Challenges toward attosecond and zeptosecond XFELs

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Outline

- Introduction
- Sub-TW & Few-fs XFEL at SACLA
- Toward Atto- & Zeptosecond XFEL

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- **Introduction**
- Sub-TW & Few-fs XFEL at SACLA
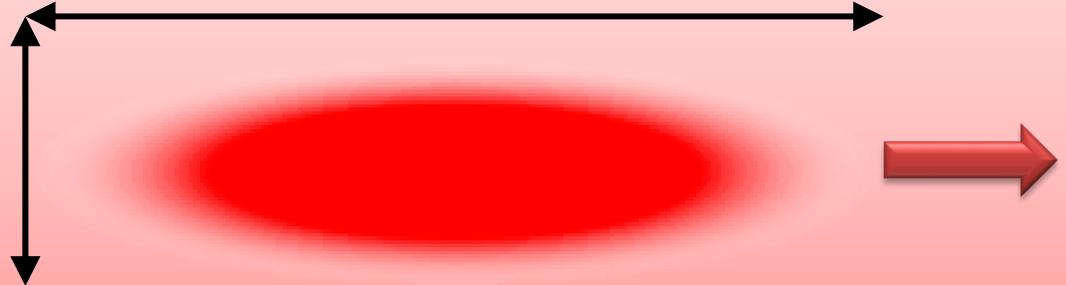- Toward Atto- & Zeptosecond XFEL

Ultimate Form of Lasers

Laser Profile in Time & Space

Optical Laser
(λ=800nm)

~several fs

~1μm

XFEL
(λ=0.1nm)

