Cavity-assisted highly efficient AFC optical memory in $Pr^{3+}:Y_2SiO_5$

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Abstract

In a quantum network, distributing entanglement over large distances is an essential feature in order to establish communication between different points. In this long-range regime, direct transmission is prohibitive due to losses in optical fibers; therefore, quantum repeaters are required to accomplish this task. Many schemes of quantum repeaters rely on the storage of quantum bits into quantum memories. In order for memories to be useful in practical implementations, they must exhibit multimodality, long storage time and a high storage efficiency.

In our experiment, we implemented a cavity-enhanced quantum memory using the atomic frequency comb (AFC) protocol in a $Pr^{3+}: Y_2SiO_5$ crystal [1].

The 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. At the single photon level, this is the highest efficiency achieved so far with a cavity-enhanced quantum memory.

Furthermore, we were able to store weak coherent time-bin qubits with 45% efficiency and analyze them by means of an unbalanced Mach-Zehnder based on a second AFC memory with a storage time equal to the time-bin separation. 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 it is planned to increase these efficiencies and to extend the storage time to tens of microseconds.

References

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Figures

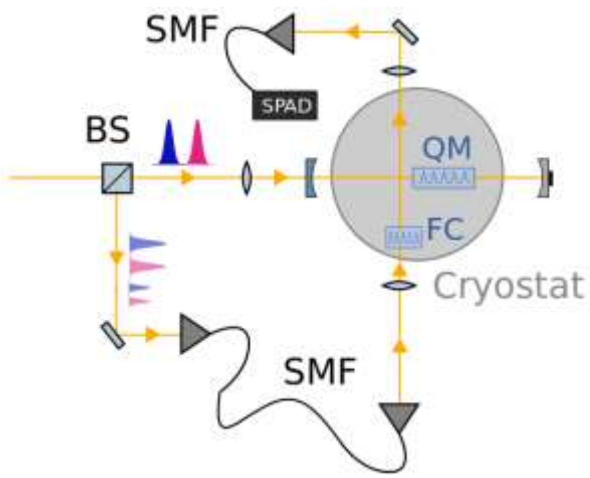

Figure 1: Sketch of our setup. The cavity is built around the cryostat vacuum chamber and has a finesse of 6. Two $Pr^{3+}: Y_2SiO_5$ crystals are sitting inside, cooled down at 3.2K: a memory crystal (QM) and a filter crystal for interfering qubits (FC).