CSR suppression at the dogleg beam transport of SACLA

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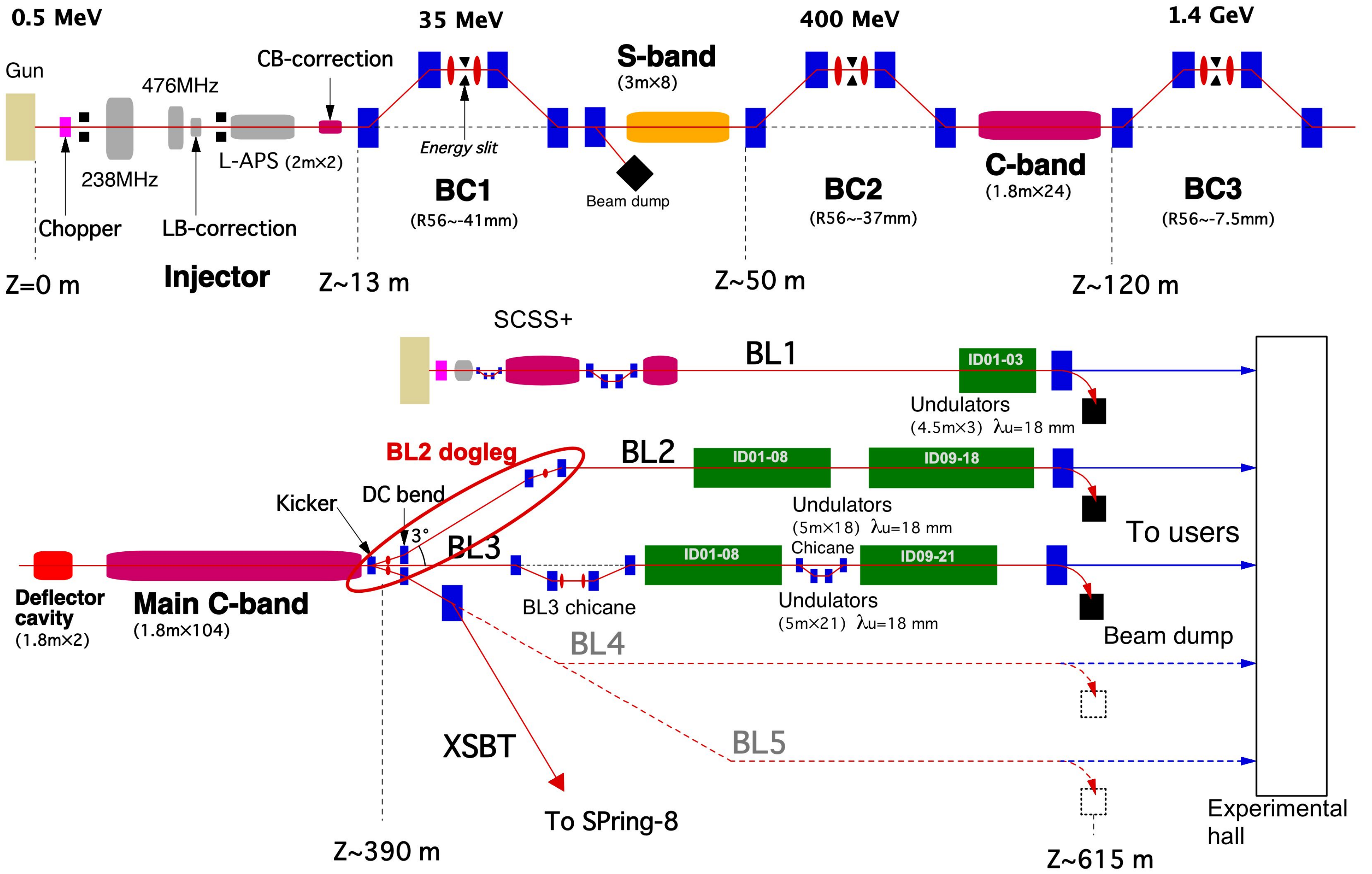
Introduction

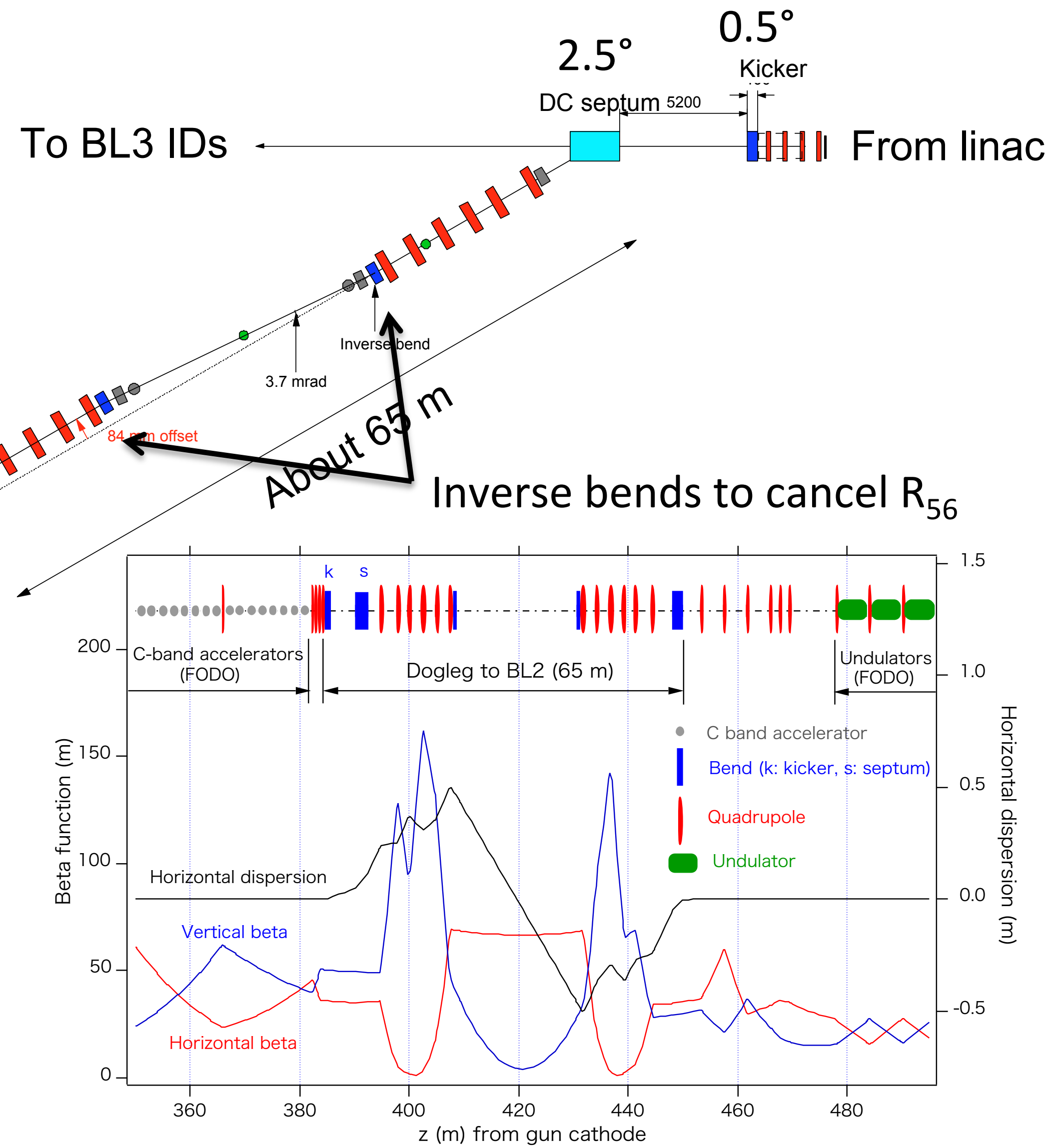
- Suppression of the CSR effects at electron beam transport is an issue for XFEL facilities for the multiple beamline operation.
- SACLA uses the electron bunches with a peak current more than 10 kA and a bunch length less than 20 fs (FWHM).
- In 2015, a 3° dogleg beam transport was installed having asymmetric beam optics to ease the stability requirement for a kicker, but beam orbit instability due to the transverse CSR effects limited the peak current below 3 kA to obtain stable lasing.
- In 2017, new optics of the dogleg based on two DBA structures is introduced to suppress the CSR effects.

