SHINE

Beamline optics commissioning updates

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On behalf of the beamline design and metrology group

Thursday, October 23, 2025

Outlines

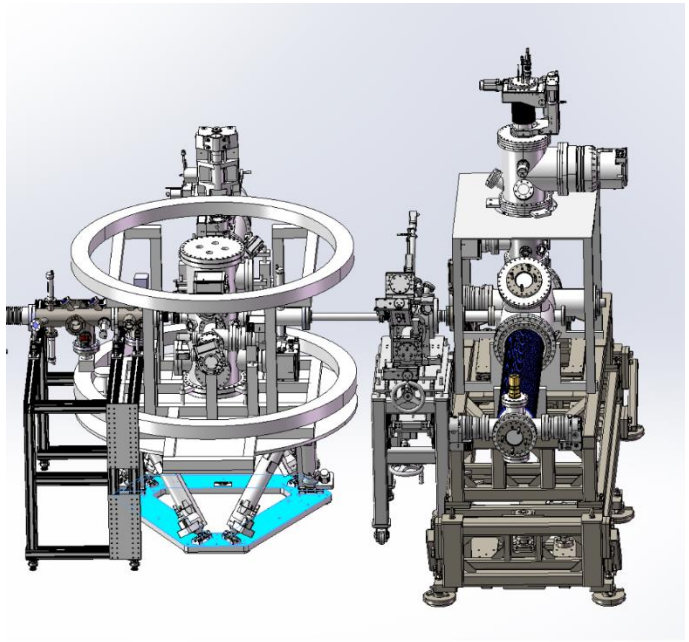
- FEL-II beamline brief
- Optical metrology update
- Installation and commissioning plan

Introduction

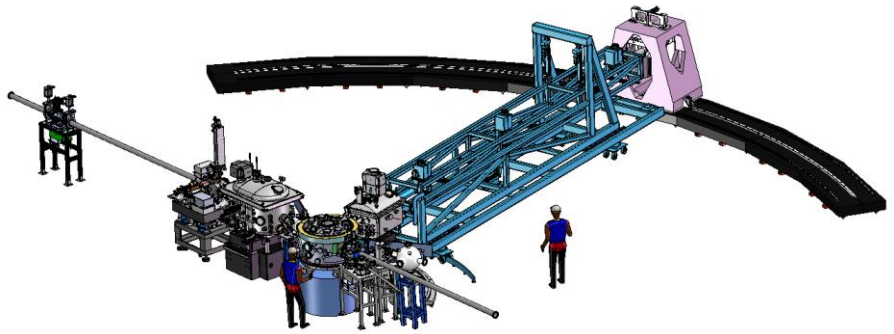
SHINE

The FEL-II beamline will deliver 0.2-3 keV high brightness and high coherence FEL pulses to 3 different endstations:

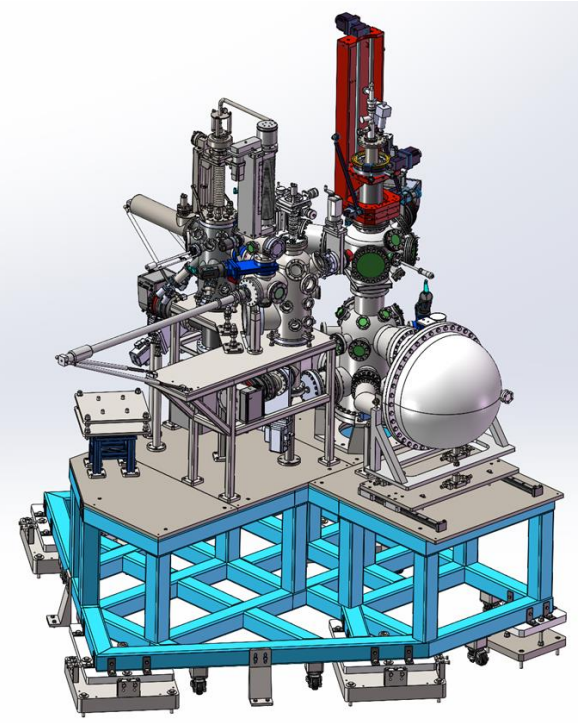
Atomic, Molecular and Optical Science (AMO)



Soft X-ray Scattering and Spectroscopy (SSS)



Spectrometer for Electronic Structure (SES)



Beamline overall layout: photon transport

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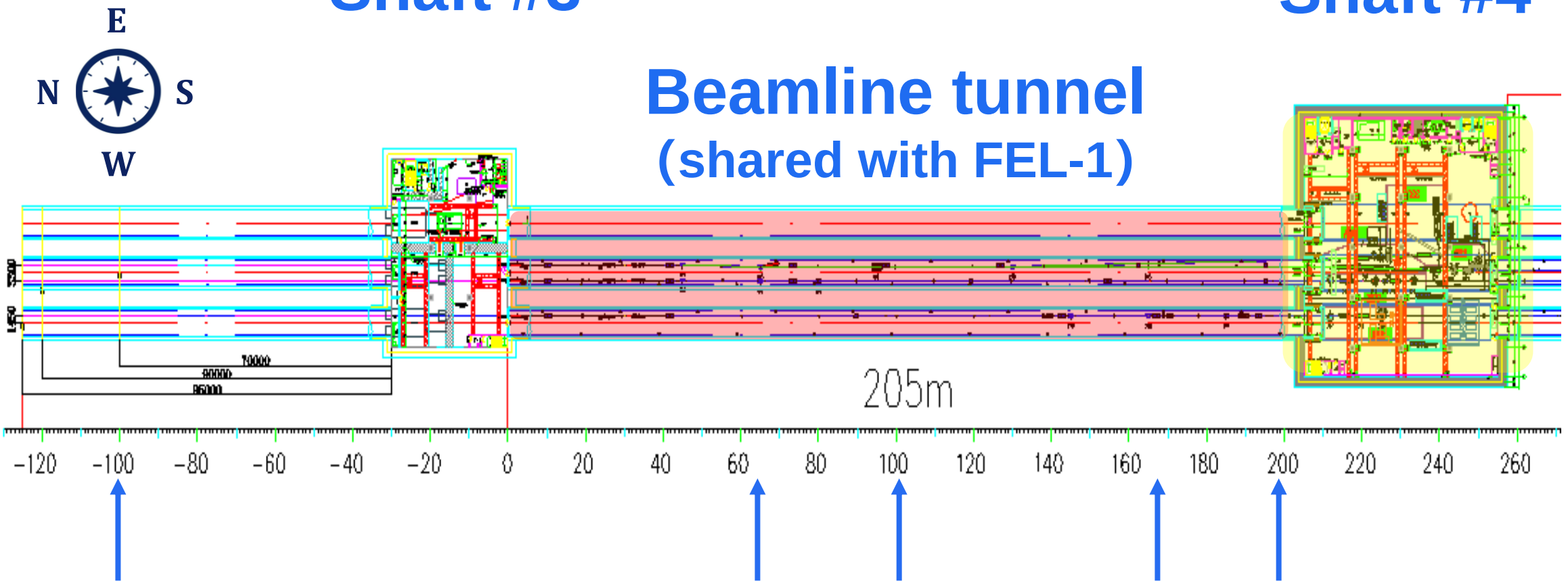
Shaft #3

Shaft #4

Beamline tunnel
(shared with FEL-1)



FEL-II Source

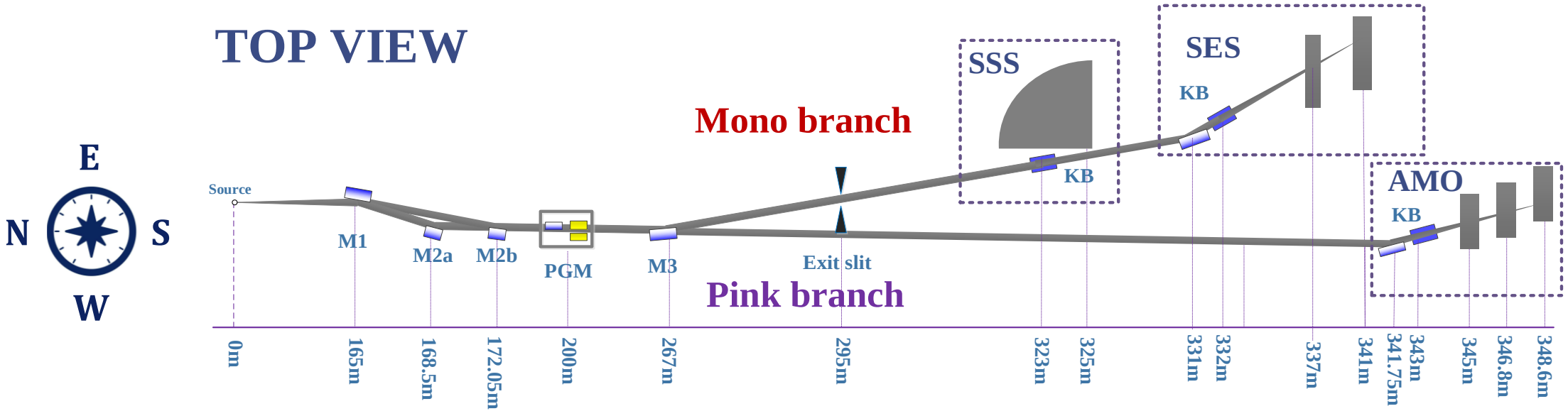
Offset mirror

PGM

Distribution Mirror

Exit slit

Beamline optical layout



Offset mirrors

- 3 plane mirrors divided into two sets for covering whole energy range

PGM

- 1 plane mirror
- 2 gratings for different energy resolving power
- 1 ECM for providing ultrafast FEL pulse

Distribution mirror

- 1 plane mirror for reflecting FEL to SES
- 1 ECM for focusing FEL to SSS in horizontal

