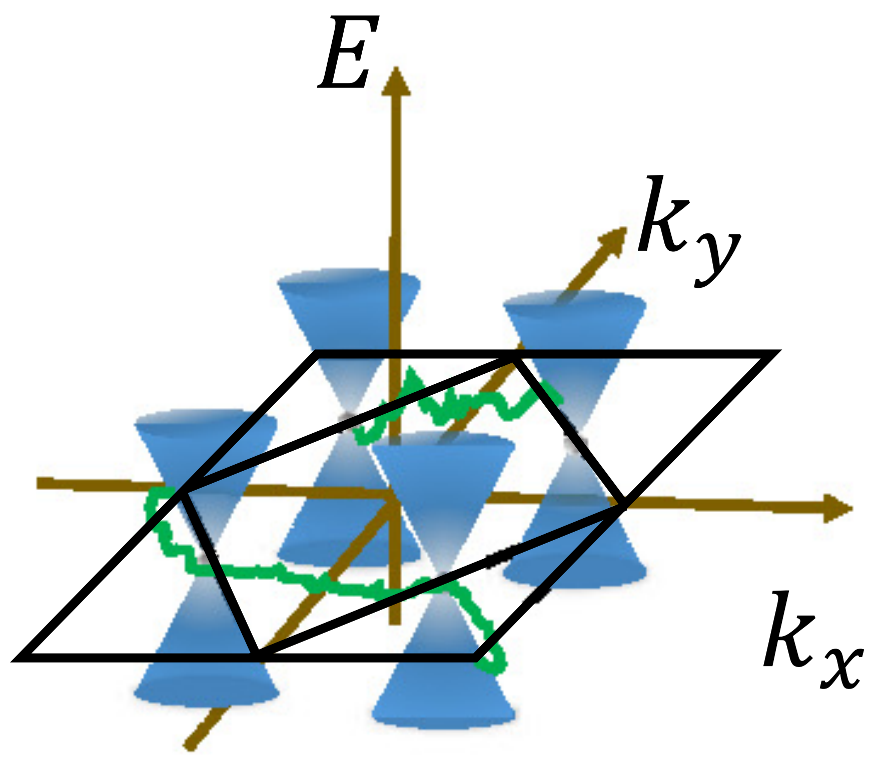
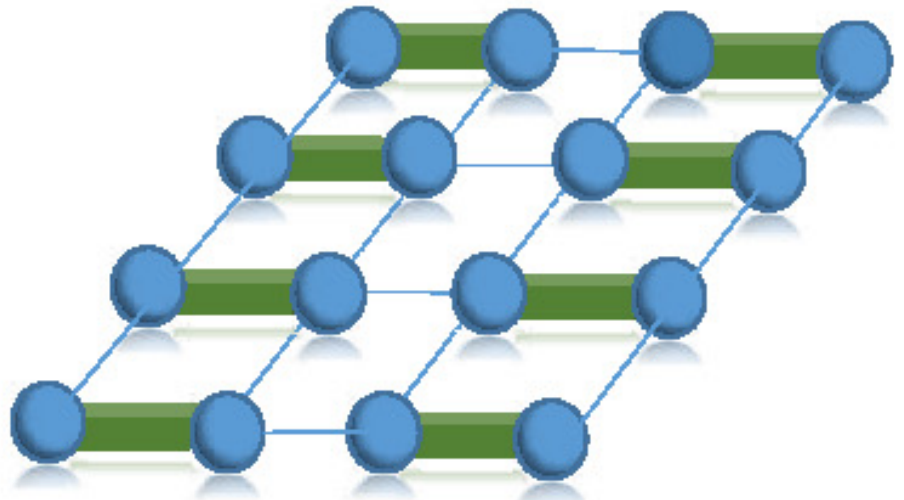
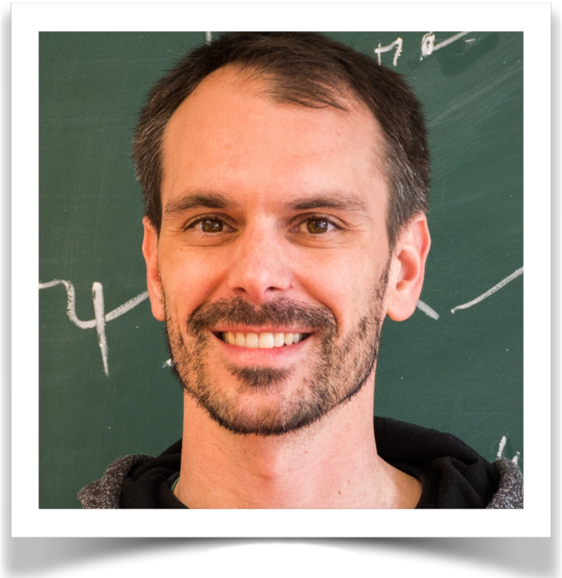
Confinement transition in the QED3-Gross-Neveu-XY universality class





Lukas Janssen
(TU Dresden)

W. Wang
(IOP Beijing)



M. M. Scherer
(U Cologne)

Z. Y. Meng
(U Hong Kong)

X. Y. Xu
(UC San Diego)

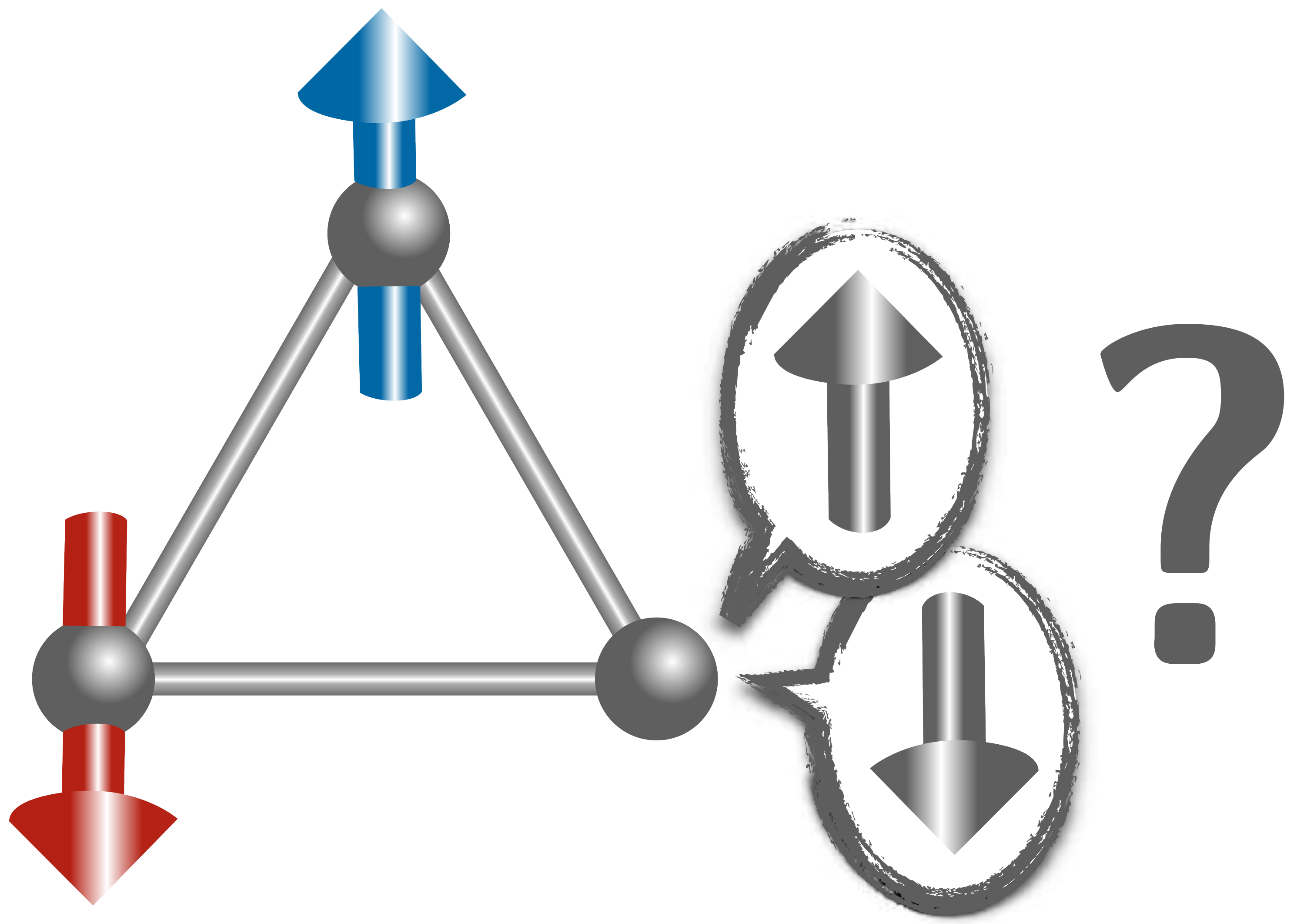
Quantum Critical Matter
JA 2306/4-1
Emmy Noether-Programm
DFG Deutsche Forschungsgemeinschaft

ct.qmat
Complexity and Topology in Quantum Matter
Würzburg-Dresden Cluster of Excellence

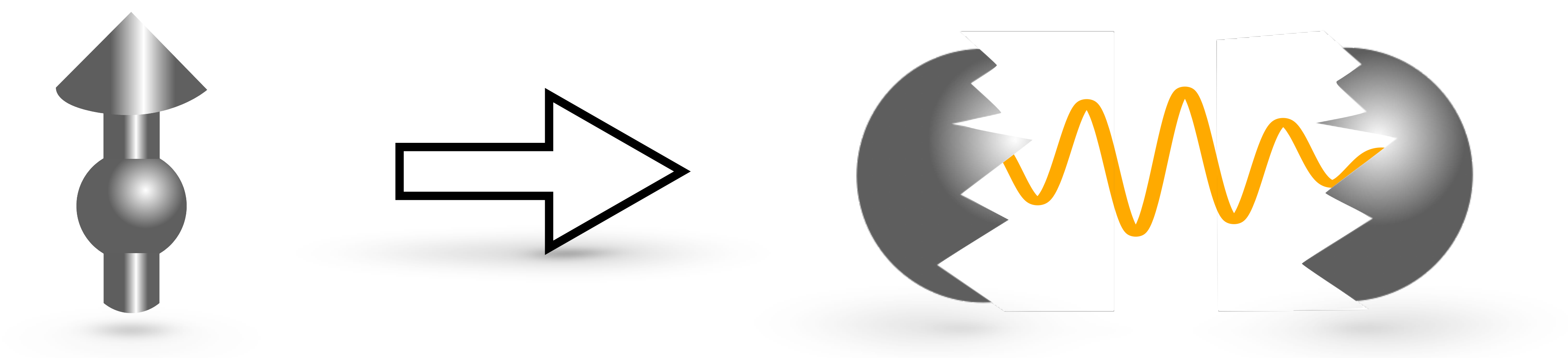
SFB 1143

Introduction: Quantum spin liquids

Frustration:



Fractionalization:



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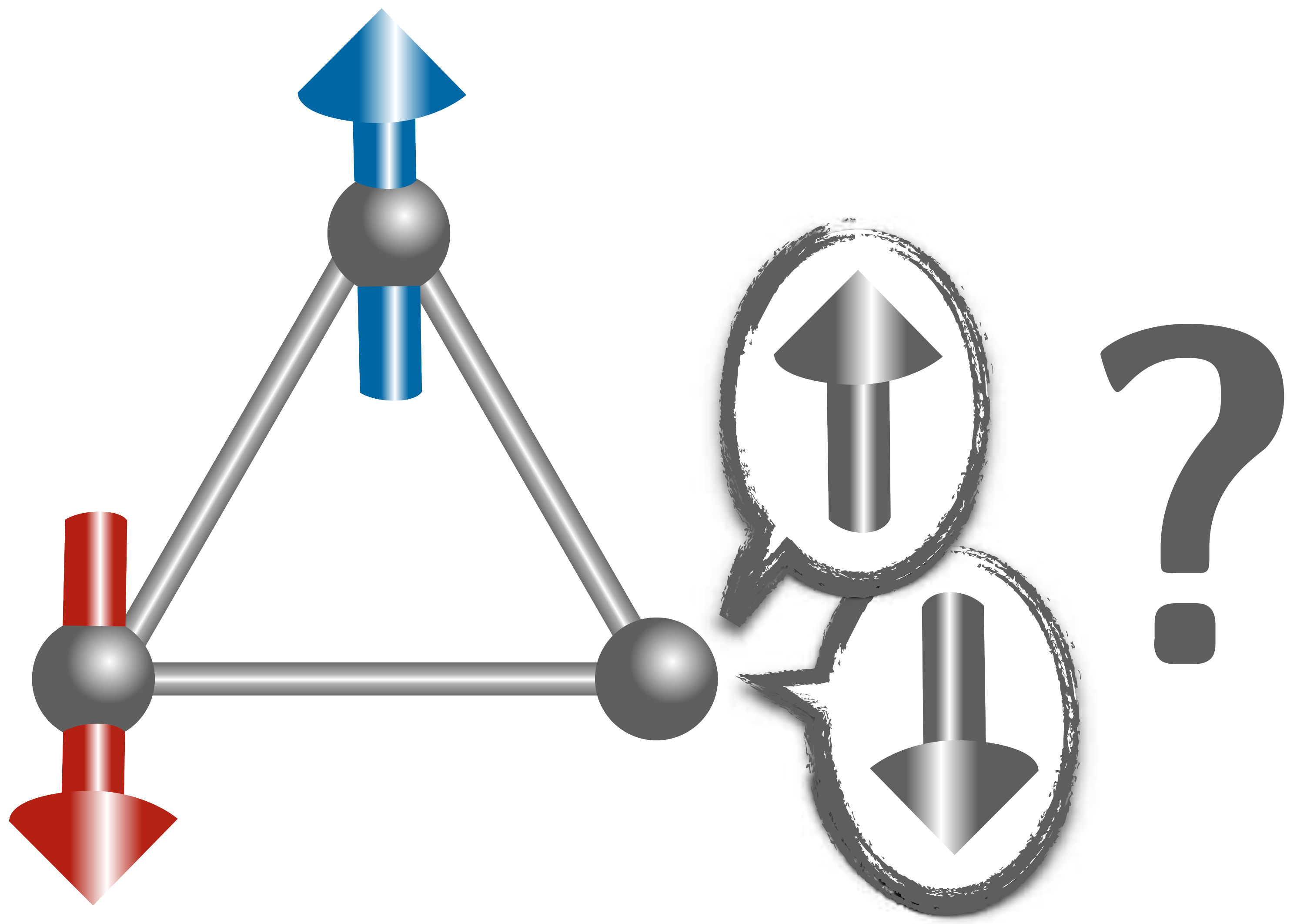

