Cheiron School

September 11, 2007 @SPring-8

X-ray Monochromator

SPring-8/JASRI

Shunji Goto

Outline

→ **X-ray beamlines at SPring-8**

→ **Fundamental of x-ray monochromator**

- Bragg's law, Dynamical theory,..

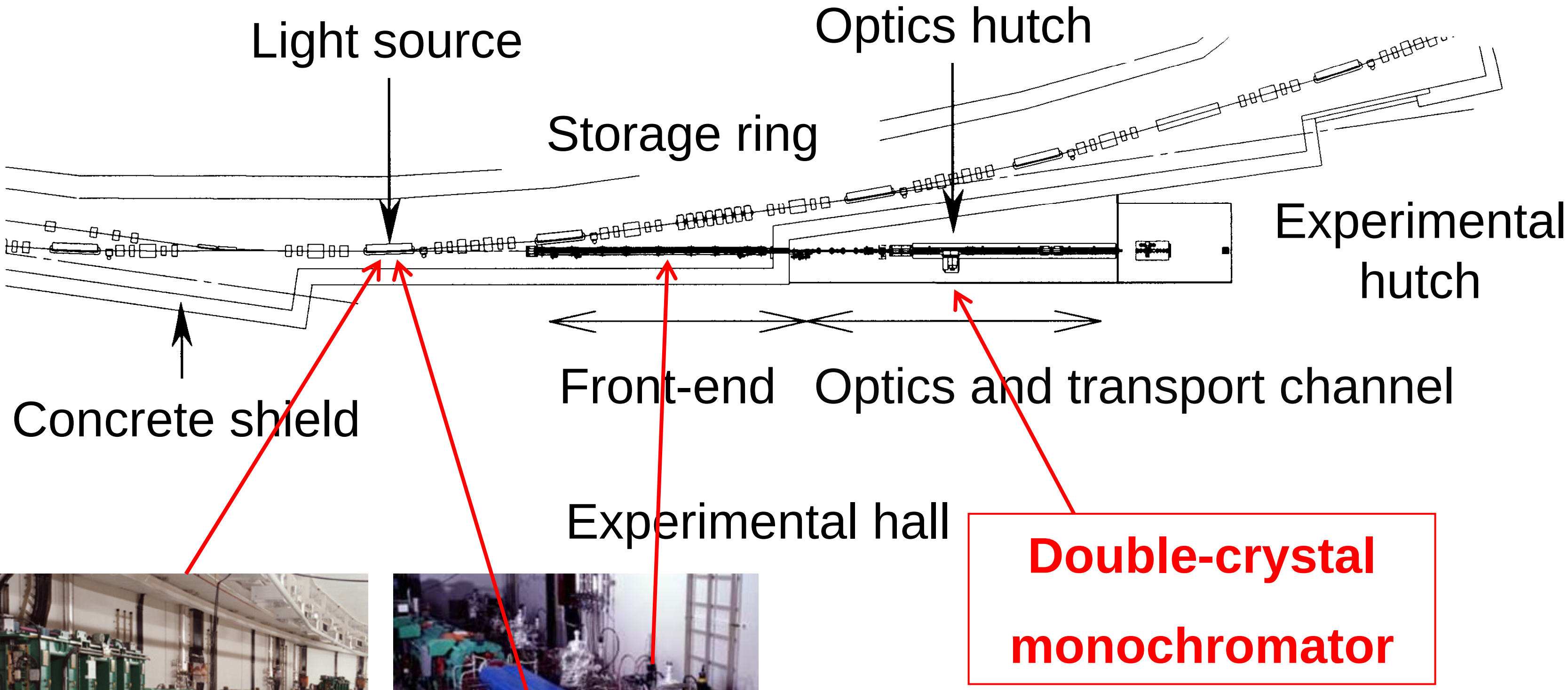
- Double crystal monochromator

- Crystal cooling

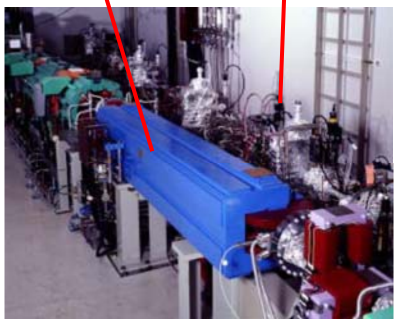
→ **Other topics**

X-ray beamlines at SPring-8

Example of beamline structure @SPring-8



Undulator



Bending magnet & front-end

SPring-8 x-ray beamlines with monochromator (1)

Bemline name		*Optics*
BL01B1	XAFS	CM (V) + DCM + FM (V)
BL02B1	Single Crystal Structure Analysis	CM (V) + DCM + FM (V)
BL02B2	Powder Diffraction	CM (V) + DCM
BL04B2	High Energy X-ray Diffraction	SBM (H)
BL05SS	Accelerator Beam Diagnosis	DCM
BL08W	High Energy Inelastic Scattering	SBM (V) & SBM (H)
BL08B2	Hyogo BM	CM (V) + DCM + FM (V)
BL09XU	Nuclear Resonant Scattering	DCM + HRM
BL10XU	High Pressure Research	DCM + Double mirror (V)
BL11XU	JAEA Quantum Dynamics	DCM + HRM
BL12XU	NSRRC ID	DCM + CM (V) + HRM + FM (V) & SBM (H)
BL12B2	NSRRC BM	CM (V) + DCM + FM (V)
BL13XU	Surface and Interface Structure	DCM + Tandem FM (H)

DCM : Double-crystal monochromator
SBM : Single-bounce monochromator
HRM : High-resolution monochromator
CM : Collimator mirror
FM : Focusing mirror
V : Vertical deflection
H : Horizontal deflection

SPring-8 x-ray beamlines with monochromator (2)

Bemline name		*Optics*	
BL14B1	JAEA Materials Science	CM (V) + DCM + FM (V)	
BL14B2	Engineering Science Research II	DCM + FM (V)	
BL15XU	WEBRAM	Tandem DCM	
BL16XU	Industrial Consortium ID	DCM + FM (V)	
BL16B2	Industrial Consortium BM	DCM + FM (V)	
BL19LXU	RIKEN SR Physics (long undulator)	DCM + Tandem FM (V)	Medium-length beamline
BL19B2	Engineering Science Research I	DCM + Tandem FM (V)	Medium-length beamline
BL20XU	Medical and Imaging II	DCM	Medium-length beamline
BL20B2	Medical and Imaging I	DCM	1st medium-length beamline
BL22XU	JAEA Quantum Structural Sci.	Tandem DCM	
BL24XU	Hyogo ID	DCM & DCM & DCM	
BL26B1	RIKEN Structural Genomics I	DCM + FM (V)	
BL26B2	RIKEN Structural Genomics II	DCM + FM (V)	
BL29XU	RIKEN Coherent X-ray Optics	DCM + Tandem FM (V)	1st 1-km-long beamline

DCM : Double-crystal monochromator
SBM : Single-bounce monochromator
HRM : High-resolution monochromator
CM : Collimator mirror
FM : Focusing mirror
V : Vertical deflection
H : Horizontal deflection

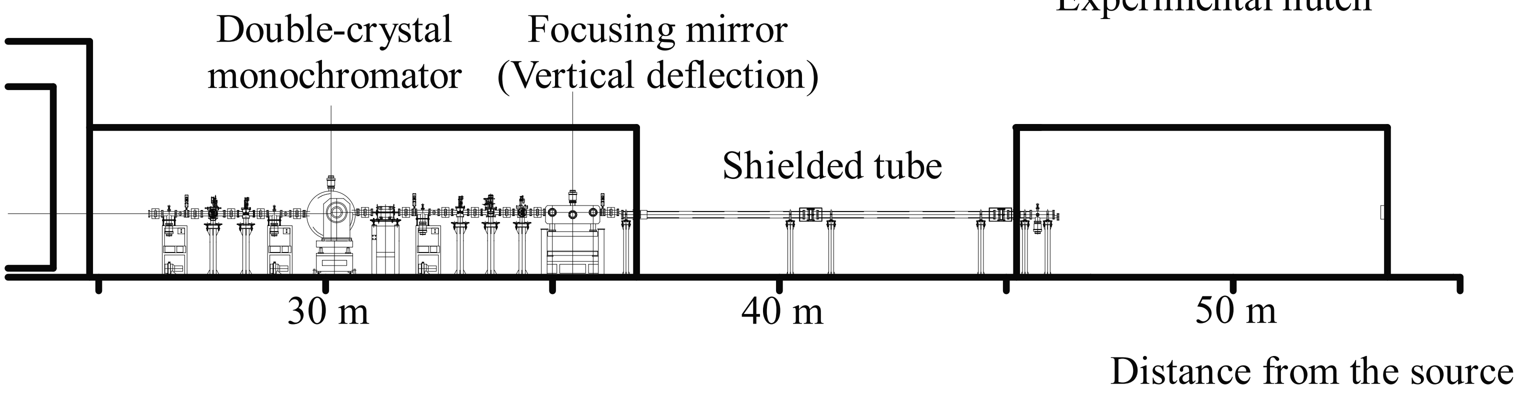
SPring-8 x-ray beamlines with monochromator (3)

Bemline name		*Optics*
BL32B2	Pharmaceutical Industry	DCM + FM (V)
BL35XU	High Resolution Inelastic Scattering	DCM + HRM + FM (V)
BL37XU	Trace element Analysis	DCM + Tandem FM (H) & SBM
BL38B1	Structural Biology III	DCM + FM (V)
BL38B2	Accelerator Beam Diagnosis	DCM
BL39XU	Magnetic Materials	DCM + FM (H)
BL40B2	Structural Biology II	DCM + FM (V)
BL41XU	Structural Biology I	DCM + K-B mirror
BL44XU	Macromolecular Assemblies	DCM + FM (H)
BL44B2	RIKEN Structural Biology II	DCM + FM (V)
BL45XU	RIKEN Structural Biology I	DCM + K-B mirror
BL46XU	R&D	DCM
BL47XU	HXPES-MCT	DCM + Tandem FM (V)

DCM : Double-crystal monochromator
SBM : Single-bounce monochromator
HRM : High-resolution monochromator
CM : Collimator mirror
FM : Focusing mirror
V : Vertical deflection
H : Horizontal deflection

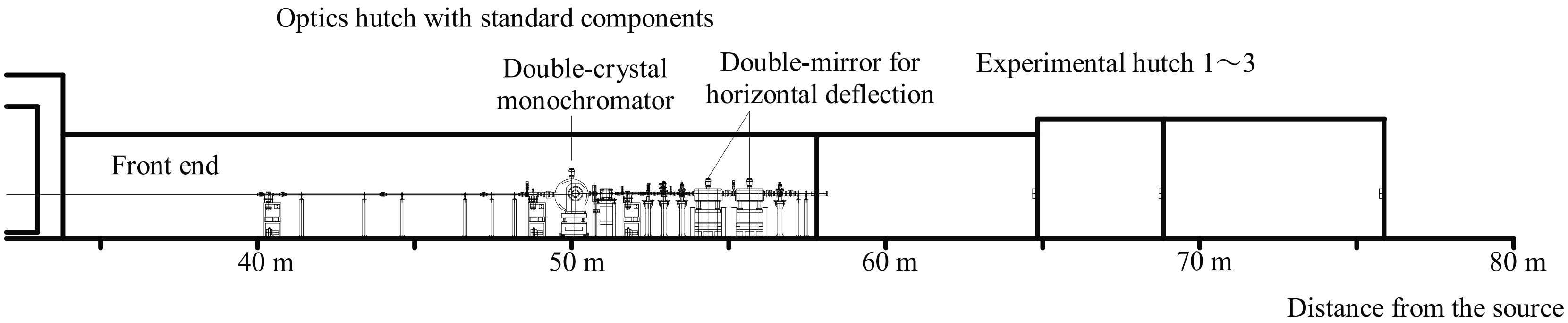
Structural biology III, BL38B1

Optics hutch with standard components



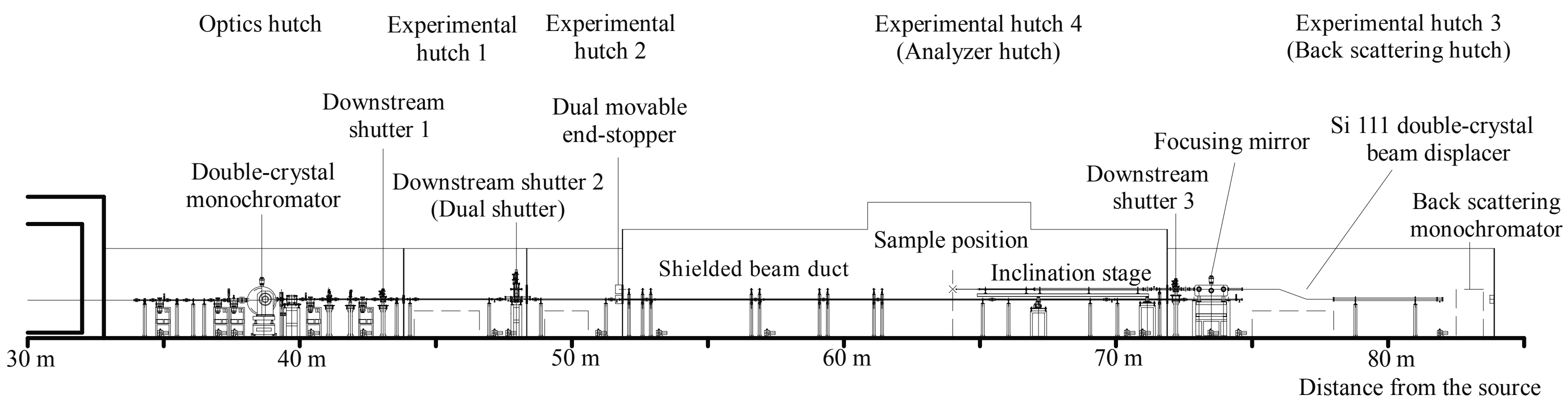
DCM + FM (V)

Surface and interface structure, BL13XU



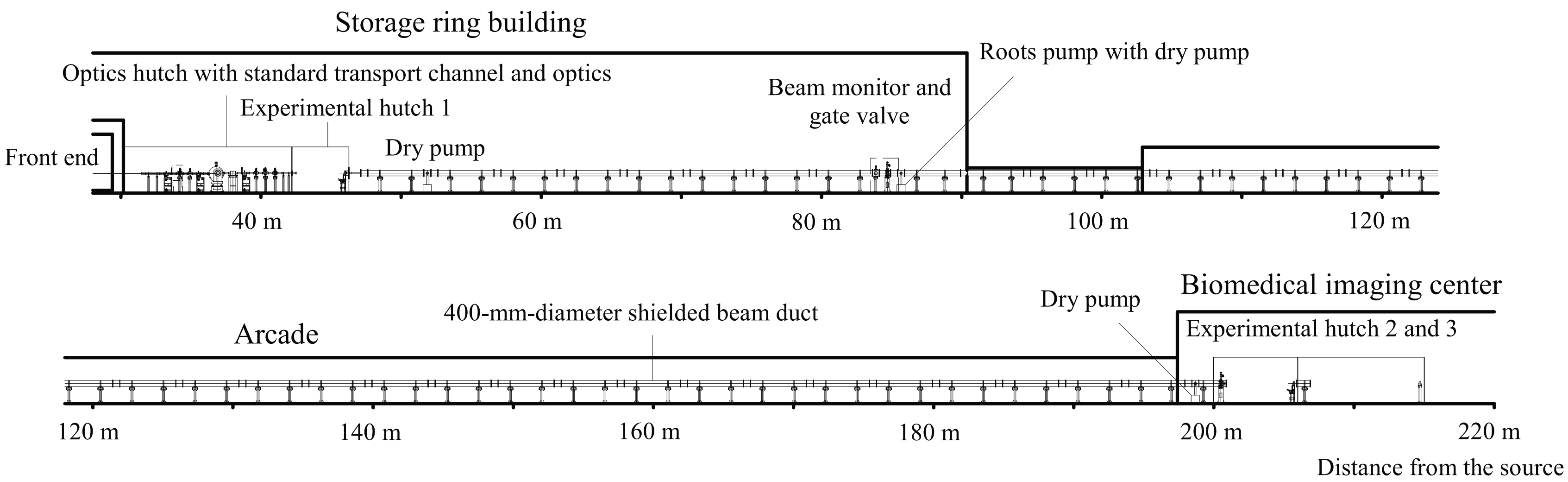
DCM + tandem FM (H)

High resolution inelastic scattering, BL35XU



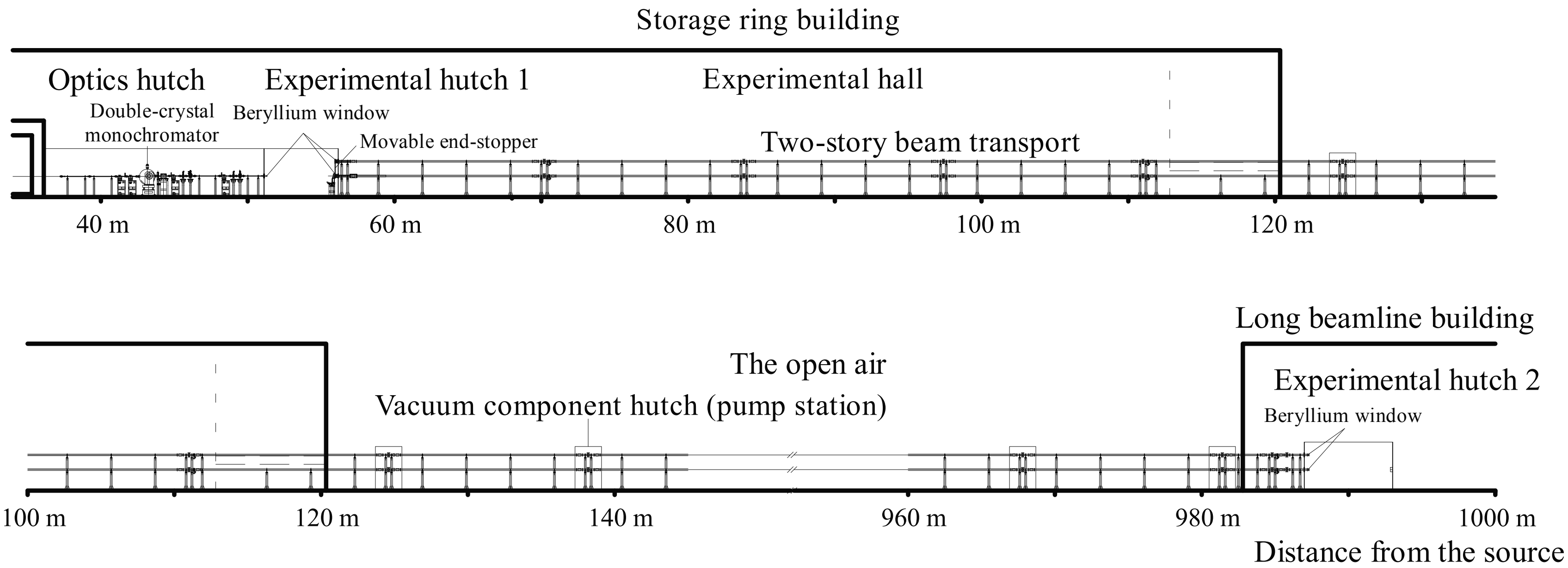
DCM + HRM + FM (V)

Medical imaging I, BL20B2



DCM

1 km beamline, BL29XU



DCM + tandem FM (V)

Monochromators @SPring-8

Beamlines with x-ray monochromator =

40 / 49 beamlines

Double-crystal monochromator:	**43**
Single-bounce monochromator:	**5**
High-resolution monochromator:	**~4**

X-ray monochomator is key component

for x-ray beamline.

