Status of PLS-II and PAL-XFEL

Changbum Kim
on behalf of PLS-II and PAL-XFEL

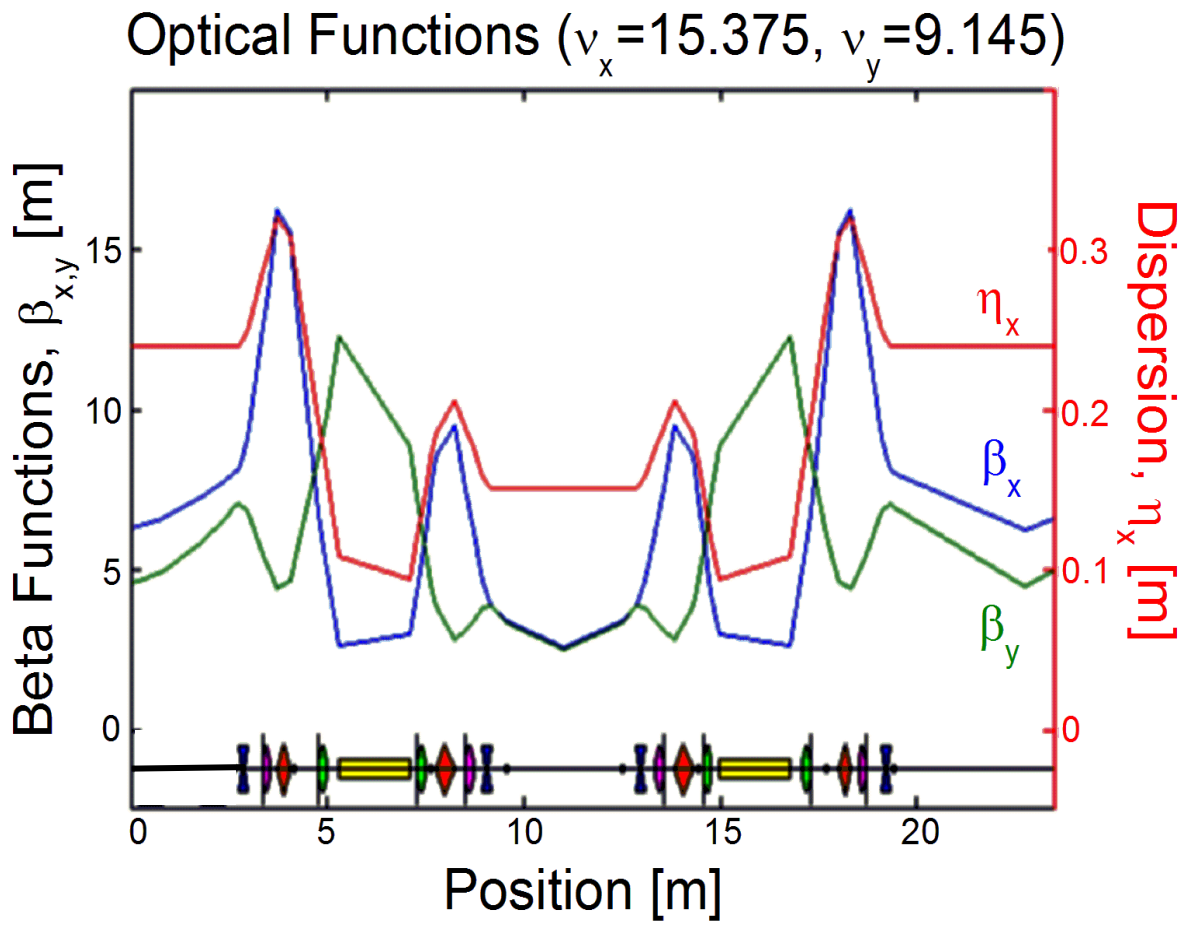
November 13, 2024

PAL POHANG ACCELERATOR LABORATORY

Pohang Accelerator Laboratory

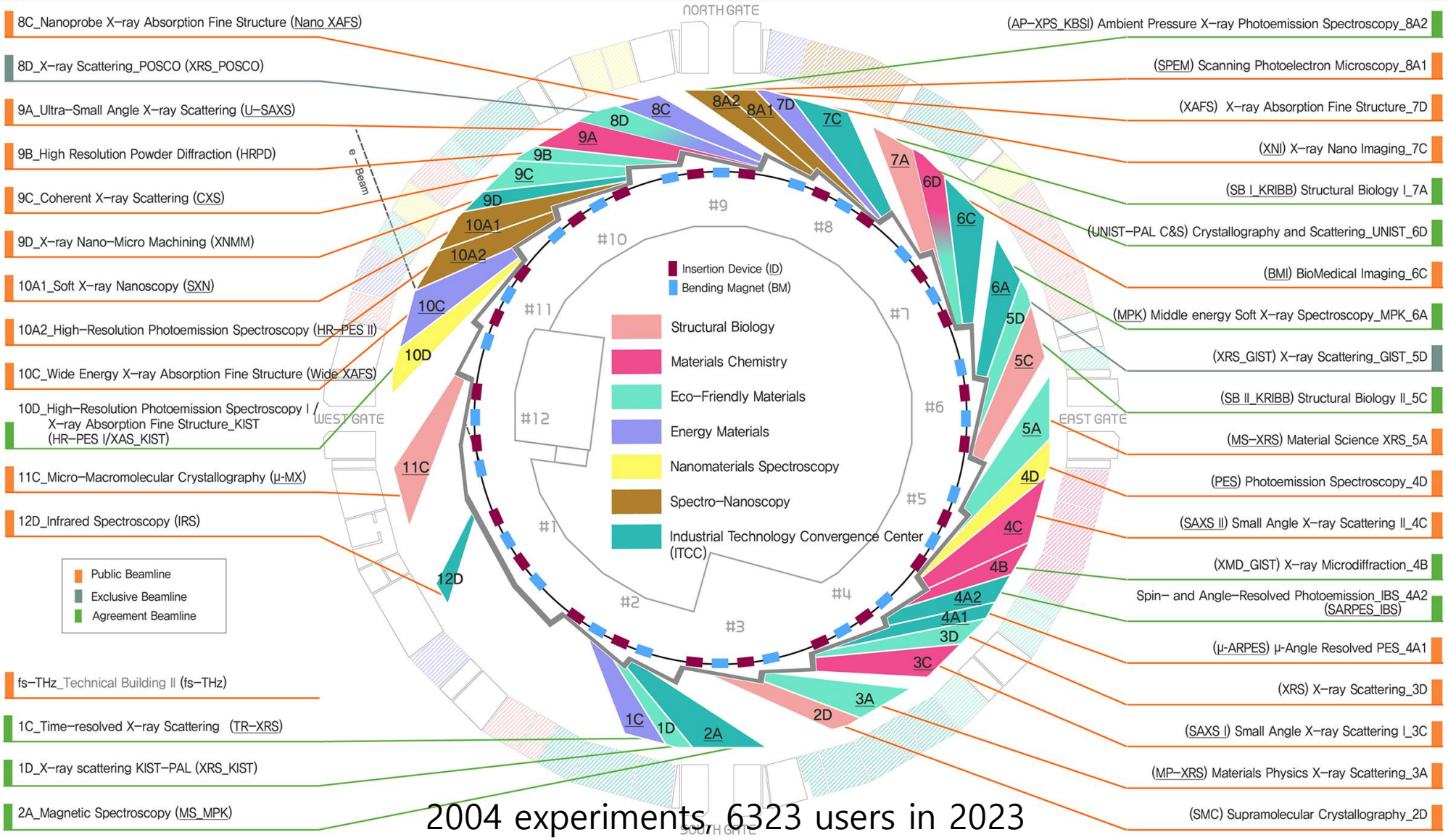
PLS-II Operation Status

PLS-II Lattice and Parameters



Parameter	Value
Circumference	281.82 m
Super-period	12
Energy	3 GeV
Beam current	250 ~ 400 mA
Emittance	5.8 nm rad
Emittance coupling	< 1 %
Energy spread	0.1 %
Momentum compaction	0.0013
Bunch length	16 ps
Tune (H/V)	15.375 / 9.145
Chromaticity (H/V)	3 / 3

36 Beamlines of PLS-II

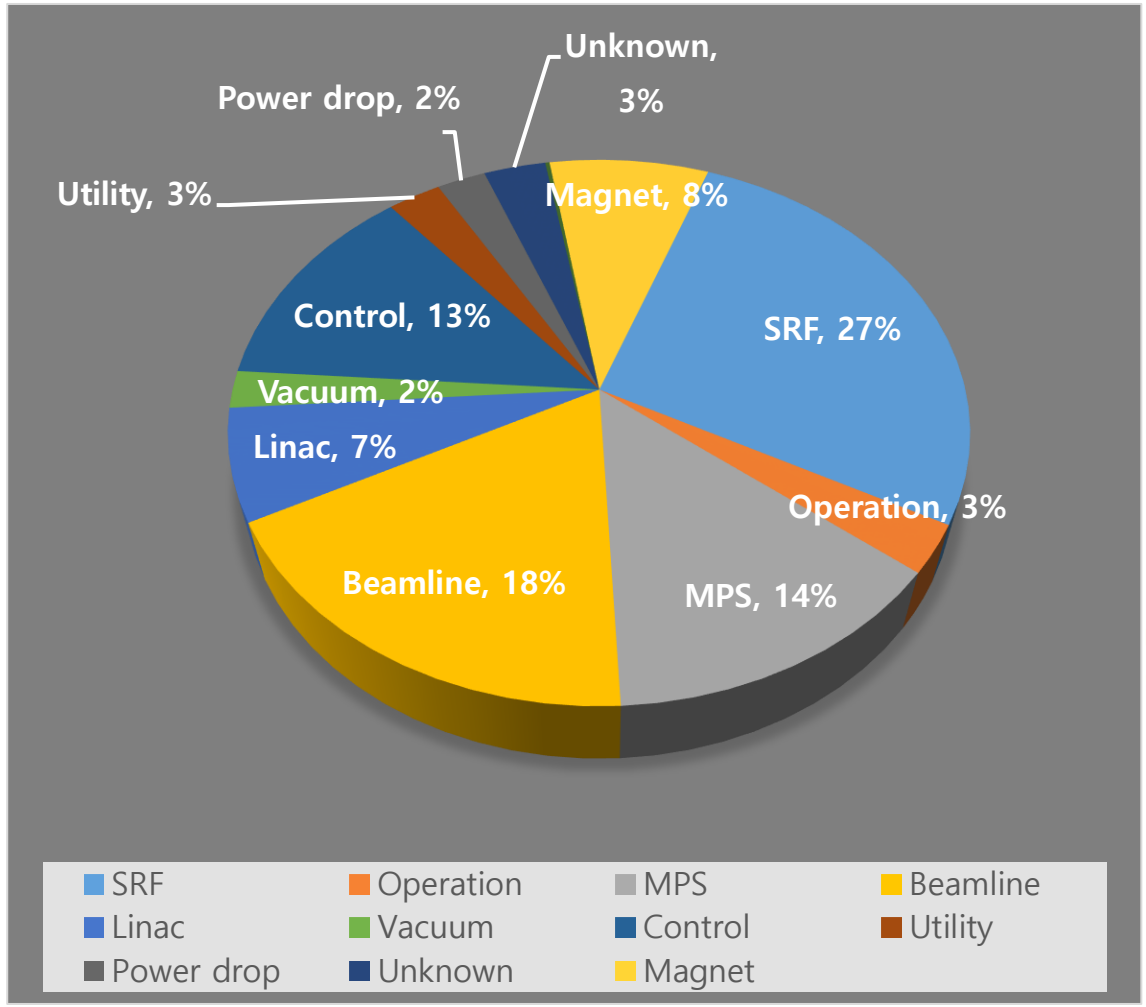


2004 experiments, 6323 users in 2023

Operation Requirements of PLS-II

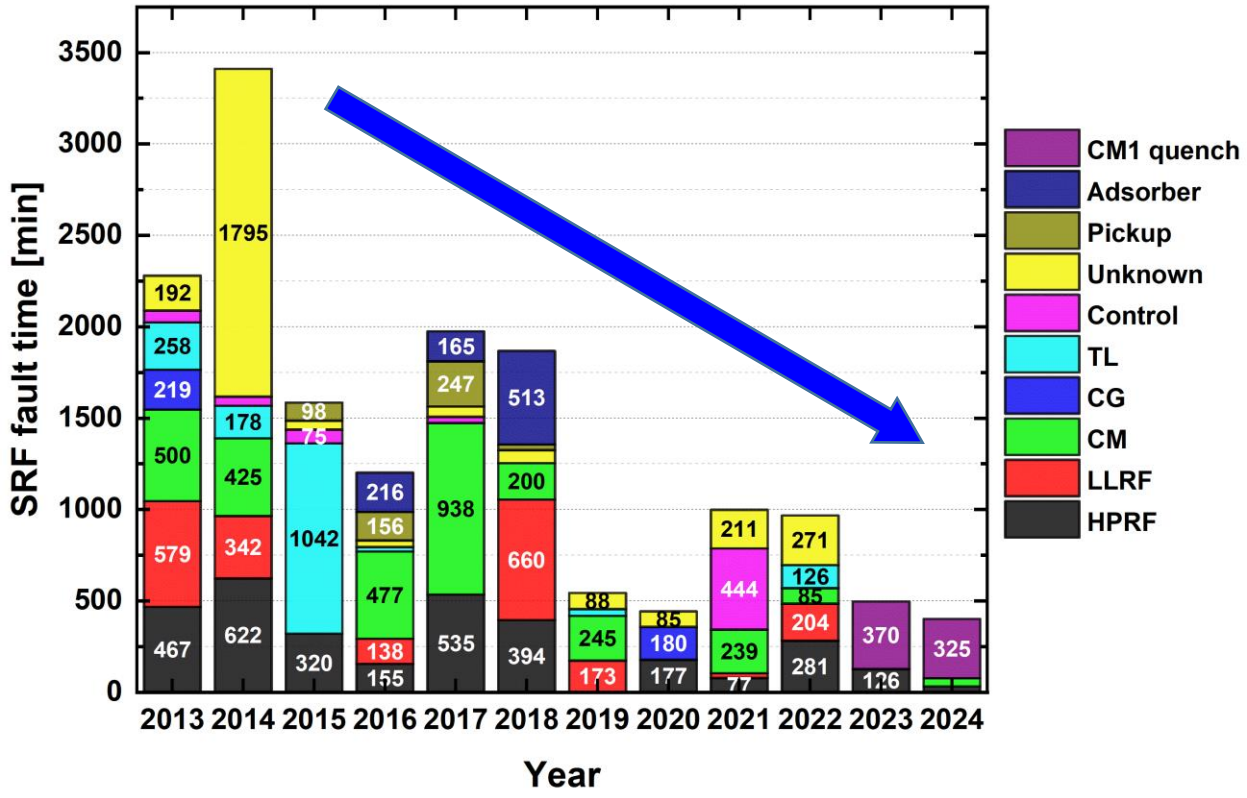
- User beamtime: 190 days
- Beam availability: > 97%
- 3 GeV top-up operation
- Beam current: 250~400 mA
- Beam stability < 1 μm rms
- Photon beam stability < 2 μm rms
- Beam stability @ ID gap change < 6 μm rms
- Hybrid single bunch current: 5 mA

