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

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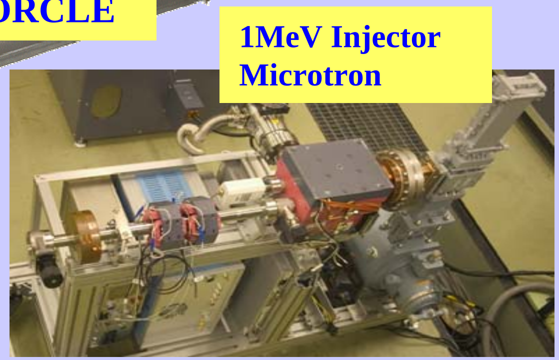
MIRRORCLE



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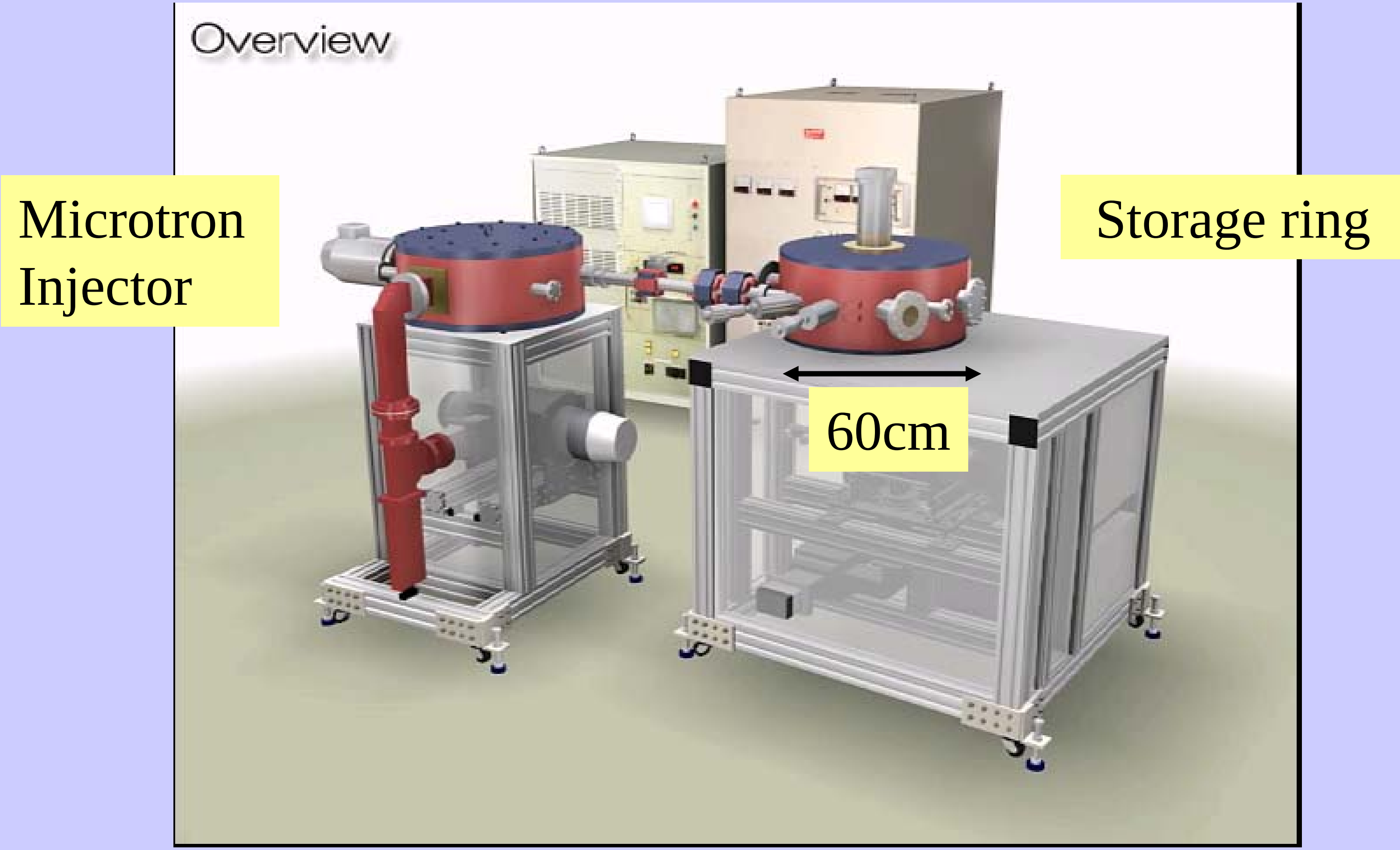
2. MIRRORCLE is a storage ring which generate extremely bright FIR
3. How to generate hard x-rays by a few MeV storage ring
4. How it's different from synchrotron light source or X-ray tube.
5. Beam line, in which different energy is extracted to the same direction by a single monochrometer
6. Demonstration 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



