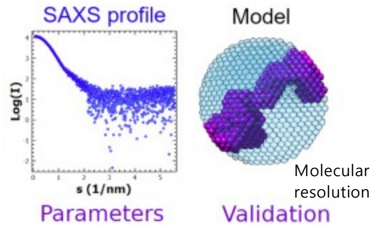
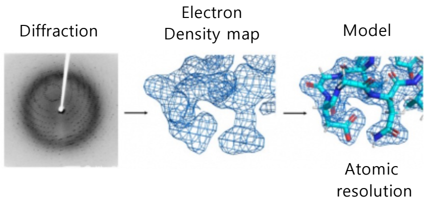
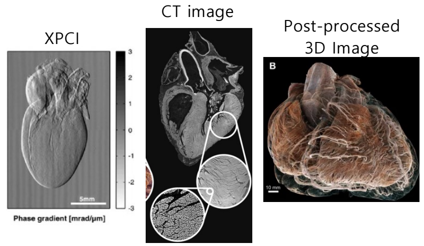
Construction and utilization of Korea-4GSR's life science and imaging beamline

1. ID21 BioPharma-BioSAXS Beamline
2. ID22 Bio Nano Crystallography (BioNX) Beamline
3. BM10 High Energy Microscopy (HEM) Beamline

2025.06.27

Mi-Jeong Kwak (ID22), Yong Sung Park (BM10), Ji-hun Kim (ID21)
Yeon-Gil Kim, Jae-Hong Lim, Kyeong-Sik Jin (PLS-II)
Yong-Seok Heo, Dong In Yu, Sang-ho Lee (KOSUA)
Michel Fodje, Marco Stampanoni, Byeong-du Lee (MAC)

Overview of the Bio and imaging beamlines

BL	Design keyword	Source	Energy (keV) (mainly)	Flux (ph/s)	Sample	Beam size at sample	Results	Applications
ID21 BioPharma -BioSAXS	q-vector optimizing layout, High-throughput, Convenience	IVU24	5~20 (optimized: 8~25) (12)	~ 2 × 10^{13}	Biomacromolecules **in solution**	~100×100 μm^2	 Current Research in Struc. Biol. (2020)	1. High-throughput Experiment 2. SEC-SAXS 3. Protein-based therapeutics 4. Development of drug carrier using Lipid
ID22 BioNX	Micro beam, High flux, Rapid beam resizing, Stable, High-throughput	IVU20	8~25 (12.4, 20)	~5 x 10^{13}	Biomacromolecules **as crystallized**	2x2~ 40x40 μm^2 @ 12.4 keV --------------- 1x1~5x5 μm^2 @ 20 keV	 https://www.biospectator.com/news/view/15766	1. Microcrystallography 2. Room temperature crystallography 3. Drug discovery 4. Quick screening of initial crystal
BM10 HEM	High energy, Large beam, X-ray Phase contrast imaging	Bending Magnet (2T)	5~100 (E_c:21.2)	~10^{13}	Biological tissue, Battery, Developmental prototype, Electronic components, Cultural heritage etc.	1.9 x 1.1 ~200x28 mm^2 @ 100 m		1. Soft tissue imaging 2. Operando or in situ CT 3. Defect inspection 4. Non-destructive diagnosis

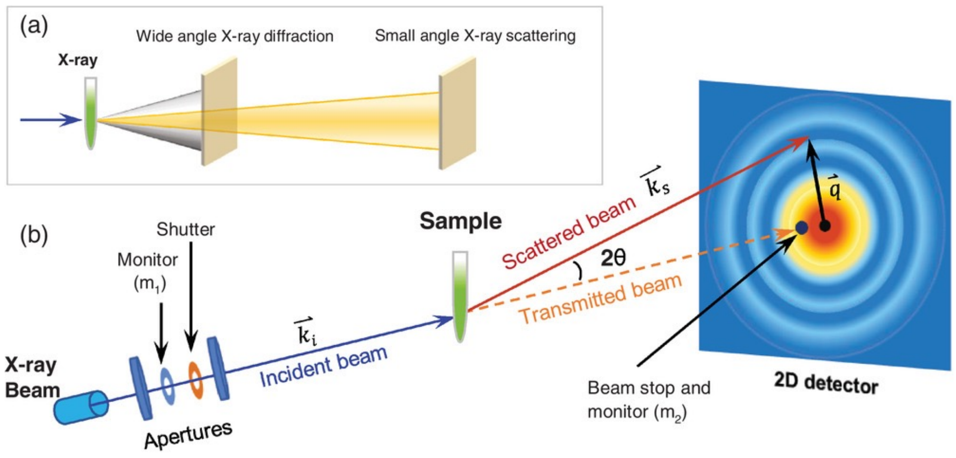
Proc. SPIE 5535, Developments in X-Ray Tomography IV (2004)

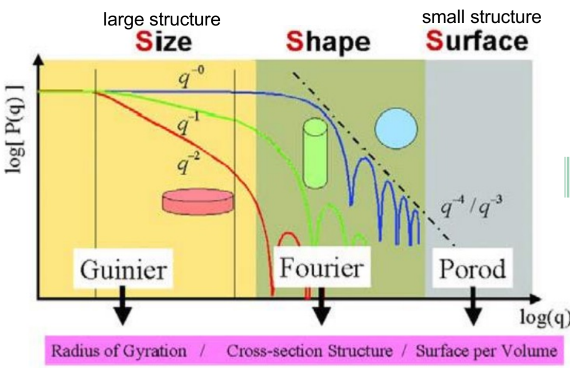
https://www.esrf.fr/home/news/general/content-news/general/a-unique-atlas-of-the-human-heart-from-cells-to-the-full-organ.html

ID21 BioPharma-BioSAXS Beamline

Priority support for industries

Solution Small Angle X-ray Scattering (SAXS)



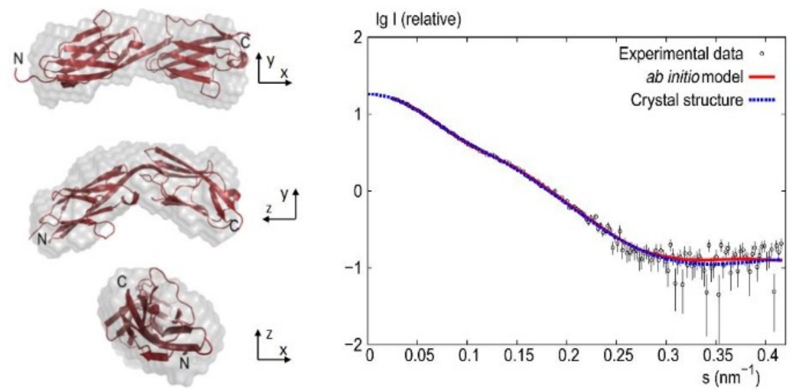


1. Size of particle
$I(q) \sim \exp(-q^2 R_g^2/3)$
(R_g: Radius of Gyration)

2. Form of particle
$I(q) \sim q^{-1\sim-2}$

3. Surface structure
$I(q) \sim q^{-4}$

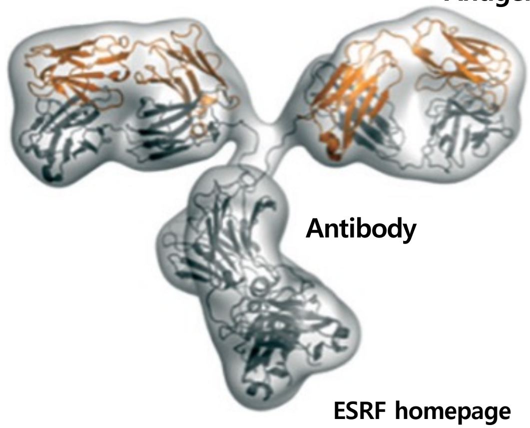
Protein structure characterization



https://biorontech.com/biosaxs

Protein-Protein interaction

Antigen

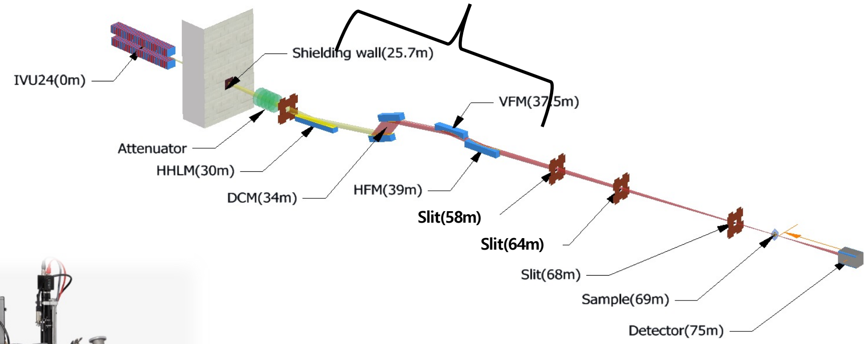


ESRF homepage

Design Summary

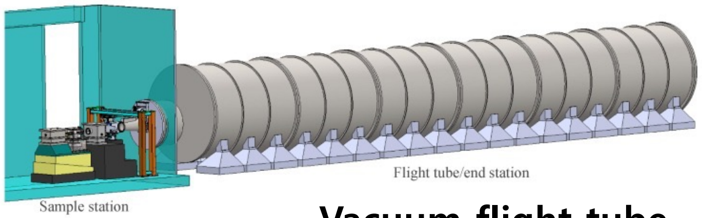
Main Optics components → Placed close to the source

1. q-vector optimizing layout



2. High-throughput

Automatic
Sample exchanger robot



Vacuum flight tube

3. Convenience

ID21 BioPharma-BioSAXS beamline comments from MAC

□ **HHLM**

- Instead of having three strips (Si, Rh, Pt) as originally planned, consider whether using only a Rh coating might suffice.

□ **Focusing Optics**

- APS uses a CRL (Compound Refractive Lens) for convenience in focusing. Is there any plan to use CRLs at the 4GSR BioPharma-BioSAXS beamline?

□ H-**DCM vs V-DCM**

- At APS-U, there were issues with vertical DCMs (V-DCMs) due to beam vibration and drift. Consequently, H-DCMs are now more commonly used, so it would be good to review this aspect.

□ **3 slit system**

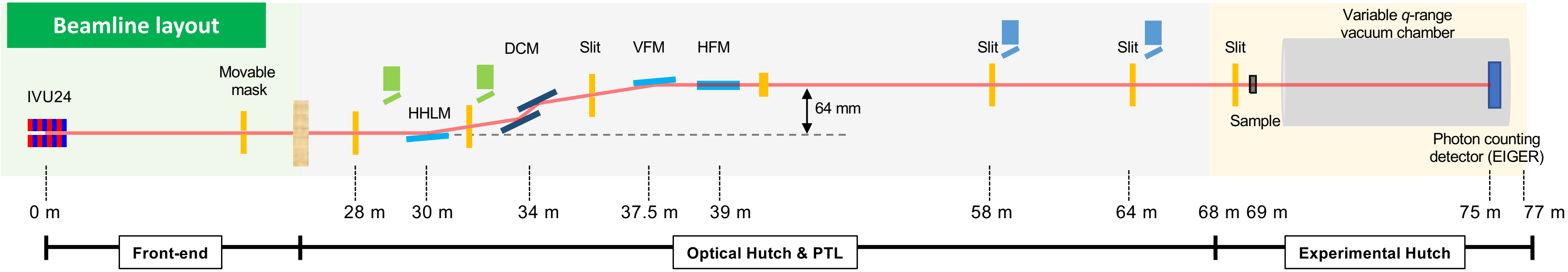
- Currently, the beam-defining slit is placed behind the KB mirror. Consider whether placing the slit between the DCM and KB mirror or leaving it behind the KB mirror is more advantageous.

- Depending on the final decision, calculate the size of the beam stopper at the detector.

□ **Focal point location**

- In APS-U, the beam is focused at the detector. In the current design, the beam is focused on the sample. This could potentially damage the sample, and might also result in a very large beam size at the detector. Therefore, the selection of the focal point is crucial. Ideally, the beam spot on the detector should be smaller or at least comparable to the detector's pixel size, but it does not have to be strictly smaller.

Overview of BioPharma-BioSAXS Beamline



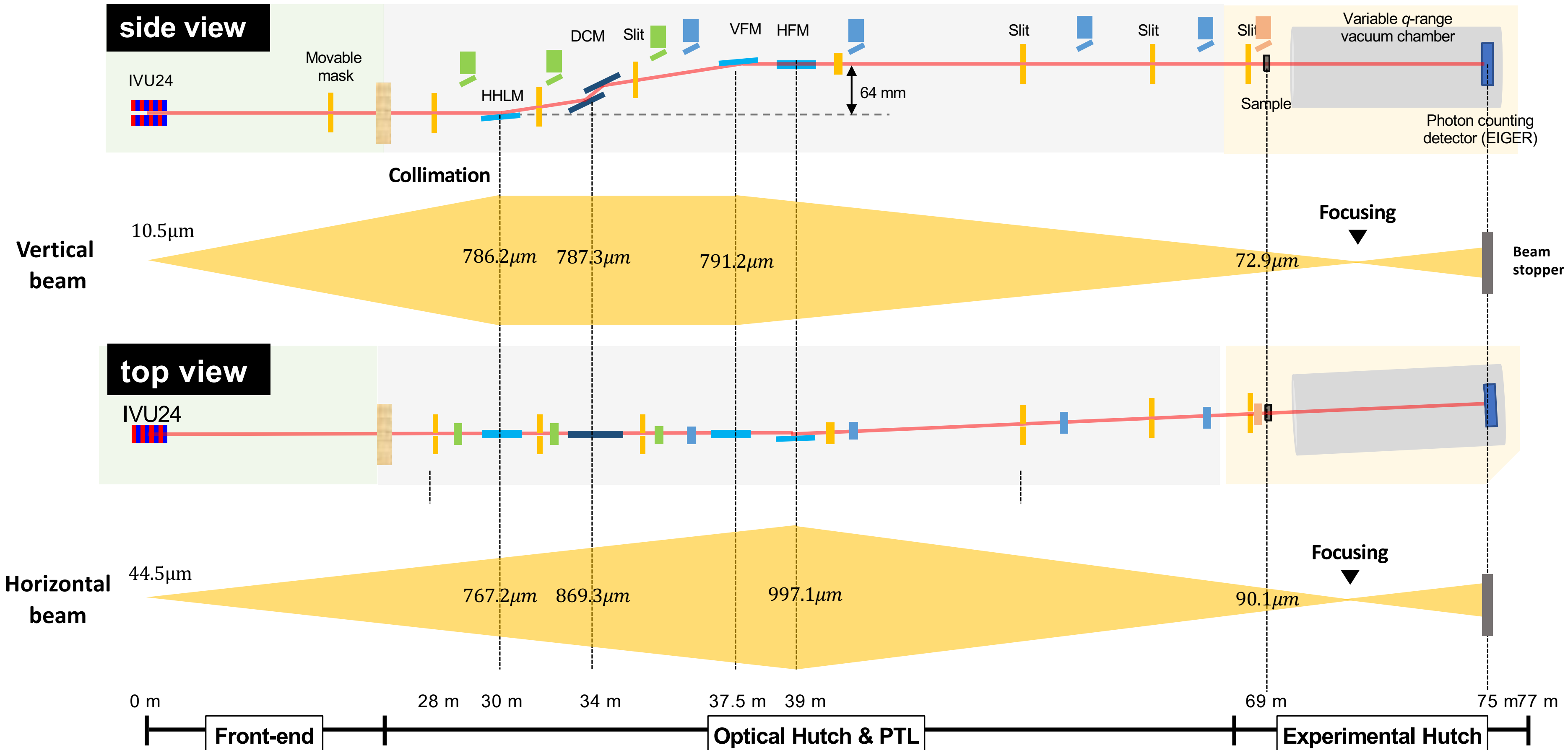
Specification

Beamline	ID21 BioPharma-BioSAXS
Light source	In Vacuum Undulator 24 (3m)
Energy range [keV] (mainly)	5 ~ 20 (optimized: 8 ~ 25) (12.4)
Energy resolution (ΔE/E)	< 2 x 10^{-4}
Techniques	Solution SAXS
Beam size at sample (μm^2) H × V, FWHM	~ 100μm × 100μm
Beam flux (ph/s)	~ 2 × 10^{13}

Beamline characteristics

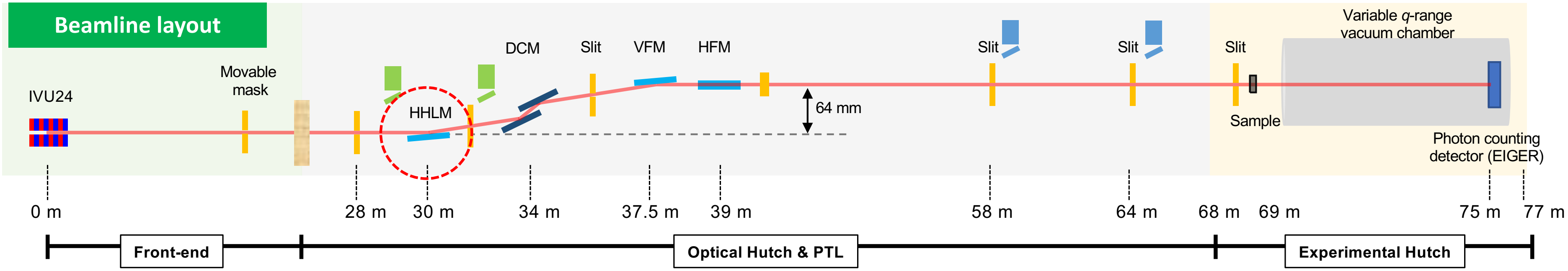
- As an industry-prioritized beamline, an **automated sample exchange robot** is implemented to enable high-throughput experiments.
- **A large vacuum chamber including the detector** allows rapid adjustment of the sample-to-detector distance from 0.5 to 6 meters, enabling efficient analysis of samples with various sizes.
- The system is designed to **perform experiments under a wide range of conditions**—such as pH, temperature, and denaturant concentration for studies on the 3D structure and stability of biomolecular proteins.

