

Low dose phase contrast imaging

Using Advapix detectors with
Timepix 3.

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Niels Bohr Institute

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DTU

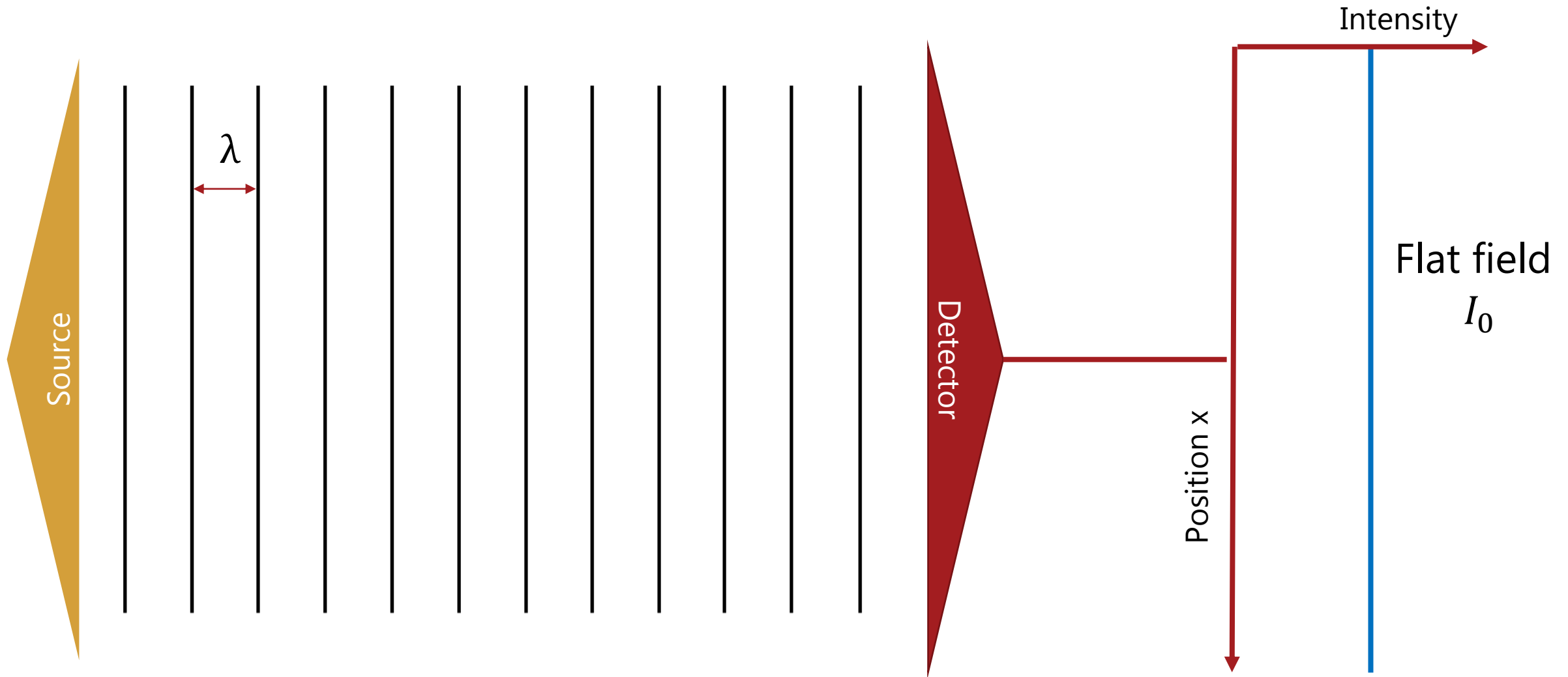


**Technical University
of Denmark**

ADVACAM

Imaging the Unseen

X-ray imaging background

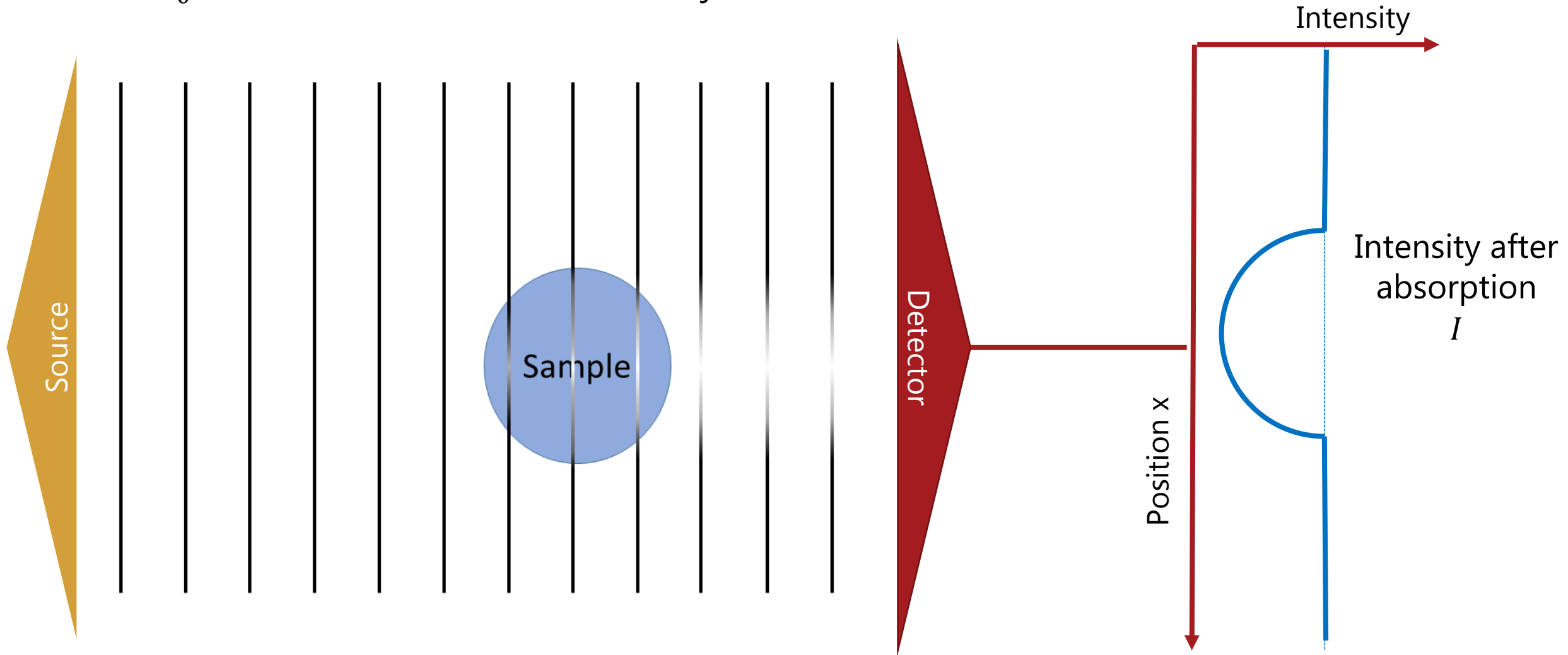


X-ray imaging – absorption

Absorption:
 $I = I_0 e^{-\mu T}$

μ : Linear attenuation coefficient (dependent on β)
T: Thickness of object

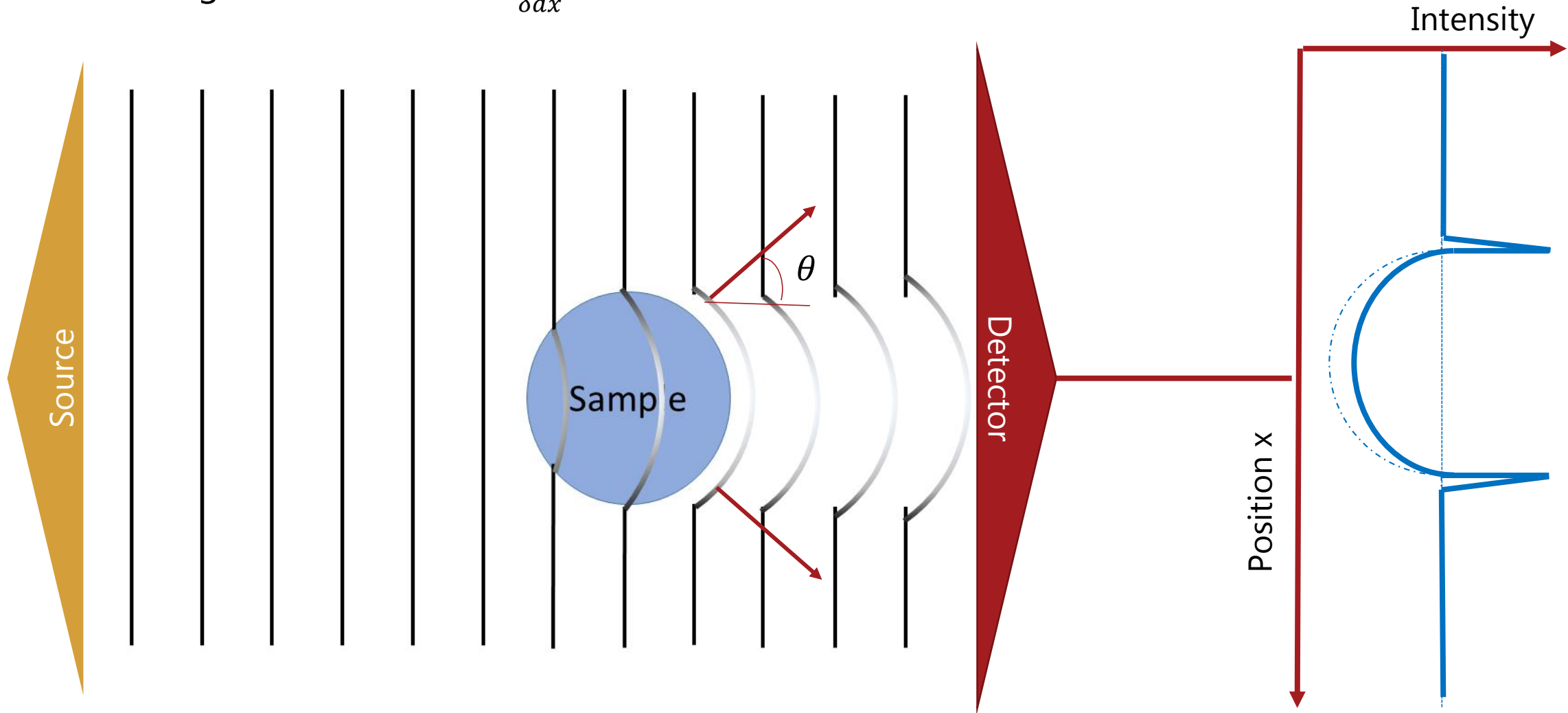
Refractive index
 $n = 1 - \delta + i\beta$



X-ray imaging – refraction

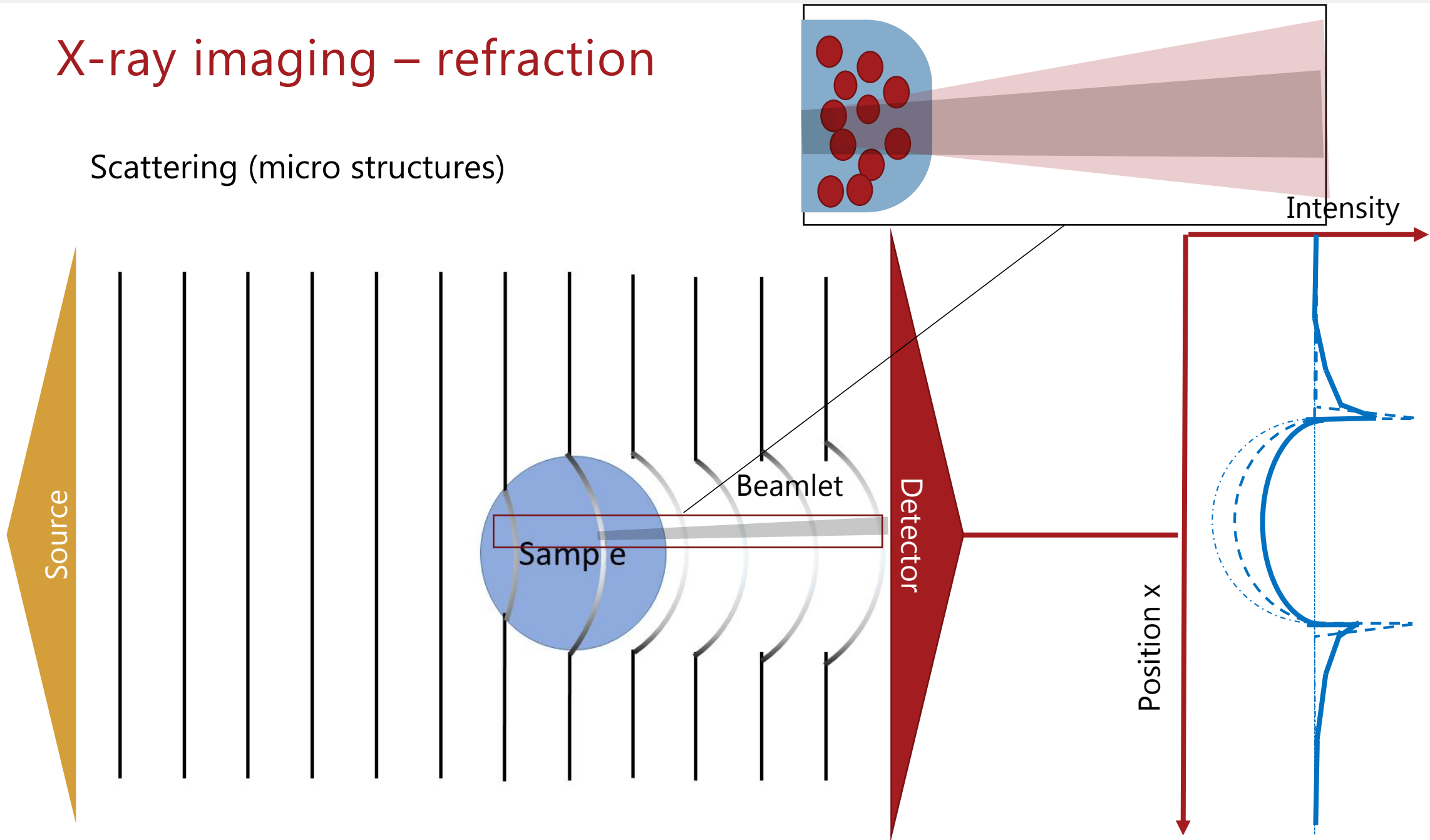
Propagation direction: $\theta = \frac{dT}{\delta dx}$

Refractive index
 $n = 1 - \delta + i\beta$



X-ray imaging – refraction

Scattering (micro structures)

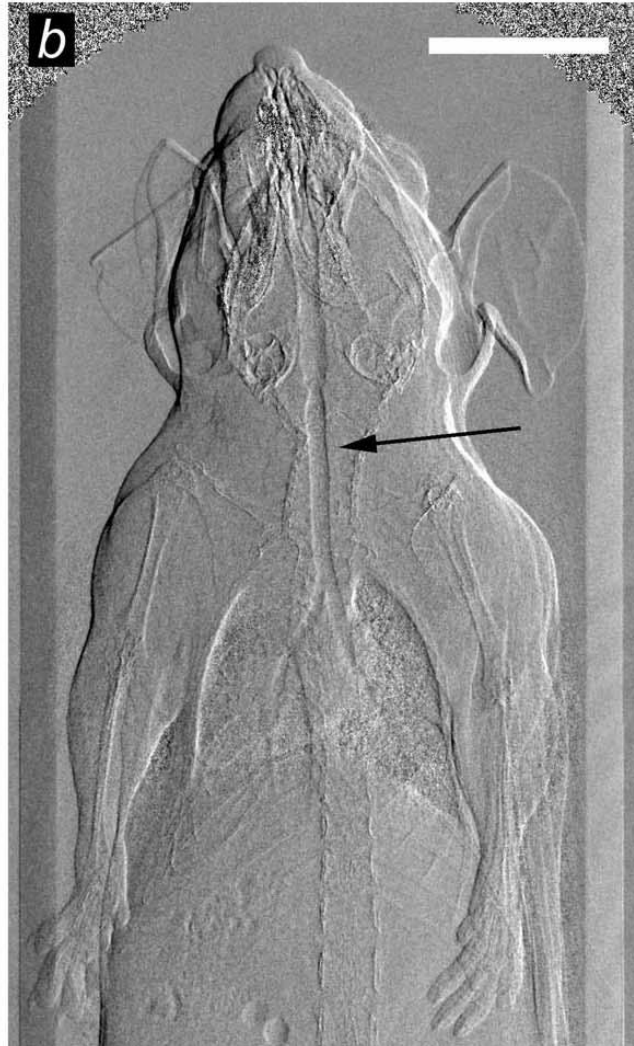


Motivation

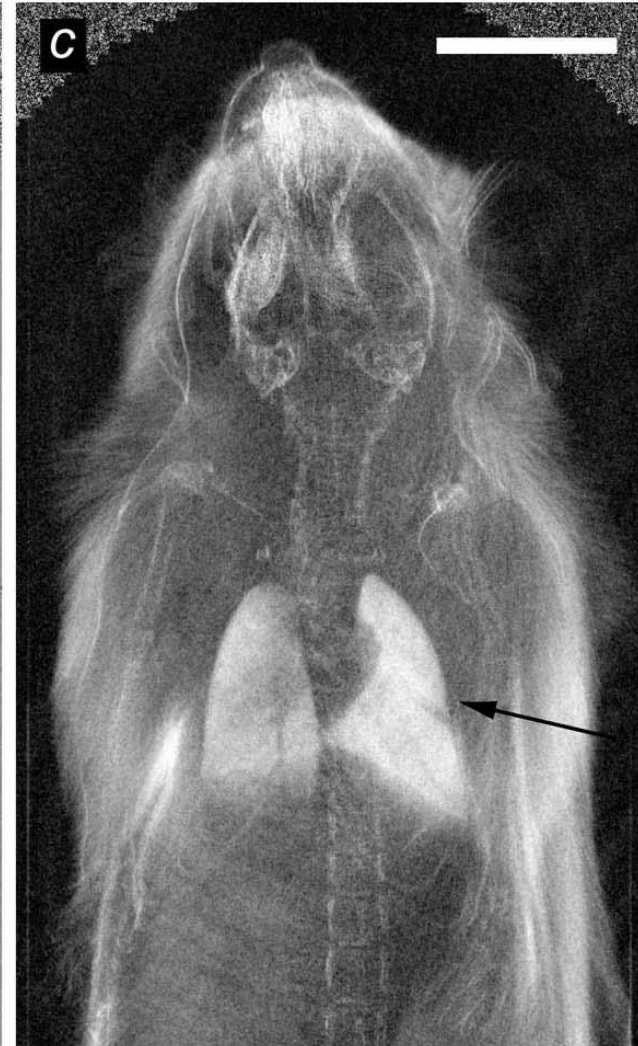
Absorption based image
(standard image)



