2nd Asia-Pacific Conference on Plasma Physics, 12-17,11.2018, Kanazawa, Japan

Structurally determined patterns of electrons in colliding super-intense laser beams

T. Zh. Esirkepov
Kansai Photon Science Institute, QST
e-mail (speaker): timur.esirkepov@qst.go.jp

The electron dynamics in electromagnetic field is determined by the field strength E_0 and wavelength λ. It becomes strongly relativistic when the dimensionless amplitude $a_0=eE_0\lambda/(2\pi m_e c)\gtrsim 1$, which corresponds to $E_0\gtrsim 13\times10^{12}$ V/m for $\lambda=1\mu$m. In terms of laser irradiance this threshold reads $I\gtrsim I_{rel}\approx 1.37\times10^{18}$ W/cm^2. At much higher irradiance of $I_{RR}\approx 10^{23}$ W/cm^2, the electron dynamics is dominated by strongly nonlinear friction. It stems from radiation reaction, due to the recoil caused by electromagnetic radiation emission from the accelerating electron. Radiation reaction recasts the electron dynamics as it permits regimes where the electron emits all the energy acquired from the electromagnetic field in a single wave cycle. If the emitted photon energy is of the order of the electron invariant mass, the electron dynamics becomes quantum, as determined by the parameter $\chi_e\sim E_0/E_S$ which characterizes the photon emission probability. Here the value of χ_e is given in the electron's rest frame of reference, $E_S\approx 1.32\times10^{16}$ V/m is the critical field of quantum electrodynamics (QED), also called Schwinger limit.

The two critical parameters, a_0 and χ_e independently determine the importance of classical radiation reaction and quantum effects, respectively. Therefore the plane (a_0,χ_e) divides into 4 regions [1]: (I) radiation reaction is negligible; (II) QED effects dominate while the radiation reaction force is small; (III) radiation reaction is mostly classical; (IV) the radiation reaction force and QED effects are both strong, Fig. 1. Changing the parameter space (a_0,χ_e) to $(I,\ \lambda)$, for the circularly polarized electromagnetic wave one can find that the point joining all 4 domains is $I_{RQ}\approx I_{RR}$, $\lambda_{RQ}\approx 1\mu$m, Fig. 2.

High power lasers will soon reach irradiance of the order of or above I_{RR} [2]. One of the technologically feasible ways of reaching so high irradiance is the multi-beam configuration [3]: in the focus of N colliding laser pulses the electric fields are summed in a transient standing wave, so that the cumulative irradiance increases N times. In a standing wave, strong fast-oscillating nonlinear friction paradoxically stabilizes the electron dynamics [4] producing limit cycles and strange attractors [1,5,6]. Due to the existence of attractors, electron dynamics motion remains bounded even in quantum regime, when electron emission becomes discreet and electron trajectories have sharp turns at each act of emission [5]. In standing waves created by multiple laser beams, in general, the electrons form various structurally determined patterns in the phase space [6]. The effect of paradoxical stabilization eliminates a well-known problem of charged particles delivery to the region of the highest electromagnetic field intensity, thus creating a new framework for high energy physics experiments. Electrons entering the collision point of multi-petawatt laser beams "forget" their initial momenta due to radiation reaction. Consequently, GeV electron and positron beams transversely propagating through that collision point become trapped in a transient microscopic collider, which reveals itself by a characteristic transverse high-power gamma-rays and a peculiar spatial and spectral electron distribution.

References

[1] T. Zh. Esirkepov, et al., Phys. Lett.A 379, 2044 (2015).
[2] G. A. Mourou, G. Korn, W. Sandner, J. L. Collier (Eds), ELI-Extreme Light Infrastructure Science and Technology with Ultra-Intense Lasers Whitebook (THOSS Media GmbH, 2011).
[3] S. S. Bulanov, et al., Phys. Rev. Lett. 104, 220404 (2010).
[4] T. Zh. Esirkepov and S. V. Bulanov, Phys. Lett. A 381, 2559 (2017).
[5] M. Jirka, et al., Phys. Rev. E 93, 023207 (2016).
[6] S. V. Bulanov, et al., J. Plasma Phys. 83, 905830202 (2017).

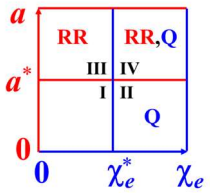

Figure 1. Two binary choices of two independent parameters, a_0 and χ_e, determine 4 different regimes where either radiation reaction (RR) or quantum effect (Q) is strong, or both, or none.

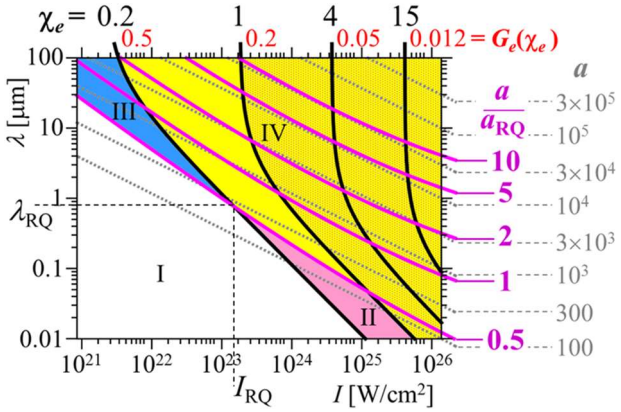

Figure 2. The same diagram as in Fig. 1, in terms of electromagnetic field irradiance I and wavelength λ, for the model of electron dynamics in a circularly polarized standing electromagnetic wave.