Transitions, Excitations, FCI (FAQH), Correlated Flat Bands

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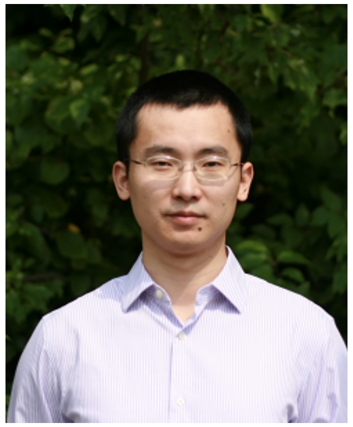
Rep. Prog. Phys. **87** (2024) 108003

From Fractional Quantum Anomalous Hall Smectics to Polar Smectic Metals: Nontrivial Interplay Between Electronic Liquid Crystal Order and Topological Order in Correlated Topological Flat Bands

Hongyu Lu[1,4], Han-Qing Wu[2,4], Bin-Bin Chen[1,*], Kai Sun[3,*] and Zi Yang Meng[1,*]



Poster on FCI-SF transition

arXiv:2408.07111

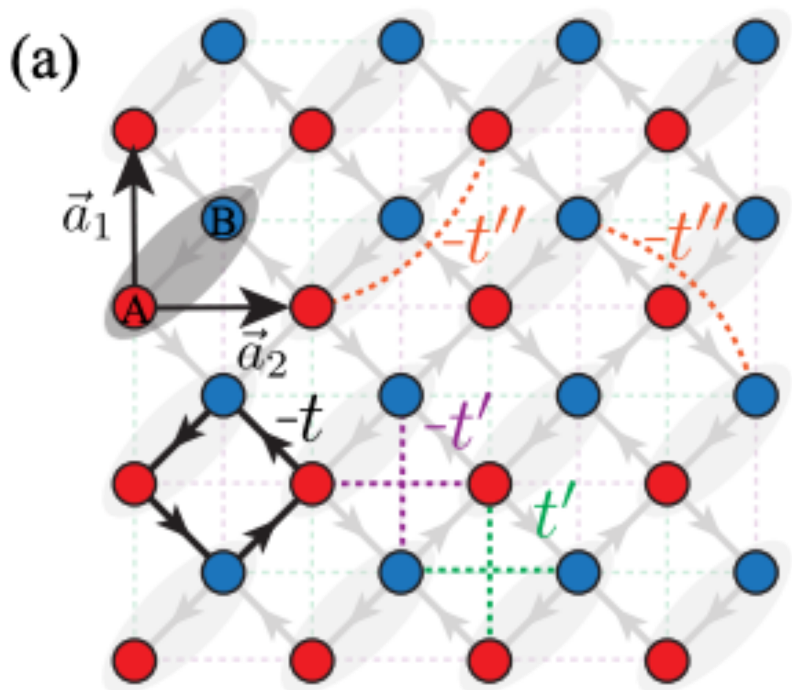
Vestigial Gapless Boson Density Wave Emerging between $\nu = 1/2$ Fractional Chern Insulator and Finite-Momentum Supersolid

Hongyu Lu,[1] Han-Qing Wu,[2] Bin-Bin Chen,[1] and Zi Yang Meng[1,*]

PHYSICAL REVIEW LETTERS **132**, 236502 (2024)

Thermodynamic Response and Neutral Excitations in Integer and Fractional Quantum Anomalous Hall States Emerging from Correlated Flat Bands

Hongyu Lu,[1] Bin-Bin Chen,[1] Han-Qing Wu,[2] Kai Sun,[3,*] and Zi Yang Meng[1,†]



$$H = H_0 + H_I$$

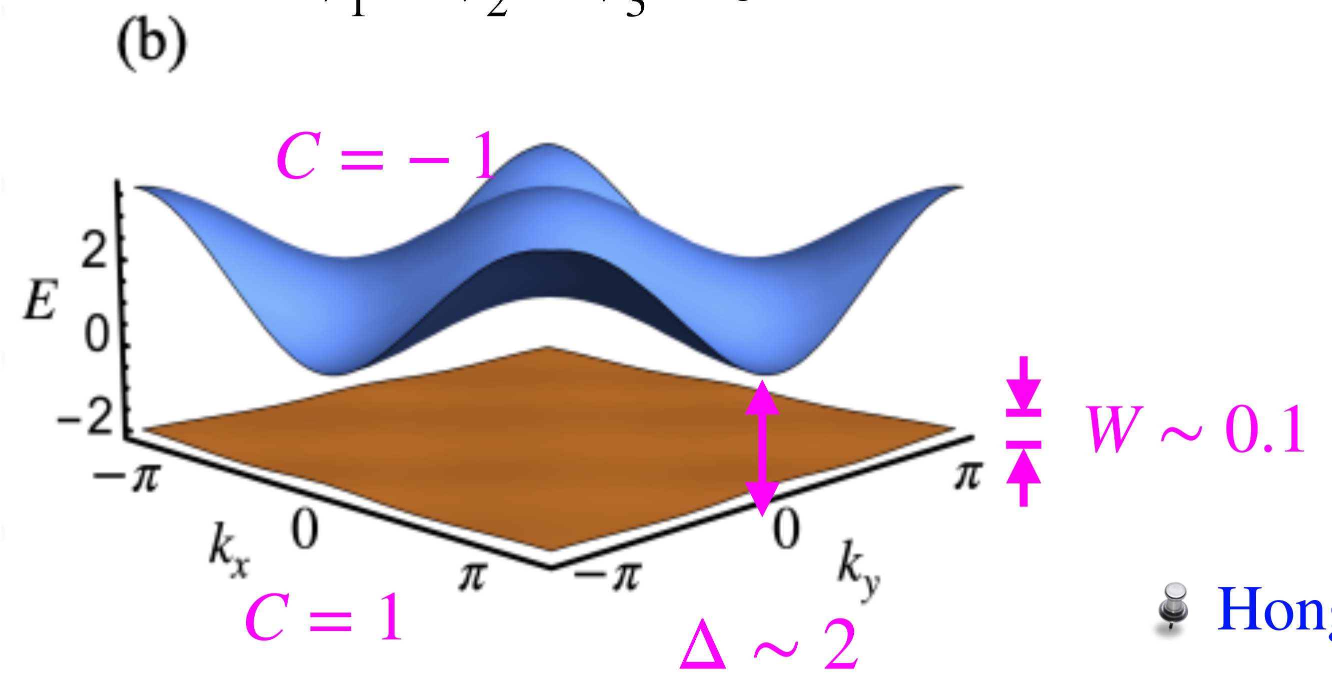
$$H_0 = -t\sum_{\langle i,j\rangle} e^{i\phi_{ij}}(c_i^\dagger c_j + h.c.) - \sum_{\langle\langle i,j\rangle\rangle} t'_{ij}(c_i^\dagger c_j + h.c.) - t'' \sum_{\langle\langle\langle i,j\rangle\rangle\rangle} (c_i^\dagger c_j + h.c.)$$

$$t = 1 \qquad t' = \pm\frac{1}{2+\sqrt{2}} \qquad t'' = -\frac{1}{2+2\sqrt{2}}$$

$$\phi_{ij} = \frac{\pi}{4}$$

$$H_I = V_1\sum_{\langle i,j\rangle} n_i n_j + V_2 \sum_{\langle\langle i,j\rangle\rangle} n_i n_j + V_3 \sum_{\langle\langle\langle i,j\rangle\rangle\rangle} n_i n_j + \mu \sum_i n_i$$

$$V_1 = V_2 = V_3 = 0$$

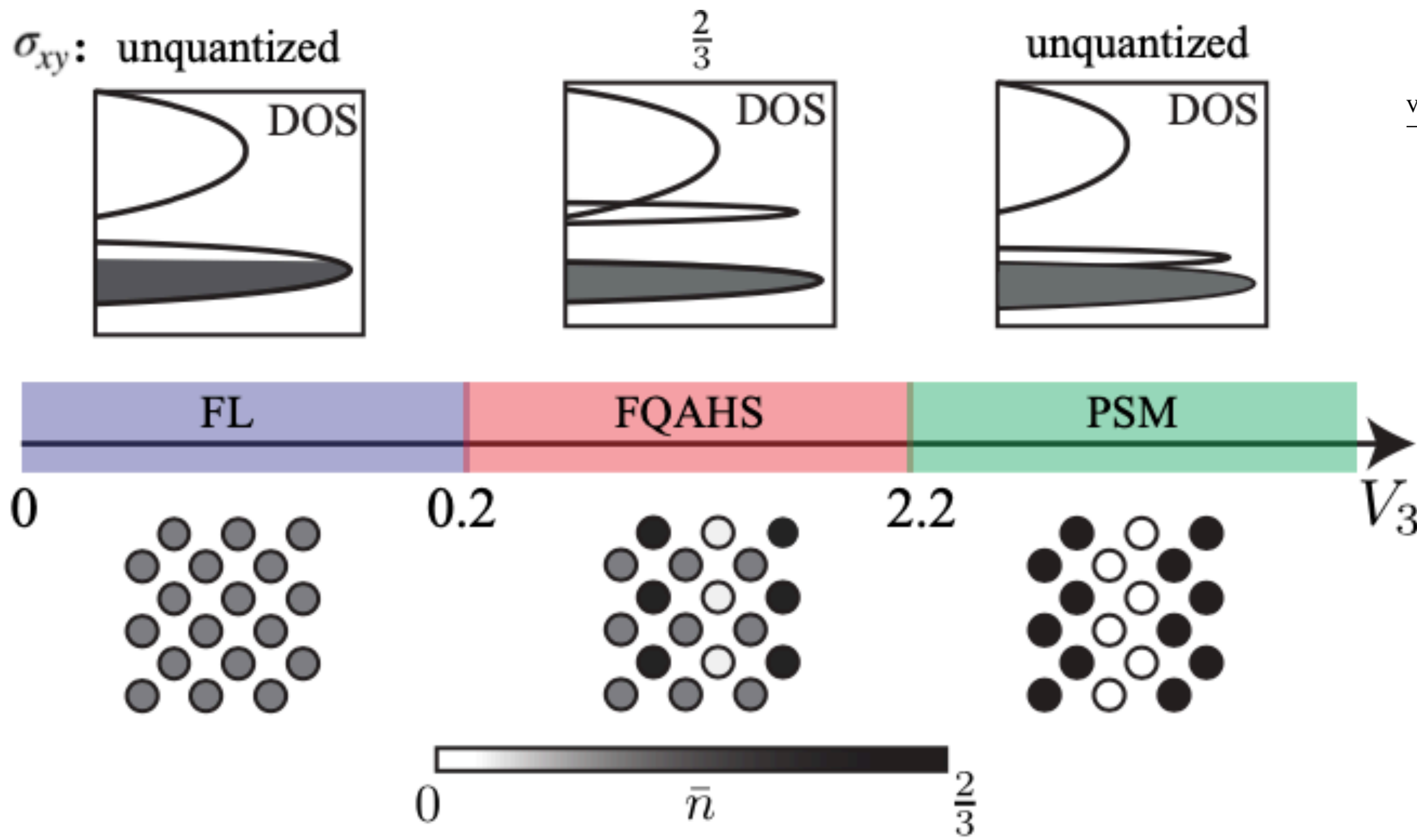


Consider filling factor of the flat band

$$\nu = \frac{2}{3}$$

and consider the NNN interaction V_3

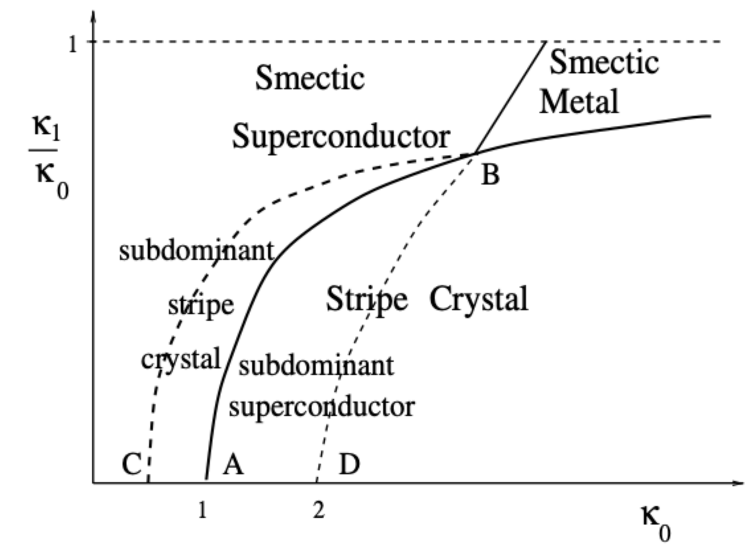
Hongyu Lu et al., Rep. Prog. Phys. 87 (2024) 108003



VOLUME 85, NUMBER 10 PHYSICAL REVIEW LETTERS 4 SEPTEMBER 2000

Quantum Theory of the Smectic Metal State in Stripe Phases

V. J. Emery,[1] E. Fradkin,[2] S. A. Kivelson,[3,4] and T. C. Lubensky[5]



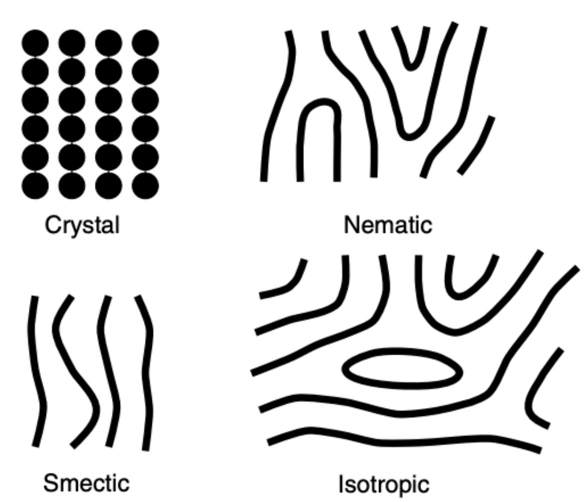
FL — Fermi liquid
FQAHS — Fractional quantum anomalous Hall smectic state
PSM — Polar smectic metal

