Studying Chiral Symmetry with SU(2) Non-Abelian Gauge Theory via Quantum Computer

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The 1st International Workshop on Physics at High Baryon Density, CCNU, 2024.11.4

Introduction

- Quantum computing: a promising new method
- Topics of interest:
  - Real-time evolution
  - Non-perturbative physics
  - Non-Abelian gauge theory
  - Thermal states
  - ...

Method

- 1+1D SU(2) model: simplest non-Abelian model

$$H = -i\bar{\psi}\gamma^1(\partial_1 + igA_1^a t^a)\psi + m\bar{\psi}\psi + \mu\psi^\dagger\psi + \frac{1}{2}\left(L^a\right)^2$$

- Mapping to quantum circuits:
  - Staggered fermion
  - Gauss's Law

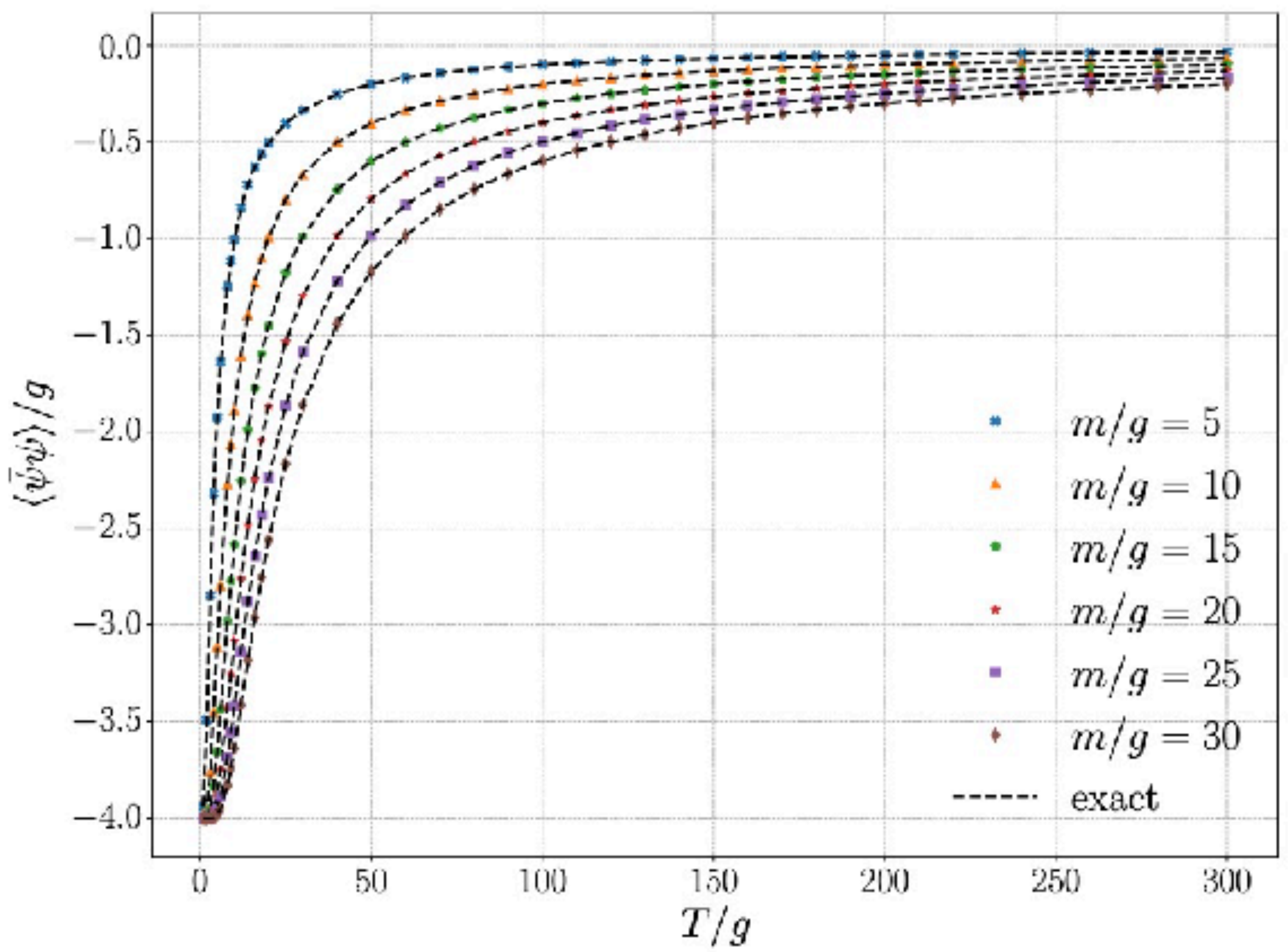
$$\mathrm{L}_n^a - \mathrm{L}_{n-1}^a = Q_{n-1}^a \rightarrow \mathrm{L}_n^a = \sum_{i<n} Q_i^a$$

