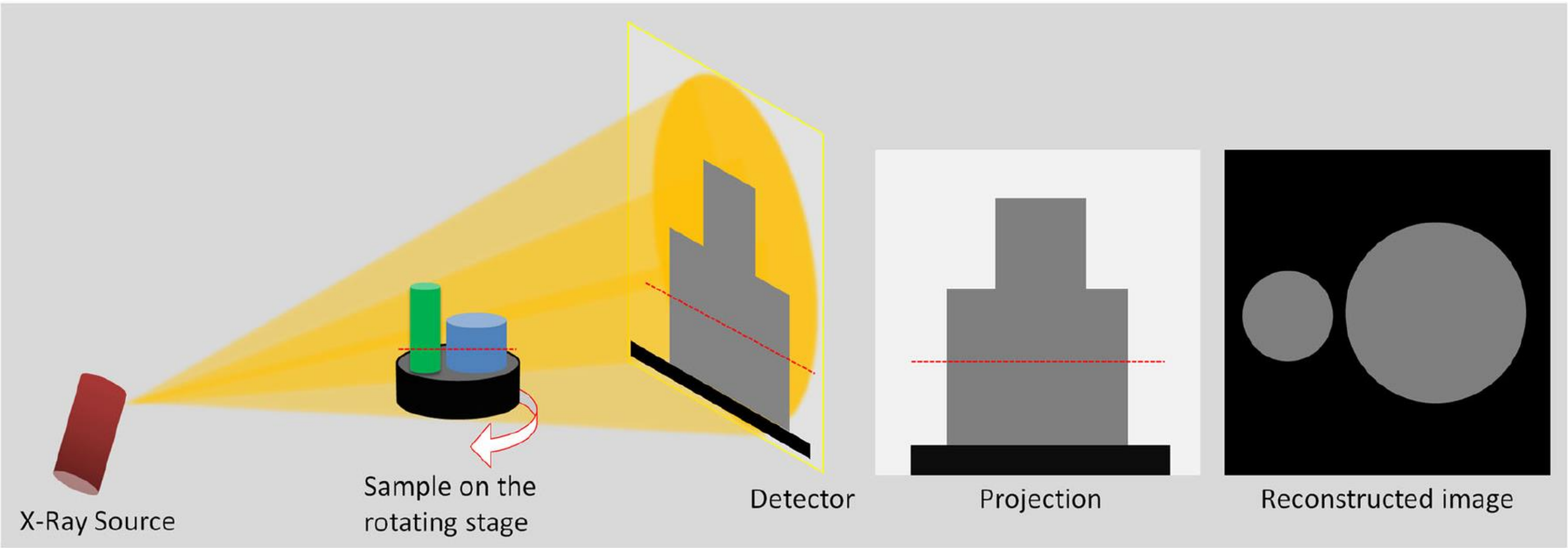
Spectral X-ray tomography for 3D mineral analysis

A new approach to achieve chemical data from a 3-dimensional CT scan

Jonathan Sittner, Jose R. A. Godinho, Axel D. Renno, Veerle Cnudde, Marijn Boone, Thomas De Schryver, Antti Roine, Jussi Liipo

EIT RawMaterials is supported by the EIT, a body of the European Union

Principle of tomography



Cengiz et al., 2018

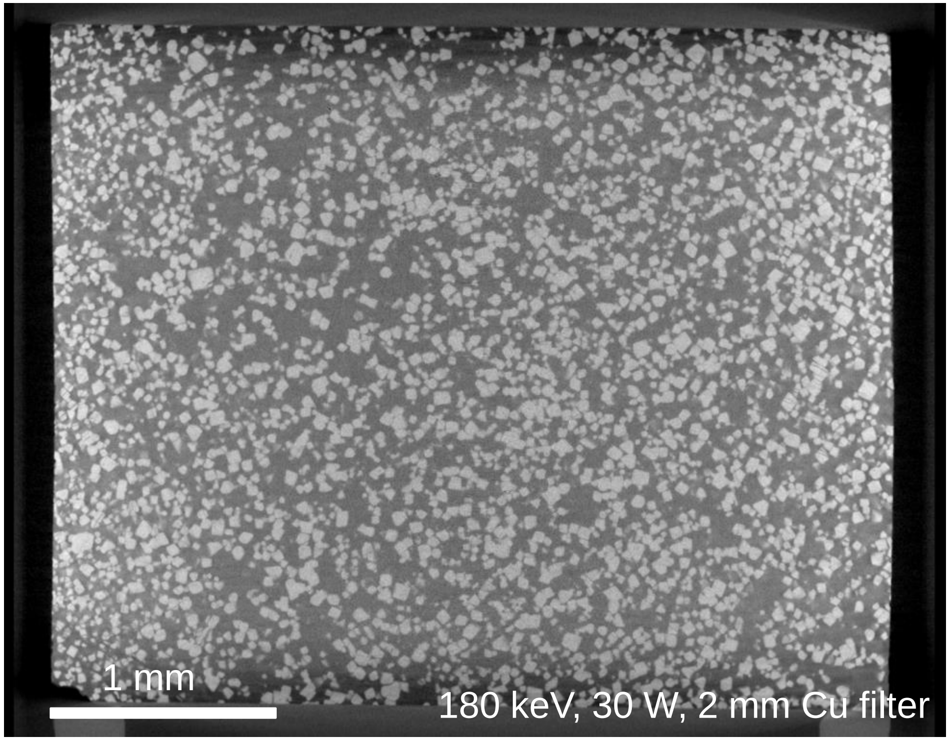
Principle of tomography

– In X-ray computed tomography (CT) the sample is in between the X-ray source and the detector

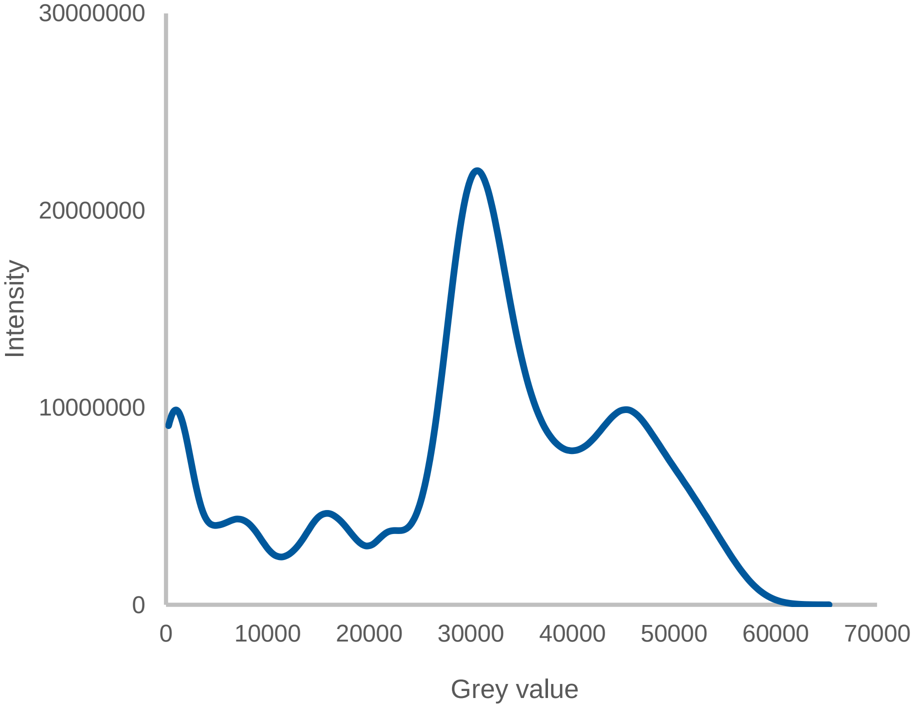
– Many X-ray absorption images (radiographs) from different rotation angles of the sample are recorded during one scan

– By using different algorithms, the 3D image can be reconstructed

Grey scale and threshold



Chromite ore, Kemi mine, Finland



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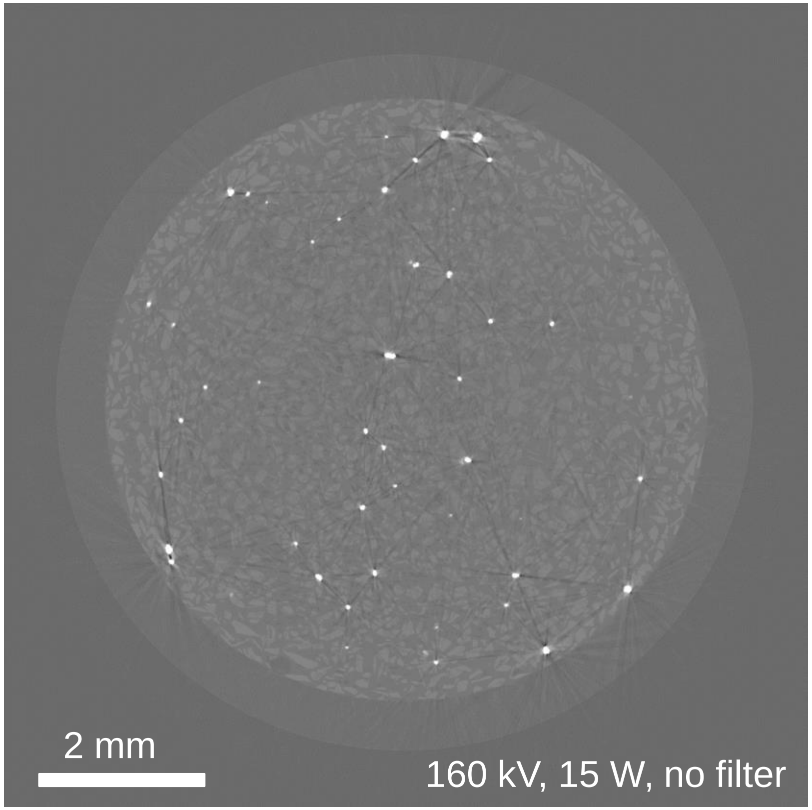
Grey scale and threshold

– Particle classification in computed tomography (CT) often exploits the greyscale histogram

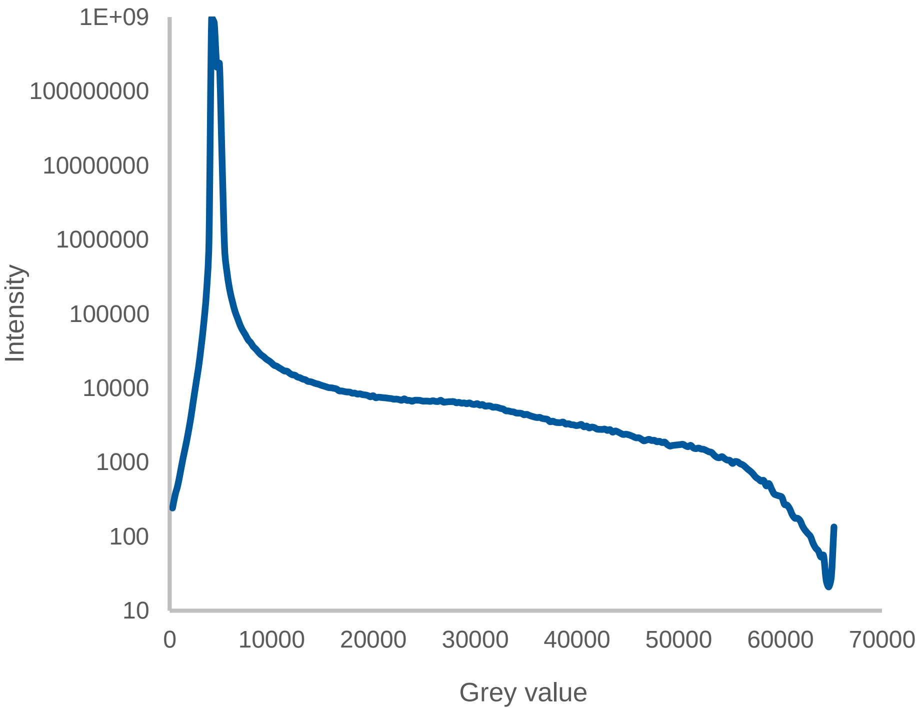
– It shows different greyscales and their intensity of the sample

