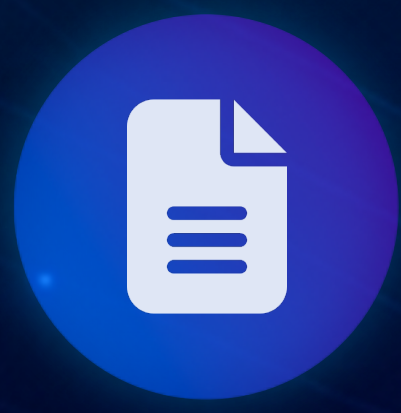


Preparation and detection of quasiparticles for quantum simulations of scattering

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ABSTRACT A model-independent method for the selective preparation and detection of quasiparticle wave packets, built from creation operators that generate dressed, localized excitations on interacting vacua of (quasi-)1D quantum many-body systems. We exploit maximally localized Wannier functions to enable species-resolved preparation and detection, separating known quasiparticles from unknown resonances. Demonstrated with MPS; tested on pure hardcore Hamiltonian QCD on a ladder, recovering scattering outputs and mass resonances.

METHOD

(a,b,c) ED and **Wannier function** minimization

$$|\phi_\theta\rangle = \frac{1}{\sqrt{l}} \sum_k e^{i\theta_k} |\phi_k\rangle \quad \sigma^2[\theta] = \sum_{j=1}^l x_j^2 p_j[\theta]$$

(d,e) Variational problem for the **creation operator**

$$\hat{\phi}_j^\dagger |\Omega_l\rangle = \text{[Diagram of a chain with a localized excitation]} \quad \hat{\Psi}^\dagger = \frac{1}{\mathcal{N}} \sum_{j=1}^L c_j \hat{\phi}_j^\dagger$$

