Laser Manipulation of the e- Beam

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- ESASE & synchronization
- few-cycle modulation & attosecond x-rays

Science Drivers for **Hard X-Ray Upgrades** to LCLS

SLAC NATIONAL ACCELERATOR LABORATORY

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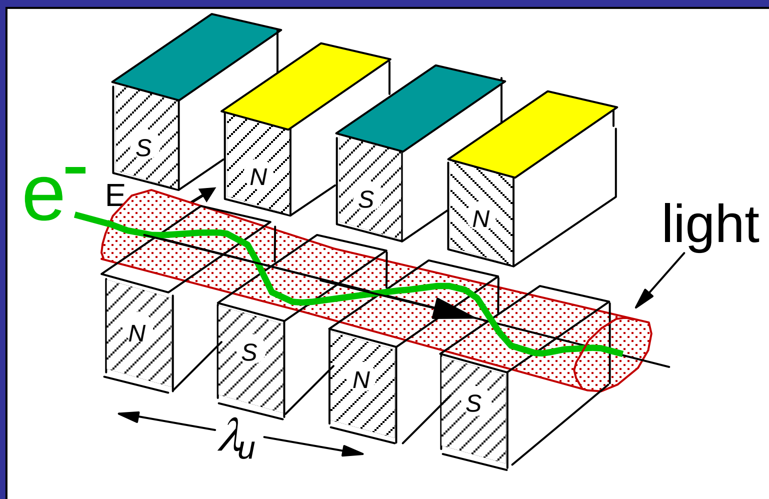
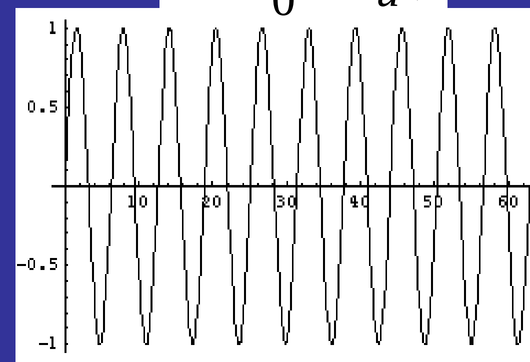
Light interaction with relativistic electron*)

Energy modulation of electrons in the undulator by the laser light



Electron trajectory through undulator

$$B = B_0 \sin(k_u z)$$



Magnetic field in the undulator

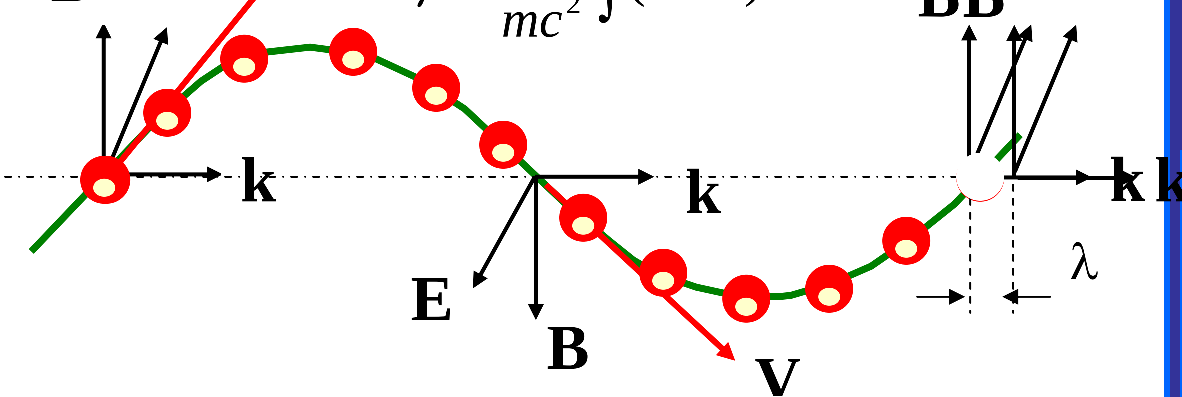
FEL resonance condition

Laser wavelength

$$\lambda = \lambda_u / 2\gamma_z^2$$

Undulator period

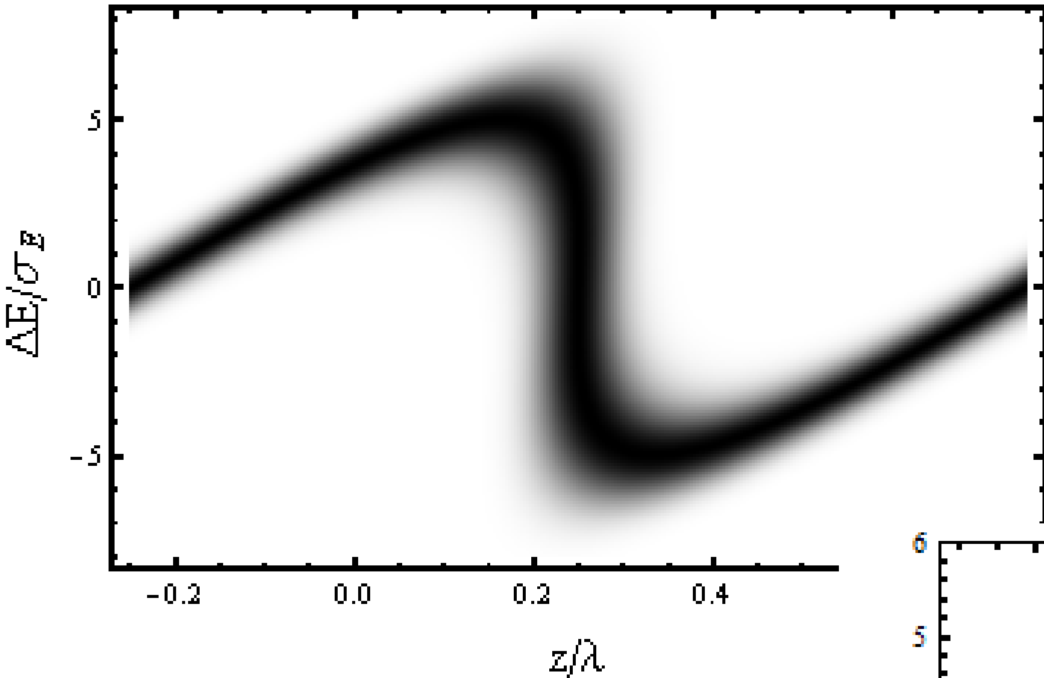
$$\delta\gamma = \frac{e}{mc^2}\int (\vec{E}\cdot\vec{V})\,dt \neq 0$$