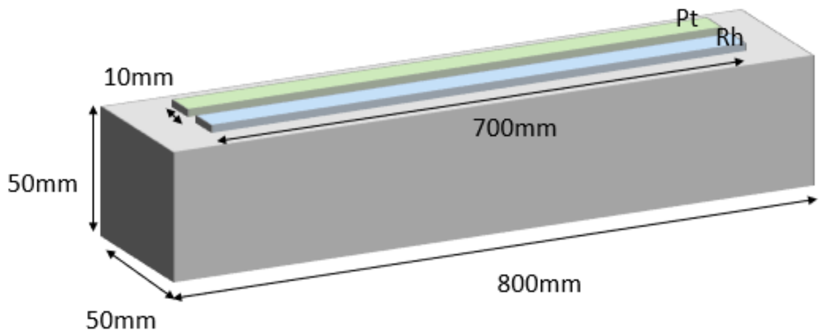
Overview of BioPharma-BioSAXS Beamline-Ray-tracing



Optics components

1. M1 mirror – High Heat Load Mirror (HHLM)





Purpose of M1

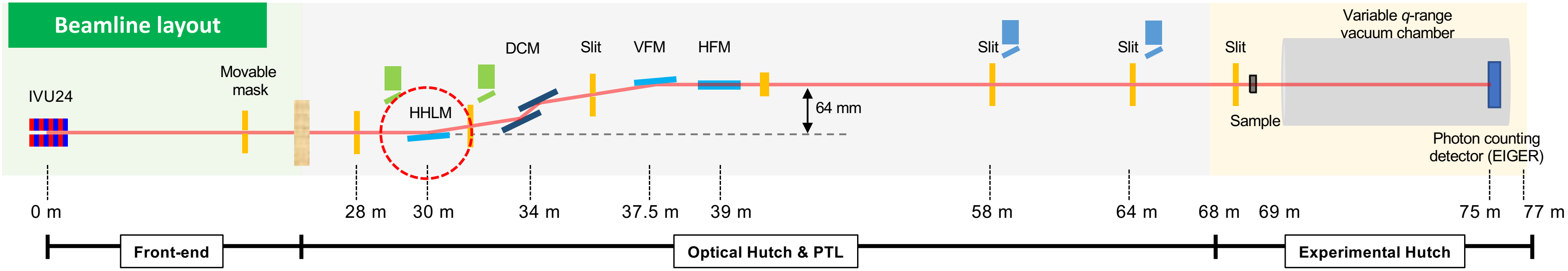
(Heat load management) **Reducing the heat of the white beam.**

The optical components can generally be positioned further upstream, which is advantageous for securing a smaller source size.

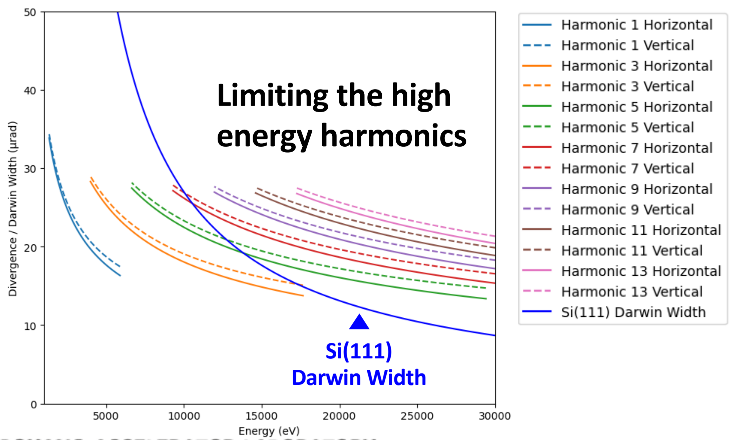
(Collimation) By reducing the beam divergence to be smaller than the Darwin width, **the flux can be preserved and energy resolution can be enhanced.**

Optics components

1. M1 mirror - Collimation

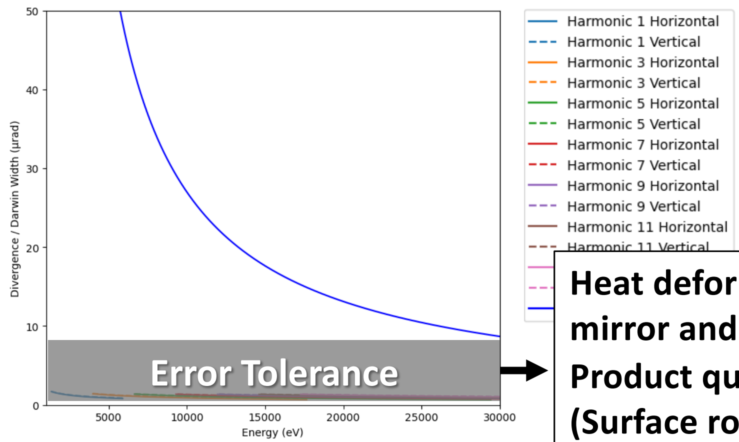


Beam divergence at the DCM without M1



Collimation

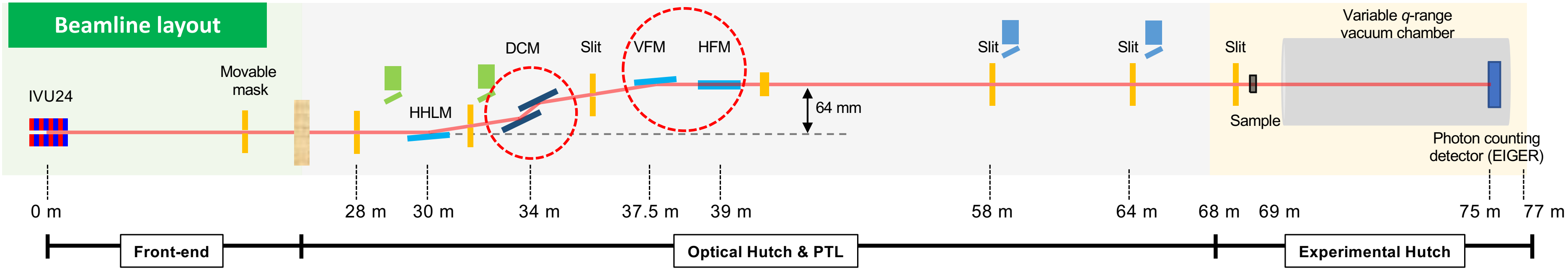
Beam divergence at the DCM after M1



Heat deformation of the mirror and crystal
Product quality tolerance (Surface roughness)

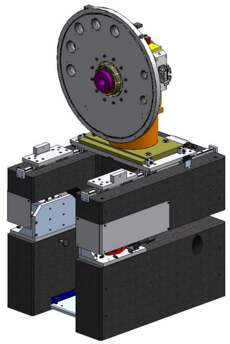
Optics components

2. Double Crystal Monochromator (DCM) and 3. Focusing mirror



2. Vertical-DCM

Specification	1st Crystal	2nd Crystal
Shape	Plane	
footprint	0.86 x 4.76 mm^2	0.86 x 4.76 mm^2
Size	60(L) x 25(W) x 50(H) mm^3	150(L) x 25(W) x 30(H) mm^3
Substrate	Si<111>	

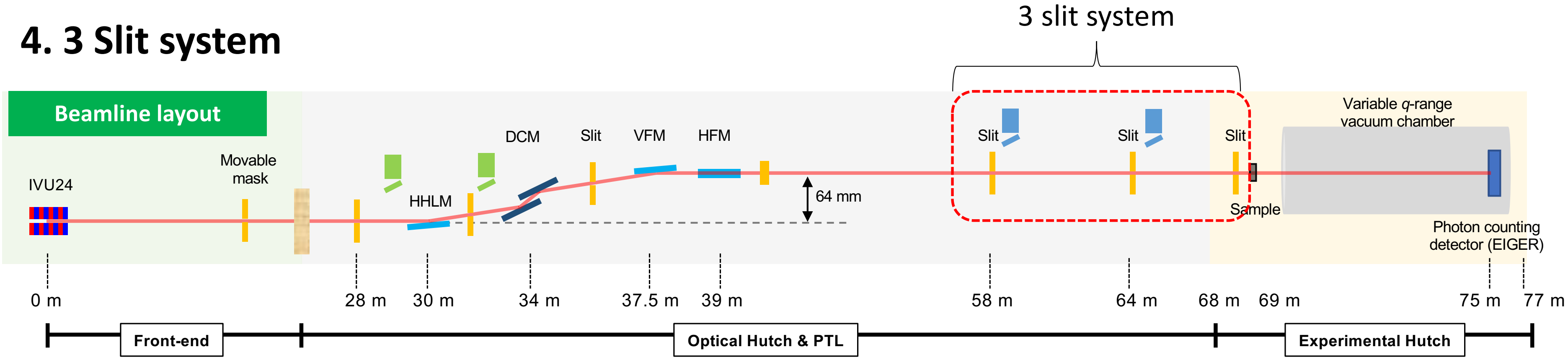


3 . Focusing mirror

Specification	Horizontal focusing	Vertical focusing
Shape	Parabolic	Elliptical
footprint(FWHM)	0.94 x 303.5 mm^2	0.74 x 377.3 mm^2
Size	50 x 500 x 50 mm^3	
Substrate	Si	
Coating material	Rh(50nm), Pt(50nm)	
Incident angle	2.6mrad	
p, q parameter	p: inf q: 34.125m	p: 39m q: 32m

Optics components

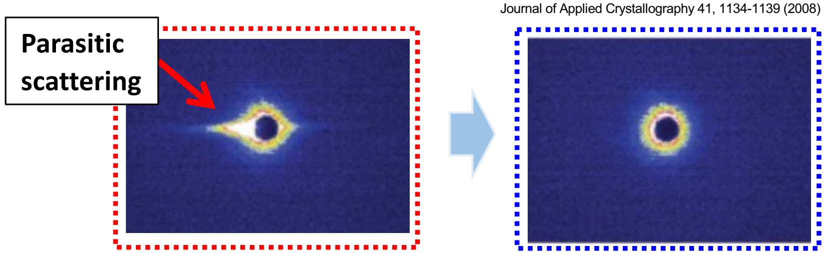
4. 3 Slit system



Purpose of 3 slit system

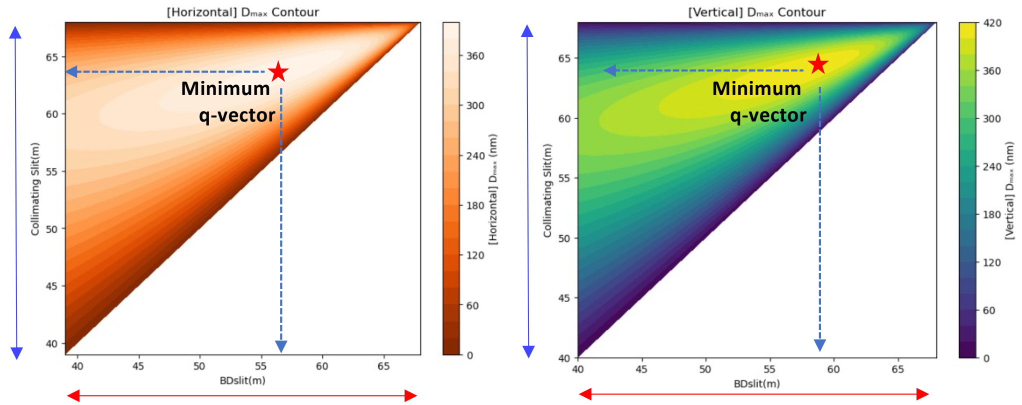
- The parasitic scattering removal
- Enhancing the q-vector

Journal of Applied Crystallography 41, 1134-1139 (2008)



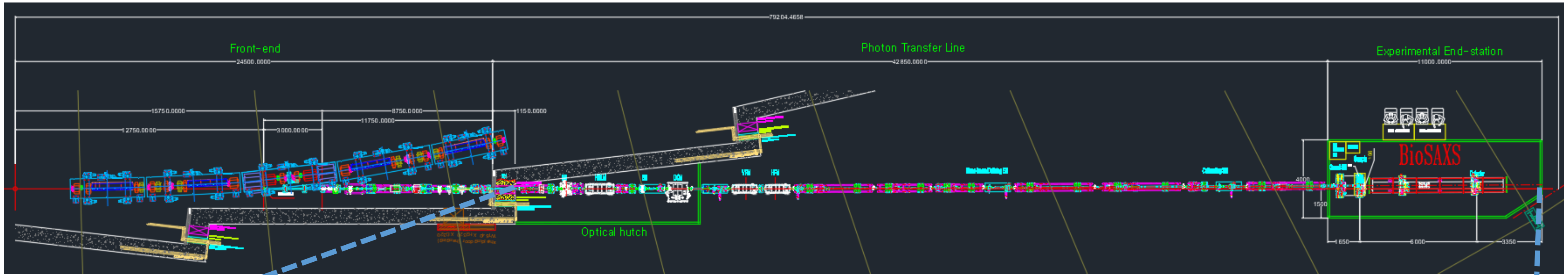
Optimized slit position and Minimum q-vector

(FWHM cutting)

