A Tale of Two Reconstructions

Amartya Saha, Suman Jyoti De, Sumathi Rao, Yuval Gefen, & GM

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Acknowledgements

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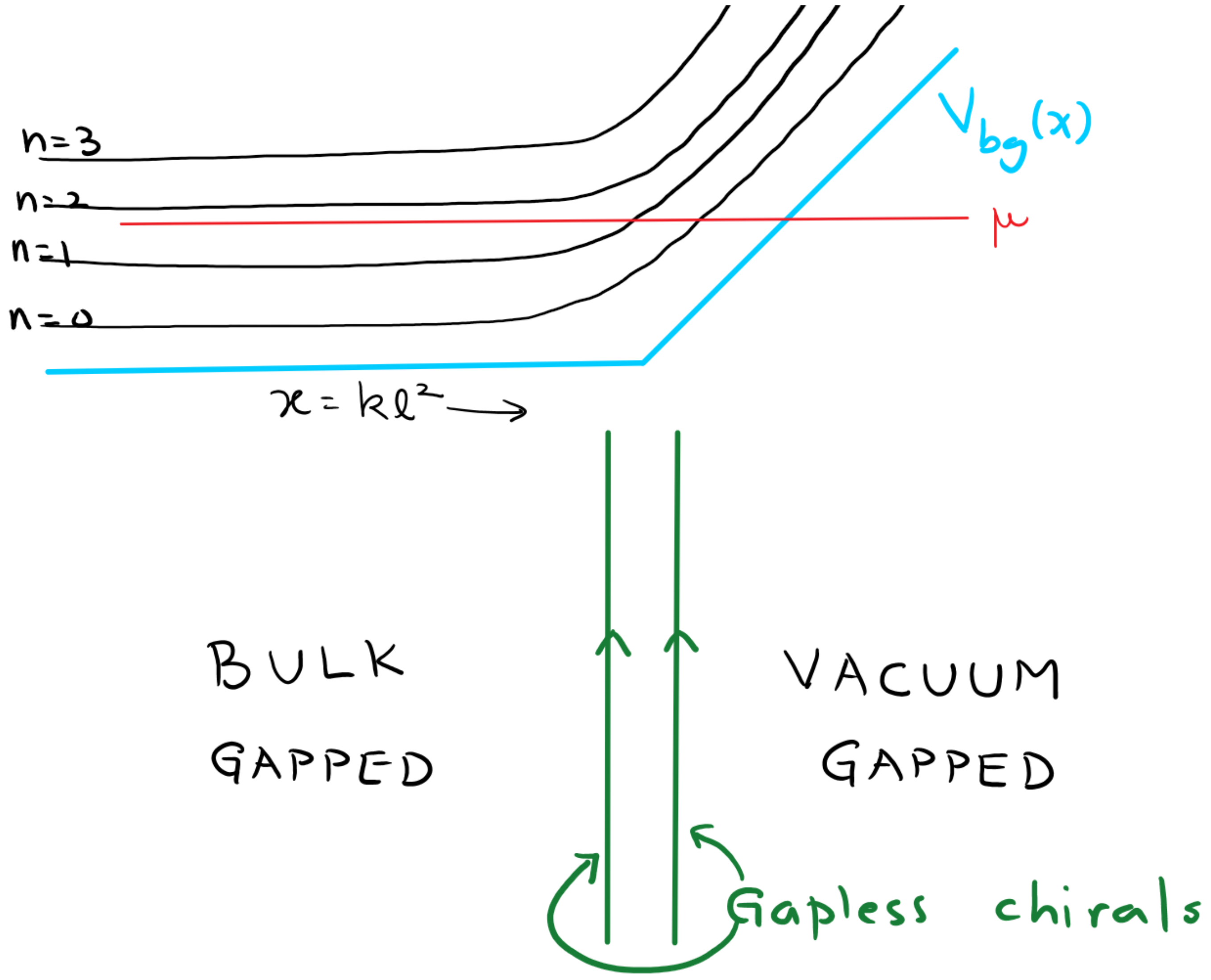
The first tale is joint with Amartya Saha, and the second is joint with Suman Jyoti De, Amartya Saha, Sumathi Rao, and Yuval Gefen.

Outline

- IQHE Edges.
- Reconstructions.
- Nu=1 revisited.
- The case of nu=2.
- Nu=2 revisited.
- A nu=4 to nu=3 edge.
- Conclusions and Open Questions.