Intertwinement of topological order and Landau order

Electronic liquid-crystal phases of a doped Mott insulator

S. A. Kivelson*, E. Fradkin† & V. J. Emery‡

Nature 393, 550 (1998)

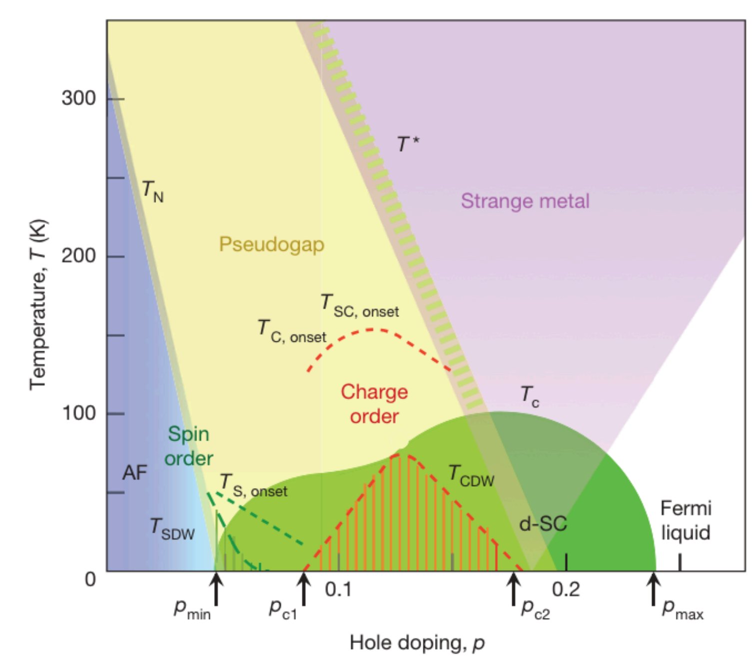


REVIEW

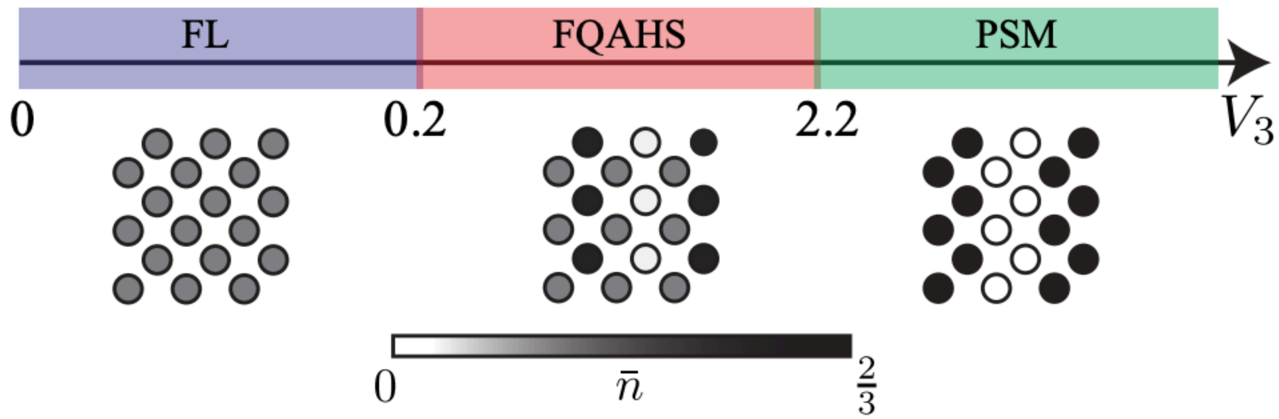
doi:10.1038/nature14165

From quantum matter to high-temperature superconductivity in copper oxides

B. Keimer[1], S. A. Kivelson[2], M. R. Norman[3], S. Uchida[4] & J. Zaanen[5]



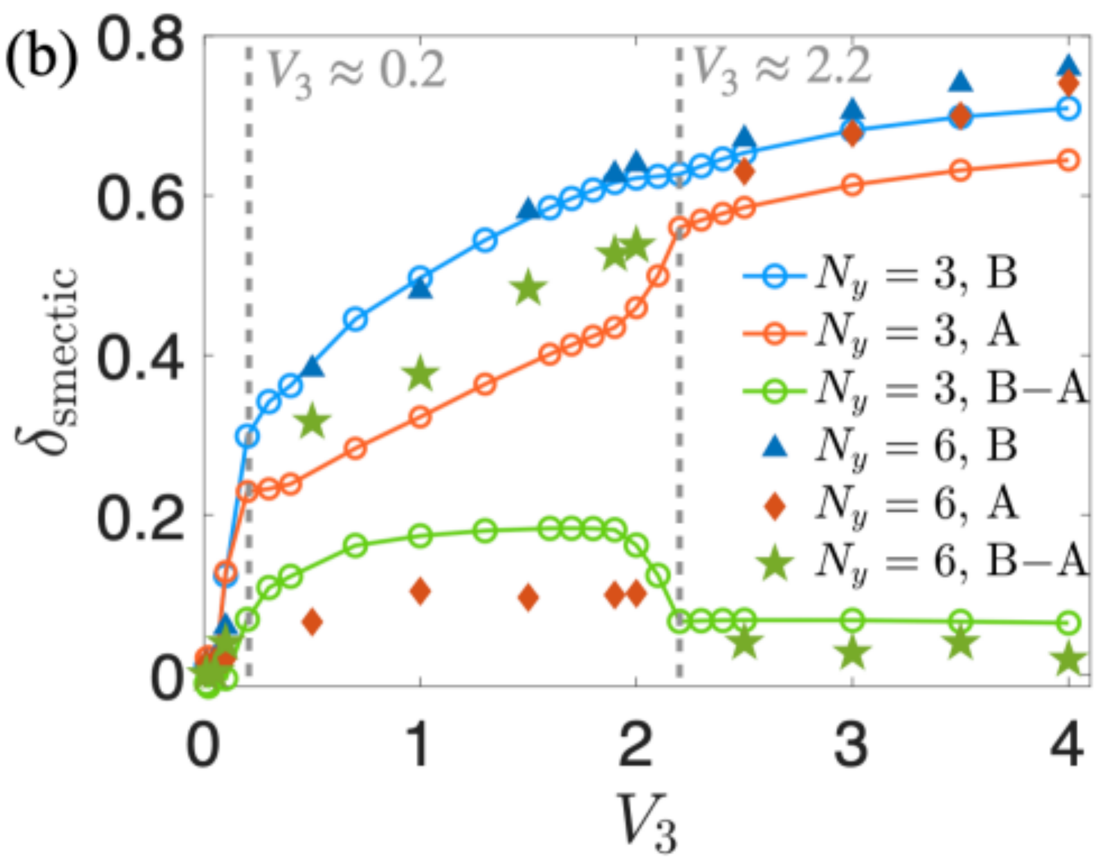
Hongyu Lu et al., Rep. Prog. Phys. 87 (2024) 108003

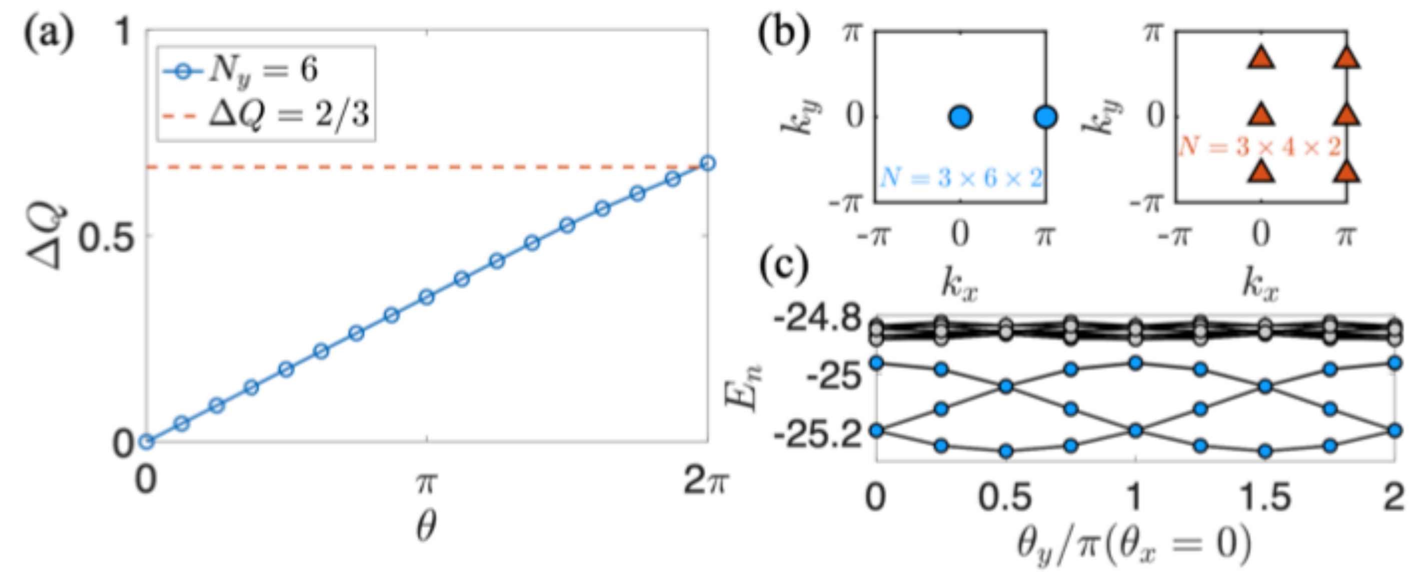


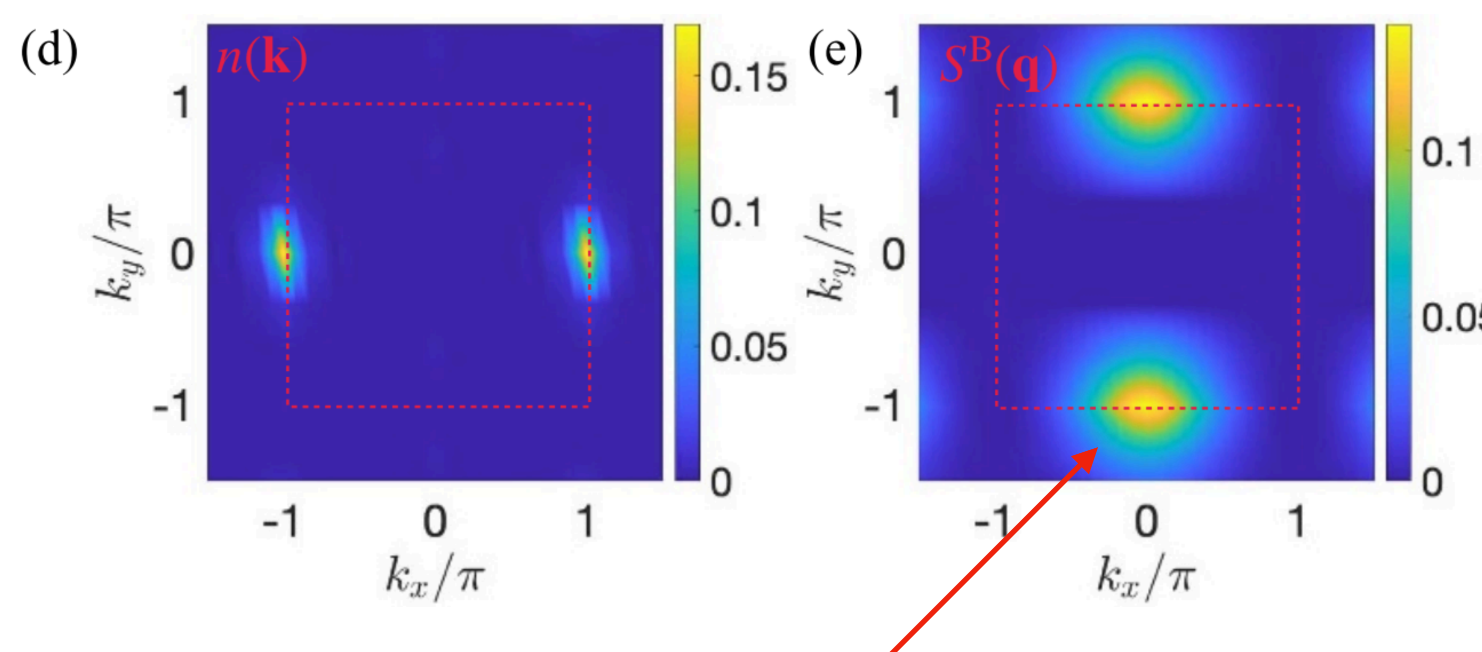
Charge pumping

$$\sigma_{xy} = \frac{2}{3}\frac{e^2}{h}$$

6-fold degeneracy





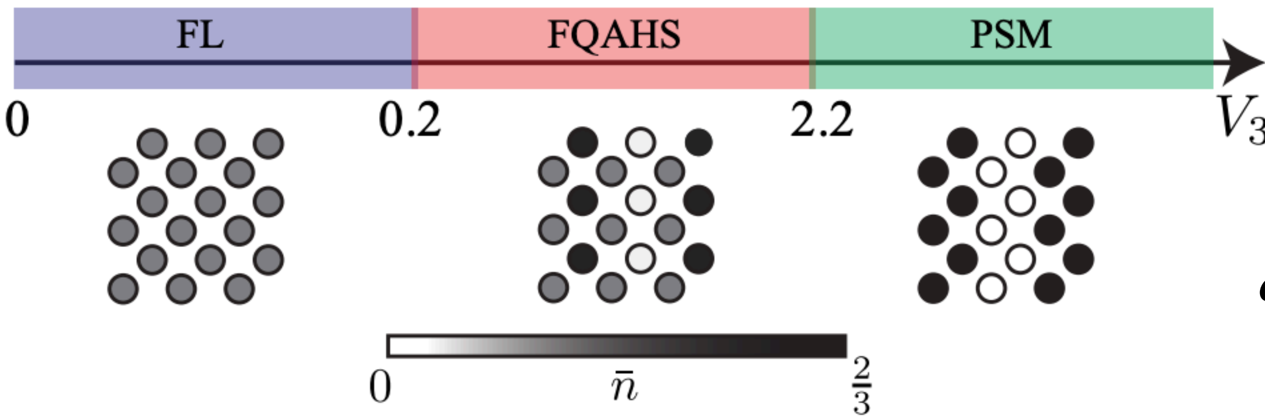


Charge-neutral magnetoroton

$$\delta^{A/B}_{smectic} = \frac{1}{N}\sum_i (-1)^{x_i}\, n_i^{A/B} \quad i \text{ unit cell}$$

$$S^{A/B}(\mathbf{q}) = \sum_i e^{-i\mathbf{q}\cdot(\mathbf{r_i}-\mathbf{r_0})}(\langle n_0^{A/B} n_i^{A/B}\rangle - \langle n_0^{A/B}\rangle\langle n_i^{A/B}\rangle)$$

