Observation of Light Extinction by a Single Trapped Atom

Tey Meng Khoon[1], Zilong Chen[1,2], Brenda Chng[1], Syed Abdullah Aljunid[1],
Gleb Maslennikov[1], Antia Lamas-Linares[1], Christian Kurtsiefer[1]
[1]Department of Physics, National University of Singapore
[2]Institute of Materials Research and Engineering, Singapore

Motivation

Atom-photon interfaces will be one of the core building blocks in future quantum information protocols. While photons are ideal carriers for transporting quantum information over long distances, atoms can be used to store and process information. Our goal is to understand the basic interaction process of a single photon and a single atom for that purpose. Specifically, we want to investigate photon-photon scattering with an atomic resonance as a provider of high optical nonlinearity. Eventually, such a scattering process can be used as a building block for a universal quantum gate for photonic qubits.

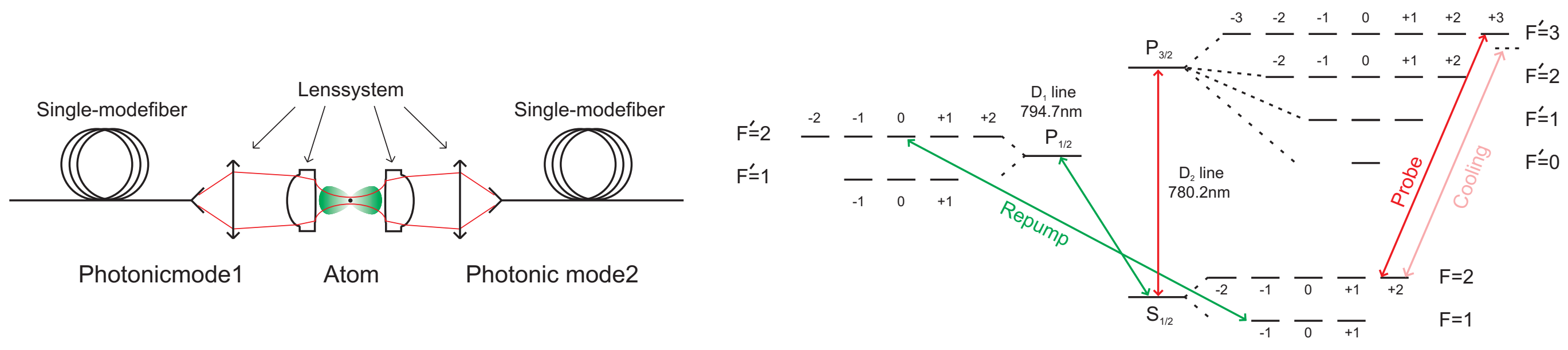

FIGURE 1: (Left) Schematic of a free-space atom-photon interface. With the help of conventional optics light from a single-mode fibers (red) is coupled to an atomic dipole absorption(emission) mode (green).(Right) Atomic energy levels of ^{87}Rb. Arrows show the lasers used to cool and probe atom in a dipole trap

Strength of coupling of a single atom to a light field can be quantified by the absorption cross-section. For a 2-level system, interacting with a resonant light, value of an absorption cross-section at resonant frequency can reach the maximal value of $3\lambda^2/2\pi$. We present an experimental setup in which this quantity can be measured directly, by monitoring a transmission of a resonant laser light that shares the same spatial mode with a localized atom.

