Isolated Monocycle Pulse Generation in Free Electron Lasers

- a proposal-

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Outline

- Introduction
- Principle of Monocycle Pulse Generation
- How to Implement in XFELs?
- Numerical Examples
- Summary and Outlook

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- **Introduction**
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Theoretical Limit of Laser Sources

Spatial Limit : Focus Size ~ Wavelength
Temporal Limit : Pulse Length ~ Wavelength

Infrared Laser
(λ=800nm)

~several fs

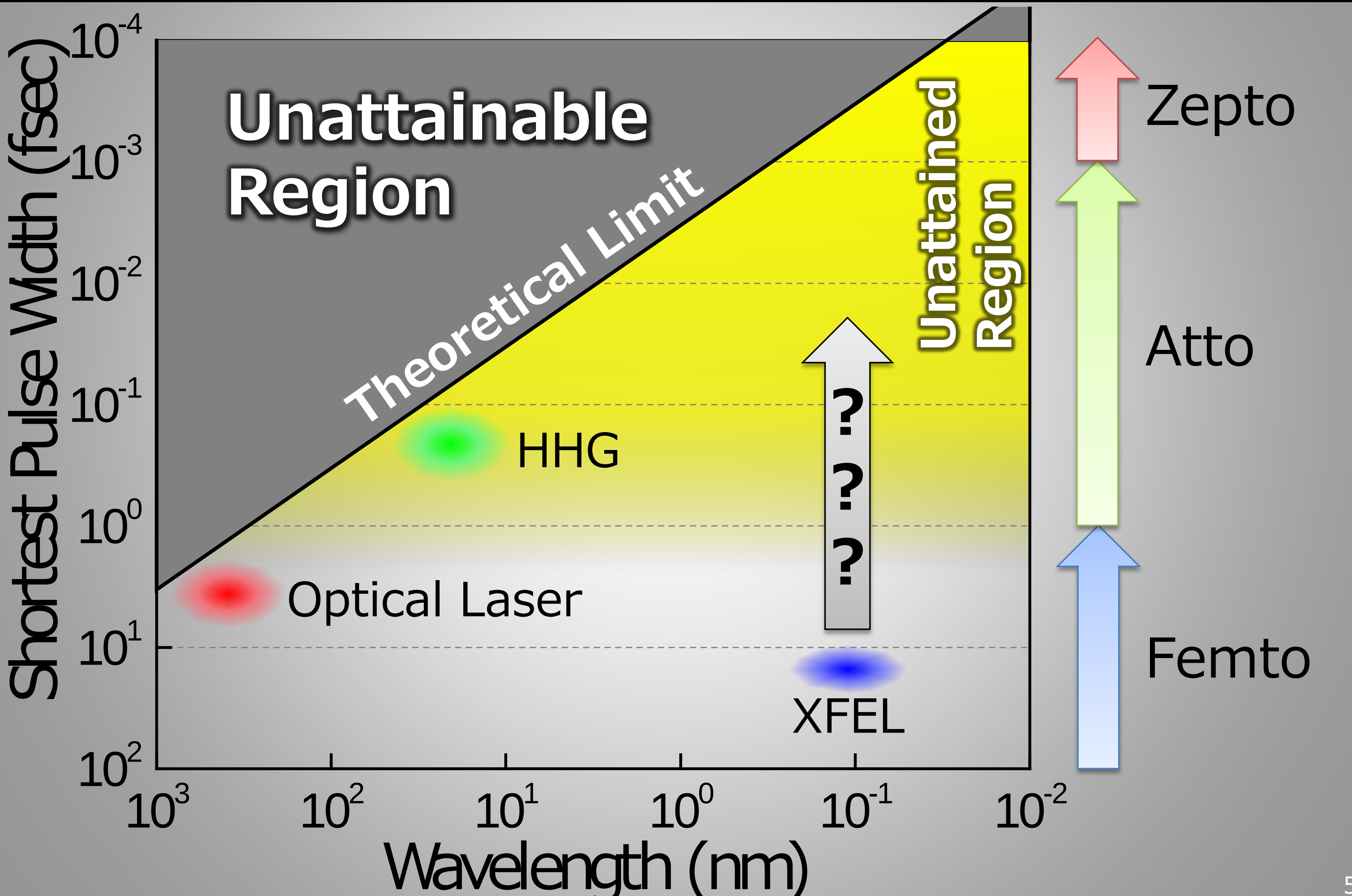
Shortening the XFEL pulse length is not as straightforward as focusing.

XFEL
(λ=0.1nm)

~several 10 fs

~50nm

Status of Laser Pulse Lengths



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 new XFEL concepts have been proposed to reduce the pulse length

Strong Compression of e- Bunch

- 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

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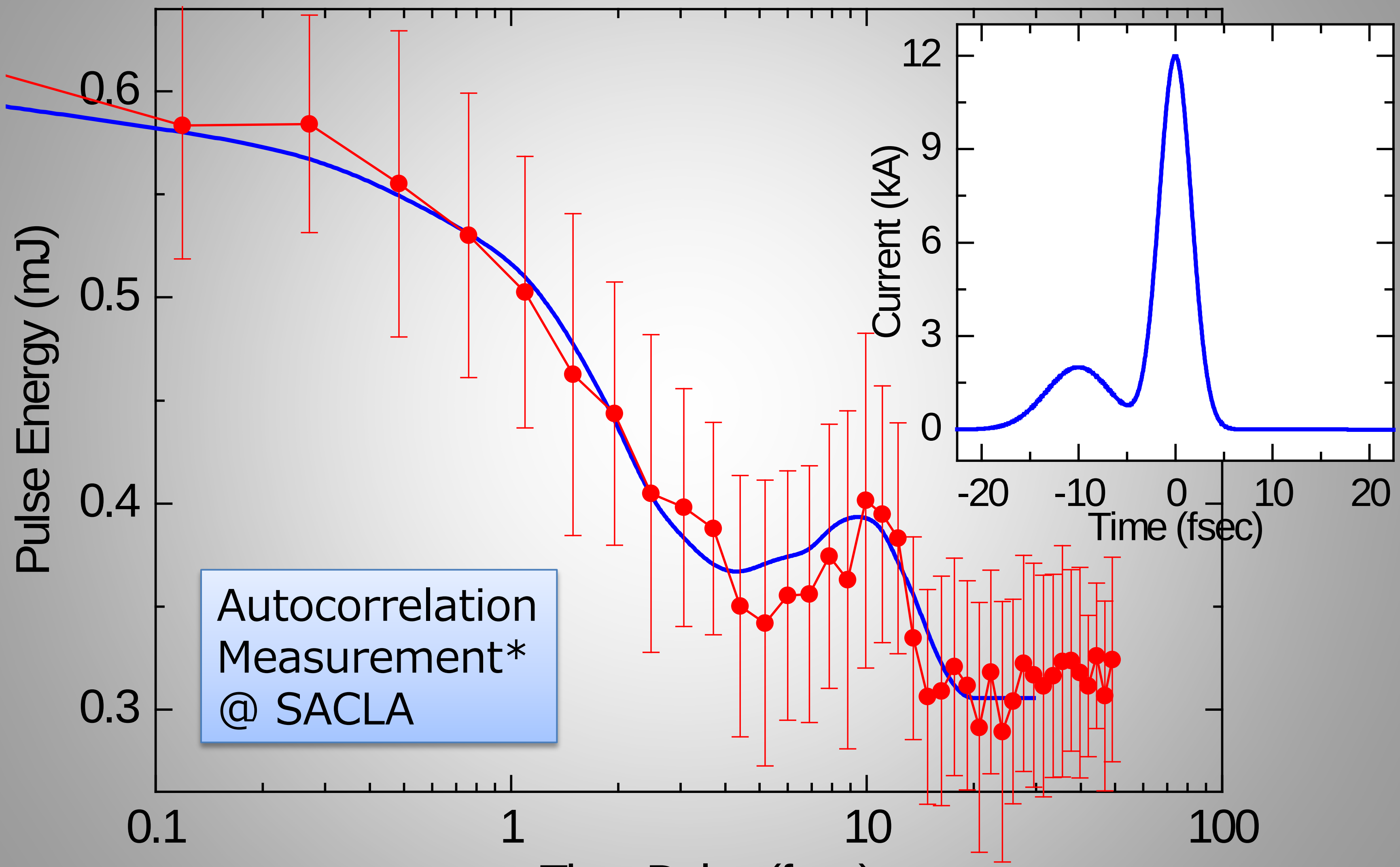
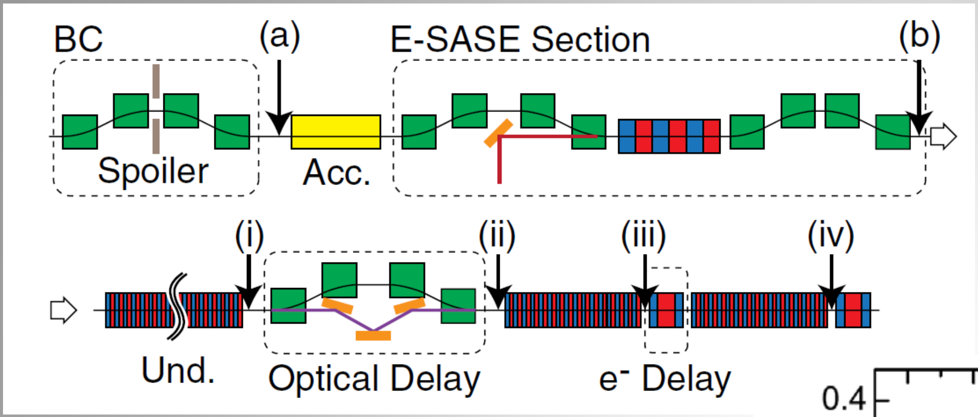
Generation of Sub-TW & Few-fs XFEL Pulse

