AFAD2018

Sub-20-femtosecond timing jitter of PAL-XFEL

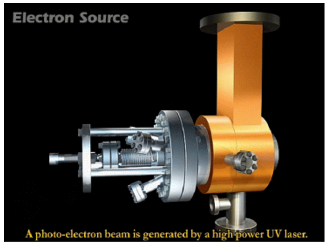
Jan 29, 2018

Chang-Ki Min
on behalf of PAL-XFEL team

Pohang Accelerator Laboratory

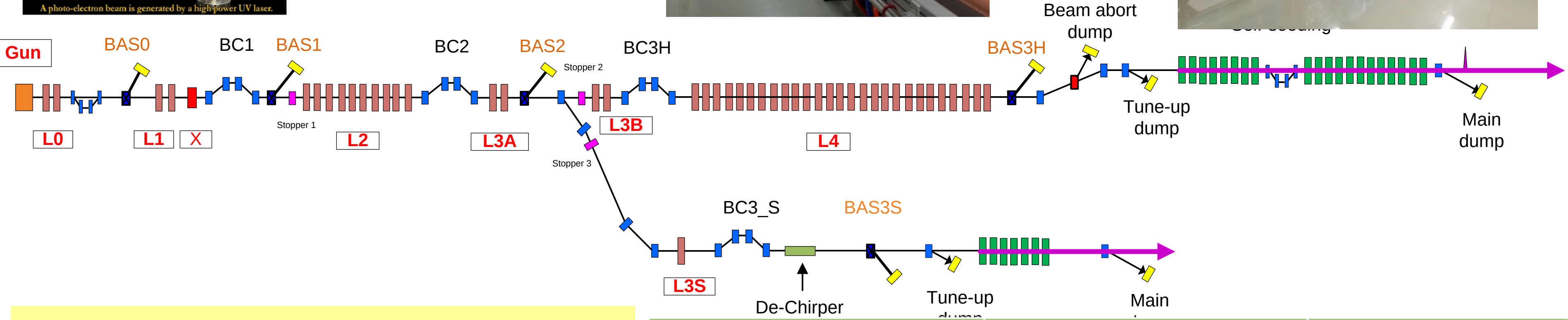
PAL-XFEL : Third Hard-Xray Femtosecond Laser

Photocathode RF-gun



Acceleration column

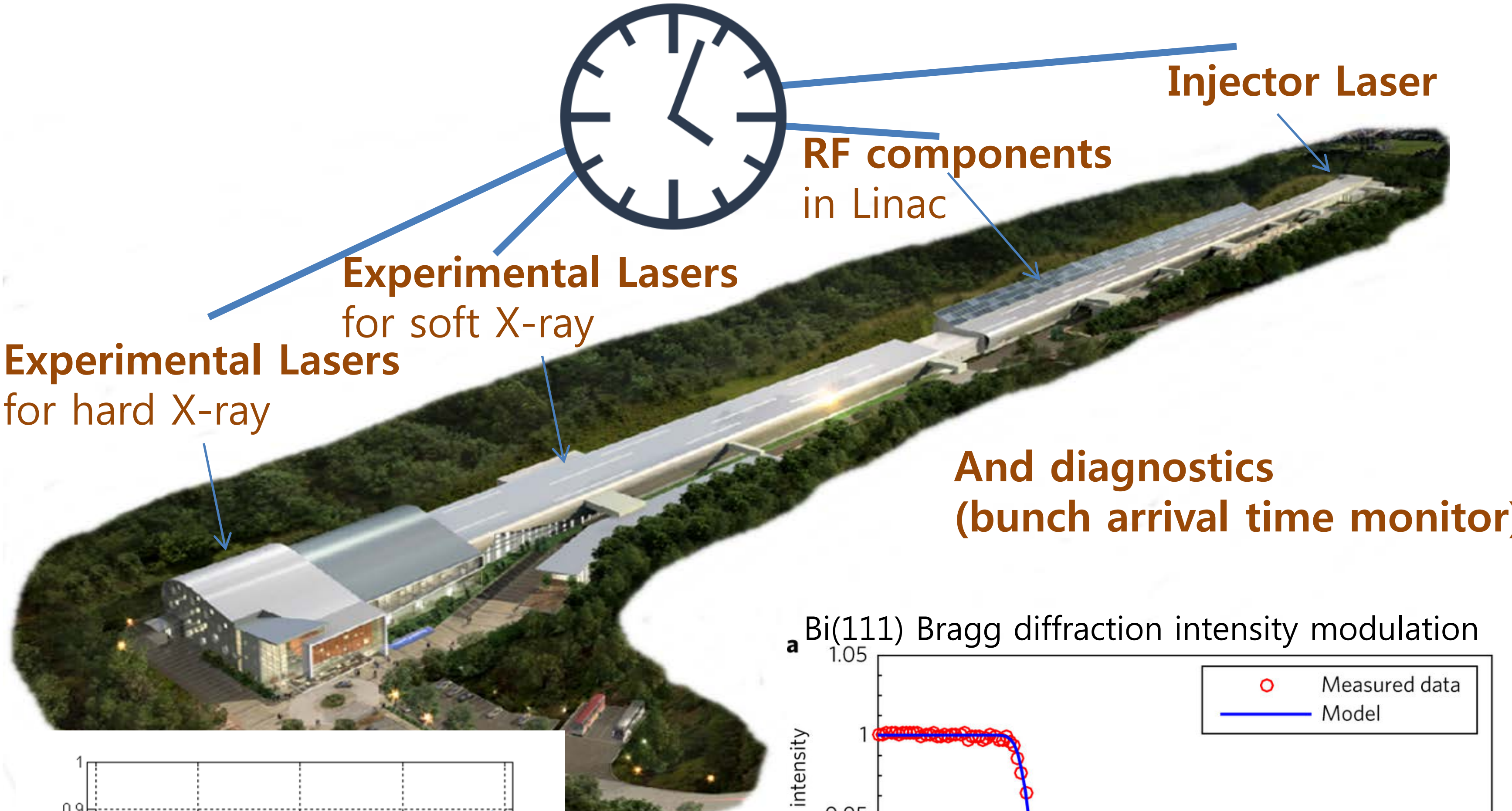
Out vacuum Undulator

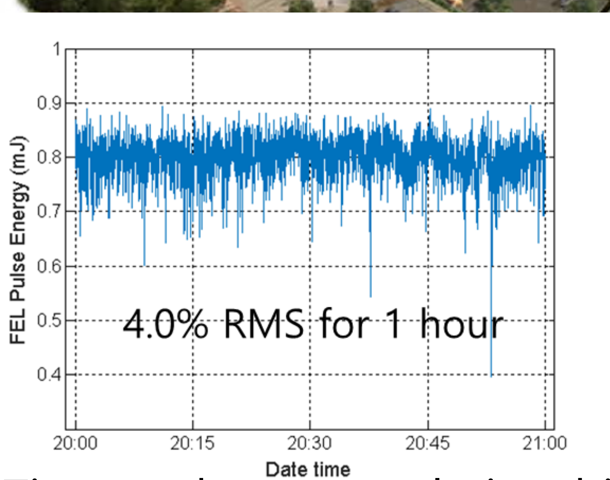


Main parameters

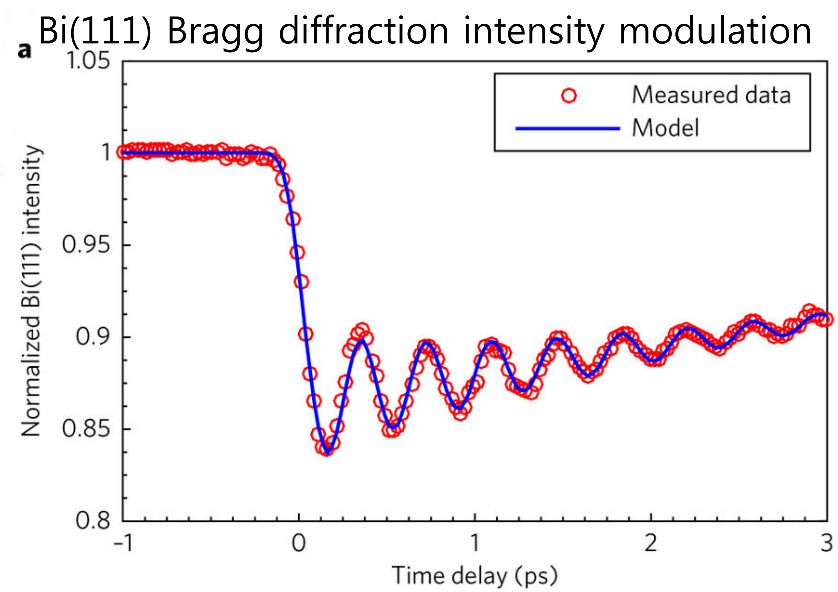
e^- Energy	10 GeV
e^- Bunch charge	20-200 pC
Slice emittance	0.5 mm mrad
Repetition rate	60 Hz
Pulse duration	5 fs – 100 fs
Peak current	3 kA
SX line switching	DC (Phase-1) Kicker (Phase-2)

