Quantum simulation of a spin ladder using germanium quantum dots

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Abstract

With high-fidelity readout and a highly tunable Hamiltonian, spins in semiconductor quantum dots offer a promising platform for quantum simulation [1]. Here, we experimentally realize a spin ladder in a 2x4 germanium quantum dot array in the presence of a weak in-plane magnetic field [2]. As the exchange interaction between spins along the ladder's rungs is reduced, we observe the number of spin triplet states rises. We also note that this increase is smeared out as the exchange along the ladder legs increases. As the number of triplets rises, the variance in the overall magnetization is seen to increase as well. The behaviour in this small-scale system is analogous to that expected for quantum phase transitions from a rung singlet phase to a canted antiferromagnetic (AFM) phase, and ultimately to a spin polarized phase. The triplets behave as hard-core bosons and in one dimension, they can be further mapped to spinless fermions, with the intermediate phase corresponding to a Tomonaga–Luttinger liquid (TLL) [3].

References

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[2] Zhang, X., Morozova, E., Rimbach-Russ, M. et al. Nat. Nanotechnol. (2024).
[3] Giamarchi, Thierry. International Journal of Modern Physics B 26.22 (2012): 1244004.

Figures

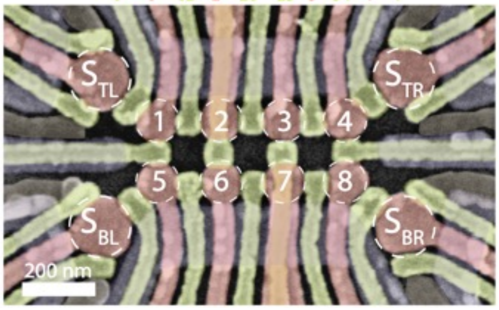

Figure 1: False-coloured scanning electron microscope image of the germanium quantum dot device. The eight quantum dots are labelled 1–8, and four charge sensors are labelled S_{TL}, S_{TR}, S_{BL} and S_{BR}.

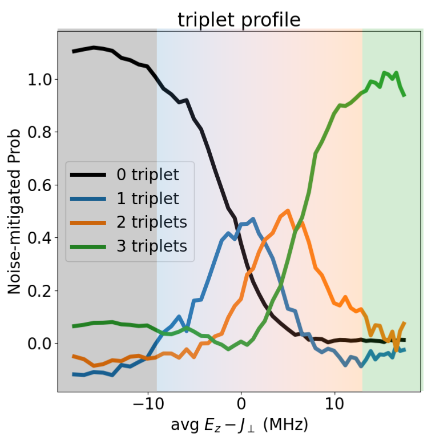

Figure 2: Noise-mitigated probabilities of the measured 0, 1, 2, and 3 triplet states along the rungs of a 2x3 spin ladder as a function of the average vertical energy gap E_z-$J_\perp$. From left to right, the system's ground state transitions from an all-singlet state to a canted antiferromagnet state and finally to a polarized state.