Spin and Polaron Correlations in the t-J Model from Hidden Fermion Determinant States

Annika Böhler[1,2], Hannah Lange[1,2,3], Christopher Roth[4], Annabelle Bohrdt[2,5]

(1) Ludwig-Maximilians-University Munich (2) Munich Center for Quantum Science and Technology (5) University of Regensburg

(3) Max-Planck-Institute for Quantum Optics (4) Center for Computational Quantum Physics, Flatiron Institute

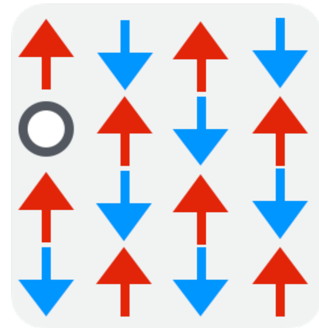
Introduction & Summary

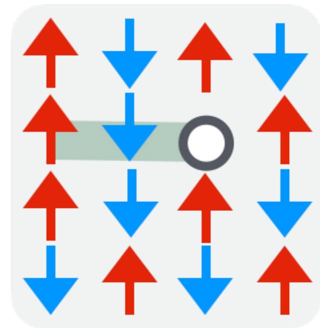
We apply a neural network parametrization to study the two-dimensional $t-J$ model. We use a *hidden fermion determinant state* (HFDS) representation, which constructs an enlarged Slater determinant of both physical and hidden fermions. We show that in particular for the finite doping regime, the neural HFDS becomes very efficient, achieving similar energies as matrix product states (MPS) at a significantly lower amount of parameters.
We apply our architecture to study multi-point correlations of the ground state for a full doping scan, allowing us to extract spin-spin and polaron correlations and compare them to experimental data.

The $t-J$ Model

* strong coupling limit of the Fermi Hubbard model
* believed to capture many phases of cuprate superconductors

$$\hat{H}_{tJ} = -t \sum_{\langle i,j\rangle} \sum_{\sigma} \mathscr{P}_G \left(\hat{c}^\dagger_{i\sigma} \hat{c}_{j\sigma} + h.c. \right) \mathscr{P}_G + J \sum_{\langle i,j\rangle} \left(\hat{S}_i \cdot \hat{S}_j - \frac{\hat{n}_i \hat{n}_j}{4} \right)$$

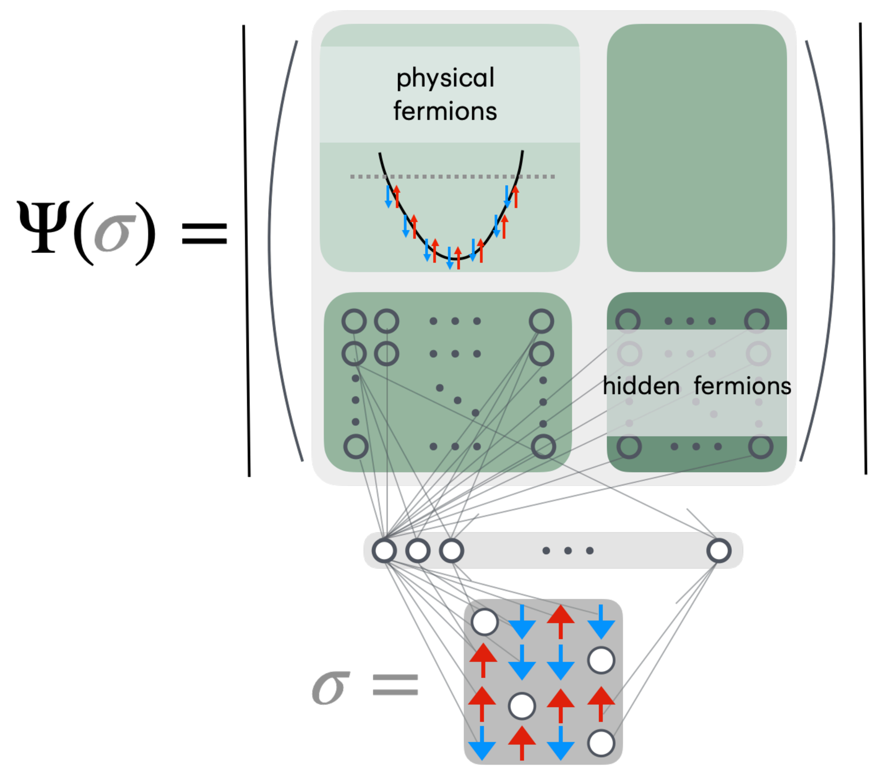




* low doping: geometric string theory [1]
* single dopant creates string Σ of displaced spins