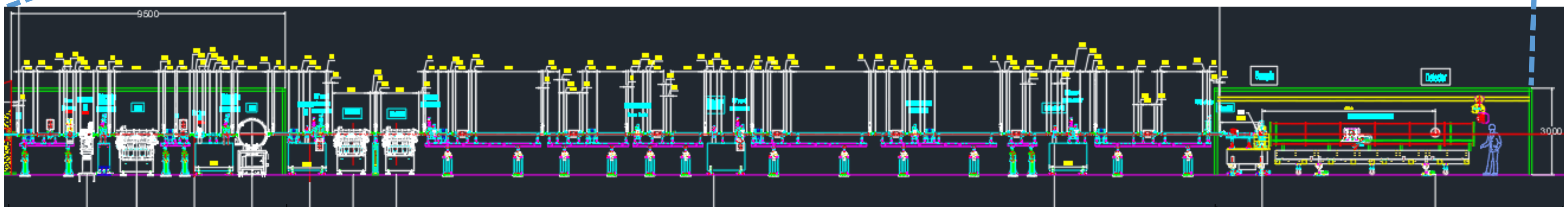


Design drawing

Top View



Side View



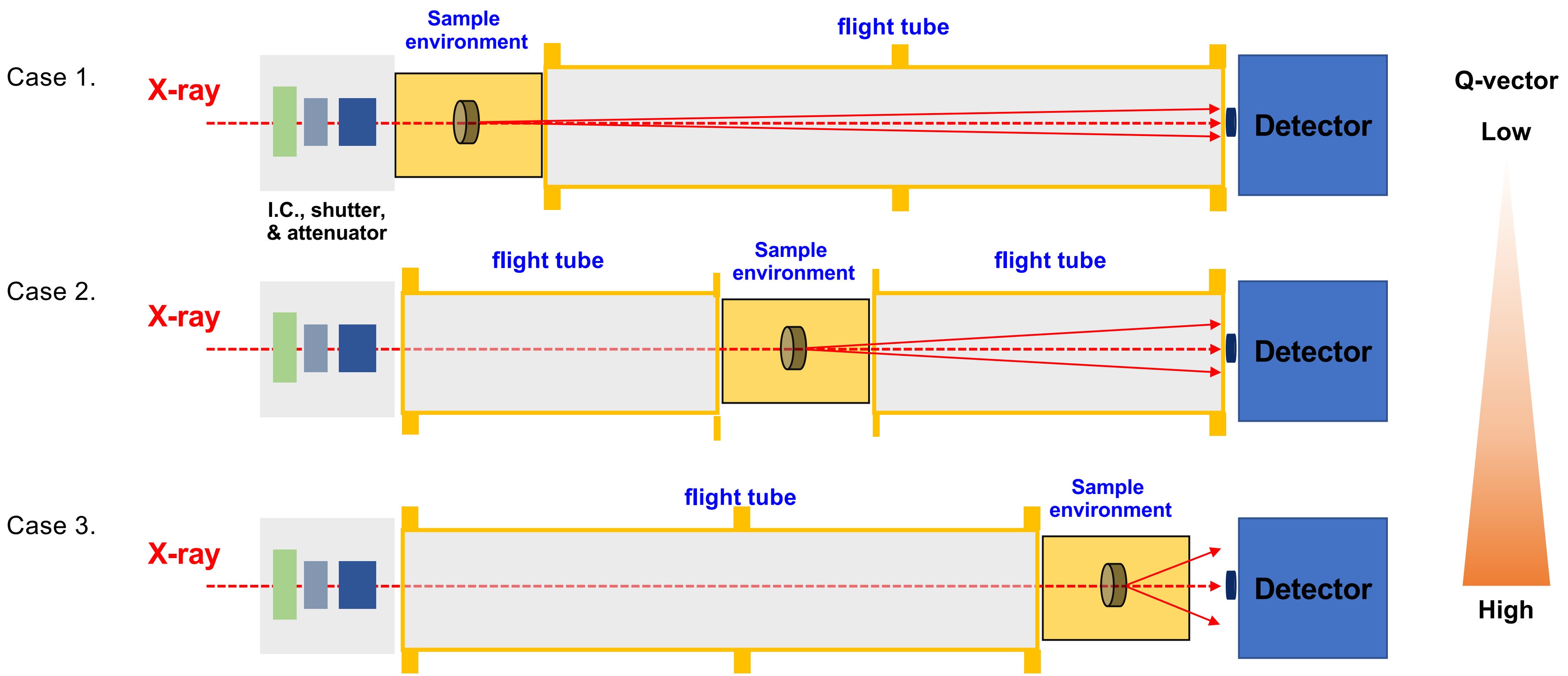
Optical hutch
9.4 m

Long spool
32.3 m

Experimental hutch
11.0 m

End-station

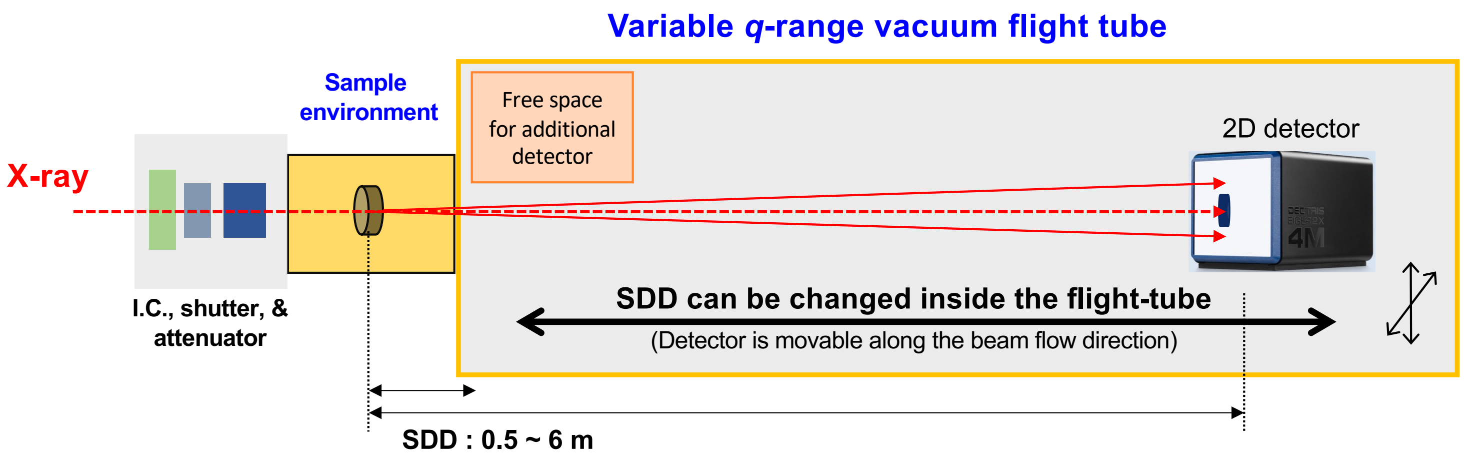
◆ **Classical SDD changing system – Sample move, Detector fixed**



Disassemble → assemble → vacuum setting : **Time-consuming process**

End-station

◆Rapid sample to detector distance (SDD) changing system – Sample fixed, Detector move

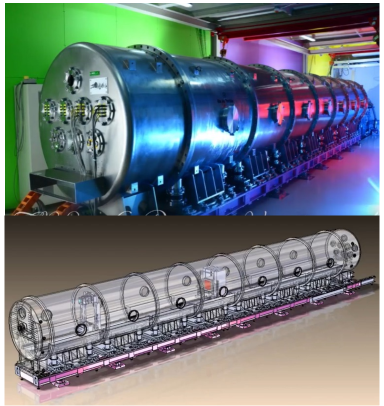


- **Time reduction** for sample to detector distance (SDD) change
- By fixing the sample environment position, it is easy to install **robot system** and build **applied experiment tools**
- **Improvement of data quality** owing to minimizing air scattering (background)

~ 0.33 electrons /Å^3 (water)
~ 0.43 electrons /Å^3 (biomolecules)

Vacuum flight tube examples

Example; 12 ID-B, APS



Example; 13A BioSAXS, TPS

Example; SWING, Soleil

End-station

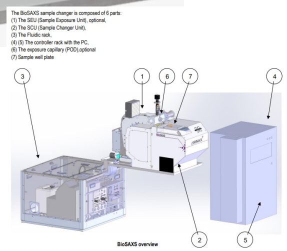
◆Sample changer robot

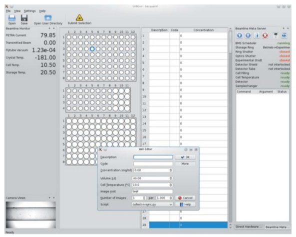
- ARINAX BioSAXS

High-throughput experiments:
~ 50 samples / 1 hour

Performances	
Solution transfer volume	5 to 200 uL
Typical cycle time - loading/unloading - cleaning (wash, rinse, dry)	50 s 15 s / 15 s 20 s
Controls	
Sample exposure modes	Static Flow (0.05 to 20 uL/s)
Temperature	Exposure (2 ~ 60 ºC) Storage (4 ~ 40 ºC)
Dimension (W x H x D)	
Main unit (robot)	550 x 800 x 1100 mm^3

- Sample Exposure Unit (SEU)
- Sample Changer Unit (SCU)
- Control Software
- Control Electronics Rack
- Fluid Management Unit (FMU)

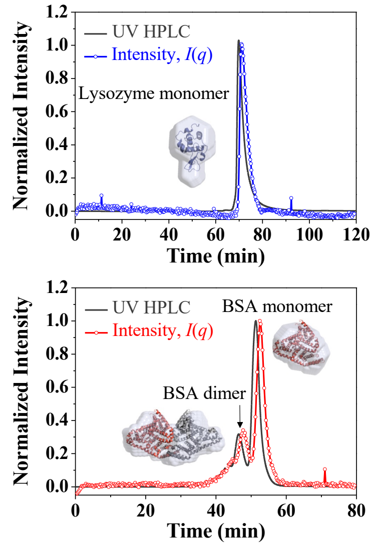




◆Size-exclusion chromatography (SEC)-SAXS

- Continuous-flow in-line sample purification

In-line purification of solution



- Agilent infinity 1260 system, RI, UV, MALS, & DLS
- Separation and Analysis of polydisperse species or mixture

Beamline applications

Conformational Ensembles of Flexible Protein

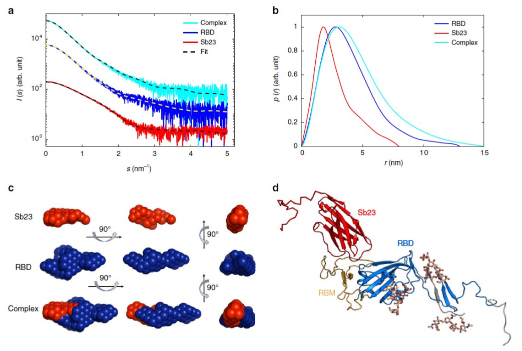
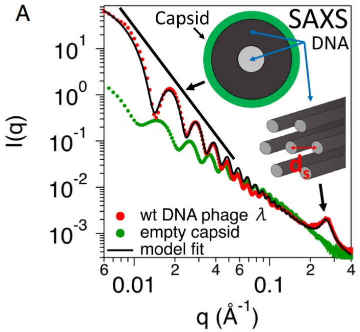


Table 1 Data collection and structure statistics for SAXS analysis.

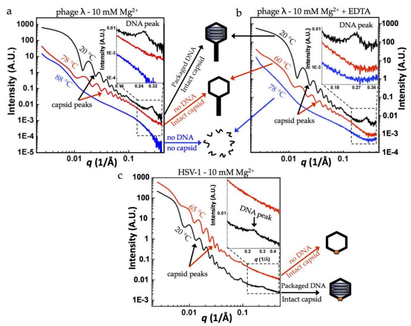
Data collection parameters	Sb23	RBD	Sb23+RBD
Data collection parameters			
Instrument		EMBL P12 (PETRA III, DESY, Hamburg)	
Beam geometry (mm^2)		0.2 × 0.12	
Wavelength (nm)		0.124	
s range (nm^{-1})		0.03–5.0	
Exposure time (s)		4 (20 × 0.2 s)	
Temperature (K)		293	
Concentration range ($mg\ ml^{-1}$)		0.37–4.0	
Structural parameters			
R_g (nm) (from $P(r)$)	2.2 ± 0.1	3.2 ± 0.2	3.7 ± 0.2
R_g (nm) (from Guinier plot)	2.1 ± 0.1	3.1 ± 0.2	3.5 ± 0.2
D_{max} (nm)	8.0 ± 0.5	13 ± 1	15 ± 1
Porod volume estimate, V_p (nm^3)	20 ± 2	66 ± 2	86 ± 5
Molecular weight determination (kDa)			
From Porod volume (V_p/~1.6)	13 ± 1	37 ± 5	54 ± 3
From consensus Bayesian assessment	15 ± 3	41 ± 1	53 ± 6
From $I(0)$	21 ± 2	33 ± 9	62 ± 9
Calculated monomeric *MW* from sequence	15.7	32.2	47.9
Software employed			
Primary data reduction	SASFLOW	SASFLOW	SASFLOW
Data processing	PRIMUS	PRIMUS	PRIMUS
Rigid body modeling	CORAL	CORAL	SASREF
Computation of model intensities	CRYSOL	CRYSOL	CRYSOL
3D graphics representations	PYMOL	PYMOL	PYMOL

Nature Communications 11, 5588 (2020)

DNA & Capsid structure



PNAS 120, e2220518120 (2023)



Journal of Virology 89, 9288-9298 (2015)

Industrial application

Therapeutic Antibody

ex) **Tracking structure of antibody molecules in solution**

Company: Boehringer
Facility: ESRF
Sample: Antibody molecule in solution

Other cases

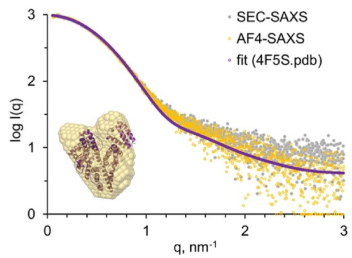
Antibody type (Company) – Beamline, year

1. IgG1 mAb (Genetech) - SSRL BL4-2, 2024
2. Pembrolizumab (Merch & Co.) – Diamond B21, 2024
3. TrYbe (UCB Pharma) – ESRF BM29, 2023
4. IgG1 mAb2 (Eli Lilly x UT Austin) – CHESS ID7A, 2023

⋮

mRNA-LNP

Quantitative size-resolved characterization of mRNA nanoparticles



Sci Rep 13 15764 (Sep 2023)

Company: BioNTech SE
Facility: PETRA III - P12
Sample: mRNA-LPX (clinical cancer vaccine candidate)

Other cases

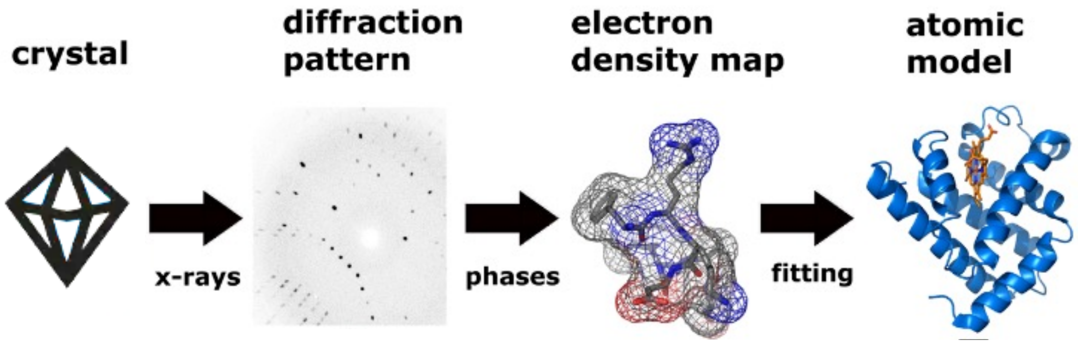
Sample type (Company) – Beamline, year

1. IMP-1 saRNA vaccine (CPI) – Diamond B21, 2023
2. ASO loaded LNP library (Genetech/Roche)– ALS 12.3.1, 2023
3. mRNA-LNP (AstraZeneca)– MAX IV SAXS, 2024
4. Moderna bivalent vaccine (Moderna) – NSLS-II I22, 2024

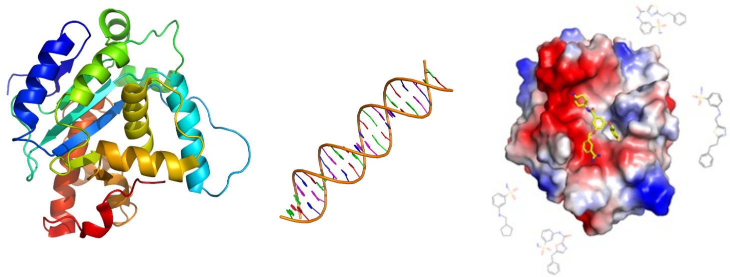
⋮

ID22 Bio Nano Crystallography (BioNX) Beamline

Macromolecular crystallography (MX)



The atomic resolution structure of the biomacromolecules



Protein DNA/RNA Complex

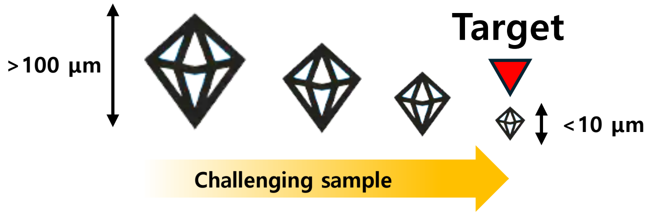
Users

Academia
Protein structure and function

Industry
Structure based drug discovery (SBDD)

Design summary

Size of Protein crystals

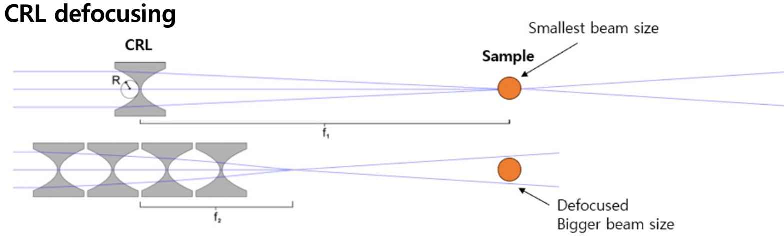


1. Micro-focusing beam
2. High flux

3. Rapid beam resizing

Compound refractive lens (CRL)

CRL defocusing



4. Stable

hDCM

CRL-only focusing mode

5. High-throughput

Sample exchange robot system

ID22 BioNX beamline comments from MAC, PLS-II, etc.

- **Optics**

  1. Compound refractive lens (CRL)
  - ✓ Simplify the step of the beam size adjustment
  - ✓ CRL-only focusing have high stability, it would be suitable for the high-throughput experiment

  2. Diagnostics
  - ✓ A diagnostic device used for DCM feedback should be placed as far from the DCM as possible to ensure high resolution.
  - ✓ For beam stability, it is essential to use a diagnostic system with high resolution.

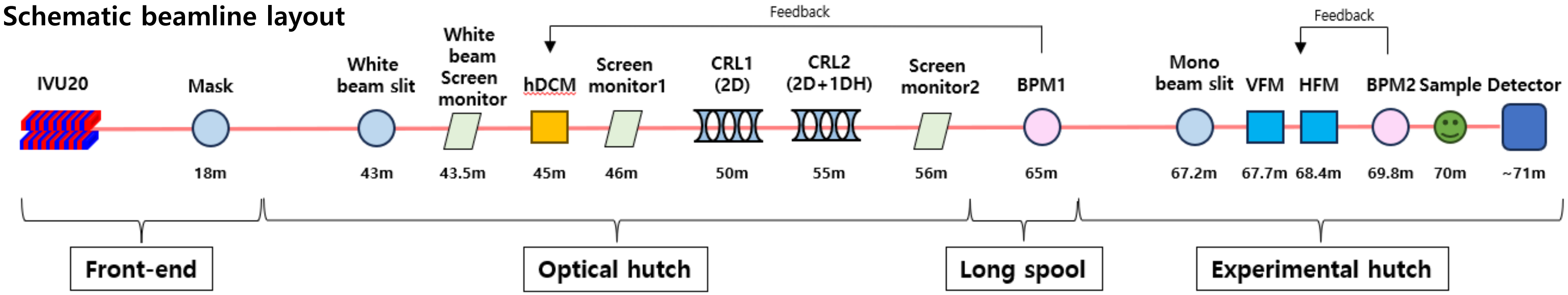
  3. Detector
  - ✓ It is advisable to make the purchase at the final stage, as new technology may emerge.