KB system

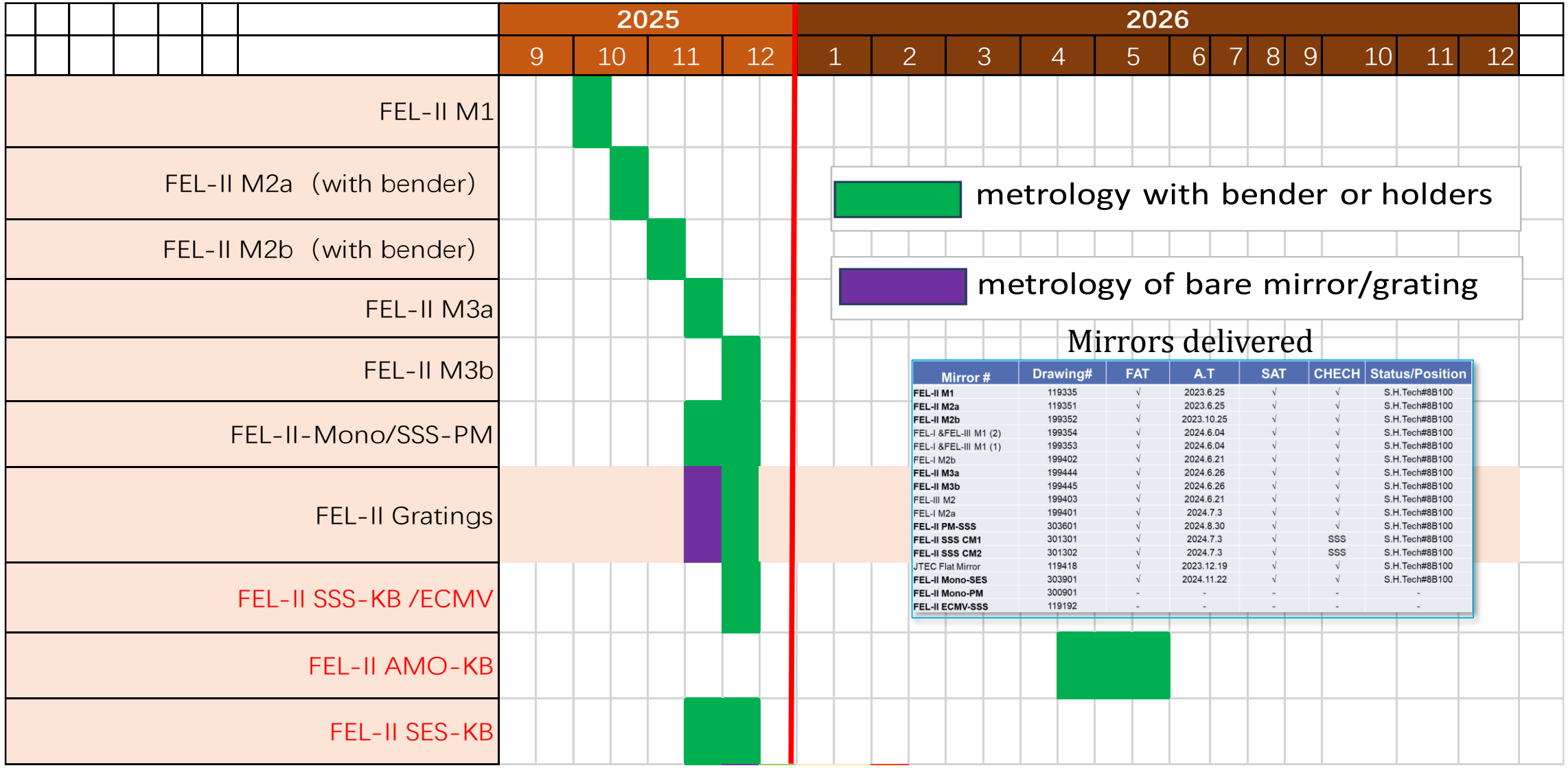
- 3 sets for focusing the photon beam at samples

- **A total of 16 mirrors / gratings are used and needed to be measured**

4 mirrors: face upward
7 mirrors: face sideward
5 mirrors / gratings: face downward

Optical metrology updates

Metrology plan: FEL-II



Mirrors delivered

Mirror #	Drawing#	FAT	A.T	SAT	CHECH	Status/Position
FEL-II M1	119335	√	2023.6.25	√	√	S.H.Tech#8B100
FEL-II M2a	119351	√	2023.6.25	√	√	S.H.Tech#8B100
FEL-II M2b	199352	√	2023.10.25	√	√	S.H.Tech#8B100
FEL-I &FEL-III M1 (2)	199354	√	2024.6.04	√	√	S.H.Tech#8B100
FEL-I &FEL-III M1 (1)	199353	√	2024.6.04	√	√	S.H.Tech#8B100
FEL-I M2b	199402	√	2024.6.21	√	√	S.H.Tech#8B100
FEL-II M3a	199444	√	2024.6.26	√	√	S.H.Tech#8B100
FEL-II M3b	199445	√	2024.6.26	√	√	S.H.Tech#8B100
FEL-III M2	199403	√	2024.6.21	√	√	S.H.Tech#8B100
FEL-I M2a	199401	√	2024.7.3	√	√	S.H.Tech#8B100
FEL-II PM-SSS	303601	√	2024.8.30	√	√	S.H.Tech#8B100
FEL-II SSS CM1	301301	√	2024.7.3	√	SSS	S.H.Tech#8B100
FEL-II SSS CM2	301302	√	2024.7.3	√	SSS	S.H.Tech#8B100
JTEC Flat Mirror	119418	√	2023.12.19	√	√	S.H.Tech#8B100
FEL-II Mono-SES	303901	√	2024.11.22	√	√	S.H.Tech#8B100
FEL-II Mono-PM	300901	-	-	-	-	-
FEL-II ECMV-SSS	119192	-	-	-	-	-

- **All of the measurement of optics with bender or holders for FEL-II beamline will be completed in this year except 2 ECMs in AMO-KB system**

Update of metrology lab.

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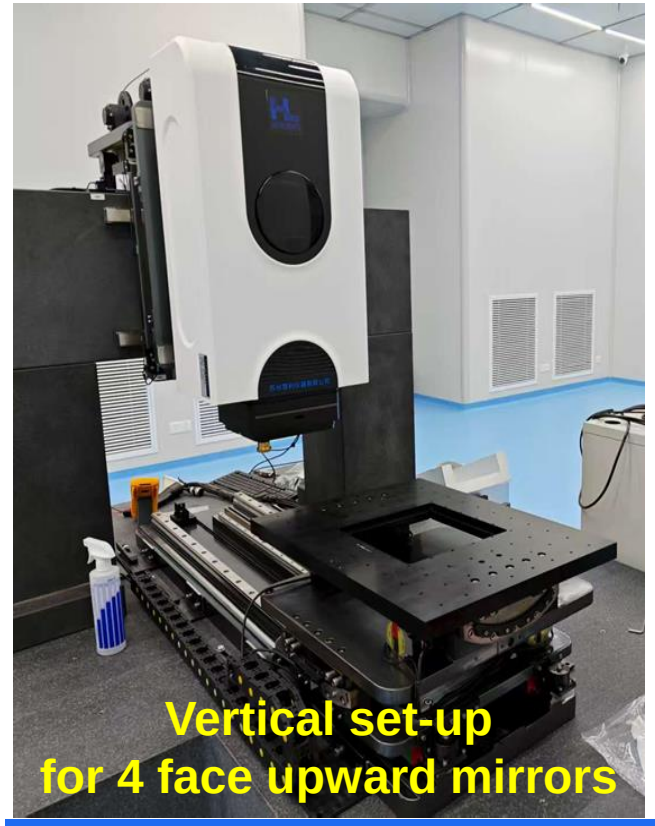
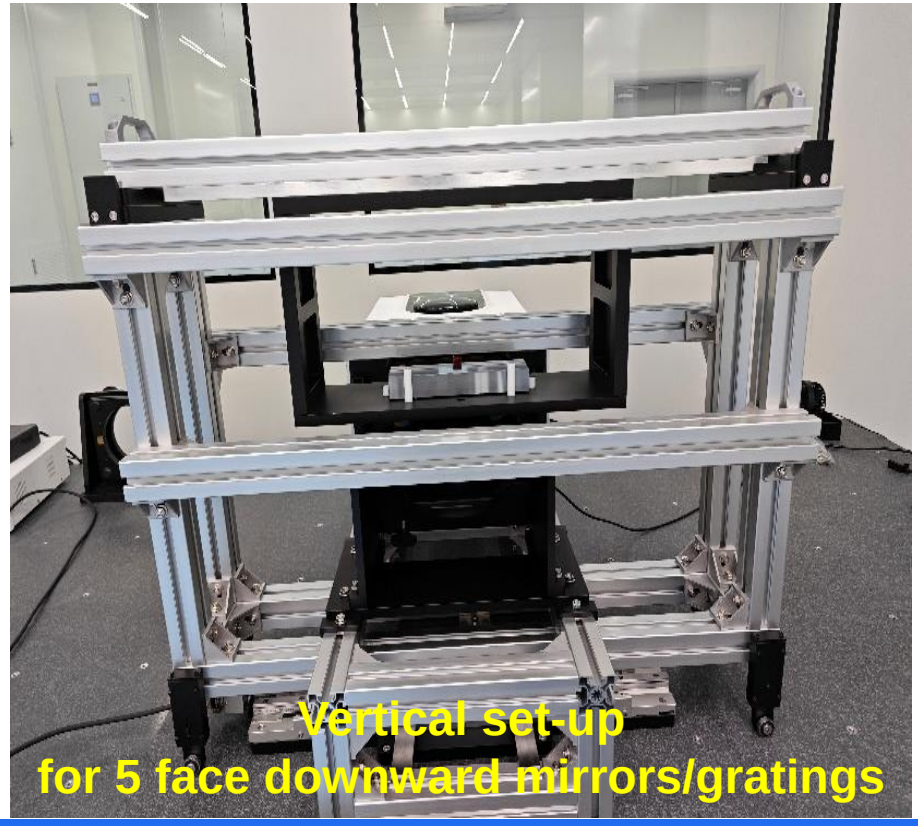
- A new laboratory is developed for the metrology of optics under working condition.
- The lab is a 120 m^2 ISO6 clean room built in #4 shaft to shorten transportation distance after clamping
- Three different set-ups are developed for working condition metrology.



