Electron storage ring based tabletop light source, MIRRORCLE for protein crystallography

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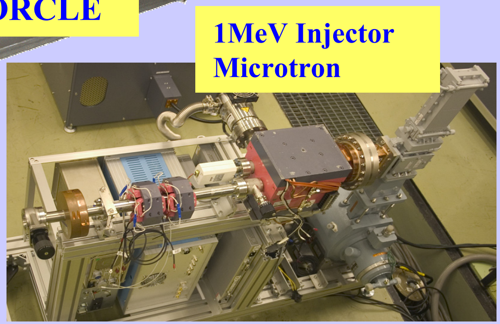
MIRRORCLE



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2. MIRRORCLE is a storage ring which generate extremely bright FIR
3. How to generate hard x-rays by a few MeV storage ring
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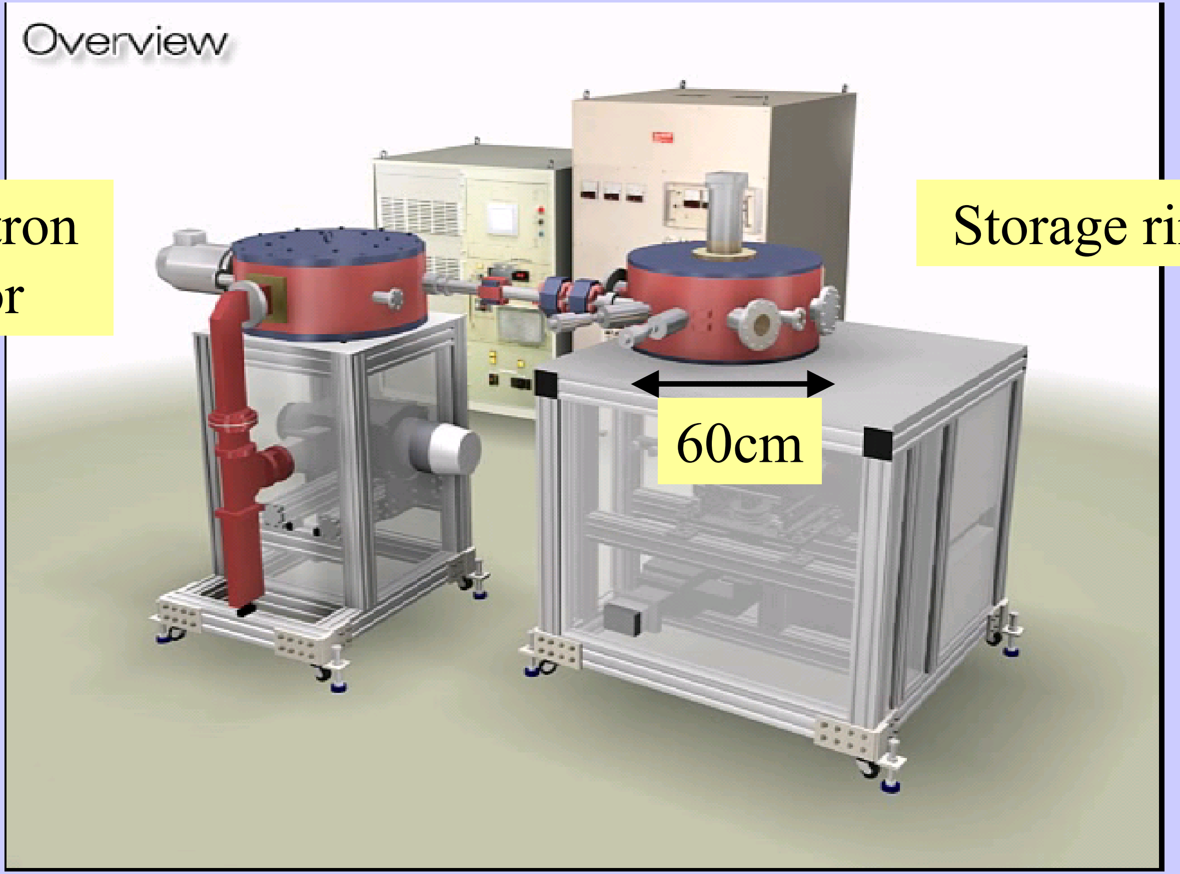
5. Beam line, in which different energy is extracted to the same direction by a single monochrometer
6. Demonstration of Dispersive EXAFS
7. Intensity of monochromatic beam is enough to proceed crystallography
8. Small angle scattering is advanced with MIRRORCLE

MIRRORCLE is a low energy, tabletop electron storage ring

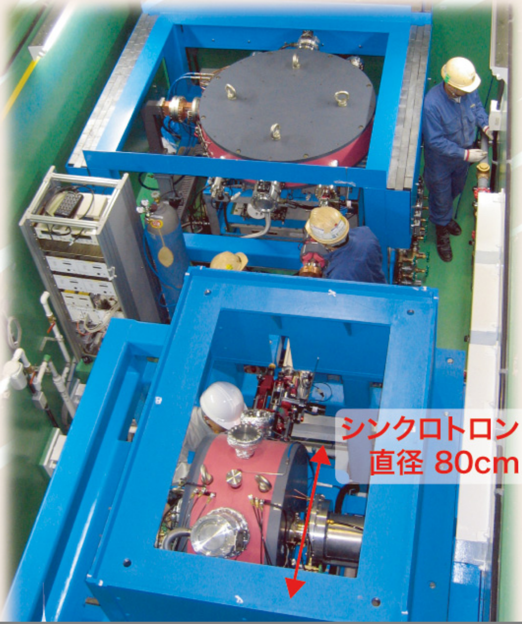
Microtron Injector



Storage ring

MIRRORCLE's

2006年稼動

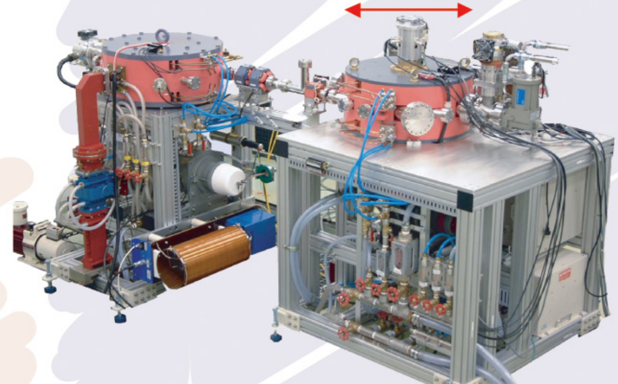


MIRRORCL 20SX

単色X線 (8～30keV)、軟X線、EUV
遠赤外線、硬X線(10～20000keV)

X-ray characterization
EUV lithography

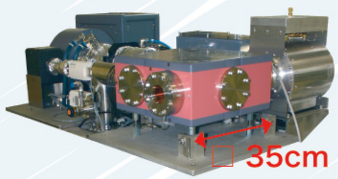
2003年稼動



MIRRORCLE 6X (6FIR)