Network Architecture [2],[3]

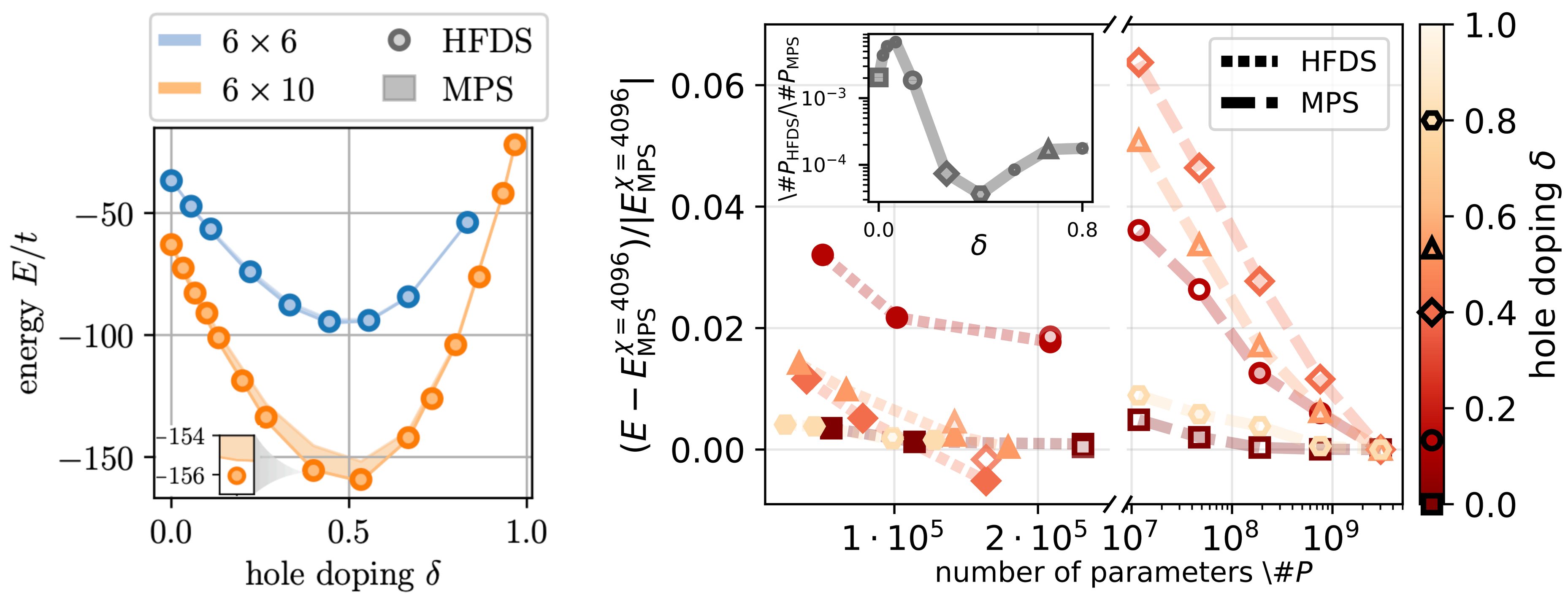
* Neural Quantum State (NQS) as variational wavefunction
* optimize parameters via VMC to minimize energy
* fermionic antisymmetry: hidden fermion determinant states



$$|\psi\rangle = \sum_{\sigma} \psi(\sigma) |\sigma\rangle$$

Comparison to MPS

* compare to SU(2) symmetric MPS calculation with $\chi_{max} = 4096$
* competitive energies at orders of magnitude lower number of parameters

