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T01

A non-perturbative cross-Kerr coupling to achieve high fidelity quantum non-demolition superconducting qubit measurement

The most common technique of qubit readout in cQED relies on the transverse coupling between a qubit and a microwave cavity, leading to the Jaynes-Cummings Hamiltonian description and dispersive readout. However, despite important progresses, implementing fast high fidelity and Quantum Non Demolition (QND) measurement remains a major challenge. Indeed, inferring the qubit state is limited by the trade-off between speed and accuracy due to Purcell effect and unwanted transitions induced by readout photons in the cavity. To overcome this, we propose [1] and experimentally demonstrate [2] a new measurement scheme based on a transmon molecule inserted inside a 3D-cavity. The full system presents a transmon qubit mode coupled to a readout mode through an original non-perturbative cross-Kerr coupling, which is definitely different from Jaynes-Cummings Hamiltonian. This novel coupling is a key point of our readout scheme which imprint new properties in our qubit such as a protection from Purcell effect and a robust QNDness. A first generation of transmon molecule had presented promising results [2]. A novel circuit has been recently developed with optimized parameters such as the circuit geometry, the electric circuit parameters, the nanofabrication process leading to relaxation time of about 20us. We will discuss some properties on this novel readout based on the cross-Kerr coupling as its fidelity (higher than 99%), QNDness (estimation near 99%) and the effect of readout photon number on the measurement and its QNDness. [1] I. Diniz et al, Phys. Rev. A 87, 033837 (2013). [2] R. Dassonneville et al, Phys.10, 011045 (2022).

T02

Inelastic decay in an integrable system

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High probability inelastic decay of a single-photon, a phenomenon rarely observed in nature, has been recently demonstrated in a circuit QED environment [1, 2]. A system comprised of a high-impedance Josephson transmission line galvanically-coupled to a small Josephson junction allows for splitting of microwave photons with order unity probability, and provides a useful tool to probe fundamental phenomena in many-body systems. I will present an ongoing collaboration with the Manucharyan group at the University of Maryland, in which single-photon splitting is utilized in order to probe the Schmid-Bulgadaev quantum phase transition between the superconducting and insulating phases of the small junction, whose observation (or lack thereof) has sparked recent debate [3–6]. The experimental system provides a realization of the boundary sine-Gordon model, which is known to be integrable and possesses an extensive number of conservation laws. These conservation laws restrict the scattering of the integrable excitations of the field theory to be purely elastic, which seems at odds with photon splitting. However, we will show that the nonlinear relation between the integrable excitations and the microwave photons not only allows for inelastic decay of the latter, but also that powerful analytical tools provided by integrability could be used to obtain exact results for the total inelastic decay rate and the spectrum of the resulting photons. The results compare nicely with measurements by the Manucharyan group.

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[6] K. Masuki, H. Sudo, M. Oshikawa, and Y. Ashida, Absence versus presence of dissipative quantum phase transition in josephson junctions (2021), arXiv:2111.13710 [cond-mat.mes-hall].

T03

Calorimetry of a Quantum Phase Slip

n a Josephson junction, which is the central element in superconducting quantum technology, irreversibility arises from abrupt slips of the gauge-invariant quantum phase difference across the contact. A quantum phase slip (QPS) is often visualized as the tunneling of a flux quantum in the transverse direction to the superconducting weak link, which produces dissipation. In this work, we detect the instantaneous heat release caused by a QPS in a Josephson junction using time- resolved electron thermometry on a nanocalorimeter, signaled by an abrupt increase of the local electronic temperature in the weak link and subsequent relaxation back to equilibrium. Beyond providing a cornerstone in experimental quantum thermodynamics in form of observation of heat in an elementary quantum process, this result sets the ground for experimentally addressing the ubiquity of dissipation, including that in superconducting quantum sensors and qubits.

T04

Multipartite Entanglement in a Josephson Junction Laser

Ben Lang, Grace Morley, Andrew D Armour

A Josephson Junction laser (JJL) is realised by coupling a voltage-biased Josephson junction to a multimode microwave cavity. The intrinsic nonlinearity of the system means that a dc voltage tuned to a high harmonic leads to a threshold for strong emission from the cavity at the fundamental mode frequency [1]. As the threshold is approached, a frequency comb develops in modes which are integer multiples of the Josephson frequency [2]. Nonlinear systems driven by comb signals are a known source of many-mode entanglement in optics [3], an approach recently demonstrated in experiments with superconducting circuits and with surface acoustic waves [4, 5]. We find that, for the JJL, the dc bias alone is sufficient to generate multipartite entanglement across the cavity modes: the JJL provides both the comb and nonlinearity. Furthermore, the time translation symmetry, set by the Josephson period, restricts the mode frequencies that can be entangled. Consequently, they entangle into larger or smaller groups, depending on the applied voltage.

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[2] Theory of the Josephson Junction Laser, S. H. Simon and N. R. Cooper, Phys. Rev. Lett. **121**, 027004 (2018)

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T05

Period tripling due to parametric down-conversion in circuit QED

Discrete time-translation symmetry breaking can be observed in periodically-driven systems oscillating at a fraction of the frequency of the driving force. However, with the exception of the parametric instability in period-doubling, multi-periodic driving does not lead to an instability threshold. This talk discusses how quantum vacuum fluctuations can be generically employed to induce period multiplication. In particular, the period-tripled states in circuit QED are discussed in a specific Josephson circuit to show that for weak dissipation or strong driving, the timescale over which the period-tripled state is generated can be arbitrarily separated from the timescale of the subsequent dephasing.

T06

Directional broadband amplification via a topological Josephson junction array

Microwave signals coming from superconducting quantum devices are typically very weak and therefore one requires efficient amplifiers to detect them. The most advanced amplifiers currently available are Josephson traveling-wave parametric amplifiers (JTWPA) which are built of a carefully engineered array of Josephson junctions. Using four-wave-mixing, these amplifiers have shown excellent performance, especially regarding the large bandwidths, which are required for multiplexed readout in large-scale quantum information devices. The main drawback is that JTWPAs are not truly directional, meaning that parasitic signals and vacuum fluctuations can be back-amplified and contaminate the quantum source. In practice, this is avoided by equipping the JTWPAs with isolators, but these are bulky and lossy external elements that strongly limit the scalability of superconducting quantum devices. Here, we show how to build truly directional and large bandwidth JTWPA by identifying the conditions under which it enters a topological amplifying phase. Microwave photons are then unidirectionally amplified with all back-reflections and backward noise exponentially suppressed. Moreover, due to the topological origin of the directional amplification, the device achieves perfect phase-matching without dispersion engineering, and it is robust to disorder. Another topological property is that the gain of the amplifier grows exponentially with system size, implying that only 8 sites are enough to surpass 20 dB of near quantum-limited amplification and -20 dB of isolation over a bandwidth of GHz. This topological JTWPA can be immediately implemented with state-of-the-art superconducting technology, opening the door for the integration of quantum processors with compact broadband pre-amplifiers on the same chip.