FIR spectroscopy

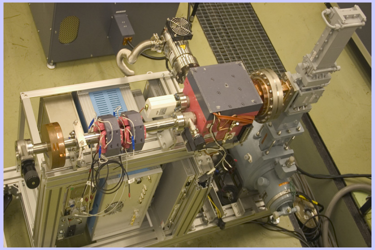
2008年に成功



MIRRORCLE CV4

X-ray imaging, NDT

MIRRORCLE-CV1

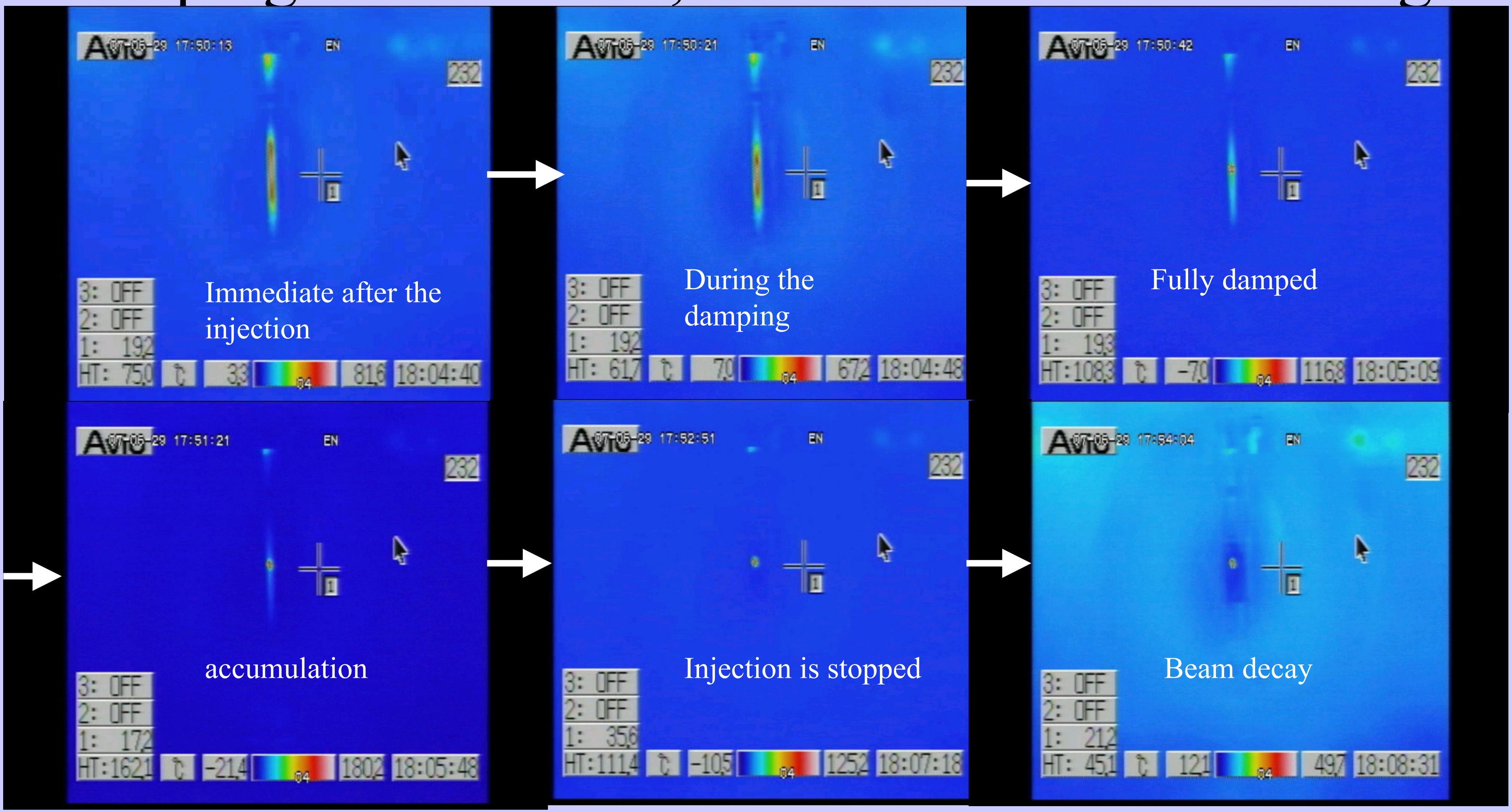


Medical imaging
X-ray microscope

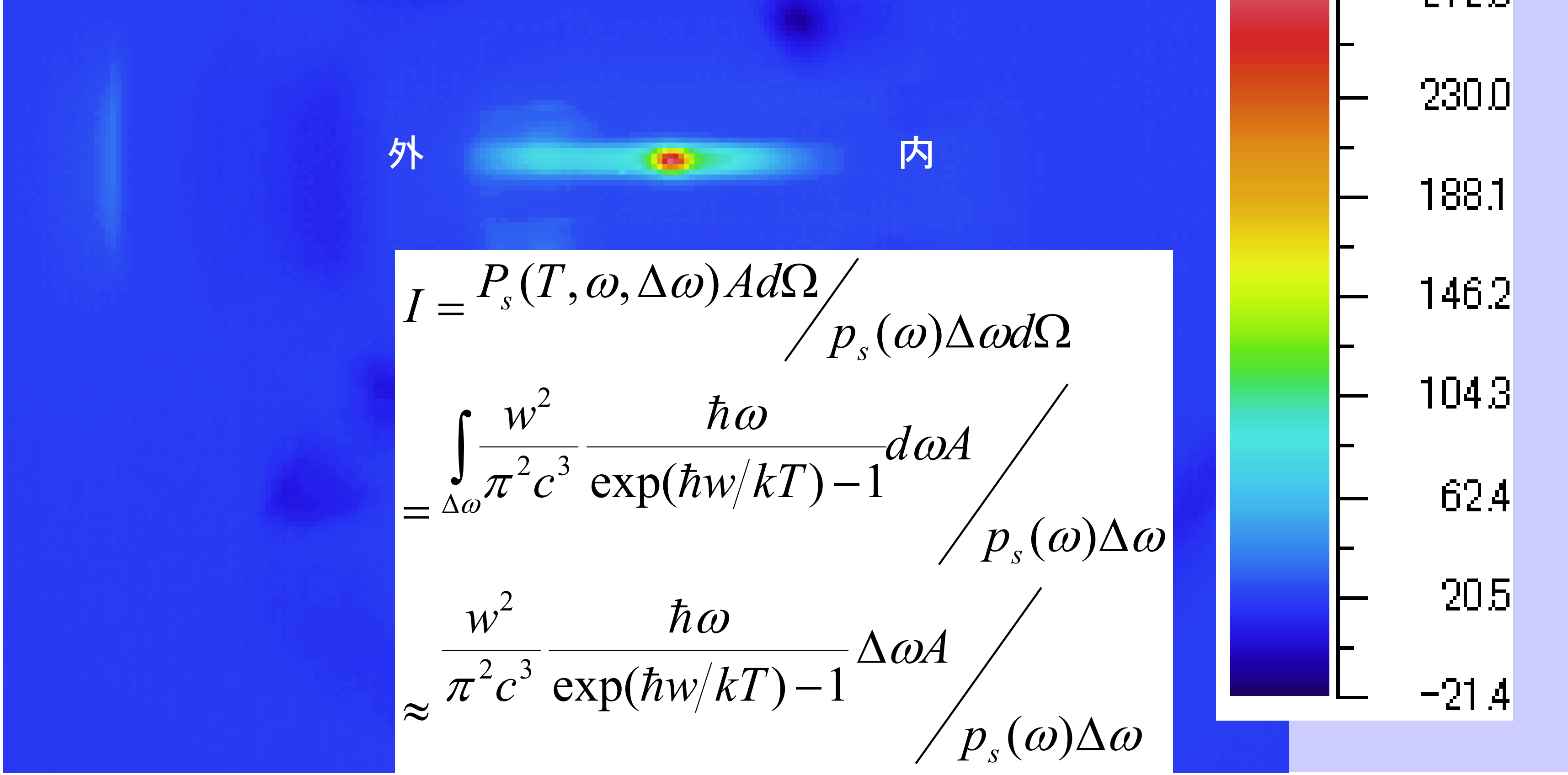
MIRRORCLE is a storage ring

4A beam current is accumulated

Damping time:10msec, lifetime:1min without target



The observed maximum temperature of the beam 300deg C represent 4A beam current, and 0.63mW/B.W. at 11μm wavelength

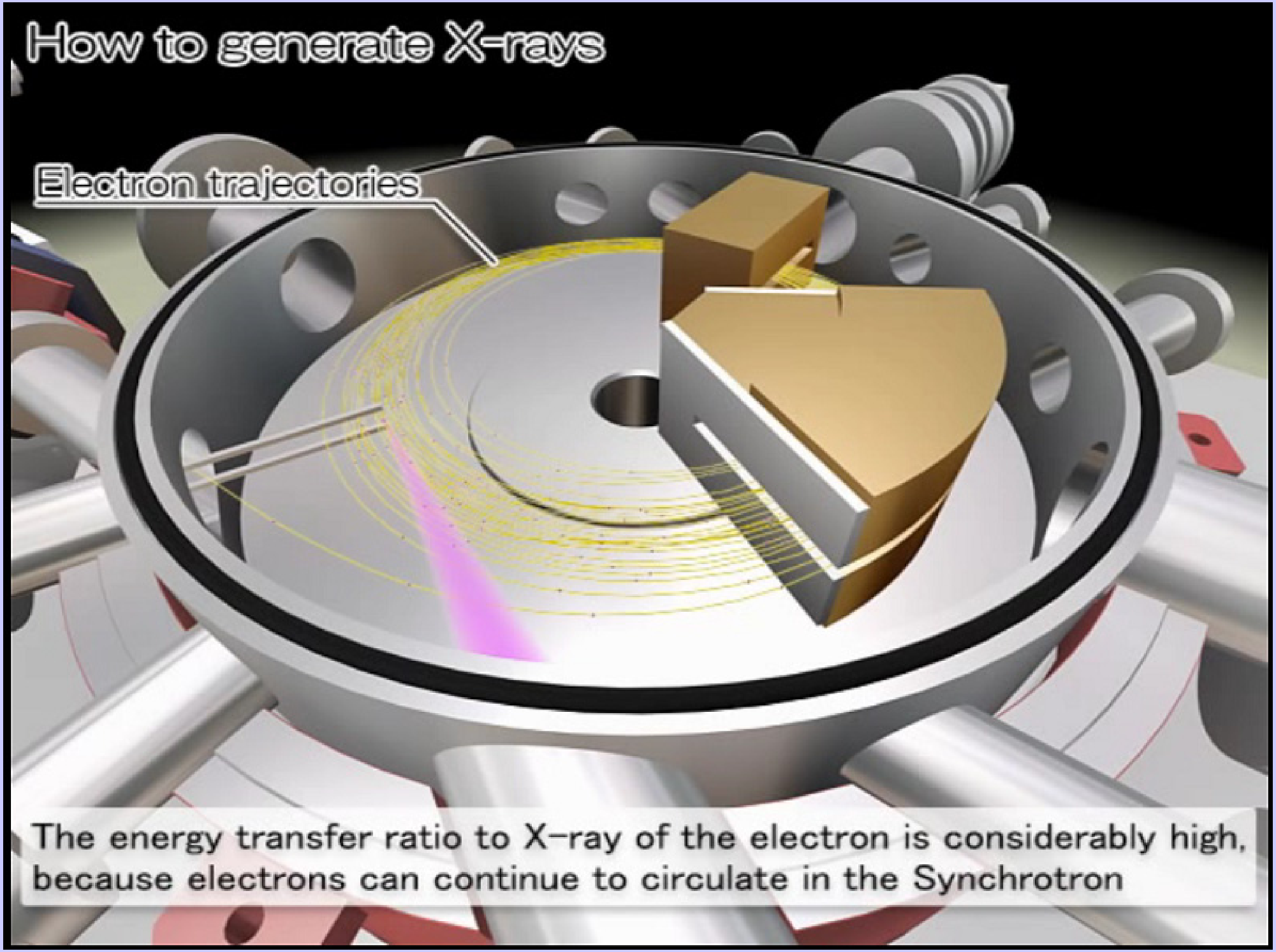


$$I = P_s(T,\omega,\Delta\omega)\,A\,d\Omega \Big/ p_s(\omega)\Delta\omega\, d\Omega$$

$$= \int_{\Delta\omega} \frac{w^2}{\pi^2 c^3} \frac{\hbar\omega}{\exp(\hbar w/kT)-1} d\omega A \Big/ p_s(\omega)\Delta\omega$$

$$\approx \frac{w^2}{\pi^2 c^3} \frac{\hbar\omega}{\exp(\hbar w/kT)-1} \Delta\omega A \Big/ p_s(\omega)\Delta\omega$$

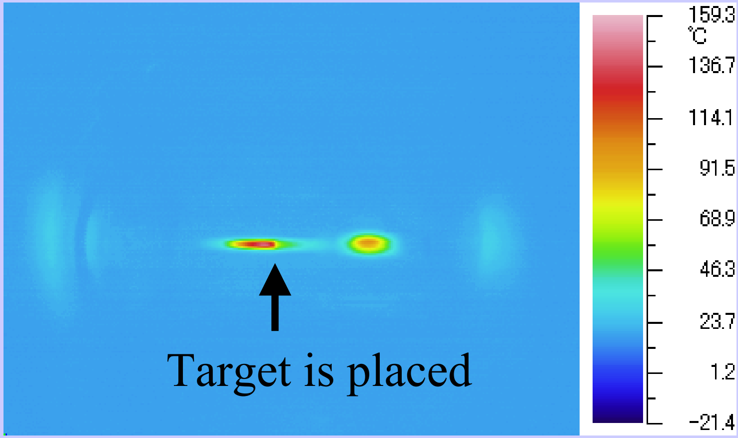
How to generate hard x-rays by a few MeV electron storage ring



