Technical Overview of CDS and HSS Endstations in FEL-I

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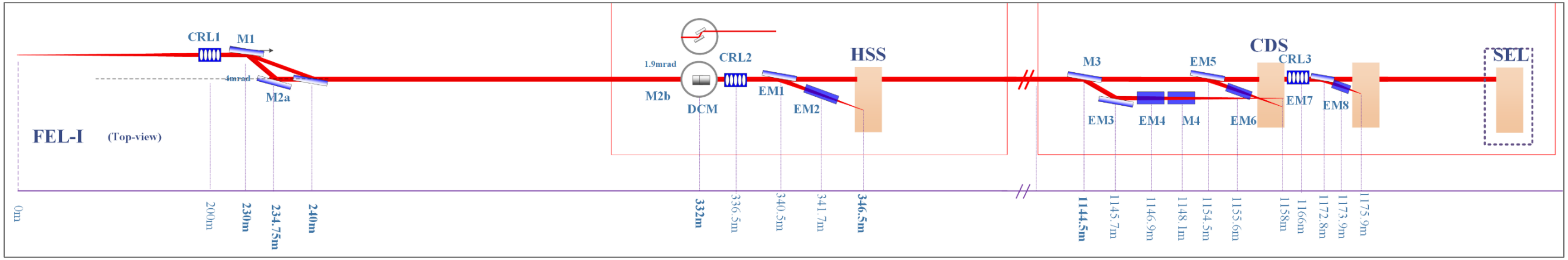
On behalf of FEL-I Department

Oct. 22, 2025

Outlines

- FEL-I Instrument Overview
- The HSS Instrument
- The CDS Instrument

FEL-I Instrument Overview: Optics and Location



Offset Mirror System	Mirrors	Arrived at SHINE
	Mechanical part	Not purchased, developed by SHINE
Crystal Mono(DCM)	Crystal	Not purchased
	Mechanical part	Expected delivery time in 2026.3
KB for HSS	Mirrors	Expected delivery time in 2026.1
	Mechanical part	Expected delivery time in 2025.11
KB for CDS	Mirrors	Expected delivery time in 2026.6
	Mechanical part	Expected delivery time in 2026.5
CRLs	/	No Be lens supplier, R&D diamond lens

Parameters	Objective
Energy range	3.0 – 15.0 keV
Energy resolution (ΔE/E)	2.0×10^{-4}@8.9 keV
Transmission efficiency	30%@7keV (no monochromator)
spot size	10 μm @HSS 0.1 μm&1 μm @CDS

HSS: Hard x-ray **S**cattering and **S**pectroscopy

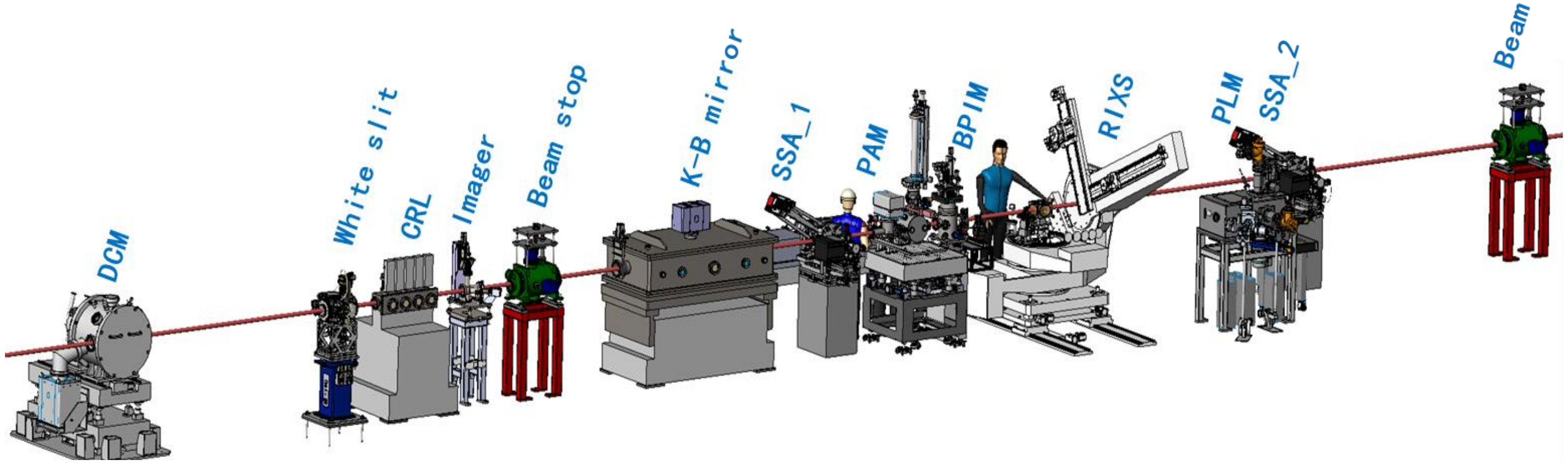
Located at NEH @ Shaft #4

CDS: Coherent **D**iffraction for **S**ingle Molecules and Particles

Located at FEH @ Shaft #5

The FEL-I Beamline will start the installation around Jan. 2026

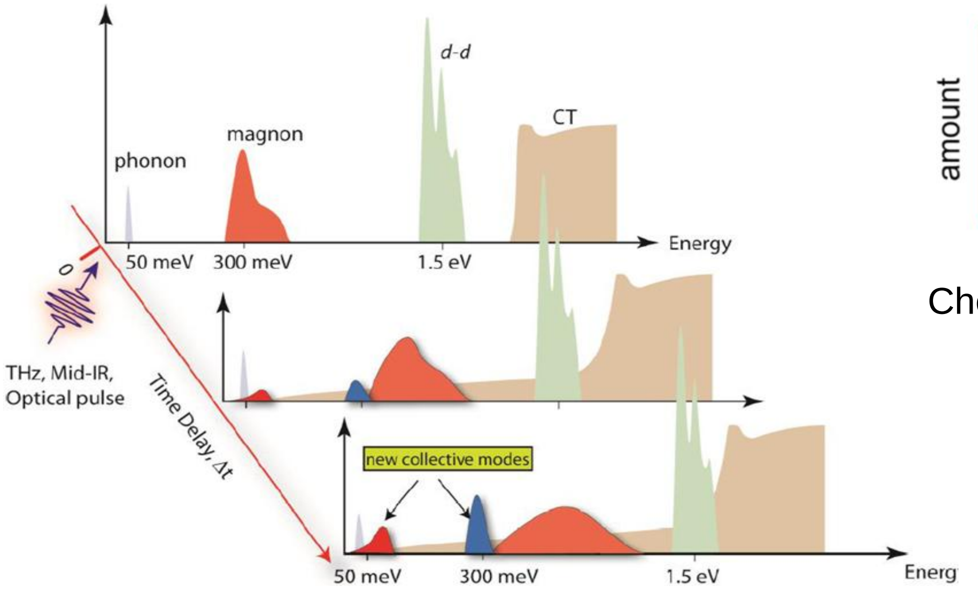
HSS Instrument: Nut in a Shell



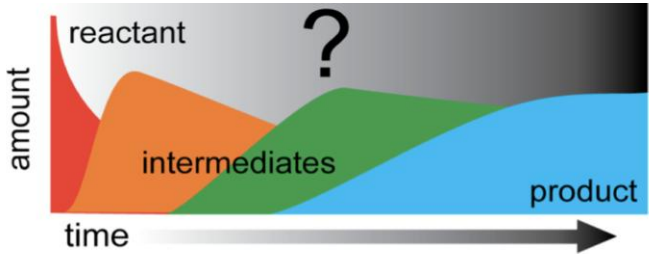
Parameters	Values
Energy range	3~15 keV
Optimized range	7~12 keV
Pulse energy @8GeV/100pC	0.17mJ@7keV 0.08mJ@12.4keV
Monochromator Energy resolution	Si(111): 2E-4 @3-15keV Si(311): 5E-5 @5.6-15keV
Type of focusing	K-B & (CRL in the future)
Focal spot size at sample (H×V, FWHM)	6μm~200μm
ΔE/E	**4E-5**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

HSS Instrument: Scientific Goals

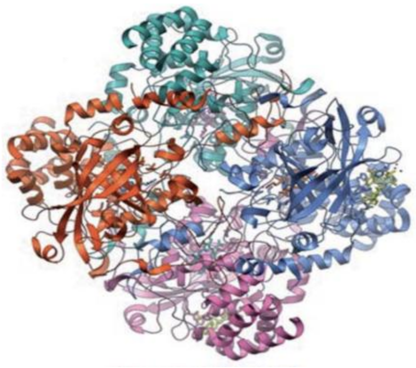
- High resolution detection of the elementary excitation in correlated quantum materials will be carried out in the dimensions of energy(e), momentum(k) and time(t).
- Electronic structure and spin dynamics changes in chemical, biological, and energy materials systems.
- Ultrafast structural evolution phenomena such as phase transitions and solvation.



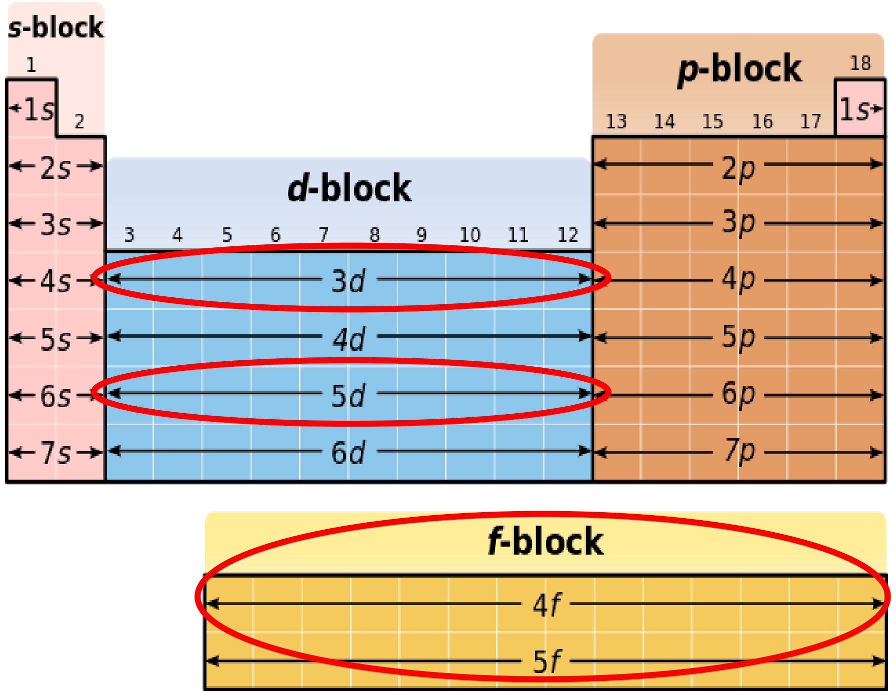
Elementary excitations in strong correlated quantum materials. No. SLAC-R-1053 (2015)