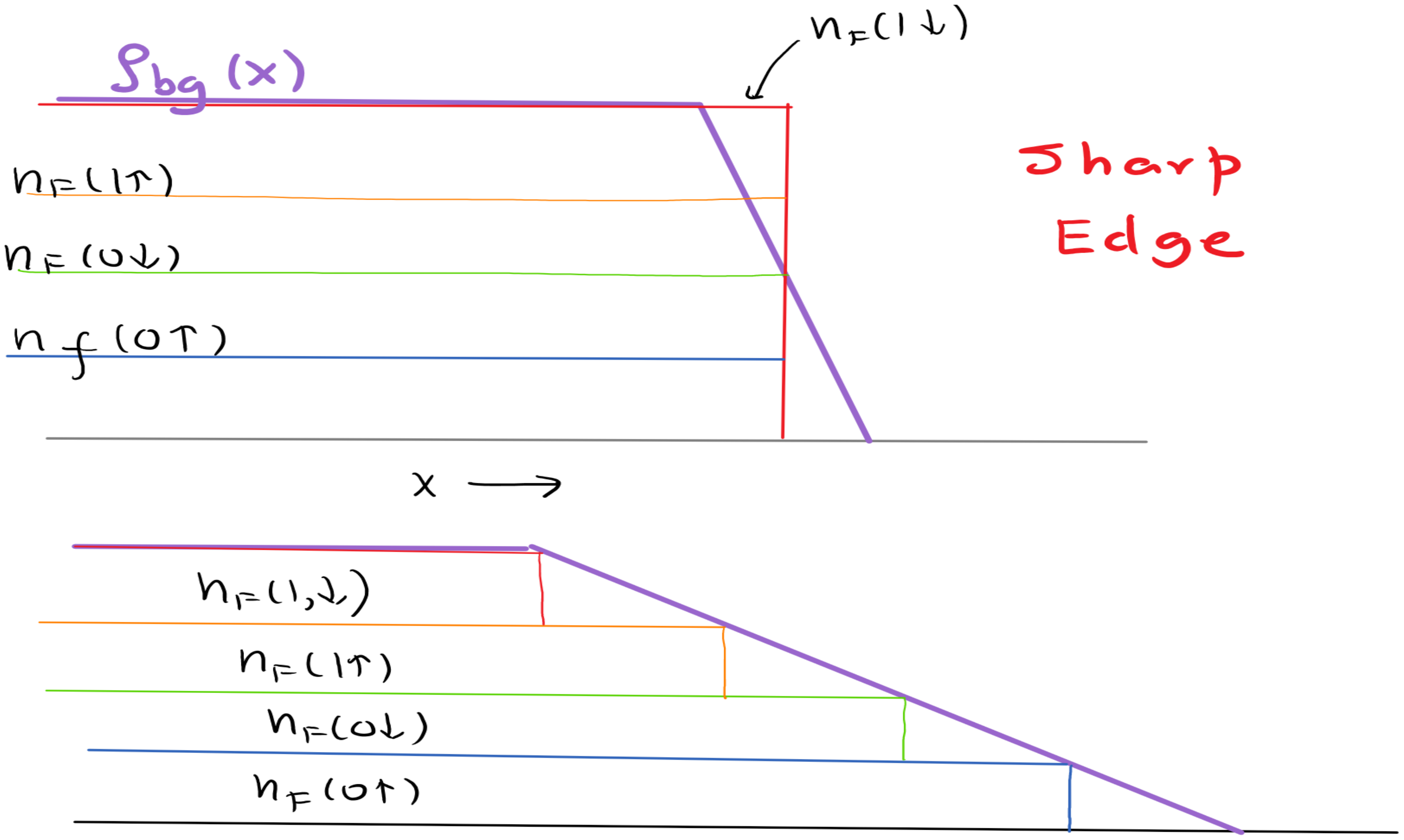
The Importance of IQHE Edges



The Importance of IQH edges

- The charge degrees of freedom are gapped in the bulk of a IQH sample.
- All transport at T=0 occurs at the edges, which consist of chiral edge modes. These can be either charged or neutral.
- Topological constraints dictate the charge conductance and the thermal conductance of the edge modes.
- Within these constraints, edge reconstructions can occur.

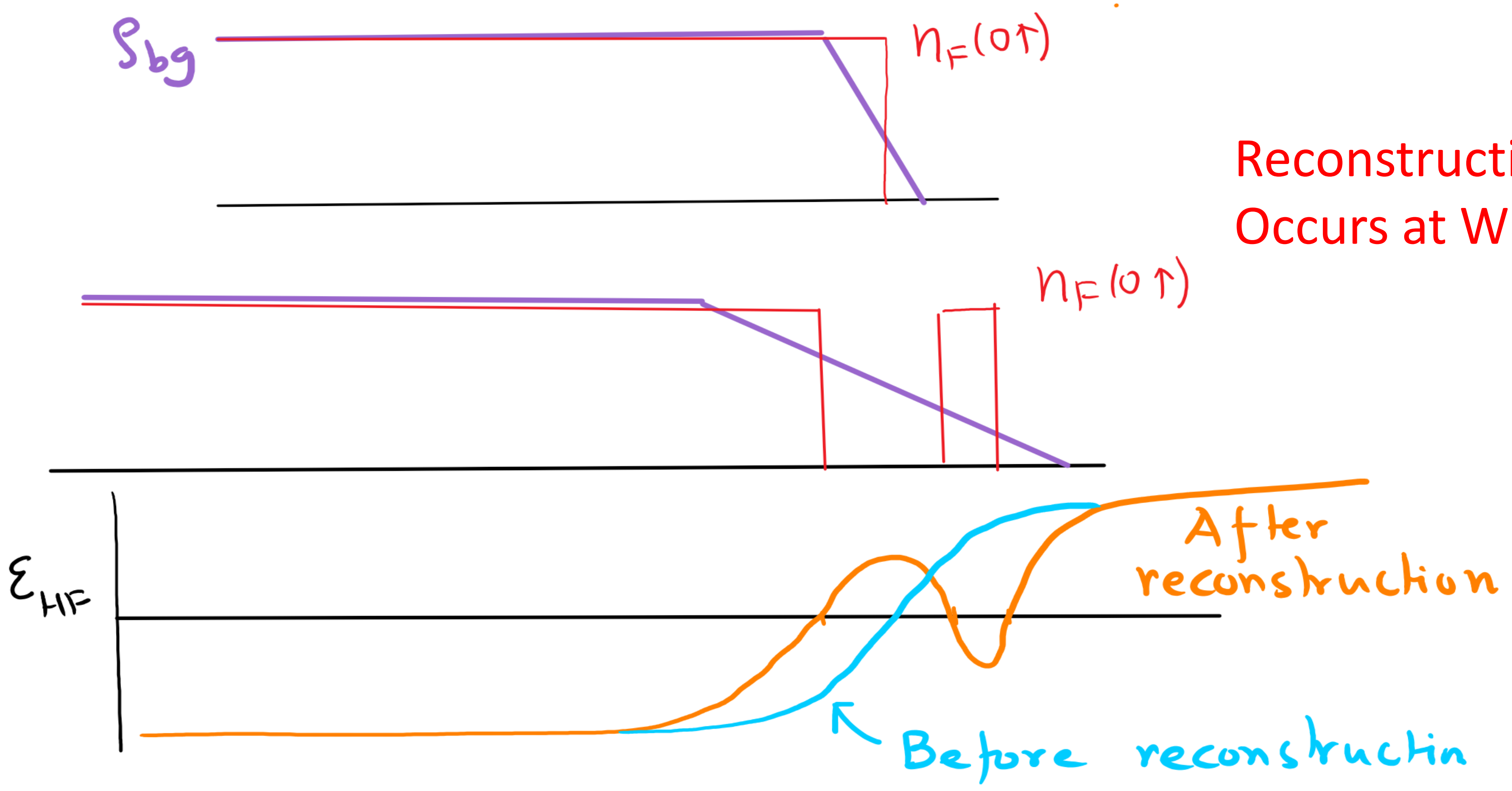
Edge Reconstructions



Edge Reconstructions

- The primary driver is electrostatics: The electron density wants to neutralize the background density. Chlovskii, Shklovskii, and Glazman 1992. Dempsey, Gelfand, and Halperin 1993.
- However, the electron liquid also wants to be at a gapped filling locally, so there is a competition between these two tendencies.
- More subtle effects occur in certain systems involving spin. Khanna, Murthy, Rao, and Gefen 2017.
- FQHE is even more challenging (MacDonald 1990 for 2/3, and many many works after).