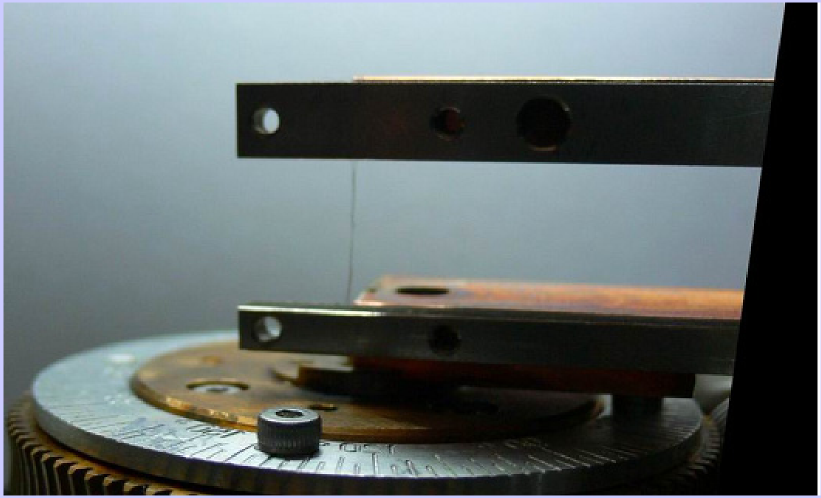
The observed X-ray power is 225mGy/min at 150mA injector peak current and 400 Hz repetitions

Measured by the ion chamber

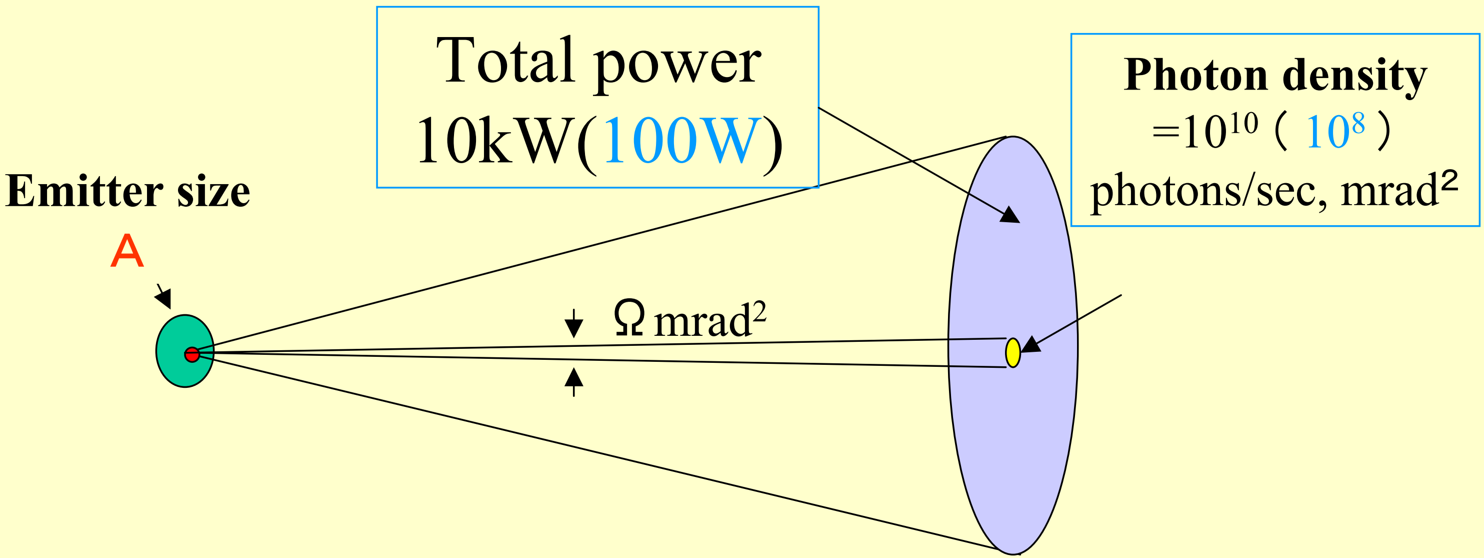
800W storage ring RF power is applied



Carbon nano tube target is one of the best



MIRRORCLE generate cone beam

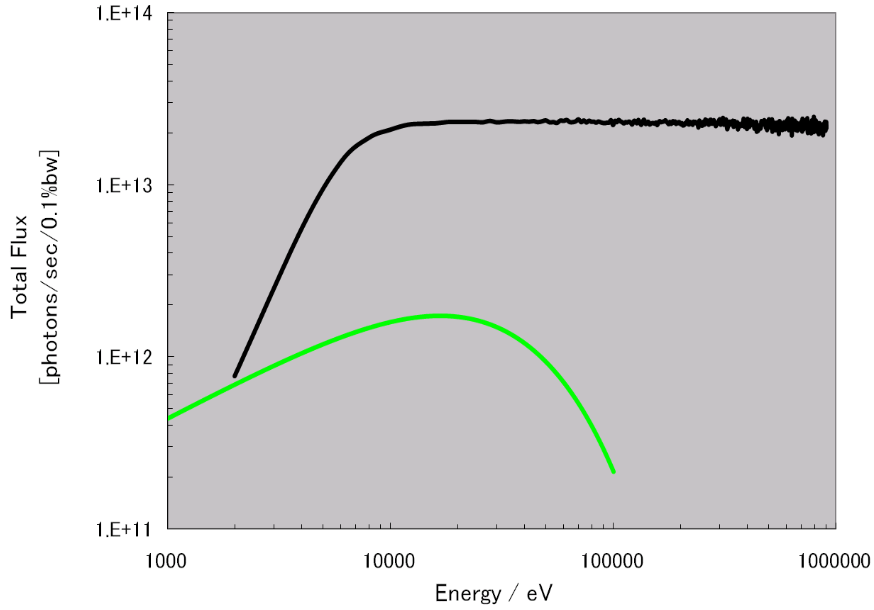


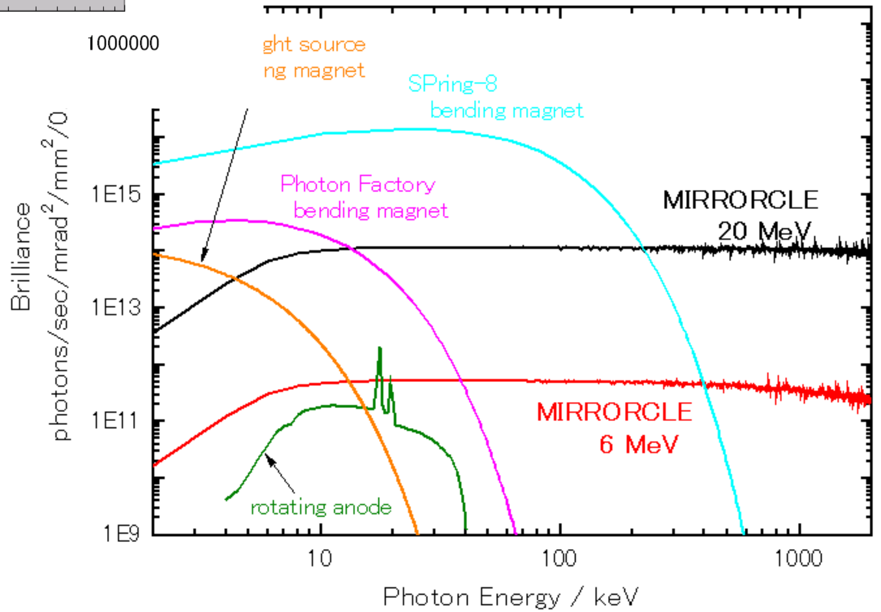
Photon density＝photons／Ω、sec、band width
(assuming point emitter size)

Brilliance＝photon density／A

Brilliance and Flux (simulation)

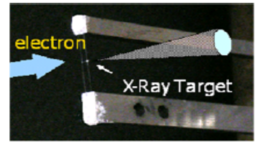
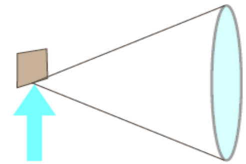
Flux[2π／γ²]





Measure X-ray flux

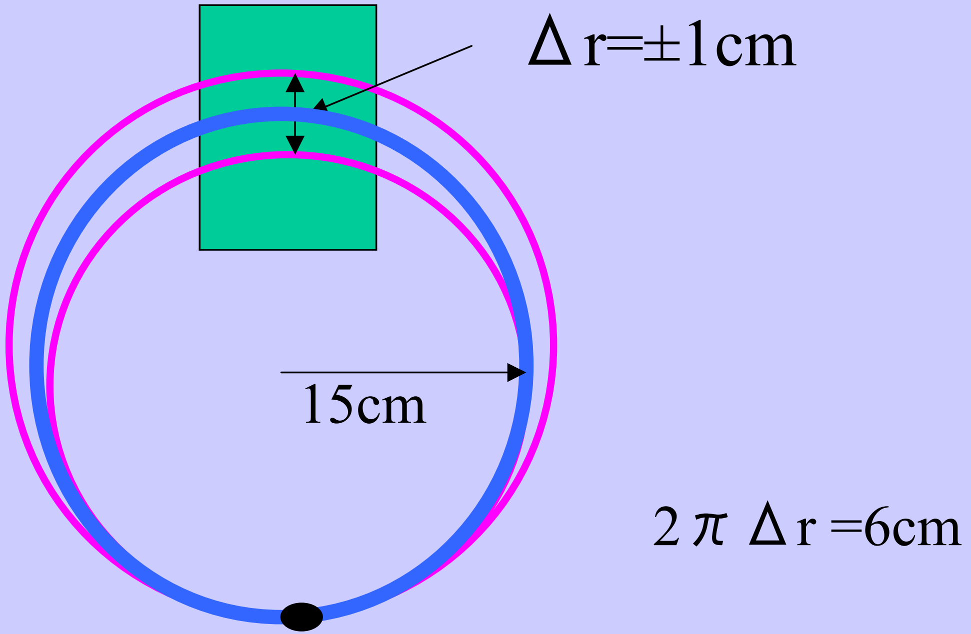
MIRRORCLE^{RAY}-20SX X-ray Intensity is compared with that of reguler 1kW tube light sources(In the atmosphere).

