Design Strategies and Progress of Coherent Beamlines at Korea-4GSR for Advanced Science

- ID03 CoXRD

- ID04 CoSAXS

- ID10 Hard X-ray Nanoprobe

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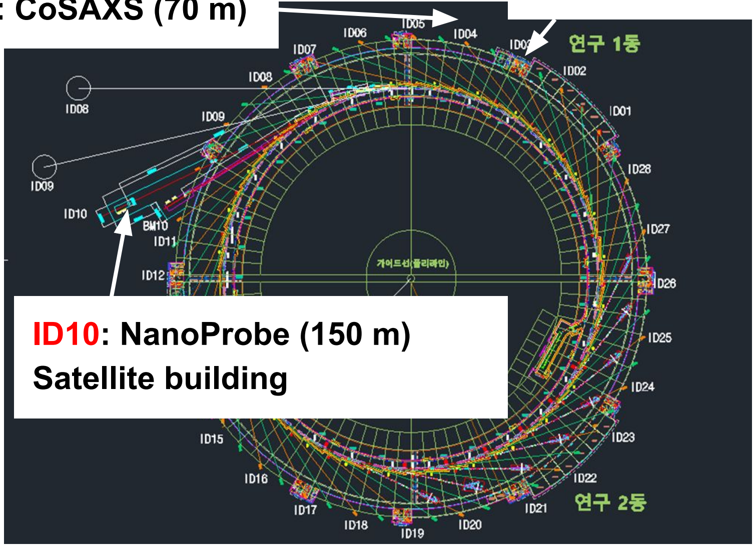
Jun Lim, Jehan Kim, Su-Yong Lee(PLS-II)

Overview

Coherent beamlines of Korea-4GSR

ID04: CoSAXS (70 m)

ID03: CoXRD (70 m)



ID10: NanoProbe (150 m)
Satellite building

Beamlines of 1st phase

① BioPharma-BioSAXS
② Material Structure Analysis
③ Soft X-ray Nano-probe
④ Nanoscale Angle-resolved Photoemission Spectroscopy
⑤ Coherent X-ray Diffraction
⑥ Coherent Small-angle X-ray Scattering
⑦ Real-time X-ray Absorption Fine Structure
⑧ Bio Nano crystallography
⑨ High Energy Microscopy
⑩ Nanoprobe

Electron Beam Energy: 4 GeV (800 m Circular Orbit)

Electron Beam Emittance: 62 pm·rad (Flat beam)

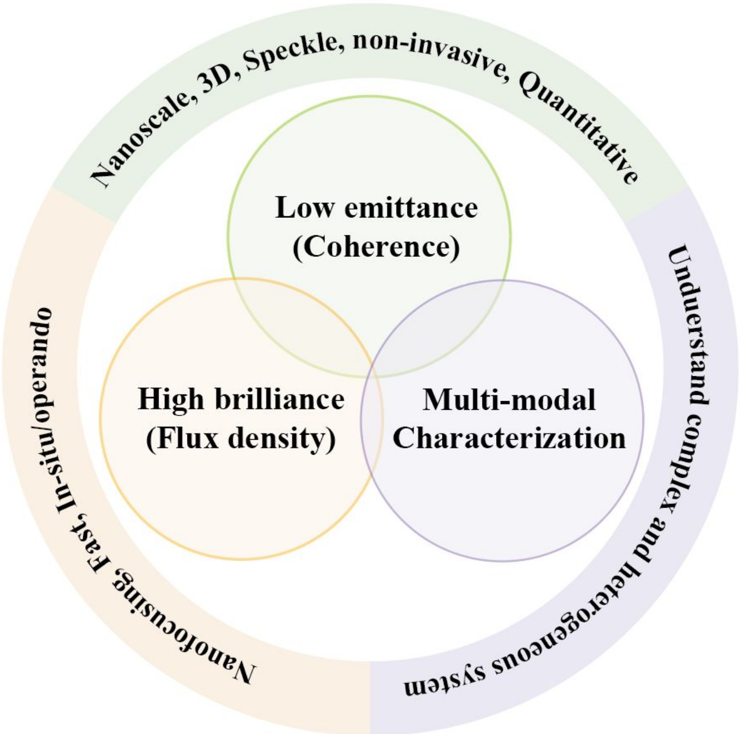
Beamlines: Over 40 (Initially 10)

Acceleration Method: Electron Gun, Injector Linac, 4 GeV Booster

Storage Ring: MBA-Based 7BA Magnet Configuration

Features of Coherent beamline

4GSR Coherent beamlines provide a variety of capabilities within "User's sweet spot"



Coherent X-ray beam (5-25 keV)

Coherent scattering & imaging
- 3D quantitative imaging with highest spatial resolution
- Photon correlation spectroscopy probe dynamics from sub-μsec onward

Small-beam diffraction & spectroscopy
- Chemical and structural Nanoscale imaging
- High sensitivity for dilute & heterogeneous sample

Multi-modal characterization
- Provide a variety of simultaneous probes in a fixed setup
- Provide multimodal analysis to understanding to complex and heterogeneous systems

Beamline design goal and strategy of Coherent beamlines

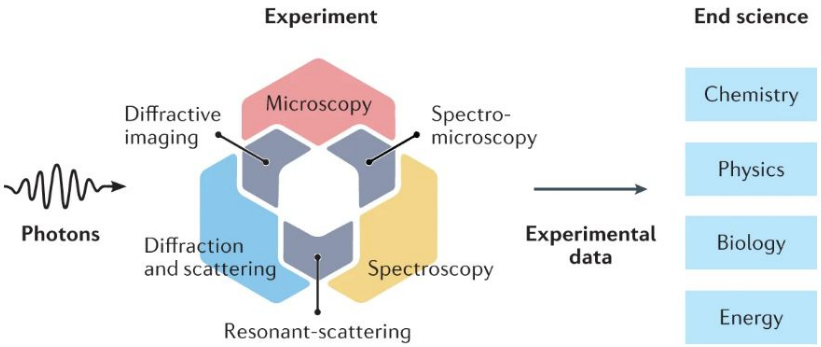
High-Fidelity Beamline Design for Advanced X-ray Science
: Optimized for High stability, Wavefront preservation, and Future Scalability

1. Stable Beam

- < 10 % rule (Beam position and intensity)
  → Using horizontal deflection optics
  → Apply to stable HVAC(0.1 ℃) and low vibration
- (Slow) Beam position feedback

2. Wavefront preservation

- High precision optics
  → Ultra-low roughness and slope error mirror
  → Polishing Diamond CRL
  → Clean surface and crystal attenuator(Silicon/Dia.)
- Simple is BEST
  (Configure with as few optics as possible)
  ↔ Secondary source
  (For scanning imaging, Nanoprobe)
- Diamond diagnostics
  → Clean and low roughness surface
- UHV Fast close shutter system
  → Few vacuum window



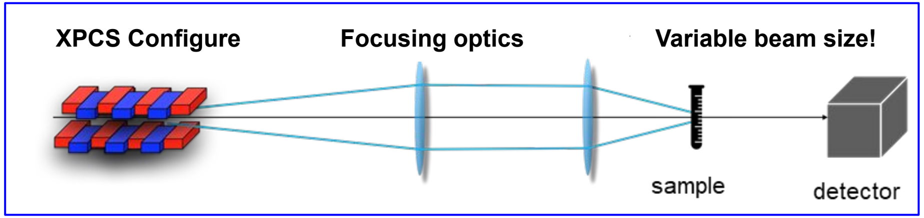
Nature Reviews Physics 3.12 (2021): 766-768.

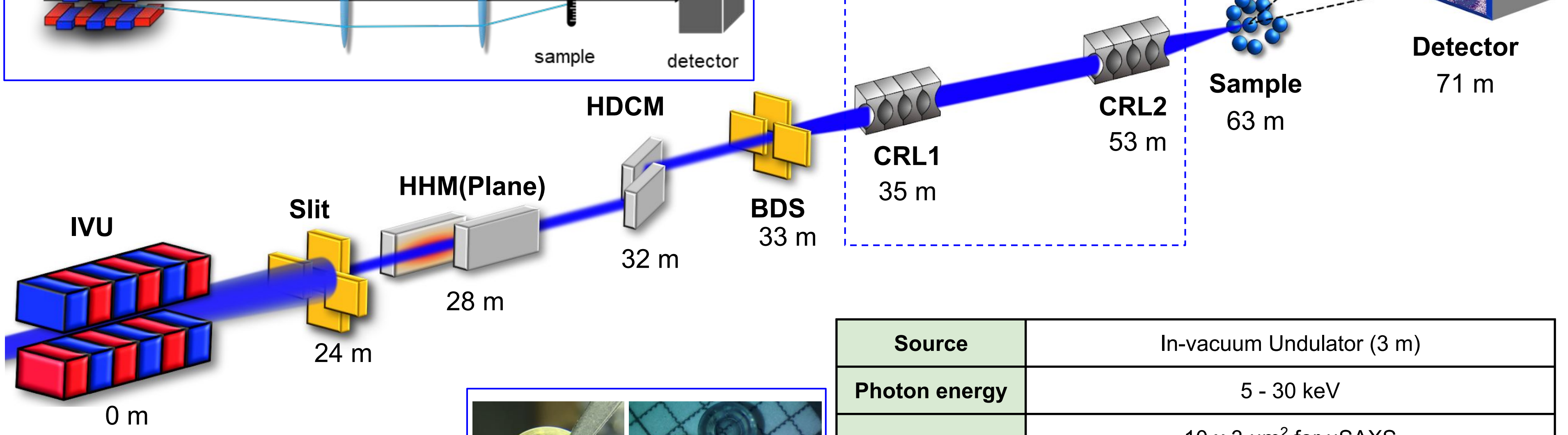
3. Scalability

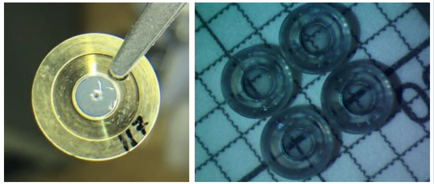
- Large experimental Hutch (or two experimental Hutch)
  → New experimental method and instrument test space
- Long working distance
  → In-situ experiments and other instrument assessments
- Domestically produced equipment
  → High speed nanoscan stage with wide scan range
  → End-station chamber etc.

ID04 CoSAXS

Beamline layout of CoSAXS



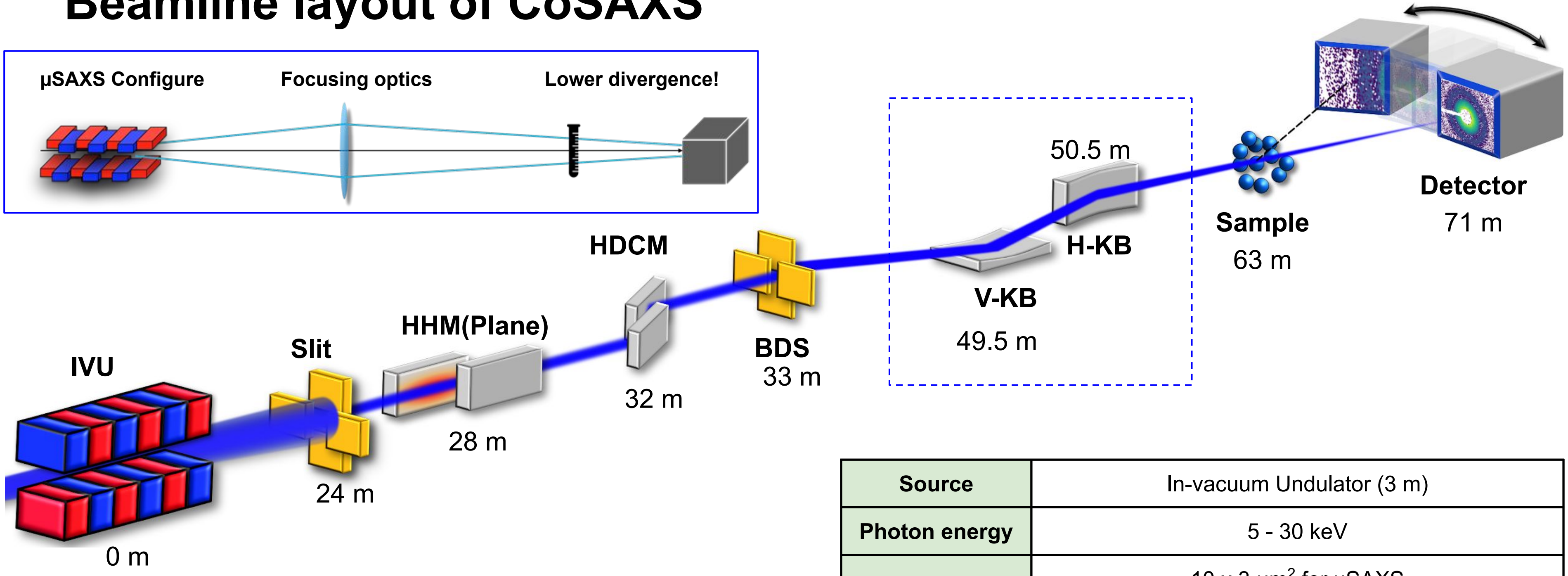




R: 3 mm, Aperture: 2.4 mm
R: 350 um, Aperture: 800 μm

Source	In-vacuum Undulator (3 m)
Photon energy	5 - 30 keV
Beam size	10 x 3 μm^2 for μSAXS 1 - 10 μm for XPCS
Resolution	Q_{min} = 0.01 $Å^{-1}$ / Q_{max} = 2.70 $Å^{-1}$
Coh. Beam flux	10^{11} - 10^{12} photons/s @ Sample
Techniques	(GI)XPCS, μ(GI)SAXS/WAXS

Beamline layout of CoSAXS



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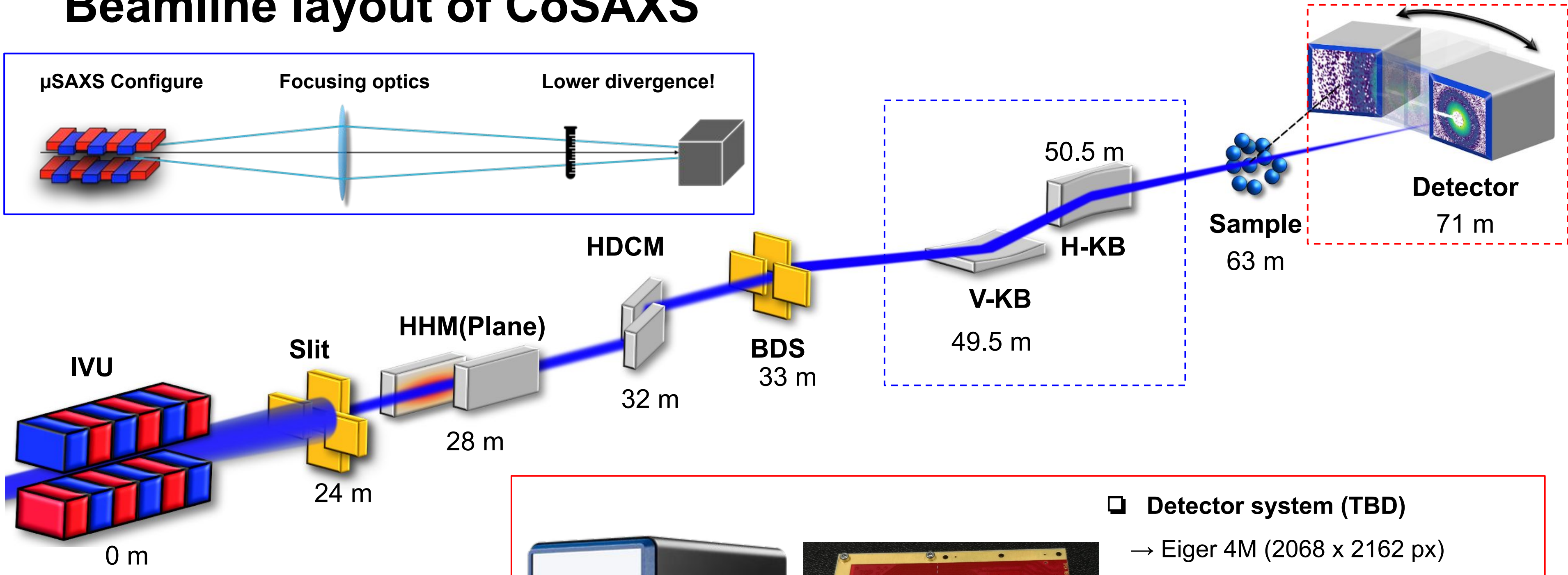
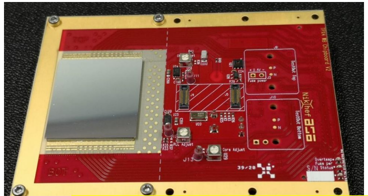
Beamline layout of CoSAXS





Timepix4v1 with full (512 x 448) Si sensor (March 2021)

- ❑ **Detector system (TBD)**
  - → Eiger 4M (2068 x 2162 px)
    (1kHz, Robust detector for uSAXS)
  - → TimePix4 (512 X 448 px)
    (40 kHz frame rates for XPCS
    + **event driven detection mode)**

Main design criteria: Signal to noise ratio (SNR) and speckle contrast

SNR = $\beta \bar{k} \sqrt{N_f N_p} > 5$

$$\beta = \beta(d_b, l_c, d, L, P, q)$$

β: speckle contrast

$\bar{k}$: intensity (photons/frame) Sample & Source flux

N_f: number of frames detector

N_p: number of pixels detector

d_b: coherent beam size at the sample Beamline Config.

