Status of PAL-XFEL

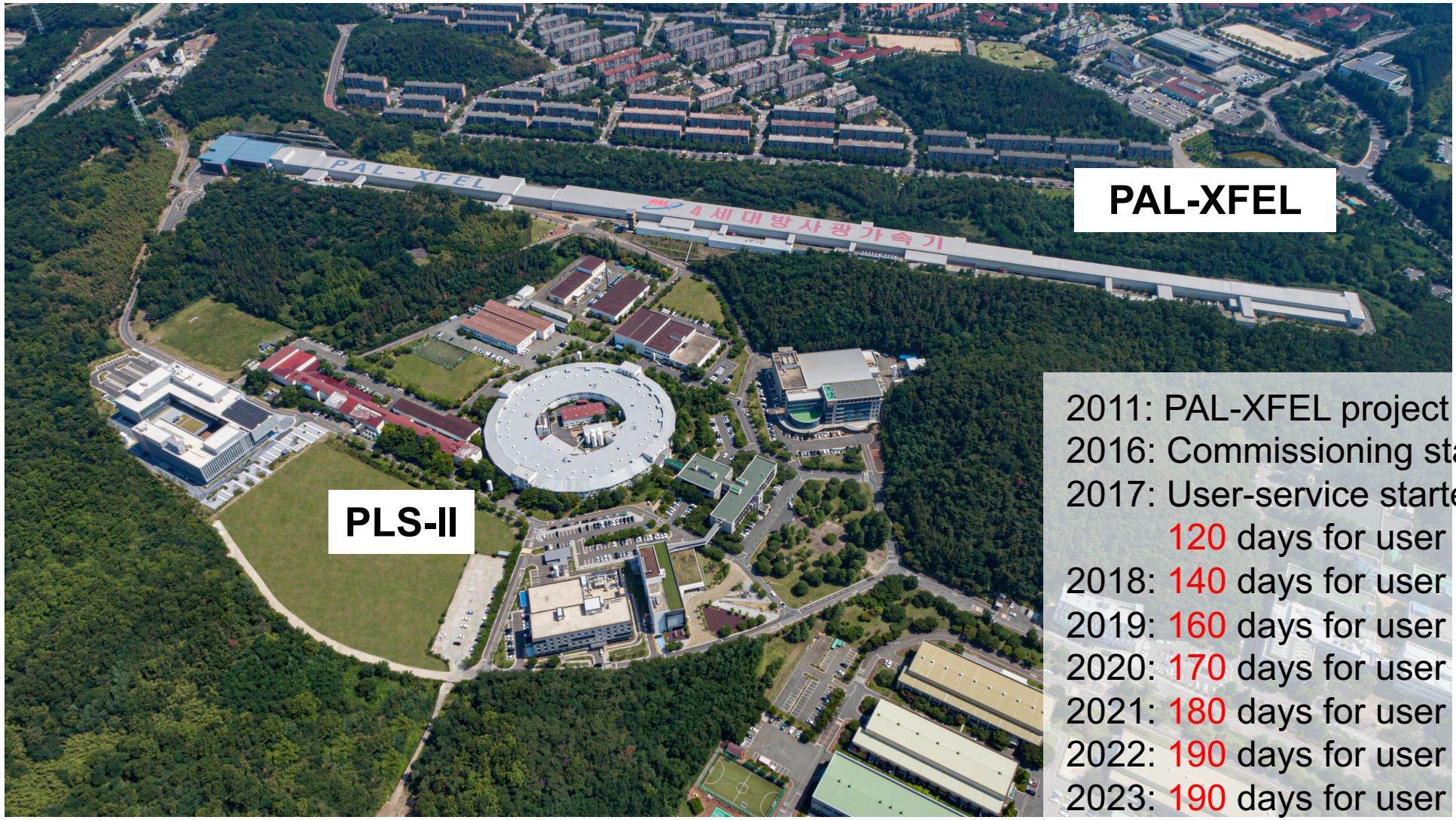
Chi Hyun Shim
on behalf of PAL-XFEL

PAL 포항가속기연구소
POHANG ACCELERATOR LABORATORY

Contents

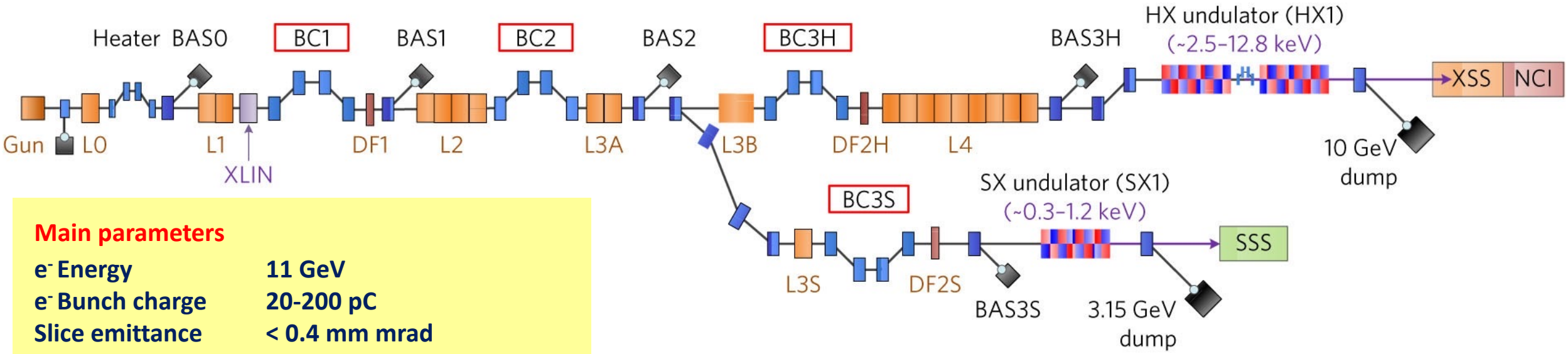
- Introduction and operation summary
- Two-color XFEL mode with time delay and pulse duration control
- Simultaneous operation of the hard and soft X-ray beamlines
- Project for new second hard X-ray beamline (HX2)
- Project for attosecond X-ray pulse generation at PAL-XFEL

Operation History of PAL-XFEL



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)

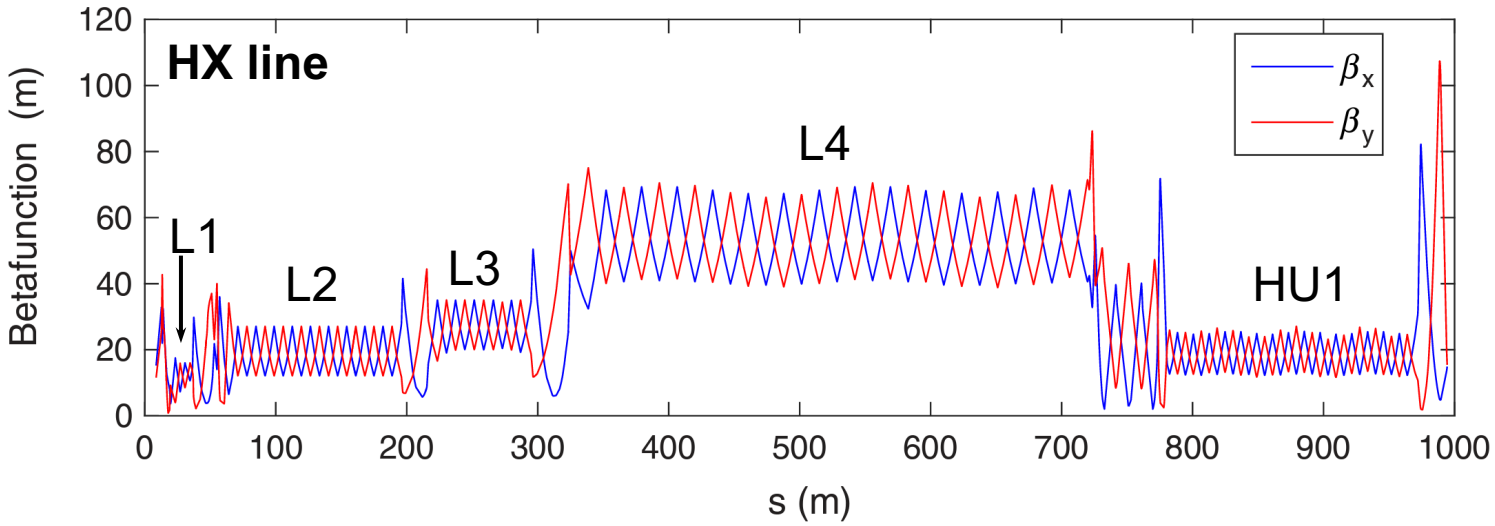
PAL-XFEL Layout & Parameters



Main parameters

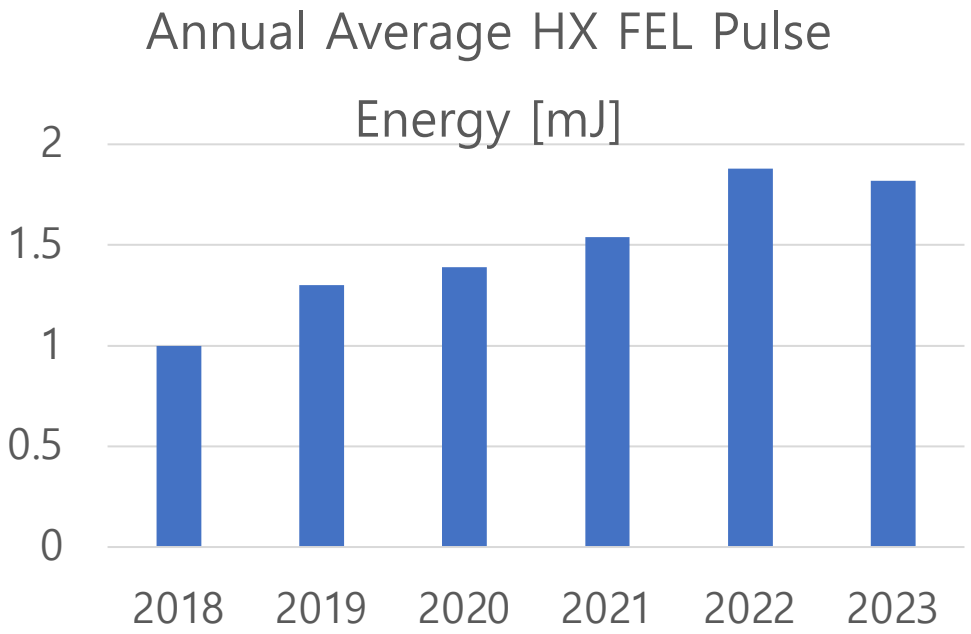
e⁻ Energy	11 GeV
e⁻ Bunch charge	20-200 pC
Slice emittance	< 0.4 mm mrad
Repetition rate	60 Hz
Bunch length	5 fs – 50 fs
Peak current	3 kA
SX line switching	Kicker Magnet