Radiation Mechanism	20SX 	1kW tube 
Crystal	sagittal bent crystal	
Target	Be 0.1mmThickness 0.8mm width	Mo
X-ray energy [KeV]	17	
intensity [mR/pixel]	138	10
Distance from source point [m]	3.1	2.6
Width of sagittal bent crystal [±mrad]	6.2	3.1
Intensity [mR/pixel/mrad]	11.1	1.6
Focused beam size [mm]	1	5
Normalized Intensity by the diffraction efficiency [mR/pixel]	25566	1202

Why MIRRORCLE is bright?

Mode is fixed by the target. All electron approaches the target again in the next collision.

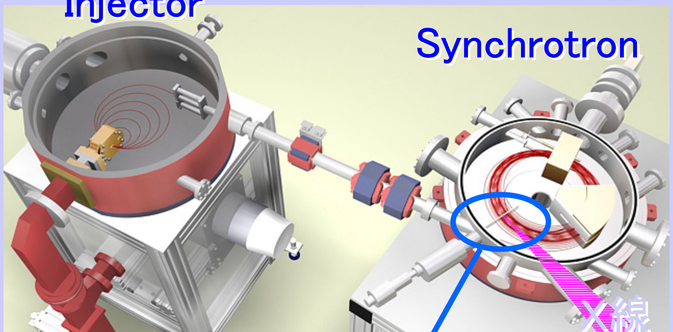
Repeat injection at 400Hz (Max intensity is the subject of repetition rate)



Betatron tune is near 0.5

How it's different from synchrotron light source and X-ray tube

A



1. High current

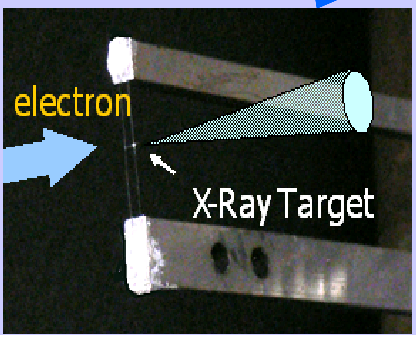
Orbit radius=8cm

> portable source

stored beam current=4A

> High power radiation source

B



2. Small emission point

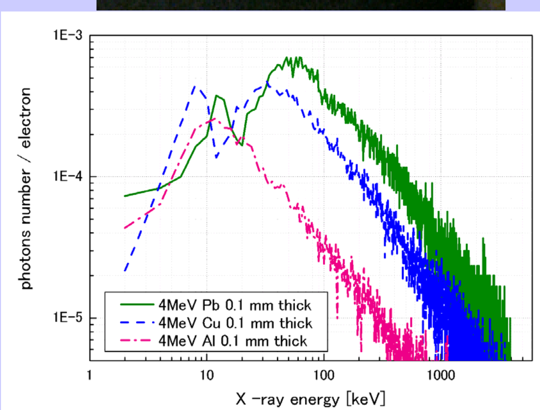
3. Cone beam

1–10 μm target

> Enables highly Magnified imaging

> distance reduces the scattering background

C



4. Polychromatic X-ray

High energy X-ray

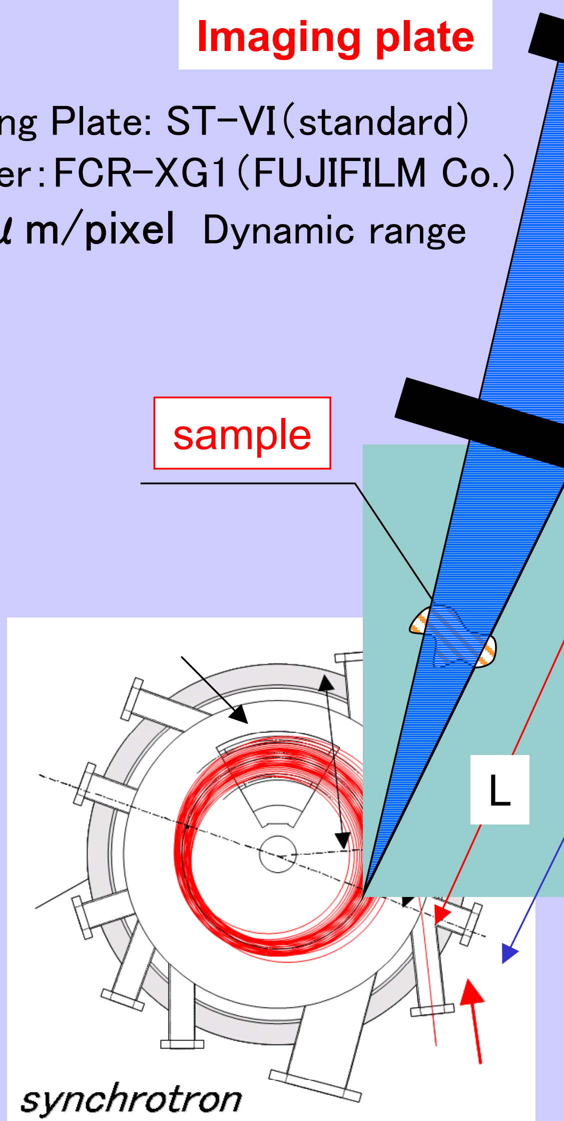
- NDT of heavy construction
- 2 color experiment
- Characterization of materials by monochromatic X-ray

Advantage of small emission point

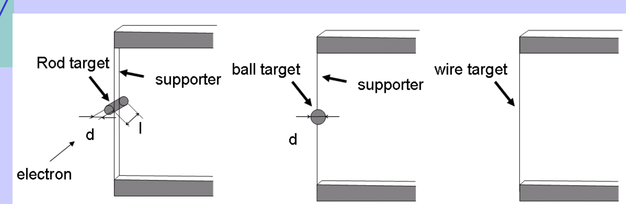
- fine space resolution in the imaging
- fine energy resolution with monochrometer

Configuration of magnified imaging

Imaging Plate: ST-VI(standard)
Reader:FCR-XG1(FUJIFILM Co.)
150μm/pixel Dynamic range 12bit

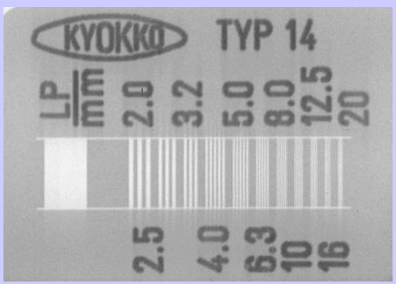


100 times magnification and 1 μm size emitter appreciate 1.5μm space resolution with 150um detector



Fine space resolution is obtained without loosing intensity

SOURCE：MIRRORCLE-6X
Detector：Imaging Plate
(FUJIFILM, XG-1 150 μm/pixel)
S-O distance 400mm



Test chart
X-ray contact image

12 times magnified imaging

Pb1mm Point

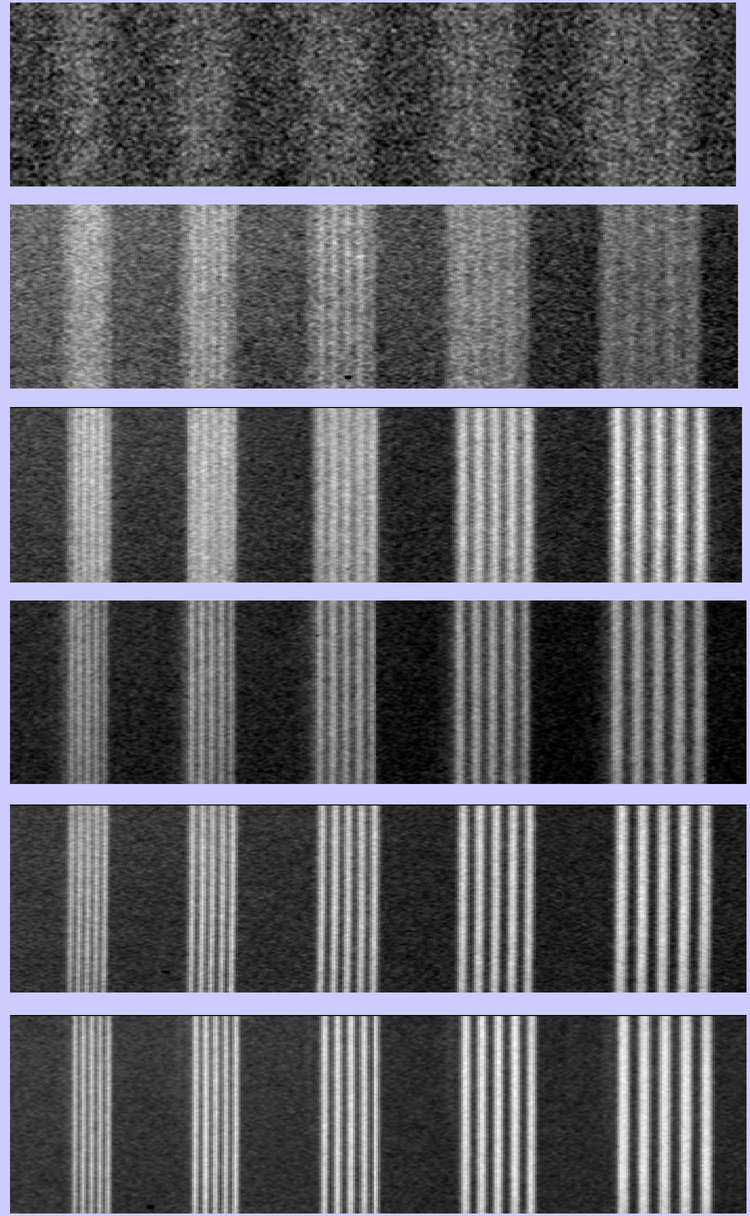
Pt100 μm Point

Cu25 μm Point

W10 μm Point

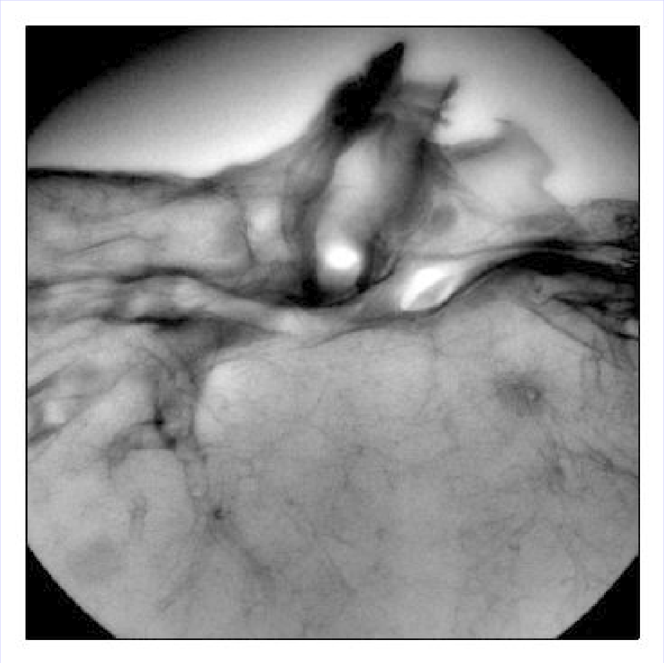
W10 μm Line

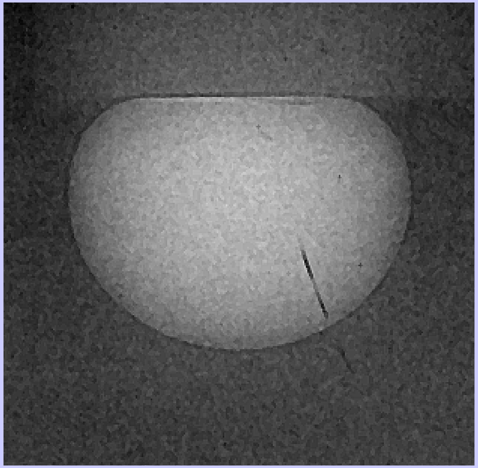
W2.5 μm Line



20 16 12.5 10 8 [LPM]

