XRM Technology
Techniques, Systems & Application Examples

N. Schott

08.06.2021

Agenda
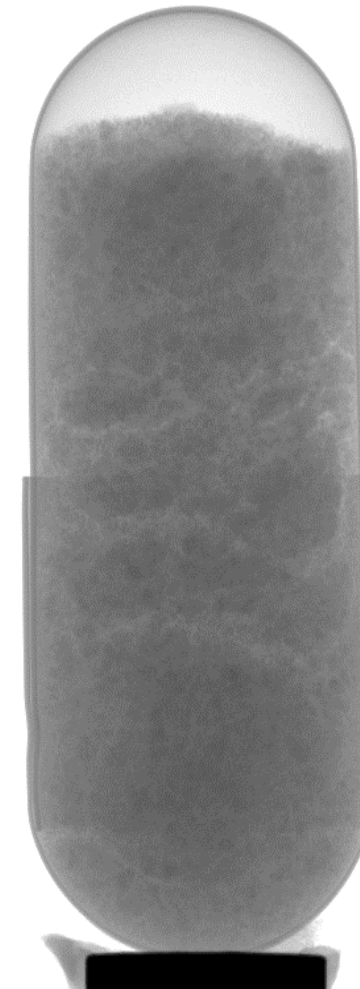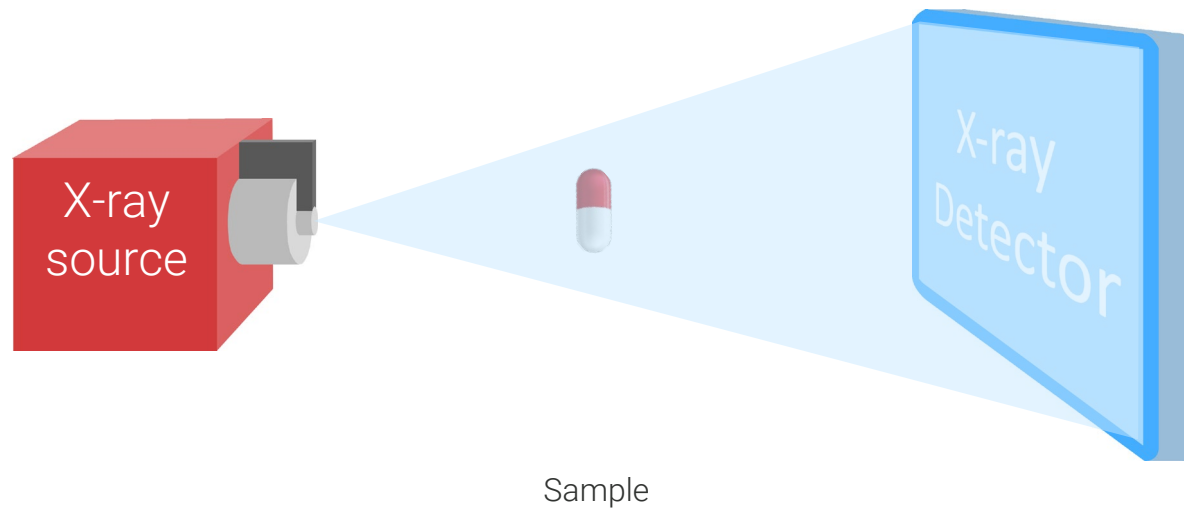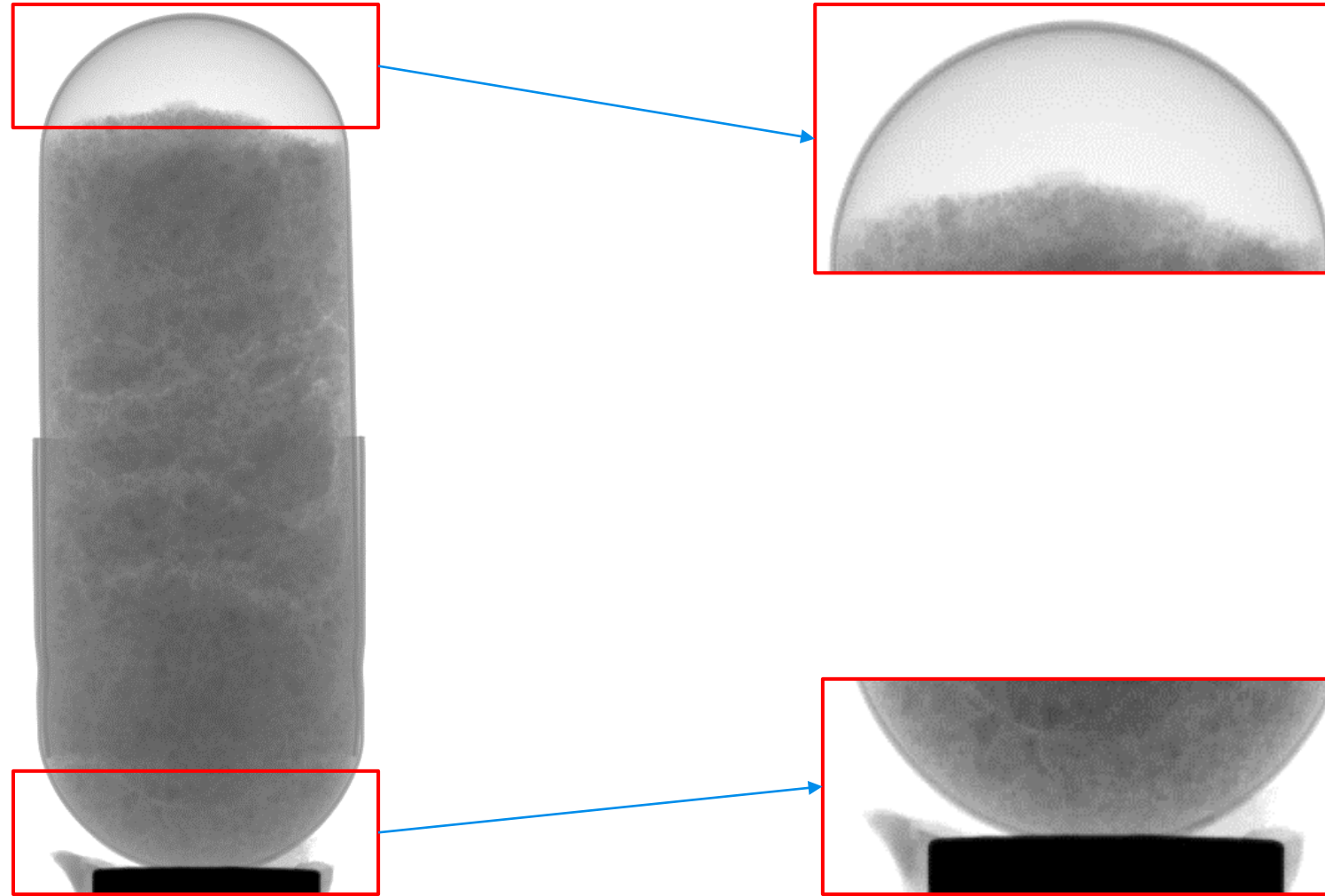
01

What is XRM?

3D X-ray Microscopy Acquisition

- 3D X-Ray Microscopy (3D XRM) is an X-ray based imaging technique using Micro Computed Tomography technology

  - Radiography = 2D projection images (no thickness information)

Sample

1 projection

3D X-ray Microscopy Acquisition
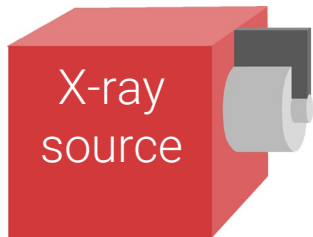
02

Key components

3D X-ray Microscopy
X-ray Source

- Wide range of types

- Specs define the application of the tube

  - Open- & sealed tubes

  - **Focal spot size**

  - Reflection- & transmission tubes

  - kV - kilovolt

X-ray
source

3D X-ray Microscopy
Detector

- Wide range of types and sizes (active area, field of view)

- Specs define the application of the detector
  - Pixel size
  - Numbers of pixels
 - Scintillator

3D X-ray Microscopy Manipulator

- Most important axis is the rotation stage.

- Number of axis can vary depending on the purpose and comfort.

  - Helical and stitching scans

  - Magnification

  - Changing focus detector distance

  - Centre of the sample

3D X-ray Microscopy Magnification

- Resolution depends on sample size
  - Geometric magnification ➔ small sample close to source = high resolution
    ➔ large sample further away = lower resolution
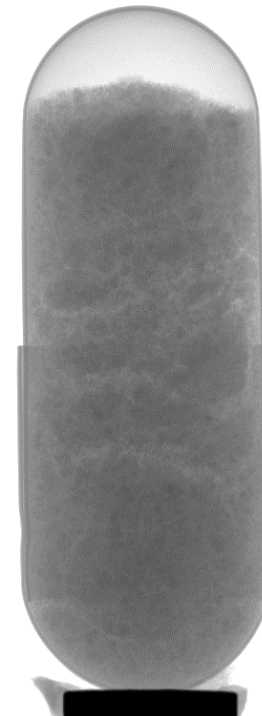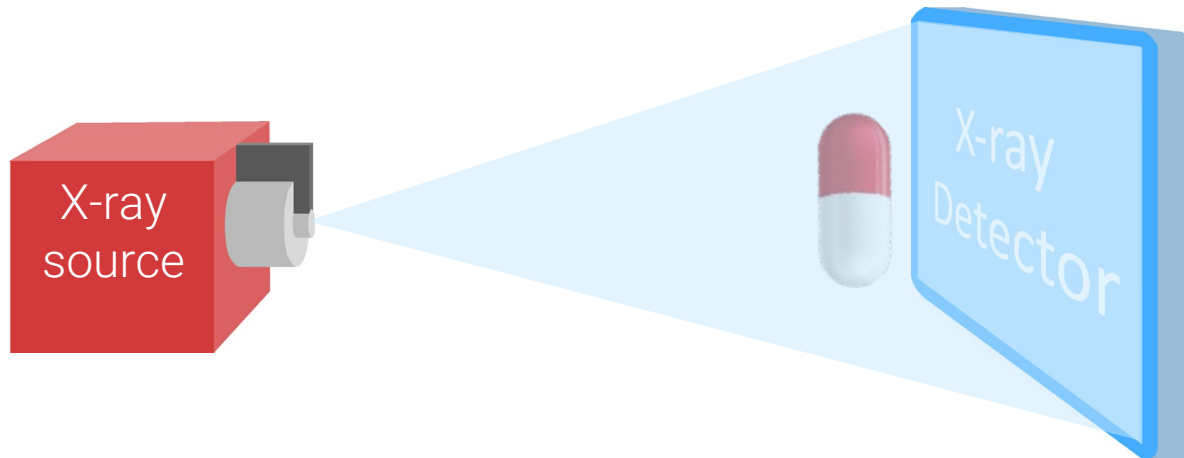
3D X-ray Microscopy Magnification

- Resolution depends on sample size

  - Geometric magnification → small sample close to source = high resolution
    → large sample further away = lower resolution
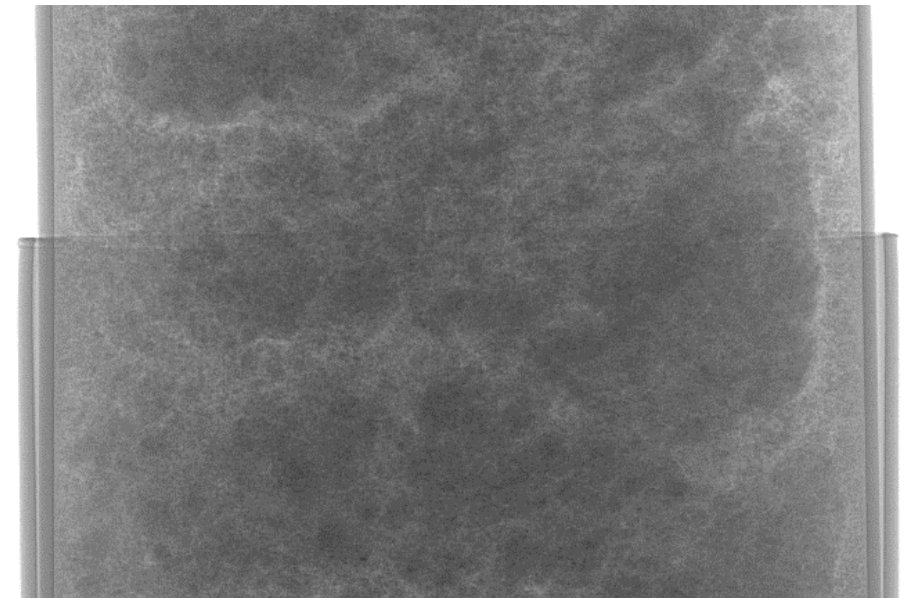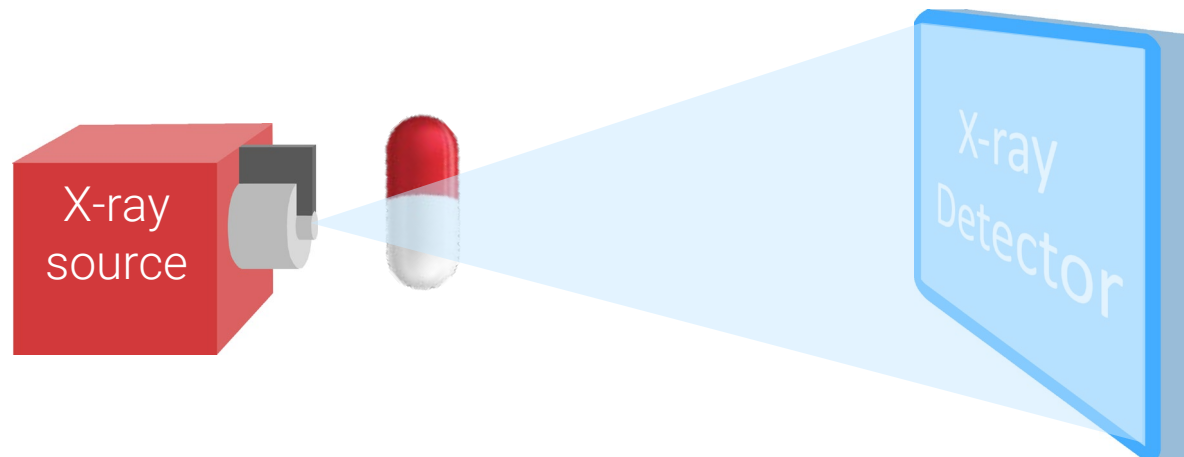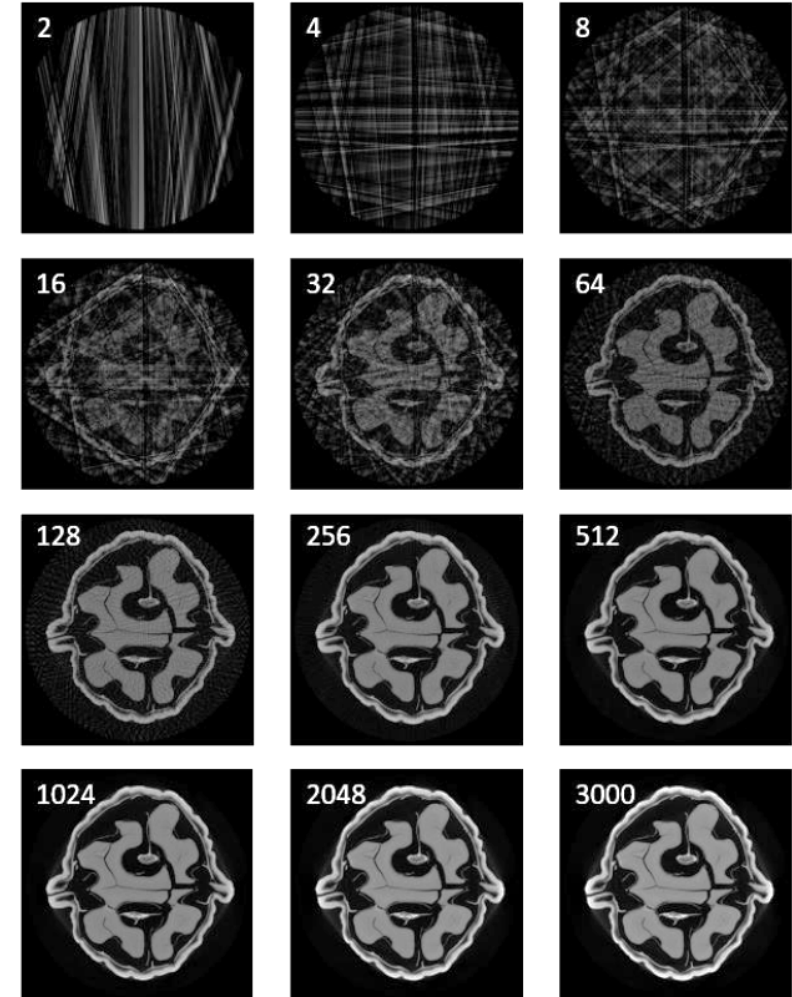
3D X-ray Microscopy
Rotation stage

3D X-ray Microscopy
How many Projection Images?

