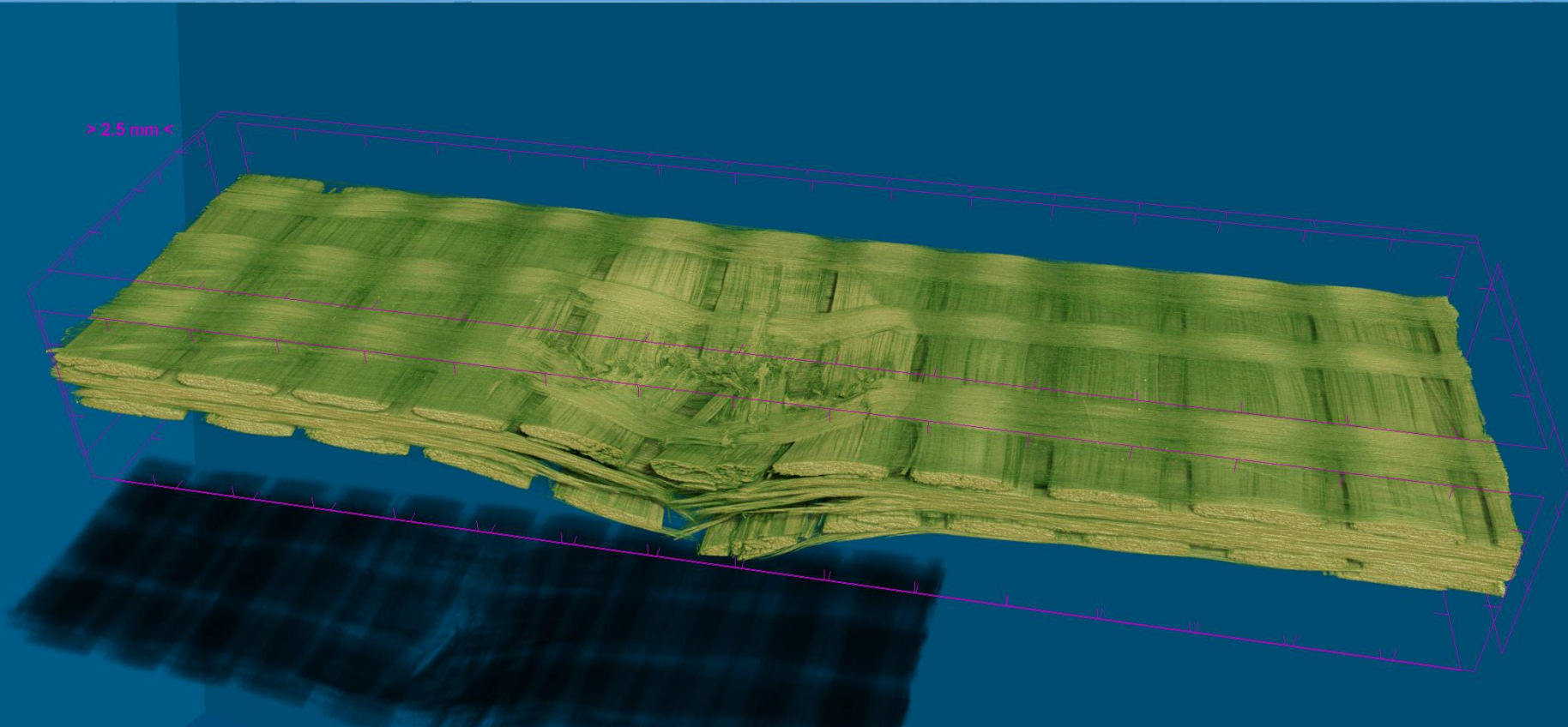
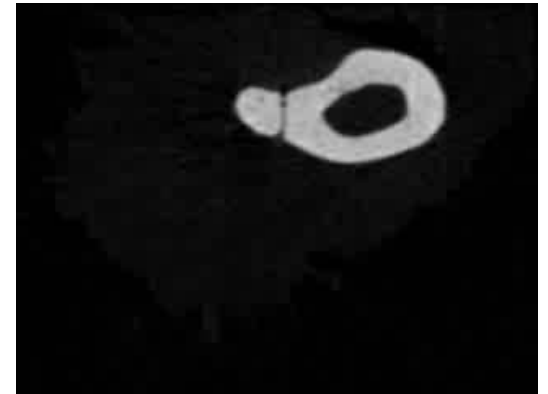
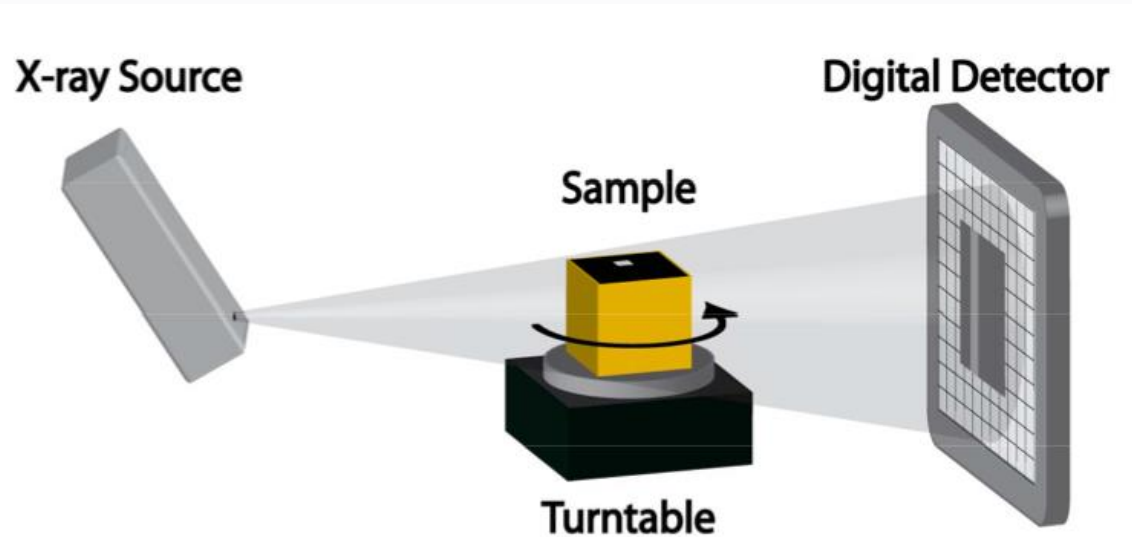


X-ray microCT

Fiber reinforced composites



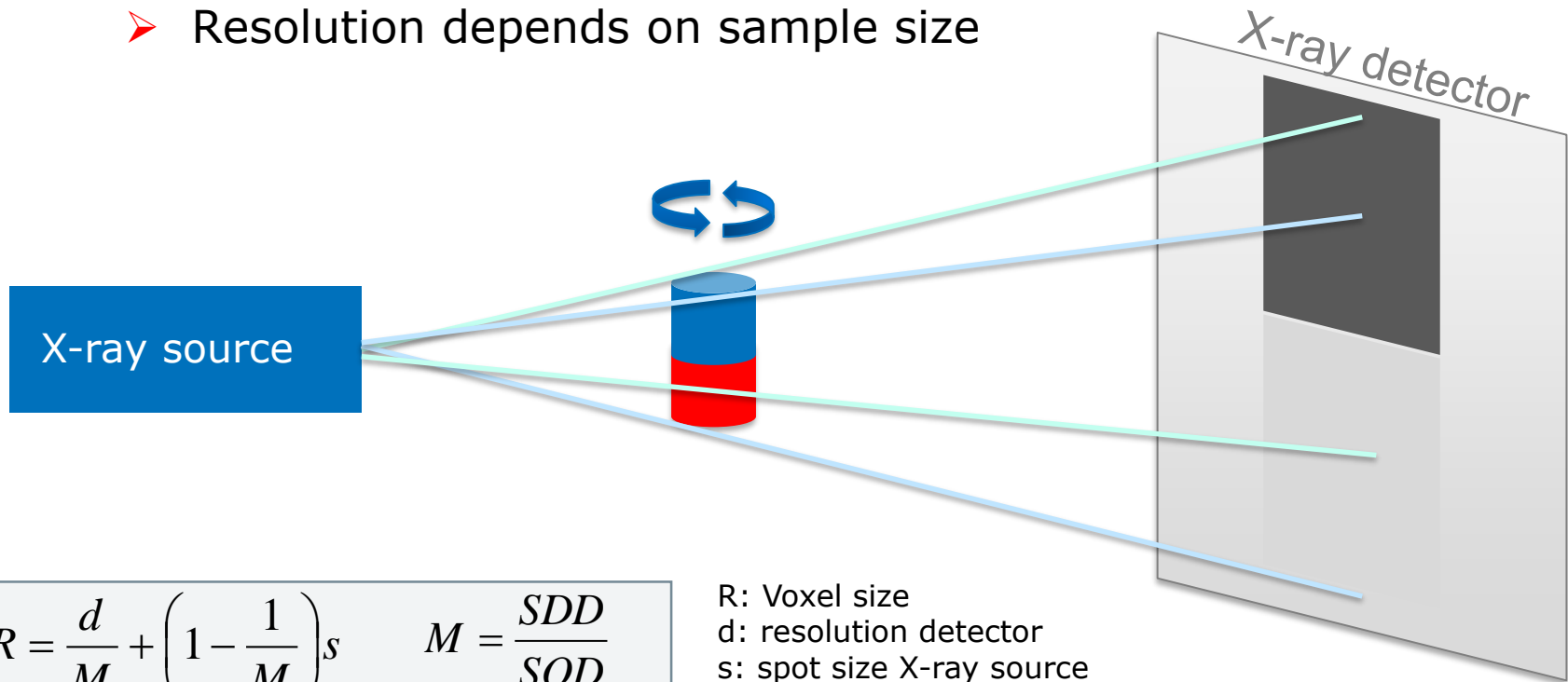
X-ray Computed Tomography (CT)



- Shadow image / projection / Röntgen photo
- 2D image of a 3D object
- No thickness information!