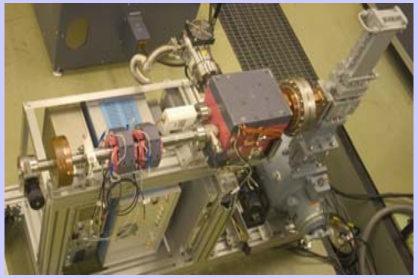
MIRRORCLE's

X-ray characterization
EUV lithography

FIR spectroscopy

X-ray imaging, NDT

MIRRORCLE-CV1

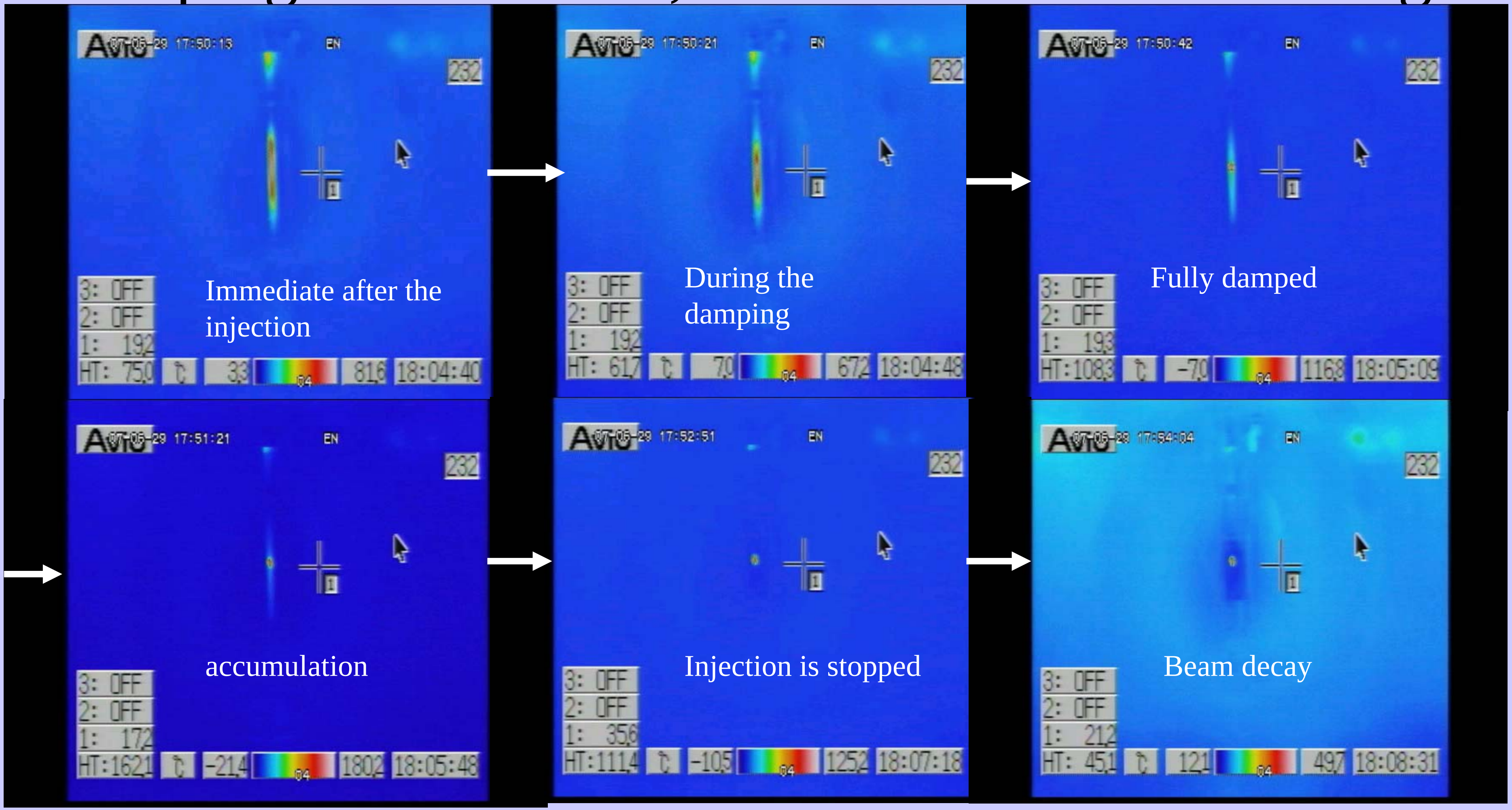


Medical imaging
X-ray microscope

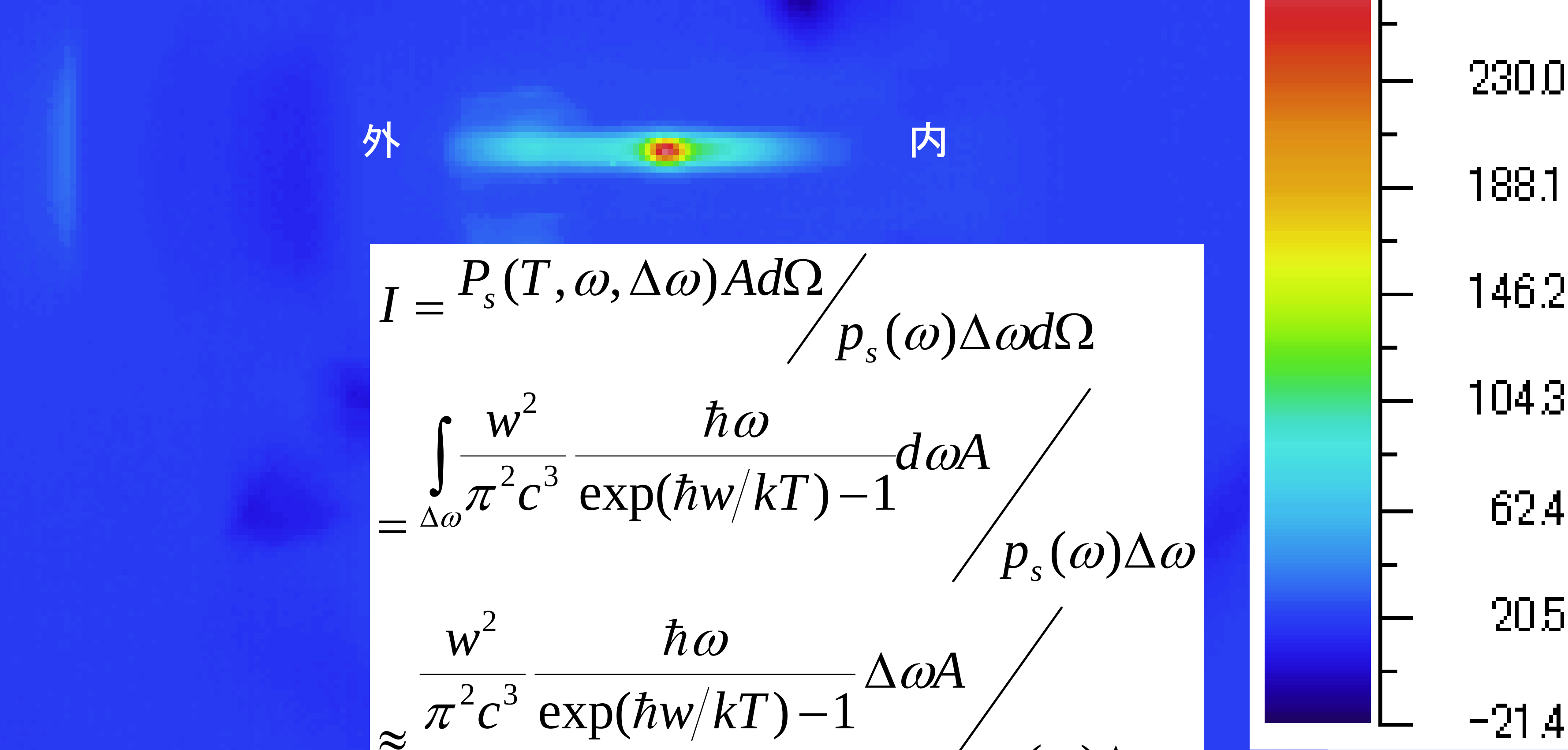
MIRRORCLE is a storage ring

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

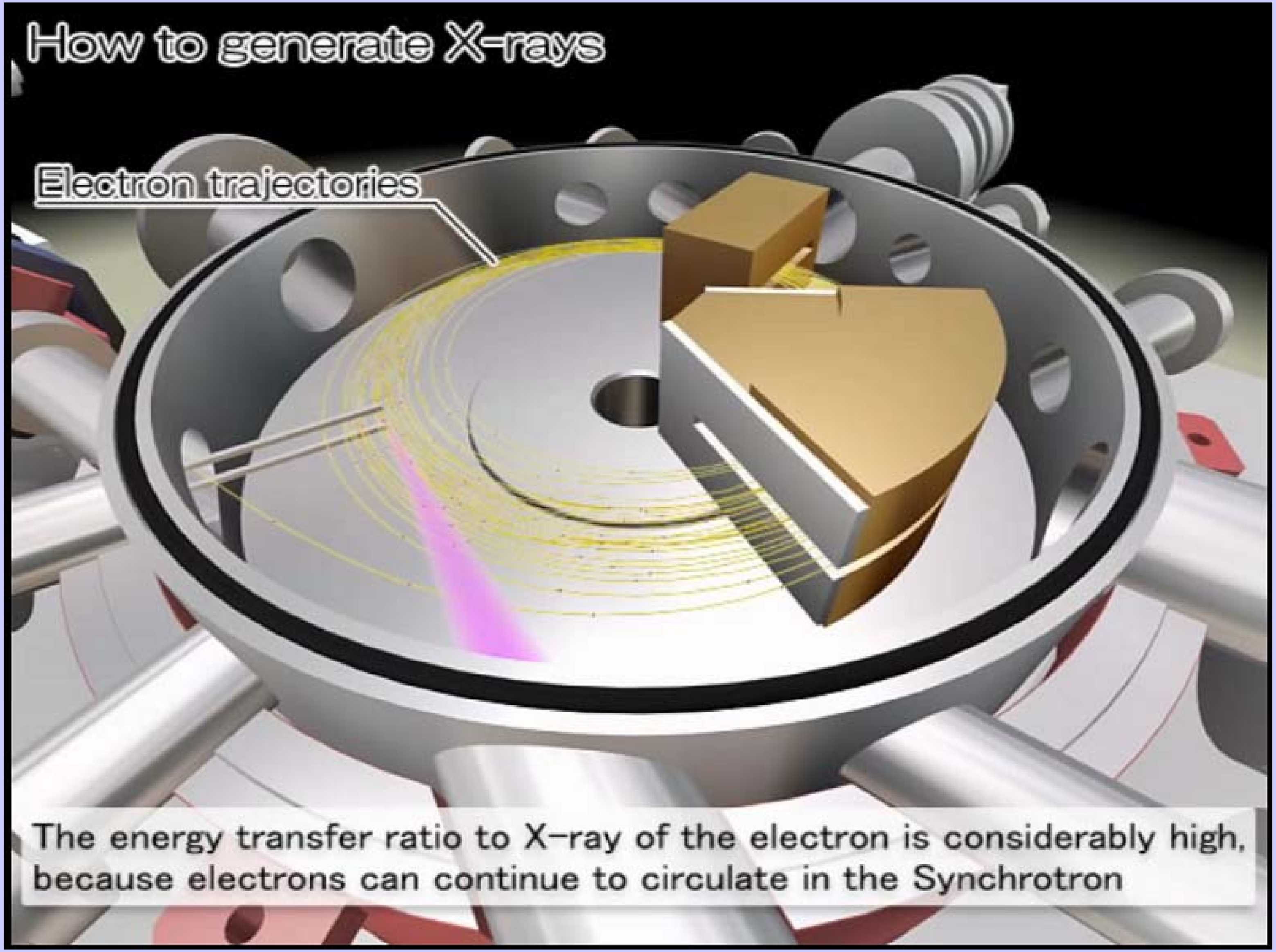


$$I = P_s(T,\omega,\Delta\omega)\,A\,d\Omega \Big/ p_s(\omega)\Delta\omega\, d\Omega$$

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

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

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

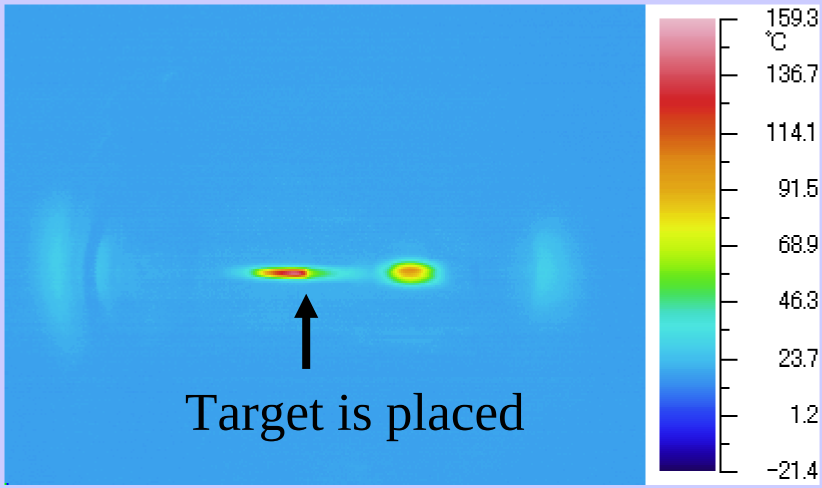


The observed X-ray power is 225mGy(625Gy)/min at 150mA injector peak current and 400 Hz repetitions

