Critical Quantum Sensing – Theory and Experiments

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Abstract: Critical quantum sensing achieves optimal precision while maintaining noise resilience. I present recent theoretical advances, and the first experimental demonstration of quantum metrological advantage with critical sensing protocols.

Critical quantum sensing (CQS) is by now a well-established approach, based on quantum properties spontaneously developed in proximity of phase transitions. Theoretical studies and first experimental demonstrations show that a quantum-enhanced sensing precision can be achieved by exploiting phase transitions in many-body systems. It has been recently shown that CQS protocols can also be implemented using driven-dissipative phase transitions, where the thermodynamic limit is replaced with a rescaling of the system parameters. This class of phase transitions can emerge in small-scale systems, such as quantum resonators with atomic or Kerr-like nonlinearities, and it is of high theoretical and experimental relevance.

Here, we discuss how optimal [1] CQS protocols can be implemented using a critical parametric resonator, without the need to implement and control complex many-body systems. We then show that a collective quantum advantage can be achieved in a multipartite CQS protocol using a chain of parametrical critical resonators [2]. Finally, we report on the first experimental implementation [3,4] of a driven-dissipative CQS protocol with a superconducting quantum resonator, with direct applications in magnetometry and superconducting-qubit readout.

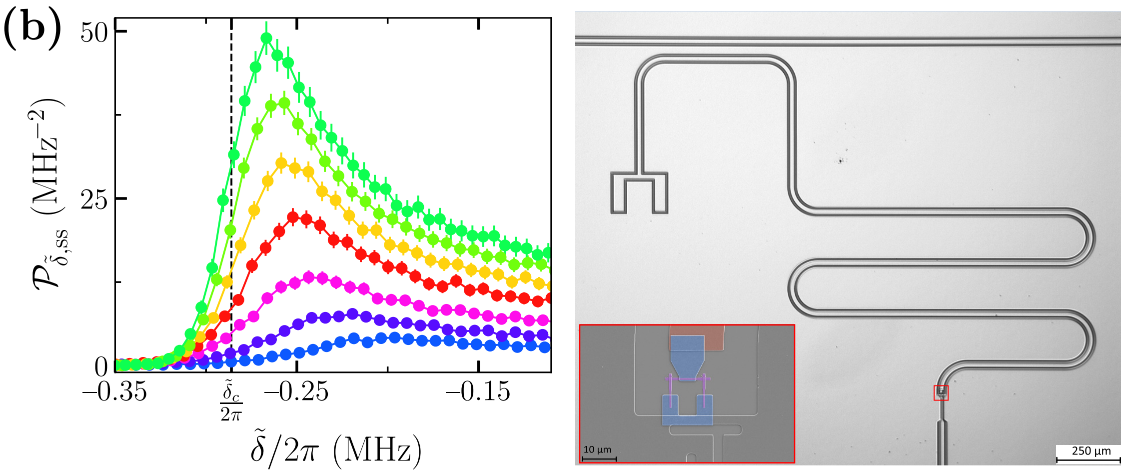

Fig. 1 Left panel: Estimation precision shows a peak at the critical point. The scaling of the maximum provides an experimental demonstration of critical quantum advantage. Right panel: Optical and SEM images of the superconducting device. Figures adapted from references [3] and [4]

Example References

[1] U. Alushi et al. Phys. Rev. Lett. 133, 040801 (2024)

[2] U. Alushi et al. Communications Physics 8, 74 (2025)

[3] G. Beaulieu et al. PRX Quantum 6 (2), 020301 (2025)

[4] G. Beaulieu et al. Nat. Comm. 16 (1), 1954 (2025)