

Latest Progress, Commissioning Plan and Scientific Experiment Planning in Spectrometer for Electronic Structure (SES) Endstation

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On behalf of SES Group

Oct. 20, 2026

Outline

- Construction Process of SES in the past half year
- Design of Pump-Probe Laser Systems in SES
- Scientific Experiment Planning

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Progress since the 3rd TAC meeting

SES has moved from installation into integrated commissioning

June–July

TAP bakeout completed
NEG pumps activated
main-chamber bakeout
reached 2×10^{-10} mbar



TAP commissioning

August

First **ARPES** band structure
from **low-temperature** tests



Beamline connection
between SES-KB and TAP

Early September

Beamline of SES section
fully connected under
vacuum



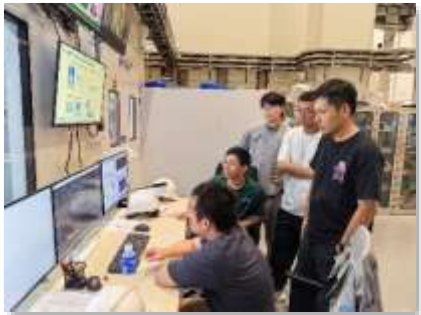
PEM integration

End-September

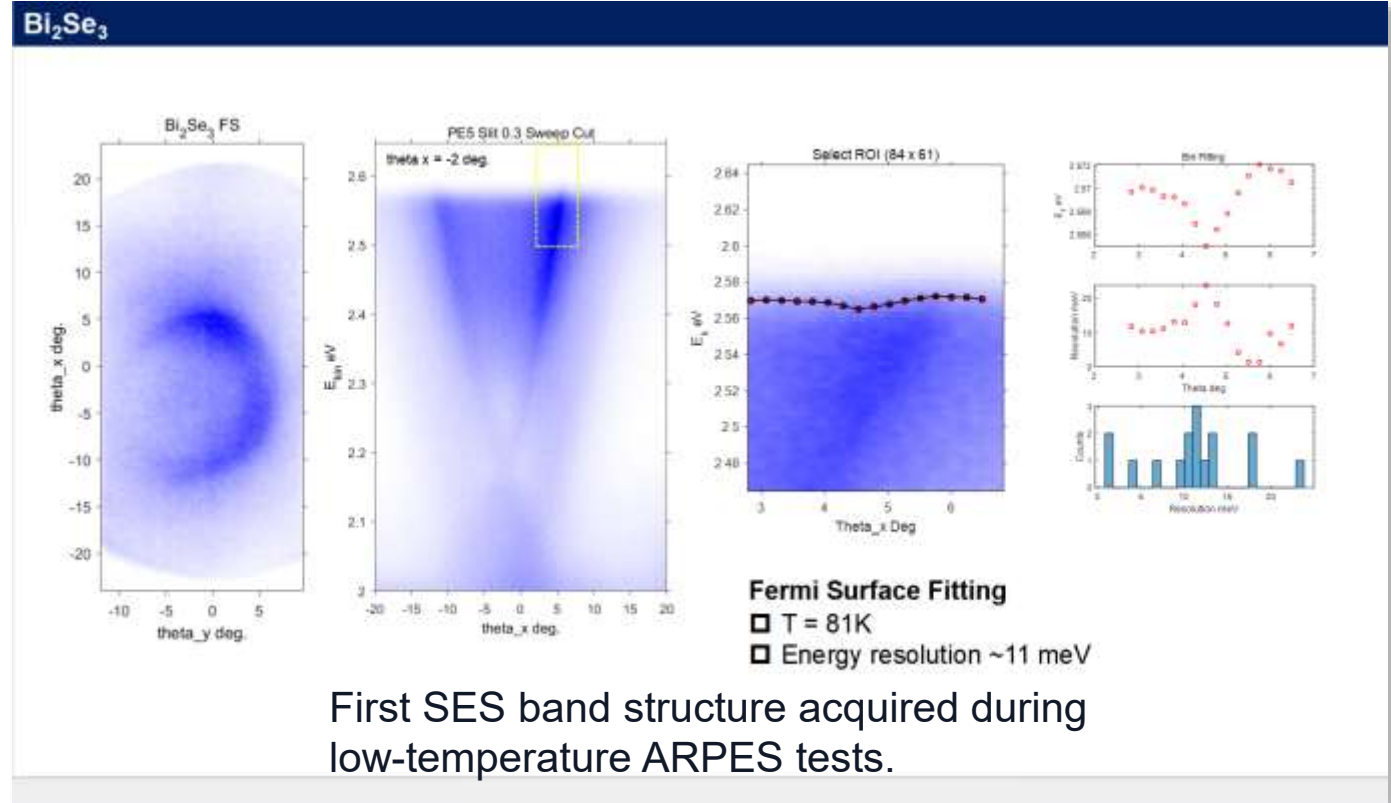
Main chamber, **LENS** and **TOF**
of PEM have been installed.
main-chamber bakeout
reached 3×10^{-9} mbar

TAP low-temperature ARPES tests – 19-20/August

Parameter	Setting / result
Light source	177 nm laser
Test samples	Bi ₂ Se ₃ single crystal Au foil
Test temperature	≈ 80 K
Energy resolution	10 – 15 meV (preliminary results)



Bi₂Se₃ Fermi surface and energy-resolution analysis



- ✓ Spectrometer Performance,
- ✓ Sample-manipulator Cooling and Motion,
- ✓ Data-acquisition Software

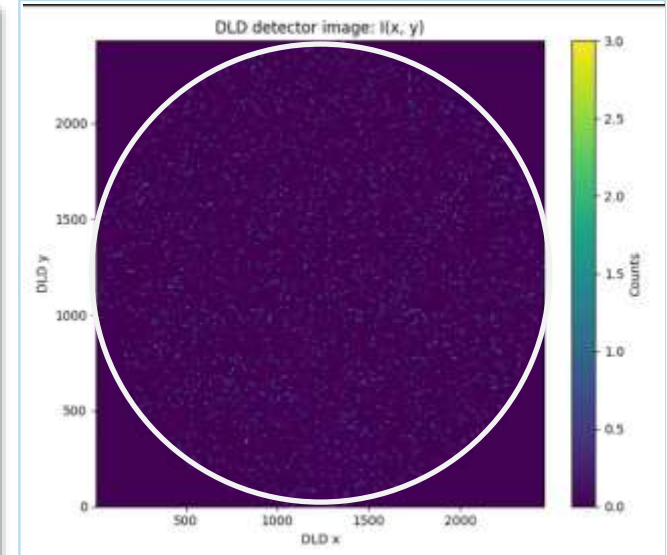
PEM subsystem integration

Integration status

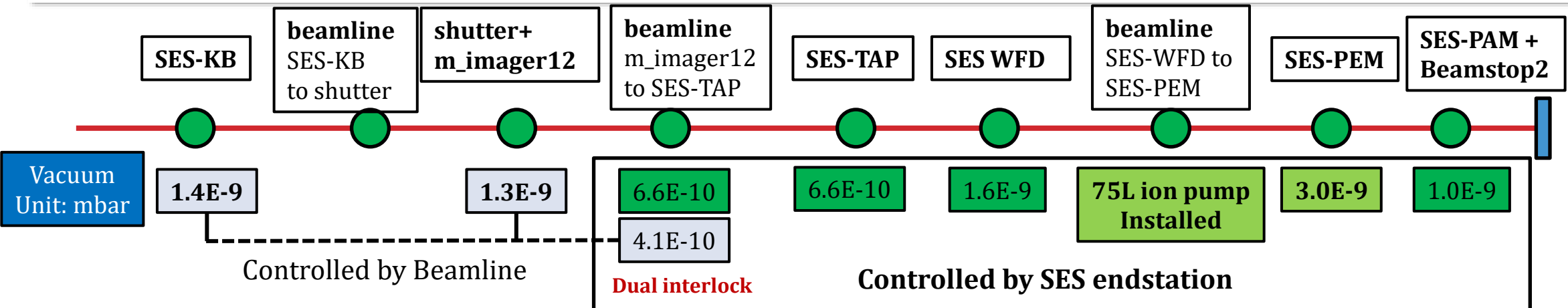
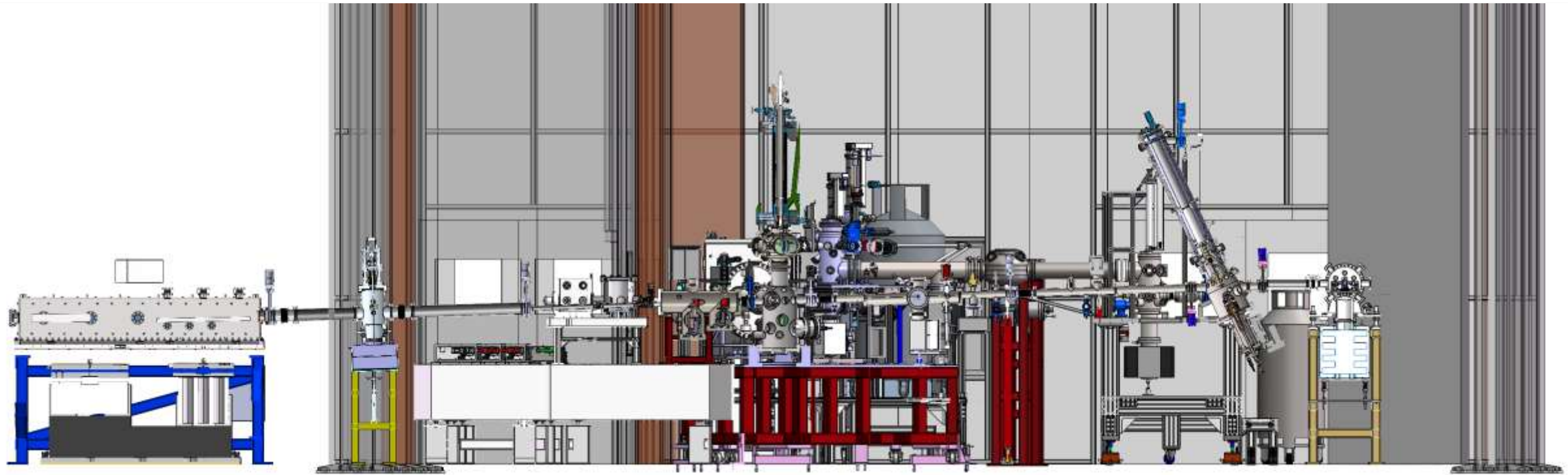
- The double-shielded main chamber completed a 120 °C bakeout and reached 3×10^{-9} mbar without the 500 L/s ion pump or NEG pumps
- TOF and electrostatic-lens assembly entered the final stage
- Cryogenic multi-axis sample manipulator assembled; offline motion tests started



