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Reliable quantum advantage in quantum battery charging

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Quantum technologies must be both miniaturized and effectively scaled in order to achieve a high level of competitiveness and efficiency. However, devices operating at the nanoscale necessitate the management of extremely small quantities of energy. But how can fluctuations be properly accounted for? Indeed, the smaller the amount of energy involved, the more significant the relative impact of energy fluctuations becomes. Here, quantum batteries come into play. They are quantum systems capable of storing energy upon being charged and subsequently delivering it on demand. Such systems can be analyzed from a thermodynamic perspective, particularly through the study of energy exchanges and fluctuations. As such, they serve as well-suited models for proof-of-principle investigations of the thermodynamic efficiency of quantum devices. Moreover, quantum batteries could be a valuable resource capable of enhancing control over the processes necessary for the deployment of quantum technologies. In our work, we investigate a Jaynes–Cummings quantum battery, namely a device composed of a flying qubit interacting with an optical resonator. By employing the Full Counting Statistics technique, we demonstrate that the charging performance of the battery can be enhanced by preparing the single-mode resonator in a genuinely quantum, non-Gaussian state. Specifically, when the cavity mode is initialized in a Fock state, the charging process proves to be more efficient than in alternative situations, e.g. where classical or even Gaussan (yet quantum) cavity states are involved. We substantiate this advantage of the Fock-state protocol by evaluating the signal-to-noise ratio (SNR), which quantifies the quality of the signal (i.e., the average energy injected into the battery) comparing it to its fluctuations (i.e., the variance). This advantage is shown to be reliable, as it accounts for the dynamical energy fluctuations that arise during the process.

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