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 + EPU
Undulator Period / Gap [mm]	26 / 8.3	35 / 8.3





Time and energy relationship
(phase space)



Time resolution
(timing jitter between FEL and optical laser)

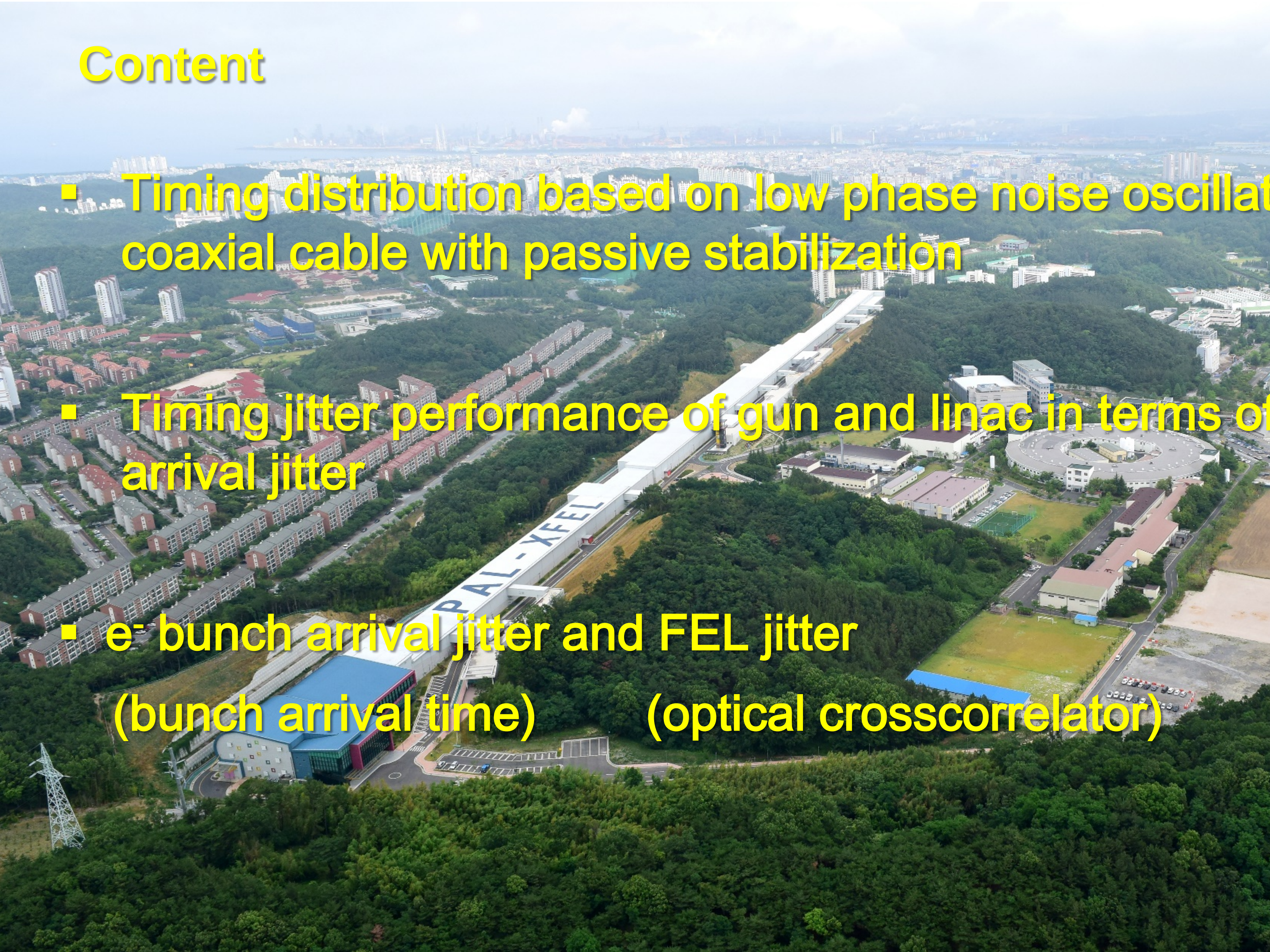
Content

- Timing distribution based on low phase noise oscillat coaxial cable with passive stabilization

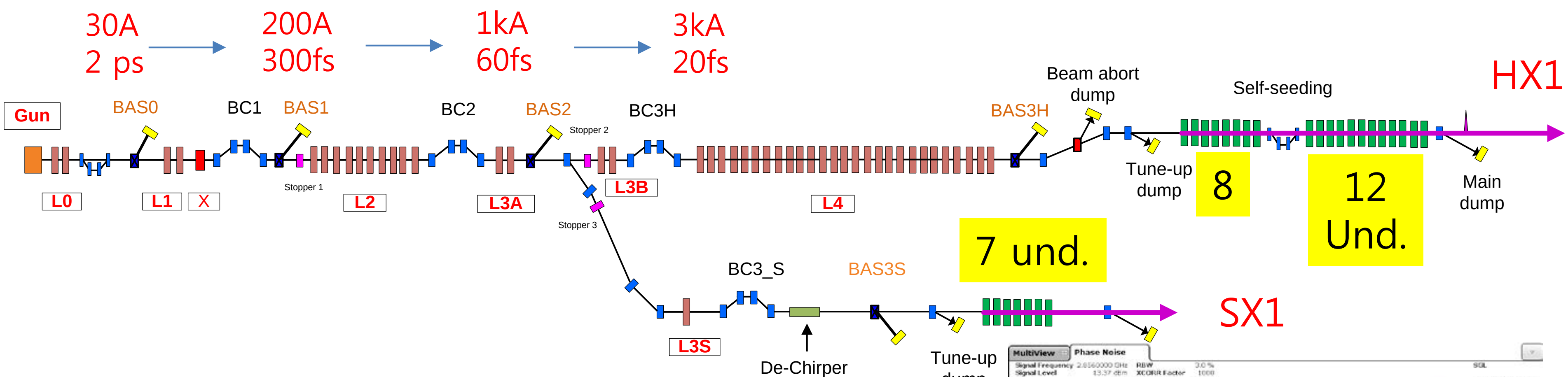
- Timing jitter performance of gun and linac in terms of arrival jitter

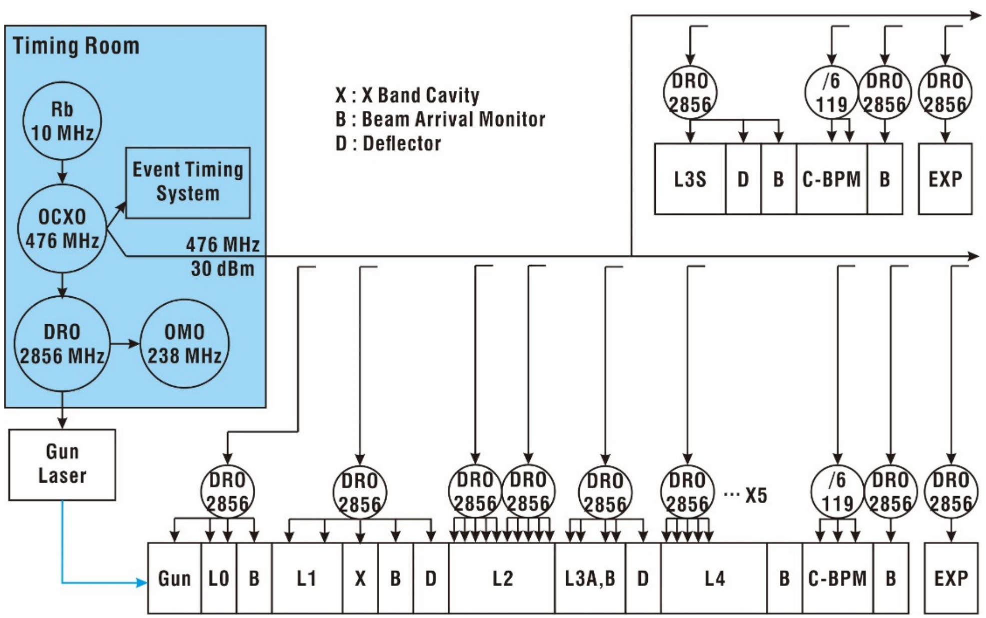
- e⁻ bunch arrival jitter and FEL jitter

