

Real-time dynamics of lattice gauge theories with a few-qubit quantum computer

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Gauge theories are fundamental to our understanding of interactions between the elementary constituents of matter as mediated by gauge bosons. However, computing the real-time dynamics in gauge theories is a notorious challenge for classical computational methods. In the spirit of Feynman's vision of a quantum simulator, this has recently stimulated theoretical effort to devise schemes for simulating such theories on engineered quantum-mechanical devices, with the difficulty that gauge invariance and the associated local conservation laws (Gauss laws) need to be implemented. We report the first experimental demonstration of a digital quantum simulation of a lattice gauge theory[1], by realising 1+1-dimensional quantum electrodynamics (Schwinger model) on a few-qubit trapped-ion quantum computer. We are interested in the real-time evolution of the Schwinger mechanism, describing the instability of the bare vacuum due to quantum fluctuations, which manifests itself in the spontaneous creation of electron-positron pairs. To make efficient use of our quantum resources, we map the original problem to a spin model by eliminating the gauge fields in favour of exotic long-range interactions, which have a direct and efficient implementation on an ion trap architecture. We explore the Schwinger mechanism of particle-antiparticle generation by monitoring the mass production and the vacuum persistence amplitude. Moreover, we track the real-time evolution of entanglement in the system, which illustrates how particle creation and entanglement generation are directly related. Our work represents a first step towards quantum simulating high-energy theories with atomic physics experiments, the long-term vision being the extension to real-time quantum simulations of non-Abelian lattice gauge theories.

References

[1] E. A. Martinez, C. A. Muschik, P. Schindler, D. Nigg, A. Erhard, M. Heyl, P. Hauke, M. Dalmonte, T. Monz, P. Zoller, and R. Blatt, *Nature* 534, 516-519 (2016).

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