

## Motivation

Recent experiments have shown that a substantial interaction between a single trapped atom and light can be established by concentrating the light field at the location of the atom with a help of a simple lens [1-4]. In particular, one can observe a noticeable extinction of a focused beam by a single <sup>87</sup>Rb atom in a tightly focused optical dipole trap.

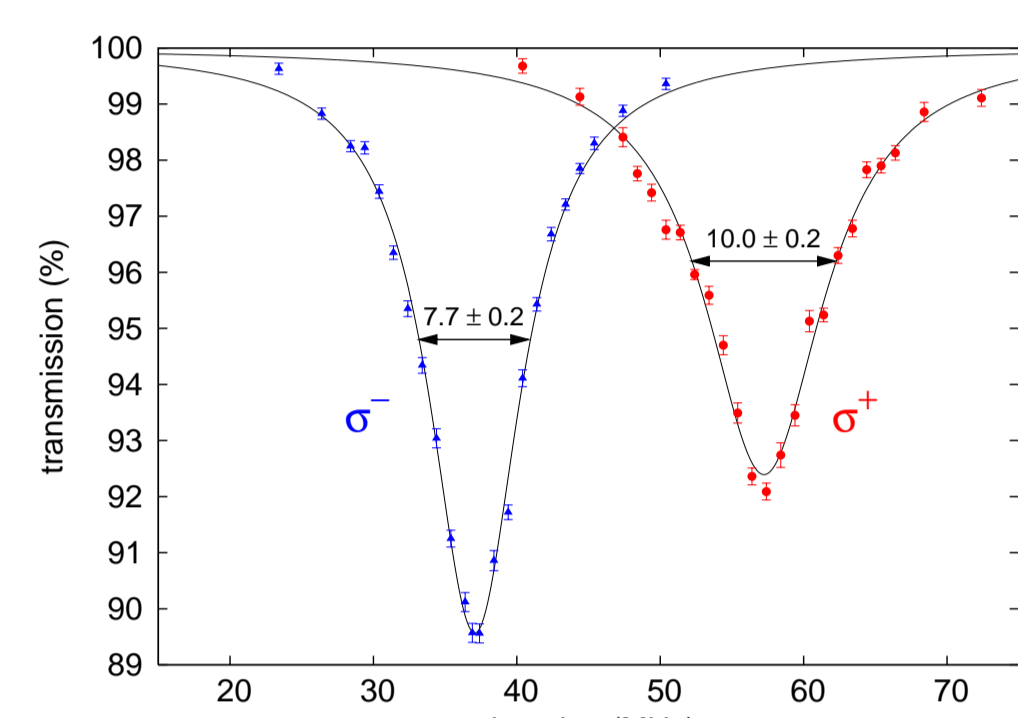
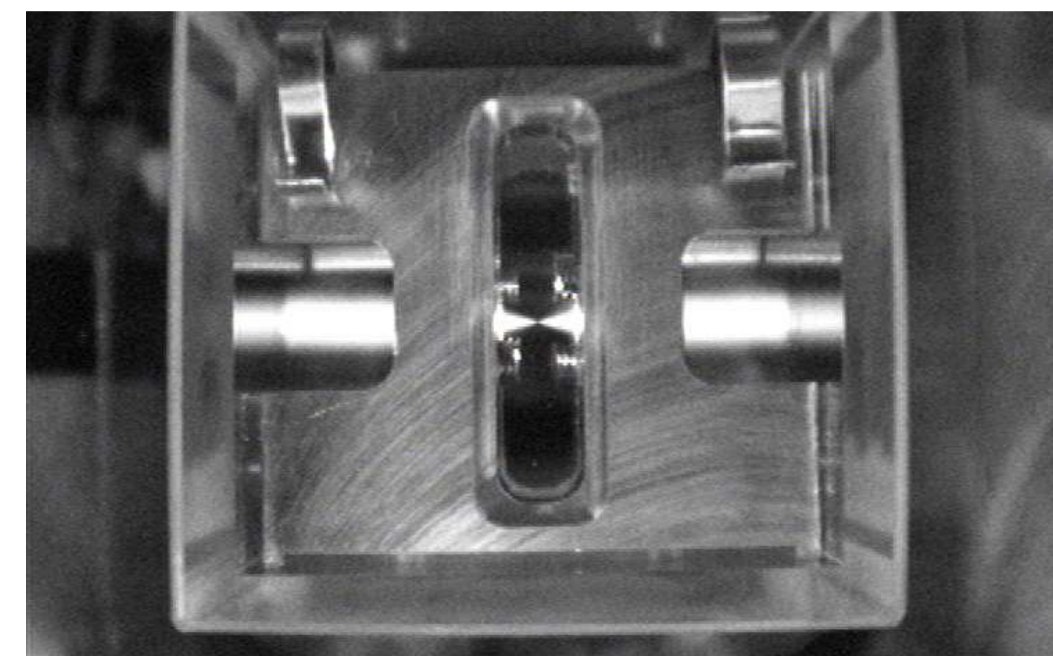
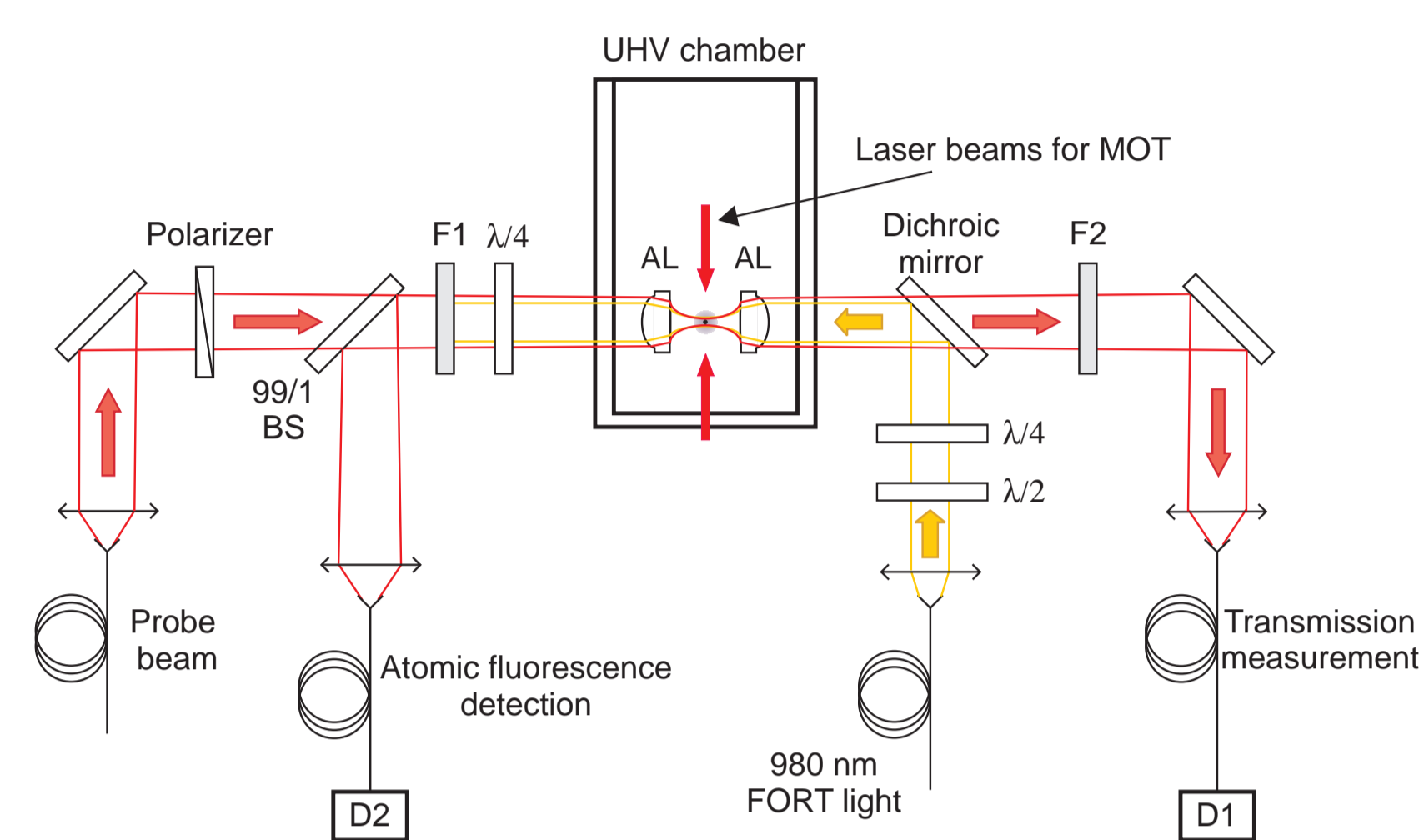