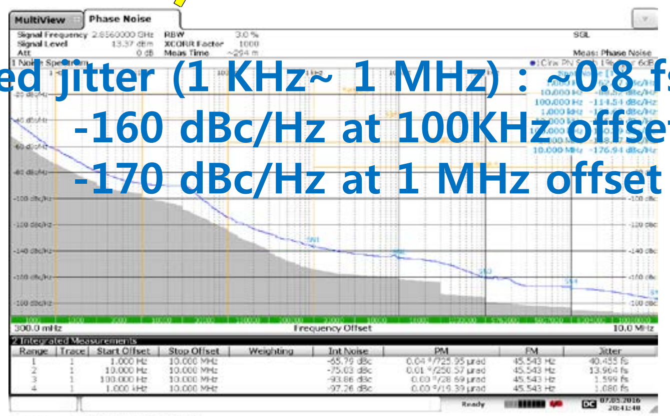
  (bunch arrival time)   (optical crosscorrelator)



PAL-XFEL timing distribution (2.856GHz RF)



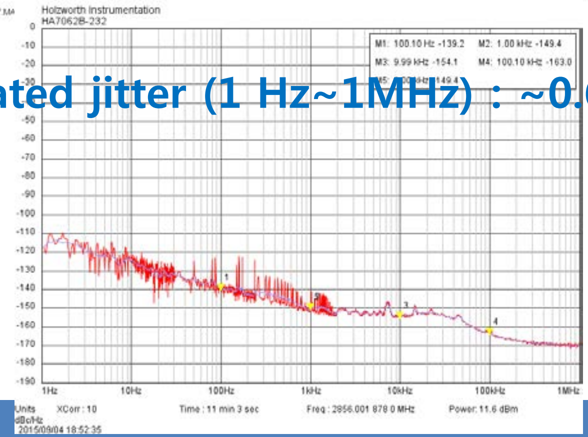




Integrated jitter (1 KHz~ 1 MHz) : ~0.8 fs

-160 dBc/Hz at 100KHz offset

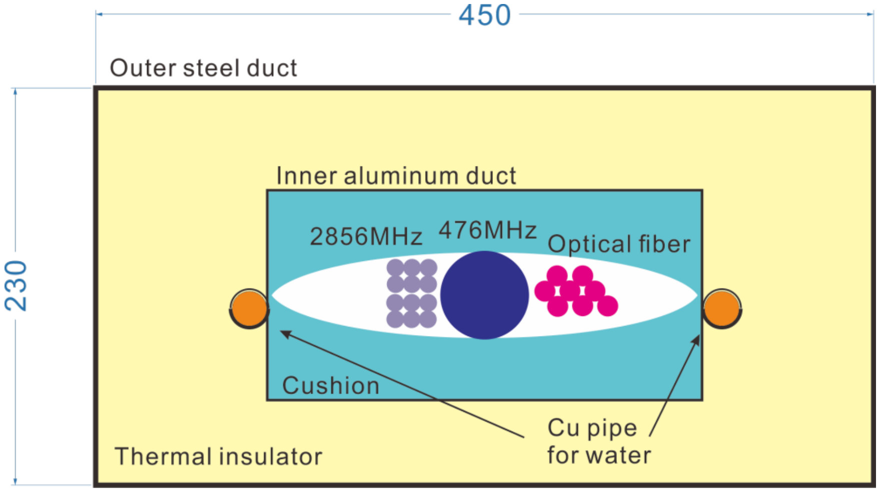
-170 dBc/Hz at 1 MHz offset



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

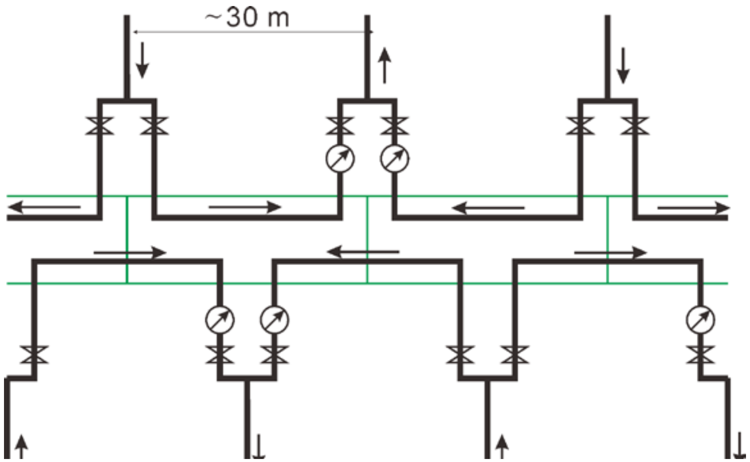