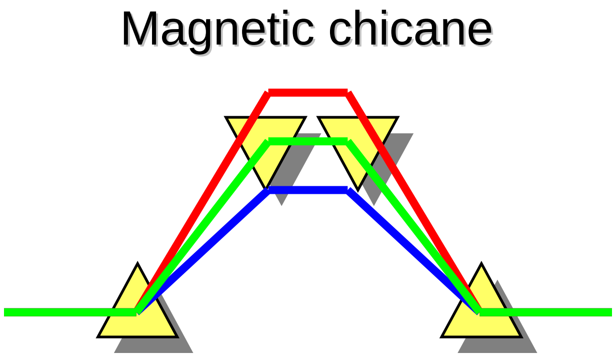


While propagating one undulator period, the electron is delayed with respect to the light on one optical wavelength

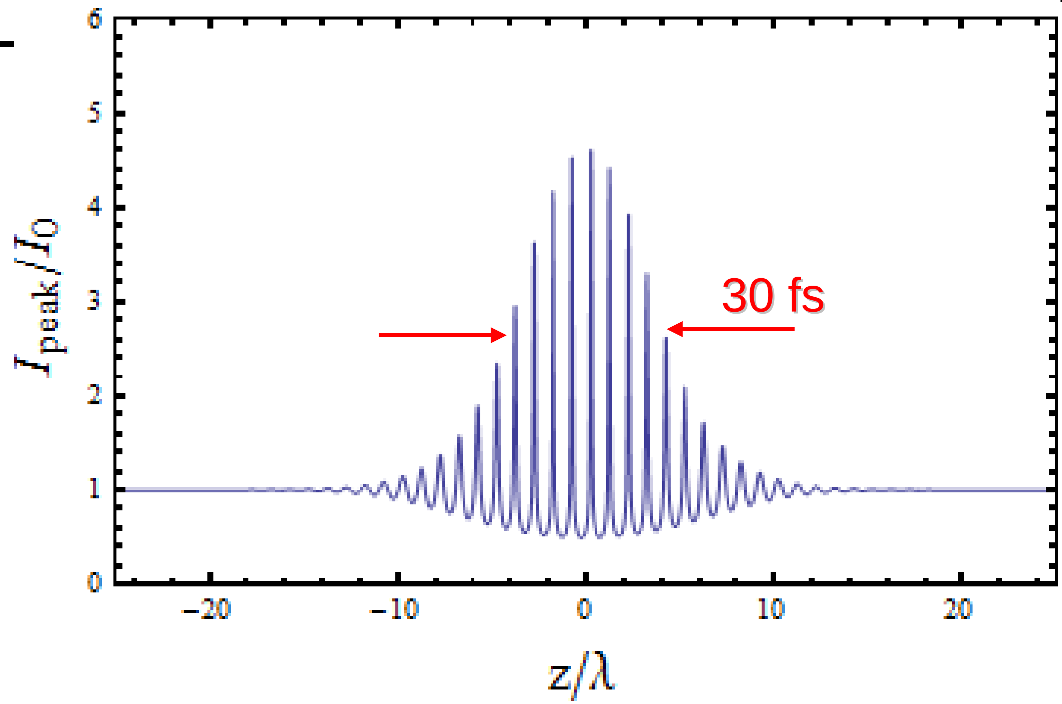
*) Motz 1953; Phillips 1960, Madey 1971

Light interaction with relativistic electron (2)

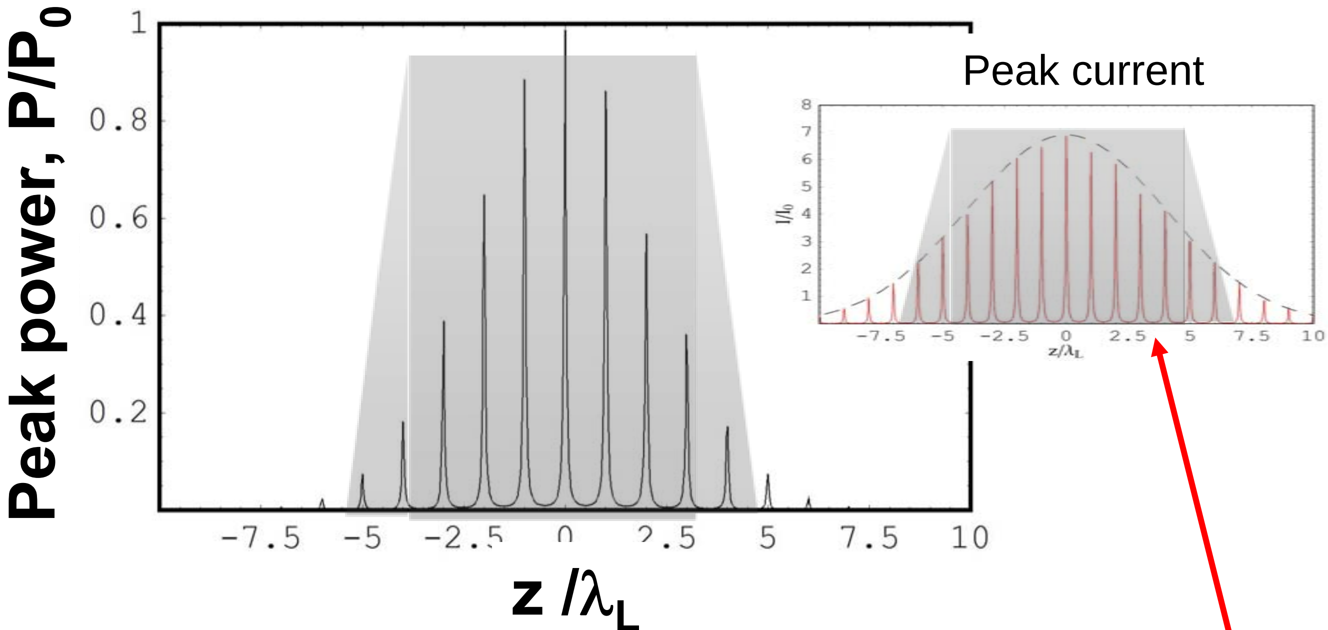




The area of the electron bunch with enhanced peak current reaches saturation earlier and produces the dominant radiation



