Progress of Beamlines Design and Key Technologies of **Hefei Advanced Light Facility (HALF)**

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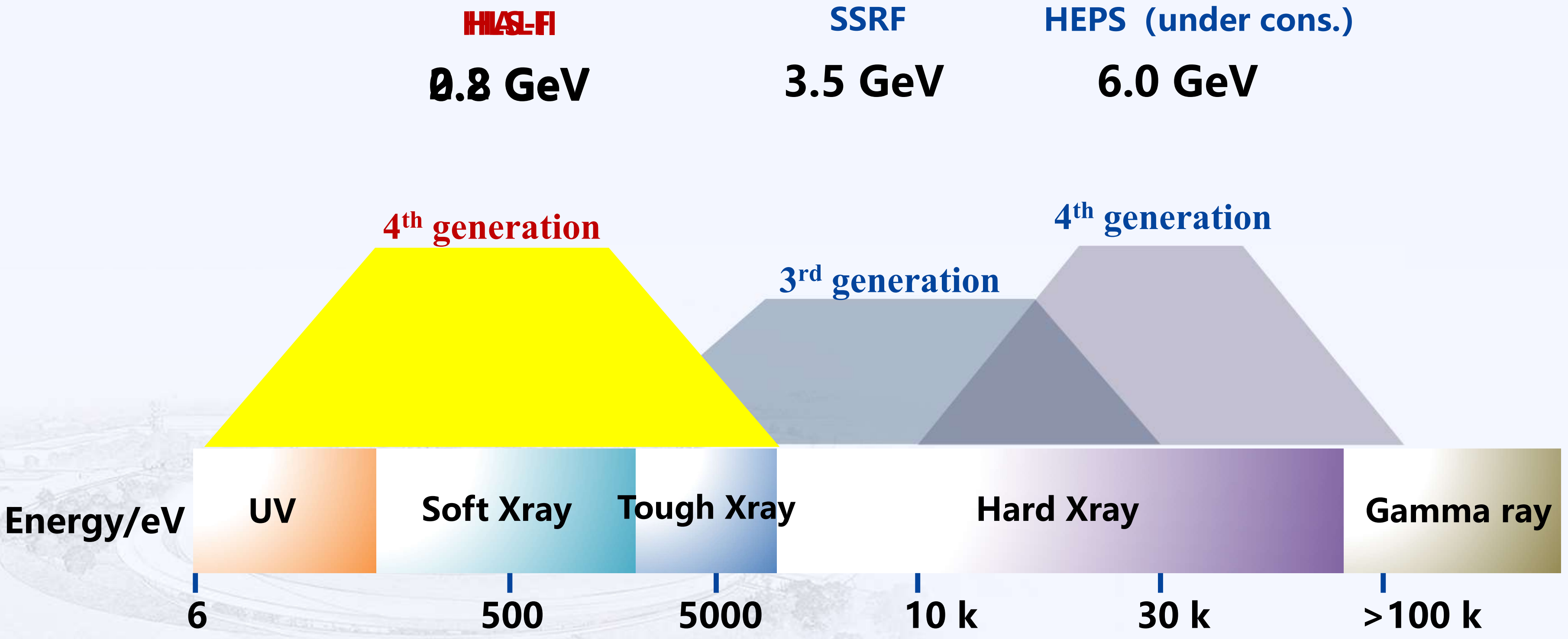
NSRL
National Synchrotron Radiation Laboratory

Outline

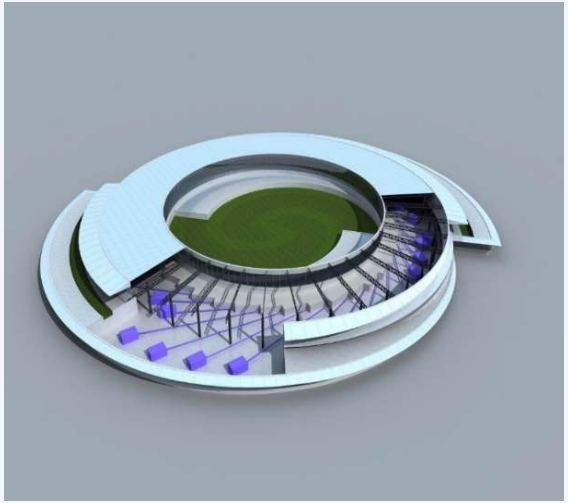
- Introduction of HALF Project
- Progress of beamline design
- Key technologies of beamlines in HALF

HALF: Full coverage of photon energy



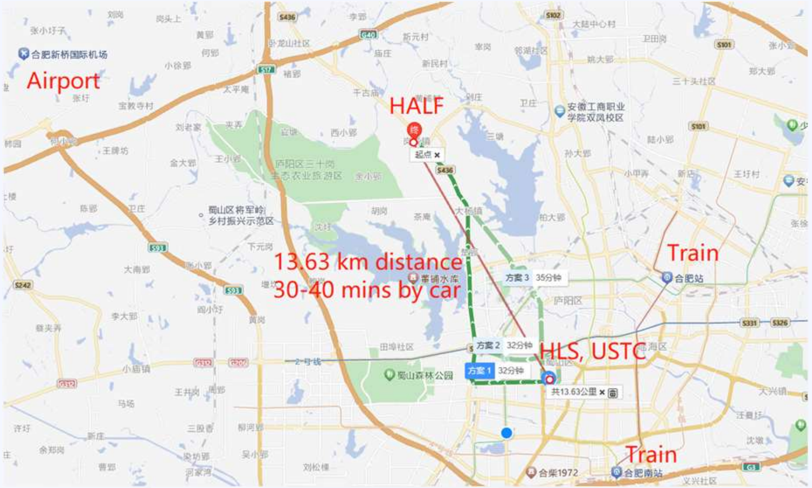
More than 3000 users expected in the phase one, more than 10000 in the future

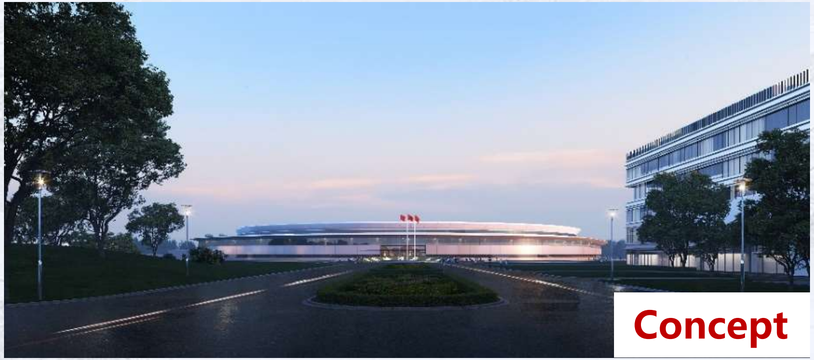
Hefei Advanced Light Facility (HALF)



- The big eye to explore the microscopic world
- HALF: Beamline scientist + User, Instrument development + Scientific application
- Users' participation is extremely important to the construction of HALF

Hefei Advanced Light Facility (HALF)

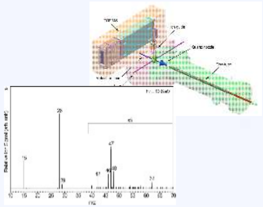




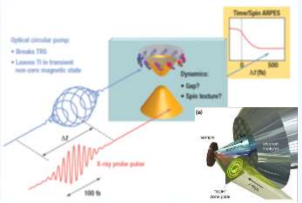
Scientific goal of HALF Phase I

Scientific goal: Accurate measurement of electronic states/chemical states/light element structures of complex systems

