

Femtosecond and sub-femtosecond pulses at LCLS-II

LCLSII-TN-15-17 5/29/2015

A.Marinelli, G. Marcus, T. Raubenheimer SLAC, Stanford, CA 94036 USA



SLAC National Accelerator Lab LCLS-II TN-15-11 May 2015

Femtosecond and sub-femtosecond pulses at LCLS-II

A. Marinelli^{*}, G. Marcus, T. Raubenheimer SLAC, Menlo Park, CA 94025

Abstract

* marinelli@slac.stanford.edu

1 Introduction

Recent X-FEL user meetings at SLAC and Ringberg have highlighted the need for ultrashort X-ray pulses, down to the sub-femtosecond limit. An obvious application of such pulses is that of improving the resolution of pump/probe experiments, which is now limited to a few femtoseconds (fs) by the available pulse duration. However, there are more fundamental reasons for going to the attosecond (as) regime. It is now well understood that the high-intensity X-ray pulses generated by LCLS can strongly ionize samples in imaging and pump/probe experiments. This means that the X-ray probe perturbs the sample itself. Probing dynamic processes with pulses that are shorter than the typical time-scale of X-ray induced ionization (e.g. the auger lifetime which is typically on the order of 1 fs) would eliminate a major source of uncertainty in FEL experiments.

Additionally, there are many enticing applications in atomic, molecular and optical physics for attosecond-scale pulses. For instance, in impulsive stimulated Raman redistribution, sub-1 fs X-ray pulses contain sufficient Fourier-limited bandwidth to produce a coherent excitation of two or more electronic states in a molecule. By recording the ensuing electron motion, experimenters could uncover exactly how photo-induced excitation energy flows through the various chemical bonds of the molecule.

2 Laser-slicing of X-ray FELs

Laser-slicing techniques for FELs have been proposed in recent years [1, 2, 3]. These techniques take advantage of the high field intensities of commercially available lasers to generate a short high-current spike in an electron bunch via particle/laser interaction in a magnetic undulator, in a scheme known as enhance SASE (eSASE). The short current spike is subsequently used in the FEL undulator to generate a short X-ray pulse. Additionally, the LCLS-II variable gap undulator allows the implementation of a chirp-taper scheme, where the undulator taper is setup to match the laser-induced chirp maintaining improving the resonant interaction in the ultra-short current spike. At soft x-ray energies this technique improves the peak power of sub-fs pulses with respect to the eSASE configuration.

Numerical studies on LCLS and LCLS-II indicate that pulses as short as 500 as at a photon energy of 1 keV can be generated by slicing the LCLS-II electron bunch with an intense laser with a wavelength of 2 μm . Moreover, recent simulations have shown that using the copper linac to drive the LCLS-II soft X-ray undulator can generate a peak power close to 1TW with SASE spikes as short as 200 as. The application of laser-slicing to this scenario would allow the generation of soft X-ray pulses of TW power levels with a pulse duration well below 1 fs.

The proposed setup relies on a long pulse (1 ps) infrared laser combined with the laserheater shaping capability currently under development. The laser will interact with the electrons in a magnetic undulator to generate a periodic energy-modulation in the electron bunch. Subsequently this modulation will be transformed into a density modulation by a down-stream magnetic chicane. By using the existing emittance spoiler a single modulation period can be isolated. Note that this requires isolating a 6 fs fraction of the electron bunch,



Figure 1

which is well within the capabilities of the energy-spoiler. This will allow the generation of an isolated sub-fs pulse in the FEL undulator.

The use of the ps-long laser is due to two main considerations: first, this scheme is currently being studied in the context of LCLS, which would make the extension to LCLS-II relatively simple; secondly, the use of a long laser pulse significantly simplifies the laser transport with respect to a single-cycle laser. Note that the use of the energy-spoiler combined with the long-pulse laser, implies that the arrival-time jitter of the sub-fs is on the order of the arrival time jitter of the LCLS-II beam, i.e. 20 fs. This could be improved upon by upgrading the laser to a single-cycle laser, according to the original eSASE concept.

3 Numerical simulations

To give an idea of the expected performance of these schemes we show the result of a threedimensional simulation of the chirp-taper scheme. Fig. 1 shows the longitudinal phase-space of the electrons after the undulator (left), as well as the resulting FEL pulse temporal profile (middle) and spectrum from a Genesis1.3 simulation. The peak power is 20GW, with a pulse duration of roughly half an attosecond and a coherent bandwidth of roughly 5eV.

4 Cost estimate

The cost of the laser-slicing schemes can be estimated to be on the order of one million dollars. The existing FFTB laser room could be used to host the infrared laser and the required optics. Transport to the LTU and recommissioning of the laser room are included in the cost estimate. The soft-x-ray self-seeding chicane (already in the baseline) may be used to reduce cost but a dedicated chicane would be the preferred option. The cost of the undulator for the laser-electron interaction can be estimated on the order of 100k\$.

References

[1] A. A. Zholents, Phys. Rev. ST Accel. Beams 8, 040701 (2005),

- [2] A. A. Zholents and W. M. Fawley, Phys. Rev. Lett. 92, 224801 (2004),
- [3] Y. Ding, Z. Huang, D. Ratner, P. Bucksbaum, and H. Merdji, Phys. Rev. ST Accel. Beams 12, 060703 (2009)