Self-Energy Pole Optimization of Superconductivity in the Bilayer Hubbard Model

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In strongly correlated superconductors, the nontrivial real-frequency dependence of the self-energy is believed to hold a key to elucidating the pairing mechanism. Indeed, a cluster dynamical mean-field analysis of the single-layer Hubbard model has shown that poles of the self-energy originating from the Mott insulator enhance superconductivity [1]. In the single-layer system, however, the pole structure is poorly controllable, which makes it difficult to control superconductivity through it.

Motivated in part by the discovery of high-temperature superconductivity in the bilayer nickelate $La_3Ni_2O_7$ [2], we focus on the bilayer Hubbard model, which possesses the interlayer hopping $t_\perp$ as a control parameter. Superconductivity in this model has been discussed mainly from the weak-coupling viewpoint [3]. In this work, we instead analyze it with the dynamical cluster approximation, a nonperturbative method, and reveal the existence of self-energy poles produced by Mott physics and their role in enhancing superconductivity [4].

At half filling, we first show that the crossover from a Mott insulator (MI) to a band insulator (BI) appears as a reorganization of the self-energy poles controlled by $t_\perp$. This pole structure is inherited by the superconducting state upon doping and yields an $s^{\pm}$-wave superconducting solution enhanced by the poles of the anomalous self-energy. The superconducting order parameter is then maximized near the MI–BI boundary in the strongly correlated regime (Fig. 1), because the anomalous self-energy poles of the two bands are simultaneously located near low energies and cooperatively enhance the pairing. We further find that these poles can be understood in terms of the same pairing-enhancement mechanism as in the single-layer system, namely hybridization with emergent fermions. The bilayer system thus provides a platform that materializes a new guiding principle for optimizing strongly correlated superconductivity: the control of self-energy poles through $t_\perp$.

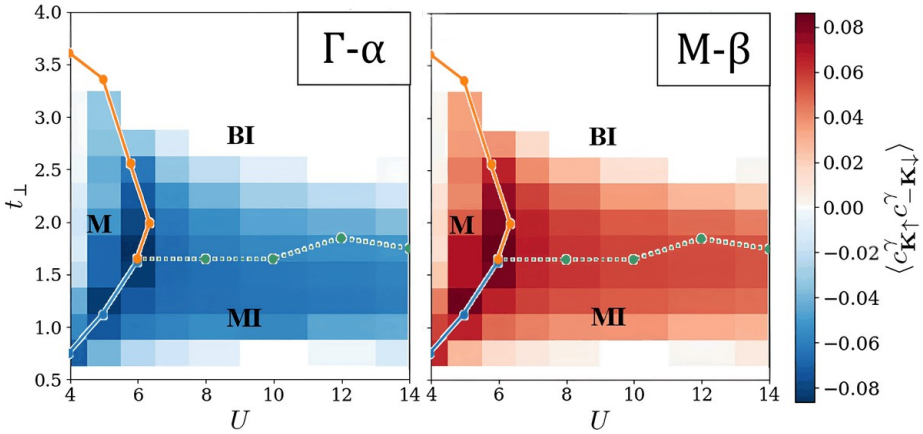


Figure 1: (U, $t_\perp$) dependence of the superconducting order parameter at δ = 0.02 (left: **K** = (0,0) antibonding component; right: **K** = (π,π) bonding component). The sign reversal indicates the $s^{\pm}$-wave symmetry. The half-filling phase diagram (M: metal, MI: Mott insulator, BI: band insulator) is overlaid.

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