Deduction of the Bunch Profile

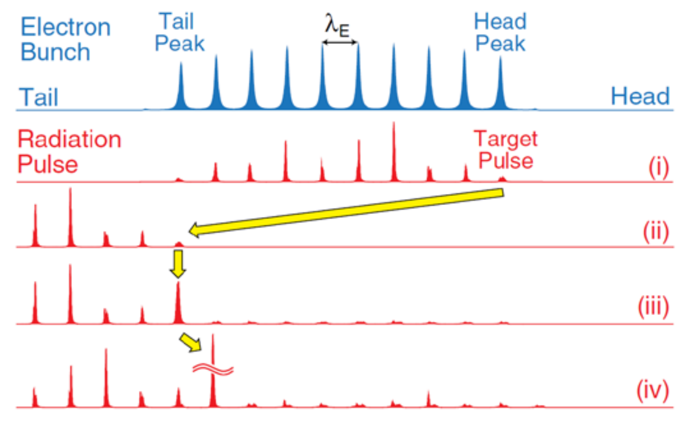


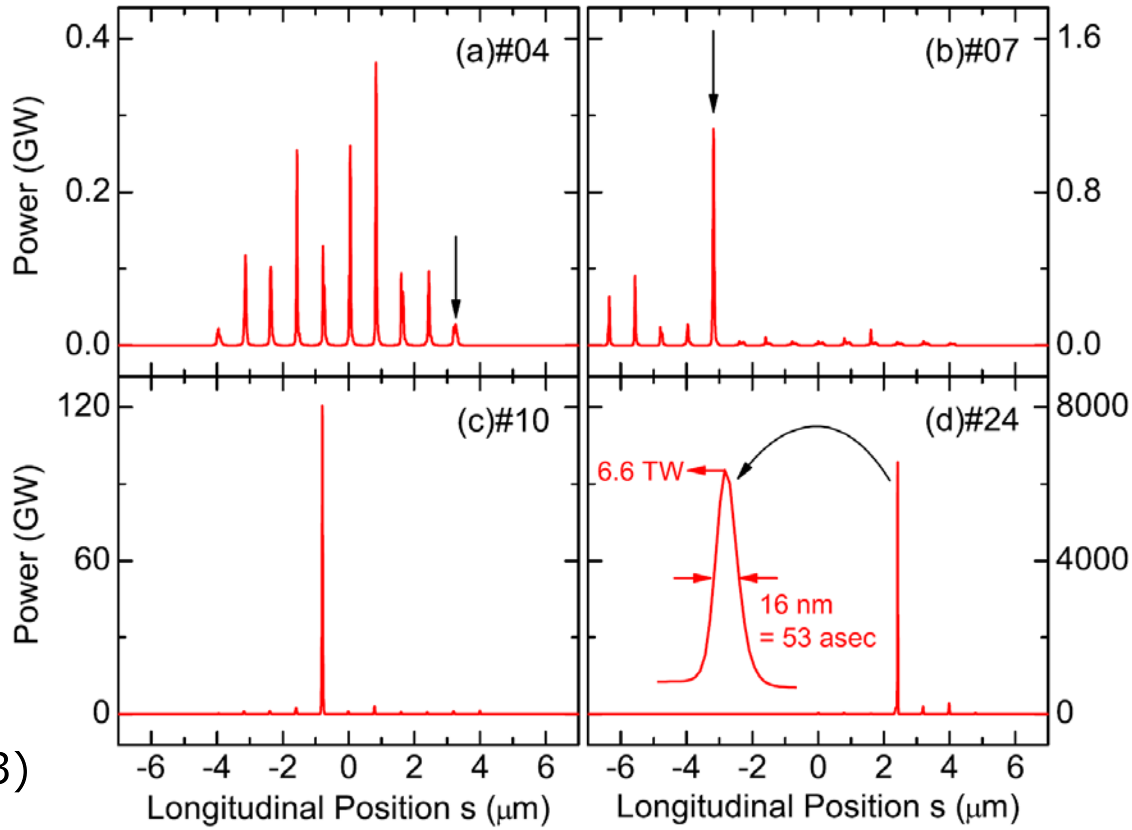
*G. Geloni, V. Kocharyan and E. Saldin, DESY 10-008

XFEL Pulse Compression Scheme



Sequential Amplification by Comb-like Current Peaks





T. Tanaka, PRL 110, 084801 (2013)

Toward Monocycle XFEL Pulse?

- Even with these schemes, it is impossible to generate a monocycle XFEL pulse.
- This is because the slippage effect in the undulator works to expand the pulse length.
- It is thus necessary to counteract this effect, in order to reduce the pulse length down to the theoretical limit.

Pulse Length of XFEL

Electron Beam Undulator XFEL

New Method* to Generate a Monocycle Pulse

- ✓ Avoid pulse lengthening by slippage, even with N=M≫1

*T. Tanaka, Phys. Rev. Lett. 114, 044801 (2015)

PRL **114,** 044801 (2015) PHYSICAL REVIEW LETTERS week ending 30 JANUARY 2015

Proposal to Generate an Isolated Monocycle X-Ray Pulse by Counteracting the Slippage Effect in Free-Electron Lasers

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(Received 30 September 2014; published 26 January 2015)

A novel scheme is proposed to generate an isolated monocycle x-ray pulse in free-electron lasers, which is based on coherent emission from a chirped microbunch passing through a strongly tapered undulator. In this scheme, the pulse lengthening by optical slippage, being intrinsic to the lasing process of free-electron lasers, can be effectively suppressed through destructive interference of electromagnetic waves emitted at individual undulator periods. Calculations show that an isolated monocycle x-ray pulse with a wavelength of 8.6 nm and a peak power of 1.2 GW can be generated if this scheme is applied to a 2-GeV and 2-kA electron beam.

DOI: 10.1103/PhysRevLett.114.044801 PACS numbers: 41.60.Cr, 42.55.Vc

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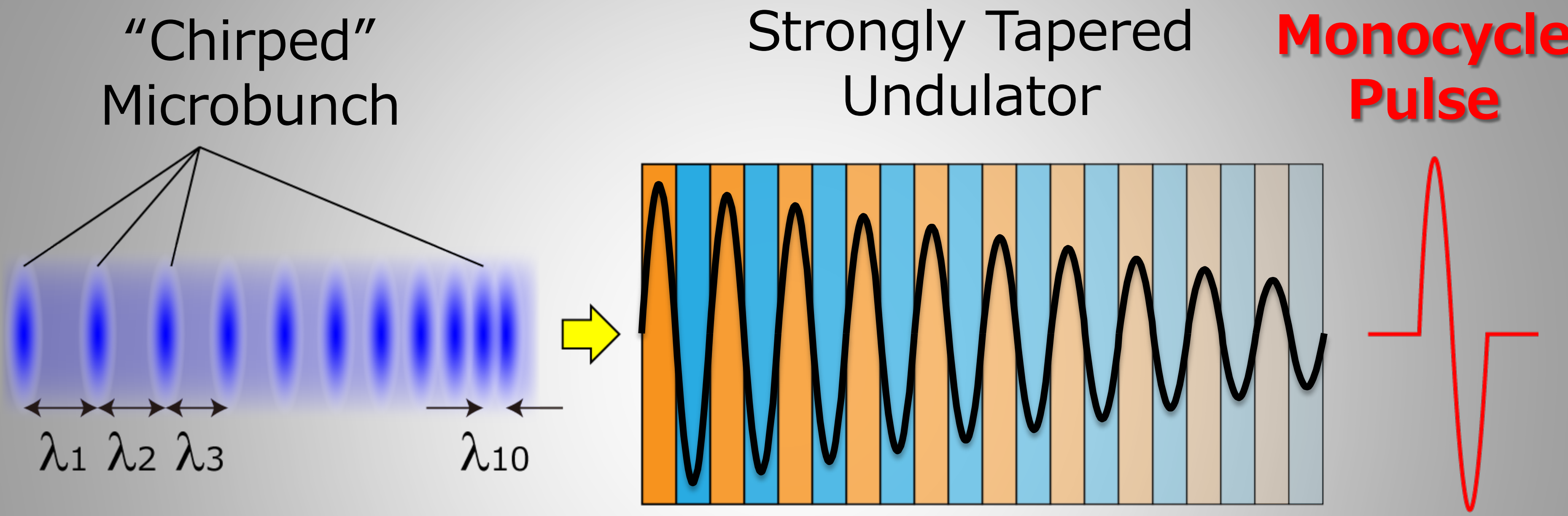
Basic Concept



<u>Necessary Condition</u>

Interval at the n-th microbunch
= Slippage at the n-th period

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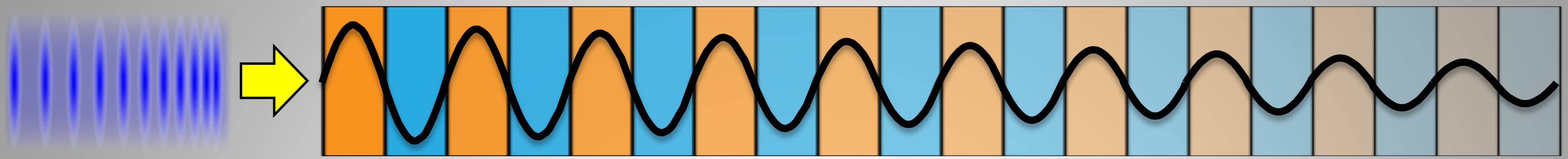
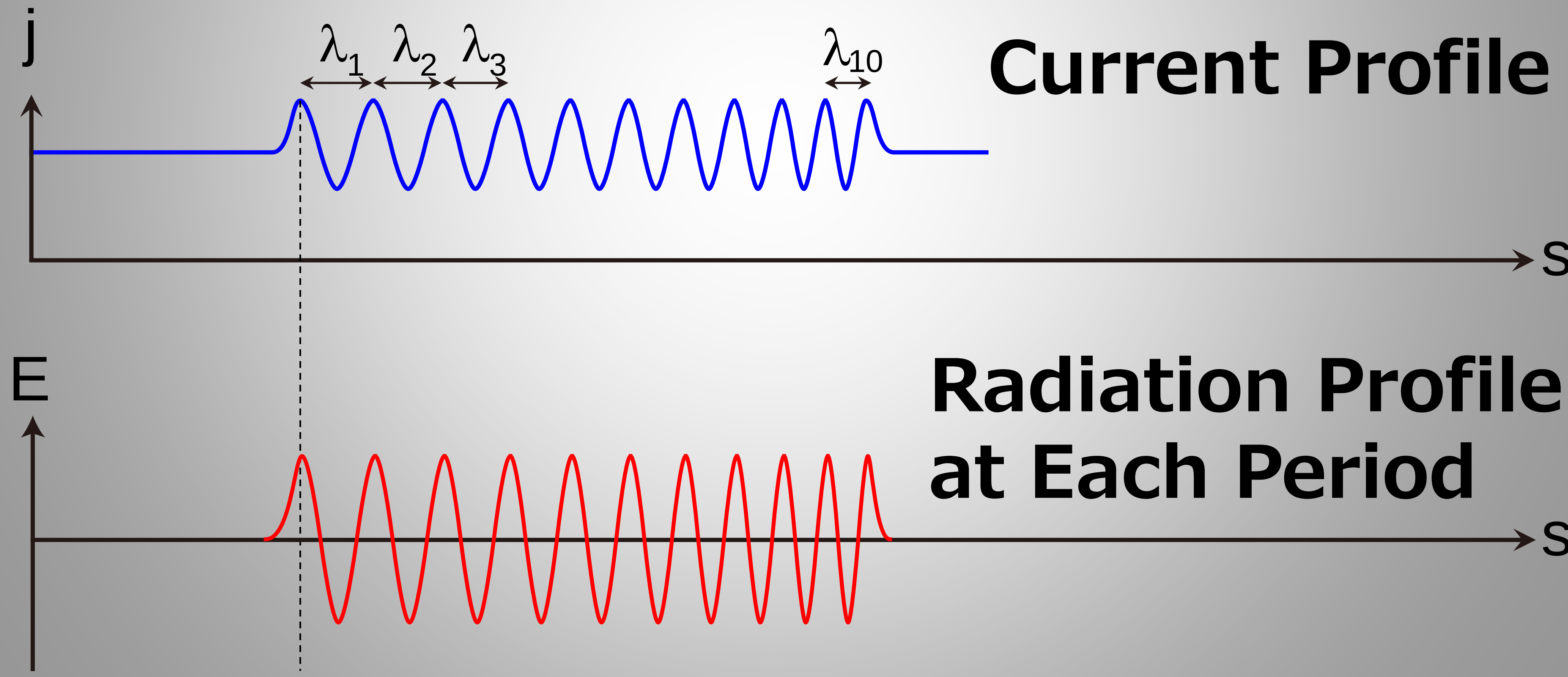
Principle of Operation

