Specifications and Performance of a Chicane Magnet for the cERL IR-FEL

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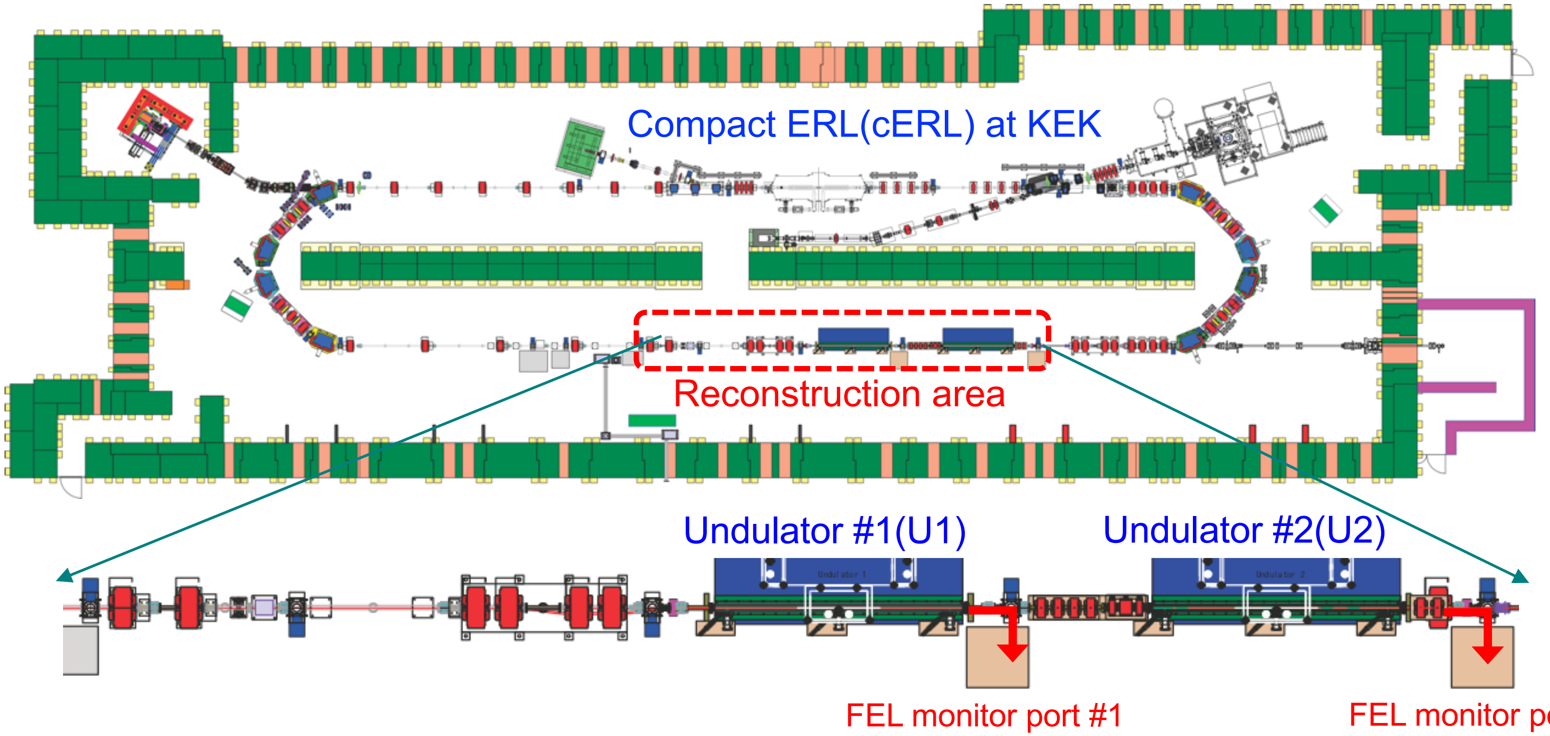
cERL IR-FEL Project

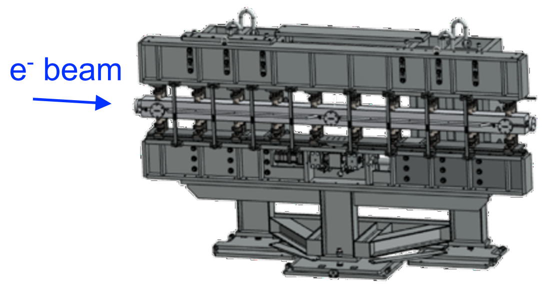
Project funded by a government organization NEDO :
"Development of high-power mid-infrared lasers for highly-efficient laser processing utilizing photo-absorption based on molecular vibrational transitions." (Dec. 2018 – Mar. 2021)