Temperature stabilization of RF Cables

Duct cross-section



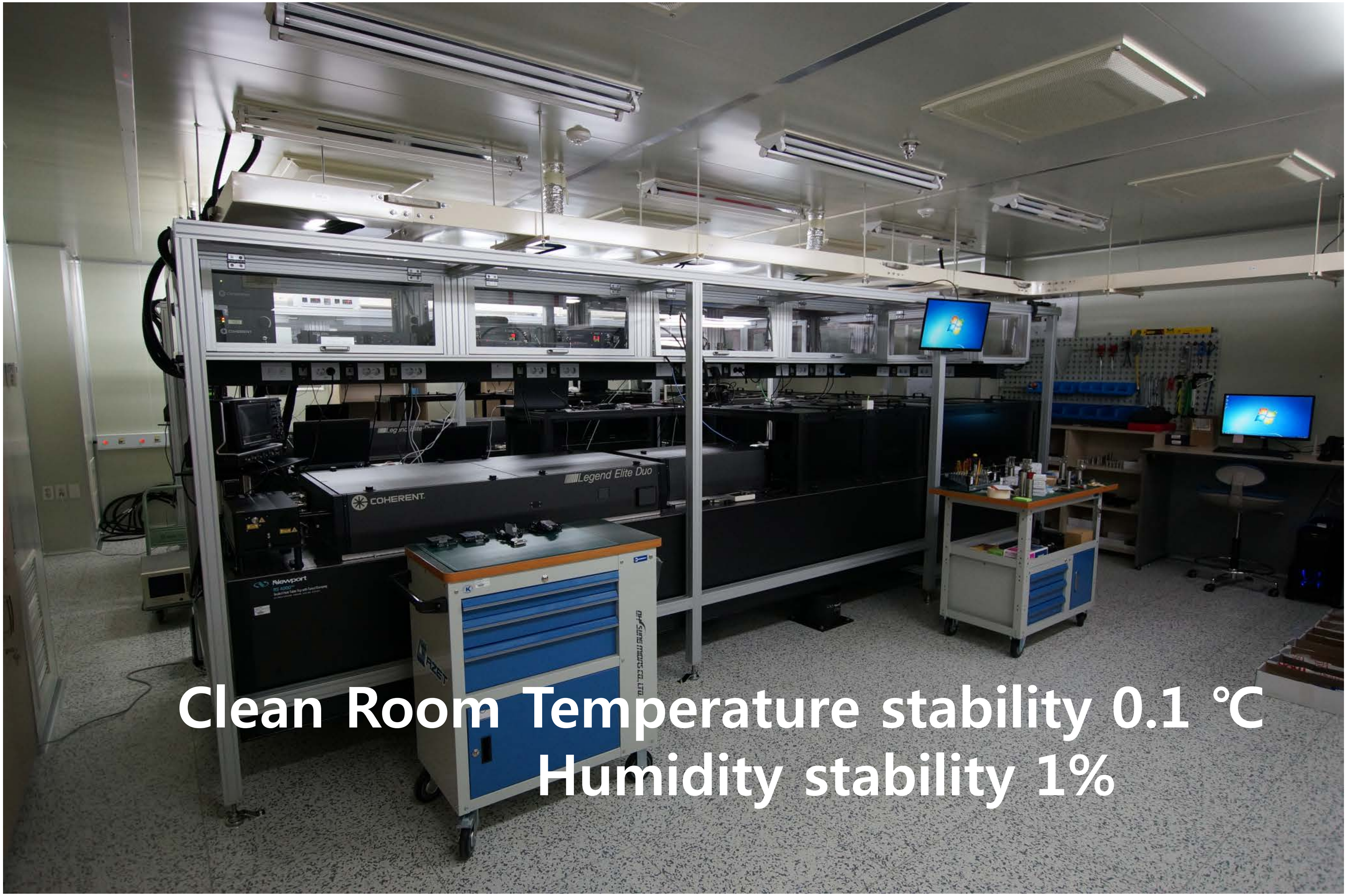
With cover open

LCW flow diagram

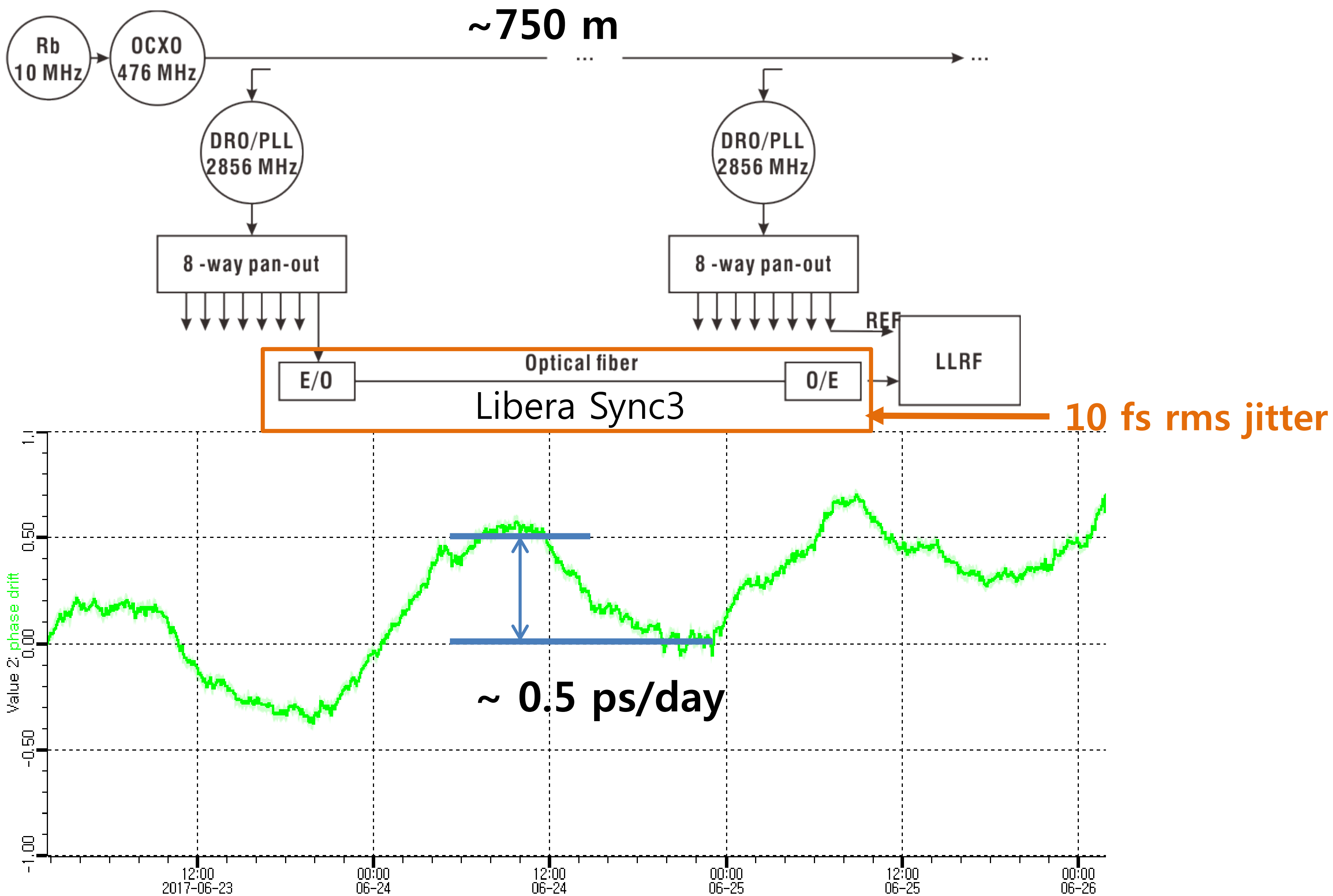


Temperature stability of Duct : **0.01℃/day**

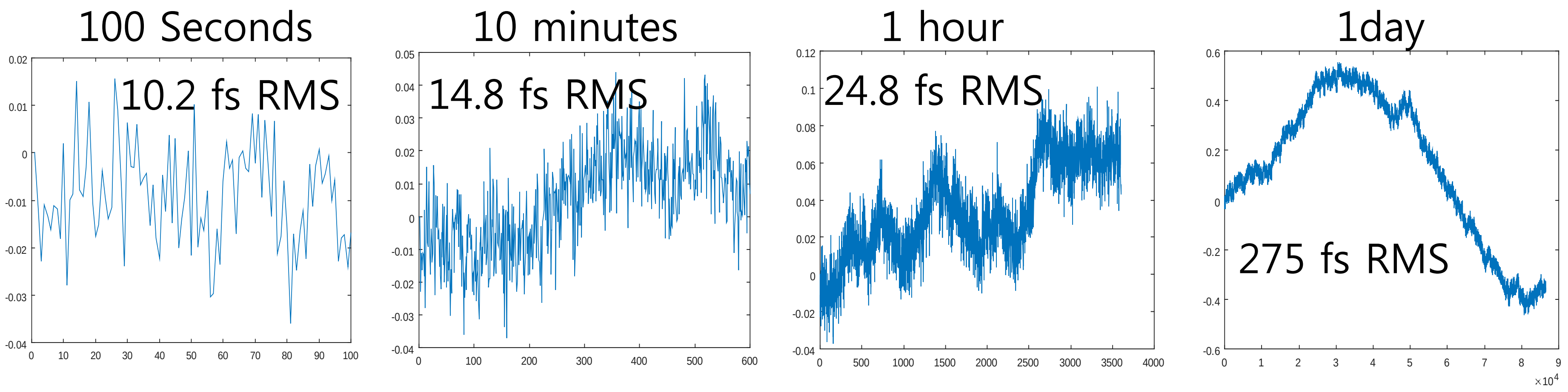
Injector laser room

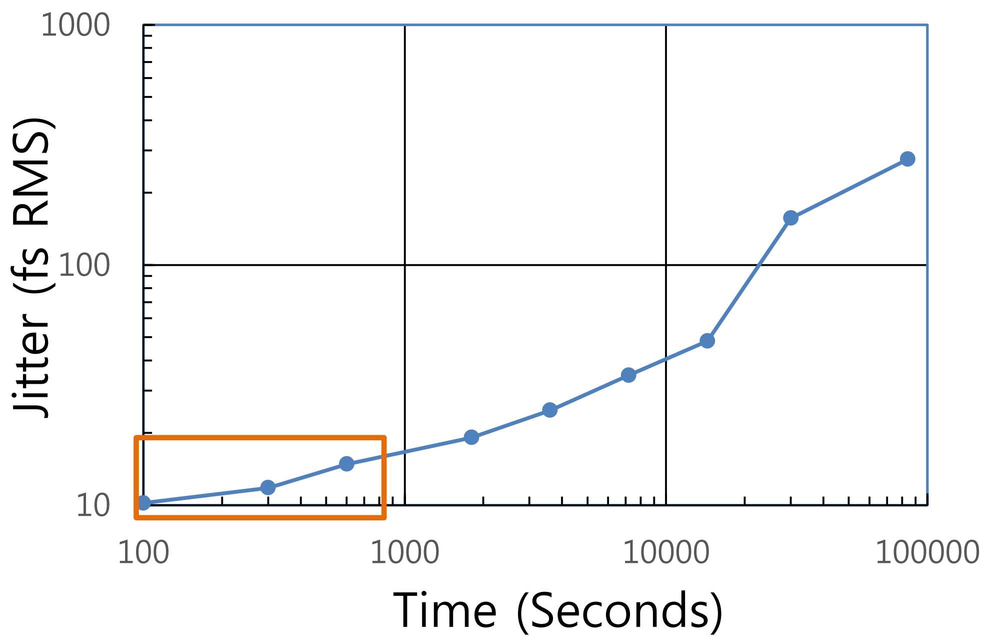


Phase Drift monitoring using drift-free optical link

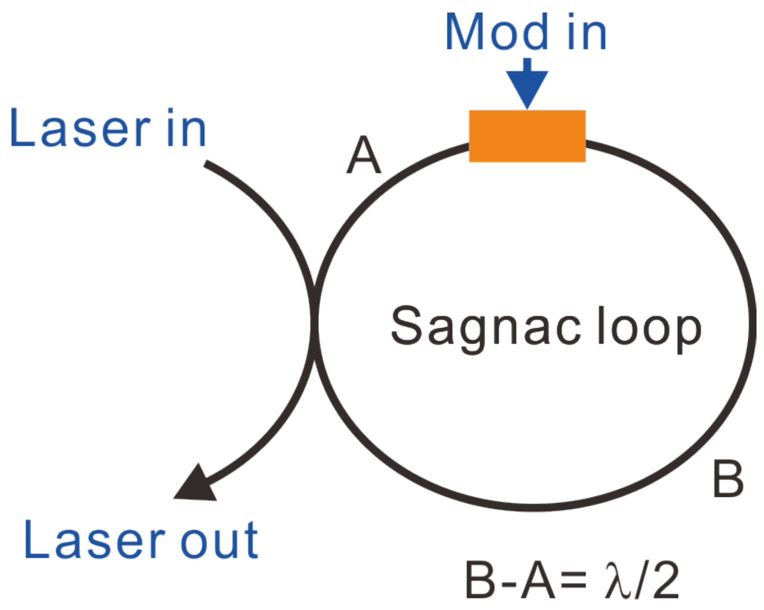