Chemical reaction dynamic process

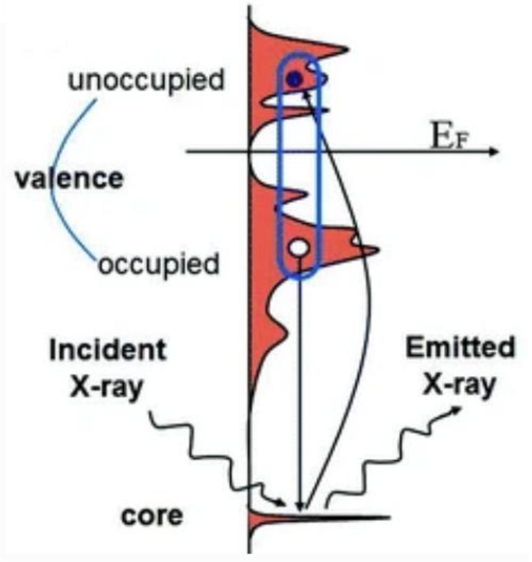


Fe^{2+} and Fe^{3+} in hemoglobin

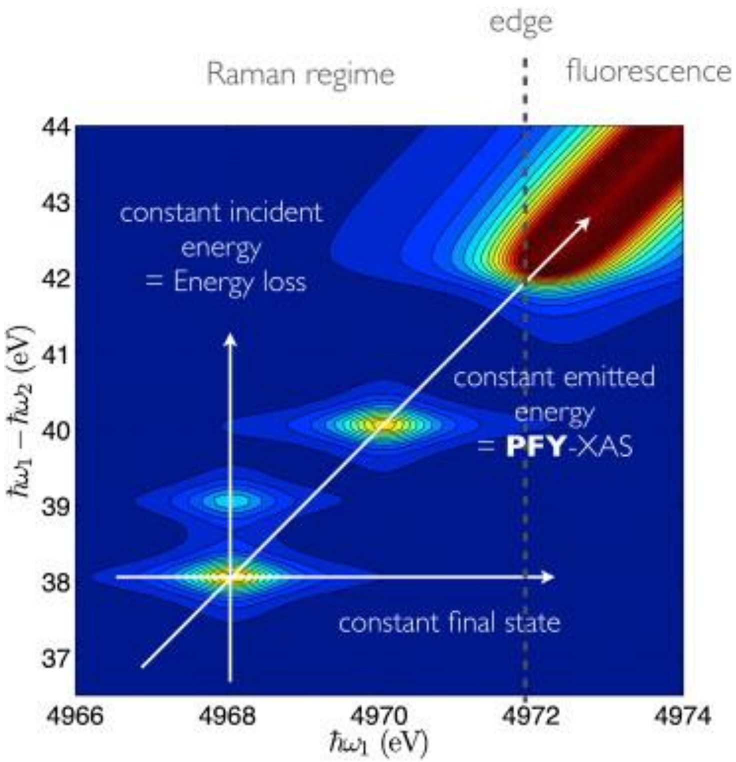


HSS Instrument: Methodology

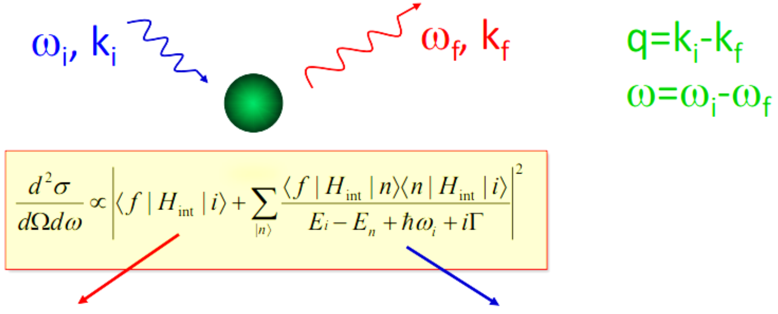
- Time-resolved resonant inelastic x-ray scattering (tr-RIXS)
- Ultrafast x-ray emission spectroscopy (tr-RXES, v2c XES, XES)
- Ultrafast high energy resolution fluorescence detected XAS (HERFD-XAS)



Harada, Y. (2018).



J.-P. Rueff, A. Shukla, 188 (2013)

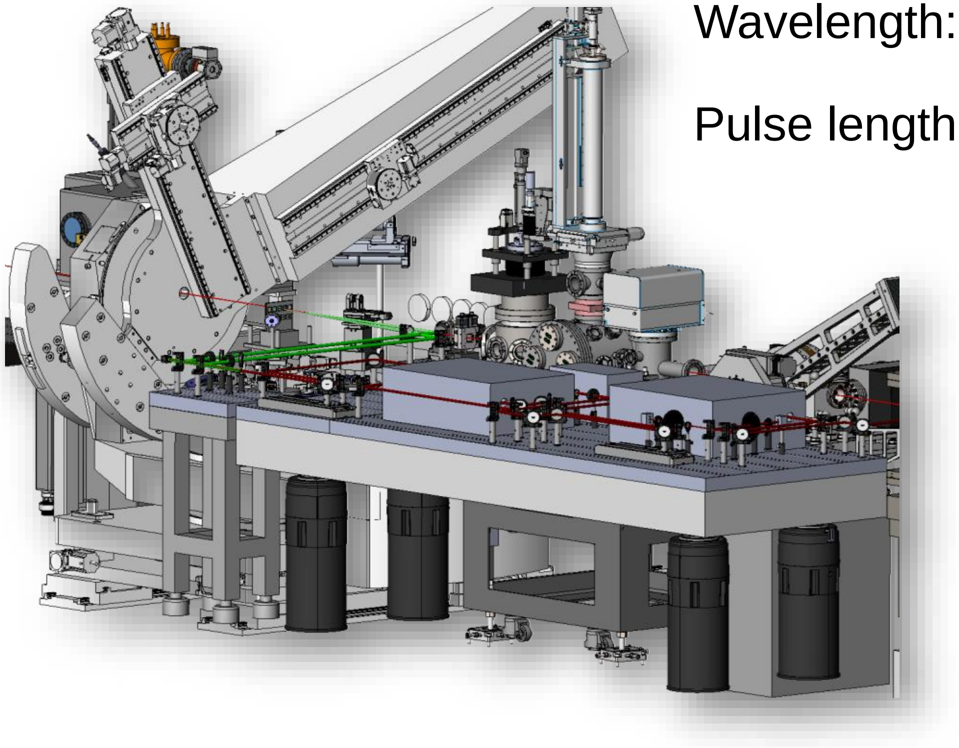


$$\frac{d^2\sigma}{d\Omega d\omega} \propto \left| \langle f | H_{int} | i \rangle + \sum_{|n\rangle} \frac{\langle f | H_{int} | n \rangle \langle n | H_{int} | i \rangle}{E_i - E_n + \hbar\omega_i + i\Gamma} \right|^2$$

PHASE I	PHASE II	PHASE III
tr-XES tr-RIXS	HERFD-XAS V2C XES	IXS XRS

HSS Instrument: The Core Instrument

PUMP LASER TABLE
Time-resolved



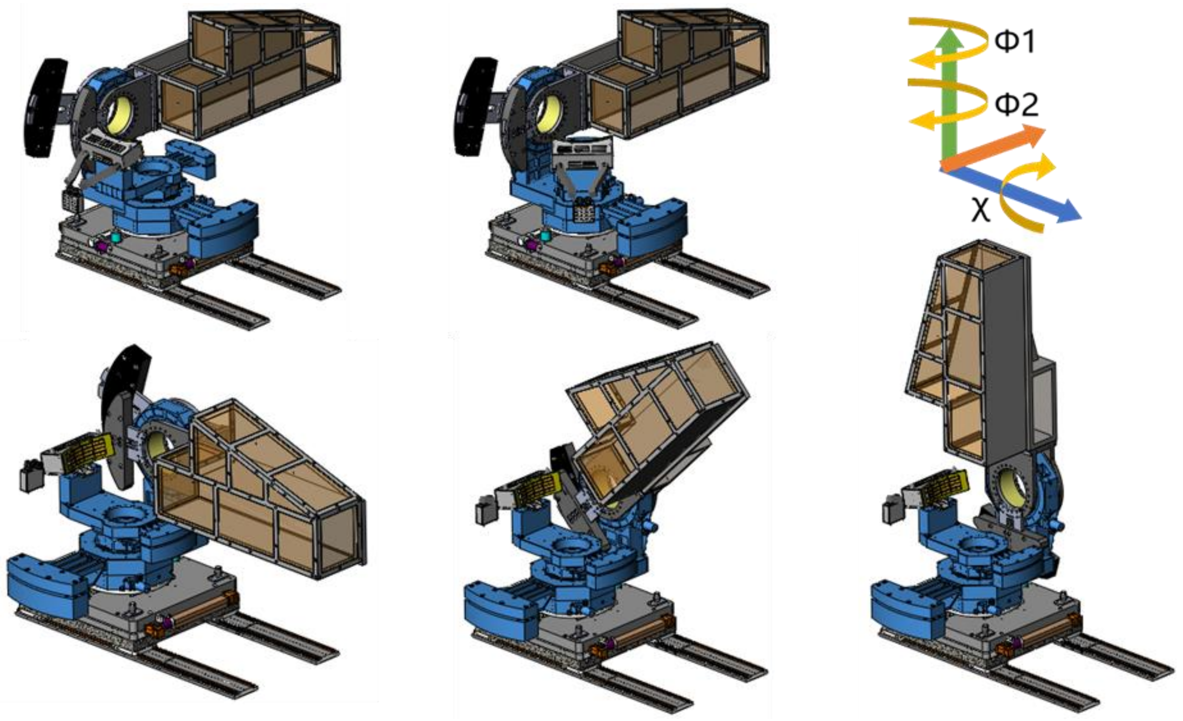
Laser: 1030nm/100kHz

Wavelength: 240-2400 nm

Pulse length： ≤35 fs

+

SPECTROMETER
Energy/Momentum-resolved



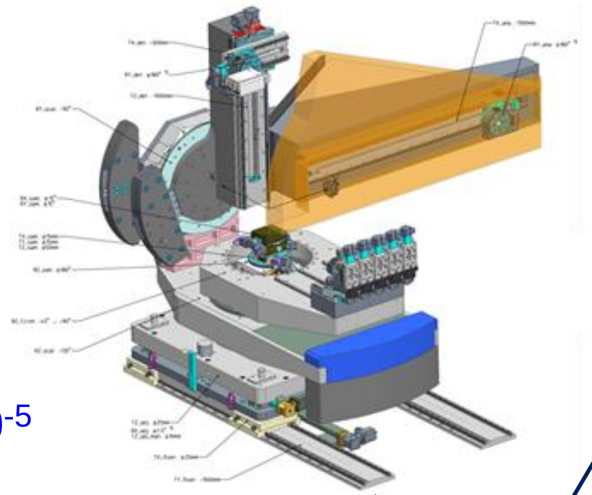
HSS Instrument: The Core Instrument Status

SHINE

RIXS Spectrometer

- 2024.12 contract signed;
- 2025.03 PDR completed;
- 2025.09 FDR completed;
- Under manufacture

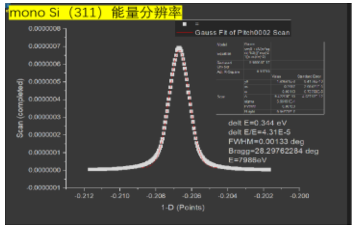
$\Delta E/E = 4\times10^{-5}$

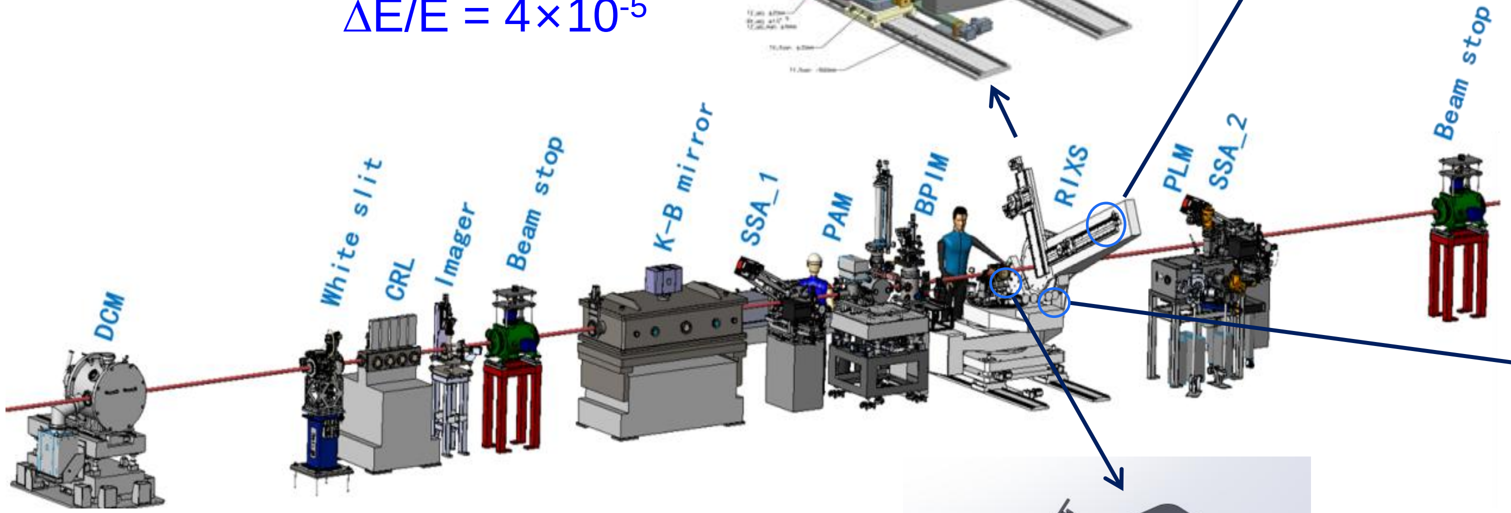


Bent Craystal Analyzers

- 2025.03 self-made strip SBCA online test;
- 2025.06 strip SBCA contract signed (11pcs)
- 2026.01 CBCA sign contract

