

# Entanglement, Tomography, and Grover's Algorithm with Trapped Ion "Clock-State" Qubits\*

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We present a series of experiments exploiting universal quantum logic gates on two  $^{111}\text{Cd}^+$  ions. Mølmer-Sorenson two-ion phase gates are used to entangle first-order magnetic-insensitive "clock" qubit states, while remaining insensitive to slow laser phase noise that can accumulate between such gates<sup>1</sup>. Single-qubit rotations are accomplished with composite pulses involving microwave radiation that drives global rotations in the qubits, and strongly focused laser beams that impart a differential ac-Stark shift on the qubits. Finally, the quantum state of each ion is measured with a CCD camera, allowing simultaneous and near-perfect qubit detection efficiency<sup>2</sup>. With these tools, we present a tomographic analysis and reconstruction of all entangled Bell states of the two ions<sup>3</sup>, as well as a demonstration of the Grover search algorithm (N=4 search space)<sup>4</sup>. The entangling gate fidelity of 80-90%, depending upon the state, is currently limited by spontaneous emission and fluctuating Stark shifts, and can be significantly improved with more laser power.

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<sup>1</sup> P. C. Haljan, K.-A. Brickman, L. Deslauriers, P. J. Lee, and C. Monroe, *Phys. Rev. Lett.* **94**, 153602 (2005).

<sup>2</sup> M. Acton, K.-A. Brickman, P.C. Haljan, P.J. Lee, L. Deslauriers, and C. Monroe, *to appear in Quant. Inf. Comp.*; *quant-ph/0511257* (2005).

<sup>3</sup> P. C. Haljan, P. J. Lee, K.-A. Brickman, M. Acton, L. Deslauriers, and C. Monroe, *Phys. Rev. A* **72**, 062316 (2005).

<sup>4</sup> K.-A. Brickman, P. C. Haljan, P. J. Lee, M. Acton, L. Deslauriers, and C. Monroe, *Phys. Rev. A* **72**, 050306 (2005).