Refraction based image
(phase contrast image)

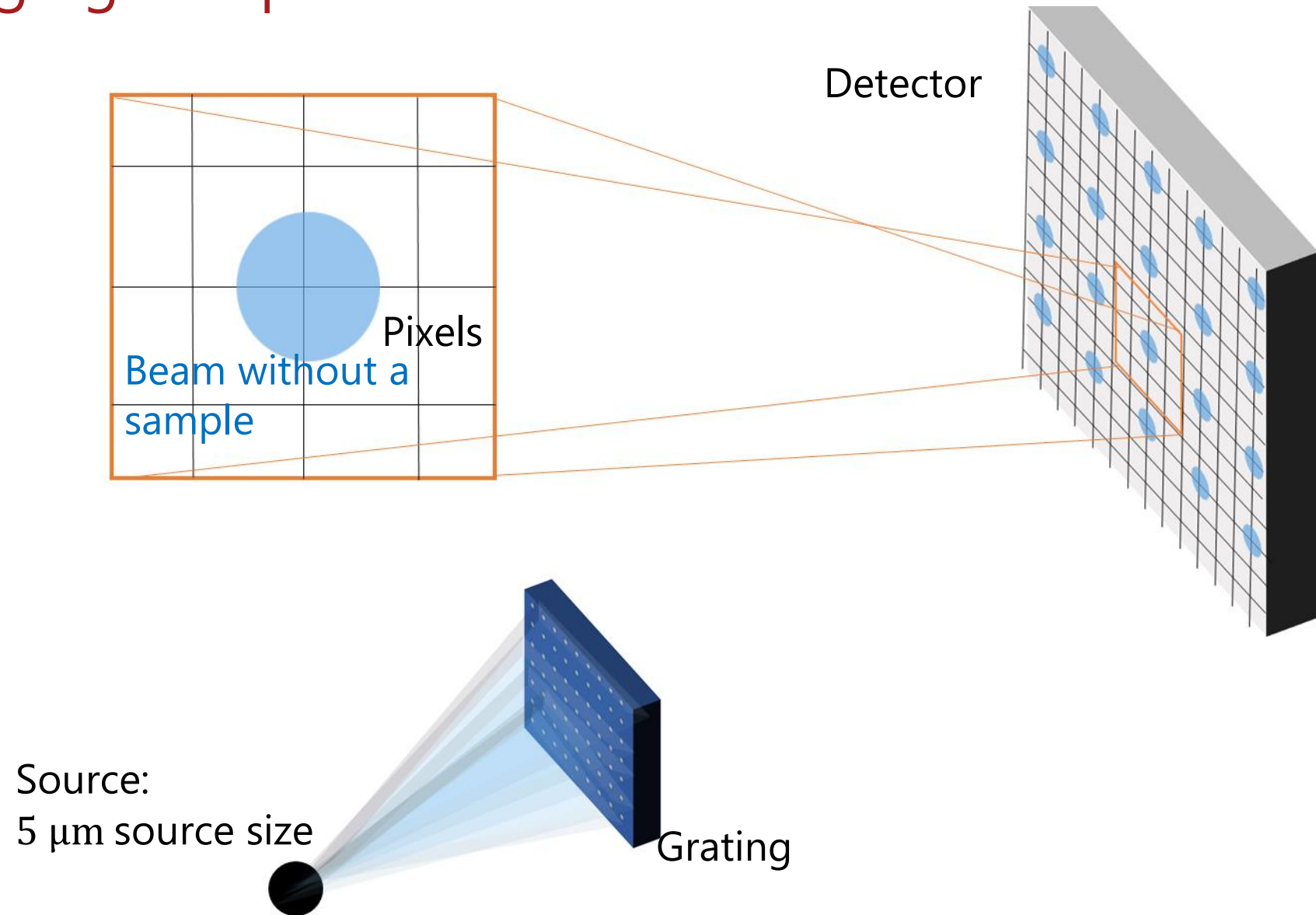


Scattering based image
(dark field)

