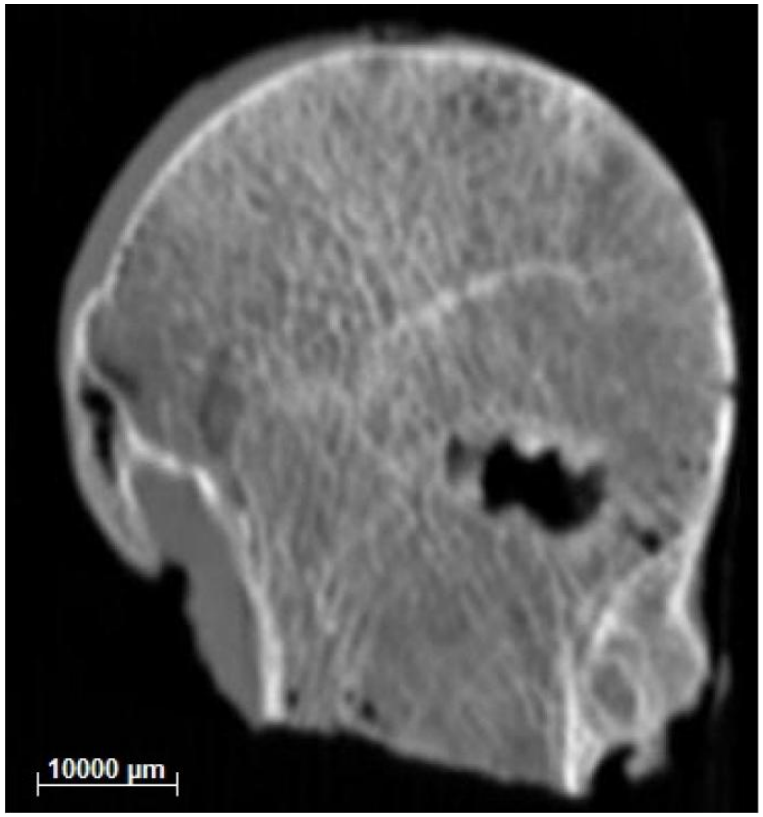
Queransicht



Schnittdarstellung

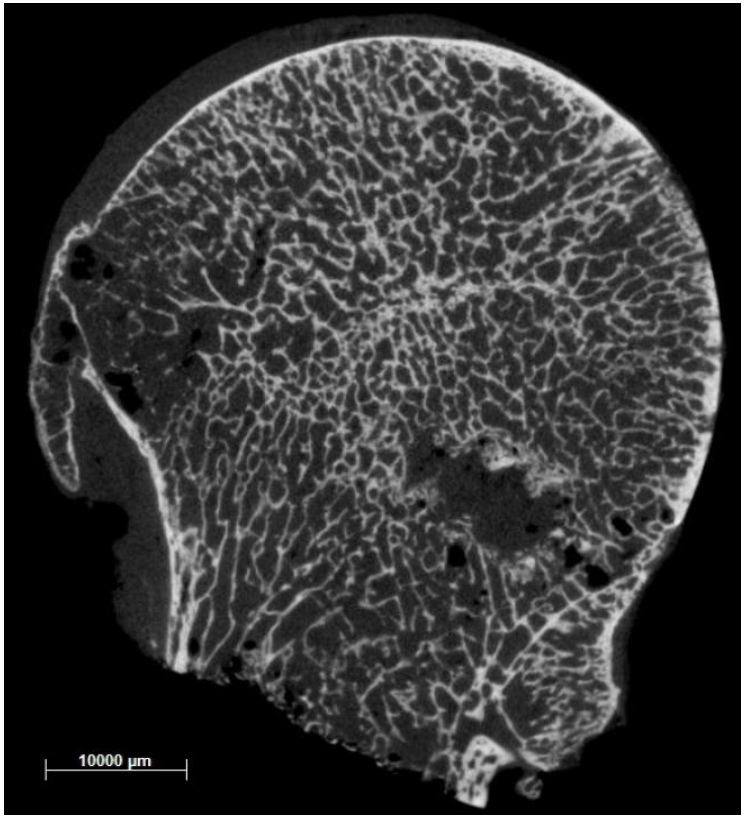
In Zusammenarbeit mit University of New South Wales, Graduate School of Biomedical Engineering, Australien

Anwendungsbeispiel Medizintechnik zur Visualisierung von Knochen (osteoporotischer Hüftgelenkkopf)



Auflösung: 105 µm/Voxel

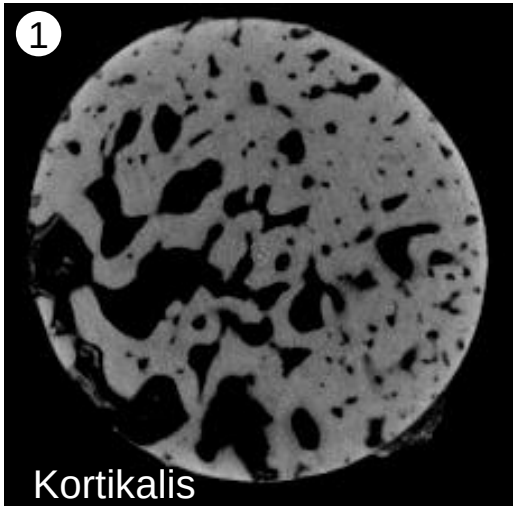
Medizinischer Computertomograph

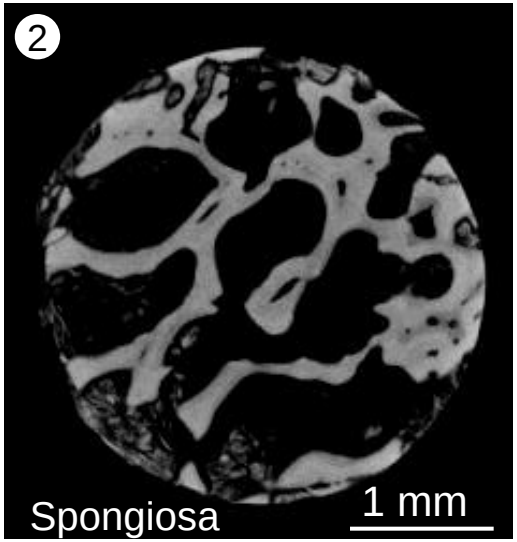


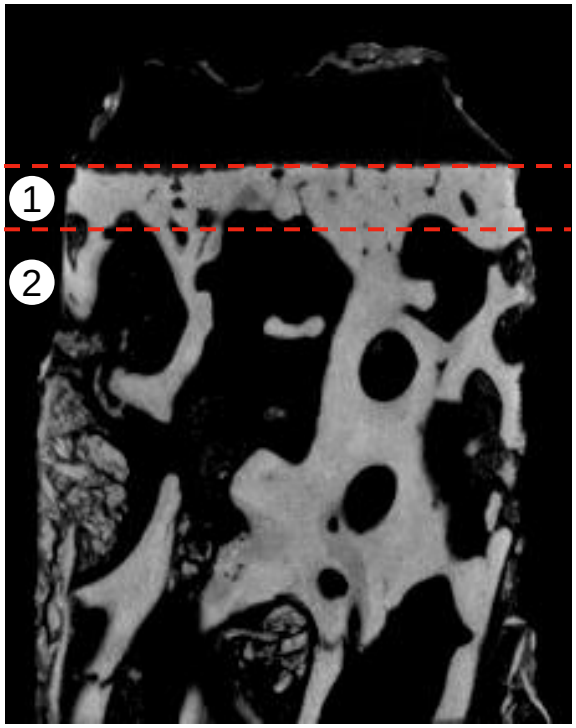
Auflösung: 90 µm/Voxel

v|tome|x s - Mikrofokusröhre

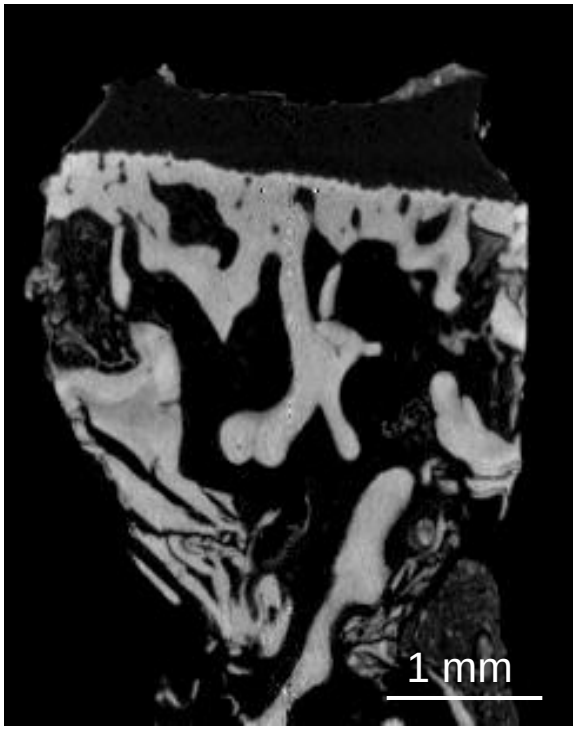
Anwendungsbeispiel Medizintechnik zur Visualisierung von Knochenstrukturen mittels Nano-CT (Bohrkern)