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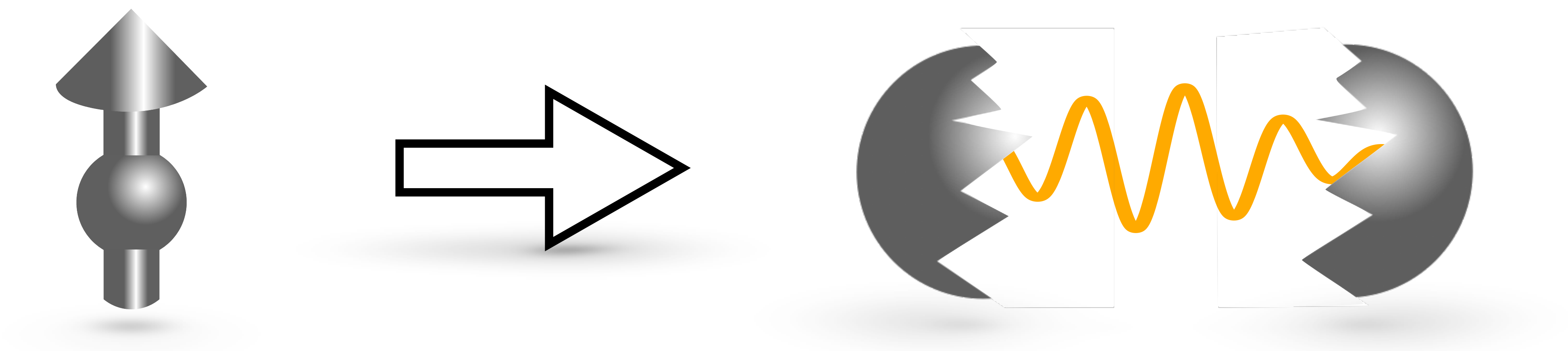


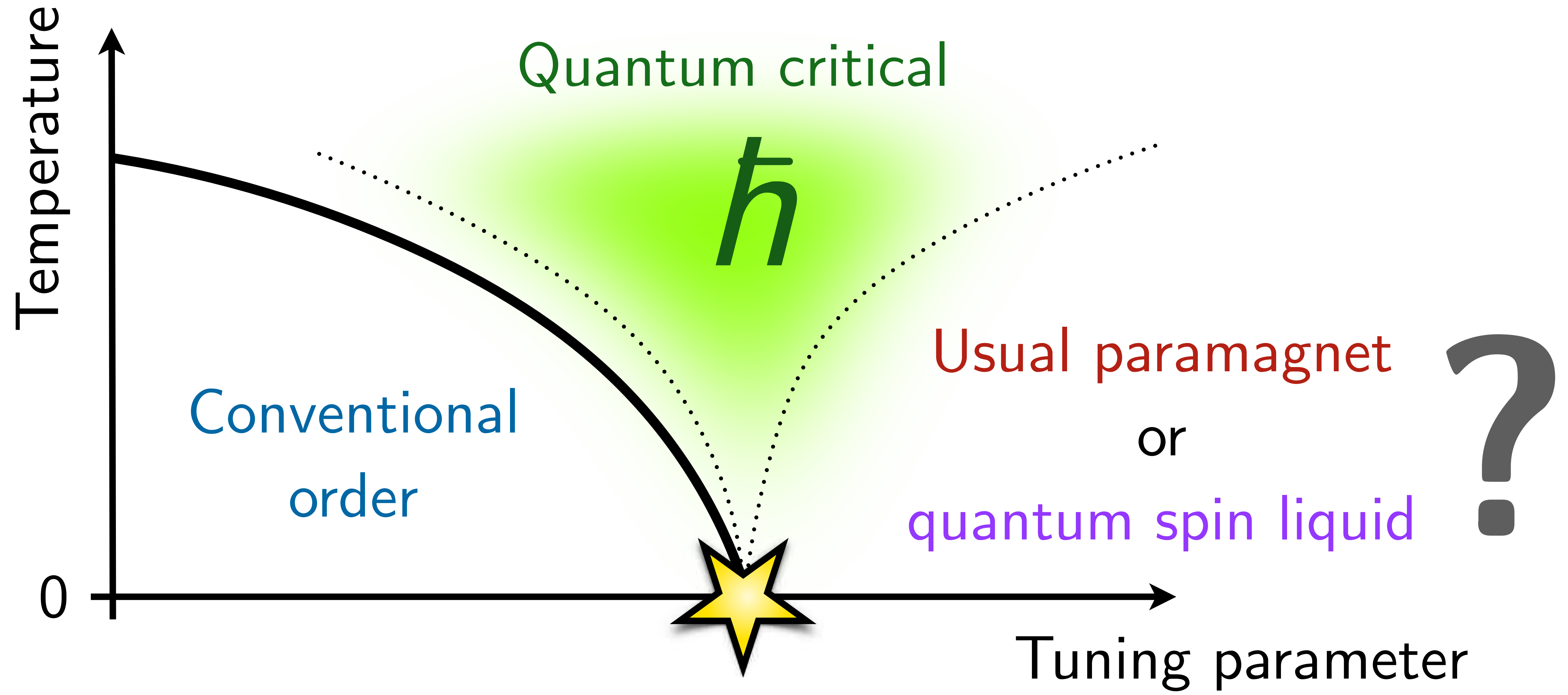
$\mathbb{Z}_2$ spin liquid: Kitaev honeycomb model [Kitaev, Ann. Phys. '06]
Toric code [Kitaev, Ann. Phys. '03]
...

→ Talk by Shouryya Ray (X44.00004)

U(1) spin liquid: Kagome model? [He *et al*, PRX '17]
Triangular model? [Hu *et al.*, PRL '19]
...

→ This talk

Motivation: Spin-liquid criticality



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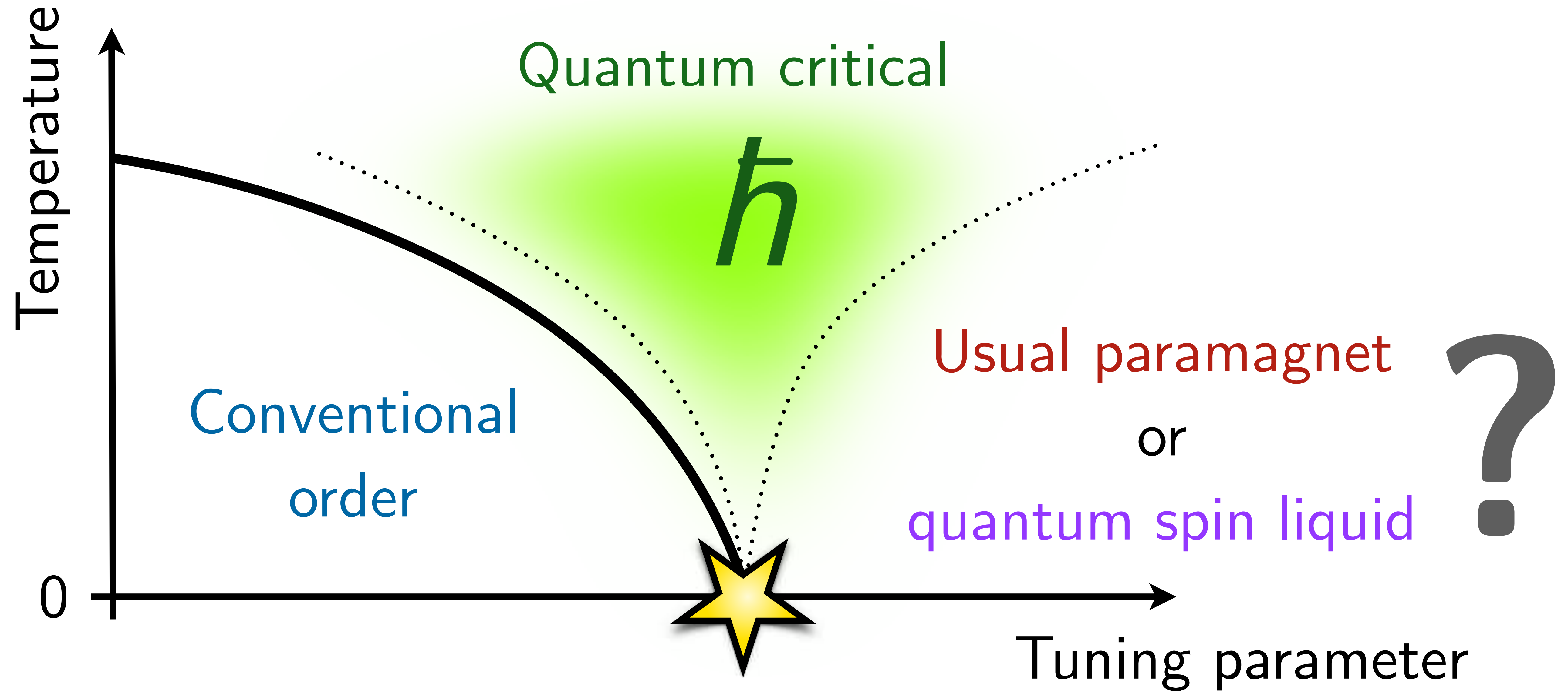
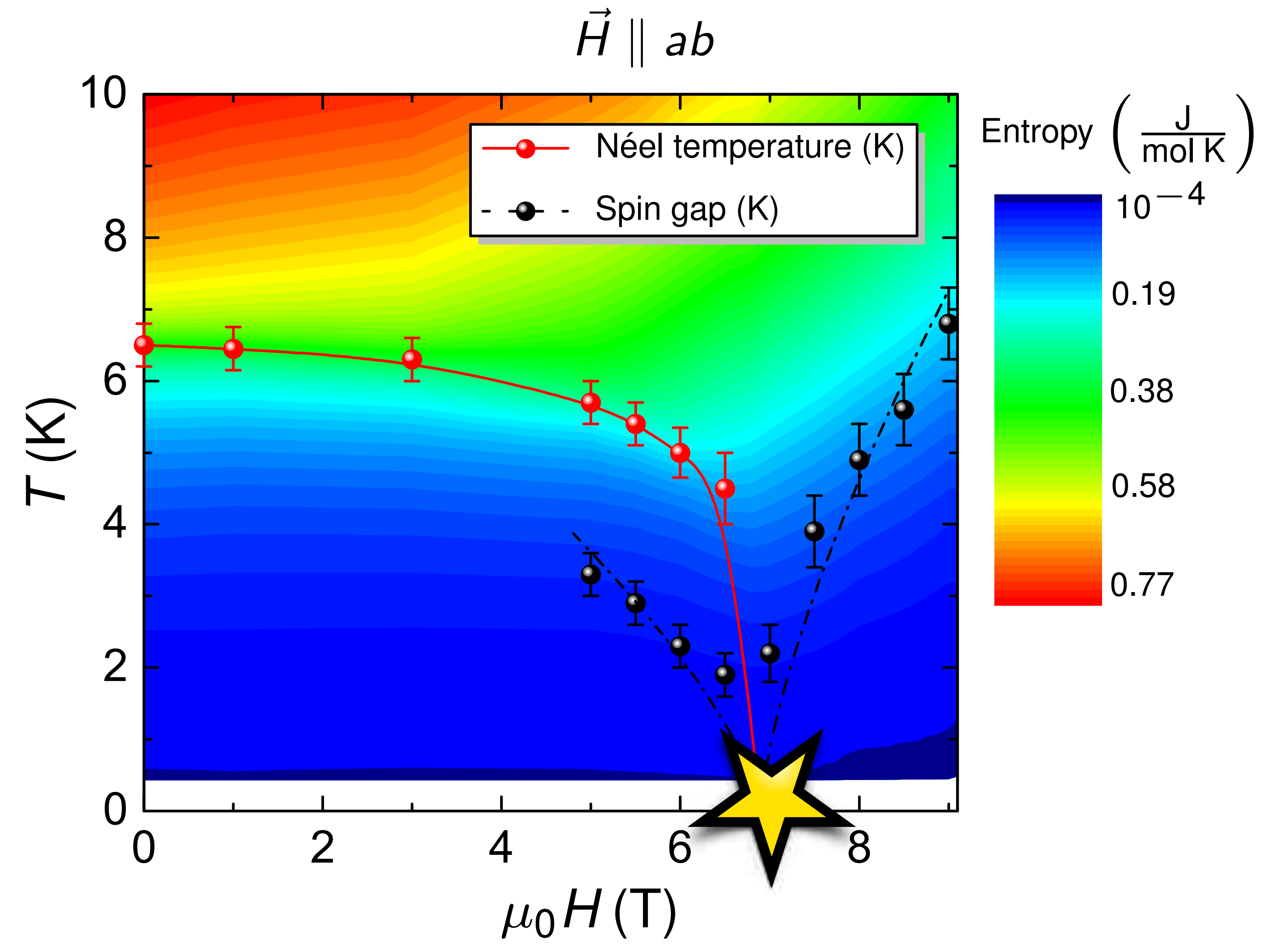


Example: α-$RuCl_3$ in field



[Wolter, Corredor, LJ, *et al.*, PRB '17]