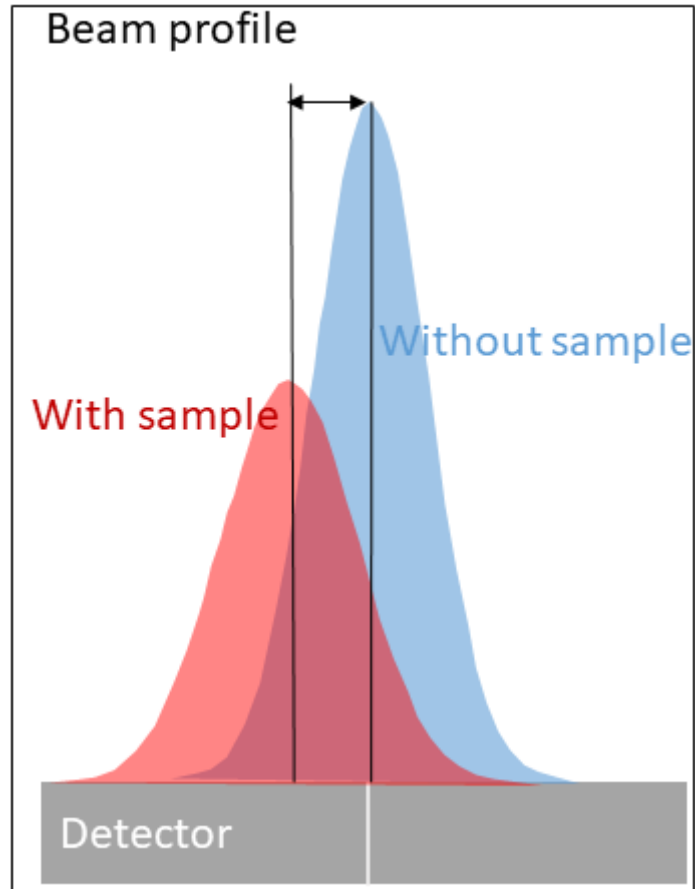


M. Bech et al.
Scientific Reports
3, 3209 (2013)

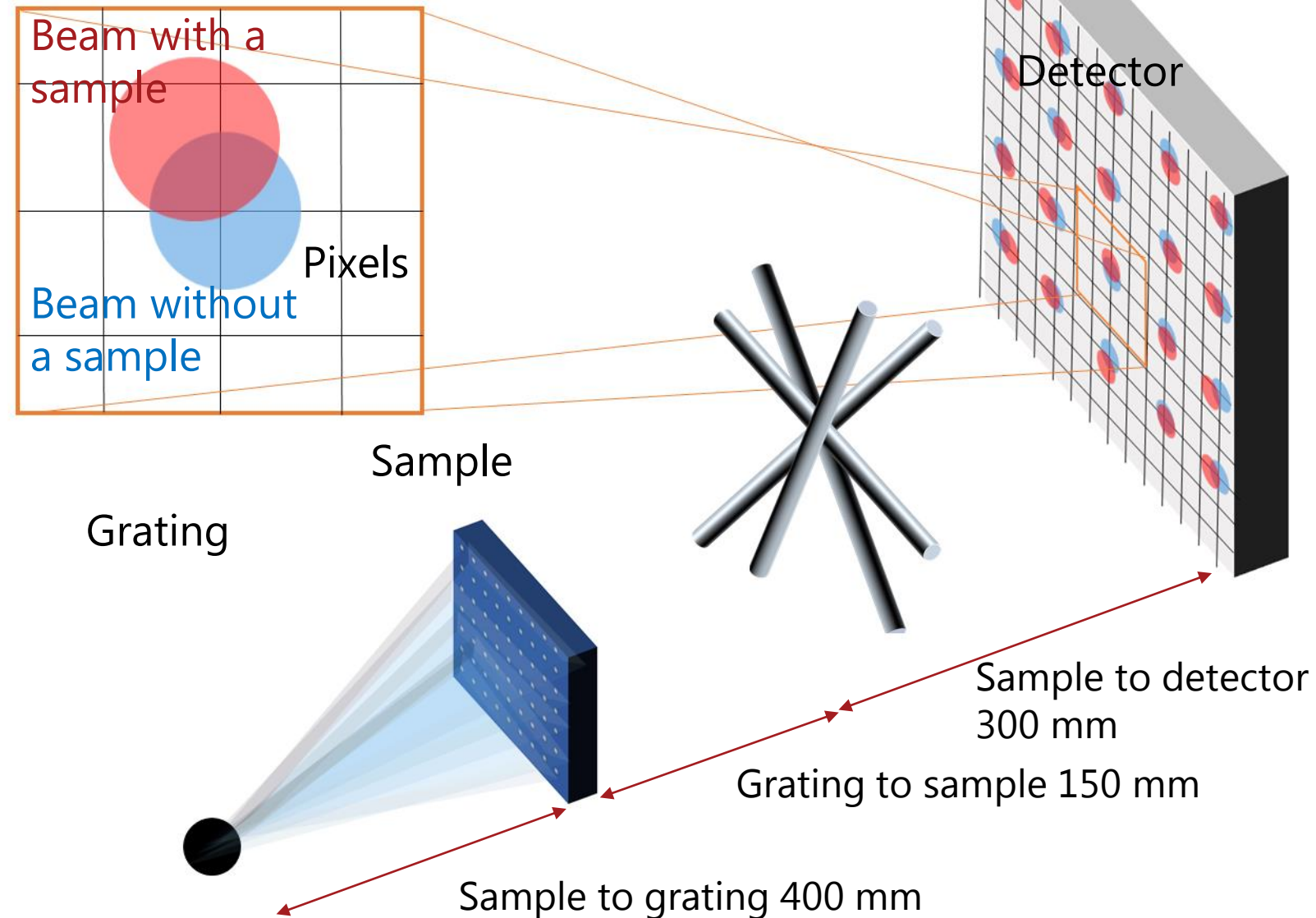
Phase contrast imaging setup



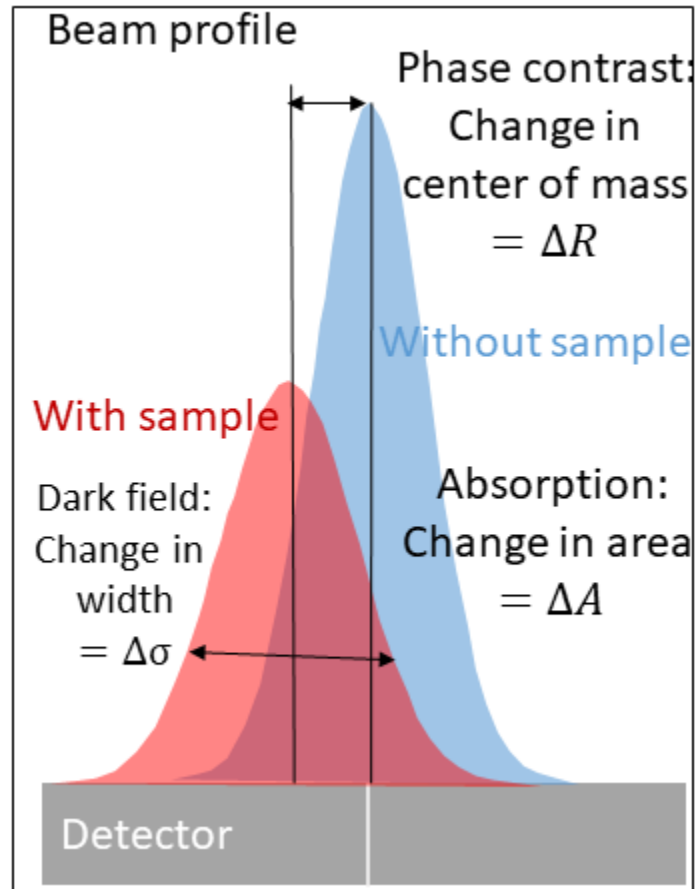
Phase contrast imaging setup



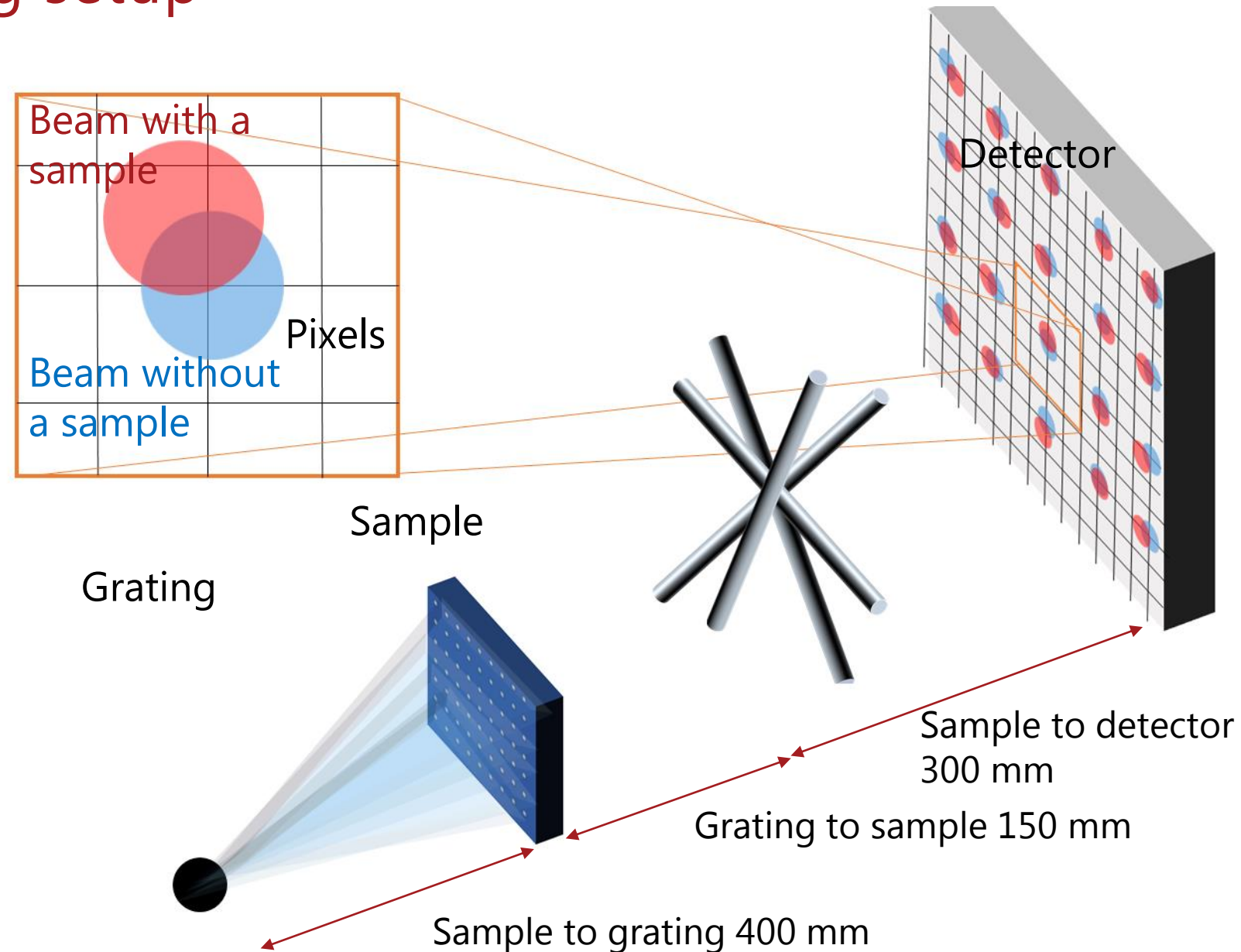
Source



Phase contrast imaging setup



Source



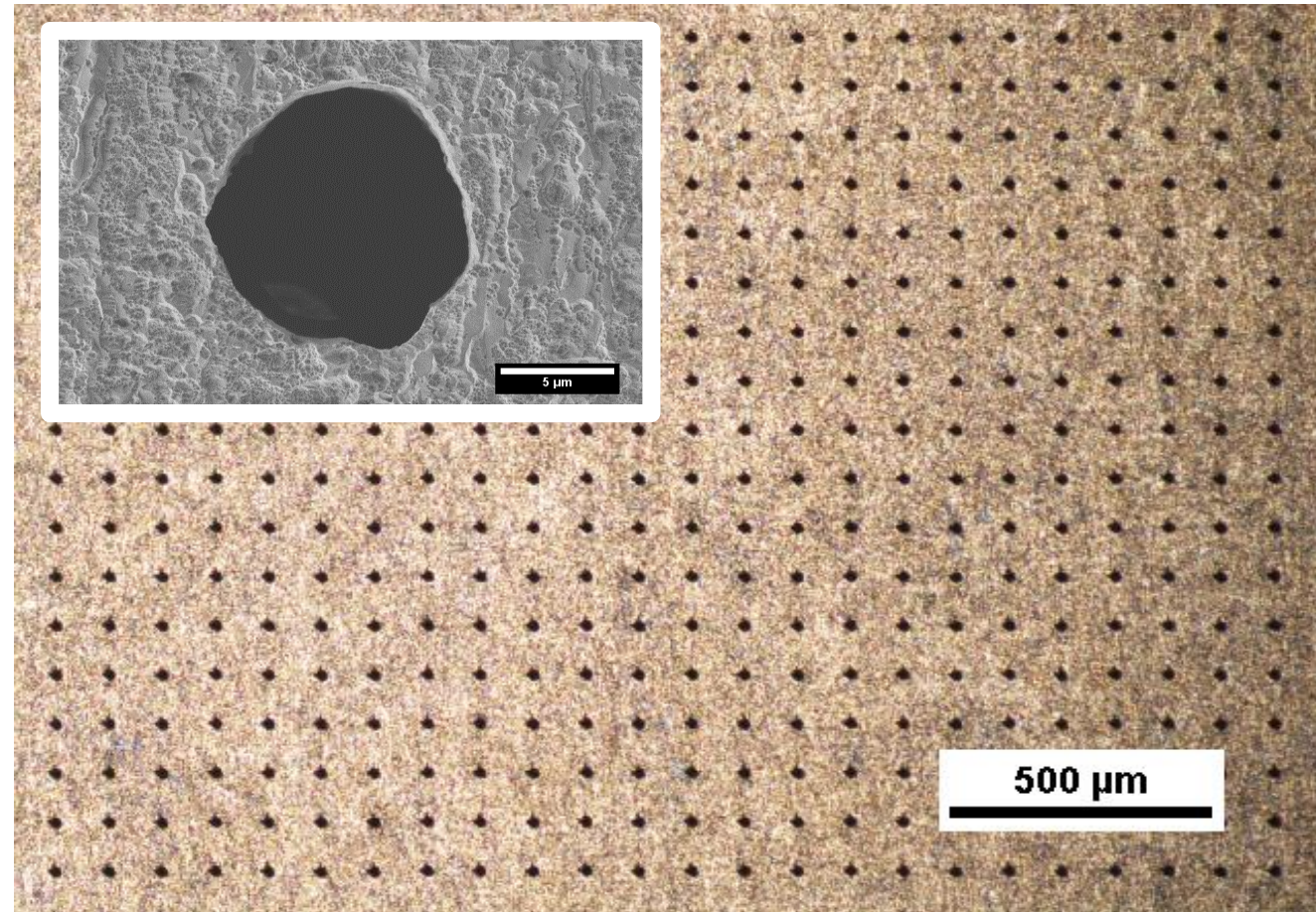
Grating

Tungsten Grating:

- Thickness : 200 μm
- Hole \varnothing : $12 \pm 0.3 \mu\text{m}$
- Pitch: 100 μm
- Laser cut.

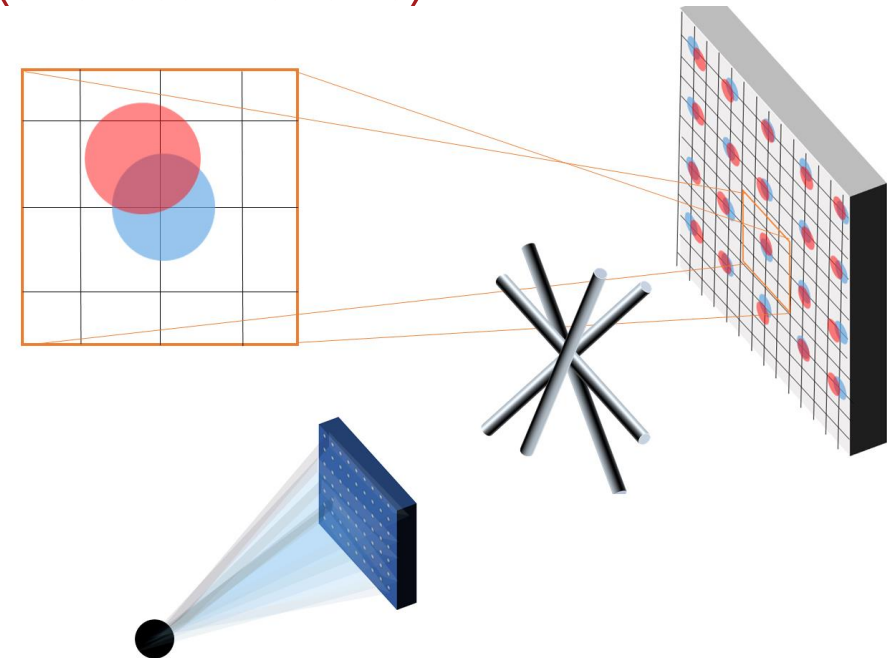
Determines the spatial resolution

Currently we need to do scanning of the sample to measure all spots.
Working on smaller pitch gratings to perform faster imaging



Phase contrast imaging setup

- Polychromatic technique with possibility for large field of view.
- Measures shifts in two directions in a single shot
- Cheap laser ablated tungsten grating
- Contrast is determined by the amount of charge sharing (and beamlet size).



Detector

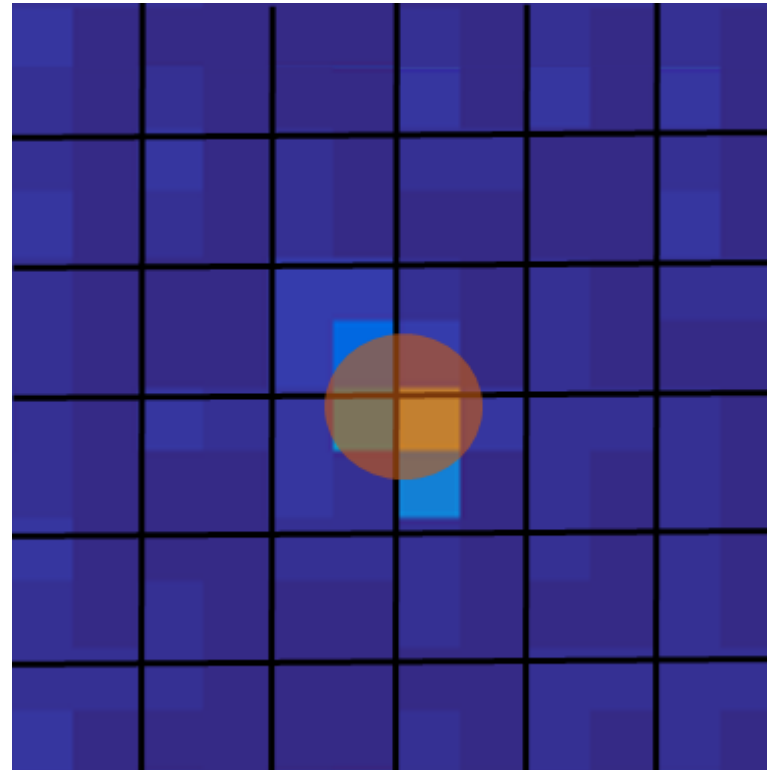
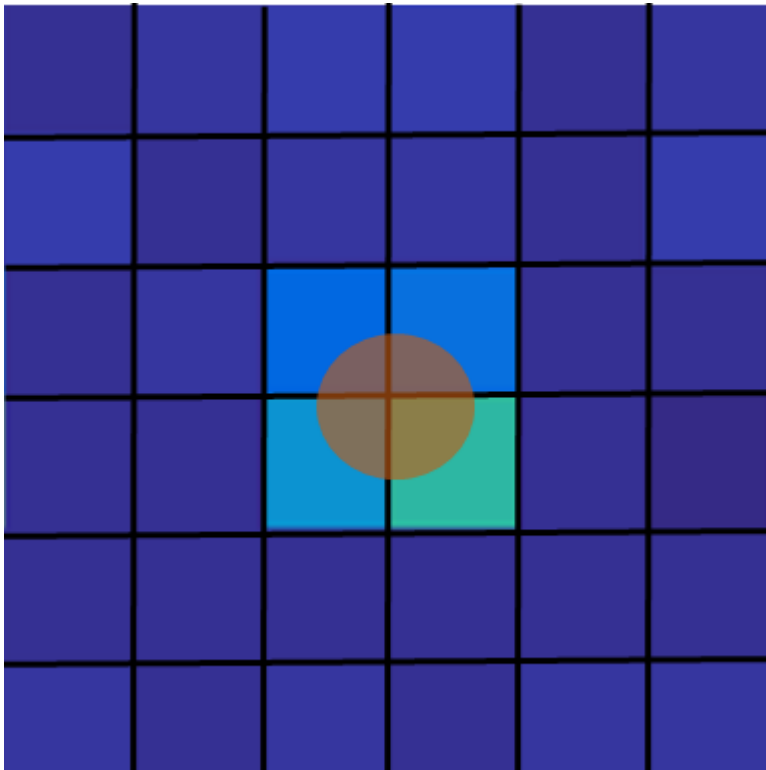
Advapix hybrid pixel Si detectors (CdTe) with Timepix-3 ASIC

- Number of pixels: 256 x 256
- Pixel size: 55 x 55 μm .



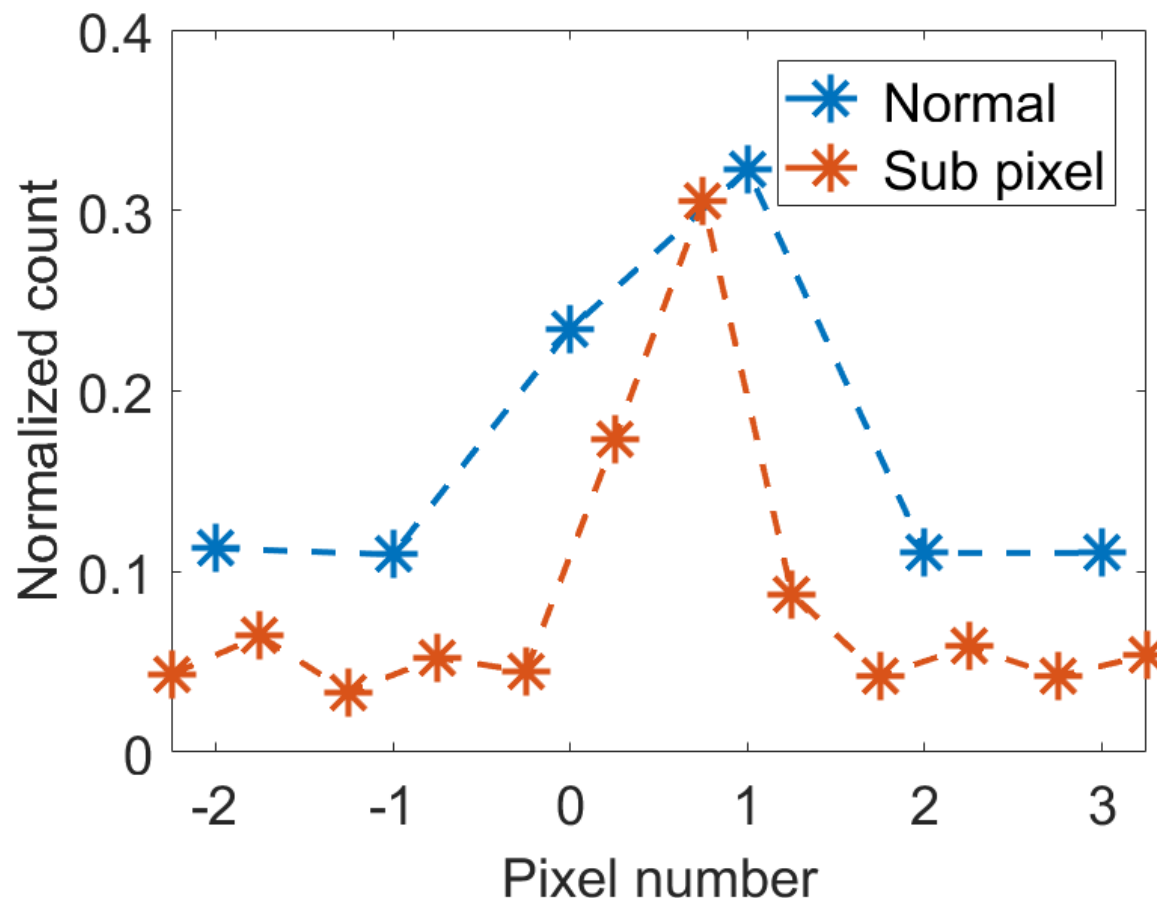
Subpixel resolution

- Use Timepix 3 fast time stamping to locate single photon's position below pixel resolution using weighted mean position of charge distribution in the pixels
- Integrated image of 36 pixels
- Using subpixel positioning



Subpixel resolution

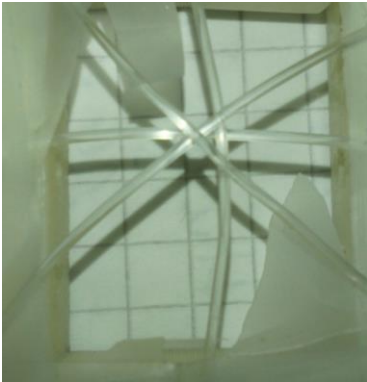
- Use Timepix 3 fast time stamping to locate single photons position below pixel resolution using weighted mean position of charge distribution in the pixels



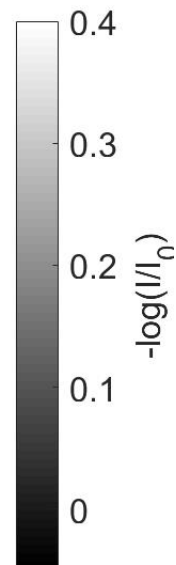
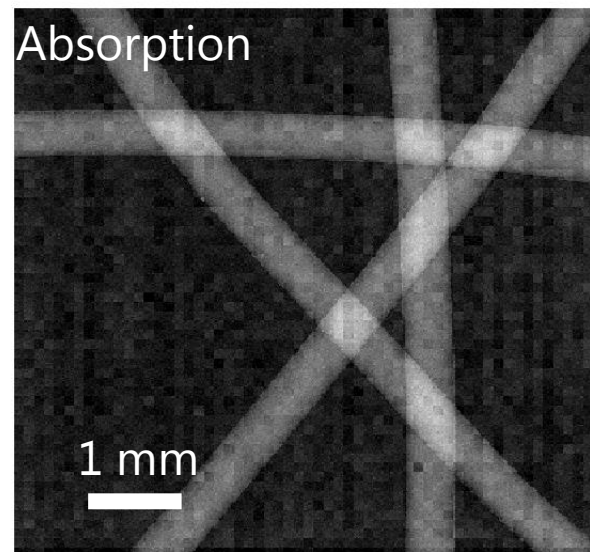
- Using subpixel gives:
- More precise beam localization
 - Reduce the background compared to peak intensity
 - Enables dark field imaging
 - Enables hitting every pixel corner

