Development and Integration of Pump-probe Laser System

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On behalf of Pump-probe Laser Group

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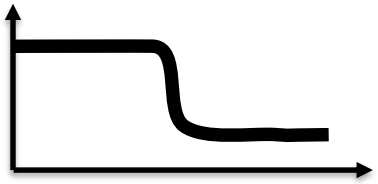
Outlines

- Laser Systems
- Optical Delivery
- Time Synchronization
- Commissioning Plan

Requirements of Pump laser

Pump-probe experiments are crucial at FEL facilities.



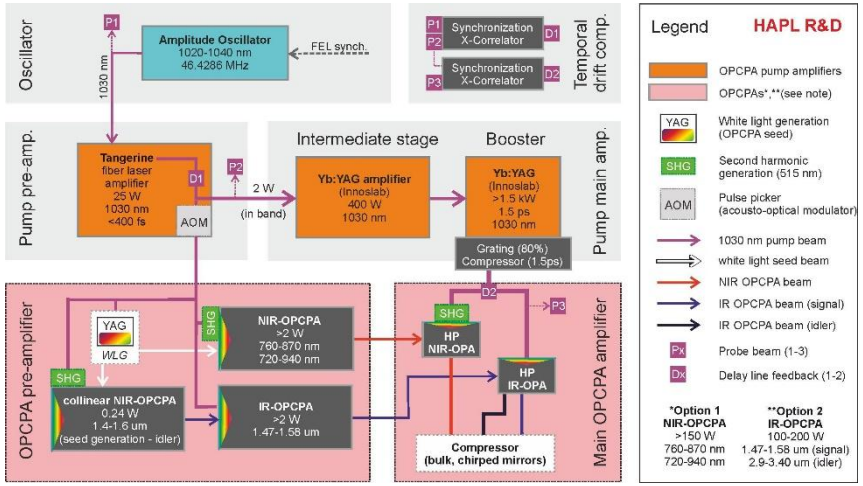
Requirements from End-stations

Parameters	Units	SSS	SES	AMO	HSS	CDS
Wavelength	nm	800/1030	800/1030	800/1030	800/1030	800/1030
Wavelength Conversion	nm	SHG/THG, 240-2600	400-15000	SHG/THG, 240-2600	SHG/THG, 240~2600	SHG/THG, 240-15000
Repetition rates	kHz	1~100	1/100	1/50/100	≥1	1/2/10
Pulse Width	fs	<35	25~35	10/35	<35	35
Spot size	μm	125	20~100	<60	50~200	10~300
Pulse density	/	>15 mJ/cm^2	10 mJ/cm^2	>5×10^{13} W/cm^2	>50 mJ/cm^2	10~10^5 GW/cm^2

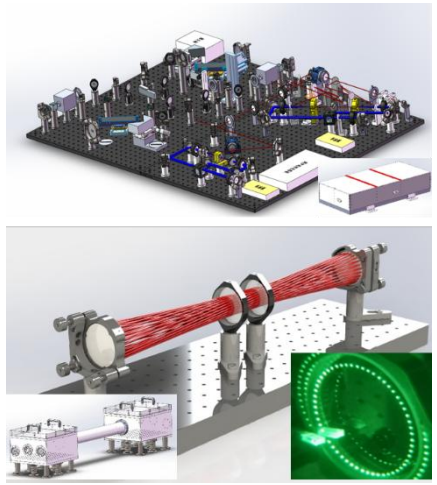
Laser Systems

Self-developed high-repetition-rate laser

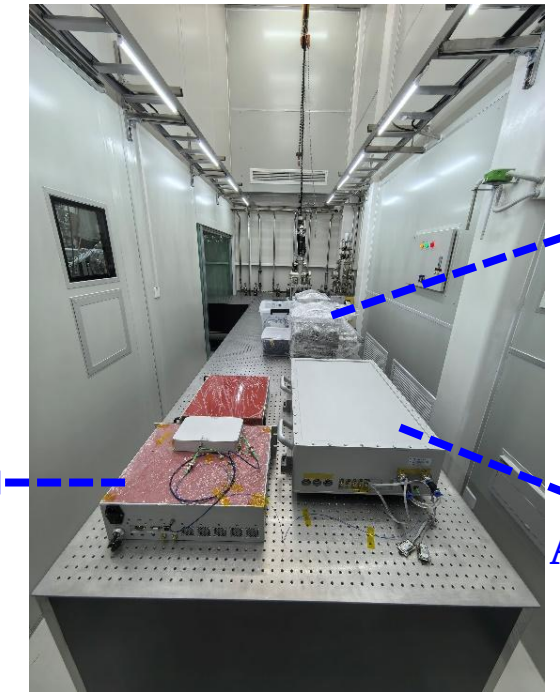
- **OPCPA** is an important technical roadmap for high-repetition-rate FEL facilities
- **Fiber oscillator** + Yb-doped **solid state laser**: 1030nm, ~150W @100kHz, **<250fs**
- High efficiency nonlinear compression based on **Multi-Pass Cell (MPC)**
- Initial goal: 1030nm, 100W @ 100kHz, **<50fs**



