

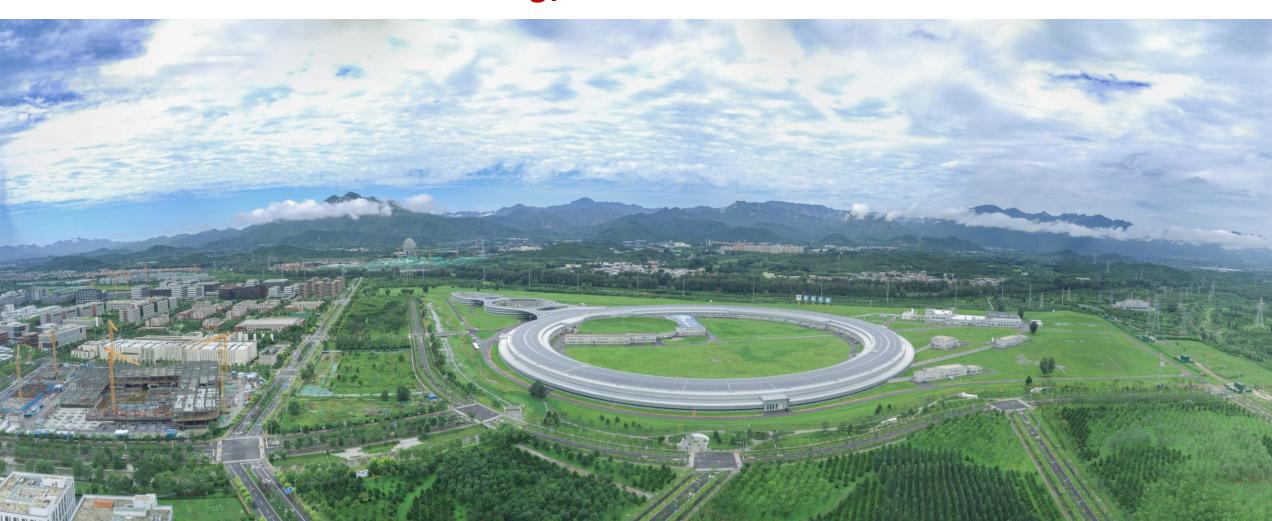




高能同步辐射光源 High Energy Photon Source | HEPS

## Status of High Energy Photon Source (HEPS)

Yi Zhang, Beamline Division



## **HEPS** progress





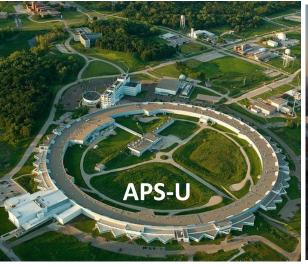




3 built
high energy
4th generation
synchrotrons









Electron Energy	6 GeV	6 GeV	6 GeV	
Emittance(achieved)	130 pm.rad (130)	42 pm.rad (40)	35 pm.rad (98)	
Beam current (mA)	200	200	200	
Storage ring length	0.84 km	1.10 km	1.36 km	
	upgrade	upgrade green field		
status	2015-2020 operational	2018-2024 operational	2019-2025 commissioning	









NEWS AND VIEWS

### **SRN2019**

### Groundbreaking Ceremony at the High Energy Photon Source in Beijing

On June 29, 2019, a sunny morning in Bei-

### **SRN2022**

#### **HEPS** is Standing (



**Update on HEPS Progress** 

PING HE, JIANSHE CAO, GUOPING LIN, MING LI, YUHUI DONG, WEIMIN PAN, AND YE TAO Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China

The High Energy Photon Source (HEPS) is Another major milestone is the successful comto unanticipated delays.

a greenfield 4th-generation light source. Its pletion of a mock-up of a standard cell of the nents for the HEPS accelerator is in good storage ring energy is 6 GeV and its ring cir-HEPS storage ring (Figure 3). All of the mag-shape. Storage ring magnets are being tested cumference is 1,360m. One year after the nets in this cell are now installed and aligned, HEPS complex buildings were constructed all of the vacuum chambers have been con-(Figure 1), we report here considerable prog-nected together and inserted into the magnets. ress, despite the COVID pandemic's impact The mock-up assembly allowed the design and the longitudinal gradient dipoles have been on supply chain and on-site personnel leading installation team to identify many necessary measured, and the integral field is tuned to less corrections, which have been integrated into the than 1E-4 deviation. About 18% of the quad-

As a necessary measure for the coming magnets have been measured. The effect of The year of 2022 witnessed completion of beam commissioning, a high-level application corrector coils to the quadrupole field has been several milestones in accelerator progress. Installation and high-power conditioning of the accelerator physics application set (Pyapas), was proposed and has been developed [3]. By applications

measured to be 4kHz. The manufacture of the more than 2 000 power supplies to power the main magnets

in batches. All of the sextupoles and octupoles

tem and met their specifications. Over 30% of

rupoles and dipole-quadrupole combined

magnets have been tested and the bandwidth

**SRN2023** 

ed, while and

and correctors has been completed and testing

s. Following the successful vali-

TECHNICAL REPORT

#### HEPS Update in 2024

PING HE, JIANSHE CAO, MING LI, YUHUI LI, YUHUI DONG, WEIMIN PAN, AND YE TAO Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China

Year 2024 witnessed two key milestones of the High Energy Photon bandwidth, high-precision fast corrector power supplies has yielded Source (HEPS) project: the beam stored in a storage ring and the first impressive results, featuring a 75-microsecond small-signal step re-X-ray light emitted from an insertion device, respectively. As a green sponse and 20 ppm current ripple. field 4th generation 6 GeV lightsource (Figure 1), commissioning of the accelerator and Phase I beamlines will be completed in 2025 and HEPS installed and sealed for the storage ring. Of these, 918 pieces have been will be gradually open to pilot users at the same time

The HEPS storage ring incorporates 1,776 advanced magnets, comprising 26 different types, designed to precisely steer and focus the elec-was made possible through comprehensive measures, including the use tron beam into a more concentrated form. These magnets were integrated of segmented solenoid magnetic fields, enhanced magnetic field into 288 modules, with each magnet's center aligned to an exceptional precision of 30 microns. The complete installation of all magnets into the storage ring tunnel was accomplished this year (Figure 2).

All magnet power supplies are situated within the Power Supply accuracy of 50 ppm, and repeatability of 20 ppm. Testing of the wide- curacy of approximately 20 µm

Approximately 1,500 vacuum chambers have been successfully treated with NEG film coating, covering a total length of 1,200 meters and providing distributed pumping capabilities. The HEPS vacuum team successfully completed the NEG coating for the 1,200 mm long antechamber, which features a narrow slit of 6mm. This achievement strength in the end solenoids, and fine tuning of discharge parameters.

Regarding the magnet support girders, all 288 units have been installed and tested, demonstrating promising performance; the first Eigen frequency exceeds 70 Hz (Figure 3), and the motion resolution hall. The high-precision current-stable power supplies demonstrate exceptional performance metrics, including long-term stability of 10 ppm. tors has been positioned with verified performance showing motion ac**Progress Released** 

#### nature

Explore content Y About the journal Y Publish with us Y

nature > news > article

NEWS | 13 May 2024

### **World's brightest X-rays: China first** in Asia to build next-generation synchrotron

The US\$665-million High Energy Photon Source (HEPS) outside Beijing puts China among only a handful of countries that have fourth-generation synchrotron light









Science

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### China poised to turn on one of world's most powerful sources of xray light

Beams from \$657 million nextgeneration synchrotron will reveal atomic-scale structure of proteins and materials

22 NOV 2024 · 5:30 PM ET · BY RICHARD STONE



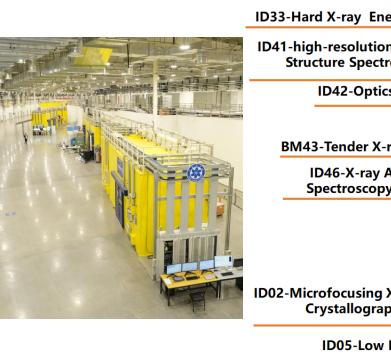
China's High Energy Photon Source is days away from funneling bright x-rays into experimental beamlines. INSTITUTE OF HIGH ENERGY PHYSICS/CHINESE ACADEMY OF SCIENCES

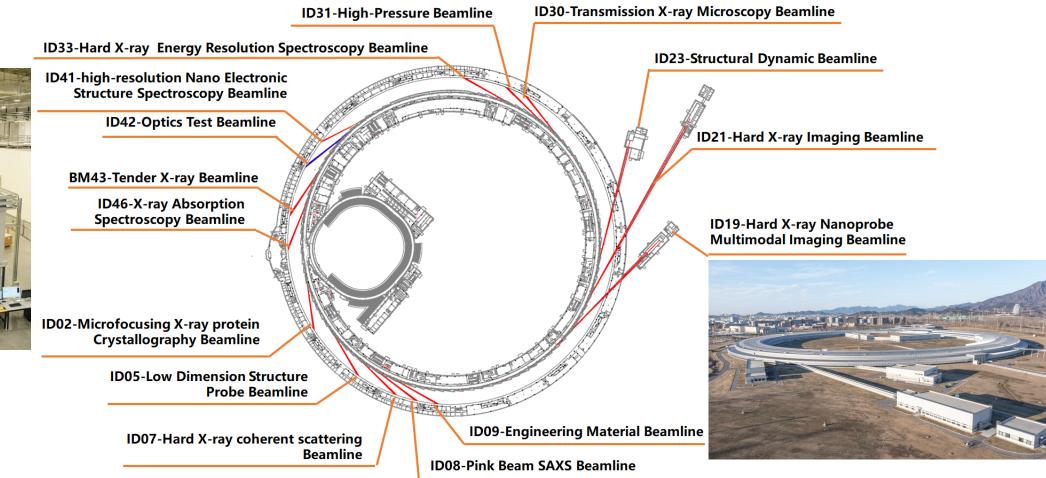
**HEPS IAC Meeting 2025** August 19, 2025



### 15 beamlines in Phase I: 14 user beamlines (3 long beamlines)+ 1 test beamline

Divided into Group 1 and 2, depending on its complexity and insertion device (ID) type Most feature beamlines, like nano and coherent beamlines, in Group 2 to give more time for design and prepare







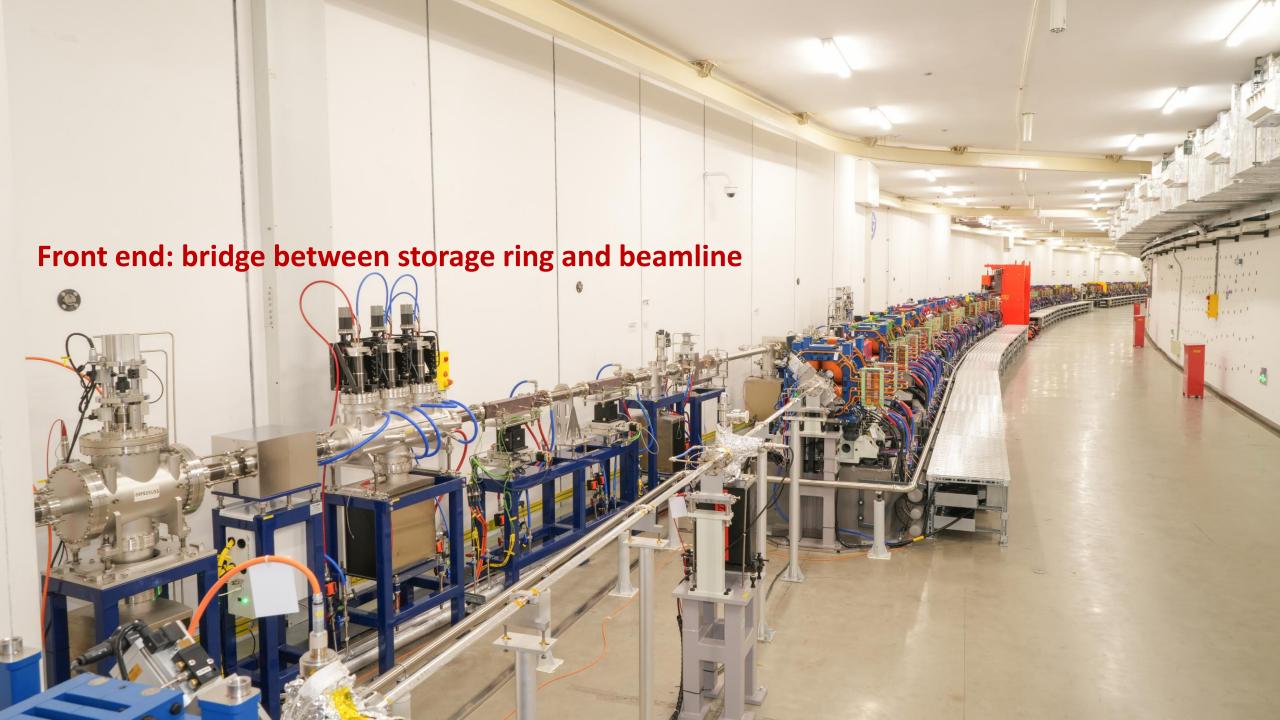


## Phase I beamlines list

Group1	Beamlines	Features			
	Tender spectroscopy (Tender)	Bending magnet, 2-10keV spectroscopy			
	XAS	routine and quick XAFS, plus 350nm microprobe			
	Hard X-Ray Imaging (Imaging, 350m)	3 IDs, 10-300keV, Phase/Diffraction contrast imaging			
	Transmission X-ray Microscope (TXM)	full field 20nm resolution imaging and spectro-imaging			
	Macromolecular Crystallography (MX)	1μm spot, standard and serial protein crystallography			
	pink SAXS (SAXS)	pink beam, lest optics			
	Optics Test (Test)	undulator and wiggler, Optics online metrology and R&D			
Group 2	NanoProbe (180m)	Nano mode, <10nm; InSitu mode, <50nm; ptycho, BCDI; SEM			
	Coherent Scattering (Coherent)	8-25keV, CDI and XPCS			
	Engineering Materials (EM)	50-170keV, XRD, SAXS, PDF			
	Structural Dynamics (Ultrafast, 200m)	15-70keV, ultrafast diffraction and imaging; nanoholography			
	High Pressure (HP)	150nm focusing, diffraction and imaging			
	Low-Dimension Probe ( LowDimension)	surface and interface scattering, surface XPCS			
	High Energy resolution spectroscopy (HERS)	Nuclear Resonant Scattering and X-ray Raman spectroscopy			
	Nano ARPES (ARPES)	100-2000eV, 100nm, 5meV@200eV, APPLE-KNOT undulator			
Н	PHOTON SOURCE	HEPS IAC Meeting 2025 August 19, 2025 9			