- Image quality improves with increasing number of projection images (decreasing rotation step)

- Insufficient angular sampling results in linear noise, roughly oriented towards the center of the object

- Example: walnut reconstructed from different number of projection images

  - Extremely low number of projections yield no info

  - From 32 projection images onwards overall structure can be recognized

  - With 512 projection images all feature in the center well resolved, still under sampling artifacts towards the edge

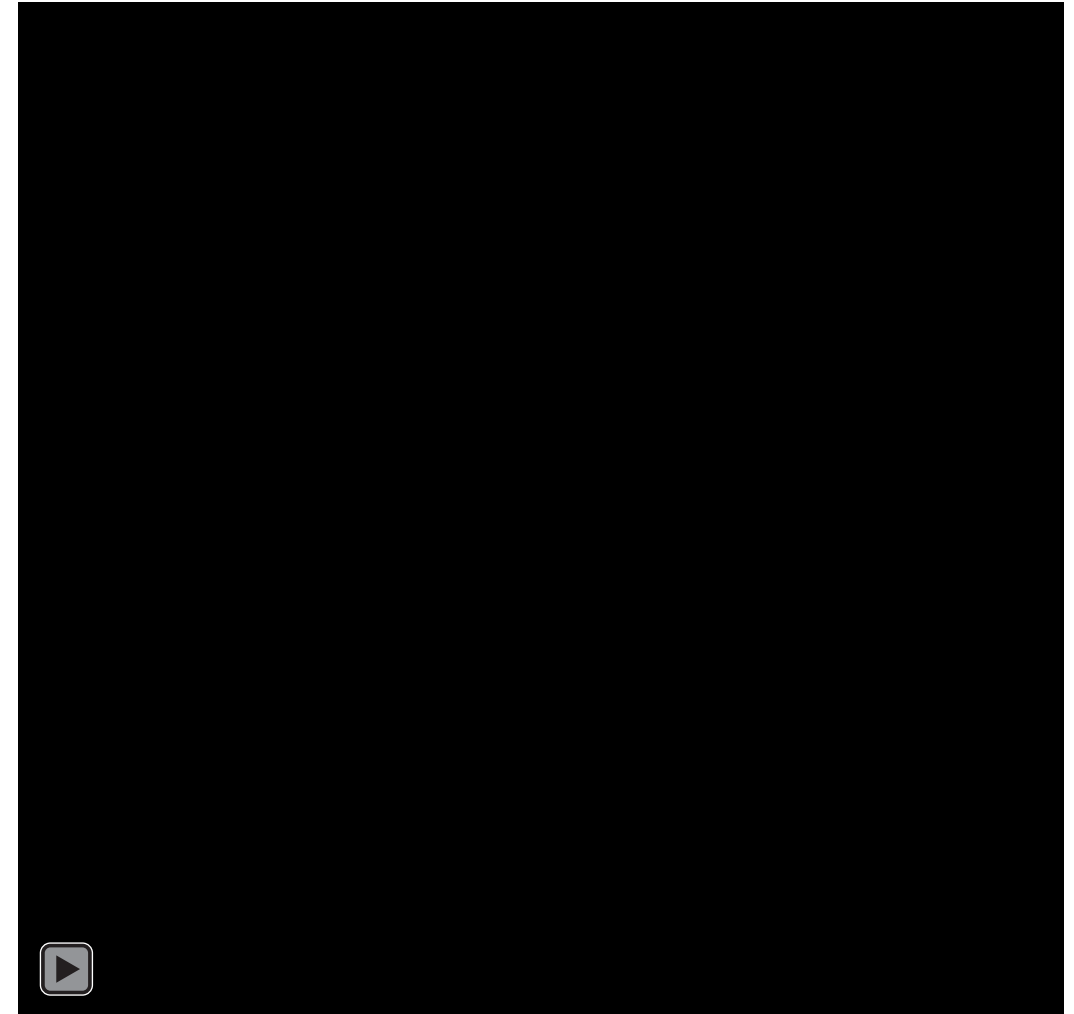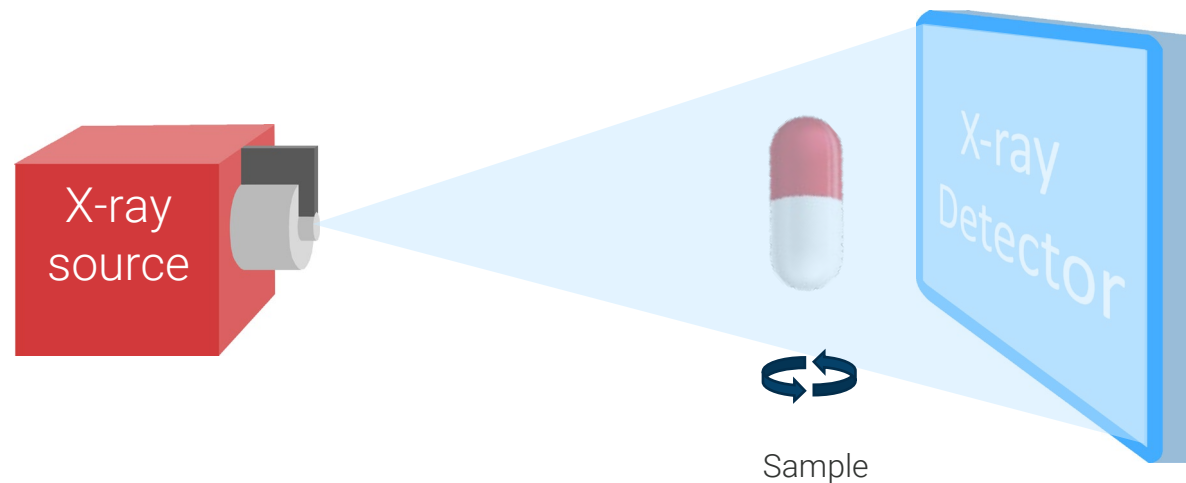 - From 2048 projection onwards no under sampling artifacts, perfect image quality

03

Scan setup

3D X-ray Microscopy Acquisition

- Position of the sample

- Choose right settings
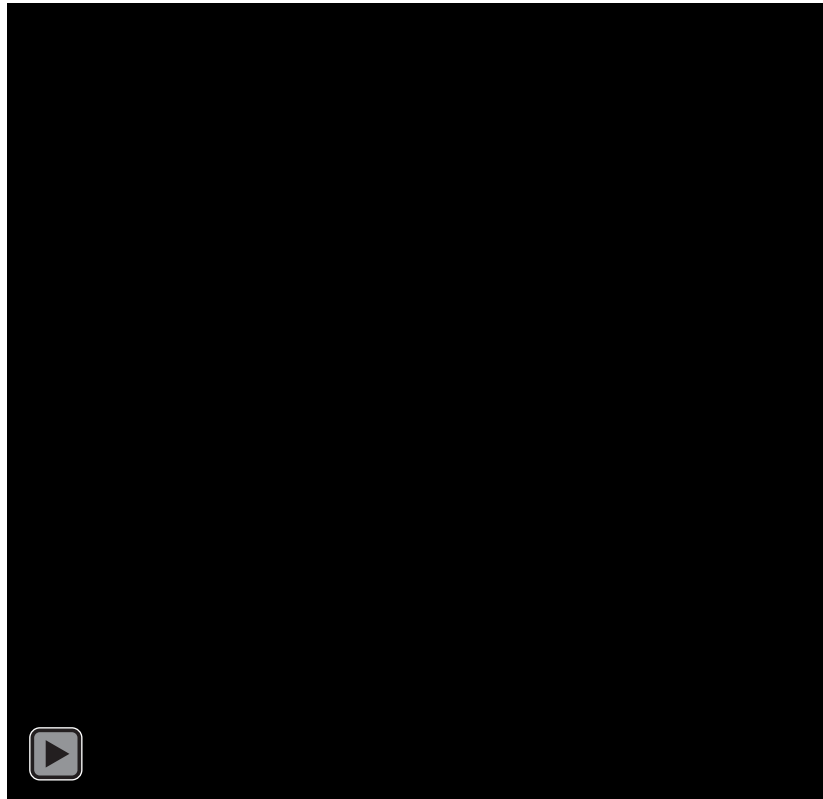
  - Tube

  - Detector

  - Projections

X-ray source
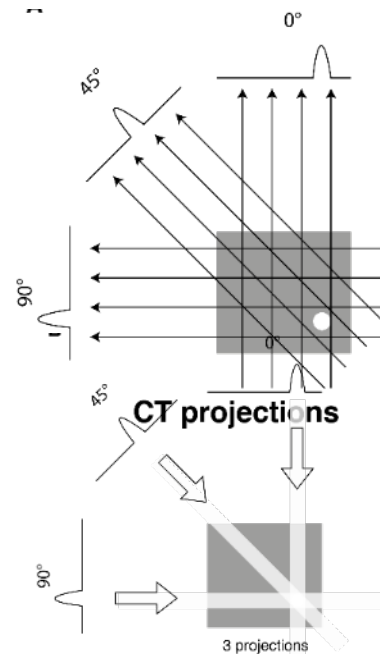
X-ray Detector

Sample

03

Output

3D X-ray Microscopy Reconstruction

- After acquisition ➔ reconstruction to a 3D volume
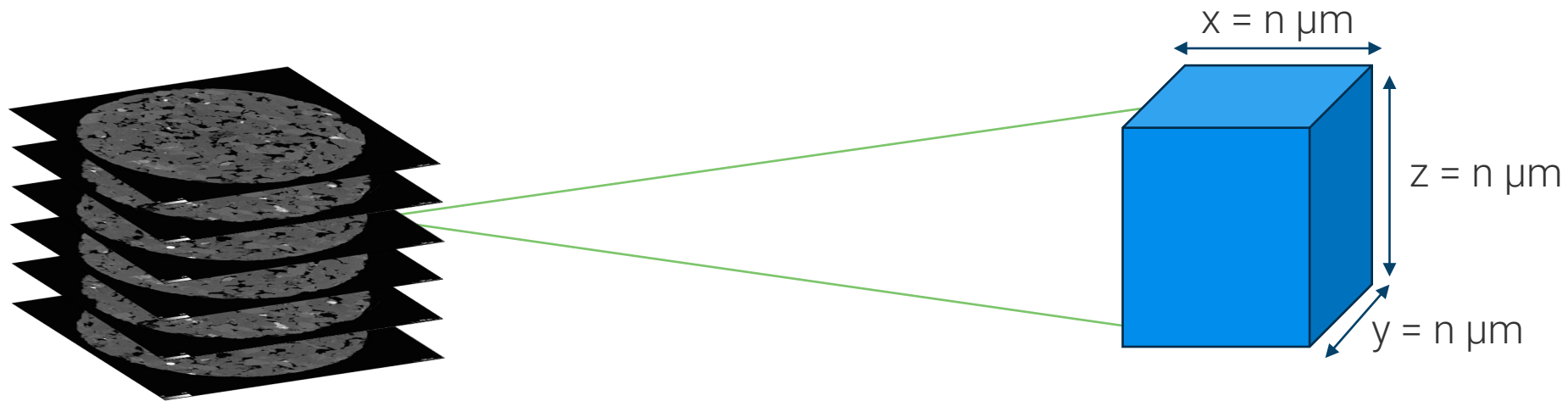

100's – 1000's of projections
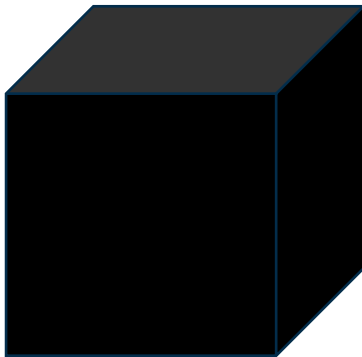

CT Reconstruction

3D X-ray Microscopy
Reconstructed Dataset

- Each slice is an image with a certain pixel size, expressed in µm

- Each slice also represents a thickness, equal to the pixel size

  - A 3D pixel is called a voxel *(volume pixel)*

  - In XRM; voxels are isotropic, or cubes (e.g. not the case in medical CT)
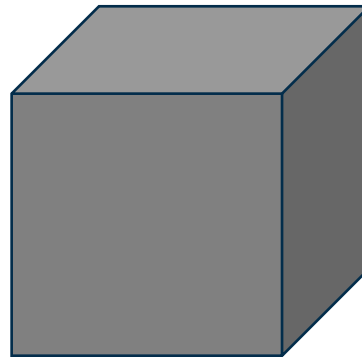
x = n µm

z = n µm

y = n µm

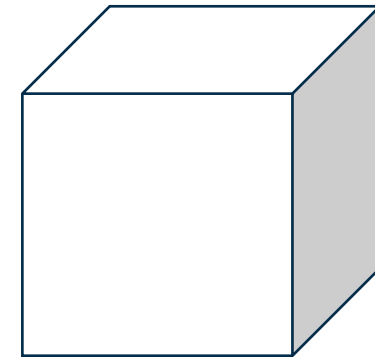# 3D X-ray Microscopy
Reconstructed Dataset

- Each slice is an image with a certain pixel size, expressed in μm

- Each slice also represents a thickness, equal to the pixel size

- Each voxel has a certain grey value

  - 0-255 in 8 bit images (2^8) or 0-65535 in 16 bit images (2^{16})
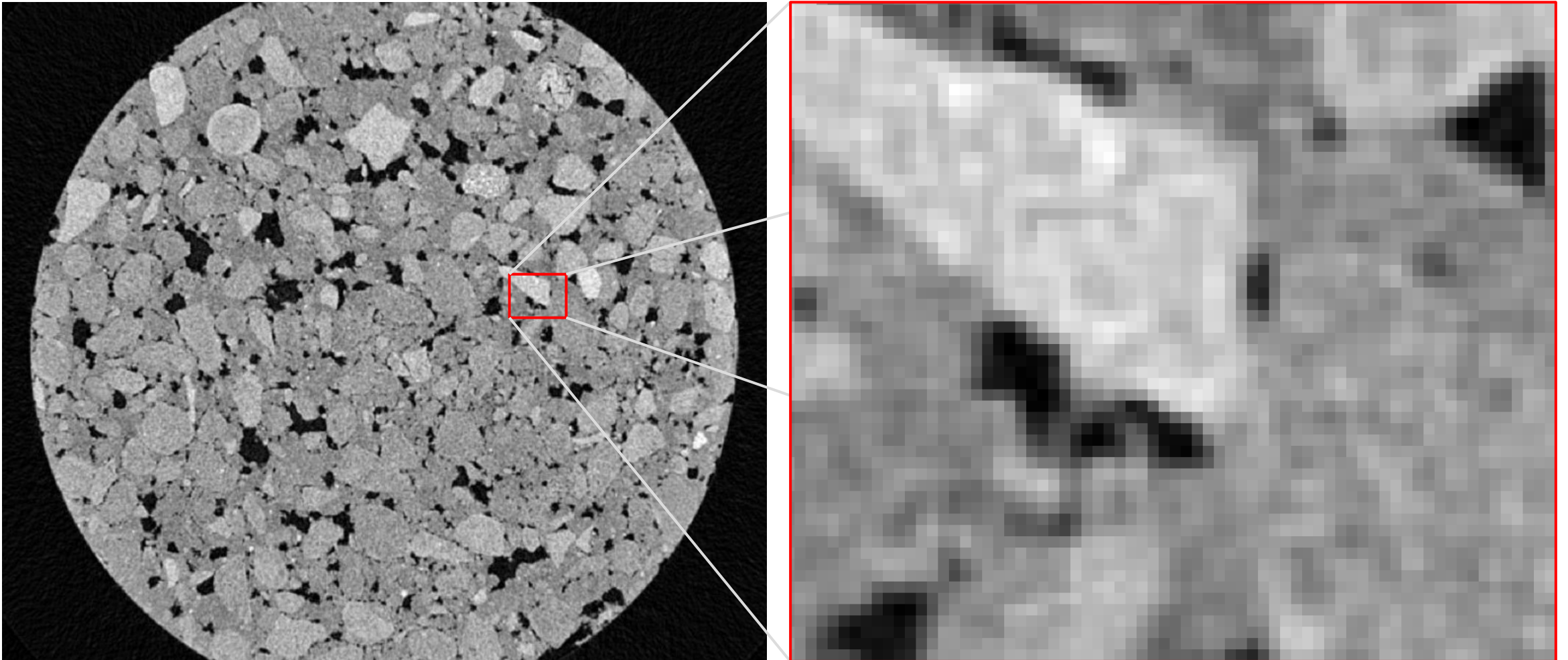
Grey value = 0   Grey value = 128   Grey value = 255

3D X-ray Microscopy
Reconstructed Dataset

04

Application examples

3D X-ray Microscopy
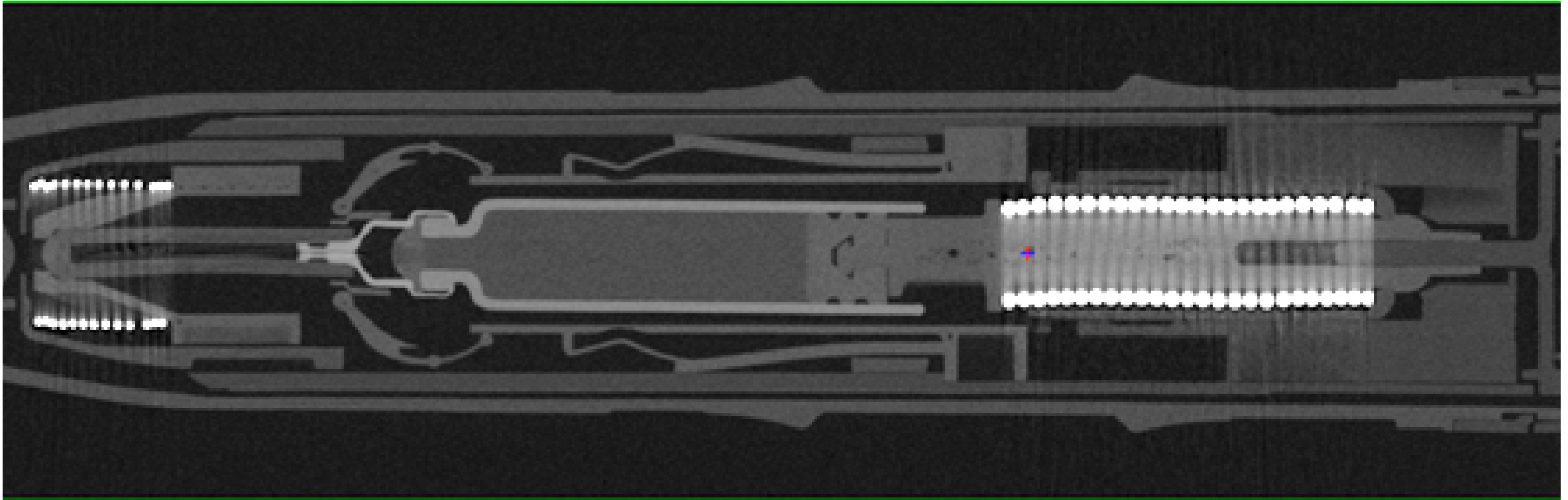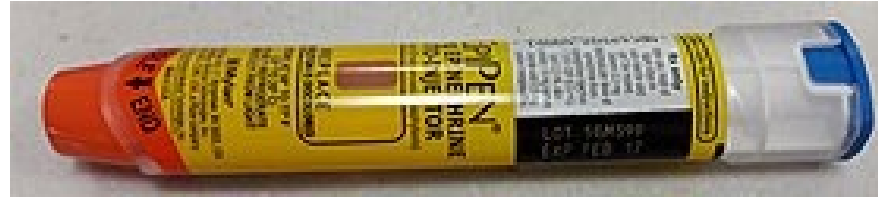## Utilize of dataset