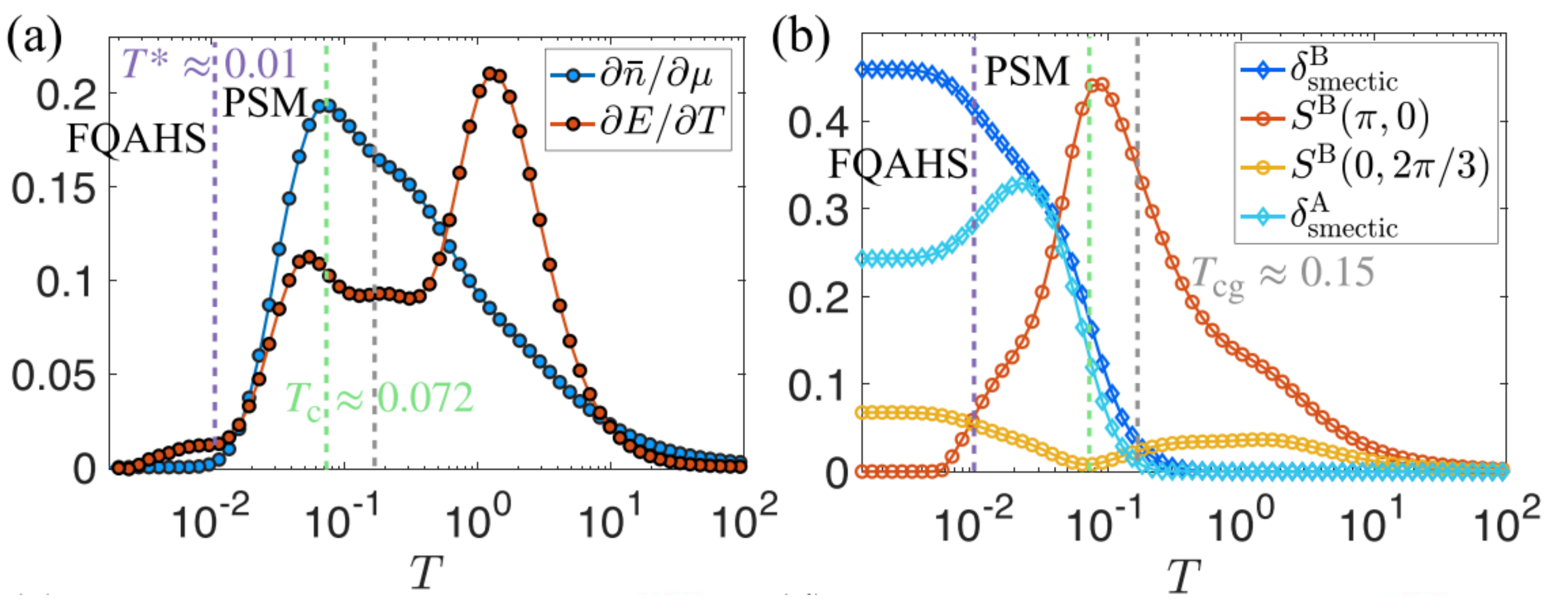
Hongyu Lu et al., Rep. Prog. Phys. 87 (2024) 108003

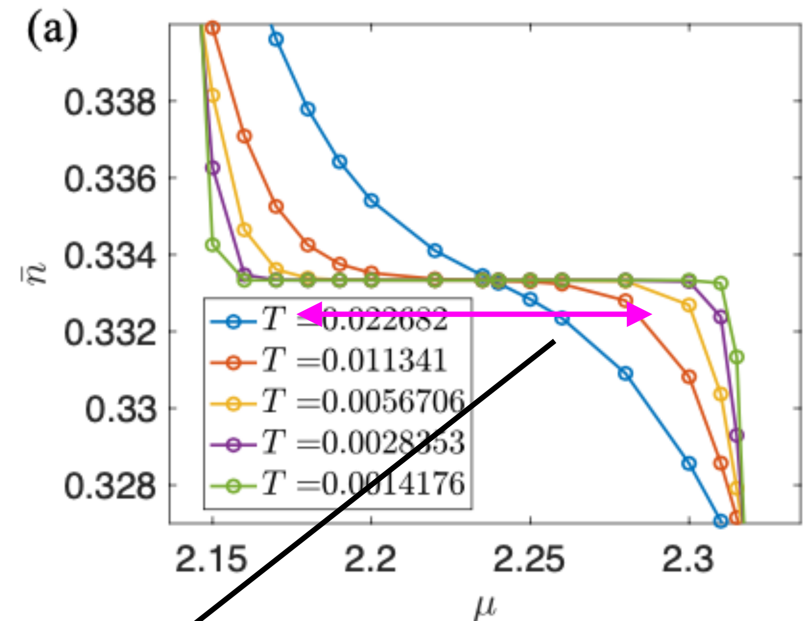


$$\delta^{A/B}_{smectic} = \frac{1}{N}\sum_i (-1)^{x_i}\, n_i^{A/B}$$

$$S^{A/B}(\mathbf{q}) = \sum_i e^{-i\mathbf{q}\cdot(\mathbf{r_i}-\mathbf{r_0})}(\langle n_0^{A/B} n_i^{A/B}\rangle - \langle n_0^{A/B}\rangle\langle n_i^{A/B}\rangle)$$

$V_3 = 1$





Magnetoroton

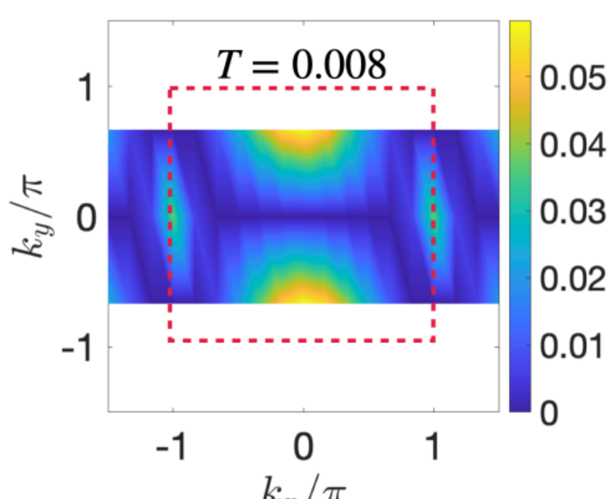
Smectic order

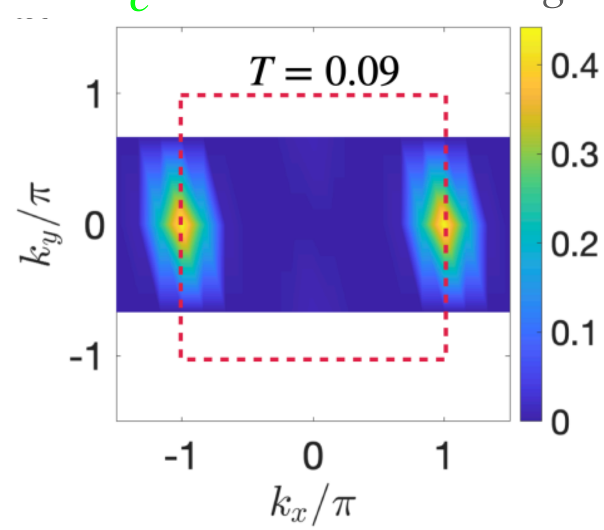
T

T^*

T_c

$T_{cg} \sim \Delta_{cg} \sim 0.15$





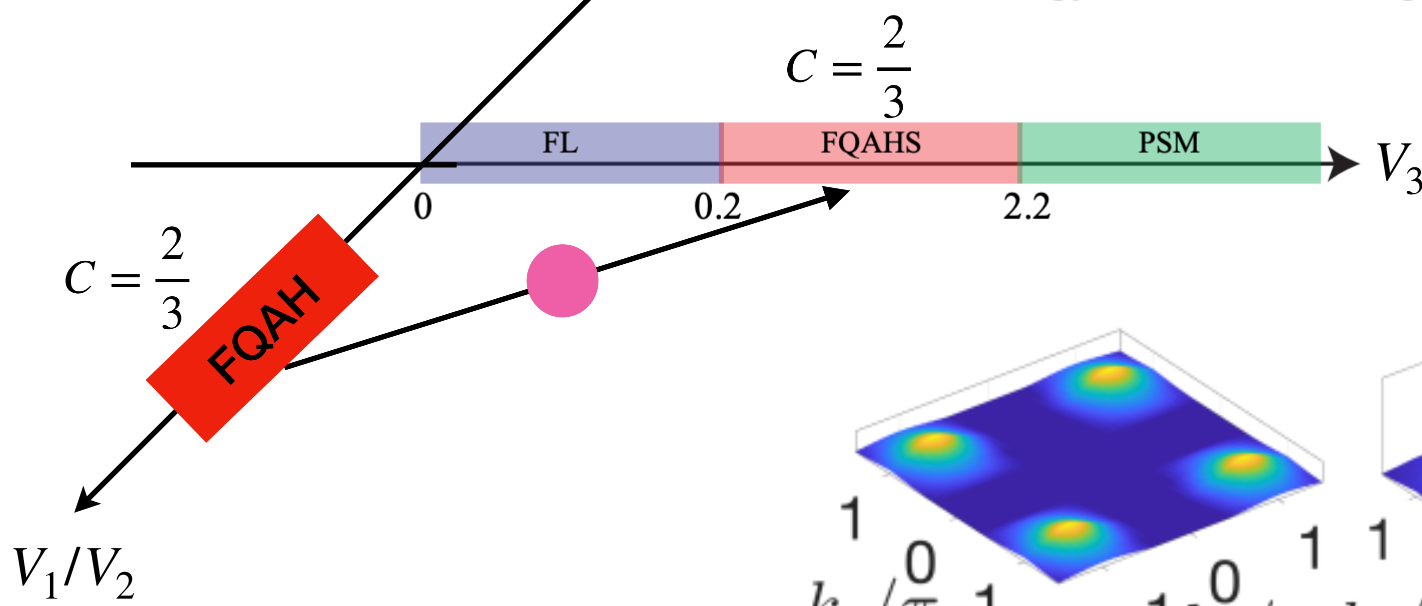
Roton gap determines the onset temperature of FCI

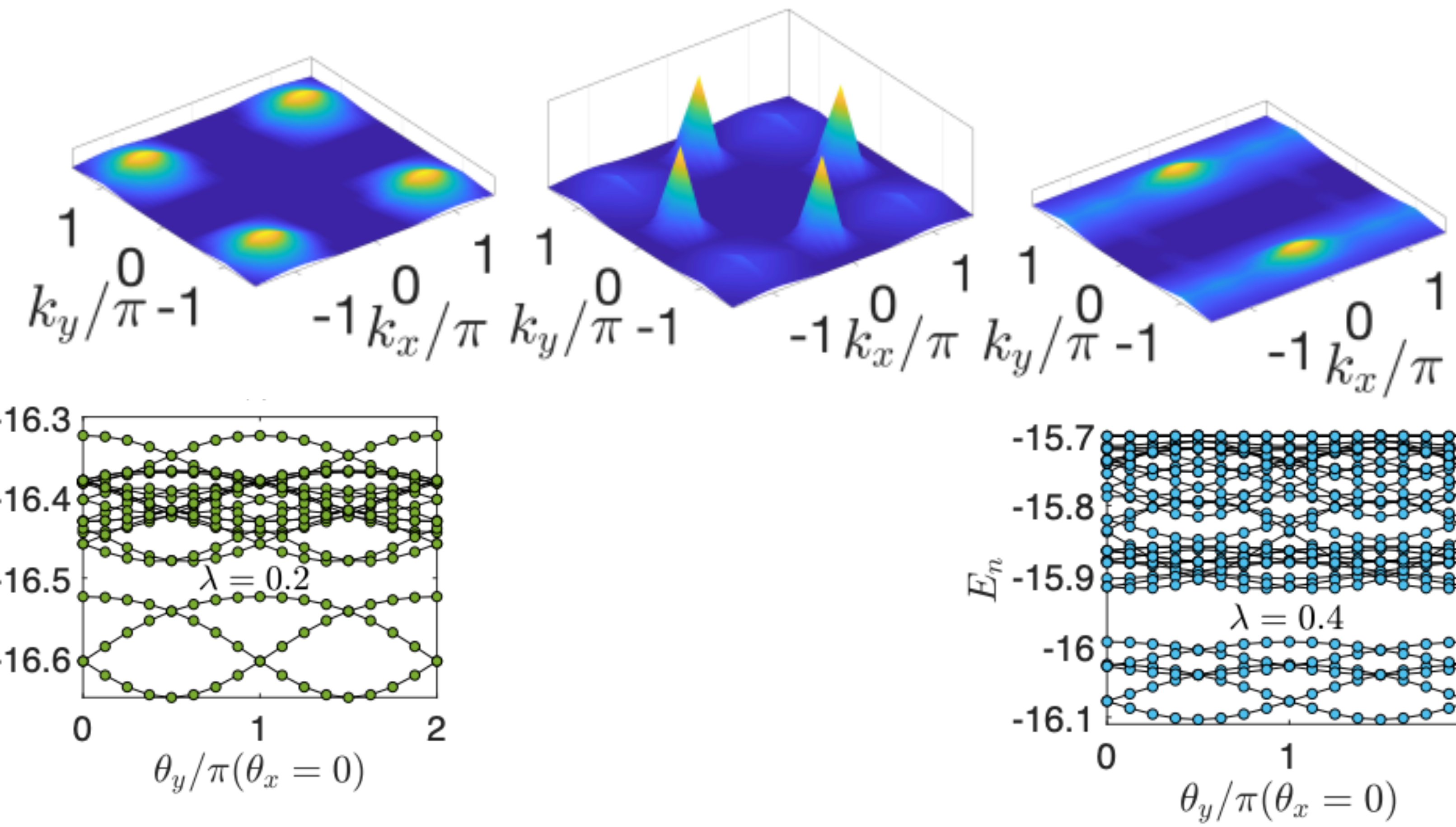
Hongyu Lu et al., PRL 132, 236502 (2024)