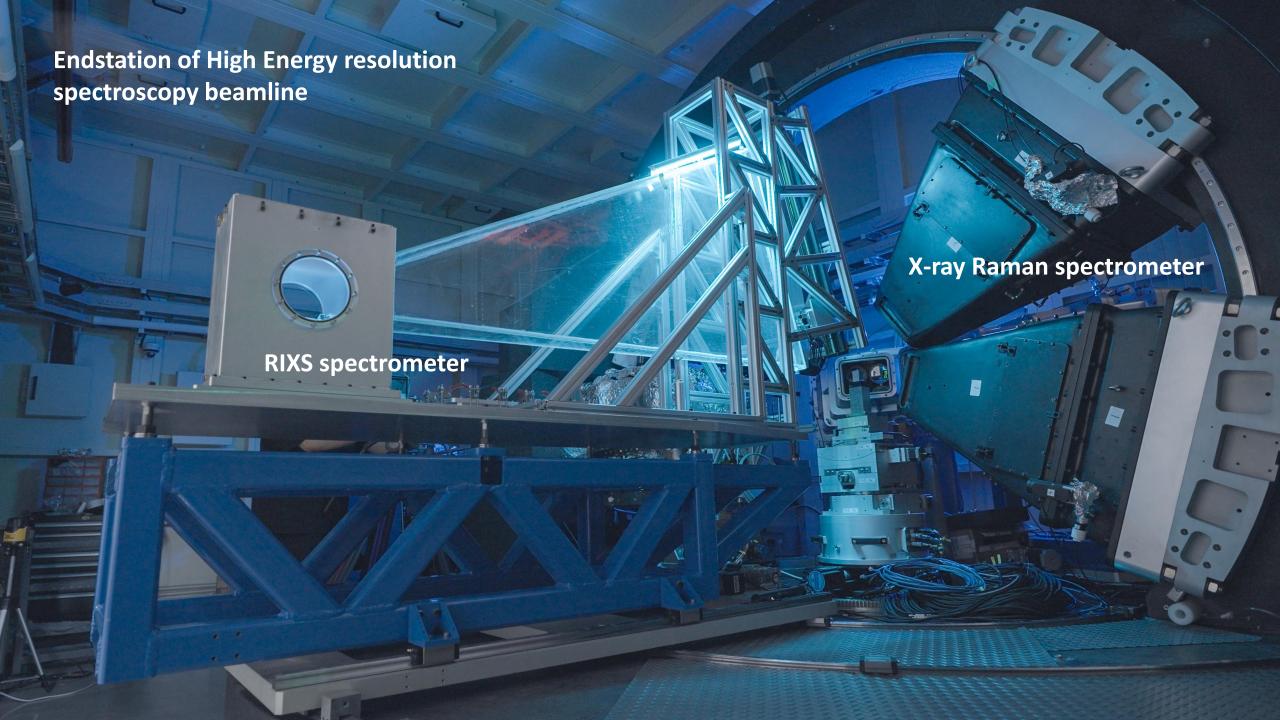












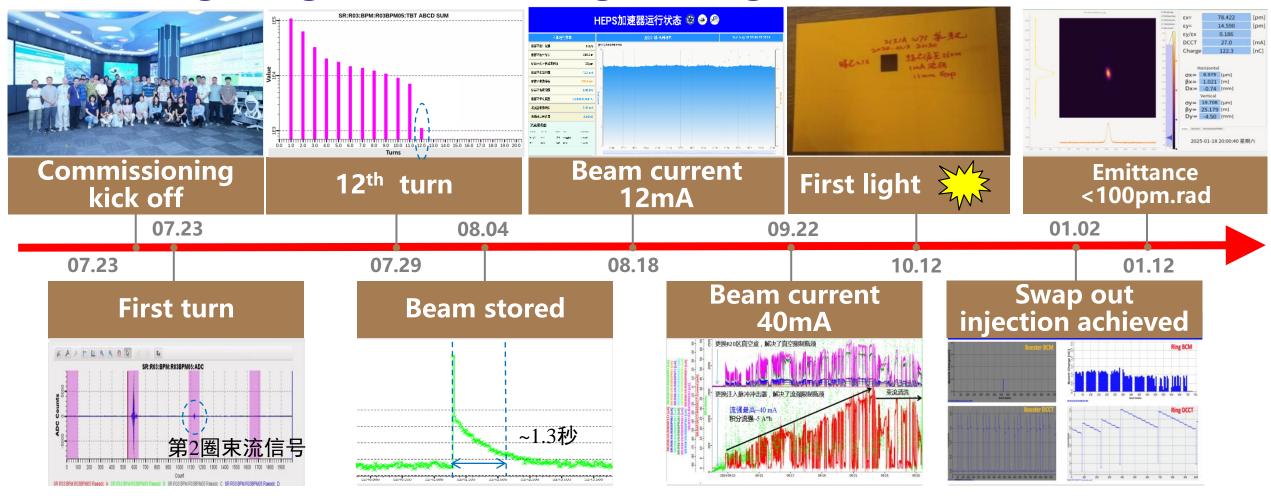






## Commissioning

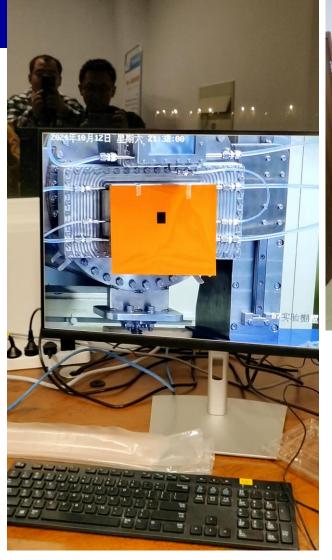
### Storage ring commissioning starting from 2024. 07.23







### Insertion device beamline commissioning starting from 2024. Oct.12 gradually





First light from Insertion device beamline on Oct.12, 2024, reaching 350m away endstation

50 days allocated for beamline commissioning until now

All of 15 beamlines saw the light and the commissioning went well within short period







# HEPS recently shutdown to install Superconducting RF cavities, gearing up for 100mA

Five 166.6MHz SRF cavities and two 499.8MHz SRF cavities installed in storage ring

### **Start new commissioning this week**







### Some feature beamlines introduction

**HEPS IAC Meeting 2025** 





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## **ID09 Hard X-ray Coherent Scattering beamline**

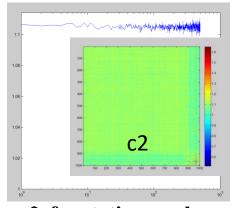
Leader: ZHOU Liang, zhouliang@ihep.ac.cn

Coherent X-ray Diffractive Imaging(CDI): including Ptychography, Bragg CDI, for nano resolution 3D imaging of structure and strain, while combining with XRF and XAFS to achieve 3D imaging of element and valence;

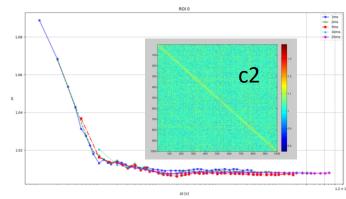
X-ray Photons Correlation Spectroscopy (XPCS) :including two scattering geometries, SAXS XPCS and WAXS XPCS, for equilibrium dynamics, non equilibrium dynamics, and dynamic heterogeneity of condensed matter, length scale µm-Å, time scale 1000s-µs.

<u> 10005-µ5.</u>	·
<b>Energy Range</b>	7-25keV
<b>Coherent Flux</b>	$10^{12} \text{ph/s} - 10^{13} \text{ph/s}$
Ptychography	Beam size:100nm-10μm; resolution: 5-50nm; field of view: 1-100μm
BCDI	Beam size:100-500nm; resolution: 1-10nm; field of view:50-500nm
WAXS XPCS	Beam size:100nm-2μm; length scale:0.1-1nm; time scale:1000s-20μs
SAXS XPCS	Beam size:10-20μm; length scale:1-200nm; time scale:1000s-20μs

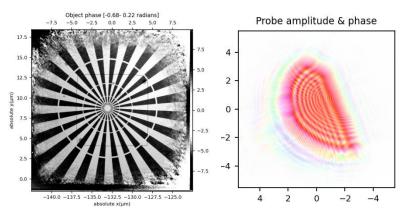
## Commissioning: SAXS XPCS has initially realized dynamics on the time scale of 1000s-



g2 for static sample (frame time 1s)



g2 for SiO<sub>2</sub> 700nm aqueous solution (1-20ms frame times )



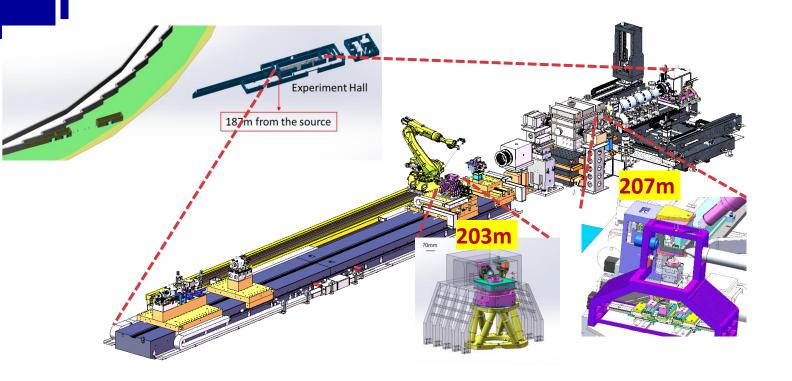
The reconstructed object and probe

22

Ptychography has achieved 2D phase contrast imaging with a resolution of approximately 30nm.

HEPS | HIGH ENERGY PHOTON SOURCE

### **ID19** nanoprobe beamline (NAMI)



Energy range: 5-50keV

Energy resolution:  $2 \times 10^{-4}$  @ Si<1,1,1>

5×10<sup>-5</sup> @ Si<2,2,0>

Nanoprobe size: down to 9nm

# Leader: CHANG Guangcai, changgc@ihep.ac.cn

### **Imaging**

- ✓ Nanoholography
- √ Ptychography
- ✓ Nano-mapping

### **Diffraction and Scattering**

- ✓ Nano-diffraction
- **✓ DFXM**
- **✓** BCDI

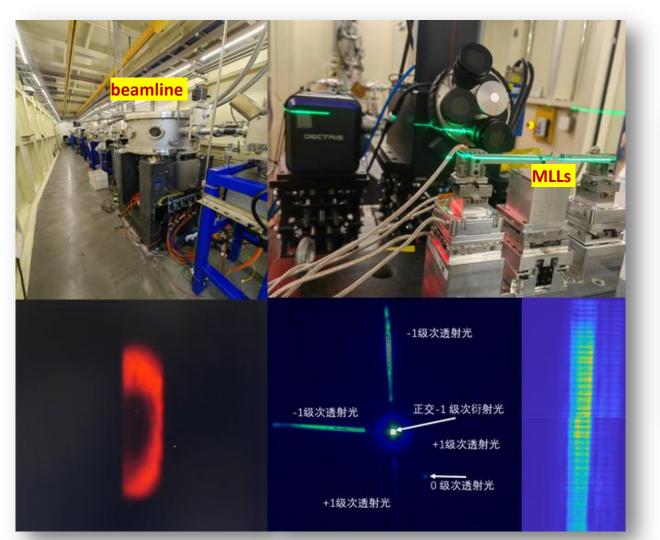
### **Spectroscopy**

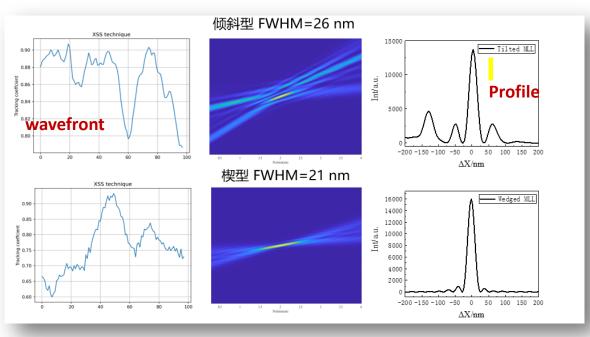
- ✓ Nano-XAS
- ✓ Nano-XRF





# Commissioning: Using Multilayer Laue Lens (MLL, in-house fabricated) wedge MLL, vertical size 26nm, horizontal size 21nm

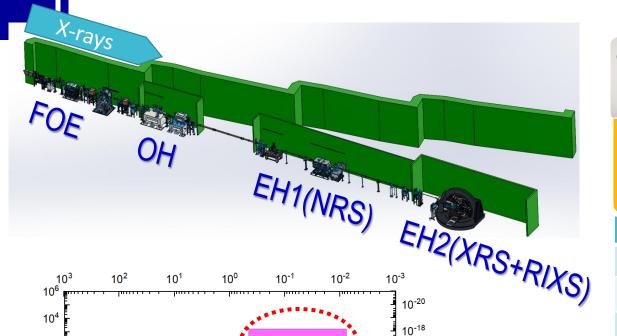






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### ID33: Nuclear Resonance Scattering & Inelastic X-ray Scattering beamline



X-ray Raman

Quantum world

 $10^{2}$ 

IXS

Neutron

10<sup>0</sup>

Momentum Q (nm<sup>-1</sup>)

10<sup>-16</sup>

10<sup>-8</sup>

10<sup>-6</sup>

10<sup>-4</sup>

10<sup>-2</sup>

### **HEPS-In-house instrumentation**







HRM:  $\frac{\delta E}{E} = 10^{-7}$ 



"Qiankun": XRS+RIXS



Bent crystal analyzer



Diced flat crystal analyzer

25

Technique	Energy resolution	Flux (ph/s)	Spot size (µm)	More to be added
NRS	1meV@14.4keV for <sup>57</sup> Fe	1.6×10 <sup>10</sup>	2(H) ×8(V)	<sup>151</sup> Eu, <sup>119</sup> Sn, <sup>161</sup> Dy,
XRS	0.7eV@9.7keV	3.5×10 <sup>13</sup>	2(H) ×2(V)	13keV, 16keV
RIXS	0.1eV@8.9keV for Cu	4×10 <sup>12</sup>	2(H) ×2(V)	Cu, Ir, Pt, Os

A suite of spectroscopic tools for Physics, Materials, Quantum Optics, Planetary sciences, Biochemistry, Catalysts, Batteries...