	Spherical			Cylindrical
	Bent	Bent-striped	Bent-diced	Bent(Von Hamos)
Energy resolution				
Adhesion	Epoxy glued	Epoxy glued	Epoxy glued	Epoxy glued
Wafer thickness	(Si/Ge)150÷500 μm	(Si/Ge)150÷500 μm	(Si/Ge)150÷500 μm	(Si/Ge)150÷500 μm
Pixel size/stripe width	-	16 mm	5 mm x 5 mm	-
Curvature radius	0.5 m & 1 m	0.5 m & 1 m	0.5 m & 1 m	0.5 m & 1 m
Dimension	Φ100 mm	Φ100 mm	Φ100 mm	25 mm x 100 mm

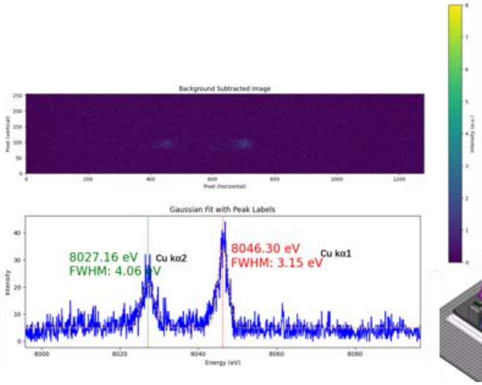


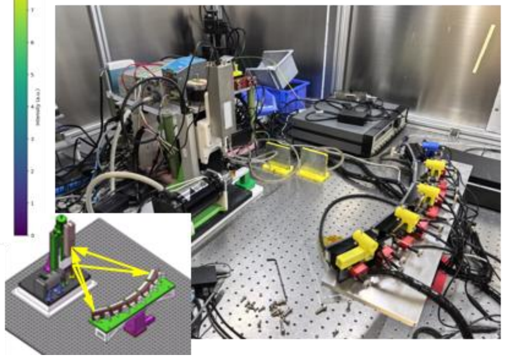


(R)XES Spectrometer

$\Delta E/E < 1\times10^{-4}$

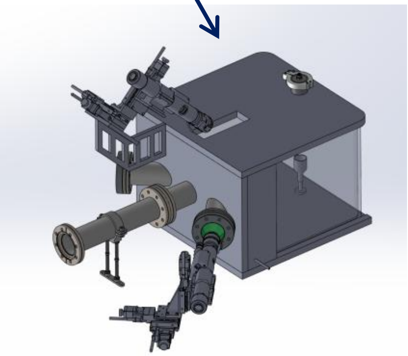
- 2025.01 start offline test;
- 2025.10 (R)XES review meeting completed;
- 2025.12 sign contract





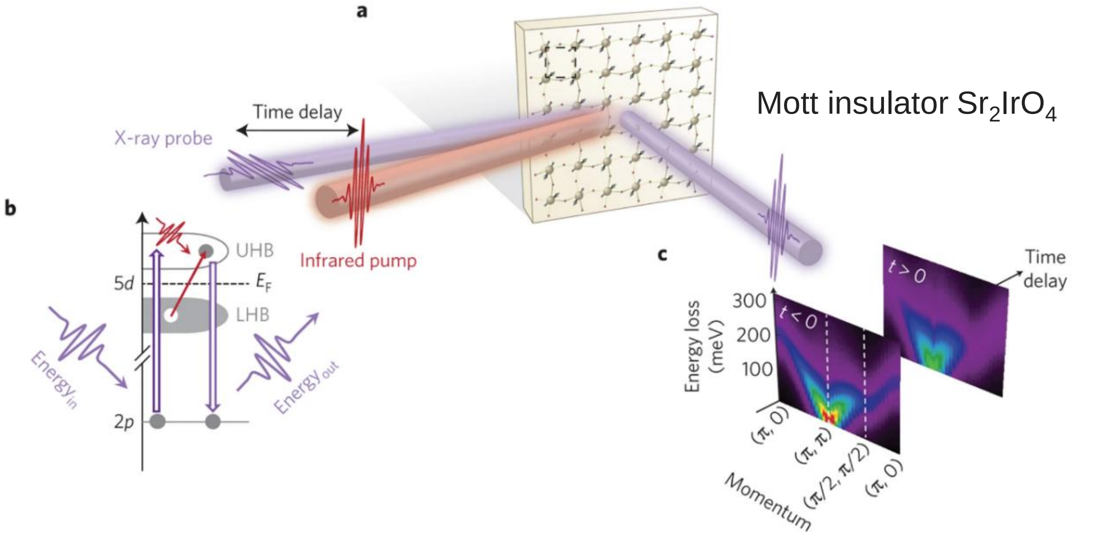
Liquid Sample Chamber

- 2025.06 PDR completed;
- 2025.12 complete FDR

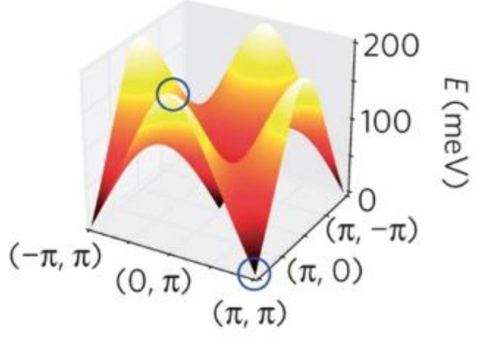


HSS Instrument: Potential Pilots (tr-RIXS)

Time-resolved magnetic RIXS at XPP, LCLS



Mott insulator Sr_2IrO_4



Pump Laser:

2 μm, ~100 fs, 0.5~13.8 mJ/cm2,

XFEL:

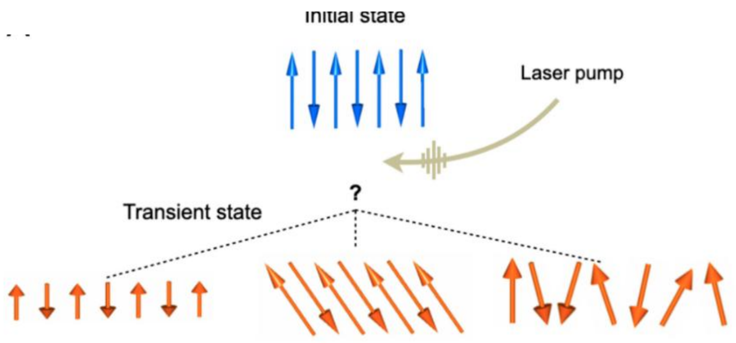
11.215 keV, ~10 fs, 120 Hz,

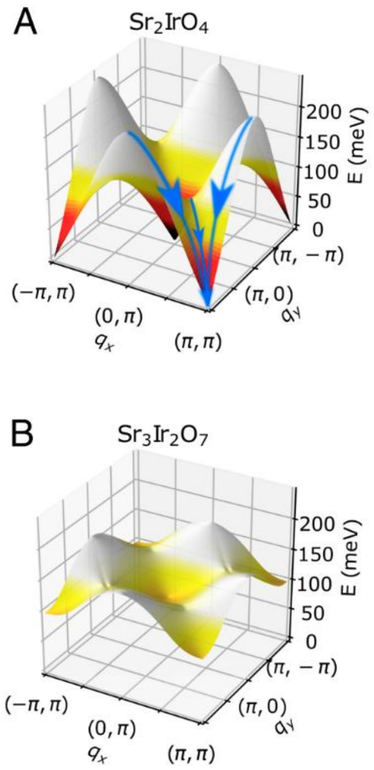
total E resolution ~70 meV

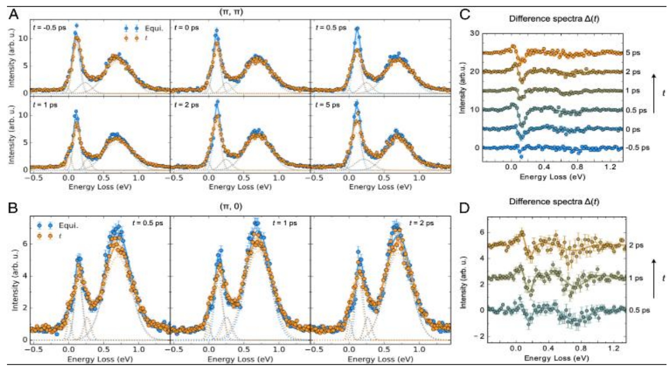
momentum resolution ±0.5 Å−1

time resolution 500 fs

Nat. Mater. 2016, 15, 601.







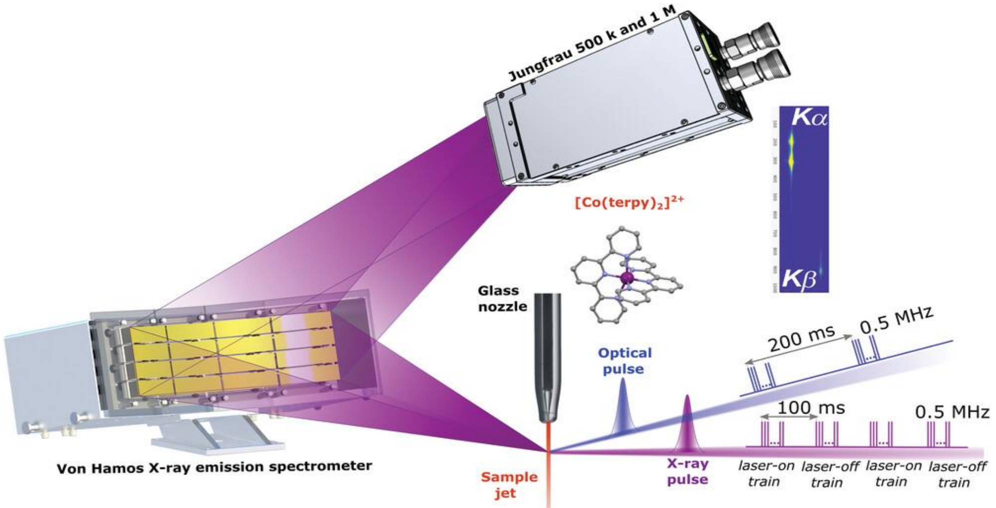
Pump Laser: 2 μm, 20 mJ/cm^2 845-μm focus;

XFEL: 11.215 keV, ~10 fs, 50-μm focus

Proc. Natl. Acad. Sci. 2021, 118(22), e2103696118.

HSS Instrument: Potential Pilots (tr-XES)

Femtosecond Co Kα1,2 & Kβ XES at FXE, EuXFEL



Pump Laser:

400 nm, 70 fs, 34 μJ / 16 μJ,

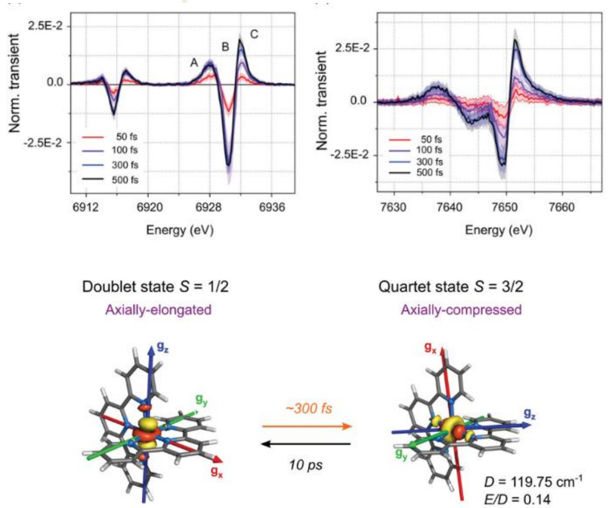
73 x 62 μm^2 μm focus spot

XFEL:

9.3 keV, ~40 fs, 350 μ J

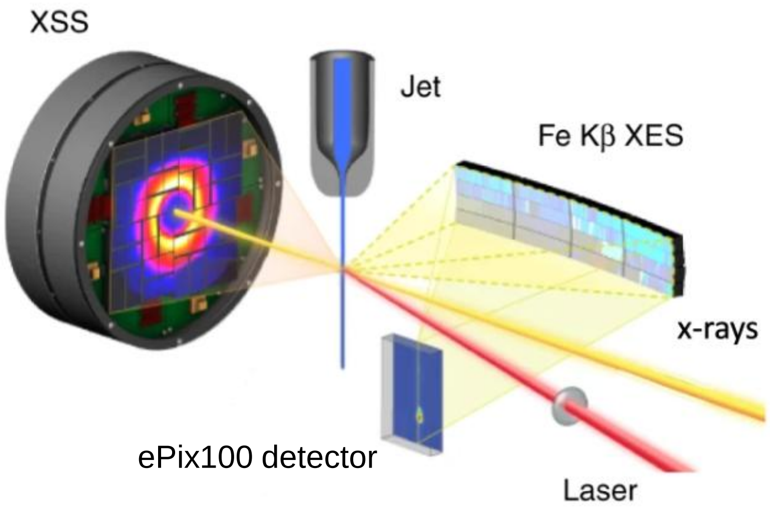
~5x10^11 photons/pulse,

564 kHz, ~7 μm focus spot



Adv. Sci. 2023, 10, 2206880.