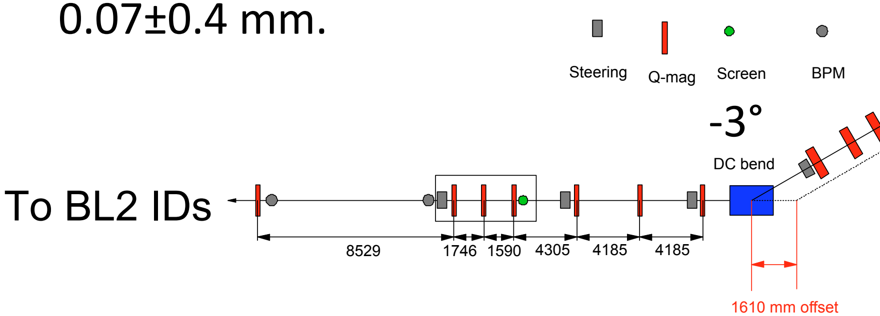
SACLA accelerator



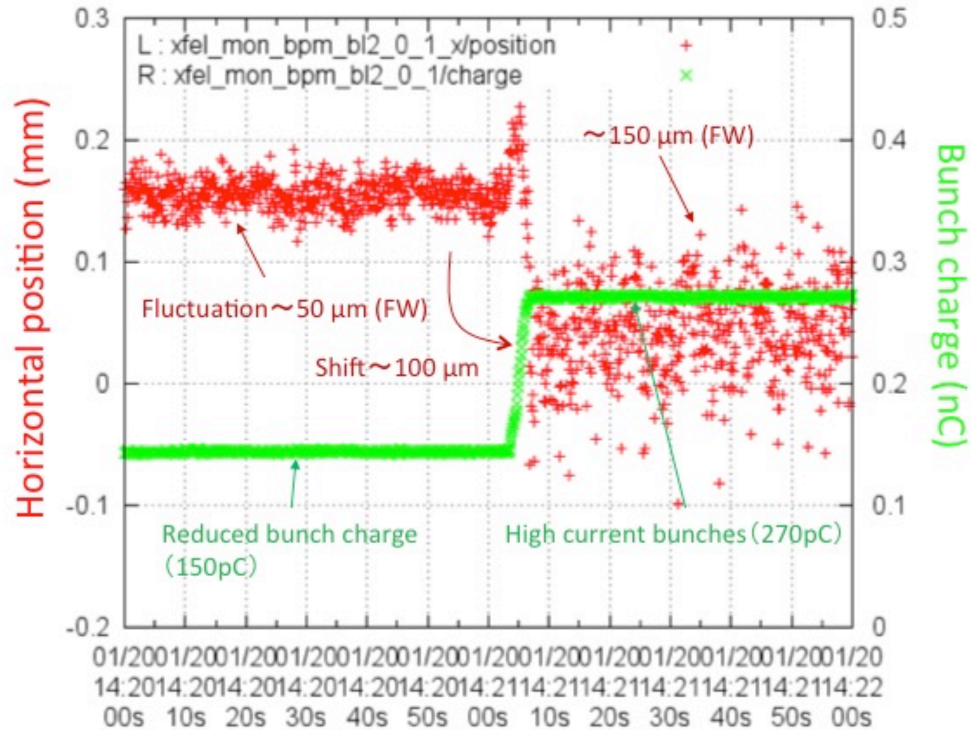
Old beam optics of BL2 dogleg

R_{56} of dogleg:
DC switching magnet 1.6 mm,
kicker + septum without correction 4.0 mm,
kicker + septum with correction 0.07±0.4 mm.





CSR effects at the BL2 dogleg



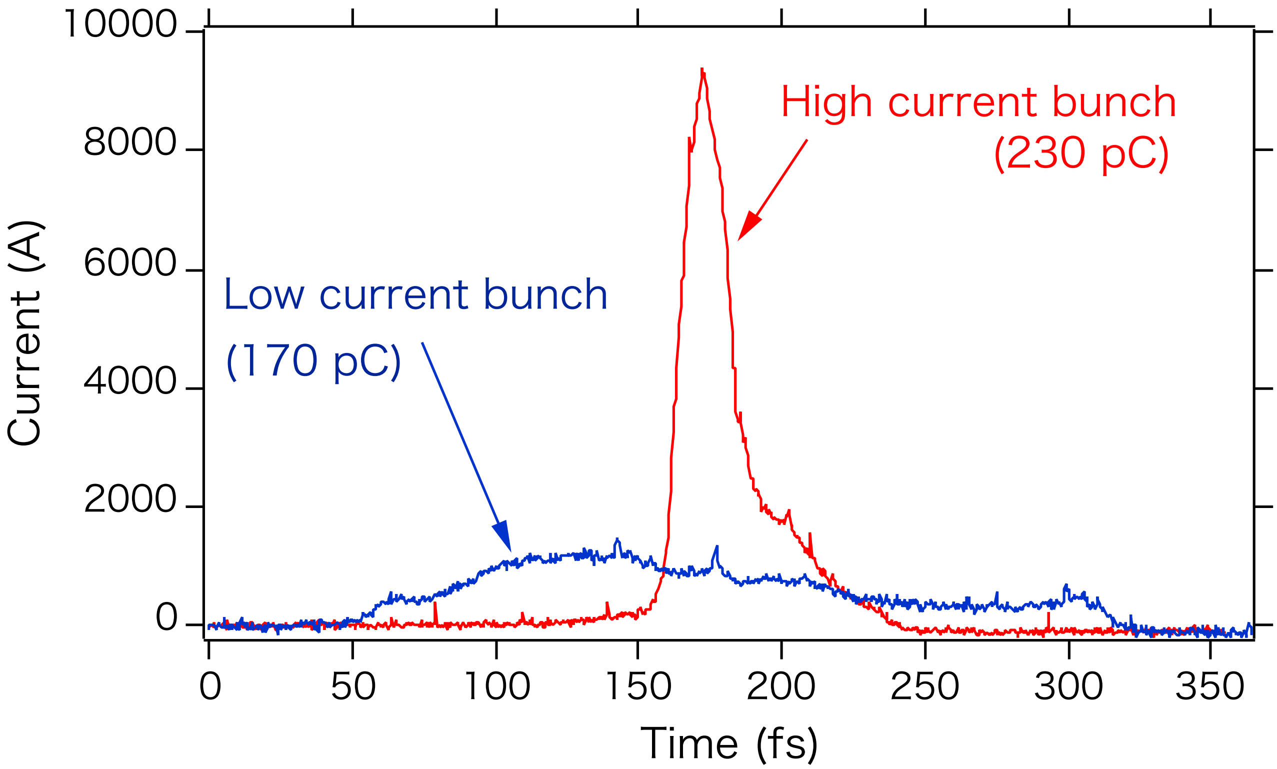
Horizontal orbit fluctuation after the dogleg.

	Horizontal (pm-rad)	Vertical (pm-rad)
BL2 high current (10 kA)	16.3	0.74
BL2 low current (1 kA)	2.7	0.64
BL3 high current (10 kA)	1.4	0.27
BL3 low current (1 kA)	0.83	0.24

Emittance beam size is 33 pm-rad assuming 7.8 GeV and 0.5 μm-rad (norm. emit.).