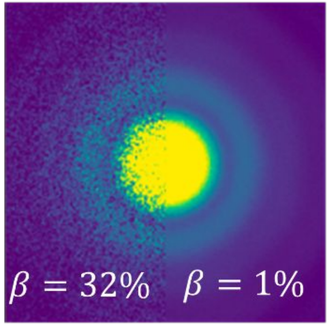
l_c: longitudinal coherence length Source (DCM)

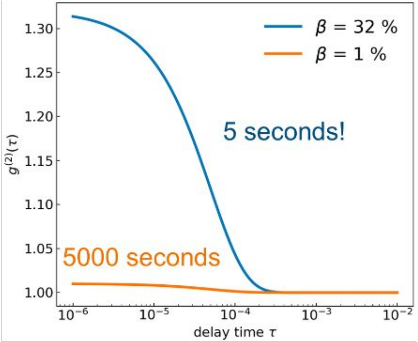
d: sample thickness Sample

L: sample to detector distance Beamline Config.

P: detector pixel size detector

q: wave vector Exp. Config.





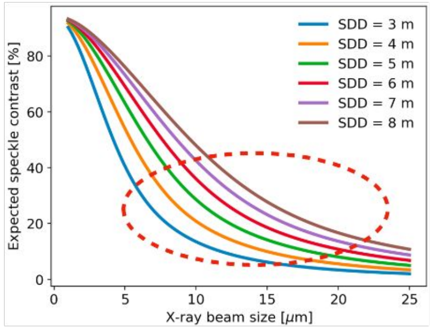
SNR higher than 5 is preferred

Higher β is crucial key for the XPCS beamline

Example

When $\bar{k}$ = 10^{-3} photons/frame and $N_p = 10^5$ (0.1 Megapixel), and detector frame rate = 500 Hz

SNR = 5			
Contrast	0.01	0.1	0.3
Needed number of frames	2500000	25000	2777
Acquisition time [s]	**5000 s**	**50 s**	**5.55 s**



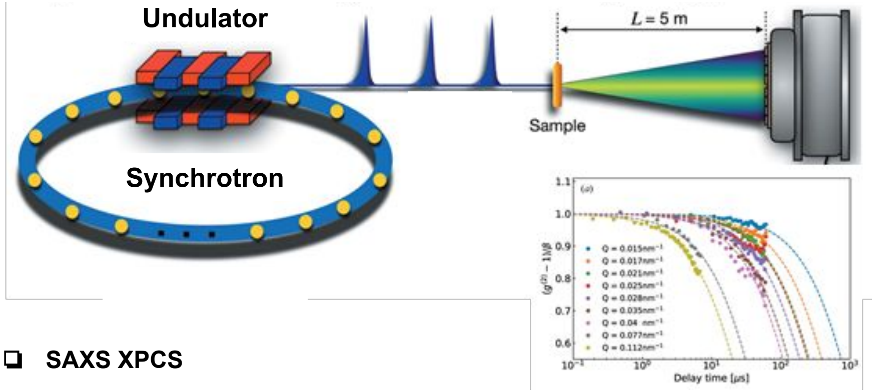
$$g^{(2)}(\tau) = 1 + \beta exp(-2\tau/\tau_c)$$

Target contrast

Coherent beam size and the detector distance are the most important!

For the X-ray sensitive sample e.g., protein or polymer, larger beam size and longer detector distance is required

Primary technique - X-ray Photon Correlation Spectroscopy



- The speckle pattern is from the spatial arrangement of the scatters.
- Speckle-based technique to study **dynamics in disordered systems**
- **Temporal changes are captured via speckle evolution**
- Intensity correlation function reveals **dynamic behavior**
- **Spatiotemporal resolution depends on coherent X-ray beam properties and detector readout speed**

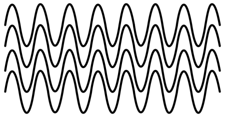
❑ **SAXS XPCS**

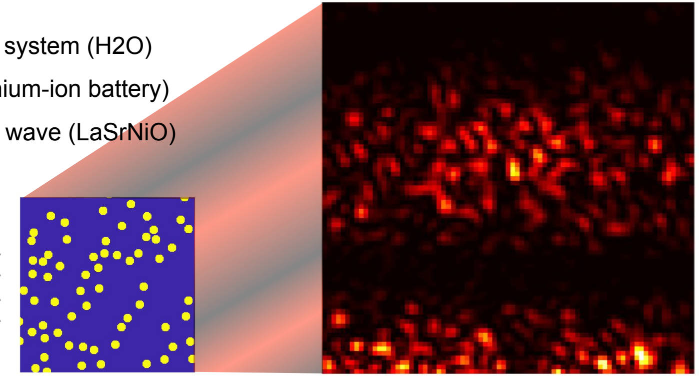
- Colloidal particle (Au, SiO2) in biological environment
- Protein (Ferritin, egg yolk)

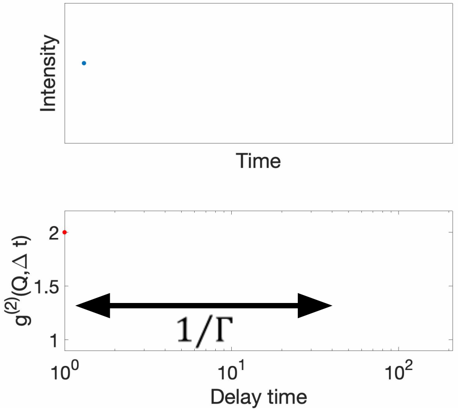
❑ **WAXS XPCS**

- Amorphous Ice system (H_2O)
- Electrolyte (Lithium-ion battery)
- Charge density wave (LaSrNiO)

Coherent beam







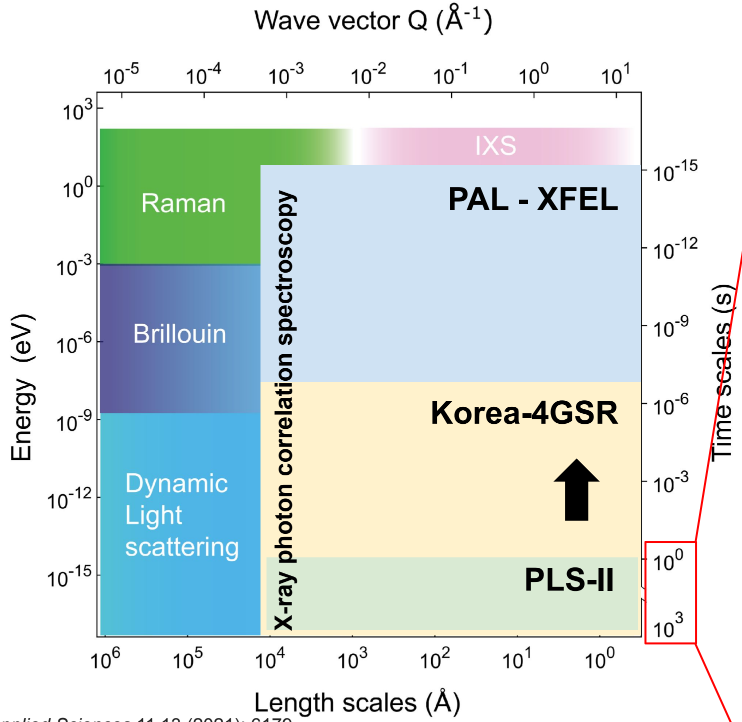
Intensity correlation function

$$g^{(2)}(q,\tau) = \frac{\langle I(q,t)I(q,t+\tau)\rangle}{\langle I(q,t)\rangle^2}$$

$$= 1 + \beta|f(q,\tau)|^2$$

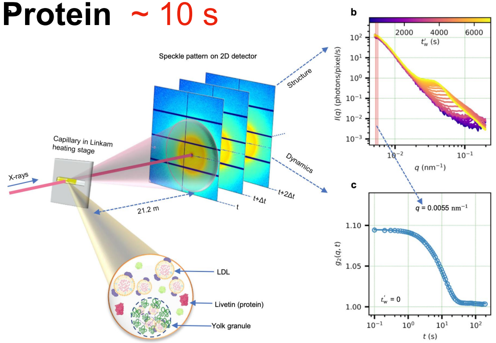
$$= 1 + \beta exp(-2\Gamma(q)t)$$

Target science of CoSAXS beamline



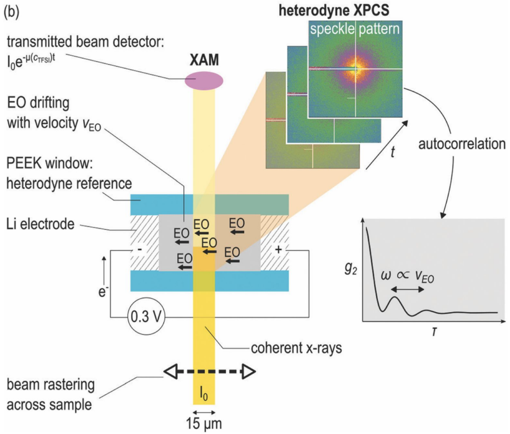
Applied Sciences 11.13 (2021): 6179.

Protein ~ 10 s



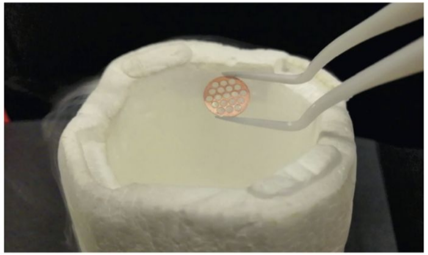
N. D. Anthuparambil et al., Nat. Commun., ***14***, *5580 (2023)*

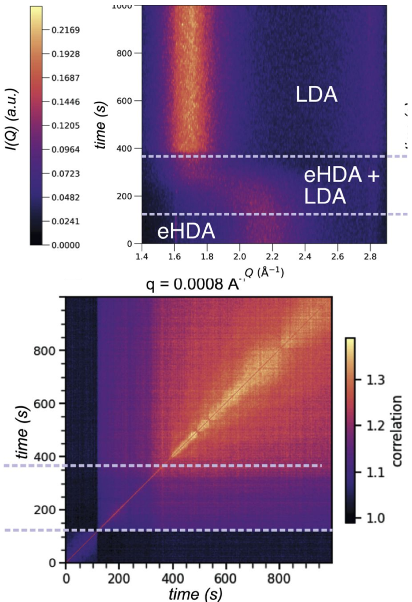
Electrolyte ~ 10 s



H. Steinrück., Energy Environ. Sci., ***13***, *4312 (2020)*

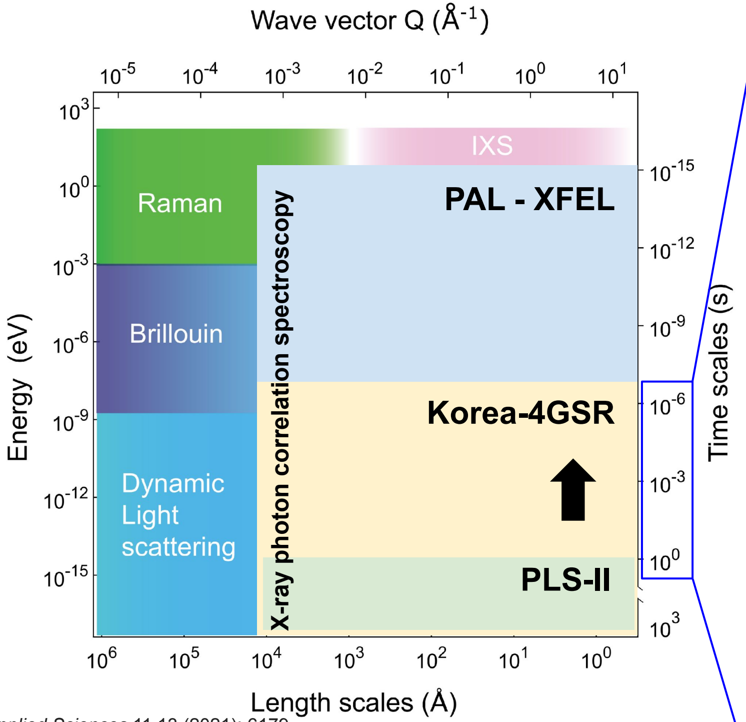
Amorphous ice ~ 100 s





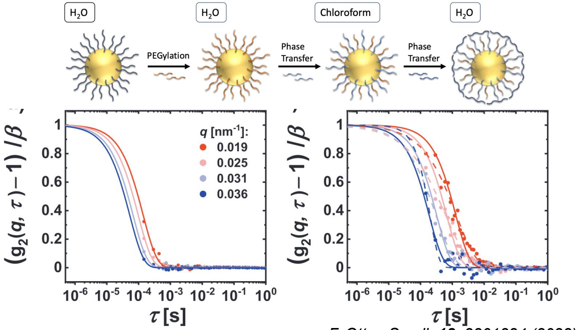
M. Ladd-Parada., Environ. Sci: Atmos, ***2***, *1314 (2022)*

Target science of CoSAXS beamline



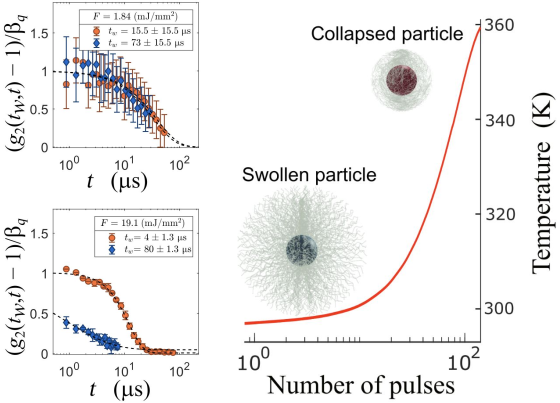
Applied Sciences 11.13 (2021): 6179.

Colloidal particles in biological environment ~ ms



F. Otto., Small, **18**, 2201324 (2022)

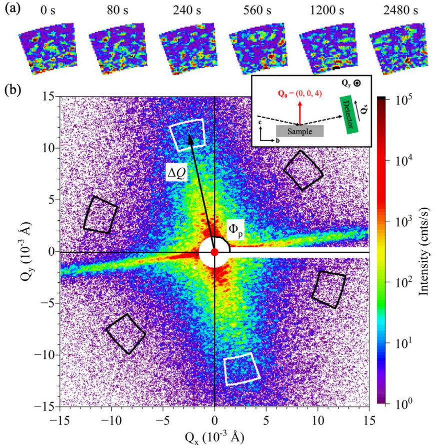
Polymer ~ s



F. Dallari., Sci. Adv., **10**, 7876 (2024)

Charge Density Wave (CDW)

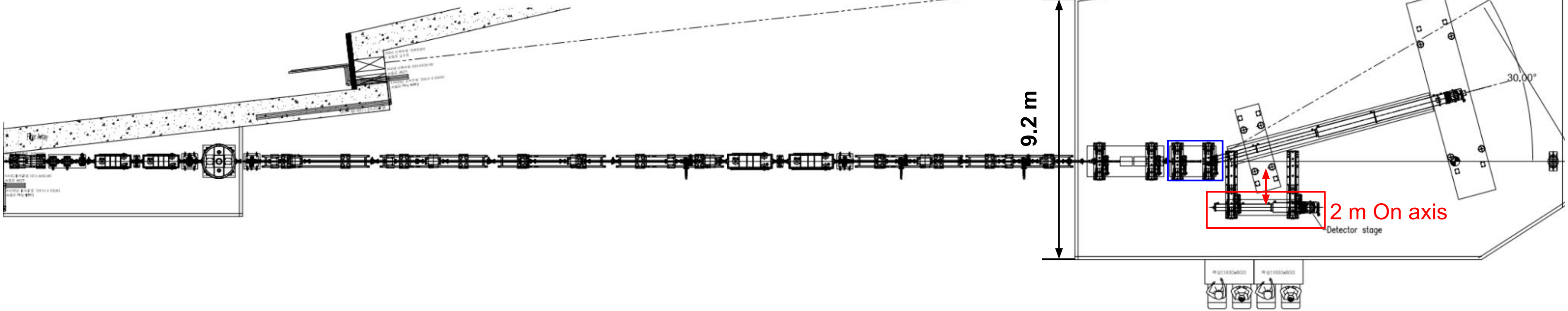
~ 0.1 s



L. Shen., Phys. Rev. B, **108**, L201111 (2023)

Experimental set up and operation mode

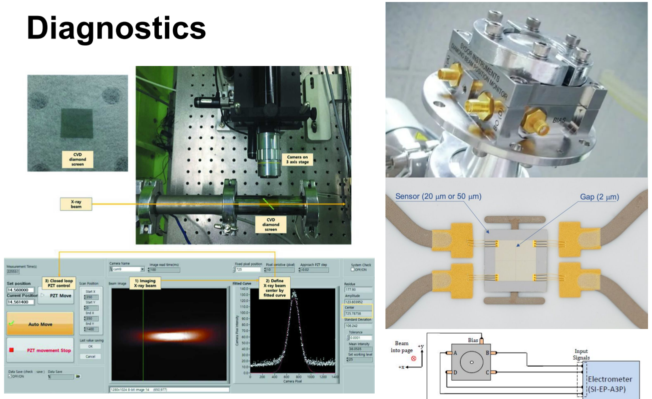
❖ Endstation - Experimental hutch (CoSAXS)



Optical Hutch

- **Hutch dimension**
  : 10.0 x 3.0 x 3.0 (L x W x H)
- **Main components**
  : High Heat Load Mirrors
  : Horizontal DCM
  : Screen monitors
  : DBPM

Diagnostics



Synchrotron Radiation 24.6 (2017): 1276-1282.

Figure 2: Diamond beam position monitor connection setup diagram.