Femtosecond Fe Kβ & VtC XES and XSS at XCS, LCLS



Pump Laser:

336 nm, ~50 fs, 3.6 μJ,

100 μm focus spot

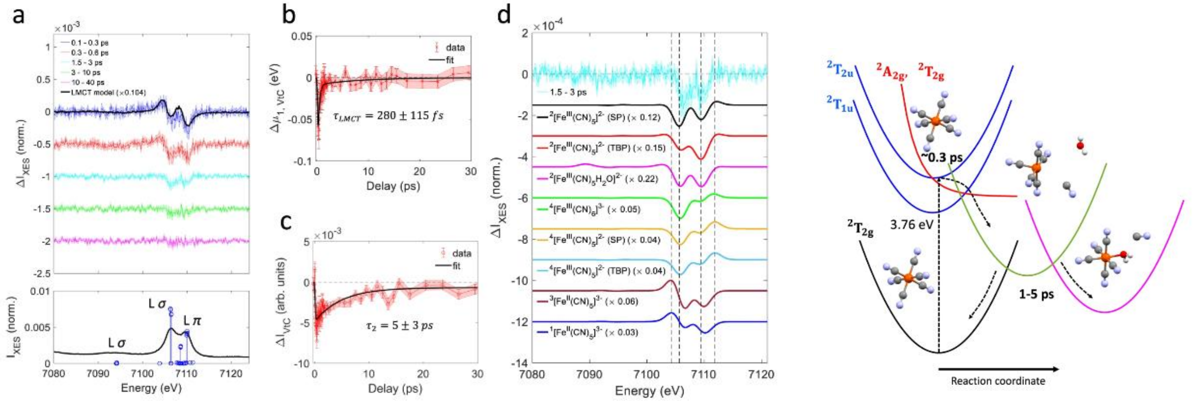
XFEL:

8.5 keV, ~40 fs,

~5x10^11 photons/pulse,

120 Hz, ~20 μm focus

$\Delta E/E \sim 5\times10^{-2}$



Nat. Commun. 2023, 14, 2443.

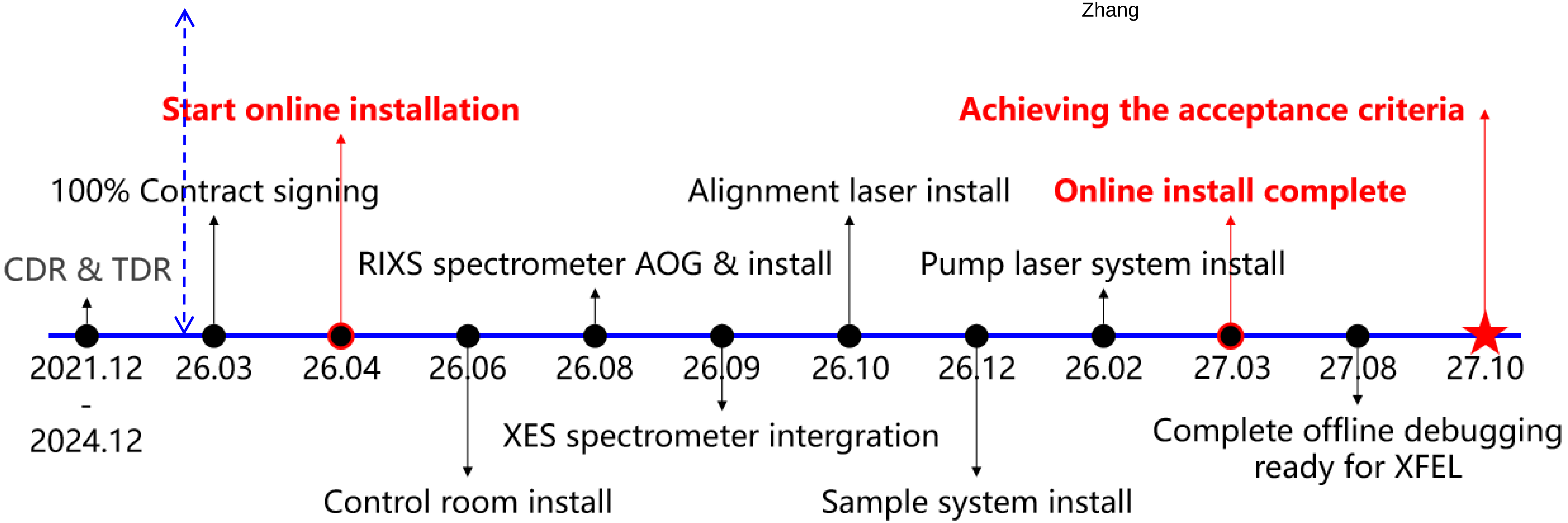
HSS Instrument: Installation and Comm. Plan


Kaiyu Zhang


Niandu Wu


Bing Li

We have finished most of the contract signing (＞90%)

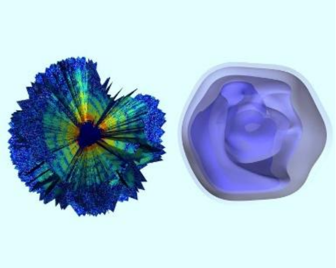


CDS Instrument: Science Programme

Ultrafast X-ray Imaging

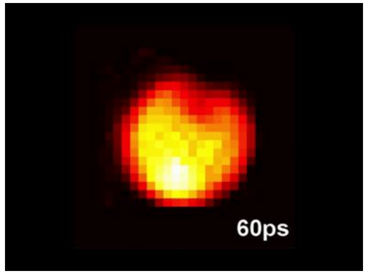
(Tr-) SPI

Nanoparticles, Virus, Aerosols, Clusters, etc.



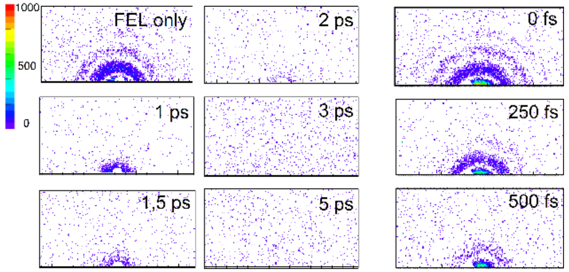
Phys. Rev. Lett. **114**, 098102 (2015).

First 3D XFEL Imaging (Mimivirus)



Nat. Commun. **10**, 2411 (2019).

Imaging of Light-induced Melting



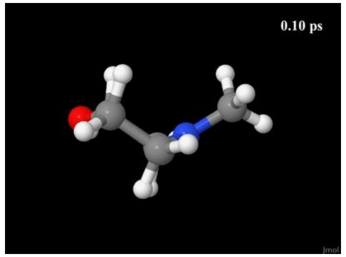
*Nat Photon **10**, 93 (2016).*

X-ray Matter Interactions (Xe Clusters)

Ultrafast X-ray Scattering

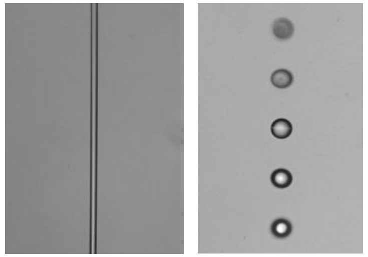
Tr-Forward Scattering (FXS, USS, etc)

Liquid, Gas, Multi-particles, etc.



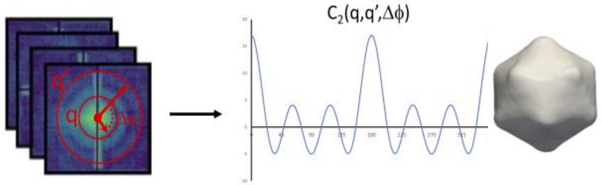
Nat. Chem. **11**, 716 (2019).

Vibrational Coherence Detection



Nature Phys **12**, 966 (2016).

X-ray Induced Explosions of Water



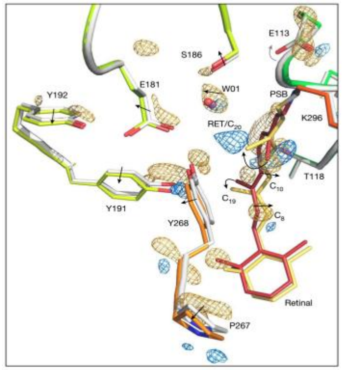
PNAS **115**, 11772 (2018).

Imaging of Giant *Paramecium bursaria* Chlorella virus

Ultrafast X-ray Diffraction

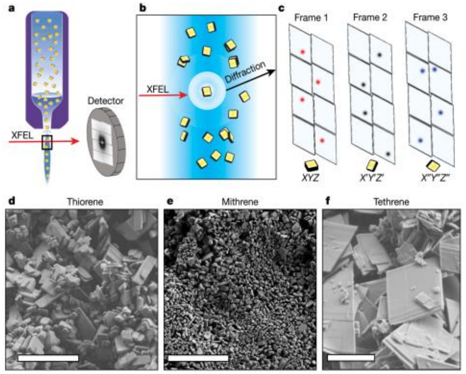
Tr-SFX

Protein Crystals, Tiny Crystals



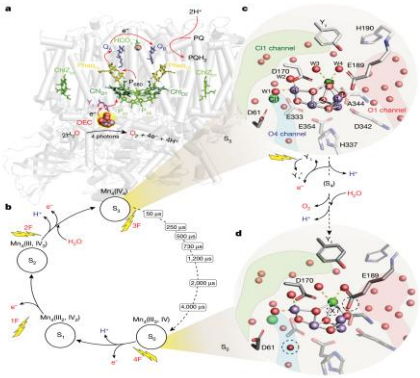
Nature **615**, 939 (2023).

Structural Change to Events of Vision



Nature **601**, 360 (2022).

