Quantum Monte Carlo study of a Z_2 gauge theory containing phases with and without a Luttinger volume Fermi surface

V44.00011
APS March Meeting, Los Angeles

Fakher Assaad, Snir Gazit, Subir Sachdev, Ashvin Vishwanath
March 8, 2018

Talk online: sachdev.physics.harvard.edu

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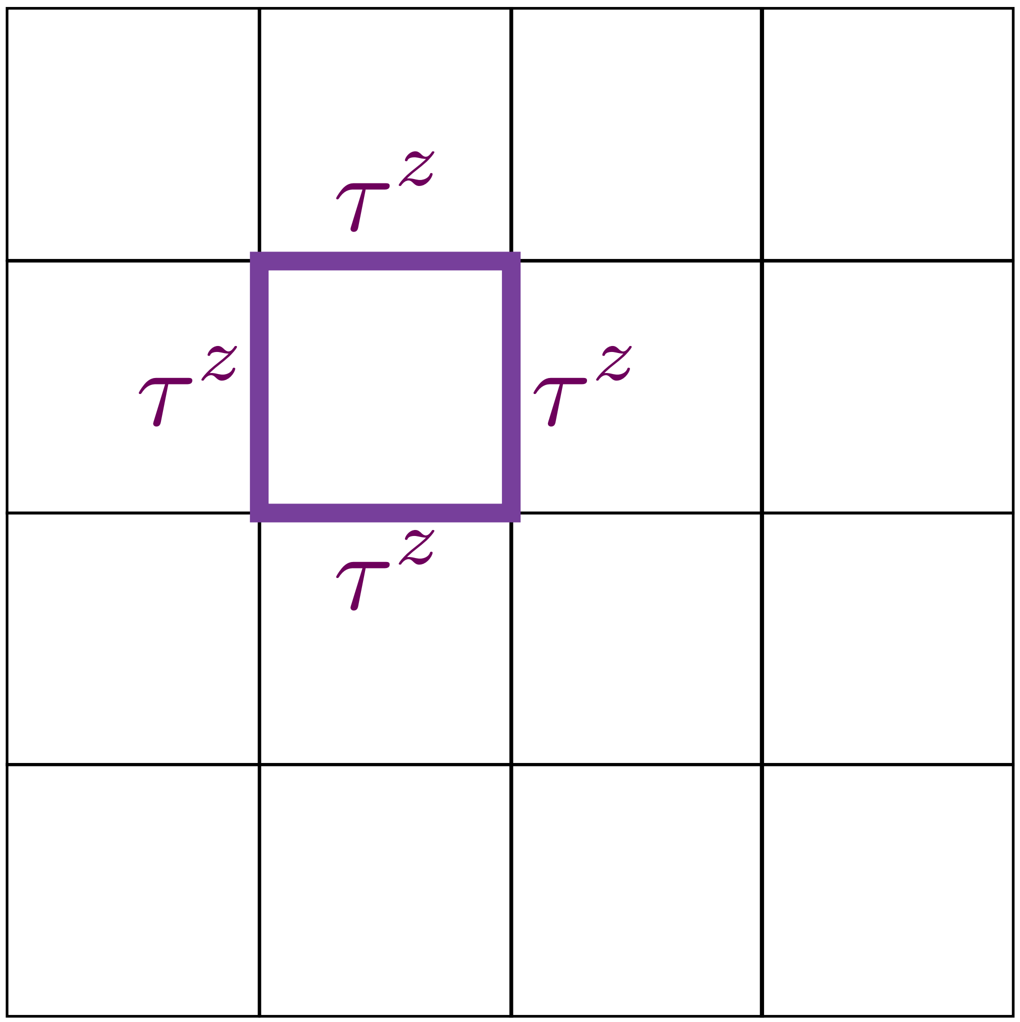
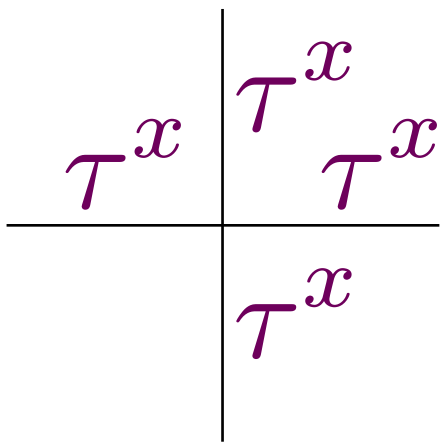
Z_2 lattice gauge theory

(Wegner, 1971)



