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


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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): \( E_c \sim 1.3 \times 10^{18} \text{ V/m} \). 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 \( E_c \) (red triangle in Fig.1). This was achieved exploiting a head-on collision of an intense laser pulse (\( I_L \sim 2 \times 10^{20} \text{ Wcm}^{-2} \)) 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