- Visual inspection

    - Assembly control, defect analysis

- Pore/ inclusion analysis

- Fibre orientation

- Thickness analysis

    - Glue, welding, brazing & soldering, foil, paper, coating,

- CAD comparison

- Advance 4D inspection with destruction of the sample
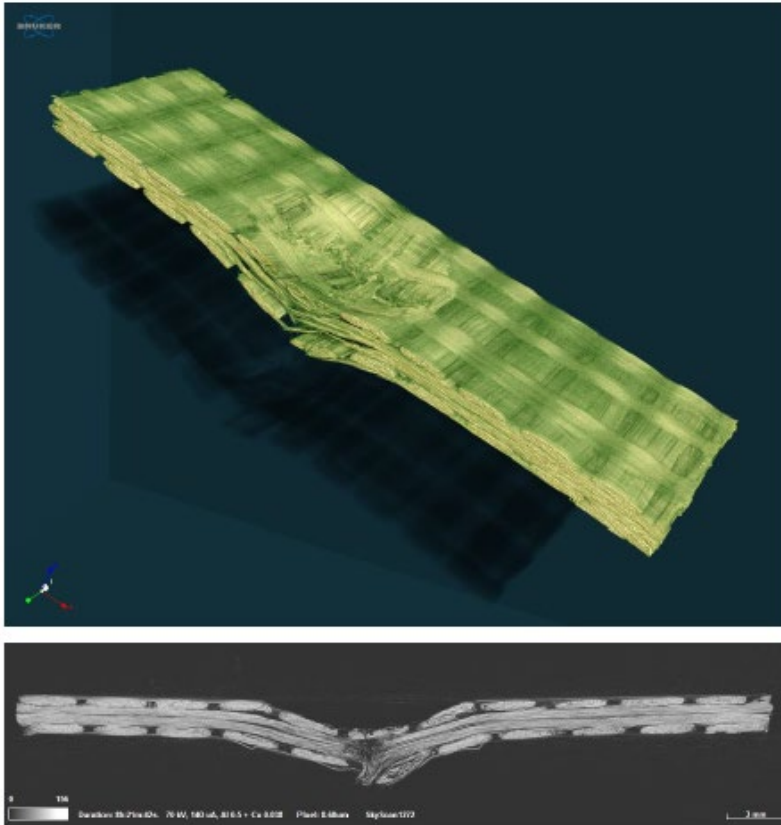
3D X-ray Microscopy
Application examples − Quality control & Packaging
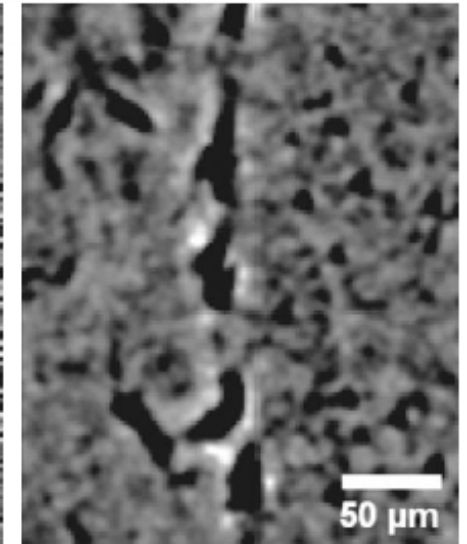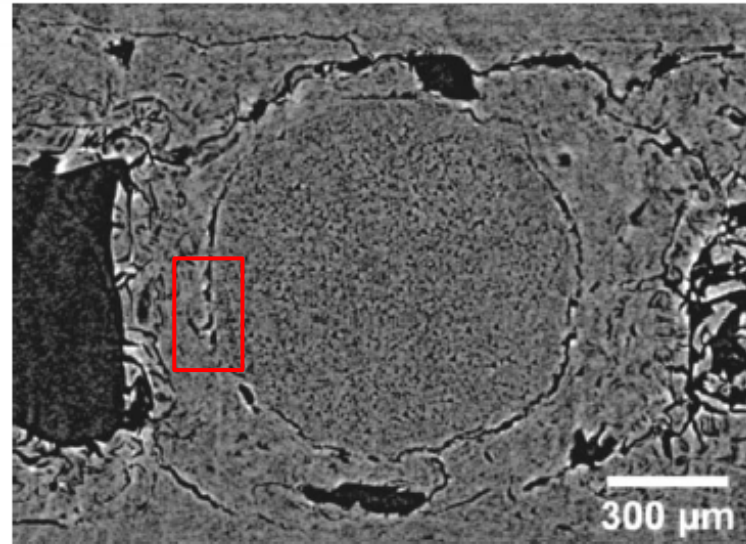
- EpiPen − ca. 18 cm long

3D X-ray Microscopy
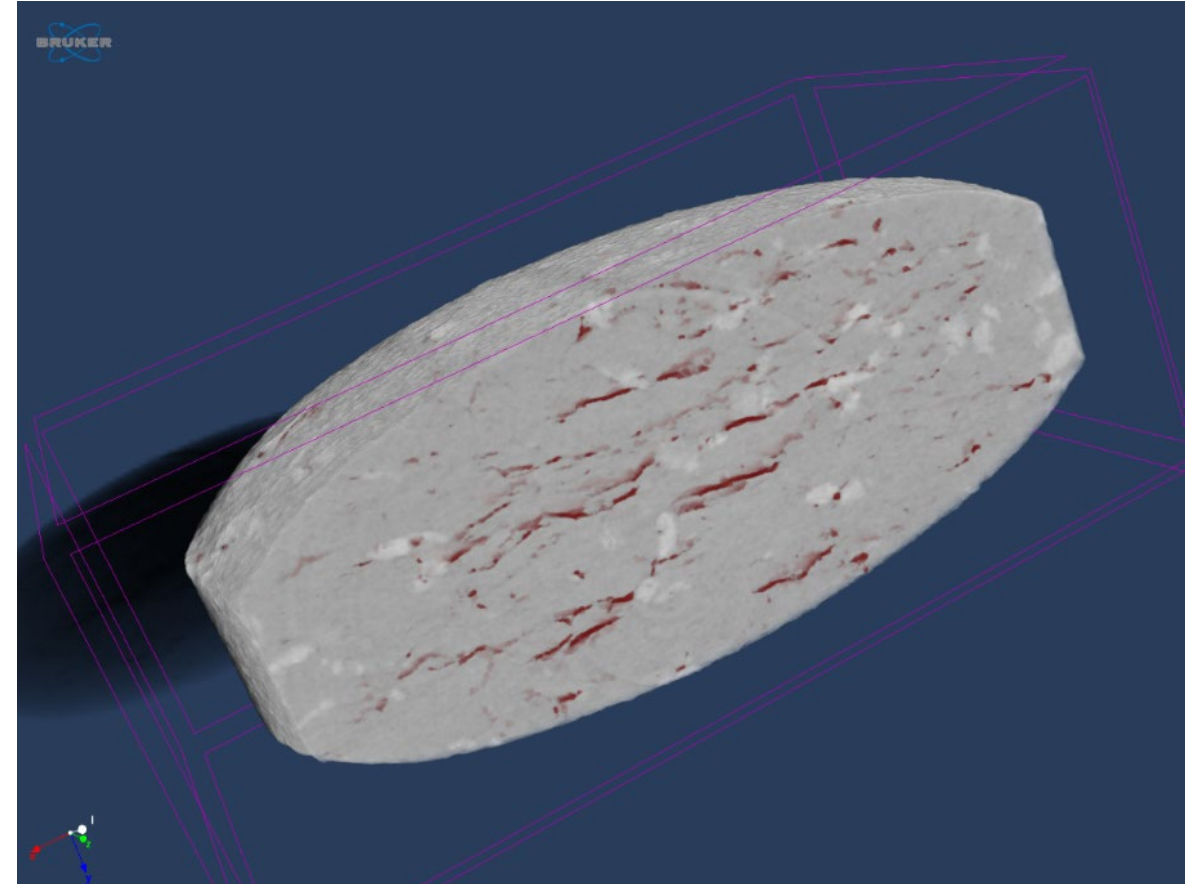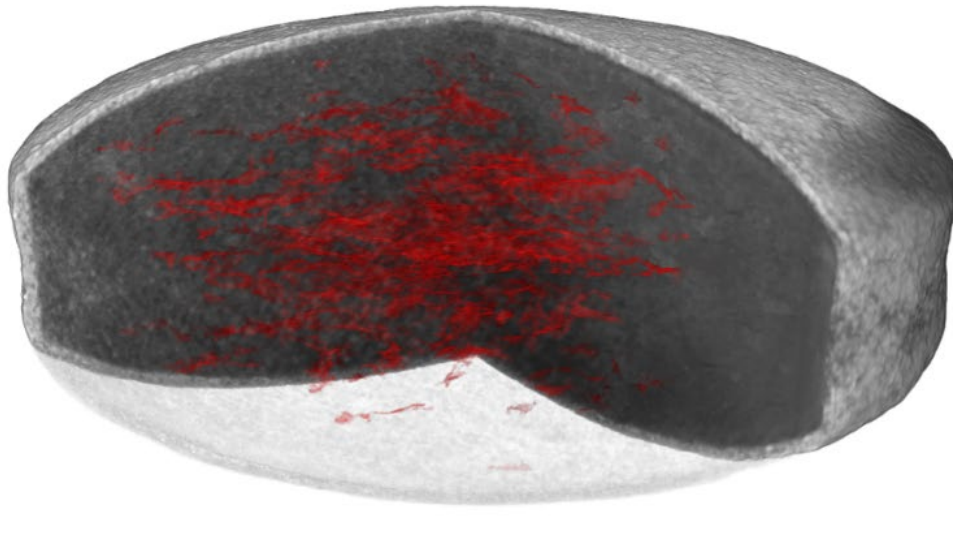## Application examples – Glass Fiber Reinforced Polymer

After impact test

8 µm voxel size – 10 x 40 mm sample size

Investigation of bonding between fibers and polymer matrix – 1.7 µm voxel size
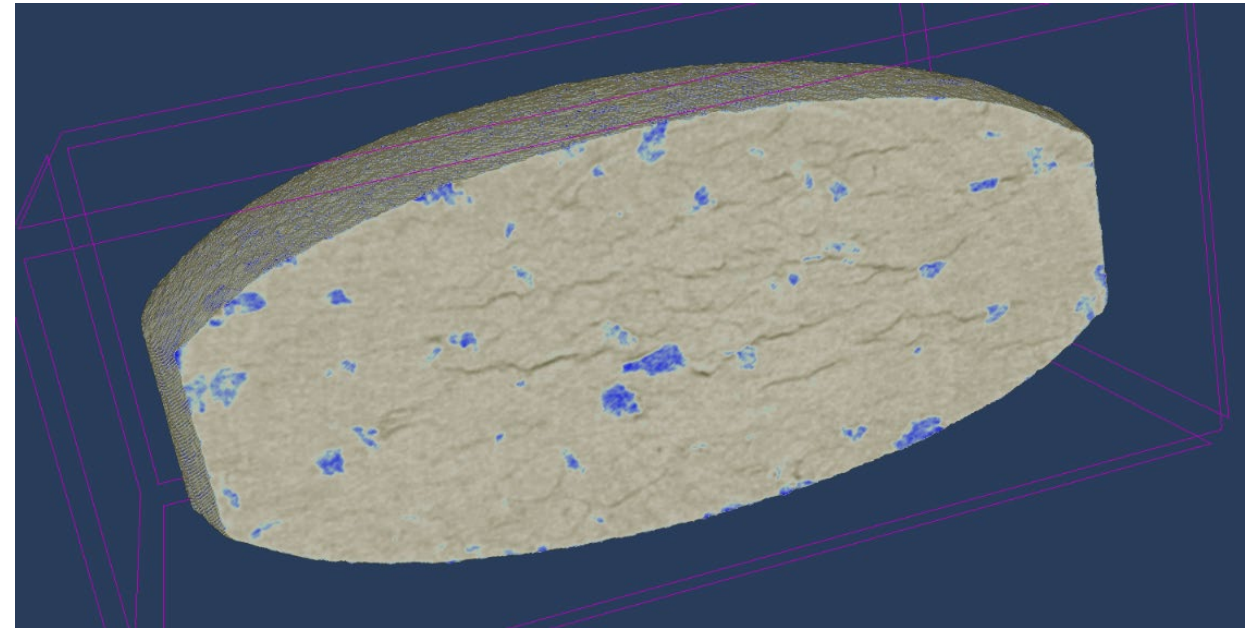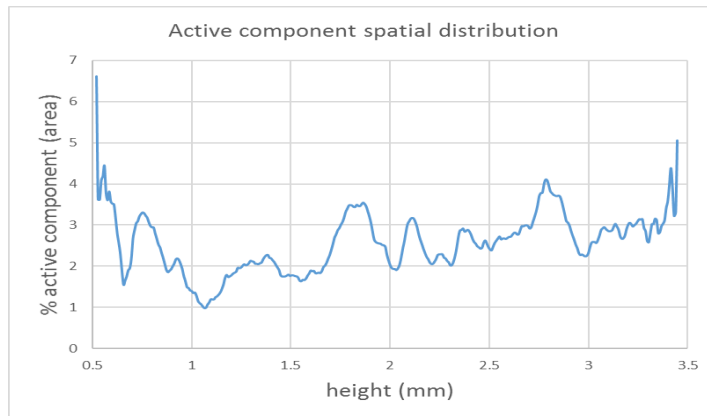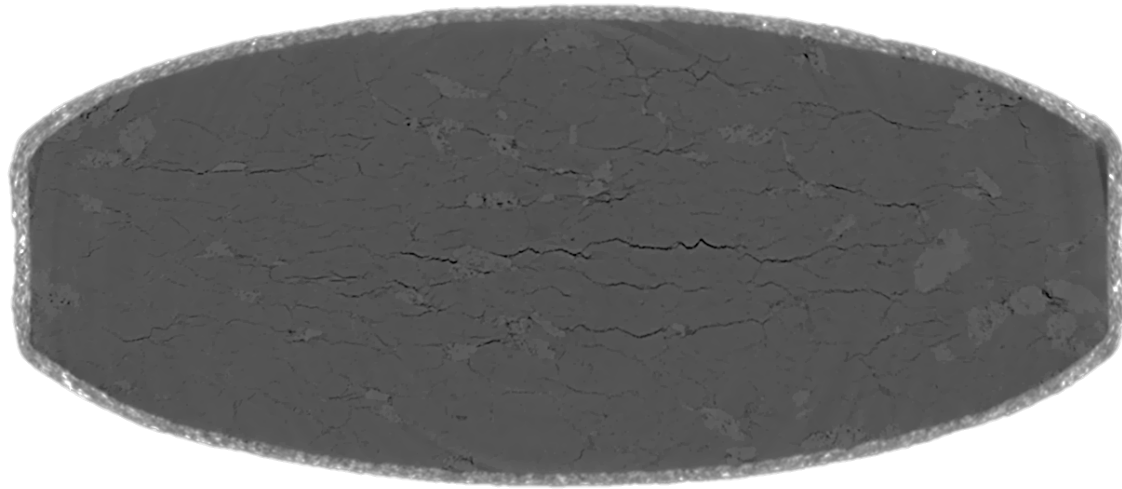
3D X-ray Microscopy
Application examples – Pores and cracks

Visualization of cracks in 2 different tablets
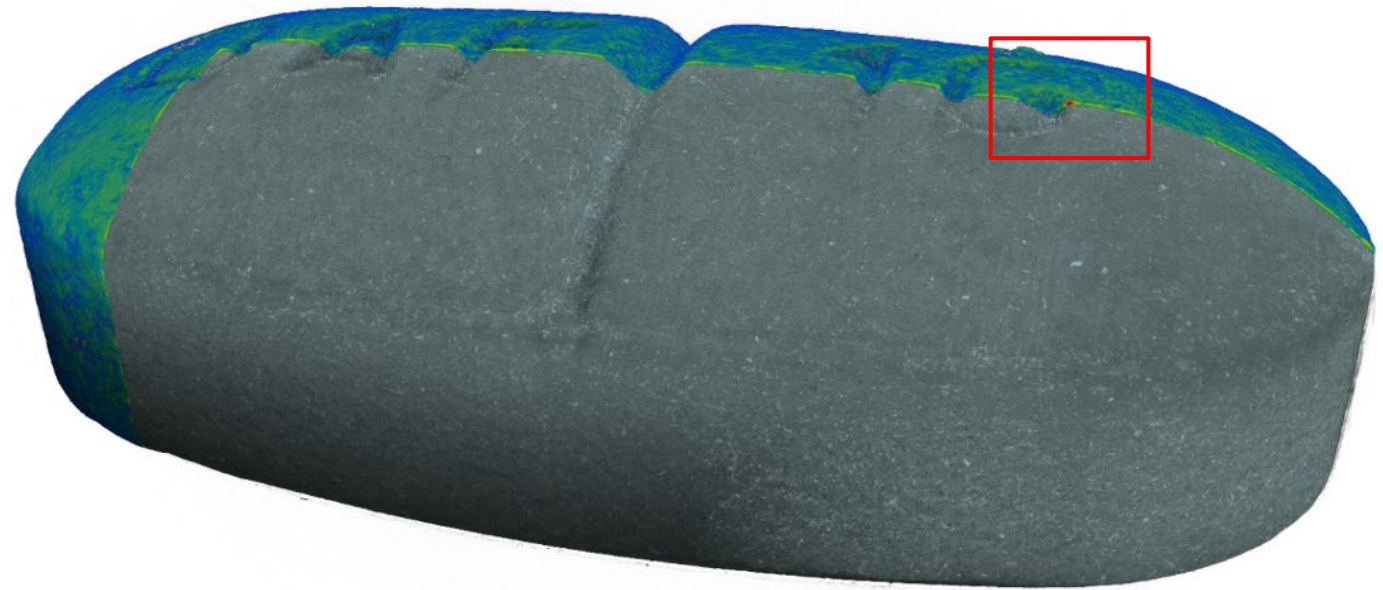Both voxel sizes 3 µm

