Challenges toward attosecond and zeptosecond XFELs

Takashi TANAKA
RIKEN SPring-8 Center

Outline

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

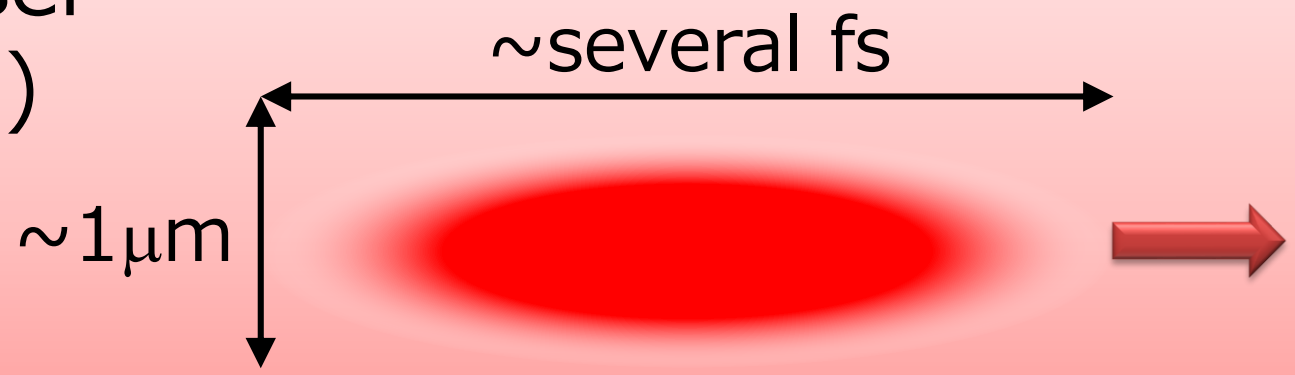
Outline

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

Ultimate Form of Lasers

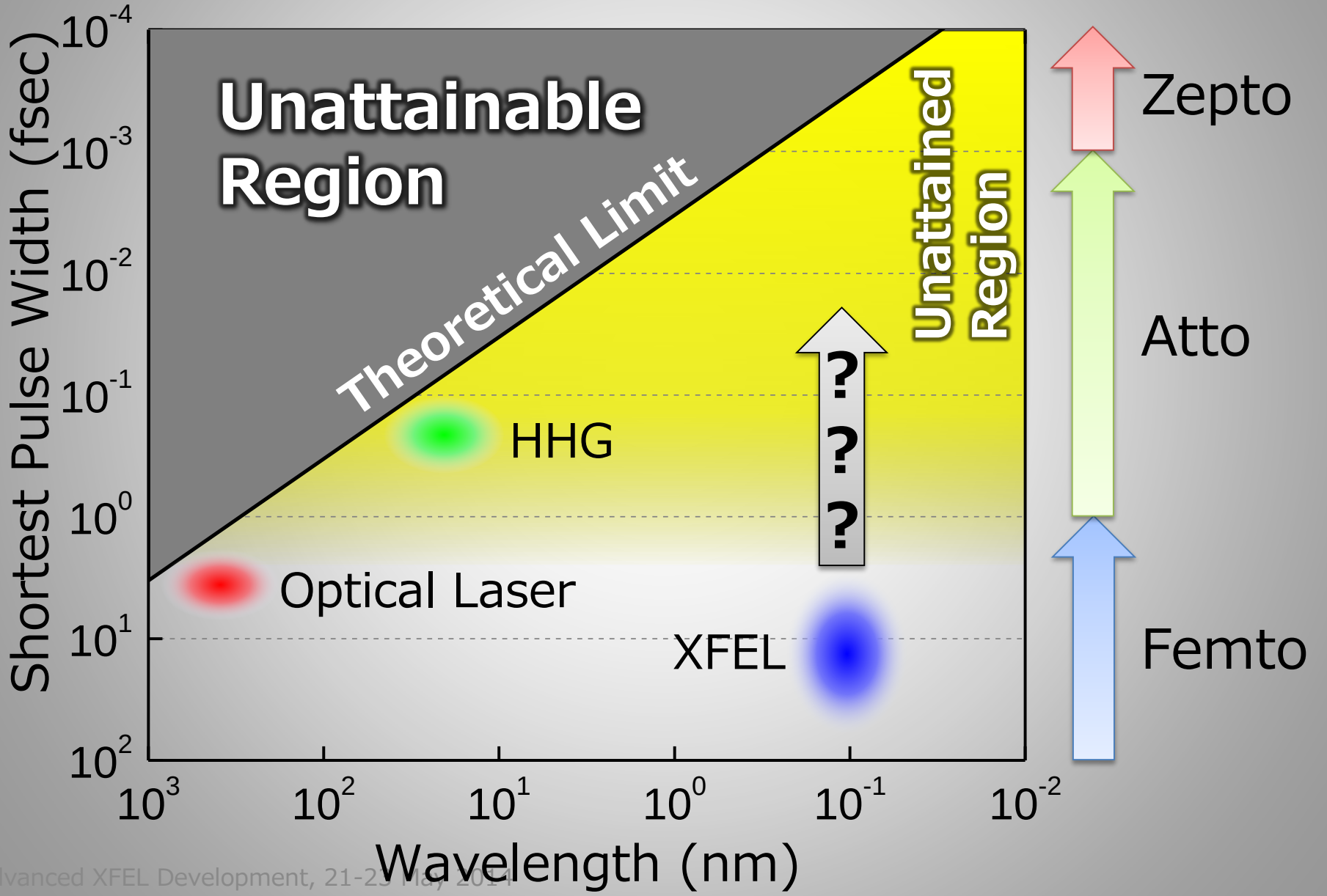
Laser Profile in Time & Space

Optical Laser
(λ=800nm)



XFEL
(λ=0.1nm)

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”