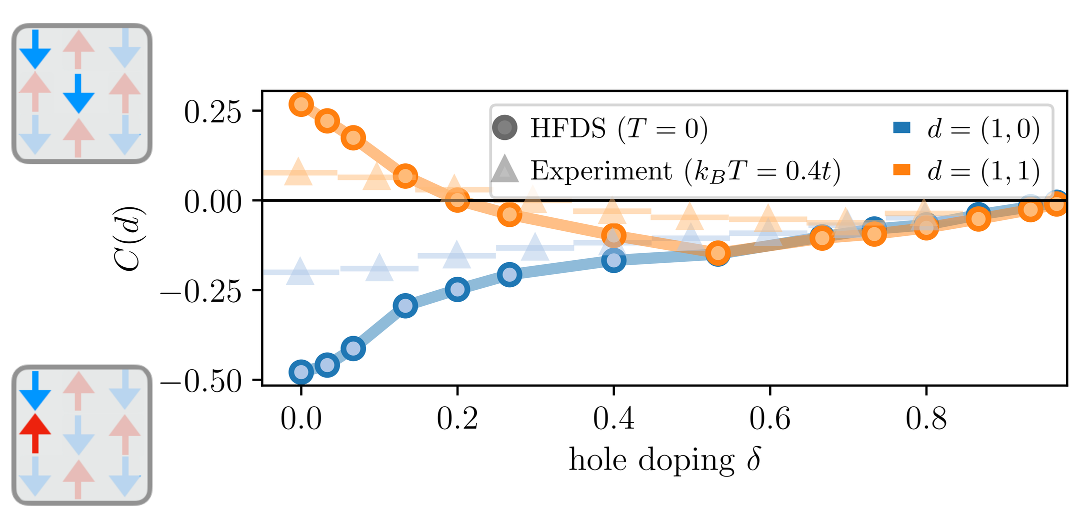


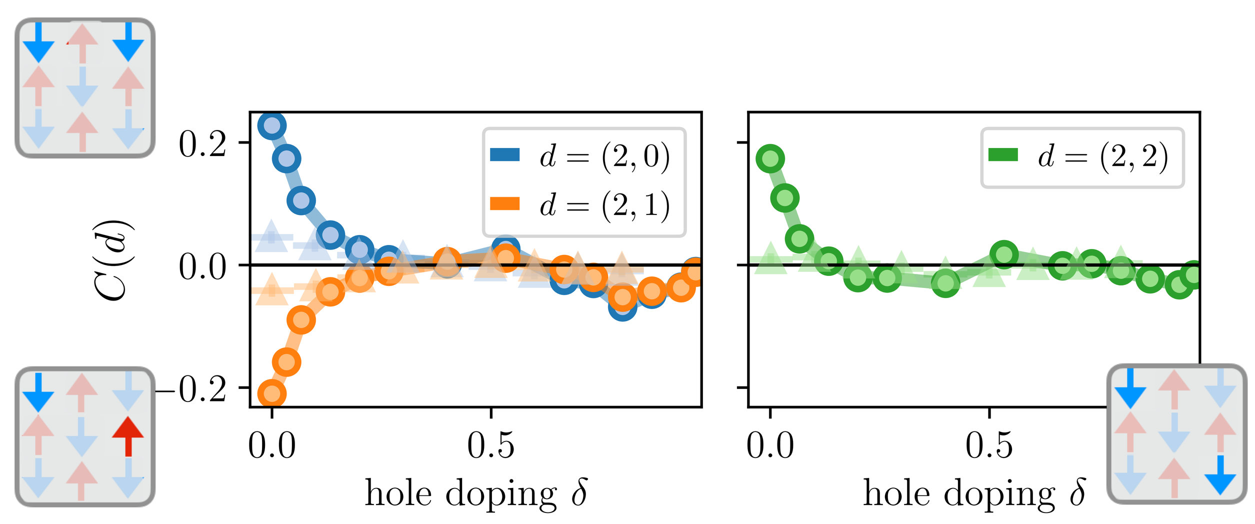
Spin and Polaron Correlations

experimental data: [4]

* **Spin-Spin Correlations**

$$C(\boldsymbol{d}) = \frac{1}{N_{\boldsymbol{d}}} \sum_{\boldsymbol{r}_1,\boldsymbol{r}_2;\boldsymbol{r}_1-\boldsymbol{r}_2=\boldsymbol{d}} \eta_{\boldsymbol{r}_1,\boldsymbol{r}_2} \langle \hat{S}^z_{\boldsymbol{r}_1} \hat{S}^z_{\boldsymbol{r}_2} \rangle_c$$