~several 10 fs

~50nm
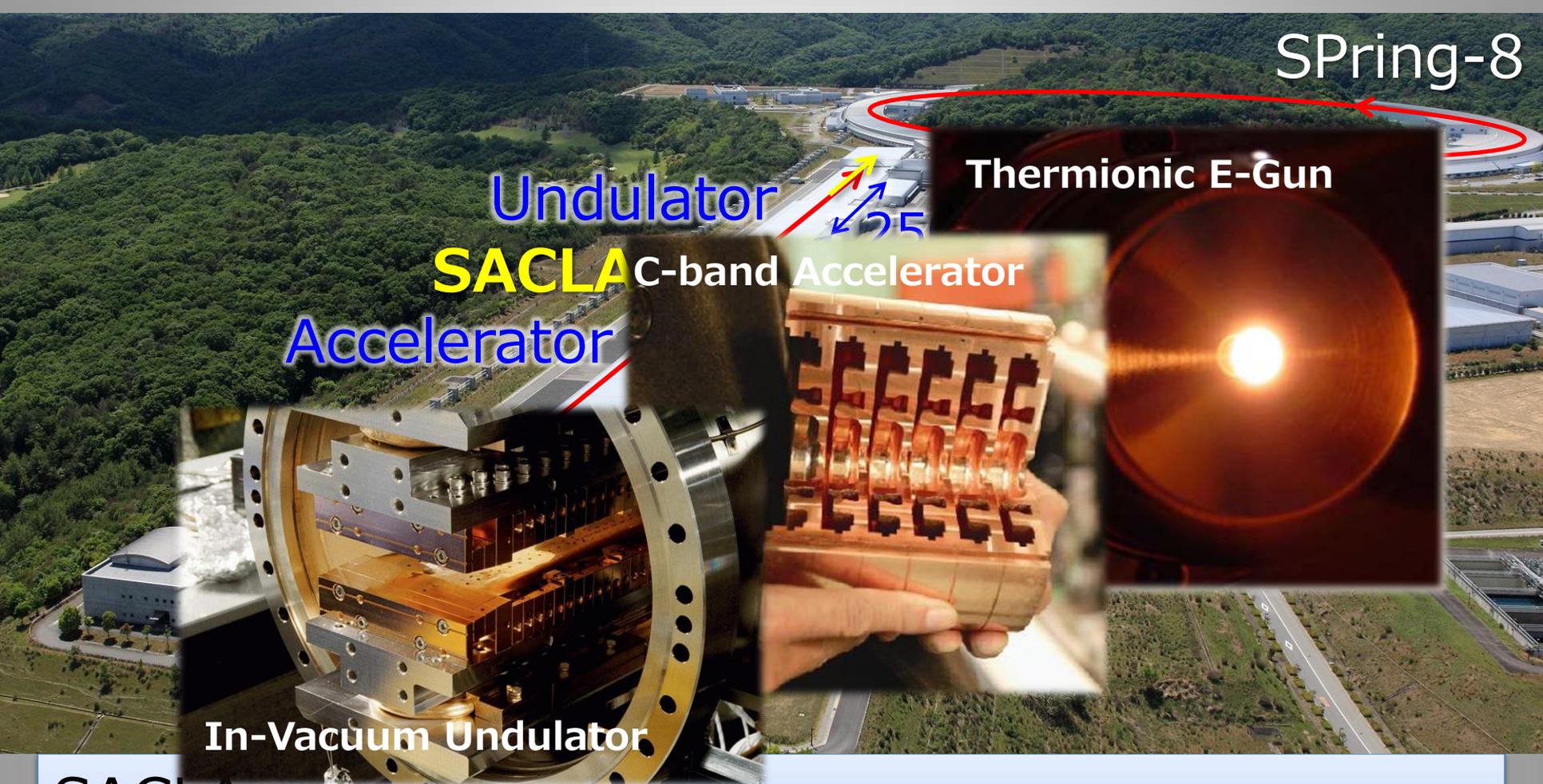
Laser Pulse Lengths as of Today
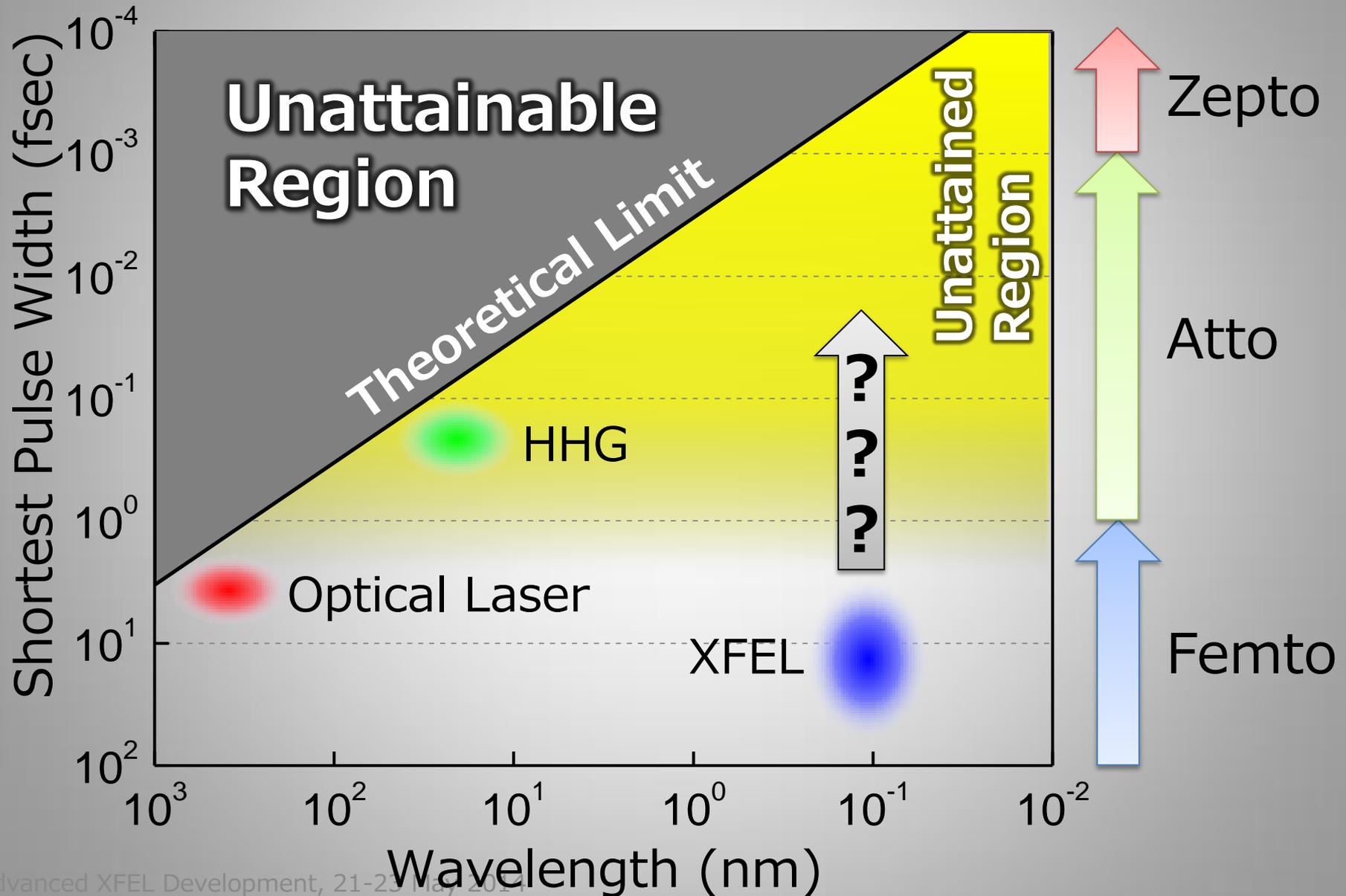
Compressing the Laser Pulse

- Pulse compression is a normal technique in optical lasers (T^3 laser)
  - Ultra-short pulse (a few cycles)
  - High peak power (TW level)
- How about in XFELs?
  - Traditional scheme with optics seems challenging
  - Strong compression of the e- beam
  - A number of techniques for "pulse shortening"

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SACLA: Japan's XFEL Facility

SPring-8

Undulator

SACLA C-band Accelerator

Accelerator

Thermionic E-Gun

In-Vacuum Undulator

SACLA:
SPring-8 **A**ngstrom **C**ompact free electron **LA**ser

Short-Pulse & High-Power XFEL@SACLA

- A lot of efforts have been made at SACLA in order to
    - improve the stability by upgrading the accelerator hardware
    - enhance the laser intensity by optimizing the beam parameters
- As a result, strongly-compressed e-beam is available in nominal operation

