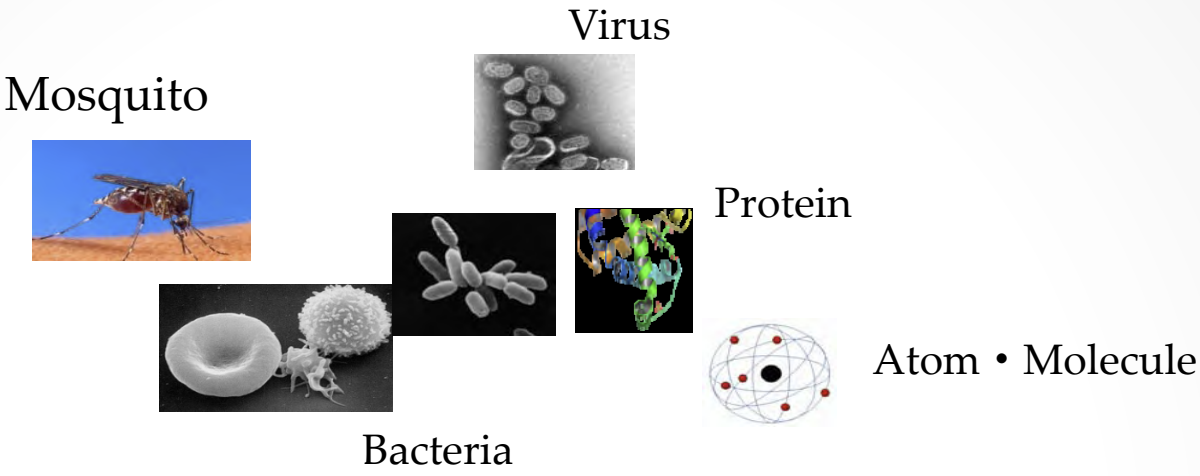
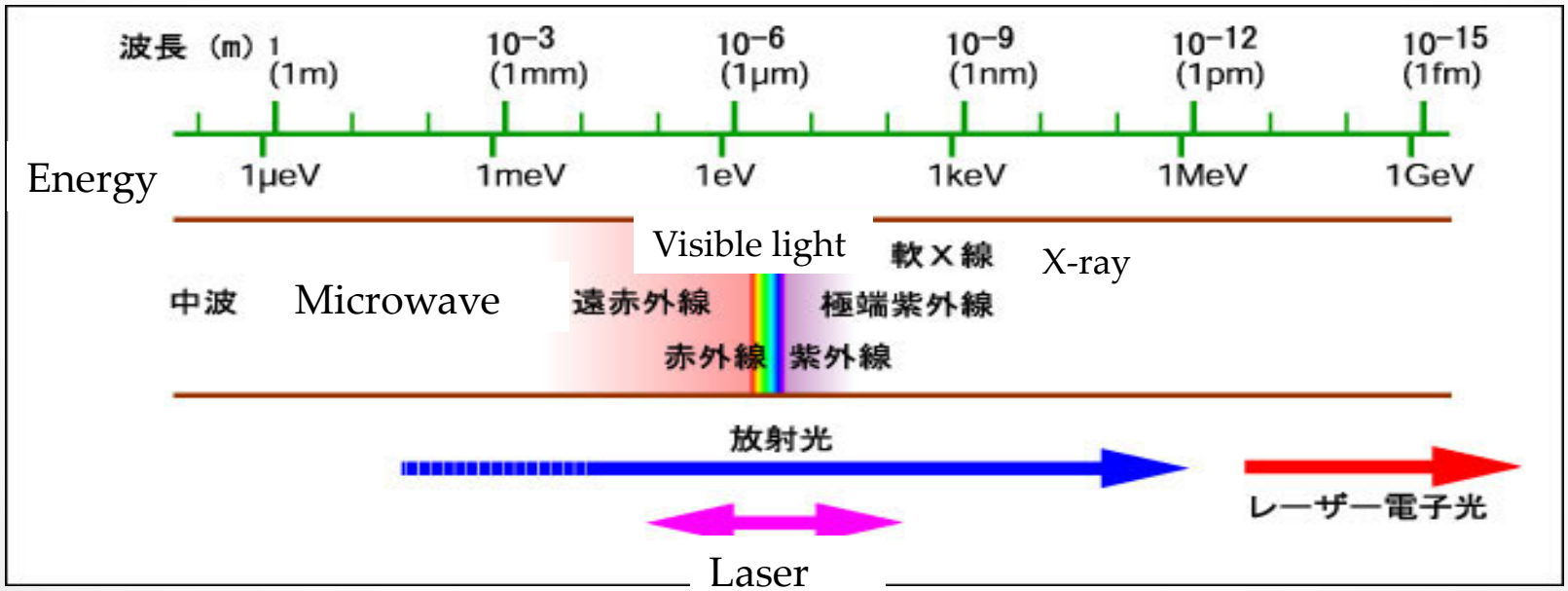
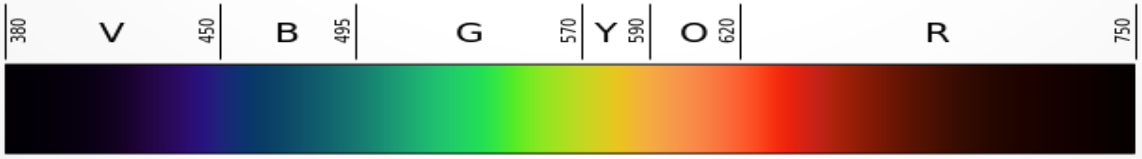
Free-electron laser "SACLA" and its basic

Yuji Otake, on behalf of the members of XFEL R&D division
RIKEN SPring-8 Center

Light and Its Wavelength, Sizes of Material

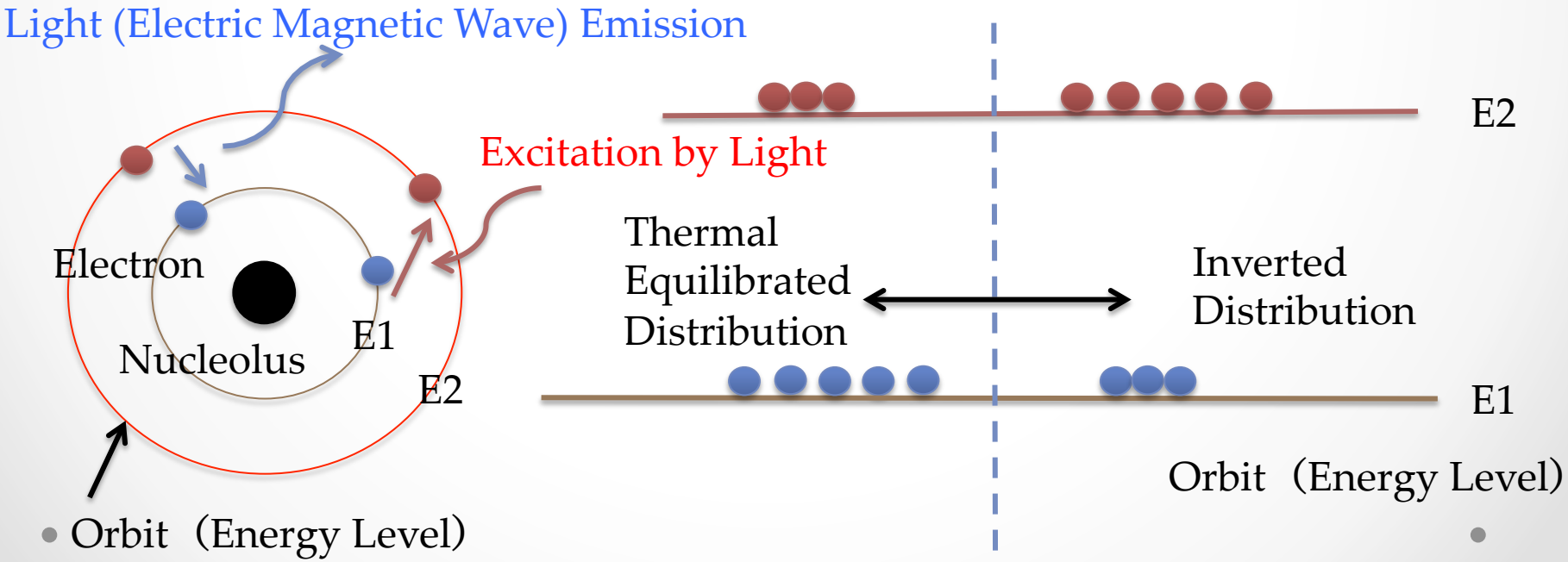




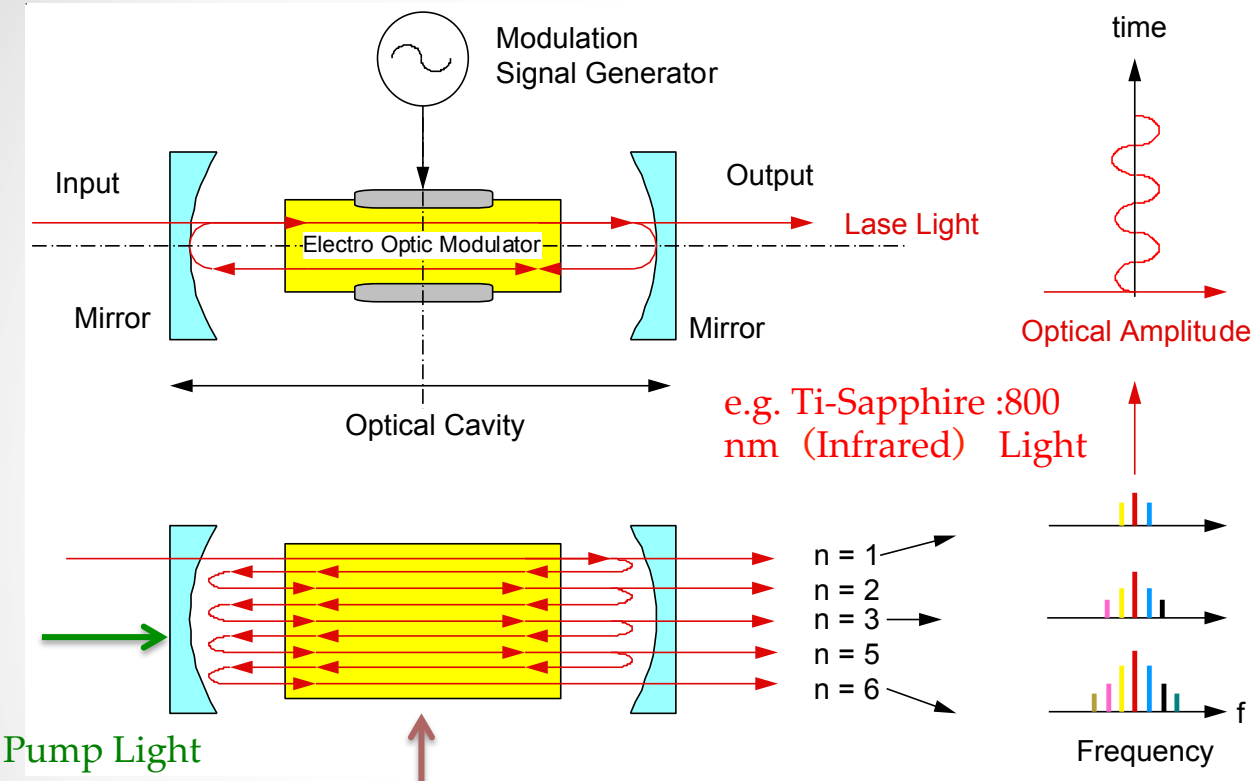


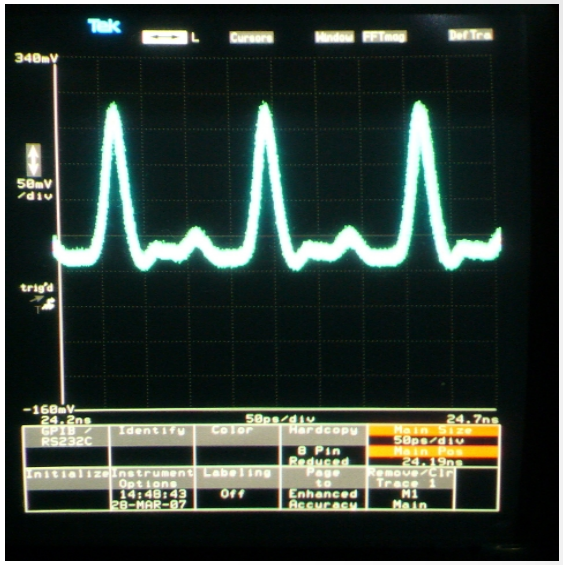
Ordinal Laser, e.g. Helium Neon Laser

- Excite the orbital electrons of an atom by external light.
- Change an orbital energy level (Pump) to make a inverted distribution of the electrons.
- Generate stimulated emission by returning the electrons to the original energy level.
- The special features of this laser are monochromatic, coherent, pointing stability and small spot size.
- Fixed wavelength (Energy), pulse width and intensity (Pulse energy).