Fundamental of
X-ray monochromator

X-ray monochromator using perfect crystal

→ **Principle of monochromator**

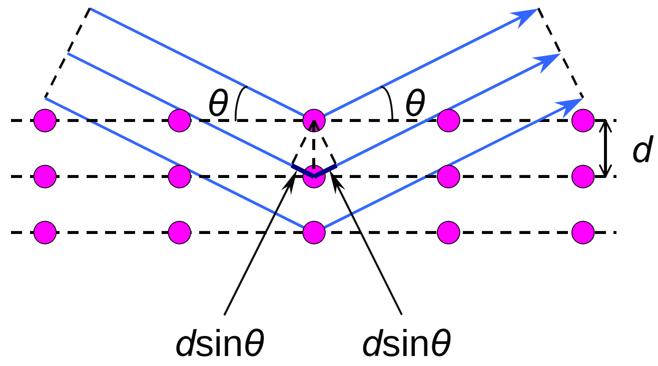
Bragg reflection from perfect single crystal

$2d \sin\theta = n\lambda$

d: Latiice *(d)*-spacing,

θ: glancing angle,

λ: X-ray wavelength



→ **Crystal: silicon, diamond,..**

Requirements for X-ray monochromator

→ **Monochromatize x-rays of required photon energy**

with required energy width

with required throughput (efficiency)

→ **Fixed-exit beam using double-crystal monochromator**

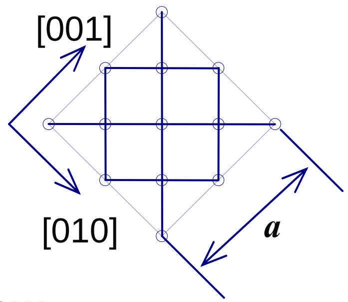
→ **Focusing using bending mechanism**

→ **Cooling under heat-load from SR beam**

…

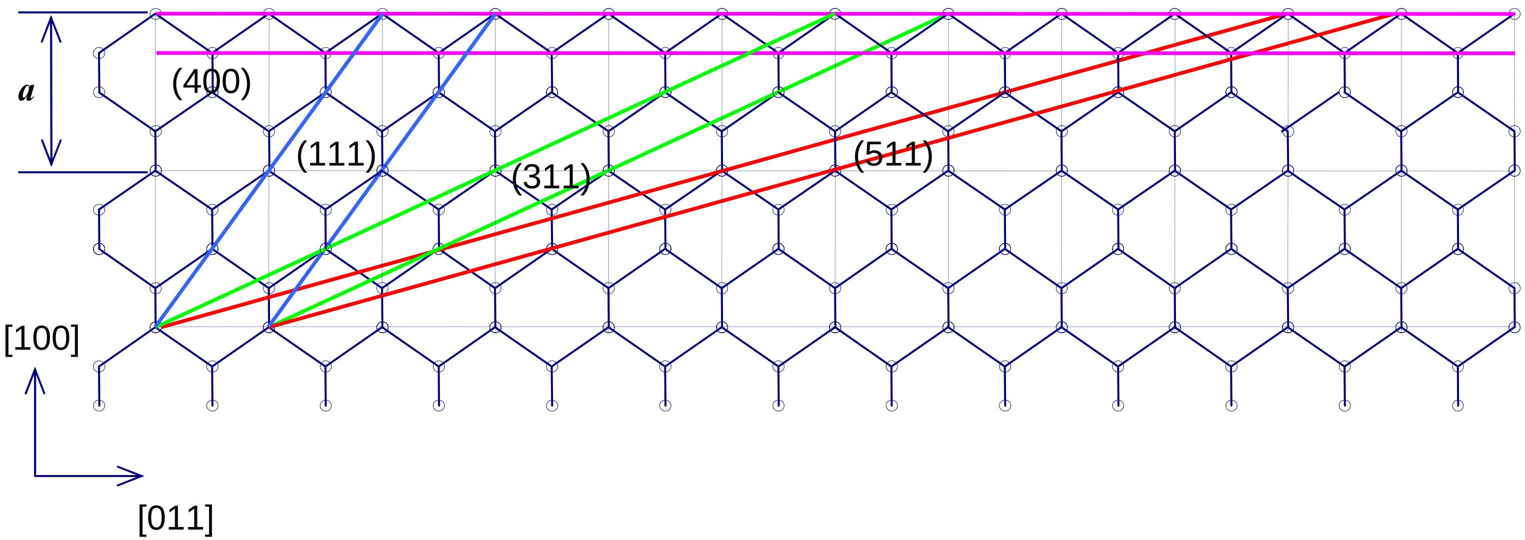
Lattice planes of silicon

Top view



d-spacing
(400) : 1.3578 Å
(111) : 3.1356 Å
(311) : 1.6375 Å
(511) : 1.0452 Å

Side view



Energy range of SPring-8 standard monochromator

e.g. For SPring-8 standard monochromator

→ **Reflection**

Si 111 refl.

Si 311 refl.

Si 511 refl.

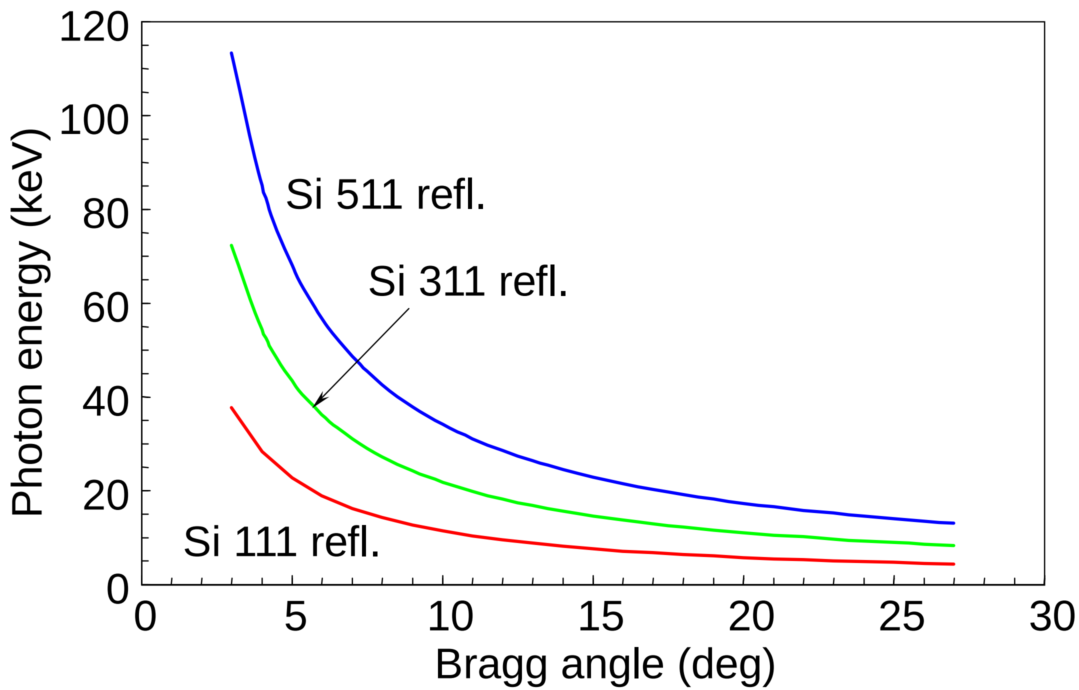
.....

→ **Bragg angles**

3～27°

→ **Energy range**

4.4～110 keV



Photon energy (wavelength) can be selected by crystal, net planes, and Bragg angle.

Dynamical theory

- Two wave case -

Two wave equations

Following two equations are derived using Maxwell's equations for 3-dimensional periodic medium (= perfect single crystal).

$$\left(\mathbf{k}_0^{\,2} - k^2\right)E_0 - \chi_{-h} P K_0^{\,2} E_h = 0$$
$$\left(\mathbf{k}_h^{\,2} - k^2\right)E_h - \chi_{h} P K_0^{\,2} E_0 = 0$$

***$\boldsymbol{k}_\mathrm{h} = \boldsymbol{k}_0 + \boldsymbol{h}$* : Momentum conservation**

$\boldsymbol{h}$: Reciprocal lattice vector

E_0, E_h : Fourier components of electric field

$\boldsymbol{K}_\mathbf{0}$: Incident wave vector in vacuum

$\boldsymbol{k}_\mathbf{0}$, $\boldsymbol{k}_\mathbf{h}$: Refracted and reflected wave vectors in crystal

k : Mean wave number in crystal

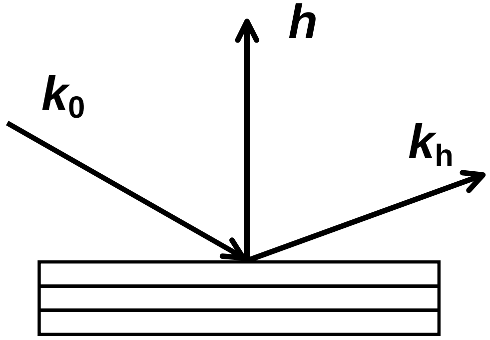
χ_0, χ_h,... : Fourier components of the polarizability (Negative values, 10^{-6}~10^{-5})

P : Polarization factor (σ : P= 1, π : P= cos2 θ_B)

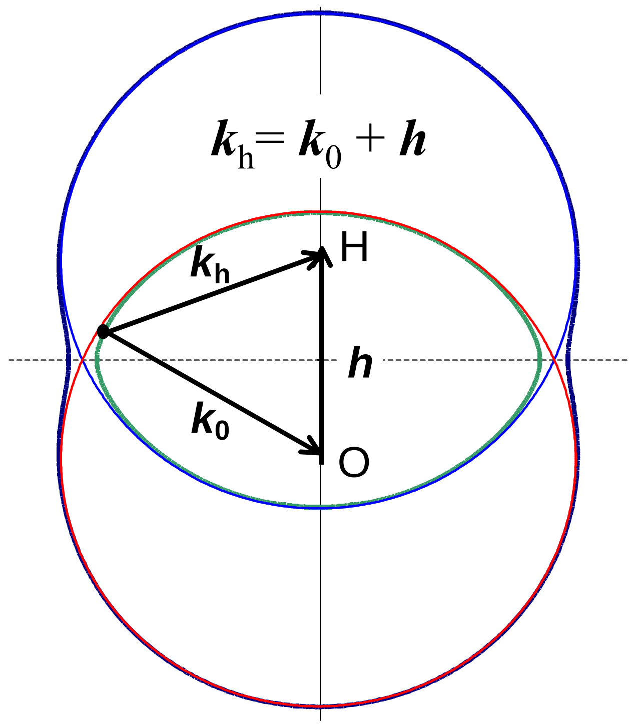
Dispersion surface

Using two equations, we obtain following :

$$\left(\mathbf{k}_0{}^2 - k^2\right)\left(\mathbf{k}_h{}^2 - k^2\right) = \chi_h \chi_{-h} P^2 K_0{}^4$$



Real space

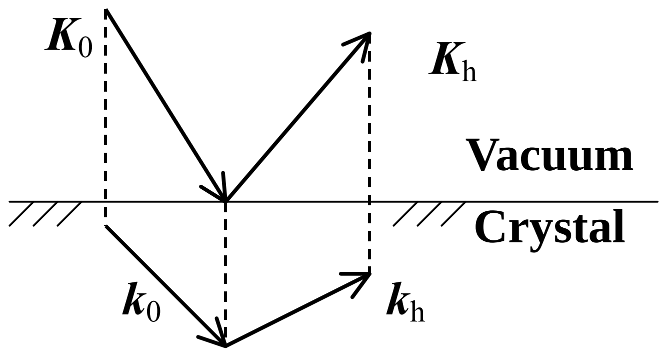


Reciprocal space

Two dispersion surfaces close to two Laue spheres (O, H) for each polarization, showing the gap near Bragg condition.

Boundary condition of wave vector

First, we must consider connections of waves from vacuum into crystal and from crystal to vacuum, to solve the equations.



Tangential component of wave vector must be continuous.

Incident wave in vacuum

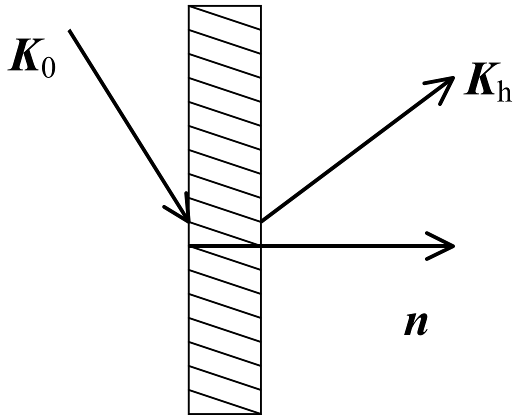
→ Refracted wave in crystal

→ Bragg reflection

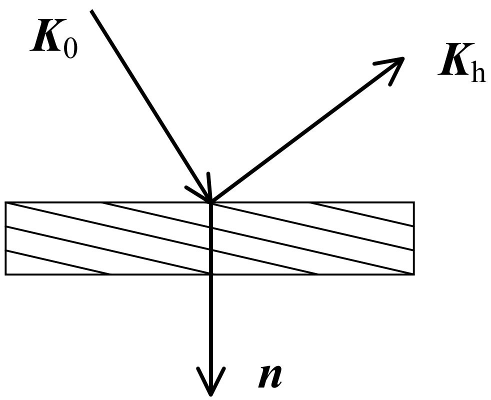
→ Reflected wave in the crystal

→ Reflected wave in vacuum

Laue case and Bragg case



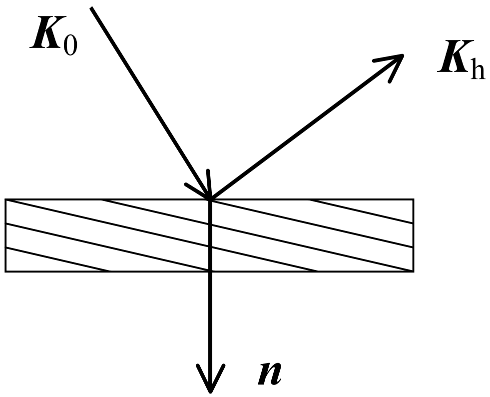
Laue case



Bragg case

Asymmetry ratio

$$\begin{cases} \gamma_0 = \hat{K}_0 \cdot n \\ \gamma_h = \hat{K}_h \cdot n \end{cases} \qquad b = \frac{\gamma_0}{\gamma_h}$$



Laue case: *b*>0

Symmetric Bragg case: *b*= 1

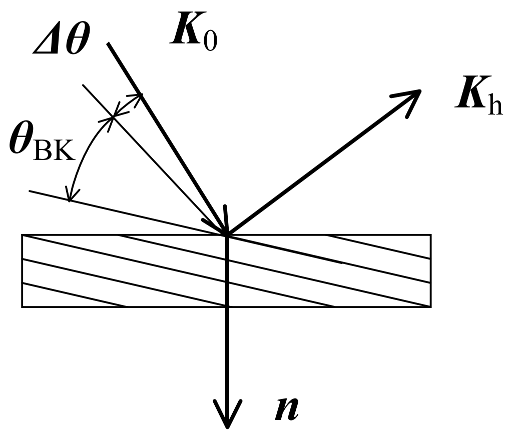
Bragg case: *b*< 0

Symmetric Bragg case: b= -1

Normalized parameter *W* for deviation from Bragg condition

Parameter W is related to the gap between two dispersion surfaces

and total reflection occurs at –1<W<1 for Bragg case.



θ_{BK} : Kinematical Bragg angle

$\Delta\theta$: Deviation angle from θ_{BK}

$\boldsymbol{K}_0, \boldsymbol{K}_h, \boldsymbol{h}$ are in the same plane.

$$W = \left\{ \Delta\theta \sin 2\theta_{BK} + \frac{\chi_{0r}}{2}\left(1 - \frac{\gamma_h}{\gamma_0}\right) \right\} \sqrt{\frac{\gamma_0}{|\gamma_h|}} \frac{1}{|\chi_{hr}| \cdot |P|}$$

For symmetric Bragg case, sigma polarization:

$$W = \{\Delta\theta \sin 2\theta_{BK} + \chi_{0r}\} \frac{1}{|\chi_{hr}|}$$

Amplitude ratio

From these equations, we obtain the ratio $r = E_h/E_0$ as a function of parameter W.

For Bragg case, no absorption, and thick crystal:

$$
\begin{cases}
r = \dfrac{E_h}{E_0} = -\sqrt{\dfrac{\gamma_0}{|\gamma_h|}}\dfrac{|\chi_{hr}|}{\chi_{-h}}\dfrac{|P|}{P}\left(W + \sqrt{W^2 - 1}\right) & (W < -1) \\
r = \dfrac{E_h}{E_0} = -\sqrt{\dfrac{\gamma_0}{|\gamma_h|}}\dfrac{|\chi_{hr}|}{\chi_{-h}}\dfrac{|P|}{P}\left(W + i\sqrt{1 - W^2}\right) & (-1 \le W \le 1) \\
r = \dfrac{E_h}{E_0} = -\sqrt{\dfrac{\gamma_0}{|\gamma_h|}}\dfrac{|\chi_{hr}|}{\chi_{-h}}\dfrac{|P|}{P}\left(W - \sqrt{W^2 - 1}\right) & (W > 1)
\end{cases}
$$

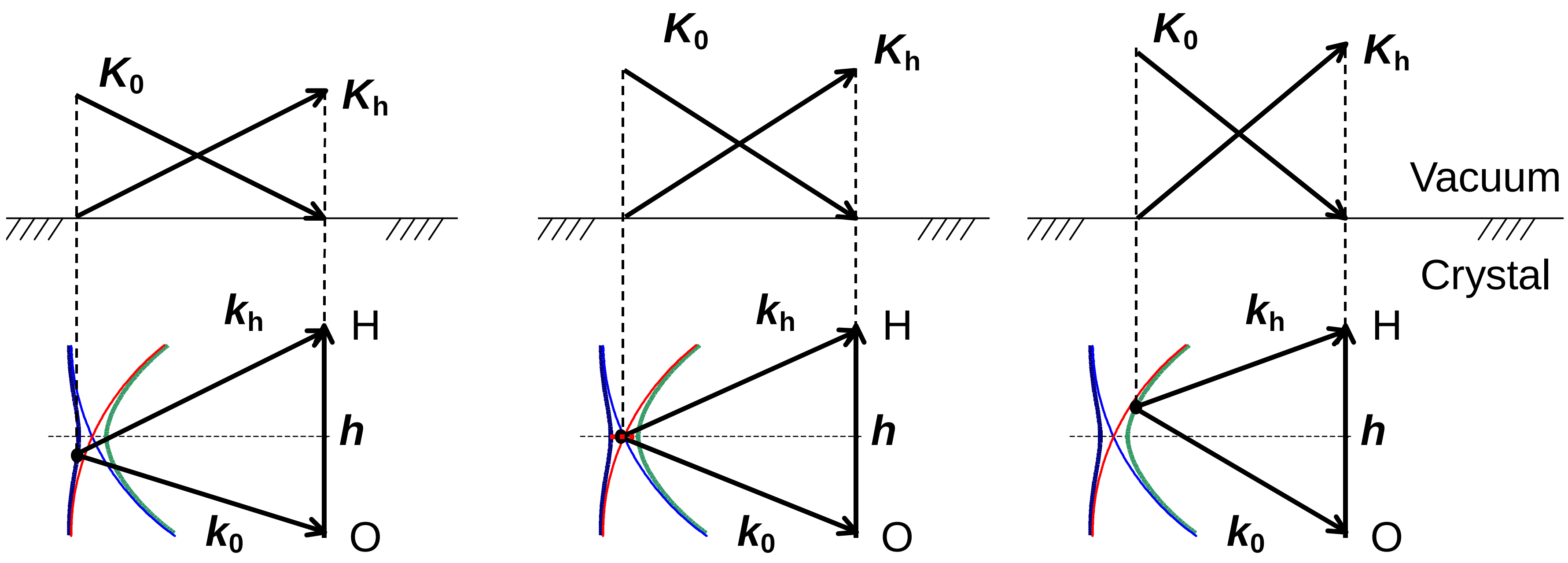
← Total reflection (for $-1 \le W \le 1$)