- The FEL output is dominated by the radiation coming from the part of the electron bunch affected by the laser

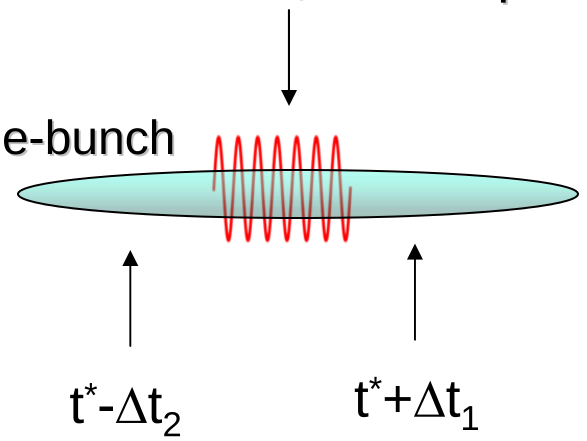


A fragment of the x-ray pulse

More uniform x-ray output one can obtain using modulating laser pulse with a flat top

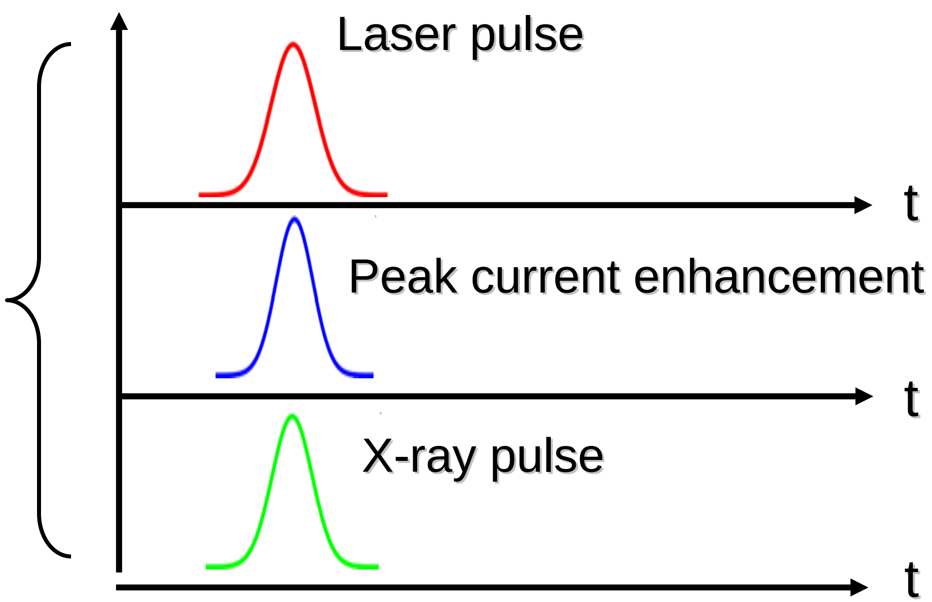
Absolute synchronization of the x-ray pulse to the pump laser source

Laser pulse arrival time, t^* → pump laser pulse



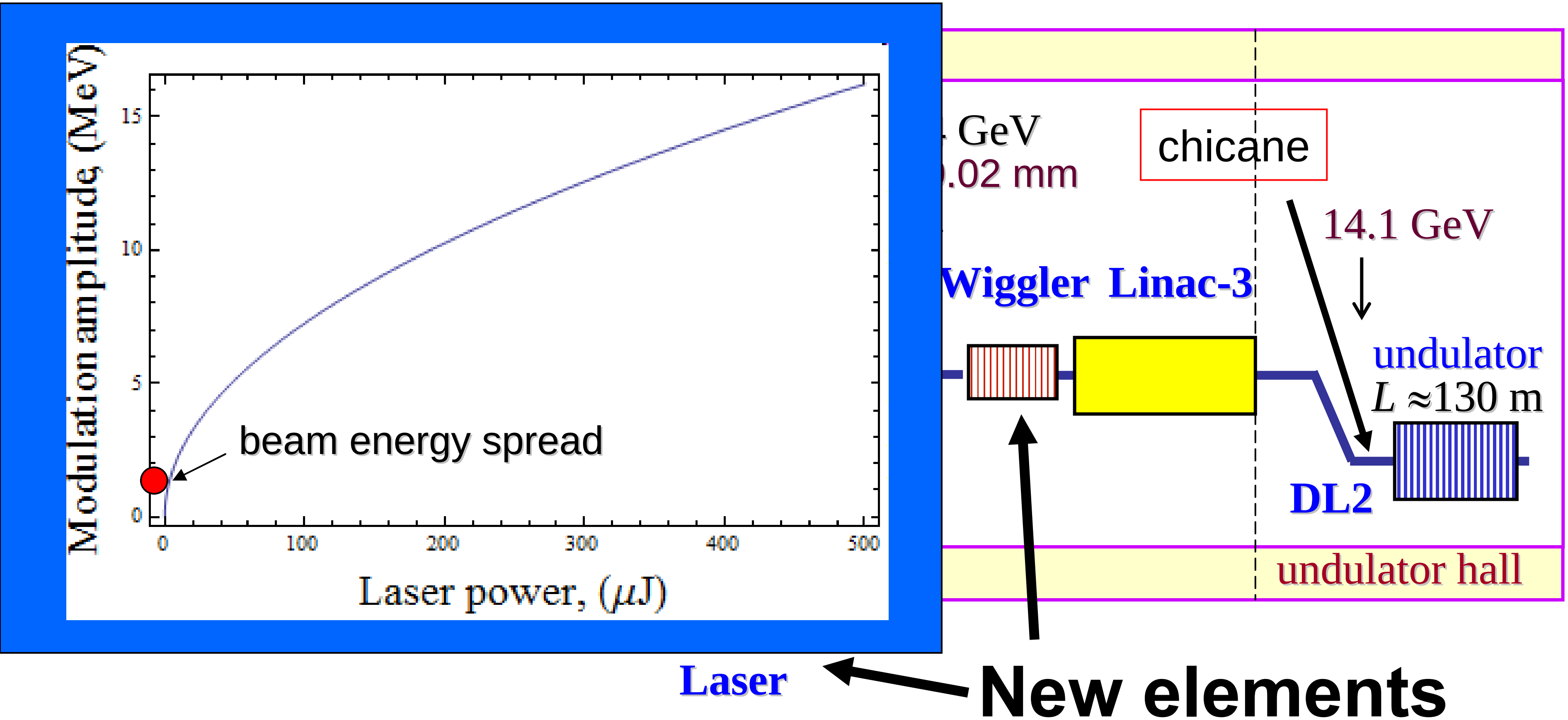
Electron bunch arrival time jitter relative to laser pulse $\sigma_{\Delta t} \sim 50$ fs

