# Non-perturbative real-time evolution in a strong coupling theory

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quantum simulation of the Schwinger model

$$H_{\text{cntn}} = \int \left(\bar{\psi}(\gamma^1(-i\partial_z - g\,A_1) + m)\psi + \frac{1}{2}\mathscr{E}^2 \right) dz \,,$$

$$\begin{pmatrix} \psi_f(z) \\ \psi_{\bar{f}}^\dagger(z) \end{pmatrix}$$

$A, \mathscr{E}$ U_n, ε_n

$$\begin{pmatrix} \chi_{2n} \\ \chi_{2n-1} \end{pmatrix}$$

$|1\rangle$: empty / $|0\rangle$: occupied — $\bar{f}$ f — $|1\rangle$: occupied / $|0\rangle$: empty
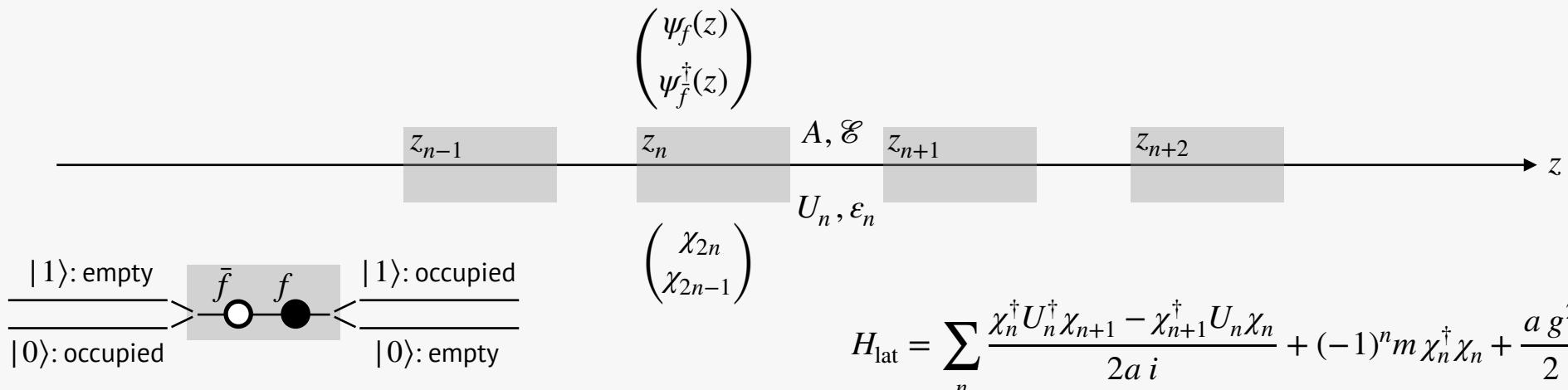
$$H_{\text{lat}} = \sum_n \frac{\chi_n^\dagger U_n^\dagger \chi_{n+1} - \chi_{n+1}^\dagger U_n \chi_n}{2a\,i} + (-1)^n m\,\chi_n^\dagger \chi_n + \frac{a\,g^2}{2}\varepsilon_n^2 \,.$$

I. phase structure

➡ critical point: chiral condensate, susceptibility, entanglement spectrum & entropy

$$\langle O \rangle_{T,\mu} = \frac{\text{tr}(O\,e^{-H/T - Q/\mu})}{Z_{T,\mu}} \,,$$