- **Data acquisition**
  - ✓ The data frame rate can be configured higher than the originally targeted 30 Hz — it is expected to be set at 100 Hz or above.
  - ✓ It is essential to secure sufficient facility computing infrastructure and local computing resources. This will be planned in conjunction with the data center strategy, and the local computing resources will be purchased at the final stage to ensure high specifications.

- **Beamline science**
  - ✓ It is necessary to consider the prioritization of beamline science objectives.

Overview of BioNX beamline

Schematic beamline layout



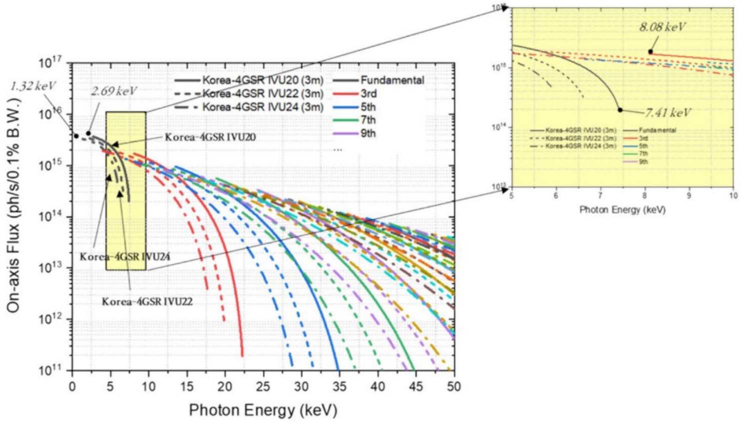
Content	Details
Light source	IVU20 (3 m)
Photon energy (keV)	8 – 25 (12.4, 20 keV mainly)
Wavelength (Å)	0.5~1.55
Energy resolution (ΔE/E)	<2 x 10^{-4}
Beam size at sample (μm²)	2x2 ~ 40x40 @ 12.4 keV 1x1 ~ 5x5 @ 20 keV
Photon flux (ph/s)	5 x 10^{13}
Techniques	RSX, SSX, ISX, HTS* MX
Measurement speed	>100 Hz
Processing capacity	600 crystals/day
Auxiliary Facilities	On-site sample preparation laboratory

*) RSX: Rotating single crystallography, SSX: Serial synchrotron crystallography, ISX: In-situ crystallography, HTS: High throughput screening

Beamline science

1. Microcrystallography
2. Room-temperature crystallography
3. Automated high-throughput screening for drug discovery

❖ Undulator: In Vacuum Undulator 20 (IVU20)

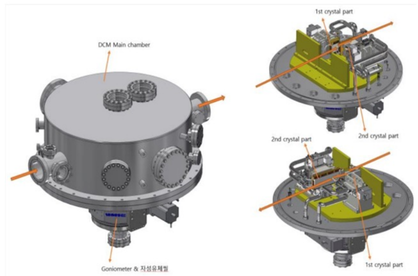


IVU Type	IVU20	IVU22	IVU24
On-Axis Flux	Best	90% of IVU20's between 10-30 keV	80% of IVU20's between 10-25 keV
Coherent Flux	Best	80% of IVU20's between 10-30 keV	60% of IVU20's beween 10-30 keV
Spectral Continuity	Missing/compromised between 7.41 keV and 8.08 keV	Perfect at gap size <5.58 mm	Perfect at gap size <6.46 mm
Heat Load on Beamline by Off-Axis Radiation	Best: 12 kW at the minimum gap size	15 kW at the minimum gap size	17 kW at the minimum gap size

Ha, *et al.,* JKPS (2024)

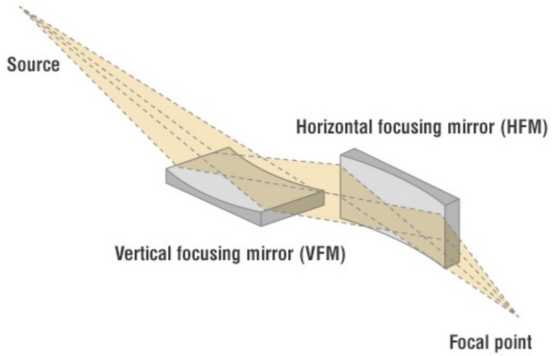
- ✓ Low heat load
- ✓ High flux
- ✓ Missing 7.41 keV and 8.08 keV (limited the usage of this range) (Cobalt (7.7 keV) energy scan range)

❖ Optics Features

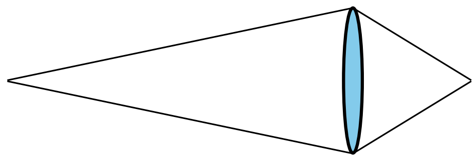


Horizontal DCM
Si(111) crystal

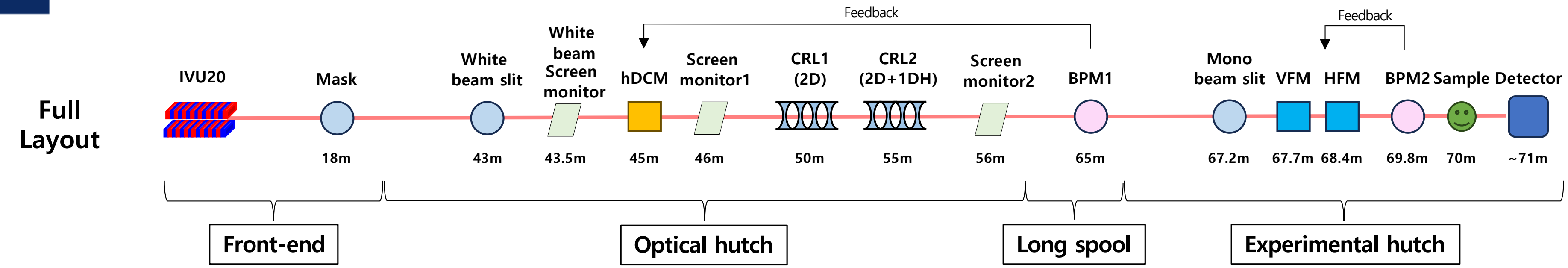
Compound refractive lens (CRL)
Diamond lens (large aperture)



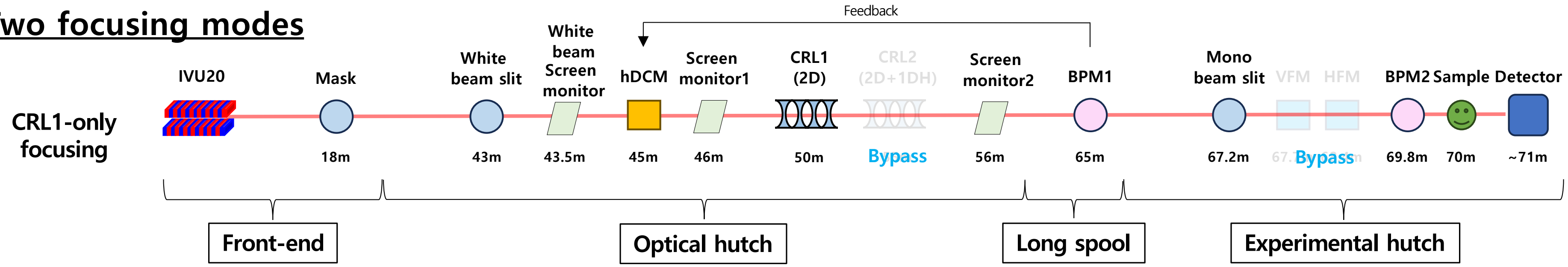
Elliptical mirrors
Si/Rh/Pt coating

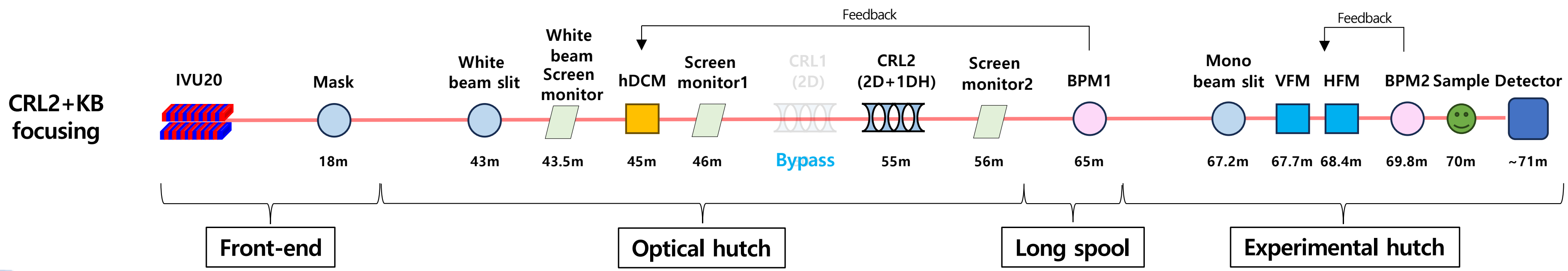


One stage direct focusing
Full beam
Simplifying optics
Improved manageability

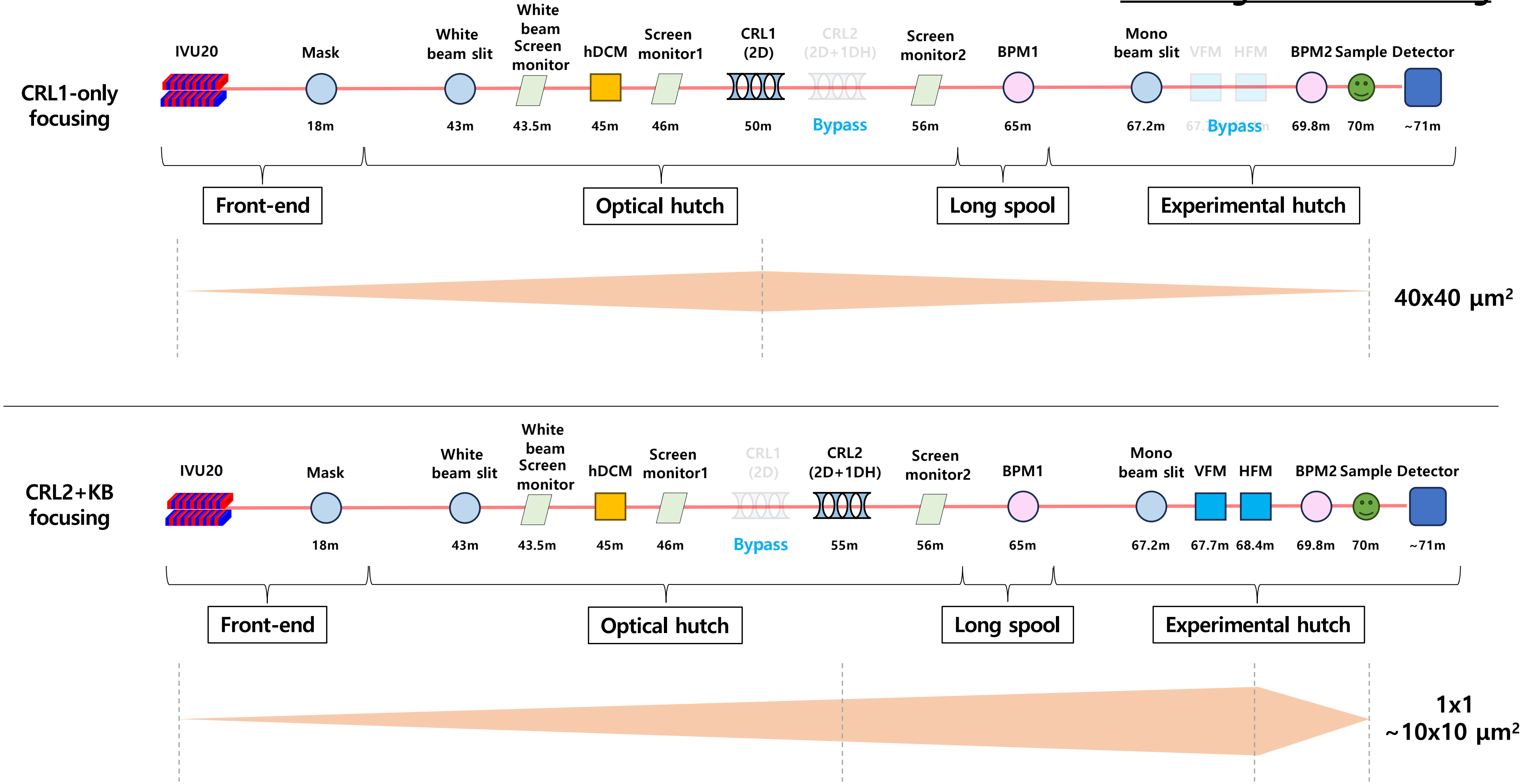


Two focusing modes





One stage direct focusing



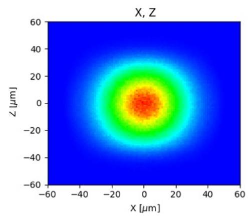
Two focusing modes

1) CRL1-only focusing mode

- High Beam position stability
  → Suitable for **continuous and long-term experiments**
- For rotating single crystallography
- For high-throughput screening
- 24 h experiment, automation, remote experiment
- 12.4 keV fixed, Beam size fixed focusing (40x40 micron)

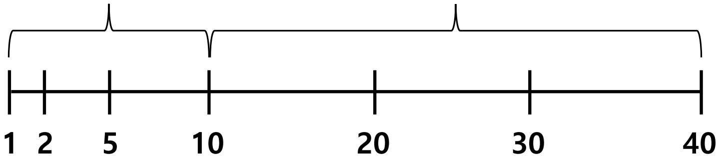
CRL spec

2D diamond CRL, ROC 1 mm, Aperture 1.5 mm, 7 ea



Beam size: 40x40 um^2 (FWHM)
Flux: 3.0×10^{13} ph/s

* 10~40 micron : diffractometer aperture

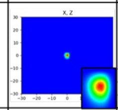
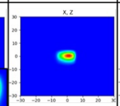
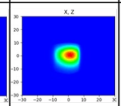
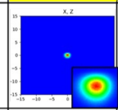
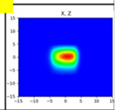


2) CRL2+KB focusing mode

- Beam position stability could be low due to the vibration of the KB mirror → Suitable for **short-term and on-site experiment**
- For micro-focusing (<10 micron)
- For serial crystallography, in-situ crystallography
- 12.4 keV or 20 keV, Beam size 1~10 micron

CRL spec

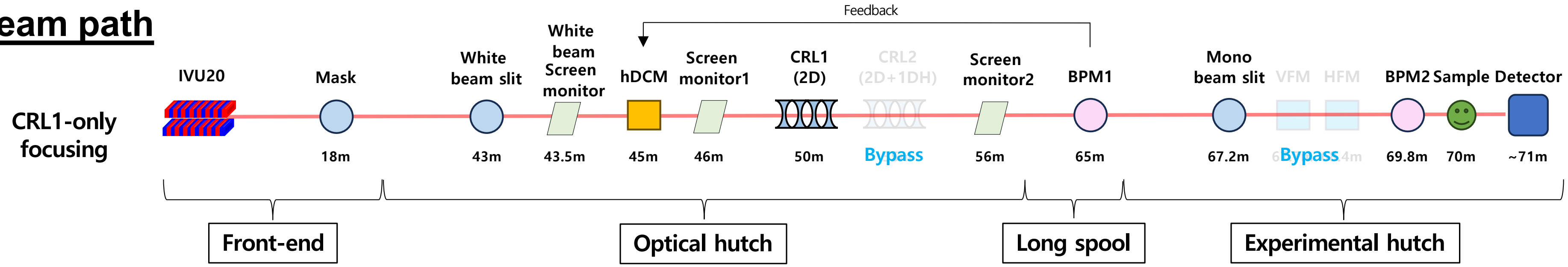
2D diamond CRL, ROC 6 mm, Aperture 2 mm, 5 ea
1D diamond CRL, ROC 2.1 mm, Aperture 2 mm, 3 ea