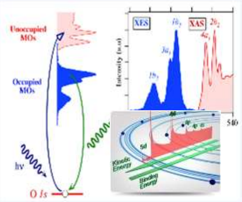
Spectroscopy/ Scattering



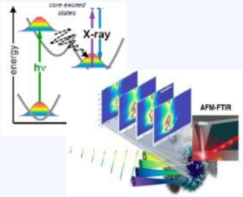
Mass spectrometry



nano-ARPES

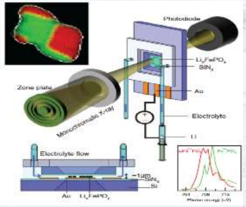


Core-level spectroscopy

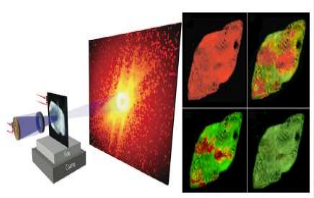


RIXS/REXS

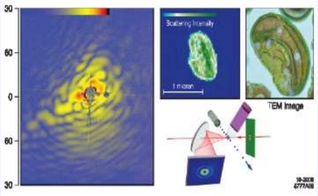
Imaging/ Diffraction



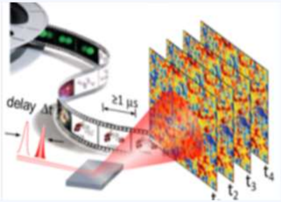
STXM



Ptychography



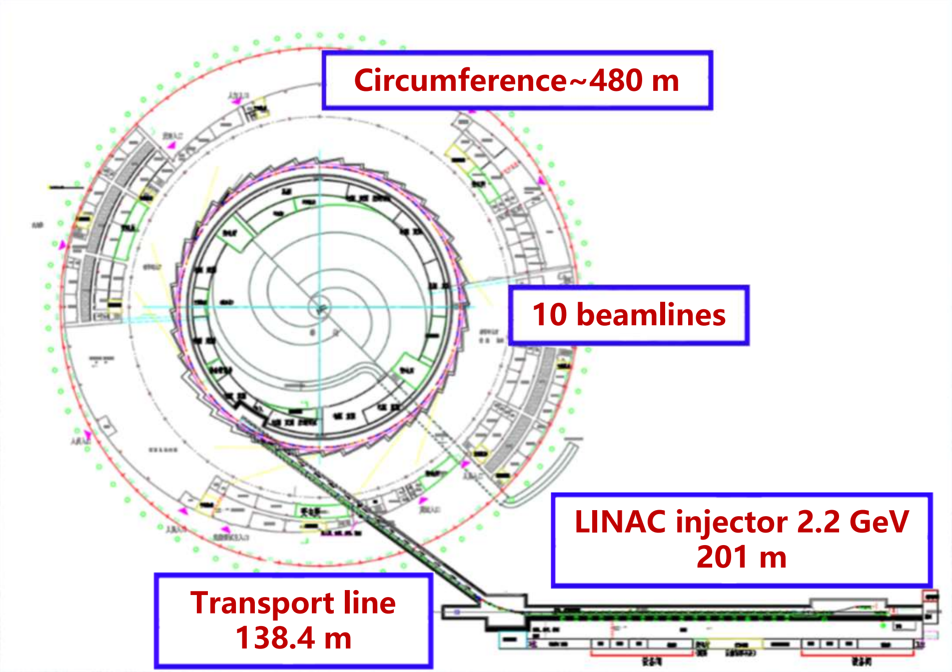
Coherent diffraction



XPCS

Engineering goal of HALF Phase I

Engineering Goal- Building the advanced 4th generation diffraction limited storage ring in the low energy range.



HALF project – Phase I：

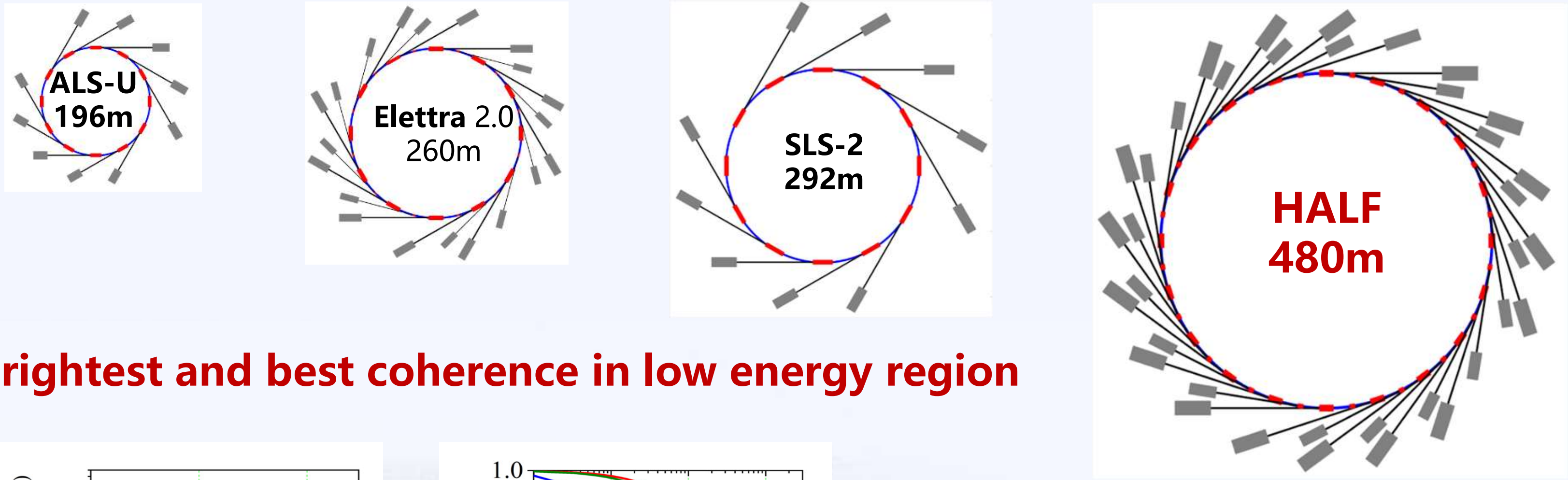
- Construction period: 64 months, to be completed in 2028.10,
- Total budget 2.78 billion RMB;
- National approved in 2023.6;
- Total of 35 beamlines planed, 10 of them to be constructed in phase I.

Key Parameters of Storage Ring

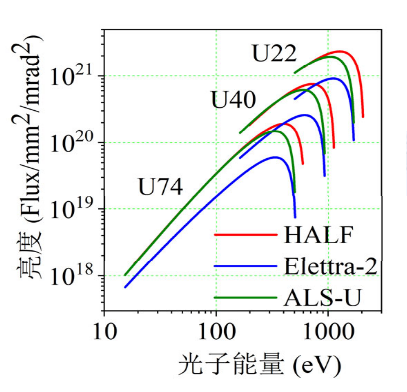
	Design	Acceptance
Energy [GeV]	2.2	2.2
Current [mA]	350	100
Circumference [m]	479.86	---
Natural emittance [pm•rad]	86.3	100
Lattice	6BA	---
Straight section number	20L+20M	---
Straight section length [m]	L/5.3，M/2.2	---
Operation mode	top-off	

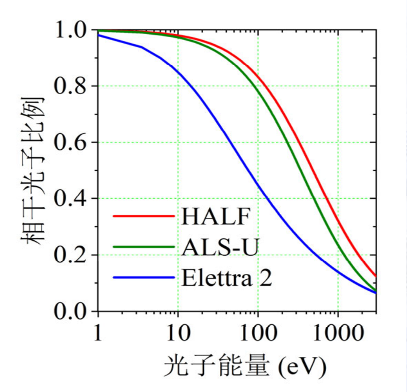
- **The design target should be achieved within 2 years after the acceptance test.**

Advantage of HALF in low energy region



Brightest and best coherence in low energy region





- ✓ **Straight section:**
  - ✓ **more quantity and longer length**
- ✓ **Brightness:**
  - ✓ **2-5 orders higher compared with HLS**

Beamline overview

	Beamline	Energy/eV	Optical System /Monochromator	Critical parameters of Beamline
1	Mass Spectrometry for Energy Transformation and Astrochemistry	5-20	Monk-Gillieson	5,000@15eV
2	Extreme Ultraviolet Electronic Structure Characterization and Lithography	6-135	VLS-PGM	Res. P: 45,000 @21eV Spot size: 3 μm
3	Electronic Structure Characterization for Operando Micro/Nano Devices	80-1000	VLS-PGM	Res. P 22,000 @244 eV Spot size: 3 μm
4	High-sensitive, Space-Resolved and Time-Resolved Electron Spin Dynamics	250-2000	VLS-PGM	Res. P 12,000 @867eV Spot size: 3 μm
5	In-situ/Operando Soft X-ray Spectroscopy and Scattering	180-2500	VLS-PGM	Res. P: 15,000@244eV Spot size: 6 μm
6	Soft X-ray Spectromicroscopy and Ptychography	250-2500	VLS-PGM	Res. P: 15,000@400eV Coherence flux: 2.5×10^{11} phs/s@Res.p
7	Multiscale Time-Space Resolved Resonant Coherent Scattering	250-4000	VLS-PGM Multilayer Grating for 1.5-4keV	Res. P: 12,000@400eV Coherence degree 25%
8	High Throughput In-situ/Operando Tender X-ray Spectroscopy	2300-6500	DCM (2300-10000) SX700 (700-1600)	Res. P 5000@4 keV, 10000@867eV Spot size 3 μm
9	Tender X-ray Spectromicroscopy and Ptychography	2100-6500	DCM	Res. P: 15,000@4keV Coherence flux: 5×10^{10} phs/s@Res.p
10	Test Beamline	250-2000	SX700-PGM	Multifunctional design Res. P: 100,000 @867eV for HR mode

