Progress in SHINE (Beamline &Endstation)

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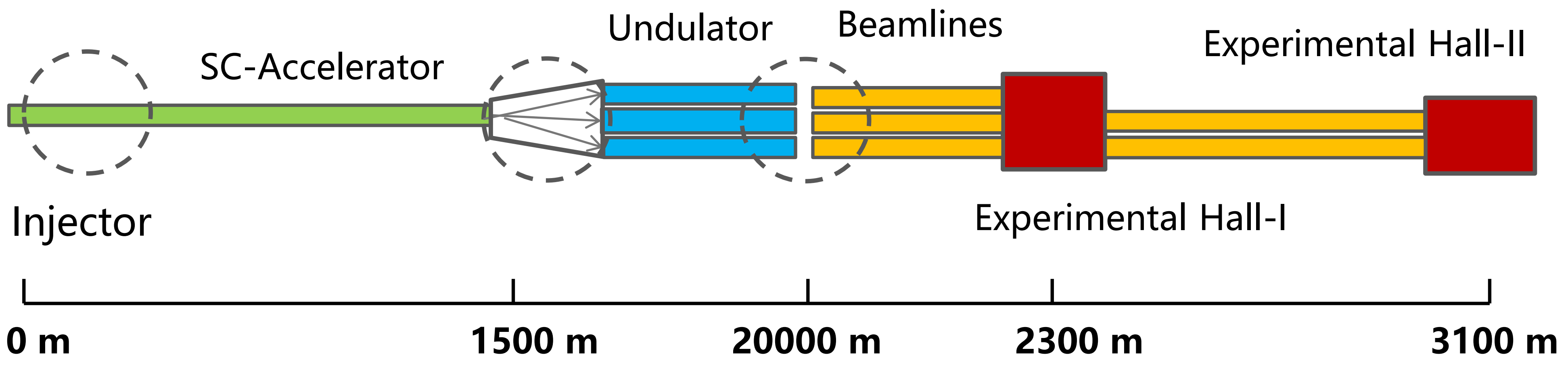
Beamline and Endstations Division of SHINE Project

Oct 22nd, 2025

SHINE

Shanghai HIgh repetitioN rate XFEL and Extreme light facility

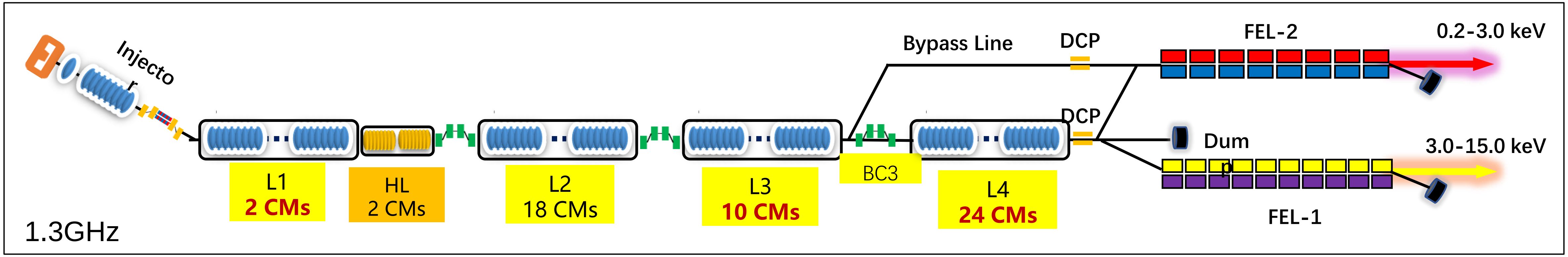
SHINE



- ✓ **An 8GeV SCRF linac, 2 undulator lines to deliver photons from 0.2-15 keV, up to 1 MHz pulse train with pulse duration of 1-100fs**
- ✓ **2 X-ray beamlines and 6 End-stations**
- ✓ **50 PW super-intense laser facility**
- ✓ **Total length 3.1 km; 29.0 m underground**

This facility is being developed by ShanghaiTech, SARI & SIOM of CAS.

SHINE: A High-rep Rate XFEL Based on SCRF

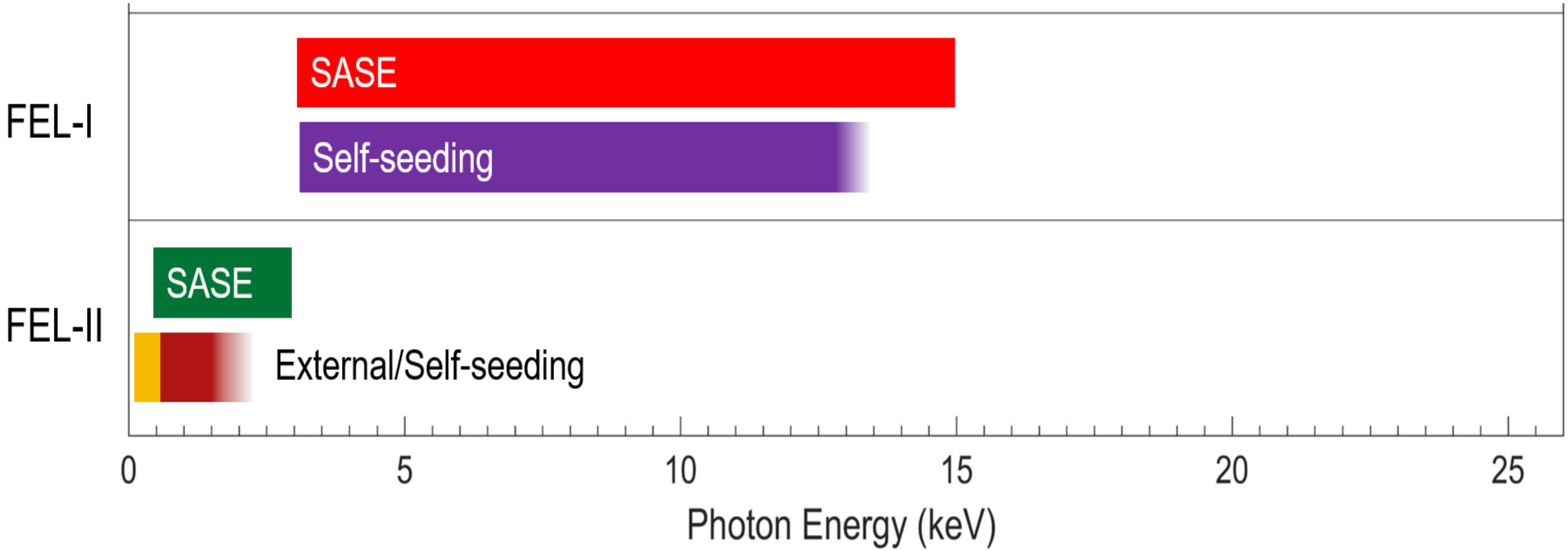


➢ XFEL Facility +50 PW Laser Facility

	Nominal	Range
Beam energy/GeV	8.0	4-8.6
Bunch charge/pC	50/100	10-300
Max rep-rate/MHz	1	up to 1
Photon energy/keV	0.2-15	0.2-15
Pulse length/fs	20-50	5-200
Peak brightness	5×10^{32}	1×10^{31}-1×10^{33}
Average brightness	5×10^{25}	1×10^{23}-1×10^{26}
2K Cryogenic power/kW	12	12
RF Power/MW	2.28	3.6

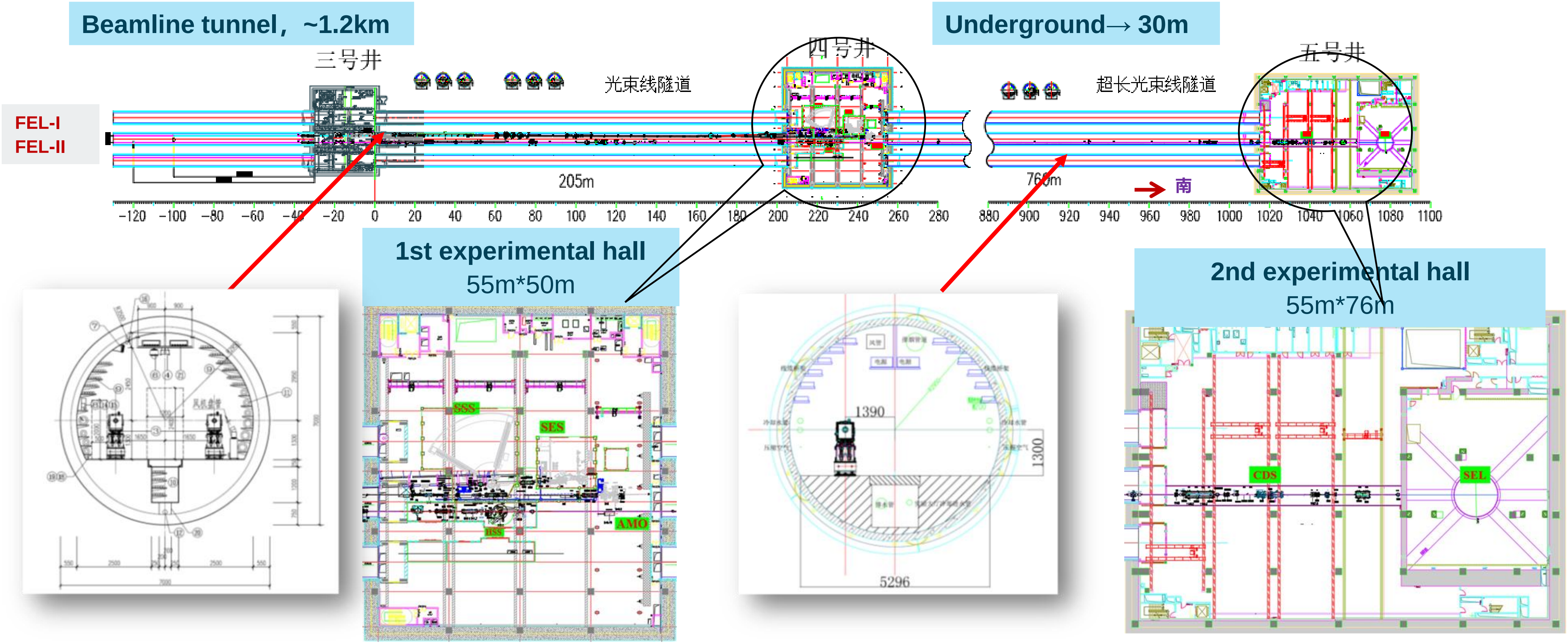
FEL Line	Nominal	Objective
FEL-I		
Photon energy/keV	3-15	3-15
Photon number per pulse @12.4keV	$>10^{10}$	$>10^{11}$
Max pulse repetition rate/MHz	0.66	1
FEL-II		
Photon energy/keV	0.2-3.0	0.2-3.0
Photon number per pulse @1.24keV	$>10^{12}$	$>10^{13}$
Max pulse repetition rate/MHz	0.66	1

Photon Energy Coverage of SHINE



Beamlines and Endstations

SHINE will build 2 beamlines, 6 endstations and experimental supporting systems.

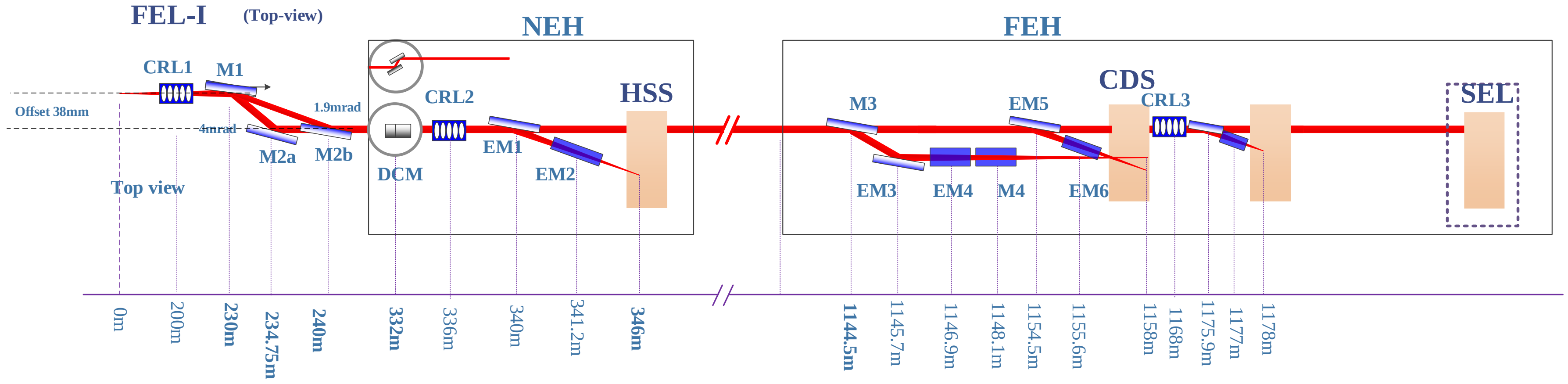


Overall Layout of Beamlines and Endstations

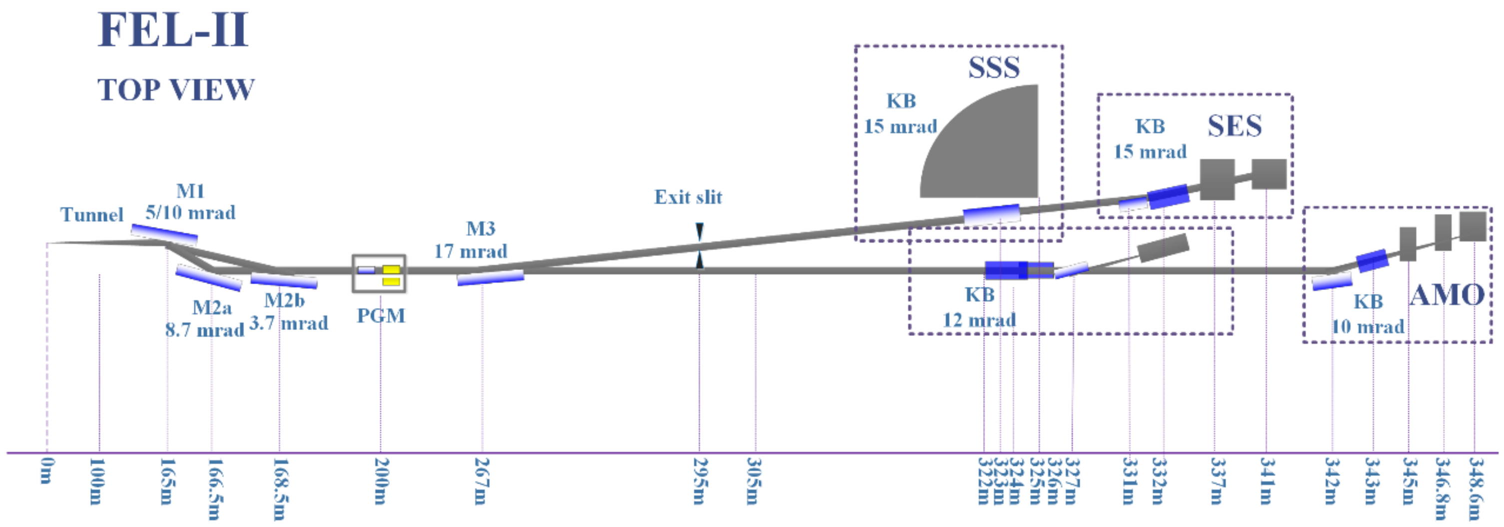
SHINE

FEL-I/II Beamlines

FEL-I:
3~15keV; up to 100nm focus



FEL-II: 0.2~3keV; up to 6μm focus



6 End-Stations @ SHINE Facility in Phase-I

- **FEL-I (3 - 15keV) Hard X-ray End-stations**
  - **HSS: Hard X-ray Scattering and Spectroscopy**
  - **CDS: Coherent Diffraction Endstation for Single Molecules and Particles**
  - **SEL: Station of Extreme Light (XFEL+ 50 PW Laser System)**

- **FEL-II (0.2 - 3keV) Soft X-ray End-stations**
  - **AMO: Atomic, Molecular, and Optical Science**
  - **SES: Spectrometer for Electronic Structure**
  - **SSS: Soft X-ray Scattering and Spectroscopy**