Vertical set-up
for 4 face upward mirrors

Horizontal set-up
for 7 face sideward mirrors

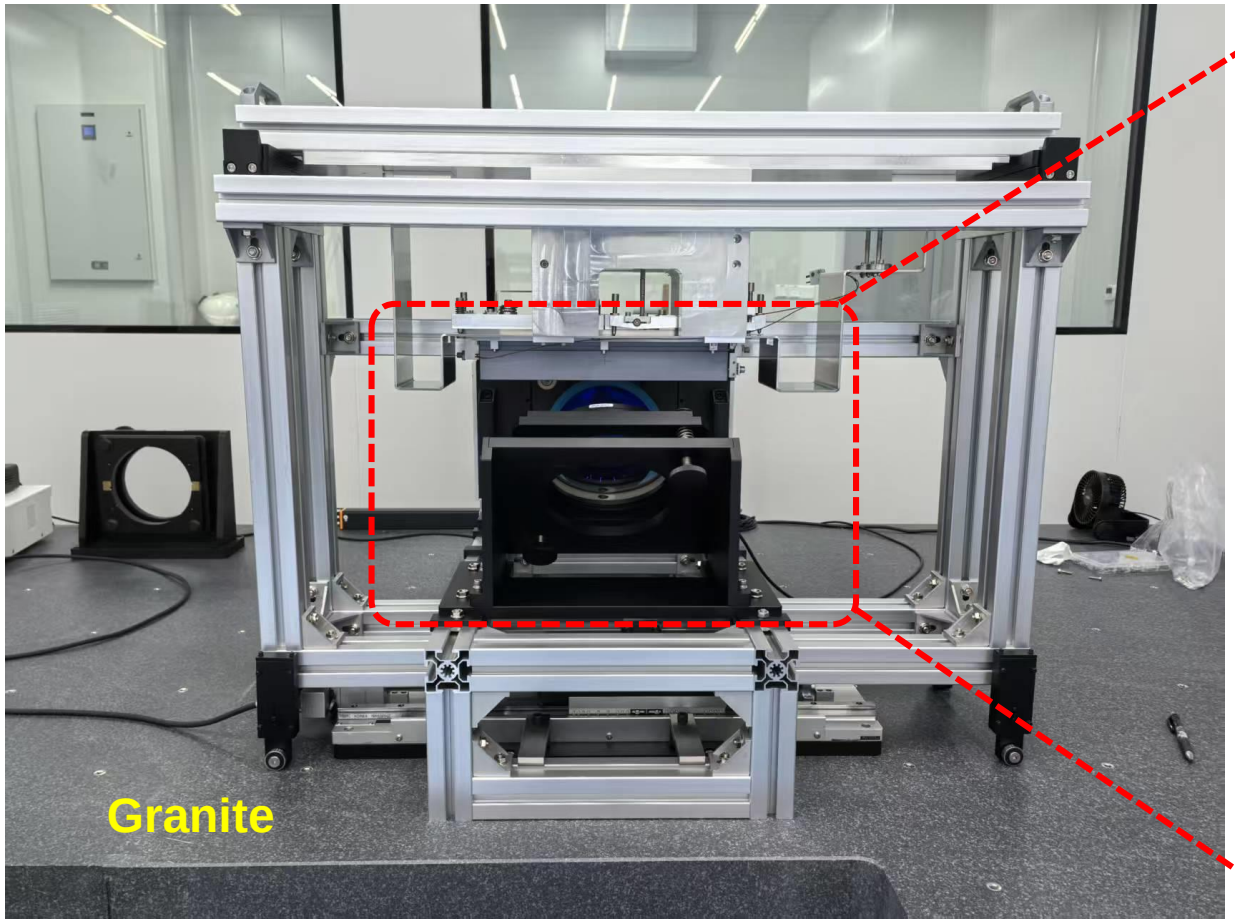


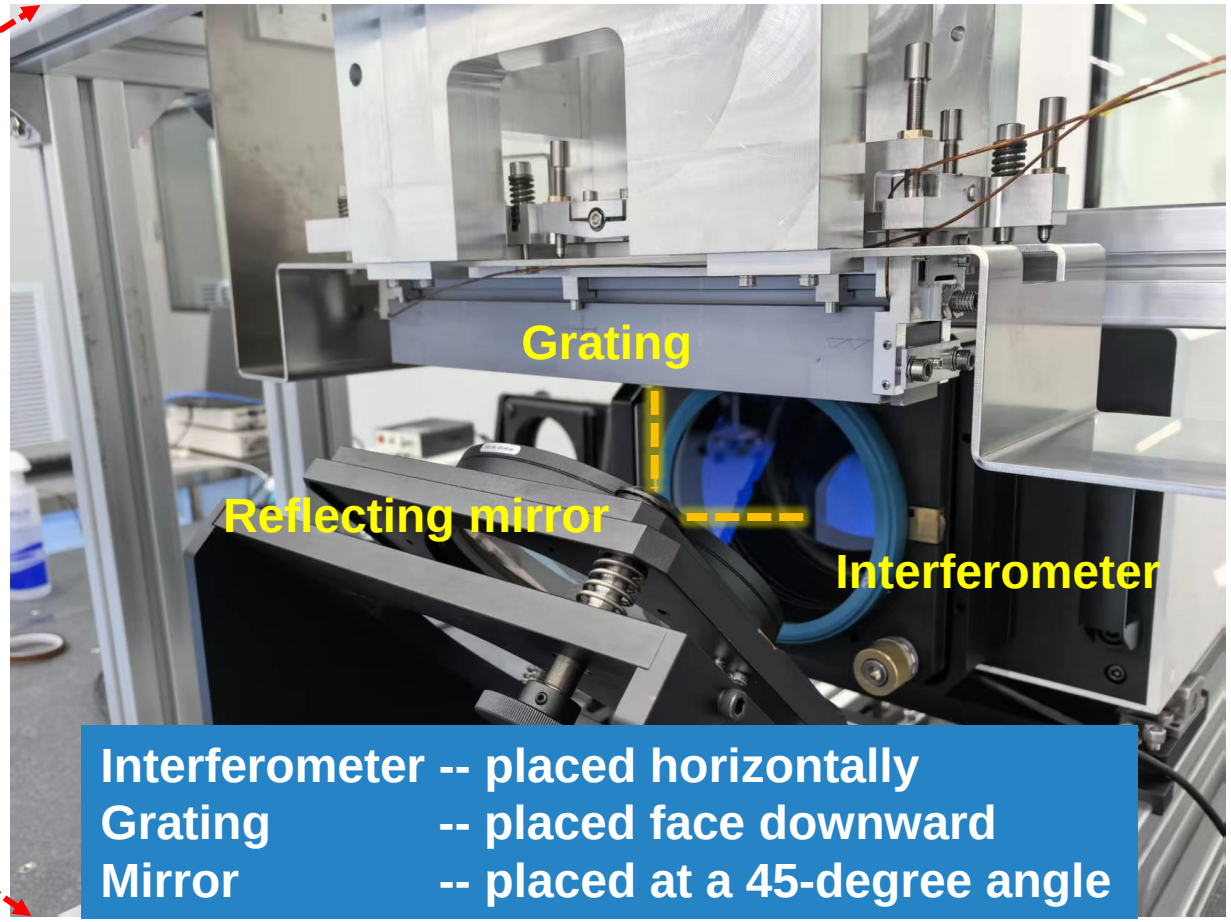
Vertical set-up
for 5 face downward mirrors/gratings

Stitching interferometry

MONO-PG / ECM:

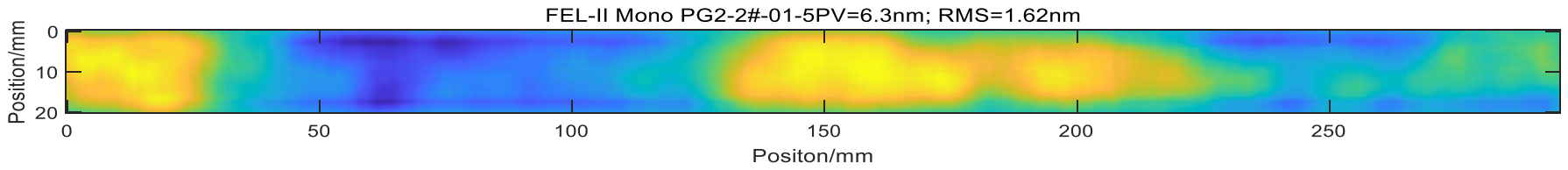
- Two gratings and one ECM have been installed in their holders and measured.



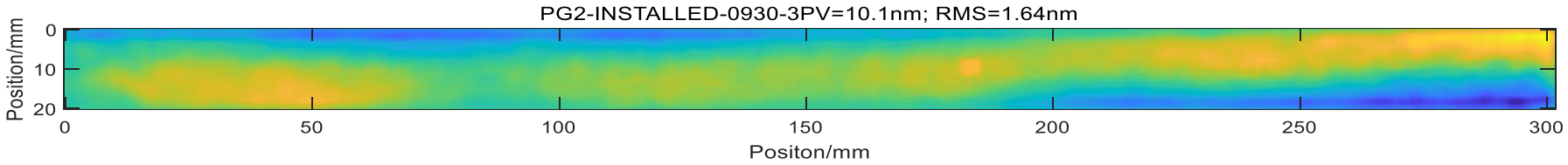


Vertical set-up for grating metrology under working condition

Measuring result of PG2

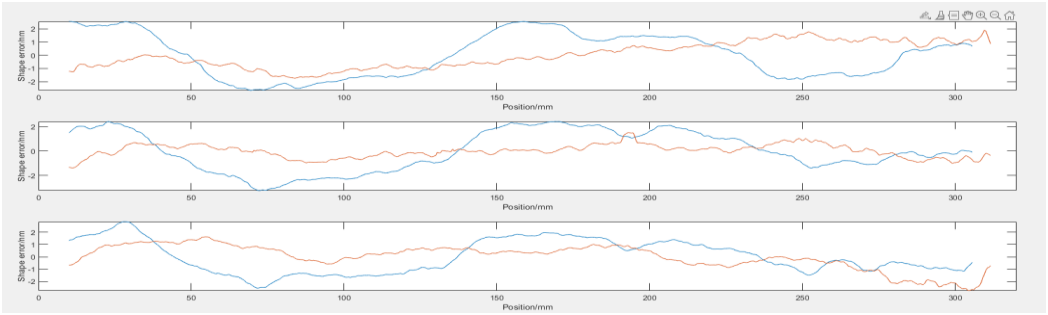


Before clamping
2D HE:**1.62 nm**(RMS)



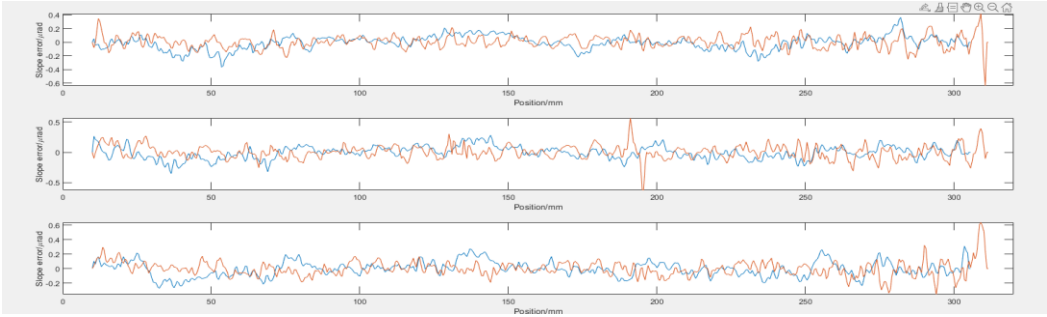
After clamping
2D HE:**1.64** nm(RMS)

Height Error (nm)



Height Error (nm)		Line1	Center	Line2
Before clamping	PV	5.21	5.67	5.37
	RMS	1.65	1.65	1.34
After clamping	PV	3.64	2.92	4.37
	RMS	0.956	0.525	0.987

Slope Error (RMS, μrad)



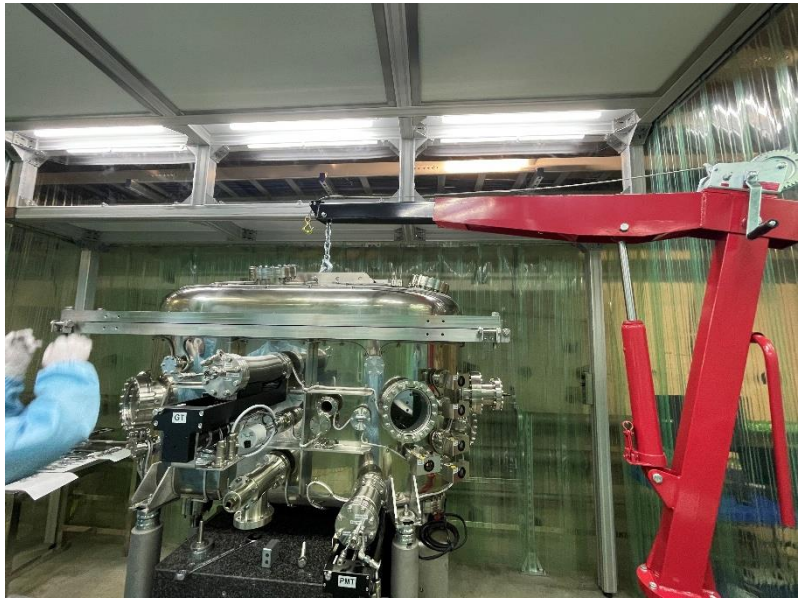
Slope Error (RMS, μrad)	Line1	Center	Line2
Before clamping	0.099	0.103	0.103
After clamping	0.095	0.111	0.103

- **The height error introduced by clamping is 0.3 nm (rms, required: 0.5nm)**

Installation (PGM & KB) and commissioning plan

Key components installation plan : PGM

- The grating monochromator now has already been in position in the tunnel.
- The alignment of grating / mirror axis have already finished.
- The optics will be installed in Dec. 2025.

