

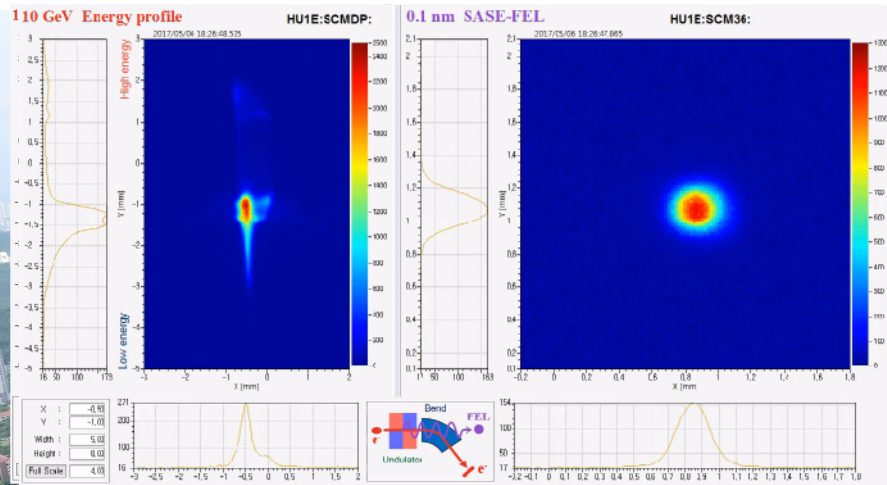
IPAC2018

Toward 10 fs Timing Stability of PAL-XFEL

Chang-Ki Min, Seonghoon Jung, Sang-Hee Kim, Soung Soo Park, Jinyul
Hu, Intae Eom, Heung-Soo Lee, Heung-Sik Kang
and on behalf of PAL-XFEL team



Pohang Accelerator Laboratory

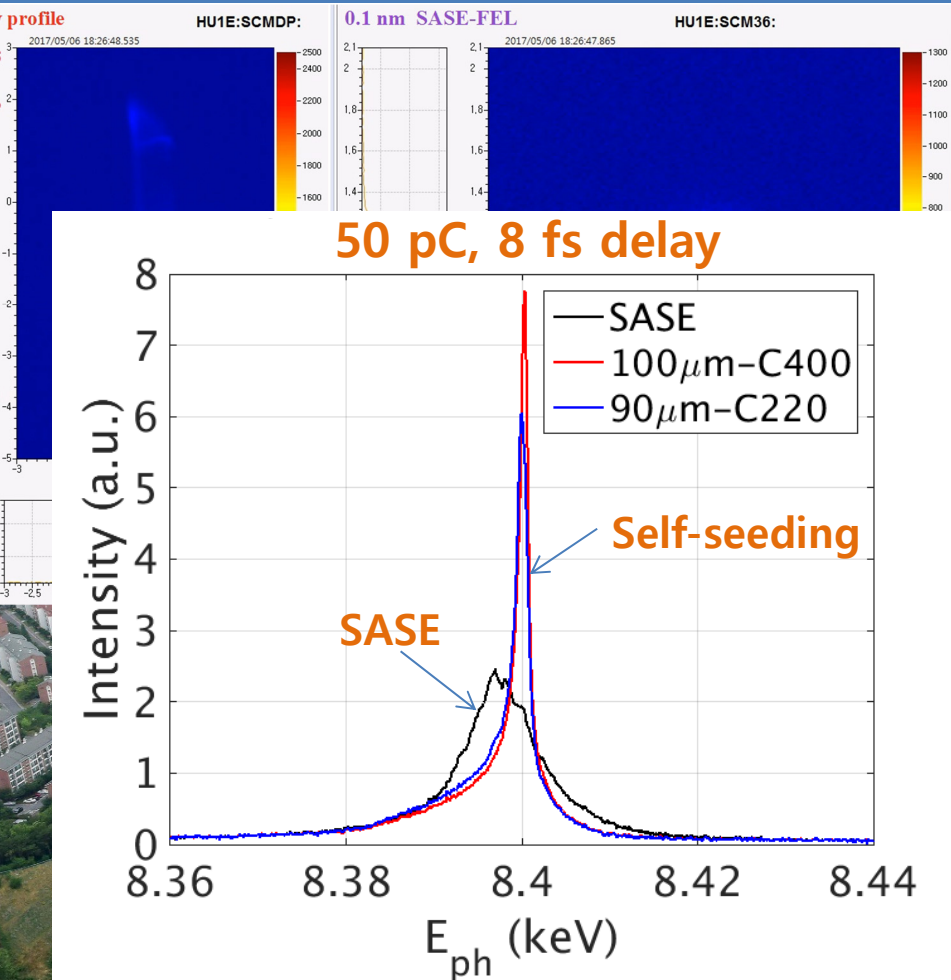


Apr. 2011: PAL-XFEL project started
Apr. 2016: Commissioning started
Jun. 2017: User-service start
 (120 days for user, >95% of availability)

- ◆ 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**

2018' Plan

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

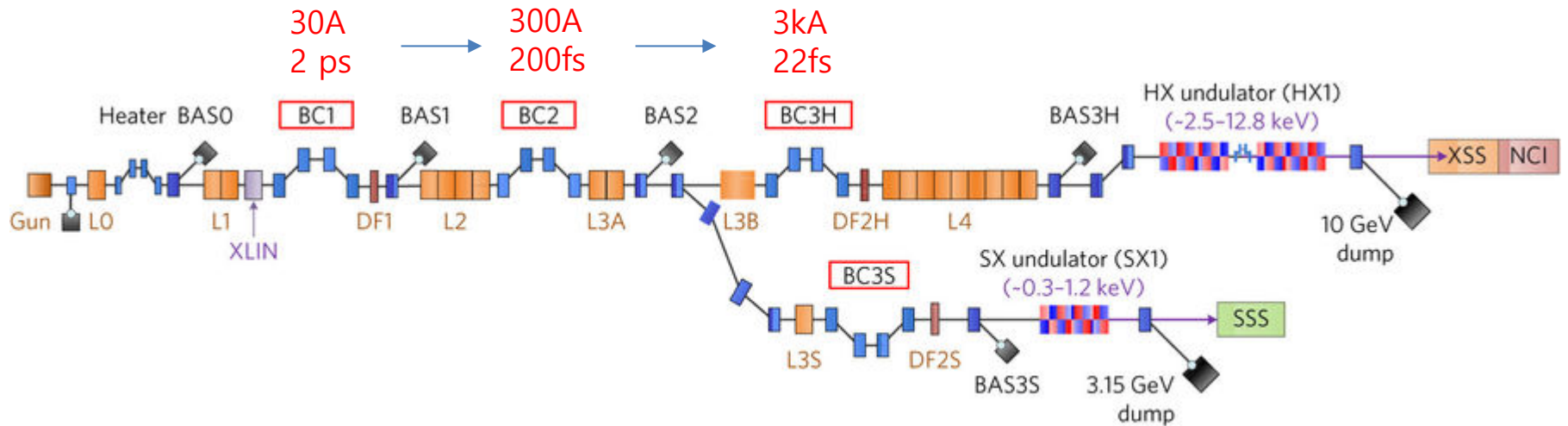


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Main parameters

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)

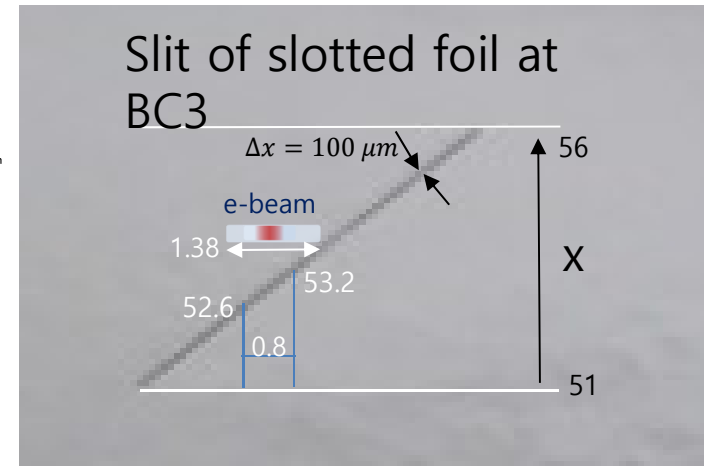
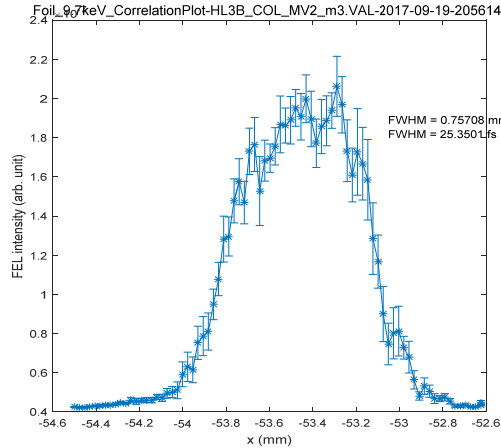
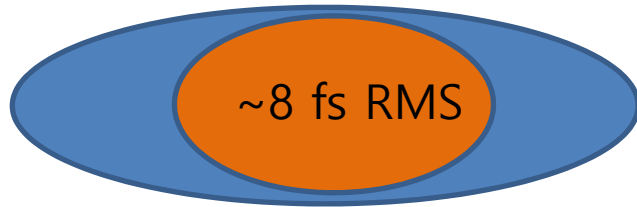
Undulator Line	HX1	SX1
Wavelength [nm]	0.1 ~ 0.6	1 ~ 4.5
Beam Energy [GeV]	4 ~ 10	3.15
Wavelength Tuning [nm]	0.6 ~ 0.1 (energy or gap)	4.5 ~ 3 (energy) 3 ~ 1 (gap)
Undulator Type	Planar, out-vac.	Planar
Undulator Period / Gap [mm]	26 / 8.3	35 / 8.3

