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Grand-Canonical Variational Approach for the *t-J* Model

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The constraint of no double occupancy enforced in the t-J model has made it difficult to carry out a variational approach with particle number varying. Thus it has been difficult to examine the true superconducting state with phase coherence. By extending a previous method proposed by Yokoyama and Shiba in 1988, we present a grand-canonical scheme allowing particle number to fluctuate. To achieve the consistency with the canonical wave function, the BCS coherence factor must be corrected with a fugacity factor as proposed earlier by Laughlin and Anderson.

Chemical potential, particle number fluctuation, and phase fluctuation of the projected BCS state, difficult or even impossible to be calculated in the canonical ensemble, have been directly measured in this grand-canonical picture. We find that except for La-214 materials, the doping dependence of chemical potential is consistent with experimental findings on several cuprates. Similar to what has been reported by scanning tunneling spectroscopy experiments, the tunneling asymmetry becomes much stronger as doping decreases. We found a very large enhancement of phase fluctuation in the underdoped regime.