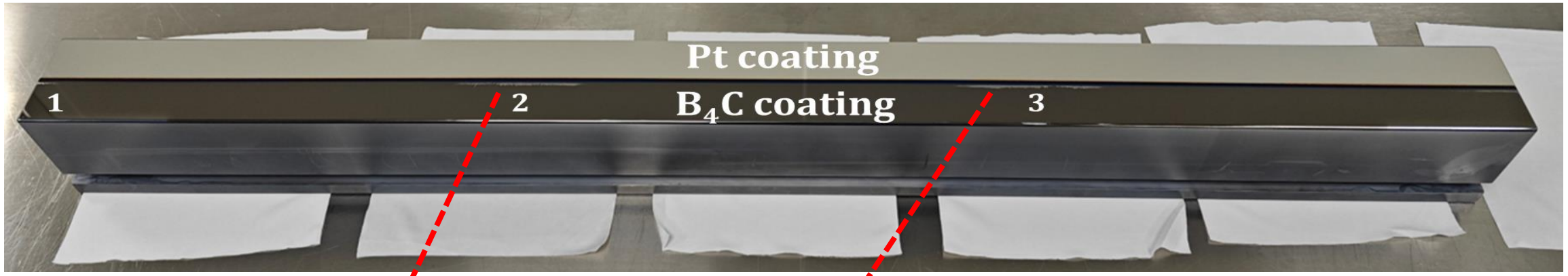


	2025				2026					
	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Jun.
PGM	In position			Optics installation	Baking					
AMO-KB	FAT		Arrival / In position			Mirror polishing completed	Bender metrology	Arrival	Bender installation	Baking
SES-KB			FAT	Arrival	Installation	Baking				
SSS-KB		FAT	Arrival	Installation	Baking					

- **The delay of optics installation is because of the repair of the plane mirror.**

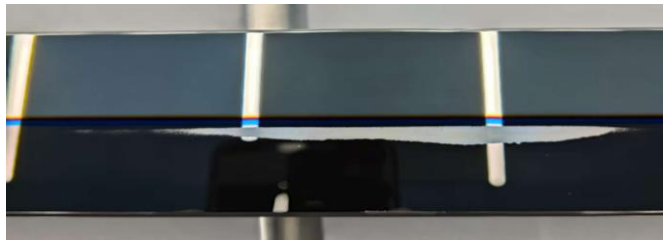
MONO-PM: Coating layer peeling off

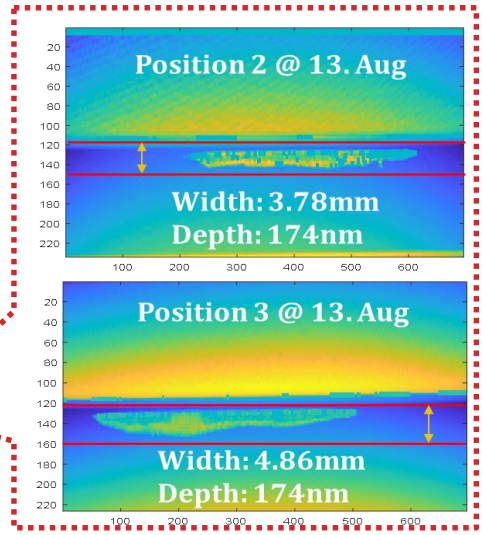
- The peeling off of B_4C coating becomes more worse over time after a period of observation.
- The mirror will return to SHINE in Nov. 2025.
- The installation of PGM is expected to be finished in Dec. 2025.



23. May

13. Aug





Key components installation plan: AMO-KB

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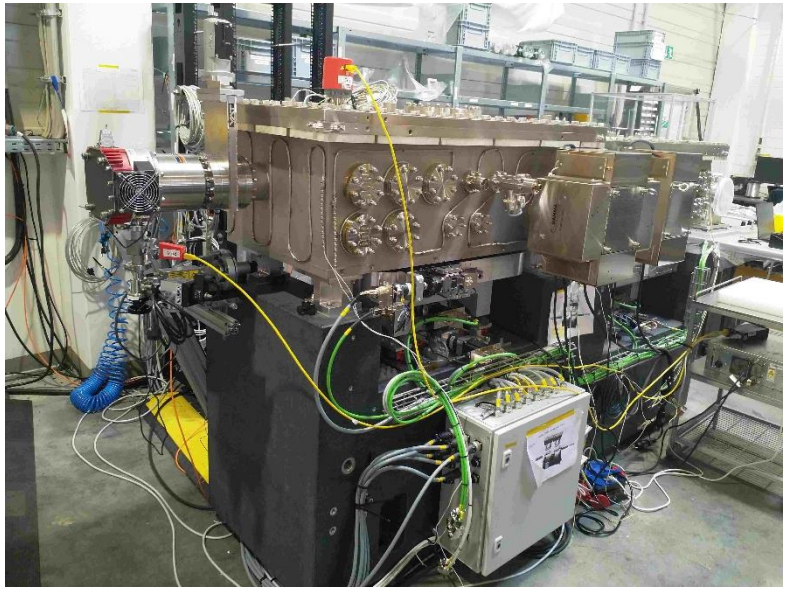
- The factory acceptance test (FAT) for the mechanical part has been finished.
- The mechanical part will arrive at SHINE in early Nov. 2025. and is planned to be in position in Nov. 2025 after arriving.
- The mirror polishing is expected to be completed in Feb. 2026
- The bender is expected to be installed in May. 2026.



	2025				2026					
	Sep.	**Oct.**	**Nov.**	**Dec.**	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May.**	**Jun.**
PGM	In position			Optics installation	Baking					
AMO-KB	FAT		Arrival / In position			Mirror polishing completed	Bender metrology	Arrival	Bender installation	Baking
SES-KB			FAT	Arrival	Installation	Baking				
SSS-KB		FAT	Arrival	Installation	Baking					

- **The pink branch of FEL-II beamline will be ready in Jun. 2026.**

Key components installation plan: SSS-KB

- The FAT of SSS KB system has been finished in this month.
- The SSS KB system will arrive at SHINE in Nov. 2025 and be installed in Dec.2025.

	2025				2026					
	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Jun.
PGM	In position			Optics installation	Baking					
AMO-KB	FAT		Arrival / In position			Mirror polishing completed	Bender metrology	Arrival	Bender installation	Baking
SES-KB			FAT	Arrival	Installation	Baking				
SSS-KB		FAT	Arrival	Installation	Baking					

Key components installation plan: SES-KB

- The SES KB system is still in the final assembly / testing stage
- The bender is also under metrology now.
- The FAT is planned in Nov. 2025 and the whole system is expected to arrive at SHINE in Dec. 2025.
- The whole system is expected to be installed in Jan. 2026.

	2025				2026					
	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Jun.
PGM	In position			Optics installation	Baking					
AMO-KB	FAT		Arrival / In position			Mirror polishing completed	Bender metrology	Arrival	Bender installation	Baking
SES-KB			FAT	Arrival	Installation	Baking				
SSS-KB		FAT	Arrival	Installation	Baking					

- **The mono branch of FEL-II beamline will be ready in Feb. 2026.**

Commissioning goal

SHINE

- The first-round commissioning of FEL-II beamline will begin in the next summer
- Main goal：To deliver the pink beam to AMO and SES for preliminary experiment

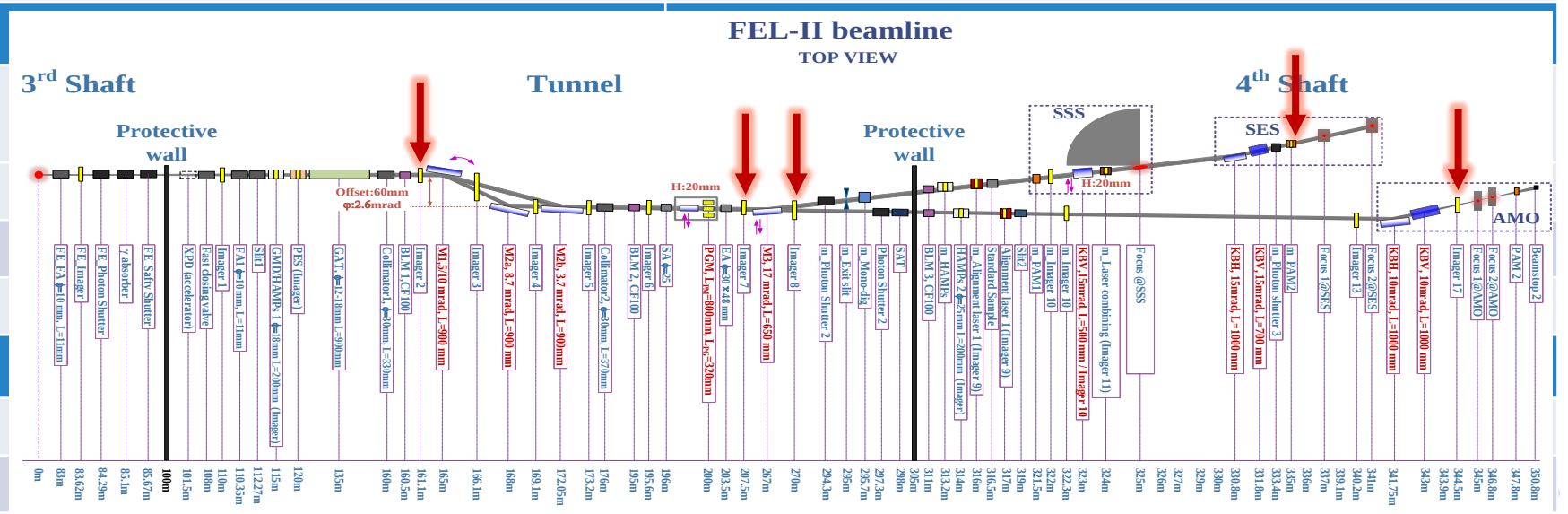
Source parameters in the 1st stage (driven by branch linac accelerator)

FEL mode	SASE		
e-Beam parameters	3GeV、50pC、500A、0.5mm*mrad		
Time (month)	T0	T0+5	T0+10
Photon energy (keV)	0.2	0.2	0.2
Pulse length (FWHM, fs)	/	≤100	≤100
Repetition rate (Hz)	10	10k	≥100k
Pulse energy (μJ)	10	≥10	≥30
Lateral stability		20%	20%
Time jitter (fs)		≤50	≤30

Commissioning plan (16 day+30 day+20 day)

