Running Quantum Algorithms on a 20-Qubit Ion Quantum Processor

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Quantum computing is one of the most rapidly developing areas of science today. Significant progress was achieved in both theory of quantum information and experimental realization of quantum processors.

One of the major obstacles on the way to build practically relevant quantum computers is a scalability problem. Despite processors with rather long coherence time and high-quality operations were demonstrated, these properties are difficult to maintain on larger scales.

A promising approach to tackle this problem is using qudits, quantum objects with more than two information encoding states, instead of qubits. Such systems not only allow to encode information more densely, relaxing requirements on the scalability, but also enable one to perform some quantum algorithms more efficiently.

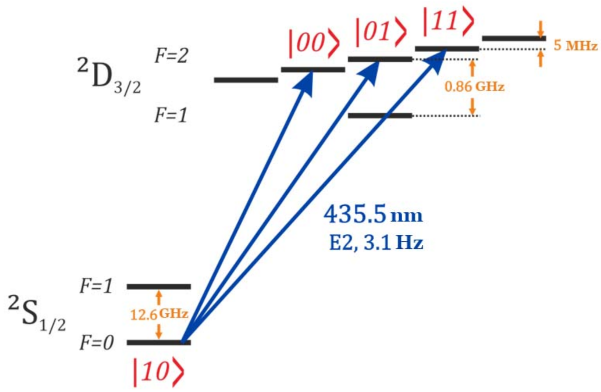

Figure 1: $^{171}Yb^+$ levels used for qudit encoding

We demonstrate a quantum processor based on $^{171}Yb^+$ ions trapped into a 3D linear Paul trap. The trap design provides high secular frequencies and low heating rate in the radial plane, which together with individual addressing and readout optical systems, allows realization of operations on up to 10 ions in a string. As a qudit states we use the ground state $^2S_{1/2}(F = 0, m_F = 0)$ and the Zeeman sublevels of $^2D_{3/2}(F = 2)$ (Figure 1). Therefore, the maximum qudit dimension equals $d = 6$. The $|0> =^2 S_{1/2}(F = 0, m_F = 0)$ state can be coupled to the upper states by the electric quadrupole transition at $\lambda = 435.5$ nm with a natural linewidth of 3 Hz (the upper states lifetime equals to $\tau = 53$ ms). Compared to the conventional scheme with a microwave qubit on the hyperfine components of the ground state, our approach provides: (i) a larger qudit dimension; (ii) a straightforward way to readout state of the whole qudit in one shot; (iii) convenient laser wavelength (435.5 nm) required for the qudit manipulation.

We realized single-qudit and two-qudit gates which constitute a universal gate set. Randomized benchmarking performed showed the fidelity of single-qudit operations $F_{1Q} = 99.4\%$. Two-qudit MS-gate showed the fidelity FMS>87% without SPAM correction which was limited by secular frequency drift and laser phase noise. For benchmarking purpose, we used two quantum algorithms: Bernstein-Vazirani and Grover algorithms. The mean fidelity reached 95% and 83% for the Bernstein-Vazirani and Grover algorithm, respectively.