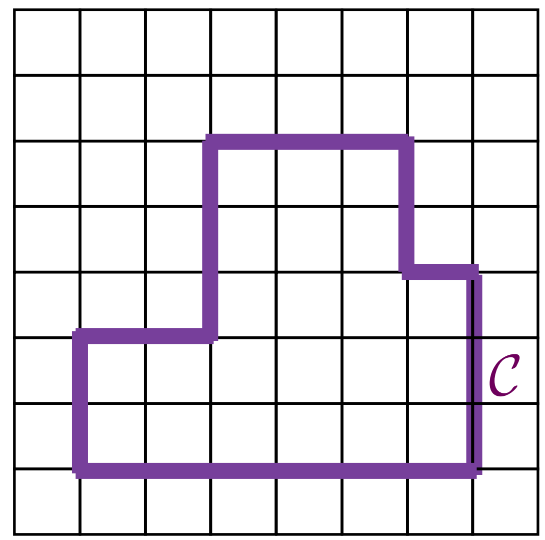
$$H = -\sum_{\Box} \tau^z \tau^z \tau^z \tau^z - g \sum_i \tau^x$$

$G_i =$ 

Gauss's Law: $[H, G_i] = 0 \quad , \quad G_i = 1$

Z_2 lattice gauge theory

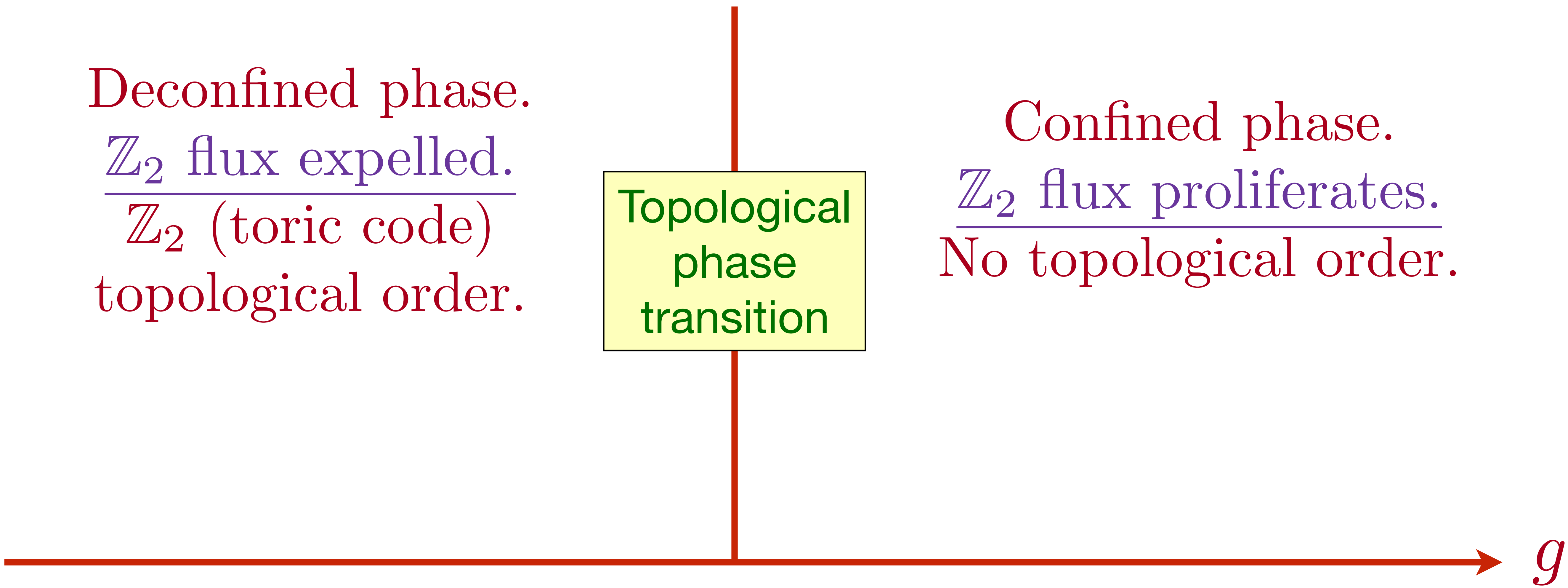
(Wegner, 1971)



$$W_{\mathcal{C}} = \prod_{\mathcal{C}} \tau^z$$

$$H = -\sum_{\square} \tau^z \tau^z \tau^z \tau^z - g \sum_i \tau^x$$

$\mathbb{Z}_2$ lattice gauge theory



$$H = -\sum_{\square} \tau^z \tau^z \tau^z \tau^z - g \sum_i \tau^x$$

E. Fradkin and S. H. Shenker, PRD **19**, 3682 (1979); N. Read and S. Sachdev, PRL **66**, 1773 (1991);
X.-G. Wen, PRB **44**, 2664 (1991); A.Y. Kitaev, Annals of Physics **303**, 2 (2003)