– The histogram can be used to select and classify particles based on different peaks but without any chemical information

Grey scale and threshold



Quartz, gold, lead, tungsten mixture



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Grey scale and threshold

– But in some samples it is not possible to see individual peaks for different phases in the greyscale histogram

– This makes a particle classification impossible

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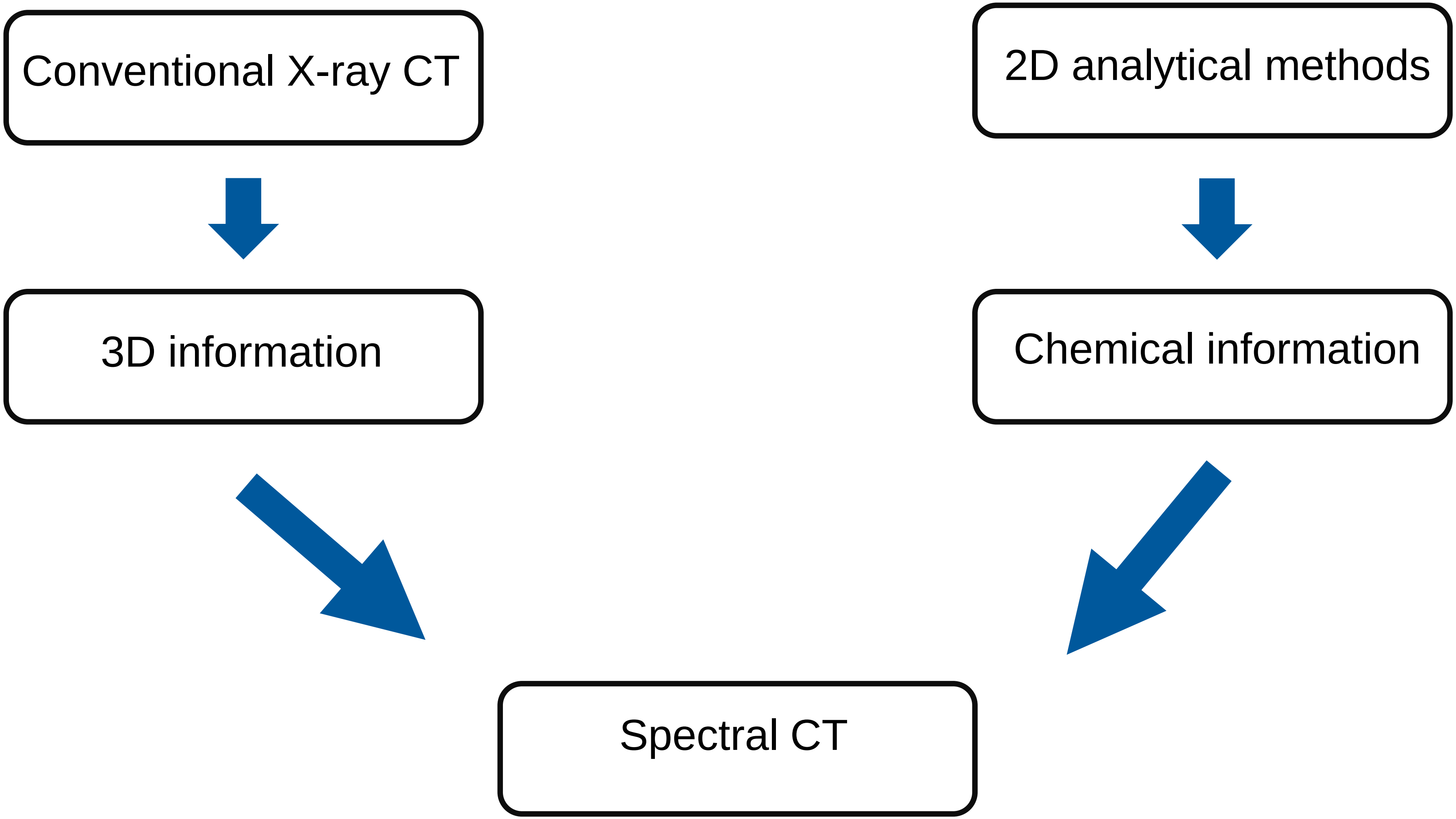
Idea of Spectral CT



Idea of Spectral CT

- The idea of spectral CT is to combine advantages of conventional CT and the chemical information you get from 2D analytical methods

- With the 3D information of CT and the chemical information of 2D methods

Idea of Spectral CT

Ore characterization

3D particle classification

Mineral processing simulations based on 3D information

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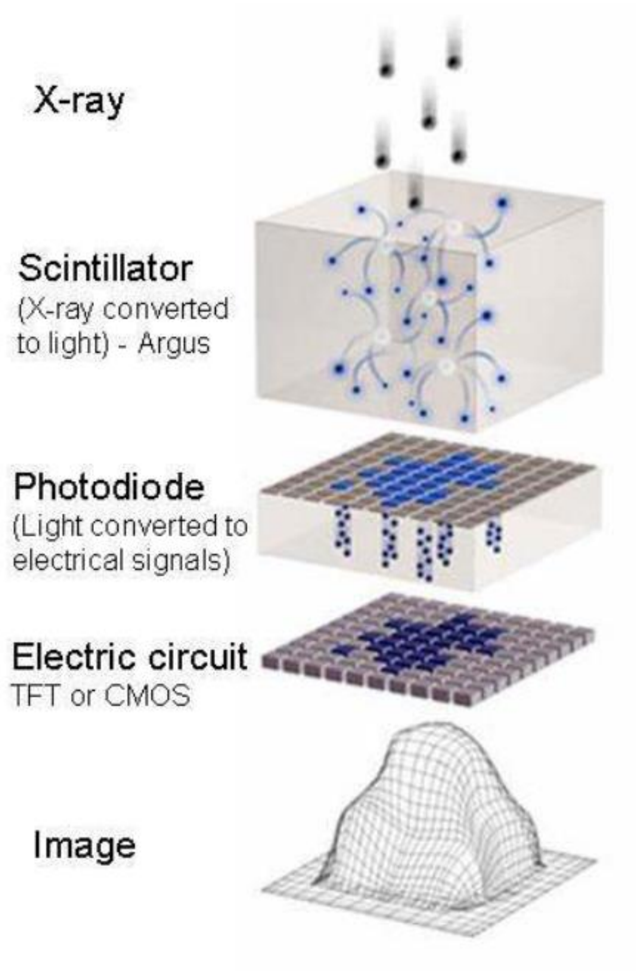
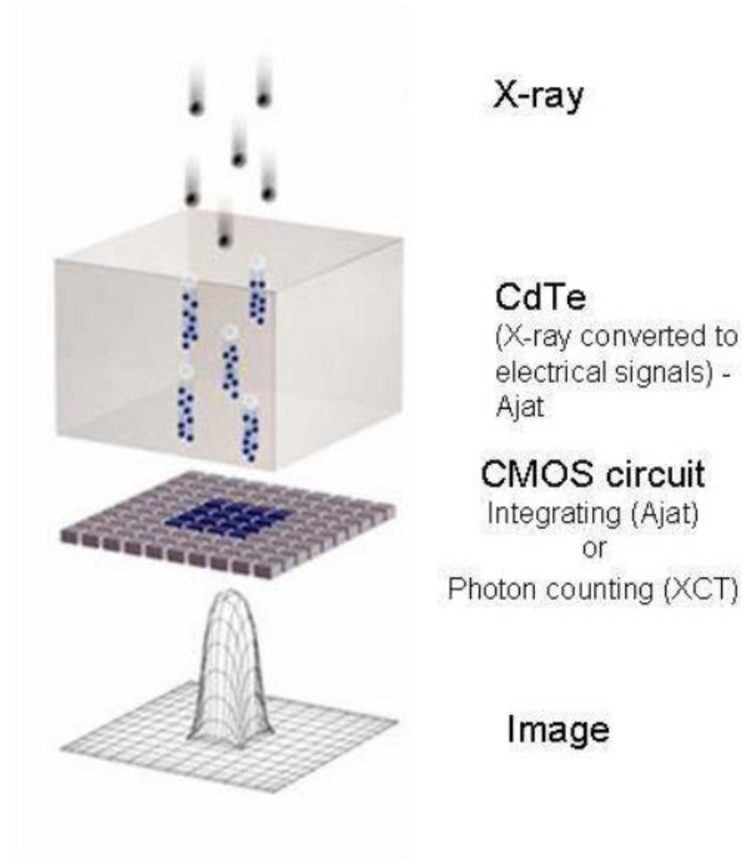
Indirect detection