Micro-CT and resolution

- Laboratory micro-CT
 - Spatial resolutions below 1 μm
 - Most systems rely on **geometric magnification**
 - Resolution depends on sample size



$$R = \frac{d}{M} + \left(1 - \frac{1}{M}\right)s \quad M = \frac{SDD}{SOD}$$

R: Voxel size
 d: resolution detector
 s: spot size X-ray source
 M: magnification

X-ray interaction with samples

- Beer-Lambert law

$$I = I_0 e^{-\mu x}$$

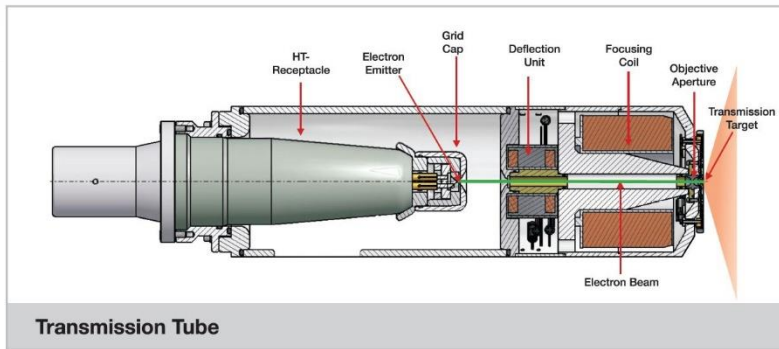
- I = intensity, μ = attenuation, x = path length

- Photo-electric absorption

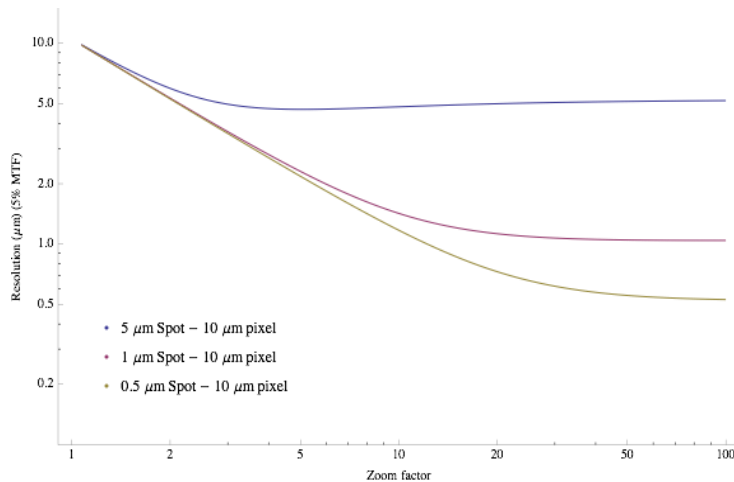
$$\tau \sim Z^4 / E^3$$

- τ = PE mass attenuation coefficient, Z = atomic number, E = photon energy

X-ray generation

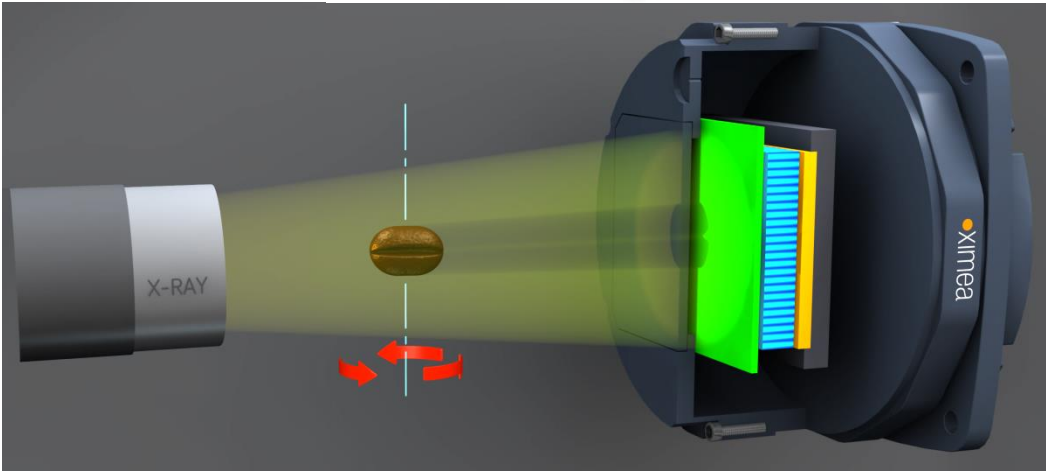
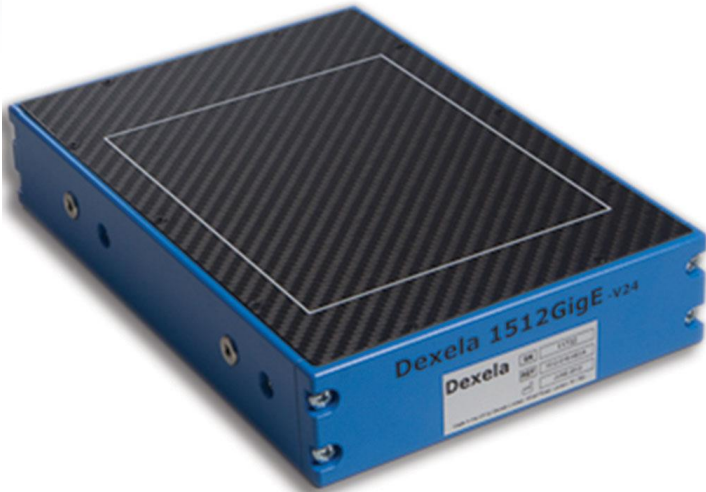


- X-ray source
 - polychromatic
 - power and voltage
 - spot size
 - focus mode
 - open vs closed
 - anode material



Detection

- Transfer X-ray photon to optical (scintillator)
 - thickness
- optical connection (fiber-optic taper, lenses)
- optical detector
 - type (CCD, CMOS)
 - pixel size
 - number of pixels



SkyScan range



44 cm



1272

- High resolution
- 100 kv
- 0.5 μm min. pixel size



1275

- Automated, high throughput
- 100 kv
- $\pm 5 \mu\text{m}$ pixel size



1173

- High energy
- 130 kv
- $\pm 5 \mu\text{m}$ pixel size

Intuitive, user friendly scanning procedure

Small desktop footprint

Low maintenance

SkyScan range



- **SkyScan 2211**

- Large laboratory system
- Highest energy (190 kV)
- Smallest pixel size (100 nm)
- Most flexible
- 2 detectors



200 cm



SkyScan 1272



High resolution desktop

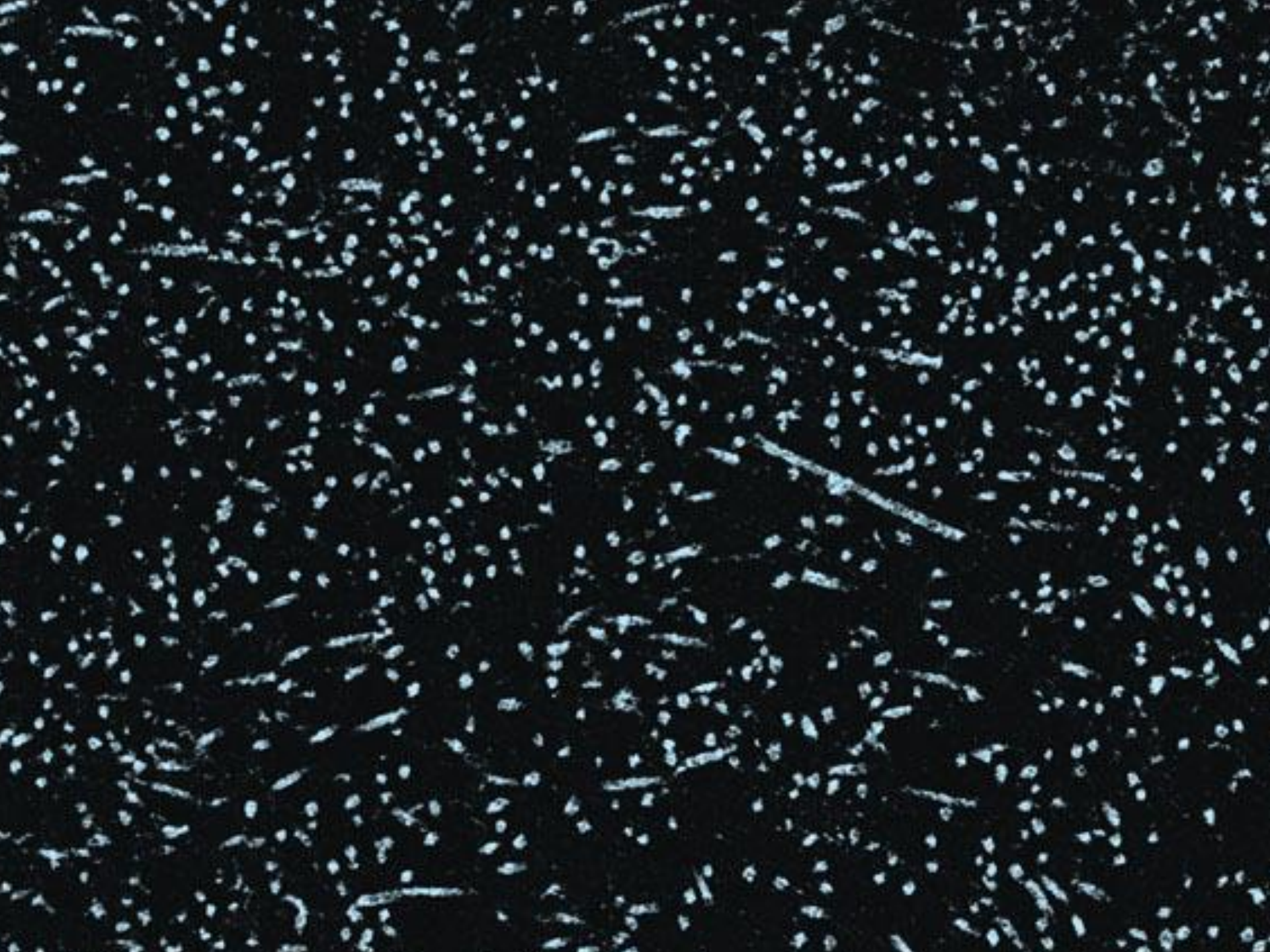


SkyScan 1272 unique selling points



1. **Large format** X-ray cameras: 16Mp and 11Mp options. One / two / **three offset positions**, up to 14450x3240 pixels in single projection, more than 200Mpixels (14450x14450) in any single reconstructed slice, more than 2600 such slices after a single scan.
2. Down to **<0.4um isotropic pixel size** @ maximum magnification, 75mm maximum scanning diameter @ minimum magnification.
3. New maintenance-free X-ray source with large beam opening, **20-100 kV** "iso-watt" (the same power for all voltages),
4. 6-positions automatic filter changer.
5. Integrated micro-positioning stage
6. Optional 16-positions **automatic sample changer** outside shielded area.