Polychromatic beam is useful which include more information



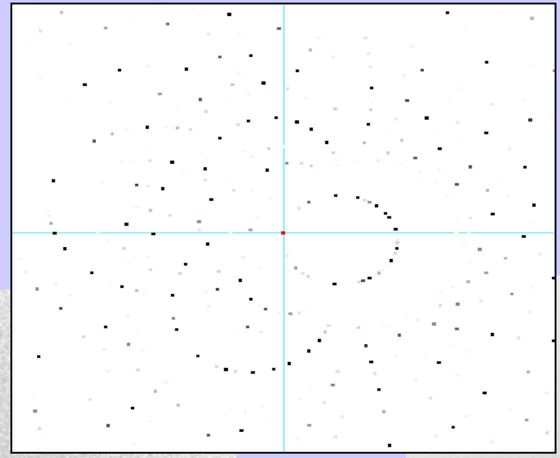


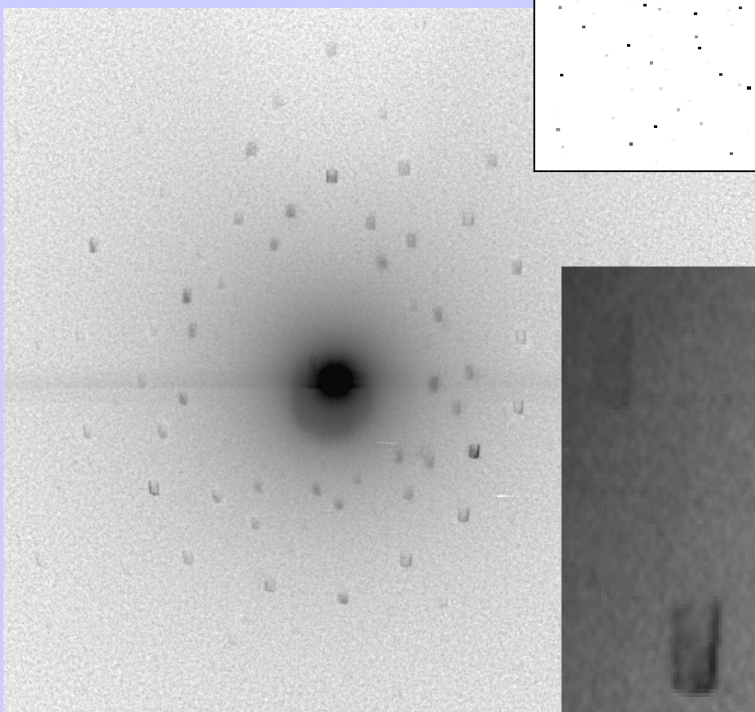
・target size: 25 μm ϕ
・Detector: Imaging plate
（FUJIFILM XG-1　150 μm/pixel）

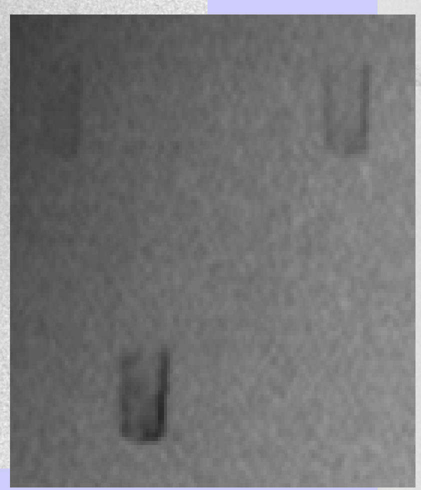
12 times magnification

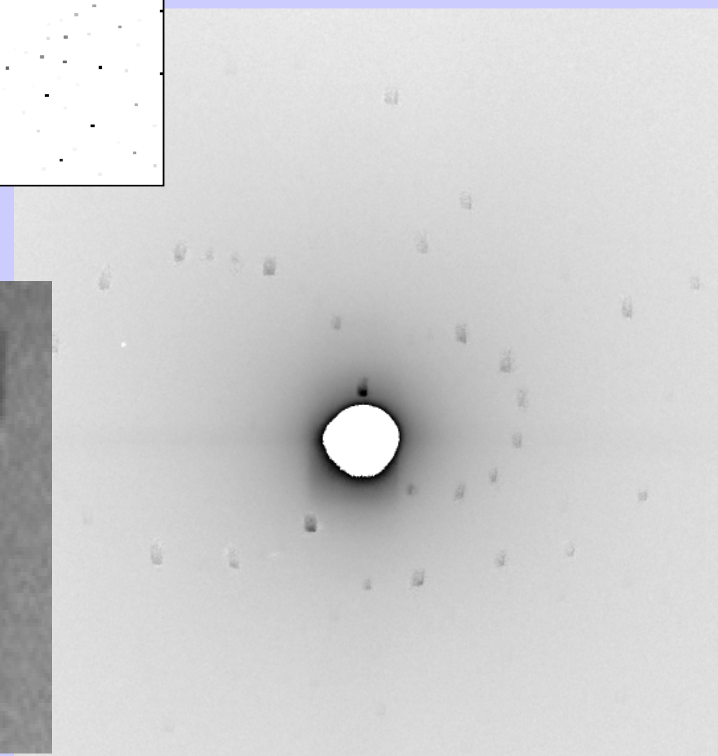
White Laue and Topography at 1.5 m dist.

SiO_2(111) sample

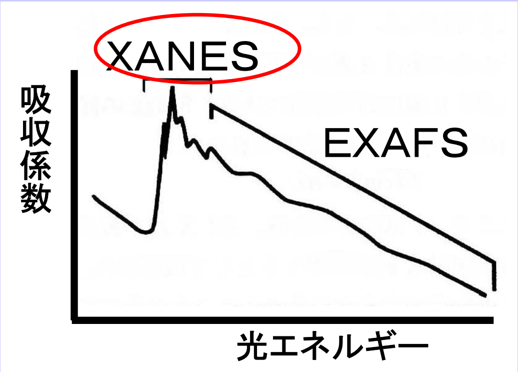








Energy resolution of monochrometer



XAFSスペクトル

$$\Delta E / E = (\sqrt{\Delta\theta^2 + \Delta\tau^2} + \Delta S / l) \cot\theta_B$$

$\Delta\theta$: slit opening
$\Delta\tau$: width of Bragg refraction
(~10^{-5})
ΔS : light source size
l: distance from the source
θ_B : Bragg angle

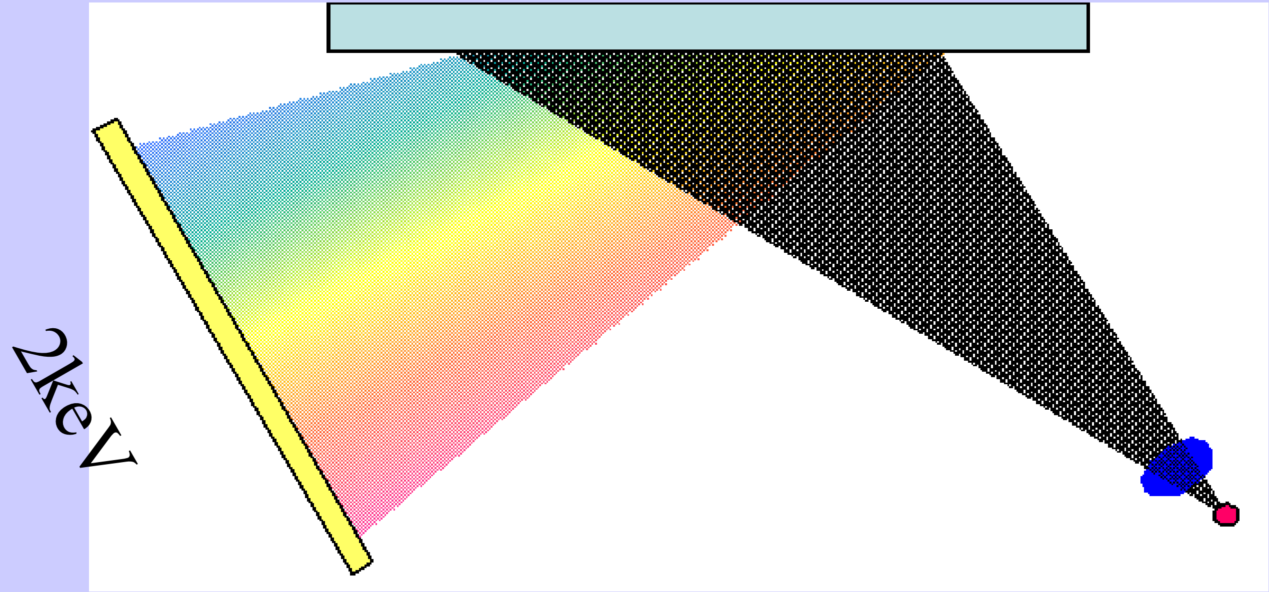
Detector size : 0.1mm

monochro:Si(111)	Source ssize [μm]	Source-detector [m]	Energy resolution E/ΔE
Photon Factory	100	25	5000
MIRRORCLE	10	3	5000
MIRRORCLE	1	1	5100

