Radiation reaction - from classical to QED regime

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Laser technology has seen a significant rise in peak laser intensity over the years, and near-future projects such as ELI are promising to reach even higher. Multi-petawatt laser systems can provide intensities of \(10^{21} - 10^{22} \text{ W/cm}^2\), where the physics stops being entirely classical and appropriate quantum corrections must be taken into account. A powerful tool that supports theoretical studies of laser-matter interactions and helps design of experiments are particle-in-cell (PIC) codes, which self-consistently use Maxwell equations to advance electromagnetic fields and Lorentz force to move the charged particles, but the standard PIC framework is entirely classical. In order to expand the validity of our PIC code OSIRIS \cite{1} for studies at higher intensities, we have added two modules: a classical radiation reaction module based on the Landau&Lifshitz equation, and a QED module that has discrete photon emission and 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. In the QED regime, radiation is a discrete process and this impacts the particle trajectory in a distinct manner from continuous emission. We have studied the differences between the two pictures in the transition regime from the classical to the quantum physics, which is the regime relevant for near-future experiments. Our configuration included a relativistic electron beam (multi - GeV) and an intense laser (\(10^{21} - 10^{22} \text{ W/cm}^2\)) in a head-on collision \cite{2}. We have found that even though the average final 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 scenarios. The differences are closely related to the length of the interaction and total number of photons expected per radiating particle. As expected, we observe better agreement for longer interactions when the number of emitted photons is higher.

References
