Congratulations to New ICFO PhD Graduate

Dr. Lukas Heller graduated with a thesis entitled ?Exploring quantum memory schemes in cold atoms for quantum repeaters'

November 06, 2023

We congratulate Dr. Lukas Heller who defended his thesis today in ICFO's Auditorium.
Dr. Lukas Heller obtained his MSc in Physics at Friedrich Schiller University of Jena in Germany. He joined the Quantum Photonics with Solids and Atoms research group at ICFO led by ICREA Prof. Dr. Hughes de Riedmatten as a PhD student.
Dr. Heller's thesis entitled ?Exploring quantum memory schemes in cold atoms for quantum repeaters' was supervised by ICREA Prof. Dr. Hugues de Riedmatten.

ABSTRACT:

Quantum memories are devices that are able to store photonic quantum states and entanglement. Future quantum networks, which could enhance cybersecurity through quantum key distribution, improve the precision in atomic clock networks, and connect quantum devices over long distances, rely on them. This thesis reports on experiments towards improved quantum memories for quantum repeaters used in long-distance quantum communication.

The quantum memory is based on a cloud of laser-cooled Rubidium-87. Thanks to collective interference effects, this system enhances the light-matter interaction compared to that of a single atom. This is exploited to either create long-lived quantum correlations between light and atomic excitations through probabilistic light scattering (DLCZ protocol) or to efficiently absorb an incoming single photon (Raman protocol). In both cases, the excitation is retrieved after a programmable delay as a single photon. An optical cavity around the atoms further enhances the light-matter coupling.

In a first experiment, the DLCZ protocol is combined with a photon echo protocol, allowing for the sequential creation of excitations in N distinguishable temporal modes. This is known as temporal multiplexing. Multiplexing improves the rate at which entanglement is created in a network link by a factor N. Here, the cavity is essential to suppress noise originating from the probabilistic scattering of light in the DLCZ protocol. Ten temporal modes are stored while maintaining strong quantum correlations between the scattered photon and the atomic excitation.

In a second experiment, a quasi-deterministic single photon is stored in the cloud following the Raman protocol. The photon originates from an ensemble of laser-cooled Rydberg atoms. Strong dipole-dipole interactions prevent the excitation of more than one atom to the Rydberg level, leading to the creation of a single collective Rydberg excitation which is later retrieved as a single photon. A deterministic source, opposed to a probabilistic source, improves the entanglement creation rate as it generates single photons at higher rates. The single photon is stored and faithfully retrieved from the memory while maintaining its single-photon nature. The cavity is not being used in this experiment.

In a third experiment, the retrieval efficiency of a stored excitation is increased by cavity-enhancing the read-out process. Highly-efficient memories are important because the entanglement distribution scales strongly with memory efficiency. The intra-cavity efficiency could be improved by a factor 2-3, depending on the protocol, even for a non-optimal cavity setup.

Finally, ongoing work towards efficient entanglement between an atomic excitation and a telecom photon is presented, involving a cavity-enhanced DLCZ memory, an atomic dipole trap and quantum frequency conversion (QFC) to the telecom C-band. As the memory operates in the optical domain, where photonic transmission losses are large, QFC will be needed to communicate over large distances. This setup will be used in the future for a hybrid experiment connecting the cold atomic memory to a solid state memory.

These investigations target intrinsic limitations of early, proof-of-principle quantum links. They can therefore help to build practical links in the future.

Thesis Committee:

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Thesis Committee