

The 2nd MTCA/ATCA workshop for Research and Industry

Fs-Synchronization system for Dalian Coherent Light Source

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on behalf of the Sync. team at DCLS
2021-08-23

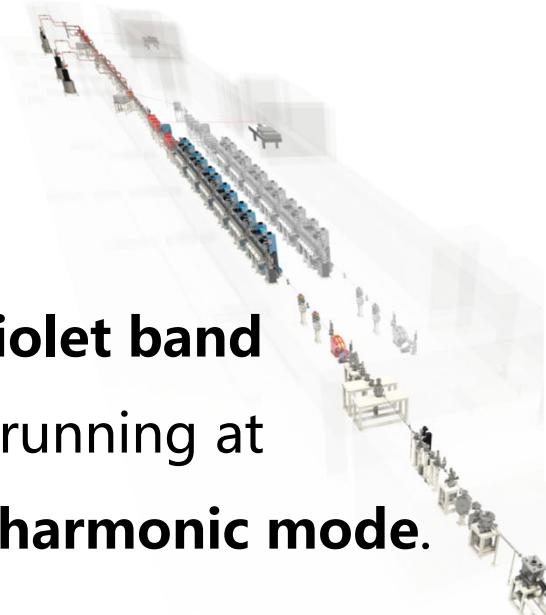


Outline

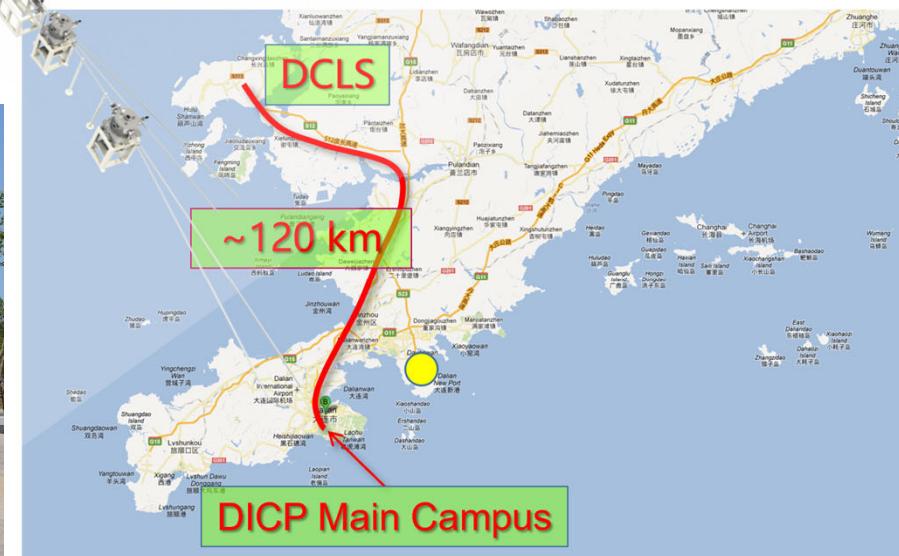
- Overview on Dalian Coherent Light Source
- Synchronization methods
- Synchronization System
- New High Repetition Injector Project
- Conclusion

Dalian Coherent Light Source

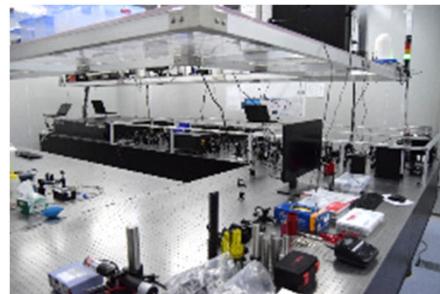
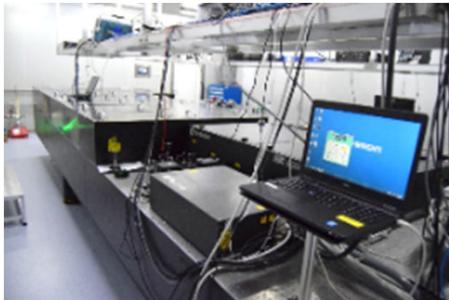
DCLS is a
Extreme Ultraviolet band
FEL user facility running at
high gain high harmonic mode.



Property	Parameter
Beam energy	300 MeV
Wavelength range	50 – 150 nm
Pulse energy	>100 µJ (1 mJ@120nm)
Duration	1ps, 100fs
Linewidth	< 3 transform limit
Synchronization	< 100 fs
Repetition rate	Up to 50 Hz

