Improvement in Property of Parametric X-ray Radiation by Use of Wedge-shaped Target Crystal

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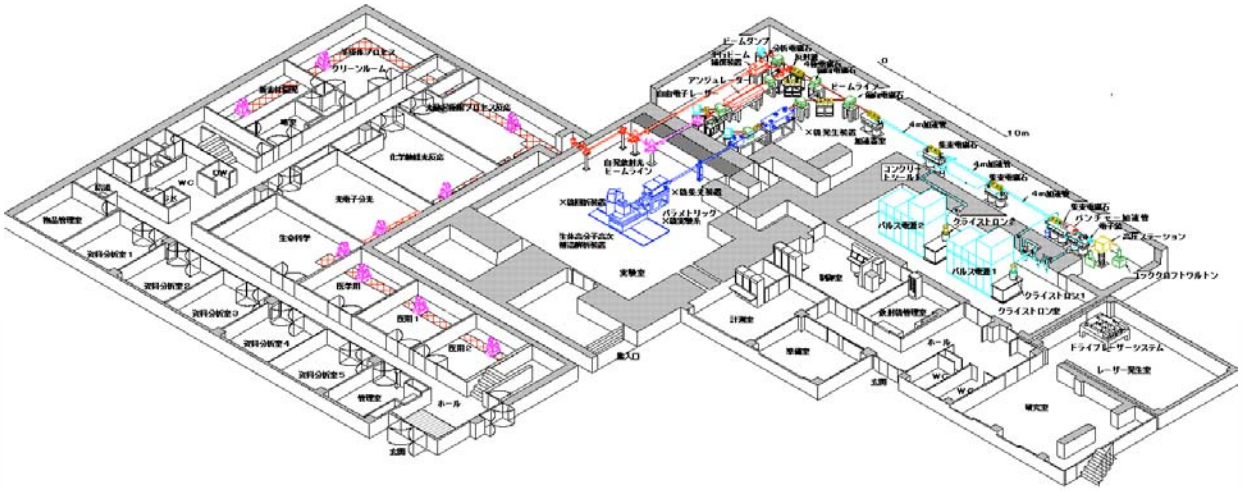
LEBRA facility of Nihon University

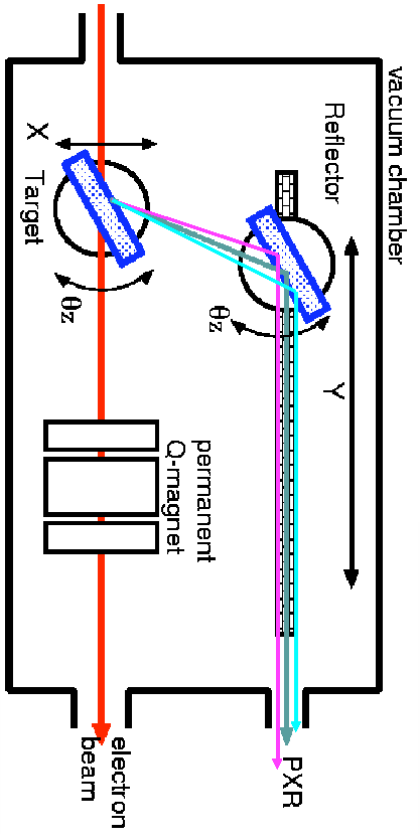
LEBRA: **L**aboratory for **E**lectron **B**eam **R**esearch & **A**pplication

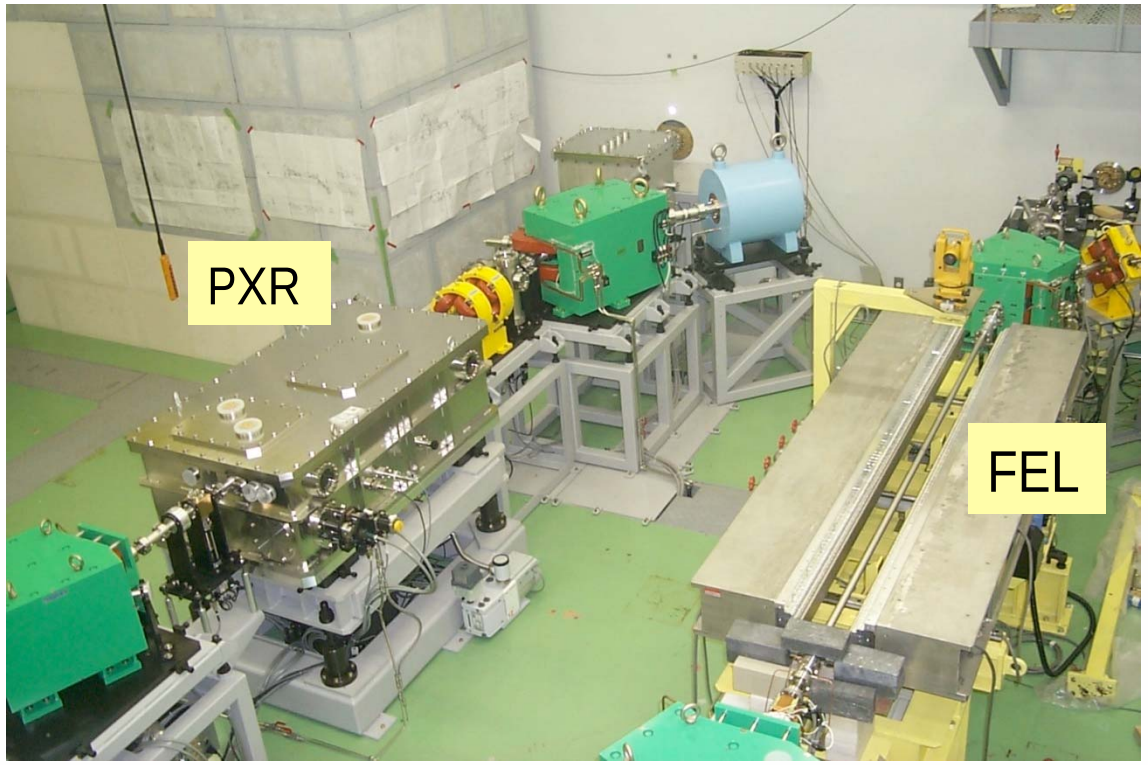


Tunable light-source facility based on
a conventional S-band electron linac

elctron energy: 125MeV(max.), 100MeV(typ.)
average current : 5μA (max.), 1 – 2 μA(typ.)

LEBRA facility: beamlines (FEL & PXR)





Free electron laser (FEL): 1 um – 6um (near-IR)

Parametric X-ray radiation (PXR): double-crystal system

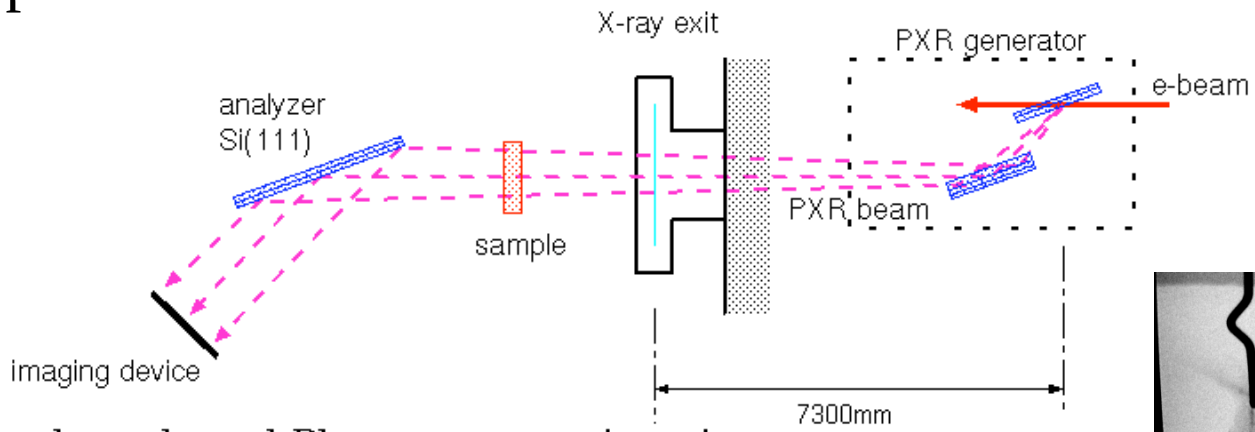
Status of LEBRA-PXR

- Electron beam energy: 100MeV
- Macro pulse of e-beam : ~130mA, 4 – 10us, 2 – 5Hz
- Average e-beam current: 1 – 5uA
- X-ray energy: 5 – 34keV

