Next generation platform for implementing fast gates in ion trap quantum computation

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February 21, 2023

XX Shorten Abstract XX
Scalable trapped-ion quantum computation relies on the development of high-fidelity fast entangling gates in a many ion crystal. Conventional geometric phase gates either suffer from scattering errors or off-resonant carrier excitations. A potential route to achieve fast entanglement is creating a standing wave which can suppress the unwanted carrier coupling [Mundt 2003].
We present the roadmap to our next-generation platform tailored for fast gates in the 1us regime where gate speeds become comparable to the secular trap frequency. The quadrupole transitions between S1/2 and D5/2 levels in Calcium 40 will be driven to perform Molmer-Sorenson gates with a standing wave rather than a typical travelling wave. The off-resonant carrier excitation may be strongly suppressed by placing ions at the nodes of the optical lattice. This new platform has scope for a multi-ion chain and a corresponding array of optical lattices which each address a single ion. The lattice array is created by a set of counter-propagating beams which are tightly focused by a symmetric setup of high-NA lenses. Control of the optical phase at the ion site will be achieved by actively stabilising the counter-propagating beam interferometer and feedbacking on the ion signal.

Why Fast Gates?

Two qubit gates realised in ion trap QC by coupling spin with motion. Molmer Sorenson interaction achieves this via a bichromatic field incident on the ions:

$$\hat{H_{MS}} = \hbar\Omega\hat{S}_{\phi-\pi/2}\cos(\delta t) + \hbar\Omega\eta\hat{S}_{\phi}\cos(\delta t)(\hat{a}e^{-i\omega_z t} + \hat{a}^{\dagger}e^{i\omega_z t})$$

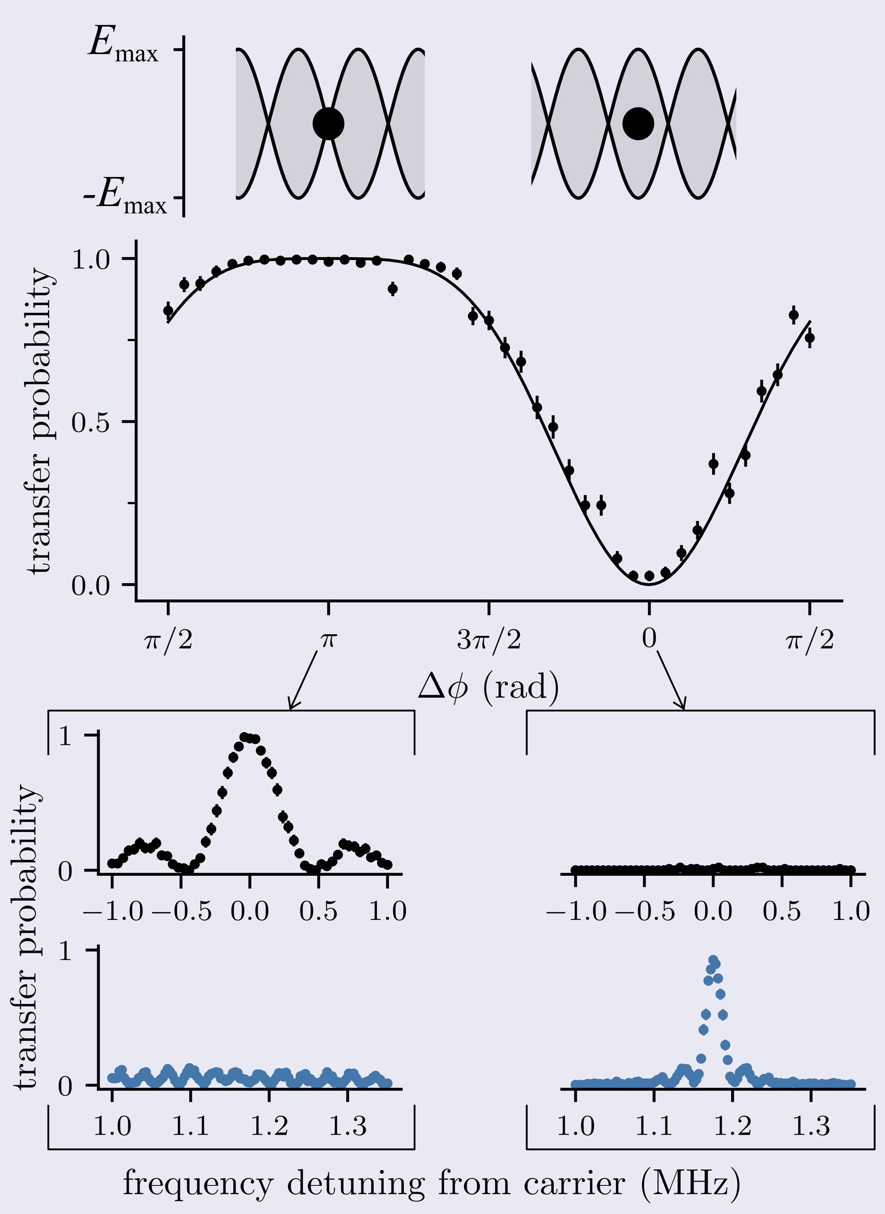
First term (carrier) a complication whilst second is desired coupling. For a quadropole transition, moving into the ??interaction picutre?? this Hamiltonian can be expressed as (modulated by $J_0 + J_2$.