OPCPA system in LCLS-II



Optical and technical design



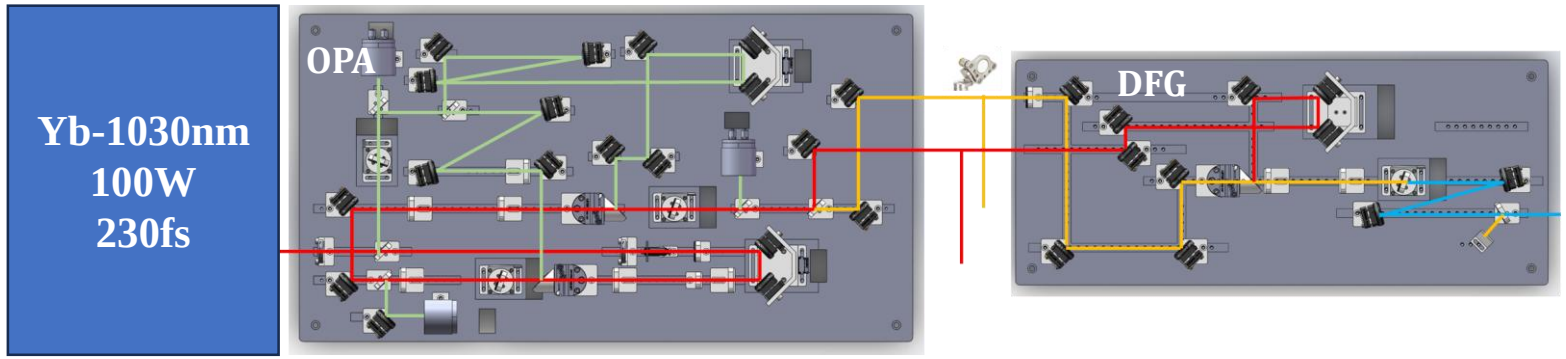
Laser hutch near SES

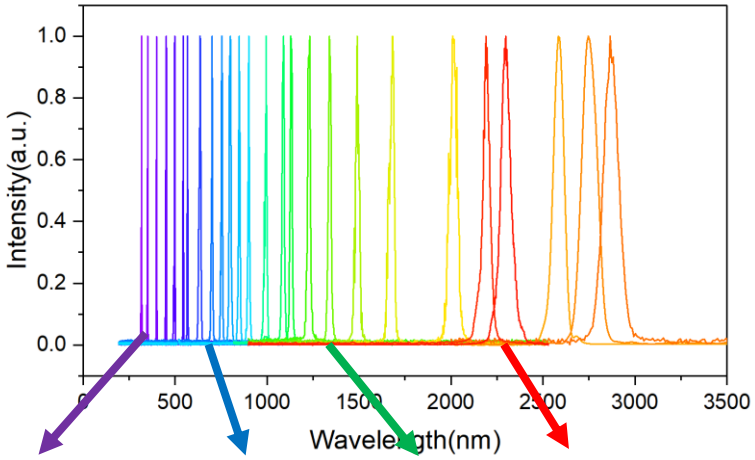
The first high-rep-rate laser system will be completed in this October.

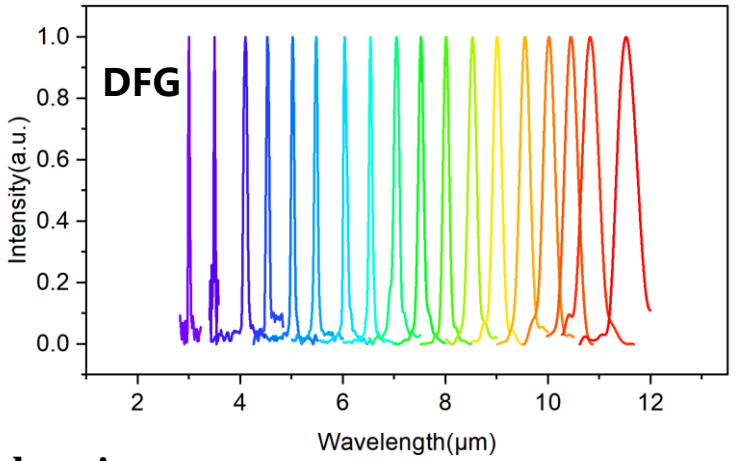
Laser Systems

Wavelength tunable

- Tunable OPA (SHG、DFG)—315nm~12μm; SHG/THG/FHG







Spectral tuning curve

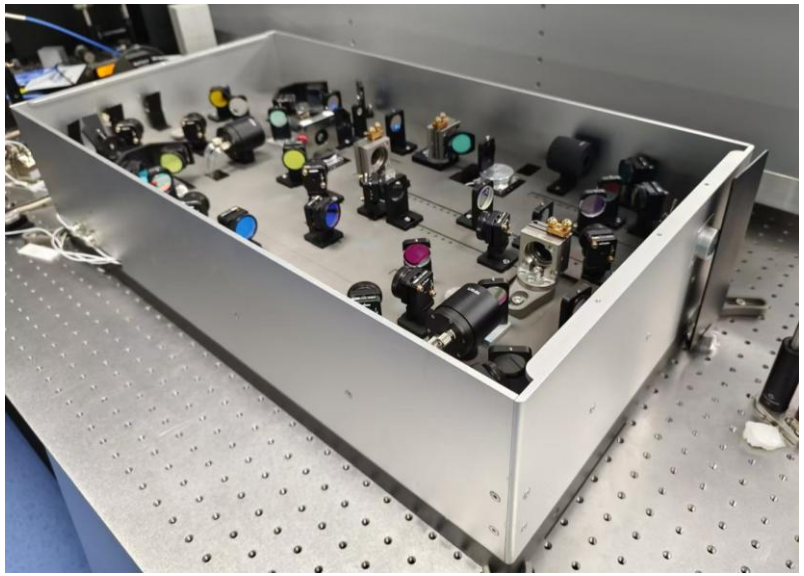
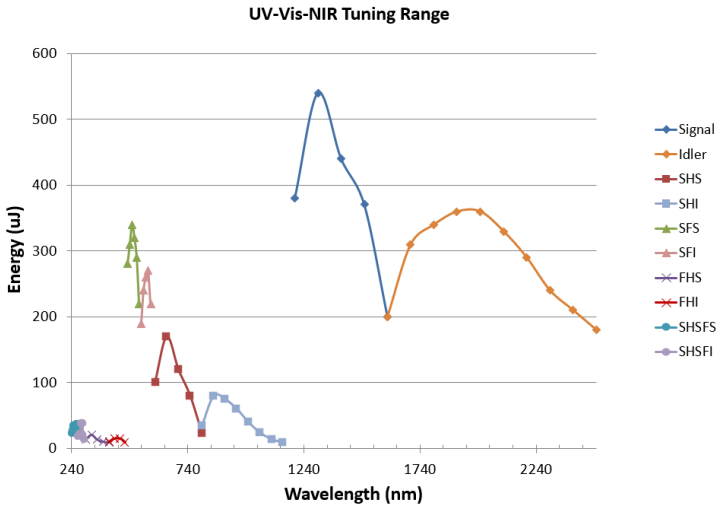