Beam parameter (Target)

- Energy : 17.5 MeV
- Bunch charge : 60 pC
- Repetition frequency : 81.25 MHz
- Bunch length : 0.5 - 2ps (FWHM)
- Energy spread : 0.1%
- Norm. emittance : 3 mm mrad

R. Kato et. al., this conference, TUPAB099.



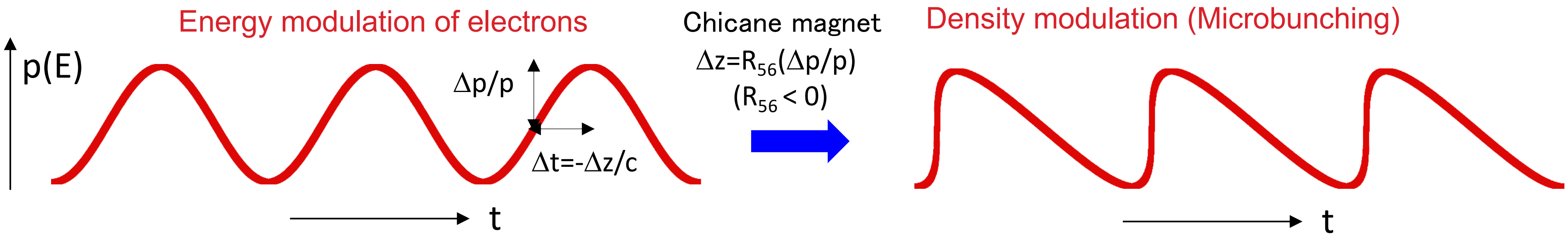
Undulator illustration

Undulator parameter

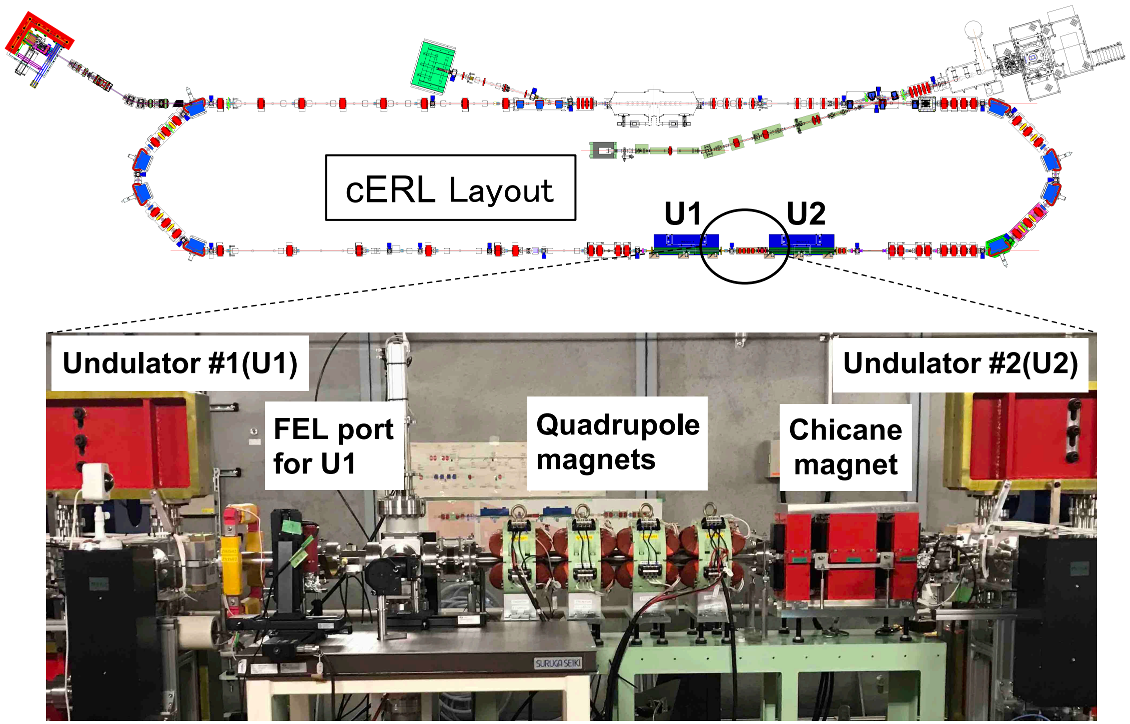
- Type : Planar (APU)
- Total length : 2.976 m
- No. of Undulator : 2
- Period : 24 mm
- Gap : 10 mm (fixed)
- K_u : 1.42 (max)
- FEL wavelength: 10 – 20 um

Role of the Chicane Magnet

The chicane magnet increases the FEL pulse energy by converting energy to density modulation (microbunching).