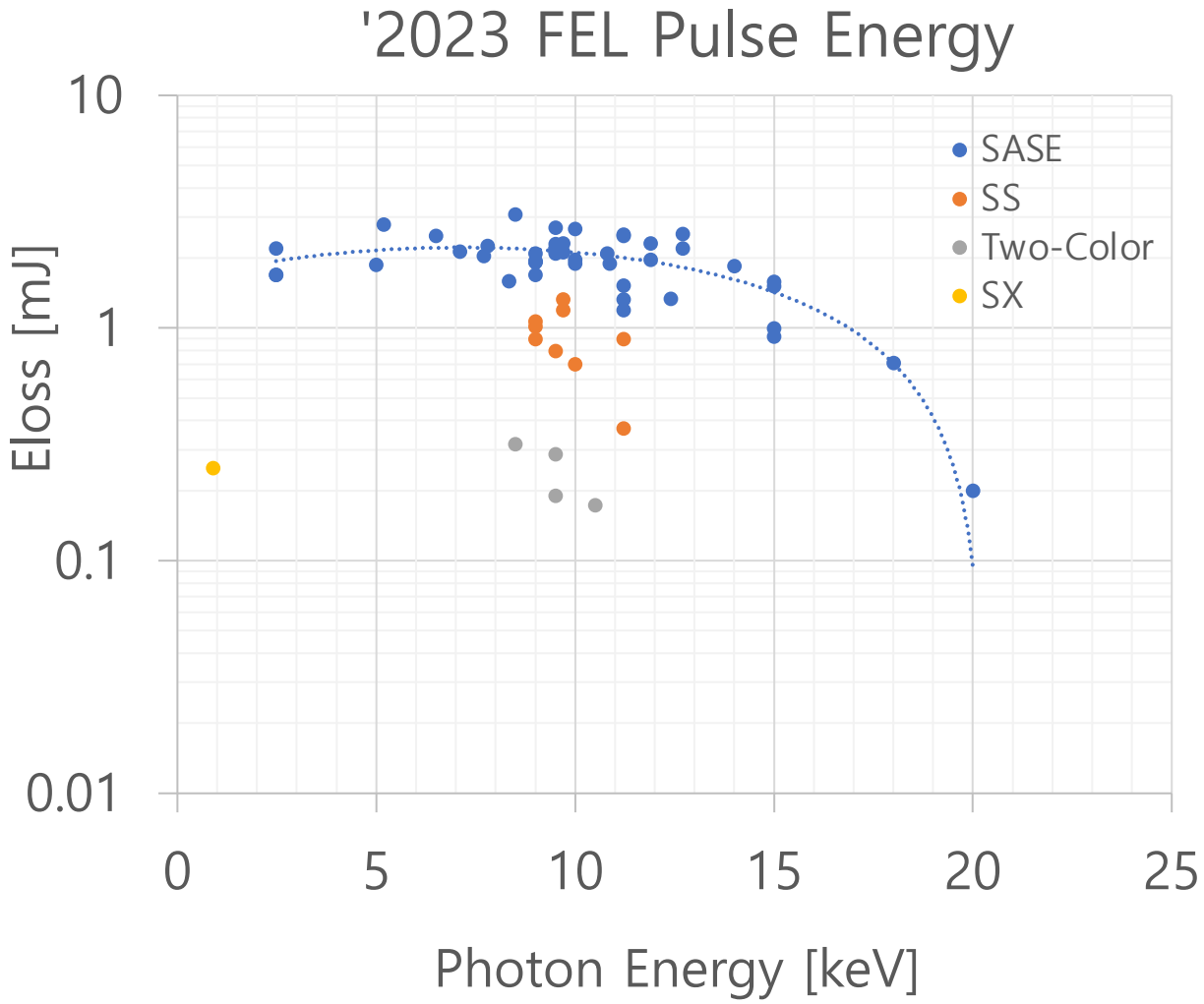
Undulator Line	HX	SX
Photon energy [keV]	2.0 ~ 15.0	0.25 ~ 1.25
Beam Energy [GeV]	4 ~ 11	3.0
Wavelength Tuning	Energy	Gap
Undulator Type	Planar	Planar
Und. Period / Gap [mm]	26 / 8.3	35 / 9.0



FEL Performance at PAL-XFEL

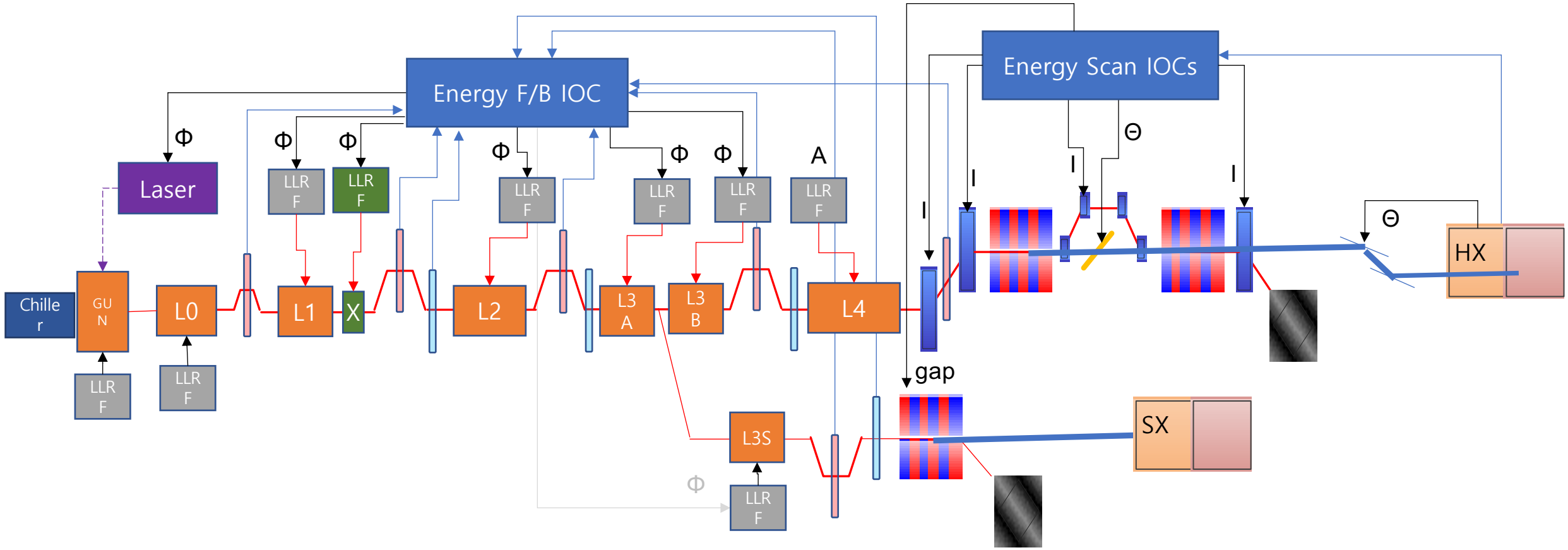
- ❖ **More than 1 mJ HX FELs are serviced**
- ❖ **Self-seeding HX FEL services increase**
- ❖ **Two-color user service has been started**
- ❖ **SX FEL pulse energy is around 250 uJ**





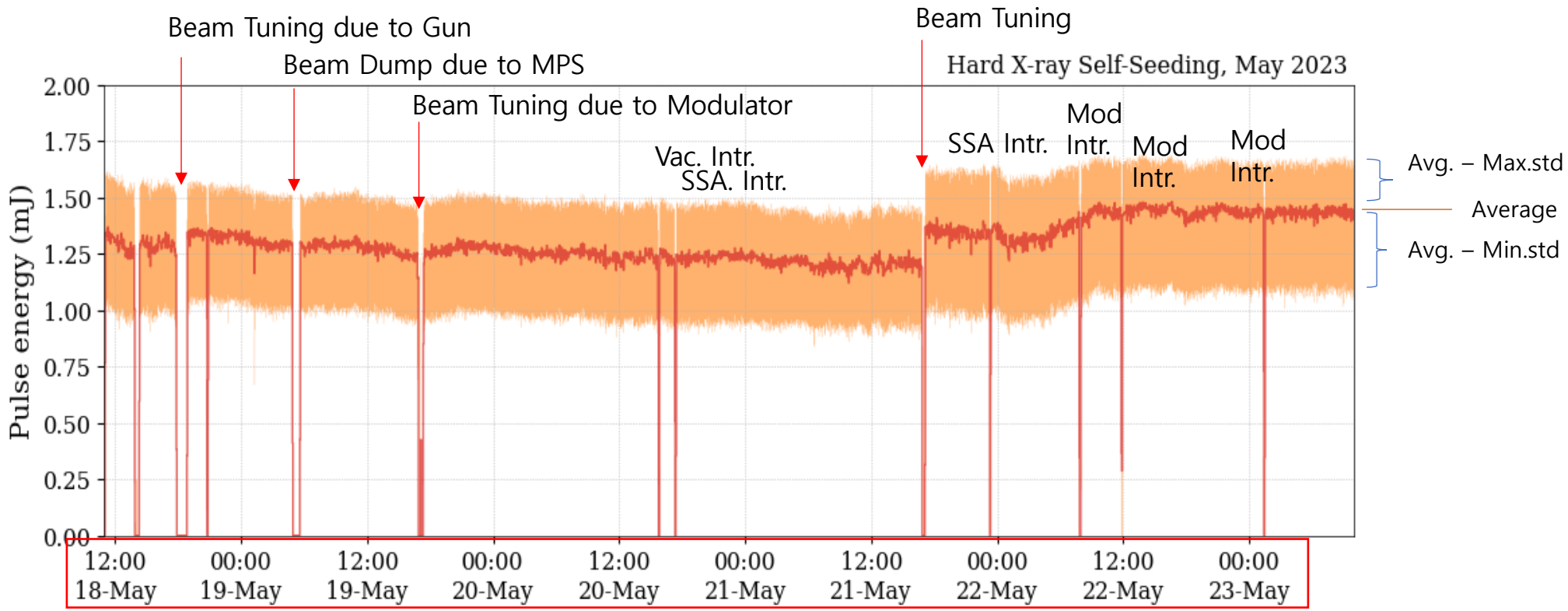
Feed-Back Controls, Energy Scan Controls and RFs

- ❖ We are upgrading the F/B system in both hardware & software.
- ❖ We are providing various energy scan services for HX-SASE, HX-SS, and SX-SASE.
- ❖ It will be more complex in case of both HX line and SX line operation.



