Status and upgrading of SACLA

August 28, 2023
Workshop on Future Light Sources 2023
Working Group-A (Linac Based Light Sources), “Status of Facilities” session

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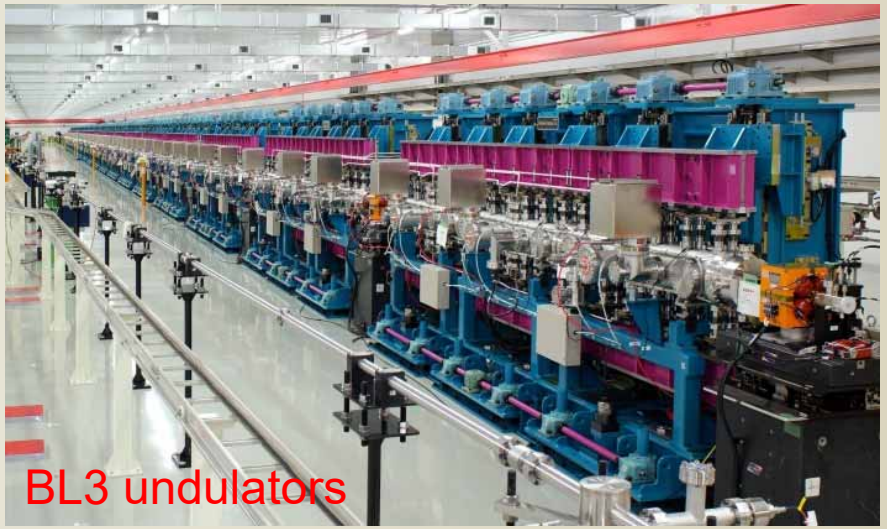