  - Jordan-Wigner transformation
- Algorithm for thermal state:
  - VQE: minimize free energy
  - Monte Carlo sampling

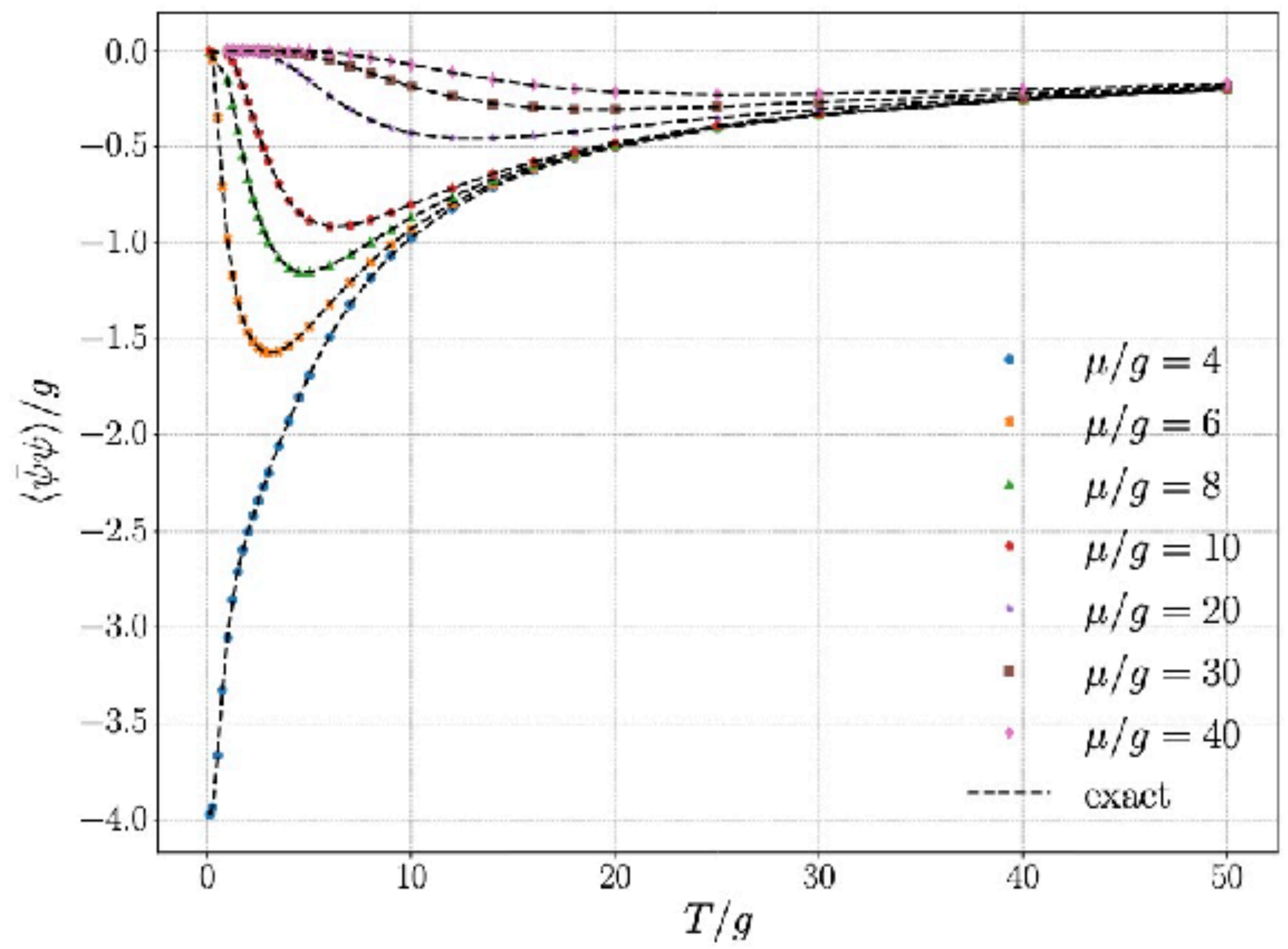
$$\rho(\alpha) = \sum_i p_i(\beta)\underline{U(\alpha)\,|\,i\rangle\langle i\,|\,U^\dagger(\alpha)}, \quad F = \sum_i p_i\left[E_i + T\ln p_i\right]$$