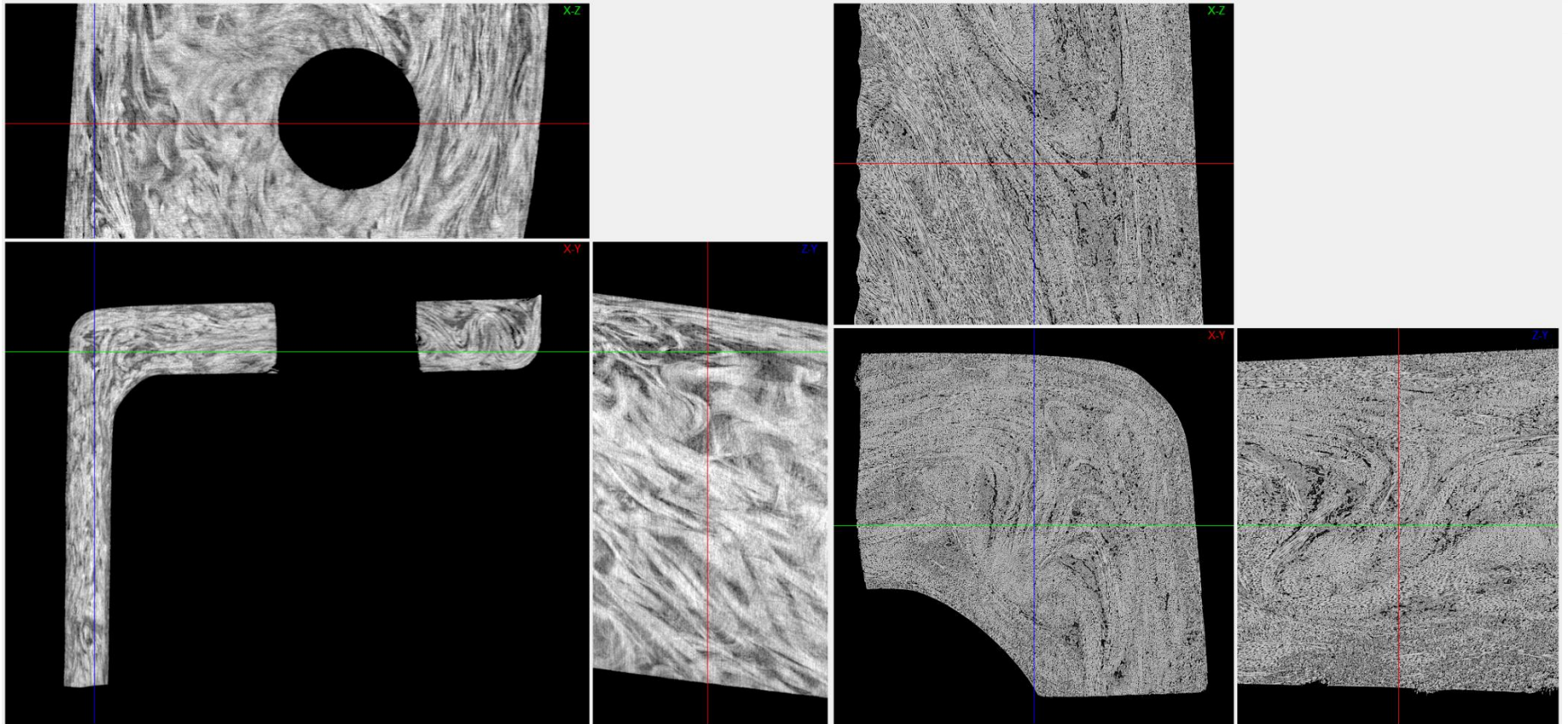




SkyScan 1272 application examples



- GFRP: multiscale approach



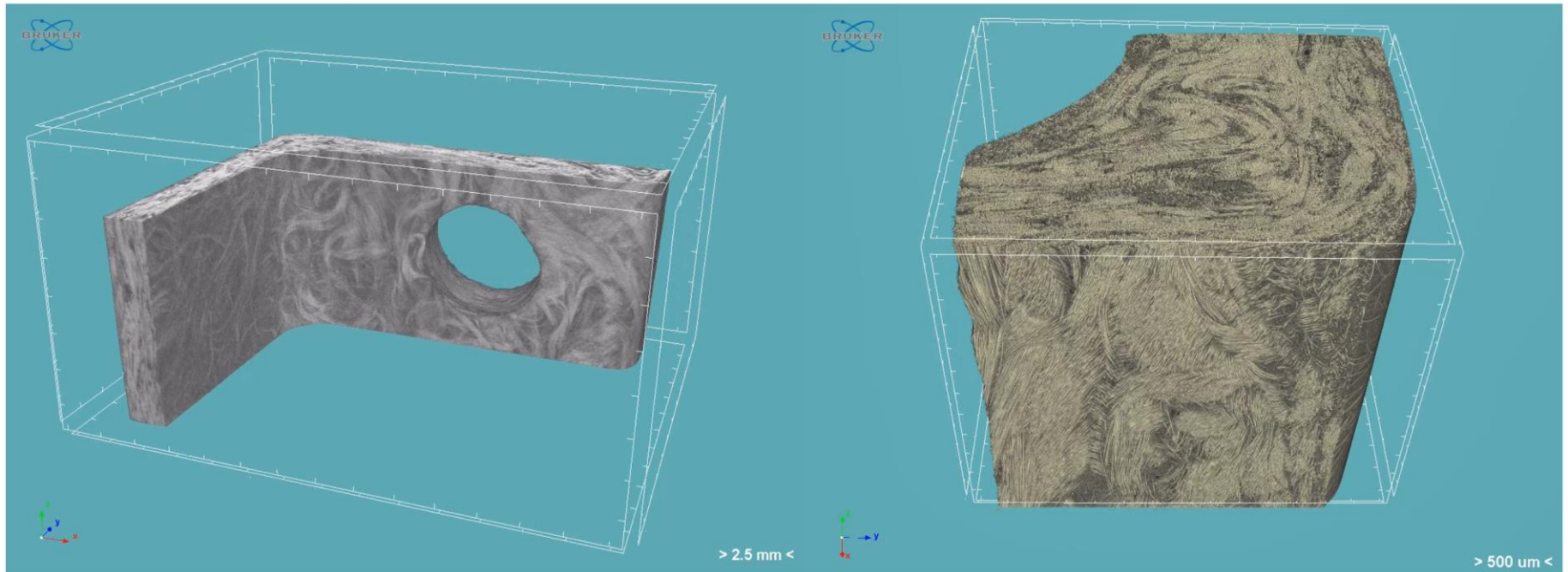
21 µm voxel size

2 µm voxel size

SkyScan 1272 application examples



- GFRP: multiscale approach



21 μm voxel size

2 μm voxel size

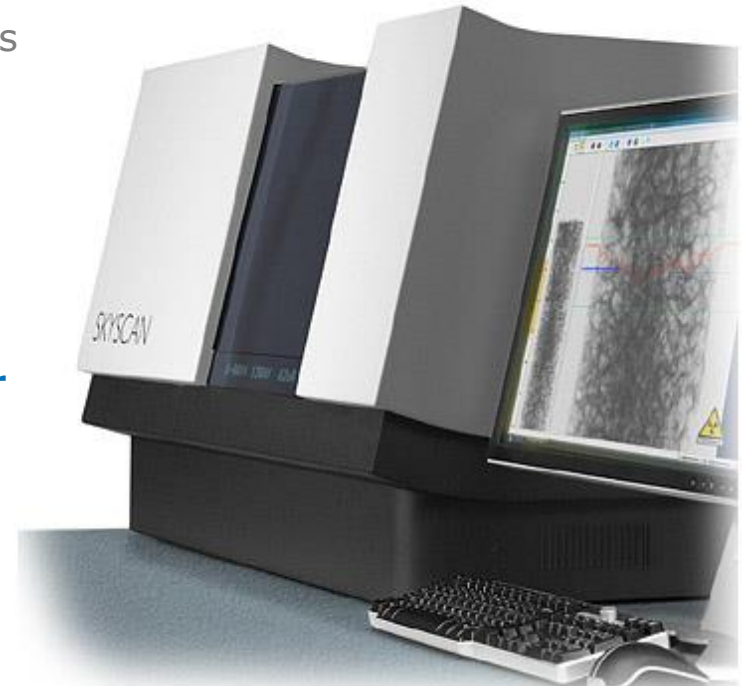
High energy large FOV desktop



SkyScan 1173 unique selling points



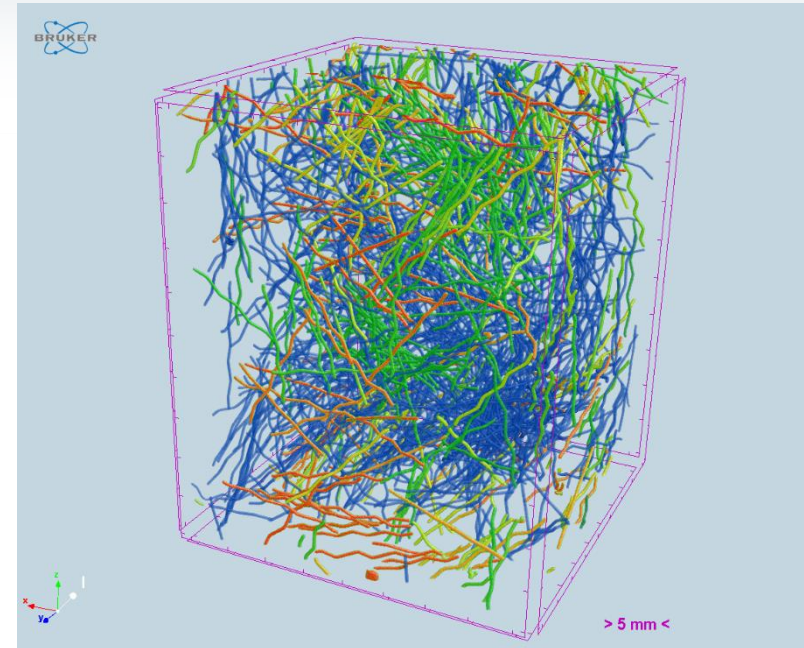
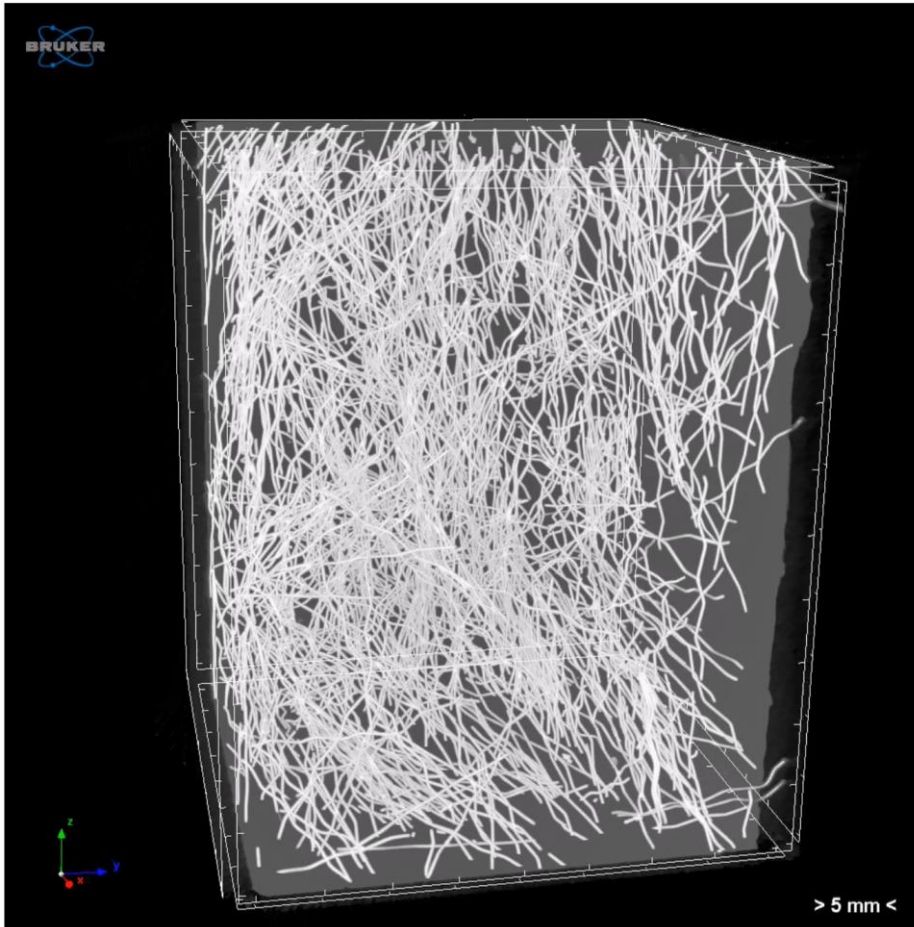
1. 5Mp distortion free **flat panel** X-ray camera. One or two offset positions, up to 4480x2240 pixels in single projection, more than 20Mpixels (4480x4480) in any single reconstructed slice, more than 2200 such slices after a single scan.
2. Maintenance-free **20-130kV** (8W) X-ray source.
3. 3-positions automatic filter changer, option to manually add additional filters.
4. Down to **5 μ m detail detectability** at maximum magnification
5. Large FOV: **140mm maximum scanning diameter** at minimum magnification.
6. Spiral scanning: no ring artifacts and continuous scanning for long objects.
7. Integrated micro-positioning stage.