Movement of tie point

(1) Lower angle $W < -1$

(2) Near Bragg condition $-1 < W < 1$

(3) Higher angle $W > 1$



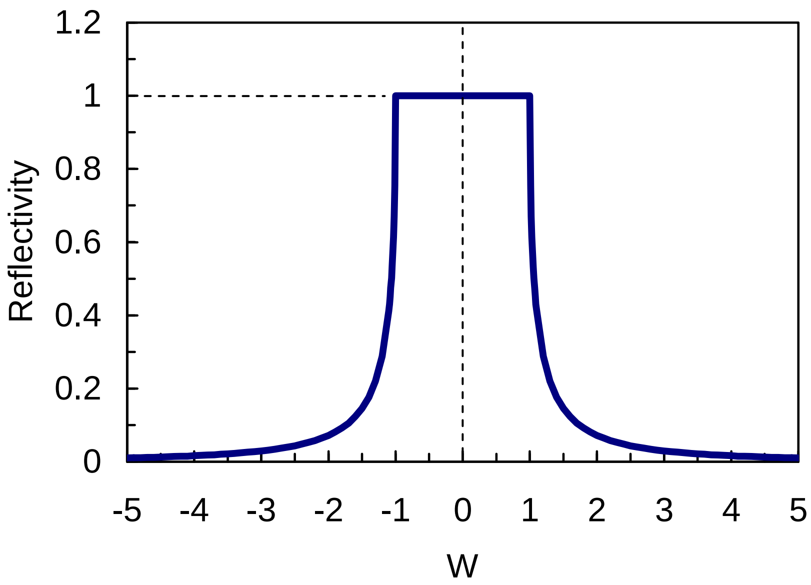
Total reflection

Reflectivity

Finally, we obtain reflectivity

for Bragg case, no absorption, and thick crystal:

$$
\begin{cases}
R = \dfrac{|\gamma_h|}{\gamma_0}\left|\dfrac{E_h}{E_0}\right|^2 = \left(W + \sqrt{W^2 - 1}\right)^2 & (W < -1) \\
R = 1 \quad (-1 \le W \le 1) & \leftarrow \text{Total reflection} \\
R = \left(W - \sqrt{W^2 - 1}\right)^2 & (W > 1)
\end{cases}
$$



For symmetric Bragg case, sigma polarization:

$$W = \{\Delta\theta \sin 2\theta_{BK} + \chi_{0r}\}\frac{1}{|\chi_{hr}|}$$

Darwin width → $\Delta W = 2$

$$\omega = \frac{2|\chi_{hr}|}{\sin 2\theta_{BK}} \propto |F_h|$$

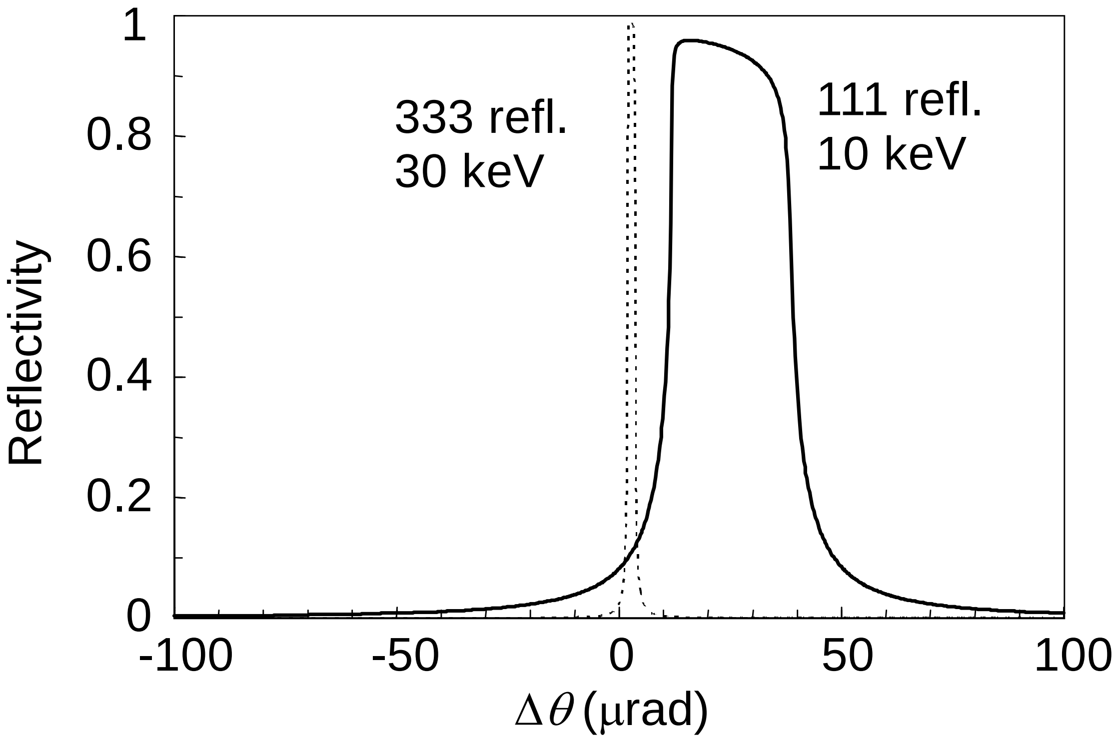
Shift of Bragg angle due to refraction:

$$\Delta\theta_{refraction} = -\frac{\chi_{0r}}{\sin 2\theta_{BK}}$$

Intrinsic rocking curve for silicon

Based on the dynamical theory for perfect crystal

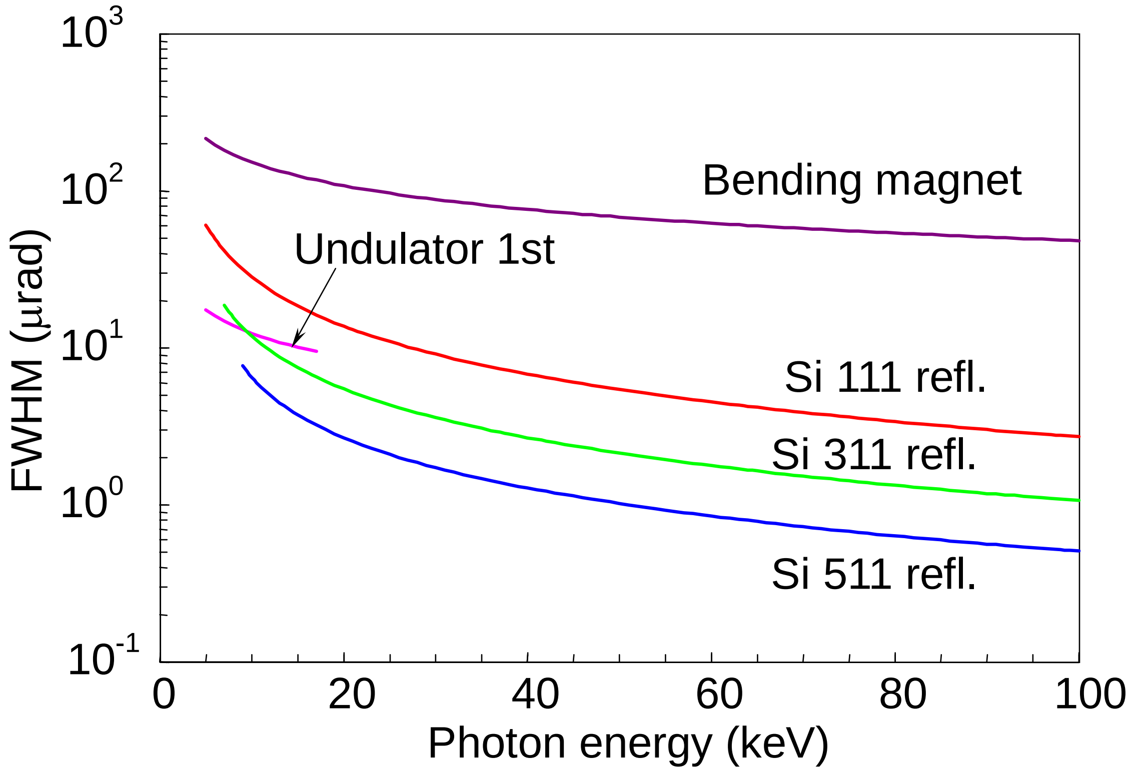
for thick crystal and absorption considered:



Features:

- Diffraction width (Darwin width) of 0.1～100 μrad
- Peak reflectivity of ~1 for low absorption case

Angular divergence of sources and diffraction width



SPring-8 bending magnet

$$\sigma_{\mathrm{r}} \approx \frac{1}{\gamma} \approx 60\,\mu\mathrm{rad}$$

Undulator (*N*= 140)

$$\sigma_{\mathrm{r}} \approx \frac{1}{\gamma\sqrt{N}} \approx 5\,\mu\mathrm{rad}$$

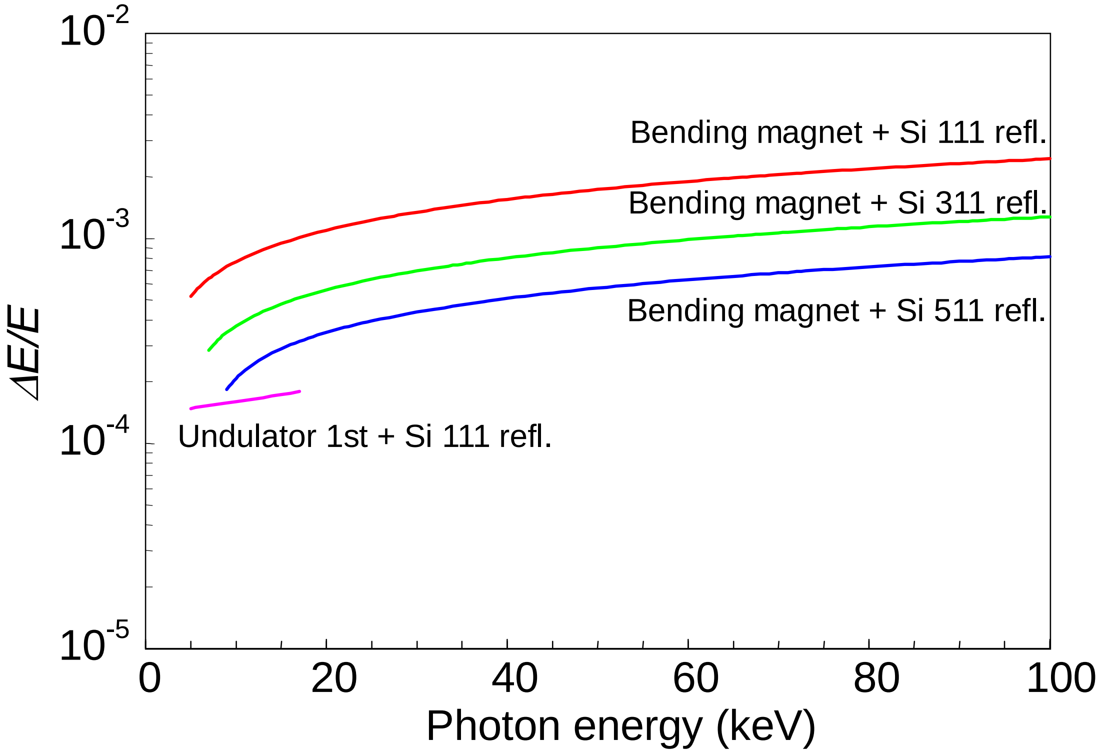
Divergence of undulator radiation is the same order as diffraction width of low order reflection.

Energy resolution

$$\frac{\Delta E}{E} = \cot\theta_B \sqrt{\Omega^2 + \omega^2}$$

Ω: divergence of source

ω: diffraction width



Using slit, collimator mirror,.. we can reduce Ω_{eff},

$\Delta E/E = 10^{-5} \sim 10^{-3}$

Double-crystal monochromator

Double crystal monochromator (DCM)

Fixed-exit operation of double-crystal monochromator is very crucial for end-users of beamlines.

To obtain fixed-exit beam

independent of Bragg angle:

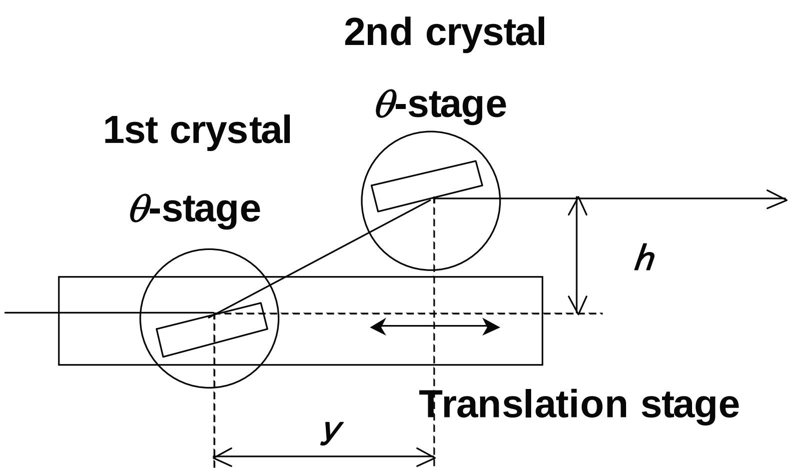
→ **Use the same crystals and *d*-spacing for 1st and 2nd crystals**

→ **Keep parallel setting**

Fixed-exit by DCM

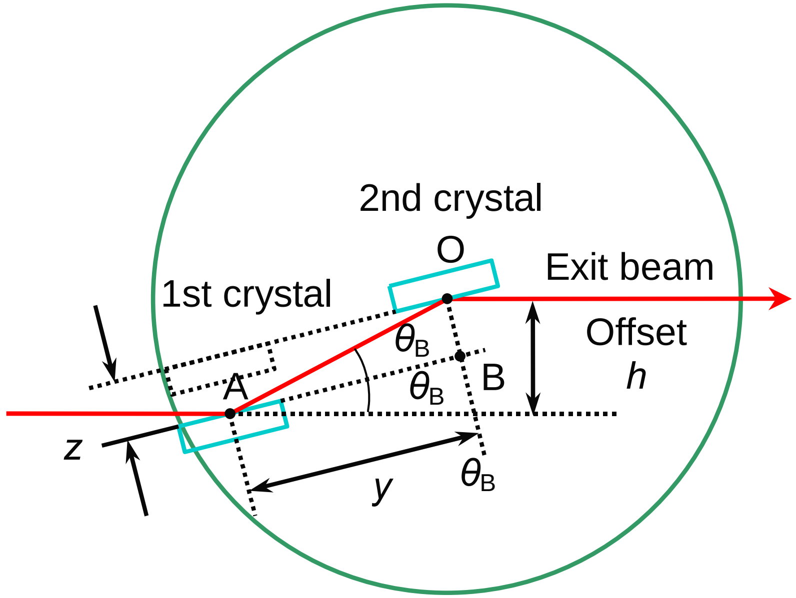
Two arrangements for DCM

(1) θ_1+translation+ θ_2 link



$$y = \frac{h}{\tan 2\theta_B}$$

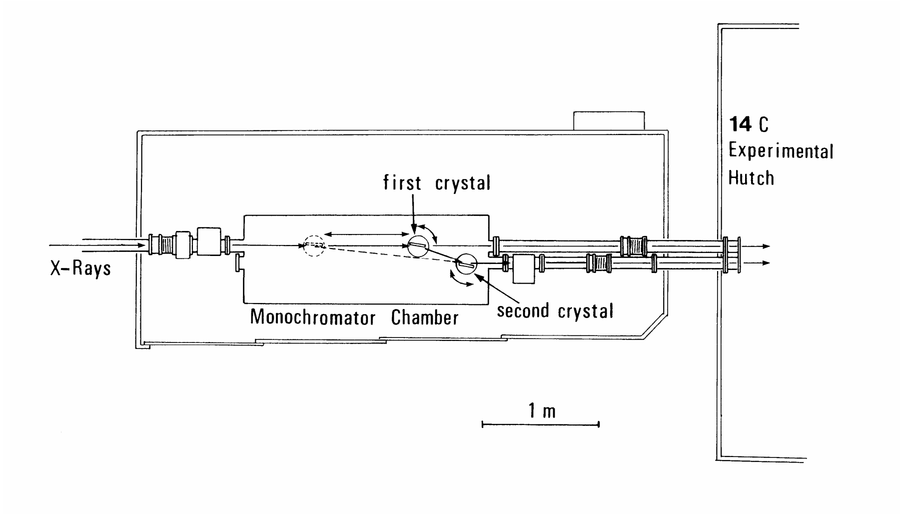
(2) θ+ two translation link



$$y = AB = \frac{h}{2\sin\theta_B} \qquad z = OB = \frac{h}{2\cos\theta_B}$$

$$(y^2 - h^2/4)(z^2 - h^2/4) = h^4/16$$

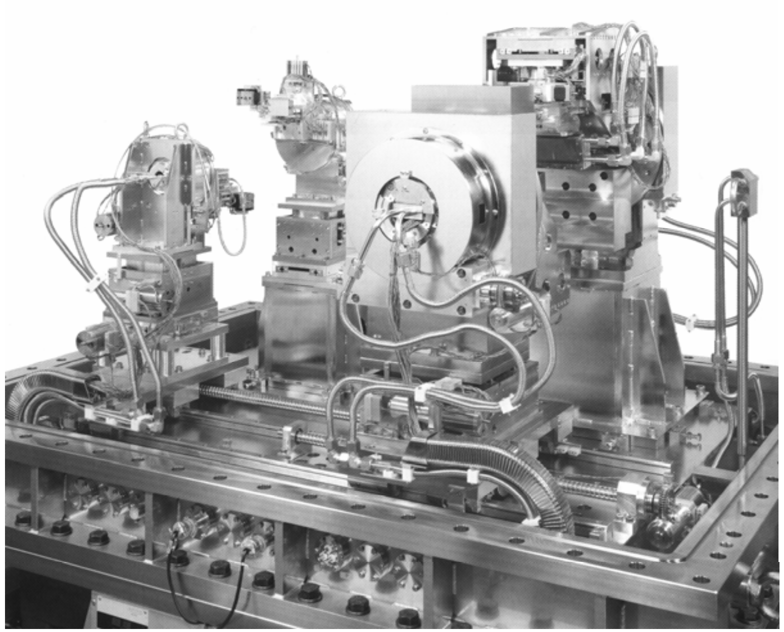
θ_1 + translation + θ_2 computer link



PF BL-14C

Kawata and Ando, NIM A246 (1986)

h= 150 mm, θ_B= 2.6～25°



SPring-8 BL15XU

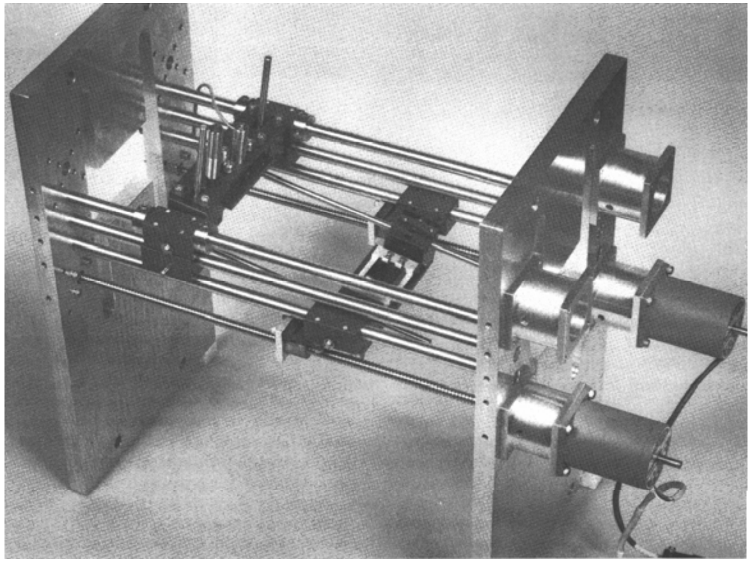
SPring-8 information Vol. 5, No.1 (2000)

h= 100 mm, θ_B= 5.7～72°

Large offset, long-stroke translation

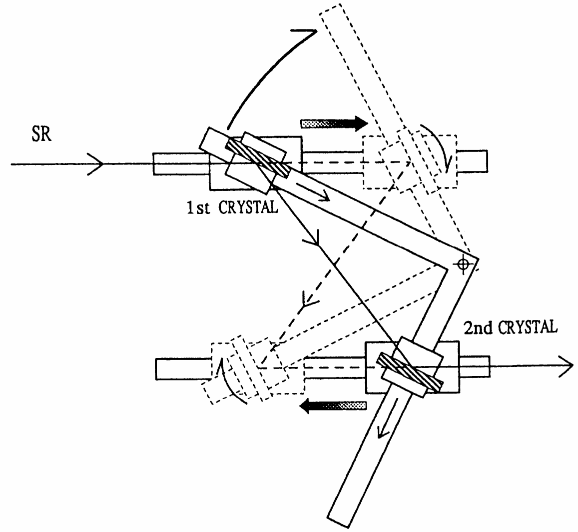
Difficulty of parallelism between 1st and 2nd crystal