- Lasing can be obtained for 10 kA bunches, but with large orbit fluctuation.
- Transverse beam profiles are horizontally elongated after the dogleg.

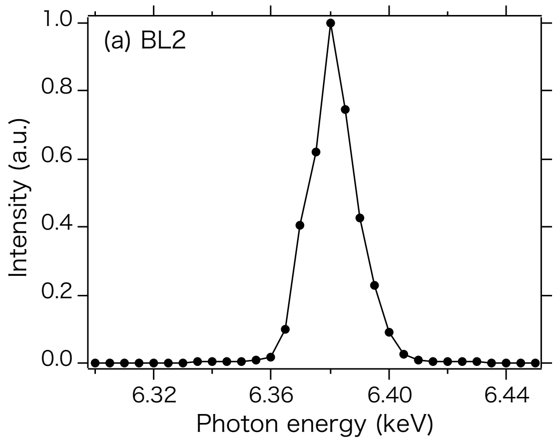
Electron bunch profiles of SACLA



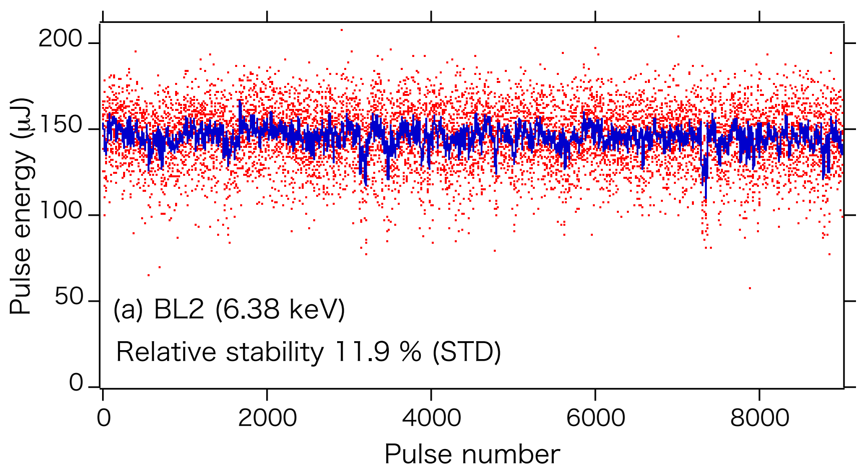
- Longitudinal electron bunch profiles measured by a C-band RF deflector, the beam size not deconvolutted.
- High current bunch used for the normal operation of SACLA BL3, ~10 kA.
- Low current bunch obtained after the parameter optimization for BL2, ~1 kA.

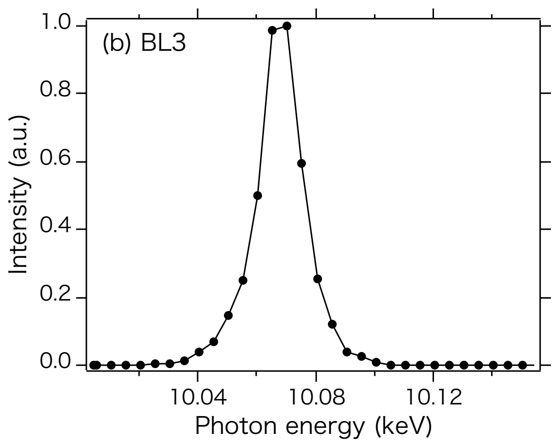
Multi-beamline operation

Electron beam energy 7.8 GeV, peak current 1.2 kA, repetition 30 Hz

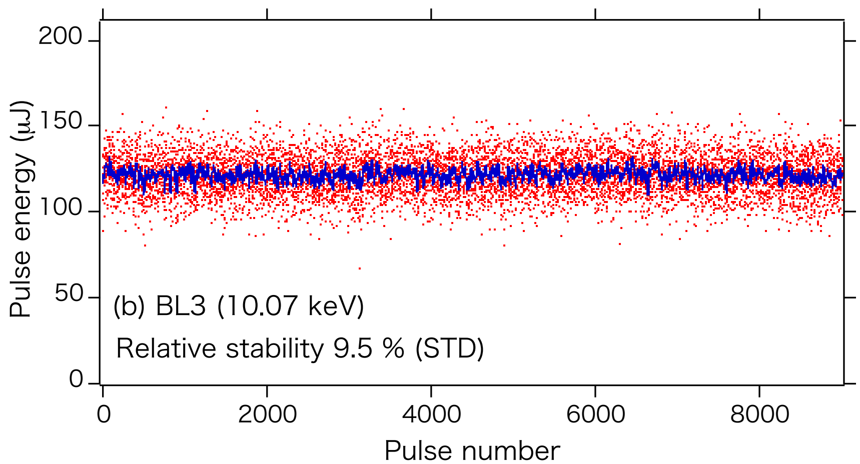


<u>BL2</u>
7.8 GeV
6.38 keV
15 Hz
K=2.85





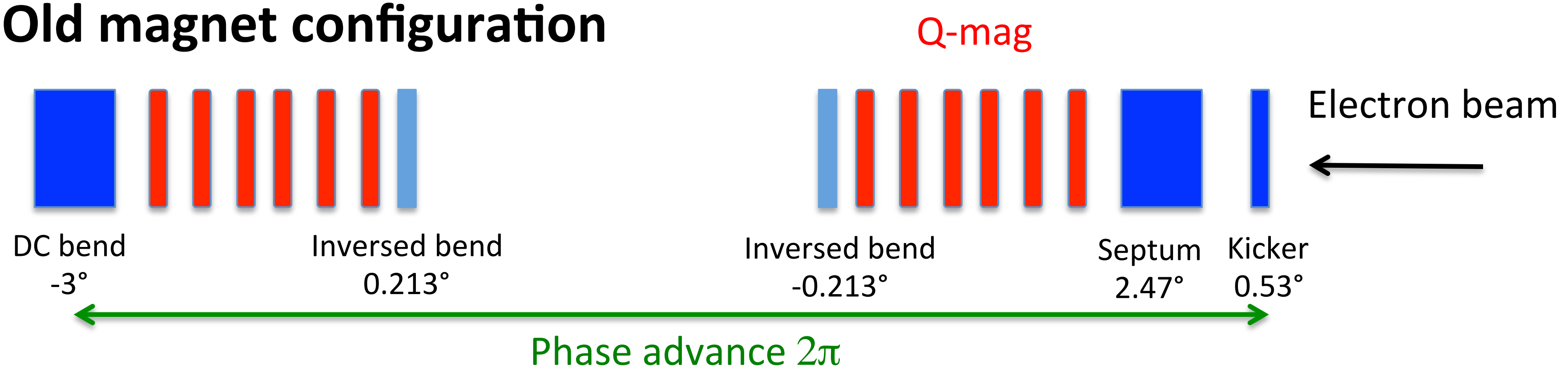
<u>BL3</u>
7.8 GeV
10.07 keV
15 Hz
K=2.1



Full horizontal scale is 10 mins.