※ 3BC improves FEL power stability and phase tolerance

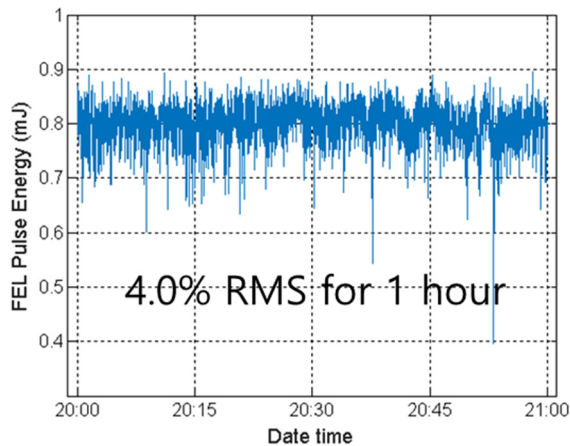
- Extremely useful FEL for time-resolved experiments
- RF timing distribution and Optical laser synchronization to RF reference
- e- bunch arrival timing jitter and Pump-probe timing jitter
- Recent stability upgrade of modulator system
- FEL operation without X-band linearizer

• Pedestal free pulses

~20 fs RMS

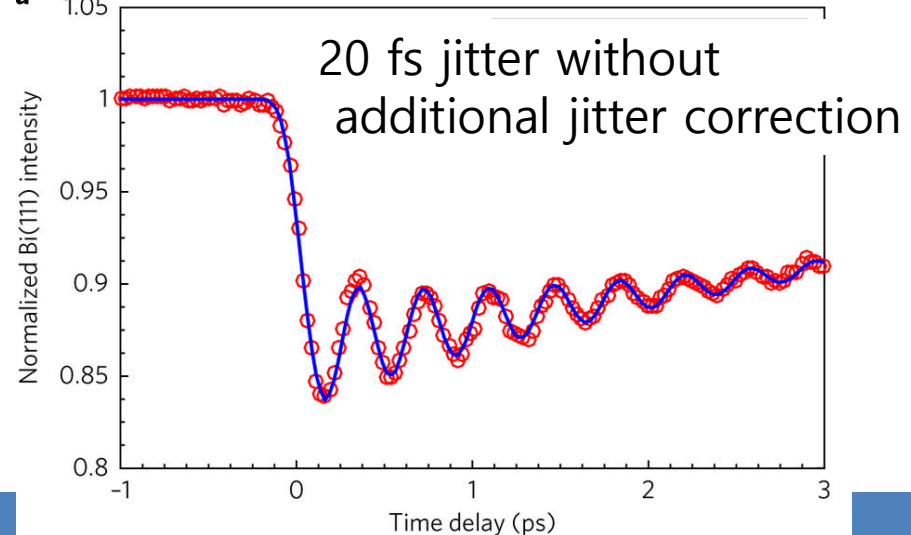


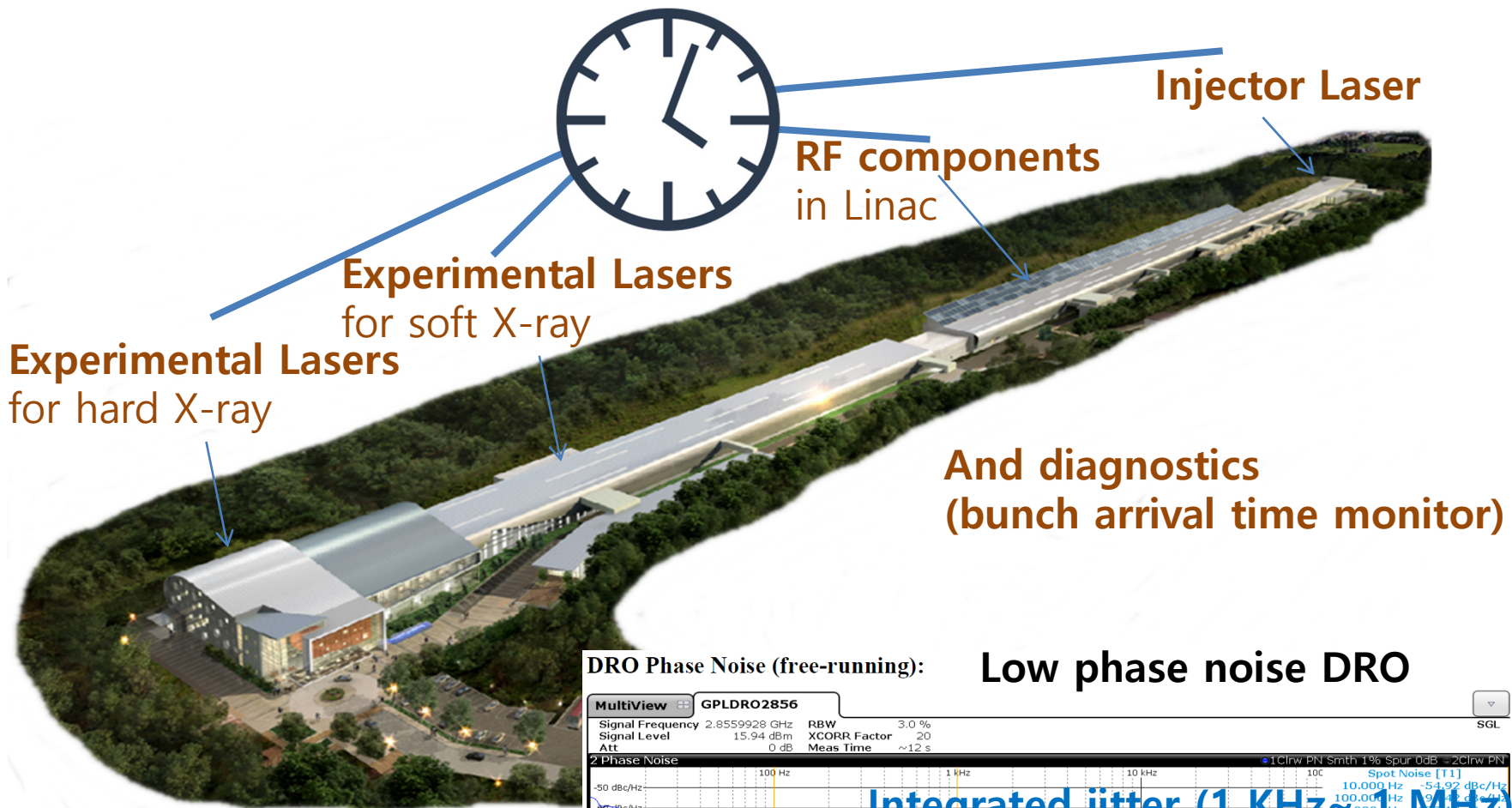
• Low timing jitter between FEL and optical pulses