Leader: XU Wei, xuw@ihep.ac.cn

### **Techniques**

- Nuclear resonant scattering spectroscopy (<sup>57</sup>Fe)
- X-ray Raman spectroscopy
- Resonant Inelastic X-ray Scattering spectroscopy

### Sample environment

- Low Temperature( down to 4 K)
- ◆ High Pressure (DAC <100GPa)</p>
- ◆ High Temperature( up to 1000K)
- Users' specific in-situ devices



10<sup>2</sup>

10<sup>-8</sup>

10<sup>-10</sup>

10<sup>-12</sup>

10<sup>-14</sup> E 10<sup>-3</sup>

Energy

**IUV** 

laser

laser

Raman

Brillouin

 $10^{-2}$ 

Nuclear Resonance

 $10^{-1}$ 

Forward scattering



10<sup>1</sup>

HEPS IAC Meeting 2025 August 19, 2025





### **ID21 Hard X-ray Imaging beamline**

### 350m long beamline, 3 insertion devices

- √ High penetration: Up to >300keV X-ray
- ✓ Large FOV: long source-sample distance (300m), X-ray spot size at sample, 300mm×100mm from wiggler, 270mm×270mm from new wiggler
- ✓ Small PSF: lower emittance, long
- ✓ High sensitivity : longest coherence length from lower emittance and long source-sample distance
   300m
- ✓ High resolution and adjustable: 0.6-100µm, long sample to detector distance, In-house developed Imaging detector: up to 30k\*18k pixels

leader: LI Gang, lig@ihep.ac.cn





Deep Penetration and High Sensitivity
Large FOV and High spatial resolution

Only two beamlines available in the world, ESRF-EBS BM18 and HEPS ID21







## **ID23 Structural Dynamics Beamline**

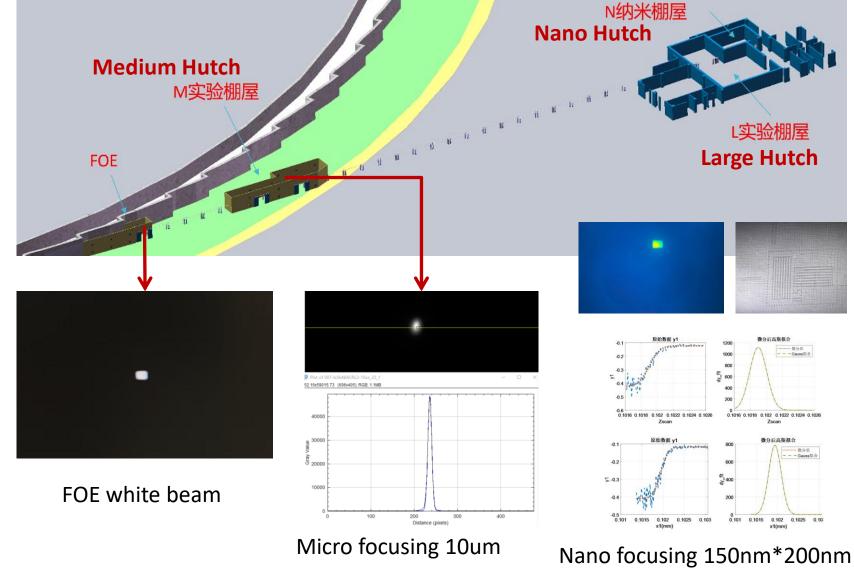
leader: ZHANG Bingbing zhangbb@ihep.ac.cn

### **High Energy**

1st harmonic 20keV Pink beam up to 70keV White beam up to 200keV

**High tempo resolution** 400ps single shot 140ns continuous detection

**High spatial resolution** White beam1um, FOV up to 14mm Nano mode, 100 nm

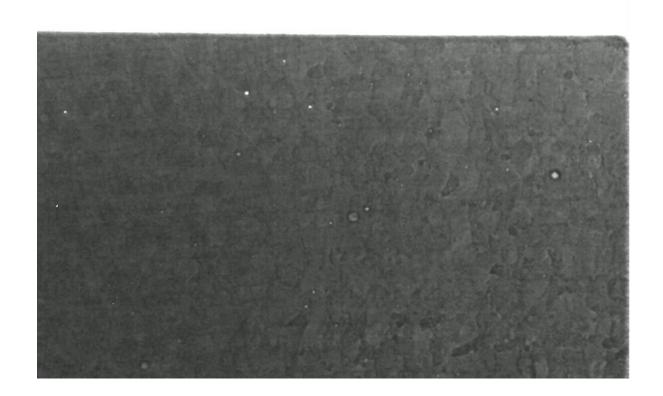




**PHOTON SOURCE** 

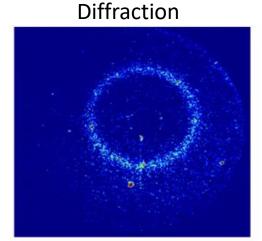
# Commissioning: only 5mA beam current ( beam current $\propto$ X-ray intensity, 100mA this September and later 200mA)

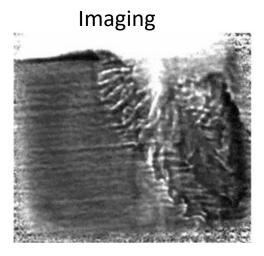
High speed x-ray imaging of Co-based superalloy AM process @ 20kHz frame rate



High speed simultaneous Diffraction and Imaging detection

August 19, 2025







### Beamline instrumentation R&D advancement





- 1. Brief Introduction
- 2. Optical Metrology
- 3. Optics Fabrication
- 4. Multi-physical Field Control
- 5. X-ray Mirror Mechanical Systems
- 6. Monochromators

- 7. Endstation Instruments
- 8. Beamline Defining
- 9. Diagnostic
- 10. X-ray beam commissioning
- 11. Detectors
- 12. Insertion Device
- 13. Recap and Outlook

## **Brief Introduction**

- For the new generation of light source, technological capabilities are crucial.
- Technological capabilities are the key to unleashing the performance of the light source.
- New technologies will give rise to new experimental methods to solve challenging scientific problems.
- Innovative and customized instruments can flexibly meet a variety of experiment needs.
- Except for high-precision mirrors, CRLs, some detectors, no scattering slits and specific sample environments, most of the beamline instruments have been in-house developed.





## International Assessment of IHEP (Sept. 2023)

The R&D for the key technologies for the HEPS beamlines covers various topics in optics, X-ray detectors, and software. The technological advances in X-ray optics manufacturing and metrology have been truly impressive over the last five years, at the level of the best centers in the world. The efforts for X-ray detector development cover some of the most advanced

Cross the street, a supporting facility-Platerform for Advanced Photon Source for HEPS

Accelerator Technology division X-ray Technology division

21,295 m<sup>2</sup> building area, Supported by Beijing Government

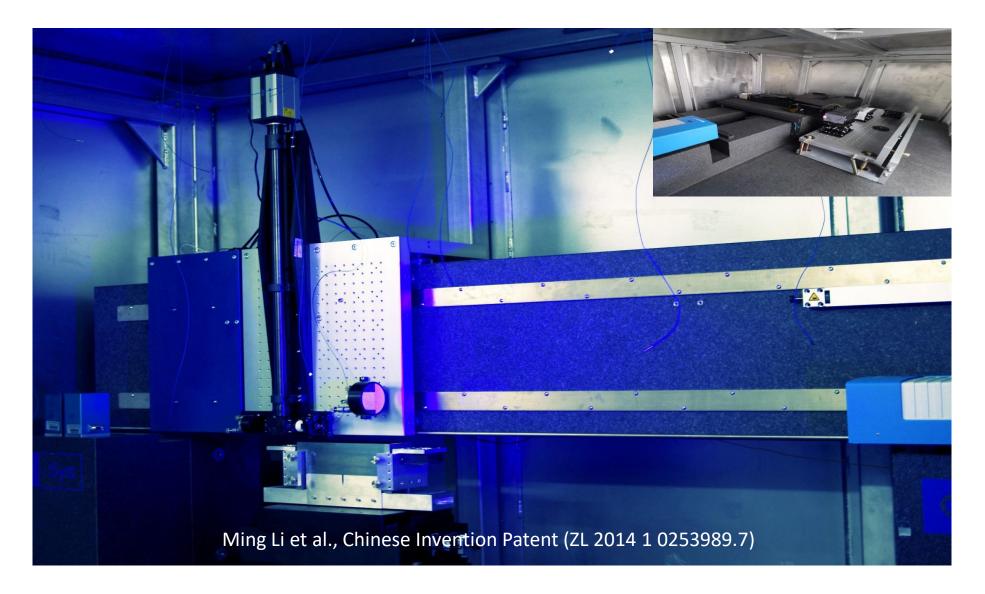






# 2 Optical Metrology

# **Optical metrology (Flag-type Surface Profiler, FSP)**







# Measurement accuracy of the plane/curved mirrors

Measurement of 360mm plane mirror (tilting 1.6mrad, translating distance with 400mm, 8+8 times of scanning)

**Spatial resolution: 1mm** 

∆Height,nm

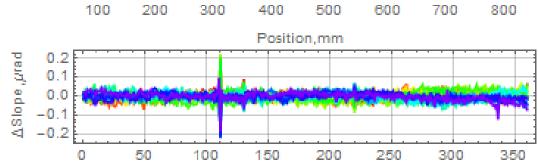
(Slope error is sensitive to spatial resolution)

Slope ,µrad 4500

100

Measurement accuracy of plane mirror:

RMS 24.5 nrad @ once scanning



Position,mm

Measurement of 120mm curved mirror with the range of 3mrad (tilting 0.35mrad / 0.7mrad, translating, 10+10+10 times of scanning)

5500

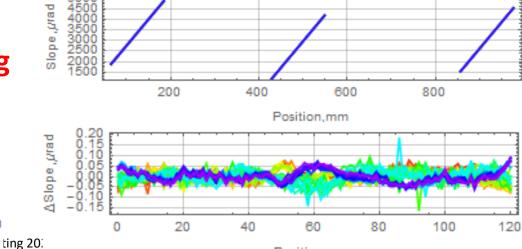
5000

#### Measurement accuracy of curved mirror:

20

RMS 29.0 nrad/RMS 0.23nm @ once scanning

Position.mm





# Mass productization of FSP



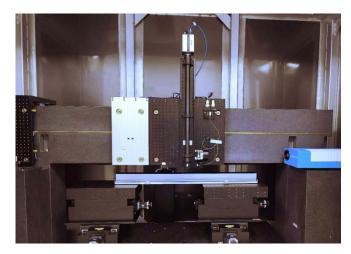
FSP-V Yuquanlu



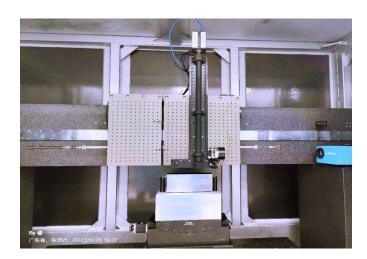
FSP-H Huairou-1



FSP-H Huairou-2



**FSP-V Huairou** 



FSP-V Dongguan

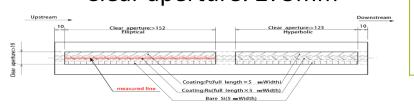
FSP Hefei - finished FSP Shenzhen - on going FSP Chengdu - on going





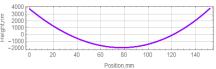
### Measurement of Vertical AKB: 0.1nm RMS

Total length: 315mm Clear aperture: 275mm

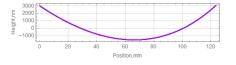


Mirror	Shape	Parameter	Specification	Measurement
B4-Wolter	Elliptical	Slope error	50nrad -	17nrad
	Hyperbola	RMS	Sullau	26nrad
	Elliptical	Height error	,	0.11nm/0.59nm
	Hyperbola	RMS/PV	0.4nm / 6nm	0.12nm/0.70nm