But,



will always be aligned in time

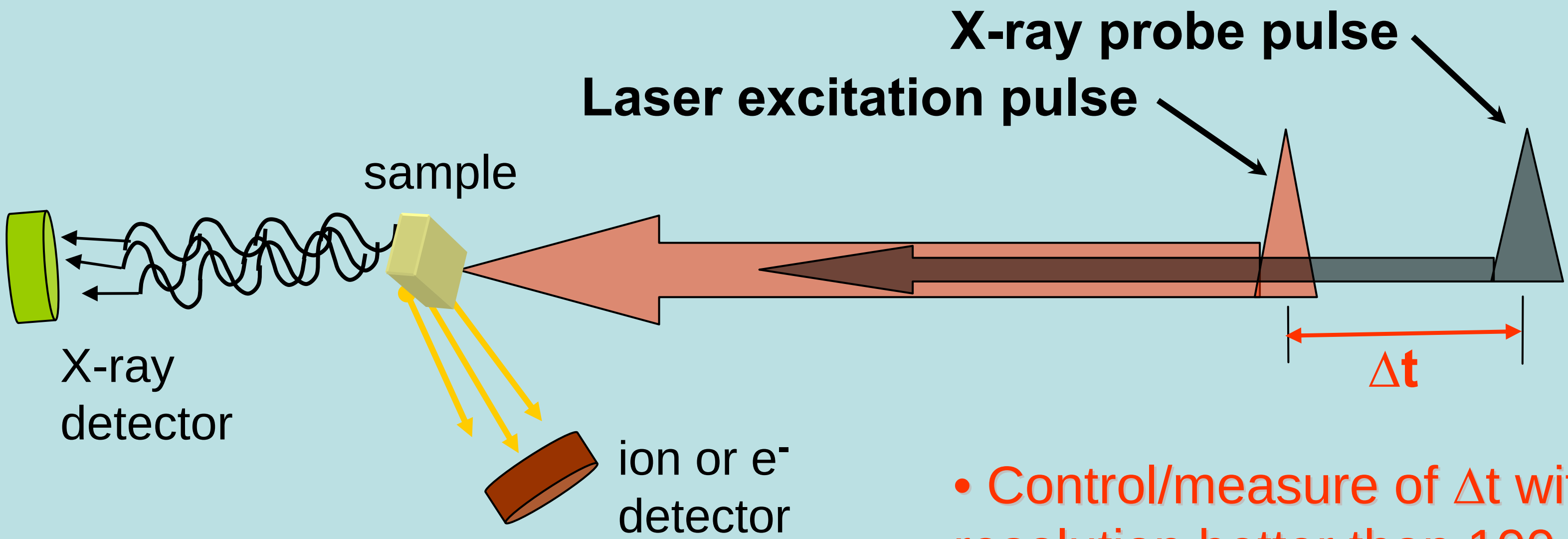
A schematic of the LCLS with ESASE



Laser:
Wavelength: 800 nm
Pulse width, FWHM intensity: 20 fs
Rayleigh length : 35 cm (w>>σ_x)
Pulse energy: up to 0.5 mJ

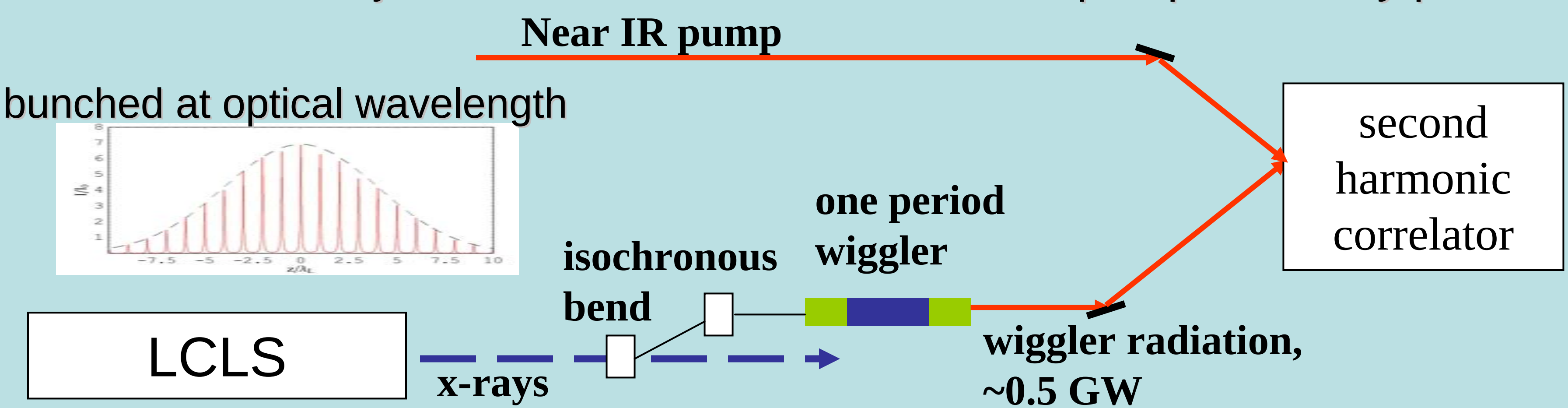
Wiggler:
Period: 25 cm
Number of periods: 9
Wiggler parameter, K=31.5
Peak magnetic field: 1.35 T