FIGURE 1: Setup for transmission measurements together with the experimental results [1]

## Temperature Estimation and Trap Parameters

However, there are technical challenges to be overcome in order to exploit strong focusing. The major one is the atomic motion due to the finite temperature obtained even after laser cooling the atomic sample. This motion leads to displacement of the atom from the focus where one expects a strong interaction (see Fig.2). For these estimates the trap frequencies were measured and found to be  $\nu_t \sim 56$  kHz for transverse confinement and  $\nu_l \sim 7$  kHz for longitudinal confinement in a tightly focused Gaussian optical dipole trap beam.

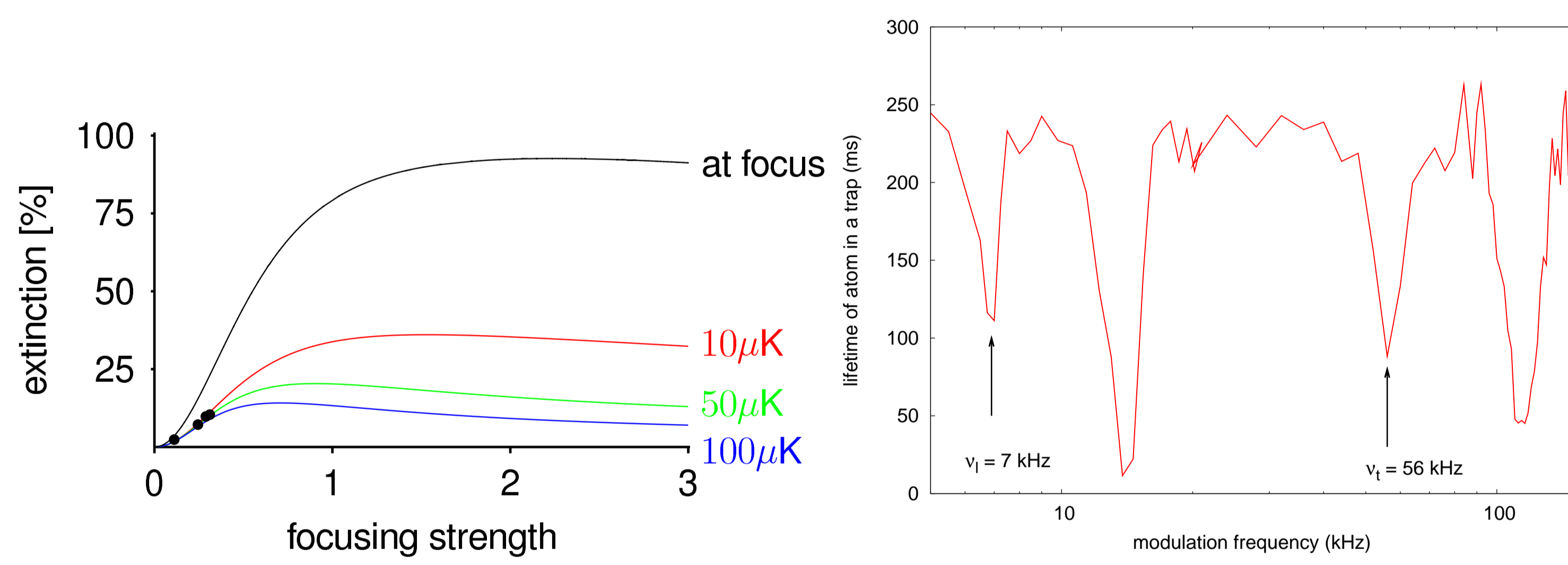
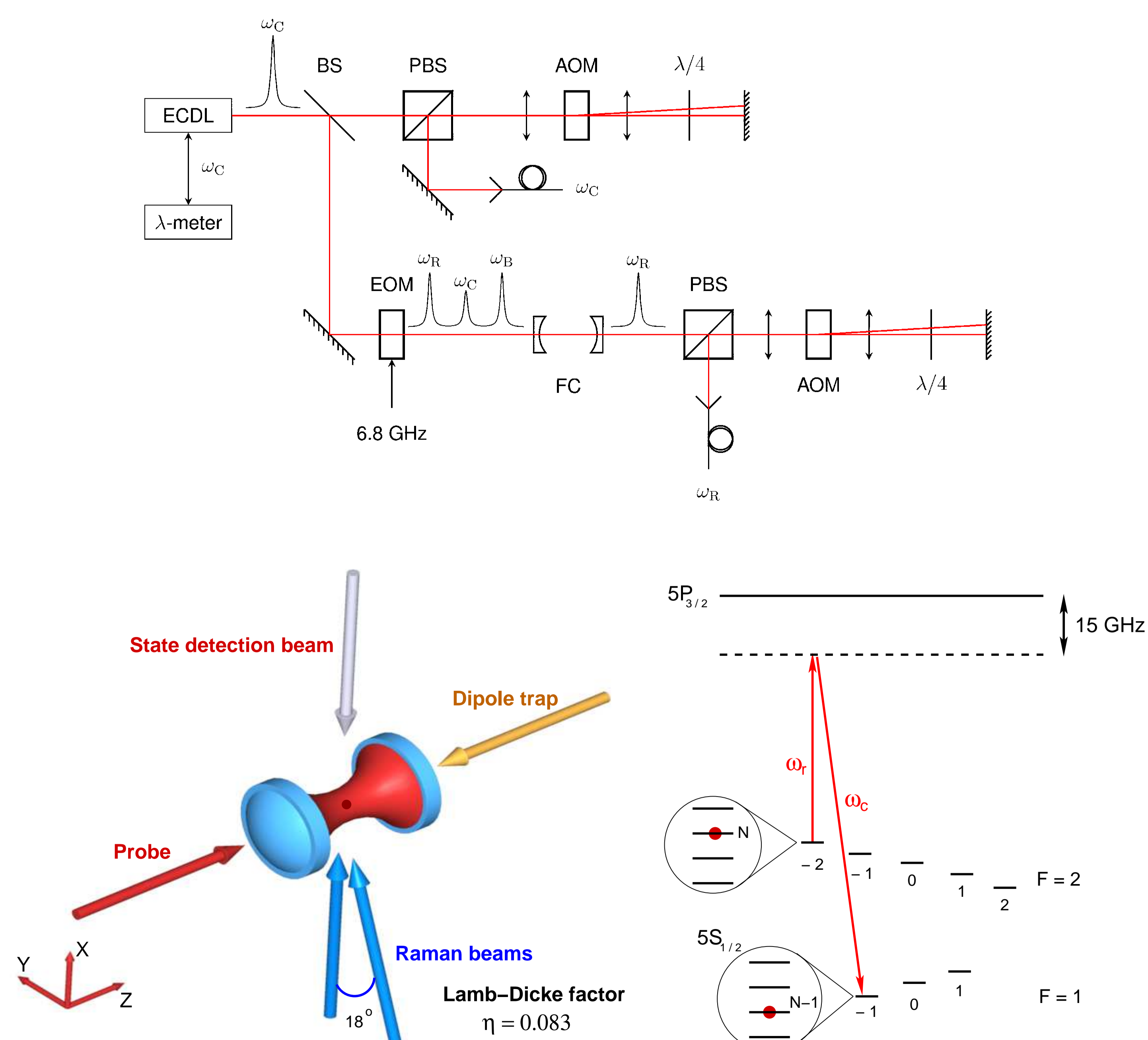


