0.1 nm Hard X-ray Lasing of PAL-XFEL

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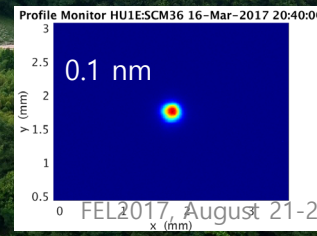
PAL-XFEL

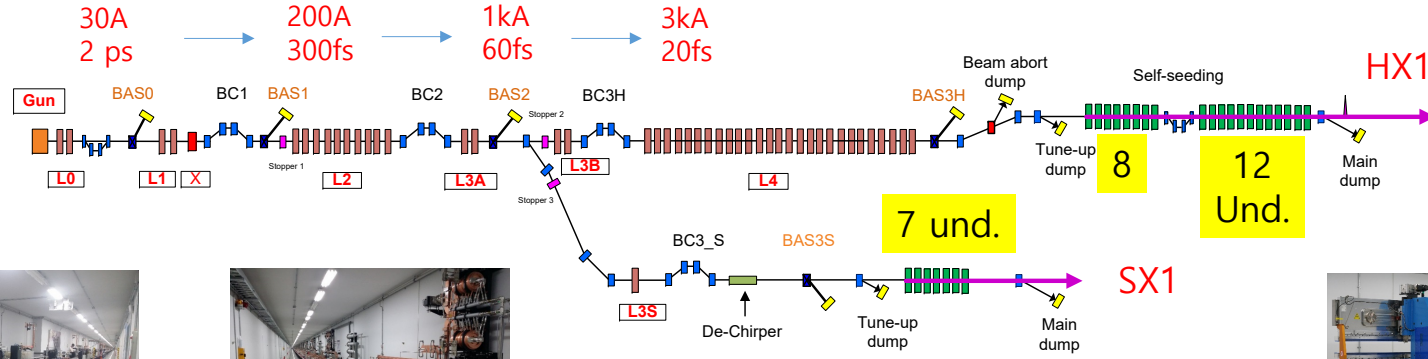
0.1 nm hard X-ray FEL using a 10 GeV normal conducting linac

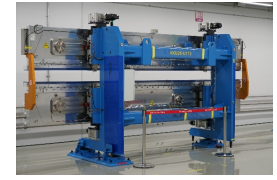
Apr. 2011: PAL-XFEL project started
Jun. 2012: Ground-breaking
Dec. 2014: Building completed
Jan. 2016: Installation completed
Apr. 2016: Commissioning started
Jun. 2017: User-service started



- **14 Jun. 2016 First SASE lasing at 0.5 nm**
- **28 Oct. 2016 Lasing at 0.15 nm**
- **27 Nov. 2016 Saturation of 0.15 nm**
- **16 Mar. 2017 Saturation of 0.1 nm**

