Upper Bound on the Duration of Quantum Jumps

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Abstract: We estimate the time scale of quantum jumps from the time correlation of photon pairs generated from a cascade decay in a cold cloud of ^{87}Rb. We find an upper bound of 21 ± 11 ps.

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1. Introduction

Since the original formulation of the quantum theory [1], there is no satisfactory description of the transition between discrete energy states of atoms, or quantum jumps. The established technique for observing quantum jumps, based on shelving configuration [2], has an intrinsically limited time resolution because it relies on a null measurement [3].

In this work [4] we consider an alternative configuration for the observation of quantum jumps in atomic systems: a monitored cascade three-level system. The second order time correlation of the generated photon pair (Fig. 1(Left)) shows an exponential decay, associated with spontaneous decay, and a sharp rise, associated with the quantum jump.

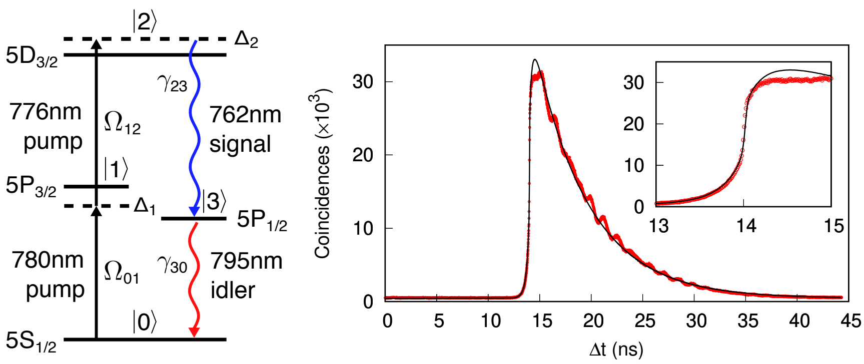

Fig. 1. (Left) Atomic level configuration in a four-wave mixing experiment and time evolution of the population of level $|3\rangle$, conditioned on the detection of a signal photon. (Right) Histogram $G_{\mathrm{FWM}}(\Delta t)$ of detection time differences for photons pairs generated by four-wave mixing in the cold cloud of ^{87}Rb. The continuous line shows the result of the best fit of the heuristic model. Inset: detail of the sharp rise corresponding to a quantum jump.

2. Experiment

Pump beams at 780 nm and 776 nm excite ^{87}Rb atoms in a cold cloud from the $5S_{1/2}, F = 2$ ground level to the $5D_{3/2}, F = 3$ level via a two-photon transition. The signal (762 nm) and idler (795 nm) photons emerge from a cascade decay back to the ground level through the $5P_{1/2}$ level, and are coupled to single mode fibers. Phase matching ensures all four modes propagating in the same direction. The linearly polarized pump mode at 780 nm is red-detuned by 40 MHz from the $5S_{1/2}, F = 2$ to $5P_{3/2}, F = 3$ while the orthogonally polarized pump mode at 776 nm is tuned such that the two-photon excitation is blue-detuned by 4 MHz from the difference between the ground state and the $5D_{3/2}, F = 3$ level. We record the detection event time differences of the photon pairs with an effective time resolution below 10 ps (Fig. 1(Right)); the single photon avalanche detectors themselves have a nominal timing jitter around 50 ps FWHM.

To improve the time resolution for observing any possible jump dynamics, we measured the impulse response of the single photon detectors using photon pairs with a large optical bandwidth generated by spontaneous parametric down-conversion in a nonlinear optical crystal.

3. Results and Conclusions

We do not have a model for the transition dynamics, but we can establish an upper bound on its duration using a smooth heuristic transition that admits the step function as a limiting scenario to describe it

$$\sigma(x) = \frac{1}{1+\exp(-x)} \tag{1}$$

combined with an exponential decay

$$y(\Delta t;\alpha,\tau) = \sigma\left(\frac{\Delta t}{\alpha}\right)\exp\left(-\frac{\Delta t}{\tau}\right). \tag{2}$$

From combining Eq. (2) with the measured detectors impulse response and fitting the resulting functions to the measured time correlation in Fig. 1(Right) we estimate$\alpha = 4.7 \pm 2.5$ ps, corresponding to a 10%–90% rise time associated with the jump of 21 ± 11 ps.

References

1. N. Bohr, "I. on the constitution of atoms and molecules," The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science **26**, 1–25 (1913).
2. W. M. Itano, J. C. Bergquist, and D. J. Wineland, "Early observations of macroscopic quantum jumps in single atoms," International Journal of Mass Spectrometry **377**, 403–409 (2015).
3. D. T. Pegg, "Wavefunction collapse time," Physics Letters A **153**, 263–264 (1991).
4. M. A. Seidler, R. Gutiérrez-Jáuregui, A. Cerè, R. Jáuregui, and C. Kurtsiefer, "Upper bound on the duration of quantum jumps," arXiv:1812.00129 (2018).