SHINE

BE@SHINE organization

AC Division

BE Division @ SHINE

EL Division

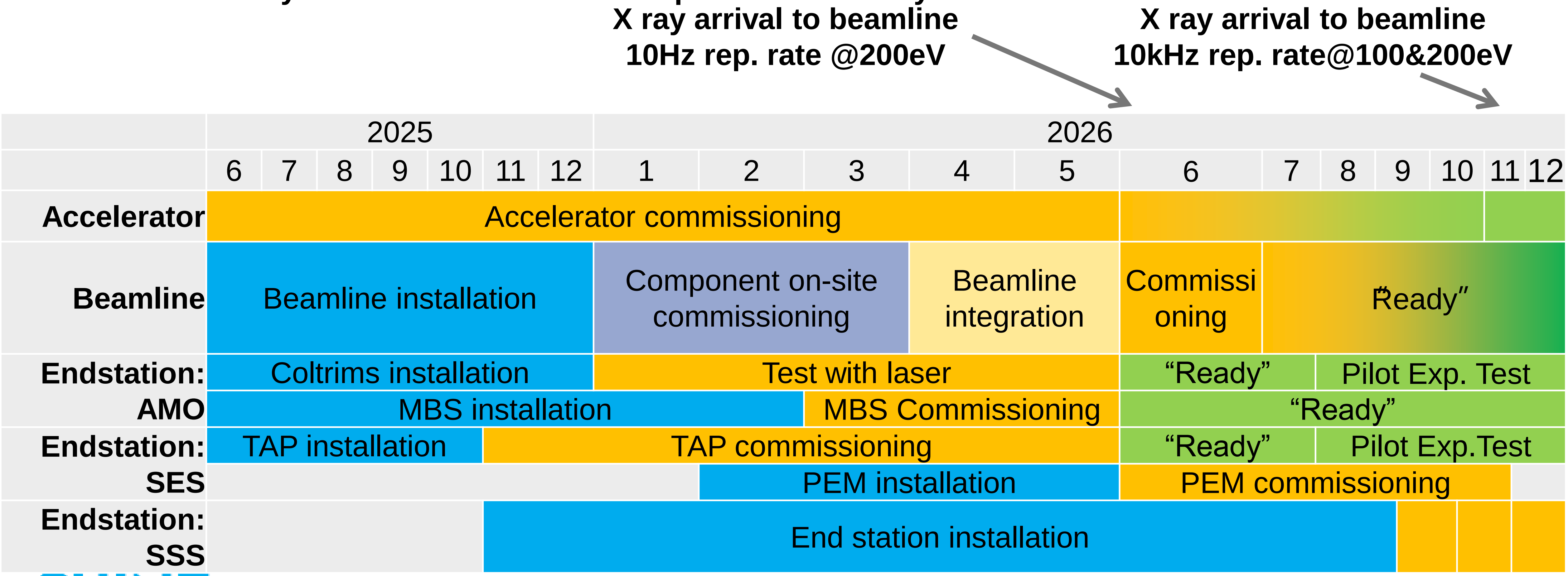
Beamline Engineering Department	Beamline Technical Department	FEL-I Department	FEL-II Department	Experiment Supporting Department
Utility Installation Control Mechanics…	Design Diagnostics Metrology	HSS CDS	SES AMO SSS	Data Laser Software Detector

SHINE

ShanghaiTech + SARI about 120 FTE

Commissioning Schedule

X ray laser ready for beamline is in 26/06→26/08 with 10Hz rep. rate at 200eV. Beamline commissioning scheduled for 1month, two endstations are ready for pilot experiments. 10kHz rep. rate beam ready in 26/11→27/01. 100kHz rep rate beam ready in 27/04→27/06



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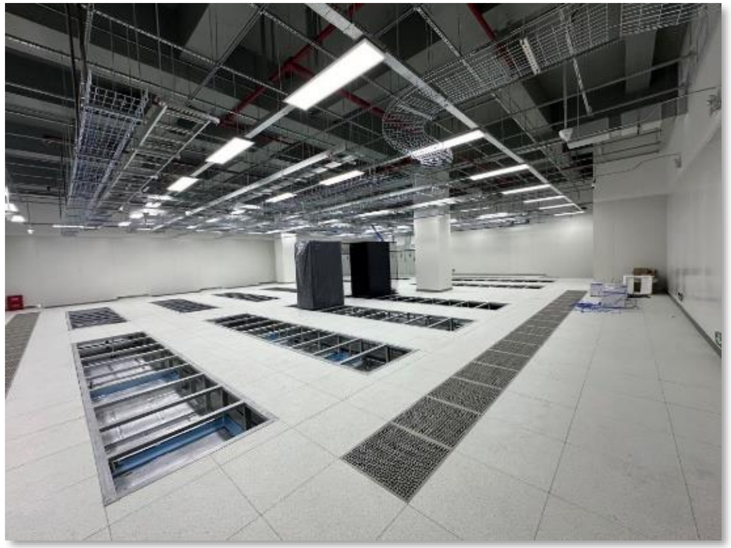
		Jun-25	Aug-25	Oct-25	Nov-25	Dec-25	Feb-26	Apr-26	May-26	Aug-26	Oct-26	Nov-26	Jan-27	Mar-27	Nov-27
FEL-II beamline										tuning with XFEL					
AMO	Coltrims	Delay line detector/ Helmholtz coils in stock	Coltrims spectrometer in stock	Gas jet and chambers in stock			Coltrims finish installation	Test of setup with NIR laser			Coltrims online				
AMO	MBS (magnetic bottle spectrometer)								MBS chambers in stock				MBS finish installation/online in 2027		
SES	TAP (Time-resolved ARPES)	TAP start install			TAP finish installation							TAP online			SES Final Acceptance Test
SES	PEM (Photonemission electron Microscope)	PEM TDR report review			Pumping laser - start installation				PEM start installation					PEM finish installation	
SSS	RIXS (Resonant inelastic X-ray scattering)			Detector& supporting installation		optical chamber installation	signal arm installation	Standard element target installation		Sample chamber installation	Front periheral device installation	expected to be ready for commissioning			

Infrastructure and Capability

SHINE

Utility Constructions

- The construction of utilities and hutches at Shaft #4 and inside Tunnel 34 are completed.
- The construction of the main computer server room and the front-end DAQ computer server room at Shaft #4 is completed
- The beamline control network of FEL-II is completed .



Constant temperature shed completed

The front-end DAQ computer server room

The establishment of the beamline control network

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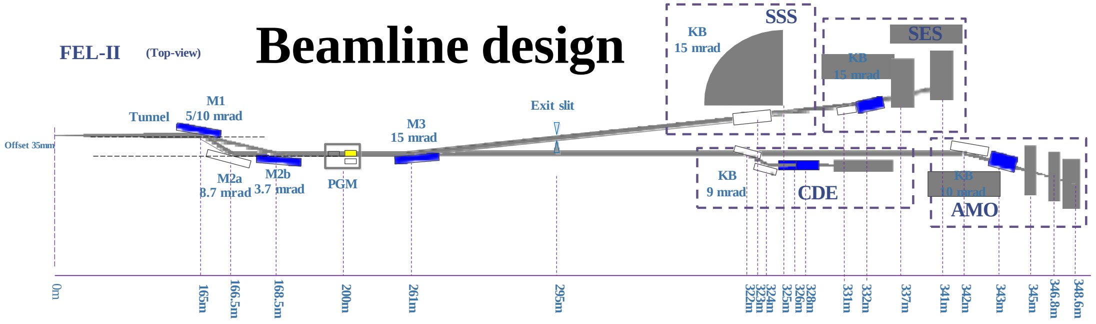
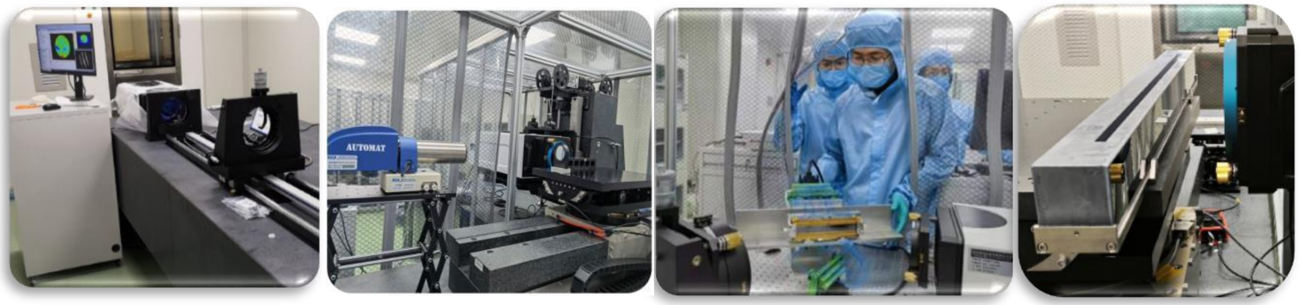
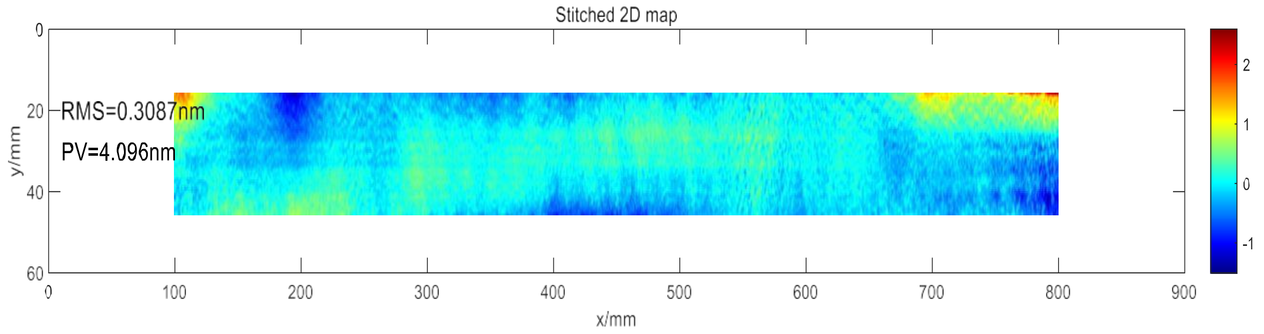
Capabilities: Design, Diagnostics & Metrology



- Finished three beamlines design **(TDR)**
- **FEL-II** beamline in implementation
- **Thirteen** types of diagnostic instruments
- PAM, XGMD, Imager, BPIM, BLM are in manufacture, other instruments will start soon



- ~30m² ISO-6 clean room metrology lab
- Fizeau stitching interferometry with 532nm,ϕ150mm interferometer for 1000mm long mirrors



- Sub-nanometer measuring repeatability was achieved
- FEL-II M1 inspection results: 0.27nm(rms); 35nrad (rms)

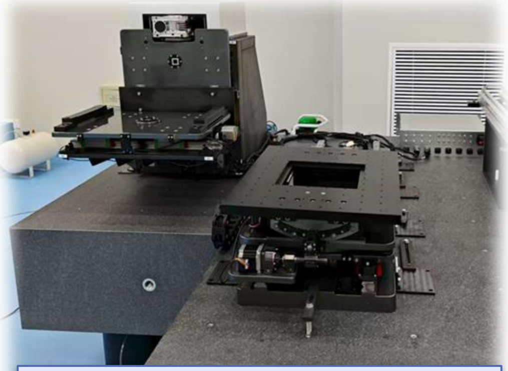
PAM

XGMD

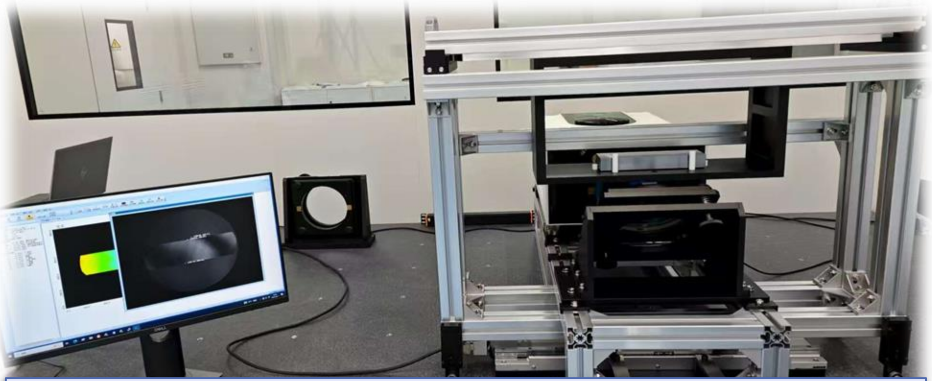
Metrology lab: measurement capability 0.5nm RMS

1m mirror facing up and side, 0.3 m mirror facing down

Facing up



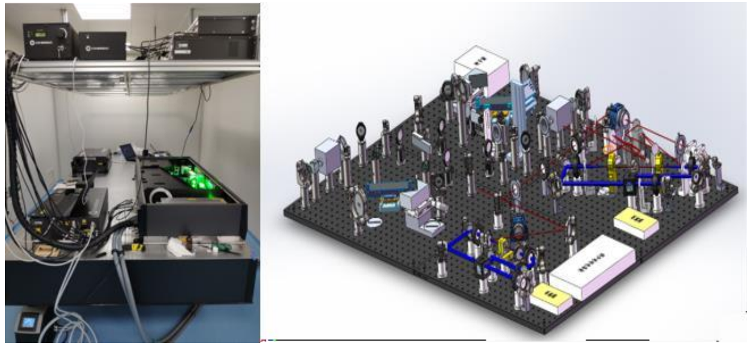
Facing side



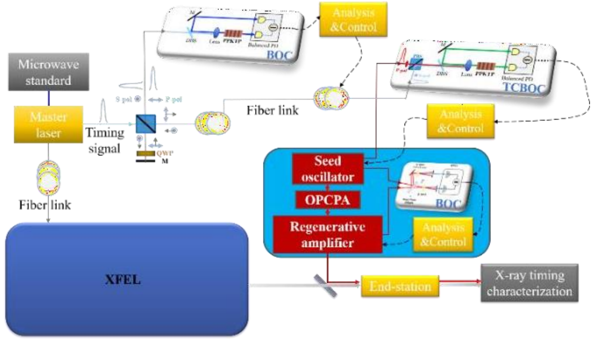
Facing down

Capabilities: Experimental Supports

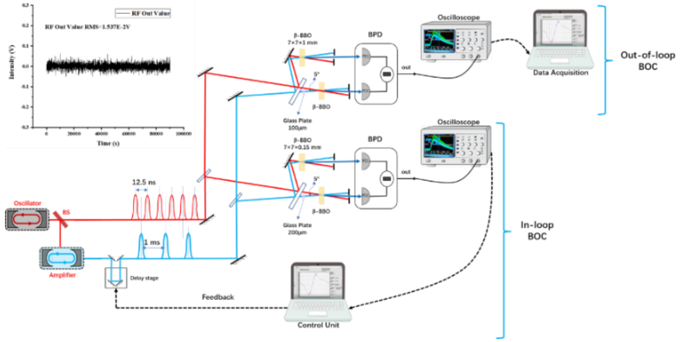
➢ Pump-probe laser system - Technical design completed



Pump-probe lasers



Synchronization between XFEL and PP laser



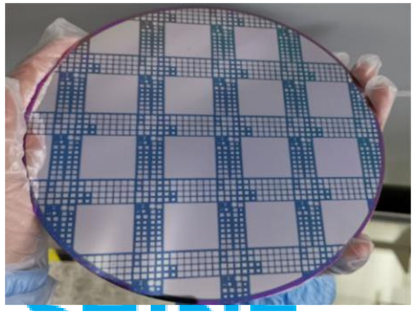
Compensation of timing drift between oscillator and amplifier based on BOC

➢ X-ray detector

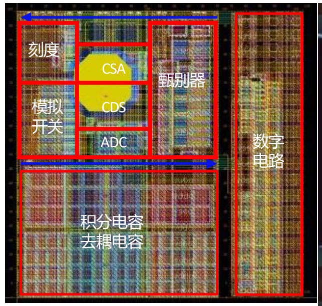
- Key technology path established
- Full system expected in 4 years

➢ DAQ & Software & Data Center

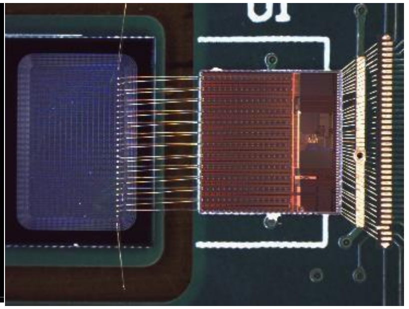
- FEL-II DAQ Technical design completed
- Data Center ready to start construction



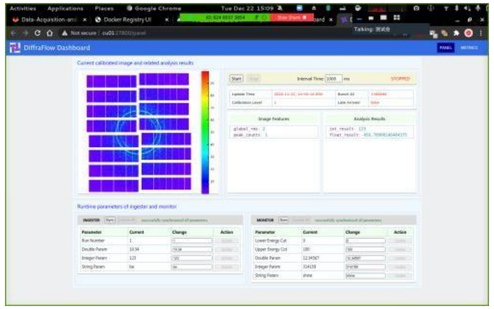
Sensor



Readout chip



Light detection



DAQ software of area detectors

Data Center Layout

Pump-Probe Laser System

- **Ultrafast optical laser required for pump-probe experiments**
- **Parameters of pump-probe lasers**