Light source facilities in SPring-8, Japan

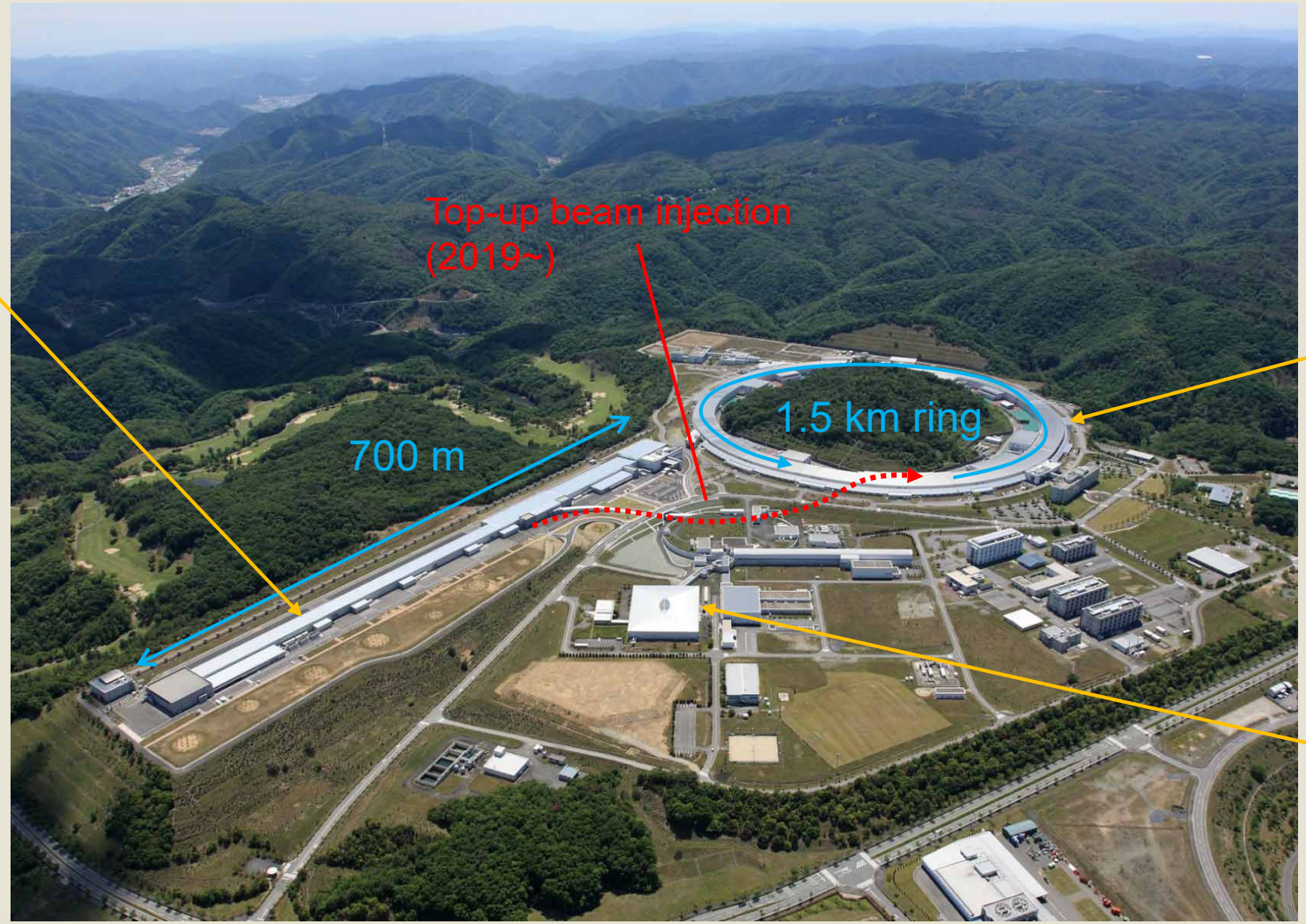
SR & XFEL, Hard X-ray to EUV

Two linac based FEL facilities

SACLA (2011~)
- 8 GeV linac
- X-ray SASE-FEL
- 2 beamlines

SACLA-BL1 (2015~)
- 800 MeV linac
- EUV SASE-FEL

Today's talk
1. Introduction
2. Ongoing upgrades
3. Long-term upgrades



Two ring based light sources

SPring-8 (1997~)
- 8 GeV storage ring
- 56 HX & SX beamlines

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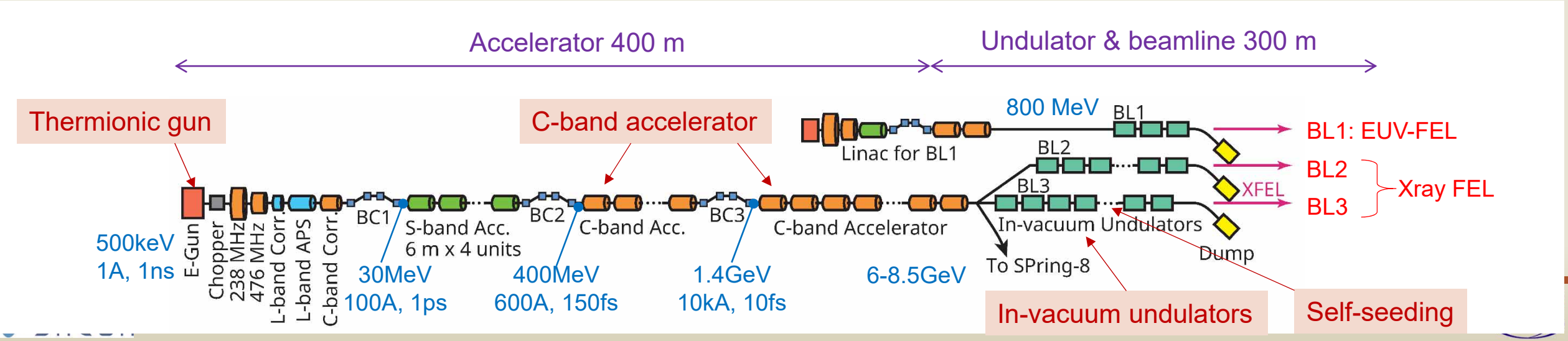
SPring-8-II (2028 ?~)
- Low emittance
- 8 GeV → 6 GeV

NewSUBARU (1998~)
- 1.5 GeV storage ring
- Soft-X & EUV beamlines

X-ray free electron laser facility SACLA

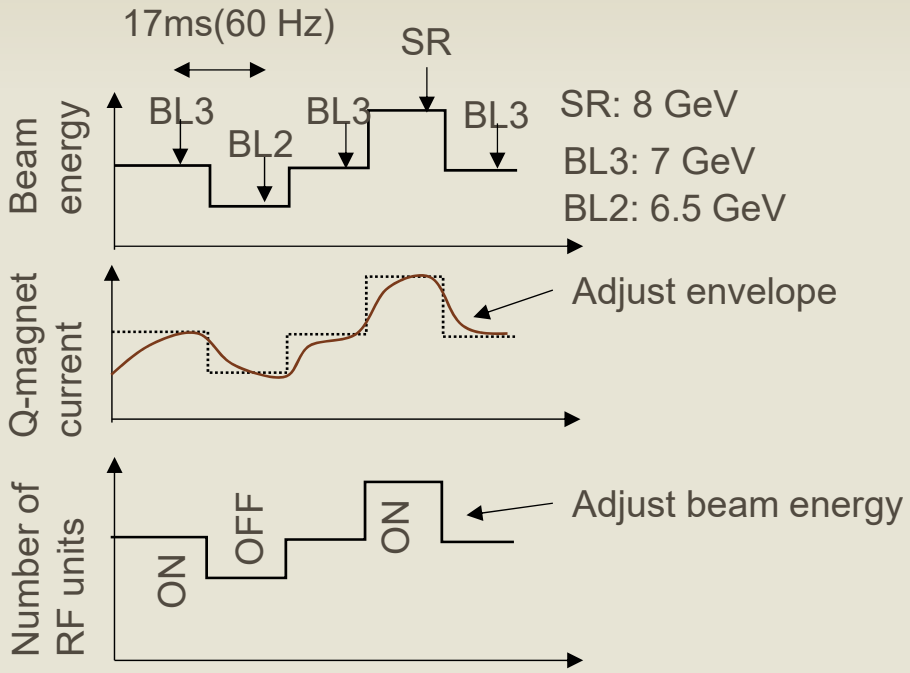
- High brilliant, stable XFEL radiation
  - Stable, low emittance beam by CeB_6 thermionic gun
  - Highly compressed to 10 kA, 10 fs.
  - Stable acceleration by C-band (5.7 GHz) NC accelerator
  - Short period, variable gap, in-vacuum undulators
- Operate 6000 hours/year, with high availability
  - About 100 user experiments per year.
- Advanced options and auxiliary equipment
  - Reflection self-seeding, two color FELs, split-and-dely optics, sub-10 nm focus,…
  - Precisely synchronized fs lasers, high power optical lasers, …

