Femtosecond Synchronization of PAL-XFEL

2018. 9. 12

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on behalf of PAL-XFEL team
Pohang Accelerator Laboratory

IBIC 2018 (9/9~9/13, Shanghai)

Pohang Accelerator Laboratory

PAL-XFEL

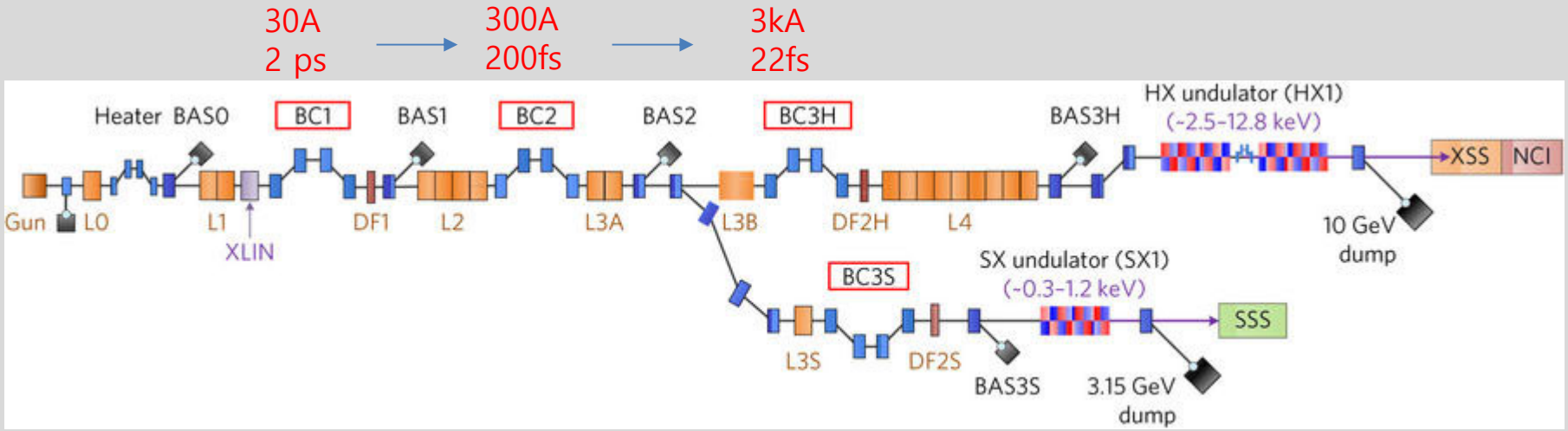
Apr. 2011: PAL-XFEL project started
(Total Budget: 400 M$)

Apr. 2016: Commissioning started

Jun. 2017: User-service started
(120 days for user, >95% of availability)

Plan in 2018
- 140 days for user
- HX self-seeding commissioning
  (user service starts in 2019)
- 30 Hz -> 60 Hz operation

PAL-XFEL Parameters

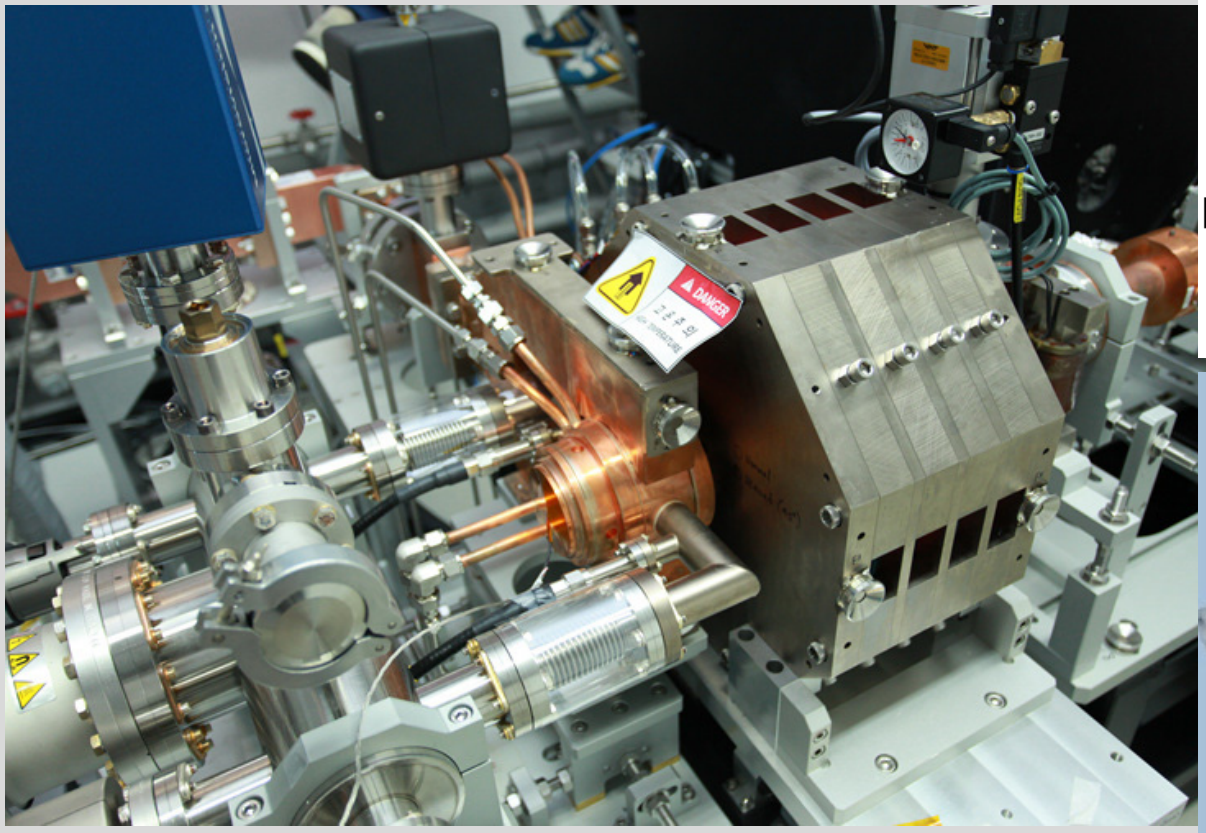


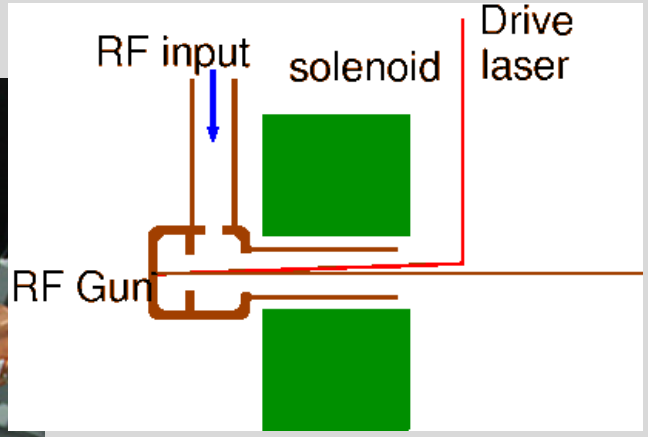
Main parameters

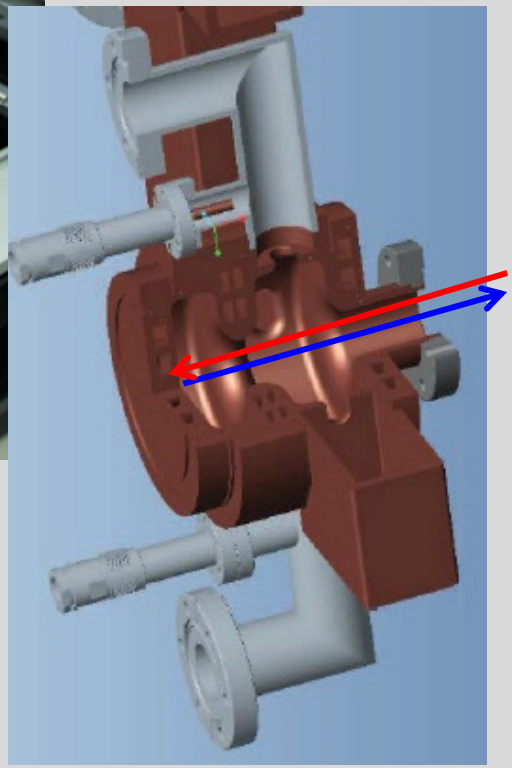
e^- Energy	10 GeV
e^- Bunch charge	20-200 pC
Slice emittance	0.5 mm mrad
Repetition rate	60 Hz
Pulse duration	5 fs – 100 fs
Peak current	3 kA
SX line switching	DC (Phase-1) Kicker (Phase-2)

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

Photocathode RF Gun

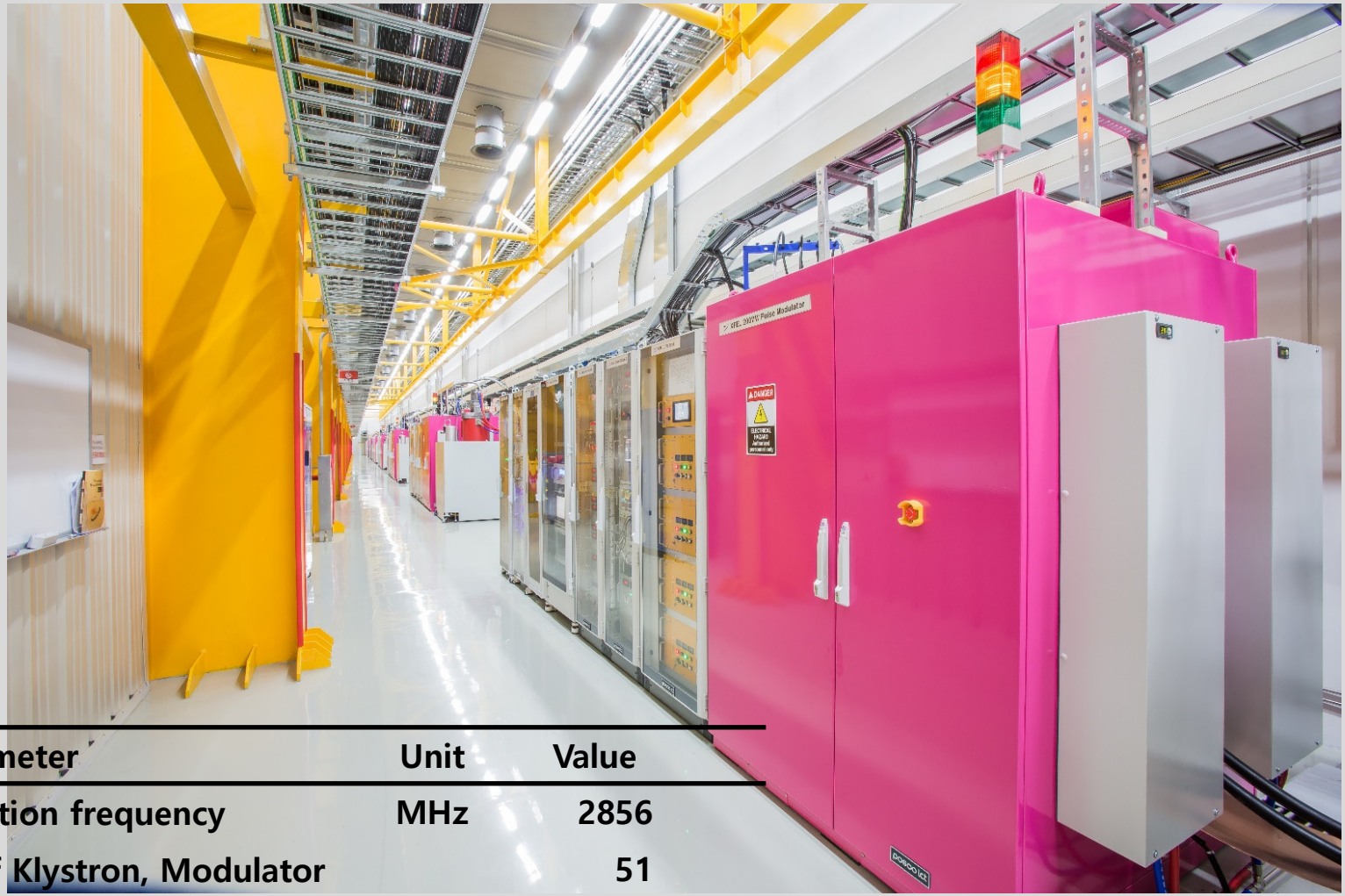






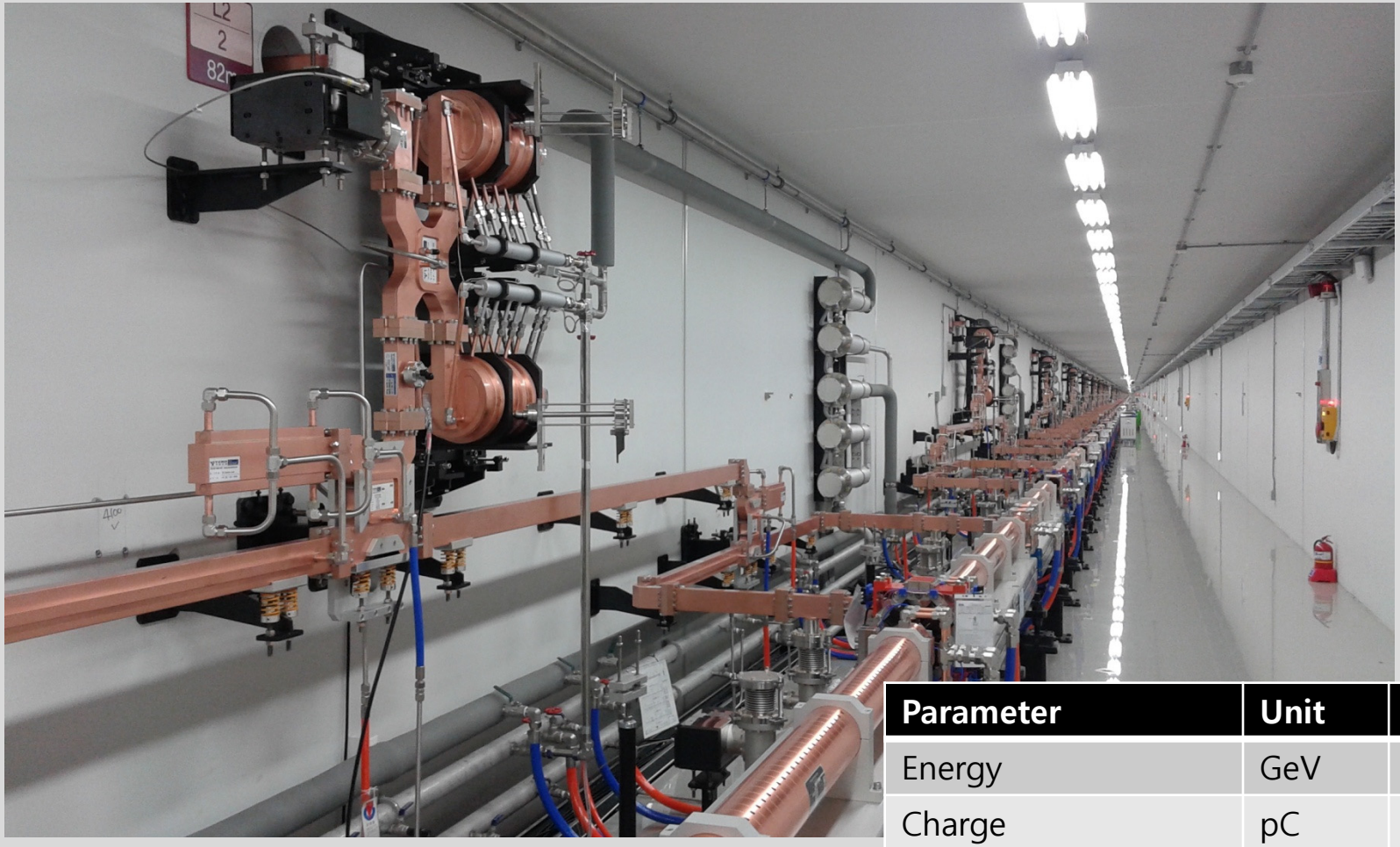
- 1.6 cell, 2.856 GHz
- 2 RF coupler ports & 2 vacuum ports at the full cell for RF symmetry