Principle of Mode-locked Laser

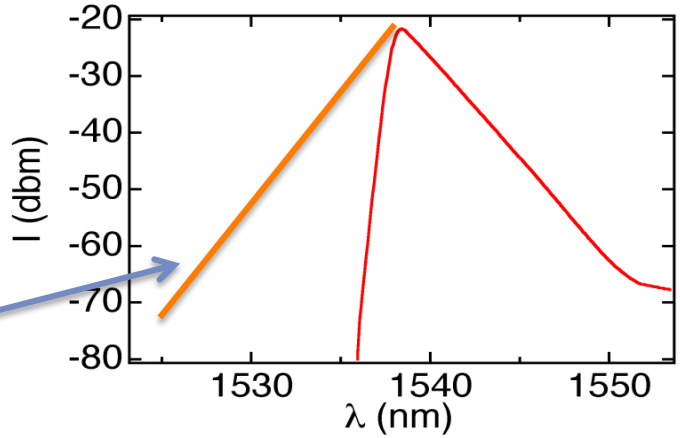




Optical Comb Pulse Train

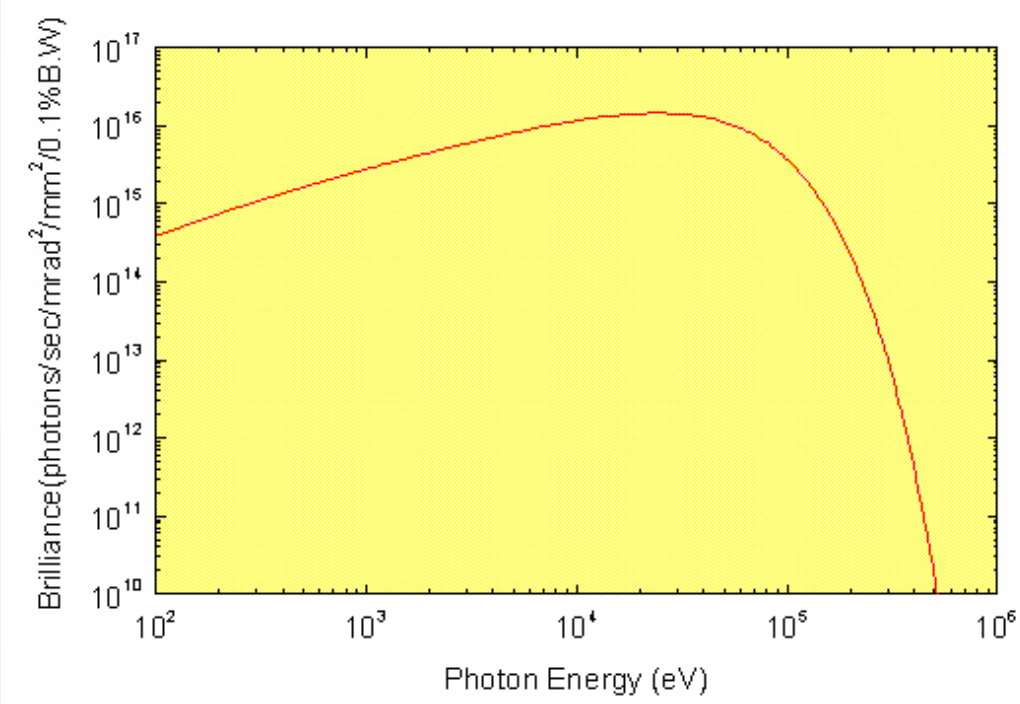
Pump Light: make the inverted energy level distribution of the orbital electrons of the atom.

Cut by an optical filter

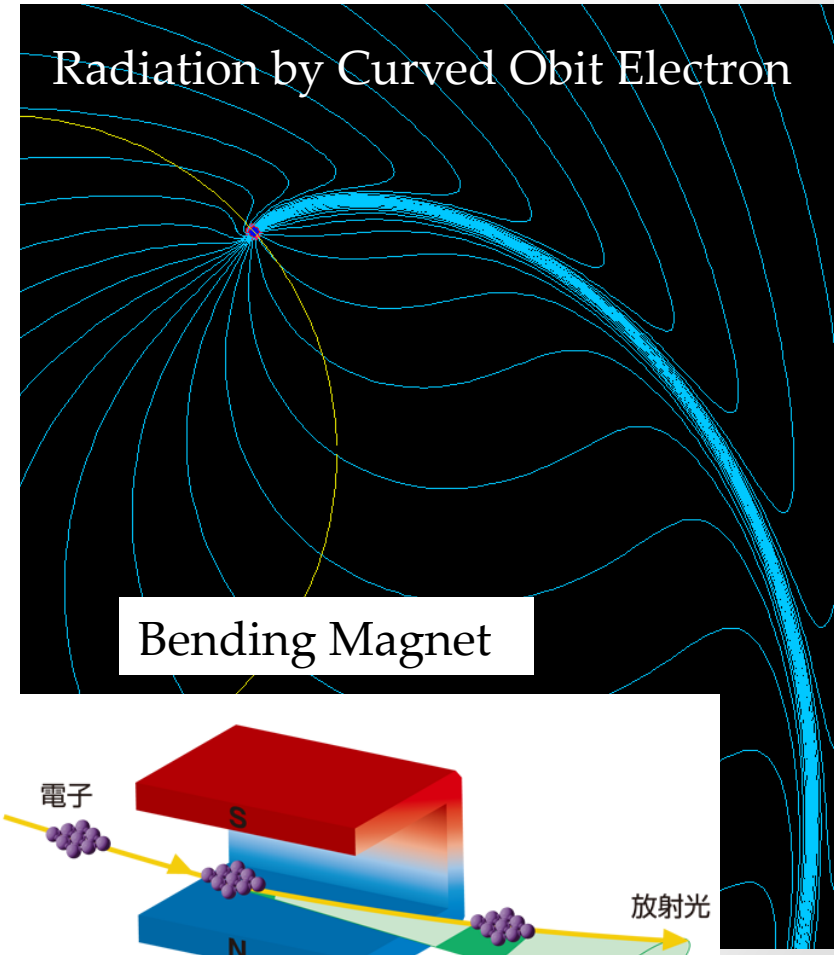


Radiation When Moving an Electron (Electromagnetic Wave Radiation)