Machine Fault of PLS-II



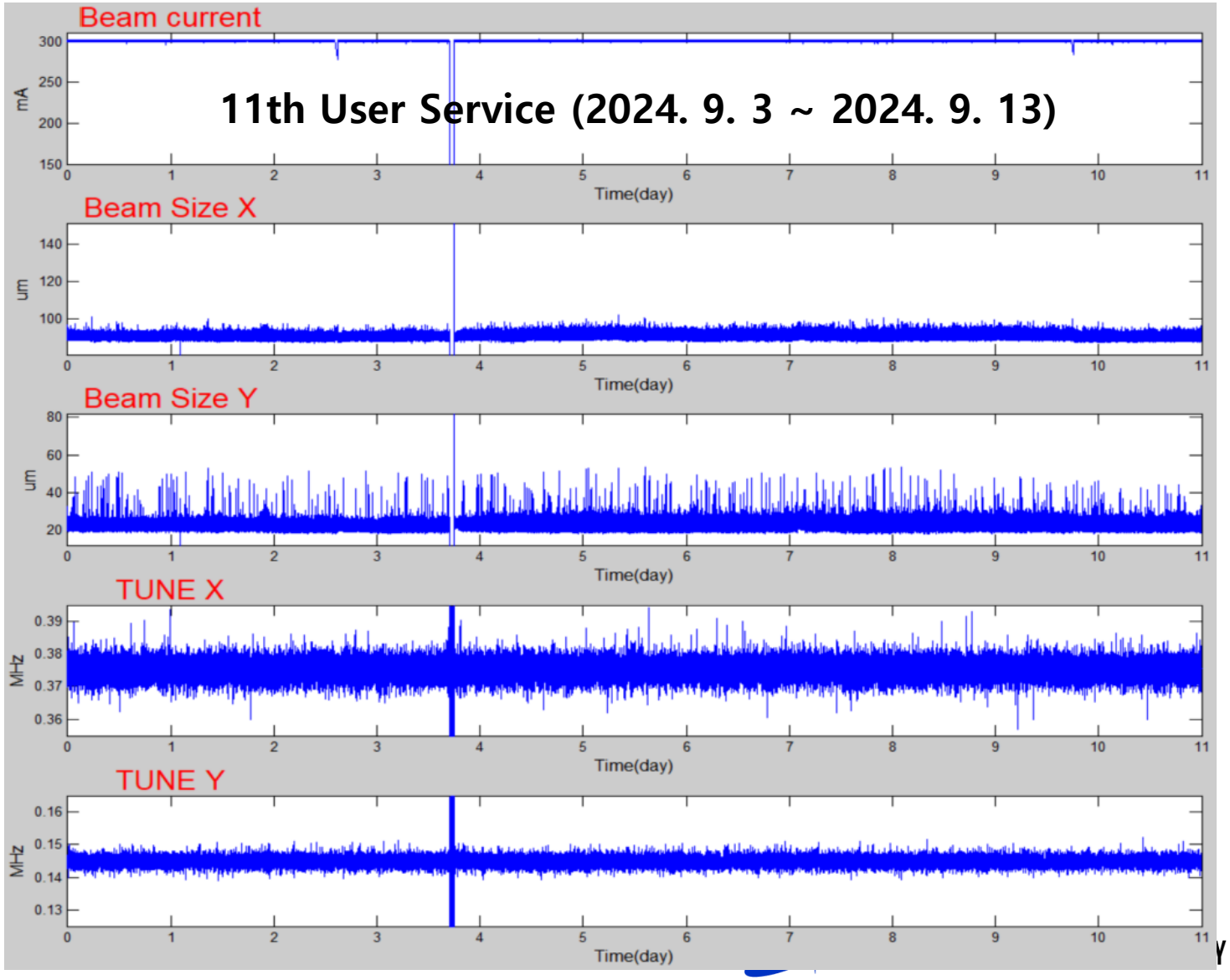
Source of Service Downtime

History of SRF Fault Time



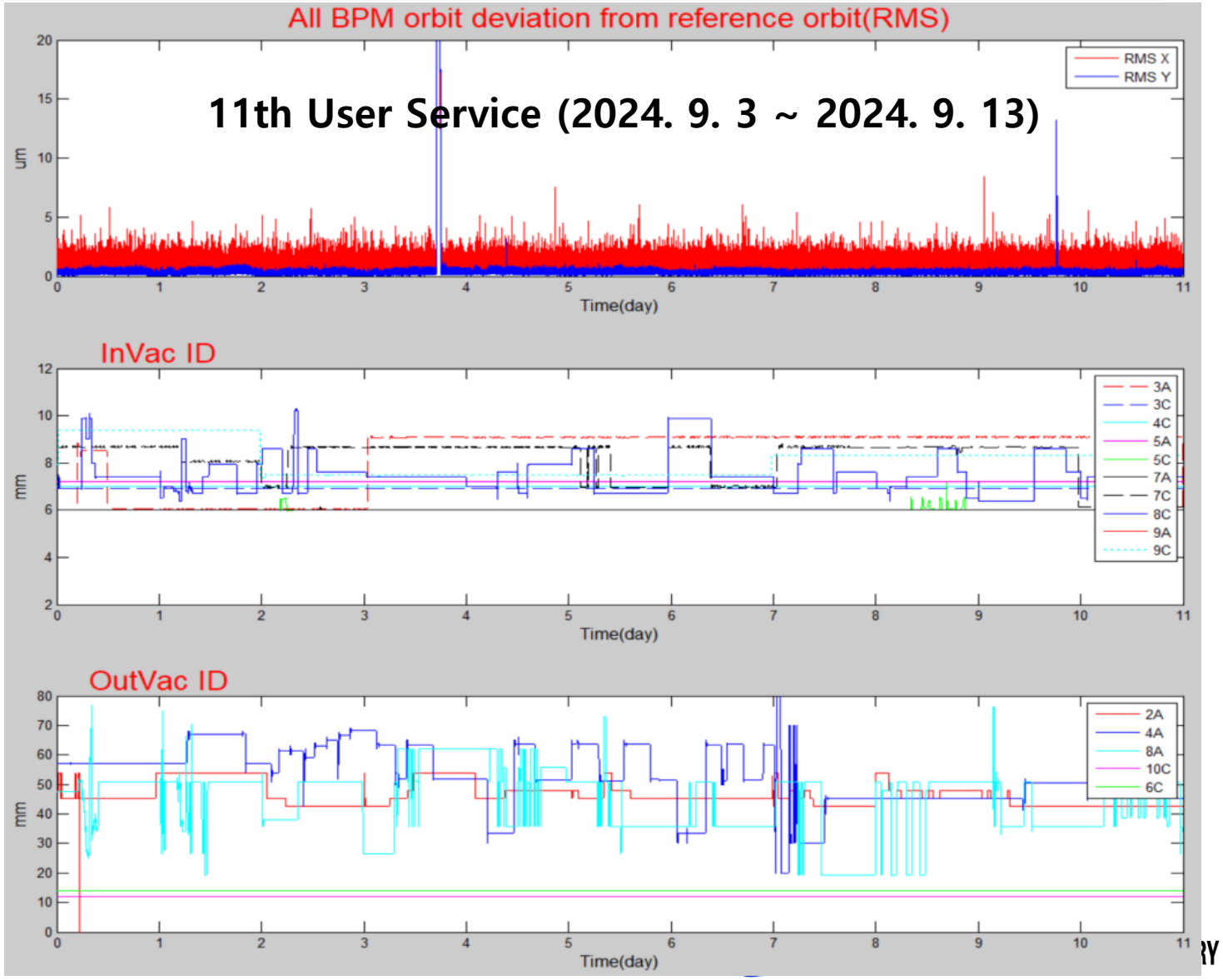
Operation Requirements of PLS-II

- User beamtime: 190 days
- Beam availability: > 97%
- 3 GeV top-up operation
- Beam current: 250~400 mA
- Beam stability < 1 μm rms
- Photon beam stability < 2 μm rms
- Beam stability @ ID gap change < 6 μm
- Hybrid single bunch current: 5 mA



Operation Requirements of PLS-II

- User beamtime: 190 days
- Beam availability: > 97%
- 3 GeV top-up operation
- Beam current: 250~400 mA
- Beam stability < 1 μm rms
- Photon beam stability < 2 μm rms
- Beam stability @ ID gap change < 6 μm
- Hybrid single bunch current: 5 mA



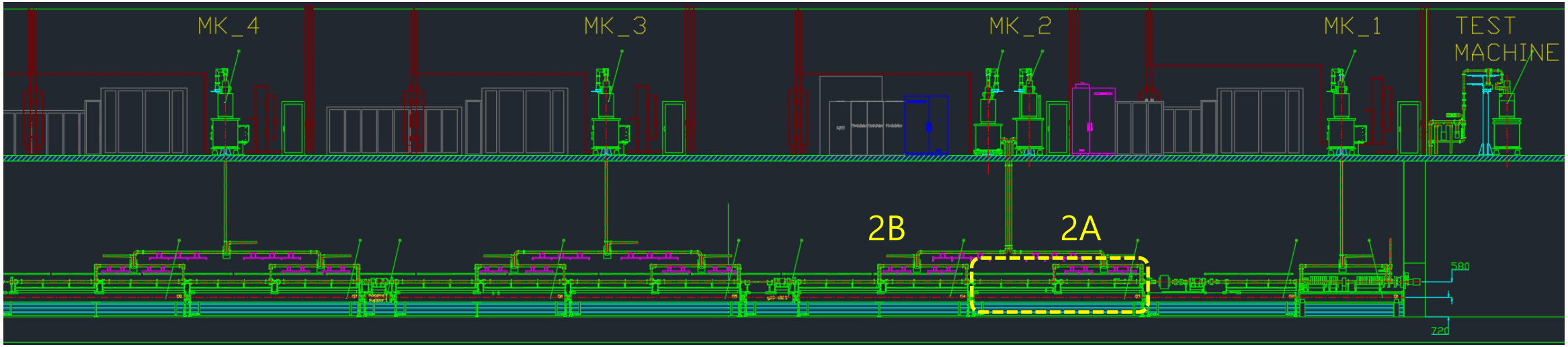
PLS-II Machine Upgrade

Electron Beam Energy of PLS-II Linac

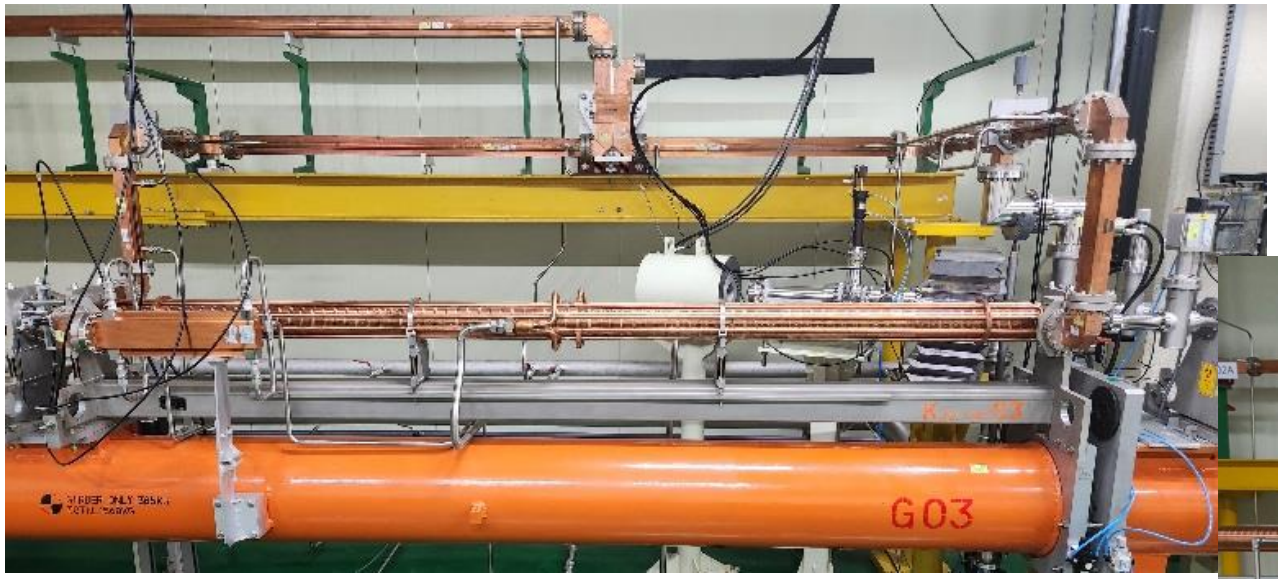
- Linac energy increasement for uninterrupted Top-up operation
  - 17 klystrons and modulators are used for 3.0 GeV electron beam
  - 3.3 GeV is needed for injection in the case of 1 klystron failure
  - Replacement of old acceleration columns and SLEDs

Replacement of Acceleration Columns (MK02A)

- Frequent tunnel vacuum faults even at lower high voltage (36 kV) than other modules, making it difficult to supply enough RF power
- Frequent vacuum interlock caused by arcing in the acceleration column
- Two acceleration columns of MK02A were replaced with spare parts to increase RF power



Replacement of Acceleration Columns (MK02A)

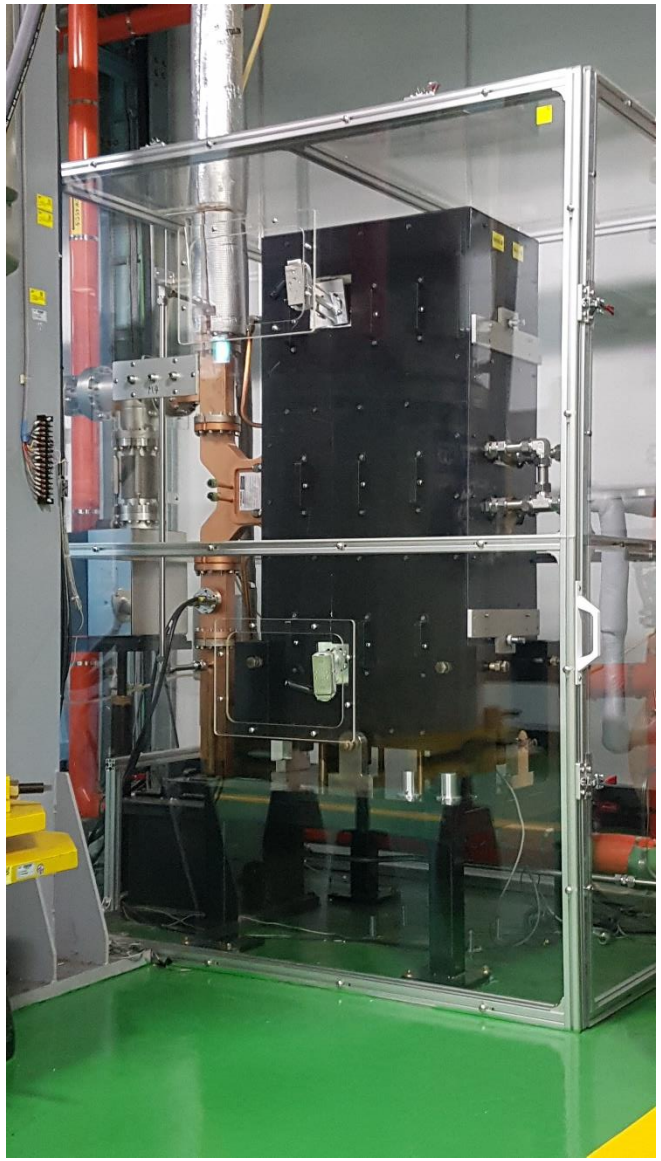


Before replacement (IHEP)

After replacement (Mitsubishi)

Energy gain from MK02A and MK02B: 273.5 -> 332.0 MeV

Replacement of SLED (MK06)



SLED: SLAC Energy Doubler

Energy gain from MK06:
206.3 -> 251.5 MeV

Beam Stability of PLS-II Storage Ring

- Increased beam stability
  - Additional application of PBPM feedback in every beamline
- Stable operation of 400 mA & high current of single bunch in hybrid mode
  - Upgrade of bunch-by bunch feedback system (SPring-8 electronics -> Dimtel electronics)

