Expected Trapped-Ion Fast Gate Performance with Ultrafast Pulsed Lasers

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Trapped-ion qubits are a promising technology for building large-scale quantum computers and numerous high-fidelity qubit gate operations have been demonstrated in these platforms. However, they are typically performed adiabatically and the gate speeds are unable to exceed the MHz secular frequencies of the trapped-ions. A alternative method to overcome the inherent speed limit is a fast two-qubit entangling gate [1], which uses a sequence of precision counter-propagating on-resonant laser π-pulse pairs to realize a sub-microsecond controlled-phase gate [Fig.1a]. We aim to demonstrate the fast gate operations using our arbitrary switchable pico-second pulsed laser with a repetition rate of 300.0000 MHz.

We have demonstrated a creation of π-pulses with accuracy of 94(1)% from single pulses, mainly limited by the stability of the laser's detuning and intensity ($\sim 10^{-2}$) [Fig.1b]. The accuracy in the π-pulses can be improved further using a novel real-time stabilization system with UV diffraction grating spectrometer that can tune the laser's central frequency around the atomic $^{171}Yb^{+}$ resonance with a resolution of 3.6(2) GHz. The experimental results and numerical simulations indicate our system can perform a sub-microsecond fast gate using less than ten π-pulse pairs with an expected gate fidelity of 77.8%. With the laser's stability improved to 10^{-3} (10^{-4}) and the detuning minimized, the gate fidelity can improve up to 90% (99%). These results pave the way to demonstrate scalable fast gates and enhance the gate speeds up to sub-microsecond order. This will increase the total number of gate operations that can be performed within the coherence time of the trapped-ion systems by two to three orders of magnitude.

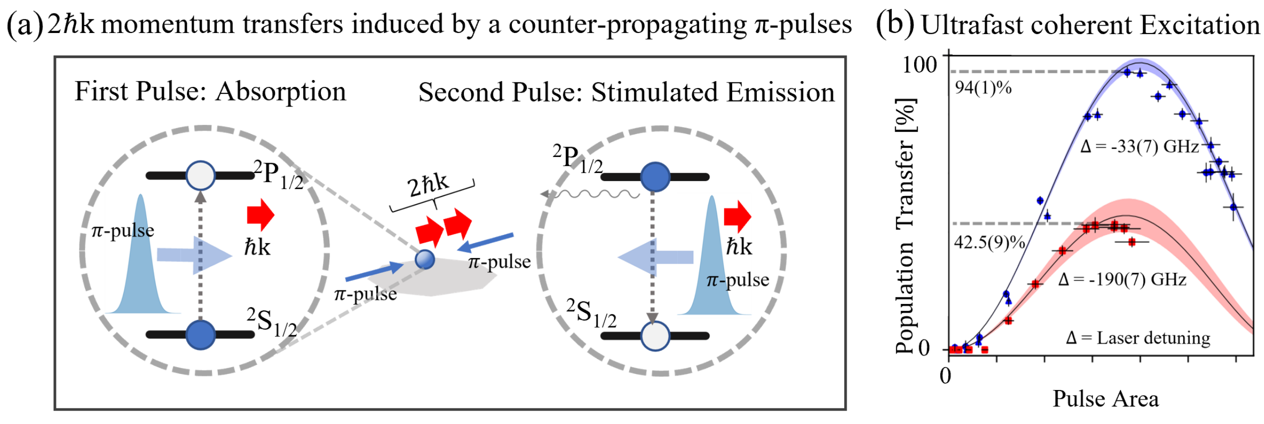

Figure 1: *(a) A sequence of momentum transfers moves the trapped-ions in phase-space to acquire a relative phase between two qubit states. (b) Ultrafast coherent excitation of a $^{171}Yb^{+}$ across the $^{2}S_{1/2}$ - $^{2}P_{1/2}$ transition as a function of the pulse area, showing the maximum population of 94(1)% is achieved.*

[1] J. J. García-Ripoll et al. *Phys. Rev. Lett.* **91**, 157901 (2003)