Uniting Quantum Processing Nodes of Cavity-coupled Ions with Rare-earth Quantum Repeaters Using Single-photon Pulse Shaping Based on Atomic Frequency Comb

[1,2]**Pierre Cussenot**
[1]B. Grivet, [3]B.P. Lanyon, [3]T.E. Northup, [4,5]H. de Riedmatten, [6]A.S. Sørensen, & [1]N. Sangouard

[1] *Université Paris–Saclay, CEA, CNRS, Institut de physique théorique, 91 191 Gif-sur-Yvette, France*
[2] *Direction Générale de l'Armement, 75 015 Paris, France*
[3] *Institut für Experimentalphysik, Universität Innsbruck, Technikerstraße 25, 6020 Innsbruck, Austria*
[4] *ICFO – Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, Spain*
[5] *ICREA – Institució Catalana de Recerca i Estudis Avançats, 08015 Barcelona, Spain*
[6] *Center for Hybrid Quantum Networks (Hy-Q), The Niels Bohr Institute, University of Copenhagen, Blegdamsvej 17, DK-2100 Copenhagen Ø, Denmark*

pierre.cussenot@ipht.fr

Connecting quantum processing nodes at a distance is an important challenge in the context of distributed quantum computing. Here [1], we present a new network architecture for remotely connecting cavity-coupled trapped ions processing nodes via a quantum repeater backbone based on rare-earth-doped crystals. The main challenge for its realisation lies in interfacing these two physical platforms, which produce photons with a typical temporal mismatch of one or two orders of magnitude. To address this, we propose an efficient method that enables custom temporal reshaping of single-photon pulses whilst preserving purity. Our approach is to modify a commonly used memory protocol, called cavity-assisted Atomic Frequency Comb [2], for systems exhibiting inhomogeneous broadening like rare-earth-doped crystals. Using a custom sequential readout technique, it is possible in the impedance-matching regime to achieve an arbitrary temporal shaping at the quantum level. In a feasibility study based on recent experiments, it is shown that the photon waveform from a Pr^{3+}:Y_2SiO_5 memory [3] can be made almost indistinguishable from a pure component of the photon mixed state emitted by a single $^{40}Ca^{+}$ ion embedded in a high finesse cavity [4] (99 % overlap instead of 32 %). Addressing the general problem of how to interface two physical platforms that interact with light on very different timescales, we thus offer a viable and tangible solution for uniting quantum processing nodes with a quantum repeater backbone.

References

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