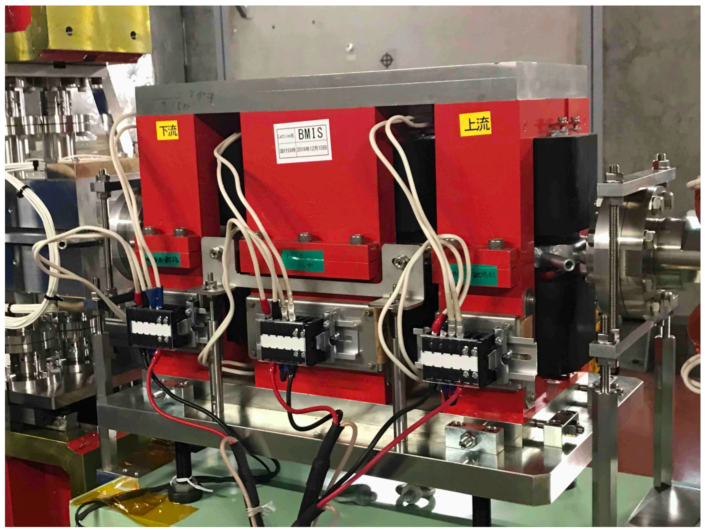


Schematic view of role of the chicane magnet for the cERL IR-FEL



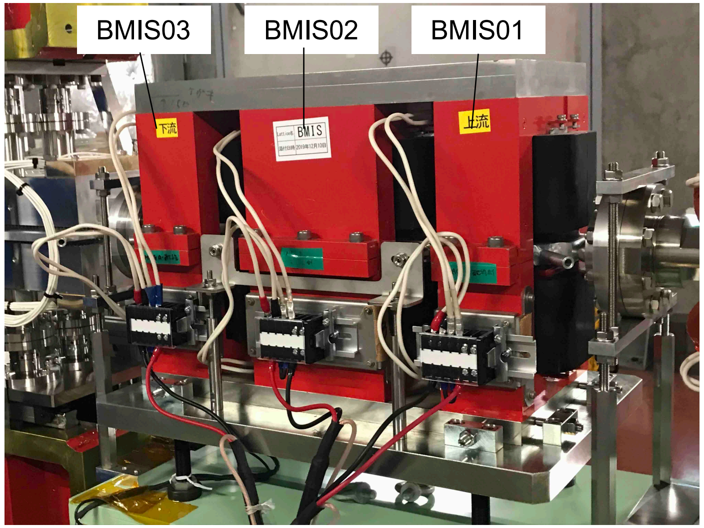
Layout of components between two undulators

The chicane magnet is placed between the two 3-m undulators in the cERL and used to increase the FEL pulse energy.