3D X-ray Microscopy
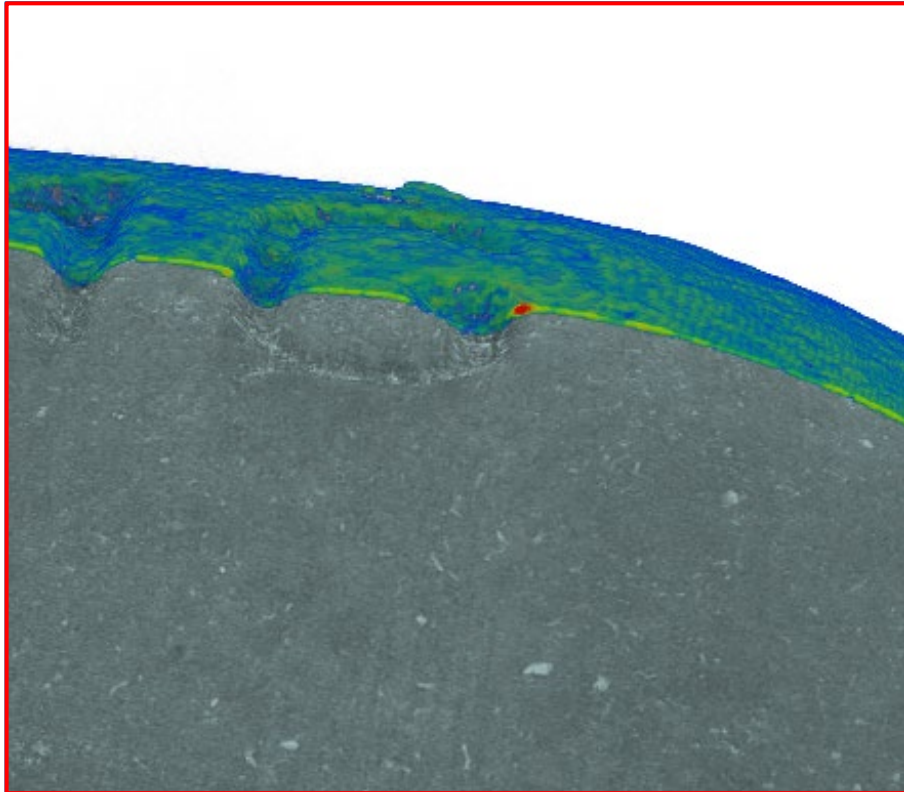## Application examples – Inclusions

Distribution of active ingredients
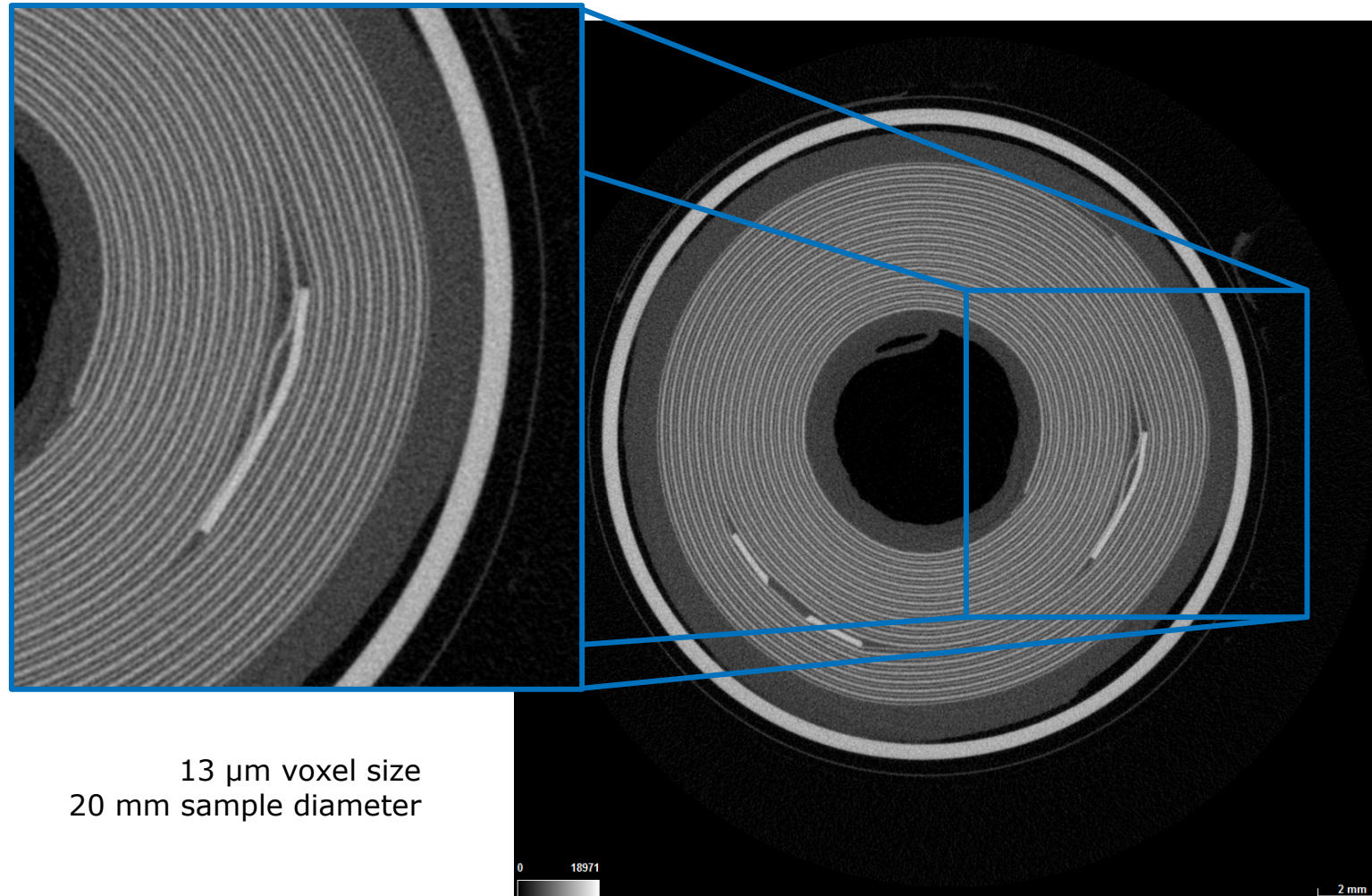
3D X-ray Microscopy
Application examples − Coating thickness

5 μm voxel size, 50 kV, no filter, 11mm sample size.

3D X-ray Microscopy
Application examples – Batteries

13 µm voxel size
20 mm sample diameter

+ve/–ve Terminals and safety vent
Metal case

Anode

Separator
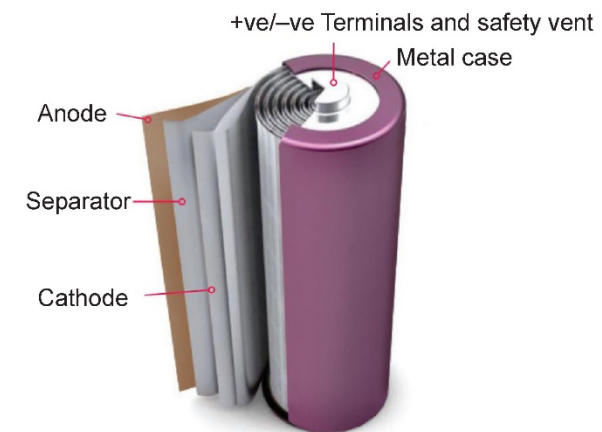
Cathode

Cylindrical battery: Li-ion

3D X-ray Microscopy
Application examples − Batteries

▪ Imaging of Cathode / Anode − evaluation of different production methods

Cathode foil with Aluminium layer

Production method A
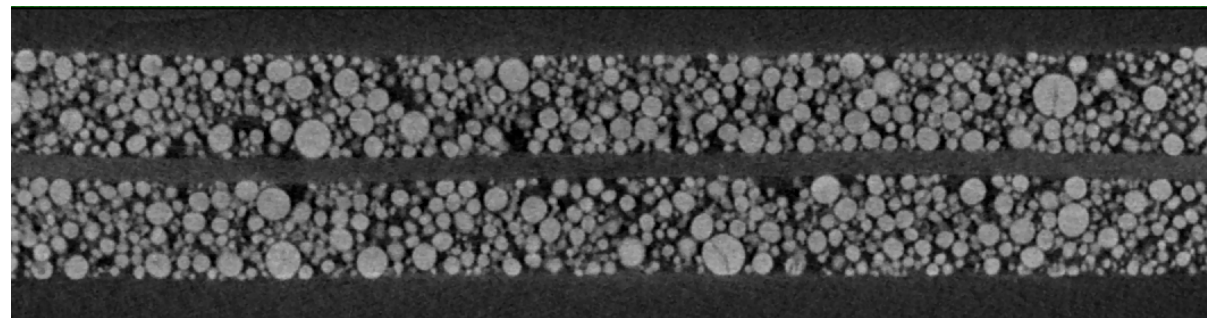
Production method B

Both scans: 0.3 µm voxel size

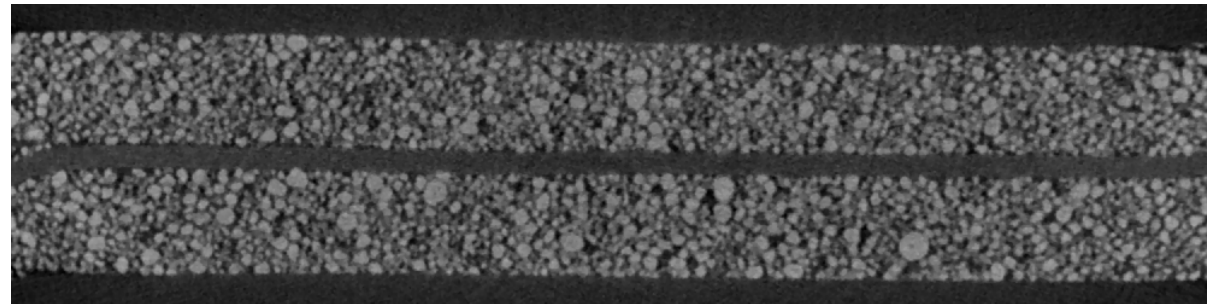# 3D X-ray Microscopy
Application examples – Batteries

- Imaging of Cathode / Anode – highest resolution allows quantification of particle and pore sizes
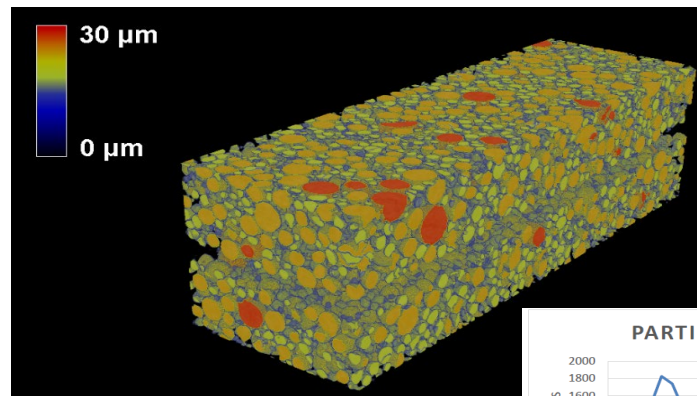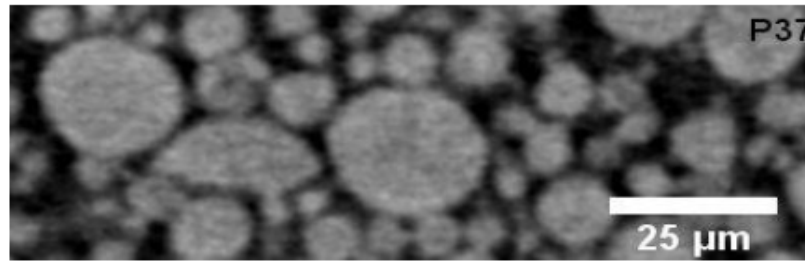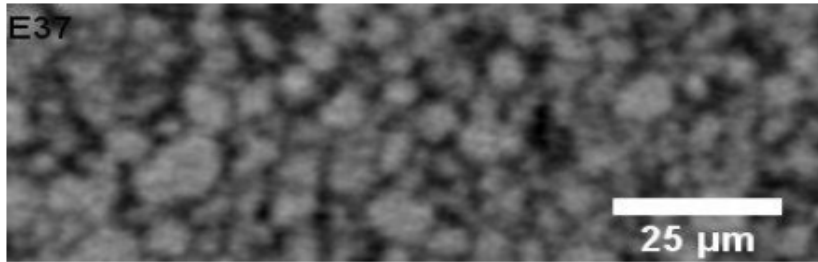
0.3 µm voxel size
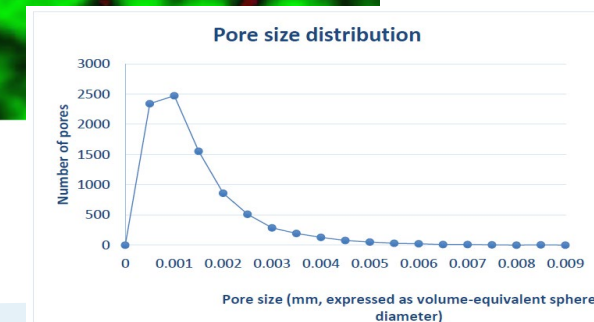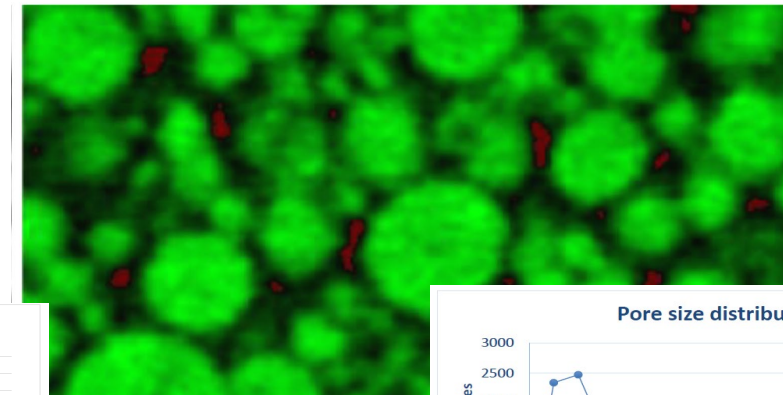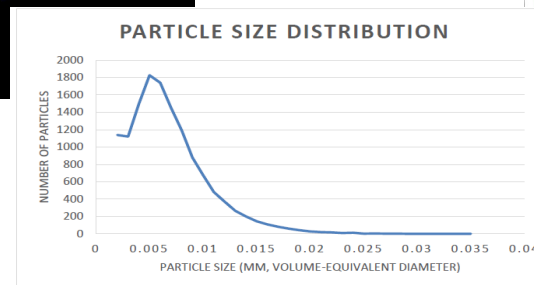
3D X-ray Microscopy
Application examples – Concrete
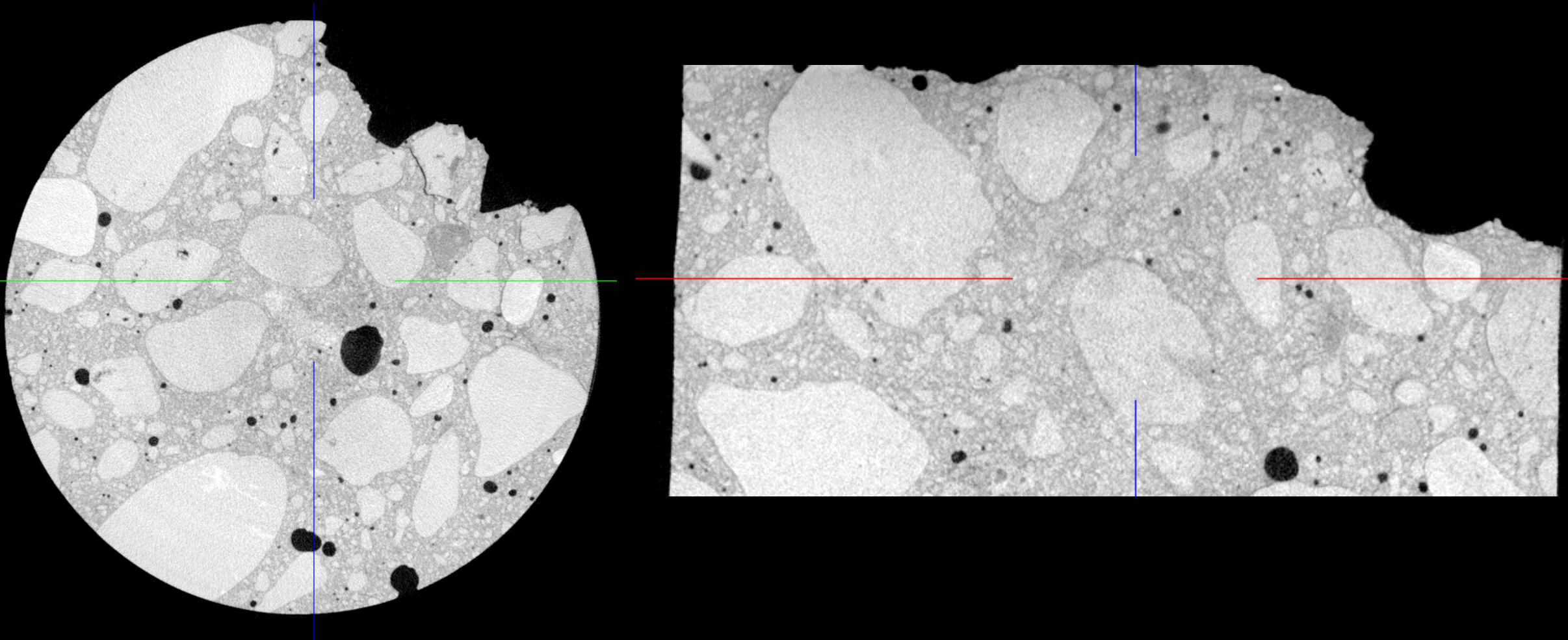
3D X-ray Microscopy
Application examples − Concrete

- In this movie, voids are color-coded to size (dark = small, bright = big).