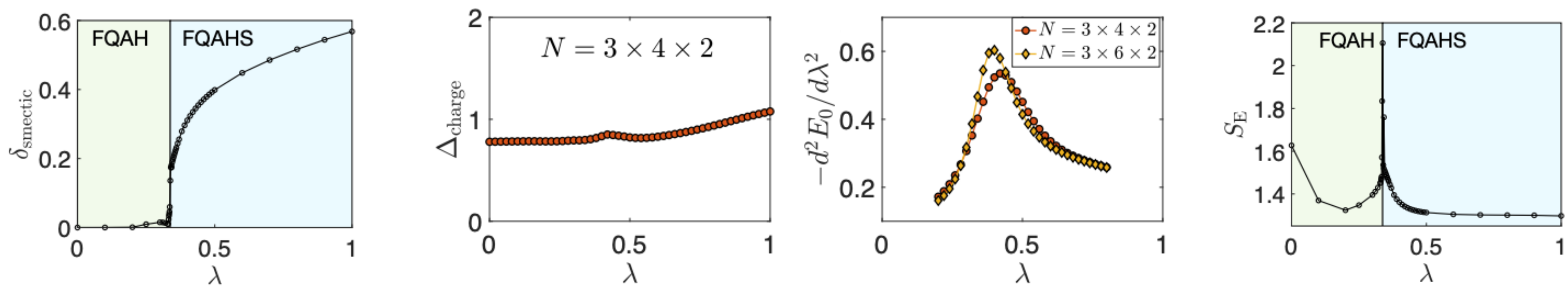
Hongyu Lu et al., arXiv:2404.06745

From a fractional quantum anomalous Hall state to a smectic state with equal Hall conductance

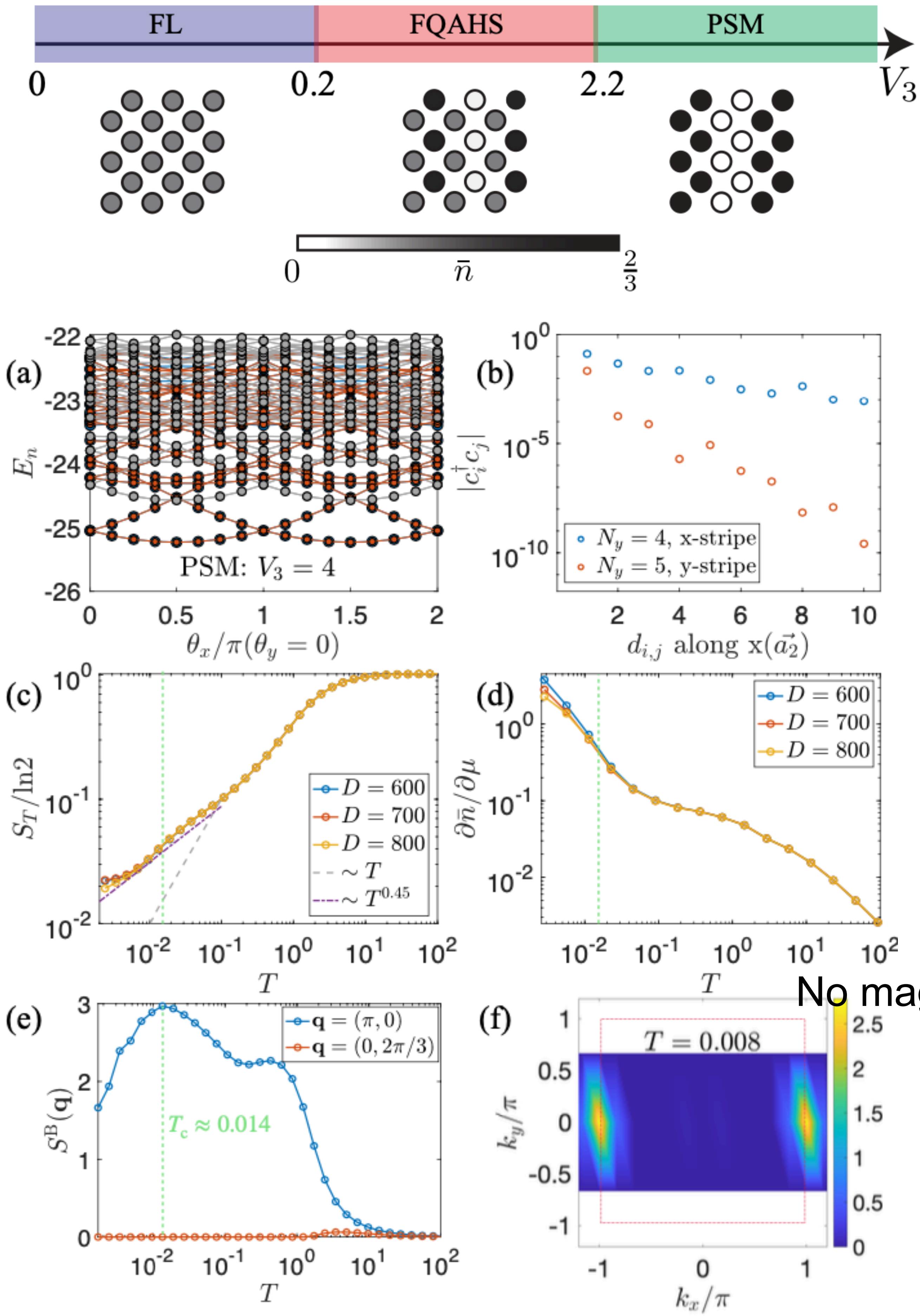
Hongyu Lu,[1,*] Han-Qing Wu,[2,*] Bin-Bin Chen,[1] and Zi Yang Meng[1,†]







Hongyu Lu et al., Rep. Prog. Phys. 87 (2024) 108003

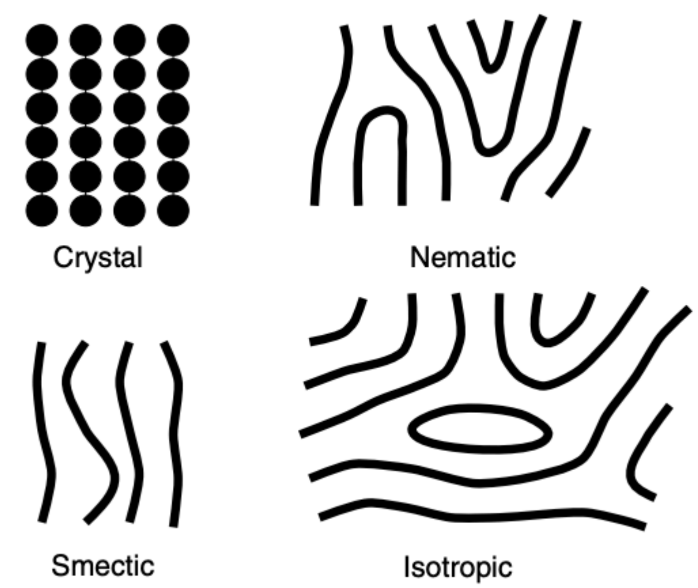


No magnetoroton

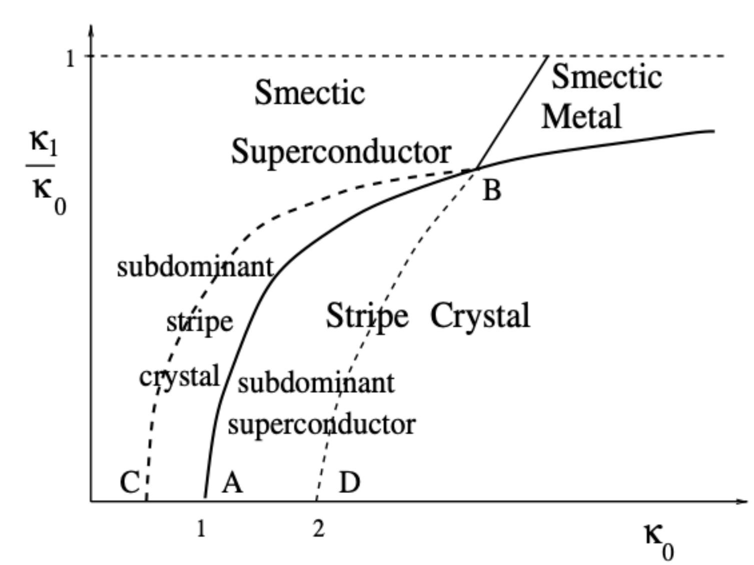
Electronic liquid-crystal phases of a doped Mott insulator

Nature 393, 550 (1998)

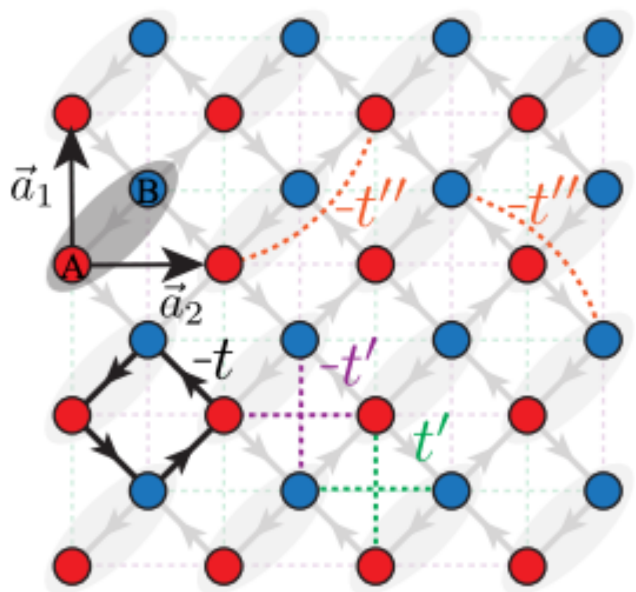
S. A. Kivelson*, E. Fradkin† & V. J. Emery‡

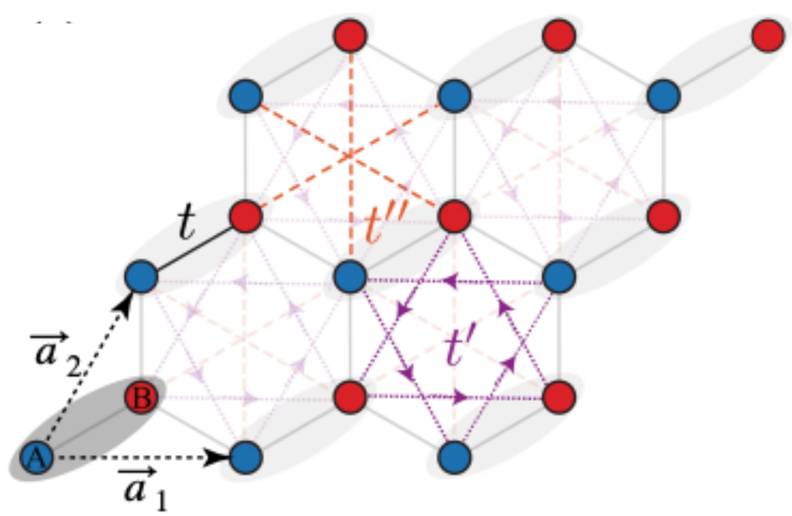


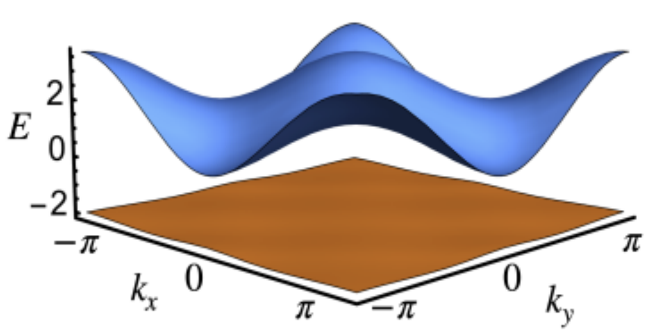
Coupled Luttinger liquid (non-Fermi liquid)