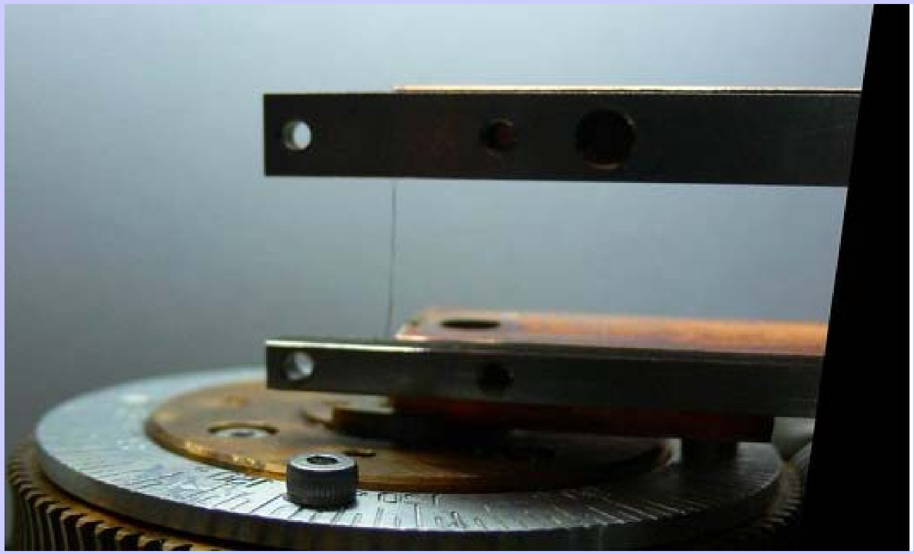
integrated value over the cone

Measured by the ion chamber

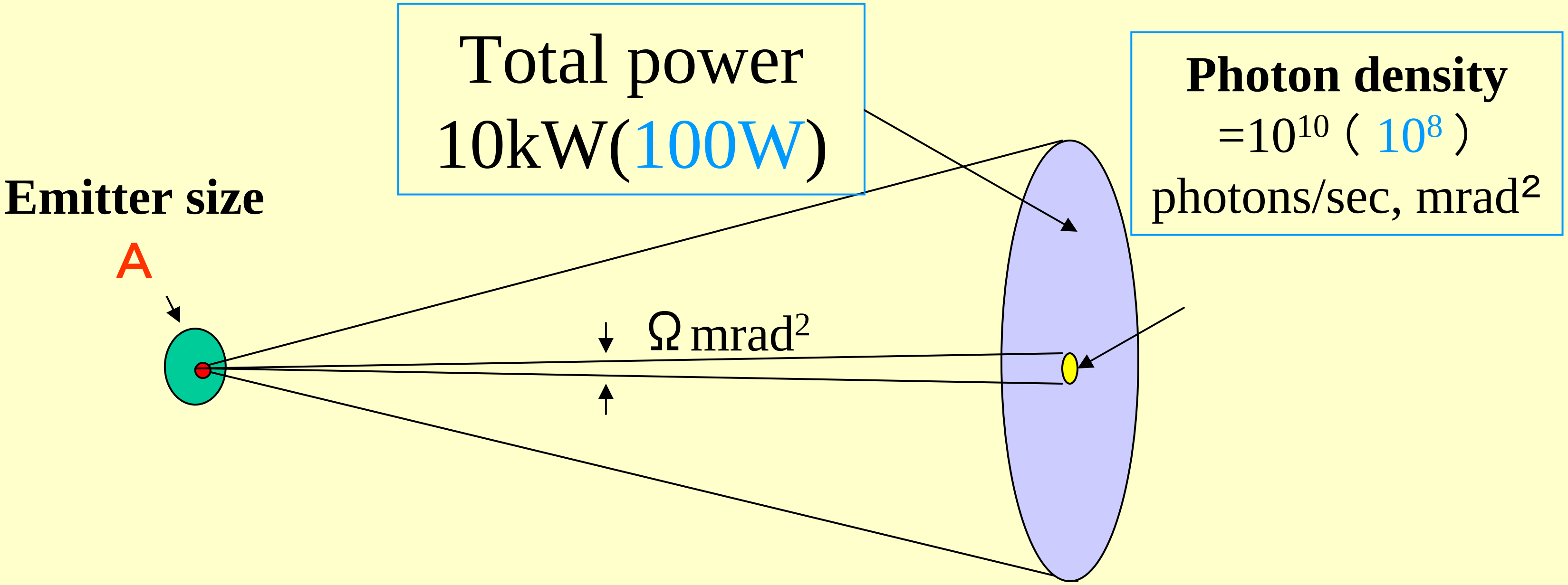
800W storage ring RF power is applied



Carbon nano tube target is one of the best



MIRRORCLE generate cone beam

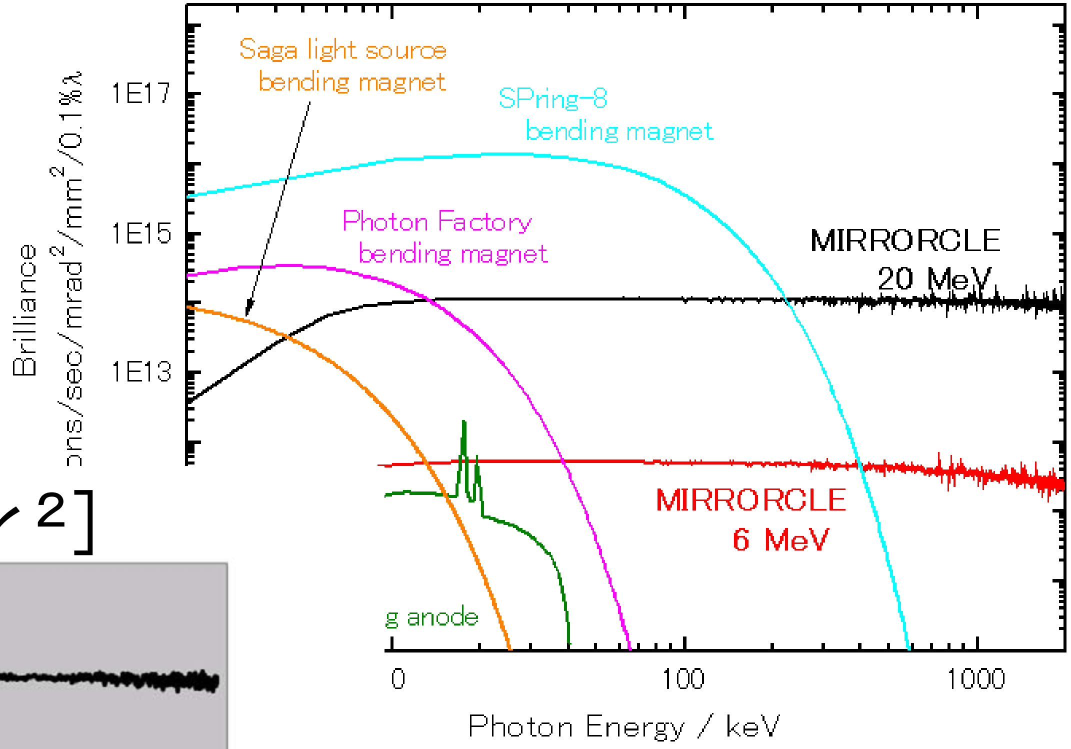


Photon density＝photons／Ω、sec、band width

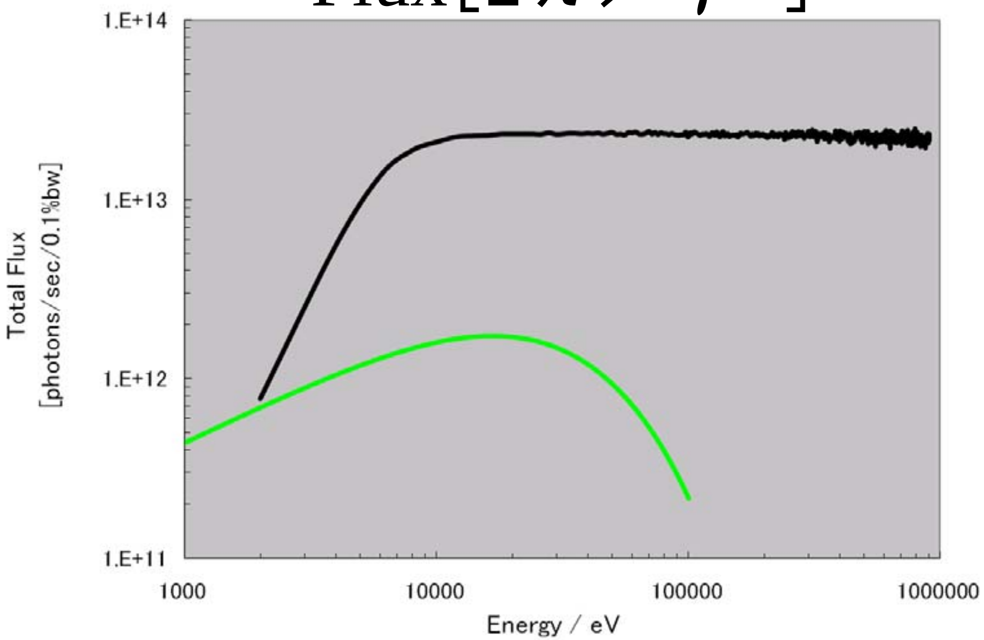
(assuming point emitter size)

Brilliance＝photon density／A

Brilliance and Flux (simulation)



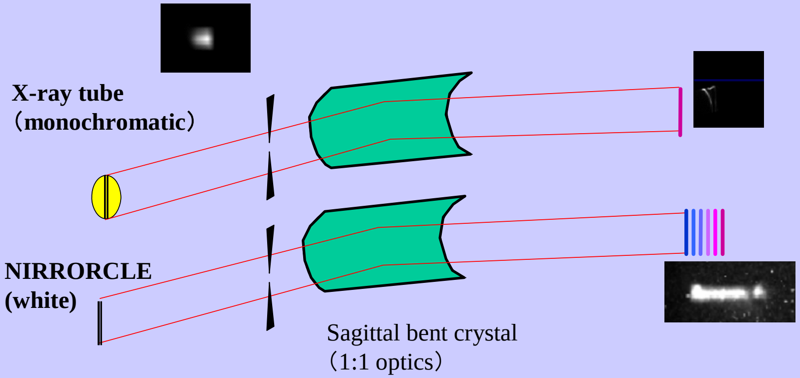
$$\mathrm{Flux}[2\pi / \gamma^2]$$



Measure X-ray flux

Measurement of x-ray density

X-ray intensity is compared with X-ray tube by the same measurement configuration

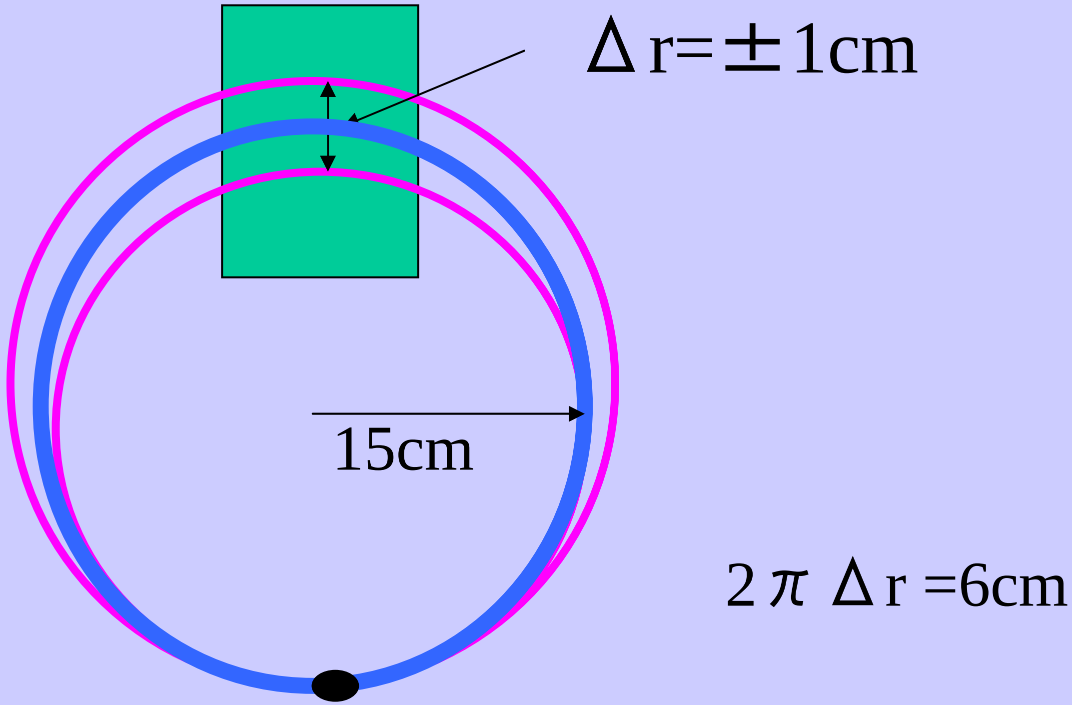


	1KW RF 20 MeV MIRRORCLE	1KW Cu tube
Intensity (mR/pixel/s)	69	30
Distance from the source point (m)	3.1	2.6
X-ray energy (keV)	13.4	8
Width of sagittal bent crystal (± mrad)	3.1	3.1
Intensity (mR/mrad^2)	11.1	4.8
Focused beam size	<1mm	3mm
Normalized value by the diffraction efficiency (mR/s/mrad^2)	12873	3606

Why MIRRORCLE is bright?

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

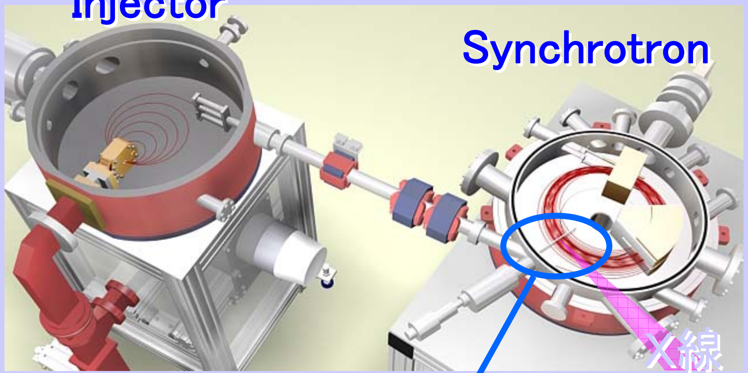
Large intensity is the subject of repetition rate 1kHz – 10kHz



Betatron tune is near 0.5

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

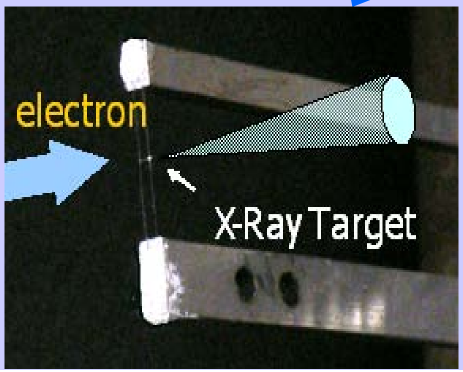
A



1. High current

@ Orbit radius=8cm
> portable source
@ stored beam current=4A
> High power radiation source