Replacement of the beam optics

- **Old magnet configuration**

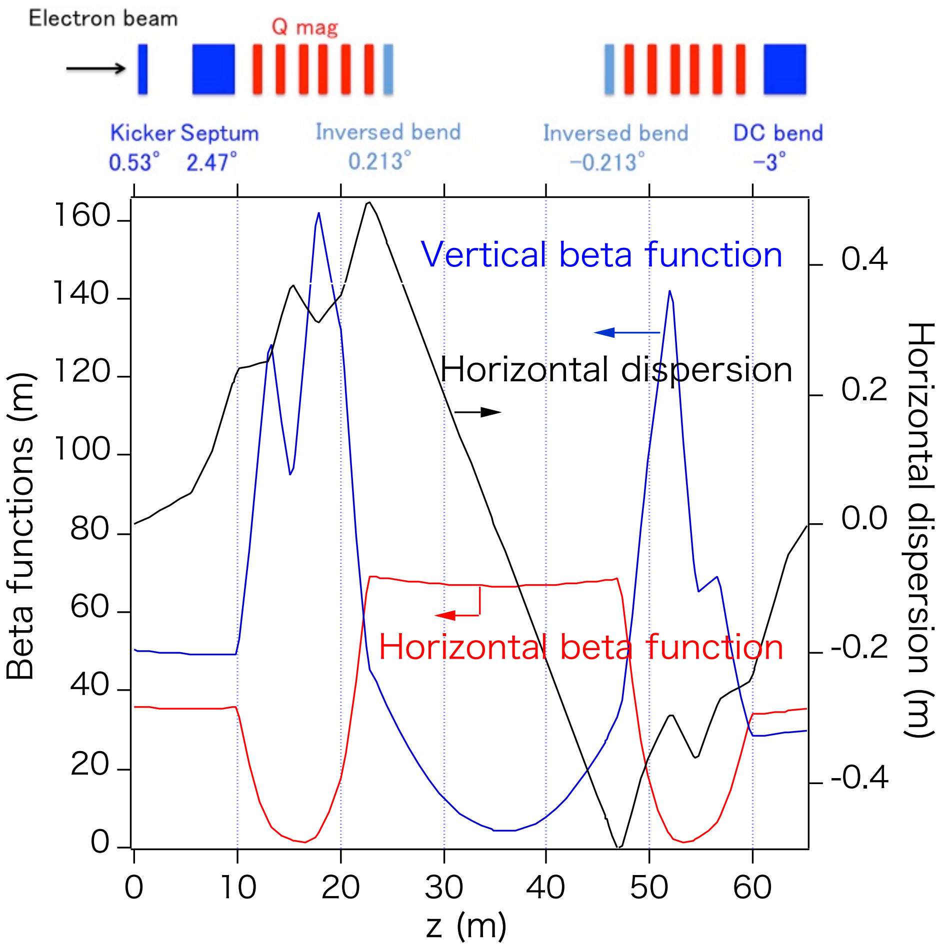


January 2017

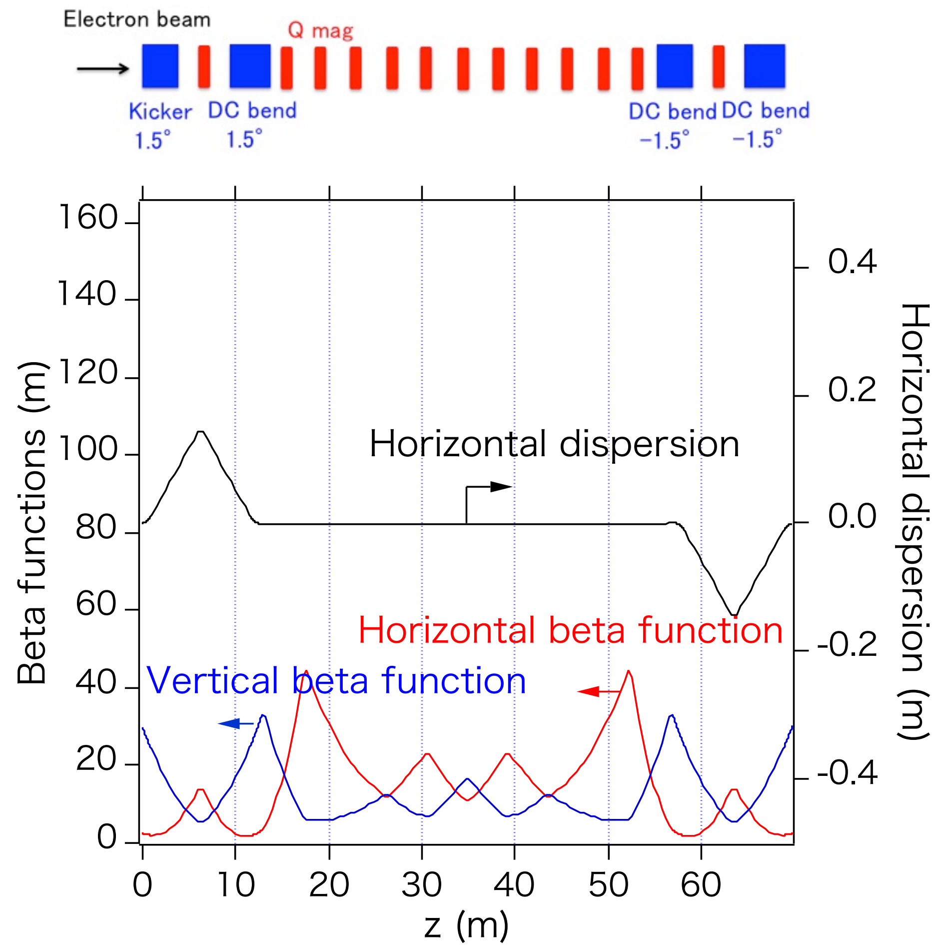
- **New magnet configuration（two DBA）**

To make R_{56} zero and maintain the same longitudinal bunch profile, the electron beam passes off-center at Q-mags of DBA.

Beam optics functions



Old optics functions

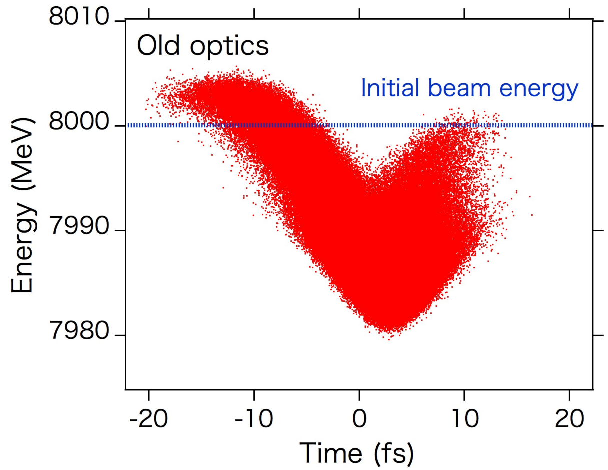


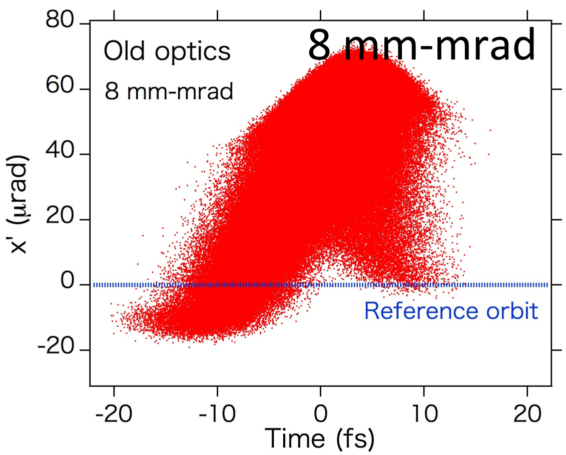
New optics functions

Small horizontal beta at bending magnets in new beam optics.