FIGURE 2: (Left) Influence of the finite atomic temperature on the extinction measurements. (Right) Trap frequencies determined by parametric resonance heating

## Experiment

To bring the atom close to the vibrational ground state of the trap with characteristic frequencies of 20-80 kHz, we implement a Raman Cooling technique similar to the one commonly used in ion traps [5].



## Experimental Sequence

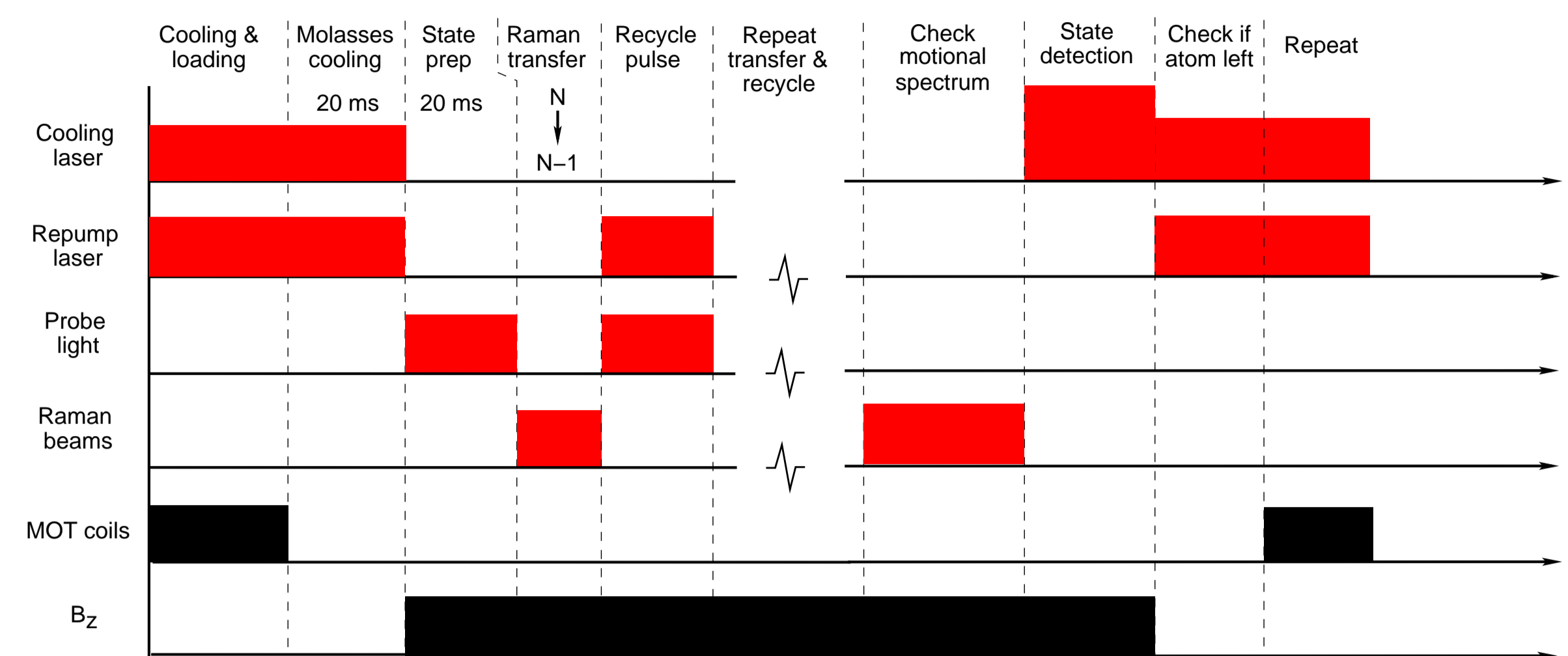


FIGURE 3: Experimental sequence for Raman sideband cooling. First the atom is loaded into dipole trap from Magneto-Optical Trap (MOT) and pre-cooled by molasses beams. Then the atom is optically pumped into  $|F = 2, m_F = -2, N\rangle$  state by a circularly polarized probe beam. A bias magnetic field of 2.1 Gauss is applied to define quantization axis. Raman beams transfer the atom into  $|F = 1, m_F = -1, N - 1\rangle$  with a target Rabi frequency of  $\sim 700$  Hz thus inducing loss of one motional quanta. Then the atom is recycled back into  $|F = 2, m_F = -2\rangle$  state via spontaneous emission. Transfer and recycle processes are repeated several times to achieve a net cooling of the atom to the ground state of the trap. The motional spectrum of the atom is obtained by frequency scan of the narrow Raman pulse and subsequent state detection.

## Raman Rabi Oscillations

A possibility to coherently transfer atomic population between hyperfine ground states of the atom is essential for sideband cooling. In Fig. 4 we show the results of such transfer. This allows us to measure two-photon carrier Rabi frequency and estimate the power of the beams that we set for cooling.