PAL-XFEL Parameters



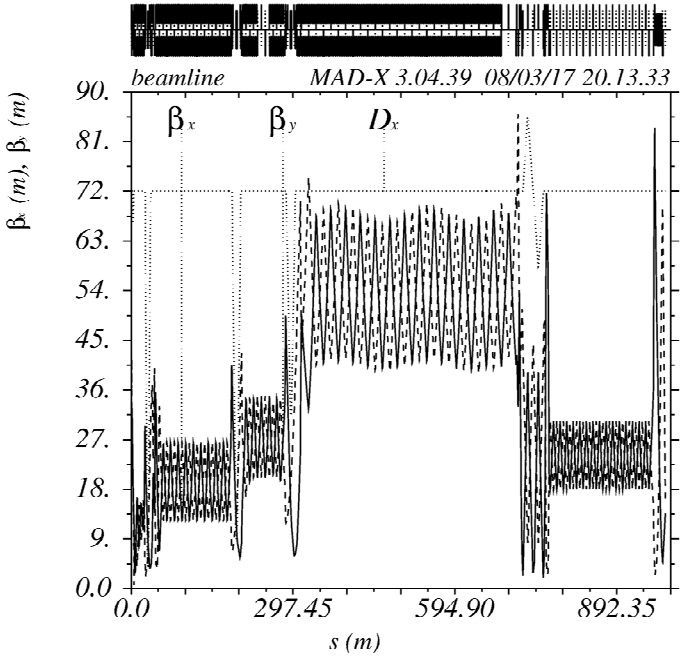


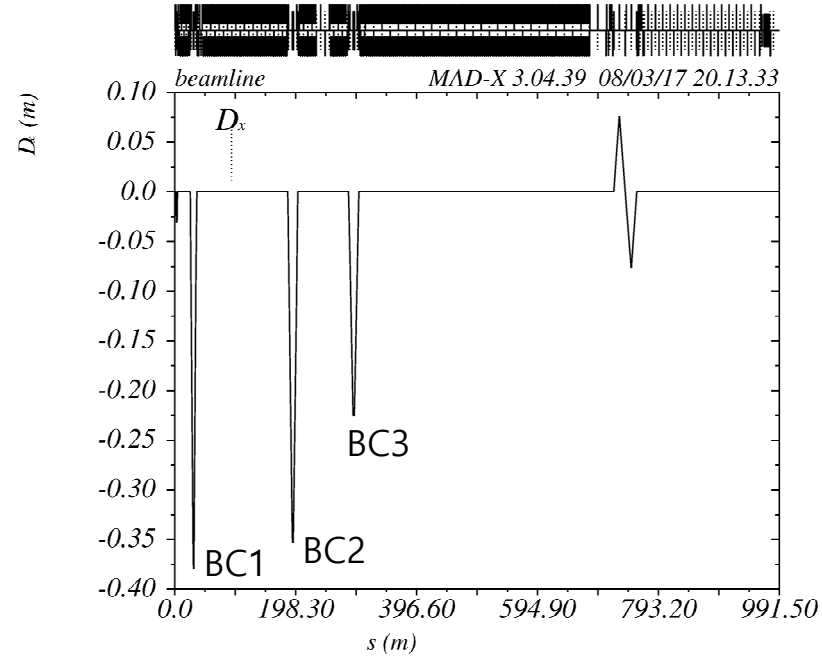
Main parameters

e⁻ Energy	10 GeV
e⁻ Bunch charge	20-200 pC
Slice emittance	< 0.5 mm mrad
Repetition rate	30 Hz (60 Hz)
Pulse duration	10 fs – 100 fs
Peak current	3 kA
SX line switching	DC (Phase-1) Kicker (Phase-2)

Undulator Line	HX1	SX1
Wavelength [nm]	0.1 ~ 0.6	1 ~ 4.5
Beam Energy [GeV]	4 ~ 10	3.15
Wavelength Tuning [nm]	0.6 ~ 0.1 (energy or gap)	4.5 ~ 3 (energy) 3 ~ 1 (gap)
Undulator Type	Planar, out-vac.	Planar
Undulator Period / Gap [mm]	26 / 8.3	35 / 8.3