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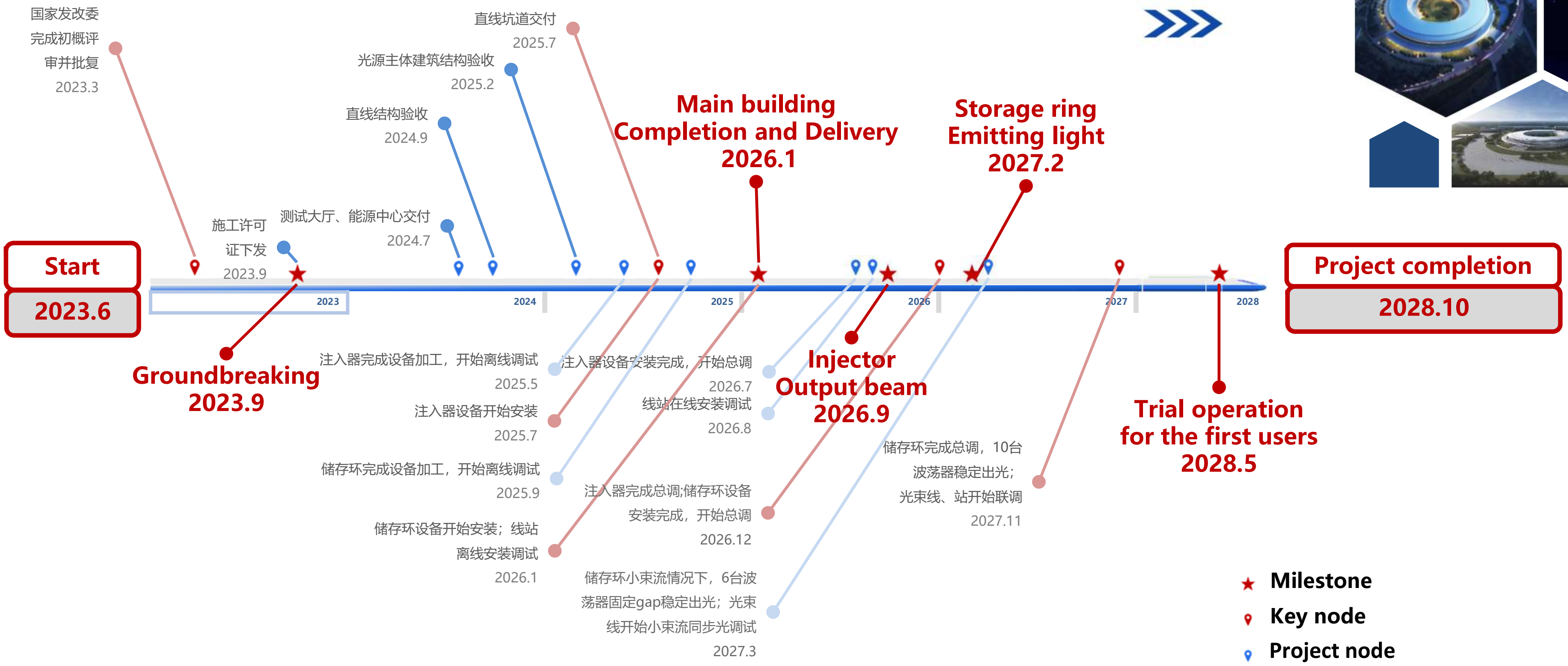
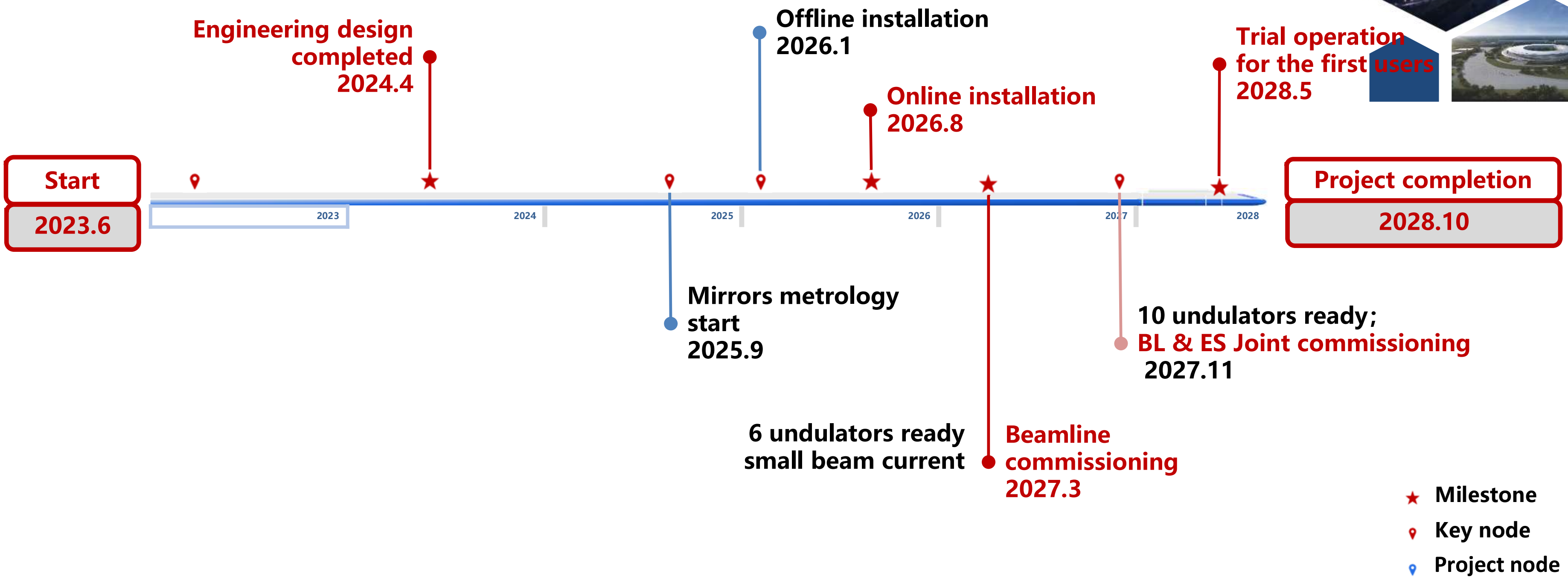
HALF Schedule