Elliptical area



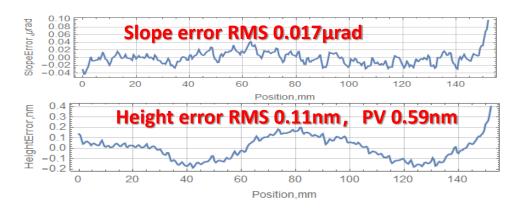
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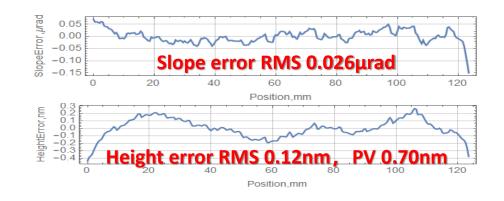


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Parameter	Nominal	Height fit	Deviation
p(m)	79.6200	79.6200	-
q (m)	0.6786	0.6769	-0.0017
θ (mrad)	3.170	3.158	-0.012

Parameter	Nominal	Height fit	Deviation
p (m)	0.6769	0.6769	-
q (m)	0.3800	0.3798	-0.0002
θ (mrad)	2.470	2.472	0.002







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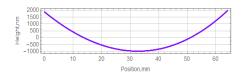
# Measurement of Horizontal AKB: 0.05nm RMS

Total length: 149mm

Clear aperture 109mm

Mirror	Shape	Parameter	Specification	Measurement
	Elliptical	Slope error	50nrad –	30nrad
DA Maltan	Hyperbola	RMS	Sullau	38nrad
B4-Wolter	Elliptical	Height error	0.4000 / 6000	0.051nm/0.27nm
_	Hyperbola	RMS/PV	0.4nm / 6nm -	0.052nm/0.35nm

Elliptical area



Hyperb	ola area
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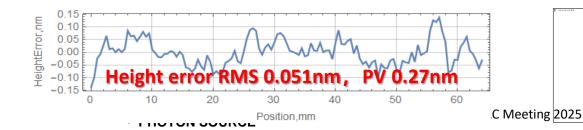


Parameter	Nominal	Height fit	Deviation
p(m)	79.8700	79.8700	-
q (m)	0.2259	0.2241	-0.0018
θ (mrad)	3.250	3.240	-0.010

Parameter	Nominal	Height fit	Deviation
p(m)	0.2239	0.2239	-
q (m)	0.1300	0.1297	-0.003
θ (mrad)	2.390	2.413	0.023

Slope error RMS 0.030µrad

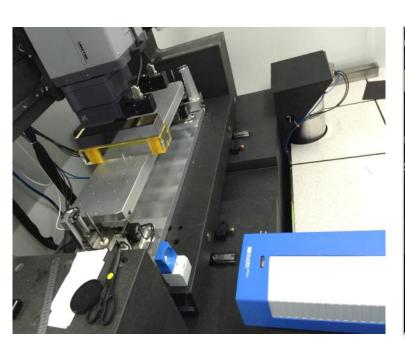


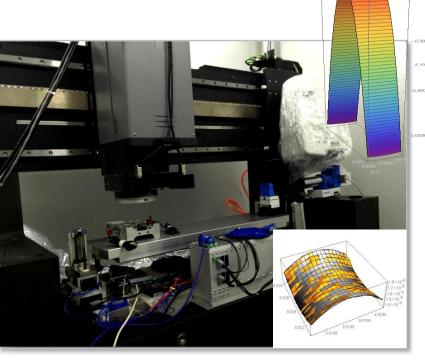


Height error RMS 0.052nm, PV 0.35nm

August 19, 2025

# **Stitching Interferometer**







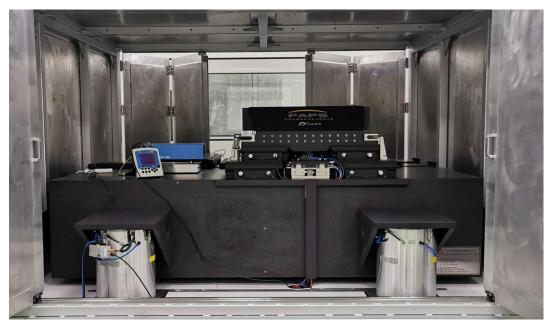
**Angle-measurement assisted SI** 

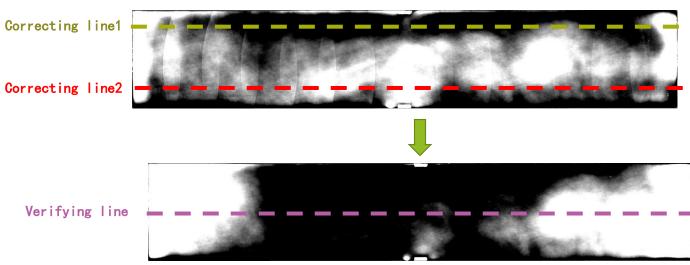
θ-R SI Elastic SI





# **Stitching Interferometer**





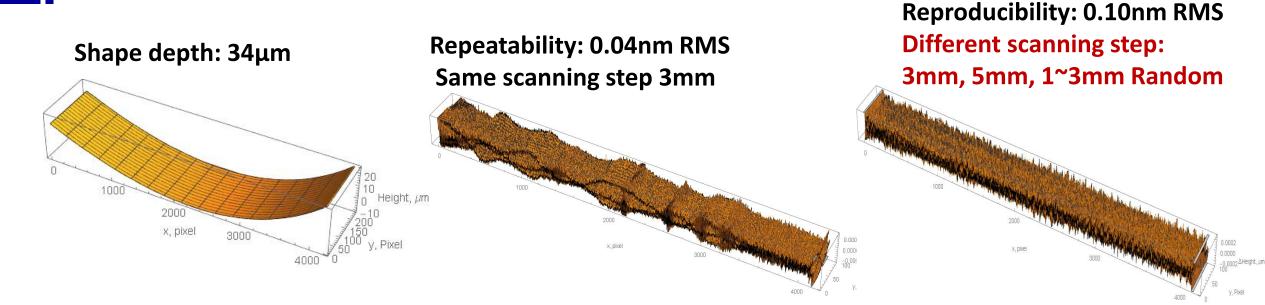
A Frequency-decomposed Stitching Interferometer (FSI) has been proposed and developed, which combines the SI & FSP, providing feedback for mirror processing with 2D sub-nanometer measurement accuracy.

Dongni Zhang, Ming Li\*, Changrui Zhang, Zhibang Shen et al. To be published

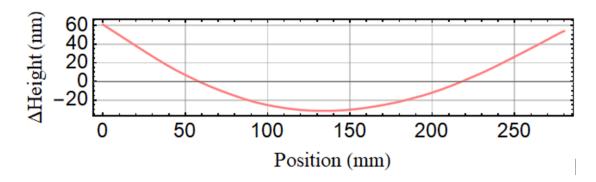




# Measurement result of elliptical mirror (B8-HKB) by FSI

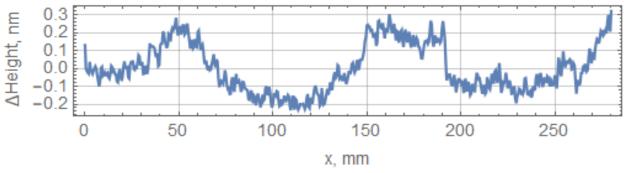


#### Traditional Pure SI - FSP ~ 90nm PV @ Verifying line



#### FSI - FSP ~0.13nm RMS @ Verifying line

45



Dongni Zhang, Ming Li\*, Changrui Zhang, Zhibang Shen et al. To be published

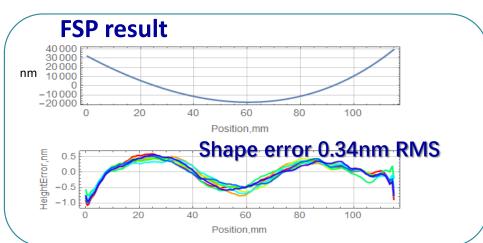


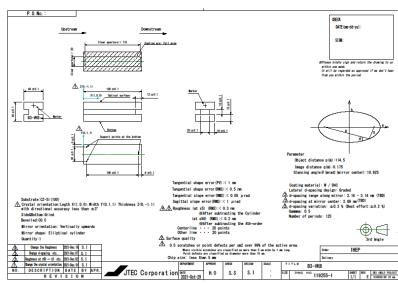
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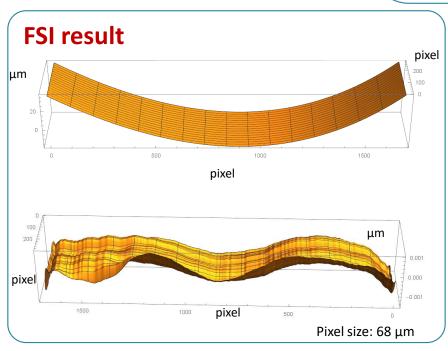
# **Applying FSI to mirror polishing**

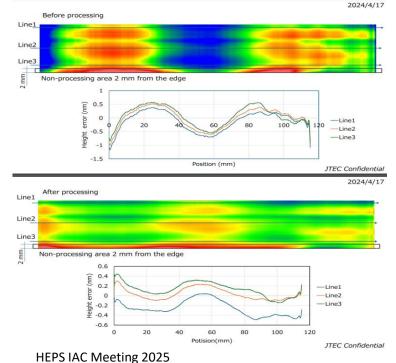
#### **B3-VKB**

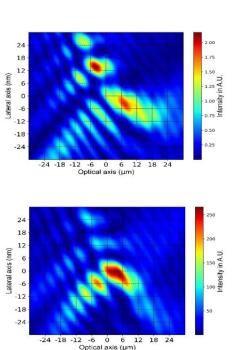
- ♦ Shape depth: 57μm
- **♦** Slope range: 3.9mrad
- ◆ Minimal radius: 17m









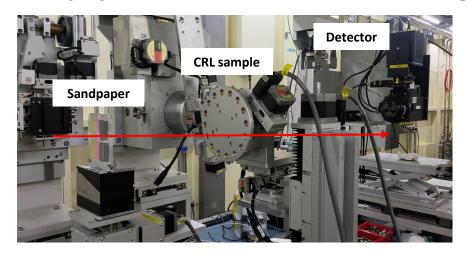




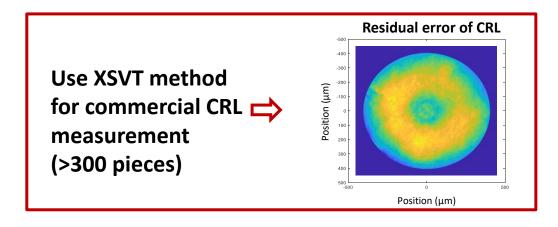
HEPS | HIGH ENERGY PHOTON SOURCE

### **Wavefront Metrology**

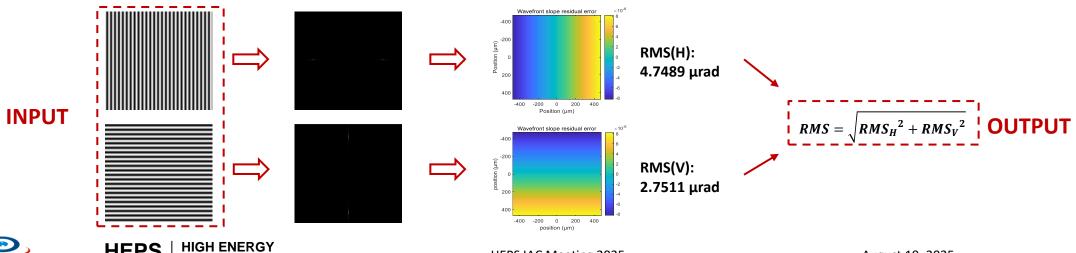
> Develop speckle based wavefront metrology method at SSRF-BL09B



PHOTON SOURCE



> Develop grating based wavefront metrology method for fast optics alignment.



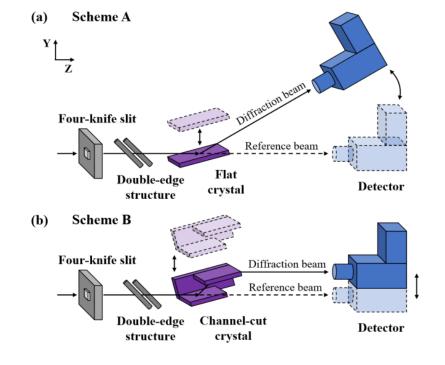


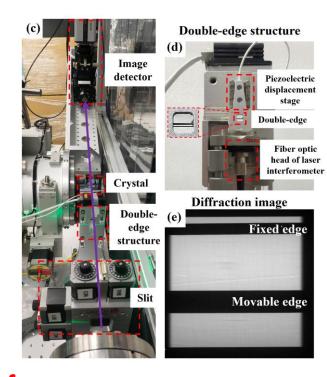
August 19, 2025

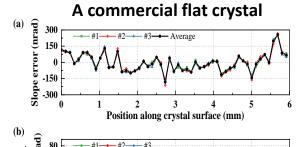
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### **Wavefront measurement**

#### **Double-edge Method for wavefront measurement**







Position along crystal surface (mm)

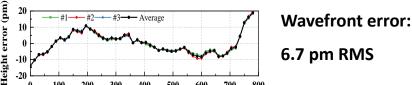
Position along wavefront (µm)

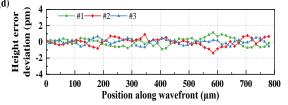
Slope error:

82.1 nrad RMS

Repeatability:

13.5 nrad RMS





Repeatability:

0.5 pm (0.65%λ)

Method test in BSRF

#### Overcome the wavefront blurring effect from:

- Low coherence source @ 1<sup>st</sup> G SR (BSRF)
- Crystal extinction

Realize diffraction-limited level measurement in a Full beam range.

