

Status of PAL-XFEL

Chi Hyun Shim

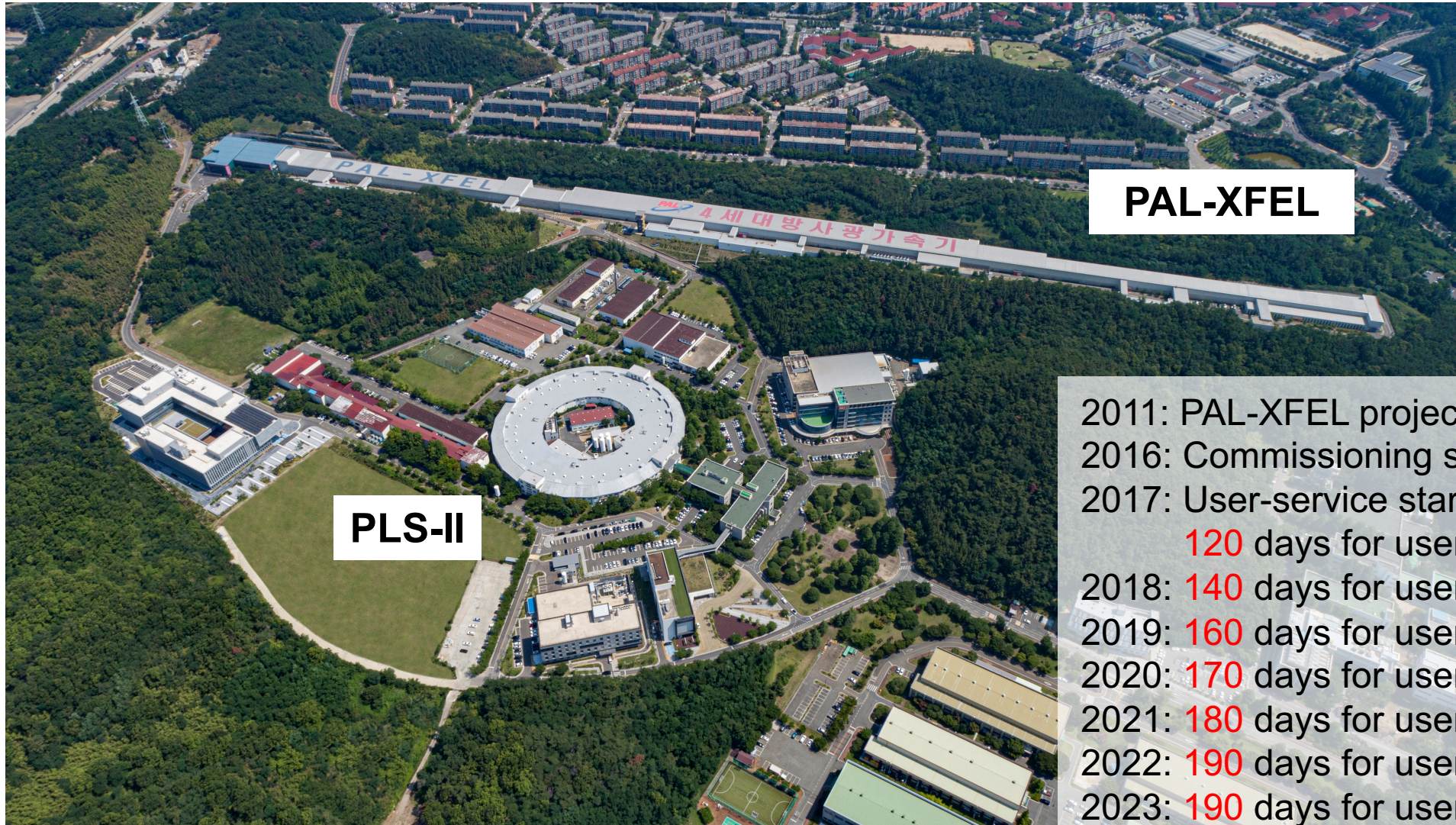
on behalf of PAL-XFEL



Contents

- **Introduction and operation summary**
- **Two-color XFEL mode with time delay and pulse duration control**
- **Simultaneous operation of the hard and soft X-ray beamlines**
- **Project for new second hard X-ray beamline (HX2)**
- **Project for attosecond X-ray pulse generation at PAL-XFEL**

Operation History of PAL-XFEL

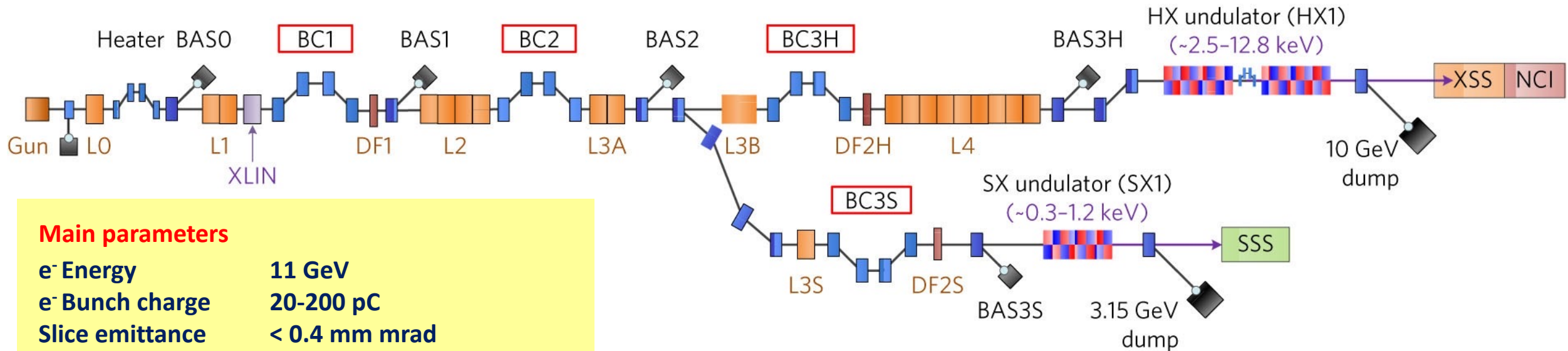


PAL-XFEL

PLS-II

- 2011: PAL-XFEL project started (Apr.)
- 2016: Commissioning started (Apr.)
- 2017: User-service started (Jun.)
 - 120 days for user (95% of availability)
- 2018: 140 days for user (95% of availability)
- 2019: 160 days for user (96.3% of availability)
- 2020: 170 days for user (96.9% of availability)
- 2021: 180 days for user (96.9% of availability)
- 2022: 190 days for user (97.1% of availability)
- 2023: 190 days for user (97.0% of availability)
- 2024: 190 days for user (98.5% of availability)
(~4/11)

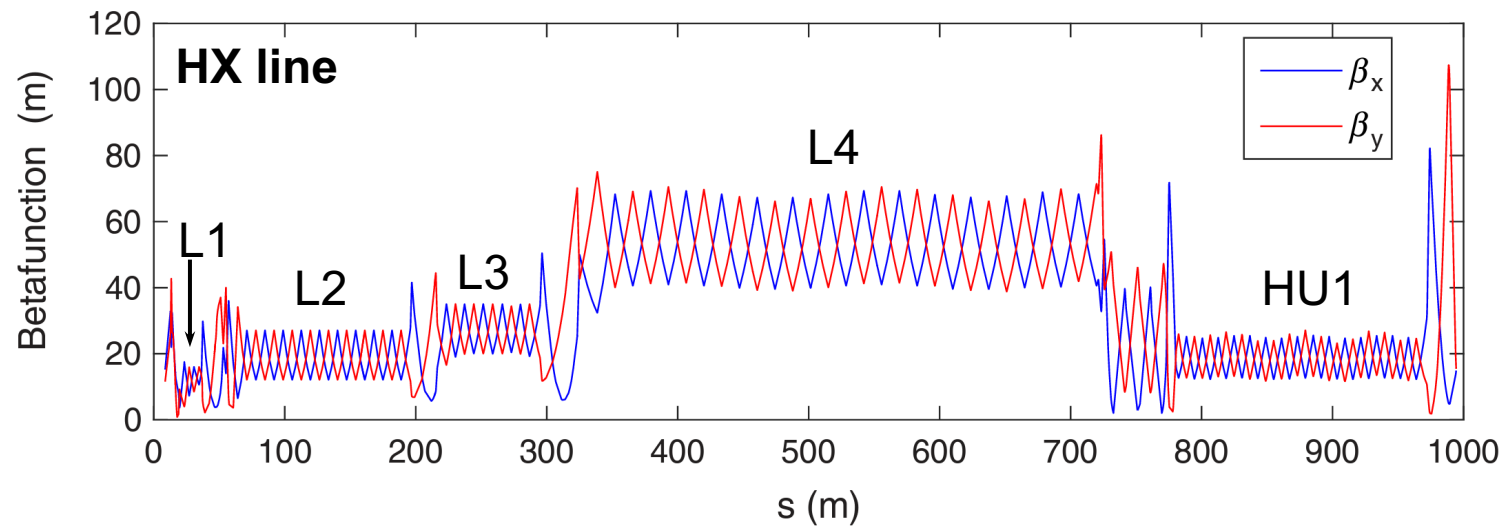
PAL-XFEL Layout & Parameters



Main parameters

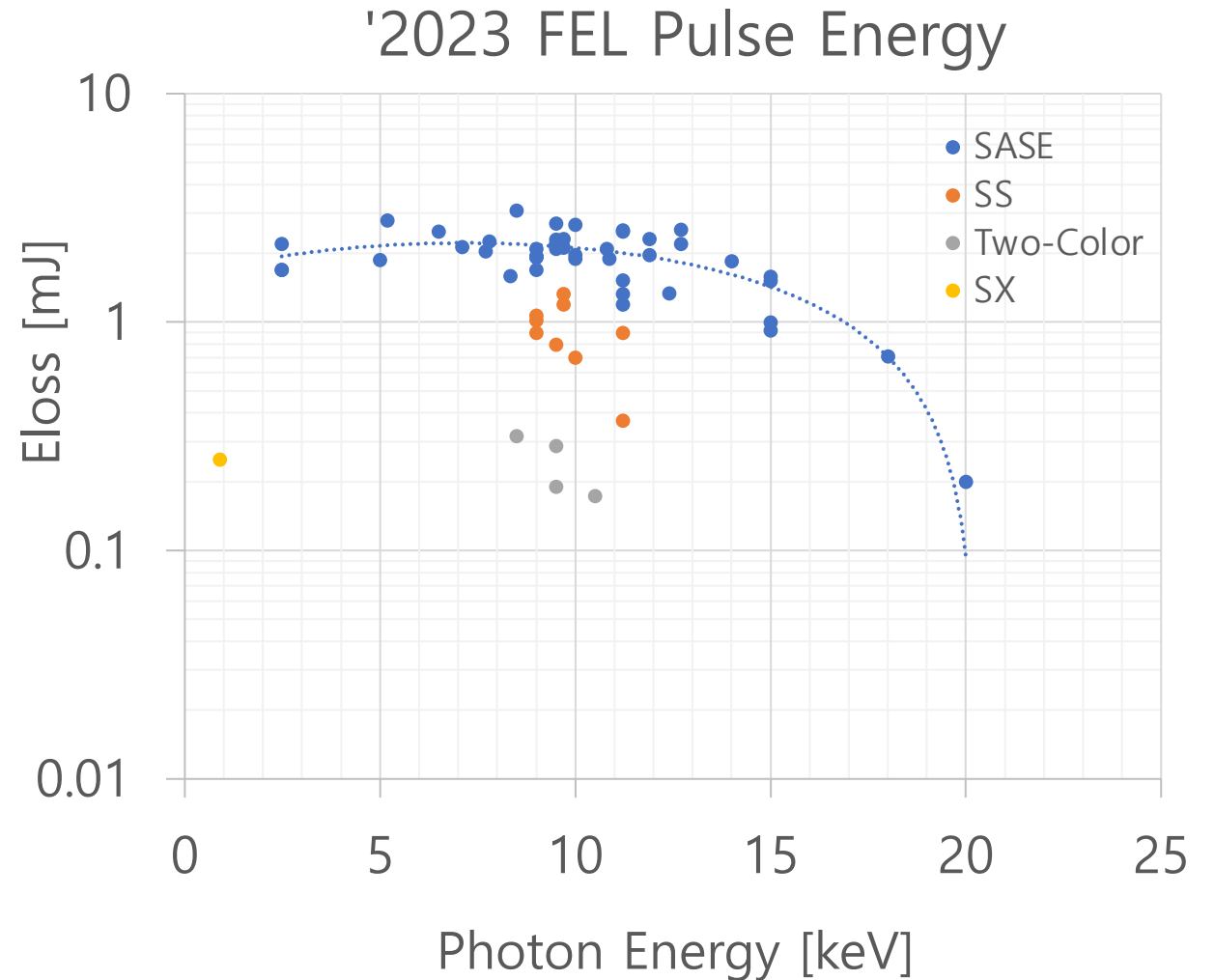
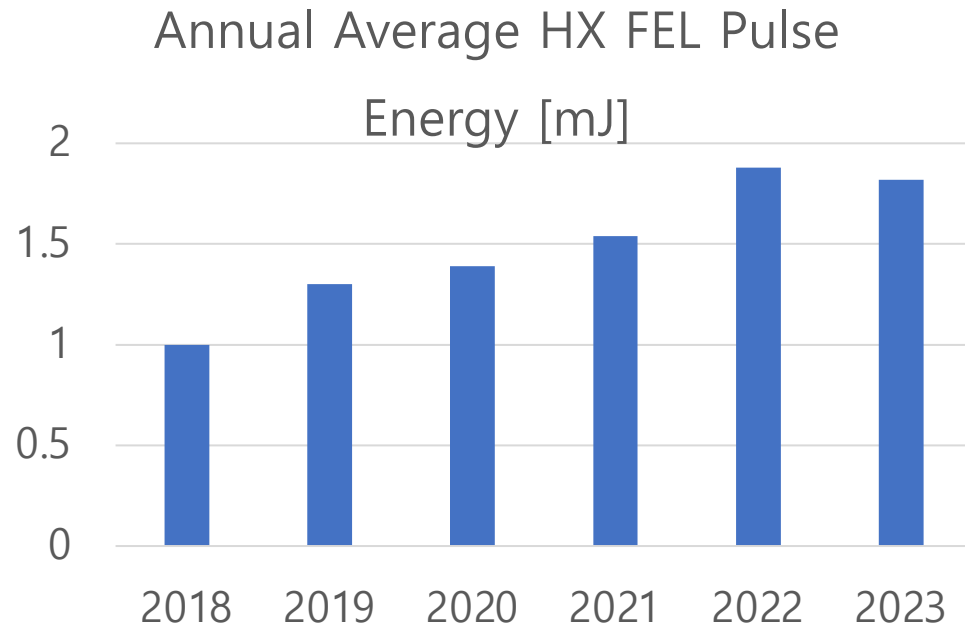
e ⁻ Energy	11 GeV
e ⁻ Bunch charge	20-200 pC
Slice emittance	< 0.4 mm mrad
Repetition rate	60 Hz
Bunch length	5 fs – 50 fs
Peak current	3 kA
SX line switching	Kicker Magnet