SHINE

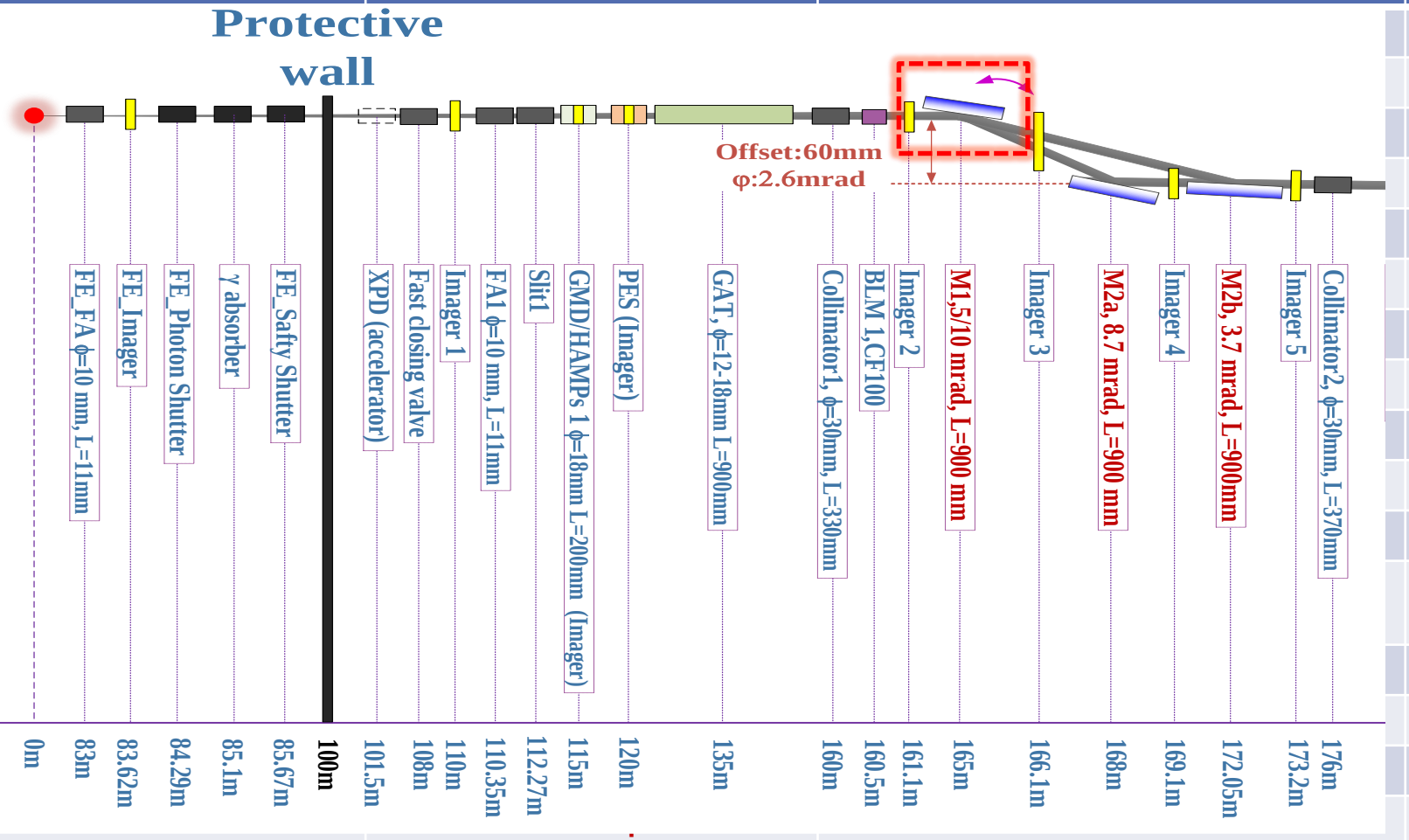
Beamline			
Front-end	≥2 day	The beam passes through FE_Imager, Imager1, GMD/Hamps, and GAT to reach Imager2	Spot can be observed on Imager2
M1/M2a AMO-KB	≥2 day	The beam reaches AMO-KB through M1, M2a. The PGM will be moved out of the beam path here.	Spot can be observed at AMO
PGM(ECM) + M3	≥2 day	The pink beam passes through the PGM and M3. The ECM in the PGM will be moved in the beam path.	Spot can be observed on Imager 7/8
SES-KB	≥2 day	The pink beam reaches SES-KB	Spot can be observed at SES
AMO-KB	≥4 day	Commissioning of AMO-KB	An acceptable spot size for AMO
SES-KB	≥4 day	Commissioning of SES-KB	An acceptable spot size for SES
Diagnostic Equipment			
Imager	≥30 day		
GMD / HAMPs			
PES			
BLM			
Endstation			
AMO	12 day		
SES	8 day		



Commissioning difficulties

- Photon beam will be optimized by accelerator with the center of FE_Imager as a reference.
- The accelerator is required to have an ability to move the photon beam by ± 0.5 spot size.
- The minimum aperture before M1 is 82 μrad at the GAT (the divergence at 200eV is expected to 50 μrad).

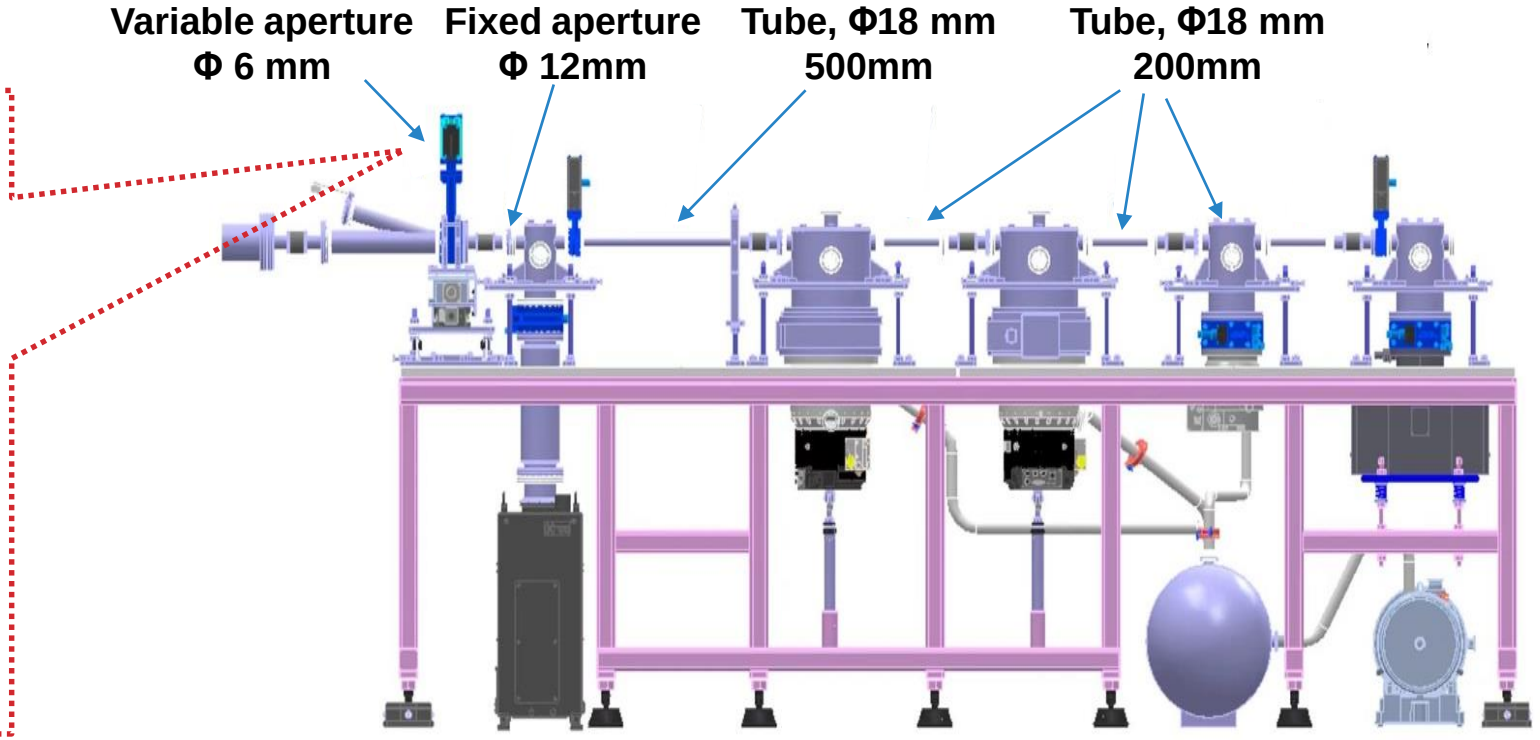
Device	Position (from source)	Aperture	Length	Observation
FE_Fixed aperture				FE_Imager
FE_Imager				
Photon shutter				*Out of beam path*
γ-absorber				Imager 1
Safty shutter				*Out of beam path*
Fast closing valve				*Out of beam path*
Imager 1				*Out of beam path*
Fixed aperture 1				GMD/ HAMPs1
Slit 1				Imager in HAMPs
GMD/HAMPs1				Imager in HAMPs
PES				Imager in PES
GAT				Imager 2
collimator 1				Imager 2
BLM 1				Imager 2
Imager 2				*Out of beam path*
M1				



Commissioning challenges

- GAT differential section may be the biggest challenge
- 3 differential sections at each end of the GAT

  1×Differential hole: Φ12 mm，
  4×Differential tube: Φ18 mm，500mm+200mm×3



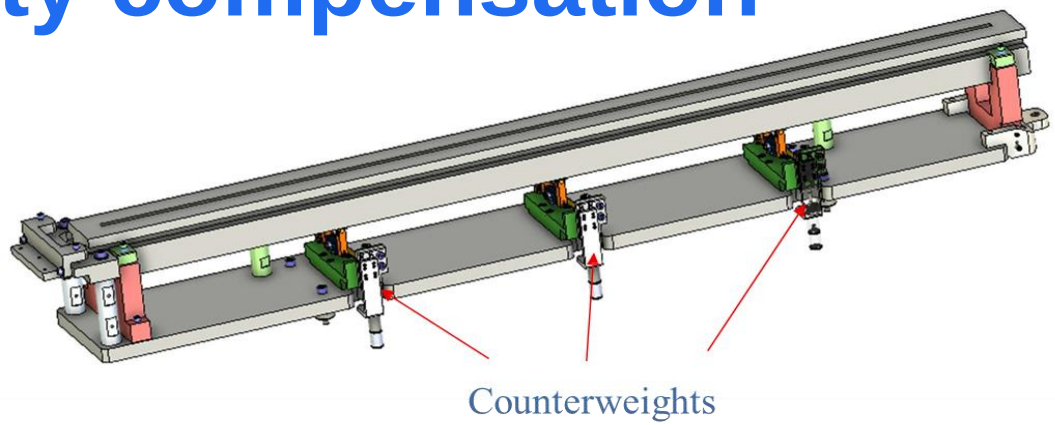
Summary

- A new metrology laboratory is built for under working condition measurement. 3 different set-ups are developed for optics upward, downward and sideward.

- The key optical components of FEL-II beamline are in final testing and installation stage. The mono branch is expected to be ready in Mar. 2026 and the pink branch is expected to be ready in Jun. 2026.

Question:
Face downward mirror gravity compensation

Mirror shape	Elliptical （fixed shape）
Working orientation	Face downward
Cooling type	Eutectic slot on the backward



Problem: It can not be measured in the working orientation, and can not compensate online.