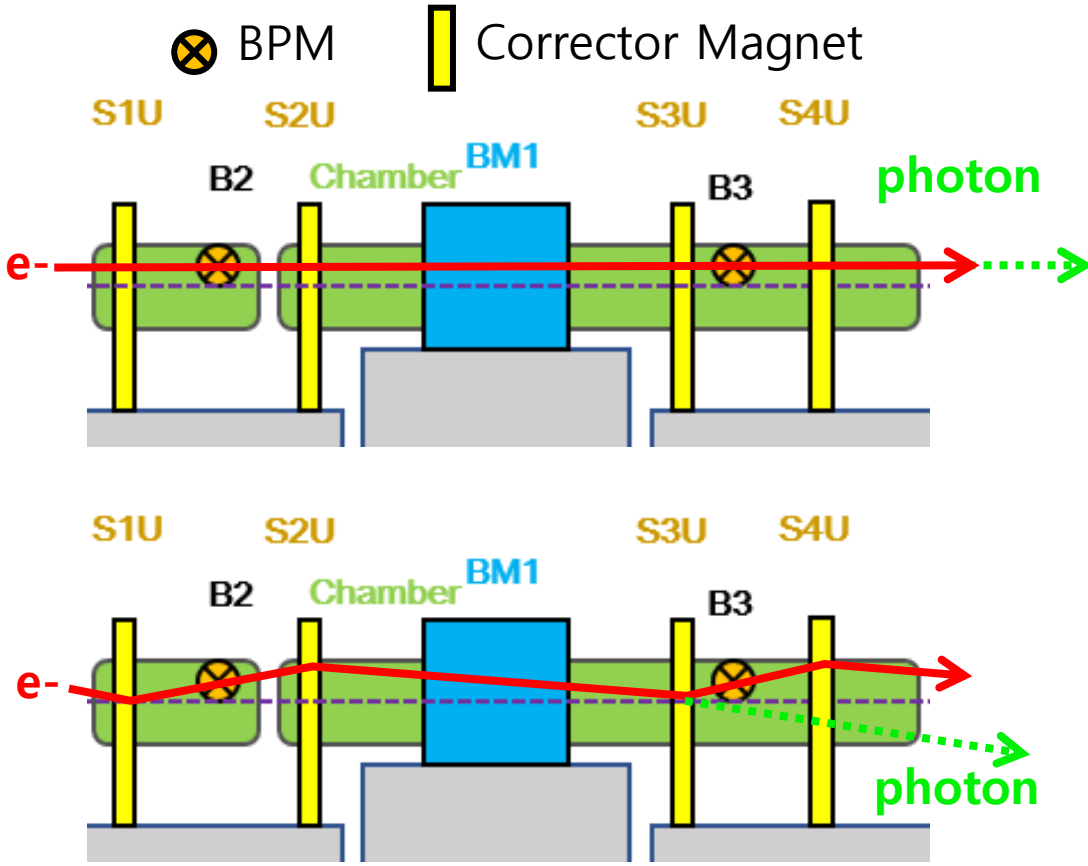
BPM & PBPM

e-BPM Y

PBPM Y

Corrector Y

ID Gap



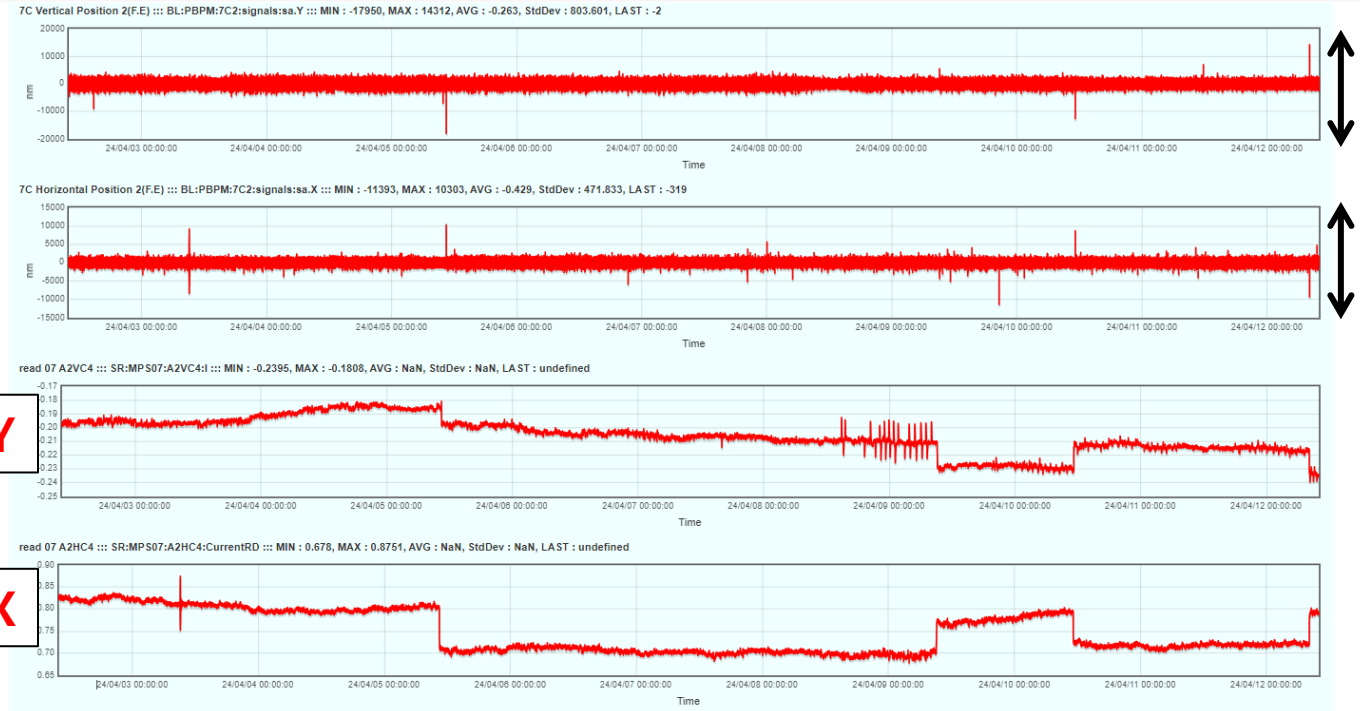
Performance of PBPM Feedback

PBPM_Y

PBPM_X

Corrector Y

Corrector X



40 μm

30 μm

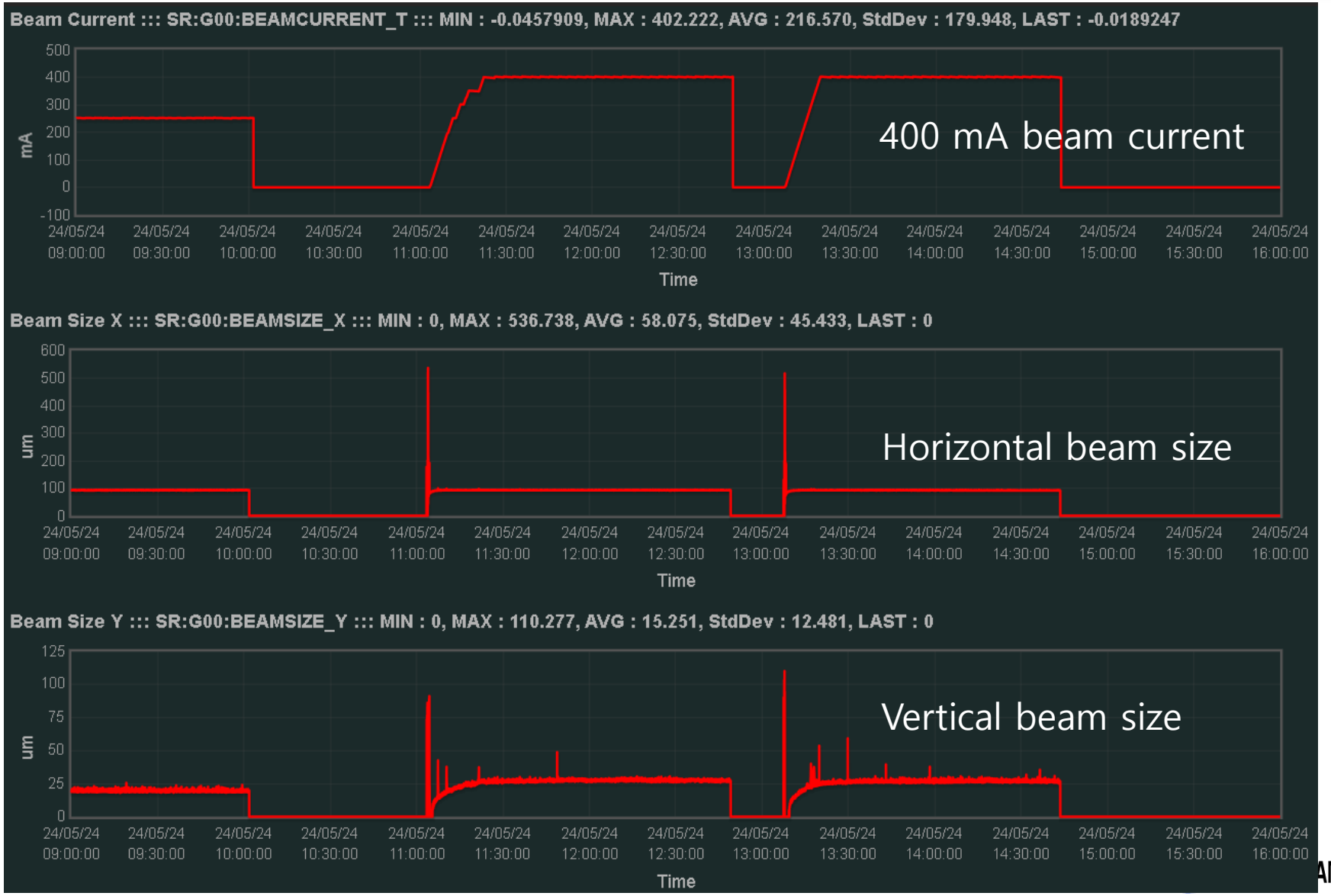
Beamline	3C		4C		5A	5C		6D	7A	
Hori./Vert.	X	Y	X	Y	Y	X	Y	Y	X	Y
rms [μm]	0.47	2.20	0.81	0.69	0.38	0.54	1.00	0.61	0.56	0.79

Beamline	7C		8A	9A		9B	9C		10D	11C	
Hori./Vert.	X	Y	Y	X	Y	Y	X	Y	Y	X	Y
rms [μm]	0.66	0.97	1.24	0.93	1.02	0.27	1.42	1.90	1.04	0.68	0.95

Beam Stability of PLS-II Storage Ring

- Increased beam stability
  - Additional application of PBPM feedback in every beamline
- Stable operation of 400 mA & high current of single bunch in hybrid mode
  - Upgrade of bunch-by bunch feedback system (SPring-8 electronics -> Dimtel electronics)

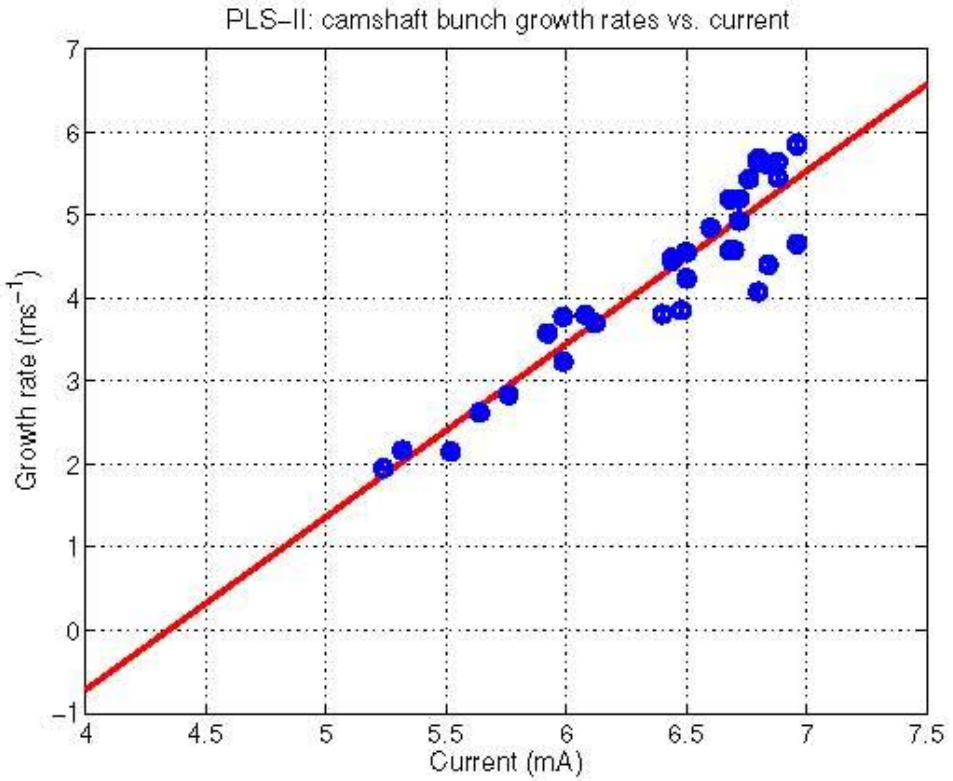
400 mA Machine Study Result (2024. 5. 24)



Hardware Used (Dimtel Bunch-by-Bunch Feedback Electronics)

- Three Dimtel units:
  - iGp12 baseband processor;
  - FBE-500LT analog front/back-end;
  - BPMH-20-2G BPMH hybrid network.
- Used buttons A and C, adjustable delays to compensate for cable length errors;
- Only two amplifiers driven differentially: A and C.

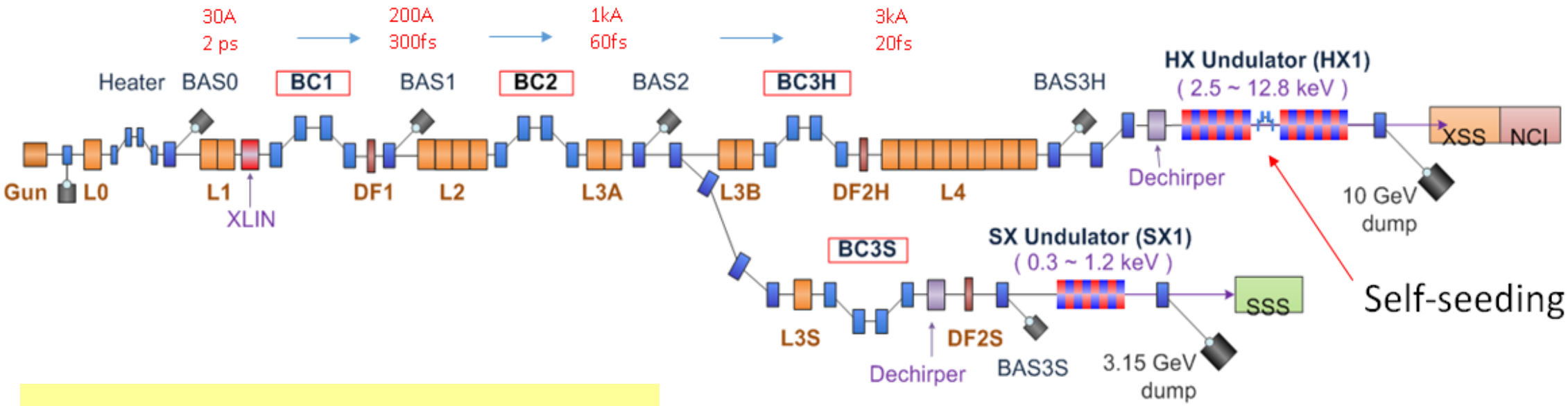
Growth Rate vs. Camshaft Current



- Growth rates vs. camshaft bunch current;
- Current is estimated from the scope peak-to-peak amplitude;
- Steep rise in growth rates, reaching 6 ms^{-1} at 7 mA — 180 turns;
- Reached 7.6 mA with the demonstration setup;
- With a separate X and Y processors (each driving four amplifiers) one can expect to reach even higher camshaft currents.