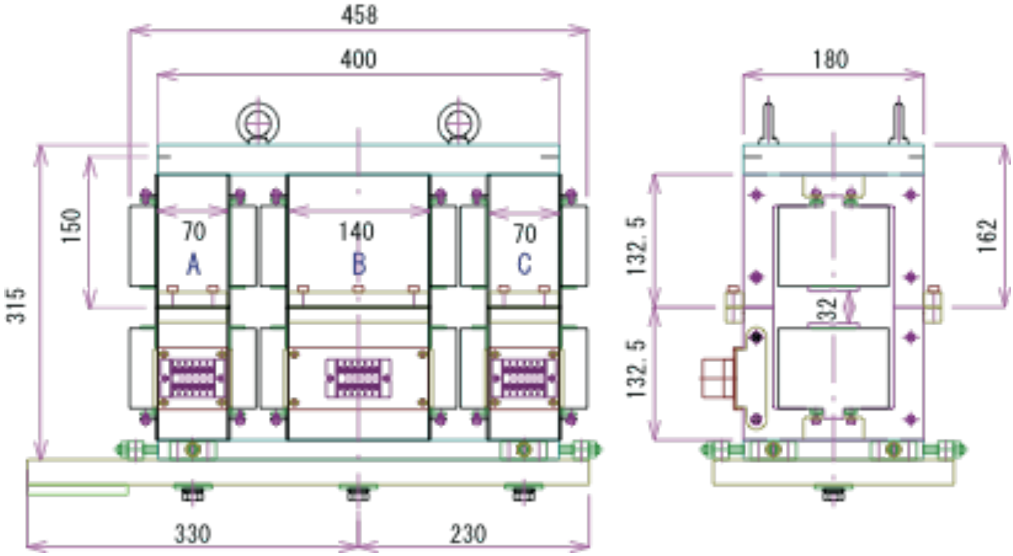


Chicane magnet installed in the cERL

Specifications of the Chicane Magnet



Chicane magnet



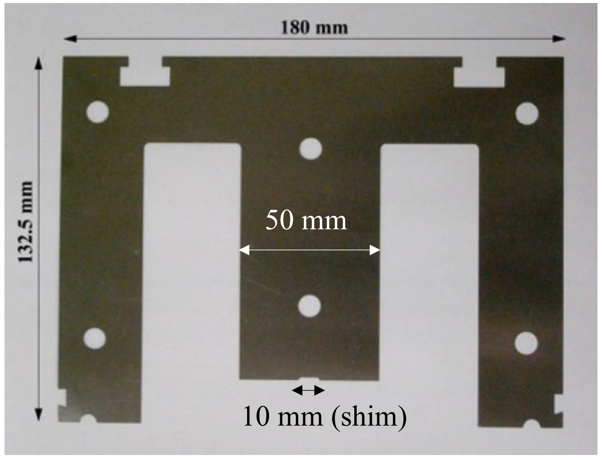
Structure and dimensions of the chicane magnet

Yoke

Material	0.1mm-thick permalloy lamination (low hysteresis and eddy currents)
Permeability	400000 (max.)
Saturation field	0.75 T
Adhesive insulation	Varnish

Coil

Turn number	168
Material	Rectangular copper wire (2 x 3 mm)
Adhesive	Epoxy resin
Current per turn	10 A (max.)

