Extremely high-intensity laser interactions: from fundamental quantum systems to quantum plasma simulations and experimental confirmations

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The field of laser-matter interaction traditionally deals with the response of atoms, molecules, and plasmas to an external light wave. However, the recent sustained technological progress is opening up the possibility of employing intense laser radiation to trigger or substantially influence physical processes beyond atomic-physics energy scales. Available optical laser intensities exceeding 10^{22} W/cm^2 can push the fundamental light-electron interaction to the extreme limit where radiation-reaction effects dominate the electron dynamics, can shed light on the structure of the quantum vacuum, and can trigger the creation of particles such as electrons, muons, and pions and their corresponding antiparticles. Also, novel sources of intense coherent high-energy photons and laser-based particle colliders can pave the way to nuclear quantum optics and may even allow for the potential discovery of new particles beyond the standard model.

Following the introduction into the physics of particle gases and plasmas in extremely strong laser pulses, I will focus in my overview on radiative reaction and spin effects, laser acceleration and colliders, electron-positron cascades processes in focussed laser pulses as well as on polarized lepton and x-ray generation. Emphasis will also be placed on related recent experiments and applications in laboratory astrophysics.