PAL-XFEL Operation Status

PAL-XFEL Layout & Parameters



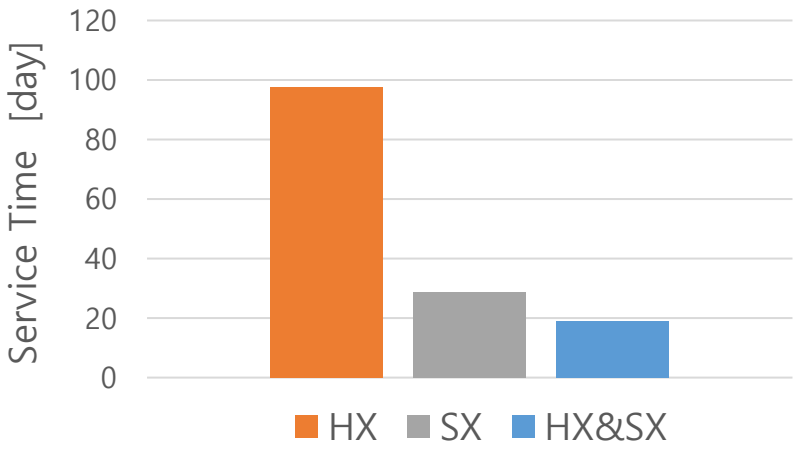
Main parameters

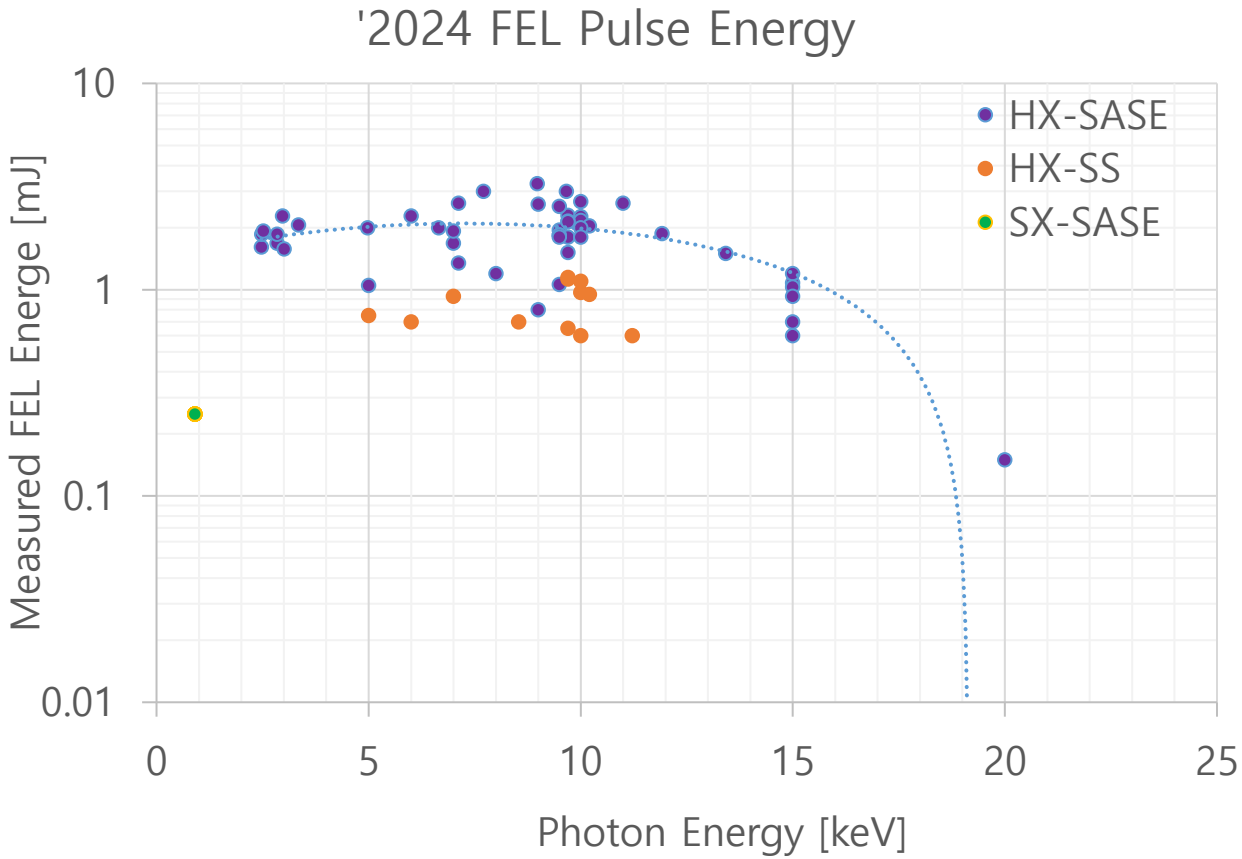
e^- Energy	11 GeV
e^- Bunch charge	20-200 pC
Slice emittance	< 0.4 mm mrad
Repetition rate	60 Hz
Bunch length	5 fs – 50 fs
Peak current	3 kA
SX line switching	Kicker Magnet

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
Undulator Period / Gap [mm]	26 / 8.3	35 / 9.0

PAL-XFEL Operation Result (FEL Performance)

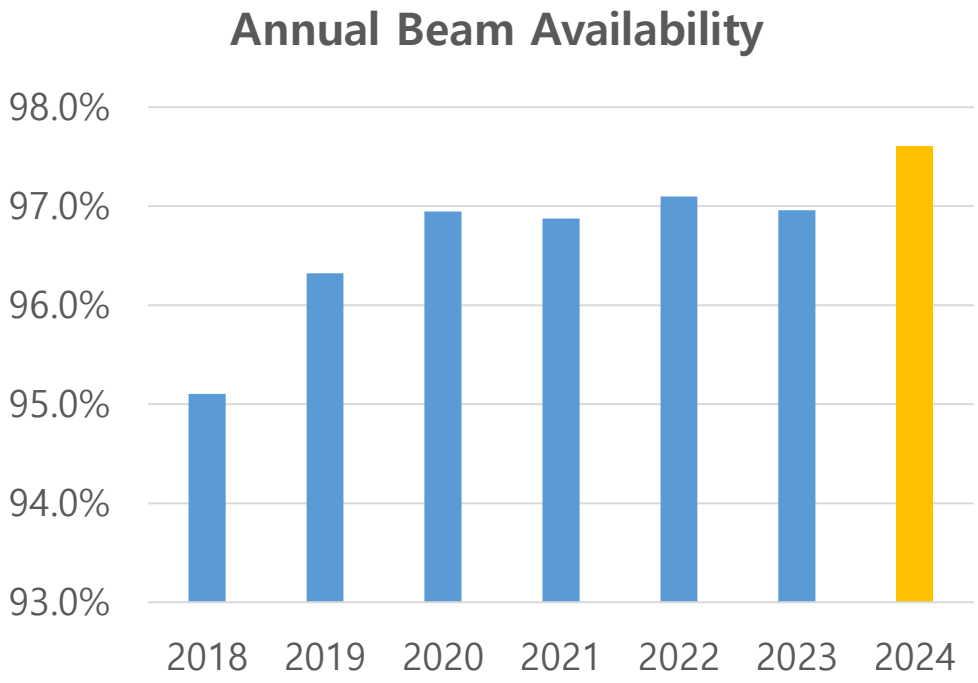
- More than 1 mJ SASE HX FEL is serviced in 2.4 keV~15 keV photon range
- Self-seeding HX FEL is available
- SX FEL pulse energy is around 250 μJ
- HX & SX multi-beamline operation was about 15% of beam service time in 2024

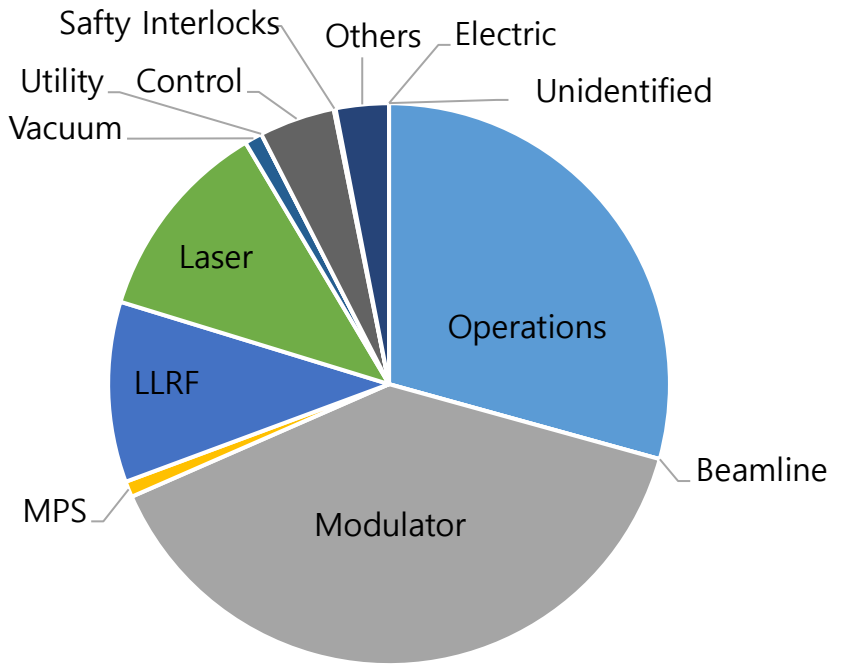




Operation Status (Stability)

- Scheduled beam time : 3489 hour (2024.1.1 ~ 10.31)
- Delivered beam time : 3405 hour (> 97.6%)
- Downtime: 85 hour