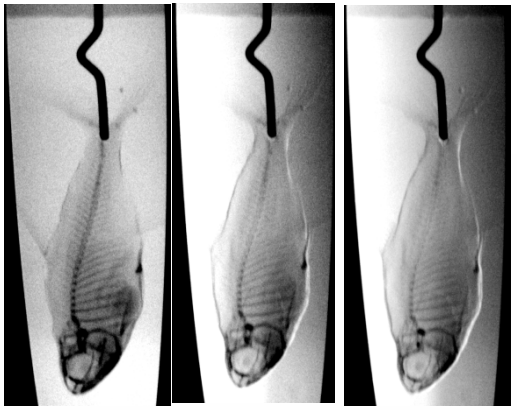
  (Si(111): 5 – 20keV, Si(220): 6.5 – 34keV)
- Irradiation field: 100mm in diameter @ exit port
- Total photon rate: > 10^6 - 10^7 photon/s
- Application: imaging, XAFS, radiobiology, ...

Diffraction-enhanced imaging （DEI）

top view



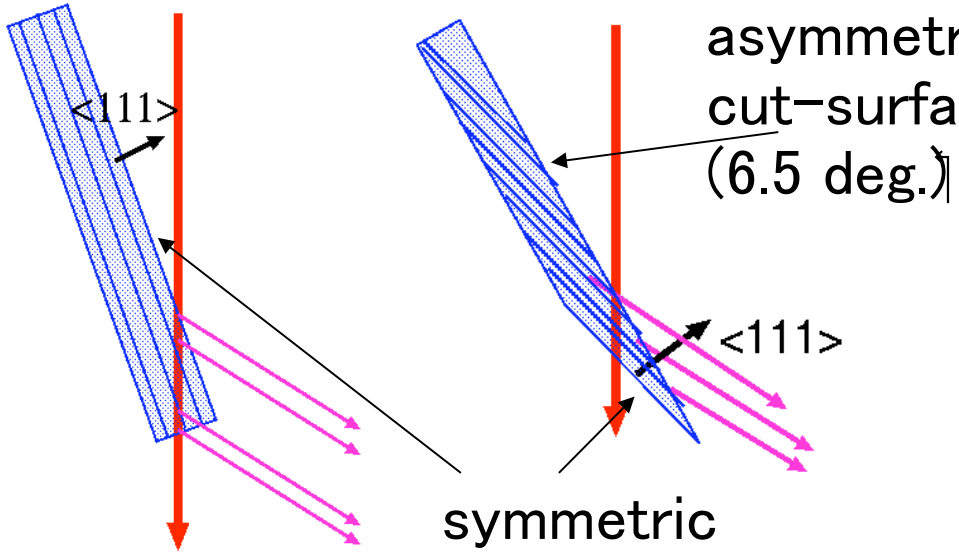
Analyzer-based Phase-contrast imaging
(DEI: Diffraction-enhanced imaging)



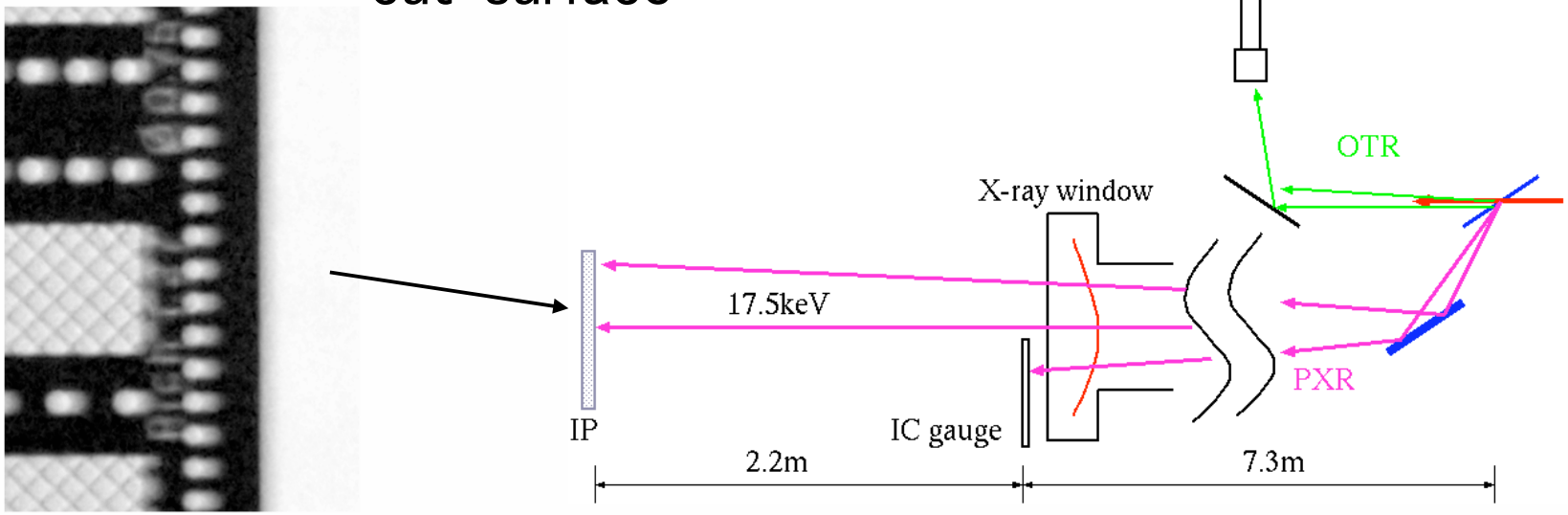
DEI has been one of the intensive applications of PXR at LEBRA.

The X-ray refraction due to passing through the sample can be detect using an analyzer crystal.

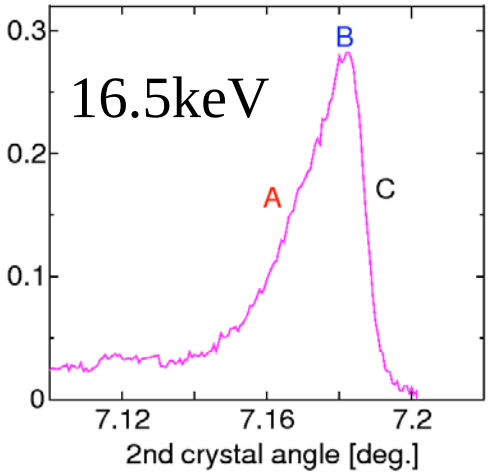
Multi-beam effect at the edge of the target

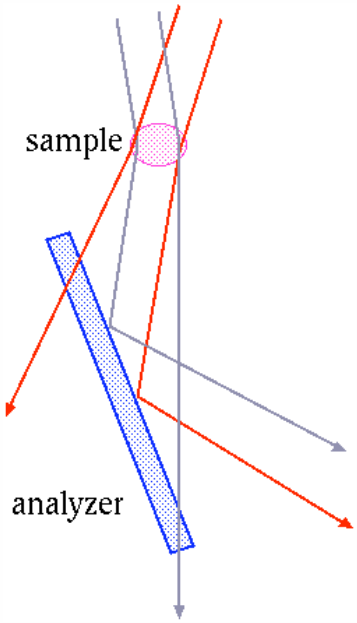


PXR beam from the edge of the target consists of 2 X-ray beams.
The effect disturbs imaging experiments.