Volume-equivalent sphere diameter
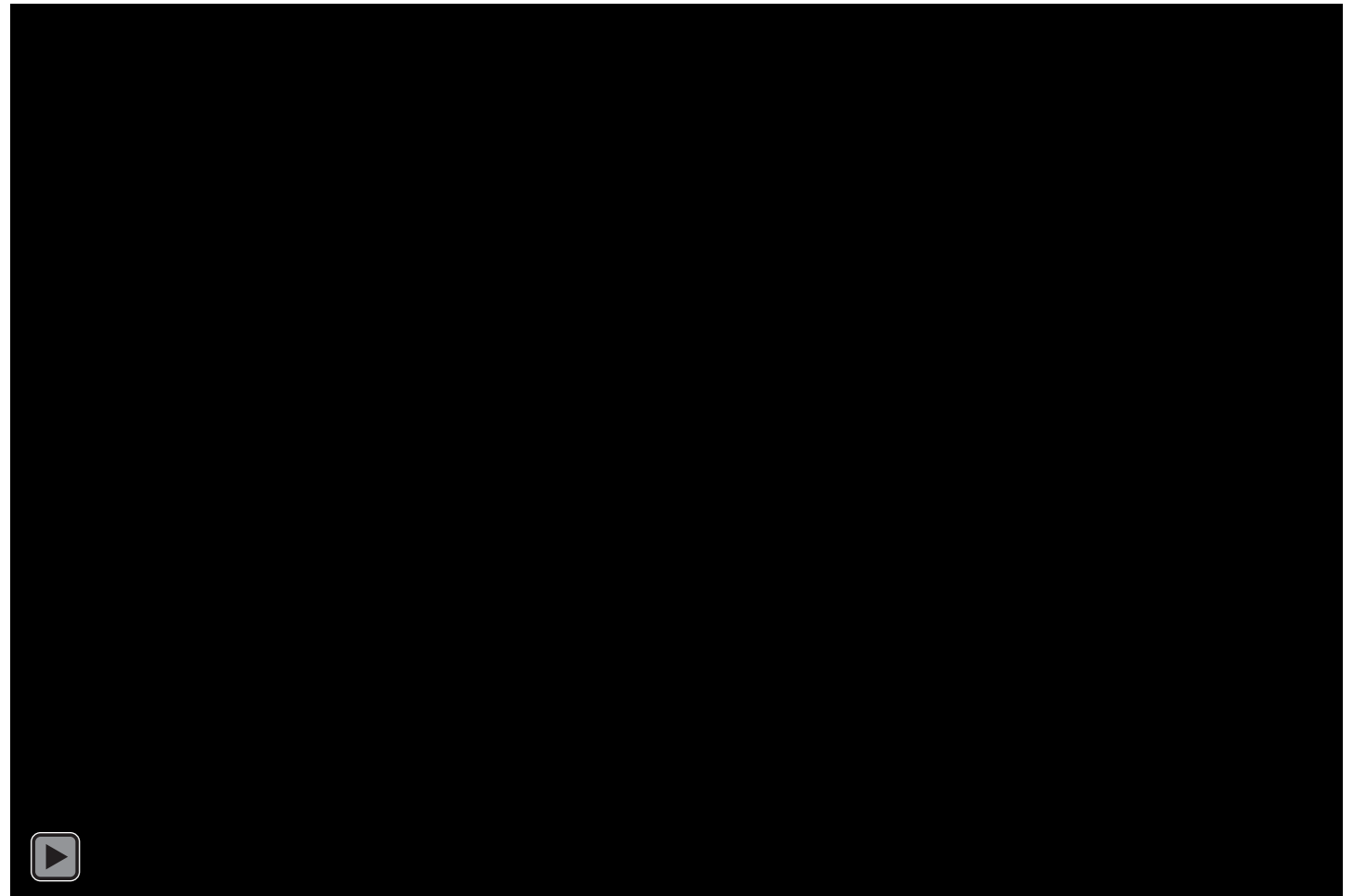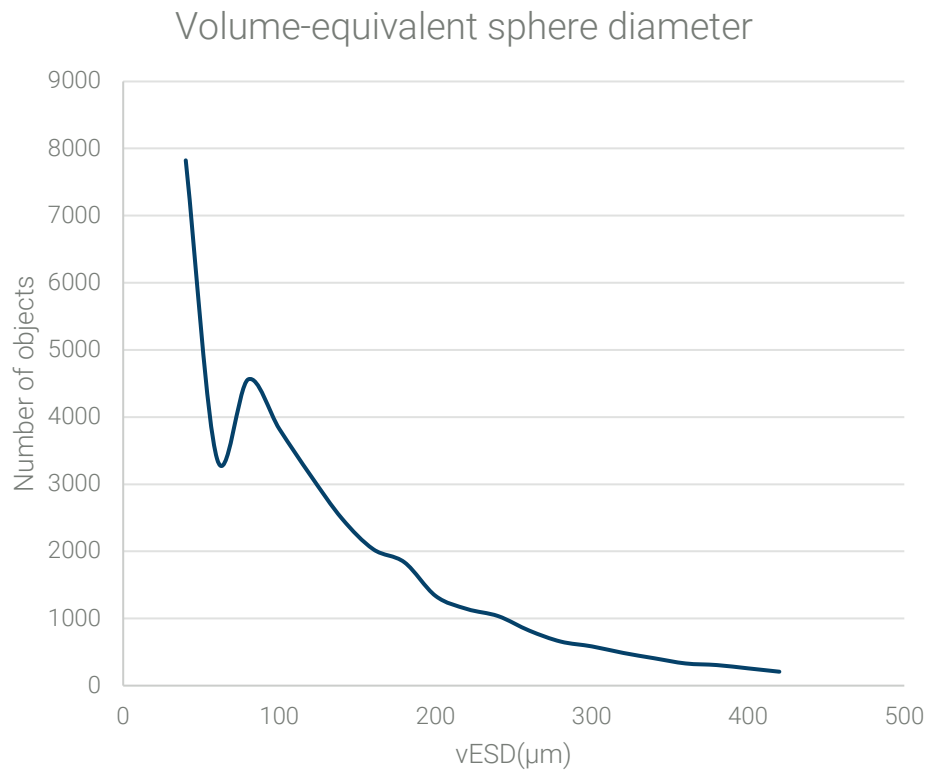
3D X-ray Microscopy
Application examples – Concrete

- XRM allows 3D analysis of fiber thickness and orientation in composite materials.

  - Steel fibers in concrete
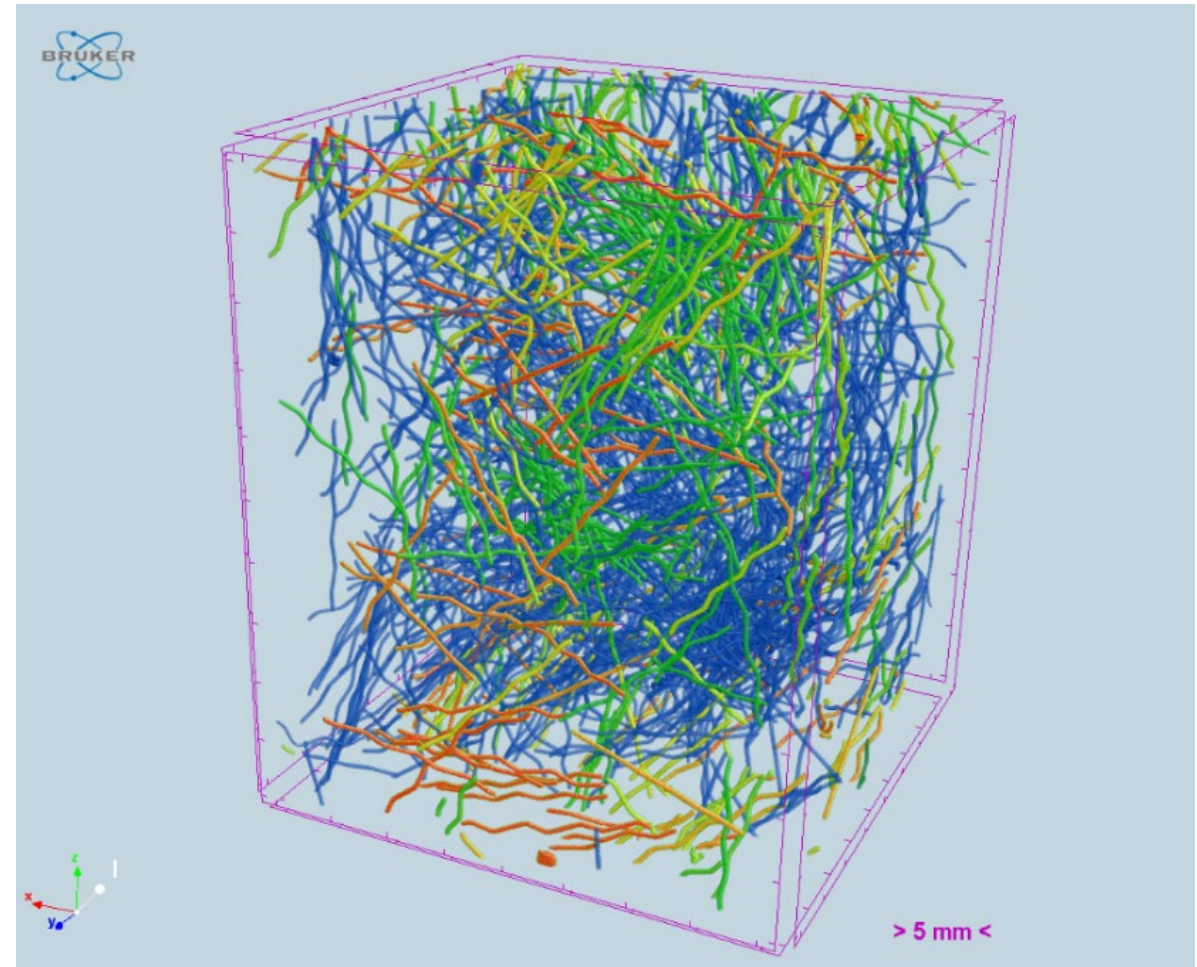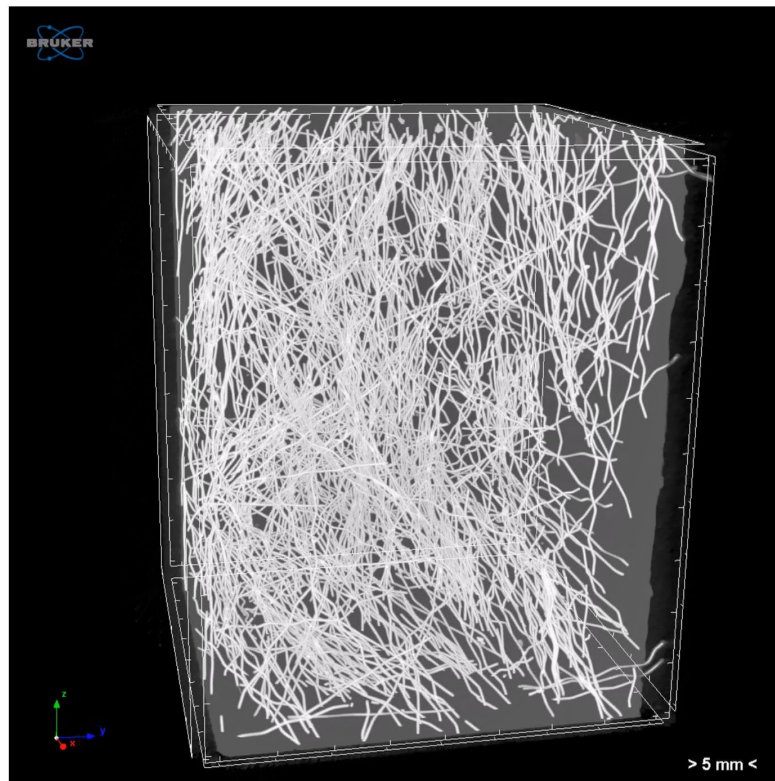
3D X-ray Microscopy
Application examples – Glass Fiber Reinforced Polymer

- Scanned at 50 kV

- Pixel size: 0.85 µm

- Observation of the individual fibers
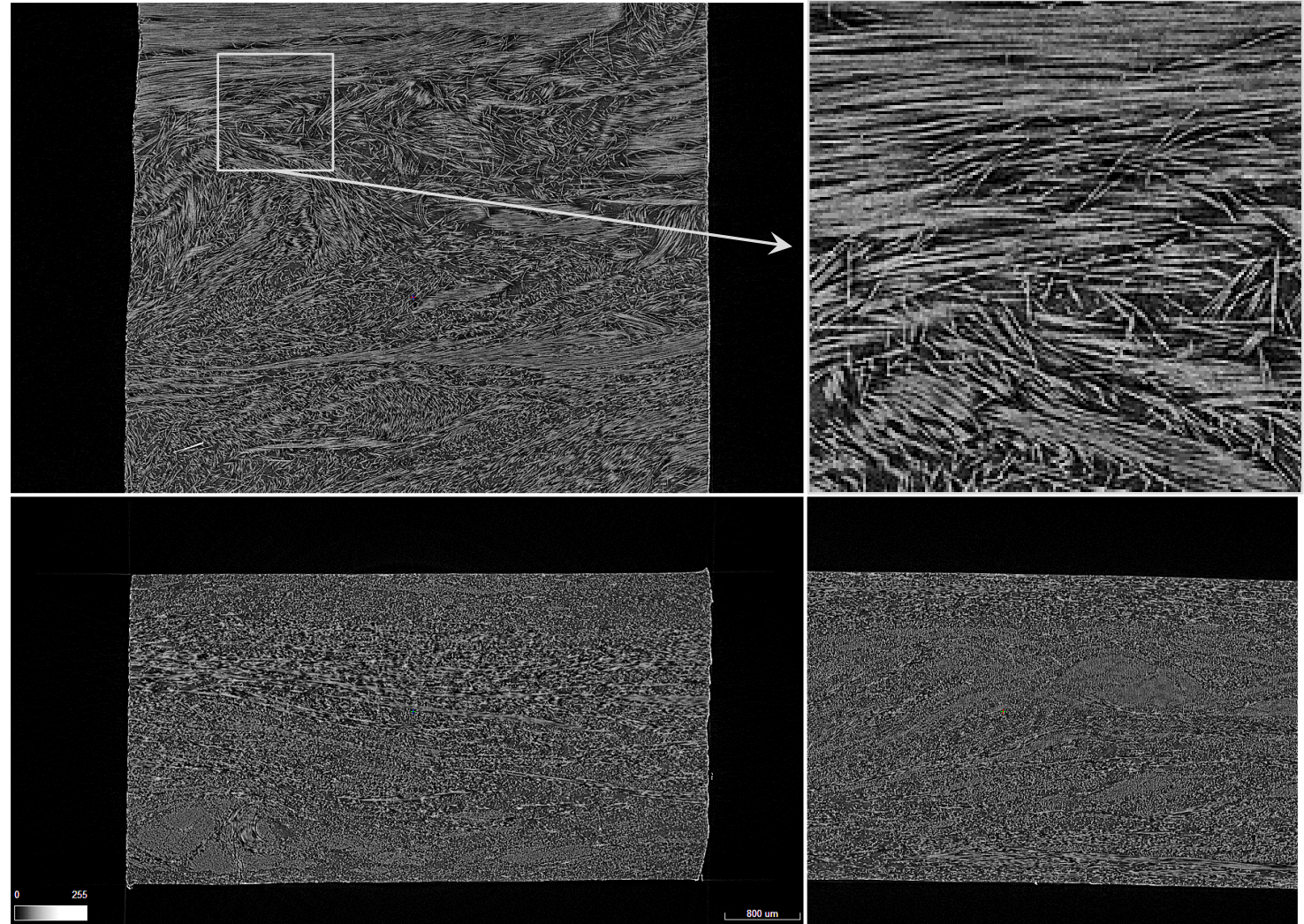
3D X-ray Microscopy
Application examples − Carbon Fiber Reinforced Polymer

- Color-coded by the orientation angle

- Different fiber orientation close to the surface vs. inside the bulk

8 µm below surface
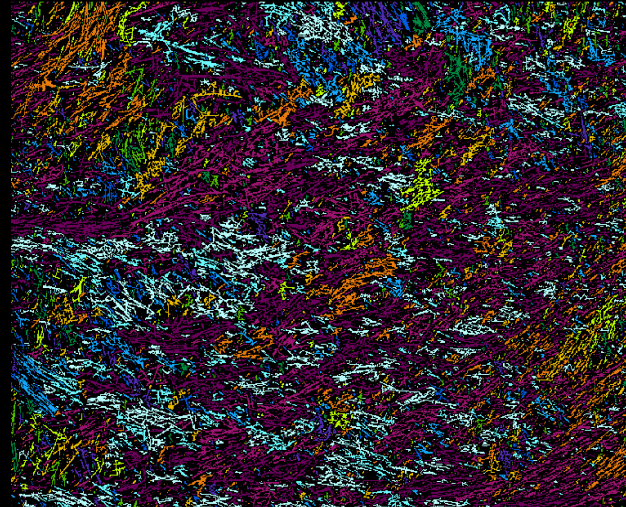
2 mm below surface
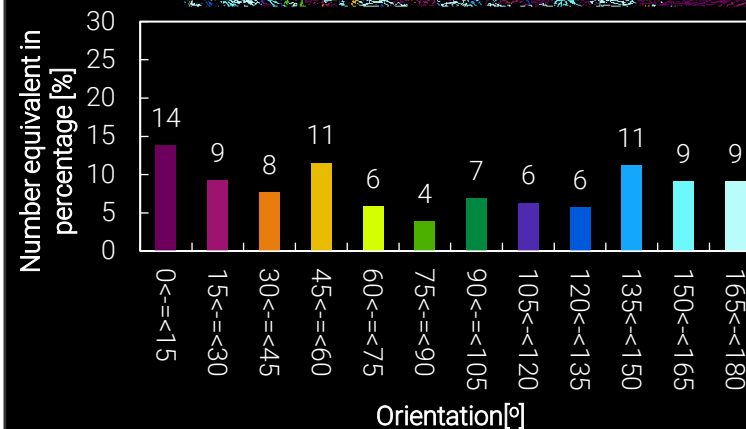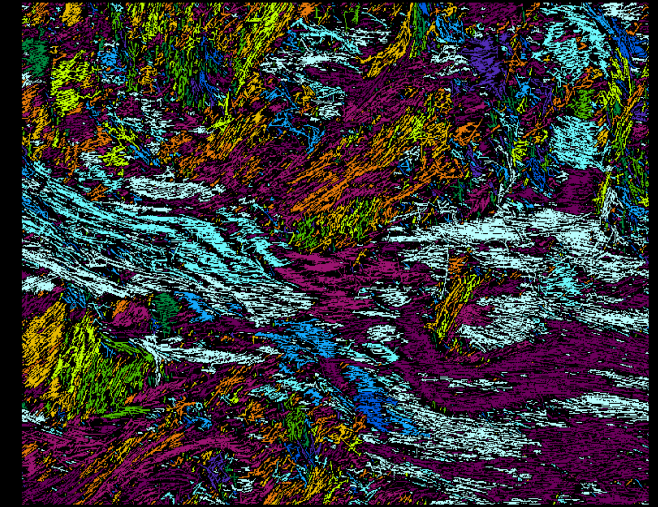
3D X-ray Microscopy
Application examples − Carbon Fiber Reinforced Polymer

