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Probing Quantum Phases of Matter on Quantum Processors

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Quantum fluctuations and interactions give rise to exotic phases of matter with remarkable properties, pushing the boundaries of our understanding of many-body quantum systems. Solving these problems is notoriously difficult on classical computers due to the exponential complexity of quantum many-body physics. Quantum processors, on the other hand, provide a powerful new way to explore these systems, offering a more direct and potentially groundbreaking approach. In this talk, we will first discuss how to prepare the ground state of the toric code Hamiltonian using an efficient quantum circuit on a superconducting quantum processor [1]. The measured topological entanglement entropy is found to be near the expected value of log 2, we simulate anyon interferometry to extract the braiding statistics of the emergent excitations, and study the dynamics of the confinement transition. We will then investigate a class of novel, highly entangled quantum phases that exist only in non-equilibrium settings and demonstrate how to probe their stability using a quantum processor [3].

[1] Satzinger, Liu, Smith, et al., Knap, FP, Roushan, Science 374, 1237 (2021).
[2] Cochran, Jobst, et al., FP, Knap, Roushan, Nature 642, 320 (2025).
[3] Will, Cochran, Rosenberg, Jobst, Eassa, Smith, Roushan, Knap, FP, arXiv:2501.18461

Primary author: Prof. POLLMANN, Frank (TMU)

Presenter: Prof. POLLMANN, Frank (TMU)

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