Suppression of the CSR effects (simulations)

Old beam optics



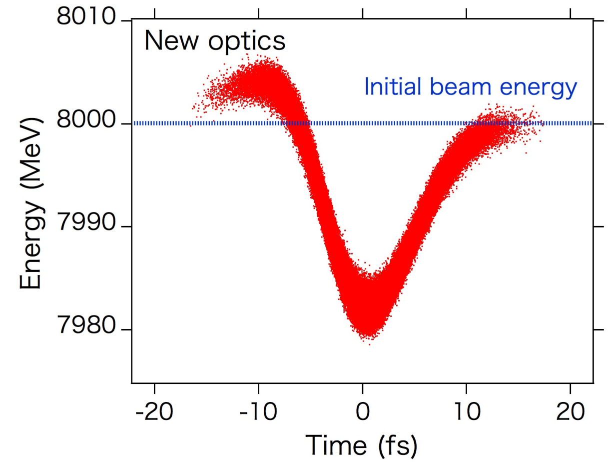


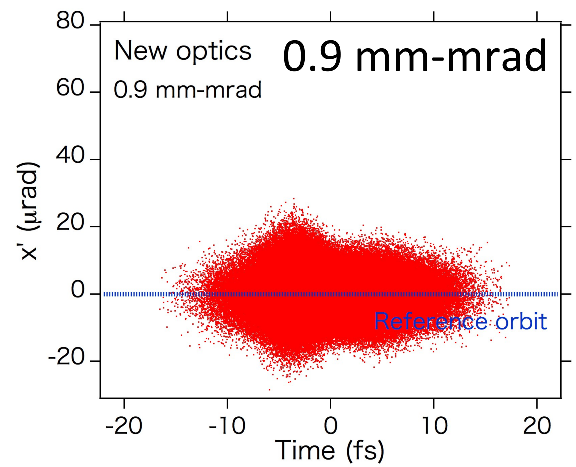
<u>Energy deviation after BL2 dogleg</u>

Initial bunch conditions
Gaussian, 8 GeV,
10 fs (FWHM), 10 kA
0.8 mm-mrad.

<u>t-x' phase space after BL2 dogleg</u>

New beam optics



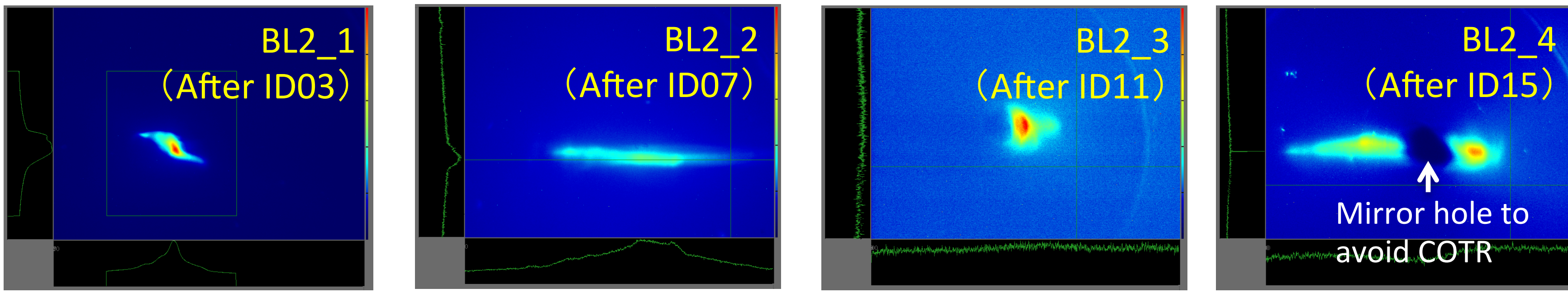


Projected emittance growth is about 10 % for the new beam optics.

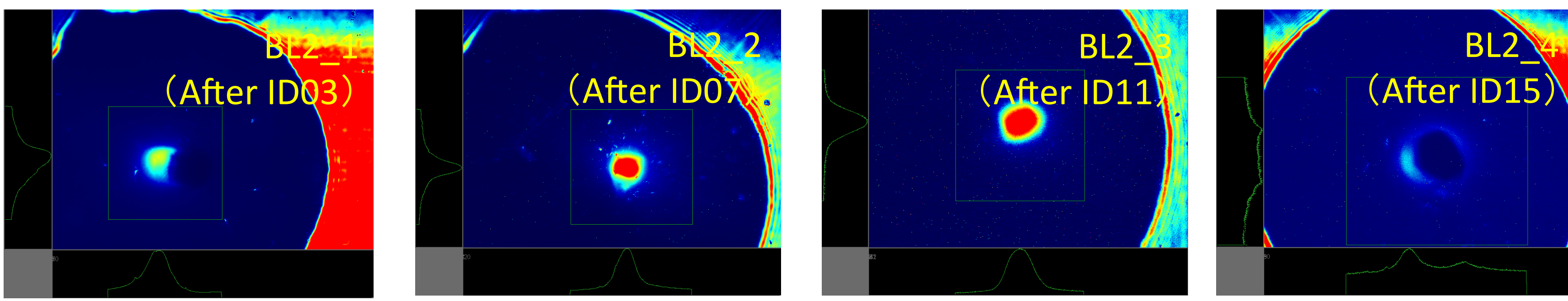
Electron beam profiles at BL2

Electron beam 7.8 GeV, 10 kA

- Old beam optics

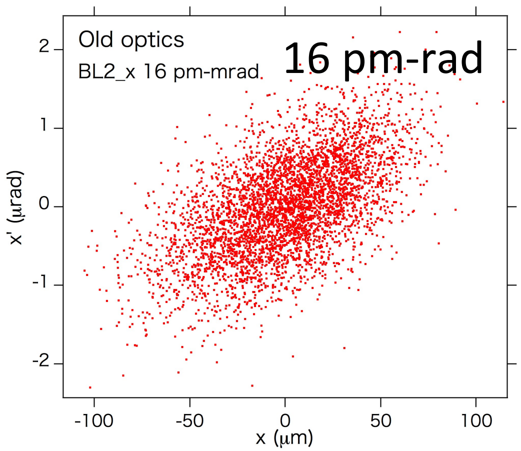


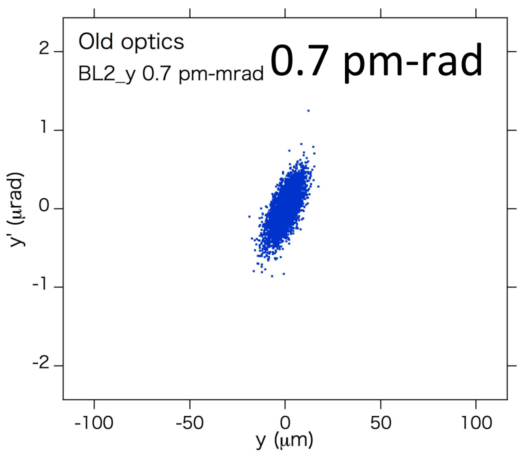
- New beam optics



Suppression of the CSR effects (measured)

Old beam optics





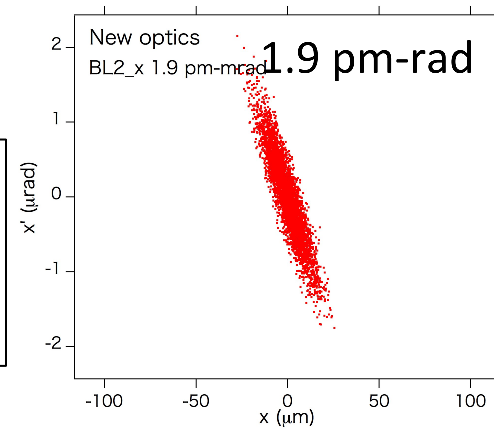
<u>Horizontal orbit stability after BL2 dogleg</u>

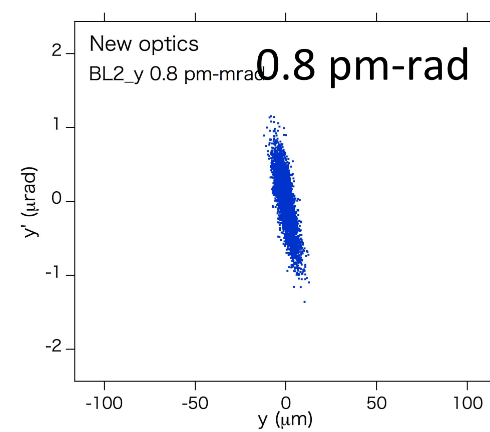
Beam energy 7.9 GeV, peak current ~10 kA, bunch repetition 30 Hz, electron bunches are alternately sent to BL2 and BL3.