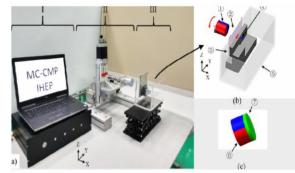




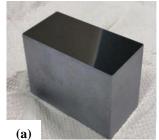
# **Optics Fabrication**

# Silicon mono-crystal fabrication

■ With chemical-mechanical polishing methods, the ultra-high wavefront preservation within the full beam of nearly **10mm** has been achieved.

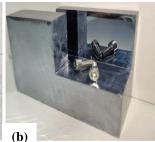


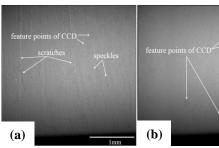
Magnet controlled-chemical mechanical polishing system for Channel-cut fabrication

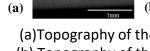


(a) Flat silicon crystal

(b) Channel-cut silicon crystal

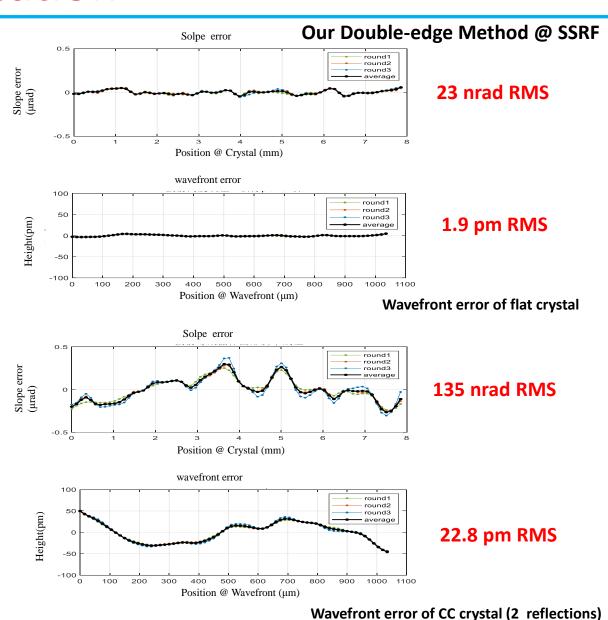






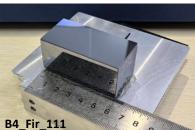
- (a)Topography of the etching CC (b) Topography of the polishing CC
- ☐ The fabricated flat and Channel-cut silicon crystals also qualified sub-nanometer surface roughness, X-ray topography with uniform contrast

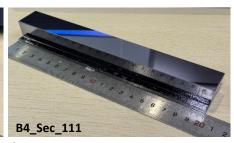
Zhen Hong et al. J Synchrotron Radiat. 2023 Jan 1;30(Pt 1):84-89.

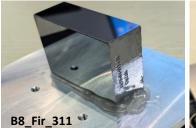


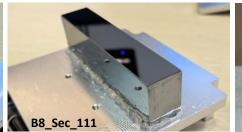
# In-house crystal manufacturing for HEPS Phase-I













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Partial crystals photos

Crystals in detail ▼

Beamline	Crystal type	Design Wavefront error (nrad)	1st crystal (nrad)	2nd crystal (nrad)	Quantity	Quantity in total
B1	Tri-curved Laue crystal @(111)	/	200 (single Crystal)		2 (1 Spare part)	
B4	Flat Crystal @(111)	170	60.94	75.93	4 (2 Spare parts)	
B5	Flat Crystal @(111)		31.18	84.89	4 (2 Spare parts)	
БЭ	Flat Crystal @(311)	170	57.74	39.67	4 (2 Spare parts)	
B8	Flat Crystal @(111)		24.27	43.87	4 (2 Spare parts)	
Во	Flat Crystal @(311)	170	62.67	77.58	4 (2 Spare parts)	
В9	Flat Crystal @(111)	140	39.41 31.72		4 (2 Spare parts)	40.5
ВА	CC Crystal @(111)	200	135 (single Crystal)		2 (1 Spare part)	48 Pieces
BD	Flat Crystal @(111)	170	46.15 (single Crystal)		2 (1 Spare part)	(24 spare parts)
BE	Flat Crystal @(111)	170	105.89	66.99	4 (2 Spare parts)	
BF	Flat Crystal @(111)	170	46.87	23.15	4 (2 Spare parts)	
B2	Flat Crystal @(111)	170	Waiting for inspection	Waiting for inspection	4 (2 Spare parts)	
В6	Flat Crystal @(111)	170	Waiting for inspection	Waiting for inspection	4 (2 Spare parts)	
В7	Laue curved crystal @(111)	/	In Processi	ing	2 (1 Spare part)	

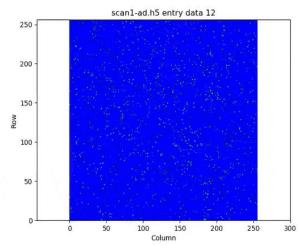




# **Analysis Bent-crystal**

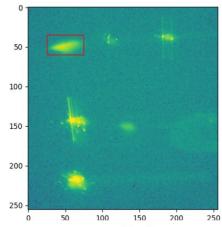
**Spherically bent Si(660)** ~1eV @ 9.7keV



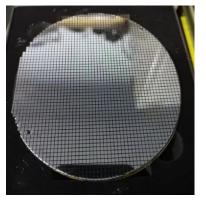


Bent striped Si(660) ~0.53 eV@ 9.7keV

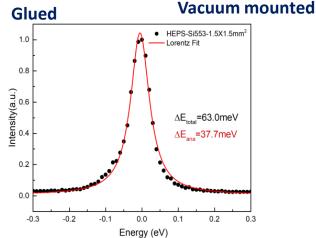




Mosaic-diced Si(553) ~0.037 eV@ 8.9keV







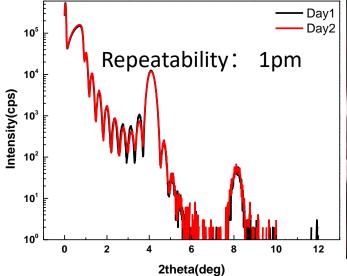
- Spherically bent analyzers for XRS: excellent focusing & energy resolution
- Bent-striped analyzers for XRS: energy resolution improved
- Mosaic-diced analyzers for RIXS: highly improved energy resolution



# **Mirror Coating**

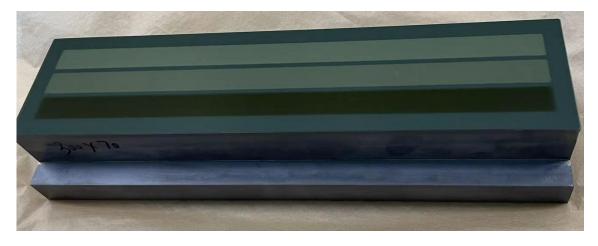
Features: up to 1.2 m mirror, figuring module integration







#### Mirror for HEPS BD Tender X-ray Beamline



#### Multilayer monochromator for B3 Structural Dynamics Beamline



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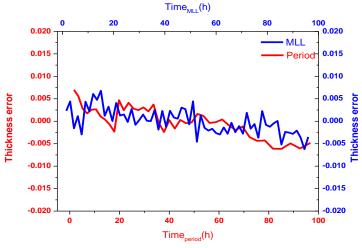




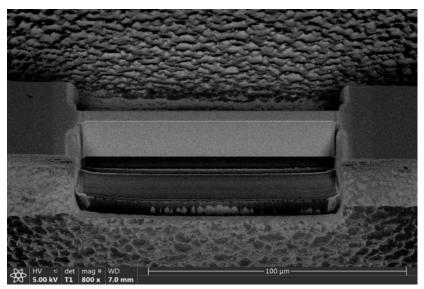
# Multilayer Laue Lens (MLL)

Para.	Req.
Material	WSi <sub>2</sub> /Si
N. Layer	13030/8030
Thickness	64μm/44μm
Focus	8×8nm²

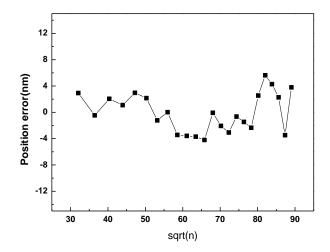




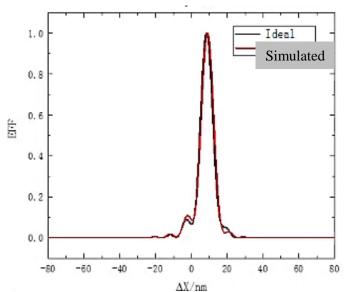
**Growth rate drift 0.3%** 



**Magnetron sputtering** 



Layers position error (PV) ±5nm



Simulated focusing FWHM 8nm

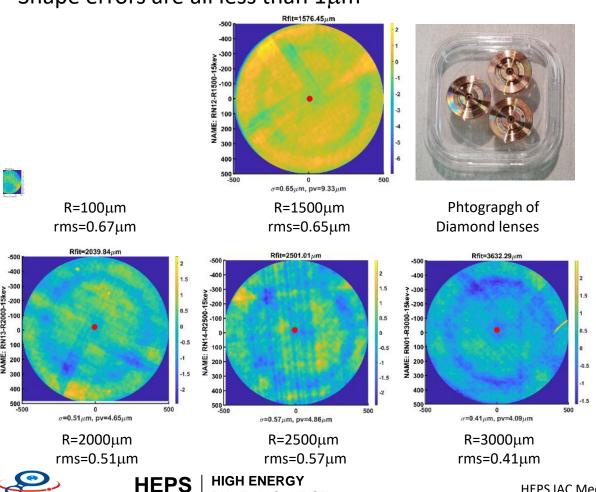


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# Diamond refractive lenses and phase plate

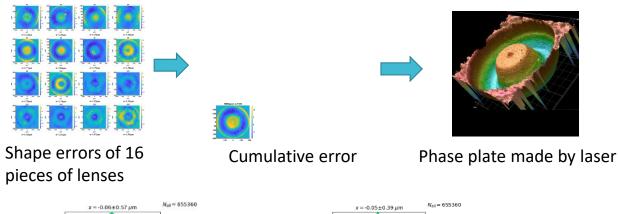
Self-developed diamond lenses with various radius of curvature specifications

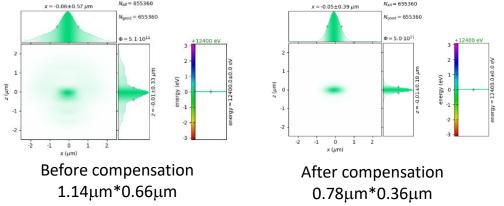
Shape errors are all less than 1µm



**PHOTON SOURCE** 

• Self-developed diamond phase compensation plate



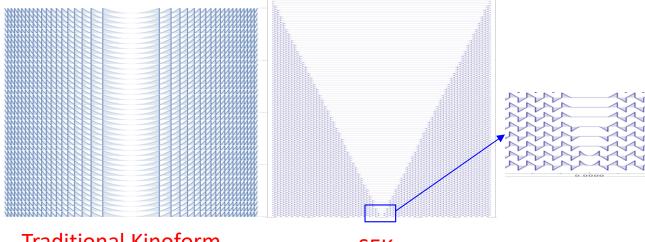


Simulation: Signification improvement in tailing, Strehl ratio improved from 0.44 to 0.66 (ideal value is 0.7)

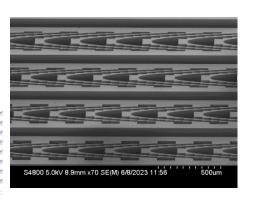
August 19, 2025 **55** 

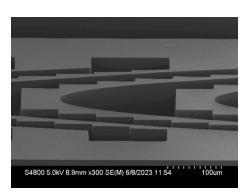
# Kinoform lens— by LIGA

Novel Super Efficient Kinoform (SEK)

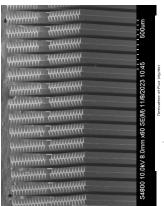


**OVAL SU8** 

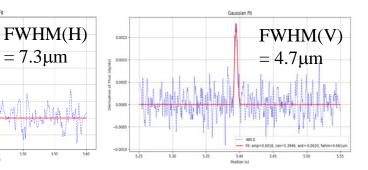




**Traditional Kinoform** 



**SEK** 



**BPM** simulation result

Nickle SEK Tested @ 80keV in BL12SW, SSRF (F~1m)

Ming Li, Weiwei Zhang, Chinese Invention Patent (applying)

Tested @15keV in B16,Diamond (corporated with SSRF)

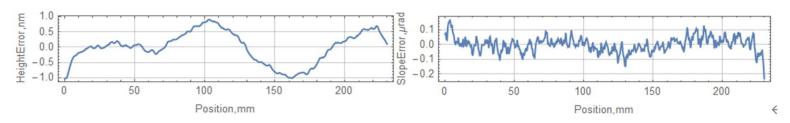
Yuanze Xu et al. To be published





# Mirror Fabrication (collaborated with other Chinese company)

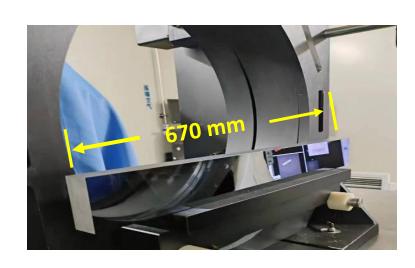


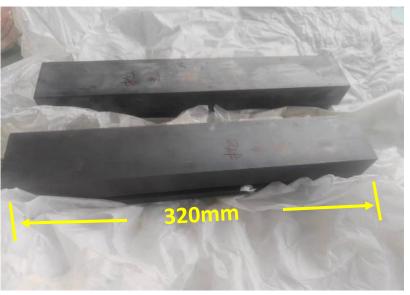


Flat mirror with the optical length of 230mm

Height error: 0.50nm RMS







Large flat mirror and elliptical mirror are on the way

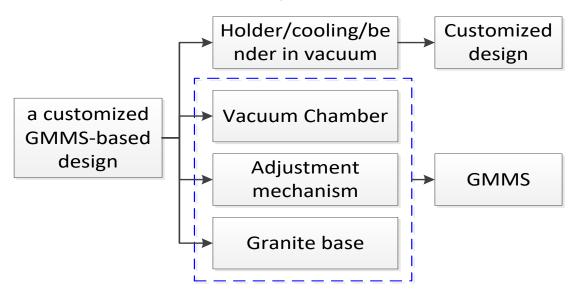




# X-ray mirror mechanical systems

# Overall design strategy of mirror mechanical system

- Stable generic mirror mechanical system (GMMS) is developed firstly shown in Fig.1.
- Customized GMMS-based mechanical design
  - Clamping / water-cooled / bender in vacuum design
  - Double mirror system