$$\rho_A \equiv \text{tr}_{\bar{A}}\rho = \sum_i p_i |i\rangle\langle i| \,,$$

$$S_{\text{EE}} = -\sum_i p_i \ln p_i \,,$$

$N=20$, $T=g/10$, $L=4/g$ — $\langle Q \rangle$ — $\langle \bar{\psi}\psi \rangle g$ — $\chi_{Q,2}\,g^2$ — $S_{\text{EE}}(T=0)$ — p_i — $\theta=0$, $\theta=\pi/2$
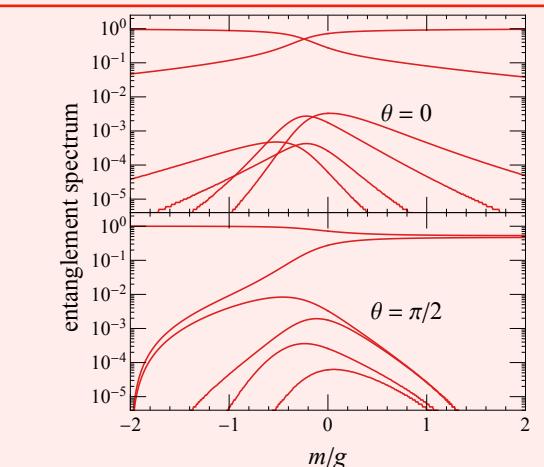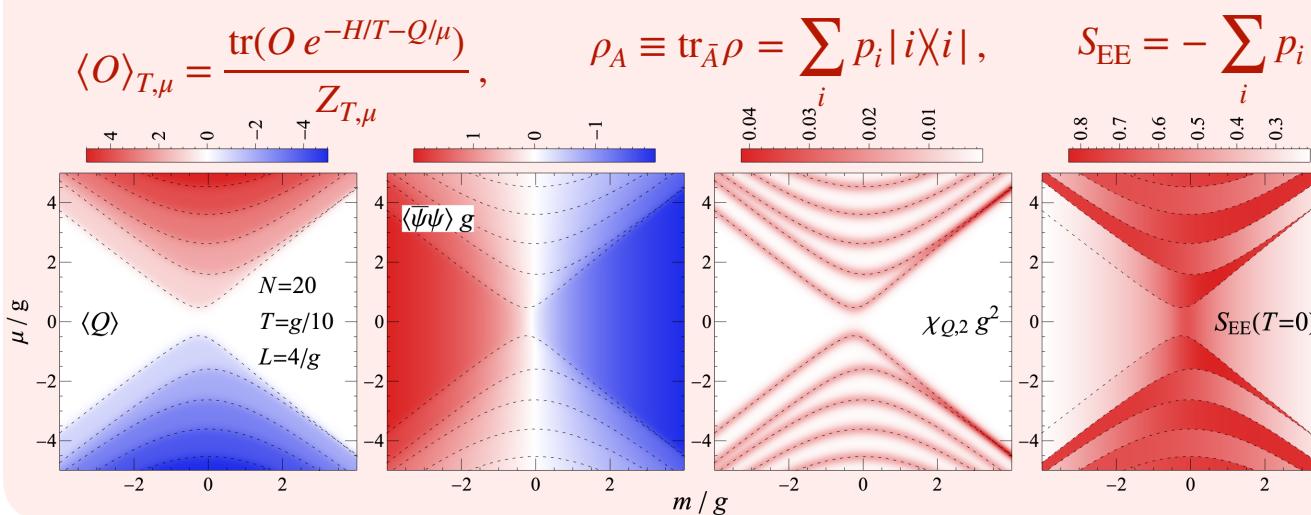
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II. jet production

➡ jet production perturbs vacuum condensate and generates entropy

source — fermion — anti-fermion — electric charge — dynamical electric field

A B

$\dfrac{E_{\text{ele},t} - E_{\text{ele},0}}{a\,g^2/2}$, external only, $\nu_t - \nu_0$, S_{EE}, Q_t

$10^2 \times \langle \Delta\nu_{-\eta_s}\,\Delta\nu_{+\eta_s}\rangle$, $t = 10\,a$, correlated, uncorrelated, η_s

$10^2 \times \langle \Delta\nu_{N/2+l}\,\Delta\nu_{N/2+1-l}\rangle$, correlated, uncorrelated, $l=3,5,7,4,6,9,8$
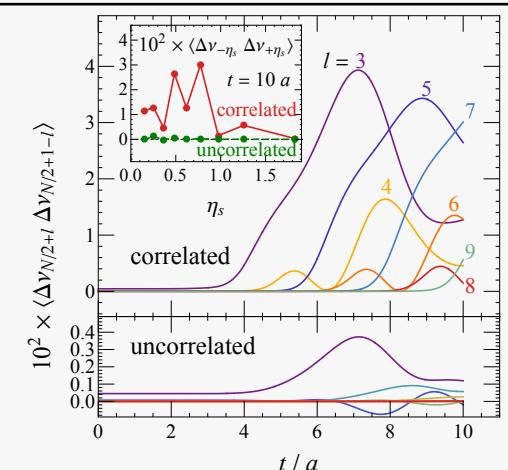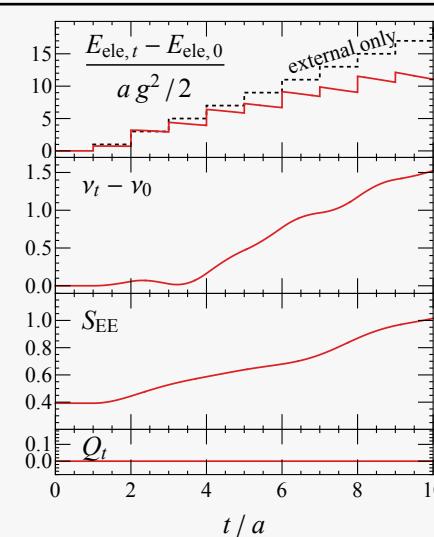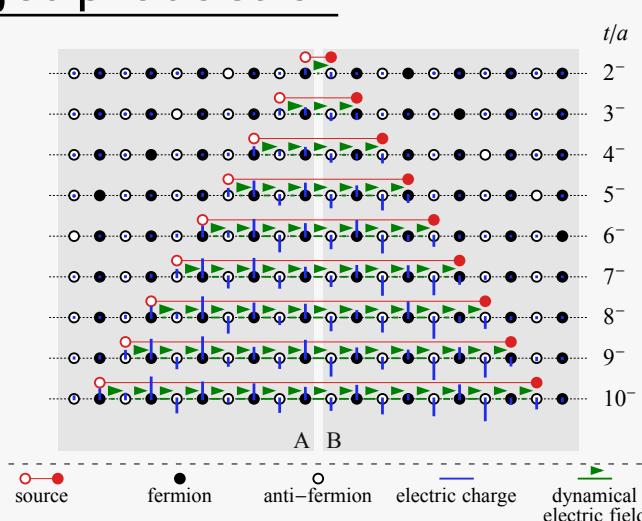
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III. charge transport