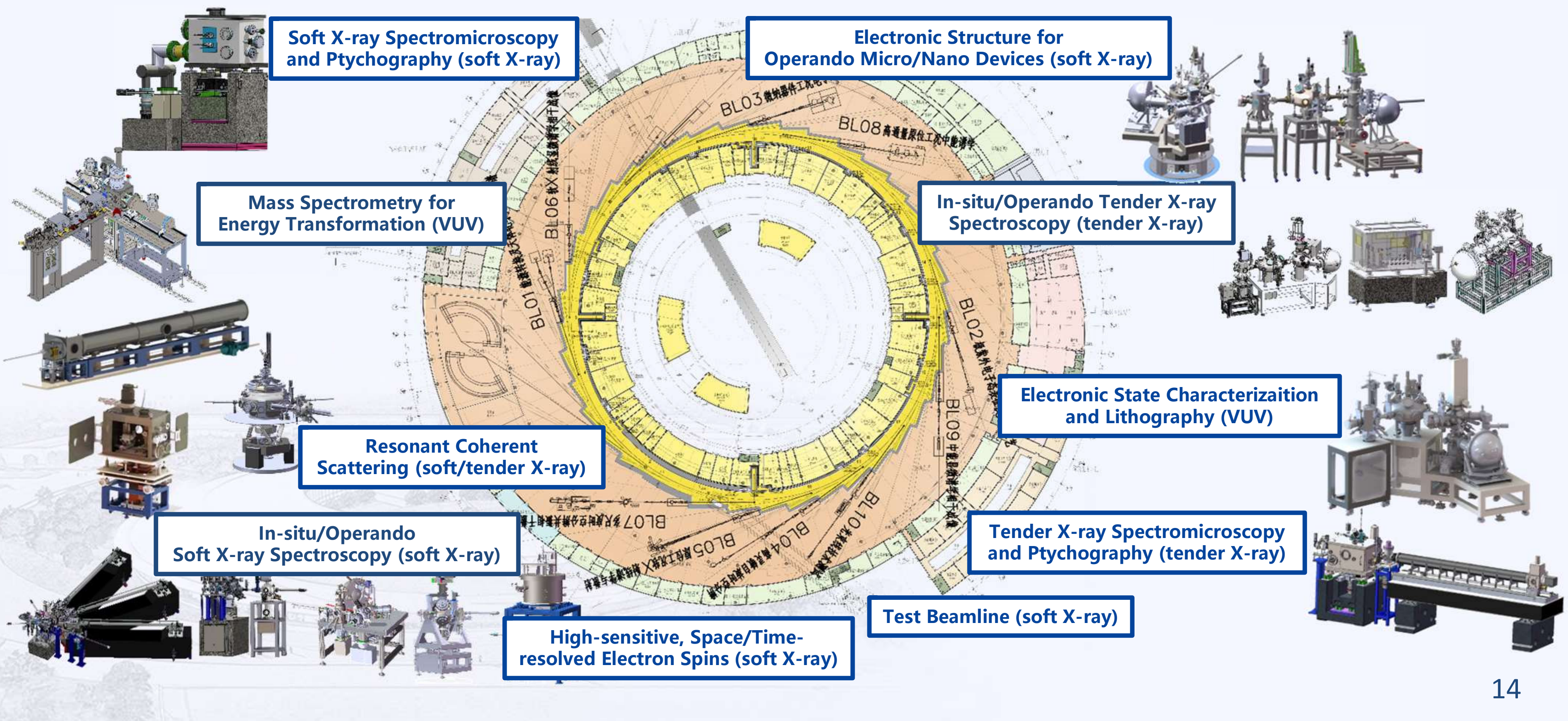
Total period of 64 months

Beamline Schedule

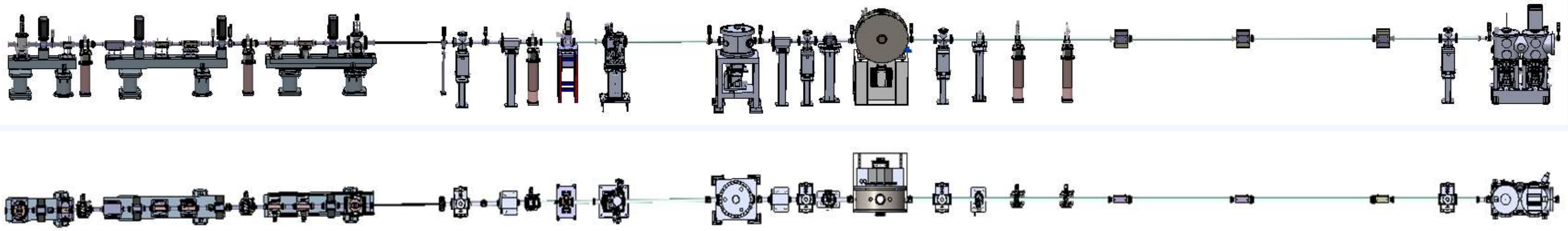


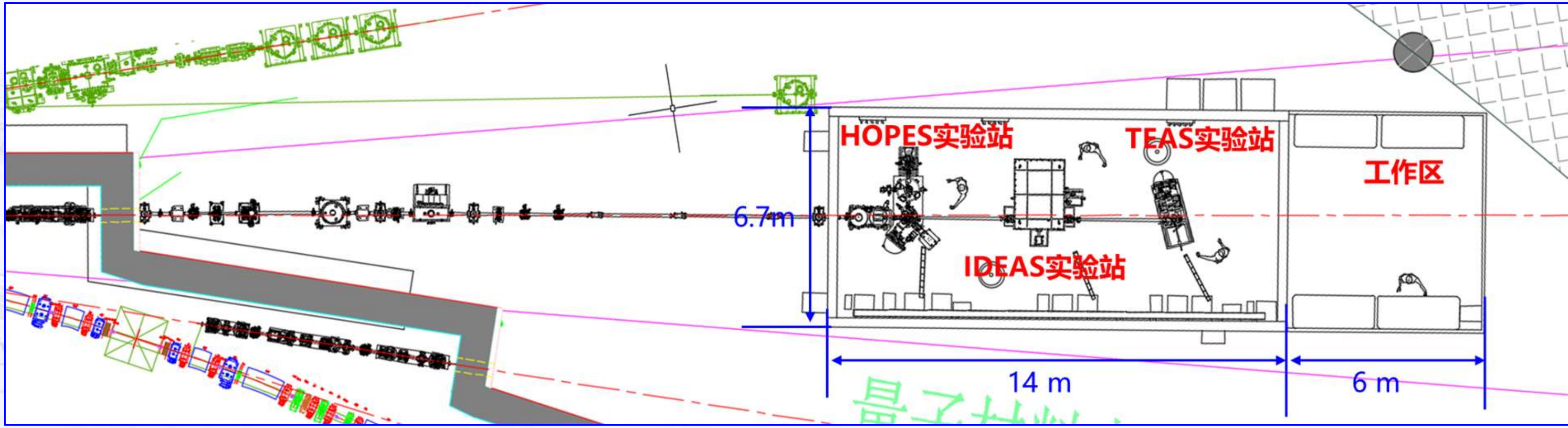
Total period of 64 months

Currently in the stage of engineering design

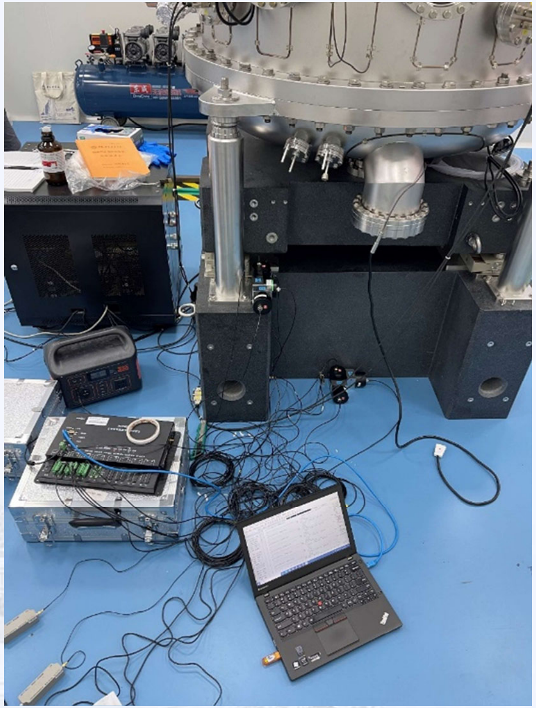


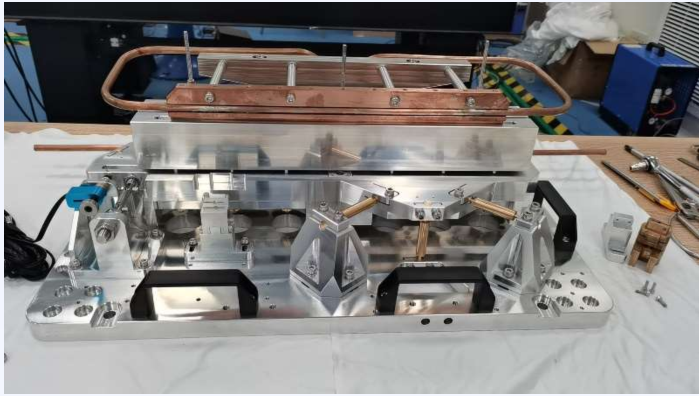
Overall layout of a beamline

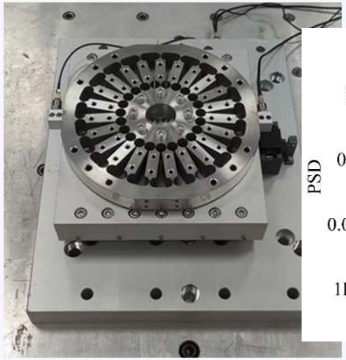


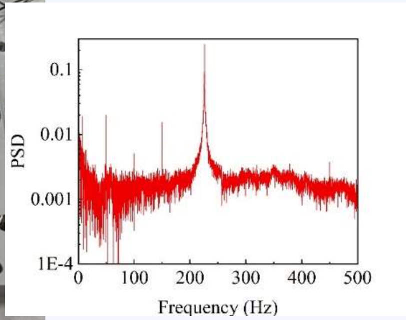


Test of completed prototype

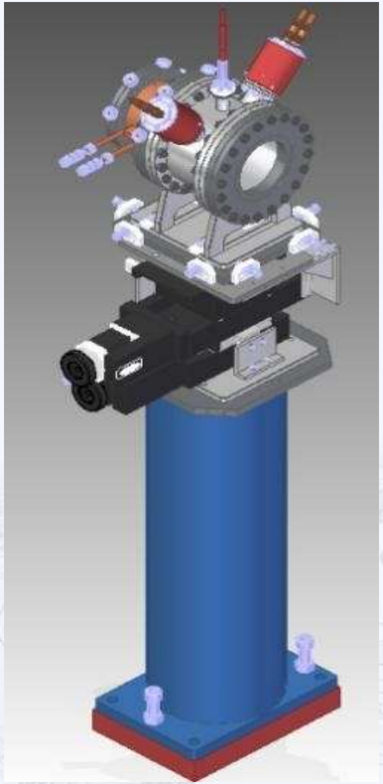


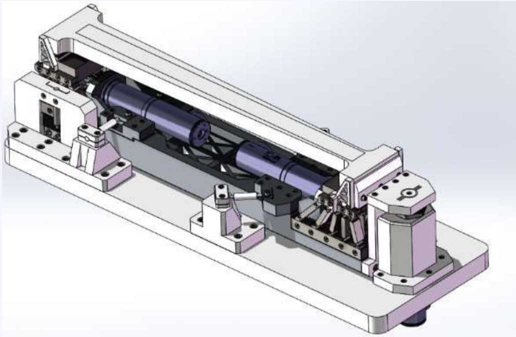


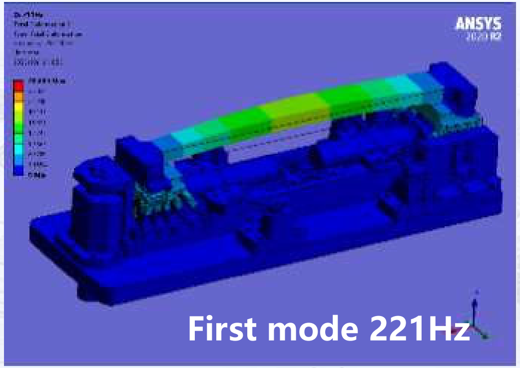




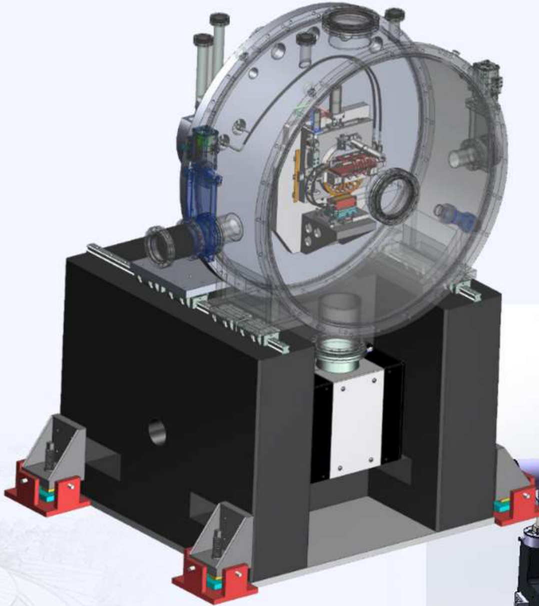
Key components design and analysis

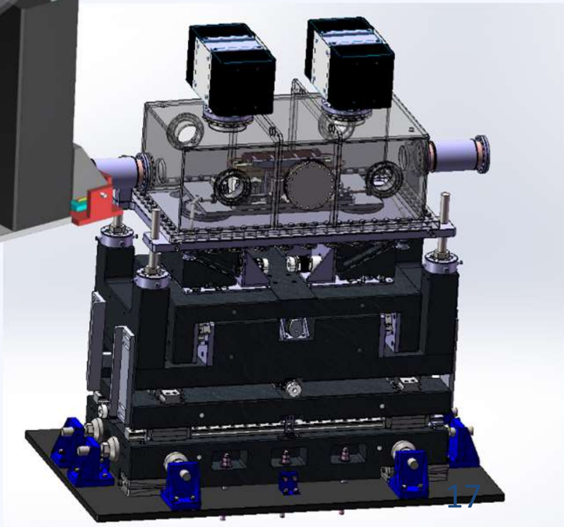






First mode 221Hz





Outline

- Introduction of HALF Project
- Progress of beamline design
- Key technologies of beamlines in HALF
  - Optics:
    - Coherence, Metrology
  - Mechanism:
    - High resolution of energy and space, High stability, Minimum stress clamping
  - Cooling:
    - High density thermal power on mirrors with ~100 nrad slope error and ~50 nrad stability

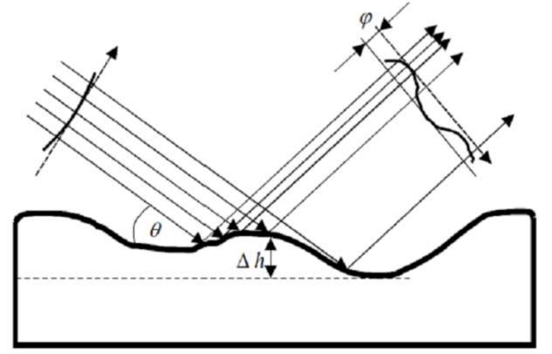
Optics: Dealing with coherent light

- Wavefront phase difference: $\varphi = 2\Delta h \times \sin\theta / \lambda$
- Marechal (wavefront): $\Delta h \leq \frac{\lambda}{14 \cdot \sqrt{N} \cdot 2\theta}$(rms)
- Rayleigh : $\Delta h \leq \frac{\lambda}{4N\theta}$ (P-V)
- Δh is rms value, working in the full spatial frequency range
- $\theta \propto \lambda$, so Δh does not change much with λ

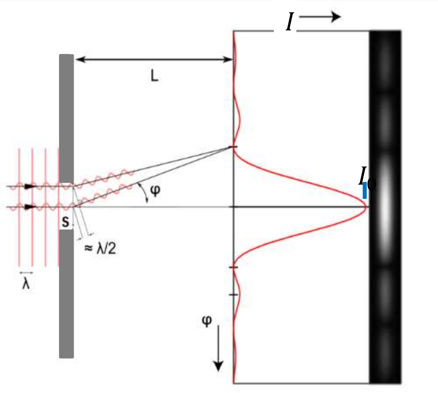
N is the quantity of OEs

For example: θ=2°, N=5;
Δh_{rms}= 0.55 nm, $\Delta h_{p\text{-}v}$= 1.7 nm

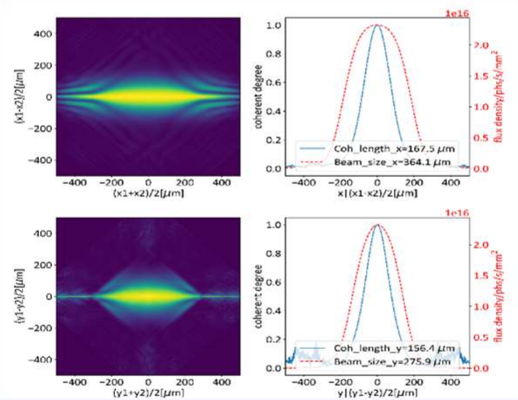
For HALF, Δh_{rms}~ 0.5 nm,
Δh_{p-v} ~ 2 nm



Influence of height error on coherent light



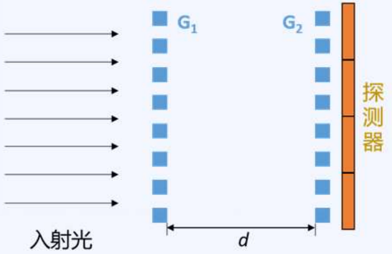
Control diffraction effect



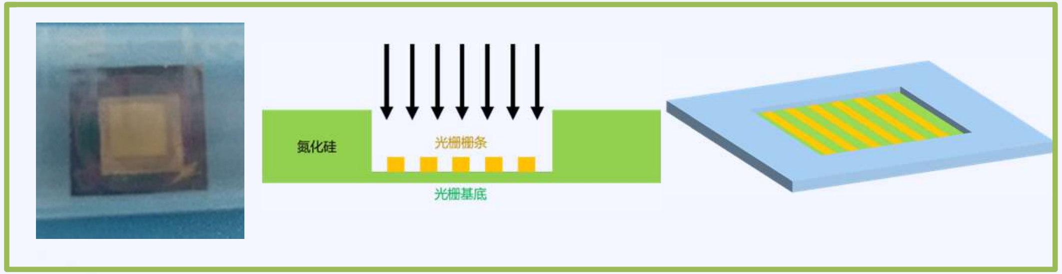
Coherence simulation

Coherence and wavefront measurement

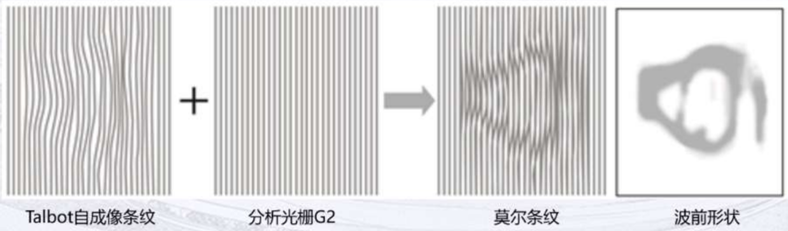
HALF requires high-precision measurement of beam quality.



