Detection of virtual photons in ultrastrongly coupled quantum systems

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Ultrastrong coupling (USC) between light and matter has been achieved in several physical systems [1], including architectures of solid-state artificial atoms (AA) coupled to cavities. This non-perturbative regime is expected to display new phenomena related to the highly entangled nature of the eigenstates. In particular, the ground state of a two-level AA coupled to a mode contains virtual photons [1]. They could be detected by using a third lower-energy level of the AA allowing the entangled (false) vacuum to decay [2,3], which converts virtual photons to real, the emission of photon pairs being a smoking gun of the effect [1].

However, despite many theoretical predictions, experiments at USC are mostly limited to detecting spectral features. In particular, the three-level approach [2,3] is sensitive to a stray coupling between the AA's "uncoupled" level and the mode, possibly yielding the production of photon pairs without USC [3]. The unambiguous detection of virtual photons requires a combination of spectra and matrix elements of the system which is not met in architectures with state-of-the-art superconducting AAs, such as the transmon or the flux qubit.

We address the design of a multilevel superconducting AA, showing that a superinductor-based architecture where a fluxonium AA is coupled galvanically to a resonator may provide the desired solution. The system is driven by two-tone fields implementing Raman oscillations or STIRAP [4] achieving coherent amplification of the conversion rate of virtual photons to real with 100% efficiency. Supplemented by advanced control, our multilevel design can be exploited for further quantum tasks in the USC regime, also providing a viable strategy to demonstrate coherent dynamics in USC structures.

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