Results

Fishing thread

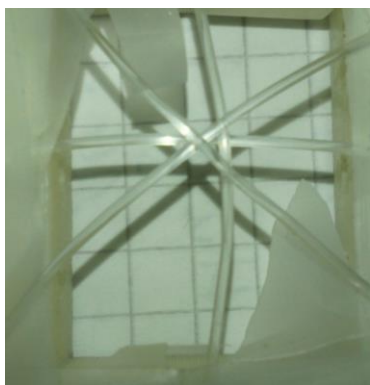


Source voltage:
 $U=50 \text{ kVp}$

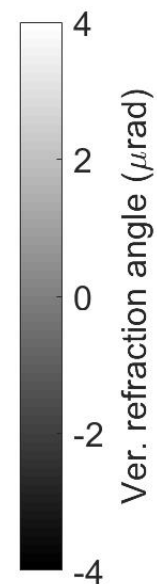
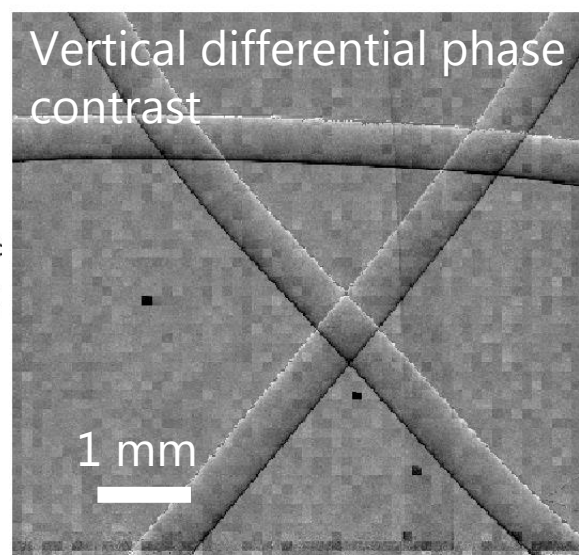
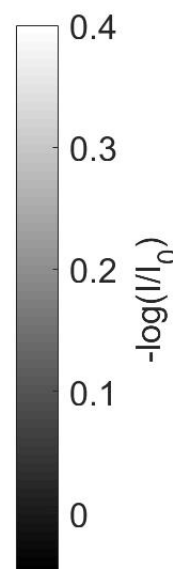
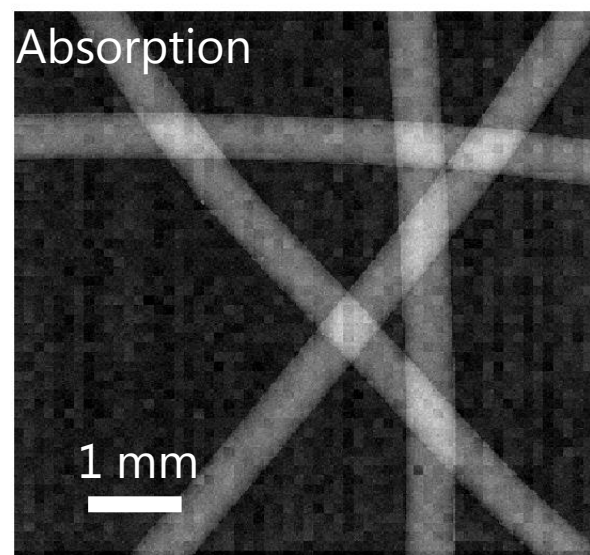
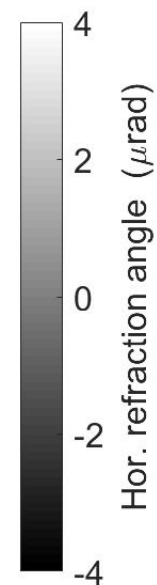
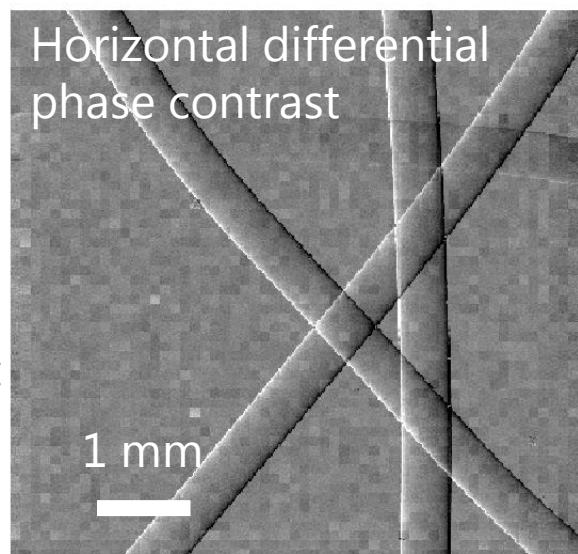


Results

Fishing thread

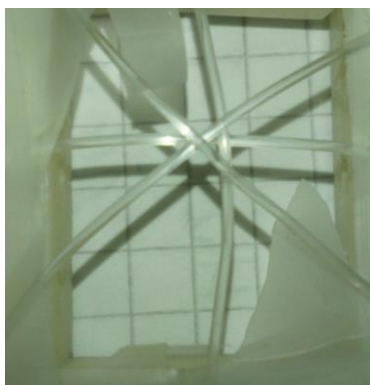


Source voltage:
 $U=50$ kVp

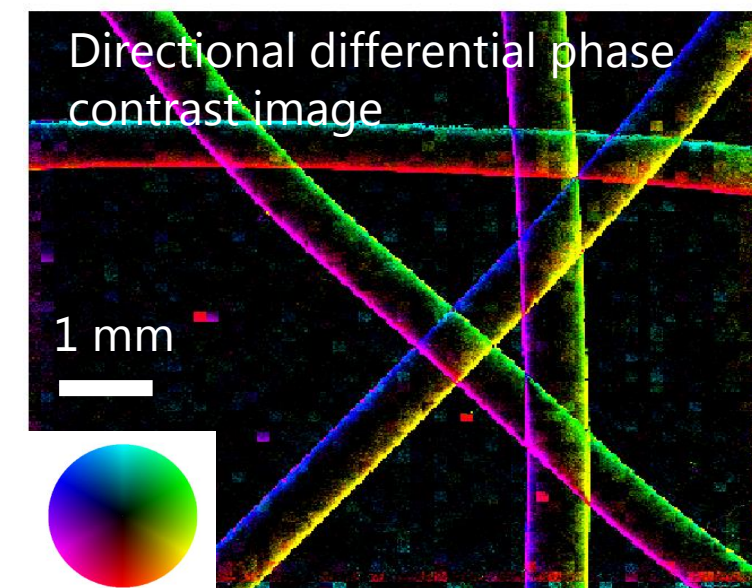
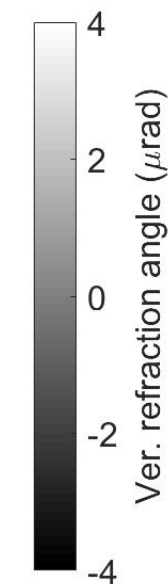
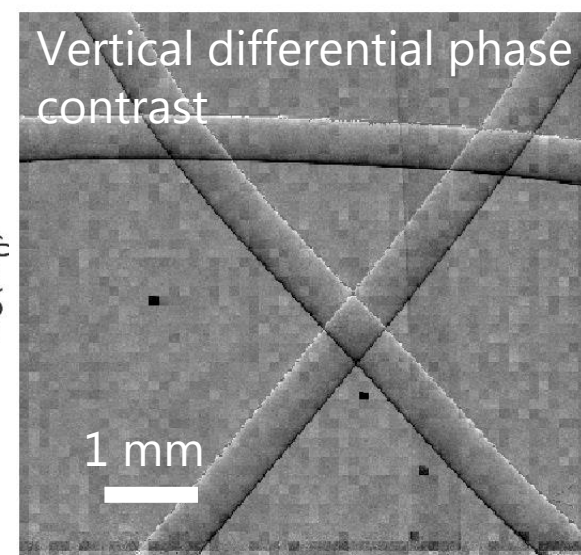
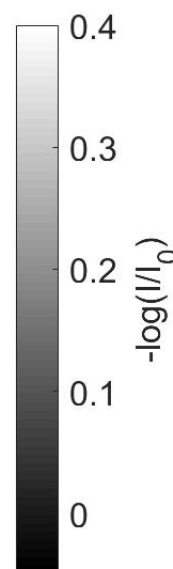
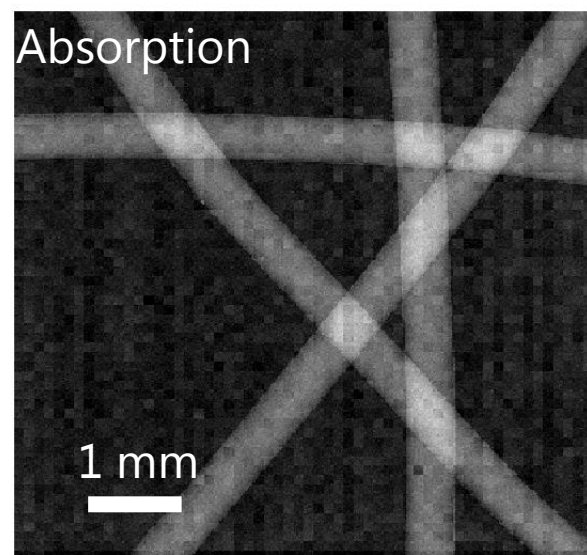
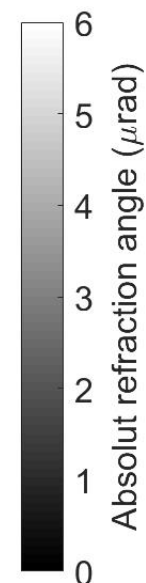
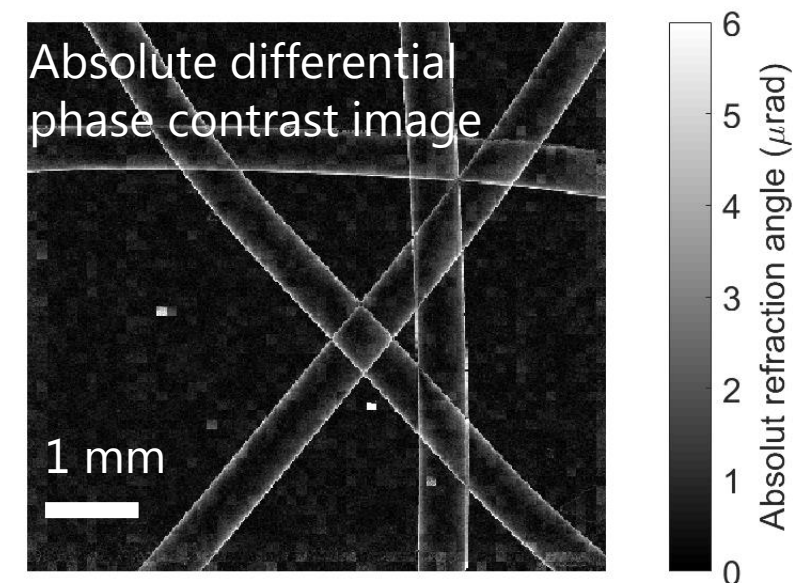
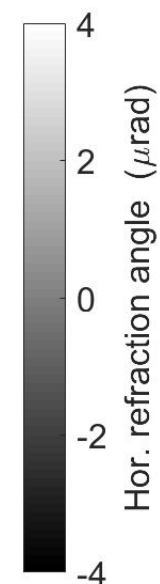
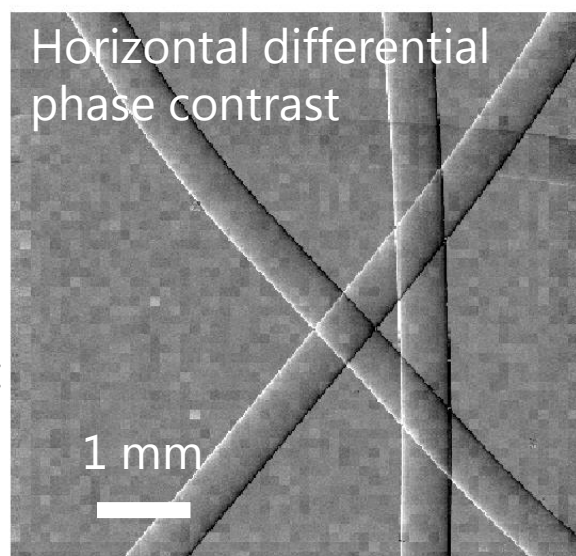


Results

Fishing thread

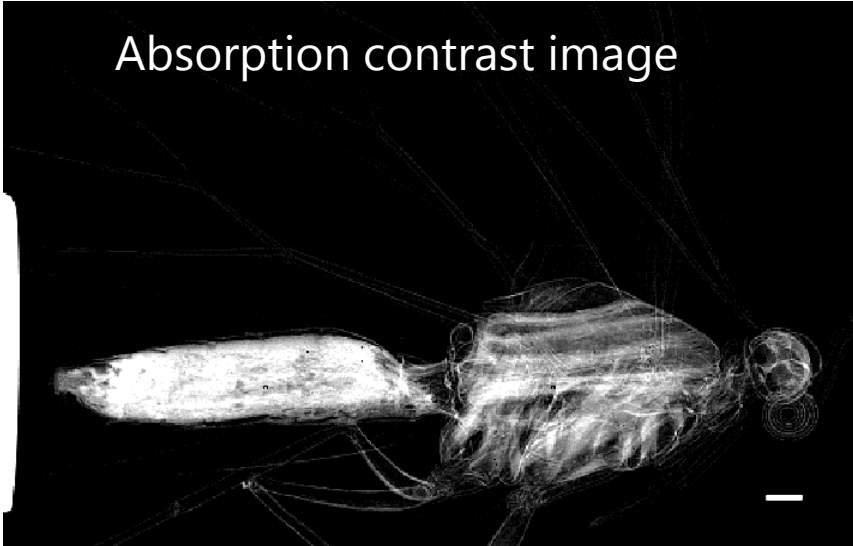


Source voltage:
 $U=50$ kVp

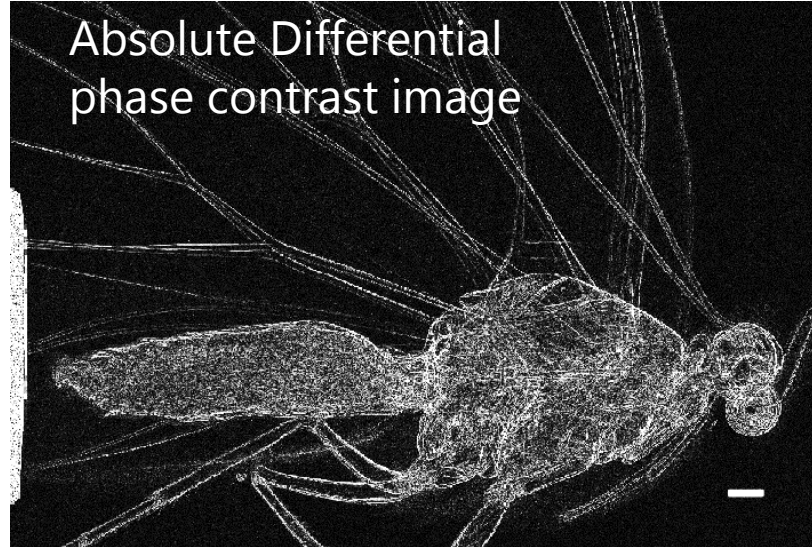


- Image of butterfly
- Source voltage 50 kVp

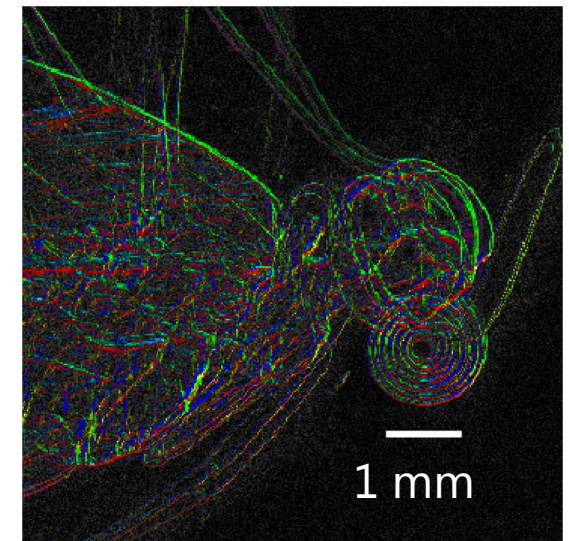
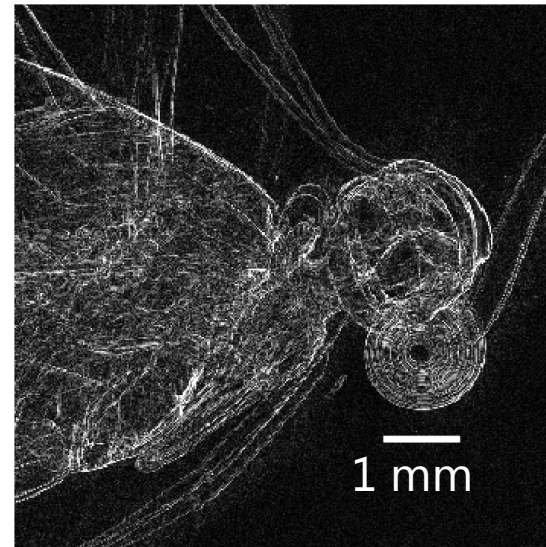
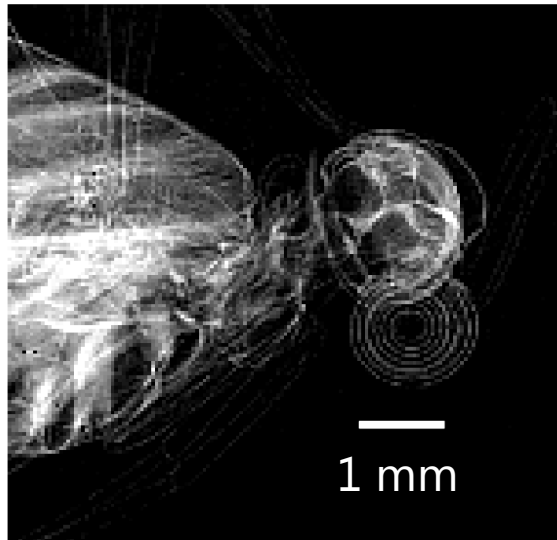
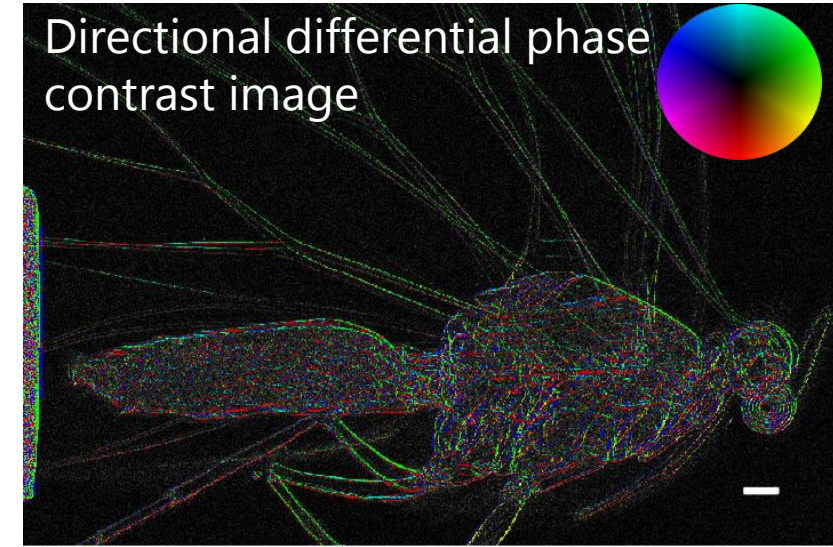
Absorption contrast image