Pump-probe experiment concept



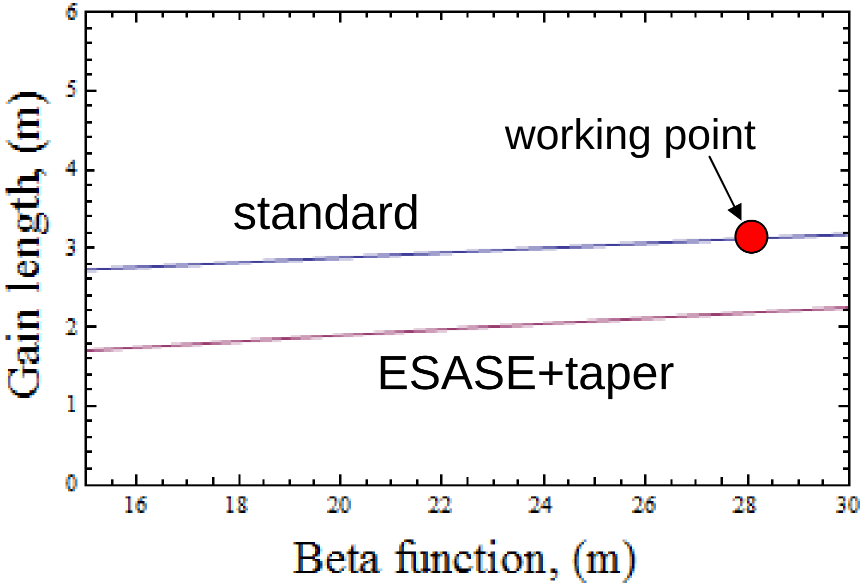
- Control/measure of Δt with a resolution better than 100 attoseconds is desirable

After “fact” time jitter measurement between laser pump and x-ray probe

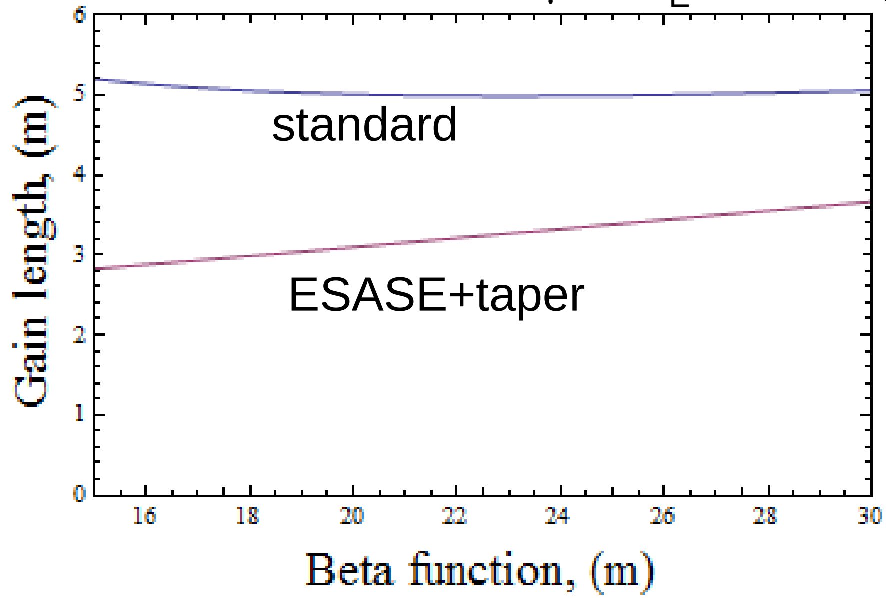


Gain length*)

λ=1.5 Å, emit=0.6 μm, σ_E=0.01%



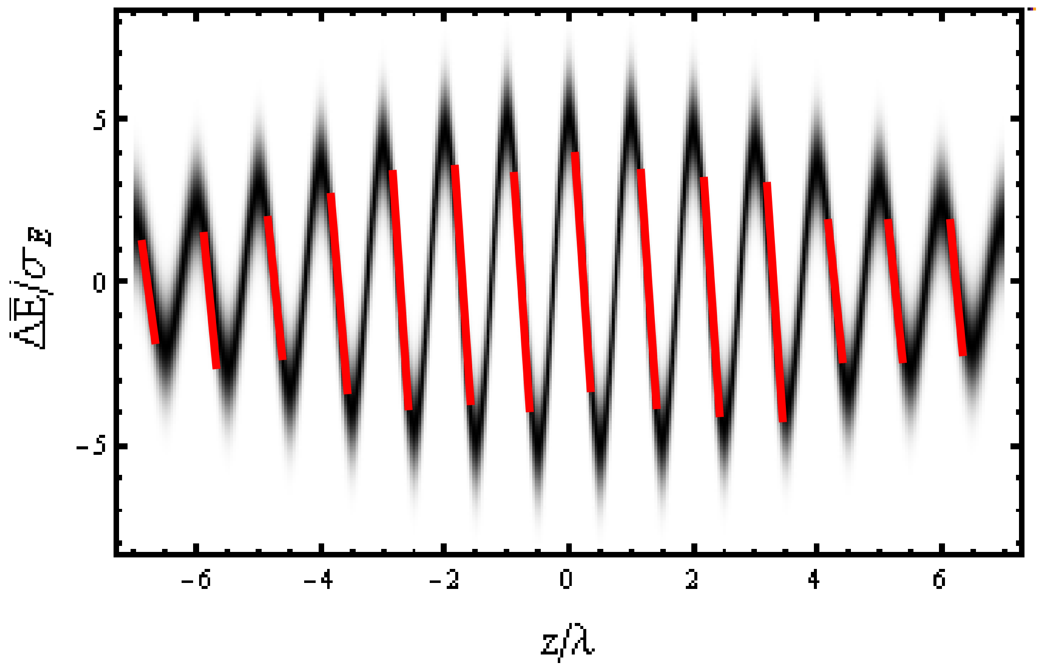
λ=0.5 Å, emit=0.4 μm, σ_E=0.01%

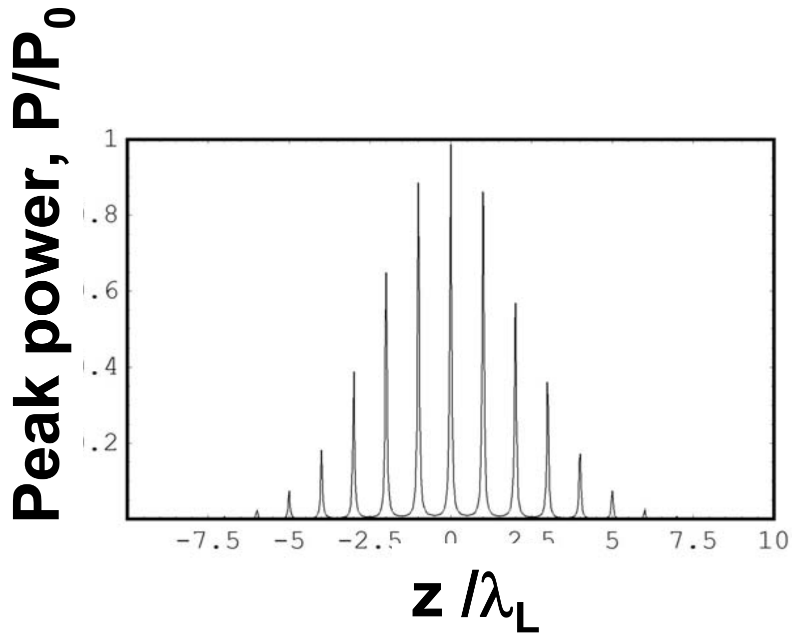


*) Ming Xie formulas

Taper should be used to compensate energy chirp induced by space charge,
Note I_{peak} ~ 20 kA