Undulator Line	HX	SX
Photon energy [keV]	2.0 ~ 15.0	0.25 ~ 1.25
Beam Energy [GeV]	4 ~ 11	3.0
Wavelength Tuning	Energy	Gap
Undulator Type	Planar	Planar
Und. Period / Gap [mm]	26 / 8.3	35 / 9.0



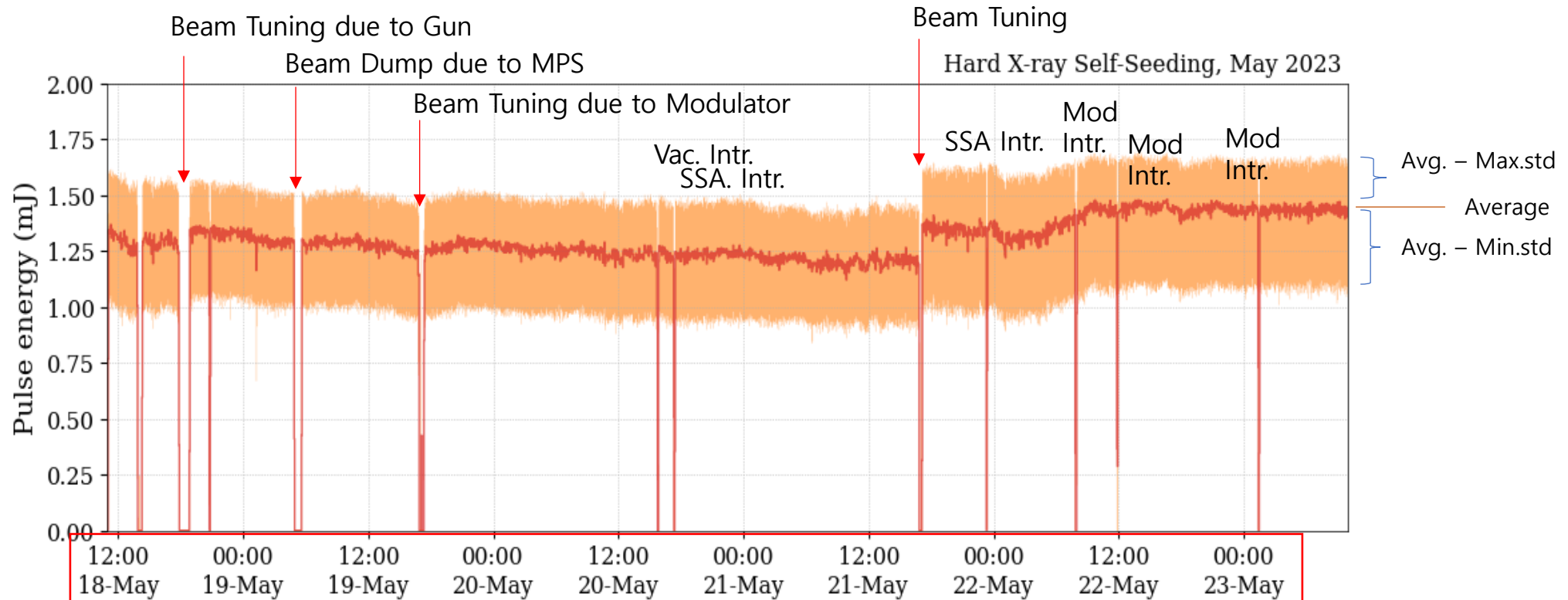
FEL Performance at PAL-XFEL

- ❖ More than 1 mJ HX FELs are serviced
- ❖ Self-seeding HX FEL services increase
- ❖ Two-color user service has been started
- ❖ SX FEL pulse energy is around 250 μ J



Long period self-seeding FEL user service

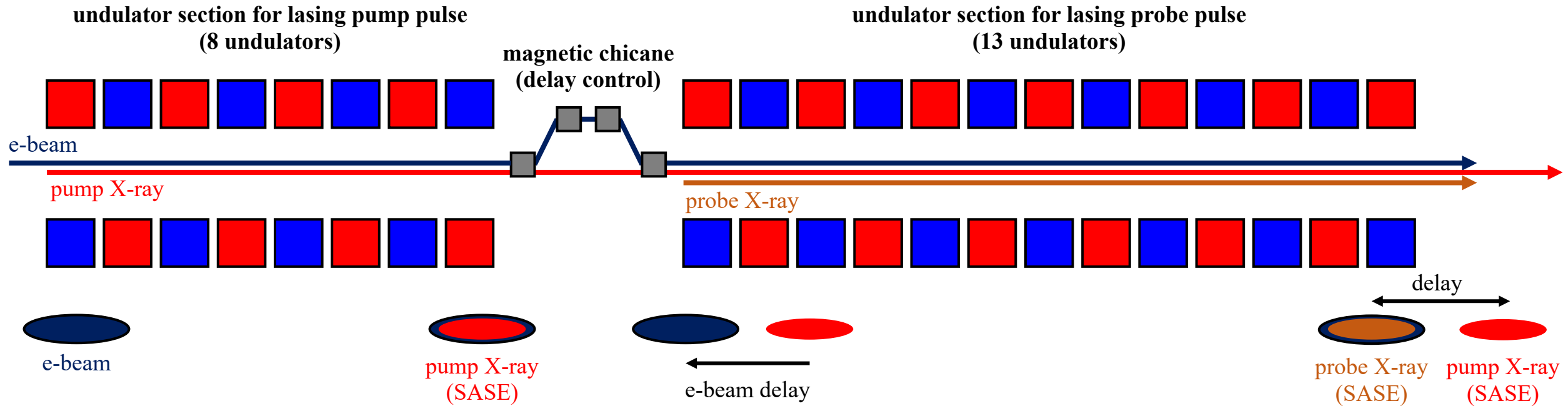
❖ We have serviced stable self-seeding FEL beams.



*Pulse energy is calculated by using e-loss factor

*Averaging sampling time is 180 sec

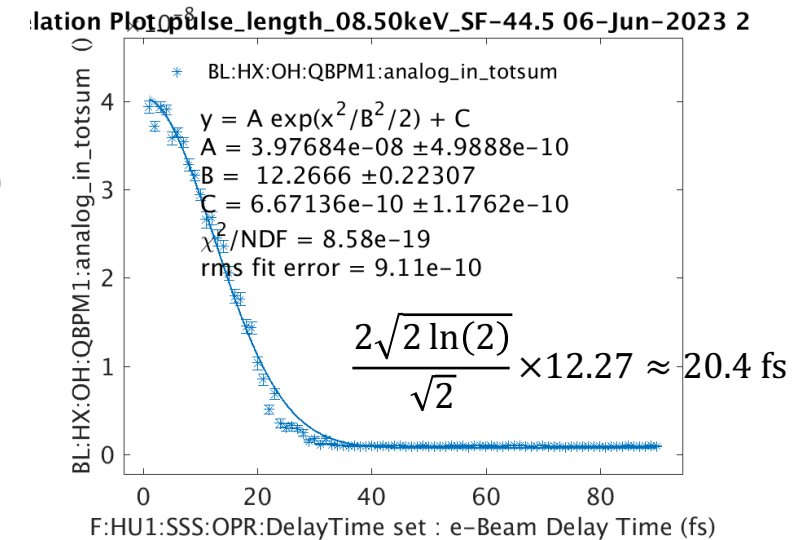
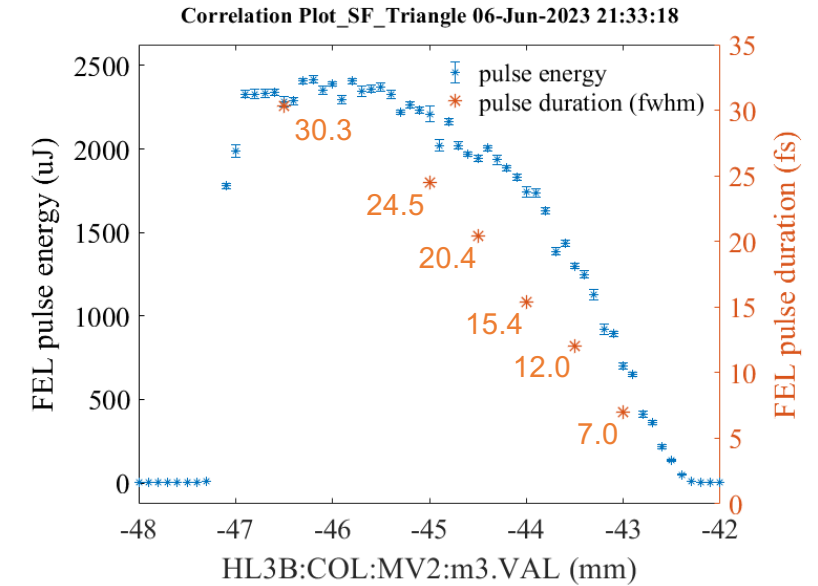
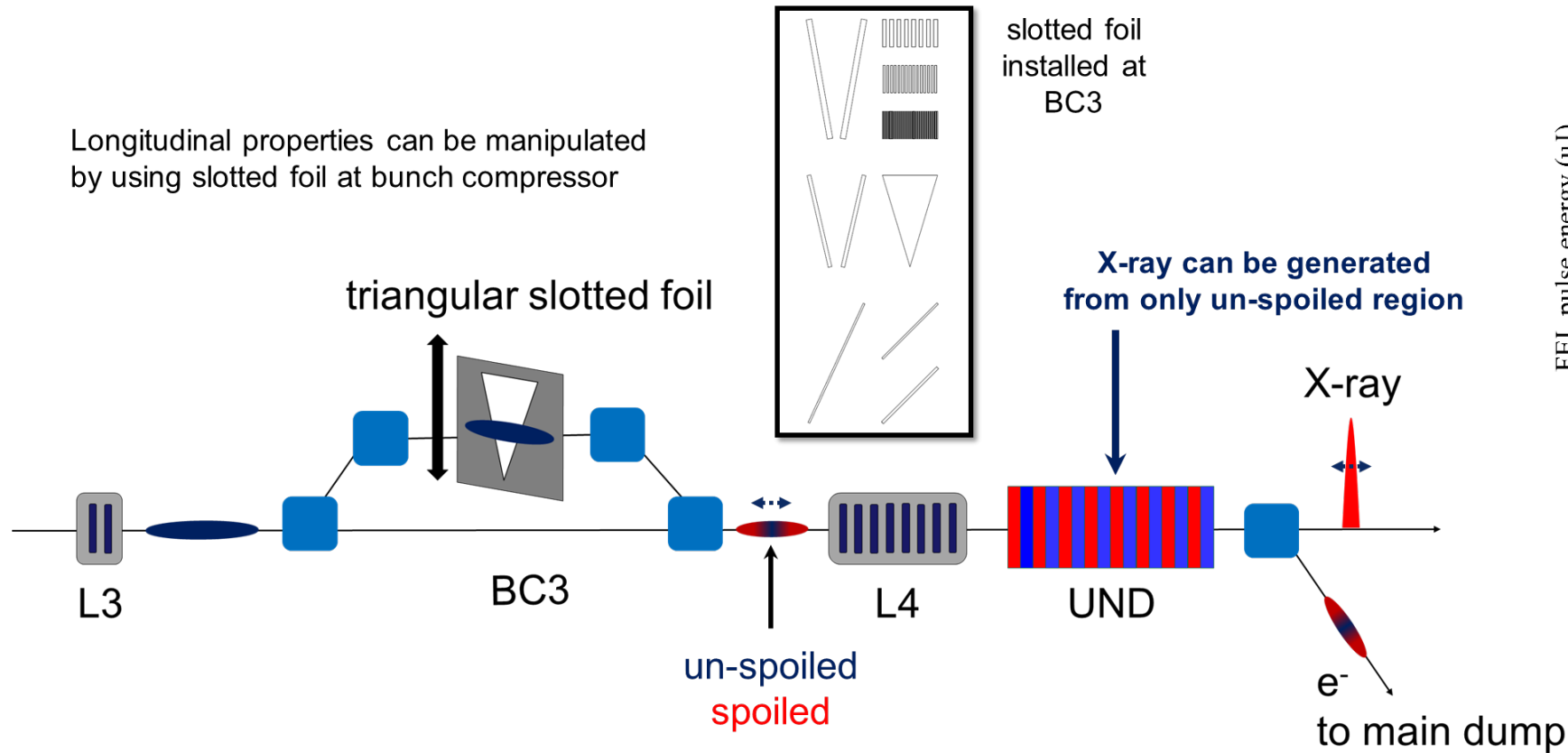
Two-color XFEL with time delay control



