High intensity laser – electron interaction in the transition between the classical and the QED regime

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The rise in peak laser intensities has been steady in recent years, and this trend continues with new multi-petawatt laser systems being built in several laboratories around the world. The near-future experiments in these systems open the way to insights in new physics – combining relativistic electron beams with intense lasers allows for the exploration of the transition from classical to quantum regime across a wide range of parameters that were not accessible before. A powerful tool supporting theoretical studies of laser-matter interactions and contributing in the design of experiments have been particle-in-cell (PIC) codes. PIC codes self-consistently use Maxwell equations to advance electromagnetic fields, and the Lorentz force to move the charged particles. Energy, momentum and charge are conserved in this scheme, but the standard PIC framework is entirely classical. In order to expand the validity of our PIC code OSIRIS [1] for higher intensities, we have implemented two additional modules: a classical radiation reaction module based on the Landau & Lifshitz formalism, and a QED module that accounts for these processes including discrete photon emission and Breit-Wheeler electron-positron pair production.

Classical radiation reaction is a continuous process - a particle is emitting continuous radiation and loses energy as a consequence of the emission. This approximation is considered valid as long as the emitted single photon energy is small compared with the energy of the particle. However, in QED, the particle has a certain probability to emit a photon, and only if the emission takes place, the particle energy changes. We have studied the differences between the two pictures for Compton scattering in the transition regime - a regime around the quantum limit but still on average well described by the classical radiation reaction. Our configuration included a relativistic electron beam (multi - GeV) and an intense laser ($10^{21} - 10^{22}$ W / cm^2) in a head-on collision. We have found that even though the average energy can be well-predicted by the classical formulas, other properties such as energy spread, divergence and emittance are affected by the discrete nature of photon emission in some situations. The differences are closely related to the length of the interaction and the total number of photons expected per radiating particle - we observe better agreement for longer interactions when the number of emitted photons is higher. We have found that in the transition regime studied here, the rate of pair creation is very small, so this does not influence the laser-electron beam interaction.

[1] R. A. Fonseca et. al., *Plasma Physics and Controlled Fusion* **50**, 124034 (2008)