PAL-XFEL K&M Gallery



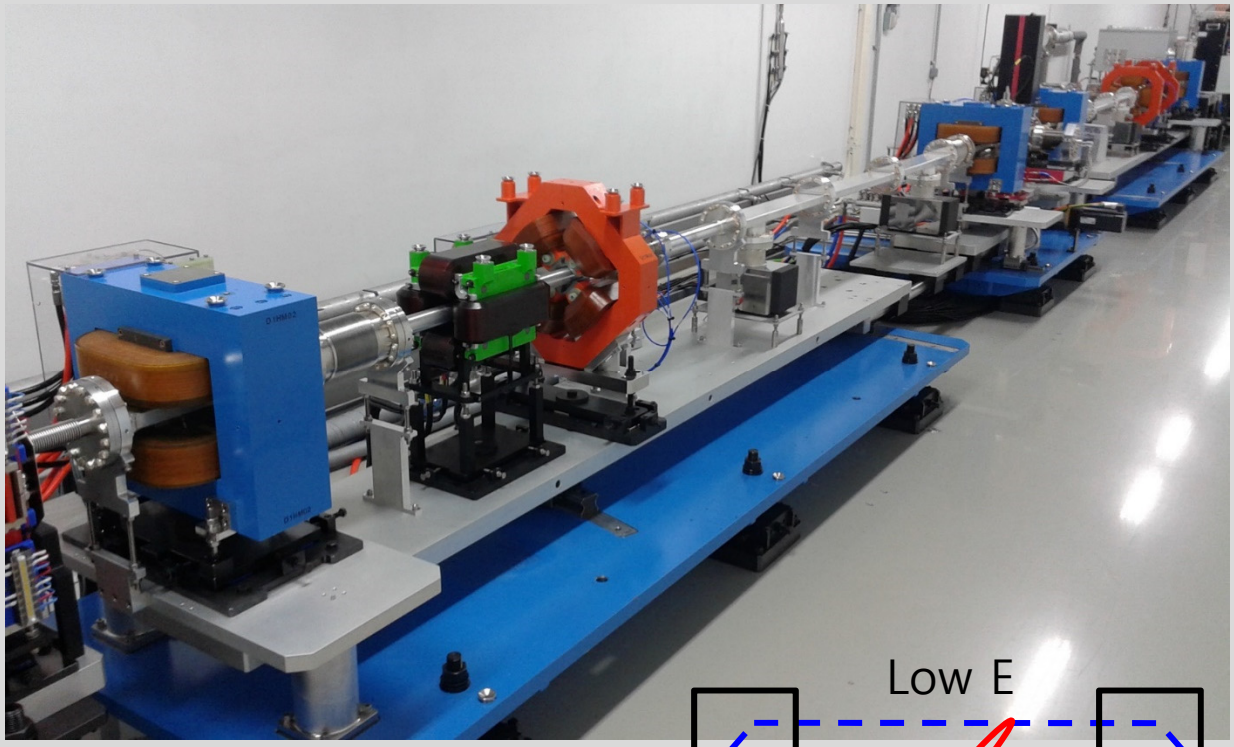
Parameter	Unit	Value
Operation frequency	MHz	2856
No. of Klystron, Modulator		51
Max. repetition rate	Hz	60
Operation pulse length	μs	4

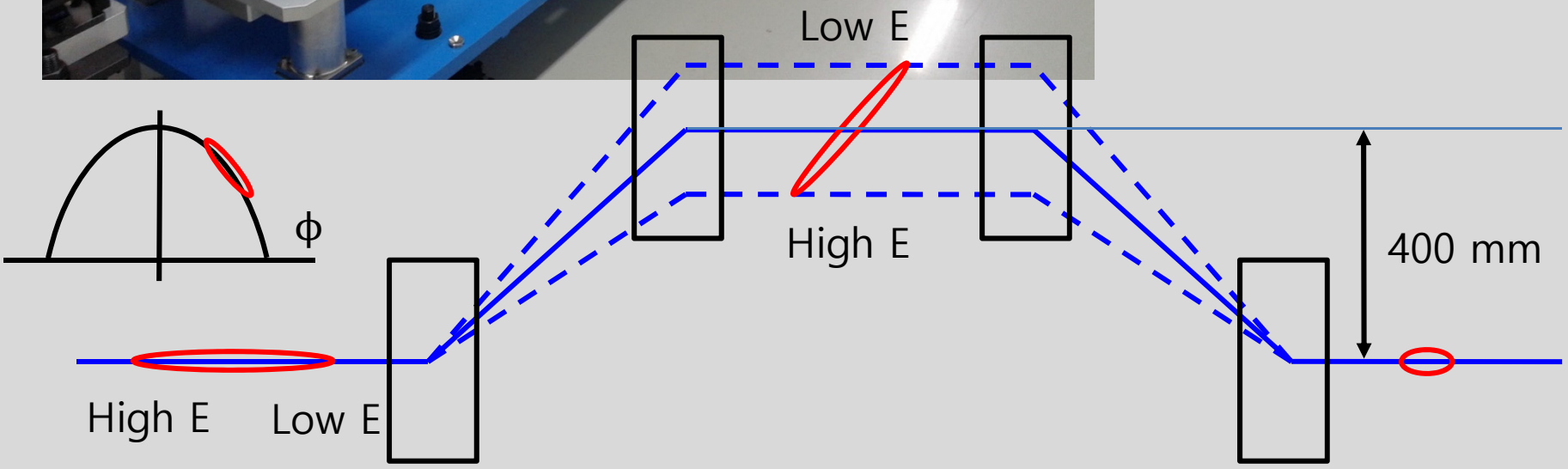
PAL-XFEL Linac



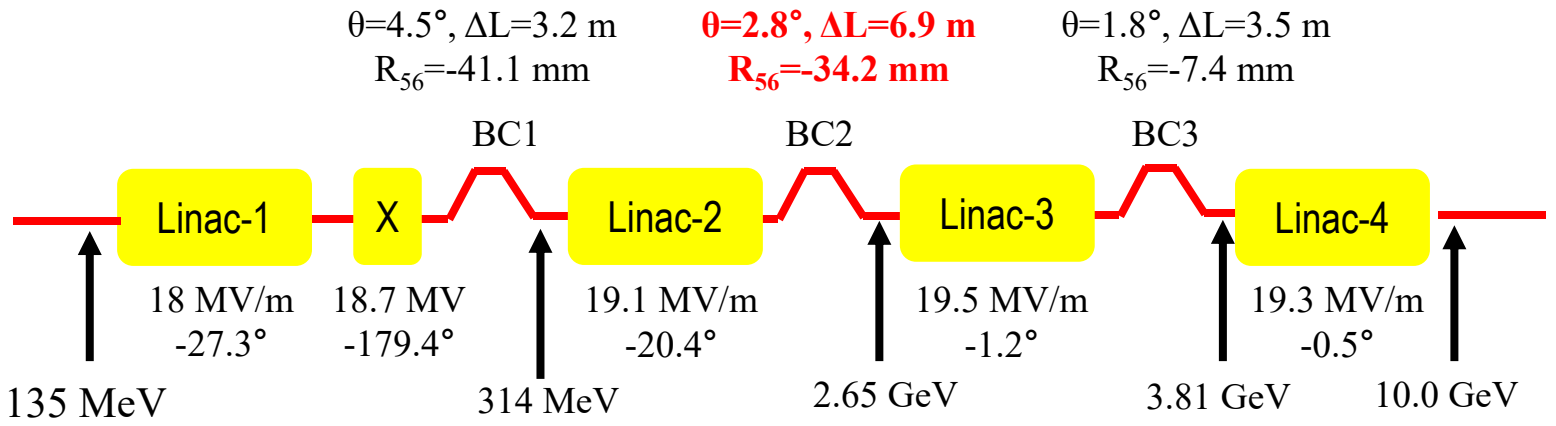
Parameter	Unit	Value
Energy	GeV	10
Charge	pC	200
No. of SLED		42
No. of Acc. Column		173

PAL-XFEL Bunch Compressor

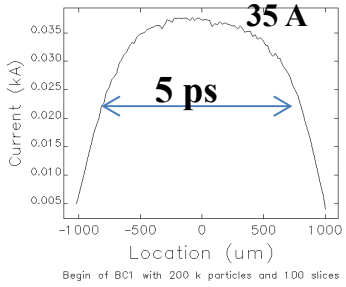




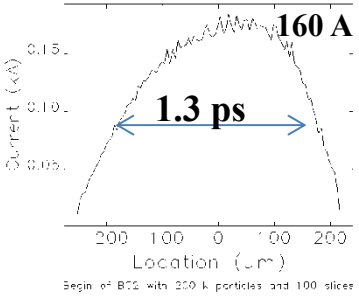
Start-to-End Simulation of Hard X-ray Line



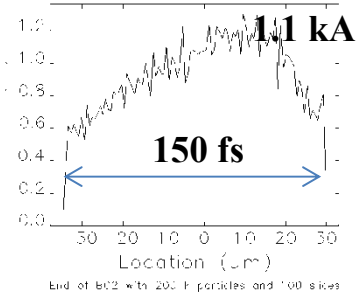
Before BC1



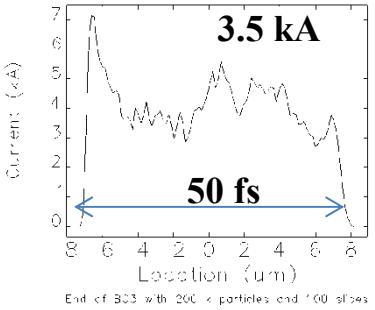
After BC1

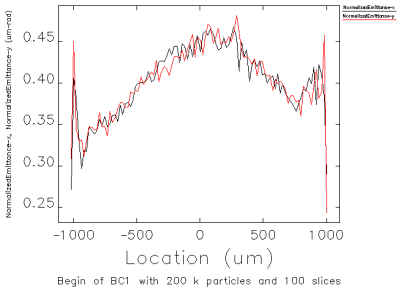


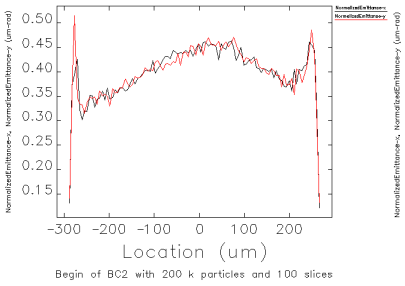
After BC2

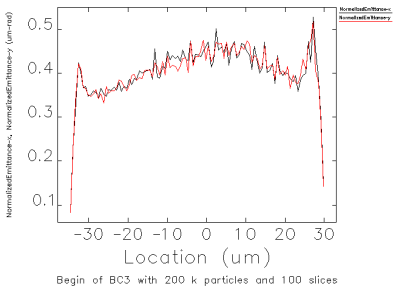


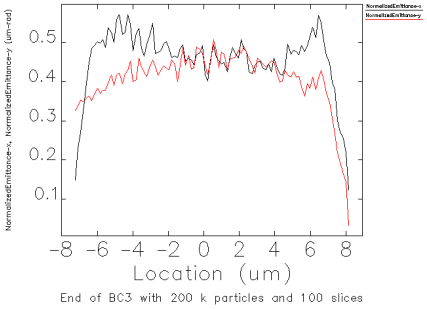
After BC3



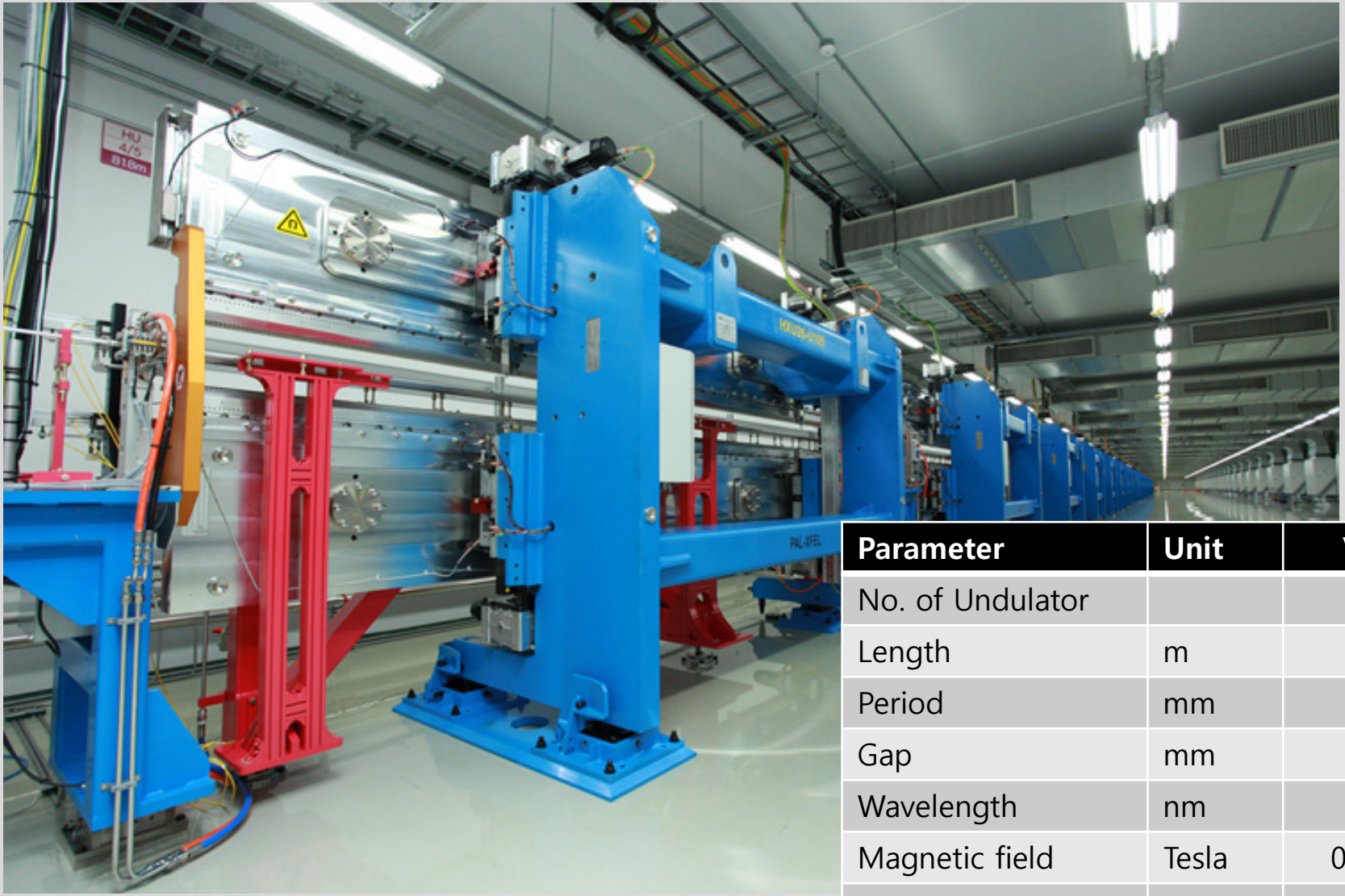






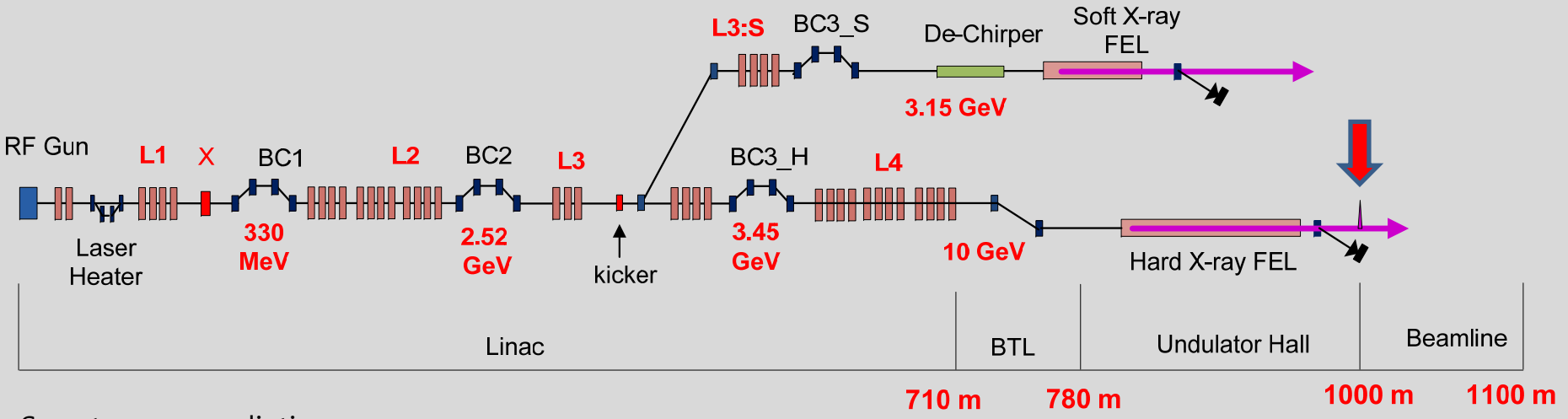


PAL-XFEL Undulator

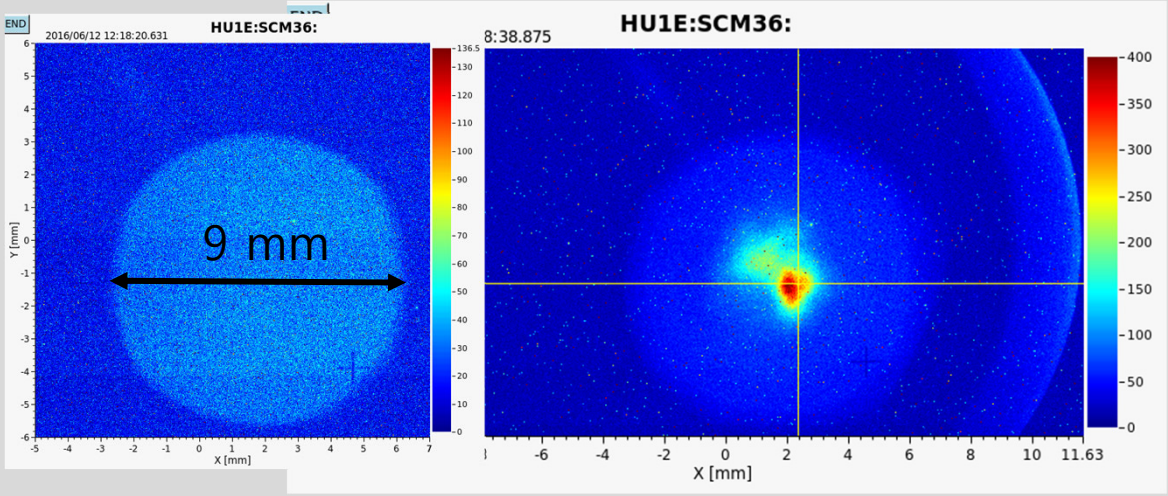


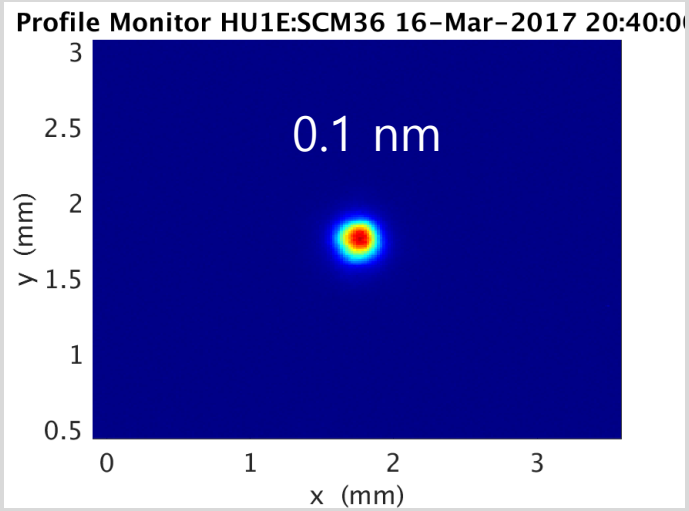
Parameter	Unit	Value
No. of Undulator		20
Length	m	5
Period	mm	26.0
Gap	mm	8.3
Wavelength	nm	0.1
Magnetic field	Tesla	0.8124
K		1.9727