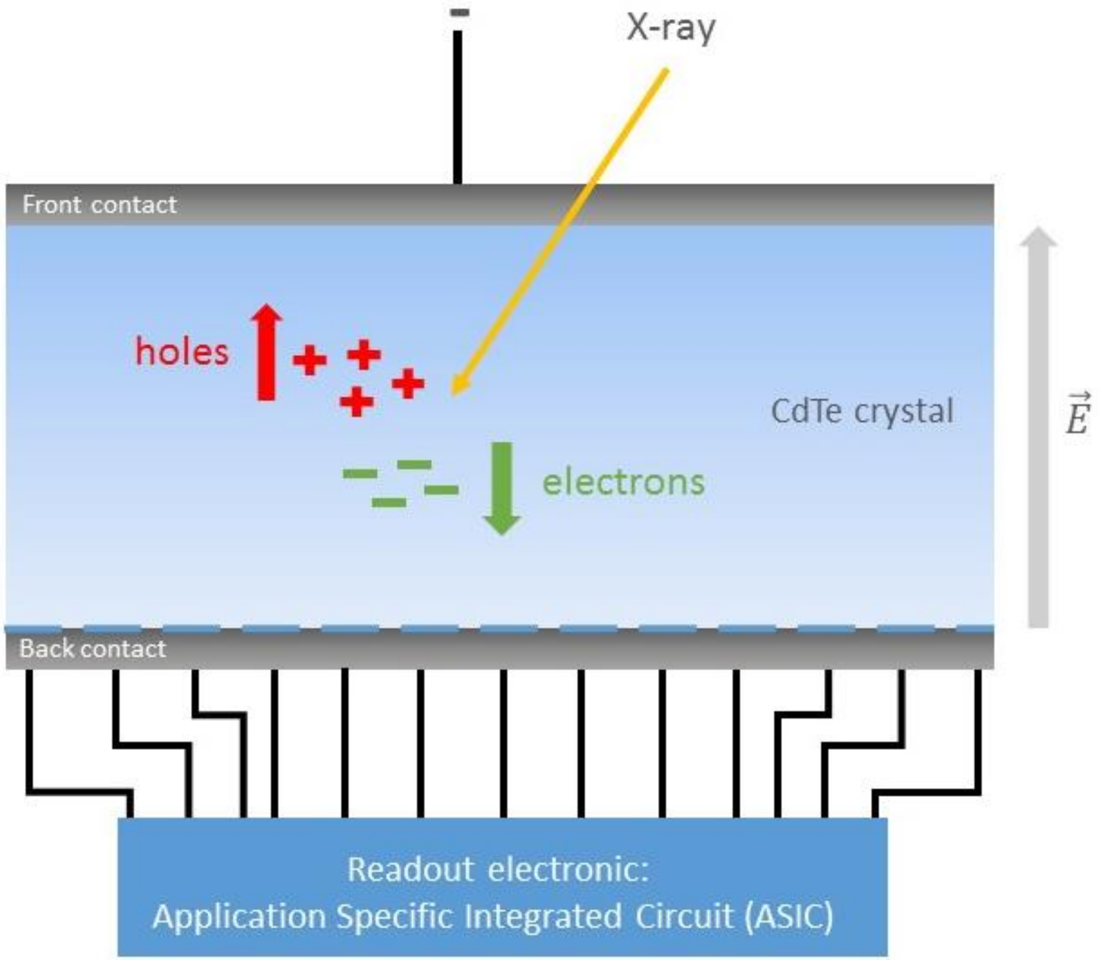


Direct detection



Schumacher et al., 2016

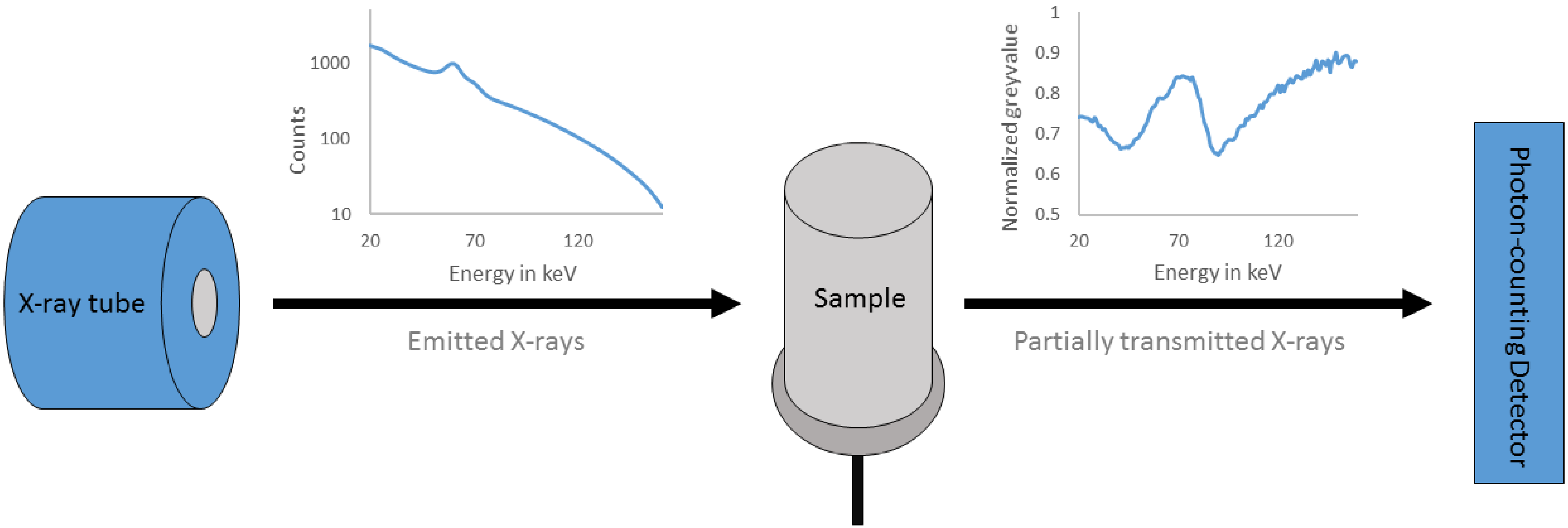
Principle of direct detection



Principle of direct detection

- Spectral CT uses a photon-counting semiconductor detector
- If an X-ray photon hits the detector it generates electron-hole-pairs in the semiconductor
- The applied voltage causes a separation of these charge carriers to the contacts
- The readout electronics further process and amplify the signal
- The detected signal is proportional to the energy of the incident X-ray photon

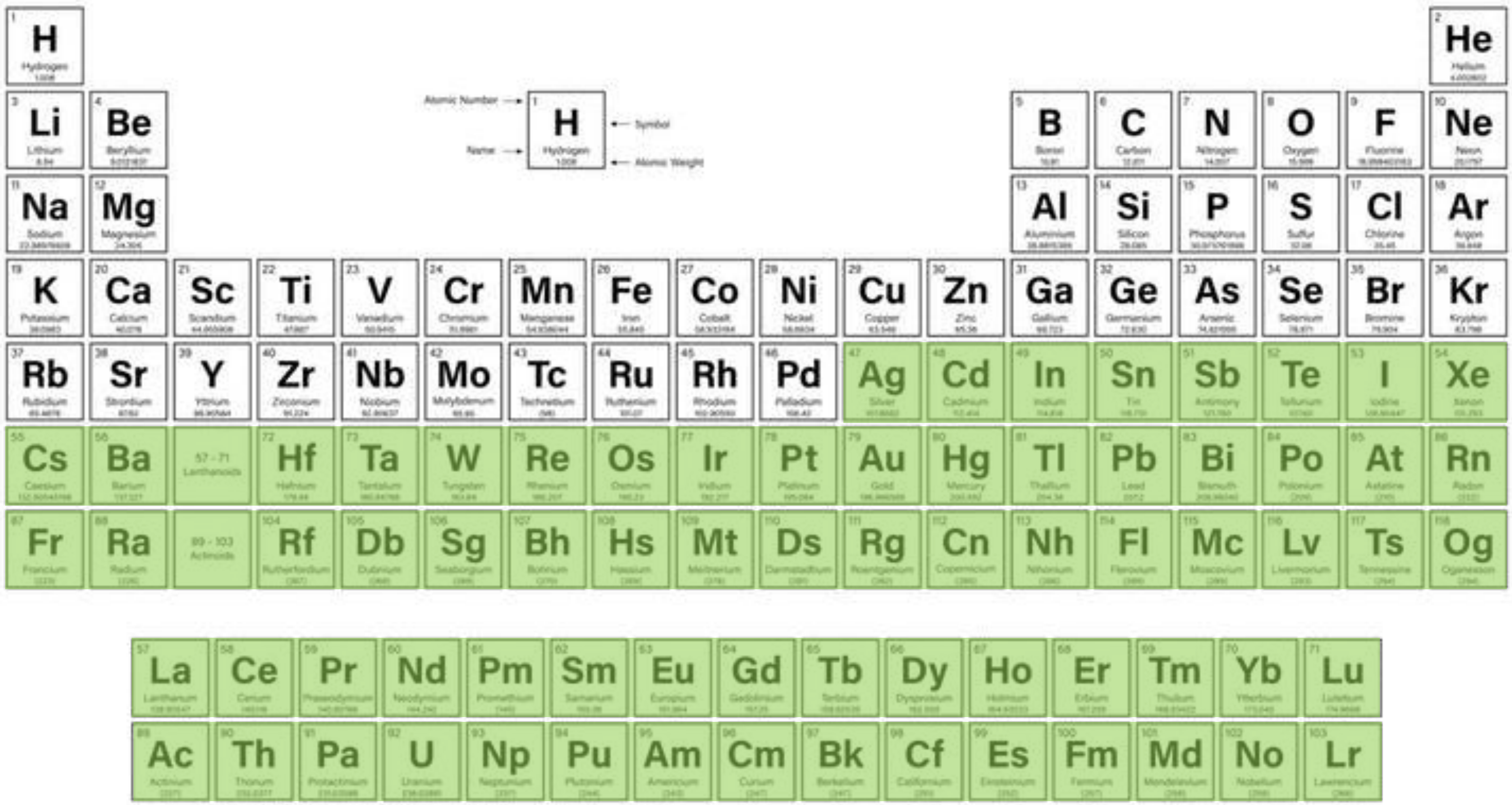
Principle of spectral CT



Principle of spectral CT

- Spectral CT uses the X-ray absorption spectrum of the sample
- It shows rapid changes in form of absorption edges (K-edges), which are element specific due to electronic transitions (Knoll, 1999)
- Based on the position of the absorption edge (K-edges), the element can be determined
- With a spectral range from 20 to 160 keV, elements from silver up to actinides can be analyzed by using the K-edge position

Principle of spectral CT – list of elements



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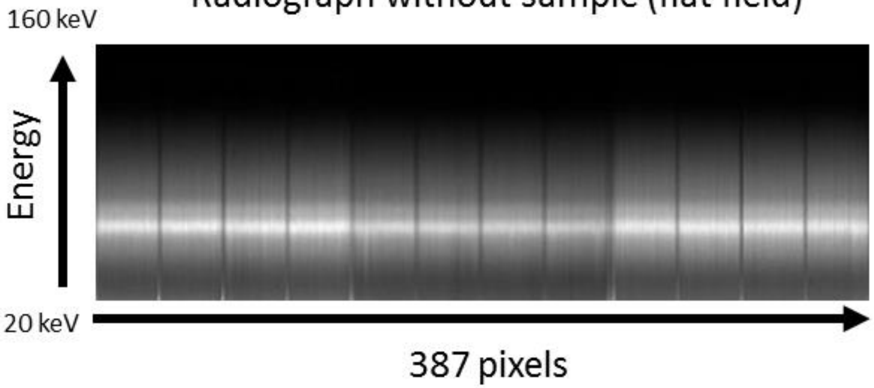
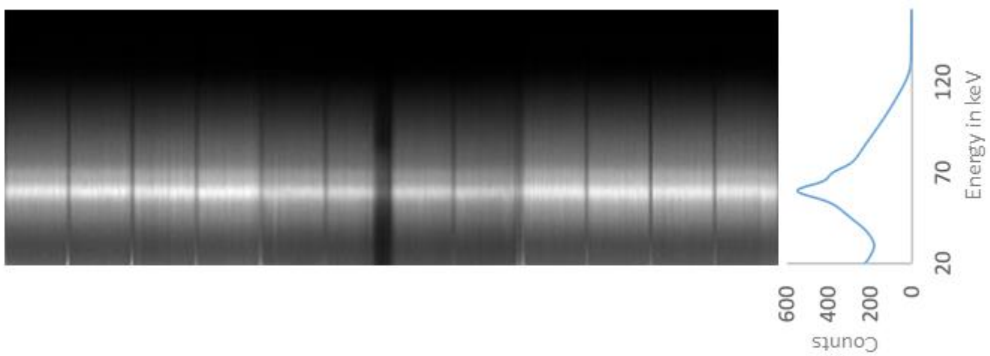
Principle of spectral CT

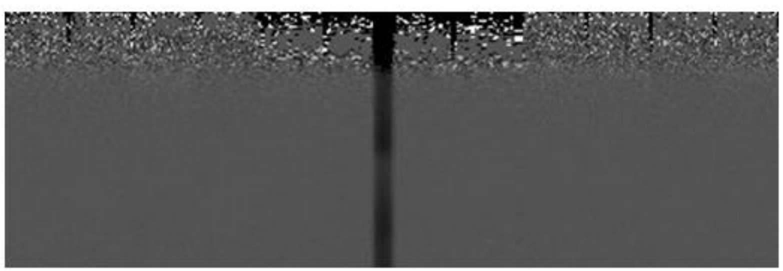
Radiograph without sample (flat field)