<u>Vertical orbit stability</u>

Orbit stability of BL3 is 0.8 pm-rad in horizontal and 0.5 pm-rad in vertical.

New beam optics

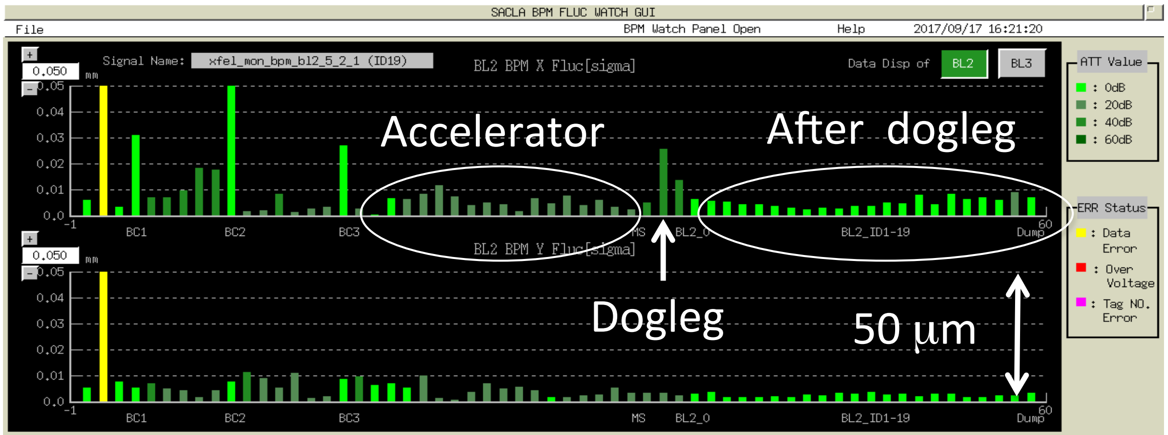




Horizontal orbit stability is improved by an order.
10 kA bunches are stably transported to BL2 through the dogleg.

Multi-beamline operation

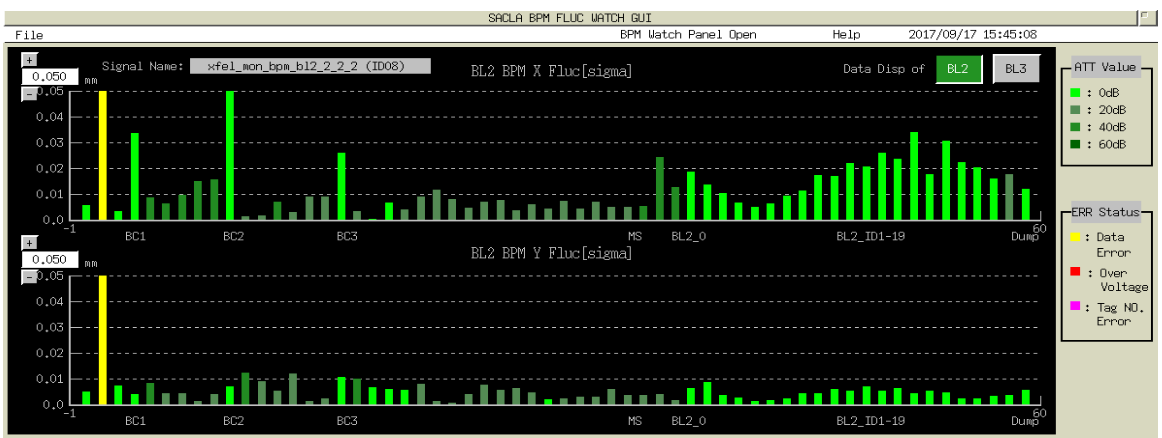
- Phase advance between two DBAs is π (design optics).



RMS dispersion of BPM data is plotted along the accelerator.

Top: horizontal position
Bottom: vertical position

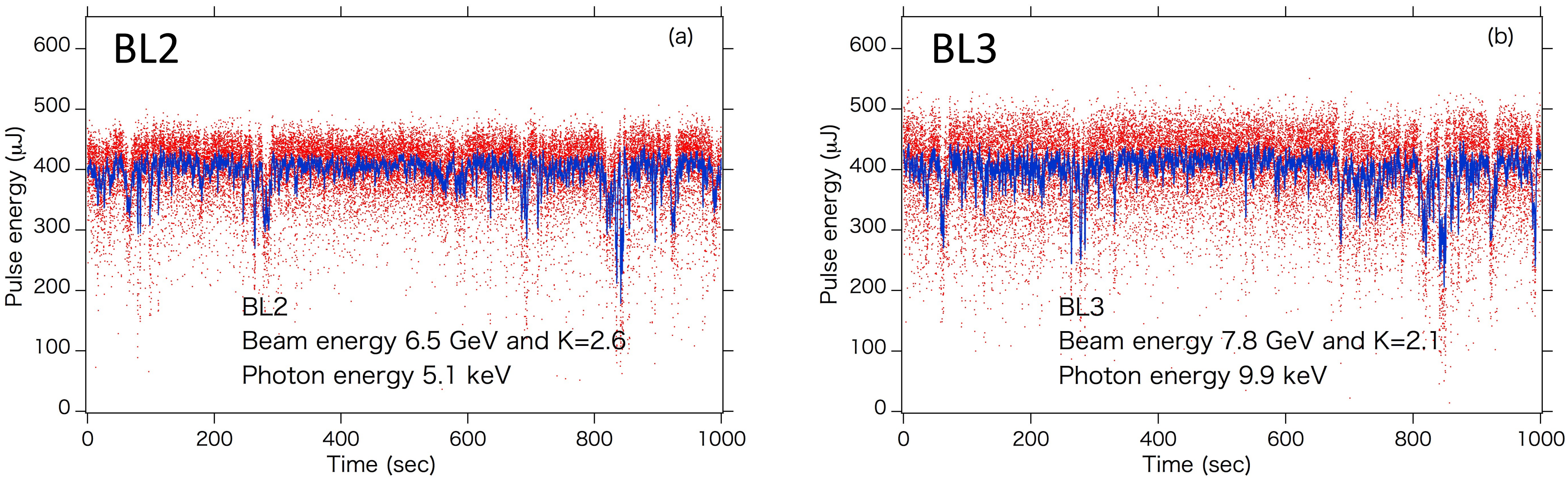
- Phase advance between two DBAs is almost 2π.