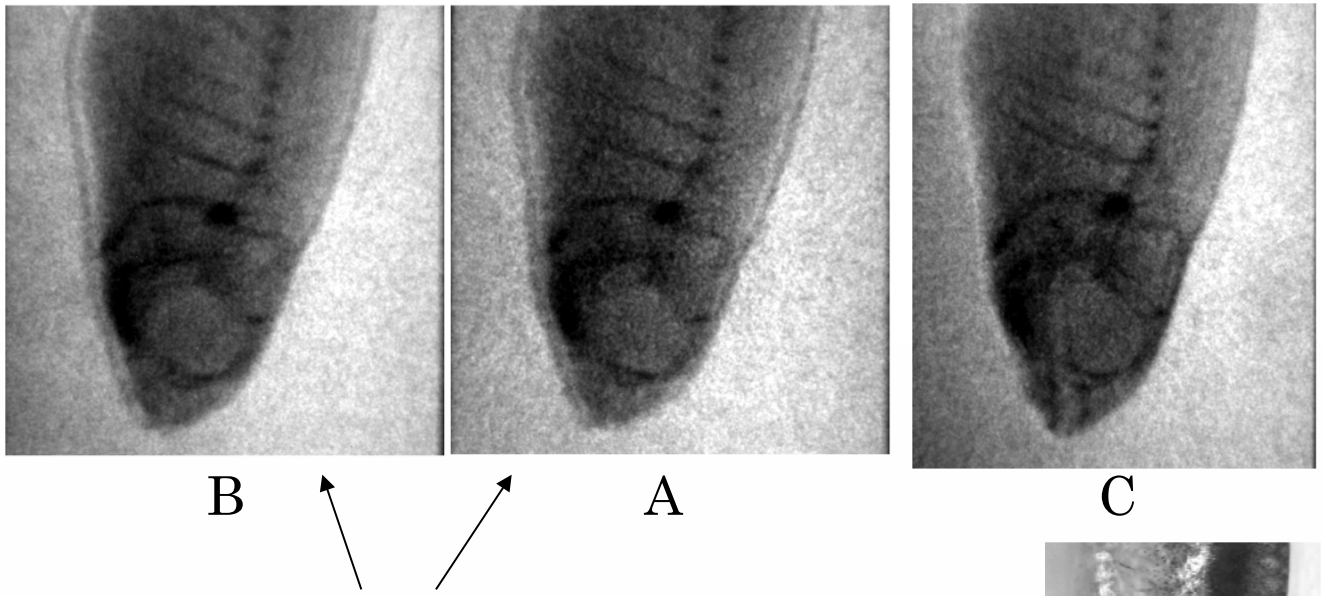


Deterioration of DEI



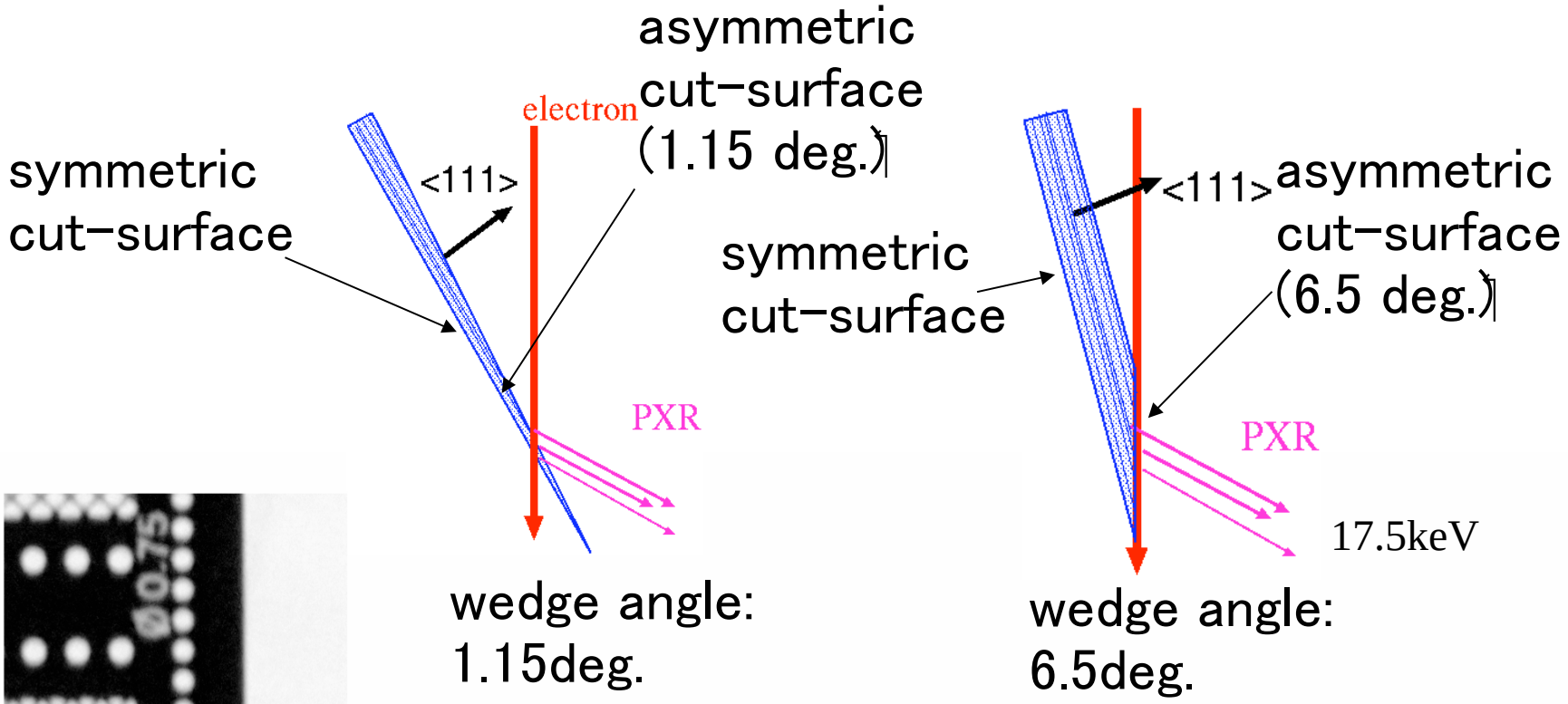


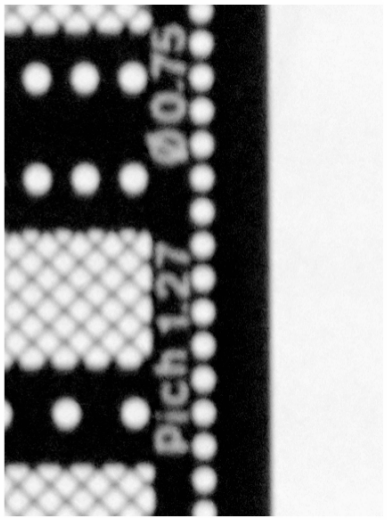
The multi-beam effect seriously affects the measurement of DEI.



bright and dark lines appear on the both sides due to two PXR beams.