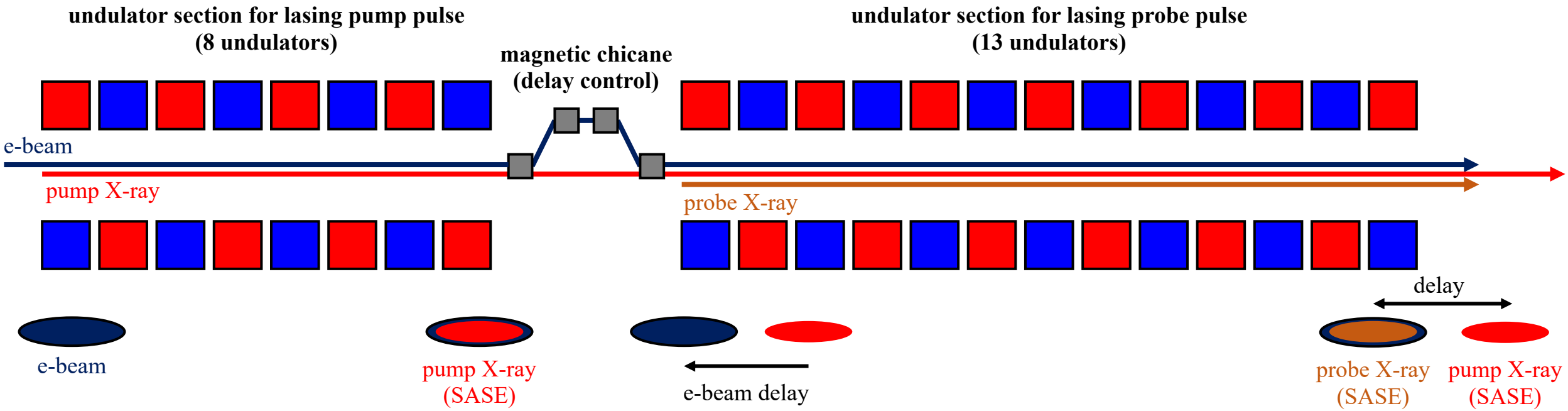
Long period self-seeding FEL user service

❖ **We have serviced stable self-seeding FEL beams.**



*Pulse energy is calculated by using e-loss factor
*Averaging sampling time is 180 sec

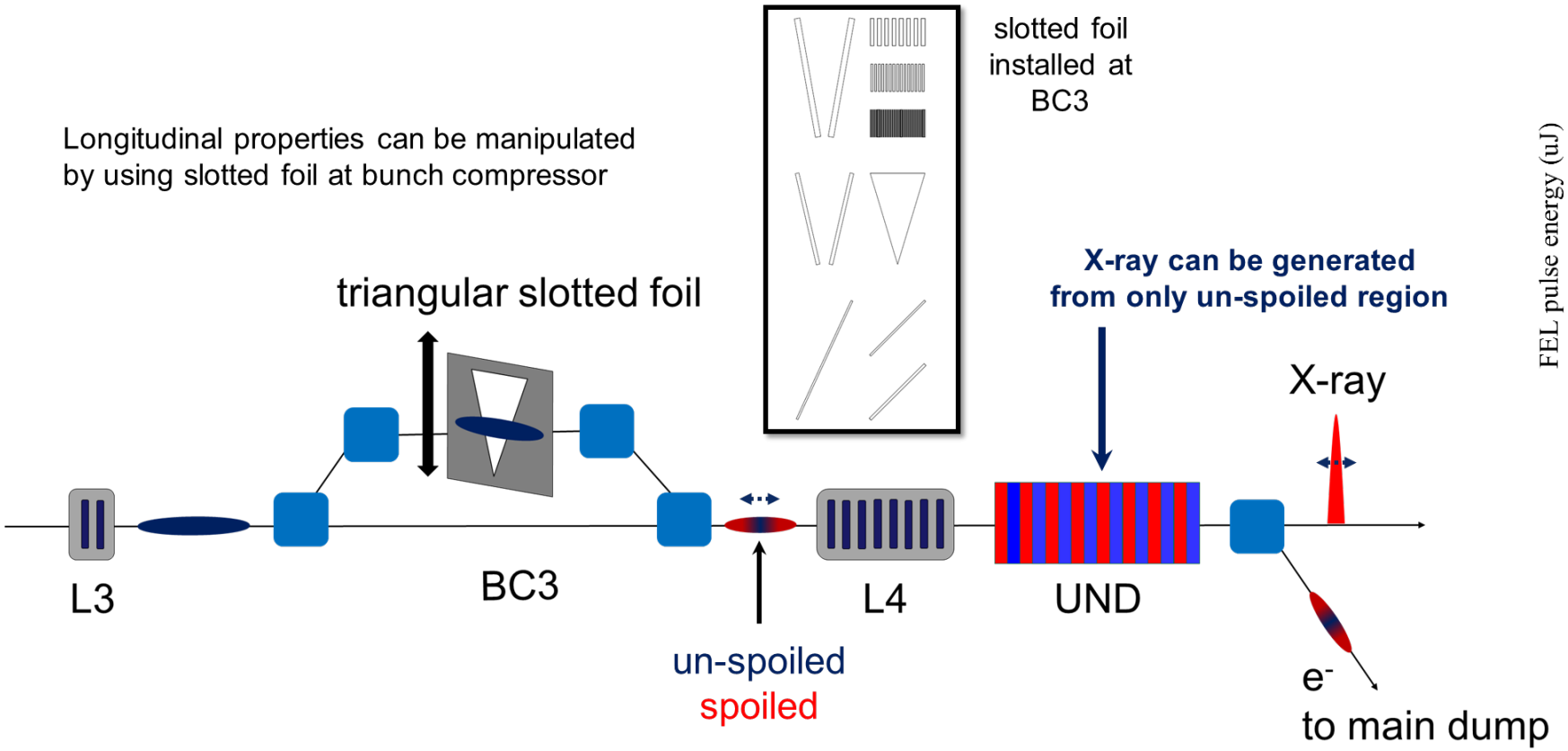
Two-color XFEL with time delay control

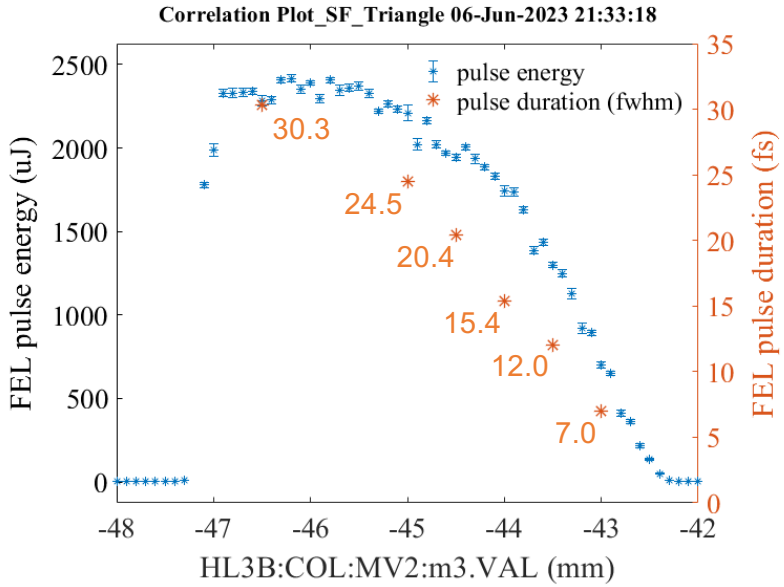


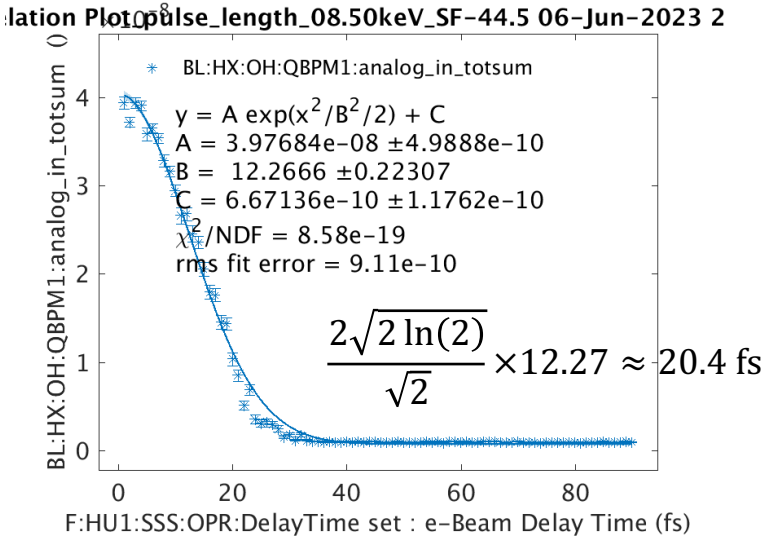
- ✓ By utilizing variable gap undulator and dipole magnet for self-seeding section, two-color pump-probe XFEL pulses can be generated from single electron bunch
- ✓ Time delay between pump and probe pulse can be controlled by changing the current of the dipole magnet (**max. time delay is 120 fs**)