Three Bunch Compressor Lattice



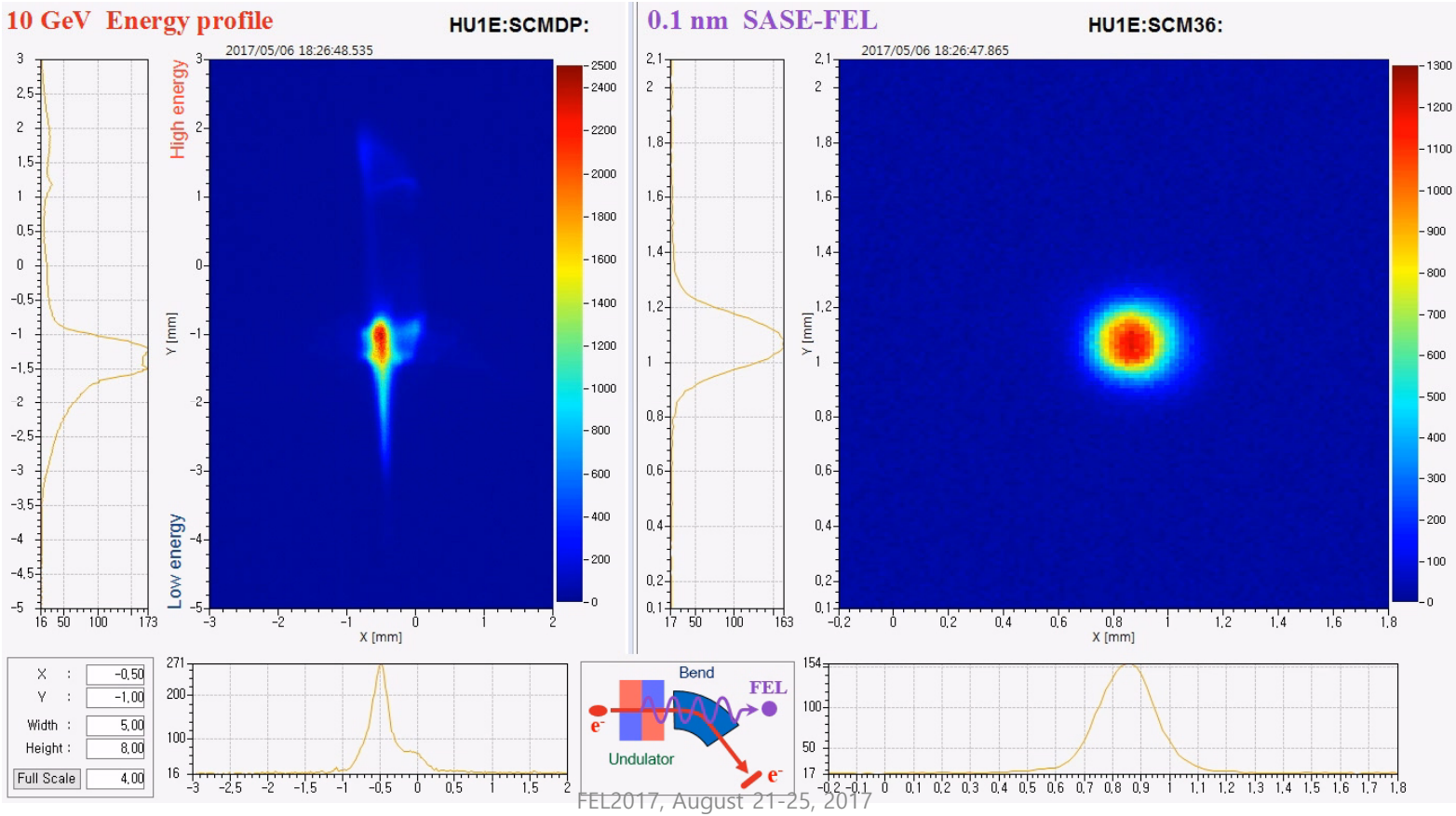


Klystron Gallery

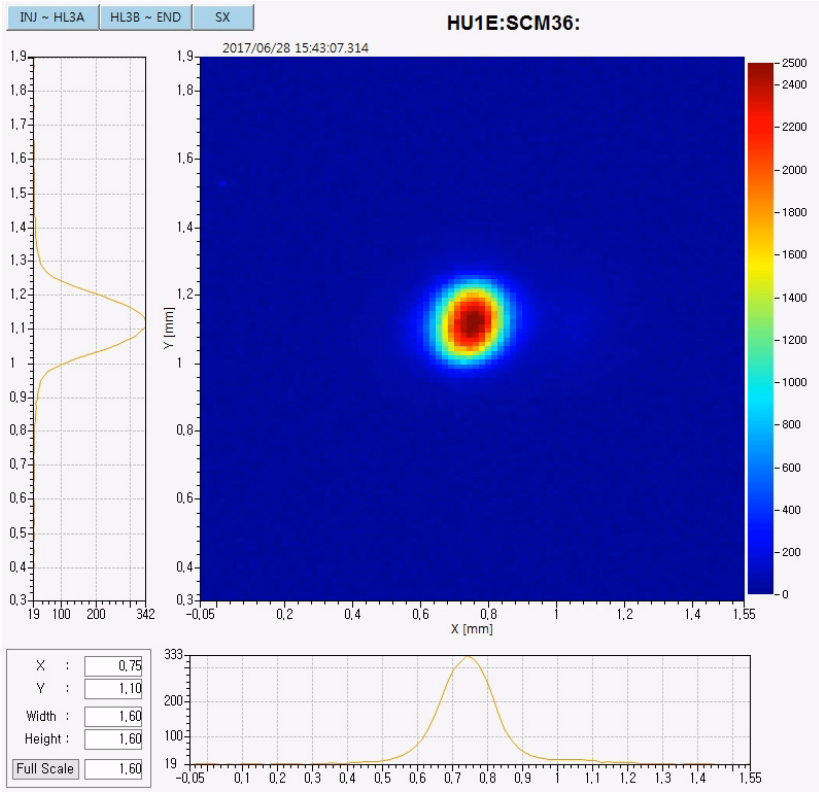
Linac Tunnel