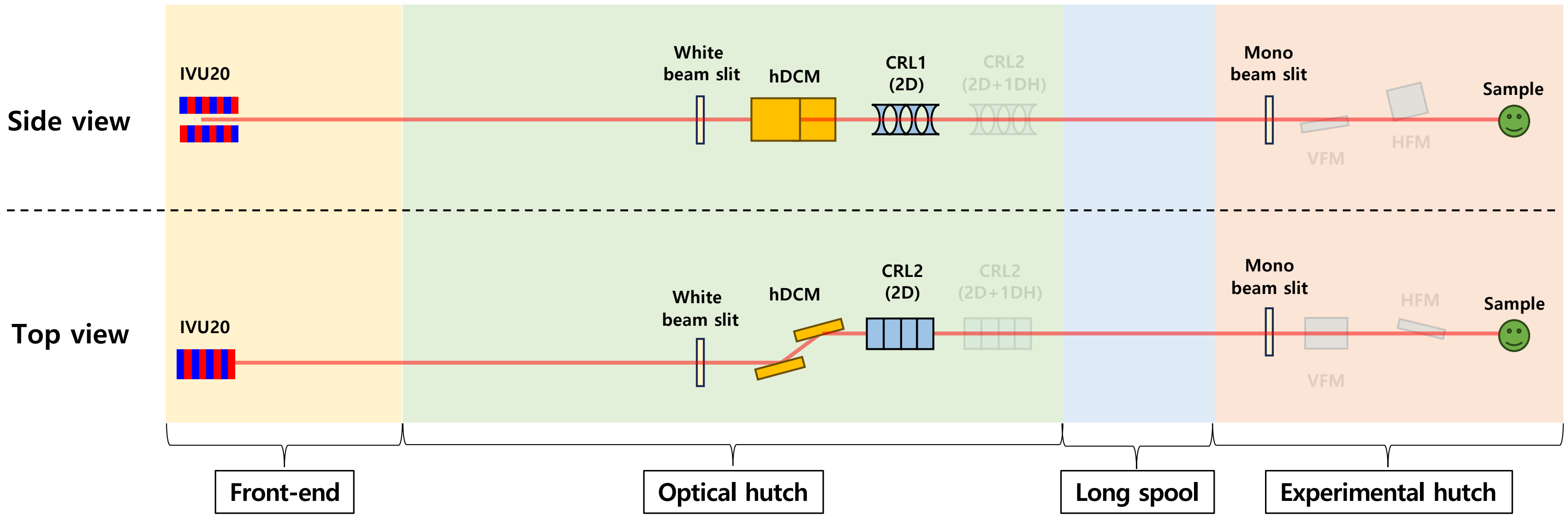
Energy	CRL-2D /CRL-H number	1/0	2/1	4/1	5/3
12.4 keV	Beam shape				
	Beam size FWHM (um^2) Flux (ph/s)	1.83 x 2.72 4.87×10^{13} **2 micron**	7 x 5.34 4.68×10^{13} **5 micron**	9.74 x 10.47 4.5×10^{13} **10 micron**	
20 keV	Beam shape				
	Beam size FWHM (um^2) Flux (ph/s)	1.14 x 1.11 1.37×10^{13} **1 micron**			5.39 x 5.15 1.33×10^{13} **5 micron**

3 beam sizes
2~10 micron
~5×10^{13} ph/s

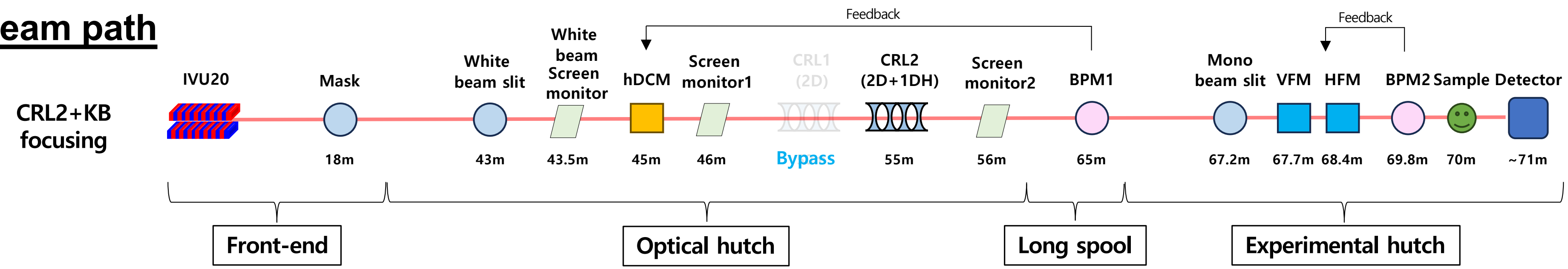
2 beam sizes
1~5 micron
1.3×10^{13} ph/s

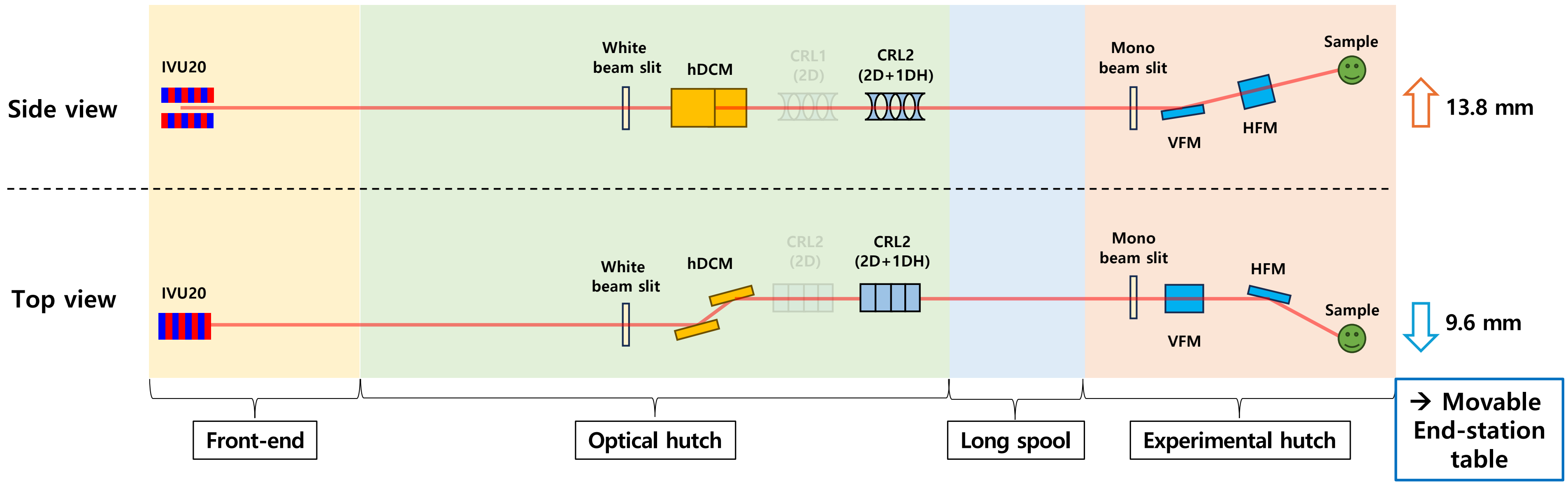
Beam path


Feedback
CRL1-only focusing
IVU20
Mask
18m
White beam slit
43m
White beam Screen monitor
43.5m
hDCM
45m
Screen monitor1
46m
CRL1 (2D)
50m
CRL2 (2D+1DH)
Bypass
Screen monitor2
56m
BPM1
65m
Mono beam slit
67.2m
VFM
HFM
Bypass
BPM2
69.8m
Sample
70m
Detector
~71m
Front-end
Optical hutch
Long spool
Experimental hutch


Side view
IVU20
White beam slit
hDCM
CRL1 (2D)
CRL2 (2D+1DH)
Mono beam slit
VFM
HFM
Sample
Top view
IVU20
White beam slit
hDCM
CRL2 (2D)
CRL2 (2D+1DH)
Mono beam slit
HFM
VFM
Sample
Front-end
Optical hutch
Long spool
Experimental hutch

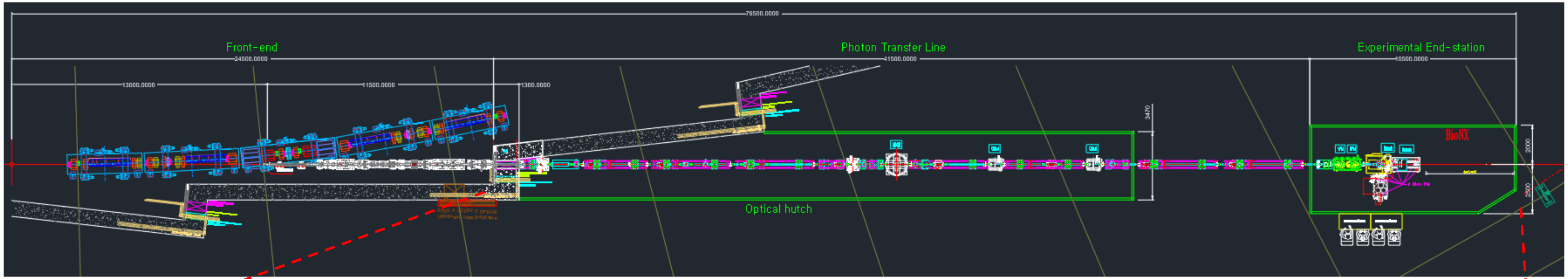
Beam path


CRL2+KB focusing
IVU20
Mask
White beam slit
White beam Screen monitor
hDCM
Screen monitor1
CRL1 (2D)
CRL2 (2D+1DH)
Screen monitor2
BPM1
Mono beam slit
VFM
HFM
BPM2
Sample
Detector
Feedback
Feedback
18m
43m
43.5m
45m
46m
Bypass
55m
56m
65m
67.2m
67.7m
68.4m
69.8m
70m
~71m
Front-end
Optical hutch
Long spool
Experimental hutch

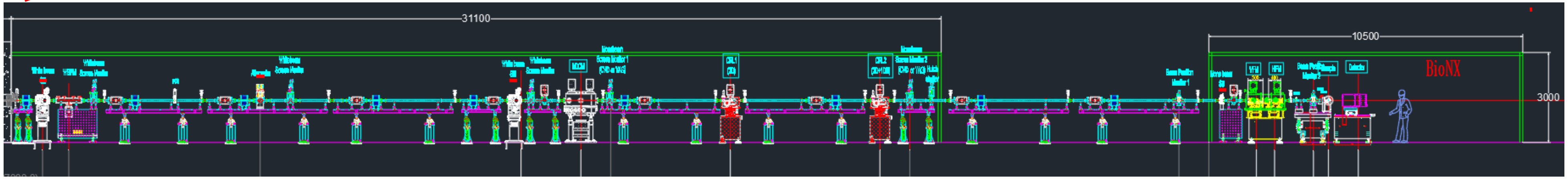

Side view
IVU20
White beam slit
hDCM
CRL1 (2D)
CRL2 (2D+1DH)
Mono beam slit
VFM
HFM
Sample
13.8 mm
Top view
IVU20
White beam slit
hDCM
CRL2 (2D)
CRL2 (2D+1DH)
Mono beam slit
VFM
HFM
Sample
9.6 mm
Front-end
Optical hutch
Long spool
Experimental hutch
→ Movable End-station table

Design drawing

Top view



Side view

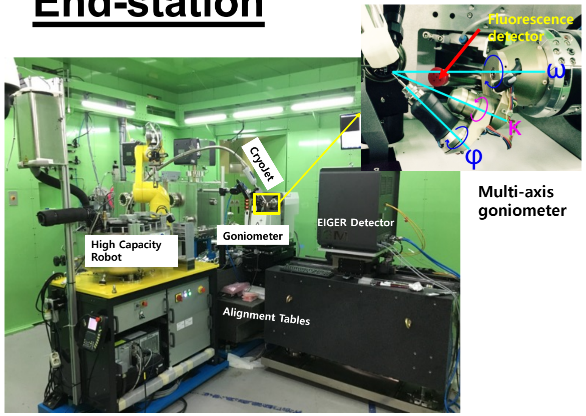


Optical hutch 31.1 m

Long spool 9 m

Experimental hutch 10.5 m

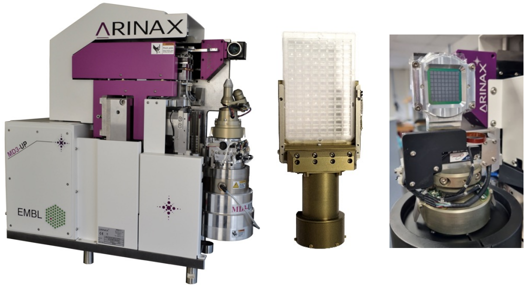
End-station



Multi-axis goniometer

Layout

High precision diffractometer



- Sphere of confusion: 100 nm
- Raster scan at 15 mm/s
- Rotation speed: 720 deg/s
- Easy to change various goniometer heads

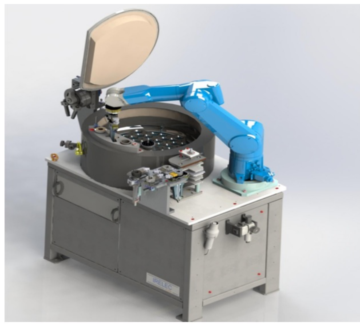
Silicon drift X-ray detector

- X-ray fluorescence
- Element scan

EIGER2 XE 16M

- Frame rate: 560 Hz (16 bit), 700 Hz (8 bit)
- Active area: 311 x 328 mm2
- Energy range: 6-40 keV

High-Capacity Sample Exchange Robot



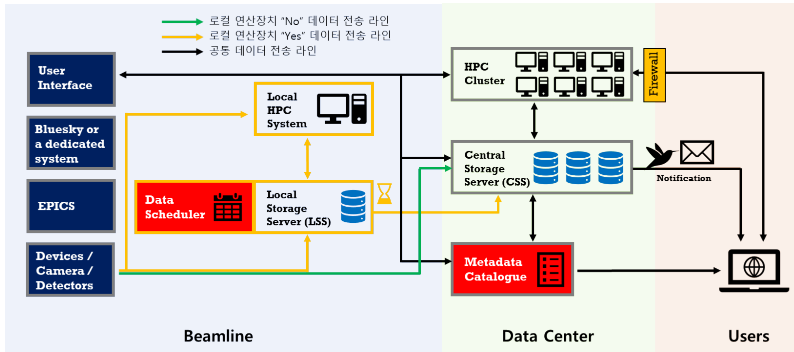
592 sample/storage chamber
~600 sample/day

DAQ

Data acquisition/management

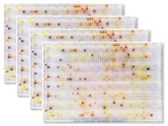
Web-based User Interface (WUI)
Remote access

Computing infrastructure

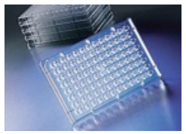


- Local HPC system and data center

Sample preparation laboratory



~ fragment library
on ECHO plates
(ex. 1200 fragments)

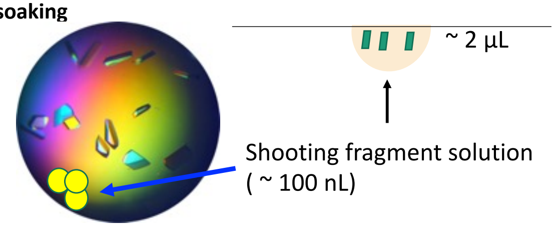


~ Crystallization Plates
(ex. 1200 crystal drops)

Crystallization robot Crystal imaging system

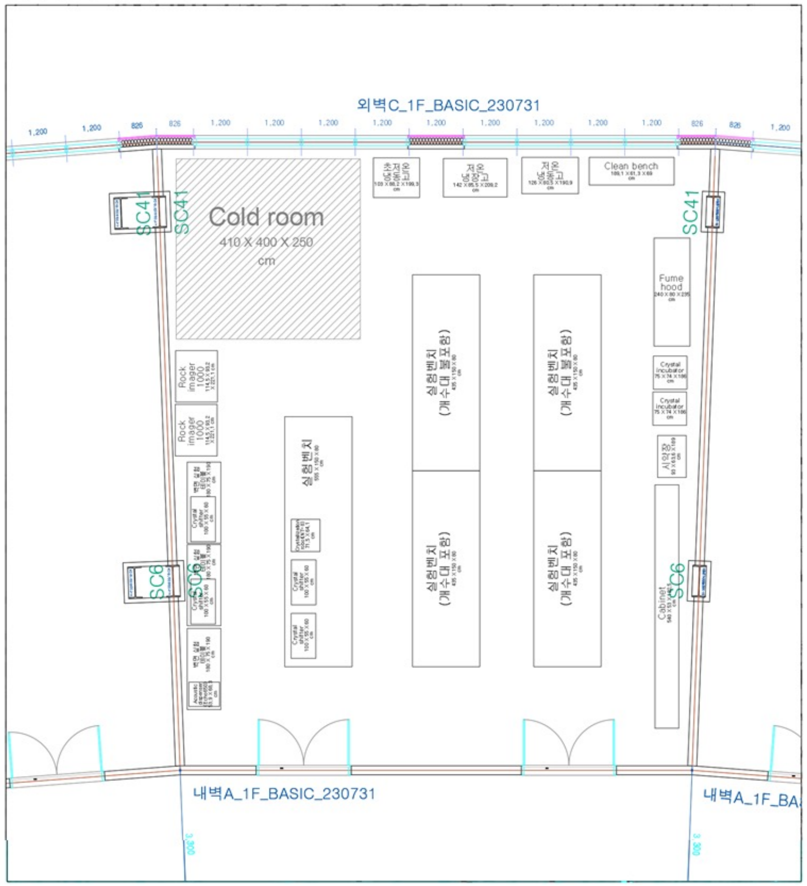
Precise, Accurate, and Efficient Liquid transfer using sound