Absolute Differential phase contrast image

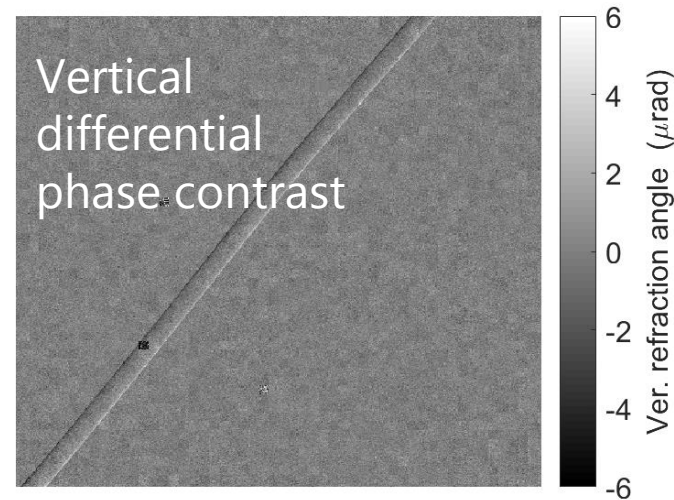
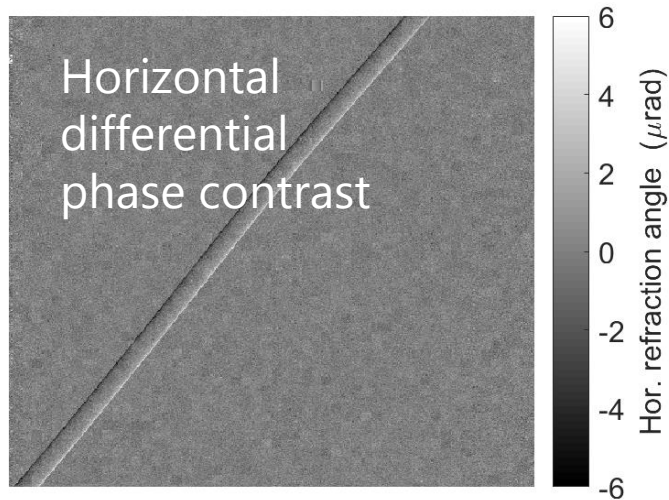


Directional differential phase contrast image



Low dose evaluation

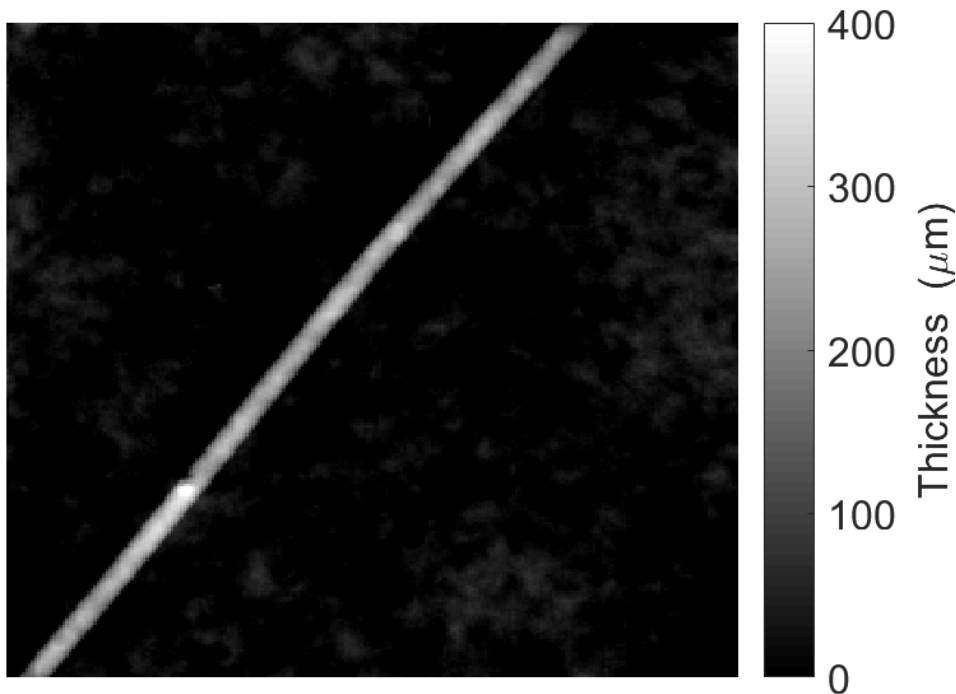
- Thin nylon wire $\sim 300 \mu\text{m}$.
- Retrieve thickness from integrating differential phase contrast using :
 - $\phi = \frac{1}{\delta} \nabla T$



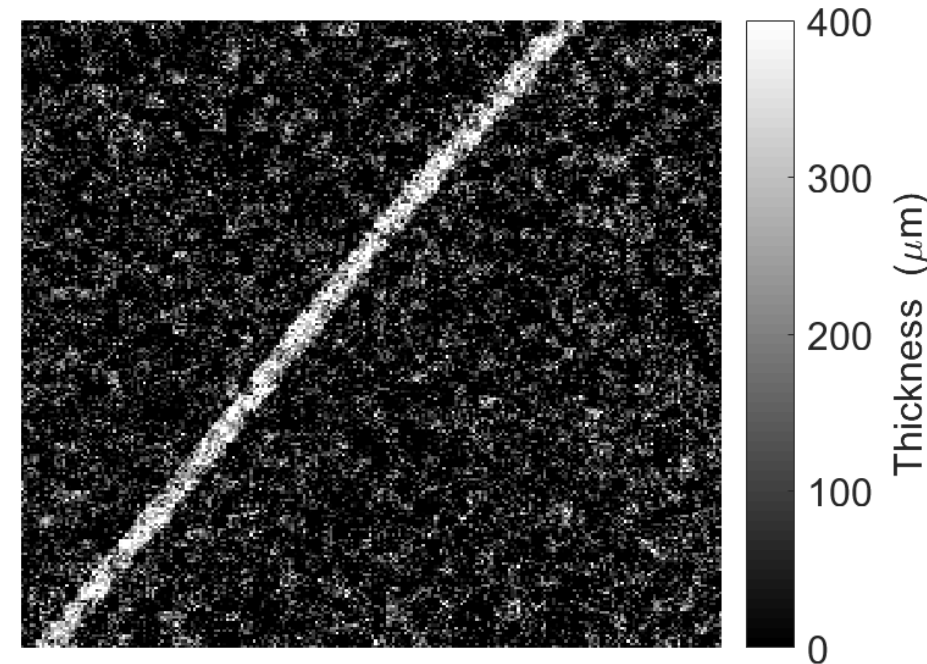
Low dose evaluation

- Thin nylon wire $\sim 300 \mu\text{m}$.
- Retrieve thickness from integrating differential phase contrast using :
 - $\phi = \frac{1}{\delta} \nabla T$
- Compared to thickness retrieved by absorption image at same dose

Thickness retrieved from differential phase contrast

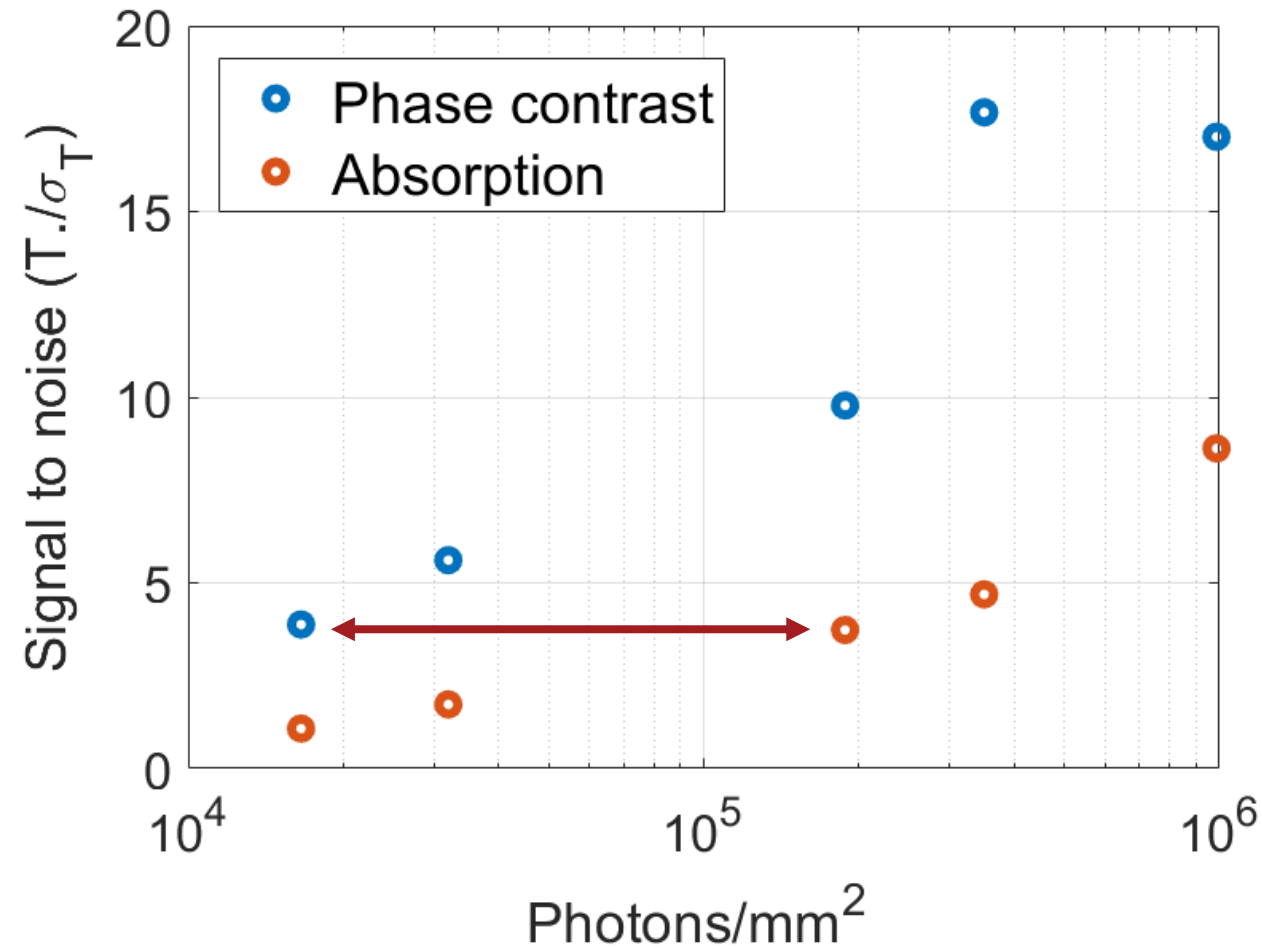


Thickness retrieved from absorption

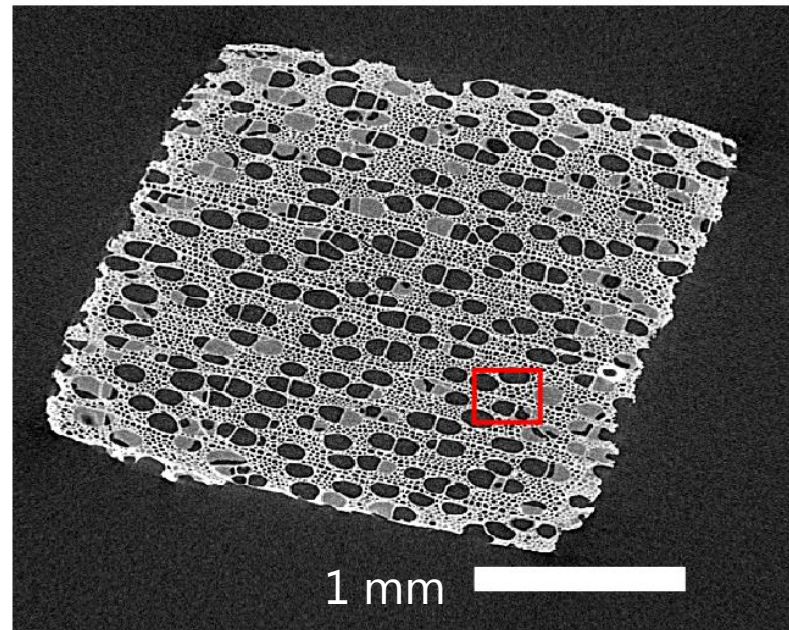
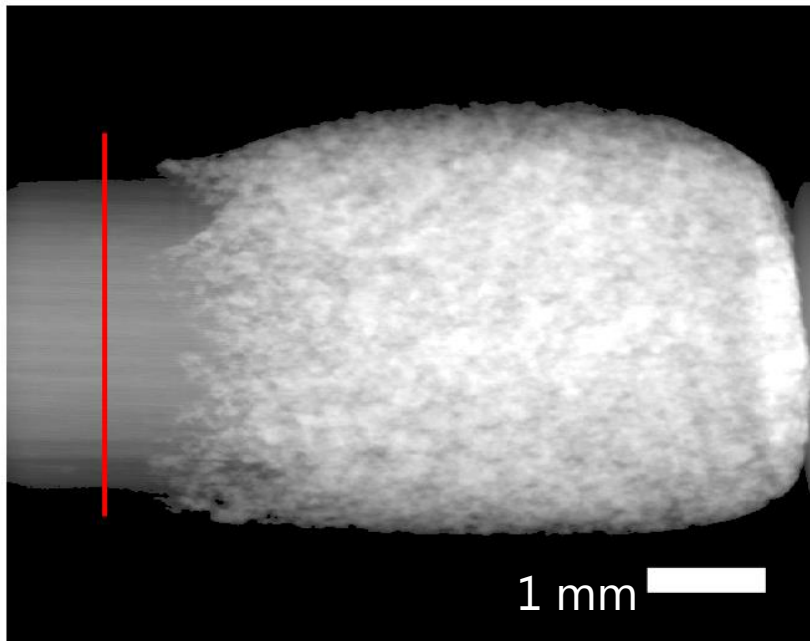
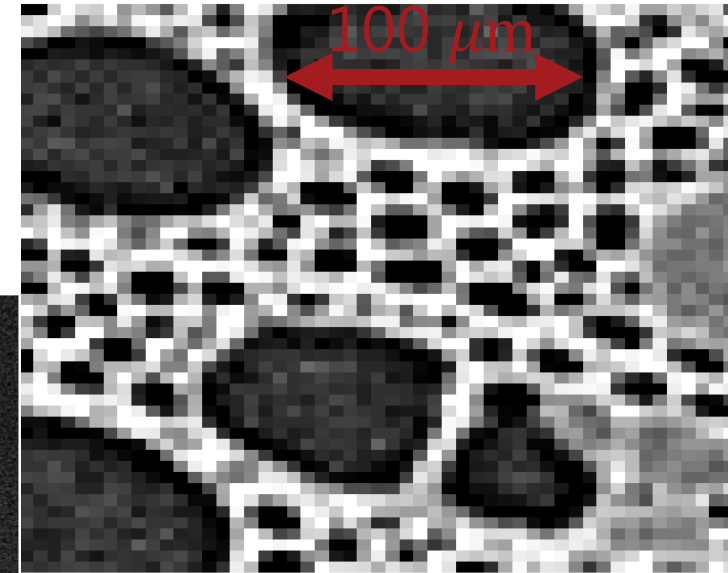