Stable phase space contents

a Bi(111) Bragg diffraction intensity modulation





Experimental Lasers
for hard X-ray

Experimental Lasers
for soft X-ray

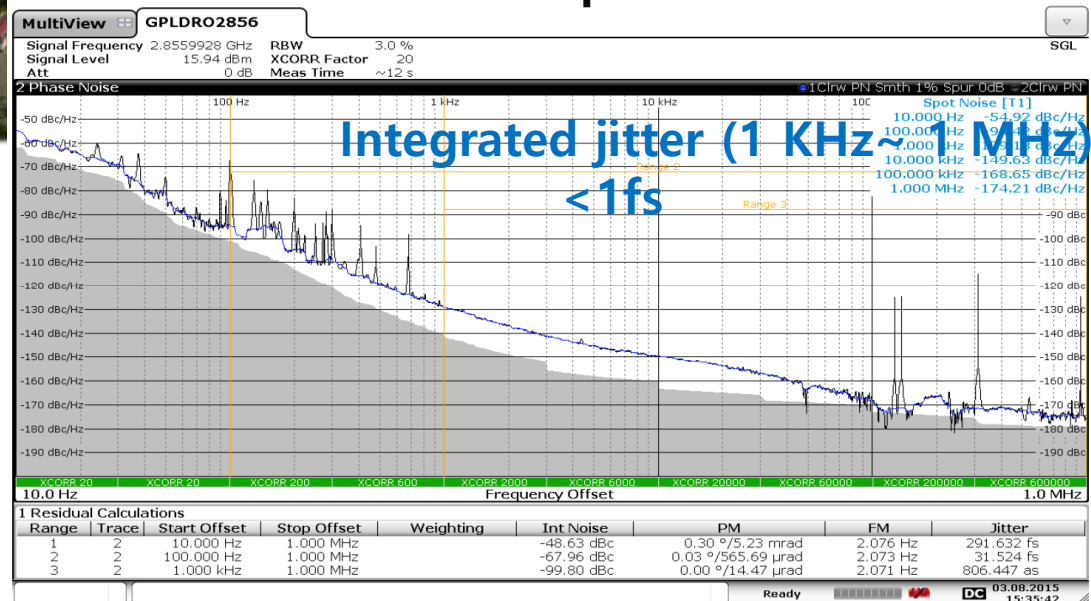
RF components
in Linac

Injector Laser

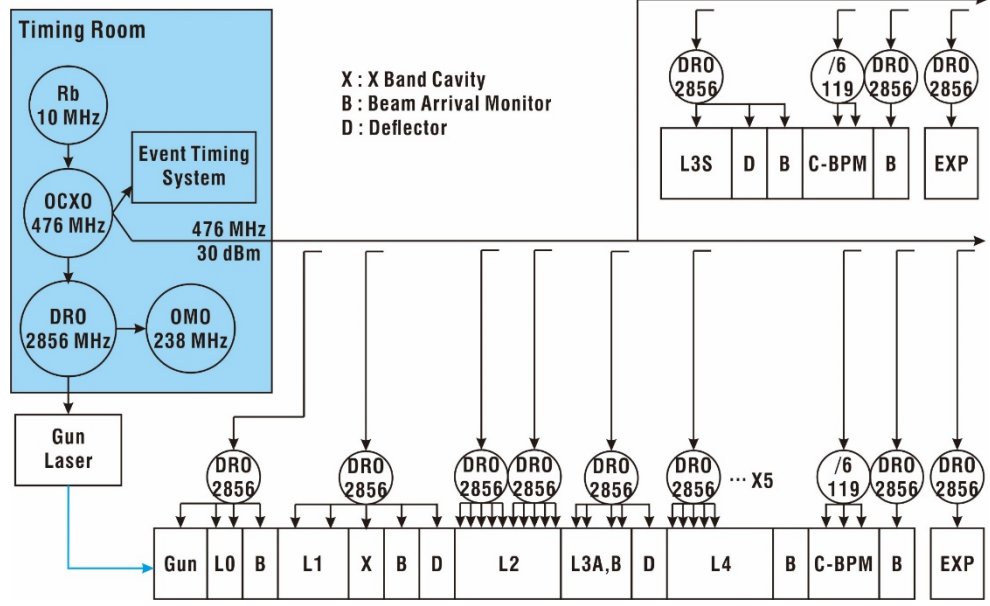
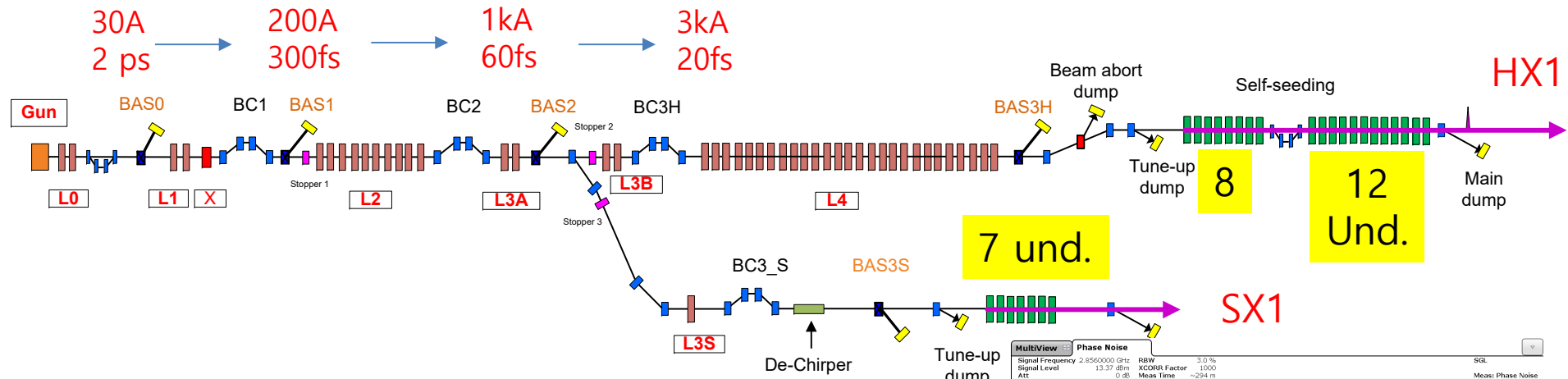
And diagnostics
(bunch arrival time monitor)

DRO Phase Noise (free-running):

Low phase noise DRO

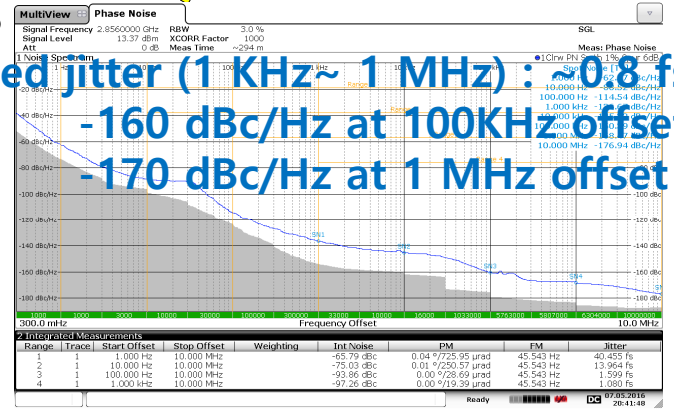


PAL-XFEL timing distribution (2.856GHz RF)

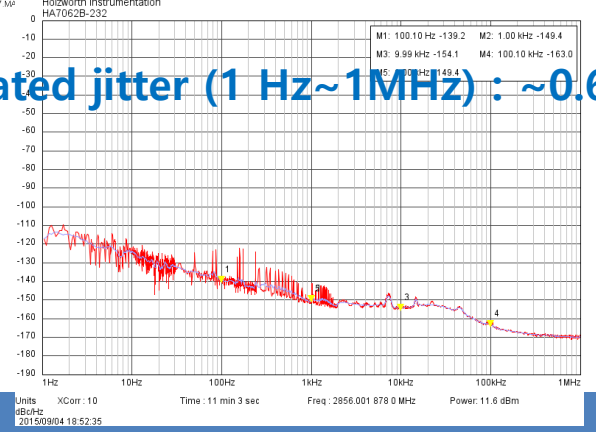


RF only and Passive stabilization

Integrated jitter (1 KHz~ 1 MHz) : ~ 0.8 fs
 -160 dBc/Hz at 100KHz offset
 -170 dBc/Hz at 1 MHz offset

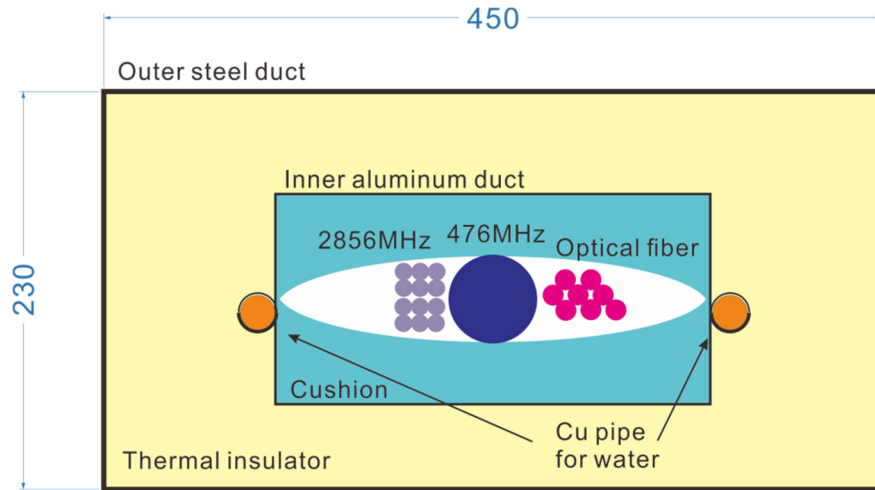


Integrated jitter (1 Hz~1MHz) : ~ 0.6 fs



Temperature stabilization of RF Cables

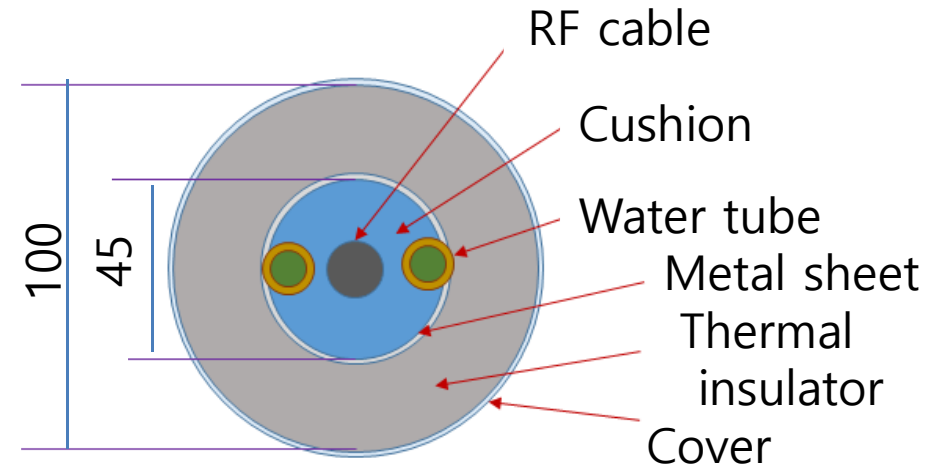
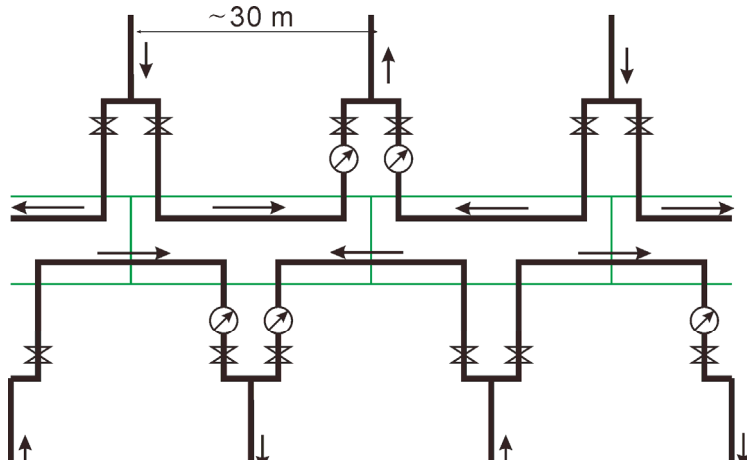
Duct cross-section