First FEL Lasing



Spontaneous radiation





June 12, 2016

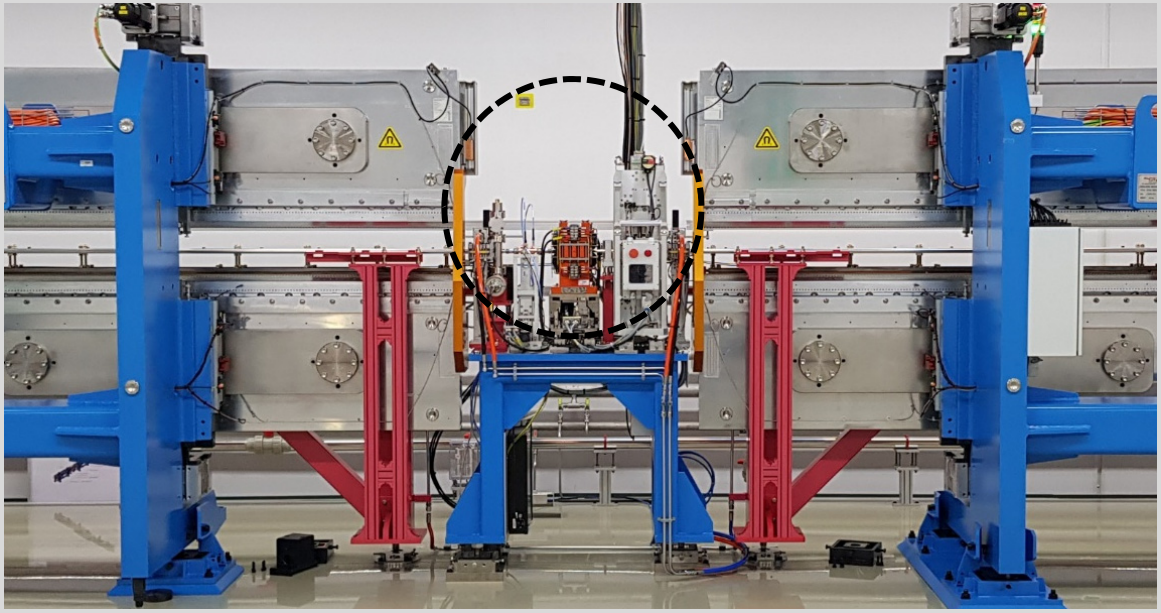
June 14, 2016

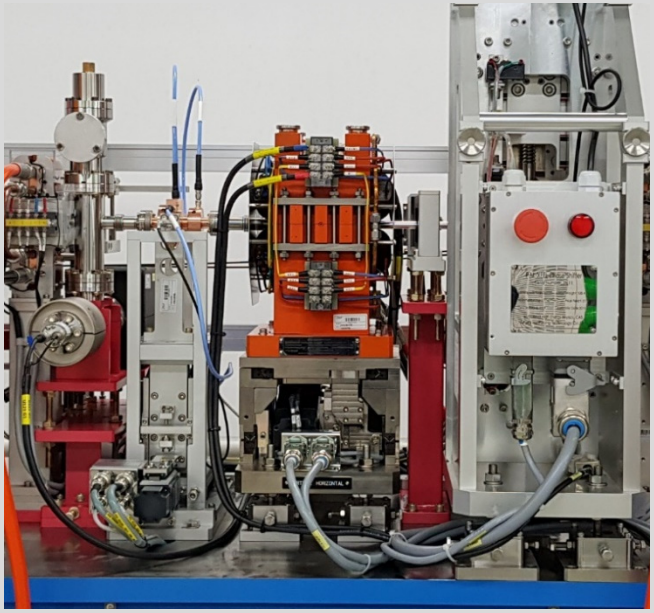
March 16, 2017

FEL Optimization

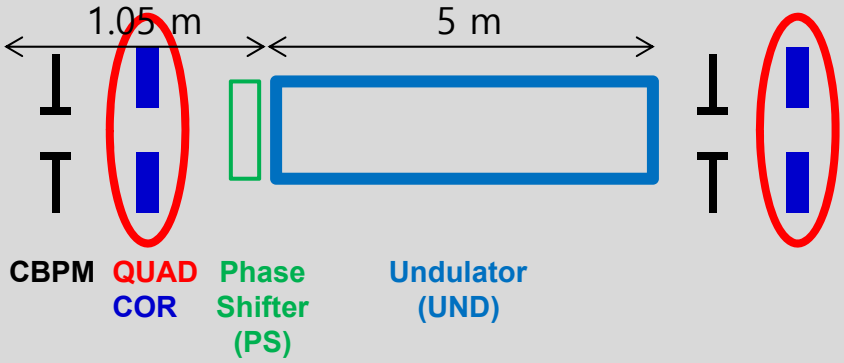
- Beam based alignment in undulator section
- e-beam size matching in undulator section
- Undulator gap tuning
- Undulator offset tuning
- Undulator tapering
- Phase shifter gap tuning

Undulators in PAL-XFEL



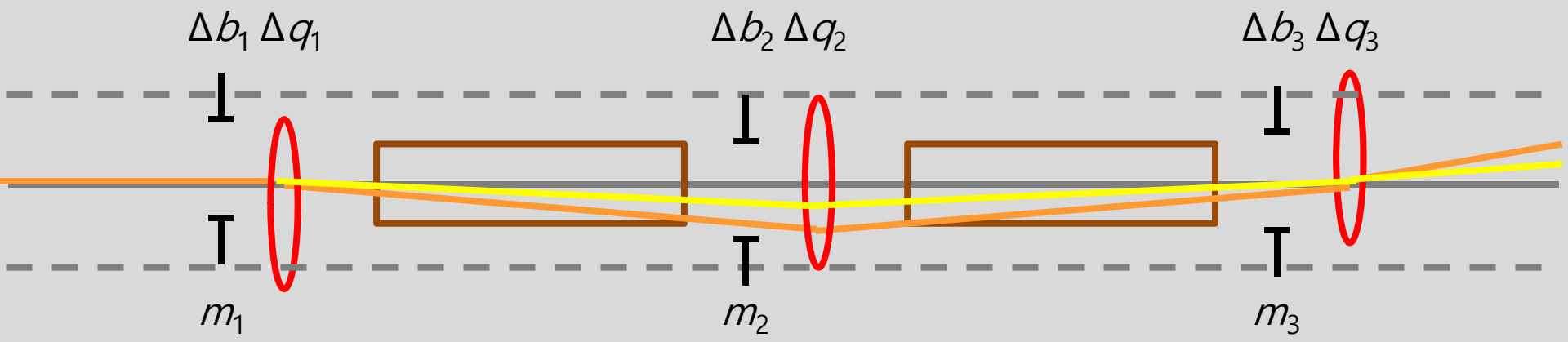


Configuration of UND section



Device	Control parameters
CBPM	H/V-offset (in PV) H/V-position (by mover)
QUAD	Field, H/V-position (by mover)
COR	H/V-kick
PS	Gap
UND	Gap, V-offset

Beam Based Alignment



$E_1 < E_2$

CBPM Offsets Δb_i, Quad Offsets Δq_i

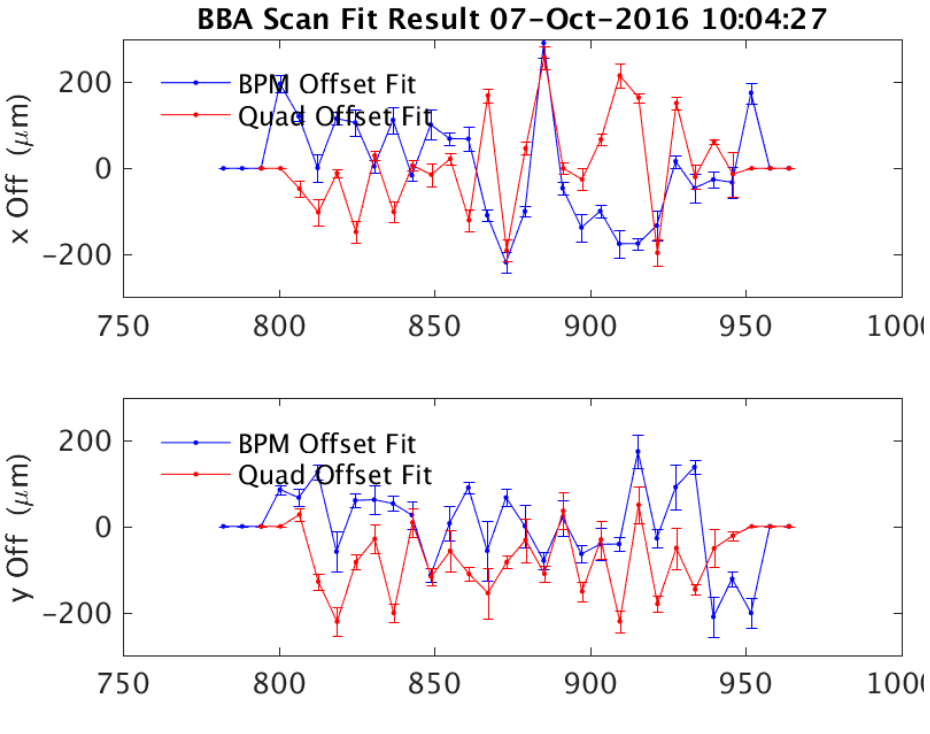
- Model beam position (m_j) at CBPMs as a function of initial launch at 1st CBPM(x_i), quad offsets (Δq_i), CBPM offsets (Δb_i) ($\boldsymbol{m = [R_x\ R_q\ R_b][x'\ \Delta q'\ \Delta b]'}$)
- Calculate response matrix for 4 energies (4 ~ 10 GeV for HX)
- Measure ~200 orbits and average for each energy
- Generate final response matrix, Δq_i, Δb_i and apply Δq_i and Δb_i

Henrik Loos, LCLS FAC (2009), P. Emma *et al. NIM* A **429**, 407-413 (1999)

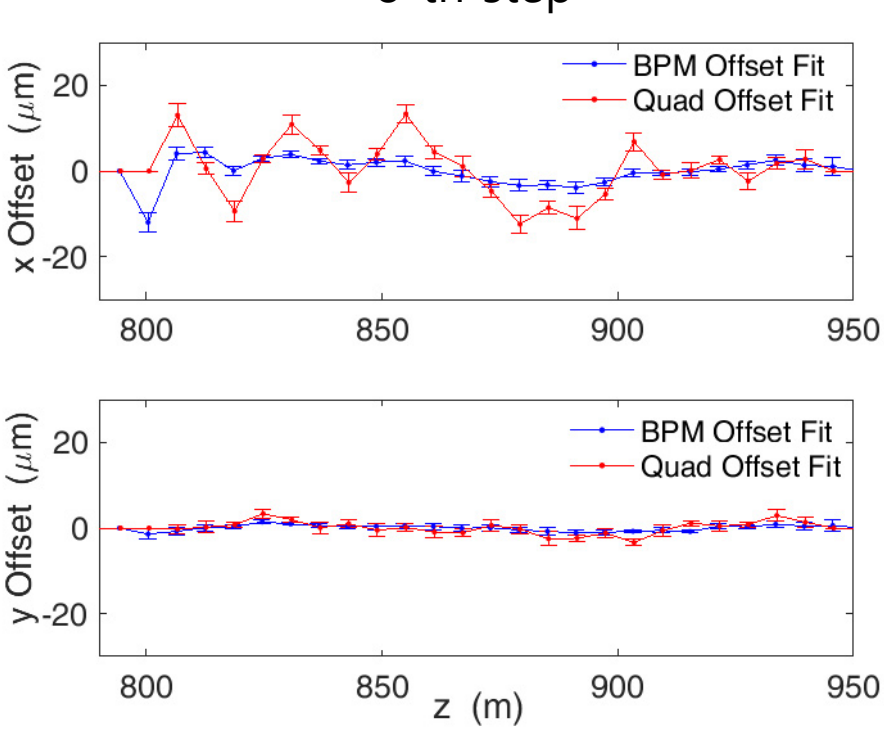
Undulator BBA

- Beam positions are measured at four different beam energy: 4, 5, 7, 10 GeV
- BPM offsets and quad offsets are calculated to get dispersion-free straight orbit
- All cavity BPMs and quads have its own mover which can move up to +/-1 mm with precision of 1 um for horizontal and vertical directions

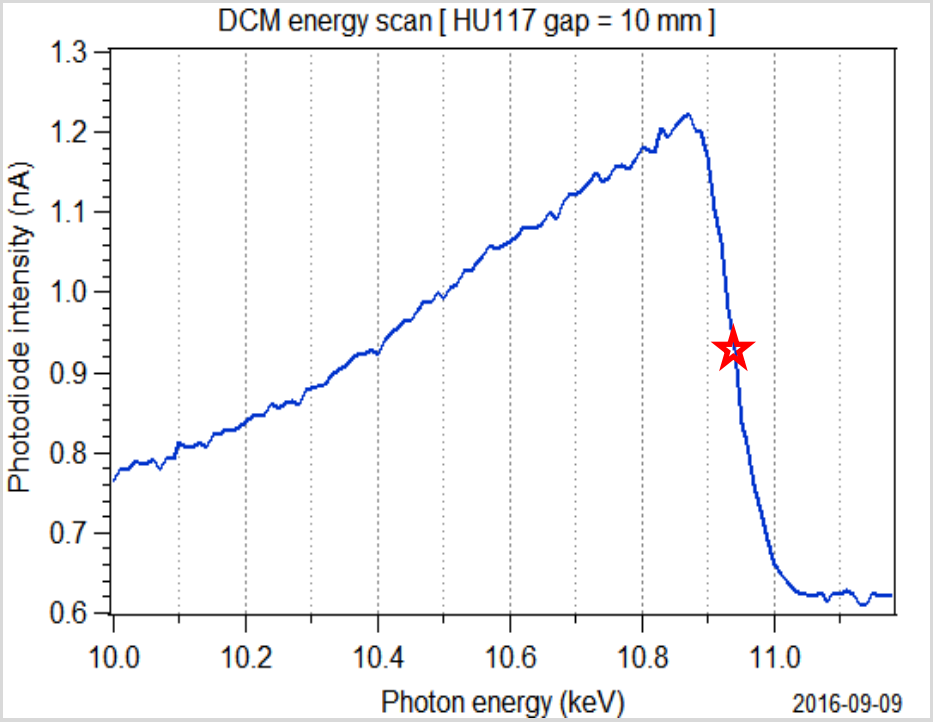
1-st step

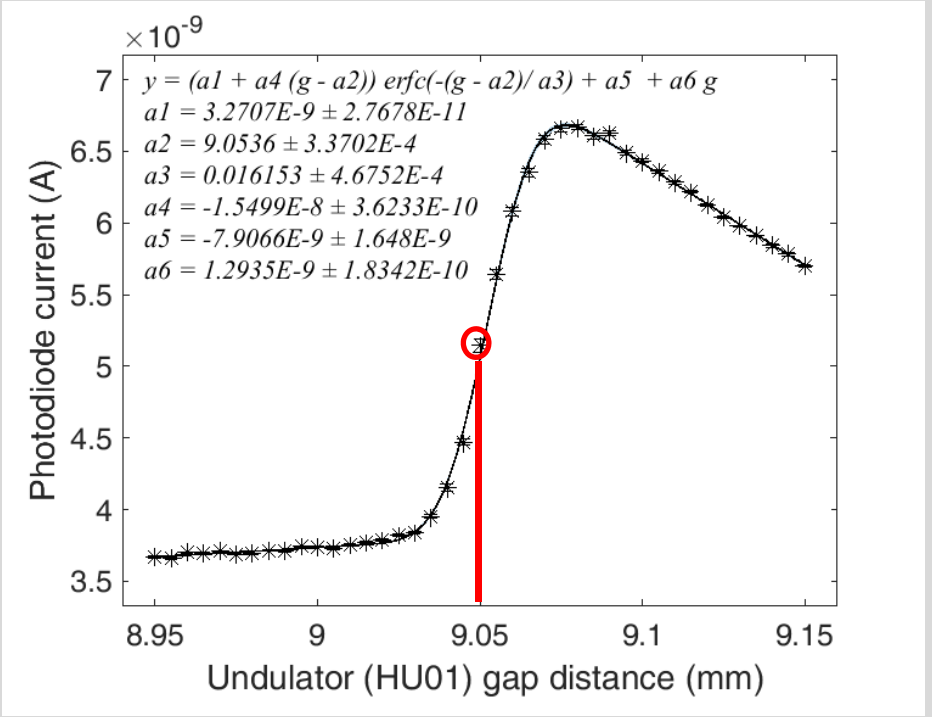


8-th step

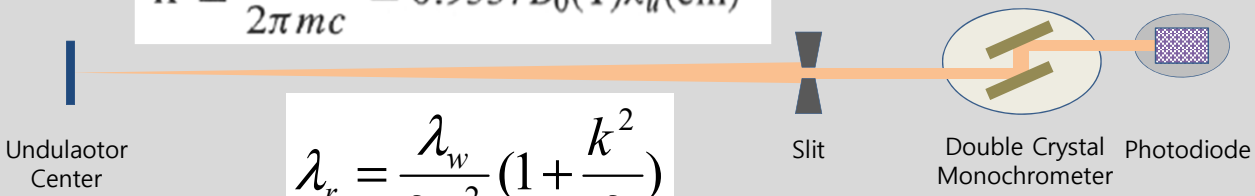


Undulator Gap Tuning





$$K \equiv \frac{eB_0\lambda_u}{2\pi mc} = 0.9337 B_0(\mathrm{T})\lambda_u(\mathrm{cm})$$