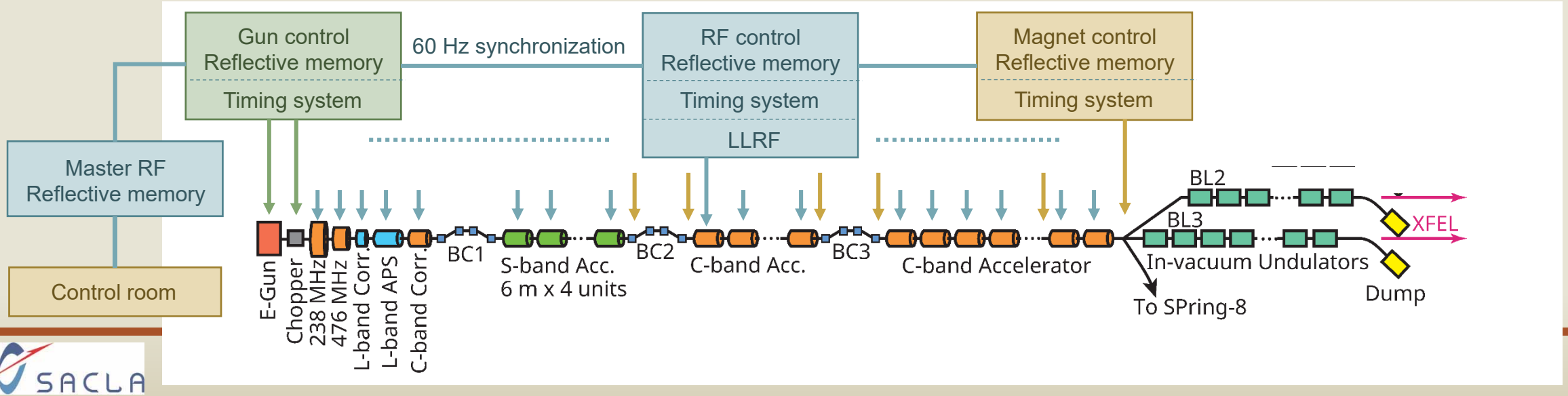
Parameter	BL3, BL2 Xray-FEL	BL1 EUV-FEL
Beam energy	6 – 8 GeV	~ 800 MeV
Photon energy	4 - 22 keV	40~150 eV
Pulse energy	~ 700 μJ	~ 50 μJ
Pulse width	< 10 fs	~ 30 fs
Peak power	70 GW	2 GW
Pulse rep. rate	60 Hz	60 Hz
Operation mode	SASE, seed	SASE



Ongoing upgrade 1: pulse-to-pulse beam optimization

- 60 Hz beam distribution to BL2, BL3 and SR injection
  - Different beam energy, peak current and envelope
- Synchronized control using reflective memory network
  - Gun & beam chopper
  - RF amplitude, phase and timing
  - Kicker magnet and quad. magnets
- Independent beam optimization, like virtual 3 accelerators