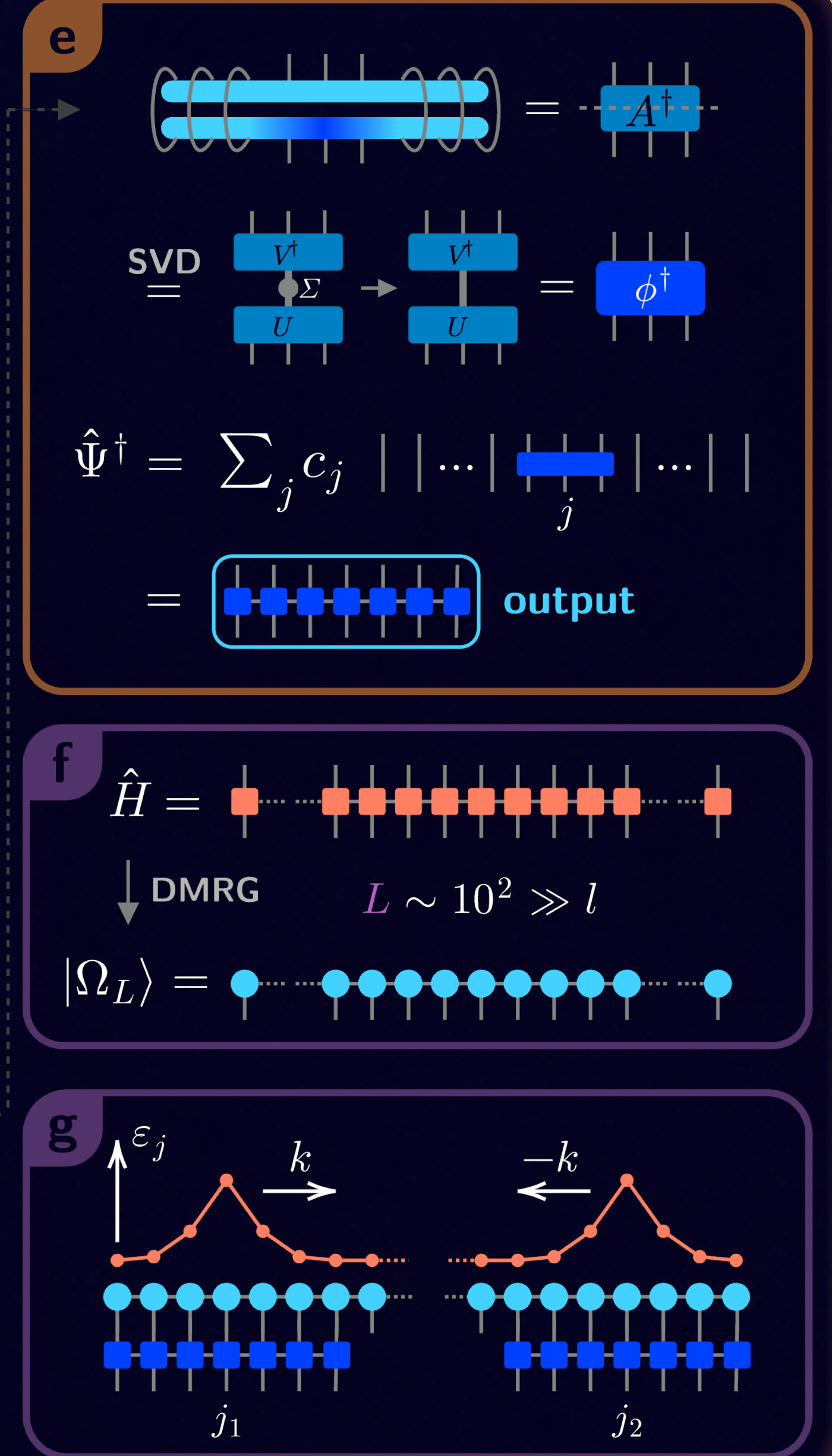
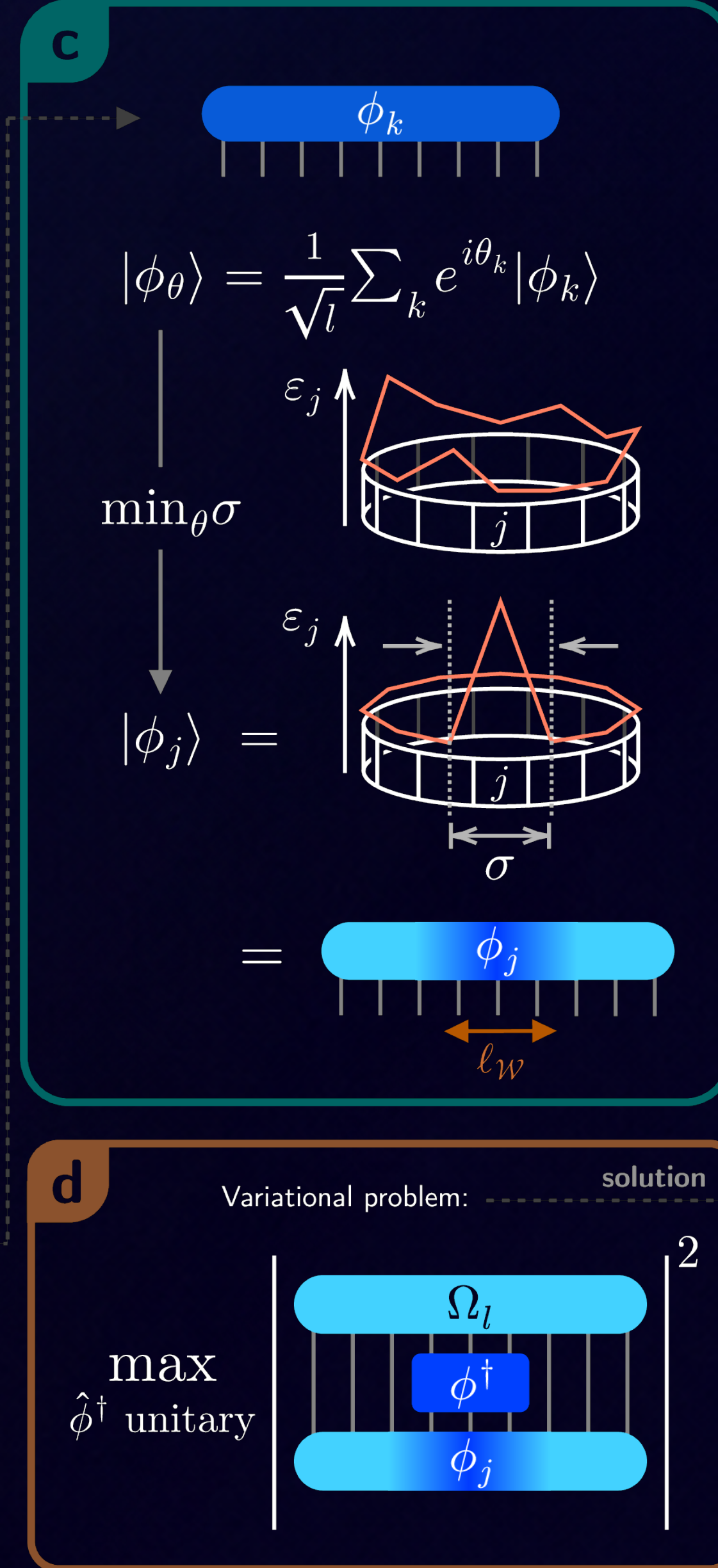
