Q 56: Quantum effects: QED II

Time: Friday 10:30–12:00 Location: DO26 208

Q 56.1 Fri 10:30 DO26 208

Inducing coherent oscillations between a superconducting resonator and an ensemble of NV spins I. Experiment — •Stefan Putz[1], Dmitry Krimer[2], Robert Amsüss[1], Abhilash Valookaran[1], Jörg Schmiedmayer[1], Stefan Rotter[2], and Johannes Majer[1] — [1]Atominstitut, Vienna University of Technology, Vienna, Austria — [2]Institute for Theoretical Physics, Vienna University of Technology, Vienna, Austria

Hybrid quantum systems are promising candidates for robust experiments in cavity quantum electrodynamics and for future technologies involving the processing of quantum information. A particularly attractive system in this respect is realized by strongly coupling an ensemble of spins to a cavity, which enables both the storage and the transfer of quantum information. Here we report on the observation of coherent oscillations between a superconducting resonator in the microwave regime and a large ensemble of diamond nitrogen vacancy (NV) spins deeply in the strong coupling regime. Inhomogeneous broadening in the spin ensemble and its effects on the dynamical behavior are modeled by solving Volterra integral equations as discussed in the subsequent talk. These numerical calculations show good agreement with our experimental results, and underline that a precise knowledge of the inhomogeneous spin distribution is crucial for the understanding of time domain measurements. Furthermore, we show experimentally that a reduction of the coupling strength leads to a transition between non-Markovian and Markovian decay regimes.

Q 56.2 Fri 10:45 DO26 208

Inducing coherent oscillations between a superconducting resonator and an ensemble of NV spins II. Theory — •Dmitry Krimer[1], Stefan Putz[2], Abhilash Valookaran[2], Robert Amsüss[2], Johannes Majer[2], and Stefan Rotter[1] — [1]Institute for Theoretical Physics, Vienna University of Technology, Vienna, Austria — [2]Atominstitut, Vienna University of Technology, Vienna, Austria

We study the dynamics of an ensemble of negatively charged NV centers in diamond with a strong magnetic coupling to a superconducting coplanar single-mode waveguide resonator. To accurately describe the experiment we set up a Volterra integral equation for the cavity amplitude, taking into account that the spin ensemble consists of many spins with individual frequencies, inhomogeneously distributed around a certain mean frequency. When shifting this mean frequency into resonance with the cavity mode, Rabi oscillations are found between the spin ensemble and the cavity mode which we describe accurately, including their damping which is mainly due to the non-negligible inhomogeneity of the spin distribution. Our theory predicts that this rapid decoherence process can be overcome by pumping the system by a sequence of rectangular pulses with a carrier frequency equal to the cavity mode frequency and with pulse durations matching a special resonance condition. This approach implemented successfully in the experiment, allows us not only to sustain the coherent oscillations, but even to enhance them substantially. Furthermore, our theoretical analysis discloses a crossover between Markovian and non-Markovian dynamics which is realized by varying the collective coupling strength.

Q 56.3 Fri 11:00 DO26 208

Semiclassical dynamics of laser-driven atoms in optical cavities — •Stefan Schütz[1], Hessam Habibian[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany — [2]Institut de Ciències Fotòniques, Mediterranean Technology Park, E-08860 Castelldefels (Barcelona), Spain

The formation of self-organized structures of atoms is studied when the atoms are driven by a laser and couple to the optical mode of a high-finesse cavity. Self-organization emerges due to the mechanical forces of the cavity photons on the atoms, where the cavity field is pumped by the photons scattered by the atoms from the laser and hence depends on the atomic position [1]. We derive a theoretical model where the atomic motion is treated semiclassically and the cavity field quantum mechanically. This model is valid when the cavity linewidth exceeds the atomic recoil frequency and allows us to determine the quantum state of the intracavity field at the self-organization threshold [2]. In the regime of low pump intensities we analyze the dynamics of cavity cooling [3]. The first and second order correlation functions of the cavity field are then calculated close to the self-organization threshold. The predictions are compared with the results in [4].