Generation of Sub-TW & Few-fs XFEL Pulse

Gain Curve Measurement

2014 May
L_g~1.9m
I_p=??
$\gamma\varepsilon$=??

2011 Oct.
L_g~4.4m
➢ I_p~3.5kA
➢ $\gamma\varepsilon$~0.7μm
➢ Δt~20fsec

$$L_g \propto j^{1/3}$$

e-bunch may be strongly compressed!
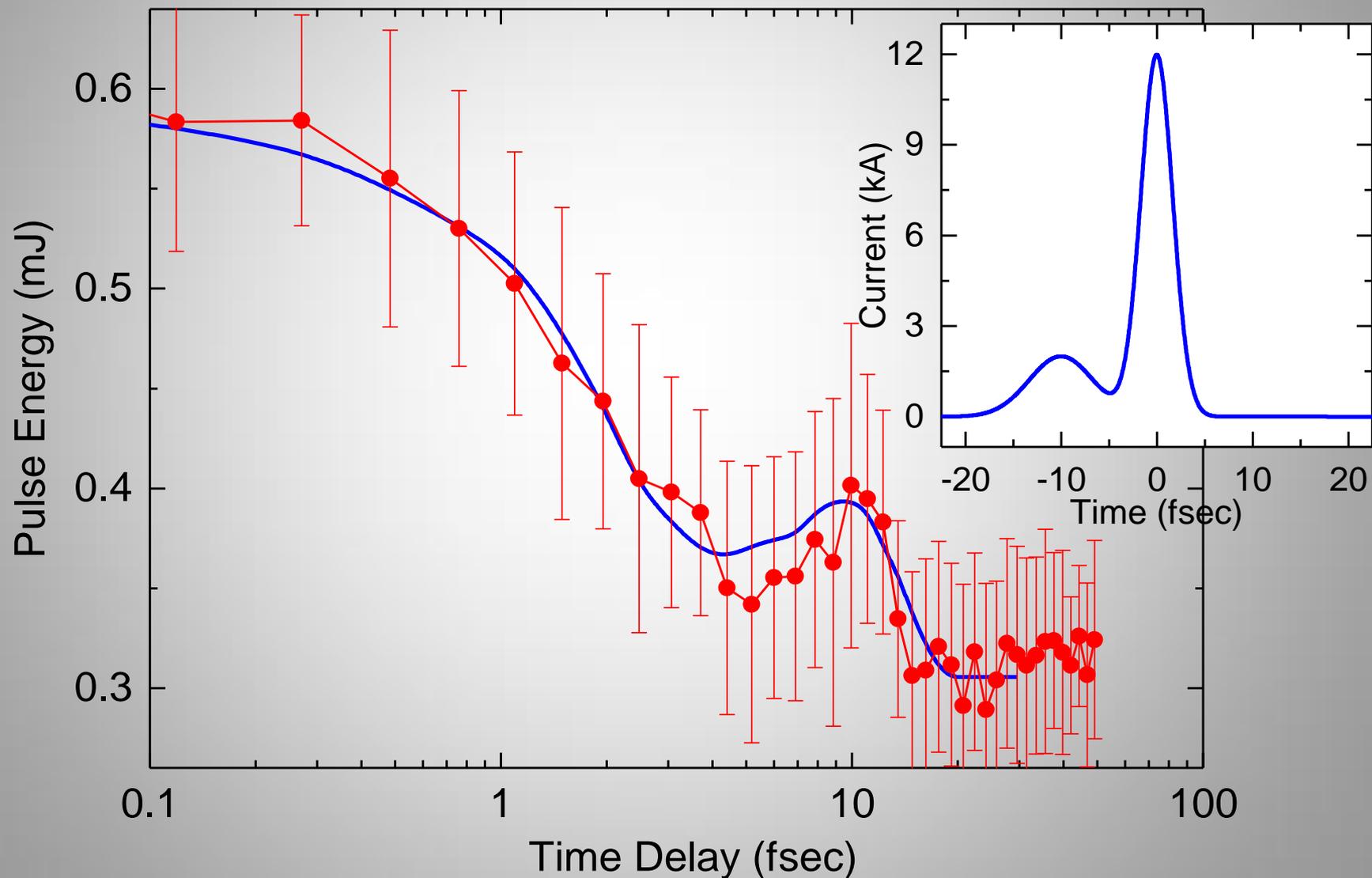
Pulse Enegy (m)