Low dose evaluation

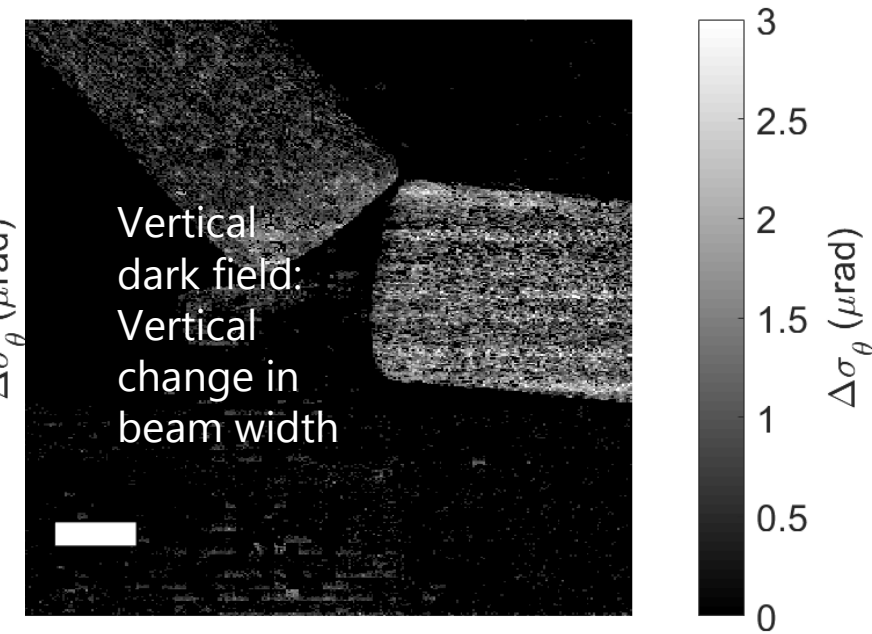
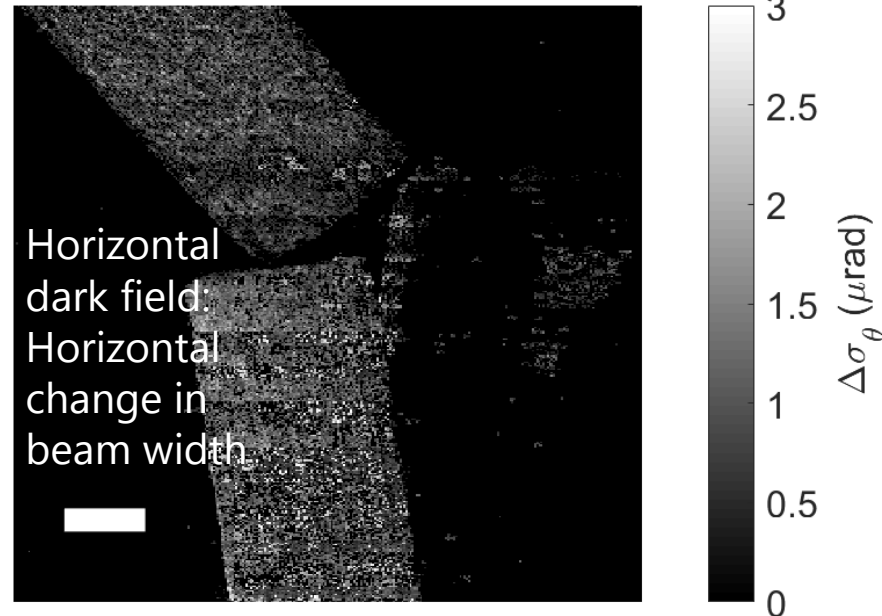
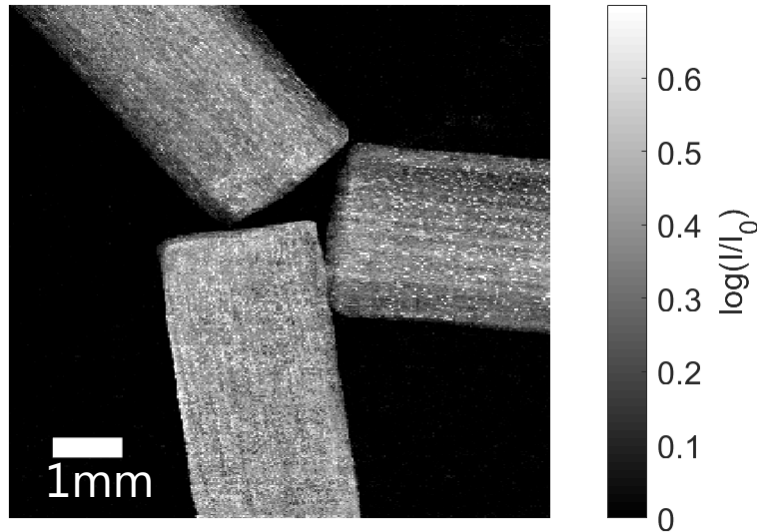
Our phase contrast imaging obtains same signal to noise at 1/10 the dose.



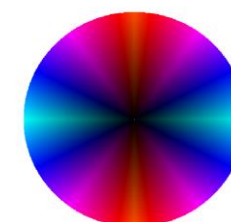
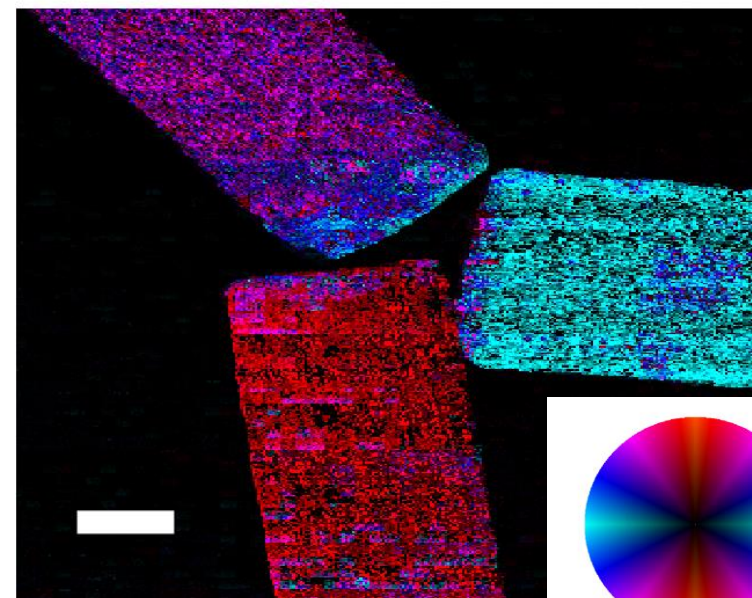
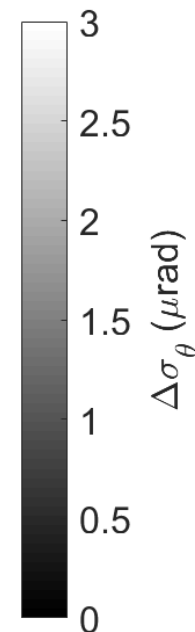
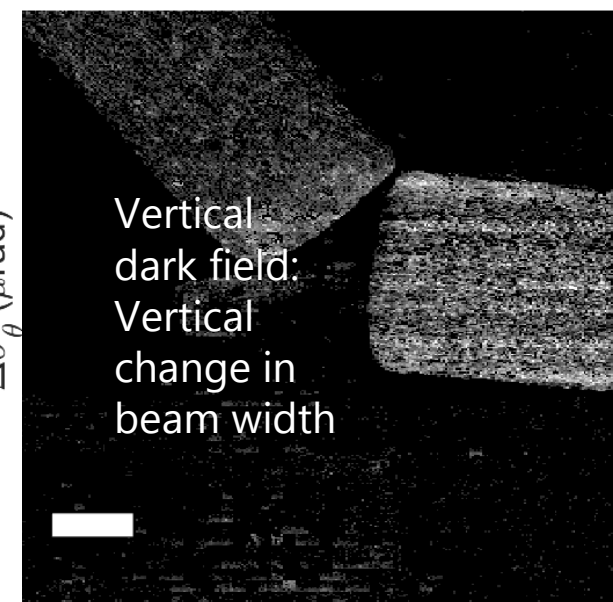
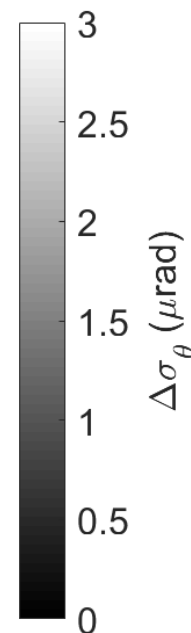
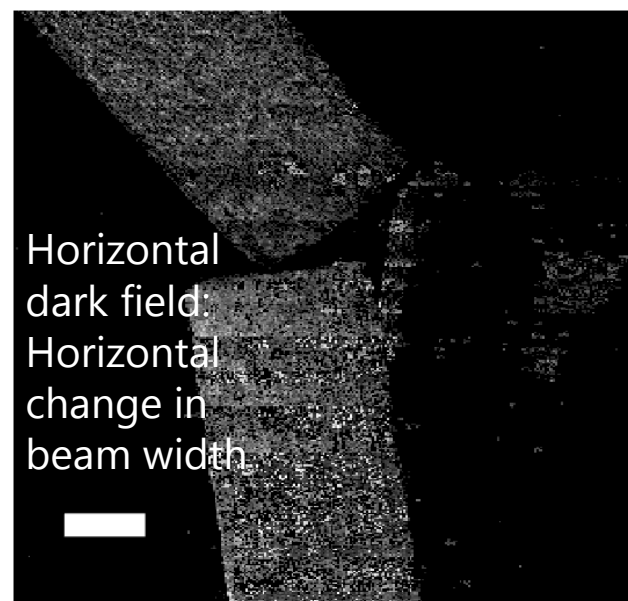
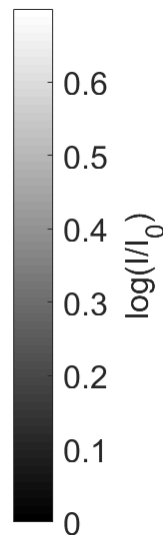
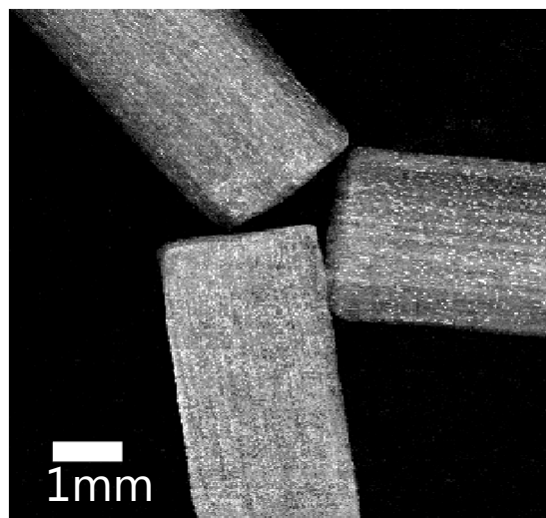
Directional dark field Imaging



Dark field imaging



Dark field imaging



Conclusion

- We have shown an imaging setup with Advapix Timepix 3 detector that is capable of making 2D phase contrast and dark field imaging in a single shot at a low dose.
- With possibility for larger field of view at high resolution with cheap gratings.
- And high energy X-rays with CdTe sensors.
- Next step: Possible applications of our dark field and phase contrast imaging setup:
 - Low dose medical imaging.
 - Foreign body detection in food products using dark field.
 - Material identification using spectral phase contrast for security screening.
 - Defects in composite materials, like carbon fiber reinforced polymers.
 - And many more?

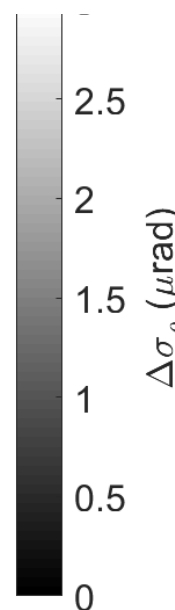
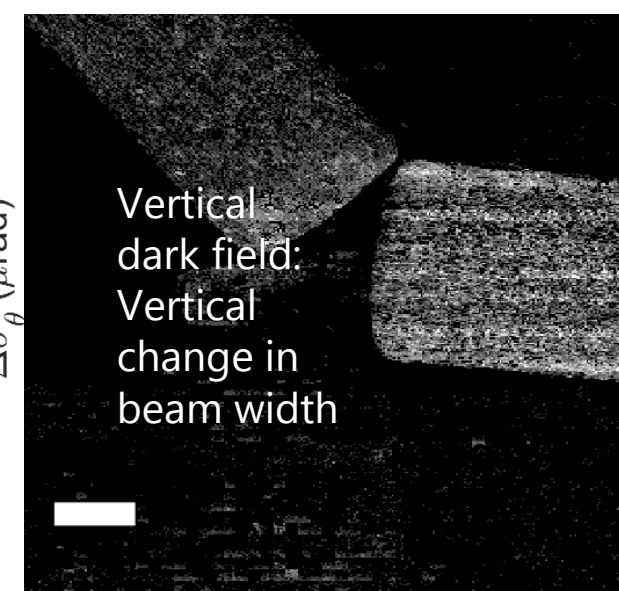
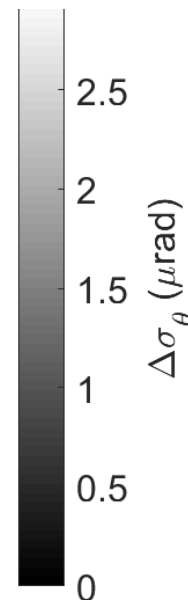
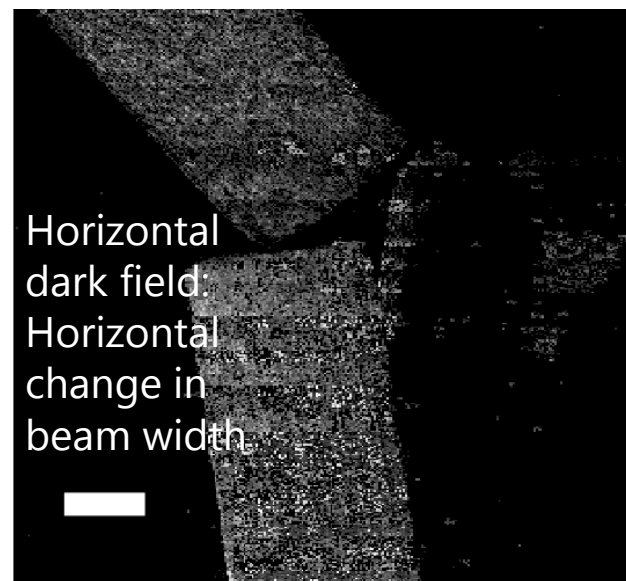
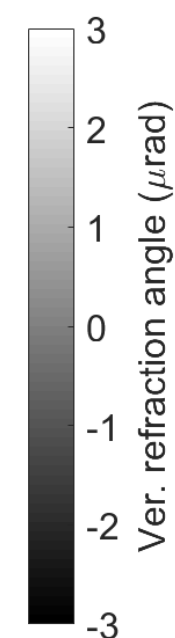
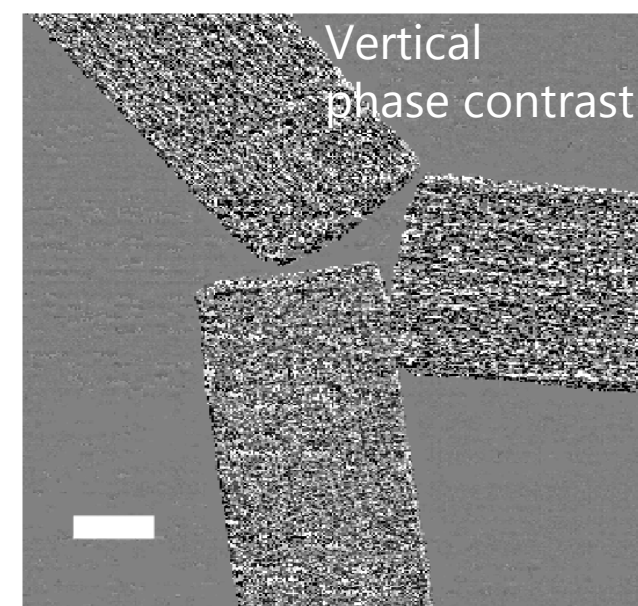
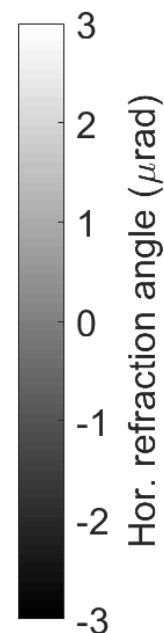
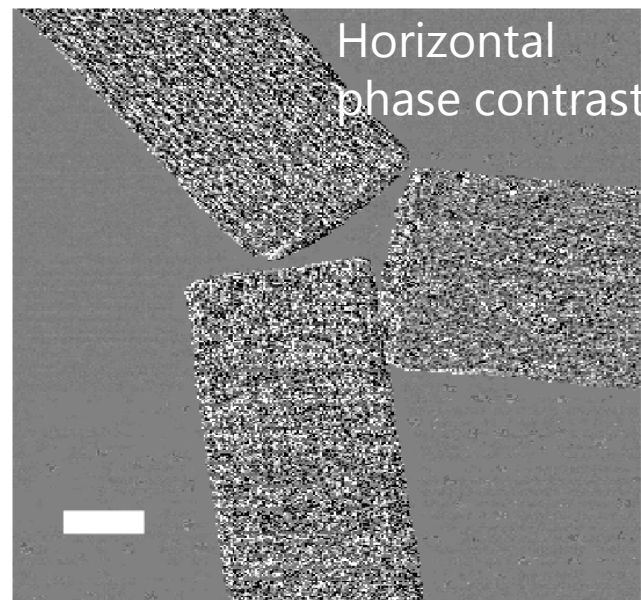
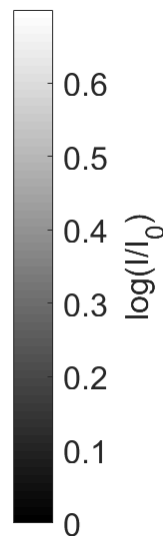
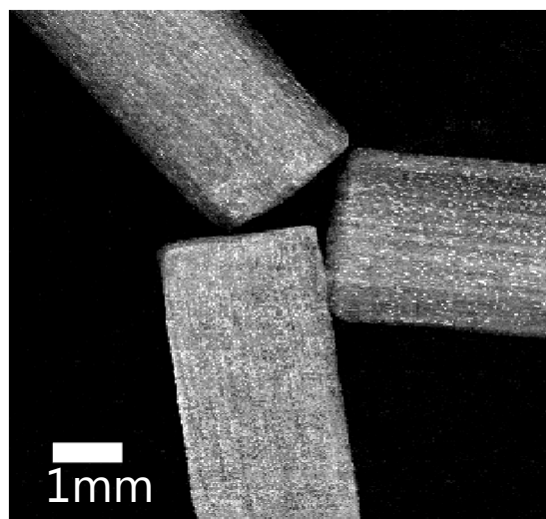