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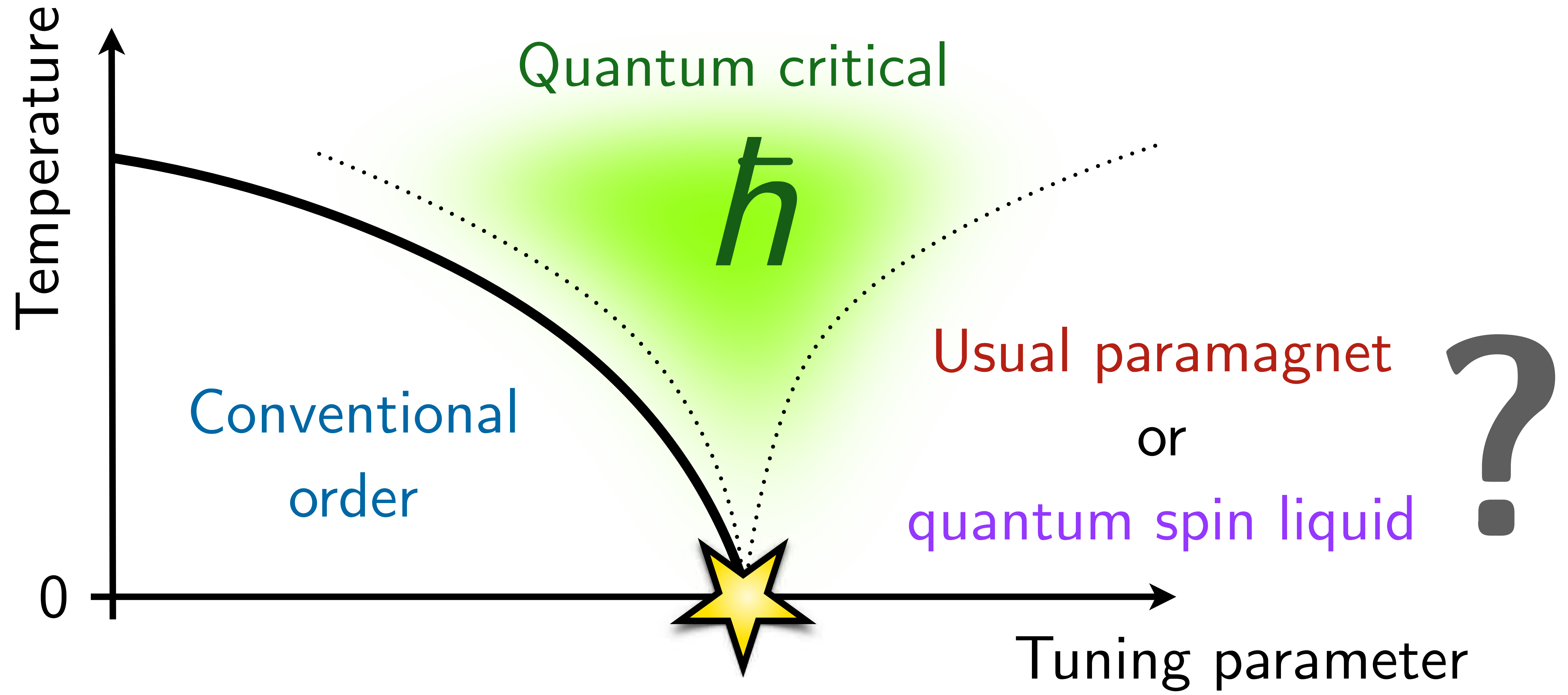

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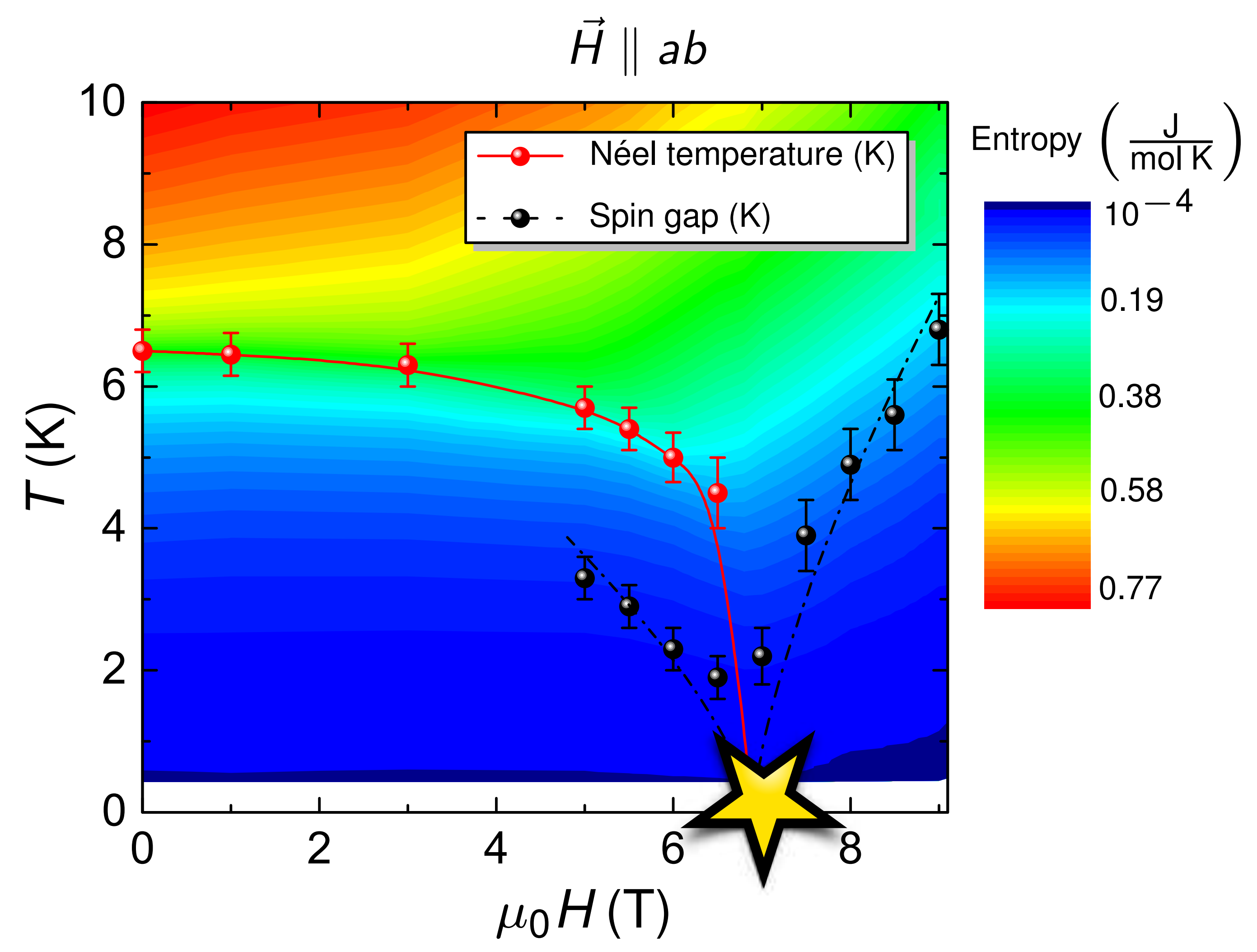
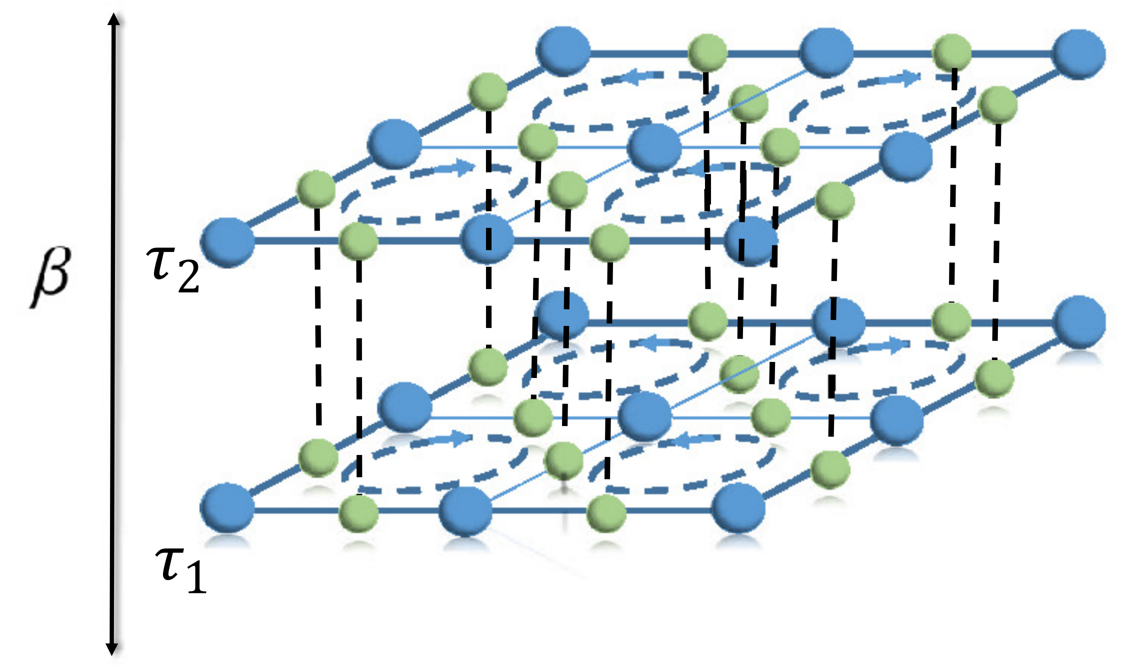


[Wolter, Corredor, LJ, *et al.*, PRB '17]

Main question:

How do fractionalized excitations affect quantum criticality?

Model: Lattice compact QED$_3$



Action (square lattice):

Compact $U(1)$ gauge field

Fermions

$$S = \int_0^\beta d\tau \left[\sum_{\langle ij \rangle, \alpha} \psi^\dagger_{i\alpha} (\partial_\tau \delta_{ij} - t e^{i\varphi_{ij}}) \psi_{j\alpha} + \text{H.c.} \right.$$

$$\left. + \frac{4}{J N_f} \sum_{\langle ij \rangle} \frac{1 - \cos[\varphi_{ij}(\tau+1) - \varphi_{ij}(\tau)]}{\Delta\tau^2} + \frac{K N_f}{2} \sum_{\Box} \cos(\text{curl}\,\varphi) \right]$$

... favors π flux for $K > 0$

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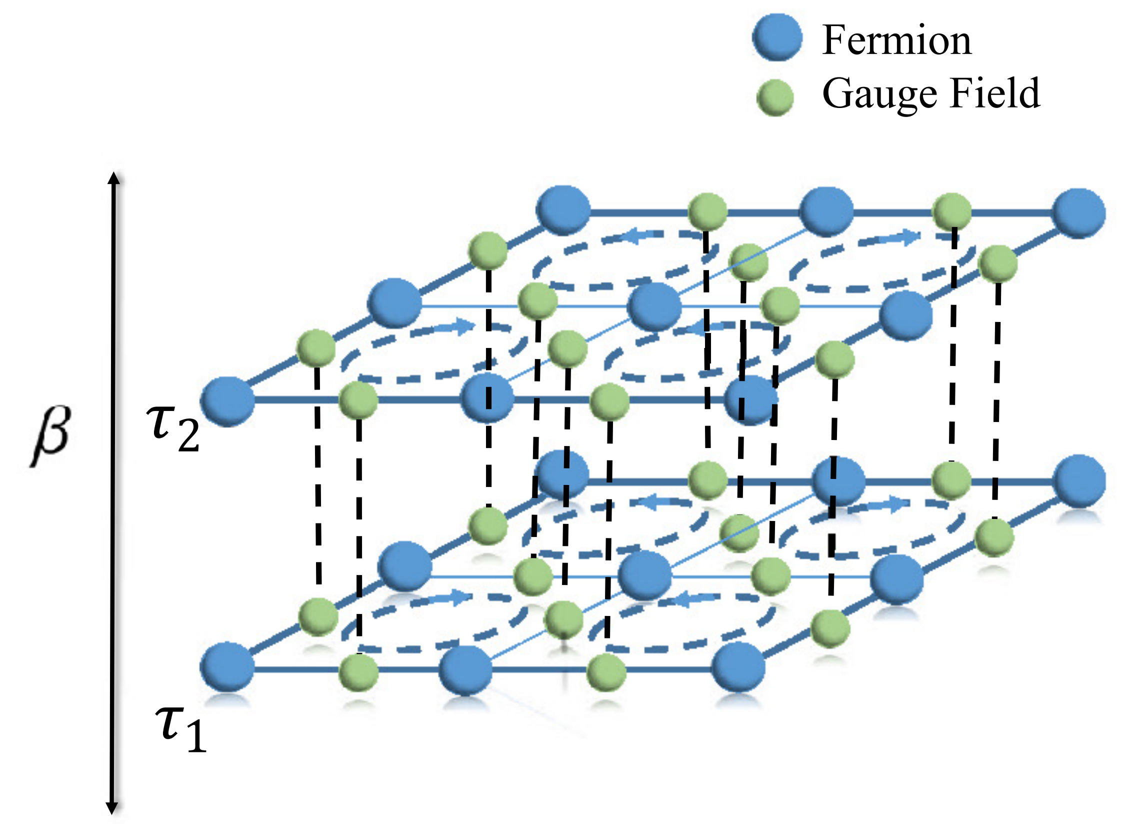

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Compact U(1) gauge field

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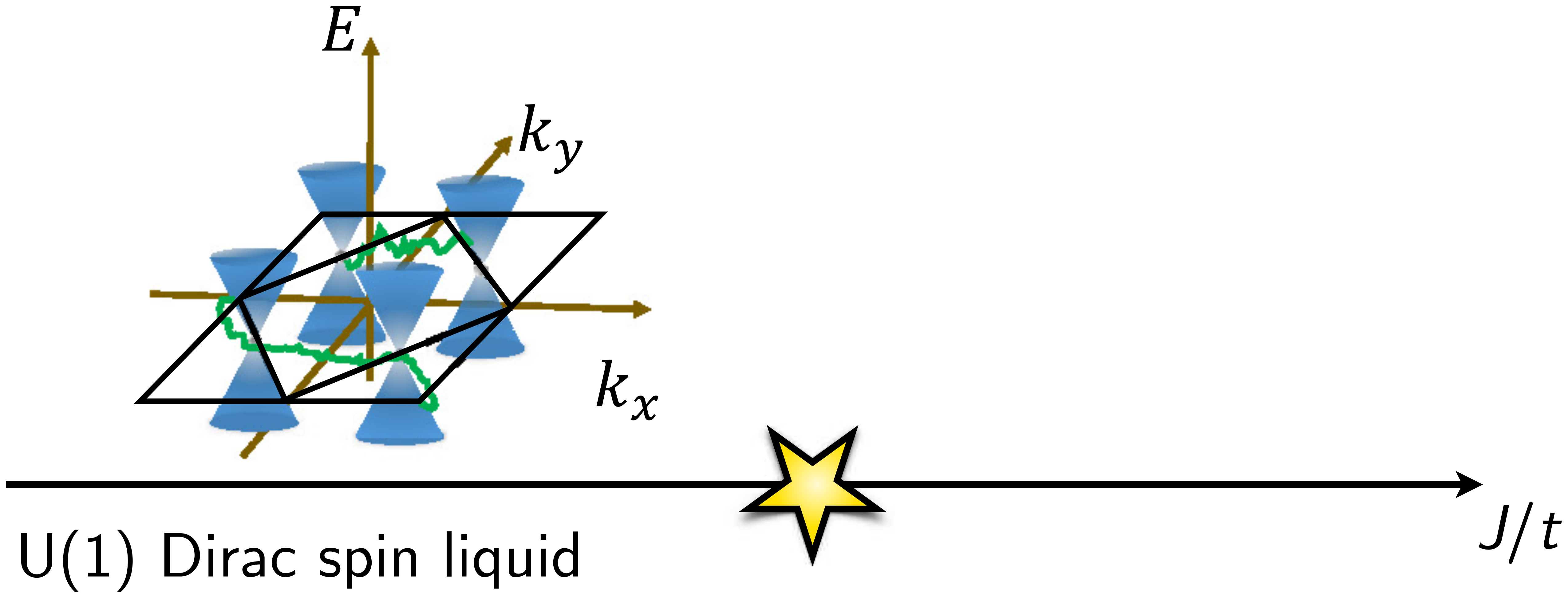
Phase diagram ($K > 0$):