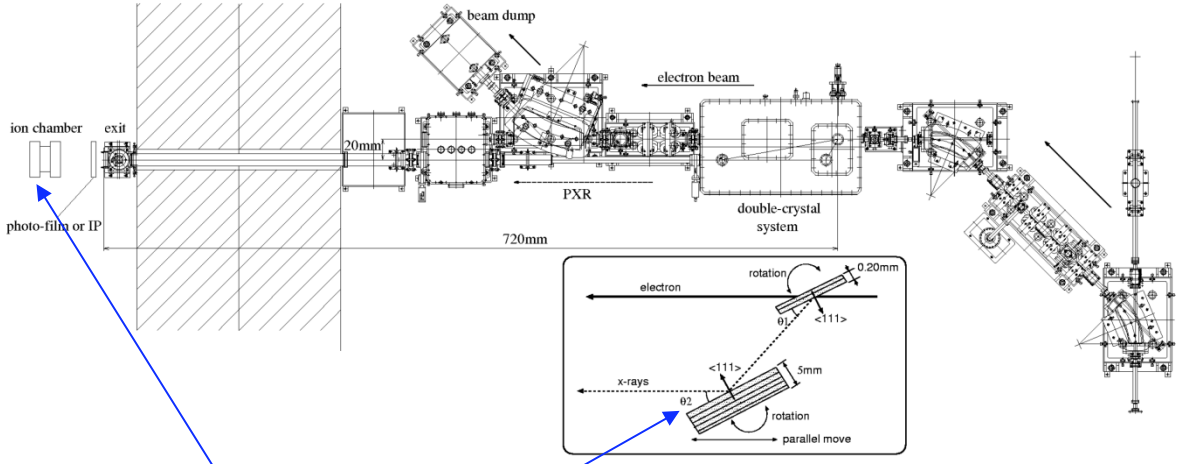
New wedge-shaped target crystal





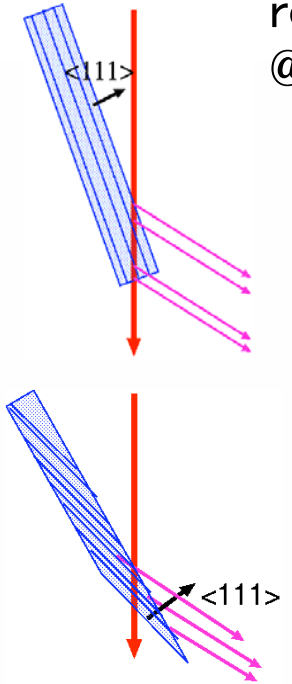
To reduce the multi-beam effect,
new wedge-shaped target crystals were prepared.
Using these targets, the deterioration in imaging was suppressed.

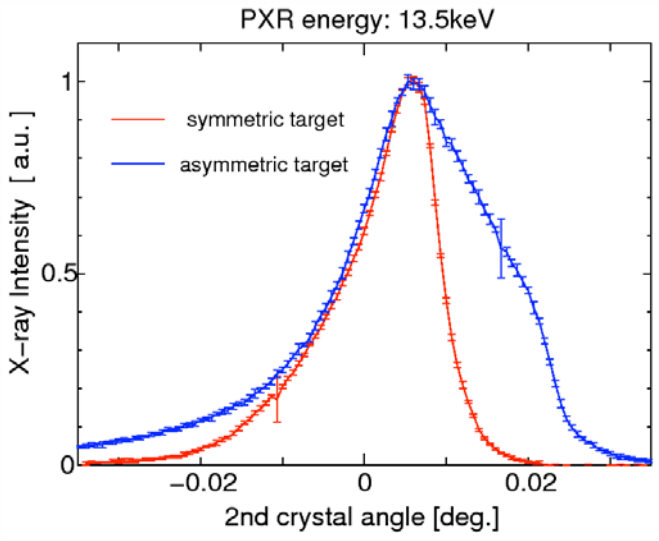
Narrow diffraction width at the 2nd crystal

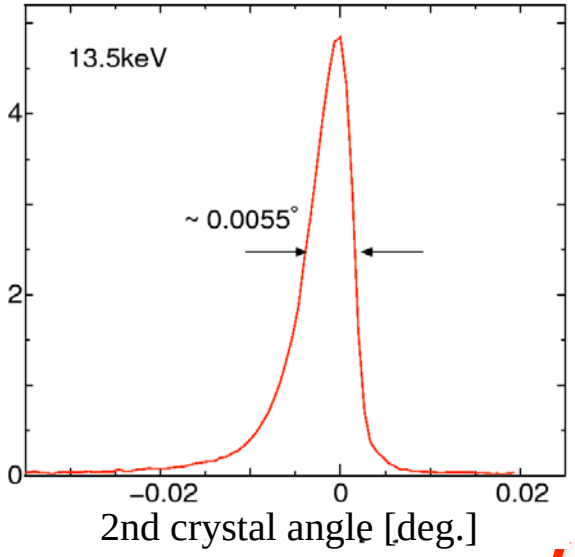


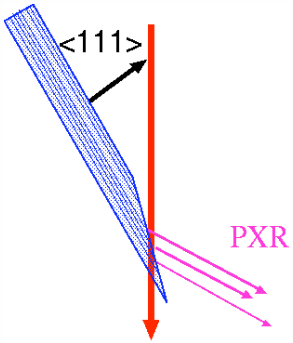
rocking curve measurement
@ 2nd crystal in the PXR generator

The diffraction curve for PXR from the wedge-shaped target has a narrow width.

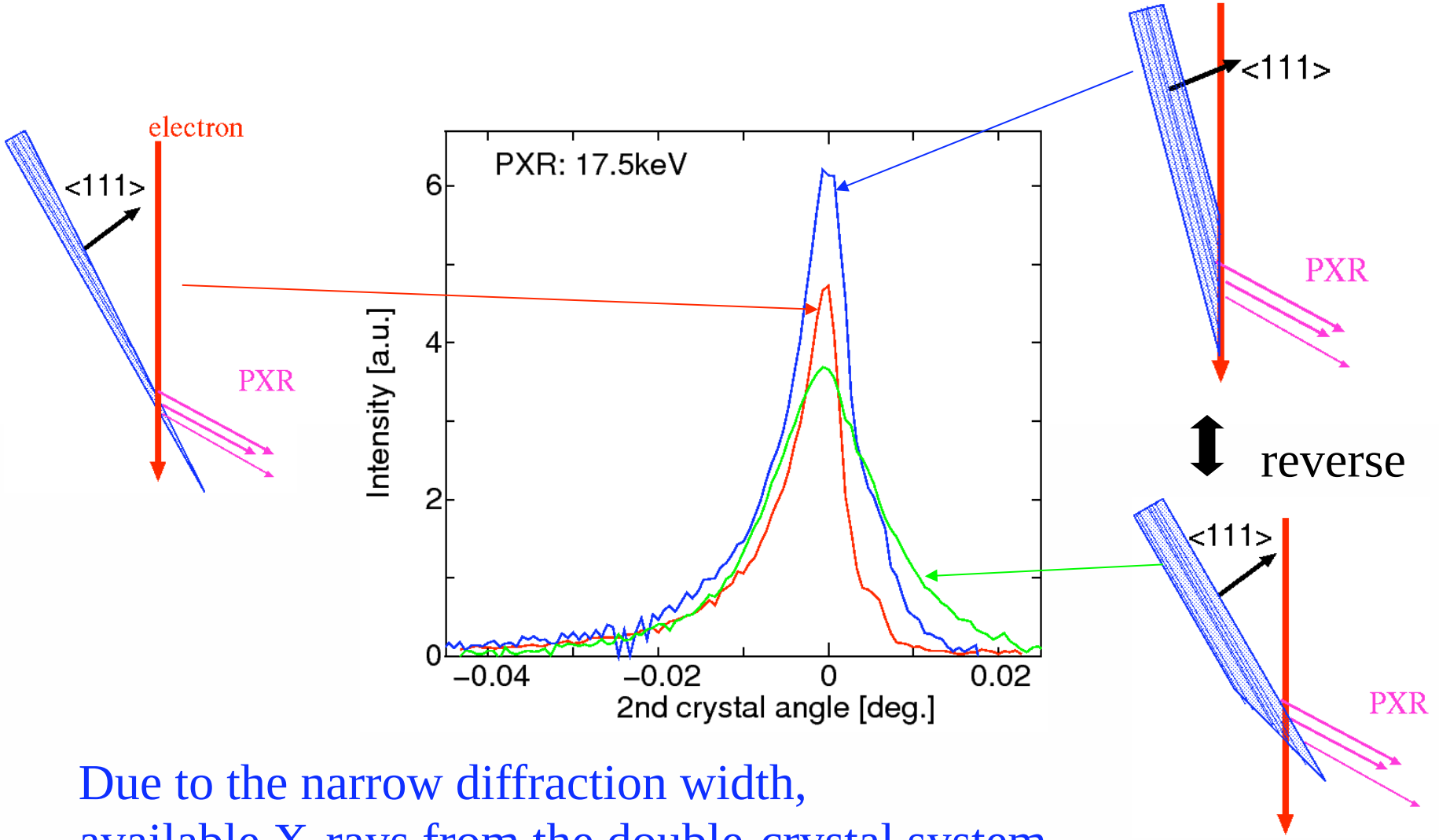








Dependence of the rocking curve on the target geometry



Due to the narrow diffraction width,
available X-rays from the double-crystal system
increase at the peak.