B



2. Small emission point

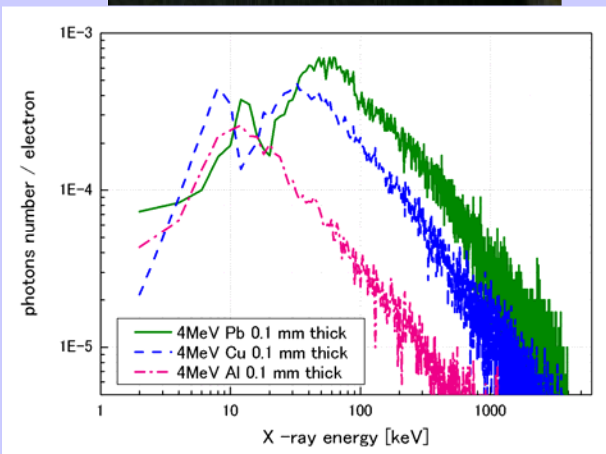
3. Cone beam

@ Enables highly Magnified imaging
> distance reduces the scattering background

> Enables imaging of large body

> Enables Dispersive XAFS

C



4. Polychromatic X-ray

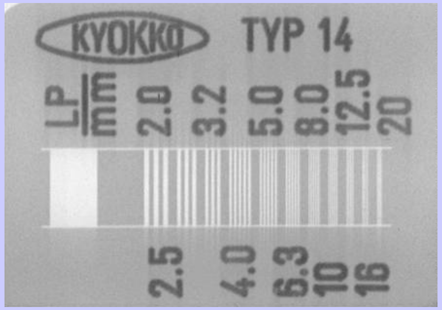
@ High energy X-ray
> NDT of heavy construction
@ Multi color experiment
> Characterization of materials
> Enables MAD method

Advantage of small emission point

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

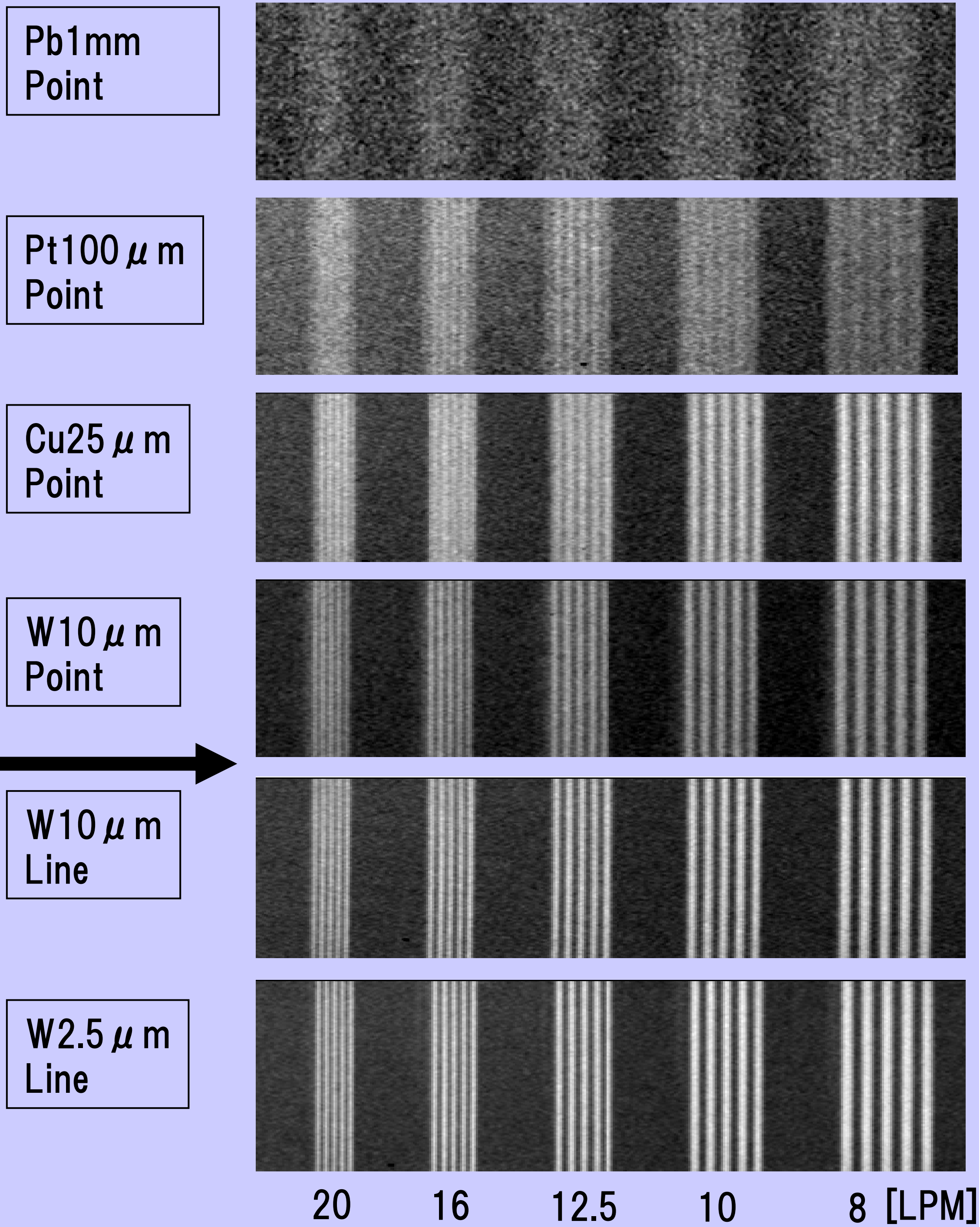
Fine space resolution is obtained without loosing intensity

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



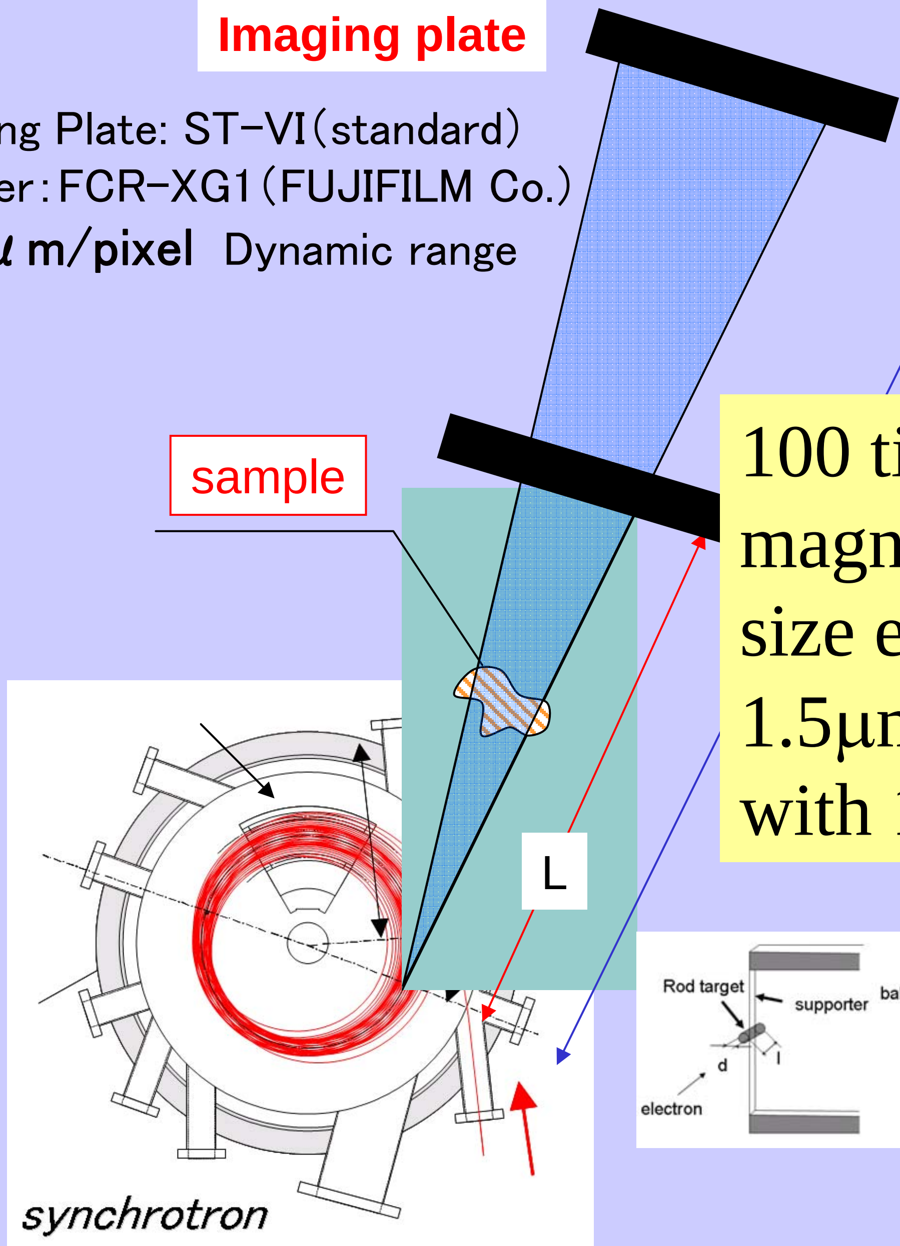
Test chart
X-ray contact image

12 times magnified imaging

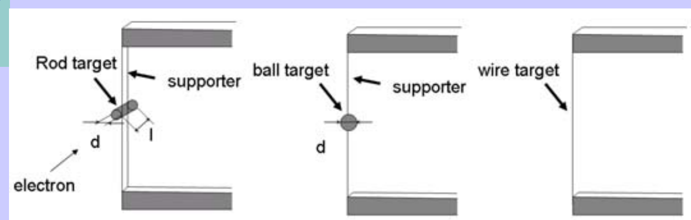


Configuration of magnified imaging

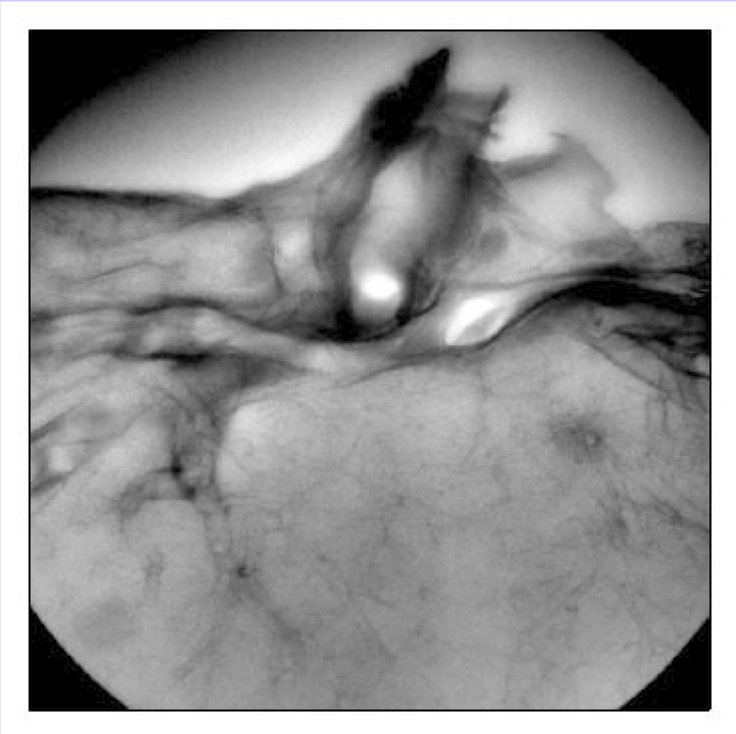
Imaging Plate: ST-VI (standard)
Reader : FCR-XG1 (FUJIFILM Co.)
150 μm/pixel Dynamic range 12bit