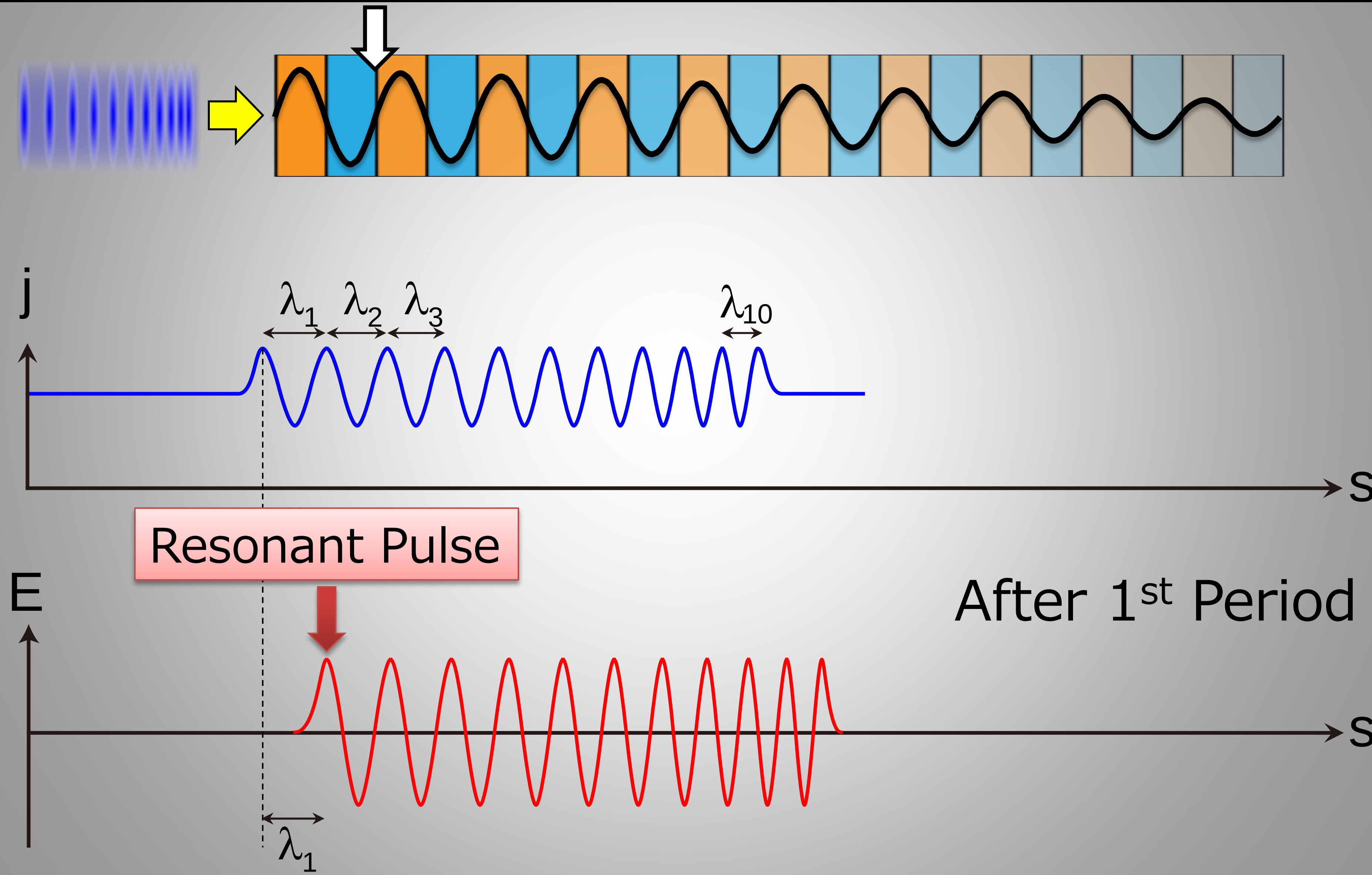




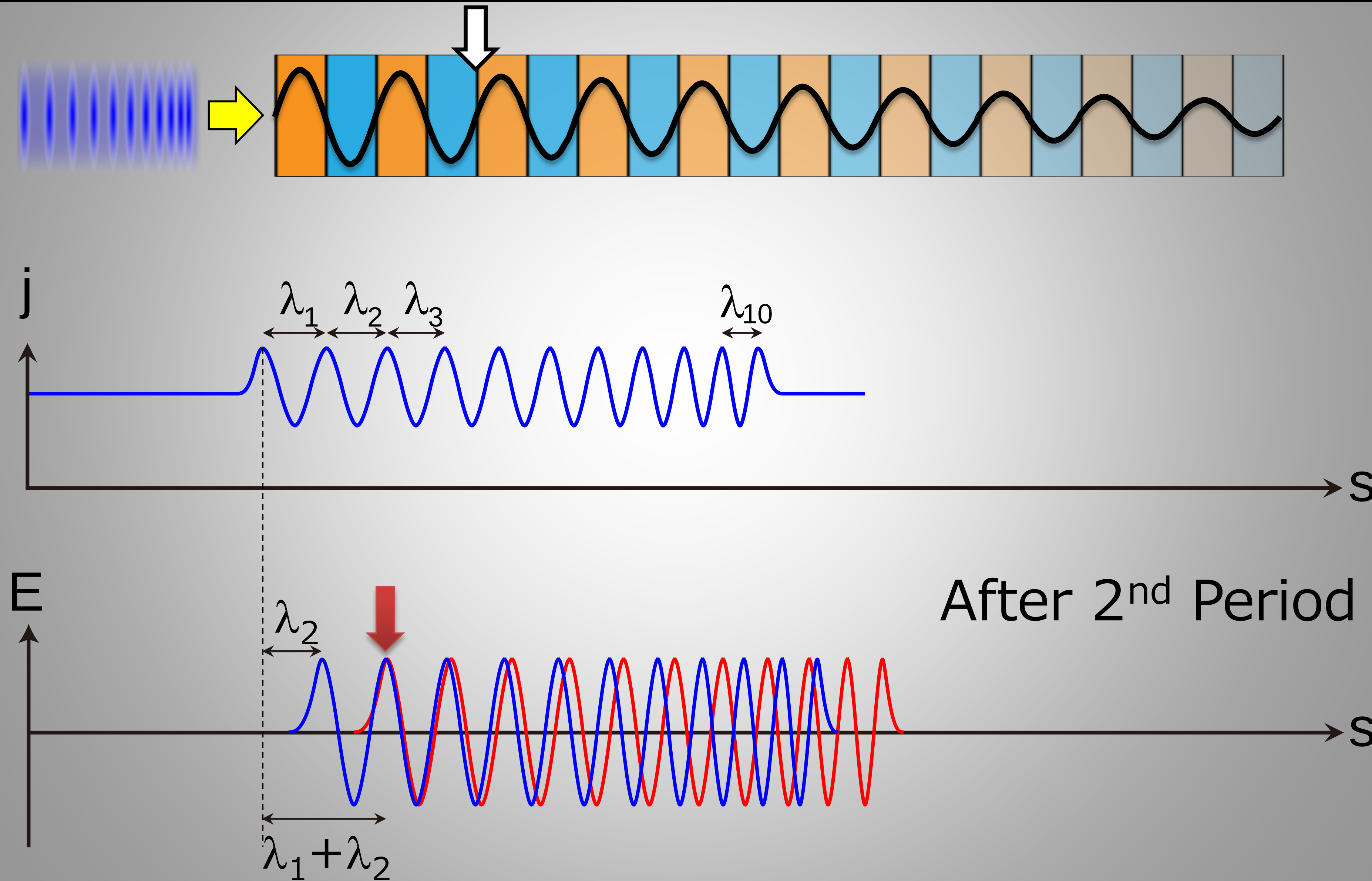
Current Profile

Radiation Profile at Each Period

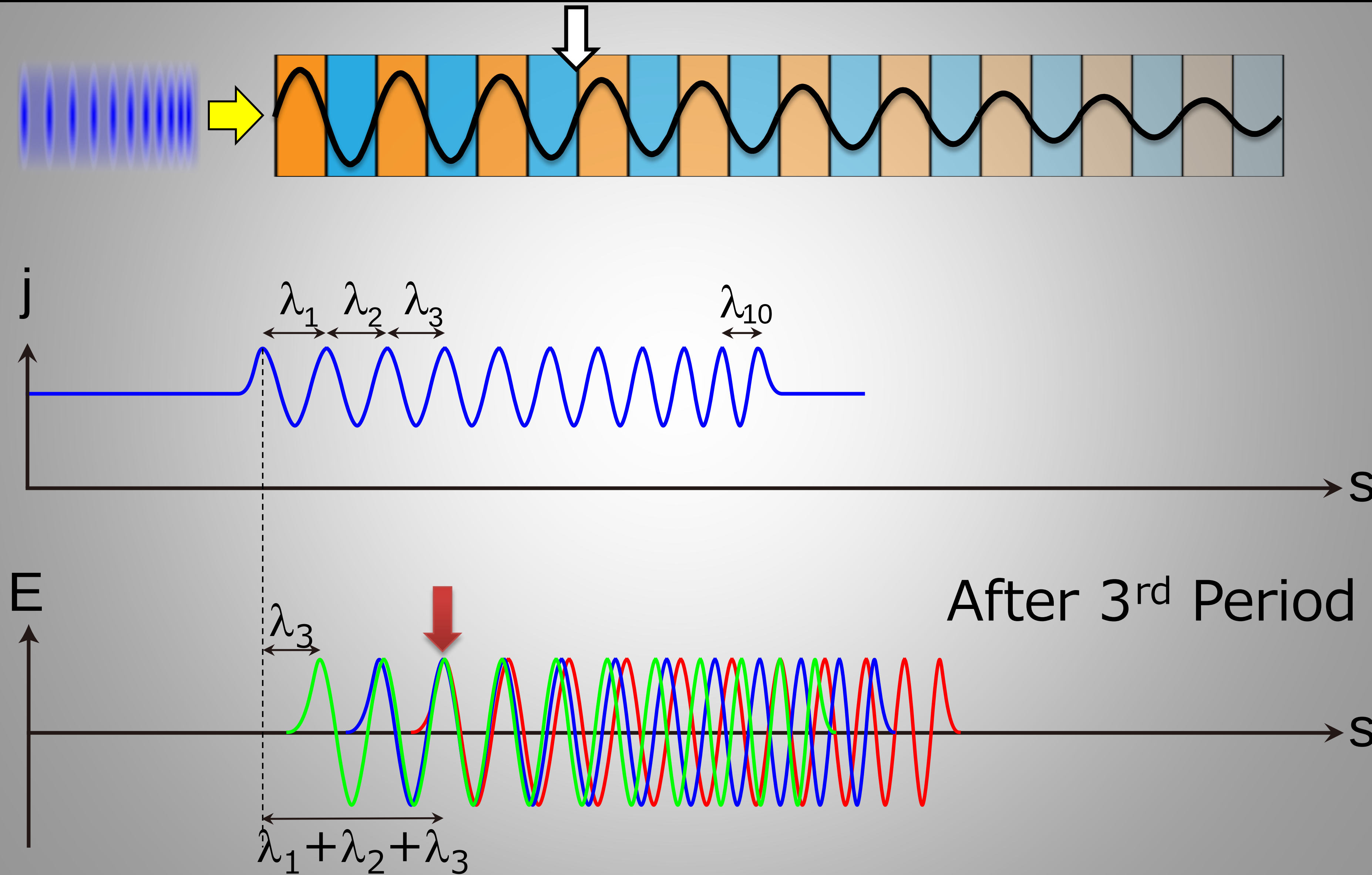
Principle of Operation



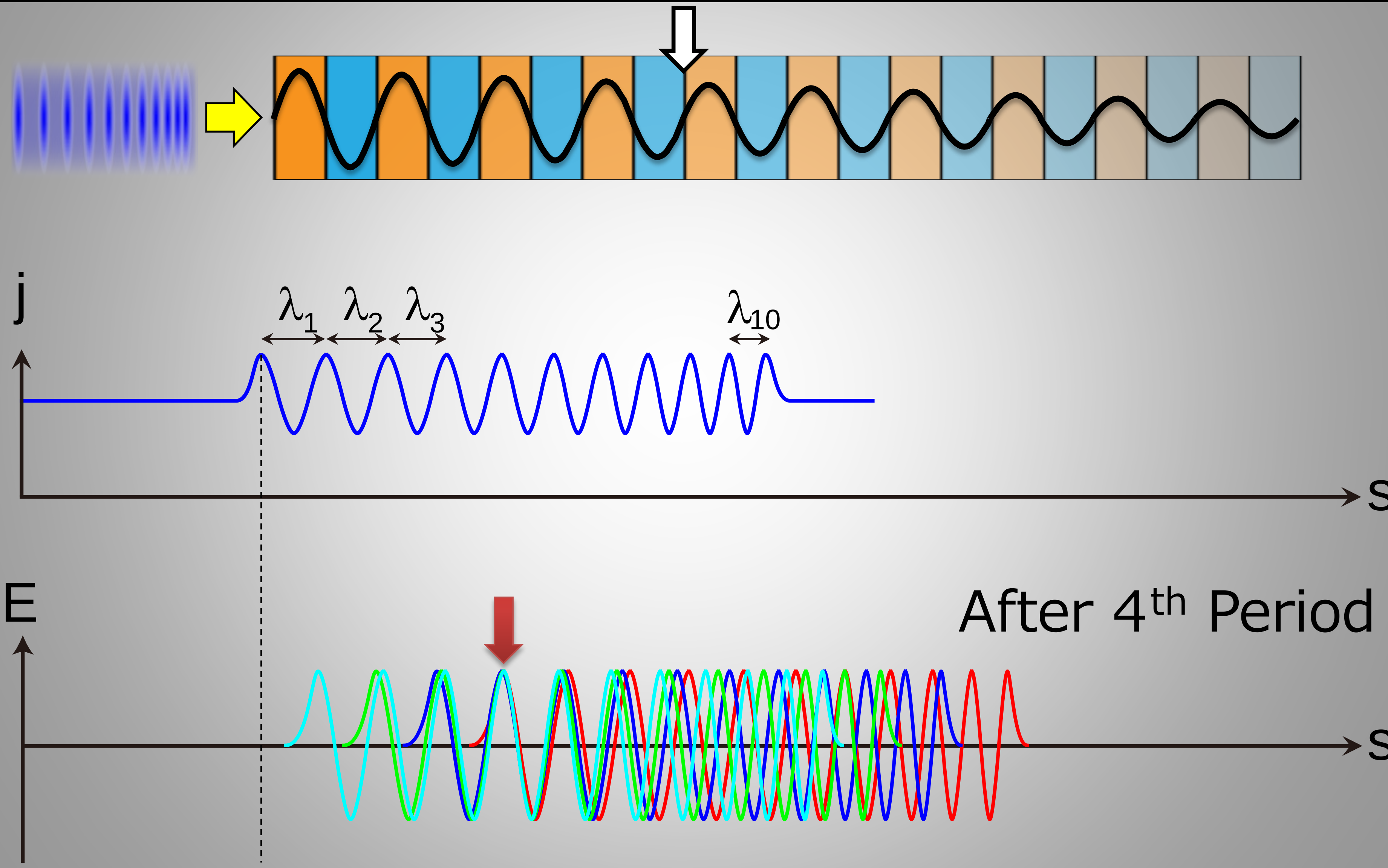
Principle of Operation



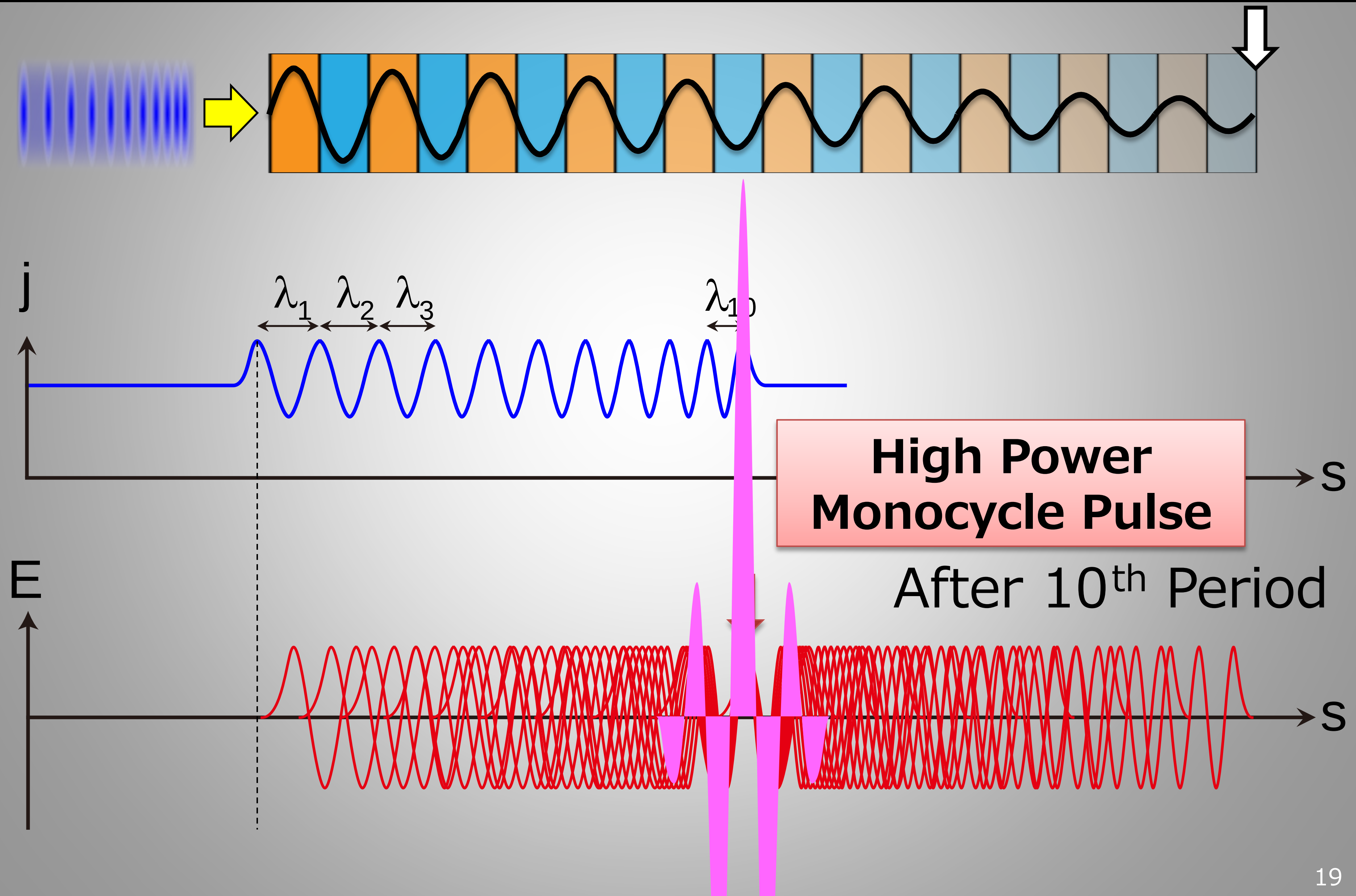