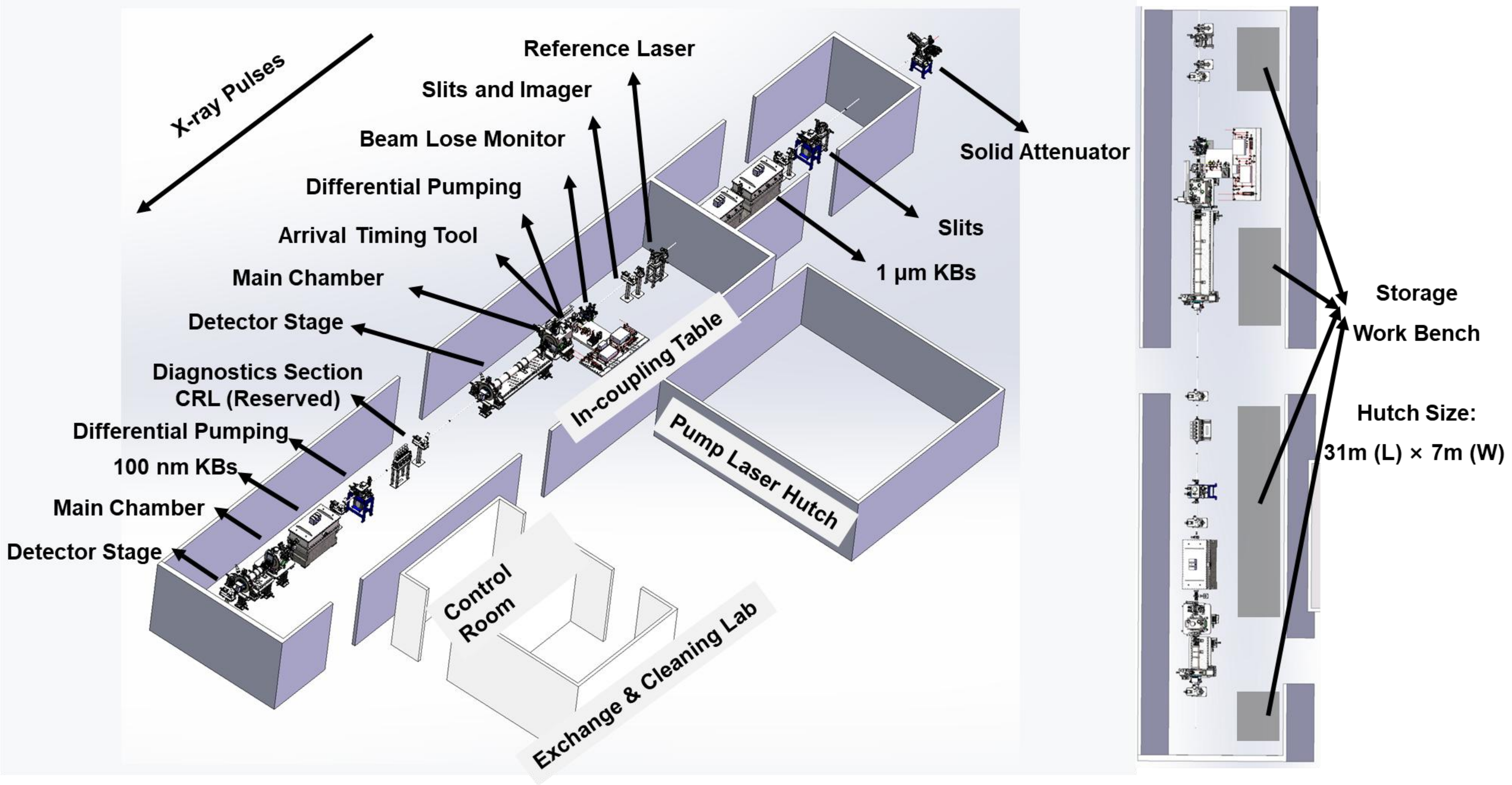
Chemical Crystallography with SFX



Nature **617**, 629 (2023).

Structural evidence for intermediates during O_2 formation in PS-II

CDS Instrument: The General Layout

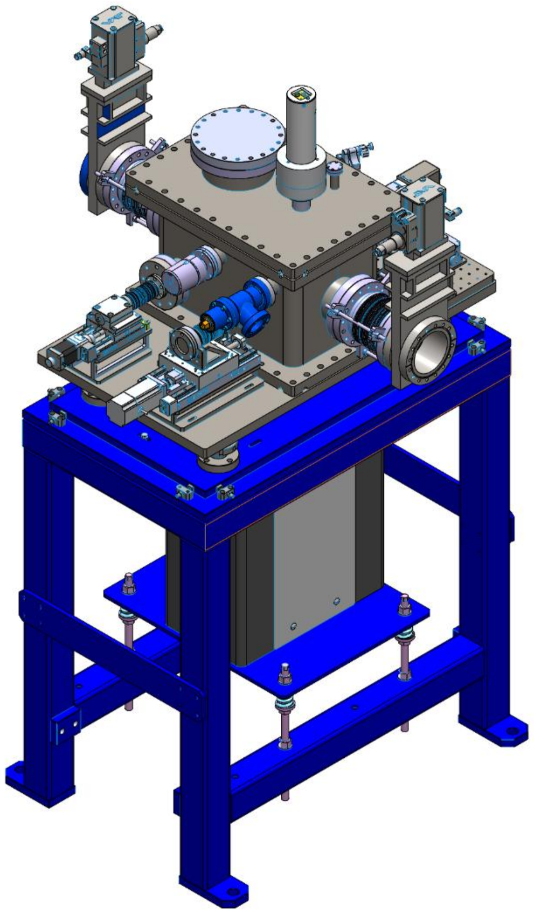


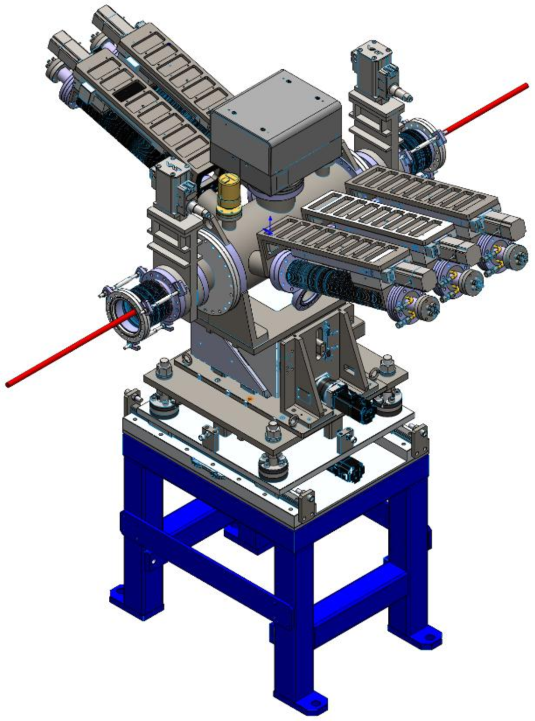
CDS Instrument: The DAY-1 Main Parameters

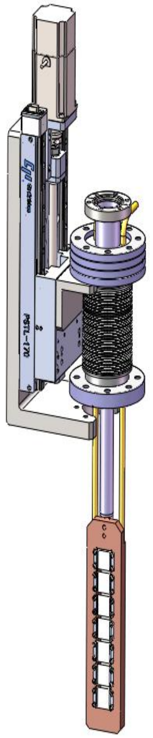
Time	March ~ June 2027	December 2027
Photon Energy	5 keV	3~13 keV
Average Pulse Energy	≤ 100 μJ (General Mode; Source Point)	≥ 100 μJ (Source Point)
Beam Stability	10%	≤ 10%
Repetition Rate	≤ 1kHz	≤ 2 kHz
Bandwidth	≤ 0.1%	≤ 0.1%
Pulse Length	≤ 100 fs	≤ 100 fs
Focusing Capability	1.0 μm & 300 nm (Two IPs)	1.0 μm & 300 nm (Two IPs)
Sample Environment	▪ High Vacuum: 10^{-4} to 10^{-7} mbar	▪ High Vacuum: 10^{-4} to 10^{-7} mbar; ▪ Helium: 100-600 mbar
Sample Delivery	▪ Aerosol Injector (with Electrospray) ▪ Fixed Target (Lower Repe. Rate)	▪ Aerosol Injector ▪ GDVN & LCP ▪ Fixed Target
Detectors	Jungfrau 4M (Repe. Rate: 2.2 kHz Max.)	Jungfrau 4M (Two detectors)
Pump Lasers	N/A for first days	1 KHz with 255, 400, 800 nm

CDS Instrument: Core Instrument-FEE

Reference Laser and Solid Attenuator







Items	Technical parameters
Laser Diode	Power>1W; Central wavelength: 450nm、630nm
Motorized Linear Manipulator	Travel range:75mm Repeatability: 1μm
Ce：YAG Crystal	Diameter: 20mm Thickness: 0.7~1mm Ce^{3+}: 0.3~0.5mol%
Long WD Microscope	W.D.: >150mm Zoom range: 0.3~1.5 Resolution: 50μm ~10μm

- Materials: CVD diamond/ Si/ B_4C
- 10 grade attenuation, 3 steps per grade
- Collimated beam: 10 mm aperture
- Max repetition rate: 10 kHz
- Vacuum compatible：10^{-9} Torr (Ion pump)

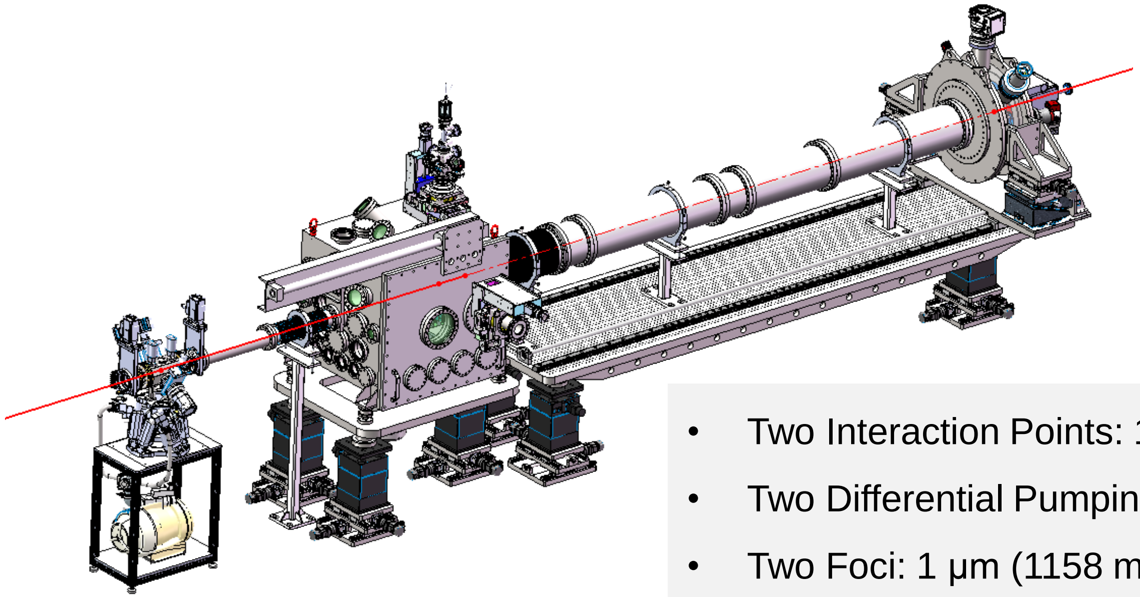
Current Status: Contract Signed

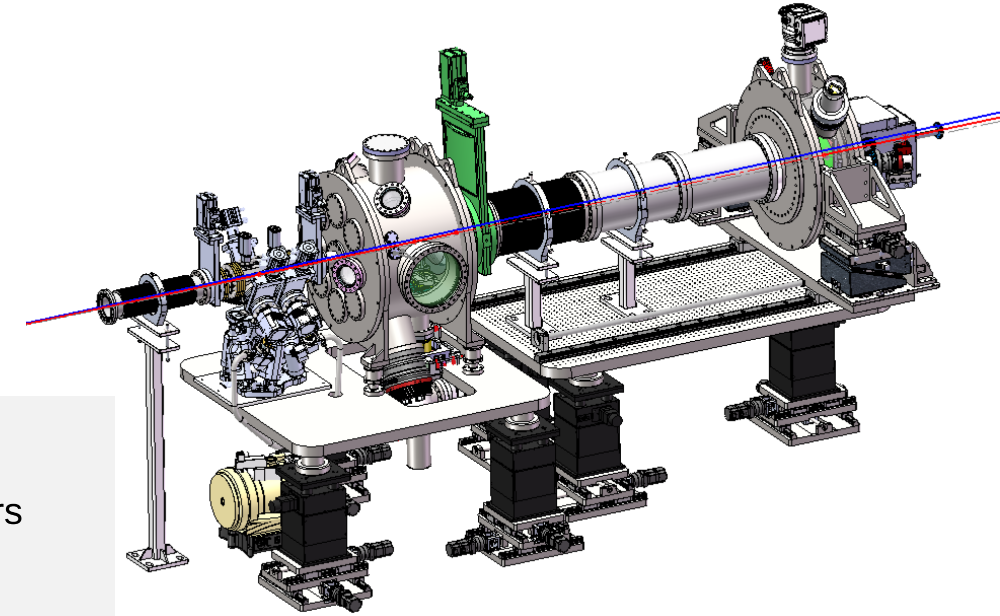
TDR-OK, PDR-OK, FDR-Nov. 2025

Installation: Aug. 2026

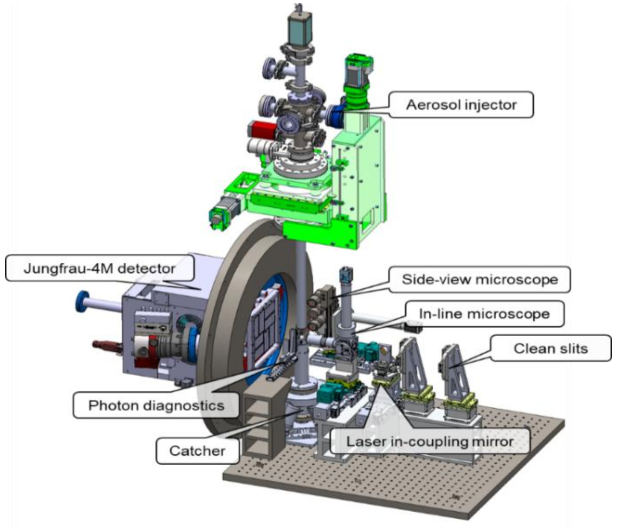
CDS Instrument: Chambers and Mover Systems