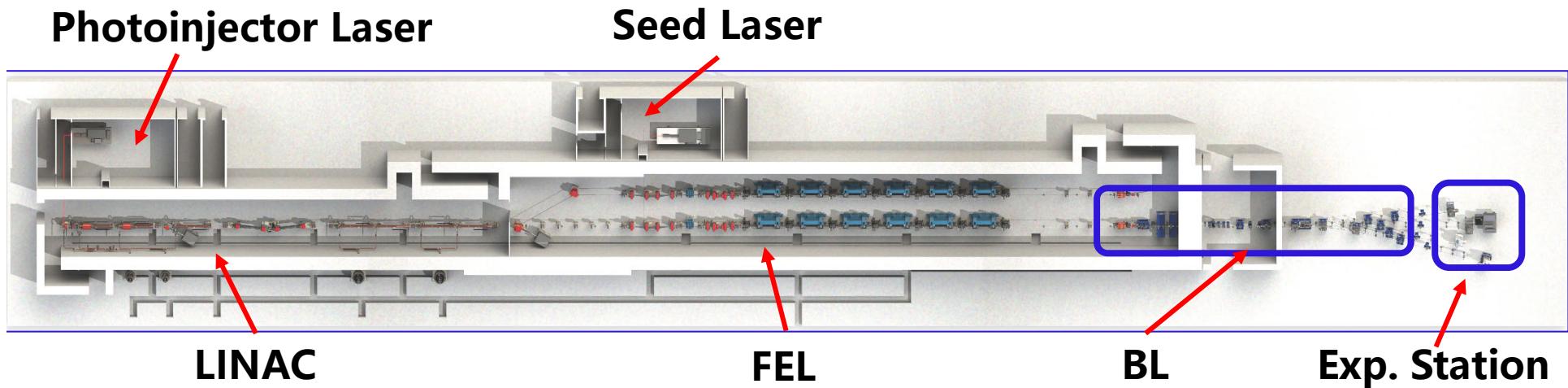


Dalian Coherent Light Source



DCLS L~150m

- LINAC : 40m
- FEL : 60m
- BL : 50m

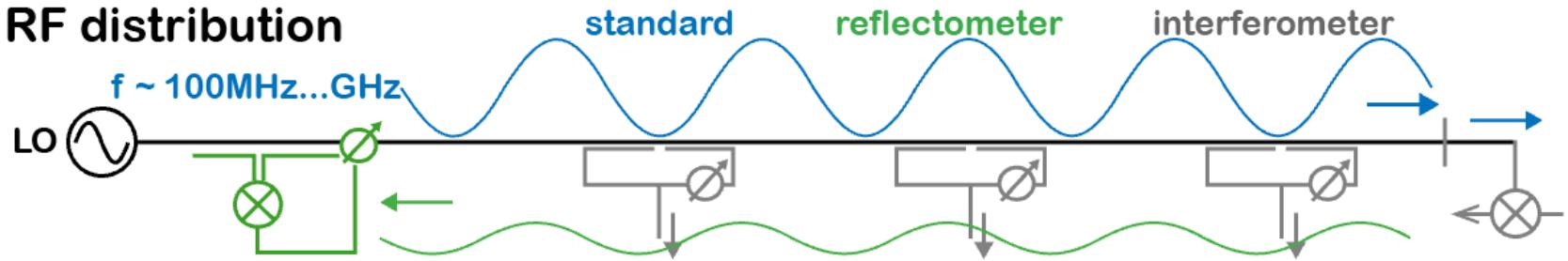


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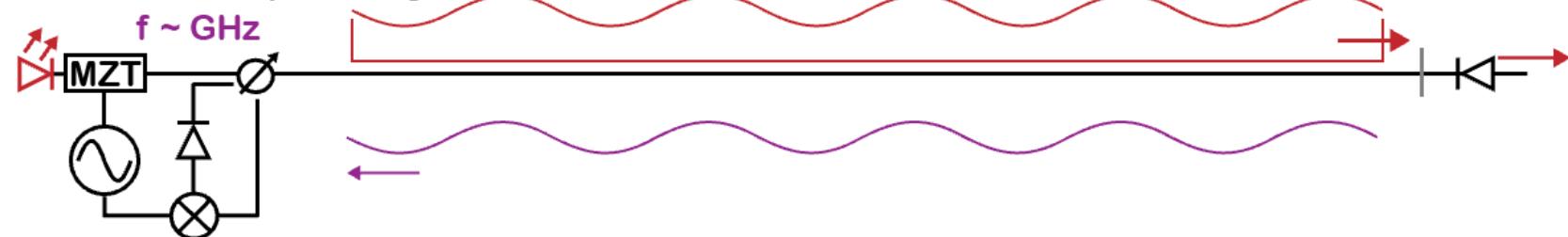
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Synchronization Methods

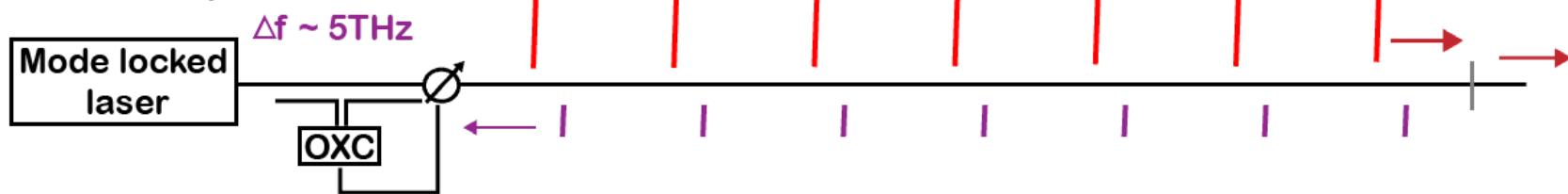
1) RF distribution



2) Carrier is optically



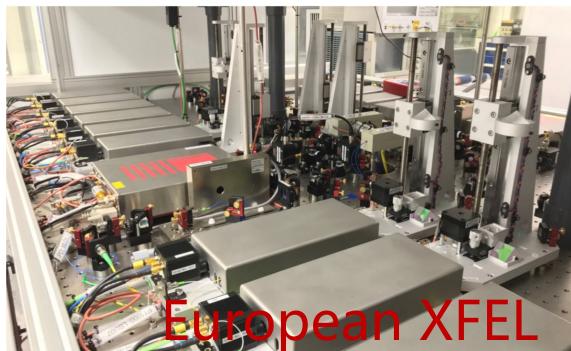
3) Pulsed optical source



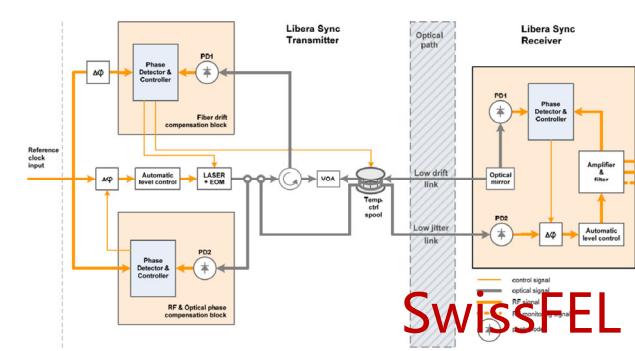
Adapted from Holger Schlarb slides

Synchronization Methods

		Developed by	Jitter/fs	Drift /fs	Advantage	Disadvantage
Fiber link	Pulsed Laser	DESY CFEL-MIT	<0.5	~5	Lowest jitter Drift free Large distance	Expensive
	CW Laser	PSI PAL	<20	~40	Low jitter Long distance	Certain drift
RF link	RF Cable	PAL SACLA	<10	>250	Lower jitter Stable	Large drift Power loss



European XFEL



SwissFEL



PAL XFEL

Synchronization Methods

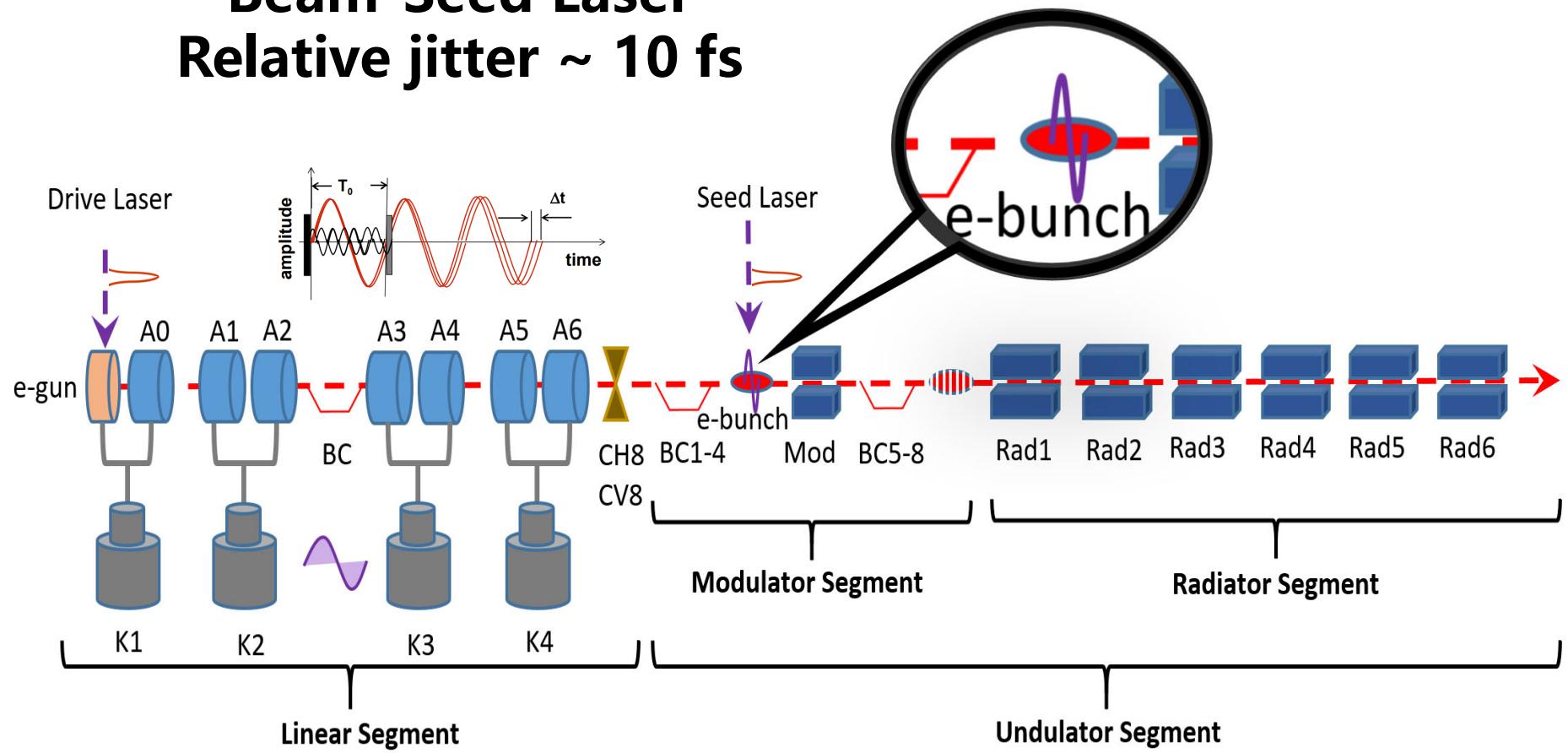
Facility	RF	CW Laser	Pulsed Laser
LCLS	•		•
SwissFEL	•	•	•
FERMI	•	•	•
PAL XFEL	•	•	
SACLA	•	•	
SXFEL	•	•	•
DCLS	•		•
LCLS-II	•		•
FLASH	•		•
EuXFEL	•		•
SHINE	•		•

