Measurement of total phase fluctuation in cold atomic quantum simulators

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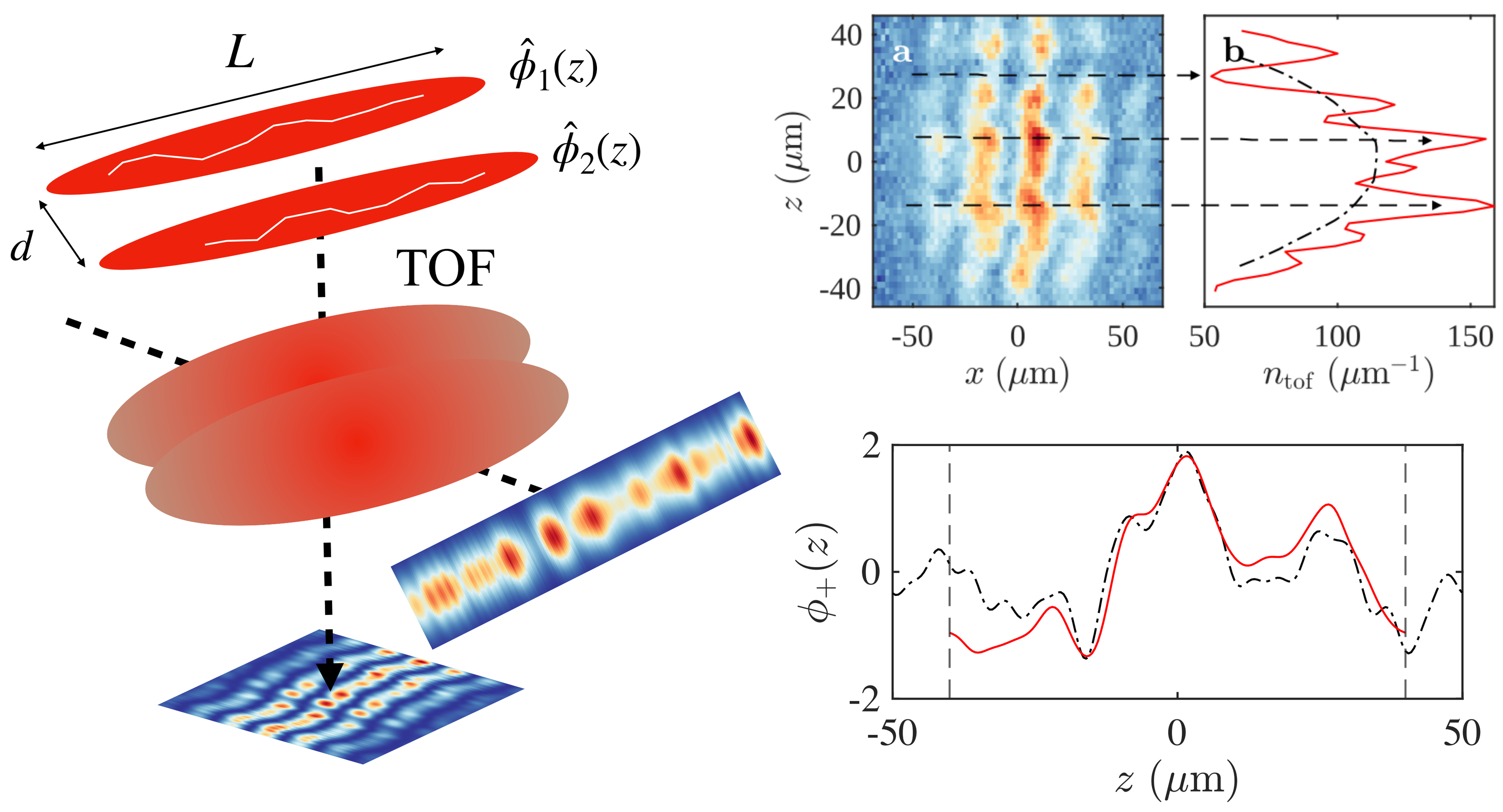
Introduction