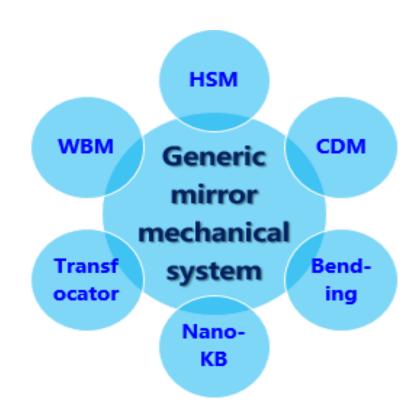


Fig. 1: The promoted strategy of design for MMS

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# Generic mirror mechanical system (GMMS) design and manufacturing

#### • Features: upper of vacuum Ion pump chamber Support **Bellows** ■ 5-DOF (Pitch/Yaw/Roll/Tx/Tz) Table 1: Main parameters of 5-DOF for GMMS Highly stable (Eigenfreq. >80Hz) **Heat-insulating Clamping** ceramic Resolution Type. Stressless clamping Horiz. Translation (Tx) motorized-Flexure hinge for Vert. Translation (Tz)motorized-Rz Vibration decoupling ≤0.1µrad motion compensaion Vert.angle (Rx) . Manual adjus. Roll (Ry) ≤10µrad-±17.5mrad High compatibility for many for chamber types of mirrors Lower of vacuum chamber **Damping** Water-cooled by eutectic Tz & Rx **Grouting hole** Ga-In Clamping Surface control with 7 support points by FEA **Ground screw** Manual adjustment **AirLoc**





Fig. 2: The overall structural design of GMMS.

August 19, 2025

#### Manufacturing, assem. & test

#### Motion evaluation

◆ 5-DOF adjustment by motor

#### Vacuum test

Vacuum degree: ≤1E-7Pa (typical)

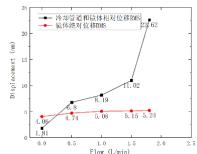
Vacuum leak rate: ≤ 3E-11Pa m3/s

#### Stability tests by accelerometer and interferometer

Pitch stability: 13.7nrad rms@5-500Hz

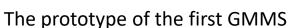
◆ Mirror vibration of variable flow rate: 4-6nm rms



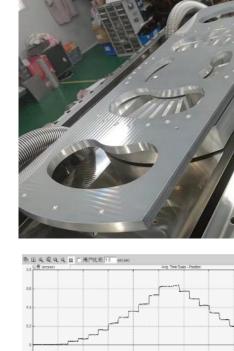


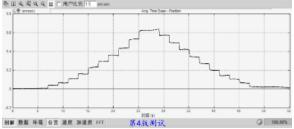
Result on mirror by interferometer: 4~6nm RMS @1-120Hz with flowing water



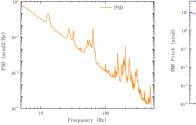


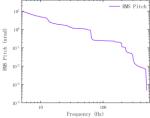






0.25urad angular step test results





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Pitch stability: 13.7nrad RMS @ 5-500Hz 20230901 22:48 by AM

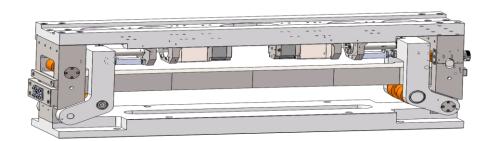




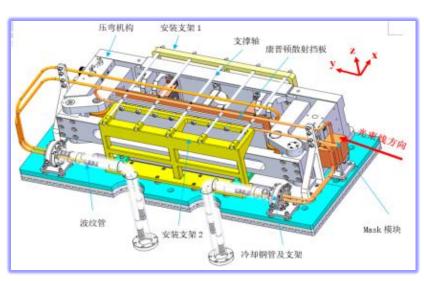
# A customized GMMS-based design and manufacture

# Clamping design for many types of mirrors

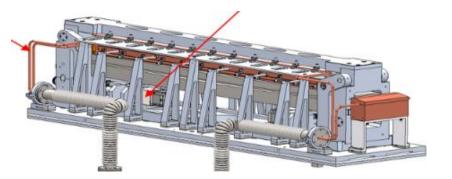
- White beam mirror (H)
- Focusing mirror with bender (V-up) / (v-down) / (H)
- White beam mirror with bender (V) / (H)
- Double mirror system (combined with BB-WBM, HRM, fixed exiting height HRM)
- Transfocator etc.



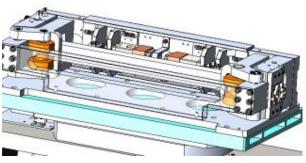
Focusing mirror with bender (V-down)



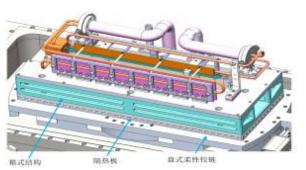
White beam mirror with bender (H)



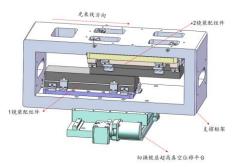
White beam mirror with bender (V)



Focusing mirror with bender (H)



Combined BB-WBM (H)

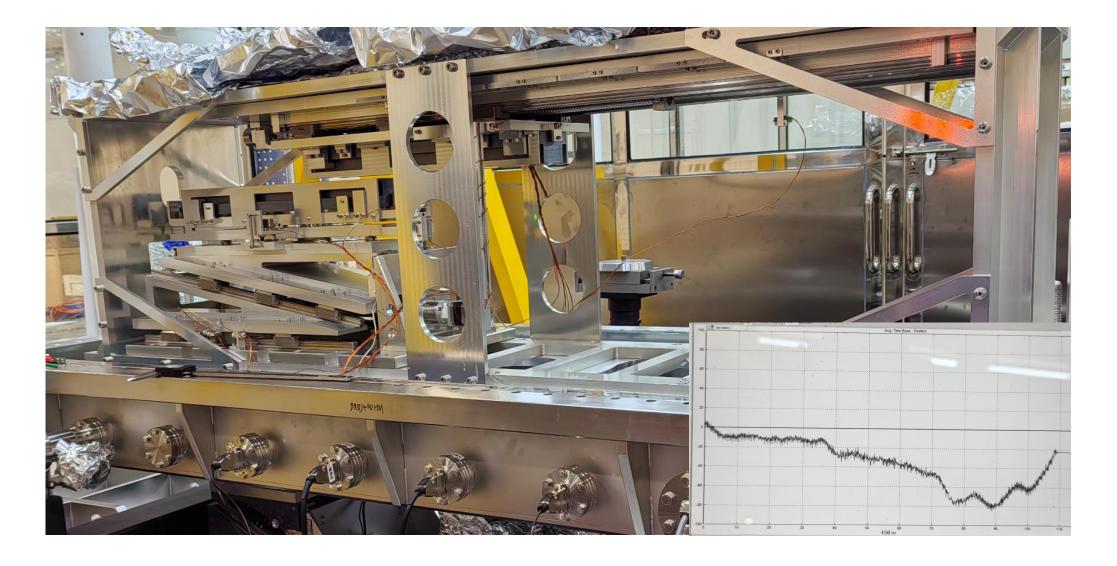


harmonic rejection mirrors (HRM)



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# **HRM**







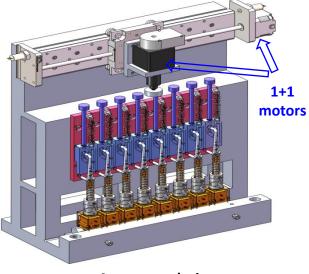
# A compact transfocator

#### • A compact CRL transfocator design

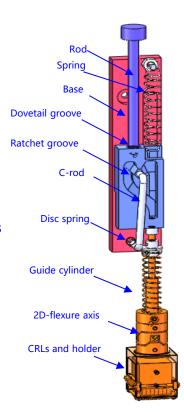
- Orthogonal parallel design scheme instead of traditional series structure
- Two sets motors or actuators instead N sets for N arms
- A self-locking and state-keeping mechanism

#### Advantages

- Compact
- Larger work distance
- Simplified structure



A compact design





**Test result online** 



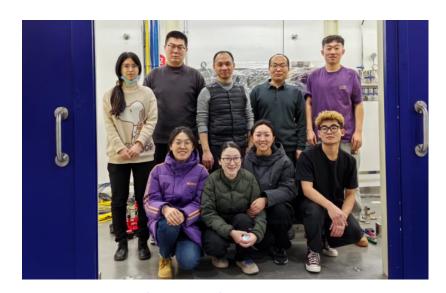


the P-P self-locking structure





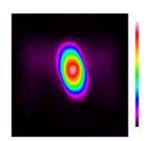
#### **R&D MMS installation and commissioning (1st)**



First MMS (BE WBM) installation finished



**BL8** commissioning



**BLD** commissioning





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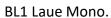
**BLB Combined-WBM** 

BLA Transfocator 1#、2#、3#、4#

August 19, 2025

#### **R&D MMS installation and commissioning (2<sup>nd</sup>)**







**BL1 2D Transfocator** 



BL2 WBM-Bender



**BL2 2D Transfocator** 



**BL4 2D Transfocator** 



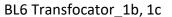
BL4 1D CRL one for-V & one for -H

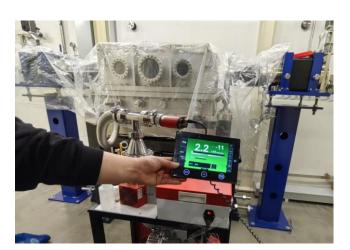


BL3 water-cooled Transf.



00





BL5 WBM



BLC M3 Bender

August 19, 2025



BLC M4





HEPS IAC Meeting 2025

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# Summary of mirror mechanical systems

#### First GMMS (BE-WBM):

- Manufactured and delivered in Dec. 2022
- Stability (Test): 14nrad RMS @ 5-500Hz
- Positioning: 5-DOF, accuracy is OK

#### 1<sup>st</sup> batch GMMS (9 sets):

- FAT finished
- Manufactured and delivered in Jul. 2023
- Indicating available design, manufacturing, and assembling
- Installation finished

#### 2<sup>st</sup> batch GMMS (9 sets):

- FAT and delivered in May and August2024
- Installation ongoing

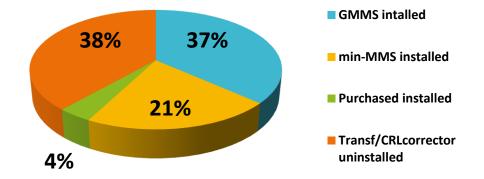
#### Min-MMS (11 sets):

- Min-Transfocator
- CRL corrector
- NanoKB

#### Purchased (2 sets)



- The all MMS of 10 BLs have been installed.
- Two BLs commissioning got light spot, indicating MMS was OK.



