# Phase-contrast 3D imaging of fibre-reinforced polymers: comparison of laboratory and synchrotron X-ray sources

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CTLAB X-ray Computed Tomography

## Introduction

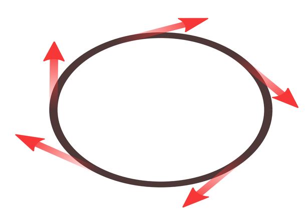
Absorption X-ray computed tomography (CT) is based on X-ray absorption of the sample. In case of weakly absorbing samples, such as biology soft tissue and scaffolds, the contrast is mostly insufficient and for CT measurements, these samples have to be stained or phase contrast imaging methods (PCI) have to be applied [1].

PCI relies on the fact that X-rays transmitted through the sample are not only attenuated, but they are also phase shifted due to their interaction with the material. X-rays transmitted through the sample are also slightly deviated from the original direction as they diffract on inner structures of material. When X-ray deviations associated to different structure sizes propagate through a certain distance, their wavefronts interfere and form a phase contrast. If tomographic setup is modified just by enlarging the distance between the sample and the detector, this phase contrast becomes visible in form of edge enhancement. This approach is called propagation based imaging (PBI) [2].

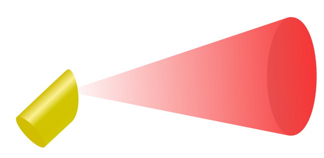
Post processing of PBI data cover application of phase retrieval algorithm [3]. It calculates map of phase shift of transmitted X-rays. From an image processing point of view, application of phase retrieval algorithm is necessary to remove the edge enhancement and to get data with less noise and multi-modal histogram, which allows to segment different object structures more easily.


3D render of CT data from laboratory source with CCD camera. The sample consists of PE matrix, carbon fibres (orange) and air voids (blue).

## Influence of X-ray source on PCI



An X-ray beam with a sufficient degree of spatial coherence is required for propagation based imaging. Third generation synchrotron sources provide coherent, high flux X-ray beam which allows to use large sample-to-detector distances.



For laboratory X-ray sources, a high degree of coherence can be achieved by a small focal spot size (microfocus and nanofocus X-ray tubes) and for appropriate image acquisition conditions. Most of industrial laboratory-based CT systems use flat panel detectors systems. Utilization of CCD or CMOS detectors significantly improves detection and segmentation of data with edge enhancement even with laboratory-based CT systems.

