Towards Non-Linear Interaction of Rydberg Atoms with Quantum States of Light

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A promising approach to future quantum communication & processing builds on quantum states of light and light-matter interfaces [1]. Light would act as carrier of information, while light-matter interfaces provide storage or processing capabilities.

Collective Rydberg excitations have recently sparked interest for its potential to realize deterministic two-qubit gates and efficient coupling to photons, vital for the above-mentioned applications. Due to dipole-dipole interactions present in highly-excited atoms, such Rydberg media show a non-linear response already at the single input photon level. However, to date, all demonstrations of this light-matter interaction used classical input states of light, or Rydberg media without strong non-linearity [2,3].

Here, we aim at showing the interaction of a strongly nonlinear Rydberg medium with quantum states of light. To that end, we derive single photons from a DLCZ quantum memory [4]. In a laser-cooled cloud of Rubidium, a four-wave-mixing process is driven. Pairs of signal and idler photons are emitted, where the detection of the signal projects the idler onto a single photon with sub-Poissonian statistics. The idler photon is collected and guided to a second laser-cooled cloud. Here, it is collectively absorbed in a two-photon transition (facilitated by a strong coupling pulse), creating a spin wave in a highly-excited Rydberg state. The excitation can be retrieved by switching on the coupling pulse again.

After showing the successful interaction of a single photon with a single collective Rydberg excitation, we plan to investigate several fundamental aspects of light-matter interaction & quantum optics. For example, the Rydberg media should prohibit the promotion of two excitations simultaneously to the Rydberg state. This means that if the idler photon carried a two-photon component, the Rydberg interaction should block the transmission of this second photon. Furthermore, it is expected that the atomic excitation is differently affected by the interaction with single photons compared to Poissonian light.

While both setups are already operational, we are currently implementing the improvements necessary for the upcoming experiment.

References

[1] Sangouard, Simon, de Riedmatten, Gisin, Rev Mod Phys **83**, 33 (2011)
[2] Stolz et. al., arXiv:2111.09915 (2021)
[3] Distante et. al., NatComm **8**, 14072 (2017)
[4] Duan, Lukin, Cirac, Zoller, Nature **414**, 413-418 (2001)

Figures

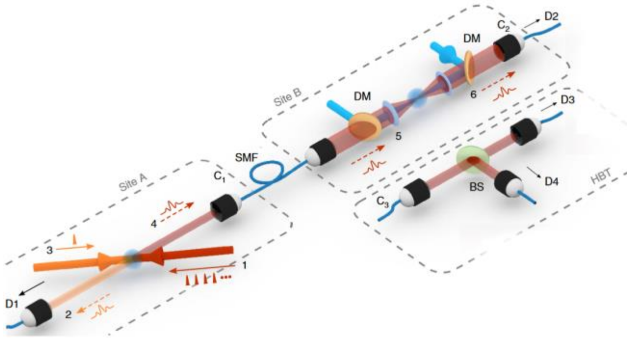

Figure 1: Sketch of the planned experiment, with the source, the Rydberg media and the detection setup. Sketch adapted from [3].