Intensity Spectrum of Radiation

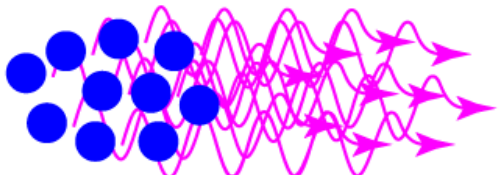


Electron



Synchrotron Radiation

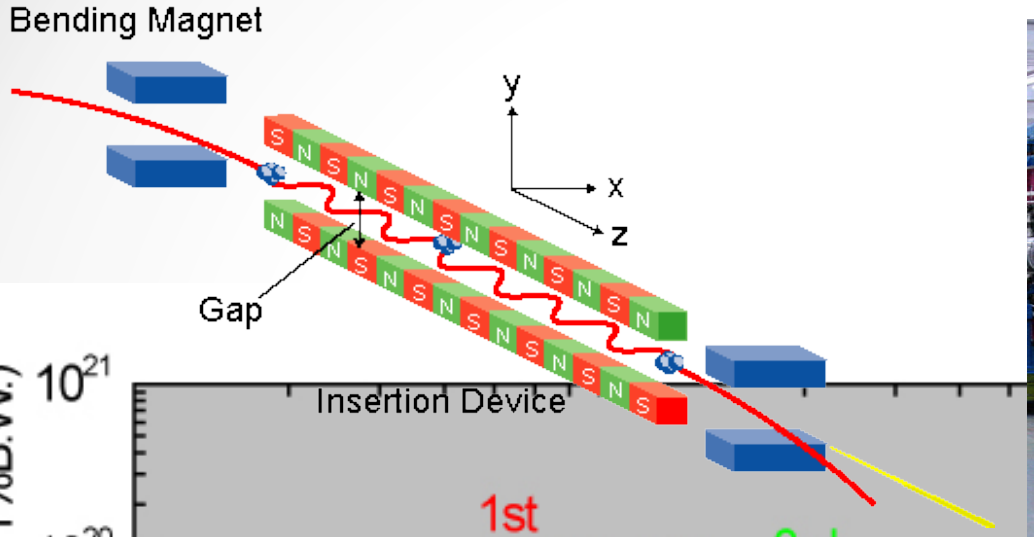
Electrons

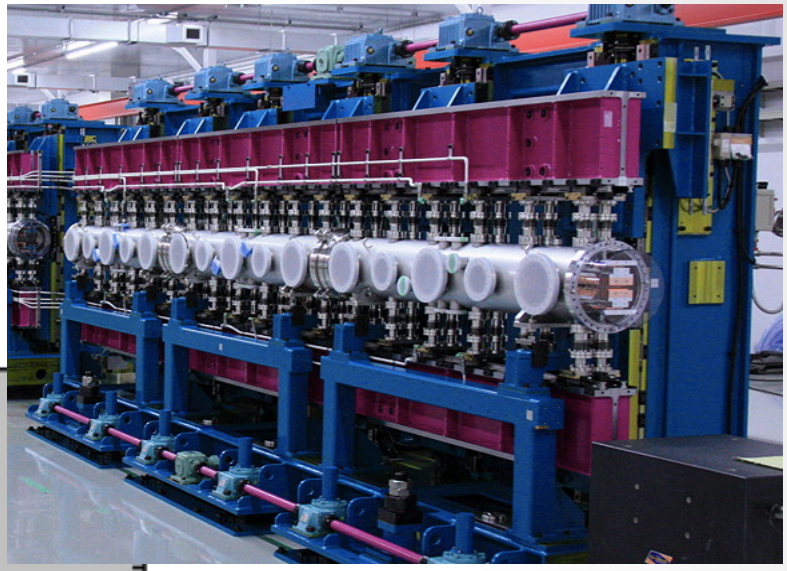


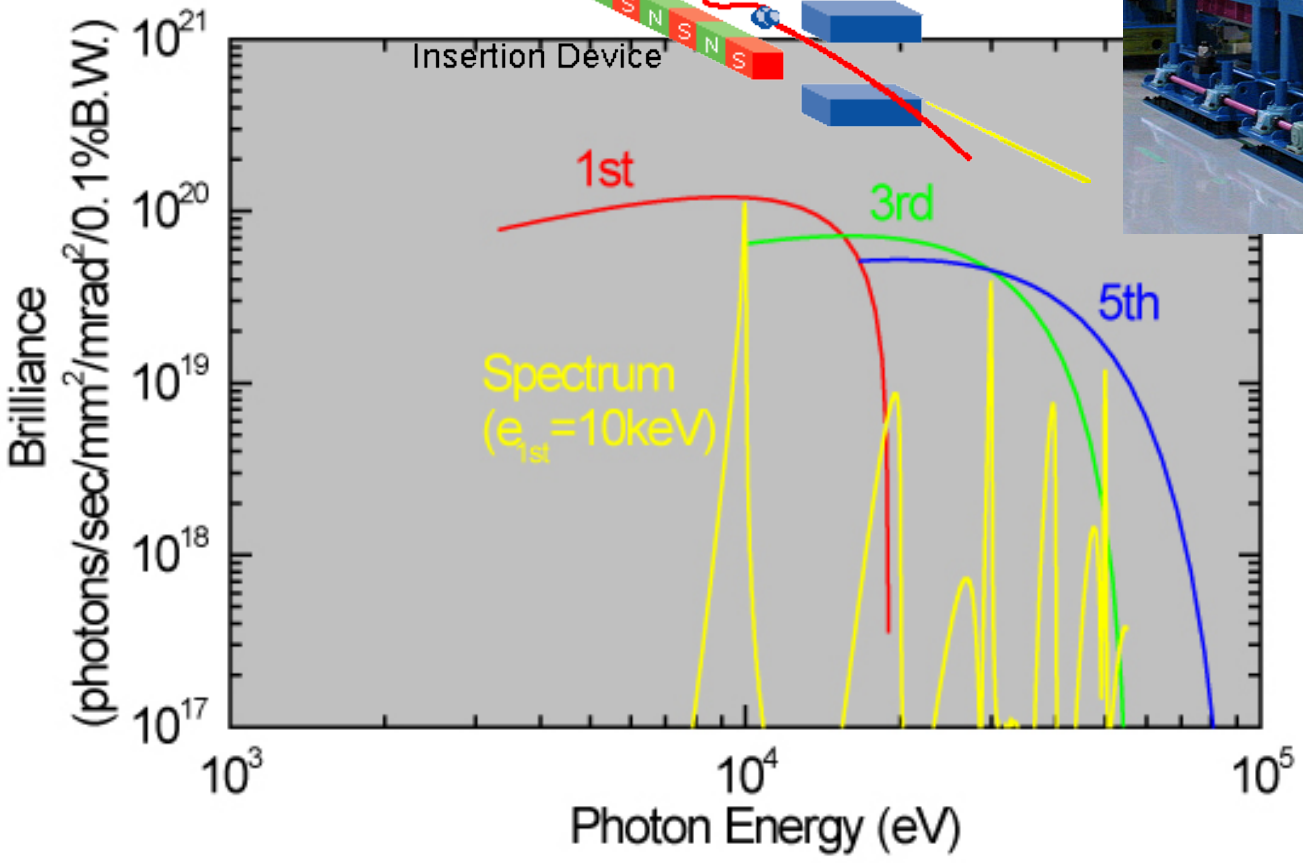
$P \propto N$

Incoherent light

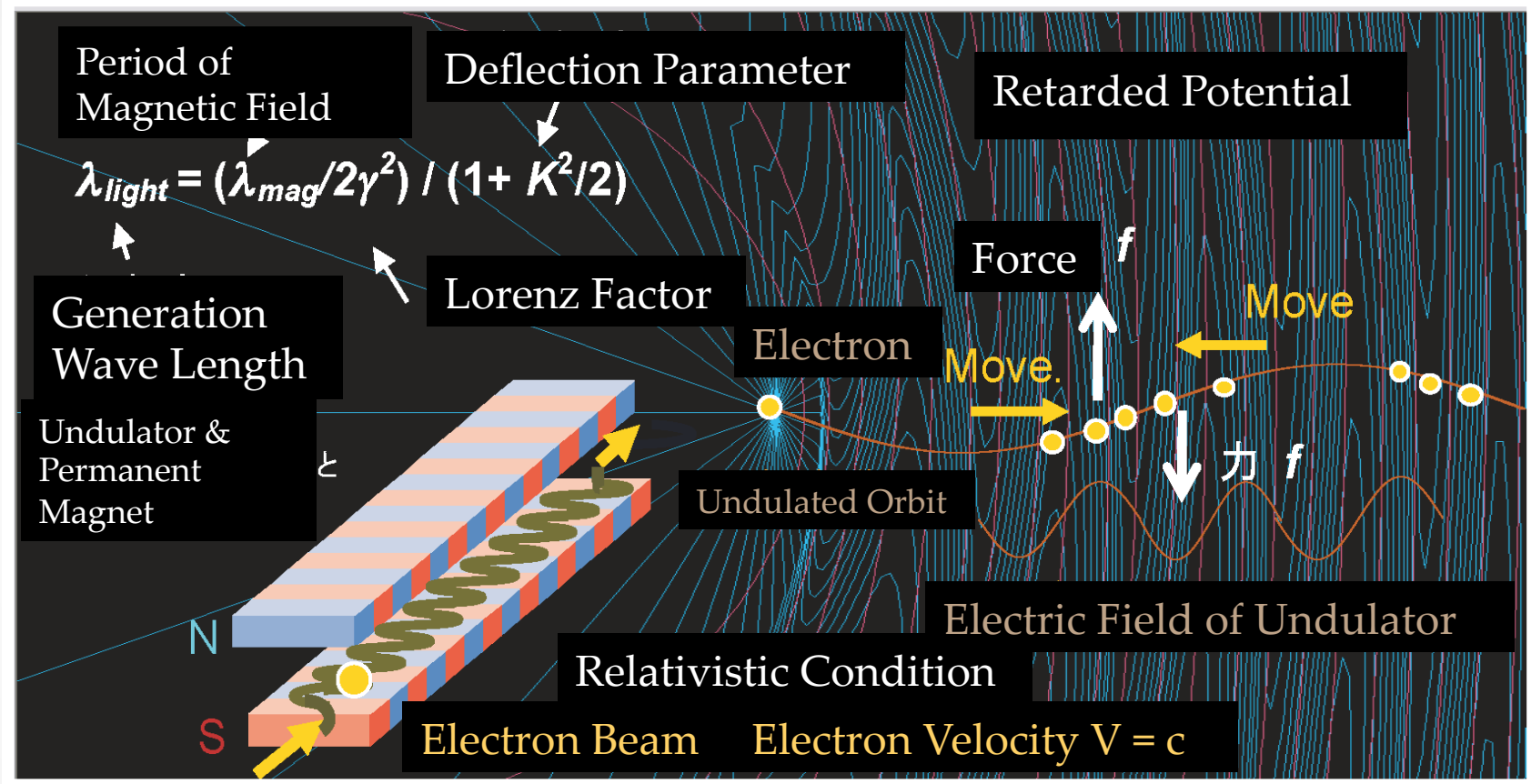
Undulator Principle



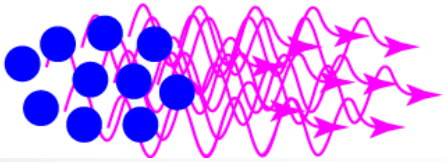




Electron Movement by Its Radiation (SASE)



Synchrotron Radiation



$P \propto N$

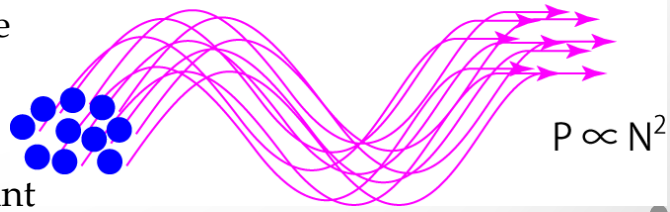
P : Electron Charge

$|E|^2 = (\rho/\varepsilon)_1^2 + (\rho/\varepsilon)_2^2 + \cdots$

ε : Dielectric Constant

ρ : Electron Charge

Coherent Synchrotron Radiation



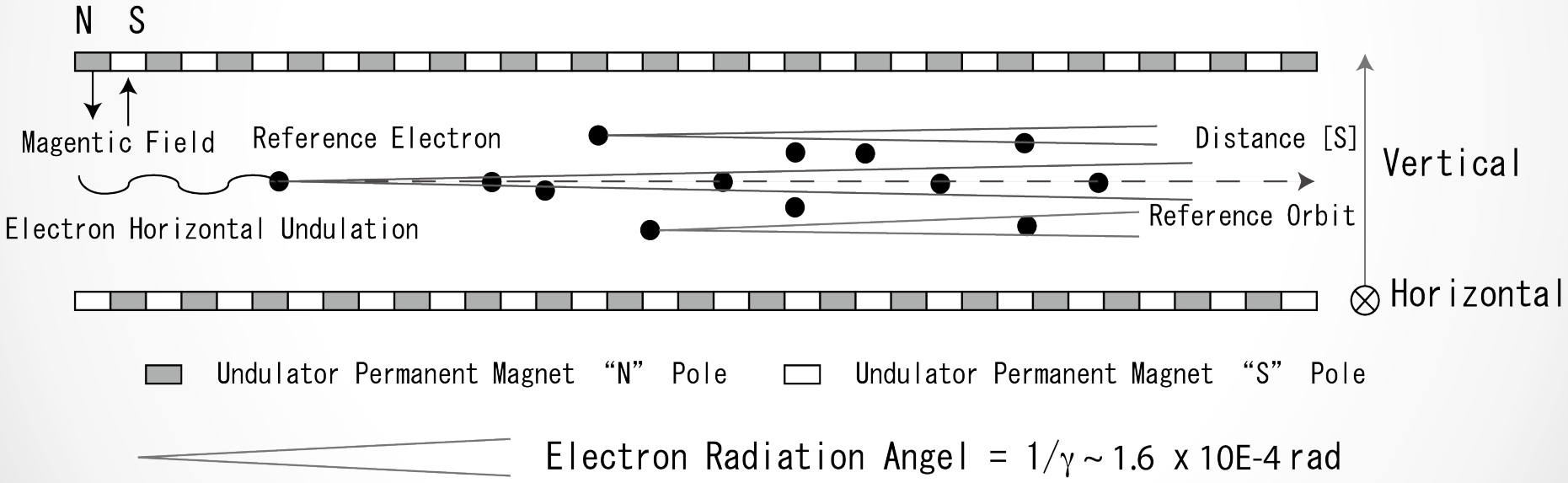
$P \propto N^2$

$|E|^2 = (\Sigma^n(\rho/\varepsilon))^2$

Electron Radiation Angle in Undulator

The radiation angle from the electrons is $1/\gamma$.

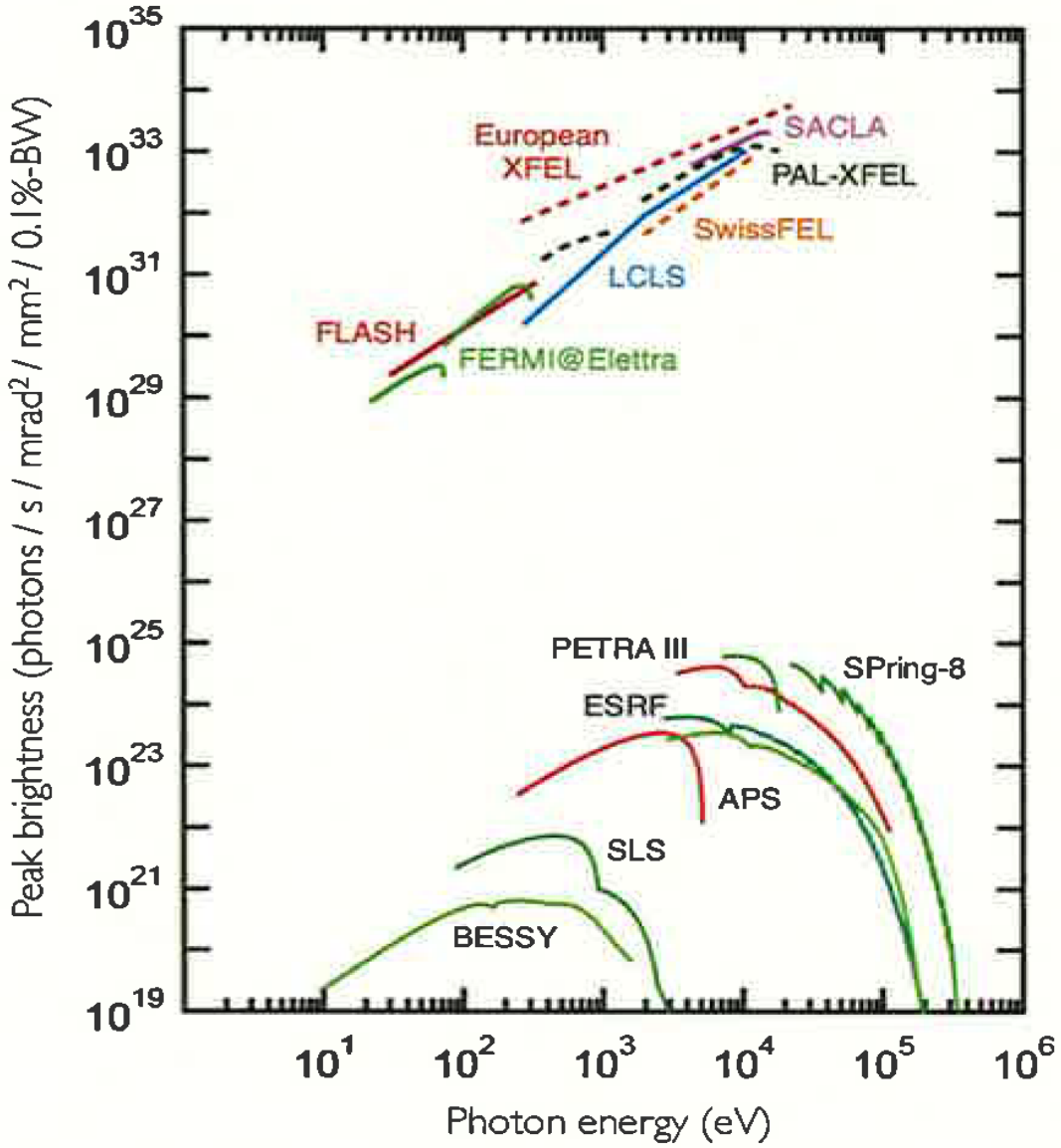
The radiations form the behind electrons modulates the transvers motion of the advanced electron.