With cover open

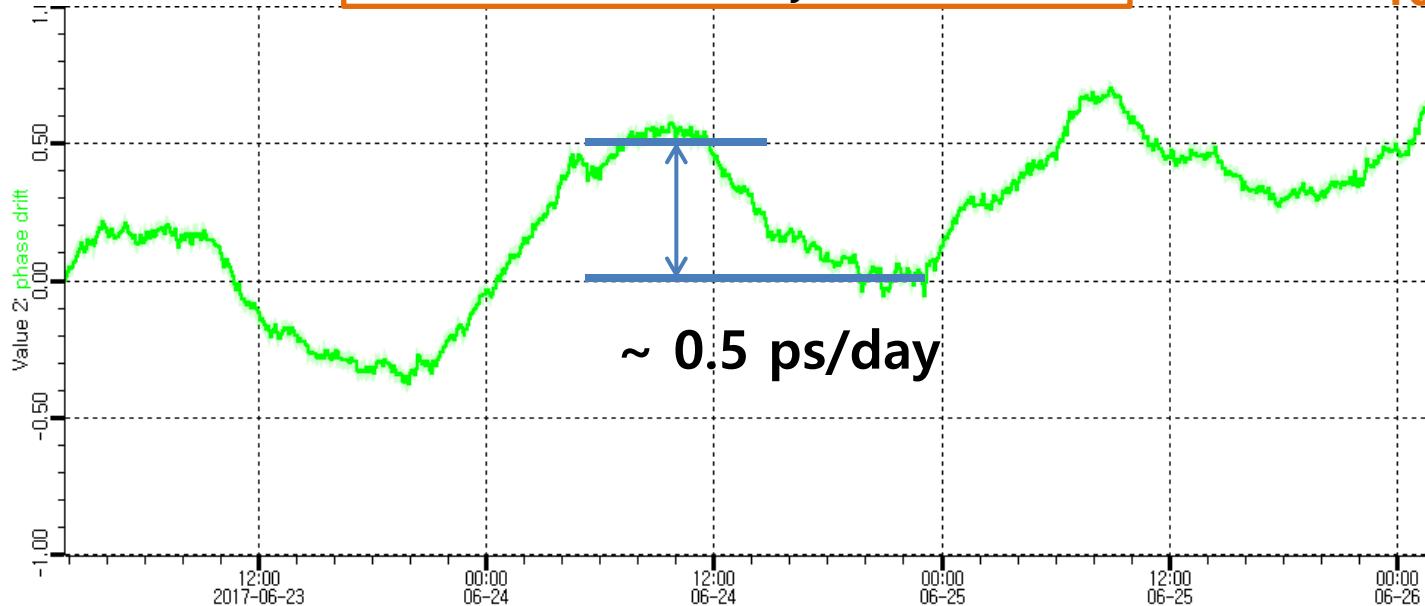
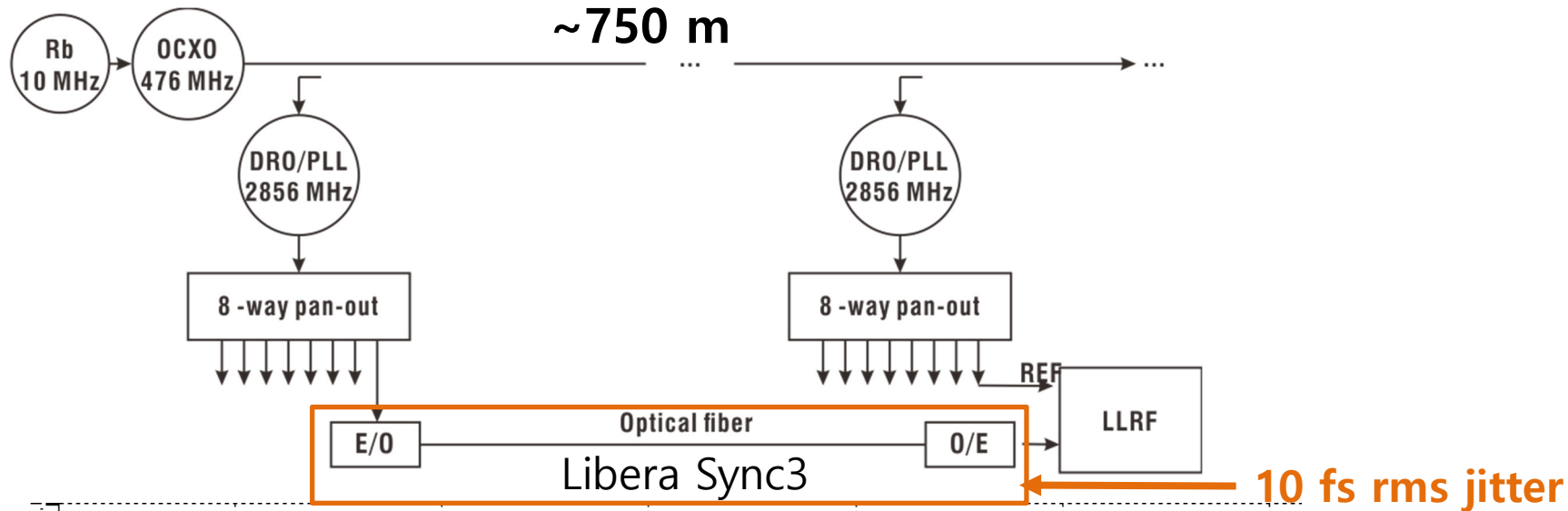


LCW flow diagram

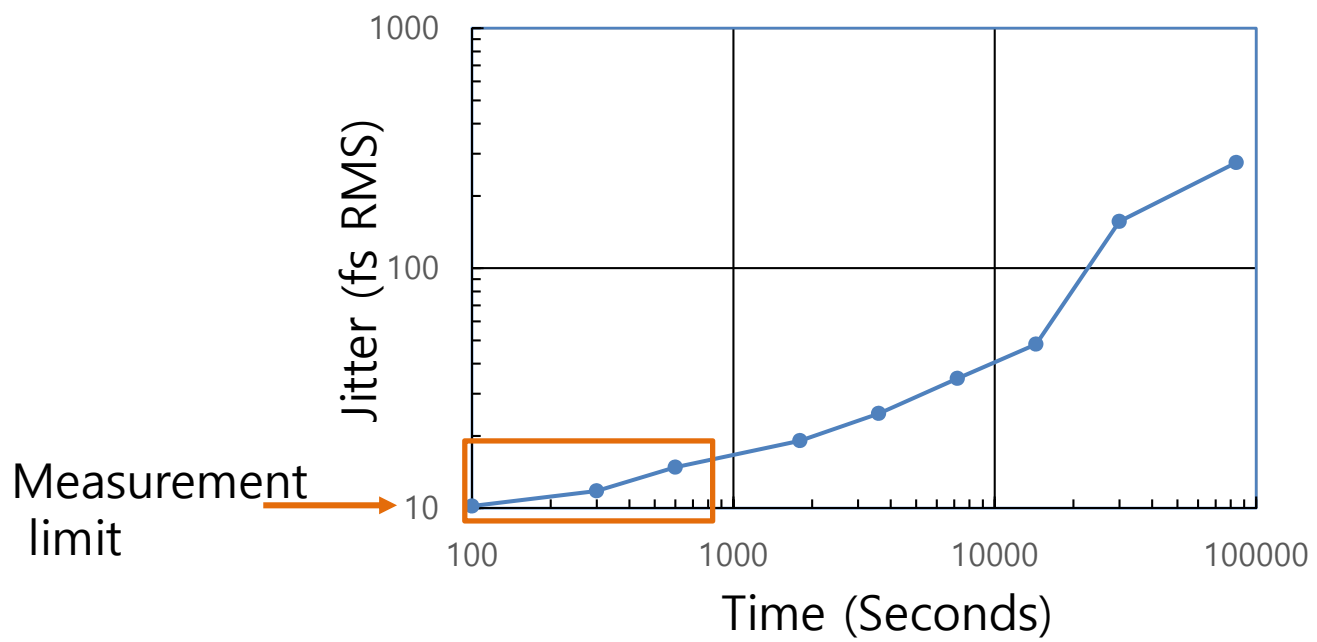
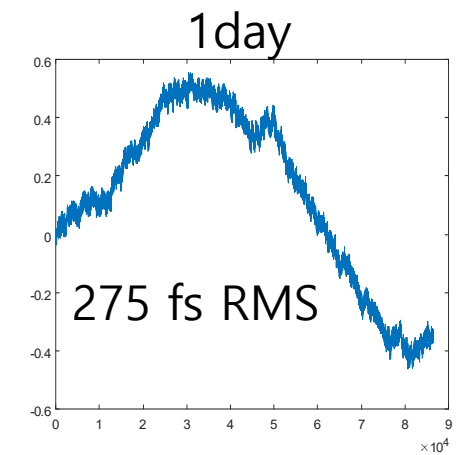
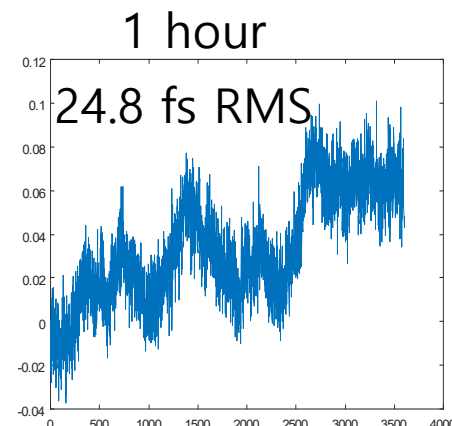
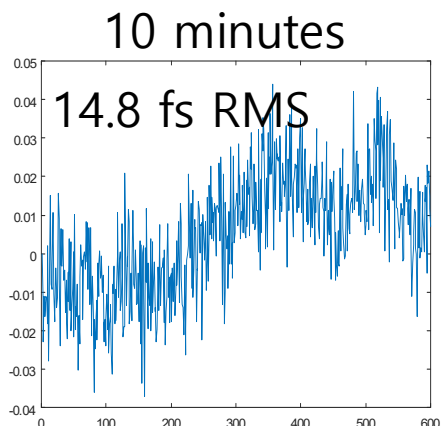
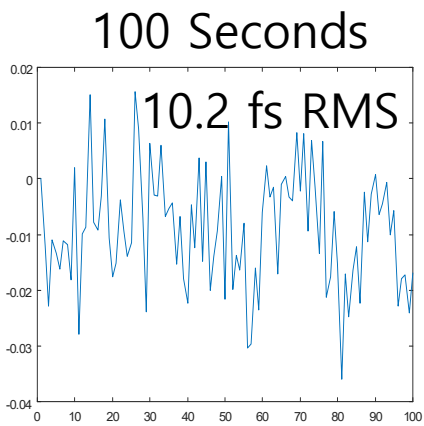


