Q 42: Quantum Effects: QED II

Time: Wednesday 14:30–16:30 Location: B/SR

Q 42.1 Wed 14:30 B/SR

Solutions of the Dirac equation for space-time dependent fields via an inverse approach — •Johannes Oertel and Ralf Schützhold — Universität Duisburg-Essen

Solving the Dirac equation is crucial for the understanding of pair creation via the Sauter-Schwinger effect in space-time dependent fields. However, for the very few exact solutions known today, the field often depends on one variable (e.g., space or time) only. By swapping the roles of known and unknown quantities in the Dirac equation, we are able to generate families of solutions of the Dirac equation in the presence of space-time dependent electromagnetic fields. Using this inverse approach, solutions with an electromagnetic field depending on either one of the light cone coordinates or both can be found in $1 + 1$ and $2 + 1$ dimensions.

Q 42.2 Wed 14:45 B/SR

Analogue Sauter–Schwinger effect in semiconductors — •Malte F. Linder and Ralf Schützhold — Fakultät für Physik, Universität Duisburg-Essen, Lotharstraße 1, D-47057 Duisburg, Germany

The Sauter–Schwinger effect is the non-perturbative excitation of electron-positron pairs from the Dirac quantum vacuum due to high electric field strengths E. This pair creation mechanism can be explained as a tunnelling process of electrons from the Dirac sea into the energy states above the mass gap $2m_ec^2$. The tunnelling rate is exponentially suppressed by the factor $\exp(-\pi E_S/E)$ with the critical field strength $E_S \approx 10^{18}$ V/m and thus too small for an experimental verification with currently attainable fields strengths E.

To approach the observation of this quantum effect in the laboratory, we show that a quantitative analogue of the Sauter–Schwinger effect can be realised in semiconductors at low temperatures. The filled valence band acts as Dirac sea, while the empty conduction band corresponds to the positive-energy continuum of the Dirac equation. Since the band gap of a typical semiconductor like GaAs is much smaller than the mass gap $2m_ec^2$, the critical field strength for the analogue Sauter–Schwinger effect is much smaller than E_S. Furthermore, the pair creation rate can be enhanced by adding time-dependent components (i.e. laser beams or pulses) to the strong static background field (dynamically assisted Sauter–Schwinger effect). The semiconductor analogue could facilitate the study of the Sauter–Schwinger effect and the various assistance mechanisms in the laboratory.

Q 42.3 Wed 15:00 B/SR

Dynamically assisted Sauter-Schwinger effect in inhomogeneous electric fields — •Christian Schneider and Ralf Schützhold — Universität Duisburg-Essen

Via the world-line instanton method, we study electron-positron pair creation by a strong (but sub-critical) electric field of the profile $E/\cosh^2(kx)$ superimposed by a weaker pulse $E'/\cosh^2(\omega t)$. If the temporal Keldysh parameter $\gamma_\omega = m\omega/(qE)$ exceeds a threshold value $\gamma_\omega^{\rm crit}$ which depends on the spatial Keldysh parameter $\gamma_k = mk/(qE)$, we find a drastic enhancement of the pair creation probability – reporting on what we believe to be the first analytic non-perturbative result for the interplay between temporal and spatial field dependences $E(t, x)$ in the Sauter-Schwinger effect.

Q 42.4 Wed 15:15 B/SR

High-energy recollision processes of laser-generated electron-positron pairs — •Sebastian Meuren, Karen Z. Hatsagortsyan, Christoph H. Keitel, and Antonino Di Piazza — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg

By combining modern petawatt laser systems with highly energetic photon beams, the non-linear regime of QED becomes experimentally accessible with presently available technology [1]. In particular, the decay of a photon into a real electron-positron pair becomes feasible [2]. Once the pair is produced, the classical equations of motion predict that the electron and the positron are further accelerated by the laser field and – under certain circumstances – brought to a recollision [3]. We have shown rigorously for the first time that such recollision processes can be described in the realm of quantum field theory and that they are encoded in electron-positron loop Feynman diagrams [4]. By investigating the polarization operator in a plane-wave laser field, we have identified the contribution describing recollisions, which differs qualitatively and quantitatively from the one describing radiative corrections. As a consequence, recollision processes may significantly alter the tree-level predictions of QED in a strong laser field.