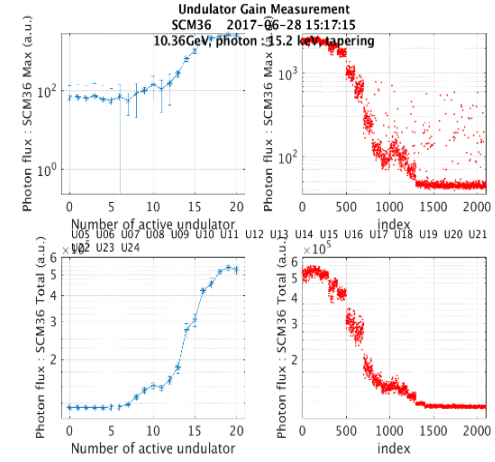
Undulator Hall

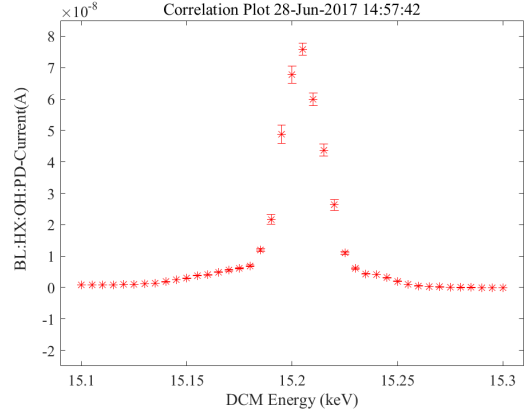
Stability of 0.104 nm FEL



Lasing of 15.2 keV FEL (2017. 06. 28)