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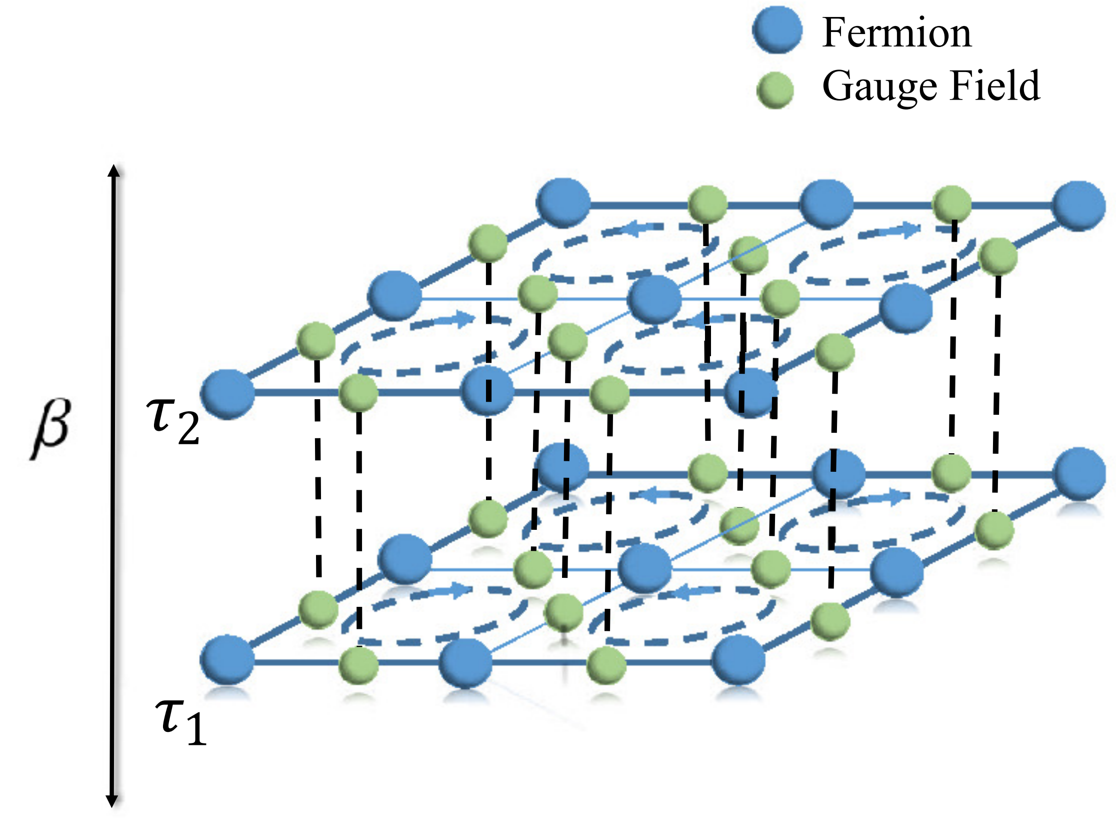

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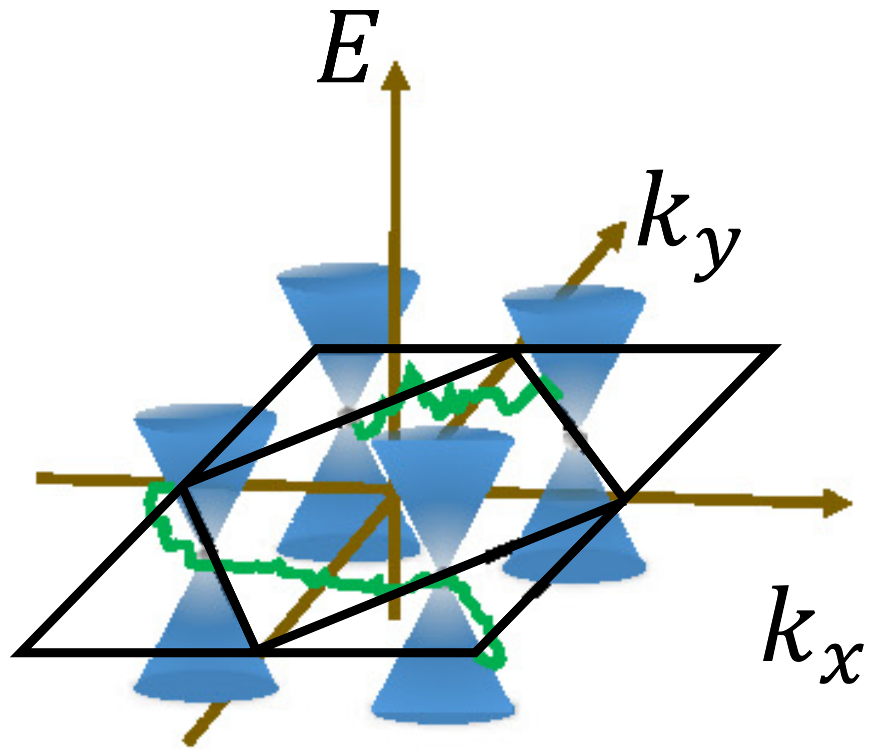

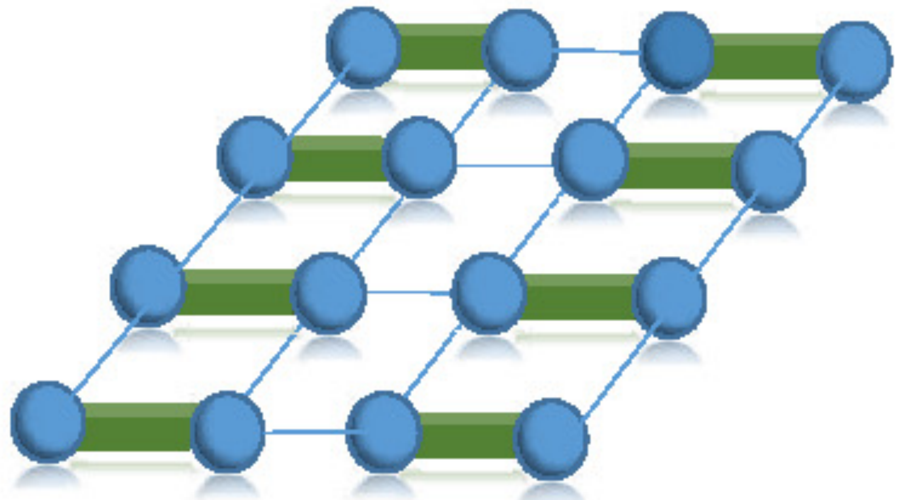

U(1) Dirac spin liquid — VBS order — J/t

[Xu *et al.*, PRX '19]

Field theory: QED$_3$-Gross-Neveu-XY

Action (continuum):

$$S = \int d\tau \int d^2\vec{x} \left[\bar{\psi}\gamma_\mu(\partial_\mu - iA_\mu)\psi + \phi^a \bar{\psi}\mu^a\psi + \frac{r}{2}\phi^a\phi^a + \frac{1}{2e^2}(\epsilon_{\mu\nu\rho}\partial_\nu A_\rho)^2 \right]$$

Noncompact $U(1)$ gauge field

Dirac fermions

XY order parameter

$a = x, y$

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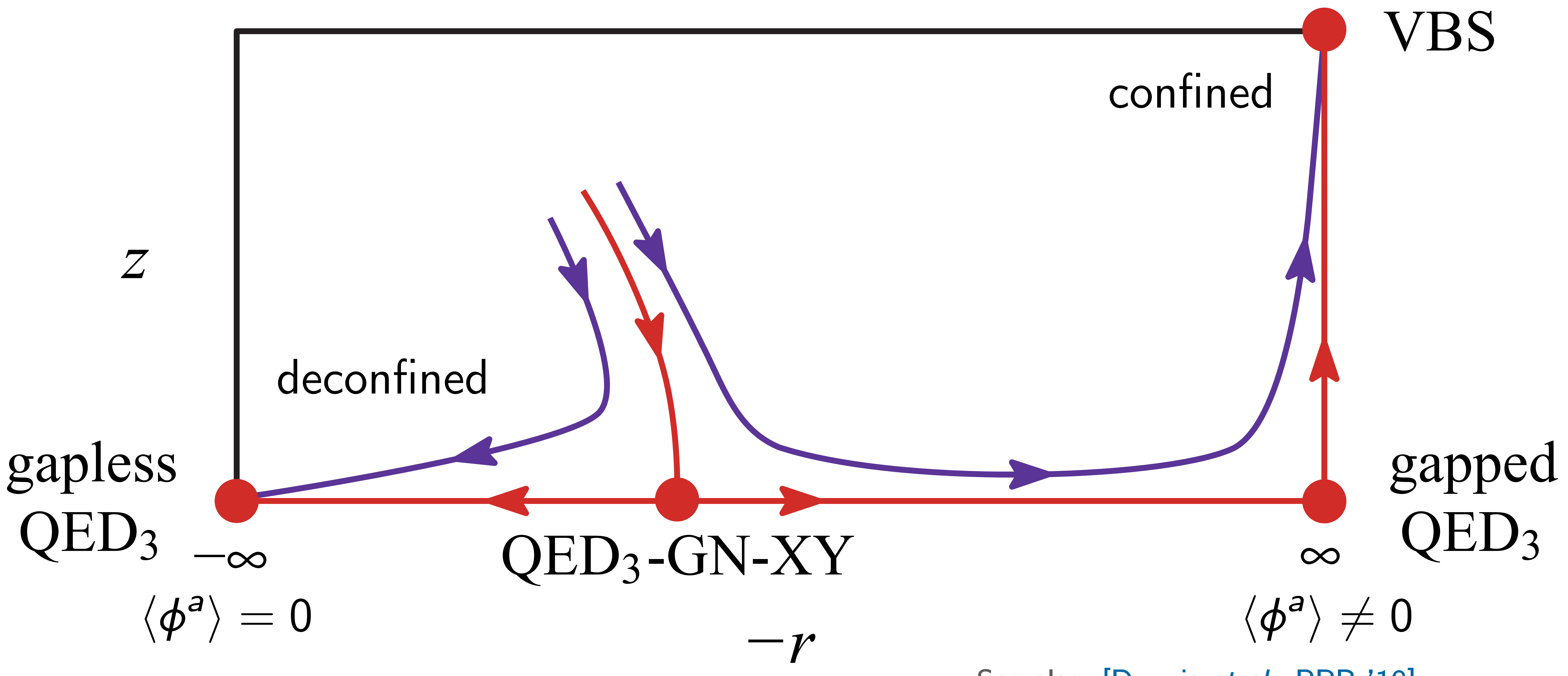
RG flow:



QED$_3$-GN-XY criticality:

$$\nu^{-1} = 1 - \frac{80}{3\pi^2 N_f} + \mathcal{O}(1/N_f^2)$$

$$\eta_\phi = 1 + \frac{56}{3\pi^2 N_f} + \mathcal{O}(1/N_f^2)$$

$$\Delta_{\text{VBS}} = 1 + \frac{28}{3\pi^2 N_f} + \mathcal{O}(1/N_f^2)$$

$$\Delta_{\text{AFM}} = 2 - \frac{40}{3\pi^2 N_f} + \mathcal{O}(1/N_f^2)$$

[LJ, Wang, Scherer, Meng, Xu, PRB '20]

Extension to $\mathcal{O}(1/N_f^2)$: [Zerf *et al.*, PRD '20]

See also: [Dupuis *et al.*, PRB '19]

Evidence for QED$_3$-Gross-Neveu-XY criticality

Scenario 1: Conventional paramagnet

XY: $\nu \simeq 0.672$

$\eta_\phi \simeq 0.039$

Scenario 2: Dirac fermions

Gross-Neveu-XY: $\nu \simeq 1.07$

$\eta_\phi \simeq 0.97$

... for $N_f = 8$

Scenario 3: Dirac fermions + U(1) gauge field

QED$_3$-Gross-Neveu-XY: $\nu \simeq 1.51$

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[LJ, Wang, Scherer, Meng, Xu, PRB '20]

