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Learning field theory Hamiltonians in continuous quantum systems

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Verifying quantum simulators by learning the Hamiltonian is essential for future applications. Recently, sample-efficient Hamiltonian learning (HL) methods were developed for lattice systems, realizable with neutral atoms, trapped ions, or superconducting qubits. These methods rely on constraining coupling parameters in a local Hamiltonian ansatz by exact relations among local correlation functions, which requires resolution at the lattice scale through detailed measurements. In continuous systems, for instance, quantum gases, the measurement introduces an additional (spatial resolution) scale on which the system –and the Hamiltonian –can be probed. At this scale, collective excitations are well described by Effective Field Theories (EFTs) in terms of a few relevant local operators in the Hamiltonian. Here, we present a protocol to learn the EFT Hamiltonian from measurements of a Sine-Gordon field theory simulator realized with tunnel-coupled superfluids. Starting from an EFT, we derive a resolution scale-dependant ansatz Hamiltonian to formulate constraint equations, which tie the Hamiltonian coupling parameters to the observable correlations. We test our method by learning the EFT from numerical data with known parameters; we check the scale independence and the required statistics. Finally, we apply our method to experimental measurements to show useability in current experimental systems.

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