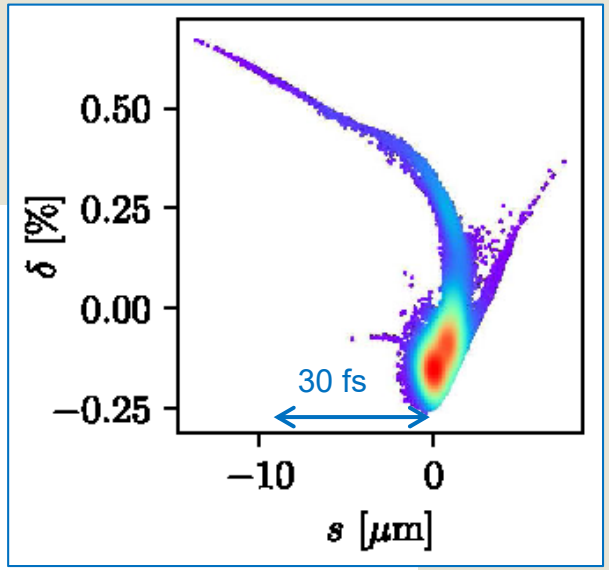




Ongoing upgrade 2: Manipulation of short pulse length

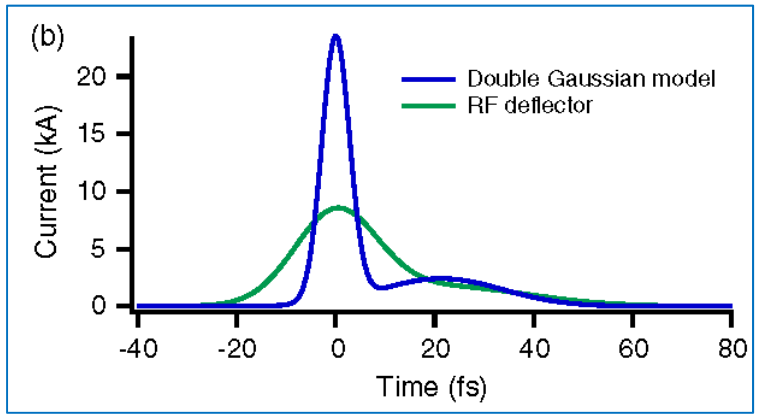
- Short pulse length (< 10 fs) is important, for ultra-fast and high-intensity science
  - But existing RF deflector cavity at BC3 has not enough resolution
  - We plan to install new RF deflector cavity (X-band, high field cavity)
  - Slotted foil spoiler installed in BC2 dispersive section
  - Optimization using machine-learning algorism

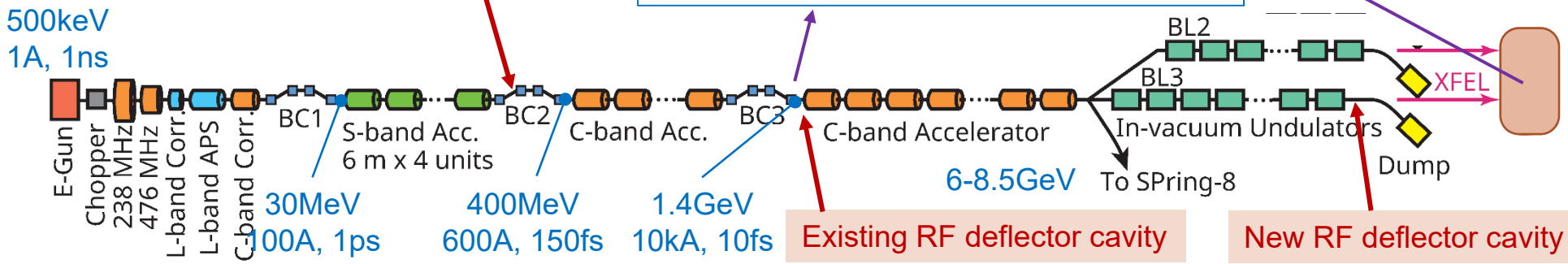
Simulated electron distribution
H. Maesaka, et.al., PRAB 21, 050703 (2018)



New spoiler

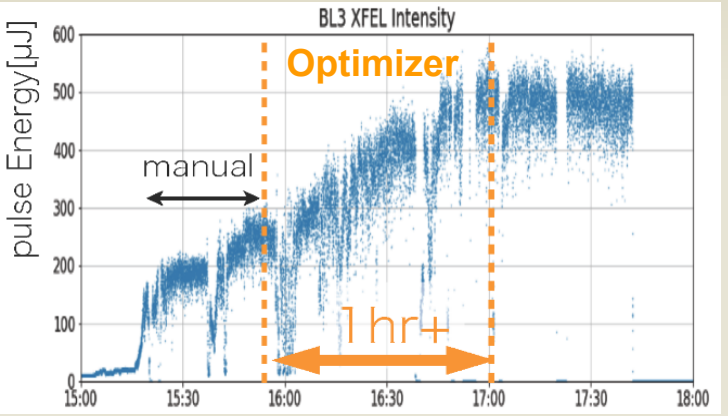
Measured electron temporal profile
I.Inoue, et. al., PRAB 21, 080704 (2018)