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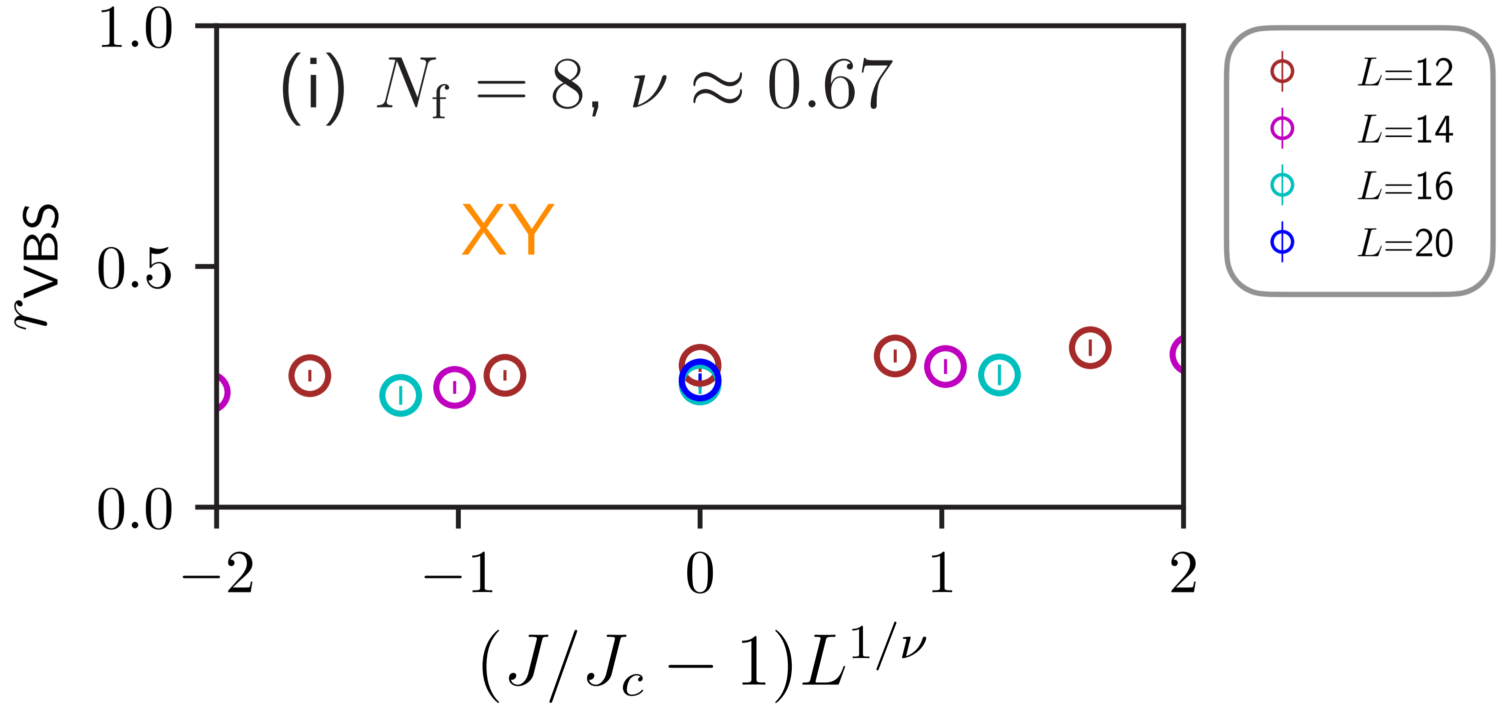

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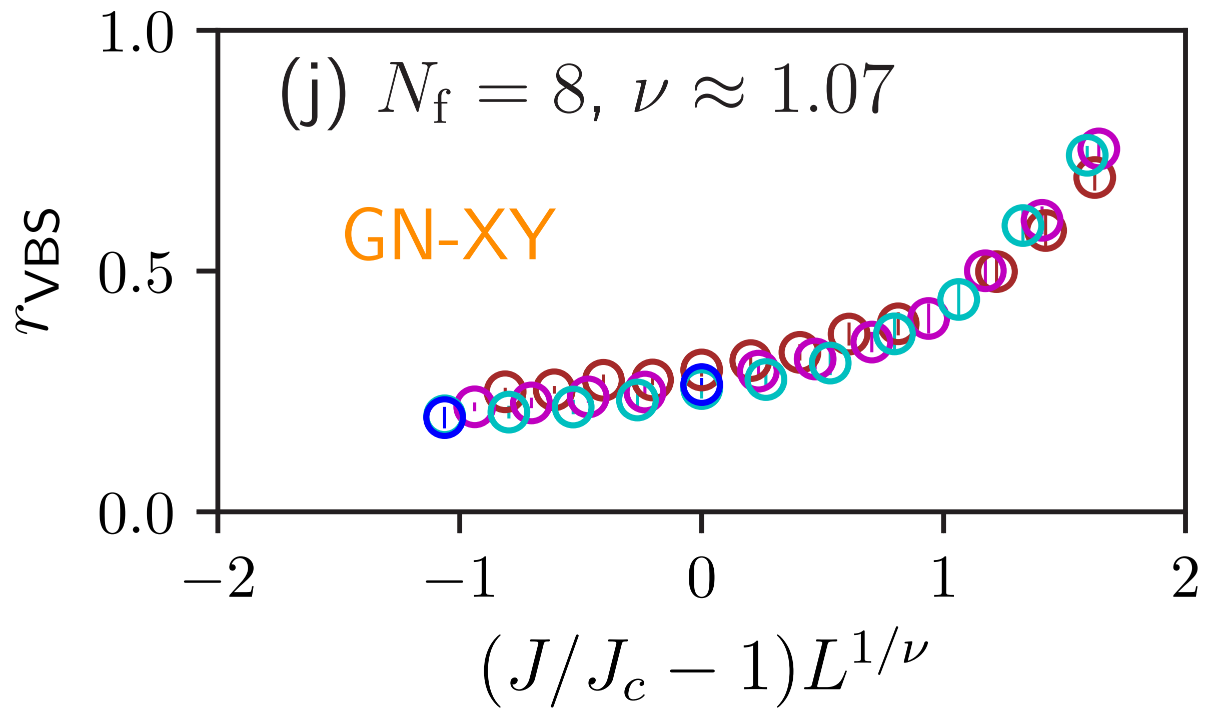

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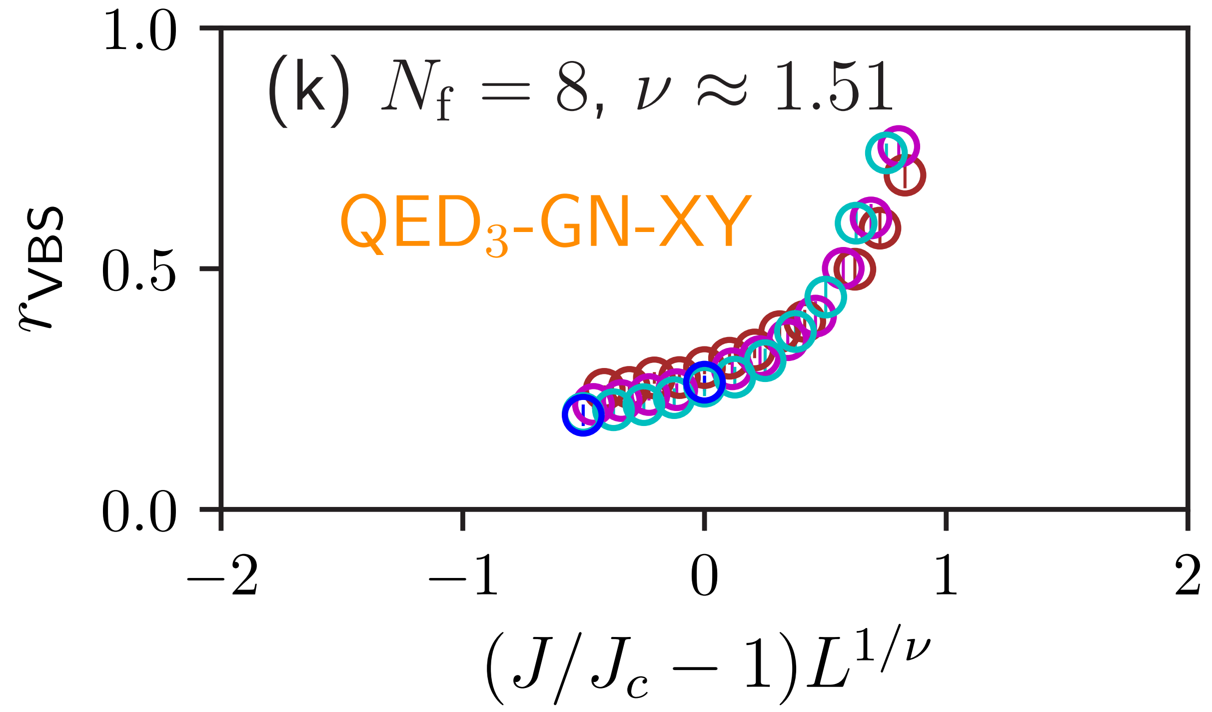

[LJ, Wang, Scherer, Meng, Xu, PRB '20]

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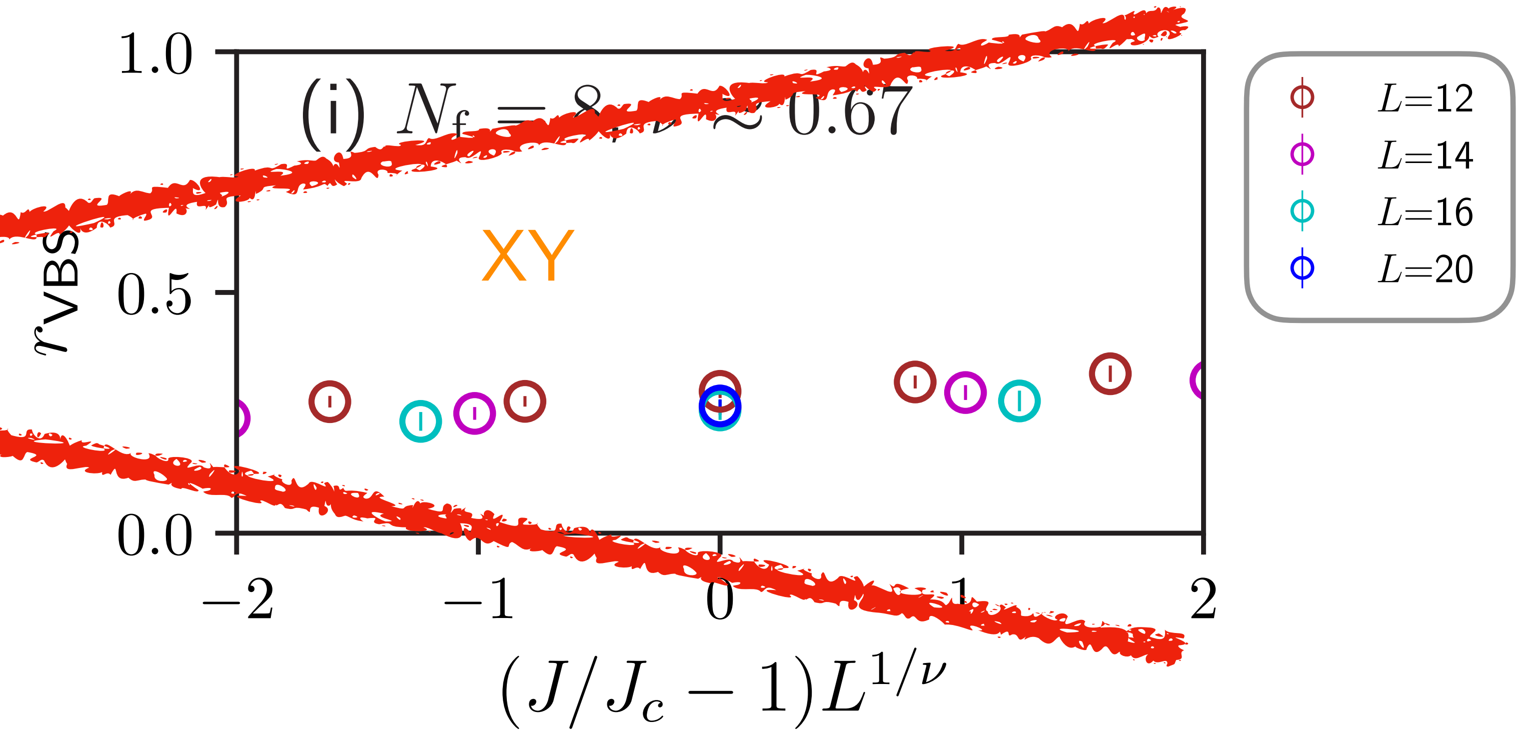

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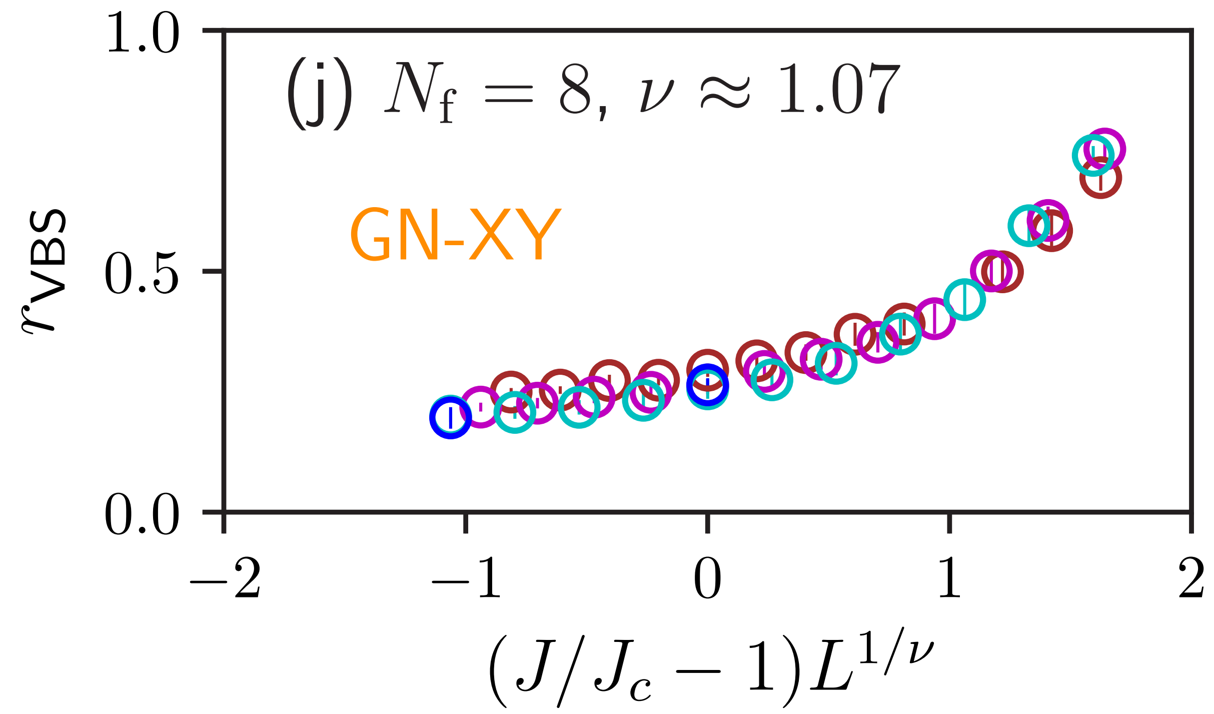