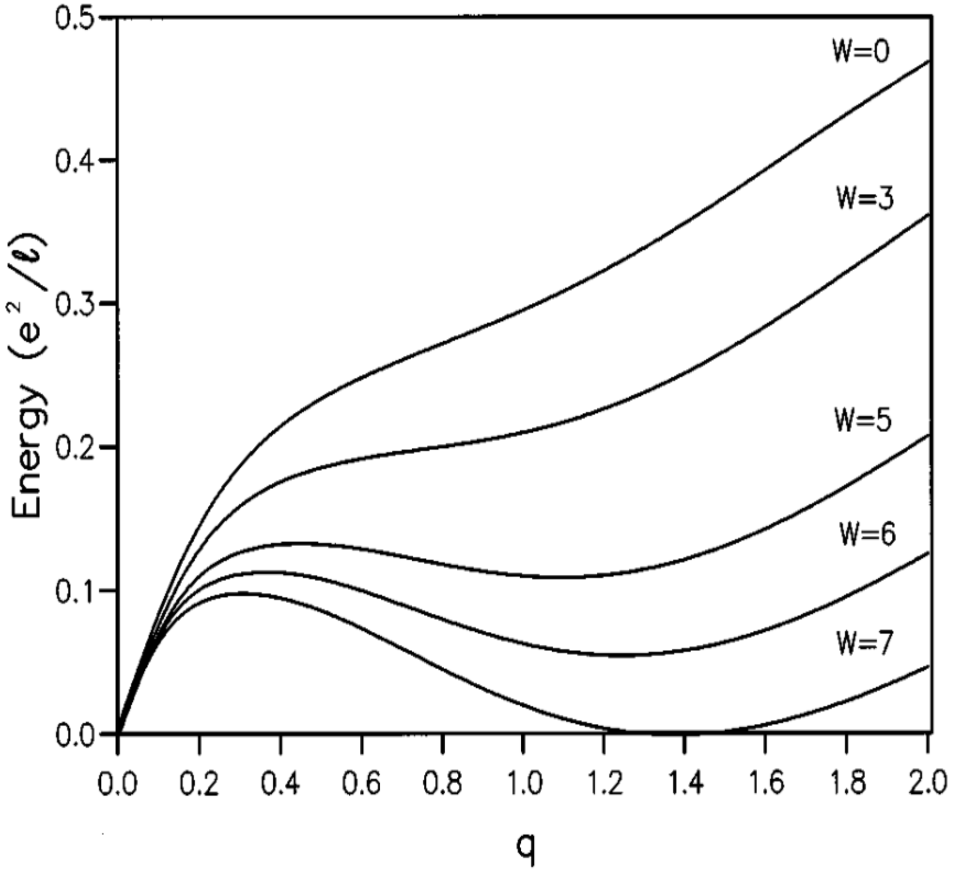
The case of nu=1. Chamon & Wen 1994

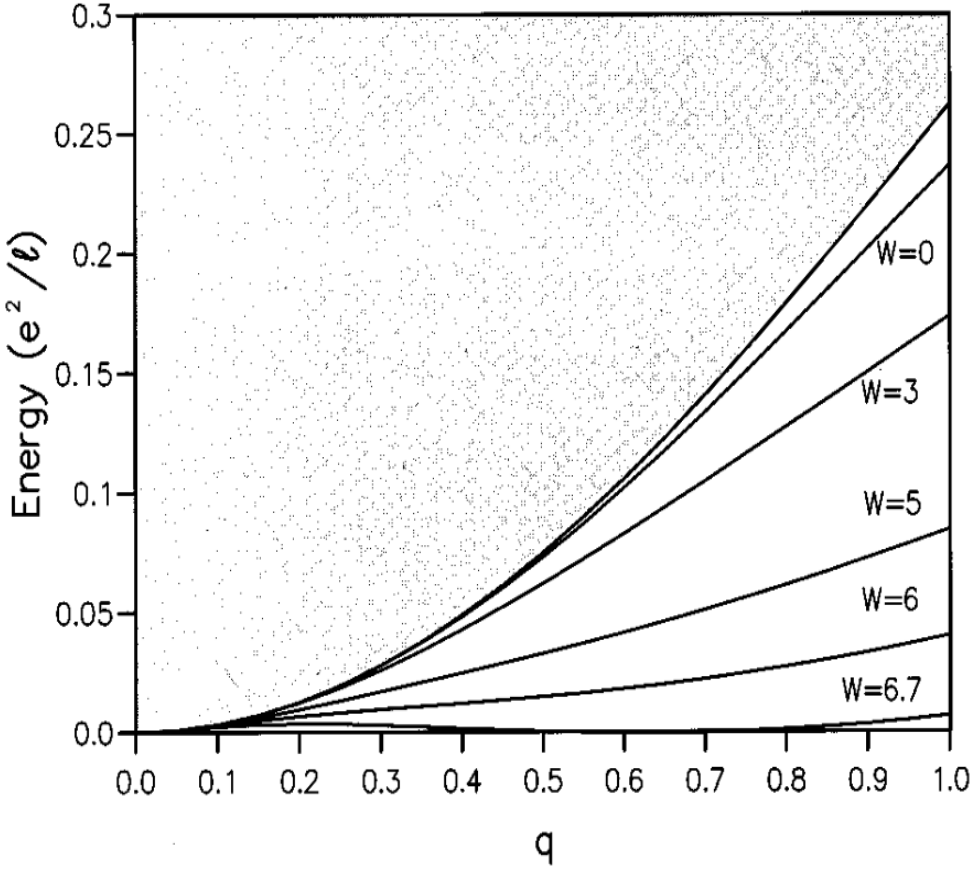


Reconstruction Occurs at W=11

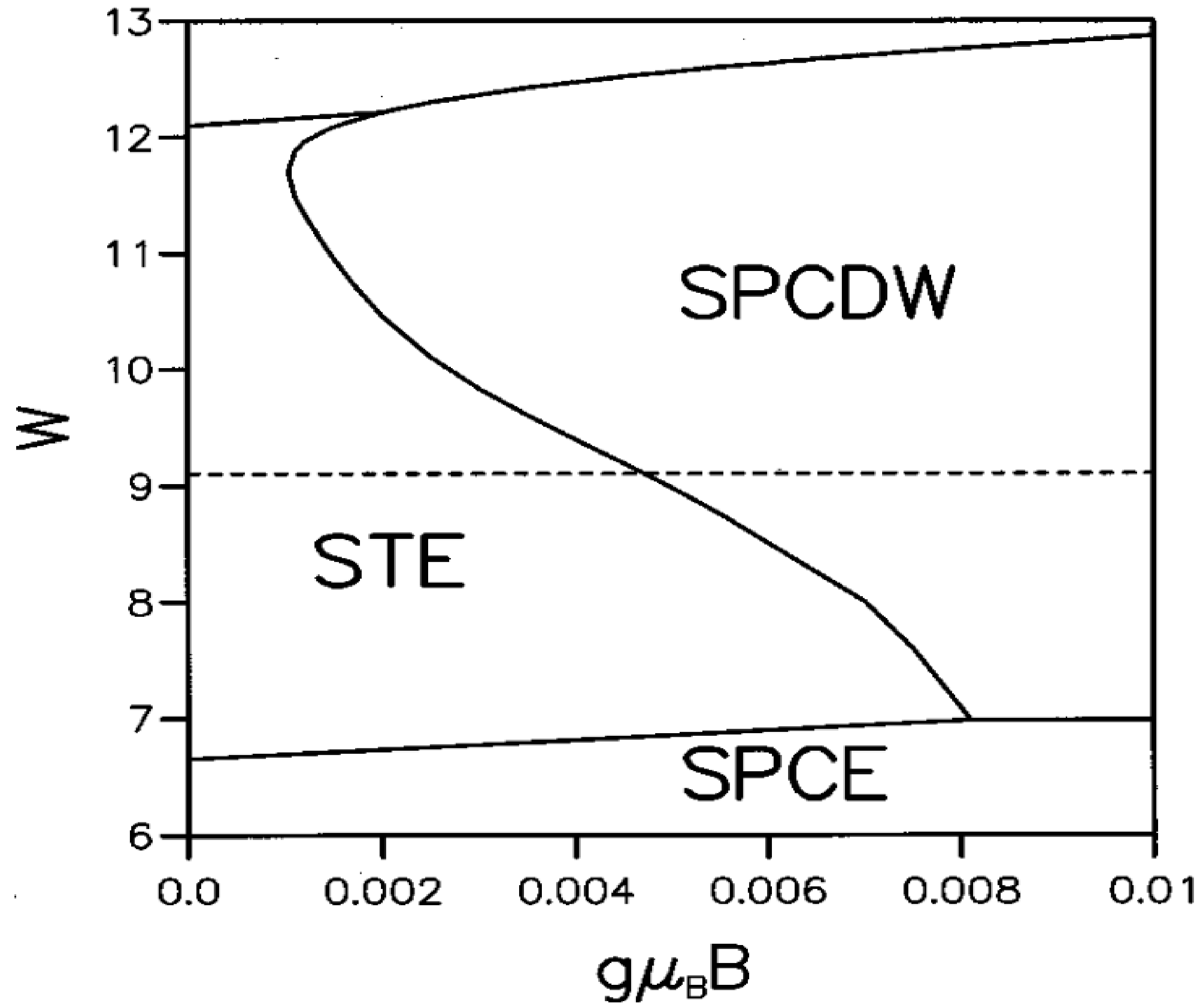
Revisiting nu=1: Franco & Brey 1997

Instabilities occur before the Chamon-Wen reconstruction



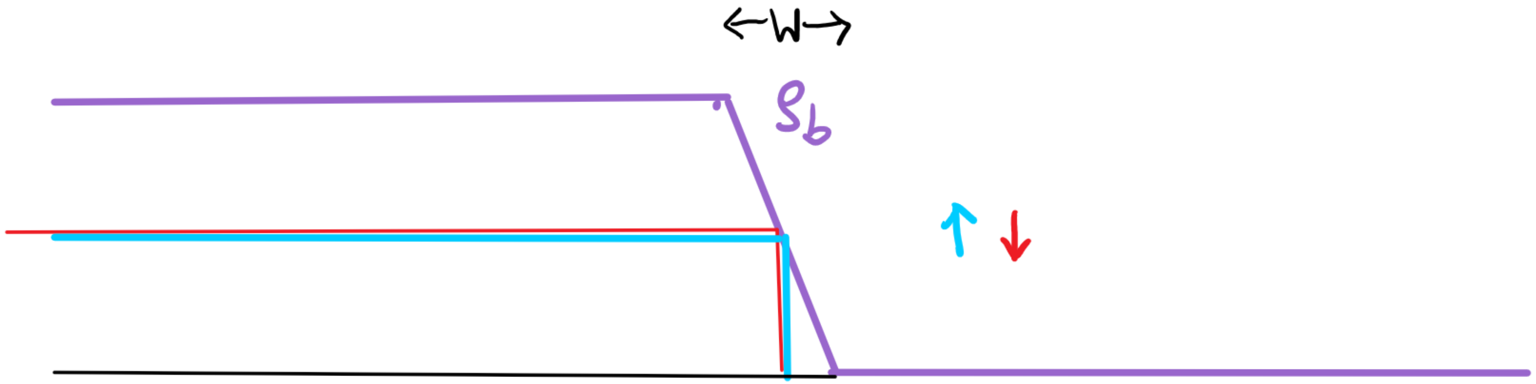