  ----fundamental lasers: 800 nm/35 fs/7 mJ @1kHz; 1030 nm/100W/20~50 fs @100 kHz

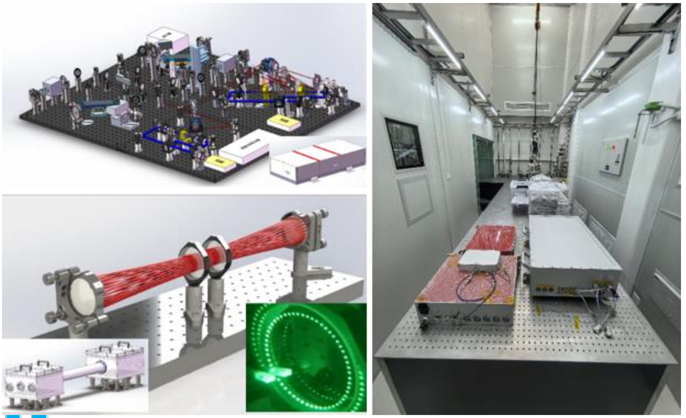
  ----frequency conversion units: UV to IR by OPA; Harmonic Generator (SHG/THG)

- **Laser transportation and synchronization between XFEL and PP laser**

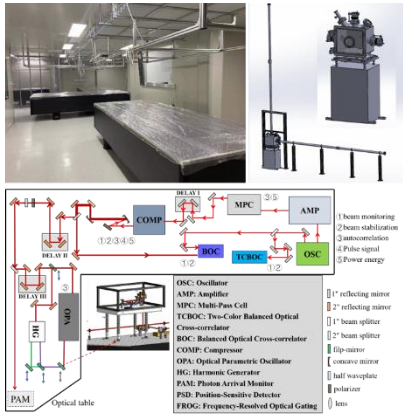
  ----laser clean room and technical design of transportation has been done

  ----timing synchronization scheme between XFEL and PP laser has been determined

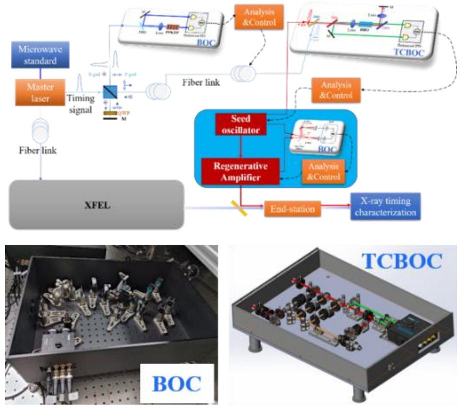
  ---- Most of time synchronization devices were developed in-house



Self-developed high-repetition-rate pump laser



Laser transportation



Time sync. scheme and self-developed devices

SHINE

Advanced X-Ray Detectors

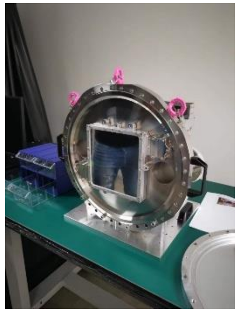
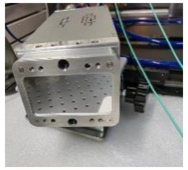
❑High frame rate, high dynamic range and large area semiconductor pixel detector

Baseline: JUNGFRAU detector

- 4M system for CDI, SFX, etc.
- 0.5M system for spectroscopy

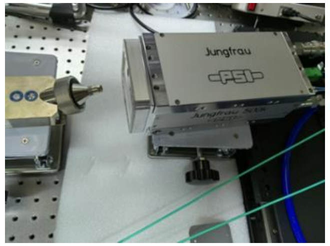
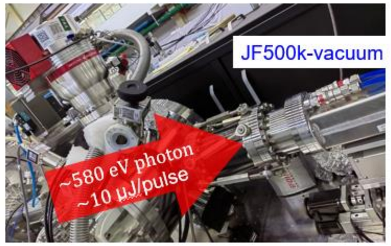
Detector being tested at SHINE in lab and beam

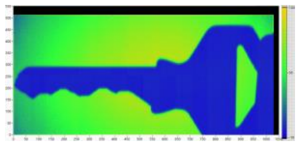
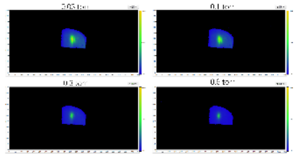
Pixel size	75 μm
Pixel number	0.5 M / 4 M
Frame rate	2 kHz
Energy range	3 – 15 keV
Dynamic range	1 – 10^4 ph./pixel/pulse @ 12keV


JUNGFRAUs in Shanghai

Lab and in-beam test

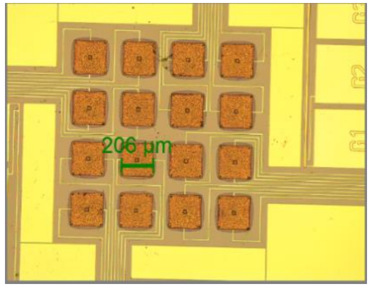



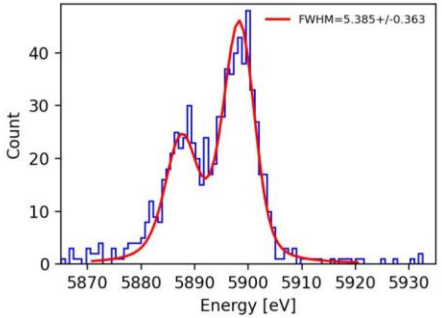
❑High energy resolution TES X-ray detector

Multi-channel sensor chips successfully manufactured

Measured energy resolution < 7eV@6keV



TES sensor



SHINE

Capabilities: Data Management

☐ Data Center

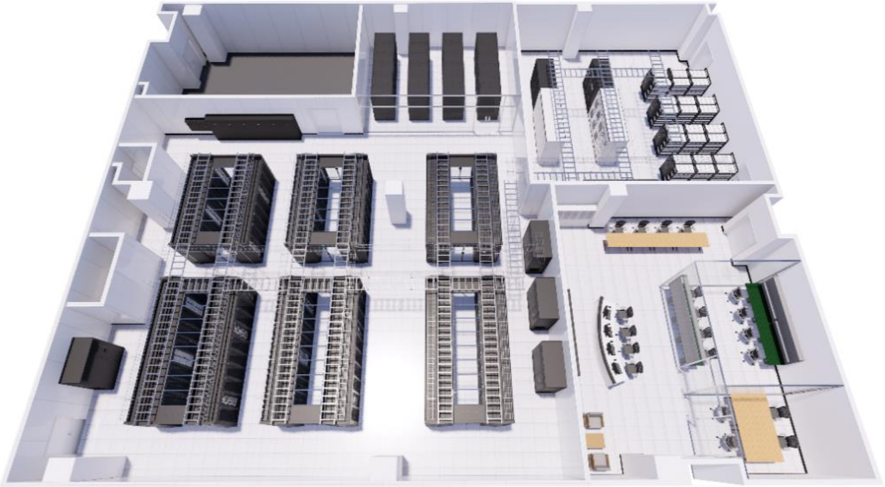
- DAQ & Main Server Rooms in Shaft 4 & 5

☐ IT Infrastructure of Phase I (II)

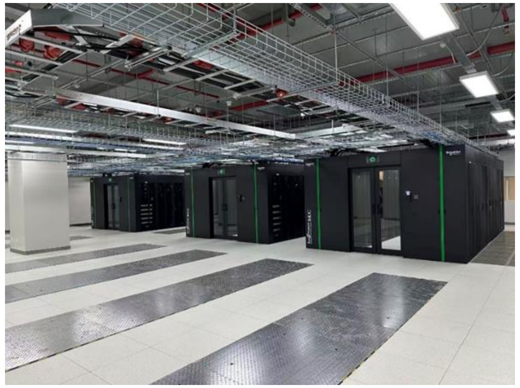
- Fast SSD storage 2PB (10PB), Massive storage 8PB (100PB)
- Capacity over 50 (1000) CPU/GPU nodes

☐ Life cycle data management system

- XFEL metadata standard & acquisition scheme
- Integrated scientific data service

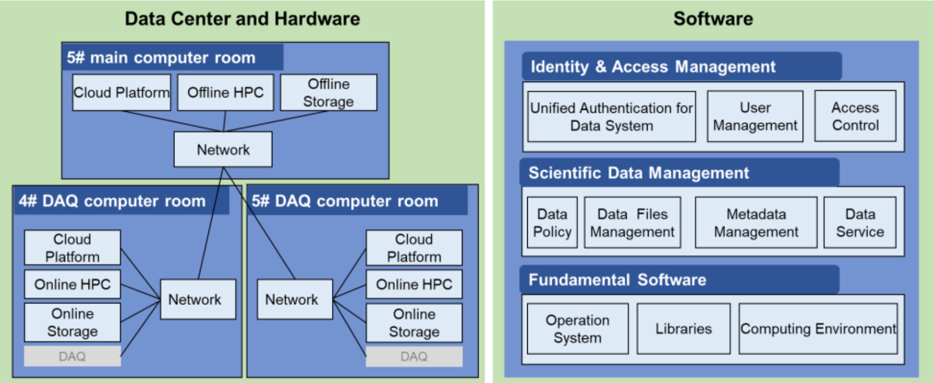


Main Server Room Layout in Shaft 5



Main server room

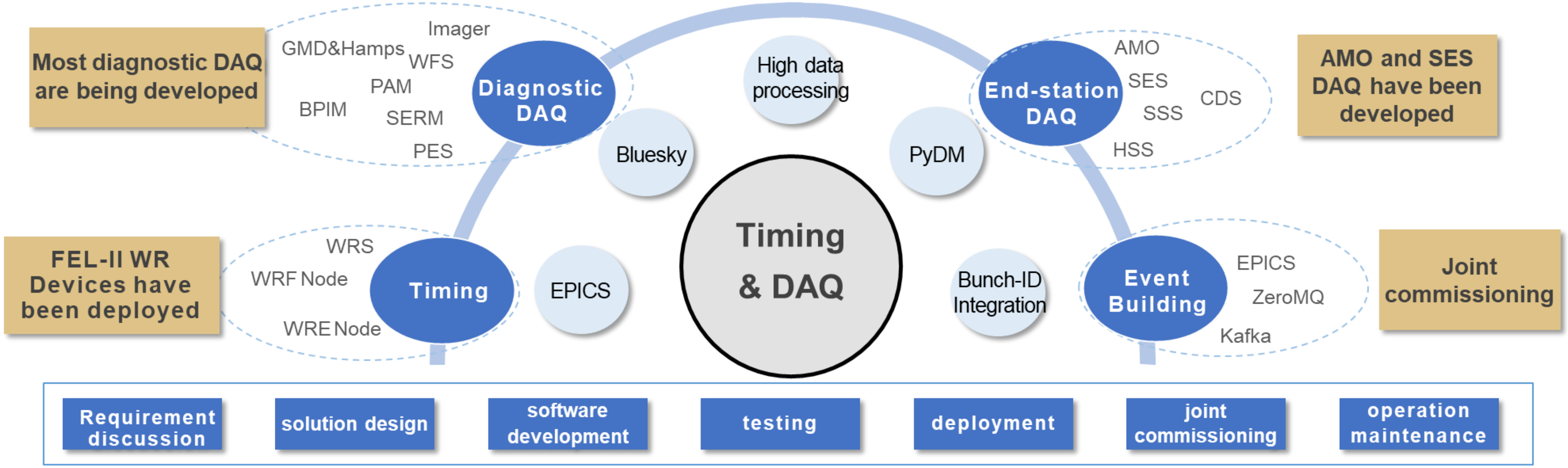
High-throughput data prototype

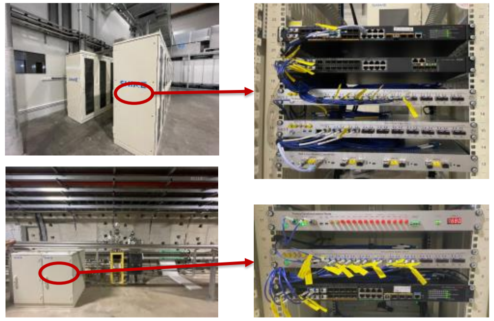


Hardware and software services

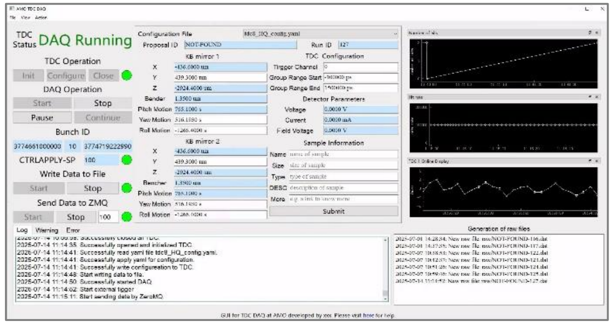
Timing and DAQ

- FEL-II timing hardware has been deployed across tunnel beamline and end-stations
- Two End-stations DAQ Software has been developed

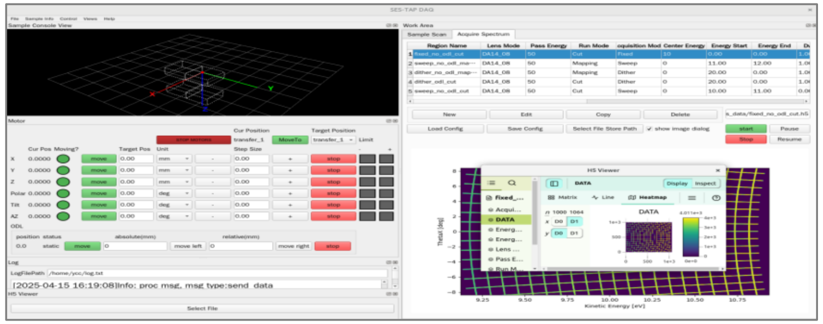




FEL-II timing deployment



AMO DAQ

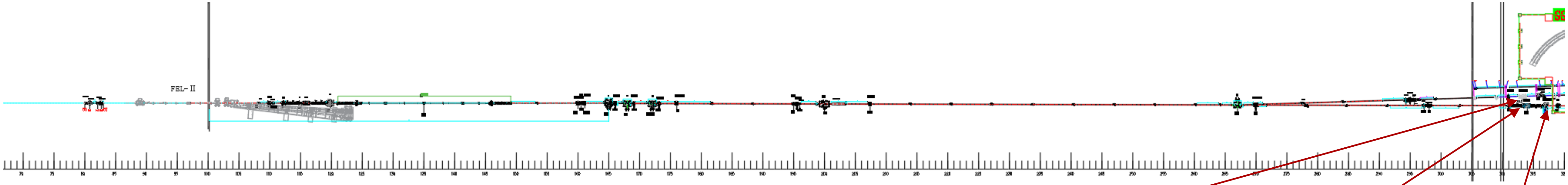


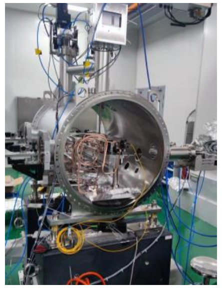
SES DAQ

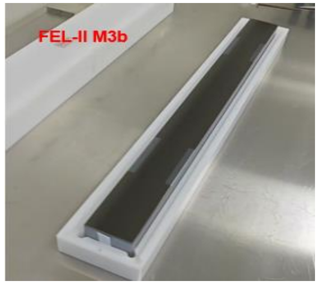
Progress (FEL-II)

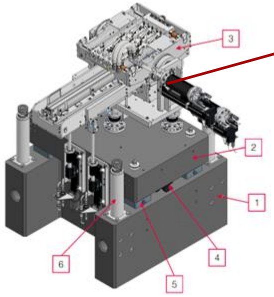
Progress of FEL-II Beamline

- The installation of FEL-II beamlines began in the middle of this June.
- The FEL-II beamline will be ready for receiving FEL radiation in March 2026.