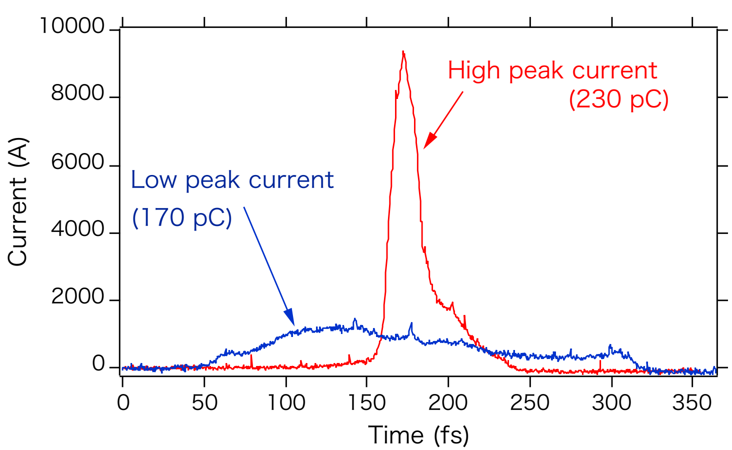


Electron beam
7.8 GeV, 250 pC, 10 kA

Multi-beamline operation

60 Hz electron bunches are alternately deflected to BL2 (6.5 GeV) and BL3 (7.8 GeV).

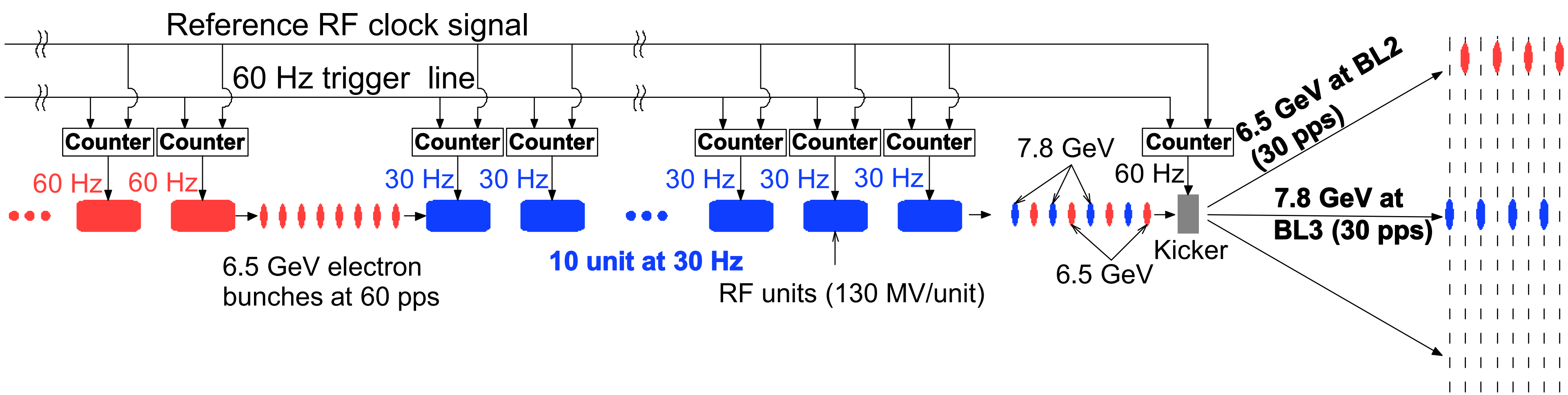




- The peak current is increased from 3 kA to 10 kA, consequently the laser pulse energy is also increased by a factor of 2~3.
- The laser wavelength of each beamline can be independently adjusted over a wide spectral range through the beam energy and undulator K-value.

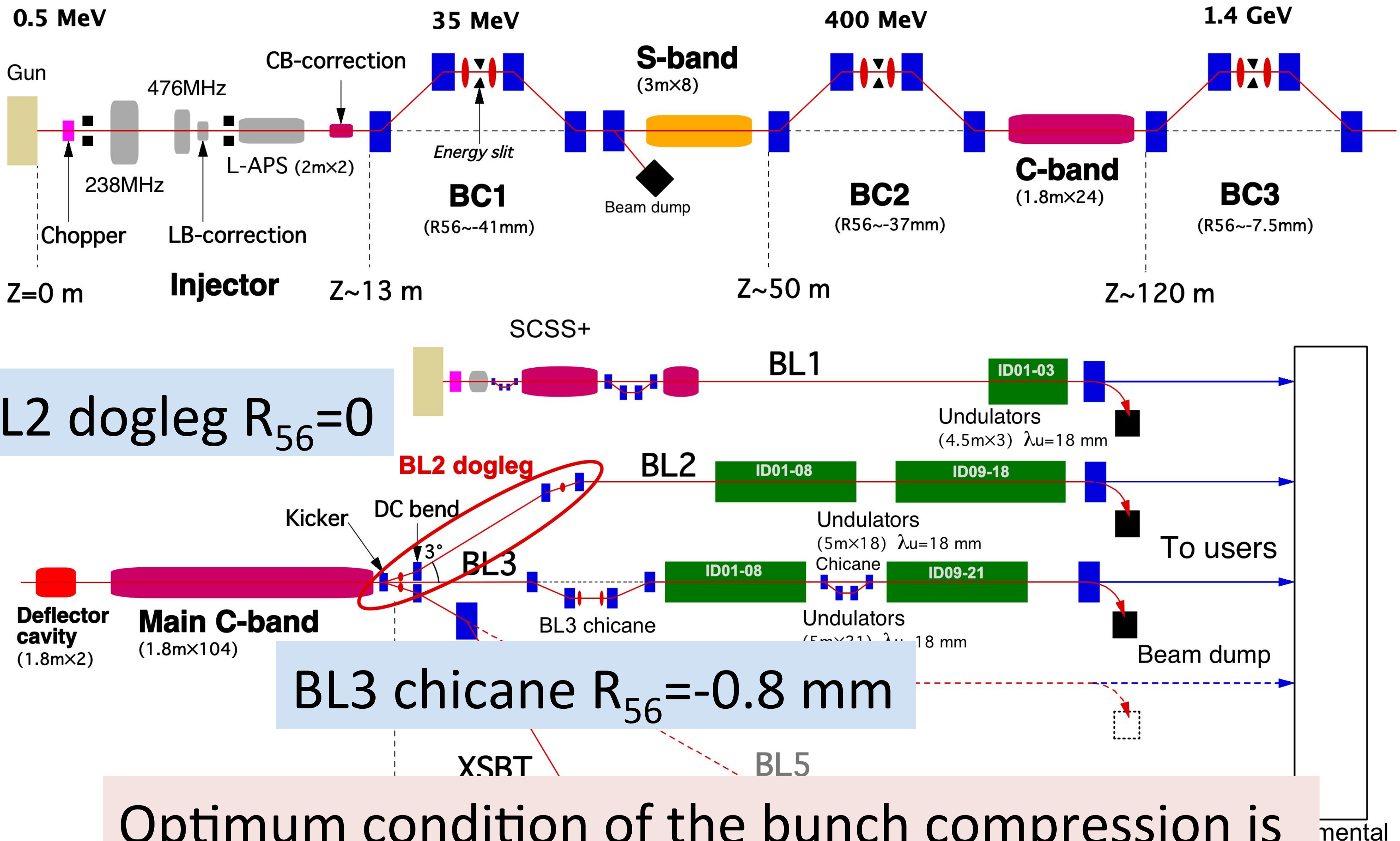
Multi-energy acceleration of linac

For wide spectral tunability of XFEL multi-beamline operation.



- Twenty C-band accelerating structures downstream of BC3 are operated at 30 Hz.
- One half of the 60 Hz electron bunches are accelerated to 6.5 GeV and other half to 7.8 GeV.
- The kicker magnet deflect low energy bunches to BL2 and high energy bunches to BL3.