TOF and electrostatic-lens assembly in progress



Beamline, vacuum and control readiness

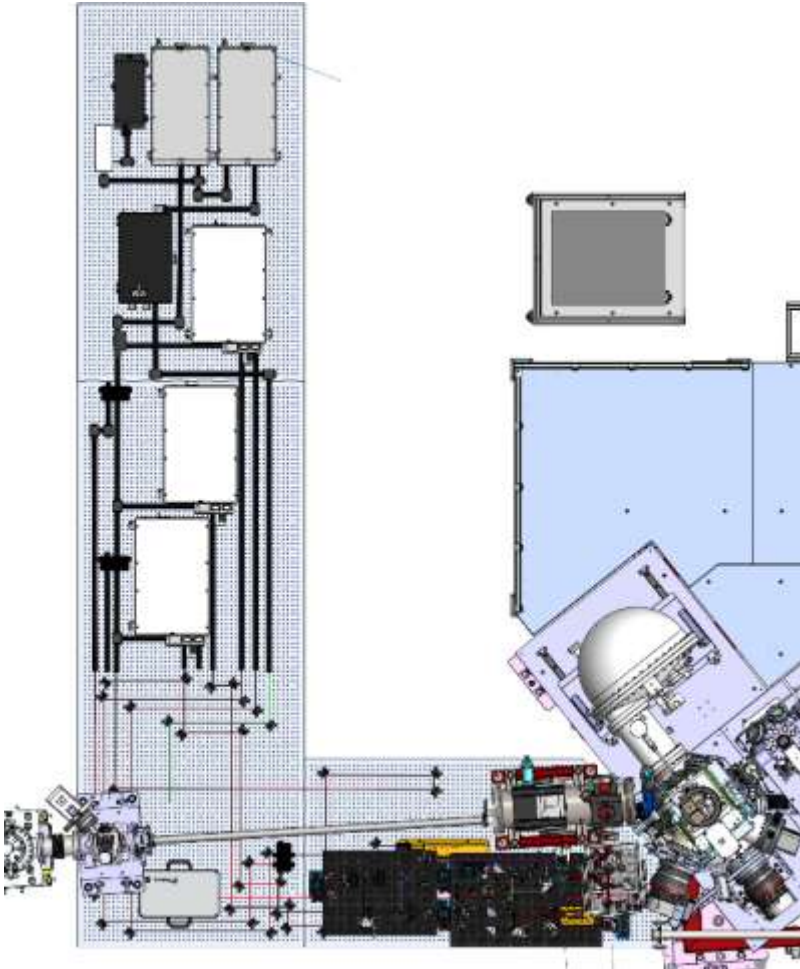


Outline

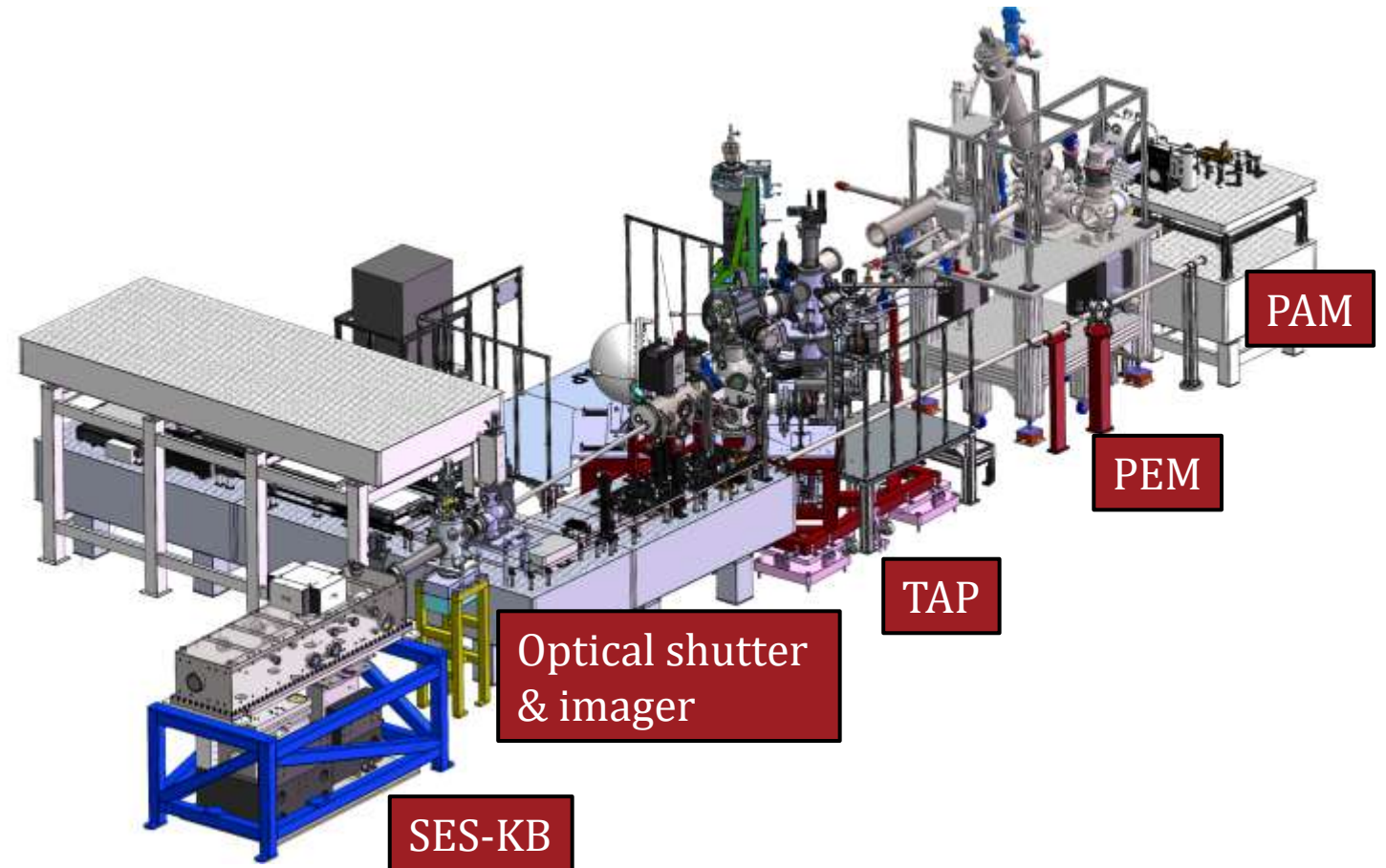
- Construction Process of SES in the past half year
- Design of Pump-Probe Laser Systems in SES
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Overview of the Laser Systems

- 1st level: LC carbide for 1030+5X, THz, HHG



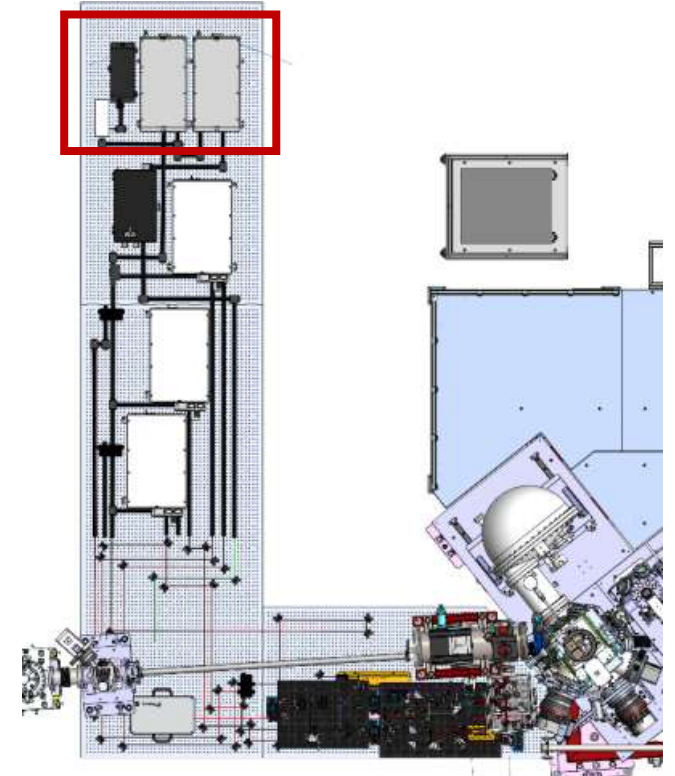
- 2nd level: 100W 1030nm in SHINE (laser group), for XFEL-pp and PAM



Lower level: Laser Sources (LC carbide X2 + OPA X3)

■ 2X LC carbide

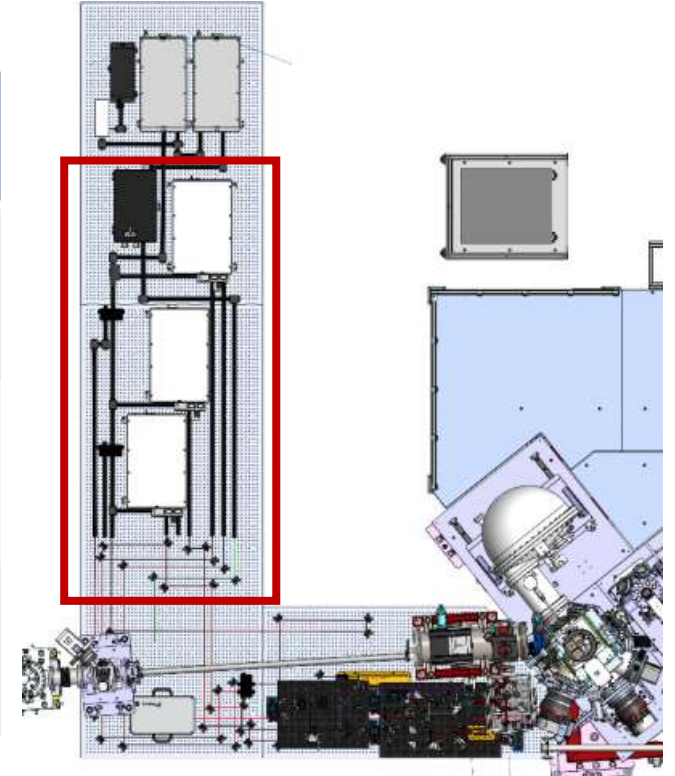
Name	Model	Repetition rate	Pulse duration	Pulse energy	Power
Master CB3	Carbide	200 kHz	250 fs	145 μ J	29 W
Slave CB3	Carbide	200 kHz	250 fs	145 μ J	29 W
	Flint	60-100 MHz	100 fs	12.5 nJ	1 W



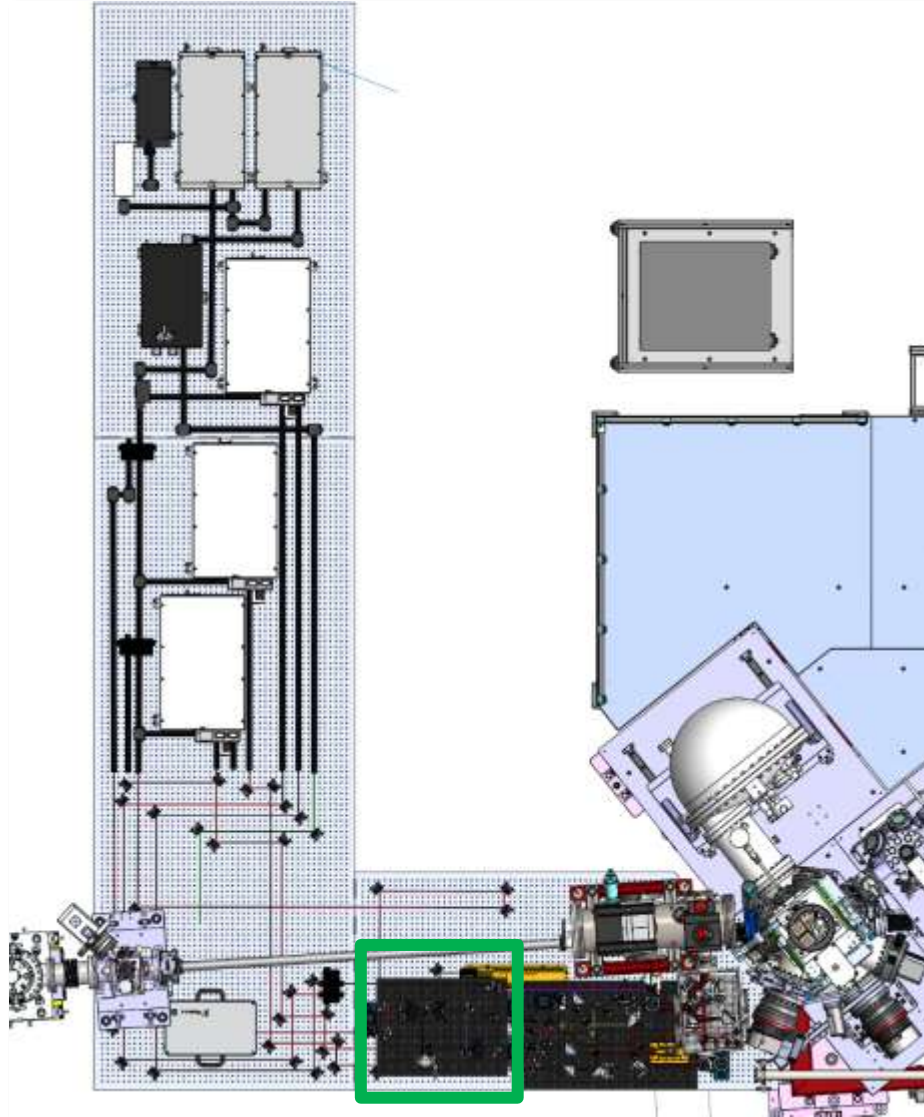
Lower level: Laser Sources (LC carbide X2 + OPA X3)

■ 3X OPA

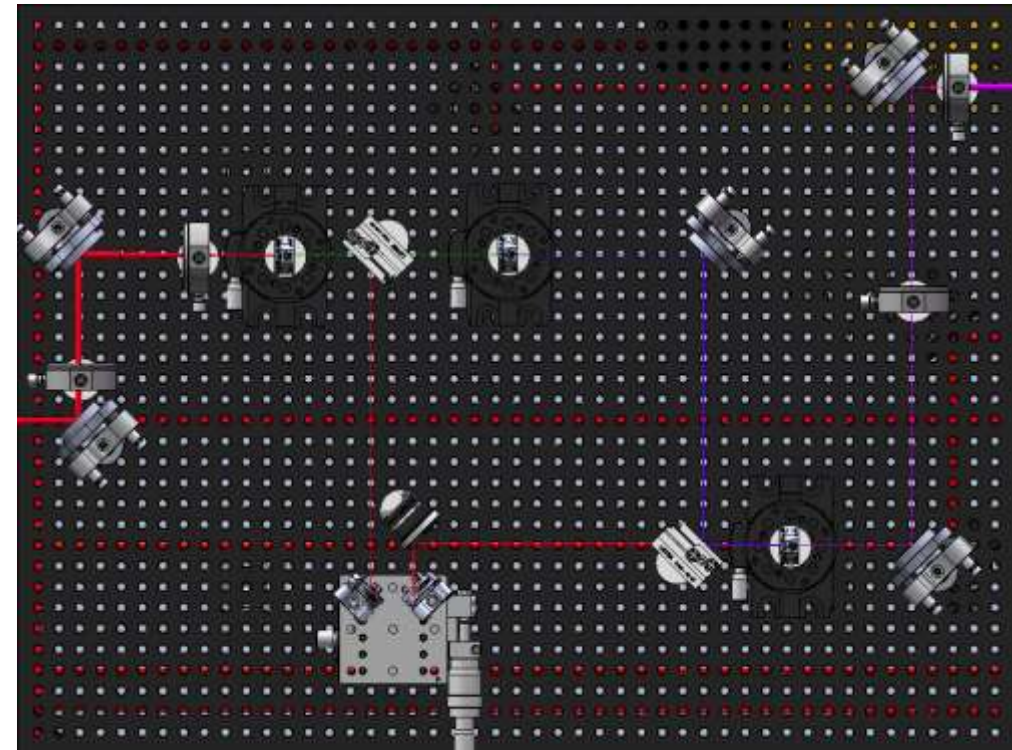
Name	Model	Repetition rate	Wavelength range
OPA-1	ORPHEUS-NEO-ONE	200 kHz	640 - 1000 nm, 1050 - 1350 nm 1350 - 2000 nm, 2100 - 4200 nm 4 - 16 μm (> 19 THz)
OPA-2	ORPHEUS-NEO-ONE	200 kHz	640 - 1000 nm, 1050 - 1350 nm 1350 - 2000 nm, 2100 - 4200 nm
OPA-3	ORPHEUS-NEO (SHG)	200 kHz	320 - 2600 nm