Franco & Brey's phase diagram

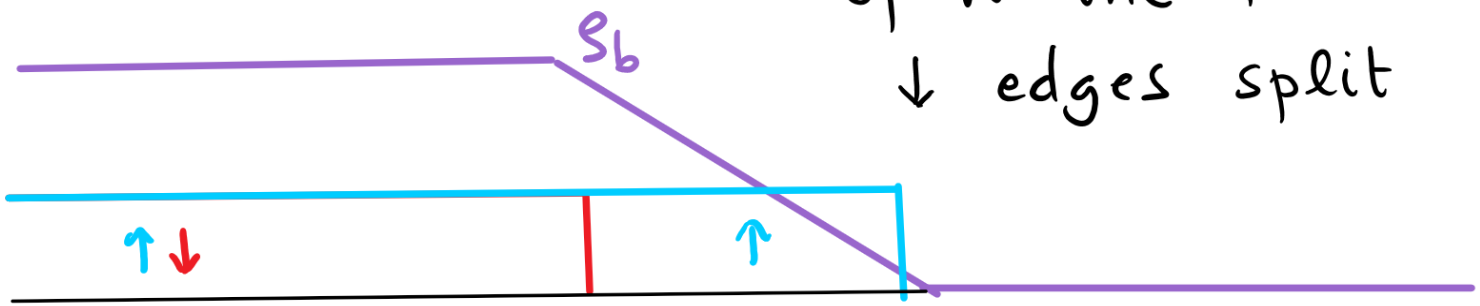


The case of nu=2

Dempsey, Gelfand & Halperin 1993

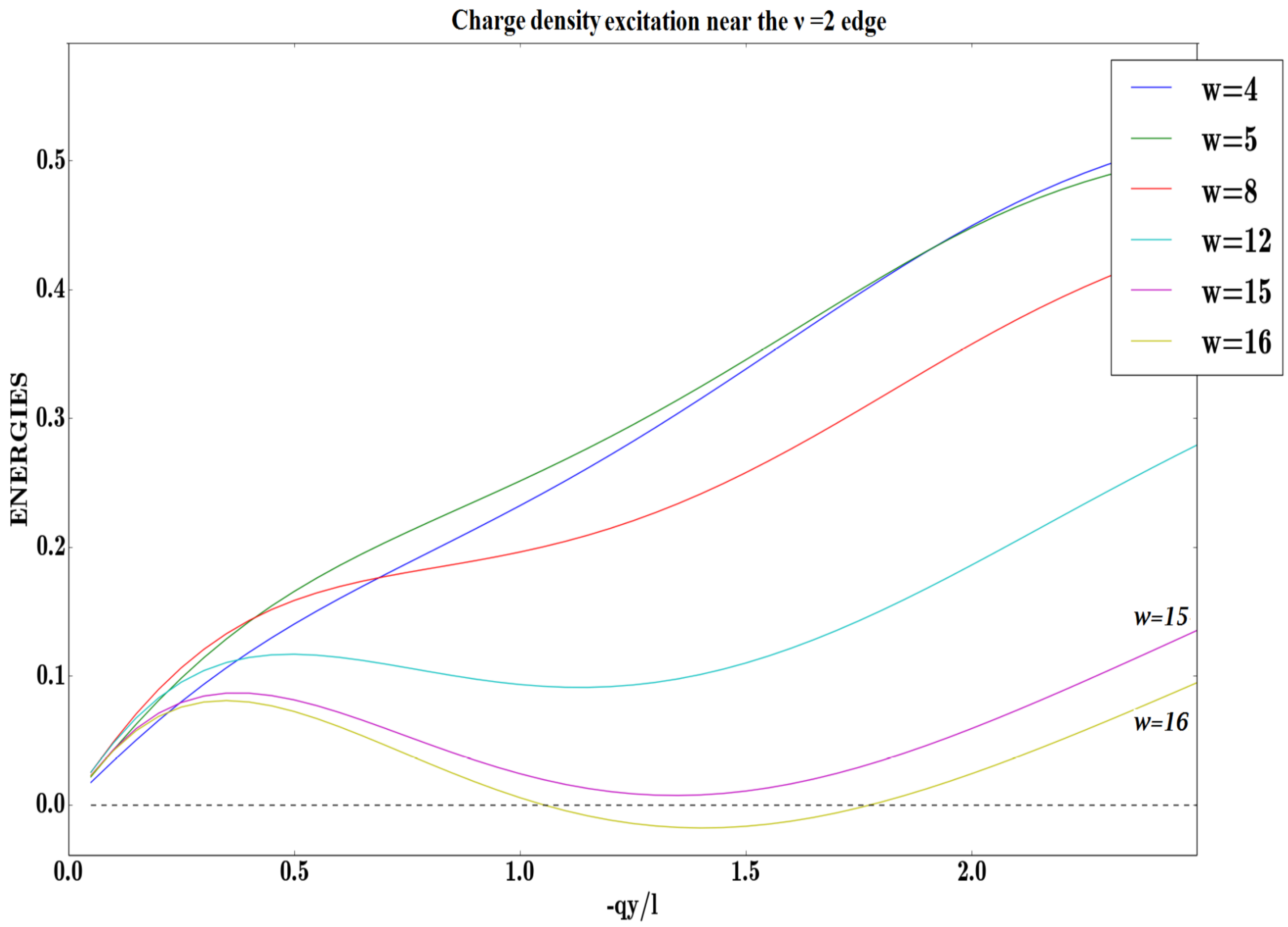


At a critical value of W the ↑ and ↓ edges split

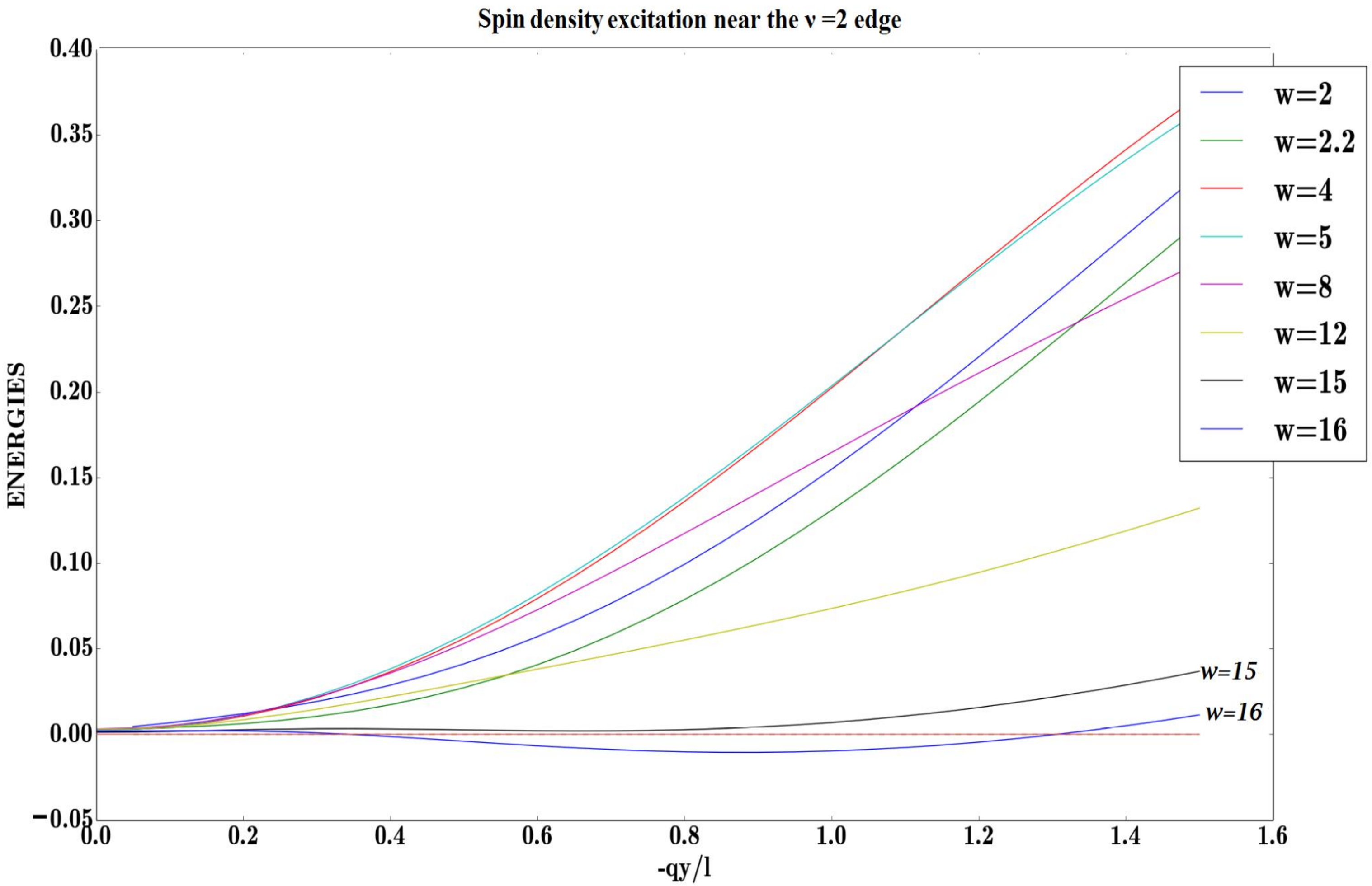


The First Tale (with Amartya Saha)