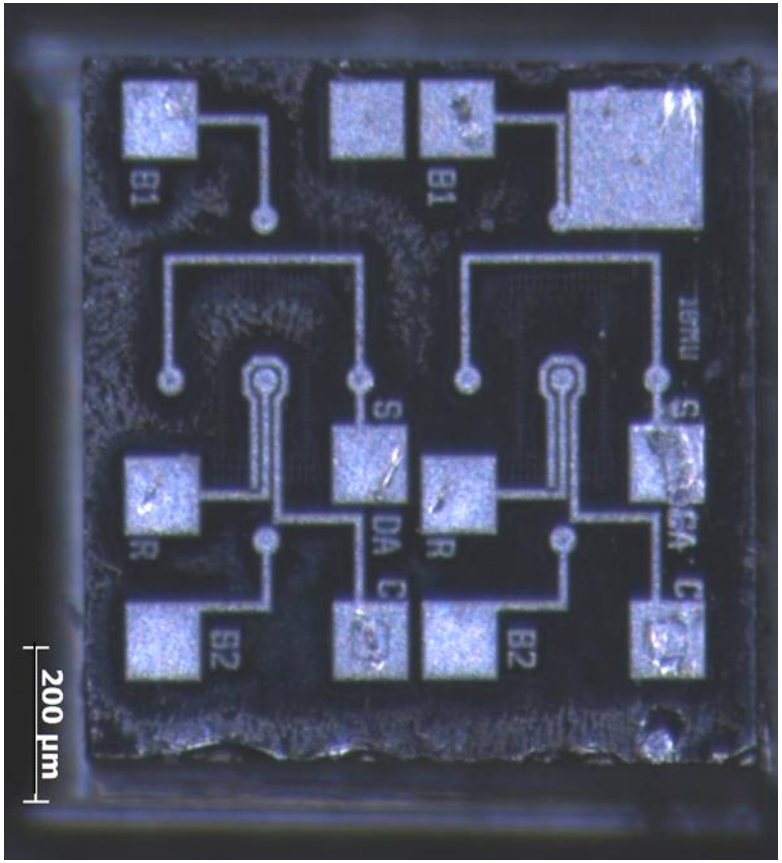
Sagittal-Ebene



Frontal-Ebene

- Bohrkerntomographie (∅ ca. 3 mm), Auflösung ~ 8 µm/Vx
- Qualitativ anisotrope Spongiosastruktur erkennbar
  - „durchlässiger“ in Z-Richtung (Höhe)
  - X und Y-Richtung relativ gleich im Aufbau

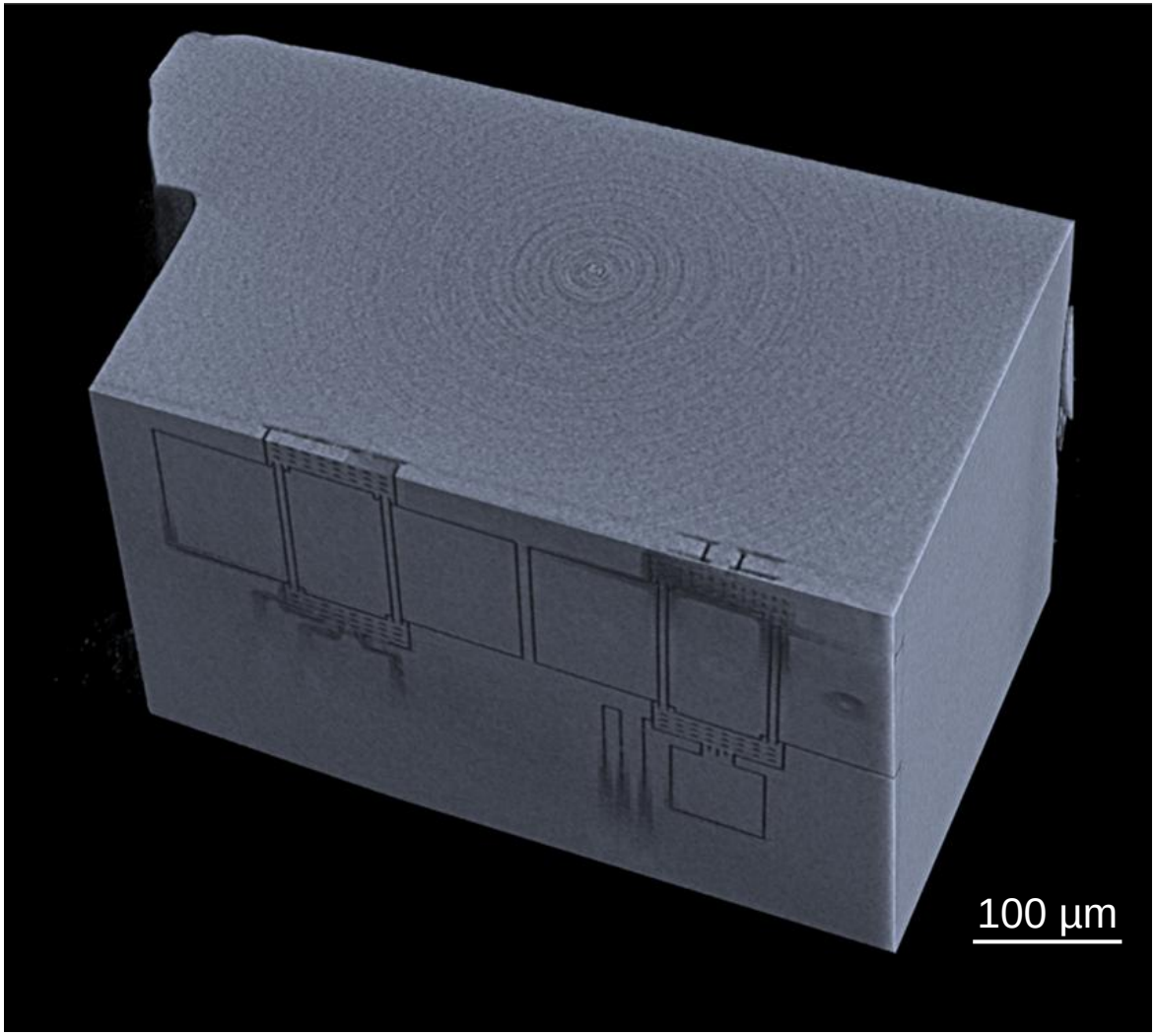
Zerstörungsfreie Untersuchung in Höchstauflösung, Beispiel Silicium-Mikrosystem für Sensoren (MEMS)



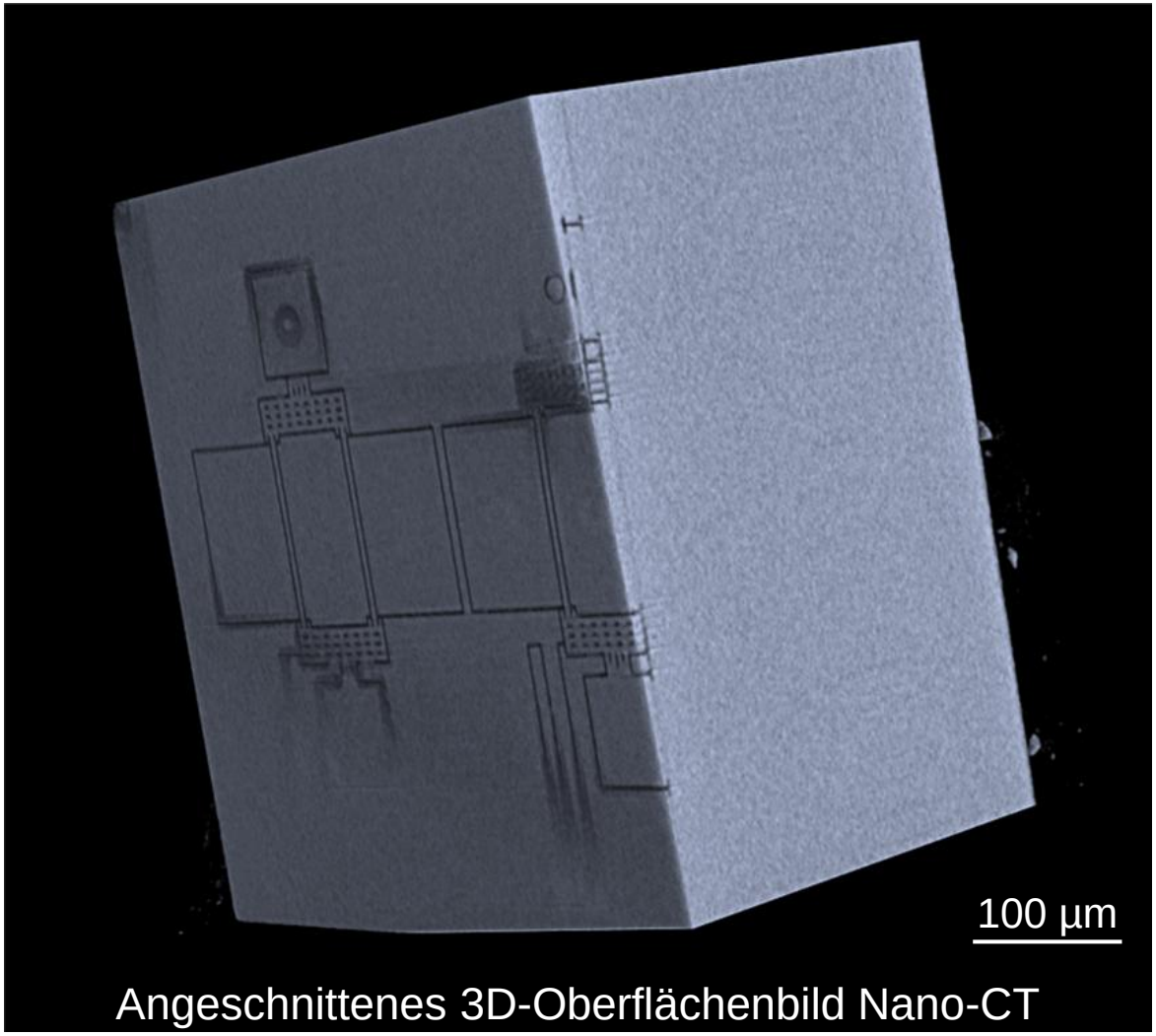
Stereomikroskop

3D-Oberflächenbild Nano-CT

Zerstörungsfreie Untersuchung in Höchstauflösung, Beispiel Silicium-Mikrosystem für Sensoren