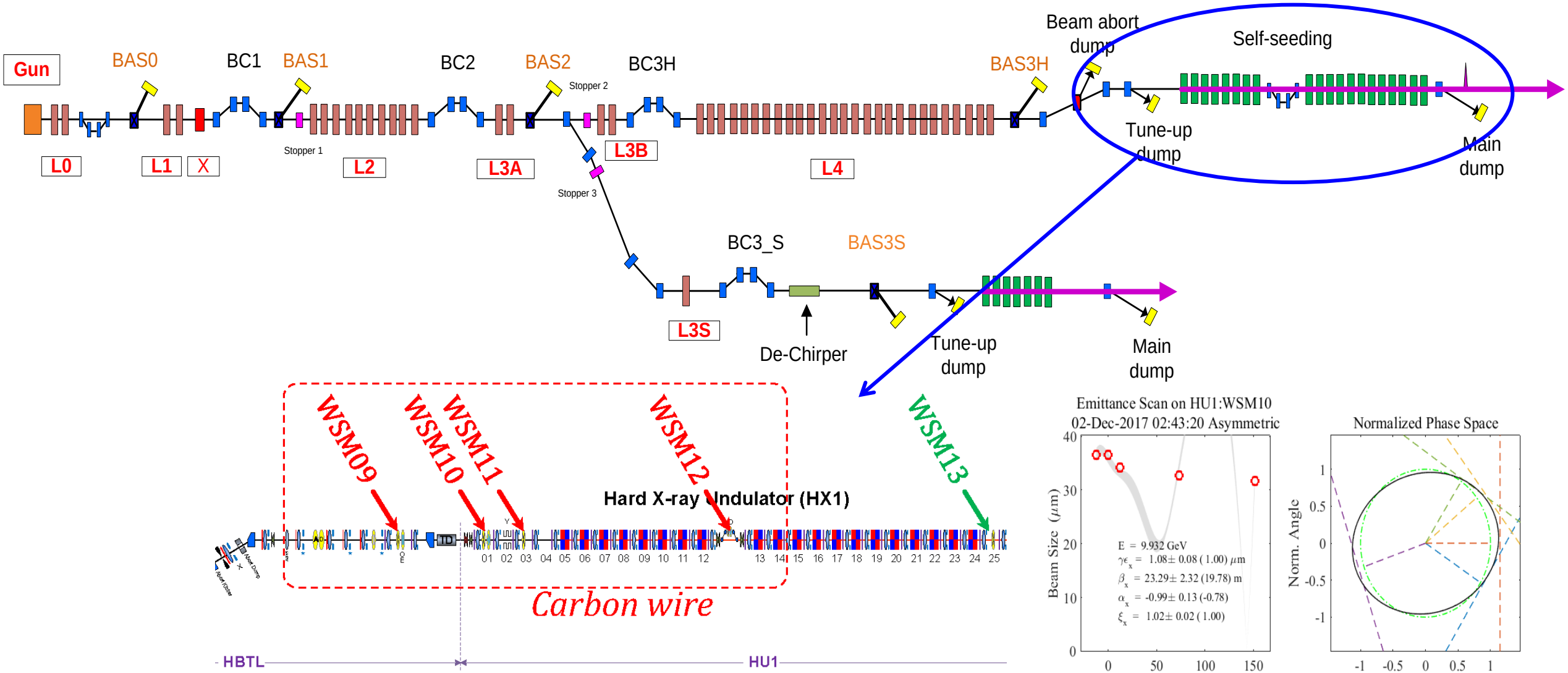




Service Downtime Sources in 2024

PAL-XFEL Machine Upgrade

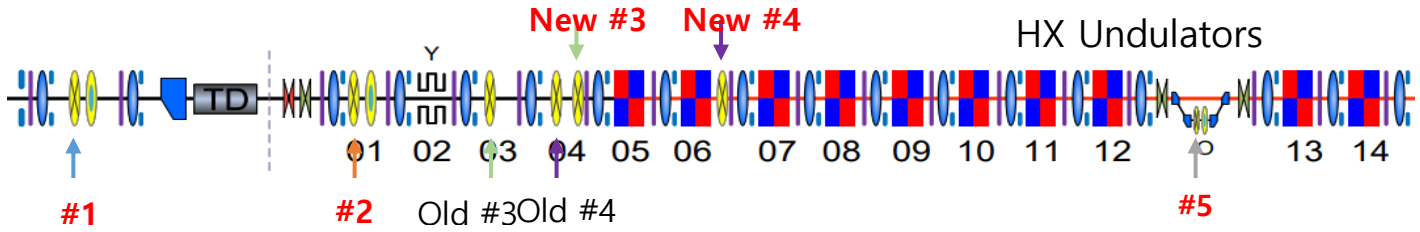
Lattice Matching of PAL-XFEL

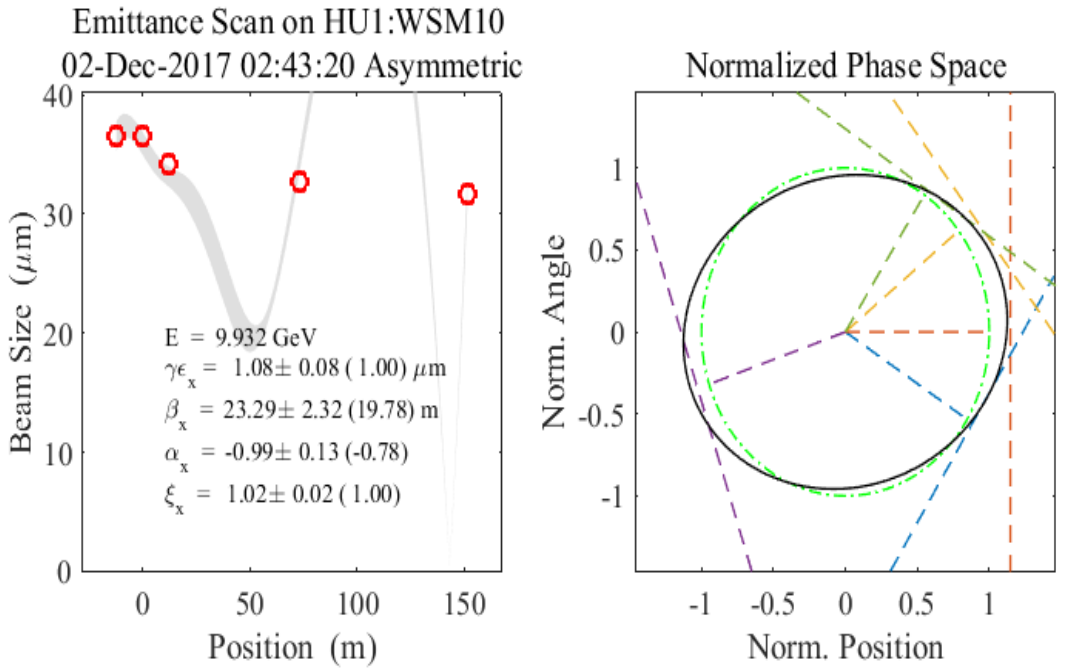


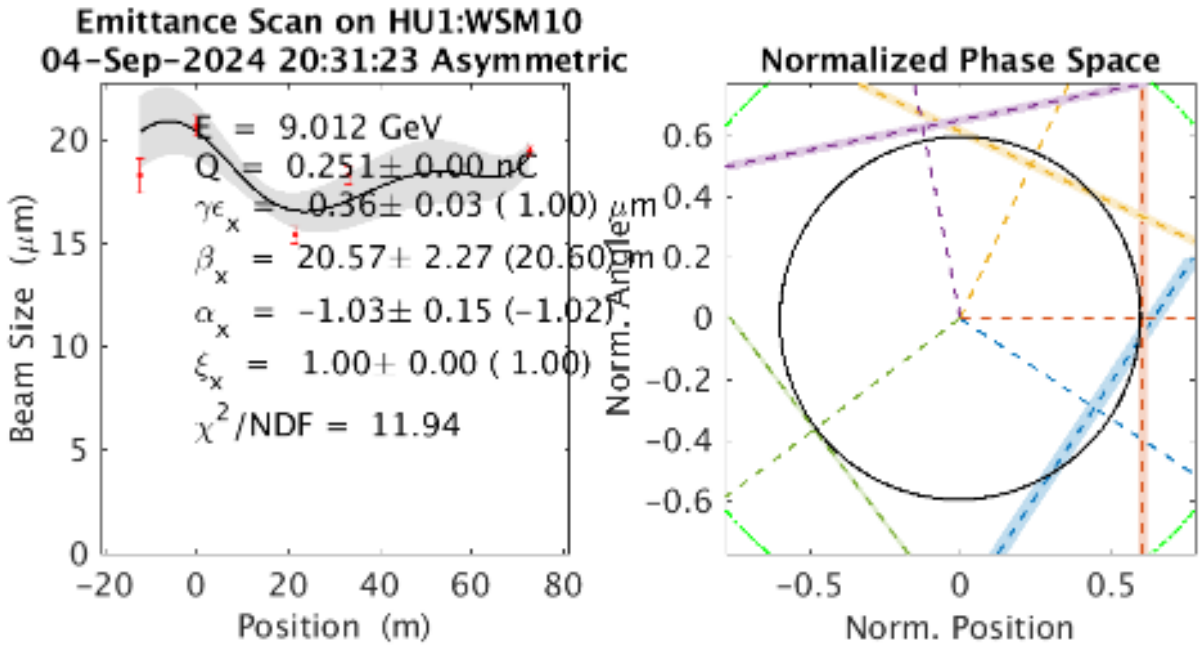
Performance of Moved Wire Scanners

- **Moved wire scanners for HX undulator matching**

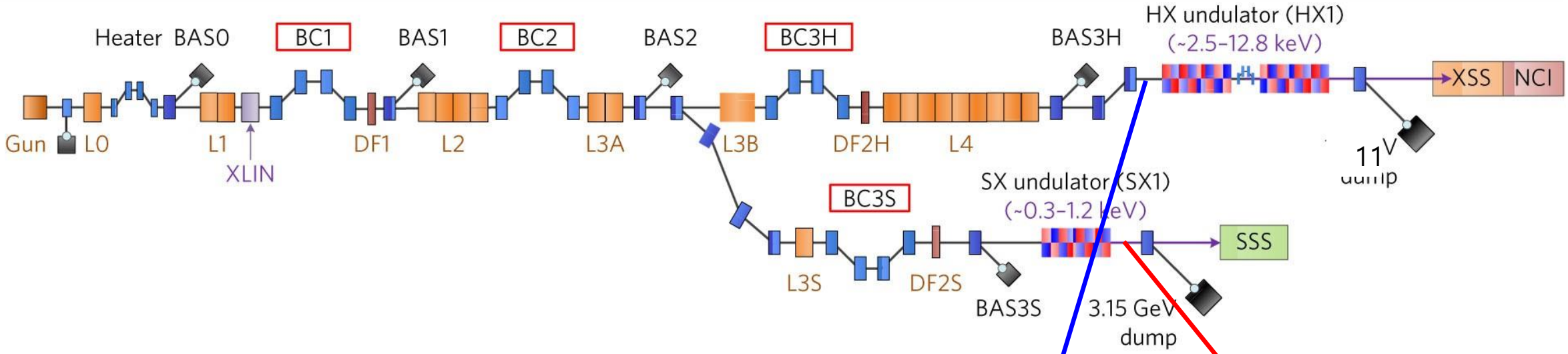
  Beam matching performance with new wire-scanner positions are better than previous scanning positions.





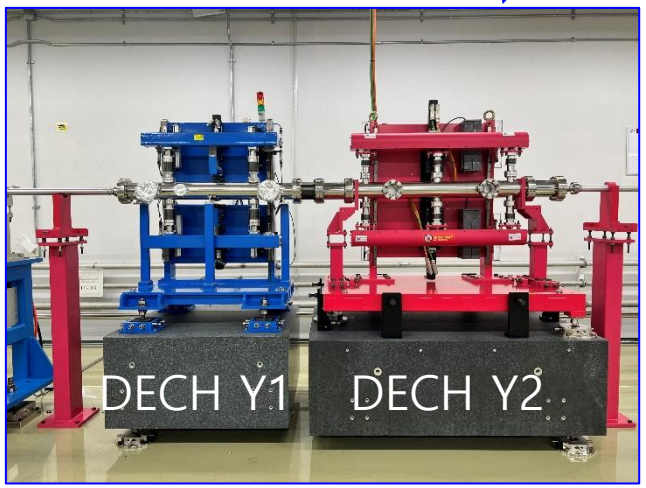


Dechirpers in PAL-XFEL

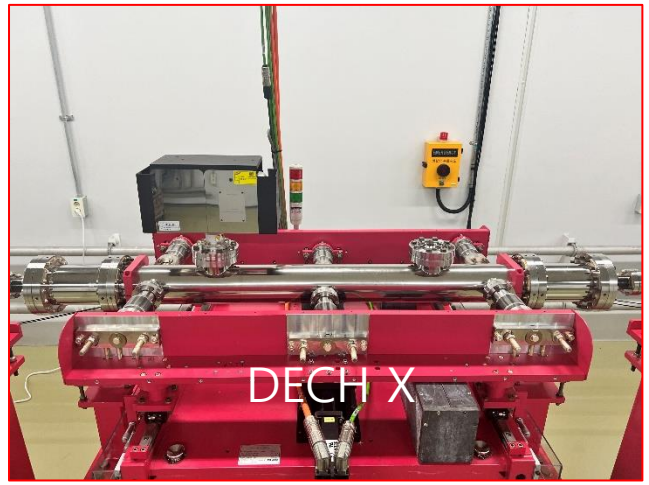


- 2 Dechirpers for HX
  - Undulator upstream
  - Vertically movable flat parallel plate
- 1 Dechirper for SX
  - Undulator downstream
  - Horizontally movable flat parallel plate

Vertically moving

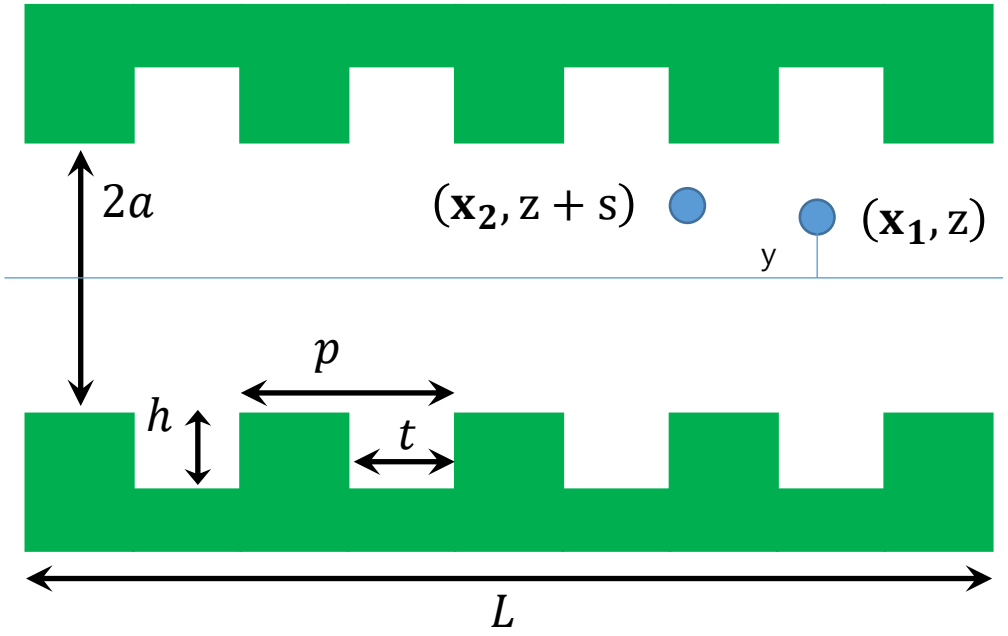


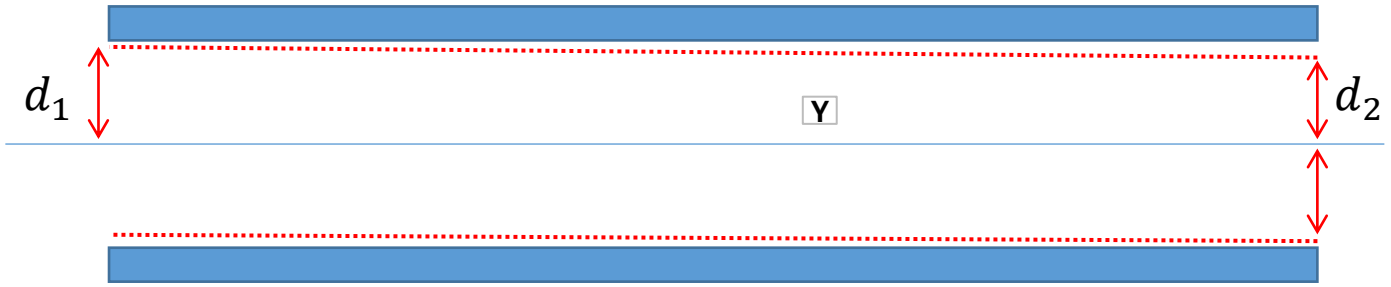
Horizontally moving



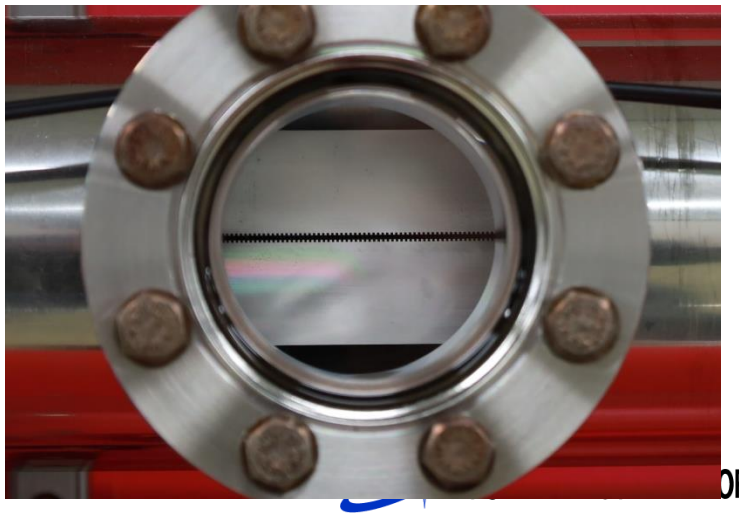
Corrugated Structure of Dechirper

Parameters	DECH Y1 (HX)	DECH Y2 (HX)	DECH X (SX)
L	1 m	1 m	1 m
a_{min}	200 μm	200 μm	200 μm
p	500 μm	1000 μm	1000 μm
h	600 μm	500 μm	500 μm
t	300 μm	500 μm	500 μm
*Flatness	59 μm / 4 μm	23 μm / 23 μm	5 μm / 35 μm





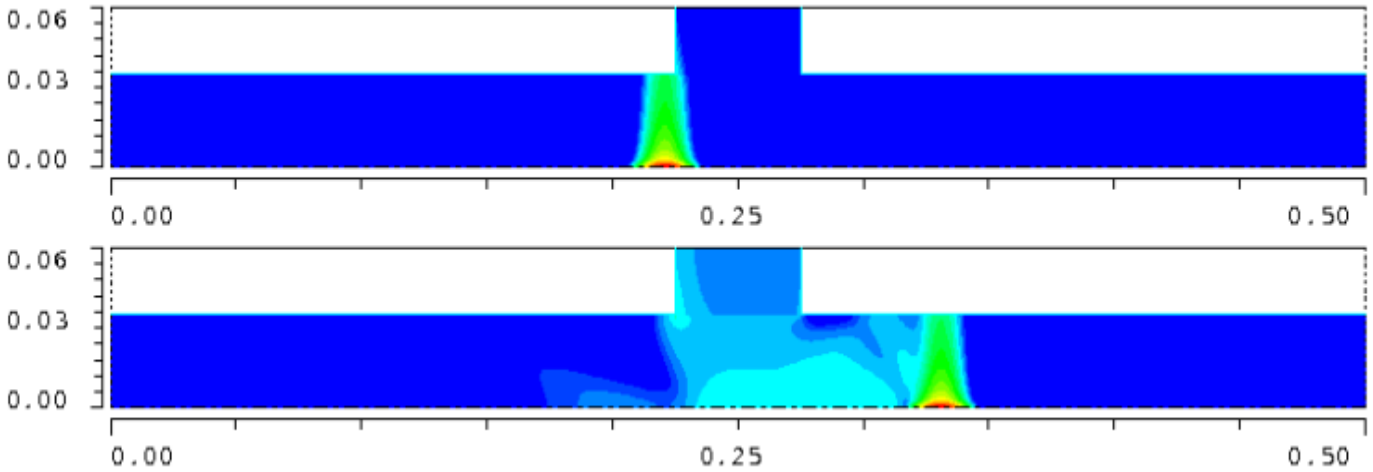
$$*Flatness = (d_1 - d_2)$$



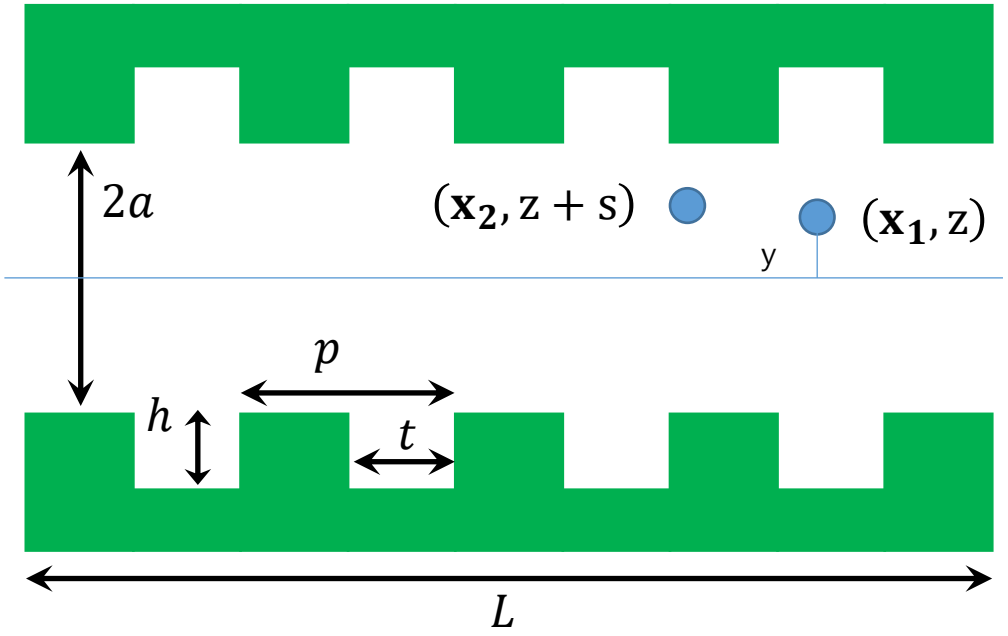
Wakefield from Corrugated Structure

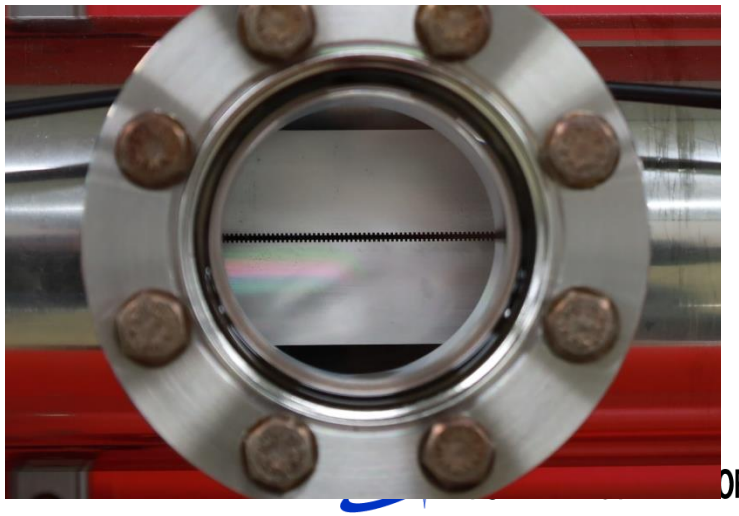
- **Wakefield** is an electromagnetic field generated when a beam traverses a vacuum chamber with a discontinuity
- **Dechirper** is a well-established **wakefield** structure with a periodic discontinuity in a vacuum chamber

