X-ray Beamline Design

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SPRING-8/JASRI
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3. Monochromator
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5. Others
   Phase retarder
   Spatial coherence
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Process of beamline construction

Beamline design is first step and crucial for success of the beamline!

- Fundamental of X-ray beamline: light source, monochromator, mirror,...
Beamline structure

Beamline = “Bridge” between light source & experimental station

- **Light source**
  - Bending magnet
  - Insertion device

- **Front-end**

- **Experimental station**

- **Shielding hutch**

- **Ring tunnel**

- **Exp. hall**

- **Optics & transport**
  - Monochromator, mirror
  - Shutter, slit
  - Pump,...php

→ **Transport and processing of photons**
  - photon energy, energy resolution,
  - beam size, beam divergence, polarization,..

→ **Vacuum**
  - protection of ring vacuum and beamline vacuum

→ **Radiation safety**
  - Shielding and interlock
Light sources & X-ray optics

Check points to be considered for your application:

- White or monochromatic
- Energy range
- Energy resolution
- Flux & flux density
- Beam size at sample (micro beam, ...)
- Beam divergence/convergence at sample (Resolution in k-space)
- Higher order elimination w/ mirror
- Polarization conversion
- Spatial coherency

→ Light source, monochromator, mirror, and other optical devices and components
BL classification (energy region)

Photon energy (eV) →

IR Visible ~ UV~ SX HX

10^0 10^1 10^2 10^3 10^4 10^5

Bending magnet

Inelastic

SAXS

Earth,.. HP/HT

XAFS

Powder XRD

PX

Wiggler

Inelastic

SAXS

PEEM

HX-PES

Inelastic

HP/HT XRD

Undulator

NRS

SX-PES

SX-MCD
BL classification (energy resolution)

Energy resolution ($\Delta E/E$) →

- **Bending magnet**
  - 10^{-7}
  - 10^{-5}
  - 10^{-3}
  - White
  - XAFS
  - SAXS
  - Single crystal XRD
  - PX
  - Powder XRD
  - Imaging
  - Topograph
  - Earth,.. HP/HT

- **Wiggler**
  - Inelastic

- **Undulator**
  - Inelastic
  - XAFS
  - XMCD
  - HX-PES
  - PX
  - Surface · interface
  - Microbeam, imaging
  - XRF
  - HP/HT XRD
  - Powder XRD

**Energy resolution ($\Delta E/E$)**
Light sources

Bending magnet or insertion devices?

Bending magnet:
- for wide energy range, continuous spectrum
- for wide beam application for large samples

Undulator (major part of 3GLS beamline):
- for high-brilliance beam
- for micro-/ nano-focusing beam

Wiggler:
- for higher energy X-rays > 100 keV.
  - short-period-length undulator

Power, brilliance, flux density, partial flux,.. can be calculated using code.

- e.g. “SPECTRA” by T. Tanaka & H. Kitamura

Brilliance for SPring-8 case
Light sources

Angular divergence and band width

- Bending magnet

\[ \sigma_r \approx 0.597 \frac{1}{\gamma} \sqrt{\frac{\lambda}{\lambda_c}} \]

- Undulator

\[ \sigma_r \approx \sqrt{\frac{\lambda_n}{2N\lambda_u}} = \frac{1}{2\gamma} \sqrt{\frac{1+K^2/2}{nN}} \]

\[ \frac{\Delta E}{E} \approx \frac{1}{nN} \]

SPring-8 in-vacuum undulator
Monochromator

Key issues from experimental request:

White or monochromatic? → monochromatic

Energy region ← Bragg’s law

Energy resolution ← Source divergence, Darwin width,..