~ Soaking fragments into crystal drops on plate
~ 30 sec for 100 fragments (one crystallization plate)
~ singleton soaking



- **Facility for sample preparation of FBDD experiment**
- **Support drug discovery experiment**

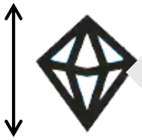
Floor plan of sample preparation laboratory



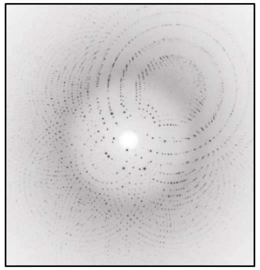
Beamline applications

High-quality data from microcrystal

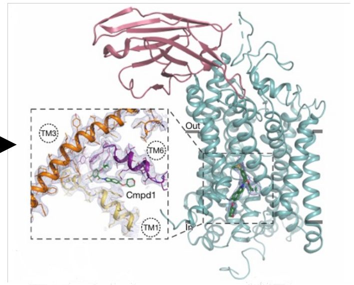
<10 µm



Microcrystal

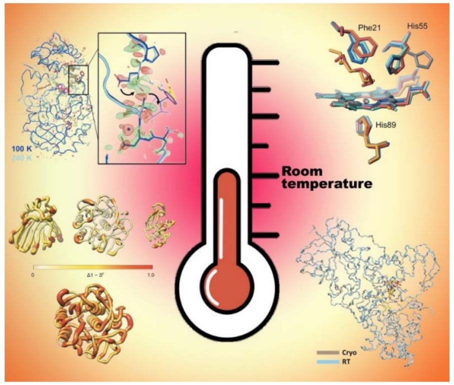


Diffraction pattern



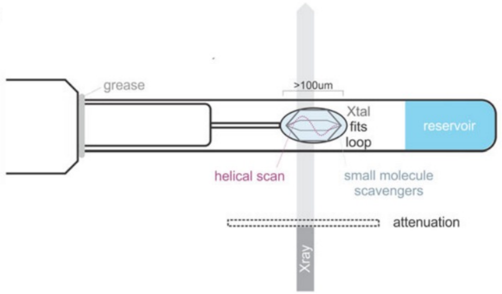
Shahsavar, A., *et al. Nature (2021)*

Room-temperature crystallography



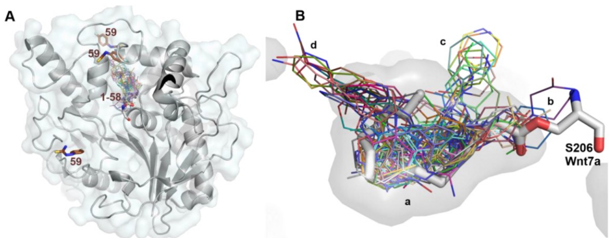
Steiner, R. A., *Struct. Biol.* (2023)

Data collection using capillary tool



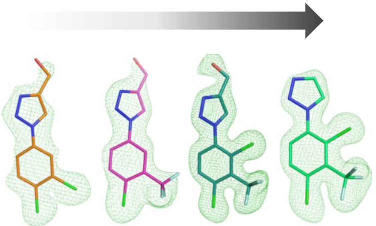
Fischer, M., *Quarterly Reviews of Biophysics* (2021)

Drug discovery



Merged structures of the bound fragments in the enzymatic pocket

Optimization

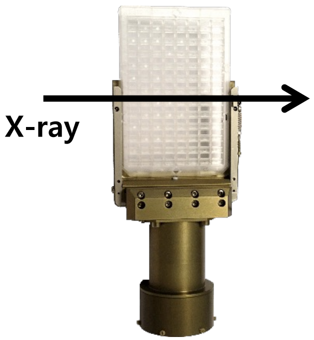


7 IC_{50} 0.5 µM | 7b IC_{50} 0.065 µM | 7c IC_{50} 0.009 µM | 7d IC_{50} 0.0067 µM

Zhao, Y., *et al. ACS Chem. Neuro. (2022)*

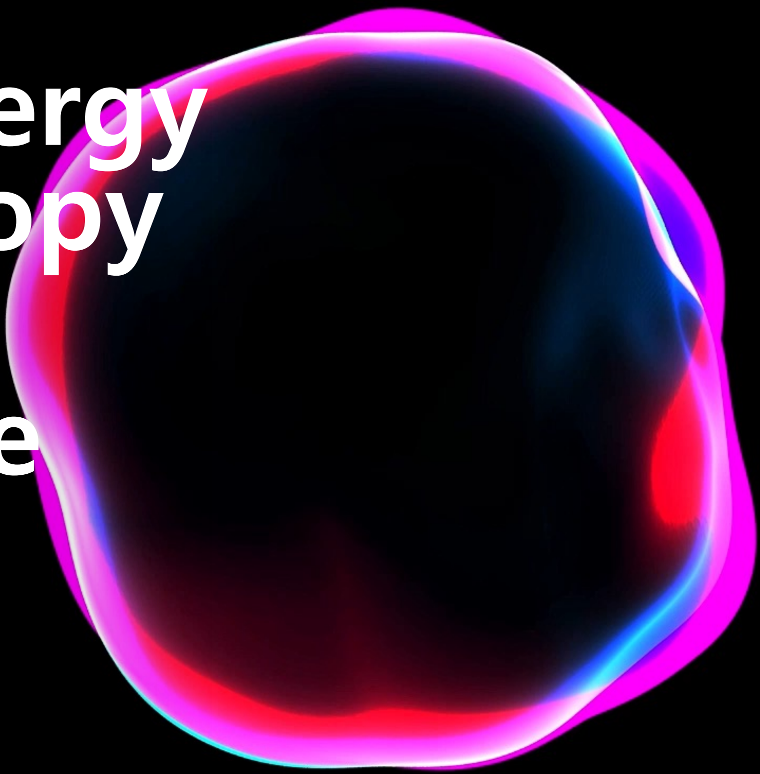
Quick screening of initial crystal

Initial screened crystals



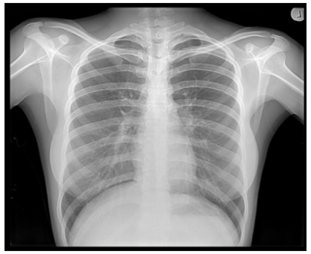
Diffraction or not?

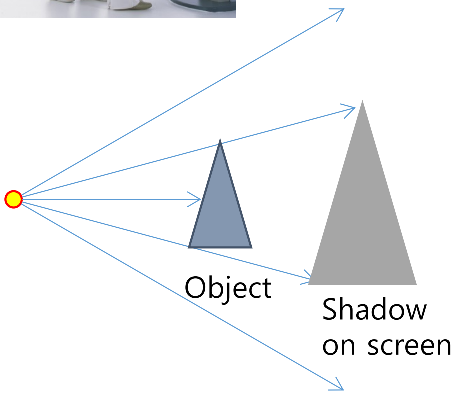
BM10
High Energy Microscopy (HEM) Beamline



Projection imaging

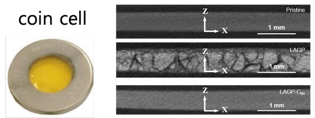
Conventional projection image





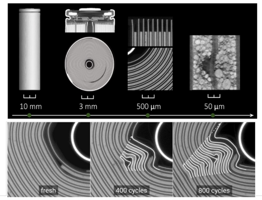
Synchrotron source

- High resolution imaging
- High photon flux
  - Fast scan
  - In situ/operando imaging studies

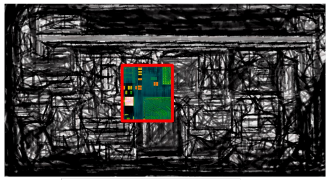


Soft tissue (small sample) image

Increased penetration depth

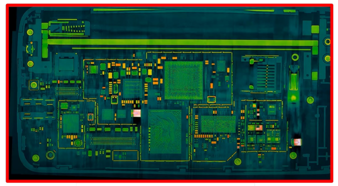


Hard tissue (large sample) image

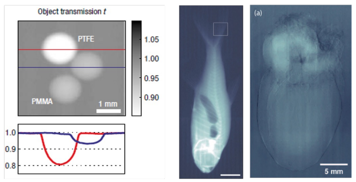


Small FOV

Large Beam

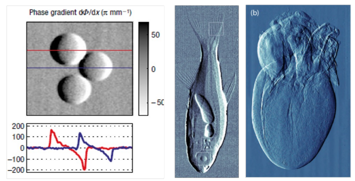


Large FOV



Conventional X-ray transmission image

Contrast and edge enhanced imaging

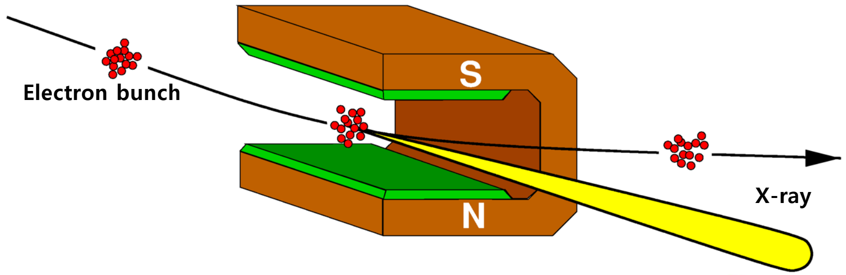


Contrast enhanced image

Design summary

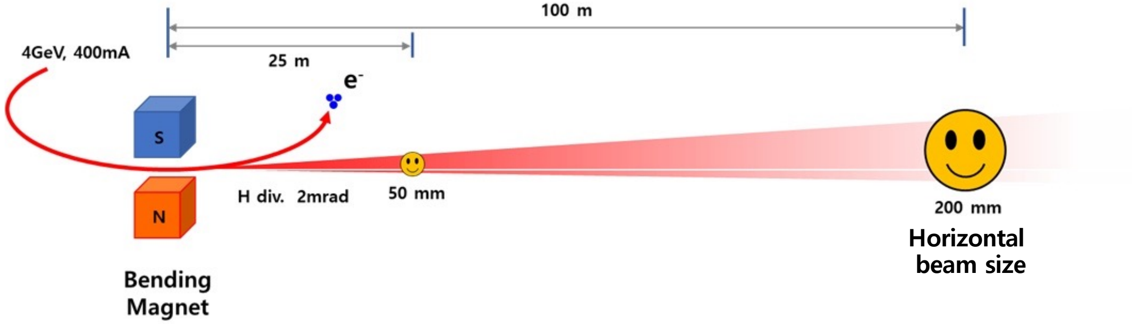
1. High energy beam

Light source: Bending magnet



2. Large beam

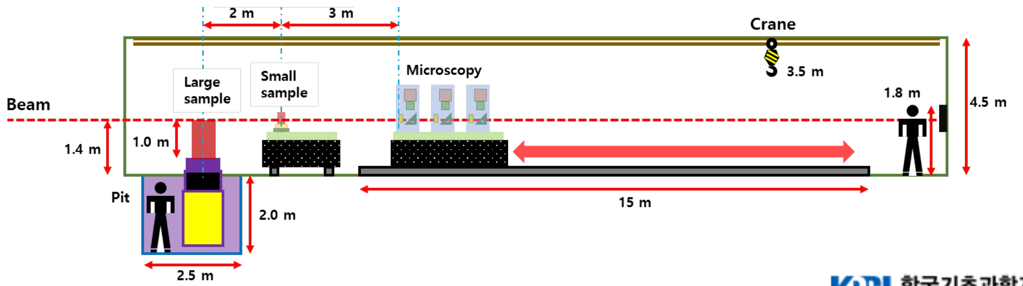
Long beamline 121 m



3. Phase contrast effect

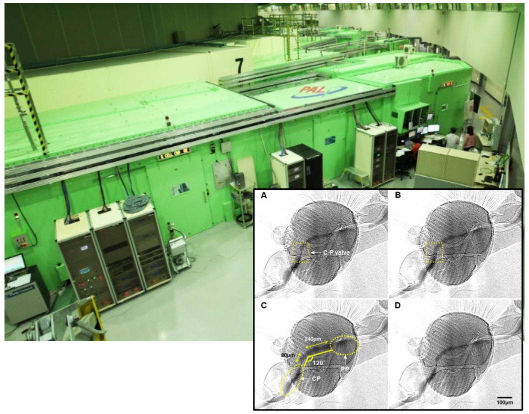
SDD: 5~20 m

End-station design



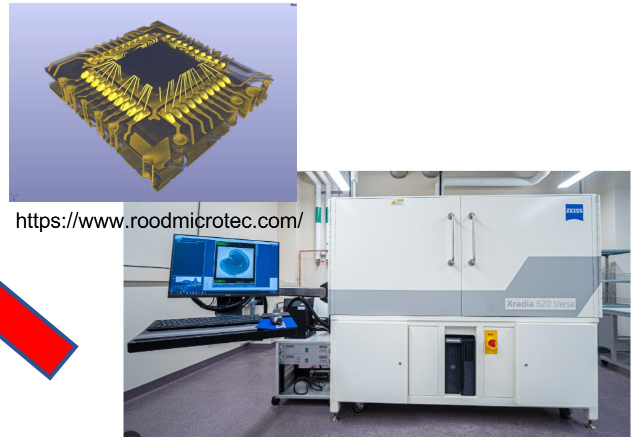
Beamline Design concept

- Full field imaging
- Hard sample — > 100 keV
- Large sample — 200 mm beam size (Bending magnet or Wiggler and Long beamline)
- Fast scan
  - ✓ e.g. 20 hours/scan conventionally -> 10 minutes/scan using synchrotron radiation
- In situ/operando imaging studies



PLS-II X-ray imaging beamlines

High Energy Microscopy beamline



https://www.roodmicrotec.com/

Commercial X-ray imaging systems

BM10 HEM beamline Comments

Source

- Was the possibility of using a 3-pole wiggler as a source investigated? (MAX-IV Dr. Aymeric Robert)

☞ In low-emittance storage rings, the use of a wiggler can produce a spectrum similar to that of an undulator, with discrete harmonic peaks rather than a broad bending magnet spectrum. Furthermore, the photon beam profile tends to exhibit a donut shape rather than a Gaussian distribution.

☞ Although the flux from a 4th-generation storage ring (4GSR) bending magnet is generally lower than that of a wiggler, it is still possible to meet the beamline requirements (~100 keV) by utilizing a 2 T bending magnet source.

☞ At the sample position, the photon flux achievable with this setup is comparable to that of the ESRF-EBS BM18 beamline, which employs a 3-pole wiggler, particularly in the key energy range of 40–100 keV.

End-station

- In designing the beamlines, it is important to utilize state-of-the-art technologies, rather than those available today, for key components such as X-ray optics and detectors. International technical reviews will be recommended for this purpose. (IAC)

☞ We have already recruited International Machine Advisor Committee (IMAC) for each beamline, and as of January 2025, most beamlines have undergone reviews of their key components (optics, end-stations, detectors, etc.), with corresponding reports completed.

Data acquisition

- Is it possible to improve the time resolution of the detector? (KOSUA)

☞ It is possible to achieve higher time resolution by replacing the detector with one that offers faster readout speed. However, the primary objective is to obtain high-quality images.

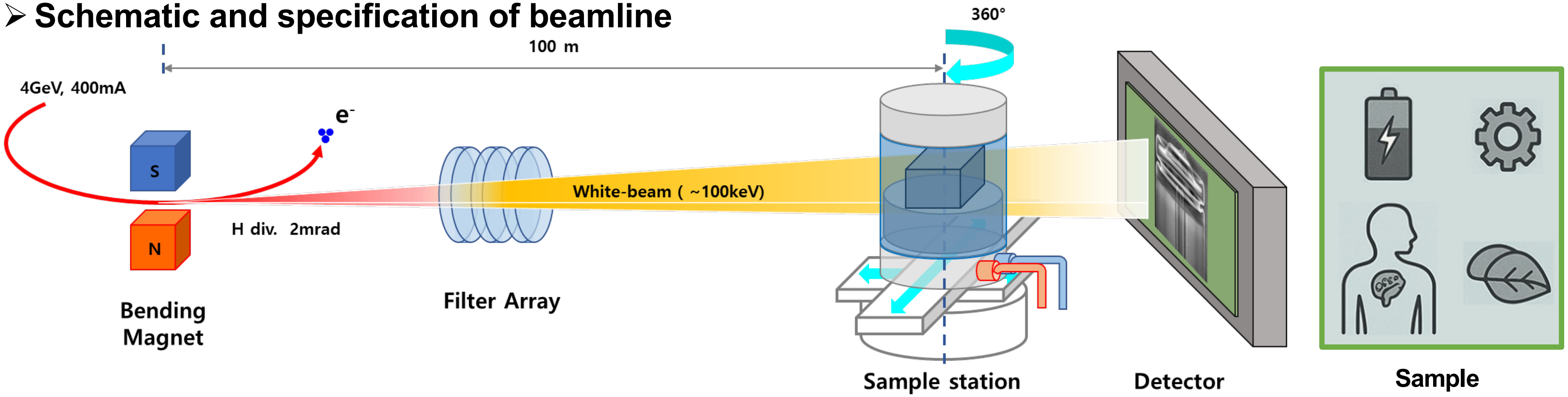
Application

- Is bio-medical research feasible? (KOSUA)

☞ Yes, it is feasible. The experimental hutch is designed with ample space to accommodate a wide range of experiments beyond animal studies.