August 19, 2025





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# 6 Monochromators

# Requirements overview of monochromators in HEPS

- 18 in total, 8 types, 12 developed by HEPS
- 13 LN2 cooled, 3 water cooled, 2 without cooling

• The most challenging matters are stability and slope error requirements

Yellow: in house

Green: purchased

Mono. Type	ID	Beamline	Coolant	Optics	Optics Pair	Energy range (keV)	Slope error (µrad)	Stability in Pitch (nrad)	Stability in Roll (nrad)	Heat load (W)	Peak Power density (W/mm2)
	B2	Hard X-ray Nanoprobe Multimodal Imaging Beamline	LN2	Si(111)/Si (220)	2	4.8-30,7.8-40	0.1λ	25	50	150	63
HDCM	B4	Hard X-ray Coherent Scattering Beamline	LN2	Si(111)/(311)	1	7-25,12-25	0.1λ	25	60	210	99
	В9	Low-Dimension Structure Probe Beamline	LN2	Si(111)	1	4.8-40	0.50	50	100	145	28
	BB	Pink Beam SAXS Beamline	LN2	Si(111)	1	7-30	0.30	100	200	20	19.8
	B6	High Pressure Beamline	LN2	Si(111)/Si (220)	1	20-42,42-75	0.31	30	350	330	32.7
HCCM	ВА	Microfocusing X-ray Protein Crystallography Beamline	LN2	Si(111)	1	5-18	0.30	100	150	161.1	
	B5	Hard X-ray High Resolution Spectroscopy Beamline	LN2	Si(111) /Si (311)	2	5-26	0.50	50	150	144	61
VDCM	B8	XAFS beamline	LN2	Si(111) /Si (311)	2	4.8-20,10-45	0.30	100	100	140	45
VDCIVI	BE	Transmission X-ray Microscope Beamline	LN2	Si(111)	1	5-15	0.60	100	350	435	19.14
	BF	Test Beamline	LN2	Si(111)	1	5-40	0.30	100	100	900	11.7
	BD	Tender X-ray Beamline	Water	Si(111)	1	2.1-8	1.00	200	200	50	0.1
QCCM	B8	XAFS beamline	LN2	Si(111)/Si (311)	2	4.8-23,4.83-22.3	0.45			147	22.7
HDMM	В3	Structural Dynamics Beamline	Water	DMM	1	20-70	0.50	50	350	65	0.14
HRM-NRS	B5	Hard X-ray High Resolution Spectroscopy Beamline	None	Si(400)/Si(10 6 4)	2	14.4125	0.50	80	200	/	/
HRM-RIXS	B5	Hard X-ray High Resolution Spectroscopy Beamline	None	Si(400)	2	8-10	0.50	175	/	/	/
DLCM	B7	Hard X-Ray Imaging Beamline	LN2	Si(220)	1	40-200		100	100	1073	0.245
DLCIVI	B1	Engineering Materials Beamline	LN2	Si(111)	1	50-170		1000	1000	38	38.4
PGM	ВС	High Resolution Nanoscale Electronic Structure Spectroscopy Beamline	Water	PGM	3	0.1-2	0.15	50	100	56	0.32

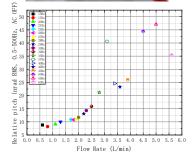


IEPS | HIGH ENERGY PHOTON SOURCE

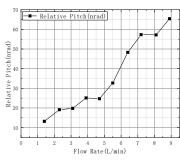
# Status and test results of monochromators

#### VDCM-Vertical diffracting DCM

- 3 VDCM developed, installed, 2 online tested, different variations
- Stability and performance
  - Best stability: 6 nrad RMS with cooling
  - 11 nrad RMS with 2L/min LN2 which is capable of cooling 435W heat load
  - Good spectroscopy and parallelism performance
  - Over 1 month operation without problems







BE stability results BF stability results

#### **HIGH ENERGY PHOTON SOURCE**

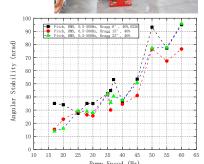
#### HDCM-Horizontal diffracting DCM

• 4 HDCM or HCCM developed, 3 installed, 1 online tested, different variations

#### Stability

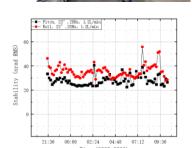
- Best: 15 nrad with cooling
- 25 nrad RMS with 2L/min flowing rate
- Clamping deformation: < 0.1 urad RMS under clamping and cryogenic condition





BA stability results







BA clamping deformation 0.063 urad RMS

BF Cu XAFS result

BA long-term stability

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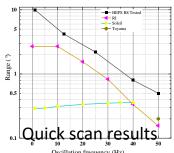
### Status and test results of monochromators

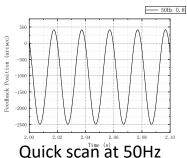
- QCCM-Quick EXAFS Channel-cut Crystal Mono, installed and tested
  - One single direct drive Bragg axis design allowing quick scanning and step scanning
- Test results
  - 0.6 degree at 50Hz, 100 spectra/s

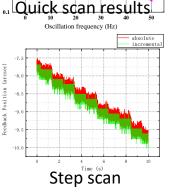
**HEPS** 

Step scan: 1 μrad resolution









**HIGH ENERGY** 

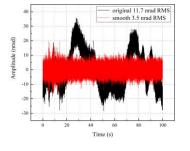
**PHOTON SOURCE** 

- HRM and MRM, High energy Resolution and Medium energy Resolution mono, install
  - Large travel range flexures for high precision and high stability
- Test results
  - Pitch resolution: 10 nrad for HRM
  - Stability: 3.5 nrad RMS in pitch for HRM
  - Travel range for MRM: ±5 degree for pitch









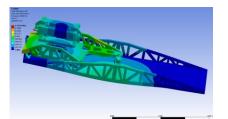
Step scan 10 nrad

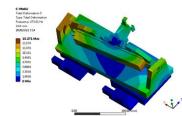
Stability 3.5 nrad RMS

- DLCM, installed
  - In house developed bending mechanism allowing high precision bending
- HDMM, Horizontal Double Multilayer Monochromator, installed
  - First model > 200Hz in pitch
  - Special pitch adjustment with 2 motorized stages and flexures



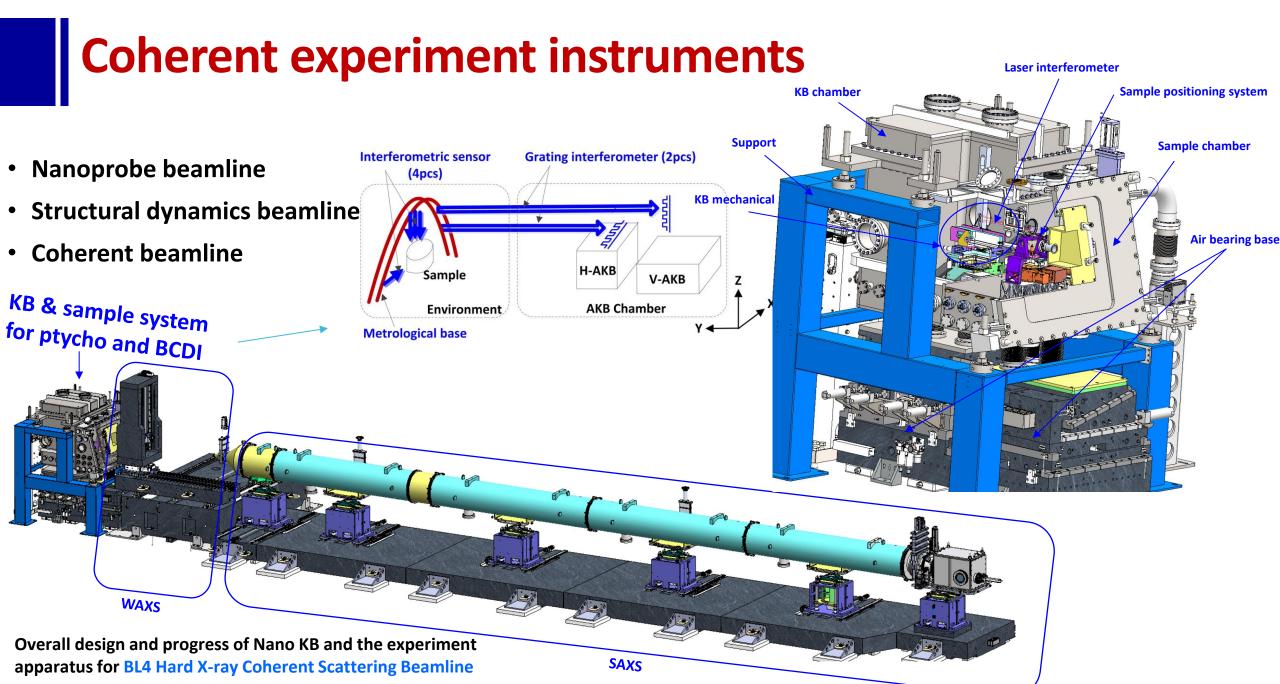






FEA model > 200Hz for pitch

# **Endstation Instruments**





HEPS | HIGH ENERGY PHOTON SOURCE

## **SAXS/WAXS XPCS** instrumentation

# Nano positioning instrumentation for ptycho and BCDI





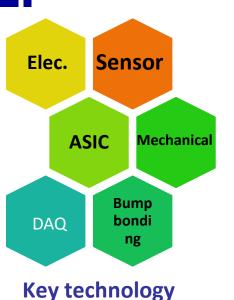


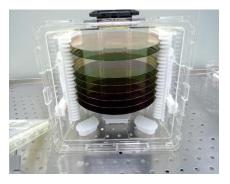


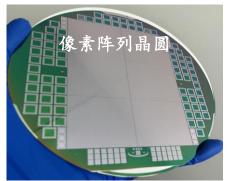


# 11 Detectors

# **Development of the detector** (Photon counting detector for HEPS)

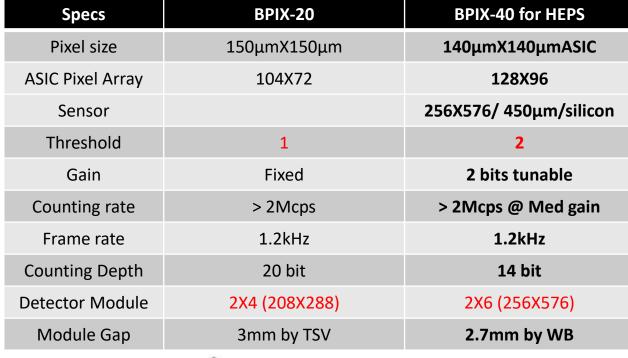




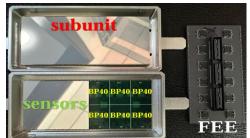




Silicon pixel sensor



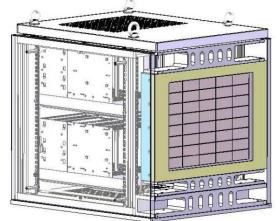








HEPS IAC Meeting 2023



- A 6M system will be assembled for the HEPS before 2025
- A series of detector with different dimension (2M/1M ...) will also be scheduled



**HEPS** HIGH ENERGY PHOTON SOURCE

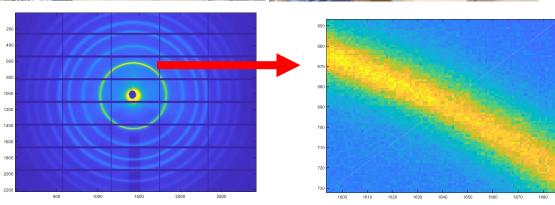
Figure 1 The 6M detector system

# Assembling and test of detector for ID03 PX beamline







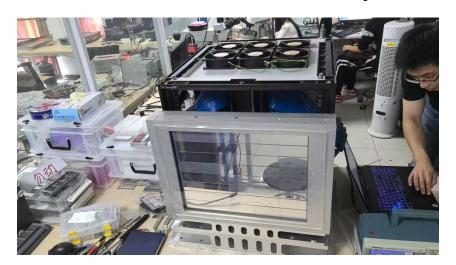


Cooling system: water, 20-25  $^{\circ}$ C

Data transfering: fiber to the server

Data bandwidth: ~10Gbps @ 100 Hz

Area: 40cm×28.6cm @ 6Mpixels





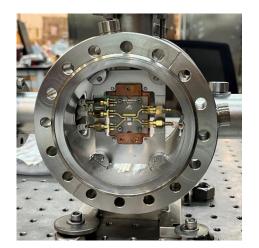
Powder diffraction HEPS | HIGH ENERGY PHOTON SOURCE

# **Development of the detector** (Diamond XBPM for HEPS)

### The diamond XBPM detector is applied to the beam position monitor in HEPS.



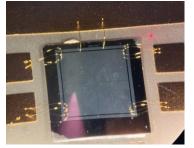
Diamond sensor
With 50µm thickness

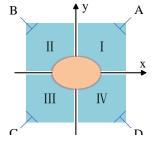


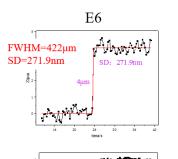
Installed in a vacuum chamber

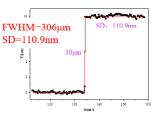


Electronics for the current measurements



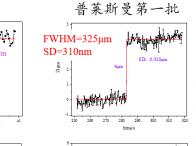


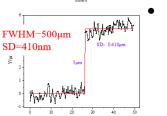






DAQ for XBPM system





- Current range: 0-2mA
- Sampling rate: 4MHz
- Position accuracy: <0.3um @1mm



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# Development of the detector (Silicon Drift Detector)

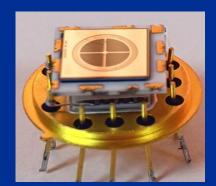
► To meet future requirements, we have conducted key technological research and development on singleelement and array Silicon Drift Detectors (SDDs).

### Semiconductor Device Development



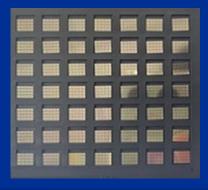
- SDD Sensor Design
- Fabrication process
- ♦ I <sub>leakage</sub>: 10pA @ -20 ℃

# Semiconductor Packaging Technology



- **♦** Temperature control
- **♦** Vacuum packaging

## Ultra-Low Noise ASIC



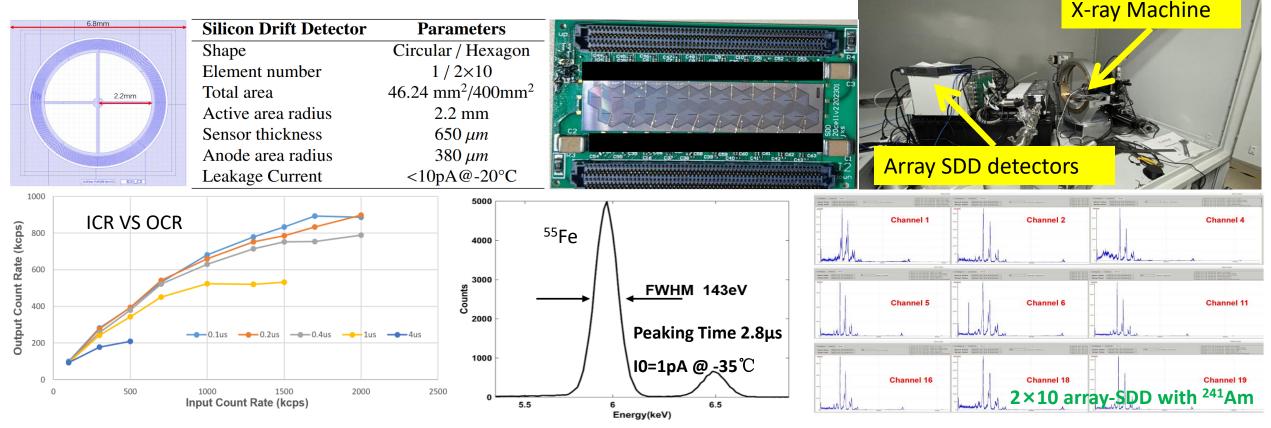
- Charge-sensitivePreamplifier design
- ◆ ENC: 5e<sup>-</sup>+6e<sup>-</sup>/pF

### Signal Processing Electronics



- High-speed data acquisition
- High-efficiency signal processing algorithms
- ♦ OCR: 1Mcps

- ▶ Up to now, we have fulfilled all of the key technologies.
- ► We have initiated the prototype development of both single-element and array SDD detectors, and also made significant progress.
- ► FWHM=143eV @ 5.9keV (-35°C) for single element SDD; FWHM=240eV ~ 300eV @ 13.96keV (-40°C) for 2x10 array-SDD.