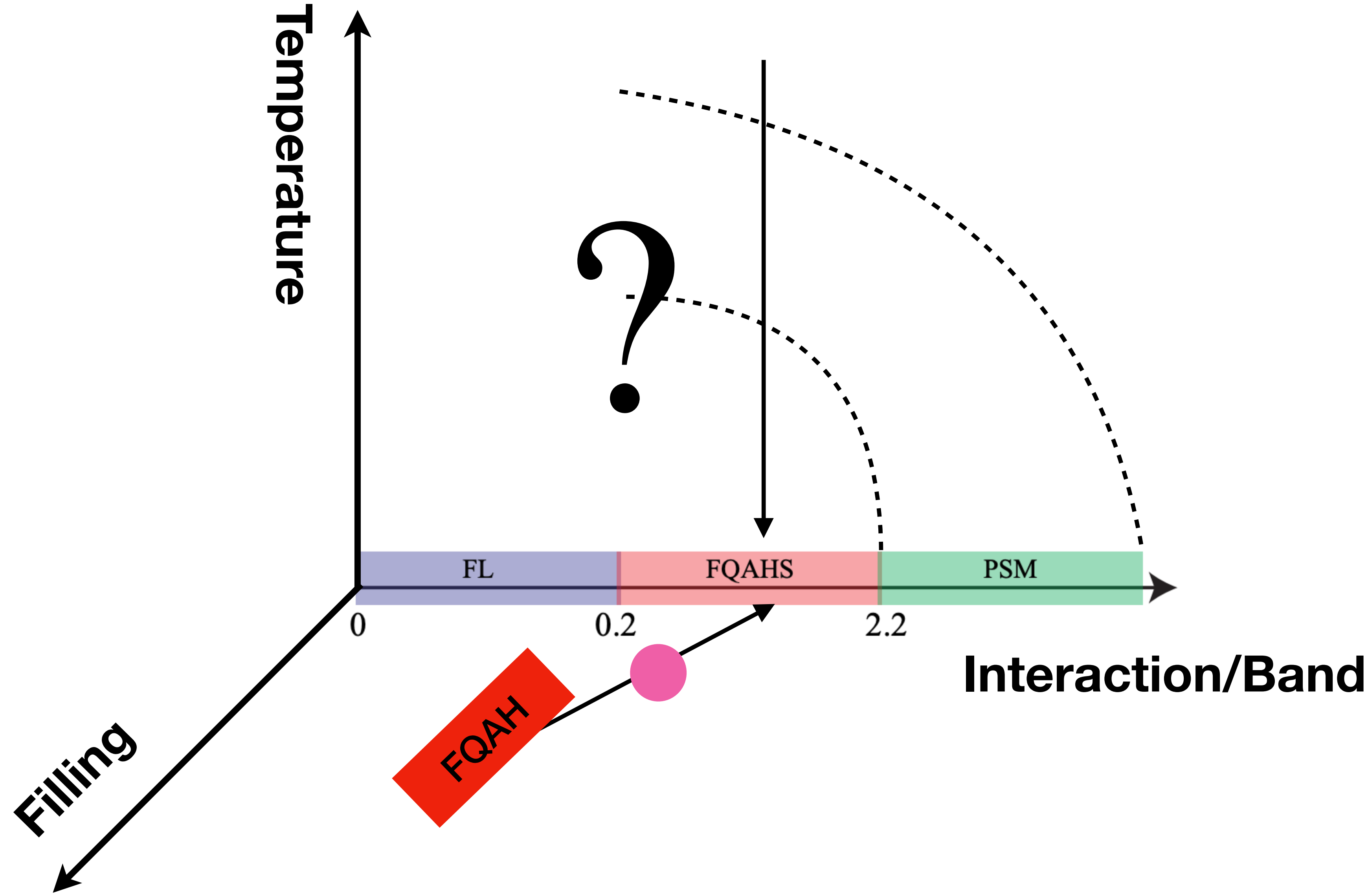


Emery, Fradkin, Kivelson, Lubensky, PRL 85, 2160 (2000)









More questions:

1. Different fractional fillings of correlated flat bands
2. Different lattice geometries
3. Different excitations: magnetoroton, geometric graviton
4. Different techniques: ED, DMRG, Tensor, QMC
5. Different experiments: transport, STM, thermal measurements
6. Different communities: FQH, Stripe, FCI, Intertwinement, Vestigial
7. ……

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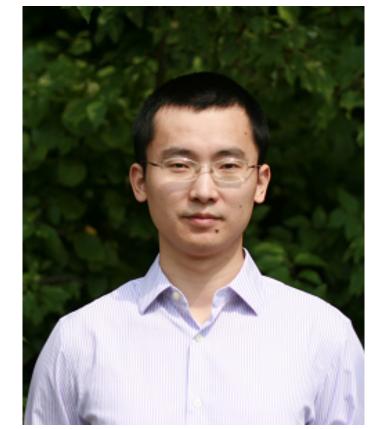

Poster on FCI-SF transition

arXiv:2408.07111

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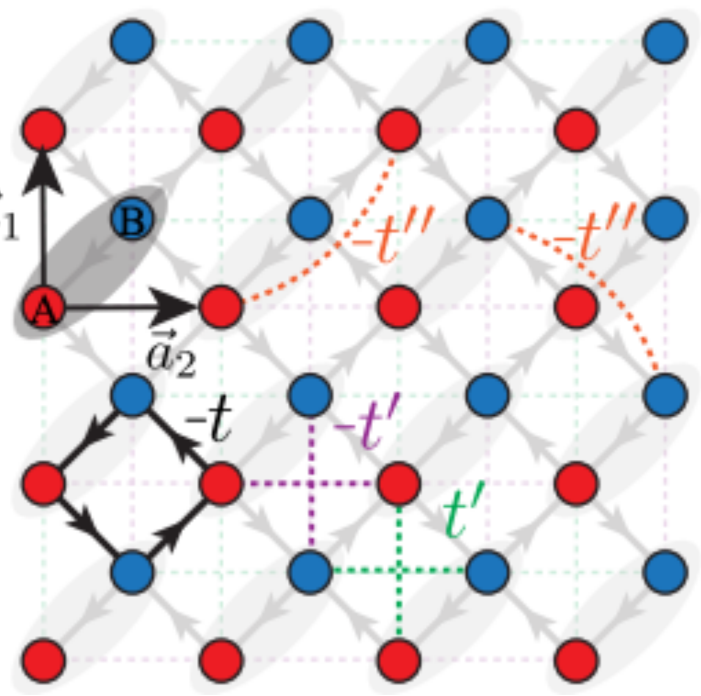
(a)



$$H = H_0 + H_I$$

$$H_0 = -t \sum_{\langle i,j \rangle} e^{i\phi_{ij}}(b_i^\dagger b_j + h.c.) - \sum_{\langle\langle i,j \rangle\rangle} t'_{ij}(b_i^\dagger b_j + h.c.) - t'' \sum_{\langle\langle\langle i,j \rangle\rangle\rangle} (b_i^\dagger b_j + h.c.)$$

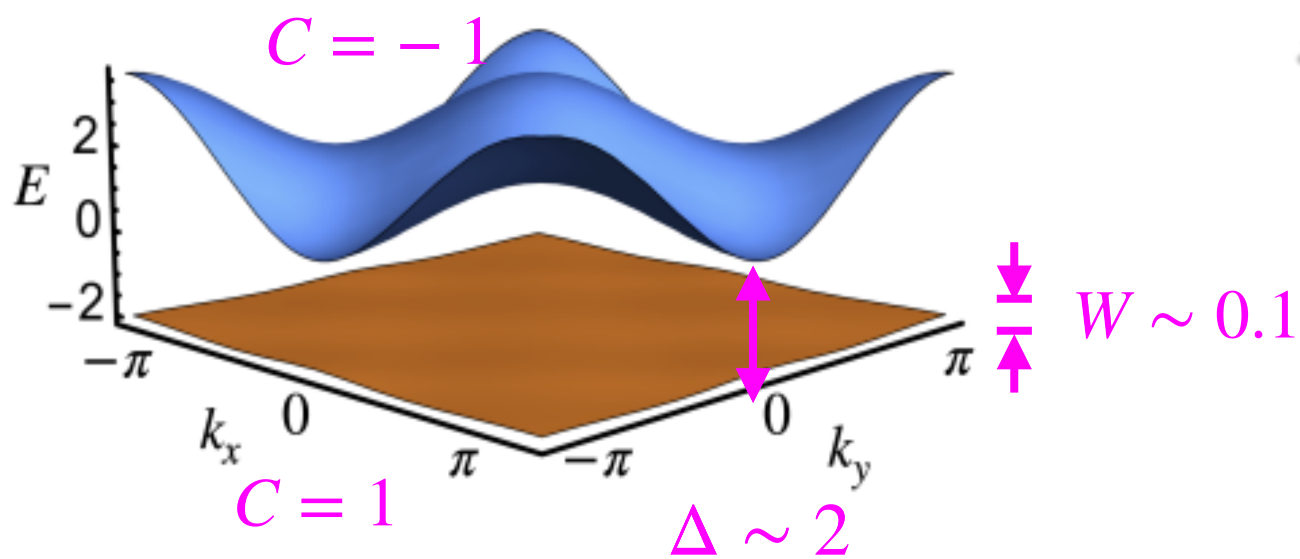
$$t = 1 \qquad t' = \pm \frac{1}{2+\sqrt{2}} \qquad t'' = -\frac{1}{2+2\sqrt{2}}$$

$$\phi_{ij} = \frac{\pi}{4}$$

$$H_I = V_1 \sum_{\langle i,j \rangle} n_i n_j + V_2 \sum_{\langle\langle i,j \rangle\rangle} n_i n_j$$

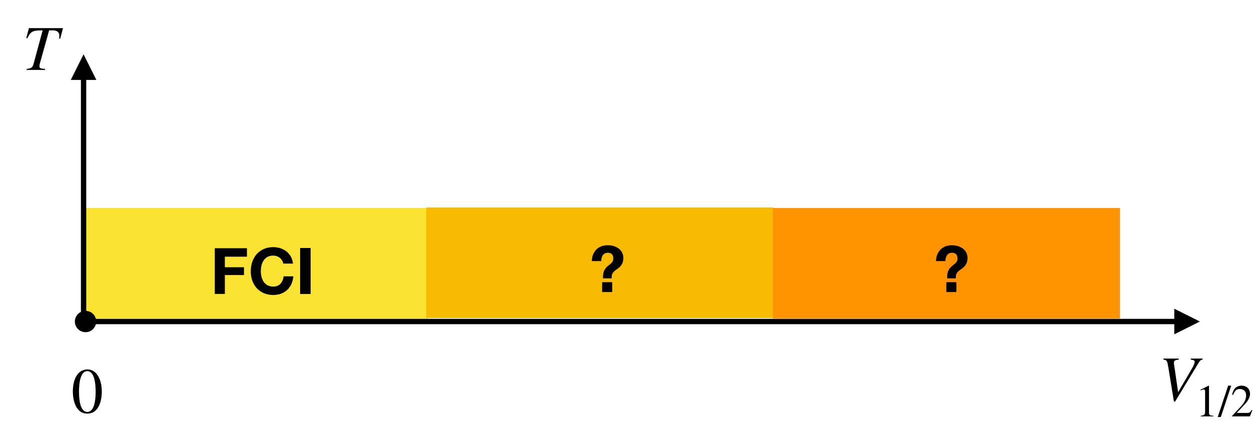
Hard-core boson and Consider filling factor of the flat band $\nu = 1/2$

(b)



Bosonic FCI at $V_1 = V_2 = 0$ limit

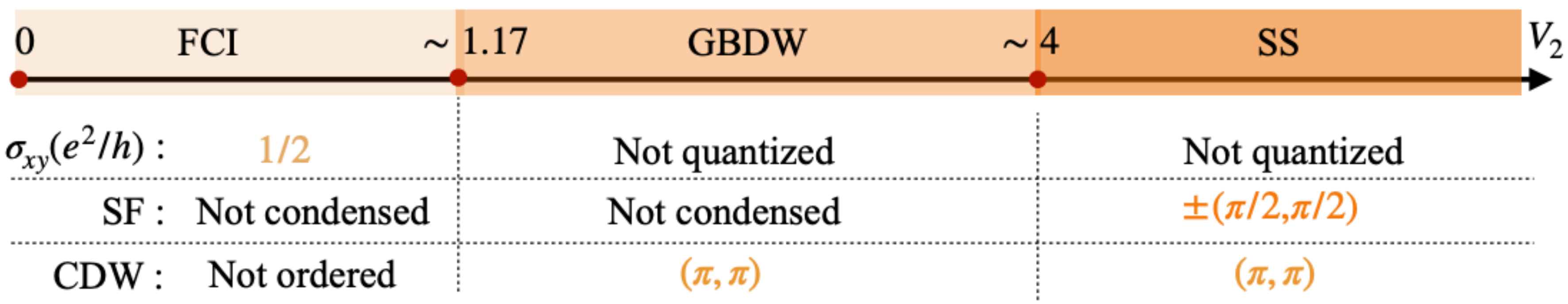
Y.-F. Wang, …, and D. N. Sheng, PRL 107, 146803 (2011)



Hongyu Lu et al., arXiv:2408.07111

$(V_1 = 1)$

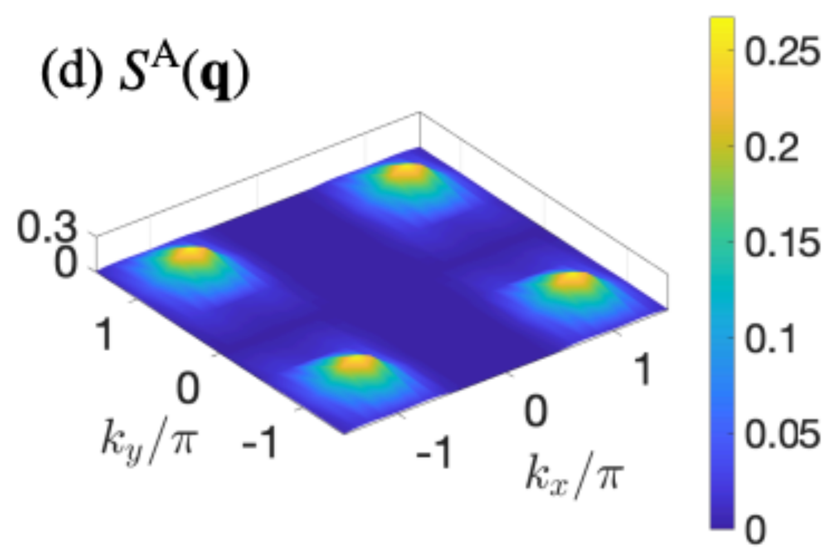
Hongyu Lu et al., arXiv:2408.07111

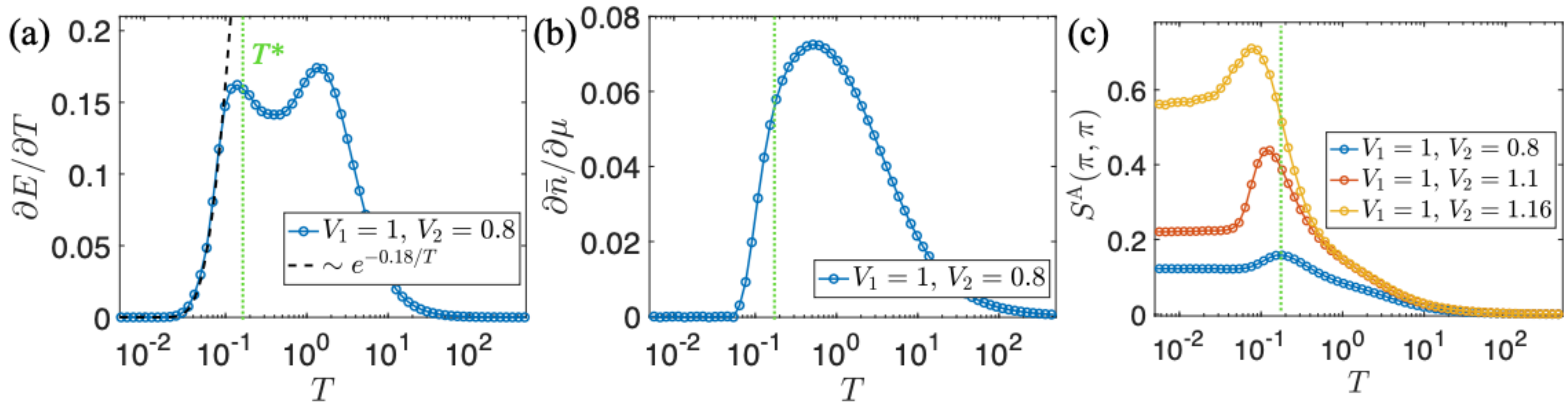


Boson FCI

$$S^{\alpha}(\mathbf{q}) = \frac{1}{N}\sum_{i,j} e^{-i\mathbf{q}\cdot\mathbf{r}_{i,j}}(\langle n_{i,\alpha}n_{j,\alpha}\rangle - \langle n_{i,\alpha}\rangle\langle n_{j,\alpha}\rangle)$$