Principle of Operation



Principle of Operation



Principle of Operation



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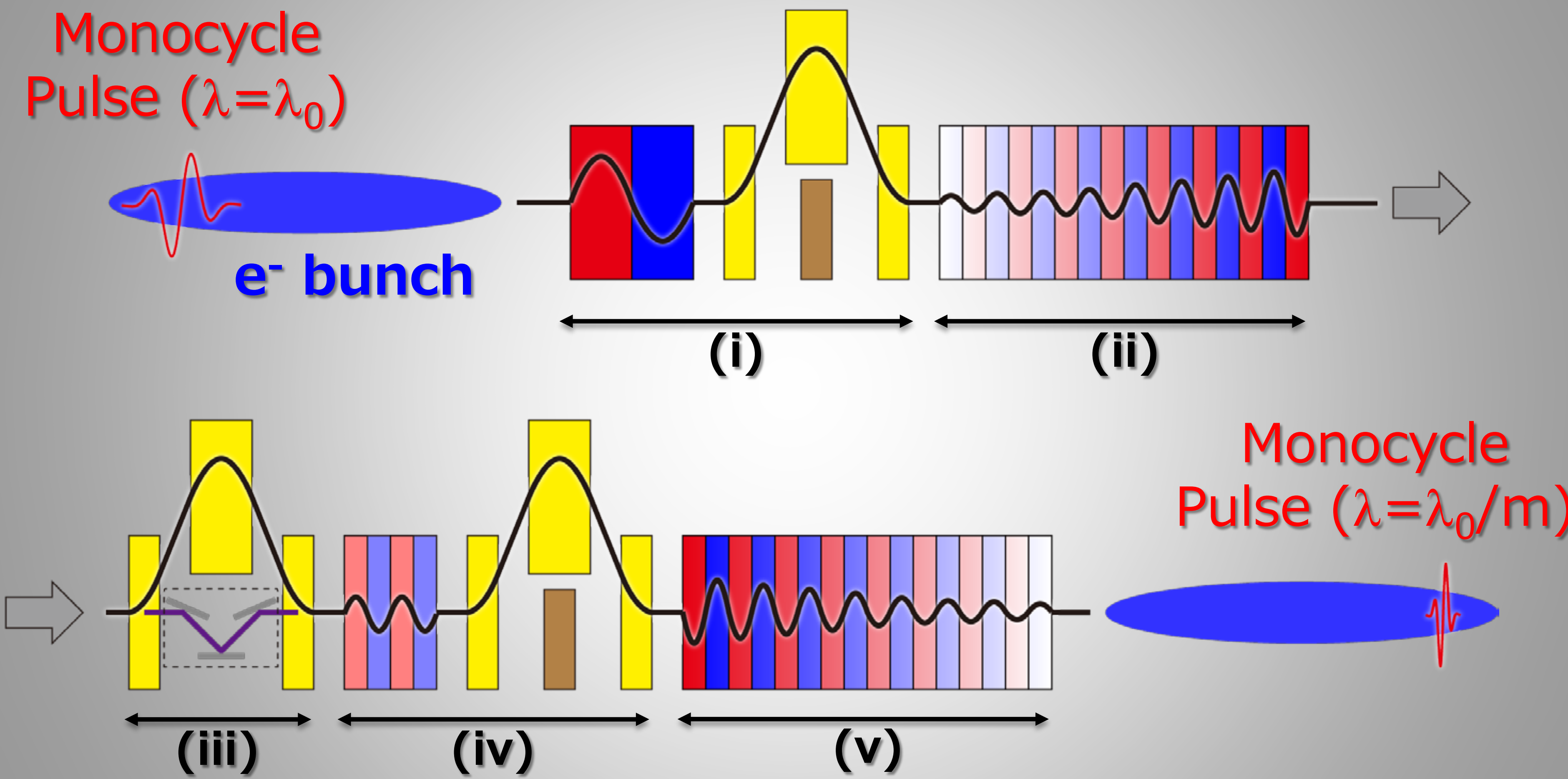
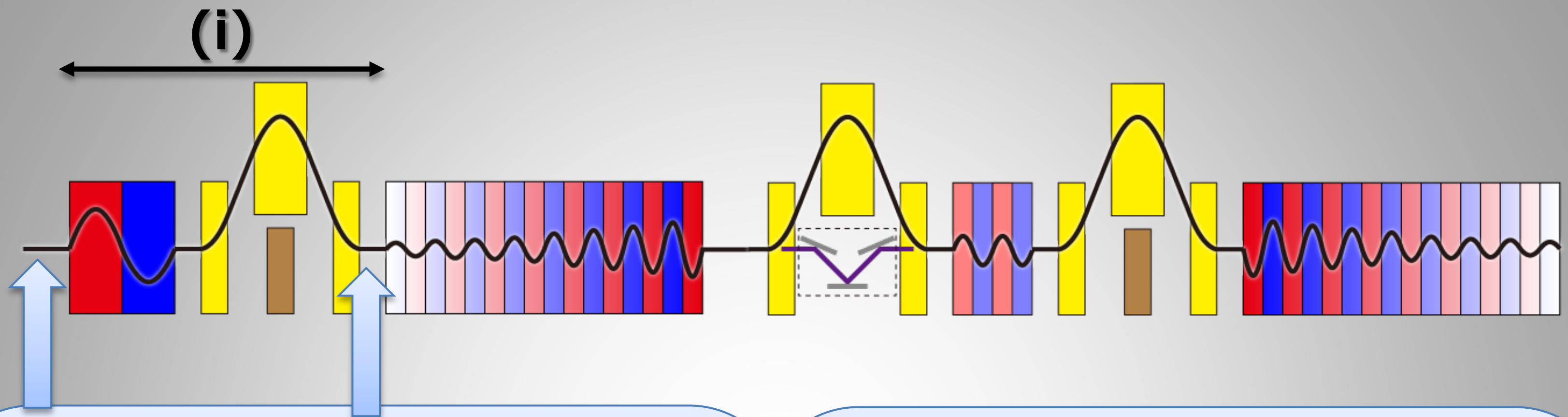
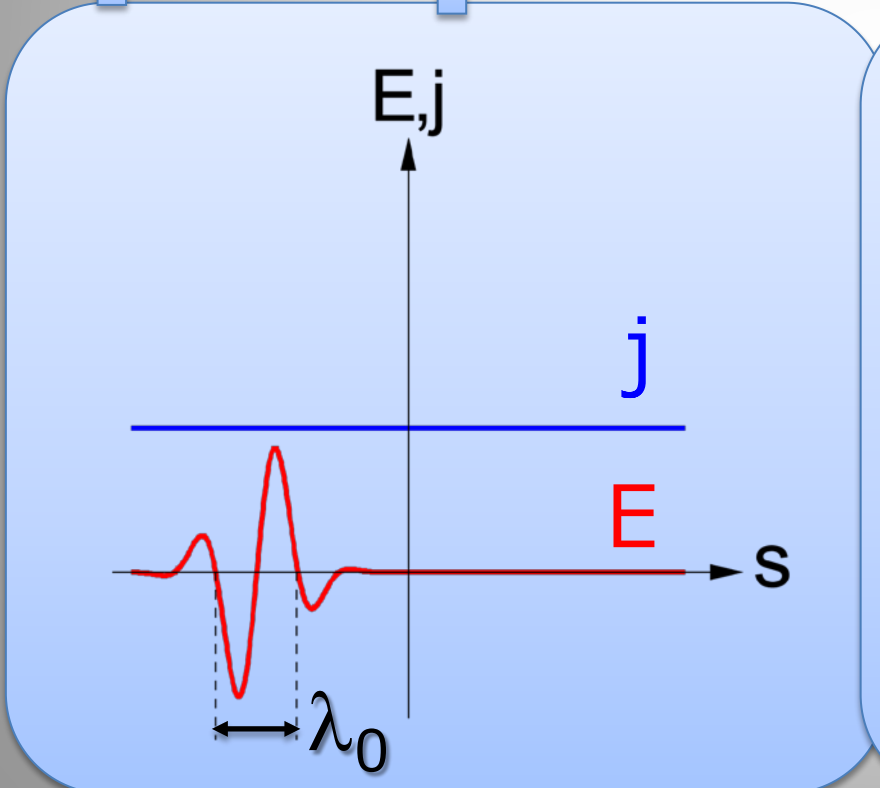
Accelerator Layout

