Will a single two-level atom simultaneously scatter two photons?

Luke Masters\textsuperscript{1}, Xinxin Hu\textsuperscript{1}, Martin Cordier\textsuperscript{1}, Gabriele Maron\textsuperscript{1}, Lucas Pache\textsuperscript{1}, Arno Rauschenbeutel\textsuperscript{1}, Max Schemmer\textsuperscript{1}, Jürgen Volz\textsuperscript{1}

\textsuperscript{1}Department of Physics, Humboldt-Universität zu Berlin, 10099 Berlin, Germany.

The interaction of light with a two-level emitter is the most fundamental process in quantum optics and key to many applications in quantum science and technology. One peculiarity is that two photons are never simultaneously detected in the light scattered by a single quantum emitter. This is commonly interpreted to mean that a single two-level quantum emitter can only absorb and emit single photons. Here we show by spectrally filtering the fluorescence of such an emitter, that the remaining light consists of a stream of photon pairs that have been simultaneously scattered by the two-level emitter [1].

In our experiment, we trap a single $^{85}$Rb atom in an optical dipole trap and collect the fluorescence photons that are emitted by the atom, see Fig. 1. This resonance fluorescence consists of two components that are typically referred to as the coherent and incoherent component. Using an extremely narrow-band interference filter, we spectrally reject the coherent component of the collected fluorescence light, while allowing the incoherently scattered light to pass through the filter. We then measure the photon statistics of the filtered fluorescence light using a Hanbury-Brown-Twiss setup and, depending on the reduction of the coherently scattered field, observe a transition from perfect photon anti-bunching to strong photon bunching. This confirms the interpretation that photon anti-bunching in the fluorescence of a single emitter is an interference between the coherently and incoherently scattered two-photon component [2,3].

Our results provide fundamental insights into the quantum mechanical interaction between light and matter and open up new approaches for the generation of highly non-classical light fields, e.g. where a single two-level emitter can act as a source of narrowband entangled photon pairs.

Fig. 1 Schematic of our experimental setup. We trap a single $^{85}$Rb atom inside an optical dipole trap and collect its fluorescence using a high NA microscope. The collected light is subject to a narrow-band band-block filter that is realized using a fiber-based ring resonator with a variable coupler. Depending on the incoupling rate, we can change the photon statistics of the collected atomic fluorescence from anti-bunching to strong photon bunching which we measure using a Hanbury-Brown Twiss setup. Inset: Time trace of the atomic fluorescence measured without resonator.

References

[1] L. Masters, X. Hu, M. Cordier, G. Maron, L. Pache, A. Rauschenbeutel, M. Schemmer, and J. Volz, arXiv:2209.02547 (2022).
[2] J. Dalibard and S. Reynaud, Journal de Physique 44, 1337 (1983).
[3] S. Mahmoodian, M. Čepulkovskis, S. Das, P. Lodahl, K. Hammerer, and A.S. Sørensen, Phys. Rev. Lett. 121, 143601 (2018).