Independent of T

Results: Full Gibbs State



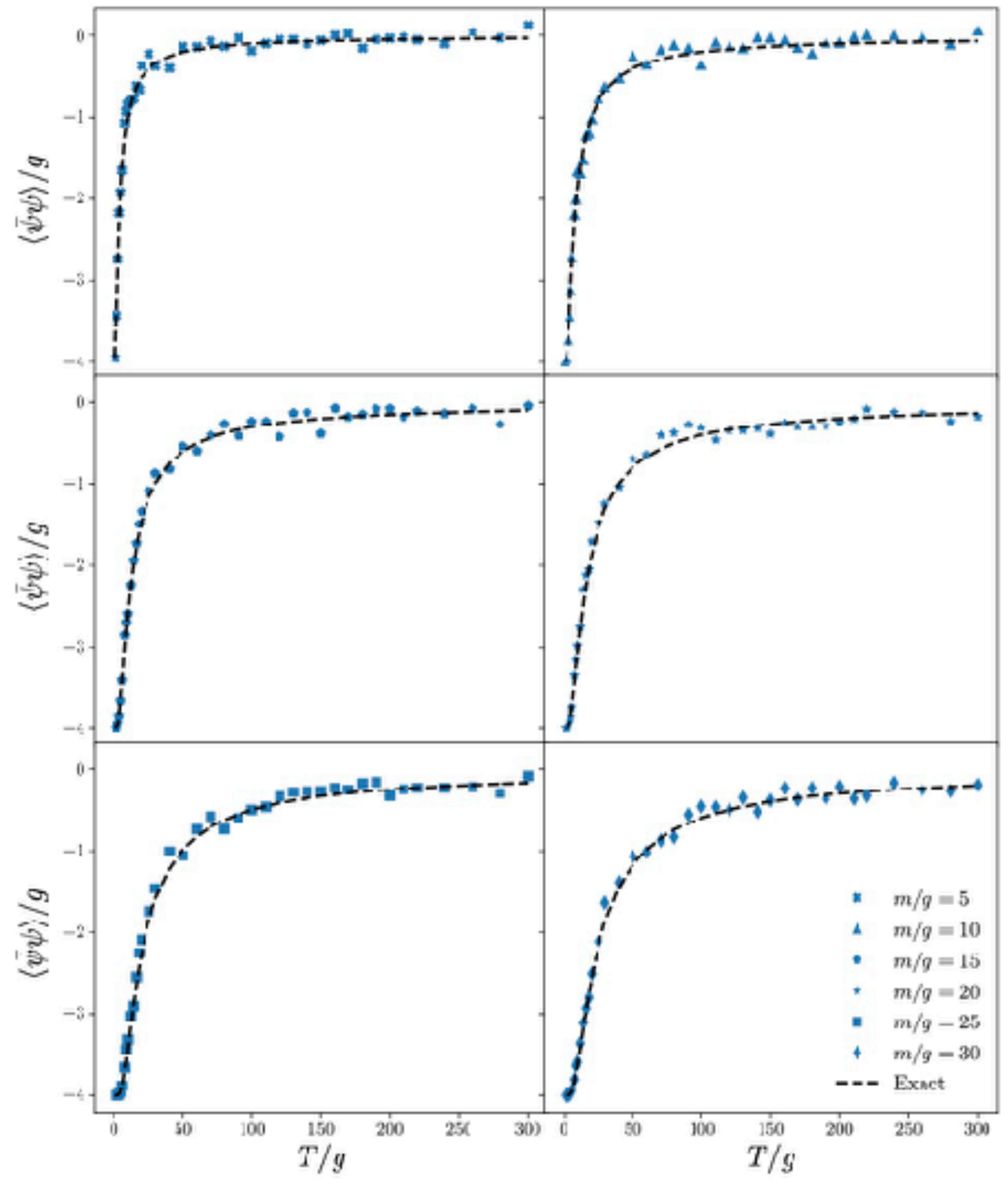
$n_q = 8, \mu/g = 0$