Throughput ← related to energy resolution

Double-crystal monochromator for fixed-exit

Single-bounce monochromator is for limited case

Heat load ← depending on light source
X-ray monochromator using perfect crystal

→ Principle of monochromator

Bragg reflection from perfect single crystal

\[ 2d \sin \theta_B = n \lambda \]

\( d \): Lattice \((d)\)-spacing,
\( \theta_B \): Glancing angle (Bragg angle),
\( \lambda \): X-ray wavelength

→ Crystal: silicon, diamond, ...

e.g. for SPring-8 standard DCM

Bragg angle: 3~27°

Photon energy range:
- Crystal & lattice plane
- Bragg angle range
Reflectivity (intrinsic rocking curve)

Darwin curve (intrinsic rocking curve for monochromatic plane wave) for Bragg case, no absorption, and thick crystal:

\[
R = \left( \frac{\gamma_h}{\gamma_0} \right) \left( \frac{E_h}{E_0} \right)^2 = \left( W + \sqrt{W^2 - 1} \right)^2 \quad (W < -1)
\]

\[
R = 1 \quad (-1 \leq W \leq 1) \quad \leftarrow \text{Total reflection region}
\]

\[
R = \left( W - \sqrt{W^2 - 1} \right)^2 \quad (W > 1)
\]

For symmetric Bragg case, sigma polarization:

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

Darwin width \( \Delta W = 2 \)

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

Crucial for energy resolution and throughput!
Intrinsic rocking curve for silicon

For Bragg case, with absorption, and thick crystal:

- Darwin width of 0.1~100 µrad
- Peak ~1 with small absorption
Source divergence and diffraction width

Divergence of undulator radiation \(\sim\) diffraction width

Natural divergence
- Bending magnet
  \[ \sigma_r \approx 0.597 \frac{1}{\gamma} \sqrt{\frac{\lambda}{\lambda_c}} \propto \sqrt{\frac{1}{\hbar \omega}} \]
- Undulator
  \[ \sigma_r \approx \sqrt{\frac{\lambda}{2N\lambda_u}} \propto \sqrt{\frac{1}{\hbar \omega}} \]

For SPring-8 case:
- Bending magnet
  \[ \sigma_r \approx 60 \mu\text{rad} \]
- Undulator \((N=140)\)
  \[ \sigma_r \approx 5 \mu\text{rad} \]

Divergence of undulator radiation \(\sim\) diffraction width
Energy resolution

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

\( \Omega \): source divergence, 
\( \omega \): diffraction width

For usual beamline: \( \Delta E/E = 10^{-5} \sim 10^{-3} \)
DuMond diagram: undulator ~ DCM

SPring-8 standard undulator
($\lambda u = 32$ mm, $N = 140$, $K = 1.34$, $E_{1st} = 10$ keV)
+ DCM (Si 111 refl.)

Intensity distribution of undulator

Acceptance by crystal

Wider slit increases unused photons (power) on the monochromator!
Improvement of energy resolution

(A) Collimation using slit

(B) Collimation using pre-optics w/ collimation mirror, CRL,..

(C) Additional crystal w/ (+,+) setting

(D) HR monochromator of $\pi/2$ reflection (~meV)

(B)~(D): restriction on photon energy
Photon flux after monochromator

Photon flux (throughput) after monochromator can be estimated using effective band width:

\[
\text{Photon flux (ph/s)} = \text{Photon flux from light source (ph/s/0.1\%bw)} \times 1000 \times \text{Effective band width of monochromator}
\]

Throughput is estimated by overlapped area.

Note difference from energy resolution.
Starting with Darwin width and neglecting anomalous scattering factor $f'$

\[ \chi_{hr} \propto \lambda^2 f_0(d_{hkl}) \]

\[ \frac{\Delta \lambda}{\lambda} = \omega \cot \theta_B = \frac{2 |\chi_{hr}|}{\sin 2 \theta_B} \cot \theta_B \]

\[ \frac{\Delta \lambda}{\lambda} = \frac{|\chi_{hr}|}{\sin^2 \theta_B} = 4d_{hkl}^2 \frac{|\chi_{hr}|}{\lambda^2} \]

Energy width:

\[ \frac{\Delta E}{E} = -\frac{\Delta \lambda}{\lambda} \propto d_{hkl}^2 f_0(d_{hkl}) \]

Independent of photon energy

Note relative energy width is constant.
Effective band width (Integrated intensity)