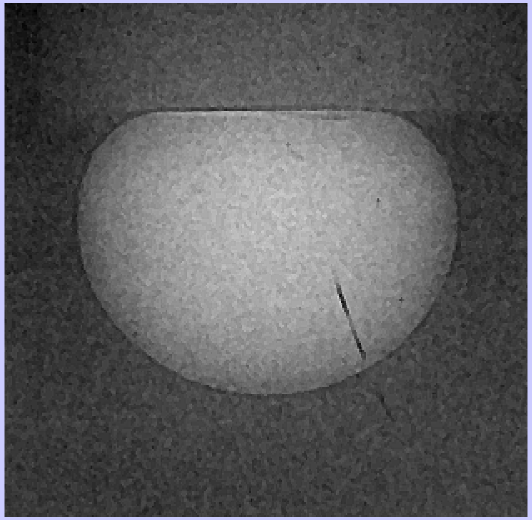


100 times magnification and 1 μm size emitter appreciate 1.5μm space resolution with 150um detector



Polychromatic beam is useful which include more information



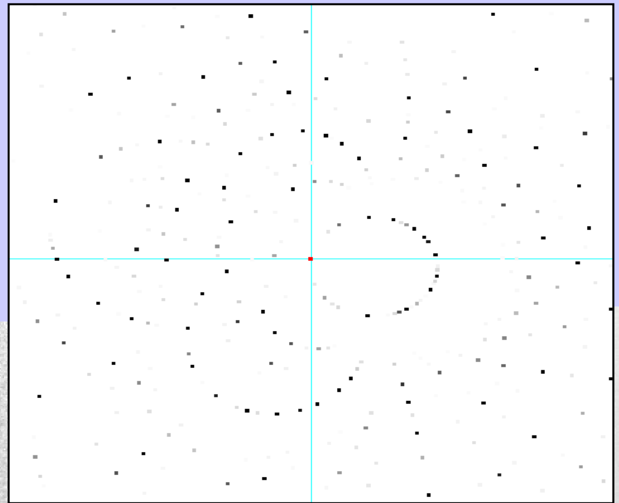


Phase contrast image of mouse born

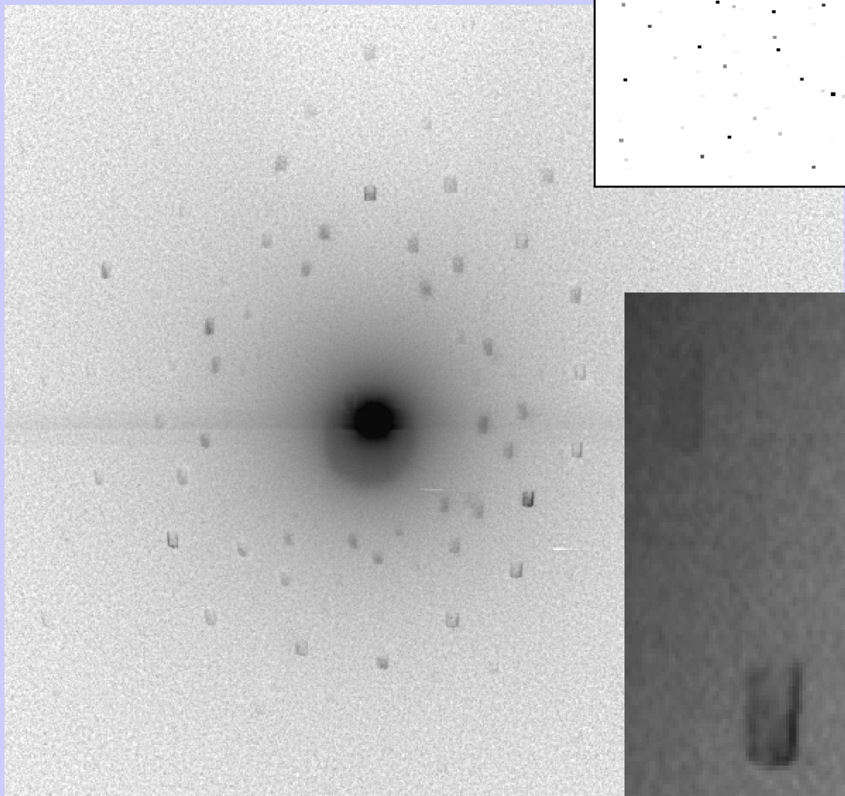
- target size: 25 μm ϕ
- Detector: Imaging plate (FUJIFILM XG-1 150 μm/pixel)

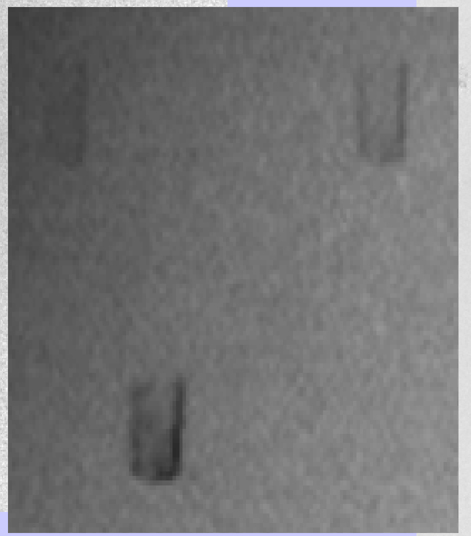
12 times magnification

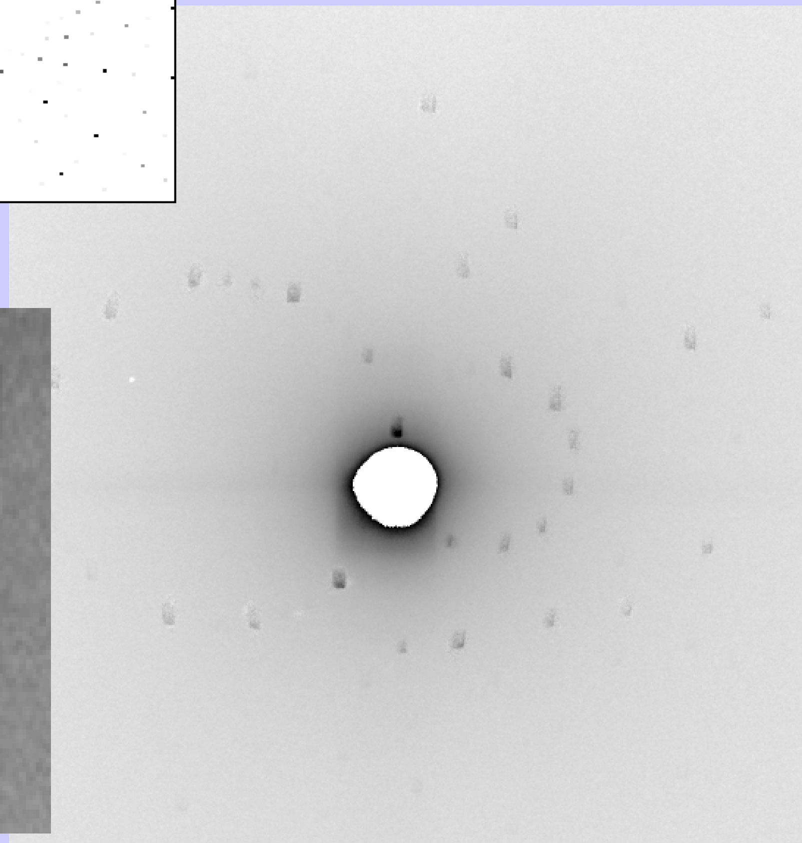
White Laue and Topography at 1.5 m dist.



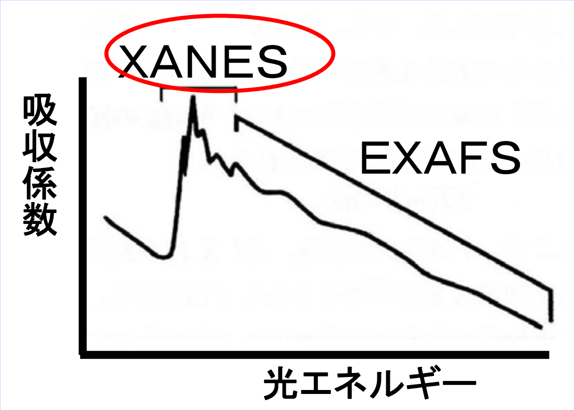
SiO_2(111) sample







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 ($\sim 10^{-5}$)
ΔS : emitter size
l: distance from the source
θ_B : Bragg angle

