Ultrastrong Interactions in Circuit Quantum Electrodynamics

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Cavity Quantum Electro-Dynamics (QED) is the study of quantum light-matter interactions with real or artificial atoms coupled to radiation modes. The vast literature on cavity QED systems mainly concerns the weakly coupled regime. The opposite limit of extremely strong interactions, where the atom-photon coupling dominates over the system's bare energy scales, is to a large extent still unexplored. This paradigm has been recently challenged in circuit QED, where artificial atoms (superconducting two level systems or qubits) can already be coupled ultrastrongly [1, 2] to a microwave mode (a LC-resonator) [3-6]. In the ultrastrong coupling (USC) regime the physics changes drastically and nontrivial effects like light-matter decoupling [7-8] and different degrees of entanglement [8, 9] can occur.

In this seminar, after a brief introduction to quantum superconducting circuits, I will consider a prototype circuit QED system consisting of multiple artificial atoms coupled to a single mode of a microwave resonator. In the USC light and matter decouple and the system exhibits a manifold of non-superradiant ground and low-energy states with a high degree of entanglement [8]. I will then describe a time-dependent protocol for extracting these quantum correlations and converting them into well-defined multipartite entangled states of non-interacting qubits. The protocol operates in a fast and robust manner, while still being consistent with experimental constraints on switching times and typical energy scales encountered in experiments. Ultimately, this procedure serves as a probe for otherwise inaccessible correlations in strongly coupled QED systems, and shows how such correlations can potentially be exploited as a resource for entanglement-based applications [10].

References:

[1] C. Ciuti, G. Bastard, and I. Carusotto, *Quantum vacuum properties of the intersubband cavity polariton field,* Phys. Rev. B **72**, 115303 (2005).
[2] J. Casanova, G. Romero, I. Lizuain, J. J. Garcia-Ripoll, and E. Solano, *Deep Strong Coupling Regime of the Jaynes-Cummings Model*, Phys. Rev. Lett. **105**, 263603 (2010).
[3] T. Niemczyk et al., *Circuit quantum electrodynamics in the ultrastrong-coupling regime*, Nat. Phys. **6**, 772 (2010).
[4] P. Forn-Diaz et al., *Observation of the Bloch-Siegert Shift in a Qubit-Oscillator System in the Ultrastrong Coupling Regime*, Phys. Rev. Lett. **105**, 237001 (2010).
[5] P. Forn-Diaz et al., *Ultrastrong coupling of a single artificial atom to an electromagnetic continuum*, Nat. Phys. **13**, 39 (2017).
[6] F. Yoshihara, T. Fuse, S. Ashhab, K. Kakuyanagi, S. Saito, and K. Semba, *Superconducting qubit-oscillator circuit beyond the ultrastrong-coupling regime*, Nat. Phys. **13**, 44 (2017).
[7] S. De Liberato, *Light-Matter Decoupling in the Deep Strong Coupling Regime: The Breakdown of the Purcell Effect*, Phys. Rev. Lett. **112**, 016401 (2014).
[8] T. Jaako, Z.-L. Xiang, J.J. Garcia-Ripoll, and P. Rabl, *Ultrastrong coupling phenomena beyond the Dicke model,* Phys. Rev. A **94**, 033850 (2016).
[9] S. Ashhab and F. Nori, *Qubit-oscillator systems in the ultrastrong-coupling regime and their potential for preparing nonclassical states*, Phys. Rev. A **81**, 042311 (2010).
[10] F. Armata et al., *Harvesting Multiqubit Entanglement from Ultrastrong Interactions in Circuit Quantum Electrodynamics*, Phys. Rev. Lett. **119**, 183602 (2017).