10^{-2}

10keV

80   100   120   140
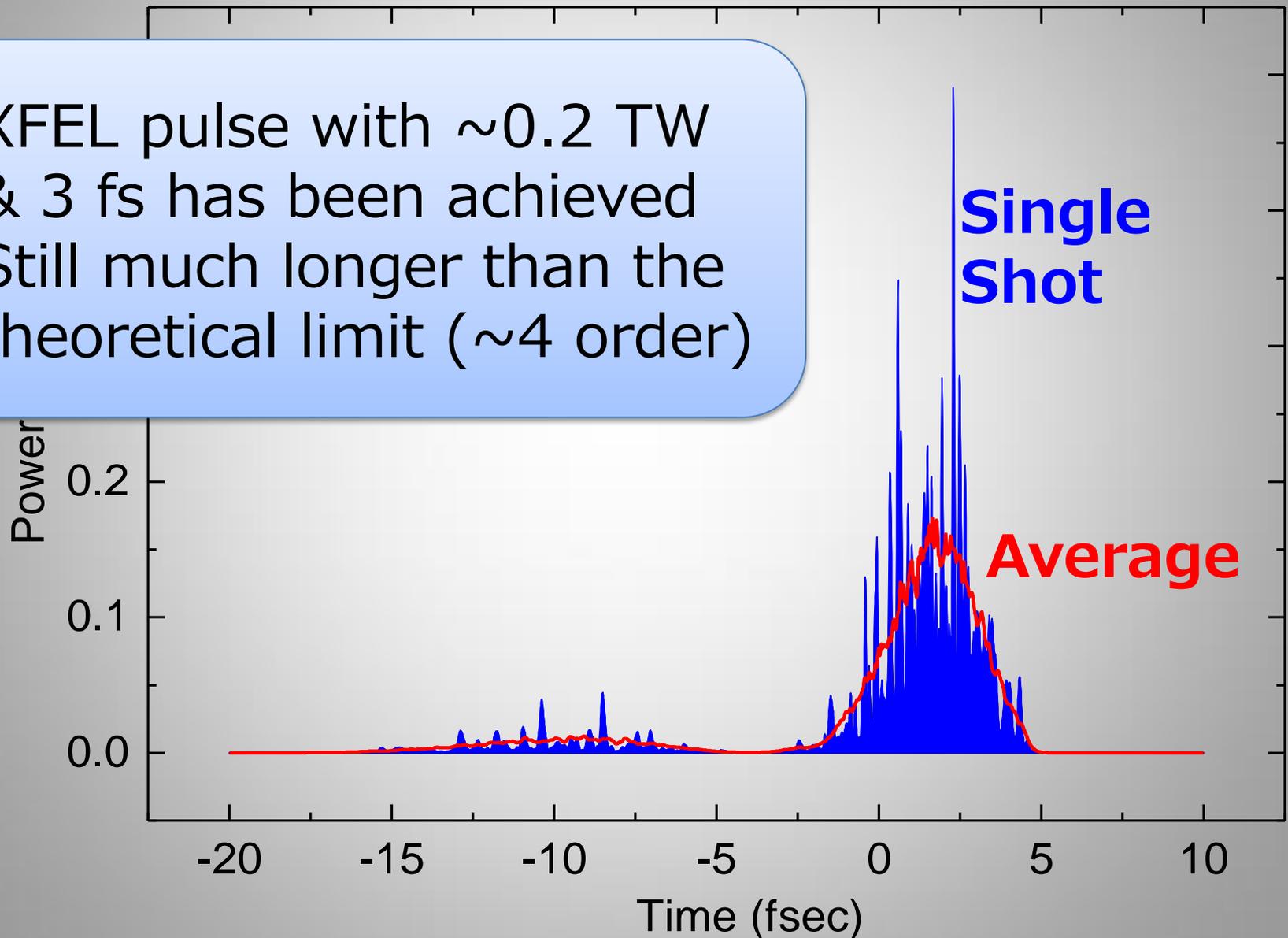
...ator Length (m)

Autocorrelation Measurement
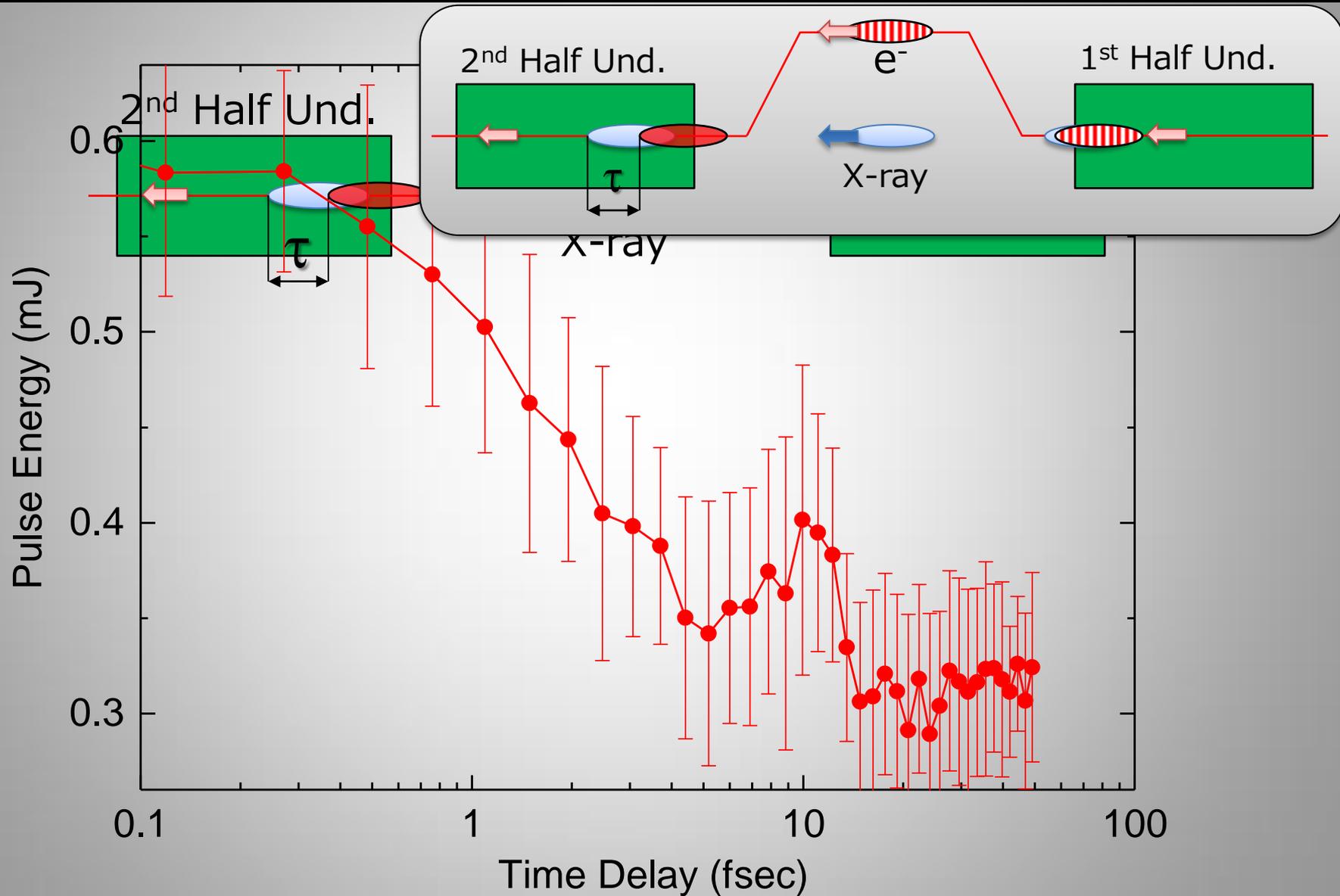
Deduction of the Bunch Profile