The straightness of the electron orbits are within 1.6 x 10E-4 rad, $1/\gamma$ @8 GeV.

γ : Lorentz Factor

Laser Brightness and Photon Energies of XFELs and Synchrotrons



Refernce
Springer Tracts in Modern Physics Volume 258 2014
Free-Electron Lasers in the Ultraviolet and X-Ray Regime, 2nd Ed,
Physical Principles, Experimental Results, Technical Realization

Feature of FEL

- Electrons passing Undulated with the undulators emit the free-electron laser, FEL.
- The special features of FEL are monochromatic, coherent, pointing stability and small spot size.
- Variable wavelength (Energy), pulse width and intensity (Pulse energy) by the electron energy, the bunch compress, the K value (Magnetic field strength) of the undulator and the electron peak current.

SPring-8 Campus

SACLA

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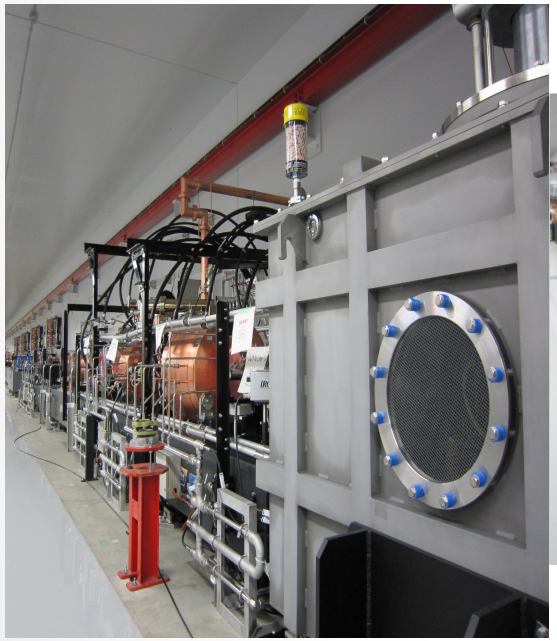
SACLA Accelerator Main Components

500 kV low-emittance pulsed thermionic electron-gun

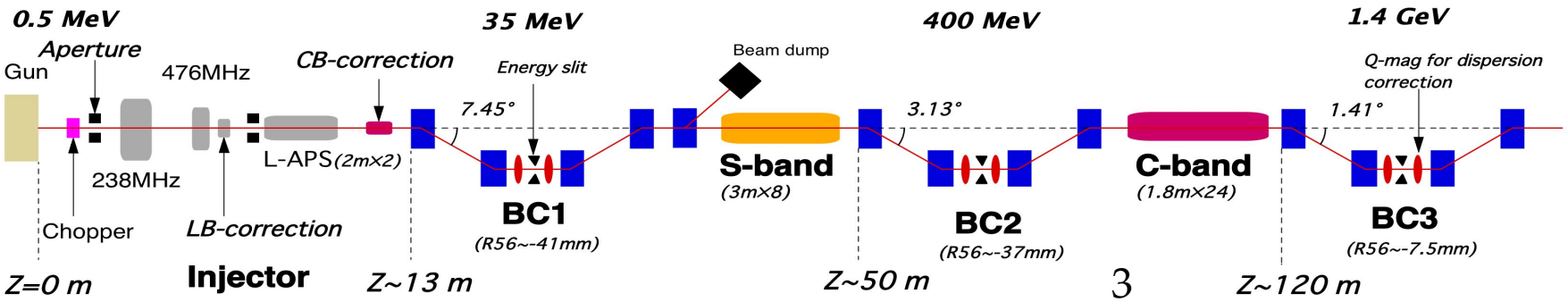
C-band acceleration structures (37MV/m @SACLA)

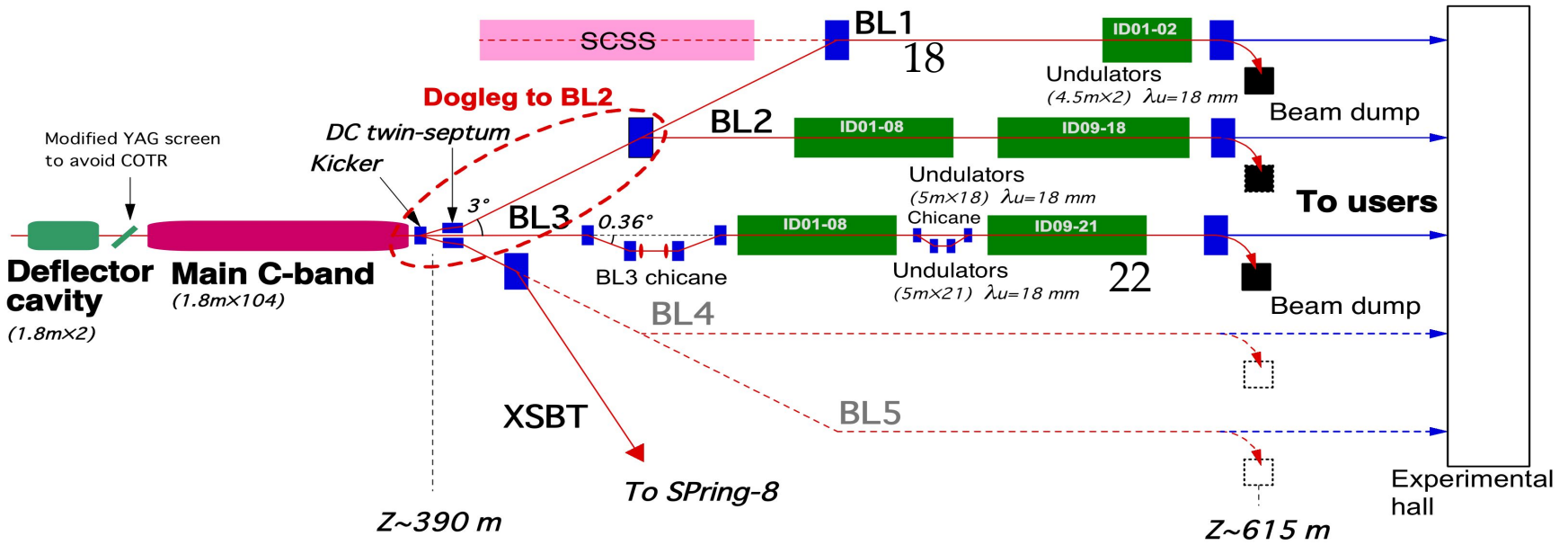
Short-period in-vacuum undulators (K～2.1)



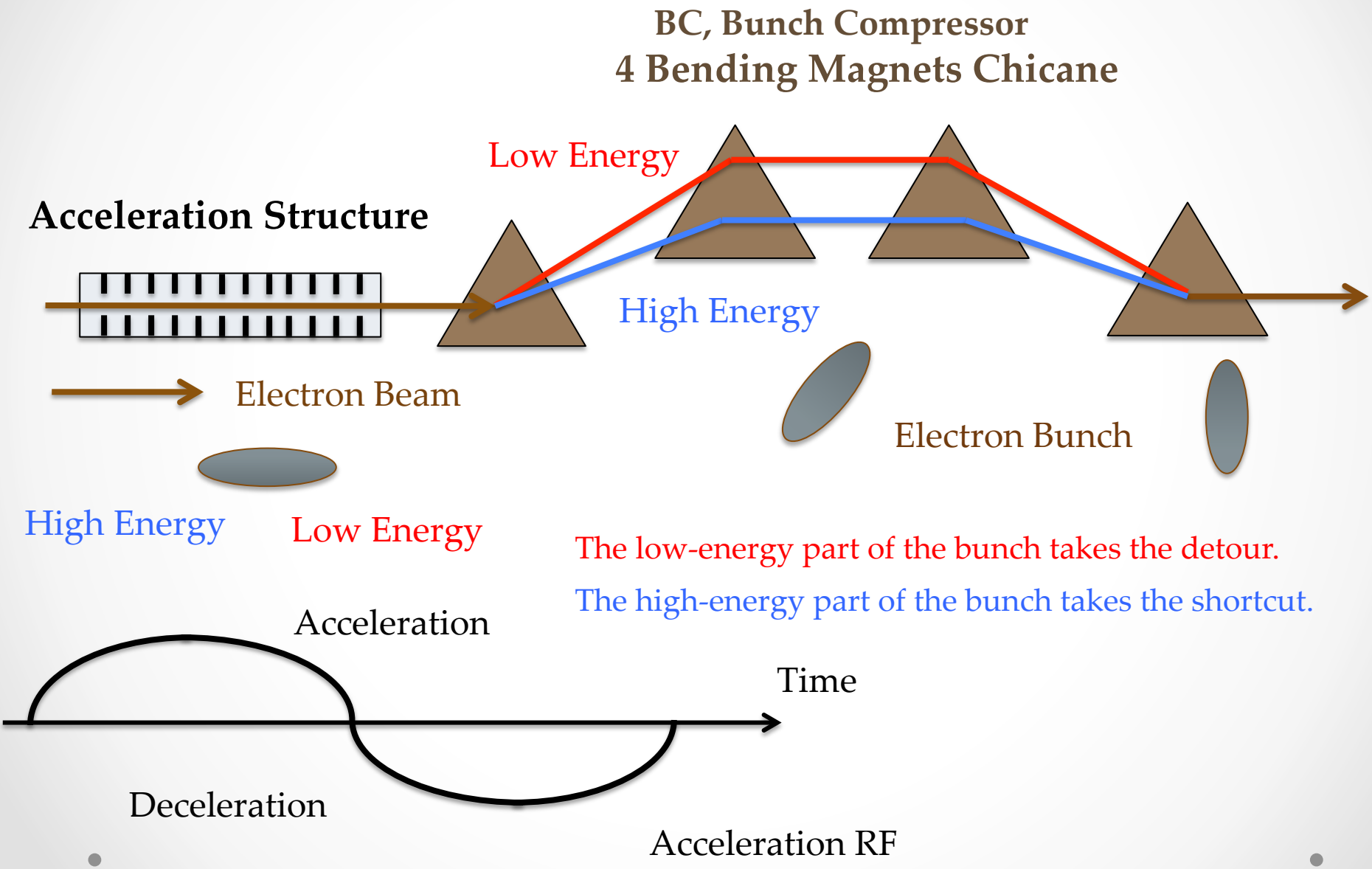
Machine Configuration of SACLA

We have 2 laser sources, which are SACLA and SCSS+. They mainly comprise thermionic electron-guns, C-band acceleration structures, and in-vacuum undulators.

