Controlled Injection of Kiloampere, Attosecond Duration Electron Bunches in a Laser Wakefield Accelerator

M. P. Tooley¹, B. Ersfeld¹, S. R. Yoffe¹, A. Noble¹, Z. M. Sheng¹,²,³, D. A. Jaroszynski¹

¹Department of Physics, SUPA & University of Strathclyde, Glasgow, United Kingdom
²Laboratory for Laser Plasmas and Department of Physics and Astronomy, Shanghai, China
³Collaborative Innovation Center of IFSA, Shanghai Jiao Tong University, Shanghai, China

Intense light pulses and relativistic electron bunches have become key diagnostic tools for imaging physical, chemical and biological processes, which occur on extremely fast timescales and require ultra-short duration (sub-femtosecond to attosecond) probes to resolve them. Such probes are usually produced by very large conventional accelerators. The Laser Wakefield Accelerator (LWFA) presents a compelling alternative: an ultra-compact source of electron bunches with high peak current and ultra-short duration.

Although femtosecond electron bunches have already been produced by the LWFA, it remains challenging to produce attosecond bunches in a controlled manner. Here we describe a model for the production of such ultra-short electron bunches in LWFA by modulating the plasma density, which in turn controls the self-injection process. We find a threshold condition for self-injection due to a downward plasma density gradient, which is confirmed using particle-in-cell simulations. We numerically demonstrate the injection of sub-femtosecond electron bunches with high (∼20 kA) beam current. We further show that the bunch charge and bunch length can easily be controlled, and that trains of short bunches can be produced by appropriately tailoring the plasma density profile.