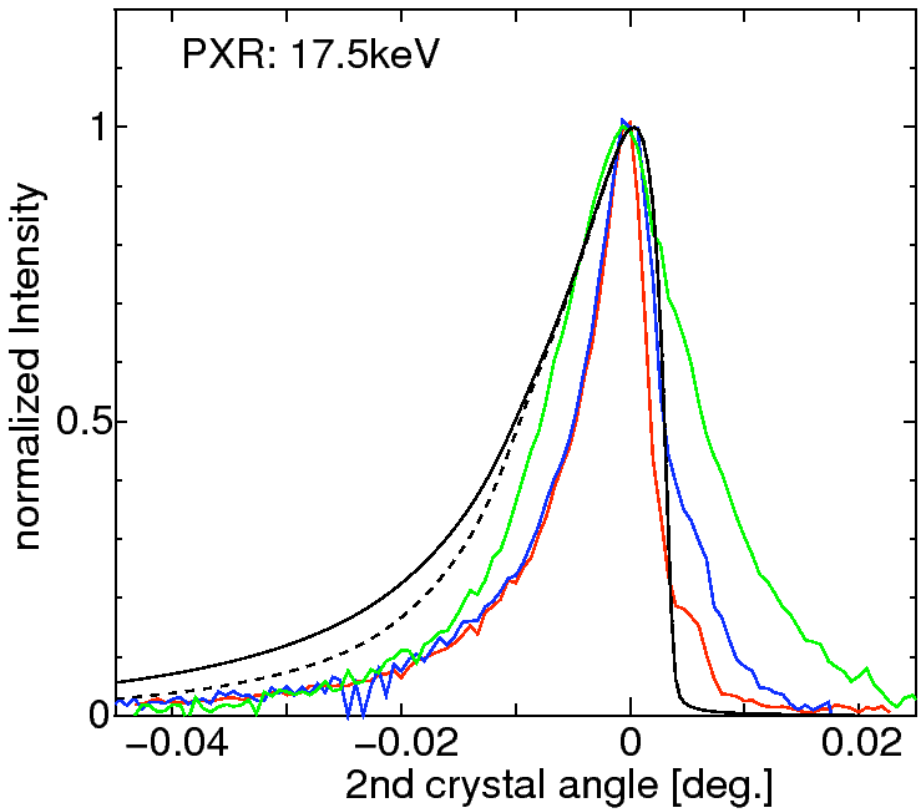
Comparison with MC & ray-tracing simulation

theoretical curves calculated by Monte Carlo method & ray-tracing including the electron scattering in the target medium.

X-ray absorption

——— no absorption

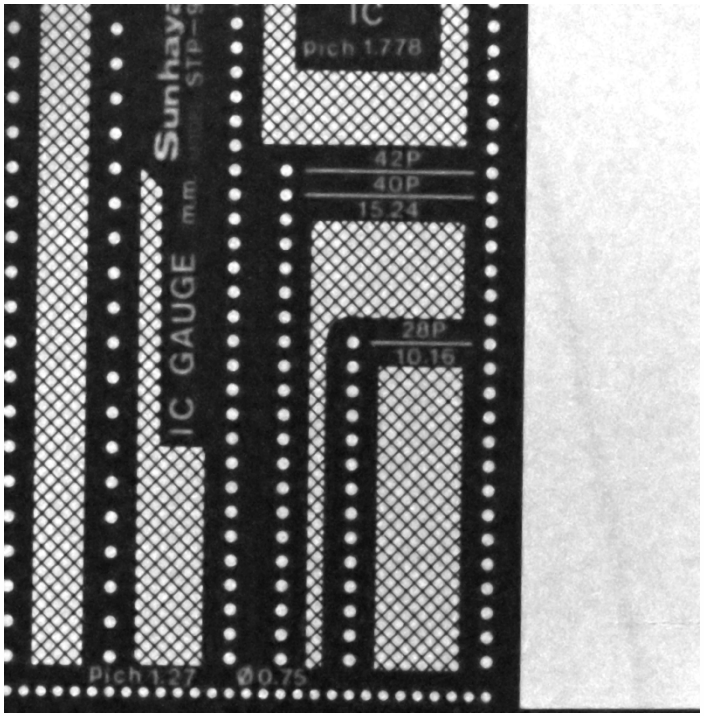
····· amorphous absorption



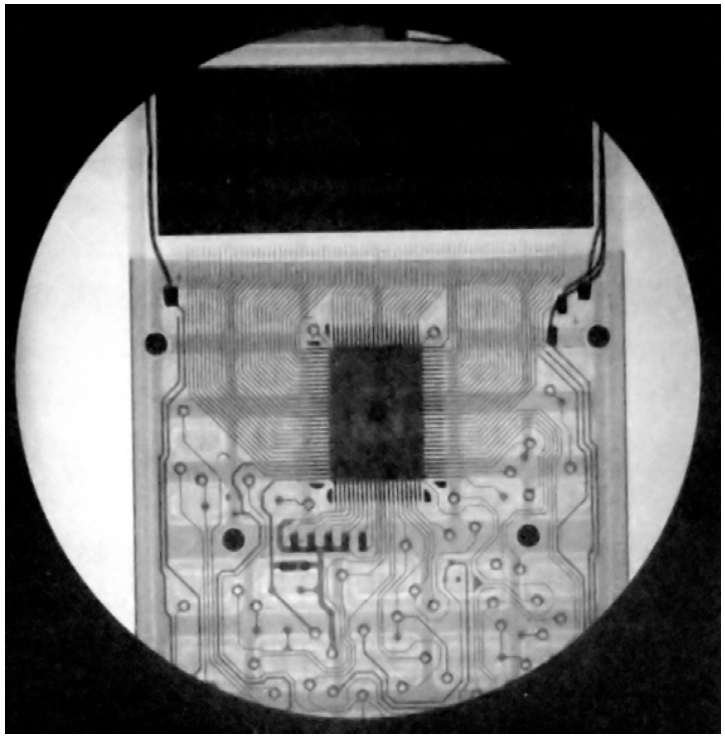
The observed diffraction curves have narrower widths than calculation based on the kinetic theory of PXR.

Conventional X-ray imaging using wedge-shaped target

target: wedge-shaped Si(111) (6.5deg.)
PXR: 17.5keV (grazing incidence)
e-beam: 2.6uA (average)

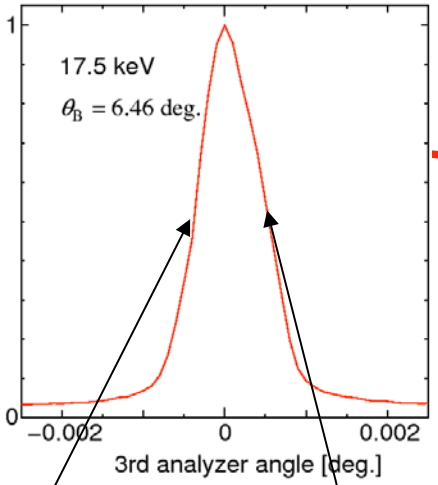


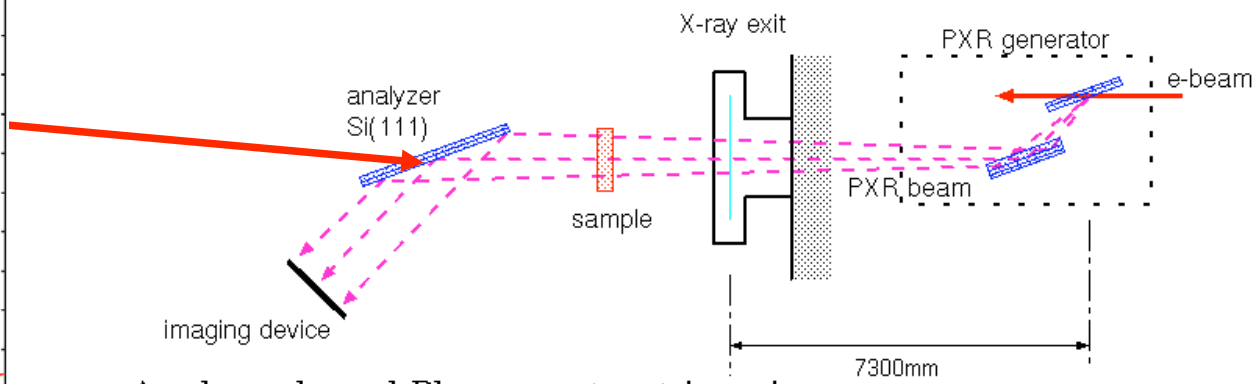
IC gauge
detector: flat-panel detector (FPD)
measurement time: 10s
pixel size: 50um x 50um (1M pixels)



calculator
detector: imaging plate (IP)
measurement time: 10s
pixel size: 60um x 60um