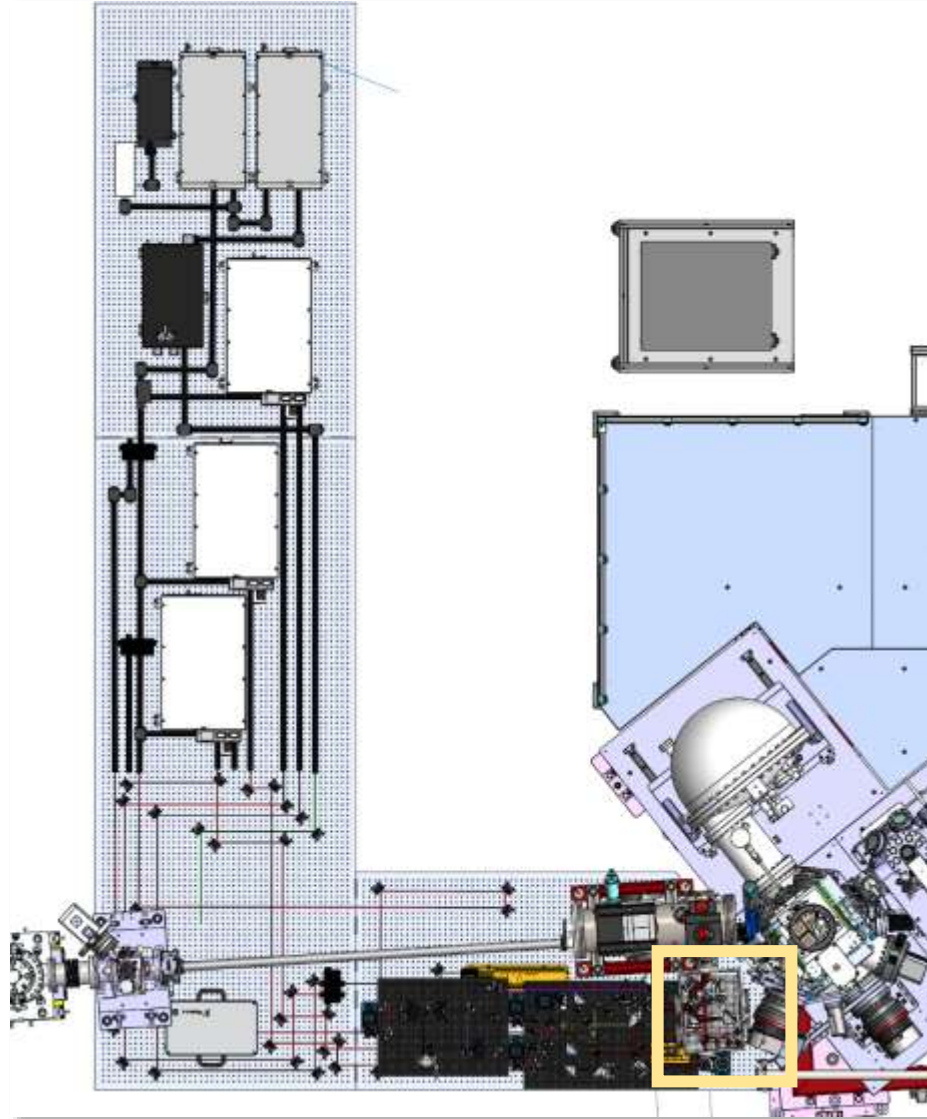
FiTH of 1030 nm



Wavelength	Repetition rate	Pulse duration
~206 nm (~6 eV)	200 kHz	< 60 fs

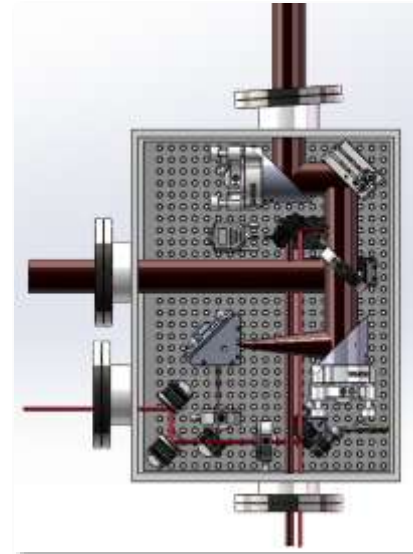


Optical Rectification – OR-THz

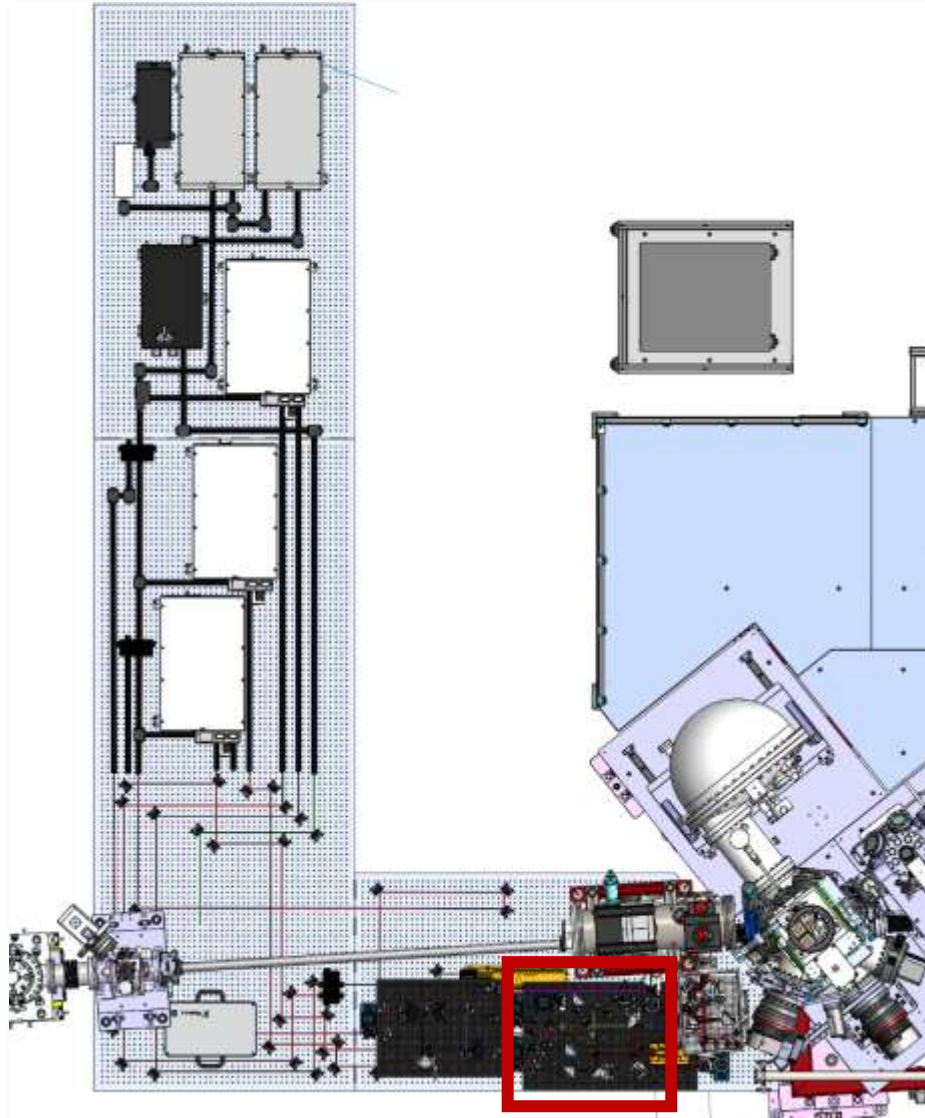


THz range	Repetition rate	Electric field	Crystal
1-4 THz	200 kHz	> 100 KV/cm@2 mm (spot size)	BNA (cooling)
1-4 THz	200 kHz	> 200 KV/cm@2 mm (spot size)	ZGP

Estimated performance

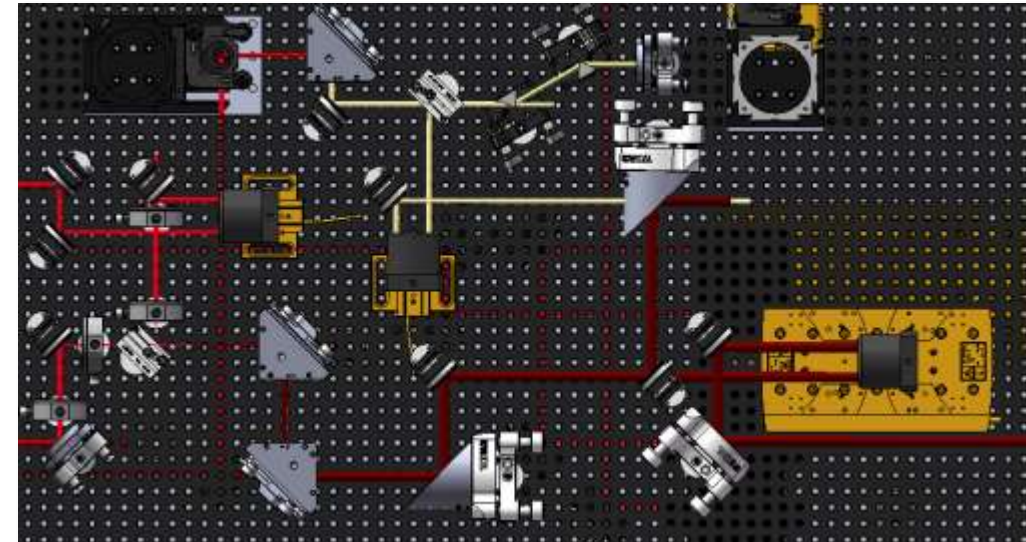


Difference Frequency Generation – DFG-THz



THz range	Repetition rate	Electric field	Crystal
12-42 THz	200 kHz	> 100 KV/cm@500 μ m (spot size)	GaSe
4-18	200 kHz	> 100 KV/cm@500 μ m (spot size)	Organic crystal (cooling)