8 μm below surface

3D X-ray Microscopy
Application examples – Carbon Fiber Reinforced Polymer

2 mm below surface

3D X-ray Microscopy
Application examples – AM Powder

SKYSCAN 1272

Resolution : 0.8 µm
Scan time : 4h

3D X-ray Microscopy
Application examples − AM Powder

SKYSCAN 1272

Resolution : 0.8 µm
Scan time : 4h

107µm

10µm

200 um
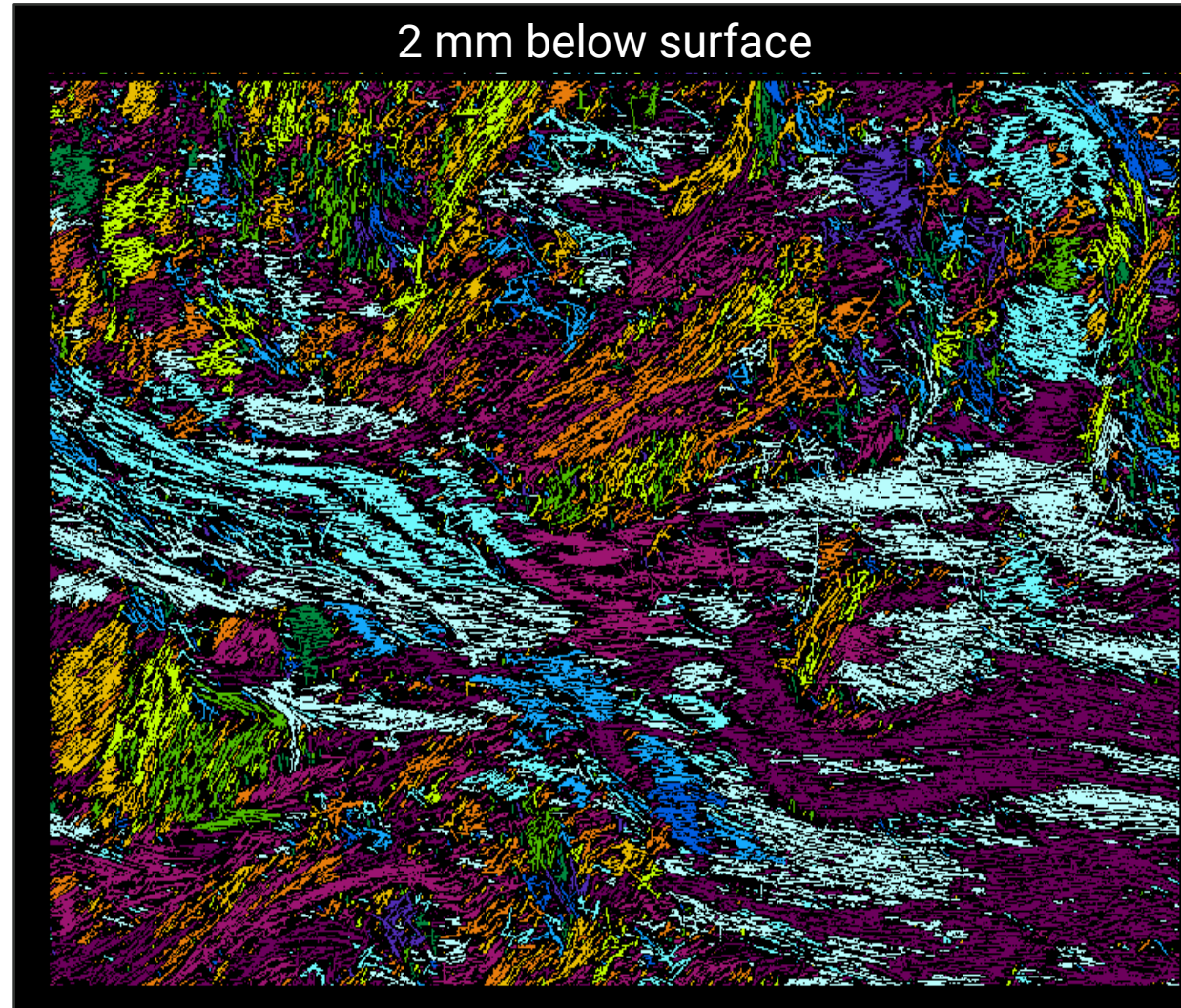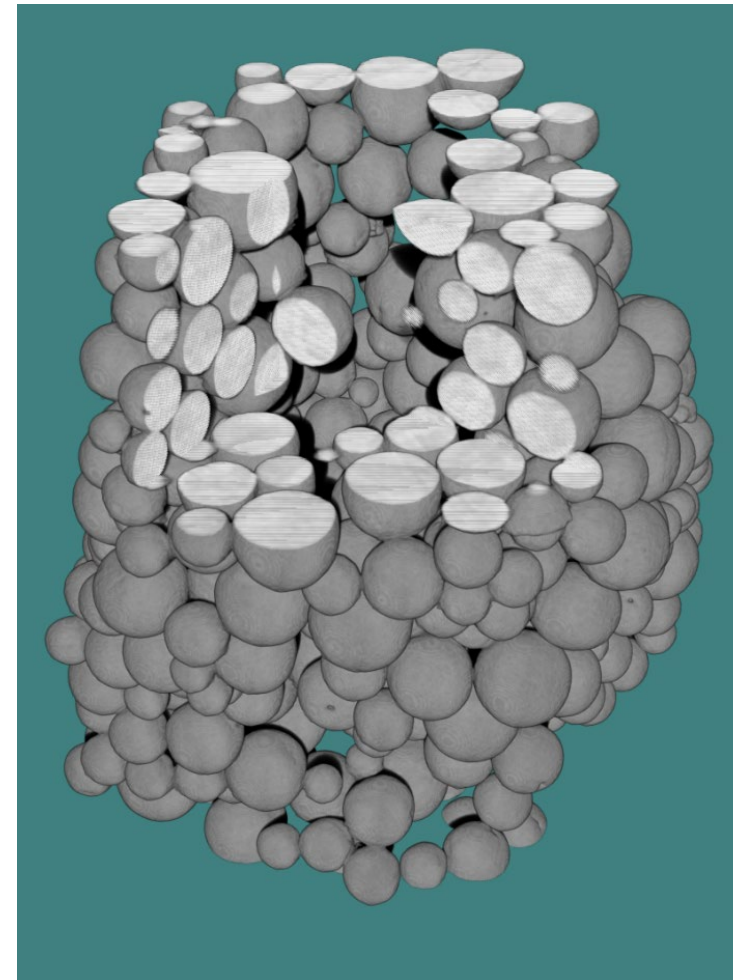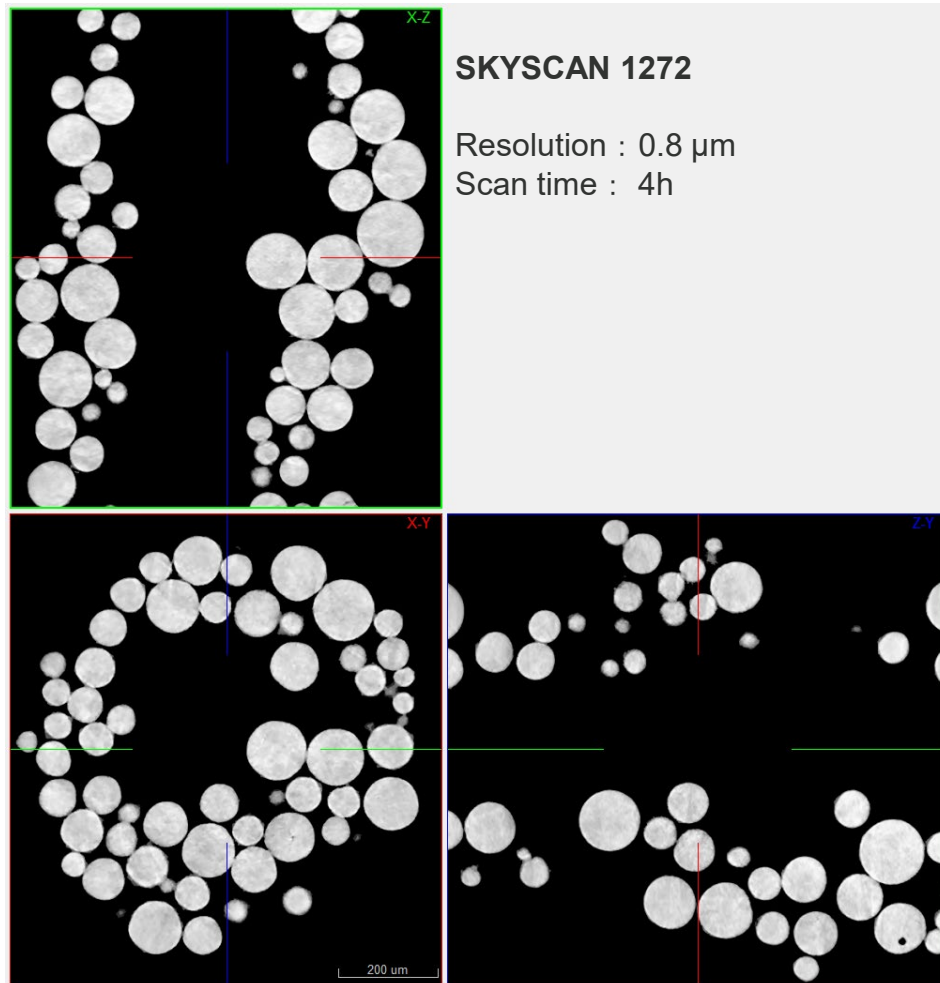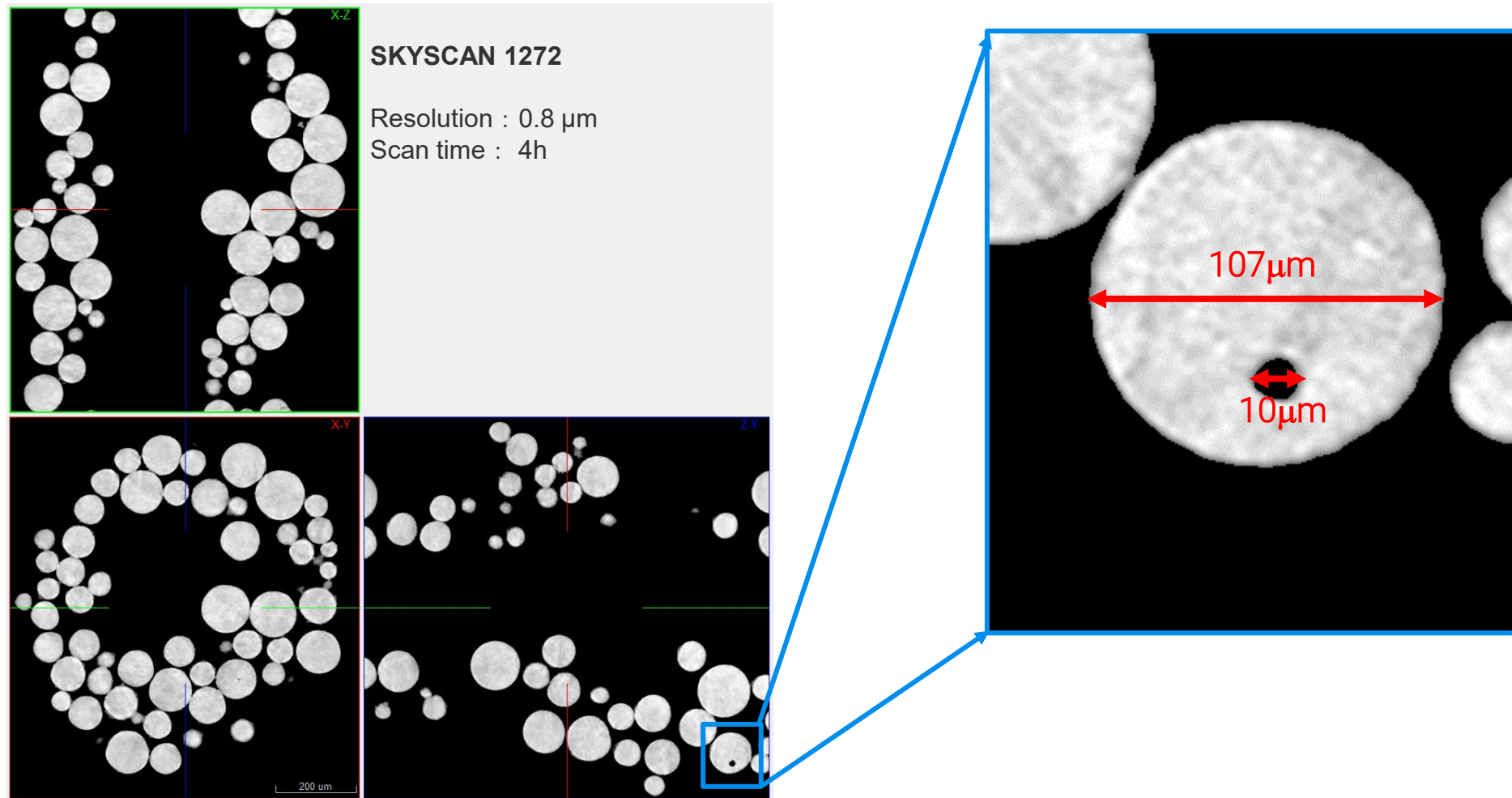
3D X-ray Microscopy
Application examples − AM Powder
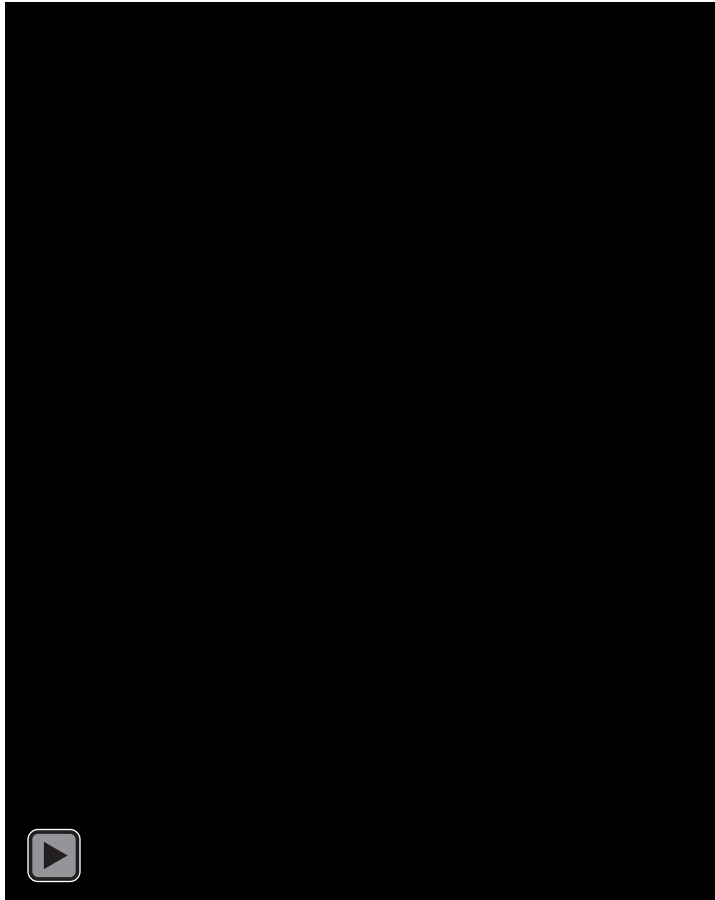
3D analysis
Local particle size distribution
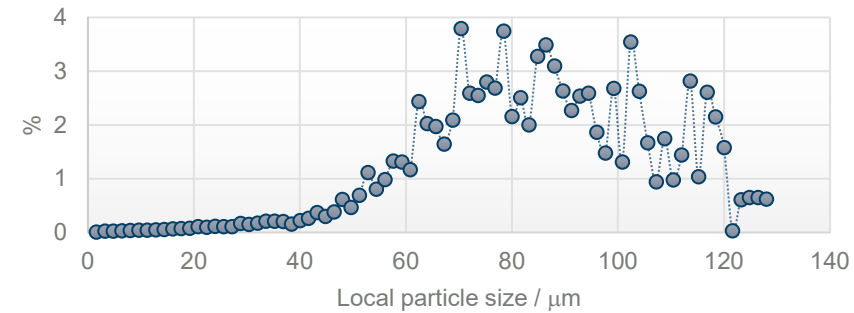
3D individual analysis