Outline

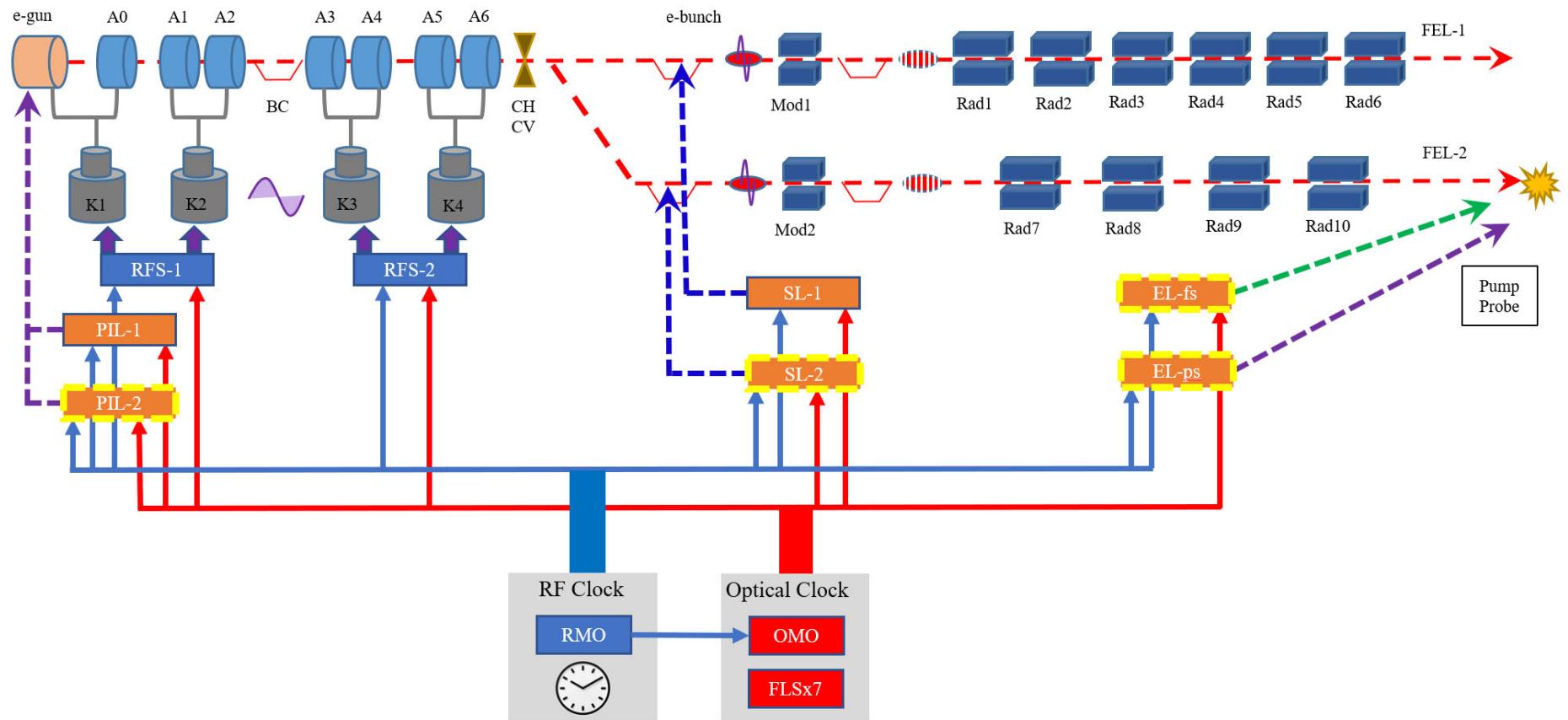
- Overview on Dalian Coherent Light Source
- Synchronization methods
- **Synchronization System**
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Fs-Synchronization System

Beam-Seed Laser
Relative jitter $\sim 10 \text{ fs}$



Two system: Pulsed laser & RF

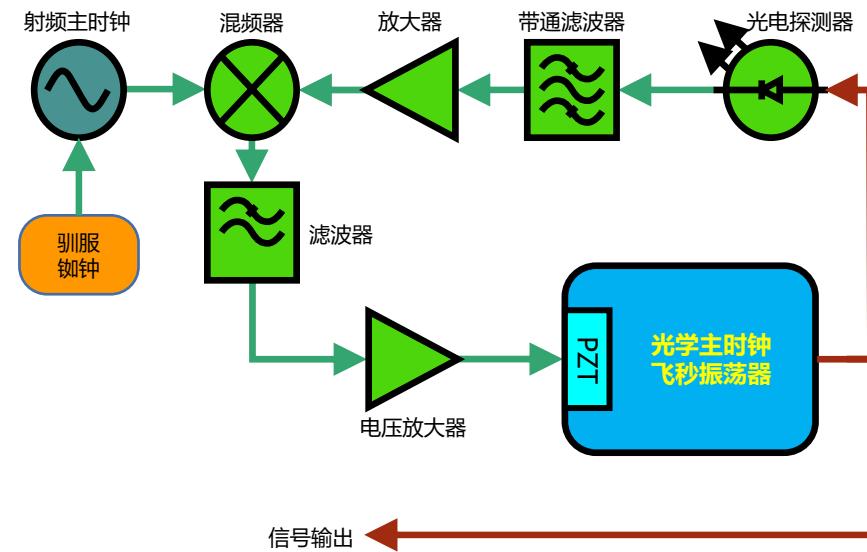
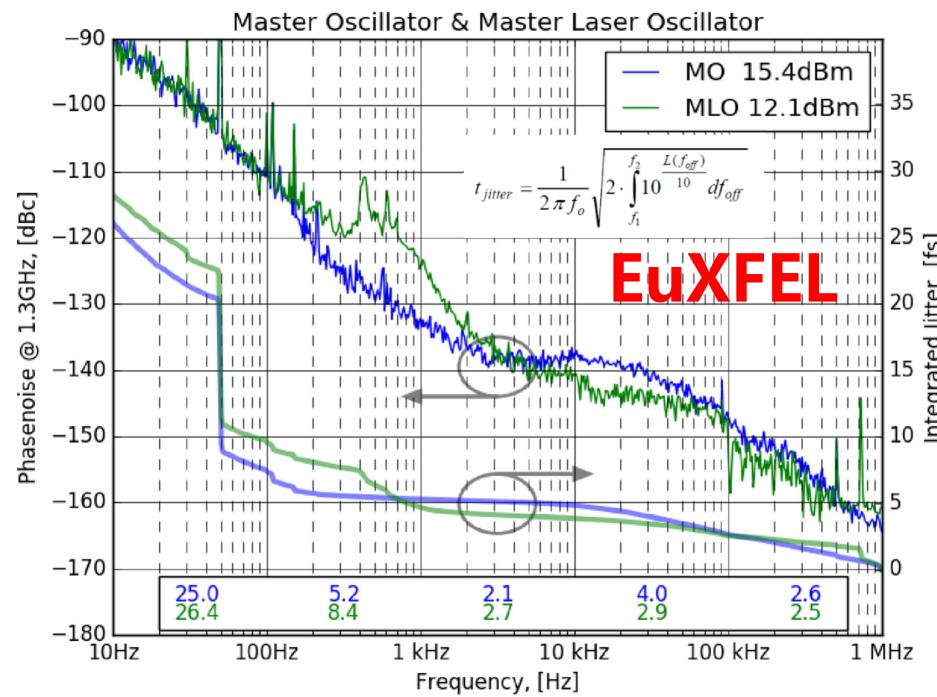