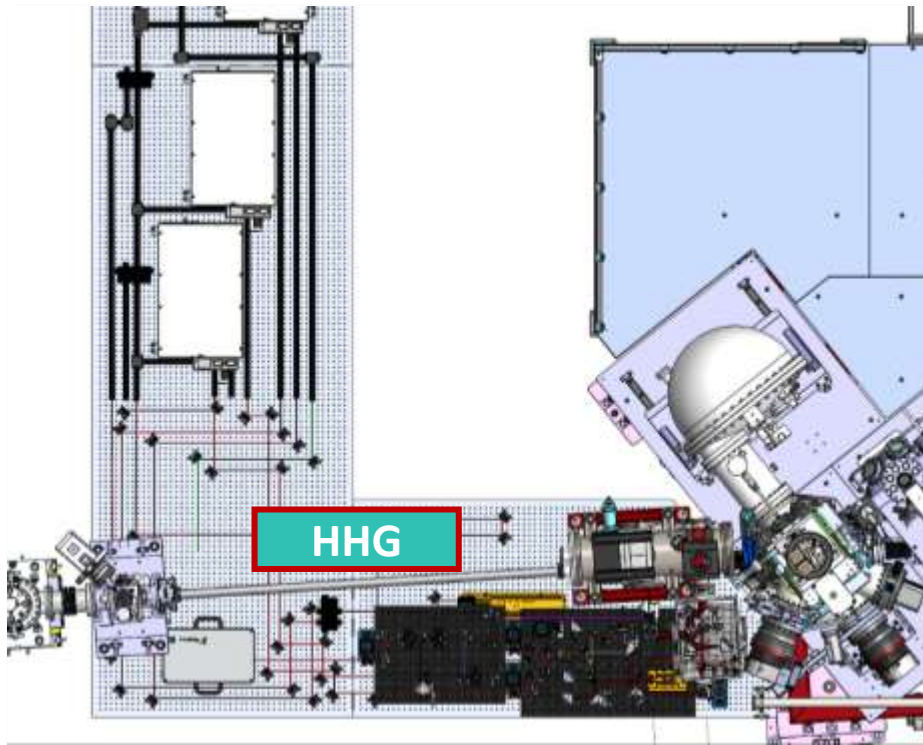
Estimated performance



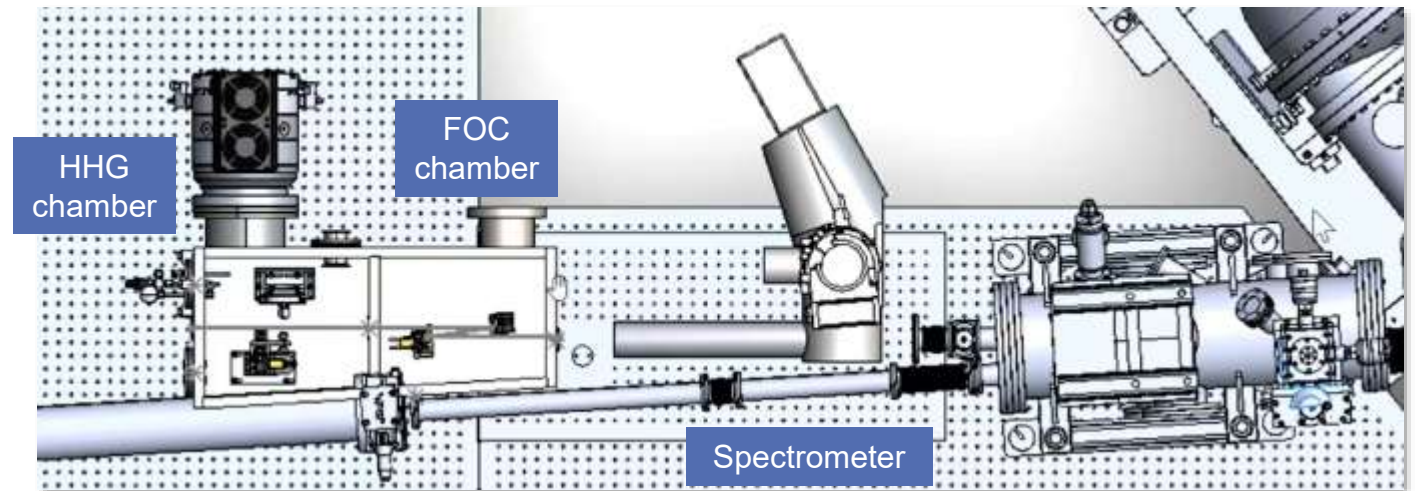
High Harmonic Generation (HHG) from AFS Jena

Photon Energy	Repetition rate	Pulse duration	Energy resolution	Pulse intensity	Focusing beam size
26.6 eV	200 kHz	< 150 fs	150 meV	2E+10 photon/s @ focusing point	< 150 μm

Parameters in Design

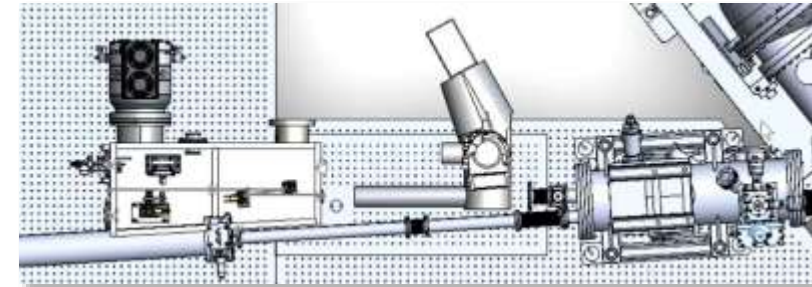
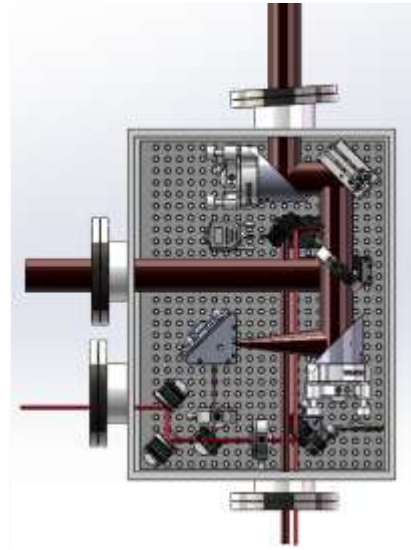
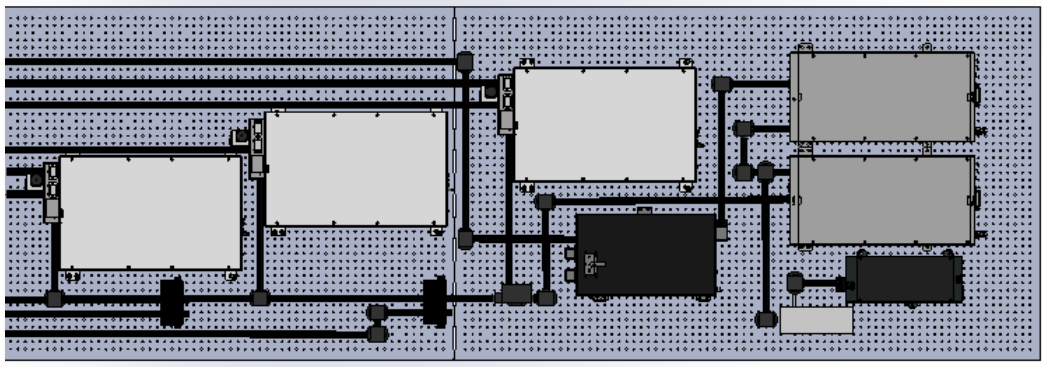
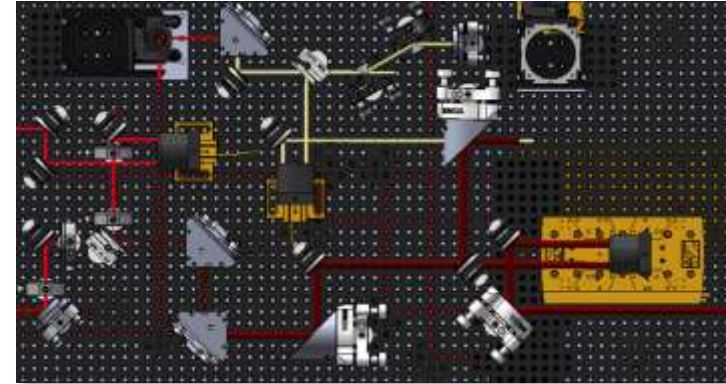
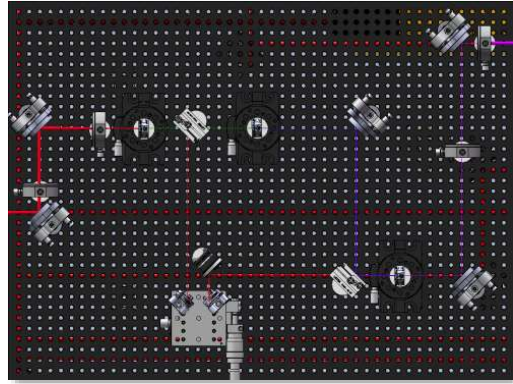


The final version (third version) of HHG drawing



Timeline of LC Carbide Driving Laser Systems

LC carbide Arrival
EST: 2026.12



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Main parameters of XFEL at different stages

	XFEL delivery	FAT test	Initialize experiments	diagnostic tools
Date	2026.11	2027.12	2028	
Photon energy (eV)	200	200	200	Energy analyzer
Beamspot size (um)	20 μm	10 μm	10 μm	Imager or knife edge
Pulse duration (FWHM-fs)	50	50	50	None
Band width (FWHM- %) @ 200eV	0.5	0.25	0.2 (required)	PES
Energy resolution (pink)	1eV @ 200eV	500meV @ 200eV	50-100meV @ 200 eV (200 Line mono) (required)	PES
Energy resolution (mono 200 Line)			<100 meV	
Jitter (fs)		< 50	< 30 (required)	PAM (offline)
Repetition rate	10 Hz	(unknown)	100 kHz	
Pulse Energy (source point)	10 μJ	10 μJ	10 μJ	GMD+HAMPS
Time resolution	80 fs (pink) Specs in FAT	60 fs (pink) Specs in design	< 200 fs (200 Line mono)	
Experimental plan	- Temporal & spatial alignment - Check the Photon Energy of XFEL	First PES spectra of standard samples	CDW materials TI materials for benchmark	

■ External Seeding Mode is very beneficial for ARPES instruments.

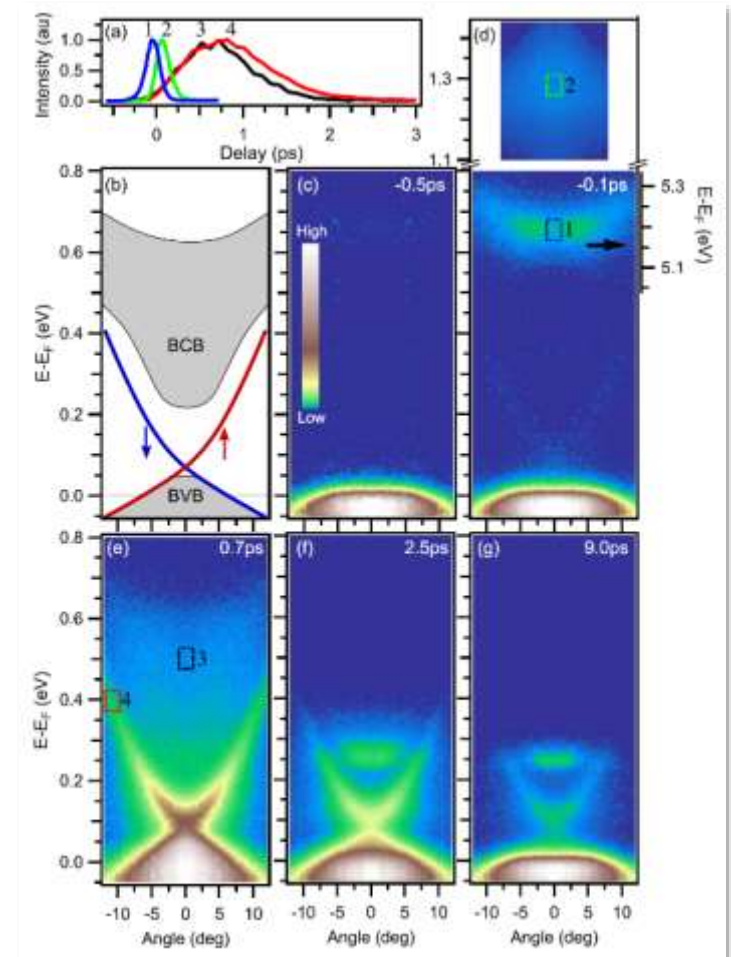
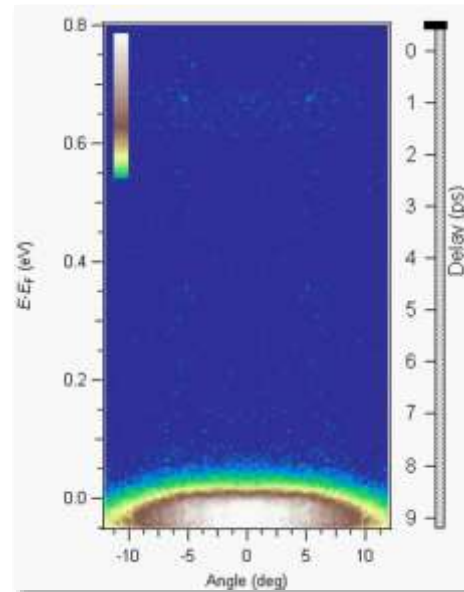
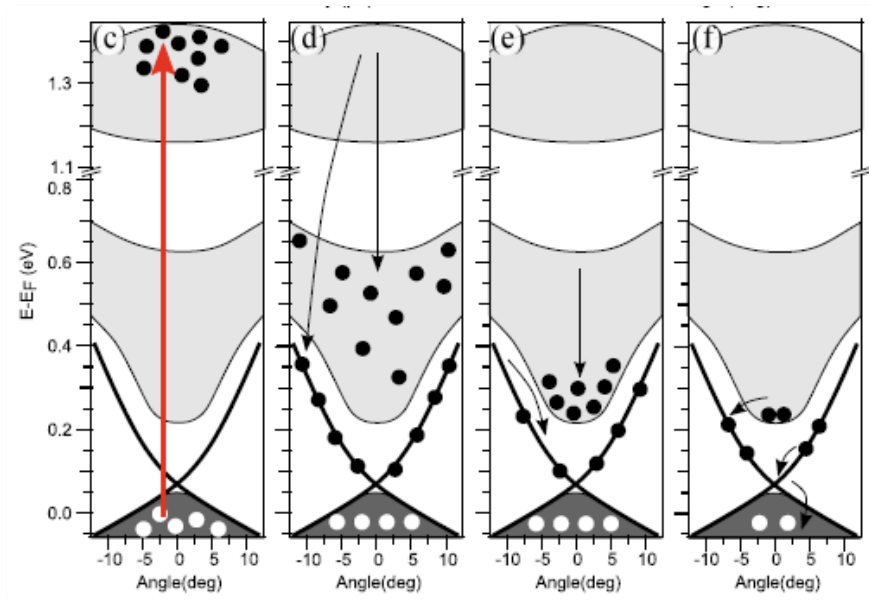
SES Commissioning: Rep-rate 10 ~ 50 Hz

- **Photon-energy calibration** across 0.2–3 keV.
- **Monochromator resolution / bandwidth test.**
- **Flux and transmission measurement** vs energy.
- **Spot size and focal position** at the sample.
- **Timing-jitter characterization** between pump laser and XFEL.
- **Detector linearity / MCP-analyzer response / dead-time checks.**
- **Space-charge test:** linewidth and Fermi-edge broadening vs pulse energy.
- **Pump–probe timing scan** on a benchmark sample with a large response.
- **Damage threshold / charging threshold / drift tests.**
- **Pulse-to-pulse normalization workflow** using gas monitor / intensity monitor signals.

