Bragg reflection from an ultra-cold Rubidium gas

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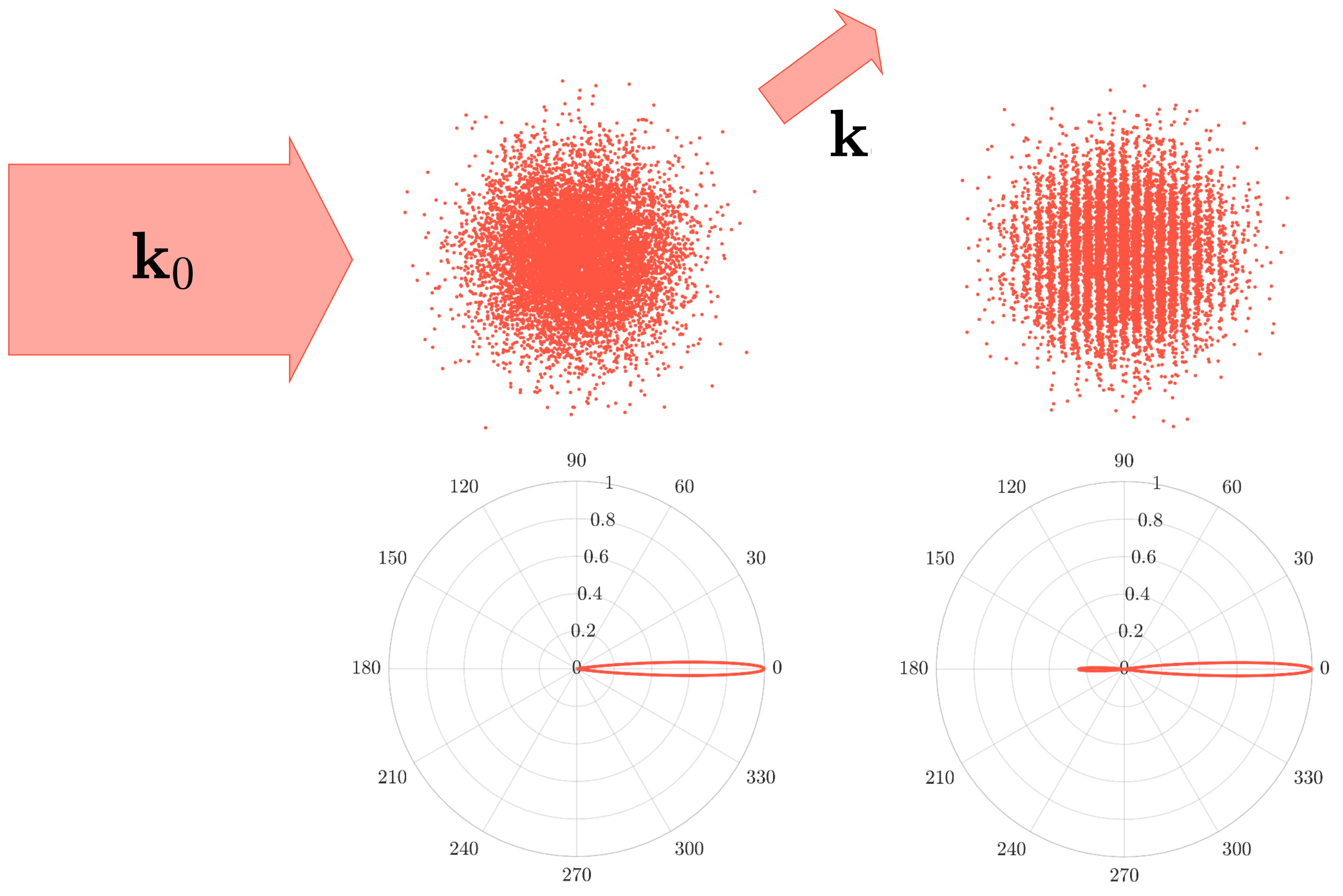
Abstract

The fields of optomechanics and collective light scattering by ultra-cold atomic ensembles are active and prolific - they have seen numerous recent experimental and theoretical developments, on effects such as superradiance [1], subradiance [2] and cooperative shifts [3]. Most of the recent experimental efforts have been focused on the understanding of the collective response of an ensemble to a probe beam, in the regime of dense atomic samples, in which dipole-dipole interactions are predominant. The experimental work presented here, however, focuses on mechanisms of momentum transfers between light and matter in a regime where dipole-dipole interactions are negligible but in the case of inhomogeneous ensembles. We present a study of the reflection of light by a structured thermal cloud or a matter-wave grating and measure the momentum transfer that ensues. We demonstrate how measuring populations of recoiling atoms yields information about the time-dynamic of matter-wave interference and of bosonic amplification.