For double-crystal monochromator

\[
\left( \frac{\Delta E}{E} \right)_{\text{Eff}} = \frac{|\chi_{hr}|}{2 \sin^2 \theta_{BK}} \int R(W)^2 dW
\]

= \sim 2

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

When you need flux → Lower order (Si 111 refl.,..)
When you need resolution → Higher order (Si 311, Si 511 refl.,..)
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 $10^{13} \sim 10^{14}$ ph/s/100 mA/mm$^2$ using standard undulator sources and Si 111 reflections at SPring-8 beamlines.
Double-crystal monochromator

Fixed-exit operation for usability at experimental station.

Choose suitable mechanism for energy range (Bragg angle range).

Precision, stability, rigidity,...
\( \theta_1 + \text{translation} + \theta_2 \) computer link

\begin{align*}
\text{1st crystal} & \quad \theta\text{-stage} \\
\text{2nd crystal} & \quad \theta\text{-stage} \\
\text{Translation stage} & \quad h \\
\end{align*}

\( h = 100 \text{ mm}, \ \theta_B = 5.7^\circ \sim 72^\circ \) (for lower energy range)

Large offset, long-stroke translation

Difficulty of adjustment between 1st and 2nd crystal
$\theta + \text{two translation (KEK-PF)}$

- Two cams for two translation-stages
- Rotation center at 2\textsuperscript{nd} crystal

$h=25 \text{ mm, } \theta_B = 5\text{~}70^\circ$

Two cams for two translation-stages
Rotation center at 2\textsuperscript{nd} crystal

Matsushita et al., NIM A246 (1986)
SPring-8 standard DCM

Offset $h = 30$ mm

$\theta_B = 3\sim 27^\circ$ for higher energy range


High-precision adjustment stages for undulator beamline DCM

Sub-μm & sub-μrad control
Why crystal cooling?

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

→ with temperature rise $\Delta T$

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

$\alpha$: 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: $\alpha$,
- Thermal conductivity in crystal: $\kappa$,
- Heat transfer to coolant and crystal holder.

Solutions:

(S-1) $\kappa / \alpha \rightarrow$ Larger
(S-2) Large contact area between crystal and coolant/holder
  $\rightarrow$ larger
(S-3) Irradiation area $\rightarrow$ Larger, and power density $\rightarrow$ smaller
### Figure of merit

<table>
<thead>
<tr>
<th></th>
<th>Silicon 300 K</th>
<th>Silicon 80 K</th>
<th>Diamond 300 K</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\kappa) (W/m/K)</td>
<td>150</td>
<td>1000</td>
<td>2000</td>
</tr>
<tr>
<td>(\alpha) (1/K)</td>
<td>2.5x10^{-6}</td>
<td>-5x10^{-7}</td>
<td>1x10^{-6}</td>
</tr>
<tr>
<td>(\kappa / \alpha \times 10^6)</td>
<td>60</td>
<td>2000</td>
<td>2000</td>
</tr>
</tbody>
</table>

**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/mm² @40 m
Method:
→ Direct cooling with fin crystal \( \leftrightarrow \) S-2

Undulator beamline
(Linear undulator, \( N = 140, \lambda_u = 32 \text{ mm} \))
Power and density: ~500 W, ~500 W/mm² @40 m
Methods:
→ Direct cooling of silicon pin-post crystal \( \leftrightarrow \) S-2
  + Rotated inclined geometry (\( \rightarrow 10 \text{ W/mm}^2 \)) \( \leftrightarrow \) S-3
→ or Cryogenic cooling using LN₂ circulation \( \leftrightarrow \) S-1
→ or Indirect cooling of IIa diamond crystal \( \leftrightarrow \) S-1
Crystal monochromator at SPring-8

<Bending magnet beamline>
Power & power density:
~100 W, ~1 W/mm²
Fin crystal direct-cooling - (S2)

<Undulator beamline>
Linear undulator, \( N = 140, \lambda_u = 32 \text{ mm} \)
Power & power density: 300~500 W, 300~500 W/mm²

a) Direct cooling of silicon pin-post crystal – (S2) & (S3)
b) Silicon cryogenic cooling - (S1)
c) IIa diamond with indirect water cooling - (S1)
Mirror

- Higher harmonics rejection
- Bent mirror for focusing/collimation
- Figured mirror for micro~nanobeam
Mirror quality

Mirror quality must be considered.