SES Commissioning: Rep-rate ~ 100 kHz

Test on benchmark sample to
Determination of temporal, momentum and energy resolution

Usual and Topological bands' dynamics

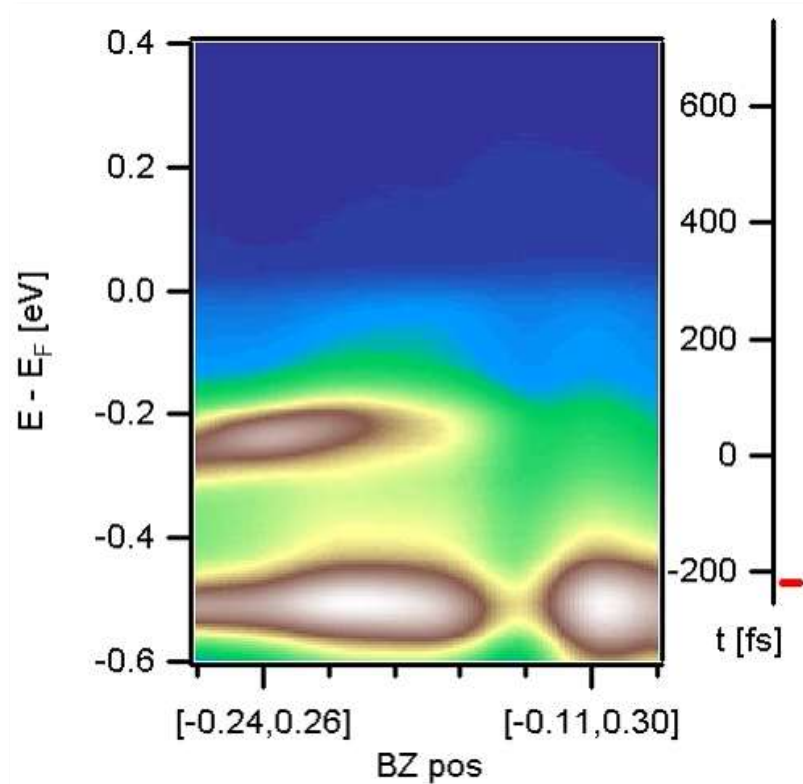


J. Sobota, et al. Phys. Rev. Lett. **108**, 117403 (2012)

SES Commissioning: Rep-rate ~ 100 kHz

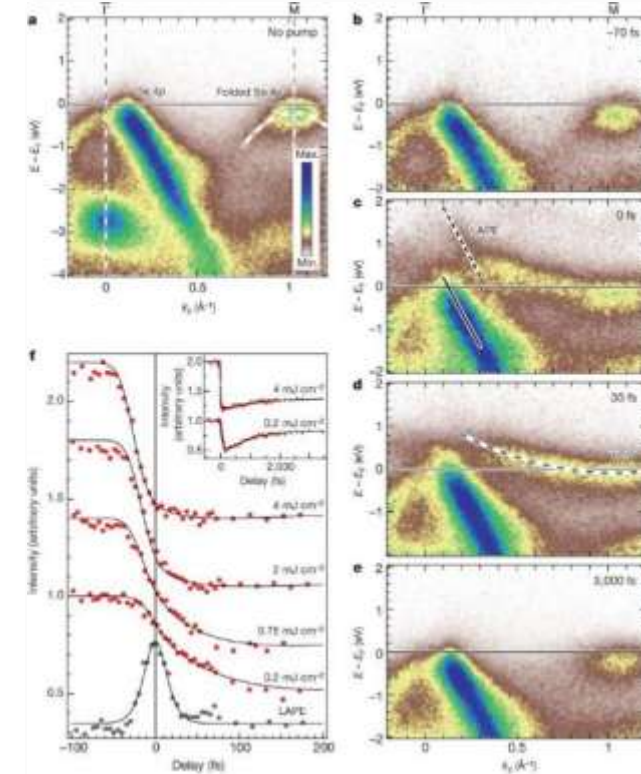
Test on benchmark sample to Determination of temporal, momentum and energy resolution **Ultrafast Charge Ordering Dynamics**

Charge ordering dynamics TbTe_3



F. Schmitt, et. al., Science, 321, 1649 (2008)

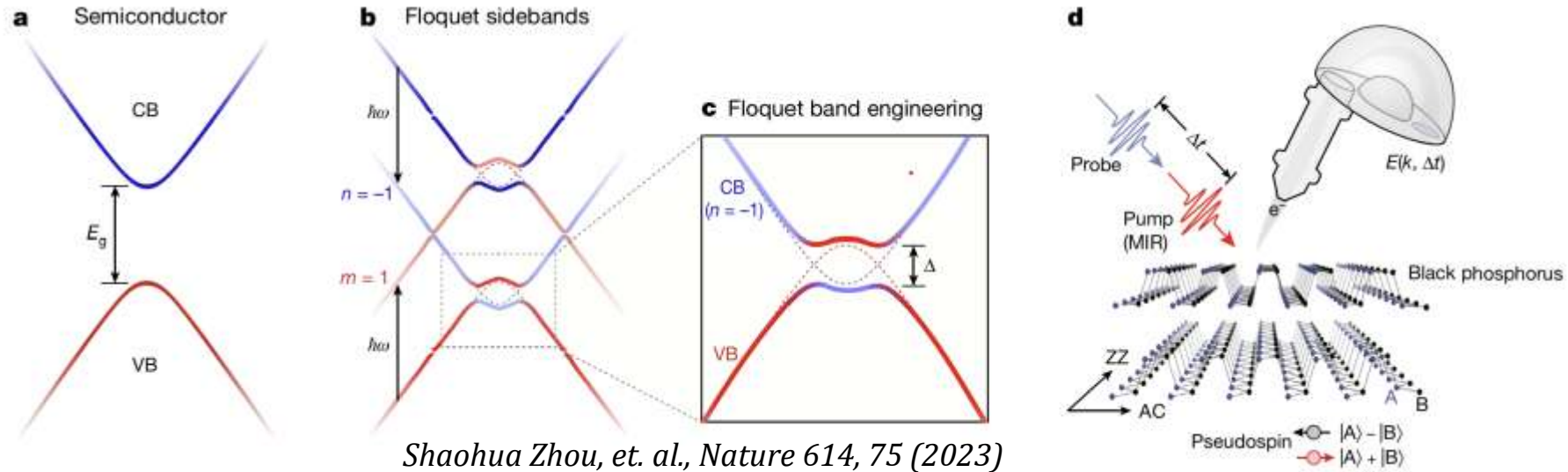
Charge ordering dynamics 1T-TiSe_2



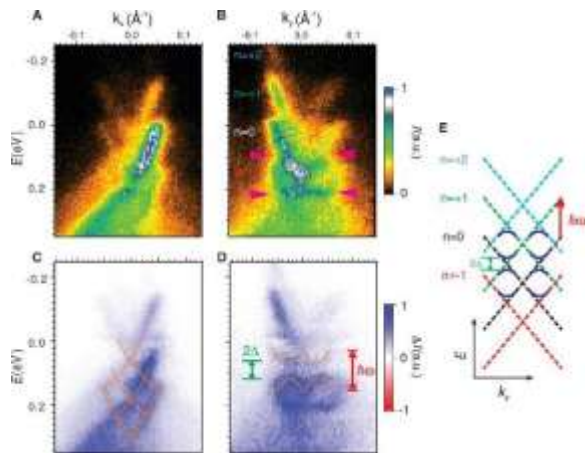
T. Rohwer, et.al., Nature, 471, 490 (2011)

SES Commissioning: Rep-rate ~ 100 kHz

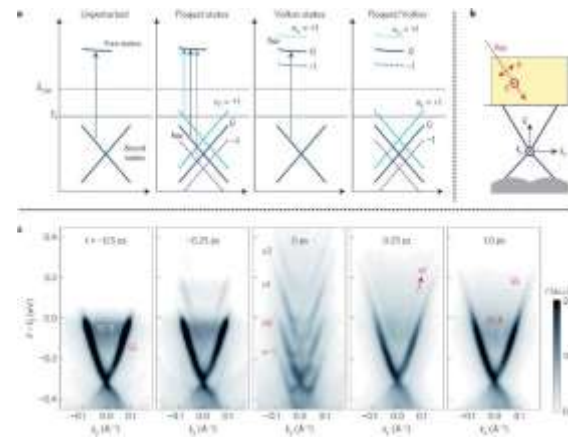
Floquet Physics & Engineering



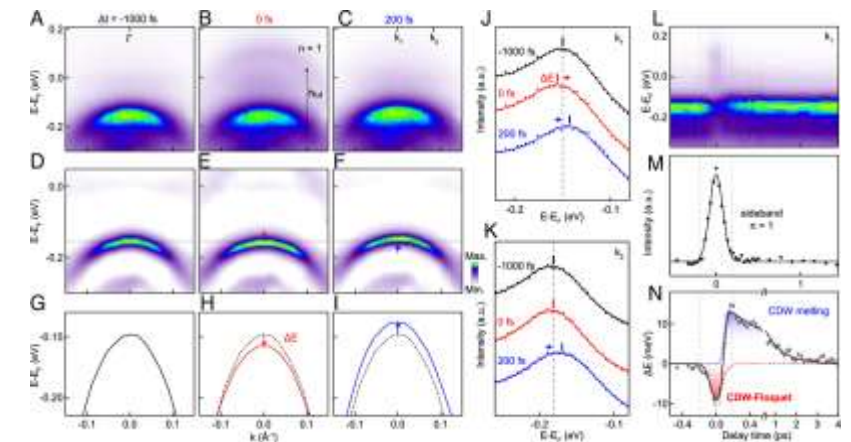
Shaohua Zhou, et. al., Nature 614, 75 (2023)



Y. Wang, et. al., Science, 342, 453 (2013)



F. Mahmood, et. al., Nature Physics, 12, 306 (2016)



Fei Wang, et. al., PANS, 123, 24 (2026)

THz Science: THz-driven Dirac Currents in Bi_2Te_3

Bi_2Te_3 at 80 K. In-plane THz field ≈ 2.4 kV/cm. UV probe: 201 nm, 100 fs.

