Coherent states detection for light dark matter searches using multi-qubit sensor

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Abstract: The development of superconducting quantum devices has enabled advancements in quantum sensing, particularly for light-dark matter searches. We propose an enhanced detection scheme leveraging multiple qubits to reduce dark-count rates.

The versatility of superconducting quantum devices, regarded as one of the most promising platforms for quantum computing, has opened up new opportunities for their application in quantum sensing. Notably, these devices, operating in the few-GHz frequency range, show significant potential for fundamental physics research, such as searching for weakly coupled electric fields linked to light dark matter candidates, including hidden photons and axions [1-10]. In recent years, two main approaches have been investigated for designing superconducting quantum chips capable of detecting coherent states originating from dark matter. The first involves direct qubit excitation [5,6], where the kinetic mixing of the hidden photon with the standard photon produces a weak coherent effective electromagnetic field that induces transitions between the ground state and the first excited state of the qubit. The second approach is based on a quantum non-demolition (QND) measurement [7-9], where a storage cavity traps photons generated either by the kinetic mixing transformation of hidden photons or through the inverse Primakoff effect of axions. In this scenario, the qubit's frequency shifts depending on the number of photons in the storage cavity. This method enables mapping the cavity population onto the qubit state without destroying the photon state.

We propose an enhanced detection scheme based on the QND measurement, leveraging multiple qubits to reduce dark-count rates [10]. The theoretical framework for this detection scheme utilizes input-output theory in a pulse mode to model the traveling coherent state on a transmission line interacting with the storage cavity. This approach allows for evaluating the state of the qubits coupled to the storage cavity and determining whether a coherent state is present. Factors such as thermal excitation, state preparation, and measurement errors can lead to false positives in the standard approach using a single qubit. Our method mitigates dark counts more effectively by employing multiple qubits and defining a robust detection metric. Here, we present our progress in simulating this enhanced detection scheme and outline the initial design of a prototype chip for future implementation.

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