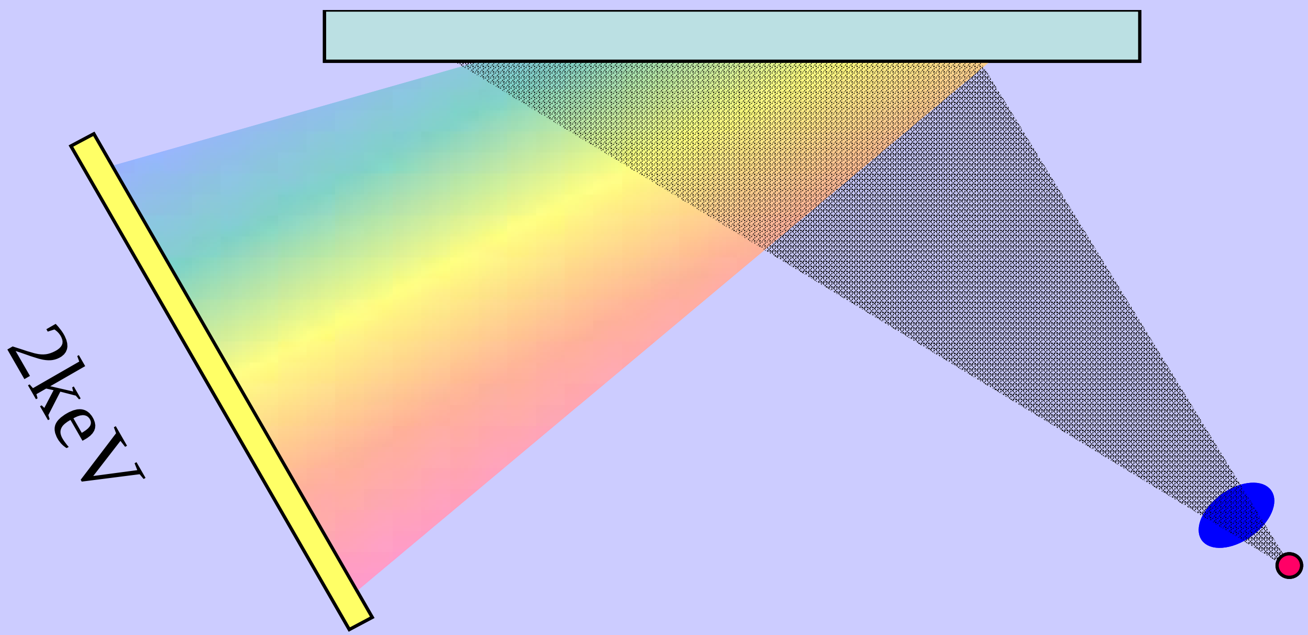
Detector size : 0.1mm

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

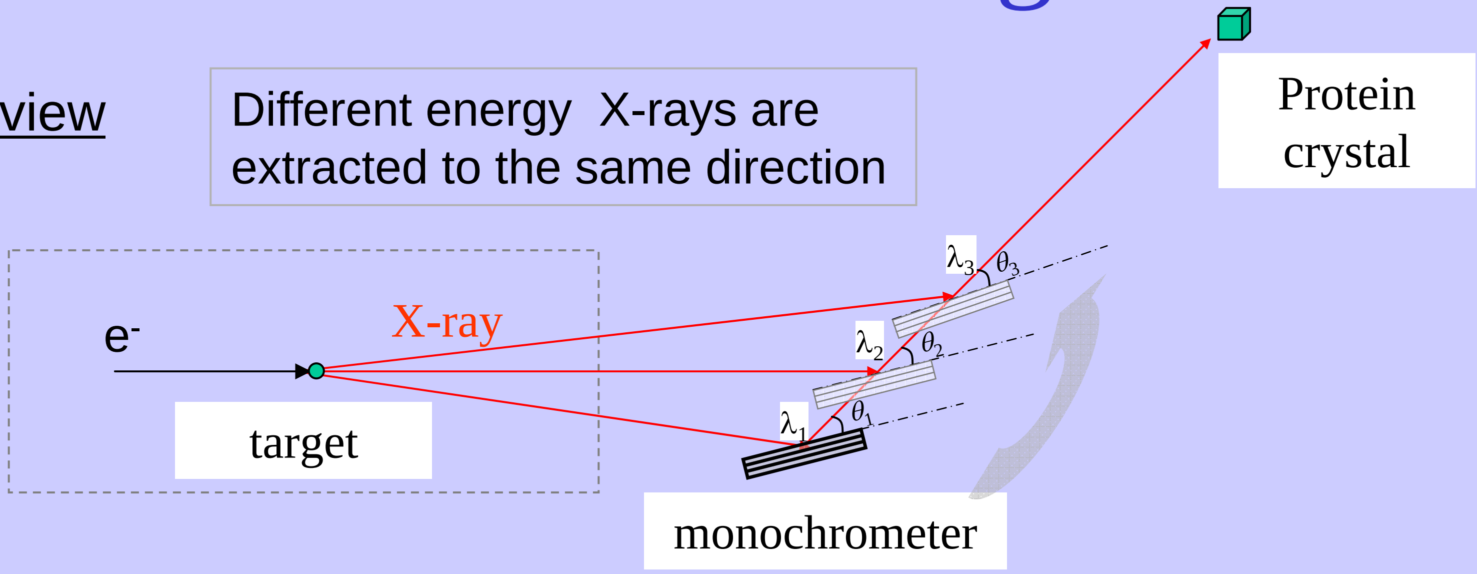
- 1(10)μm ϕ wire target provide E/ΔE=5000(3000) at 1m distance
- 50mrad spread gives 2keV dispersion