Overview High Energy Microscopy Beamline

➢ **Schematic and specification of beamline**



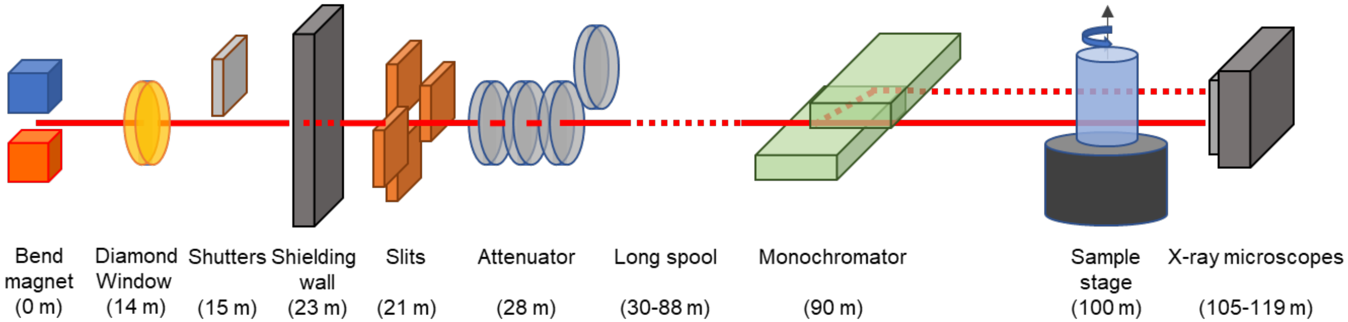
➢ **Beamline Science**

- **High-energy beam : Energy & Materials applications**
- **Large beam size : Industrial applications**
- **Phase contrast effect : Bio-medical imaging**

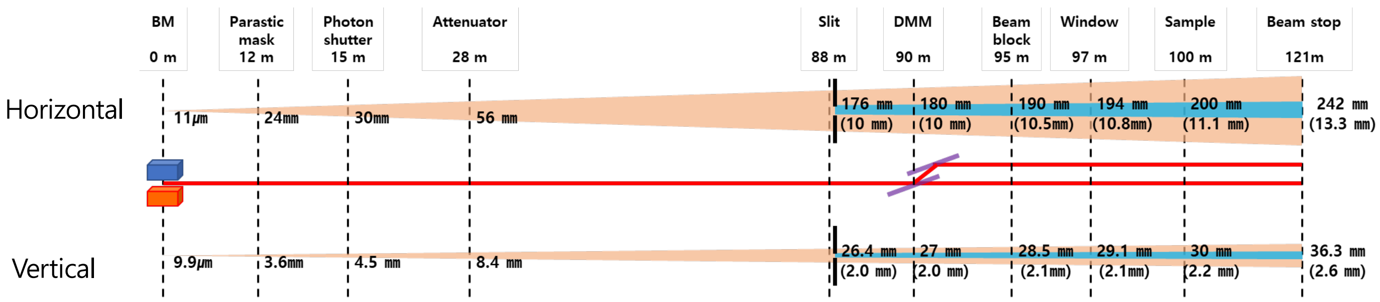
Light Source	Bending Magnet (2T)
Photon energy	5 ~ 100 keV (E_c:21.2 keV)
Beam size (FWHM)	200 mm x 28 mm @ 100 m
SDD	< 20 m
Spatial resolution	> 0.5 um
Technique	Projection imaging
Sample space	a few m (100 kg)

Layout of the HEM beamline

➢ Beamline Layout



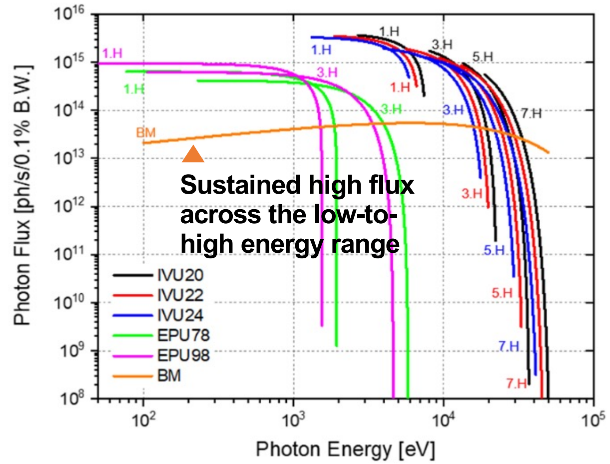
➢ Raytracing



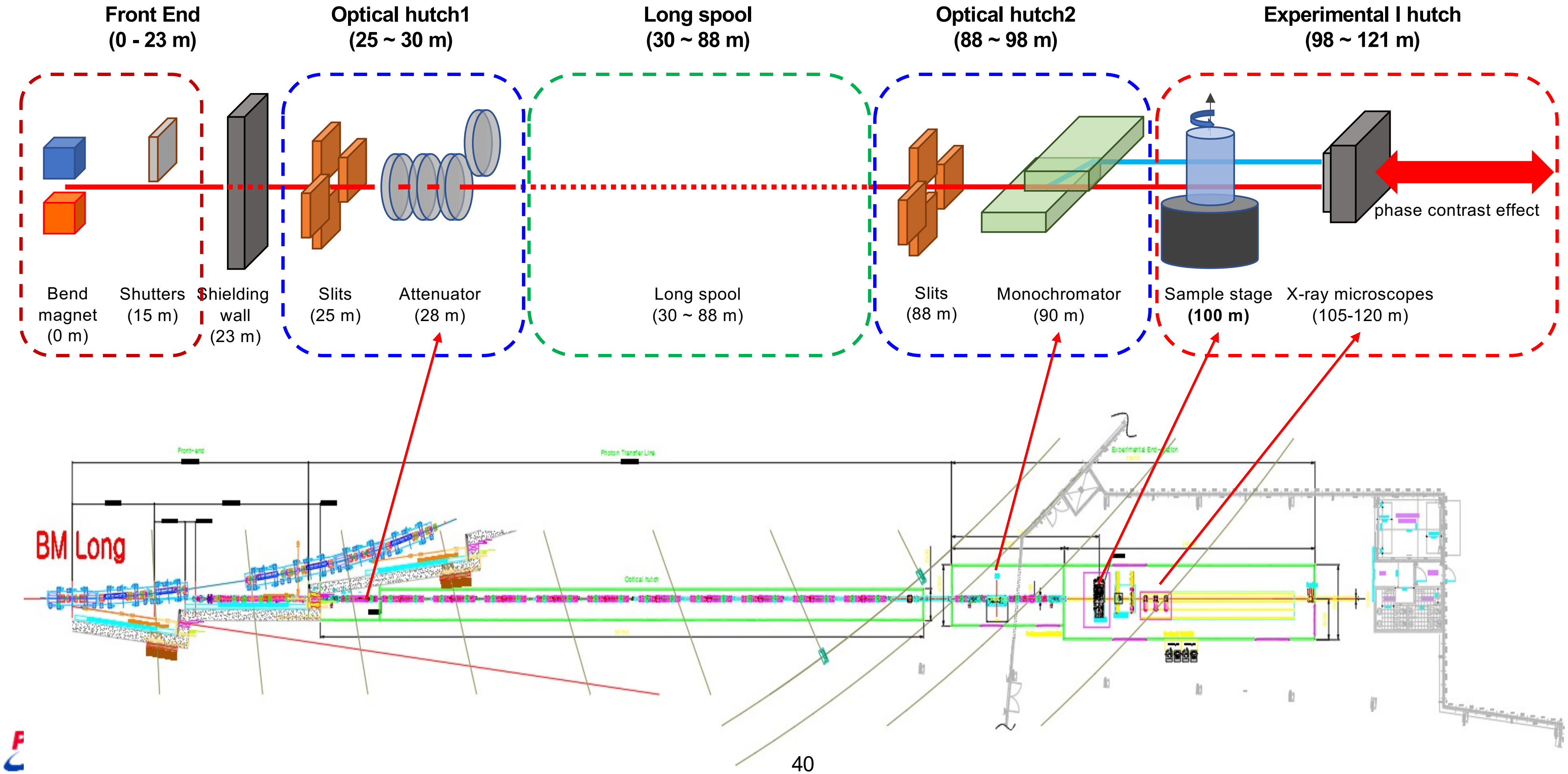
➢ Source

Source Type	**Bend Magnet (BM)**
Magnetic Field	2 T
Magnetic Radius	6.67 m
Total Power	1.36 kW
Critical Energy	21 keV
Electron source size (σ_x, σ_y)	4.6 μm, 4.4 μm
Electron source divergence (σ'_x, σ'_y)	12 μrad, 1.3 μrad
Photon source size in FWHM (Horizontal, Vertical)	**11 μm, 9.9 μm**
Photon source divergence in FWHM (Horizontal, Vertical)	**2 mrad (433 W)** 0.3 mrad @ 10 keV

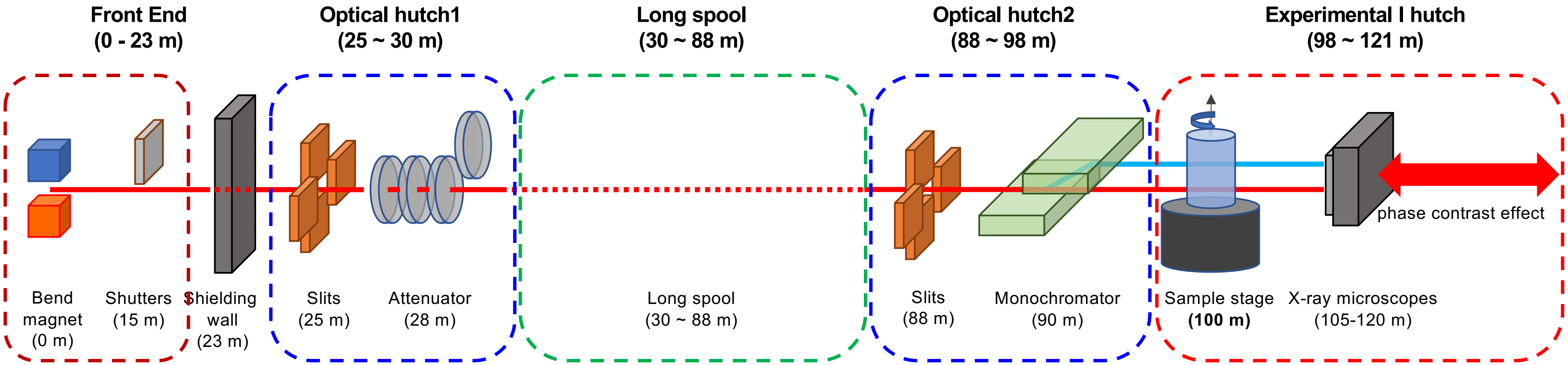
Photon flux of Bending magnet



Layout of the HEM beamline



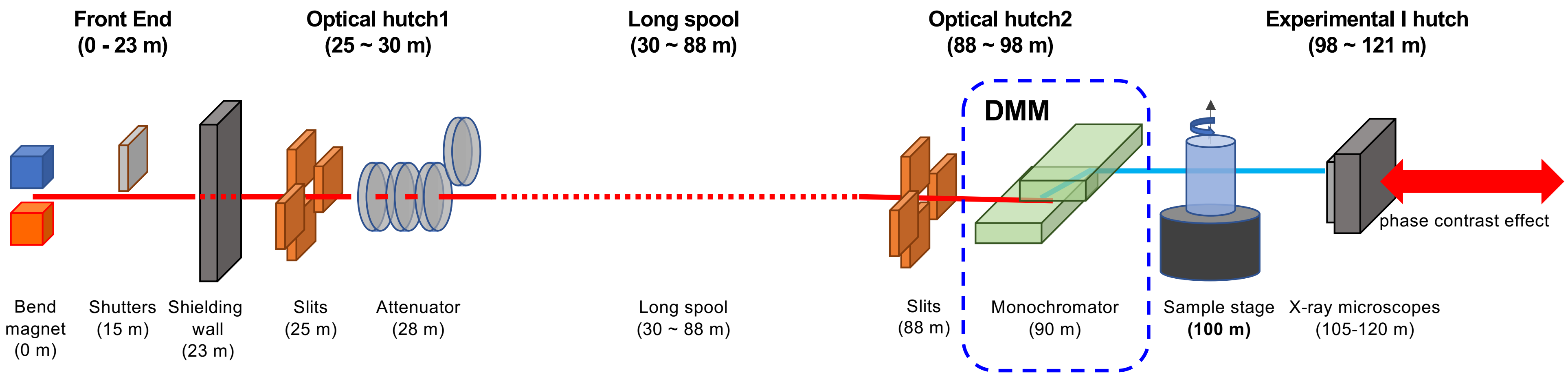
Layout of the HEM beamline



Operation mode

- **Monochromatic-beam mode at 5 ~ 40 keV**
- **White-beam mode at > 40 keV**

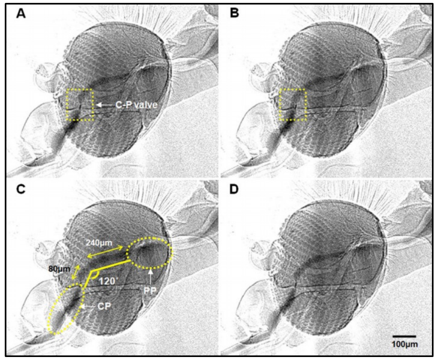
Monochromatic-beam mode (5 ~ 40 keV)



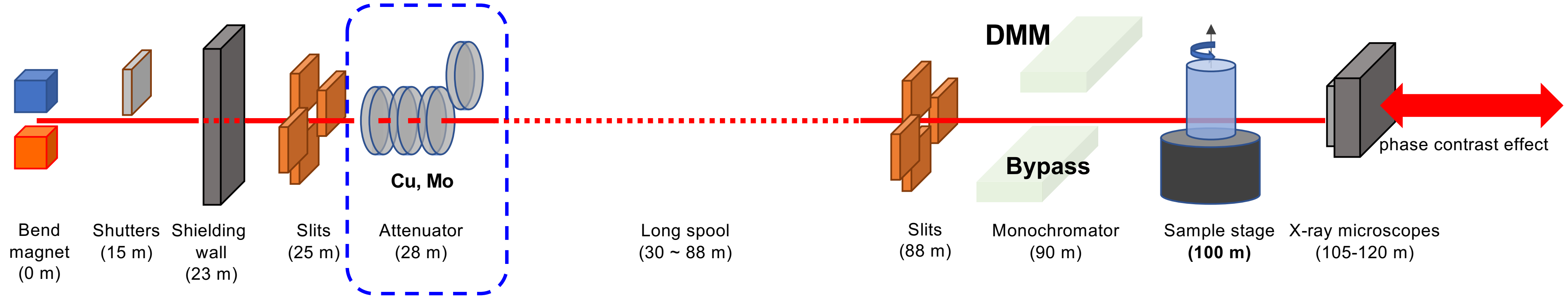
Double Multilayer Monochromator (DMM) Specifications

Properties	DMM (2strips)	
	Ru/C (5~20keV)	**W/B4C (20~40keV)**
Mirror size	55 mm (W) x 310 mm (L) x 50 mm (H)	
Optical footprint	10 mm (W) x 258 mm (L)	10 mm (W) x 258 mm (L)
Coating strip number	2 ea	
Coating strip size	24 mm (W) X 304 (L) mm	24 mm (W) X 304 (L) mm
Beam size	10 mm x 2.0 mm @ 20 keV	10 mm x 2.0 mm @ 40 keV
Coating material	**Ru/C**	**W/B4C**
Period Thickness	4 nm	2 nm
Number of Periods	100	200
Substrate material	Si	
Mirror surface shape	Plane	
Reflection direction	vertical	