Time scale of timing error in reference timing distribution



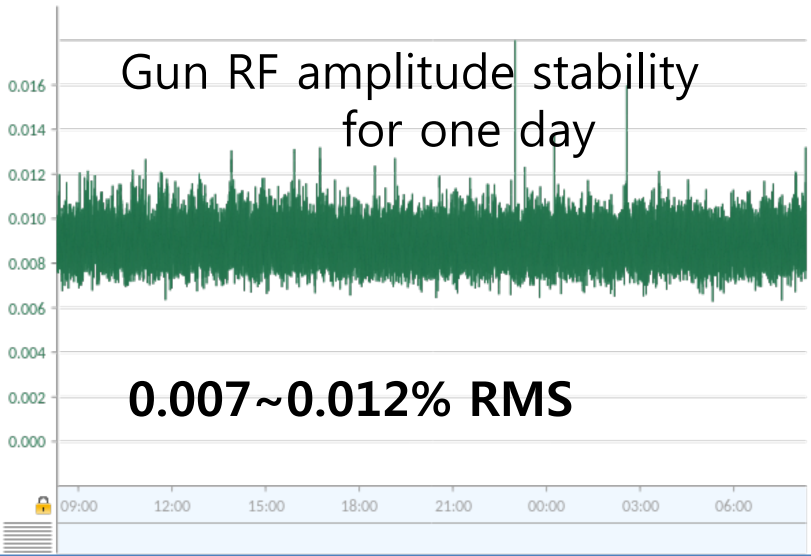


Photocathode gun - e^- bunch arrival jitter



Home-built sensitive phase detector
Between RF and optical laser
(2.856 GHz) (79.33MHz Ti:S)

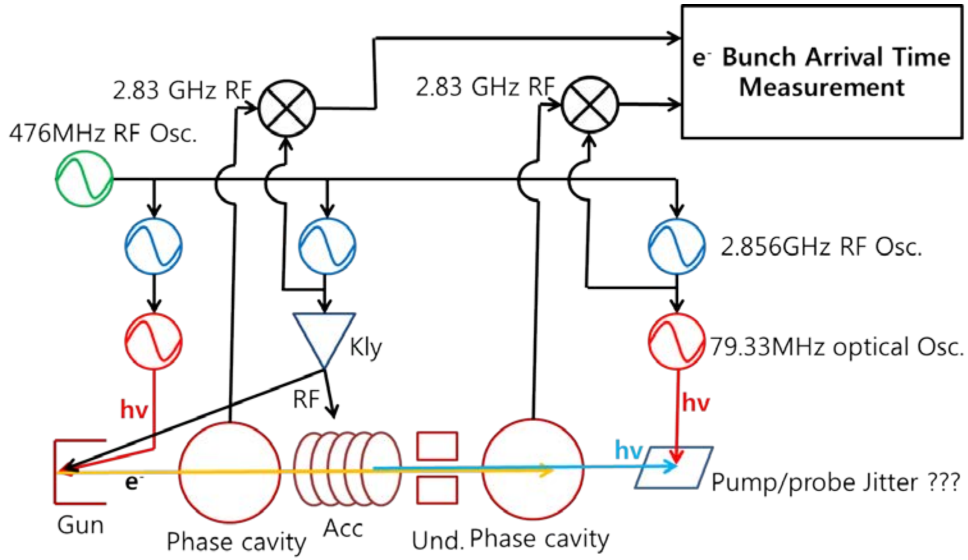
Provides **10 fs level jitter**

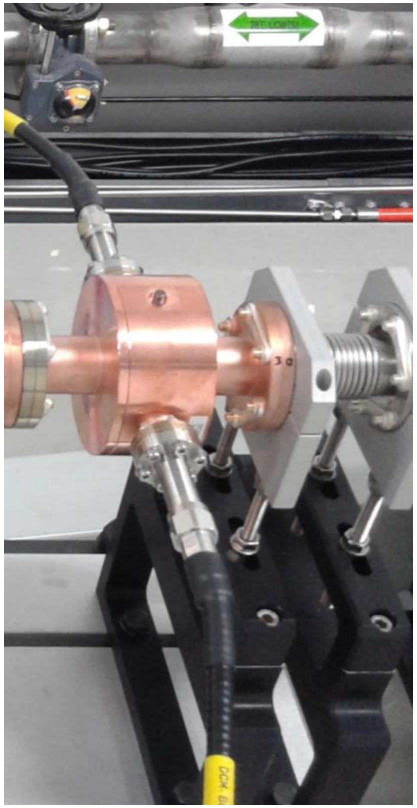


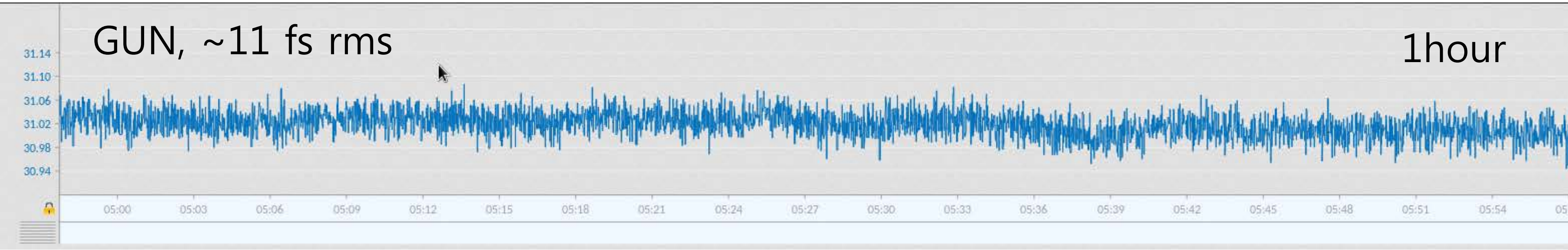
RF system adds ~10^{-4} amplitude jitter
~10 fs timing jitter

