Magnetically mediated hole pairing in fermionic ladders of ultracold atoms

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The Fermi-Hubbard model is of great interest in the study of strongly correlated electronic materials, such as high-temperature superconductors, where electron-electron (or hole-hole) interactions play a vital role in determining the material properties. In our experiment, we perform quantum simulation of the Fermi-Hubbard model using ultracold ^{6}Li atoms in optical lattices. Quantum gas microscopy enables us to directly study high order, spatially resolved spin and charge correlations of the resulting many-body states.

Here I will present our recent experiment in which we observed hole-hole pairing that is mediated by magnetic correlations [1]. To achieve this, we engineer antiferromagnetic mixed dimensional ladders where an additional potential offset between neighboring legs suppresses the interchain tunneling, while simultaneously enhancing the spin exchange and singlet formation [2]. Our observations reveal that the holes in this system prefer to occupy sites on the same rung of the ladder, resulting in a decrease in pair size and an increase in binding energy, which we extracted to be on the order of the superexchange energy. Furthermore, we detect the formation of spatial structures consisting of pairs of hole-pairs, indicating repulsion between bound hole pairs. Our work provides insights into the pairing mechanism that is conjectured to occur in many unconventional superconductors [3]. I will also discuss the recent technical upgrade of our optical lattices, that allows us to now realize larger and colder systems and possibly explore strongly correlated phases in low-temperature region of the Fermi-Hubbard model.

References

[1] S.Hirthe et al., Nature 613, (2023) 463-467
[2] A.Bohrdt et al., Nat. Phys. 18, (2022) 651-656
[3] D.J.Scalapino, J. Low Temp. Phys. 117, (1999) 179-188

Figures

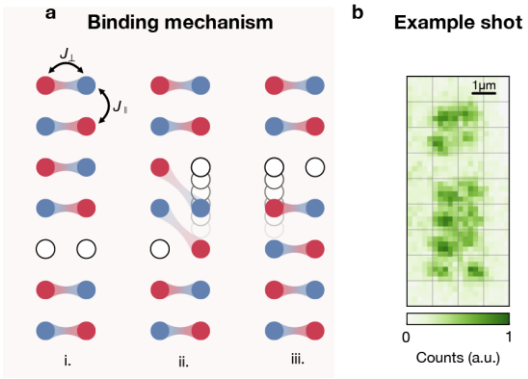

Figure 1: Hole pairing in mixD ladders. a, When a single hole from (i) moves through the system (ii), it breaks the spin order. (iii) The magnetic energy cost can be avoided if the second hole restores the spin order by moving together with the first hole. **b**, Single experimental shot with two holes on the same rung

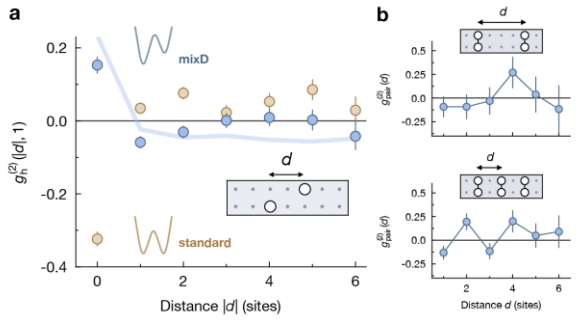

Figure 2: a, Hole–hole correlator between sites on opposite legs for mixD (blue) and standard (brown) ladders. Correlations at this distance are strongly enhanced in the mixD system. **b**, Measured pair–pair correlation of rung hole pairs in the experimental system.