Main parameters of SYN

	Item	Property	Parameter
Master clock	RF Master Oscillator (RMO) (2856 MHz)	Jitter	<30 fs [10Hz, 10MHz]
	Optical Master Oscillator (OMO) (238 MHz)	Jitter	<10 fs [1kHz, 10MHz]
Link	Pulsed Laser	Added Jitter & Drift	<10 fs [35μHz, 10MHz]
Client	Photoinjector Laser (79.33 MHz)	Added Jitter & Drift	<100 fs [35μHz, 10MHz]
	Seed Laser (79.33 MHz)	Added Jitter & Drift	<20 fs [35μHz, 10MHz]
	LLRF (2856 MHz)	Added Jitter & Drift	<30 fs [35μHz, 10MHz]
	BI (2856 MHz)	Added Jitter	<200 fs [10Hz, 10MHz]

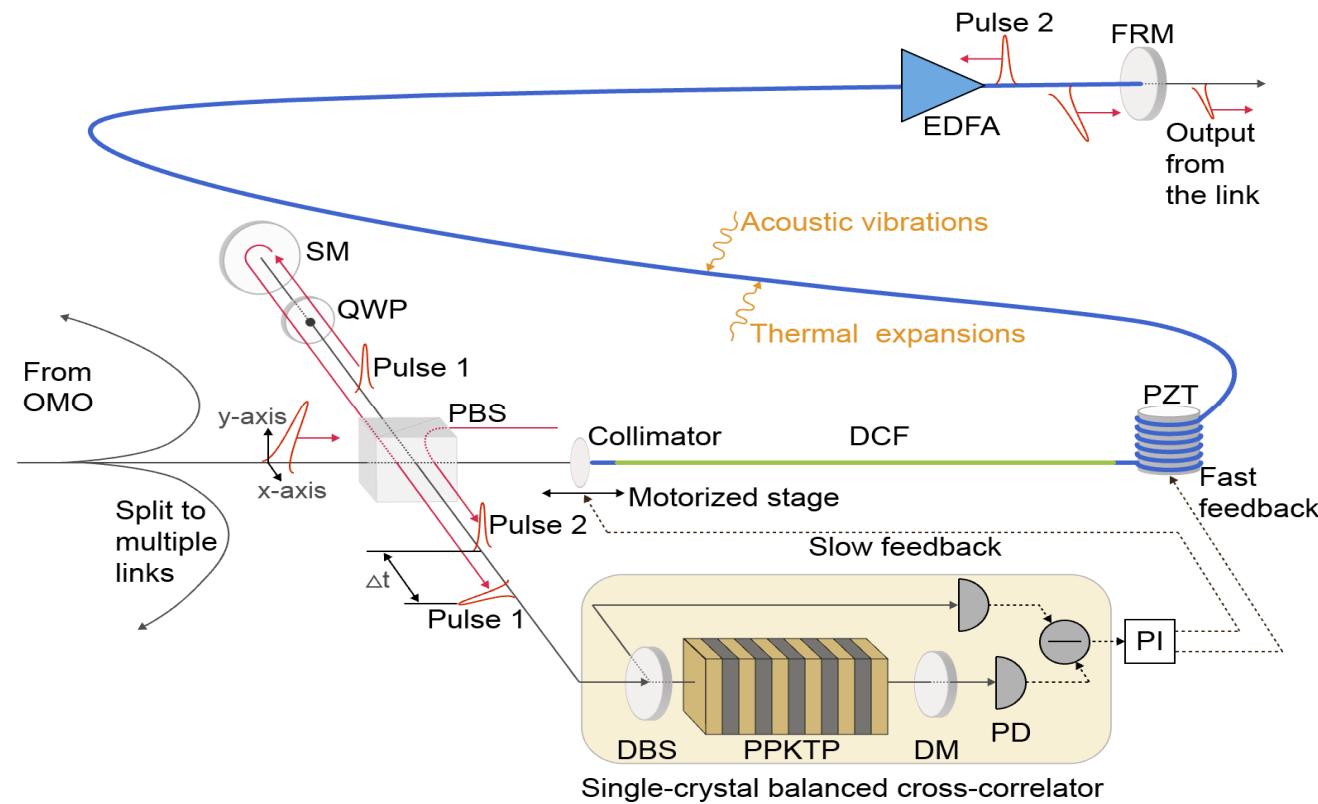
Master clock

RMO + OMO



RMO & OMO → Lower Phase Noise

Pulsed Laser Link