Q_n, $Q_{5,n}$, $m=0$, $m=4g$
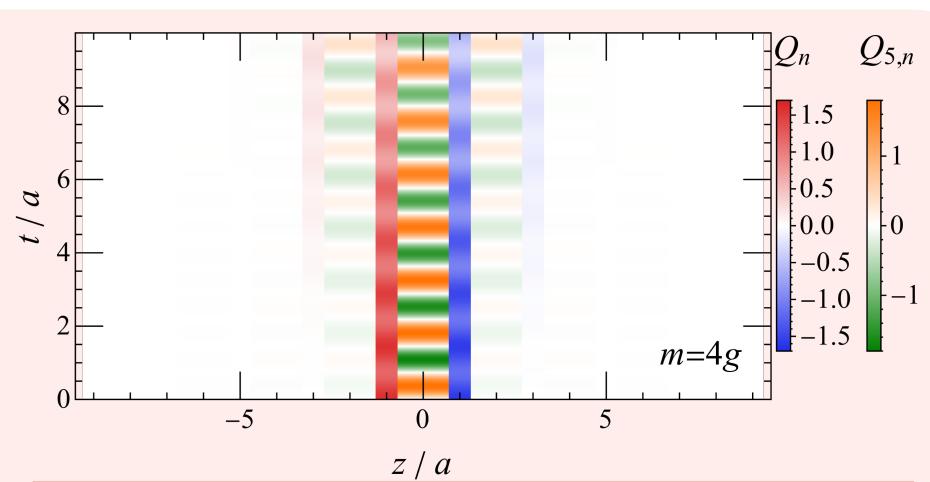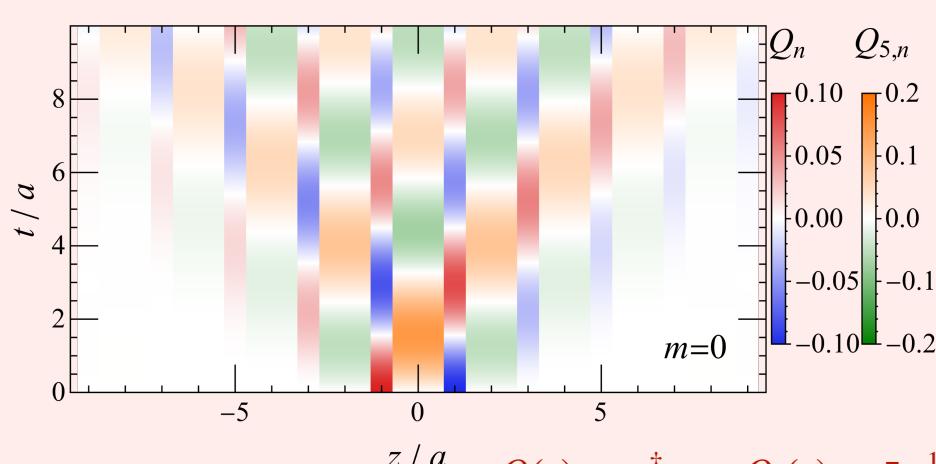
➡ localization of dipole ↔ weak coupling/massive

$$Q(z) = \psi^\dagger\psi \,, \quad Q_5(z) = \bar{\psi}\gamma^1\psi \,.$$

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