Short beam line

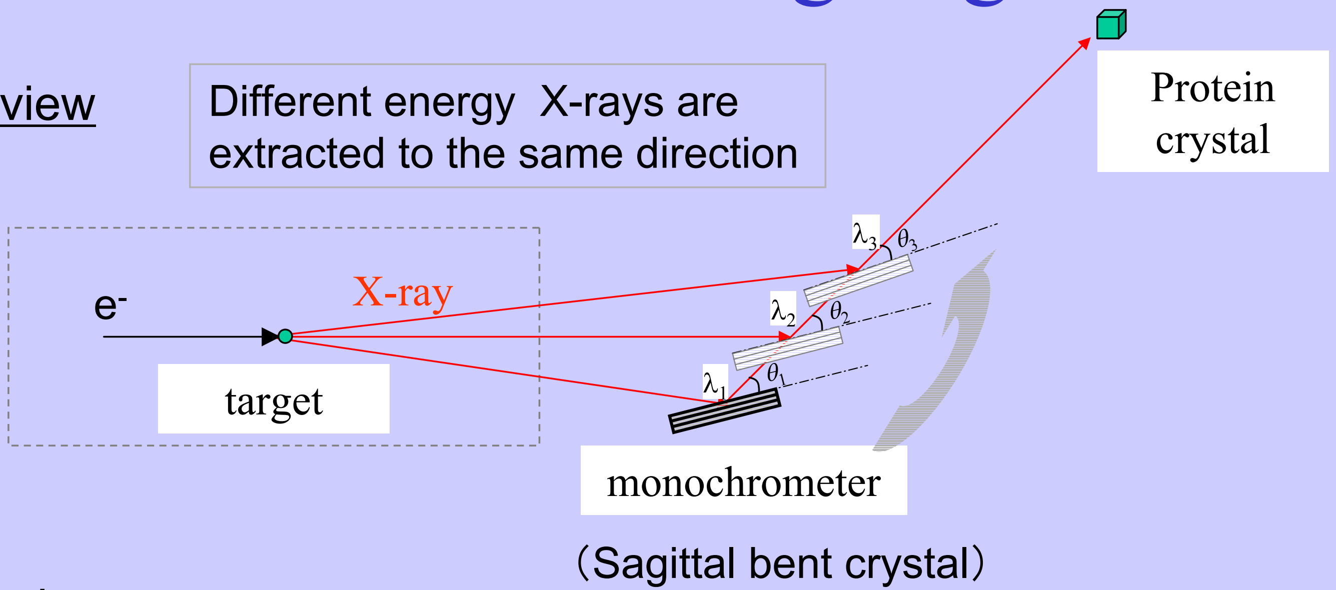
Advances of widely spread radiation from small emitter and polychromatic beam

- 1(10)μmϕ wire target provide E/ΔE=5000(3000) at 1m distance
- 50mrad spread gives 2keV dispersion