→ Micro-roughness
  - Reduction of reflectivity
  - Lower-energy shift of critical energy
  - Diffuse scattering
    Optical (Zygo) range (<1 mm): ~ 0.3 nm rms or less
    AFM range (<1 µm): ~ 1 nm rms or less

→ Insufficient coating
  - Reduction of reflectivity
  - Lower-energy shift of critical energy
  Should be ~100%

→ Slope error
  - Beam shape deformation
  - Wave-front distortion
  - Flux density loss
    LTP range (<1 m): ~1 µrad or less
Mirror reflectivity

Mirror reflectivity for sigma-polarization:

\[ R = \left| \frac{k_{iz} - k_{tz}}{k_{iz} + k_{tz}} \exp(-2k_{iz}k_{tz}\sigma^2) \right|^2 \]

\[ k_{iz} = \frac{2\pi}{\lambda} \cos \theta, \quad k_{tz} = \frac{2\pi}{\lambda} \sqrt{n^2 - \cos^2 \theta} \]

- \( k_{iz}, k_{tz} \): Normal components of incidence and transmitted wave vectors
- \( n \): complex index of refraction
- \( \theta \): glancing angle
- \( \sigma \): high-spatial-frequency roughness (AFM region)

Surface roughness must be considered around critical energy (angle).
Effect of roughness

e.g. reflectivity of Pt mirror
s-polarization
Glancing angle: 3 mrad
Film thickness: 50 nm

![Graph showing the effect of roughness on reflectivity. The x-axis represents photon energy (keV), and the y-axis represents reflectivity. The graph compares different surfaces with varying roughness and density.]

- Smooth surface w/ 100% density
- 1 nm rms w/ 100% density
- 2 nm rms w/ 90% density
Example of mirror reflectivity

Thickness 50 nm, roughness 1 nm
Material, glancing angle, length

- **Material**
  - Si, SiC for white radiation
  - SiO₂, Glass,.. for monochromatic beam

- **Coating**
  - 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
Focusing with mirror

For beam focusing or collimation, we need:
- elliptical mirror, ellipsoidal mirror, parabolic mirror, paraboloidal mirror,...

We can approximate by bending:
- flat $\rightarrow$ meridional cylinder,
- sagittal cylinder $\rightarrow$ toroidal,...

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

**Sagittal focusing w/ sagittal cylinder**

\[ R = \frac{2pq}{(p + q) \sin \theta} \]

**Meridional focusing w/ meridional cylinder**

\( \theta = 5 \text{ mrad}, \ p = 40 \text{ m}, \ q = 10 \text{ m} \)

\( r = 80 \text{ mm}, \ R = 3.2 \text{ km} \)

※ When \( q \rightarrow \infty \)
We obtain parallel beam:

\[ r = 2p \sin \theta \]

\[ R = \frac{2p}{\sin \theta} \]
SPring-8 standard mirror support

For SPring-8 X-ray beamline

For undulator beamline
400-mm-long, vertical deflection, plane
700-mm-long, horizontal deflection, plane

For bending magnet beamline
1-m-long, vertical deflection, plane/cylindrical

Options
  • Bender
  • Indirect water-cooling (side cooling)

High heat-load 1st mirror for undulator beamline is installed with cryogenic cooling or water-cooling at some BL in SPring-8.
Focusing with mirror

Beam size using meridional cylinder mirror:

\[ F_{\text{coma}} = 2.35\Sigma M \]
\[ F_{\text{spherical}} = \frac{3L^2 \theta (1 - M^2)}{16 p M} \]
\[ F_{\text{Fabrication}} = 2 \times 2.35 \Delta_{\text{fabrication}} Mp \]
\[ F_{\text{total}} = \left[ (F_{\text{coma}} + F_{\text{spherical}})^2 + F_{\text{fabrication}}^2 \right]^{1/2} \]