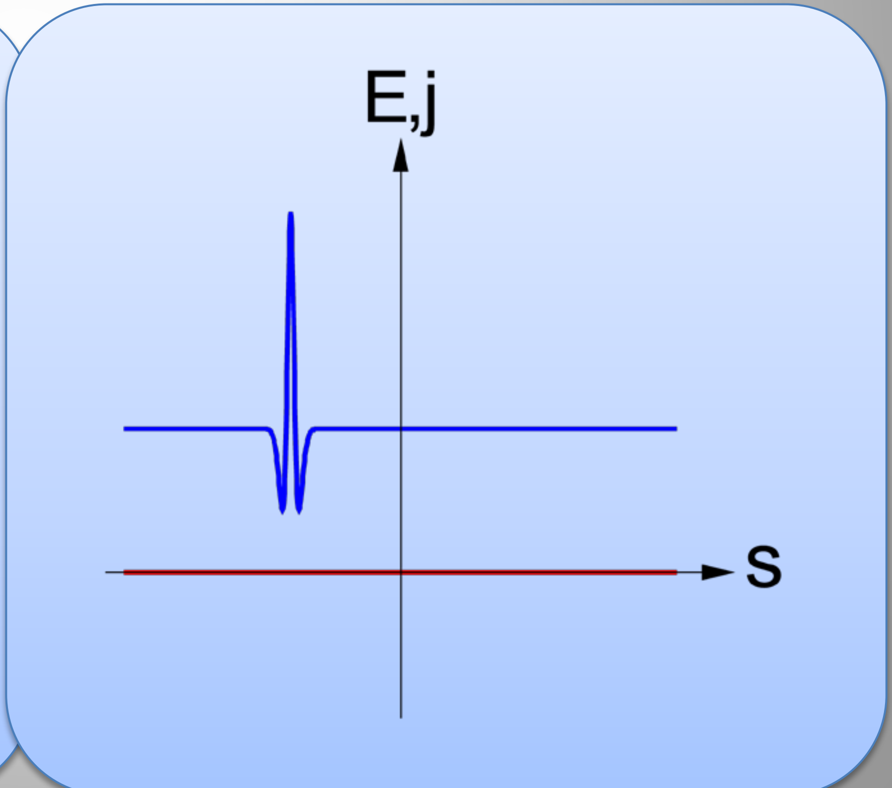


Upconvert the monocycle pulse with $\lambda=\lambda_0$
➡ Monocycle Harmonic Generation (MCHG)

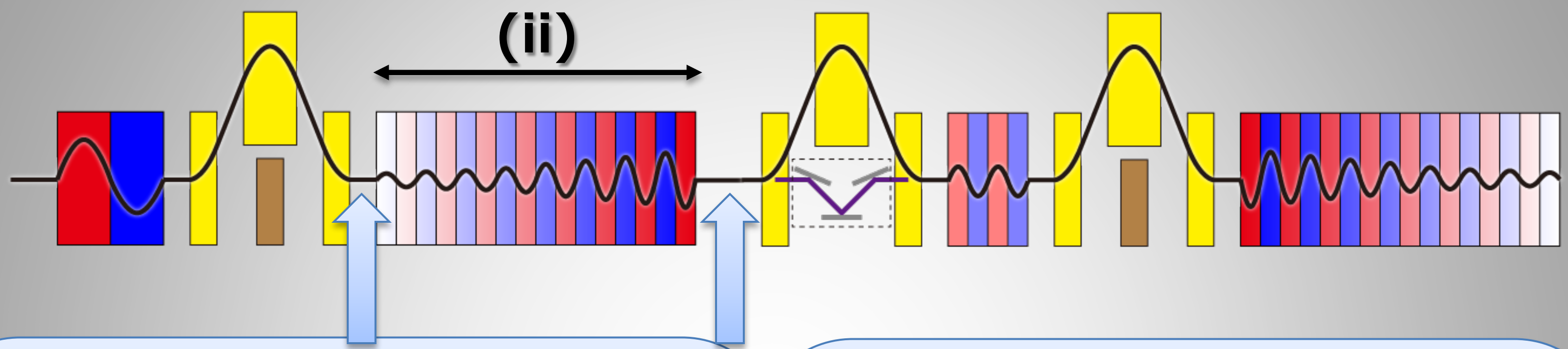
Sec.(i) : Generating a Single Microbunch