THz field reversal switches Dirac occupations

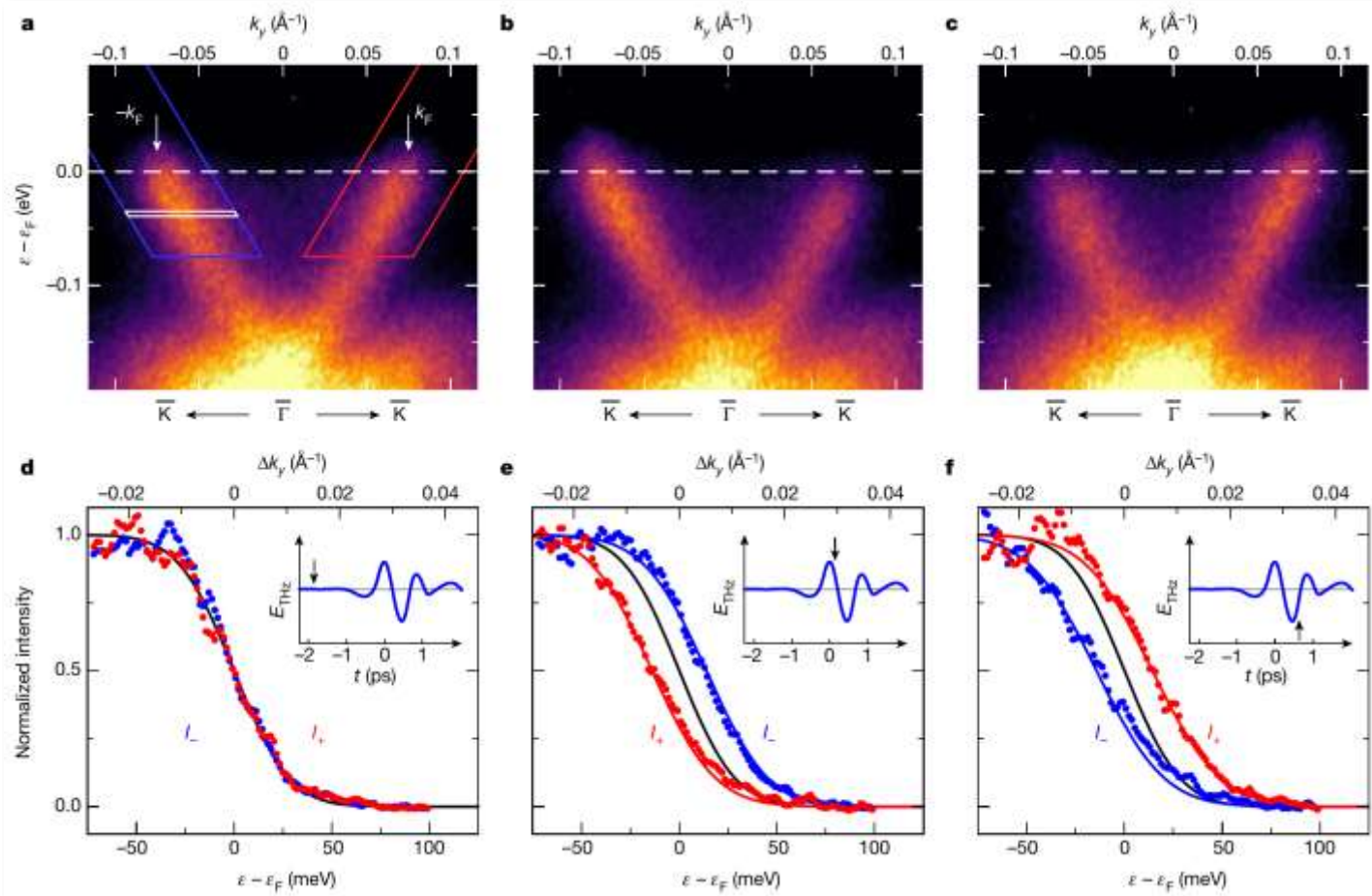


Fig. 3. Momentum distributions and Boltzmann fits

Nearly ballistic surface current

≈ 2 A/cm

Peak surface current density

Scattering times > 1 ps (model)

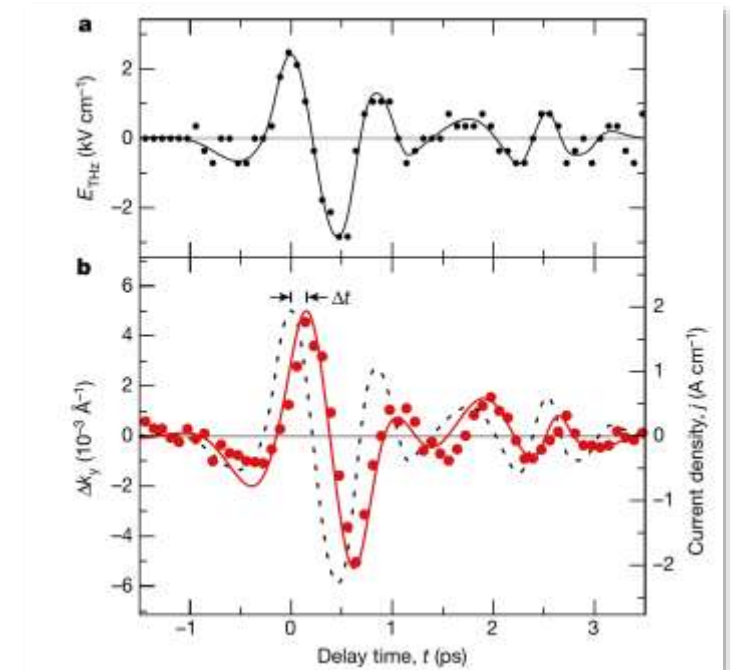
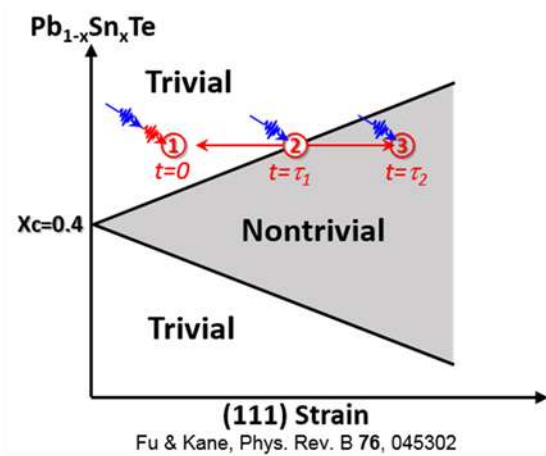