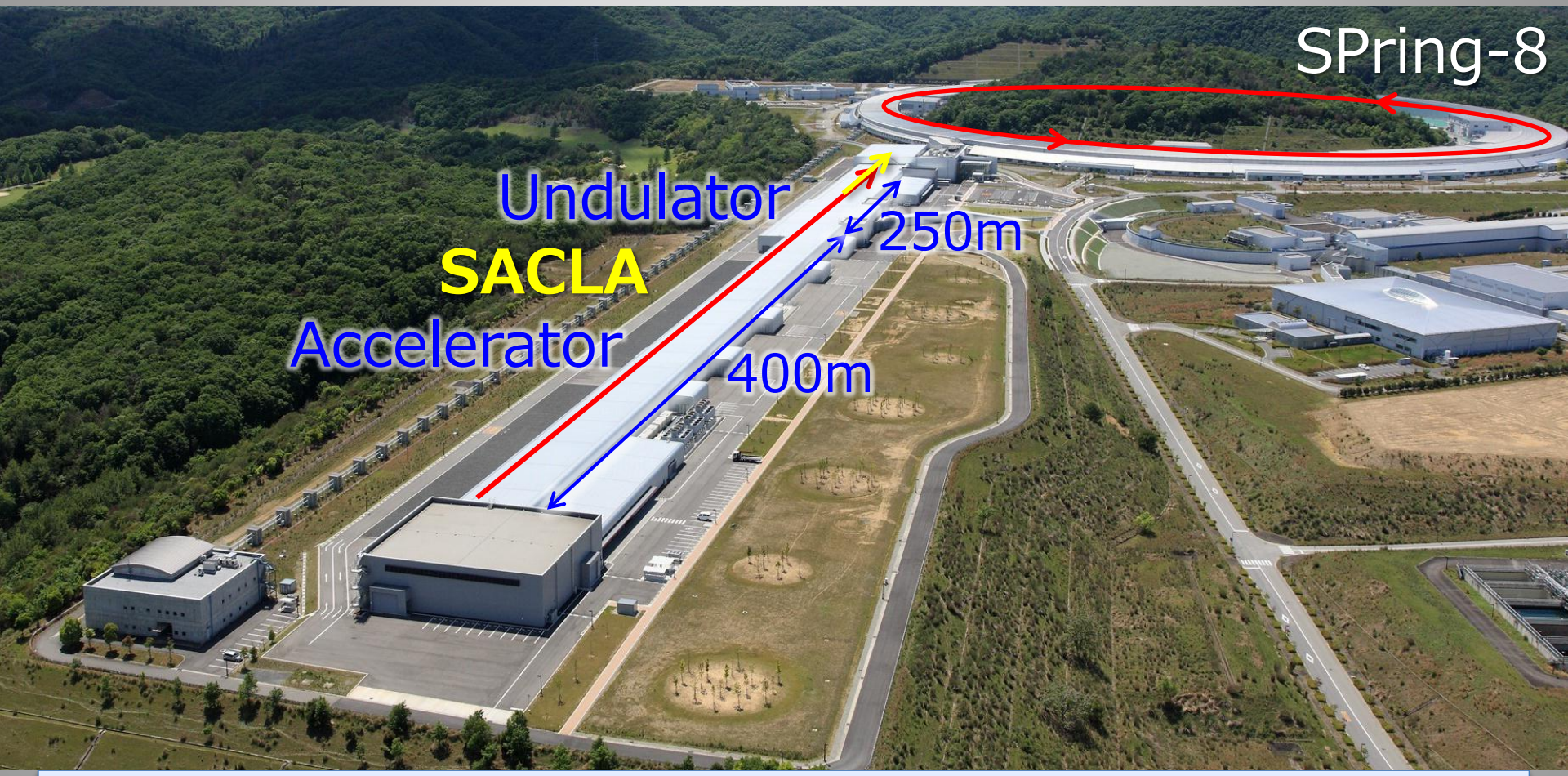
Outline

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

SACLA: Japan's XFEL Facility

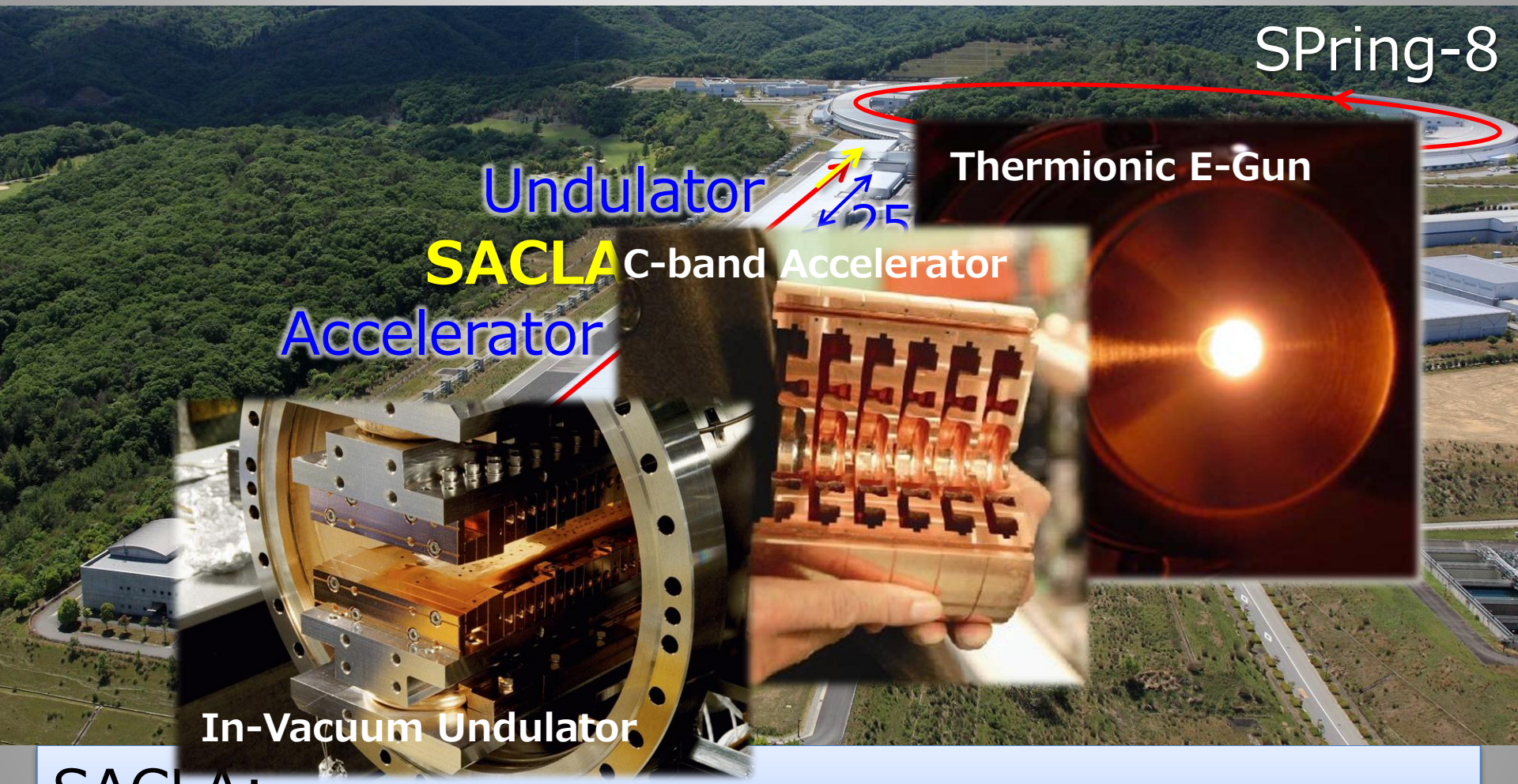
SACLA:
SPring-8 **A**ngstrom **C**ompact free electron **LA**ser

SACLA: Japan's XFEL Facility



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

SACLA: Japan's XFEL Facility



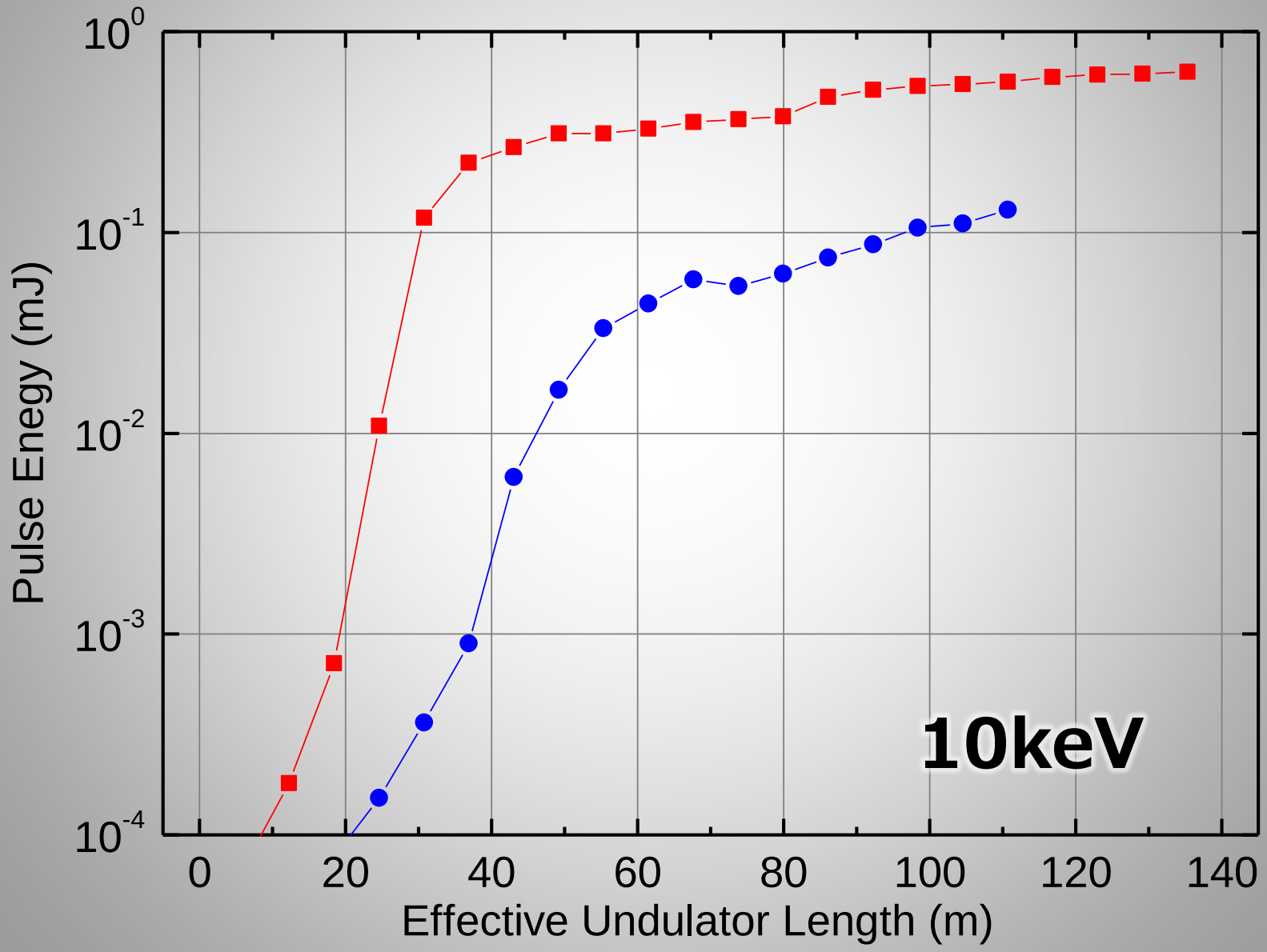
SACLA:
SPring-8 **A**ngstrom **C**ompact free electron **LA**ser

Short-Pulse & High-Power XFEL@SACLA

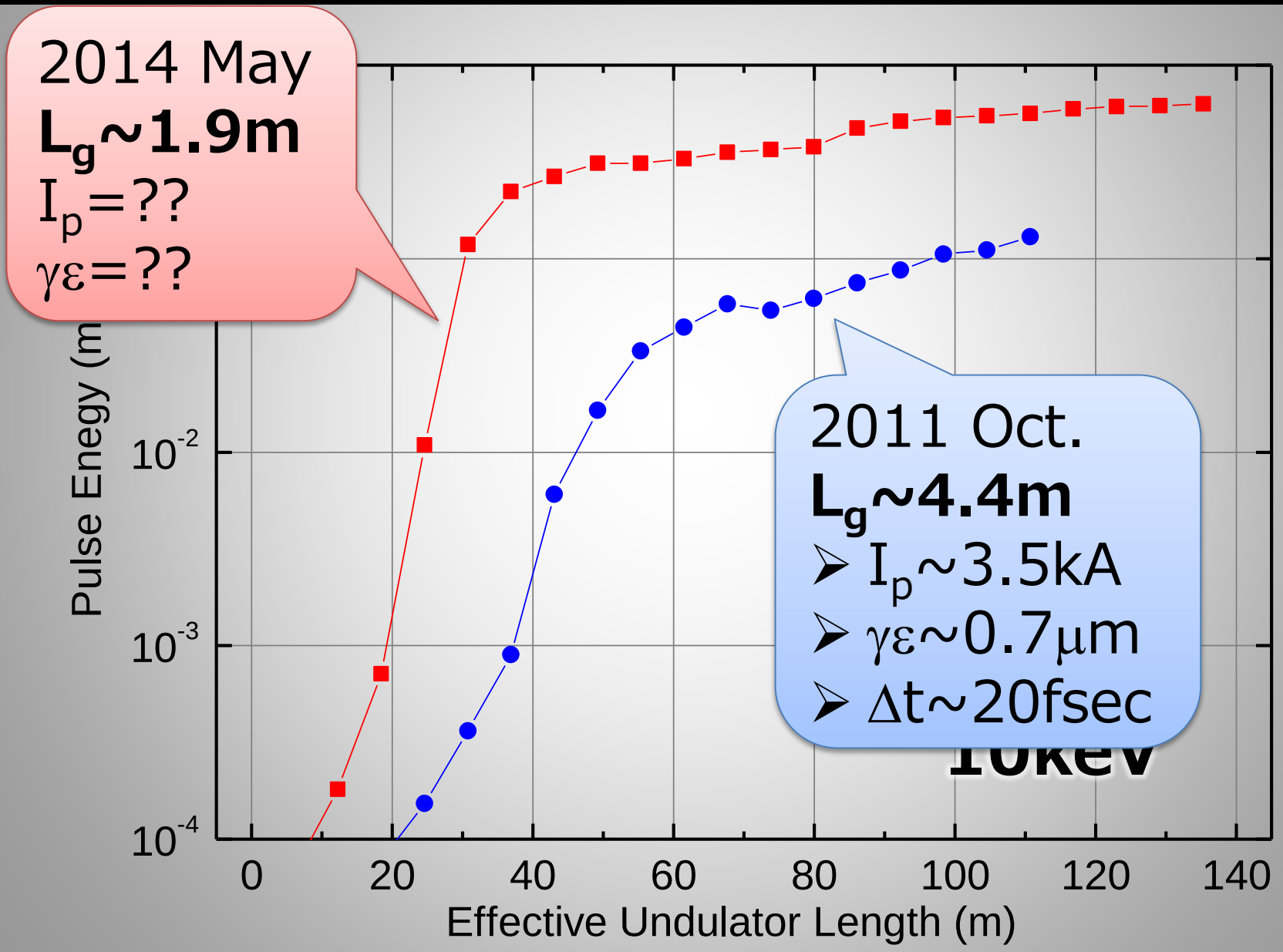
- A lot of efforts have been made at SACLA in order to
  - improve the stability by upgrading the accelerator hardware
  - enhance the laser intensity by optimizing the beam parameters
- As a result, strongly-compressed e-beam is available in nominal operation