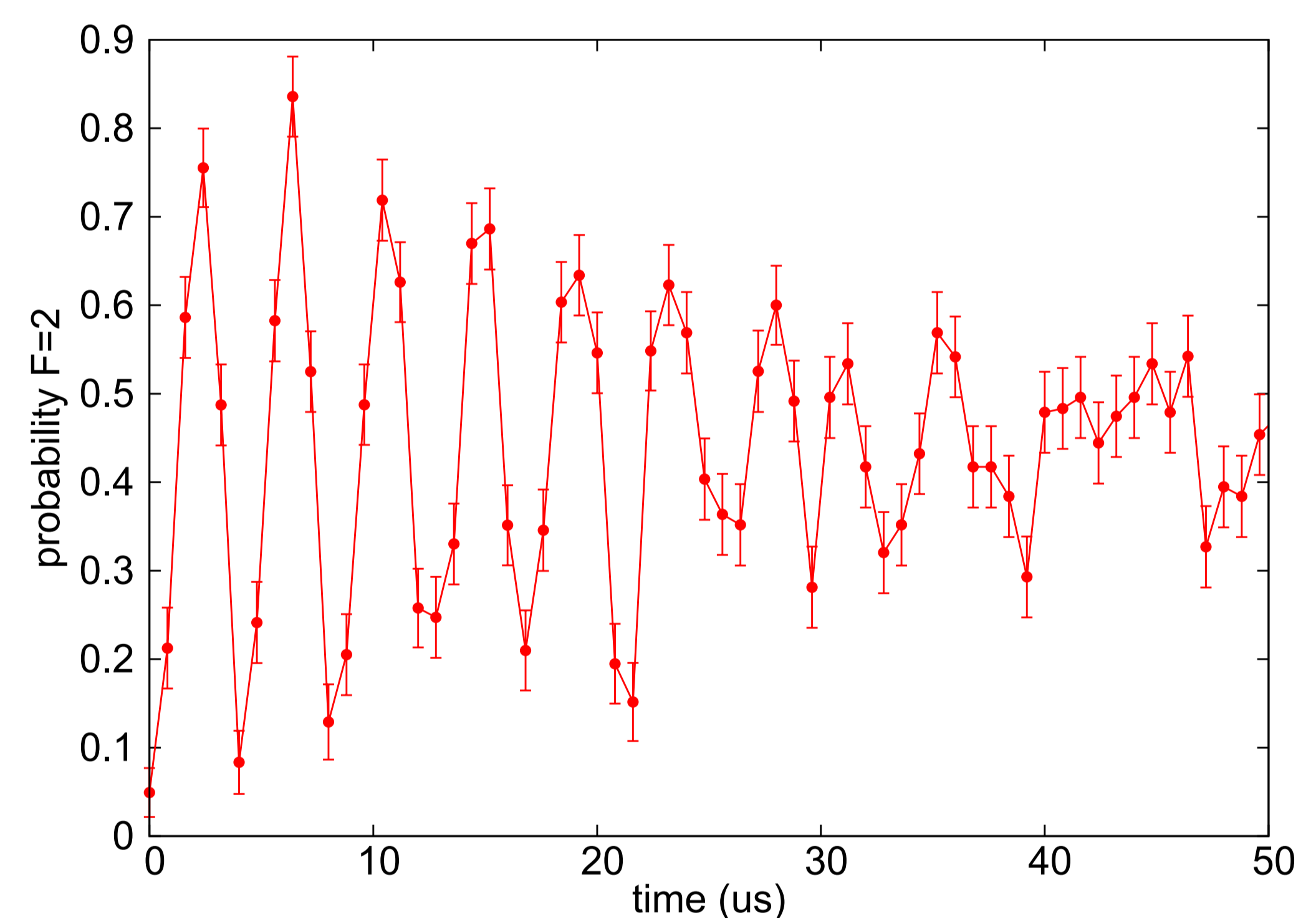


FIGURE 4: The probability of transferring atomic population into  $|F = 1, m_F = 1\rangle$  state versus the duration of the Raman laser pulses. The oscillation reveal the two-photon Rabi frequency of  $(2\pi) \cdot 220$  kHz. The damping constant of the oscillation  $\tau_d$  is on the order of 40 microseconds. This constant gives a measure of the decoherence time that the atom experiences while being transferred.