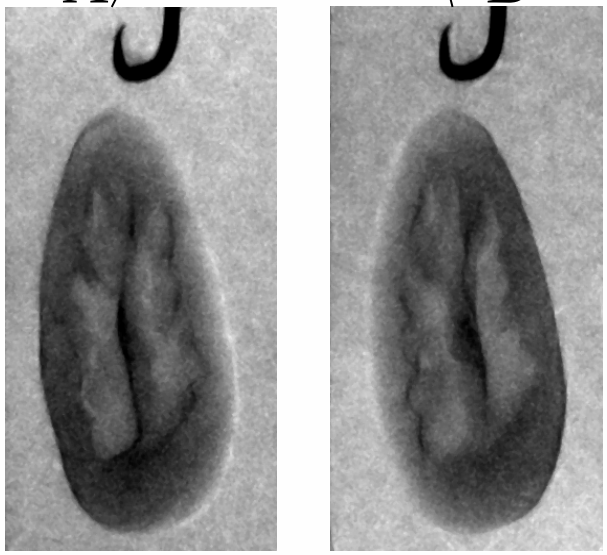
DEI image processing





Analyzer-based Phase-contrast imaging
(DEI: Diffraction-enhanced imaging)

A B

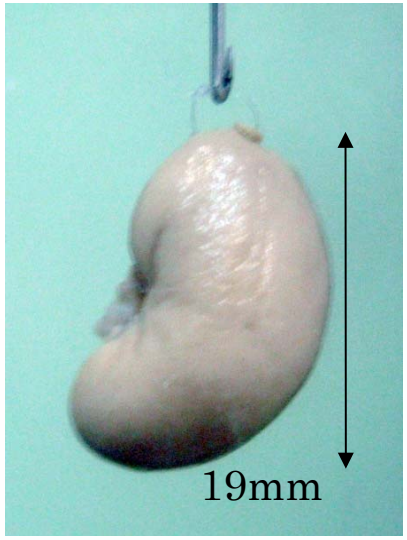


A+B: absorption contrast
(integral of density)

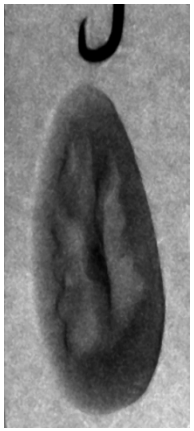
A-B: phase contrast
(differential of density)

The processing requires the quality and the stability of the X-ray beam.

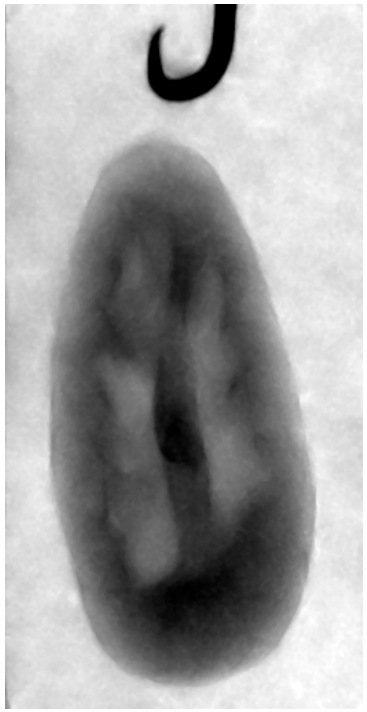
Separation of absorption and refraction



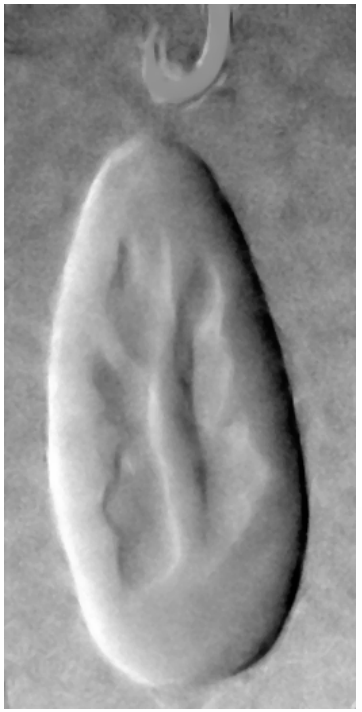
kidney of mouse



DEI images@17.5keV
measurement time
30s/image using CCD



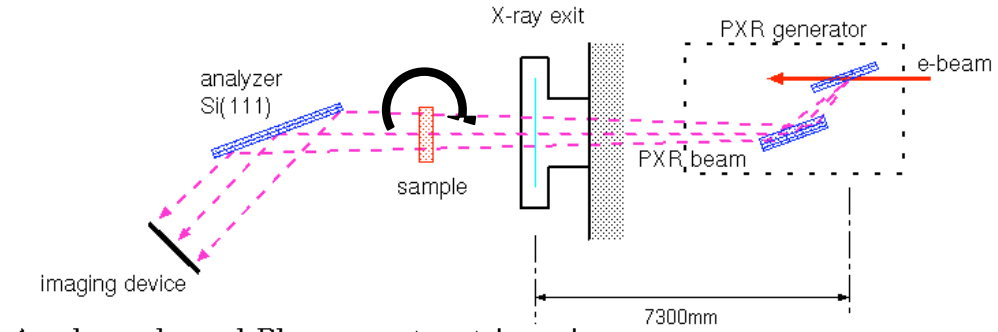
absorption contrast image



phase contrast image

As the result of the improvement in PXR property, phase-contrast can be separated from absorption-contrast easily.

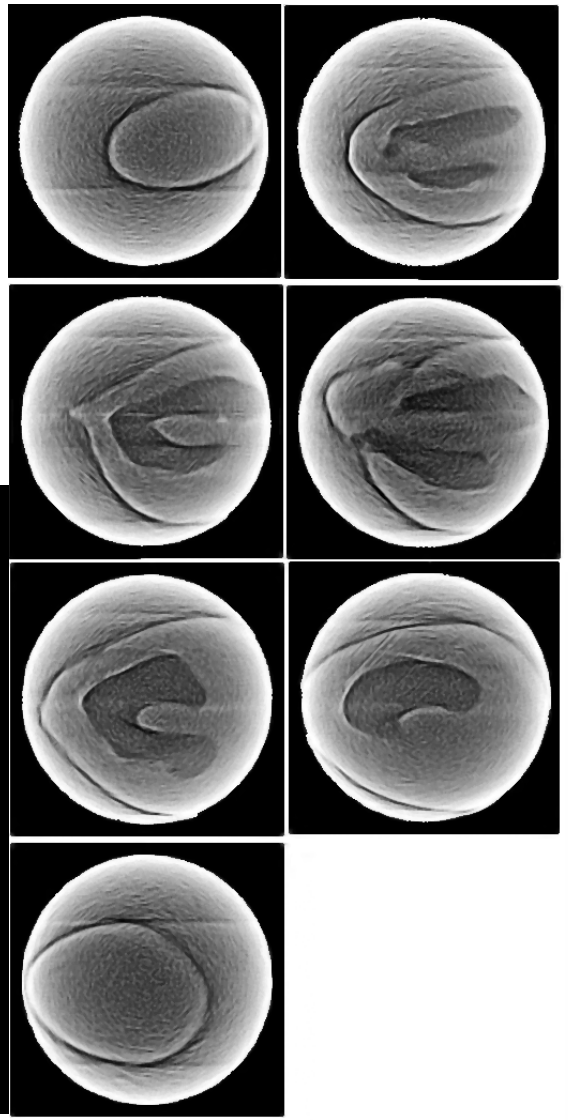
DEI-CT(computed tomography)