## Methodology

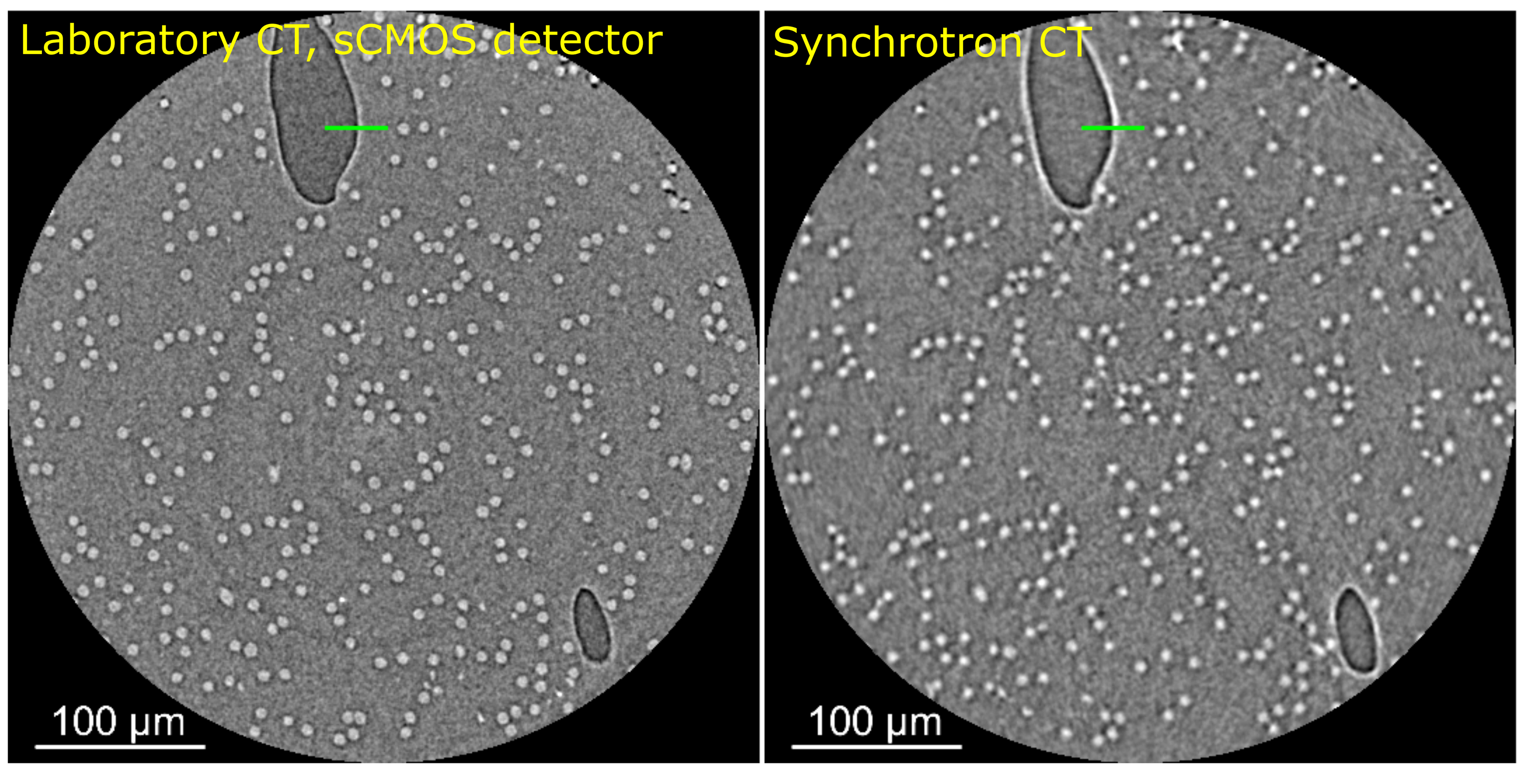
The sample of carbon fibres reinforced polyethylene (PE) was scanned on the laboratory CT RIGAKU Nano3DX at Brno University of Technology, with both CCD and sCMOS detector (reconstruction by RIGAKU software), and at synchrotron Elettra, Trieste, in Italy (reconstruction with SYRMEP Tomo Project [5].

Phase retrieval was applied using ANKAphase [3] for data from laboratory CT and Paganin algorithm [4] for synchrotron data.

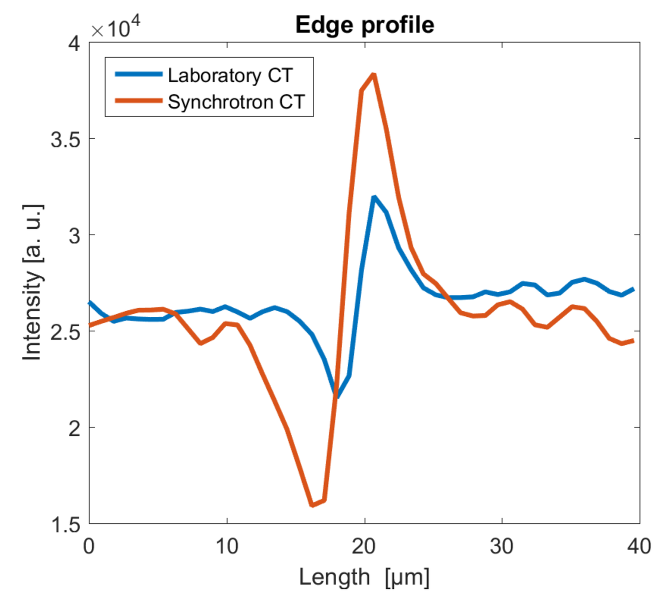
Edge enhancement due to phase contrast effects over edges was observed on edge profiles and signal to noise ratio (SNR) was calculated.