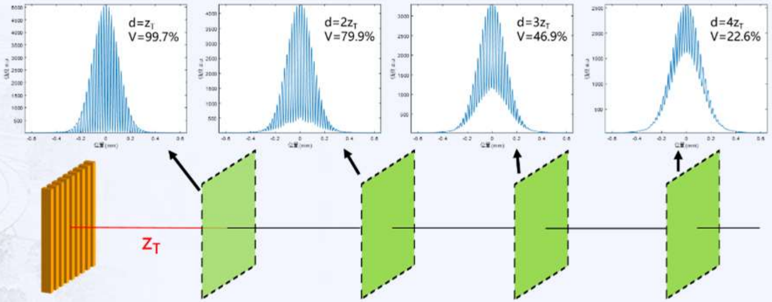
Talbot interferometer



Thin substrate / high aspect ratio transmissive optics

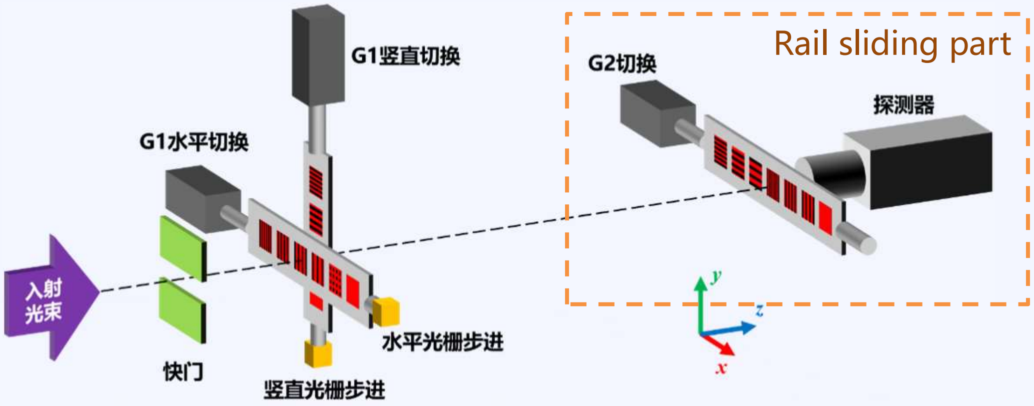


Wavefront retrieval based on Moiré fringes

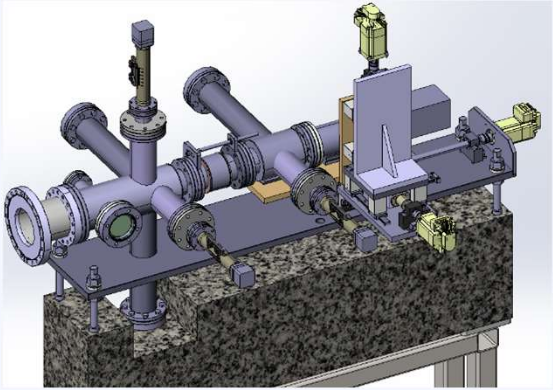


Spatial coherence measurement based on visibilities at variable distances

Coherence and wavefront measurement device



Optical layout



Chamber 3D design

A portable, integrated device for **spatial coherence** and **wavefront** measurement

Spatial coherence measurement tools

- Talbot interferometer
- Double slits

Wavefront measurement tools

- Talbot interferometer
- Shack-Hartmann sensor

Spectrum detector can also be installed.

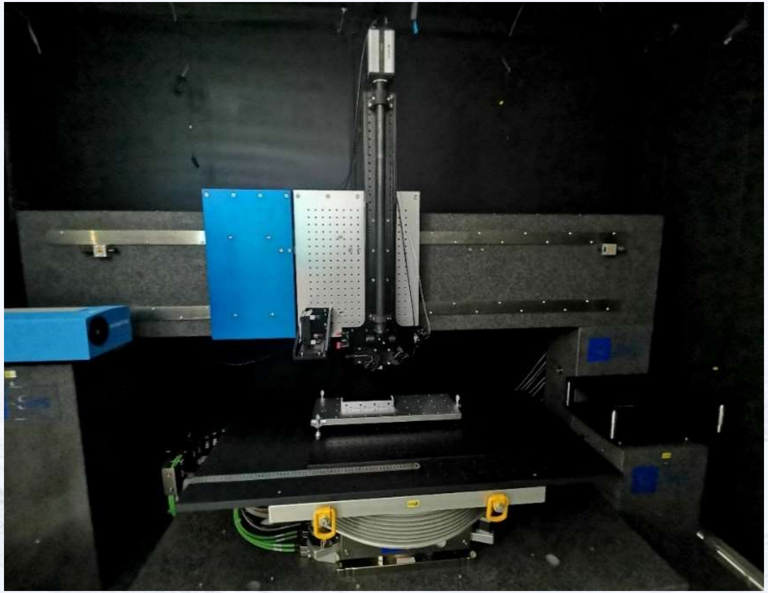
Specifications

Energy range	250-2000 eV
Local wavefront precision	100 nrad
Spatial resolution	10-25 um (Talbot) 60-80 um (Hartmann)
Field of view	35×35 mm

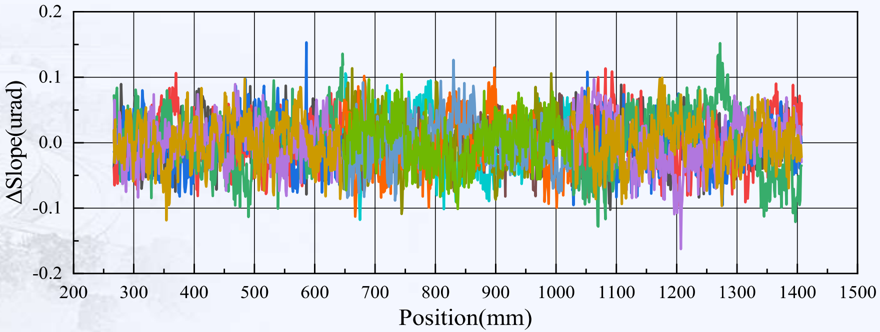
Optics: Metrology

Slope error measurement -LTP

Completed LTP system

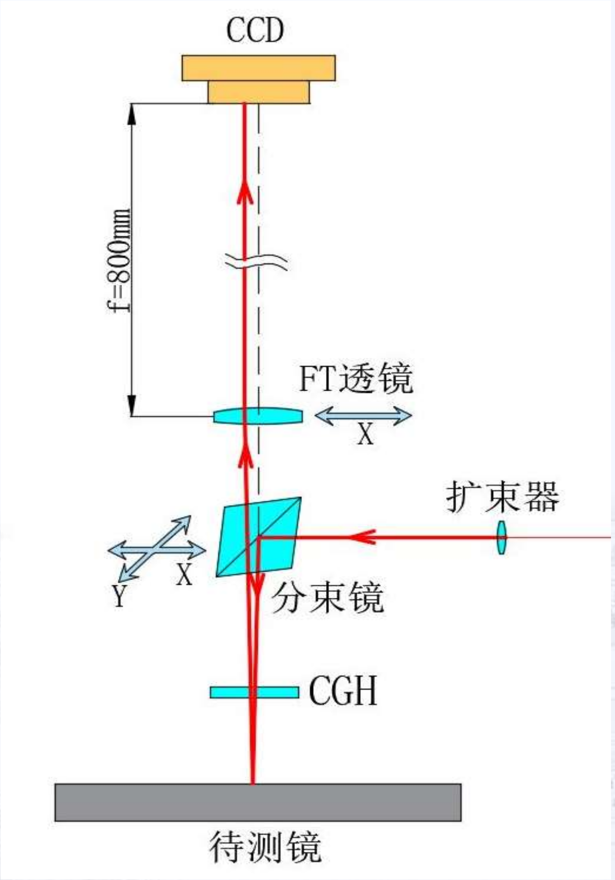


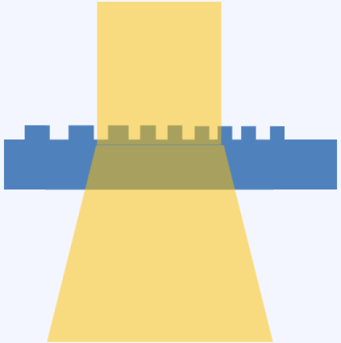
Item	Acceptance index	Measured data
Test accuracy for flat surfaces (nrad)	100 （RMS）	50 （RMS）
Test accuracy for curved surfaces (nrad)	250 （RMS）	100 （RMS）
Angular range(mrad)	±1.5	±1.5
Length range （mm）	1000	1000



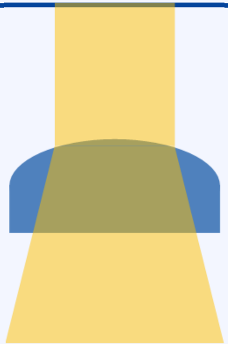
Repeatability for flat mirrors： 37.5nrad