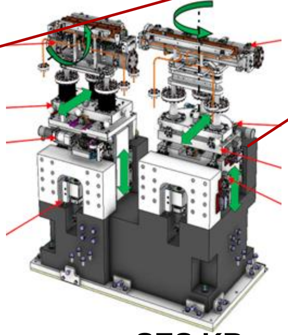




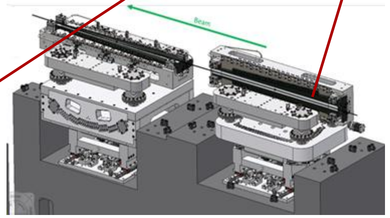




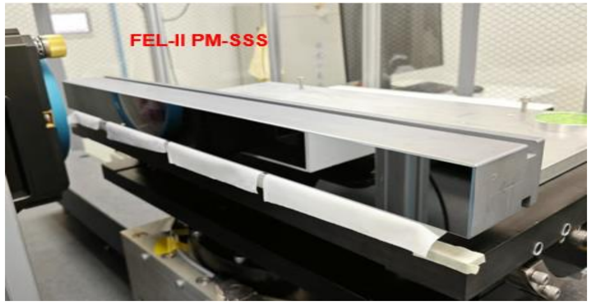
SSS-KB



SES KB



AMO-KB

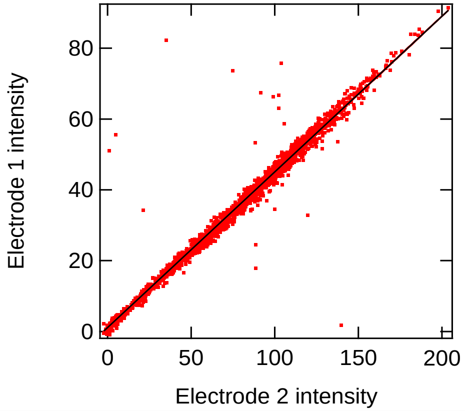


SHINE

FEL-II Beamline Key Components

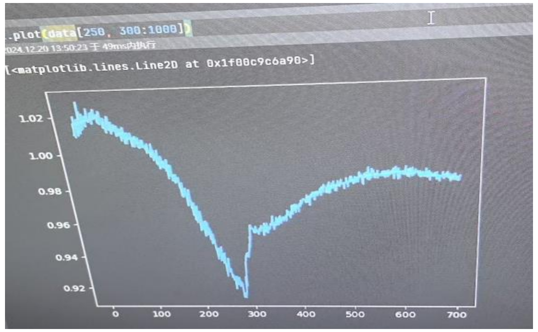
FEL-II Pulse Energy and Position Diagnostic Equipment

➢ Position Measurement Accuracy of 3.8%.



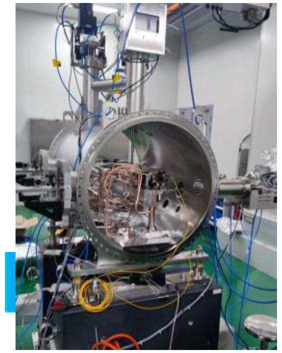
FEL-II Pulse Arrival Time Diagnostic Equipment

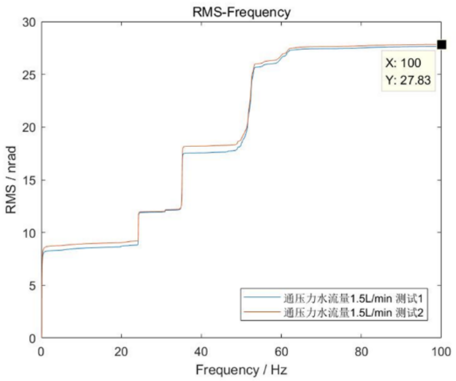
➢ Time measurement accuracy of ~20fs obtained in the online test at SXFEL-SBP.



FEL-II M1 Deflector Box Passes Technical Acceptance

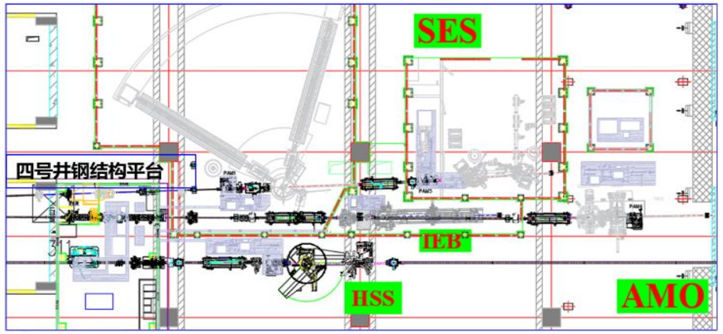
➢ The self-developed FEL-II M1 deflector box reflector mirror angle stability is better than 28nrad/10min（0.1-100Hz).





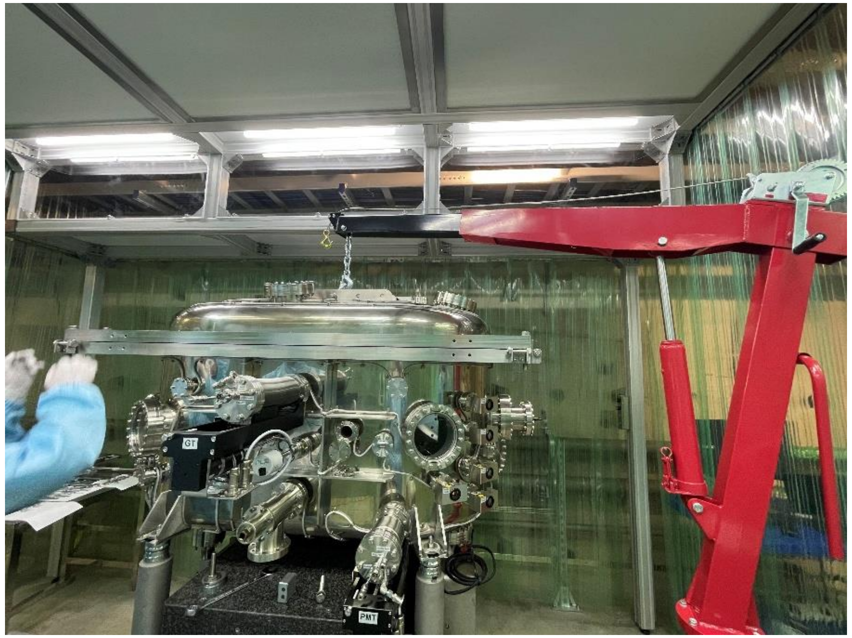
FEL-II Laser to Experimental Station Vacuum Transfer Chamber and Pipelines

➢ Determine the layout of the experimental station laser platform, laser transmission path, and freeze the design of the transmission chamber, etc.

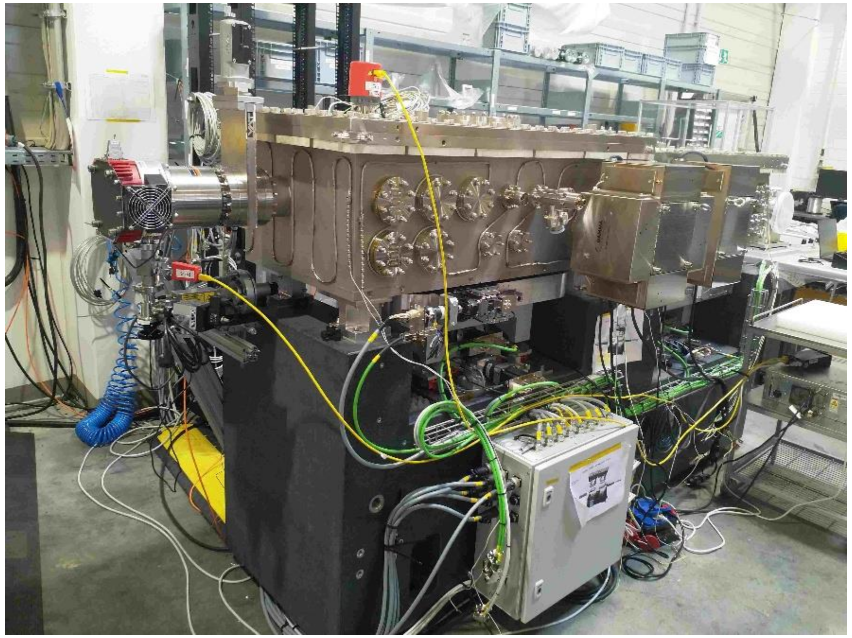


FEL-II Monochromator and KB-pairs

Monochromator installed on site



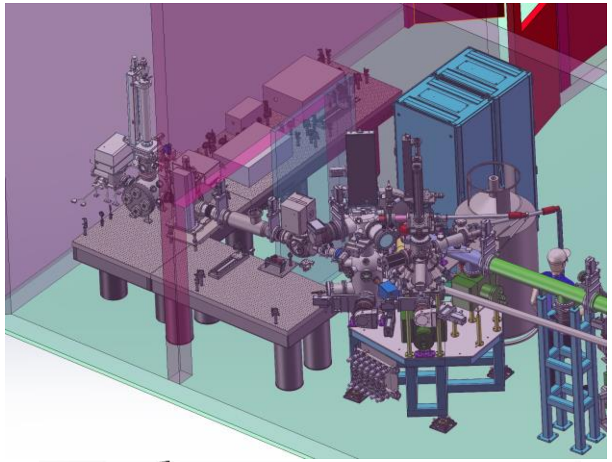
AMO-KB FAT finished

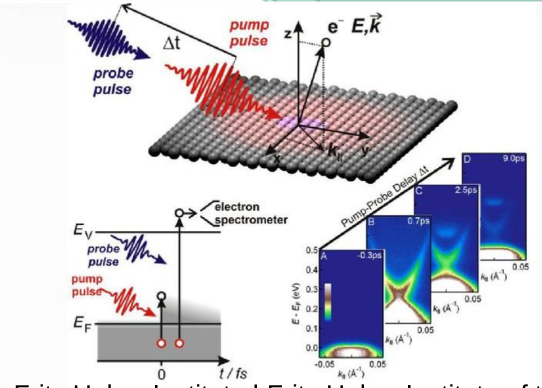


SSS-KB FAT finished

SES Endstation: Spectrometer for Electronic Structure

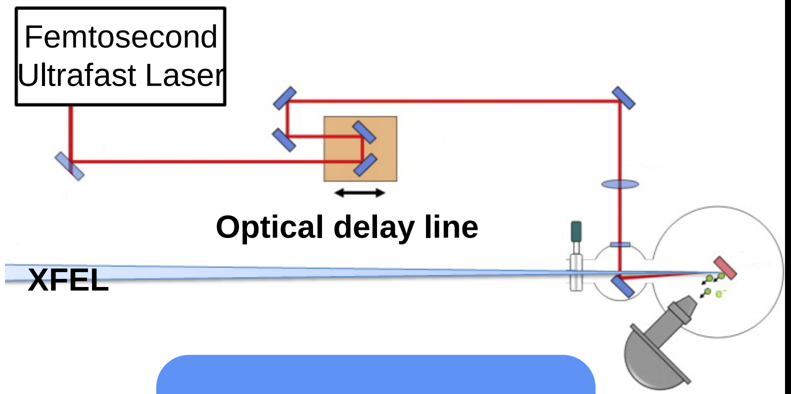
Ultrafast electronic dynamics subsystem (TAP)



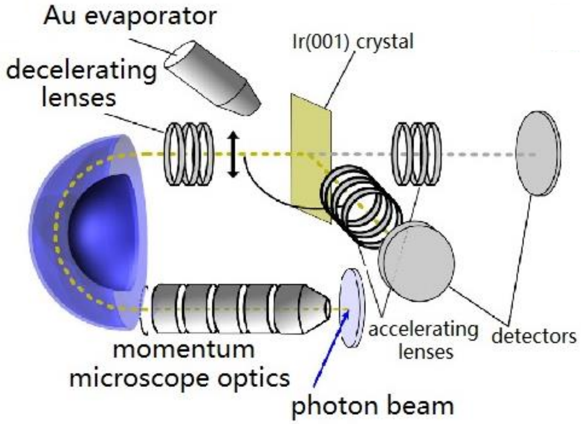


[Fritz Haber Institute | Fritz Haber Institute of the Max Planck Society (mpg.de)]

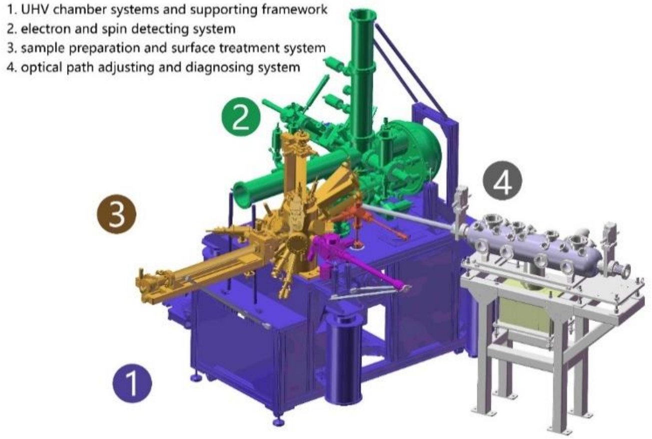
Femtosecond Ultrafast Laser + High repetition XFEL

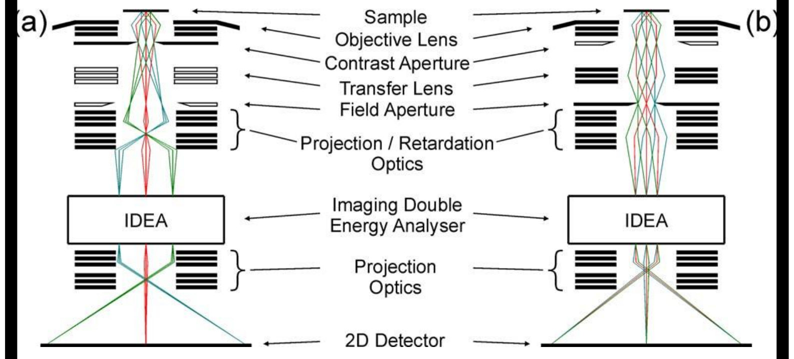


High efficiency 2D Spin detector

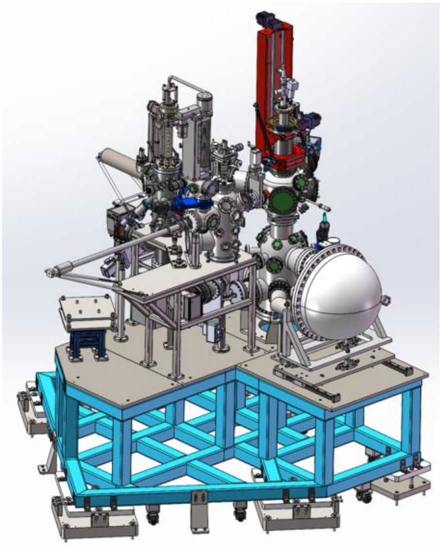


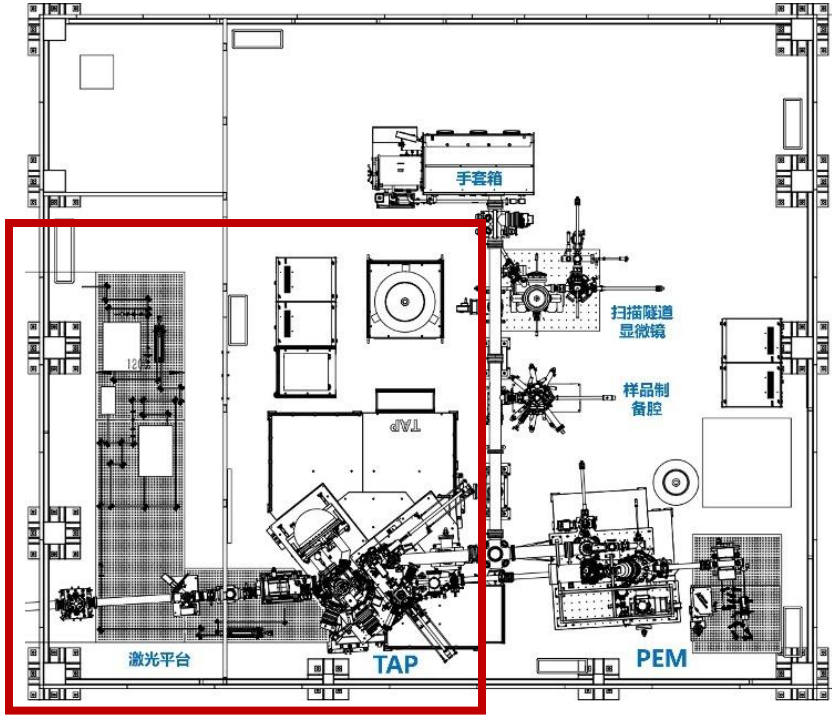
dual mode photoelectron microscopy subsystem (PEM)





Current Status of the SES-TAP subsystem





- ✓ Most of the components of TAP have been installed
- ✓ Laser system has started its installation

