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

<u>Pau Farrera</u> [1]***, Emanuele Distante*** [1]***, Auxiliadora Padrón-Brito*** [1]***, Boris Albrecht*** [1]***, David Paredes-Barato*** [1]***, Georg Heinze*** [1]***, and Hugues de Riedmatten*** [1,2]

1. ICFO-Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels (Barcelona), Spain

2. ICREA-Institució Catalana de Recerca i Estudis Avançats, 08015 Barcelona, Spain

Melvyn Ho [3]***, Matías Chávez*** [3]***, Colin Teo*** [4,5]***, and Nicolas Sangouard*** [3]

3. Department of Physics, University of Basel, Klingelbergstrasse 82, 4056 Basel, Switzerland

4. Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, A-6020 Innsbruck, Austria

5. Institute for Theoretical Physics, University of Innsbruck, A-6020 Innsbruck, Austria

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 tunablility 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 Rubidum 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

[1] D. E. Chang, V. Vuletić, and M. D. Lukin, Nat. Photonics **8**, 685-694 (2014).

[2] P. Farrera, G. Heinze, B. Albrecht, M. Ho, M. Chávez, C. Teo, N. Sangouard, and H. de Riedmatten, Nat. Commun. **7**, 13556 (2016).

[3] L. M. Duan, M. D. Lukin, J. I. Cirac, and P. Zoller, Nature **414**, 413 (2001).

[4] E. Distante, P. Farrera, A. Padrón-Brito, D. Paredes-Barato, G. Heinze, and H. de Riedmatten, Nat. Commun. **8**, 14072 (2017).