Photon bound state dynamics from a single artificial atom

Nadia O. Antoniadis[1]

Natasha Tomm[1], Sahand Mahmoodian[2], Rüdiger Schott[3], Sascha R. Valentin[3], Andreas D. Wieck[3], Arne Ludwig[3], Alisa Javadi[1], Richard J. Warburton[1]

[1]*University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland*
[2]*The University of Sydney, Physics Road, AU-2006 Camperdown, Australia*
[3]*Ruhr-Universität Bochum, DE-44780 Bochum, Germany*

nadia.antoniadis@unibas.ch

The interaction between photons and a single two-level atom constitutes a fundamental paradigm in quantum physics. The nonlinearity provided by the atom means that the light-matter interaction depends strongly on the number of photons interacting with the two-level system within its emission lifetime. This nonlinearity gives rise to the formation of strongly correlated quasi-particles known as photon bound states [1]. While signatures consistent with the existence of photon bound states have been measured in strongly interacting Rydberg gasses, their hallmark excitation-number-dependent dispersion and propagation velocity have not yet been observed on a single emitter.

Here we report on the direct observation of a photon-number-dependent time delay of photons scattering off a single semiconductor quantum dot coupled to a one-sided optical cavity (Fig. 1a) [2, 3]. By scattering a weak coherent pulse off the cavity-QED system and measuring the time-dependent output power and correlation functions, we show that single photons, two- and three-photon bound states incur different time delays of 144.0 ps, 66.5 ps and 45.5 ps respectively (Fig. 1b) [4]. The reduced time delay of the two-photon bound state is a fingerprint of the celebrated example of stimulated emission, where the arrival of two photons within the lifetime of an emitter causes one photon to stimulate the emission of the other from the atom. Furthermore, we show that at the optimal pulse width the two-photon scattering results in the efficient creation of two-photon bound states with a temporal wave function that matches theoretical predictions very precisely.

Figures

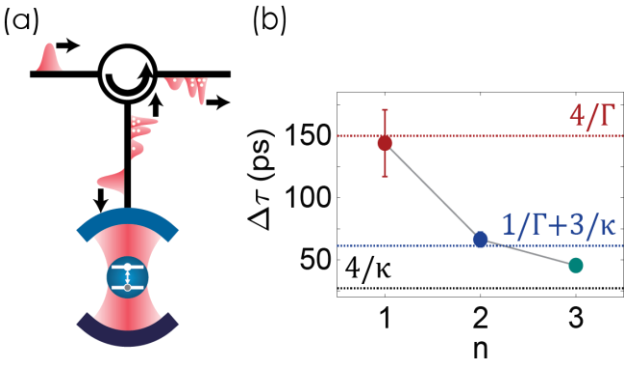

Figure 1: (a) Schematic of experimental setup for photon-number-dependent pulse scattering measurement: a Gaussian-shaped pulse of light is launched into a circulator, which guides the pulse towards a semiconductor quantum dot coupled to a one-sided cavity. States of light with different photon-number emerge at the output with different time delays; (b) Delay Δτ of scattered single-, two- and three-photon components.

References

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