Experimental Setup

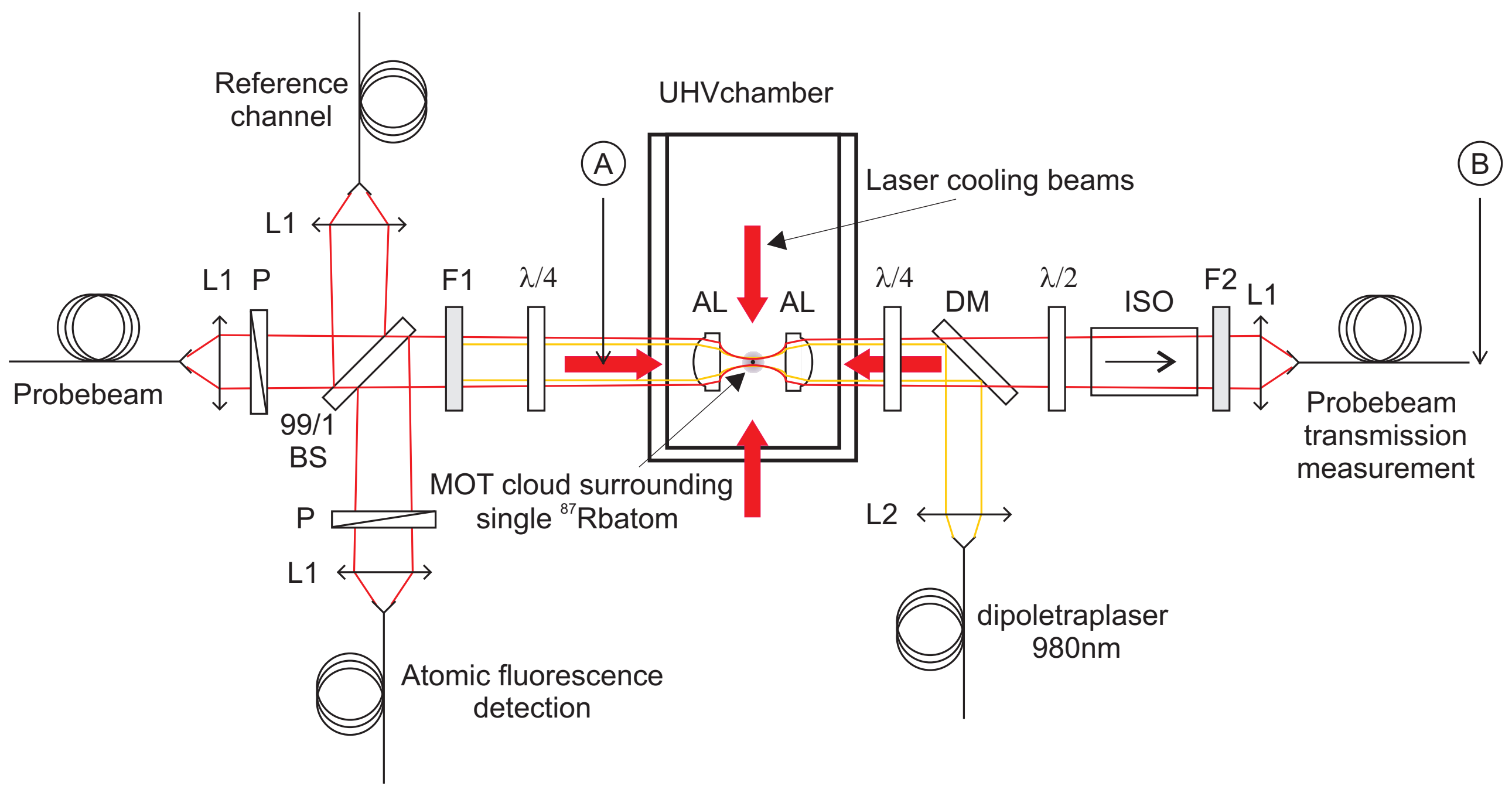

FIGURE 2: AL — confocal aspheric lenses (NA = 0.55), DM — dichroic mirror, reflecting a dipole trap laser at 980 nm, transmitting atomic fluorescence and probe at 780 nm, BS — nonpolarizing beamsplitter with a splitting ratio of 99/1, F1 — set of filters suppressing dipole trap laser, F2 — laser line filter centered at 780 nm, P — polarization beamsplitters, ISO — optical isolator, blocking a backreflected light.

In the presented setup, atoms are loaded in a far-off detuned dipole trap (FORT) from a magneto-optical trap (MOT). The center of a MOT cloud is overlapped with a focus of a dipole trap laser. The small size of the trap ensures that at a given time there is either one or no atom in it. In order to verify this, we perform an experiment in which the antibunching effect in an atomic fluorescence is observed.

Detection of Single Atoms by their Fluorescence

Once the atom is trapped in a dipole potential, the atomic fluorescence from a single atom is collected in a confocal arrangement, through the same lens which focuses the trap beam. Observation of a binary signal in atomic fluorescence is a "necessary" condition for stating that we have captured a single atom.