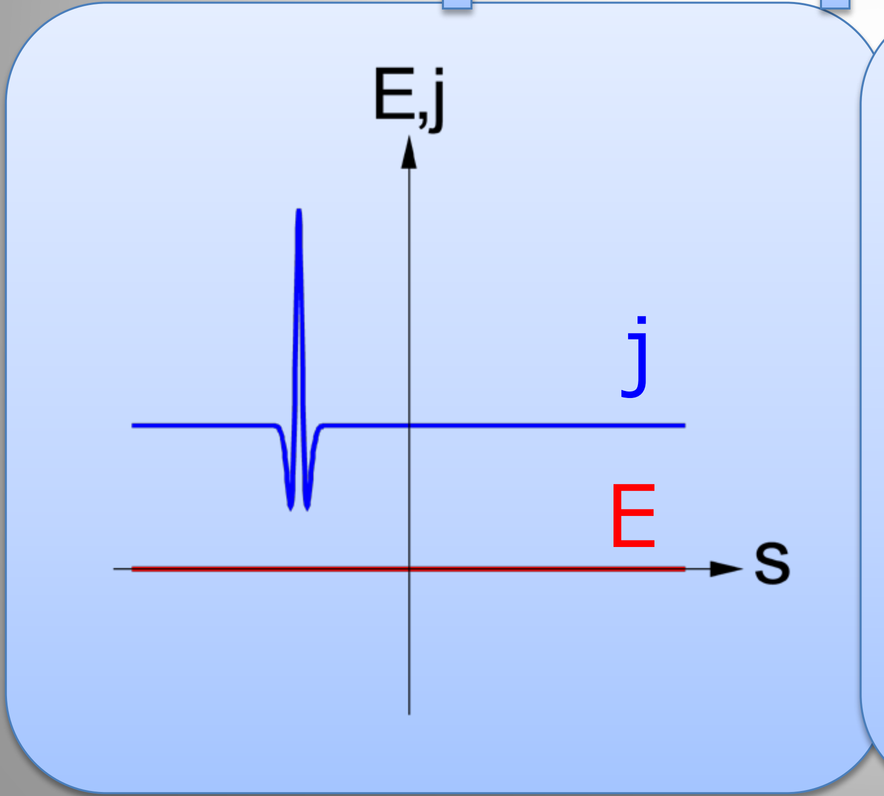


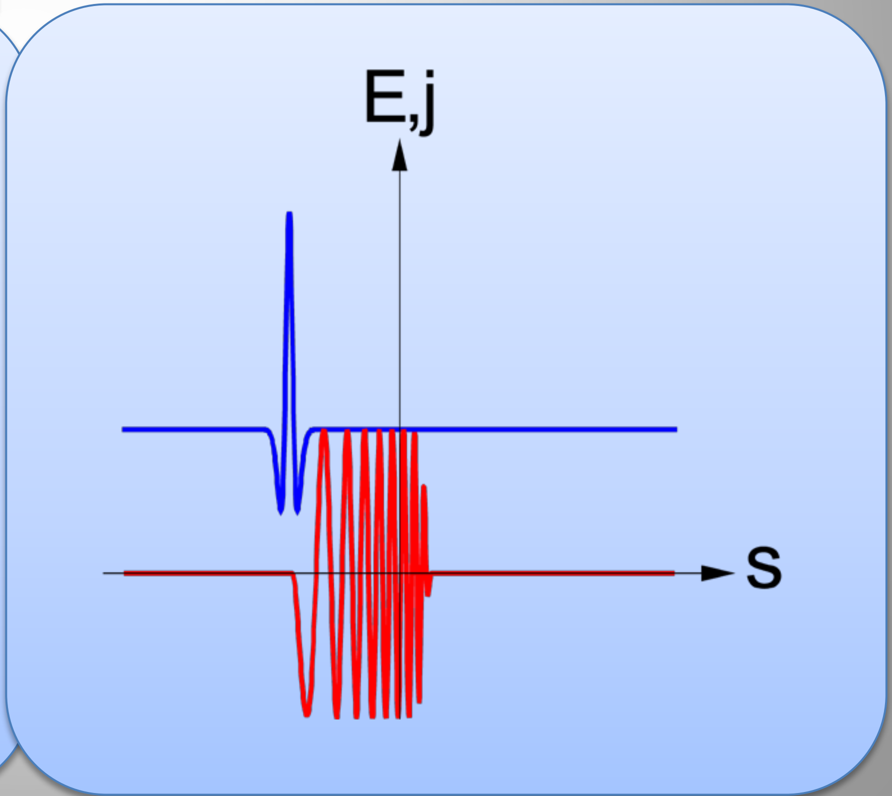




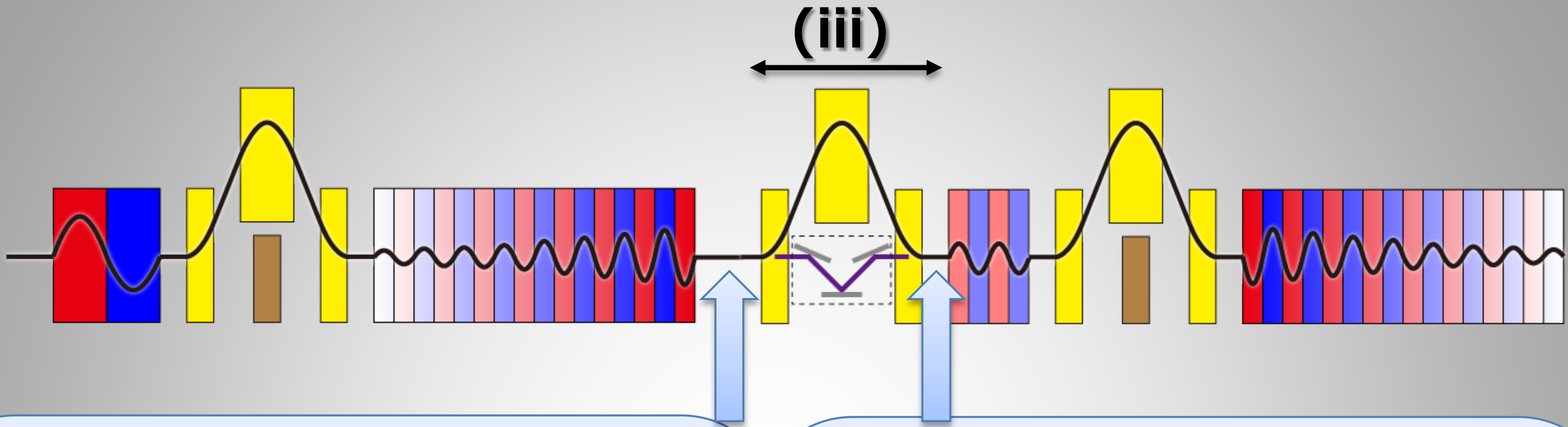
Sec.(ii) : Generating a Chirped Pulse

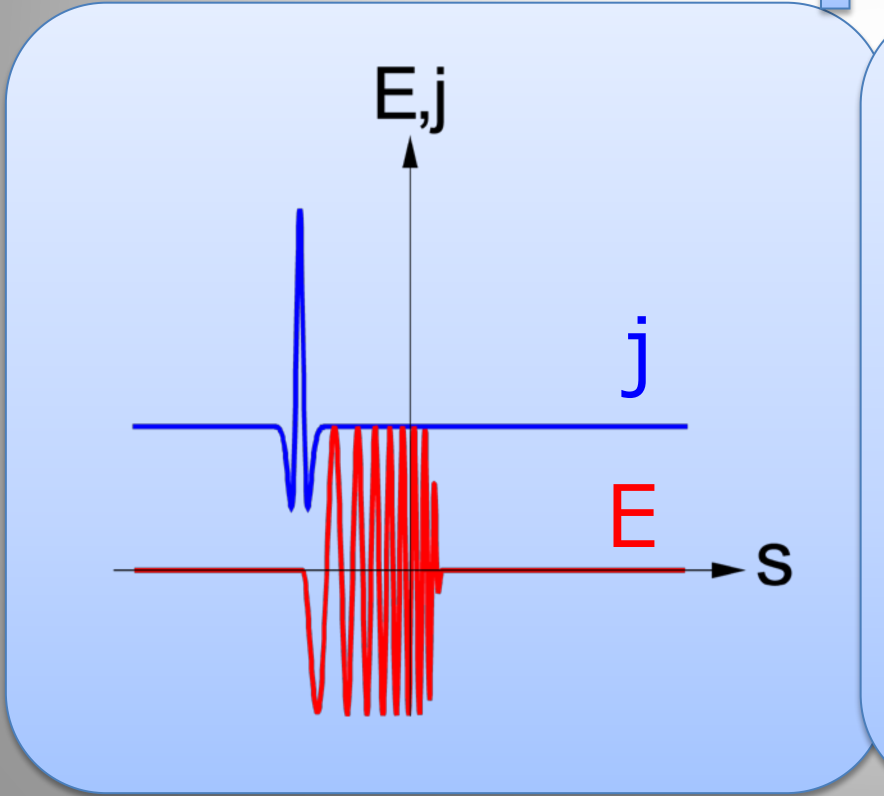


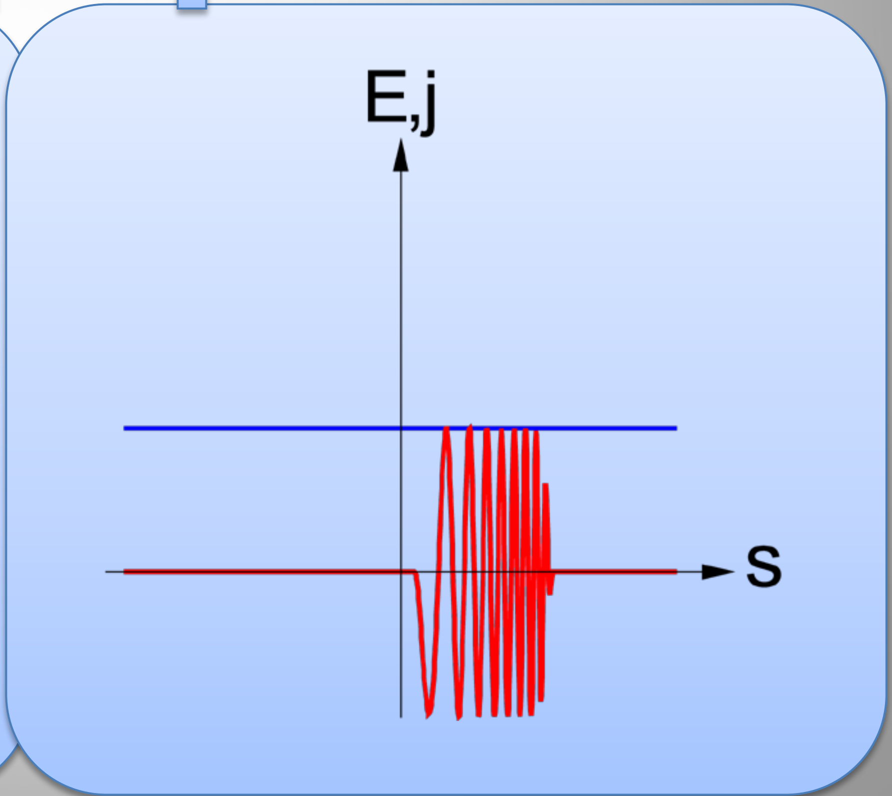




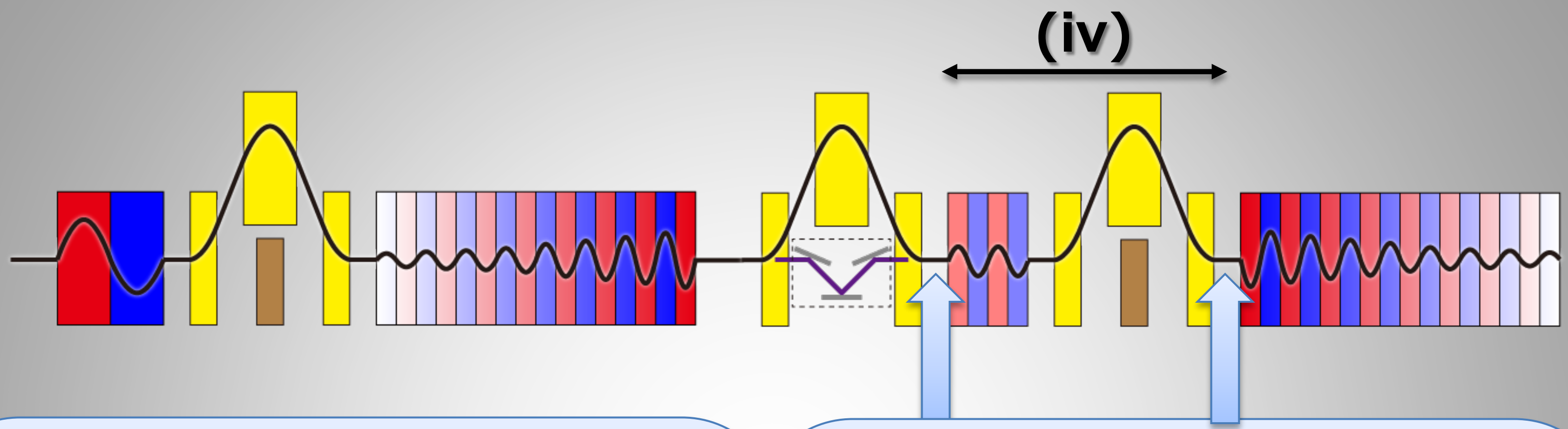
Sec.(iii) : Applying Fresh Bunch

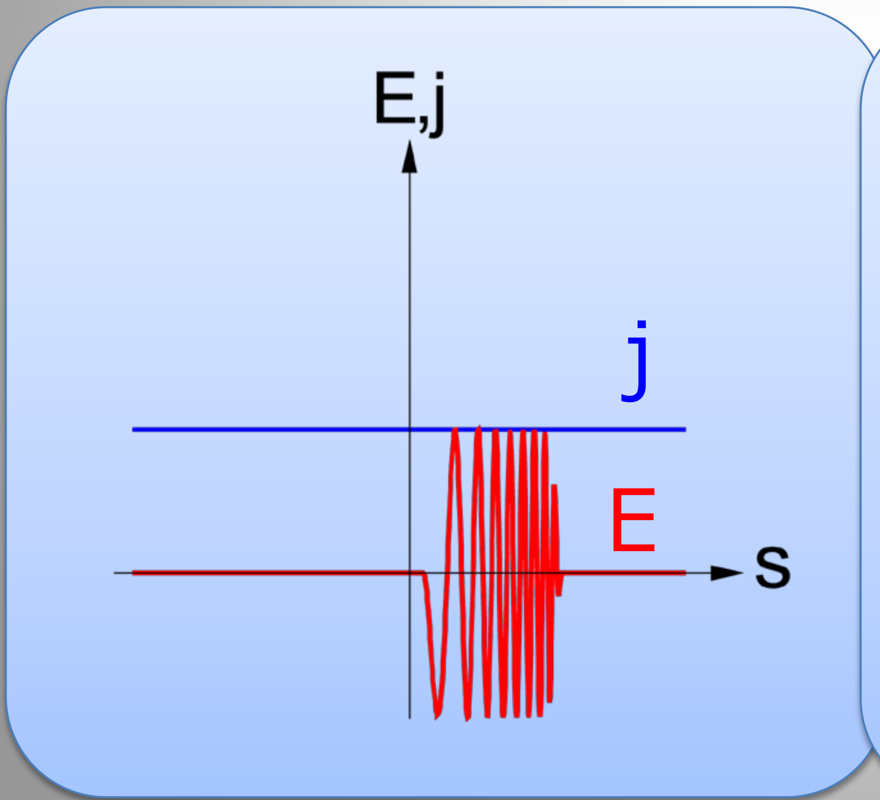


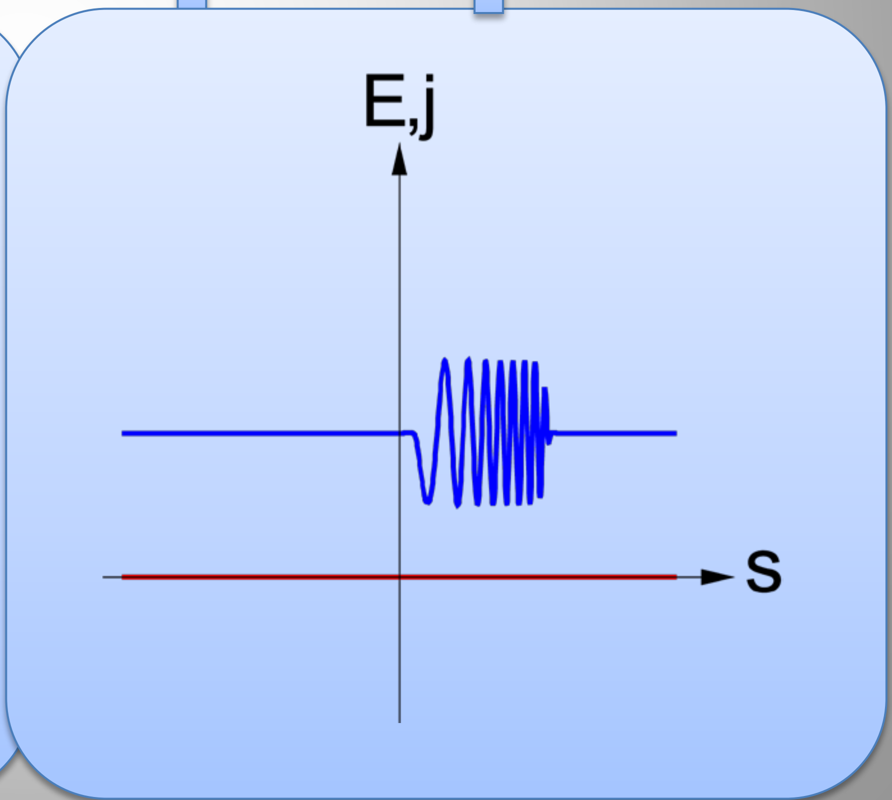




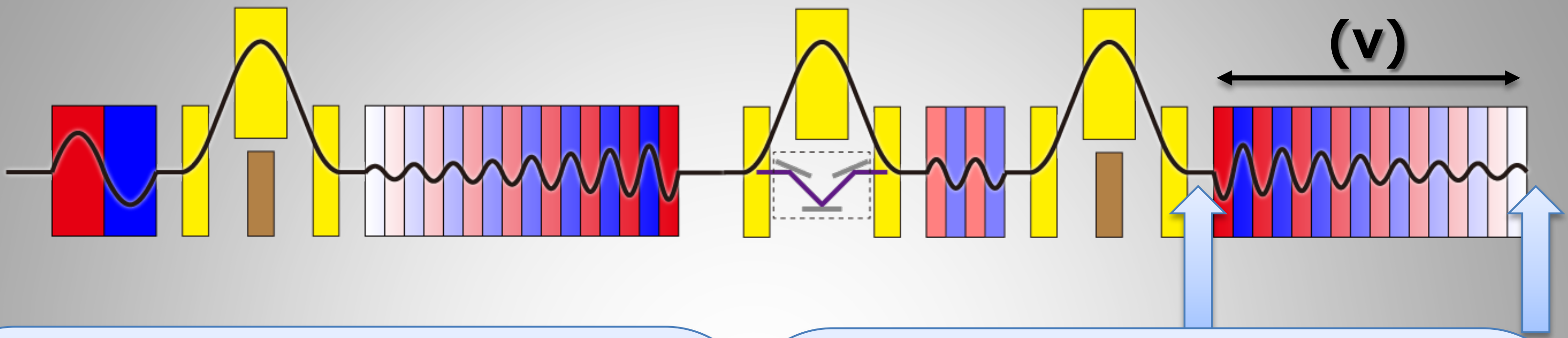
Sec.(iv) : Generating a Chirped Microbunch