## Sideband Cooling Results

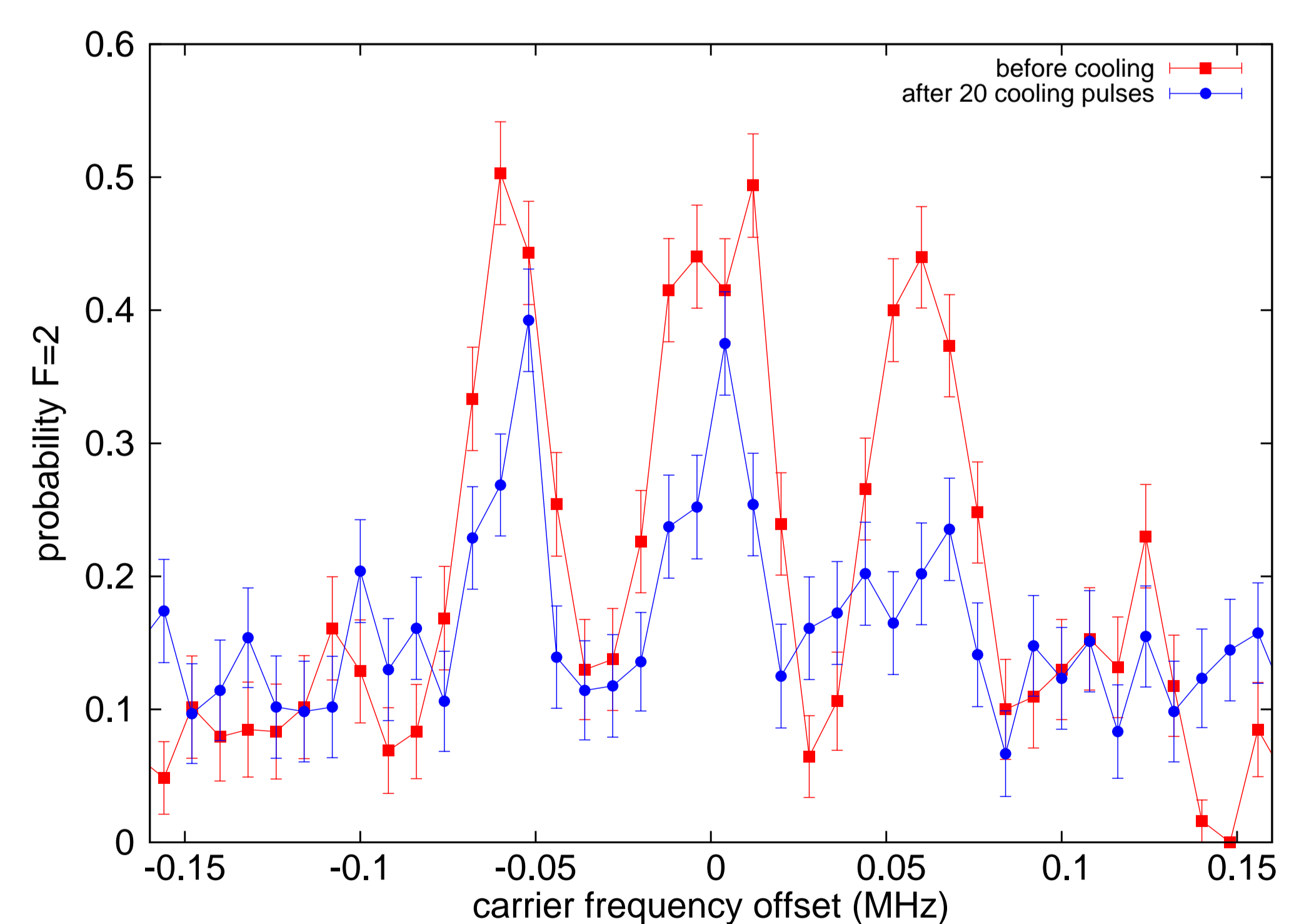


FIGURE 5: Resolved motional sidebands of an atom in a trap before and after Raman cooling.

One can determine the mean vibrational quantum number  $\langle n \rangle$  in the trapping potential from the ratio of Stokes and anti-Stokes signal 'intensities' [5]. From our data we extract  $\langle n \rangle = 0.55 \pm 0.07$ . We are now optimizing the sequence to achieve better cooling and possibly extending to 3D cooling of the atom in a tweezer. This result is important for boosting the efficiency of free-space atom-photon coupling.

## References

- [1] M. K. Tey, et al., Nature Physics **4**, 924 (2008)
- [2] M. K. Tey et al., New J. Phys. **11**, 043011 (2009)
- [3] S.A. Aljunid et al., Phys. Rev. Lett. **103**, 153601 (2009)
- [4] C. Monroe et al., Phys. Rev. Lett. **75**, 4011 (1995)