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Quantum simulations with cold trapped ions

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The quantum toolbox of the Innsbruck ion-trap quantum computer is applied to simulate the dynamics and to investigate the propagation of entanglement in a quantum many-body system represented by long chains of trapped-ion qubits. Quantum dynamics can be described by particle-like carriers of information that emerge in the collective behavior of the underlying system, the so-called quasiparticles. These elementary excitations are predicted to distribute quantum information in a fashion determined by the systems interactions. First, we observe the entanglement distributed by quasiparticles as they trace out light-cone-like wavefronts. Second, using the ability to tune the interaction range in our system, we observe information propagation in an experimental regime where the effective-lightcone picture does not apply [1]. Moreover, a spectroscopic technique is presented to study artificial quantum matter and use it for characterizing quasiparticles in a many-body system of trapped atomic ions [2]. Our approach is to excite combinations of the systems fundamental quasiparticle eigenmodes, given by delocalized spin waves. By observing the dynamical response to superpositions of such eigenmodes, we extract the system dispersion relation, magnetic order, and even detect signatures of quasiparticle interactions. In the second part of the talk, it will be shown how strings of trapped ions can be used for quantum simulations of a lattice gauge field theory. As an example, we map the real-time evolution of the Schwinger mechanism to a string of trapped ions in a few-qubit quantum computer, simulating the spontaneous creation of electron-positron pairs. [1] P. Jurcevic et al., Nature 511, 202 (2014) [2] P. Jurcevic et al., Phys. Rev. Lett. 115, 100501 (2015)