- By designing the trapping potential, **ultracold atomic gases can be confined to 1D** where they behave differently from 3D.
- **Interference experiment** is used as a probe of spatial correlations of *relative* phase fluctuation $\phi_-(z) = \phi_1(z) - \phi_2(z)$ by fitting density after time of flight (TOF)

$$\rho_{\rm tof}(x,z) = A(z)e^{-x^2/\sigma_t^2}\left[1 + C(z)\cos\left(qx + \phi_-(z)\right)\right].$$

- **Is it possible to also measure the *total* phase**

$$\phi_+(z) = \phi_1(z) + \phi_2(z)?$$

Result 1: YES, we can measure $\phi_+(z)$

- We reconstruct $\phi_+(z)$ from *density ripple* data

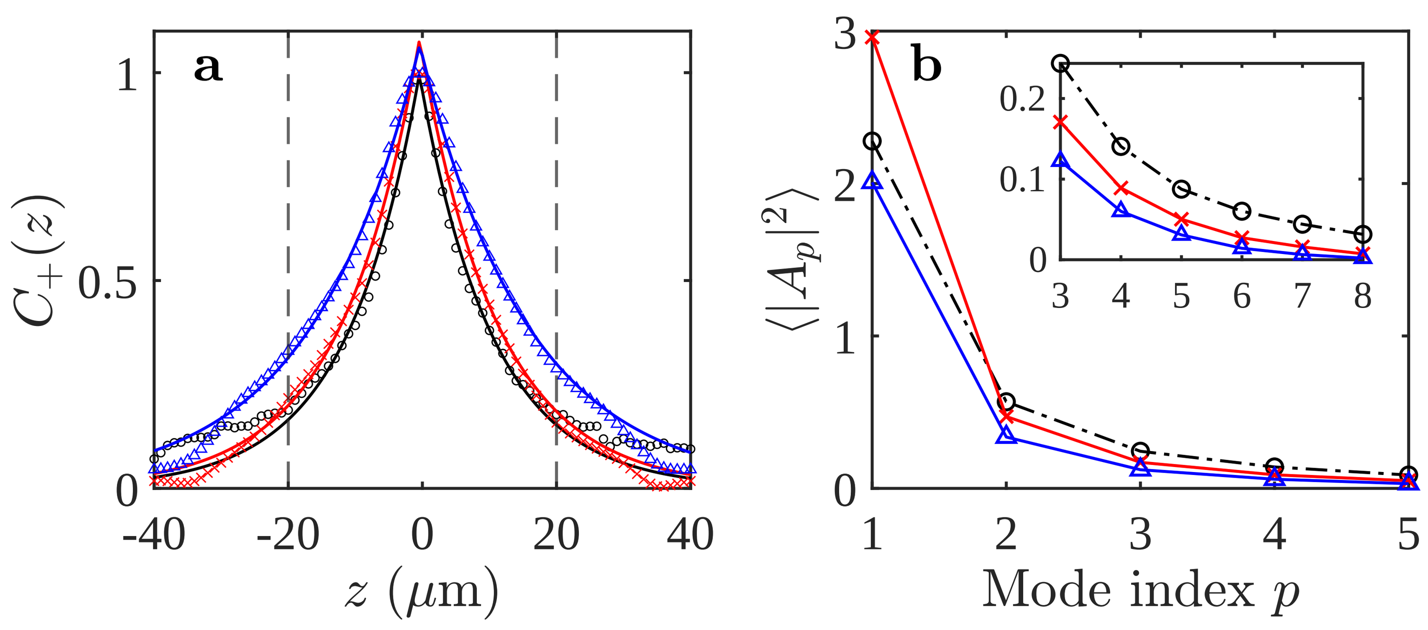
$$n_{\rm tof}(z,t_{\rm tof}) = \int dr\, \left|\psi_1(r,z,t_{\rm tof}) + \psi_2(r,z,t_{\rm tof})\right|^2$$

- From the continuity equation, we obtain

$$\phi_+(z) = \sum_{k>0} \mathrm{Re}(A_k)\cos(kz) + \mathrm{Im}(A_k)\sin(kz)$$

$$A_k = \frac{-2}{(k\ell_{\rm tof})^2}\frac{1}{L}\int_{-L/2}^{L/2}\left(1 - \frac{n_{\rm tof}(z,t_{\rm tof})}{n_0(z)}\right)e^{ikz}\,dz,$$

where $\ell_{\rm tof} = \sqrt{\hbar t_{\rm tof}/(2m)}$ is the length scale of longitudinal expansion and $n_0(z)$ is in situ mean density.