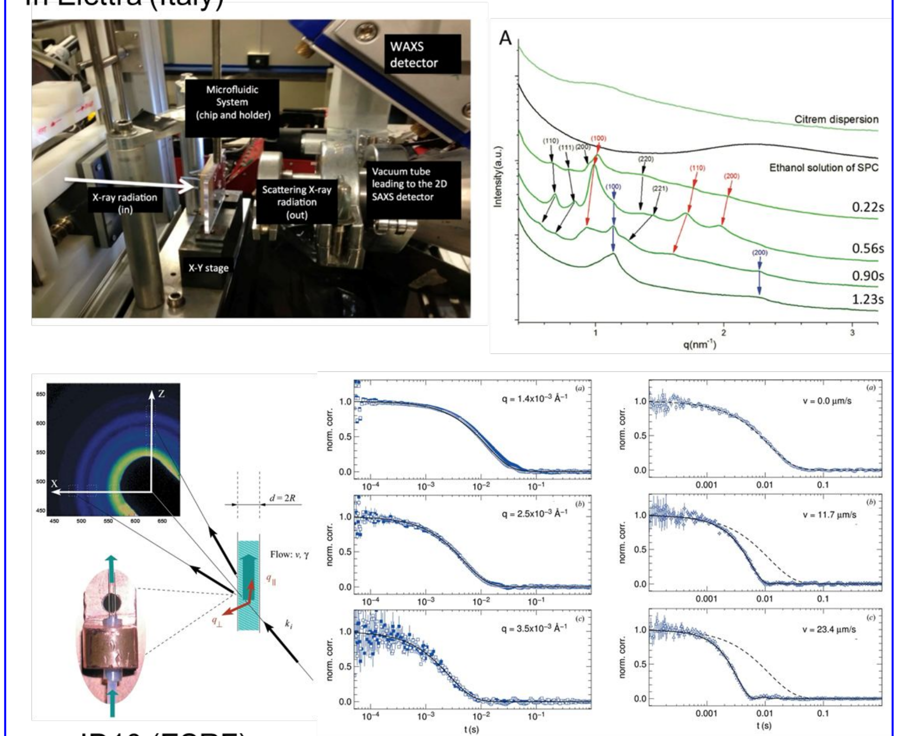
Experimental Hutch

- **Hutch dimension**
  : 16.0 x 9.2 x 4.0 (L x W x H)
- **Sample position**
  : 63.0 m
- **Sample to detector**
  : 8 m (Adjustable 0 - 30 °); 2 m (On axis)
- **Beam path aperture**
  : 200 mm
- **Purpose**
  : XPCS, SAXS/WAXS

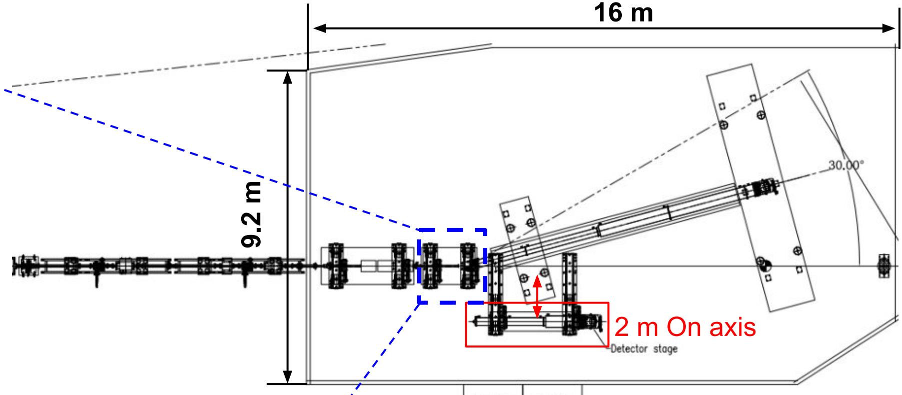
Experimental set up and operation mode

❖ Endstation - Experimental hutch (CoSAXS)

In Elettra (Italy)



ID10 (ESRF)



Microfluidic system

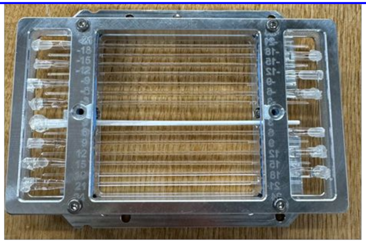
- Enables **automatic sample refreshing**
- Supports **in-situ measurements** during **sample synthesis**
- Requires **less sample volume**, ideal for limited or precious materials
- Commonly used in **SAXS measurements** for **biological** and **polymer systems**

XPCS at Microfluidic system

- Demonstrated **XPCS measurements** in a **microfluidic setup**
- **Sample flow** influences the observed dynamics
- With **high temporal resolution** and **proper data analysis**, it is possible to **decouple intrinsic sample dynamics** from **flow-induced motion**

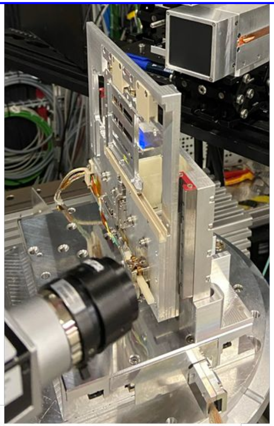
Experimental set up and operation mode

❖ Endstation - Experimental hutch (CoSAXS)

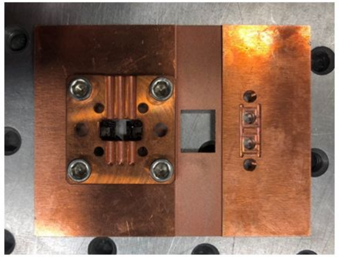


Capillary sample holder

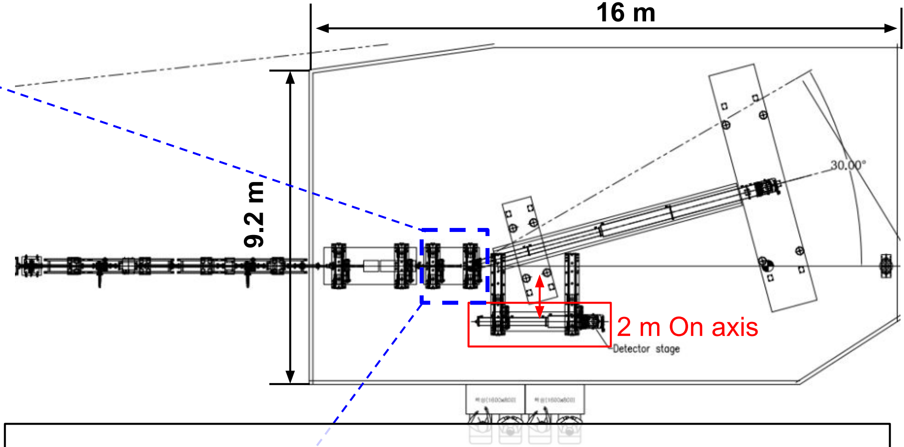
Piezo-driven translation scanner at MID (European XFEL)



Example for a sample chamber



Sample holder from P10 (PETRA III)



Capillary Measurement Strategy

- X-ray sensitive samples must be translated during exposure to prevent radiation damage
- A continuous translation is required, especially for long working distances (~10 cm, v_{max} = 50 mm/s)
- A piezo-driven translation scanner will be implemented for precise and stable motion

In-situ vacuum chamber with temp. control system

- A compact vacuum chamber with minimal windows along the beam path reduces scattering and is ideal for photon-hungry experiments
- A copper capillary holder combined with a Feltie-based temp. control system enables in-situ experiments within moderate temperature ranges

ID03 CoXRD

Overview CoXRD Beamline

❖ Schematic and specification of beamline

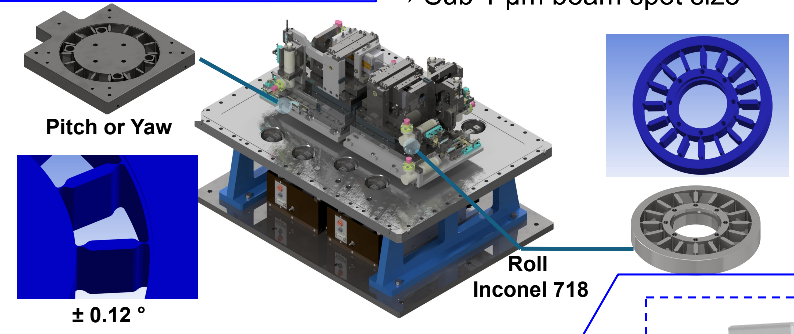
: 3D Strain and structure analysis with various environment

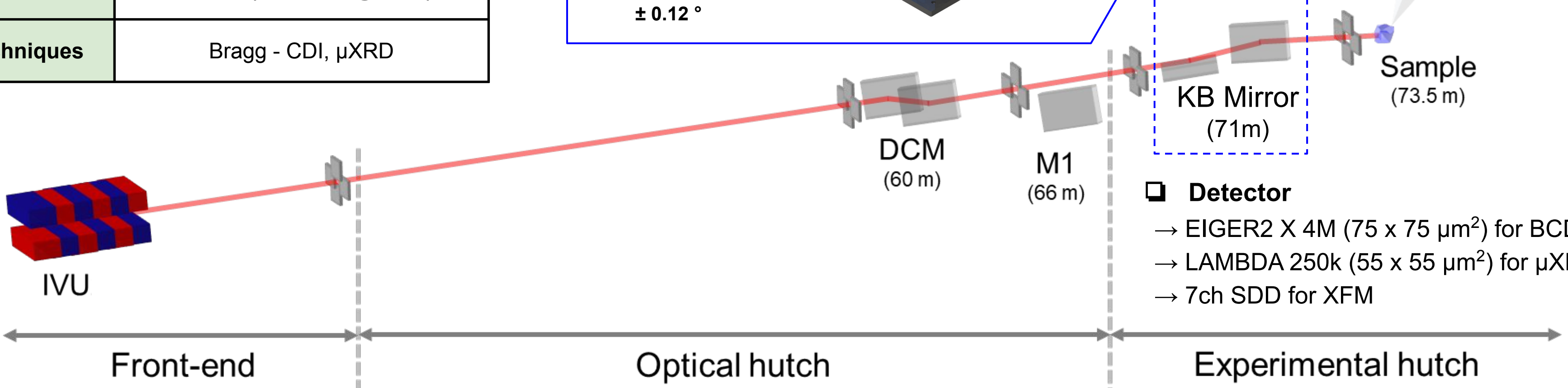
Source	In-vacuum Undulator (3 m)
Photon energy	5 - 25 keV
Beam size	< 1 - 5 um @ Sample
Coh. Beam flux	10^{11} - 10^{12} photons/s @ Sample
Techniques	Bragg - CDI, µXRD

Flexure Pivot Type KB (In house)

→ 1.5 m Working distance

→ Sub 1 µm beam spot size





❑ **Detector**

→ EIGER2 X 4M (75 x 75 µm^2) for BCDI

→ LAMBDA 250k (55 x 55 µm^2) for µXRD

→ 7ch SDD for XFM

Overview CoXRD Beamline

❖ Schematic and specification of beamline

: 3D Strain and structure analysis with various environment

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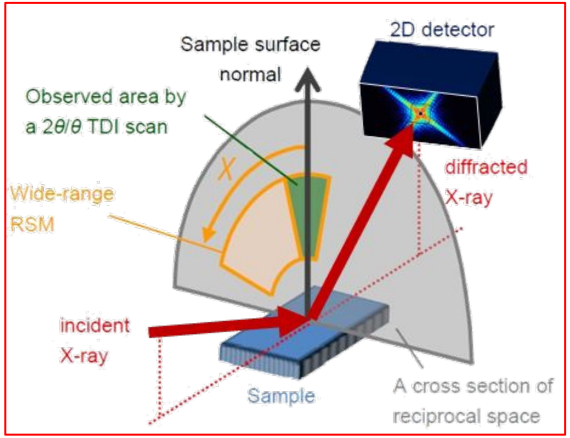
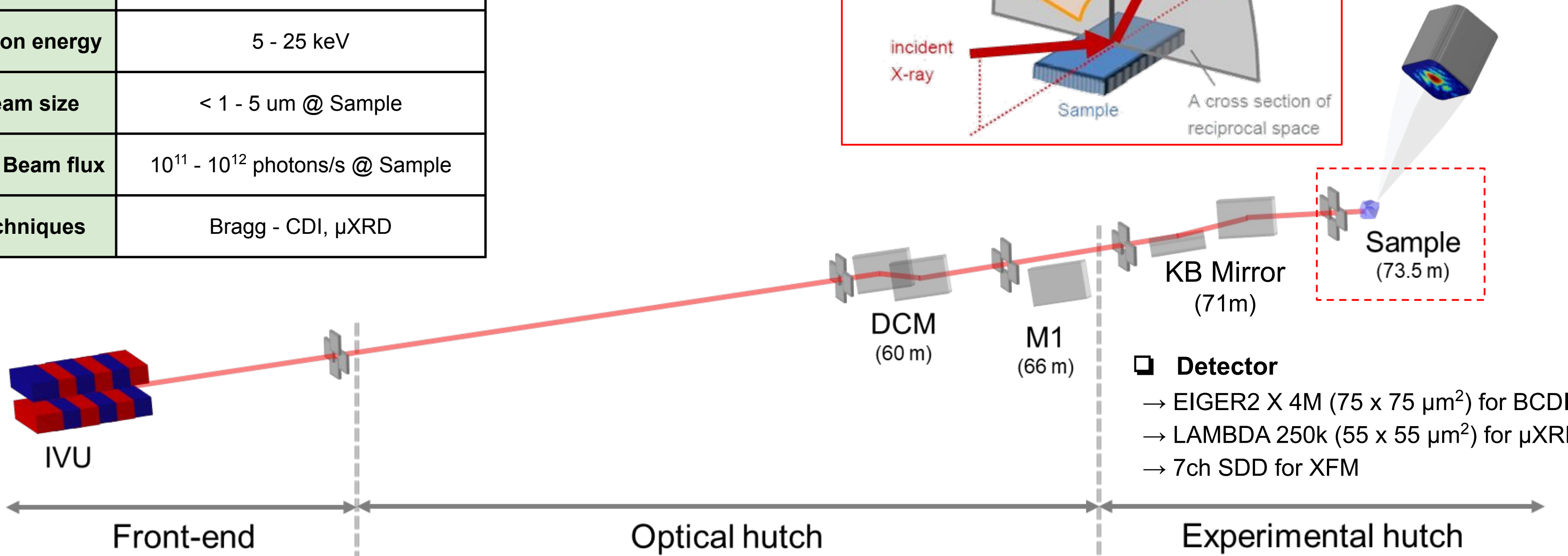


❑ **Goniometer**

→ 6-Axis Kappa Diffractometer

→ Huber 6-circle Diffractometer



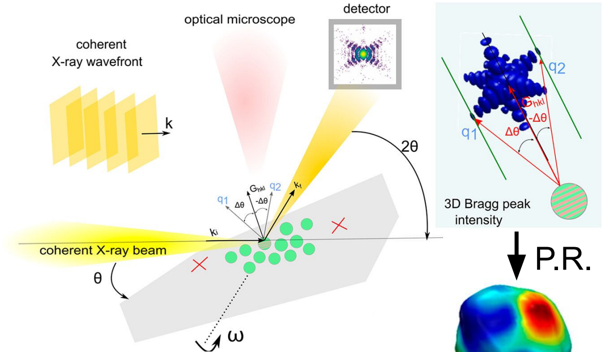
❑ **Detector**

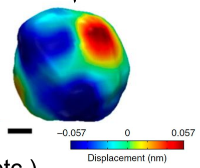
→ EIGER2 X 4M (75 x 75 μm^2) for BCDI

→ LAMBDA 250k (55 x 55 μm^2) for μXRD

→ 7ch SDD for XFM

Primary technique - Bragg Coherent X-ray Diffraction Imaging (BCDI)



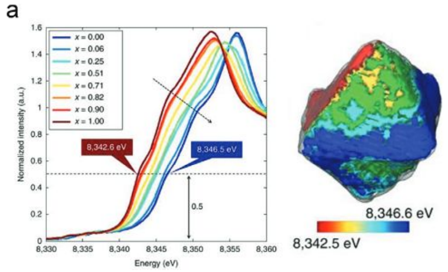


ACS nano **15.4 (2021): 6129-6146.**

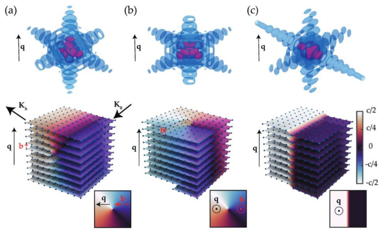
- **Target sample**
  - → Energy material (NMC, NRO, etc.)
  - → Micro-particle (Catalyst, etc.)
- **Sample environment**
  (Compact chamber)
  - → Temperature(< 1000 °C)
  - → Voltage(< 20 V)
  - → Liquid system
  - → Gas system
  - → Photocatalytic chamber

[Battery]

Ni oxidation state



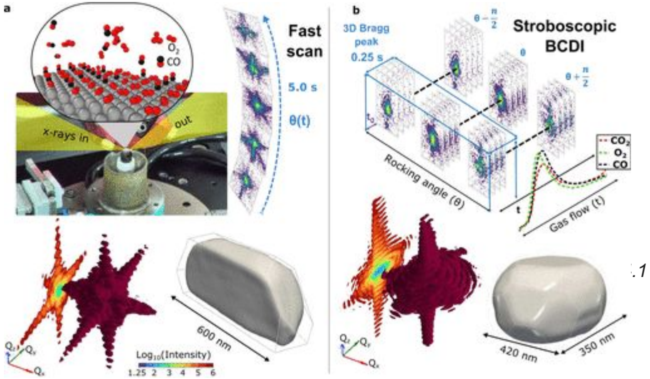
Defect in Na-Ion batteries



Advanced Energy Materials 13.21 (2023): 2203654.