Pulse duration control using slotted foil at BC

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

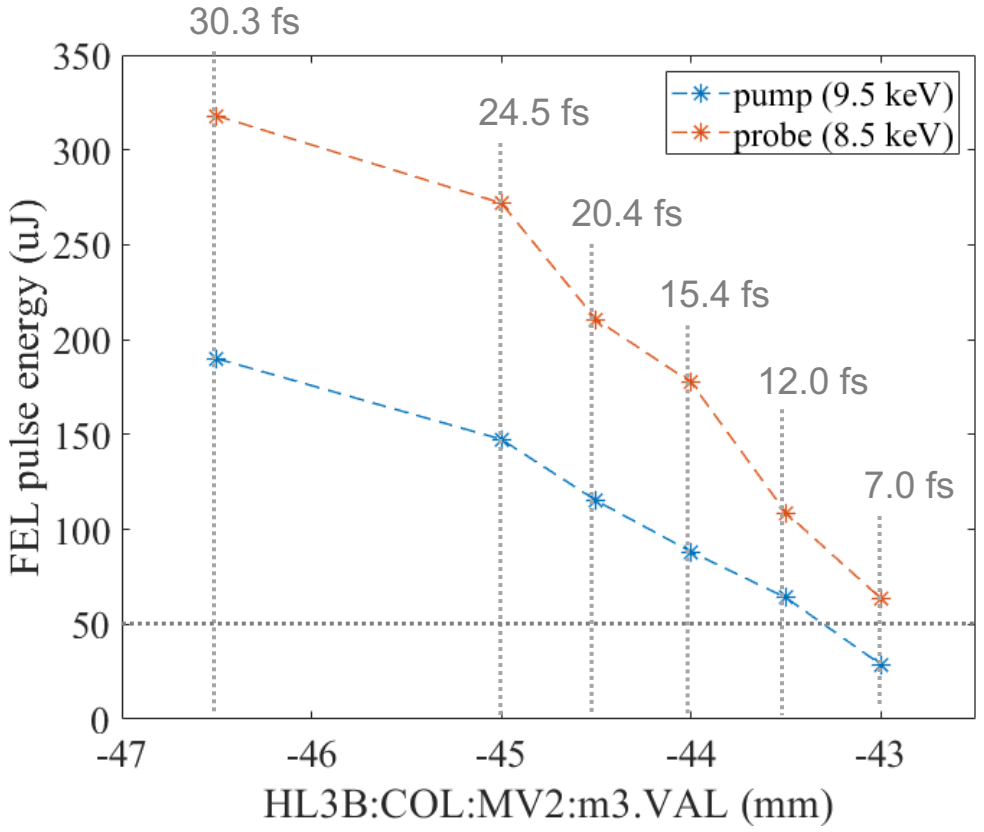


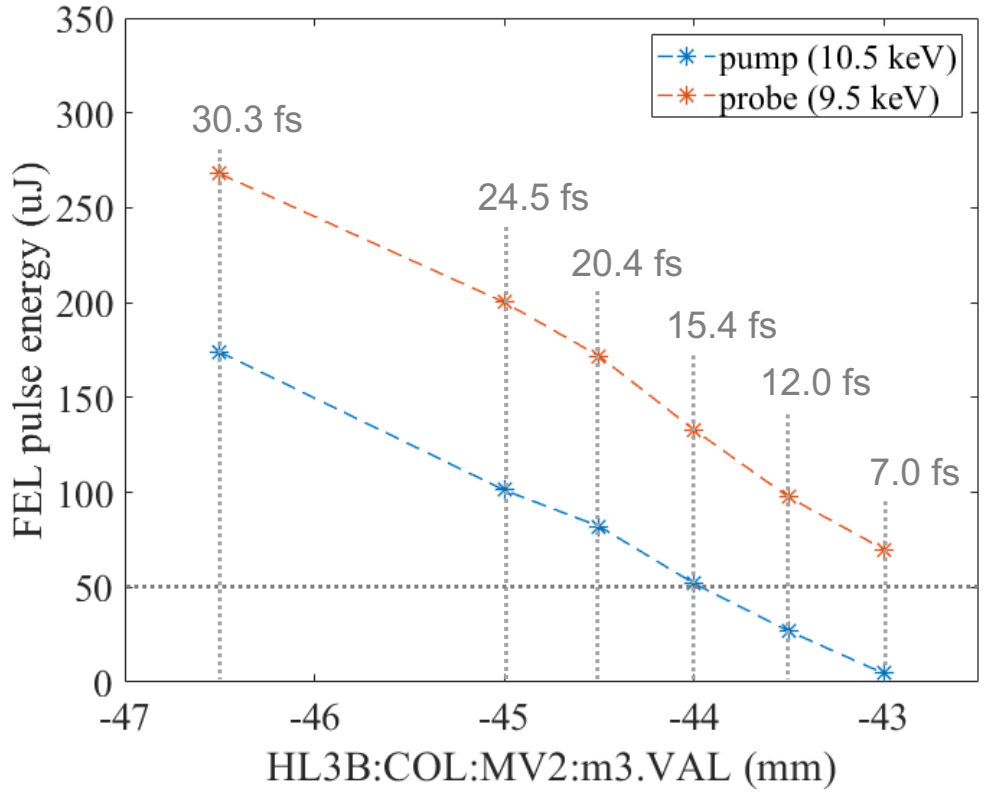




- ✓ Pulse duration is measured by using intensity autocorrelation with magnetic chicane installed in the self-seeding section.
- ✓ We assumed that the XFEL pulse is a Gaussian pulse.

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

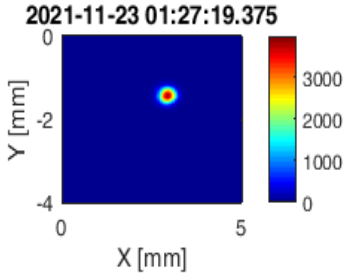




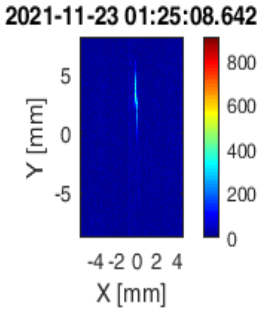
✓ Pulse duration according to SF position is measured by using single-color SASE XFEL

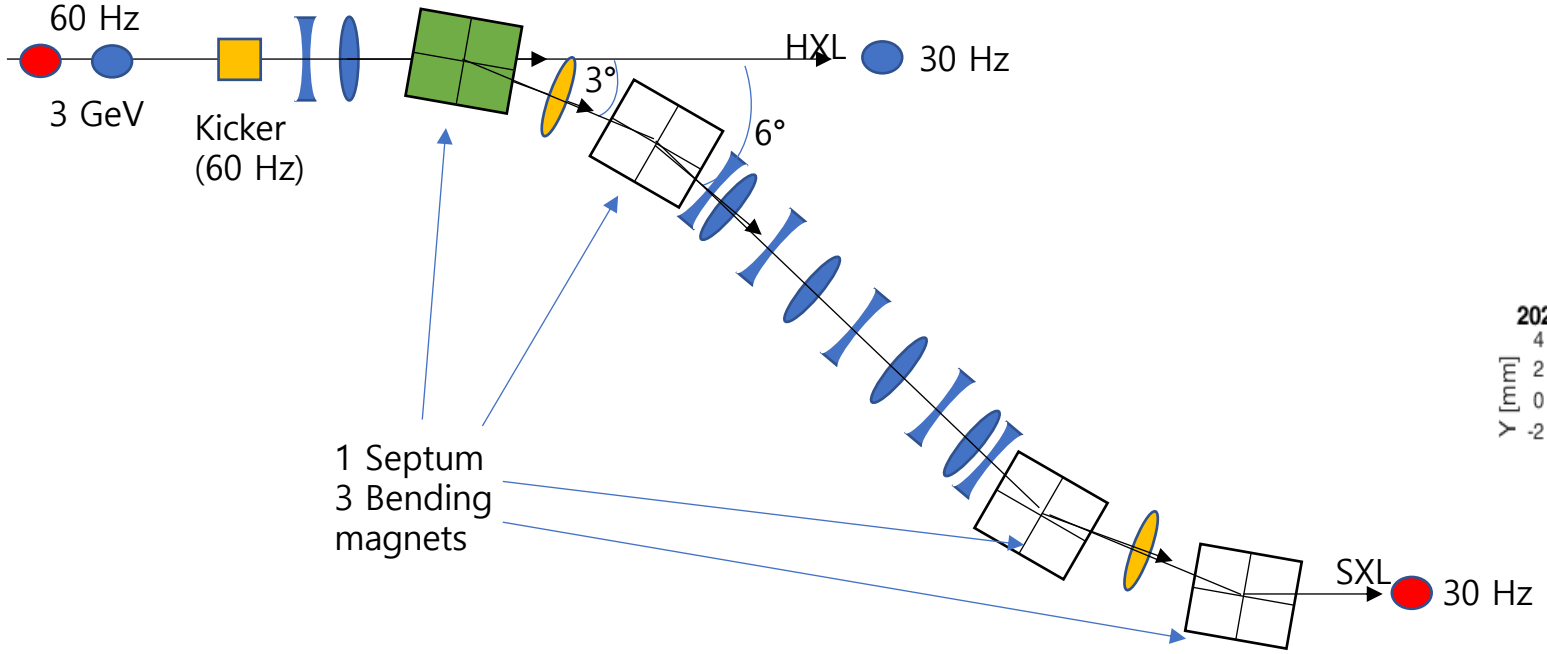
Beam Images of Multi-Beamline Operation of HX and SX