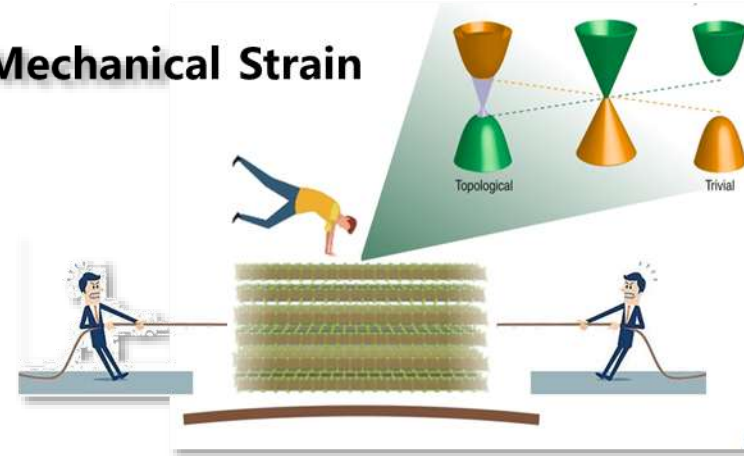
Fig. 4. Subcycle current reversal

THz Science: Ultra-fast Topological Phase Transition

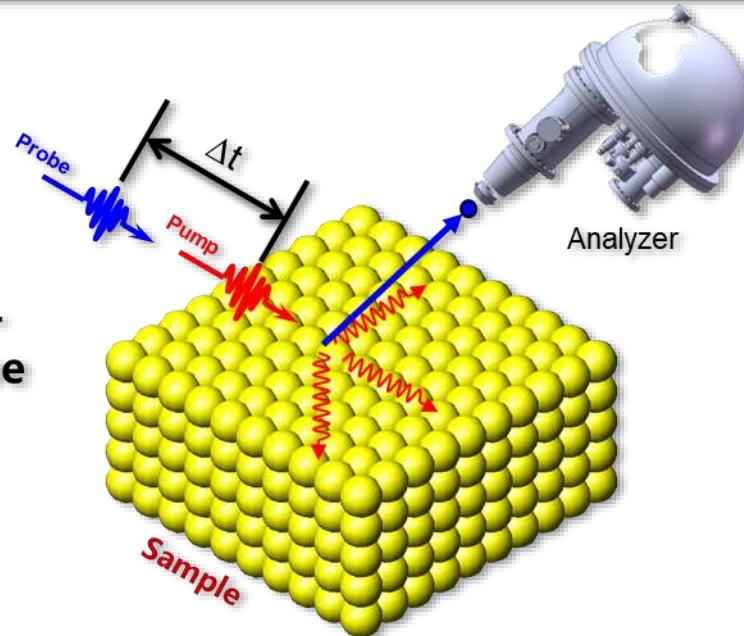
Strain induced TPT



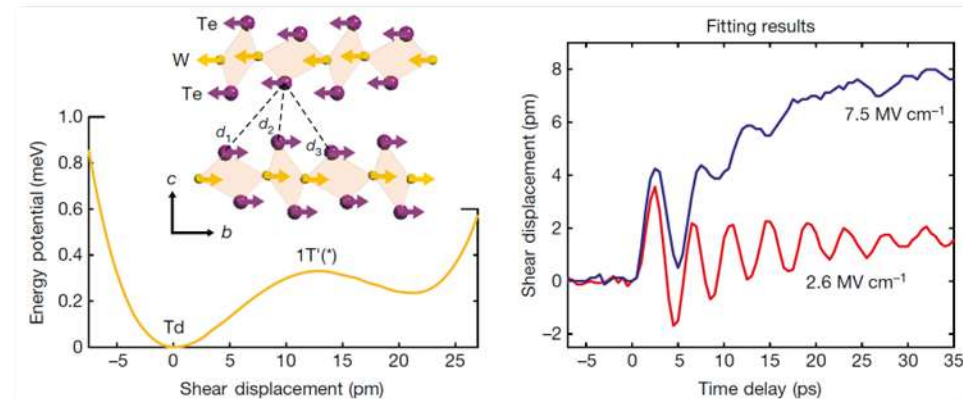
Mechanical Strain



THz Pump-ARPES Probe

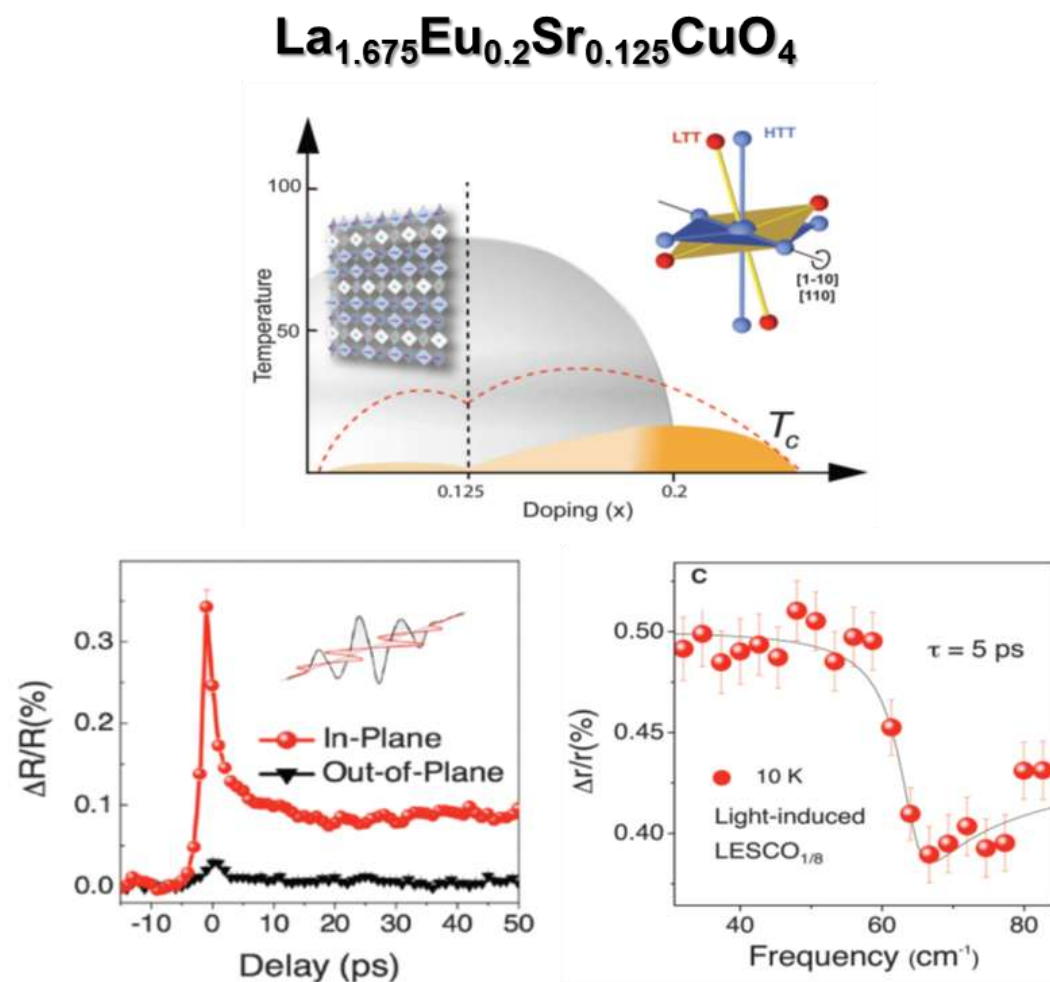


WTe₂ 1% Lattice constant engineer

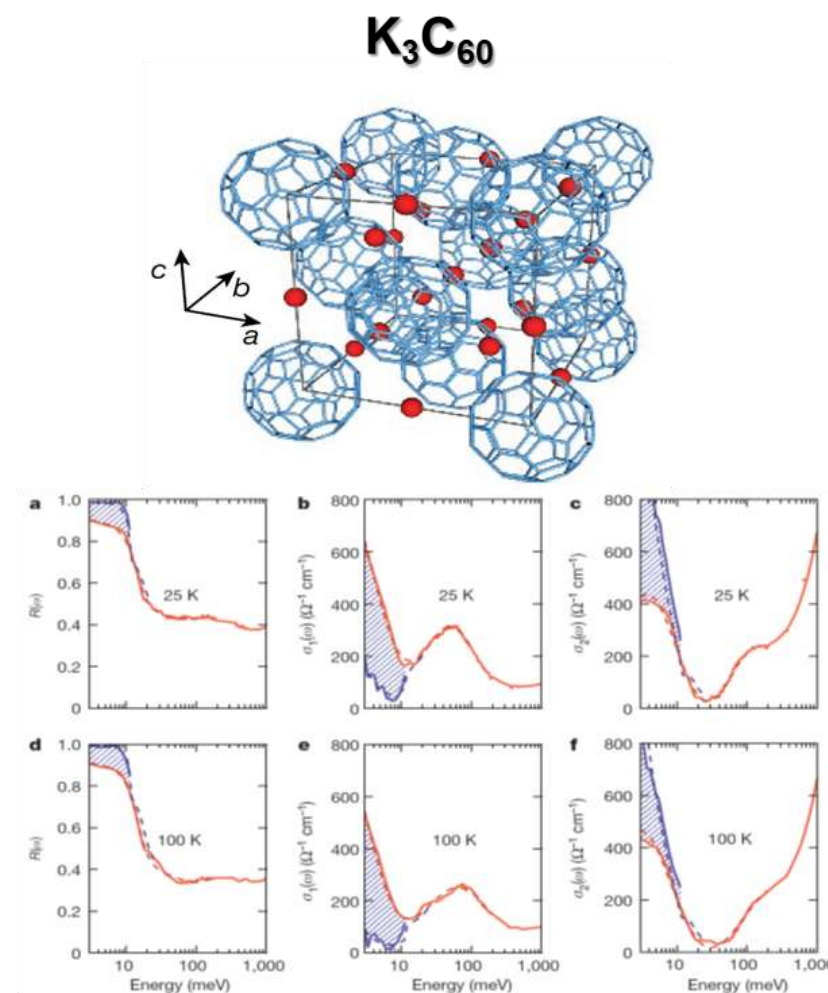


Nature 565, 61 (2019)

THz Science: Transient superconductivity



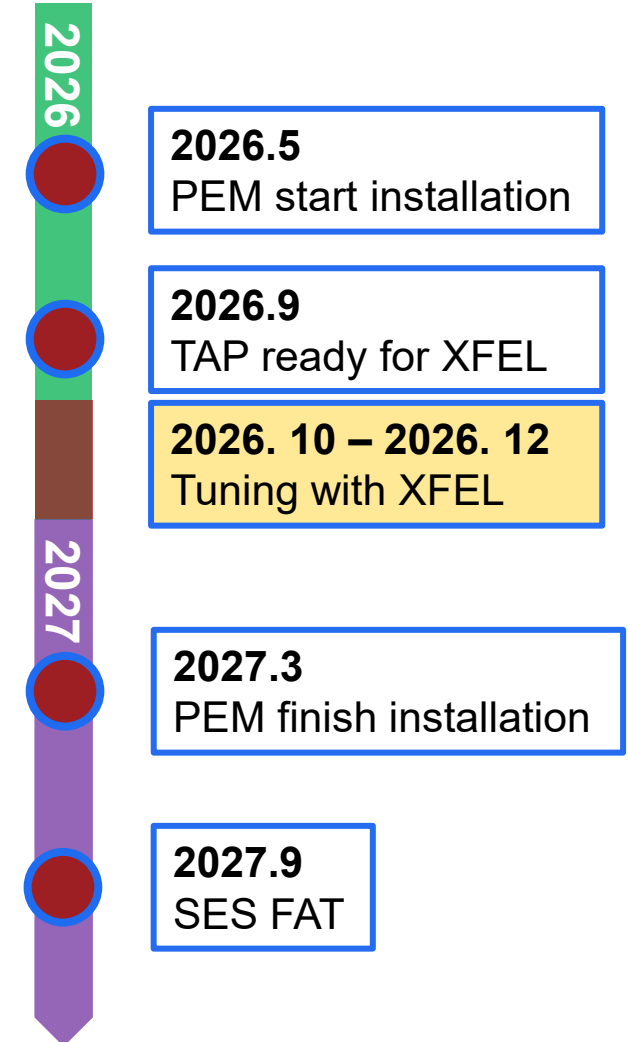
D. Fausti, et. al., Science 331, 14 (2011)



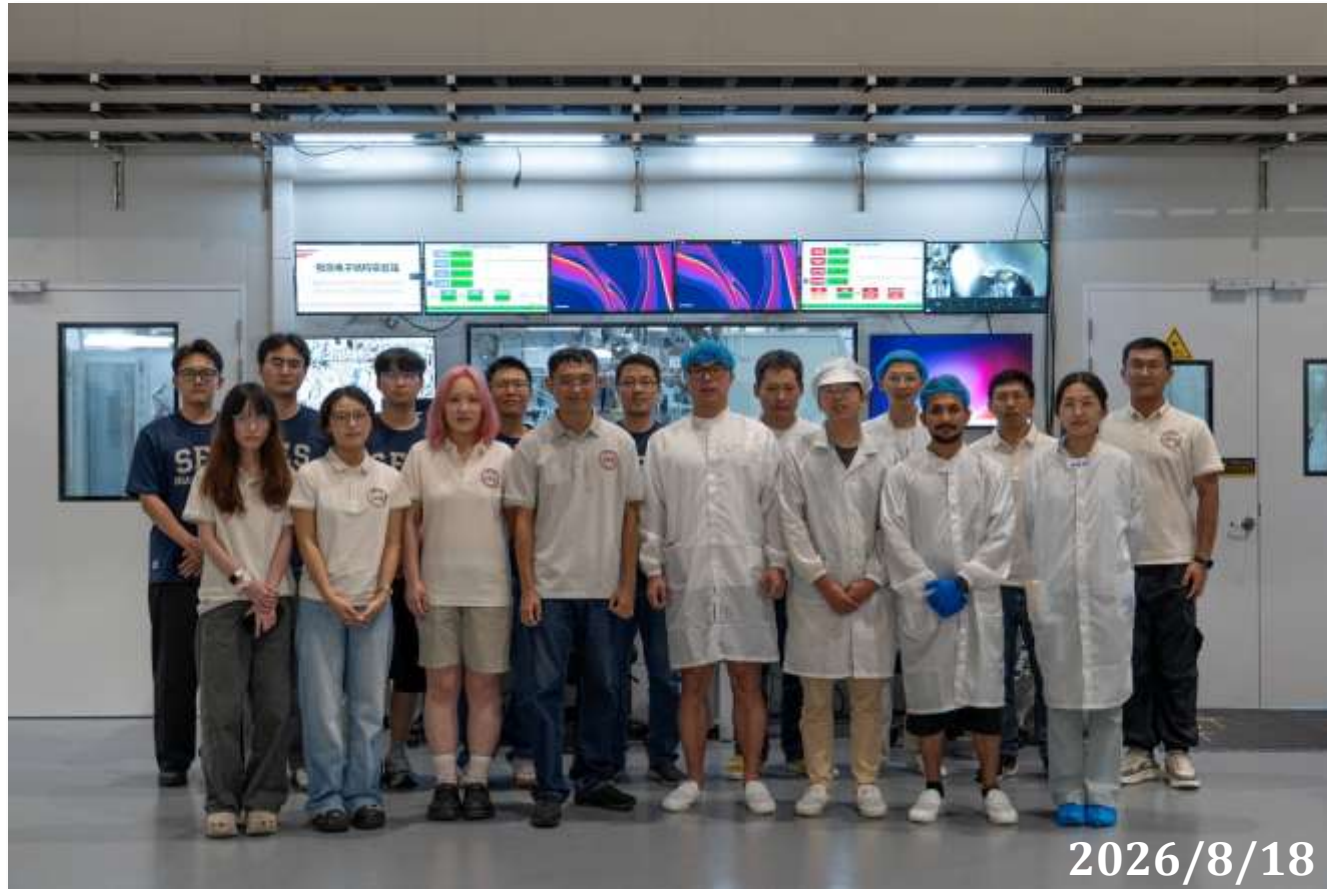
M. Mitrano, et. al., Nature 530, 461 (2016)

Summary

- SES (TAP + PEM) has moved from installation into integrated commissioning.
- 1030+5X, HHG (26.6eV) and THz laser systems are both indispensable in SES, accommodated in a double-level laser table.
- XFEL Experiments at different stages are planned, balancing time resolution and energy resolution.



Acknowledgement



A picture of members coming from SES endstation,
Laser system (SHTU and BUAA) and DAQ system

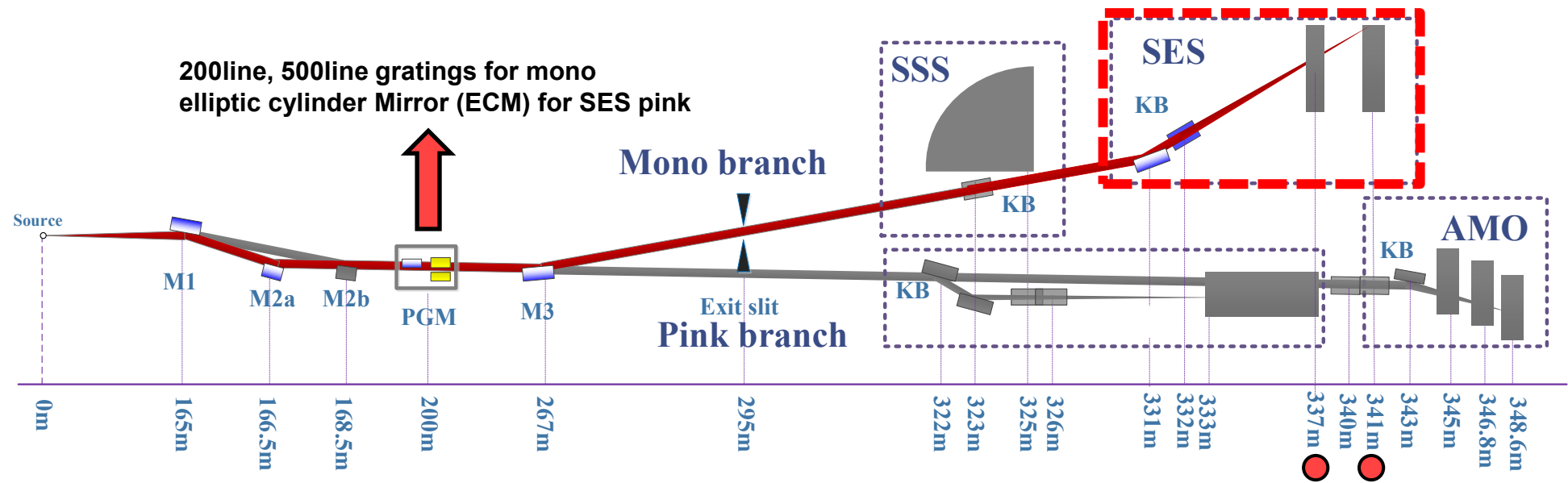
- **Laser group**
姜甲明、王康、海婷
- **Software - DAQ - IT group**
尹聪聪、姜栋、史武军
- **Beamline and diagnostic**
薛超凡、佟亚军、郭智
- **Infrastructure**
李欣盛
- **AI discussion**
怀平, 雷蕾, 张晓峰



Thank you for your attention!