SkyScan 1173 application examples



- Steel fibers in concrete

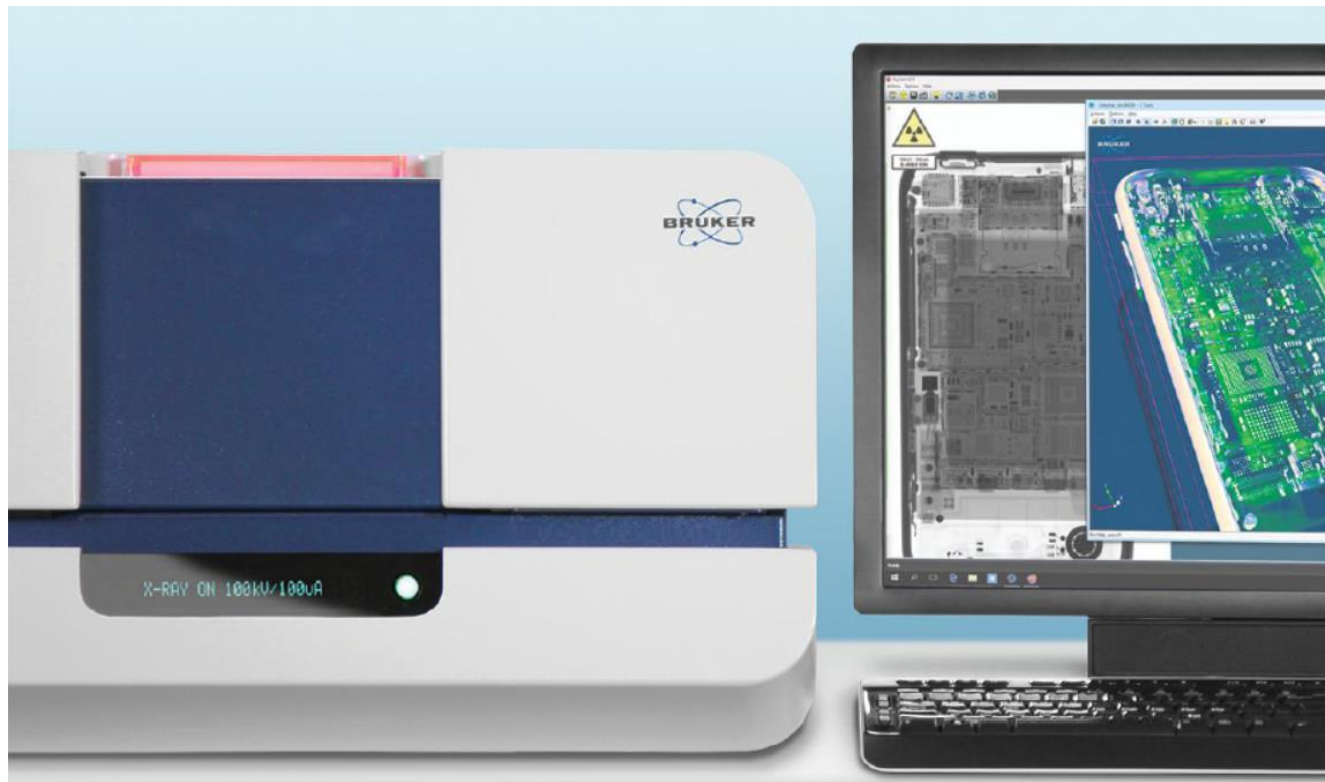


56.07 μm voxel size

SkyScan 1275



Fast large FOV desktop



SkyScan 1275 unique selling points



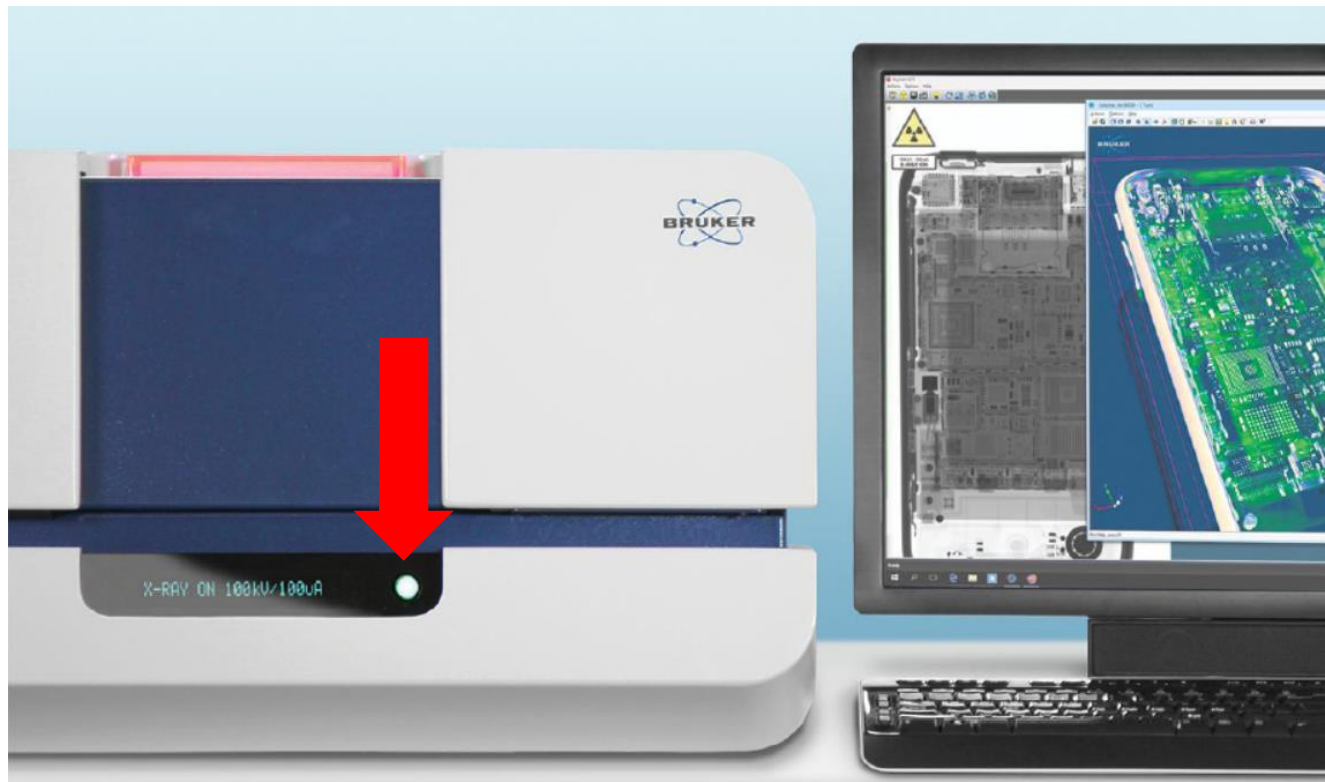
- X-ray energies 20-100kV with small spot size
- Nominal resolution **<4 μ m**
- Generous object size range: up to **96mm diameter** and 120mm in length
- **Flatpanel** 3Mp detector
- **Fast**: Shortest scanning takes only 80 sec
- Optional automatic **sample changer**



SkyScan 1272 unique selling points



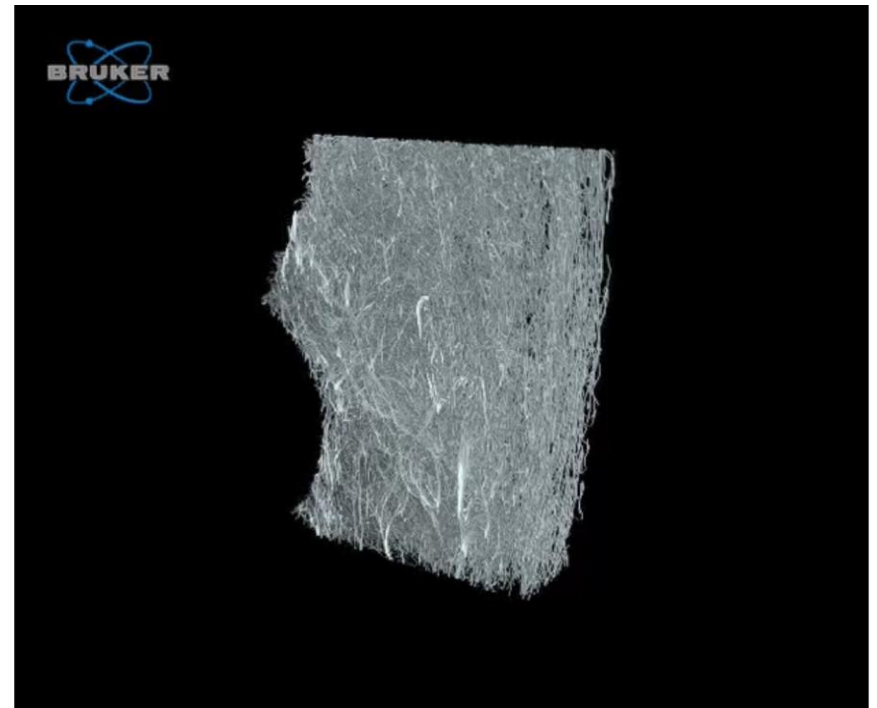
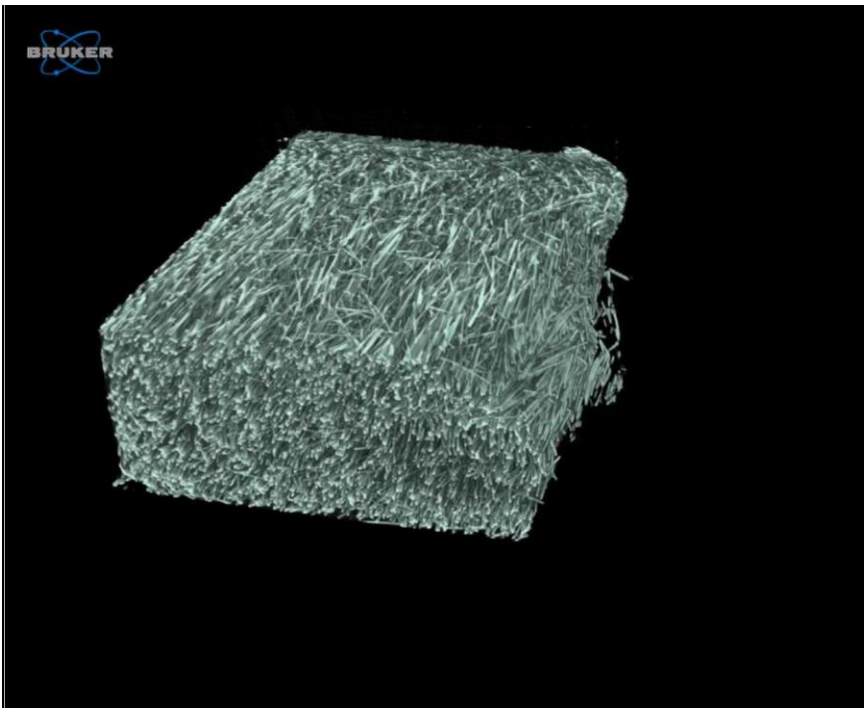
- Highly **automated** with pushbutton