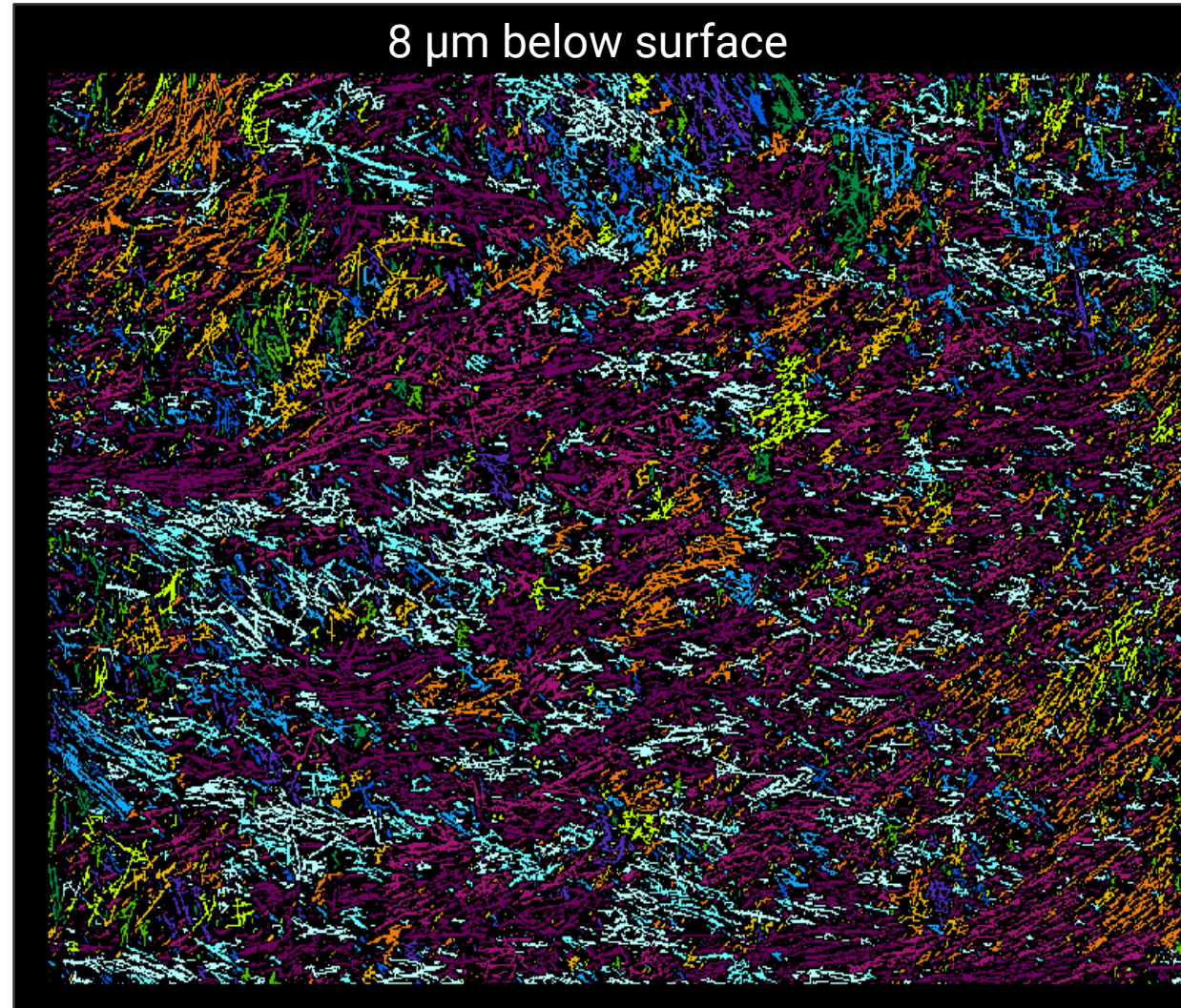| Number of objects	544								
#	Object volume	Object surface	Centroid x	Centroid y	Centroid z	Volume-equivalent sphere diameter	Surface-equivalent sphere diameter	Sauter diameter	Sphericity
	Obj.V	Obj.S	Crd.X	Crd.Y	Crd.Z	ESDv	ESDs	Sau.Dm	Sph
	um^3	um^2	um	um	um	um		Index	Index
1	553720.85	38601.22	- 100.89	- 219.83	64.51	101.88	110.85	86.07	0.84
2	170330.33	18605.49	- 269.13	- 215.84	53.86	68.78	76.96	54.93	0.80
3	218778.73	19668.76	107.53	- 221.09	67.83	74.76	79.12	66.74	0.89
4	303407.76	29676.89	41.90	- 160.38	53.01	83.37	97.19	61.34	0.74

3D X-ray Microscopy
Application examples − AM Sample
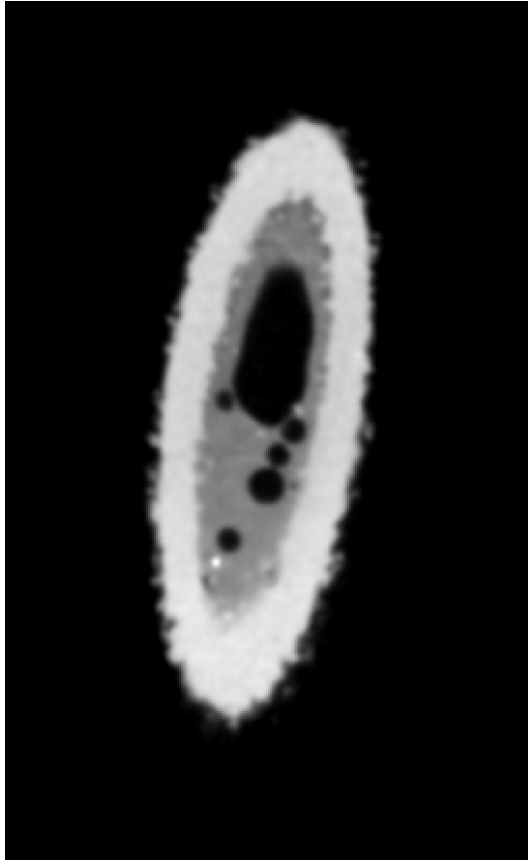
Air bubbles
Residual powder
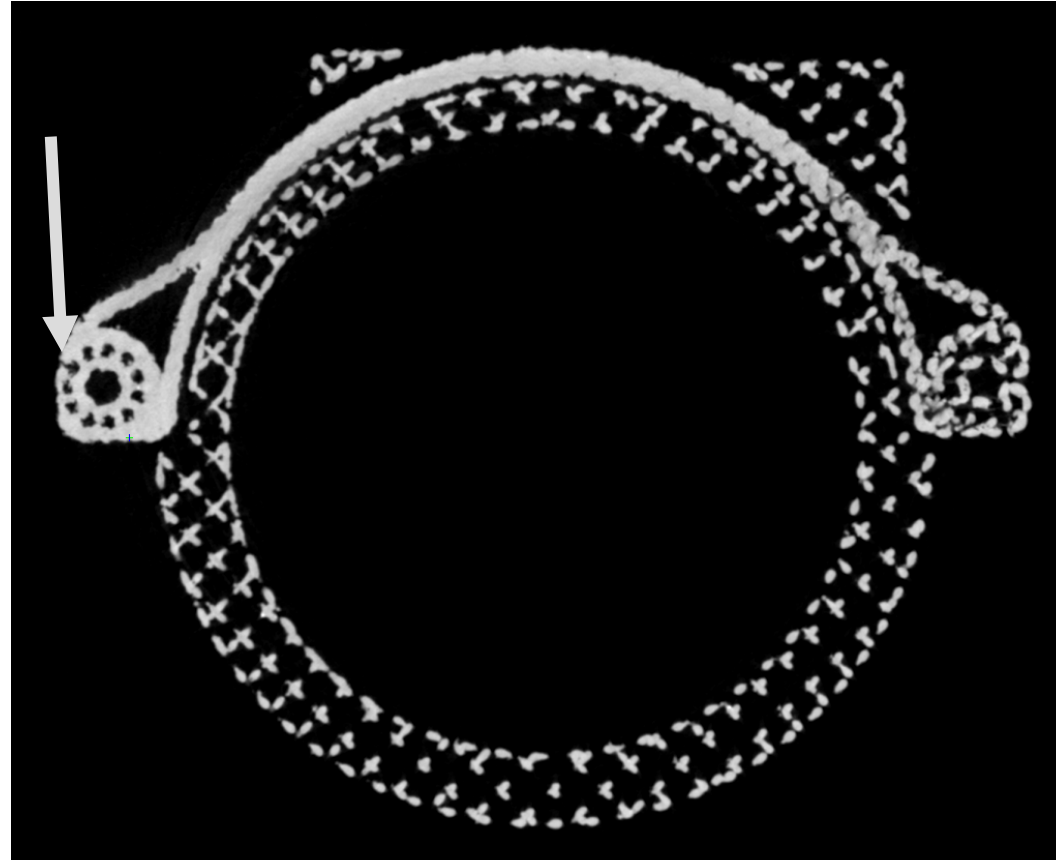
Layer discontinuities

3D X-ray Microscopy
Application examples – AM Sample
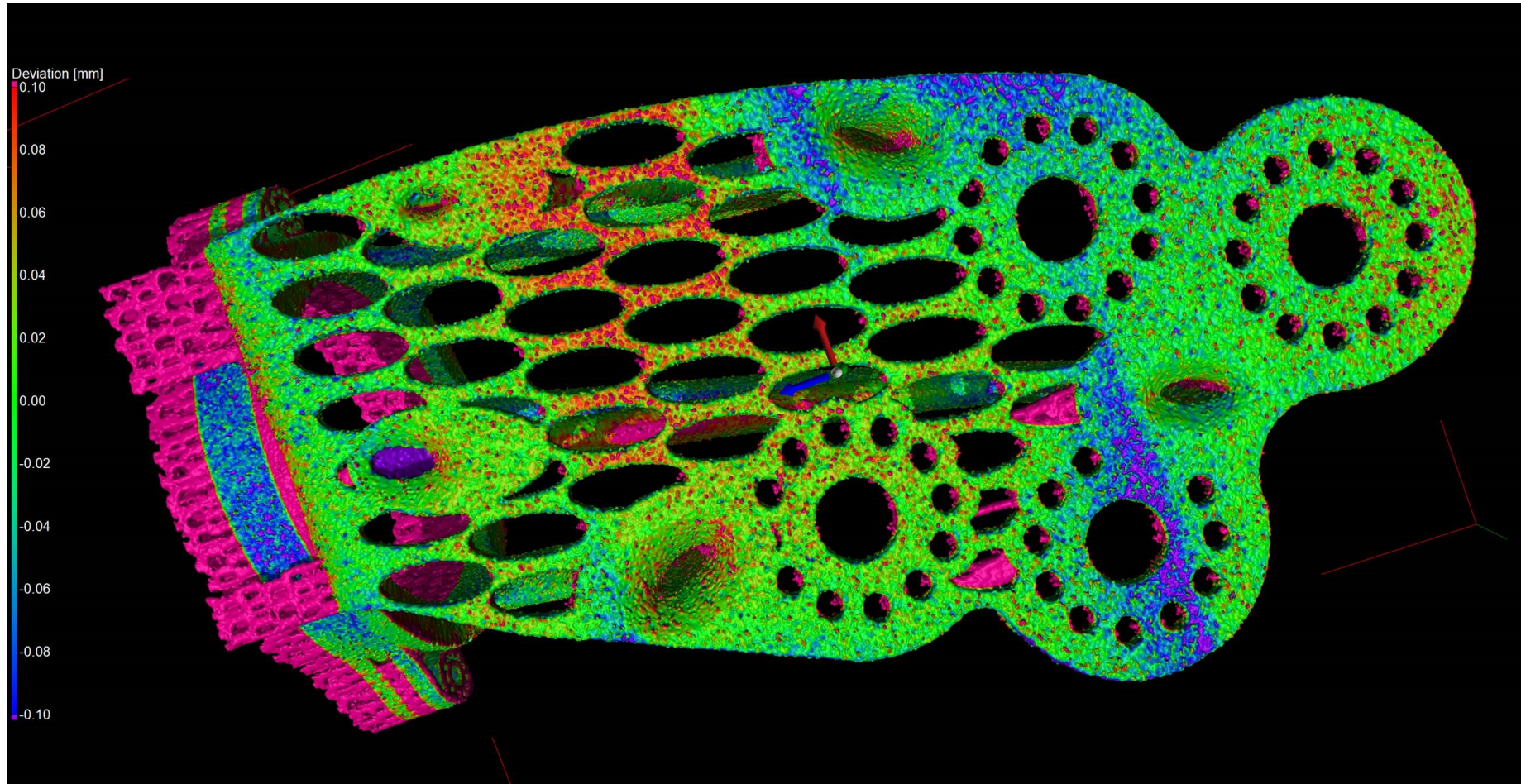
3D X-ray Microscopy
Accessories for 4D CT

- Non-destructive imaging allows for follow-up of changing samples / dynamic processes

- 4th dimension: time, pressure, temperature,…
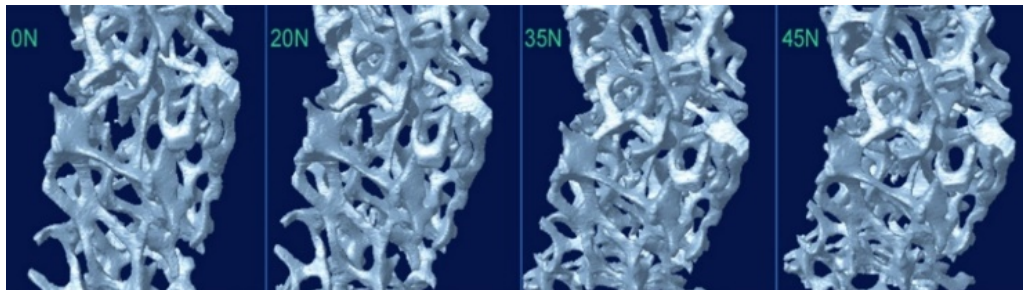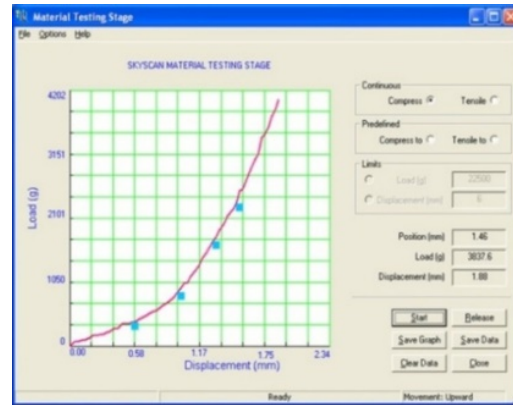
Temperature, Tensile and Compressing stage.

3D X-ray Microscopy
Application examples – Food / Ice cream

- Ice cream is an aerated emulsion in frozen state.

- SKYSCAN 2214 enables **fast scanning** at good resolution to analyze the 3D structure

- **Additional cooling** keeps the ice cream in frozen state

- Easy sample preparation

  - Ice cream is taken with a plastic straw and mounted in the cooling stage preset to -20°C

  - Additional foam added around the sample for thermal isolation

SKYSCAN 2214	
Detector	CCD 11 MP
Pixel size	5.0 µm
Voltage	60 kV
Current	150 µA
Filter	None
Scan time	12 min
Temp.	-20°C

3D X-ray Microscopy
Application examples – Food / Ice cream

1.1 mm

200 μm

2 mm
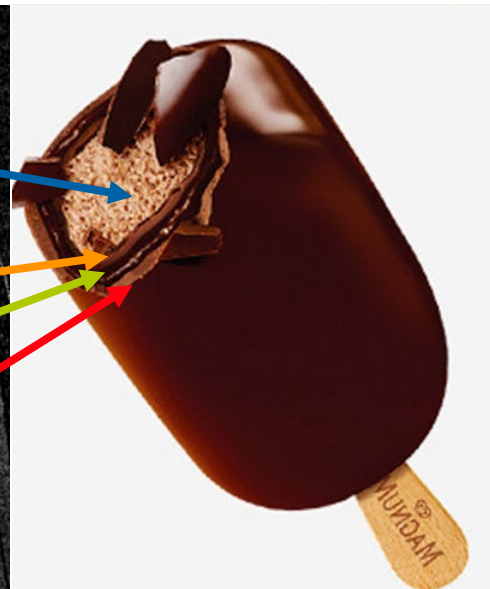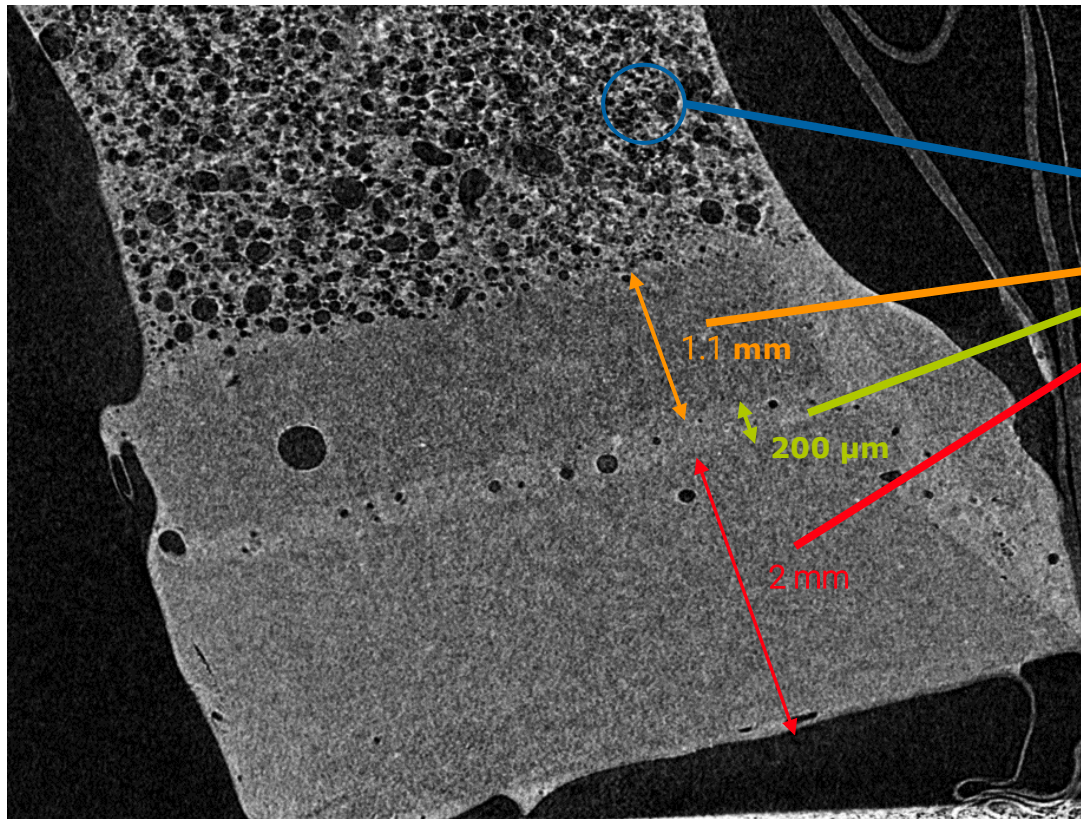
Ice cream
Inner chocolate coating
Interlayer chocolate fondant
Outer chocolate coating