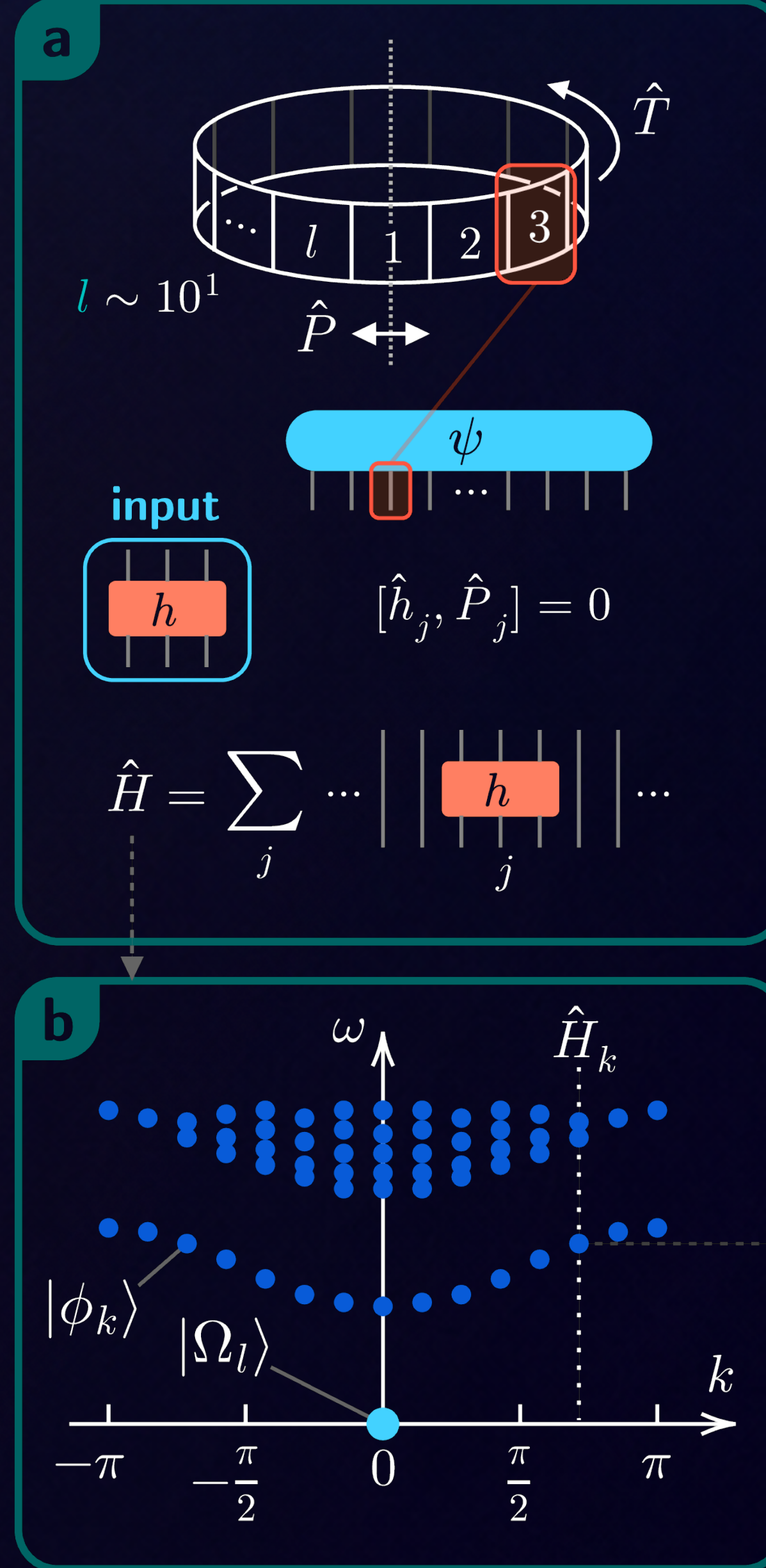
(f,g) Initial state **preparation** and time evolution