Temperature stability of Duct : **0.01°C/day**

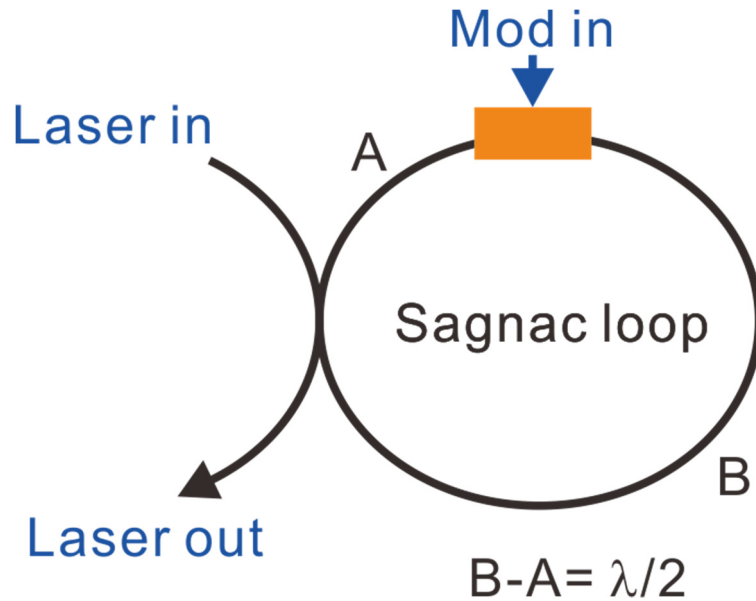
Phase Drift monitoring using drift-free optical link



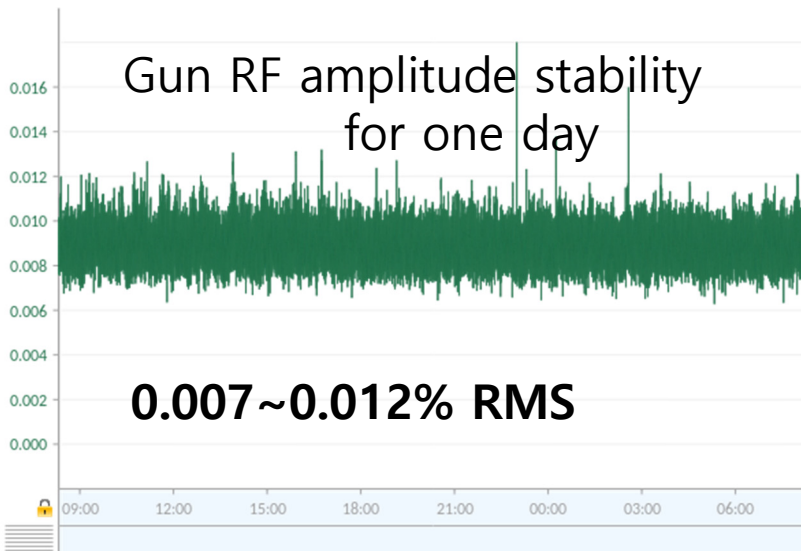
PAL Time scale of timing error in reference timing distribution



Photocathode gun - e⁻ bunch arrival jitter



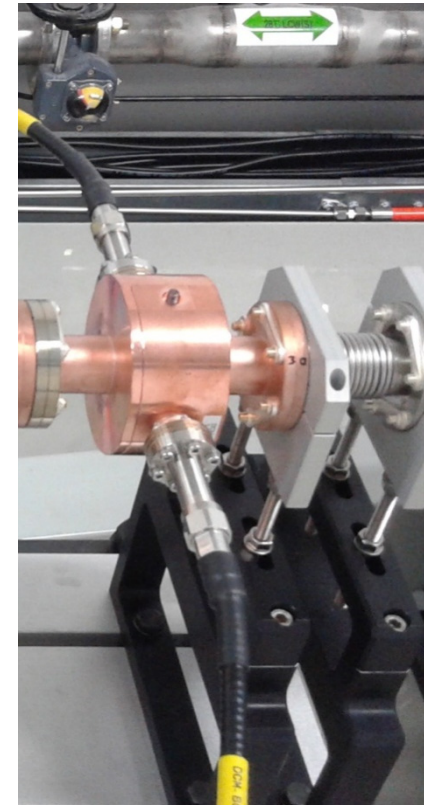
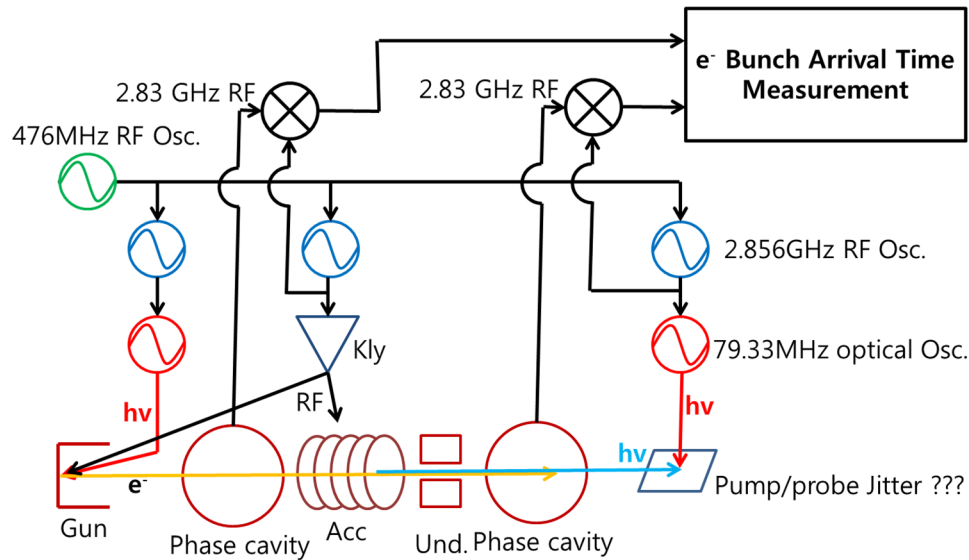
Home-built sensitive phase detector
 Between RF and optical laser
 (2.856 GHz) (79.33MHz Ti:S)
 Provides **10 fs level jitter**



RF system adds $\sim 10^{-4}$ amplitude jitter
 ~ 10 fs timing jitter

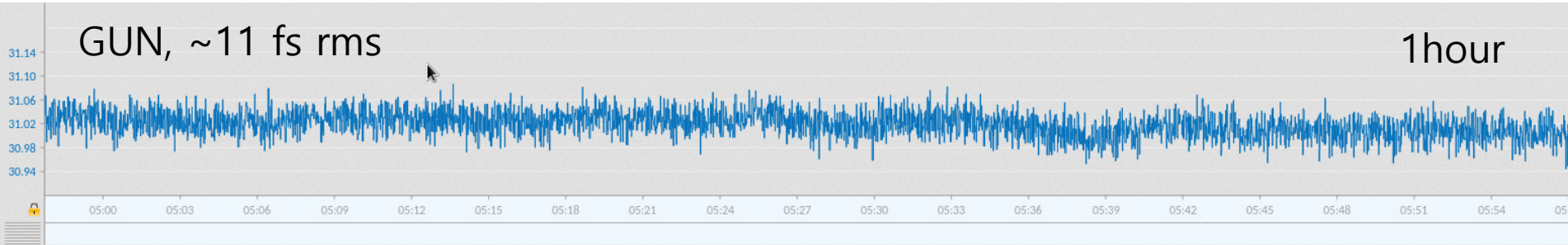
Beam arrival time jitter at gun

Monopole S-band cavity (phase cavity)