[1] H. Ritsch et al., Rev. Mod. Phys. 85, 553 (2013)
[2] J. Dalibard et al., J. Phys. B 18, 1661 (1985)
[3] S. Schütz et al., Phys. Rev. A 88, 033427 (2013)
[4] F. Brennecke et al., PNAS 110, 11763 (2013)

Q 56.4 Fri 11:15 DO26 208

QED with vortex electrons: quantum states and Compton scattering — •Dmitry Karlovets[1,2] and Antonino Di Piazza[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg, Germany — [2]Tomsk Polytechnic University, Lenina 30, 634050 Tomsk, Russia

We investigate theoretically quantum processes with electrons carrying orbital angular momentum ℓ with respect to the propagation axis. These so-called vortex electrons, which were created experimentally just a few years ago, possess helical wave-fronts and a magnetic moment which is proportional to ℓ. So far, the values of $\ell \sim 100\hbar$ have been realized in experiments that corresponds to the magnetic moment roughly 100 times higher than the Bohr magneton. It has recently been predicted that such a high magnetic moment can notably influence characteristics of radiation by vortex electrons [1]. We study basic QED phenomena with such electrons like Compton scattering as well as their quantum states in external field of a plane wave of arbitrary strength [2] and discuss some possibilities for experimental observation of the corresponding effects.

[1] I.P. Ivanov, D.V. Karlovets, Phys. Rev. Lett. **110**, 264801 (2013).
[2] D.V. Karlovets, Phys. Rev. A **86**, 062102 (2012).

Q 56.5 Fri 11:30 DO26 208

Spontaneous Scattering in the Quantum Regime of the Free-Electron Laser — •Rainer Endrich[1], Peter Kling[1,2], Enno Giese[1], Wolfgang P. Schleich[1], and Roland Sauerbrey[2] — [1]Institut für Quantenphysik, Universität Ulm, 89069 Ulm, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf, 01314 Dresden, Germany

Free-Electron Lasers (FEL) provide coherent and widely tunable radiation of high brilliance. Most theoretical descriptions are based on classical physics in agreement with experimental results. However, in the near future an FEL working in the quantum regime, is within reach at the Helmholtz-Zentrum Dresden-Rossendorf. In our previous work we have used a one-dimensional single-mode theory to identify an effective two-level system in which the lasing process is intuitive and the natural linewidth can be easily calculated. We now extend this model to three space dimensions and include spontaneous scattering into non-resonant modes analogously to the spontaneous emission of a two-level atom. We investigate this scattering mechanism, derive the corresponding decay constant and discuss the fundamental differences in comparison to conventional lasers.

Q 56.6 Fri 11:45 DO26 208

Polarization operator for plane-wave laser fields — •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 particle or photon beams, the non-linear regime of QED becomes experimentally accessible with presently available technology [1]. In particular, non-linear vacuum polarization effects could be investigated. For an incoming photon they are described theoretically by the polarization operator, which was – for a plane-wave background field – first calculated in [2] using an operator formalism. In [3] we have shown how this result can be obtained by using the Volkov propagator and by directly evaluating the appearing space-time integrals. Starting from this analytical expression, we have now calculated the remaining integrals numerically [4]. In particular, we have considered pair creation inside strong laser fields based on the polarization operator.

[1] A. Di Piazza, et al., Rev. Mod. Phys. **84**, 1177–1228 (2012)
[2] V. N. Baier et al., Sov. Phys. JETP **42**, 961 (1975)
[3] S. Meuren, C. H. Keitel and A. Di Piazza, Phys. Rev. D **88**, 013007 (2013)
[4] S. Meuren, K. Z. Hatsagortsyan, C. H. Keitel and A. Di Piazza, in preparation.