HX FEL



HX Electron

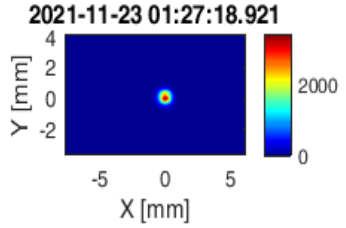




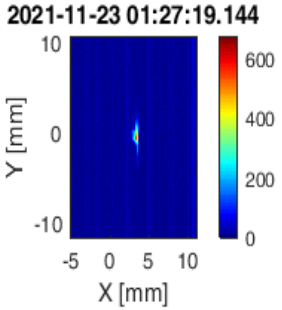
- **Available configurations (Hz)**

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

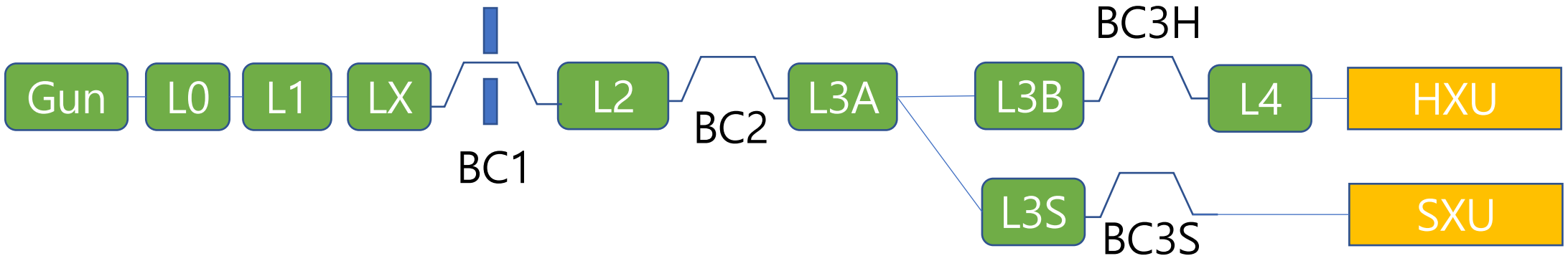
SX FEL



SX Electron



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	

CS-Studio

RF Main

RF Panel

RF Overview | RF Control | Phase Control | Phase Cont.(Dual) | RF Trigger

FEL Mode	Linac Mode	Beam End Point	Beam	MIS
HX & SX Mode	FEL mode	HX main dump	ON	Clear

User guide

Laser Delay (ns) : 10850

RF Phase Control (HX & SX Simulatenous operation)

Station	Crest	BL1 : HX Feedback	BL1 : HX Operation	BL1 : HX Set value	BL1 : HX Error (10^-2)	BL2 : SX Feedback	BL2 : SX Operation	BL2 : SX Set value	BL2 : SX 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	BL1 : HX Operation	BL1 : HX Set value	BL1 : HX 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	-0.0
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 Ope. (FB + OP => OP)

Phase controller (Mini)

Dual-BL Enable/Disable

Multi OFF

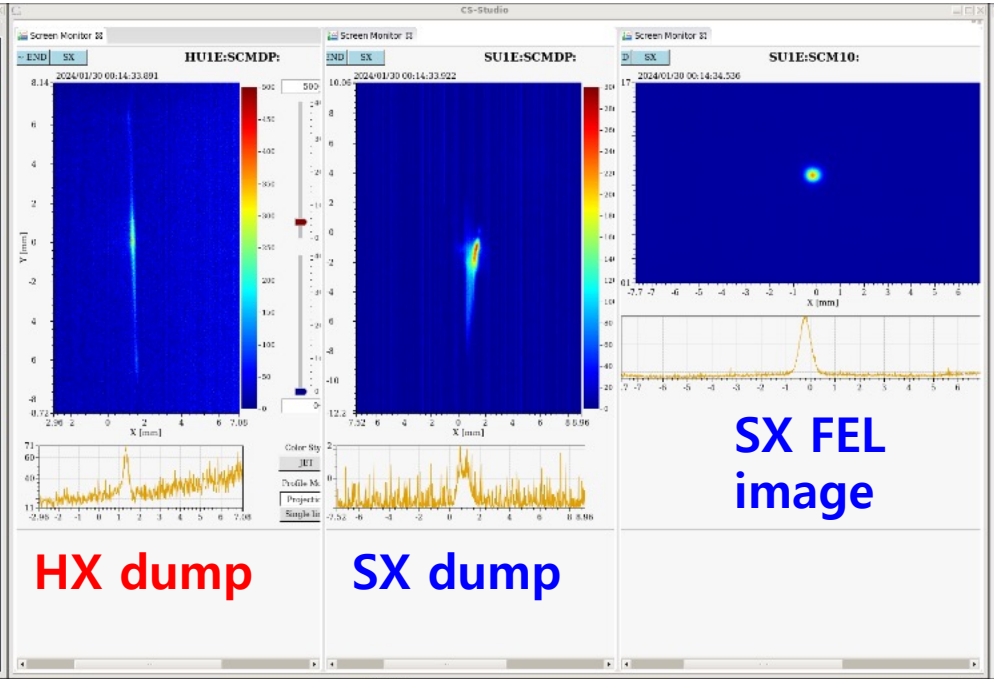
BL1 : HX

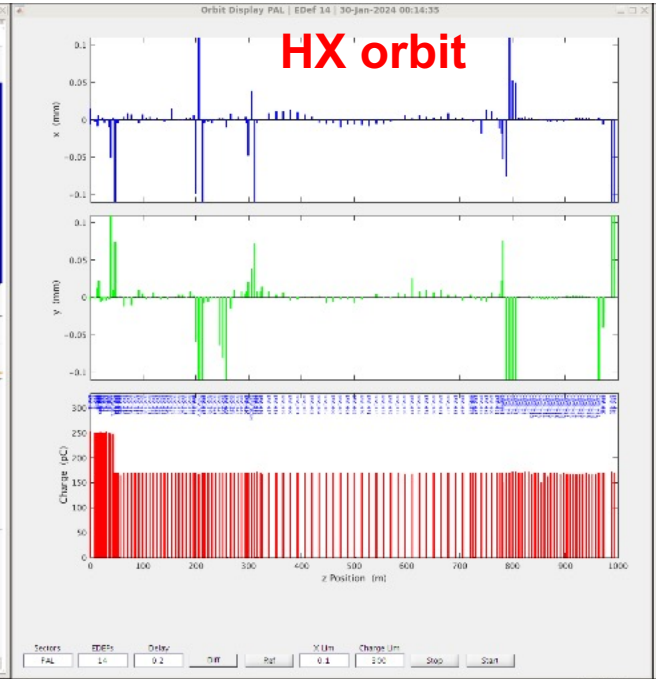
	L0_02	L1	XLIN	L2	L3_A	L3_B	L3_H	L4
Feedback :	0.000	-0.015	-0.411	0.089	0.612	0.612	0.612	0.000
Operation :	-2.000	-10.750	-179.000	-19.400	-8.000	-8.000	-8.000	-1.000
tweak step :	0.000	0.100	0.500	0.100	1.000	2.000	1.000	0.000

