Q 38: Quantum Effects (QED) I

Time: Wednesday 14:00–16:00 Location: f442

Q 38.1 Wed 14:00 f442

Optical Signatures of Quantum Vacuum Nonlinearities in the Strong Field Regime — •Leonhard Klar[1,2], Felix Karbstein[1,2], and Holger Gies[1,2] — [1]Theoretisch-Physikalisches Institut, Friedrich-Schiller-Universität Jena, 07743 Jena, Germany — [2]Helmholtz-Institut Jena, 07743 Jena, Germany

Quantum electrodynamics (QED) is the most precisely tested quantum field theory. Nevertheless, particularly in the high-intensity regime it predicts various phenomena, that so far have not been directly accessible in experiments, such as light-by-light scattering phenomena induced by quantum vacuum fluctuations. Our focus is on all-optical signatures of quantum vacuum effects which can be probed in high-intensity laser experiments with state-of-the-art technology. More specifically, we aim at identifying experimentally viable scenarios where the signal photons encoding the signature of QED vacuum nonlinearity can be distinguished from the large background of the driving laser photons.

We present a promising setup allowing to find signal photons discernible from the background. To this end, we envision the collision of several tightly focused high-intensity laser beams, which are assumed to be generated by two lasers and suitable frequency doubling, and identify a superposition scheme of these lasers that induces prominent signal properties. A key mechanism consists in producing a narrow scattering center. We calculate the differential number of signal photons attainable in this field configuration analytically.

Q 38.2 Wed 14:15 f442

Quantum and classical phase-space dynamics of a free-electron laser — •C. Moritz Carmesin[1,2], Peter Kling[2,3], Enno Giese[2], Roland Sauerbrey[2], and Wolfgang P. Schleich[2,3] — [1]Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany — [2]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm, 89069 Ulm, Germany — [3]Institute of Quantum Technologies, German Aerospace Center (DLR), Söflinger Straße 100, D-89077 Ulm, Germany

In a quantum mechanical description of the free-electron laser (FEL) the electrons jump on discrete momentum ladders [1], while they follow continuous trajectories inside a separatrix in phase space according to the classical description. We show that it is not sufficient to have many momentum levels involved in order to observe the transition from quantum to classical dynamics. Only if additionally the initial momentum spread of the electron beam is larger than the quantum mechanical recoil caused by the emission and absorption of photons, the quantum dynamics in phase space resembles the classical one. Beyond these criteria, quantum signatures of averaged quantities like the FEL gain might be washed out. Our results [2] are not limited to the highly relativistic electron energies of FELs but are also applicable to different setups with electron-light interaction at lower electron energies.

[1] P. Kling et al. 2015 *New J. Phys.* **17** 123019
[2] C. M. Carmesin et al. *arXiv* 1911.12584

Q 38.3 Wed 14:30 f442

Numerical simulation of non-linear Compton scattering in counter-propagating laser beams — •Qingzheng Lyu, Erez Raicher, Karen Z. Hatsagortsyan, and Christoph H. Keitel — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

The non-linear Compton scattering process of an electron in counter-propagating laser beams is considered. Employing the semiclassical operator approach [Sov. Phys. JETP 26, 854 (1968)], we can obtain the emission spectrum of an ultra-relativistic electron propagating in the counter-propagating laser beams. Because of the ultra-relativistic energy of the particle, the emission can be approximated by the classical trajectory of the particle instead of the full wave function in the background field. We investigate the spectrum for various laser and particle parameters. In particular, the validity conditions of the local constant field approximation, which is relevant for simulating QED processes in laser-plasma interactions, are examined in this more general situation.

Q 38.4 Wed 14:45 f442

X-ray coherent control with nuclear resonances — •Adriana Pálffy and Xiangjin Kong — Max Planck Institute for Nuclear Physics, 69117 Heidelberg, Germany

The resonant interaction between x-ray photons and nuclei is one of the most exciting subjects of the burgeoning field of x-ray quantum optics [1]. A resourceful platform used so far are thin-film x-ray cavities with embedded layers or Mössbauer nuclei such as ^{57}Fe. Interesting physics was reported in such thin-film cavities with several nuclear layers. For instance, the first observation of Rabi oscillations of an x-ray photon between two resonant 57 Fe-layers embedded in two coupled cavities was predicted theoretically and confirmed experimentally [2].

Here we present a new quantum optical model based on the classical electromagnetic Green's function that has been developed to investigate theoretically the nuclear response inside the x-ray cavity. The model is versatile and provides an intuitive picture about the influence of the cavity structure on the resulting spectra. Benchmarking with simulations using the semiclassical Parratt formalism and other semi-classical or quantum models is performed. In this context, we discuss our results for increasing complexity of layer structures.

[1] B. Adams *et al.*, J. Mod. Opt. 60, 2 (2013).
[2] J. Haber *et al.*, Nature Photonics 11, 720 (2017).