$$\hat{H_{MS}} = \hbar\eta\Omega(J_0(2\Omega/\delta) + J_2(2\Omega/\delta))\cos(\delta t)\hat{S}_{\phi}(\hat{a}e^{-i\omega_z t} + \hat{a}^{\dagger}e^{i\omega_z t})$$

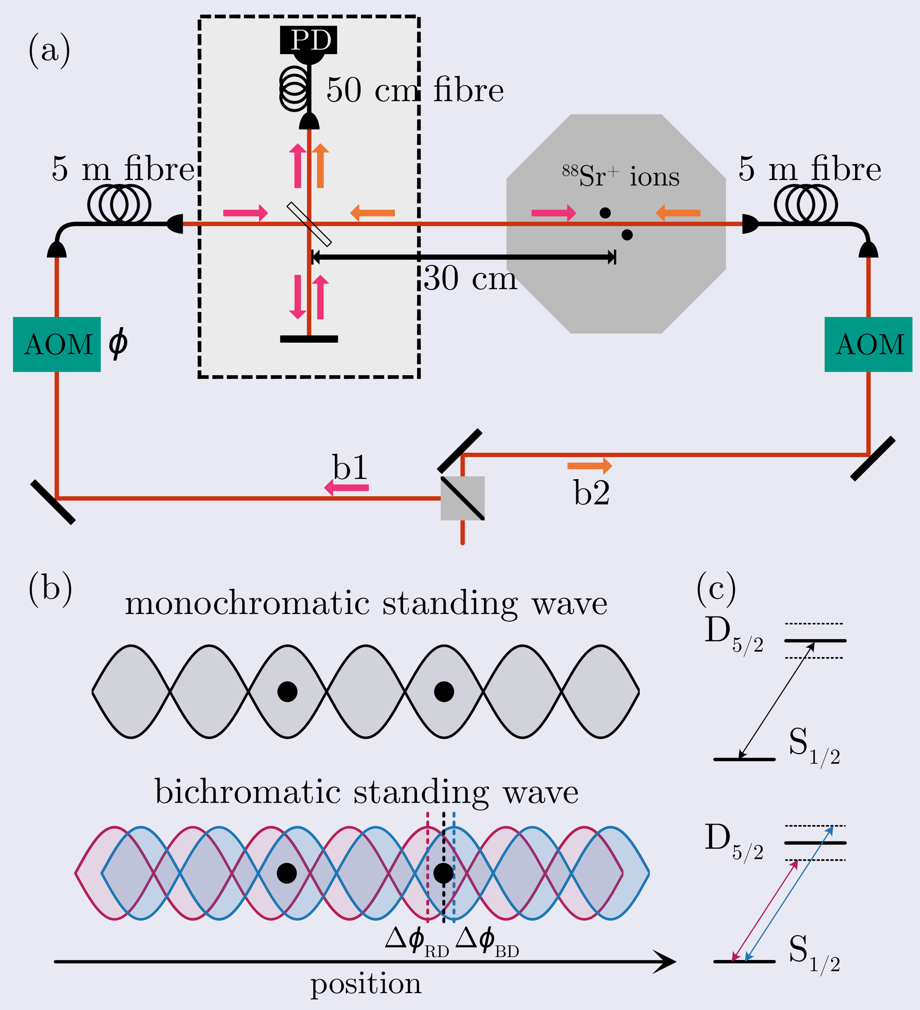
- Define a gate - MS hamiltonian
- fig: alkali metal zero spin structure diagram
- quadropole transition vs Raman
- Long coherence time of ions
- Clock speeds of ion trap qc
- issues with scaling (commutivity of quadropole MS hamiltonian bessel) and proposed solution
- issue with exciting spectators. Use fancy pulse shaping (Vera paper).
- fig: pulse shaping
- fig: interaction strength with motion saturates.

Fast Gates with a Lattice

- MS Hamiltionian with lattice removes this saturation.
- choosing phase diff of 0 and sitting at antinode to get maximal sb coupling
- fig: Control of phase visible to ions
- fig: MS gate fidelity with gate time



Phase Stabilization



- fig: experimental set up (fig1 cnulled)
- using ion feedback
- fig: RBM data to show no worse

New Platform

- whats new: double NA, Ca40, NPL trap (3D heating rates), MuMetal shield, perm magnets.
- quadropole used.
  "In practice, the dominant error source in [quadropole] gates is laser frequency noise resonant with the carrier transition, uncontrolled light shifts arising from the carrier, and laser phase noise at time scales comparable with the gate; all of these are exacerbated by the relatively small Lamb-Dicke parameter (typically 0.05), which also sets a practical limit to the gate speed because it limits gates to the adiabatic regime [Roos 2008]."
- fig: solidworks of new experiment
- fig: array of single addressing SW