SkyScan 1275 application examples



GFRP: 5.5 μm voxel size

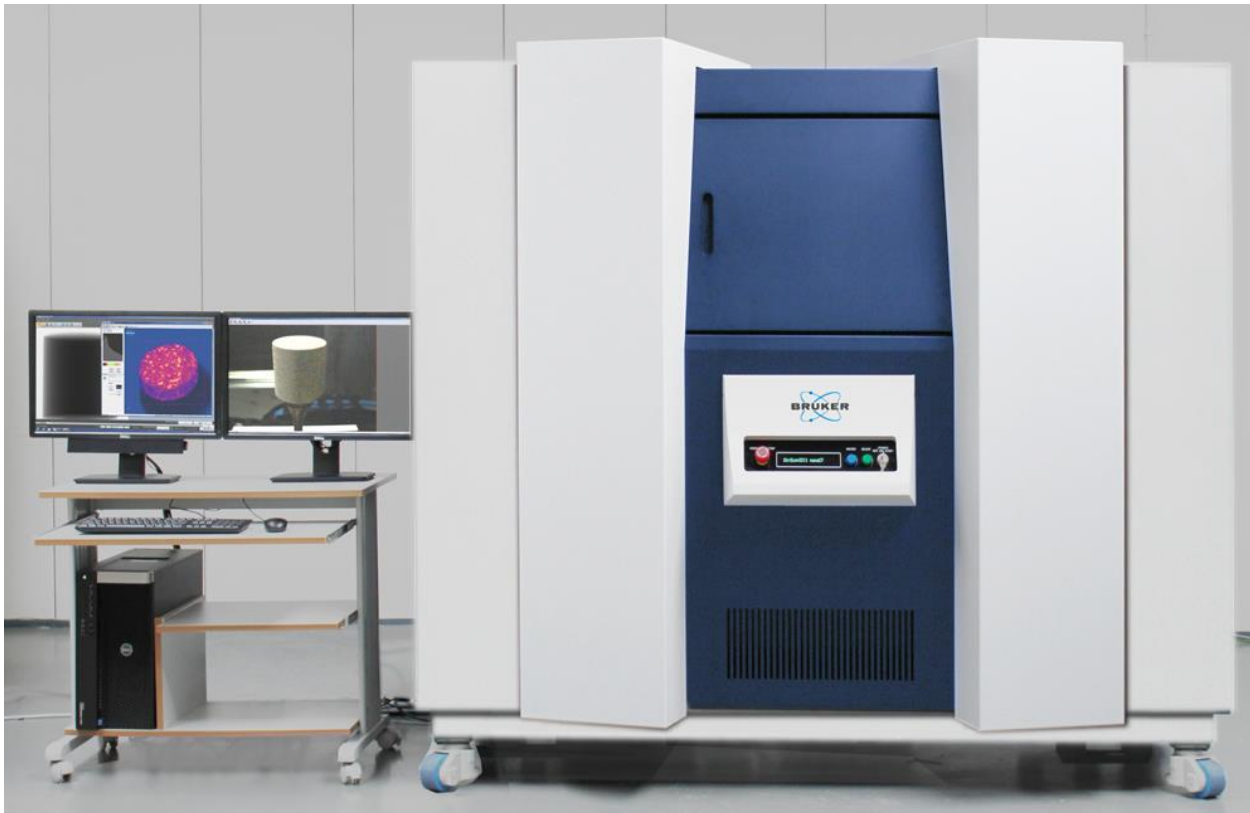


Steel fiber reinforced composite
5.5 μm voxel size

SkyScan 2211



Multi-scale nanoCT system



<http://bruker-microct.com/next/SkyScan2211introduction.mp4>

SkyScan 2211 unique selling points



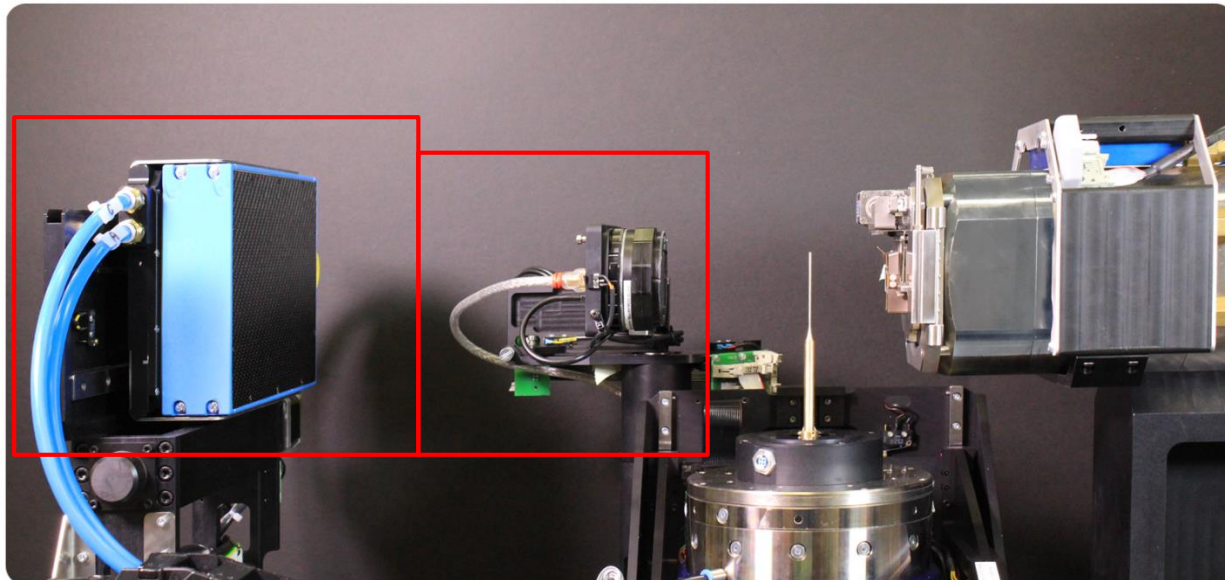
LABORATORY NANO-CT SYSTEM

- Accelerating voltage – 20...190kV
- Maximum power – 25W with diamond window (optional); 10W with Be window (standard)
- Three focus modes (nano, micro, high power)
- Down to 900nm spatial resolution
- Detail detectability (smallest pixel size) under 100 nm

SkyScan 2211 unique selling points



- **CCD detector**
 - Cooled CCD 4000x2670 pixels (11Mp) for high resolution

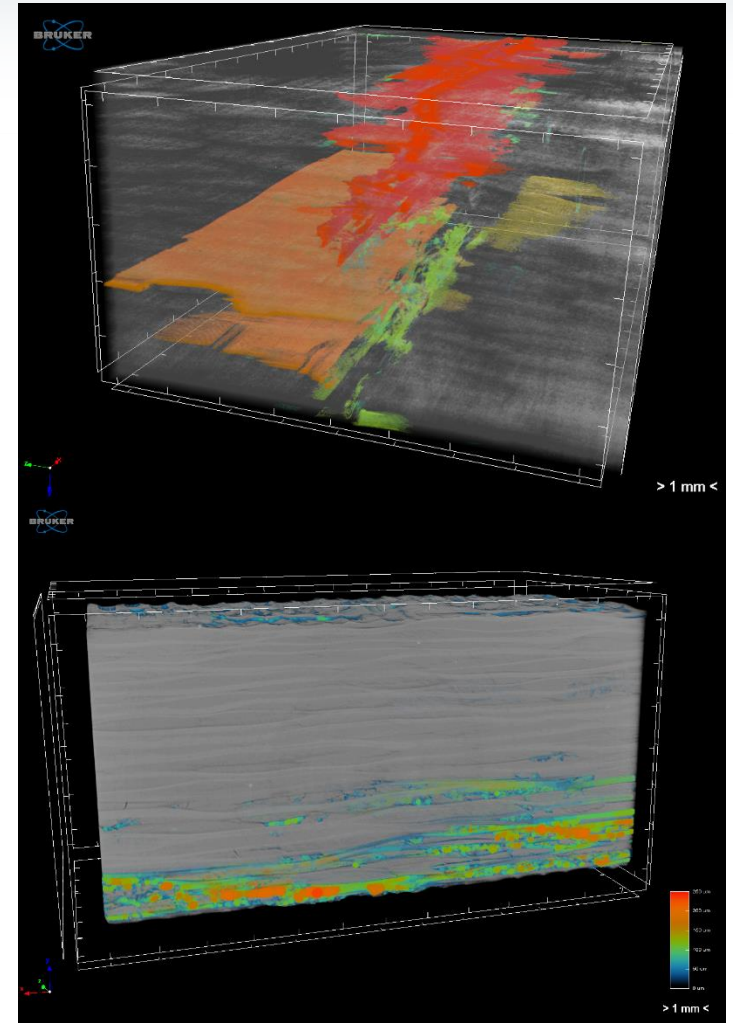
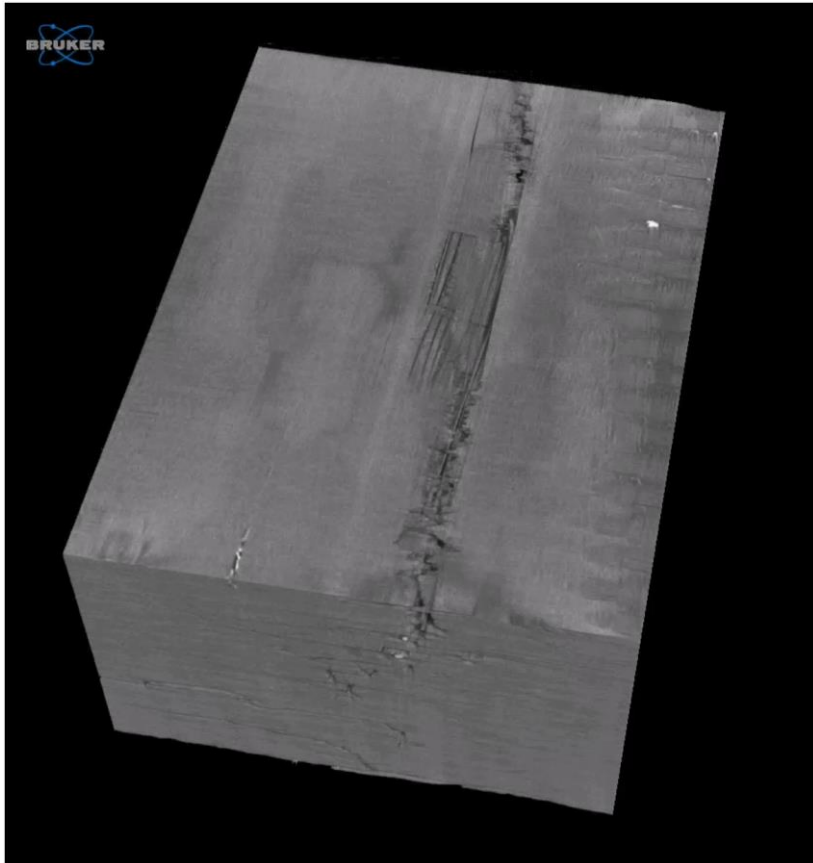


- **Flat-panel detector**
 - Active pixel CMOS sensor,
 - 1944x1536 pixels (3Mp) in central position or 6Mp in two offset positions large objects/high energy