Q 38.5 Wed 15:00 f442

Attractive force between equally-charged ions — •Johannes Fiedler[1] and Stefan Yoshi Buhmann[1,2] — [1]University of Freiburg, Freiburg, Germany — [2]Freiburg Institute for Advanced Studies, Universität Freiburg, Freiburg, Germany

The multipole expansion of the electric field for an ion yields the charge, dipole, quadrupole and higher order contributions [1]. Beyond these classical interactions, fluctuations of these quantities play a role when considering interactions between such particles, which manifest in the forms of the van der Waals and Keesom forces [2]. Typically, the Coulomb interaction dominates the total force. The dominating effect upon adding an environmental medium is the damping of the interaction caused by its refractive index. This screening depends on the spectrum of the medium, which leads to differing orders of dominant interactions. We will present a theory of medium-assisted intermolecular interactions [3] and illustrate scenarios where the higher order forces dominate the Coulomb interactions.

[1] J. D. Jackson, Classical electrodynamics, 3rd ed. (Wiley, New York, NY, 1999).
[2] J.N. Israelachvili, Intermolecular and Surface Forces, 3rd ed. (Academic Press, Waltham, MA, 2011).
[3] J. Fiedler, S.Y. Buhmann, submitted to PCCP (2019).

Q 38.6 Wed 15:15 f442

Appearance of a half-integer power in the small-distance expansion of the Casimir energy — •Benjamin Spreng[1], Michael Hartmann[1], Paulo Maia Neto[2], and Gert-Ludwig Ingold[1] — [1]Institut für Physik, Universität Augsburg, Germany — [2]Instituto de Física, Universidade Federal do Rio de Janeiro, Brazil

The proximity force approximation (PFA) is a widely used tool to study the Casimir interaction in experiments between for example a plane and a sphere. Within the PFA, the finite curvature of the sphere is accounted for by averaging the Casimir energy of parallel plates over the local distances of the two bodies. The approximation becomes valid when the ratio L/R is small where L is the distance of the sphere's surface to the plane and R is the sphere's radius.

At zero temperature, leading corrections beyond the PFA are linear in L/R and have been studied extensively. Here, we are interested in the expansion of the Casimir energy beyond the linear term. If applicable, the method of the derivative expansion suggests a correction quadratic in L/R. However, our numerically exact computation of the Casimir energy strongly suggests a correction of the form $(L/R)^{3/2}$. This result is not limited to specific material classes and can also be found for other geometries such as for two spheres (with R replaced by the effective radius), and a cylinder opposite to a plane. A mechanism explaining the emergence of the half-integer power is provided.

Q 38.7 Wed 15:30 f442

Quantum radiation in dielectric media with dispersion and dissipation — •Sascha Lang[1,2], Ralf Schützhold[1,3], and William G. Unruh[4] — [1]Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany — [2]Fakultät für Physik, Universität

Duisburg-Essen, 47057 Duisburg, Germany — [3]Institut für Theoretische Physik, Technische Universität Dresden, 01062 Dresden, Germany — [4]Department of Physics and Astronomy, University of British Columbia, Vancouver BC V6T 1Z1, Canada

By a generalization of the Hopfield model, we construct a microscopic Lagrangian describing a dielectric medium with dispersion and dissipation. This facilitates a well-defined and unambiguous *ab initio* treatment of quantum electrodynamics in such media, even in time-dependent backgrounds. As an example, we calculate the number of photons created by switching on and off dissipation in dependence on the temporal switching function. This effect may be stronger than quantum radiation produced by variations of the refractive index $\Delta n(t)$ since the latter are typically very small and yield photon numbers of order $\Delta n^2(t)$. As another difference, we find that the partner particles of the created medium photons are not other medium photons but excitations of the environment field causing the dissipation (which is switched on and off).

Q 38.8 Wed 15:45 f442

Quantum radiation reaction in aligned crystals beyond the local constant field approximation. — •Tobias Wistisen and Antonino Di Piazza — Max-Planck-Institut für Kernphysik, Heidelberg, Deutschland

When an electron or a positron hits a crystal target with a small angle of incidence with respect to a crystal symmetry axis or plane, it experiences a strong electromagnetic field. If the particle energy is high enough, one can reach the QED critical (Schwinger) field $E_{\mathrm{cr}} = m^2c^3/(\hbar e) \approx 1.3 \times 10^{18}$ V/m in the rest frame of the particle. Quantum radiation reaction corresponds to the emission of multiple photons in this regime. In [1] we investigated this using a positron beam with 180 GeV directed along a crystalline axis in Silicon. The radiation emission process could then be approximated as if taking place in a constant field, in each moment of time, often called the local constant field approximation (LCFA). For lower particle energies this approximation is no longer applicable. With this in mind, a new theoretical model based on a semiclassical approach for calculating radiation emission in the quantum regime beyond the use of the LCFA was devised. In 2017 an experiment, at lower energies, was carried out at the CERN H4 beamline, and we compared the experimentally measured photon emission spectra to the LCFA model, and the new theoretical model. It is seen that the new approach is in convincing agreement with the data, while the LCFA is in disagreement [2].

[1] T.N. Wistisen et. al. Nat. Commun., 9(1):795. Feb. 2018.
[2] T.N. Wistisen et. al. Phys. Rev. Research 1, 033014. Oct. 2019