- ✓ By utilizing variable gap undulator and dipole magnet for self-seeding section, two-color pump-probe XFEL pulses can be generated from single electron bunch
- ✓ Time delay between pump and probe pulse can be controlled by changing the current of the dipole magnet (max. time delay is 120 fs)

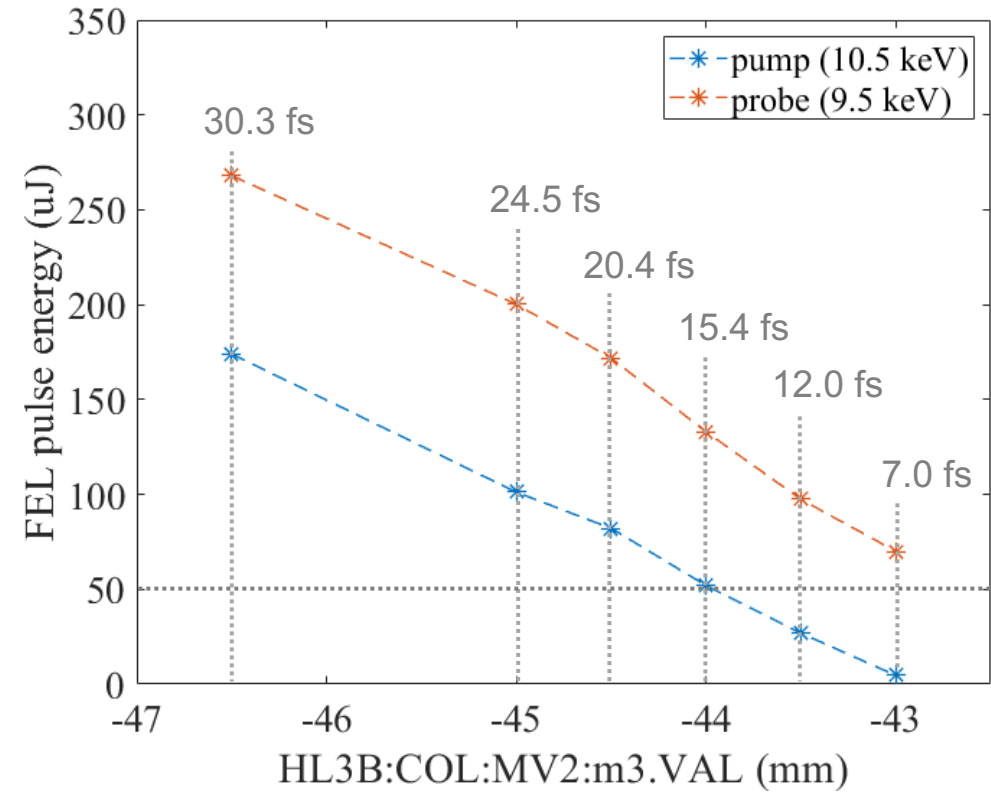
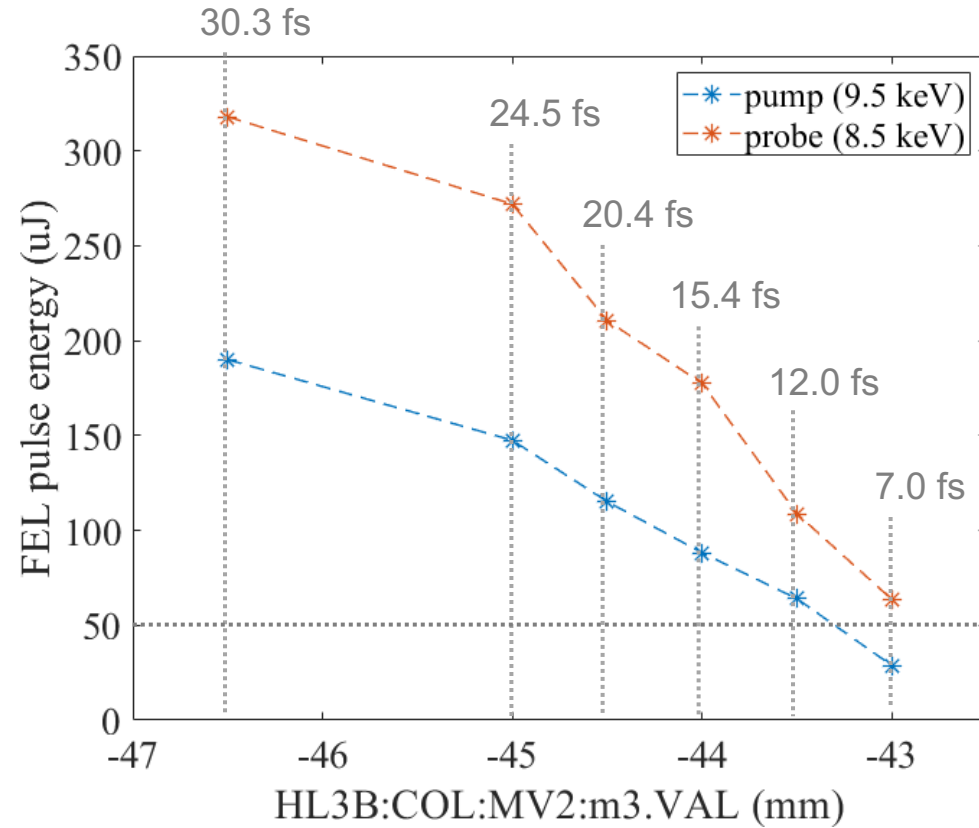
Pulse duration control using slotted foil at BC

Longitudinal properties can be manipulated by using slotted foil at bunch compressor



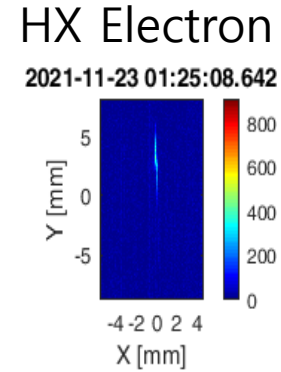
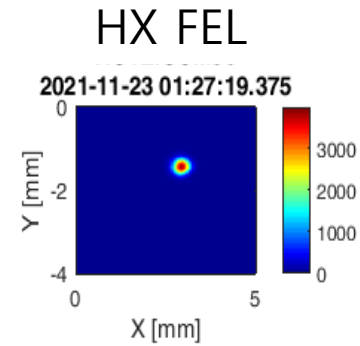
- ✓ Pulse duration is measured by using intensity autocorrelation with magnetic chicane installed in the self-seeding section.
- ✓ We assumed that the XFEL pulse is a Gaussian pulse.

Two-color XFEL for user service (2023. 6. 8~9)



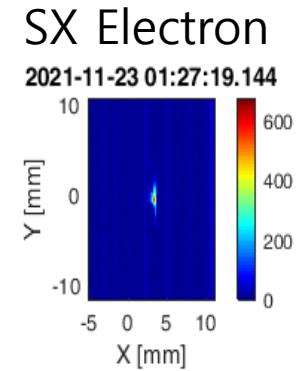
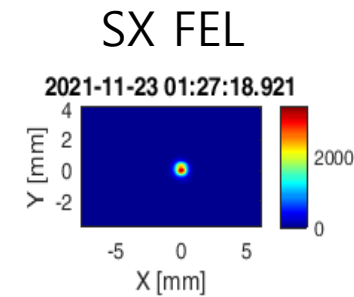
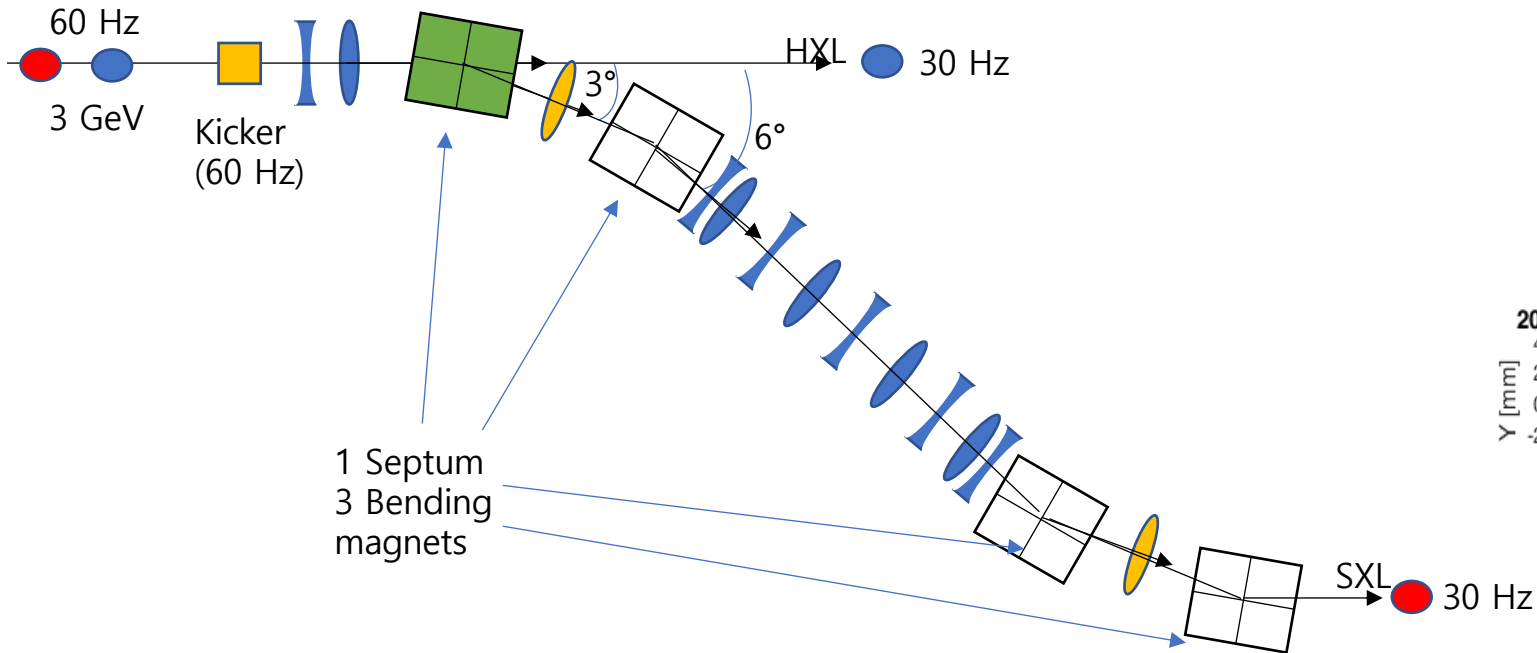
✓ Pulse duration according to SF position is measured by using single-color SASE XFEL