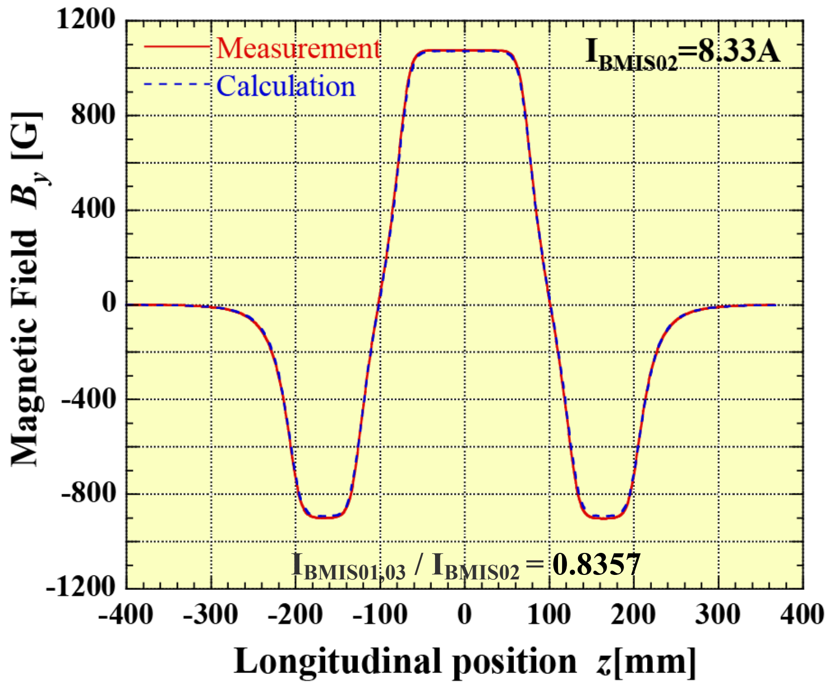


Yoke sheet（0.1mm-thick permalloy）

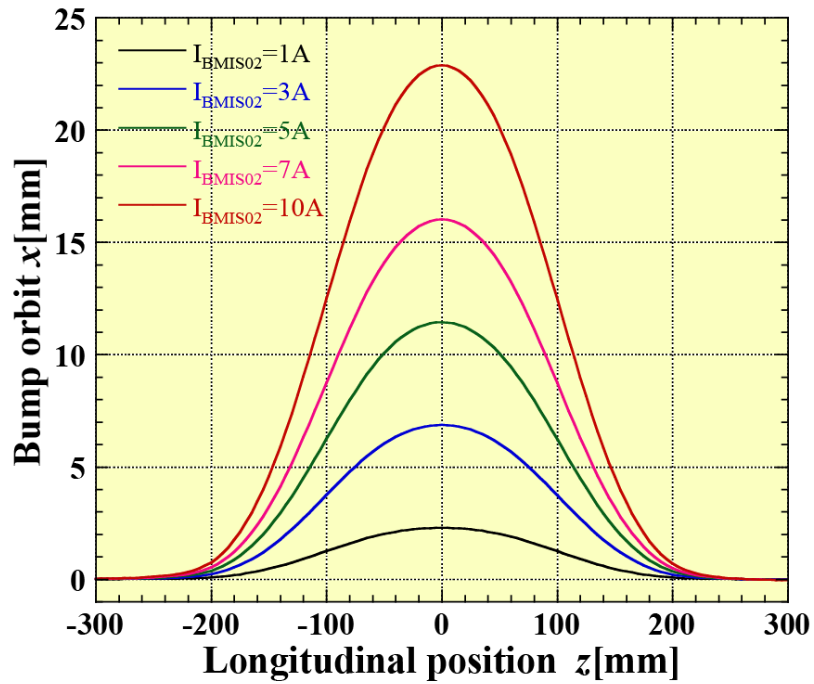
Coil

The chicane magnet was originally produced as the phase shifter prototype of a polarization-controlled undulator and reused for the cERL IR-FEL.
N. Nakamura et al., Proc. of PAC09, Vancouver, Canada, pp.342-344 (2009).