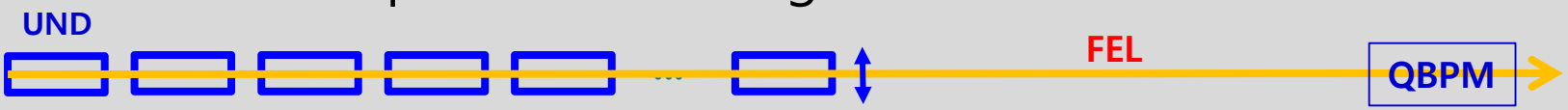


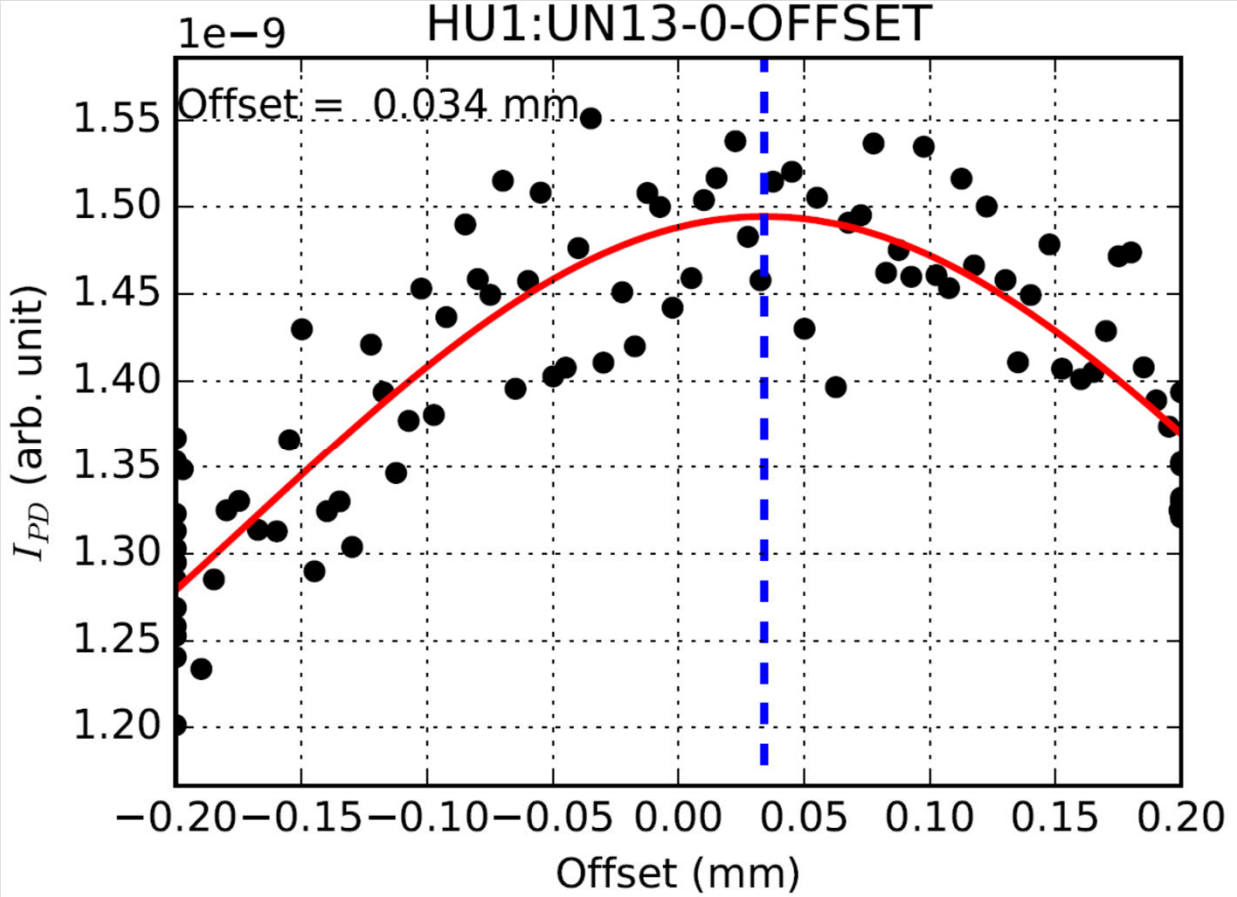
$$\lambda_r = \frac{\lambda_w}{2\gamma^2}\left(1+\frac{k^2}{2}\right)$$

T. Tanaka *et al. Phys. Rev. ST Accel. Beam* **15**, 110701 (2012).

Undulator Offset

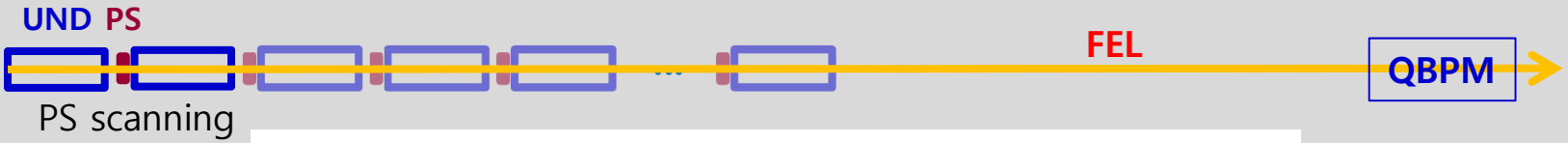
- Finding of an undulator mid-plane by vertical offset scan
- To use the optimum field region in an undulator

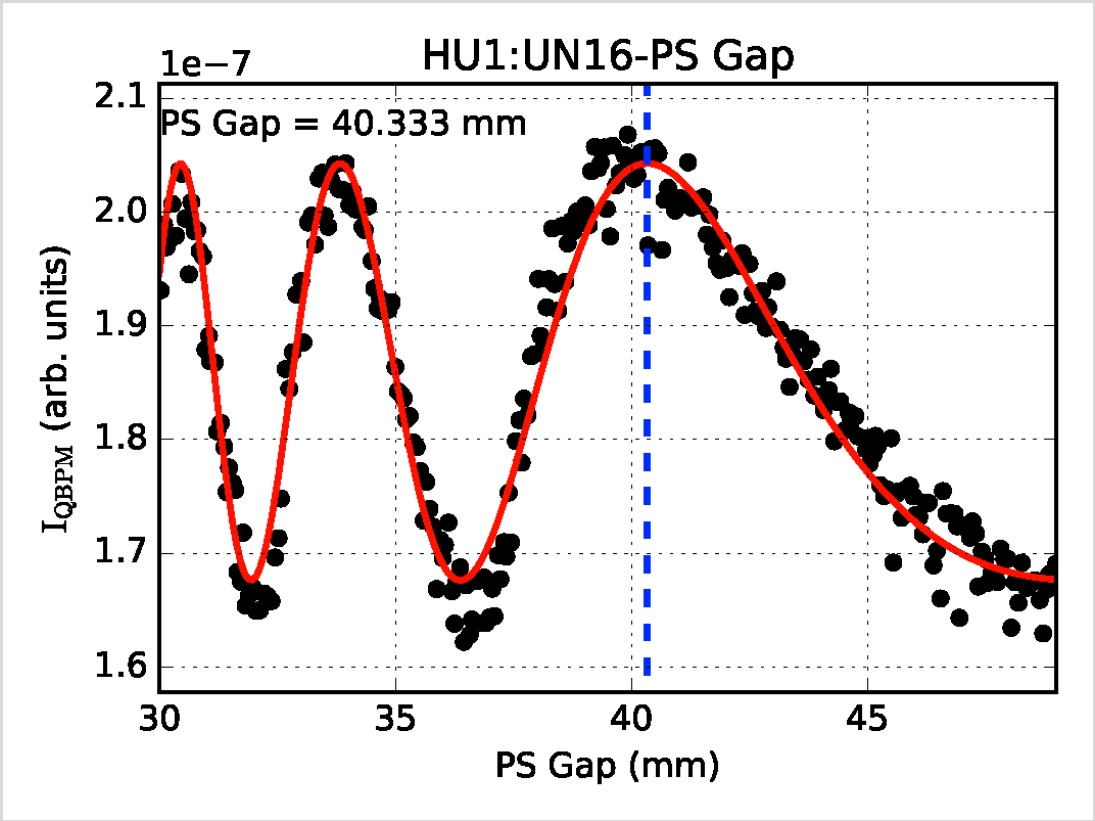




Phase Shifter Gap Tuning

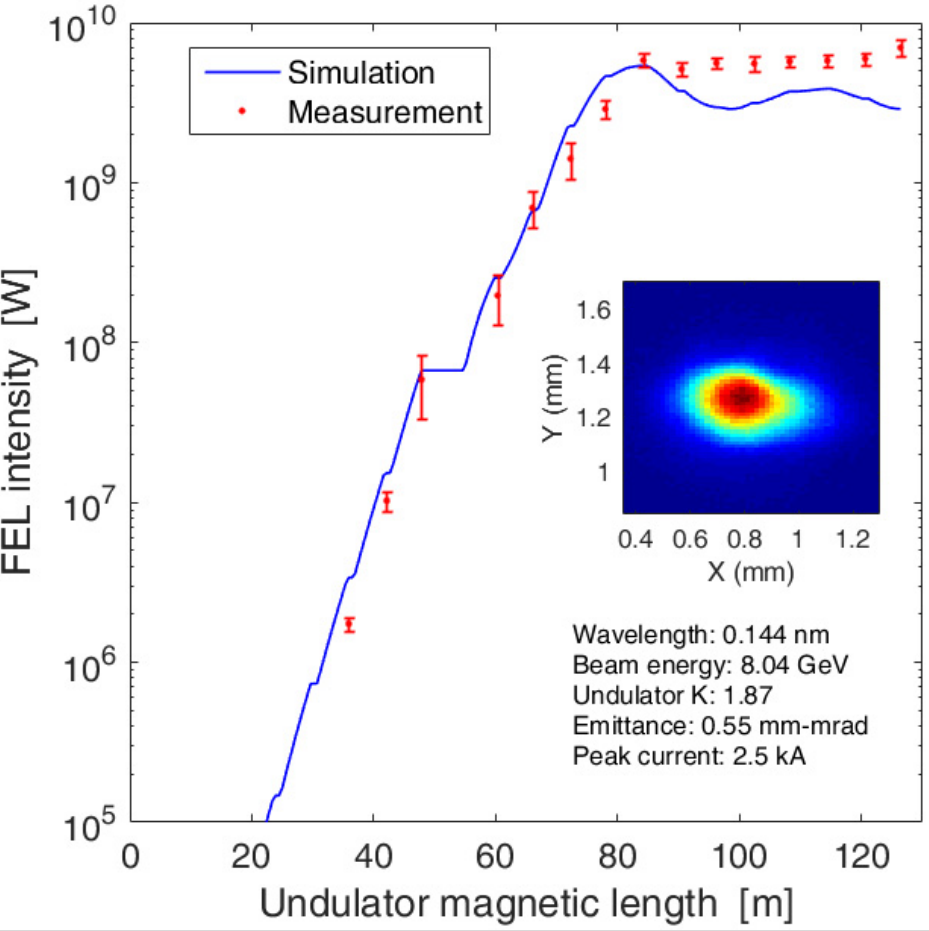
- PS scanning with the FEL power measurement
- To find optimum PS gap in the tapering condition





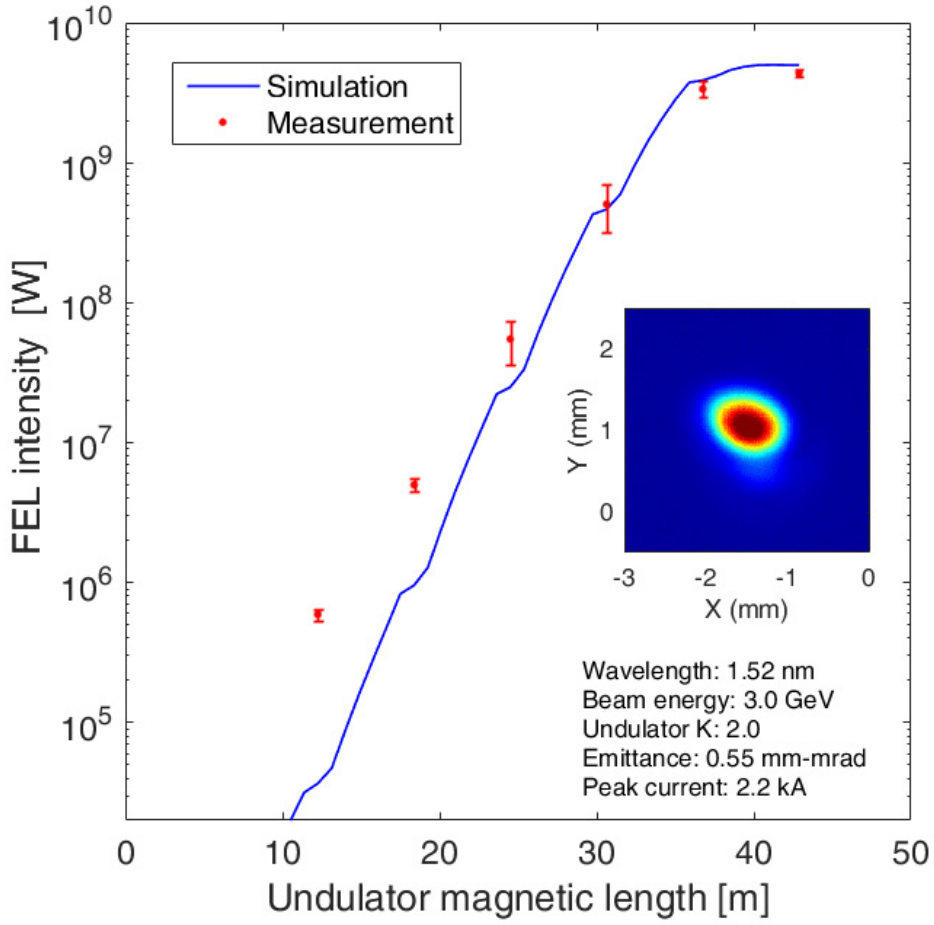
FEL Saturation (HX & SX)