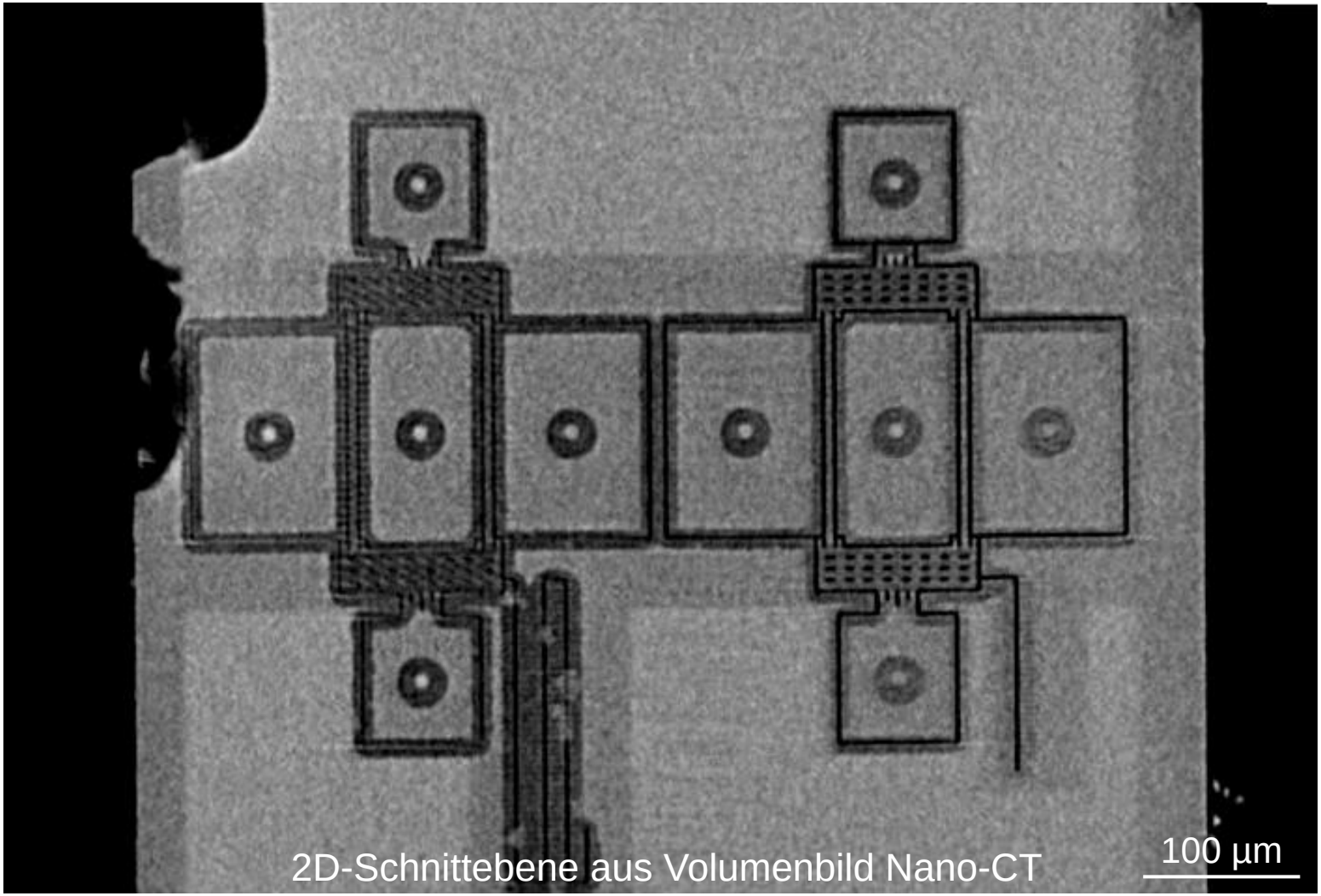


Zerstörungsfreie Untersuchung in Höchstauflösung, Beispiel Silicium-Mikrosystem für Sensoren



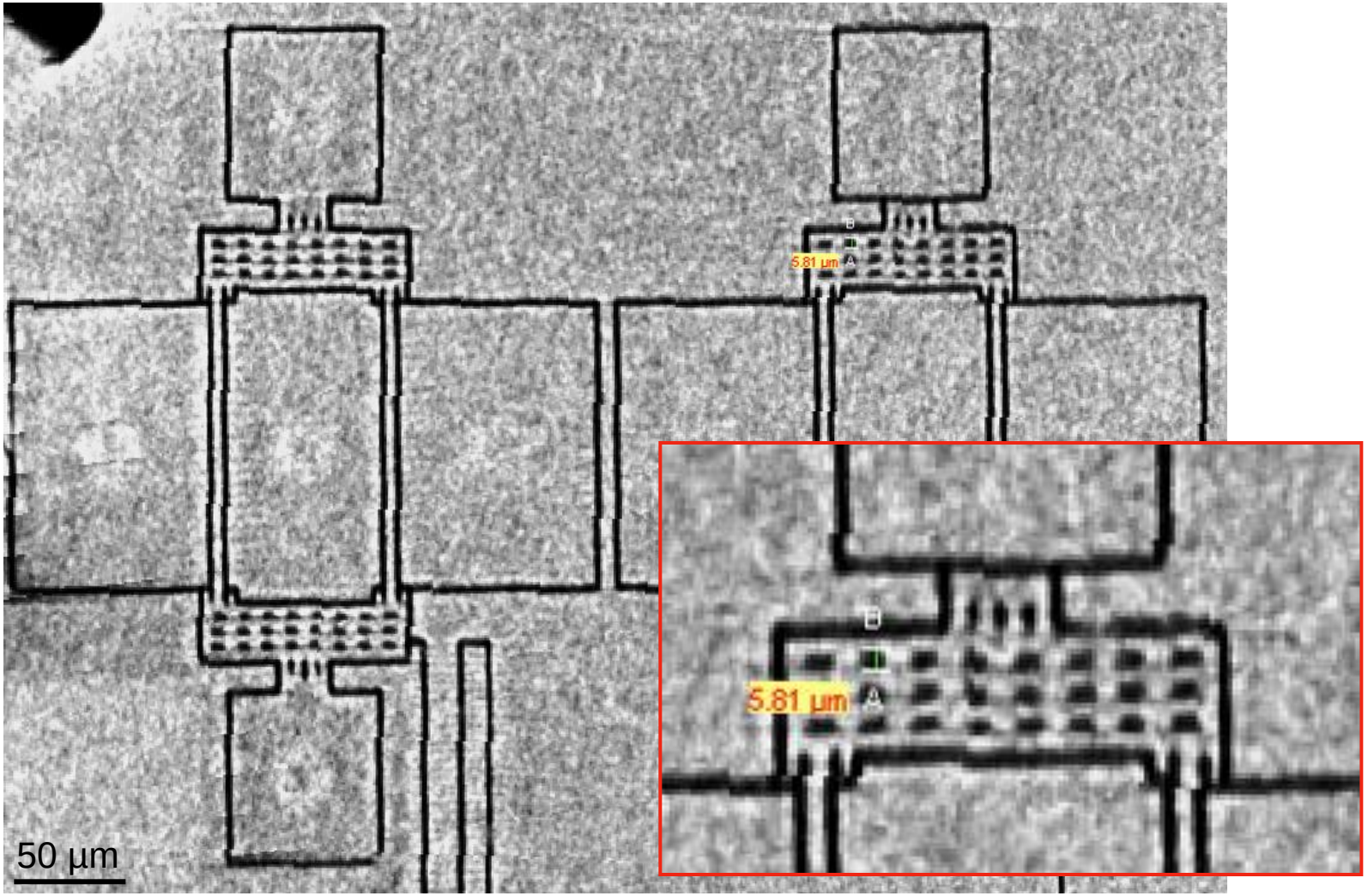
Angeschnittenes 3D-Oberflächenbild Nano-CT

Mikrometerfeine innere Strukturen in 3D in MEMS
Auflösung 0,5 µm/Voxel → struktureller Aufbau



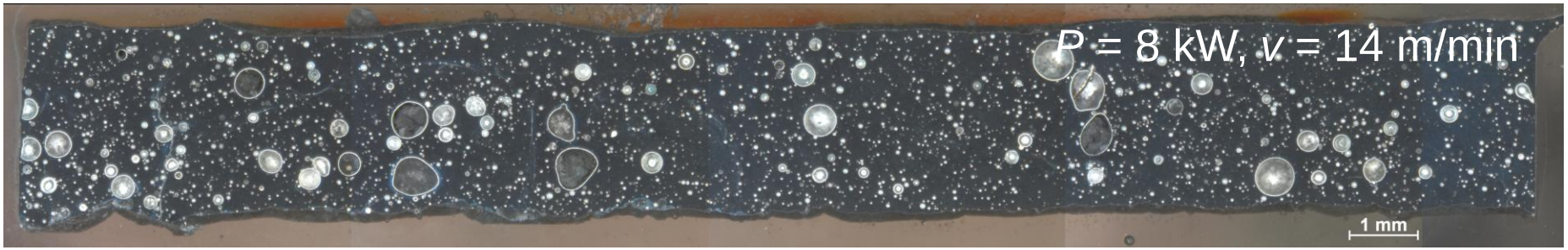
Mikrometerfeine innere Strukturen in 3D in MEMS
Auflösung 0,5 µm/Voxel → struktureller Aufbau