Magnetoroton at (π, π)





$(V_1 = 1)$

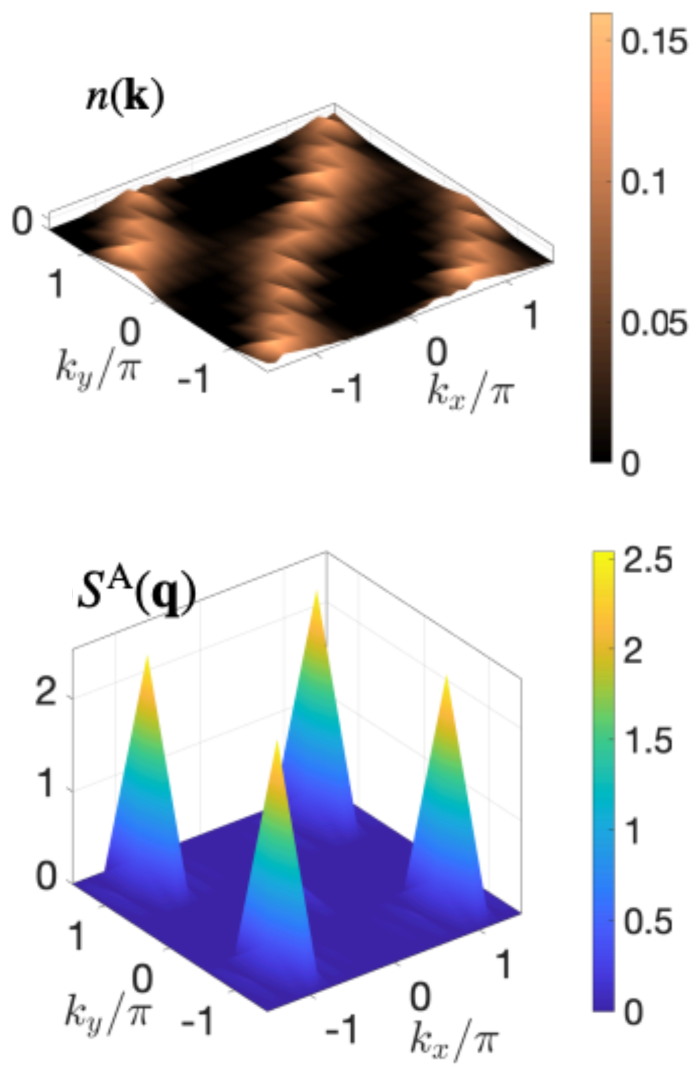
Hongyu Lu et al., arXiv:2408.07111

	FCI	GBDW	SS
$\sigma_{xy}(e^2/h)$:	1/2	Not quantized	Not quantized
SF :	Not condensed	Not condensed	$\pm(\pi/2, \pi/2)$
CDW :	Not ordered	(π, π)	(π, π)

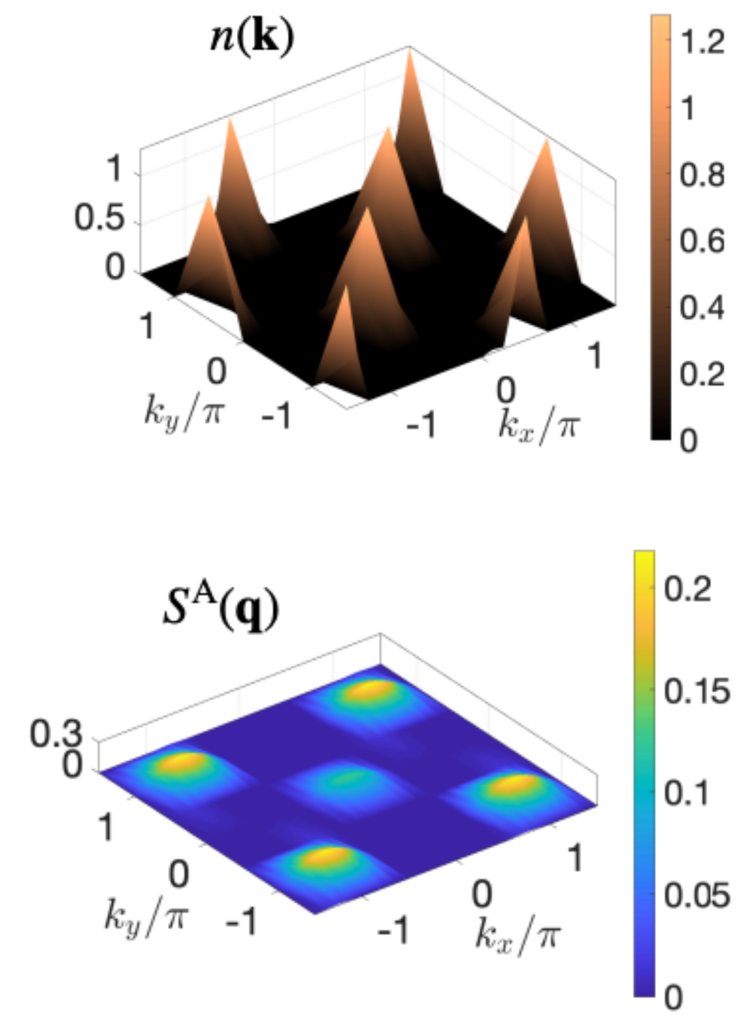
$$n(\mathbf{k}) = \frac{1}{2}\sum_{\alpha=A,B} n_\alpha(\mathbf{k}) = \frac{1}{N}\sum_{i,j} e^{-i\mathbf{k}\cdot\mathbf{r}_{i,j}}\langle b^\dagger_{i,\alpha} b_{j,\alpha}\rangle$$

$$S^\alpha(\mathbf{q}) = \frac{1}{N}\sum_{i,j} e^{-i\mathbf{q}\cdot\mathbf{r}_{i,j}}(\langle n_{i,\alpha} n_{j,\alpha}\rangle - \langle n_{i,\alpha}\rangle\langle n_{j,\alpha}\rangle)$$