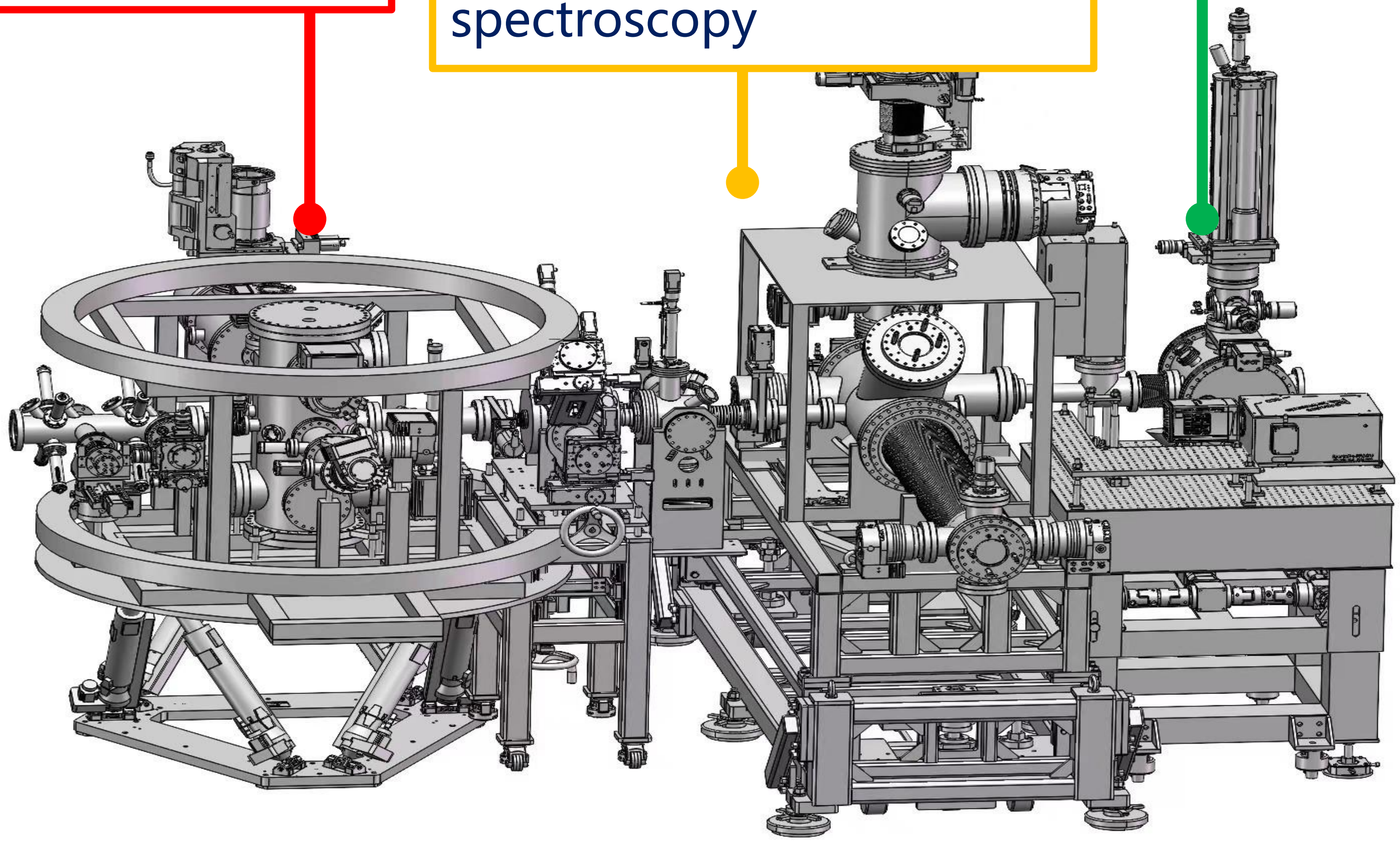
2025.Q4	2026.Q1	2026.Q2	2026.Q3
✓ TAP finish installation ✓ Pumping laser finish	✓ TAP control/motion/data acquisition test		■ Ready for initial test with XFEL

AMO Endstation: Atomic, Molecular, and Optical Science

COLTRIMS:
Coincident electron and ion measurements

eMBS/iTOF:
High-resolution electron spectra/ion TOF spectroscopy

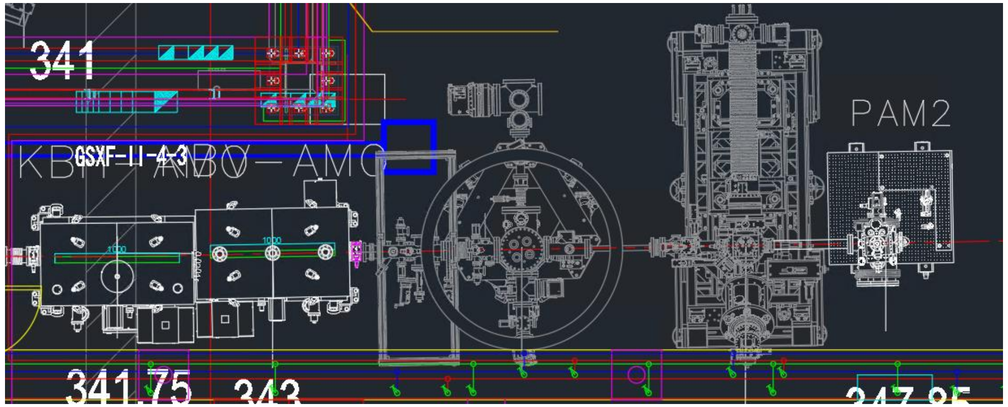
TM diagnostic of pulse/PIPO

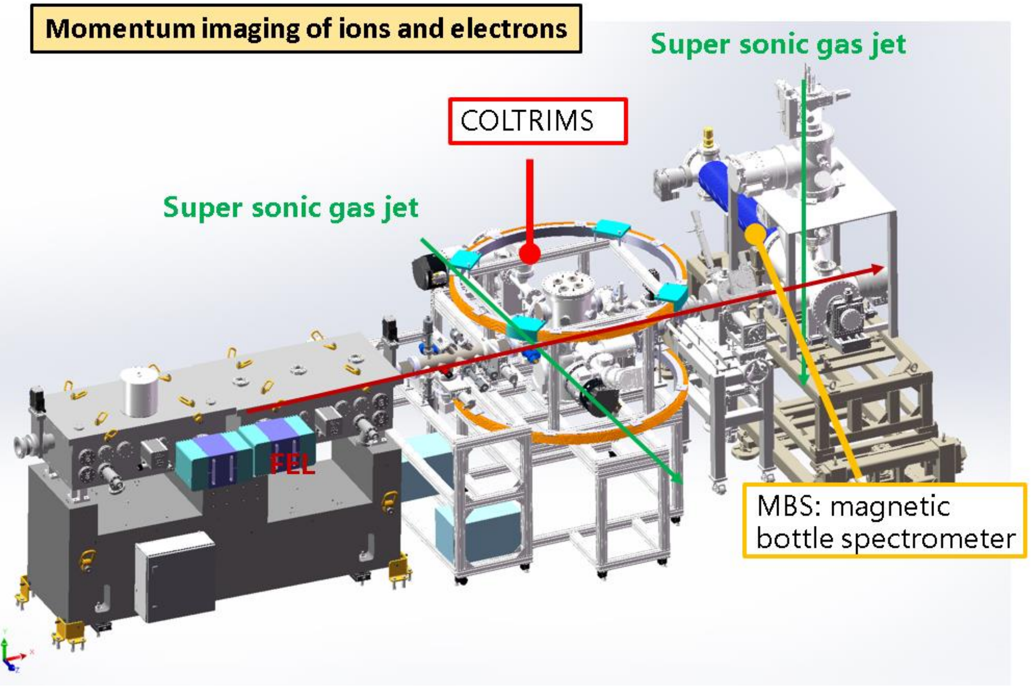


Three foci are separated by 180 cm

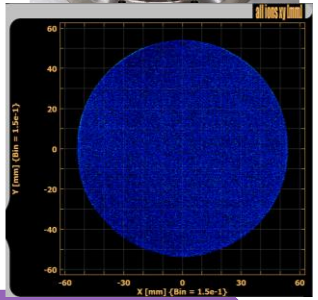
SHINE

Current Status of AMO Endstation





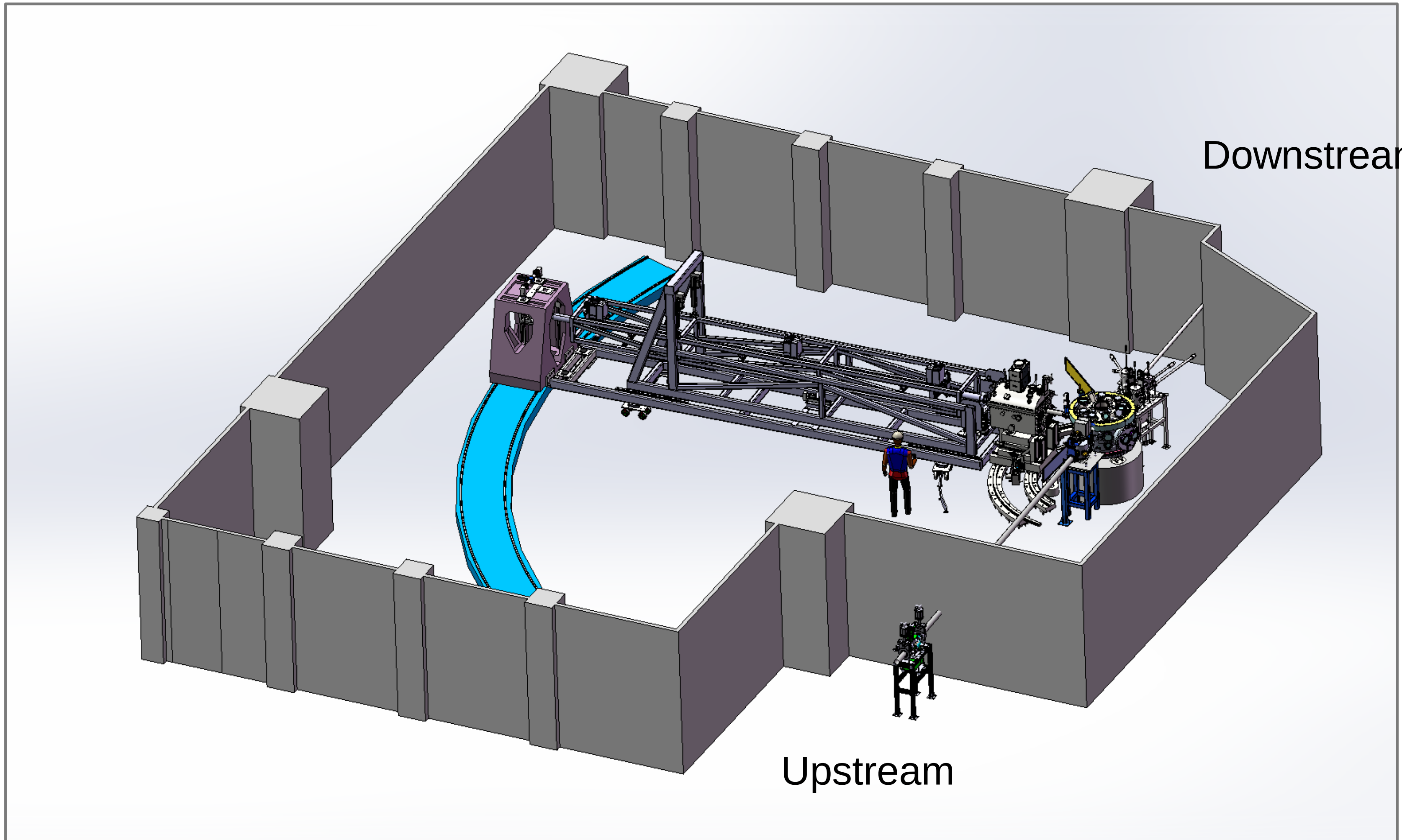
	COLTRIMS	MBS
Detectors	delay-line detectors assembled	Timed pixel camera in stock
Spectrometer	assembled	Finish design
Supersonic gas jet	Expected this month	Finish design
Laser in-coupling system	Expected this month	Finish design
Vacuum pumps & gauges	in stock	in stock



2026.Q1	2026.Q2	2026.Q3	2026.Q4
✓ COLTRIMS finish installation	✓ COLTRIMS test with NIR laser	✓ Ready for initial test with XFEL	

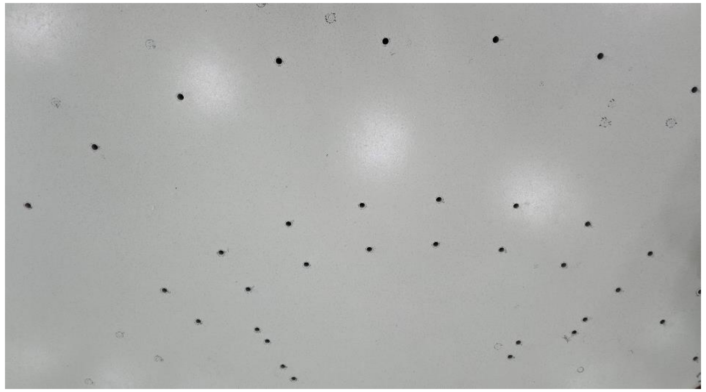
SSS Endstation: Layout

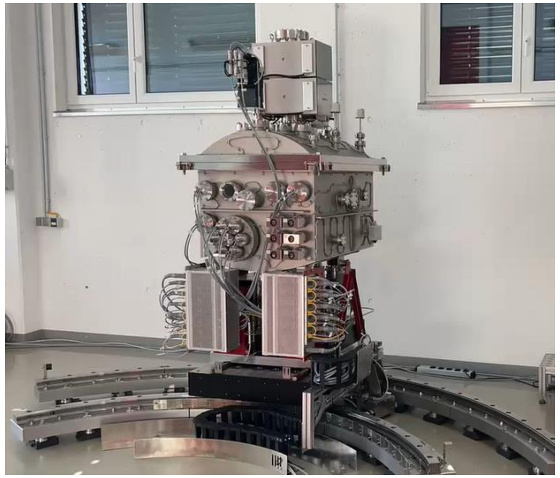
- Hettrick-Underwood scheme for energy dispersed spectroscopy measurements;
- Sample-to-detector distance 11.5m;
- Two-theta ranges from 75~145 degrees for momentum resolved studies;



SHINE

Current Status of SSS Endstation





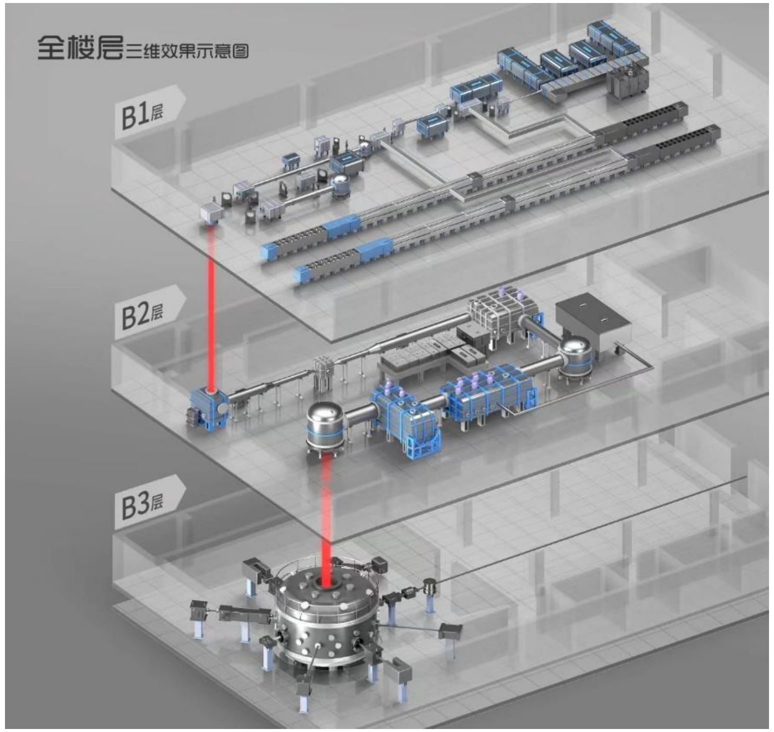
- Optics (mirrors, gratings) are in manufacturing.
- Major mechanical instruments are in manufacturing.

- High precision temperature controlled hutch is ready.
- First major instrument – optical chamber is shipped out.
- Installation holes for optical chamber rail have been drilled.
- Installation tool kits for the detector supporting system have arrived.