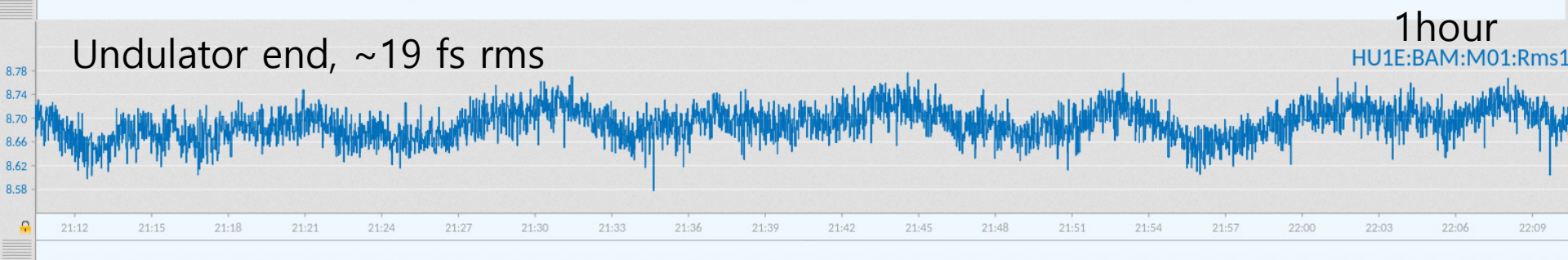
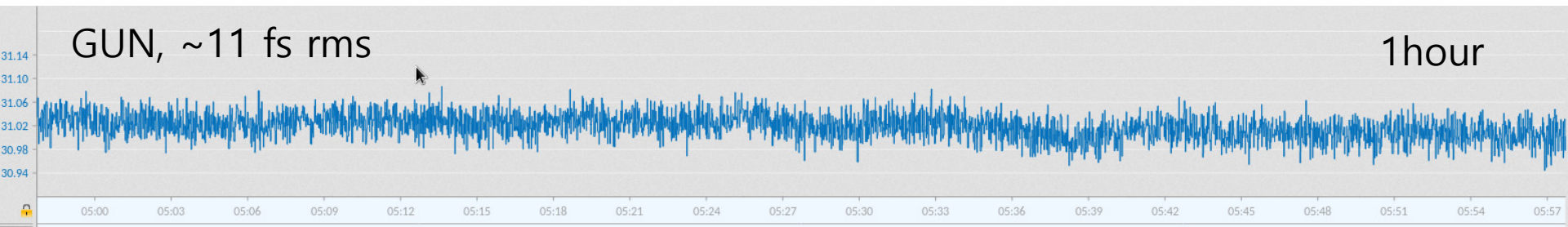
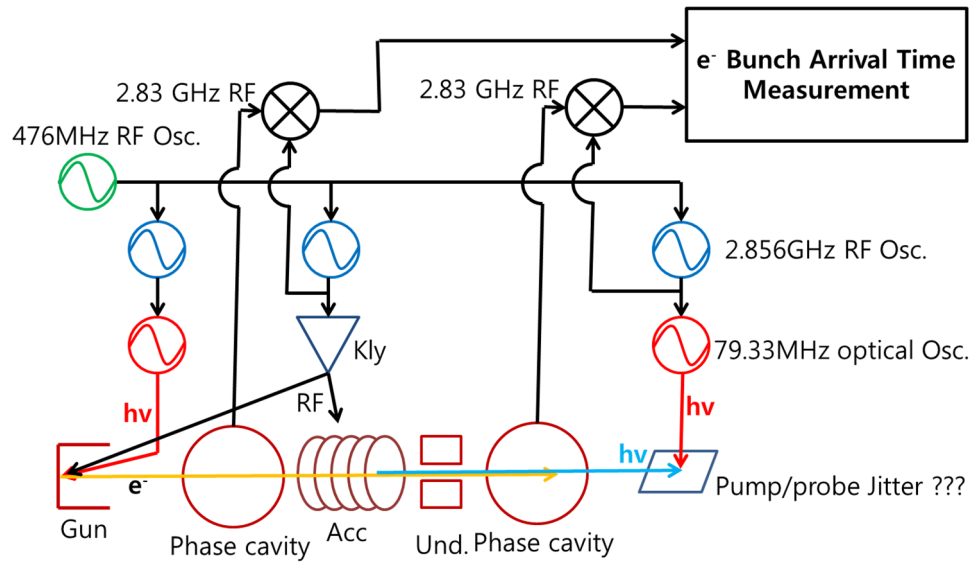


GUN, ~11 fs rms

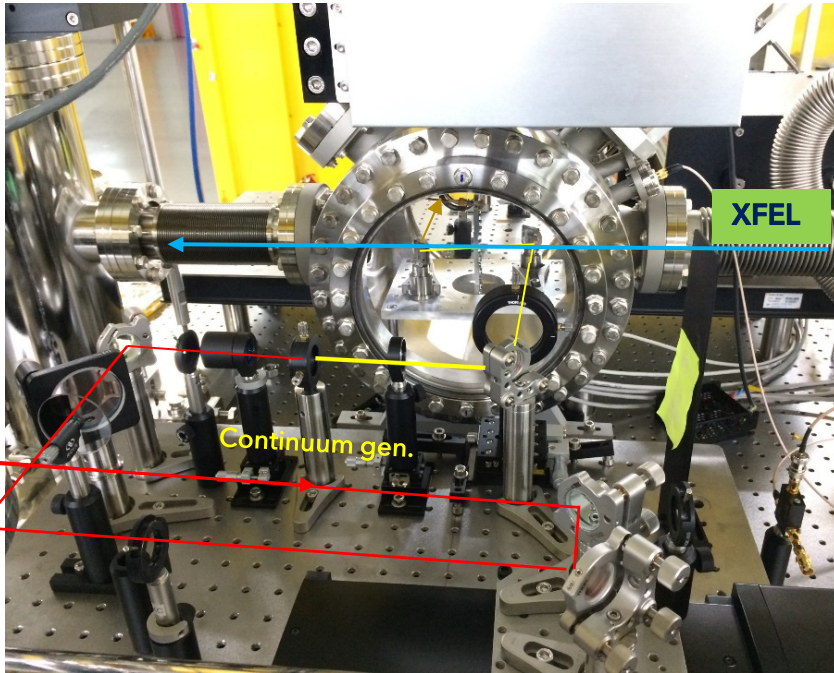
1 hour



PAL Beam arrival time jitter at gun and undulator end



OXC (Optical laser & XFEL Cross-correlator) at EH1 (XSS)



SiN Membrane holder



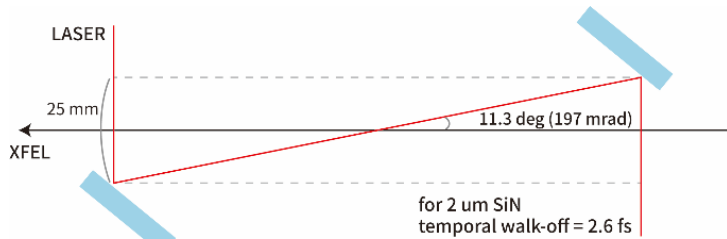
Fast photodiode
(30ps rise)
YAG:Ce

Pin-hole (100 μm)

SiN 500 nm

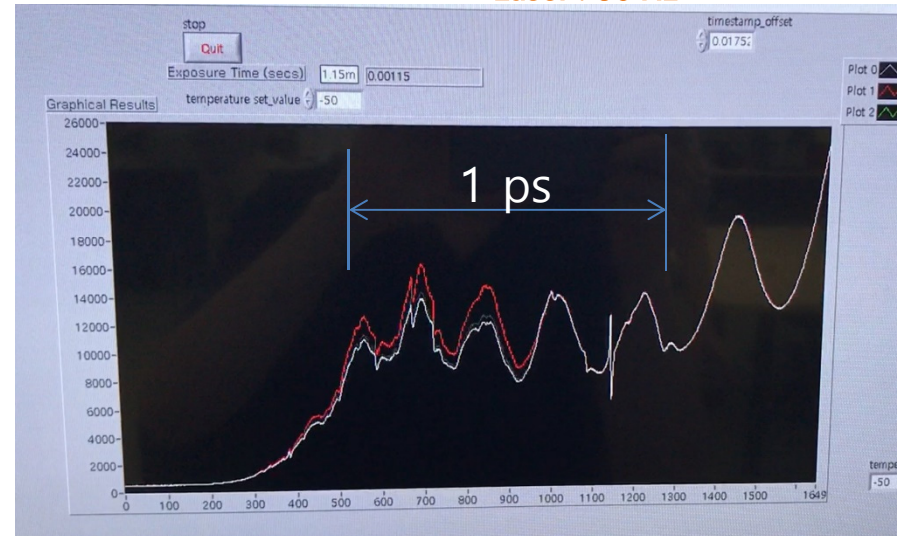
SiN (1 μm)

SiN (2 μm)



CCD spectra (single shot)