Generation of Sub-TW & Few-fs XFEL Pulse

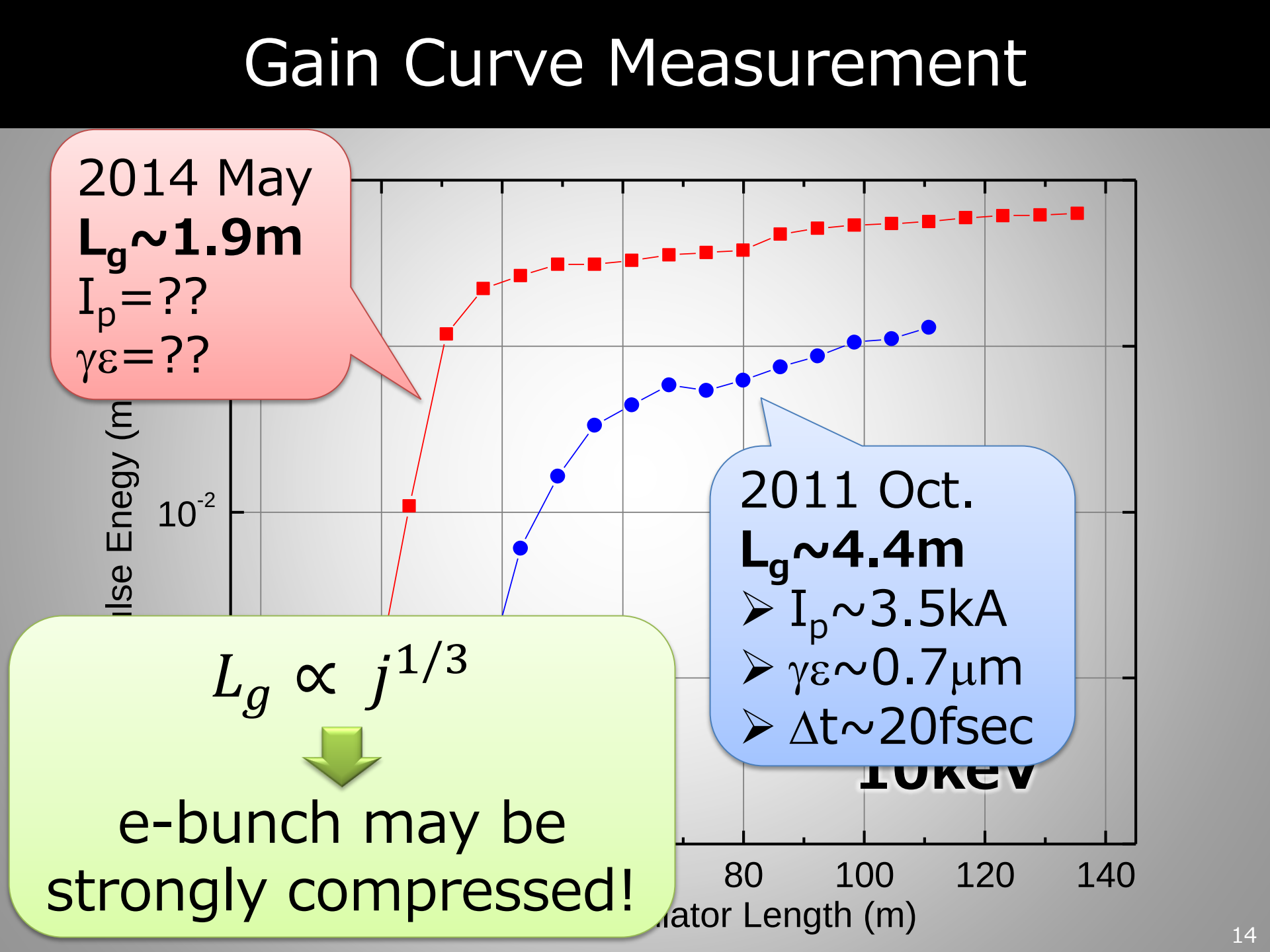
Gain Curve Measurement



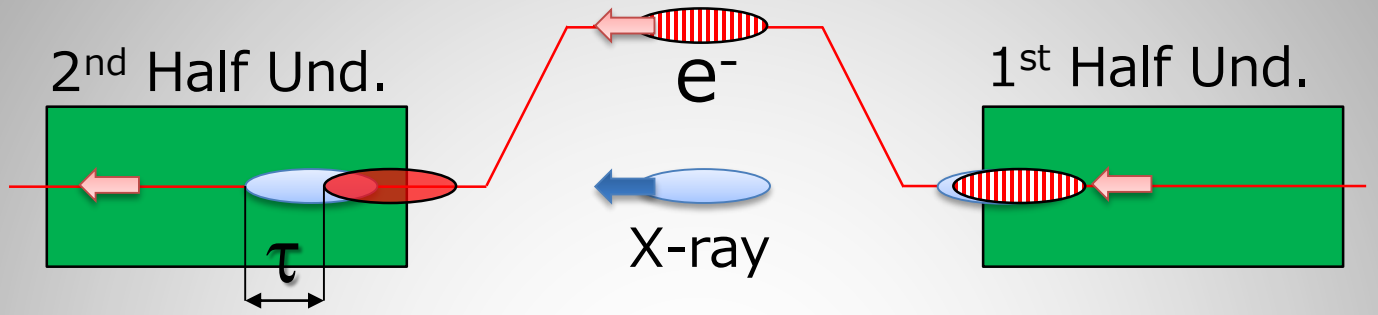
Gain Curve Measurement



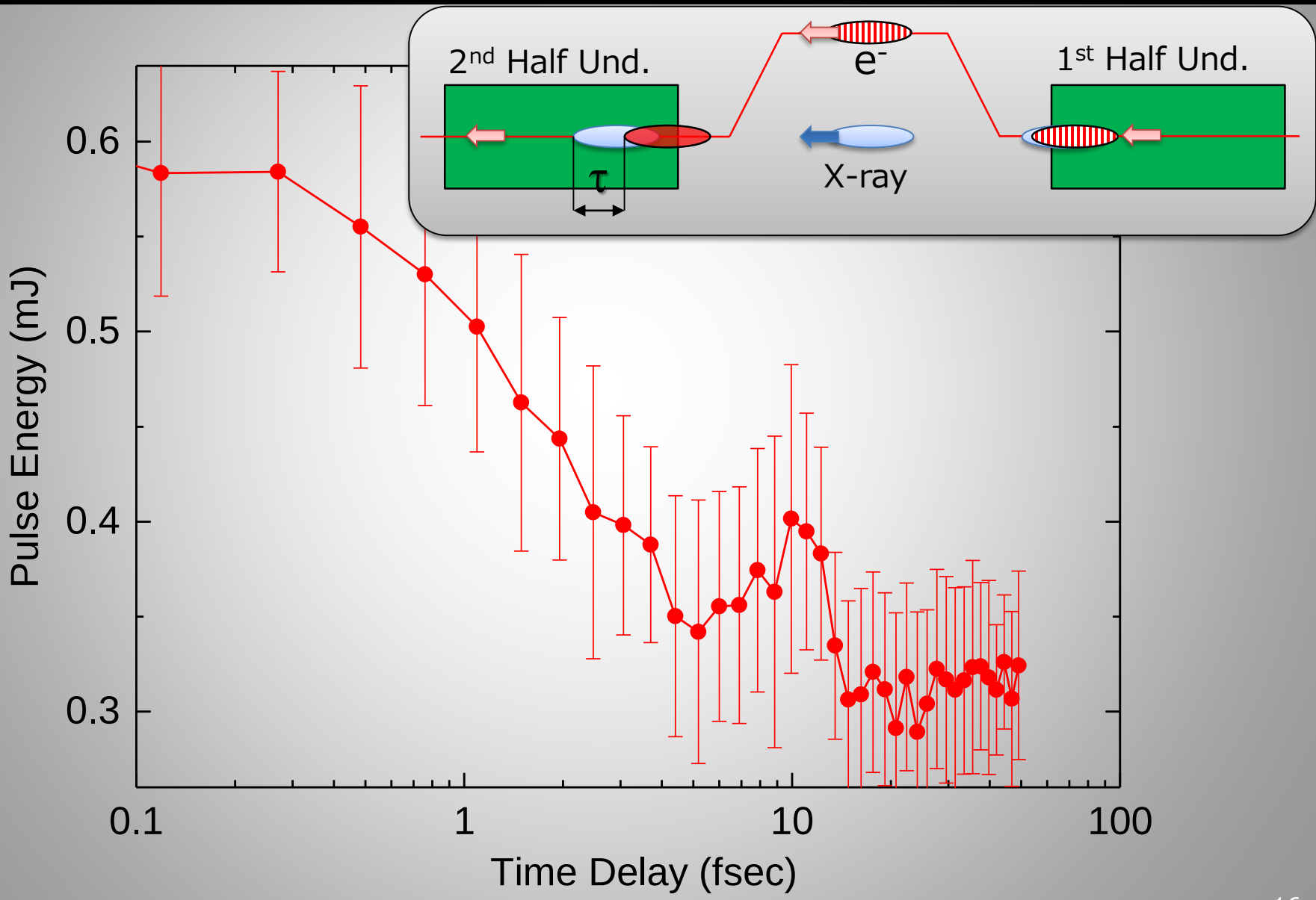
Gain Curve Measurement



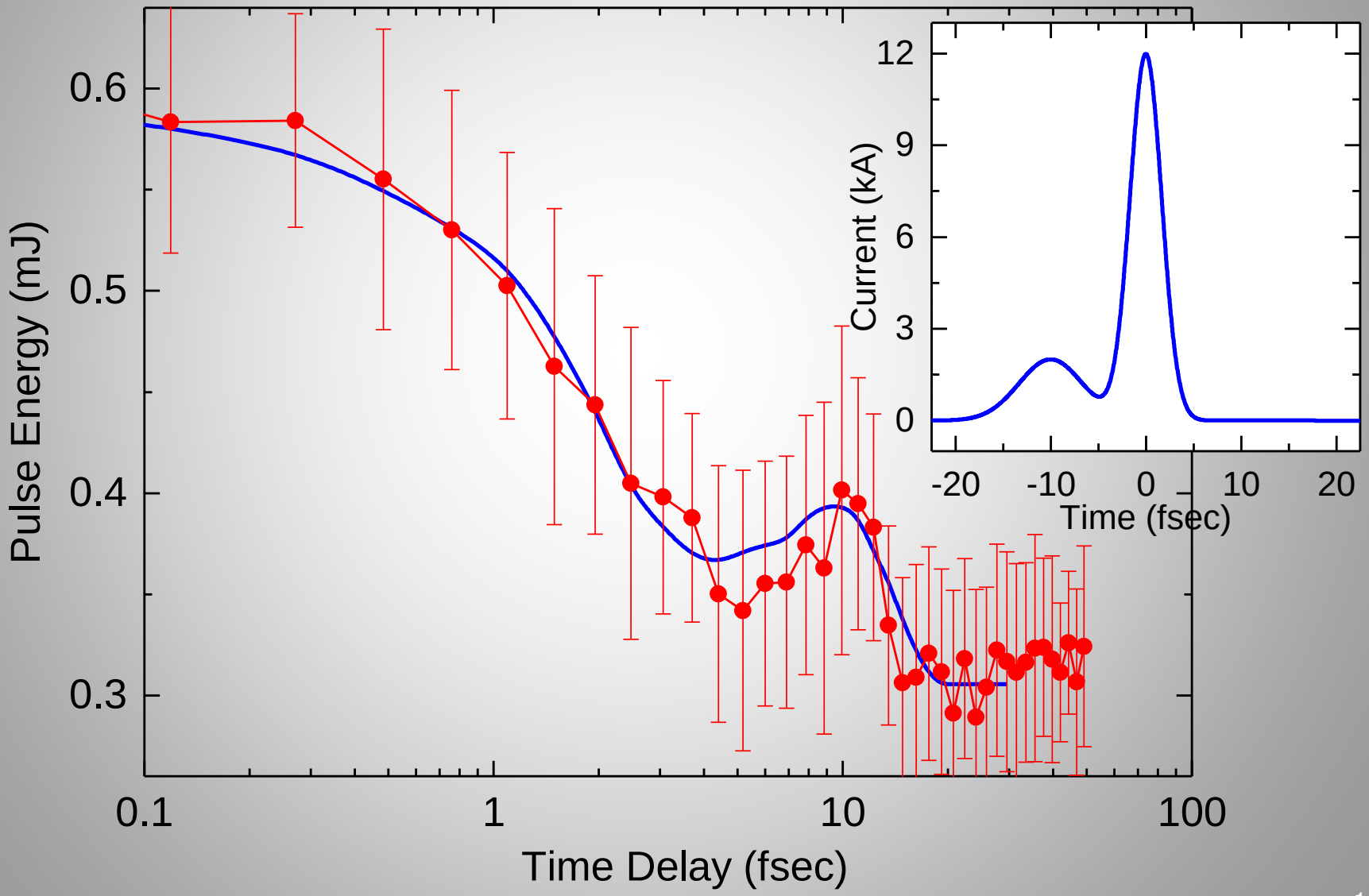
Autocorrelation Measurement



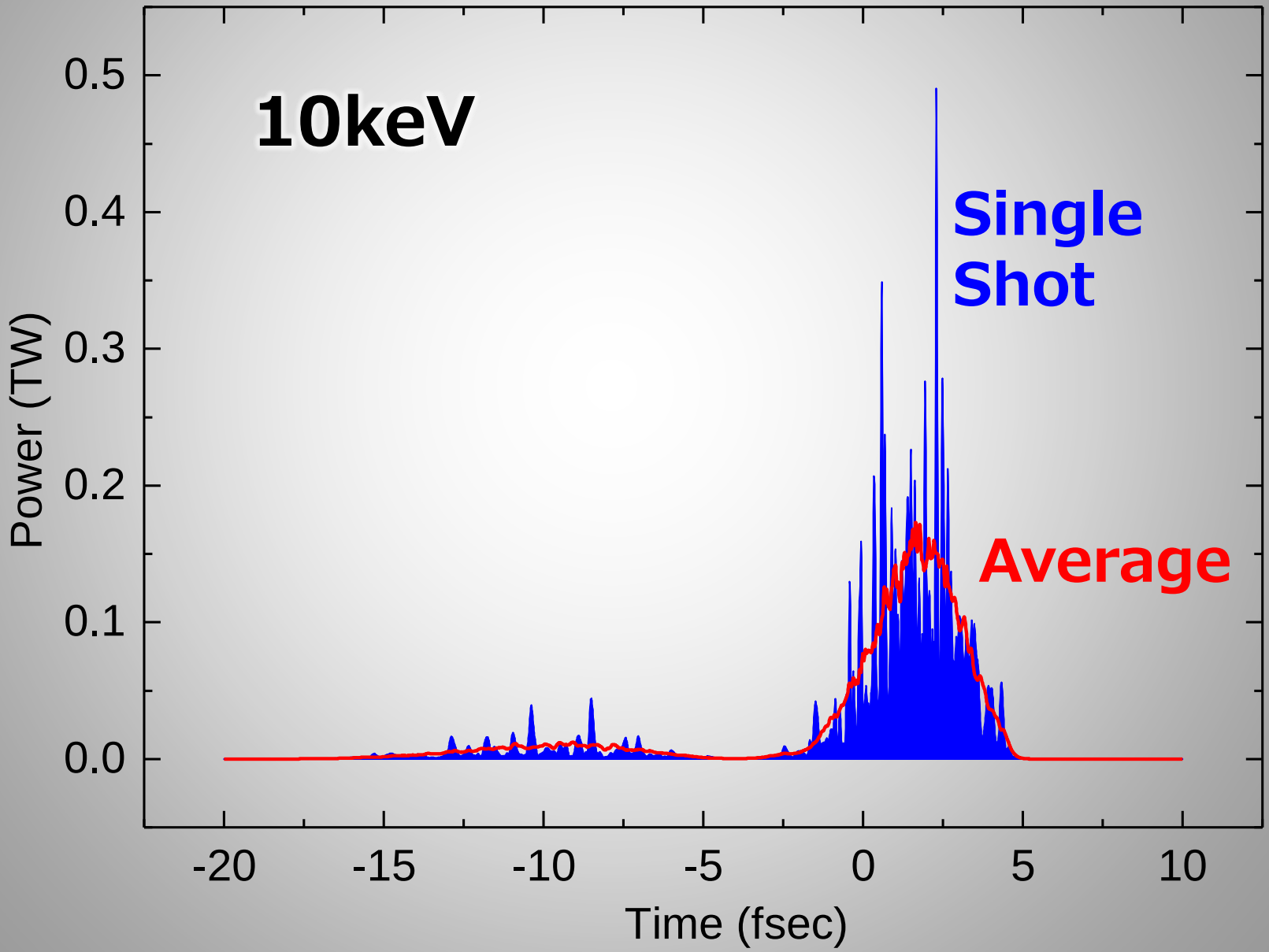