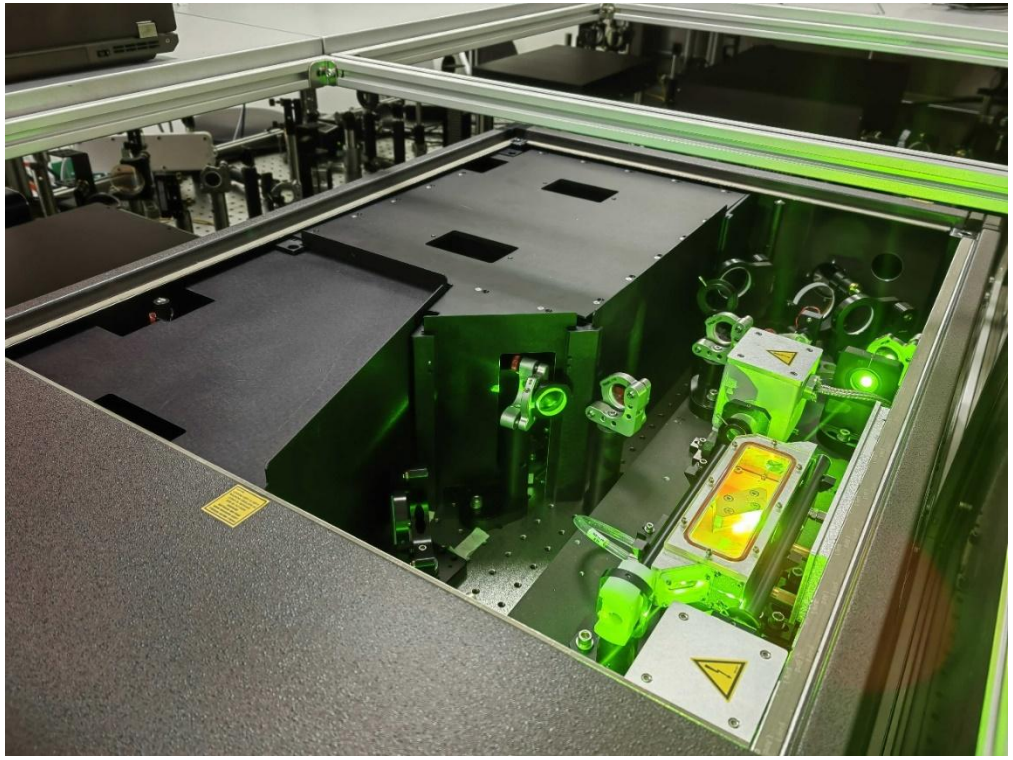
Photo of OPA

Laser Systems

1kHz repetition rates laser

- Commercial **Ti:sapphire** laser
- **Parameters**
  - Oscillator: 72.22MHz
  - Amplifier: 800nm, 35fs, 7mJ @ 1kHz
  - Frequency conversion: SHG/THG & OPA

