Constraints on Pulse Duration Produced by Echo-Enabled Harmonic Generation*

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Abstract

Echo-enabled harmonic generation (EEHG) is well-suited for producing long, coherent pulses at high harmonics of seeding lasers. There have also been schemes proposed to adapt EEHG to output extremely short, sub-fs pulses by beam manipulations or through extremely short seed lasers, but the photon flux is generally lower than that produced by other schemes. For the standard EEHG layout, it is still interesting to consider different parameter regimes and evaluate how short a pulse can be generated. EEHG at high harmonics uses a large dispersive chicane which can change the relative distance of electrons by substantial distances, even longer than a typical FEL coherence length. We evaluate the ability to produce short pulses (in the femtosecond to 10-fs range) using a combination of theory and simulations.

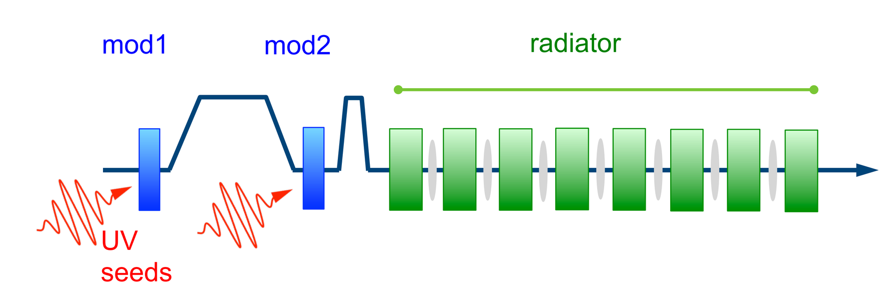
Nominal Parameters (based on LCLS-II)

Electron Beam:
- 4 GeV energy, 0.5 MeV energy spread
- 800 A peak current
- 0.4 micron emittance
- idealized flat-top current profile

Laser:
- 2 input laser pulses at 260 nm
- output radiation at 1 or 2 nm

Undulators:
- for x-rays, 39 mm period, 3.4 m long
- for modulation, 100 to 400 mm period

EEHG layout



starting bunch flat in energy
wake fields included
- not much impact

simulations use GENESIS

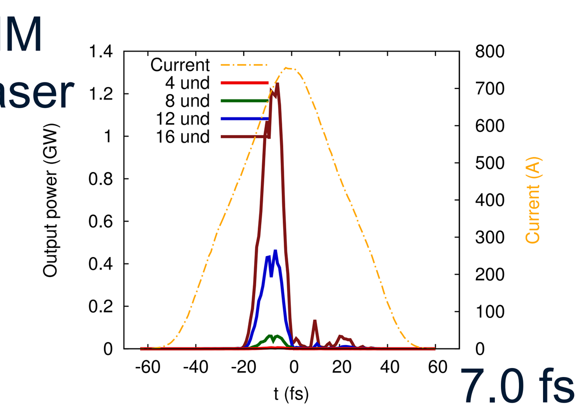
2 ways to generate short pulses

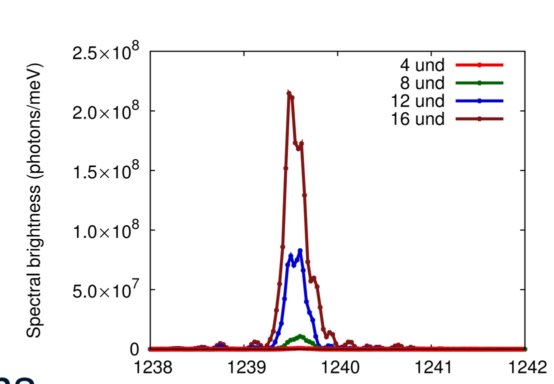
Long bunch, short laser

- first laser kept long to avoid hollowing out current profile
- second laser determines pulse duration
- problem is SASE background from unseeded parts of bunch
- 2 nm pulses limited by coherence length? slippage?