2D-Schnittebene aus Volumenbild der Nano-CT

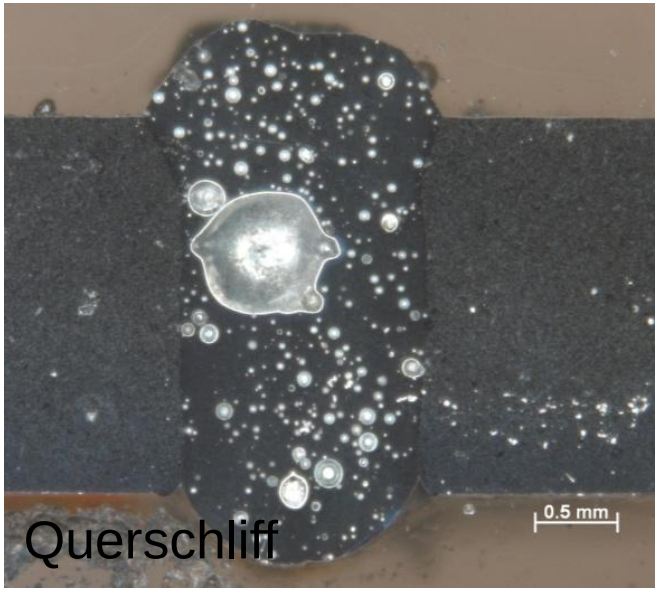


Fehler in Bauteilen: Poren in lasergeschweißtem Aluminiumdruckguss

AlSi10Mg, TruDisk 8002, bifokal, d_f = 0,4 mm, He/Ar (1:1), Blechdicke: 2 mm



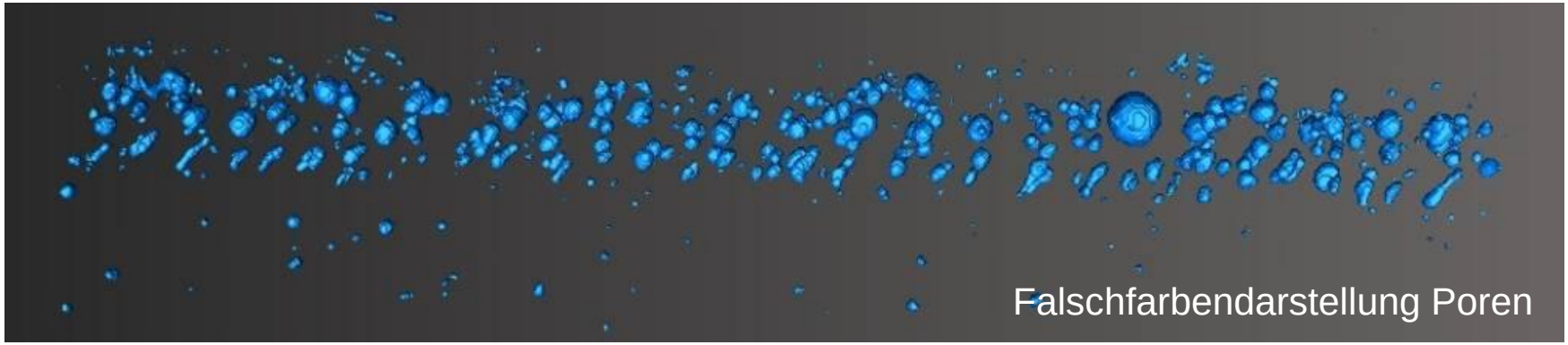
Längsschliff

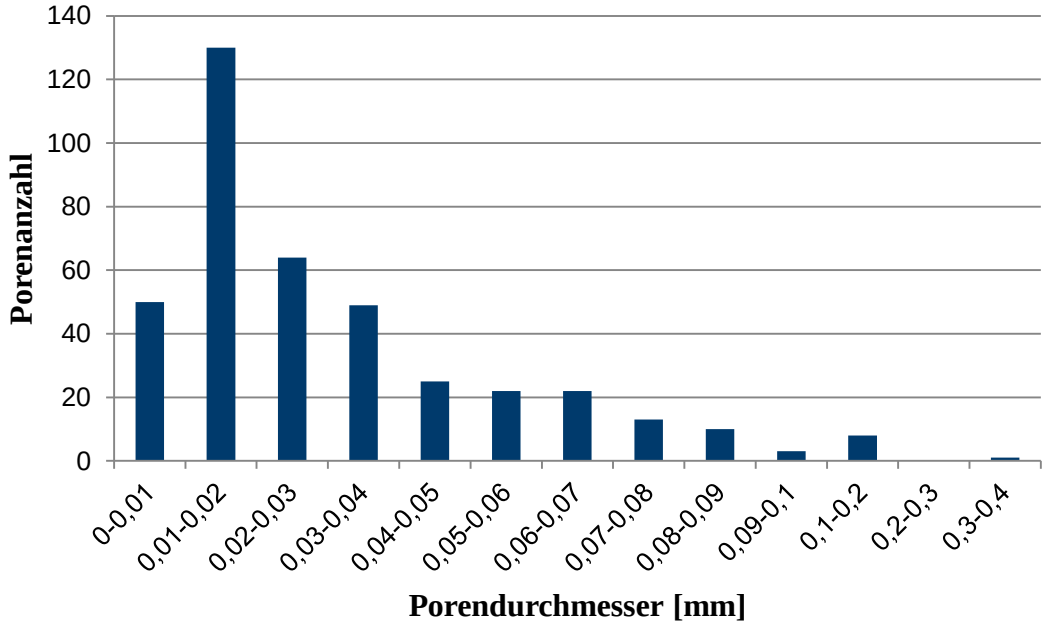


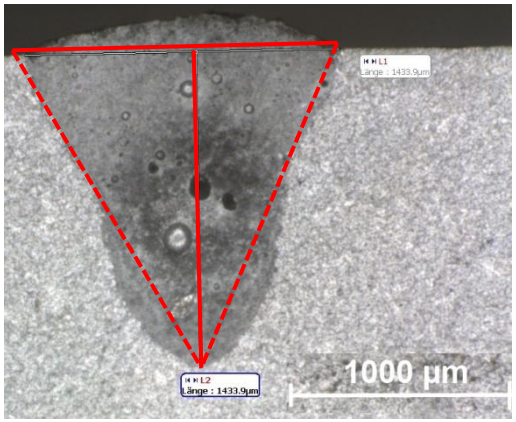
Querschliff

Lichtmikroskopie

Fehler in Bauteilen: Räumliche Quantifizierung der Poren und Größenverteilung mittels µCT in Laserschweißnaht