Beam arrival time jitter at gun

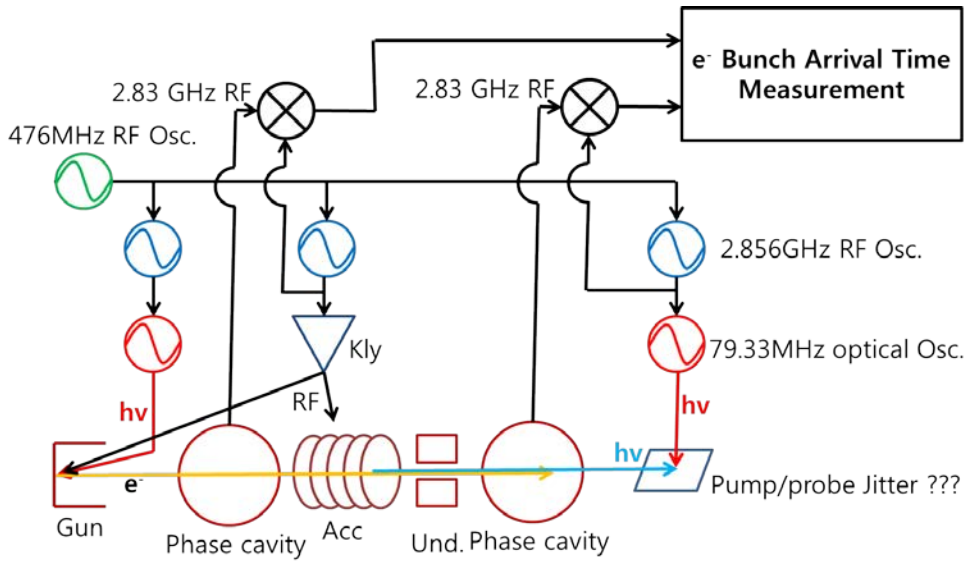
Monopole S-band cavity (phase cavity)