50 fs FWHM
2nd input laser

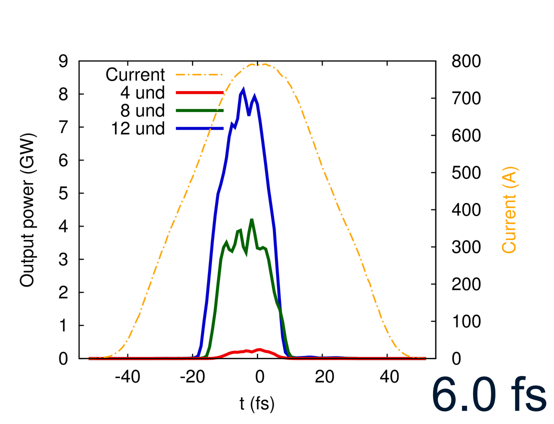
1 nm

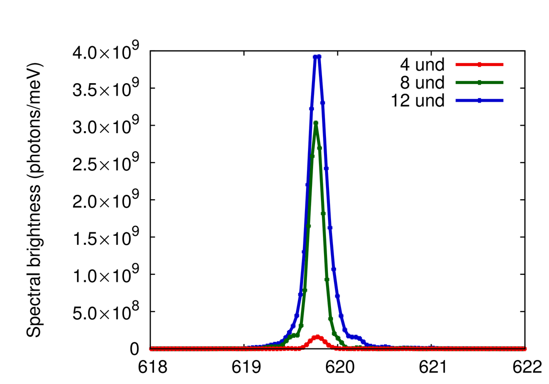




7.0 fs rms

2 nm

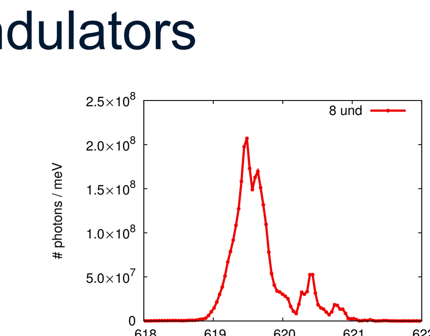


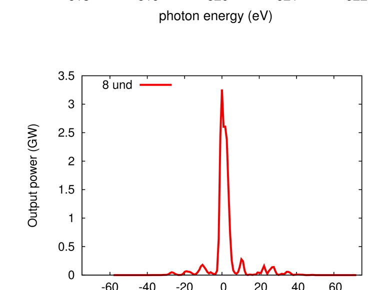


6.0 fs rms

Cleaner to stop a little before saturation:
1 nm, 50 fs FWHM seed laser is best
- output pulse, 6.0 fs rms after 12 undulators
- < factor 2 improvement vs. using long laser

2 nm, even 10 fs FWHM seed laser is effective
- output pulse, 3.3 fs rms after 8 undulators
- slippage dominated
- spectrum a little messy





2 nm pulse for 75 fs bunch, 10 fs laser
low-level SASE background

Selected References

EEHG:
G. Stupakov, Phys. Rev. Lett. 102 (2009) 074801.
GENESIS:
S. Reiche, Nucl. Instrum. Meth. A 429 (1999) 243.
LCLS-II:
G. Marcus et al., FEL 2015 paper TUP007.

Short bunch, long laser

- current profile gets distorted in first chicane
- pulse duration determined by bunch length *after* chicane
- reduced current limits shortest usable bunch length
- very short bunches, see a minimum of bunching in center
  - results in double-peak output pulse

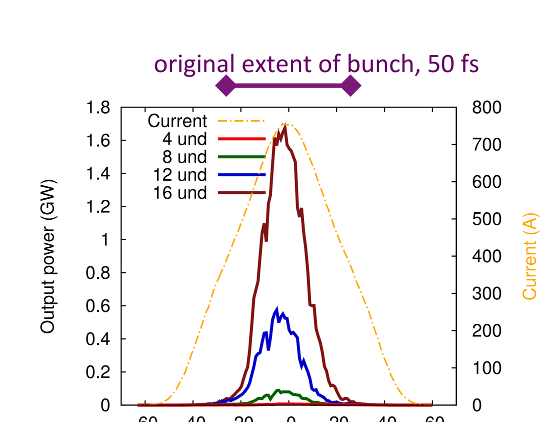
$$\sigma_z > \frac{\lambda_1 \lambda_2}{\lambda_{\mathrm{echo}}} \frac{E_{M1}}{E_{M2}} \frac{1}{\sqrt{2}\,\pi(|n|^{4/3}+|n|^{2/3})}$$ (approximate)

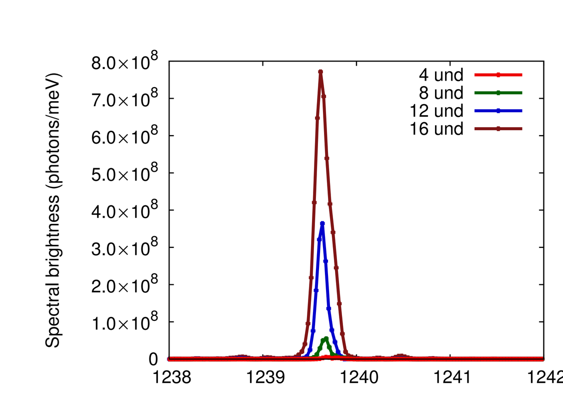
input laser wavelengths λ_1, λ_2 (here 260 nm)
resulting energy modulations E_{M1}, E_{M2}
output wavelength λ_{echo}
n is mode number, usually n=-1

2 nm radiation:
E_{M1}/E_{M2}=3/4: σ_z/c > 9.5 fs

1 nm radiation:
E_{M1}/E_{M2}=1/2: σ_z/c > 13 fs

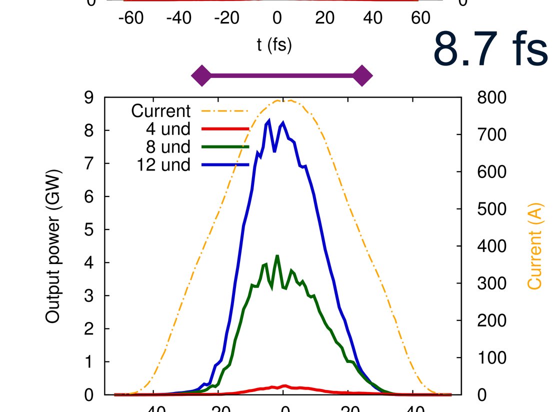
1 nm

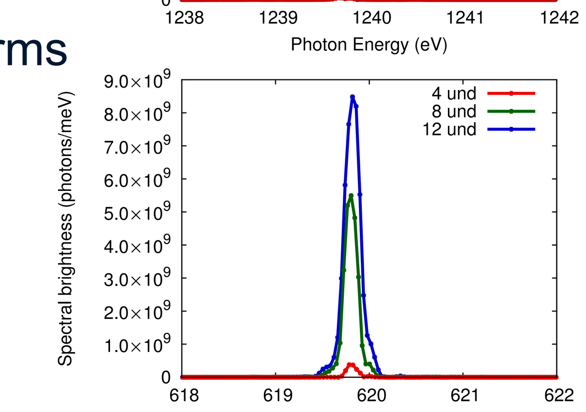




8.7 fs rms

2 nm





10.4 fs rms

at 2 nm, pulse can be as short as 7.5 fs rms with a 25 fs bunch