How to remove the gravity effect？？？

Solution provided by manufacturer:

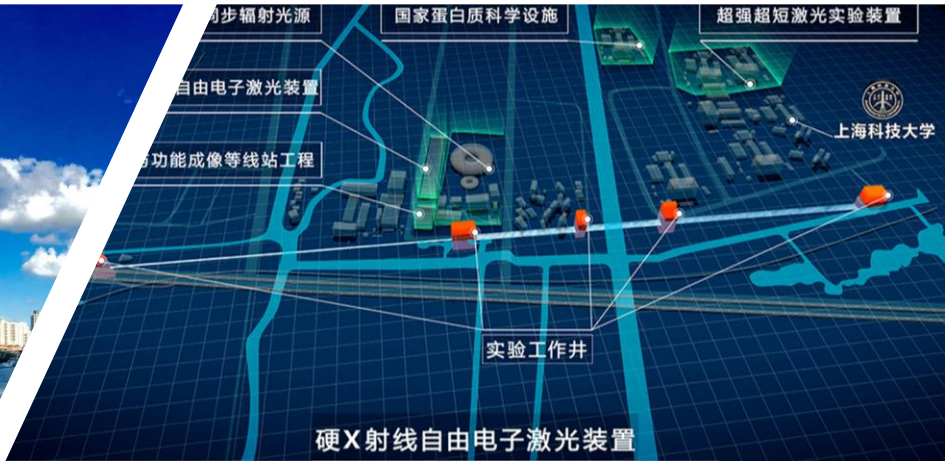
1. The mirror gravity sag will be removed by polishing.
2. The eutectic gravity sag will be removed by motorized shape compensators (counterweights).

During the mirror metrology:

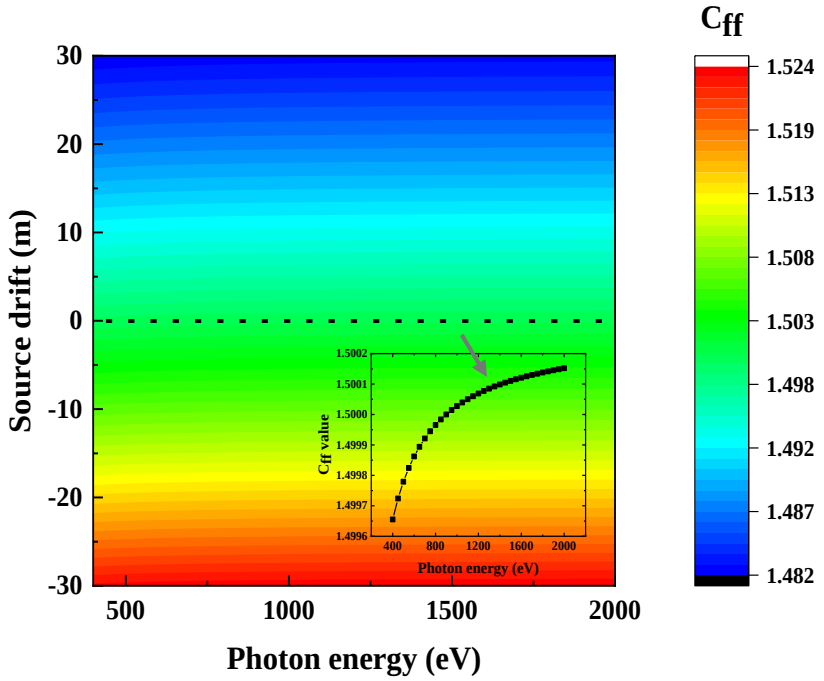
1. Install the mirror **facing upward** to enable LTP/interferometer metrology.
2. Adjust the compensator based on the metrology results to achieve 50 nrad slope error.
3. Then turn the mirror over and install the mirror **face downward**, the adjustments made while face upward are considered equally effective.

Is this method feasible？？

Thank you for your attention!

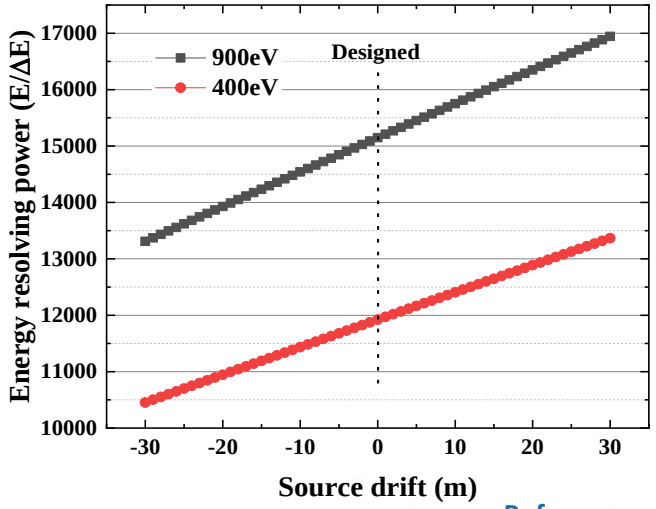


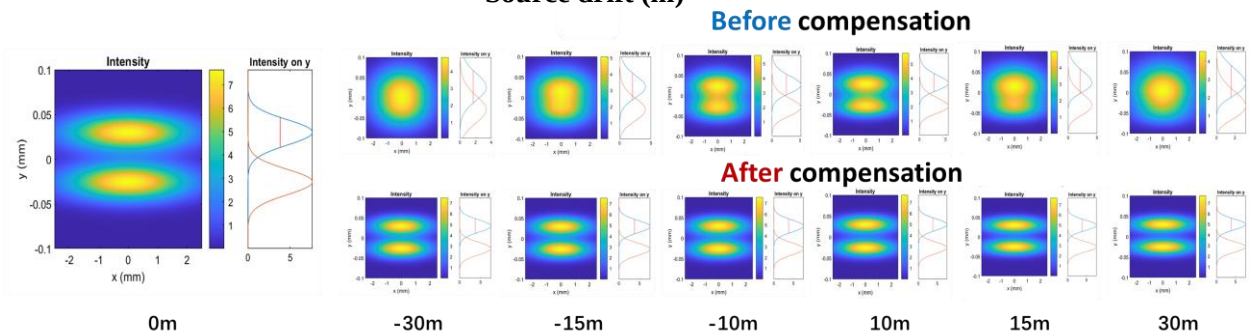
C_{ff} compensation for source point drift



The required Cff value for different photon energies under different source point drift conditions

Theoretical energy resolving power of the PGM after Cff compensation





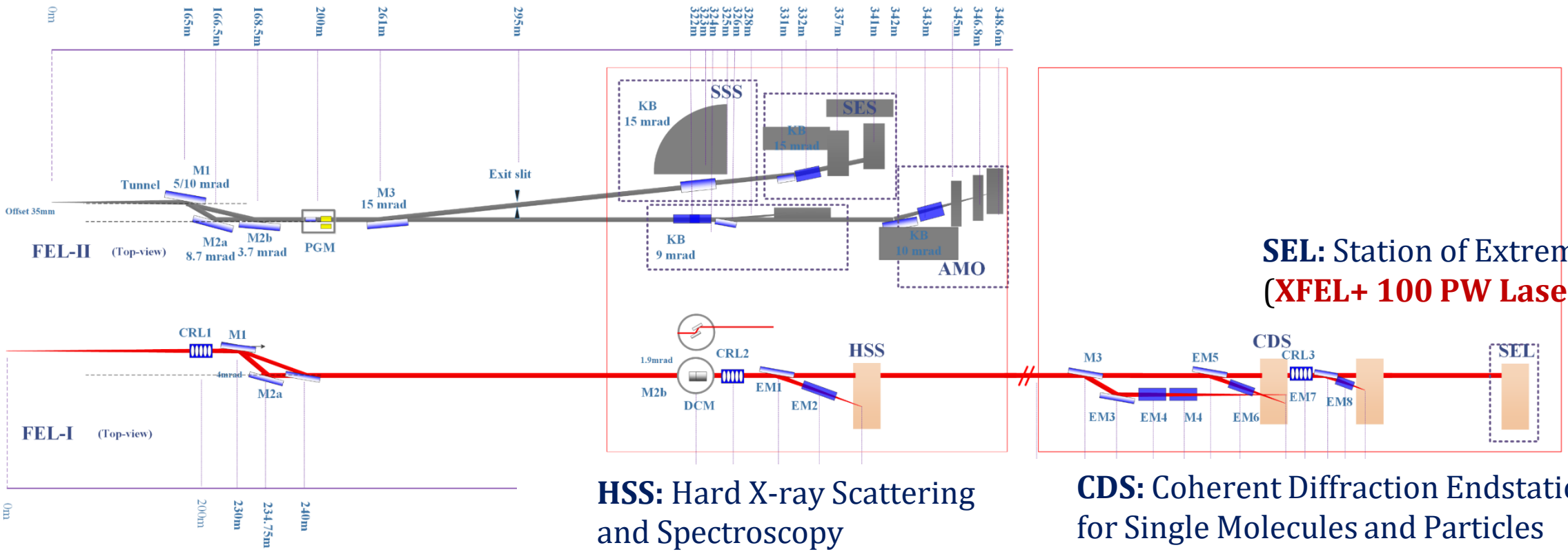
Simulation results @900eV

The decrease in energy resolving power of the PGM caused by source point drift can be compensated by adjusting the Cff value

FEL-I Beamline overview

Introduction of FEL-I beamline

- FEL-I beamline is a hard X-ray beamline in SHINE and covers the photon energy 3-15 keV.
- FEL-I beamline shares the middle tunnel with FEL-II beam and will deliver the photon beam to 3 endstations.



SEL: Station of Extreme Light (**XFEL+ 100 PW Laser System**)

HSS: Hard X-ray Scattering and Spectroscopy

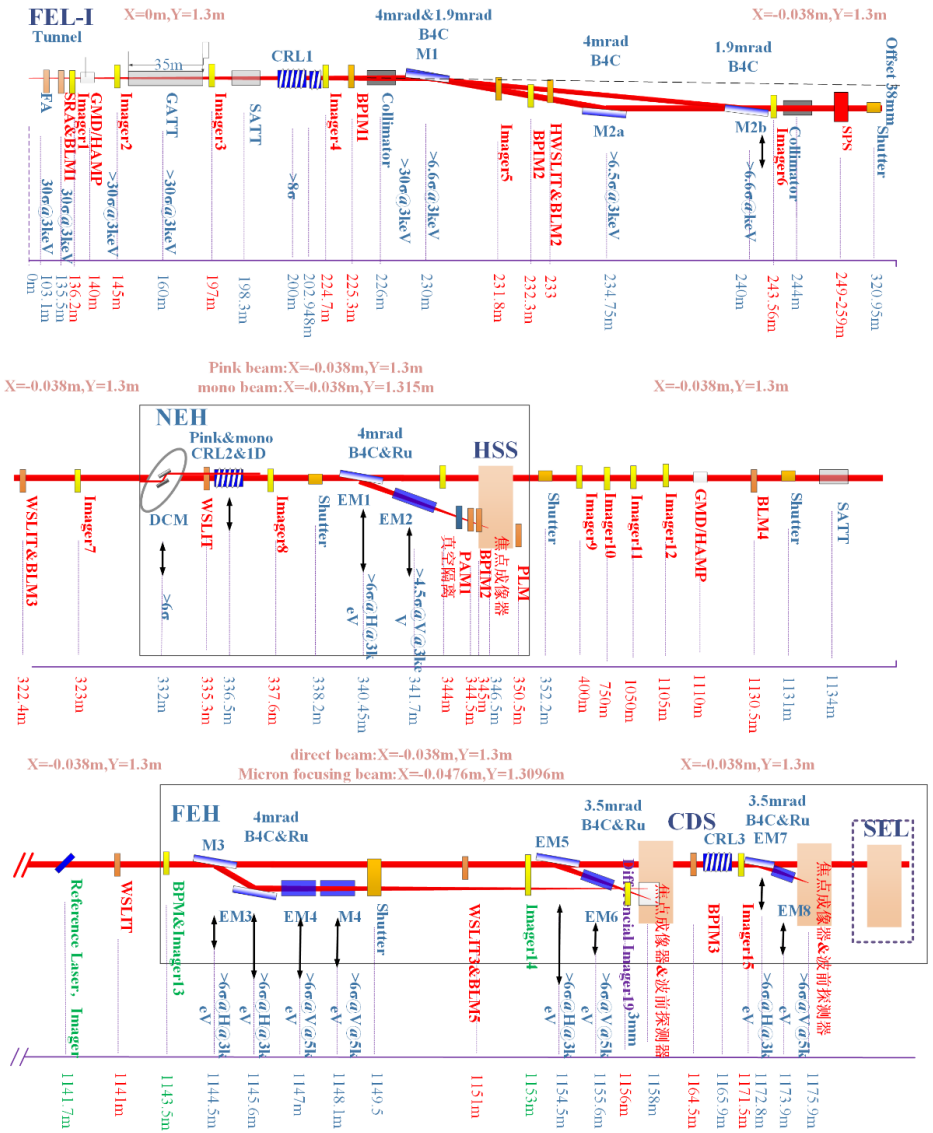
CDS: Coherent Diffraction Endstation for Single Molecules and Particles