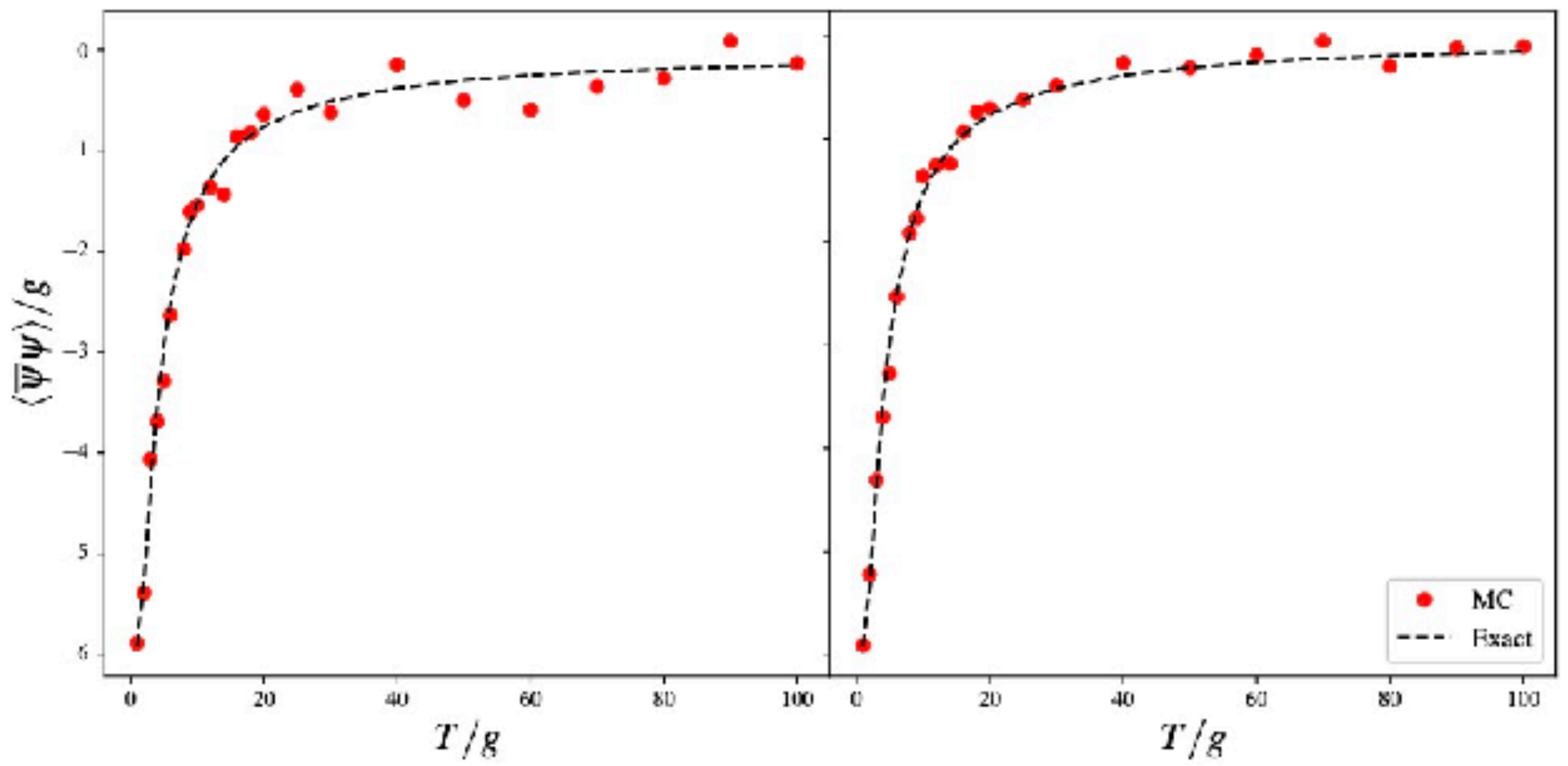
$n_q = 8, m/g = 5$

- The VQE method produces the Gibbs state very accurately.