Nov. 27, 2016



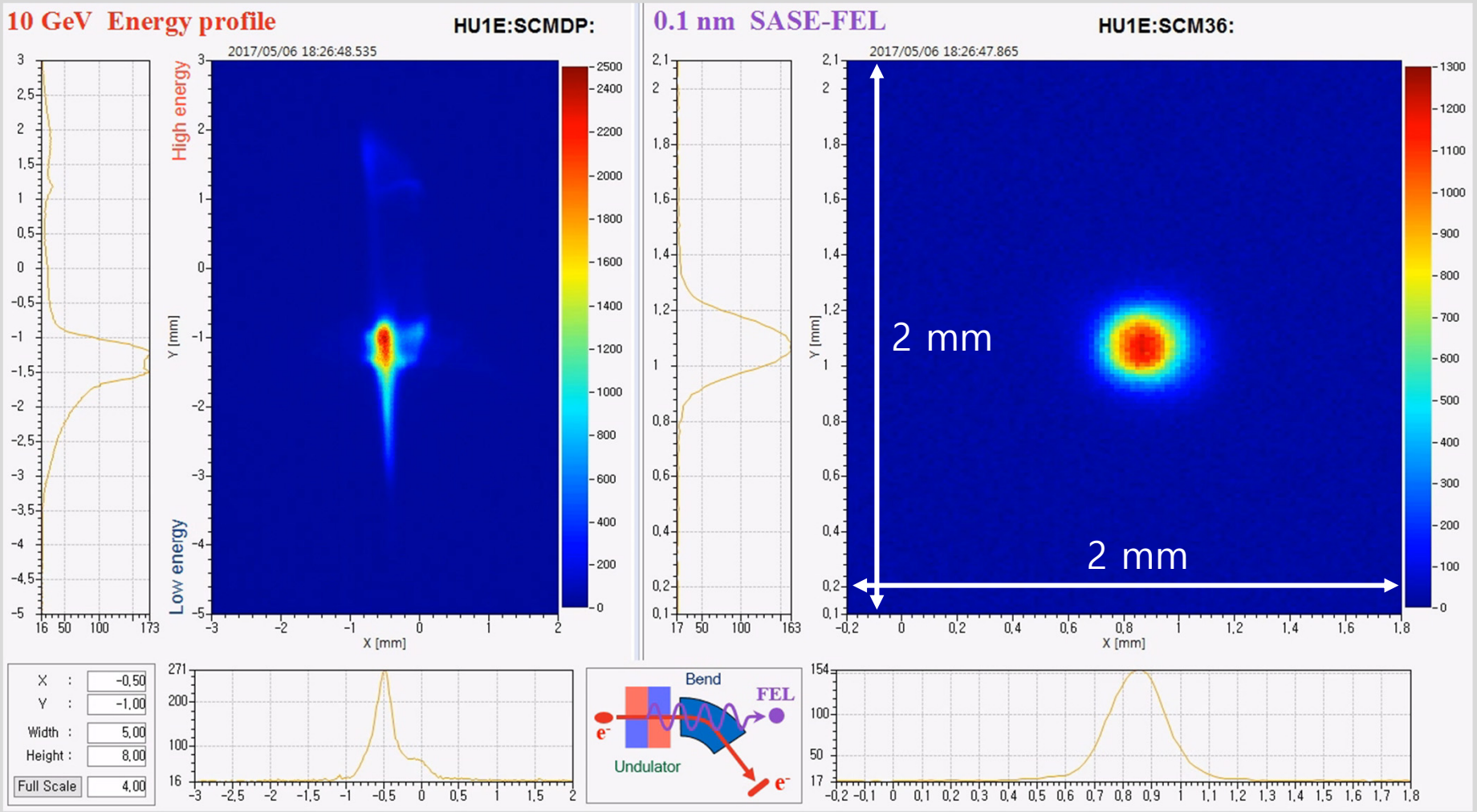
Simulation:
emittance: 0.55 mm-mrad
peak current: 2.5 kA

Feb. 02, 2017

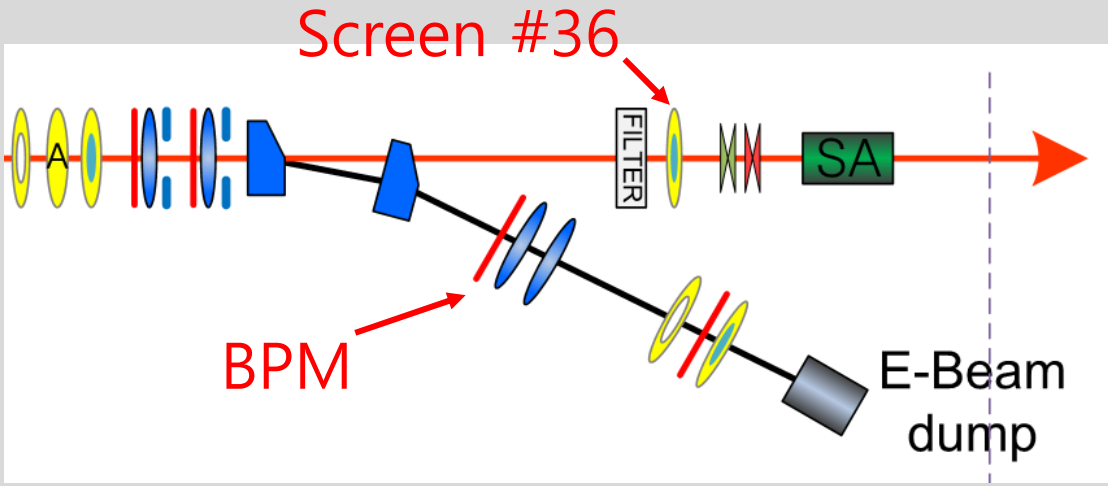


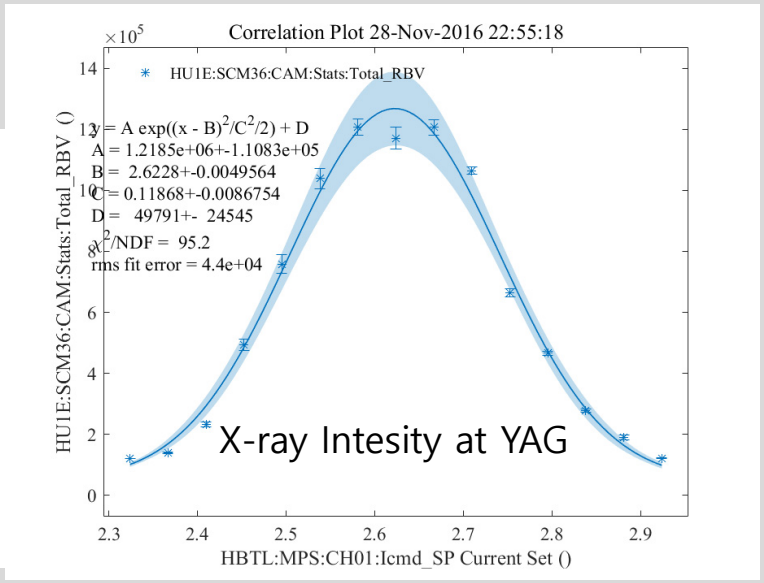
Simulation:
emittance: 0.55 mm-mrad
peak current: 2.2 kA

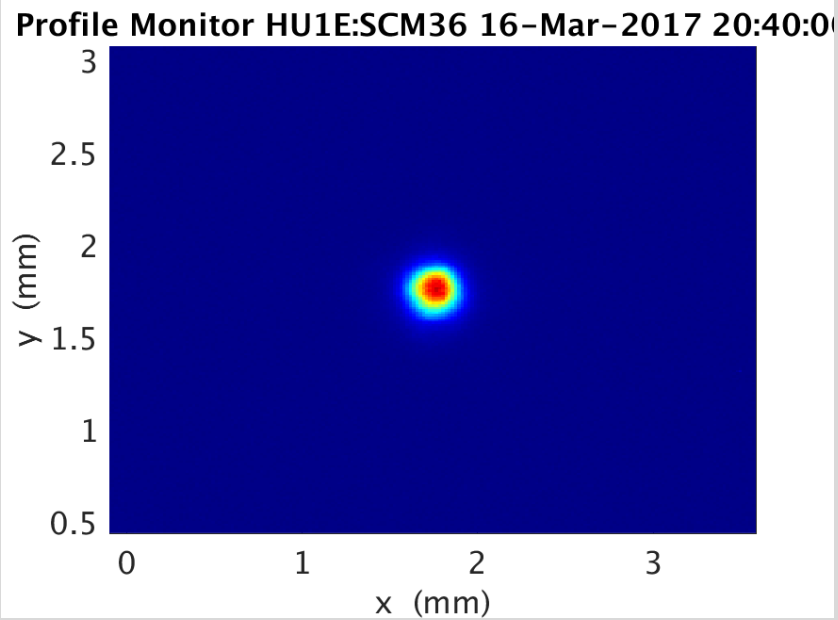
Stability of 0.1 nm FEL

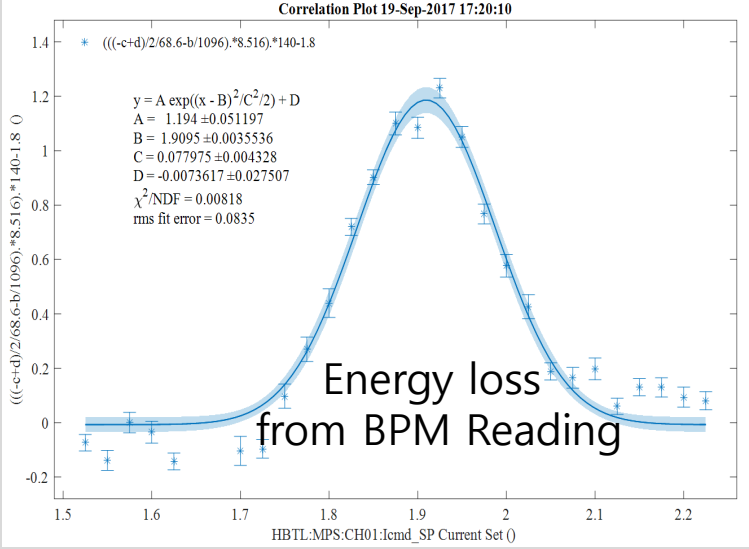


Energy Loss Scan





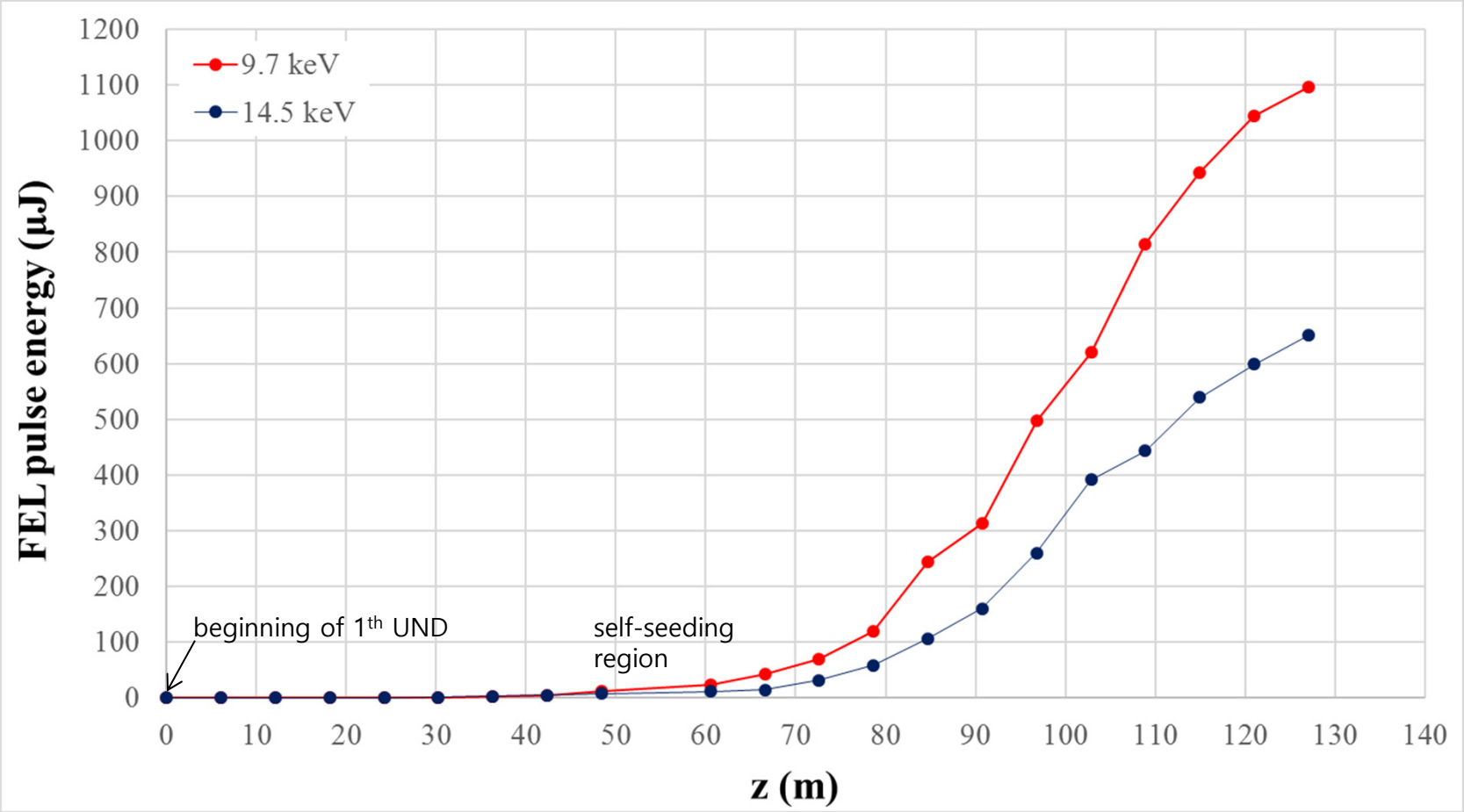




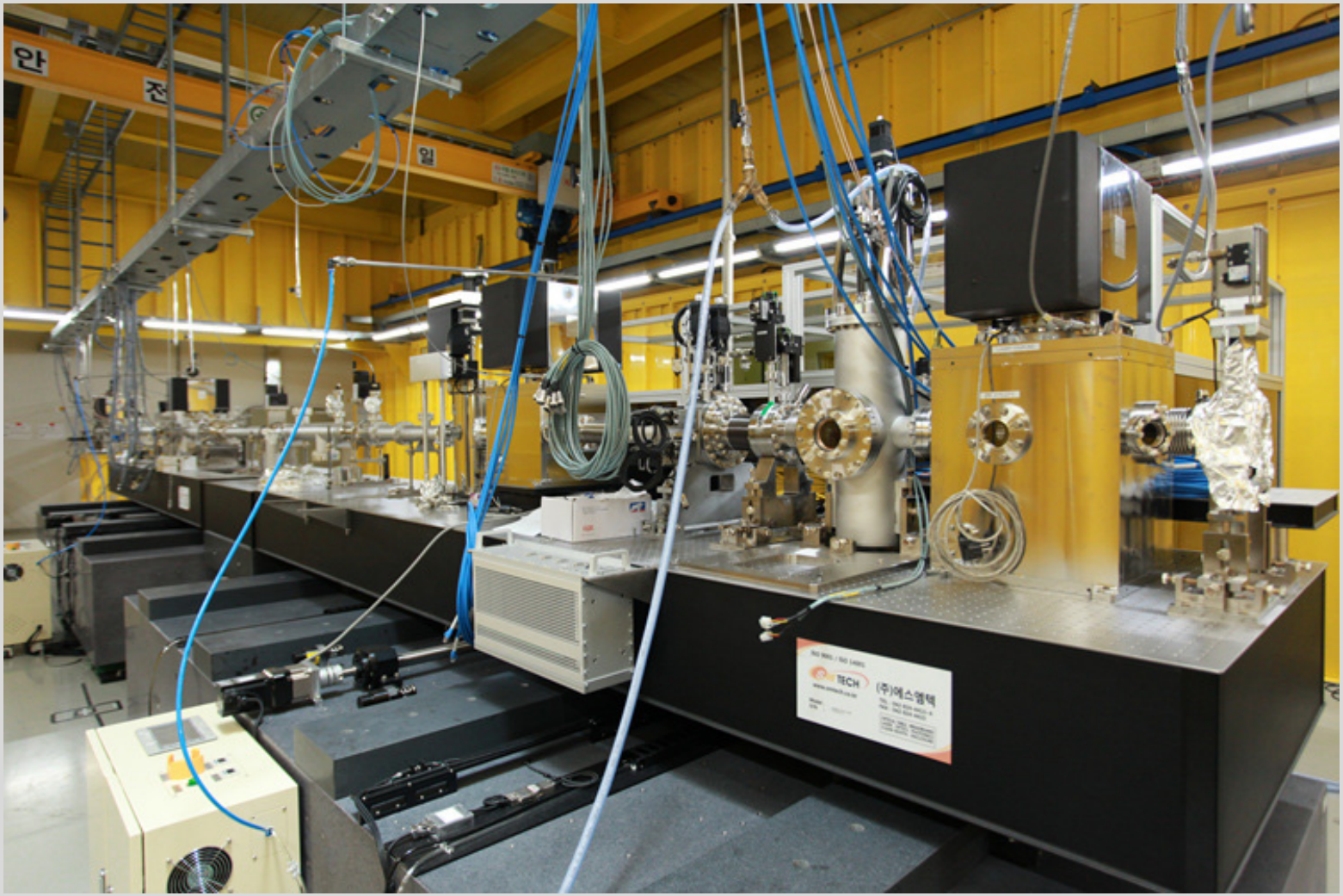
FEL Energy

~ 1.0 mJ for 7 ~ 10 keV FEL (1.3 mJ @ 12.7 keV)