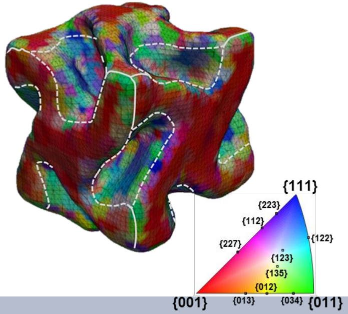
[Catalyst]

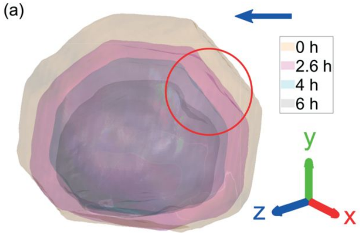
CO Oxidation



ACS nano 18.30 (2024): 19608-19617.

Chiral NP





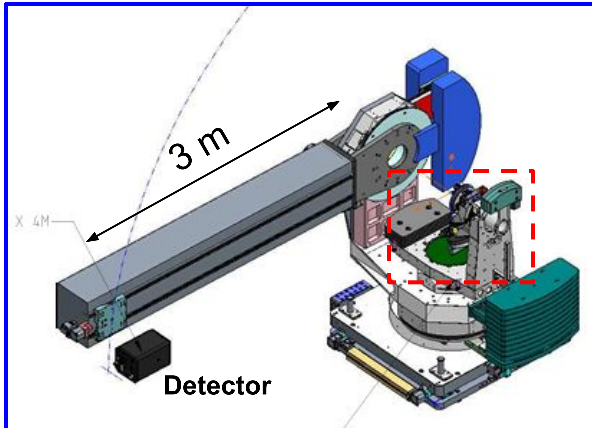
CrystEngComm 24.7 (2022): 1334-1343.

Experimental set up and operation mode

❖ Endstation - Experimental hutch (CoXRD)

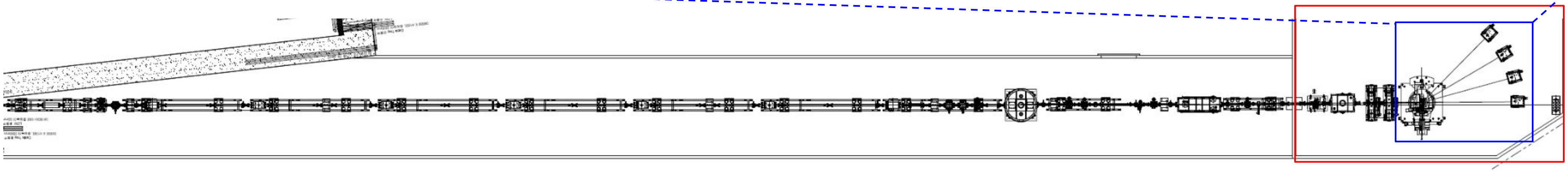
EH1

- **Hutch dimension**
  : 9.2 x 5 x 5 m^3 (L x W x H)
- **Sample position**
  : 73.5 m
- **Maximum sample to detector**
  : 3 m (0 - 90 °)
- **Beam path aperture**
  : 150 mm
- **Purpose**
  : Bragg CDI and uXRD

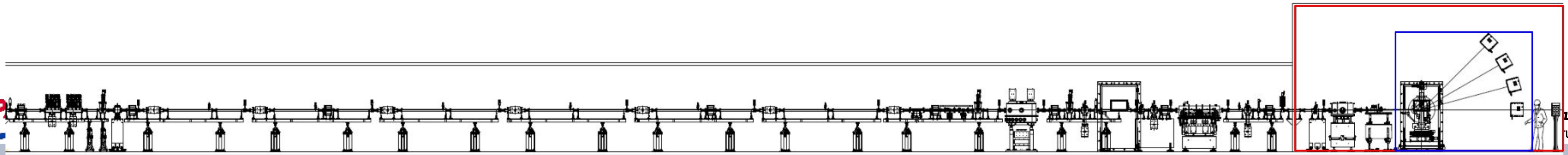


Diffractometer

- 6-Circle Kappa type
- SDD automation (with EIGER 2X 4M)
- SDD : 0.5 ~ 3 m
- Max. load capacity : ~ 20 kg

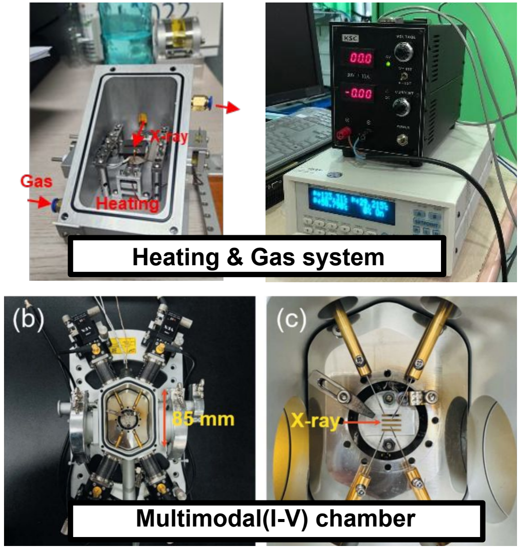


Optical hutch: Simple is best!

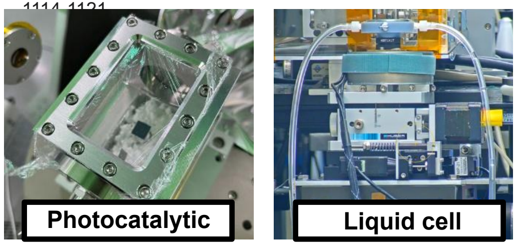


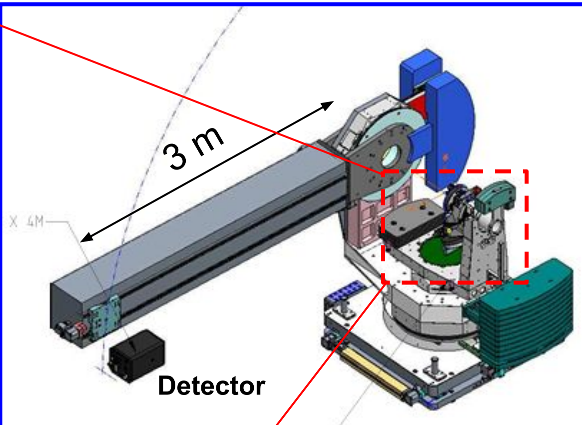
Experimental set up and operation mode

❖ Endstation - Experimental hutch (CoXRD)



Synchrotron Radiation 29.4 (2022): 1114-1121





Diffractometer

- 6-Circle Kappa type
- SDD automation (with EIGER 2X 4M)
- SDD : 0.5 ~ 3 m
- Max. load capacity : ~ 20 kg

Endstation compact chamber

→ Thermal button cell and gas system (< 1000 °C)

→ Multimodal(V-I) Chamber

→ Photocatalytic

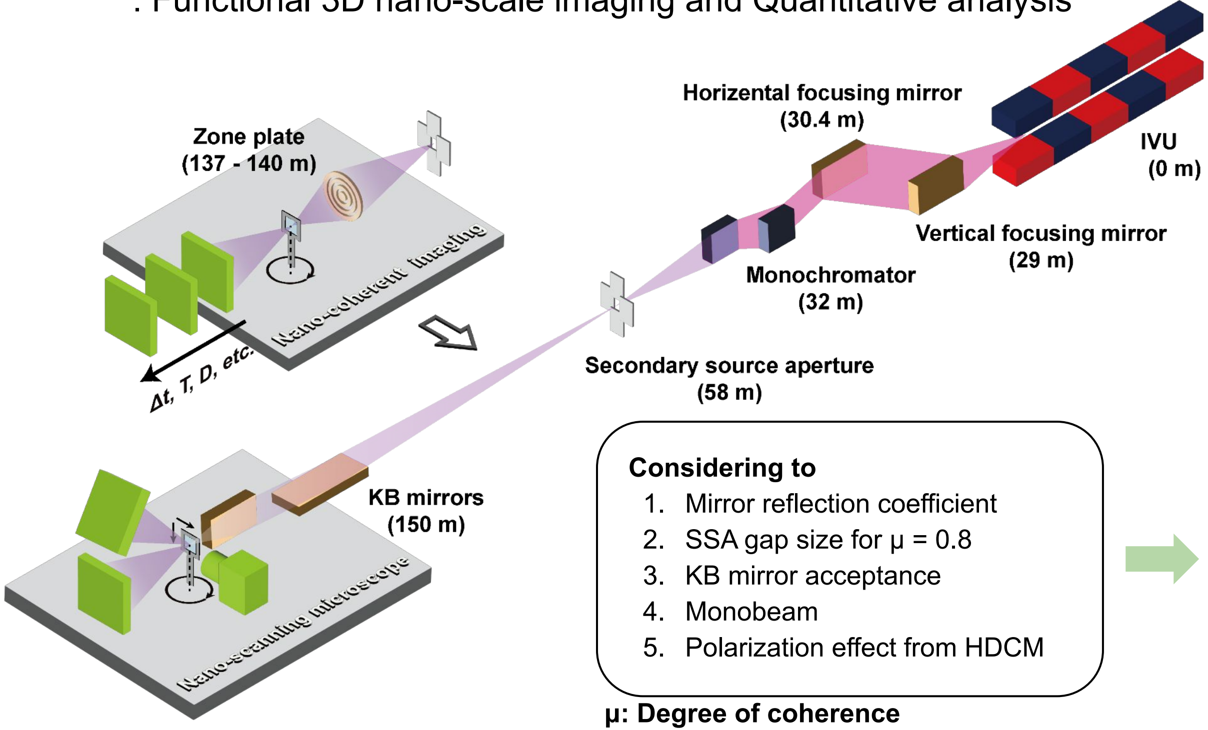
→ Liquid cell

→ Photocatalytic chamber

ID10 Nanoprobe

Overview Hard X-ray Nanoprobe Beamline

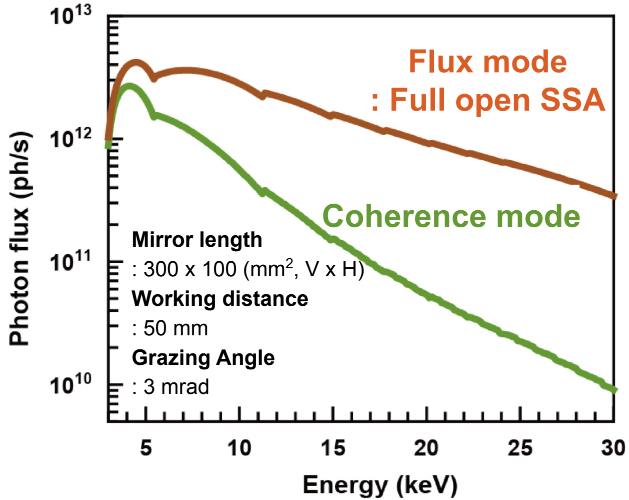
❖ **Schematic and specification of beamline**
: Functional 3D nano-scale imaging and Quantitative analysis



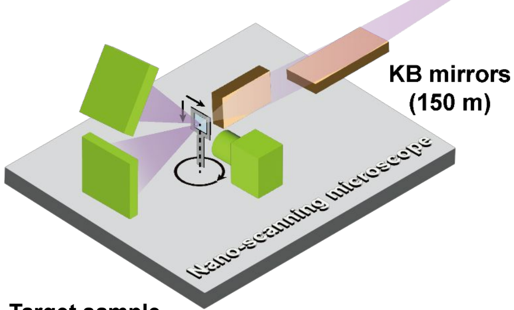
Considering to
1. Mirror reflection coefficient
2. SSA gap size for μ = 0.8
3. KB mirror acceptance
4. Monobeam
5. Polarization effect from HDCM

μ: Degree of coherence

Light Source	IVU (L=3.0m)
Photon energy	5 - 25 keV
Beam size	100 - 50 nm @ sample(Focusing) > 10 um @ sample(Unfocusing)
Working distance	50 mm (KB mirror) 100 mm (ZP or DCRL)
Spatial resolution	< 50 nm (Scanning) < 10 nm (Imaging)
Coh. photon flux	10^{10} -10^{12} phs/s @ Sample



Primary technique - Multimodal analysis with 3D imaging



❑ **Target sample**

→ Semiconductor (CPU, HBM, etc)

→ Energy material (NMC, NRO, etc)

→ Quantum material (Vanadium Kagome metal, CDW, etc)

→ Micro/Nano-particle (Mesoporous silica, Metallic glass-NiB, etc)

❑ **Primary method**

→ Ptychography with Nano-XFM

→ Tomography

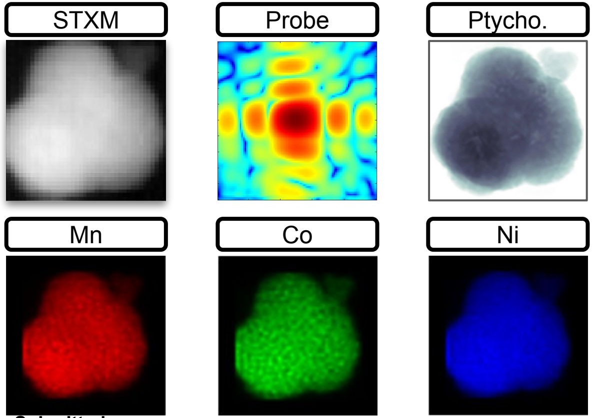
❑ **Auxiliary method**

→ Diffraction mapping

→ Spectro-ptychography; Nano-XANES

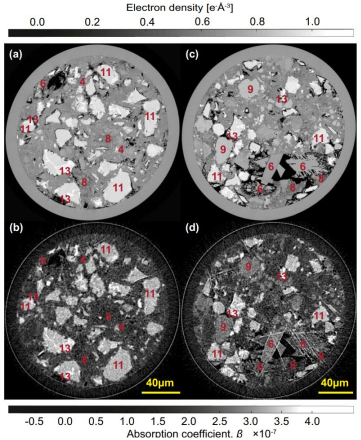
→ SAXS/WAXS; Nanoparticle

- **Multimodal imaging (PLS-II 9C)**



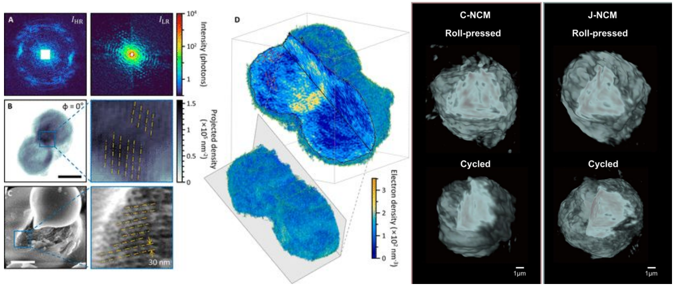
Submitted

- **Near-field ptychography**



Cement and Concrete Research 185 (2024): 107622.

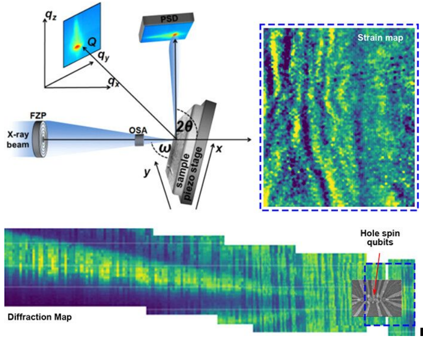
- **Tomography (PLS-II 9C)**



***ACS nano* 17.22 (2023): 22488-22498.**

Submitted

- **X-ray Diffraction Mapping**



ACS Applied Materials & Interfaces 15.2 (2023): 3119-3130.

Imaging and Scanning Method

❖ Imaging method

Large

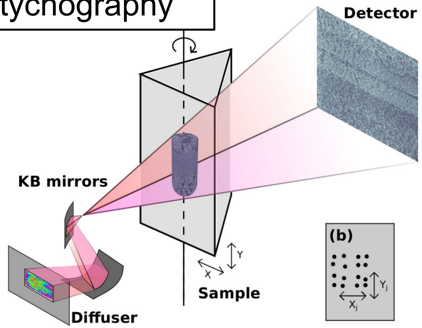
> 100 x 100 um^2

FOV

Small

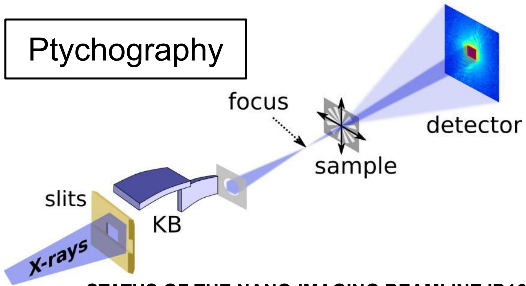
< 50 x 50 um^2

Near-field ptychography



Optics express 23.10 (2015): 12720-12731.