Autocorrelation Measurement



Deduction of the Bunch Profile

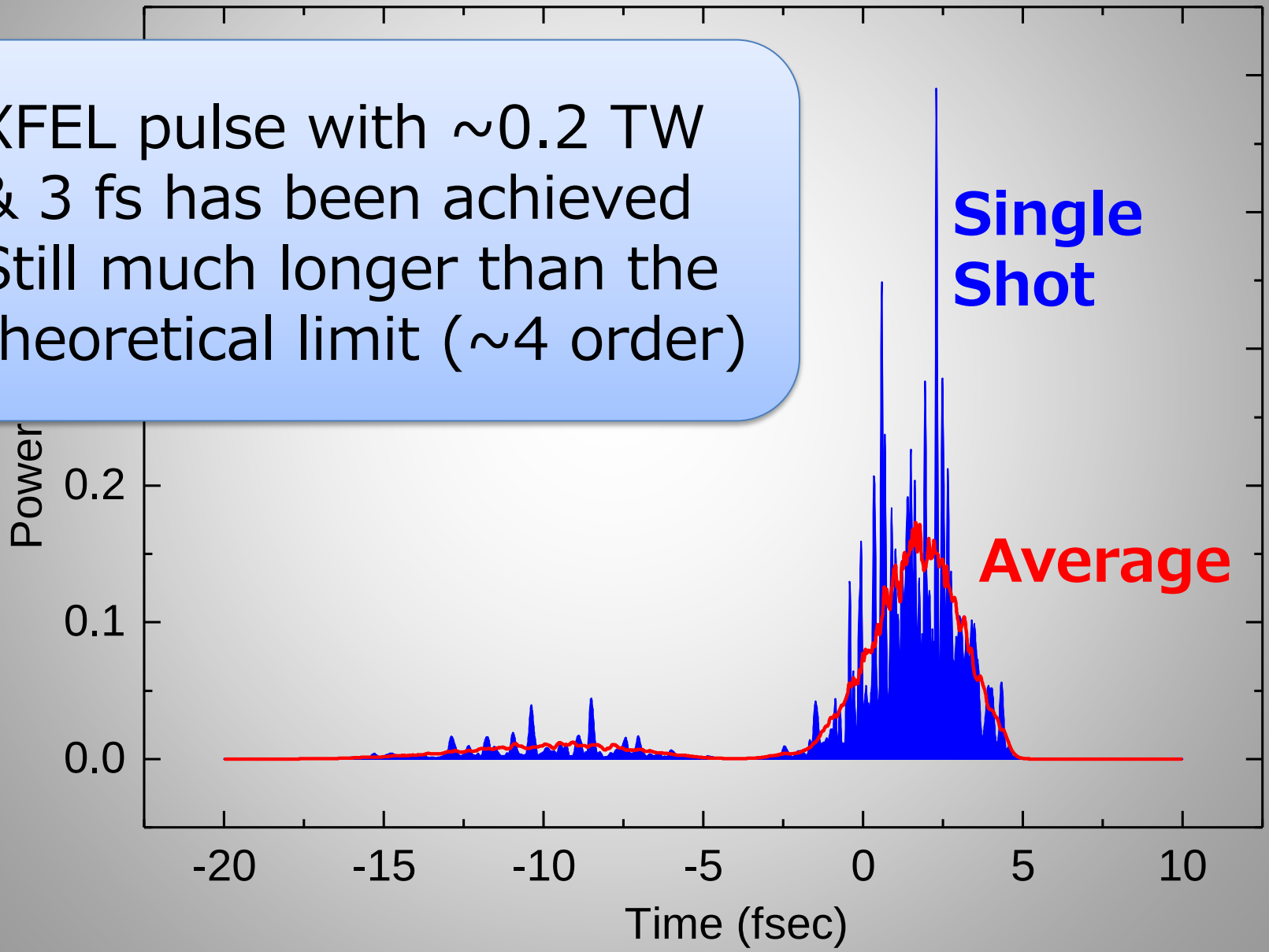


Estimation of the XFEL Pulse



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)



Outline

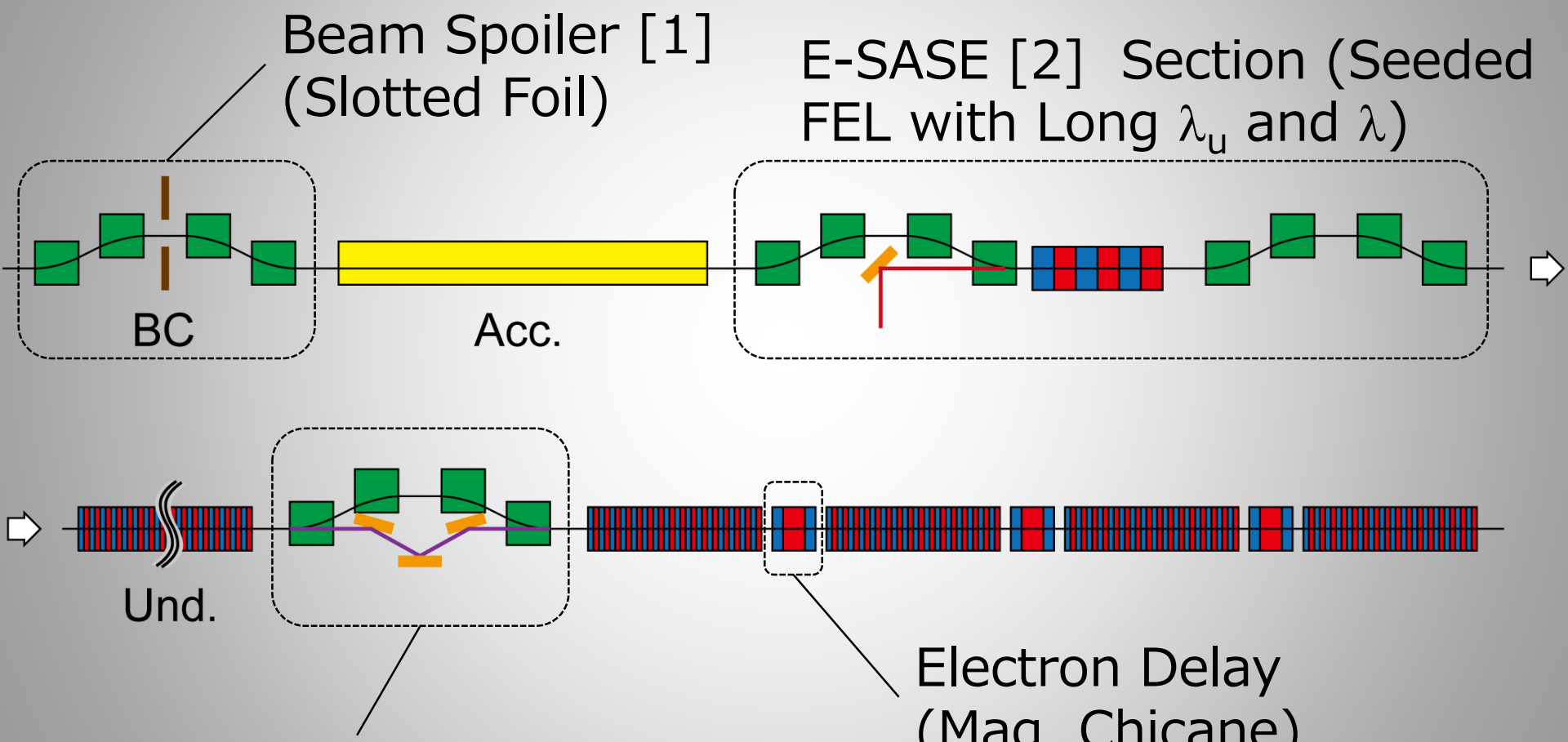
- Introduction
- Sub-TW & Few-fs XFEL at SACLA
- **Toward Atto- & Zeptosecond XFEL**