Boomerang link type



Kirkland, NIM-A291 (1990)

h= 50 mm, θ_B= 5～85°



UVSOR BL 1A, BL 7A

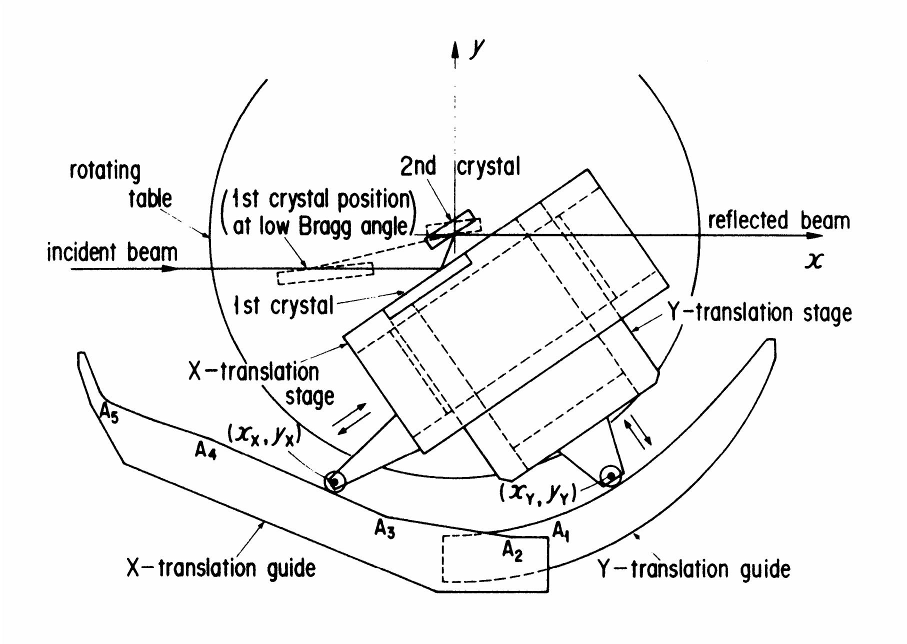
Hiraya et al., RSI 66 (1995)

θ_B= 18.5～71.5°

→ **Difficulties for crystal cooling and multi-stage adjustment**

→ **Low rigidity**

θ + two translation (KEK-PF)



PF BL-4C..

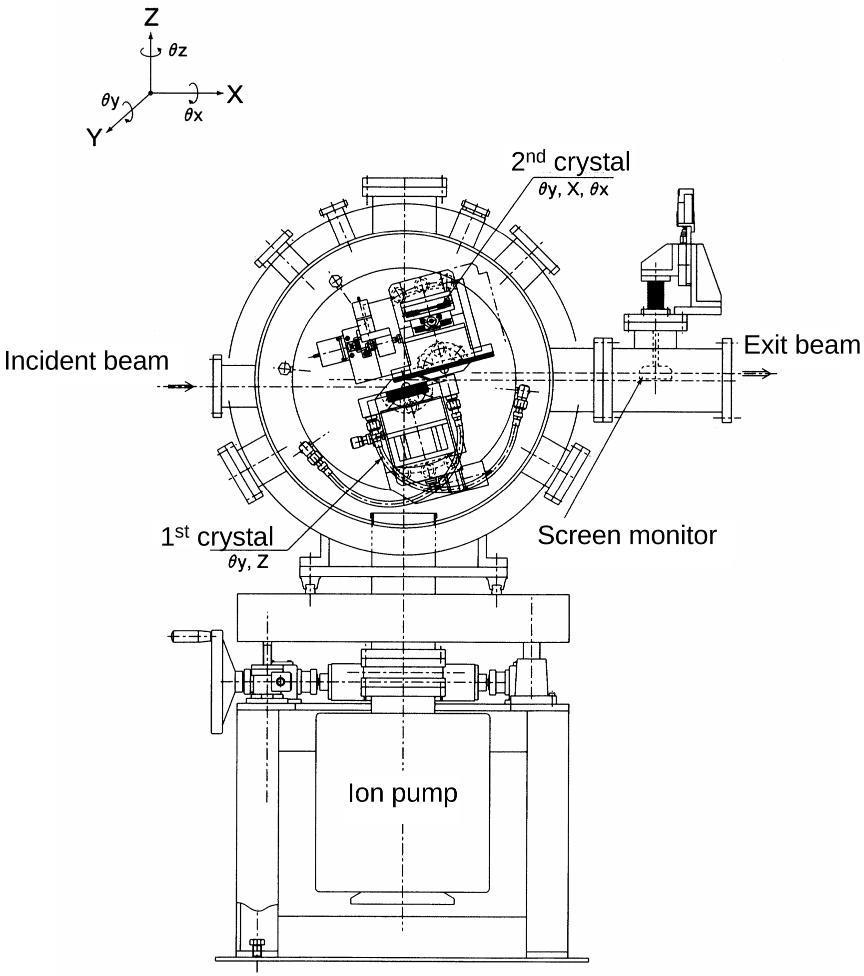
Matsushita et al., NIM A246 (1986)

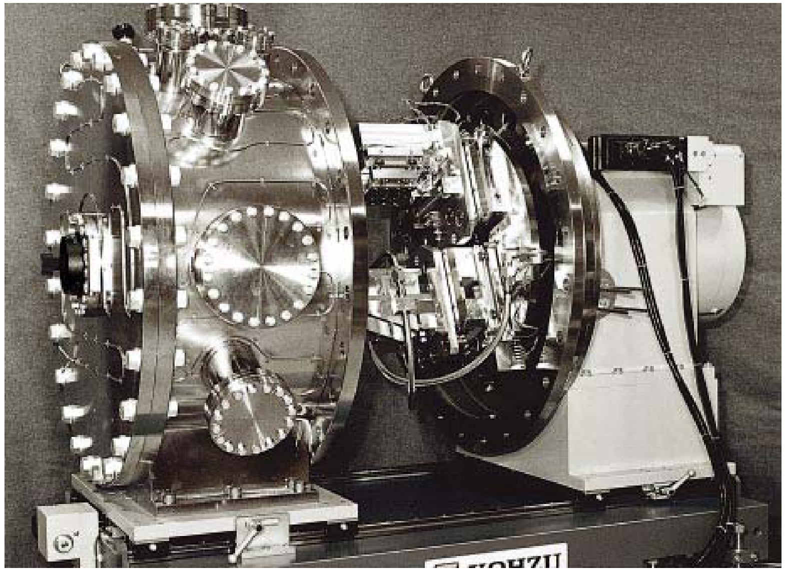
h= 25 mm, θ_B= 5～70°

Two cams for two translation-stages

Rotation center at 2nd crystal

θ + two translation (APS)



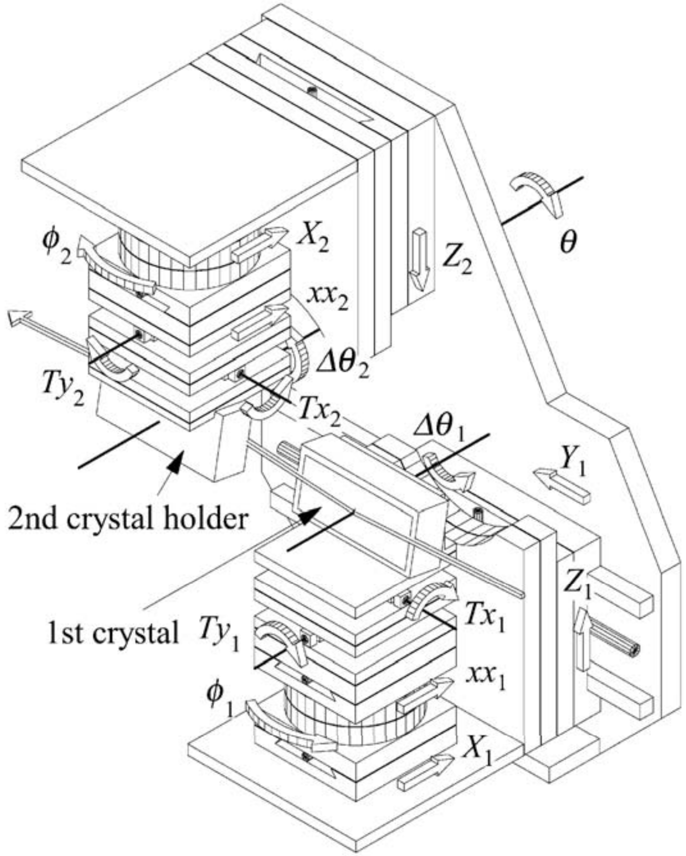


h= 35 mm, θ_B= 5～30°

θ-y-z computer link

Rotation center at h/2-height

SPring-8 standard DCM



$3^o < \theta_B < 27^o$

Offset *h*= 30 mm

Adjustment stages

for undulator beamline DCM

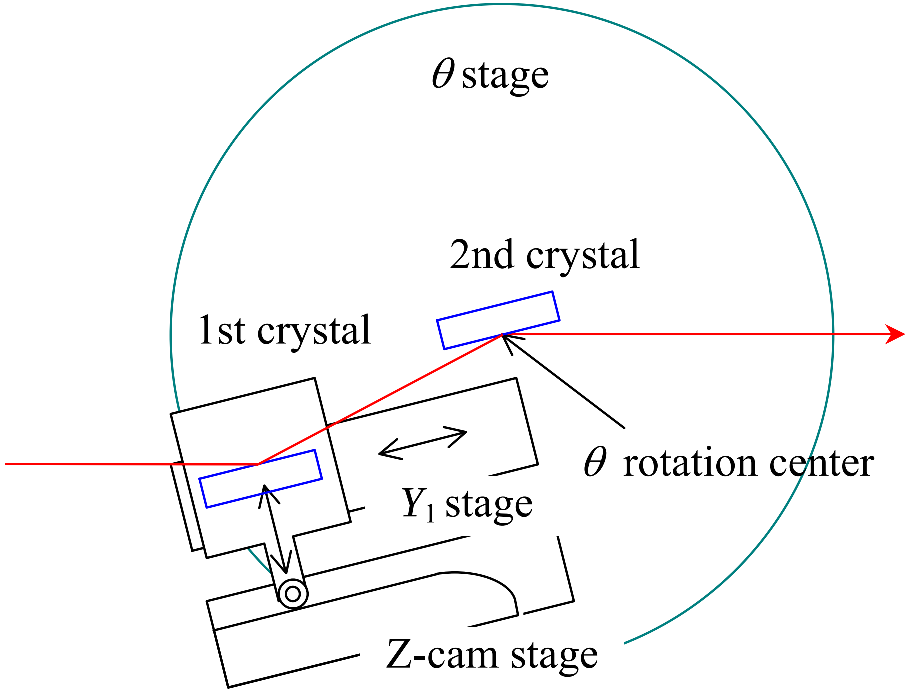
Sub-micron, sub-μrad control

θ-*y*-*z* computer-cam link

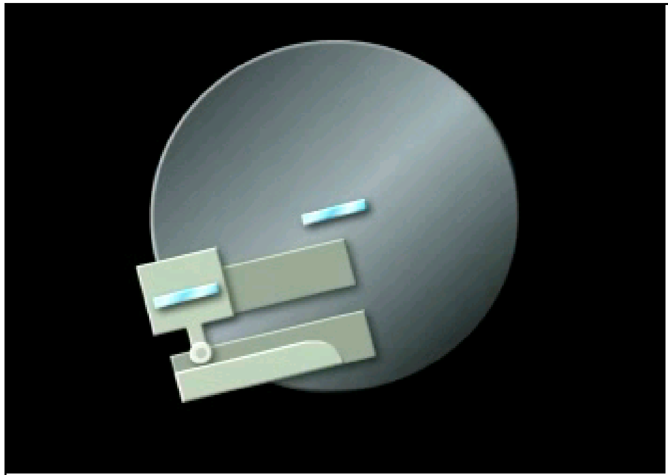
θ-*y*: linked by computer control
y-z: linked by cam

Cam shape for fixed-exit

$$\left(y^2 - \frac{h^2}{4}\right)\left(z^2 - \frac{h^2}{4}\right) = \frac{h^4}{16}$$



θ-y computer + y-z cam link



m29.mpg

Crystal cooling

Heat load on 1st Crystal

Heat load on the mochromator 1st crystal:

→ For SPring-8 bending magnet source
100 W & 1 W/mm^2

→ For SPring-8 standard undulator source
~500 W & ~ 500 W/mm^2

cf.	**Hot plate**	**: ~ 0.02 W/mm^2**
	CPU	**: ~ 0.3 W/mm^2**

Crystal cooling

Why crystal cooling？

Qin (Heat load by SR) = Qout (Cooling + Radiation,..)

→ with temperature rise ΔT

→ $\alpha \Delta T = \Delta d$ (*d*-spacing change)

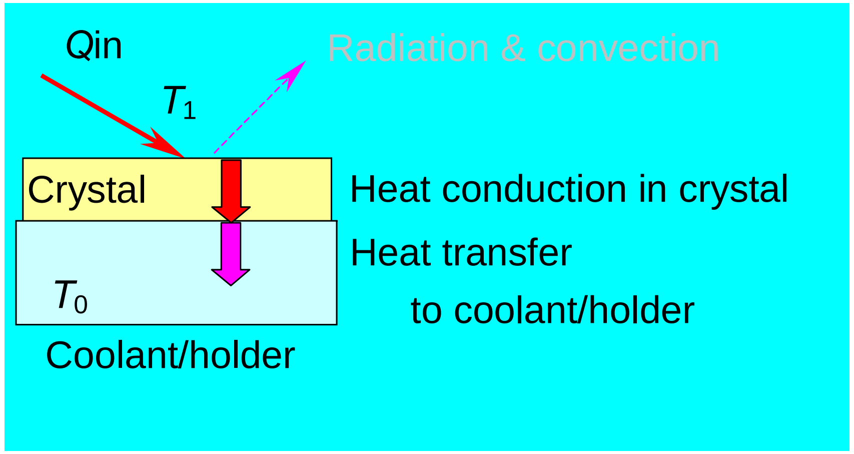
α: thermal expansion coefficient

or → $\Delta \theta$ (bump of lattice due to heat load)

Miss-matching between 1st and 2nd crystals occurs:

→ Thermal drift, Loss of intensity, Broadening of beam, loss of brightness

→ Melting or limit of thermal strain → Broken !



Solution for crystal cooling

We must consider:

Thermal expansion of crystal: α,

Thermal conductivity in crystal: κ,

Heat transfer to coolant and crystal holder.

Solutions:

(S-1) κ / α → Larger

(S-2) Large contact area between crystal and coolant/holder

→ larger

(S-3) Irradiation area → Larger, and power density → smaller

Figure of merit

	Silicon 300 K	Silicon 80 K	Diamond 300 K
κ (W/m/K)	150	1000	2000
α (1/K)	$2.5x10^{-6}$	$-5x10^{-7}$	$1x10^{-6}$
κ / α $x10^6$	60	2000	2000

Figure of merit of cooling:
Good for silicon (80 k) and diamond (300 K)

For SPring-8 case

Bending magnet beamline

Power and density : ~ 100 W, ~1 W/mm^2 @40 m

Method:

→ Direct cooling with fin crystal ← S-2

Undulator beamline

(Linear undulator, *N*= 140, λu= 32 mm)

Power and density : ~500 W , ~500 W/mm^2 @40 m

Methods:

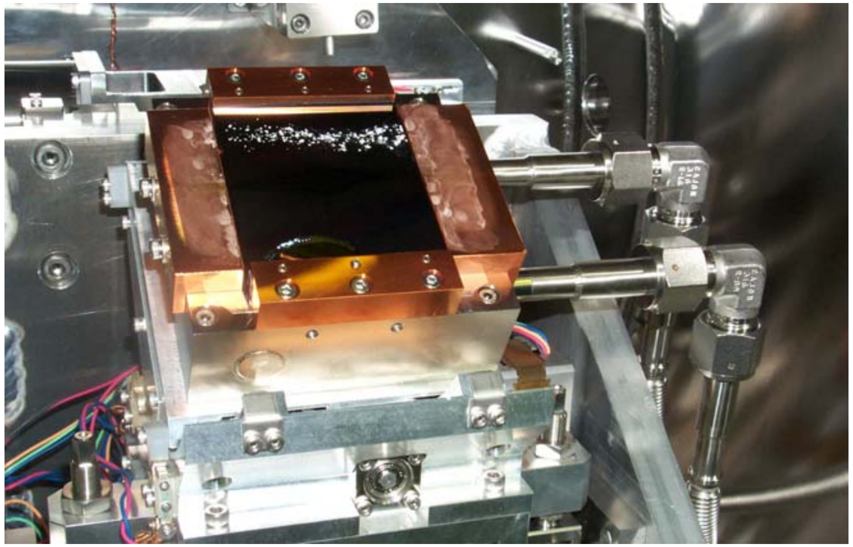
→ Direct cooling of silicon pin-post crystal ← S-2

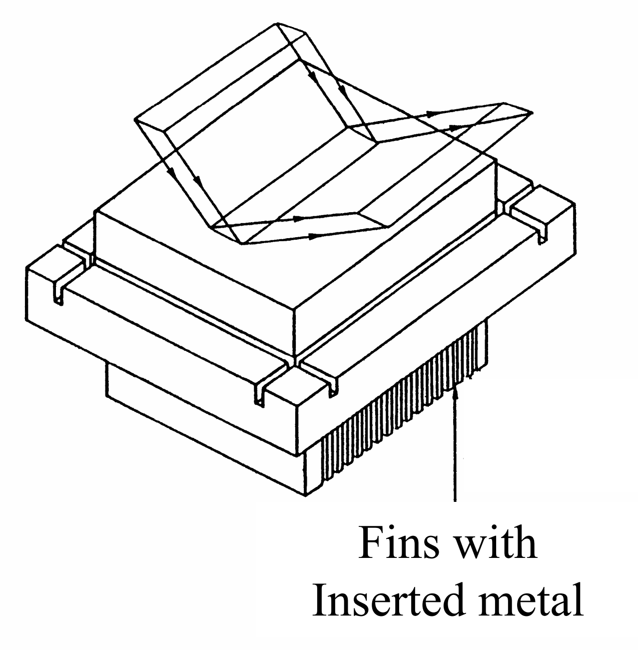
+ Rotated inclined geometry (→10 W/mm^2) ← S-3