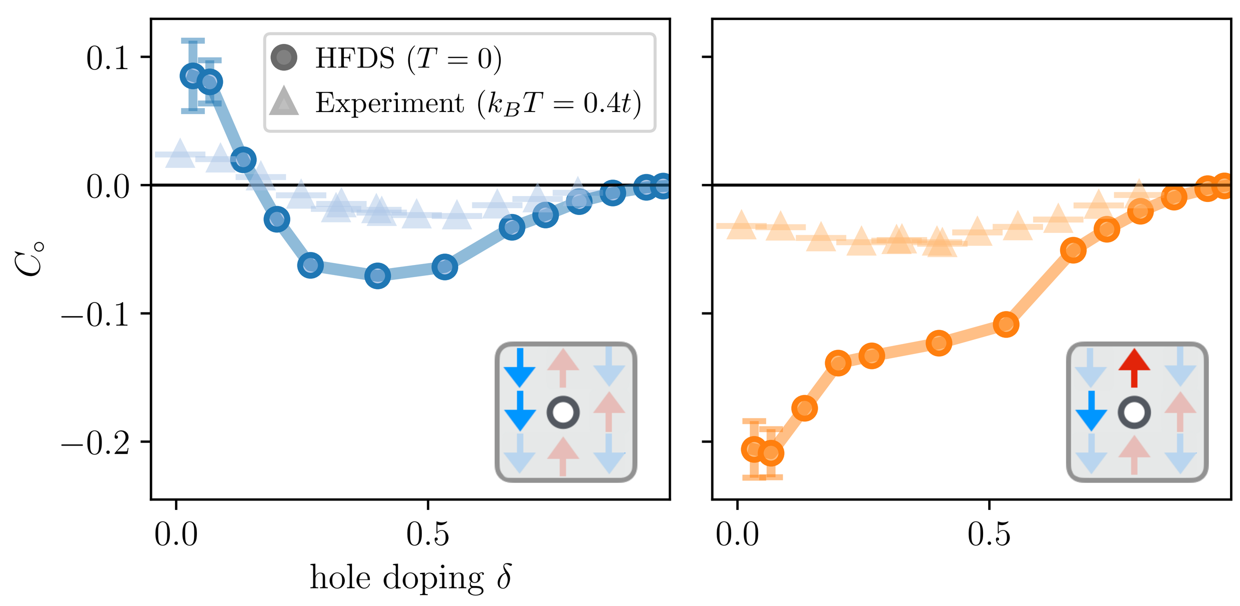


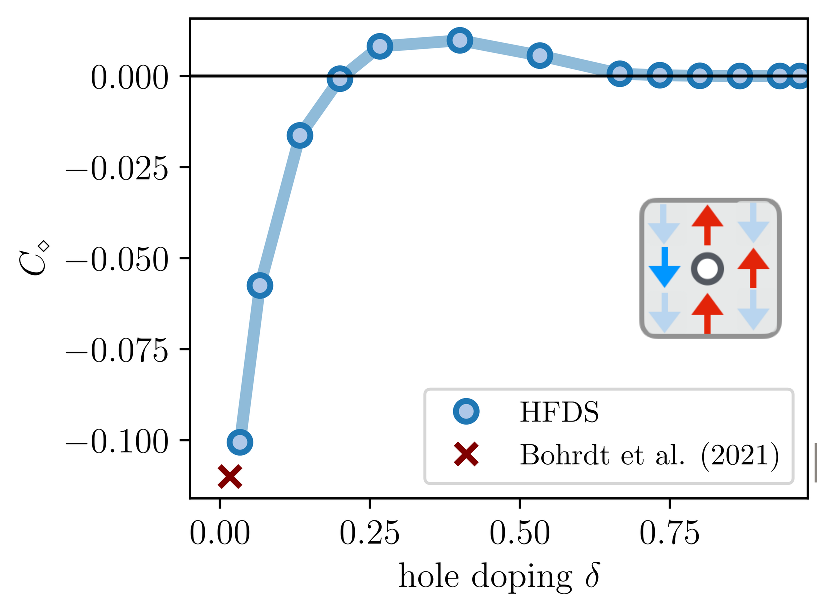


* **Polaron Correlations**

$$C_\circ(\boldsymbol{d}, \boldsymbol{r}_h) = \frac{1}{N_{\boldsymbol{d}} N_{\boldsymbol{r}_h}} \sum_{\boldsymbol{r}_h} \sum_{\boldsymbol{r}_1,\boldsymbol{r}_2;\boldsymbol{r}_1-\boldsymbol{r}_2=\boldsymbol{d}} \tilde{\eta}_{\boldsymbol{r}_1,\boldsymbol{r}_2,\boldsymbol{r}_h} \langle \hat{S}^z_{\boldsymbol{r}_1} \hat{S}_{\boldsymbol{r}_2} \hat{n}^h_{\boldsymbol{r}_h} \rangle_c$$

$$C_\diamond = \frac{2^4}{N_r} \sum_{\boldsymbol{r}_h} \frac{1}{\langle \hat{n}^h_{\boldsymbol{r}_h} \rangle} \langle \hat{n}^h_{\boldsymbol{r}_h} \hat{S}^z_{\boldsymbol{r}_h+\hat{e}_x} \hat{S}^z_{\boldsymbol{r}_h-\hat{e}_x} \hat{S}^z_{\boldsymbol{r}_h+\hat{e}_y} \hat{S}^z_{\boldsymbol{r}_h-\hat{e}_y} \rangle$$





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References

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