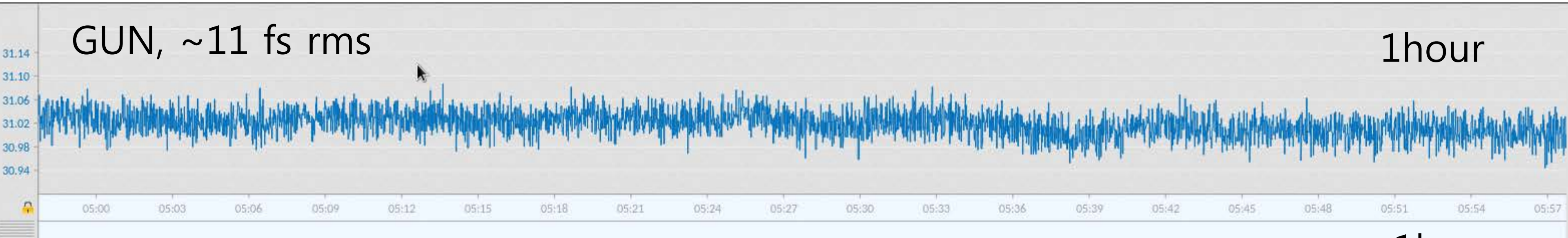


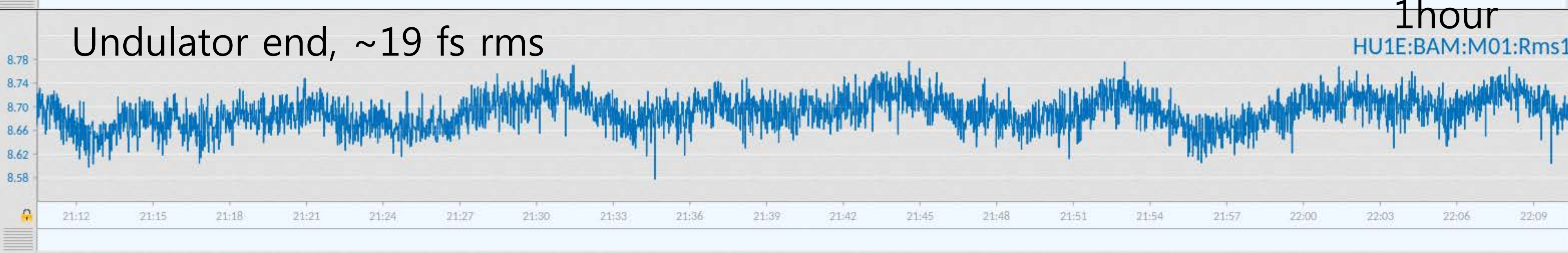




Beam arrival time jitter at gun and undulator end

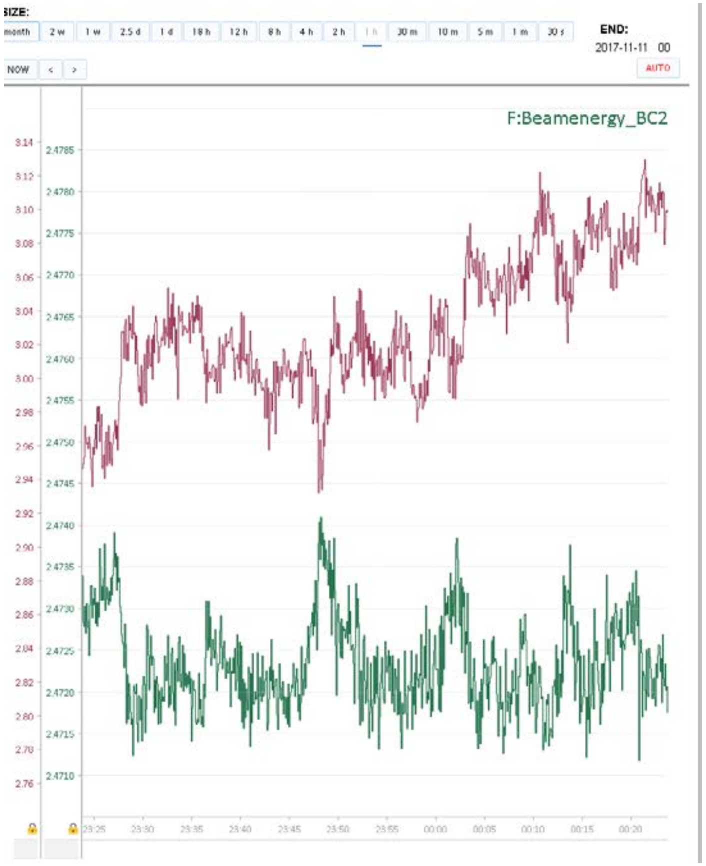


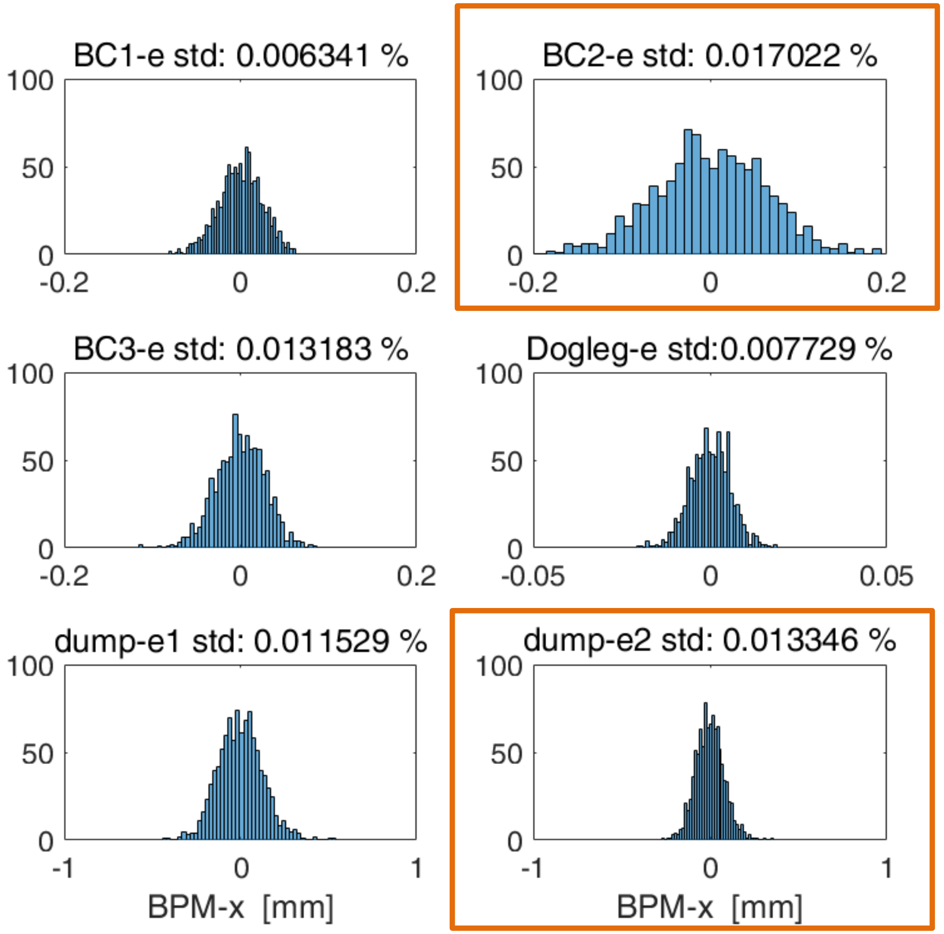




E-beam energy jitter

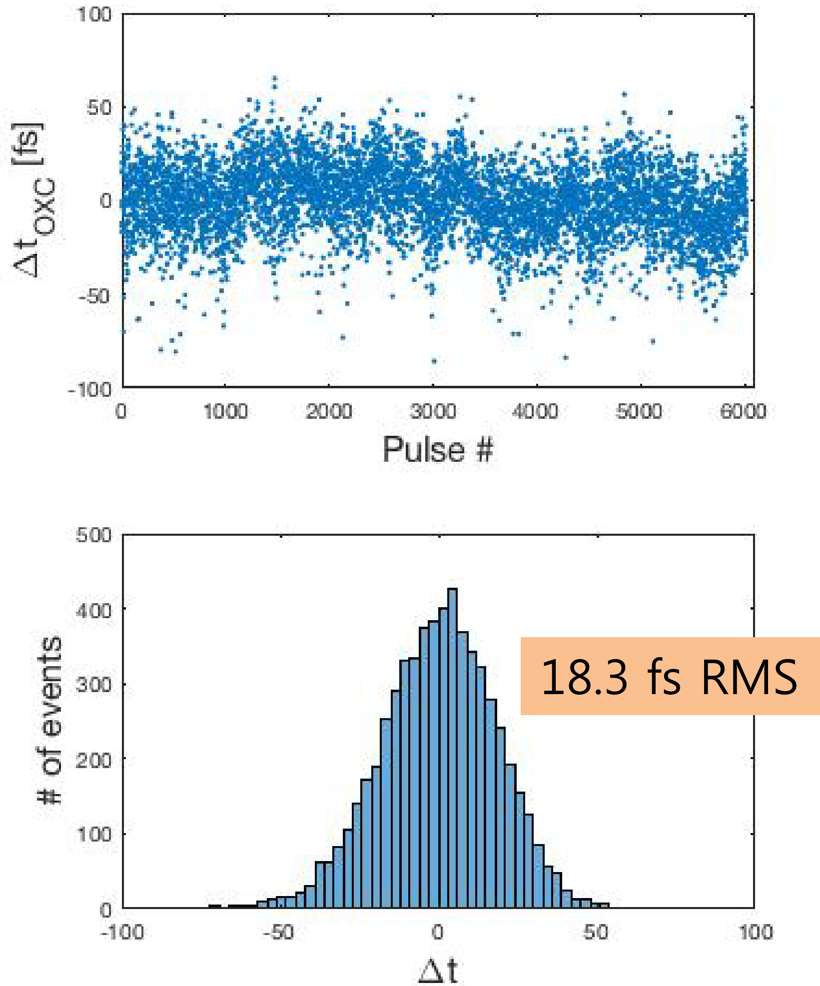
100 fs drift /10^{-3} energy change at BC2



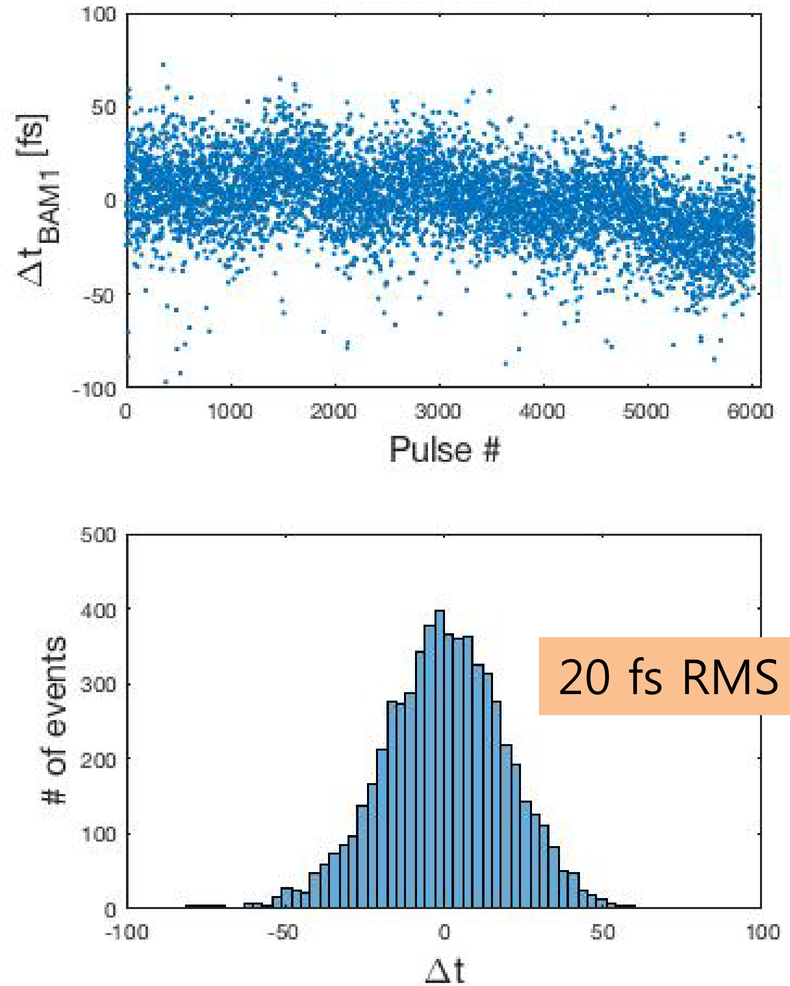


FEL timing jitter

FEL/optical laser cross-correlation



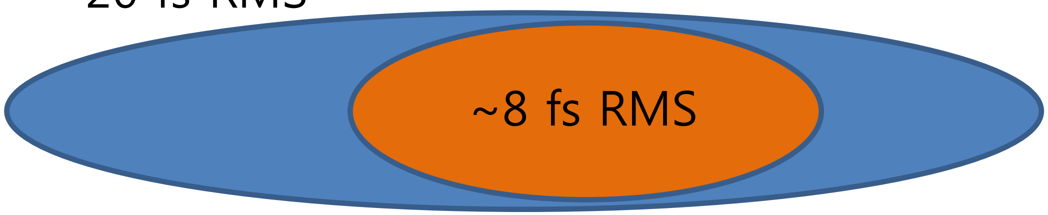
e⁻ bunch arrival time at undulator end



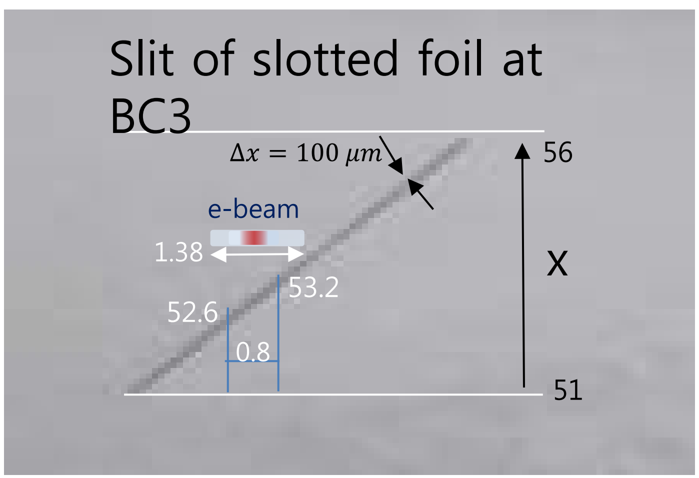
Stability of electron beam and FEL generation