Analyzer-based Phase-contrast imaging
(DEI: Diffraction-enhanced imaging)

sample: mouse kidney
PXR energy: 17.5keV

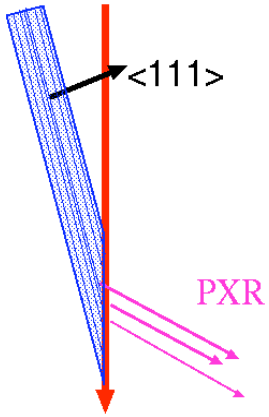
angular step: 2 deg.
projection: 90 images
(180 DEI images)
measurement time (net)
30s x 2 x 90 = 5400s
= 90min



phase-contrast tomography calculated from DEI images

Summary

- The multi-beam effect at the edge of the target crystal for PXR degrades X-ray property.
- To reduce the multi-beam effect, new wedge-shaped target crystals were prepared and has been tested.



- Due to the wedge-shaped target, the X-ray property and available yield improve.
- As the results of the improvement in X-ray property, phase-contrast images can be obtained by DEI method within 1min.
- First success in phase-contrast tomography computed from DEI projections using PXR

Staffs&Collaborators

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  University
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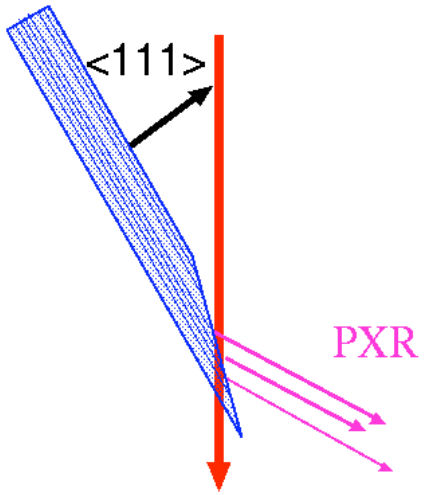
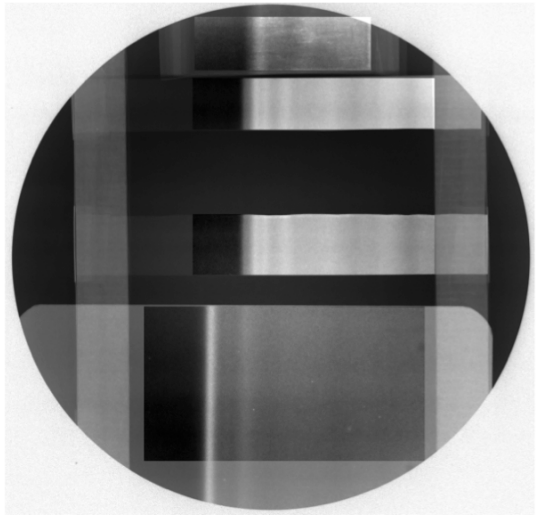
  (21686088, 21560055)

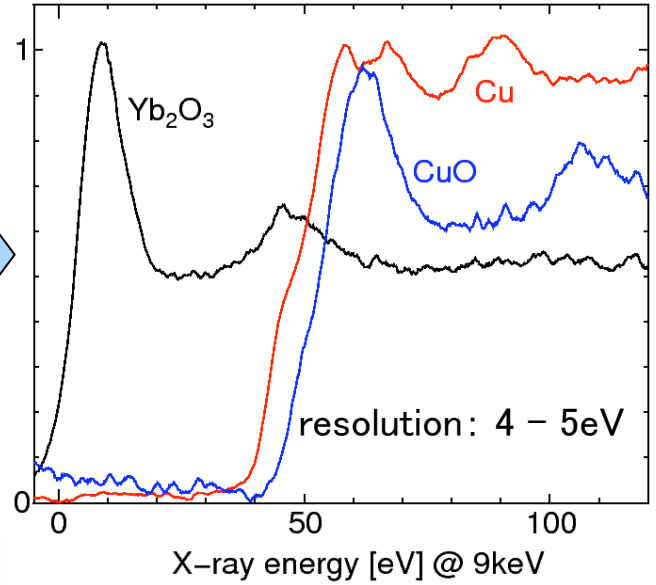
Thank you for your kind attention !!

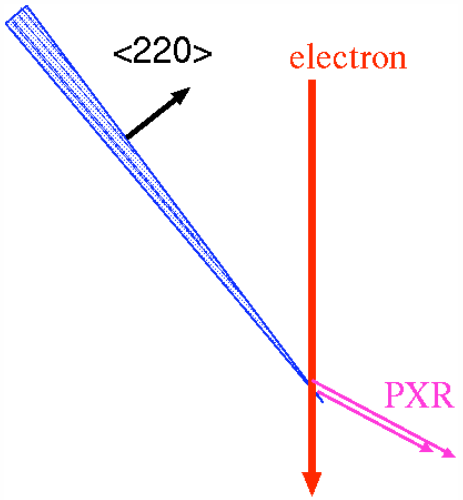
Appendix

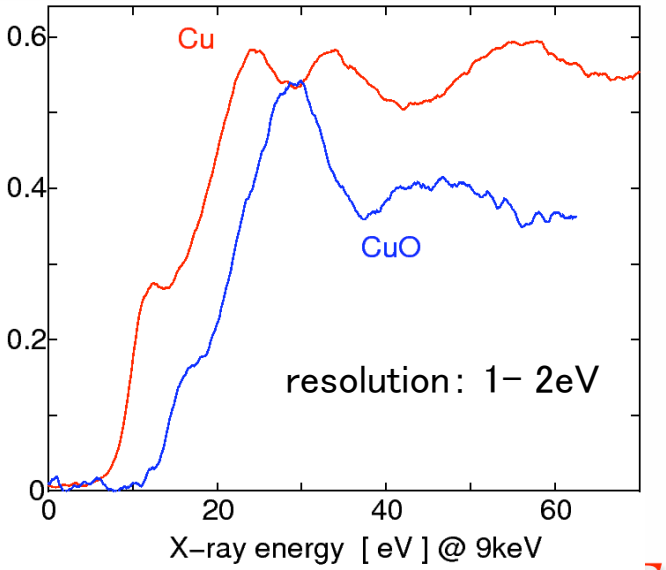
Dispersive XAFS (DXAFS)