Beam Images of Multi-Beamline Operation of HX and SX

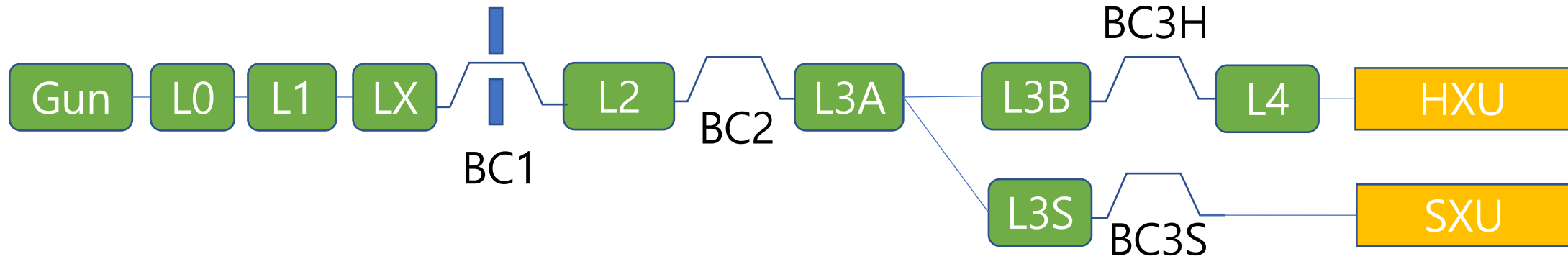


• Available configurations (Hz)

	HX	SX
1	60	0
2	0	60
3	30	30
4	50	10
5	10	50
6	58	2
7	2	58



Soft X-ray FEL Schemes during simultaneous operation



		L1 RF Φ	LX RF Φ	BC1 Collimator	L2 RF Φ	L3A RF Φ	BC1, BC2 Magnet	Control
HX_Only		Φ_{L1_HX}	Φ_{LX_HX}	Gap_HX	Φ_{L2_HX}	Φ_{L3_HX}	TWQ_HX	Bunch by bunch Orbit F/B
SX_Only		Φ_{L1_SX}	Φ_{LX_SX}	Gap_SX	Φ_{L2_SX}	Φ_{L3_SX}	TWQ_SX	Bunch by bunch Orbit F/B
Scheme 1	HX	Φ_{L1_HX}	Φ_{LX_HX}	Gap_HX	Φ_{L2_HX}	Φ_{L3_HX}	TWQ_HX	Bunch by bunch Orbit & Long. F/B
	SX	Φ_{L1_SX}	Φ_{LX_SX}	Gap_HX	Φ_{L2_SX}	Φ_{L3_SX}	TWQ_HX	
Scheme 2	HX	Φ_{L1_HX}	Φ_{LX_HX}	Gap_HX	Φ_{L2_HX}	Φ_{L3_HX}		Bunch by bunch Orbit F/B
	SX	Φ_{L1_HX}	Φ_{LX_HX}	Gap_HX	Φ_{L2_HX}	Φ_{L3_HX}	TWQ_HX	

RF Panel

RF Overview

RF Control

Phase Control

Phase Cont.(Dual)

RF Trigger

FEL Mode

HX & SX Mode

Linac Mode

FEL mode

Beam End Point

HX main dump

Beam

ON

MIS

Clear

User

guide

Laser Delay (ns) : 10850

RF Phase Control (HX & SX Simultaneous operation)

Station	Crest	BL1 : HX				BL2 : SX			
		Feedback	Operation	Set value	Error (10^-2)	Feedback	Operation	Set value	Error (10^-2)
Gun	16.843 +	0.000 +	33.700 =	50.543 ~	-3				
L0_01	242.650 +	0.000 +	1.000 =	243.650 ~	4				
L0_02	47.516 +	0.000 +	-2.000 =	45.516 ~	2				
L1_01	71.903 +	-0.015 +	-10.750 =	61.138 ~	1	0.000 +	-10.800 =	61.103 ~	71
L1_02	71.617 +	-0.015 +	-10.750 =	60.852 ~	-3	0.000 +	-10.800 =	60.817 ~	53
XLIN	426.274 +	-0.411 +	-179.000 =	246.863 ~	-3	0.000 +	-170.200 =	256.074 ~	21
DF1	95.000 +	0.000 +	90.000 =	185.000 ~	-0				
L2_01	79.883 +	0.089 +	-19.400 =	60.572 ~	2	0.000 +	-18.420 =	61.463 ~	138
L2_02	82.107 +	0.089 +	-19.400 =	62.797 ~	1	0.000 +	-18.420 =	63.687 ~	79
L2_03	112.858 +	0.089 +	-19.400 =	93.547 ~	-1	0.000 +	-18.420 =	94.438 ~	115
L2_04	80.289 +	0.089 +	-19.400 =	60.979 ~	-3	0.000 +	-18.420 =	61.869 ~	90
L2_05	79.498 +	0.089 +	-19.400 =	60.187 ~	1	0.000 +	-18.420 =	61.078 ~	131
L2_06	84.691 +	0.089 +	-19.400 =	65.381 ~	-2	0.000 +	-18.420 =	66.271 ~	152
L2_07	87.391 +	0.089 +	-19.400 =	68.080 ~	5	0.000 +	-18.420 =	68.754 ~	-2
L2_08	36.990 +	0.089 +	-19.400 =	17.680 ~	-4	0.000 +	-18.420 =	18.570 ~	141
L2_09	83.673 +	0.089 +	-19.400 =	64.363 ~	-2	0.000 +	-18.420 =	65.253 ~	147
L2_10	85.515 +	0.089 +	-19.400 =	66.204 ~	-0	0.000 +	-18.420 =	67.095 ~	171
L3_A1	116.383 +	0.612 +	-8.000 =	108.994 ~	7	0.000 +	-10.000 =	106.383 ~	135
L3_A2	143.884 +	0.612 +	-8.000 =	136.495 ~	-1	0.000 +	-10.000 =	133.884 ~	118
L3_S1	103.636 +	0.000 +	0.000 =	103.636 ~	-4	0.000 +	90.000 =	193.636 ~	0
DF2S	105.100 +					0.000 +	90.000 =	195.100 ~	7

Station	Crest	BL1 : HX			
		Feedback	Operation	Set value	Error (10^-2)
L3_B1	70.756 +	0.612 +	-8.000 =	63.367 ~	2
L3_B2	70.456 +	0.612 +	-8.000 =	63.068 ~	-3
DF2	170.900 +	0.000 +	90.000 =	260.900 ~	2
L4_01	69.804 +	0.000 +	-1.000 =	68.804 ~	6
L4_02	73.177 +	0.000 +	-1.000 =	72.177 ~	-1
L4_03	94.458 +	0.000 +	-1.000 =	93.458 ~	3
L4_04	75.150 +	0.000 +	-1.000 =	74.150 ~	-2
L4_05	156.656 +	0.000 +	-1.000 =	155.656 ~	1
L4_06	41.412 +	0.000 +	-1.000 =	40.412 ~	-3
L4_07	41.436 +	0.000 +	-1.000 =	40.436 ~	1
L4_08	329.640 +	0.000 +	-1.000 =	328.640 ~	-1
L4_09	42.803 +	0.000 +	-1.000 =	41.803 ~	-1
L4_10	187.464 +	0.000 +	-1.000 =	186.464 ~	2
L4_11	42.235 +	0.000 +	-1.000 =	41.235 ~	2
L4_12	173.120 +	0.000 +	-1.000 =	172.120 ~	-25
L4_13	76.812 +	0.000 +	-1.000 =	75.812 ~	-3
L4_14	84.000 +	0.000 +	-1.000 =	83.000 ~	0
L4_15	73.667 +	0.000 +	-1.000 =	72.667 ~	-2
L4_16	77.252 +	0.000 +	-1.000 =	76.252 ~	1
L4_17	138.579 +	0.000 +	-1.000 =	137.579 ~	-4
L4_18	85.120 +	0.000 +	-1.000 =	84.120 ~	-2
L4_19	83.504 +	0.000 +	-1.000 =	82.504 ~	2
L4_20	82.211 +	0.000 +	-1.000 =	81.211 ~	-0
L4_21	100.229 +	0.000 +	-1.000 =	99.229 ~	-1
L4_22	90.830 +	0.000 +	-1.000 =	89.830 ~	-0
L4_23	90.091 +	0.000 +	-1.000 =	89.091 ~	2
L4_24	334.572 +	0.000 +	-1.000 =	333.572 ~	1
L4_25	332.682 +	0.000 +	-1.000 =	331.682 ~	0
L4_26	331.487 +	0.000 +	-1.000 =	330.487 ~	-1
L4_27	336.050 +	0.000 +	-1.000 =	335.050 ~	2

Feedback Phase Initialization

All set zero

All Reset

Update Op. (FB + OP => OP)

Phase controller (Mini)

Dual-BL Enable/Disable

Multi OFF

BL1 : HX

	L0_02	L1	XLIN	L2	L3_A	L3_B	L3_H	L4
Feedback :	0.000	-0.015	-0.411	0.089	0.612	0.612	0.612	0.000
Operation :	-2.000	-10.750	-179.000	-19.400	-8.000	-8.000	-8.000	-1.000
tweak step :	0.000	0.100	0.500	0.100	1.000	2.000	1.000	0.000

BL2 : SX

	L1_M2	XLIN_M2	L2_M2	L3_A_M2	L3_S1_M2
Feedback :	0.000	0.000	0.000	0.000	0.000
Operation :	-10.800	-170.200	-18.420	-10.000	90.000
tweak step :	0.100	0.100	0.100	0.100	0.100