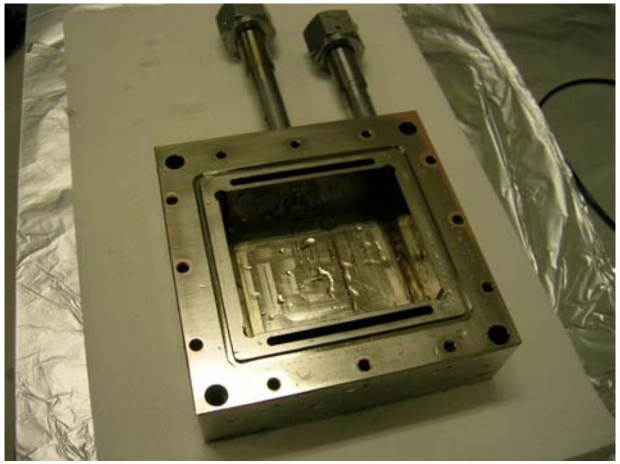
→ or Cryogenic cooling using LN_2 circulation ← S-1

→ or Indirect cooling of IIa diamond crystal ← S-1

Direct cooling with fin crystal

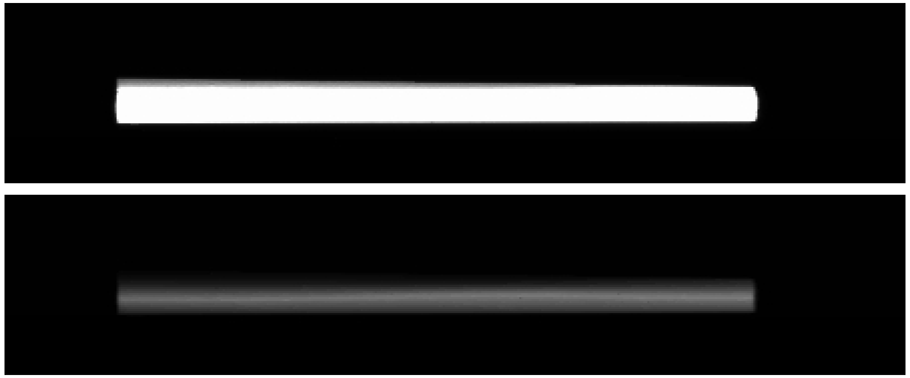






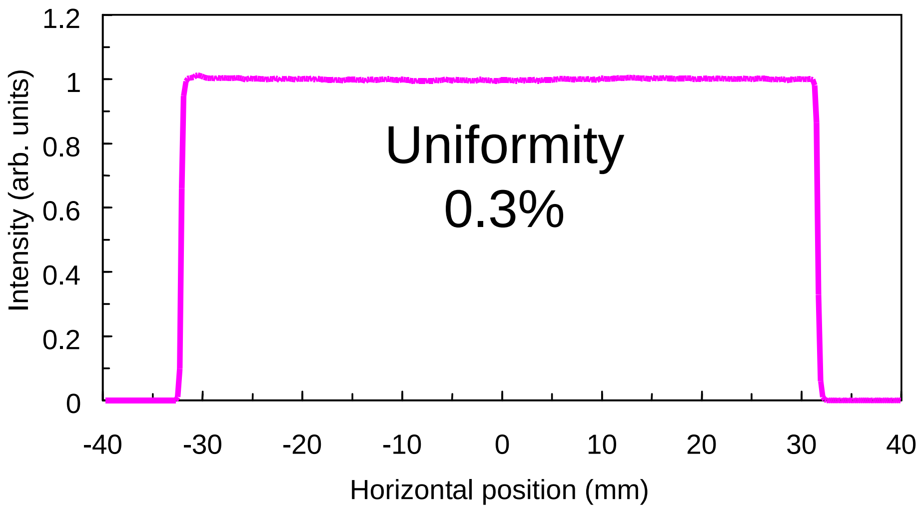
Applied to bending magnet beamline

Performance of fin crystal (1)



Si 111 refl.

Si 333 refl.



$h\nu$= 25 keV

Si 111 refl.

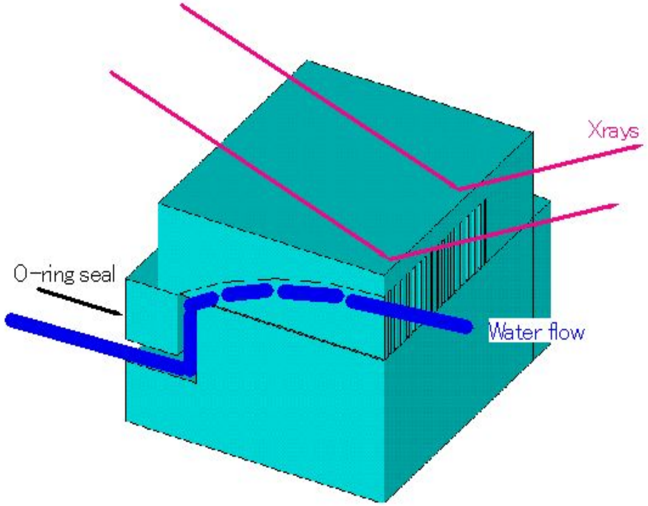
Ring current= 1 mA

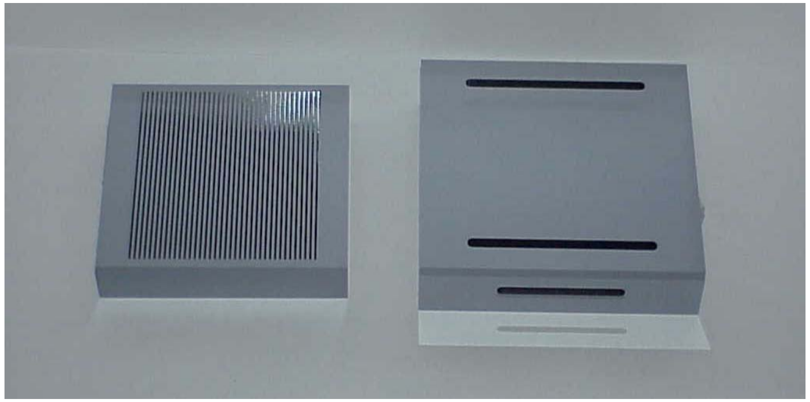
Mechanical deformation removed

Direct cooling with fin crystal

Improvement of fin-cooling crystal

Reduce radiation damage of rubber O-ring

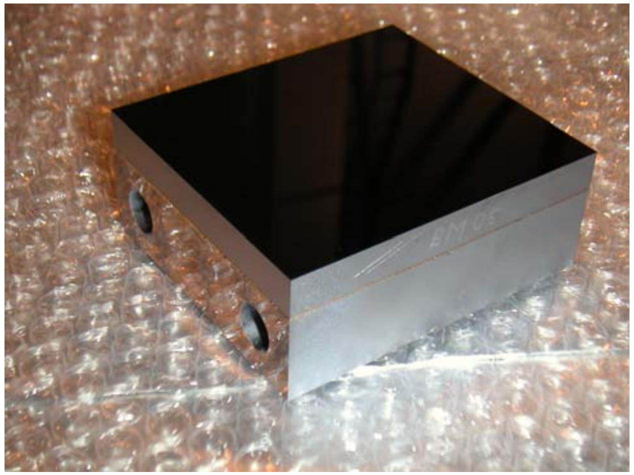


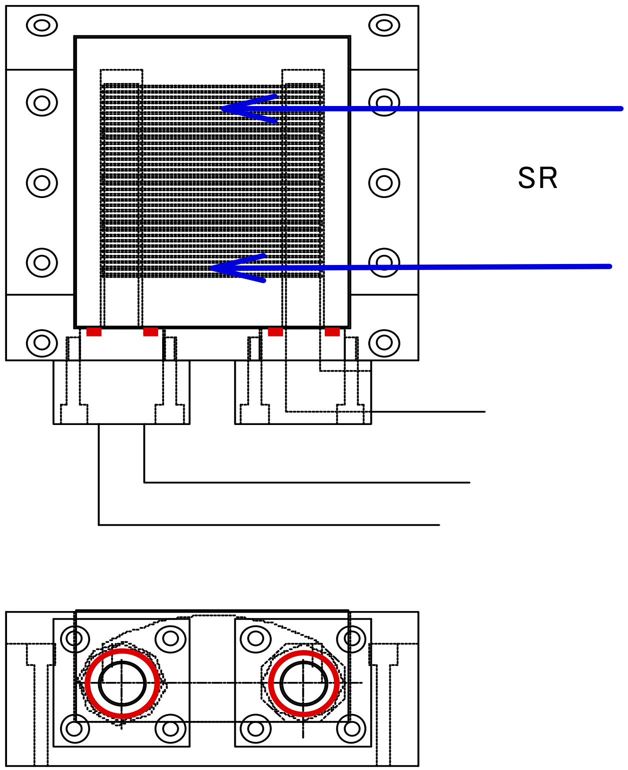


Au-Si eutectic bonding

Direct cooling with fin crystal

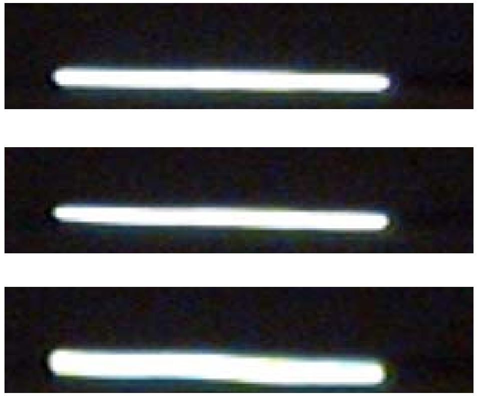
Reduce radiation damage of rubber O-ring





Performance of fin crystal (2)

X-ray image for Si 311 refl.



θ_B= 5°, E = 43.4 keV

θ_B= 10°, E = 21.8 keV

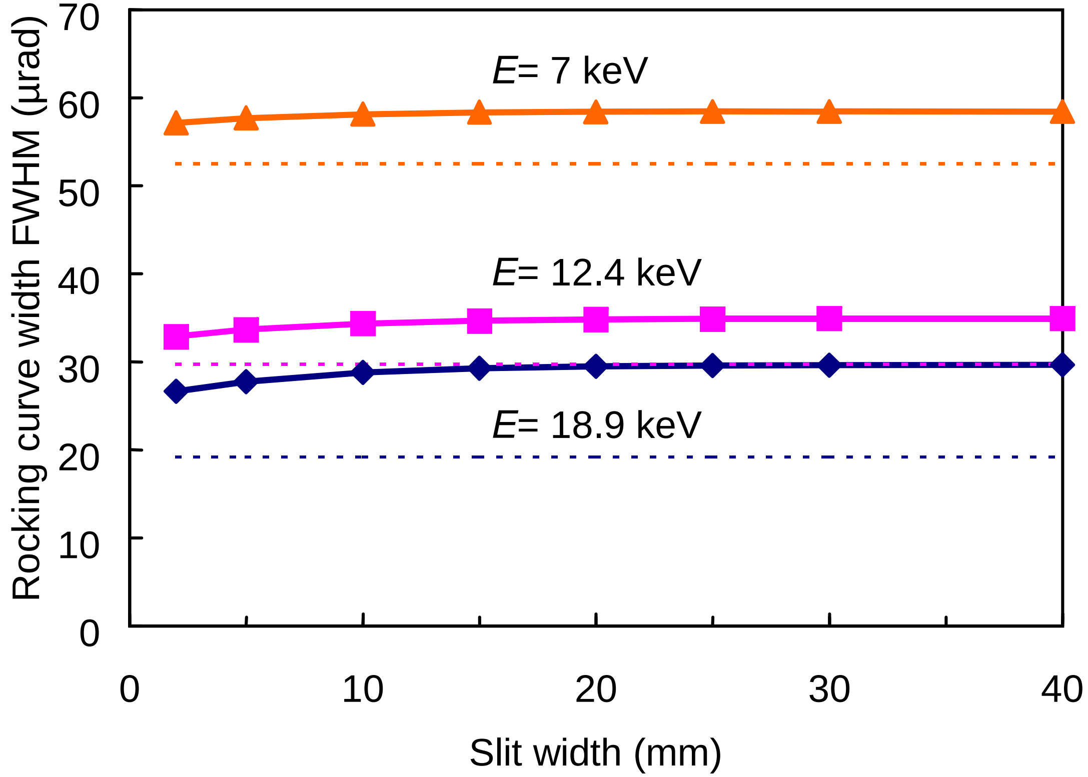
θ_B= 20°, E = 11.1 keV

Slit: 3 mm^V × 40 mm^H

Current status

- Practical use both (311) and (111) crystals
- 2～4 sec. twist due to fabrication process must be reduced.
- No heat strain for (111) crystal at 12 keV photon
- Radiation damage of O-ring is improved by side-inlet.
- Durability test is under way.

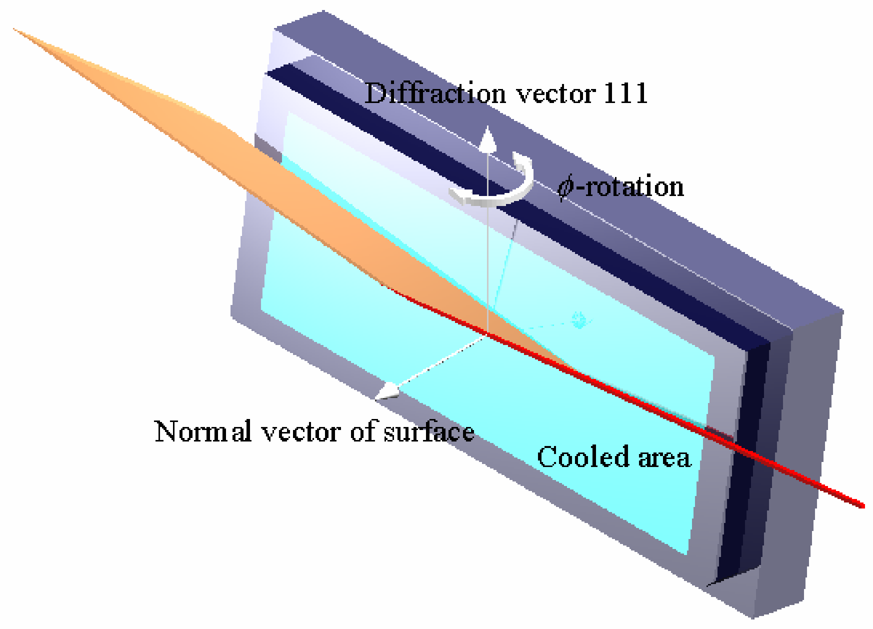
Performance of fin crystal (3)

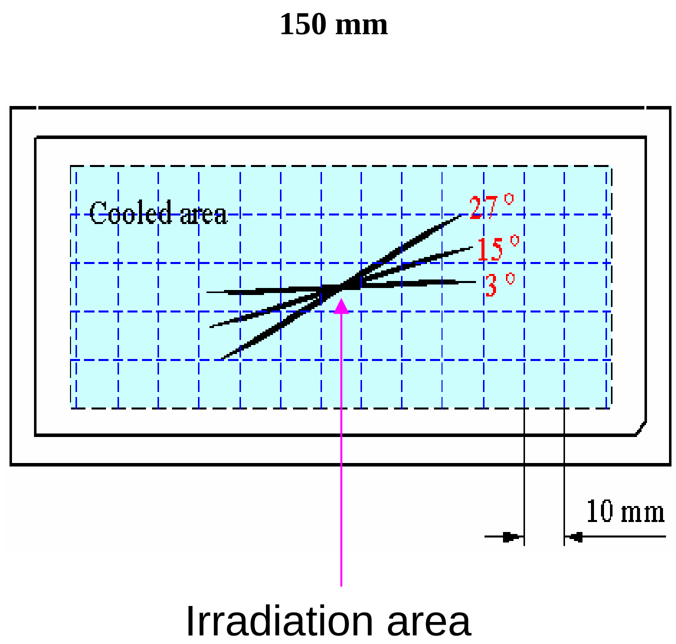


Si 111 refl.

Ring current= 100 mA

Direct cooling of silicon pin-post crystal + Rotated inclined geometry





Inclination angle β= 80°

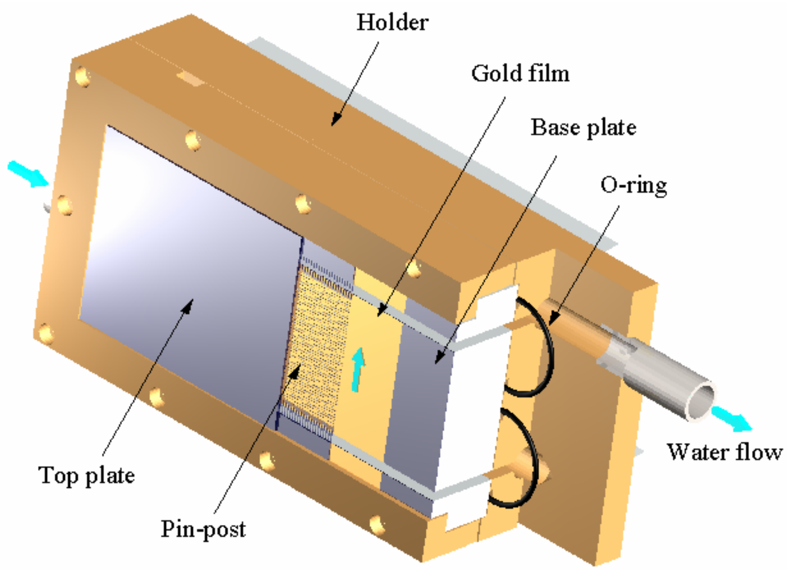
Grazing angle down to 1° using ϕ-rotation

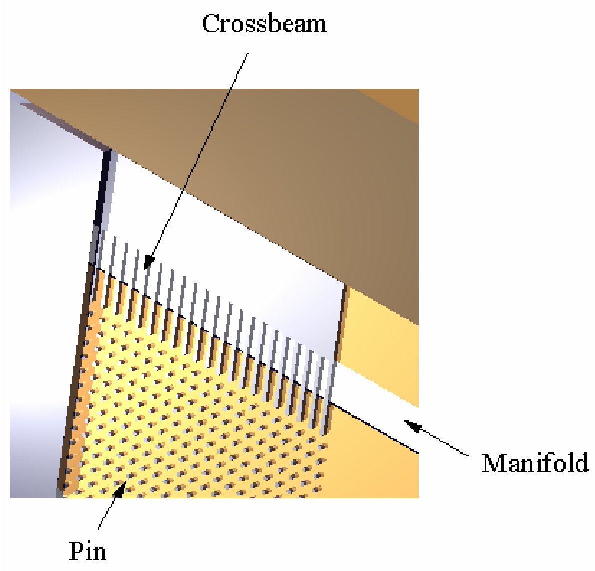
Irradiation area enlarged to x50, power density reduced to 1/50

Applied to undulator beamline

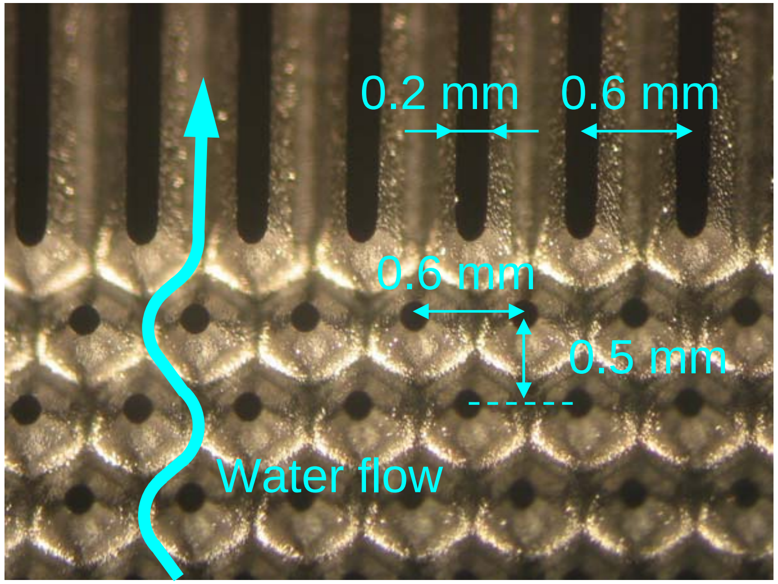
Structure of pin-post crystal

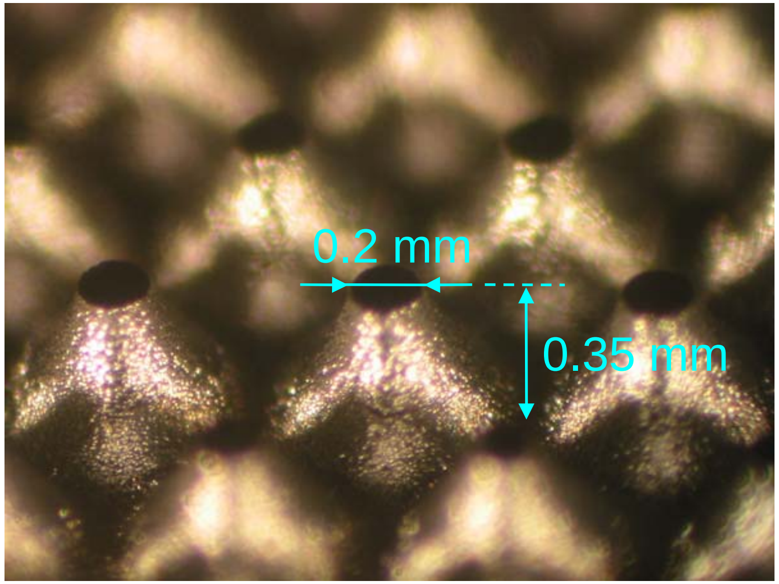
Top plate with pin-post is bonded to base plate (manifold) using Au-Si eutectic bonding.