$$|\psi(t)\rangle = \hat{U}_{\text{TDVP}}(\delta t)^N \hat{\Psi}_1^\dagger \hat{\Psi}_2^\dagger |\Omega_{\text{DMRG}}\rangle$$

Real-space **detection** of a single-quasiparticle species

$$\hat{\rho}_j^\Psi = \text{[Diagram of a chain with a localized excitation]} \quad \hat{\rho}^\phi = \text{[Diagram of a chain with a localized excitation]}$$

$$\text{Tr}[\hat{\rho}^\phi \hat{\rho}_j^\Psi] = \text{[Diagram of a chain with a localized excitation]}$$



MODEL

Hamiltonian lattice Yang-Mills (e.g. **QCD**) without matter on a **ladder geometry**

$$\hat{H} = \lambda \hat{H}_E + (1 - \lambda) \hat{H}_B \quad (\text{Kogut-Susskind Hamiltonian})$$

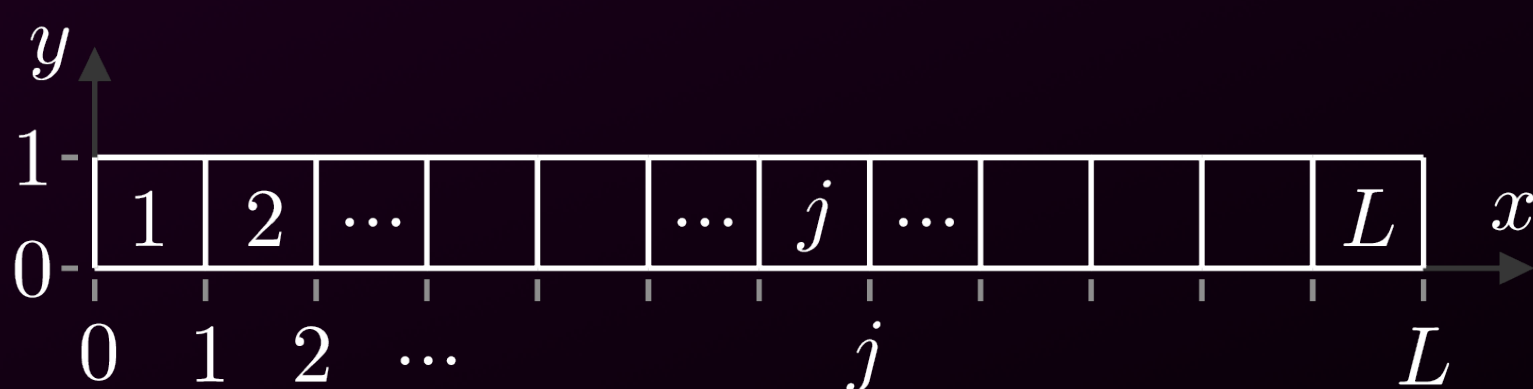
Electric terms (sums over links) and **magnetic** term (sums over plaquettes)

$$\hat{H}_E = \sum_j \hat{E}_j^2 + \hat{E}_j^2 + \hat{E}_j^2 \quad \hat{H}_B = - \sum_j \hat{U}_j + \hat{U}_j^\dagger$$

Magnetic flux (Wilson loop) and **electric field** squared (quadratic Casimir)

$$\hat{U}_j = \text{Tr}[\hat{U}_j^\dagger \hat{U}_j^\dagger \hat{U}_j^\dagger \hat{U}_j^\dagger] \quad \hat{E}_\ell^2 = \sum_a (\hat{L}_\ell^a)^2 \quad [\hat{L}_\ell^a, \hat{U}_{\ell'}] = +\delta_{\ell\ell'} \hat{U}_\ell T^a$$

$$[\hat{L}_\ell^a, \hat{U}_{\ell'}] = -\delta_{\ell\ell'} T^a \hat{U}_\ell$$



Gauge group **irrep truncation**

$$\eta_n \otimes \eta_m = \eta_{n+m \bmod 3}$$

$$G = \mathbb{Z}_3 \rightarrow \{1, e^{i2\pi/3}, e^{-i2\pi/3}\}$$

$$\mathbf{j}_n \otimes \mathbf{j}_m = \mathbf{j}_{n+m \bmod 3} \oplus \text{truncated}$$

$$G = \text{SU}(3) \rightarrow \{1, 3, \bar{3}\} \oplus \{6, \bar{6}, 8, \dots\}$$