SACLA accelerator

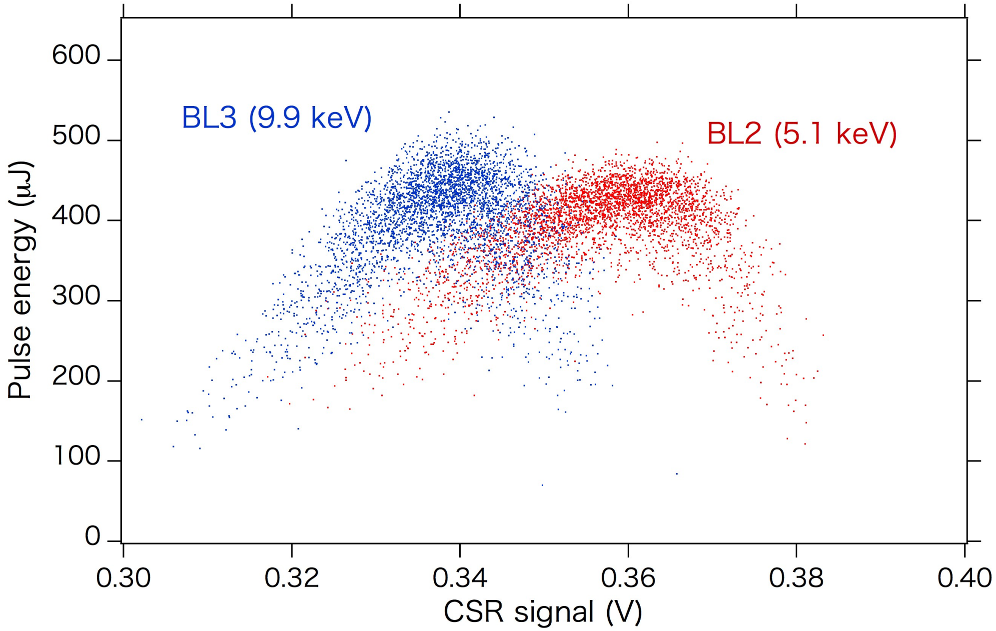


BL2 dogleg R_{56}=0

BL3 chicane R_{56}=-0.8 mm

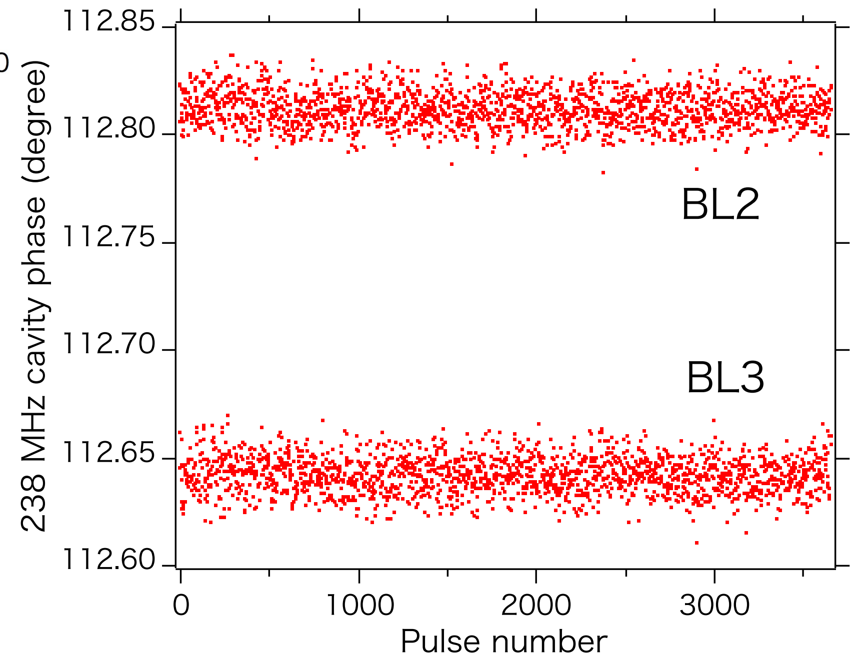
Optimum condition of the bunch compression is slightly different between the two beamlines.

Bunch to bunch RF phase control



Laser pulse energy as a function of BC3 CSR monitor output.

Beam energy	BL2 6.5 GeV
	BL3 7.8 GeV
Undulator K-value	BL2 2.6
	BL3 2.1
Electron beam repetition	60 Hz
BL2 laser repetition	30 Hz
BL3 laser repetition	30 Hz



RF phase of 238 MHz cavity in injector

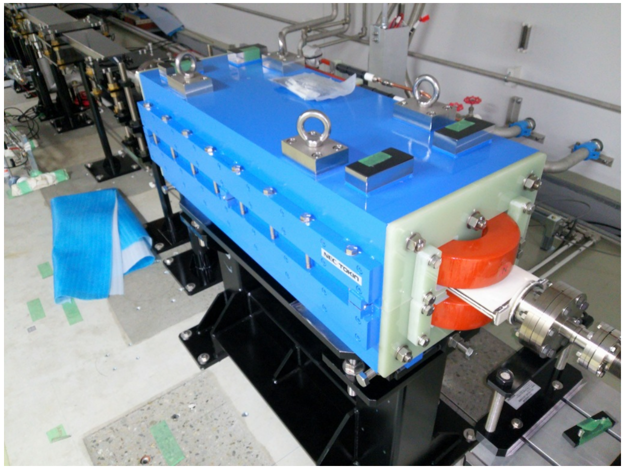
Summary

- The new beam optics of the BL2 dogleg based on two DBA structures successfully suppresses the transverse CSR effects.

- The laser pulse energy of BL2 increases from 150 μJ to 400 μJ due to the higher peak current.

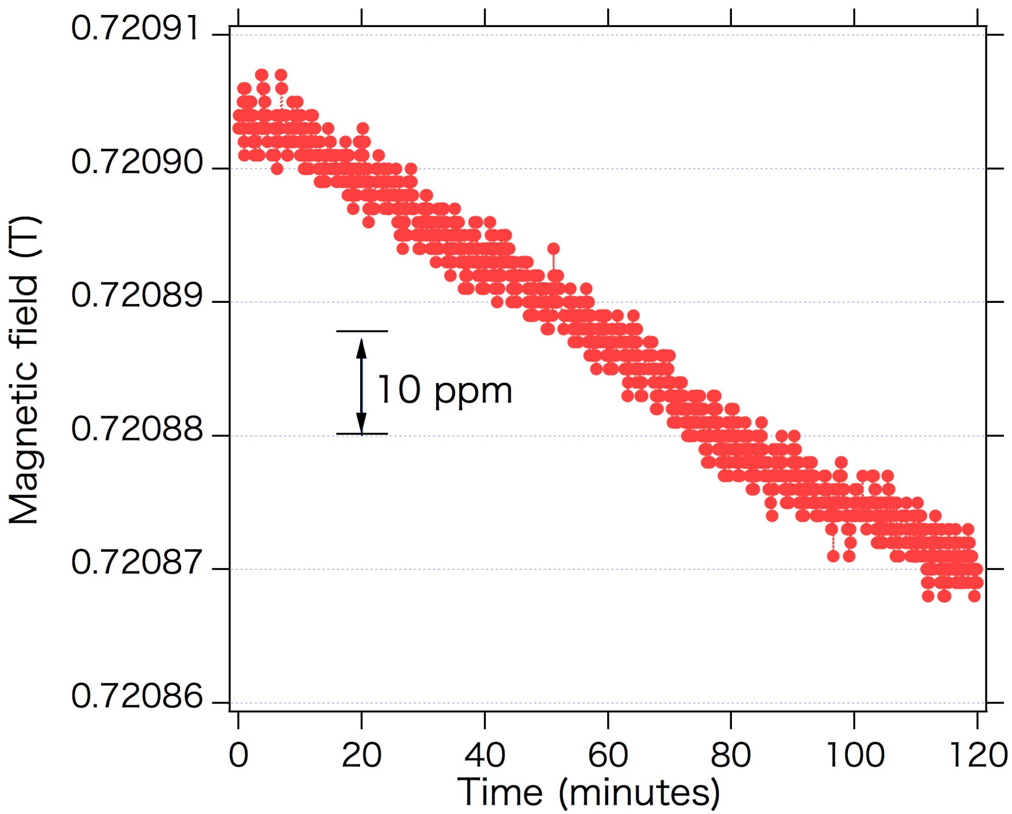
- In the multi-beamline operation, the beam energy and the bunch compression parameters are controlled from bunch to bunch and independently optimized for the two beamlines. Thus the laser pulse energies can be maximized for both beamlines and wide spectral tunability of XFEL is maintained.

Pulsed power supply of the kicker magnet



Kicker magnet
（Yoke length 0.95 m, B_{max}=0.9 T）

Power supply（60 Hz, 1 kV-299 A）



Stability of the kicker magnetic fields

SiC MOSFETs are used as switching elements.