Differential Pumping Section, Chambers, Stages, Detector Support, Mover Systems





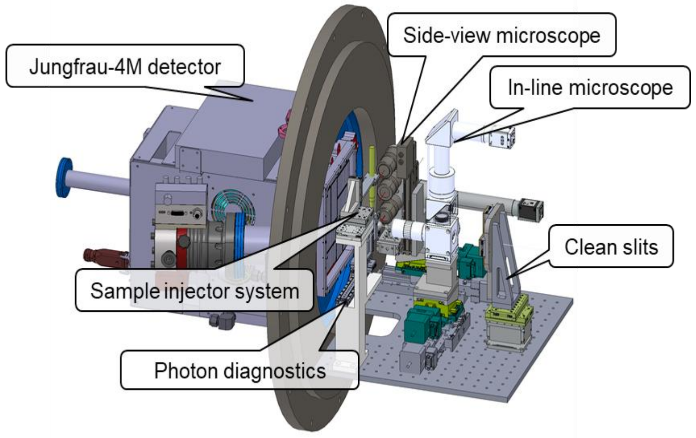
- Two Interaction Points: 1158 m and 1175.9 m
- Two Differential Pumping Section and Chambers
- Two Foci: 1 μm (1158 m), 300 nm (1175.9 m)
- Two 4M Jungfrau Detector (4 mm and 10 mm Hole)
- Sample-to-Detector Distance: 150-4000 mm
  70-2000 mm



Current Status: Contract Signed

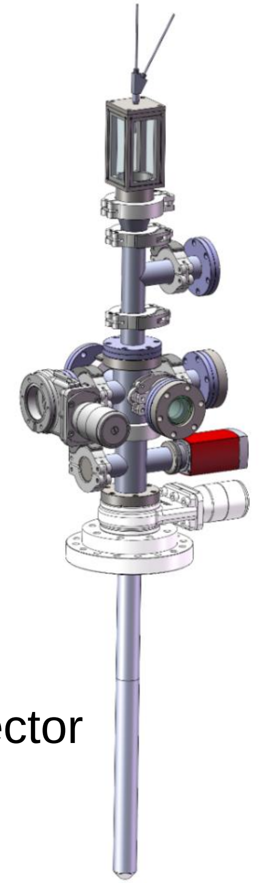
TDR-OK, PDR-OK, FDR-Dec. 2025

Installation: Oct. 2026

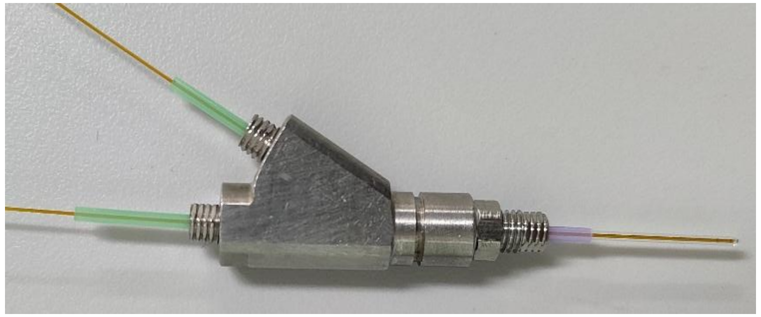


CDS Instrument: Sample Environ. and Delivery

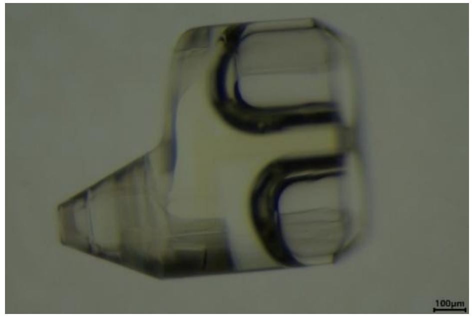
Sample System	Injector	Full Name	Status
Powder	FT	Fixed Target	Ready
Film	FT	Fixed Target	Ready
Liquids	GDVN	Gas Dynamic Virtual Nozzle	Ready
Liquids	Cylinder	Cylinder Jet	Ready
Crystals	LCP	Lipid Cubic Phase	Under Development
Crystals	HVE	High Viscosity Extrude	Under Development
Particles	ADL	Aerosol Injector with ESI/Atomizer	Under Development
Gases	Gas Cell	Customer Designed Gas Cell	User Consortium



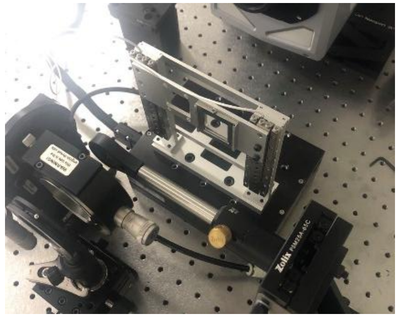
Aerosol Injector



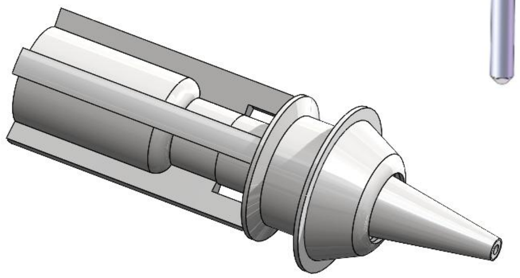
GDVN



GDVN/Cylinder



Fixed Target



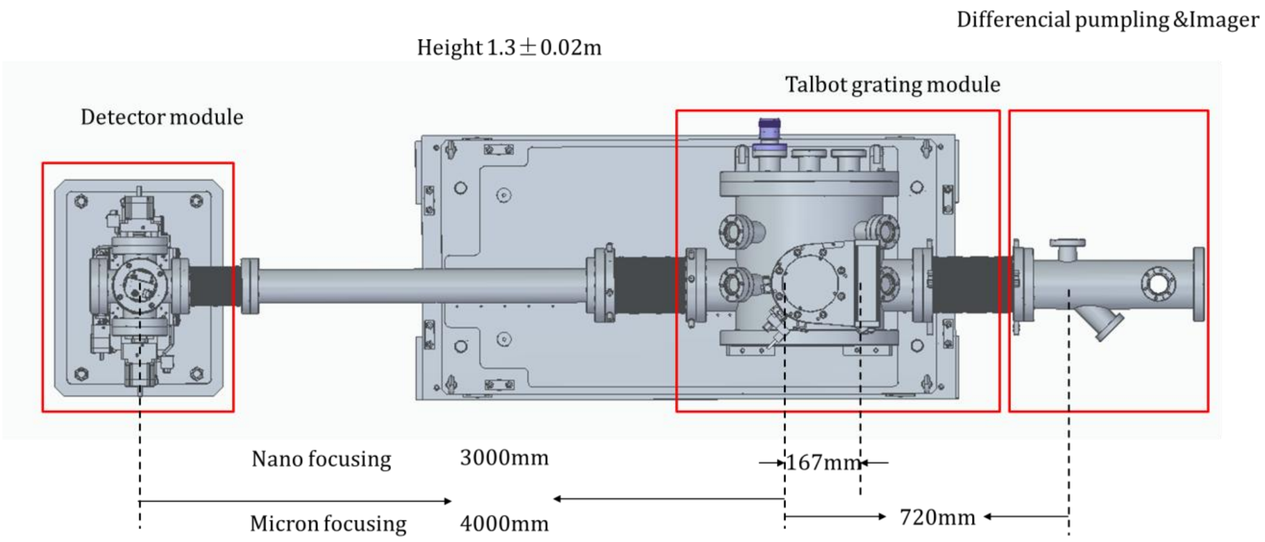
LCP

CDS Instrument: Relative Working Packages

- **Timing Tool, Wavefront Diagnostics, Pump Laser, and Detectors *(Later Talks)***
- **DAQ, Control, Timing, Trigger, and Synchrotron *(Talks tomorrow: GET Depart.)***

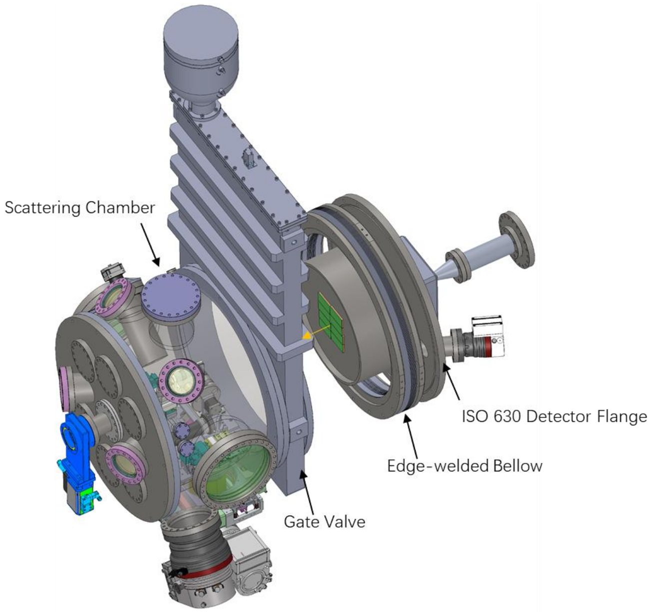
Wavefront Diagnostic: Talbot Grating

Beamline Design Group



JF Detector: 2 kHz, 4M

SHINE and PSI Detector Group

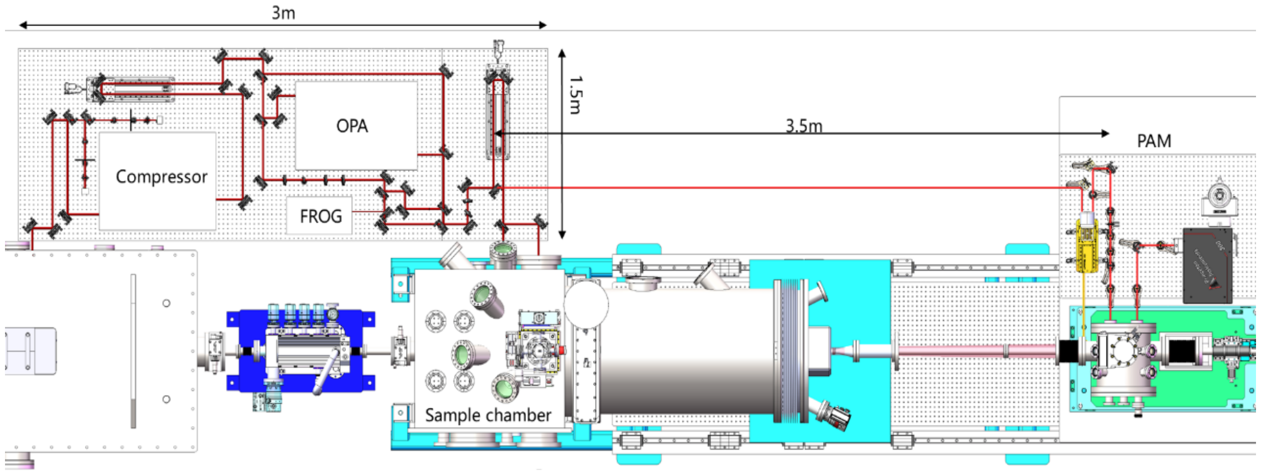


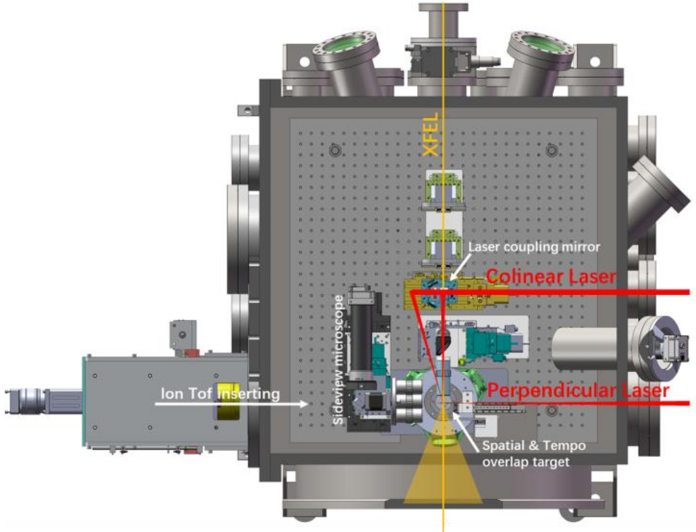
CDS Instrument: Pump Laser and In-coupling