$\mathbb{Z}_2$ lattice gauge theory + matter

Deconfined phase.
$\mathbb{Z}_2$ flux expelled.
$\mathbb{Z}_2$ (toric code) topological order.
Non-Luttinger volume Fermi surface

Topological phase transition

Confined phase.
$\mathbb{Z}_2$ flux proliferates.
No topological order.
Luttinger volume Fermi surface

g

$$H = -\sum_{\square} \tau^z \tau^z \tau^z \tau^z - g \sum_i \tau^x + \ldots + \ldots$$

T. Senthil, M. Vojta, and S. Sachdev, PRB **69**, 035111 (2004)

Orthogonal metal

$$c_\alpha \quad \Rightarrow \quad \sigma^z f_\alpha$$

Electron fractionalizes into an "orthogonal fermion" f_α, carrying both the spin and charge of the electron,

'

and an Ising matter field, σ^z, carrying only energy ('dark matter').

Theory should be invariant under the $\mathbb{Z}_2$ gauge transformation

$$f_{i\alpha} \rightarrow \eta_i f_{i\alpha} \quad , \quad \sigma_i^z \rightarrow \eta_i \sigma_i^z$$

Also need a $\mathbb{Z}_2$ gauge field τ_{ij}^z transforming as

$$\tau_{ij}^z \rightarrow \eta_i \tau_{ij}^z \eta_j$$

Rahul Nandkishore, Max A. Metlitski, and T. Senthil. PRB **86**, 045128 (2012)

Lattice model with no sign problem

$$\mathcal{H} = \mathcal{H}_{\mathbb{Z}_2} + \mathcal{H}_\tau + \mathcal{H}_f + \mathcal{H}_c,$$

where

$$\mathcal{H}_{\mathbb{Z}_2} = -K \sum_{\Box} \prod_{b\in\Box} \tau_b^z - g \sum_b \tau_b^x$$

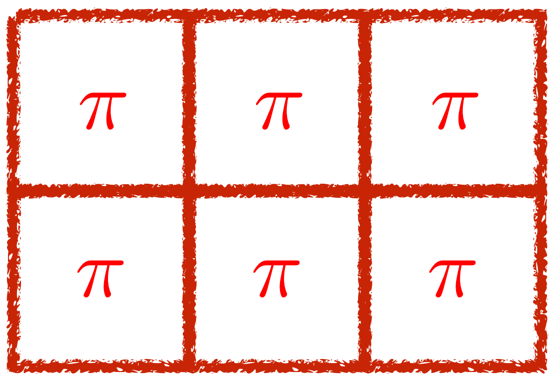
$$\mathcal{H}_\tau = -J \sum_{r,\eta} \tau_{r,\eta}^z \sigma_r^z \sigma_{r+\eta}^z - h \sum_r \sigma_r^x$$

$$\mathcal{H}_f = -w \sum_{r,\eta,\alpha} \tau_{r,\eta}^z f_{r,\alpha}^\dagger f_{r+\eta,\alpha} + h.c - \mu \sum_{r,\alpha} f_{r,\alpha}^\dagger f_{r,\alpha}$$