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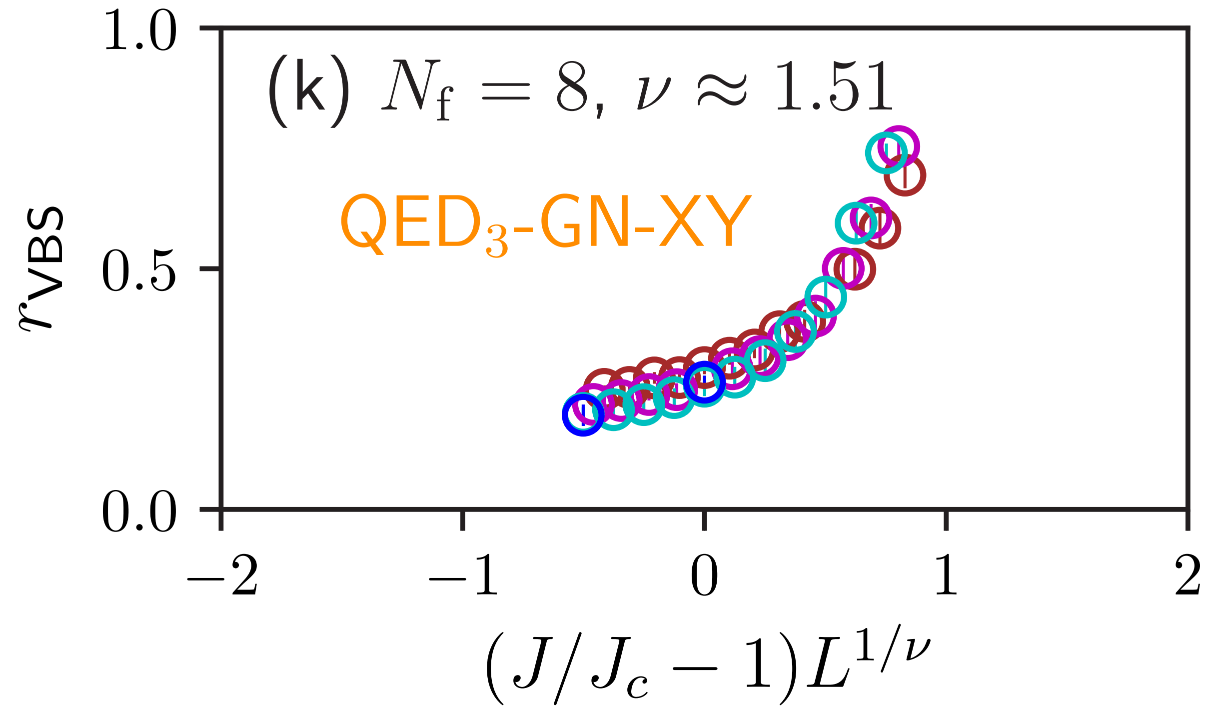

[LJ, Wang, Scherer, Meng, Xu, PRB '20]

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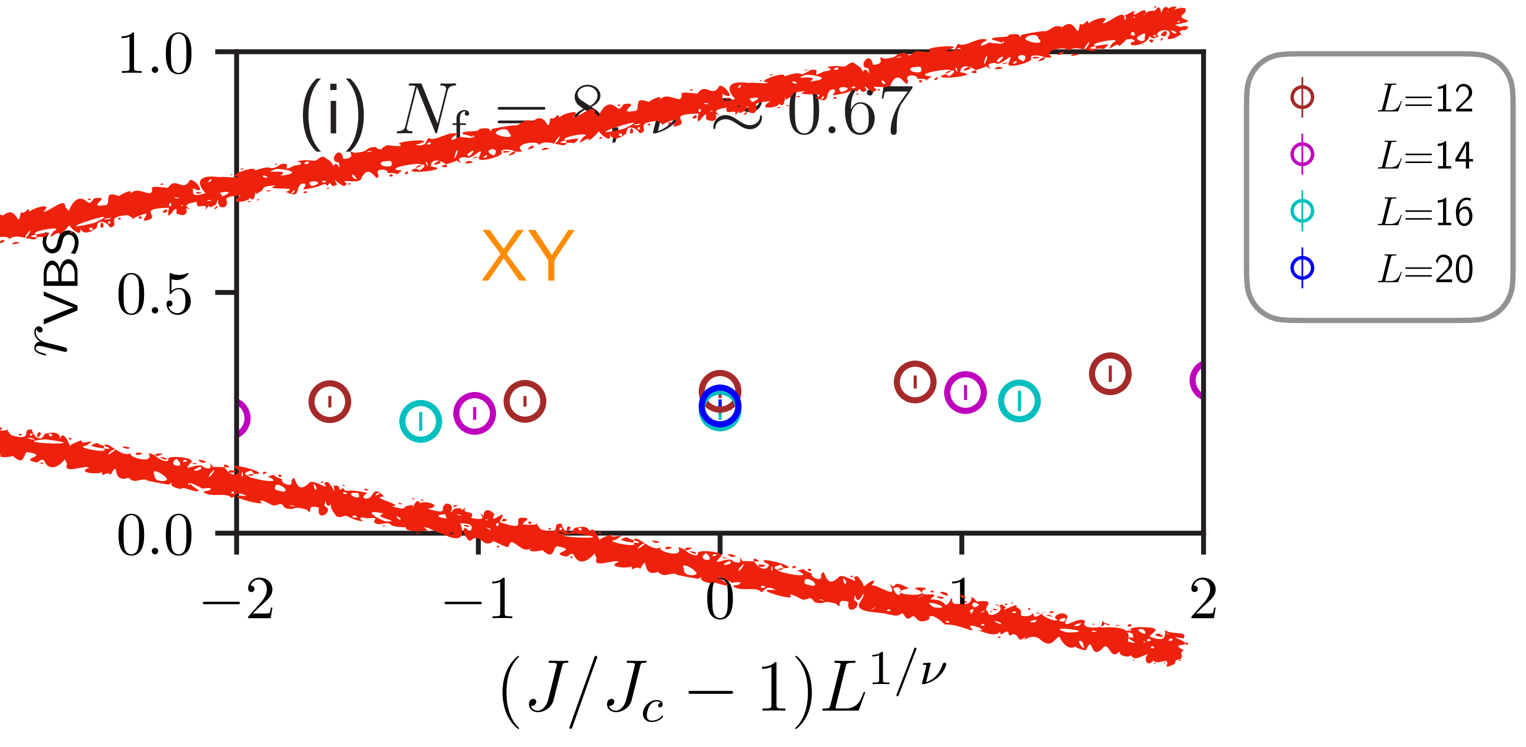

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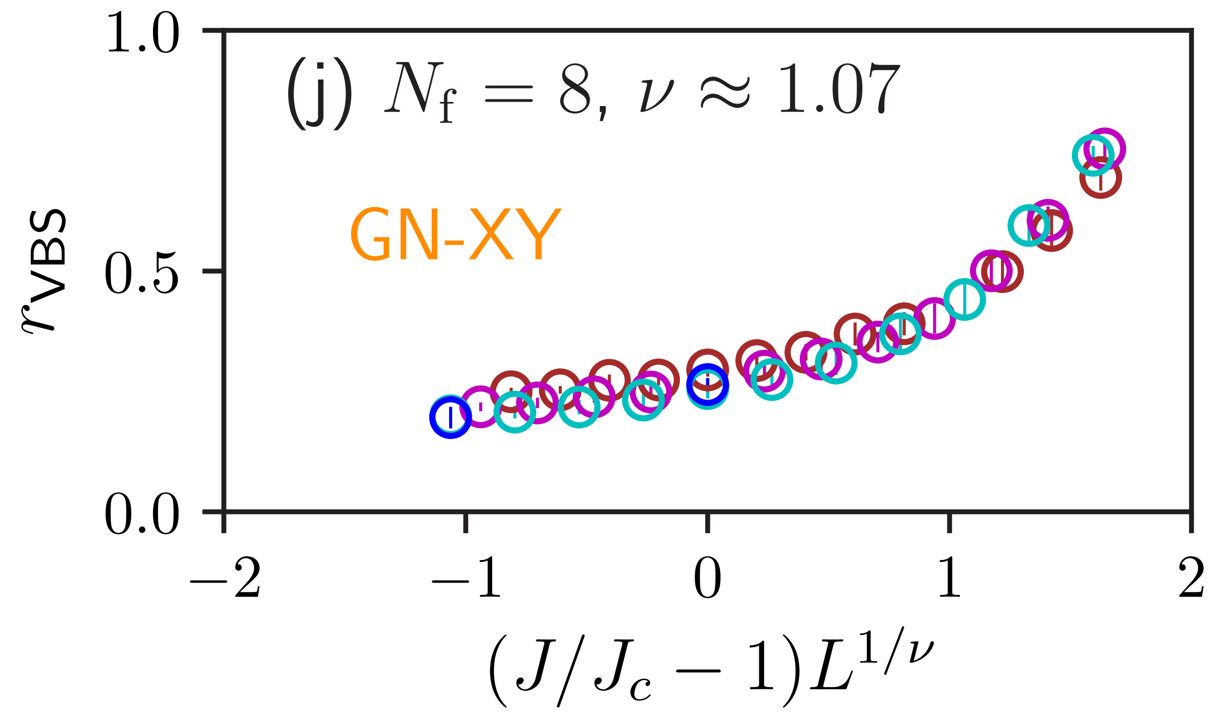

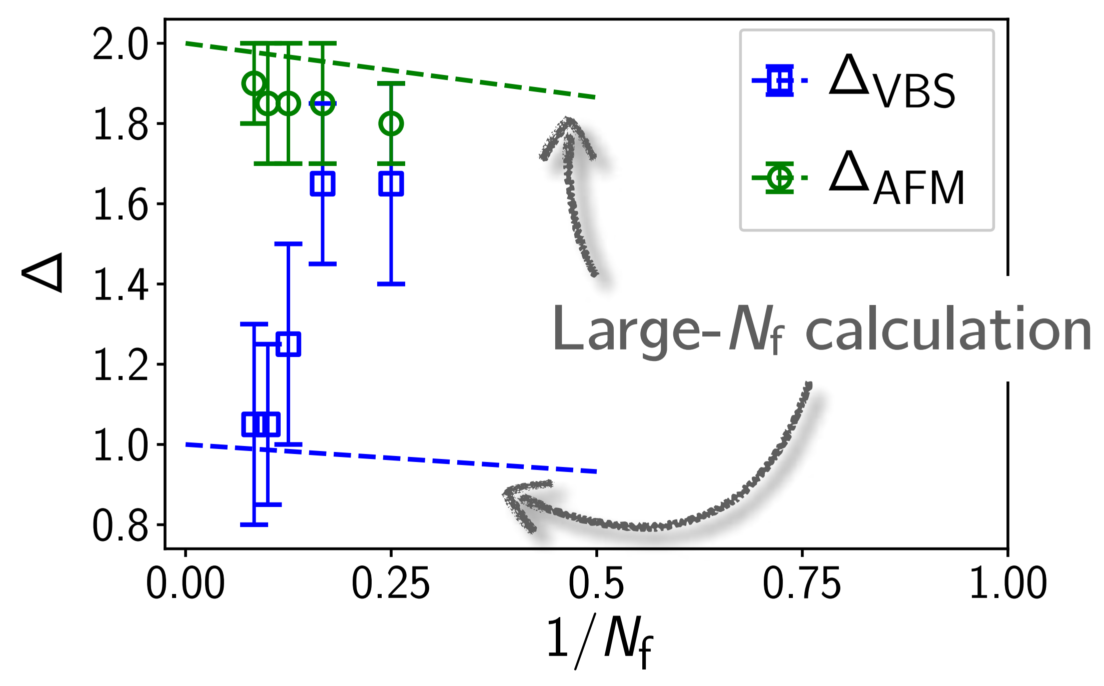

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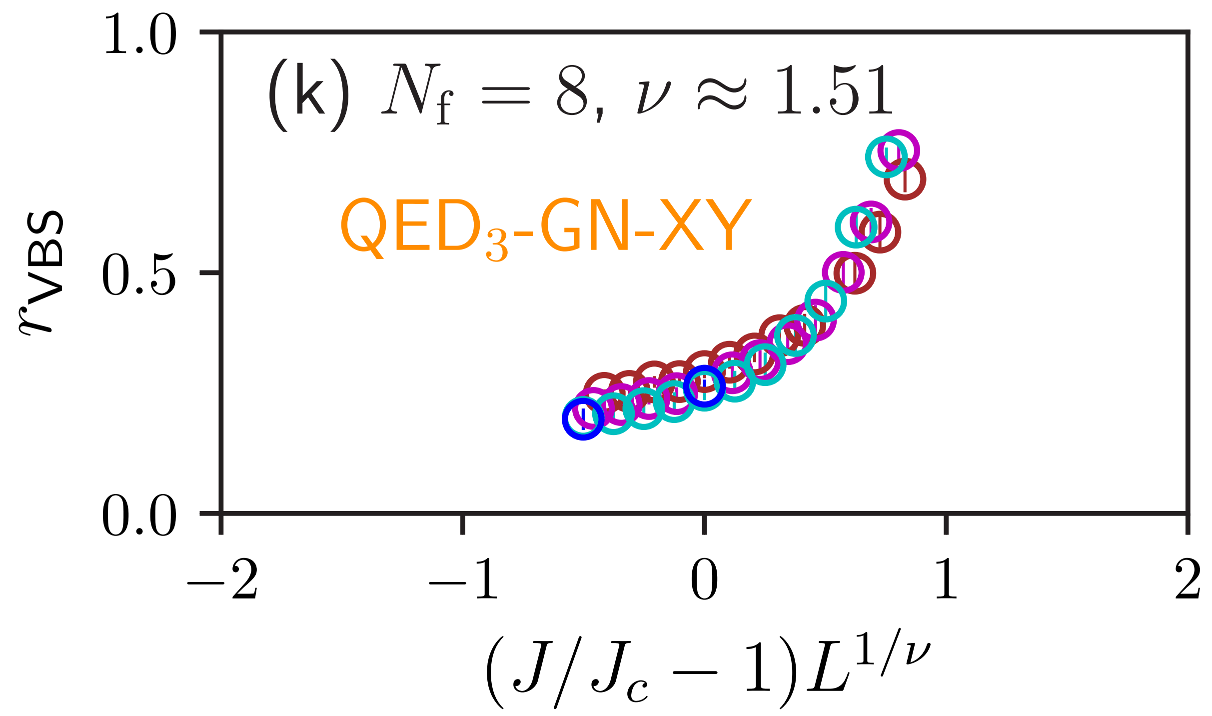