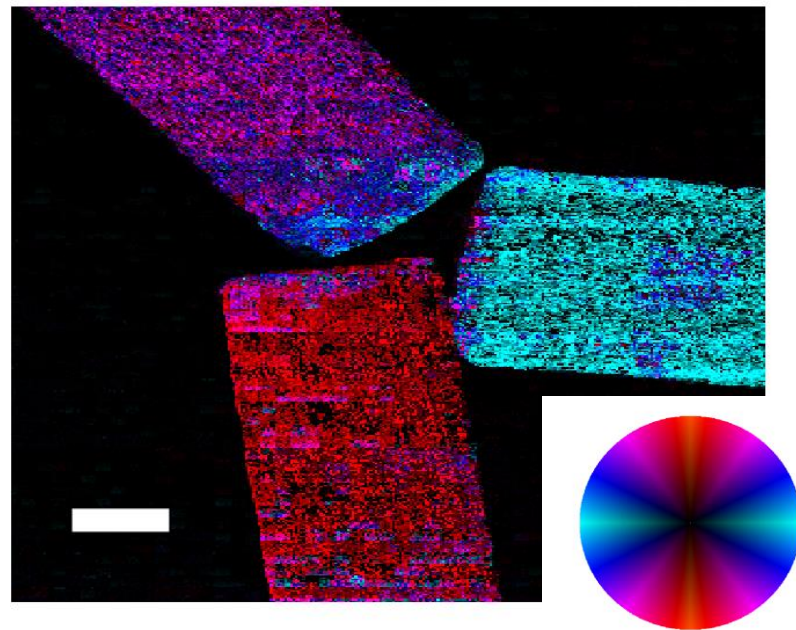
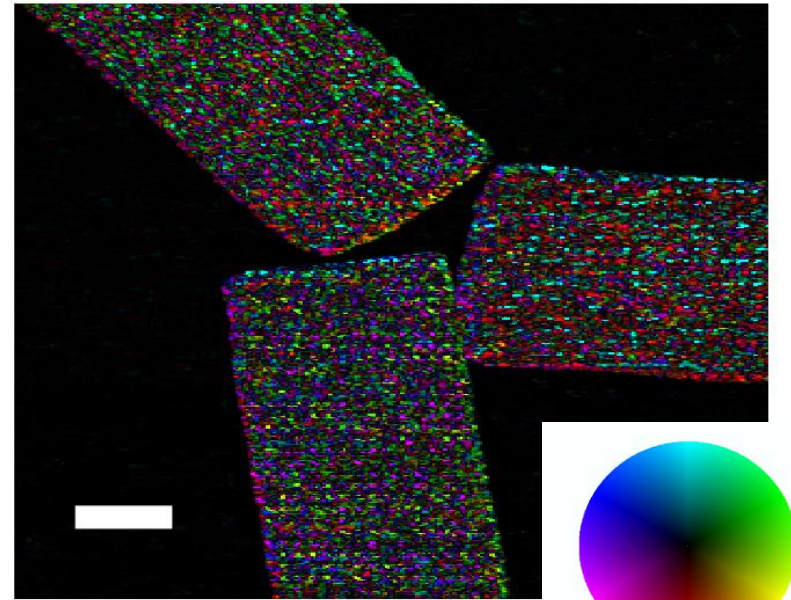
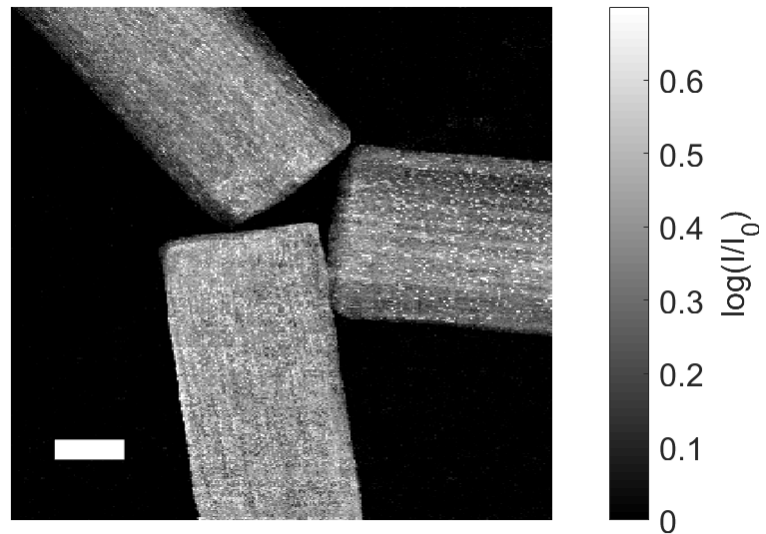




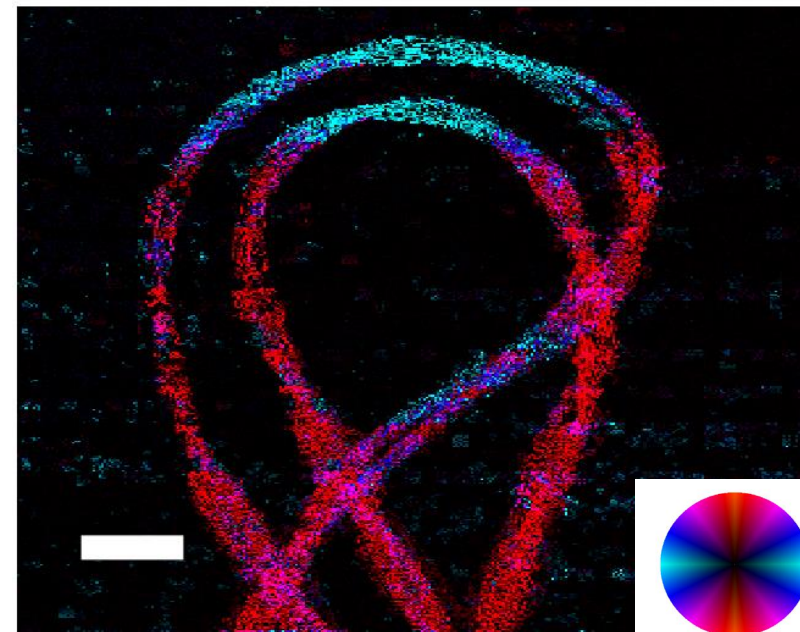
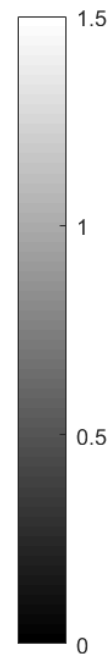
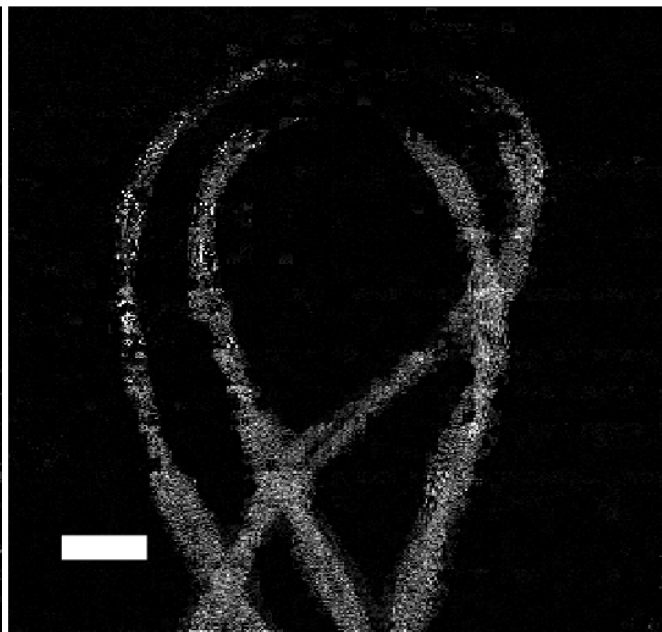
Dark field imaging



Dark field imaging

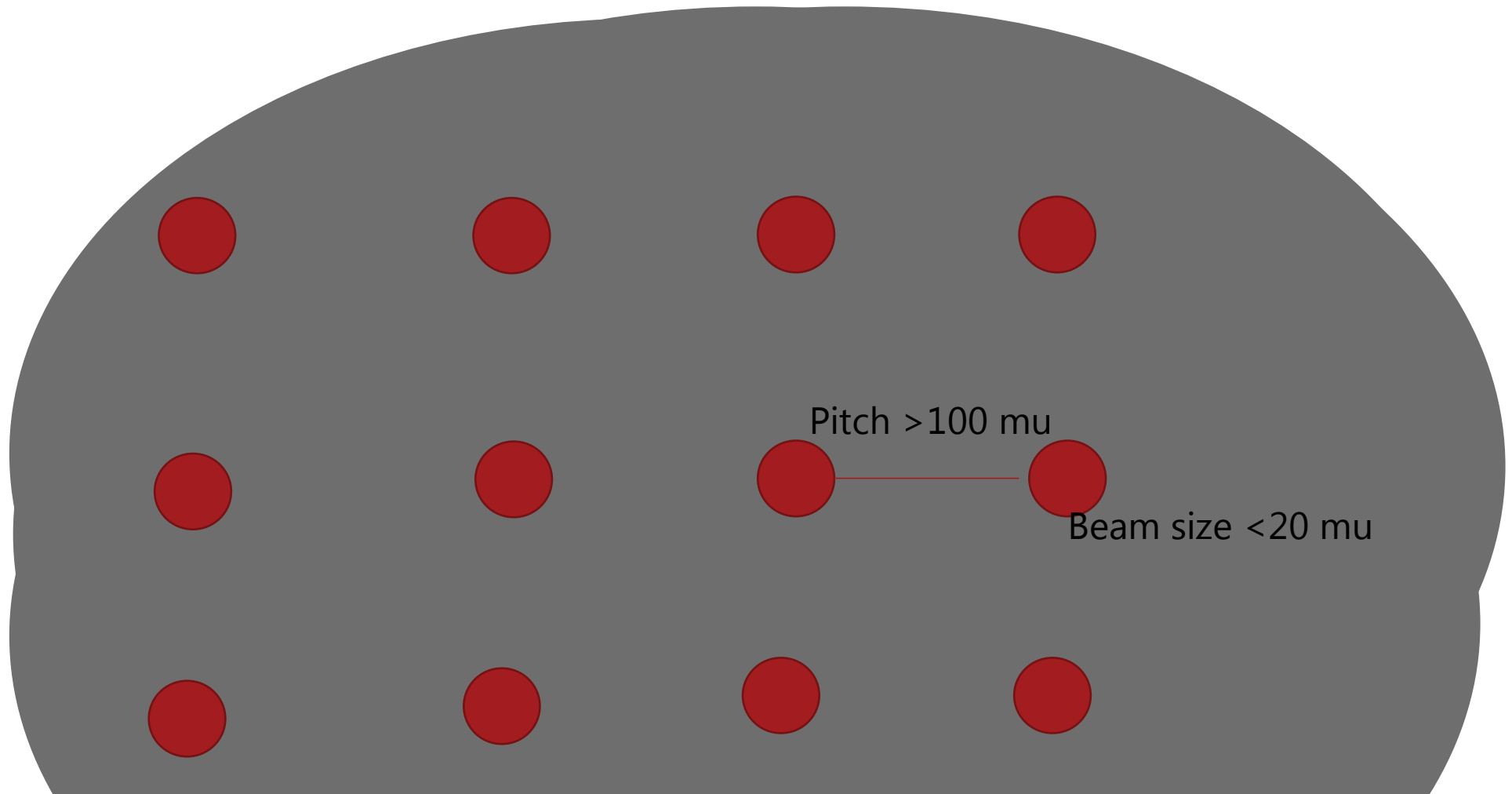


Kevlar wire



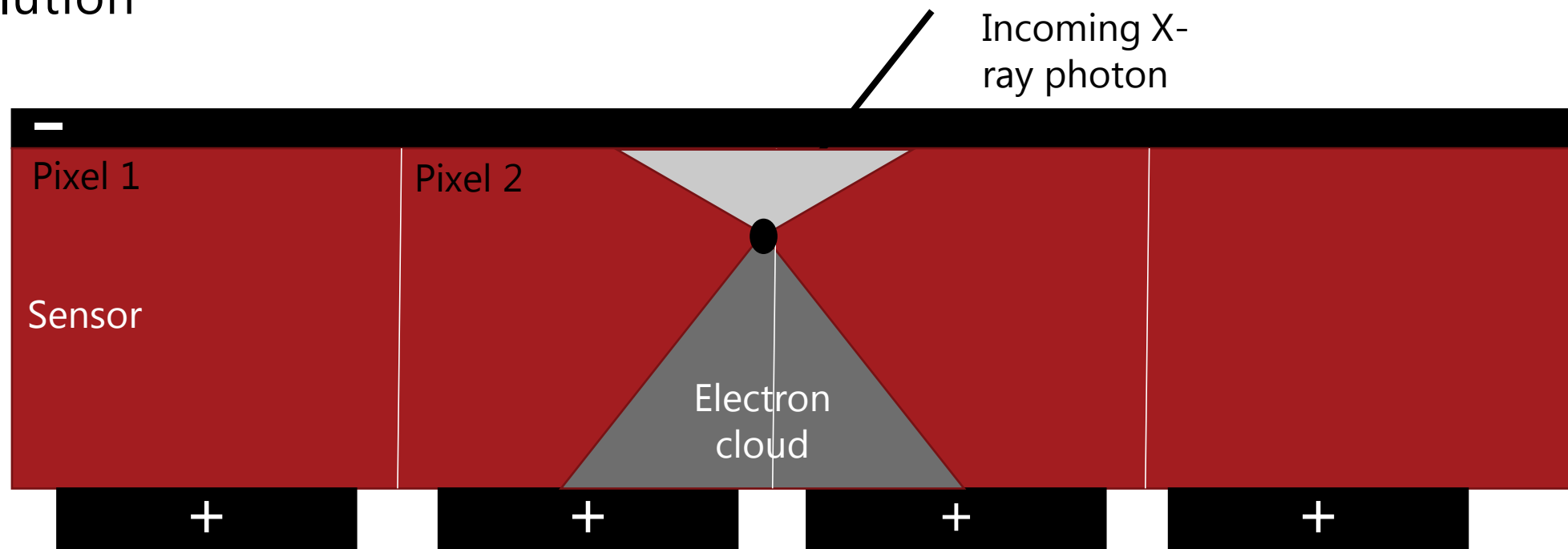
First test

- Higher resolution than 100 mu is obtained through raster scan by stepping sample