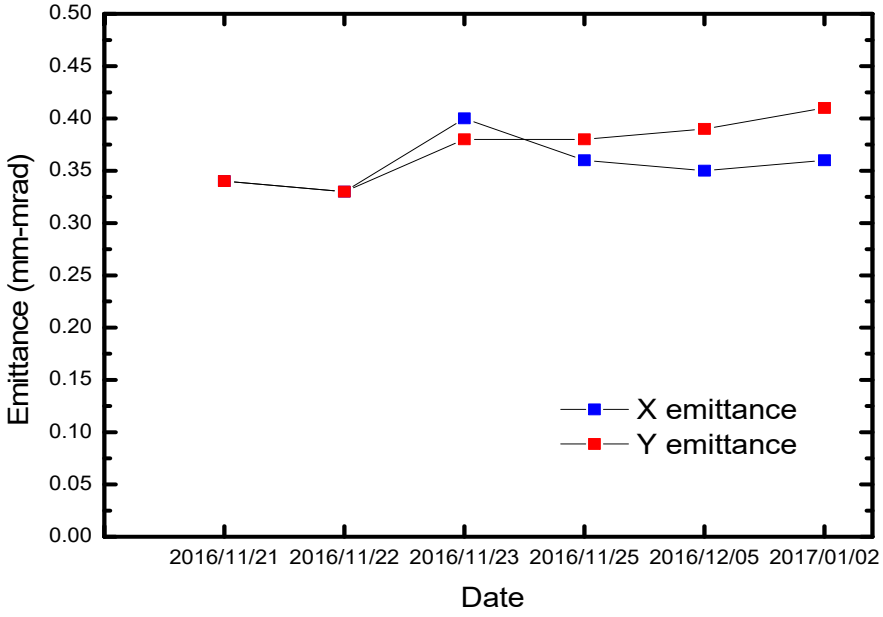




Beam Operation Status

- Undulator BBA is routinely applied
  - E-beam-based BBA for dispersion free orbit
  - undulator radiation spectrum analysis for undulator's gap distance and midplane height
- Three bunch compressor operation
  - During the FEL commissioning, two BCs were used
  - Since 2 June 2017, three BC scheme is a normal operation mode.
  - Improve the jitter performances; energy, position, and arrival time
- User service operation started from this June
  - Hard X-ray beamlines are in service
  - Soft X-ray beamlines are still in commissioning, will be available for user service operation this September
  - 30 Hz FEL beam is provided. A 60 Hz operation is scheduled in early next year

Injector Emittance (Projected)