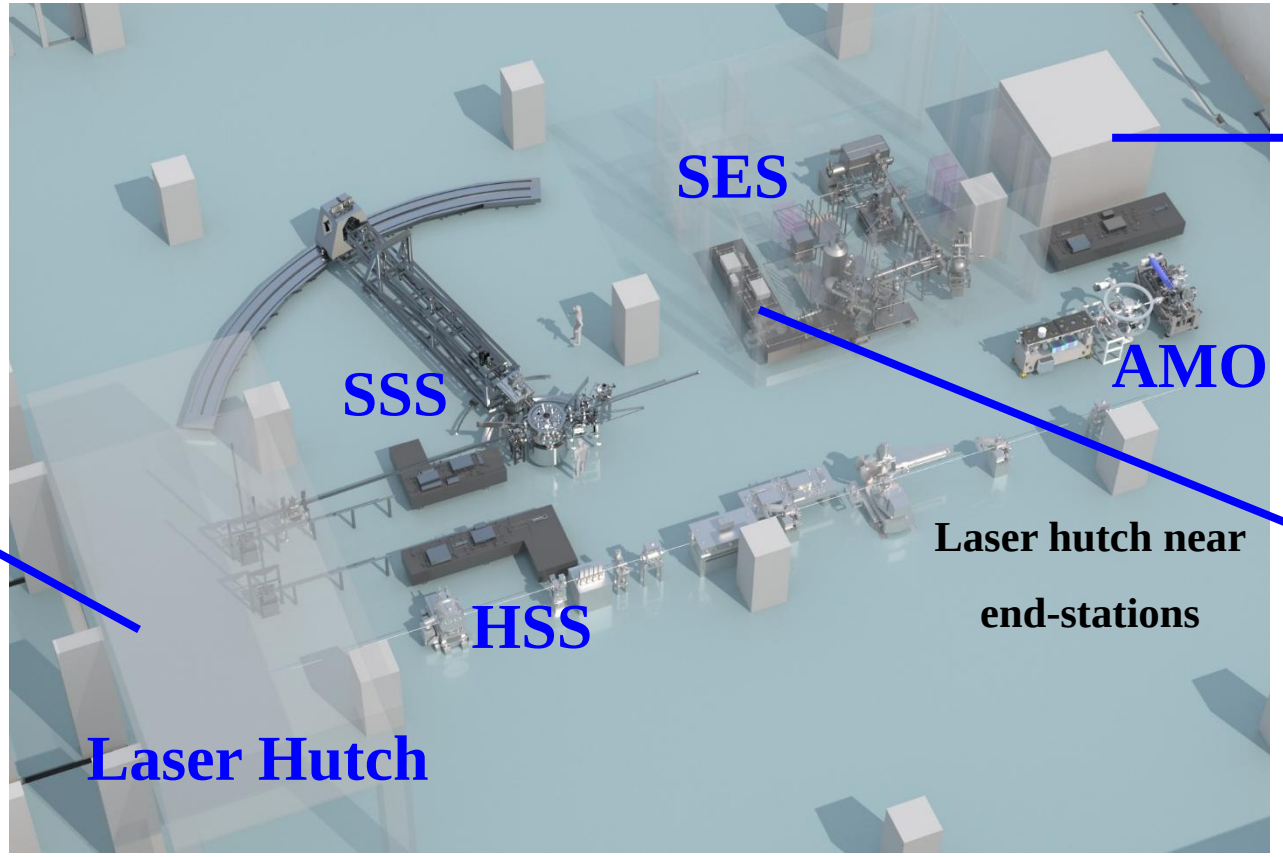




Laser Hutch

Overall layout at Shaft #4 experimental hall

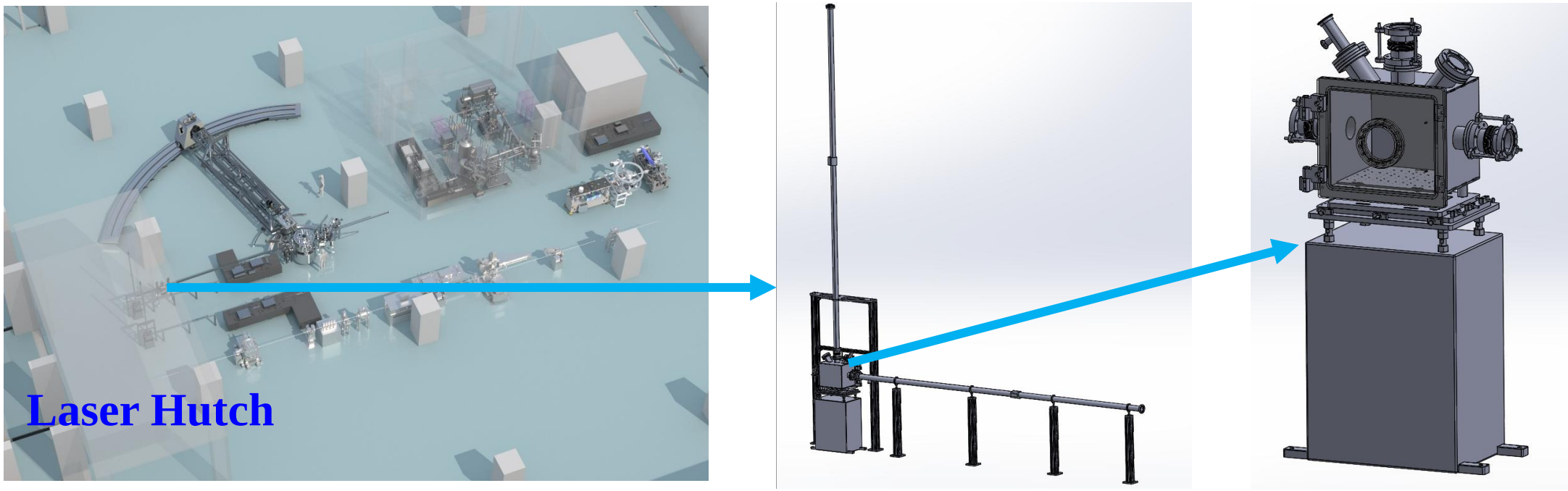
- Every end-station is equipped with an independent pump-probe laser system
- Environmental conditions of the laser hutch: Temp. 23±0.1 ℃; Humidity <45±5%; Clean room ISO6



Laser Transportation

Transportation from laser hutch to end-stations

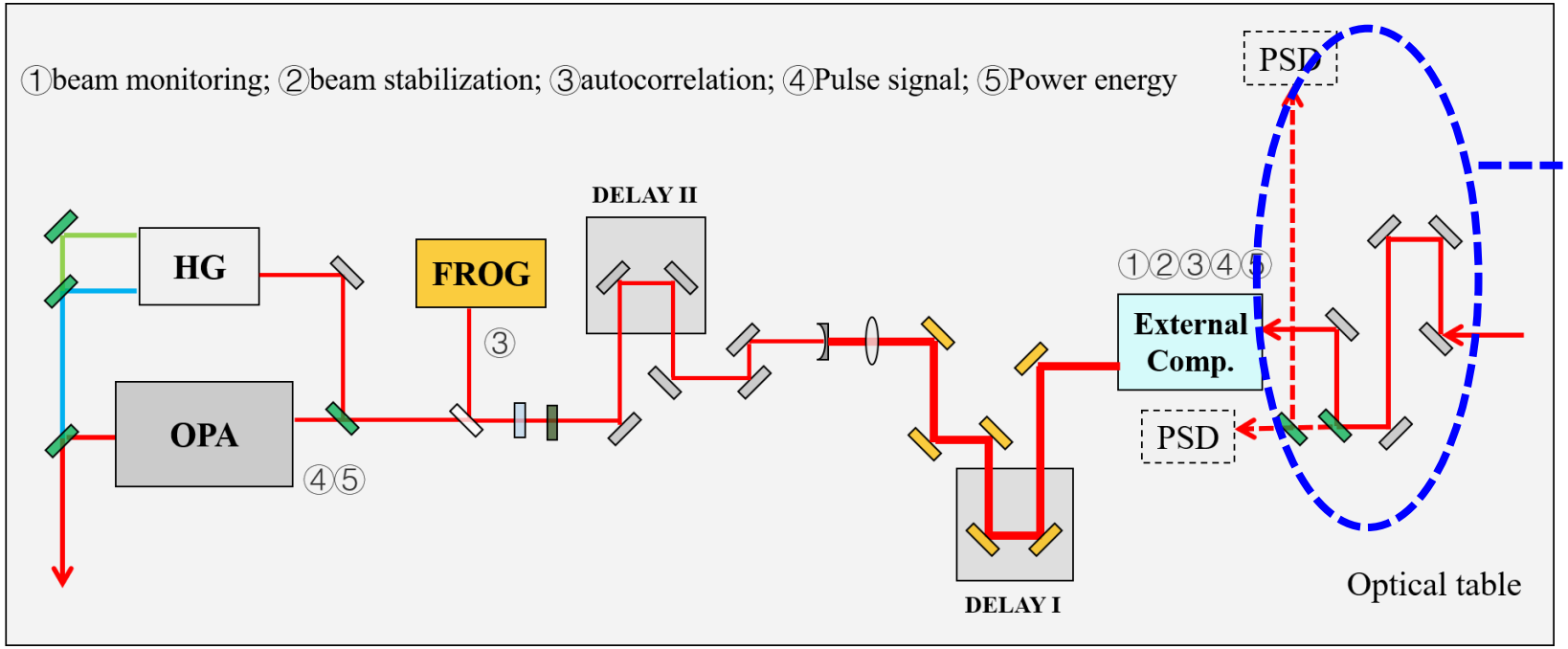
- Laser for SSS & HSS end-stations installed on the second floor
- **Uncompressed** fundamental laser pulse delivered through **evacuated pipelines** and **relay imaging**
- Deflection chamber is fixed on a marble base to enhance overall stability



Optical path near end-stations

Optical layout near end-stations

- **External compressor:** recompressed the fundamental laser pulse to several-tens of fs
- **Frequency conversion units**: UV to IR provided by OPA; SHG/THG
- **Laser diagnostics:** laser power, beam profile, spectral characterization, etc.