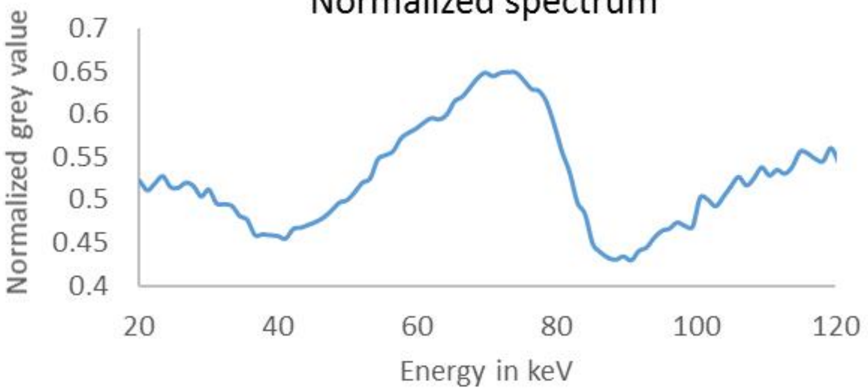
Raw radiograph with sample



Normalized image (radiograph)



Normalized spectrum



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Principle of spectral CT

- The raw signal of the detector shows a local information at the x-direction
- The y-direction of the image (radiograph) represents the energy, from 20 to 160 keV
- The bright horizontal band in the radiographs is the tungsten K-α fluorescence caused by the X-ray tube
- The numerous dark vertical lines are caused by the readout electronics of the detector
- By normalization of the flat field and the radiograph with the sample, artifacts can be removed
- The spectrum can be extracted from the normalized image

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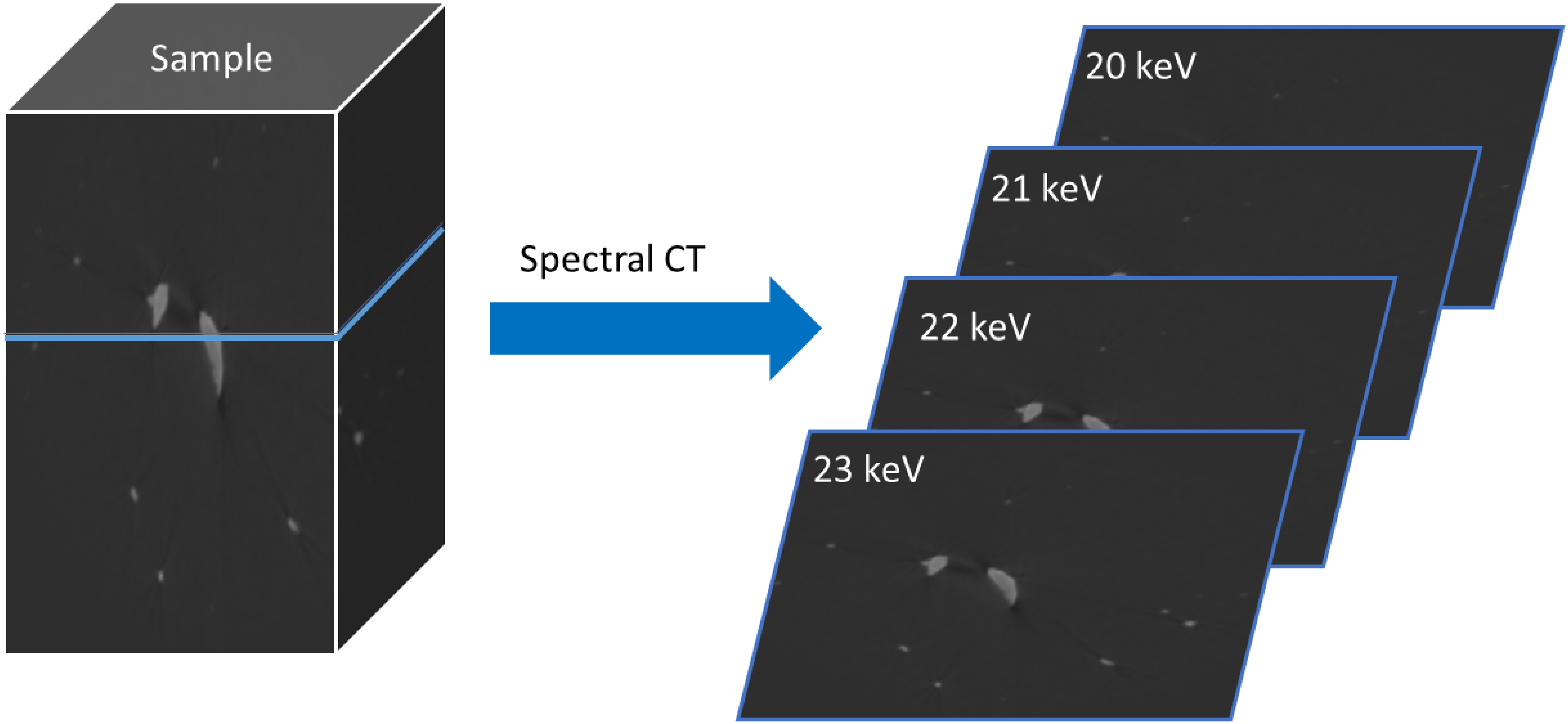
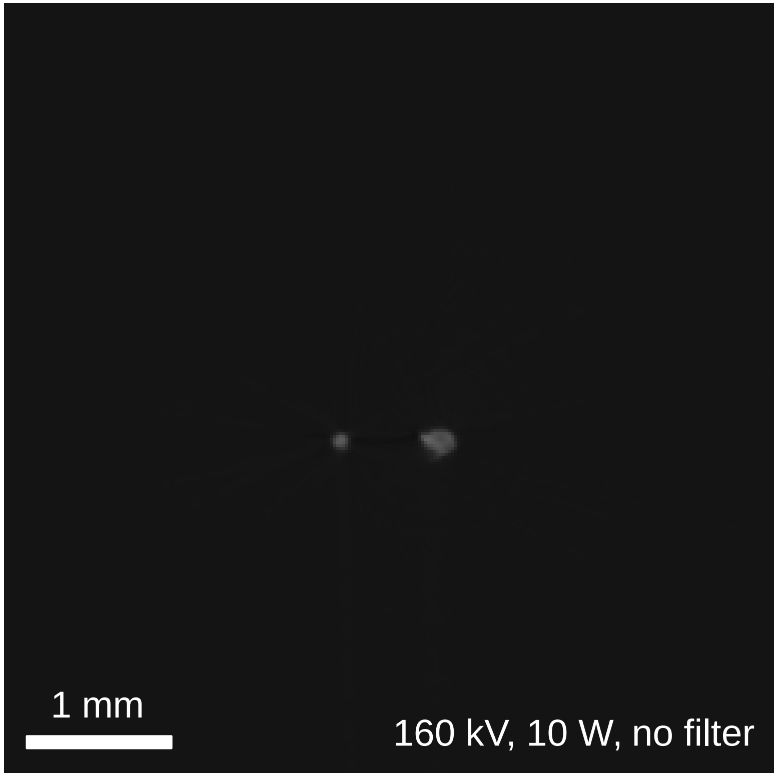
Principle of spectral CT



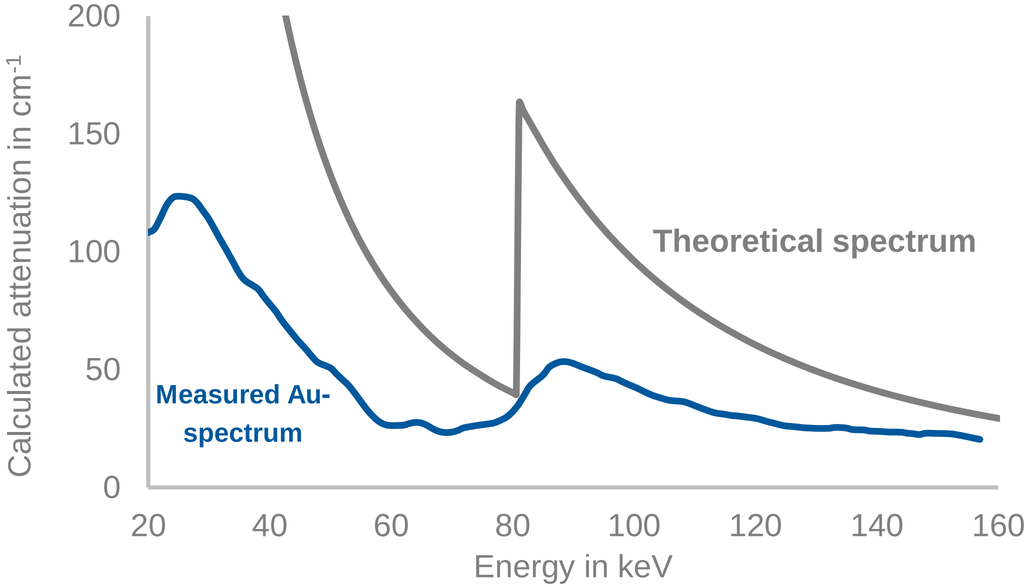
Principle of spectral CT

- One radiograph represents only one rotation angle
- For a full scan, many radiographs from different angles are required
- The result is a stack of images for a 2D plane of the sample, each representing one energy (20 to 160 keV)

K-edge of gold



Gold particles



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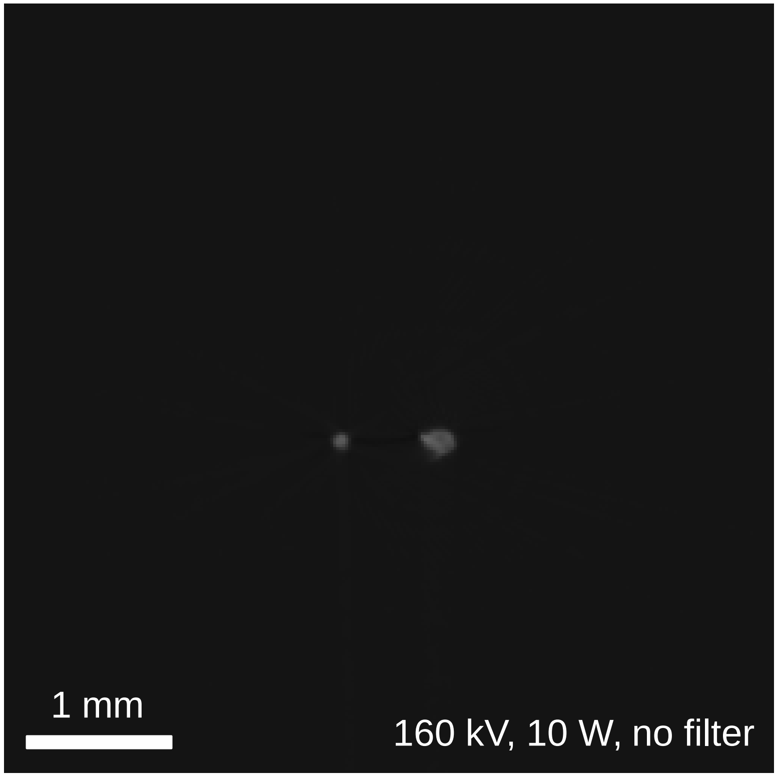
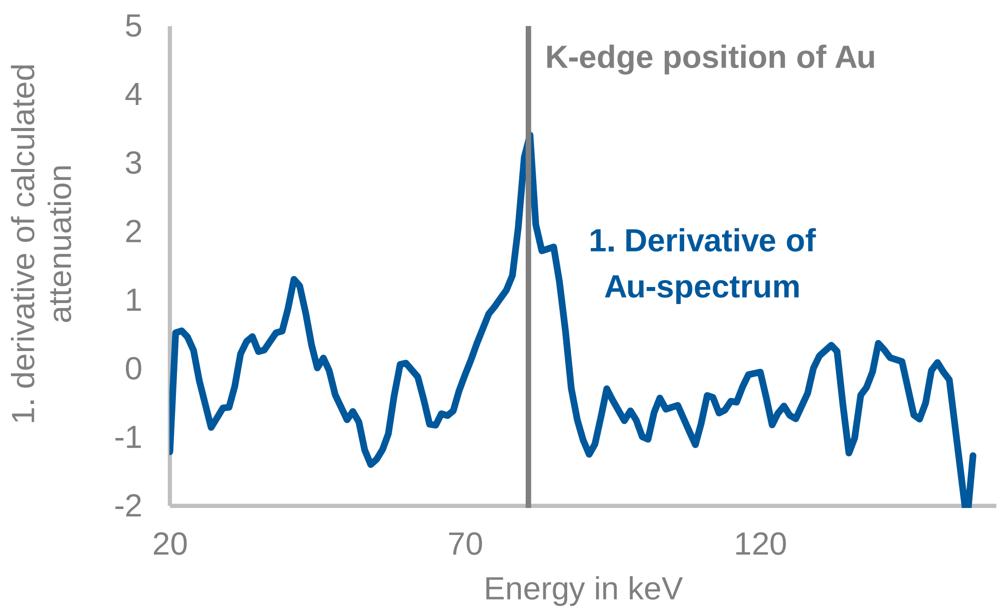
K-edge of gold