~ 0.7 mJ for 10 ~ 15 keV FEL

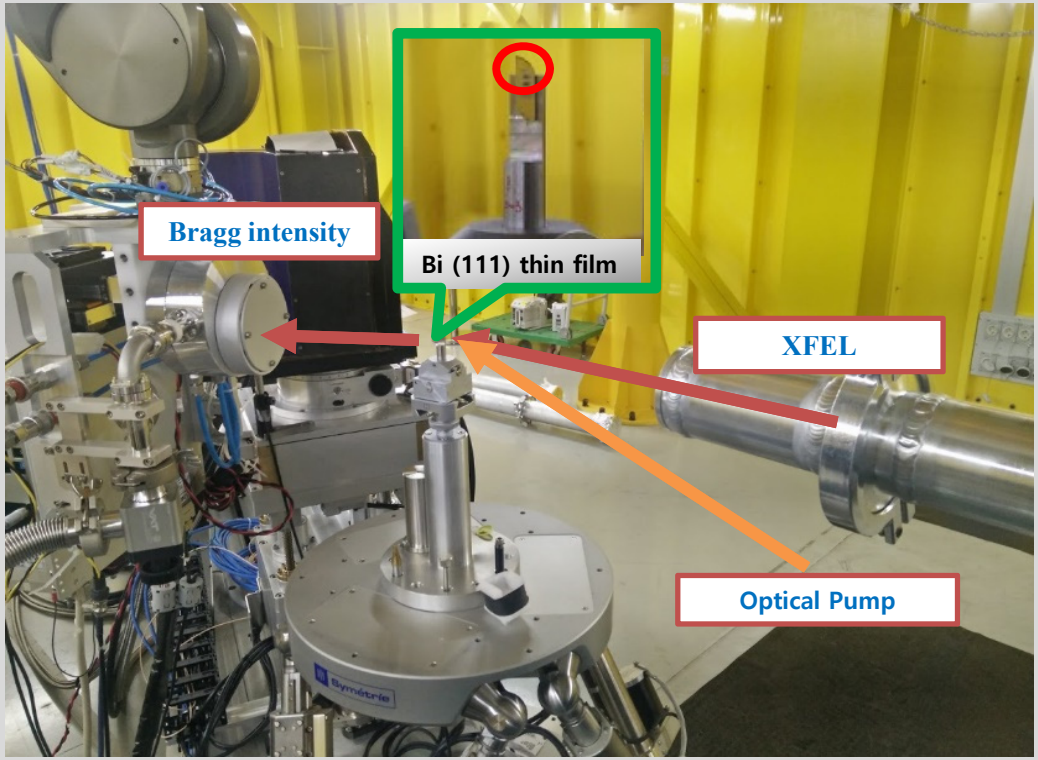


PAL-XFEL Beamline



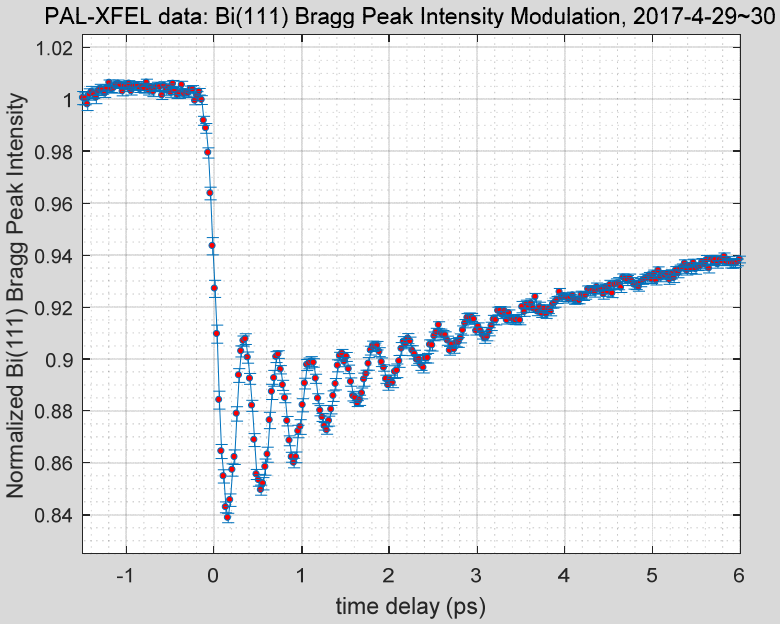
3 Experimental Station:
Coherent X-ray Imaging, Hard X-ray Pump & Probe, Soft X-ray Pump & Probe

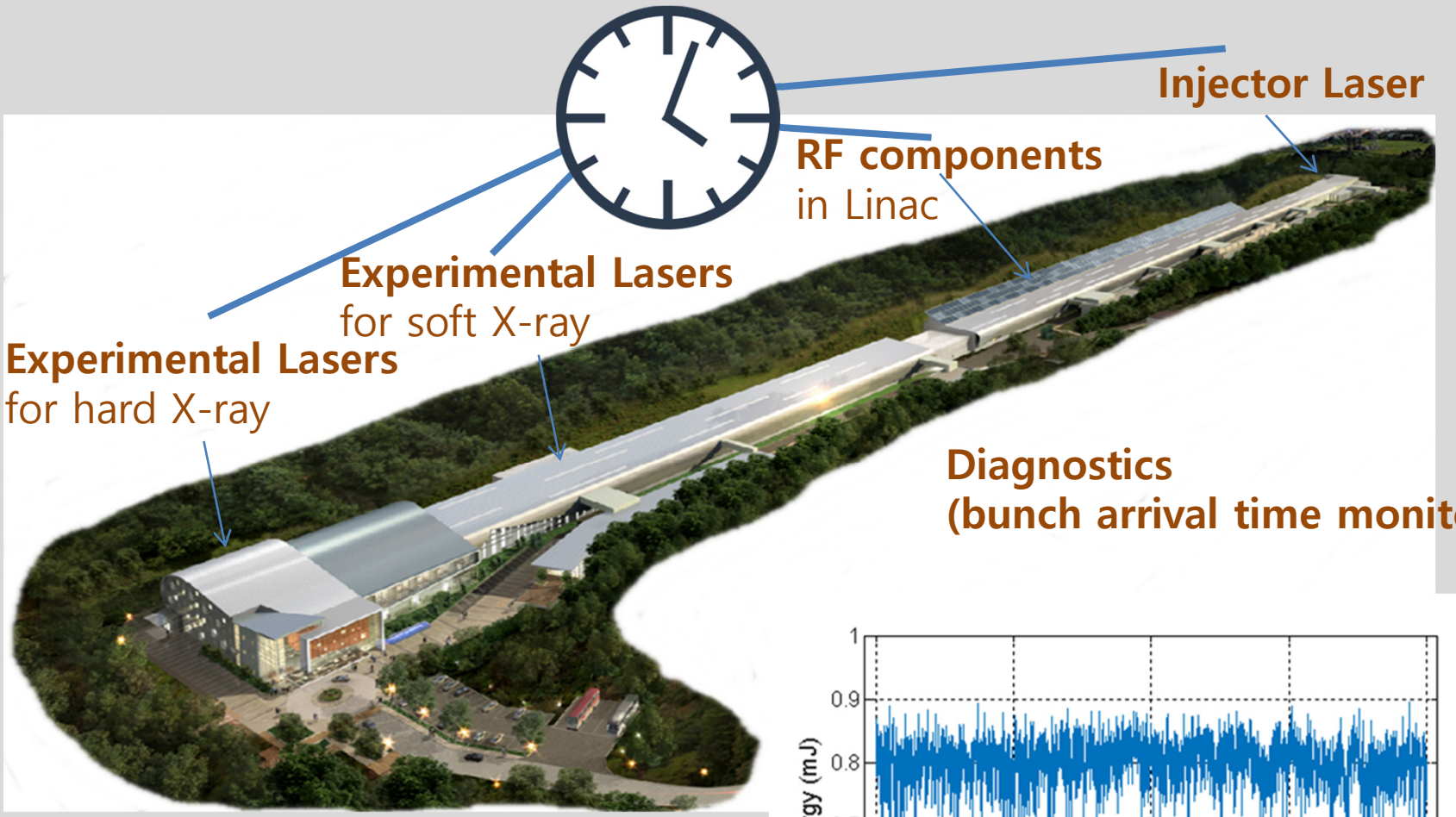
Pump-Prove Experiment



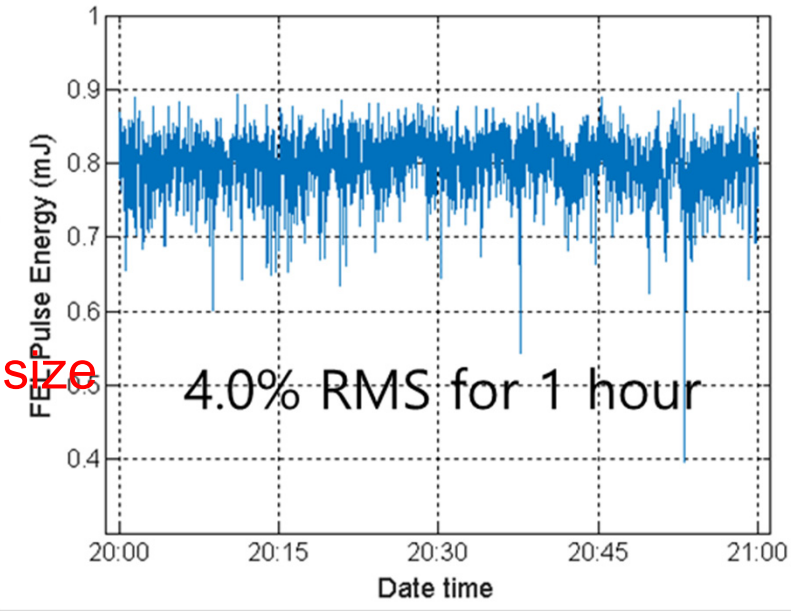
Bi(111) thin film (50 nm) on GaSb(111)/Si(111)
X-ray: 6 keV
X-ray size: ~ 60 x 60 um^2
Laser: 800 nm, 100 fs
Detector: MPCCD 0.5 Mega pixel

- **No timing jitter correction**
- Averaged by 50 trials of the time delay scan and normalized by GaSb(111) Bragg peak intensity
- **Only slow time-drift correction**
- **Vibration Frequency : 2.7 THz**
- Instrument Response: 137 fs (FWHM)



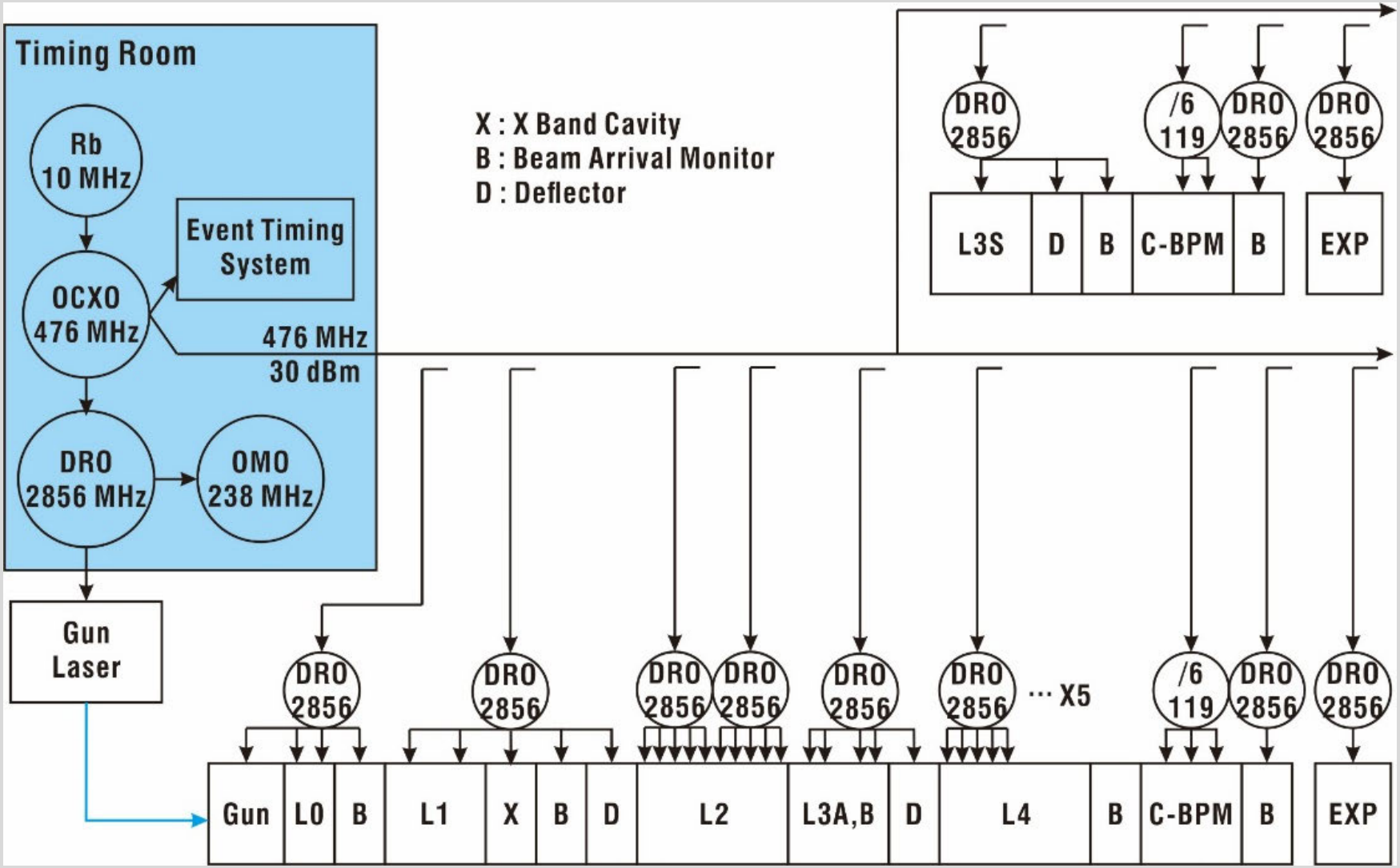


- FEL position stability: 8~9% of beam size
- FEL power stability: ~ 4.0% RMS
- E-beam energy jitter: < 0.02 %
- E-beam arrival time jitter: < 20 fs
- FEL pulse energy: >1 mJ at 9.7 KeV