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*

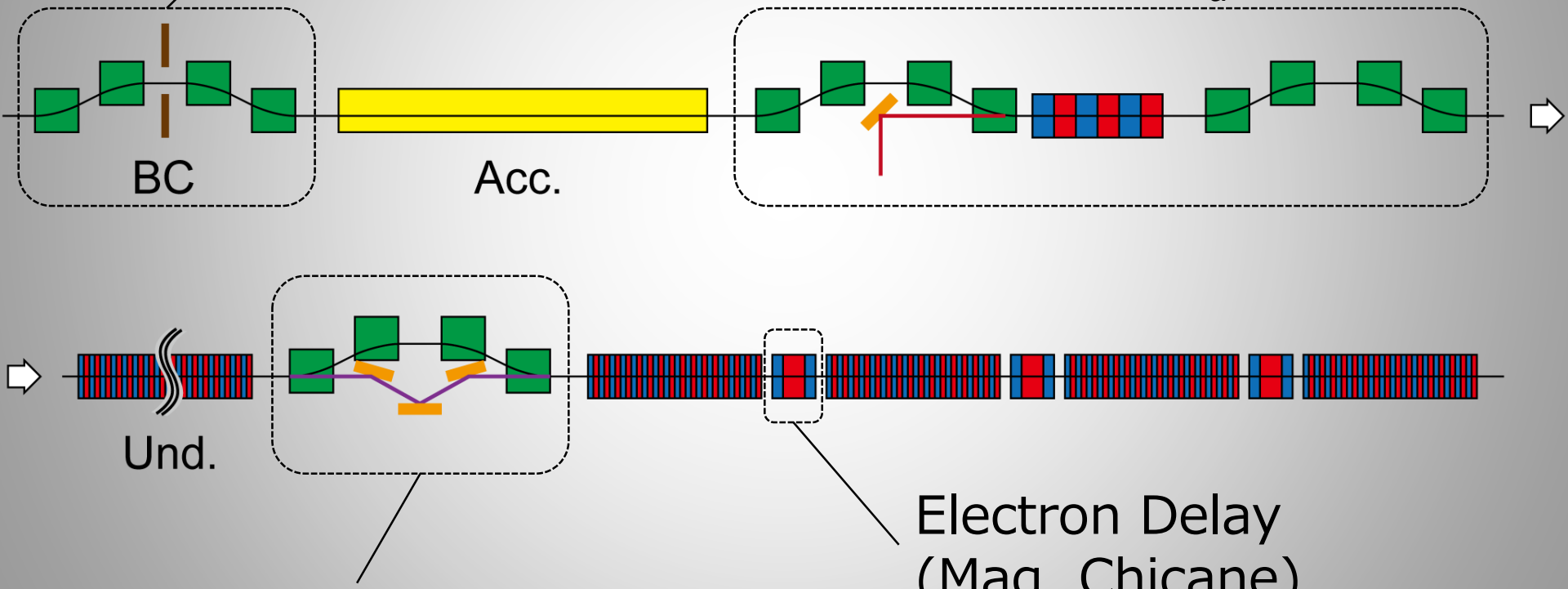
*T. Tanaka, PRL 110, 084801 (2013)



[1] P. Emma et al. PRL 92, 074801 (2004)
[2] A. A. Zholents, PRST-AB 8, 040701 (2005)
[3] G. Geloni et al., DESY 10-004

XFEL Pulse Compression*

*T. Tanaka, PRL 110, 084801 (2013)