Radiation dominance due to energy gradient*)





Energy gradient can be matched with undulator taper to provide the dominance of the radiation from selected group of electrons –

a different way to tied up x-ray signal to the modulating laser

*) Saldin, Schneidmiller, Yurkov

Problem with the slippage of the radiation with respect to the electron pulse

SASE: saturation requires ~ 1000 undulator periods:

a) Slippage length for hard x-rays, i.e. λ=0.1 nm

1000 x 0.1 nm = 100 nm -> 330 asec

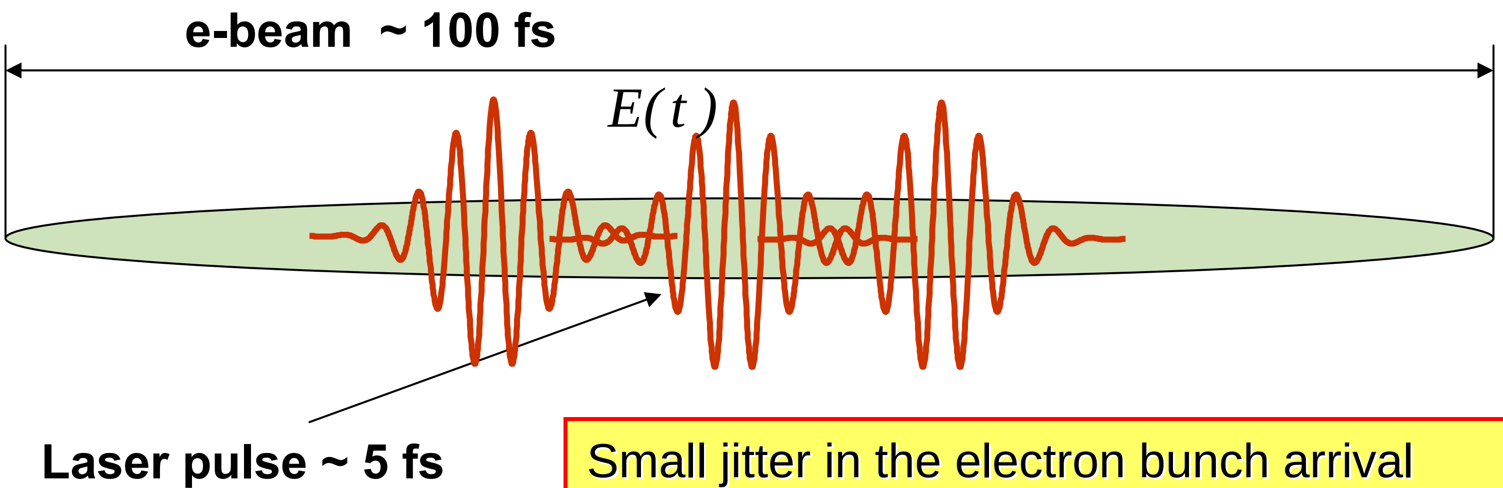
b) Slippage length for soft x-rays, i.e. λ=1 nm

1000 x 1 nm = 1000 nm -> 3.3 fs

This is about one period of the modulating laser

Single cycle optical pulses and attosecond x-ray pulses

Attosecond pulse generation via electron interaction with a few cycle carrier-envelop phase stabilized laser pulse



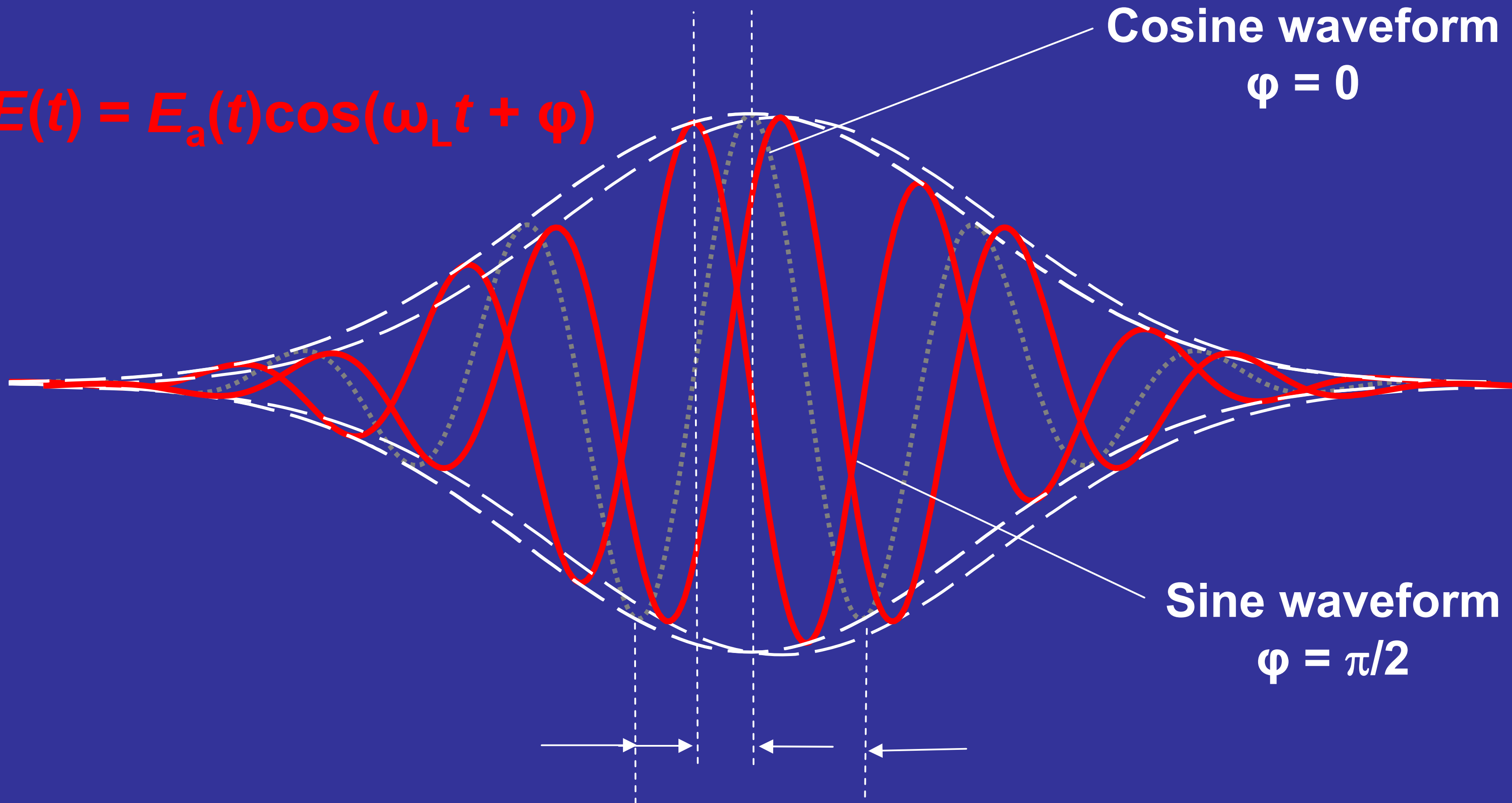
Small jitter in the electron bunch arrival time is not important – good for pump-probe experiments using variety of pump sources derived from initial laser signal

