Engineering noiseless quantum memories for temporal mode manipulation

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Our quantum memory (QM) system of choice operates using warm caesium vapour, based on an off-resonant Raman scattering protocol [1], which combines high storage efficiencies, GHz bandwidth storage, and single-mode operation. It can manipulate temporal modes (TM) of light - complex temporal amplitudes of pulsed single photons - which have been identified as an appealing quantum information basis for quantum networks [2]. We show TM manipulation and conversion between different Hermite-Gaussian (HG) modes (Figures 1a,b), fully converting between the first five basis states. This shows that our QM is a versatile device for TM manipulation in this qudit basis ($d \geq 5$).
Additionally, noise-free operation is of utmost importance. Four-wave mixing (FWM) noise within the Raman memory has previously been identified as the key limiting factor in reaching quantum level operation [3]. Here we present a novel noise suppression scheme by arranging the memory interaction such that the FWM is resonantly absorbed (Figure 3). By developing a model for the output $g^{(2)}$ we are able to predict the statistics for the retrieved state, given a single photon input. We are able to show that this method could retrieve a non-classical state from a single-photon, providing the heralding efficiency was greater than 27% [4].
Eliminating the noise pathway means our system is capable of manipulating and storing an arbitrary and user-chosen quantum states in the temporal mode basis, with additional applications such as temporal wavepacket re-shaping for efficient interfacing in hybrid quantum systems.

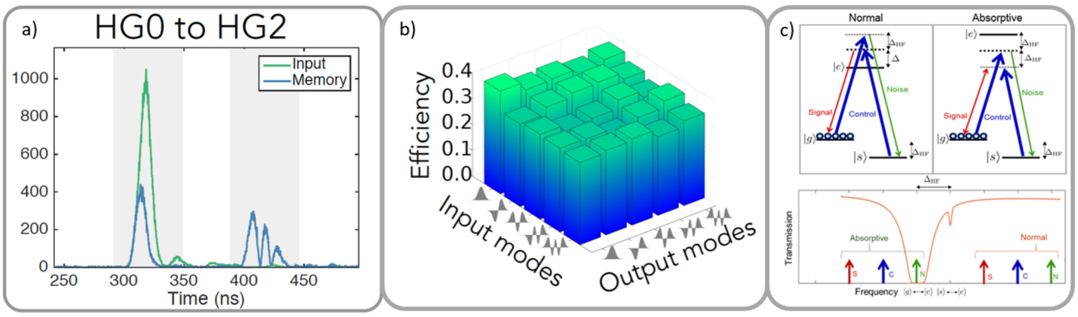

Figure 1a Input/output (green/blue) of QM demonstrating conversion from the 0th to 2nd order HG modes. **1b** Conversion efficiency between first five HG modes. **1c** (upper) Energy level diagram showing Raman memory & FWM fields. (lower) Transmission spectra of Cs field detunings in normal QM operation and in absorptive suppression mode.

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