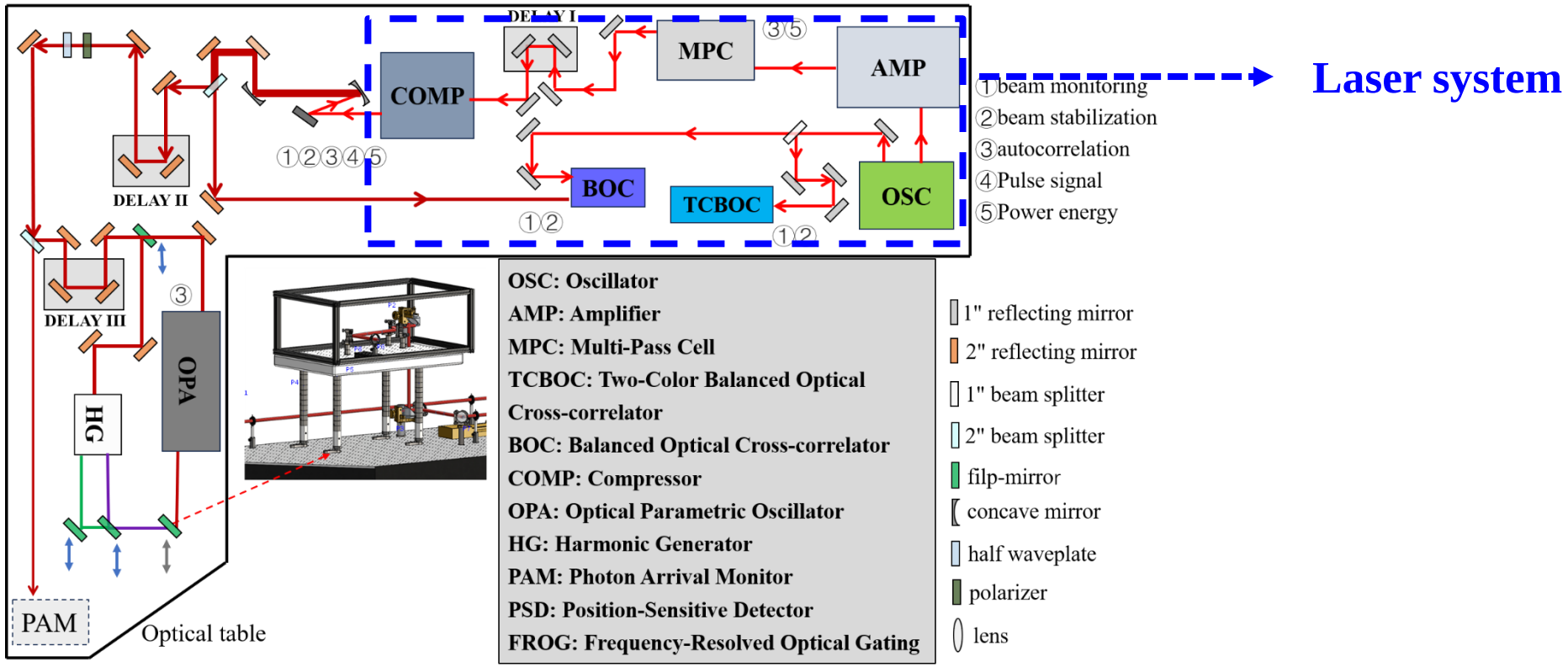


- Extra active pointing stability module before compressor

Optical path near end-stations

Optical layout near end-stations

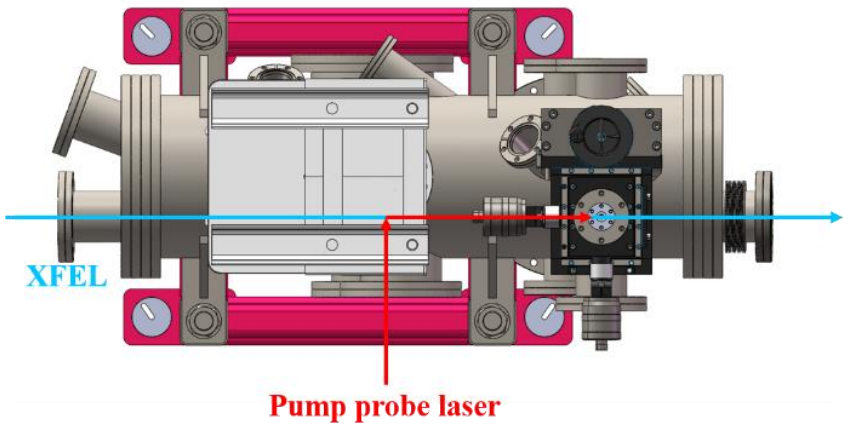
- Lasers for SES, AMO & CDS installed in laser hutch adjacent to end-stations
- **Frequency conversion units; Laser diagnostics; Optical devices for synchronization**