SkyScan 2211 application examples



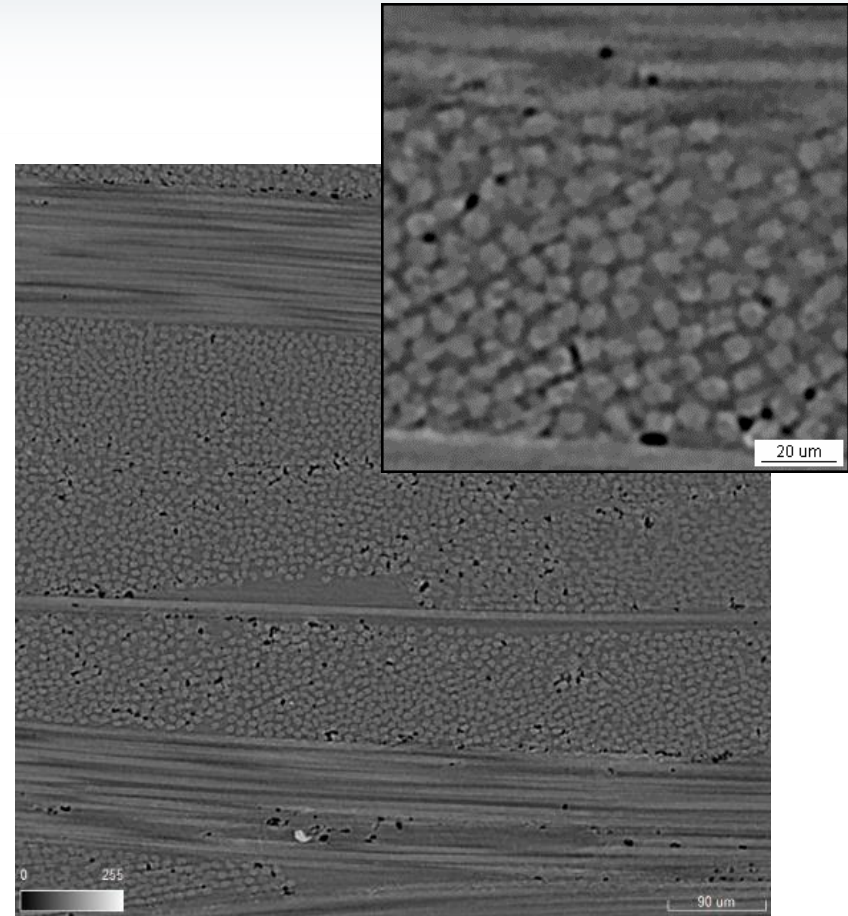
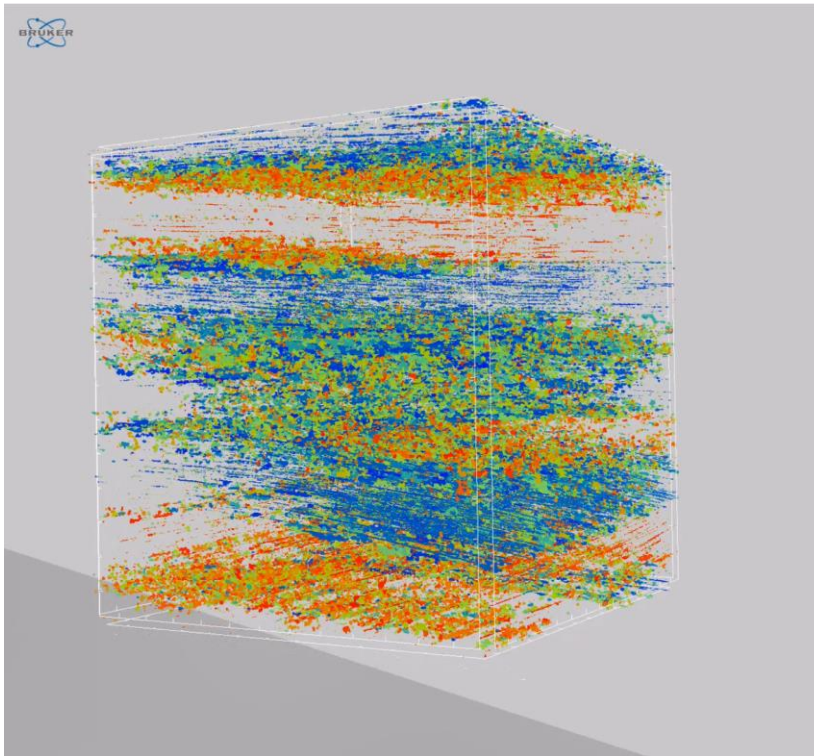
- CFRP after bending test:
 - 8.25 μm voxel size



SkyScan 2211 application examples



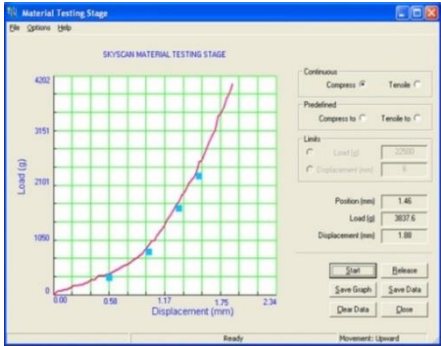
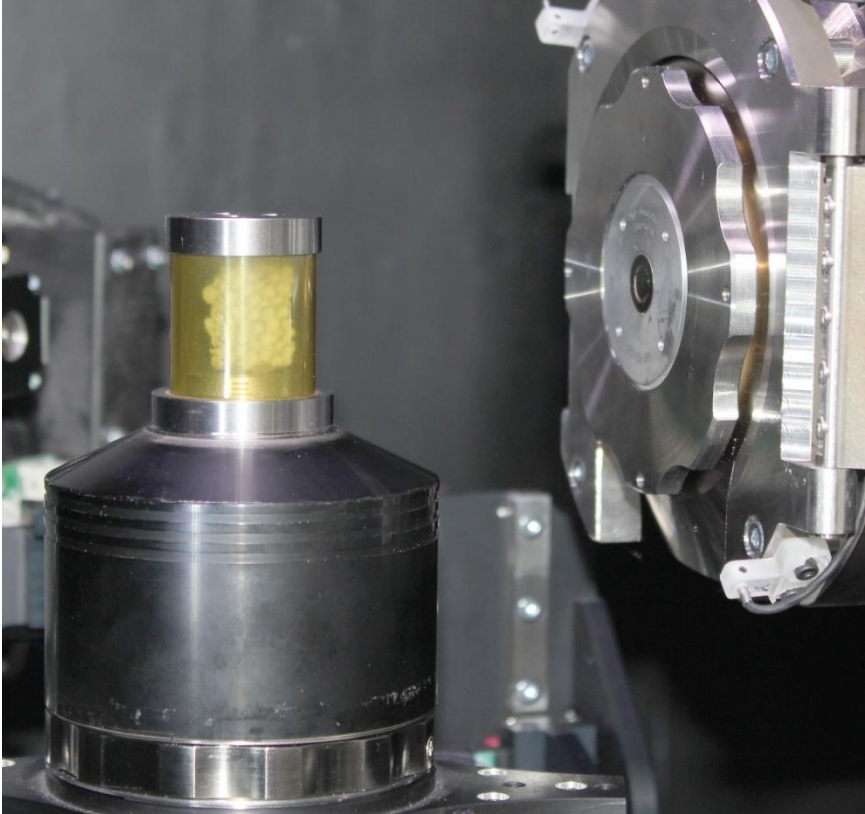
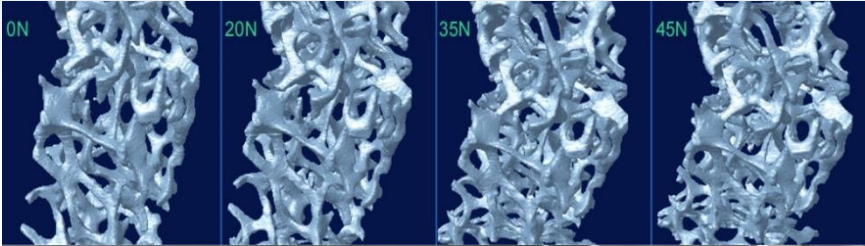
- CFRP after bending test:
 - 350 nm voxel size



Pore orientation analysis

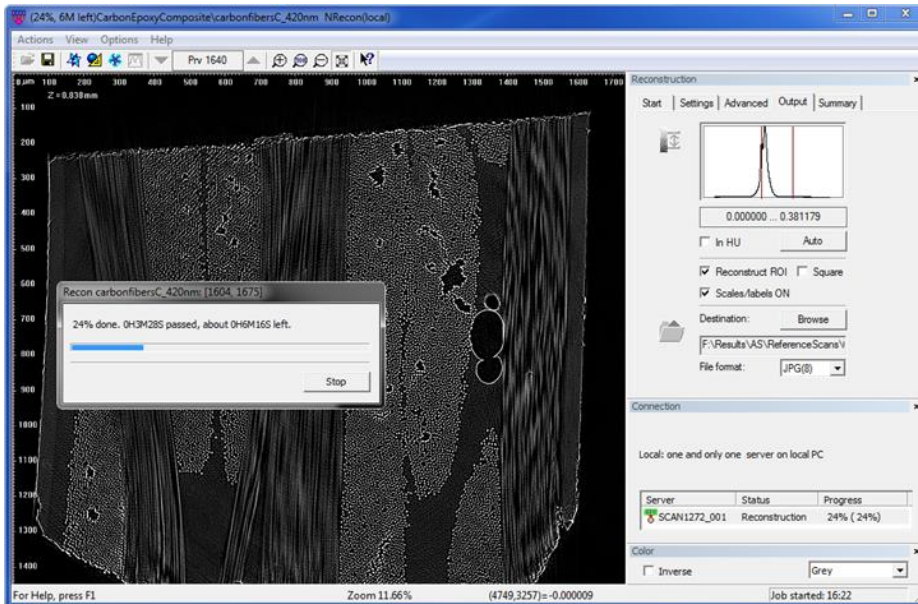
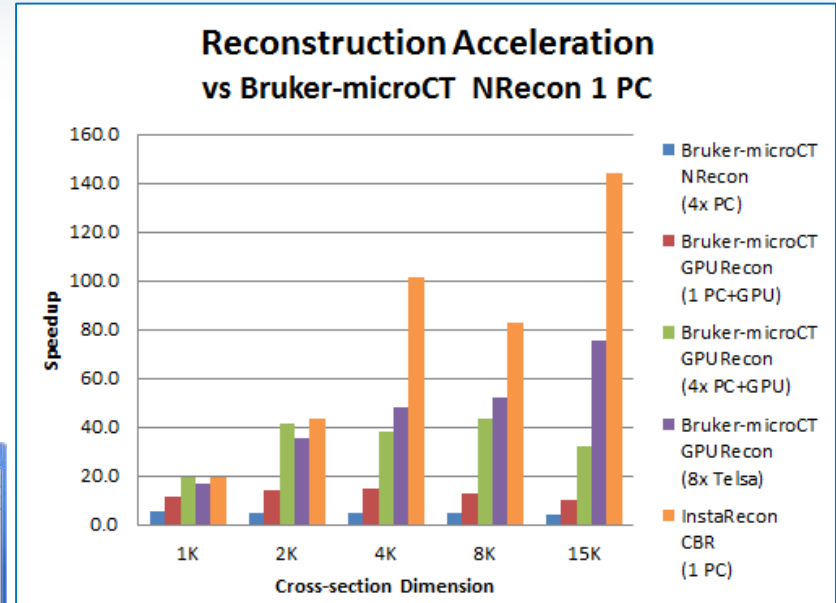
Object stages in-situ examination