2025 Q4	2026 Q1~2	2026 Q3~4	2027 Q1~2	2027 Q3
• Optical chamber • Detector supporting	• Spectrometer arm	• Sample Chamber	• Peripheral components	• Commissioning

SEL Endstation: Station of Extreme Light

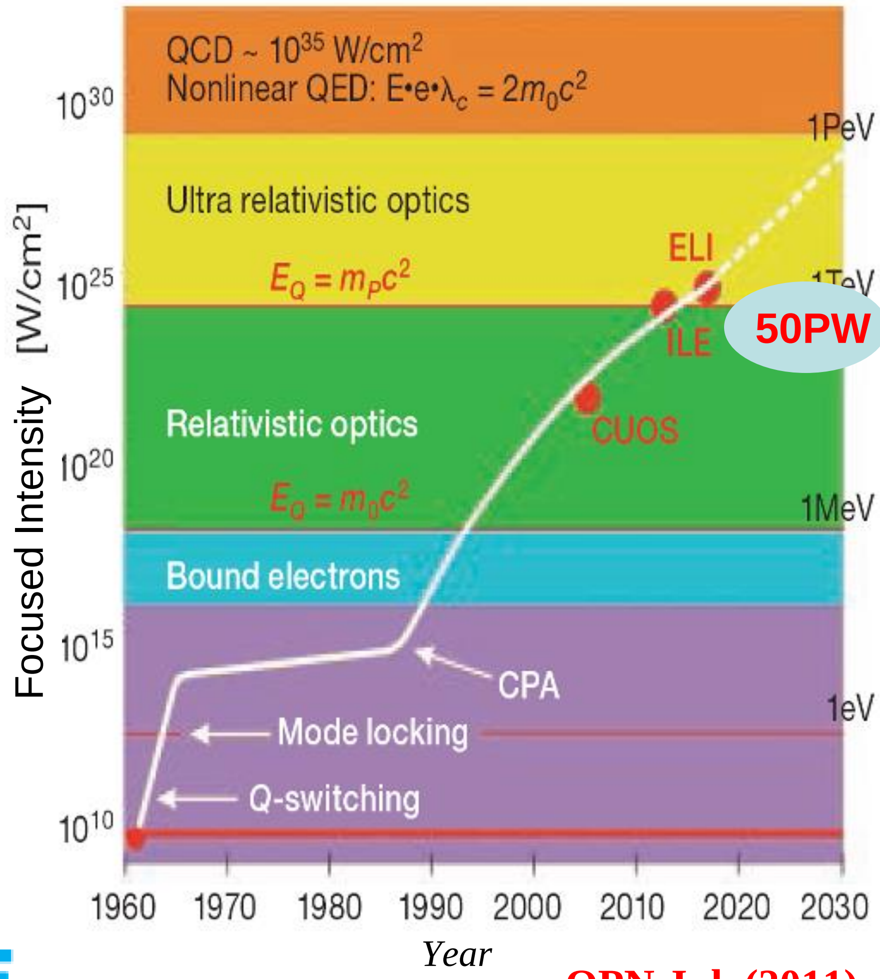
This station is based on the world first 100PW super-intense ultra-fast laser facility， combined with XFEL to carry out pump-probe research. This provides an irreplaceable means for exploring vacuum QED effects and the state of matter under extreme conditions. The SEL is also downward compatible, providing high repetition rate femtosecond laser pulses of 0.1~1PW and nanosecond pulse outputs of 1-10kJ, comprehensively covering the high energy density science research fields involved in the three major international XFEL facilities (LCLS, SACLA, and EU XFEL).



The parameters of SEL	
Focused intensity	**1×10^{23} W/cm^2**
Peak power	**50-100 PW**
Pulse duration	**15fs**
Pulse energy	**1~10kJ**
Pulse Width	**3~10ns**

SEL Endstation: 50PW + Hard XFEL

With focused intensity 10^{23}W/cm^2 + hard XFEL, vacuum QED effect can be verified experimentally in laboratory for the first time.



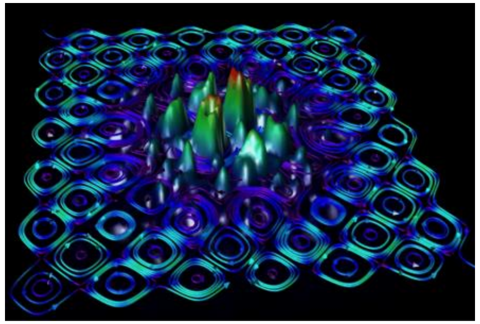
OPN July(2011)

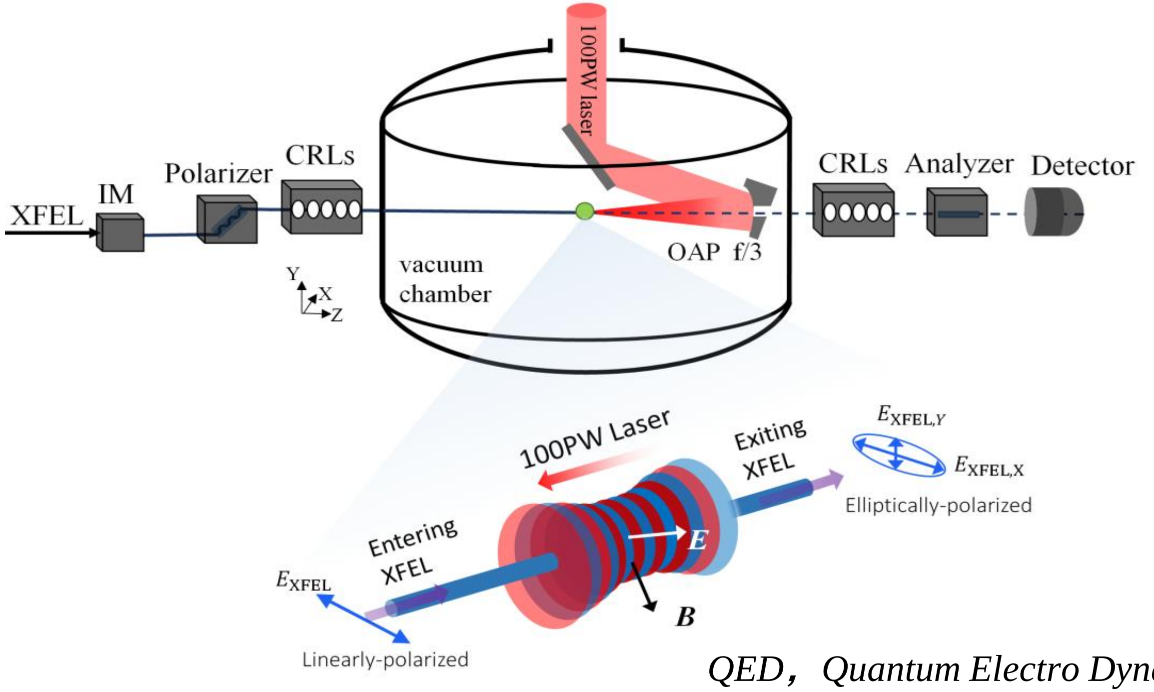
50PW

QED

10^{23} W/cm^2

New era





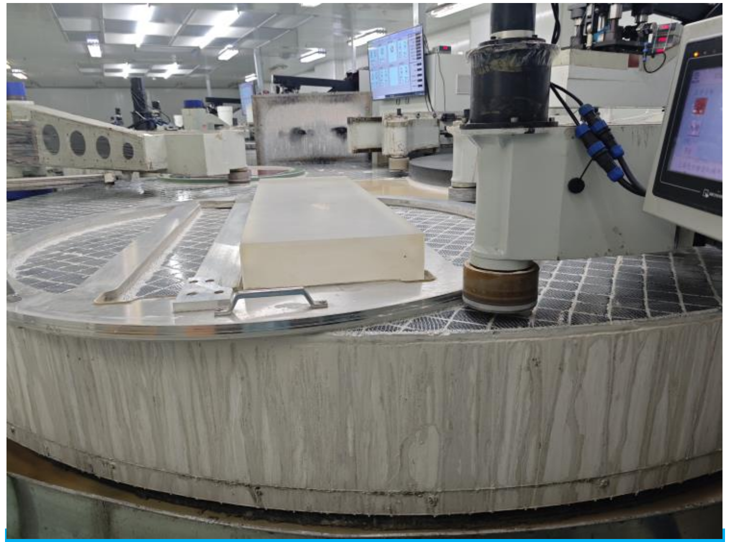
QED, Quantum Electro Dynamics

SHINE

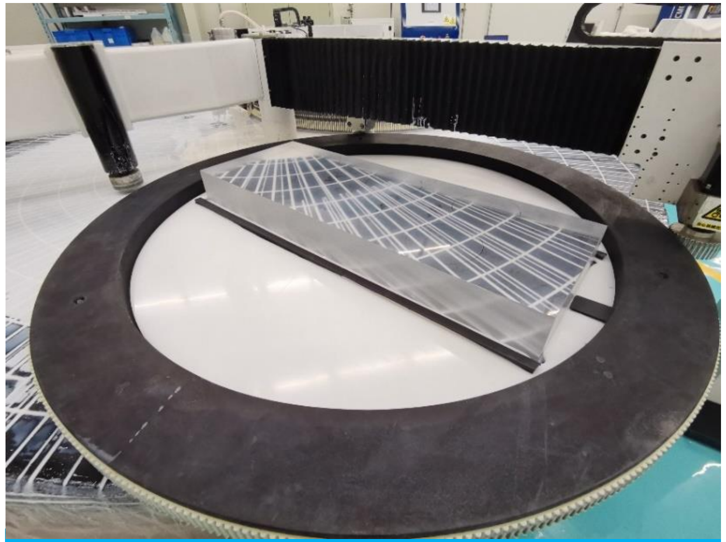
Progress of Station of Extreme Light (SEL)

➢ **The technical R&D for the 50PW Super-intense Ultrafast Laser system has been completed, including large-sized optical components and equipment**

- Terminal beam expander and grating compressor vacuum chamber,
- Optical components of terminal beam expansion system,
- Large-aperture optical components and adaptive optics system.



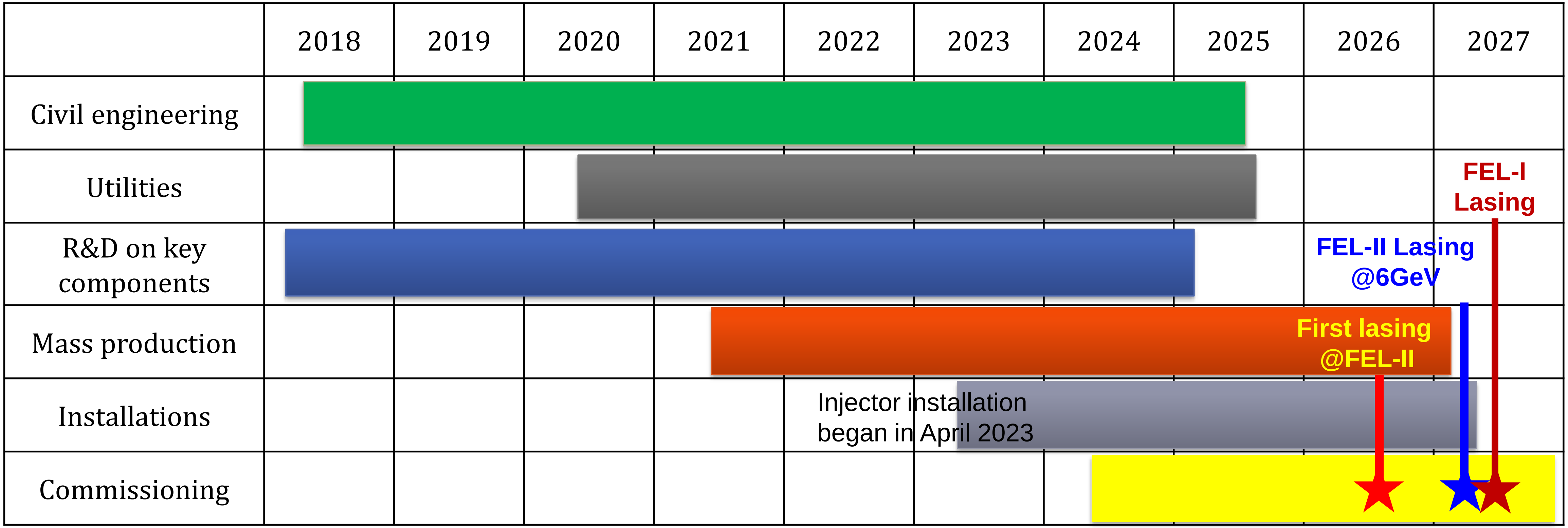
Large grating substrate ring polishing process



Large flat mirror ring polishing process

ultra-thin Deformable mirror surface processing

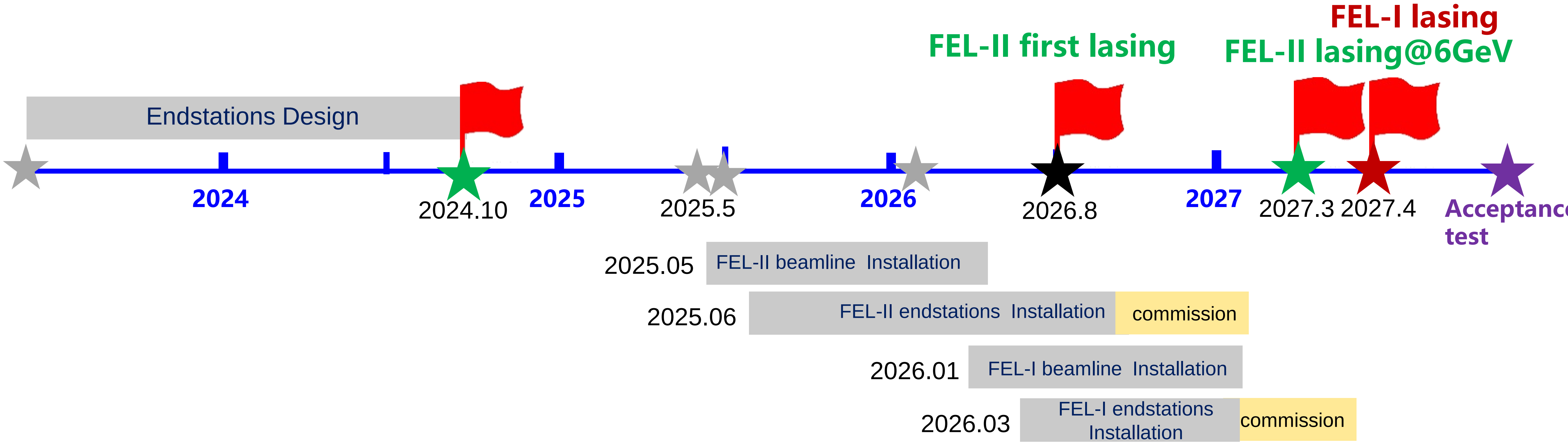
Construction Timeline



First lasing is expected in the August 2026.

SHINE

Beamline and Endstations Schedule



- **Aug. 2026:** FEL-II first lasering, complete FEL-II beamline Installation
- **Mar. 2027:** complete FEL-I beamline Installation
- **Jul. 2027 :** The FEL-II beamline, endstations, ready for the acceptance tests.
- **Nov. 2027:** The FEL-I beamline, endstations, ready for the acceptance tests.