Feedbacks

Gun Charge Feedback
 Gun Charge: 245.687, 250.000, 1.762, -251.512

Orbit Correction

Laser Shutter: LASER ON

F.F.R. ORBIT1 (J1): HL1-HL4, Auto Gain: ON, OFF

F.F.R. ORBIT2 (J2): SBL, Auto Gain: ON, OFF

F.F.D. ORBIT (J3): IU1, Auto Gain: ON, OFF

F.H. ORBIT (J4): SUI, Auto Gain: ON, OFF

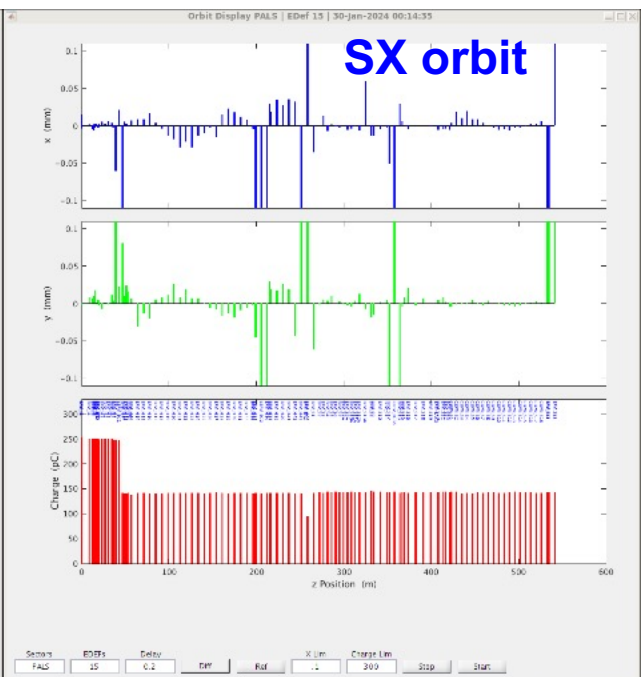
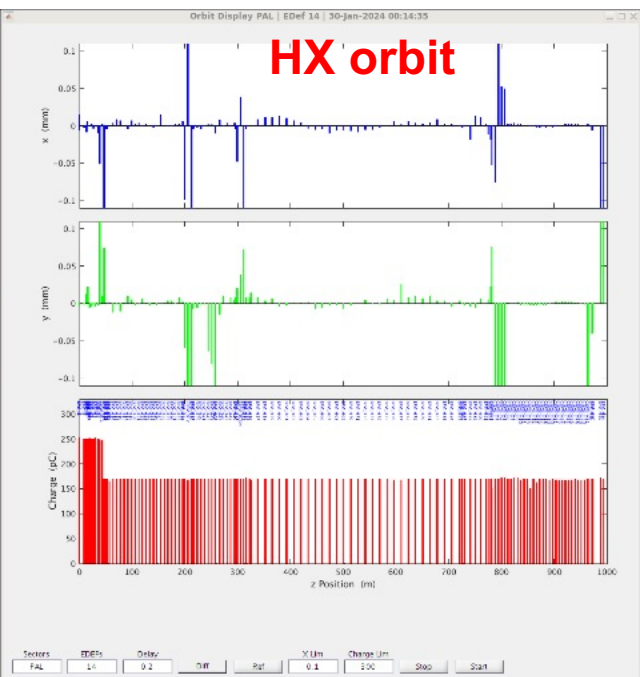
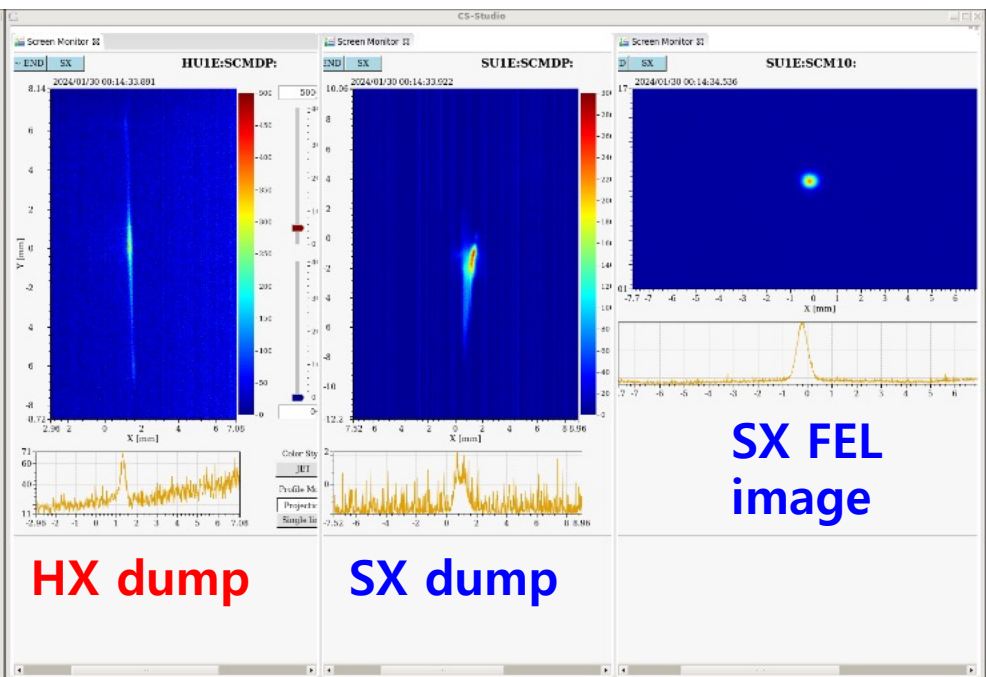
F.F.R. ORBIT (J5): S13, Auto Gain: ON, OFF

F.F.R. ORBIT (J6): S15, Auto Gain: ON, OFF

Iniac Energy

Mode: HX SX, Get Target: ON, OFF

User	reference	target	set	level
GLN PHASE	0.750	0.780	0.020	1.0 %
BC1 ERPM	0.000	0.000	0.000	7.2 %
BC2 ERPM	0.000	-160.000	-160.000	7.2 %
BC3 ERPM	0.000	0.000	0.000	7.2 %
BC3H ERPM	0.000	0.000	0.000	7.2 %
BC4 ERPM	0.000	-86.000	-86.000	7.2 %
BC5 ERPM	0.000	-160.000	-160.000	7.2 %
BC6 ERPM	0.000	-160.000	-160.000	7.2 %
BC7 ERPM	0.000	-160.000	-160.000	7.2 %
BC8 ERPM	0.000	-160.000	-160.000	7.2 %
BC9 ERPM	0.000	-160.000	-160.000	7.2 %
BC10 ERPM	0.000	-160.000	-160.000	7.2 %
BC11 ERPM	0.000	-160.000	-160.000	7.2 %
BC12 ERPM	0.000	-160.000	-160.000	7.2 %
BC13 ERPM	0.000	-160.000	-160.000	7.2 %
BC14 ERPM	0.000	-160.000	-160.000	7.2 %
BC15 ERPM	0.000	-160.000	-160.000	7.2 %
BC16 ERPM	0.000	-160.000	-160.000	7.2 %
BC17 ERPM	0.000	-160.000	-160.000	7.2 %
BC18 ERPM	0.000	-160.000	-160.000	7.2 %
BC19 ERPM	0.000	-160.000	-160.000	7.2 %
BC20 ERPM	0.000	-160.000	-160.000	7.2 %
BC21 ERPM	0.000	-160.000	-160.000	7.2 %
BC22 ERPM	0.000	-160.000	-160.000	7.2 %
BC23 ERPM	0.000	-160.000	-160.000	7.2 %
BC24 ERPM	0.000	-160.000	-160.000	7.2 %
BC25 ERPM	0.000	-160.000	-160.000	7.2 %
BC26 ERPM	0.000	-160.000	-160.000	7.2 %
BC27 ERPM	0.000	-160.000	-160.000	7.2 %
BC28 ERPM	0.000	-160.000	-160.000	7.2 %
BC29 ERPM	0.000	-160.000	-160.000	7.2 %
BC30 ERPM	0.000	-160.000	-160.000	7.2 %
BC31 ERPM	0.000	-160.000	-160.000	7.2 %
BC32 ERPM	0.000	-160.000	-160.000	7.2 %
BC33 ERPM	0.000	-160.000	-160.000	7.2 %
BC34 ERPM	0.000	-160.000	-160.000	7.2 %
BC35 ERPM	0.000	-160.000	-160.000	7.2 %
BC36 ERPM	0.000	-160.000	-160.000	7.2 %
BC37 ERPM	0.000	-160.000	-160.000	7.2 %
BC38 ERPM	0.000	-160.000	-160.000	7.2 %
BC39 ERPM	0.000	-160.000	-160.000	7.2 %
BC40 ERPM	0.000	-160.000	-160.000	7.2 %
BC41 ERPM	0.000	-160.000	-160.000	7.2 %
BC42 ERPM	0.000	-160.000	-160.000	7.2 %
BC43 ERPM	0.000	-160.000	-160.000	7.2 %
BC44 ERPM	0.000	-160.000	-160.000	7.2 %
BC45 ERPM	0.000	-160.000	-160.000	7.2 %
BC46 ERPM	0.000	-160.000	-160.000	7.2 %
BC47 ERPM	0.000	-160.000	-160.000	7.2 %
BC48 ERPM	0.000	-160.000	-160.000	7.2 %
BC49 ERPM	0.000	-160.000	-160.000	7.2 %
BC50 ERPM	0.000	-160.000	-160.000	7.2 %



HX1 DCM Energy Control

BL:HX:OH:DCM

Energy Control

Set: 9.50000 keV

Read: 9.50000 keV

error: 0.00000 keV

ALL STOP

Photon Energy: 9.500 keV

undulator Period: 100 mm

undulator K: 1.860

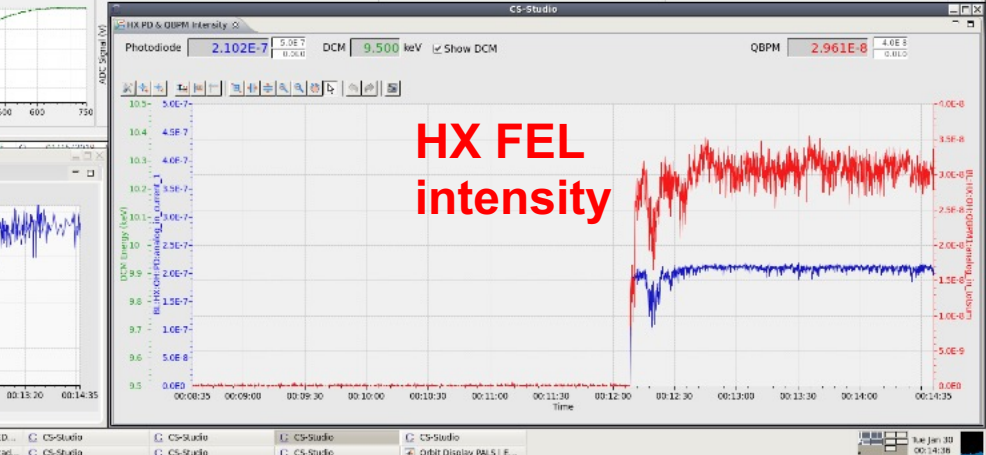
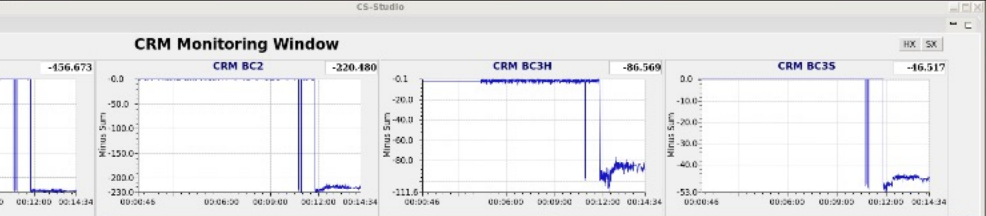
electron energy: 0.500 GeV