Estimation of the XFEL Pulse

✓ XFEL pulse with ~0.2 TW & 3 fs has been achieved
✓ Still much longer than the theoretical limit (~4 order)

Single Shot

Average

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- **Toward Atto- & Zeptosecond XFEL**

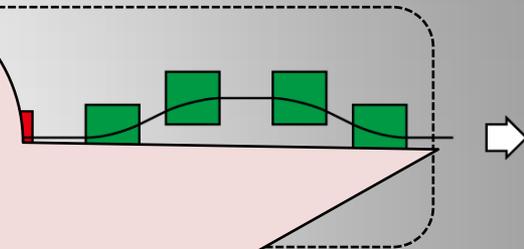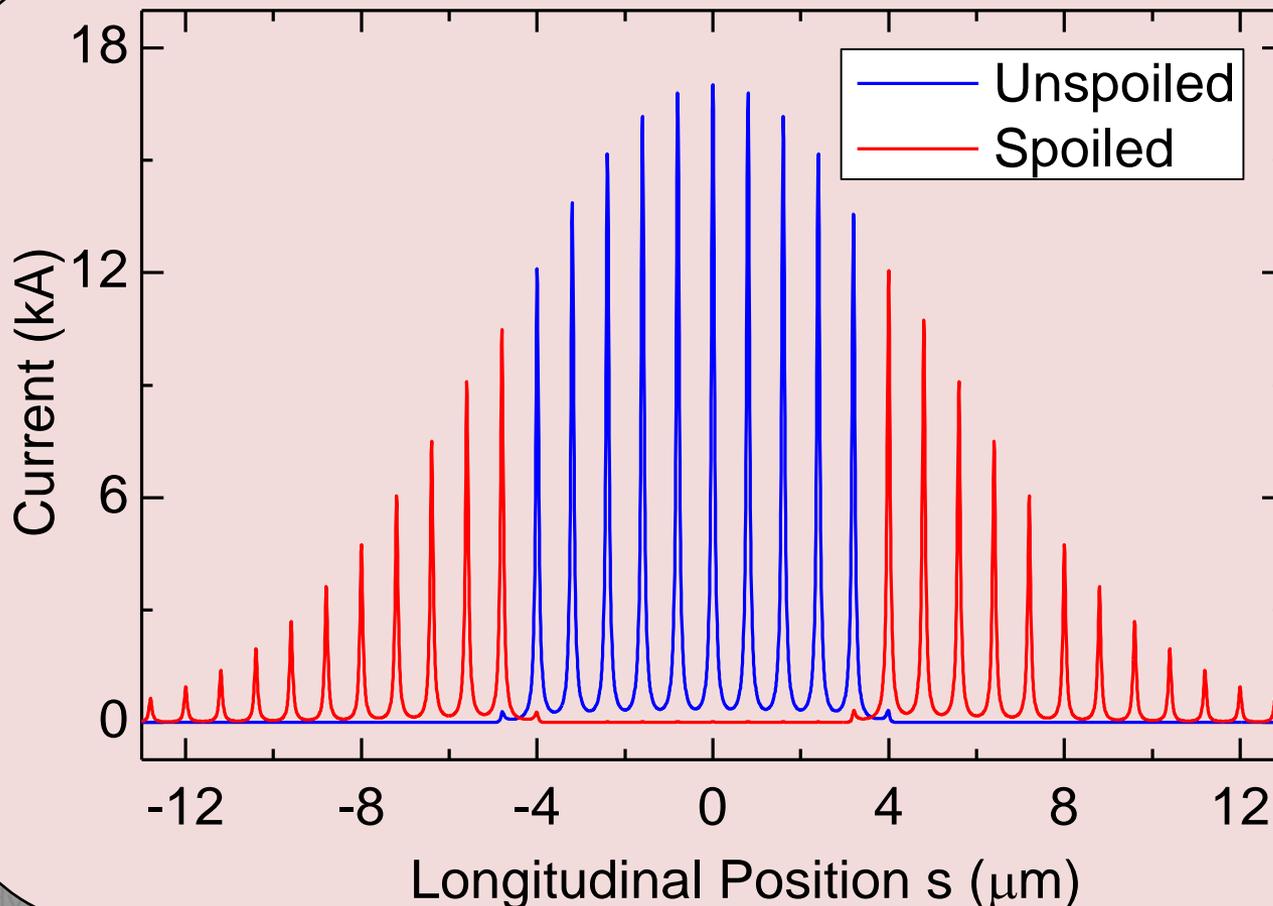# How to Further Shorten the XFEL Pulse ?

