§4. Simulation of Generation of Intense Attosecond Photon Pulses in Relativistic Plasma Interaction

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Rapid progresses in ultra-short high-intensity lasers toward the attosecond regime have opened the avenues of a novel ultra-fast science, in particular, as sub-disciplines of plasma, atomic, molecular and solid-state physics and real-time chemistry [1-2]. Furthermore, to approach regimes relevant to nuclear and high-energy physics new type of large-scale extreme light infrastructure (ELI) will be constructed with close to exawatt (10^{18} W) and beyond peak power [1-2]. By focusing this power over a micrometer spot size on a target will yield intensities well into the ultra-relativistic regime. Accordingly, toward extreme intensities, effort to increase the laser energy and compress the pulse width is underway. Here, we propose attosecond photon pulse generation based on a reflection of a femtosecond (FS) optical pulse from a relativistic electron beam plasma. While many previously proposed schemes for attosecond light pulses are based on a low-efficiency nonlinear high-harmonics generation in strongly-relativistic intensity laser-plasmas, our method is based on a linear reflection, which allows to use a standard moderate energy laser with a high-repetition rate. Moreover, we could find analytical solutions of linear time-dependent EM pulse compression by using Lorentz transformations, covariance of Maxwell's equations and the principle of phase invariance [3], to transform between the laboratory (rest) frame and the moving relativistic electrons frame. Closed form formulae for obliquely reflected pulse, predict both, temporal compression and intensity amplification, by 2γ and $4\gamma^2$, respectively [3]; where γ- is the relativistic Lorentz factor of the relativistic electron plasma. Further, we test a feasibility of the scheme by 2D relativistic EM particle-in-cell (PIC) simulations. Since in applications single attosecond pulse is preferred, we inject a half-cycle cosine low-intensity FS laser pump with the peak at β_0=0.01 (in units of electron quiver velocity over the speed of light) into the plasma slab at the critical plasma density. Good agreement between PIC data and analytical formula scaling is found, as shown in figure 1; while time snapshots of the reflected pulse compression and intensity amplification obtained by particle simulations are given in figure 2, [4].

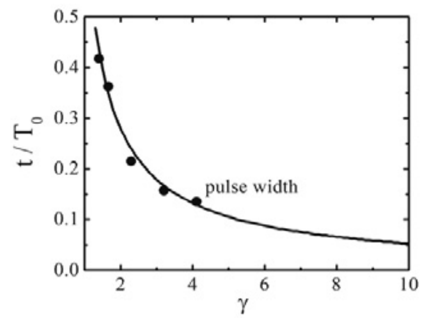

Fig .1 Agreement between analytical and PIC data (dots) for compressed pulse width, as a function of γ - factor [4].

Transient response reveals reflected pulse compression and amplification which evolves toward the analytical solution. Some differences between PIC and analytical results could be attributed to a fact that Green function analytical results for an ideal Dirac function excitation are compared against particle simulation data for a finite width half-cosine pump. As an example, half-cycle green laser reflected off 10 MeV relativistic electron beam can amplify and compress a pulse to 50 attoseconds. Finally, some fresh ideas for proposing relevant proof-of principle experiments could be envisaged.

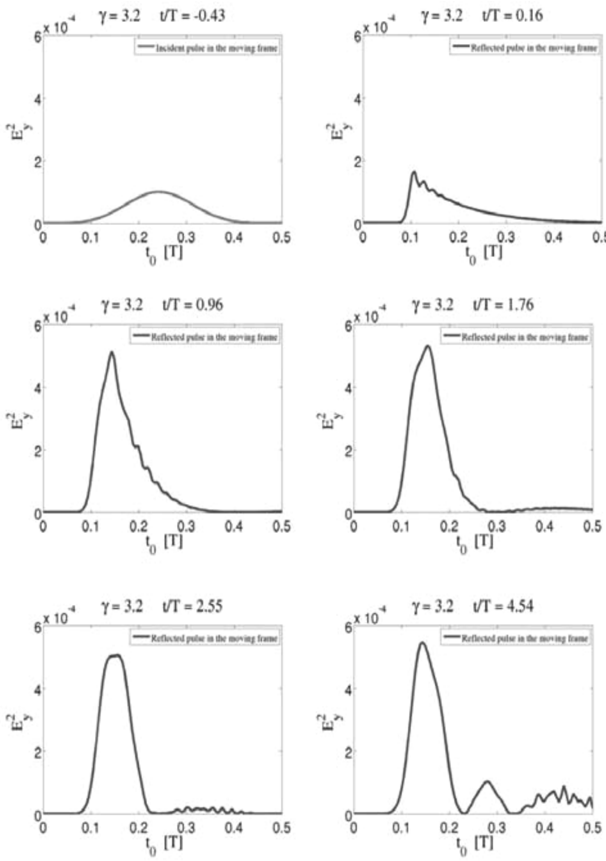

Fig.2. Compression and amplification of a reflected laser pulse by a relativistic electron beam (~2 MeV) from 2D PIC simulations. Top left, is incident half-cosine laser pulse.

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2. P.B. Corkum and F. Krausz, Nat. Phys. 3, 381 (2007).
3. M.M. Škorić, B. Stanić, Lj. Hadzievski and Lj. Nikolić, J. Plasma Phys. 75, 111-115 (2009).
4. M.M. Škorić, Lj. Nikolić, S. Ishiguro, Phys. Scr. T149 014081 (2012).