Motor Status

Angle: 0.000 deg

Gap: 0.000 mm

Status: STOP



PAL-XFEL Control - HX & SX

HX & SX Mode: FEL mode

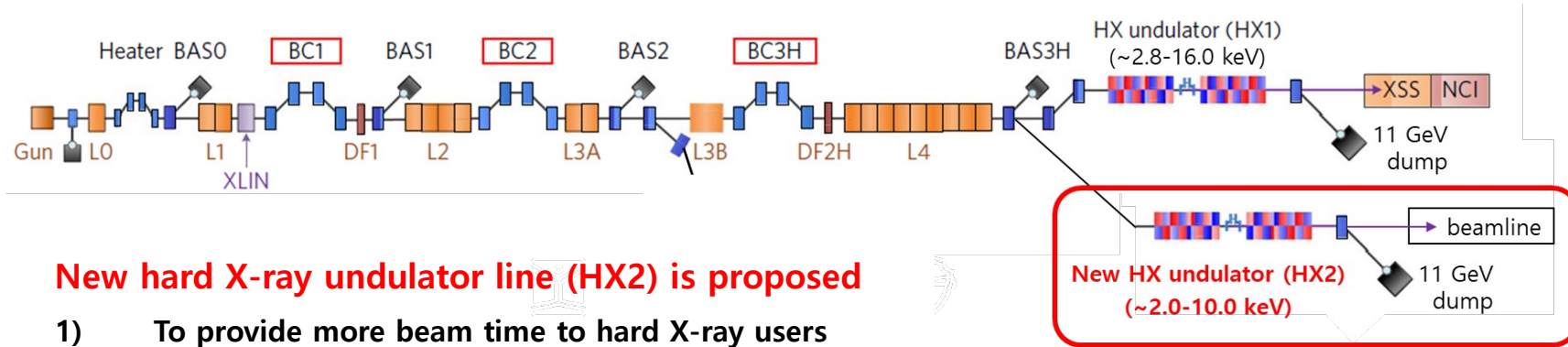
Beam End: HX main dump SX main dump

RF: ON Beam: ON MIS: Clear

14 MV 35.00 AMP HV Time: 600 APPLY RRA Mode: Operation Mode: Operation GUI FEL Tuning Daily FEL Set COL COL: UNATT

HOME LASER UNDO MOV BCM FEL SF VAC HX OP MI Gain 1.0 0.1 0.0 1.1 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2 2.3 2.4 2.5 2.6 2.7 2.8 2.9 3.0 3.1 3.2 3.3 3.4 3.5 3.6 3.7 3.8 3.9 4.0 4.1 4.2 4.3 4.4 4.5 4.6 4.7 4.8 4.9 5.0 5.1 5.2 5.3 5.4 5.5 5.6 5.7 5.8 5.9 6.0 6.1 6.2 6.3 6.4 6.5 6.6 6.7 6.8 6.9 7.0 7.1 7.2 7.3 7.4 7.5 7.6 7.7 7.8 7.9 8.0 8.1 8.2 8.3 8.4 8.5 8.6 8.7 8.8 8.9 9.0 9.1 9.2 9.3 9.4 9.5 9.6 9.7 9.8 9.9 10.0 10.1 10.2 10.3 10.4 10.5 10.6 10.7 10.8 10.9 11.0 11.1 11.2 11.3 11.4 11.5 11.6 11.7 11.8 11.9 12.0 12.1 12.2 12.3 12.4 12.5 12.6 12.7 12.8 12.9 13.0 13.1 13.2 13.3 13.4 13.5 13.6 13.7 13.8 13.9 14.0 14.1 14.2 14.3 14.4 14.5 14.6 14.7 14.8 14.9 15.0 15.1 15.2 15.3 15.4 15.5 15.6 15.7 15.8 15.9 16.0 16.1 16.2 16.3 16.4 16.5 16.6 16.7 16.8 16.9 17.0 17.1 17.2 17.3 17.4 17.5 17.6 17.7 17.8 17.9 18.0 18.1 18.2 18.3 18.4 18.5 18.6 18.7 18.8 18.9 19.0 19.1 19.2 19.3 19.4 19.5 19.6 19.7 19.8 19.9 20.0 20.1 20.2 20.3 20.4 20.5 20.6 20.7 20.8 20.9 21.0 21.1 21.2 21.3 21.4 21.5 21.6 21.7 21.8 21.9 22.0 22.1 22.2 22.3 22.4 22.5 22.6 22.7 22.8 22.9 23.0 23.1 23.2 23.3 23.4 23.5 23.6 23.7 23.8 23.9 24.0 24.1 24.2 24.3 24.4 24.5 24.6 24.7 24.8 24.9 25.0 25.1 25.2 25.3 25.4 25.5 25.6 25.7 25.8 25.9 26.0 26.1 26.2 26.3 26.4 26.5 26.6 26.7 26.8 26.9 27.0 27.1 27.2 27.3 27.4 27.5 27.6 27.7 27.8 27.9 28.0 28.1 28.2 28.3 28.4 28.5 28.6 28.7 28.8 28.9 29.0 29.1 29.2 29.3 29.4 29.5 29.6 29.7 29.8 29.9 30.0 30.1 30.2 30.3 30.4 30.5 30.6 30.7 30.8 30.9 31.0 31.1 31.2 31.3 31.4 31.5 31.6 31.7 31.8 31.9 32.0 32.1 32.2 32.3 32.4 32.5 32.6 32.7 32.8 32.9 33.0 33.1 33.2 33.3 33.4 33.5 33.6 33.7 33.8 33.9 34.0 34.1 34.2 34.3 34.4 34.5 34.6 34.7 34.8 34.9 35.0 35.1 35.2 35.3 35.4 35.5 35.6 35.7 35.8 35.9 36.0 36.1 36.2 36.3 36.4 36.5 36.6 36.7 36.8 36.9 37.0 37.1 37.2 37.3 37.4 37.5 37.6 37.7 37.8 37.9 38.0 38.1 38.2 38.3 38.4 38.5 38.6 38.7 38.8 38.9 39.0 39.1 39.2 39.3 39.4 39.5 39.6 39.7 39.8 39.9 40.0 40.1 40.2 40.3 40.4 40.5 40.6 40.7 40.8 40.9 41.0 41.1 41.2 41.3 41.4 41.5 41.6 41.7 41.8 41.9 42.0 42.1 42.2 42.3 42.4 42.5 42.6 42.7 42.8 42.9 43.0 43.1 43.2 43.3 43.4 43.5 43.6 43.7 43.8 43.9 44.0 44.1 44.2 44.3 44.4 44.5 44.6 44.7 44.8 44.9 45.0 45.1 45.2 45.3 45.4 45.5 45.6 45.7 45.8 45.9 46.0 46.1 46.2 46.3 46.4 46.5 46.6 46.7 46.8 46.9 47.0 47.1 47.2 47.3 47.4 47.5 47.6 47.7 47.8 47.9 48.0 48.1 48.2 48.3 48.4 48.5 48.6 48.7 48.8 48.9 49.0 49.1 49.2 49.3 49.4 49.5 49.6 49.7 49.8 49.9 50.0 50.1 50.2 50.3 50.4 50.5 50.6 50.7 50.8 50.9 51.0 51.1 51.2 51.3 51.4 51.5 51.6 51.7 51.8 51.9 52.0 52.1 52.2 52.3 52.4 52.5 52.6 52.7 52.8 52.9 53.0 53.1 53.2 53.3 53.4 53.5 53.6 53.7 53.8 53.9 54.0 54.1 54.2 54.3 54.4 54.5 54.6 54.7 54.8 54.9 55.0 55.1 55.2 55.3 55.4 55.5 55.6 55.7 55.8 55.9 56.0 56.1 56.2 56.3 56.4 56.5 56.6 56.7 56.8 56.9 57.0 57.1 57.2 57.3 57.4 57.5 57.6 57.7 57.8 57.9 58.0 58.1 58.2 58.3 58.4 58.5 58.6 58.7 58.8 58.9 59.0 59.1 59.2 59.3 59.4 59.5 59.6 59.7 59.8 59.9 60.0 60.1 60.2 60.3 60.4 60.5 60.6 60.7 60.8 60.9 61.0 61.1 61.2 61.3 61.4 61.5 61.6 61.7 61.8 61.9 62.0 62.1 62.2 62.3 62.4 62.5 62.6 62.7 62.8 62.9 63.0 63.1 63.2 63.3 63.4 63.5 63.6 63.7 63.8 63.9 64.0 64.1 64.2 64.3 64.4 64.5 64.6 64.7 64.8 64.9 65.0 65.1 65.2 65.3 65.4 65.5 65.6 65.7 65.8 65.9 66.0 66.1 66.2 66.3 66.4 66.5 66.6 66.7 66.8 66.9 67.0 67.1 67.2 67.3 67.4 67.5 67.6 67.7 67.8 67.9 68.0 68.1 68.2 68.3 68.4 68.5 68.6 68.7 68.8 68.9 69.0 69.1 69.2 69.3 69.4 69.5 69.6 69.7 69.8 69.9 70.0 70.1 70.2 70.3 70.4 70.5 70.6 70.7 70.8 70.9 71.0 71.1 71.2 71.3 71.4 71.5 71.6 71.7 71.8 71.9 72.0 72.1 72.2 72.3 72.4 72.5 72.6 72.7 72.8 72.9 73.0 73.1 73.2 73.3 73.4 73.5 73.6 73.7 73.8 73.9 74.0 74.1 74.2 74.3 74.4 74.5 74.6 74.7 74.8 74.9 75.0 75.1 75.2 75.3 75.4 75.5 75.6 75.7 75.8 75.9 76.0 76.1 76.2 76.3 76.4 76.5 76.6 76.7 76.8 76.9 77.0 77.1 77.2 77.3 77.4 77.5 77.6 77.7 77.8 77.9 78.0 78.1 78.2 78.3 78.4 78.5 78.6 78.7 78.8 78.9 79.0 79.1 79.2 79.3 79.4 79.5 79.6 79.7 79.8 79.9 80.0 80.1 80.2 80.3 80.4 80.5 80.6 80.7 80.8 80.9 81.0 81.1 81.2 81.3 81.4 81.5 81.6 81.7 81.8 81.9 82.0 82.1 82.2 82.3 82.4 82.5 82.6 82.7 82.8 82.9 83.0 83.1 83.2 83.3 83.4 83.5 83.6 83.7 83.8 83.9 84.0 84.1 84.2 84.3 84.4 84.5 84.6 84.7 84.8 84.9 85.0 85.1 85.2 85.3 85.4 85.5 85.6 85.7 85.8 85.9 86.0 86.1 86.2 86.3 86.4 86.5 86.6 86.7 86.8 86.9 87.0 87.1 87.2 87.3 87.4 87.5 87.6 87.7 87.8 87.9 88.0 88.1 88.2 88.3 88.4 88.5 88.6 88.7 88.8 88.9 89.0 89.1 89.2 89.3 89.4 89.5 89.6 89.7 89.8 89.9 90.0 90.1 90.2 90.3 90.4 90.5 90.6 90.7 90.8 90.9 91.0 91.1 91.2 91.3 91.4 91.5 91.6 91.7 91.8 91.9 92.0 92.1 92.2 92.3 92.4 92.5 92.6 92.7 92.8 92.9 93.0 93.1 93.2 93.3 93.4 93.5 93.6 93.7 93.8 93.9 94.0 94.1 94.2 94.3 94.4 94.5 94.6 94.7 94.8 94.9 95.0 95.1 95.2 95.3 95.4 95.5 95.6 95.7 95.8 95.9 96.0 96.1 96.2 96.3 96.4 96.5 96.6 96.7 96.8 96.9 97.0 97.1 97.2 97.3 97.4 97.5 97.6 97.7 97.8 97.9 98.0 98.1 98.2 98.3 98.4 98.5 98.6 98.7 98.8 98.9 99.0 99.1 99.2 99.3 99.4 99.5 99.6 99.7 99.8 99.9 100.0 100.1 100.2 100.3 100.4 100.5 100.6 100.7 100.8 100.9 101.0 101.1 101.2 101.3 101.4 101.5 101.6 101.7 101.8 101.9 102.0 102.1 102.2 102.3 102.4 102.5 102.6 102.7 102.8 102.9 103.0 103.1 103.2 103.3 103.4 103.5 103.6 103.7 103.8 103.9 104.0 104.1 104.2 104.3 104.4 104.5 104.6 104.7 104.8 104.9 105.0 105.1 105.2 105.3 105.4 105.5 105.6 105.7 105.8 105.9 106.0 106.1 106.2 106.3 106.4 106.5 106.6 106.7 106.8 106.9 107.0 107.1 107.2 107.3 107.4 107.5 107.6 107.7 107.8 107.9 108.0 108.1 108.2 108.3 108.4 108.5 108.6 108.7 108.8 108.9 109.0 109.1 109.2 109.3 109.4 109.5 109.6 109.7 109.8 109.9 110.0 110.1 110.2 110.3 110.4 110.5 110.6 110.7 110.8 110.9 111.0 111.1 111.2 111.3 111.4 111.5 111.6 111.7 111.8 111.9 112.0 112.1 112.2 112.3 112.4 112.5 112.6 112.7 112.8 112.9 113.0 113.1 113.2 113.3 113.4 113.5 113.6 113.7 113.8 113.9 114.0 114.1 114.2 114.3 114.4 114.5 114.6 114.7 114.8 114.9 115.0 115.1 115.2 115.3 115.4 115.5 115.6 115.7 115.8 115.9 116.0 116.1 116.2 116.3 116.4 116.5 116.6 116.7 116.8 116.9 117.0 117.1 117.2 117.3 117.4 117.5 117.6 117.7 117.8 117.9 118.0 118.1 118.2 118.3 118.4 118.5 118.6 118.7 118.8 118.9 119.0 119.1 119.2 119.3 119.4 119.5 119.6 119.7 119.8 119.9 120.0 120.1 120.2 120.3 120.4 120.5 120.6 120.7 120.8 120.9 121.0 121.1 121.2 121.3 121.4 121.5 121.6 121.7 121.8 121.9 122.0 122.1 122.2 122.3 122.4 122.5 122.6 122.7 122.8 122.9 123.0 123.1 123.2 123.3 123.4 123.5 123.6 123.7 123.8 123.9 124.0 124.1 124.2 124.3 124.4 124.5 124.6 124.7 124.8 124.9 125.0 125.1 125.2 125.3 125.4 125.5 125.6 125.7 125.8 125.9 126.0 126.1 126.2 126.3 126.4 126.5 126.6 126.7 126.8 126.9 127.0 127.1 127.2 127.3 127.4 127.5 127.6 127.7 127.8 127.9 128.0 128.1 128.2 128.3 128.4 128.5 128.6 128.7 128.8 128.9 129.0 129.1 129.2 129.3 129.4 129.5 129.6 129.7 129.8 129.9 130.0 130.1 130.2 130.3 130.4 130.5 130.6 130.7 130.8 130.9 131.0 131.1 131.2 131.3 131.4 131.5 131.6 131.7 131.8 131.9 132.0 132.1 132.2 132.3 132.4 132.5 132.6 132.7 132.8 132.9 133.0 133.1 133.2 133.3 133.4 133.5 133.6 133.7 133.8 133.9 134.0 134.1 134.2 134.3 134.4 134.5 134.6 134.7 134.8 134.9 135.0 135.1 135.2 135.3 135.4 135.5 135.6 135.7 135.8 135.9 136.0 136.1 136.2 136.3 136.4 136.5 136.6 136.7 136.8 136.9 137.0 137.1 137.2 137.3 137.4 137.5 137.6 137.7 137.8 137.9 138.0 138.1 138.2 138.3 138.4 138.5 138.6 138.7 138.8 138.9 139.0 139.1 139.2 139.3 139.4 139.5 139.6 139.7 139.8 139.9 140.0 140.1 140.2 140.3 140.4 140.5 140.6 140.7 140.8 140.9 141.0 141.1 141.2 141.3 141.4 141.5 141.6 141.7 141.8 141.9 142.0 142.1 142.2 142.3 142.4 142.5 142.6 142.7 142.8 142.9 143.0 143.1 143.2 143.3 143.4 143.5 143.6 143.7 143.8 143.9 144.0 144.1 144.2 144.3 144.4 144.5 144.6 144.7 144.8 144.9 145.0 145.1 145.2 145.3 145.4 145.5 145.6 145.7 145.8 145.9 146.0 146.1 146.2 146.3 146.4 146.5 146.6 146.7 146.8 146.9 147.0 147.1 147.2 147.3 147.4 147.5 147.6 147.7 147.8 147.9 148.0 148.1 148.2 148.3 148.4 148.5 148.6 148.7 148.8 148.9 149.0 149.1 149.2 149.3 149.4 149.5 149.6 149.7 149.8 149.9 150.0 150.1 150.2 150.3 150.4 150.5 150.6 150.7 150.8 150.9 151.0 151.1 151.2 151.3 151.4 151.5 151.6 151.7 151