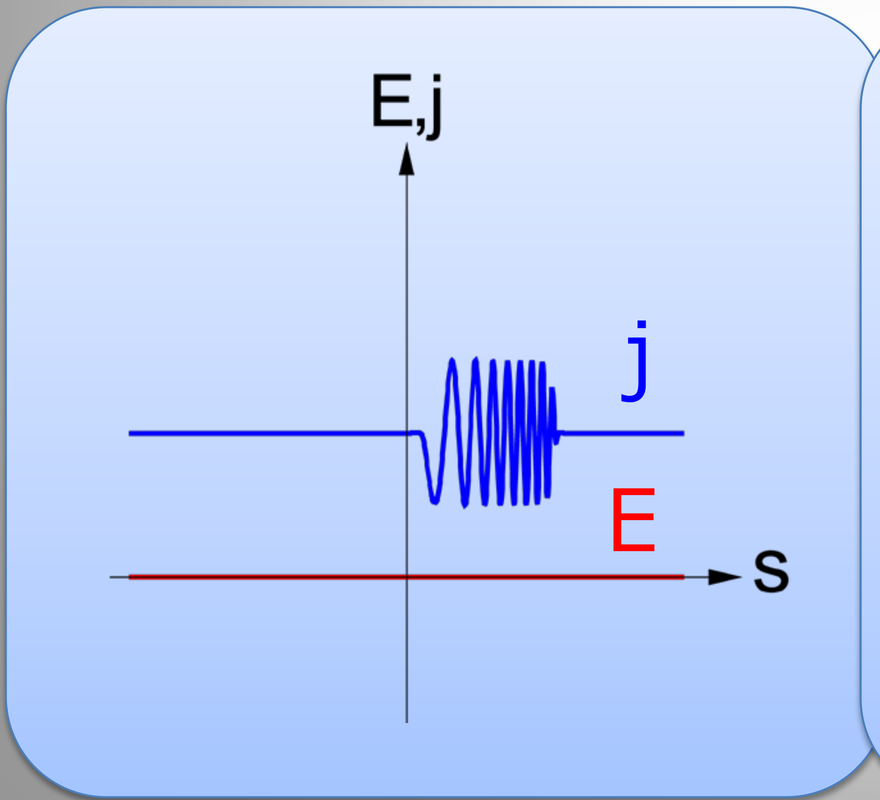


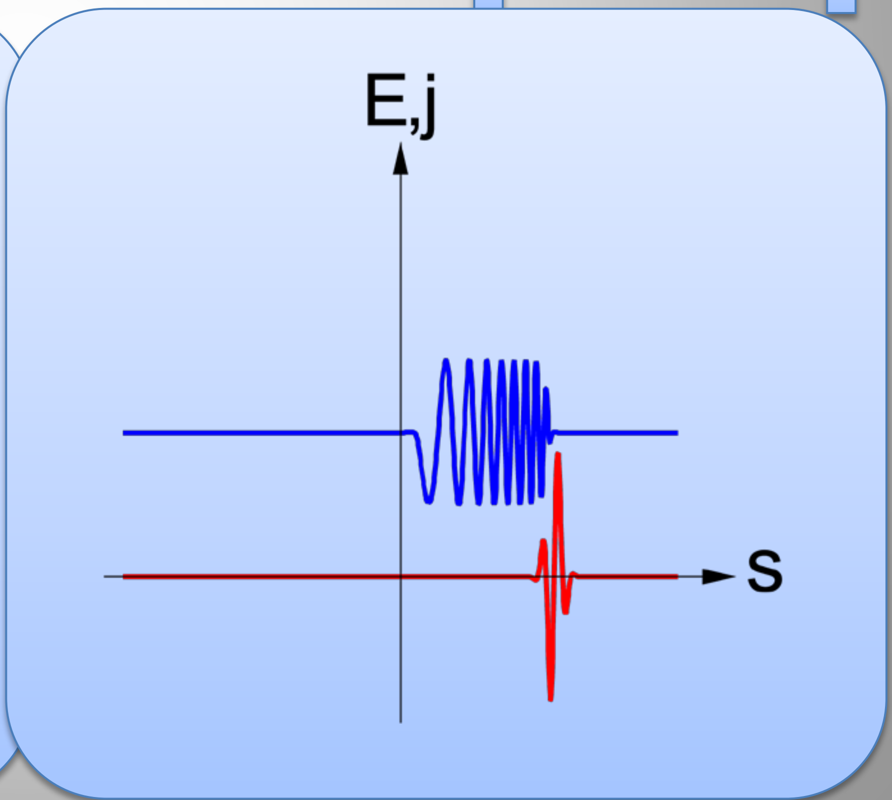




Sec.(v) : Generating a Monocycle Pulse







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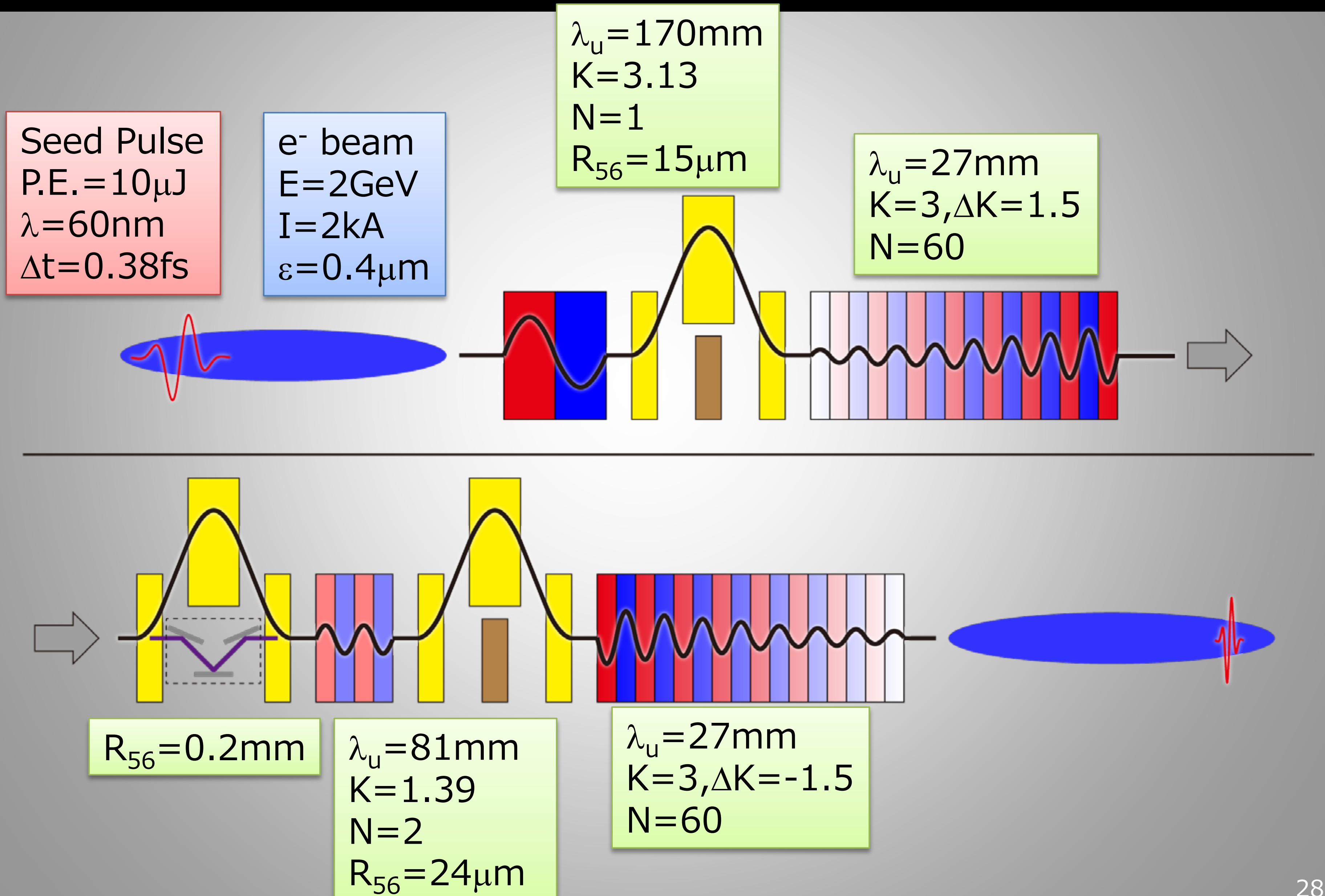
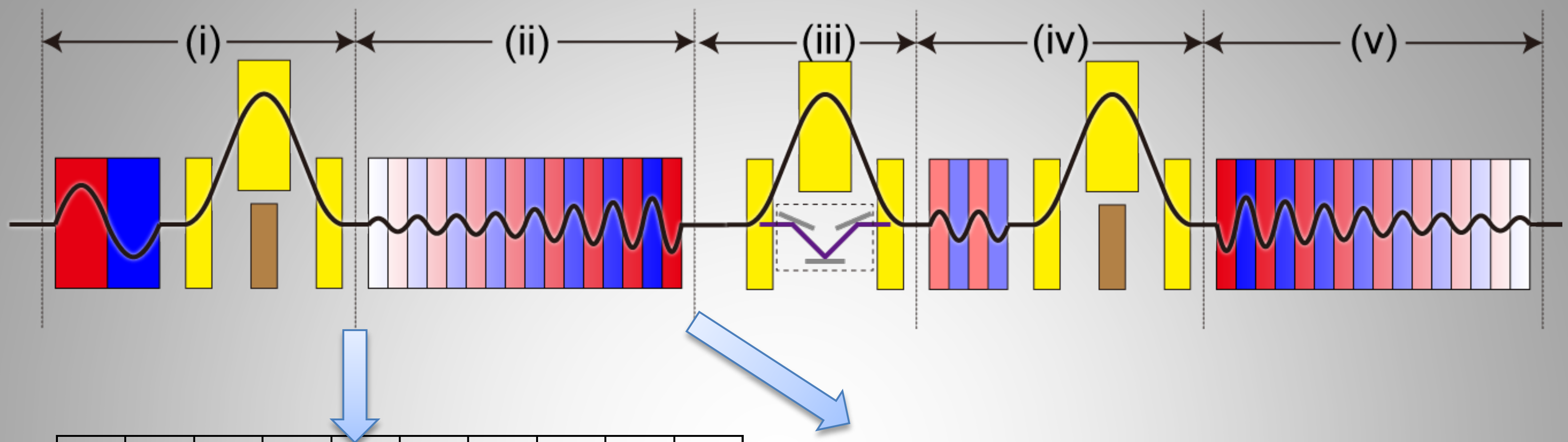
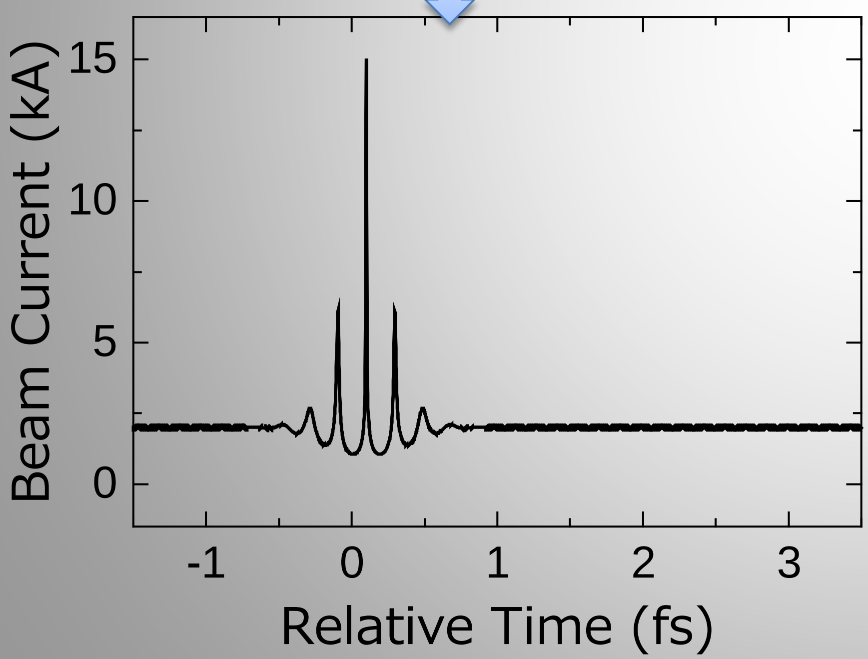
Assumed Parameters



Example (m=7, $\sigma_\gamma/\gamma=5\times10^{-5}$)





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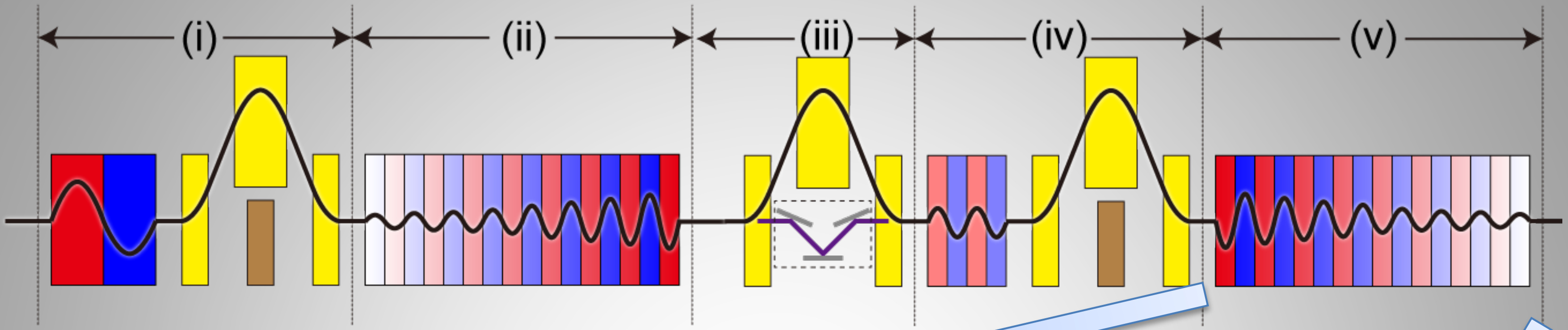
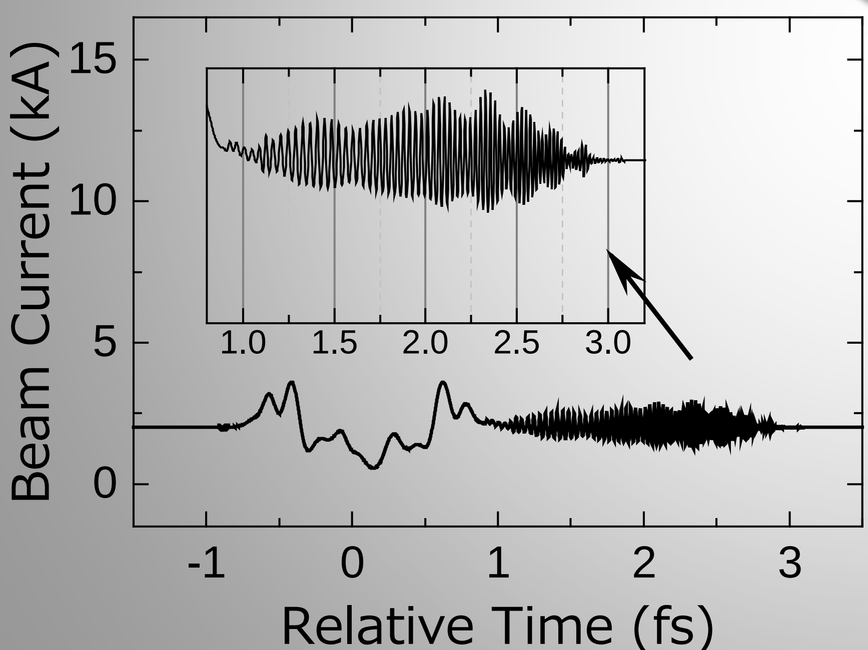