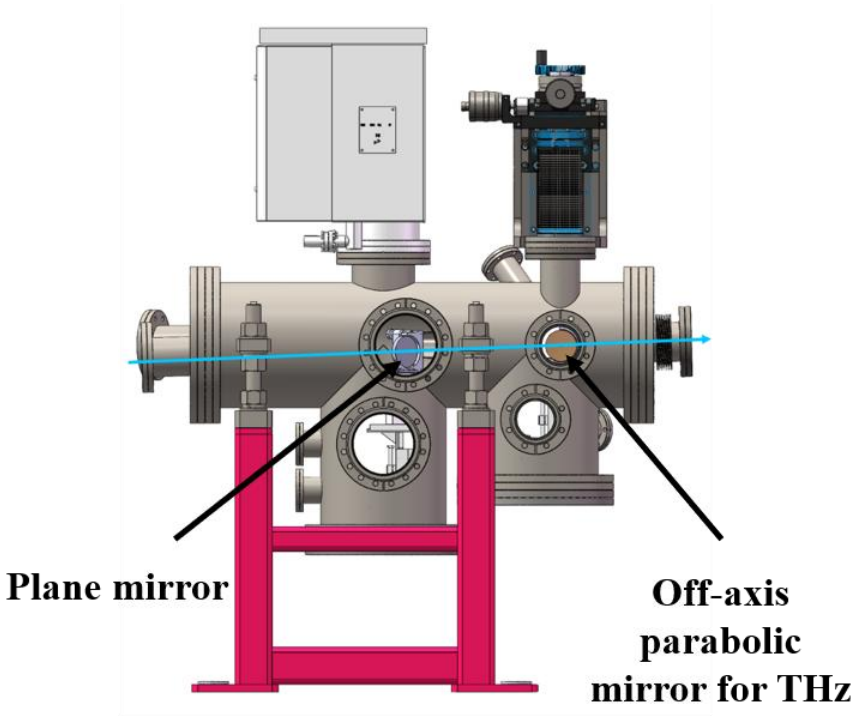


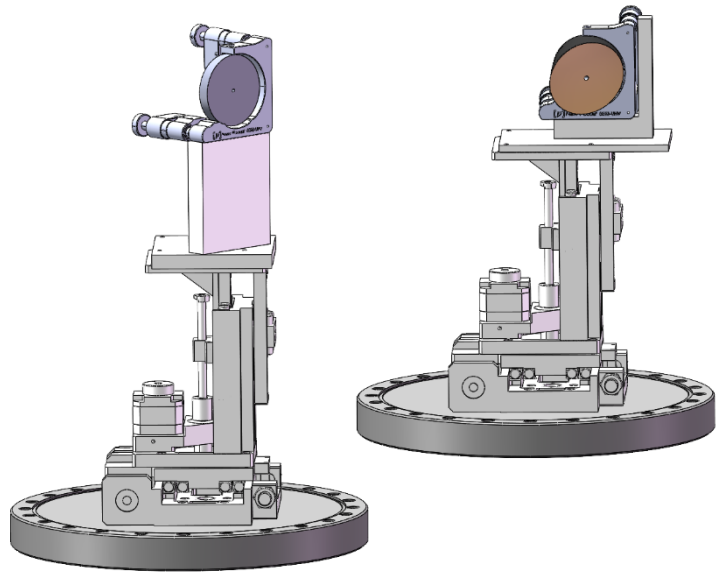
Laser in-coupling

Laser in-coupling: Mirror in vacuum on 4-axis manipulator

- Plane mirror for fundamental pulse, OPA, SHG/THG
- Off-axis parabolic mirror for THz