- Dynamic experiments
 - In-situ compression / tensile testing
 - Cooling / heating



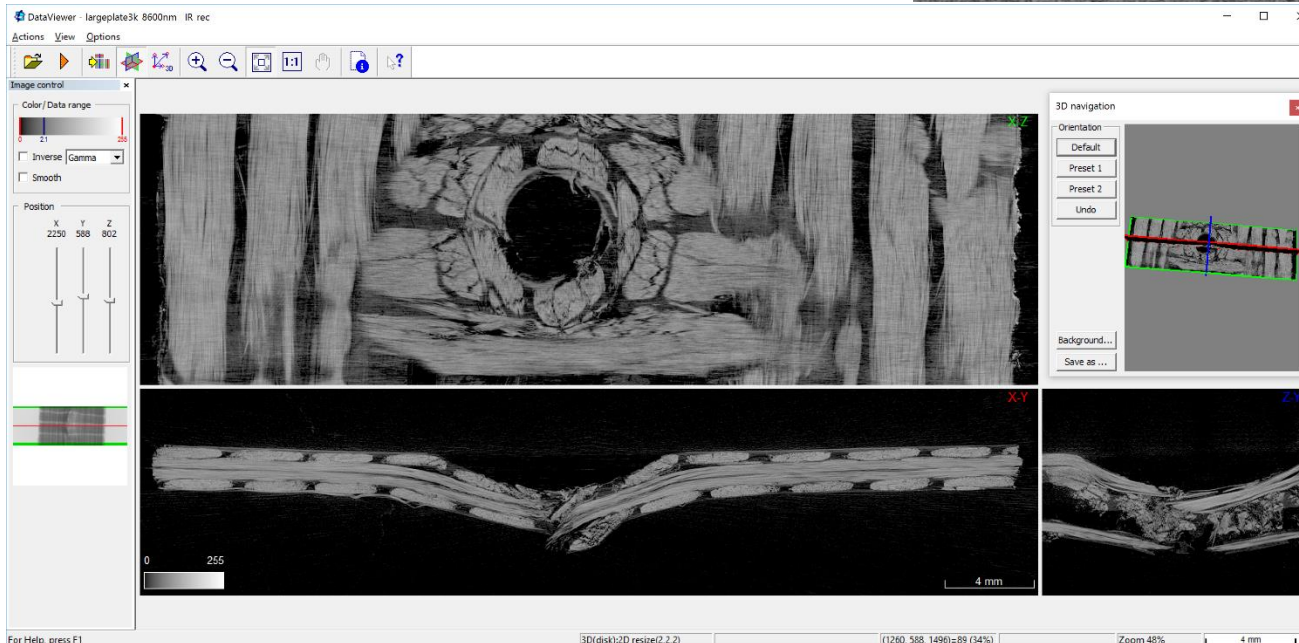
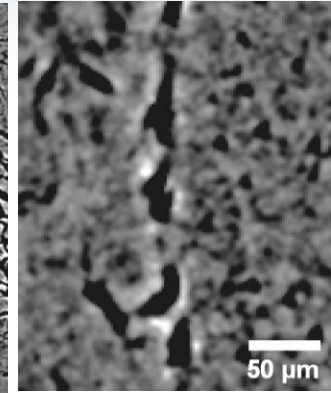
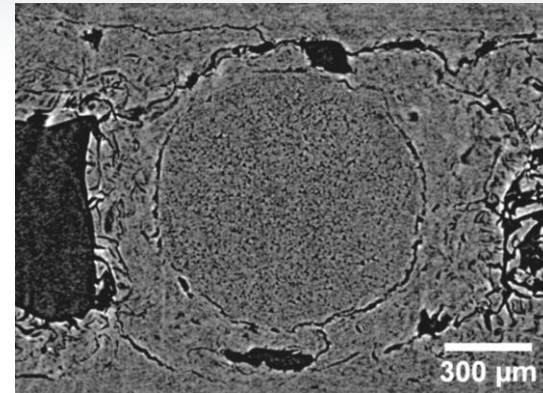


- NRecon reconstruction software
 - standard GPU and CPU accelerated
 - InstaRecon
 - world's fastest reconstruction algorithm
 - standard provided with high resolution systems



| Cross section format | 2K x 2K | 4K X 4K |
|-----------------------|---------|---------|
| # cross sections | 1229 | 2255 |
| # projections | 996 | 1990 |
| NRecon (1 PC) | 5' | 1h 4m |
| GPURecon (1 PC + GPU) | 1' 38" | 19' |
| InstaRecon (1PC) | 1' 21" | 9' |

- DataViewer
 - Orthogonal slices viewer
 - 3D rotation and measurement
 - 3D registration

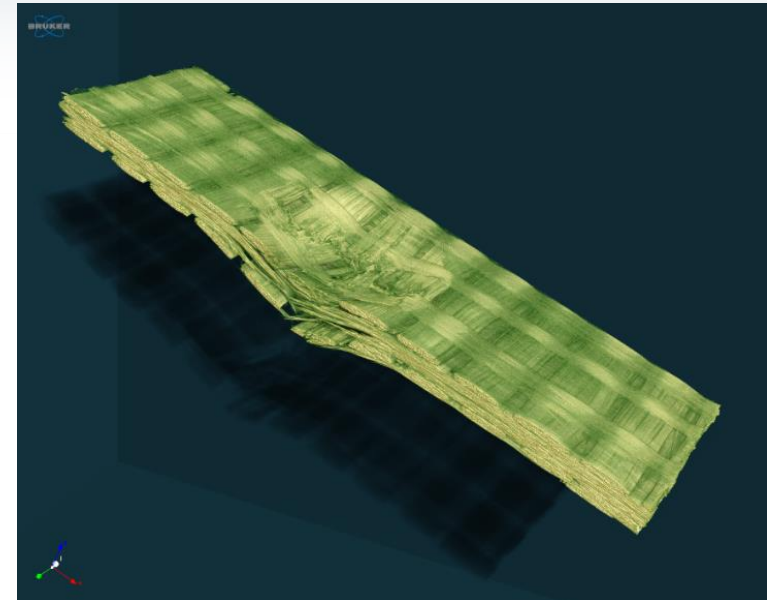


Investigation of bonding between fibers and matrix
1.7 μm voxel size

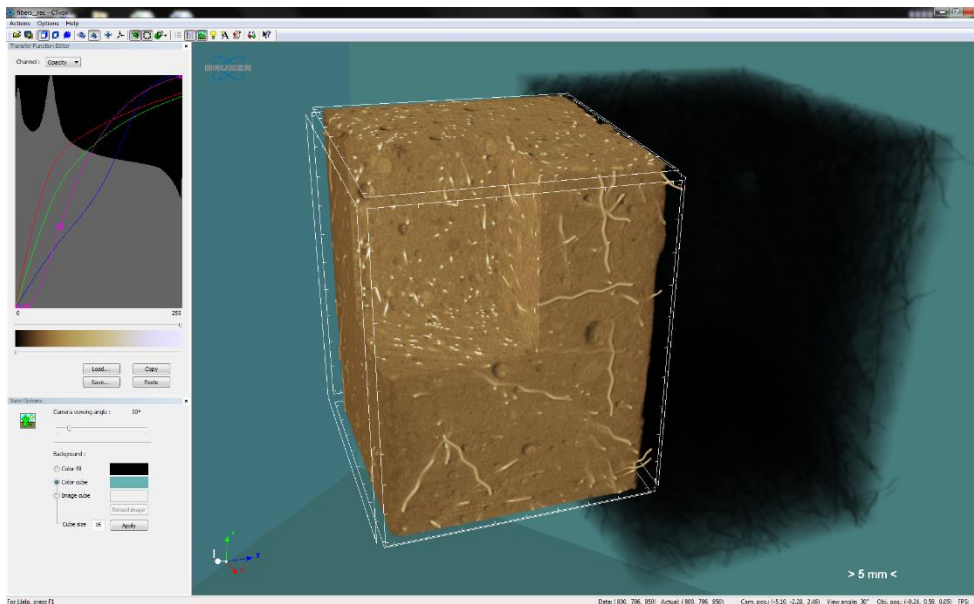
Investigation of part after impact test
8.6 μm voxel size



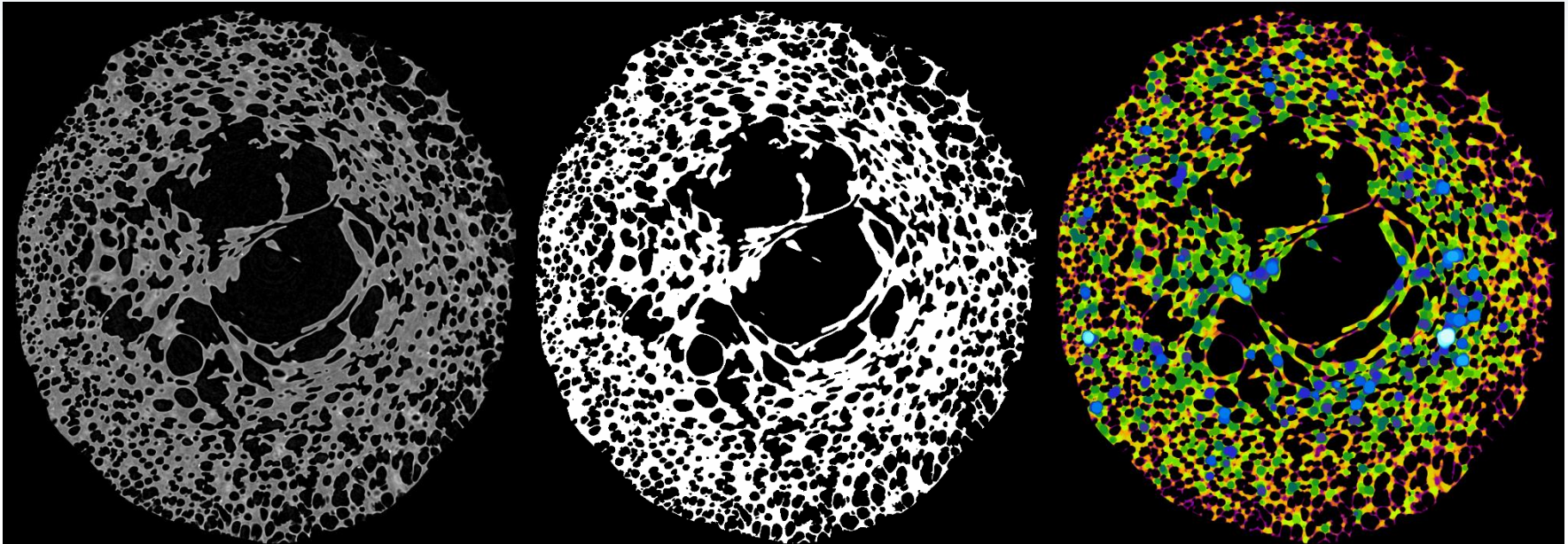
- CTvox
 - Volume rendering
 - Multiple volume support
 - Movie creation
 - Mobile app