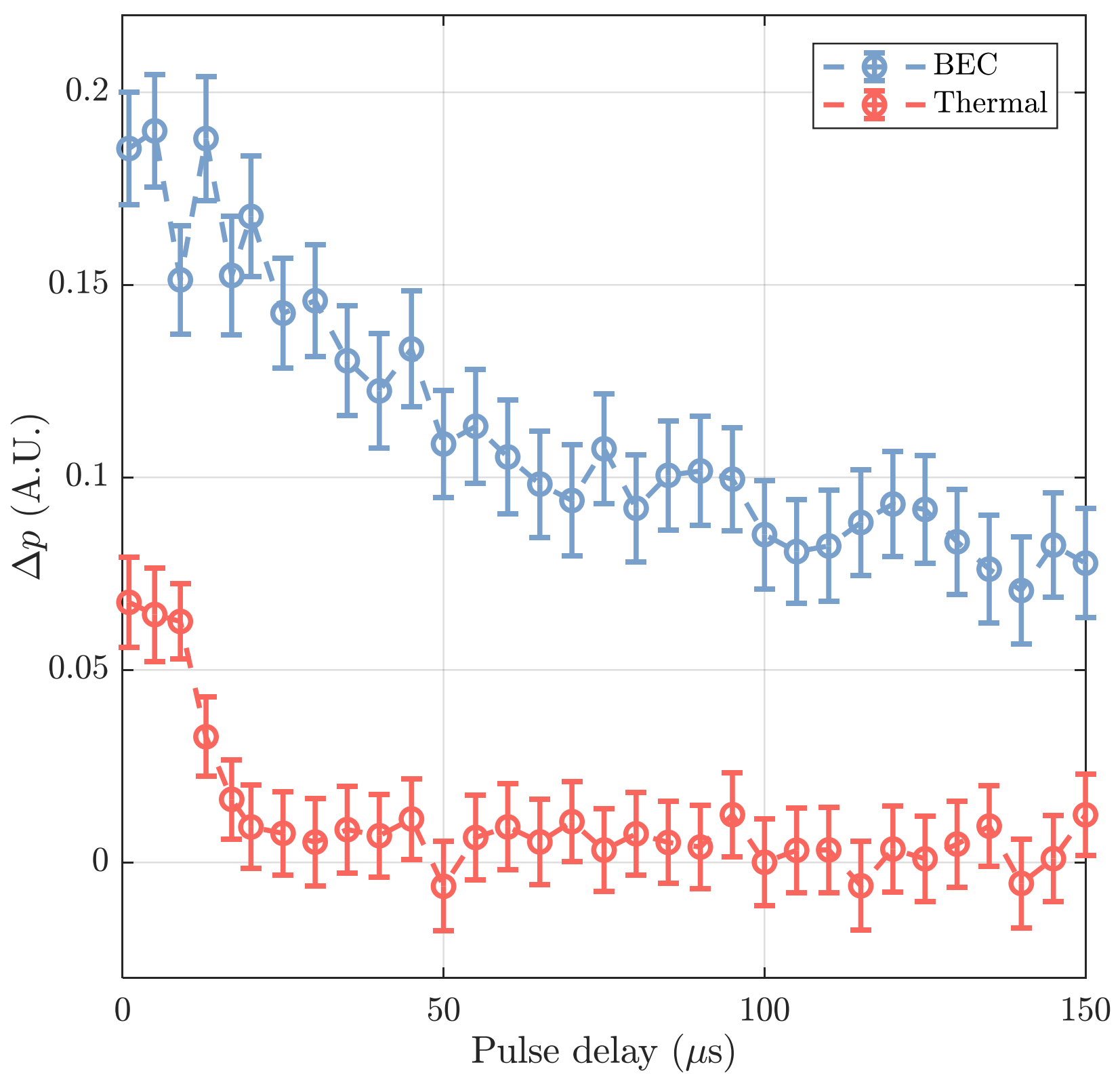
Bragg reflection

An incoming plane wave impinging on an atomic cloud will be redistributed outside of the driving mode when one considers the interference of the field radiated by each and every dipole that constitute the cloud. In the far-field of the cloud, the intensity $I_r(\mathbf{k})$ radiated in the unit solid angle centered around direction **k** is [1,2]