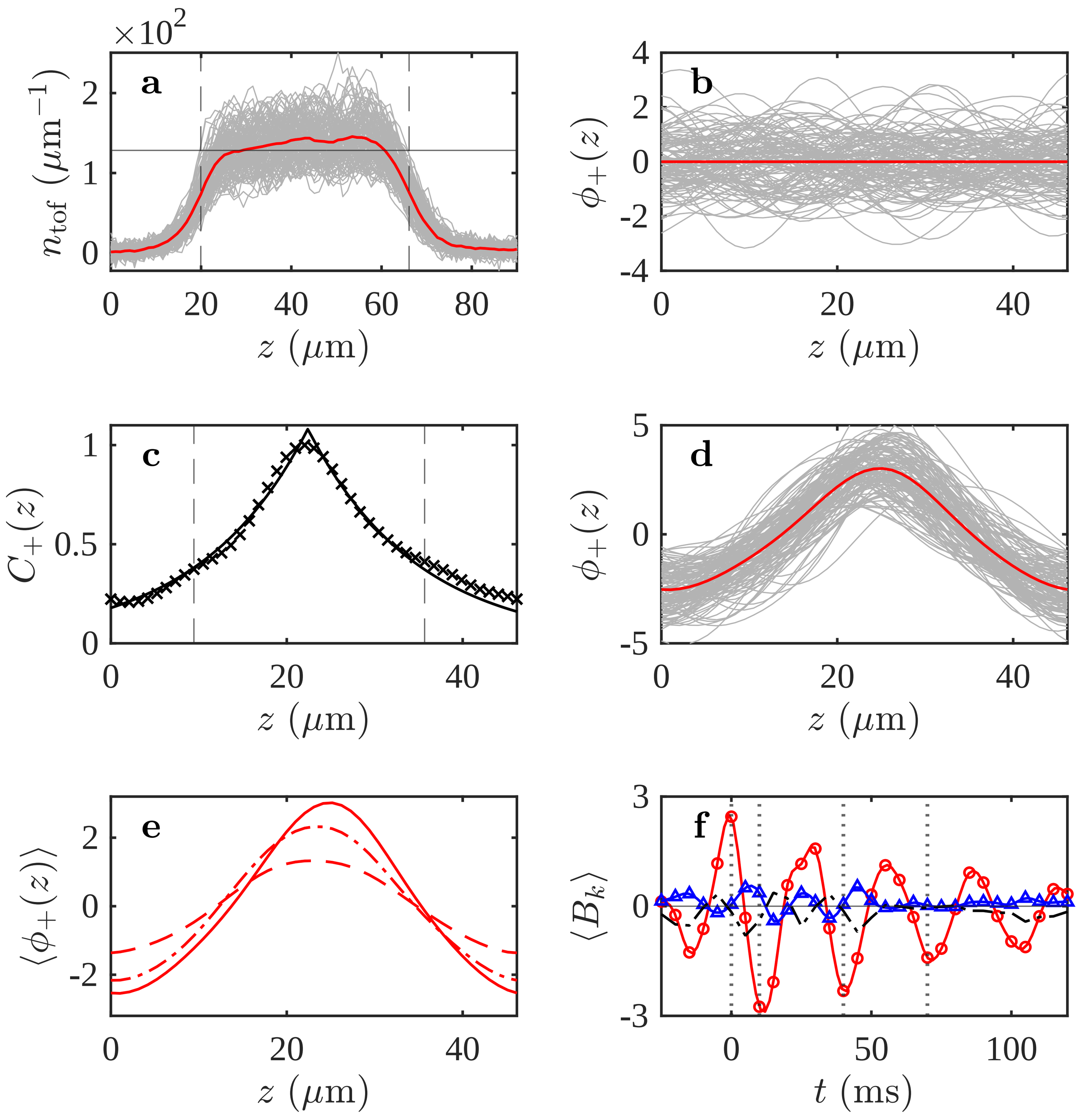
- To validate our method, we study the reconstruction fidelity of the correlation function