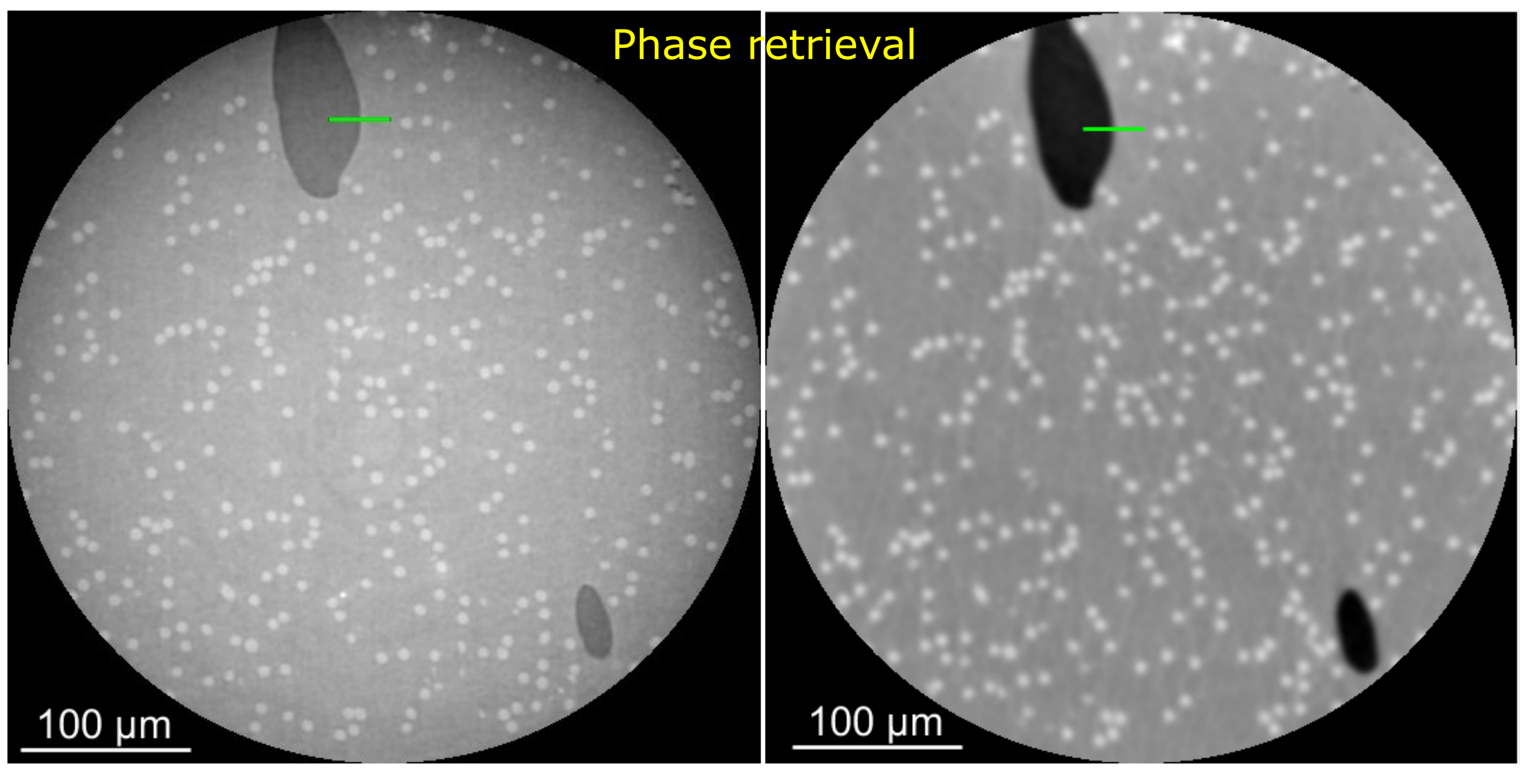
| | Laboratory CT RIGAKU Nano3DX | | Synchrotron CT SYRMEP, Elettra |
|---|---|---|---|
| X-ray source settings | X-ray tube with Cu target working at 40 keV | | White beam mode, filters 1.5 mm Si, 0.025 mm Mo |
| Detector | CCD | sCMOS | sCMOS |
| Voxel size | $(0.53\ \mu m)^3$ | $(0.64\ \mu m)^3$ | $(0.9\ \mu m)^3$ |
| Exposure time | 6 s | 1.6 s | 1.5 s |
| Projections | 800 | 800 | 2000 |
| Time of scanning | 1 h 43 min | 48 min | 50 min |
| Sample-detector distance | 2 mm | | 200 mm |
| Signal-noise ratio | 16 dB | 12 dB | 9 dB |