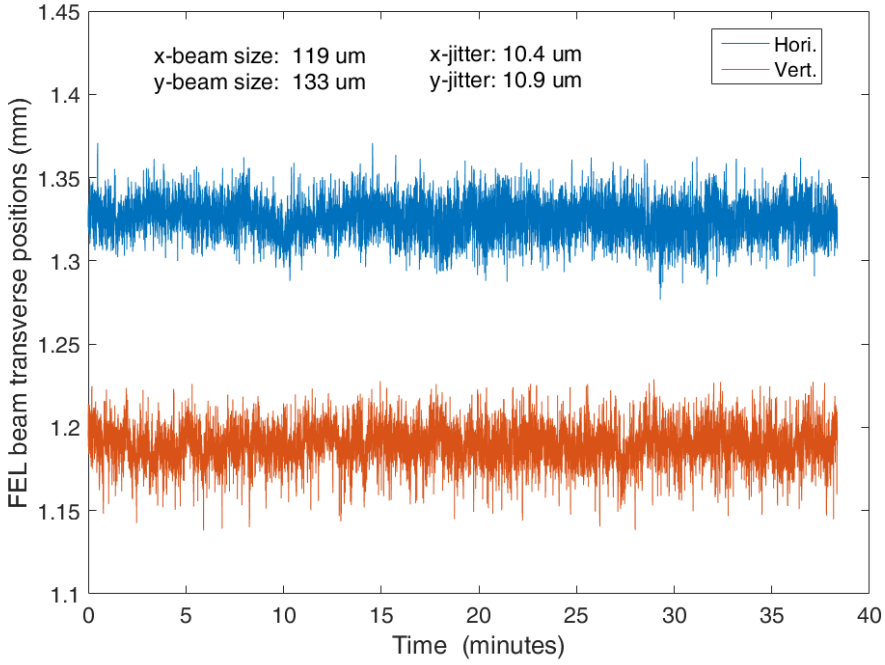


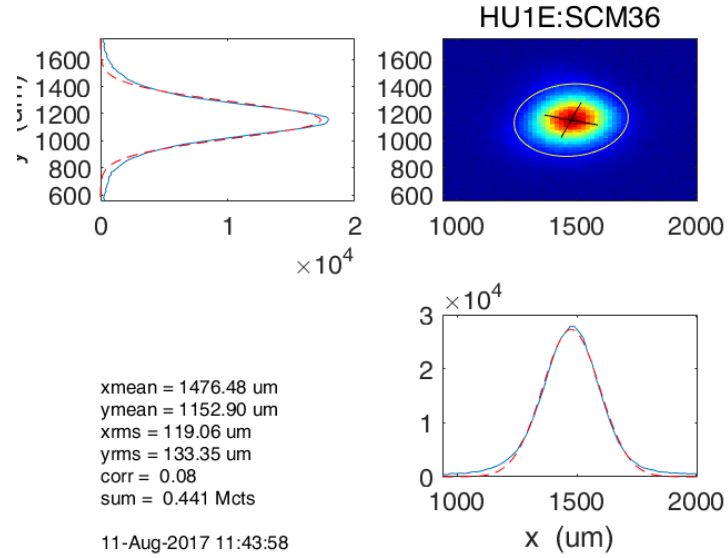
- Beam change at the injector: 220 pC
- Beam energy: 135 MeV

- The beam charge is reduced to 150 pC by BC1 collimator

FEL beam position jitter (3-BC operation)

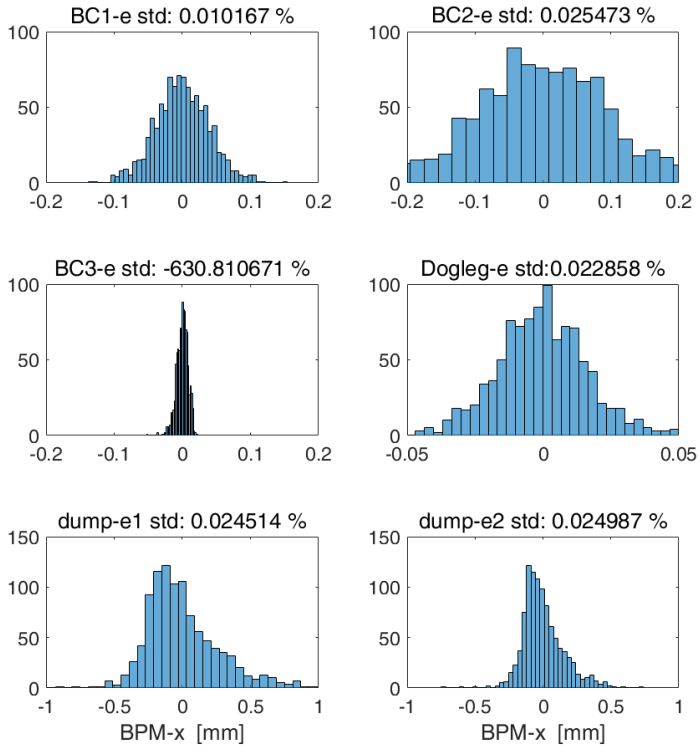
(measured at a 40-m downstream YAG-screen from last undulator)