Summary

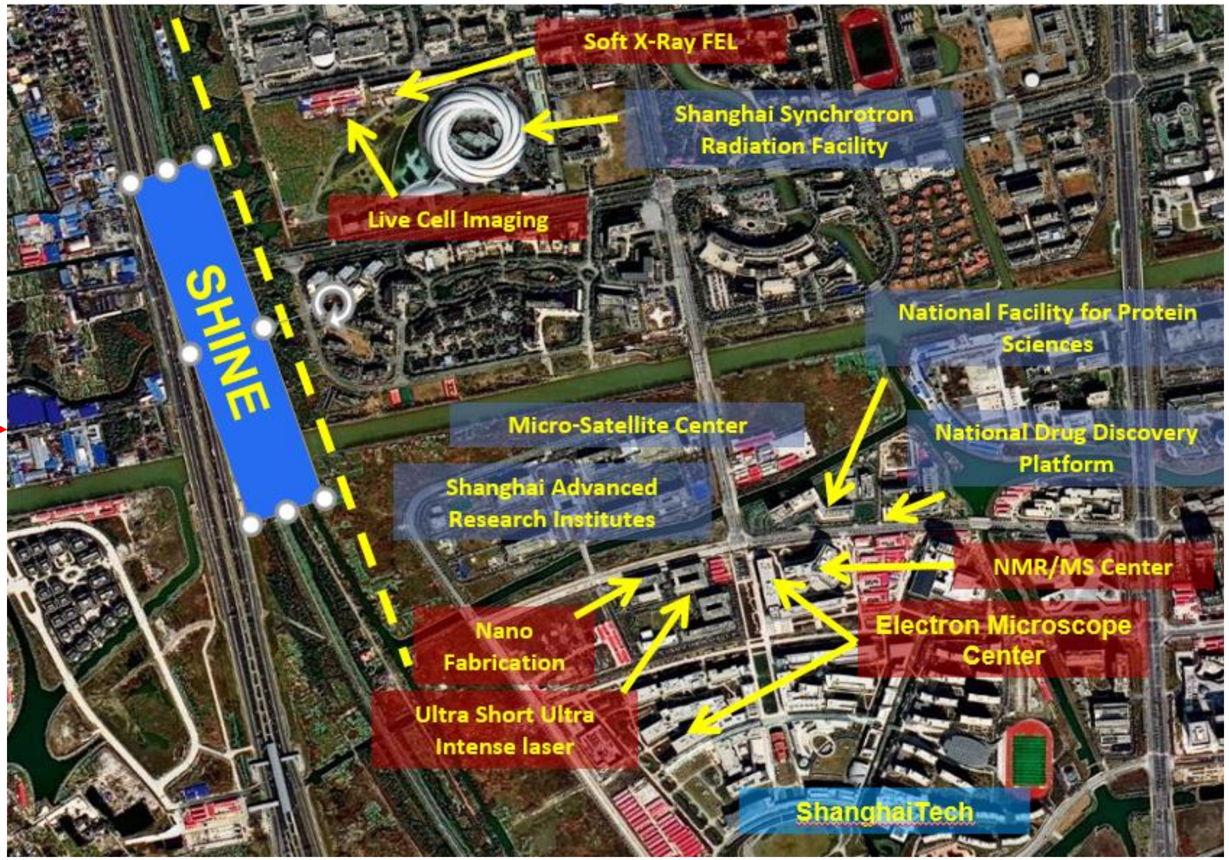
- The construction of the SHINE project is in good progress, but it is still facing challenges, particularly in its tight schedule;
- The civil engineering and utility constructions are completed to meet timely the facility construction requirements;
- Majority of the FEL II installation will be completed by the end of 2025.
- Majority of the FEL I installation will be completed by the end of 2026.
- Great efforts are being made to realize the first lasing of FEL-II in the first half of 2026, towards completing the SHINE project at the end of 2027.

SHINE

Thank you for your attention!

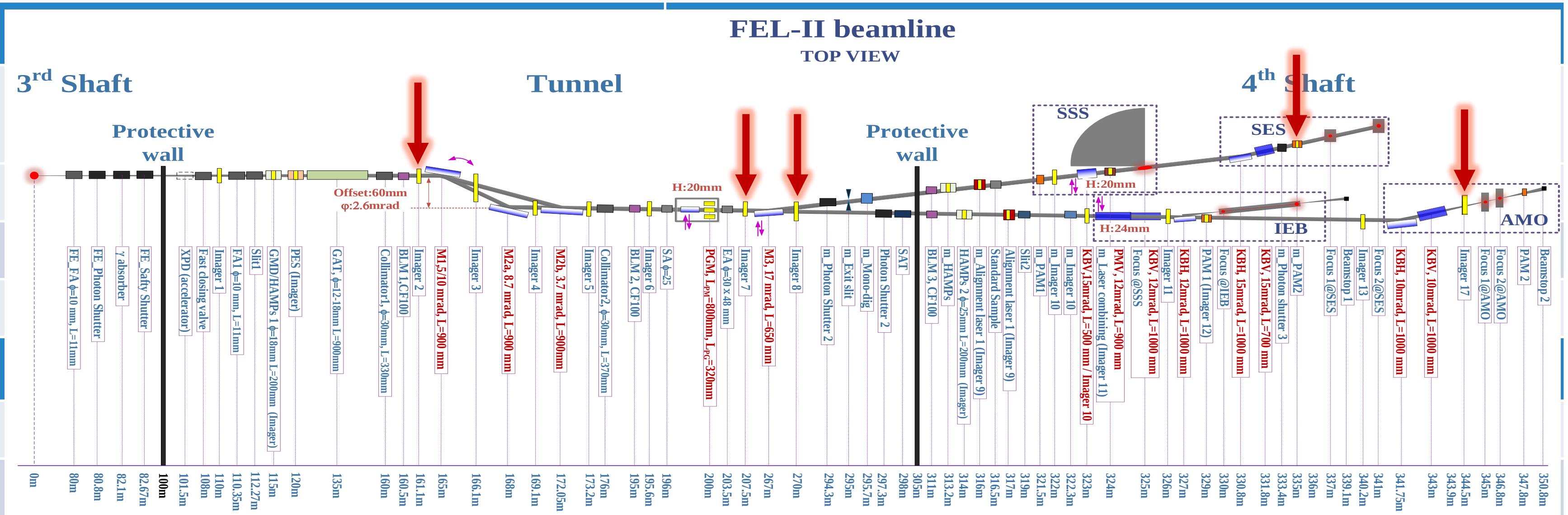
Chinese F4

Large Research Infrastructures Cluster
Zhangjiang Photon Science Facilities



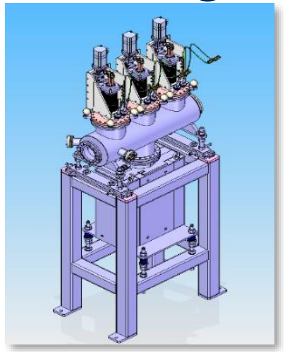
Commissioning plan(16day+30day+20day)

Beamline			
Front-end	≥2 ×24 h	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 ×24 h	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 ×24 h	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 ×24 h	The pink beam reaches SES-KB	Spot can be observed at SES
AMO-KB	≥4 ×24 h	Commissioning of AMO-KB	An acceptable spot size for AMO
SES-KB	≥4 ×24 h	Commissioning of SES-KB	An acceptable spot size for SES
Diagnostic Equipment			
Imager	≥30 ×24 h		
GMD / HAMPs			
PES			
BLM			
Endstation			
AMO	12 ×24 h		
SES	8 ×24 h		



Progress of FEL-I Beamline

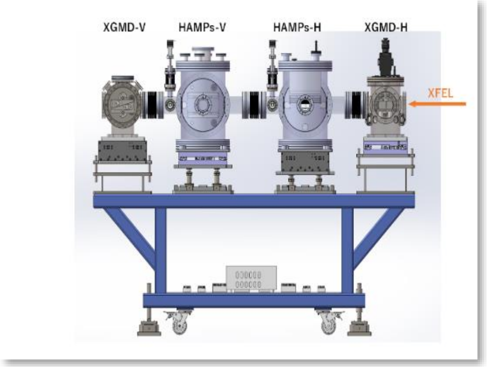
- The installation of FEL-I beamlines will begin in Jan. 2026.
- The FEL-I beamline will be ready for receiving FEL radiation in March 2027.
- The FEL-I beam line equipment, diagnostic equipment, etc. are basically delivered in the design or processing.



SAT

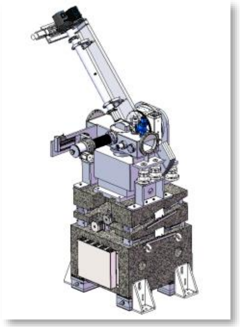
CRL

Imager

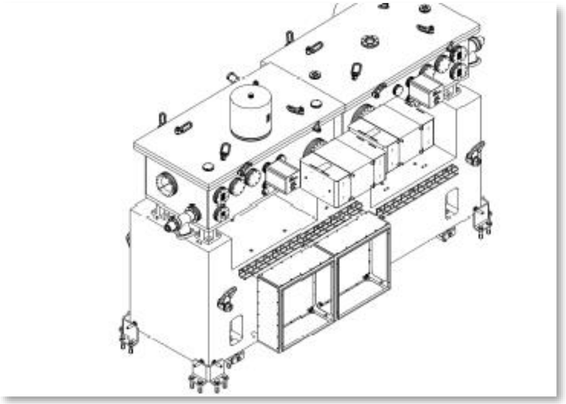


Hamps

PAM



Monopulse spectrometer



HSS KB

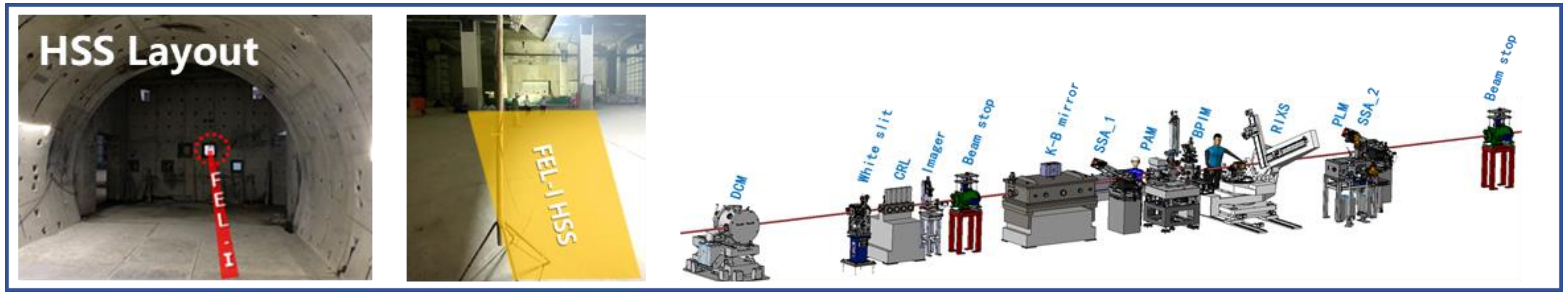
BLM

FEL-I Wavefront Sensor

SHINE

HSS Endstation: Hard X-ray Scattering & Spectroscopy

Probing the **elementary excitations** & **electronic dynamic processes**

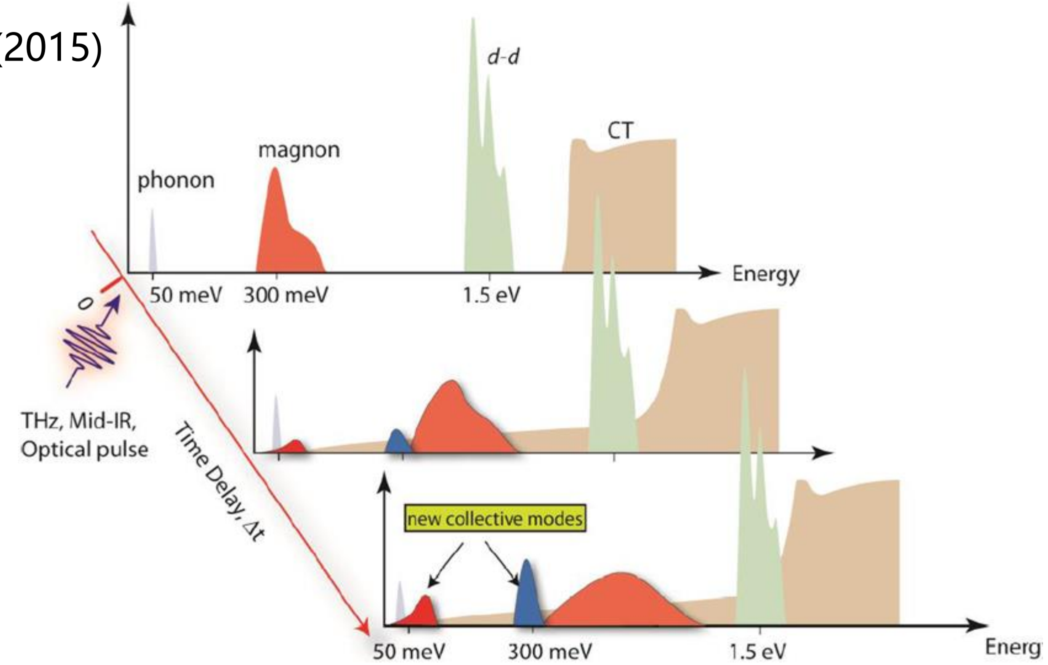


Photon energy:	3-15 keV
Spot size:	10 μm × 6 μm
Energy resolution:	~0.28eV@7112eV
Time resolution:	~100 fs

Revolution by XFEL

New science opportunities enabled by LCLS-II X-ray lasers. No. SLAC-R-1053 (2015)

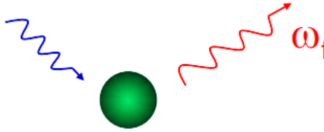
Degree of freedom	Elementary excitation	Energy range
Lattice	phonon	0-200 meV
Spin	magnon, spinon	0-500 meV
Orbital	crystal field	1-5 eV
Charge	charge transfer	0-100 eV



HSS Endstation: Layout & Program

Methodology：**tr-RIXS**, tr-RXES, v2c XES, XES, HERFD-XAS

ω_i, k_i



ω_f, k_f

$q=k_i-k_f$

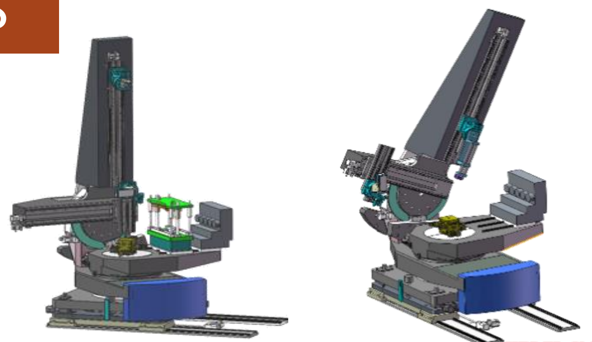
$\omega=\omega_i-\omega_f$

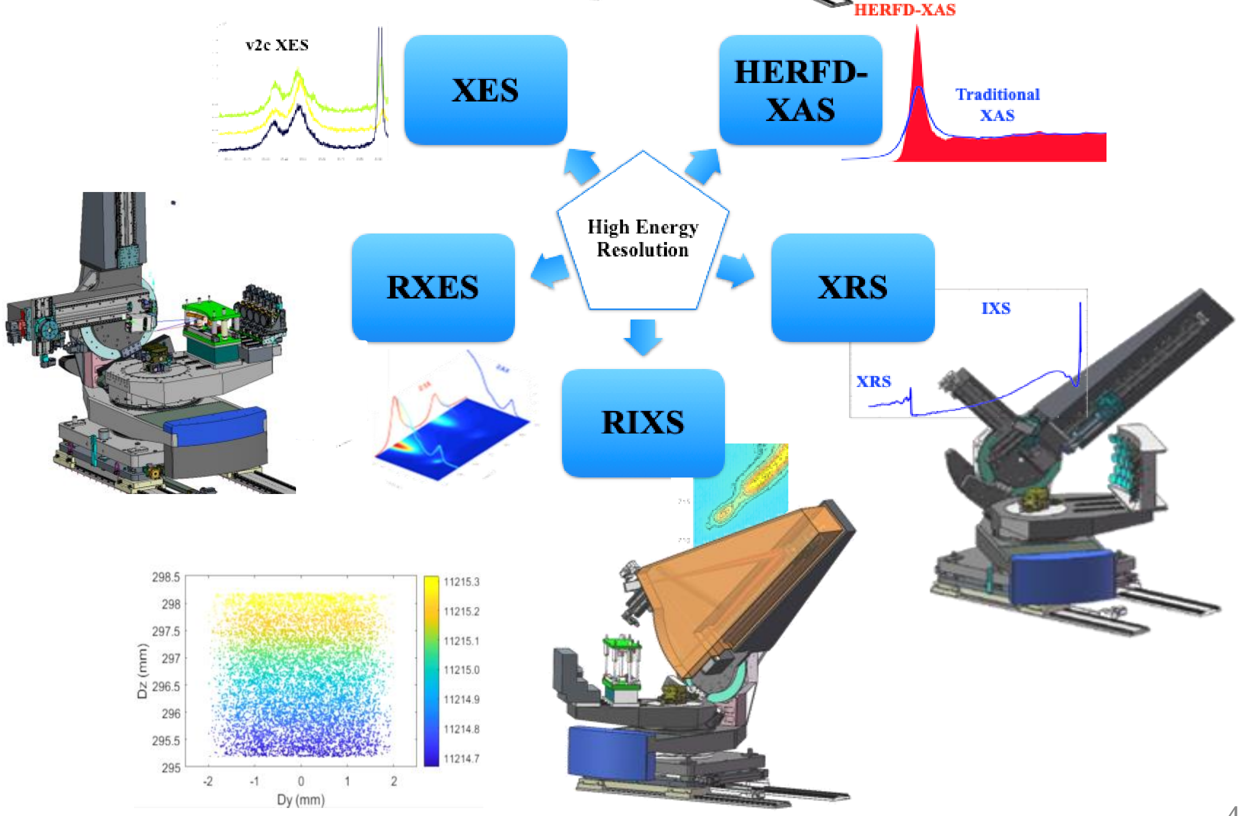
$$\frac{d^2\sigma}{d\Omega d\omega} \propto \left| \langle f|H_{int}|i\rangle + \sum_{|n\rangle} \frac{\langle f|H_{int}|n\rangle\langle n|H_{int}|i\rangle}{E_i - E_n + \hbar\omega_i + i\Gamma}\right|^2$$