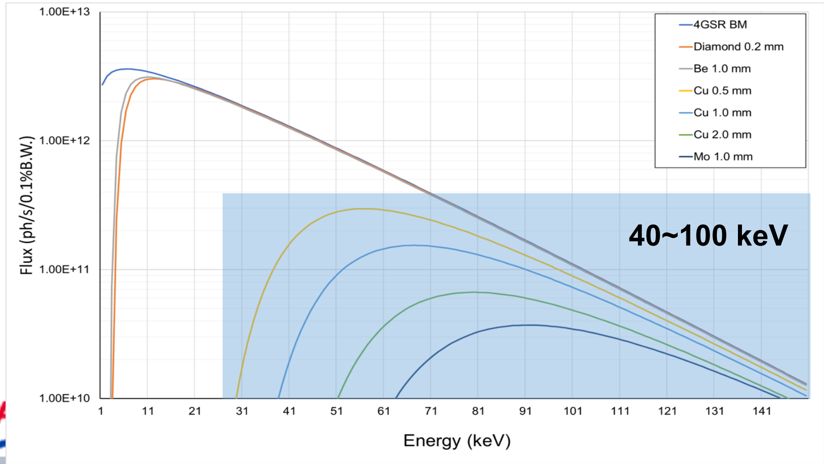
Sub-micron High resolution imaging



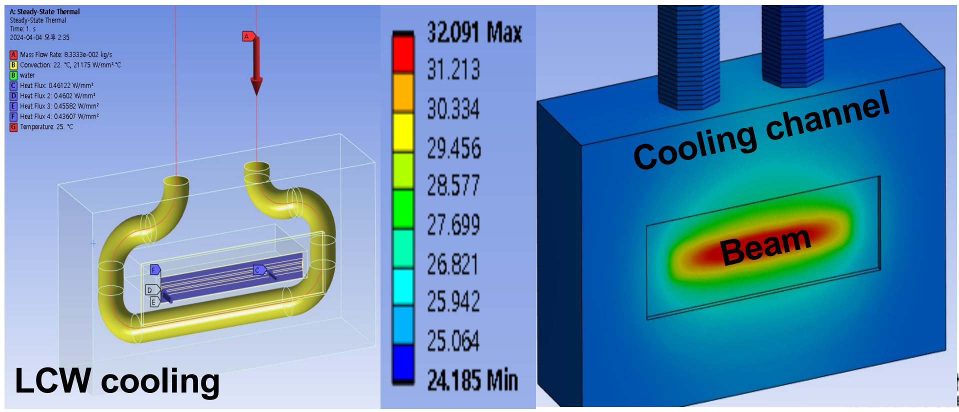
White-beam mode (40 keV ~)



➢ Attenuator (Energy filters)

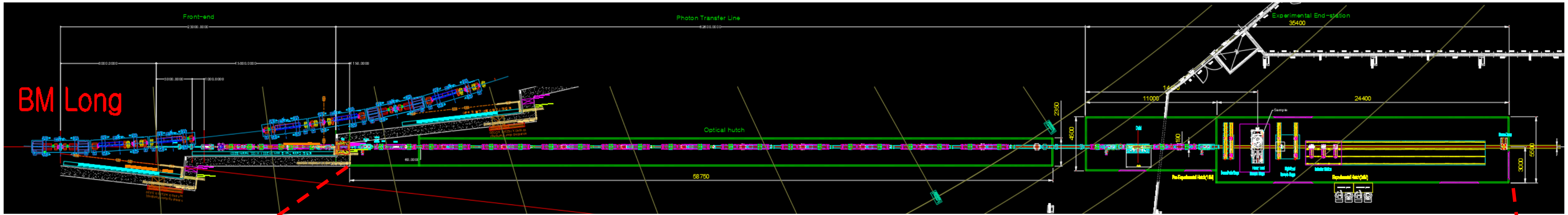


➢ Thermal analysis for attenuator (The white beam attenuator is under development)

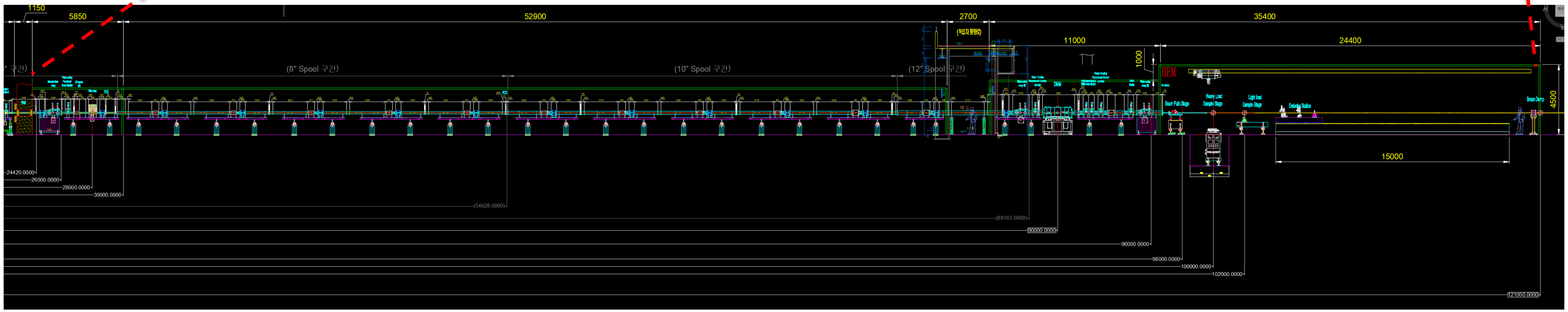


Design drawing

Top view



Side view



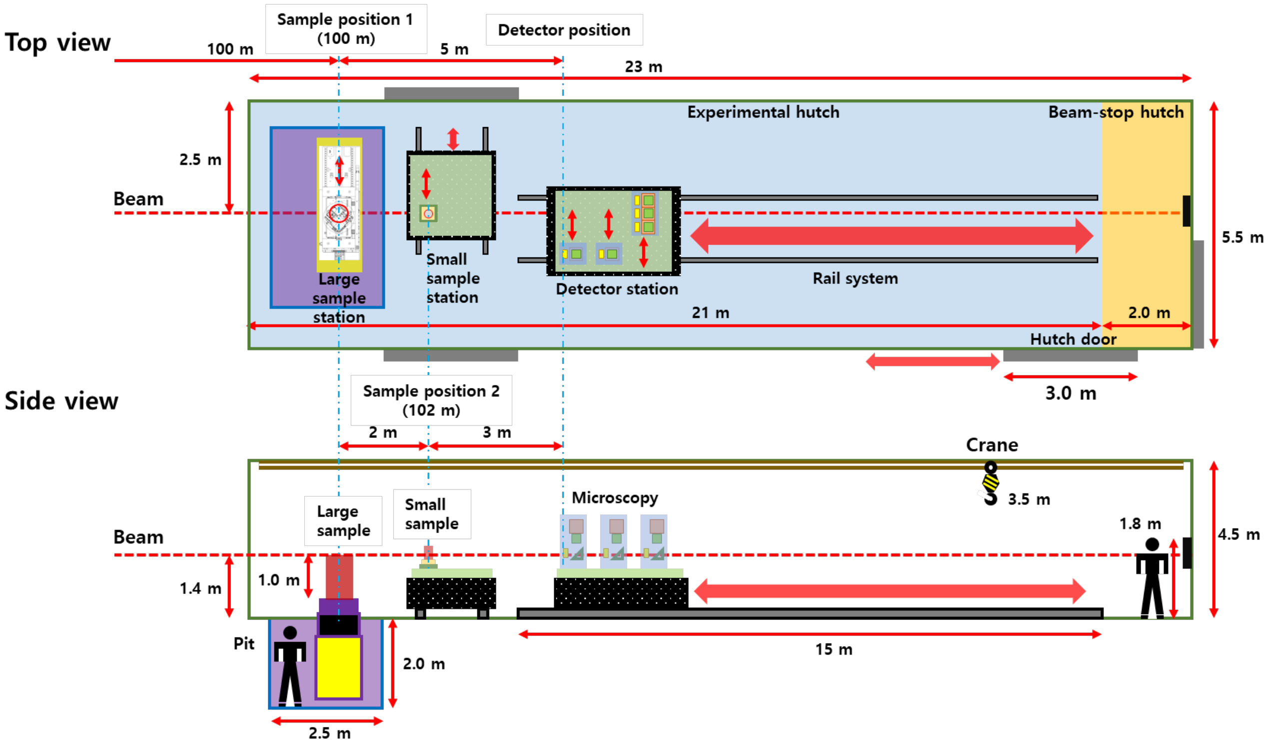
Optical hutch1
5 m

Long spool
58 m

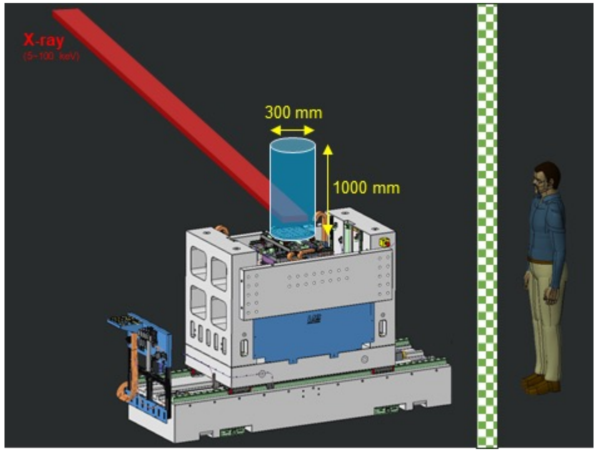
Optical hutch2
10 m

Experimental hutch
23 m

End-station



➢Large sample station



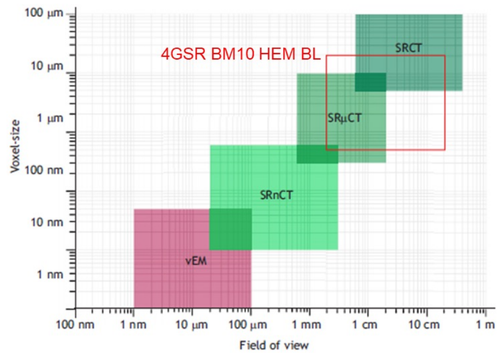
➢Large sample stage Specifications

Data	Dimension
Sample weight	100 kg
Sample dimensions	H=1.0 m, D=0.3 m
Rotation stage	RT500S
Angular accuracy	< 2 arcsec
Max. speed	60 rpm

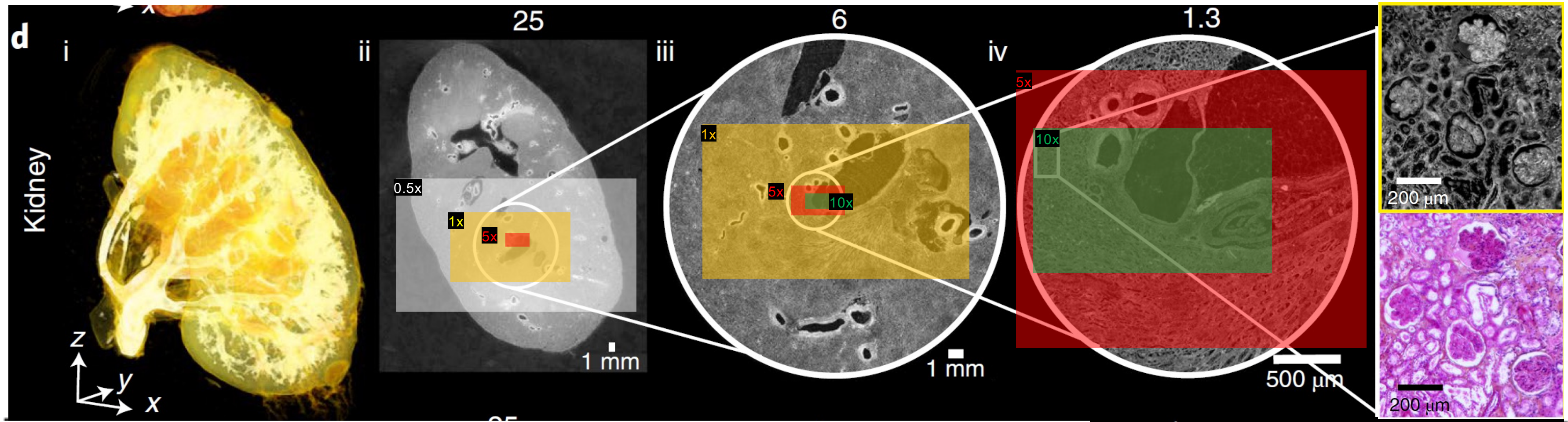
Multiple scale CT scan (Establishing a strategy of the collection of Large FOV image and Mass Data Process)

➢ Image specification (4GSR BM10)

X-ray microscope	Array detector	Single detector			
Field of View	200 x 25 mm^2	38 x 21 mm^2	19 x 11 mm^2	3.8 x 2.1 mm^2	1.9 x 1.1 mm^2
Magnification	0.25x	0.5x	1x	5x	10x
Pixel size	20 µm	9.2 µm	4.6 µm	0.92 µm	0.46 µm
Pixel number	26 million	9 million			
Data size	**52 MB/image**	**18 MB/image**			
3D data size	**205 GB/set**	**25 GB/set**			



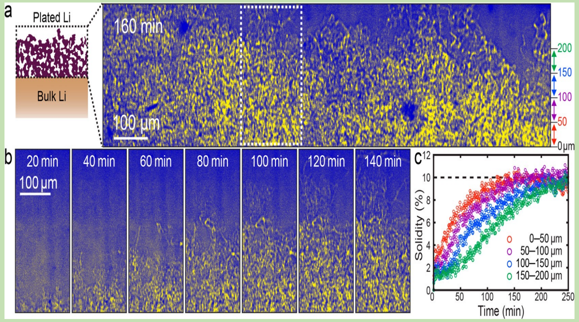
Multiscale Phase-Contrast Tomography (ESRF-EBS BM18)



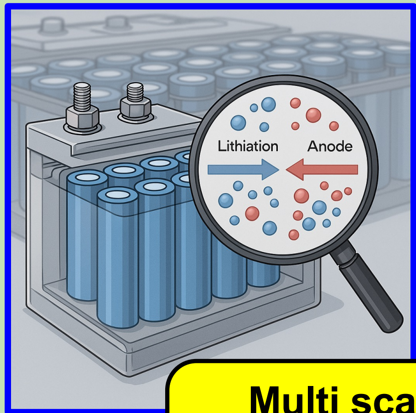
Walsh, C. L., et al. (2021). *Nature methods*, *18*(12), 1532-1541. Images taken at BM05, a predecessor beamline, at 60-80 keV

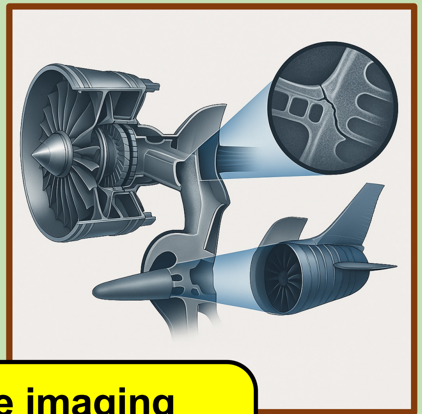
Beamline applications

Energy Material Science

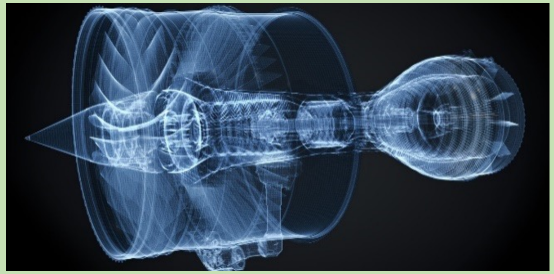


Seung-Ho Yu et al., *J. Am. Chem. Soc.* 41(21) 8441 (2019)





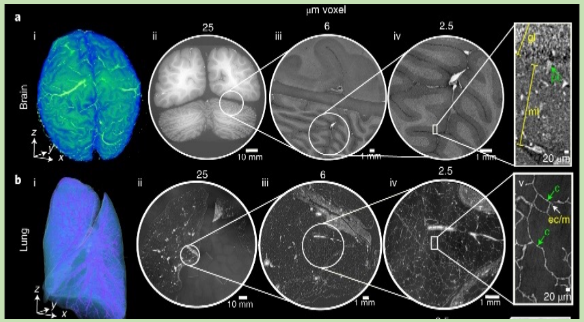
Industrial Applications



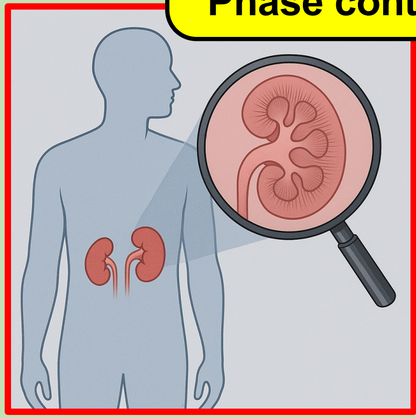
Dragoljub Vujić, Scientific-Technical Review,vol.LIII,no.2,(2003)

Multi scale imaging
In-situ X-ray imaging
Phase contrast imaging

Life Science



Walsh, C. L., et al. (2021). Nature methods, *18*(12), 1532-1541.



Cultural Heritage

불상 속 비밀, 관음보살좌상 (2019) 국립중앙 박물관

Thank you for your attention!

Mi-Jeong Kwak (ID22) (mjkwak@postech.ac.kr)
Yong Sung Park (BM10) (yongsung@postech.ac.kr)
Ji-hun Kim (ID21) (kjh804@postech.ac.kr)