- Just as Franco and Brey asked, we ask whether the DGH reconstruction is stable by computing the collective excitations of both spin and charge. Beyond some large W (approx. 16) they are unstable.
- When the DGH reconstruction is unstable, we look for a Hartree-Fock solution which breaks translation invariance along the edge.
- We obtain two different such states. In Phase 2, the spin density is breaks translations but the charge density does not. In Phase 3, both break translations.

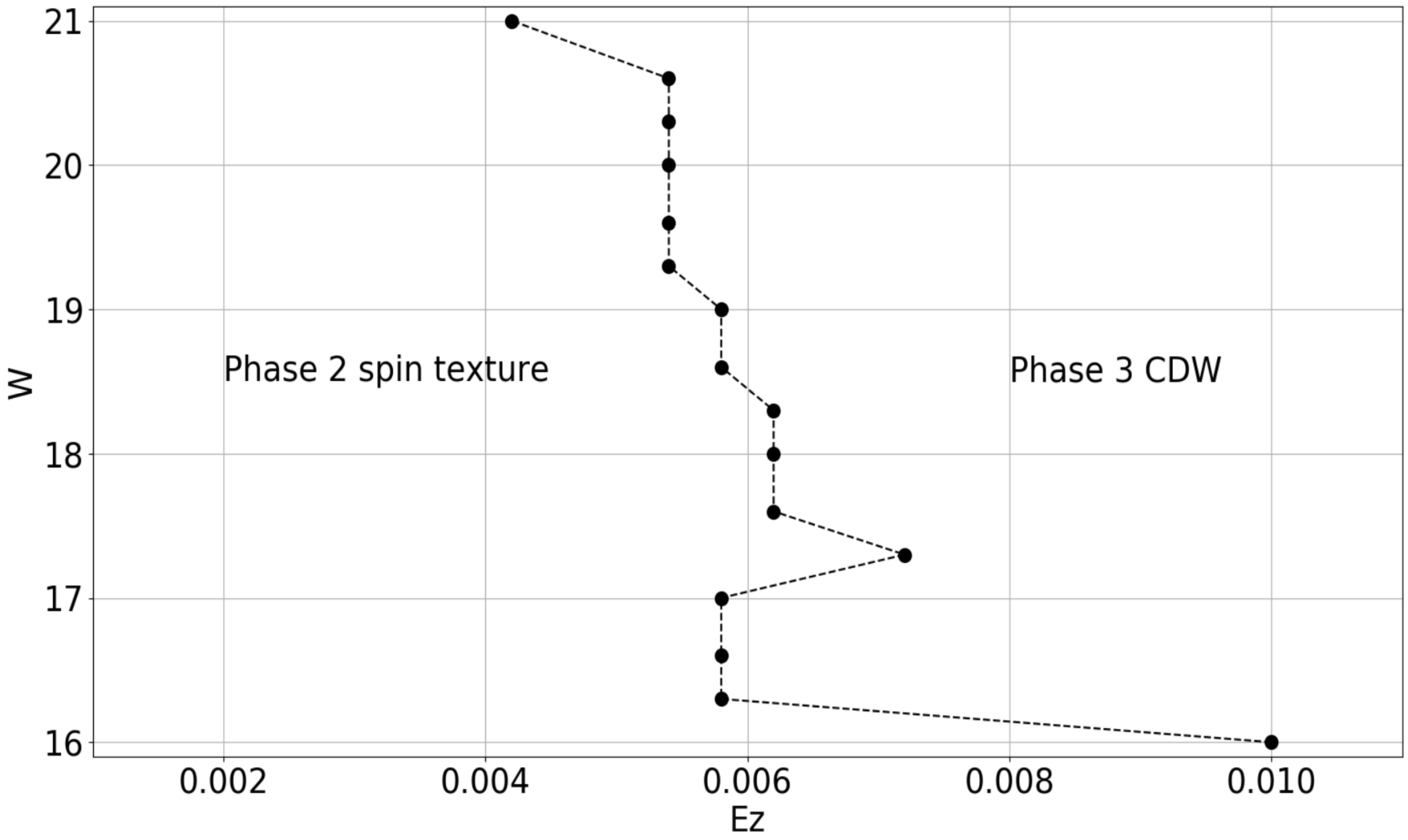


Charge density excitation near the ν =2 edge
ENERGIES
-qy/l
0.0
0.1
0.2
0.3
0.4
0.5
0.0
0.5
1.0
1.5
2.0
w=4
w=5
w=8
w=12
w=15
w=16
w=15
w=16