Gapless boson density wave

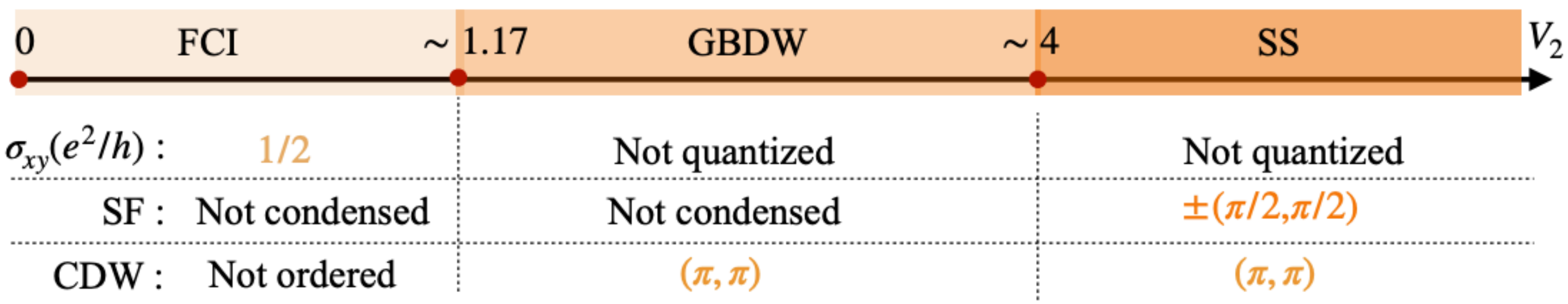


Supersolid

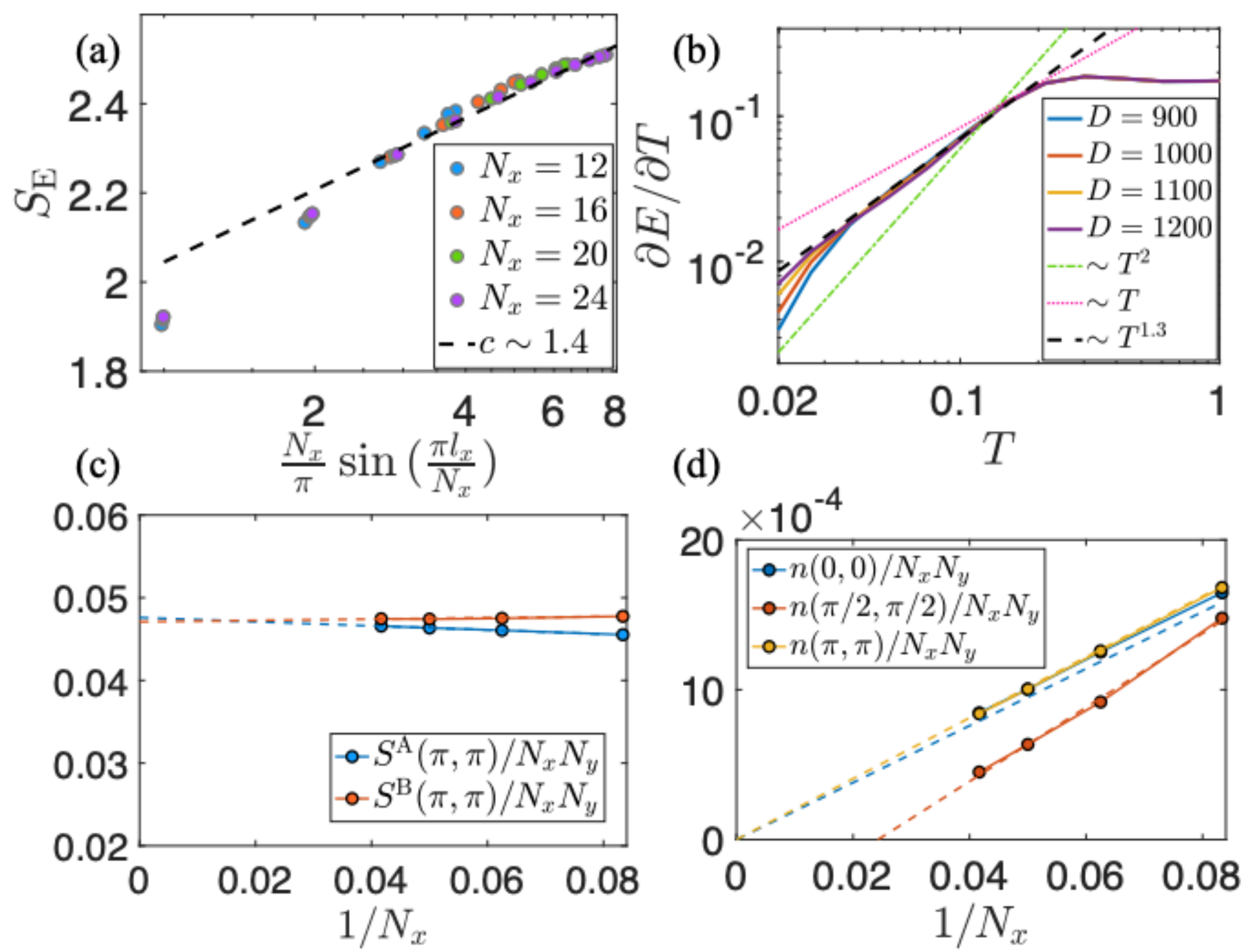


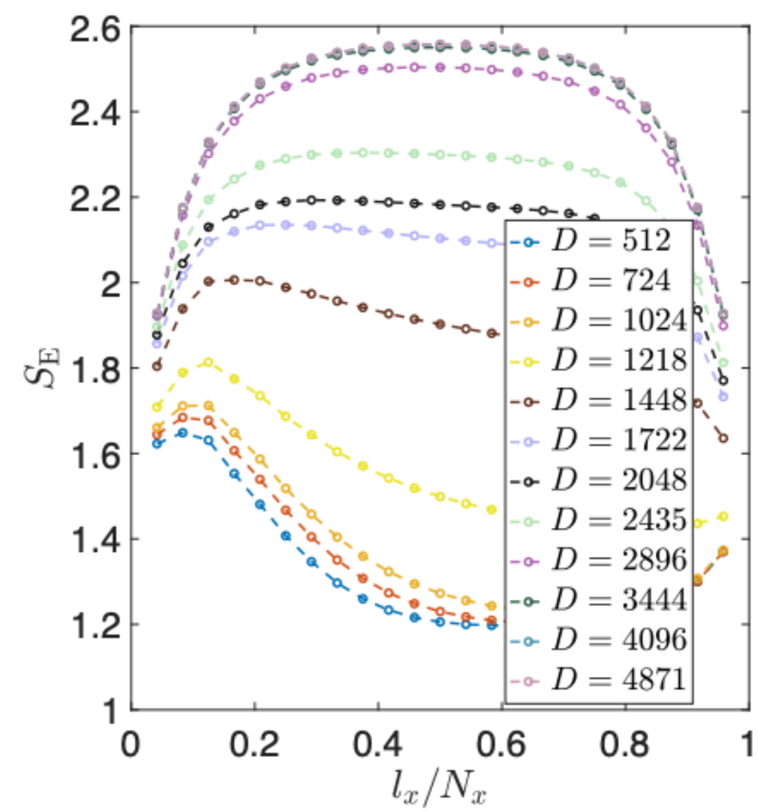
$(V_1 = 1)$

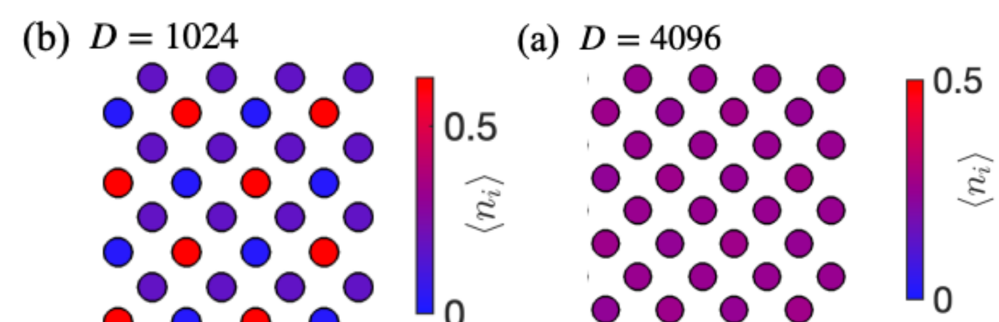
Hongyu Lu et al., arXiv:2408.07111



Gapless boson density wave

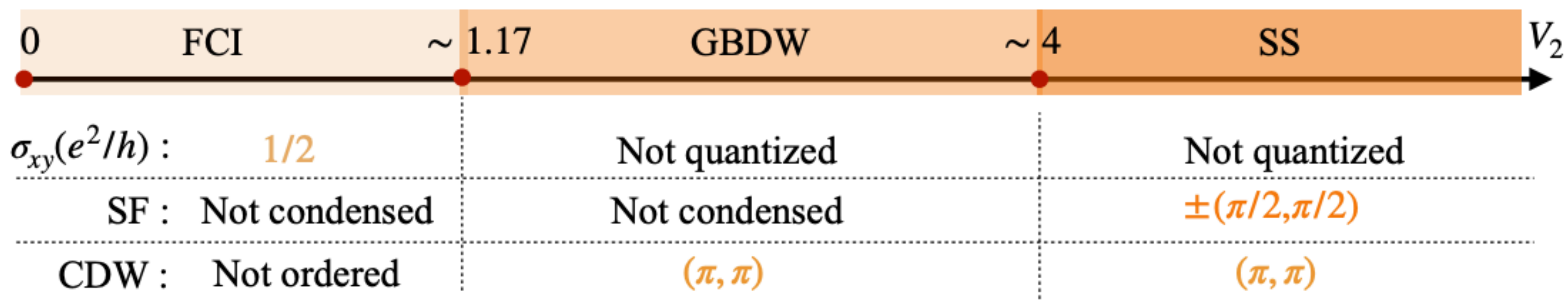




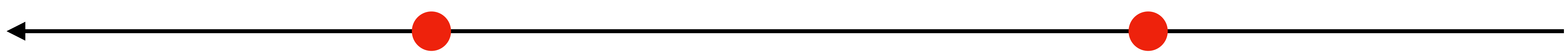


$(V_1 = 1)$

Hongyu Lu et al., arXiv:2408.07111



FCI | Gapless boson density wave | Supersolid



"Bose metal"

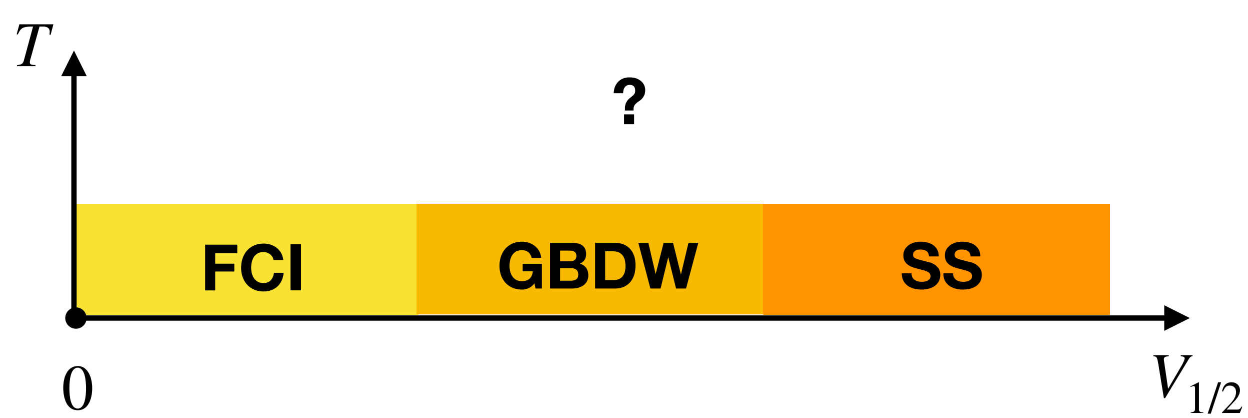
$\langle b_{\pm(\frac{\pi}{2},\frac{\pi}{2})} \rangle$

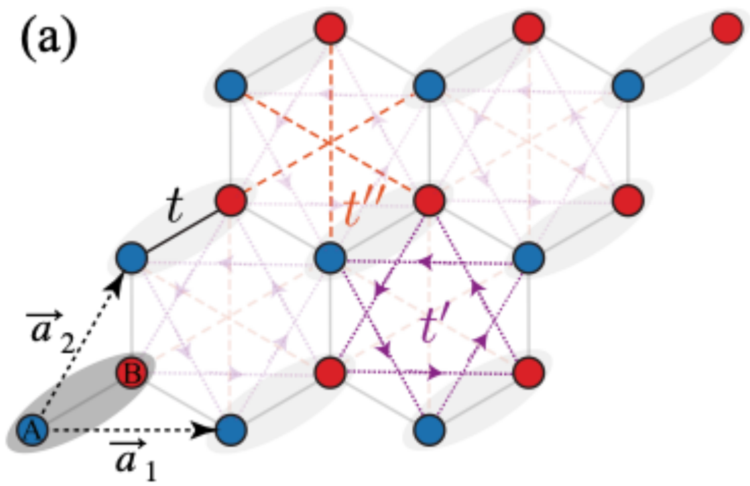
Topological order

$\langle \rho_{(\pi,\pi)} \propto b^\dagger_{(\frac{\pi}{2},\frac{\pi}{2})} b_{-(\frac{\pi}{2},\frac{\pi}{2})} \rangle$

$\langle \rho_{(\pi,\pi)} \propto b^\dagger_{(\frac{\pi}{2},\frac{\pi}{2})} b_{-(\frac{\pi}{2},\frac{\pi}{2})} \rangle$

Roton softening | **Vestigial / pair density wave transition**





$$H = H_0 + H_I$$

$$H_0 = -t \sum_{\langle i,j \rangle} (b_i^\dagger b_j + h.c.) - t' \sum_{\langle\langle i,j \rangle\rangle} (e^{i\phi} b_i^\dagger b_j + h.c.) - t'' \sum_{\langle\langle\langle i,j \rangle\rangle\rangle} (b_i^\dagger b_j + h.c.)$$

$t = 1$ $\quad t' = 0.6$ $\quad t'' = -0.58$

$\phi = 0.4\pi$

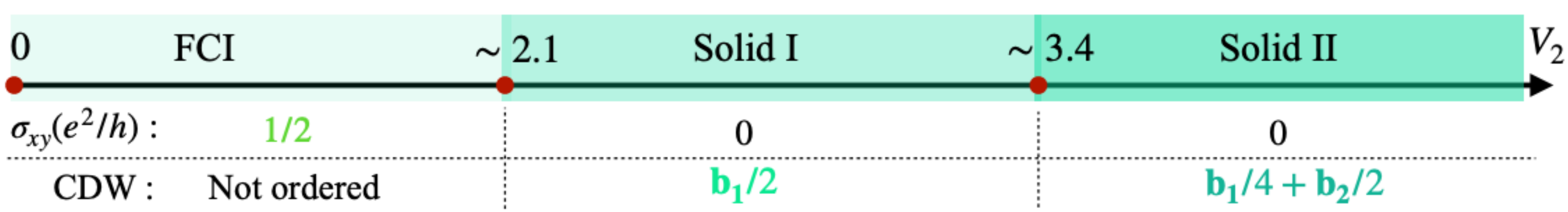
$$H_I = V_1 \sum_{\langle i,j \rangle} n_i n_j + V_2 \sum_{\langle\langle i,j \rangle\rangle} n_i n_j$$

Hard-core boson and Consider filling factor of the flat band $\nu = 1/2$

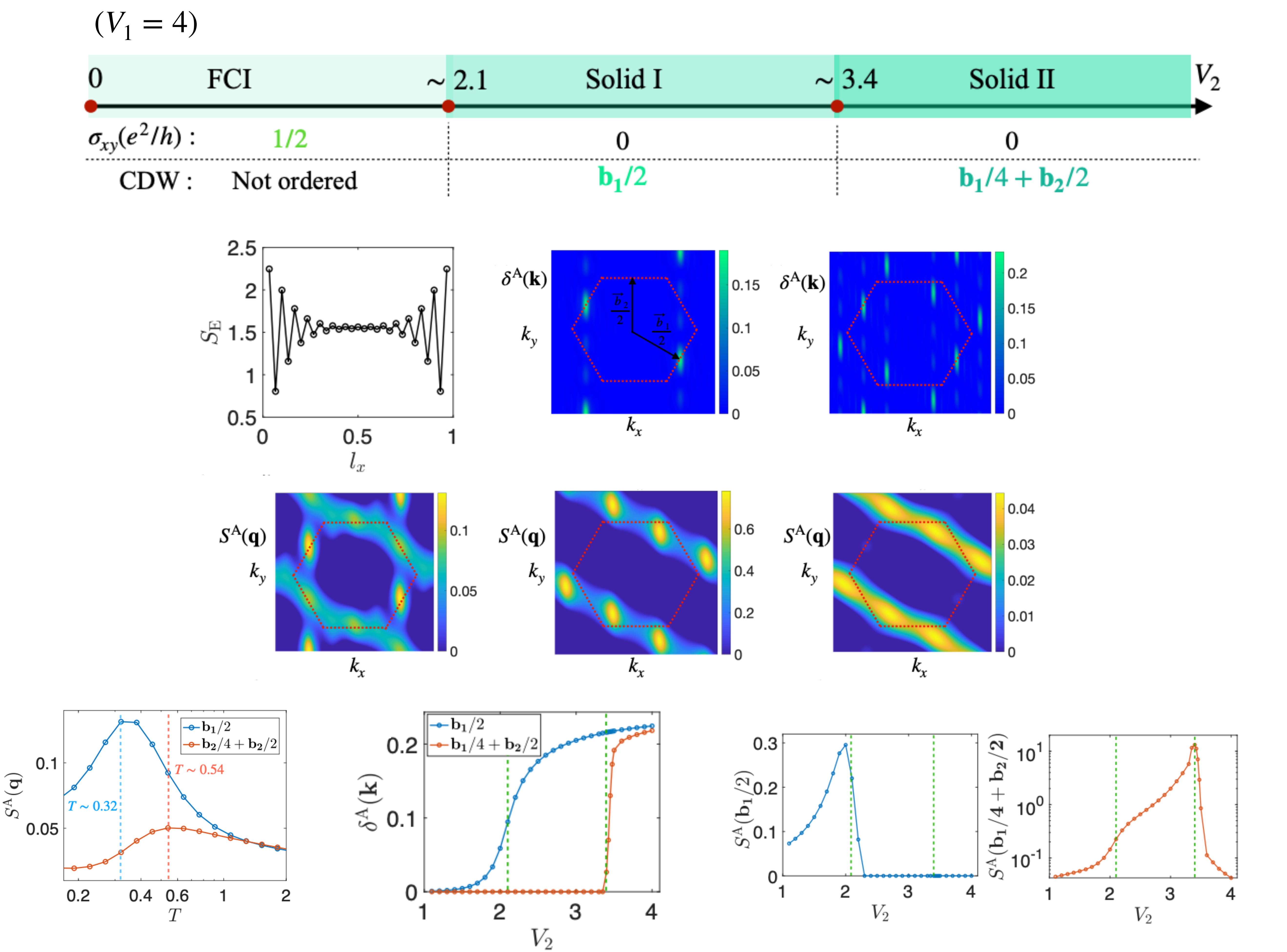
Bosonic FCI at $V_1 = V_2 = 0$ limit

- Y.-F. Wang, …, and D. N. Sheng, PRL 107, 146803 (2011)
- W.-W. Luo, …, and C.-D. Gong, PRB 102, 155120 (2020)