Gold particles



K-edge of gold

- The spectrum of a gold particle shows the K-edge

- Compared with the theoretical spectrum, there are some differences

- The first derivative shows the exact position of the peak better, to compare it with the theoretical value

- The K-edge position matches with the theoretical position

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Particle classification

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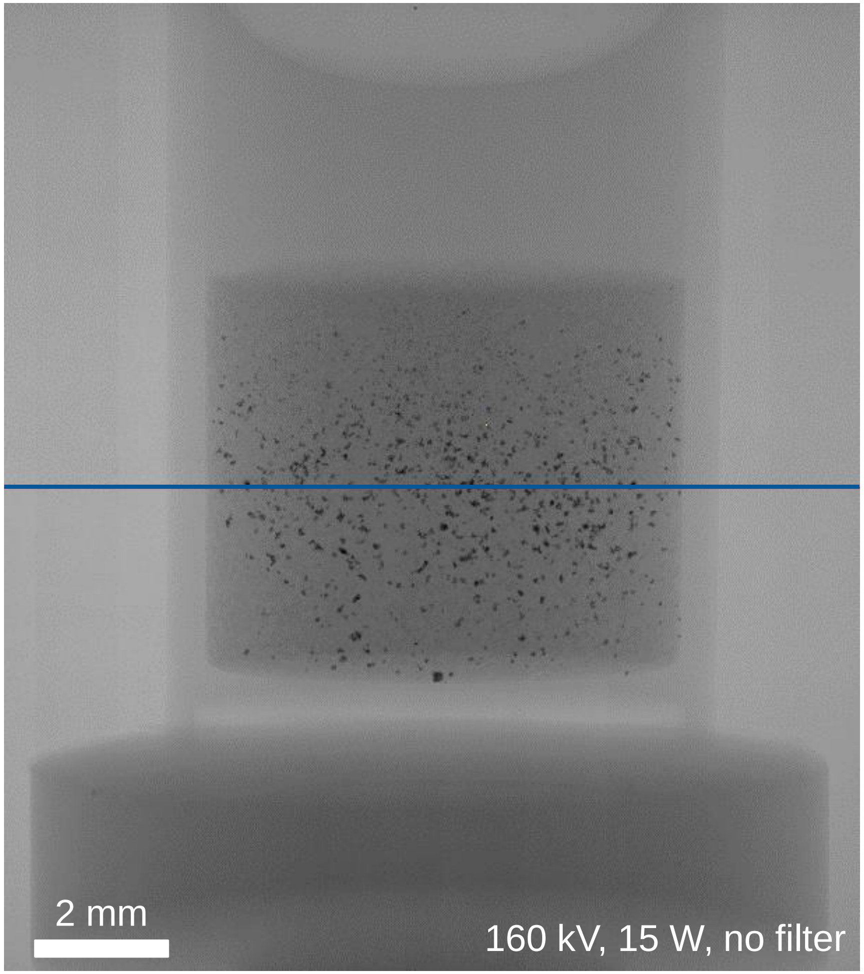
Preparation of a quartz-gold-lead-tungsten mixture

X-ray CT



Quartz, gold, lead, tungsten mixture embedded in epoxy resin

Preparation of a quartz-gold-lead-tungsten mixture

- To test the particle classification using spectral CT, a sample with gold, lead and tungsten was prepared

- Quartz was used as a matrix material, as it shows no absorption edge in the spectral range of interest

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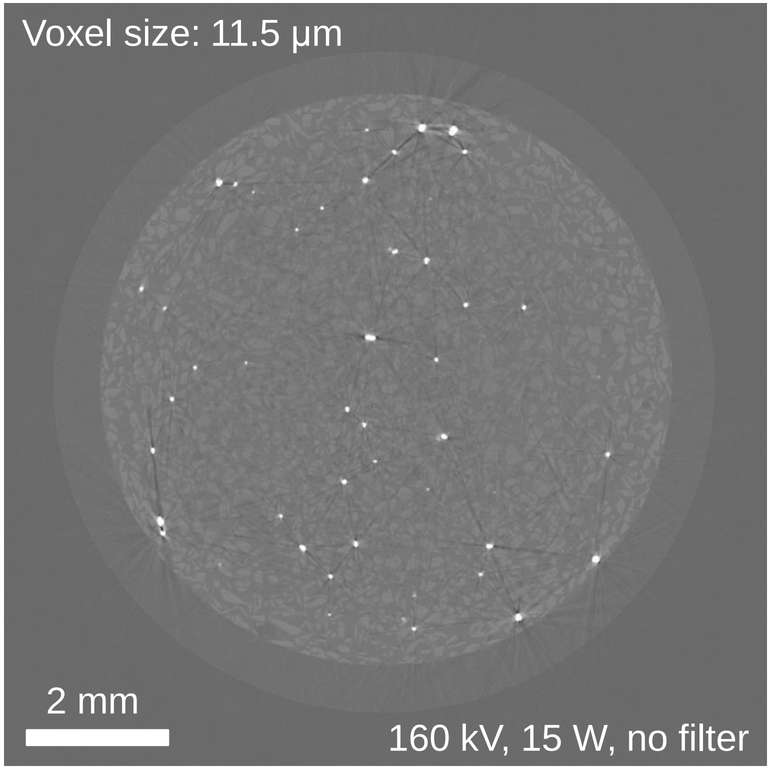
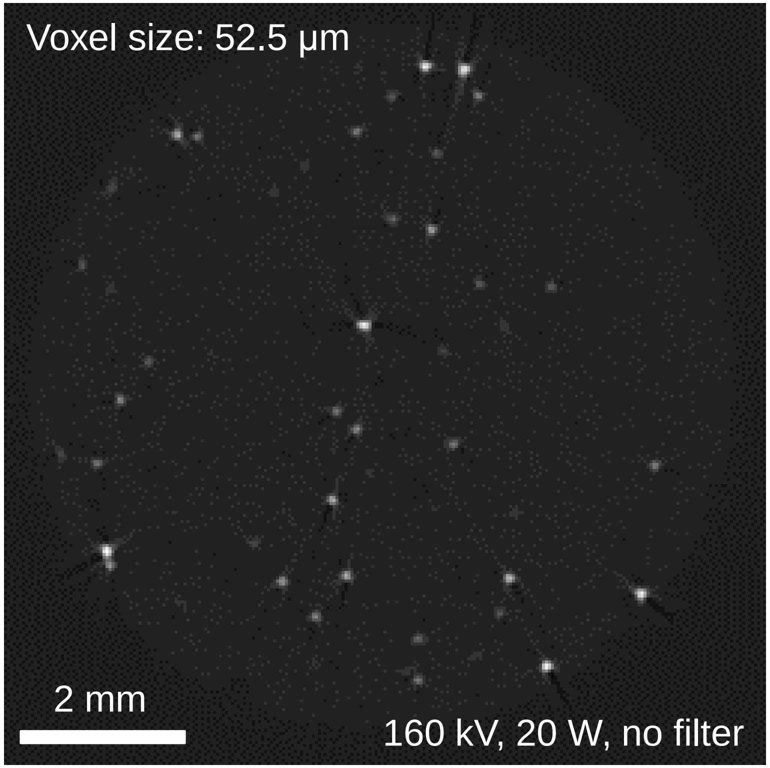
Conventional CT and spectral CT



