Physicists observe novel quantum effect that limits the number of emitted photons

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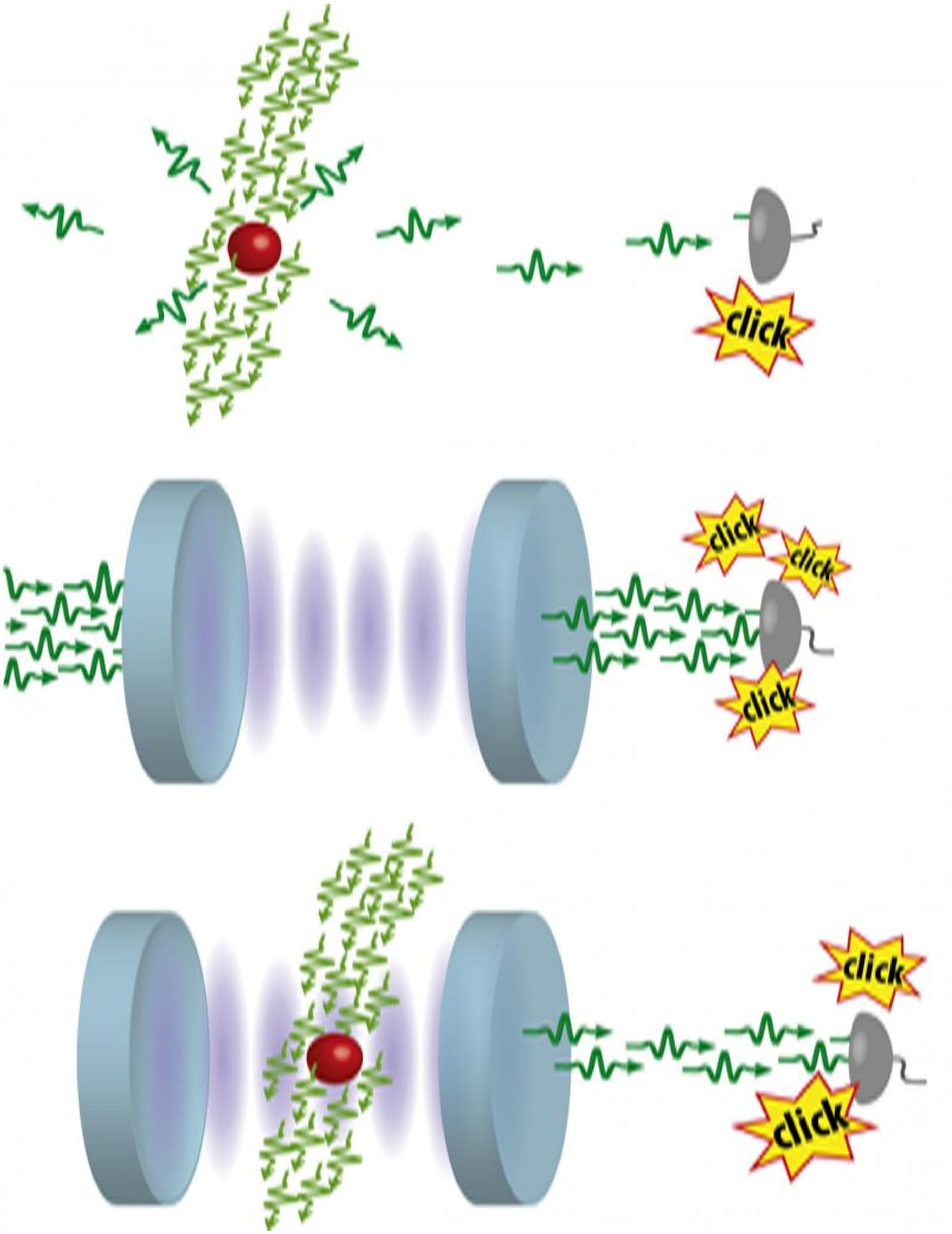