Requirements of FEL-I endstations

SHINE

	Parameter	CDS	HSS
1	Energy range	3~15 keV	3~15 keV
2	Energy resolution	/	Si(111): 2×10^{-4}@3~15keV Si(311): 5×10^{-5}@5.6~15keV
3	Efficiency of beamline	≥50%@7keV (1)	≥60%@7keV (1)
4	Percent of Harmonics	≤0.05%	≤0.01%
5	Beam size (FWHM)(H×V)	Objective：300 nm×100nm@7keV (2) Nominal：600 nm×300nm@7keV	Objective：(5μm~200μm)×(5μm~200μm) Nominal：10μm×10μm
6	Working distance	>0.2m@100nm	
7	Beam stability（RMS）	/	≤3um
8	Focusing	/	CRL and K-B
9	Attenuator	6 orders	4 orders

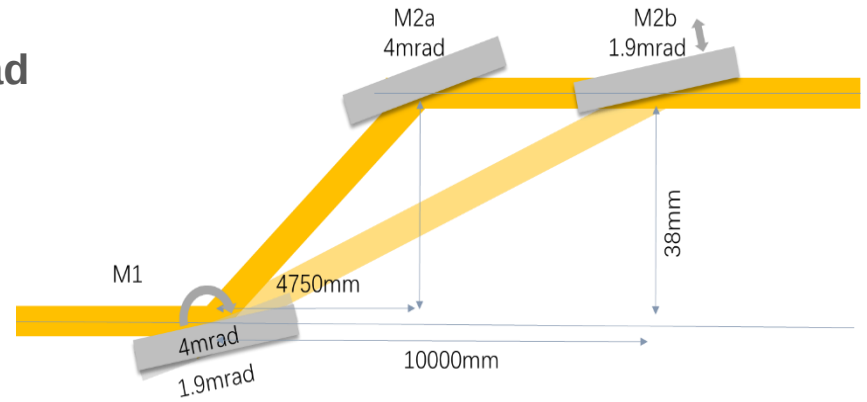
FEL-I beamline Layout



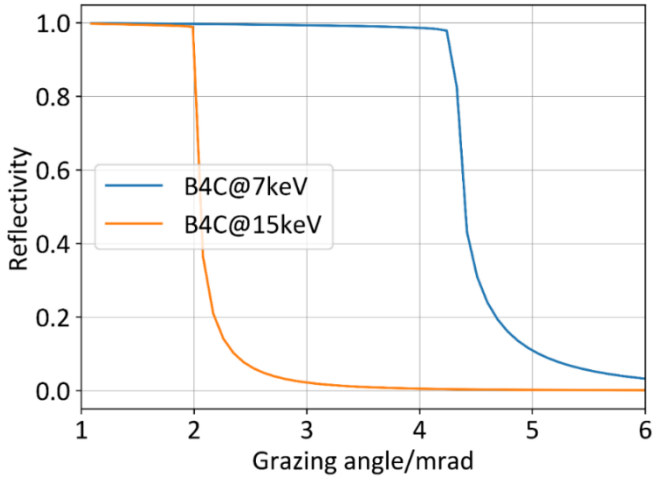
- Offset mirrors with three mirror to cover different photon energy range
- A cryo-cooling DCM for HSS endstation
- Benderable KB for HSS endstation
- Fixed shape micron and nano KB for CDS
- Attenuators: GATT + SATT
- Diagnostics: pulse energy, pulse spectra, beam position and profile, beam loss monitor

Offset mirror

- M1：
  - Energy range：3-15keV
  - Grazing angle：4/1.9mrad
  - B_4C coating
- M2a：
  - Energy range：3-7keV
  - Grazing angle：4mrad
  - Divergence：5.5-2.7μrad
  - B_4C coating
- M2b：
  - Energy range：6-15keV
  - Grazing angle：1.9mrad
  - Divergence：2.6-1.3μrad
  - B_4C coating



(a) Diagram of offset mirrors



(b) Reflectivity at 7 keV & 15 keV

- Decrease the power density,
- Increase the working repetition rate
- Reject the high order harmonics of lower energy range

Crystal monochromator

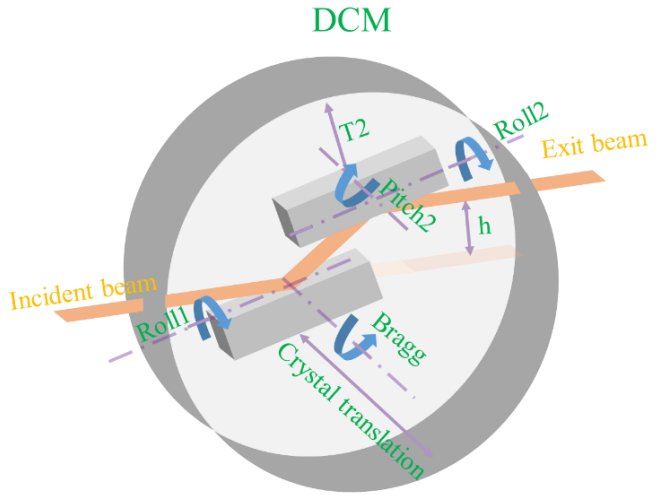
SHINE

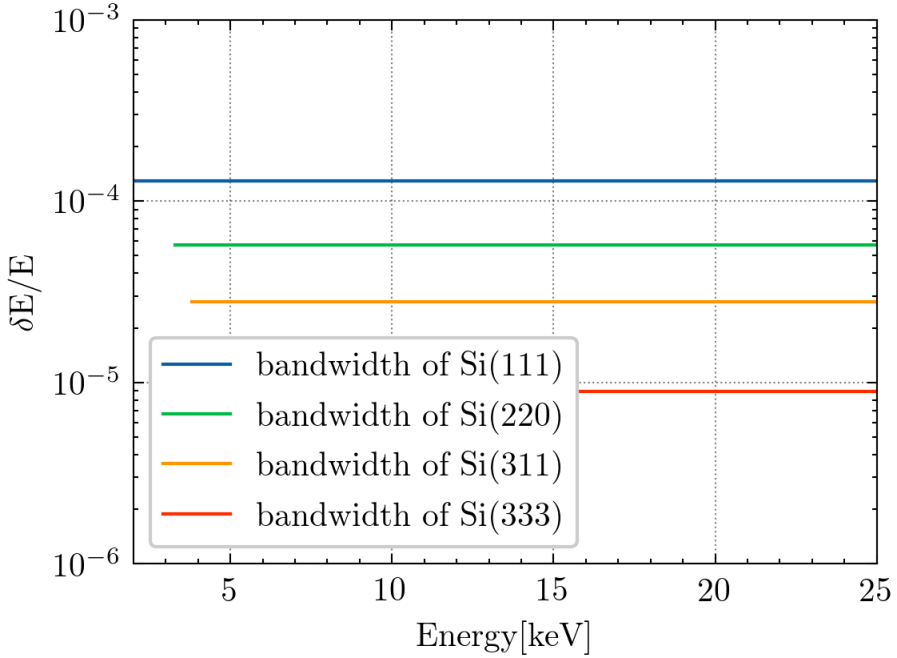
Energy range：3-15keV

Energy resolution：2×10^{-4} Si(111)，5×10^{-5} Si(311)

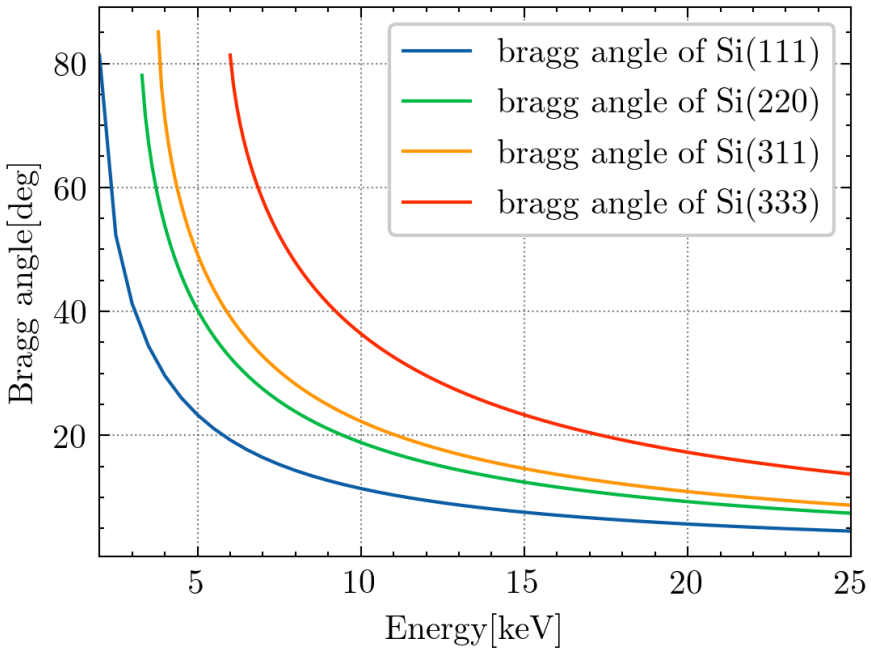
Fixed exit beam height

Double crystal monochromator with cryo-cooling





(a) Energy resolution for different lattice plane

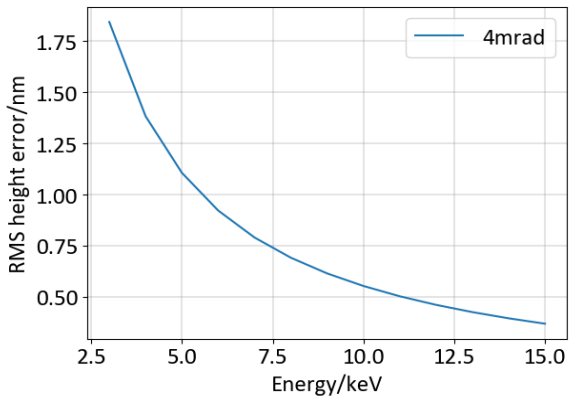


(b) Bragg angle for different lattice plane

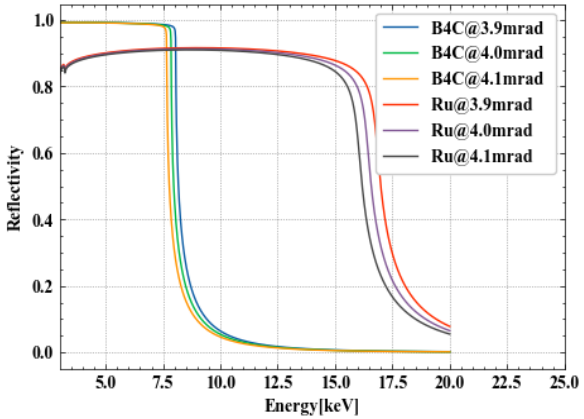
KB focusing for HSS

Energy range: 3-15 keV
Beam size : < 5 μm, and can be enlarged to 200μm in both direction separately