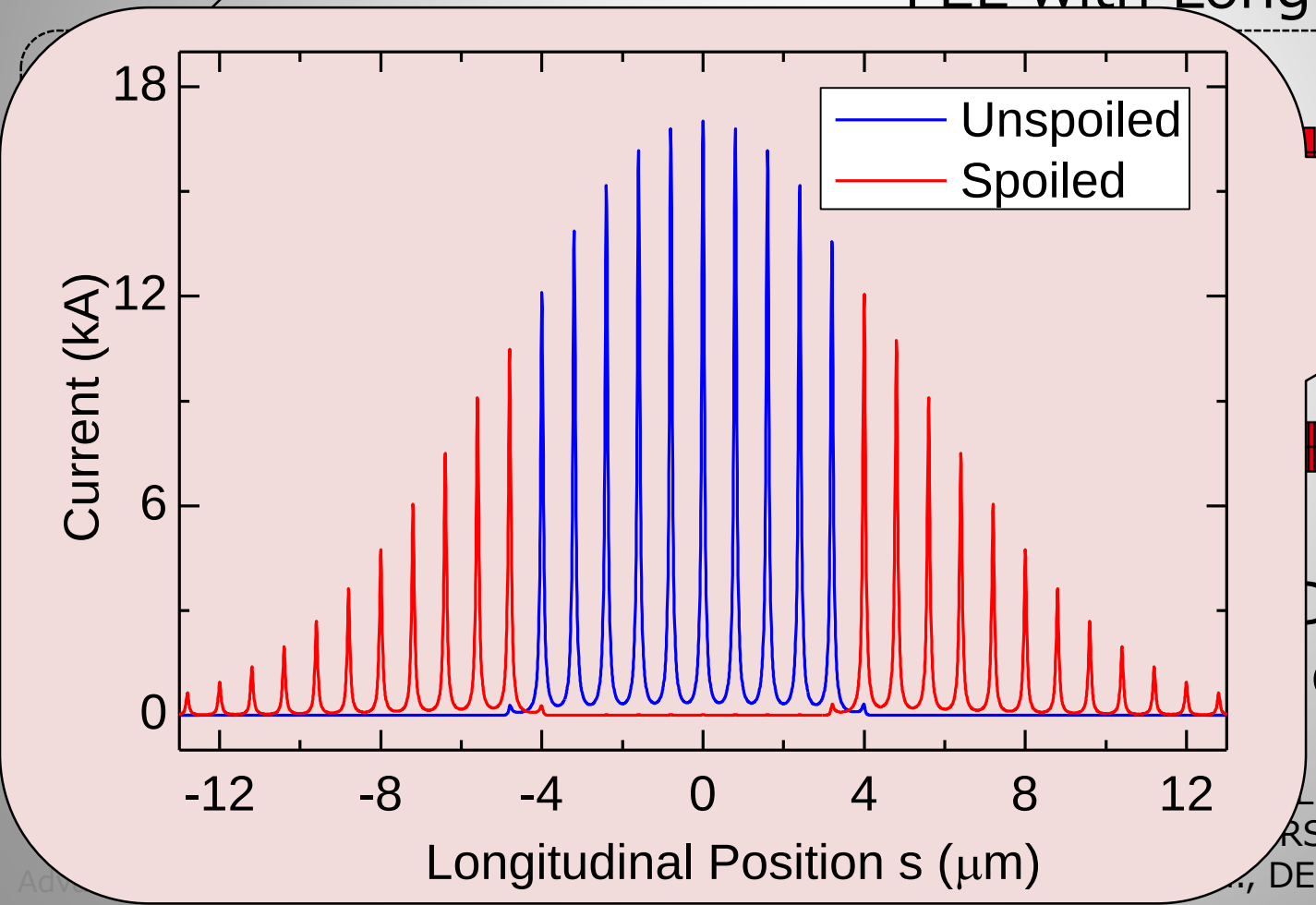
[1] P. Emma et al. PRL 92, 074801 (2004)
[2] A. A. Zholents, PRST-AB 8, 040701 (2005)
[3] G. Geloni et al., DESY 10-004

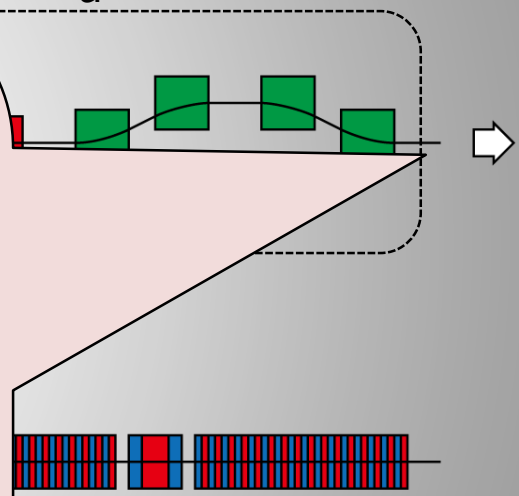
XFEL Pulse Compression*

*T. Tanaka, PRL 110, 084801 (2013)

Beam Spoiler [1] (Slotted Foil)

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

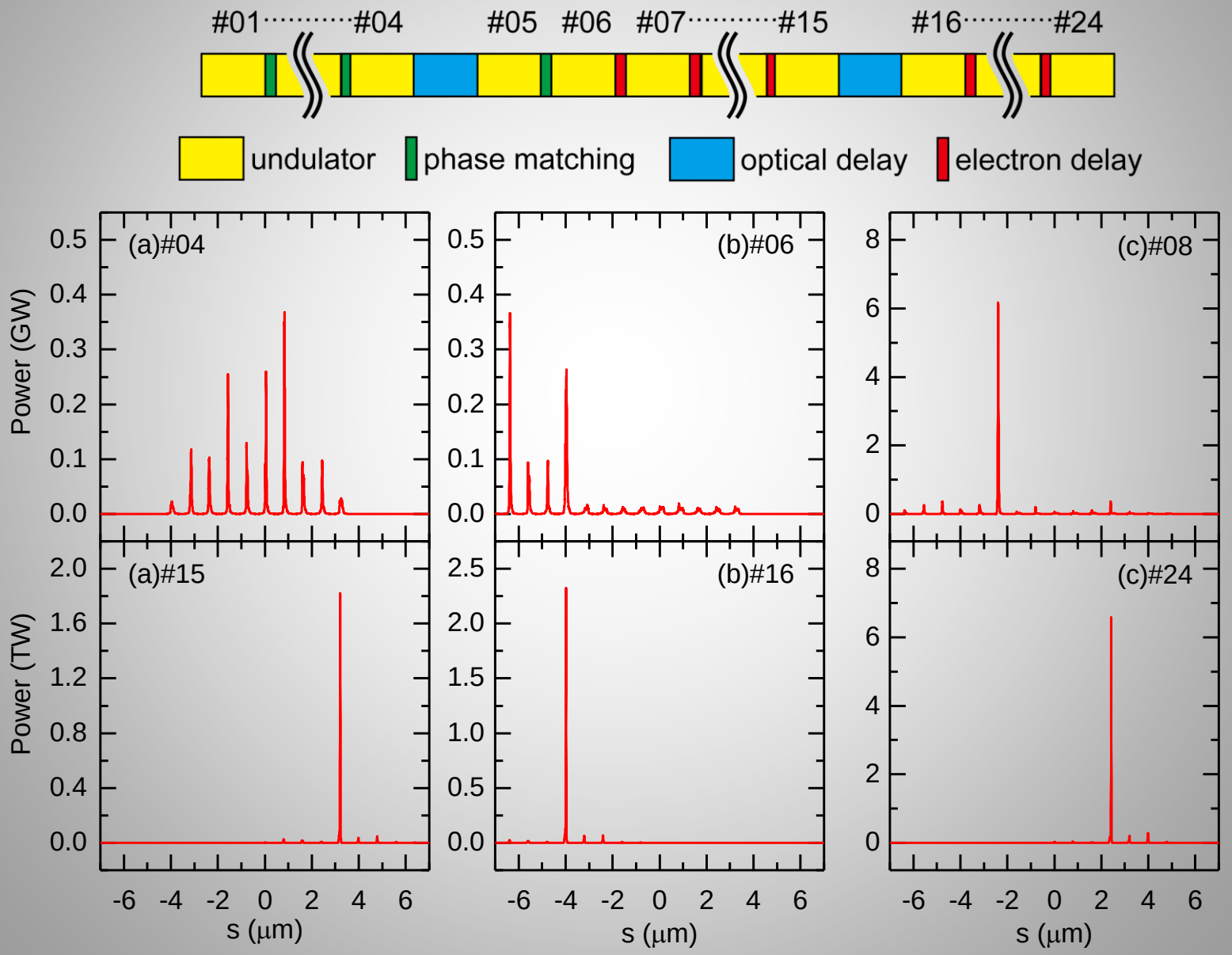




Delay
cane)

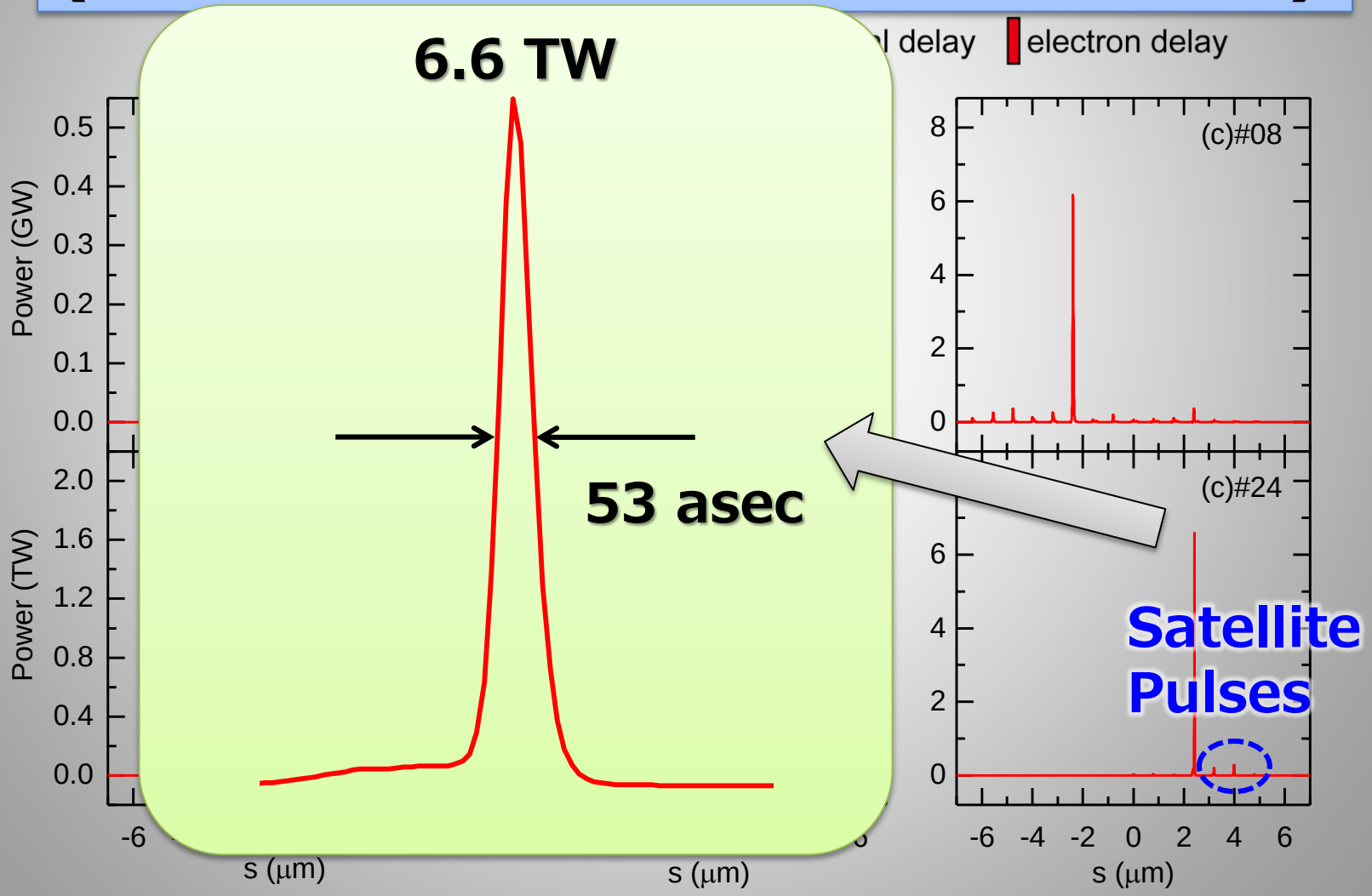
L 92, 074801 (2004)
RST-AB 8, 040701 (2005)
., DESY 10-004