Pin-post structure

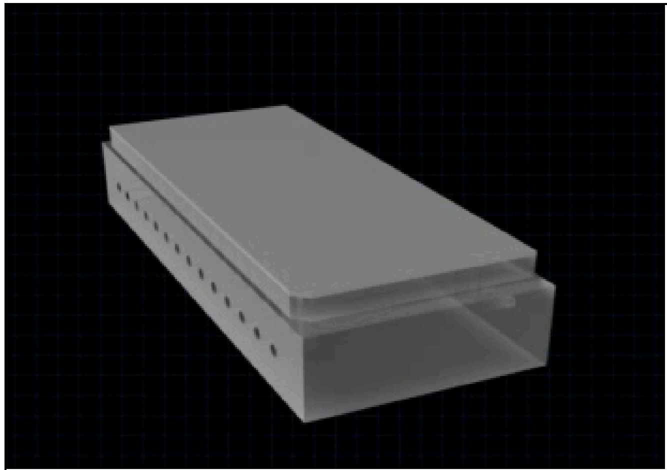




Fine pins are fabricated to increase cooling efficiency.

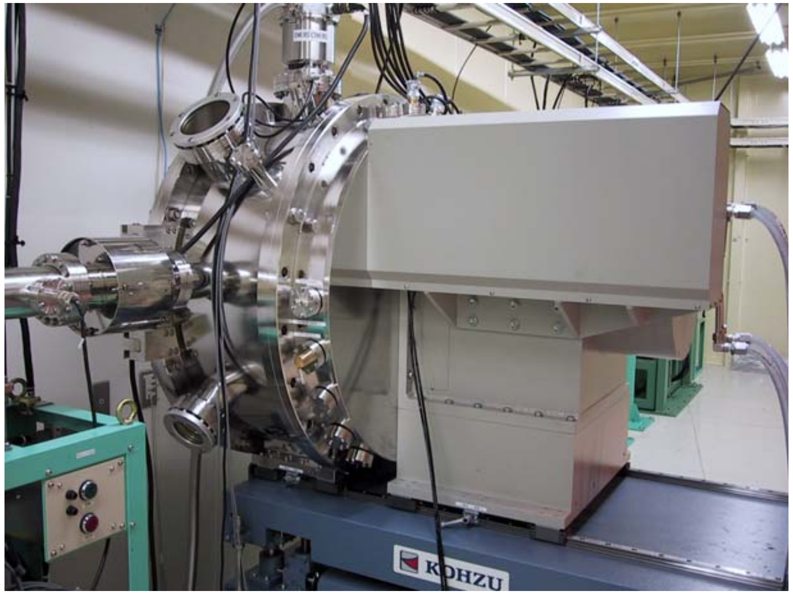
Limitation of sandblast

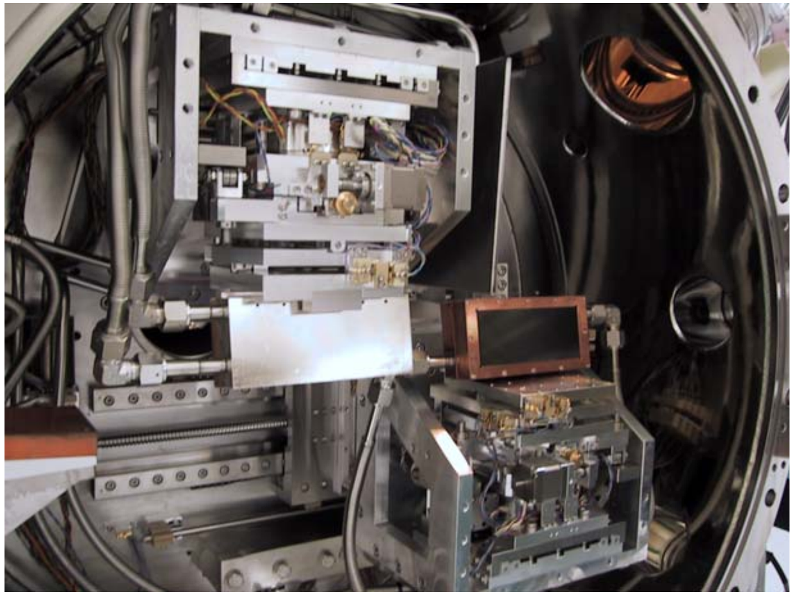
Water flow in the pin-post crystal



m30.mpg

DCM with pin-post crystal

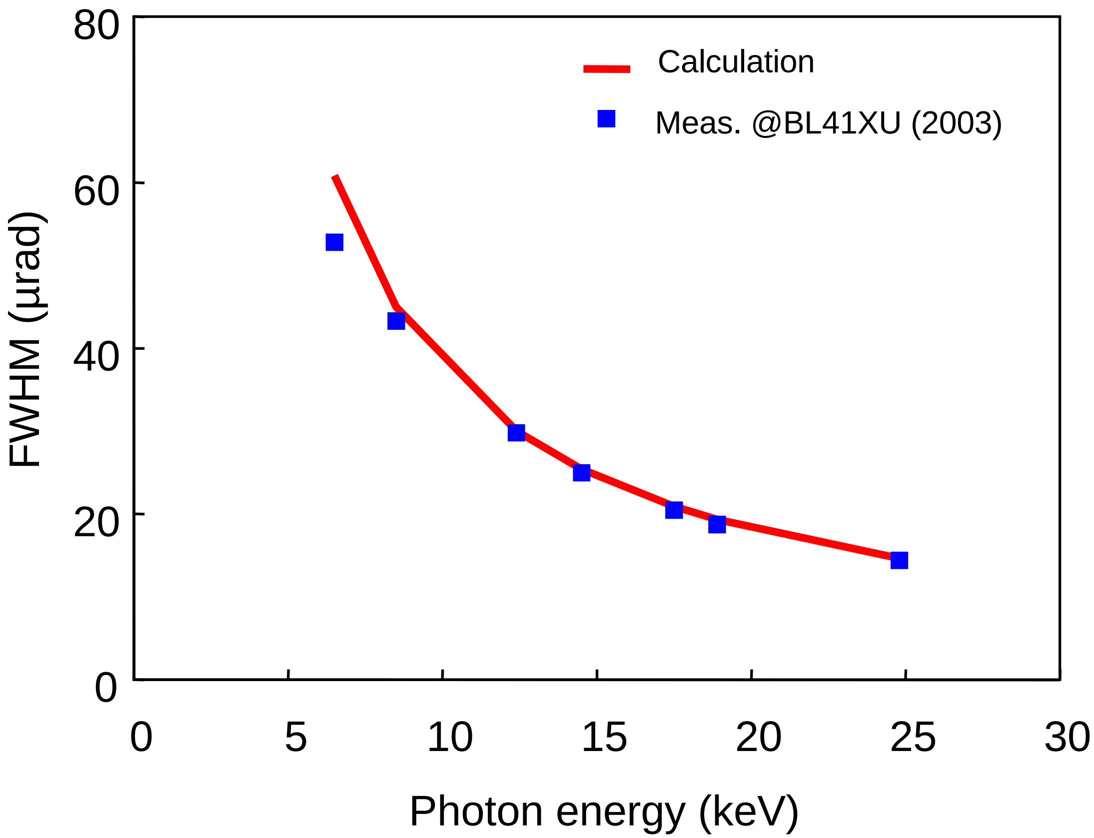




DCM view from upstream

Inside DCM: Stages + pin-post crystal

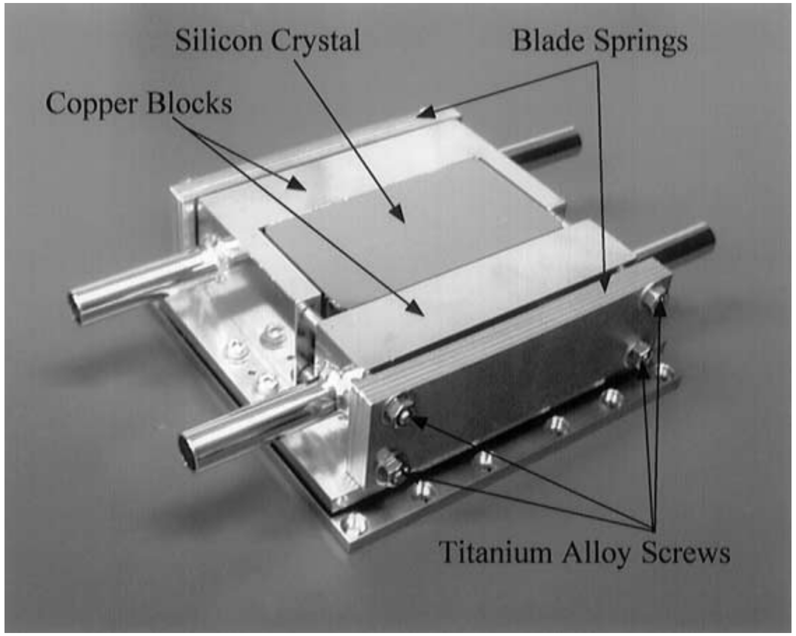
Performance of pin-post crystal



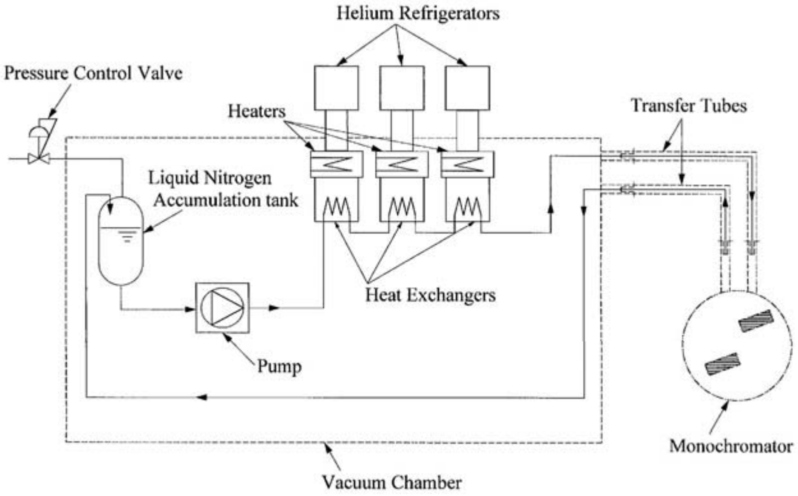
Rocking curve widths agree well.

Cryogenic cooling

Indirect side cooling



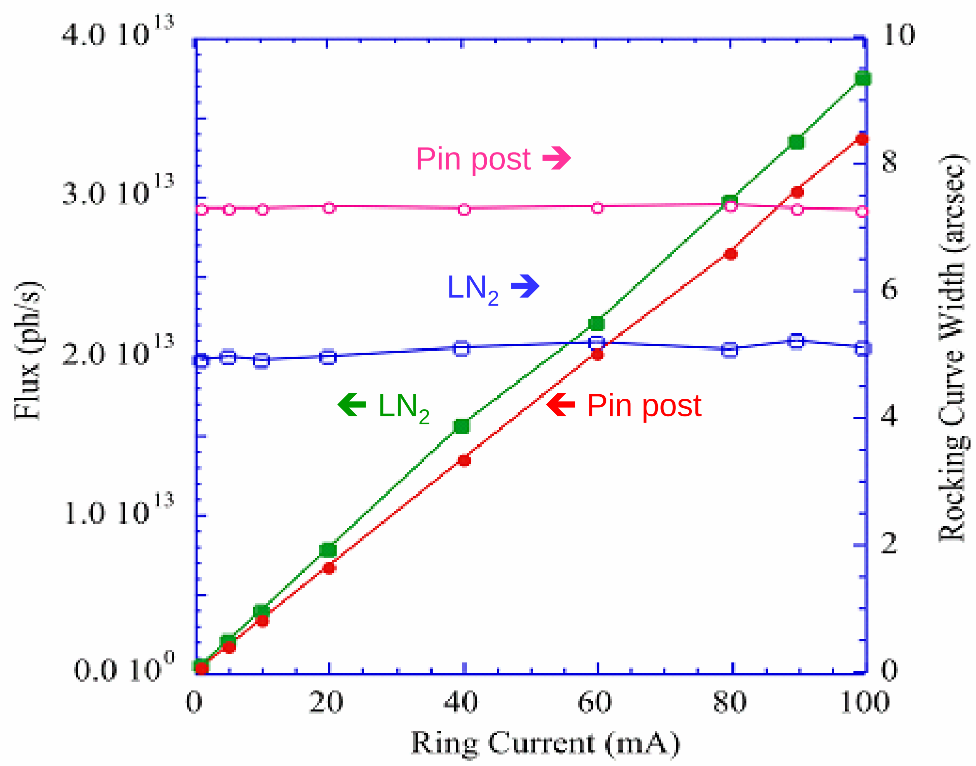
LN_2 circulator with He refrigerator



Applied to undulator beamline

Performance of pin-post cooling and cryogenic cooling

Heat load test (June 2000) up to 500 W, 500 W/mm^2



IIa diamond indirect cooling

Merit:

- Good thermal properties → Capability of indirect cooling
- Higher resolution (←→ Less throughput (30～40% of Si))

Issues:

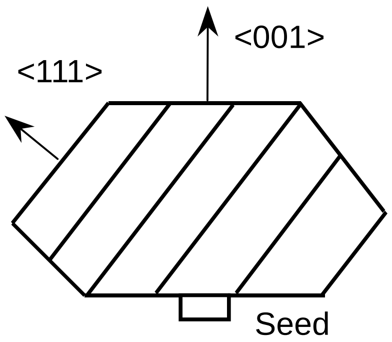
- Perfection of crystal → HPHT IIa diamond (Sumitomo)…

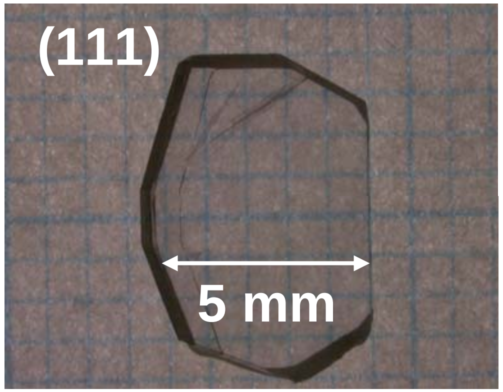
  Successive upgrade is crucial !
- Holding of crystal → X-ray topograph, Zygo
- Optimization of thermal contact → New process with In insert
- Small crystal (< 10 mm□)
- Alignment: using CCD camera, PIN photodiode, thermocouple

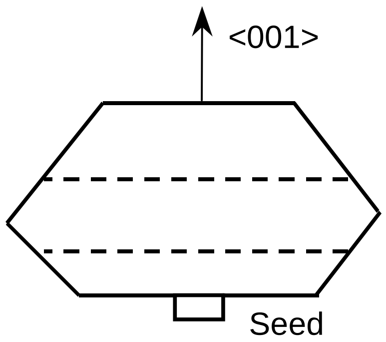
IIa diamond crystal

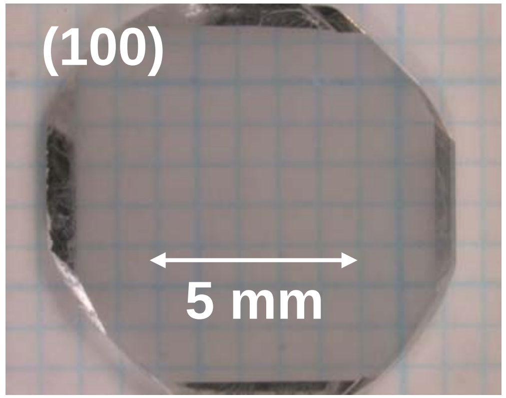
Nearly perfect crystal using High Pressure High Temperature (HPHT) synthesis is available in <001> growth direction.

To maximize the photon flux, 111 refl. in Bragg case is used.
Effective size of Diamond (111) is, however, small !