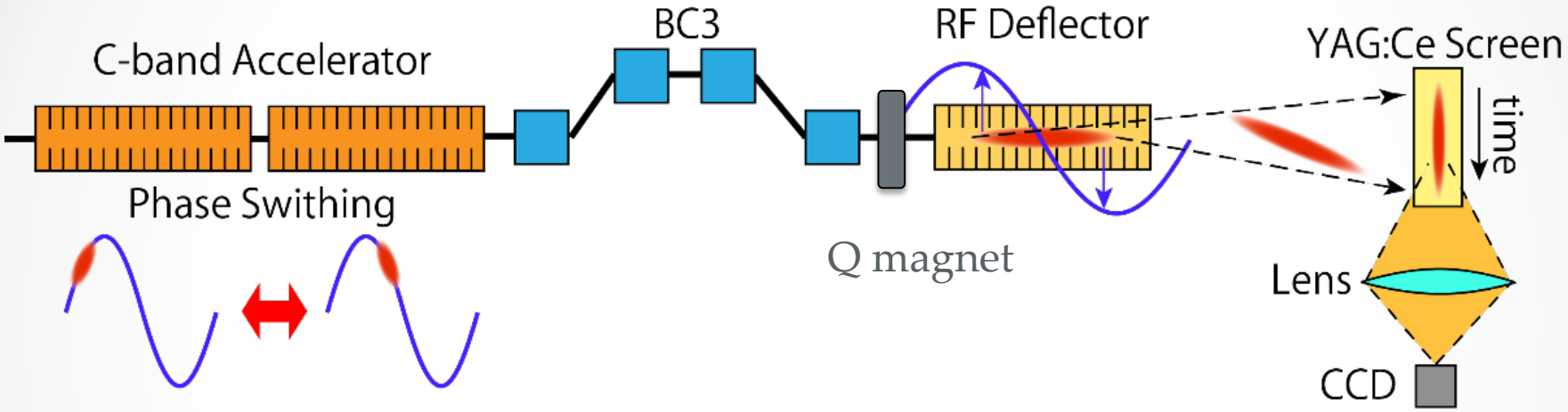


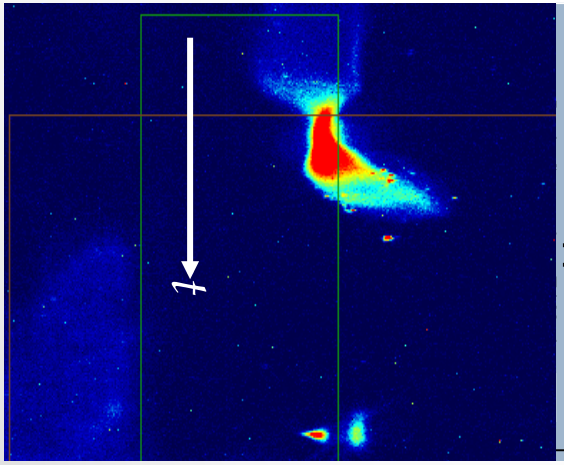


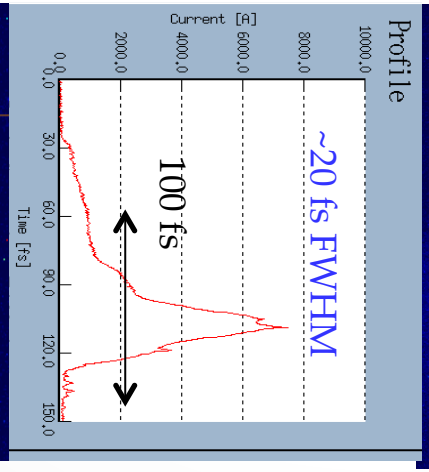
Magnetic Bunch Compression

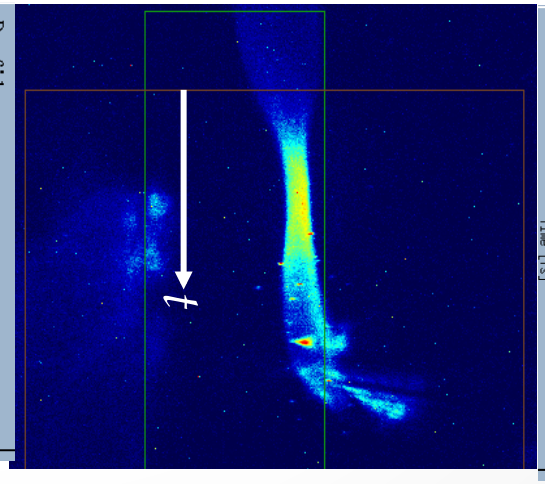


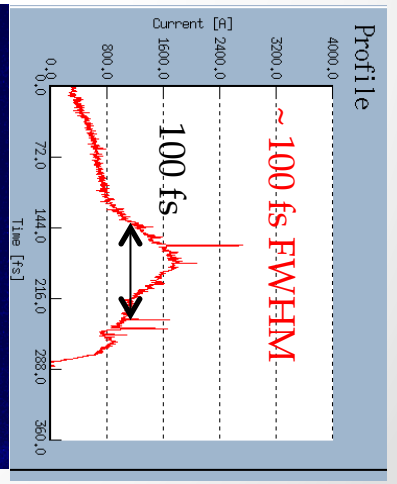
Measurement of Beam Bunch Length by the RF Deflector System



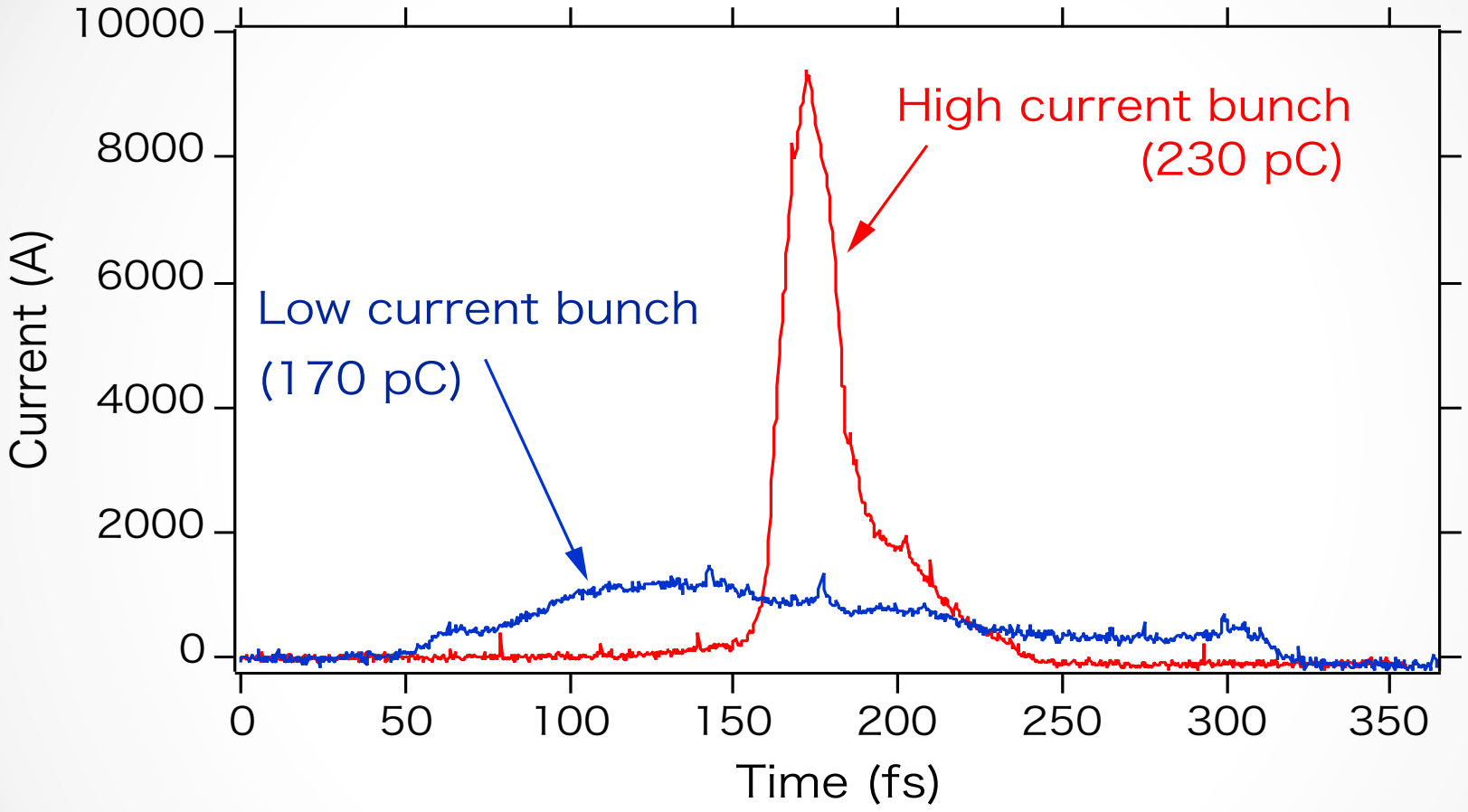








Temporal Electron Bunch Structures of BL3 and BL2

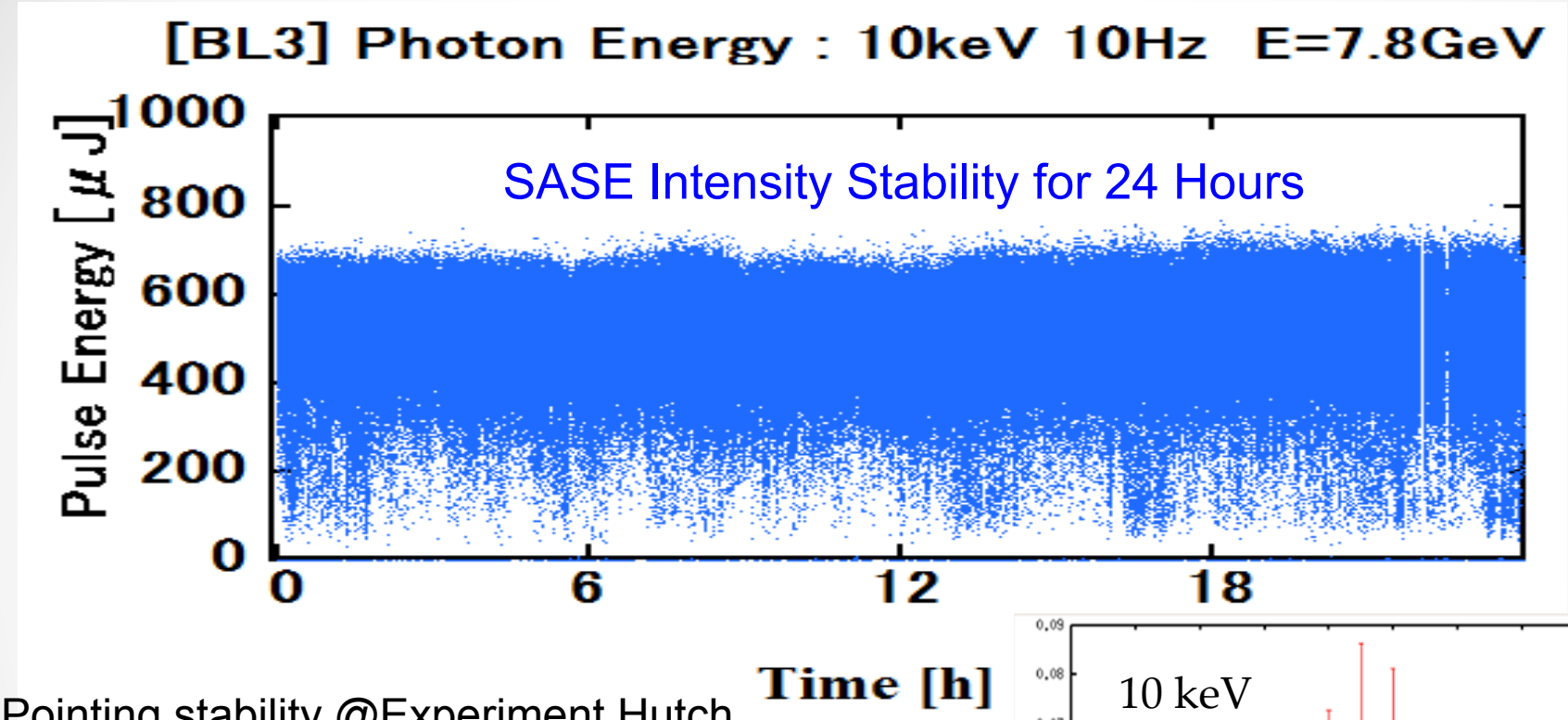


- Red: A peak current of the BL3 is ~10 kA at 8.0 GeV.
- Blue: A peak current of the BL2用 is ~1 kA at 6.3 GeV.