$$\mathbf{w}(\mathbf{x_1}, \mathbf{x_2}, \mathrm{s}) = \frac{1}{q_1} \int_{-\infty}^{\infty} \mathrm{dz}\, [\mathbf{E}(\mathbf{x_2}, \mathrm{z}, \mathrm{t}) + c\mathbf{e_z} \times \mathbf{B}(\mathbf{x_2}, \mathrm{z}, \mathrm{t})]_{\mathrm{t}=(\mathrm{s}+\mathrm{z})/c}$$



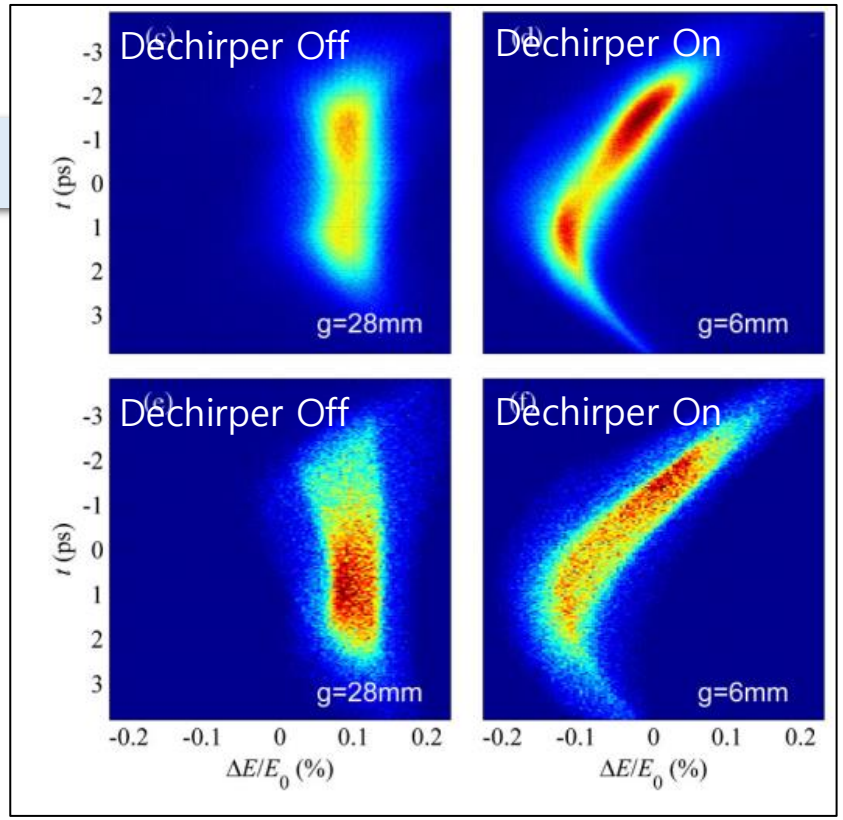
Wake fields in a cavity (figure from *CERN-2017-006-SP, 2017*)





Application of Wakefield

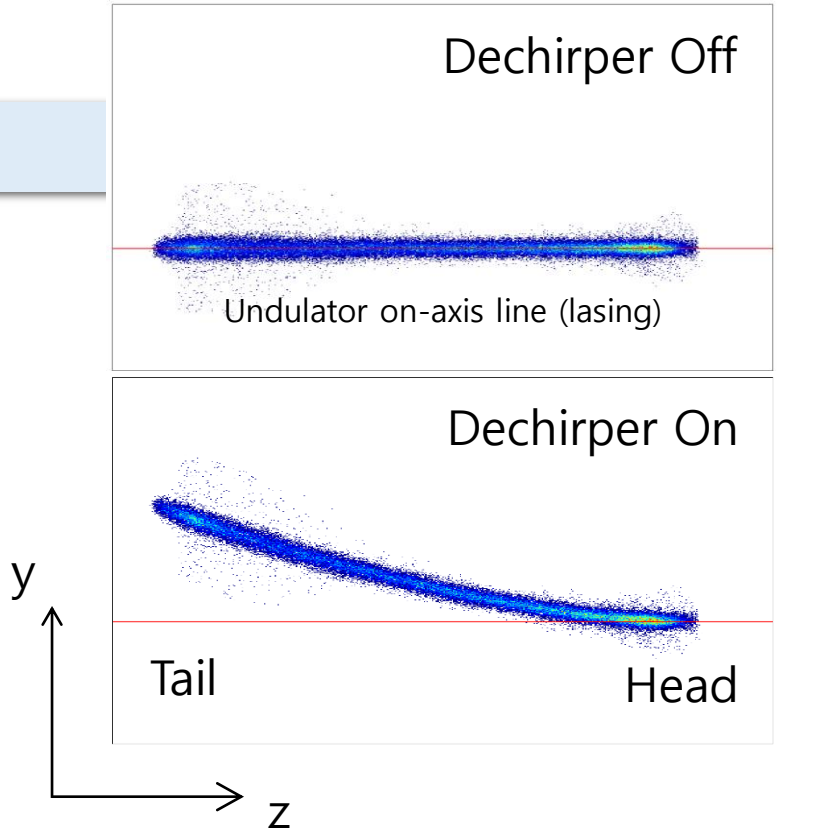
- Longitudinal Wakefield
  - ➢ Control of linear energy chirp
    - ✓ Experimentally demonstrated at PAL-ITF (2014)
- Transverse Wakefield
  - ➢ "Fresh-Slice" technique
    - ✓ Fresh-slice self-seeding
    - ✓ Multi-color FEL pulse generation
    - ✓ Multistage amplification for short pulse high power XFEL generation
  - ➢ Passive deflector (or streaker)
    - ✓ Longitudinal phase space diagnostics and time-resolved FEL power profile



Energy chirp-induced by the longitudinal wakefield by corrugated dechirper
*PRL.**112**,* 034801 (2014)

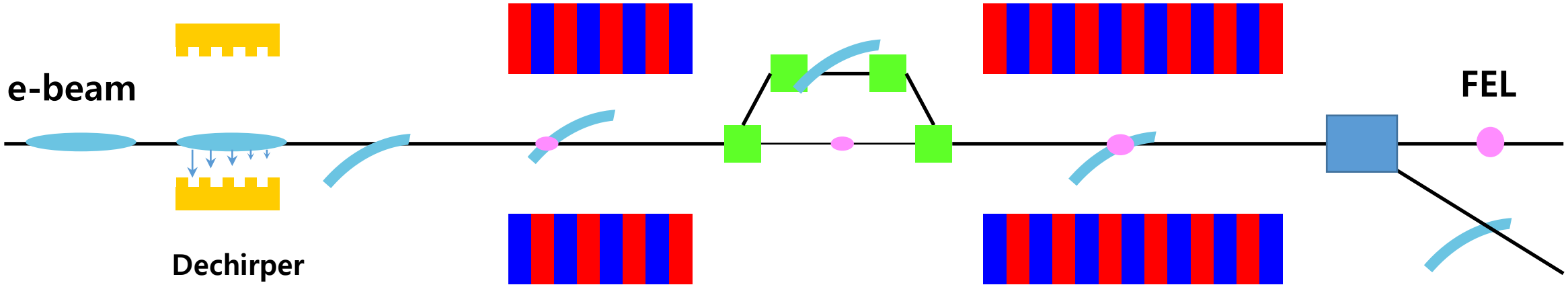
Application of Wakefields

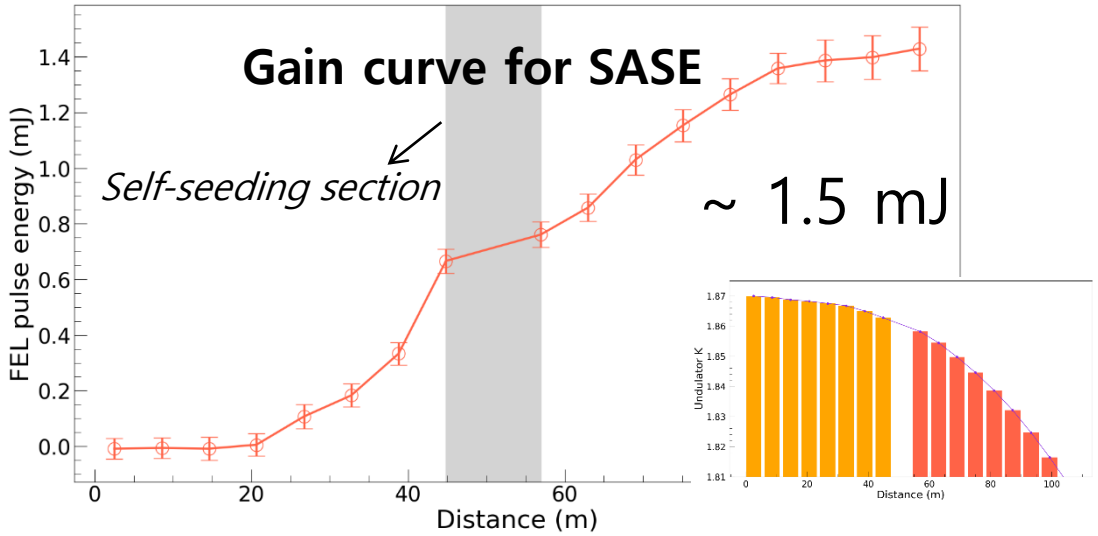
- Longitudinal Wakefield
  - ➢ Control of linear energy chirp
    - ✓ Experimentally demonstrated at PAL-ITF (2014)
- Transverse Wakefield
  - ➢ "Fresh-Slice" technique
    - ✓ Fresh-slice self-seeding
    - ✓ Multi-color FEL pulse generation
    - ✓ Multistage amplification for short pulse high power XFEL generation
  - ➢ Passive deflector (or streaker)
    - ✓ Longitudinal phase space diagnostics and time-resolved FEL power profile

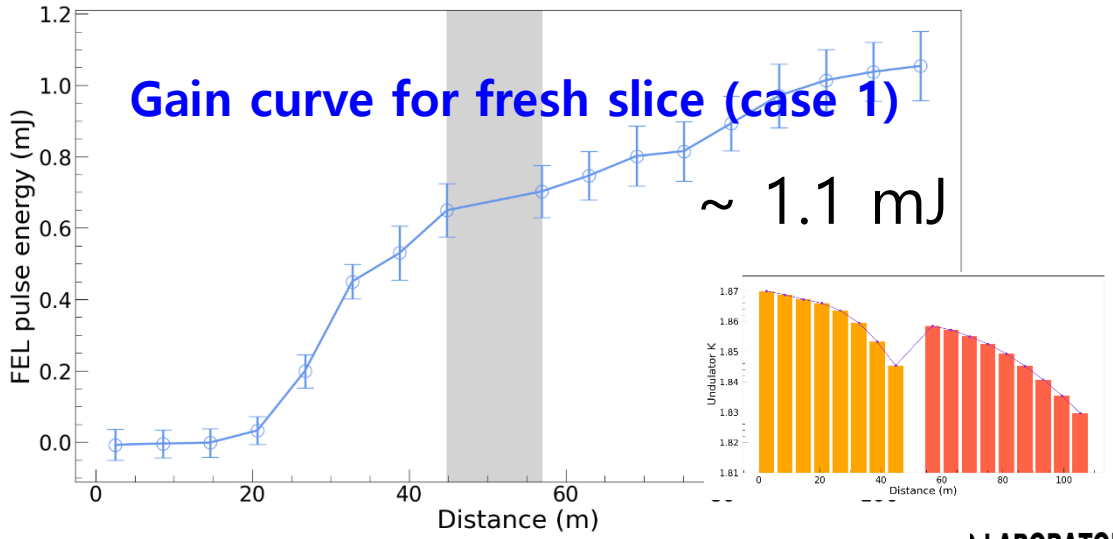


Particle distribution by simulation (elegant)

Measurement Result of Fresh Slice FEL Generation (Hard X-ray)