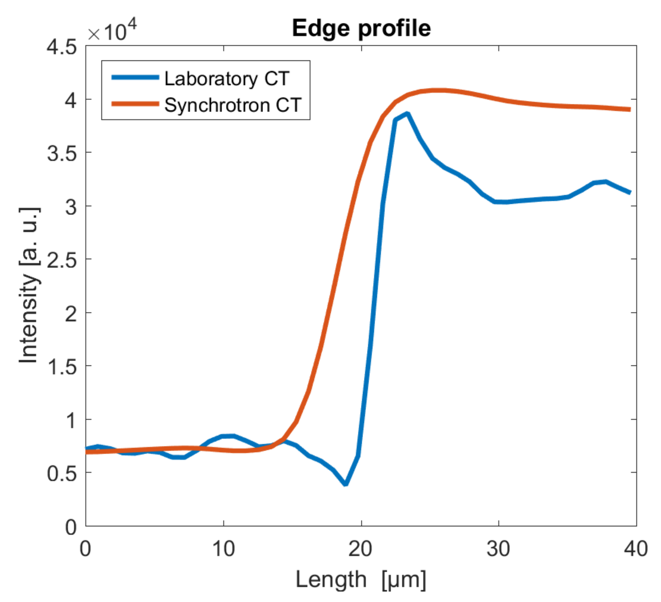
## Results

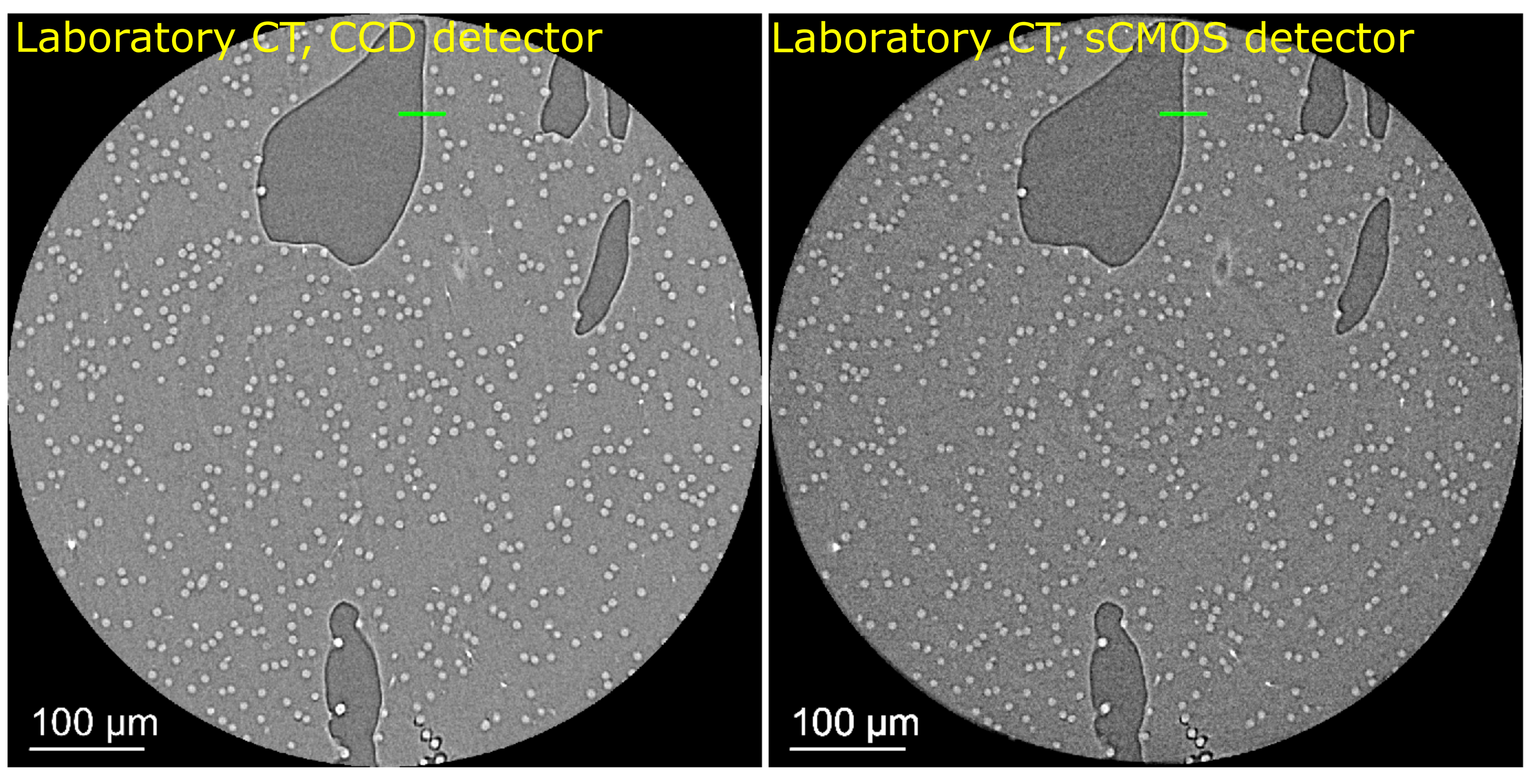


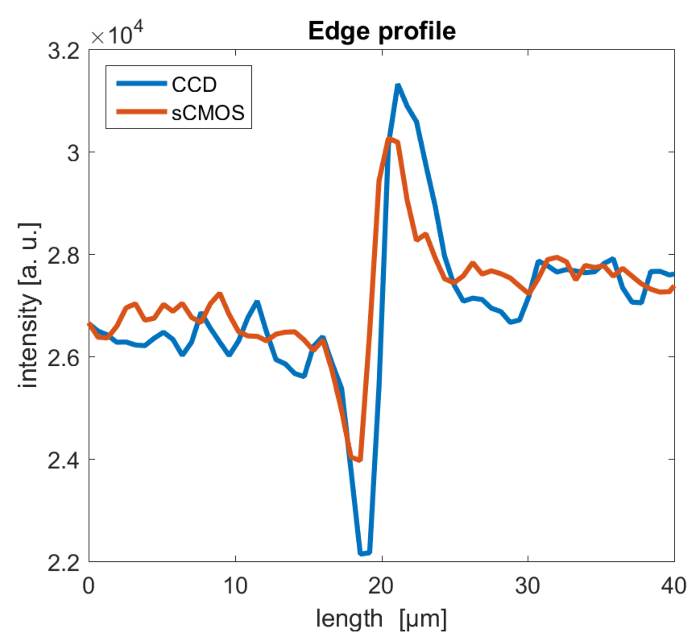

For demonstration of edge enhancement, edge profiles were generated. 10 pixels above and below the green line slices were averaged to reduce the




## Summary

Phase contrast imaging in propagation based method was examined on measurement of carbon fibres reinforced PE sample. Laboratory CT with CCD and sCMOS detector and synchrotron CT with CCD detector were compared.

Looking at edge profile, synchrotron measurement shows higher amount of edge enhancement as expected. The same effect is also observed with laboratory source to a lesser extent, and SNR is higher in this case. The fibers can be better resolved in laboratory CT data, partially because of the better voxel resolution. Phase retrieval removed edge enhancement in both cases, the edge is smoother in synchrotron data.

Comparison of CCD and sCMOS detector with laboratory X-ray source show CCD data as with less noise and also stronger edge enhancement. sCMOS, on the other hand, allows faster measurement thanks to its higher sensitivity.

At synchrotrones, PBI is commonly utilized method. As it was shown, it is possible to exploit advantages of PBI also with laboratory X-ray sources. Possible applications include imaging of light, low contrast materials like soft tissue, scaffolds, polymers etc., with high spatial resolution. Much higher accessibility of laboratory CT allows users to perform long-term PBI experiments in laboratory conditions.

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