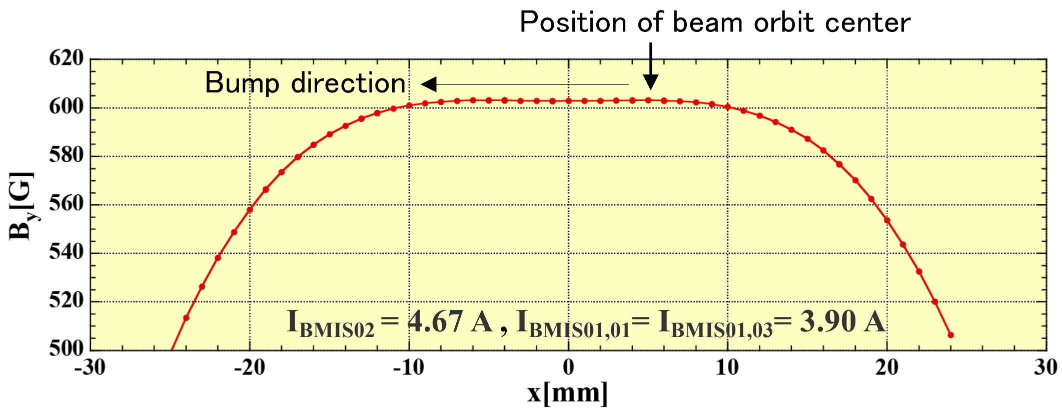
Field Distribution and Bump Orbits



Field distribution on the central axis of the chicane magnet



Bump orbit by the chicane magnet



Transverse field distribution at the BMIS02 center

$$x'(z) = \frac{e}{mc\gamma\beta}\int_{-\infty}^{z} B_y(z_1)dz_1$$

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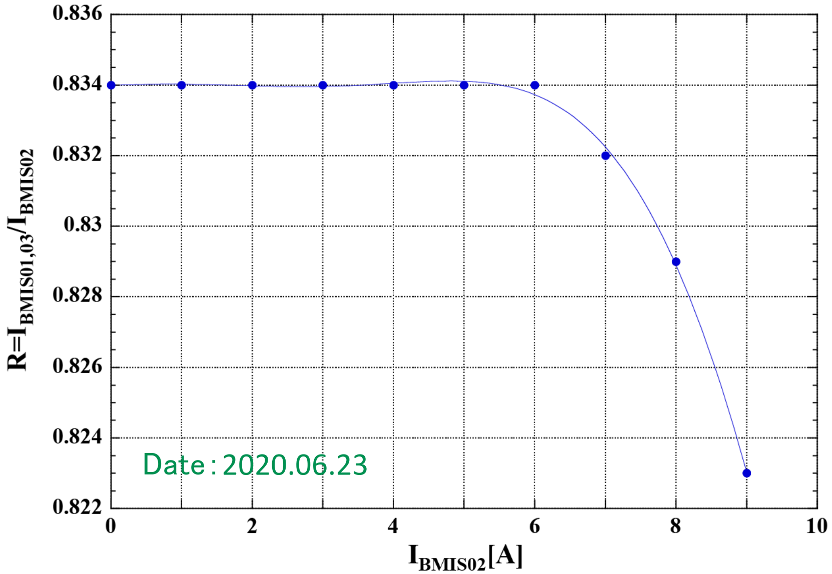
$$R_{56} = -\int_{-\infty}^{\infty} x'(z)^2 dz = -2\Delta L_z$$

ΔL_z : change of path length

$$I_{BMIS02} = 10\ A,\ E = 17.5\ MeV \rightarrow \Delta L_z = 3.0\ mm,\ R_{56} = -6.0\ mm$$

The chicane magnet center is horizontally displaced from the beam orbit center by 5 mm to improve the field uniformity for bump orbits at I_{BMIS02} > 5A.

Tuning of Bump Orbits



Current ratio for closed bump orbit ($R = I_{\mathrm{BMIS01,03}} / I_{\mathrm{BMIS02}}$) :
Result of fitting measured data to a sixth order polynomial

$R= a_6 I^6+ a_5 I^5+a_4 I^4+a_3 I^3+a_2 I^2+a_1 I+a_0$ （$I = I_{\mathrm{BMIS02}}$）

$a_0 = 0.83399$, $a_1 = 6.8774\text{e-}5$

$a_2 = -5.2135\text{e-}4$, $a_3 = -5.2346\text{e-}5$

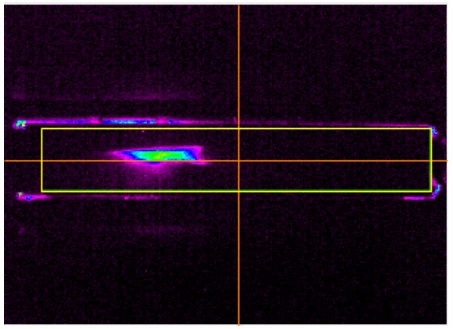
$a_4 = 2.4306\text{e-}5$, $a_5 = -3.4936\text{e-}6$

$a_6 = 1.3889\text{e-}7$

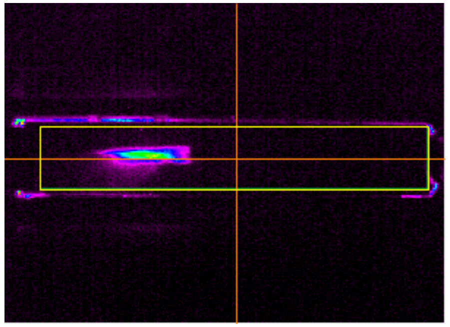
$I_{\mathrm{BMIS01,03}} / I_{\mathrm{BMIS02}} \sim 0.834$ @ $I_{\mathrm{BMIS02}} = 0$ - 6 A

（Calculated current ration：0.8357）

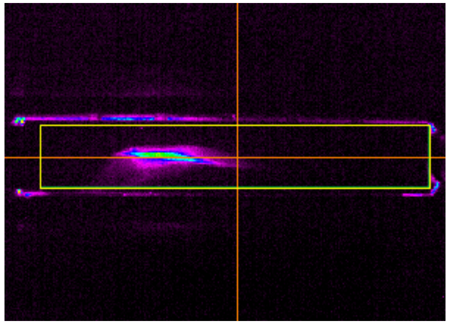
Measured current ratio of $I_{BMIS01,03}$ to I_{BMIS02} for making bump orbits closed