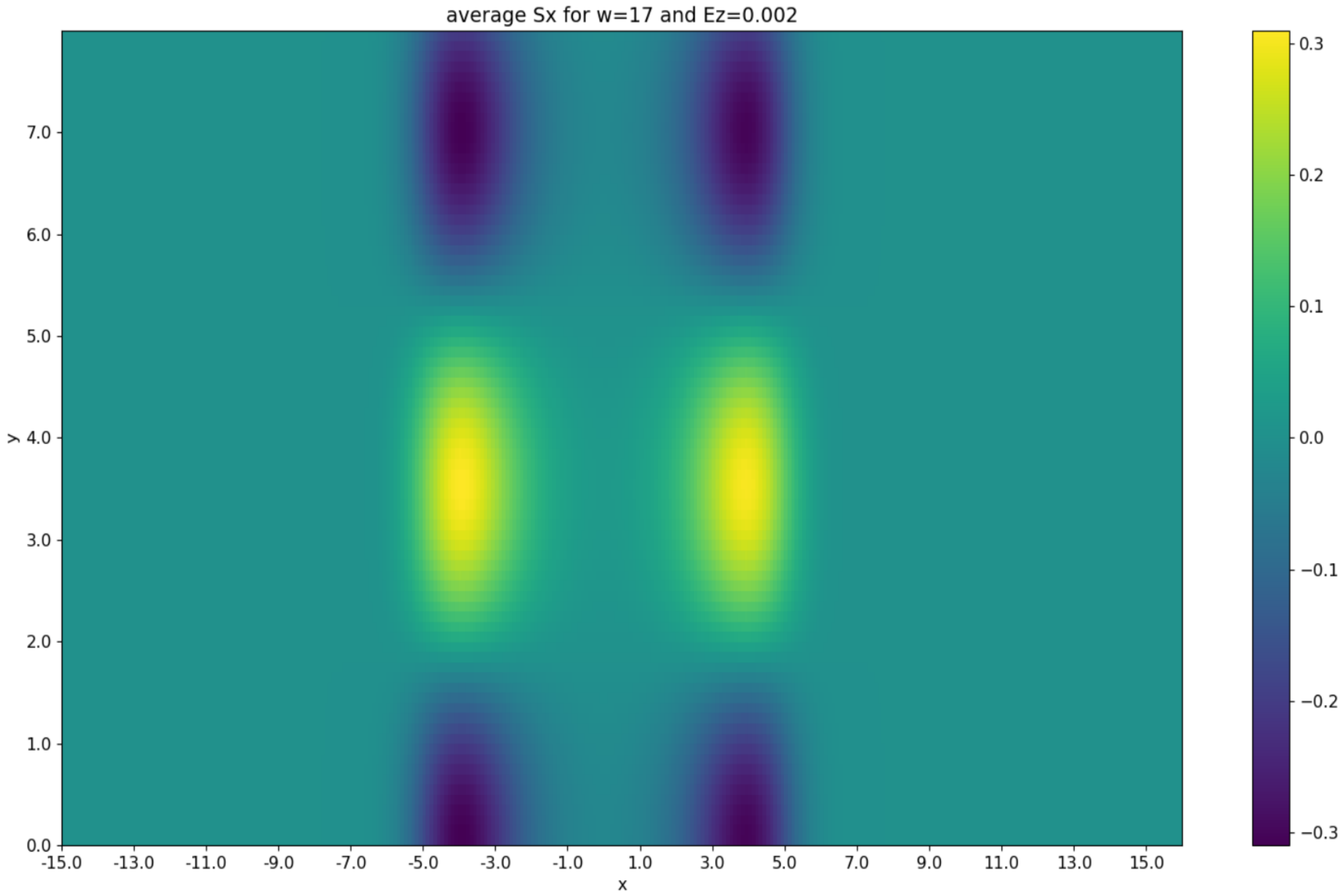


Spin density excitation near the ν =2 edge
ENERGIES
-qy/l
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
−0.05
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
w=2
w=2.2
w=4
w=5
w=8
w=12
w=15
w=16
w=15
w=16