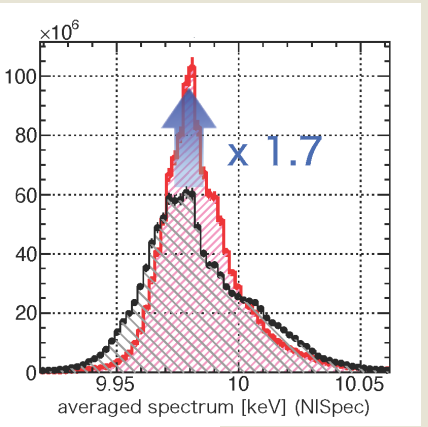


Ongoing upgrade 3: Machine learning based accelerator tuning

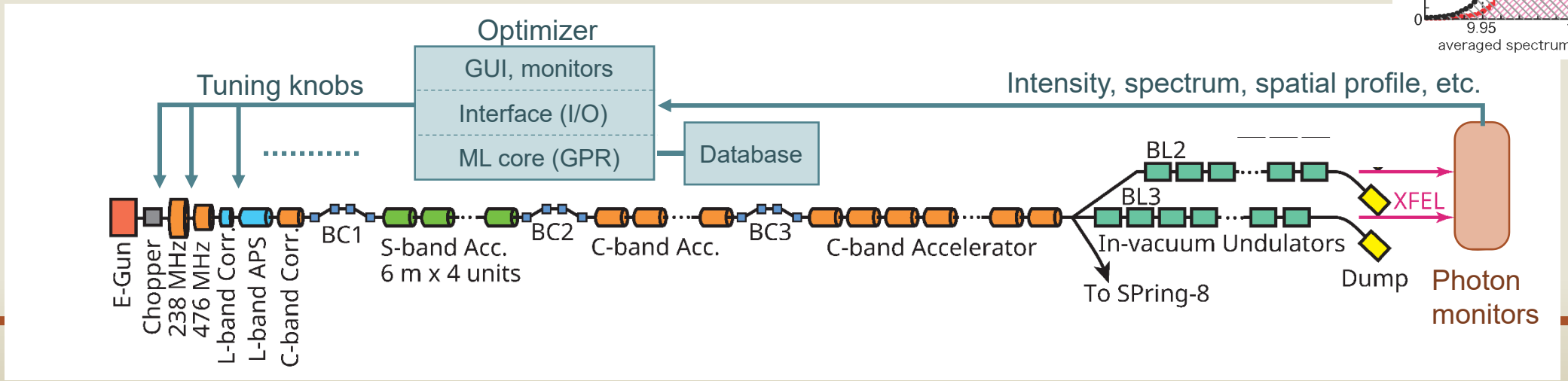
- SASE generated from complex pulse structures
  - Many tuning knobs (RF, focus magnets, trajectory, undulator gap,…)
  - Many parameters are involved, making simple adjustments difficult
- Machine-learning (ML) based optimizer
  - Gaussian Processing Regressor (GPR) based optimization
  - Well established and used for daily tuning by operators
- Applications and upcoming plans
  - Special tuning in response to user's requirement (spectrum, profile, …)
  - Introduction of deep-learning and deep Q-network