XFEL : 30 Hz at 7 keV
Laser : 60 Hz

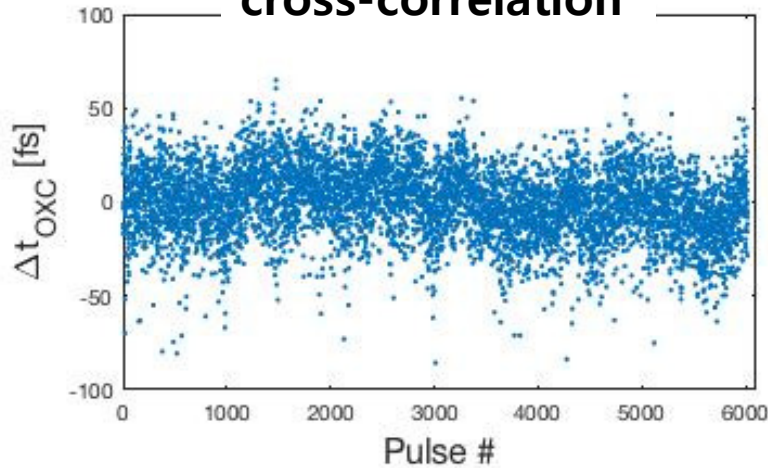


Optical Cross-correlator

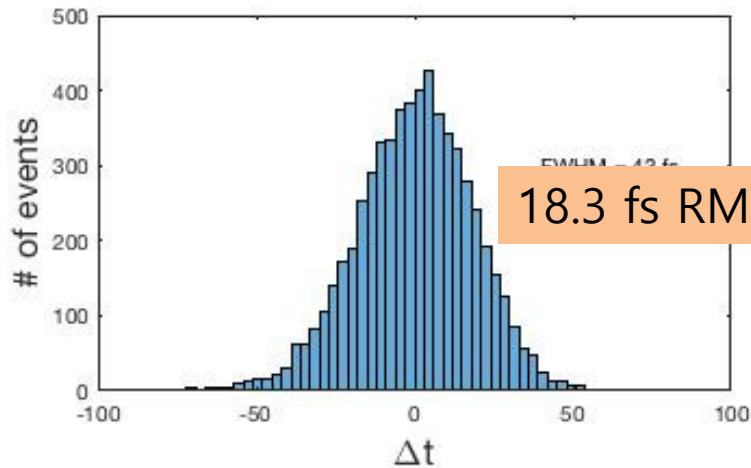
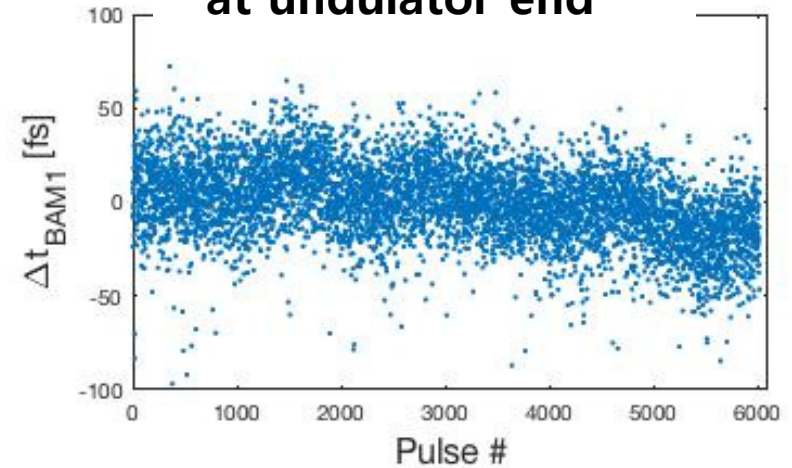
Dr. Eom

FEL timing jitter

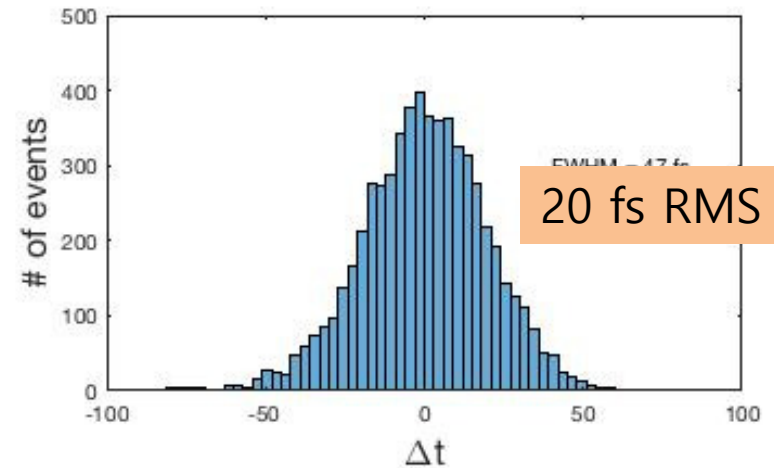
FEL/optical laser
cross-correlation



e^- bunch arrival time
at undulator end



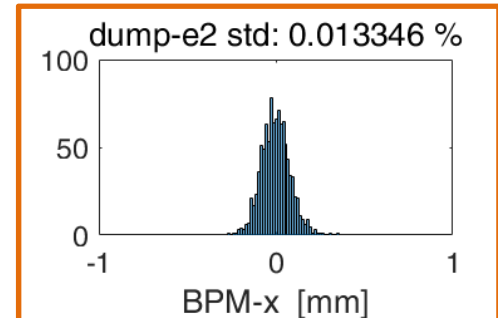
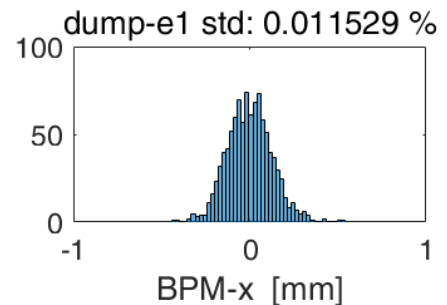
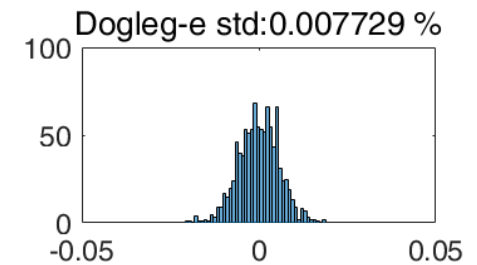
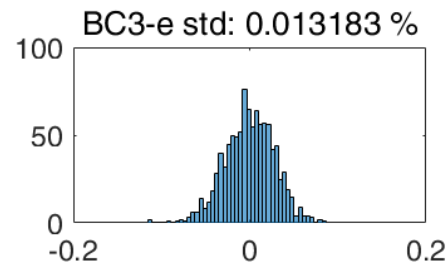
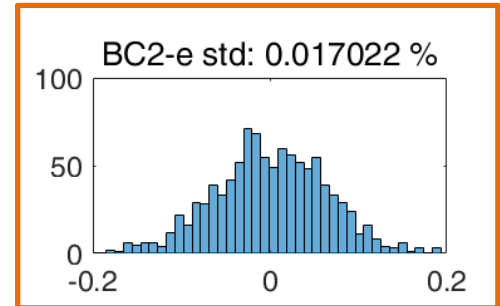
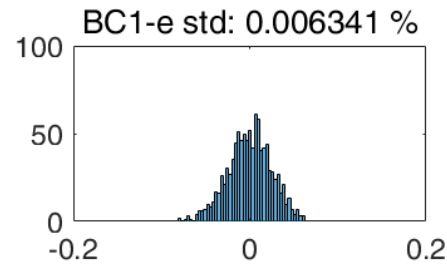
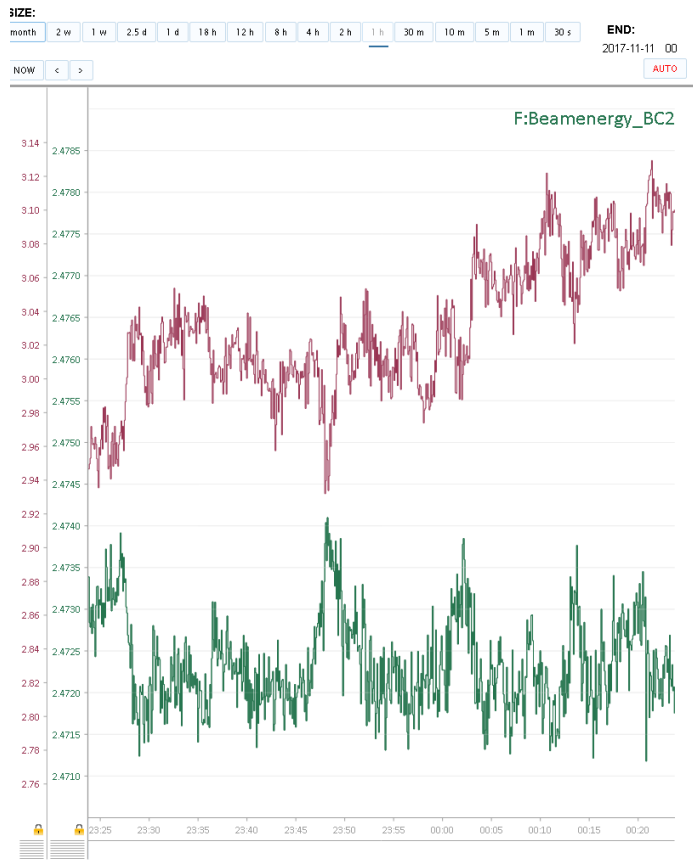
Optical laser synchronization jitter
Added ~ 10 fs