SHINE

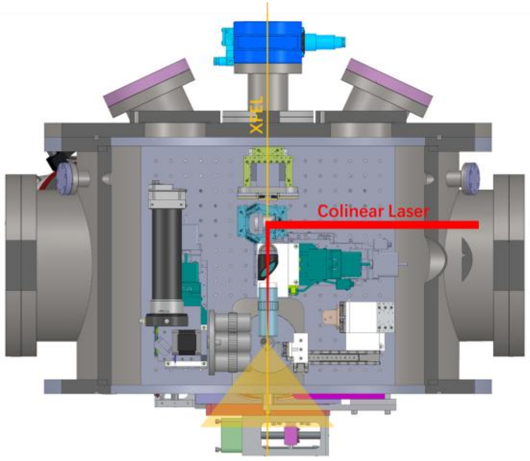
Pump Laser Parameters and Transportation to Hutch

- 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

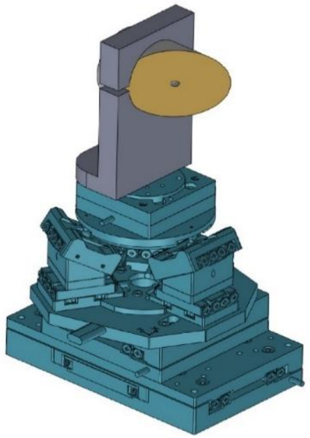




0°~ 15° / 90°



Co-linear



In-coupling to Two Chambers

OAP mirror with taper hole

Dia: 2mm @mirror face

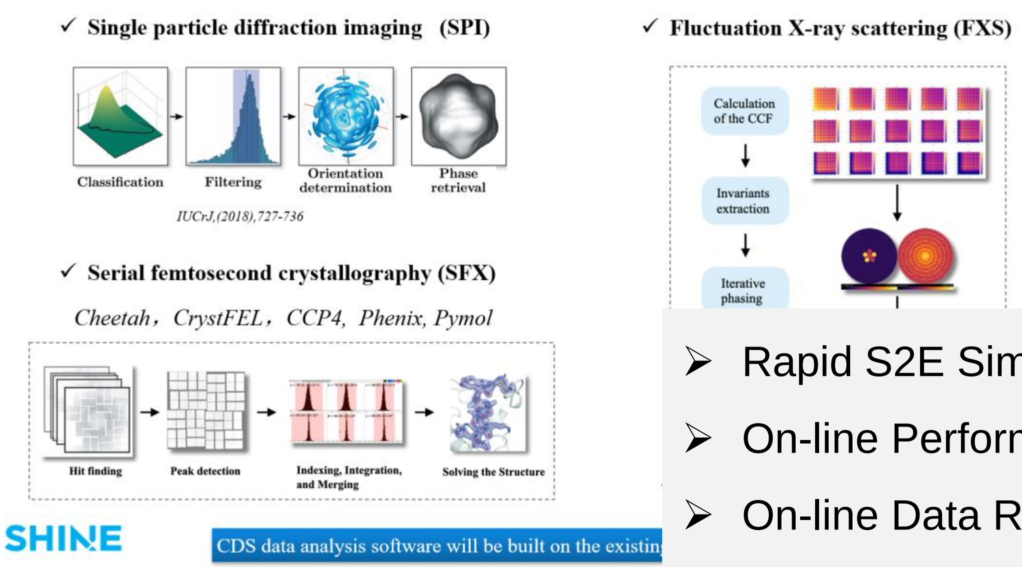
Coating: depend on wav.

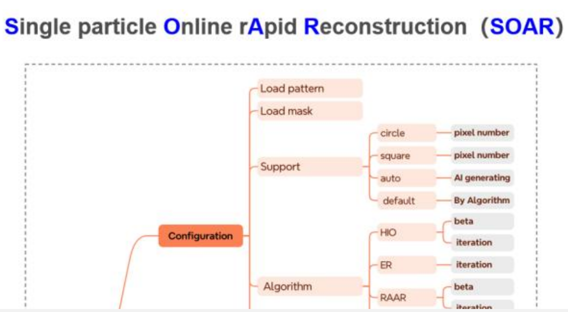
Smaract TRIPOD system

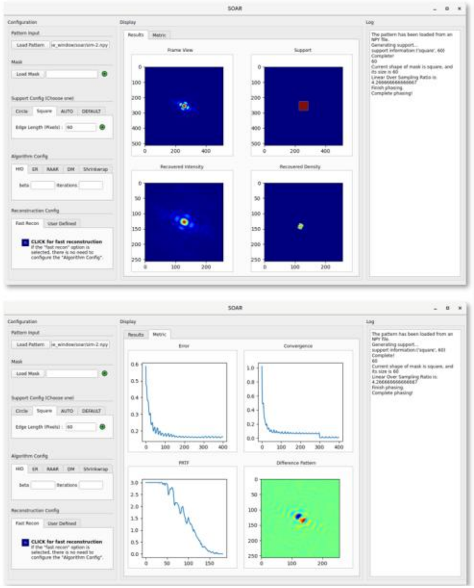
Diagnostics: TT by Diag. Group

CDS Instrument: High-throughput Data Analysis

SHINE





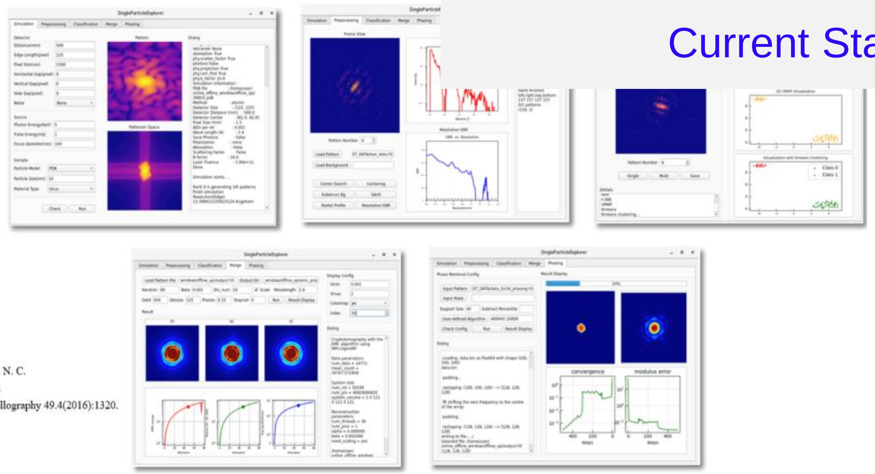


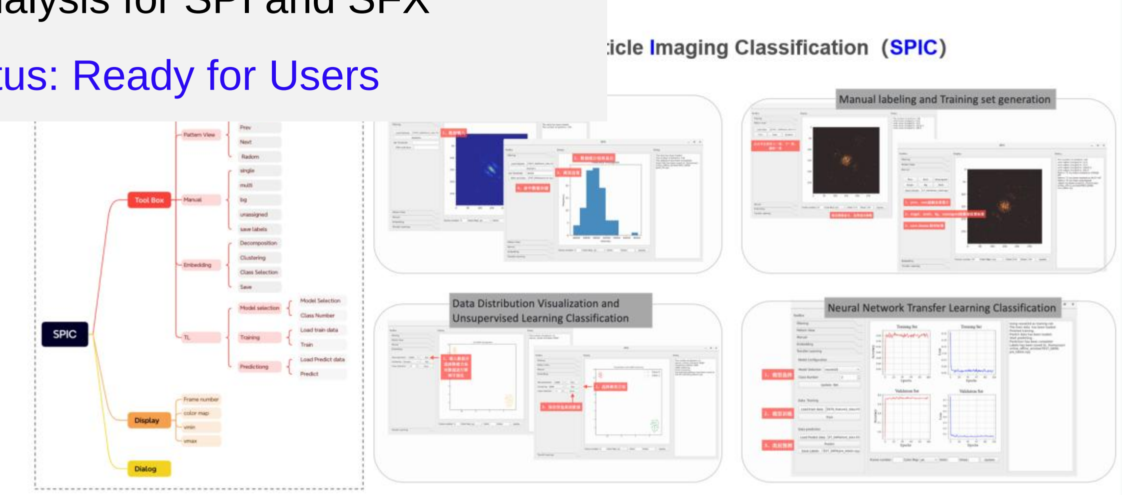
- Rapid S2E Simulations
- On-line Performance and Fast Recon.
- On-line Data Reduction and Classification
- Off-line AI-driven Analysis for SPI and SFX

Current Status: Ready for Users

Single Particle Explorer

- Simulation[1]
- Preprocessing
- Classification
- Merging[2]
- Phase retrieval[3]





[1] Hantke, Max F.Ekeberg, TomasMaia, Filipe R. N. C. Journal of Applied Crystallography 49.4(2016).
[2] Ayyer, Kartik , et al. Journal of Applied Crystallography 49.4(2016):1320.
[3] https://github.com/LiuLab-CSRC/spipy/

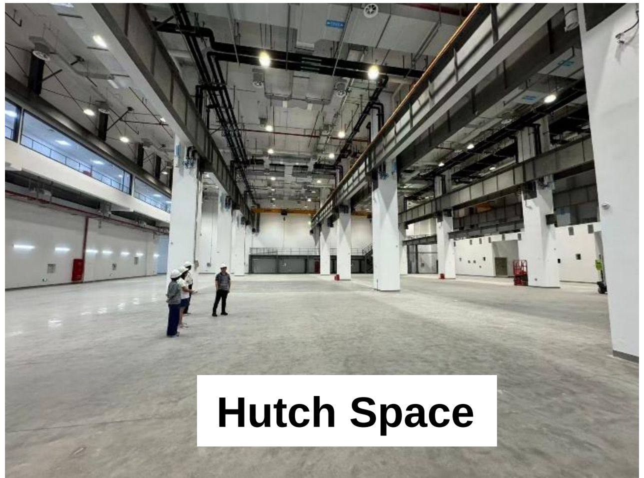
SHINE

Based on the Infrastructure Constructed by GET Depart.

CDS Instrument: Hutch Facilities and MPS, RP & PPS

Hutch Facilities will be ready before June 2026, FDR OK

1. **Power:** 59.6 kW (Maximum with all equipment on, 220V & 380V)
2. **Cable Trays and Feedthroughs:** need further discussions in detail.
3. **Thermal:** 22 ± 0.5 ℃
4. **Water:** Inlet 20℃; Outlet 24℃; Flow 65 L/Min
5. **Air and Gases:** Yes, some gases will be provided and others will be possible with gas cylinder, gas sensor and gas cabinet.
6. **Exhaust:** Yes, based on the national standards.
7. **Lighting:** Yes, control inside and outside of the hutch.
8. **Hutch Cameras:** Yes, planned.
9. **Crane:** Yes, working height 3.2 m, weight load around 2,000 kg.
10. **Control Room:** need further discussion on the exact location.
11. **Anteroom/Storage Cabinet:** limited space within the experimental hall.