Ptychography



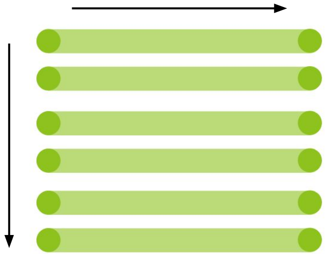
STATUS OF THE NANO-IMAGING BEAMLINE ID16A

❖ Scanning method

Fast

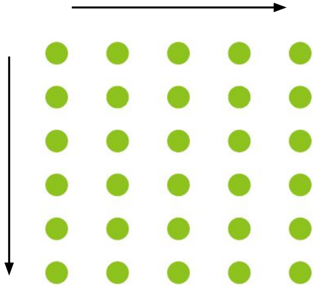
Speed

Slow



Fly-scan

- Ptychography
- Nano-XFM
- Tomography



Raster scan

- Ptychography
- Nano-XFM
- Tomography
- Nano-XANES
- Nano-XDM
- SAXS/WAXS

Imaging and Scanning Method

❖ Imaging method

Large

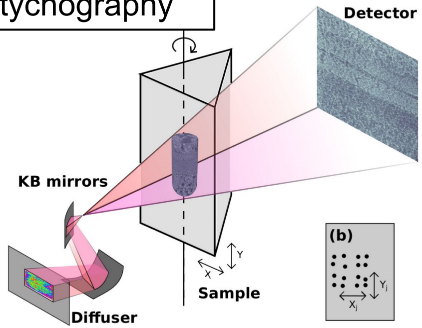
> 100 x 100 um^2

FOV

Small

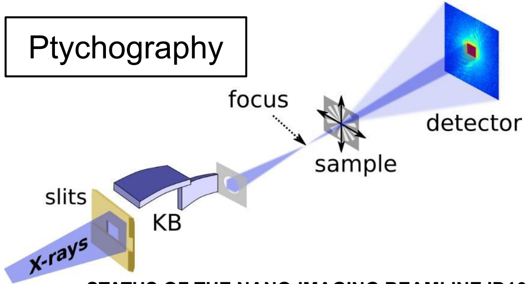
< 50 x 50 um^2

Near-field ptychography

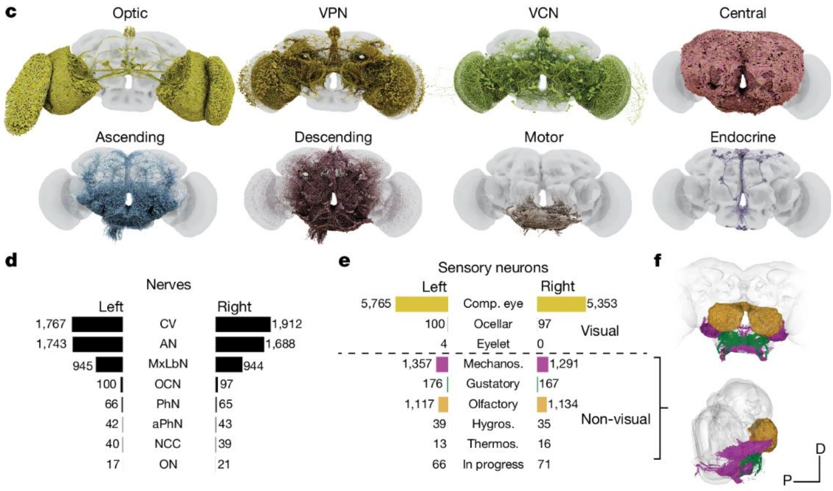


Optics express 23.10 (2015): 12720-12731.

Ptychography

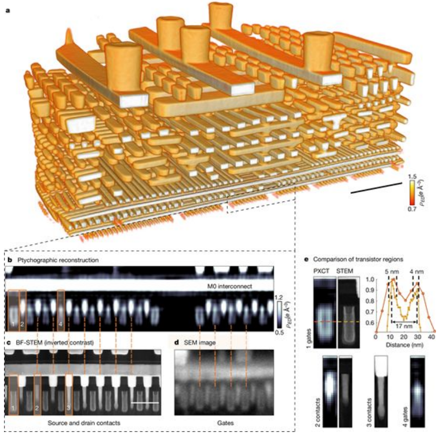


STATUS OF THE NANO-IMAGING BEAMLINE ID16A

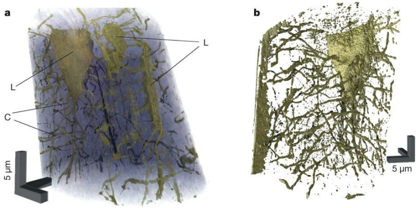


Nature 634, 124–138 (2024)

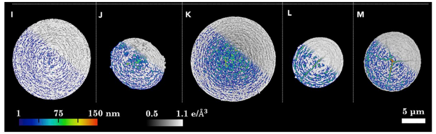
- **Non-destructive** whole brain mapping of small bugs and exploring neuron connectivity
- **Non-destructive** whole bio-cell imaging



Nature 632.8023 (2024): 81-88.



Nature 467.7314 (2010): 436-439.



IScience 11 (2019): 356-365.

- Need < 1 hour times for 3D imaging
- > 3 nm resolution

Imaging method for thick sample

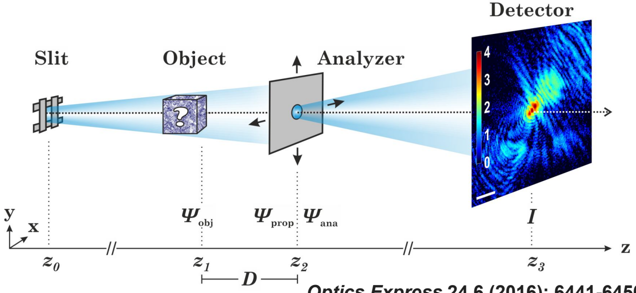
❖ Imaging method

Thickness

Thick
> 100 um

Thin
< 100 um

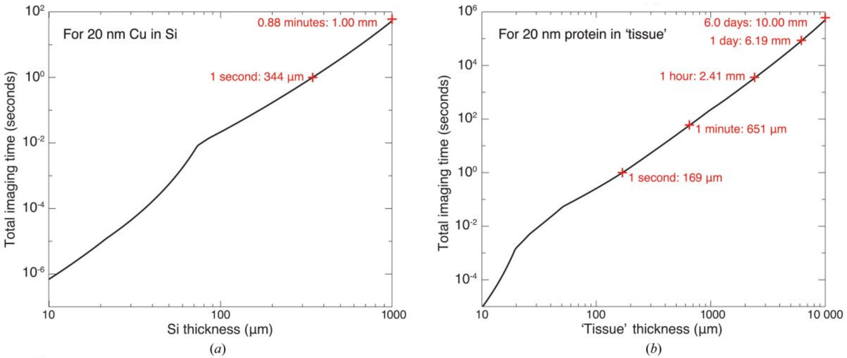
Tele-ptychography with unfocused beam



Optics Express 24.6 (2016): 6441-6450.

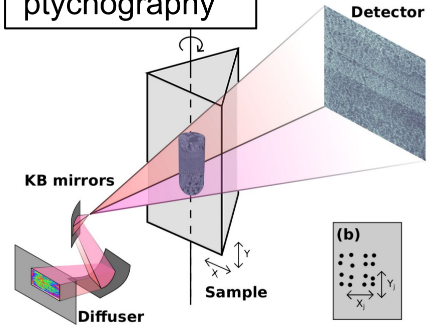
- **Total imaging time of copper features in silicon**

Applied Crystallography 54.2 (2021): 386-401.



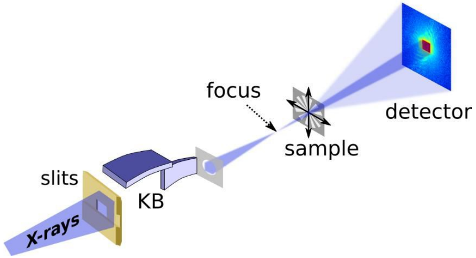
$$T_p = \bar{n}_{pixel}/(B\lambda^2).\ T_{tot} = T_p N^2 = \frac{\bar{n}_{pixel}}{B\lambda^2} N^2 = \frac{4\bar{n}_{pixel}}{B\lambda^2}\frac{t^2}{\delta_r^2}$$

Near-field ptychography



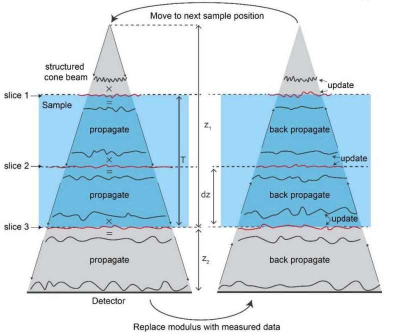
Optics express 23.10 (2015): 12720-12731.

Ptychography



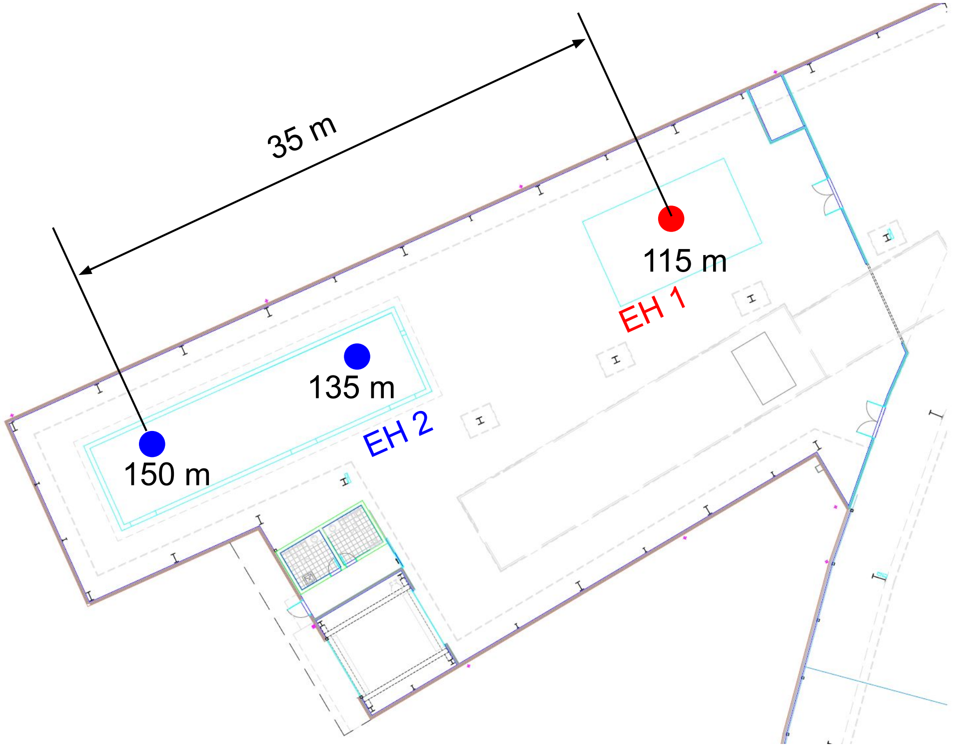
STATUS OF THE NANO-IMAGING BEAMLINE ID16A

Multi-slice approach



Optics Express 31.10 (2023): 15791-15809.

Experimental hutch and operation mode



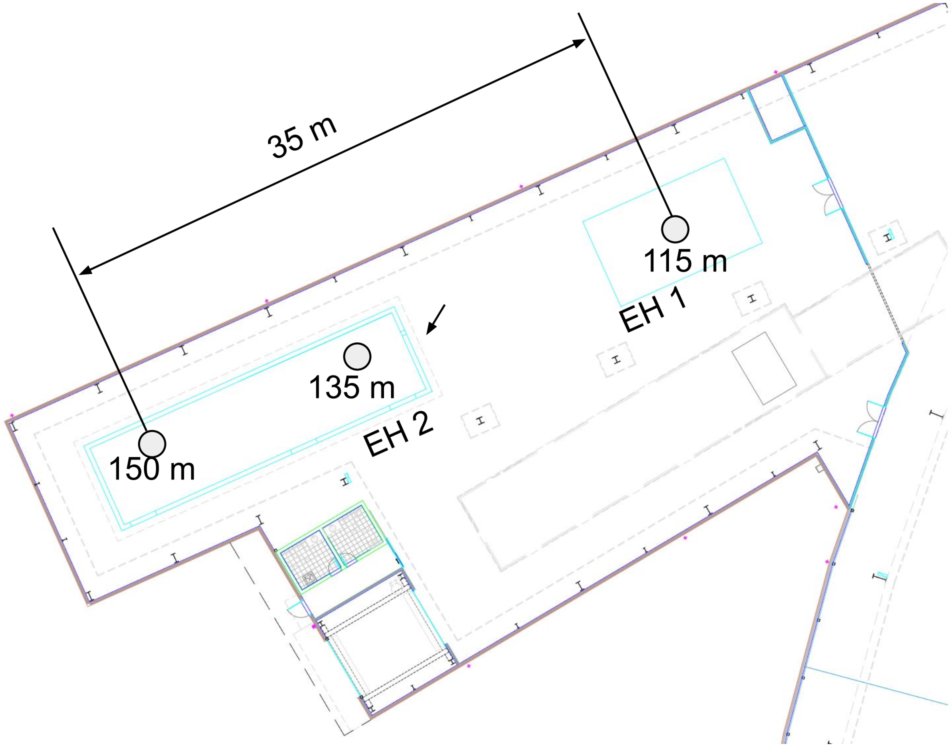
EH1(Design in progress)

- **Hutch dimension**
  : 10 x 6 x 3.5 m^3(L x W x H)
- **Sample position**
  : 115 m
- **Maximum sample to detector**
  : 35 m (On-axis)
- **Beam path aperture**
  : 300 mm (30 nm resolution)
- **Purpose**
  : (Tele-)Ptychography with unfocused beam
  : Test space for new experimental instrument

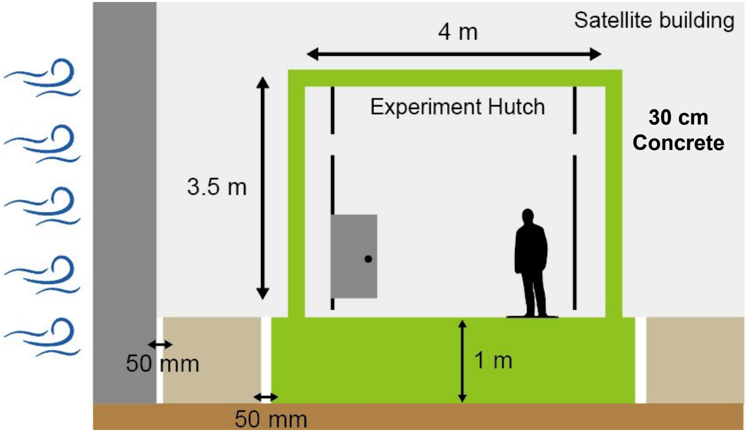
EH2

- **Hutch dimension**
  : 20 x 6 x 3.5 m^3(L x W x H)
- **Sample position**
  : 135 m and 150 m
- **Sample to detector**
  : 20 m (12°)
  : 18 m; 0.5 - 2.0 m (On-axis)
- **Beam path aperture**
  : 200 mm (< 10 nm resolution)
- **Purpose**
  : Multimodal imaging using nanobeam(Primary)
  : SAXS, WAXS, XDM, Nano-XANES, Spectro-ptychography(Auxiliary)

Experimental hutch and operation mode



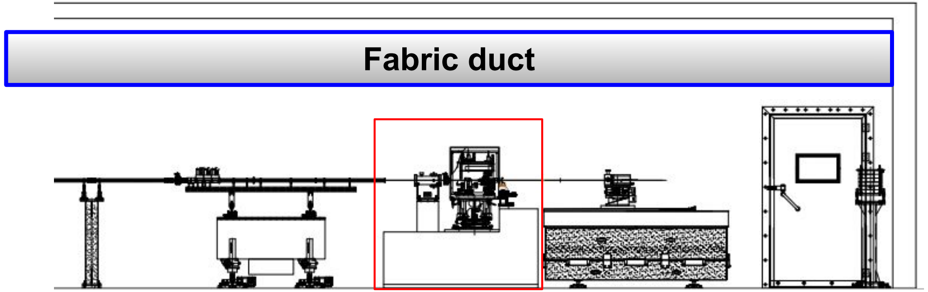
Building structure



- No pilling to stone ground
  → 1 m Concrete slab
- Isolate the storage ring slab from the experimental hutch
- House in house structure
  → Satellite building temp. ± 0.5 ℃
- Concrete hutch
  → Low vibration, stable temperature

Hybrid approach for hutch cooling system (On going development)

❖ Strategies for high thermal stability in exp. hutch



Heating, Ventilating, and Air Conditioning system
- ± < 0.1 ℃ / h
- 20 x 6 x 3.5 m^3 (L x W x H)

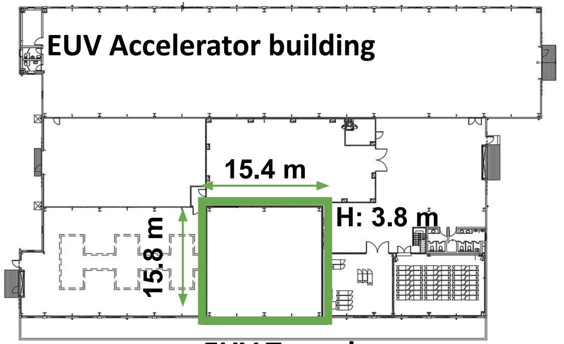
\+

Air curtain or enclosure for exp. equipments
- ± 0.02 ℃ / h
- 2 x 1.5 x 2 m^3 (L x W x H)