Spectral CT



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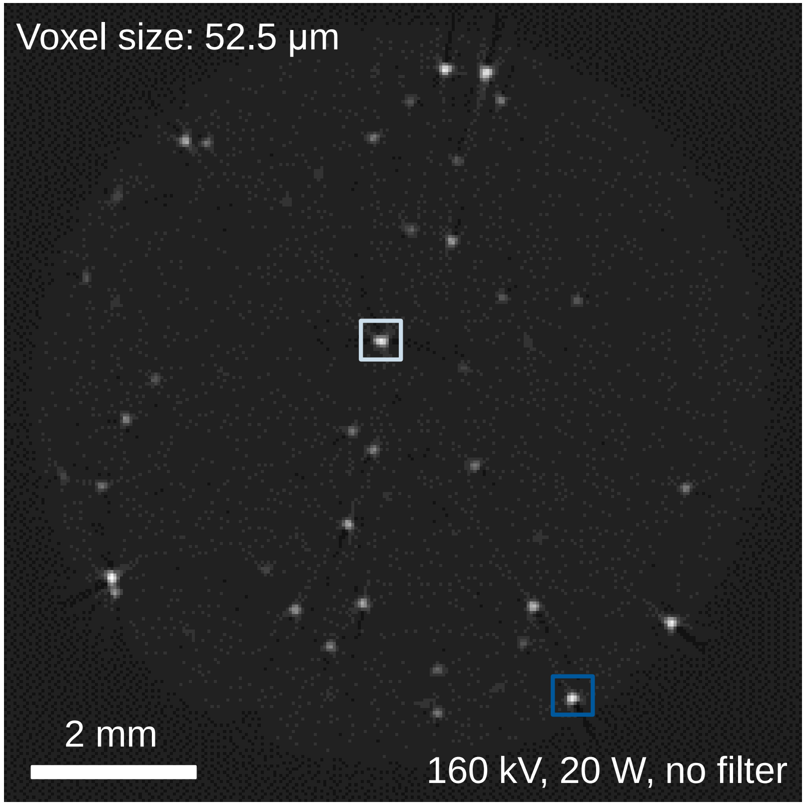
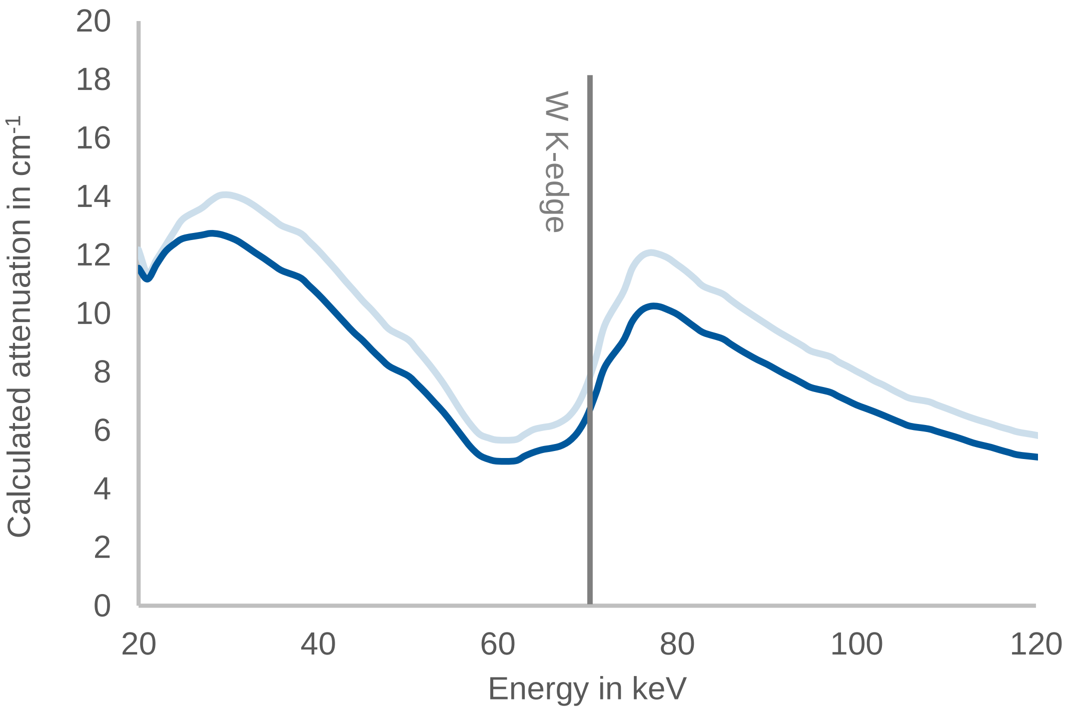
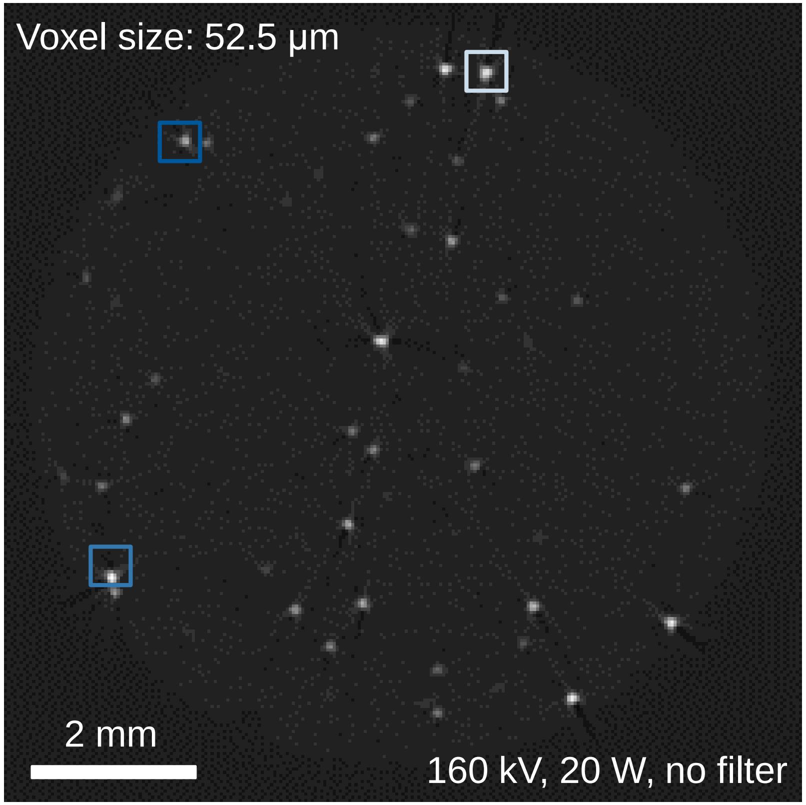
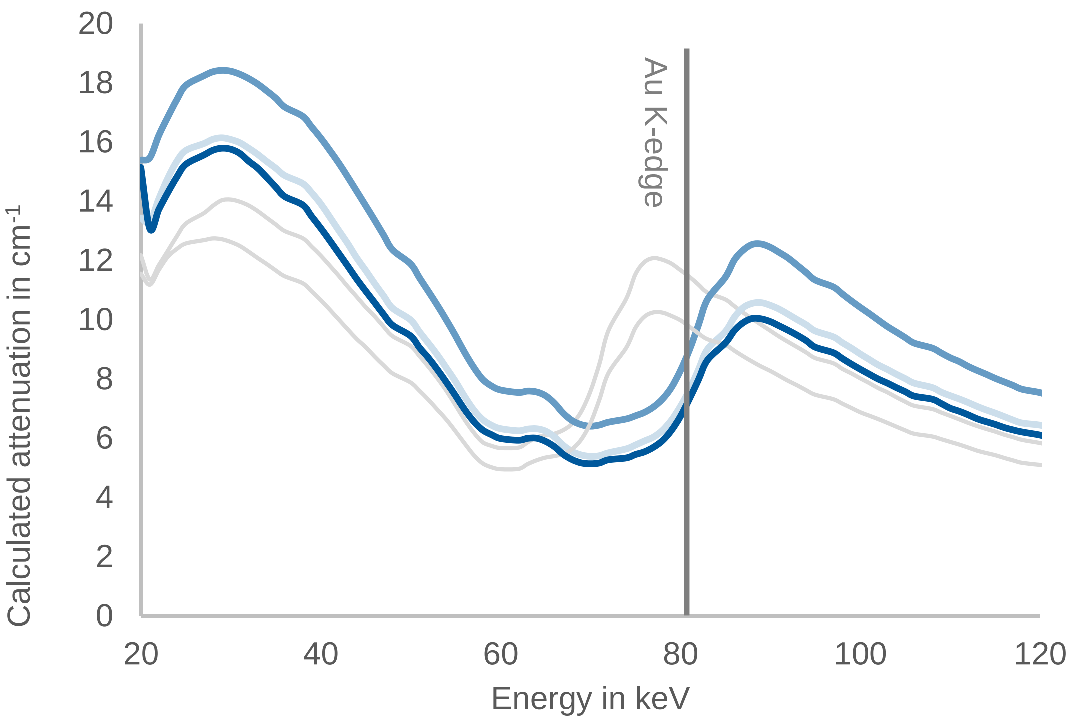
Particle classification – tungsten





Particle classification – gold





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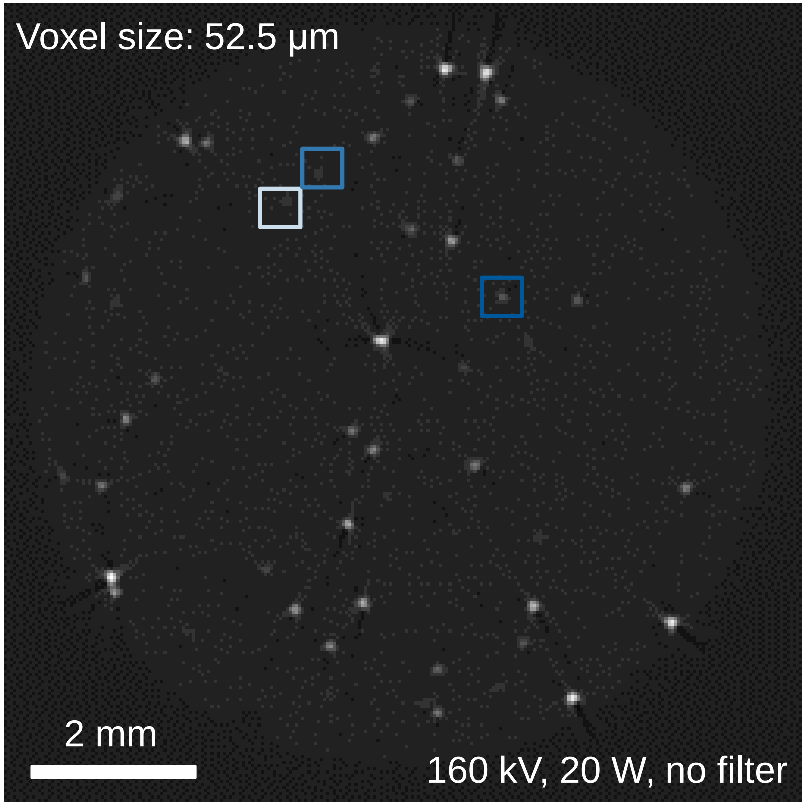
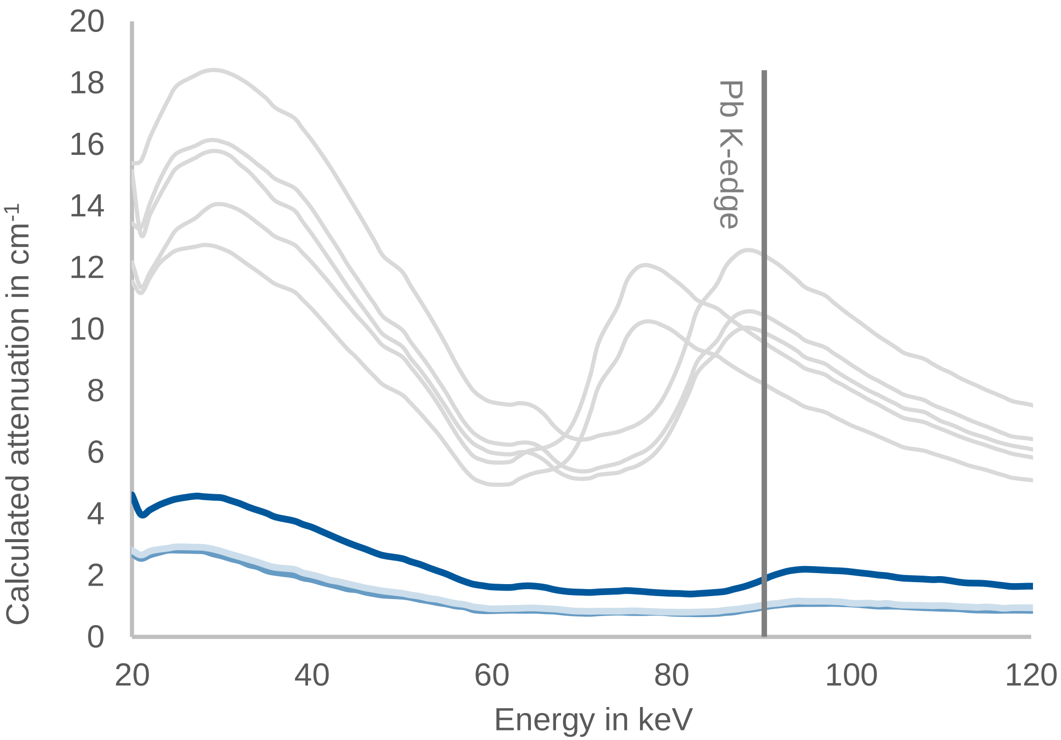
Particle classification – lead





Based on the position of the K-edges in the spectrum, gold, lead and tungsten can be distinguished