Gauss' Law

$$n_j^\uparrow - n_{j+1}^\uparrow + n_j^x = 0 \pmod{3}$$

Longitudinal polarization

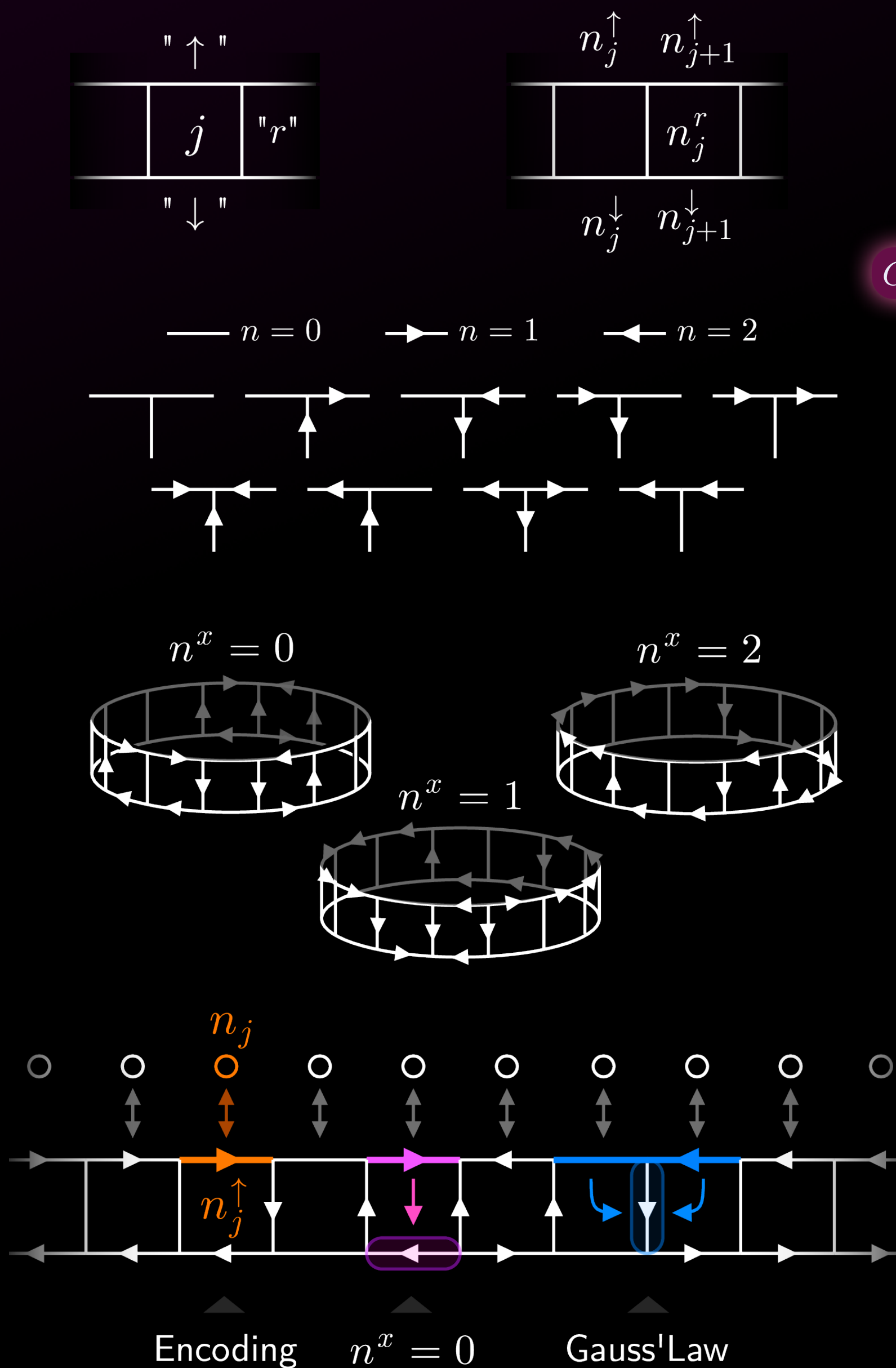
sector splitting

$$n_j^x = n_j^\uparrow + n_j^\downarrow \pmod{3}$$