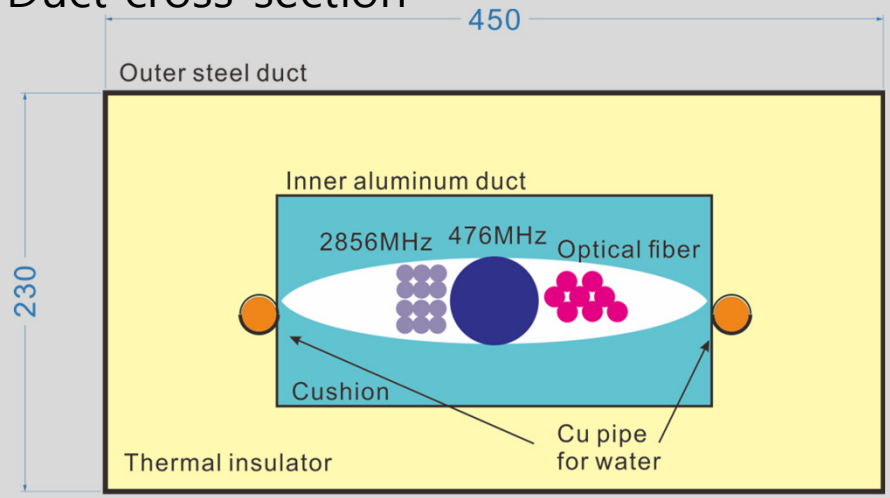
FEL Energy Stability

PAL-XFEL Timing Distribution



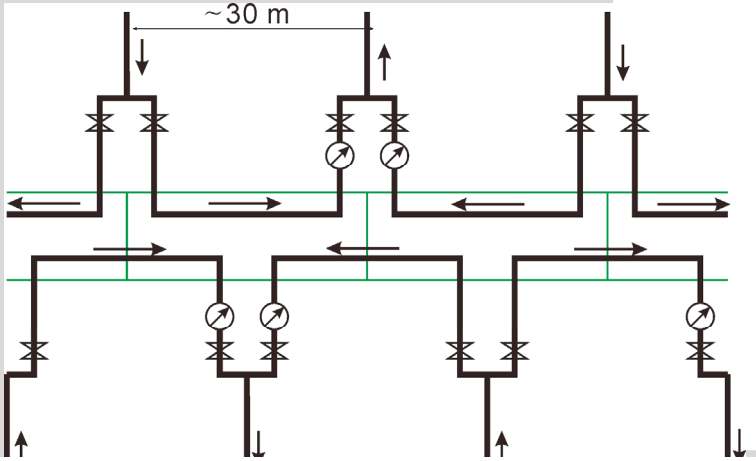
Temperature Stabilization

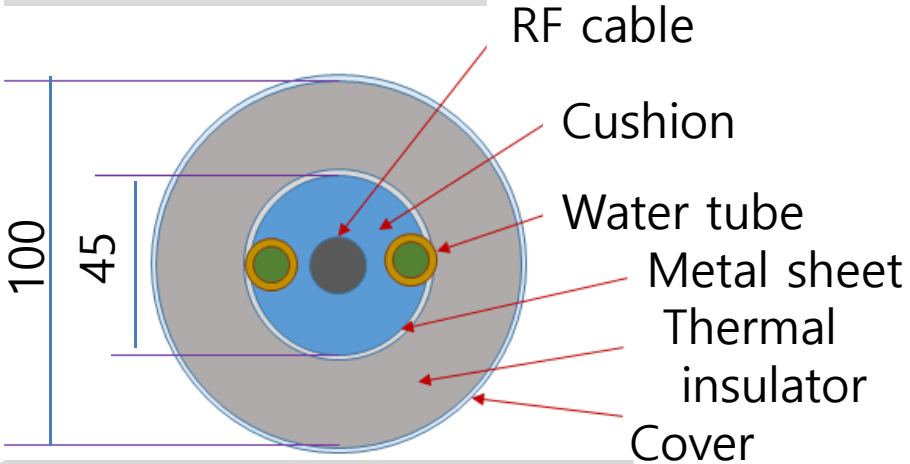
Duct cross-section



With cover open

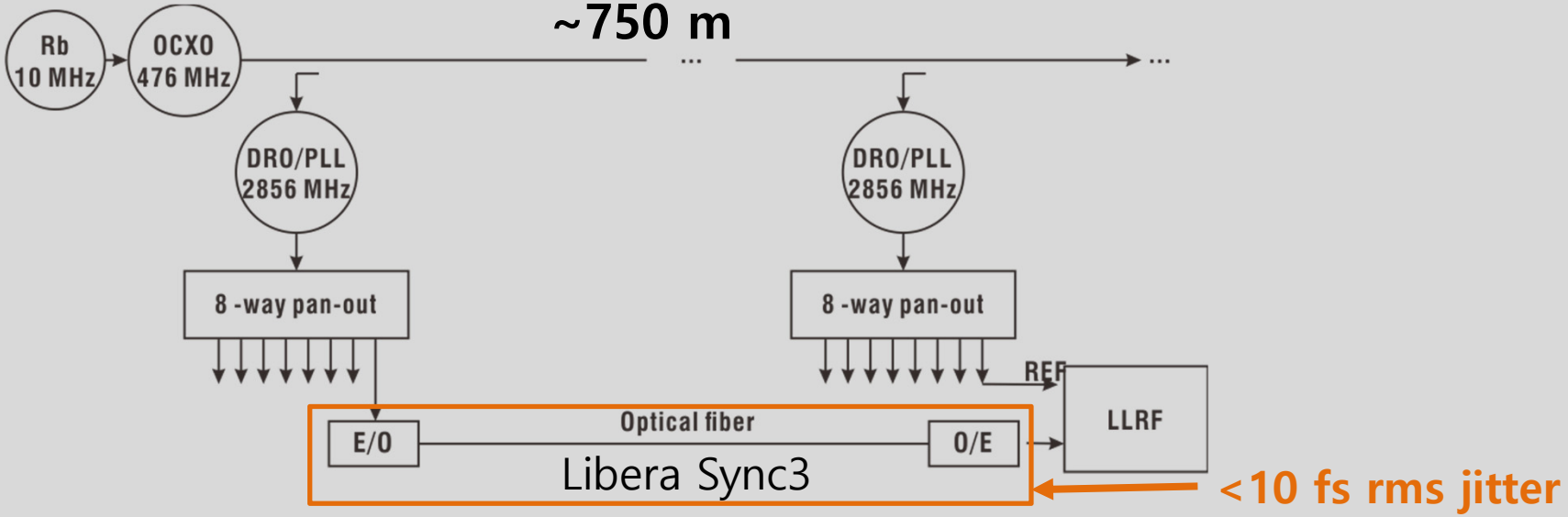
LCW flow diagram

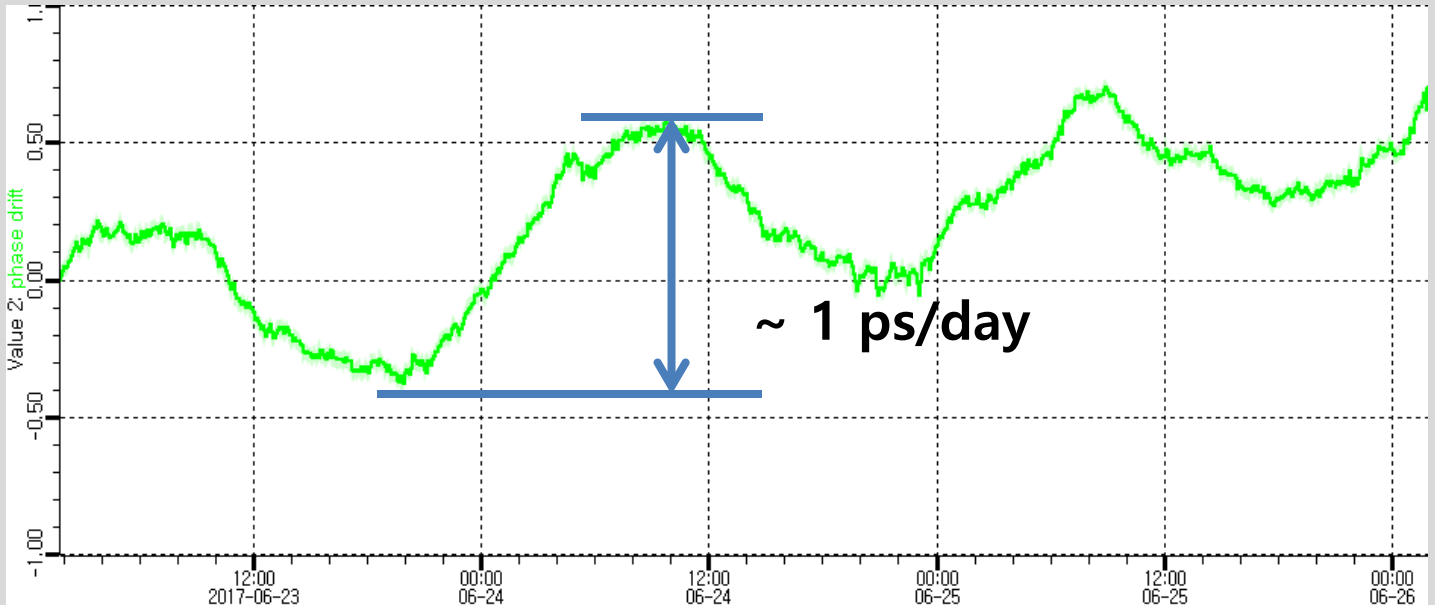




Temperature stability of Duct : **0.01℃/day**

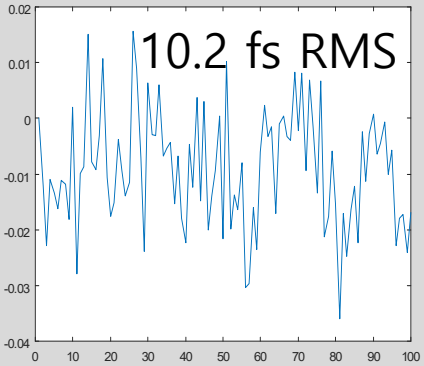
Phase Drift Measurement



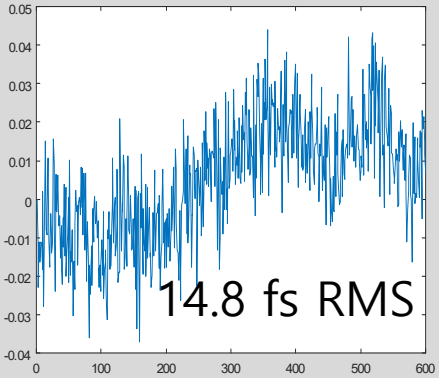


Timing Jitter Measurements

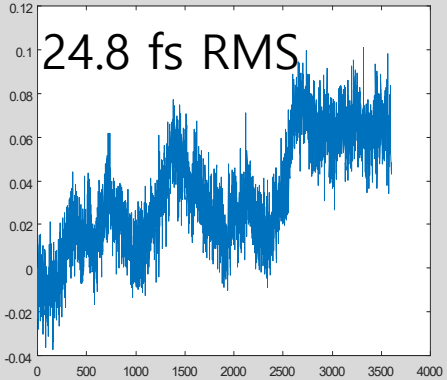
100 Seconds



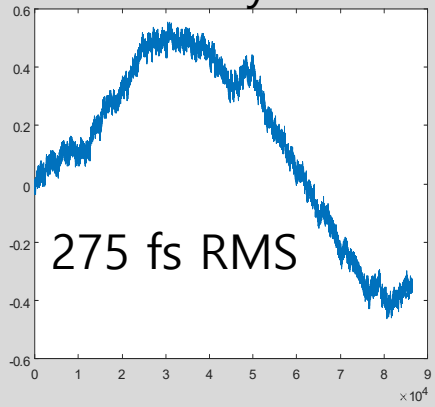
10 minutes

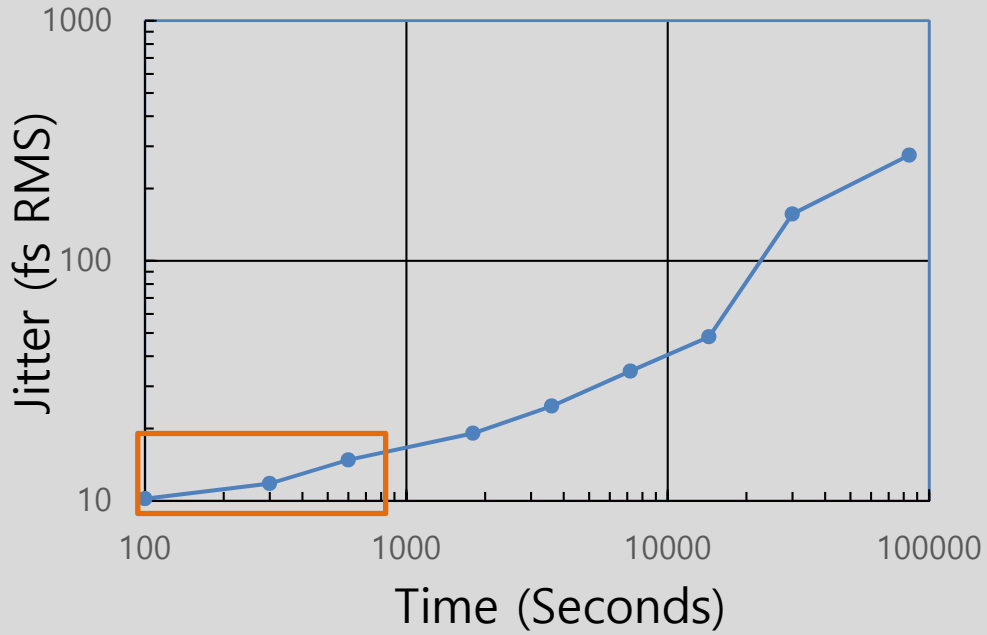


1 hour

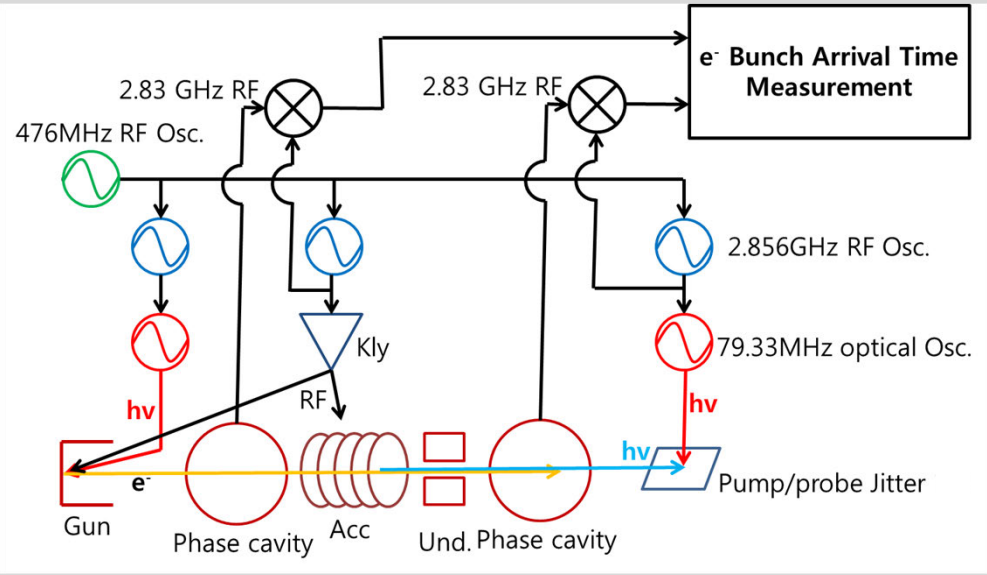


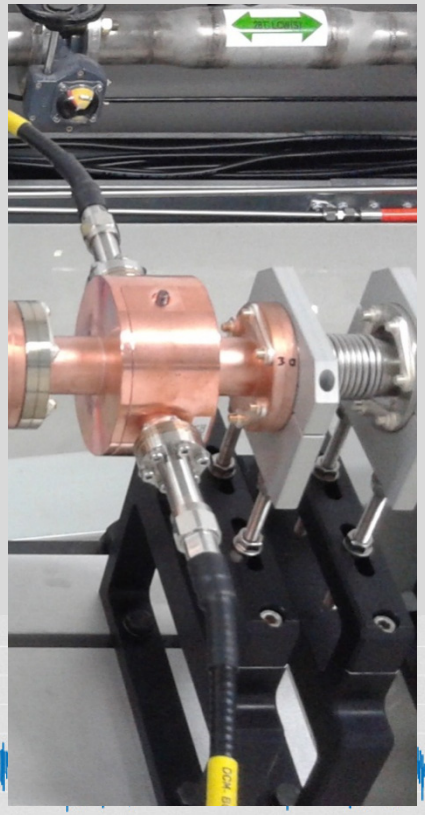
1day

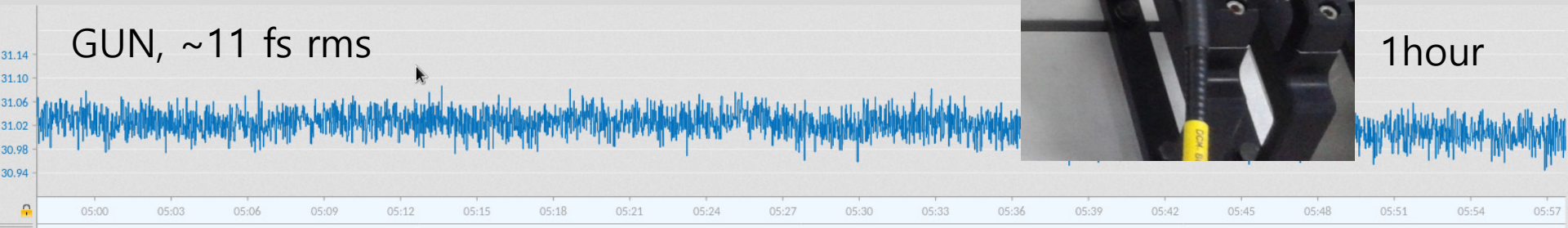


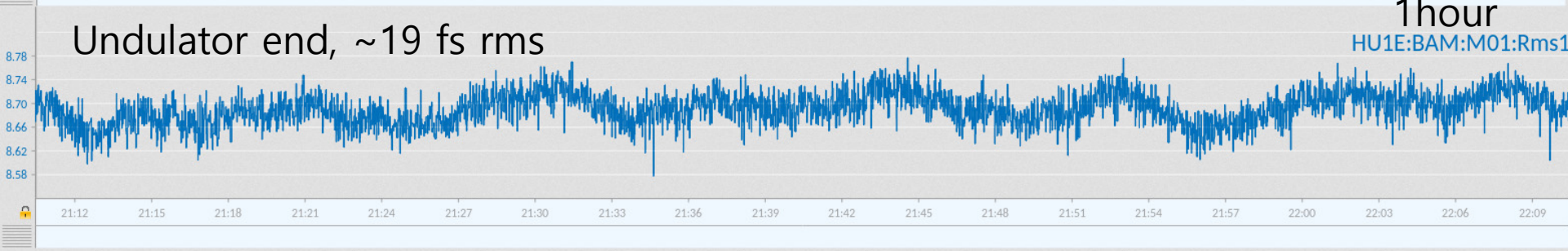