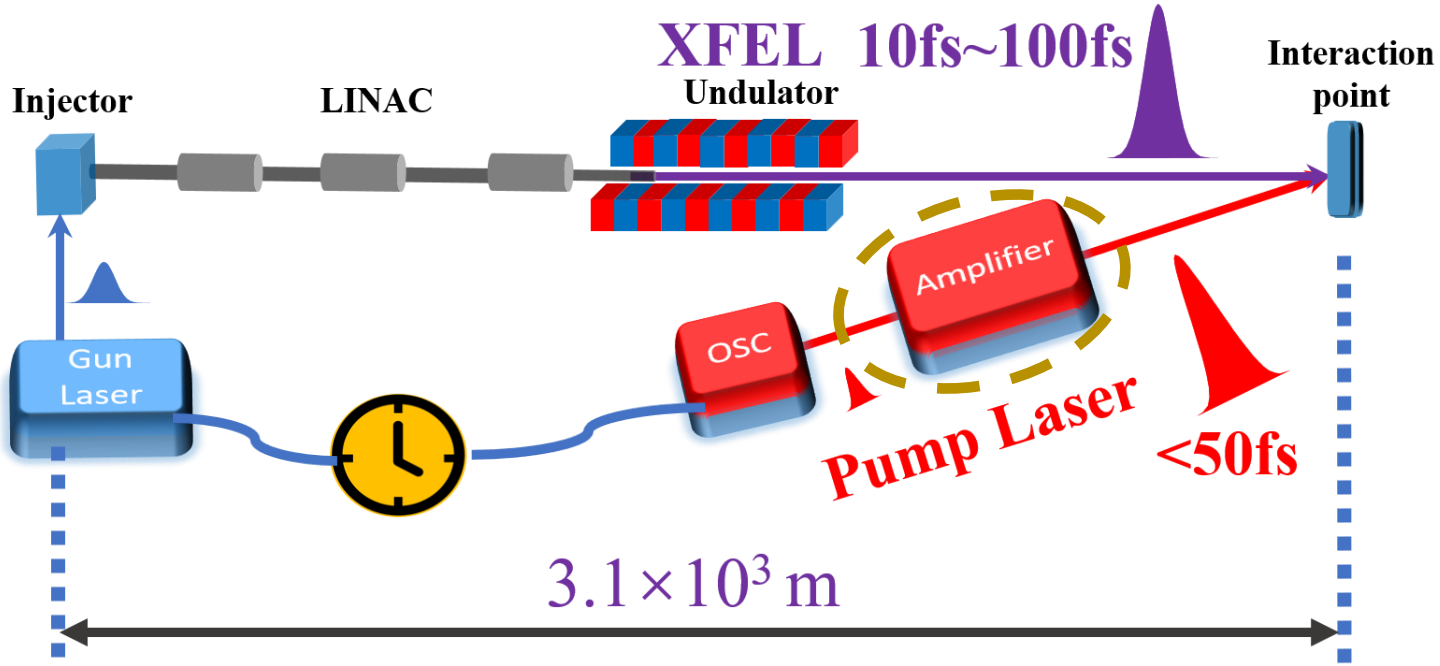




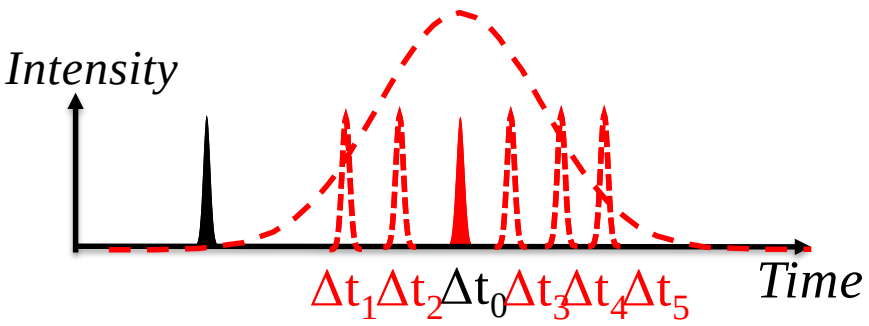
Time Synchronization

Time synchronization is crucial to pump-probe experiments.

- XFEL pulse and pump laser pulse originate from independent systems
- Temporal resolution determined by the pulse width and relative time jitter



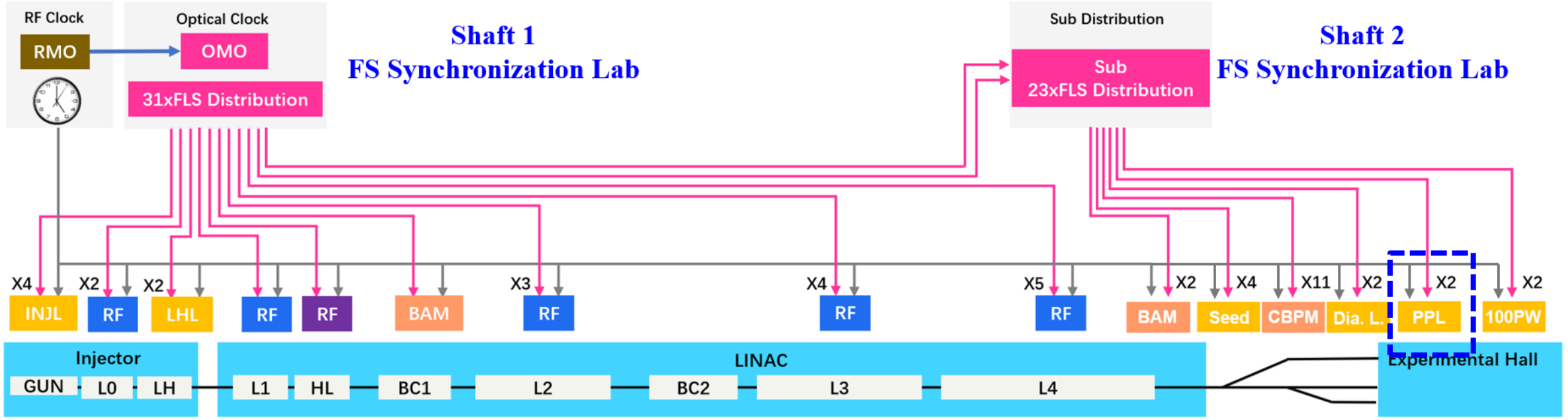
$$R_t = \sqrt{\tau_{laser}^2 + \tau_{x-ray}^2 + \tau_{jitter}^2}$$



Time Synchronization

Femotosecond synchronization system

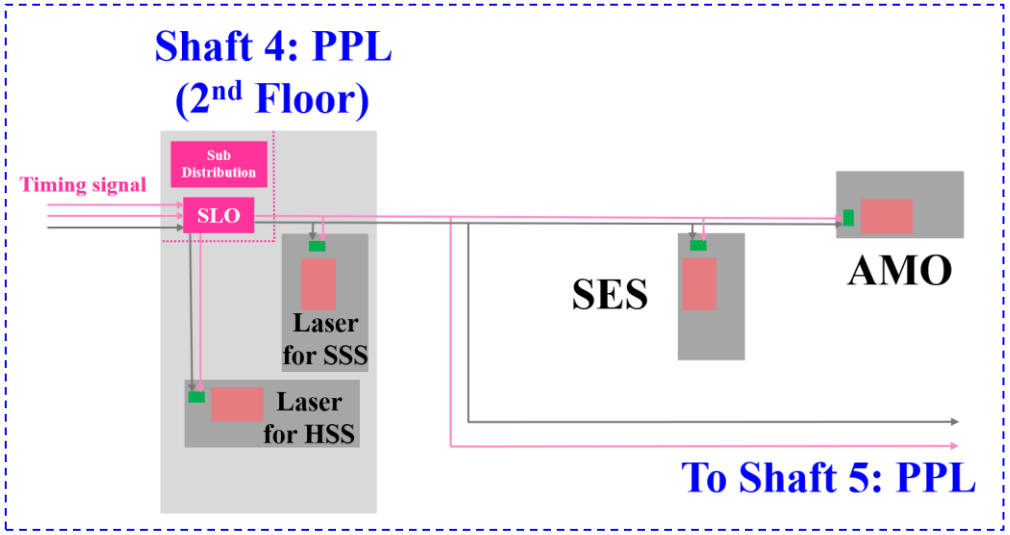
- **Technical roadmap:** The time reference distribution scheme based on **pulse link + RF link**
- **RMO**: RF Master Oscillator—microwave standard source with 1.3GHz as a master clock
- **OMO:** Optical Master Oscillator—passively mode-locked laser (1550nm) as an optical clock
- Laser pulse reference signals delivered through **phase-stabilized optical fiber links**