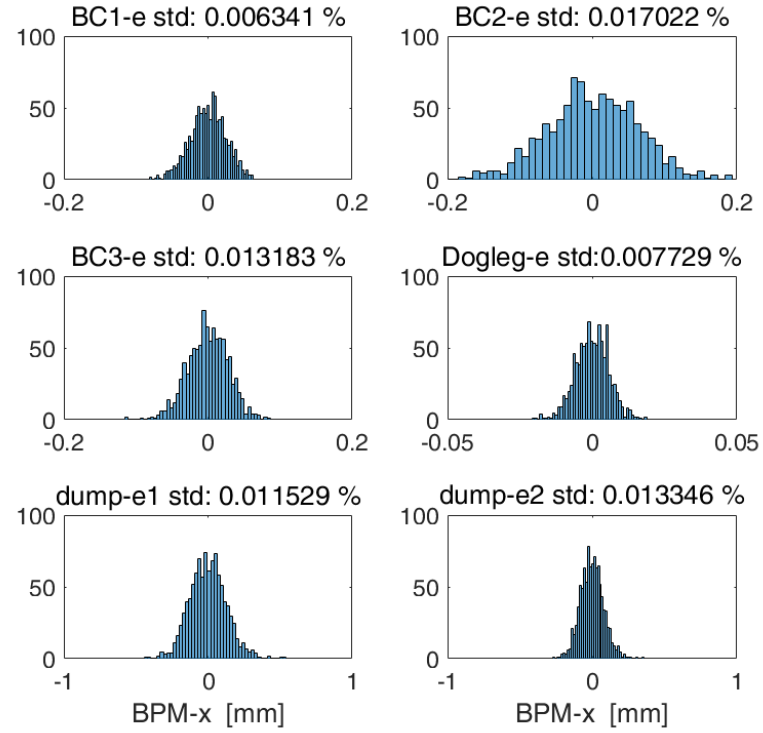


E-beam energy jitter

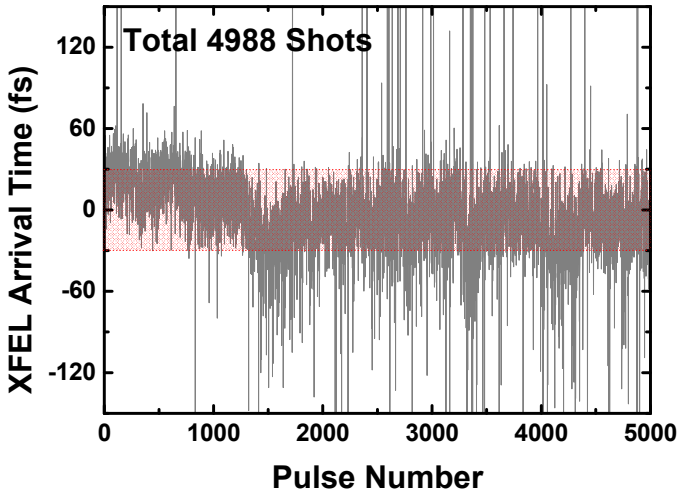
2 - BCs

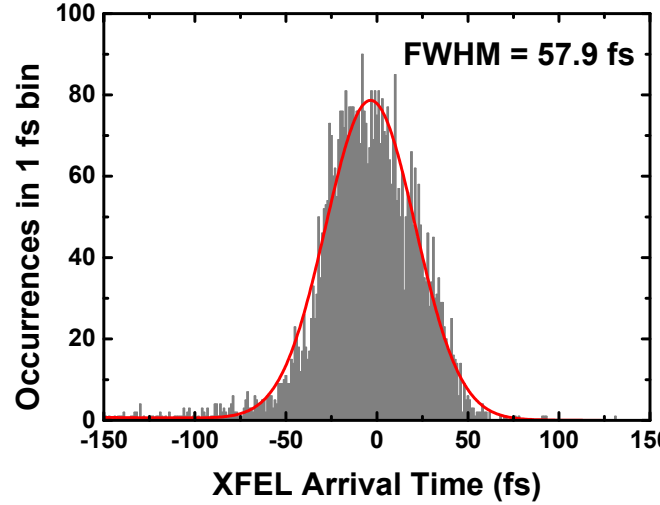


3 - BCs



Optical Laser – XFEL Arrival Time Measurement





Optical Laser

Wavelength = 800 nm
Pulse Width = 100 fs

XFEL

Energy = 5.223 keV
Pulse Width < 20 fs
Unfocused Beam

Interaction Material

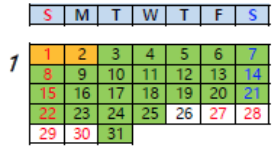
Si_3N_4 2 mm

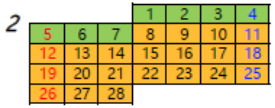
1. Optical Laser – XFEL Arrival Time Jitter Characteristics

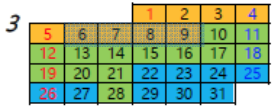
PAL-XFEL Beamline

- Photon energy: 2.8~12.9 keV
- Beam lines: 3 hard 2 soft X-ray beamlines (~80 m)