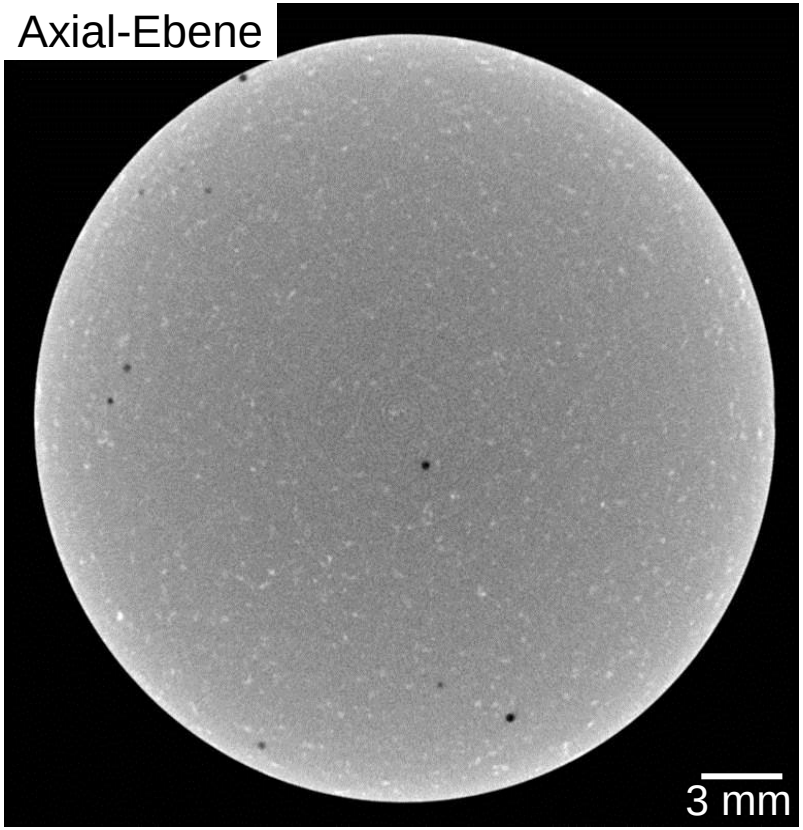




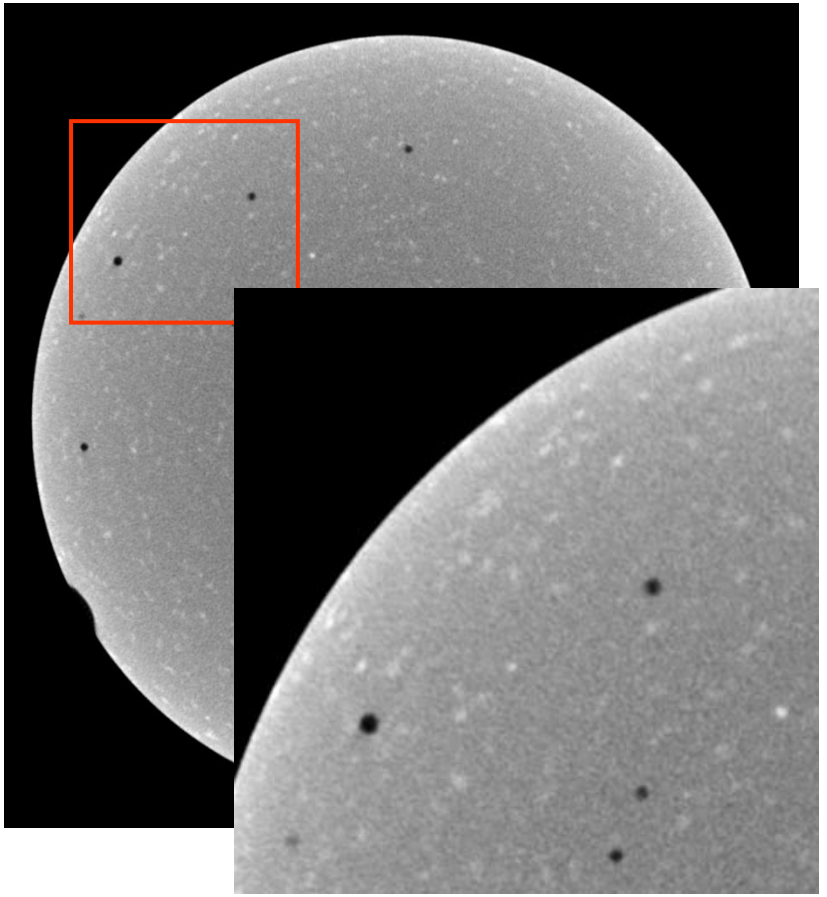


AlSi10Mg, *v* = 5 m/min, Druckguss

Fehler in Bauteilen
Beispiel: Al_2O_3-Keramik + künstlich eingebrachte Fehler



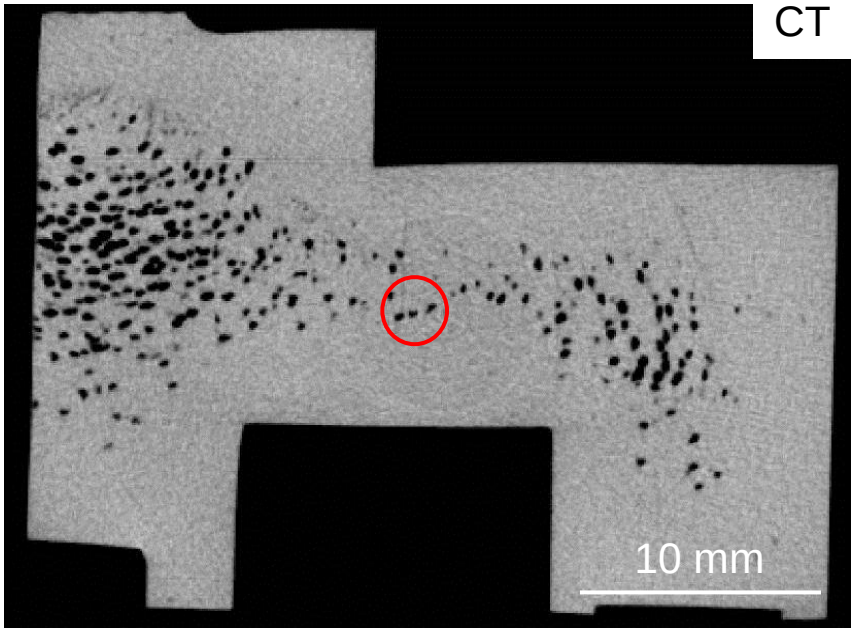
Direktstrahlröhre 225 kV, Auflösung 24 µm/Voxel



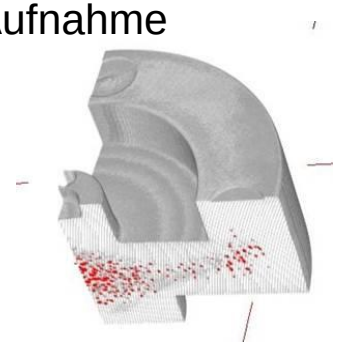
➔ *Zuverlässigkeit und Festigkeit von Bauteilen*

Fehler in Bauteilen
Beispiel: Lunkerverteilung in Kunststoffspritzgussteil

Kachelbild einer zielpräparierten Ebene
Bildauflösung ~2 µm/Pixel



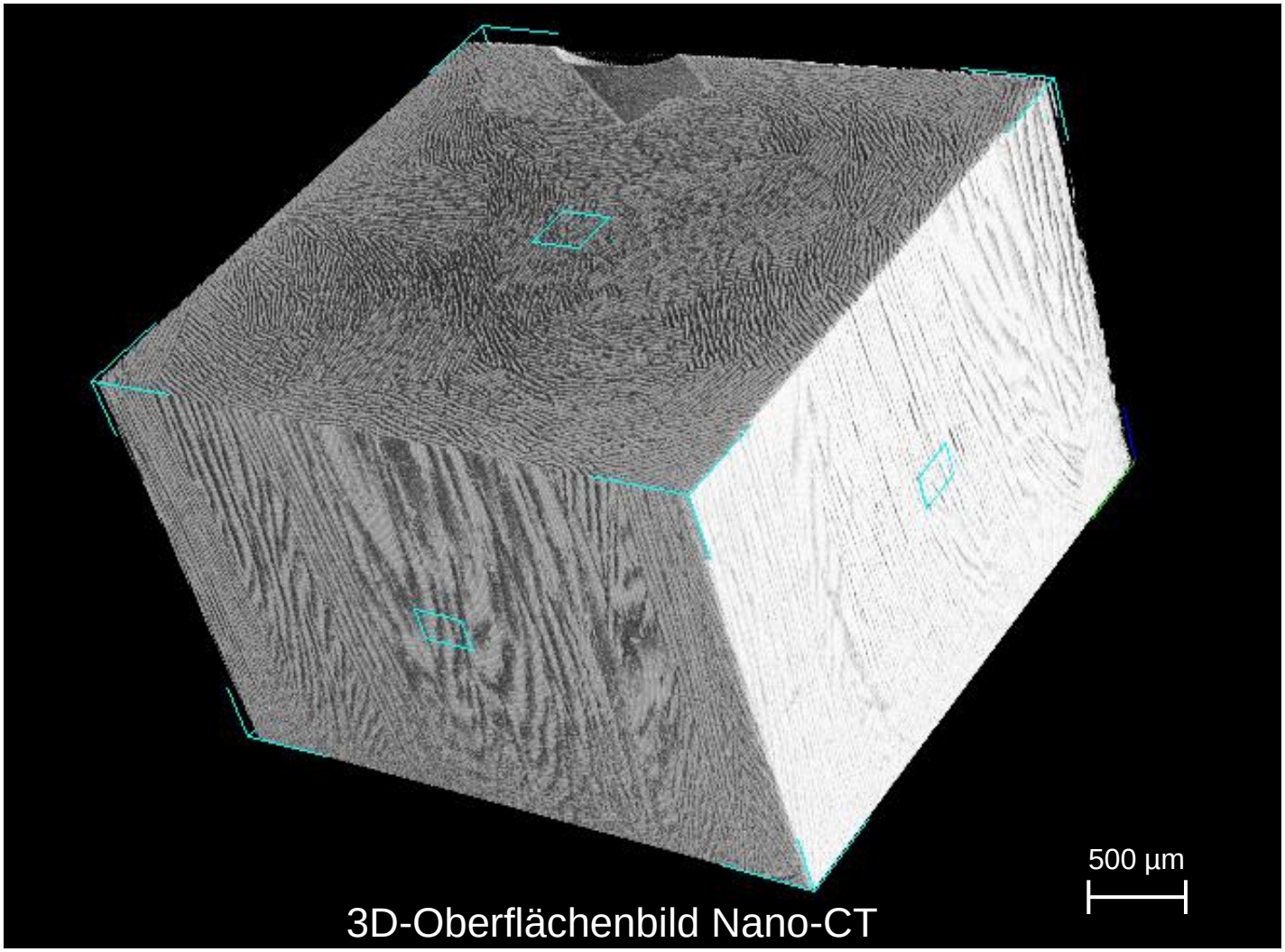
Identische Ebene aus µCT-Aufnahme
Bildauflösung 60 µm/Voxel



- radialsymmetrische Lunkeranordnung
- Größenverteilung und Position abhängig von Herstellungsprozess

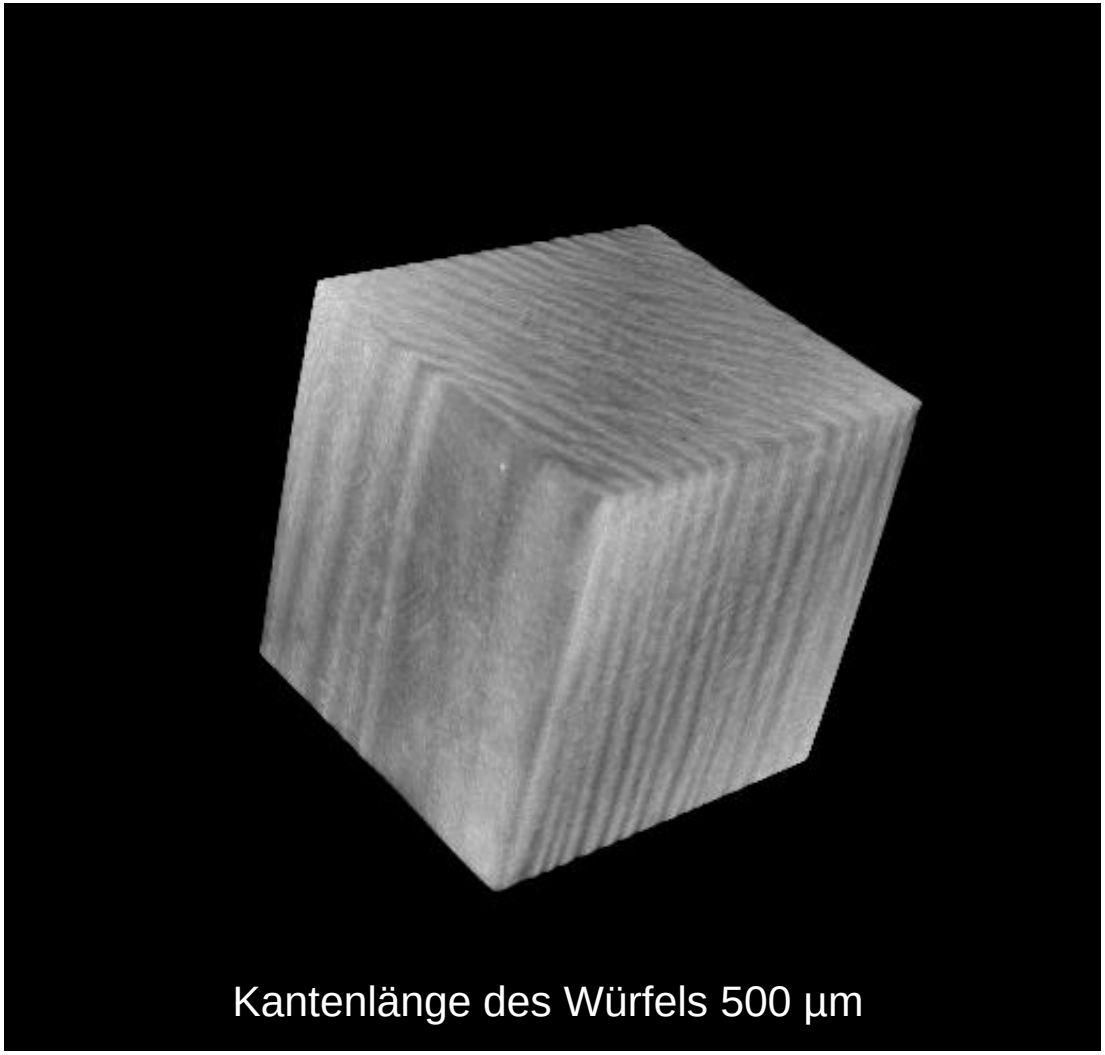
➔ *Zuverlässigkeit und Festigkeit von Bauteilen*