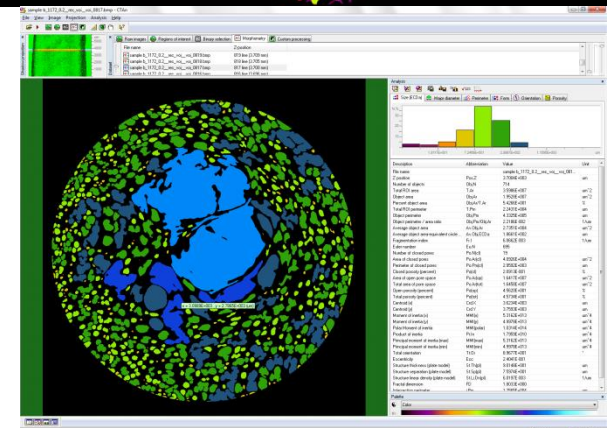
Investigation of part after impact test
8.6 μm voxel size



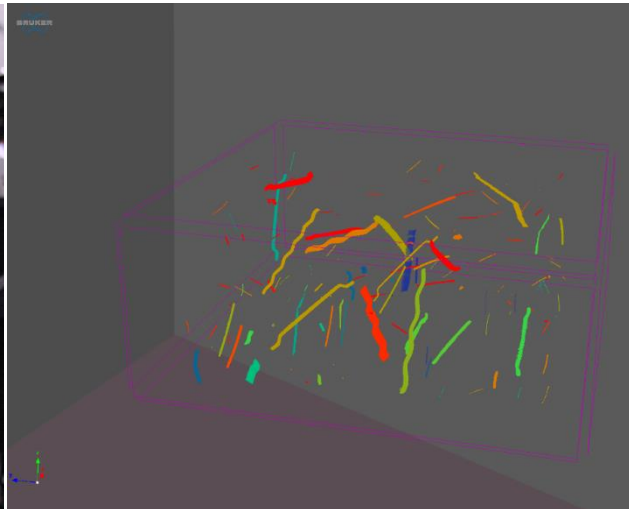
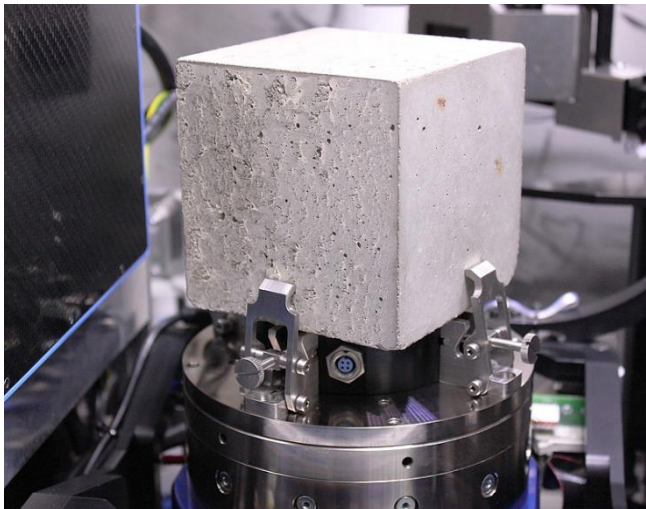
Steel fibers in concrete
56.07 μm voxel size



- CTAnalyser
 - Define region of interest (ROI)
 - Image processing
 - Binarize images
 - Generate surface rendered models
 - 3D / 2D analysis



- Two major cases for fibre analysis:
 1. Individual fibres can and need to be separable
 - e.g. greatly advantageous for fibre length distribution
 - image filtering (edge preserving filters and sharpening tools) and morphological operations (e.g. watershed separation) can be of great help
 - individual object analysis in 3D; output to other software

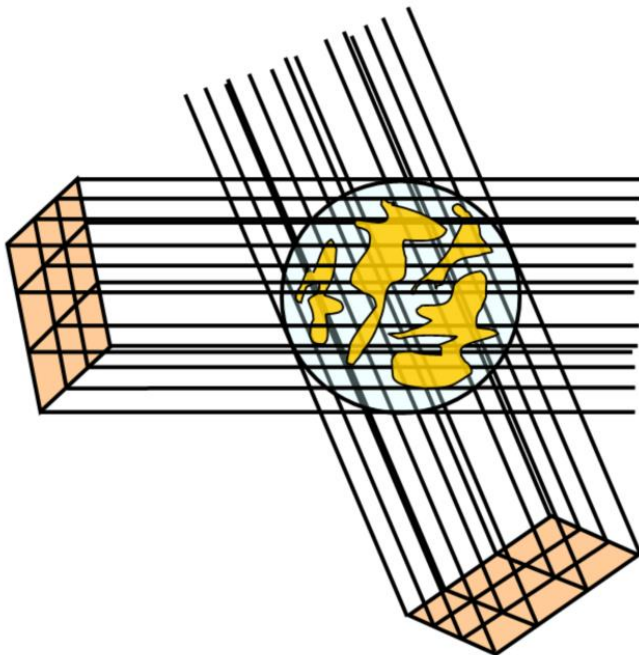


| # | Object volume, ... | Object surface,... | Volume of pore... | Surface of pore... | Porosity, % |
|----|--------------------|--------------------|-------------------|--------------------|-------------|
| 1 | 1.1865E+012 | 1.4009E+010 | 1.5864E+005 | 4.3143E+004 | 0.0000 |
| 2 | 1.6126E+008 | 2.0936E+006 | 0.0000E+000 | 0.0000E+000 | 0.0000 |
| 3 | 8.5550E+008 | 1.0386E+007 | 0.0000E+000 | 0.0000E+000 | 0.0000 |
| 4 | 4.1765E+008 | 5.5632E+006 | 0.0000E+000 | 0.0000E+000 | 0.0000 |
| 5 | 2.0805E+008 | 2.9155E+006 | 0.0000E+000 | 0.0000E+000 | 0.0000 |
| 6 | 1.2133E+009 | 1.4601E+007 | 0.0000E+000 | 0.0000E+000 | 0.0000 |
| 7 | 2.9844E+008 | 4.0765E+006 | 0.0000E+000 | 7.1482E+010 | 0.0000 |
| 8 | 5.9067E+008 | 8.4100E+006 | 0.0000E+000 | 0.0000E+000 | 0.0000 |
| 9 | 2.2876E+008 | 3.7971E+006 | 0.0000E+000 | 0.0000E+000 | 0.0000 |
| 10 | 9.8883E+008 | 1.2597E+007 | 0.0000E+000 | 0.0000E+000 | 0.0000 |
| 11 | 4.2851E+008 | 5.2537E+006 | 0.0000E+000 | 0.0000E+000 | 0.0000 |
| 12 | 3.6572E+008 | 4.5265E+006 | 0.0000E+000 | 0.0000E+000 | 0.0000 |
| 13 | 7.2113E+008 | 9.0164E+006 | 0.0000E+000 | 0.0000E+000 | 0.0000 |
| 14 | 1.8429E+009 | 2.1004E+007 | 0.0000E+000 | 0.0000E+000 | 0.0000 |

Steel fiber in concrete
48.01µm voxel size

2. Individual fibres are not or don't need to be separable

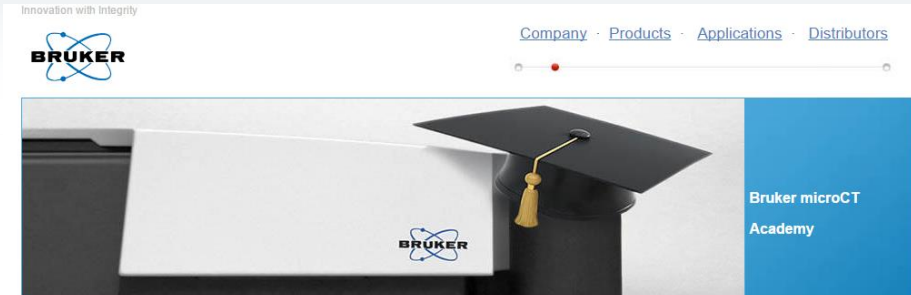
- e.g. for fibre orientation distribution it is much less required
- global 3D analysis



- e.g. degree of anisotropy determined from the eigenvalues from the tensor describing Mean Intercept Length

For the MIL analysis, a grid of lines is sent through the volume over a large number of 3D angles (just two are illustrated here). The MIL for each angle is calculated as the average for all the lines of the grid.

Bruker microCT



- Newsletter
- Application and method notes
- Annual User Meeting
- abstracts available online

Welcome to Bruker microCT Academy newsletter!

The goal is to update you on a monthly basis on our latest developments. In every Bruker microCT Academy newsletter we will focus on a method note highlighting the use of specific functions in hardware or software which you can apply to your research area. You will also find links to new software releases and upcoming conferences where we will exhibit.

For our users, you are welcome to take the advantages to download detailed Method Notes for further information. The registration page is at <http://partners.bruker-microct.com/subscribe>.

| | |
|--|--|
| | <p>Bruker micro-CT Academy 2016 Issue 2</p> <ul style="list-style-type: none">• Fiber analysis• Orientation• Bruker microCT news• Upcoming events• Image of the month |
| | <p>Bruker micro-CT Academy</p> <ul style="list-style-type: none">• When are stains needed?• Blood vessels: contrast agents• Image of the month• Bruker microCT news• Upcoming events |
| | <p>Bruker micro-CT Academy</p> <ul style="list-style-type: none">• Bitwise operations• Bruker micro-CT news• Upcoming events• Image of the month |



Bruker microCT
2016 Micro-CT
User Meeting

Conclusions and take-home messages



- Micro-CT is capable of producing 3D images with resolutions down to $< 1 \mu\text{m}$.
- Measuring time – resolution – feasibility – image quality are all very sample dependent.
- Use the right tool for the job!
- More information available on the website
 - <https://www.bruker-microct.com>

Q&A session

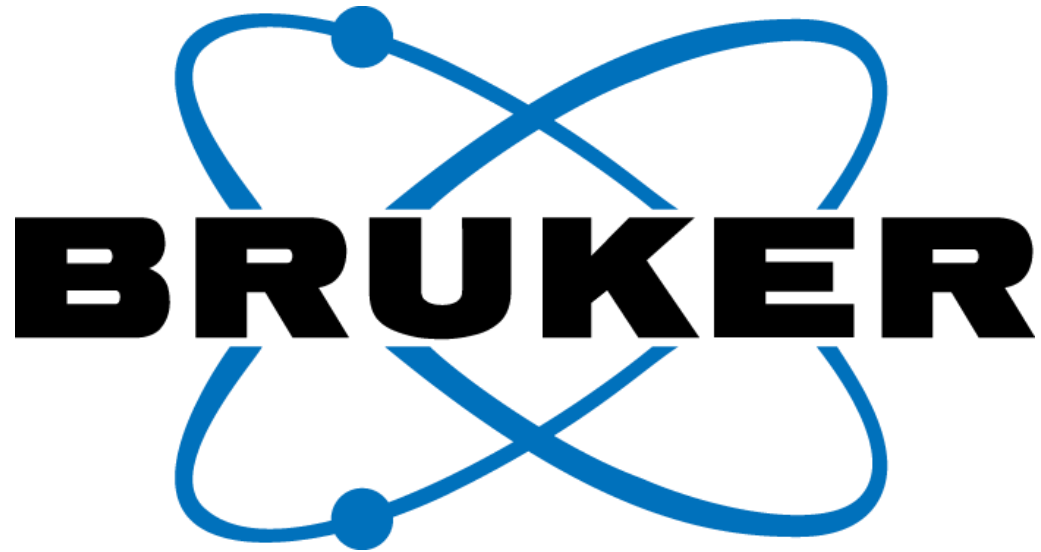


Any questions?

Please type any questions you may have in the [Q&A panel](#) and click Send.

Thank you!





Innovation with Integrity