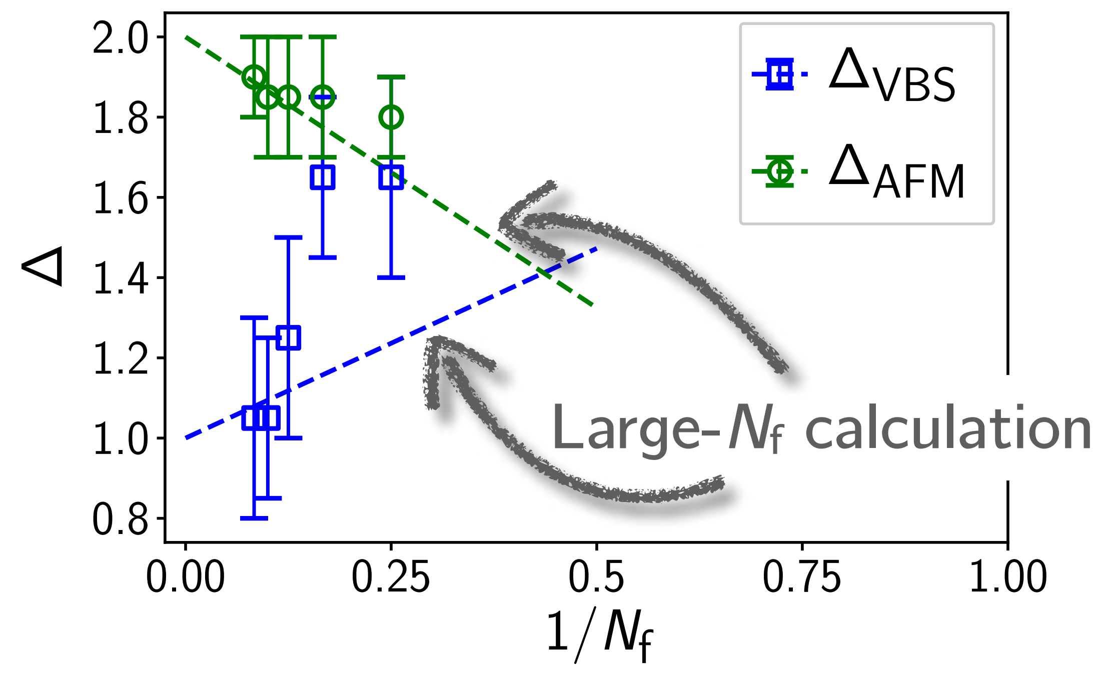

[LJ, Wang, Scherer, Meng, Xu, PRB '20]

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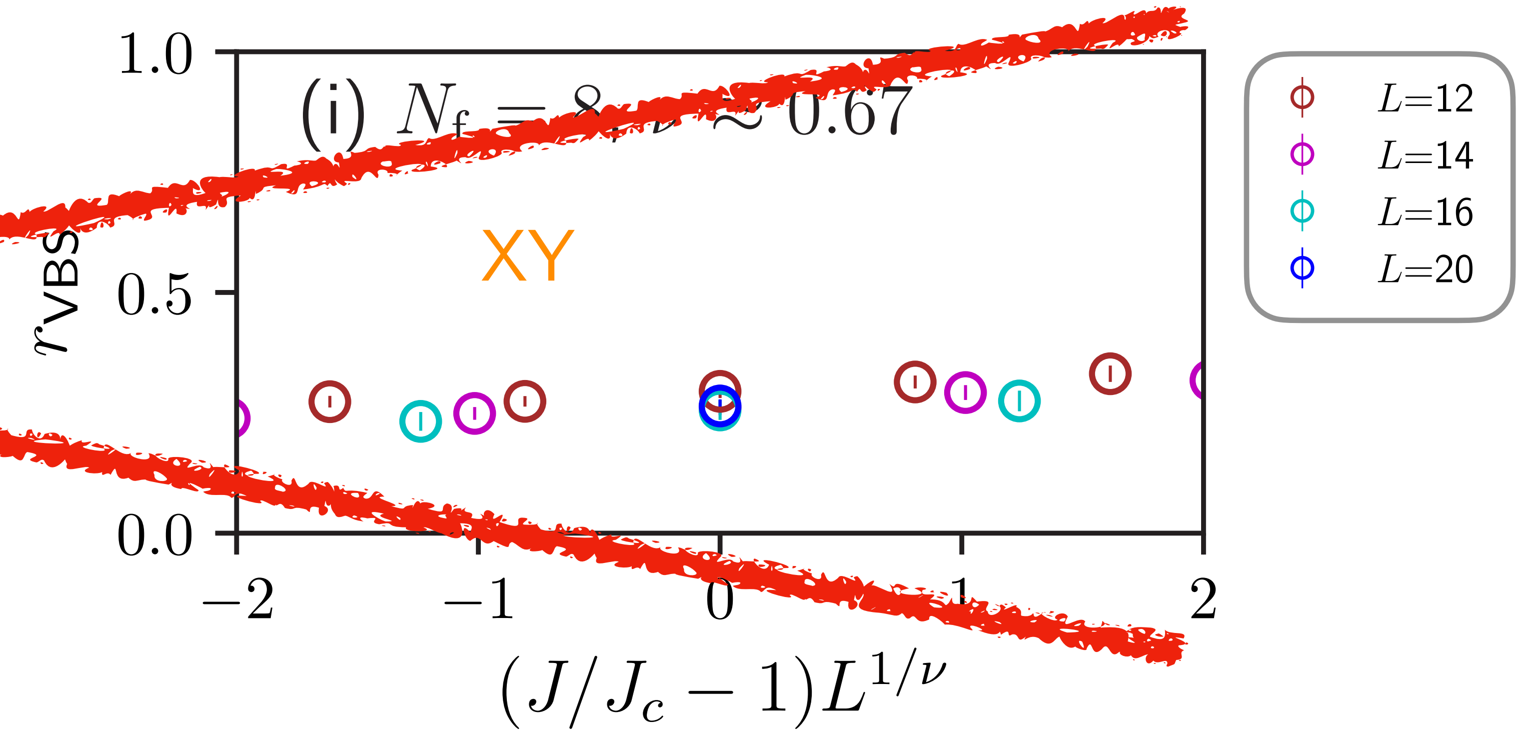

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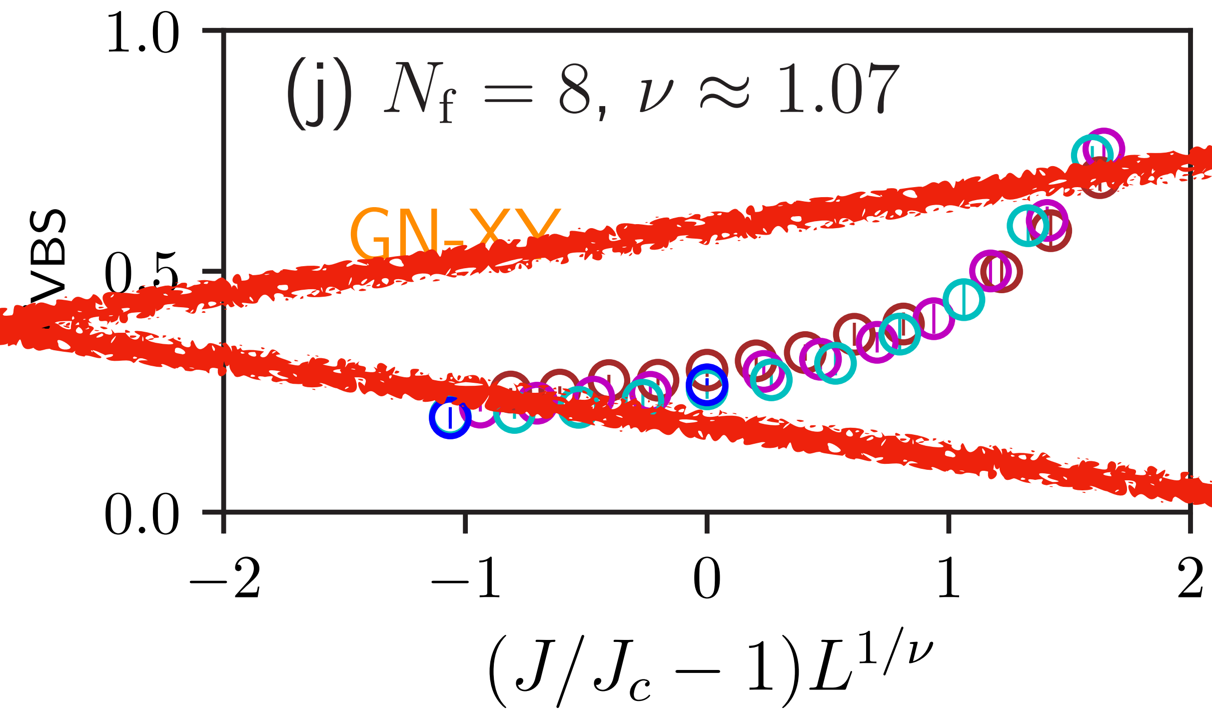