⇒

Temperature derivation
± 0.02 ℃ / h

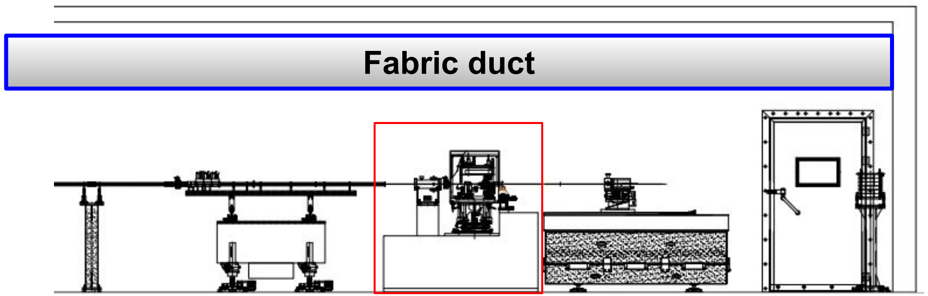
❖ HVAC system of PAL-EUV tunnel



EUV Tunnel

Hybrid approach for hutch cooling system (On going development)

❖ Strategies for high thermal stability in exp. hutch



Heating, Ventilating, and Air Conditioning system
- ± < 0.1 ℃ / h
- 20 x 6 x 3.5 m^3 (L x W x H)

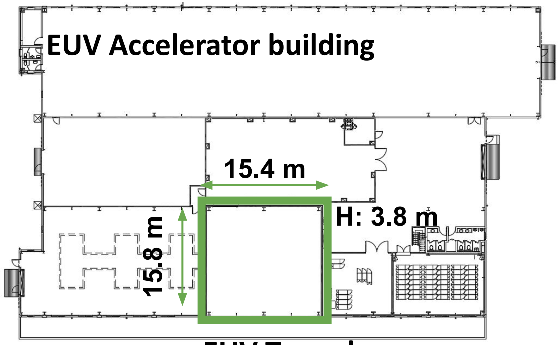
➕

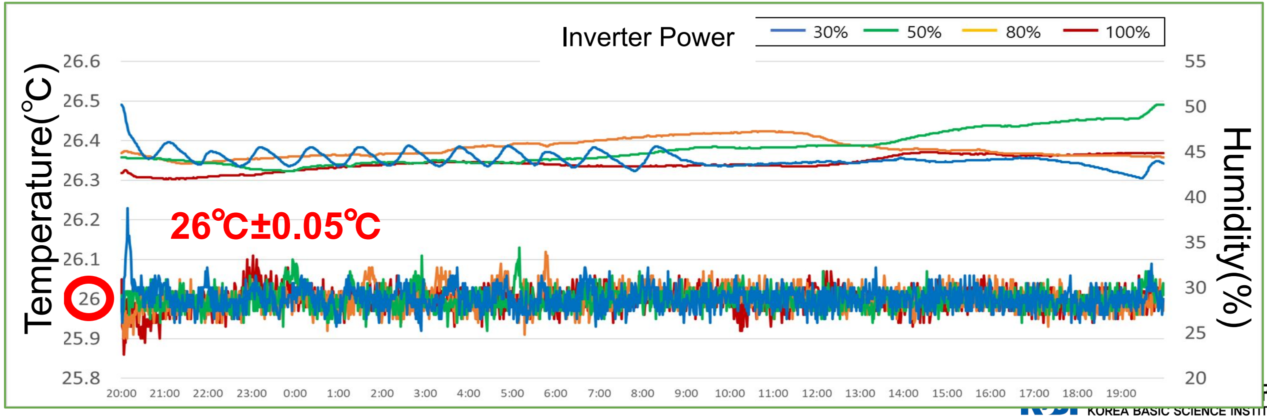
Air curtain or enclosure for exp. equipments
- ± 0.02 ℃ / h
- 2 x 1.5 x 2 m^3 (L x W x H)

⇨

Temperature derivation ± 0.02 ℃ / h

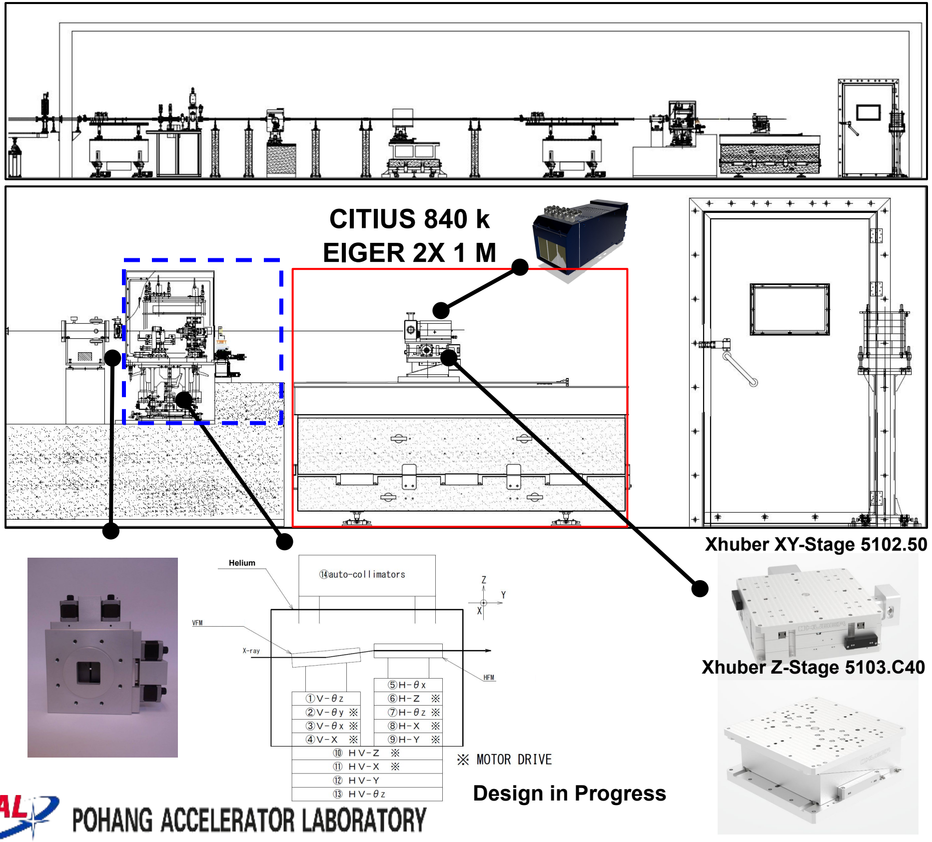
❖ HVAC system of PAL-EUV tunnel

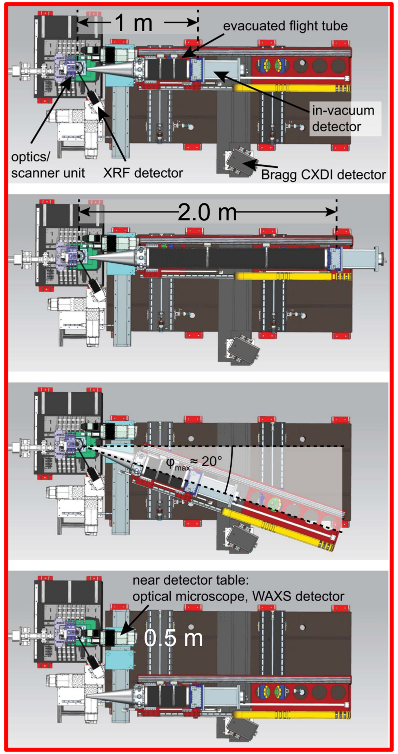




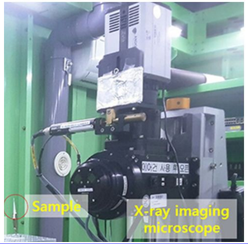
Experimental set up and operation mode

❖ Overview of EH2 - Beam path and detector stage stage





J. Appl. Cryst. (2020). 53, 957–971



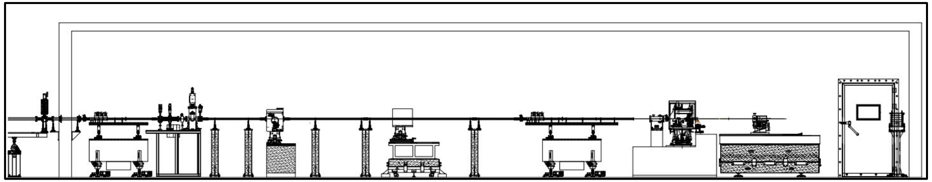
Motorized scintillator and magnification change camera system (PLS-II 6C)

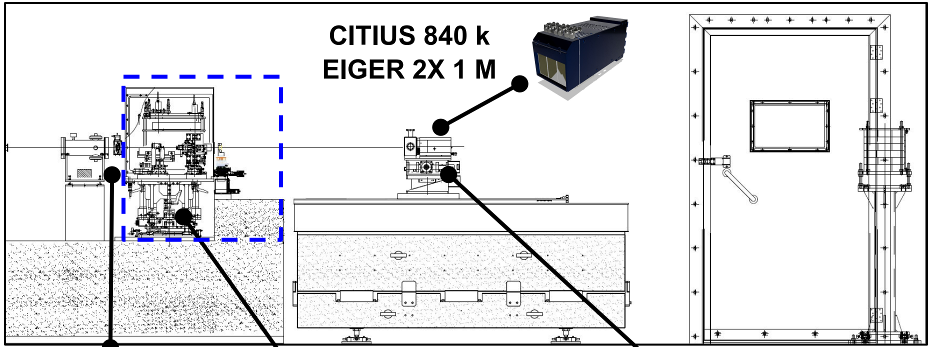
Microscopy 70.5 (2021): 469-475.

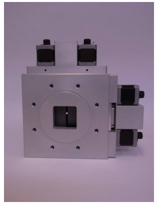
- **Working distance**
  : 50 mm (KB mirror)
- **Detector**
  : CITIUS 840 k, SDD 7 ch
- **Sample to detector**
  : 0.5 m - 2.0 m (On rail, up to 20。)
  : 0.5 m - 4.2 m (On axis)
  : 0.5 m - 5.2 m (Up to 45。)
- **Macro-nanoscale multiplexing 3D imaging**
  >100 um FOV, < 30 nm spatial resolution
- **High temperature env.**
  > 600 ℃ (Nano-chip mems)
- **In-situ/operando multiplexing imaging**
  < 10 min time step
- **Thermal stability:** ± 0.02 ℃ / h

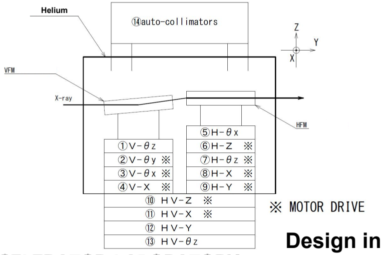
Experimental set up and operation mode

❖ Endstation - KB mirror design (Design in progress)









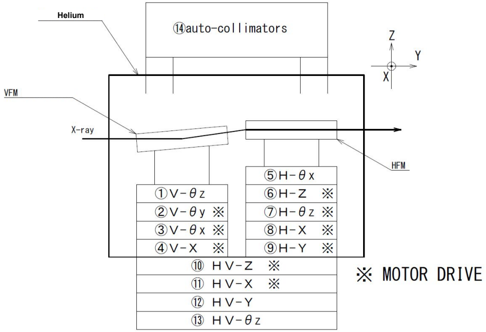
Design in Progress

Xhuber XY-Stage 5102.50

Xhuber Z-Stage 5103.C40

- **PLS-II 8C**

- **Motor configure for HXNP**

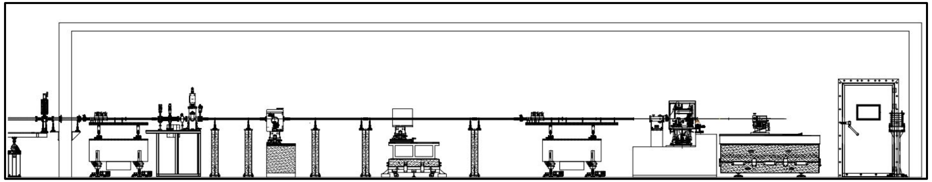


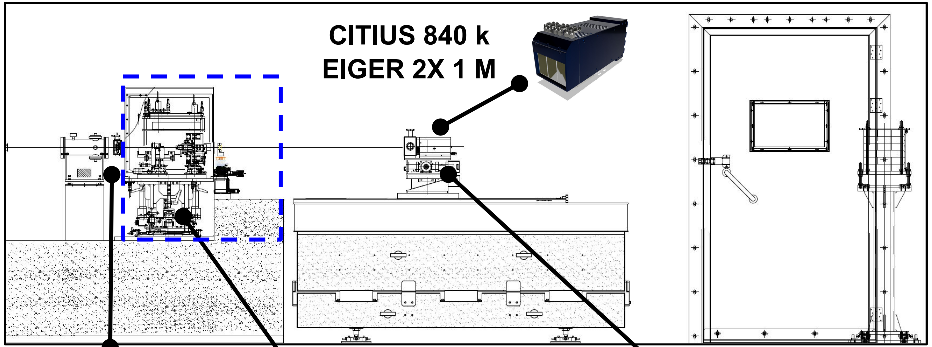
Design in Progress

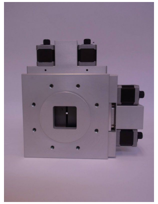
- **Working distance**
  : 50 mm (KB mirror); Sample stage table size: 75 mm
- **Mirror length**
  : 300 mm(V) x 100 mm(H)
- **Laser interferometer system for verifying angular motion**
- **Helium purging / thin wall**
- **Limit DOF for high stability**
  → Single coating(Pt)

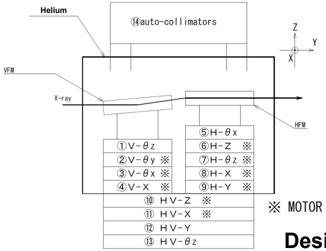
Experimental set up and operation mode

❖ Endstation - Sample stage



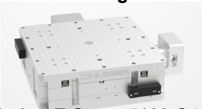




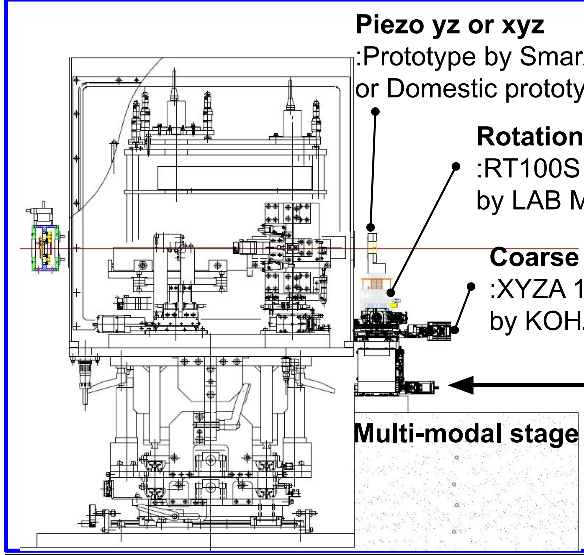


Design in Progress

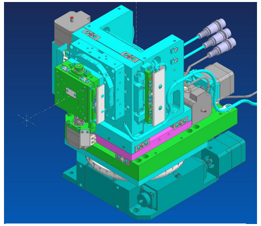
Xhuber XY-Stage 5102.50



Xhuber Z-Stage 5103.C40



Nano-XDM stage

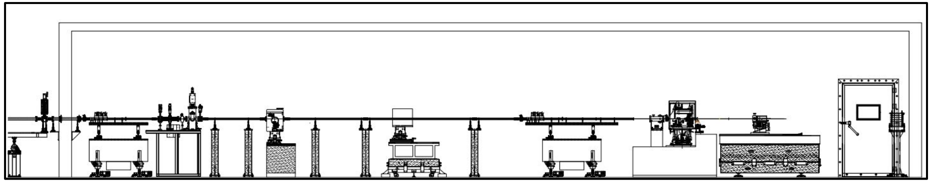


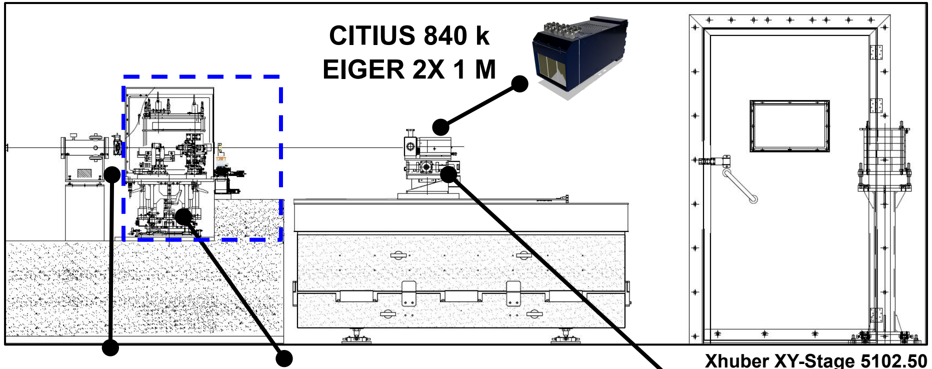
Design in Progress

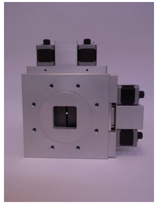
- **Coarse xyz** → Travel range(X x Y x Z): 15 x 30 x 300 mm^3
- **Piezo motor yz (Domestic prototype)**
  → Travel range : 15 um x 15 um
  → Resonant frequency : > 3kHz; Position streaming rate: 25 kHz
- **Piezo motor yz (Prototype by SmarAct)**
  → Travel range : 15 um x 15 um
  → Resonant frequency : > 1kHz; Position streaming rate: 39 kHz
- **Rotation motor**: Air bearing rotation motor with slip ring
- **Sample position reader**: Laser interferometer(Design in Progress)