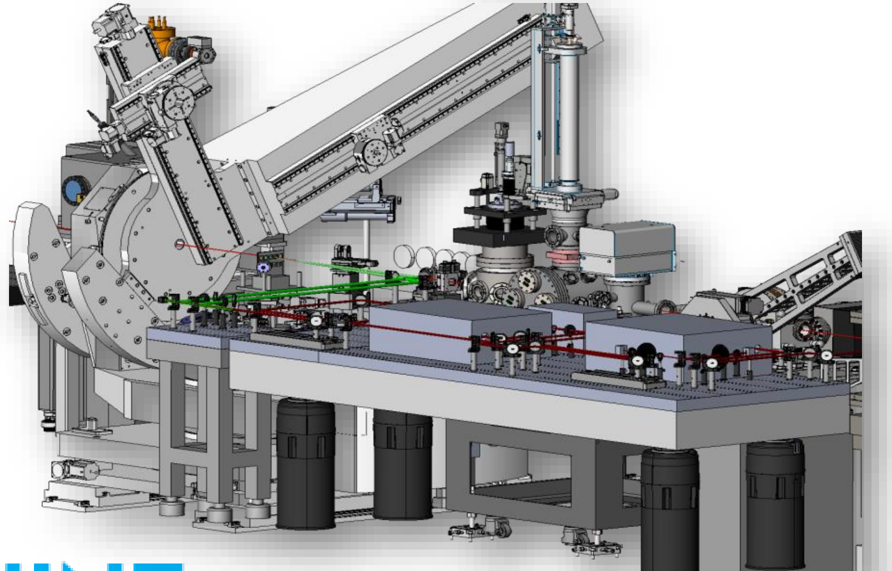
Non-resonant scattering (weak)

Resonant scattering (strong at $E_i=E_n$)

Different experimental configurations





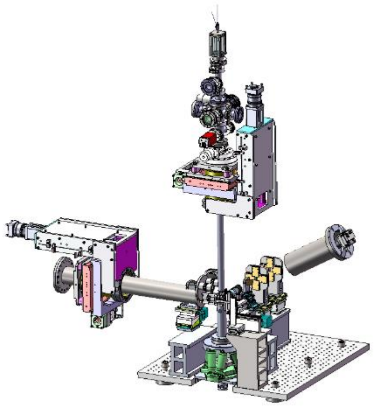


RIXS spectrometer & Pump laser system

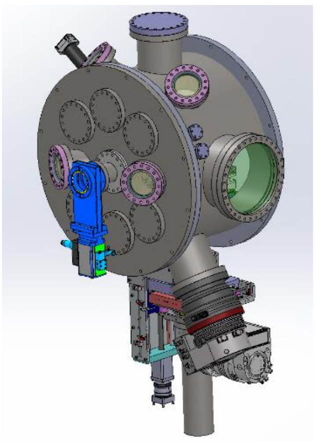
CDS Endstation: Specifications, Programs, & Capabilities

Focusing Capability	KB-1 Mirrors: 1.0 μm KB-2 Mirrors: 300 nm KB-3 Mirrors: 100 nm
Beam Divergence	KB-1 Mirrors: ~ 280 μrad KB-2 Mirrors: ~ 1300 μrad KB-3 Mirrors: ~ 3000 μrad
Sample Environment	▪ High Vacuum: 10^{-4} to 10^{-7} mbar ▪ Rough Vacuum: 200 to 500 mbar ▪ Atmosphere ▪ Fixed Targets at Room Temperature
Particle Injector	▪ Aerosol Injector (Electrospray) ▪ Liquid Jet (GDVN, Cylinder Jet) ▪ Lipid Cubic Phase (LCP)
Detectors	Jungfrau 4M (Repe. Rate: 1-2 kHz) ▪ Pixel Size: 75μm ▪ Dynamic Range: 10^4 @ 12 keV ▪ Single Photon Sensitivity

Detectors	STARLIGHT (SHINE) ▪ Pixel Size: 100 μm x 100 μm ▪ Panel: ≥ 4 M Pixel Array (Currently 4M) ▪ Dynamic Range: 10^4 photons/pixel/frame @ 12 keV ▪ Single Photon Sensitivity (12 keV) ▪ QE: ≥ 80% @ 12 keV ▪ Repe. Rate: ≥ 10 kHz
Pump Lasers	▪ Fundamental Wavelength: 800 nm @ 1 kHz, 1030 nm@ 100 kHz ▪ SHG/THG: 400 nm, 255 nm/515 nm, 343 nm ▪ OPA: 240 nm to 2600 nm ▪ Synchrotron Accuracy: finer than 40 fs ▪ Delay Tuning: - ps to ns ▪ Pulse Duration: < 35 fs ▪ Max. Pulse Energy at IP: > 7 mJ @ 800 nm, 1 kHz, 35 fs ▪ Max. Pulse Energy at IP: 1.0 mJ @ 1030 nm , 100 kHz, 35 fs
Diagnostics	▪ Intensity & Position ▪ Beam Profile Monitor (Imager) ▪ Wavefront ▪ Arrival Time/Timing Tool
DAQ & Storage	▪ Data Flowrate: Day 1: 22 GB/s @ 2.2 kHz , Day 2: 400 GB/s @ 10 kHz ▪ Online Storage: 5 PB SSD with read and write speed > 200 GB/s ▪ Offline Storage: 50 PB (Day1) to 500 PB (Day2) ▪ Long-term Storage: TDB (Budget)



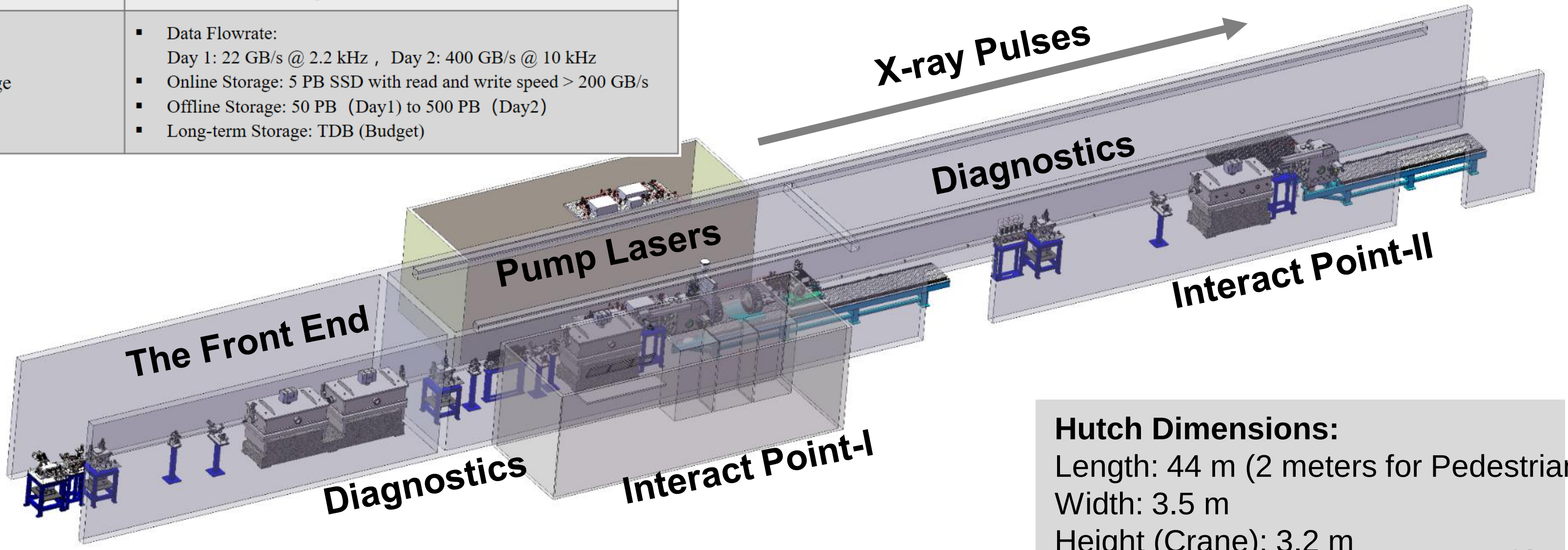
Inside Imaging Chamber



Scattering Chamber

Aerosol Injector

LCP Injector



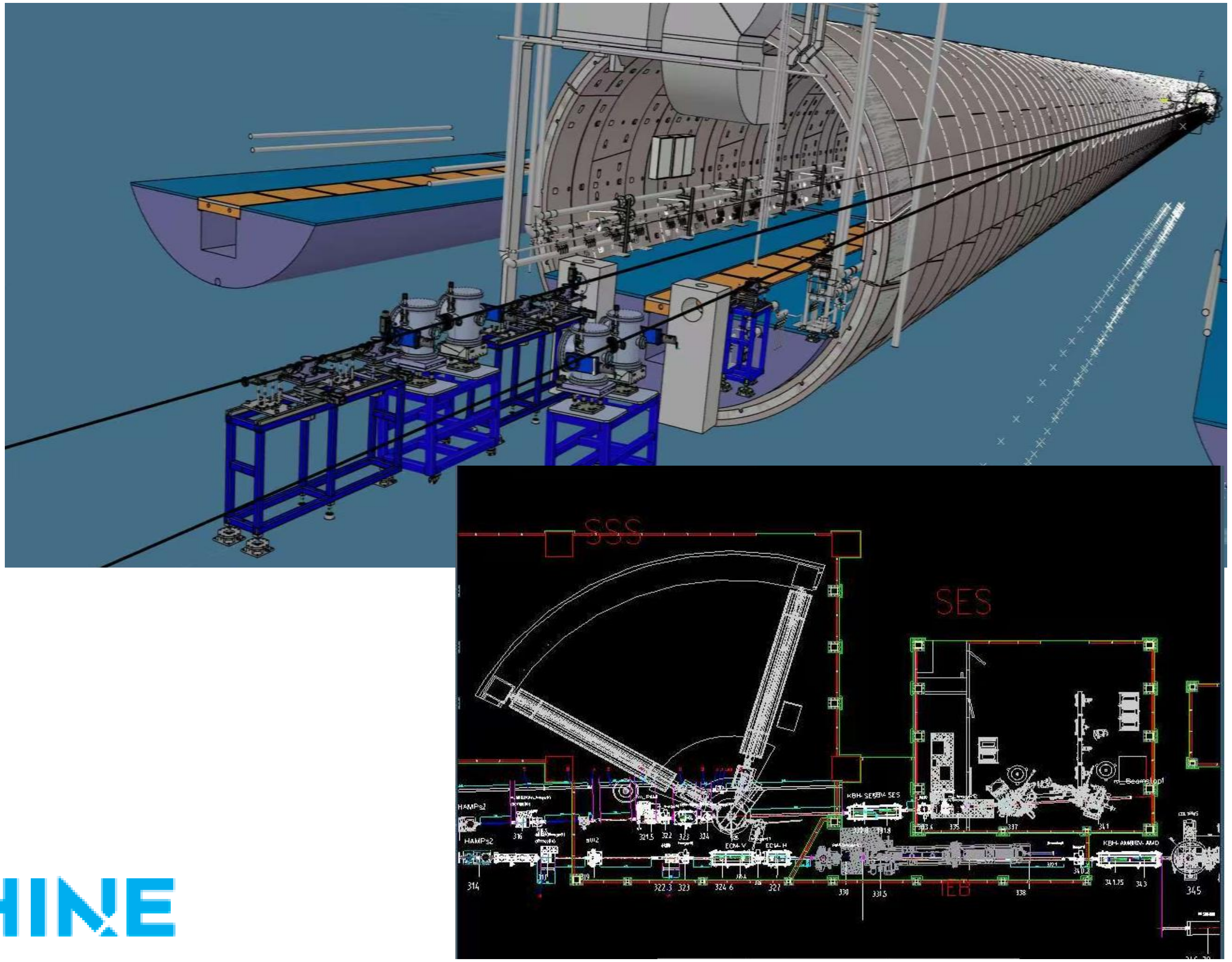
Hutch Dimensions:
Length: 44 m (2 meters for Pedestrian)
Width: 3.5 m
Height (Crane): 3.2 m

Scientific Programs:

- ➢ Single-shot Single Particle Imaging;
- ➢ Imaging of Non-reproducible Targets;
- ➢ Liquid and Gas Phase Chemistry;
- ➢ X-ray-Matter Interactions;
- ➢ Pump-probe Imaging and Crystallography;
- ➢ Matter in Extreme Conditions.

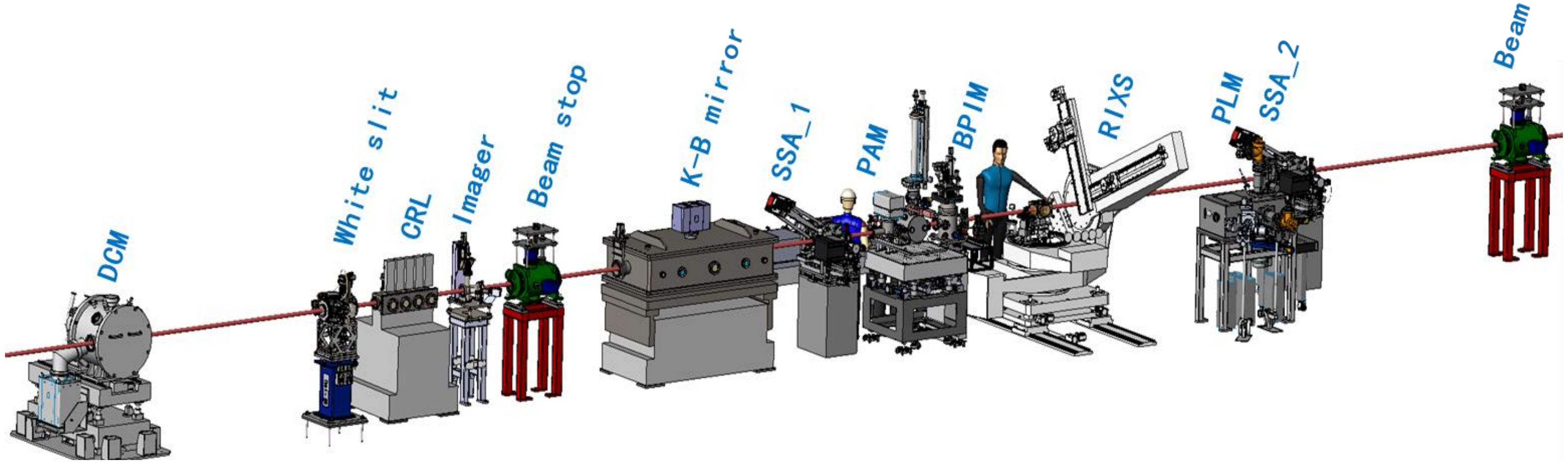
Progress of Beamlines and Endstations

- Beamline design has been completed, and endstations design has been frozen.

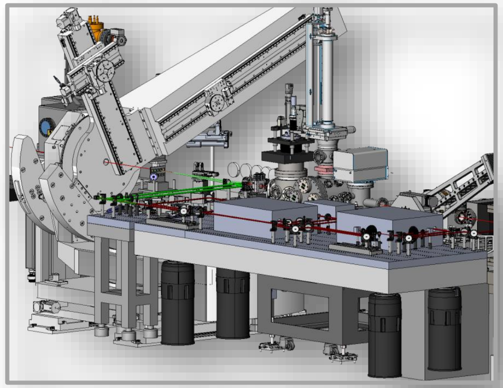


SHINE

Current Status of HSS Endstation



Parameters	Values
Energy range	3~15 keV
Optimized range	7~12 keV
Pulse energy @8GeV/100pC	0.17mJ@7keV 0.08mJ@12.4keV
Monochromator Energy resolution	Si(111): 2E-4 @3-15keV Si(311): 5E-5 @5.6-15keV
Type of focusing	K-B & (CRL in the future)
Focal spot size at sample (H×V, FWHM)	6μm~200μm
ΔE/E	**4E-5**
ΔT	**~ 100 fs**



Current Status of CDS Endstation