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Scalable Preparation of Dicke States via Global Spin Squeezing in 2D Ion Crystals

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Dicke states, permutationally symmetric superpositions of two-level excitations, are pivotal resources in quantum information science and metrology [1, 2]. Their robust multipartite entanglement makes them ideal candidates for surpassing standard quantum limits in sensing and computation. However, generating arbitrary symmetric states in ion traps, Dicke states being a subset, remains challenging due to the need for precise control in large-scale systems.

We propose experimentally implementing a variational quantum circuit protocol, as described in [3], to prepare Dicke states. The protocol consists of initializing a coherent spin state, then interleaving global one-axis twisting (OAT) gates with global Pauli rotations, optimized variationally to minimize infidelity. Numerical simulations indicate that this method can produce Dicke states, such as $|J, M\rangle = |N/2, 0\rangle$, with infidelities below 10^{-3} for a qubit number $N = 300$ [3].

In our lab, a 2D crystal of hundreds of trapped Beryllium ions, in a highly optically addressable Penning trap, is a particularly well-suited platform for this protocol. Squeezing is achieved through spin-dependent optical dipole forces (ODF) coupling the ion $2s^2 S_{1/2}$ electronic levels (the qubits) to the center-of-mass mode of the crystal (i.e., motional degrees of freedom), generating an effective Ising-type spin-spin interaction that yields entanglement, as demonstrated in large ion ensembles [4, 5]. On the other hand, arbitrary global Pauli rotations are implemented by high-fidelity microwave pulses.

This work provides a path for experimental realization of symmetric states and enables exploration of quantum simulation of Dicke state dynamics in ion trap-based quantum simulators, opening the possibility for simulating systems known for displaying distinctive collective physical phenomena [3].

- [1] Marconi et al., arXiv:2506.10185 (2025).
- [2] Kitagawa, M. and Ueda, M., Phys. Rev. A 47, 5138 (1993).
- [3] Bond et al., arXiv:2312.05060 (2025).
- [4] Bohnet et al., Science 352, 1297 (2016).
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