BAM instrumental jitter
Added > 10 fs

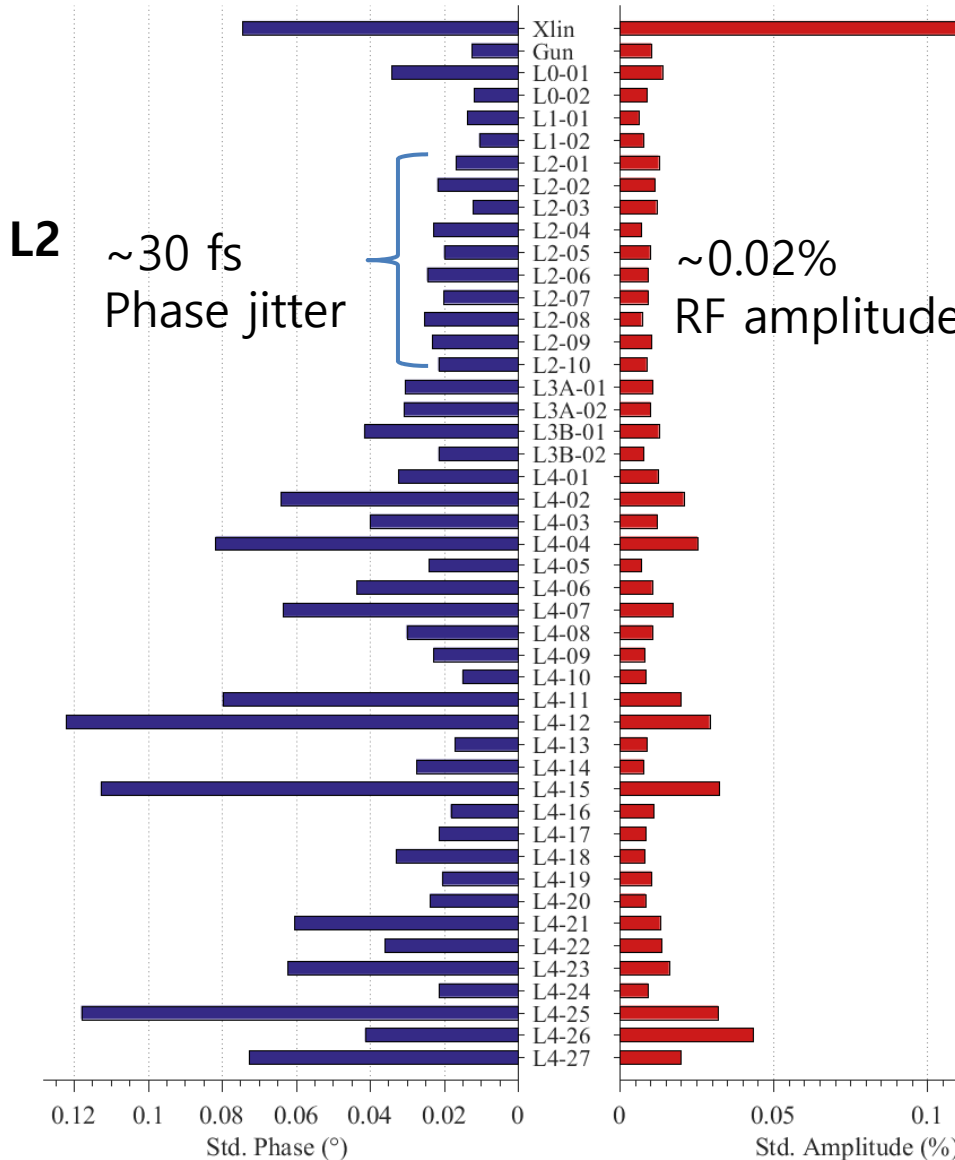
E-beam energy jitter

100 fs drift / 10^{-3} energy change at BC2

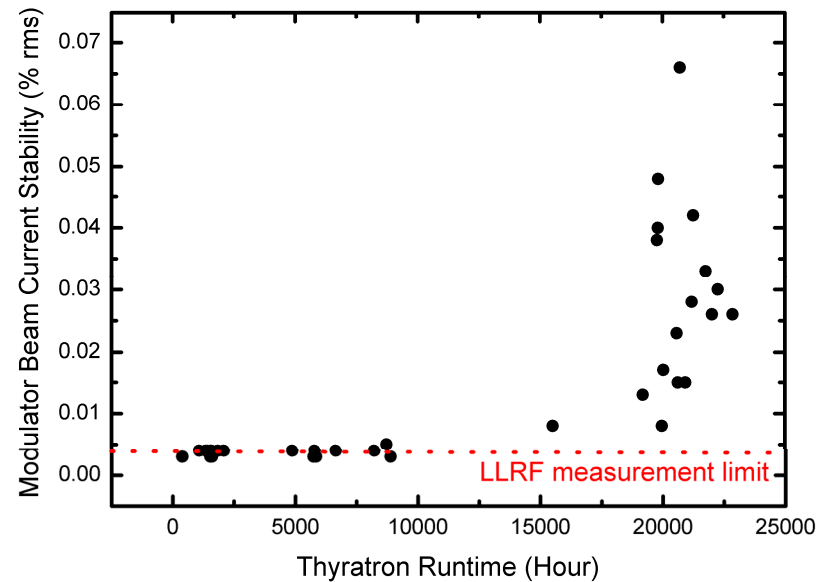


With updated modulators

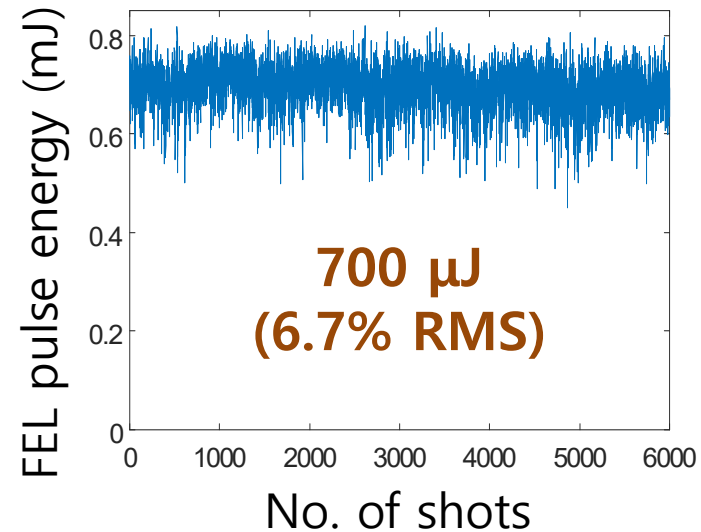
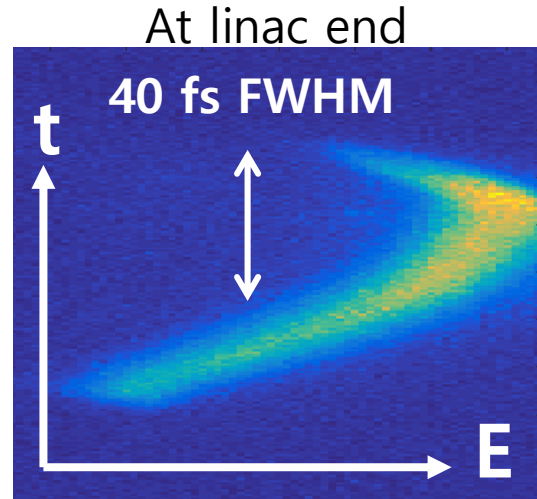
RF-stability (2018-04-17 18:47:19)



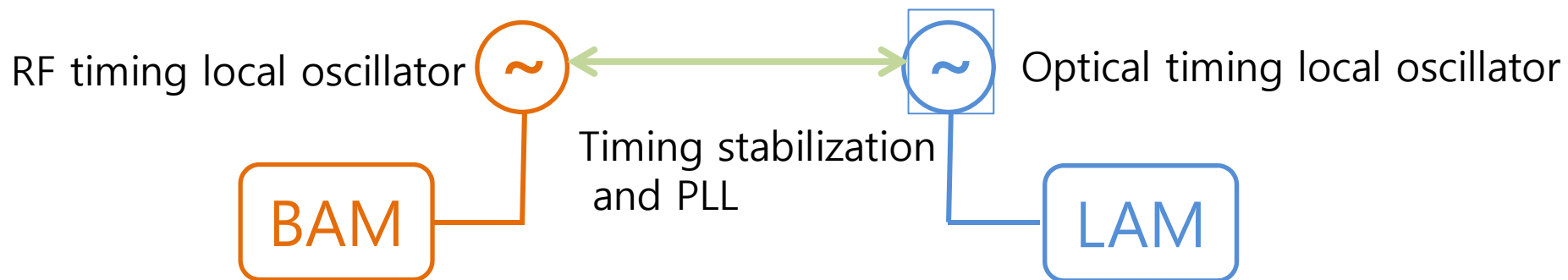
- Klystron solenoid MPS upgrade (~100ppm)
- Old thyratron replaced
- BC2 energy jitter
- L2 on crest operation, **0.007%**
- L2 off crest operation, **0.01%** (FEL mode, ~-20 deg)



- FEL operation without X-band linearizer (or using less power)



- Timing diagnostics (and feedback) using Local timing oscillators for Both BAM and laser pulses



- PAL-XFEL and optical laser for exp. shows **sub 20 fs jitter** performance at the measurement time scale of pump-probe experiment(**~10 minutes**).
- Predominant timing jitter(or drift) is correlated to **energy jitter at BC2**.
- With updated modulator system for L2, timing jitter estimated to **~10 fs**
- Plan to add timing diagnostic tools to tightly **lock FEL and optical laser pulses**

PAL ≈ 14 fs residual phase jitter from 1 Hz to 100 KHz
Out-of-loop measurement