Beam Arrival Time

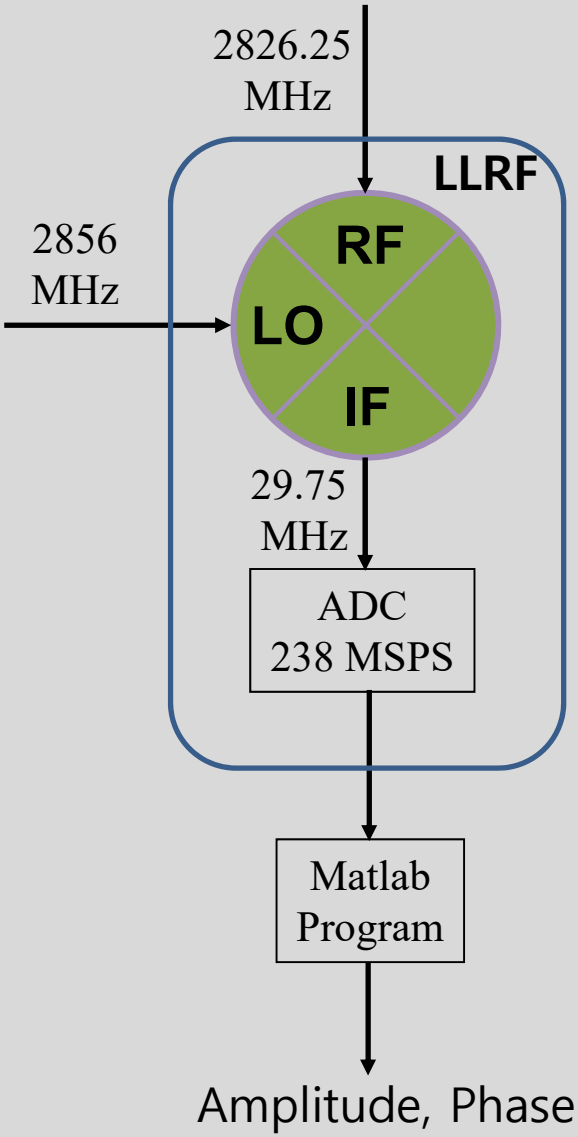


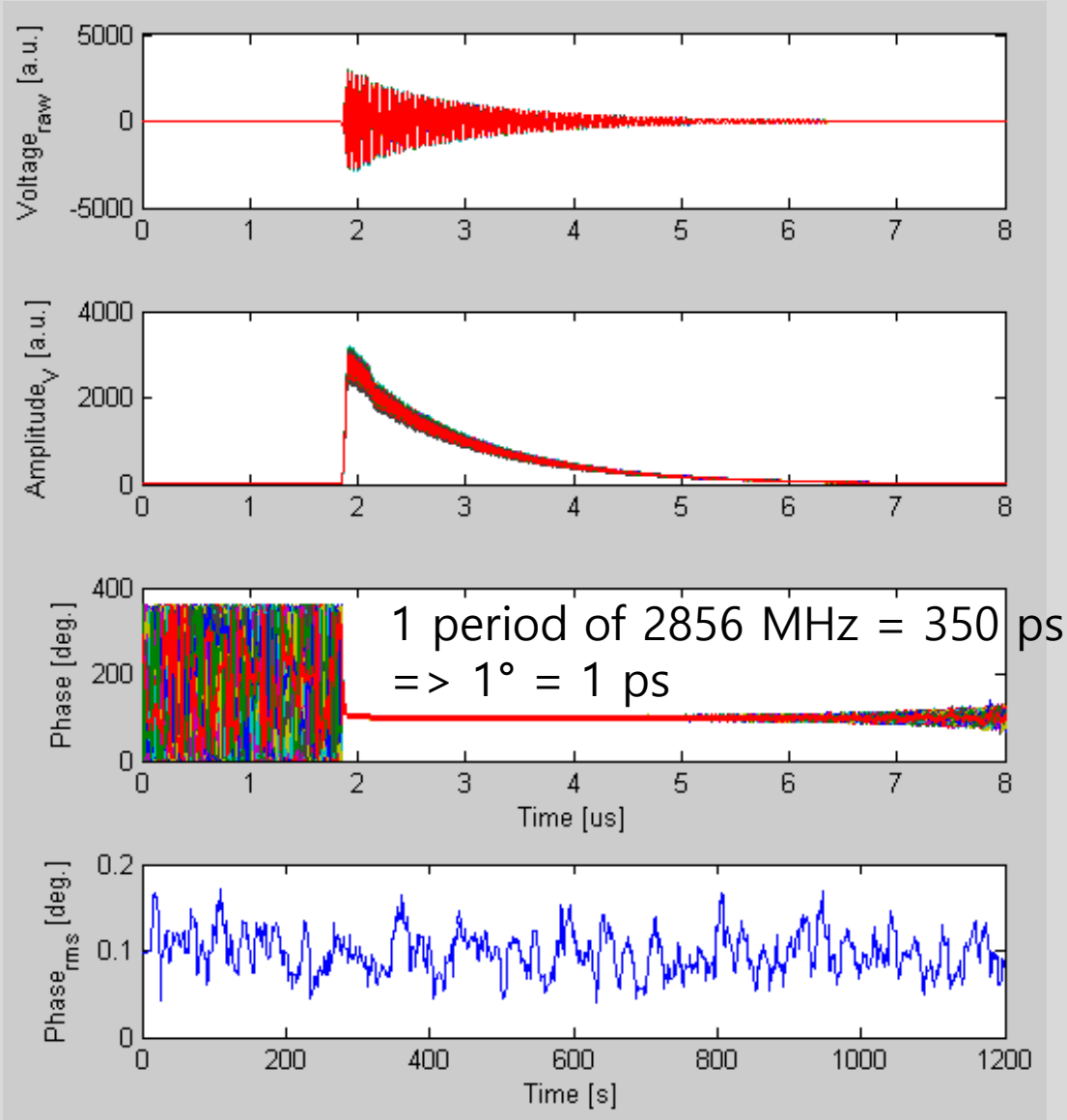




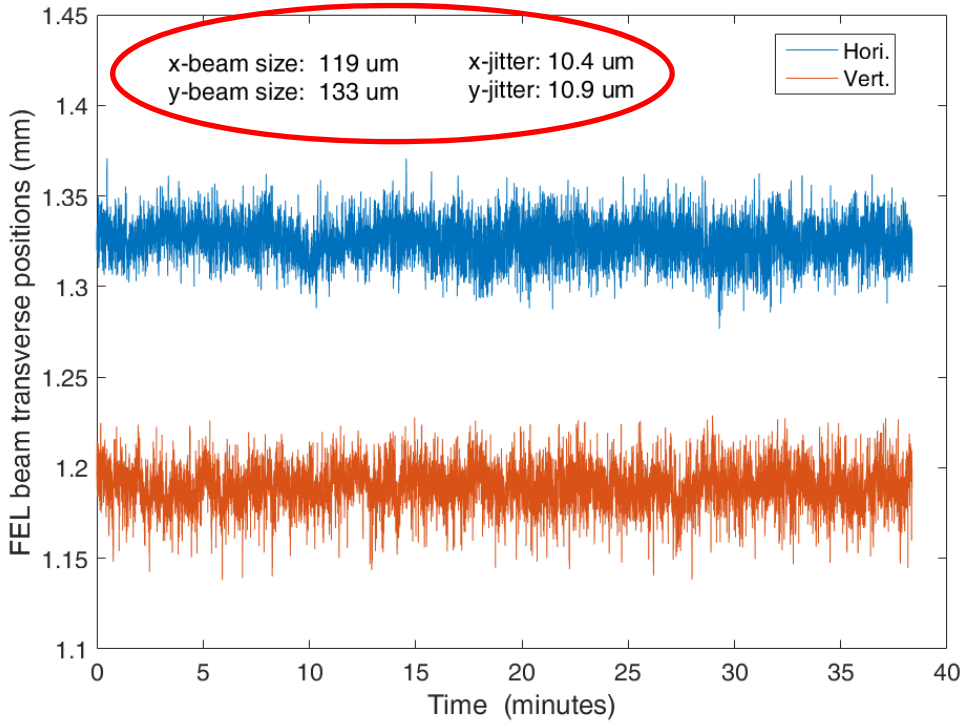


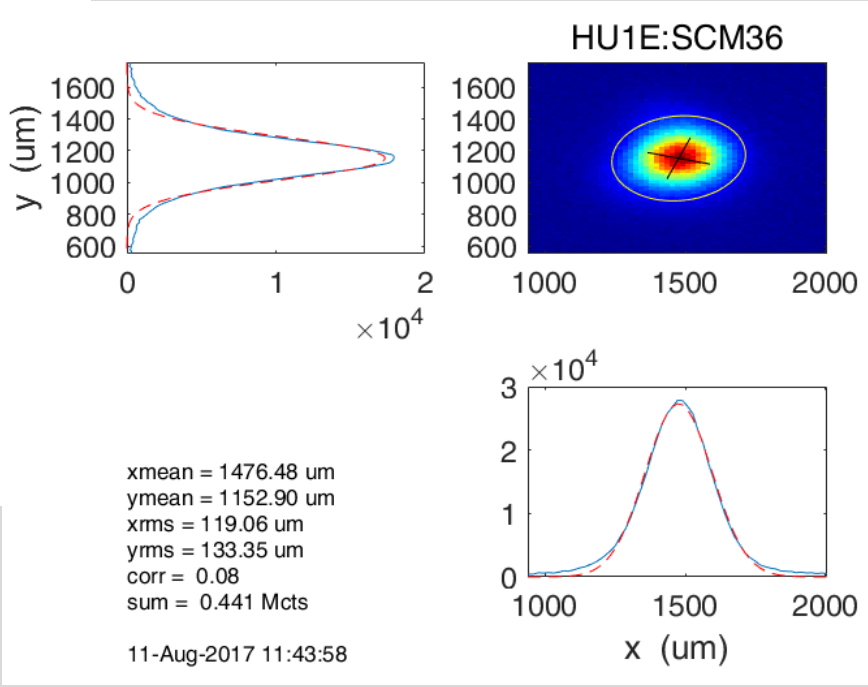
Beam Arrival Monitor





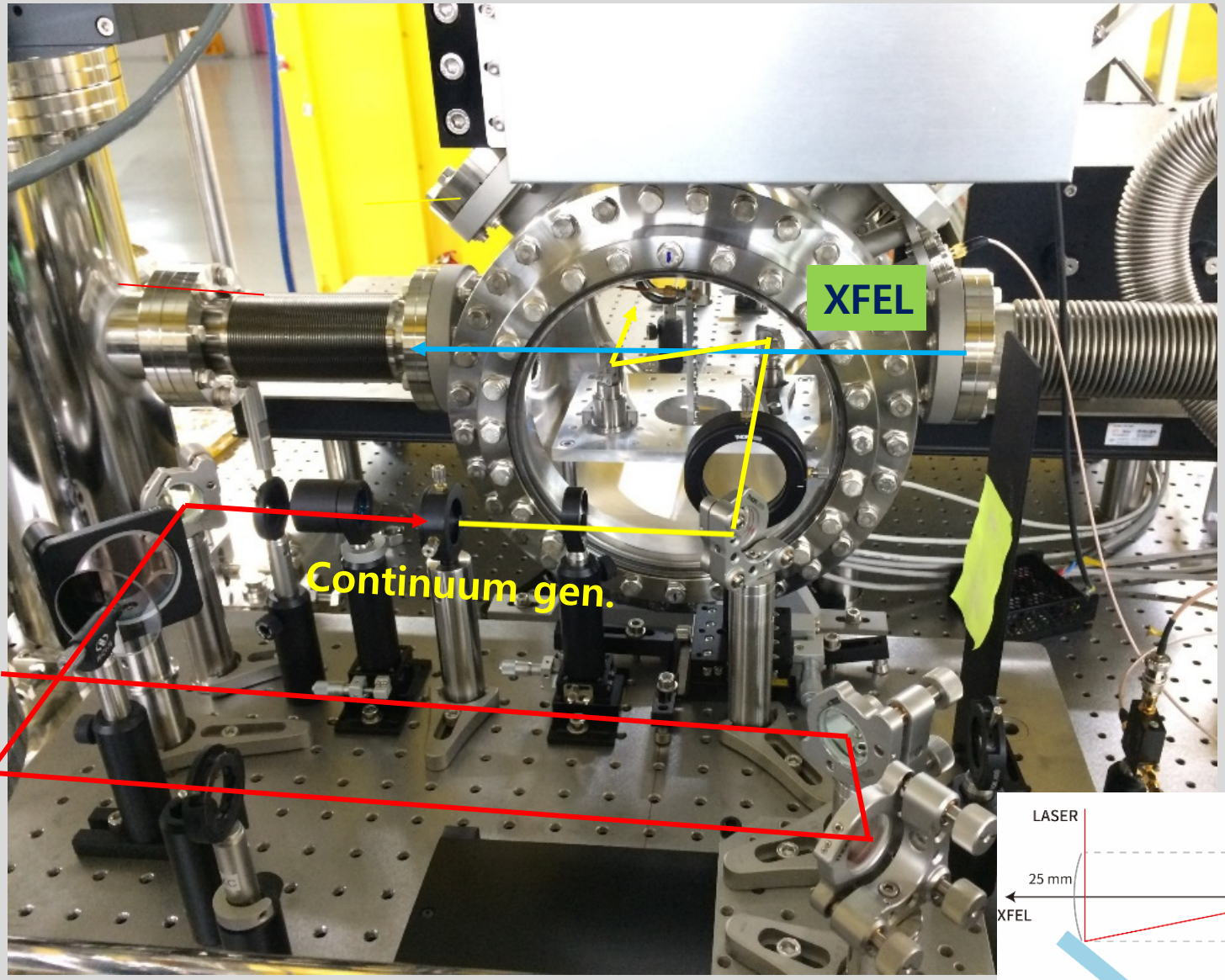
FEL Position Jitter





Measured at 40 m downstream YAG-screen from last undulator

Laser & XFEL Cross-Correlator



Fast photodiode
(30ps rise)
YAG:Ce

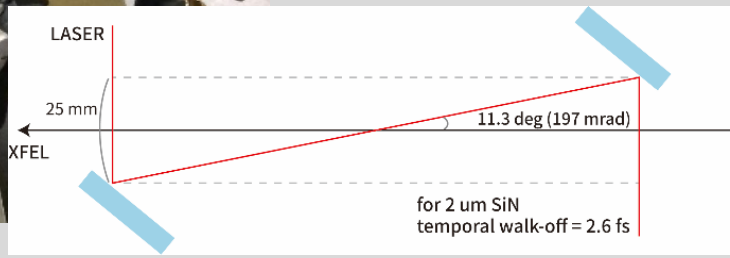
Pin-hole (100 μr

SiN 500 nm

SiN (1 μm)

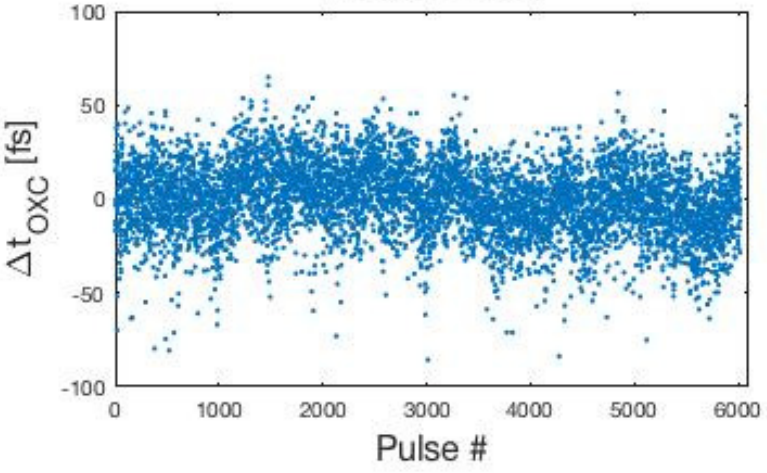
SiN (2 μm)

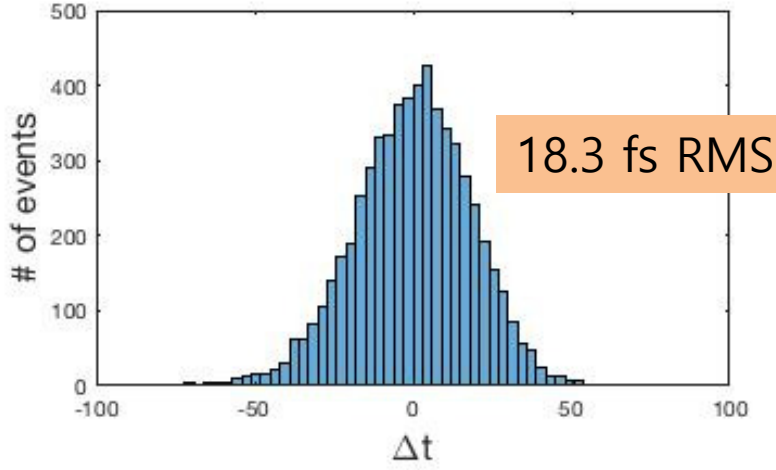
SiN Membrane holder



FEL Timing Jitter

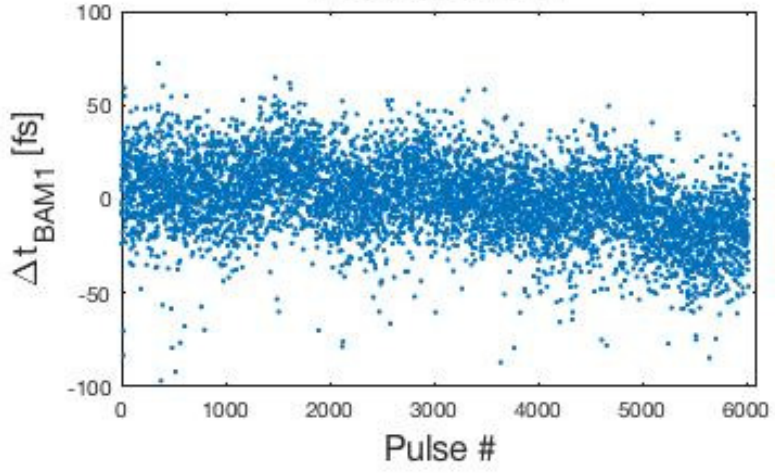
FEL-Laser Cross-correlation

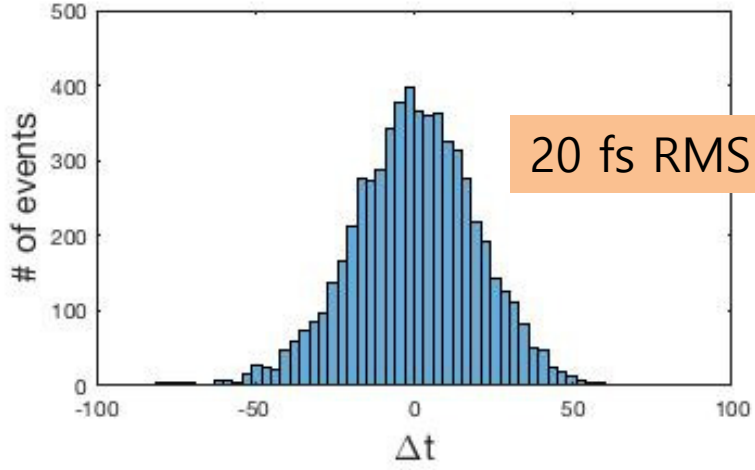




18.3 fs RMS

Beam Arrival Time at Undulator





20 fs RMS

Thank you for your attention.