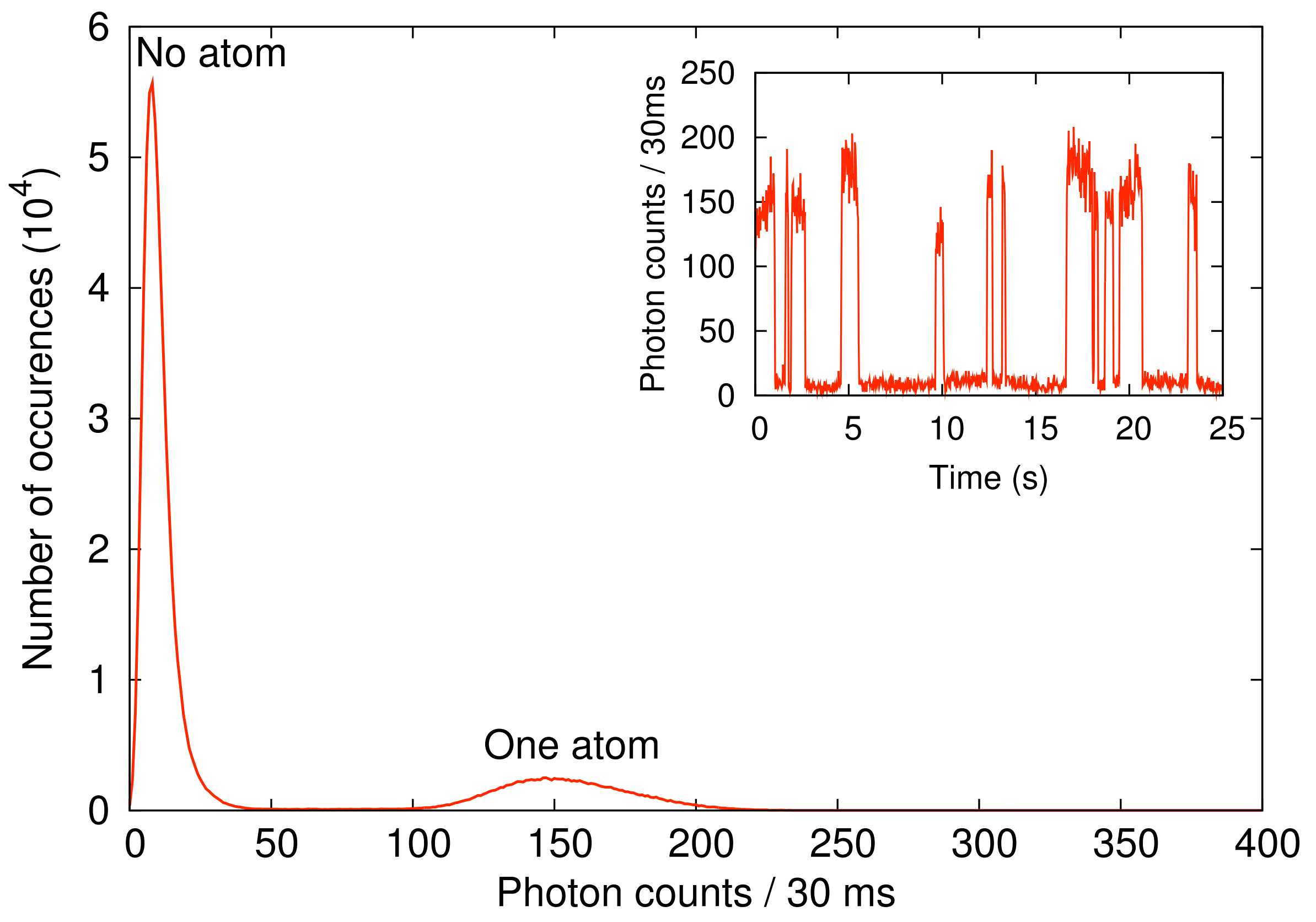

FIGURE 3: Histogram of counts showing the distribution of time events for the atom present in the dipole trap (right peak) and no-atom events (left peak). The inset shows a typical "binary" pattern of photocounts used to extract the histogram.

The "sufficient" condition is the observation of the photon antibunching effect in atomic fluorescence. It is revealed as a dip in the histogram of time difference between two consecutive detection events, from two detectors in a Brown-Twiss configuration.