[1] A. Di Piazza, et al., Rev. Mod. Phys. **84**, 1177–1228 (2012)
[2] S. Meuren et al., arXiv:**1406**.**7235** (2014)
[3] M. Y. Kuchiev, Phys. Rev. Lett. **99**, 130404 (2007)
[4] S. Meuren et al., arXiv:**1407**.**0188** (2014)

Q 42.5 Wed 15:30 B/SR

Electron polarization effects in nonlinear Compton scattering with short laser pulses. — •Oleg D. Skoromnik, Karen Z. Hatsagortsyan, Antonino Di Piazza, and Christoph H. Keitel — Max Planck Institute for Nuclear Physics, Saupfercheckweg 1, 69117 Heidelberg, Germany

The electron polarization effects in the nonlinear Compton scattering of relativistic electrons by a circularly polarized few cycle laser pulse are investigated. It is shown that a large spin asymmetry can be observed in a coincidence measurement of the scattered electrons and the emitted photons in a judiciously chosen spectral interval. In this case the spin asymmetry of the scattering is strongly dependent on the laser pulse length in a full quantum regime, when the quantum parameter χ is of the order of unity. In contrast, in the quasi-classical case ($\chi \ll 1$) the asymmetry is dependent neither on the pulse length nor the intensity. The application of the effect for spin polarimetry is discussed.

Q 42.6 Wed 15:45 B/SR

Electron-positron pair production in a bifrequent oscillating electric field — •Selym Villalba-Chavez, Ibrahim Akal, and Carsten Müller — Institut für Theoretische Physik I, Heinrich-Heine-Universität Düsseldorf, Universitätsstraße 1, 40225 Düsseldorf

The production of electron-positron pairs from the quantum vacuum polarized by the superposition of a strong and a perturbative oscillating electric field mode is studied. Our outcomes rely on a nonequilibrium quantum field theoretical approach, described by the quantum kinetic Boltzmann-Vlasov equation. By superimposing the perturbative mode, the characteristic resonant effects and Rabi-like frequencies in the single-particle distribution function are modified, as compared to the predictions resulting from the case driven by a strong oscillating field mode only. This is demonstrated in the momentum spectra of the produced pairs. Moreover, the dependence of the total number of pairs on the intensity parameter of each mode is discussed and a strong enhancement found for large values of the relative Keldysh parameter.

Q 42.7 Wed 16:00 B/SR

Lifting Shell Structures in Periodic Electric Fields — •Andreas Otto[1,2], Burkhard Kämpfer[1,2], and Daniel Seipt[3] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstraße 400, 01328 Dresden, Germany — [2]Institut für Theoretische Physik, Technische Universität Dresden, Zellescher Weg 17, 01062 Dresden, Germany — [3]Helmholtz-Institut Jena, Fröbelstieg 3, 07743 Jena, Germany

We report on strong enhancement effects in the dynamically assisted Schwinger effect. Periodic electric fields produce electron-positron-pairs distributed in special structures in momentum space. Superposing two fields with different field strength/frequency scales (i.e. adding a fast but weak field to a slow but strong field), one can significantly increase the number of produced particles, achieving enhancement factors of $\mathcal{O}(10^3)$-$\mathcal{O}(10^4)$. In the framework of a quantum kinetic equation, this enhancement can be understood by the distribution of the complex zeros of the canonical electron field energy.

Q 42.8 Wed 16:15 B/SR

Electron-beam dynamics in a strong laser field including quantum radiation reaction — •Norman Neitz and Antonino Di Piazza — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg

The effects of radiation reaction in the head-on collision of an ultrarelativistic electron beam with a strong plane-wave field are investigated by means of a kinetic approach [1]. Contrary to the predictions of classical electrodynamics, employing the Landau-Lifshitz equation [2], it is demonstrated that the final electron distribution depends on the shape of the laser envelope and on the pulse duration at a given total laser fluence. Further, we study how the dynamics of the photons and charged particles is altered by the inclusion of the pair production process. Our numerical results indicate the feasibility of measuring the investigated effects with present technology [3]. In the classical regime, nonlinear Thomson scattering has been recently exploited experimentally to produce a multi-MeV photon beam with an unprecedented high brilliance in an all-optical setup [4].

[1] V. N. Baier, V. M. Katkov and V. M. Strakhovenko, “Electromagnetic Processes at High Energies in Oriented Single Crystals” (World Scientific, Singapore, 1998).
[2] L. D. Landau and E. M. Lifshitz, “The Classical Theory of Fields” (Elsevier, Oxford, 1975).
[3] N. Neitz and A. Di Piazza, Phys. Rev. A **90**, 022102 (2014).
[4] G. Sarri *et al.*, Phys. Rev. Lett. **113**, 224801 (2014).