Evolution of a Solitary Pulse

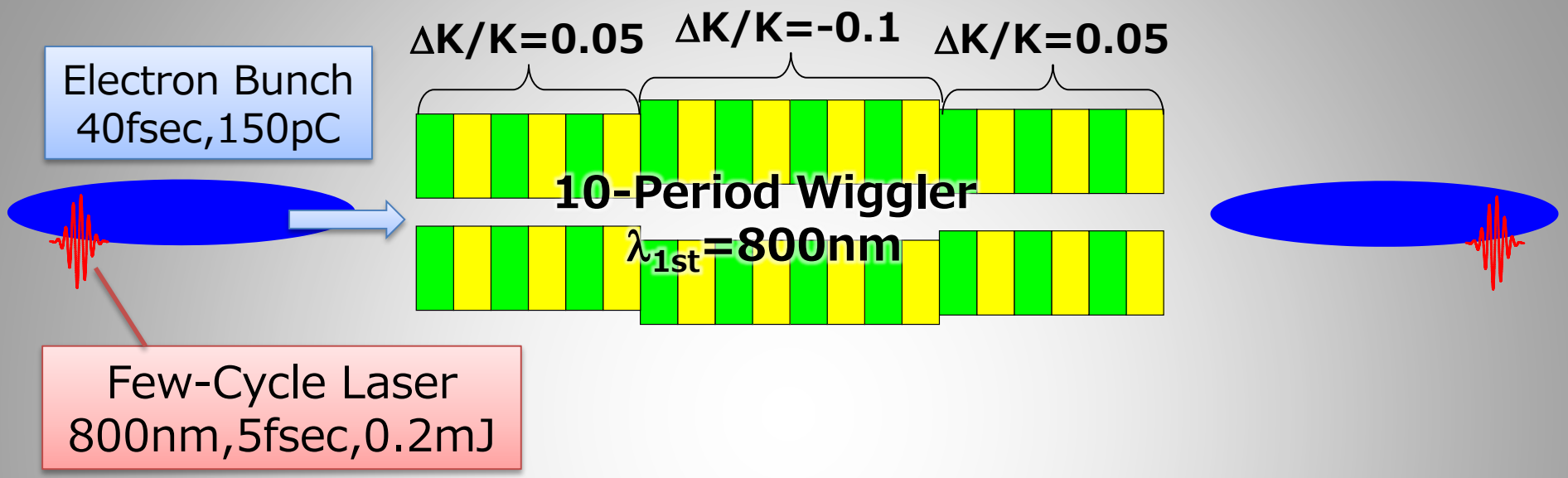


Evolution of a Solitary Pulse

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

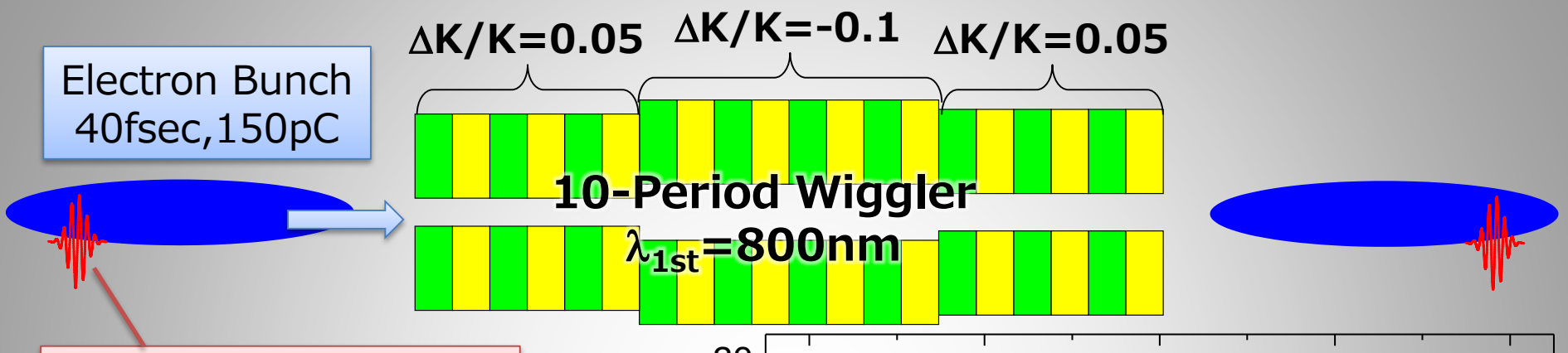


Improvement of Contrast



Improvement of Contrast

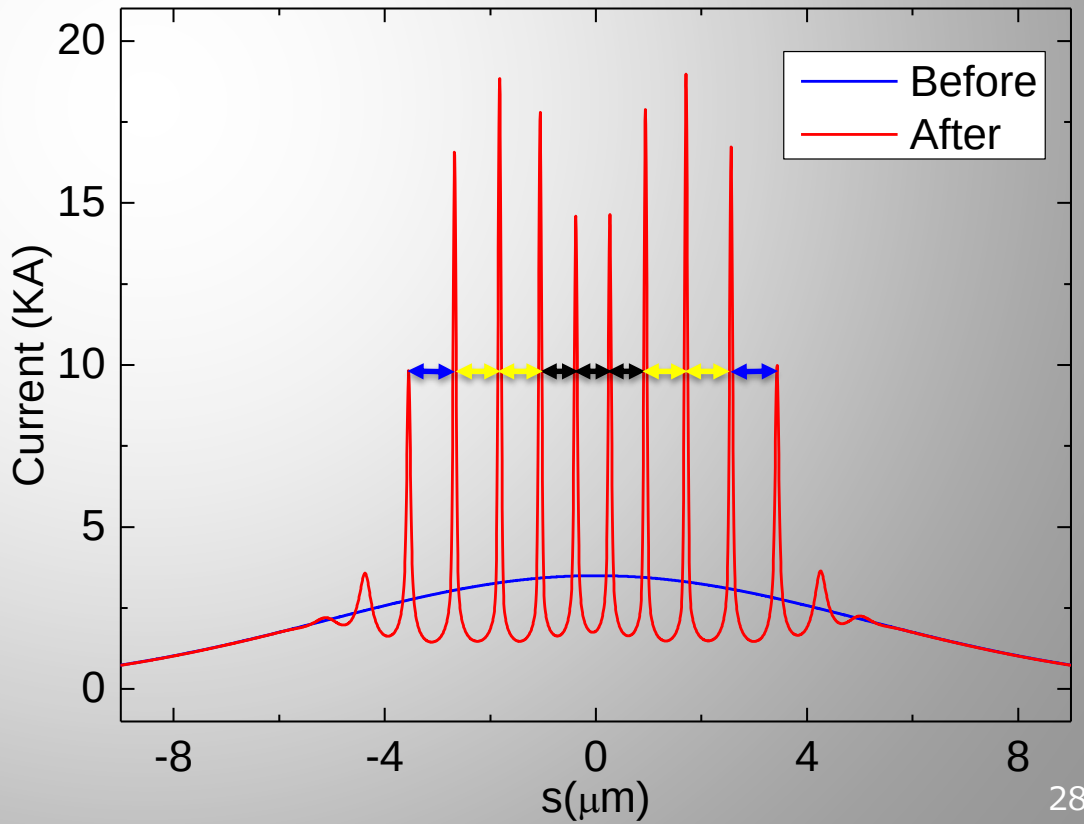
Electron Bunch
40fsec,150pC



Few-Cycle Laser
800nm,5fsec,0.2mJ

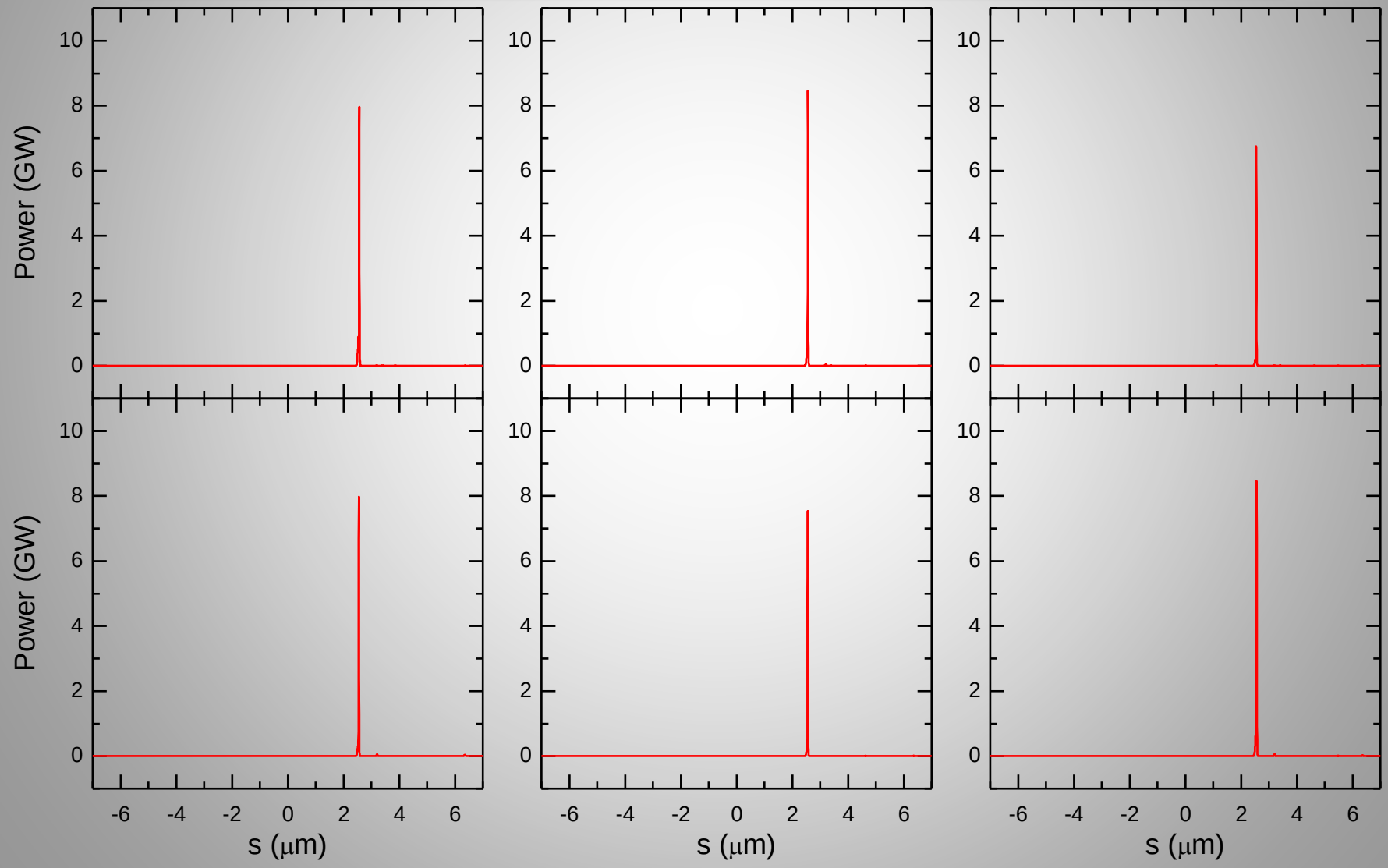