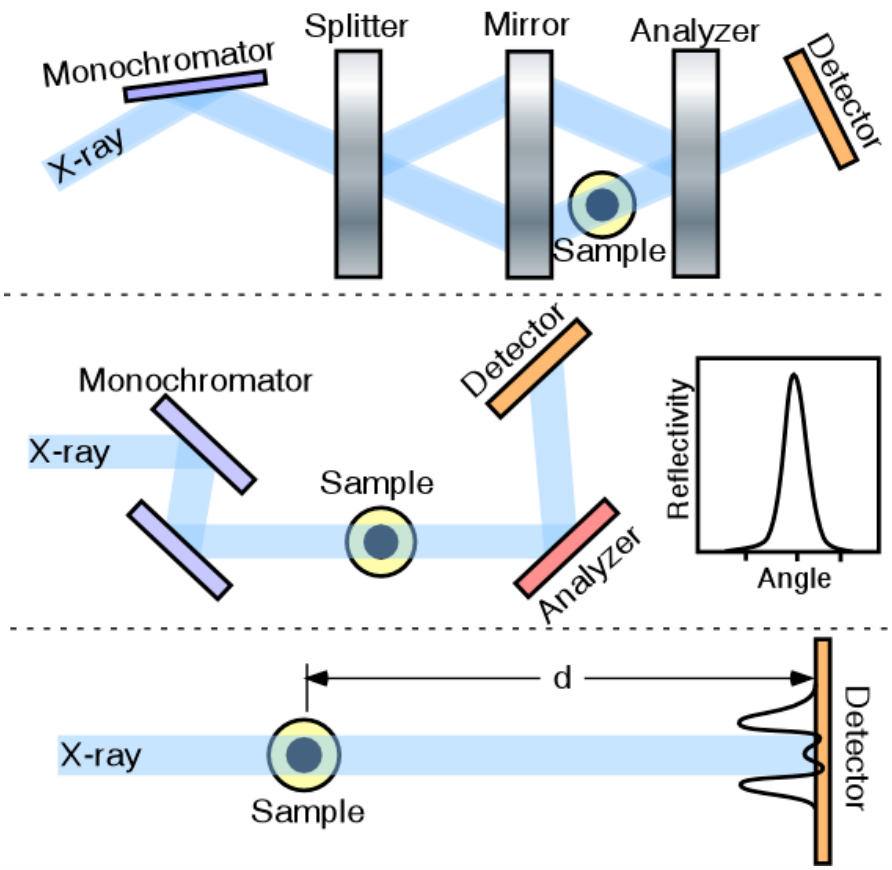








Phase-contrast(sensitive) X-ray imaging



R. Fitzgerald: Phys. Today 53 (2000) 23

•Recently, an advanced X-ray
•imaging, called phase-contrast
•imaging, has been studied using
•synchrotron radiation.

• High sensitivity to the density difference of light materials.

• Not serious damage due to X-ray absorption (using high-energy X-rays)

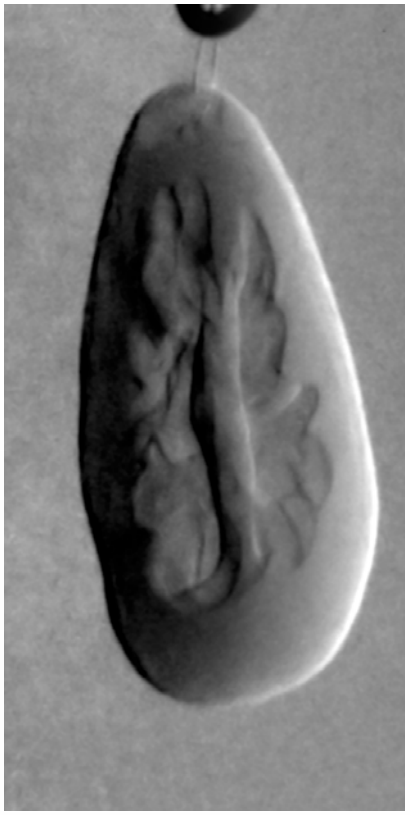
•Medical applicat ion of the technique has been expected.

The methods require X-ray beams with excellent spatial coherence.

Typical result of DEI 2 (17.5keV)

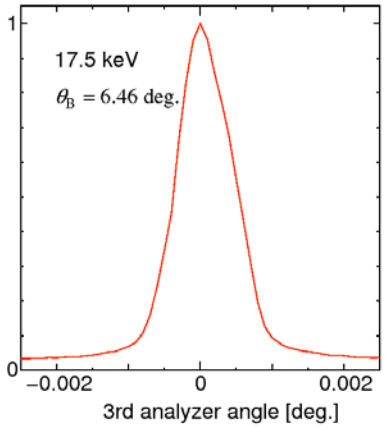
kidney of mouse

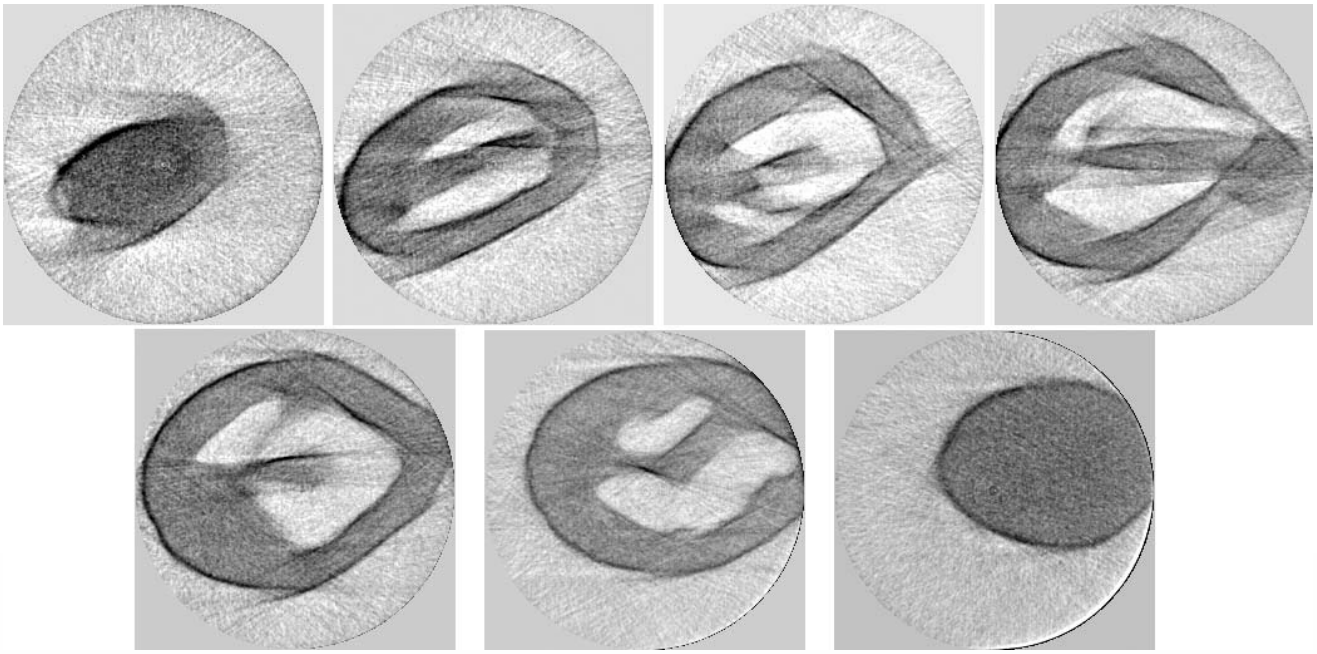
A+B
absorption

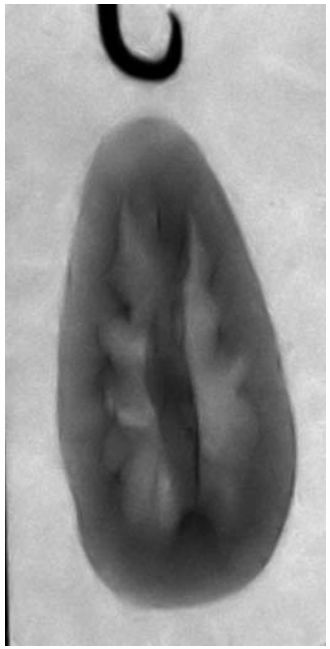


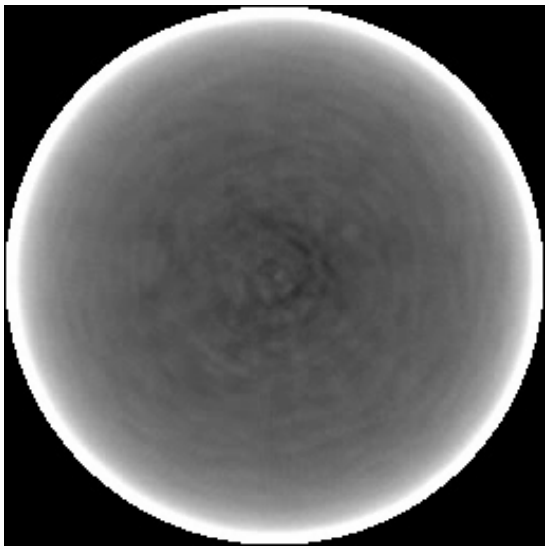
A-B
phase contrast

Computerized tomography (CT) by DEI









e-beam: 2.9 μA
exposure/projection: 2min
angular step: 2deg. (90 images)
total exposure: 3 hours