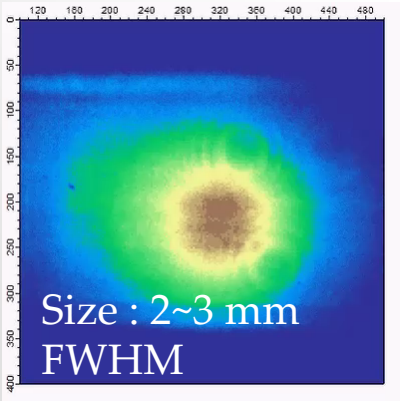
Specifications of BL3 and BL2

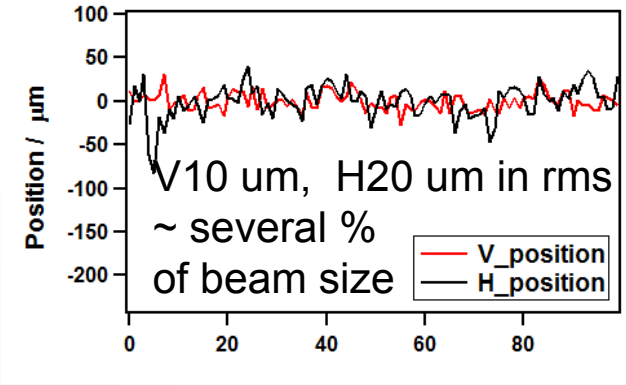
Number of undulators	22@BL3, 18@BL2
Undulator length	5 m
Number of period (undulator)	277
Minimum magnetic gap (undulator)	< 3.5 mm
Maximum K value (undulator)	< 2.85
Effective length of the beam line	~ 90 m
Output wave length	~ 0.08 nm@BL3 ~ 0.12nm@BL2
Electron beam energy	~ 8.5 GeV
Self seeding function	BL3

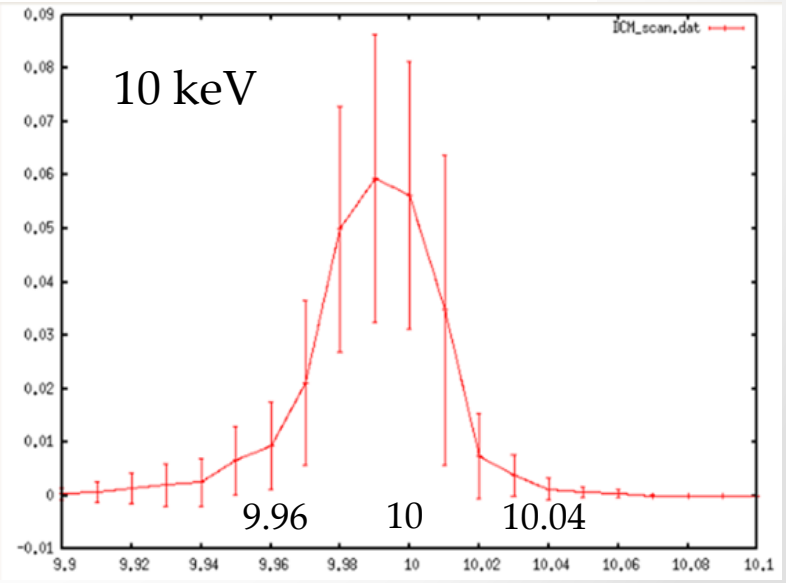
Present Laser Performance (BL3)



Pointing stability @Experiment Hutch

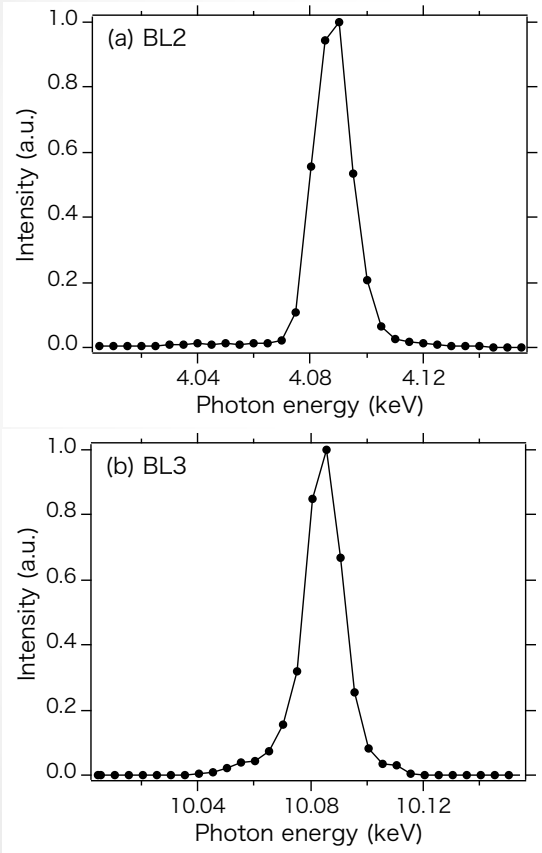






Simultaneous Double Electron Beam Energies Operation at the BL3 and BL2

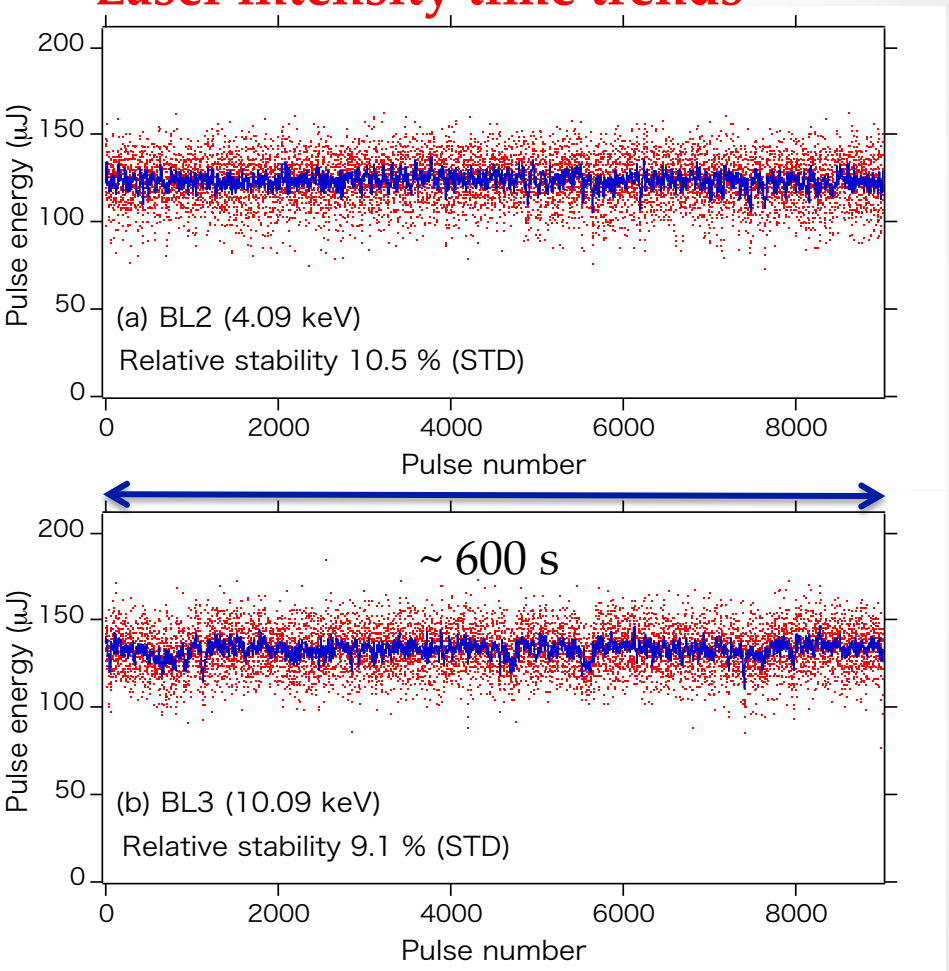
Laser Spectra at BL2 and BL3



BL2
Electron
6.3 GeV
Photon
4.09 keV
15 Hz
K=2.85

BL3
Electron 7
GeV
Photon
10.09 keV
15 Hz
K=2.1

Laser intensity time trends

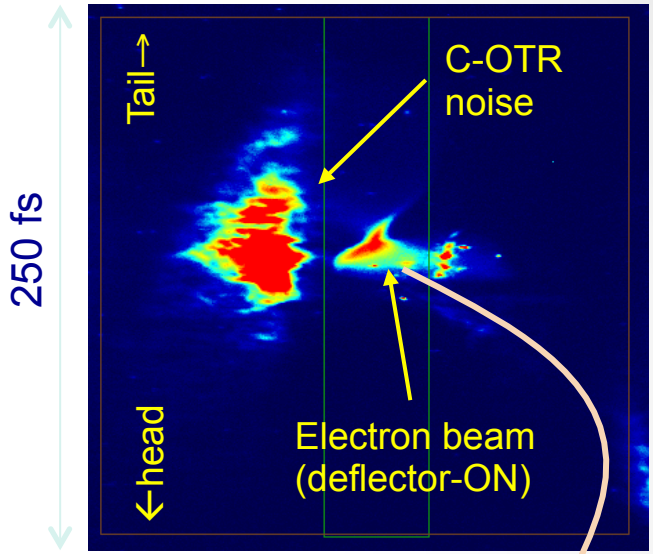


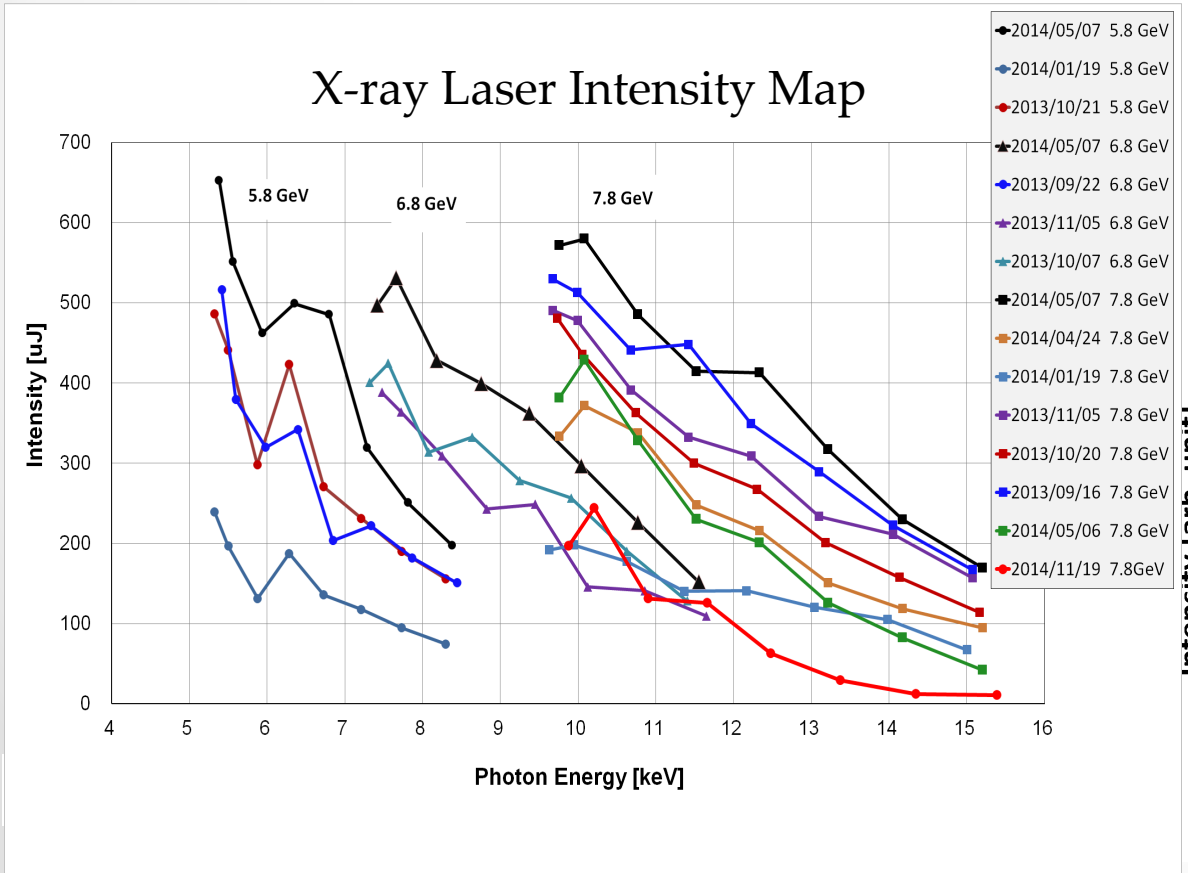
- Electron Peak Current: 1.2 kA, Pulse Width: ~150 fs FWHM, Repetition: 30 Hz at both Bl2 and BL3.