- To attain atto- and zeptoseconds pulse, we need to
  - further compress the e- bunch
  - introduce alternative schemes
- New XFEL schemes have been proposed
  - Local current enhancement (E-SASE)
  - Mode locking (Ultra-short Pulse Train)
  - E-SASE combined with selective & sequential amplification (XFEL pulse compression)

XFEL Pulse Compression*

Beam Spoiler [1]
(Slotted Foil)

E-SASE [2] Section (Seeded
FEL with Long λ_u and λ)

- Current (kA) axis: 0, 6, 12, 18
- Legend: Unspoiled, Spoiled
- Longitudinal Position s (μm): -12, -8, -4, 0, 4, 8, 12

Delay
(cane)

Compression by a factor of 300!
(Normal SASE: 20 GW & 20 fsec)

6.6 TW

53 asec

electron delay

(c)#08

(c)#24

**Satellite
Pulses**
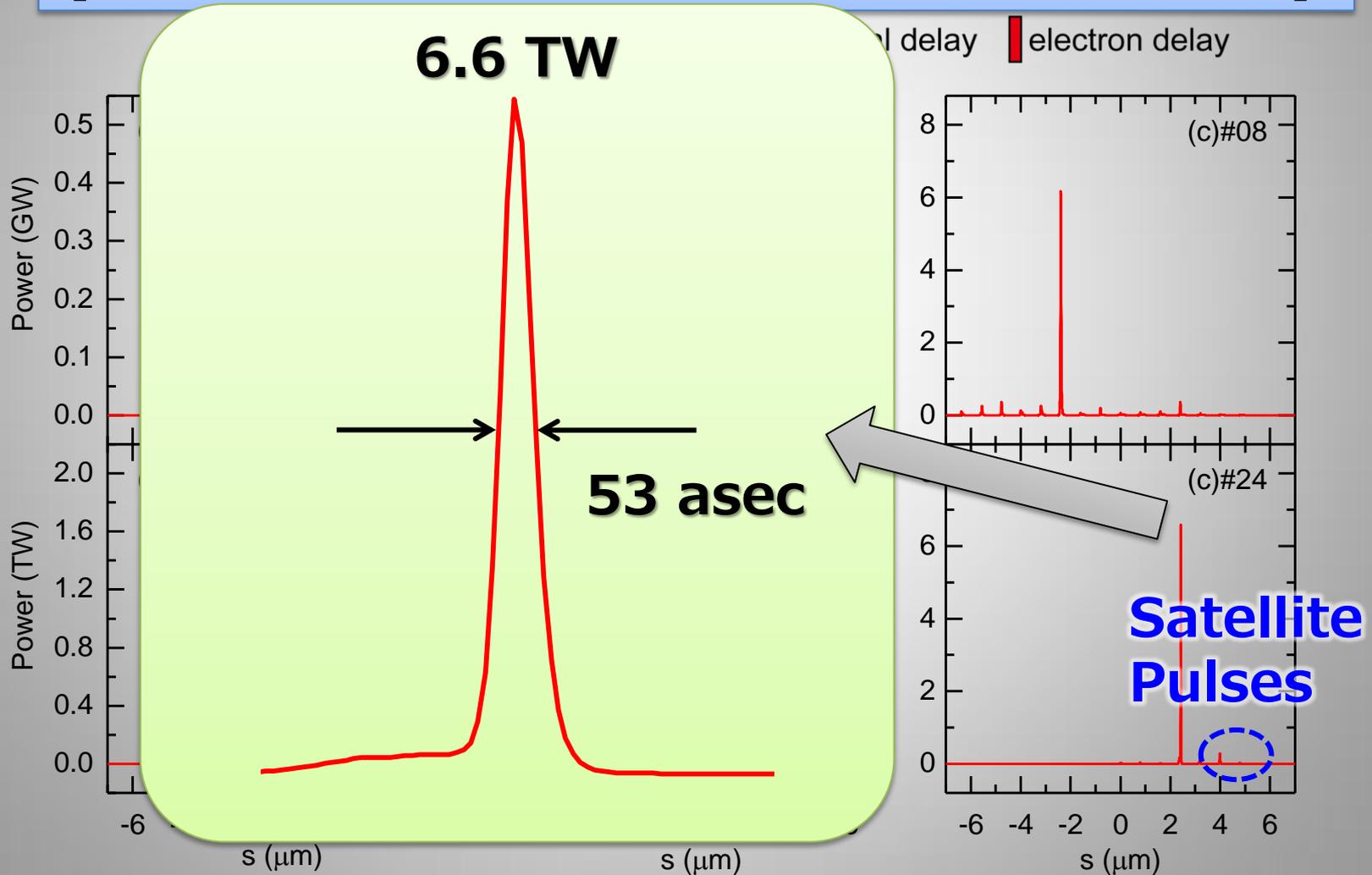
Improvement of Contrast

$\Delta K/K=0.05$ $\Delta K/K=-0.1$ $\Delta K/K=0.05$

Electron Bunch
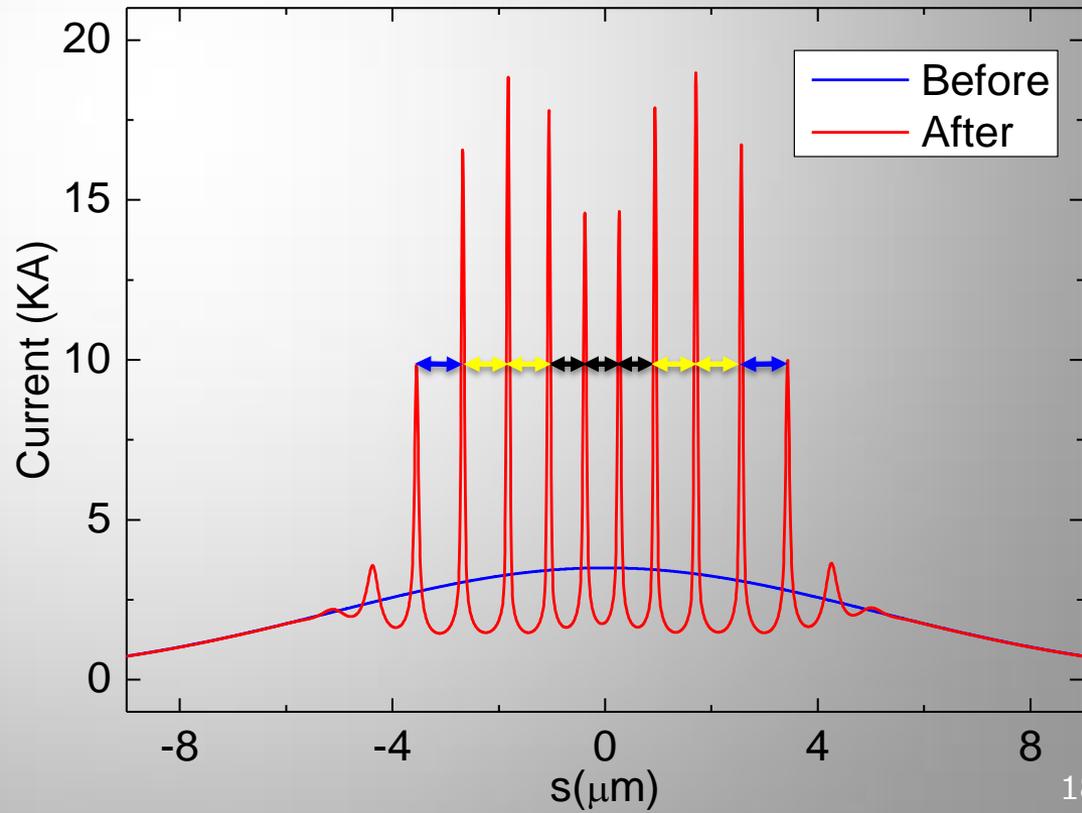40fsec,150pC

10-Period Wiggler
$\lambda_{1st}=800nm$
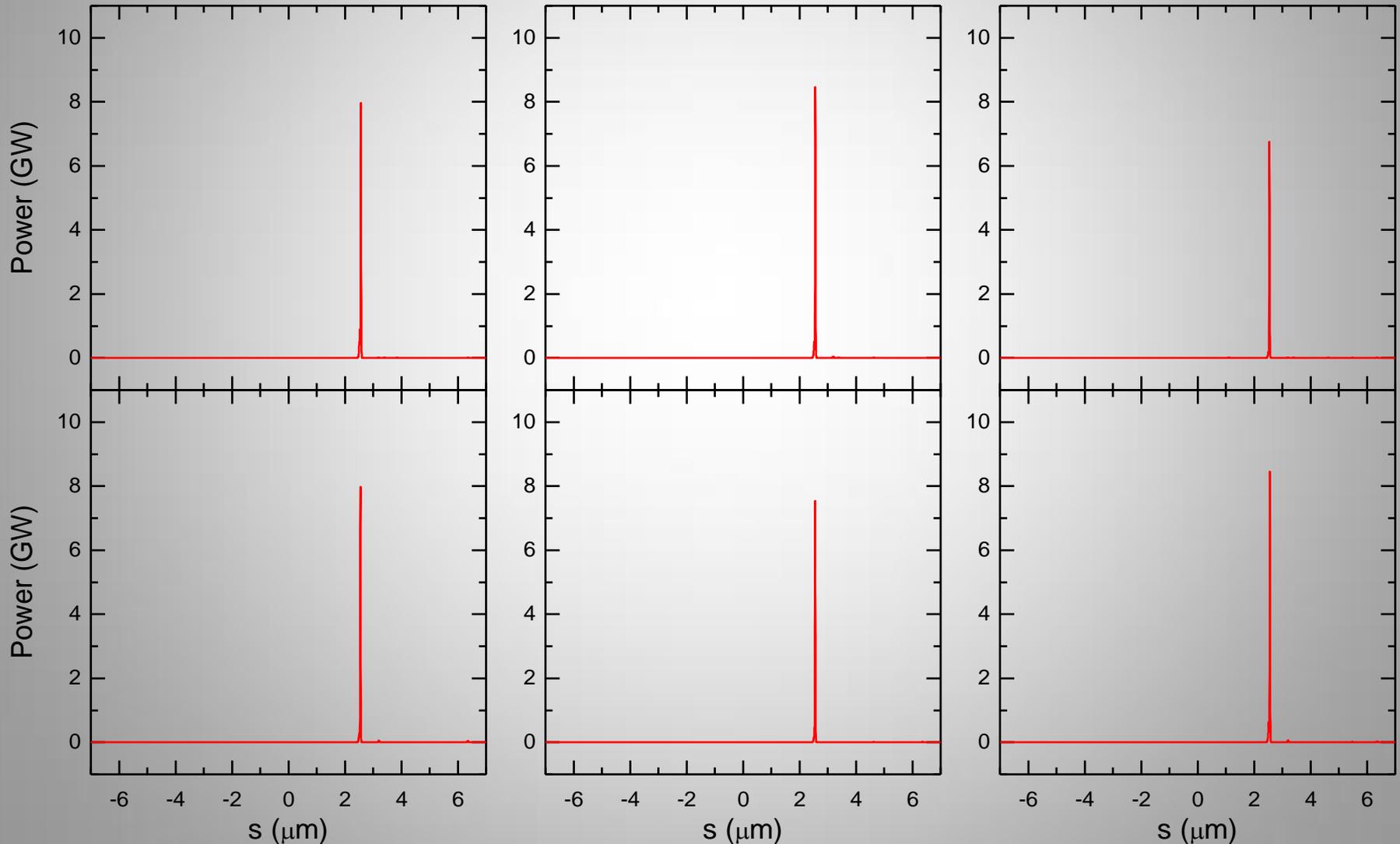
Few-Cycle Laser
800nm,5fsec,0.2mJ