$$C_+(z) = \langle\cos\left(\phi_+(z) - \phi_+(0)\right)\rangle$$

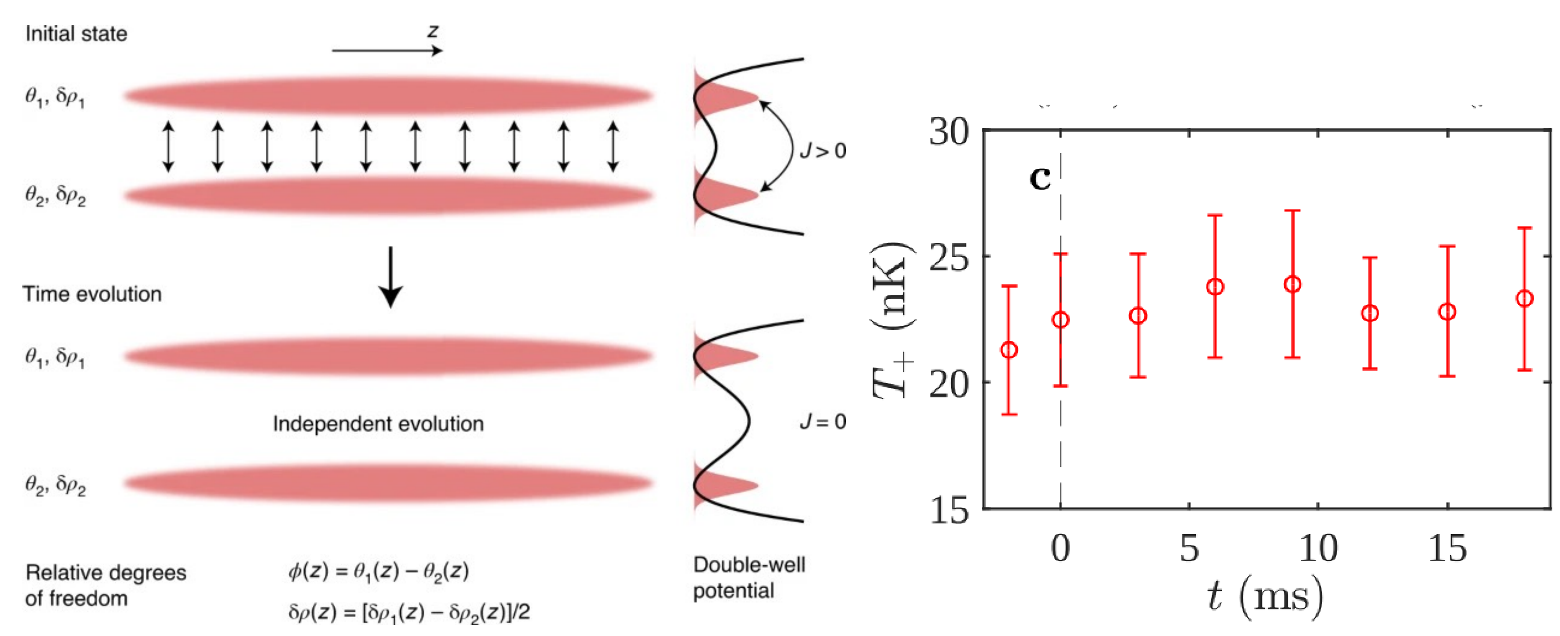
and mean spectrum $\langle|A_k|^2\rangle$ for two different expansion times $t_{\rm tof} = 11$ ms (red) and $t_{\rm tof} = 16$ ms (blue).

Result 2: Experimental Data Analysis

- We extract the **temperature of symmetric sector** T_+ and probe **relaxation dynamics after coherent driving**



- We probe **temperature dynamics of the symmetric sector after quench** from tunnel-coupled to decoupled 1D gases



Why care about measuring $\phi_+(z)$?

- Information on $\phi_+(z)$ allows experiments to probe 1D quantum gases beyond low energy descriptions, e.g: **probing long-time thermalization, testing the validity of 1D quantum field simulators, etc.**
- Our method **can be extended to other cold atom systems** with spatial phase gradients and therefore **expands the scope and capabilities of cold atomic quantum simulators**.
- **Check out our paper by scanning the QR code below!**