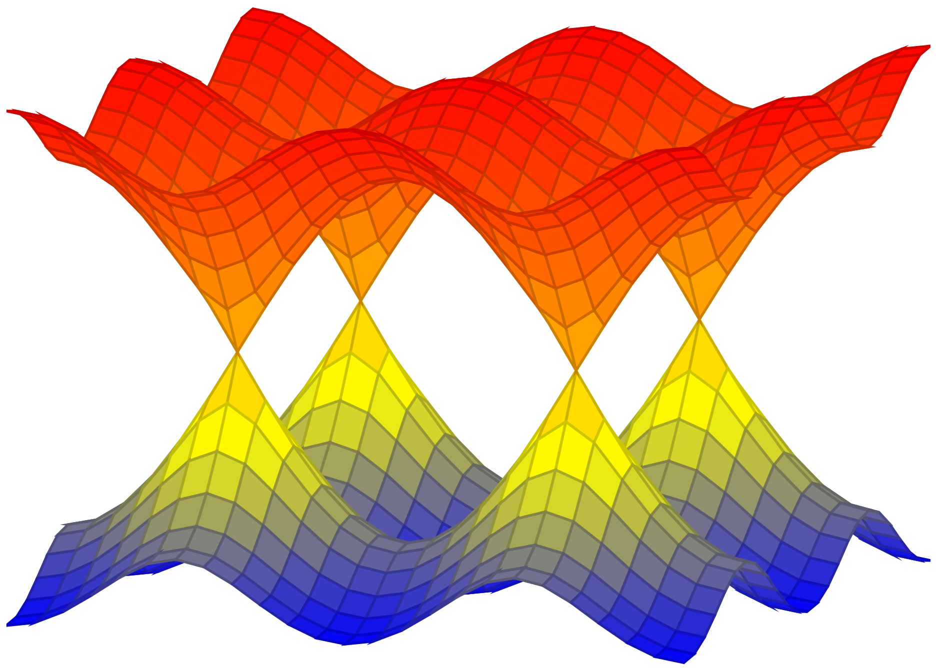
$$\mathcal{H}_c = -t \sum_{r,\eta,\alpha} \sigma_r^z f_{r,\alpha}^\dagger \sigma_{r+\eta}^z f_{r+\eta,\alpha} + h.c$$

Orthogonal semi-metal

At large h and small g, the Ising matter field is gapped, and the Ising gauge flux does not fluctuate. Then the orthogonal fermions f_α are deconfined, and they optimize their energy by inducing π flux in each plaquette: we obtain an orthogonal semi-metal at half-filling.



π–flux



No Luttinger volume Fermi surface

Snir Gazit, Mohit Randeria, and Ashvin Vishwanath, Nature Physics **13**, 484 (2017)

As we decrease h (which reduces the gap of the σ^z matter fields), with $t \neq 0$, a Fermi surface of $c \sim f\sigma^z$ appears, with a Luttinger volume.