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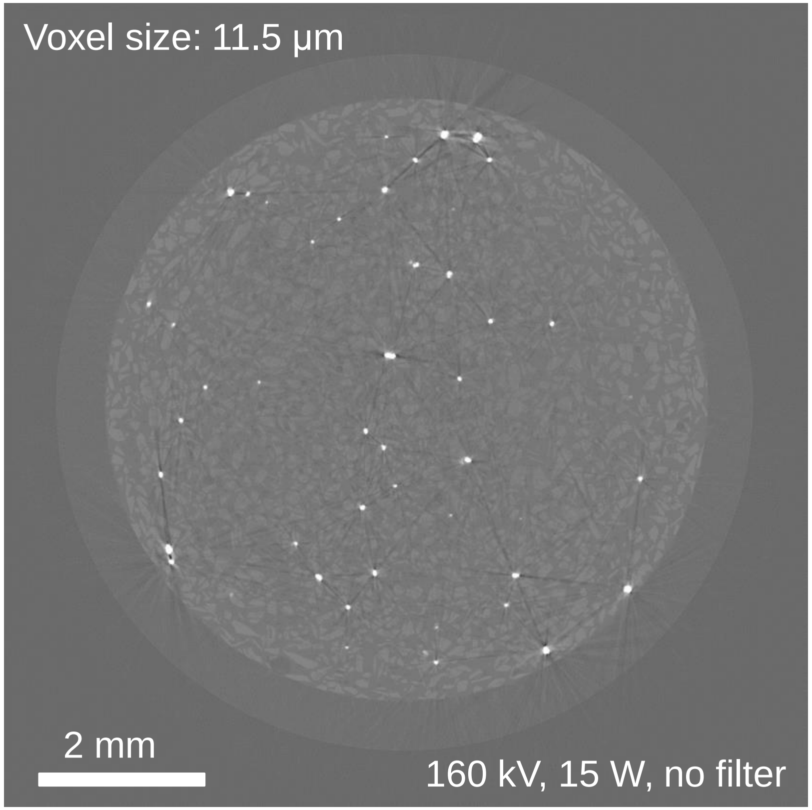
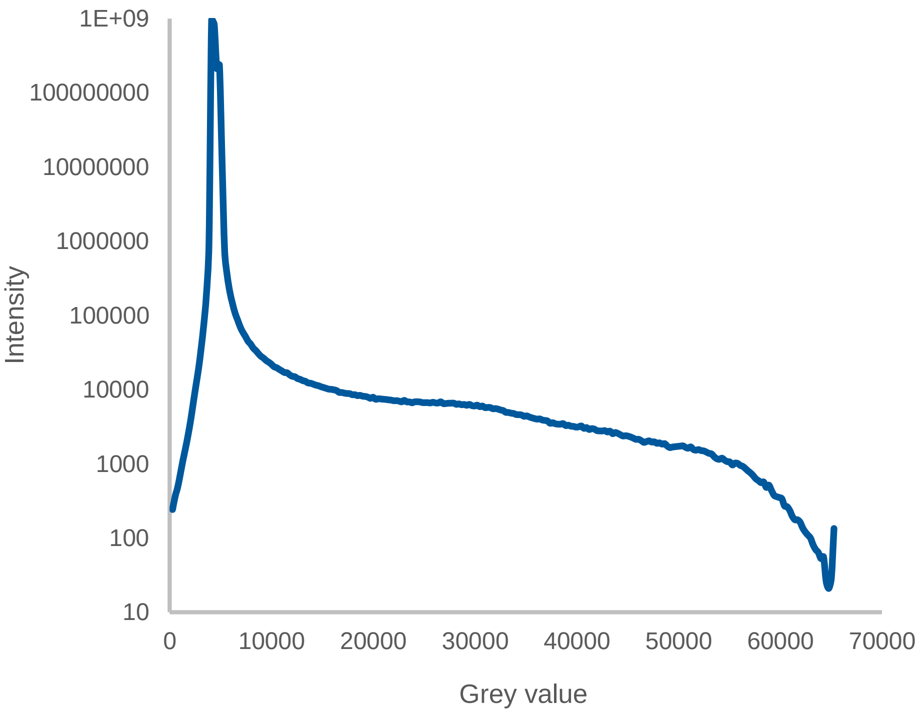
Particle classification – conventional CT



Quartz, gold, lead, tungsten mixture



It is not possible to distinguish between the particles by using conventional CT with the same sample

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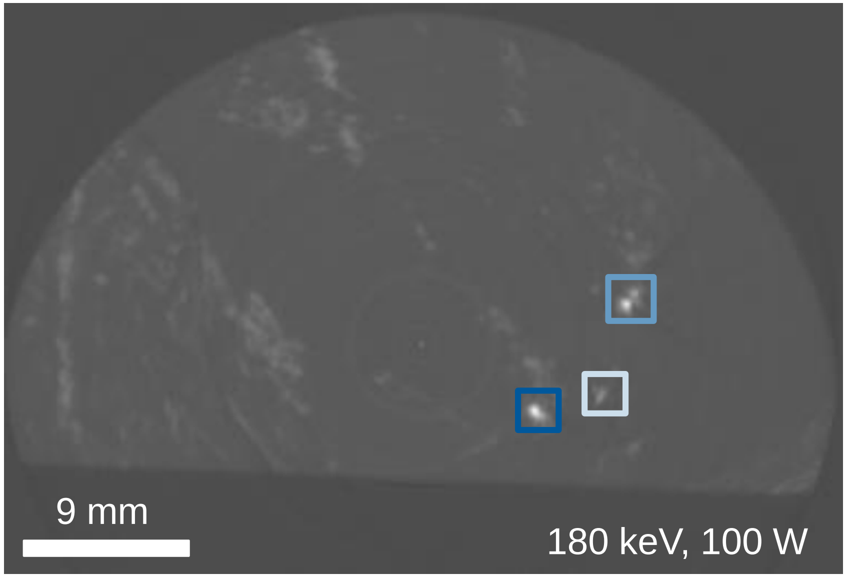
Particle classification

– All particles can be differentiated based on the position of the K-edge even though their greyscale pattern appears the same in the image

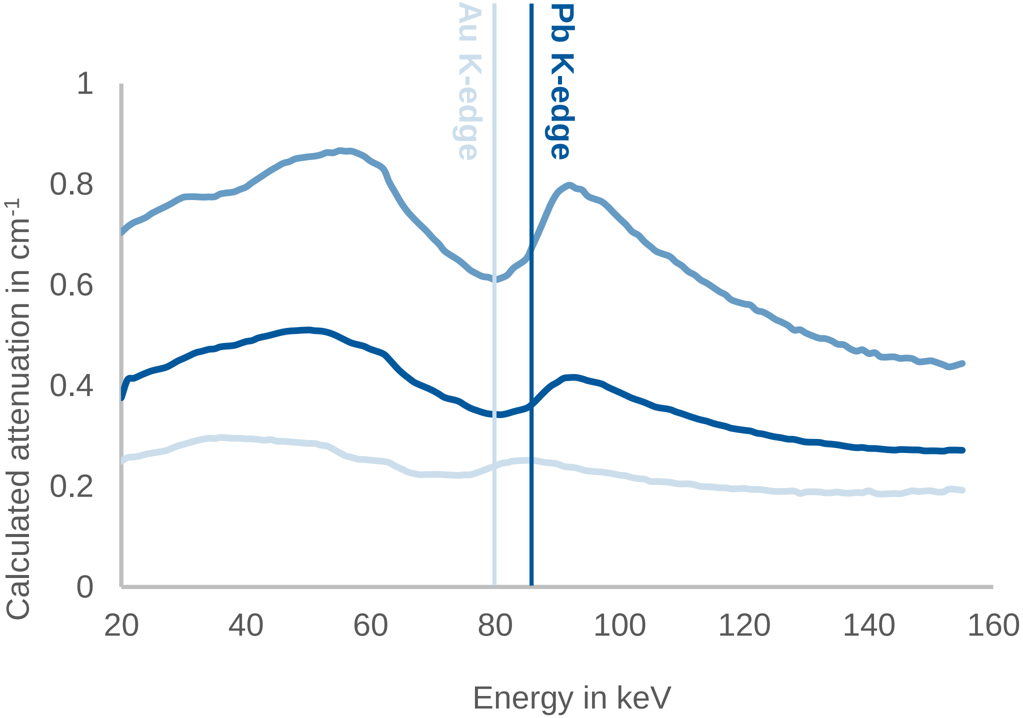
– With the greyscale histogram from a conventional CT it is not possible to differentiate the particles

– With spectral CT it is possible to obtain chemical information from a CT scan without using additional analytical methods

Particle classification – rock sample



Quartz vein with different sulfide minerals and native gold, Massawa Gold Deposit, Senegal



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Particle classification – rock sample

- This gold ore from the Massawa deposit in Senegal contains different sulfide minerals and native gold
- With spectral CT we are able to differentiated between particles containing gold and lead
- The theoretical position of the K-edges matches with the measured spectra and allows a discrimination of both elements

3D Particle Information

2D vs 3D particle information

- Usually simulations use 2D information of the particles measured in a sample
- CT provides the 3D information of the particles and can scan a larger volume, which is more representative
- Here we compare the 2D and 3D particle information in different size fractions of a gold floatation concentrate

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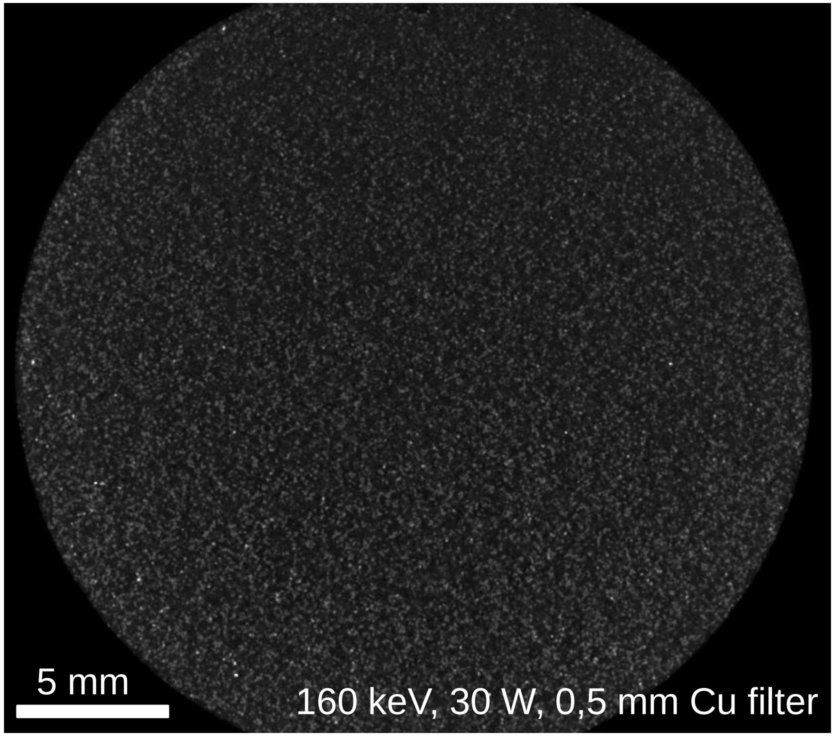
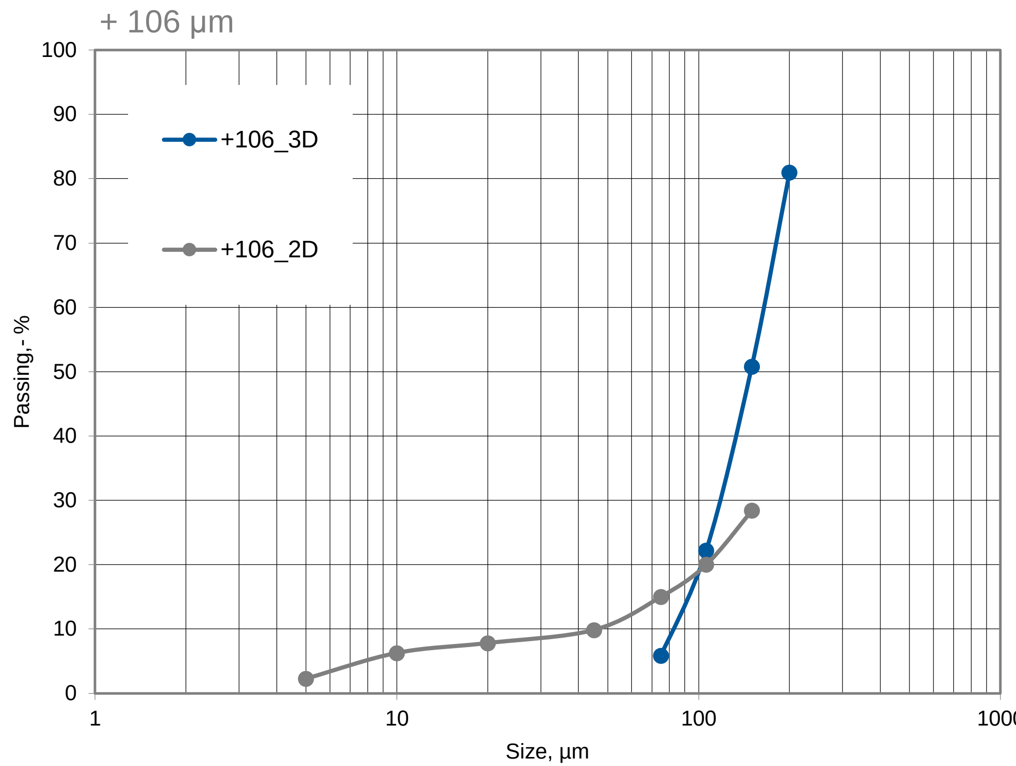
2D vs 3D particle information