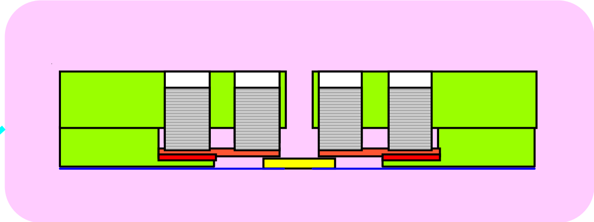


Crystal handling is crucial:
→ Mounting without strain
→ Alignment

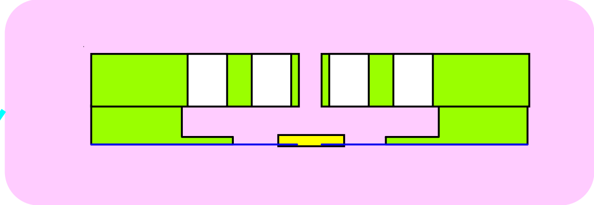
Crystal mounting

Thermal mounting method

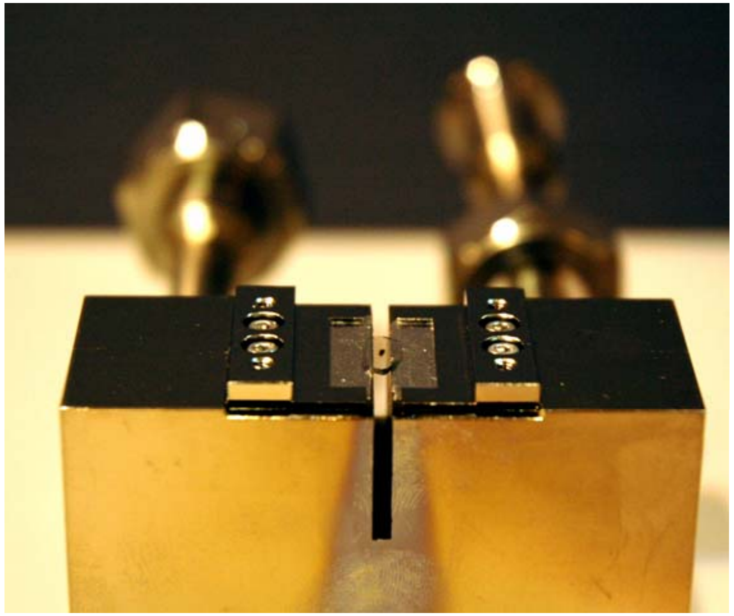
Mechanical mounting with
SS plates and screws



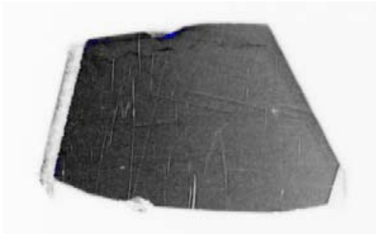
Release the screws

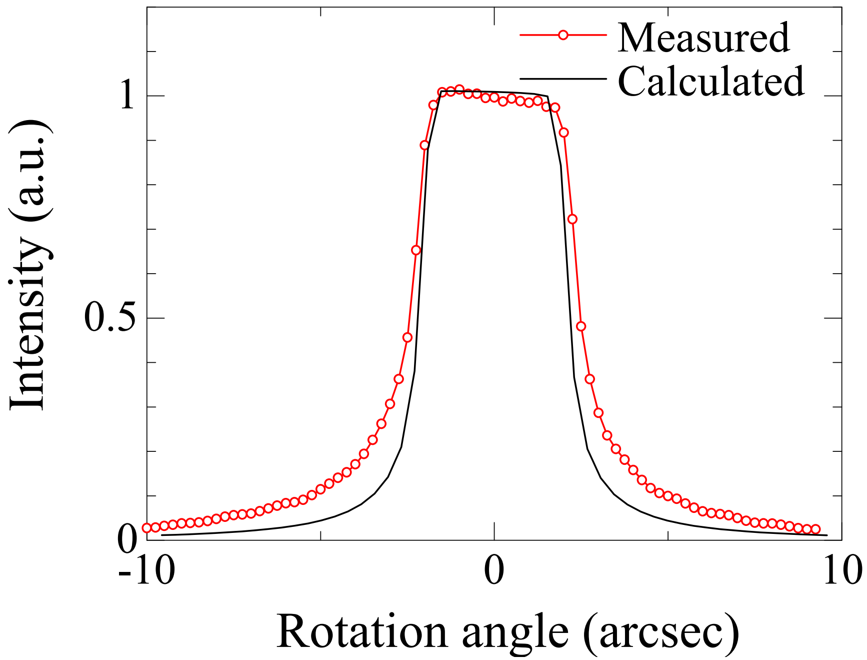


Temperature increase to ~ 130 °C
Keep 30 min
Decrease to room temperature

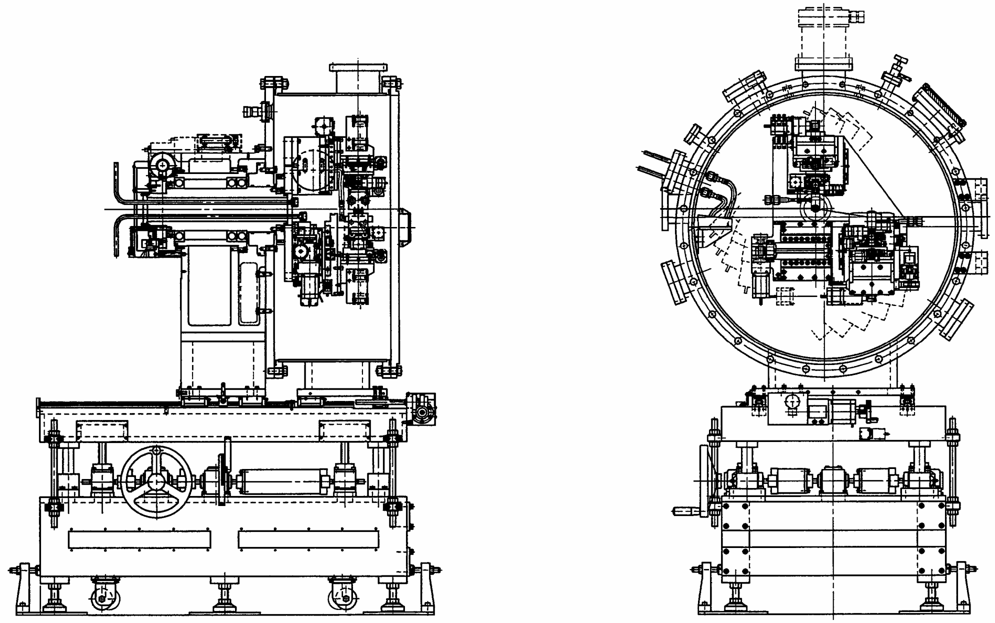


Topograph and rocking curve





Diamond monochromator (SPring-8 BL39XU)

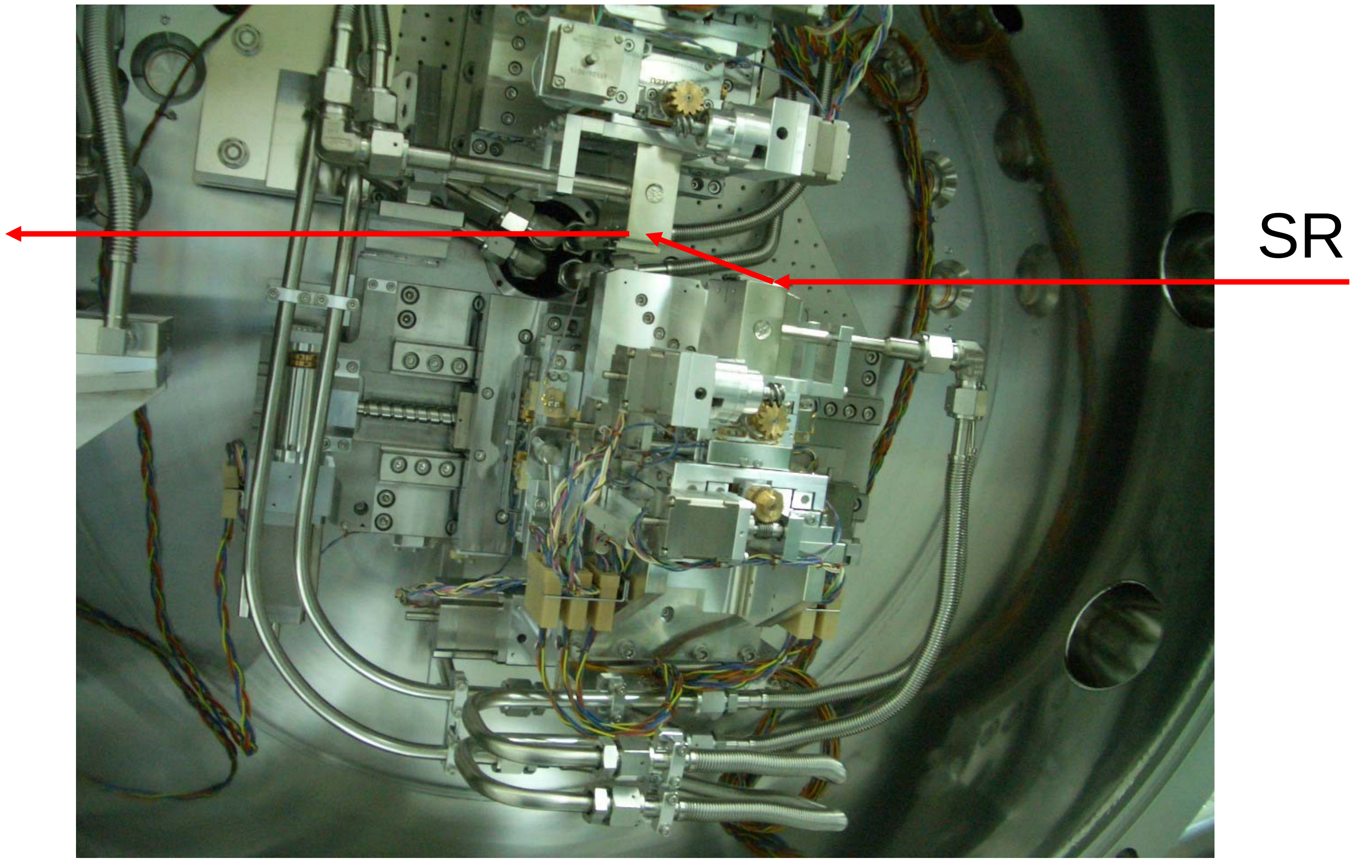


→ Bragg angles: 4.5～45°

(Photon-energy compatible with silicon)

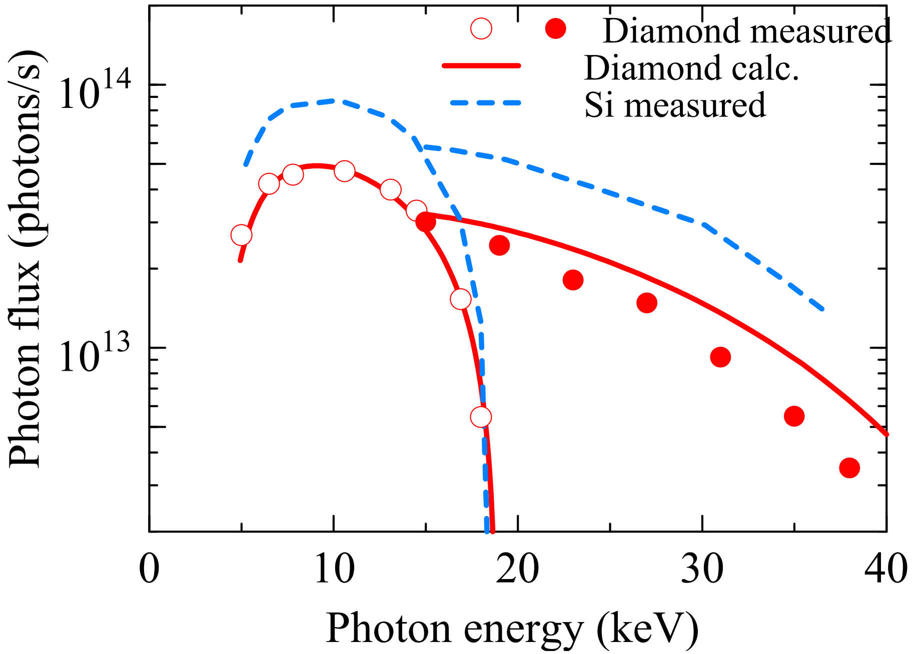
→ θ-*y*-*z* computer link

Diamond monochromator (SPring-8 BL39XU)

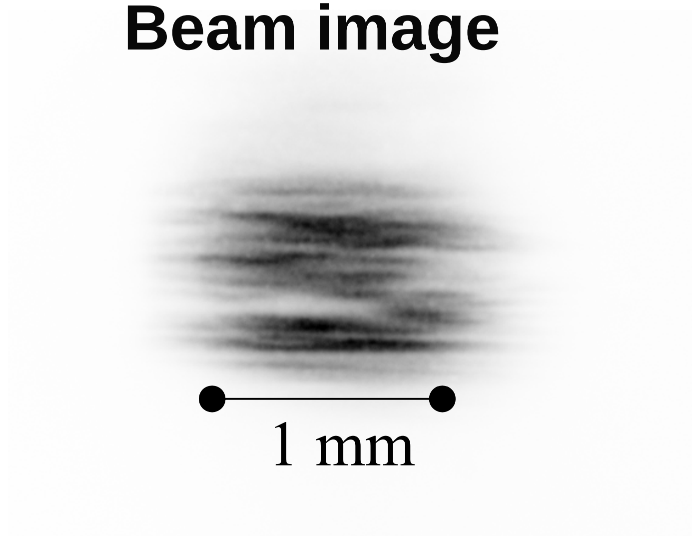


Characterization of diamond monochromator

Photon flux



Beam image



ε = 3 nm. rad, I_b = 100 mA
Front-end slit aperture = 0.7 (v) x 1.0 (h) mm^2

Low energy: 50~60% of Si DCM
High energy: Infinite size effect ?

Improvement of crystal growth and surface finish is needed.

Efficiency with monochromator

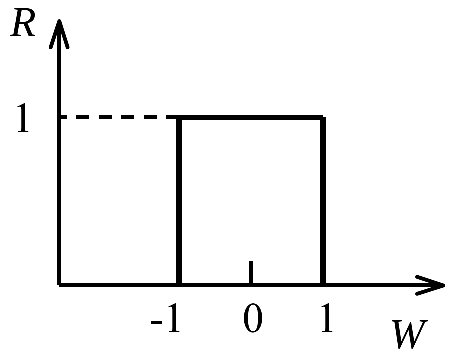
- Photon flux estimation -

Effective band width (Integrated intensity)

Simple understanding

For top-hat shape, no absorption,

sigma polarization, symmetric Bragg case



$$\left(\frac{\Delta E}{E}\right)_{\mathrm{Eff}} = \frac{2|\chi_{hr}|}{\sin 2\theta_{\mathrm{BK}}}\cot\theta_{\mathrm{BK}}$$

$$= \frac{|\chi_{hr}|}{2\sin^2\theta_{\mathrm{BK}}}\times 2$$

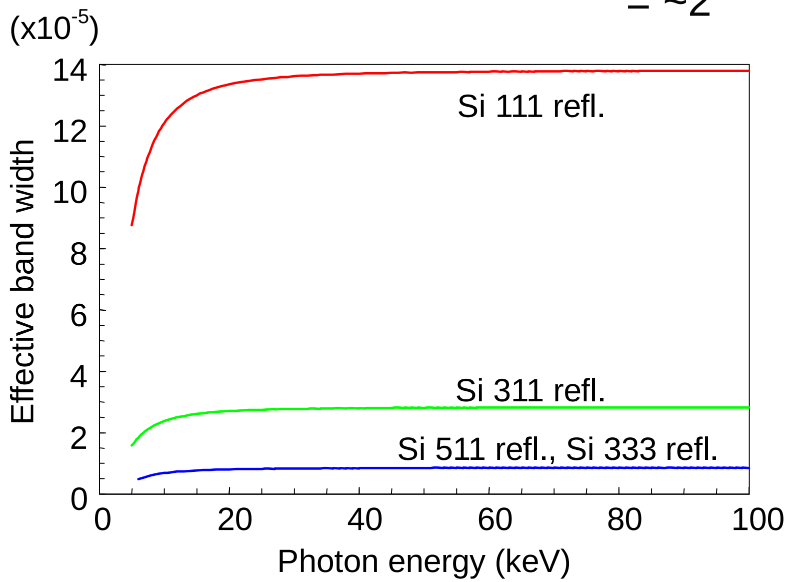
↑

= Energy resolution derived from Darwin width

For double crystal monochromator

$$\left(\frac{\Delta E}{E}\right)_{\mathrm{Eff}} = \frac{|\chi_{hr}|}{2\sin^2\theta_{\mathrm{BK}}}\underline{\int R(W)^2\,dW}$$

= ~2



Effective band-width is obtained by integration of rocking courve.

When you need flux → Si 111 refl.

When you need resolution → Si 311, Si 511 refl,..

Photon flux after monochromator

Photon flux (throughput) after monochromator can be estimated by effective band width.

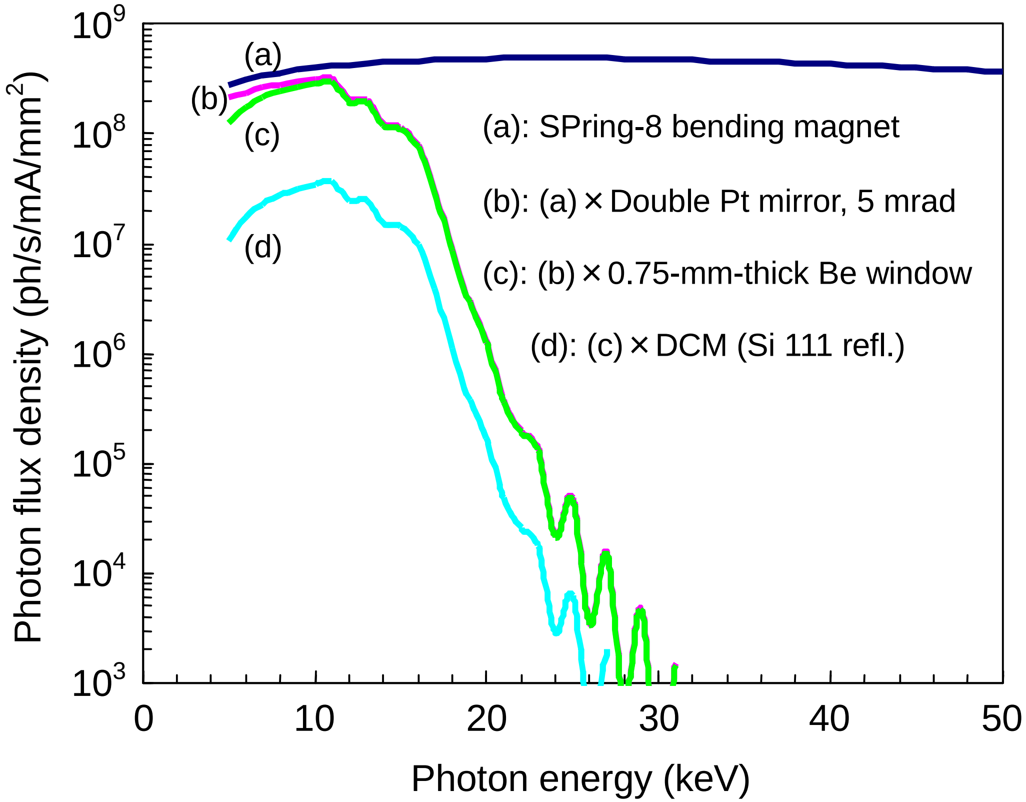
Photon flux (ph/s) =

Photon flux from light source (ph/s/0.1%bw)

x 1000

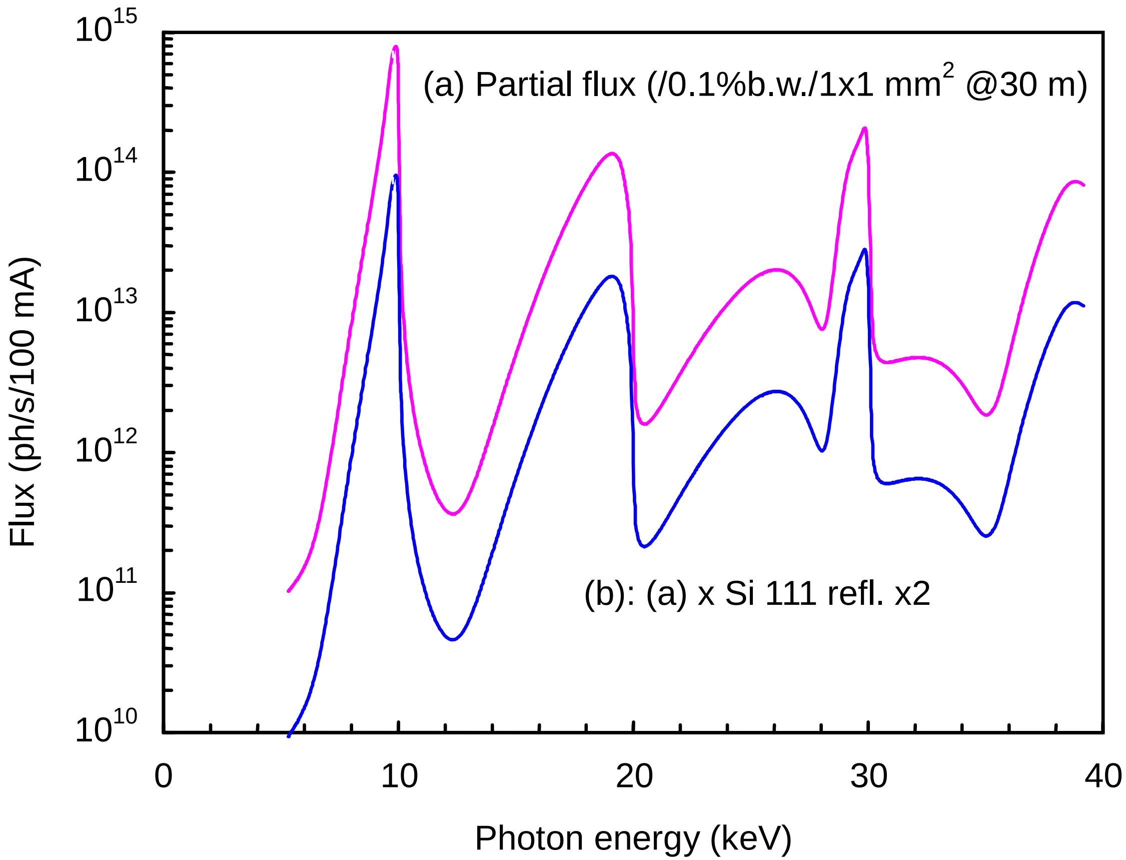
x Effective band width of monochromator

Photon flux at bending magnet beamline



Example of photon flux estimation at bending magnet beamline BL02B1. (Photon flux density at 50 m from the source)

Photon flux at undulator beamline



We can obtain photon flux of 10^{13}～10^{14} ph/s/100 mA/mm^2 using standard undulator sources and Si 111 reflections at SPring-8 beamlines.