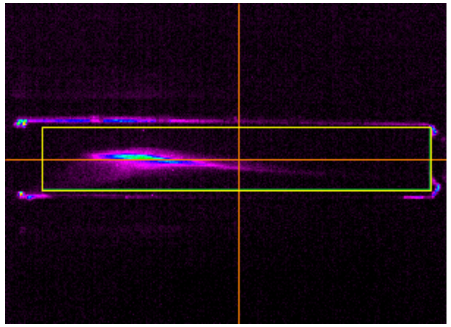
I_{BMIS02}= 0 A
R = 0.834



I_{BMIS02}= 5 A
R = 0.834



I_{BMIS02}= 6 A
R = 0.834



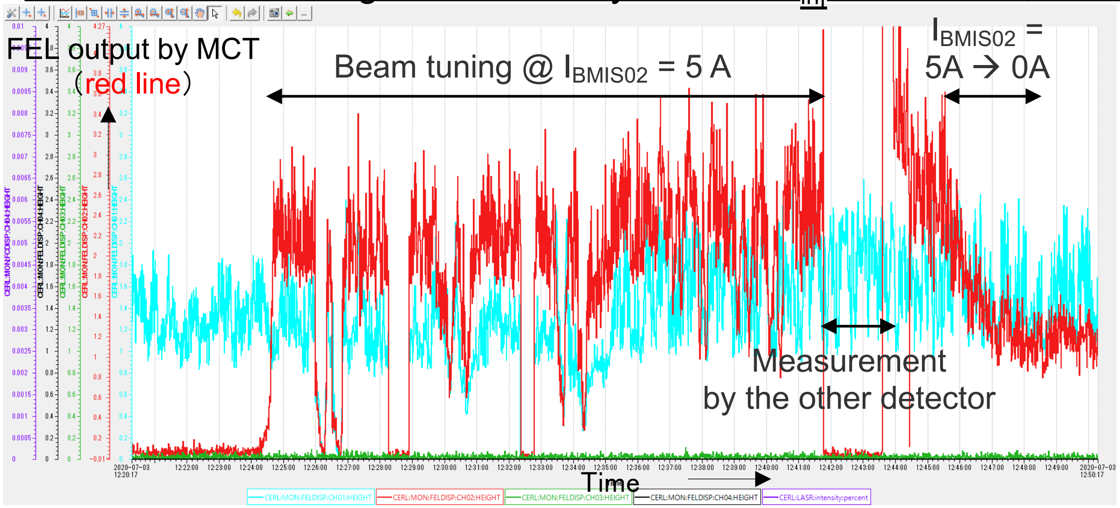
I_{BMIS02}= 7 A
R = 0.832

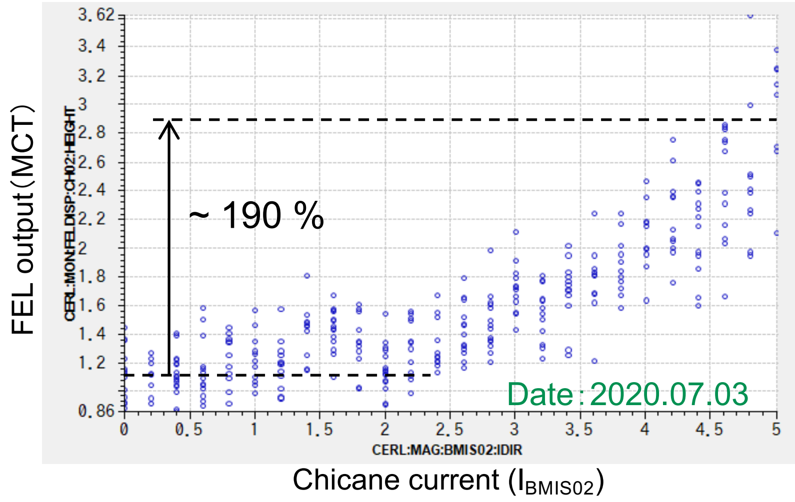
Beam profiles at the scree monitor cam23C in the Undulator #2

Current ratio of of R = $I_{\mathrm{BMIS01,BMIS03}}$ /I_{BMIS02} for closed bump orbit by the chicane magnet is kept constant for I_{BMIS02} = 0-6 A, but the current ratio and beam profile are significantly changed for I_{BMIS02} > 6 A, because the field uniformity is degraded.