Test Scheme for the Profile of Small-Curvature Mirrors





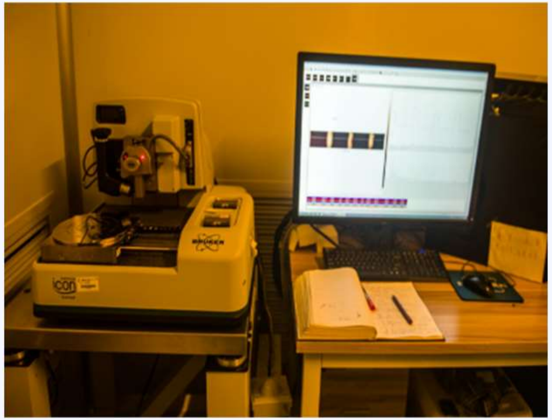
Cylindrical CGH



Cylindrical compensating mirror

Measured sagittal shape of a Cylindrical mirror（ρ=89.3mm）
repeatability： 25nrad（rms）

Optical Testing Instruments



ZYGO Verifire HDF

Performance:

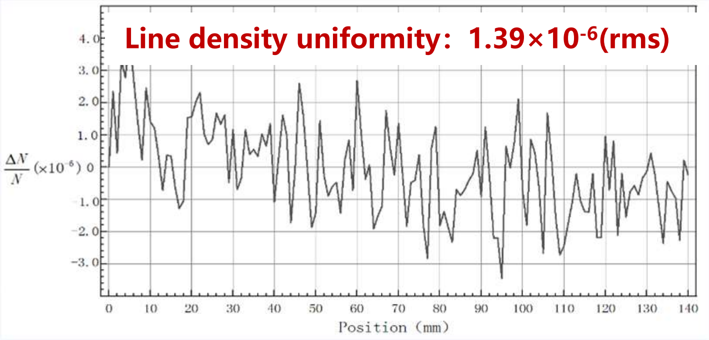
Optical Lateral Resolution: 50μm（Includes 3.4k x 3.4k @ 96 Hz camera）.

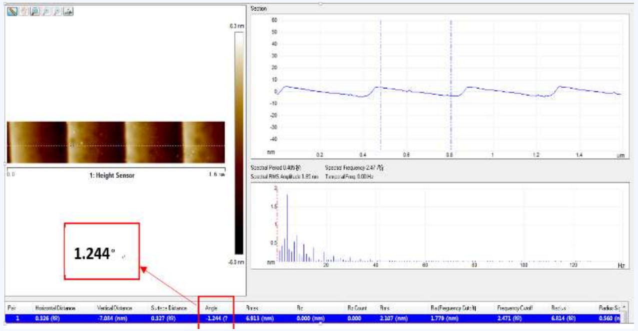
UltraFlat reference flat mirror: 6” 4% Reflectivity, λ/40μm

White Light Interferometric Microscope

AFM

Optics: Diffraction grating R&D

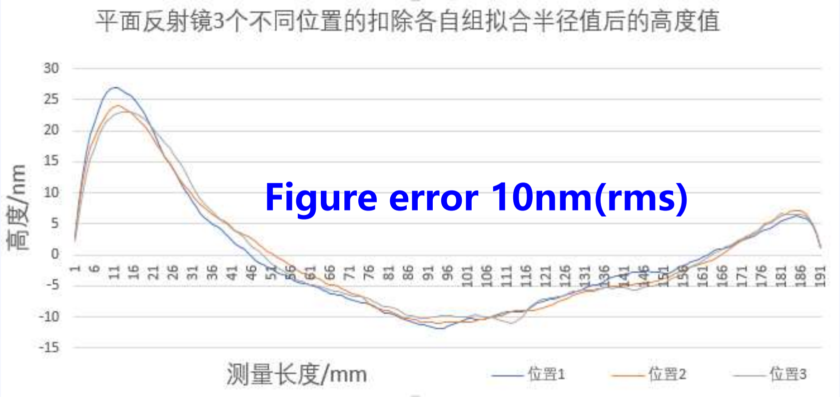


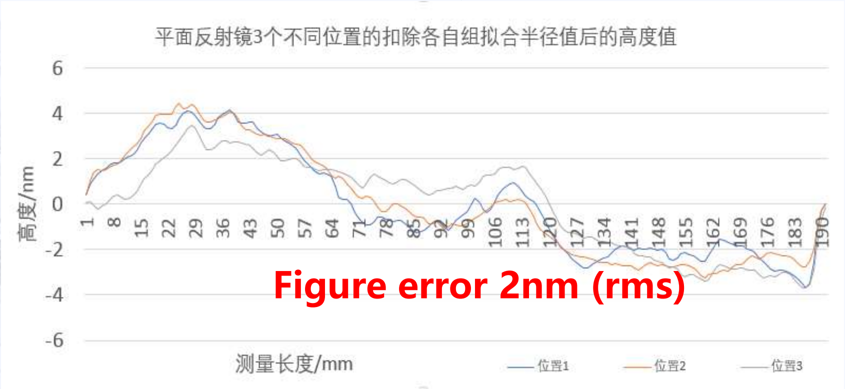


- Laminar and blazed, minimum blazed angle 0.8°, Verified to achieve 200nrad
- Production process: Holographic exposure, ion beam etching, wet etching
- More than 60% gratings are expected to be self developed

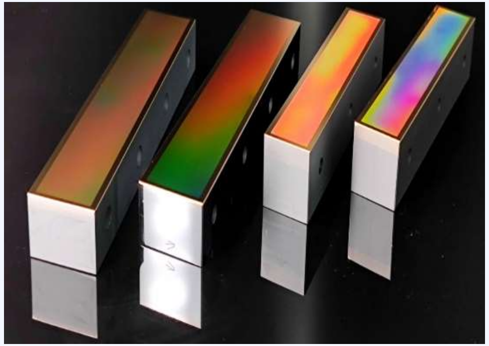
A small step forward in ion beam polishing

Dimensions of substrate: 200×40×50mm³,   (Mainly used for grating substrates)





Gratings used for HLS beamlines

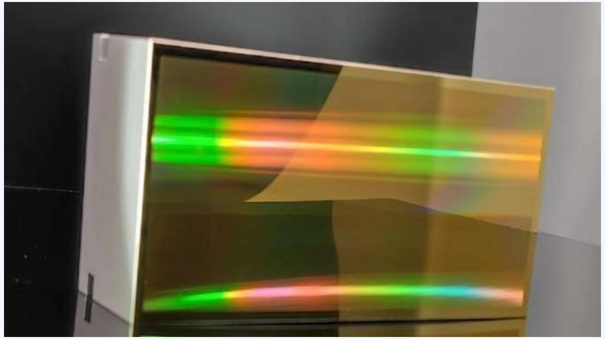


Metrology beamline

300 g/mm, 600 g/mm
VLS: 300 g/mm, 1400 g/mm

ARPES beamline

2400 g/mm, blazed
spherical, R = 9298mm
$140 \times 30 \times 30 mm^3$

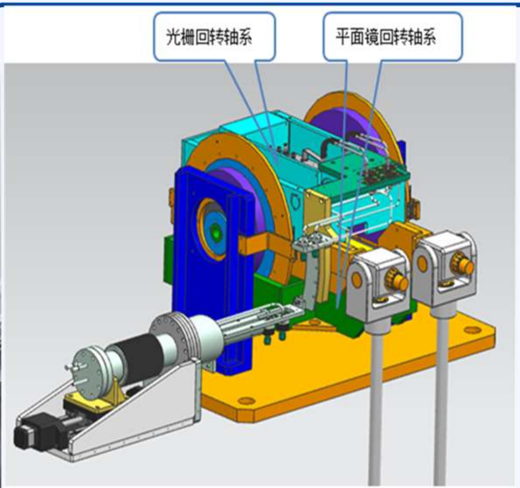


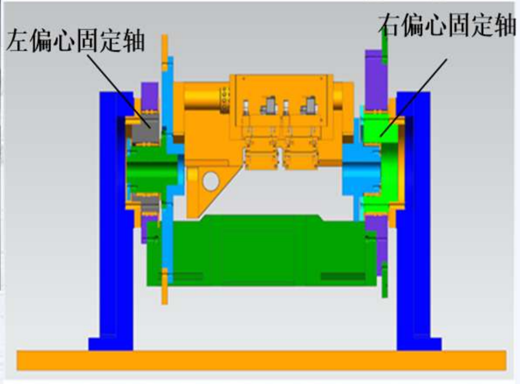
Mass Spectrometry beamline

400 g/mm, blazed, $180\times80\times50\ mm^3$

- **9 gratings had been used for beamlines of HLS.**
- **4 gratings of them are blazed**

Mechanism: PGM



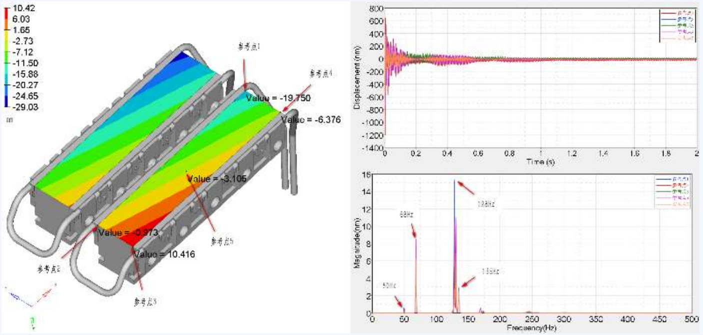


- **Self developed Close-packed ball bearings were used to replace commercial angular contact bearings.**
- **Provide better accuracy and support stability**