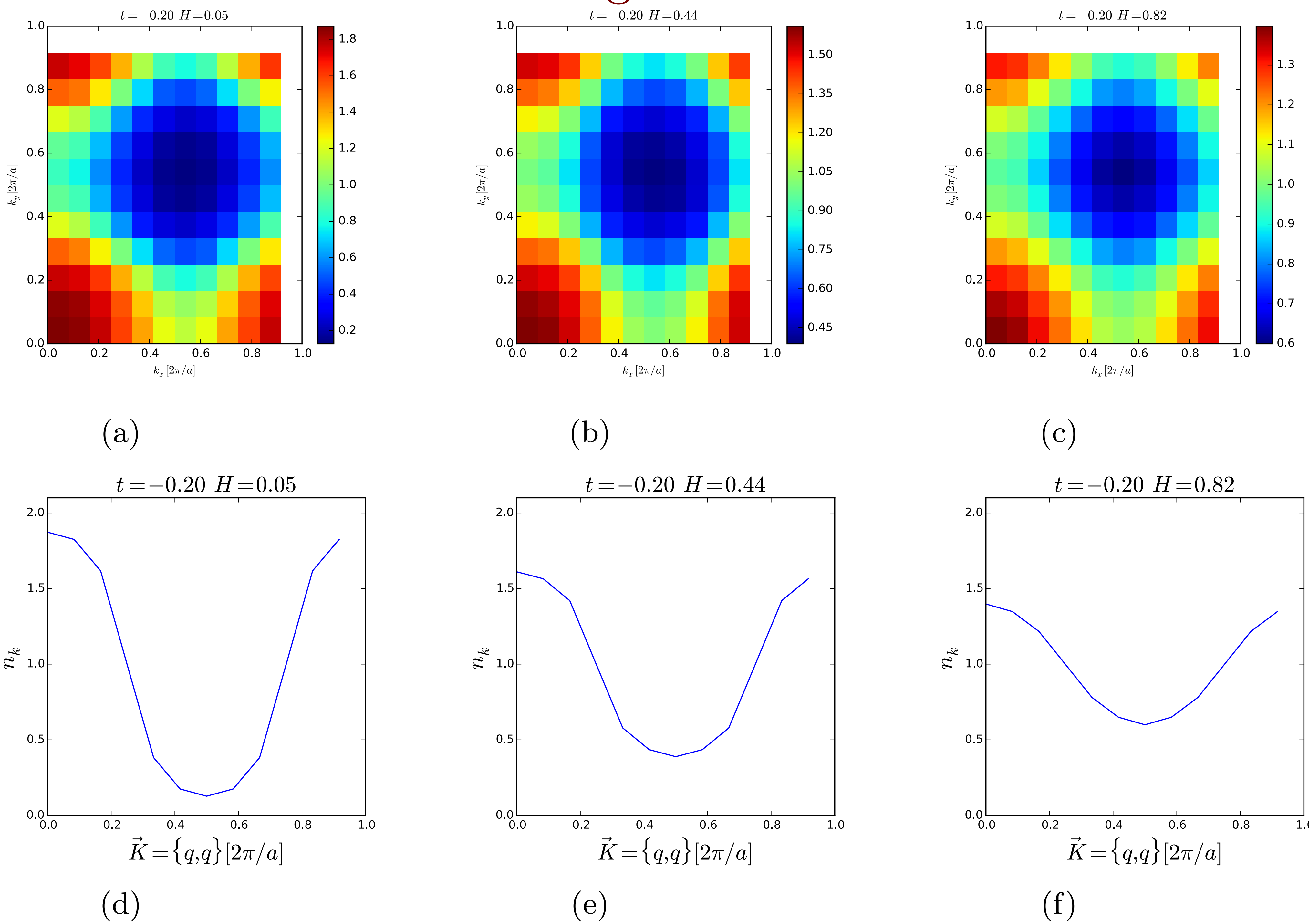
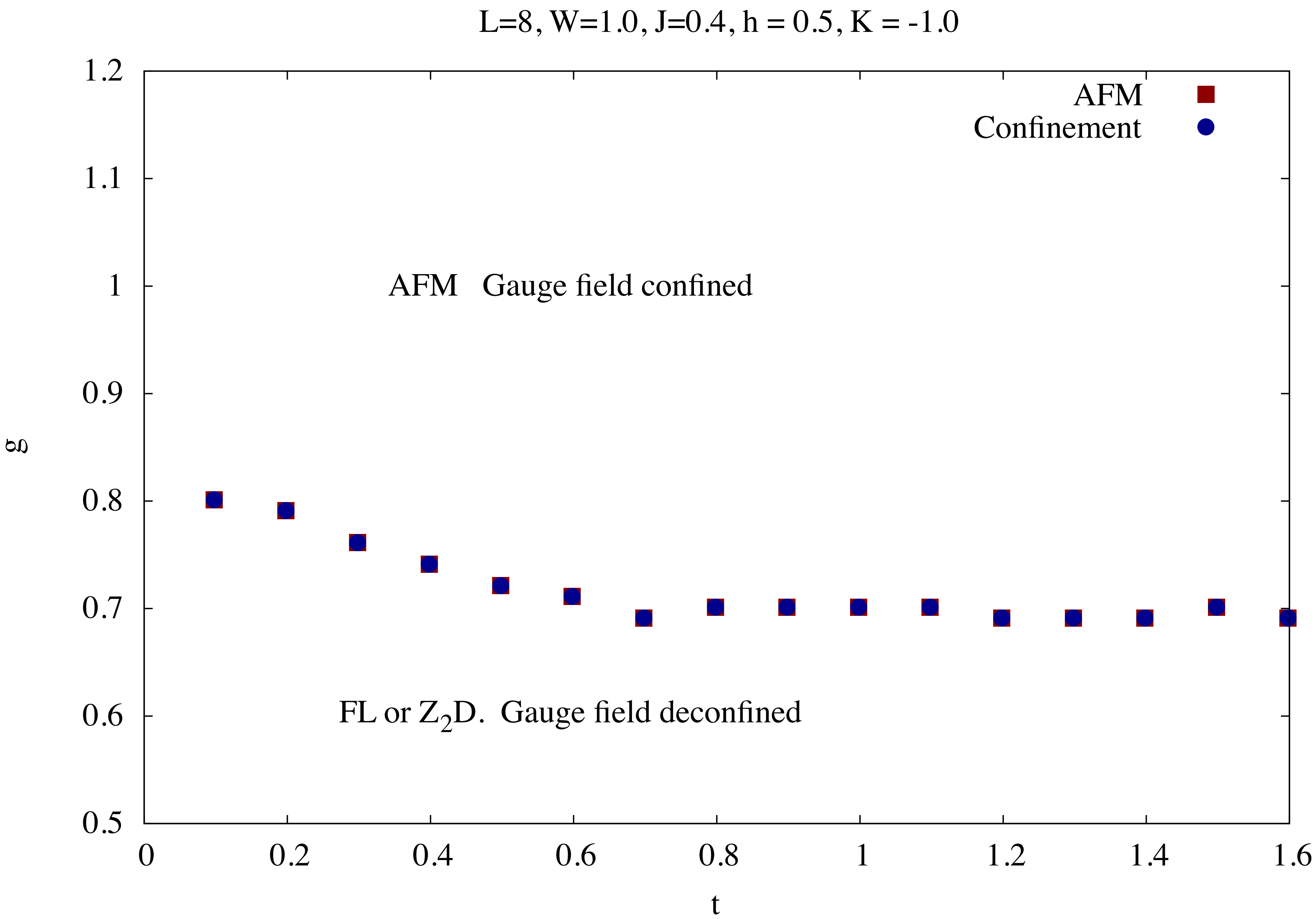
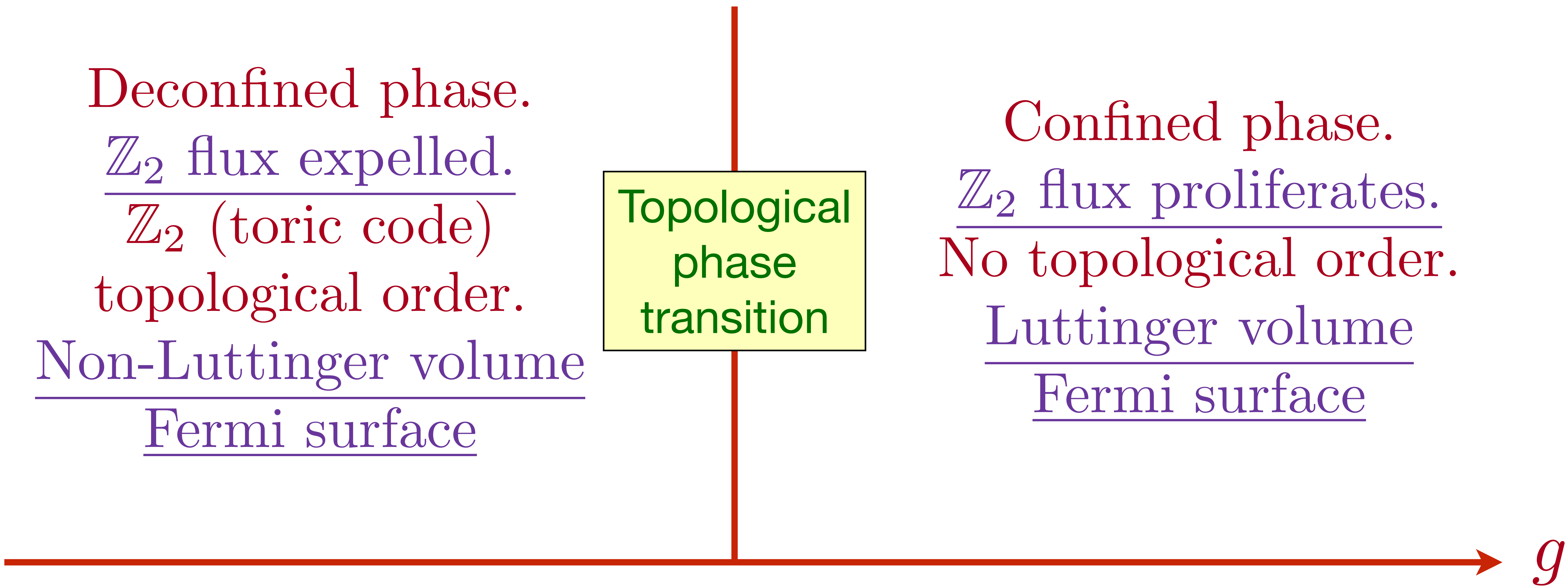


Figure 3: Momentum occupation $n_k = \left\langle c_k^\dagger c_k \right\rangle$ for $t = -0.09$, $h = 0.05, 0.44, 0.82$ and $K = -1$. (top row) Density plot in the first Brillouin zone and (bottom row) along diagonal momentum cut, $\vec{k} = \{q, q\}$.

As we increase g
(which induces confinement via $\mathbb{Z}_2$ flux fluctuations),
we obtain a phase with AF order.
The large Fermi surface of c_α appears unstable to AF order, likely due to Fermi surface nesting.



$\mathbb{Z}_2$ lattice gauge theory + matter



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T. Senthil, M. Vojta, and S. Sachdev, PRB **69**, 035111 (2004)