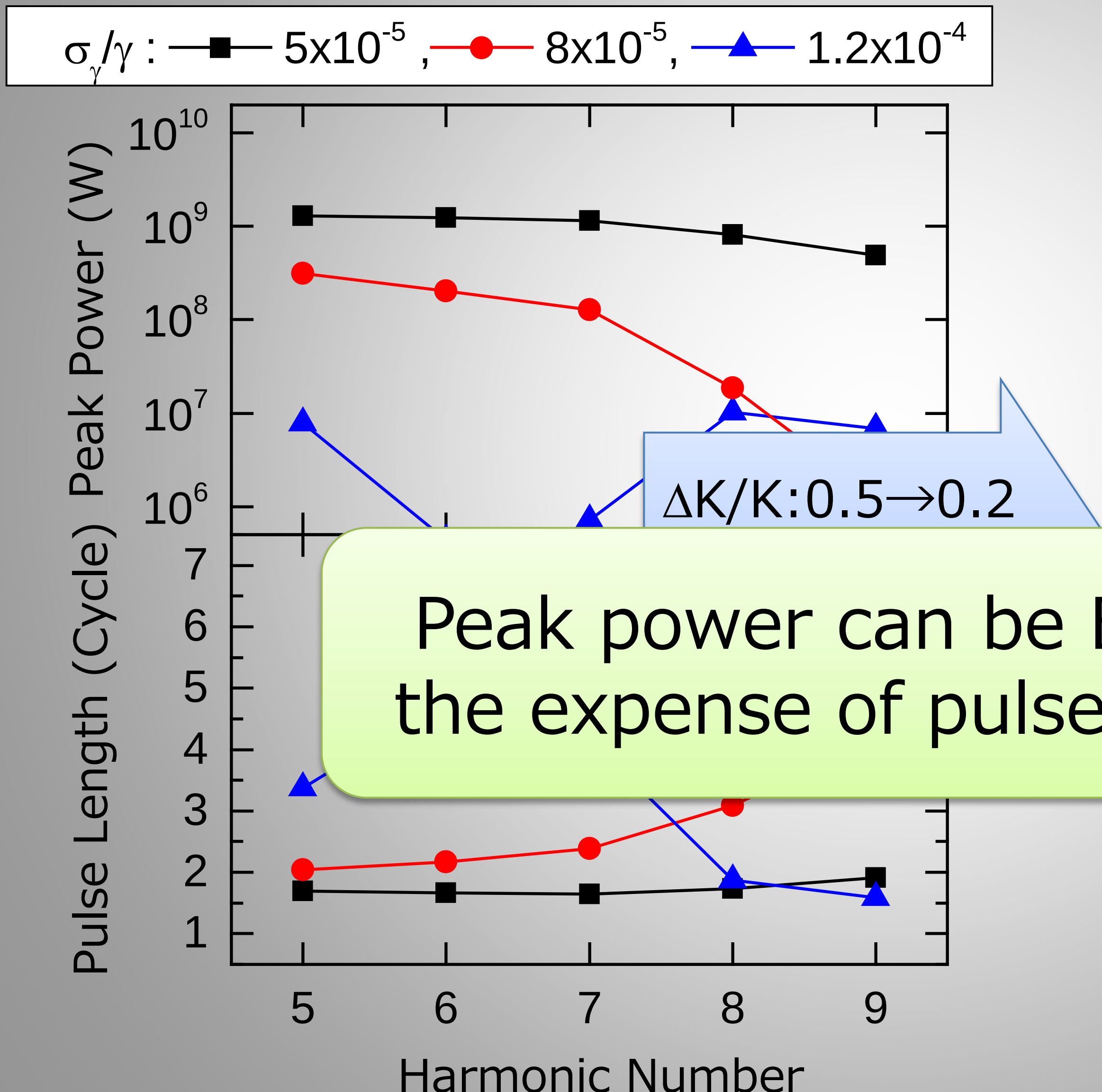




Relation between m and σ_γ/γ



Peak power can be Enhanced at the expense of pulse lengthening

Summary & Outlook

- The monocycle (or at least few-cycle) pulse realized with this scheme offers a lot of possibility for probing ultrafast dynamics, which are too fast to be investigated by the conventional schemes.
- Note that this scheme can be repeatedly used to further shorten the wavelength, and thus the pulse length of XFEL pulse.

Thank you for your attention!