Gold flotation concentrate, Jokisivu Mine, Finland

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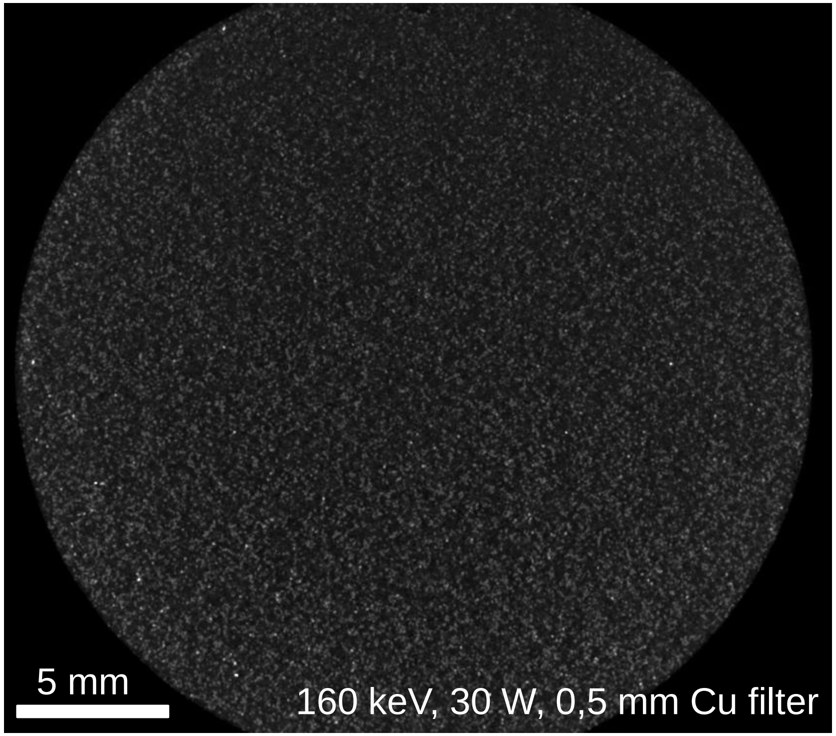
2D vs 3D particle information



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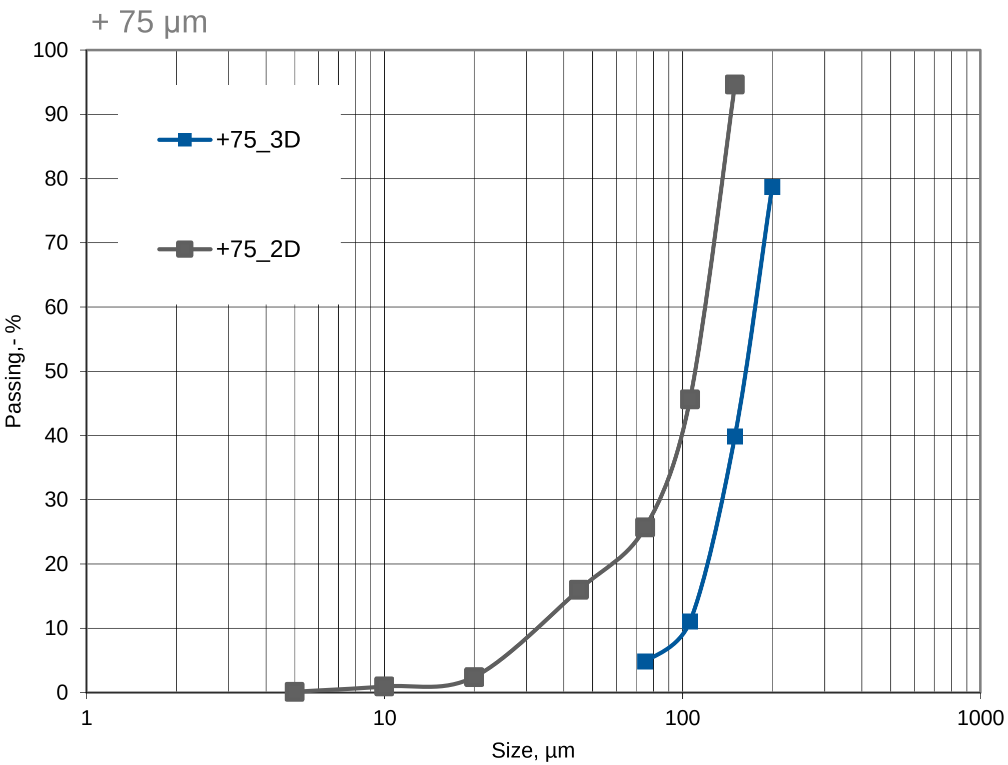
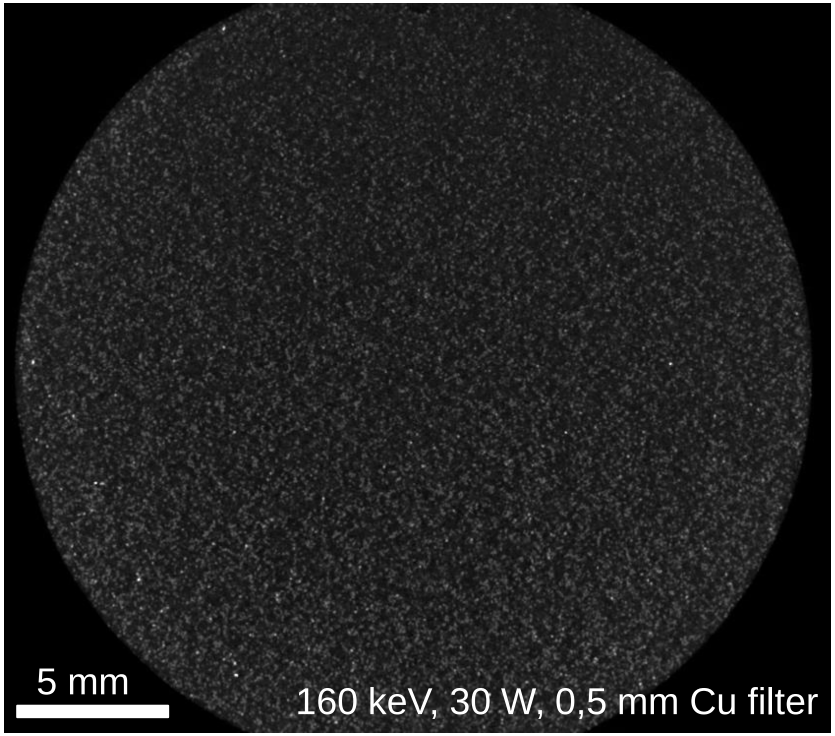


2D vs 3D particle information



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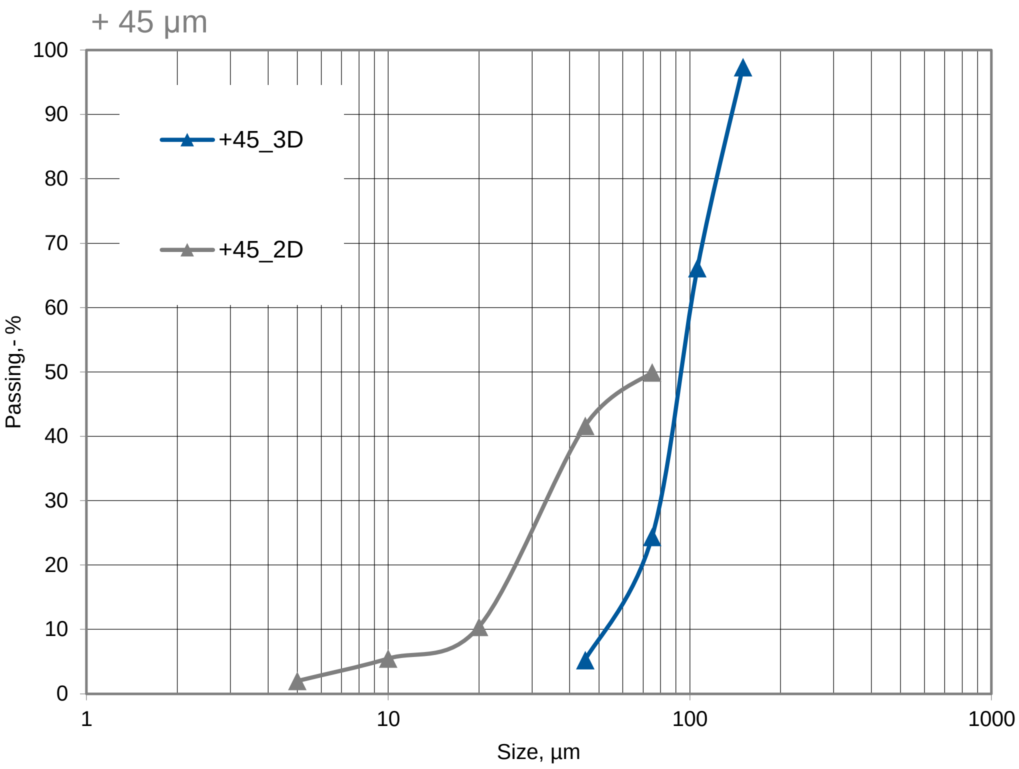

2D vs 3D particle information

- A lot of simulation in minerals processing use 2D particle information
- With CT scans the particle information are available in 3D
- The comparison between 2D and 3D shows that the maximum particle size is larger in the 3D data and their shape is comparable
- With the 3D data the simulations are more reliable according to the specific sample

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Summary

– Spectral CT combines conventional CT with a photon-counting detector

– Based on the X-ray absorption spectrum different absorption edges (K-edges) and therefore elements can be distinguished

– With the additional 3D particle information, simulations can be optimized

Thank you for your attention!

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References

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