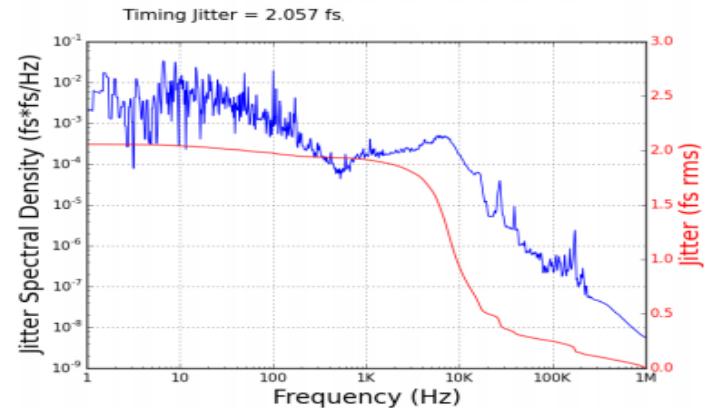


**Balanced Optical Cross-correlation
sub-10 fs jitter & drift**

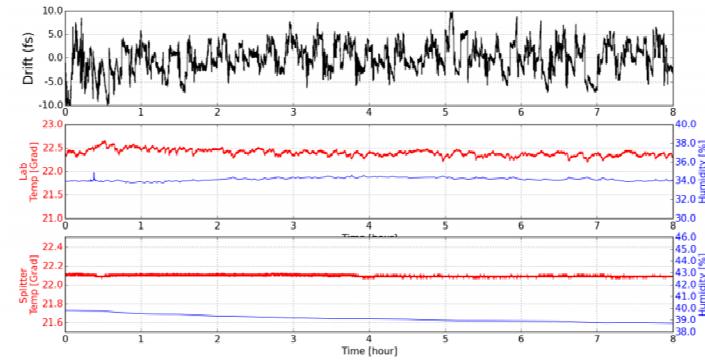
Pulsed Laser Link



Short Term Timing Jitter from 1 Hz up to 1 MHz

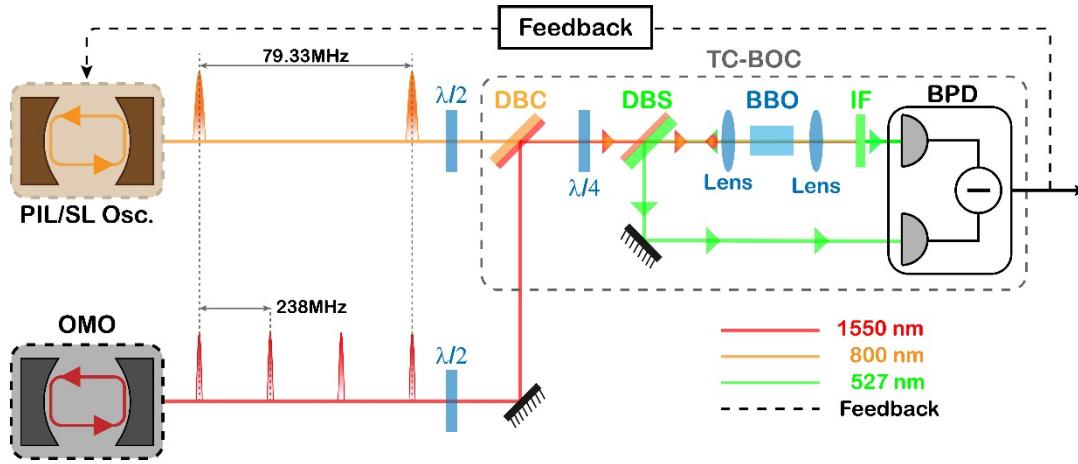


RMS Drift = 3.055 fs, Peak to Peak = 22.611 fs, (sensitivity = 7.940 mV/fs)

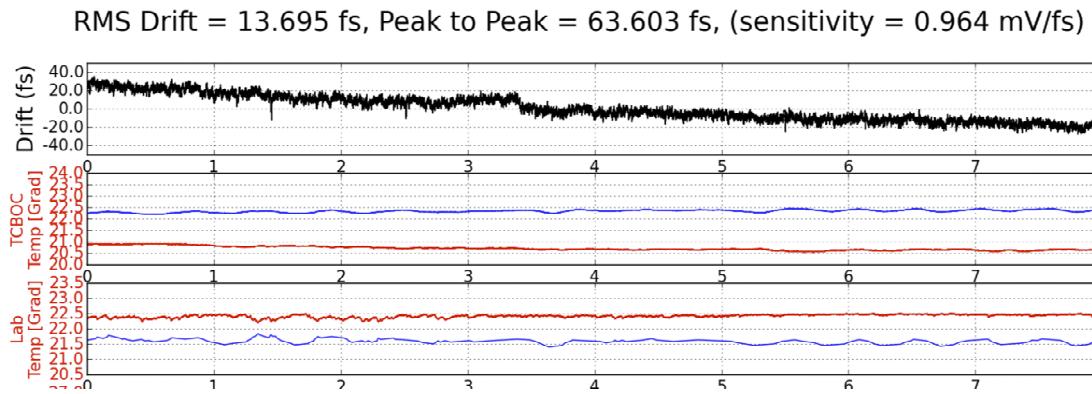
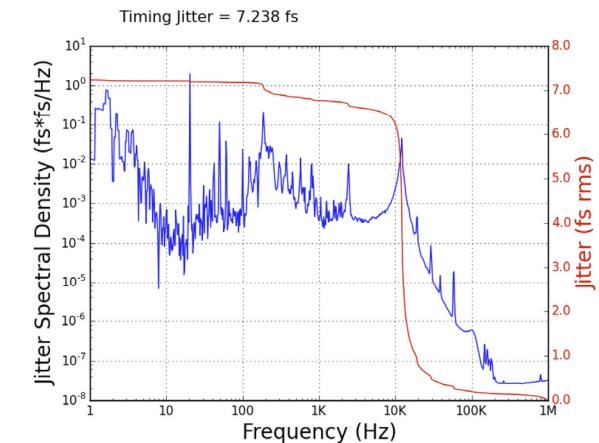


Jitter ~2 fs & Drift ~3 fs

Laser client

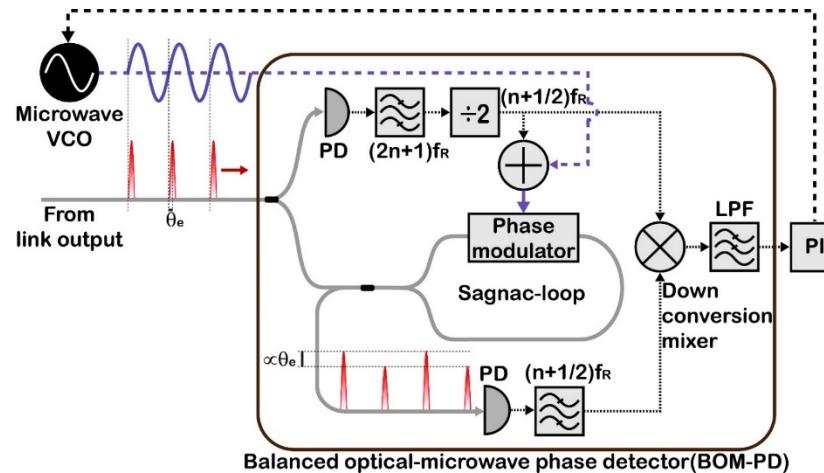


Short Term Timing Jitter from 1 Hz up to 1 MHz

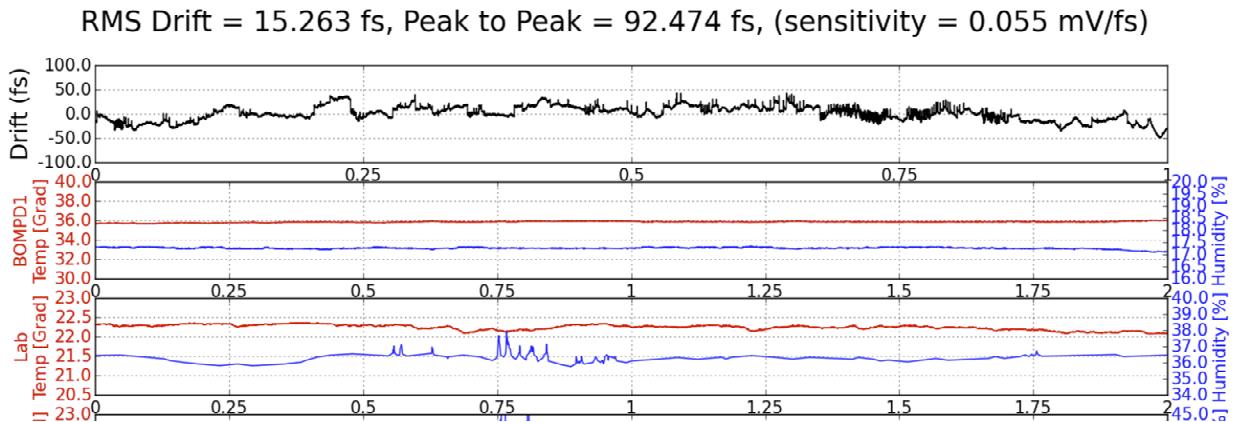
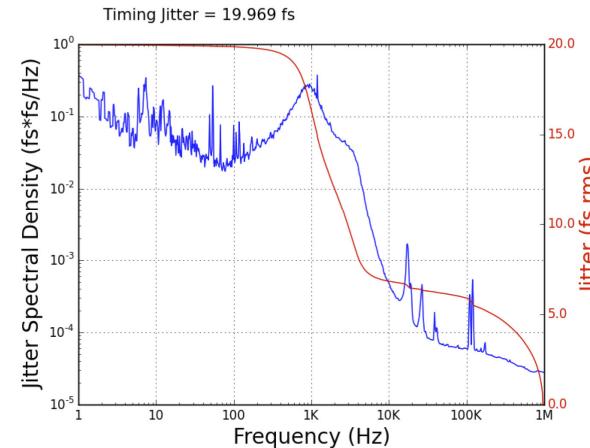