Dedicated beam line design

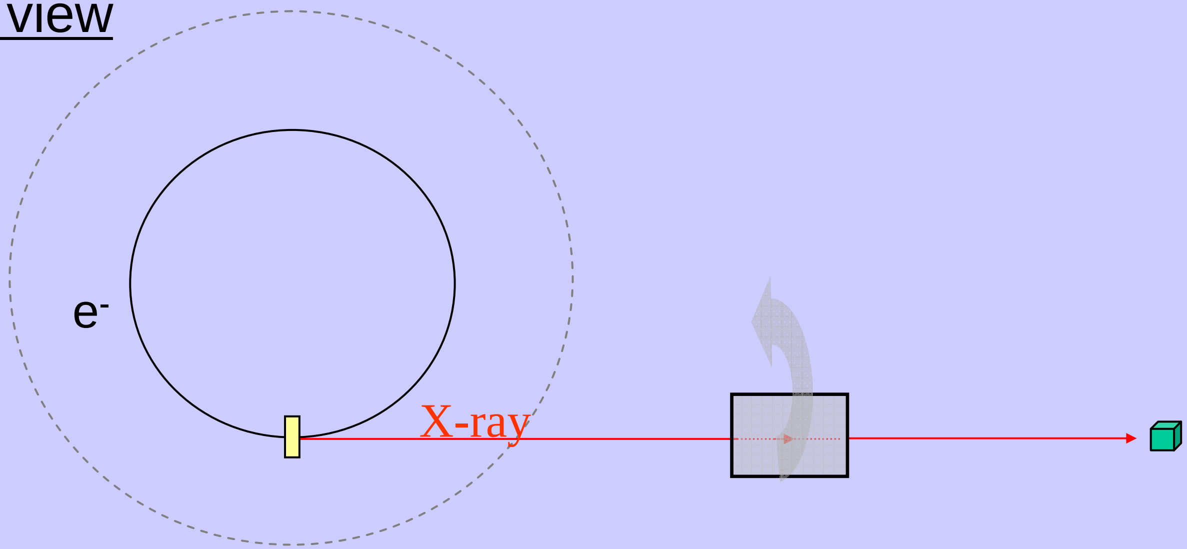
Top view

Different energy X-rays are extracted to the same direction

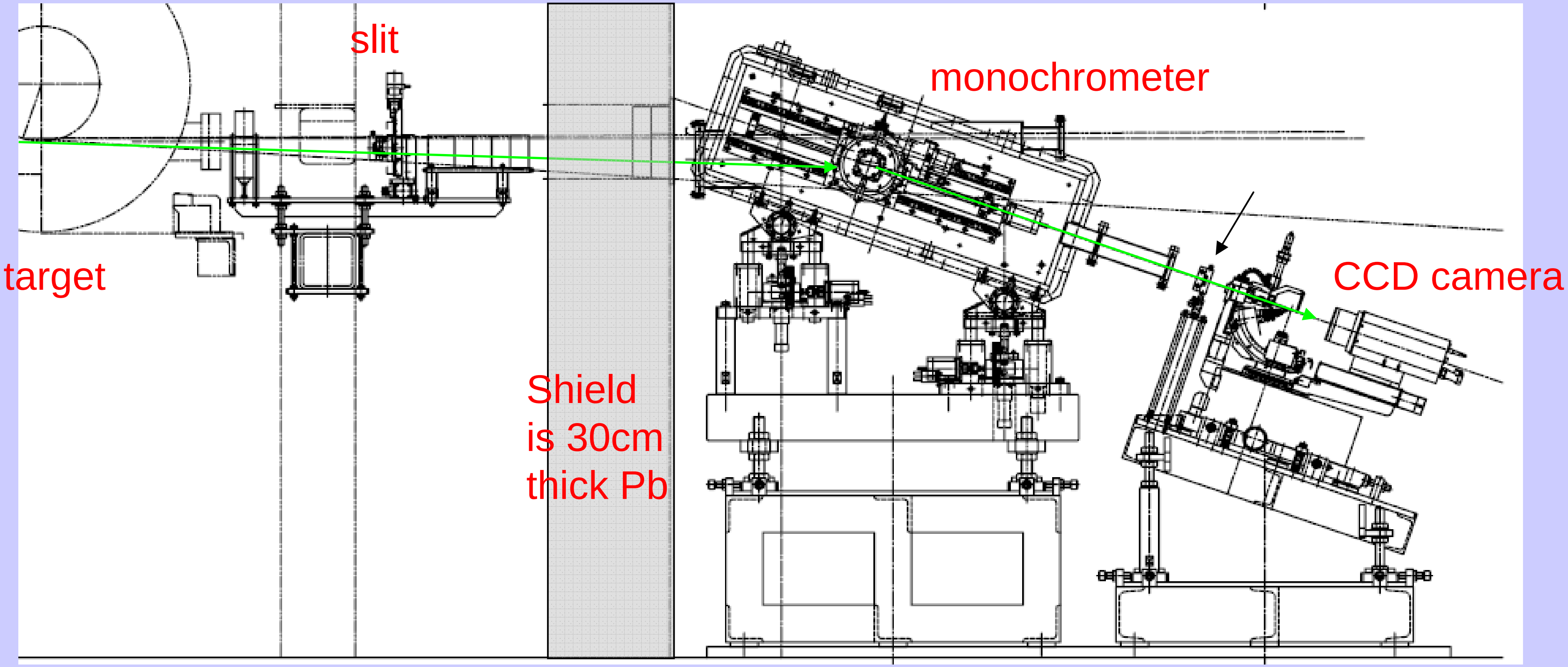


（Sagittal bent crystal）

Side view

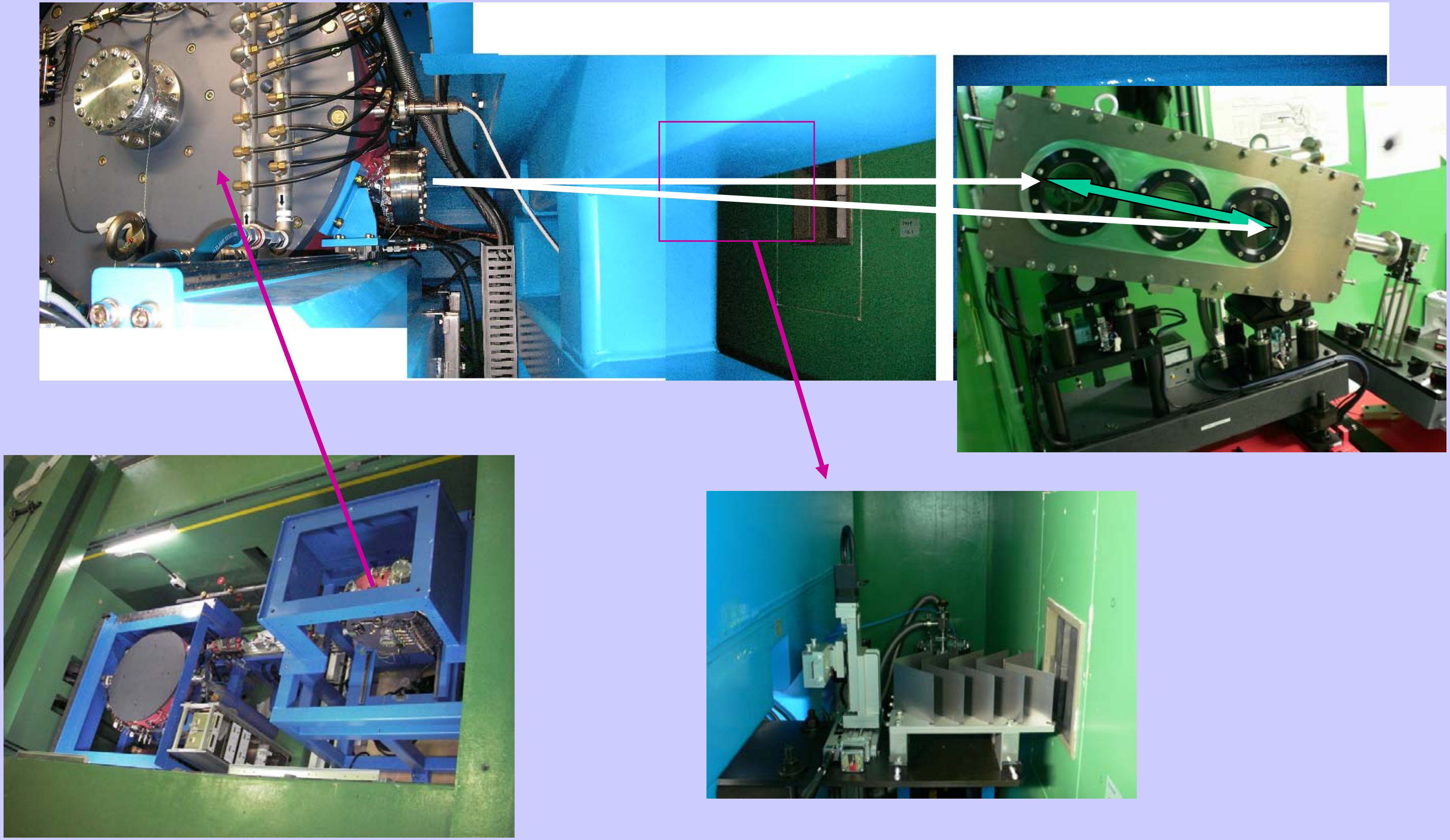


Beam line layout

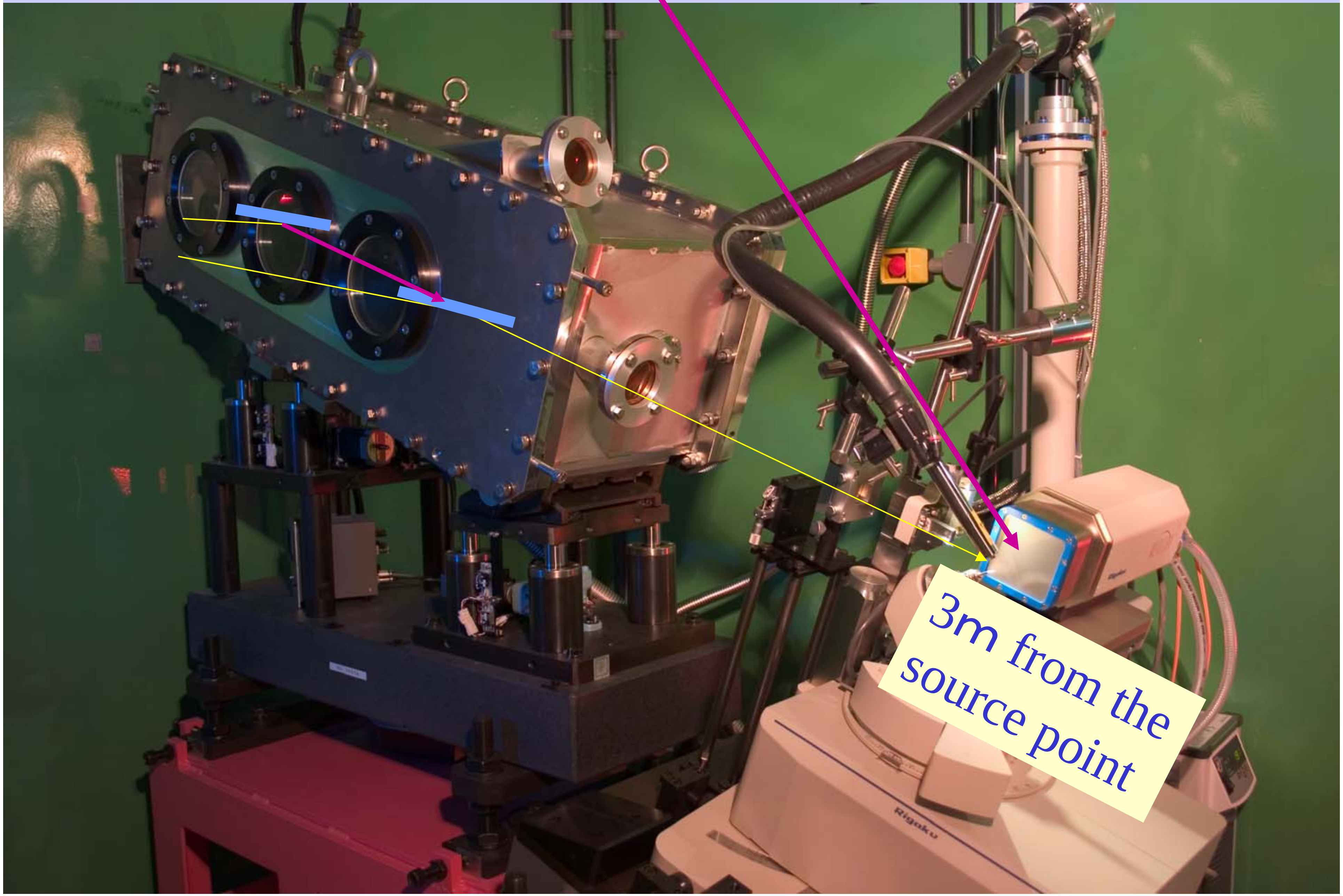


This facility was originally designed for LIGA and lithography

Beam line view

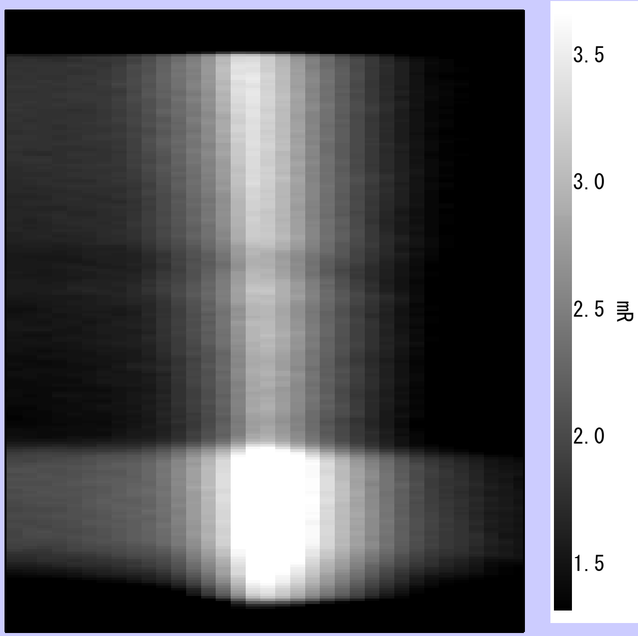


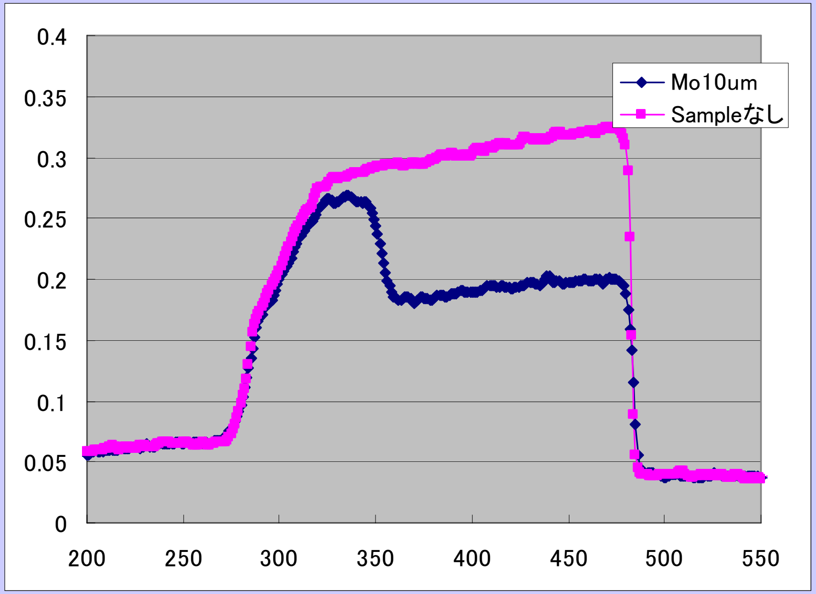
Rigaku Mercury CCD was no good



Dispersive EXAFS

Dispersive XAFS Mo10mm

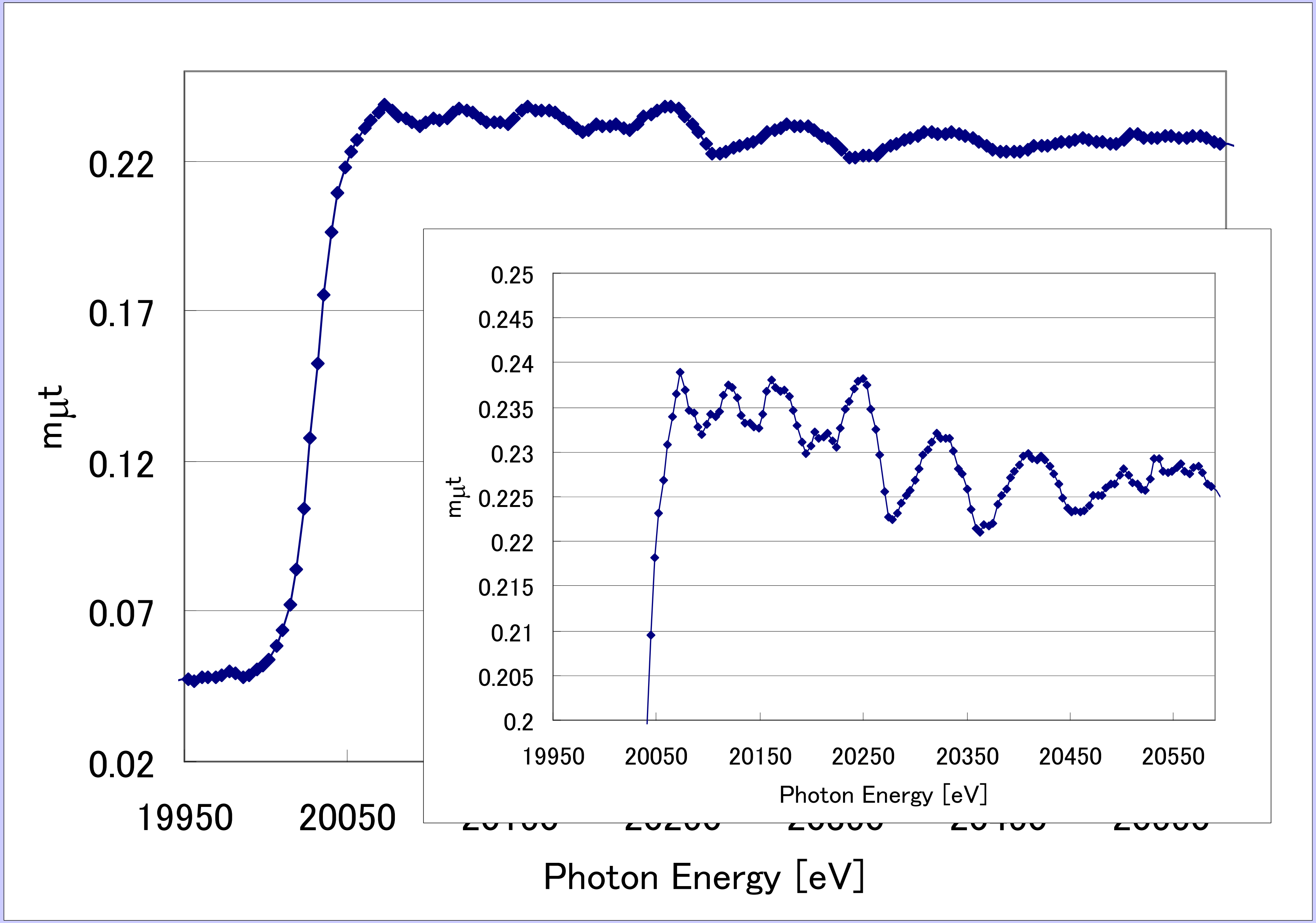




DXAFS spectrum was taken in 30 min

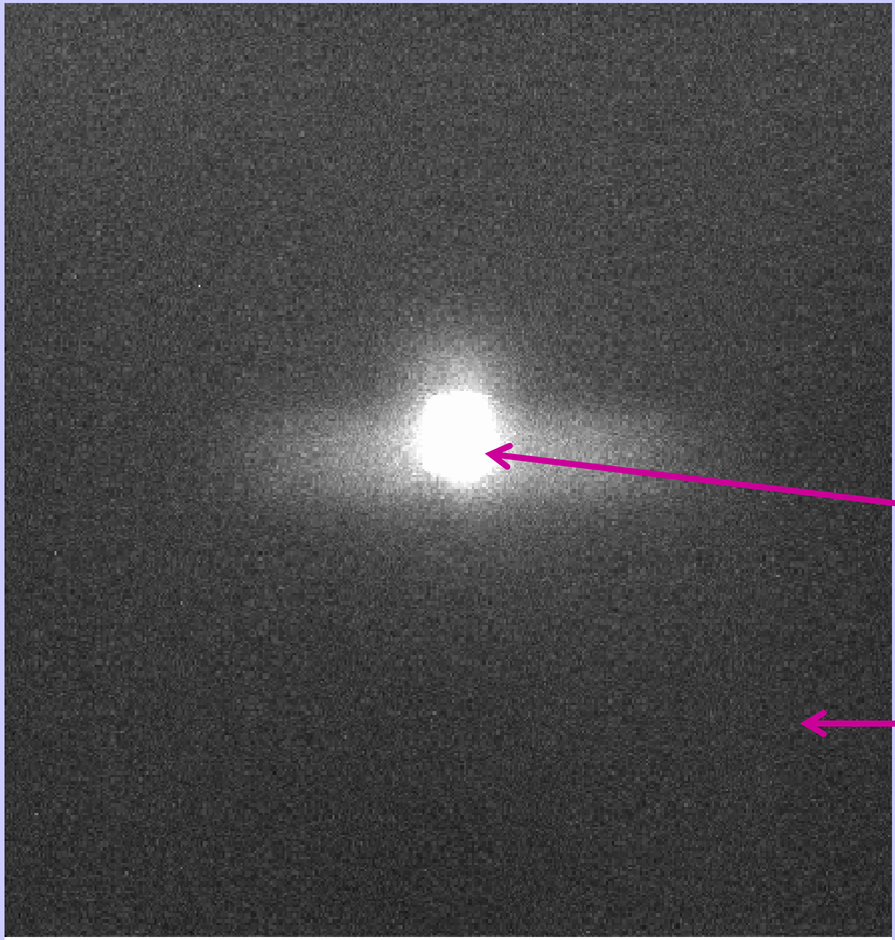
30 min＞troidal mirror＞3.6sec

Dispersive XAFS Mo10μm



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

Results of 1 hours accumulation at 3 m distance



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

S:300,000/pixel

S/B~4,200