- **KB system：**
  - **6 m and 4.8 m before the sample position**
  - **Pre shape: elliptical for focusing to 5 μm**
  - **With bender to defocus, and enlarge the beam**
  - **B_4C, grazing angle 4mrad，3-7keV**
  - **Ru, grazing angle 4mrad，6-15keV**



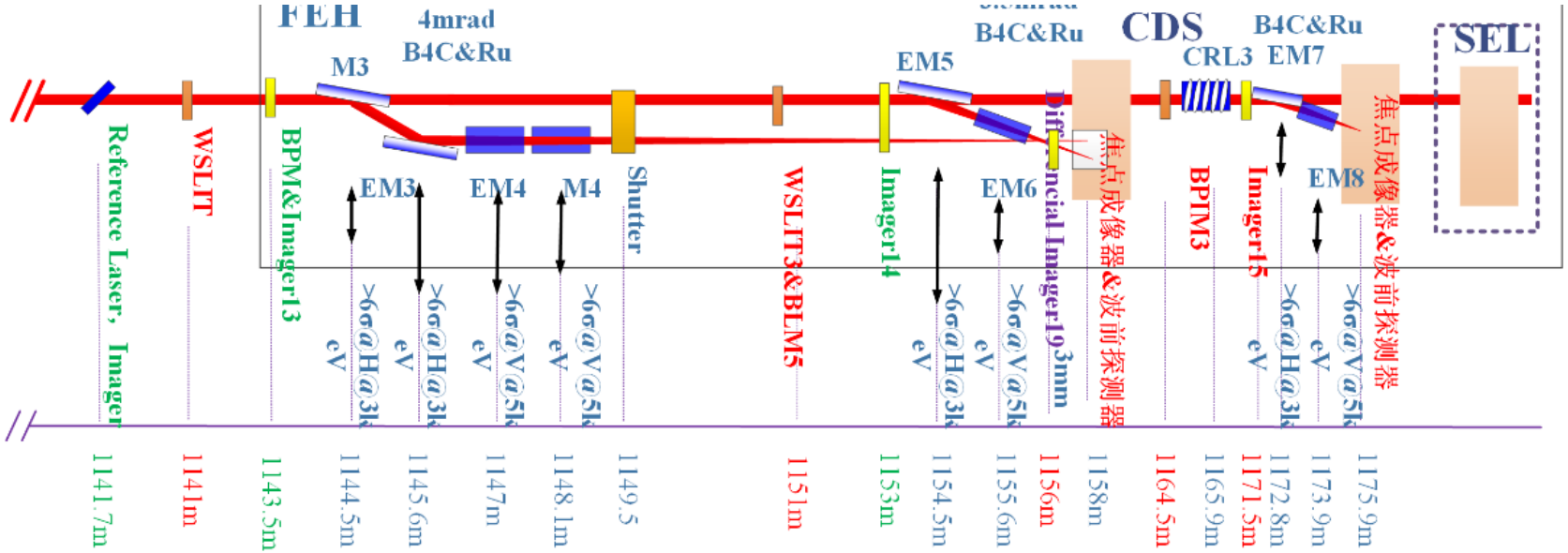
(a) Height error requirement



(b) Reflectivity of B_4C and Ru

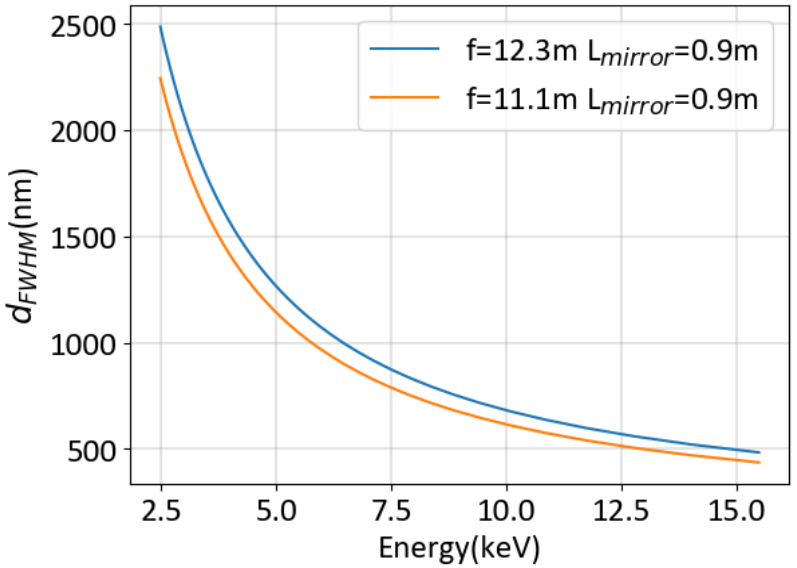
KB focusing for CDS

- Energy range:3-15keV
- Focusing to 1μm，100nm@7keV

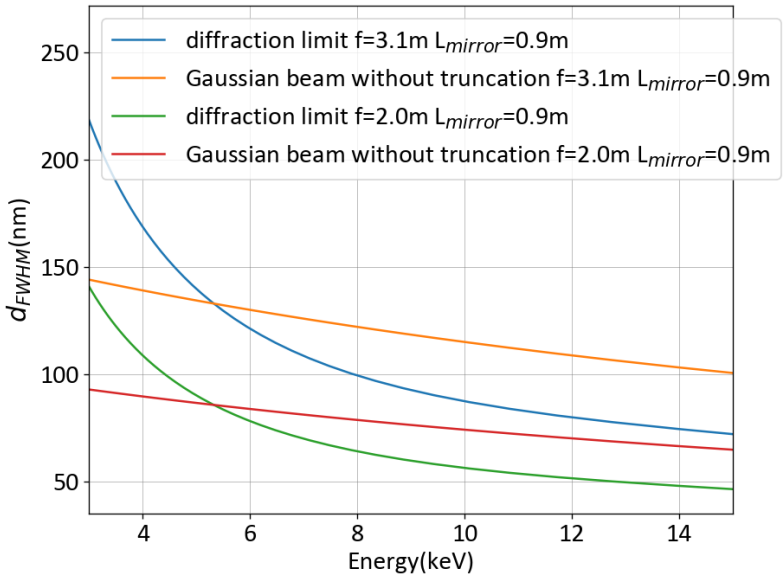


- **The Four bounce micron KB：4 mrad，B_4C for 3~7 keV and Ru 6~15 keV**
- **Nano-KB：7 mrad，Ir for 3.5~10 keV**

KB focusing for CDS



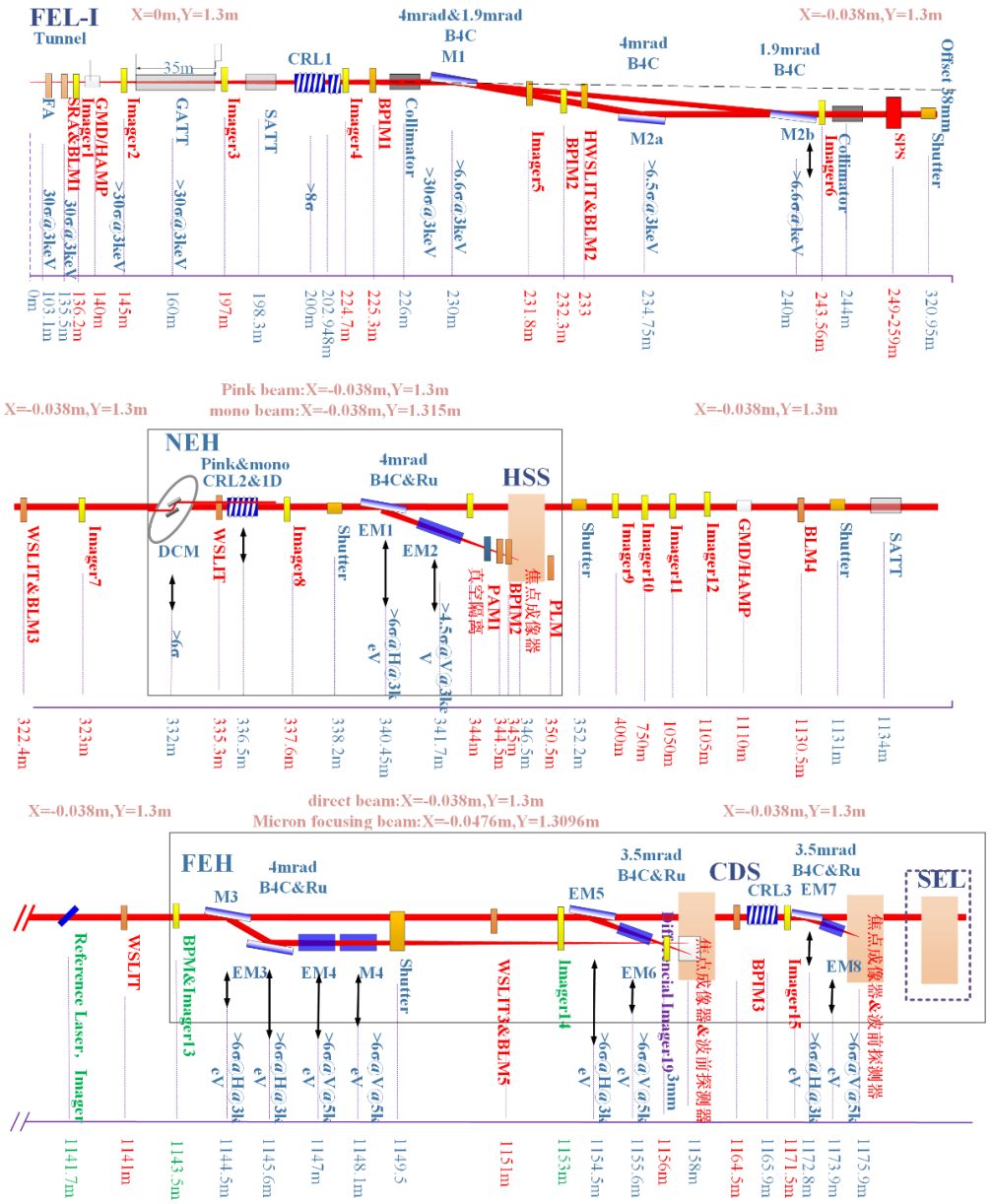
(a) Spot size of micron-KB



(b) Spot size of nano-KB

- The four bounce micron-KB with f= 12.3 m / 11.1 m : 1 μm @7keV
- The nano-KB with f= 3.1 m /2.0 m : 140nm*80nm@7keV

FEL-I Layout



- Offset mirrors with three mirror to cover different photon energy range
- A cryo-cooling DCM for HSS endstation
- Benderable KB for HSS endstation
- Fixed shape micron and nano KB for CDS
- Attenuators: GATT + SATT
- Diagnostics: pulse energy, pulse spectra, beam position and profile, beam loss monitor