Fundamental limits of multi-parameter quantum metrology and their attainability in magnetometry

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Quantum sensing and metrology exploit quantum phenomena to enable a new generation of ultra-precise sensors, with applications ranging from gravitational-wave detection [1] to non-invasive brain imaging [2]. Interacting many-body quantum systems provide promising routes to surpass classical strategies, offering enhanced robustness against noise and decoherence compared to traditional approaches based on state preparation and non-interacting unitary dynamics [3]. Recent advances have established fundamental precision bounds in many-body quantum metrology, both for probes at thermal equilibrium and in their ground state, complementing the previously derived bounds for unitary dynamics [4]. Building on these results, we generalize the bounds to the simultaneous estimation of multiple parameters across all three metrological settings. We then focus on the paradigmatic case of magnetometry, intrinsically a multiparameter task, and derive tight bounds for the simultaneous estimation of magnetic field components. Finally, we characterize optimal systems within these settings, and discuss the feasibility of their physical realization.

References

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[2] R. Zhang *et al.* Science Advances vol. 6 (2020) eaba8792
[3] Victor Montenegro *et al.* Physics Reports vol. 1134 (2025), p. 1
[4] P. Abiuso *et al.* Physical Review Letters vol. 134 (2025) 010801

Figures

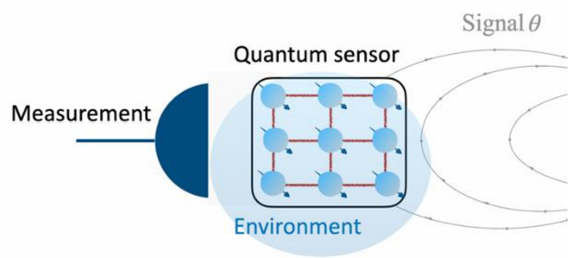

Figure 1: Sketch of a many-spin probe interacting with a signal θ.