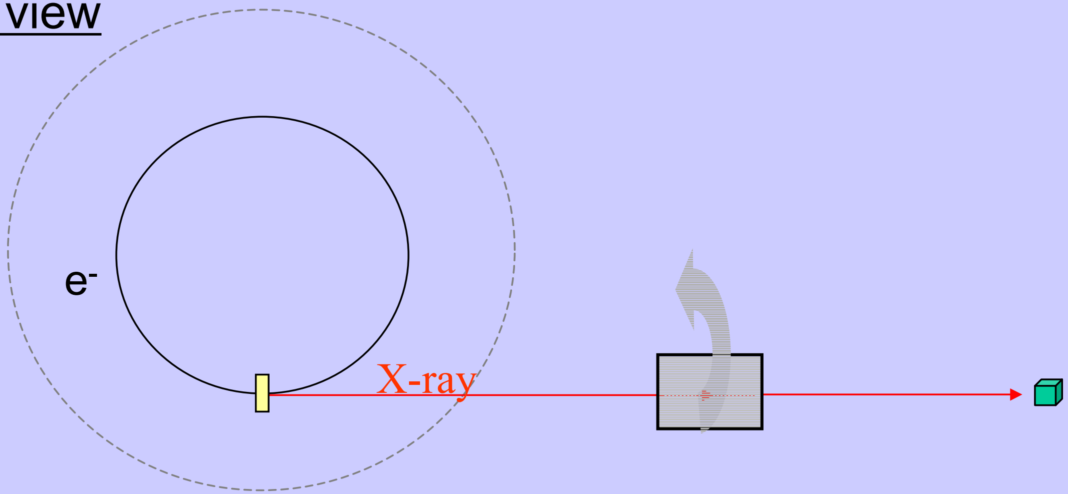


Dedicated beam line designing

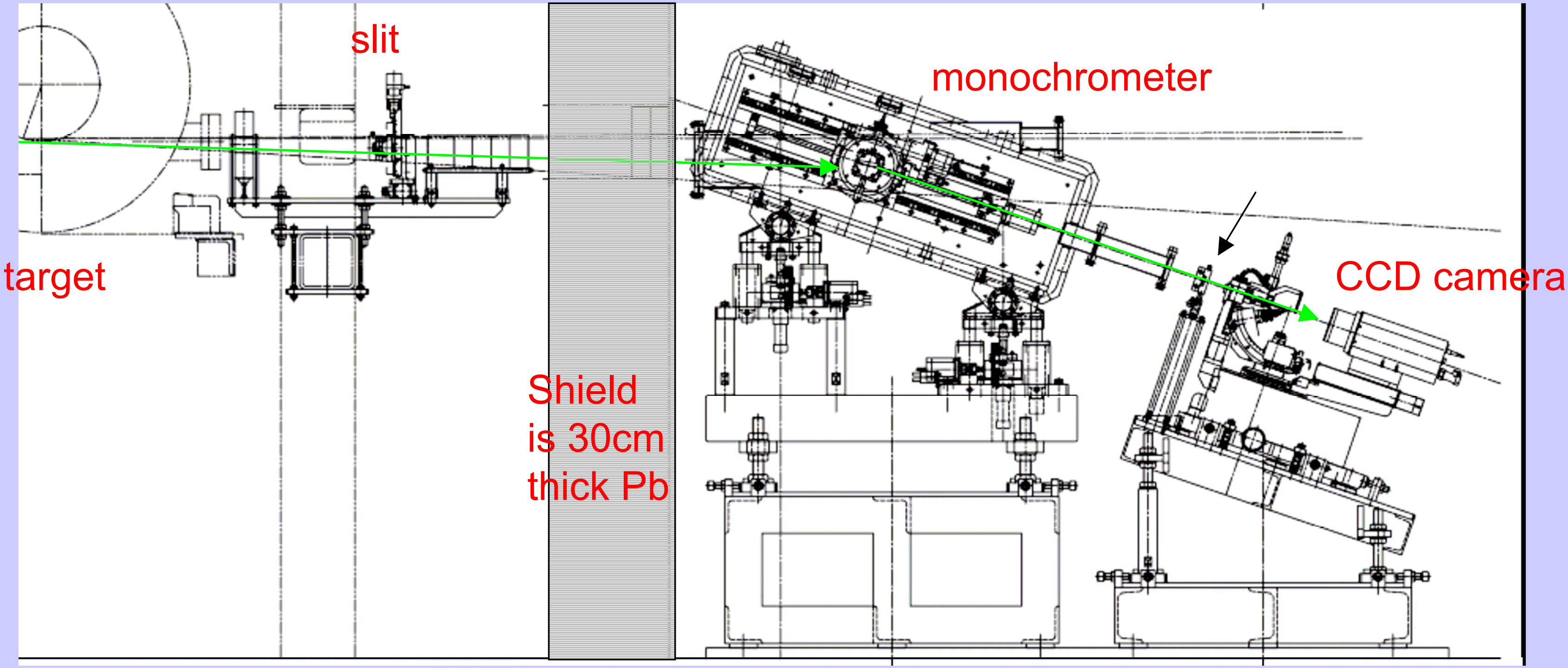
Top view



Side view

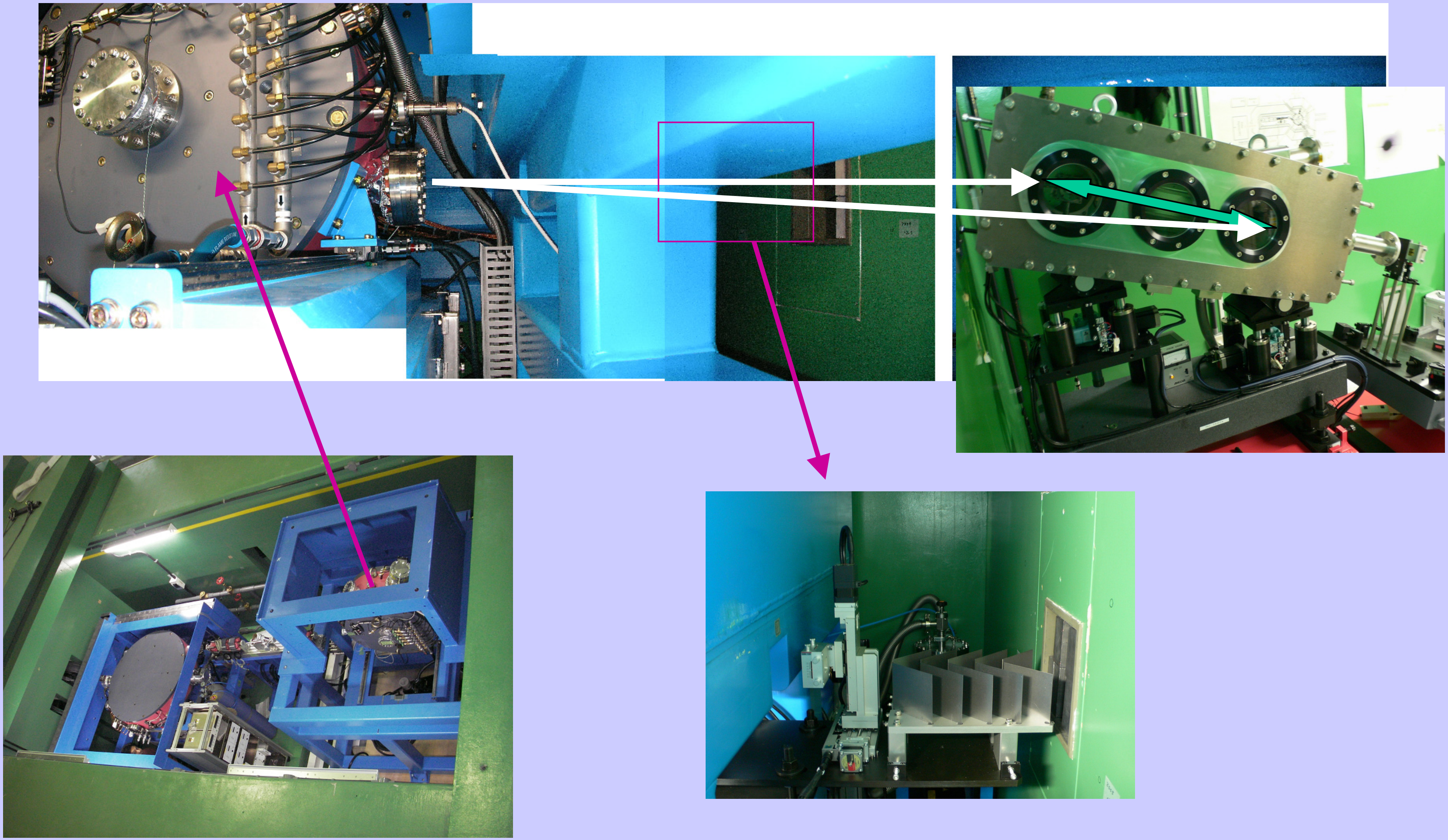


Beam line layout

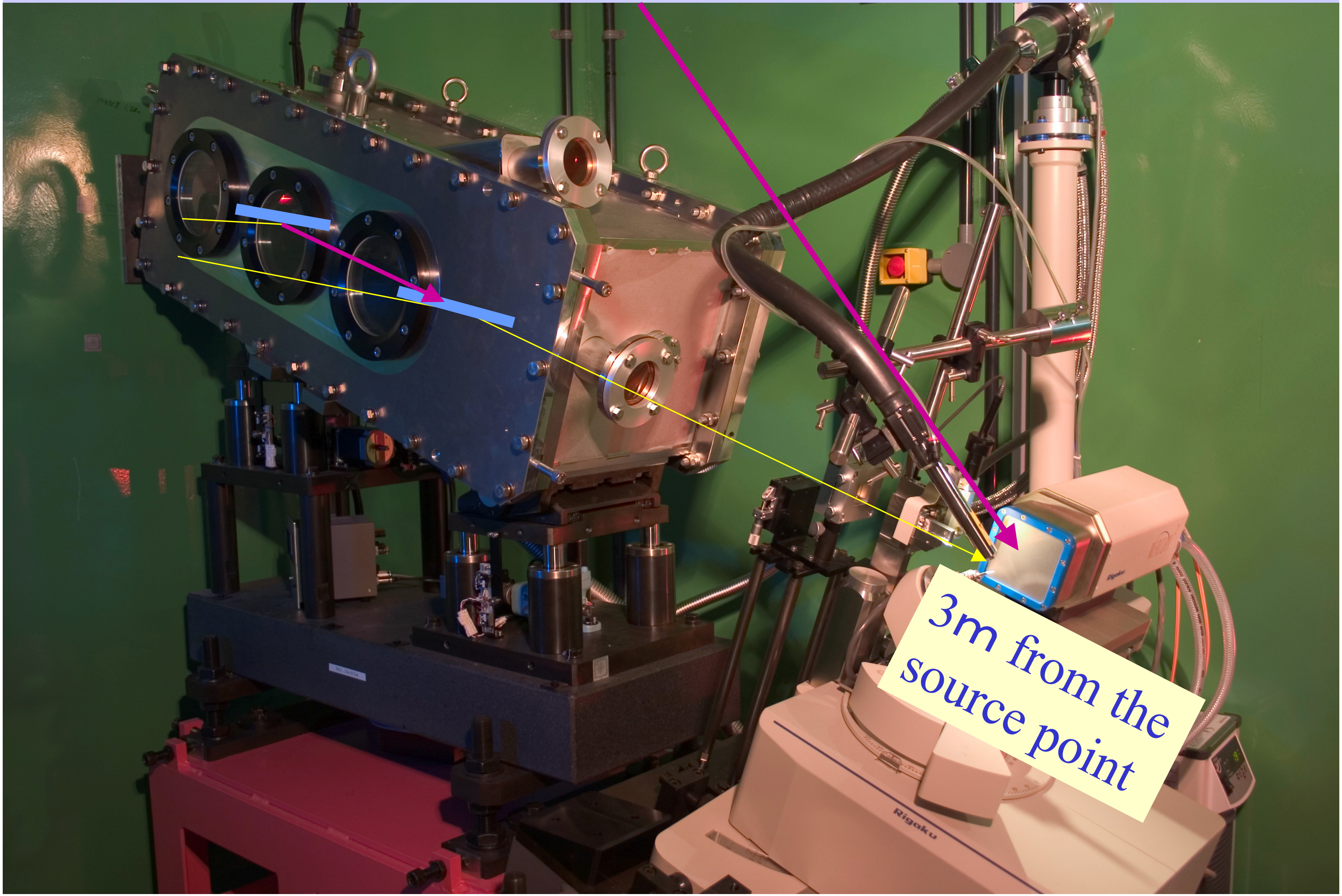


This facility was originally designed for LIGA and lithography

Beam line view

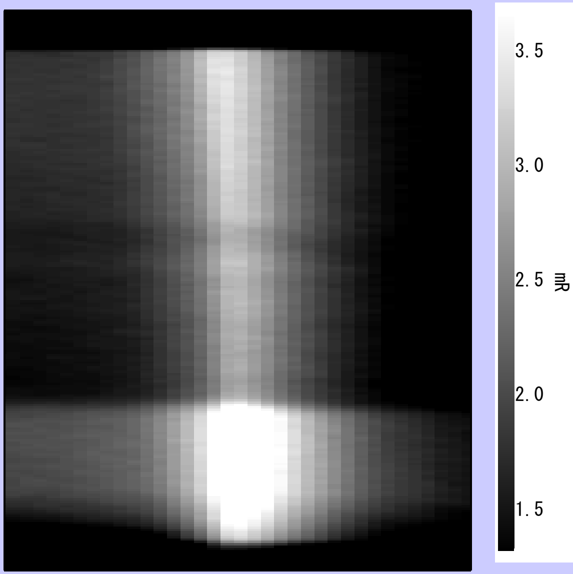


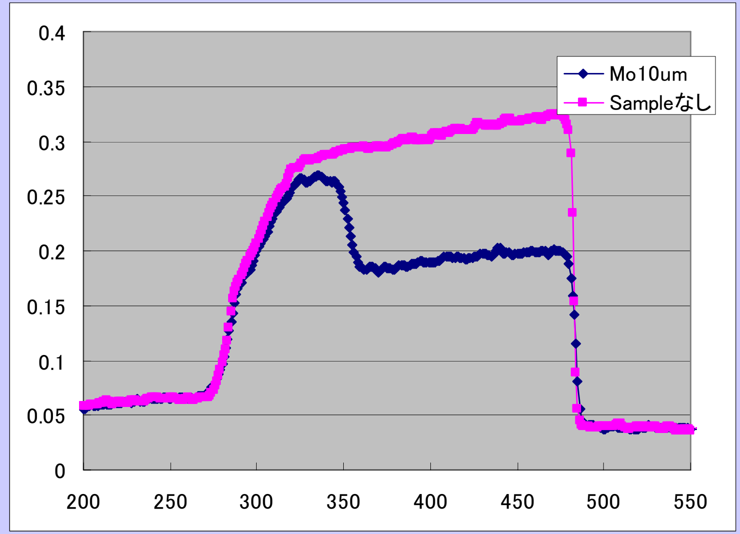
Rigaku Mercury CCD was no good



Dispersive EXAFS

Dispersive XAFS Mo10mm

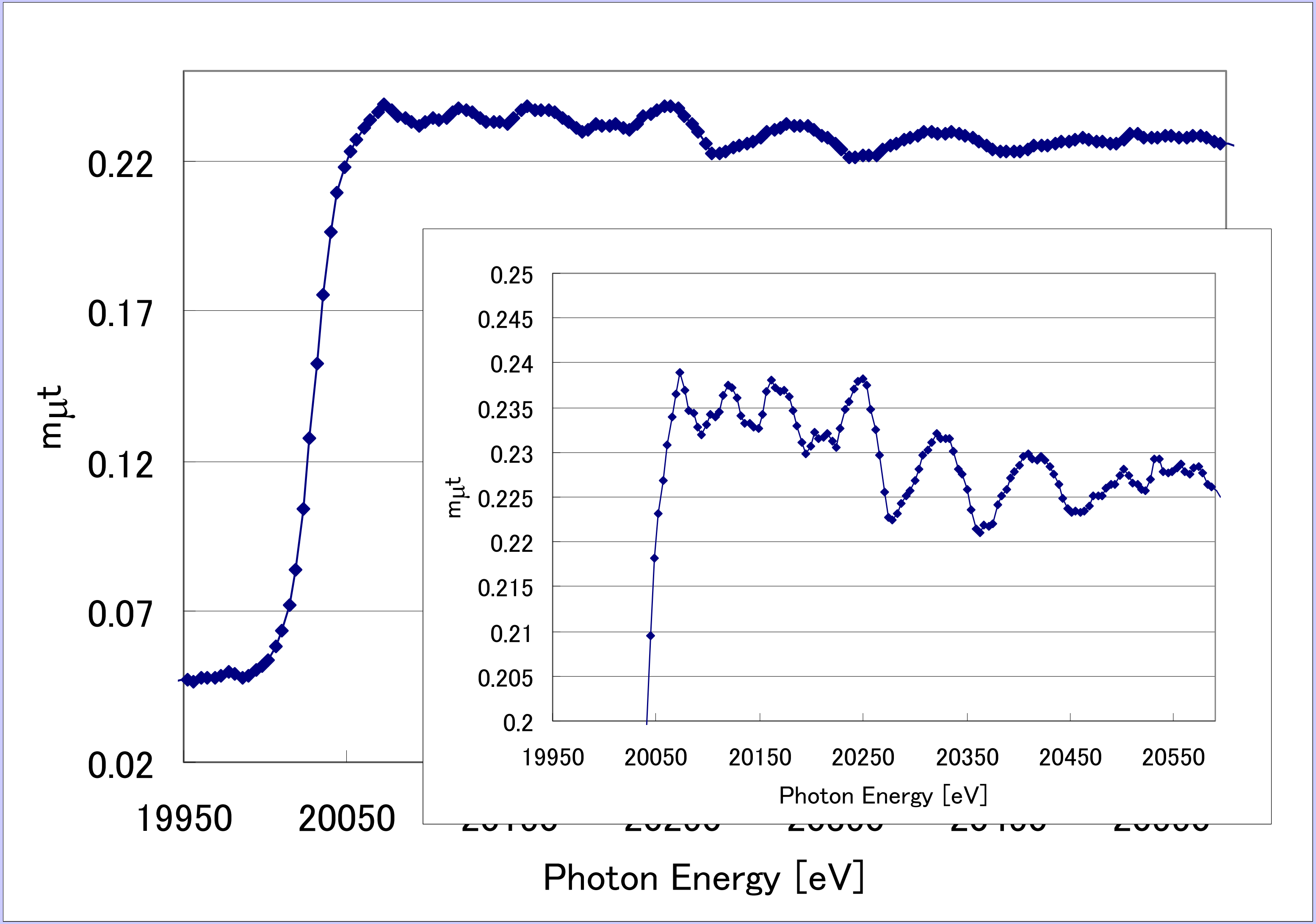




DXAFS spectrum was taken in one hour

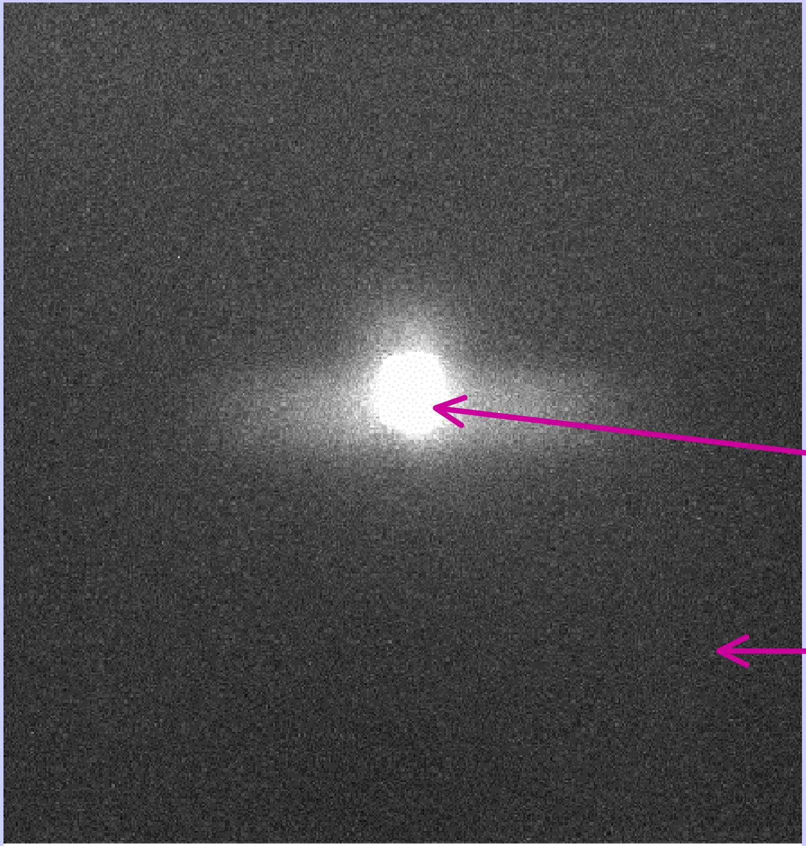
1 hour＞required troidal mirror＞3.6sec

Dispersive XAFS Mo10μm



Present MIRRORCLE's beam quality and photon density is enough for protein crystallography!

Results of 3 hours accumulation



Detector: IP (Rigaku R-AXIS)
Photon Energy :14keV
Source-Detector: 3m

S:300,000/pixel

S/B~4,200

BG:70

Problem is the background

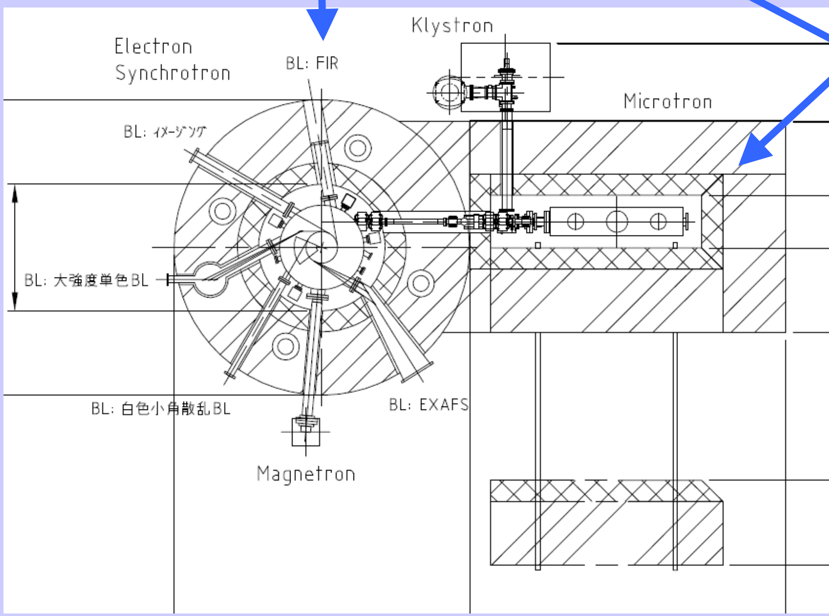
Way to manage problems

- Introduction of specific shielding
- High energy resolution short beam line
- Introduction of vertically focusing elements