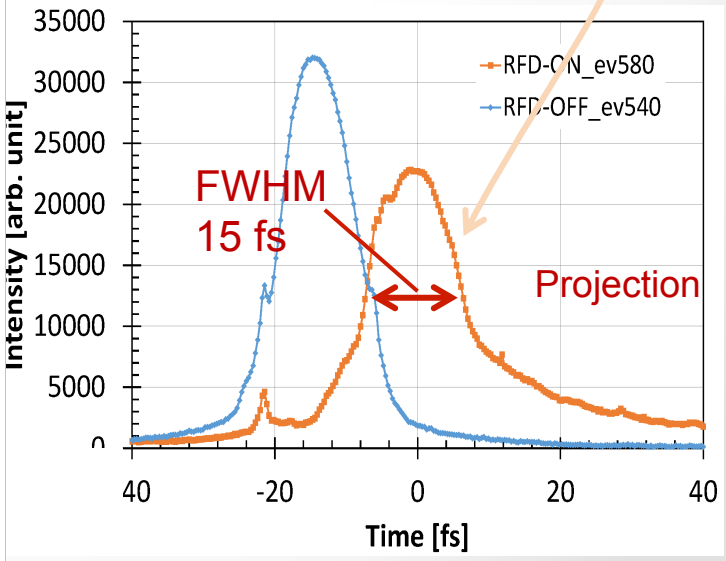
X-ray Pulse Energy

- An X-ray nominal pulse energy value is 0.6 ~ 0.7 mJ. @ 10 keV
- Possible X-ray energies are from 5 keV ~ 15 keV.
- An electron bunch length is <15 fs (FWHM) measured with RF deflector. (A measurement accuracy is ~12 fs limited by the natural emittance of the electron beam.)

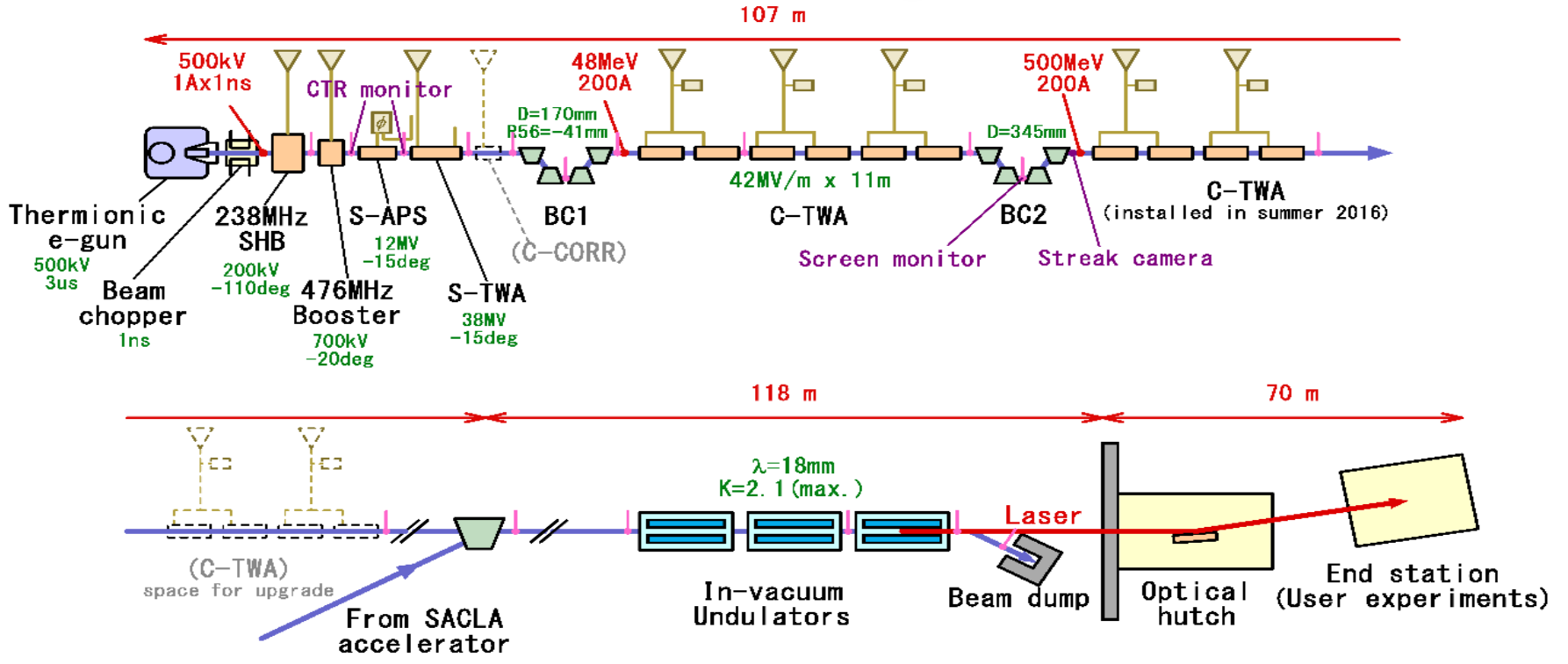
Temporal Structure of Electron Beam observed with RF Deflector.

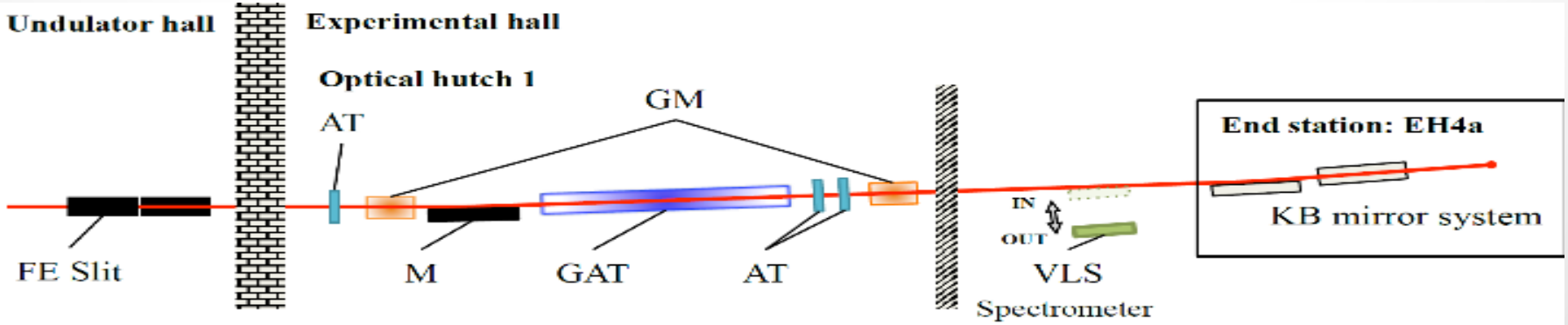






SCSS+ Configuration





AT : foil attenuator, GAT : gas attenuator, M : plane mirror (C coating/Si substrate)
GM : gas monitor, VLS : varied line spacing grating

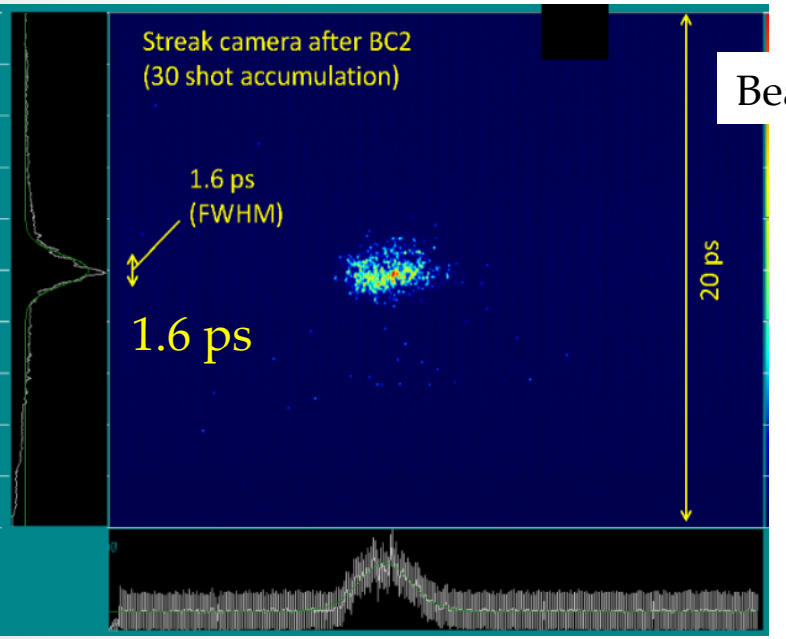
Specifications Comparison between SCSS and SCSS+

	SCSS	SCSS+
Operation period	2005 ~ 2013	2015 ~
Accelerator		
Beam energy	250 MeV	400 ~ 800 MeV
Bunch charge	~0.3 nC	~0.3 nC
Peak current	~300 A	~500 A
Repetition	60 pps (max.)	60 pps (max.)
Undulator		
Periodic length	15 mm	18 mm
K parameter	1.5 (max.)	2.1 (max.)
Photon Beamline		
Wavelength	50 - 60 nm	13 - 40 nm
Pulse energy	10-30 μJ/pulse	100 μJ/pulse

Temporal Bunch Structure Measurements by the RF Zero-cross Method and the Streak Camera

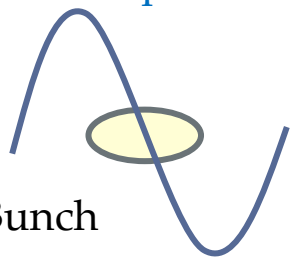
- We give energy modulation along the bunch at the RF zero-crossing point in the acceleration unit, CB1-3, and measure the energy distribution of the bunch at the BC2.

Streak Camera Case using OTR.