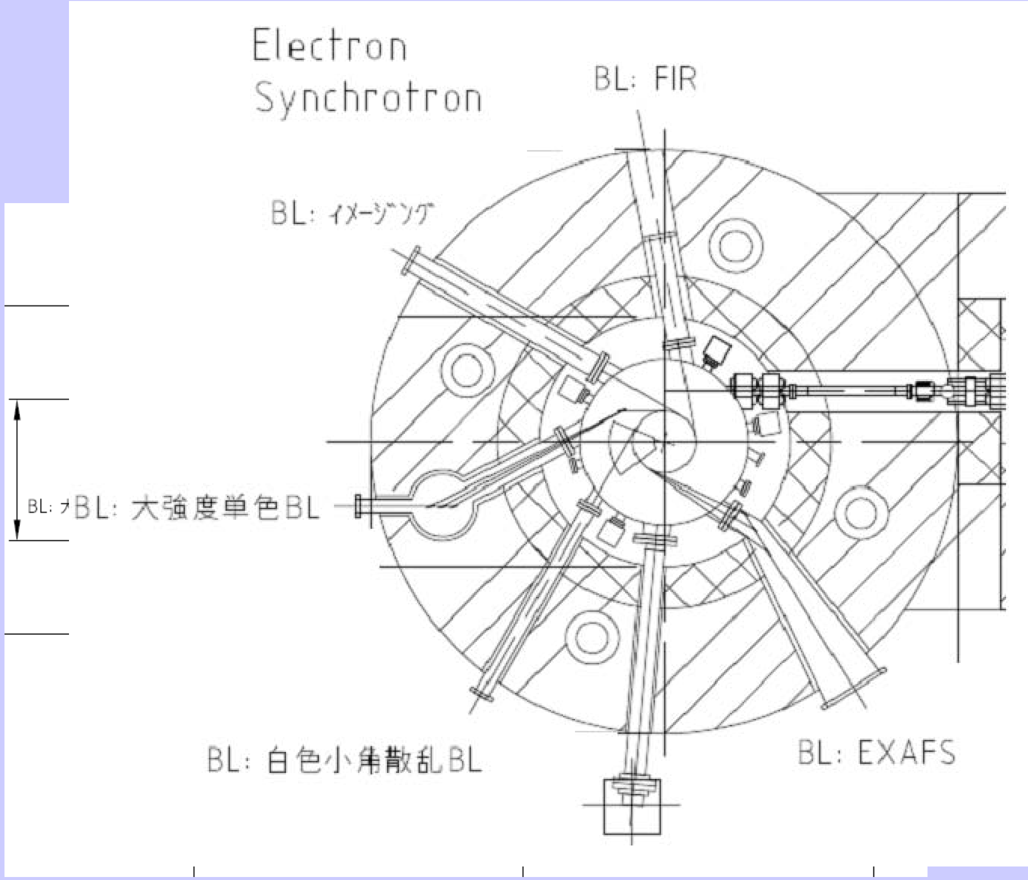
BG:70

Problem is the background

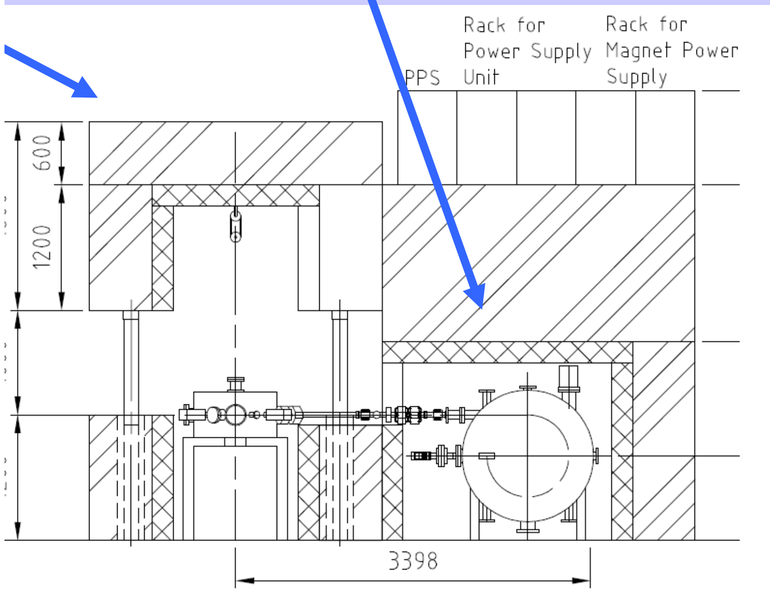
Way to manage the problems

- Specific shielding in which beam line is composed
- Make beam lines as short as possible. Small target still enables high energy resolution
- In the beam line include vertically focusing elements
- Increasing the photon density one order by increasing the injector repetition rate to 4kHz.

MIRRORCLE-20 shielding system



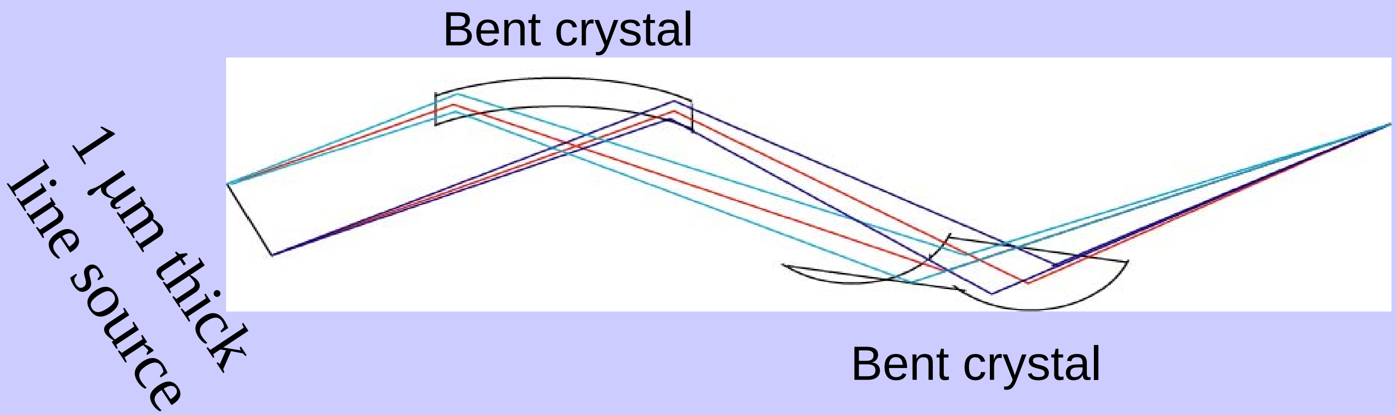
Microtron injector



Plane schematic view

Vertical view

Specific beam line designing is necessary

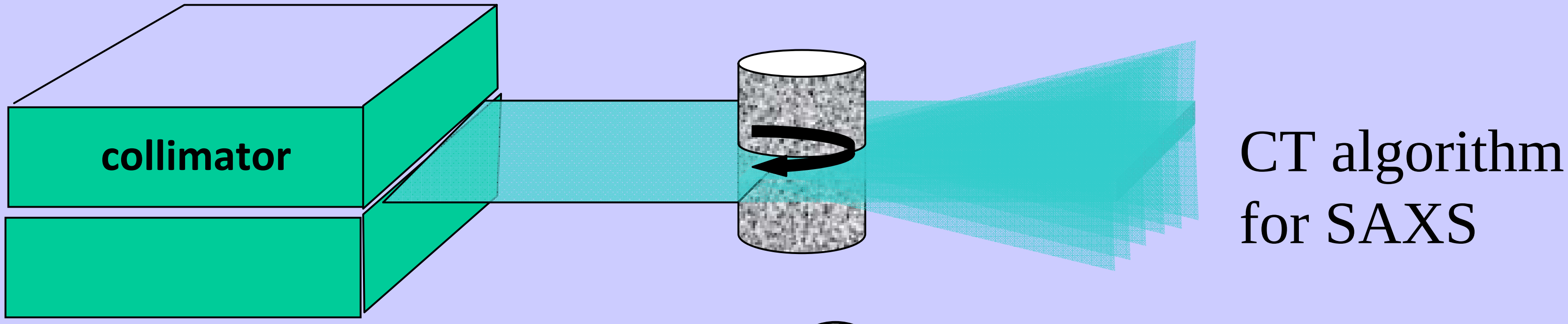


This scheme is feasible by MIRRORCLE.

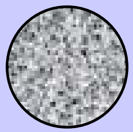
Measurement of protein shape by the small angle scattering CT feasible by MIRRORCLE

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



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