Combination of
- ✓ few-cycle laser
- ✓ wiggler having
  irregular phase slip
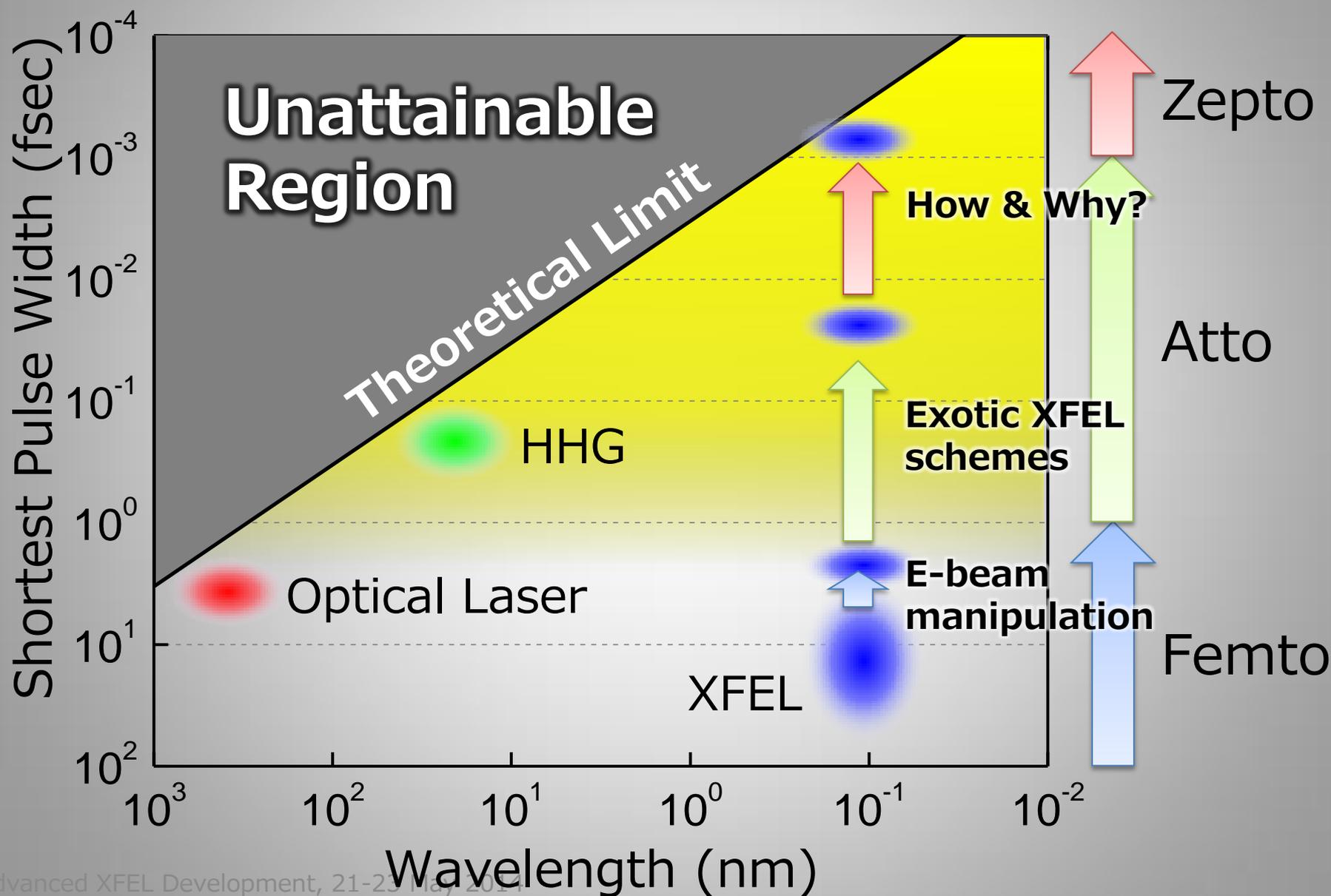creates comb-like
current profile with
irregular intervals

Example of Improvement

Toward "Ultimate" X-ray Laser?

Outlook: toward ZS XFEL

- How?

  ➢ Extending the mode-lock operation ("afterburner", sub-as pulse train) [1]

  ➢ Taking advantage of dispersive elements (multilayers) for pulse compression [2]

  ➢ Other schemes yet to be proposed?

- Why?

  ➢ New light source has always opened up a new frontier!

[1] D. J. Dunning et al., PRL 110, 104801 (2013)
[2] S. Bajt et al., JOSA 29, 218 (2012)

Thank you for attention!