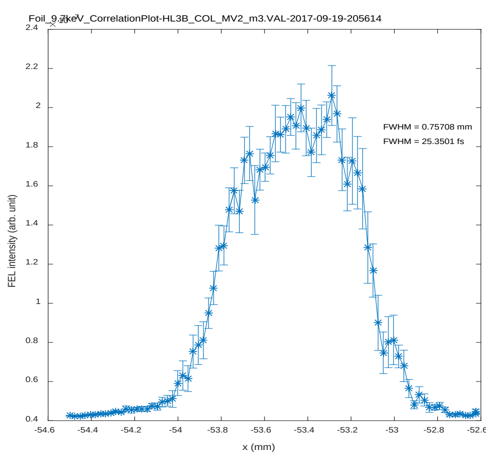
In general,
e^- beam arrival time doesn't tell FEL pulse length fluctuation and position
(optical laser temporal profile will be stable)

~20 fs RMS



In our case, e beam and FEL process seems to be stable in 10 fs scale (3 BC scheme, careful Undualtor BBA, Matching helps)



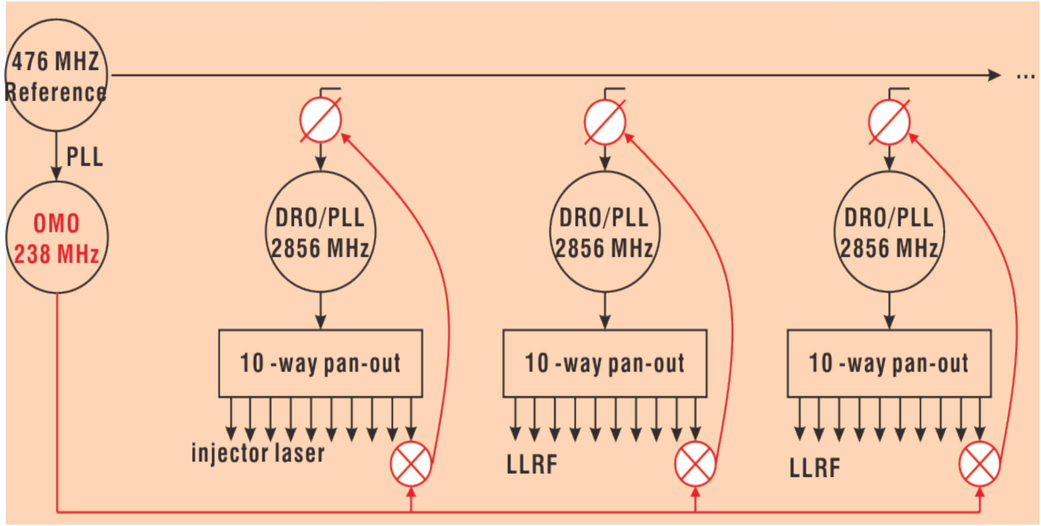


Summary

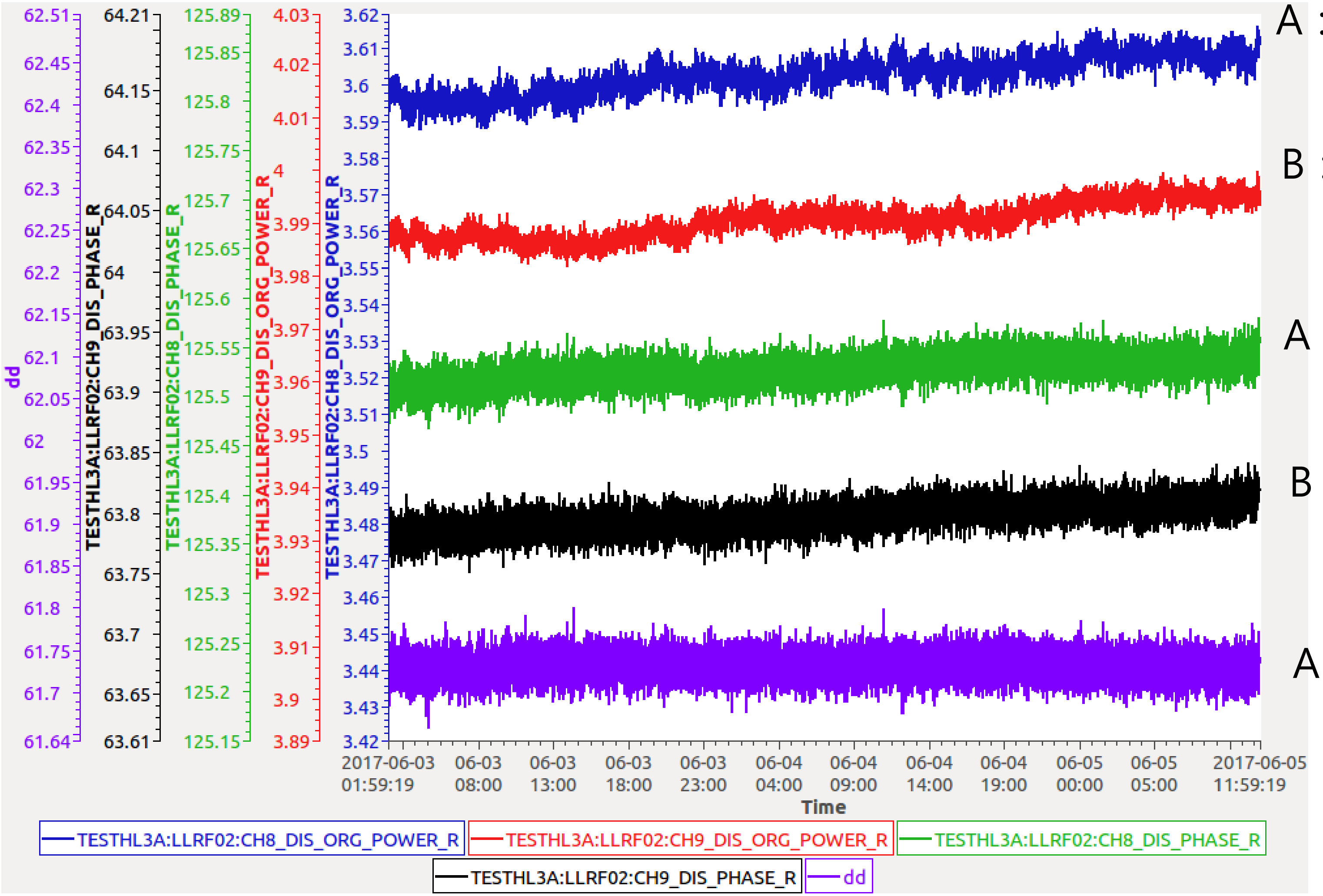
- Currently, PAL-XFEL and optical laser for exp. shows sub 20 fs jitter performance at the measurement time scale of time-resolved experiment(~10 minutes).
  - Temperature stabilized, vibration resistive coaxial cable based RF timing distribution with the combination of low phase RF oscillators provide ~ 1 fs RMS (1 second time scale), ~ 15 fs RMS (10 minutes time scale), ~500 fs drift (1 day)

- ~10 fs RMS arrival time jitter at the gun become twice at the undulator end and which is correlated with energy jitter
  : 100 fs drift /10^{-3} energy change at BC2

Beam based Feedback loop and/or



Optical timing test (Libera Sync 3, 2.2 km, 3days)



A : Libera Sync amplitude

B : Reference amplitude

A : Libera Sync Phase

B : Reference Phase

A -B

Phase drift <10fs

Phase drift estimation due to RF Cables

- 476 Mhz **low loss cables**
  : Huber+Suhner, SUCOFEED_ 1_5/8_LA**,**
  Loss : <1.5 dB/100m
  Drift : ≈ 130 fs/mK
  → For 1 km and with 0.1℃ stability, 13 ps drift is expected
  (The huge drift will be compensated by LLRF and beam based feedback) **Should be compensated**

- 2856 Mhz **low drift cables**
  : RFS, LCF38-50J 3/8" **,**
  Loss : 20.5 dB/100m at 3 GHz
  Drift : ≈ 7 fs/mK
  →For 50 m (max. distance for 2.856 GHz distribution and with 0.1℃ stability, 35 fs drift is expected. (15fs for L0, 20 fs for L1&L2) **considered as minimal**

≈14 fs residual phase jitter from 1 Hz to 100 KHz