Ice cream image enhanced with contrast enhancement filtering

Fat droplets

Water matrix

Air pores
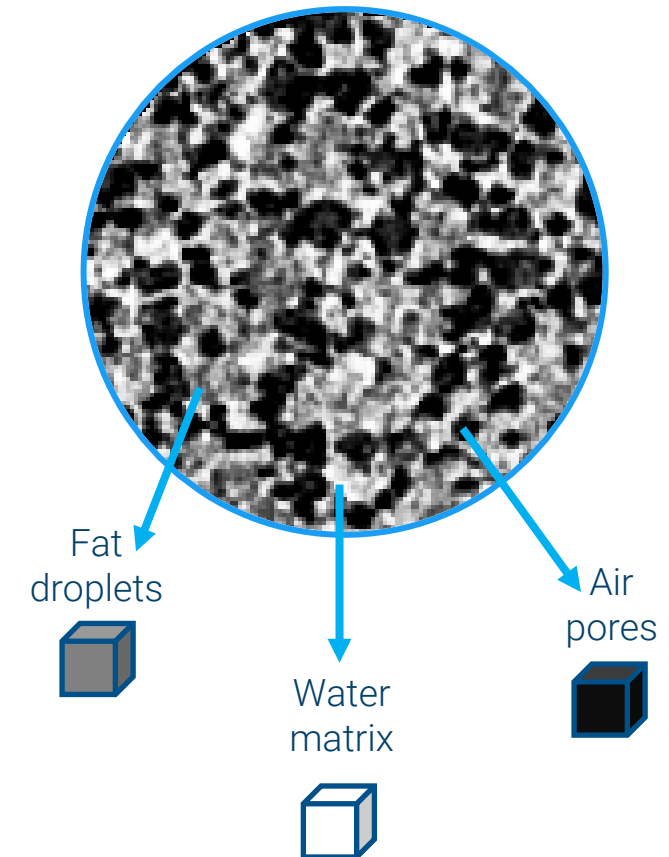
05

Product Portfolio & Software

3D X-ray Microscopy
Product Portfolio

Investment/Capabilities

SKYSCAN 2214

3D X-ray Microscopy
at the nanoscale

SKYSCAN 1272

High resolution
3D X-ray Microscopy

SKYSCAN 1273

High-Capacity
3D X-ray Microscopy

SKYSCAN 1275

3D X-ray Microscopy
for everyone

Increase Resolution

Increase Space/Speed
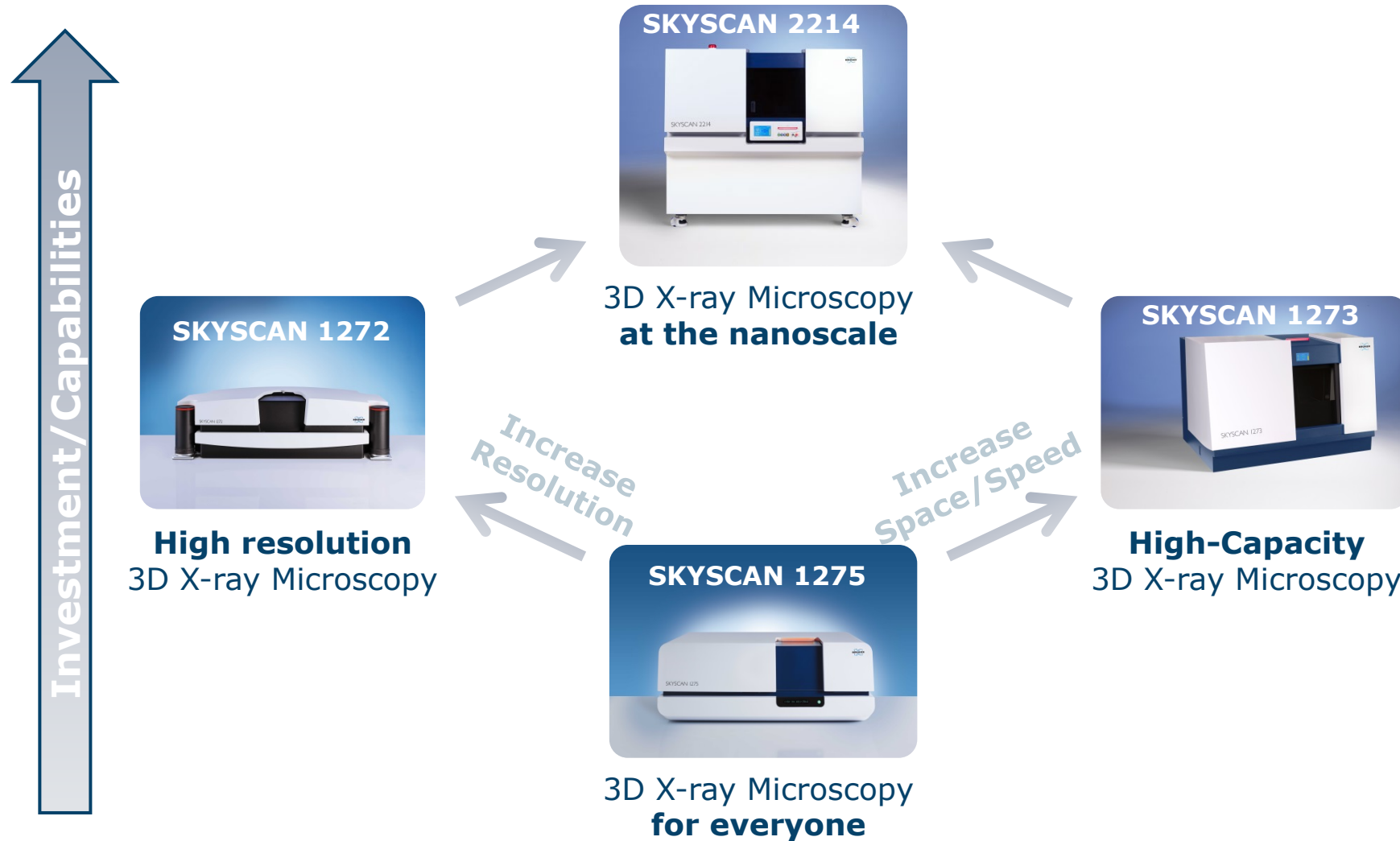
3D X-ray Microscopy
1275 - 3D X-ray Microscopy for everyone

- Space-saving **desktop system** with minimum installation requirements

  - domestic power plug, no water or compressed air, maintenance-free sealed X-ray source

- **Push button operation** with a high degree of automation

  - including automatic sample size detection, sample scanning, 3D reconstruction, and volume rendering

- 100 kV x-ray source with 3 MP Flat-Panel detector

  - 3-position filter changer for selecting the optimum energy setting

- Pixel size < 4 micron (for small samples)

- Comprehensive **3D.SUITE software**

  - 1) reconstruction, 2) visualization through surface- and volume rendering and 3) analysis

3D X-ray Microscopy
1273 - High-Capacity 3D X-ray Microscopy

- Space-saving **benchtop system** with minimum installation requirements

  - domestic power plug, no water or compressed air, maintenance-free sealed X-ray source

- **Large sample chamber** to fit the samples

  - Space for objects up to Ø 300 mm and 500 mm height, scanning volume up to Ø 250 mm and 250 mm height

- 130 kV x-ray source with 6 MP Flat-Panel detector

  - transmission through larger and higher dense materials

  - 8-position filter changer supporting automatic selection of the optimum energy setting

- Pixel size < 3 micron (for small samples)

- Comprehensive **3D.SUITE software**

  - 1) reconstruction, 2) visualization through surface- and volume rendering and 3) analysis

3D X-ray Microscopy
# 1272 - High resolution 3D X-ray Microscopy

- Space-saving **desktop system** with minimum installation requirements

  - domestic power plug, no water or compressed air, maintenance-free sealed X-ray source

- 100 kV x-ray source with 11 MP CCD detector

  - Flexible detector positioning for fully automated selection of the most compact setup for any magnification

  - 6-position filter changer supporting automatic selection of the optimum energy setting

- Pixel size < 0.45 micron (for small samples)

- Comprehensive **3D.SUITE software**

  - 1) reconstruction, 2) visualization through surface- and volume rendering and 3) analysis
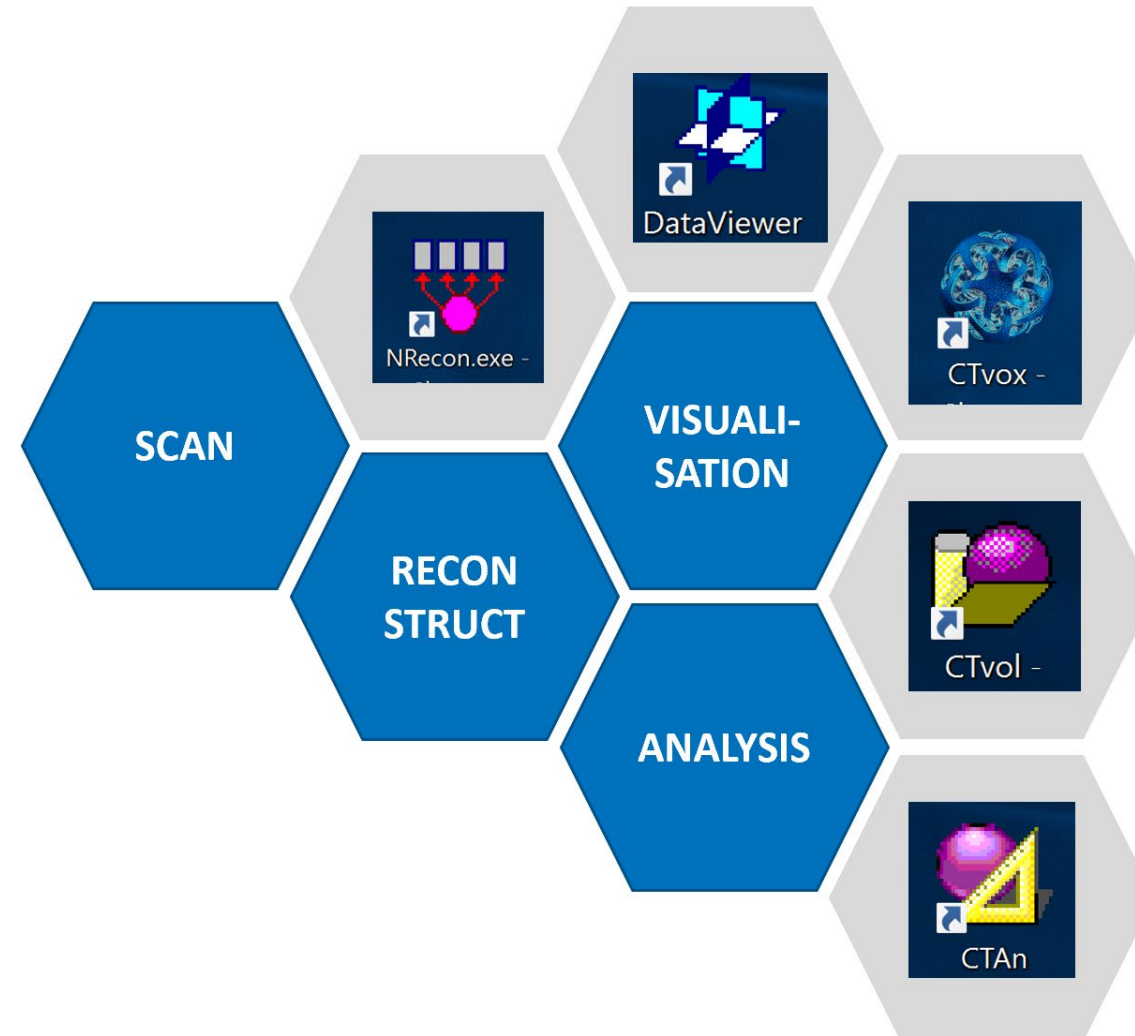
3D X-ray Microscopy
2214 - 3D X-ray Microscopy at the Nanoscale

- Compact **nano-focus** 3D X-ray microscope designed for highest resolution, with the additional capability to scan larger objects

- Innovative modular design with up to 4 detectors for unrivalled flexibility and ease-of-use

  - 3 CCD`s for high magnifications

  - 1 Flat panel for large samples

  - 6-position filter changer supporting automatic selection of the optimum energy setting

- Pixel size 60 nm (for small samples)

- Comprehensive **3D.SUITE software**

  - 1) reconstruction, 2) visualization through surface- and volume rendering and 3) analysis
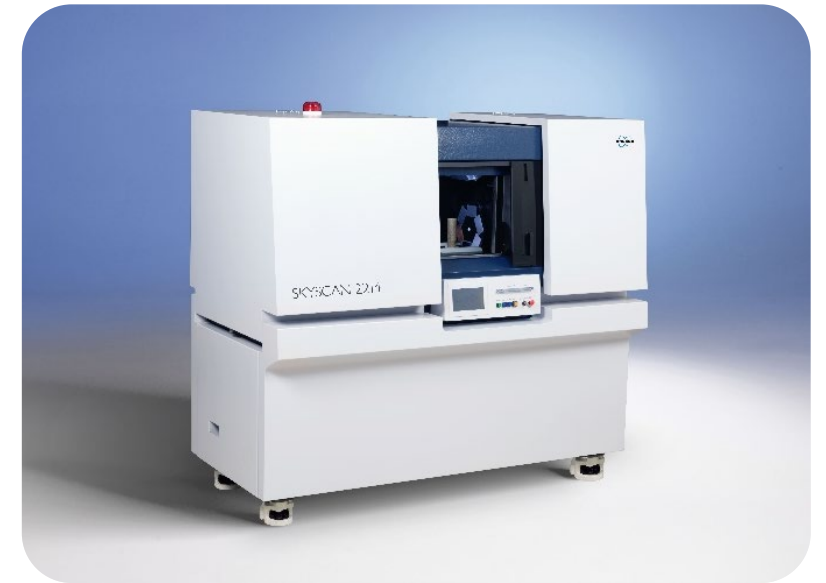
3D X-ray Microscopy
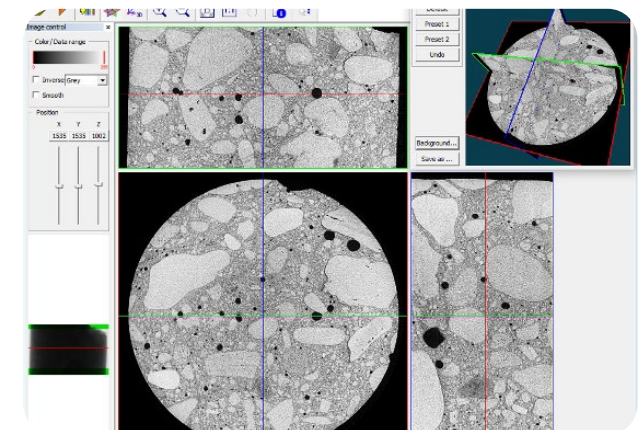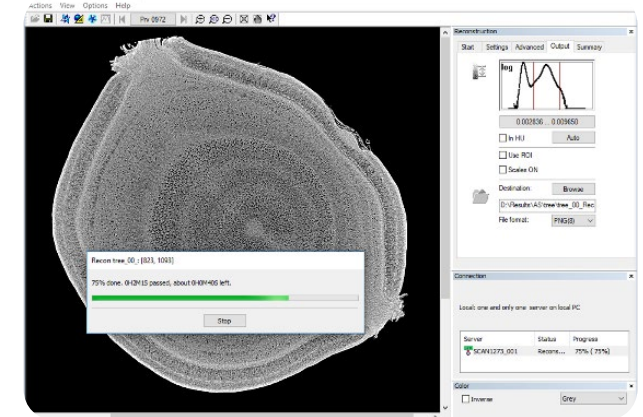## Software features

3D X-ray Microscopy
Software features

- **Genius-Mode** supports selecting appropriate scan conditions

  - Filter and energy for best image contrast

  - Scan and exposure time for efficient scanning

- NRECON 2.0 reconstructs 3D volumes from 2D projections very fast thanks to GPU acceleration
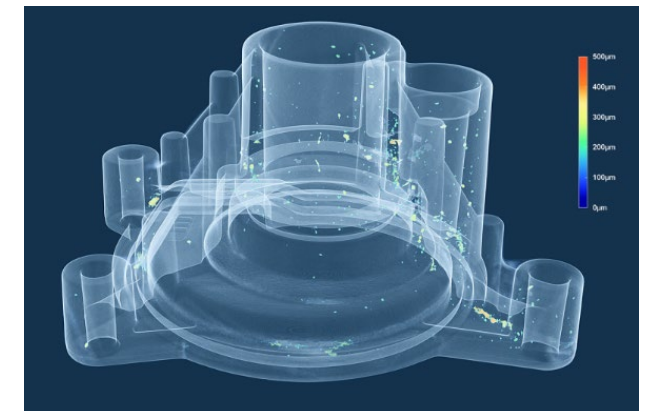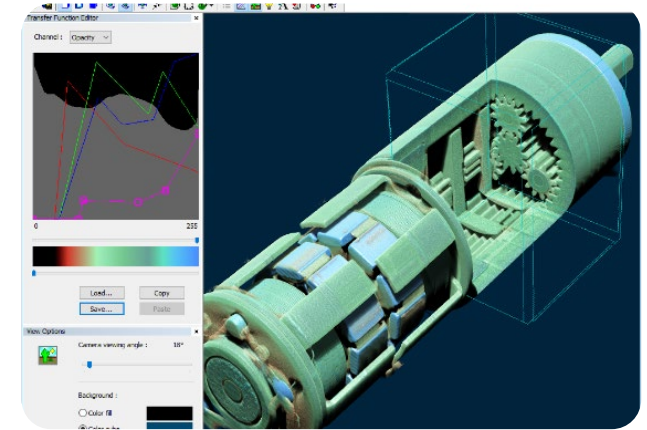
  - 25 Network licenses

- 3D Inspection with DATAVIEWER

  - Slice-by-slice movies or three orthogonal projections of reconstructed images

  - Smoothing, linear and non-linear grey scale transformations, color coding

  - Differential image analysis between samples

January 2020

3D X-ray Microscopy
Software features

- 3D Visualization with CTVOL and CTVOX

  - Volume and surface rendering

  - Animated movies

  - Produce cut-away views

  - Adjust colouring and transparency

  - Export surface-rendered models in STL format to 3D printers, or to 3D CAD software

- 3D Analysis with CTAN

  - Open/closed porosity

  - 3D distance and angles

  - Thickness and separation

  - Density analysis

3D X-ray Microscopy
BrukerSupport.com

Thank you!

Gerald.Weinacht@Bruker.com

Norman.Schott@Bruker.com
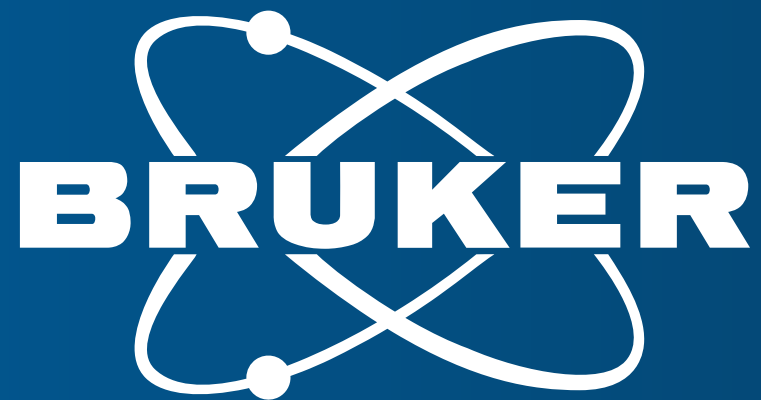
Innovation with Integrity