New second hard X-ray beamline (HX2)

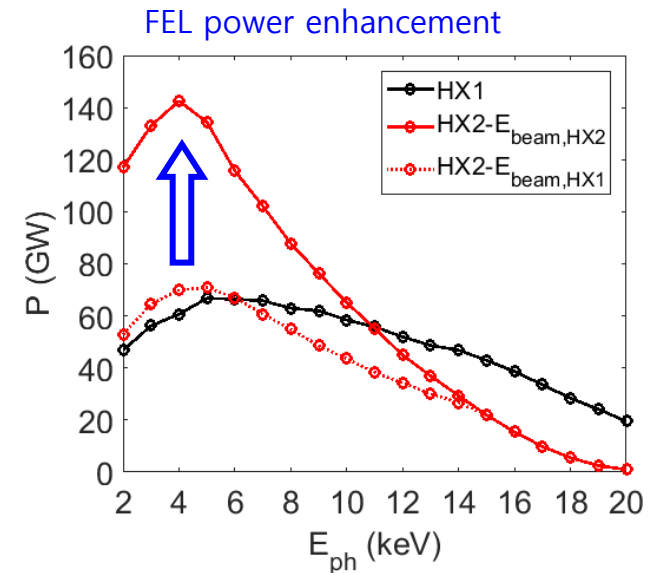
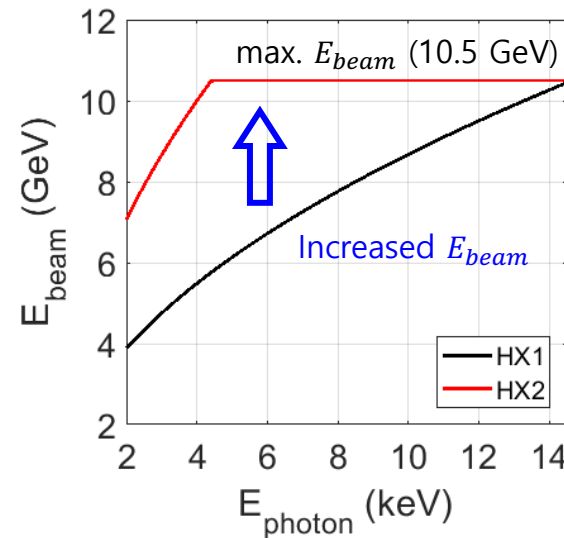


New hard X-ray undulator line (HX2) is proposed

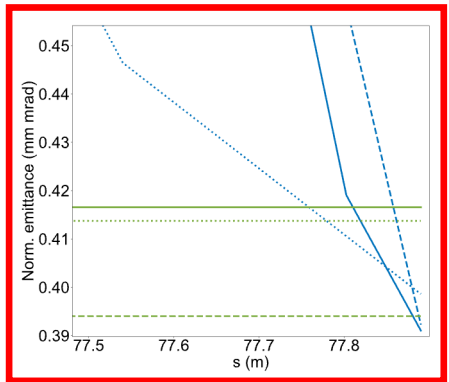
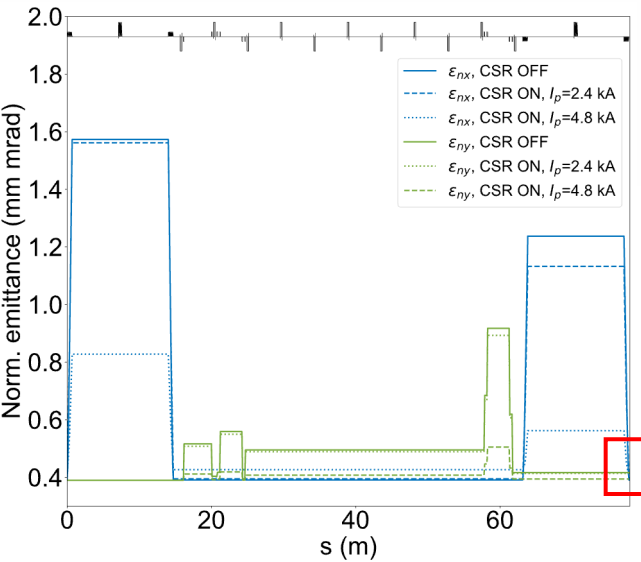
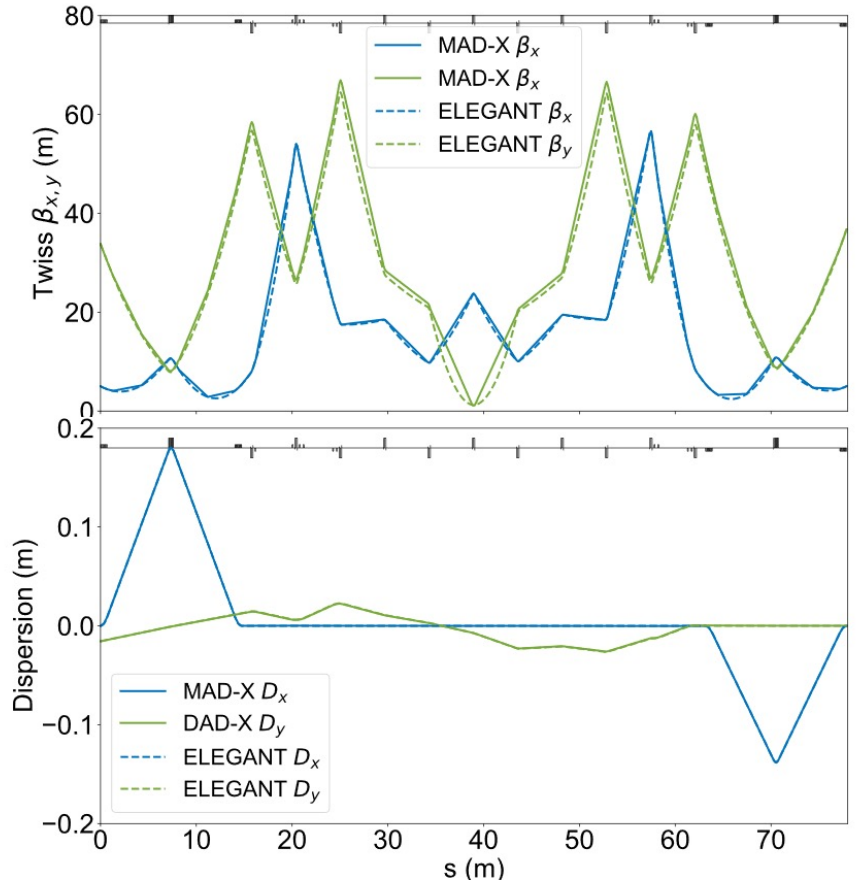
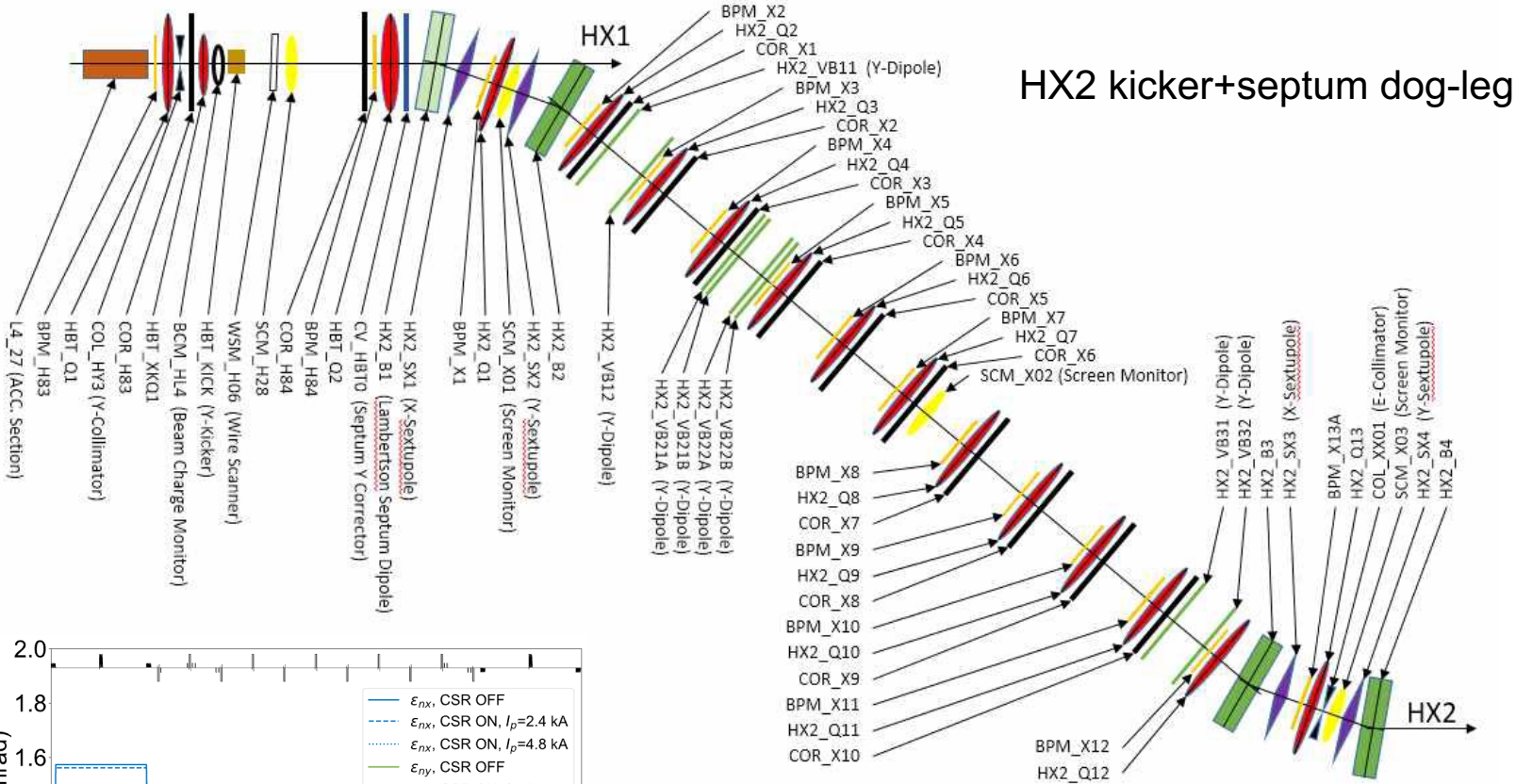
- 1) To provide more beam time to hard X-ray users by operating HX1 and HX2 simultaneously
- 2) To increase FEL intensity at photon energies lower than 10 keV by increasing E_{beam}
- 3) To expand machine performance by applying advanced schemes such as attosecond-TW XFEL, improved SASE, and etc.

$$\lambda_r = \frac{\lambda_u}{2\gamma^2} \left(1 + \frac{K^2}{2} \right)$$

	HX1	HX2	SX1
Undulator period, mm	26	35	35
Undulator length, m	5.0	5.0	5.0
Undulator K	1.94	3.48	3.48
Undulator minimum gap, mm	8.75	9.0	9.0
No. of undulators	20	20	7
Photon energy, keV	6.5 ~ 14.5	2.0 ~ 10.0	0.25 ~ 1.25