Hutch Space

Public Users' Lab is under consideration

1. Bio-chemical Labs,
2. Sample Env. and Injection
3. Final Load and Cleaning

Equipment Protection Systems (MPS)

1. Limit switches and hard stops for equipment + Software Limits;
2. Pressure gauges and interlocks;
3. Torque limiting factors;
4. Prevent the damage from the full beam;
5. Multi-sensors.

Shielding

1. Bremsstrahlung
2. Synchrotron Radiation

PPS (HPS): Keeps people away from beams

1. Access modes
2. Operation modes
3. Operation logic
4. Stoppers

BCS: Keeps beams & radiation away from people

1. Collimators
2. Terminator
3. Photon Dump
4. Ray Trace

Infrastructure Constructed by the Beamline Engineering Depart.

CDS Instrument: Installation and Comm. Plan

SHINE

Installation Phase:

Jun. 2026 to Dec. 2025: FEE, Optical Hutch, Core Instrument, and Auxiliary Equipment.

Commissioning Phase:

1. Jun. 2027 to Aug. 2027: Beamline and FEE instrument
2. Sept. 2027 to Nov. 2027: Endstation equipment with static experiments, test all sub-system.

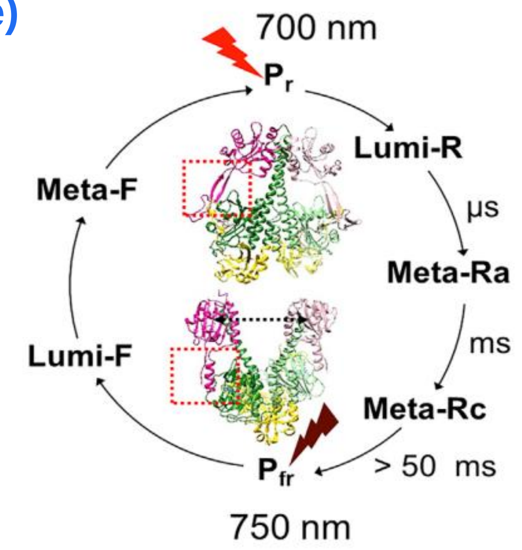
Installation Plan for CDS Instrument- Ver.1.0												
	2026											
Equipment and Functional Modules	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Reference Lasers	Manufacturing-Vendor Testing-Transportation				Arrival	Offline Tests	On-site Installation					
Solid Attennuators	Manufacturing-Vendor Testing-Transportation				Arrival	Offline Tests	On-site Installation					
Compact Differential Puming Section	Manufacturing-Vendor Testing-Transportation					Arrival	Offline Tests		On-site Installation			
High-load Multi-axes Mover System	Manufacturing-Vendor Testing-Transportation						Arrival	Offline Tests		On-site Installation		
Detector Multi-axes and Linear Stages	Manufacturing-Vendor Testing-Transportation						Arrival	Offline Tests		On-site Installation		
Experimental Chambers	Manufacturing-Vendor Testing-Transportation						Arrival	Offline Tests		On-site Installation		
Microscopy Modules inside Chambers	Offline Fabrication-Testing-Storage								Modules Fabrication	On-site Installation		
Piezo AND Step Motors	Manufacturing-Transportation		Arrival	Offline Fabrication-Testing-Storage					Modules Fabrication	On-site Installation		
Laser in-Coupling and Slits Modules	Manufacturing-Transportation		Arrival	Offline Fabrication-Testing-Storage					Modules Fabrication	On-site Installation		
The 1st 4M Jungfrau Detector	Offline Fabrication-Testing-Storage										On-site Installation	
Vacuum System and Pipelines	Offline Fabrication-Testing-Storage									On-site Installation		

Comissionning Plan for CDS Instrument- Ver.1.0												
	2027											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Equipment Functional Tests												
Equipment Conjunction Testing												
Hard-Softwares Comissionning												
Ready for Instrument's First Beam												
Beamline to Instrument Comissionning												
Self-testing Period												
Commettee Testing												
Final Acceptance On-site Testing												★

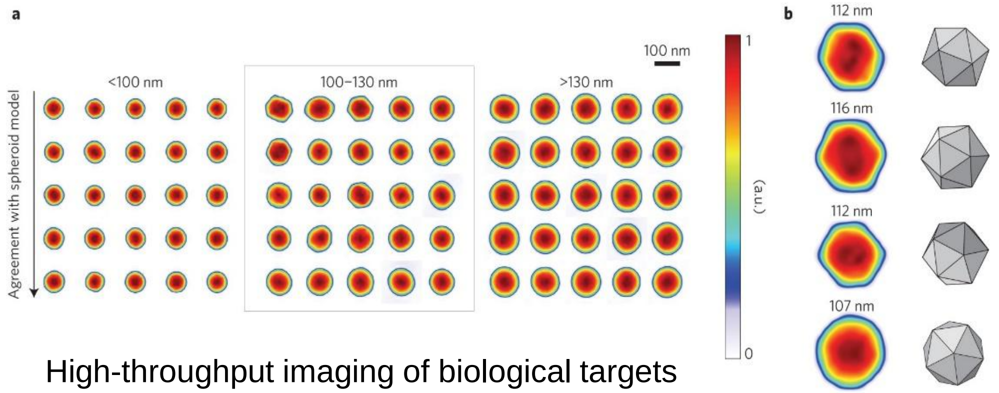
CDS Instrument: Early Science/Pilot Experiments

Potential Pilot Experiments **(Domestic and International Collaboration, Ideas are welcome)**

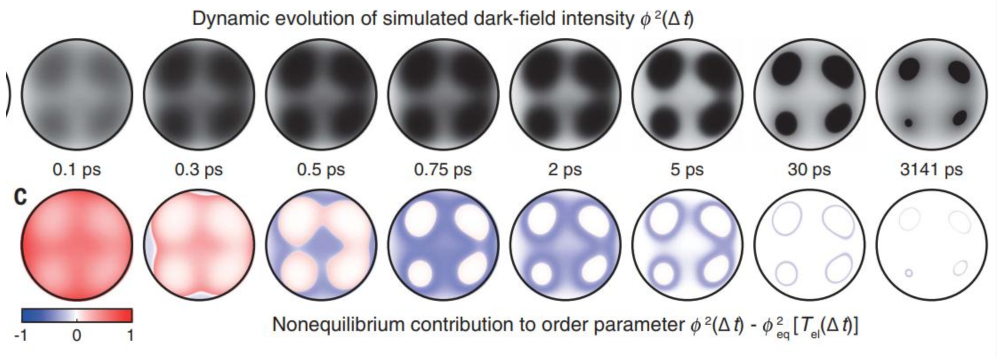
1. High-throughput imaging of biological particles with aerosol injector (100-1000 Hz).
2. Ultrafast imaging of Light-induced Melting of Metal-Metal Complex Structures.
3. Dynamic Structure Change of Receptors (UVR8, PhyA, PhyB, etc).



Dynamic Structural Changes for Receptors
Structure **29**, 743 (2021).

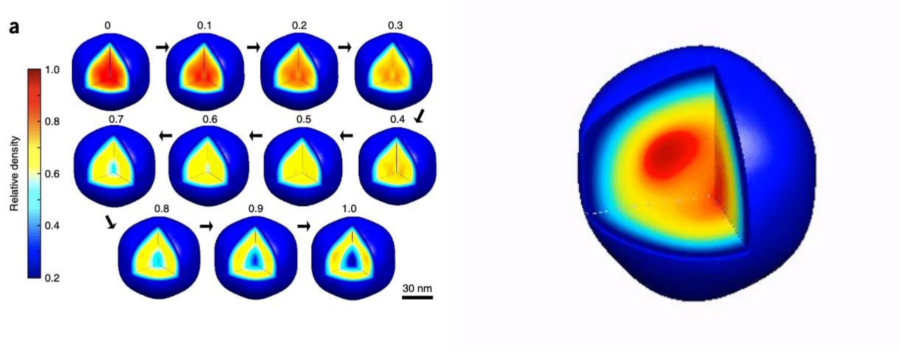


High-throughput imaging of biological targets
Nat. Photon. **8**, 943 (2014)



Ultrafast nanoimaging of the order parameter in structural phase transition

Science **371**, 371 (2021)



Nature Methods, **14**, 877 (2017)

CDS Instrument: The Core Team *

Dr. Zhibin SUN (Associate Scientist, Group Leader)
- Coordination, Construction-Commissioning-User Operation;
- Science Cases, International Collab., In-house Research;
- Core Instrument, Sample Injectors, and Data Analysis.

Dr. Qing XIE (Associate Scientist)
- User Coordination, Operation;
- Core Instrument, Diagnostics;
- Pump Laser and Hutch Facilities.

Dr. Chenxi WEI (Assistant Scientist)
- Sample Environment and Delivery Labs;
- Sample Injectors, Offline Sample Injection Testing;
- User-defied Sample Delivery Systems.

Dr. Menglu HU (Assistant Scientist)
- DAQ, Online and Offline Data Analysis;
- Big Data, Computing, and AI for Science;
- Remote Calculation Supporting, Softwares.

Dr. Jianhua Zhang (Assistant Scientist)
- Ptychography, nano-beam characterization;
- Methodology Development.

Mr. Yonggan NIE (Engineer)
- Control (EPICS);
- Interface for User Instrument.

The WBS: around 5.2 Man-Month

* Collaboration with multiple technical groups

FEL-I Depart.: Challenges and Risk Management

SHINE

Challenges:

1. Vibration influence to the beam at Interaction Points, especially for 100 nm focus at CDS.
2. Limited commissioning time for touching the final acceptance goal for FEL-I Instrument.

Risks:

1. **Thermal Issues:** Some components only work well under low frequency, high frequency version is still on the way.
2. **Vibrations:** The vibration condition is hard to judge: rivers, roads, metro go across above the tunnel.

Risk Management:

1. Taking advantages of user consortium and SAC, TAC members.
2. Collaborate with multiple groups.

What's the most efficient way to transfer from comm. to early operation?

Acknowledgement (HSS Instrument)

SHINE

We are deeply thankful to our collaborators and to the many experts whose insightful suggestions were pivotal to the successful establishment of our experimental end station!

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- Yongfeng Hu, SINOPEC
- Yohei Uemura, EuXFEL
- Yuhui Dong, IHEP, CAS
- ……

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Early Phase Conception (Since July 2017):

Dr. Andrew Aquila, SLAC
Prof. Christoph Bostedt, EPFL & PSI
Dr. Sebastien Boutet, SLAC
Prof. Adrian Mancuso, Diamond (*EuXFEL*)

Physical Design Review (Sept. 2022):

Prof. Adrian Mancuso, Diamond (*EuXFEL*)
Prof. Filipe Maia, Uppsala U
Prof. Changyong Song, POSTECH
Dr. Makina Yabashi, RIKEN Spring-8 Center

Technical Design Review (Apr. 2024):

Prof. Christoph Bostedt, EPFL & PSI
Dr. Richard Bean, EuXFEL
Dr. Chan Kim, EuXFEL
Prof. Filipe Maia, Uppsala U
Dr. Daewoong Nam, PAL-XFEL
Prof. Yoshinori Nishino, Hokkaido U.
Prof. Changyong Song, POSTECH
Dr. Xinhua Xie, SwissFEL

The SHNE and BE SHINE Management Board & Office

(Prof. Z. Zhao, Mr. H. Ding, Prof. Z. Liu *etc*)
FEL-I Dept. (Prof. H. Jiang, *etc*)
FEL-II Dept. (Dr. M. Wang, *etc*)
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The Beamline Technology Dept. (Dr. Yong Wang, Dr. X. Dong, *etc*)
The Beamline Engineering Dept. (Dr. J. Chen, *etc*)
Beamline Design Group (Dr. Y. Tong, *etc*)
Detector Group (Dr. T. Wang, Dr. S, Zhang, Dr. X. Ju, Dr. J. Xia , *etc*)
Laser Group (Dr. J. Jiang , *etc*)
Diagnostic Group (Dr. Z. Guo, Dr. Z. Xu, Dr. M. Ye, *etc*)
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The Mechanical Group (Dr. G. Zhao, *etc*)
The Vacuum Group (Dr. J. Liu, *etc*)
The Control Group (Dr. Y. Zhao, *etc*)

Thanks to all related technical groups and staffs not mentioned specifically

Our Collaborators and Vendors… + NOW OUR TAC MEMBERS

Thank you for your attention!