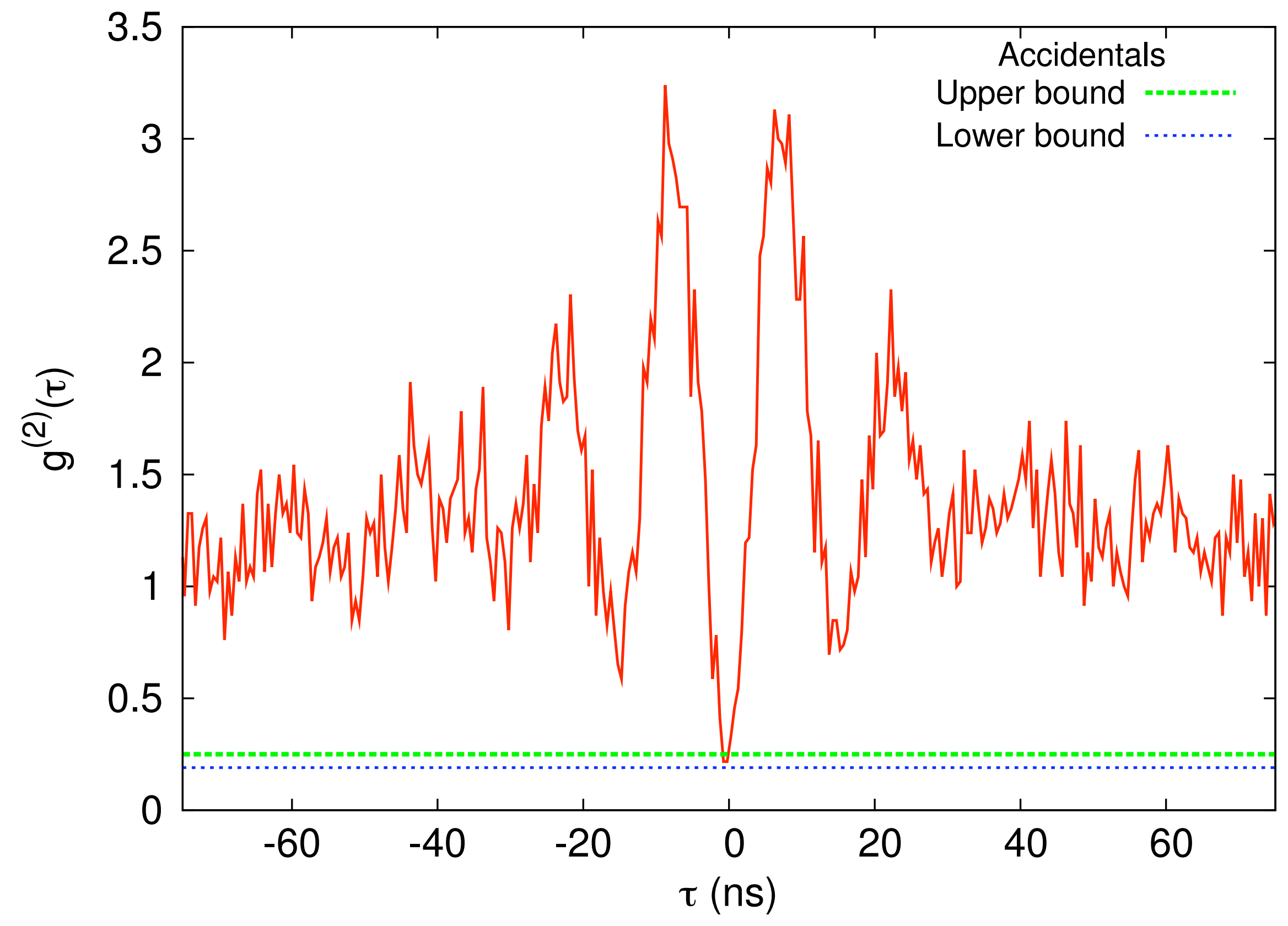

FIGURE 4: Second order intensity correlation function versus time delay between two consecutive photodetection events. One sees clear antibunching effect for time delay $\tau = 0$. This proves that we have a single quantum emitter in the observation region of our detectors. Two dashed lines indicate the amount of noise floor caused by accidental coincident events. The oscillating part reveals the coherent evolution of an atomic state driven by a near-resonant laser field (cooling beams).

Extinction of light by a single atom

Experimental parameters

$D_T \simeq (k_B) \cdot 1.4mK = (h) \cdot 25MHz$ — dipole trap depth
$\omega_0 = 1.1$ mm — waist of the probe beam before the cuvette
$\omega \simeq 1\mu$m — waist of the probe beam at the focus
$T = 49.8\%$ — transmission percentage from A to B
$N_{probe} \simeq 4 \cdot 10^6/s$ — photon flux at position A
$N_{det} \simeq 1 \cdot 10^6/s$ — average number of detected photons