Beam Charge: 0.28 nC

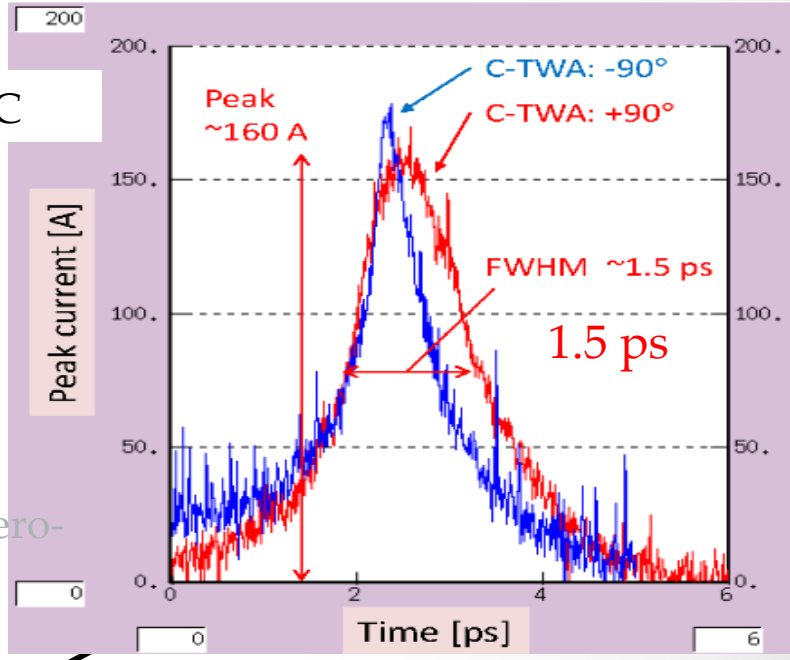
RF Amplitude

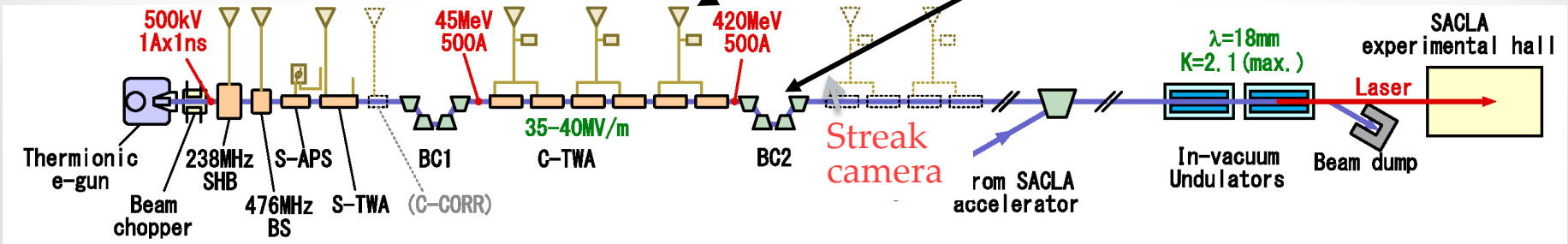


Bunch

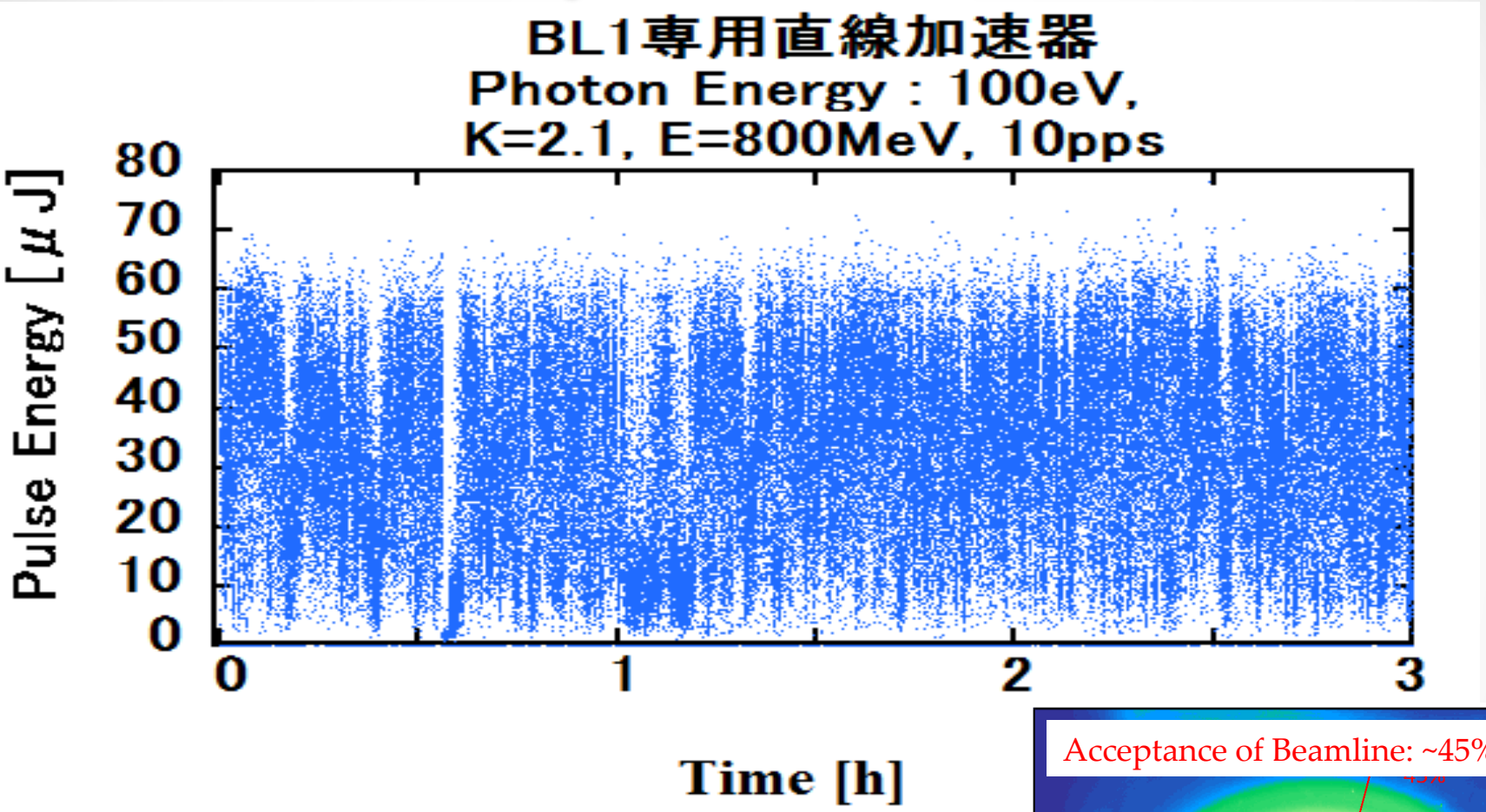
Set the RF zero-cross phase

RF Zero-cross Method Case



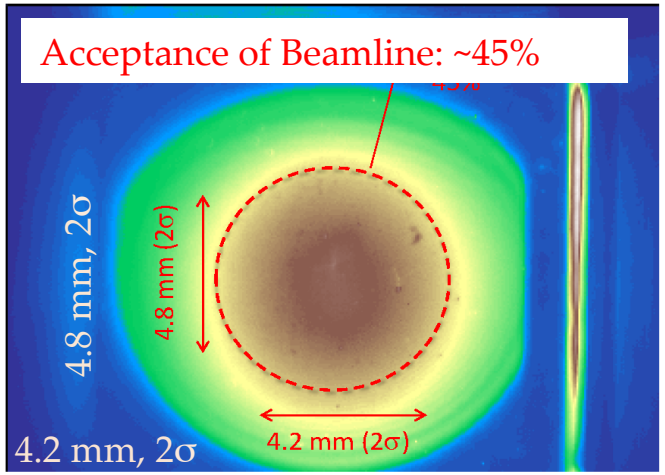


Laser Intensity Time Trend of the BL1

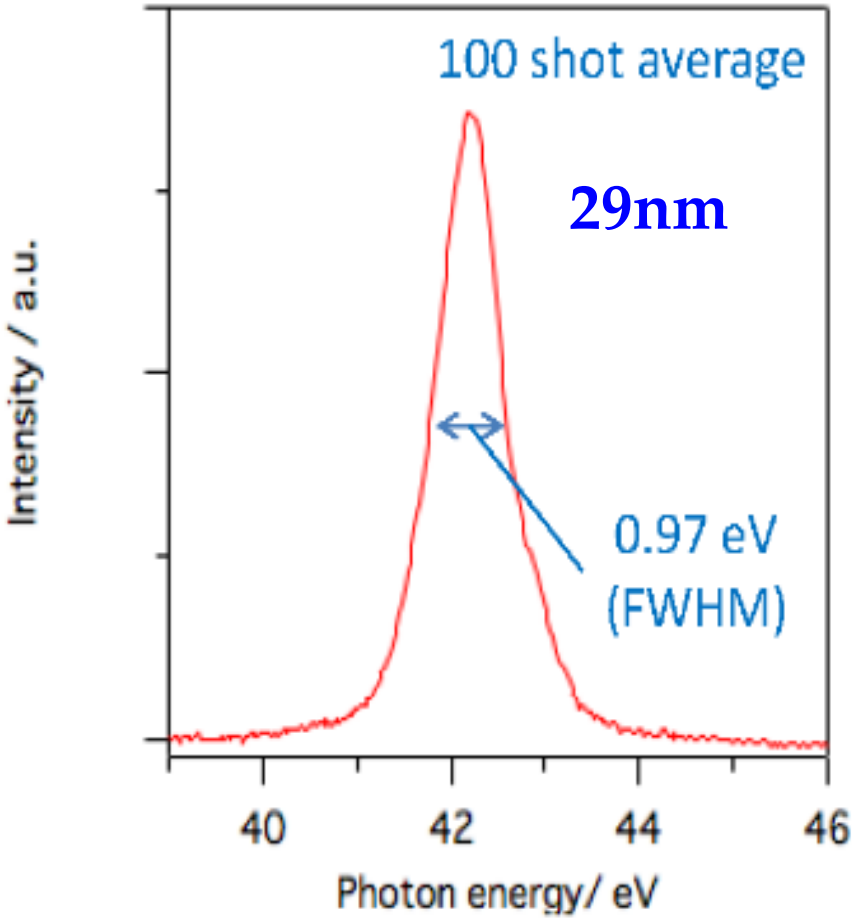


Shot by shot fluctuation is 30%（σ）.

- Laser profile in the experimental hutch



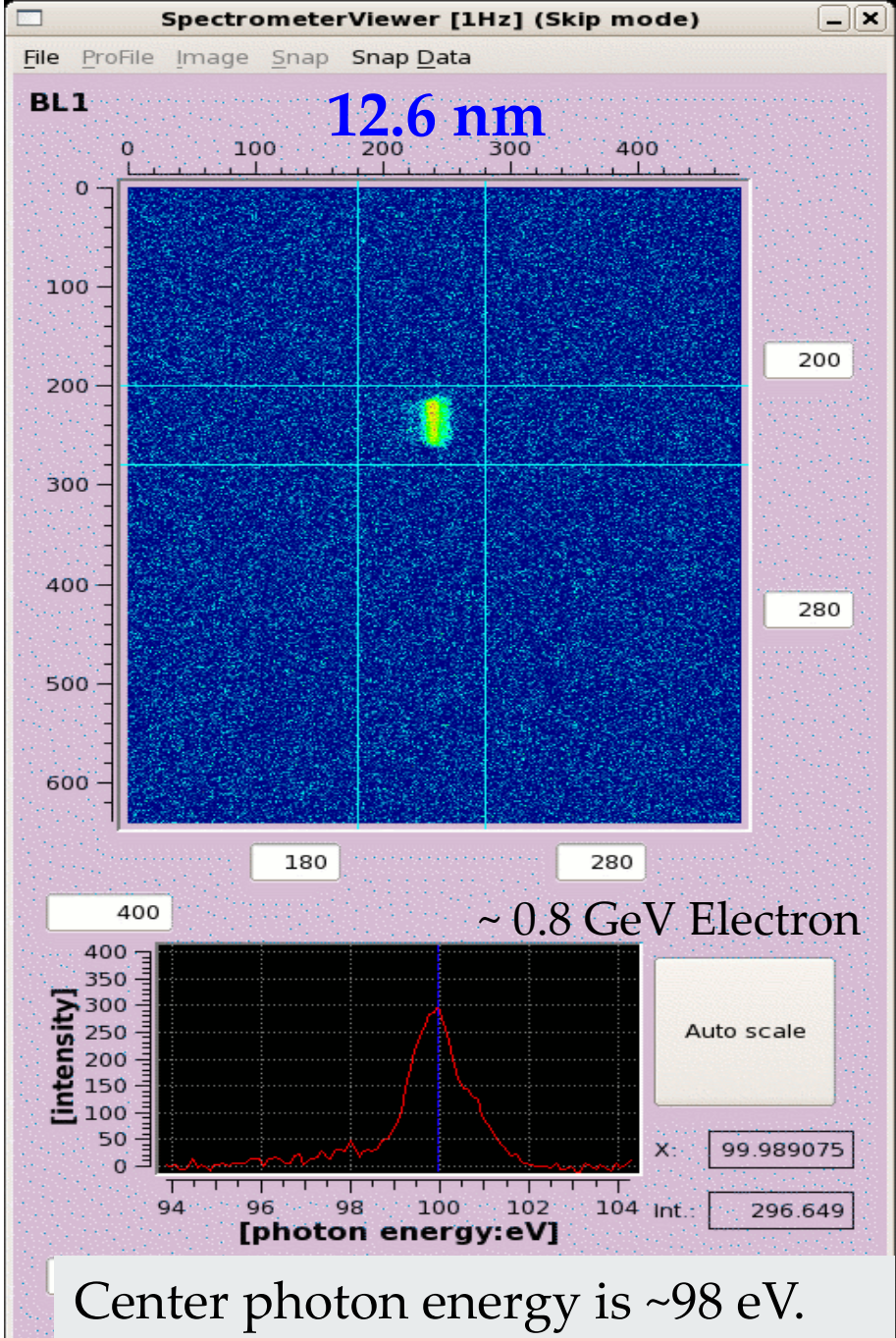
Laser Spectra of the BL1



~ 0.5 GeV Electron

Center photon energy is ~42.5 eV.

Spectrum width is ~1 eV in FWHM.



Center photon energy is ~98 eV.

Spectrum width is ~2 eV in FWHM.

Summary

- The variable wavelength (Energy), pulse width and intensity of FEL , as which I already show you, is very important characteristics for users.

Thank you for your attention.