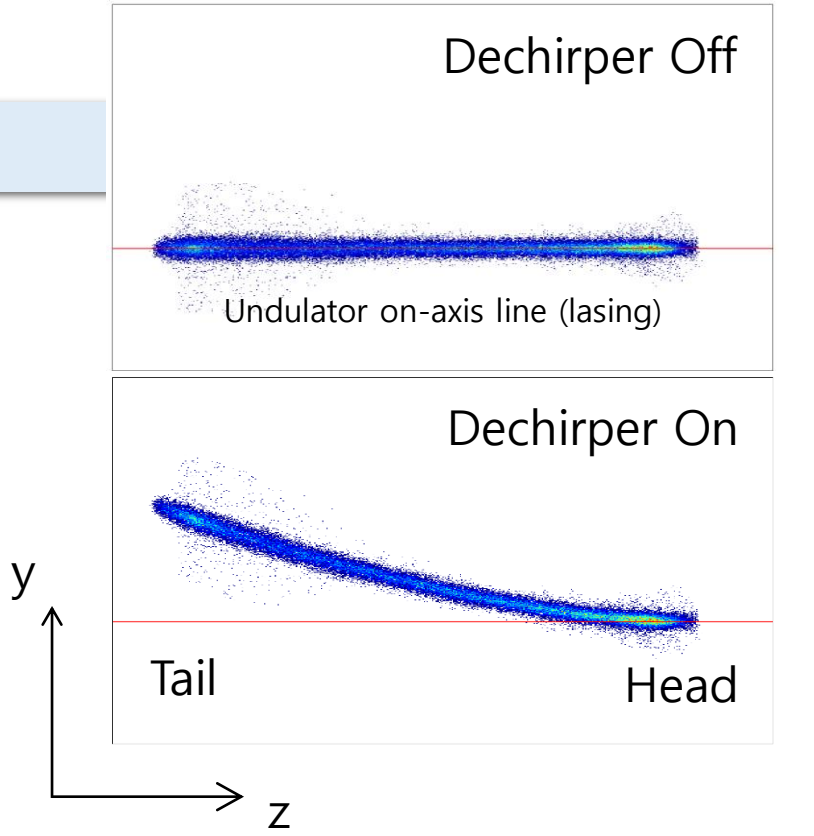






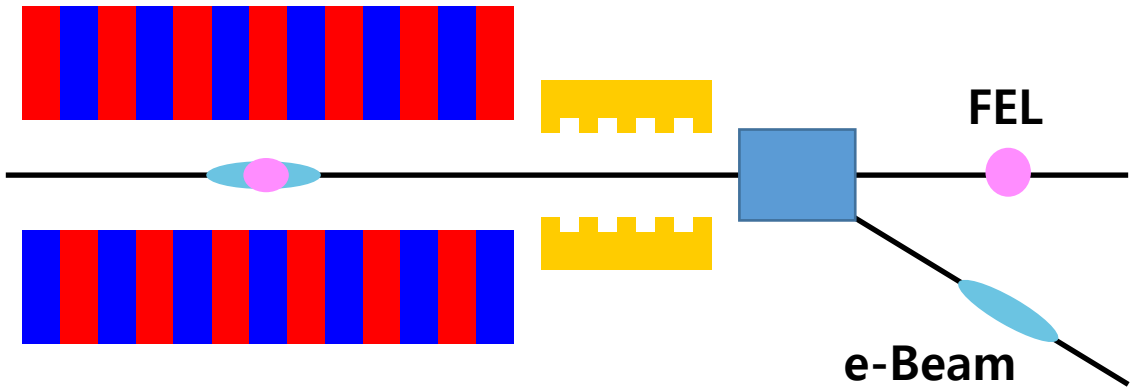
Application of Wakefields

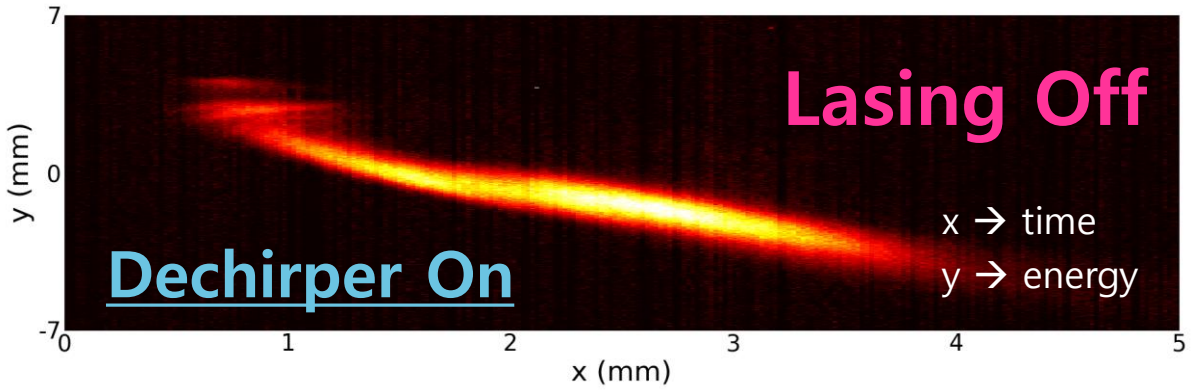
- Longitudinal Wakefield
  - ➢ Control of linear energy chirp
    - ✓ Experimentally demonstrated at PAL-ITF (2014)
- Transverse Wakefield
  - ➢ "Fresh-Slice" technique
    - ✓ Fresh-slice self-seeding
    - ✓ Multi-color FEL pulse generation
    - ✓ Multistage amplification for short pulse high power XFEL generation
  - ➢ Passive deflector (or streaker)
    - ✓ Longitudinal phase space diagnostics and time-resolved FEL power profile

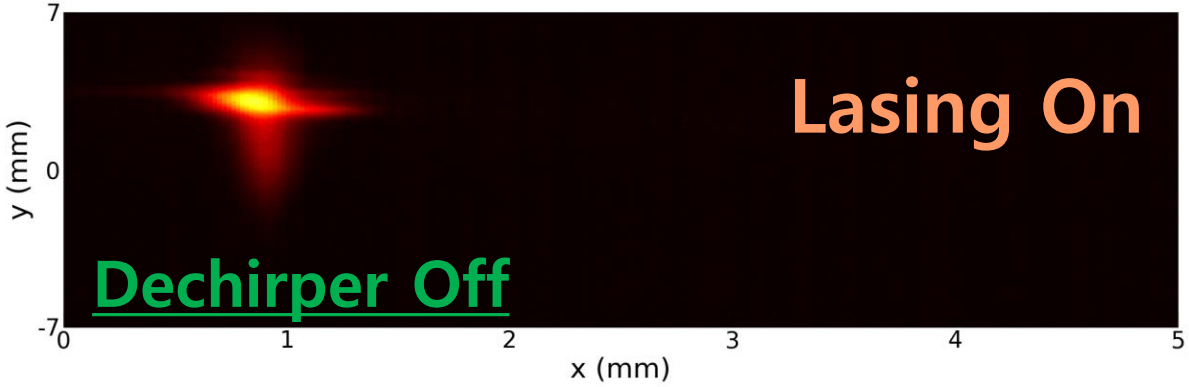


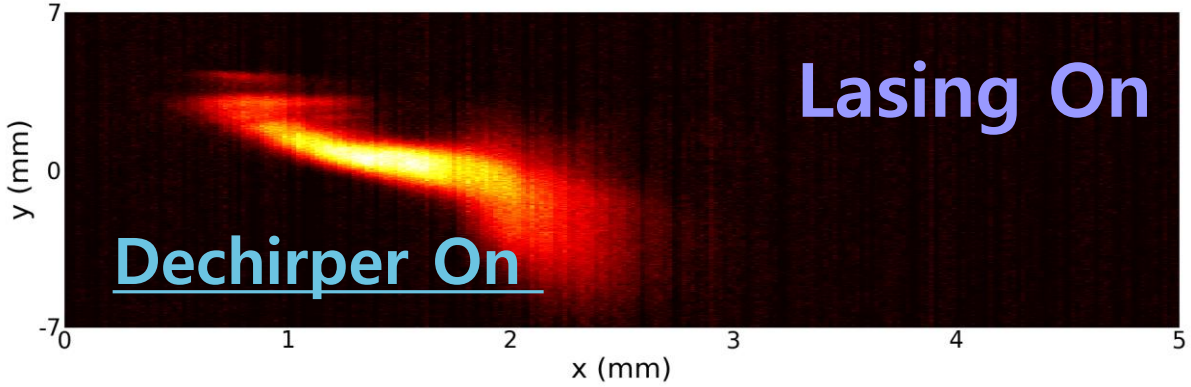
Particle distribution by simulation (elegant)

Measurement Result of Passive Deflector (Soft X-ray)



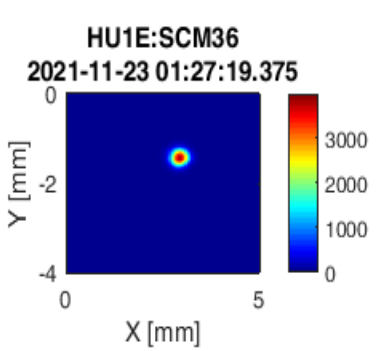


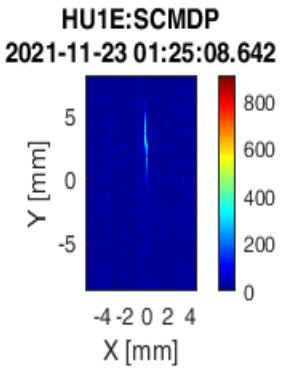




➢ Diagnostics for longitudinal phase space of 2.8 GeV e- beam after lasing on/off

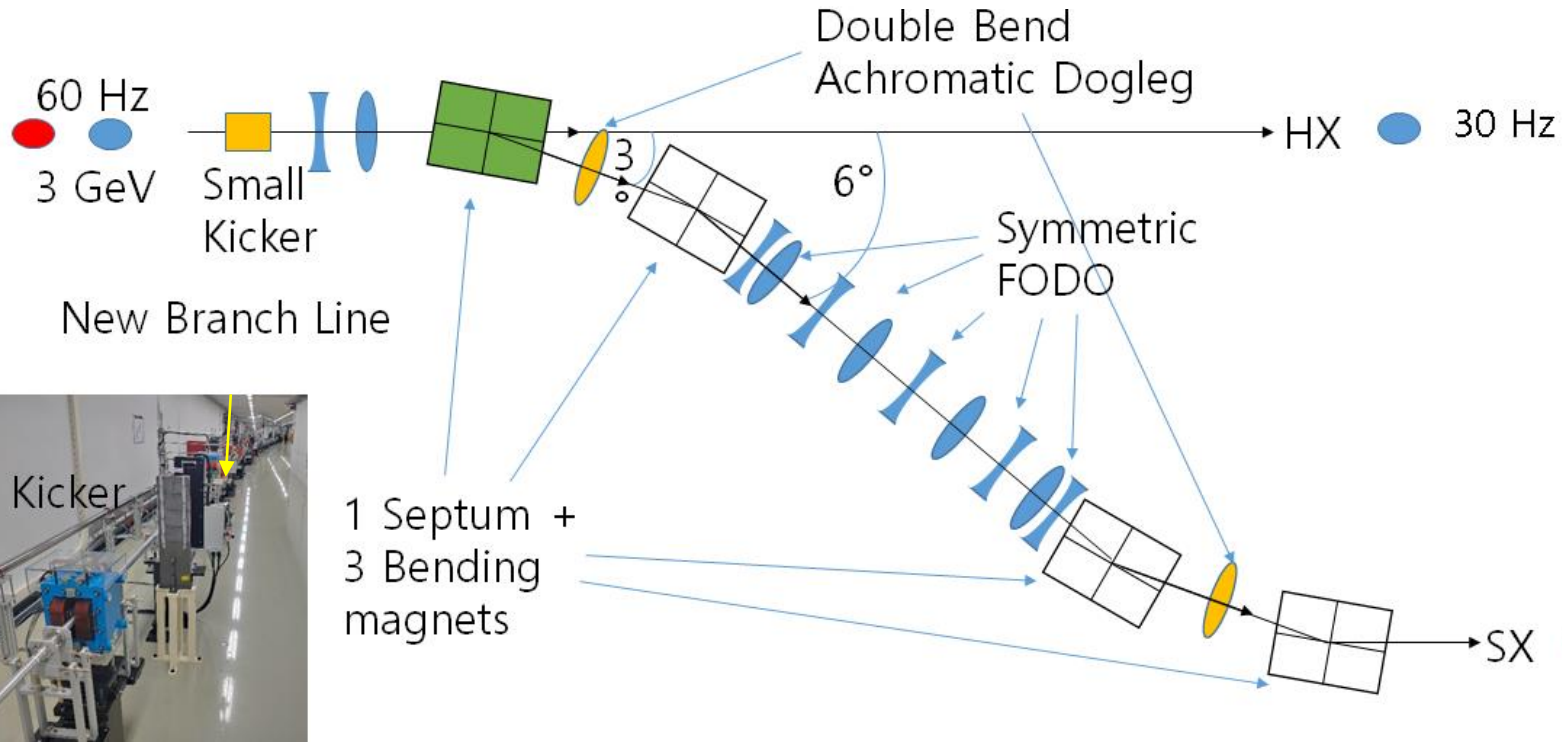
Result of Multi-Beamline Operation (HX and SX)

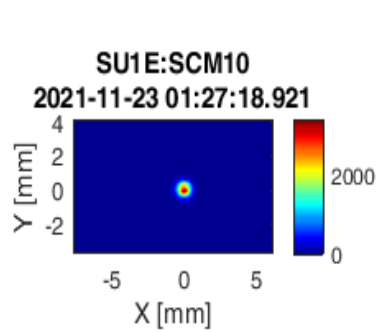


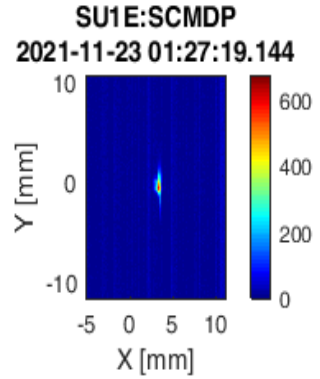


	HX	SX
1	60	0
2	58	2
3	50	10
4	30	30
5	10	50
6	2	58
7	0	60

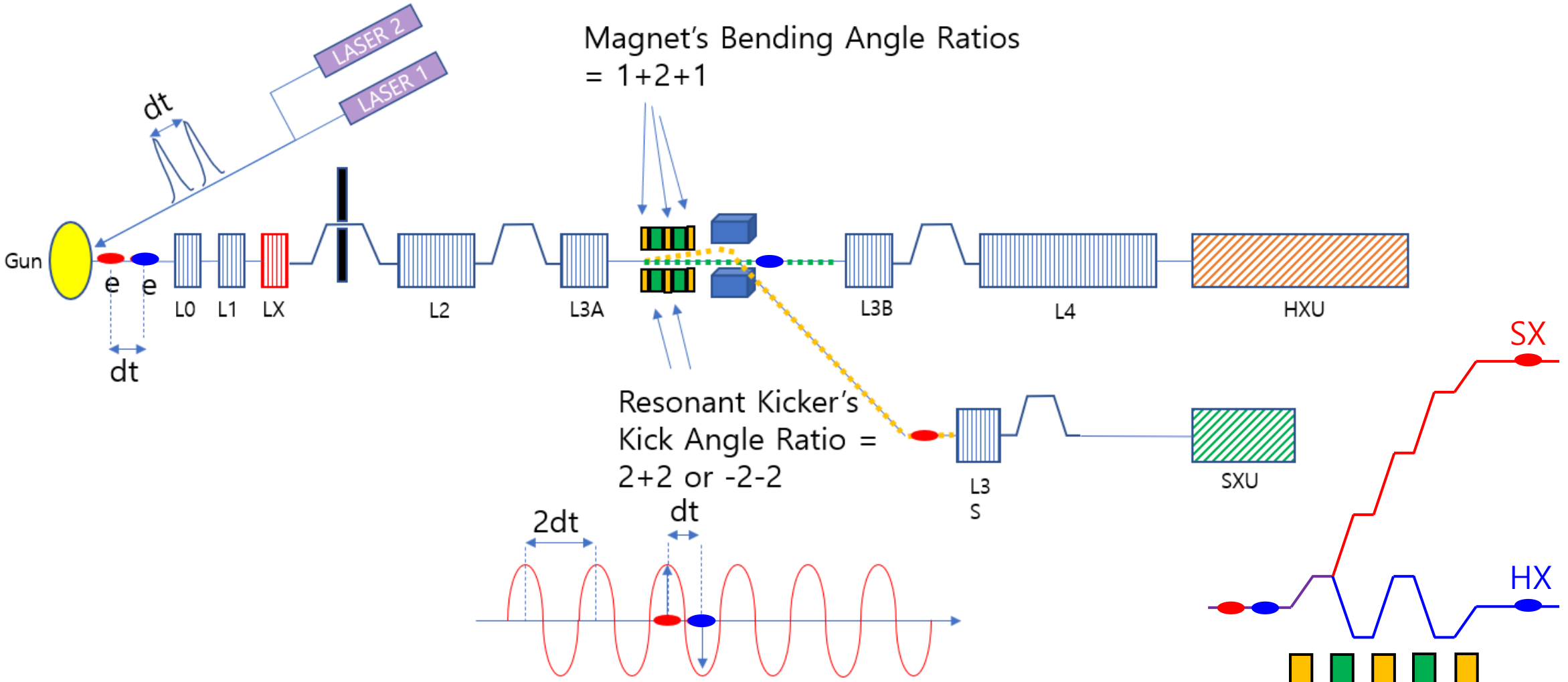
Available configurations (Hz)





