Adiabatic quantum operations in systems of ultrastrongly coupled matter and radiation

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Ultrastrong coupling (USC) between light and matter has been recently achieved in architectures of solid state artificial atoms coupled to cavities. In this regime new phenomena related to the highly entangled eigenstates appear. They contain virtual photons whose detection is a key issue in the field. A protocol basrd on STIRAP [1] is proposed to achieve coherent amplification of the conversion of virtual to real photons in present-day superconducting hardware [2]. Our protocol also provides a feasible road to demonstrate another "holy grail" in the field, namely dynamics in real USC structures,

Such architectures may provide new building blocks for quantum state processing, where ultrafast quantum gates can be performed. However in the USC regime the dynamical Casimir effect (DCE) poses severe limits on the fidelity of quantum operations based on quantum Rabi oscillations [3], used for processing in strongly coupled (SC) circuit-QED systems, since multiphoton generation deteriorates the fidelity even in absence of decoherence [3]. We show that a STIRAP-like adiabatic protocol overcomes this problem [4]. Ideally the cavity is never populated, operating as a virtual bus, thus it is expected to greatly reduce the impact of DCE. Indeed we show that high fidelity operations can be performed for moderate couplings in the USC regime [3], and that properly crafted control extends the high fidelity performance to even larger couplings. The protocol is extremely robust agaist DCE, in the absence of decoherence yields almost 100% fidelity for remote population and state transfer. It is also resilient to decay due to leakage from the cavity, which is the main decoherence mechanism for present USC architectures [3]. In this more realistic scenario it is seen that for larger coupling (entering the deep strong coupling regime) the fidelity decreases due to the interplay between decoherence and DCE. Our results suggest that adiabatic manipulations, may be a promising tool for quantum state processing in the USC regime.

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