Other topics

Higher harmonics rejection

For higher harmonics rejection

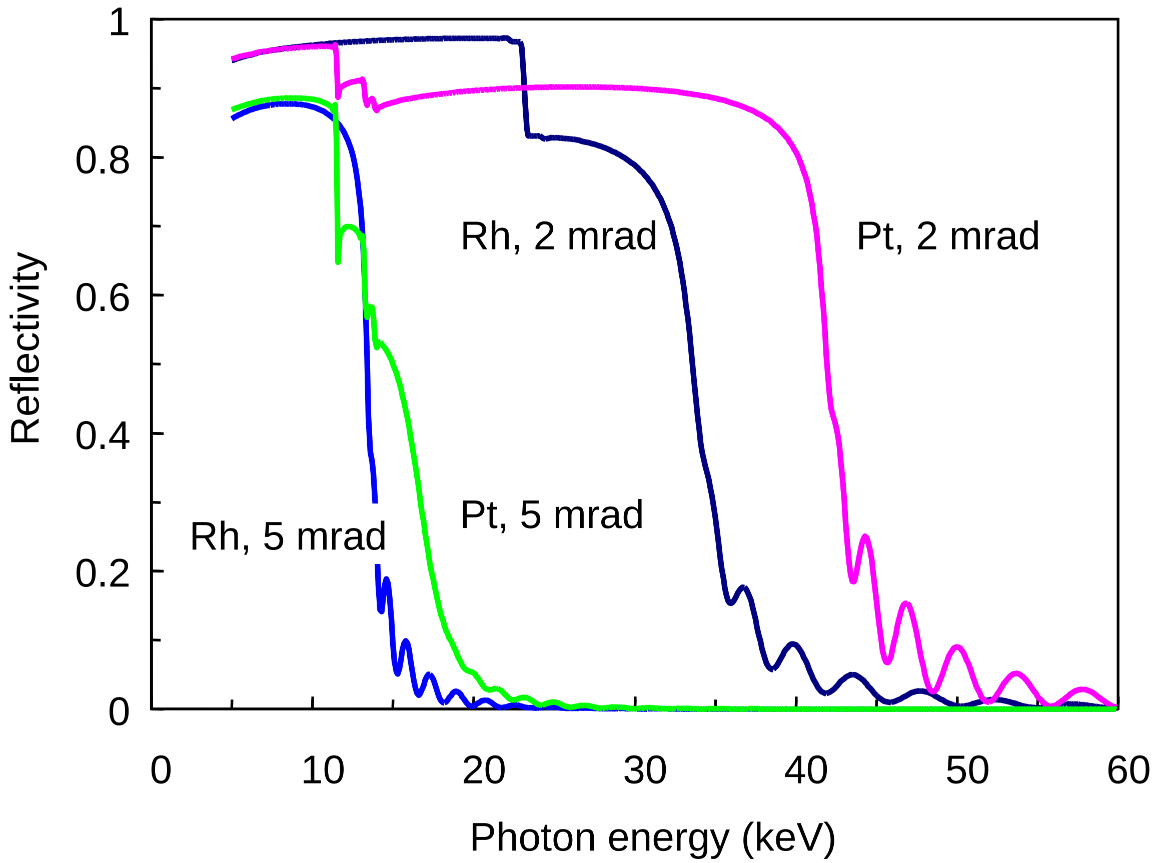
→ **Total reflection mirror**

→ **Detuning of DCM**

Total reflection mirror

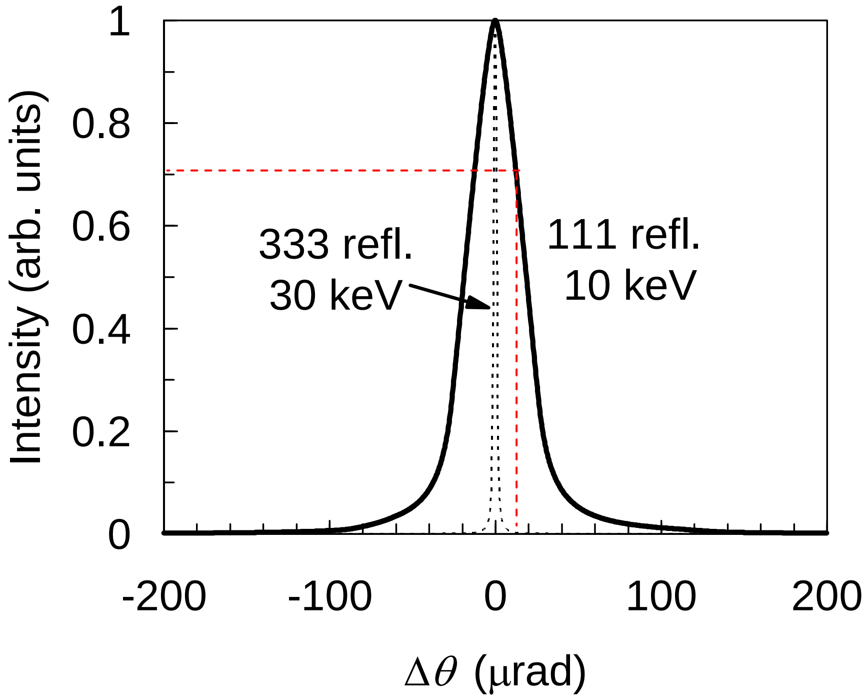
- **Substrate material**
  - Si for white radiation
  - SiO_2 for monochromatic beam
- **Coating material**
  - Pt, Rh, Ni,...
  - Depending on energy, reflectivity, absorption edges,..
- **Glancing angle**
  - 2～10 mrad (For SPring-8 X-ray beamline)
  - Depending on energy, reflectivity, absorption edges,..
- **Mirror length**
  - 400 mm～1 m (For SPring-8 X-ray beamline)
  - Depending on the beam size and glancing angle
  - e.g. 100 μrad × 50 m/5 mrad= 1 m

Example of mirror reflectivity



Film thickness: 50 nm
Surface roughness: 1 nm

Detuning of DCM



e.g. $\Delta\theta = 12$ μrad

→ 70% of peak intensity for fundamental (111 refl. @ 10 keV)

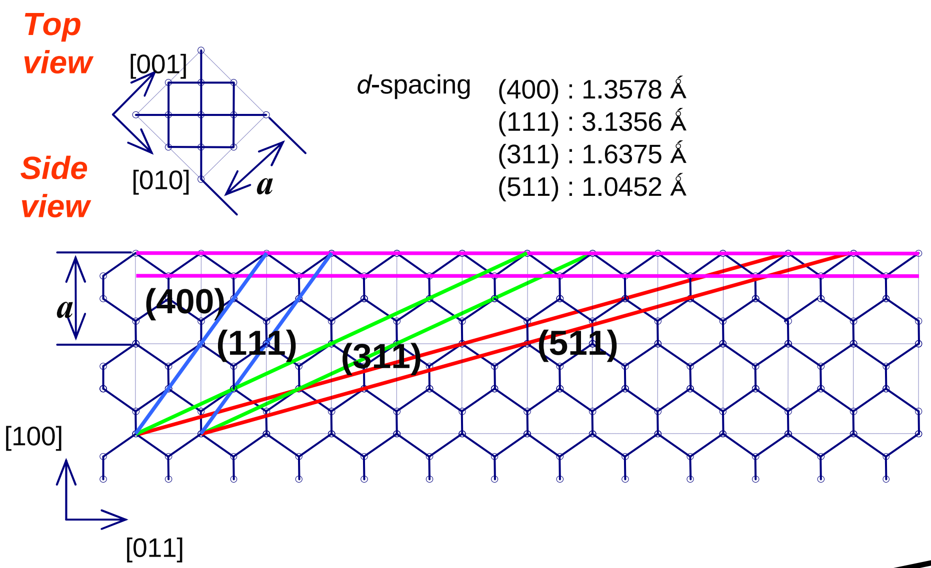
→ 0.3% of peak for 3rd harmonics (333 refl. @30 keV)

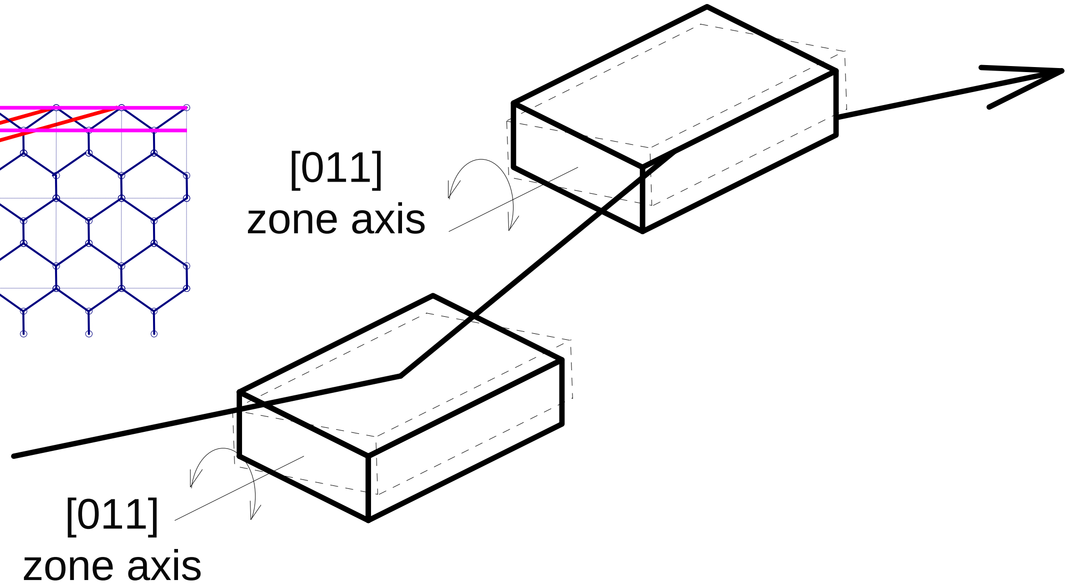
e.g. $\Delta\theta_2 = 10$ μrad → Angle change of exit beam = $2\Delta\theta_2 = 20$ μrad

Beam position change of 0.2 mm @10 m from DCM.

We should understand the beam position change by DCM detuning!

Adjustable inclined geometry



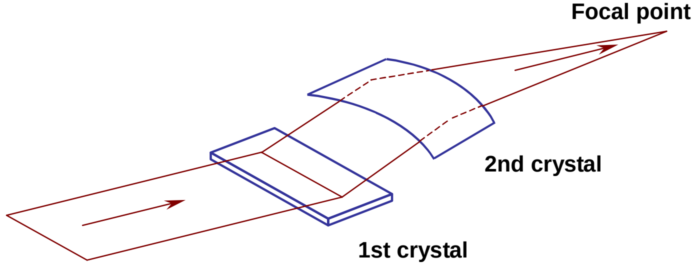


We change the lattice plane by tilting the 1st and 2nd crystals simultaneously,

and we can select 111 refl., 311 refl., 511 refl,…

Sagittal focusing

Principle of sagittal focusing



$$r = \frac{2pq}{p+q}\sin\theta$$

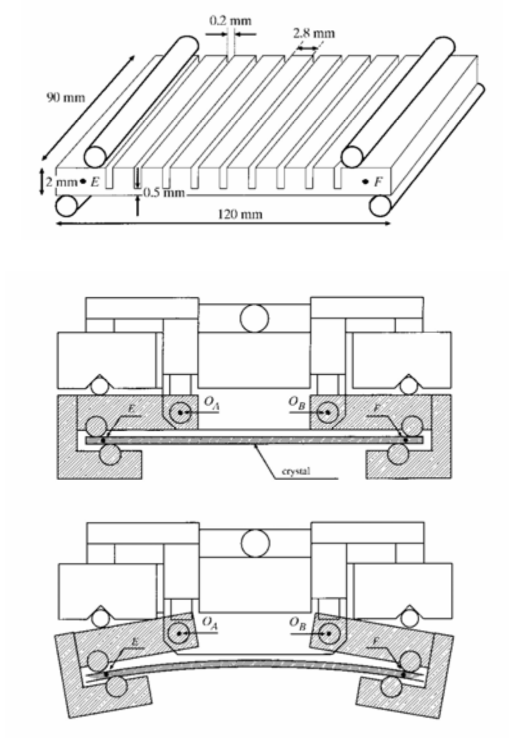
r: radius of 2nd crystal

θ: Bragg angle

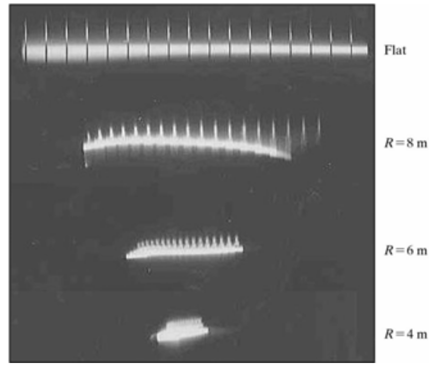
p: source ~ crystal distance

q: crystal ~ focal point distance

Bending mechanism for SPring-8 sagittal focusing



e.g. Sagittal focusing images



Si 311 refl.

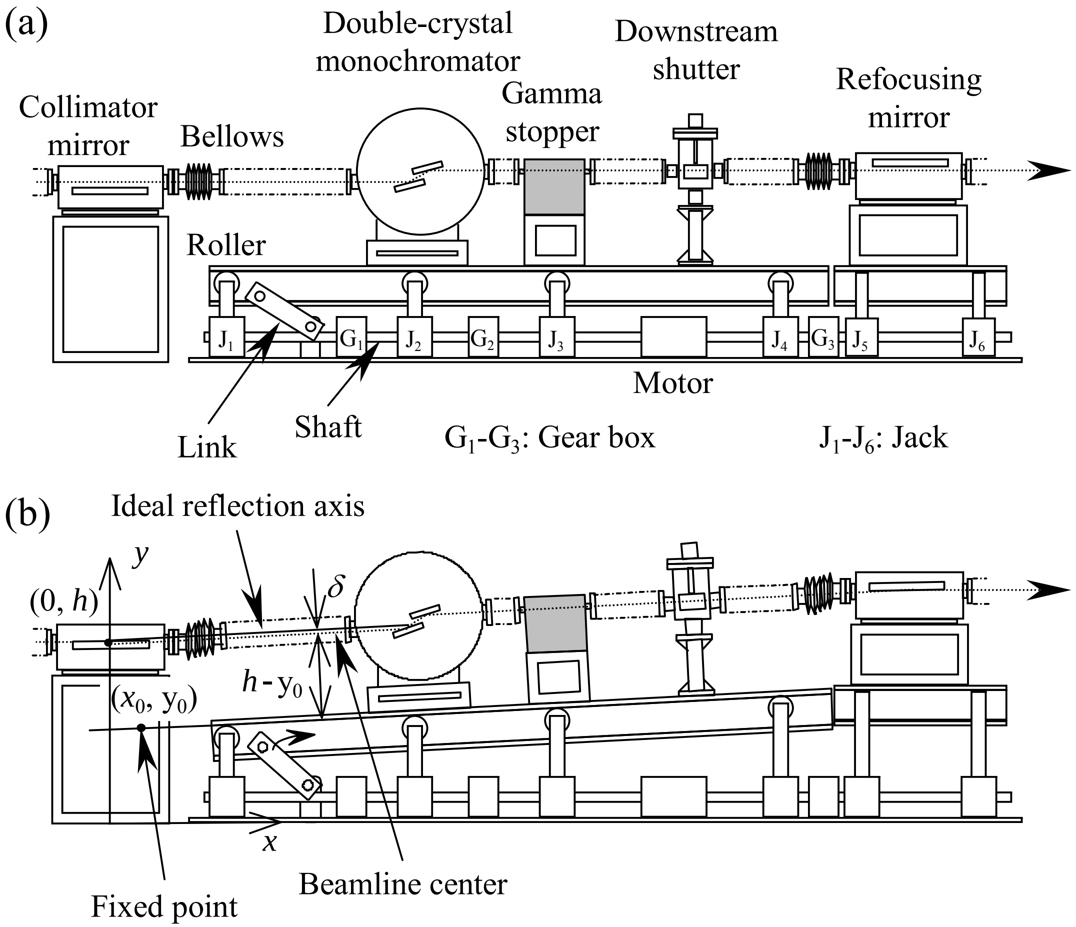
40 keV

Source～Crystal= 36.5 m

Crystal～focal point= 16.5 m

Applied for bending magnet beamline

Inclination stage and elevation stage for bending magnet beamlines



→ For higher energy resolution using collimator mirror

→ For higher photon flux using focusing mirrors

→ For higher harmonics rejection

Other issues (1)

- **Compton scattering shielding**

  Cooling for 2nd crystal, stages, and others

- **Vibration control**

  Rigidity of stages → less number of stages

  Coolant circulation, flexible tube,…

- **Radiation damages**

  Degradation of rubber O-ring

  Charge-up and damage to the control system

Other issues (2)

- **Surface contamination**

  Vacuum quality → UHV monochromator

  Recovering using ozone cleaning

- **Heat transfer analysis, simulation, fundamental data acquisition**

  Thermal conductivity measurement

  as material, surface roughness, pressure, temperature,…

Issues in the future

→ For more stable operation of monochromator

Vibration control (→ sub-microns, sub-μrad)

Prevention of degradation due to radiation damage

→ For better fabrication of crystal,

lower strain under high-heat-load condition

→ For higher power and power density

→ For wider energy range (→ lower, → higher)

→ For higher energy resolution

→ For 4GLS monochromator

Thank you for your attention