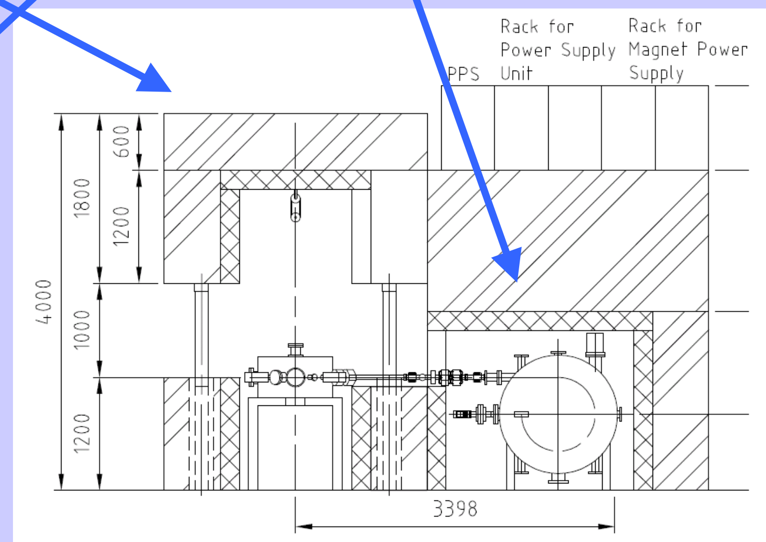
MIRRORCLE-20 shielding system

Jack up shielding

Microtron injector

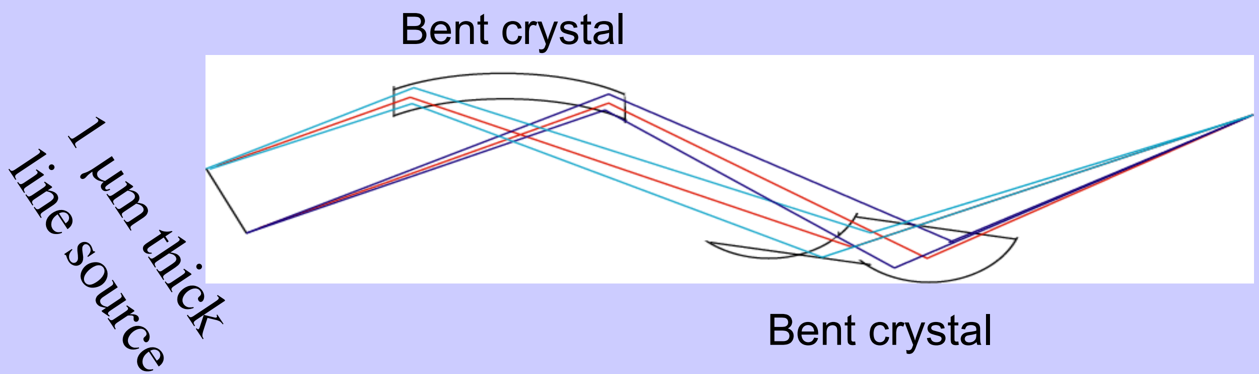


Plane schematic view



Vertical view

Specific beam line designing is necessary

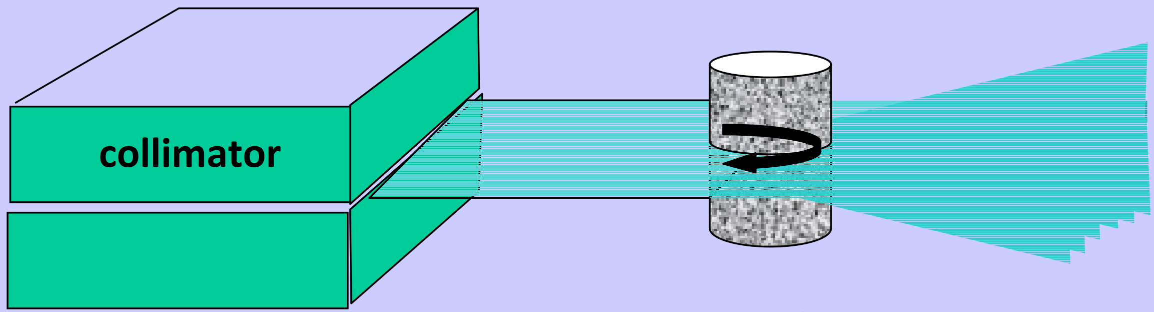


This scheme is feasible by MIRRORCLE because of its white X-ray!

Measurement of protein shape by the small angle scattering CT feasible by MIRRORCLE

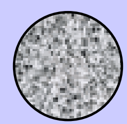
We combines SAXS and fan beam CT to measures nano to 100nm size particles and structure

MIRRORCLE enables the measurement of shape and structure of protein by using narrowly collimated fan beam. Small angle scattering and CT is combined



CT algorithm for SAXS

1 μm gap is feasible by 1 μm target of MIRRORCLE



1~100nm particle could be distinguished

summary

- Widely spread polychromatic X-ray beam generated from tiny emitter of MIRRORCLE is extremely useful in material characterization, protein crystallography, and imaging
- Protein crystallography is possible in minutes with present power of MIRRORCLE with particularly designed beam line and specific shielding structure