Two color Balanced Optical Cross-correlation
10 fs added jitter & 20 fs drift

RF client

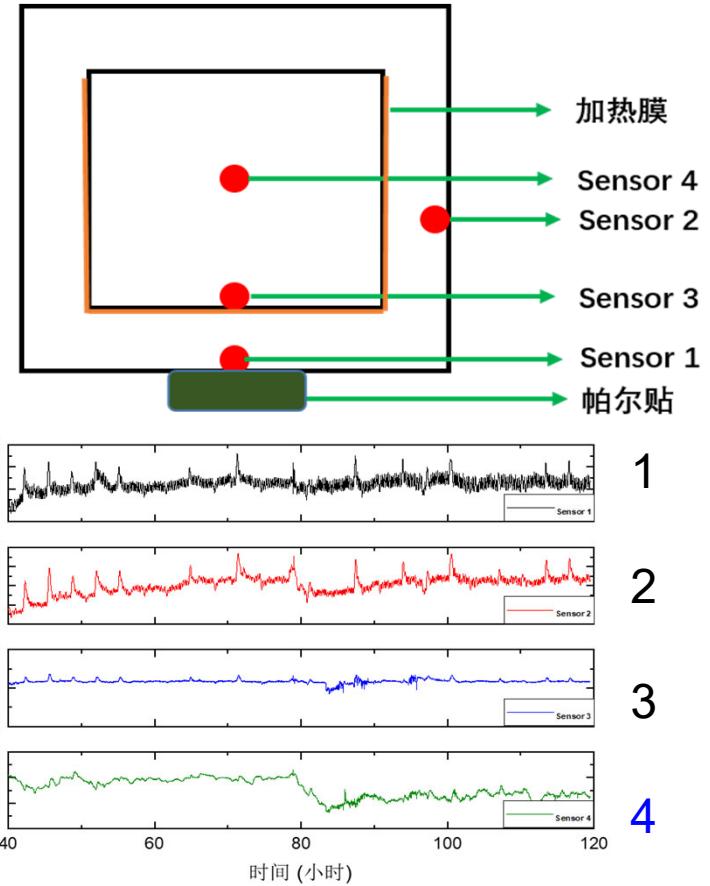
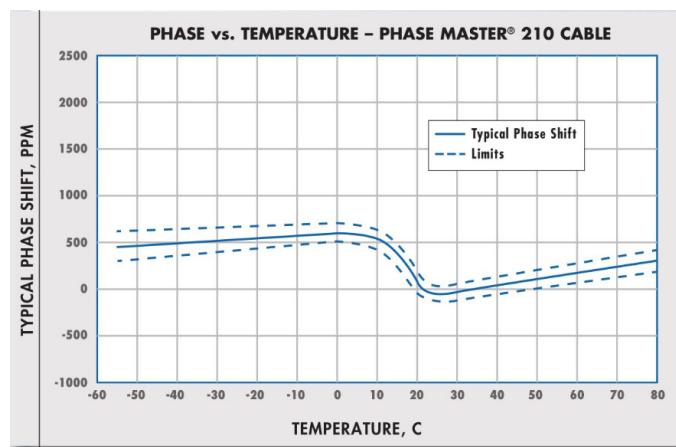


Short Term Timing Jitter from 1 Hz up to 1 MHz



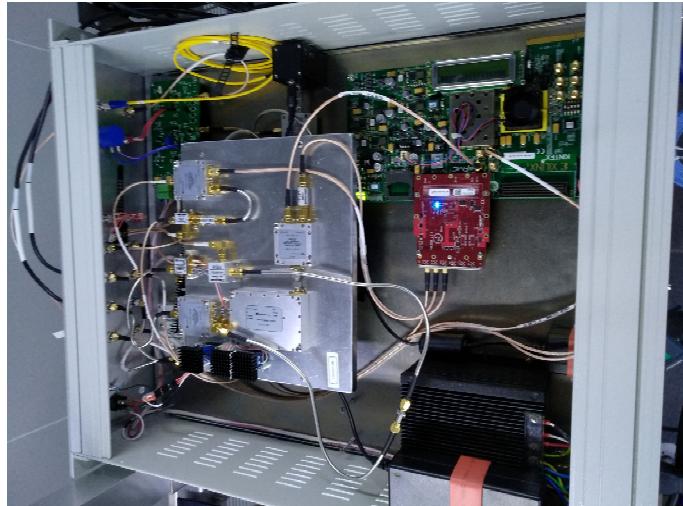
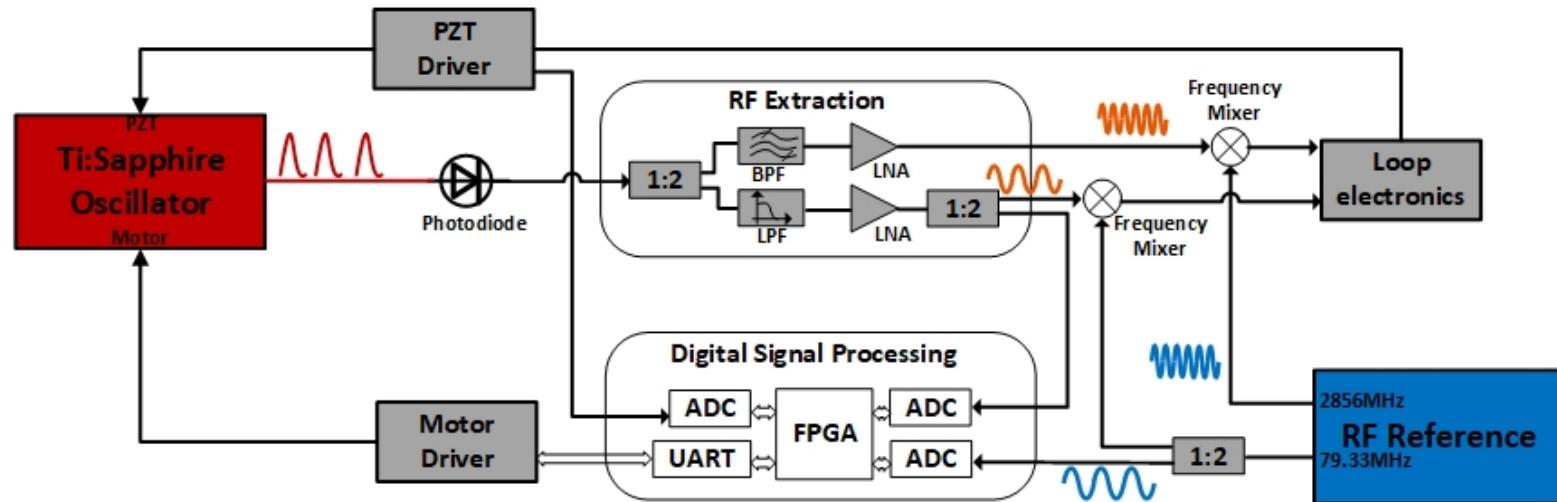
**Balanced Optical Microwave Phase Detector
20 fs added jitter & 20fs drift**

Temperature Stabilized RF Link



$\Delta T < 0.01 \text{ K(Pk-Pk)} / 5 \text{ days}$

Laser client (RF reference)



