Tunable single photon source from an atomic quantum memory for storage in a highly excited Rydberg state

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Quantum information science and technology critically rely on generation and processing of single photons, the natural carriers of quantum information in this context. The ability to realize strong interactions between single photons would enable new powerful applications like photonic quantum computing or deterministic Bell state measurements [1]. A promising approach to obtain that capability is based on mediating photon-photon interactions via strong Dipole-Dipole interactions, when one photon is stored via electromagnetically induced transparency (EIT) in a Rydberg atom. This, however, requires single photons, which are spectrally compatible with the conditions set by the atomic energy structure and EIT.

We present a single photon source based on a cold cloud of Rubidium atoms, which is capable of generating single photons with highly tunable wave shape [2]. We follow the DLCZ protocol [3] to generate single read photons, which are emitted on demand after a single collective spin excitation inside the cloud was heralded by an initial write photon. By tuning the shape of the classical read-out pulse, we demonstrate that single read photons with durations varying over three orders of magnitude up to 10 µs can be generated without a significant change of read-out efficiency. We prove the non-classicality of the emitted photons by measuring their antibunching, showing near single photon behavior at low excitation probabilities. We also show that the photons are emitted in a pure state by measuring unconditional autocorrelation functions. Finally, to demonstrate the usability of the source for realistic applications, we create ultra-long single photons with a rising exponential or doubly peaked wave shape which are important for several quantum information tasks.

The tunability of our source permitted us to generate single photons which are compatible with a Rydberg atomic system. We performed an experiment, in which we first generated single photons of subnatural linewidth and afterwards stored them via EIT as a Rydberg excitation in a different cold Rubidium cloud [4]. We demonstrated that after storage and retrieval of the single photon on a highly excited Rydberg (n=60) the quantum correlations between the initial write photon and the retrieved read photon are preserved. We show that quantum statistics persist up to storage times of around 5 µs in the Rydberg medium and 30 µs in the DLCZ system. Finally, we prove the highly nonlinear response of the Rydberg ensemble by sending weak coherent states.

Our result is an important step towards deterministic photon–photon interactions, and may enable deterministic Bell-state measurements with multimode quantum memories.

References