Beamline Machine Study & User Service Schedule of 2017







User Beam Time : 120 days
Machine Study : 123 days
Maintenance : 109 days

8/09-8/11 야간 : SSS Instrument Test
8/12-8/13 주간 : KB Mirror Alignment (5-6 keV)
8/14-8/19 (6) : 송창용 (EH2, No Laser, 5-6 keV)
8/21-8/26 (6) : 김경완 (EH1, 800nm, 8-10 keV)

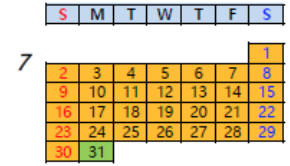
9/07-9/09 주간 : SFX@NCI (8-10 keV)
9/11-9/12 주간 : EH2 Laser setup Test
9/13-9/18 (6) : Ian Robinson (EH2, 266nm, 8-10 keV)
9/20-9/25 (6) : 김태규 (EH2, 400nm, 2.8 keV)

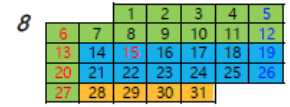
4/24 (9.7 keV) - 4/25 (2.8 keV) 주간 : Optics alignment
4/24-4/27 (2.5 - 3.0 nm) 야간 : SSS Instrument Test
4/26 (5.0 keV) - 4/27 (6.0 keV) : Timing Tool Test
4/28-5/01 (5-6 keV) : FXS@XSS Instrument test 김현정 & 송상훈; DAQ test & GMD Test

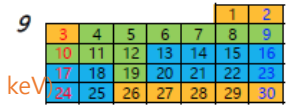
5/10 (8.7 keV); 5/11-5/12 (11.2 keV); 5/13-5/15 (8.7 keV) : FXS@XSS PreEXP 박제근1, 김범준2, 이수형3
5/17-5/22 (8.7 keV) : SFX@NCI PreEXP; GMD Test

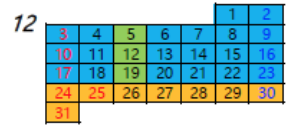
Official start of user service operation

6/04-6/06 : KB Mirror Alignment (8-10 keV)
6/14 ~ 6/23 야간: HX-EH1,2 이용자 지원 지장 없는 내에서 SSS Instrument test
6/07-6/12 (6) : 김경환 (EH2, No Laser, 8-10 keV)
6/14-6/19 (6) : 김현정 (EH1, 800nm, 8-10 keV)
6/21-6/27 (3,4) : 이효철, 김정호 (EH1, 400nm, 8-10 keV)









Summary

- PAL-XFEL was successfully commissioned and has started its user service operation since June 2017.
- Saturation of 15.2 KeV FEL beam was achieved in June 2017.
- 3-BC scheme has been a normal operation mode since June 2017, which help provide a stable photon beam in terms of position, energy, and timing jitters.
- PAL-XFEL has achieved a 24-fs timing jitter in rms between optical laser beam and hard X-ray FEL beam, which is the best performance in the world.

Poster Presentations for PAL-XFEL

- **MOP001**: Yuri Shvyd'ko et. al "Diamond Double-Crystal System for a Forward Bragg Diffraction X-Ray Monochromator of the Self-Seeded PAL XFEL"
- **MOP015**: Inhyuk Nam et. al "Demonstration of Harmonic Lasing Self-Seeded Mode for Soft X-Rays Down to 1nm at PAL-XFEL"
- **TUP020**: H.-S. Kang et. al "Optimization of PAL-XFEL's 3 Bunch Compressor Linac"
- **TUP021**: Haeryong Yang "Commissioning Procedure of Linac and Undulators in PAL-XFEL"
- **WEP019**: Soung Soo Park et. al "High Stable Pulse Modulator for PAL-XFEL"
- **WEP041**: Hyojin Choi et. al "HLS to Measure Changes in Real Time in the Ground and Building Floor of PAL-XFEL, Large-Scale Scientific Equipment"
- **WEP044**: Haeryong Yang et. al "Beam Loss Monitor for Undulators in PAL-XFEL"

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Thank you for your attention