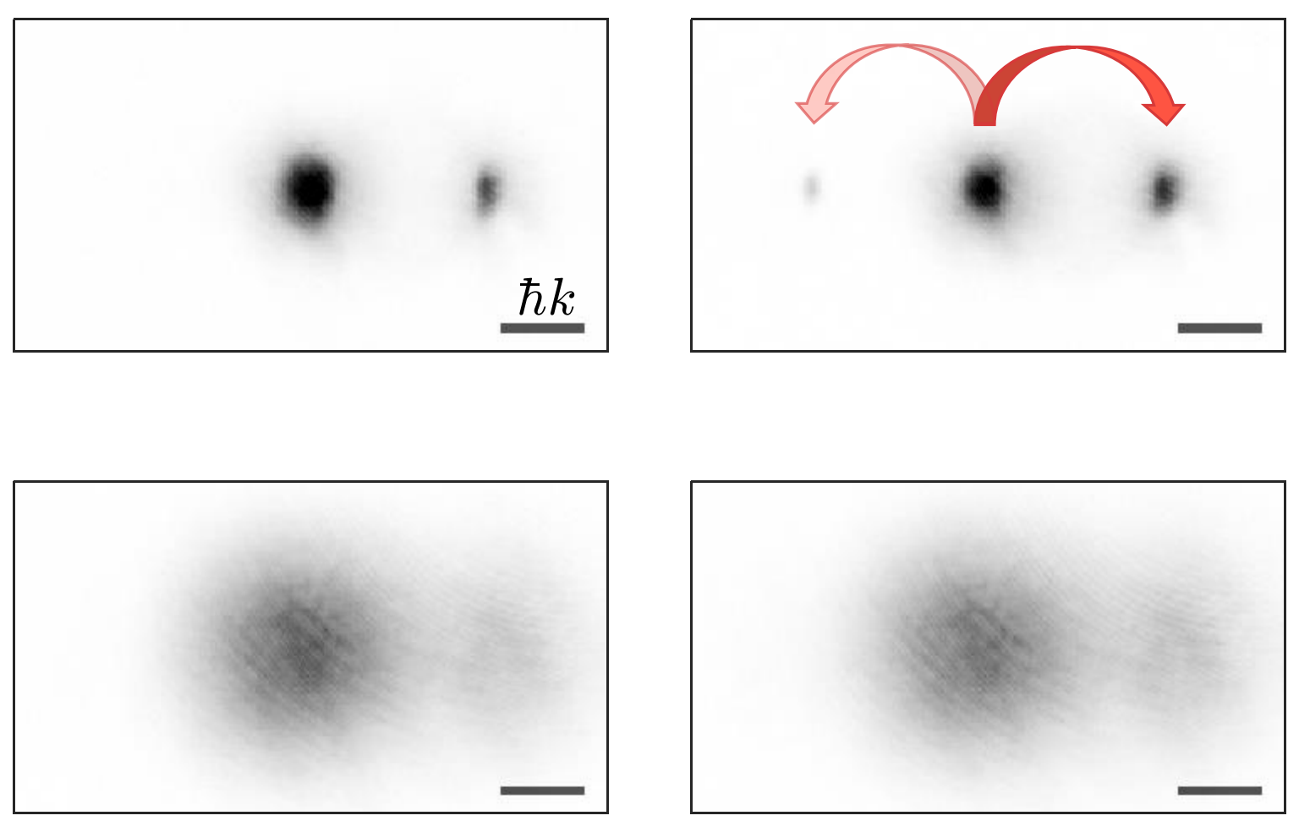
$$I_r(\mathbf{k}) = \alpha^2 I_0 \left| \sum_{j=1}^{N} e^{i(\mathbf{k}_0 - \mathbf{k})\cdot\mathbf{r}_j} \right|^2$$