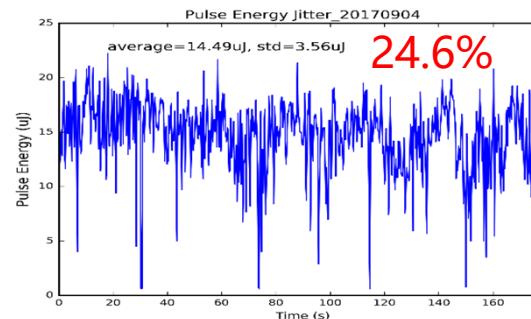
**~50 fs added jitter
&
~100 fs drift**

Adapted from Xiaoqing Liu & Bo Liu slides

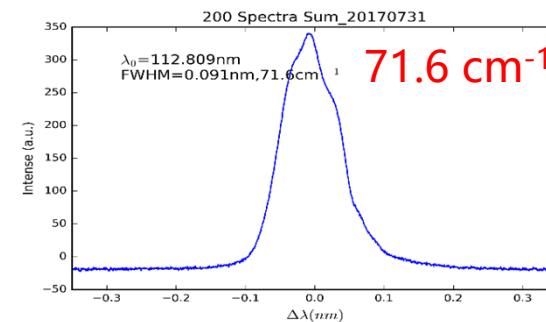
Synchronization Performance

RF

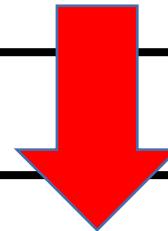
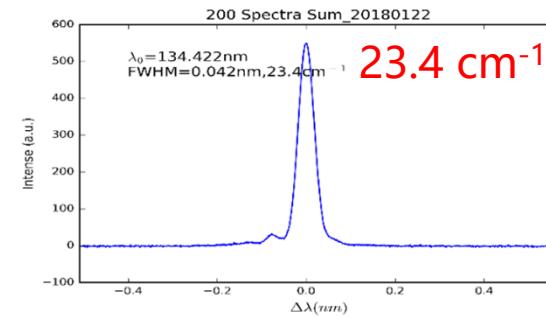
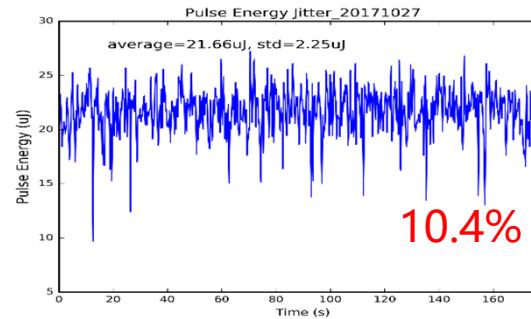
FEL Pulse Energy Stability



Spectra Stability



Pulsed
Laser



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Overview of the Injector

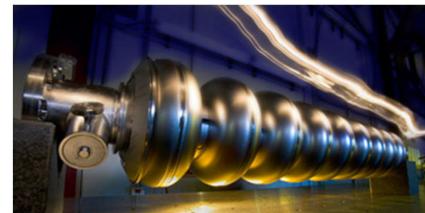
Warm Accelerator



100 Hz

Repetition
x10,000

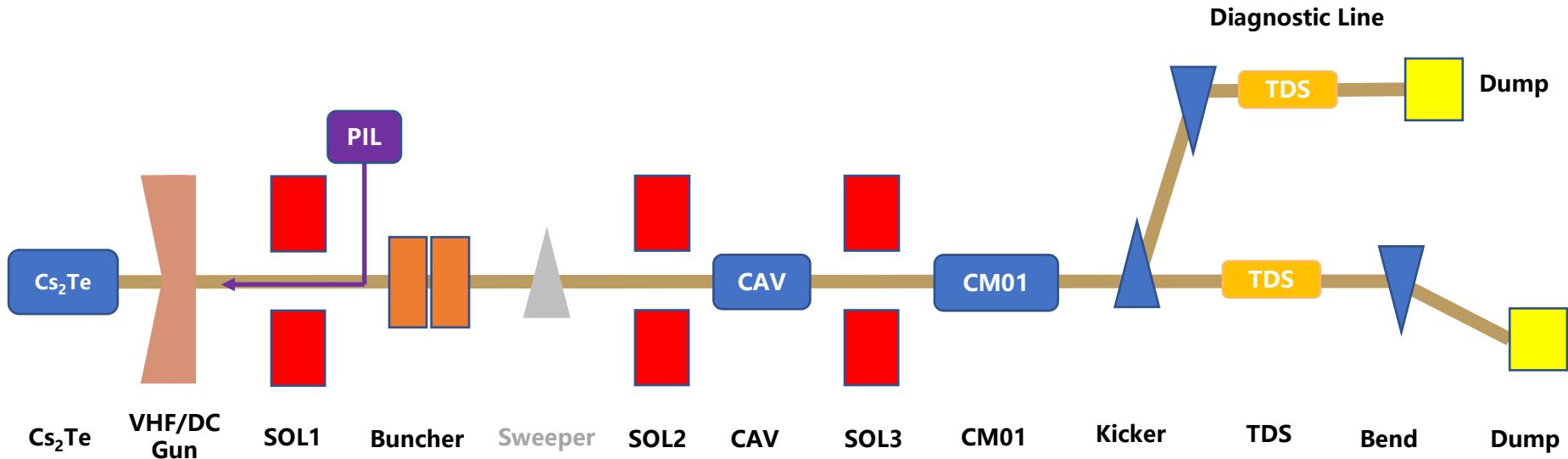
Superconductor Accelerator



1,000,000 Hz

Property

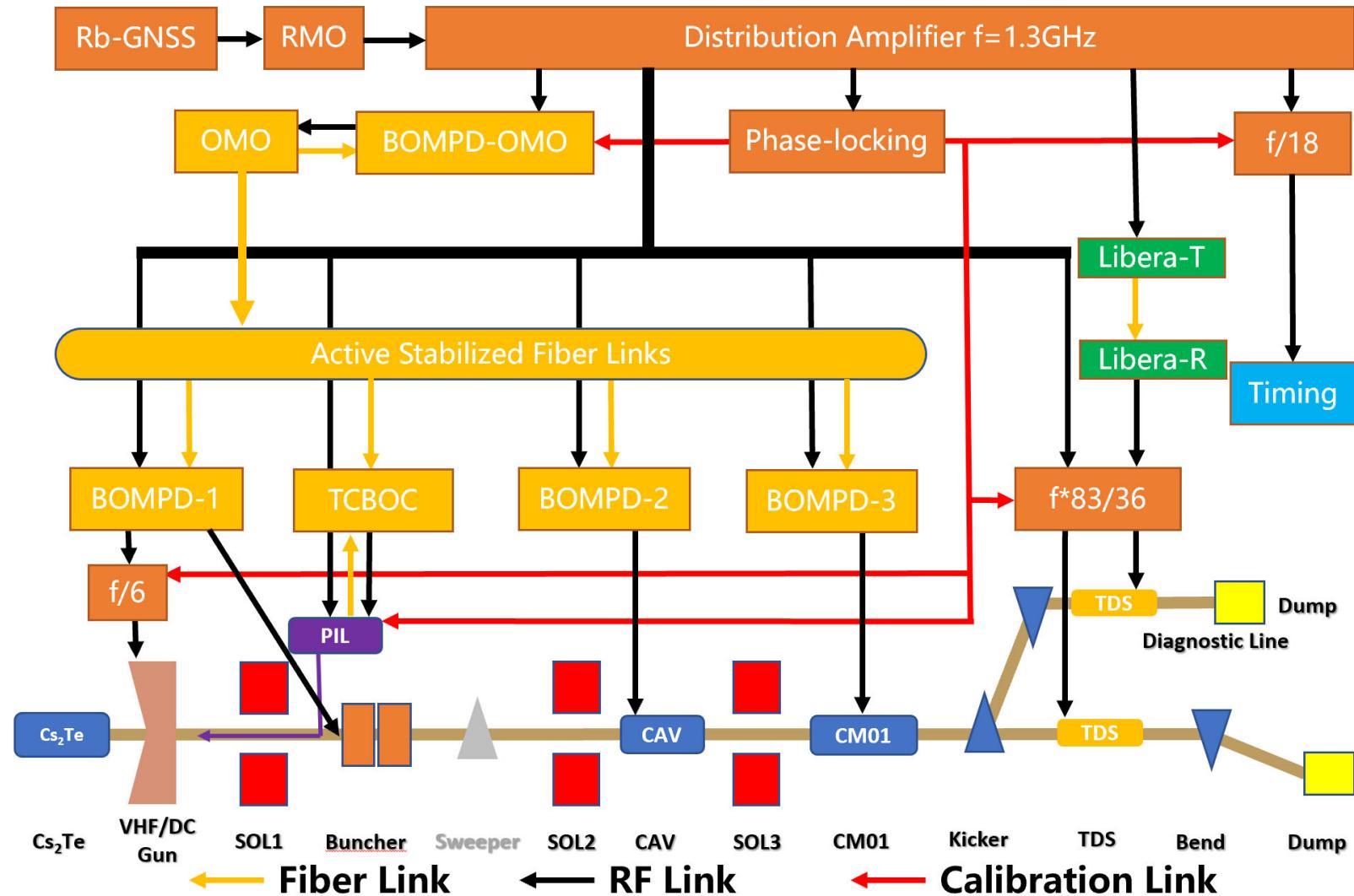
- ◆ Beam Energy: 90 MeV
- ◆ Charge: 100 pC
- ◆ Repetition: 0.1-1 MHz