$(V_1 = 4)$



- Hongyu Lu et al., arXiv:2408.07111



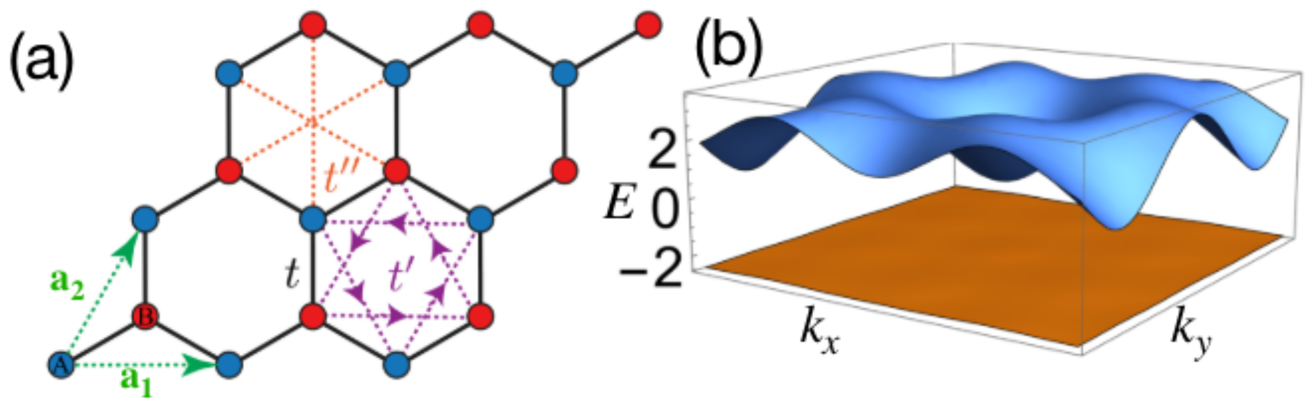
$(V_1 = 4)$
0
FCI
~ 2.1
Solid I
~ 3.4
Solid II
V_2
$\sigma_{xy}(e^2/h)$:
1/2
0
0
CDW :
Not ordered
$\mathbf{b_1}/2$
$\mathbf{b_1}/4 + \mathbf{b_2}/2$
S_E
l_x
$\delta^A(\mathbf{k})$
k_y
k_x
$S^A(\mathbf{q})$
$T \sim 0.32$
$T \sim 0.54$
T
$\mathbf{b_2}/4 + \mathbf{b_2}/2$
$S^A(\mathbf{b_1}/2)$
$S^A(\mathbf{b_1}/4 + \mathbf{b_2}/2)$

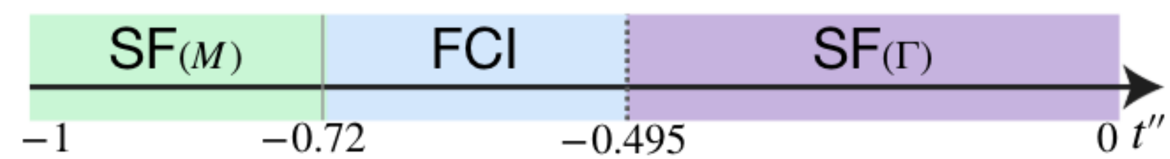
arXiv:2405.18269

Continuous Transition between Bosonic Fractional Chern Insulator and Superfluid

Hongyu Lu,[1] Han-Qing Wu,[2] Bin-Bin Chen,[1,*] and Zi Yang Meng[1,†]

Poster on FCI-SF transition

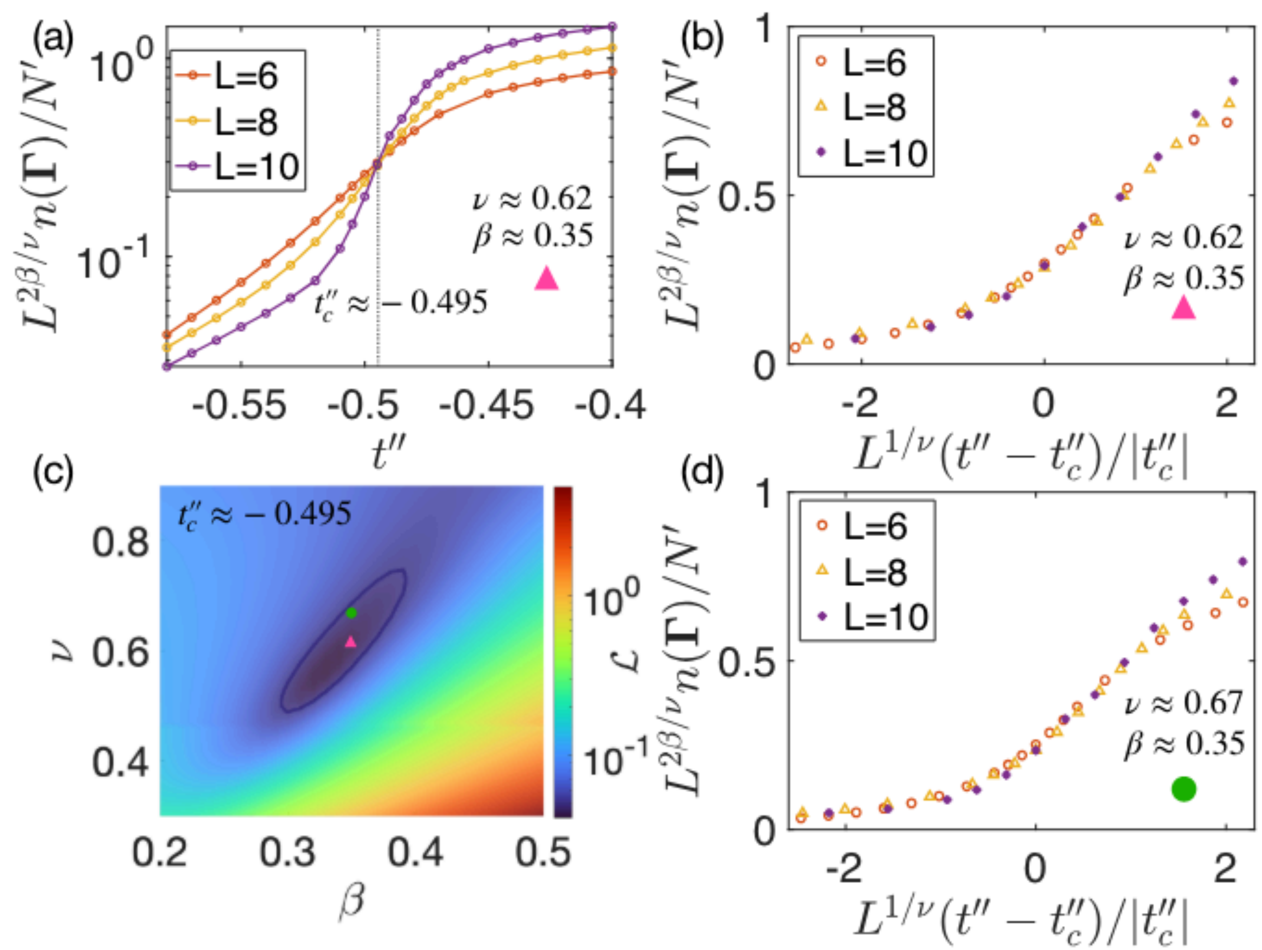


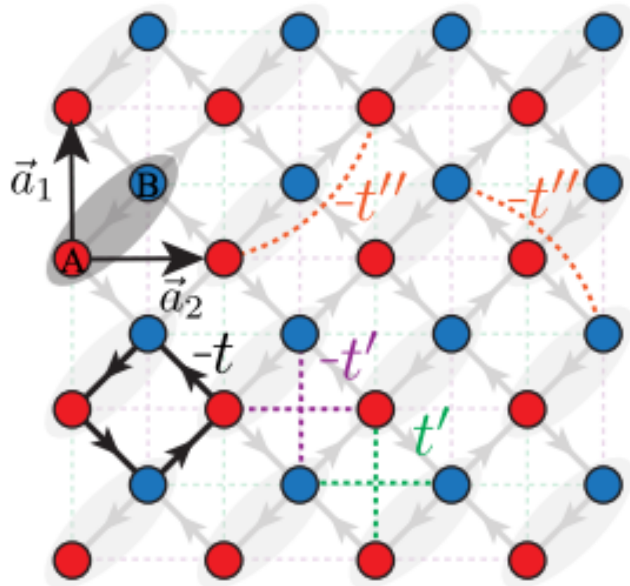


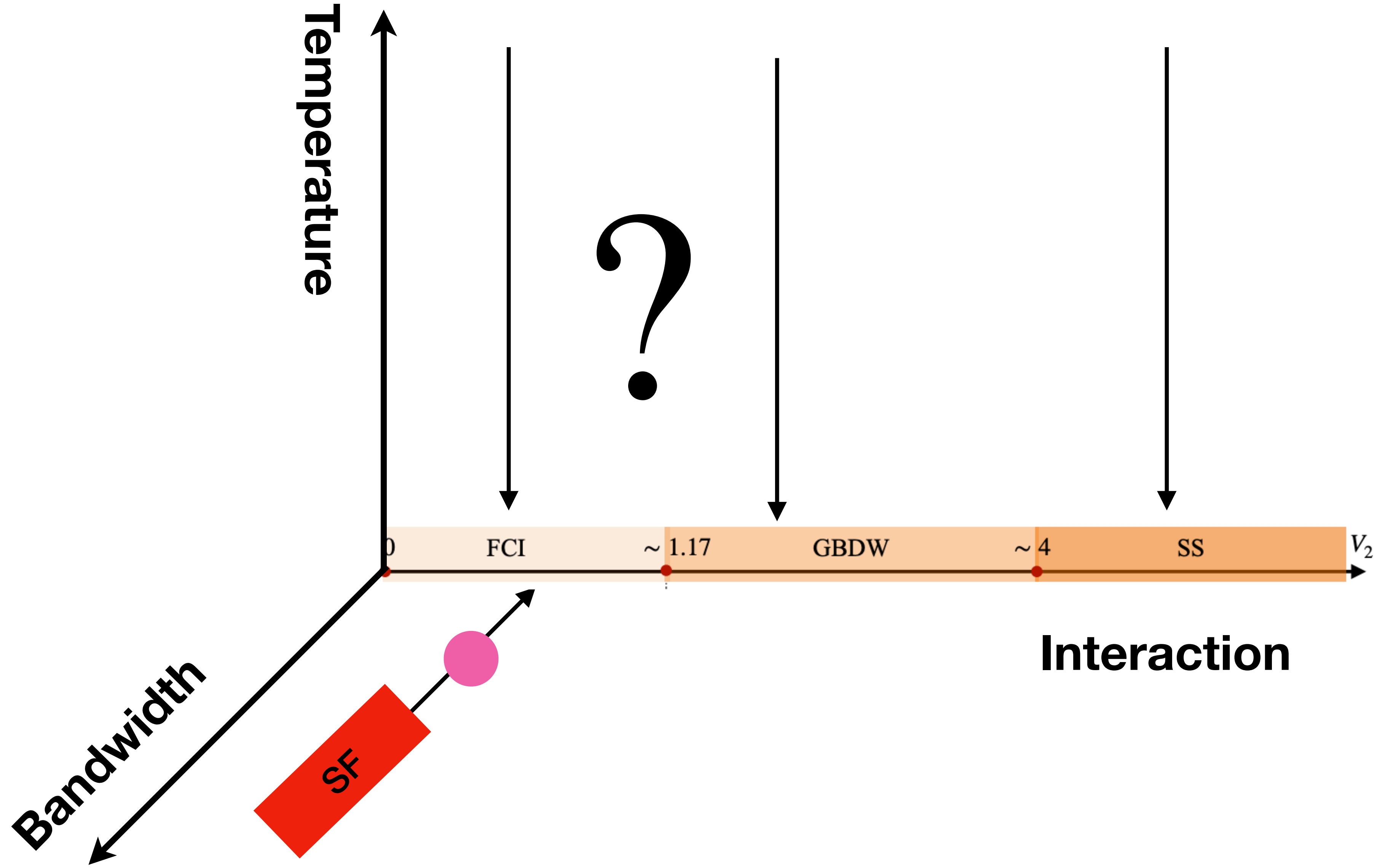
$$H = -\sum_{\langle i,j\rangle} t(b_i^\dagger b_j + \text{H.c.}) - \sum_{\langle\langle i,j\rangle\rangle} t'(e^{i\phi} b_i^\dagger b_j + \text{H.c.})$$
$$- \sum_{\langle\langle\langle i,j\rangle\rangle\rangle} t''(b_i^\dagger b_j + \text{H.c.}) + V_1 \sum_{\langle i,j\rangle} n_i n_j + V_2 \sum_{\langle\langle i,j\rangle\rangle} n_i n_j$$

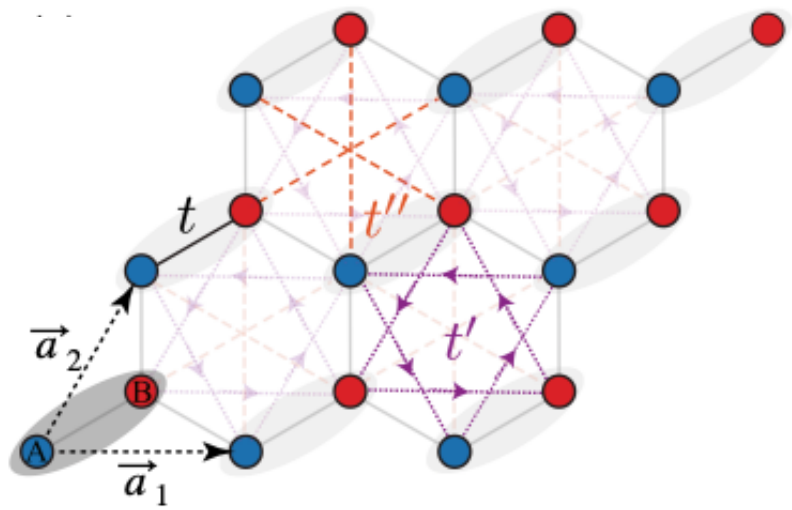
$t = 1 \quad t' = 0.6 \quad t'' = -0.58 \quad \phi = 0.4\pi$

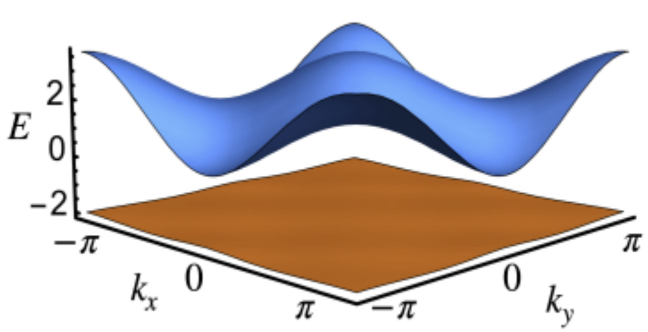
Hard-core boson $V_1 = V_2 = 0$











More questions:

1. Different fractional fillings of correlated flat bands
2. Different lattice geometries
3. Different excitations: magnetoroton, geometric graviton
4. Different techniques: ED, DMRG, Tensor, QMC
5. Different experiments: transport, STM, thermal measurements
6. Different communities: FQH, Stripe, FCI, Intertwinement, Vestigial
7. ……