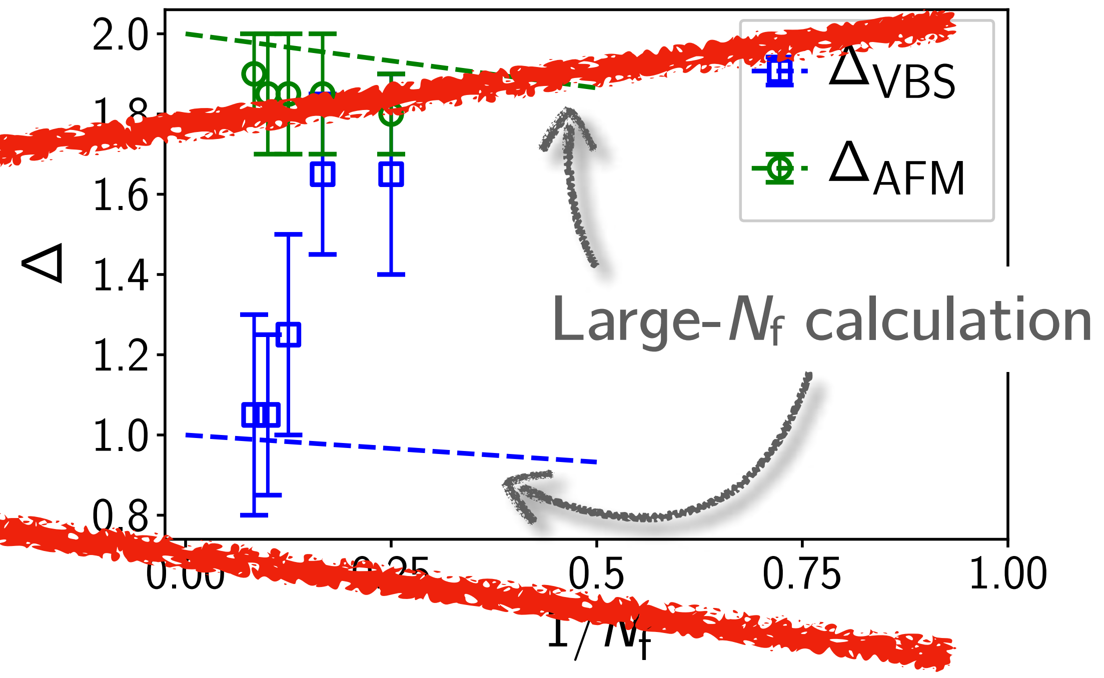

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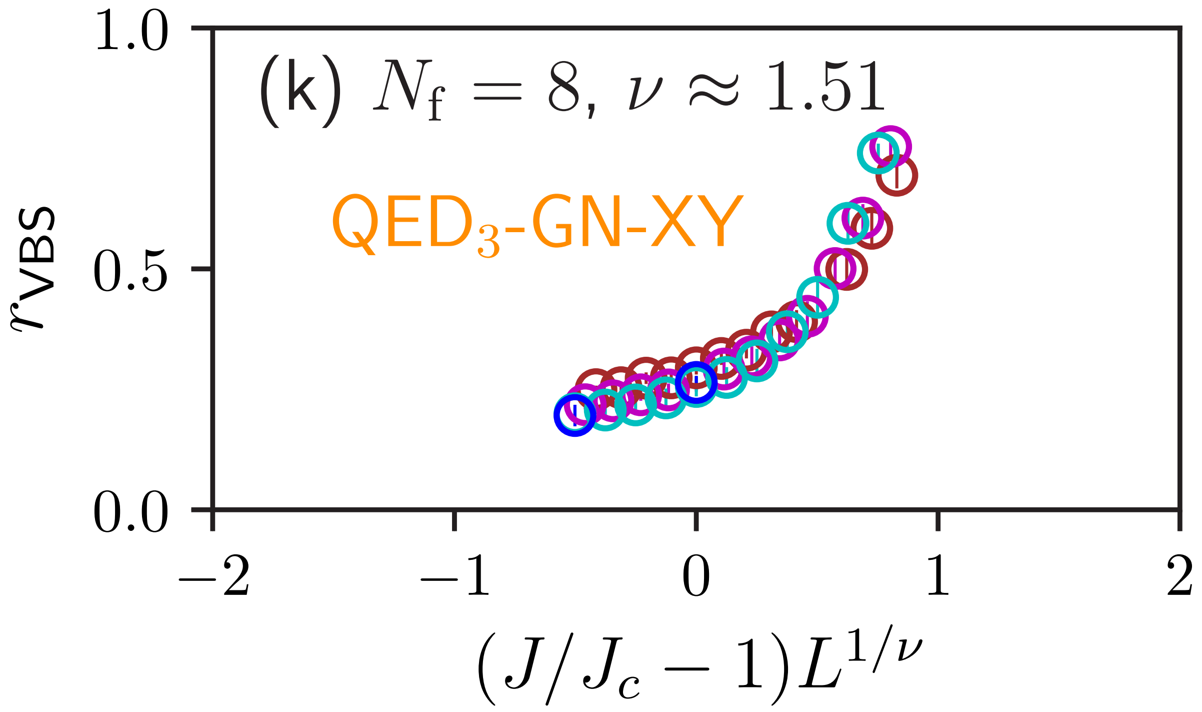
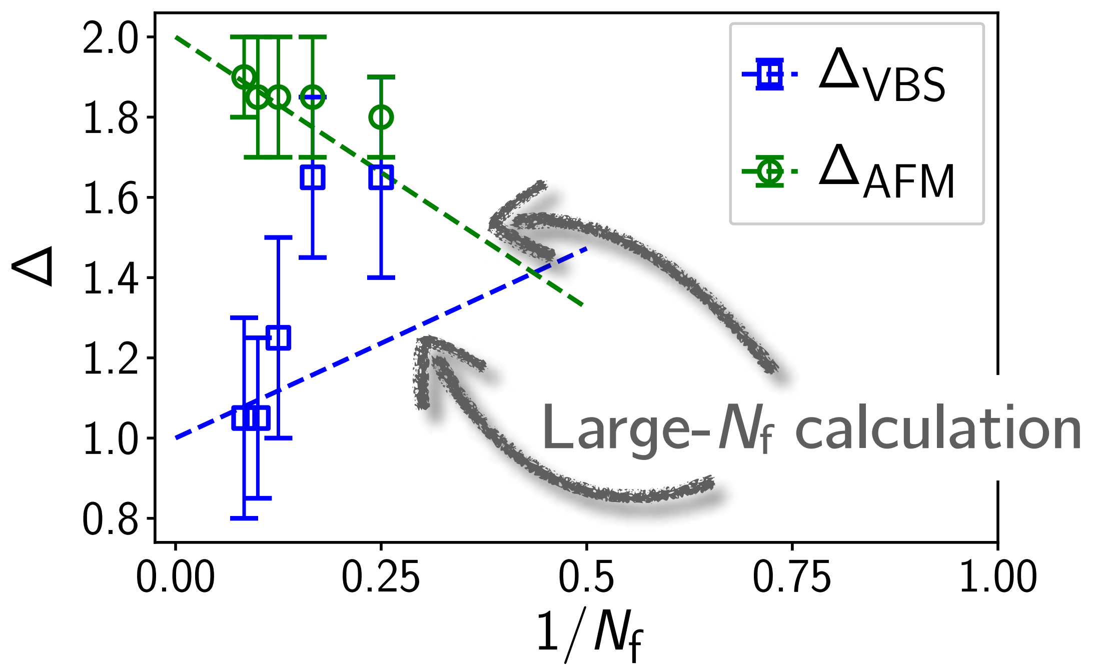
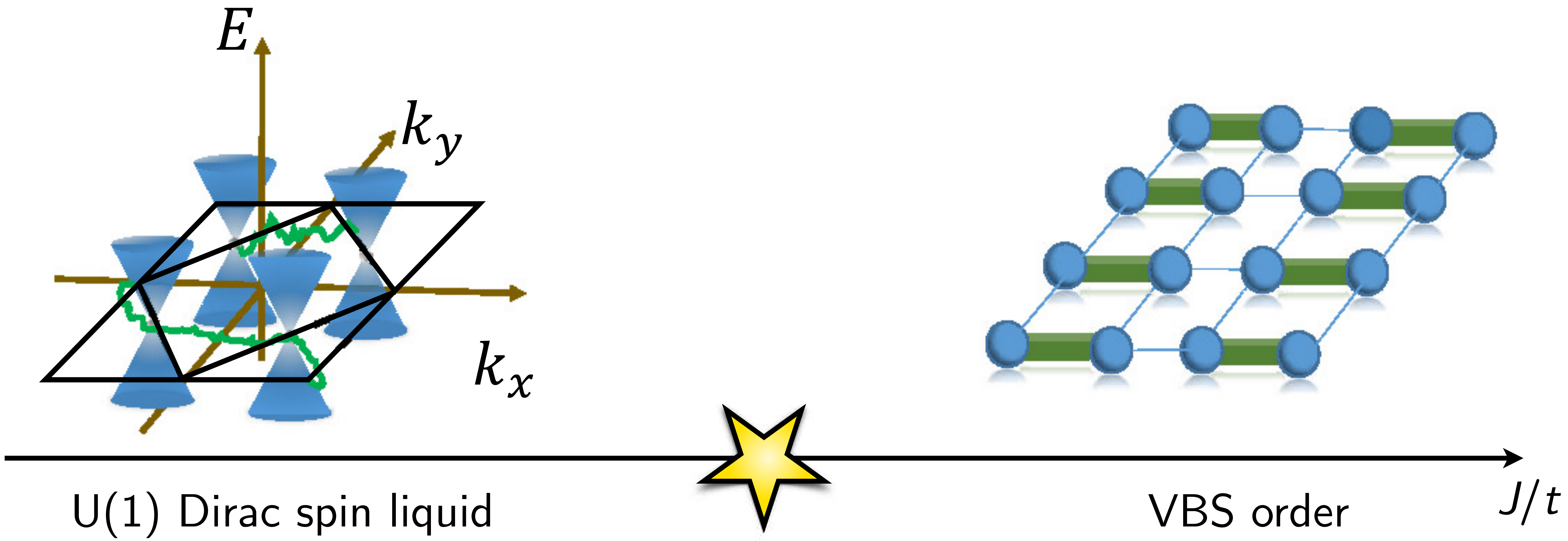




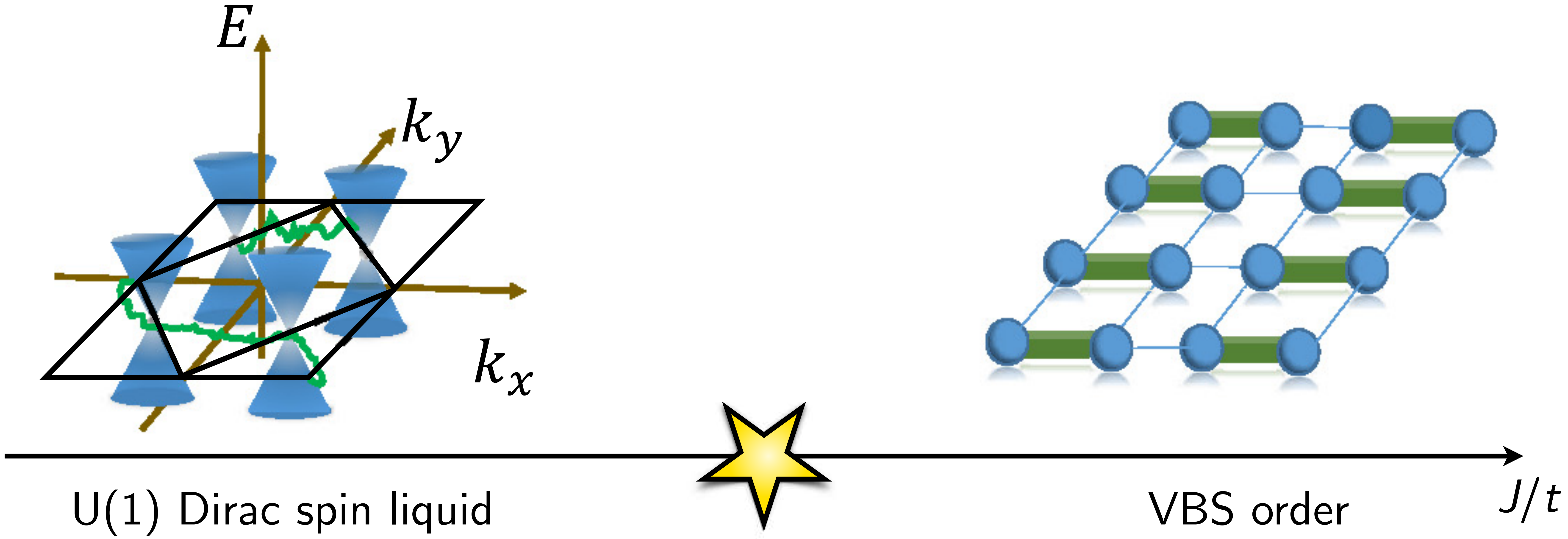
[LJ, Wang, Scherer, Meng, Xu, PRB '20]

Conclusions



QED_3-Gross-Neveu-XY

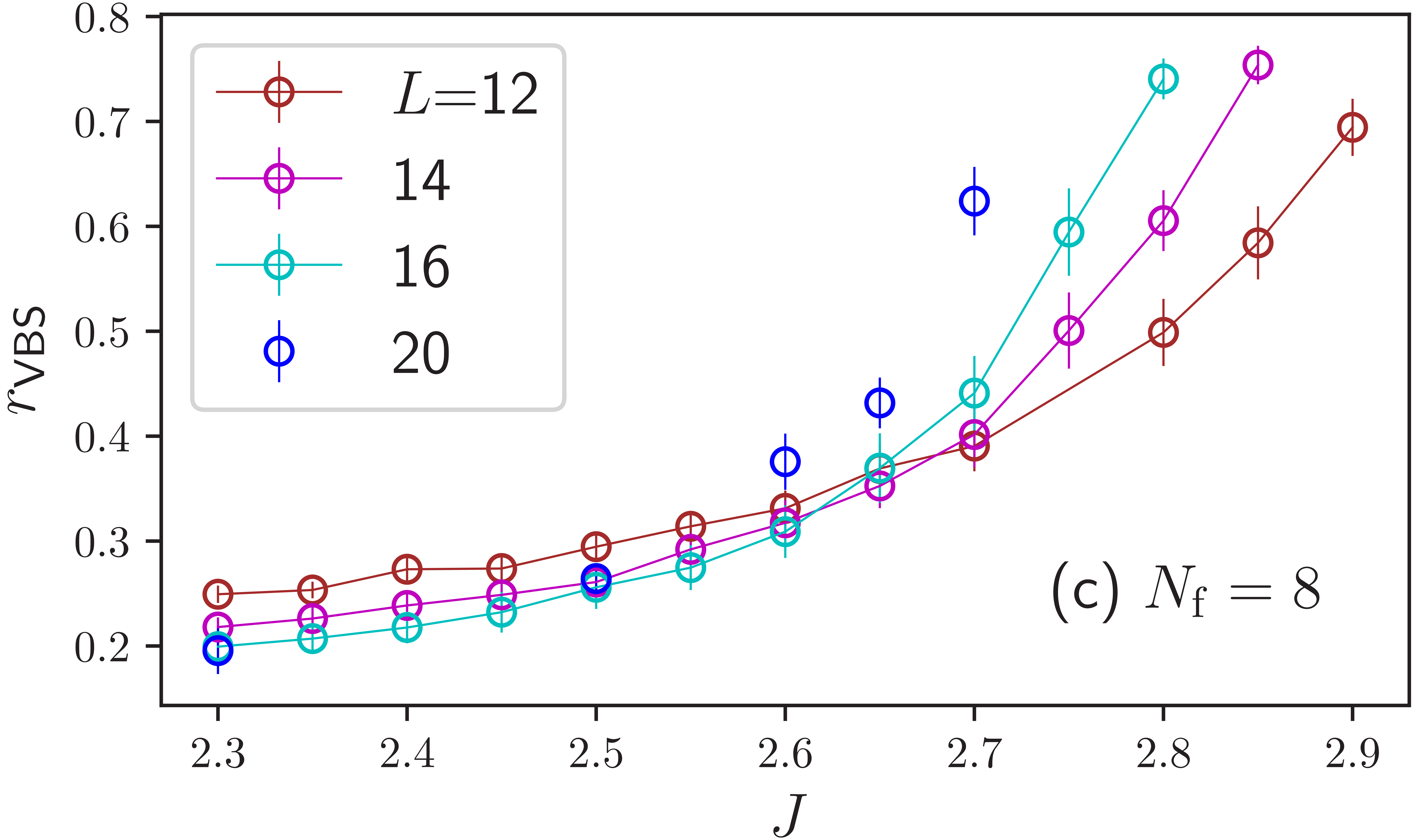
Conclusions



QED_3-Gross-Neveu-XY

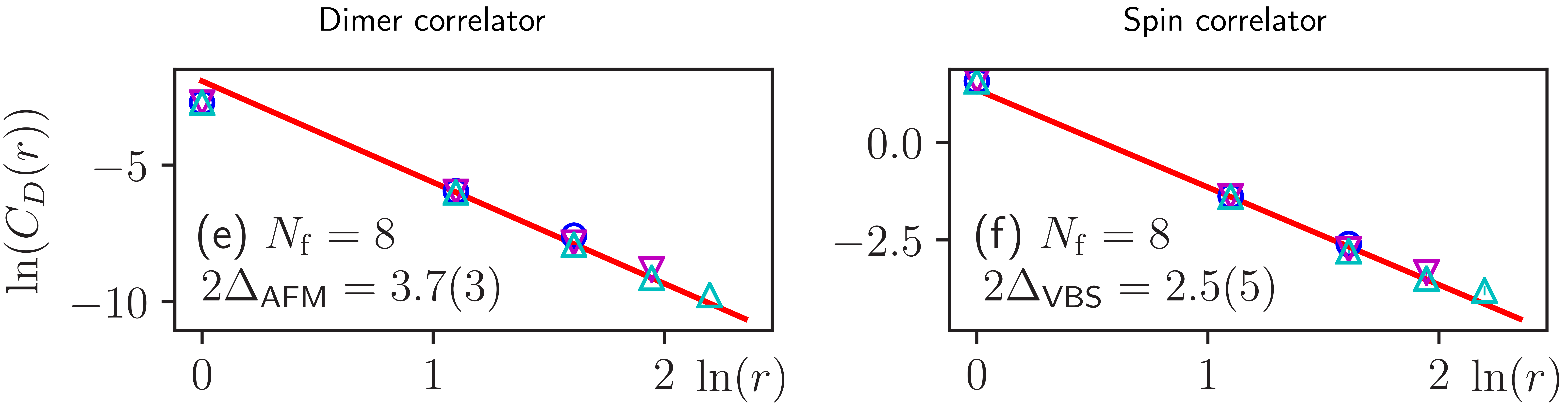
Quantum critical behavior reveals nature of adjacent exotic phase

VBS correlation ratio



[LJ, Wang, Scherer, Meng, Xu, PRB '20]

Decay of critical correlators



[LJ, Wang, Scherer, Meng, Xu, PRB '20]