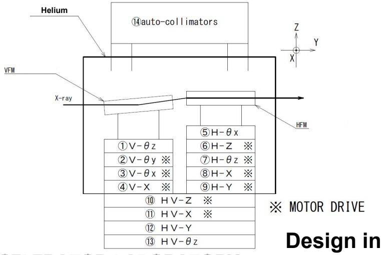
Experimental set up and operation mode

❖ Endstation - High speed precision nano-scanning stage system









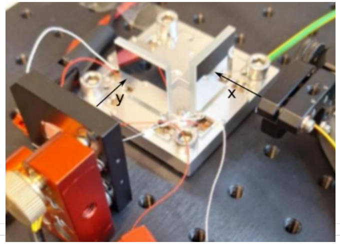
Design in Progress

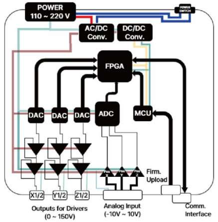
Xhuber XY-Stage 5102.50

Xhuber Z-Stage 5103.C40

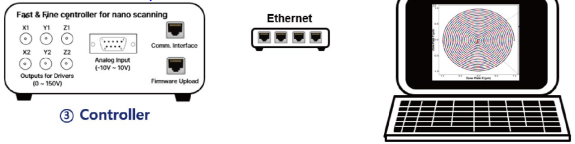
- **Fast precision nanoscan stage**

① Motor stage





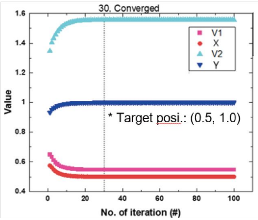
② Interferometers



③ Controller

- **Det. Frame rate**
  : > 1kHz (Target > 5 kHz)
- **Table size**
  : 50 x 50 mm^2
- **Close-loop freq.**
  : 10 kHz (Target 20 kHz)
- **FOV**
  : 15 um (Target 50 um)
- **Precision**
  : 1 nm
- **Load capacity**
  : 100 g

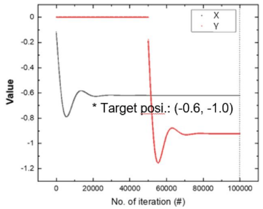
◦ **H-infinity**



30 iterations; 8.3 msec/iteration

0.25 s → 4 Hz

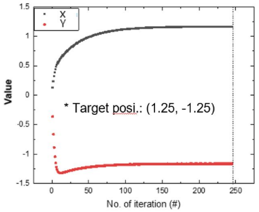
◦ **PID**



90,000 iterations; 0.2 μsec/Iteration

0.18 s → 5 Hz

◦ **Deep-learning**

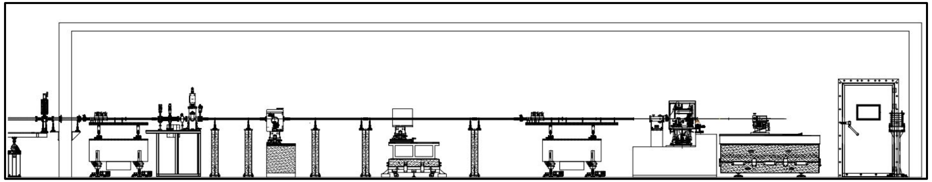


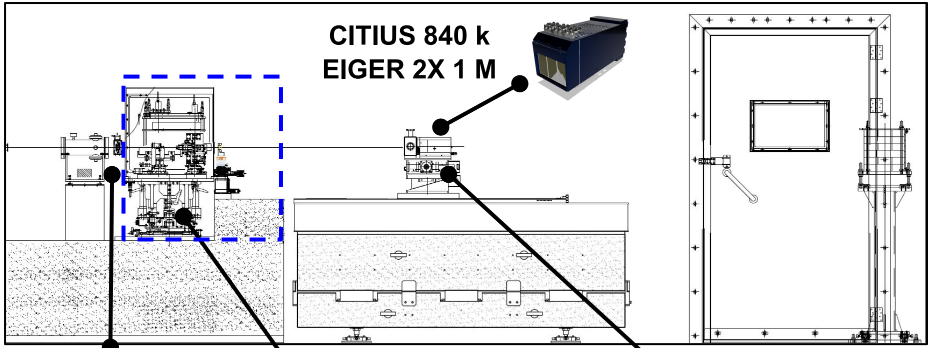
150 iterations; 0.7 μsec/iteration

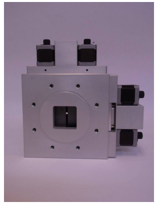
1.05E-4 s → 10 kHz

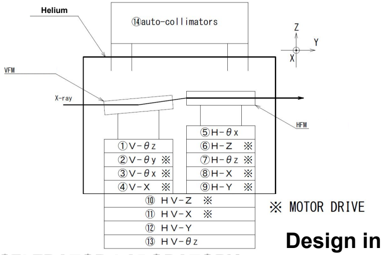
Experimental set up and operation mode

❖ Endstation - Detailed component list of sample stage



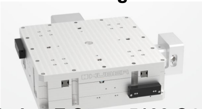




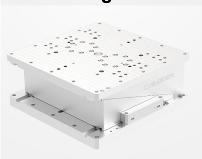


Design in Progress

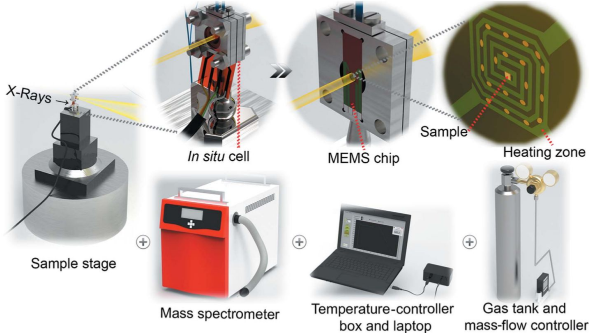
Xhuber XY-Stage 5102.50



Xhuber Z-Stage 5103.C40



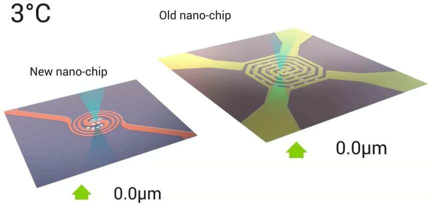
- **Mini-in situ cell (< 100g)**



J. Synchrotron Rad. (2019). 26, 1769–1781

- **Gas supply system**

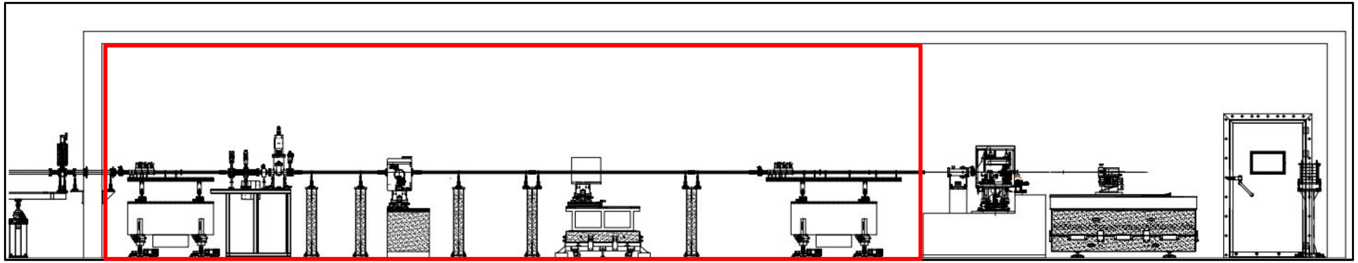
https://denssolutions.com/products/wildfire/



- FOV : 25 um; Membrane window thickness: 30 nm(SIN)

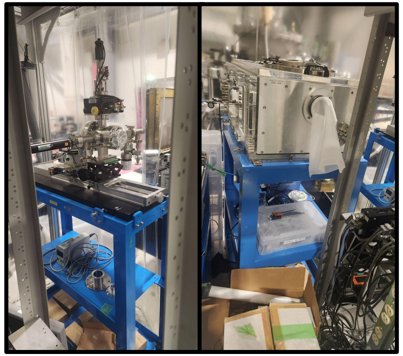
Experimental set up and operation mode

❖ Endstation - Playground for frontier scientist



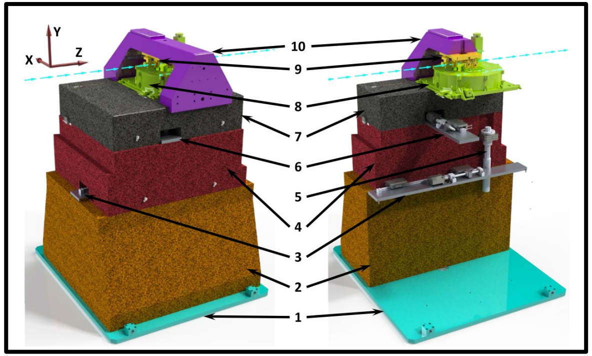
- **Working distance**
  : 100 mm (ZP or DCRL), NAN (Parallel beam)
- **Detector**
  : EIGER 4M, SDD 7 ch
- **Sample to detector**
  : 20 m (12 °) / 11.5 m (20°) / 7.5 m (30°) / 5.5 m (45°) / 18 m (On-axis)
- **Macro-nanoscale multiplexing 3D imaging**
  > 100 um FOV, < 30 nm spatial resolution
- **Temperature env.**
  > 700 ℃ or < 100 K
- **In-situ/operando multiplexing imaging**
  < 10 min time step

❖ Portable chamber



SP-8 BL29XU

❖ Air bearing-supported granite stages

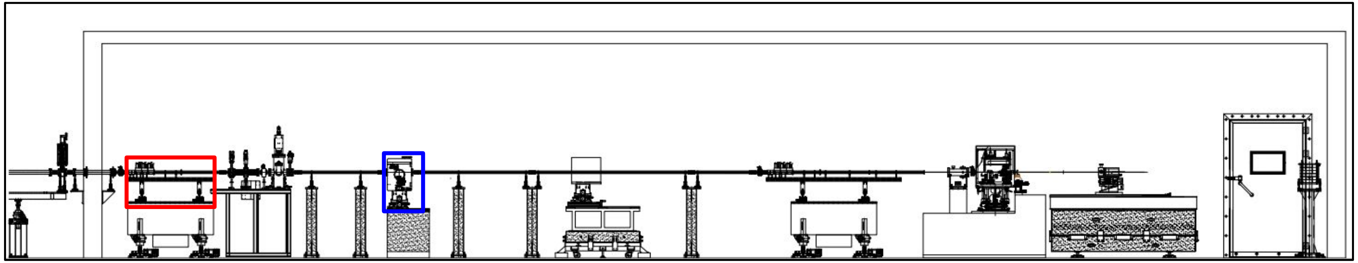


APS Nanoprobe

- **Provides custom chamber compatibility**
  : 20 Plug and play motor channel
  : Installable portable chambers
  : Extra air bearing granite support

Experimental set up and operation mode

❖ Endstation - Playground for frontier scientist



- **Working distance**
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- **Detector**
  : EIGER 4M, SDD 7 ch
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  : 20 m (12 °) / 11.5 m (20°) / 7.5 m (30°) / 5.5 m (45°) / 18 m (On-axis)
- **Macro-nanoscale multiplexing 3D imaging**
  > 100 um FOV, < 30 nm spatial resolution
- **Temperature env.**
  > 700 ℃ or < 100 K
- **In-situ/operando multiplexing imaging**
  < 10 min time step

❖ Diamond phase retarder stage (PLS-II 9C)

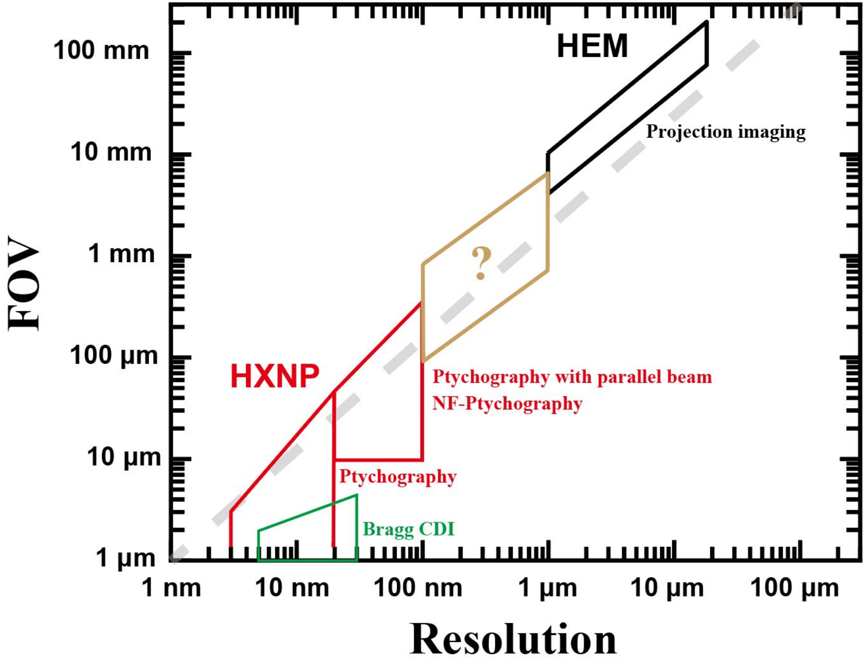
- **Circular polarization beam**
  → Dichroic diffraction exp.
- **Components:**
  2 Circle stage + linear stage + Point detector + Diamond crystal
- **Diamond thickness**
  : 0.2 mm / 0.5 mm / 1.0 mm

❖ Cryosteam (PAL-XFEL XSS Hutch)

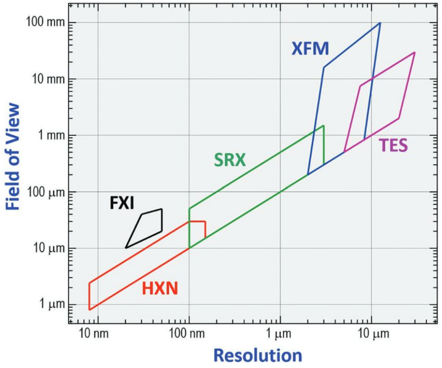
- Low temperature environment
- LN2 Cryostat
- < 100 K

Imaging scale of 4GSR beamlines

❖ **Korea-4GSR**

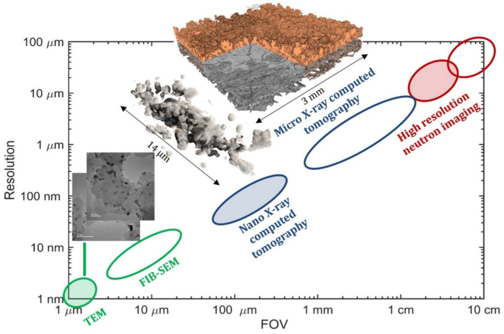


❖ **NSLS-II**



Synchrotron Radiation News 33.3 (2020): 29-36.

❖ **Typical imaging methods**



J. Phys. Energy 2 (2020) 044005

- We will provide an imaging range that complements to Electron microscopy
- An imaging range similar to that of overseas synchrotrons
- However, there are some missing areas, which can be addressed according to user's demand by constructing additional beamlines in next phase

Acknowledgement

4GSR Beamline science Team

Dr. Kim ki-jeong
Deputy director

Dr. Shin Jae-yong
Imaging science group
Hard X-ray nanoprobe

Dr. Hwang In-hui
X-ray science group
Real-time XAFS

Ham Da-seul
Imaging science group
CoXRD beamline

Dr. Jo Won-hyuk
X-ray science group
CoSAXS

PAL Utilities & Safety Team

Choi Young-ho
Team leader
HVAC system

Choi Min-cheol
HVAC system

Advisor

Korea Synchrotron User's Associate

Hyunchul Kang(Chosun University)

Moonjeong Park(POSTECH)

Seohyoung Chang(Chong-ang University)

Machine Advisory Committee

Yong Chu (NSLS-II)

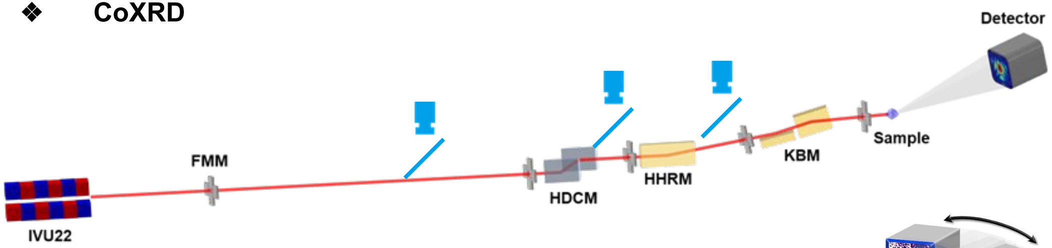
Byeongdu Lee (APS)

Wonsuk Cha (APS)