Credit: MPQ, Quantum Dynamics Division

The probability to find a certain number of photons inside a laser pulse usually corresponds to a classical distribution of independent events, the so-called Poisson-distribution. There are, however, light sources with non-classical photon number distributions that can only be described by the laws of quantum mechanics. A well-known example is the single-photon source that may find application in quantum cryptography for secret key distribution or in quantum networks for connecting quantum memories and processors. However, for many applications in nonlinear quantum optics light pulses with a certain fixed number of photons, e.g. two, three or four, are highly desirable. A team of scientists from the Quantum Dynamics Division of Professor Gerhard Rempe at the Max Planck Institute of Quantum Optics (Garching near Munich) has now succeeded to make the first steps in this direction. Using a strongly coupled atom-cavity system, they were the first to observe the so-called two-photon blockade: the system emits at most two photons at the same time since its storage capacity is limited to that number (*PRL*, 31 March 2017).

A naive approach for generating a stream of single photons would be to sufficiently attenuate the intensity of a laser beam. But in this case the number of photons still varies from pulse to pulse, and only when averaging over many pulses a mean photon number of one is observed. Applications instead require a fixed number of exactly one photon per pulse. The fluctuations of the photon number per pulse can be strongly reduced by using a single atom as a single-photon source. When the atom is illuminated by a laser beam, it can absorb only one photon at a time, thereby making a transition from the ground state to an excited state. A second photon can only be absorbed after the atom has fallen back to the ground state by emitting a photon. Therefore, no more than one photon is detected in the emitted light field at the same time, an effect that is known as "single-photon blockade".

In order to extend this principle to a "two-photon blockade" one has to go beyond a single atom and look for a system that can store more than one photon, but not more than two. To this end, the MPQ physicists combine the single atom with a cavity that provides additional storage capacities. A cavity can absorb an unlimited number of photons and exhibits a correspondingly large number of energy states that lie – similar to a "ladder" – in exactly the same distance from each other. Inserting a single atom into the cavity introduces a nonlinear element. This causes the energy levels to split by a different amount for each of the 'ladder steps'. Hence, laser light can excite the system only up to the level to which it is tuned to. The number of photons that can be stored is thus limited to a certain number, and therefore, not more photons than that can be emitted.

In the experiment, the physicists hold a single rubidium atom in an optical trap inside a cavity made of two high-finesse mirrors. The frequency of the incoming laser beam is tuned to an energy level requiring the absorption of two photons for its excitation. During the five seconds of atom storage time around 5000 measurement cycles are carried out, during which the system is irradiated by a probe laser and emission from the cavity is recorded via single-photon detectors. "Interestingly, the fluctuations in the number of emitted photons does strongly depend on whether we excite the cavity or the atom," points out the project leader Dr. Tatjana Wilk. "The effect that the absorption of two photons suppresses further absorption leading to emission of two or less photons is only achieved in case of atomic excitation. This quantum effect does not appear when we excite the cavity. In this case, we observe an enhanced signal of three and more photons per light pulse."

Christoph Hamsen, doctoral candidate at the experiment, explains the underlying processes: "When the atom is excited we are dealing with the interplay between two conflicting mechanisms. On the one hand, the atom can absorb only one photon at a time. On the other hand, the strongly coupled atom-cavity system is resonant with a two-photon transition. This interplay leads to a sequence of light pluses with a non-classical photon distribution." And Nicolas Tolazzi, another doctoral candidate, adds: "We were able to observe this behaviour in correlations between detected photons where the coincidence of three photons was significantly suppressed compared to the expectation for the classical case."

Prof. Gerhard Rempe gives an outlook on possible extensions of the experiment: "At present, our system emits light pulses with two photons at maximum, but also pulses with fewer, one or even zero, photons. It acts like a kind of 'low pass'. There are, however, a number of applications for quantum communicating and quantum information processing where exactly two, three or four photons are required. Our ultimate goal is the generation of pure states where each light pulse contains exactly the same desired number of photons. The two-photon blockade demonstrated in our experiment is the first step in this direction." Olivia Meyer-Streng

More information: Christoph Hamsen et al. Two-Photon Blockade in an Atom-Driven Cavity QED System, *Physical Review Letters* (2017). DOI: 10.1103/PhysRevLett.118.133604

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