## Single atom photon pair source

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**Abstract.** Sources of entangled photon pairs are a crucial ingredient for many applications in quantum information and communication. Of particular interest are narrow-band sources with bandwidths that are compatible with solid state systems such as atomic media for storage and manipulation of the photons. Here, we experimentally realize a source of energy-time entangled photon pairs where the photons pairs are generated by scattering light from a single two-level atom and separated from the coherently scattered light via a narrow-band filter. We verify the performance of our pair-source by measuring the second order correlation function of the atomic fluorescence and we observe that one can continuously tune the photon statistics of the atomic fluorescence from perfect photon anti-bunching to strong photon bunching expected for a photon pair source. Our experiment demonstrates a novel way to realize a photon pair source for photons with spectral bandwidths and resonance frequencies that are inherently compatible with atomic media.

### **1** Introduction

For a single quantum emitter one typically assumes that it can only emit photons one by one. As a consequence, light scattered by such emitters exhibits strong non-classical properties that e.g. manifest themselves in perfect photonantibunching in the second order correlation function. For this reason, quantum emitters are typically used in many experiments as a source of single photons. Here, we show that in general photon emission from a single quantum emitter can be described as an interference phenomena between two different two-photon amplitudes in the scattered light that are typically referred to as coherently and incoherently scattered component of the atomic fluorescence. In this picture, the perfect photon anti-bunching observed for single emitters arises from the complete destructive interference of the two components[1?, 2]. Due to their different spectral properties[4] it is possible to experimentally separate the coherently and incoherently scattered light. In this way, in our experiment we collect only the incoherently scattered part of the fluorescence and realize a single-atom-based source of ultra narrow-band energytime entangled photon pairs.

### 2 Experimental principle and setup

In general, the light scattered by a single quantum emitter can be decomposed into two parts that are coherent or incoherent with respect to the excitation light field. The coherent part has the same spectral properties as the excitation field, while the spectrum of the incoherent light is composed of energy-time entangled photon pairs that are contained within two frequency sidebands. These sidebands are separated from the excitation frequency and



**Figure 1.** Schematic of out experimental setup. We trap a single <sup>85</sup>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.

have a width given by the line-width of the atomic transitions. Using frequency selective components the amplitude of these two components can be individually controlled which we make use of to spectrally remove the coherently scattered part from the incoherently scattered light.

In our experiment, we use a single <sup>85</sup>Rb atom as photon-pair source which is trapped in an optical optical

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dipole trap located in the center of a magneto-optical trap (MOT). The fluorescence of the atom in the MOT beams is collected with a high NA lens and coupled into a single mode optical fiber, see Fig 1. The coherently scattered light has the same spectral properties as our MOT laser while the entangled photon pairs have a spectral width of 6 MHz and are spectrally separated from the MOT laser by the effective Rabi frequency of the atom of about 50 MHz. To remove the coherent part, we introduce an ultranarrow-band optical band block filter into the collected fluorescence. The filter is realized using a fiber-integrated ring resonator with an adjustable incoupling rate and a line-width of about 4 MHz. The resonator is set to resonance with the MOT light and removes the coherently scattered light from the atomic fluorescence while the photon pairs are not affected. In this way, the remaining light contains only the incoherently scattered light from the atom made of photon pairs.

# 3 Experimental characterization of our source

In order to study the performance of our photon pair source we record the photon statistics of the light after our collection and filtering optics. Using a Hanbury-Brwon Twiss setup, we record the second order correlation function of the fluorescence light. In our experiment, we can arbitrarily adjust the coupling rate to the filter-resonator, and thus the transmitted fraction of the coherently scattered light from the atom. This allows us to continuously change the second order correlation function of the collected light from perfect photon anti-bunching without frequency filter to strong photon bunching when setting the resonator to critical coupling such that it absorbs all coherently scattered light. In this way, we characterize the key features of our source such as photon pair rate and its ratio to single photon rate which we compare to the theoretical expectation for our system.

### 4 Outlook

Our results shed light on the physical mechanism that underlies atomic resonance fluorescence. At the same time it provides a new way to generate ultra narrow-band photon pairs that inherently match the spectral properties of the employed quantum emitter. This scheme is universal and will work with any type of quantum emitter. Thus, it can be employed to generate entangled photons with any spectral width for any part of the electromagnetic spectrum as long as a two-level quantum emitter with the desired spectral properties is available.

#### References

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