Operational Performance

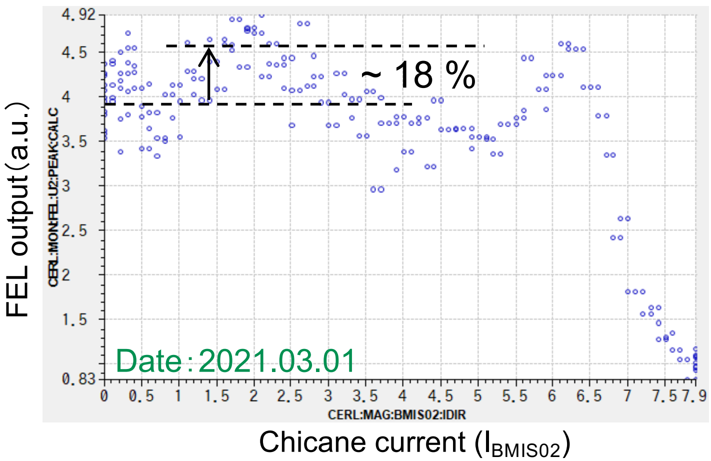
Beam commissioning of June to July 2020 : E/E_{inj}=17.6/5MeV, FEL wavelength $\lambda \sim 20\ \mu m$

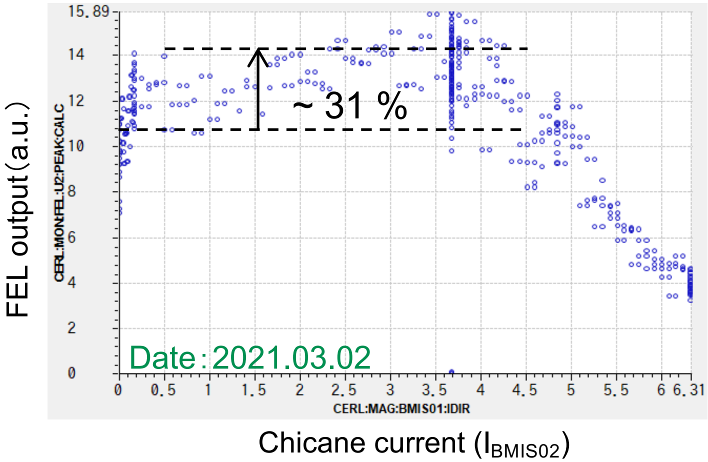


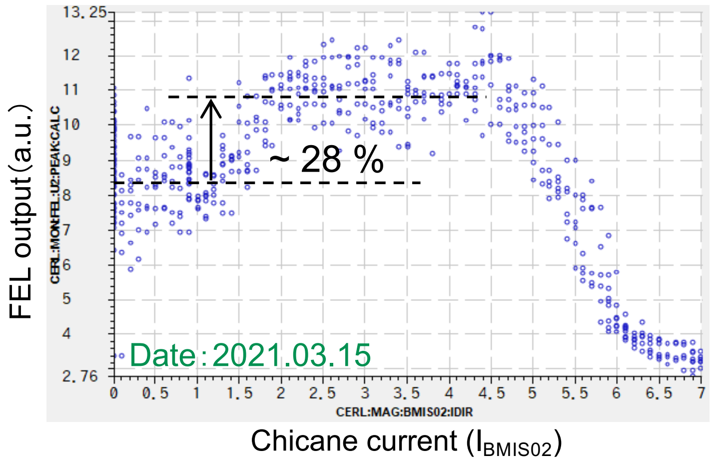


Time variation of the FEL output by an MCT detector (left) and dependence of the FEL output on the chicane current (right)

Beam commissioning of February to March 2021 : E/E_{inj}=17.6/5MeV, FEL wavelength $\lambda \sim 20\ \mu m$







Dependence of the FEL output on the chicane current for three different dates and conditions

The FEL output was differently enhanced by using the chicane magnet for different operation conditions.

Summary

1. A chicane magnet is placed between the two undulators in order to increase the FEL pulse energy of the cERL IR-FEL.

2. The chicane magnet consists of three dipole magnets, each of which has laminated yokes made of 0.1-mm-thick permalloy sheets and coils exciting the magnetic field with the maximum current of 10 A.

3. The current ratio of the three dipole magnets for making the bump orbit closed is almost the same at $I_{\mathrm{BMIS02}} < 6$ A, but it changes with the beam profile at $I_{\mathrm{BMIS02}} > 6$ A, because the field uniformity on the bump orbit is degraded.

4. The FEL output at 20 μm was increased in most cases by making use of the chicane magnet. However more systematic study and analysis on effects of the chicane magnet should be performed including different wavelengths.