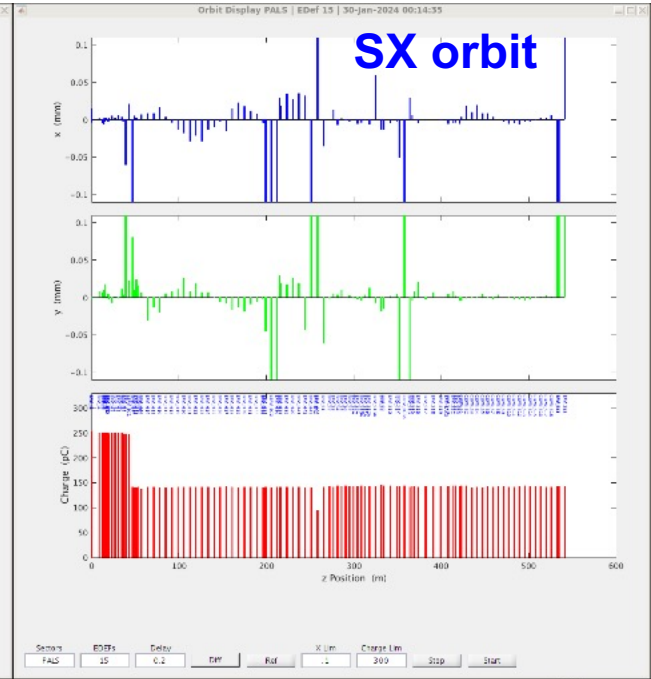
BL2 : SX

	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

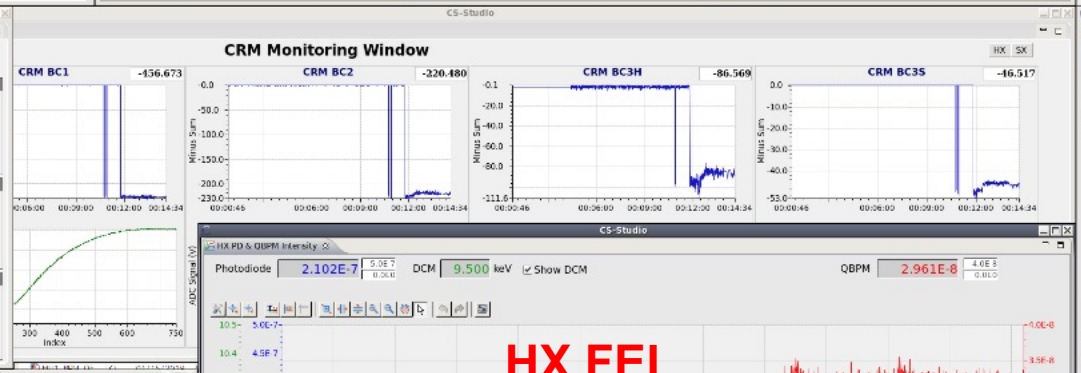

Orbit Correction
Linac Energy

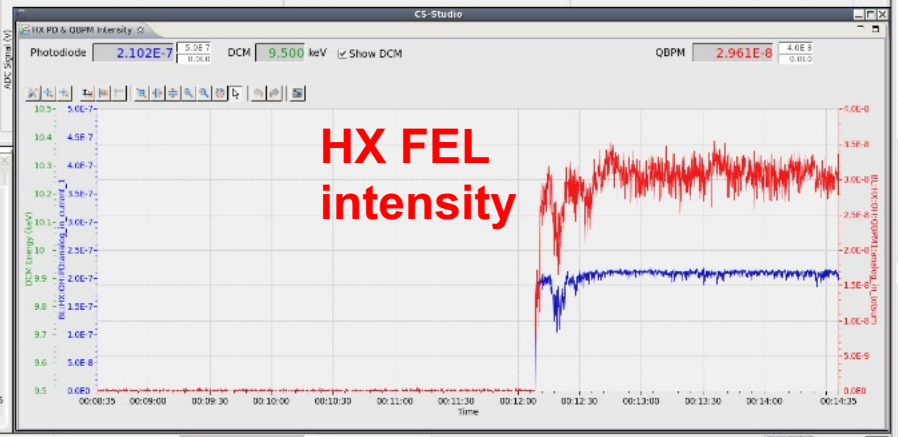

HU1E:SCMDP:
SU1E:SCMDP:
SU1E:SCM10:
HX dump
SX dump
SX FEL image


HX orbit

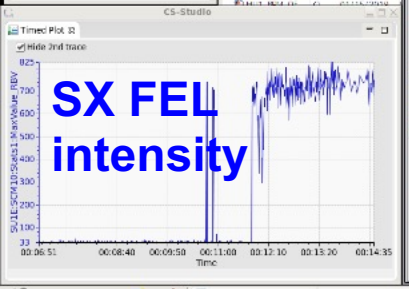

SX orbit


HX1 DCM Energy Control
BL:HX:OH:DCM:

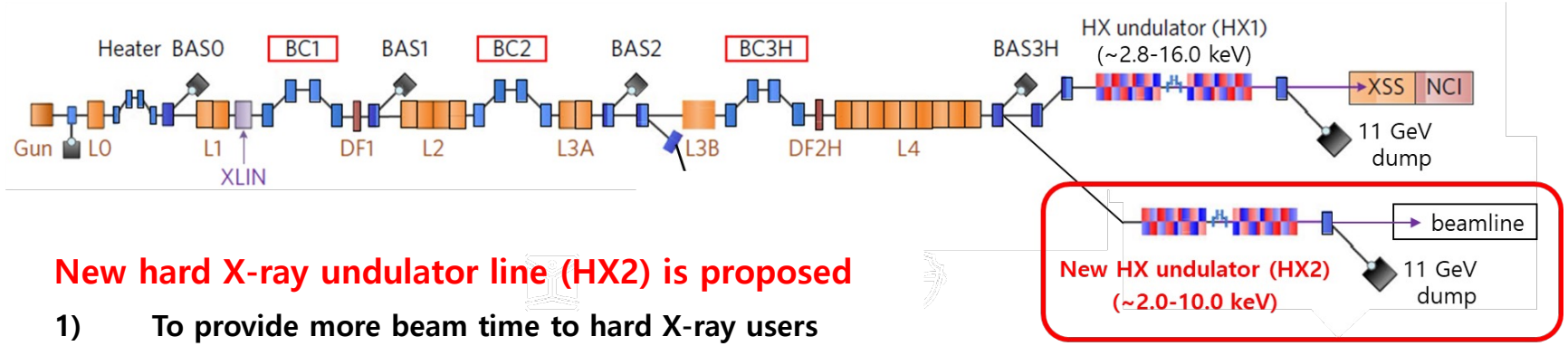

CRM Monitoring Window
CRM BC1
CRM BC2
CRM BC3H
CRM BC3S

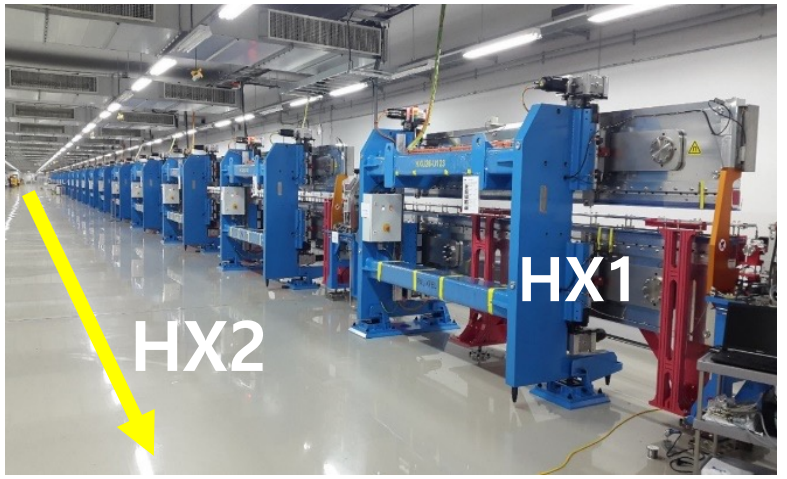

HX FEL intensity


PAL-XFEL Control - HX & SX


SX FEL intensity

New second hard X-ray beamline (HX2)



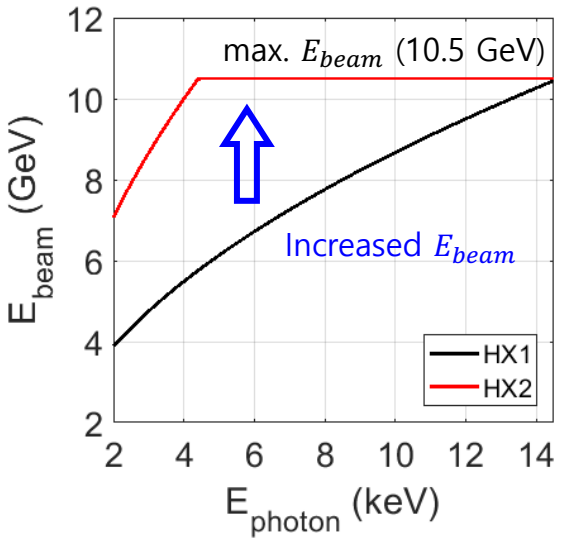


New hard X-ray undulator line (HX2) is proposed

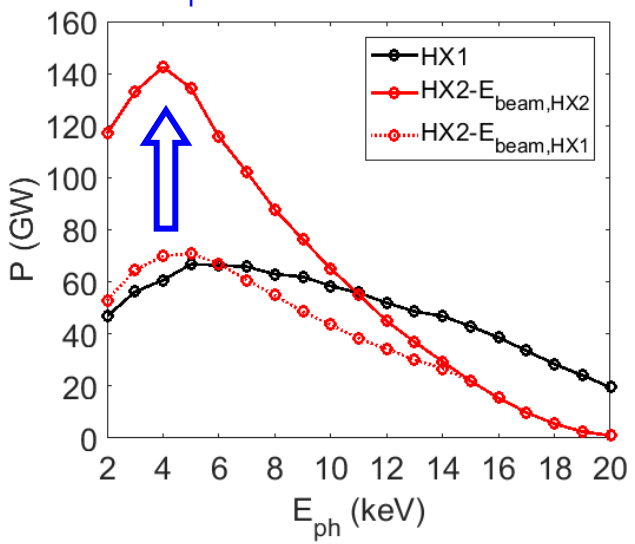
1) **To provide more beam time to hard X-ray users**
   by operating HX1 and HX2 simultaneously
2) **To increase FEL intensity at photon energies lower than 10 keV**
   by increasing E_{beam}
3) **To expand machine performance by applying advanced schemes**
   such as attosecond-TW XFEL, improved SASE,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

$$\lambda_{\mathrm{r}} = \frac{\lambda_{\mathrm{u}}}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$$

