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Native qudit entanglement in a trapped ion quantum processor

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An attractive proposition to extend the capabilities of quantum information systems is to fully utilise their high-dimensional Hilbert space. The internal electronic structure of trapped atomic ions offers a natural way to encode information not just in a two-level system, but in a high-dimensional qudit instead. One of the challenges of this approach is to achieve high fidelity interactions between them. We experimentally demonstrate a native qudit entangling gate between two $^{40}Ca^{+}$ ions in up to 5 dimensions by exploiting a novel generalization of the light-shift gate. We achieve gate fidelities of $99.6(1)\%, 98.7(2)\%, 97.0(3)\%, 93.7(3)\%$ for dimensions of $d = 2, 3, 4, 5$ respectively. This gate is able to generate genuine qudit entanglement in a single application which makes it scale favorably with dimension in terms of calibration overheads compared to previous approaches.

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