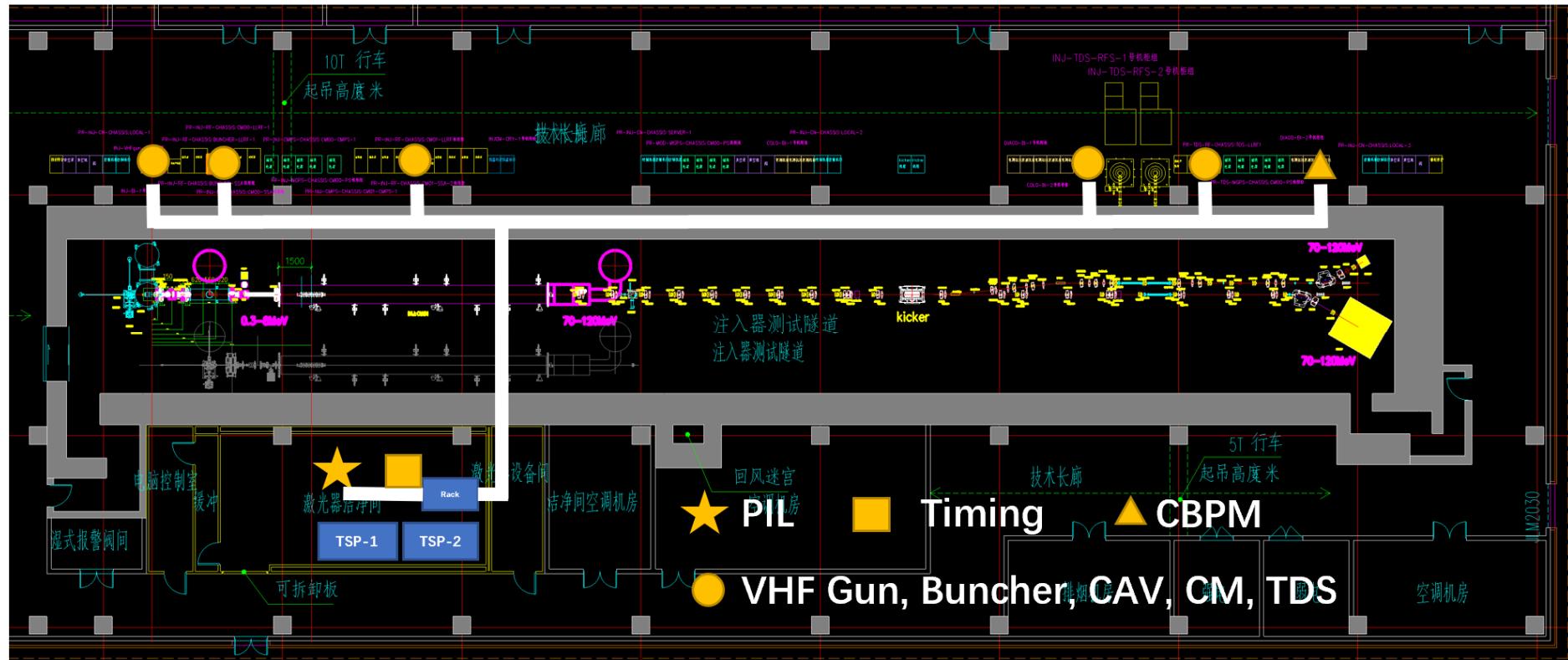
Requirements

System	Device	Reference Mode	f (MHz)	Factor $f=1300\text{MHz}$	Jitter (fs)	Unit
Laser	PIL	Pulsed Laser	36.111	1/36	<100[10Hz, 10MHz]	1
LLRF	VHF Gun	RF	216.667	1/6	<120[10Hz, 10MHz]	1
	Buncher	RF	1300	1	<30[10Hz, 10MHz]	1
	2-cell Module	RF	1300	1		1x2
	8-cell Module	RF	1300	1		1x8
Diag.	TDS	RF	2997.222	1/36*83	<60[10Hz, 10MHz]	1
	CBPM	RF	1300	1	<200[10Hz, 10MHz]	1
Timing	Timing	RF	72.222	1/18	<10 ps	1

Pulsed/CW laser, RF hybrid design

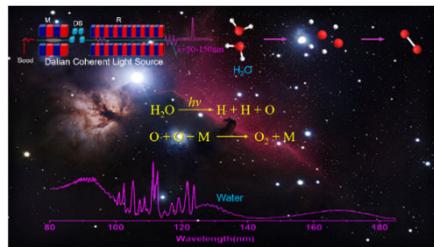


The drawing of the Injector



Conclusion

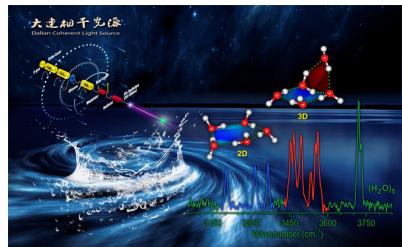
- 10 fs level Synchronization System of DCLS
FEL output jitter<10 fs & drift<15 fs
- Hybrid design for new Injector is ready
- Users highly satisfied since 2018



Sci.Adv., 2021

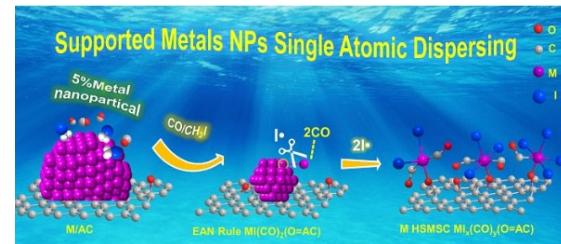
Nat. Comm., 2021

Nat. Comm., 2020



PNAS, 2020

Nat. Comm., 2020



Nat. Comm., 2019

J. Phys. Chem. Lett., 2019

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Mr. Chenyang Song

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**Thanks for your
attention!**