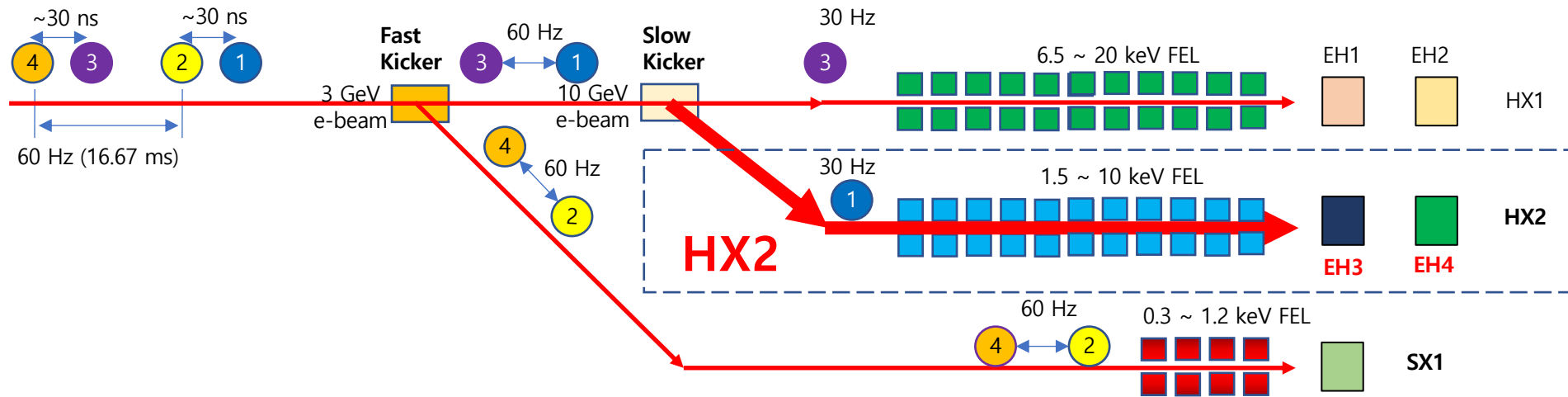


Dog-leg optics for HX2



CSR effect is well suppressed along the dog-leg beamline for 2-4 kA peak current beam

Parallel operation scheme for HX1, HX2 and SX1



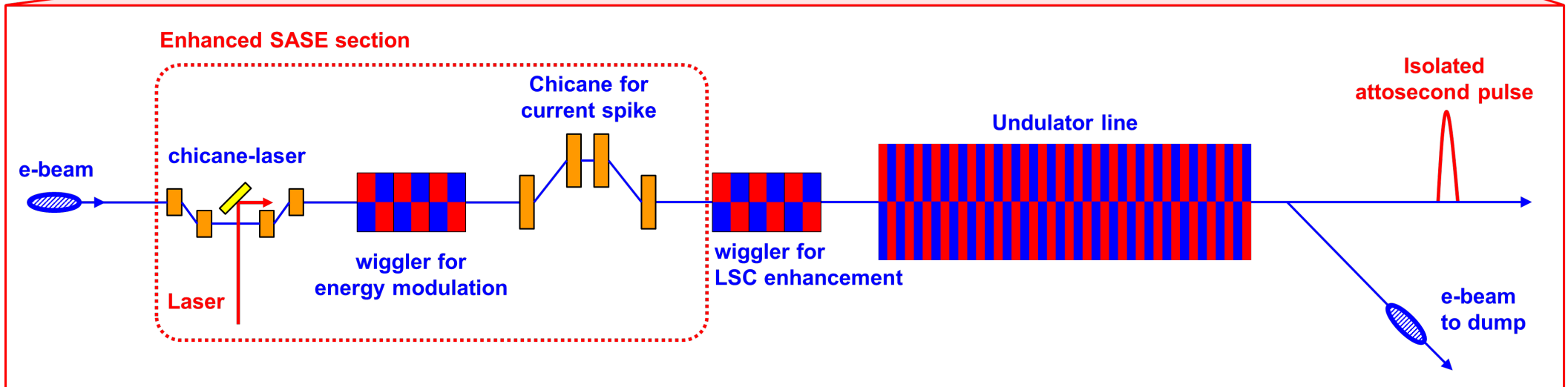
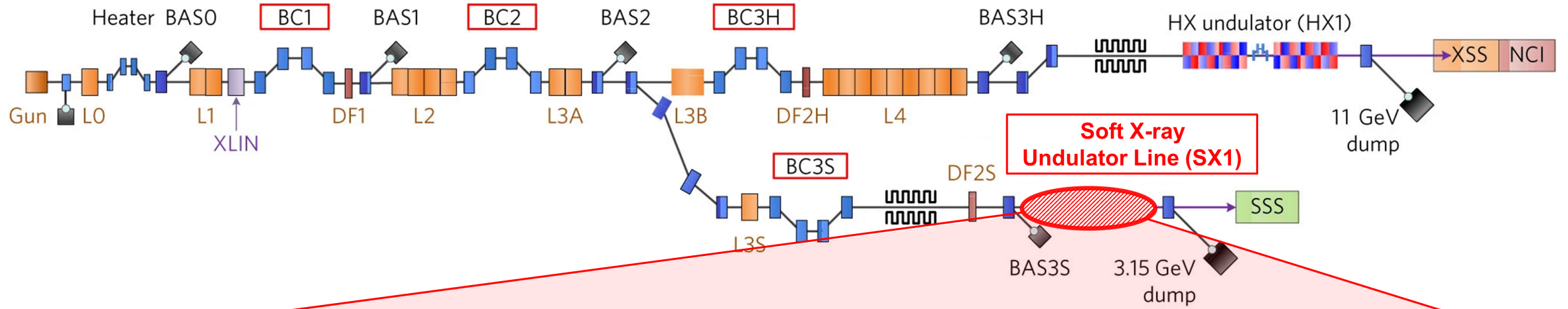
❖ Operation plan

- Repetition rate: 30/30 Hz (HX1/HX2) operation using bunch by bunch slow kicker operation
- In the beginning, both SX branch and HX2 branch utilize slow kicker (60 Hz, ms kicker)
- Fast kicker (ns kicker; resonance kicker) and two-bunch mode will be developed for simultaneous 3 independent FEL beamline operation

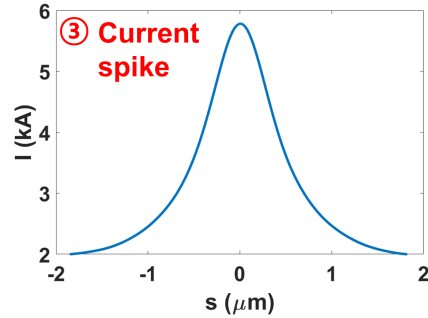
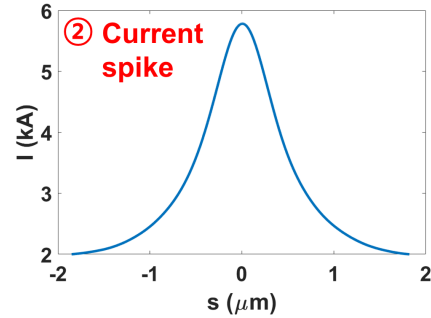
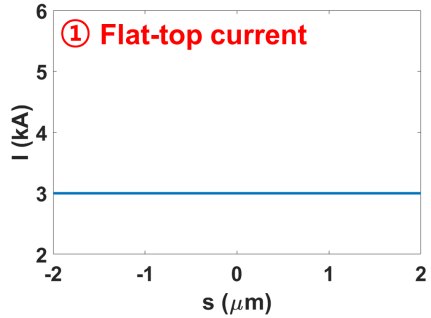
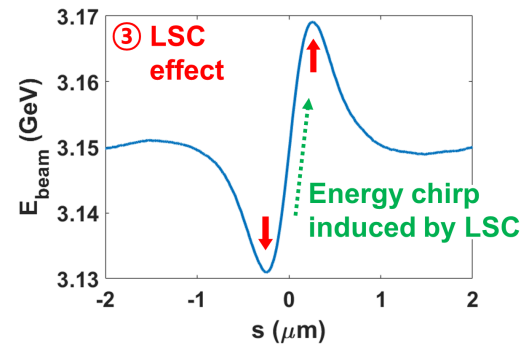
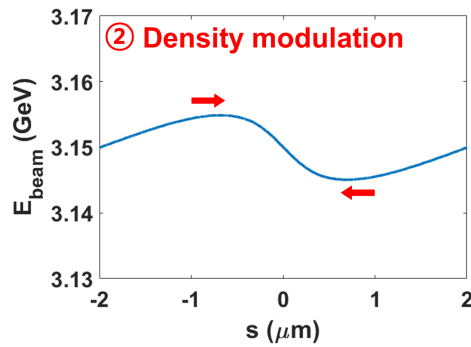
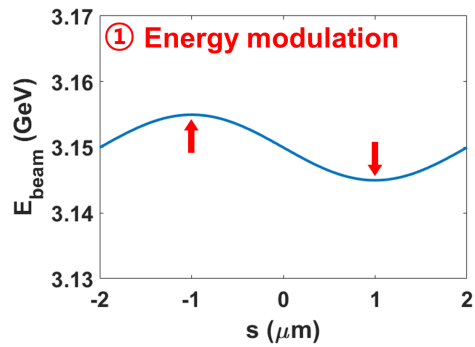
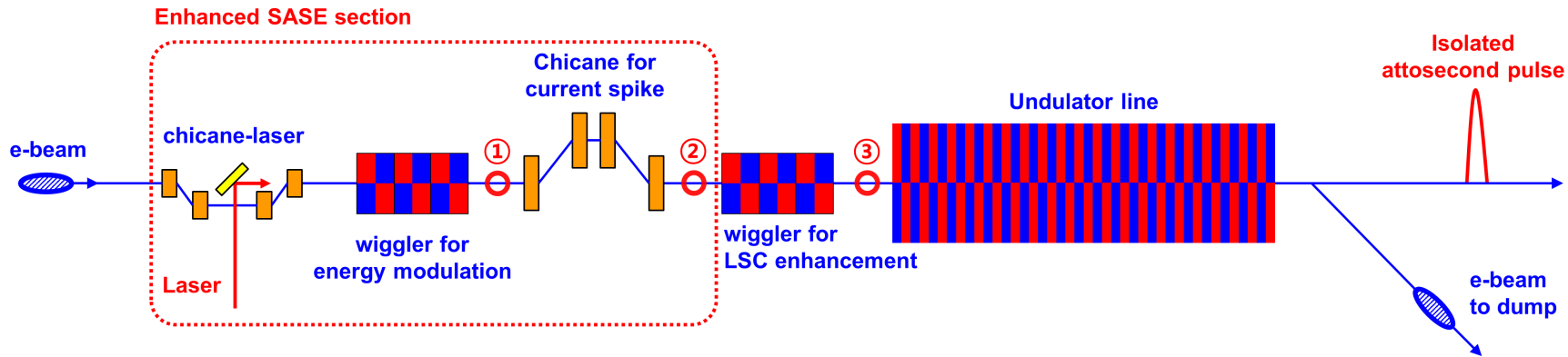
Repetition rate for 3 FEL beamline operation

SX1	HX1	HX2
60 Hz	60 Hz	0 Hz
60 Hz	58 Hz	2 Hz
60 Hz	50 Hz	10 Hz
60 Hz	30 Hz	30 Hz
60 Hz	10 Hz	50 Hz
60 Hz	2 Hz	58 Hz
60 Hz	0 Hz	60 Hz

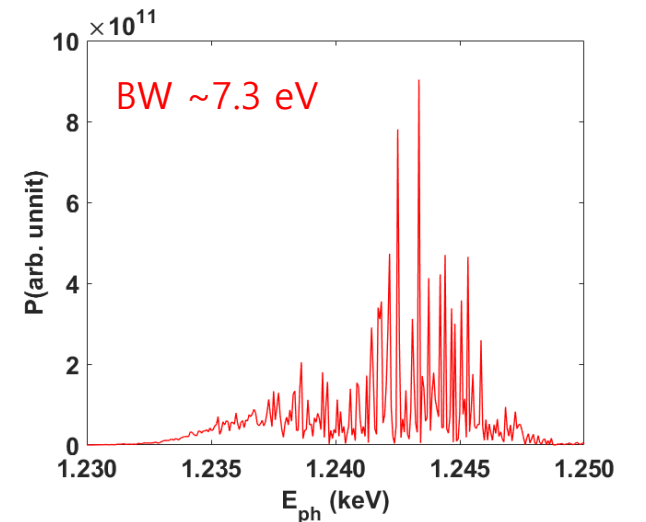
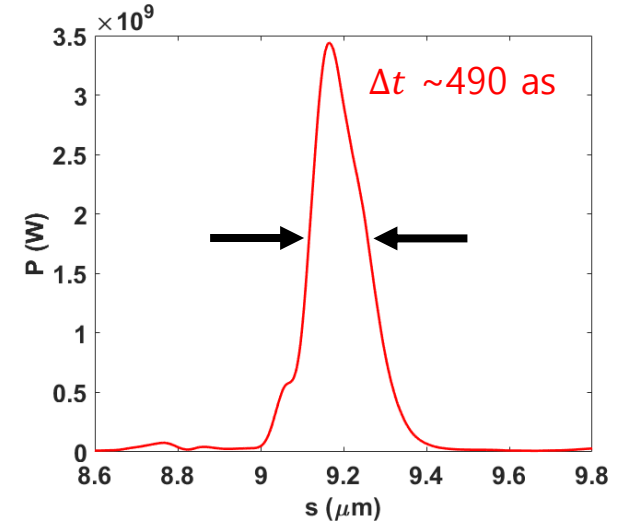
Attosecond XFEL at PAL-XFEL



Attosecond XFEL at PAL-XFEL



End of 5th undulator



Thank you for your attention!