Bao Z, Li Z, Liu Y, et al. Development of silicon drift detectors for synchrotron radiation sources[J]. Nuclear Instruments and Methods in Physics Research Section A, 2024, 1069: 169927.



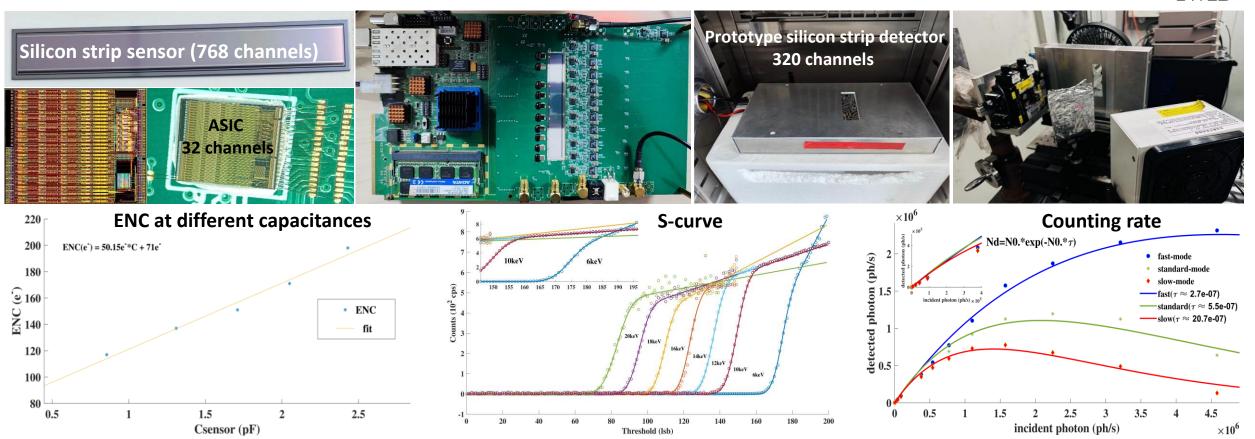
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# Development of the detector (Silicon strip detector-SSD)

BSRF 1W2B

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Main performances of the prototype detector

Parameter	Value	Parameter	Value
Strip width [µm]	100	Frame rate	16 kHz
Strip height [mm]	10	Count rate	≤ 2.3 MHz/strip
Minimum threshold [keV]	3.4	Counter depth [bit]	24
ENC	187 e⁻	Number of channels	320

- The silicon strip sensor has a strip width of 100  $\mu$ m, a strip height of 10 mm and a thickness of 320  $\mu$ m.
- ➤ The prototype silicon strip detector gain is 6.7 mV/keV and the ENC is 187 e<sup>-</sup> with a minimum threshold of 3.4 keV. The detector's maximum counting rate is 2.3 MHz/strip at fast shaping mode.
- All key technologies of the silicon strip detector are verified.

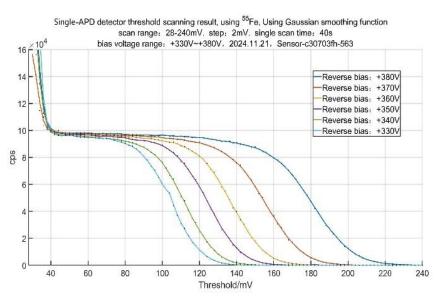


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# Development of the detector (Time-Resolved Detectors for HEPS)

### **Recent developments of APD detectors**

- Innovations in detector architecture and signal processing have enhanced accuracy, reduced noise, improved the
  integration of the detector system.
- Achieve sub-nanosecond timing resolution, enabling precise measurement of rapid phenomena.
- APD detectors are now ready, waiting to be applied to Hard X-ray High Energy Resolution Spectroscopy Beamline of HEPS (real-time data acquisition for experiments).



Data acquired by FEE CH1(model number: Array-APS, positive input, G=1)
Scan range: 0-500mV, step: 3mV, single integration time: 20s
Amplified by TDC ver4.0 one stage PreAmp.-Yichao Ma
Bias voltage range: -380V~-440V, 2024.12.26

Reverse bias: -380V Reverse bias: -400V Reverse bias: -440V Reverse bias: -44

Array-APD-II CH1 detector threshold scanning result with <sup>55</sup>Fe radioactive source.

Array CAS INDICATE TO TO TO THE TO TO THE TO TO THE TO TO THE TO THE TO TO THE TO THE

**S-curve of Single APD** 

S-curve of Array APD

APD detector system of HEPS





# **LGAD** for X-ray

Future research will focus on integrating Low Gain Avalanche Detectors (LGADs) for X-ray detection, enhancing sensitivity and timing resolution.

- ➤ LGAD designed by IHEP will contribute to 90% of ATLAS HGTD sensors, owning to its good radiation hardness.
- >IHEP LGAD sensors pre-production for HGTD has been finished (90 wafers fabricated) in 2024
- >Timing resolution of IHEP LGAD sensors is better than 40ps before and after radiation.



Pixel area: 2.6mm x 2.6mm,

Active thickness: ~80μm,

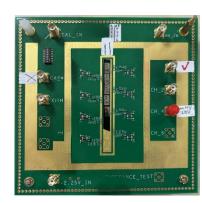
Capacitance: ~10pF

New design:

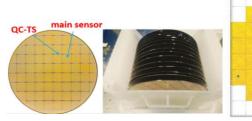
Pixel area: 2.5mm x 2.5mm, array: 1 x 16

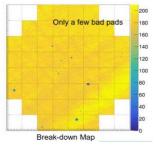
Active thickness: 50μm, 80μm,

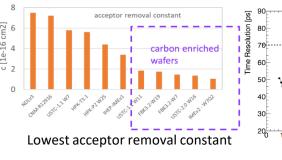
Capacitance: ~15pF (50um),9.5pF (80um)

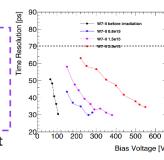


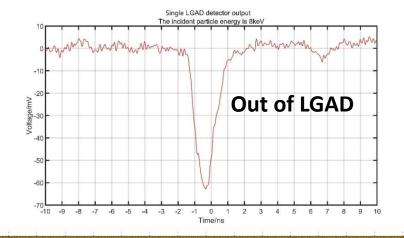
**Testing board** 











# 12 Insertion Device (ID)

# Total 19 IDs for 14 Beamlines in Phase I All In-house R&D

$Ty_{]}$	pe	Number	Magnetic structure Length (m)	With Beam
In Air	IAU	4	5	4
	IAW	2	1	2
In Vacuum	<b>CPMU</b>	6	2	5
	IVU	5	4	5
Special	AK	1	5	1
	Mango	1	1	0
Tot	tal	19		17

Apple-Knot for soft X-ray beamline

MANGO wiggler, novel design for symmetric field of view for X-ray Phase contrast imaging beamline

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# Recap

•From optics, multiphysics, mechanics to detectors and electronics, among the beamline instruments, most of them are in-house developed. And they are serving for the construction and commissioning of HEPS now.

# **Outlook**

- Optical elements with high accuracy
- Flexible and stable adaptive optics
- Highly dynamic and stable mechatronics
- New detectors for new experimental methods
- Al-ready and Al-driven hardware system



# **Collaborations and Users**





### Collaboration between Synchrotron lightsources

HEPS-SIRIUS(Brazil, 2<sup>nd</sup> 4<sup>th</sup> gen.) China-Brazil Joint Laboratory for Synchrotron Science and Technology (CBJSync) founded in June 2025





Collaboration Agreement between HEPS and ALBA (Spain) signed in July 2025 ALBA2.0







### **Collaboration between HEPS and Domestic Institutions/Enterprise**

### Joint laboratory and Consortium

- ✓ Institute of Vertebrate Paleontology and Paleoanthropology, Paleontology and Paleoanthropology Heritage Joint lab
- ✓ Center for High Pressure Science and Technology Adavanced Research (HPSTAR), High Pressure Joint Lab
- ✓ XiaMen University, XMU-HEPS Consortium for Electrochemical Operando Characterization
- ✓ Institute of Mechanics, Engineering Mechanics Join Lab
- ✓ **Eastern Institute of Technology**, HEPS-EIT Consortium
- ✓ Huairou Science City Corporation, Small Molecular Medicine Screening Platform

Joint to build Phase II beamlines (capacity to have more than 80 beamlines) Users invest to build new beamlines





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### **International Collaboration**

### Between Synchrotrons

- MoU, Agreement, Joint lab or Consortium for Synchrotron techniques advancement (accelerator and beamline) and Scientific application
- Invite to invest or jointly invest to build up new beamlines in HEPS. Joint building Build by yourself totally.

### Institutions and Enterprises

- MoU, Agreement, Joint lab or Consortium for scientific application advancement
- Invite to invest or jointly invest to build up new beamlines in HEPS.

Promote to Join the international joint research project

Open to any new ways in collaboration





### User

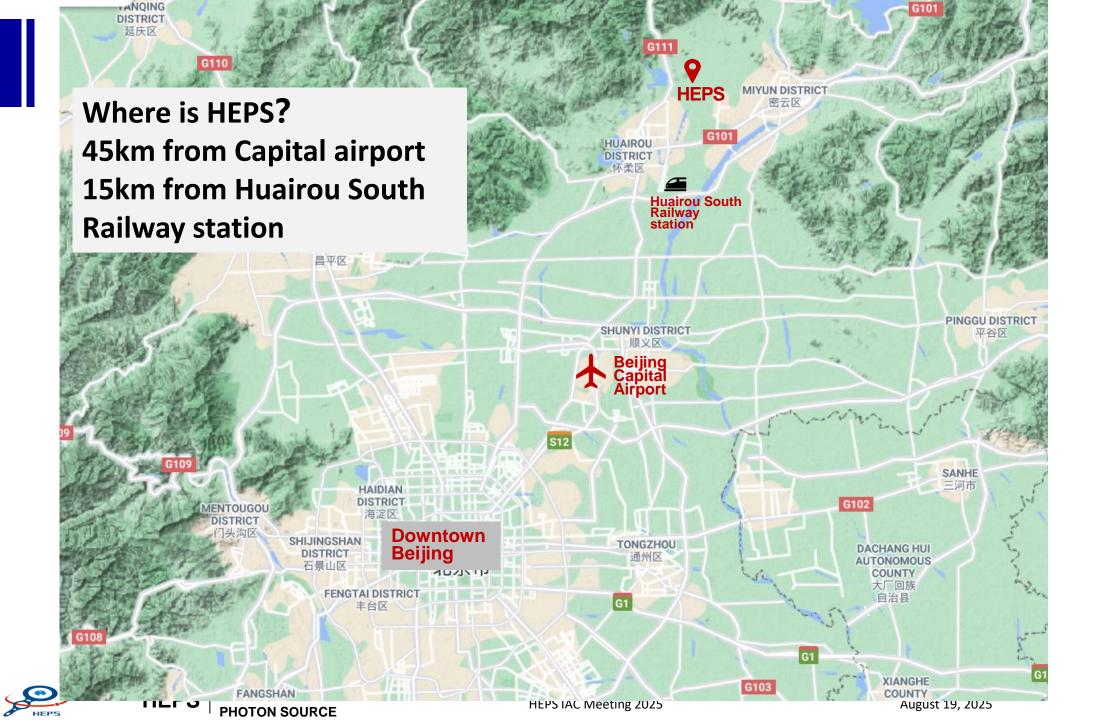
- Some beamlines has been open to the pilot users
- Beamlines formally open to global users, academia and industrial, gradually from early 2026

Support advanced foreign user group to do experiment in HEPS to develop new methodologies and produce killer applications

Pay attention to HEPS webpage: https://heps.ihep.ac.cn





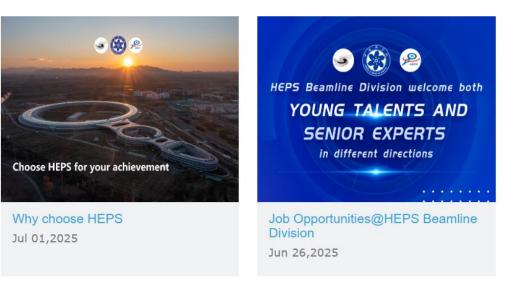


## **Talents Recruitment**

https://heps.ihep.ac.cn



### **Job Openings**







# **Summary**

- HEPS, 1<sup>st</sup> 4<sup>th</sup> generation high energy synchrotron in Asia. After six years construction and commissioning, HEPS is sprinting to final acceptance by the end of this year
- √14 user beamlines and 1 Test beamline buil in Phase I
- HEPS open to global users in 2026 to leverage high brightness, high coherence and high energy X-ray from HEPS
- HEPS expected to make substantial impact in academia and industrial application
- √Promote International Collaborations in different ways





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