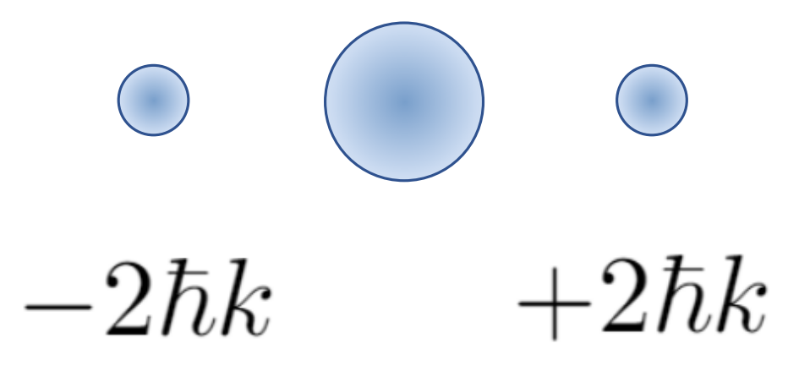
Time dynamics

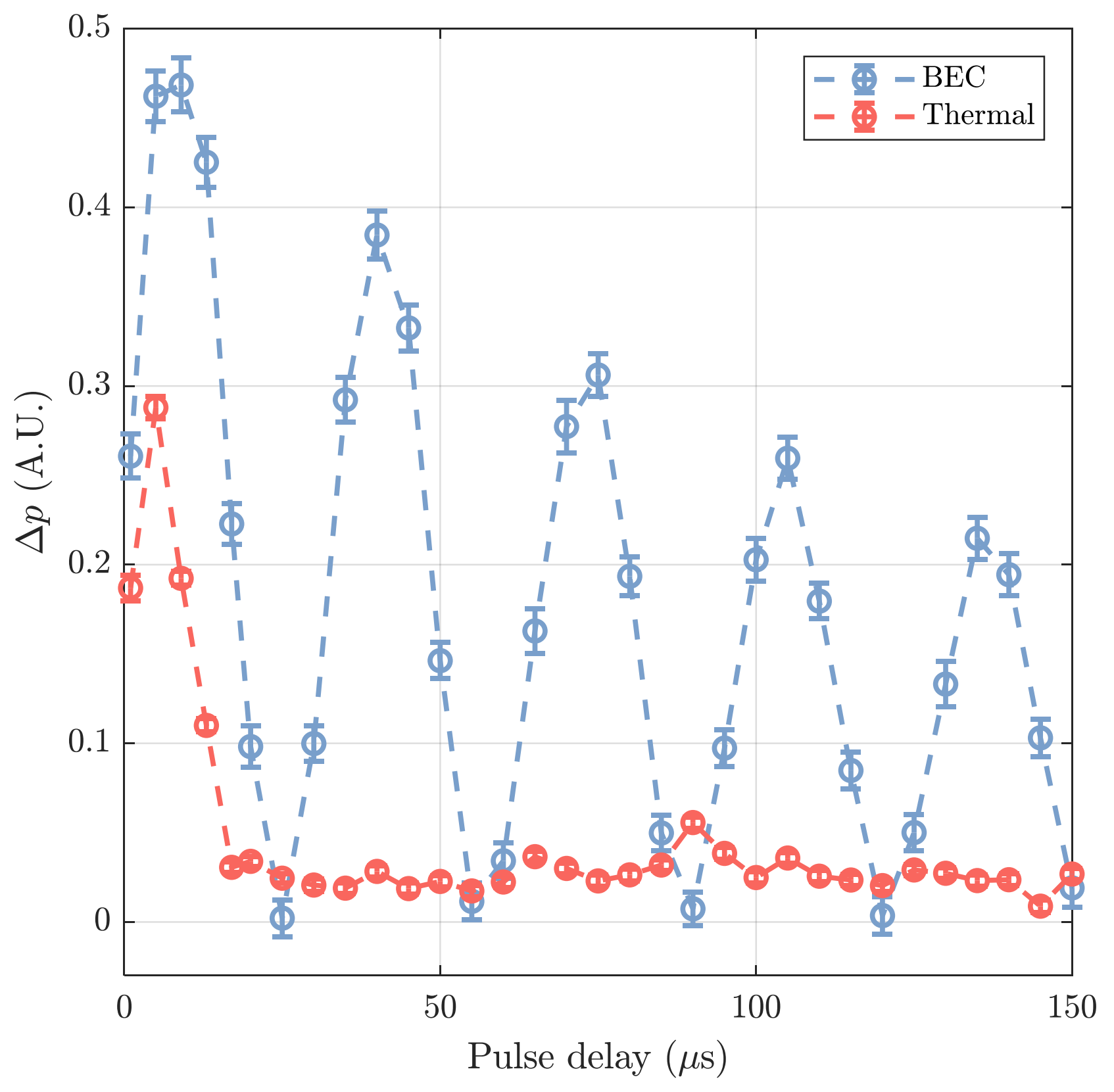


We prepare a single excitation at +2ħk via resonant Bragg scattering and scan the delay between the preparation and the probe.



We prepare equal populations in ±2ħk and use the ensemble reflection in order to