Domänenbestimmung eines gefriergegossenen Al_2O_3-Grünkörpers mittles Nano-CT



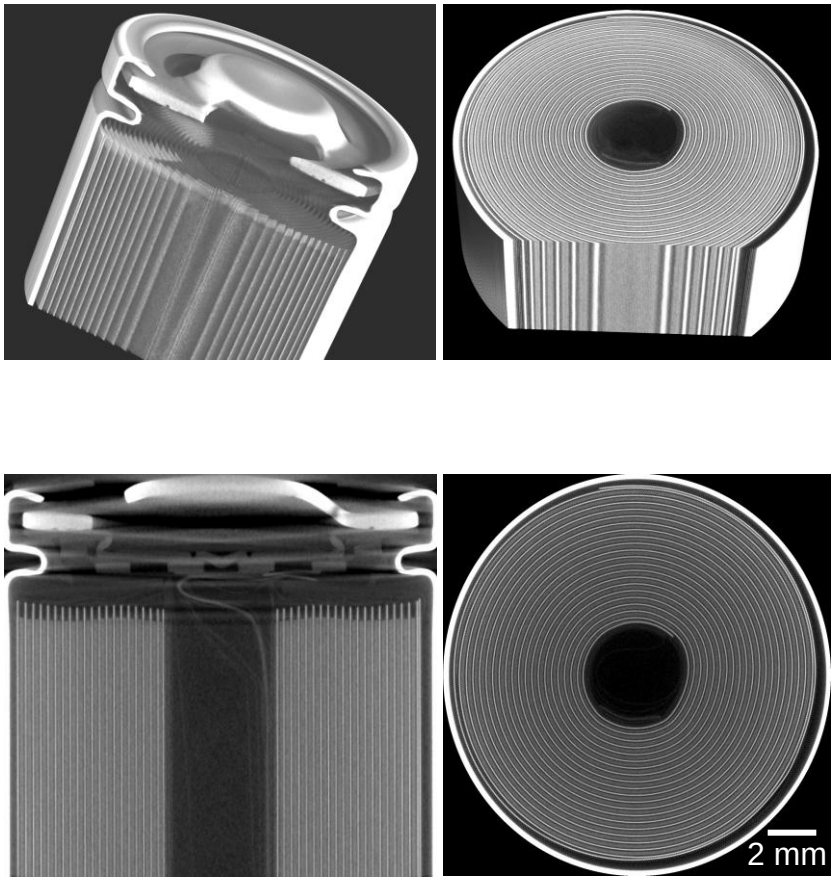
3D-Oberflächenbild Nano-CT

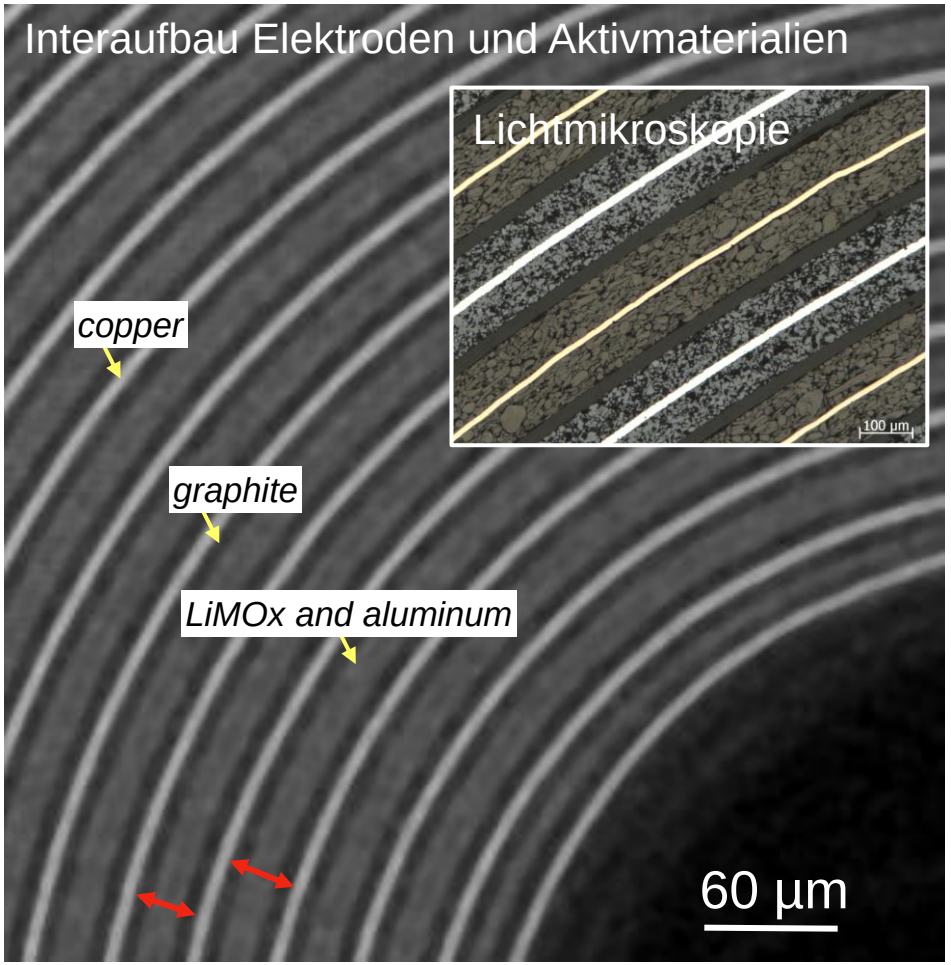
Kontrolle der Schmelzinfiltration in einer Al-MMC Einzeldomäne (AlSi12/Al_2O_3/40_{pp}) mittels Nano-CT



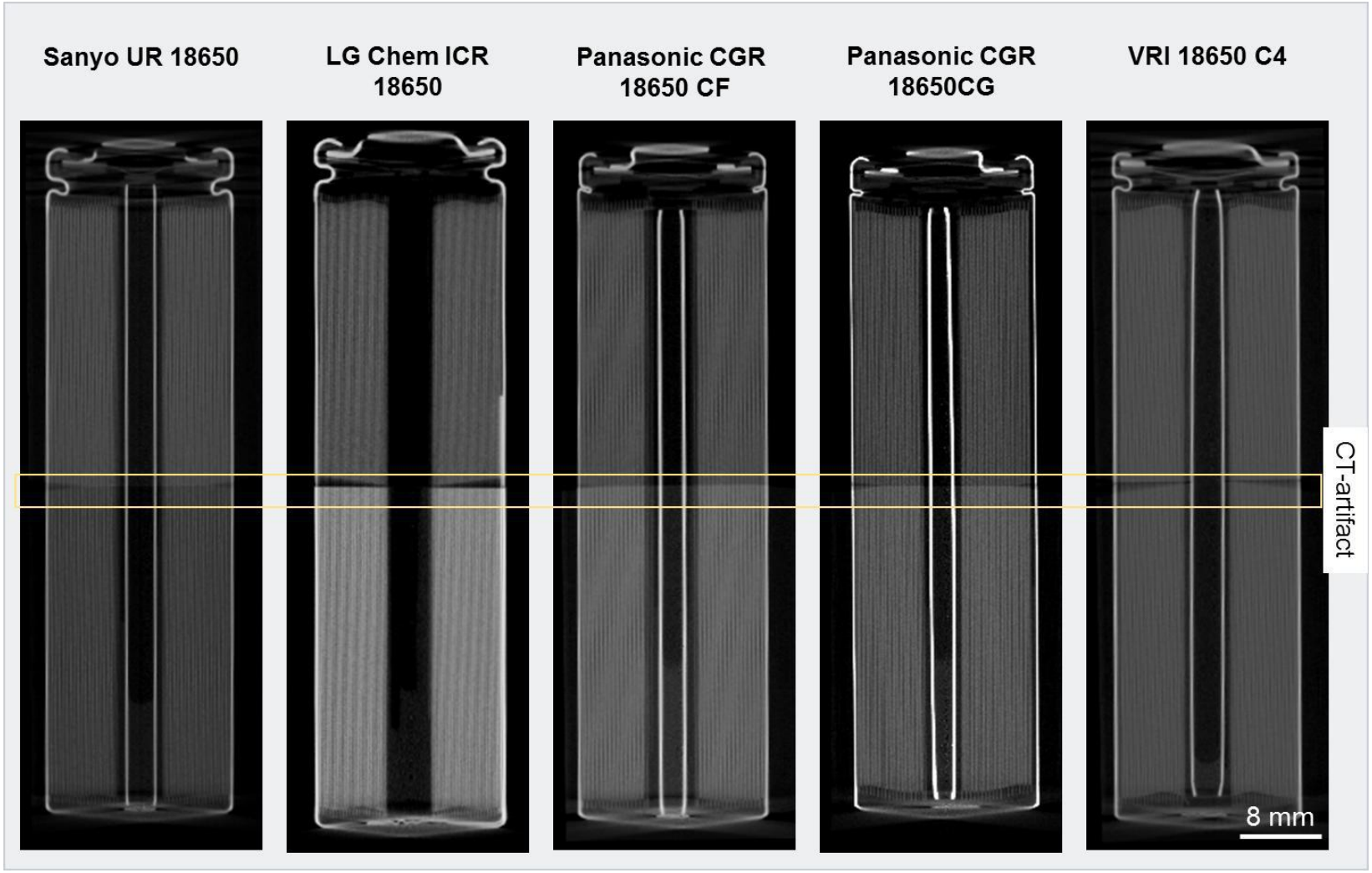
Li-Ionen-Akkumulatoren: Möglichkeit feingeometrische Auswertungen und Messen von Elektrodenparametern