Intensity increase at the start-up

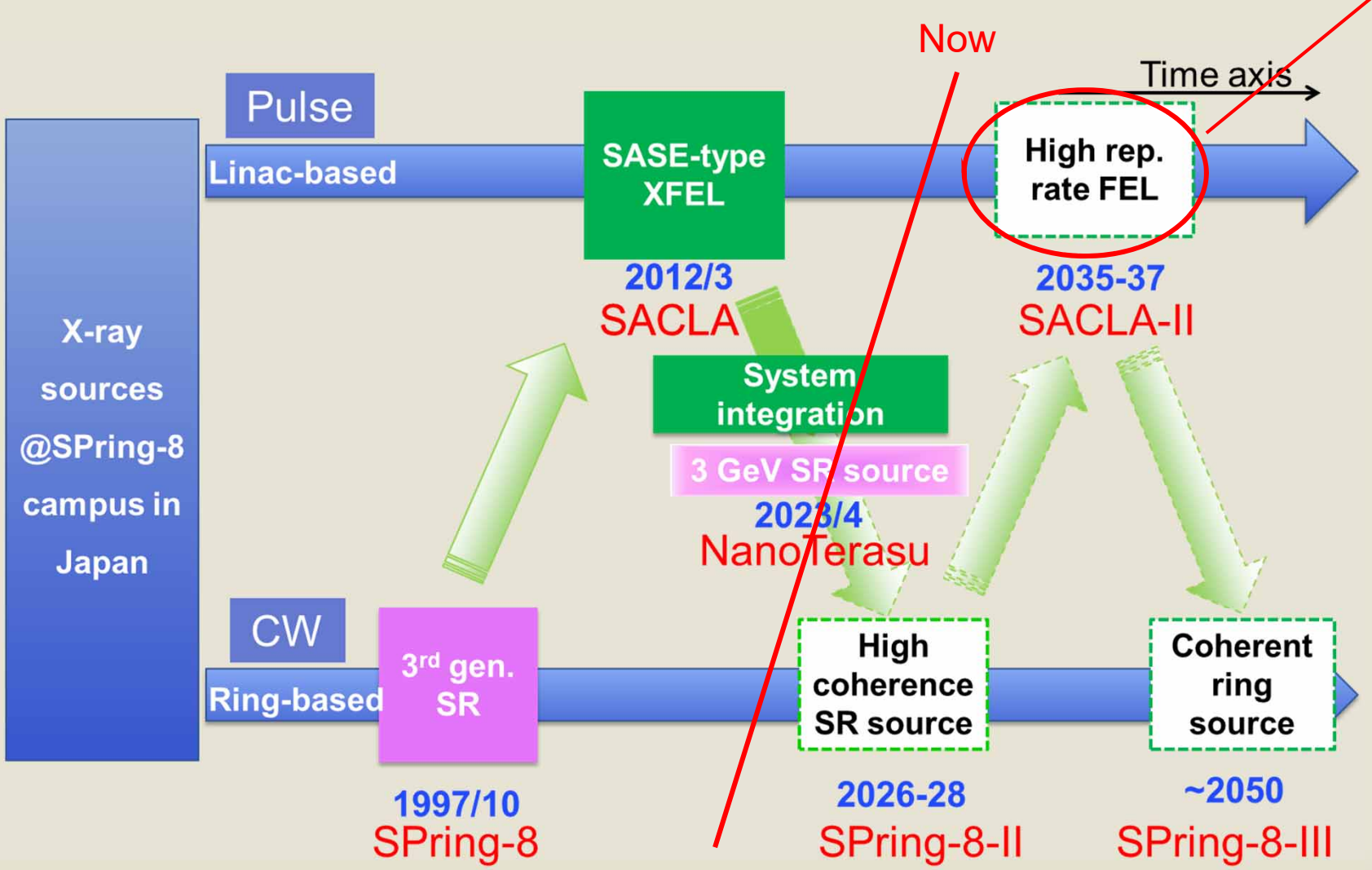


Spectral brightness Improvement

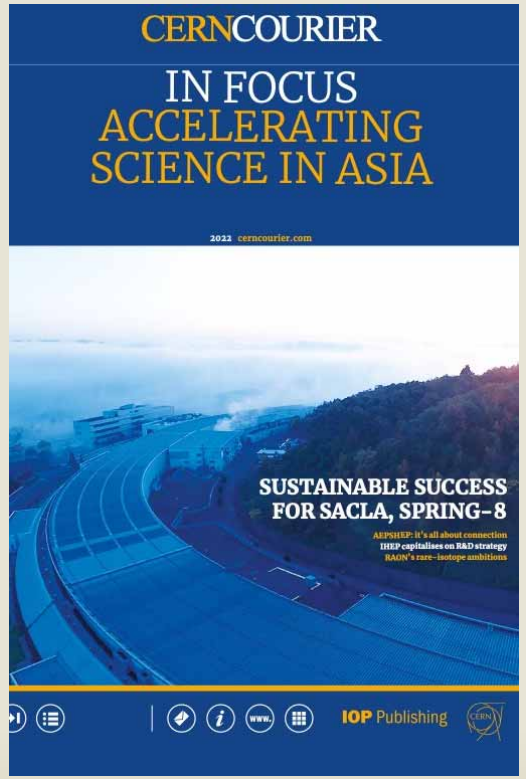


Roadmap for accelerator upgrade in SPring-8

H. Tanaka, IPAC'23 presentation
"Green-oriented upgrade of accelerator complex at the SPring-8 campus"



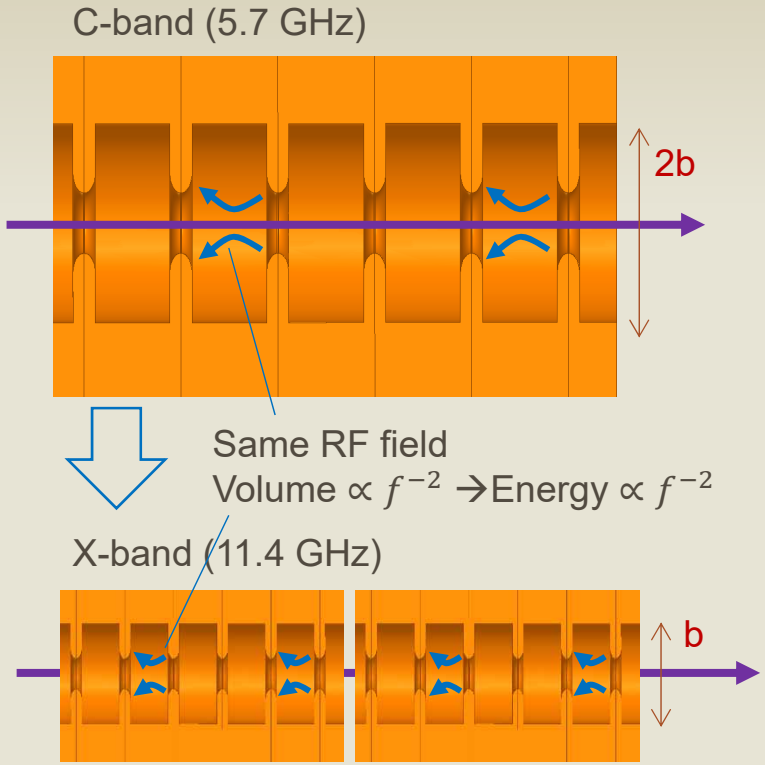
Our next target is
high repetition rate (~600 Hz)
conserving (or improve)
XFEL performance
and
electrical power consumption
for "Green facility" declaration



Methods for high repetition rate XFEL

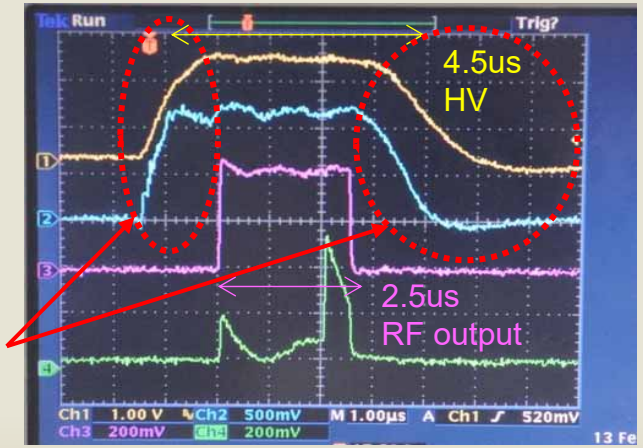
- We insists on using normal conducting RF accelerator
  - Superconducting RF accelerators have very different systems
    - Need huge cooling plants and electricity use
    - Electric field is still low, it does not reach 8 GeV at 400 m
    - Requires lots of precious niobium and liquid helium