probe the dephasing between the excitations. When excitations interfere constructively, the ensemble's reflection coefficient is high, and it vanishes when they interfere destructively.





Doppler broadening :

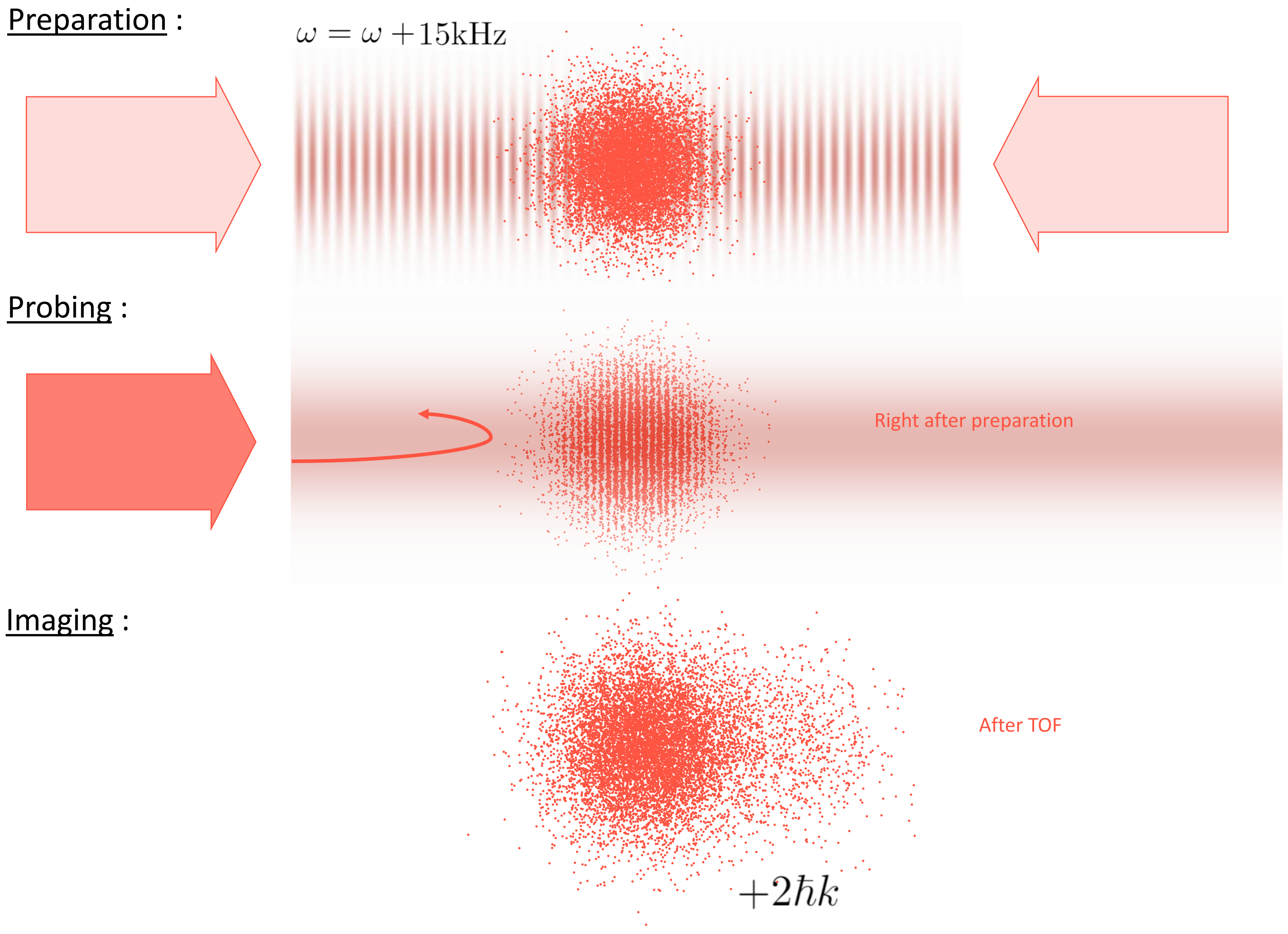
$$\Delta\omega_D = \sqrt{\frac{8}{3}}\frac{v_r}{r_{TF}}$$