Next step – Subpixel resolution

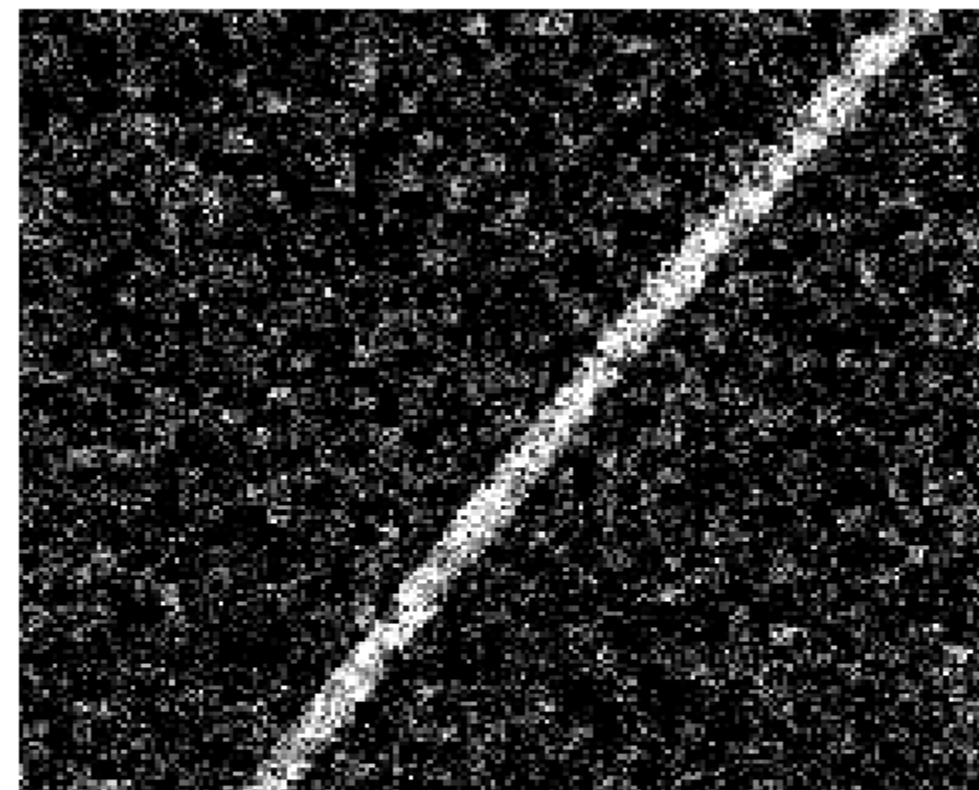
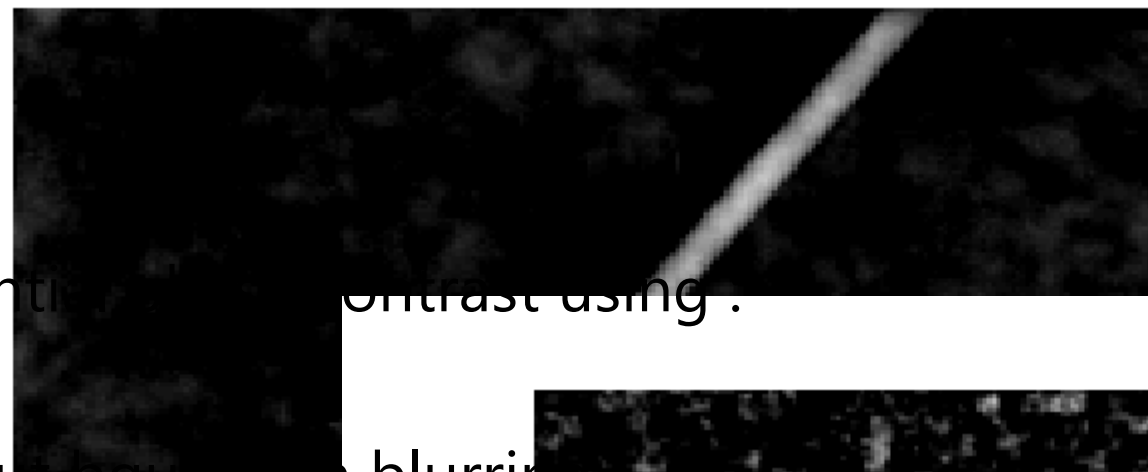
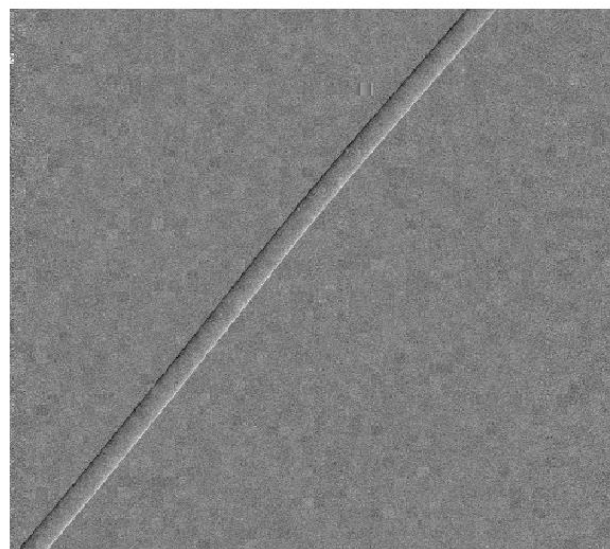
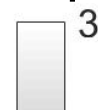
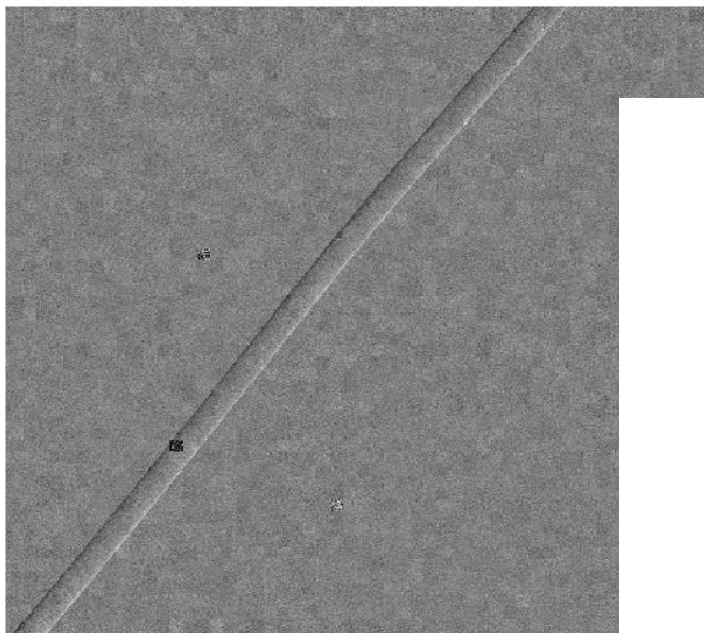
- Use Timepix 3 fast ToF to locate single photons position below pixel resolution



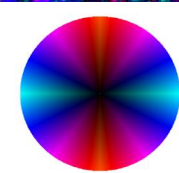
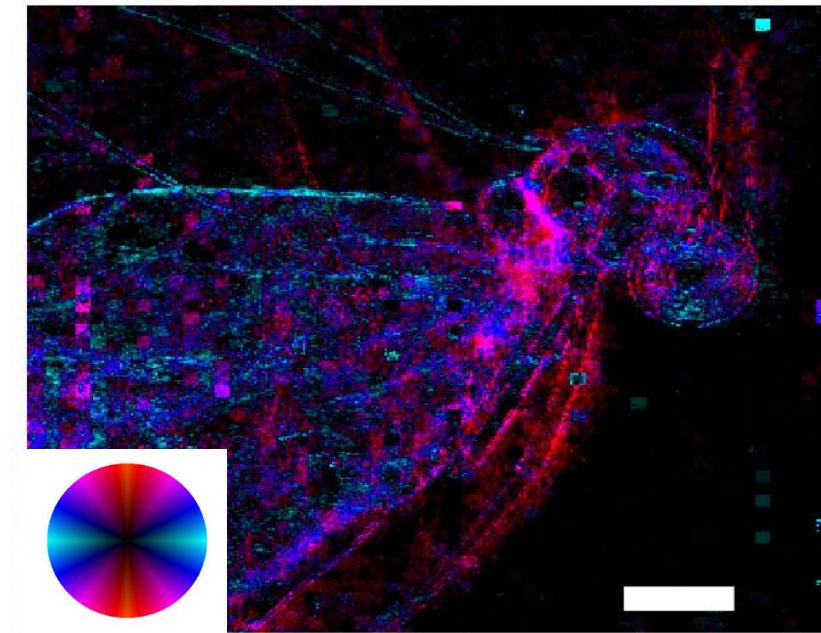
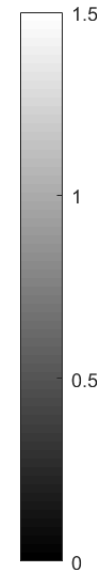
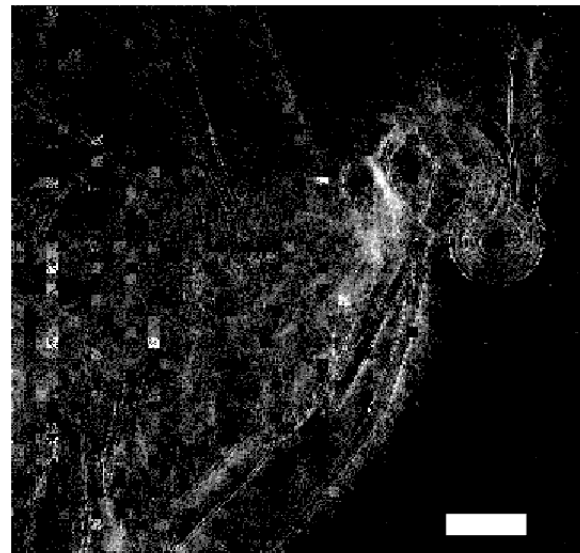
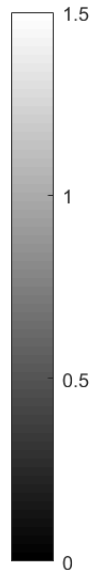
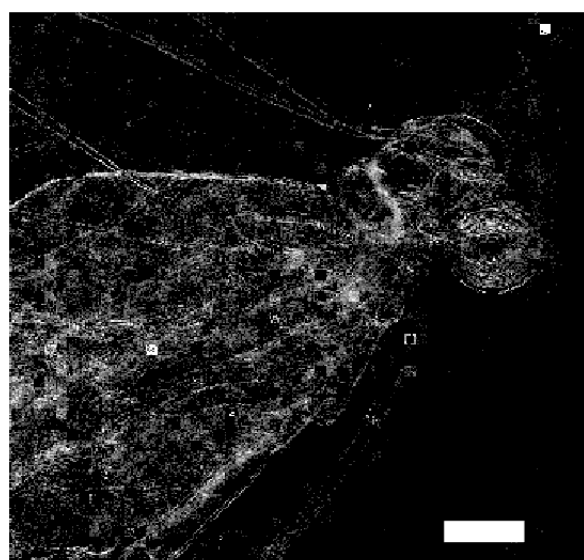
Photons subpixel position is identified by weighted mean of charge cloud.

Low dose

- Thin nylon wire $\sim 300 \mu\text{m}$.
- Retrieve thickness from integrating differential phase contrast using .
 - $\phi = \frac{1}{\delta} \nabla T$
 - Compare to absorption with and without gaussian blurring

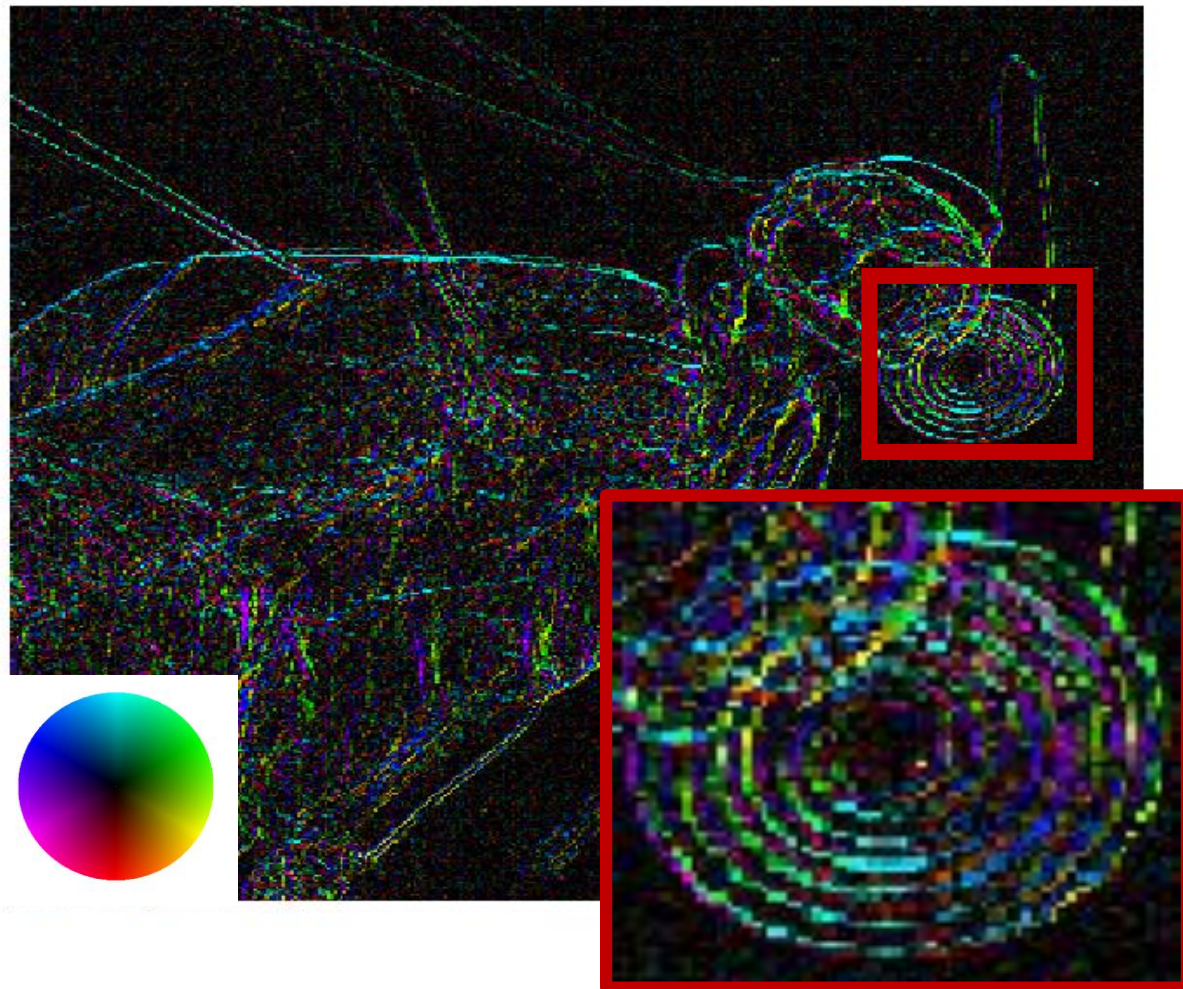


Dark field with 2x2 subpixels

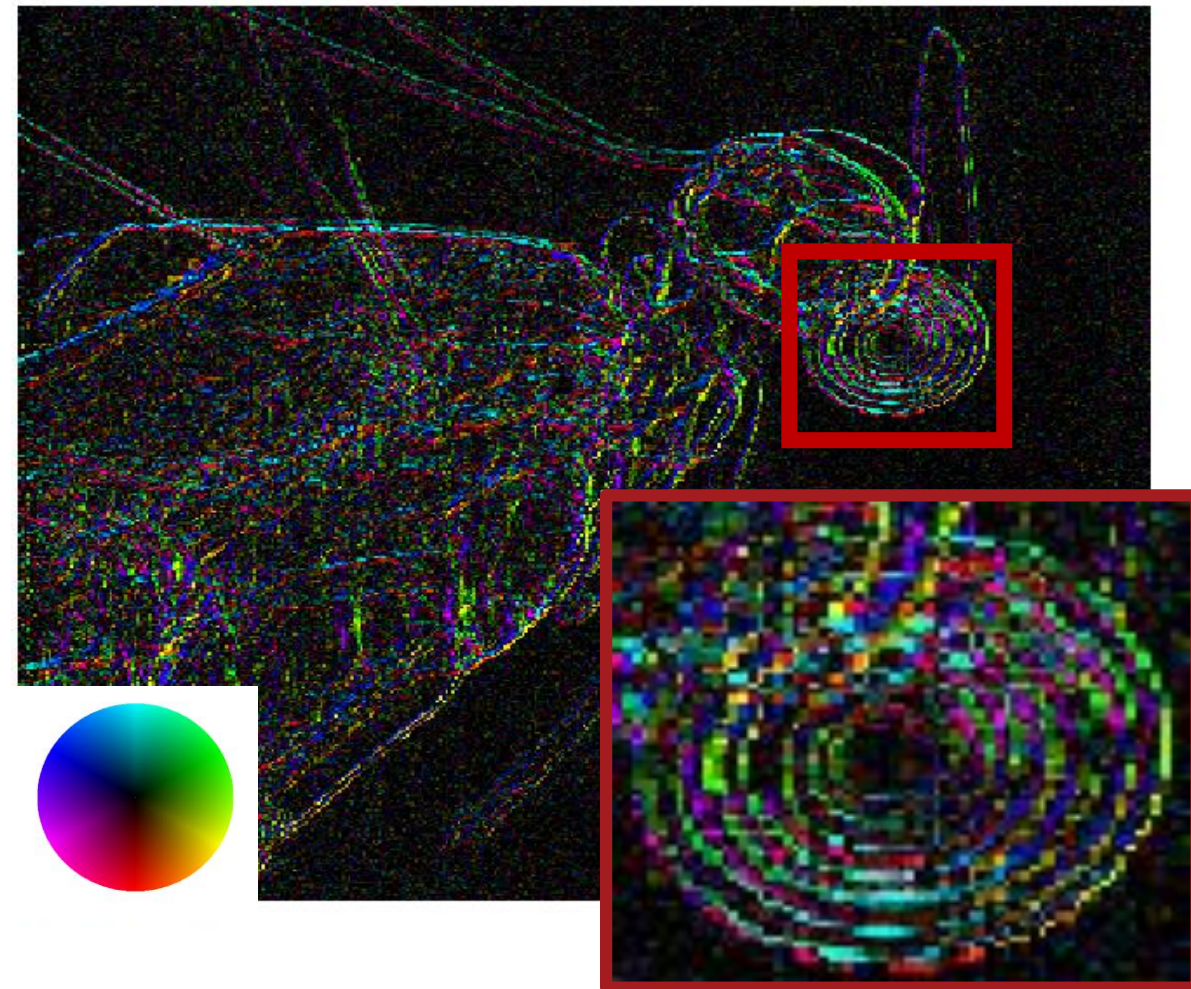


Phase contrast with 2x2 subpixels (Slightly better)

- Normal pixel



- Subpixels used



X-ray phase and dark field contrast imaging – The double grating based edge illumination technique

- Polychromatic technique that can easily be made for large field of view.
- High contrast for phase shift
- Only measures in one direction
- Requires stepping of M2 grating (More exposures)