Basic idea:
Take an ultra-short slice of electrons from a longer electron bunch to produce a dominant x-ray radiation

Few-Cycle Laser Pulses

Control of the Waveform

$E(t) = E_a(t)\cos(\omega_L t + \varphi)$

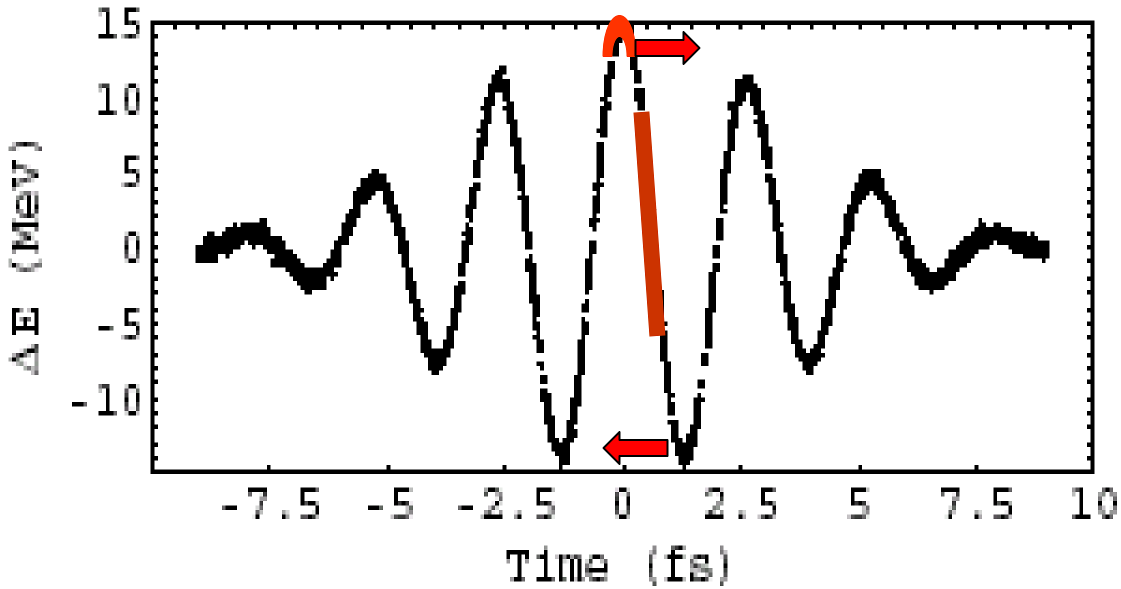


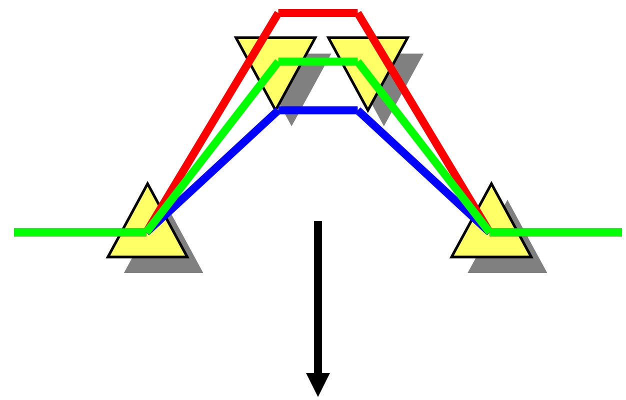
$T_0/4 \approx 625$ as (@ $\lambda_0 \approx 0.75$ µm)