\\( \Sigma \): source size
\\( M \): magnification = \( q/p \)
\\( L \): mirror length
\\( \Delta_{\text{fabrication}} \): slope error
\\( \theta \): glancing angle

\[ \Sigma = 10 \mu \text{m} \]
\[ L = 400 \text{ mm} \]
\[ \Delta_{\text{fabrication}} = 3 \mu \text{rad} \]
\[ \theta = 4 \text{ mrad} \]
\[ p = 40 \text{ m} \]

For micro~nonofocusing, we need precisely-polished and large NA elliptical K-B mirror near exp. station.

Diffraction-limited focusing

Focusing w/ figured mirror

Estimation by oblique aperture model

→ Angular spread due to Fraunhofer diffraction

\[ FWHM_\phi = 2.7831 \frac{\lambda}{\pi w} \approx 0.8858 \frac{\lambda}{L \sin \theta} \]

→ Spatial spread at \( q \)

\[ FWHM_x = 0.8858 \frac{\lambda q}{L \sin \theta} \]

\[ FWHM_x > \frac{q}{p} \sum \]

\( \iff \) diffraction-limited focusing
Diffraction-limited focusing

H. Mimura et al.,

\[
\theta_{\text{ave}} = 3 \text{ mrad}
\]

\[
\lambda = 0.083 \text{ nm} \ (E = 15 \text{ keV})
\]

\[
L = 45 \text{ mm}
\]

\[
q = 50 \text{ mm}
\]

\[\Rightarrow \text{ FWHM} \sim 27 \text{ nm}\]

H. Mimura et al.,

\[
\theta_{\text{ave}} = 7 \text{ mrad}
\]

\[
\lambda = 0.062 \text{ nm} \ (E = 20 \text{ keV})
\]

\[
L = 80 \text{ mm}
\]

\[
q = 75 \text{ mm}
\]

\[\Rightarrow \text{ FWHM} \sim 7.3 \text{ nm}\]
Polarization conversion

Phase retarder is used to convert the polarization for XMCD and other applications.

Horizontal polarization $\rightarrow$ right-/left-circular polarization
Horizontal polarization $\rightarrow$ vertical polarization

... 

Crystal: IIa diamond,..
Polarization conversion

Offset angle of crystal: \( \theta_0 \pm \Delta \theta \)

Offset angle (-) Offset angle (+)

\( K_0 \) \( K_h \)

\( \sigma \)-pol. \( \pi \)-pol.

\( h \) \( O \) \( H \)

\( k_0 \)-\( \sigma \) \( k_h \)-\( \sigma \) \( k_0 \)-\( \pi \) \( k_h \)-\( \pi \)

\( K_d \)

Transmitted x-rays

Perfect crystal

Diffracted x-rays

Right-circular pol.

Left-circular pol.

Linearly polarized incident x-rays
Diamond phase plate system BL39XU

- Diamond crystal
- Diffracted beam
- X-rays from DCM
- Transmitted beam to sample

0.45-mm-thick (111) diamond plate

Stages and vacuum chamber of phase retarder

Switcher of phase

Degree of circular polarization vs. off-set angle (arcsec):

- Measurement
- Calculation
## Selection of phase plate

<table>
<thead>
<tr>
<th>Thickness (mm)</th>
<th>Index</th>
<th>Reflection</th>
<th>Energy (keV)</th>
<th>Transmittance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.34</td>
<td>(111)</td>
<td>111 Bragg</td>
<td>5~5.8</td>
<td>3~7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>220 Laue</td>
<td>5.8~7.5</td>
<td>7~41</td>
</tr>
<tr>
<td>0.45</td>
<td>(111)</td>
<td>220 Laue</td>
<td>6~9</td>
<td>5~53</td>
</tr>
<tr>
<td>0.73</td>
<td>(111)</td>
<td>220 Laue</td>
<td>8~12</td>
<td>22~65</td>
</tr>
<tr>
<td>2.7</td>
<td>(001)</td>
<td>220 Laue</td>
<td>11~16</td>
<td>13~47</td>
</tr>
</tbody>
</table>
Spatial coherence

We need:
- small source size ($\sigma_s$) & long beamline ($L$)
  
  \[ l_{coh} \propto \frac{\lambda L}{\sigma_s} \]

(depend on machine performance and facility design !)
- w/ speckle-free optics.