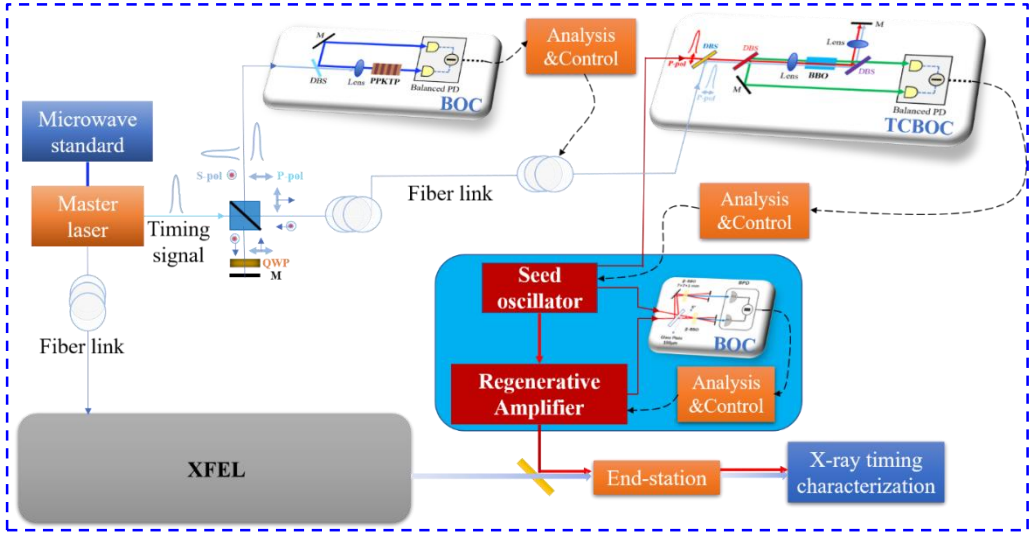


Time Synchronization

Sub distribution system at Shaft #4

- **SLO:** Slave Oscillator locked to OMO used to deliver timing reference signal
- **Balanced-Optical-Cross-Correlation (BOC)**
  - **Link BOC:** ensure few femtoseconds jitter and drift of timing signal
  - **TCBOC (Two-Color BOC):** oscillator of pump laser will be locked to SLO
  - **BOC:** compensate long-term timing drift between oscillator and amplifier

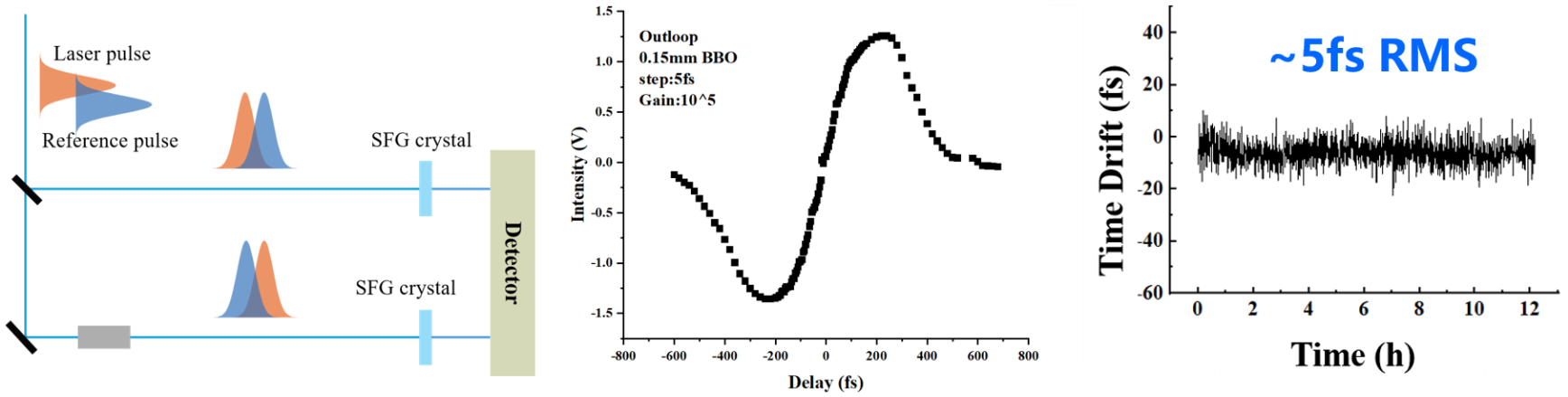




Time Synchronization

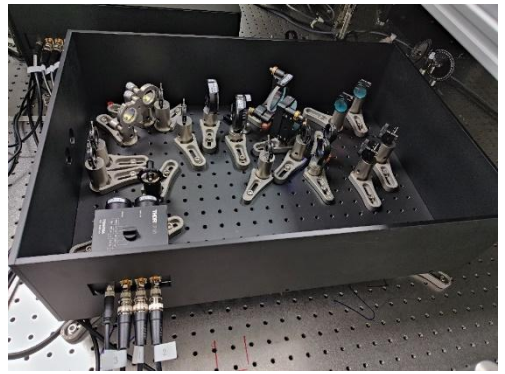
Time jitter and drift

- All of these synchronization devices were developed in-house and applied in SXFEL
- **TCBOC:** <10fs RMS time jitter between oscillator and OMO
- **BOC:** ~5fs RMS time drift between oscillator and amplifier
- **Extend-duration testing** (>48 hours) conducted on the SXFEL laser system



Principle of BOC and test results (~5 fs RMS)

BOC



Commissioning Plan

2025												2026											
1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Construction of laser hutch and local laser room				Installation of optical tables																			
Optical Components Procurement								Installation of Lasers		Buildup optical path near SES & AMO end-stations							Pump-probe experiments at SES & AMO end-stations						
Time synchronization Components Procurement				Installation of coaxial cables and fiber links					Integrated commissioning of fs sync. links			Installation and commissioning of sync. devices											

- **Laser hutch** and procurement of all optical components in Shaft #4 have been completed.
- **High repetition rate laser system** at SES end-station is under installation.
- **The buildup of optical path** near SES end-station will be started from this November.
- **Time synchronization network** will be available at the end of the year.

Summary

- A high-power, high-repetition-rate laser solution
- The demanding optical delivery infrastructure
- High accuracy time synchronization system

Acknowledgement

☐ Members of Pump Laser group

- Yuneng Shen, Ruixue Zhu, Ting Hai, Kang Wang
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☐ Colleagues from Laser group of Accelerator Division

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Challenges and questions

- The most effective strategies for active compensation of time drift of high-average-power laser ?
- The specific advice in mitigating the long-term time drift?
- The effective methods of pointing stabilization for long-term (days to weeks) operation?

Thank you for your attention!