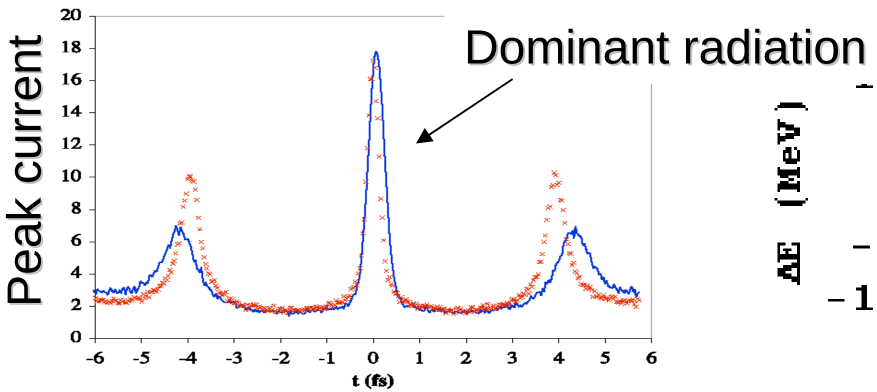
$T_0 = \lambda_0/c \approx 2.5$ fs

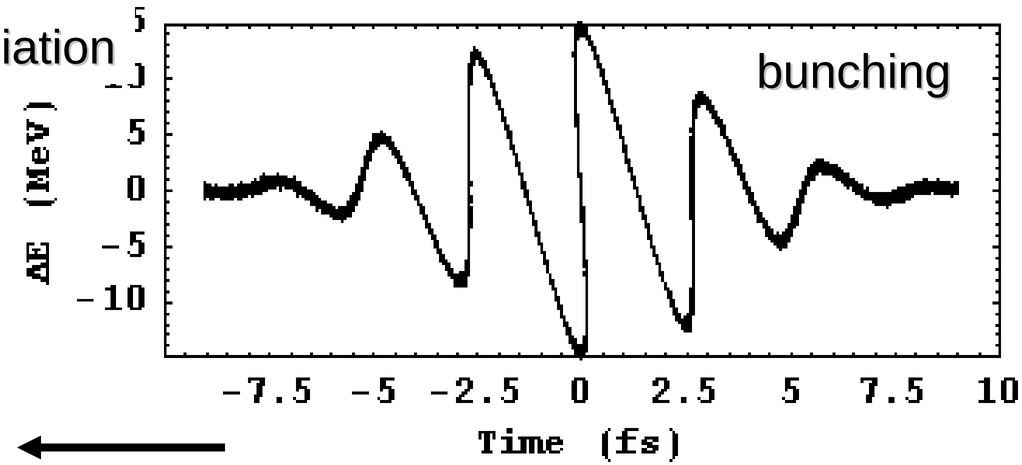
Requires measurement & control of φ

Energy modulation produced in the electron bunch during interaction with a ~1 mJ, 5 fs, 800 nm wave length laser pulse in a two period wiggler magnet with *K* value and period matched to FEL resonance at 800 nm



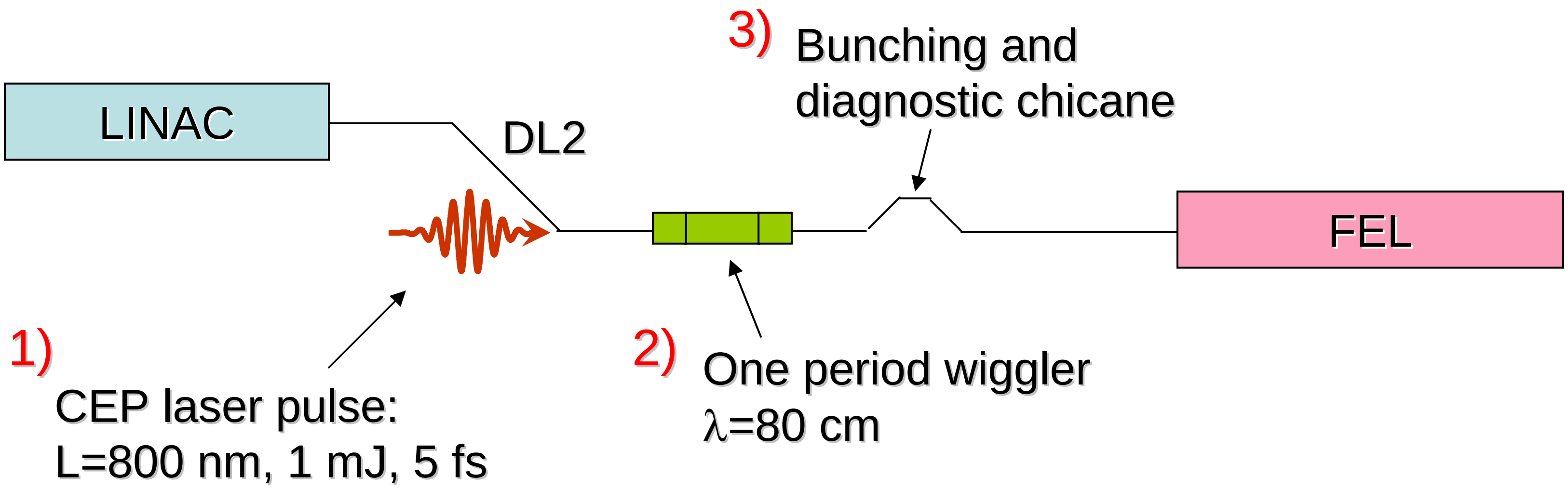




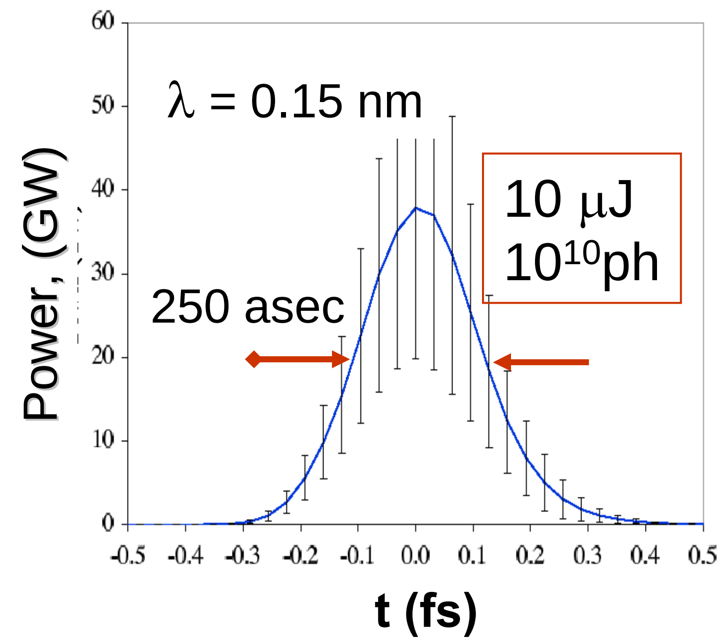


Current enhancement

Possible implementation at LCLS



Fourier transform limited and spatial coherent x-ray pulse



Summary

Lasers can play a major role at the LCLS

- assist in synchronization for pump-probe experiments
- enhance peak x-ray power
- assist in generation of attosecond x-ray pulses

What is needed?

- laser, up to 50 fs and up to 0.5 mJ, 120 Hz + wiggler, 9 periods, period length 25 cm
- CEP laser, 5 fs and up to 1 mJ, 120 Hz + wiggler, one period, period length 80 cm

Thank you for your attention