Results: Monte-Carlo



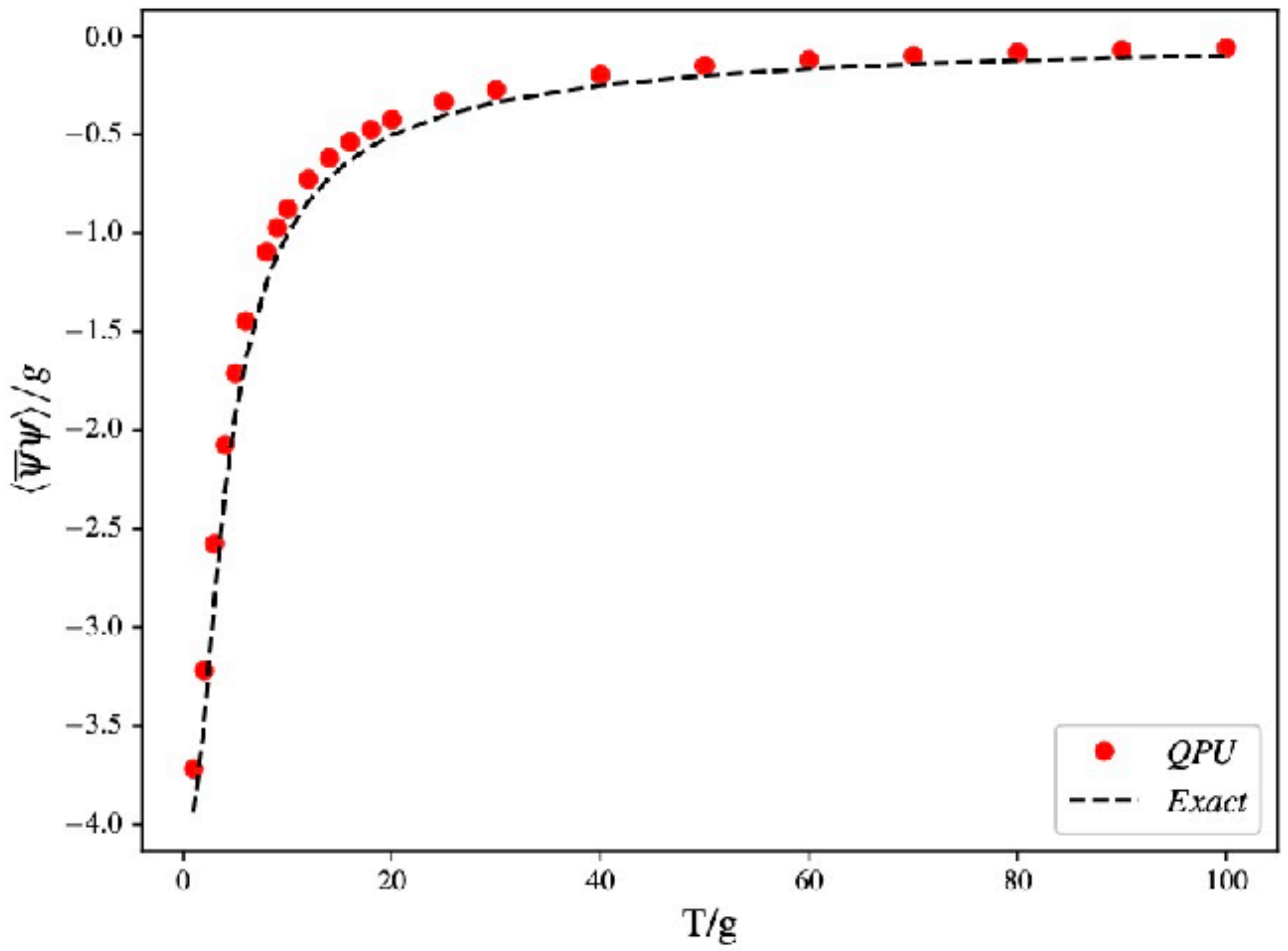
$n_q = 8, N = 1000$



$n_q = 12, N = 1000$ $n_q = 12, N = 2000$

- Required number of sampling does scale exponentially with system size.

Results: Real QC results



$n_q = 8$, full Gibbs State

- Our algorithm can achieve good precision on real QC.

Summary

- We propose a framework with VQE and Monte-Carlo method to simulate thermal states on quantum computers.
- With this frame work, the chiral condensate of 1+1D SU(2) gauge model is studied.
- Our method is efficient and accurate in classical simulations as well as on real QCs.