- e.g. x-ray images using coherent x-rays
  - Mirror
  - Be window
  - ultra smooth surface
  
  $\rightarrow$ void-free & polished

100 mm

300 µm
Front-end

(1) Vacuum chamber
(with ion pumps,..)
Pressure ($10^{-7} \sim 10^{-5}$ Pa)

(2) Main beam shutter (MBS)
  - Water-cooled absorber
  - Beam shutter

(3) Mask, XY-slit
  Spatial power control

(4) Water-cooled Be windows
  Protection of UHV

(5) Beam position monitor

e.g. SPring-8 BL19LXU front-end
It reduces source power of 33 kW down to 500 W for downstream optics

New IXS beamline 43LXU
\[\Rightarrow 50 \text{ kW to } 1.5 \text{ kW}\]

Grazing incidence technique w/ GlidCop
\[\Rightarrow 10 \text{ kW/m}\]
Reduction of power at front-end

e.g. Radiation From standard x-ray undulator $\lambda_u=32$ mm, $N=140$, fundamental peak of 10 keV

Front-end eliminates the out-of-axis power spatially and reduce the power on the first optical element
Transport channel

- Exhaustion unit (ion-pump, TMP,..)
- Down stream shutter (W or Pb)
- Gamma stopper (Pb)
- Beryllium window
- Screen monitor

e.g. BL14B2
Shielding hutch @SPring-8

- **Optics hutch**
  - contains optics and transport channel components introducing white radiation

- **Experimental hutch**
  - contains experimental station equipments introducing monochromatic beam

  - **Panel**
    - Steel/ Lead/ steel sandwich structure
  - **Lead thickness**
    - Depends on the radiation condition (3～50 mm)
  - **Module**
    - Panel, Door, Cable duct, Air inlet/exhaust duct,...
  - **Utility**
    - Compressed air, Chilled water, electric power
Other issues on beamline design

- Boundary condition
  Storage ring and tunnel, neighboring beamline,..

- Radiation safety for shielding hutch, shutter,..
  Radiation shielding calculation (EGS4, STAC8,..)

- Control and interlock
  Common scheme in the facility.
  Connection with machine and safety control

- Others
  Utilities: electricity, water, compressed air, air conditioning.
  Environmental: vibration of floor, temperature of air,..

Cooperation with specialists in the facility is crucial!
Example of x-ray beamline
- SPring-8 case -
- Bending magnet
- Collimator mirror, + DCM,
+ refocusing mirror

Optical layout for energy range less than 60 keV
Protein crystallography

- Bending magnet
- DCM + focusing mirror

Optics hutch with standard components

Double-crystal monochromator
Focusing mirror (Vertical deflection)

Distance from the source
30 m
40 m
50 m
High resolution inelastic scattering

- Undulator
- DCM + back-reflection monochromator & analyzer (w/ ~meV resolution)
200-m-long beamline

- Bending magnet
- DCM

300-mm-wide beam at end-station
1-km-long beamline

- Undulator
- DCM + tandem mirror

Wide and spatially-coherent X-rays at 1-km end station
Summary

- Starting point of X-ray beamline design is shown here, w/ light source, monochromator, mirror, and other components.

- It helps to figure out what we can do at the beamline.

- We will have to go into details of design refinement using;
  FEA (ANSYS), ray-tracing (SHADOW,...), shielding calculation,...

- Standardization of well-designed components helps beamline construction and maintenance, saves the cost, man-power, and other resources.

- Ray-tracing \(\rightarrow\) wave simulation for “diffraction limited source and optics”
Thanks to:

Thank you for your attention.