Cavity-Assisted highly efficient Atomic Frequency Comb Solid-State Quantum Memory

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The realization of large scale quantum networks requires the distribution of entanglement over large distances. In this long-range regime, direct transmission is prohibitive due to losses in optical fibers. Quantum repeaters are predicted to overcome direct transmission and allow entanglement distribution over a continental scale. Most quantum repeater schemes rely on the storage of quantum bits into quantum memories. In order for memories to be useful in practical implementations, they must exhibit several features including a long storage time, a high storage efficiency and a large multiplexing capability. Solid-state quantum memories based on rare-earth doped solids promise excellent performances in terms of storage time and multiplexing capability. However, the efficiency for the storage of quantum bits was so far limited to around 30%.

Here, we improved this efficiency by implementing a cavity-enhanced quantum memory in a Pr^{3+}: Y_2SiO_5 crystal. We use the atomic frequency comb (AFC) protocol [1], which offers intrinsic temporal multimodality. The forward retrieval efficiency of this protocol is theoretically limited to 54%. It is known that this limit can be overcome by embedding the crystal in an impedance-matched cavity to enhance the interaction with the material [2]. So far, the highest storage efficiency with this protocol was 56% for storage of classical pulses [3] and 27% for quantum storage [4]. With the setup sketched in Figure 1, we reached 62% efficiency for storing weak coherent states with a mean photon number of 0.2 photons/pulse. Furthermore, we were able to store weak coherent time-bin qubits with 52% efficiency and more than 95 % fidelity. Moreover, we report the first demonstration of cavity enhanced on-demand AFC memories at the single photon level. Currently the performance is limited by the intra-cavity losses and cavity bandwidth, which is dominated by the slow light effect caused by the sharp spectral features we burn inside our crystal.

In future experiments we plan to increase these efficiencies and to store single photons generated from a cavity-enhanced spontaneous-parametric down-conversion source.

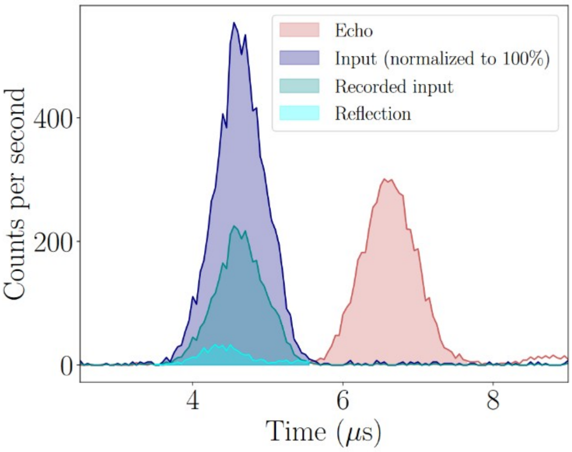

Figure 1: Histogram of both the input (cyan) and echo (red pulse) after 2μs. The mean photon number in the input pulse was 0.2 photons/pulse. The recorded input pulse (cyan pulse) is the reflected 40% of the original input pulse. The dark blue pulse is the input scaled to 100%. The ratio between the echo and the reconstructed input pulse yields 62% storage efficiency. The reflection from the cavity (light blue pulse) was 6%.

References

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