frontal ***axial***

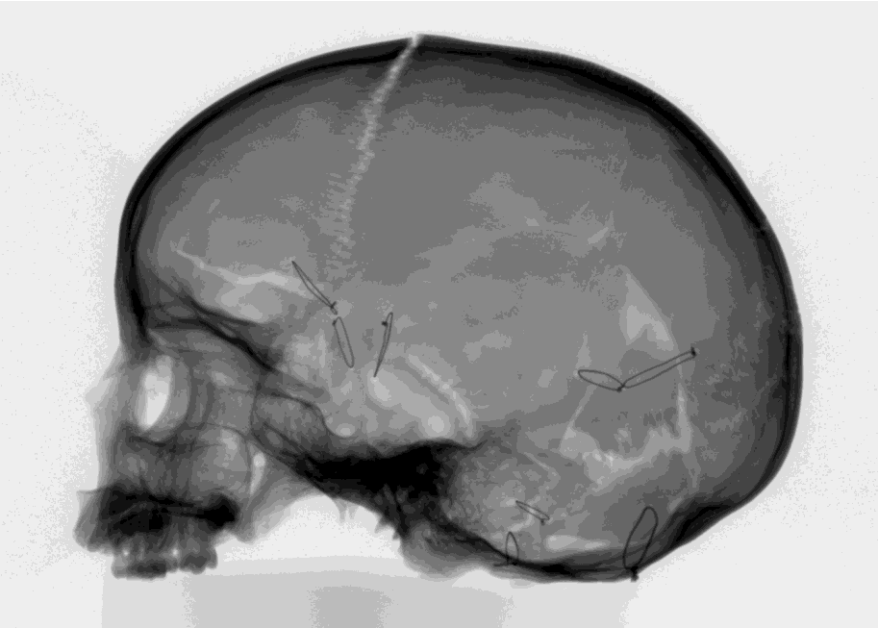




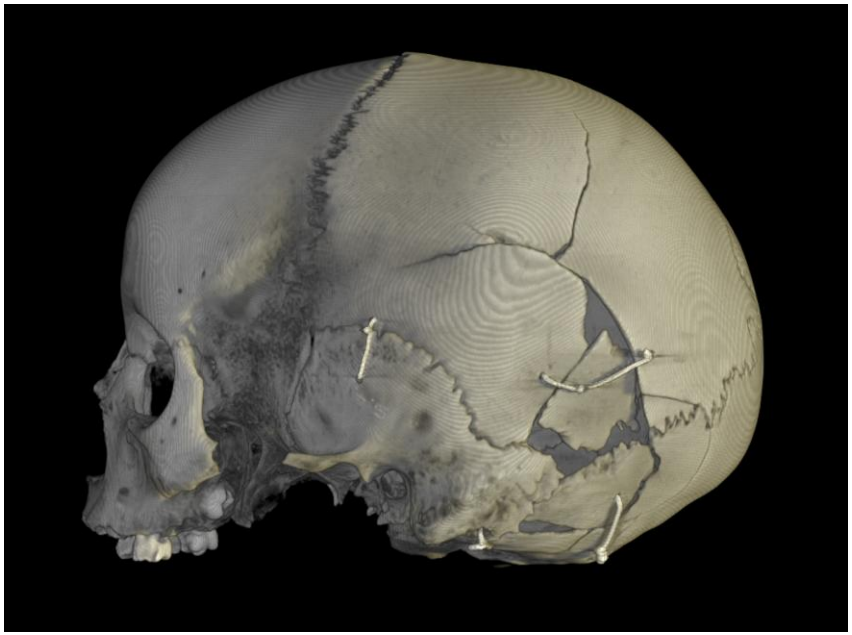
Li-Ionen-Akkumulatoren: Vergleich Feingeometrie und Aufbau von Zellen verschiedener Hersteller



Archäologie: Schädel Junge (6 Jahre) – Alter ca. 3000 Jahre



2D-Röntgenprojektionsbild



3D Oberflächendarstellung µCT

In Zusammenarbeit mit Federsee Museum Bad Buchau

Archäologie: Schädel Junge (6 Jahre) – Alter ca. 3000 Jahre; Volumenbild in Schnittbild Darstellung

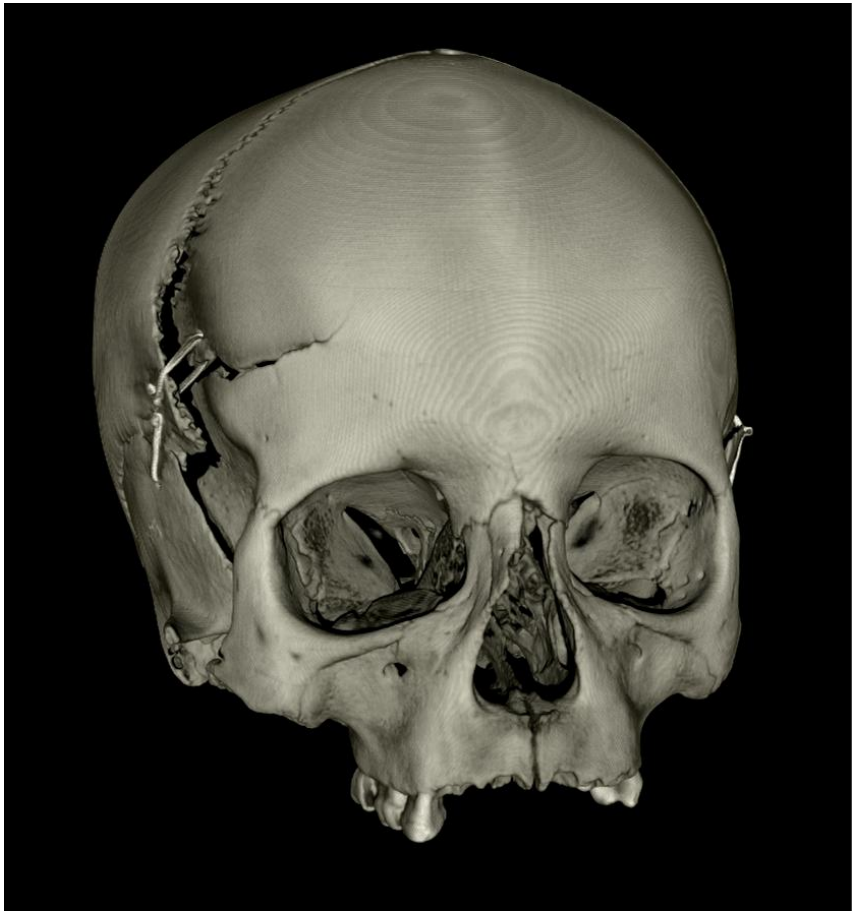
In Zusammenarbeit mit Federsee Museum Bad Buchau

Archäologie: Schädel Junge (6 Jahre) – Alter ca. 3000 Jahre; Oberflächendatensatz für Rapid-Prototyping