Combination of
- ✓few-cycle laser
- ✓wiggler having irregular phase slip

creates comb-like current profile with irregular intervals

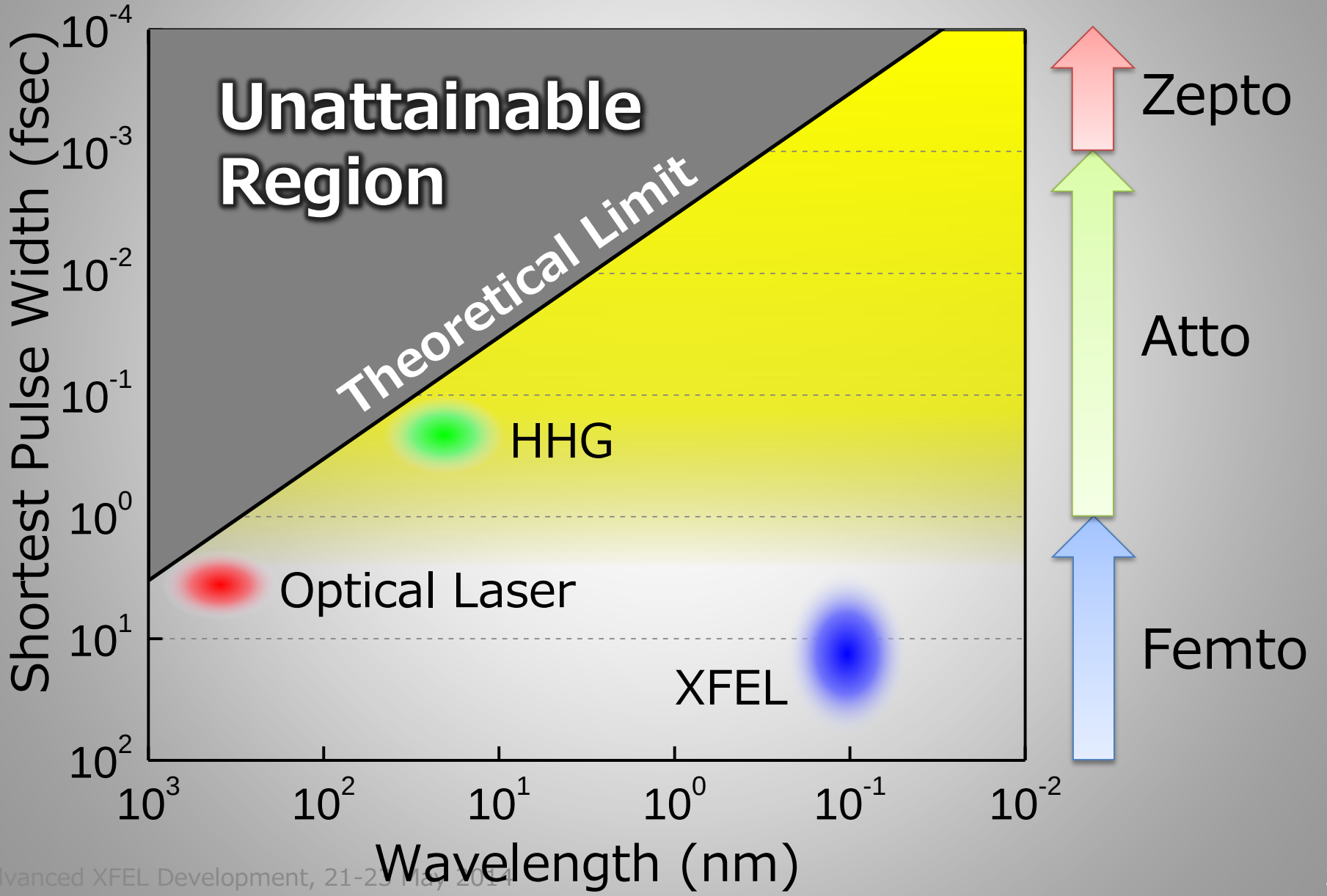


Example of Improvement

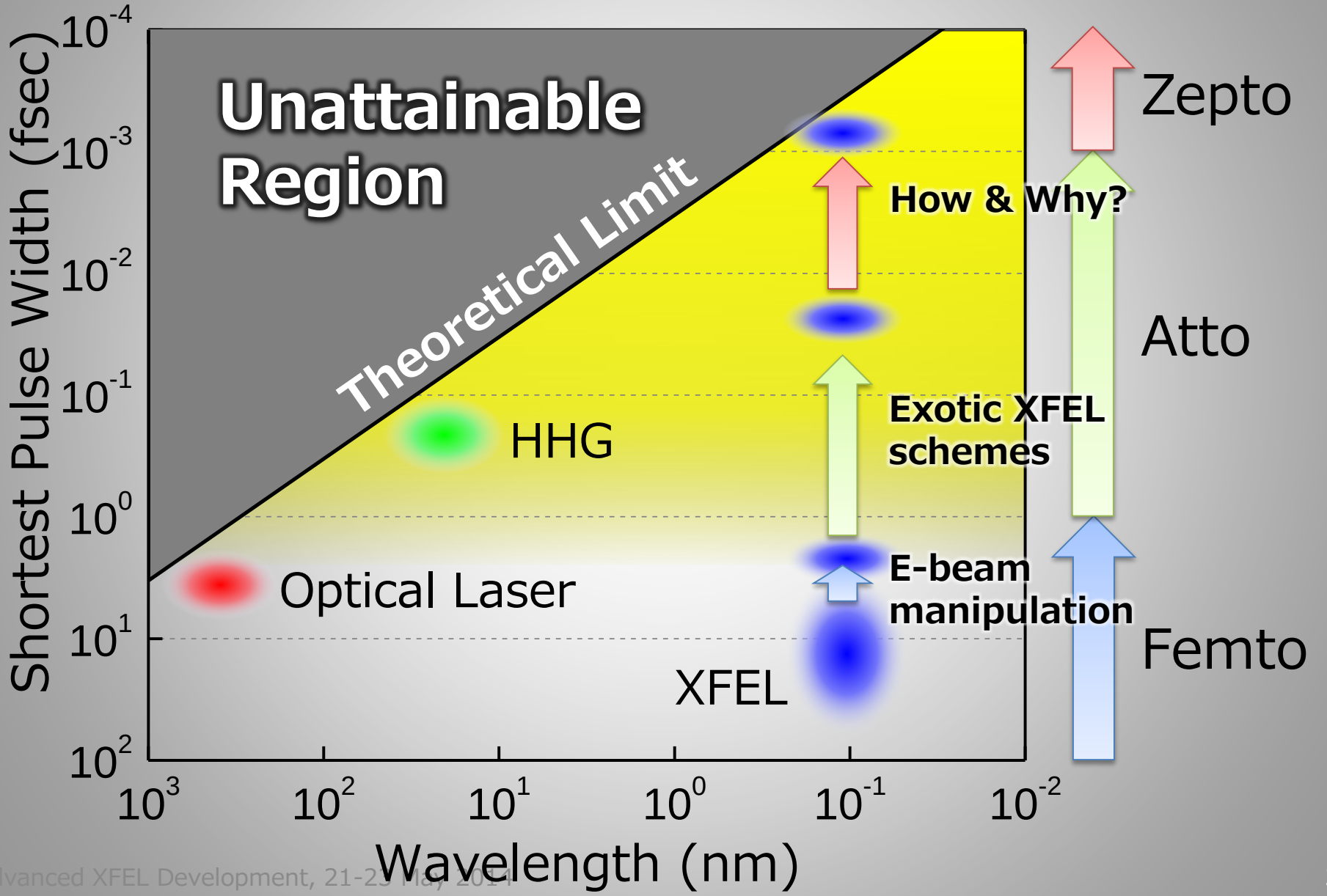
Typical 6 Shots Simulated with Different Random Seed



Toward “Ultimate” X-ray Laser?



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!