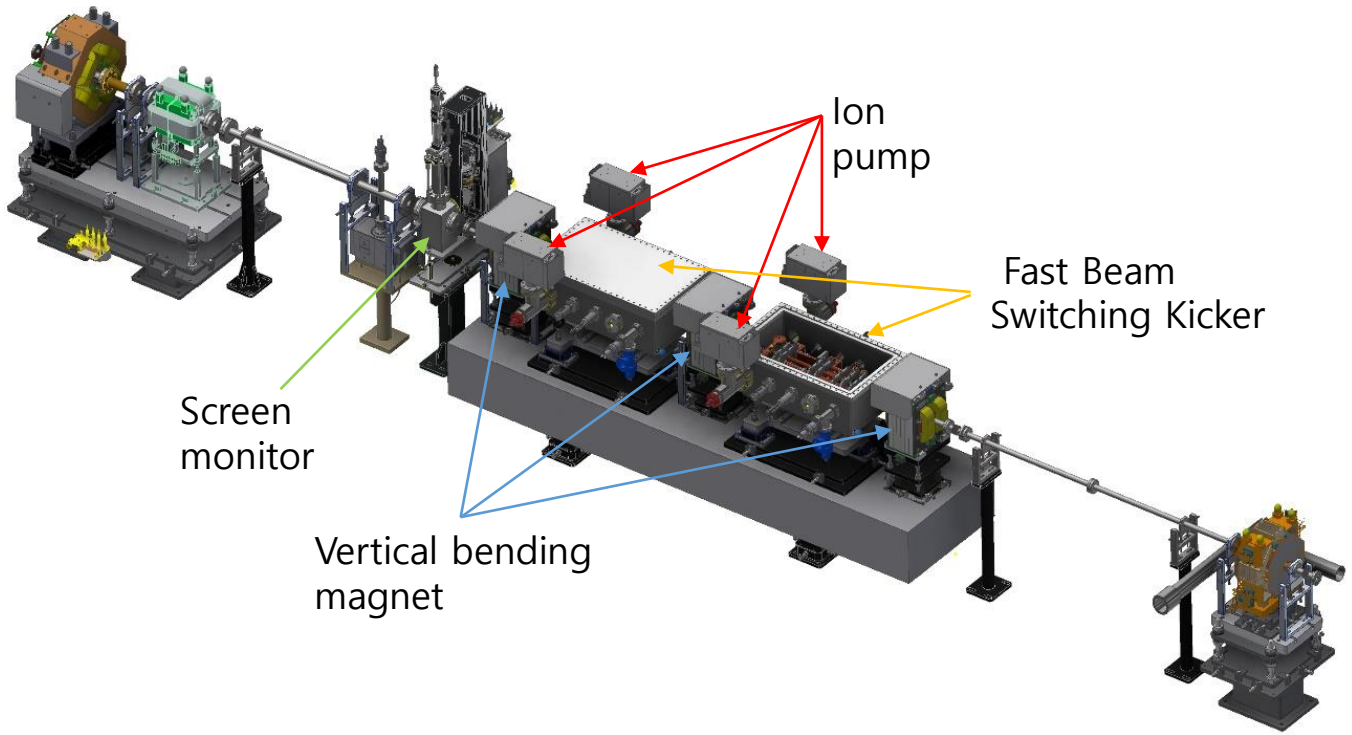


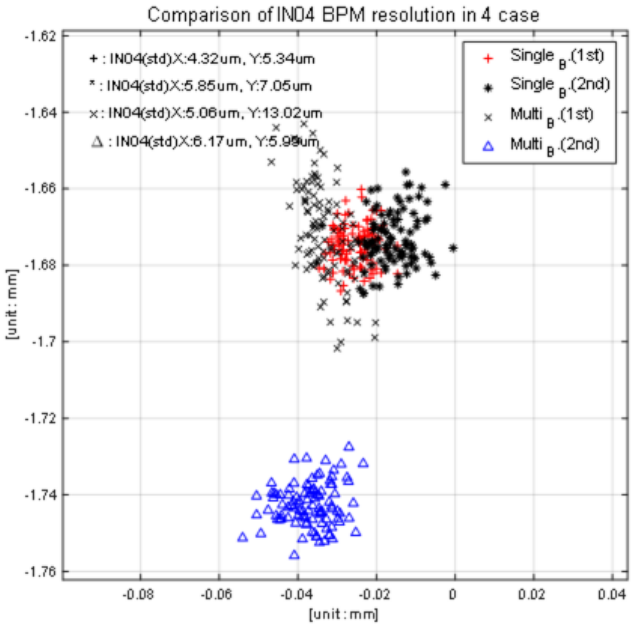
Fast Resonant Kicker



Status of 60 Hz Multi-Beamline Operation

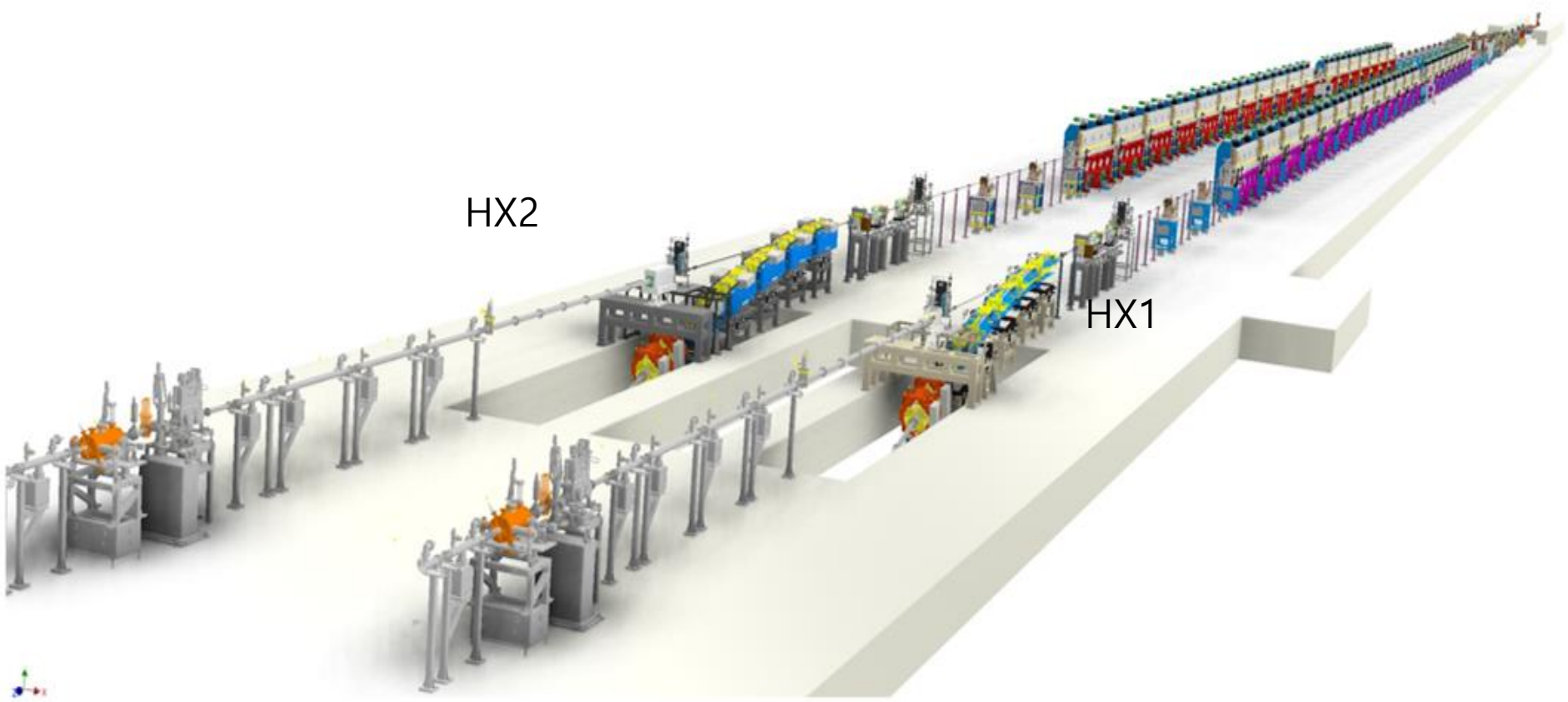
- Physics design of fast resonant kicker has been finished
- Preliminary tests with BPM electronics for double bunch have been finished



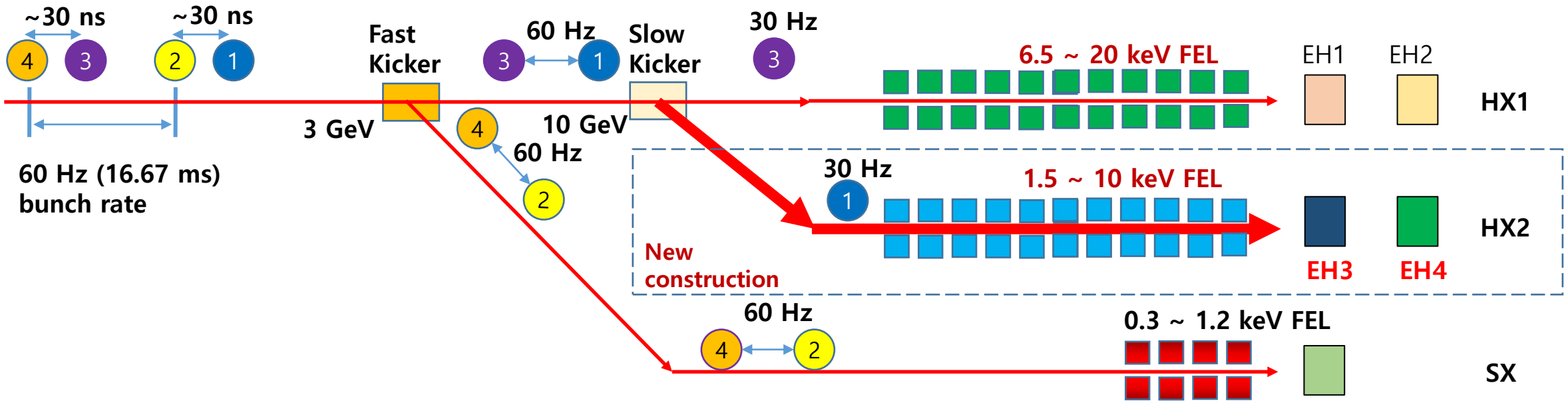


2nd Hard X-ray Undulator Line in PAL-XFEL

- Continuously discussing with the government to realize 2nd Hard X-ray undulator line project
- Also PAL-XFEL's SX undulator line upgrade is planning, considering HX2 project

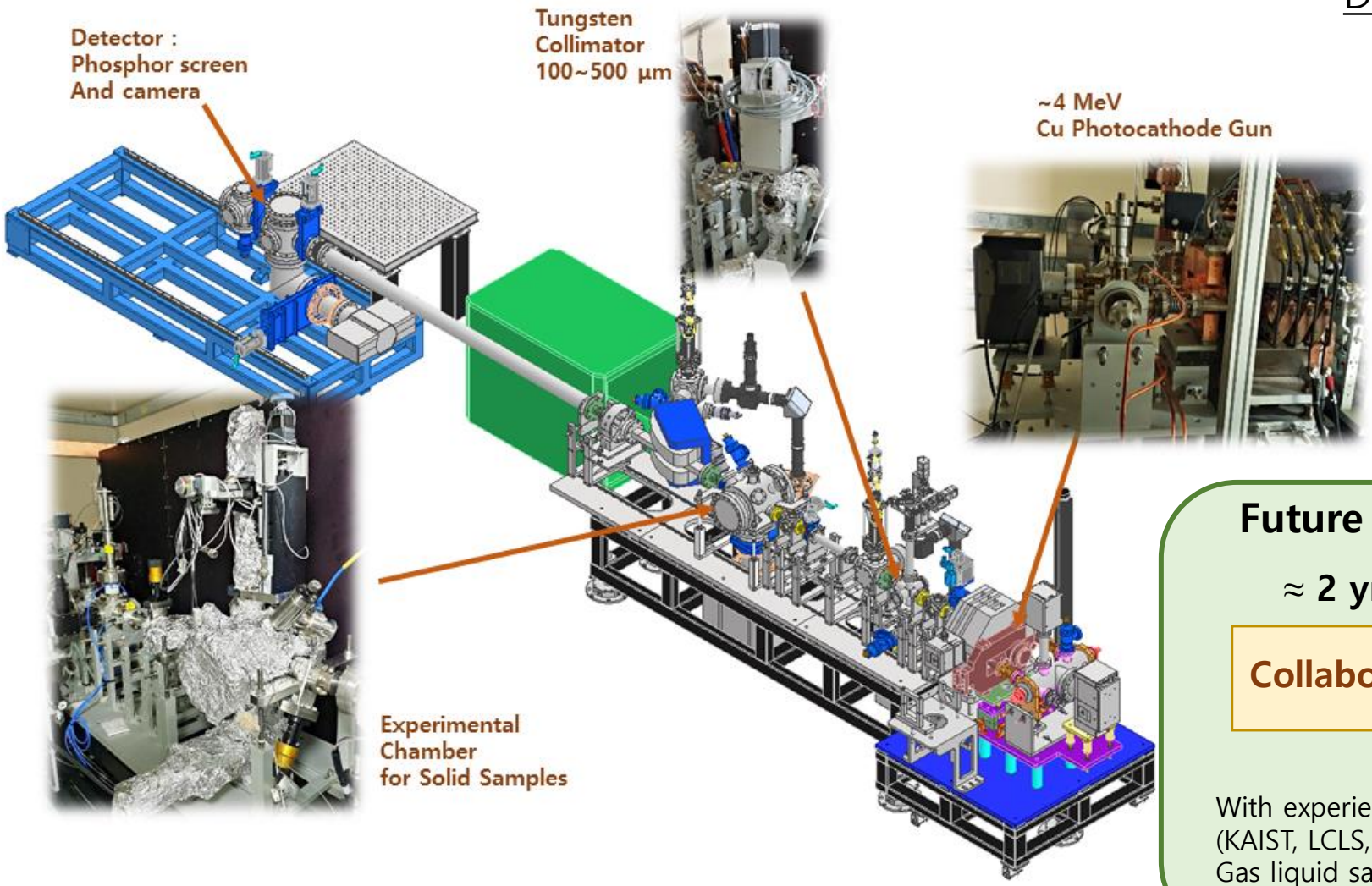


Multi-Beamline Operation of HX1, HX2, and SX

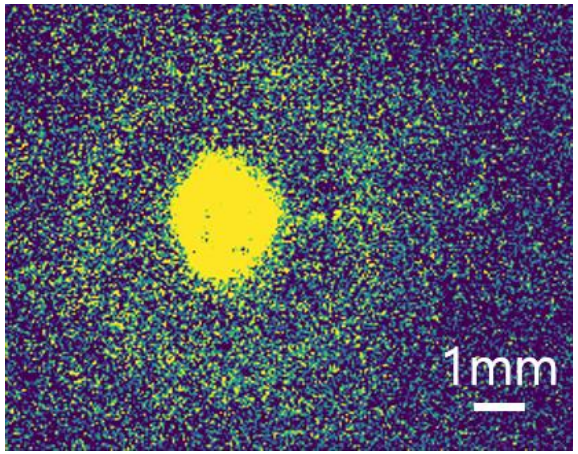


- HX2 allows…
  - An increased acceptance rate of HX user experiments with higher user demand.
    (Broaden XFEL user base and Attracting new users)
  - Dedicated and specialized science programs of the PAL-XFEL.
  - To operate 3 independent FEL lines (HX1, HX2 & SX) through the multi-beamline operation mode.
    (Increased user beamtimes of all FEL lines as a result)

Status of MeV Ultrafast Electron Diffraction



Diffraction pattern of Al foil (3 MeV e-)



Future Plan

≈ 2 yr	≈ 3 yr	≈ 3 yr
Collaboration	**Early User**	**Upgrade & User exp.**
With experienced groups (KAIST, LCLS, KAERI, …) Gas liquid sample capabilities etc.	Optimized setup and sample (low temp. gas, liquid etc.)	Major upgrade (Sample chamber, RF…)

Thanks to:

All members of PLS-II and PAL-XFEL