FEL-II beamline in SHINE

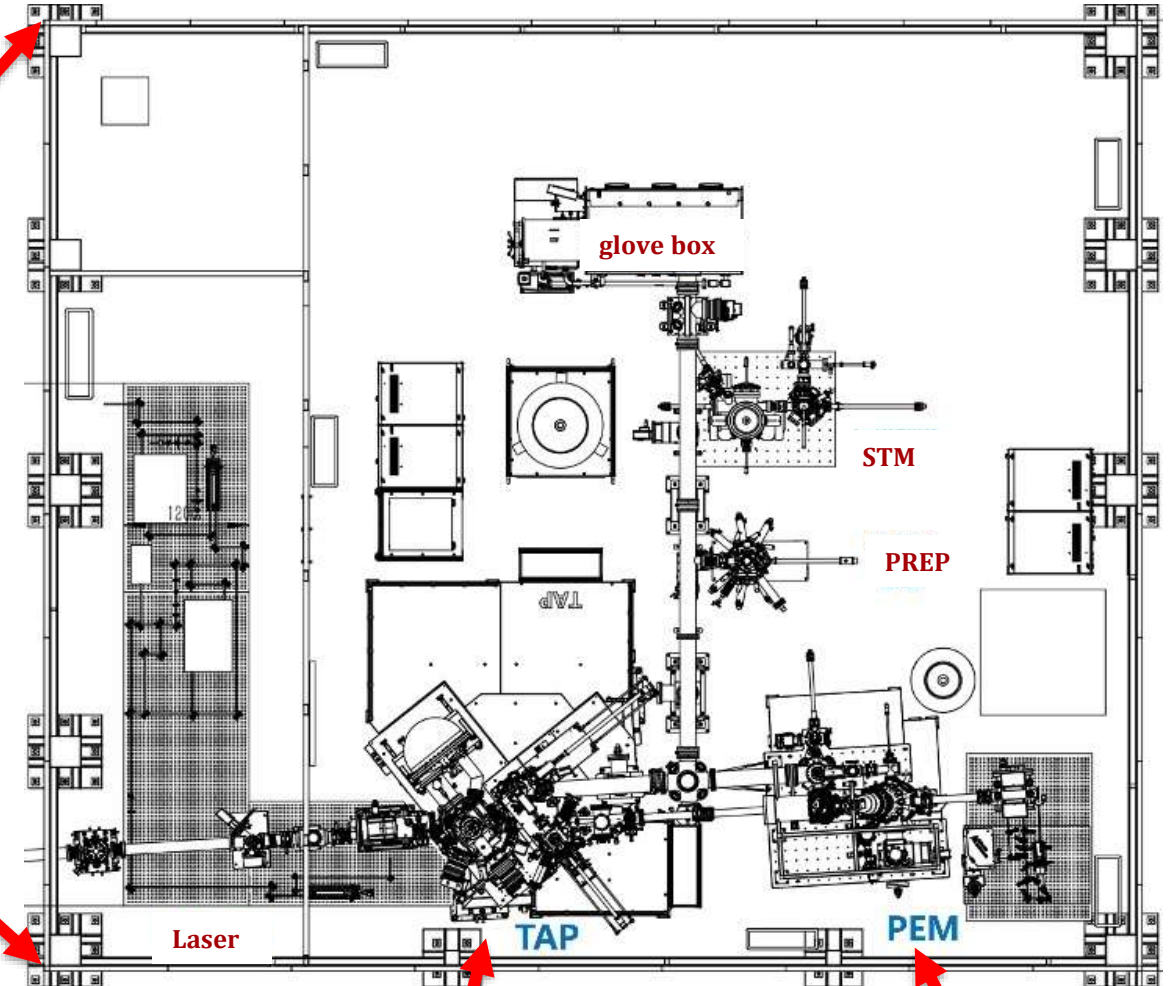
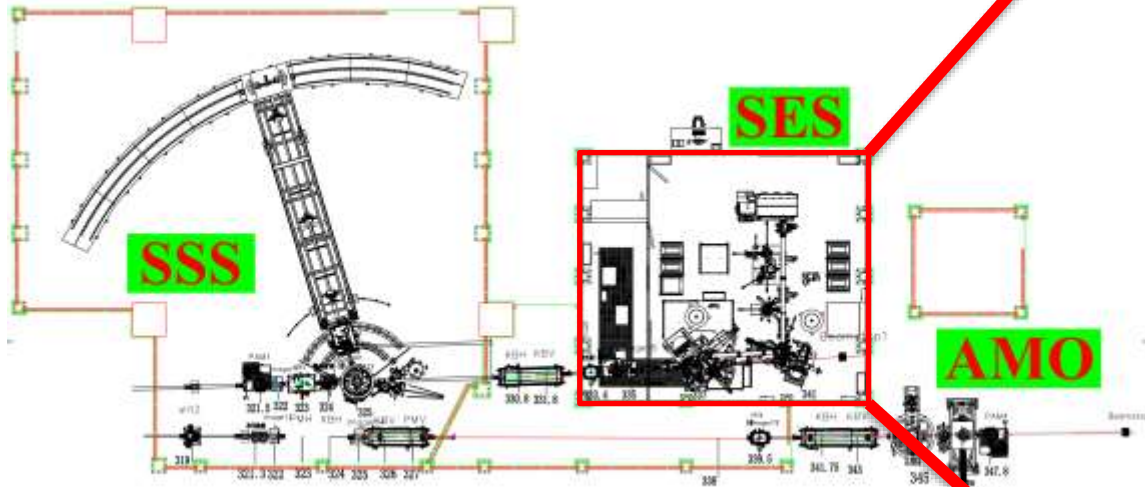


Range of Optimized Photon Energy: 0.20 ~ 3 keV



Location and Layout of SES endstation

FEL-II endstations in
4# experimental hall



SES and AMO endstations will receive
the first light in Oct. ~ Nov. 2026

TAP subsystem
@ 337m
Finish in 2025 Q4

PEM subsystem
@ 341m
Finish in 2026 Q4

Required Optical Parameters of SES endstation

No.	parameter	SES endstation
1	Energy range	0.2~3keV
2	Optimized energy or range	0.2~1.7keV
3	Energy resolution power	$\geq 40000@0.4\text{keV}\&0.93\text{keV}$
4	Transmission efficiency of single pulse	/
5	Content of high order harmonic	/
6	Focus beam spot (H×V) (FWHM)	$< 10\mu\text{m}\times 10\mu\text{m}$, double focus point @0.4keV
7	Divergence angle (FWHM)	/
8	Stability of beam (RMS)	$\leq 4\mu\text{m}$
9	Working distance of the K-B mirror	5.2 m(PEM) and 9.2 m(TAP) To the center of the mirror chamber
10	Width of single pulse	/
11	Attenuation requirement	4-6 order of magnitude, adjustable

Main specification of PEM subsystem

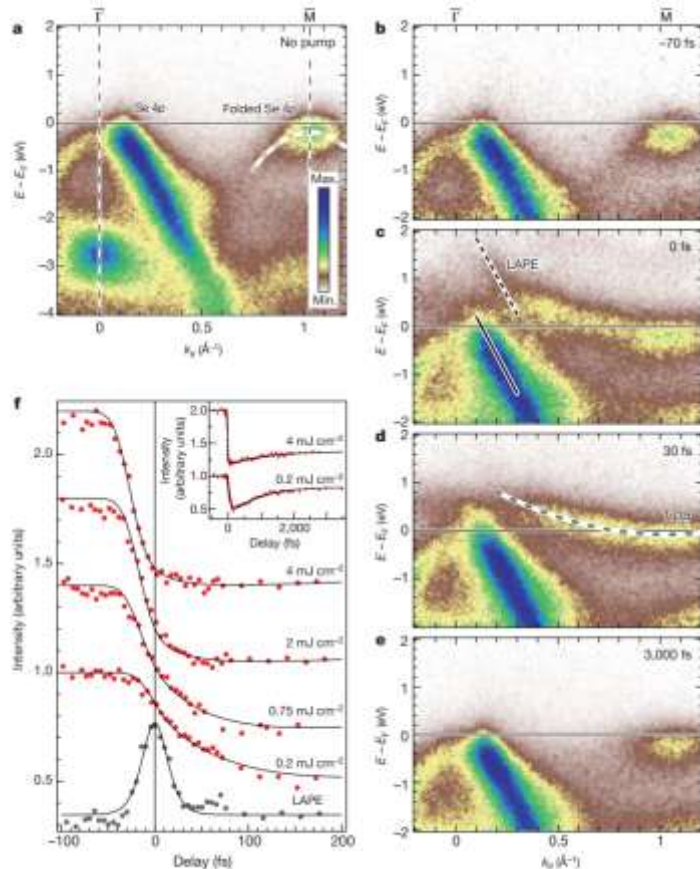
	Specification	Method for FAT
Base pressure of Main Chamber	$\leq 1 \times 10^{-10}$ mbar	Vacuum gauge installed on main chamber
Range of sample temperature	15 - 400 K	Thermo-diode on the back of the sample stage of the low temperature manipulator
Spatial Resolution	≤ 100 nm (≤ 500 nm for FAT)	The image of the a chessy sample in 500 nm $\times$ 500 nm should be clearly resolved in the measured images.
Energy Resolution	≤ 50 meV	Under kPEEM mode, fit the fermi edge of the standard sample (such as Au foil)
Momentum Resolution	$\leq 0.005 \text{\AA}^{-1}$	Under kPEEM mode, fit the MDC of the standard sample such as Au(111) surface states

Specification for FAT in SES endstation

	Spec. of Design	Spec. of Final Acceptance Test (FAT)	Method for FAT	Position for FAT
Time Resolution (fs)	60	80	Measure the step width of the optical delay line using a laser Interferometer. The measuring results should keep no larger than $24\mu\text{m}$ ($\text{speed of light} \times 80\text{fs}$) within ten minutes.	TAP
Spatial Resolution (nm)	100	500	The image of the a cheakerboard sample in $500\text{ nm} \times 500\text{ nm}$ should be clearly resolved in the measured images.	PEM

Dynamic of Electrical Structures in CDW materials

Ultrafast phase transition of CDW in TMD materials



Main Experimental Conditions:

- Beam spot size: $\sim 10 \mu\text{m}$
- Pulse duration: $40 \sim 50 \text{ fs}$ - FWHM
- Jitter: $< 30 \text{ fs}$
- Band width: $\sim 100 \text{ meV}$ @ 200-line mono
- Repetition rate: 100 kHz
- Pulse energy: $1\text{-}10 \mu\text{J}$ (sample point)

XFEL

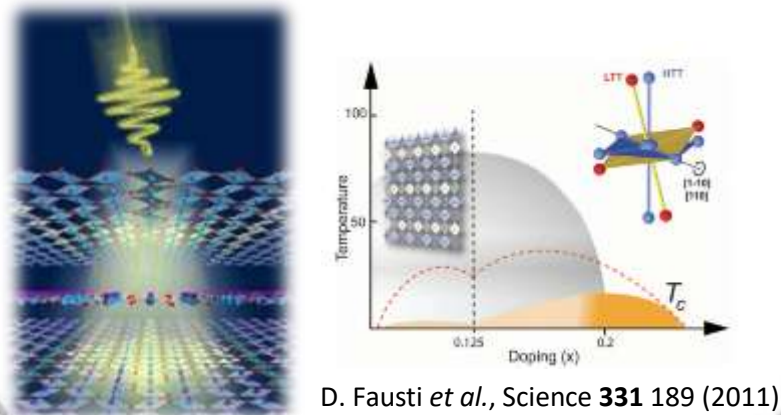
co-axis

Laser

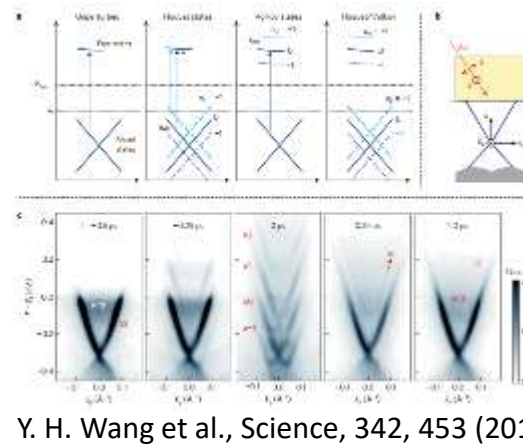
- Wavelength: tunable pump base on 1030 nm
- Repetition rate: 100 kHz
- Spot size: $\sim 50 \mu\text{m}$
- Pulse energy: $15\text{-}20 \mu\text{J}$ (tunable)
- Pulse duration: $30 \sim 40 \text{ fs}$

Scientific Cases of SES Endstation

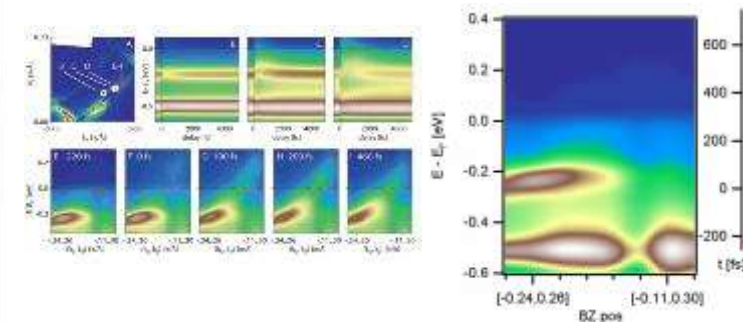
Unconventional Superconductivity



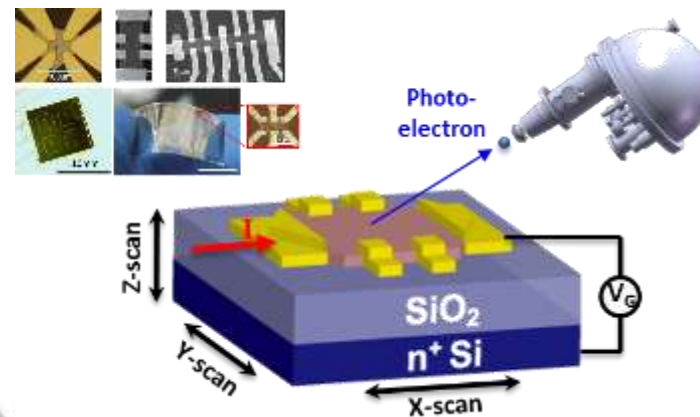
Unusual topological states



Control of quantum phase transitions



Dynamics of functional devices



SES Scientific Cases:

- Ultrafast dynamics of moiré superstructures
- Ultrafast phase transition of CDW in TMD materials
- Strong light – matter interaction and related phenomena
- Terahertz (THz) tuned/induced quantum phase transitions