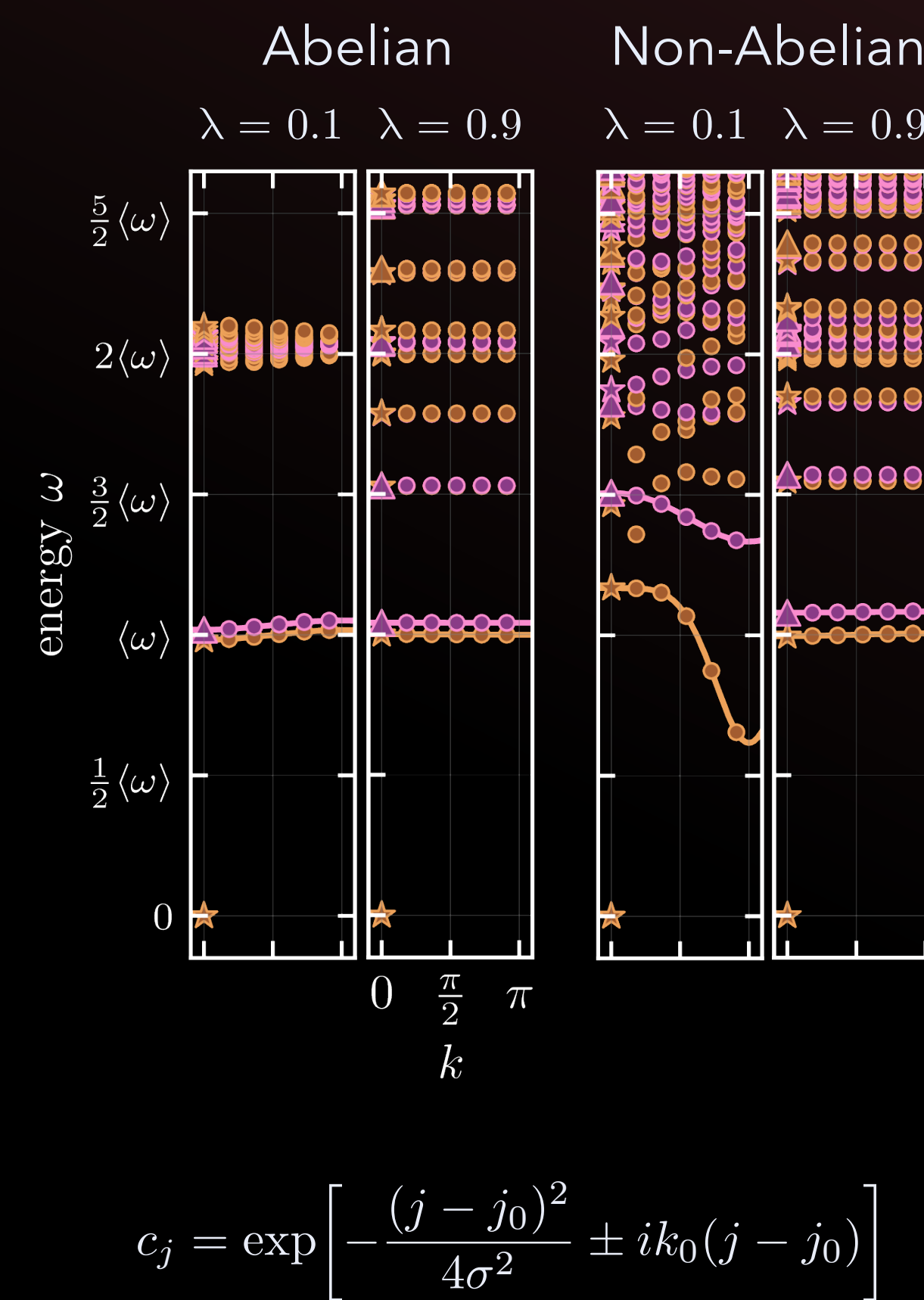
$$n_j^x = n_{j+1}^x \quad \forall j$$

$$\mathcal{H}_{\text{phys}} = \mathcal{H}_0 \oplus \mathcal{H}_1 \oplus \mathcal{H}_2$$

