QED in ultra--high laser fields: current experimental results and perspectives


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QED in ultra-high laser fields: current experimental results and perspectives

G. Sarri
School of Mathematics and Physics, Queen’s University Belfast, BT7 1NN, Belfast, United Kingdom

Quantum Electrodynamics (QED) represents thus far one of the greatest theoretical achievements in modern physics, able to elegantly combine electromagnetism, quantum mechanics, and special relativity into a unified theory. Its predictions have been tested to a high degree of precision in relatively low field intensities but, thus far, little is experimentally known about the behaviour of quantum systems in ultra-high fields. QED effects are dominant if these fields are comparable to the critical field (also known as the Schwinger field): \( E_S \sim 1.3 \times 10^{18} \) V/m. At these field intensities, exotic phenomena will occur, such as stochastic photon emission [1], electron-positron pair production even in a classical vacuum [2], and strong radiation reaction [3].

Even though electromagnetic fields of this nature are expected to be present around massive astrophysical objects (see, for instance, [4]), experimental studies have been extremely limited, only exploiting strong crystalline fields [5] or ultra-relativistic electron beams in accelerators [6].

However, the fast-paced development of laser technology and laser-driven particle acceleration [7] is finally opening up the possibility of experimentally studying non-linear (i.e. high-field) QED. Existing lasers now can produce conditions very close to the critical field (yellow box in Fig. 1) with near-term facilities under construction expected to overcome it (red box in Fig. 1).

In a recent experimental campaign at the Astra-Gemini laser we achieved conditions where electrons feel, in their rest frame, an electric field equal to 0.2 \( E_S \) (red triangle in Fig.1). This was achieved exploiting a head-on collision of an intense laser pulse (\( I_L \sim 2 \times 10^{20} \) W cm\(^{-2}\)) with a laser-driven ultra-relativistic electron beam (maximum Lorentz factor of \( \gamma_L \sim 3500 \)). Clear evidence was found, for the first time, of strong radiation reaction with a 40% electron energy loss in 40 femtoseconds of laser duration [8]. This talk will present these results, together with a discussion of current developments in order to fully access experimentally, for the first time, regimes of purely non-linear QED.

References