Inhomogeneous density broadening :

$$\Delta\omega = \sqrt{\frac{8}{147}}\frac{\mu}{\hbar}$$

Experimental procedure

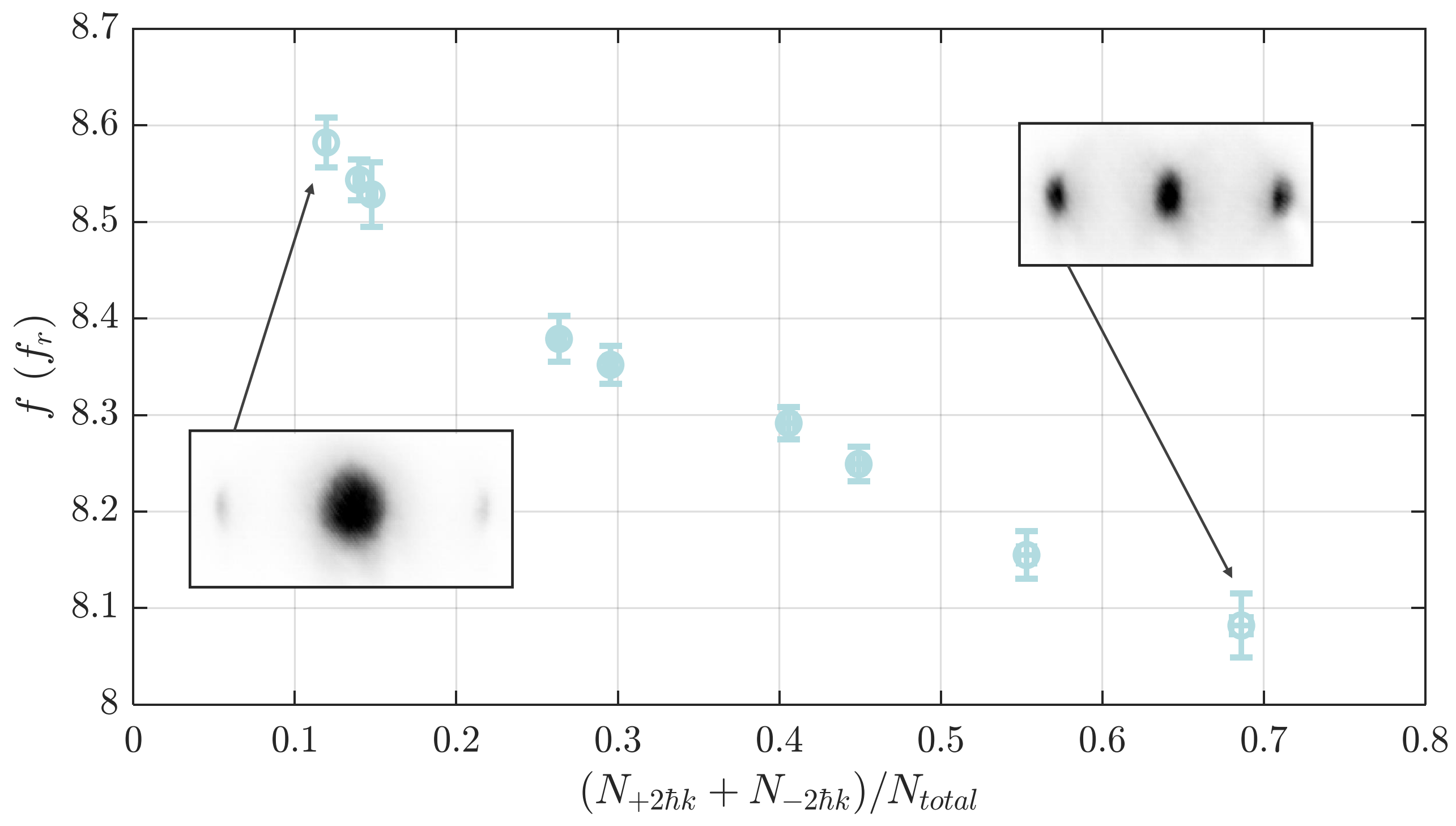
We probe the reflection of light by the structured ensemble by counting the change of population at +2ħk, which corresponds to the atoms that reflected a photon.