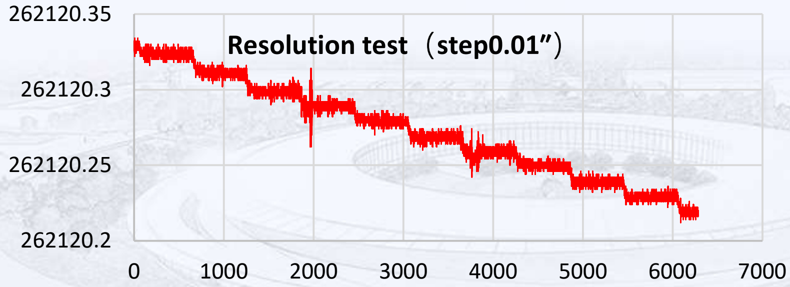
Performance of PGM

Pitch rotation range	-3°~16°
Resolution	0.01″
Pitch repeatability	0.03″
Pitch stability by encoder	0.01″@ 2 hours
Pitch stability by autocollimator	0.04″@ 2 hours*

* Testing ground is not good



Simulation of Flow Induced Vibration of Grating

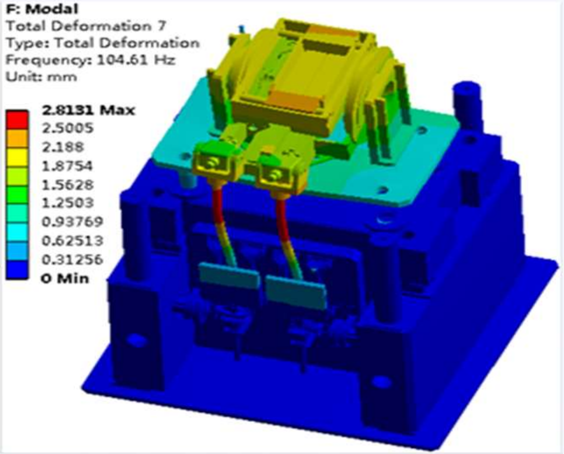


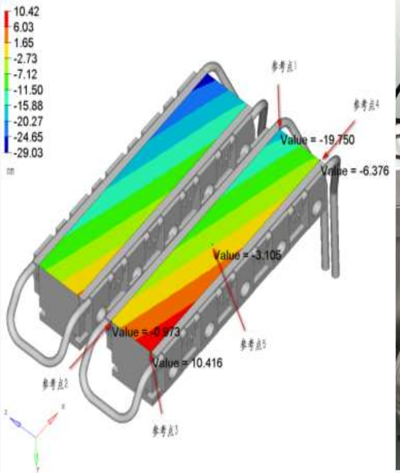
Cooling Current	0	0.5L/min	1L/min	1.5L/min	2L/min
Grating-Open Loop	16.2nrad	19.2nrad	20.2nrad	23.0nrad	29.7nrad
Grating-Close Loop	14.6nrad	14.3nrad	16.7nrad	19.8nrad	26.0nrad
PM-Open Loop	13.0nrad	15.4nrad	14.3nrad	12.5nrad	18.4nrad
PM-Close Loop	7.6nrad	3.5nrad	6.2nrad	5.2nrad	7.5nrad

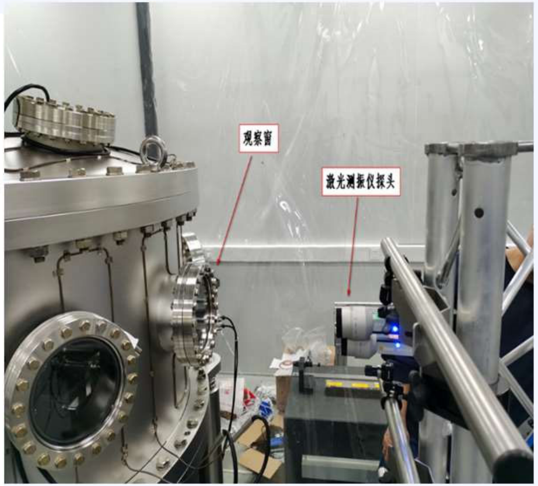
Flow Induced Vibration tested by encoder

Mechanical performance meets the requirement of 100,000 energy resolving power

Stability simulation and measuring equipments







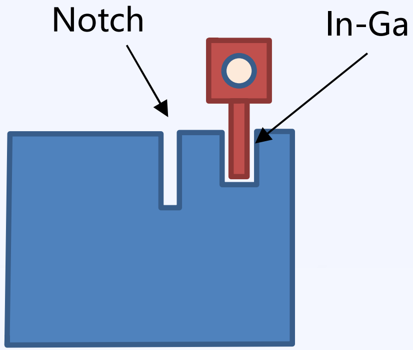
Thermal load overview

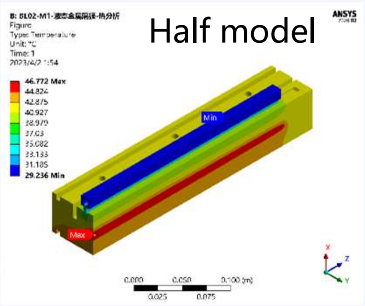
Beamline	Energy (eV) (maximum thermal load)	Thermal load (W)	Thermal density W/mm²	Thermal load (W)	Thermal density W/mm²	Thermal load (W)	Thermal density W/mm²	
		First mirror		PM in PGM		Grating		
BL01	25	< 0.1	< 0.001	< 0.1	< 0.001	0.25	1.5E-4	Water cooling
BL02	6	**413.6**	0.107	10.8	0.041	0.19	2.2E-4	
BL03	45	224.4	**0.224**	19.6	0.119	0.55	24.5E-4	
BL04	250	179.7	0.068	**125.6***	0.128*	6.50*	32.4E-4*	
BL05	180	213.0	0.165	65.7	0.140	3.54	30.3E-4	
BL06	250	77.9	0.069	45.6	0.092	2.54	36.6E-4	
BL07	250	64.5	0.030	100.9	0.209	--	--	
BL08	770	20.0	0.011	60.1	0.165	1.95	27.9E-4	
BL10	240	64.8	0.045	59.0	**0.286**	0.22	3.1E-4	
		First mirror		Crystal #1				
BL08	2300	15.3	0.014	39.1	2.81	--	--	LN cooling
BL09	2100	45.9	0.049	91.6	9.94	--	--	

Slope error is about 100nrad~500nrad

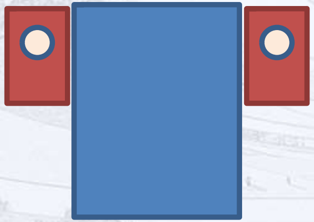
Water Cooling and LN Cooling

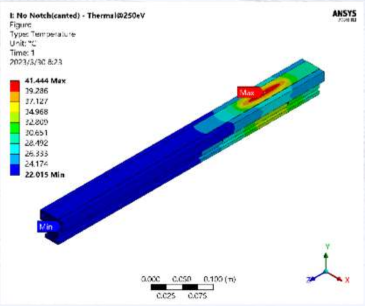
Single Side Water Cooling via In-Ga Bath



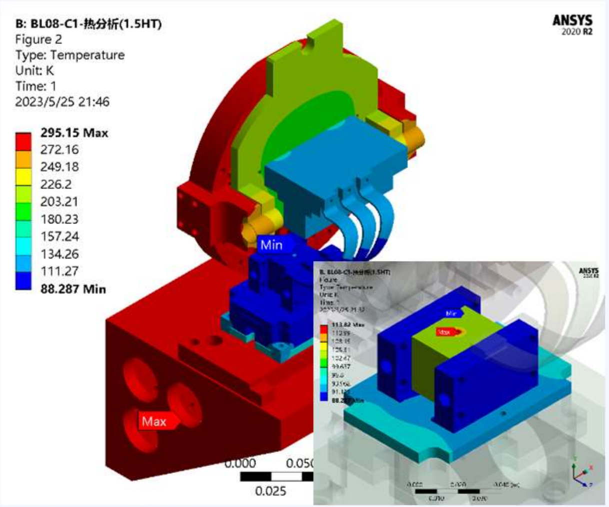


Top-Side Water Cooling （TIM：In or In-Ga）





Liquid Nitrogen Side Cooling



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The Door of HALF is open for you

- Looking for **experienced beamline engineers**
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  - Optics and Metrology
  - Cooling
  - ....

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