- Improve electrical power efficiency by one order of magnitude
  - High RF frequency C-band (5.7 GHz) → X-band (11.4 GHz)
    - Power efficiency $\propto f^2$
  - High efficiency klystrons
    - CPI & CERN developed P=55 MW, eff.=55% klystron
  - Short HV pulse
    - Fast rise-time & fall-time, using semiconductor technology?



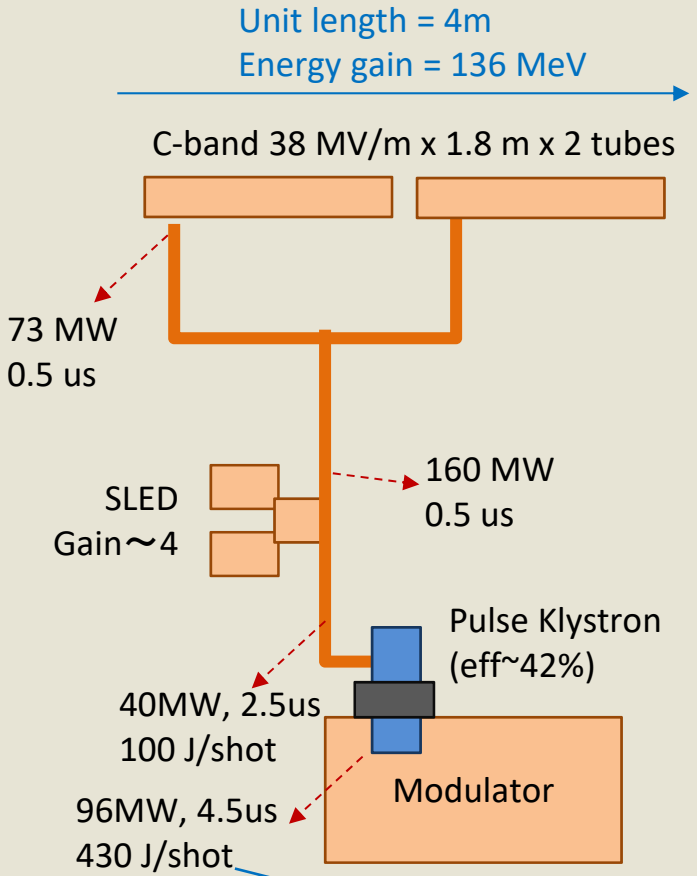
Typical waveform at SACLA

Reduce this power

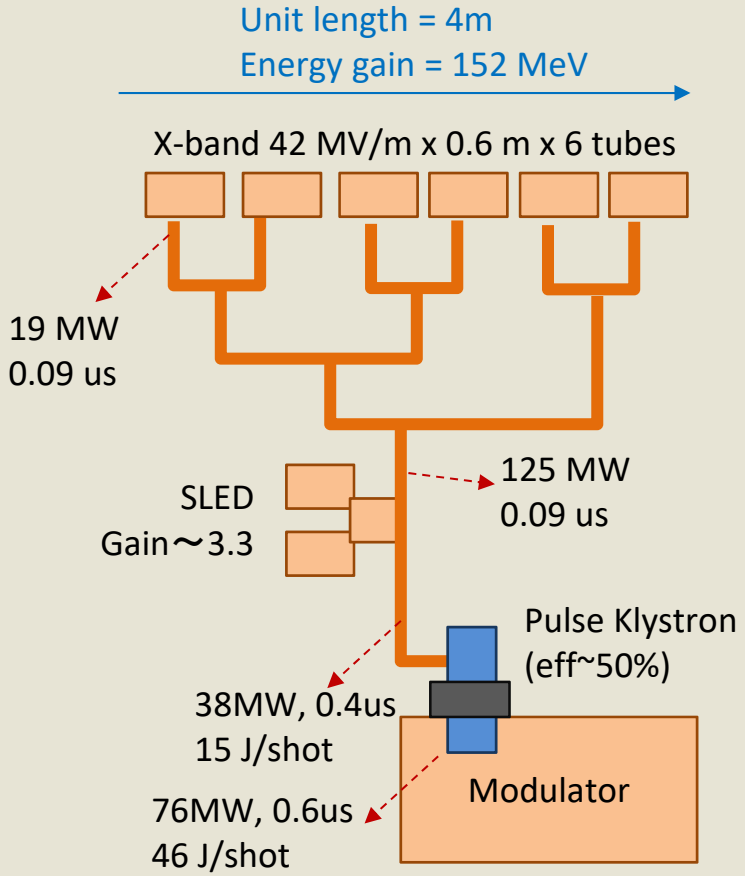


Concept of the efficient RF acceleration unit

SACLA C-band (5.7 GHz) RF unit



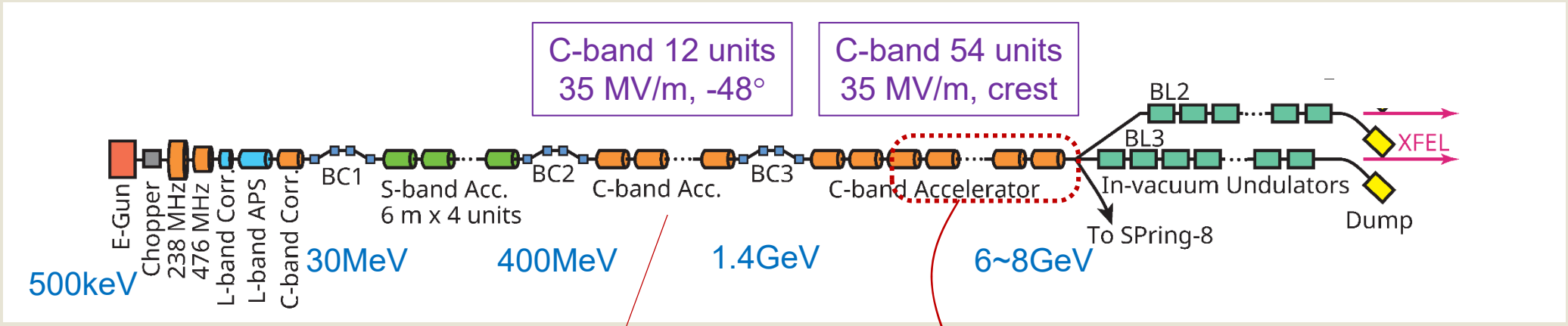
SACLA-II X-band (11.4 GHz) RF unit



Electrical power 1/10
⇒Pulse repetition rate x10

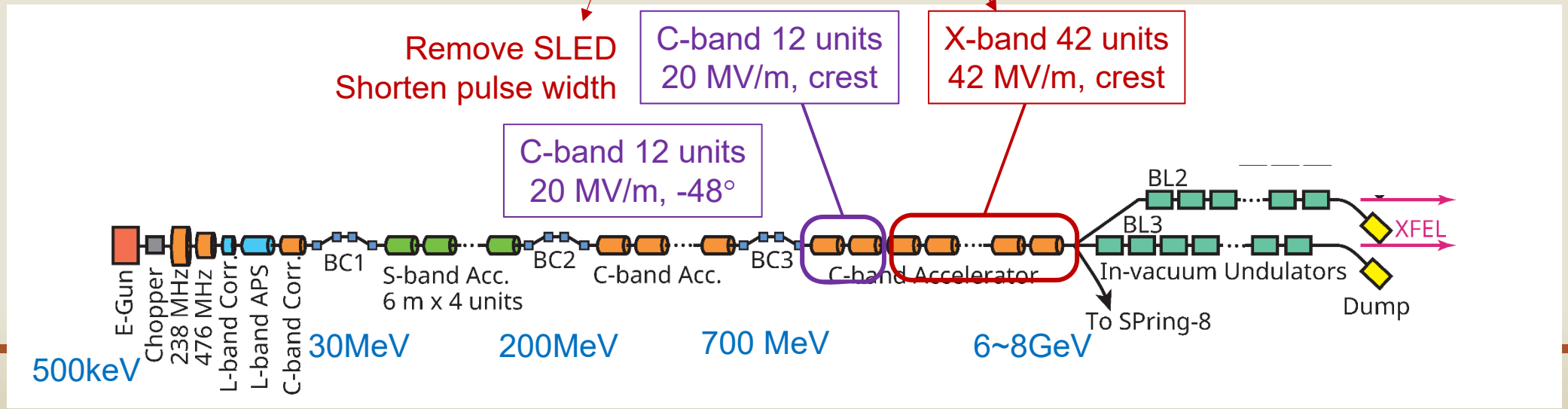
Future image of the high repetition rate XFEL

SACLA 6~8 GeV, 60 Hz



SACLA-II 6~8 GeV, **600 Hz**

Gradually replace to X-band



Summary of SACLA status

- SASE-FEL user facility, since 2012
  - Thermionic gun + C-band accelerator + in-vacuum variable-gap undulators
  - 2 XFEL beamlines 4 – 22 keV, 700 μJ, <10 fs, 60 Hz
  - 1 EUV-FEL beamlines 40 – 150 eV, 50 μJ, 30 fs, 60 Hz
  - Stably Operate 6,000 hours/year with high availability
  - Advanced options; self-seeding, two color, SDO, sub-10 nm focus, high power fs lasers, …
- On-going updates
  - 60 Hz beam optimization distributed to BL2, BL3 and SR injection
  - Manipulation of short pulse length (<10 fs)
  - Machine learning based beam tuning
- Future upgrade plan
  - High repetition rate operation using normal conducting RF
  - Maintain electricity consumption, for “Green facility”