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D1.3 Optimized pulse shapes for optimal single-photon output from microcells

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D1.3 Optimized pulse shapes for optimal single-photon output from microcells

In cooperation with the experimentalists group of Prof. Pfau in Stuttgart we analyzed a single photon source based on micro cells of thermal Rubidium vapor. The general idea is to create an entangled collective state carrying one Rydberg excitation by three driving lasers. The underlying physics that make this possible is the Rydberg blockade mechanism which means that one Rydberg excited atom shifts the excited level of its neighbouring atoms out of the resonance of the driving laser and suppresses double excitation. The obtained collective state has imprinted the phase information of the lasers and by this will decay in a collective and directed way emitting one single photon with specified spatial distribution. By means of optimal control (using the Chopped RAndom Basis (CRAB) algorithm) we can improve the laser protocol of this state preparation. To this aim and also to analyze the prepared state we use a matrix product states code to simulate the time evolution of the system.

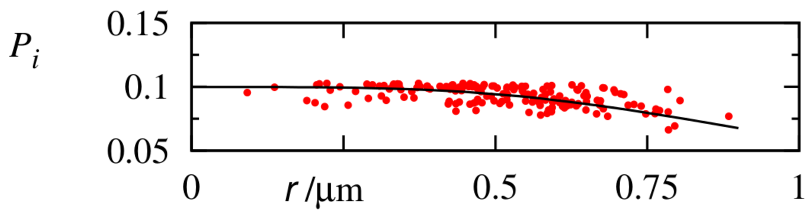

Figure 1. *3D cloud of N = 10 randomly distributed atoms: Errors in the state preparation. Pi calculated by MPS simulation compared to the theory curve obtained for a single atom excitation in homogeneous spherical cloud calculated in the thermodynamical limit.*

The main improvement is that one can construct a collective state with the single excitation shared over a bigger volume and thus more participating atoms and better directionality of the outgoing photon as the higher number of atoms and the fact that they are spread over a bigger volume both contribute to a better phase information. The thermal nature of the atomic vapor works against the desired directionality. However, we could show that within the range of experimentally feasible parameters a single photon source is possible. We have recently submitted an article on that theoretical analysis [1].

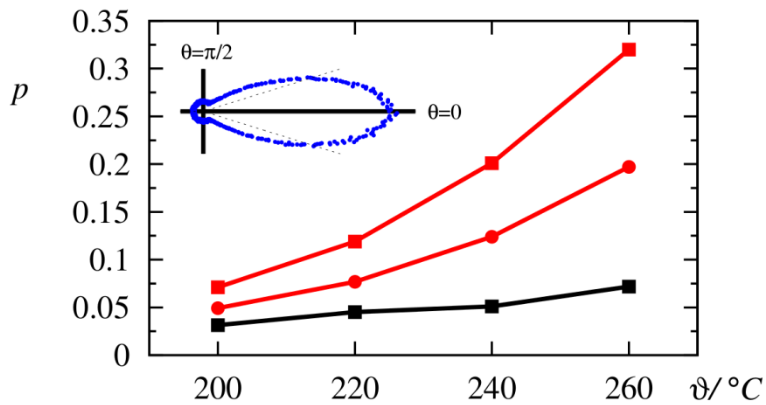

Figure 2. Directionality p as a function of temperature ϑ for parallel lasers (red) and anti parallel lasers (black). Squares are values from state preparation with optimized pulses, circles from Gaussian π-pulses. The inset shows the emission cone on resonance for ϑ = 220°C and anti parallel lasers.

Another publication [2] combines results presented at M12 on collective emission with new results on controlled emission profile through use of time dependent classical driving pulses. The work deals with an atomic ensemble of multi-level atoms where Rydberg blockade is used to prepare an initial state with a singly occupied metastable state (Fig.3). That state is driven towards an optically excited state from which collective spontaneous emission takes the atom to the common collective ground state of all atoms. Both analytical and efficient numerical tools to temporally shape the outgoing light pulse, e.g., to make it optimal for collective absorption by another ensemble (Fig.4) are presented.

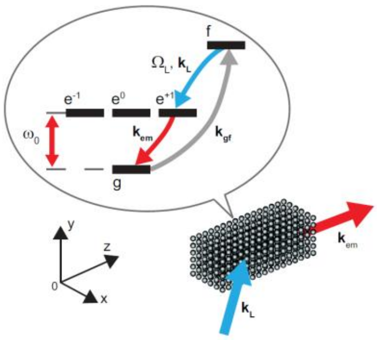

Figure 3 *Level scheme and collective emission*

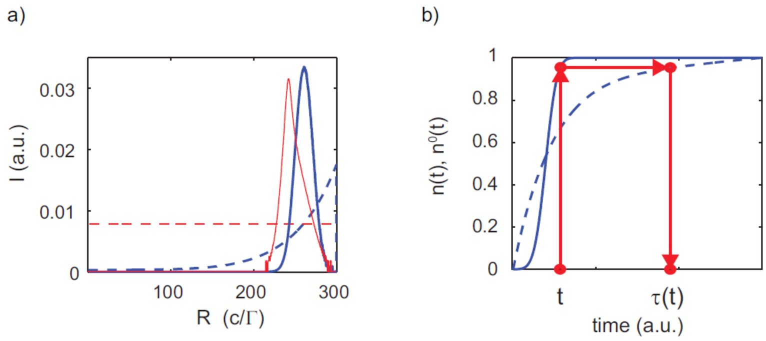

Figure 4 a) Emitted pulse (red curve), and desired Gaussian looking field (blue curve) – the dashed curves show the corresponding constant and the modulated outcoupling classical fields. **b)** Construction algorithm for production of arbitrary field by matching the time dependent integrated output power via scaled transformation of time.

[1] M. M. Müller, A. Kölle, R. Löw, T. Pfau, T. Calarco, S. Montangero, *Room Temperature Rydberg Single Photon Source*; arXiv:1212.2811

[2] Y. Miroshnychenko, U. V. Poulsen and K. Mølmer, *Directional emission of single photons from small atomic samples;* arXiv:1208.5633
[accepted in Physical Review A]