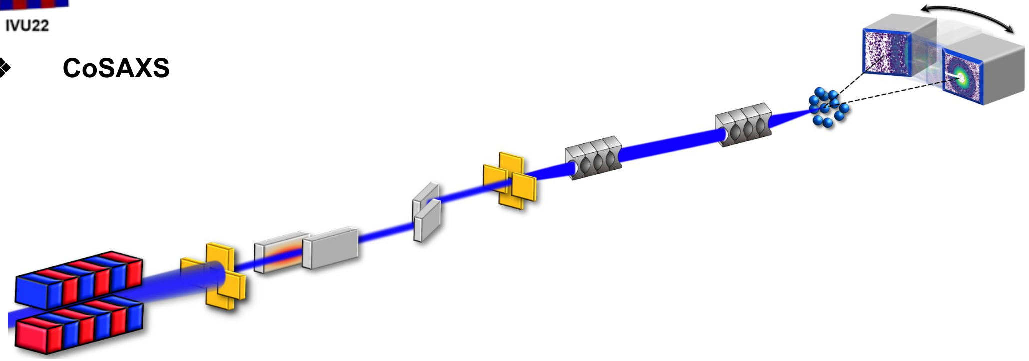
Supplementary

Beamline diagnostic and alignment strategy

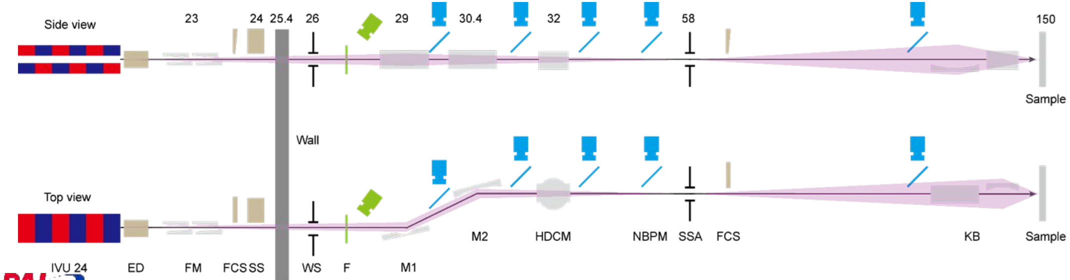
❖ **CoXRD**



❖ **CoSAXS**



❖ **Nanoprobe**



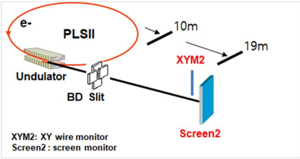
Beamline diagnostic strategy specification

- Diagnostics before and after optics
  → Automatic(Macro-based) alignment
- Retractable imager(Domestic)
- Diamond BPM(SYDOR)
  → Wavefront preservation
- Angular resolution
  → 100 - 300 nrad(Nanoprobe: 50 nrad)
  → 10% rule

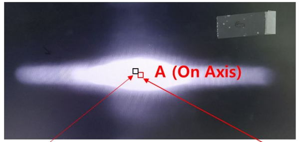
White beam alignment

: Countermeasures for high heat loads

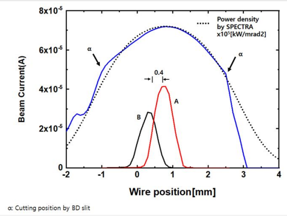
- Close photon shutter upstream of the first optics
- White beam imager to find the on-axis beam
- Ex.) PLS-II 3C BL



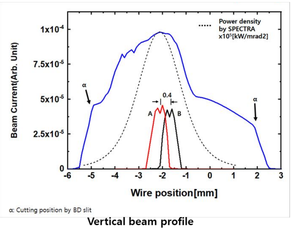
Screen2



B(Off Axis): ~0.5mm(ver) x 0.6 mm(Hor) A (On Axis) : ~ 0.5mm(ver) x 0.6 mm (Hor)



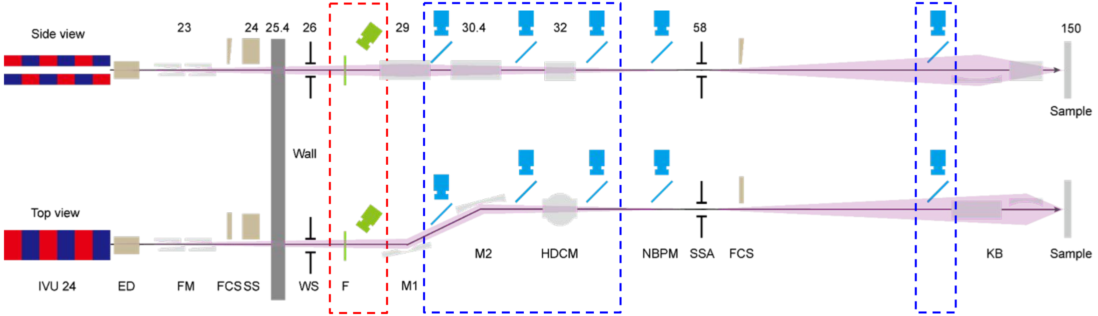
Horizontal beam profile



Vertical beam profile

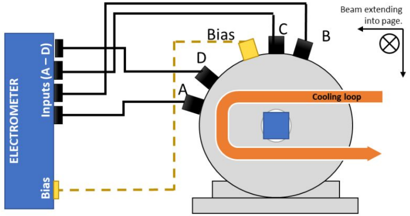
Beamline diagnostic and alignment strategy

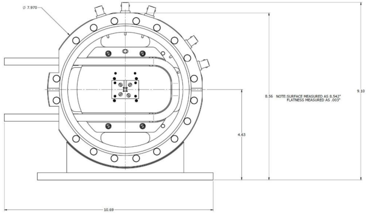
❖ **Example: Hard X-ray Nanoprobe**



Diamond White BPM(SYDOR)

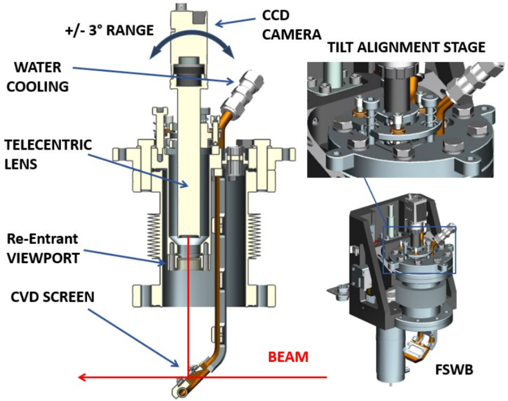
- Up to 50 W(absorption)
- Resolution: Beam size 0.1%





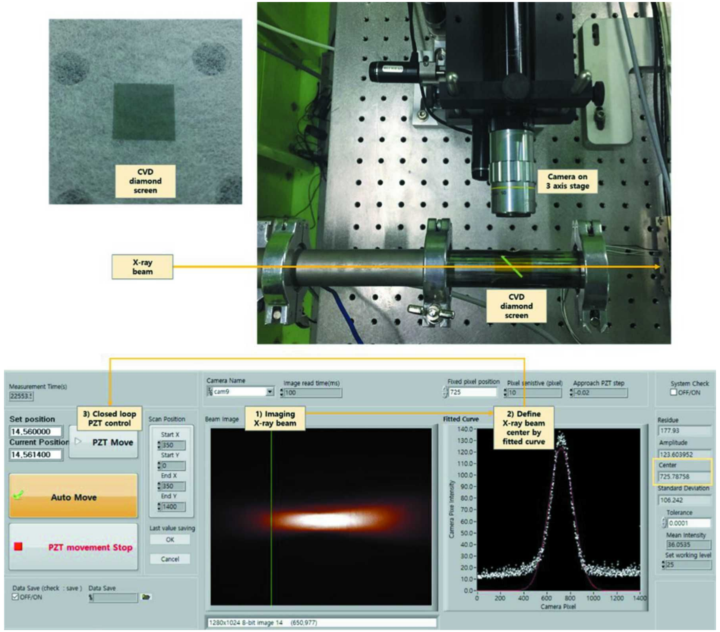
WB Diamond screen(under develop)

- Dia. thickness: 50 - 100 um
- Resolution: 10 - 100 um



MEDSI'20, Chicago, IL, USA, 24-29 July 2021.

Pink/Mono-beam Diamond/YAG screen(PLS-II 7C, PAL-XFEL)

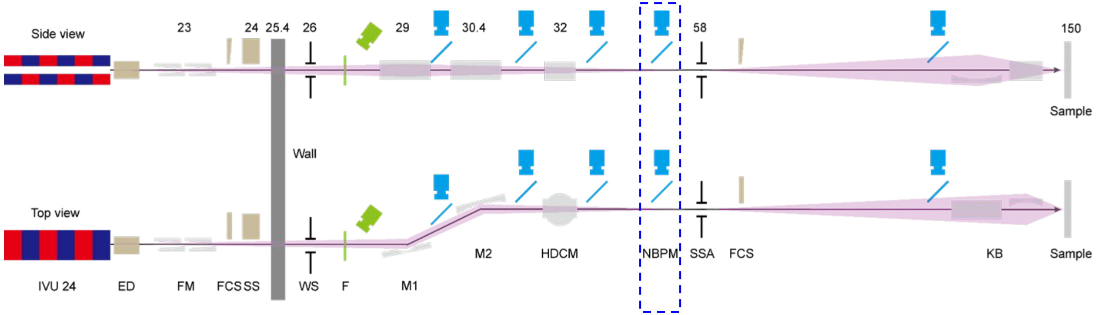


***Synchrotron Radiation* 24.6 (2017): 1276-1282.**

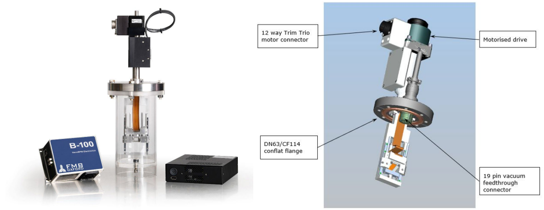
- Pink: CVD diamond 50 - 200 um
  Mono: Boron doped Diamond 50 um, YAG crystal
- Resolution: up to microscopy(1 - 10 um)
- Retractable(In/out screen)

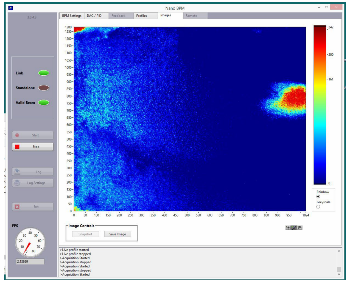
Beamline diagnostic and alignment strategy

❖ **Example: Hard X-ray Nanoprobe**

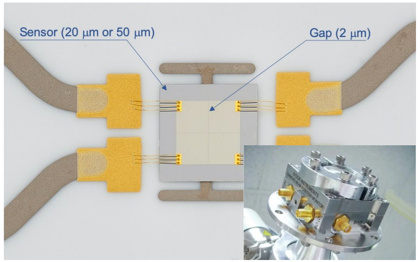


❖ **Nano BPM(Initial phase)**





❖ **Diamond BPM(Mature phase)**



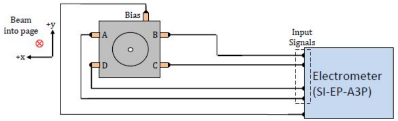


Figure 2: Diamond beam position monitor connection setup diagram.

Beamline diagnostic strategy/specification

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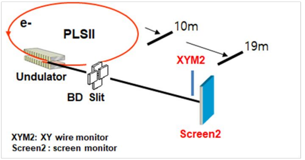
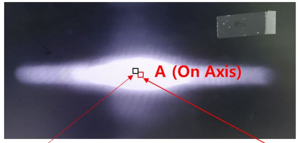


Screen2



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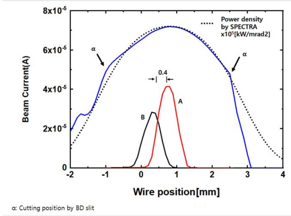
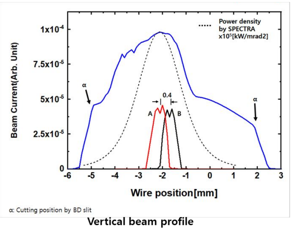


Horizontal beam profile

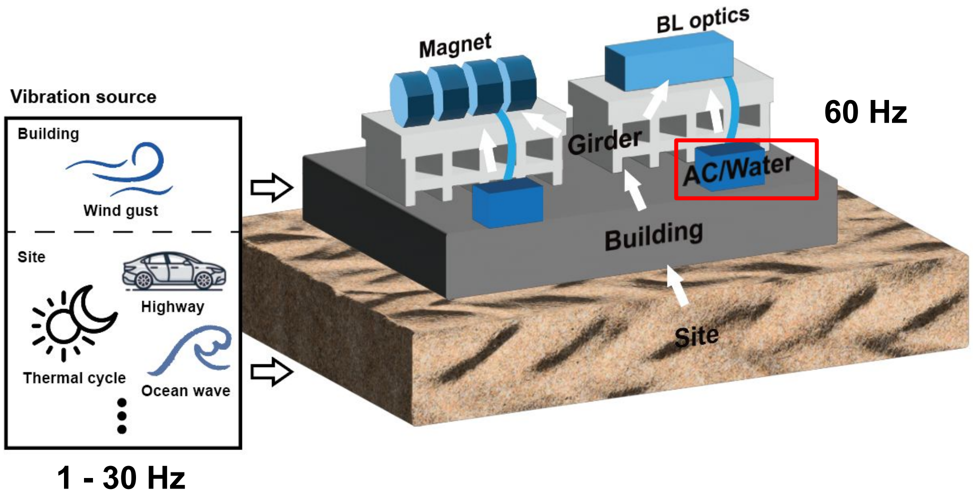


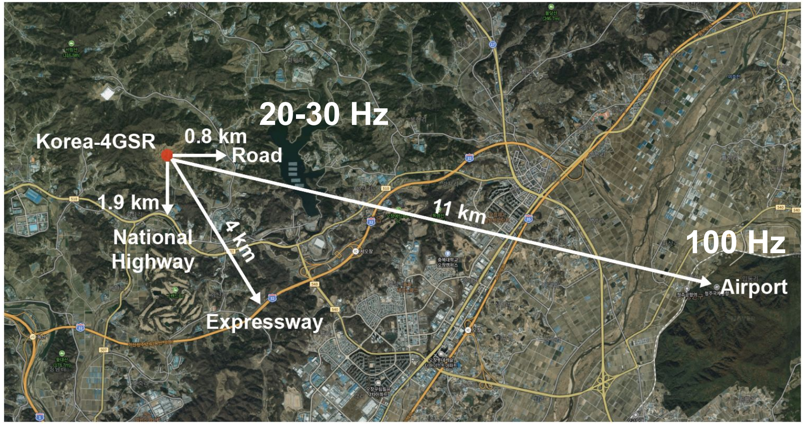
Vertical beam profile

한국기초과학지원연구원
KOREA BASIC SCIENCE INSTITUTE

Compare vibration level with other SR facility

❖ Vibration source and propagation





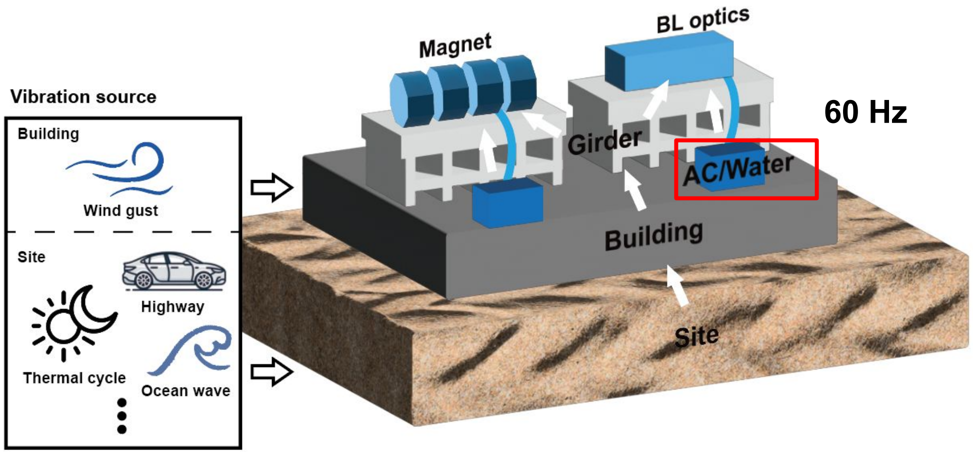
❖ Overview of vibration amplitude (RMS, 1-100 Hz)

Facility name	APS	BNL	SPRING 8	SSRF	IHEP	PLS-II 9C/2D	4GSR
Day rms (nm)	11.0	135.3	2.5	444.0	9.0	15.9 / 85.49* 15.4 / 34.39*	70 nm (1 Hz)** 11 nm (2 Hz)
Night rms (nm)	9.8	29.1	1.8	102.0	8.1		

https://vibration.desy.de/overview * Measured over 4 repetitions. **Dr. Gwang-Wook Hong from PAL** ** On construction site

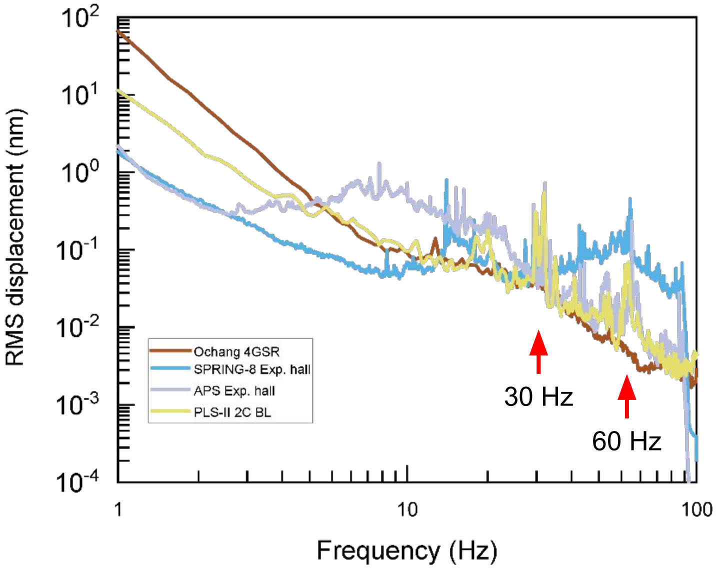
Compare vibration level with other SR facility

❖ Vibration source and propagation



1 - 30 Hz

❖ Vibration comparison of SR facility



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