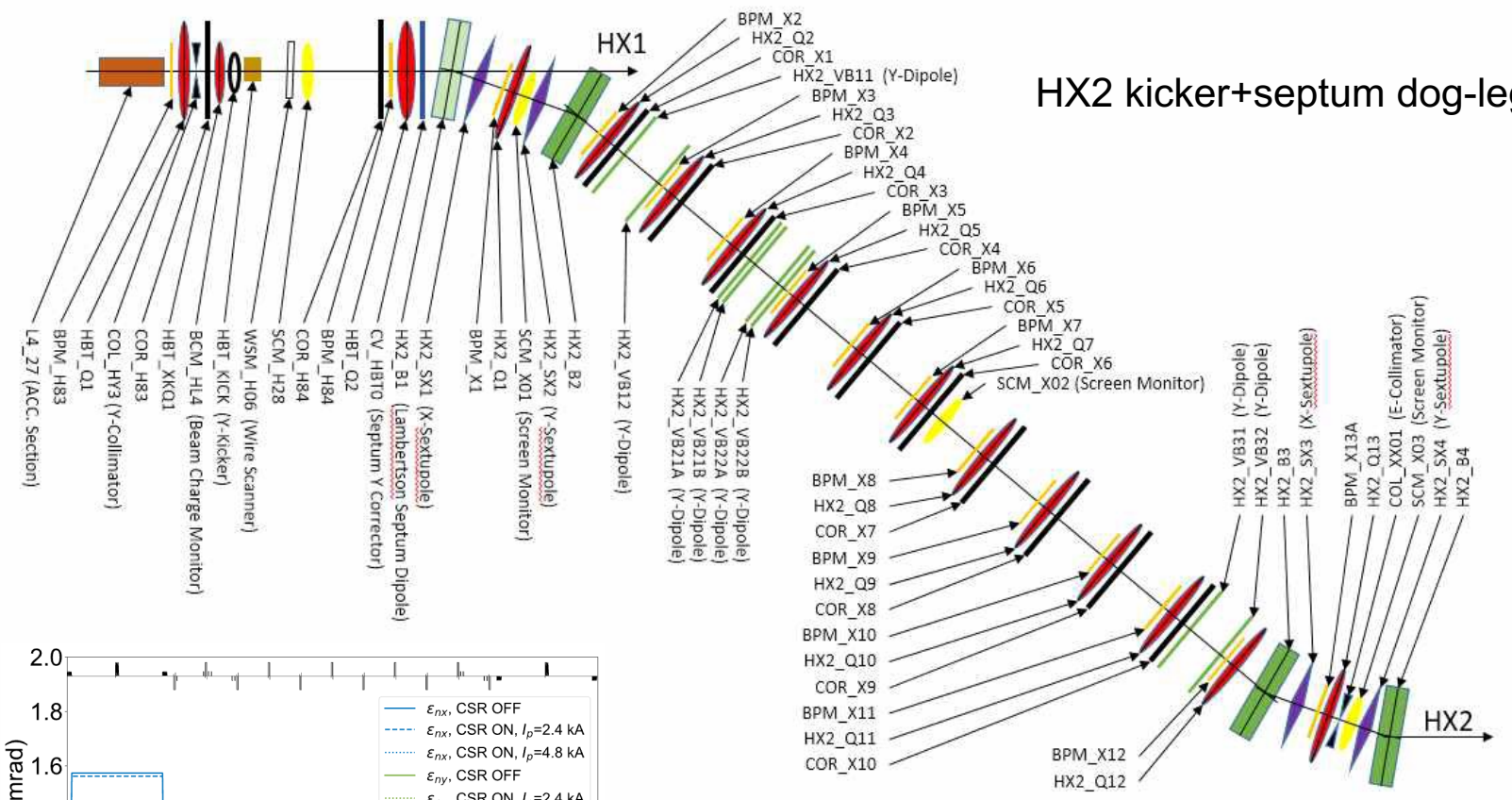
	HX1	HX2	SX1
Undulator period, mm	26	35	35
Undulator length, m	5.0	5.0	5.0
Undulator K	1.94	3.48	3.48
Undulator minimum gap, mm	8.75	9.0	9.0
No. of undulators	20	20	7
Photon energy, keV	6.5 ~ 14.5	2.0 ~ 10.0	0.25 ~ 1.25



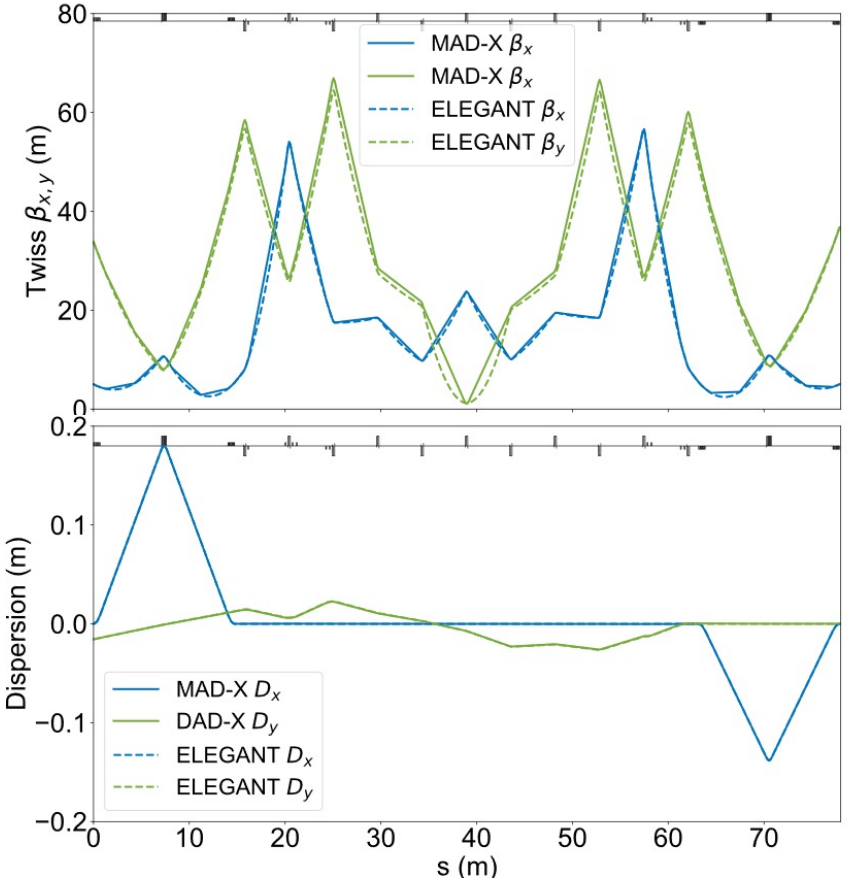
FEL power enhancement

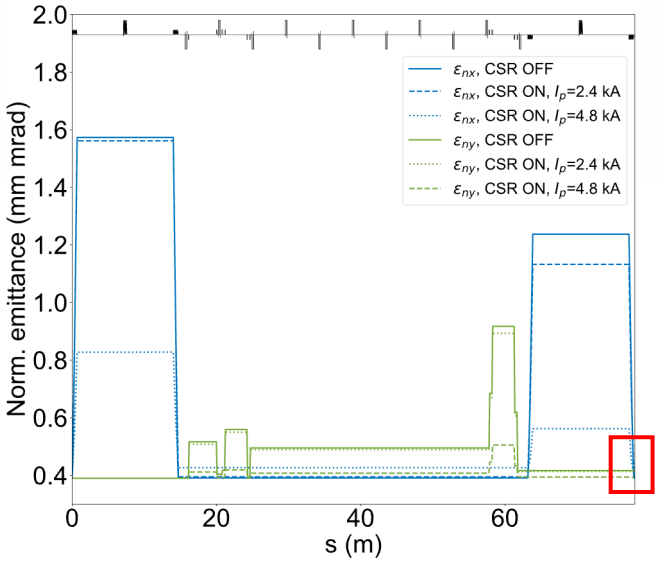


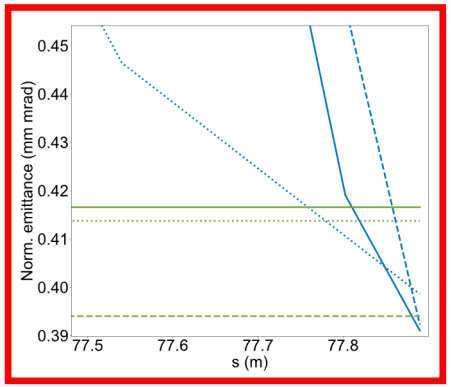
Dog-leg optics for HX2



HX2 kicker+septum dog-leg

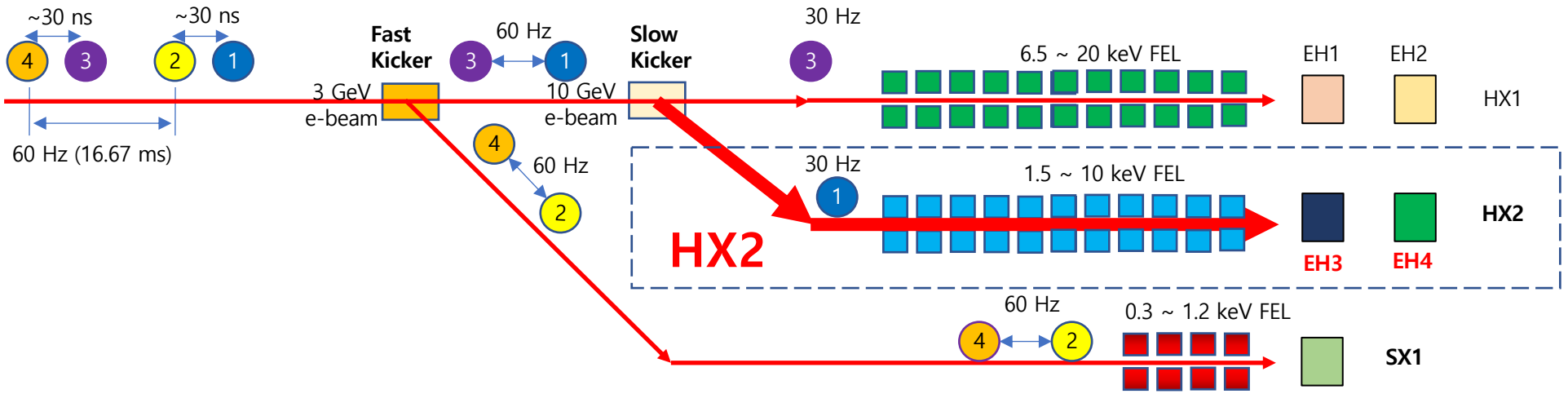






CSR effect is well suppressed along the dog-leg beamline for 2-4 kA peak current beam