In Zusammenarbeit mit Federsee Museum Bad Buchau

Archäologie: Schädel Junge (6 Jahre) – Alter ca. 3000 Jahre

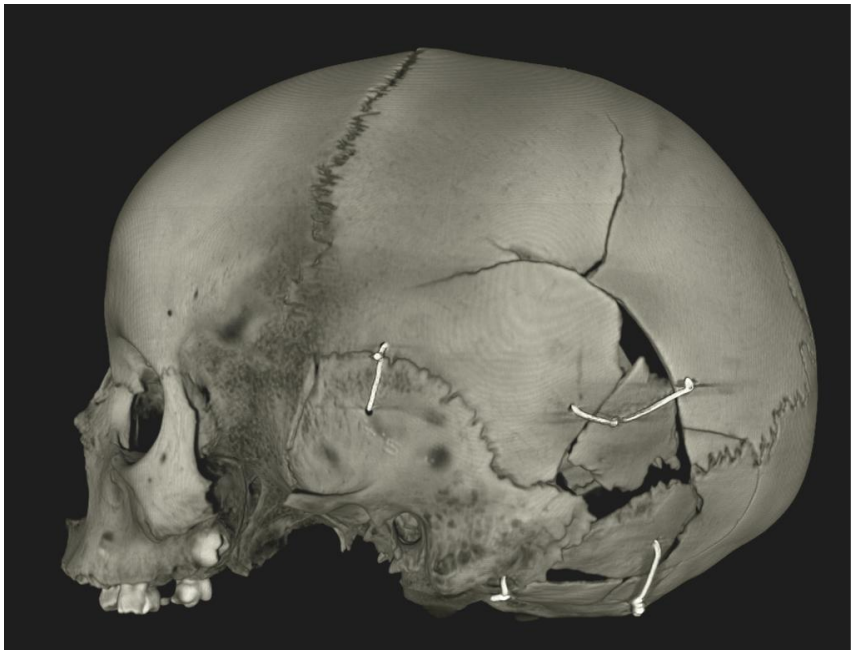
Photographie Federsee-Museum



3D Oberflächendarstellung µCT

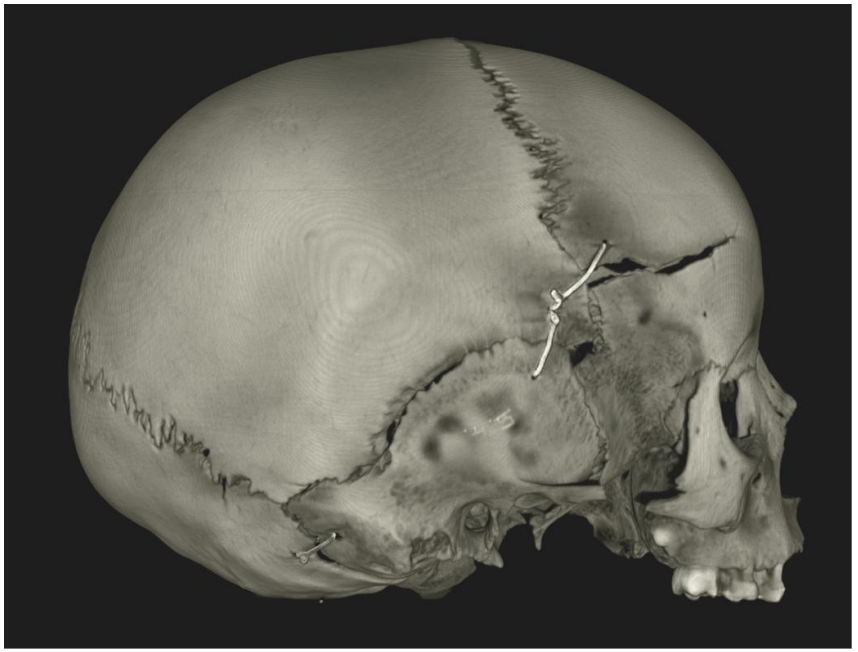
In Zusammenarbeit mit Federsee Museum Bad Buchau

Archäologie: Schädel Junge (6 Jahre) – Alter ca. 3000 Jahre



Seitenansicht links

3D Oberflächendarstellung µCT

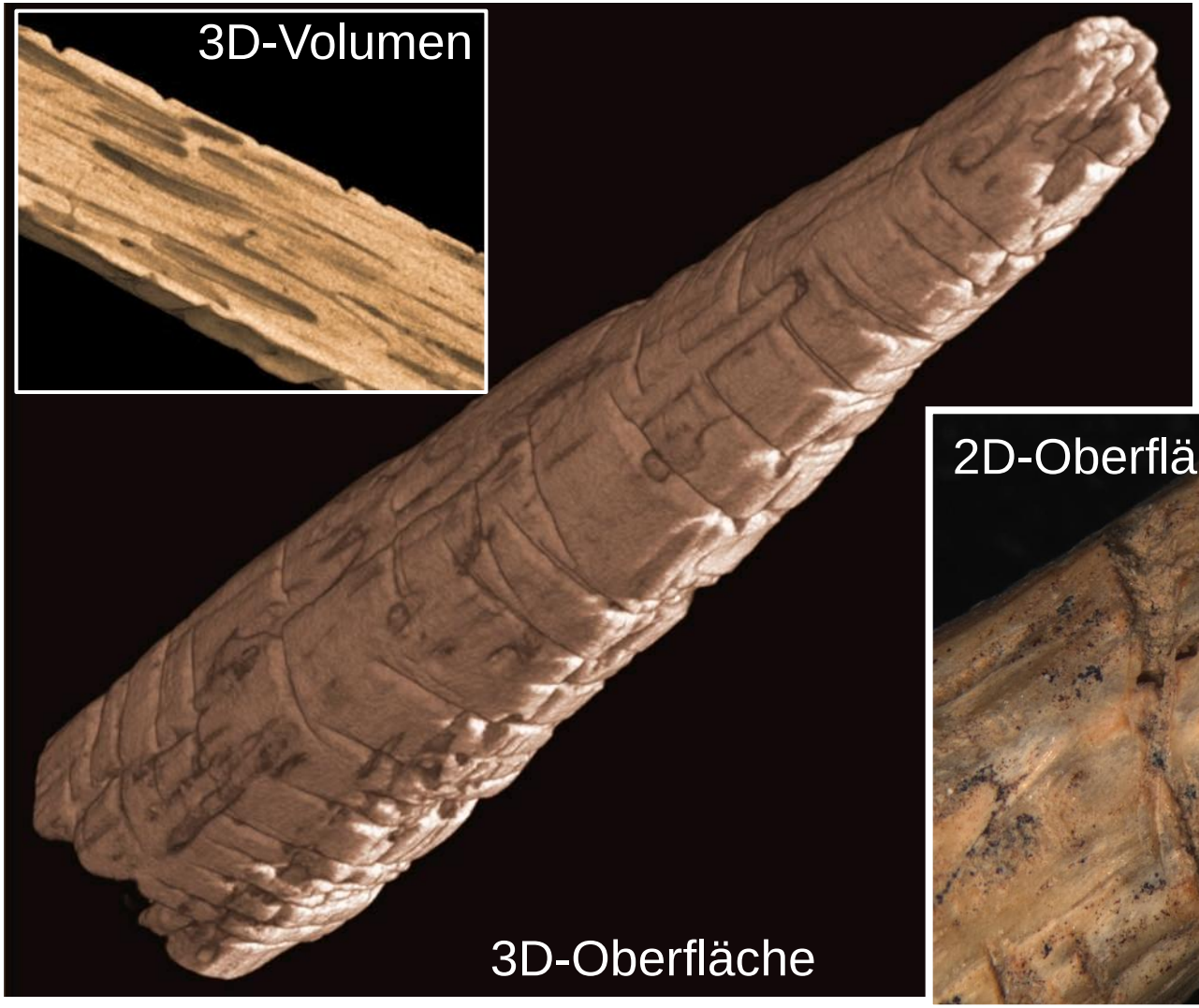


Seitenansicht rechts

3D Oberflächendarstellung µCT

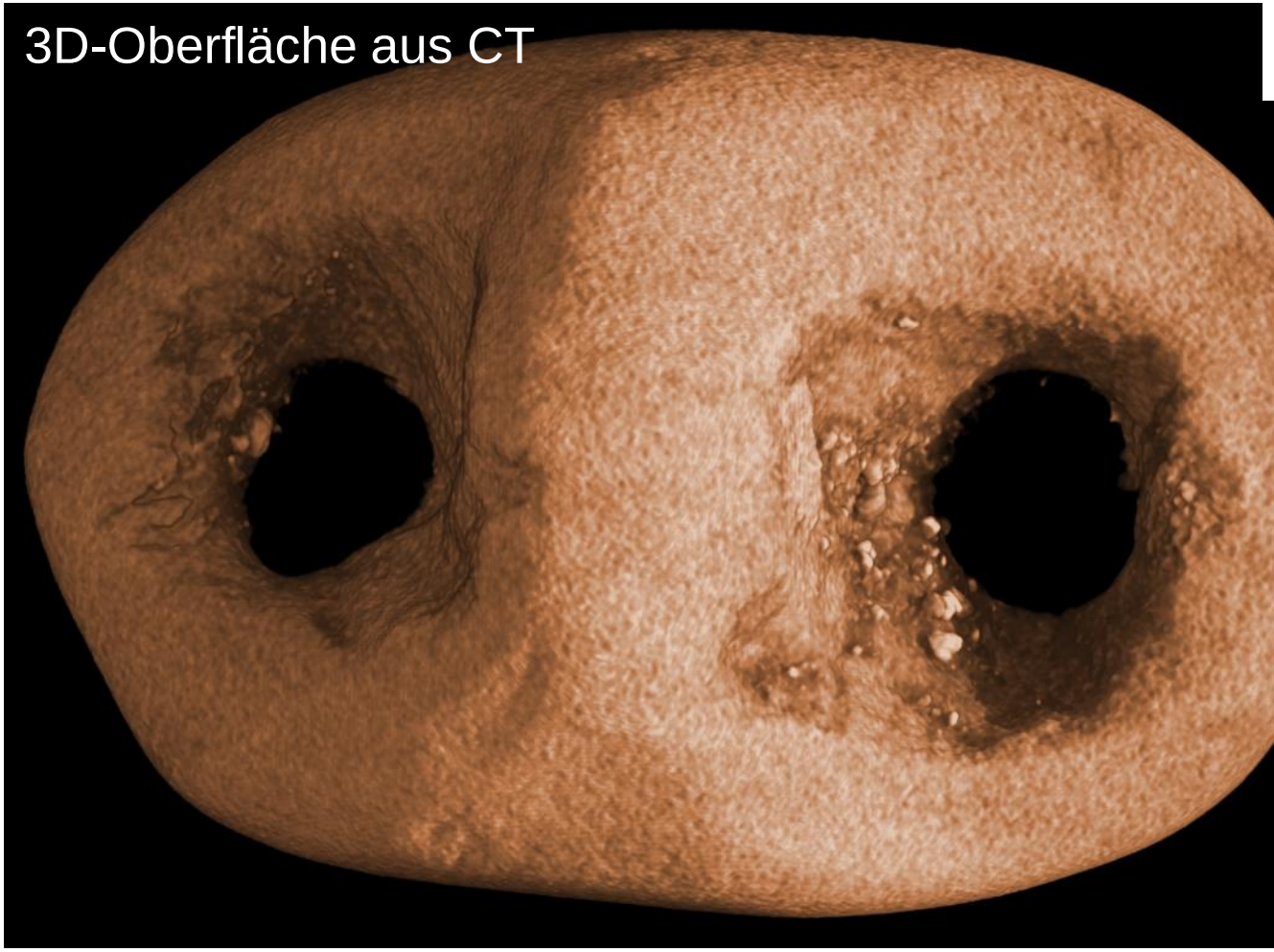
In Zusammenarbeit mit Federsee Museum Bad Buchau

Archäologie: Nano-CT an einer ca. 24.000 Jahre alten “Geschossspitze” (Lonetal) → Rapid Prototyping



In Zusammenarbeit mit
Universität Tübingen

Archäologie: Nano-CT an einer 35000 Jahre alten “Elfenbeinperle” (Lonetal) → Rapid Prototyping



In Zusammenarbeit mit Universität Tübingen

Makrobild