Mapping of the zero polarization sector to a **qutrit chain**



RESULTS

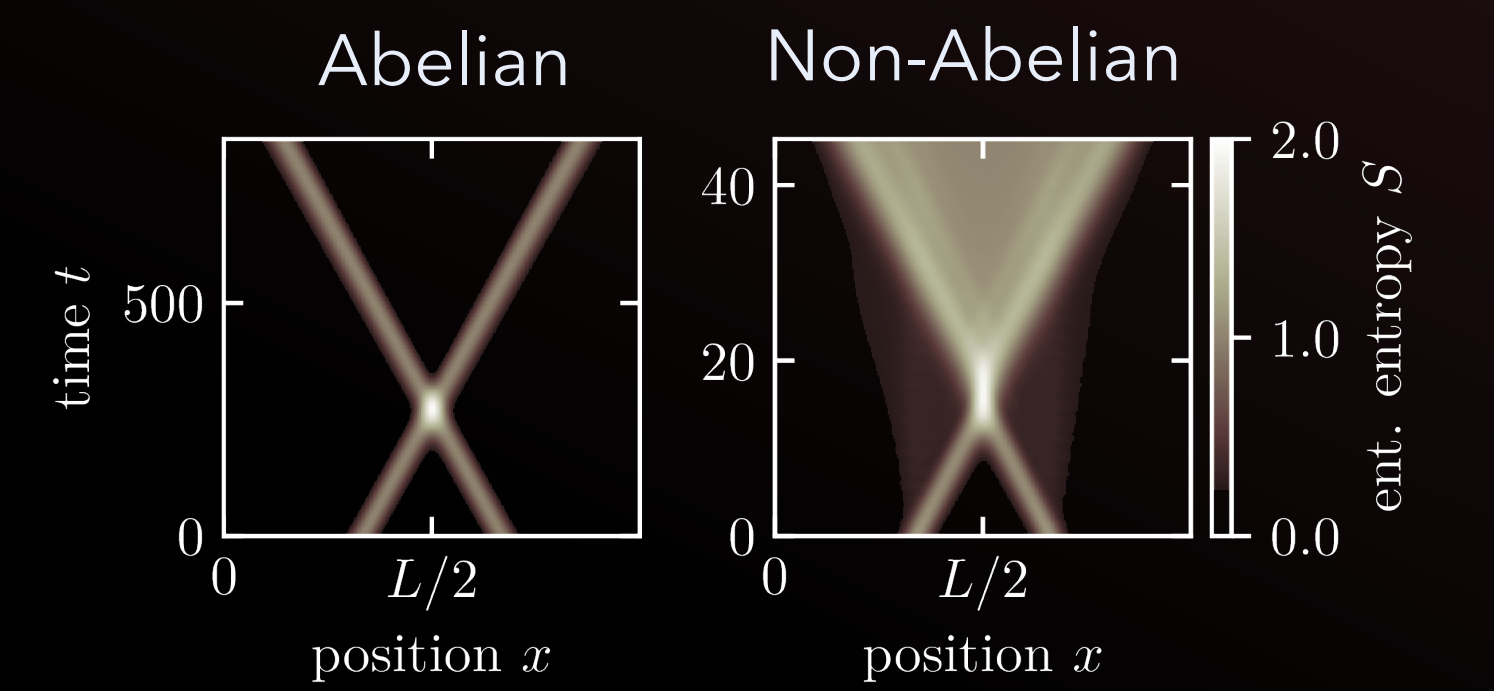


Symmetries split into **sectors**

$$|0_1^{--}\rangle = \frac{|\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle}{\sqrt{2}} \quad P = -1 \quad C = -1$$

$$|0_1^{++}\rangle = \frac{|\uparrow\uparrow\rangle + |\downarrow\downarrow\rangle}{\sqrt{2}} \quad P = 1 \quad C = 1$$

Entanglement entropy $0^{++}-0^{++}$ in scattering



Initial **Gaussian wave packets** prepared with the method above