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

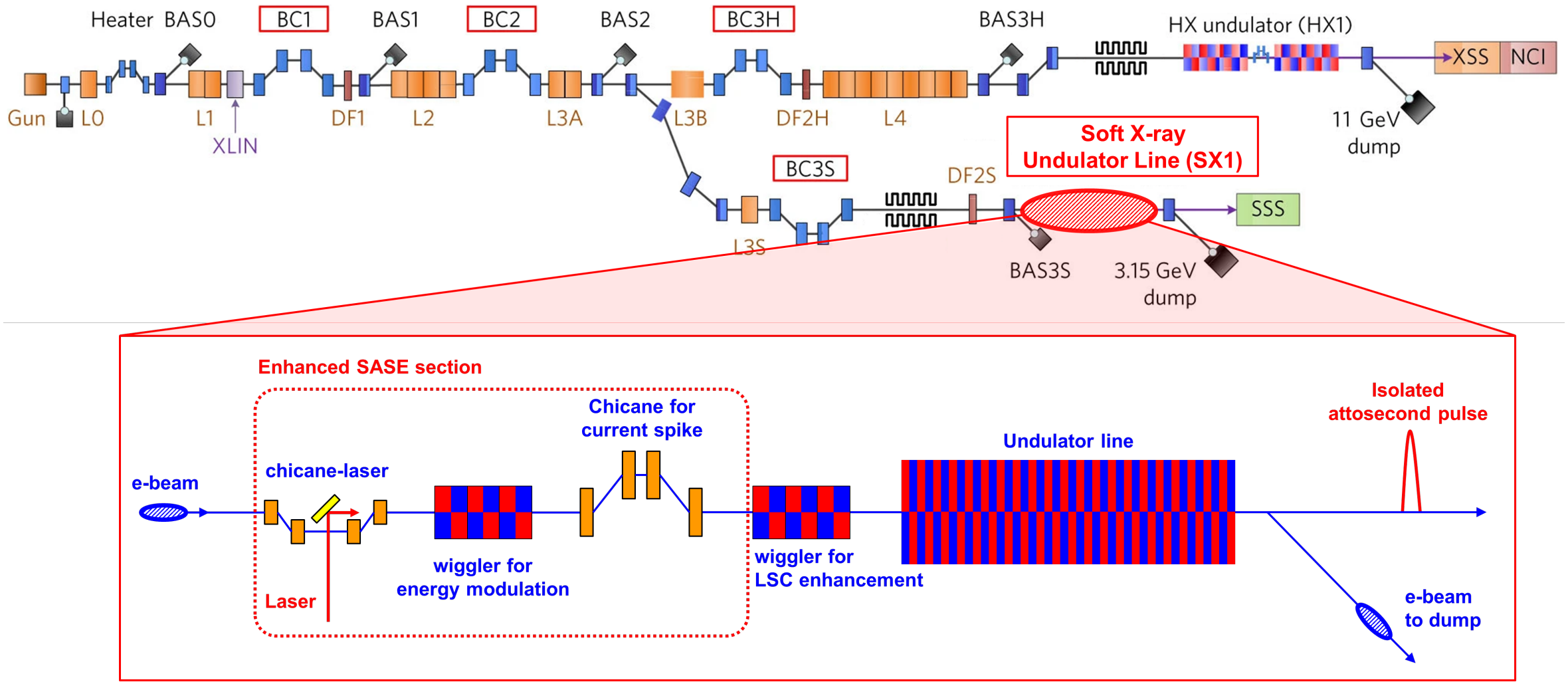
- In the beginning, both SX branch and HX2 branch utilize slow kicker (60 Hz, ms kicker)

- Fast kicker (ns kicker; resonance kicker) and two-bunch mode will be developed for simultaneous 3 independent FEL beamline operation

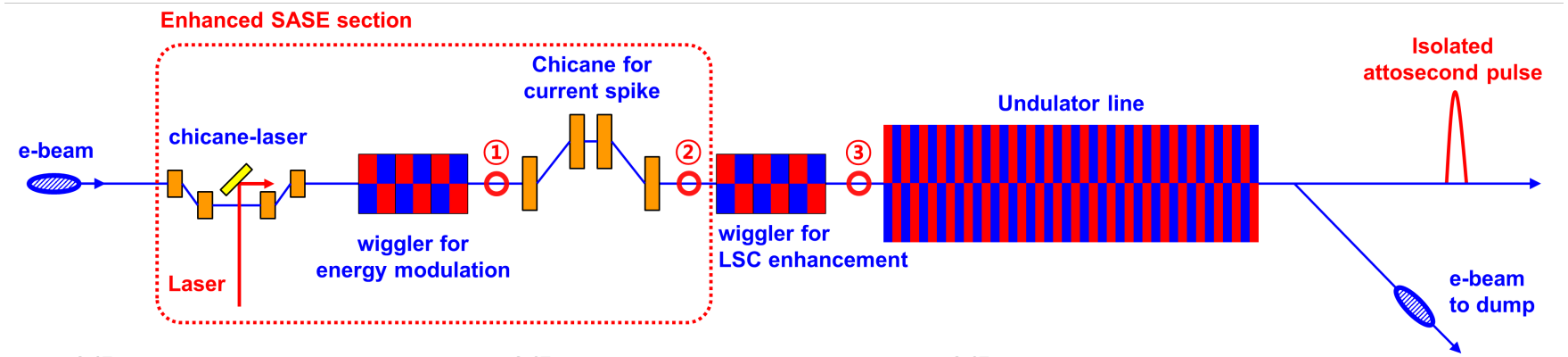
Repetition rate for 3 FEL beamline operation

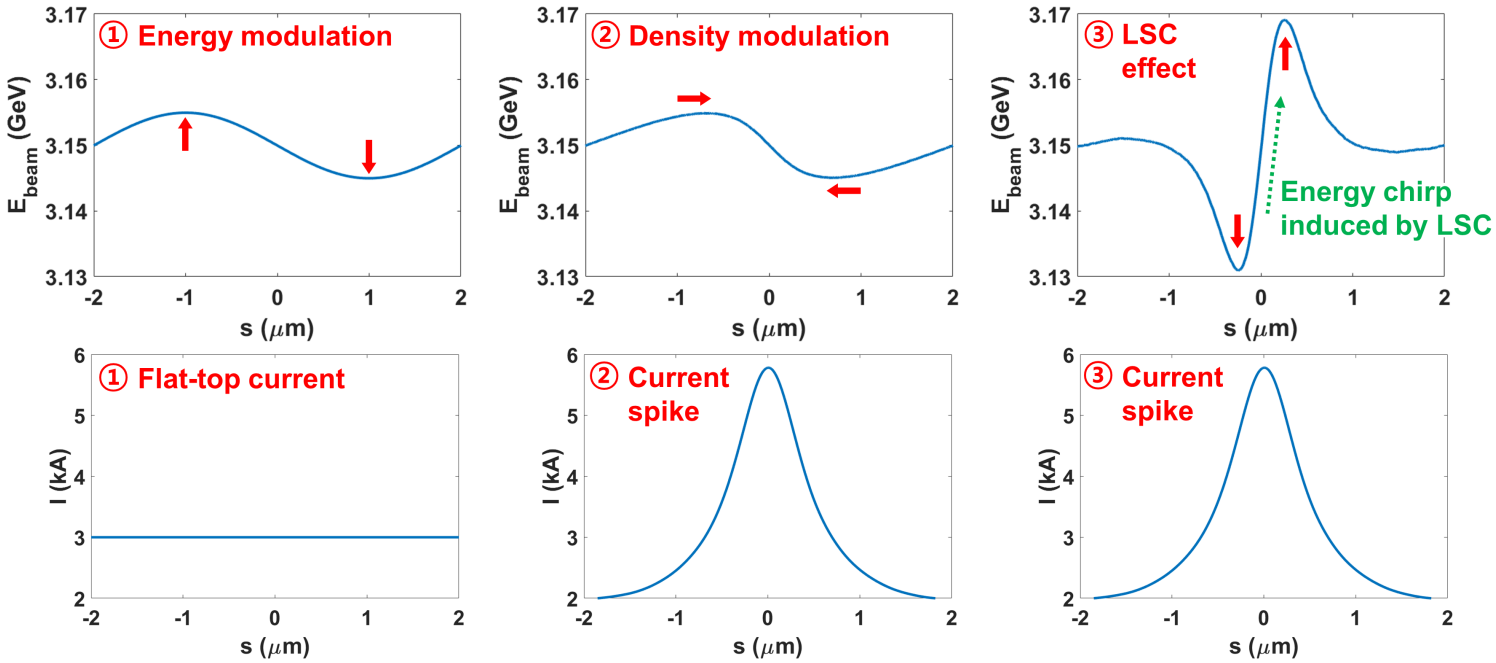
SX1	HX1	HX2
60 Hz	60 Hz	0 Hz
60 Hz	58 Hz	2 Hz
60 Hz	50 Hz	10 Hz
60 Hz	30 Hz	30 Hz
60 Hz	10 Hz	50 Hz
60 Hz	2 Hz	58 Hz
60 Hz	0 Hz	60 Hz

Attosecond XFEL at PAL-XFEL

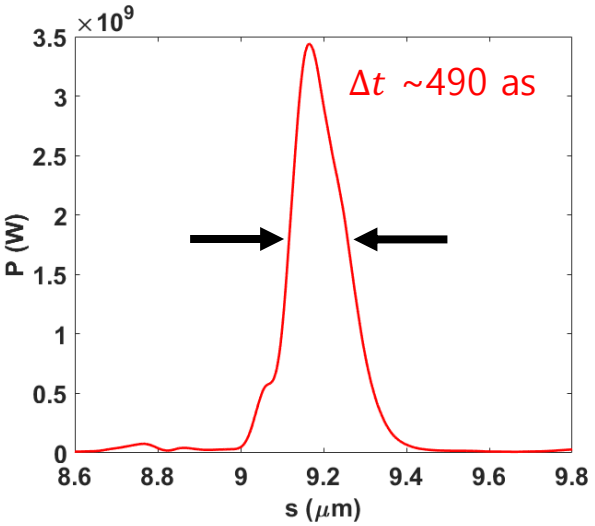


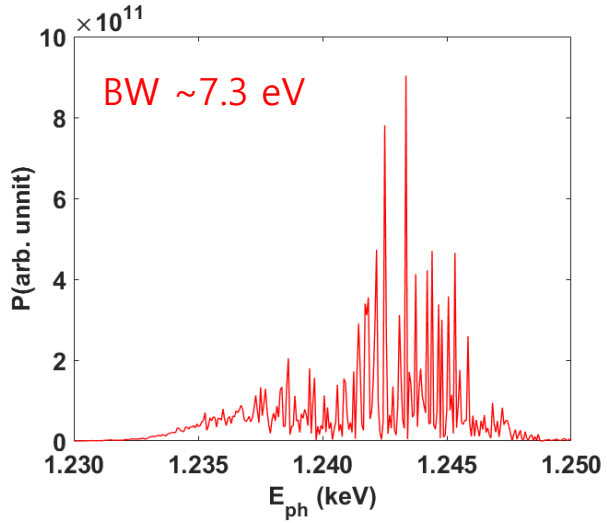
Attosecond XFEL at PAL-XFEL





End of 5th undulator





Thank you for your attention!