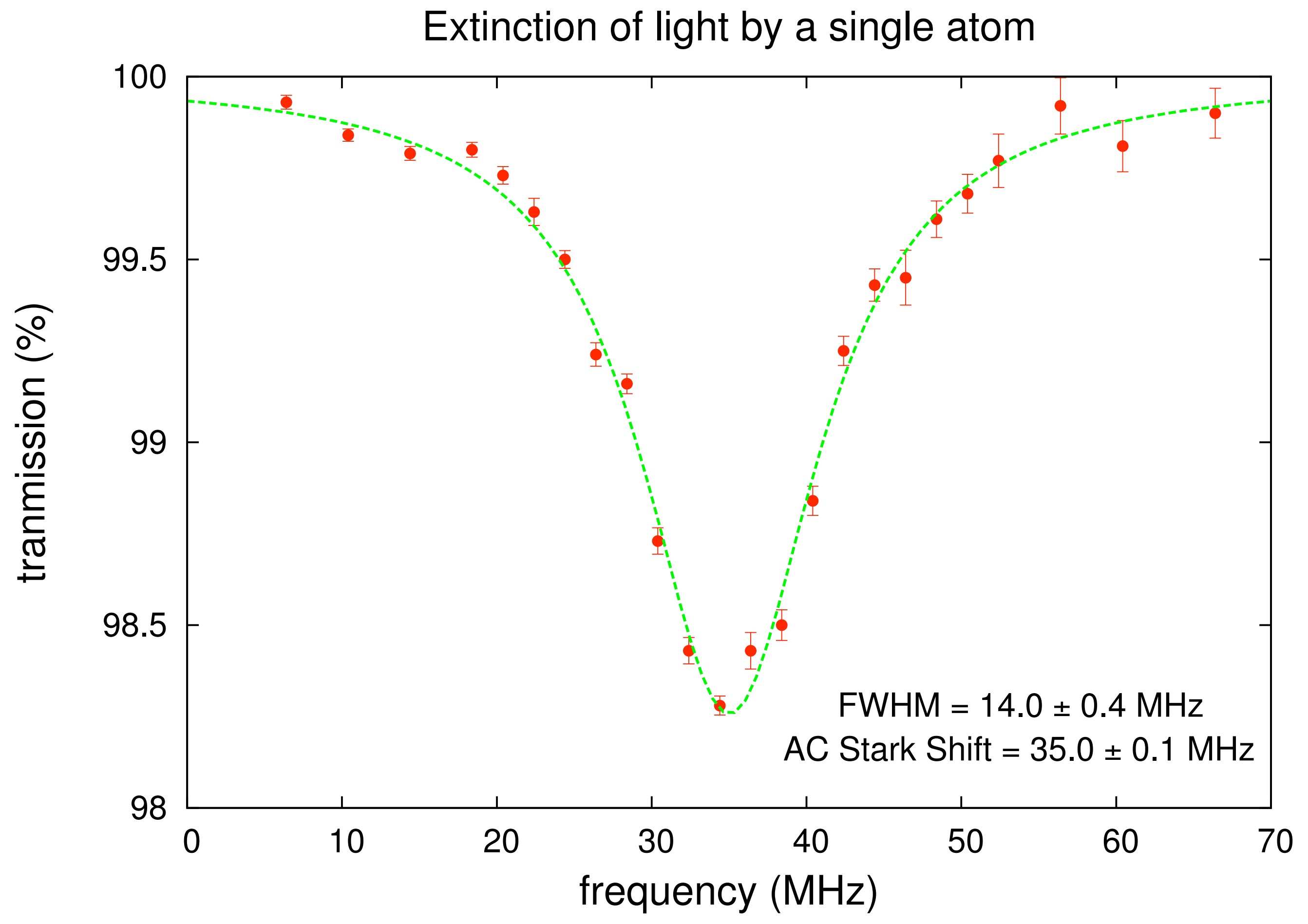

FIGURE 5: Change in transmission of the probe beam when the frequency of the laser is scanned across the atomic resonance. Zero frequency point corrspond to the natural resonance frequency without AC stark shift. One observes the probe beam extinction of $\sim 1.6\%$. The broadening of the spectrum is caused by a fact that the atom is not prepared in a well-defined state after it gets loaded in the trap. Therefore, light can interact with all Zeeman sublevels of $F = 2$ and $F' = 3$ states that experience different AC Stark shift. This diminishes the value of the extinction.

Next Steps

Our next step is to prepare an atom in a well-defined state $(F = 2, m_F = 2)$ before probing it. In this case, a σ^+ polarized probe incident on an atom will lead to a closed cycle between $\|F = 2, m_F = 2\rangle$ and $\|F' = 3, m_{F'} = 3\rangle$ states. Thus for a resonant light, an atom will behave like a real 2-level system, and the absorption probability will be enhanced as well as the spectral profile will be narrowed.

The second step is the further optimization of the interaction process. This can be achieved by shaping the temporal (frequency) and spatial modes of incident photons in such a way that they optimally match the modes given by a spontaneous decay of an atom. It can be shown that in this case (time reversal of the spontaneous emission) one can achieve the maximal possible probability of interaction of a single atom with a single photon.