Experimental results

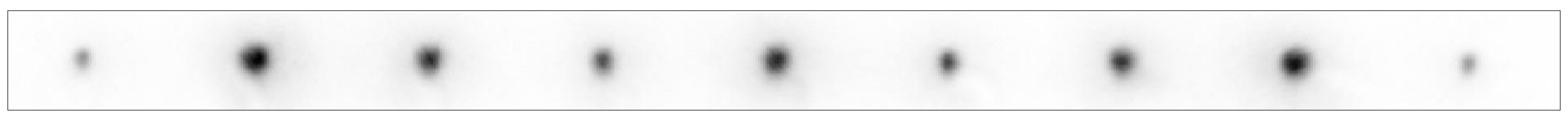
Oscillation frequency :

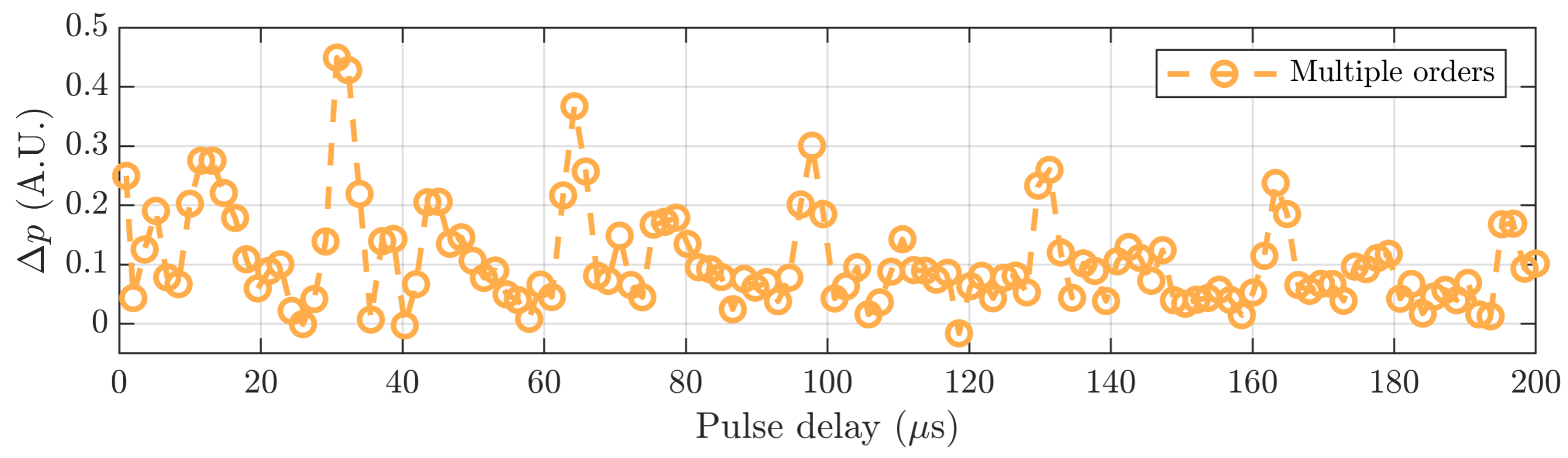
$$f = \frac{4}{\lambda}\sqrt{\frac{2}{m}}\sqrt{\frac{2\hbar^2 k^2}{m} + \left(1 - \frac{2N_{2k}}{N_0}\right)\mu}$$



Oscillation frequency of the ±2ħk momentum classes as a function of population of the initial seed. We observe the expected drop in the frequency for stronger excitations [6].

Multiple orders :





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