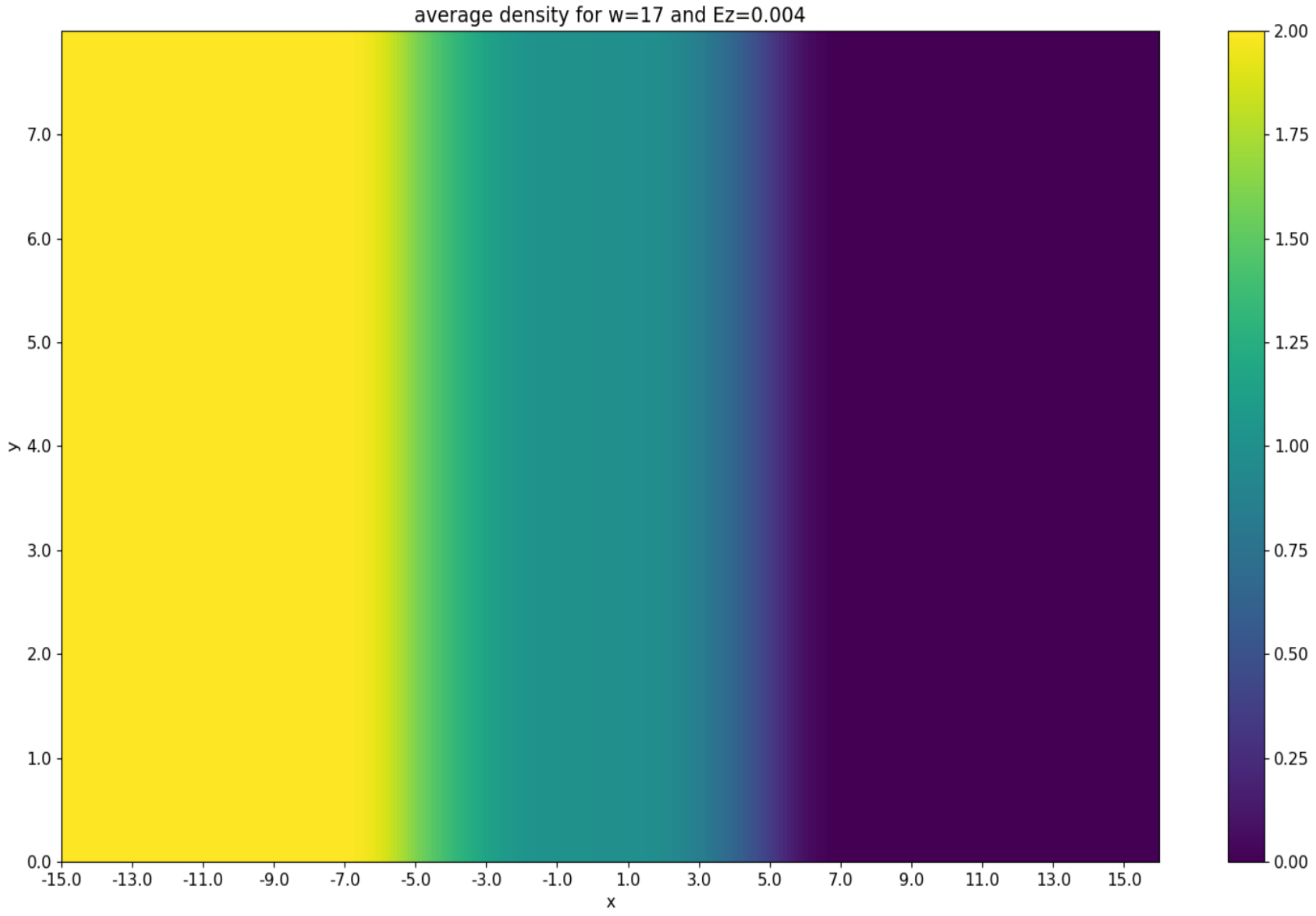
The Phase Diagram



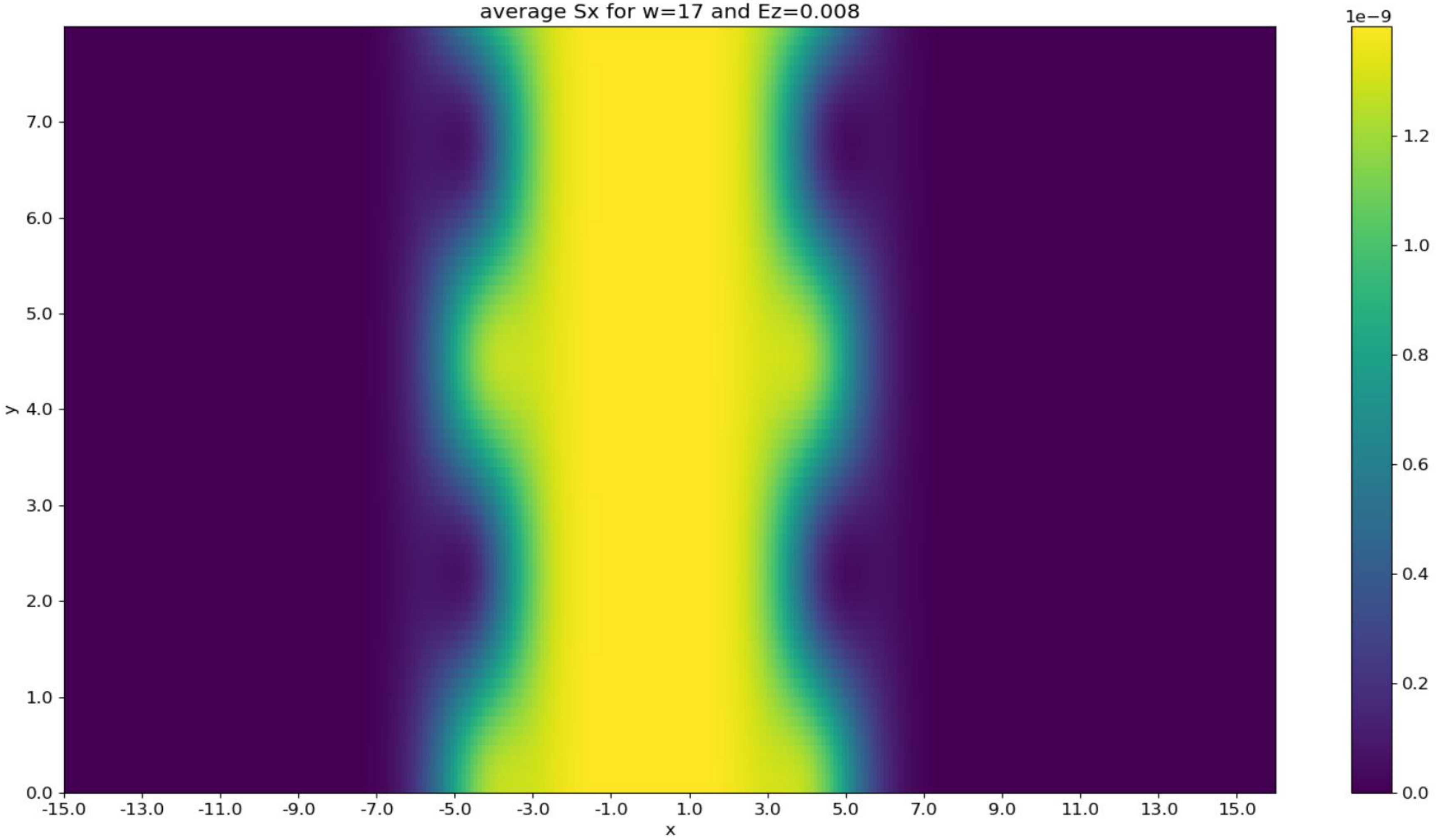
S_x density for W=17, E z=0.002



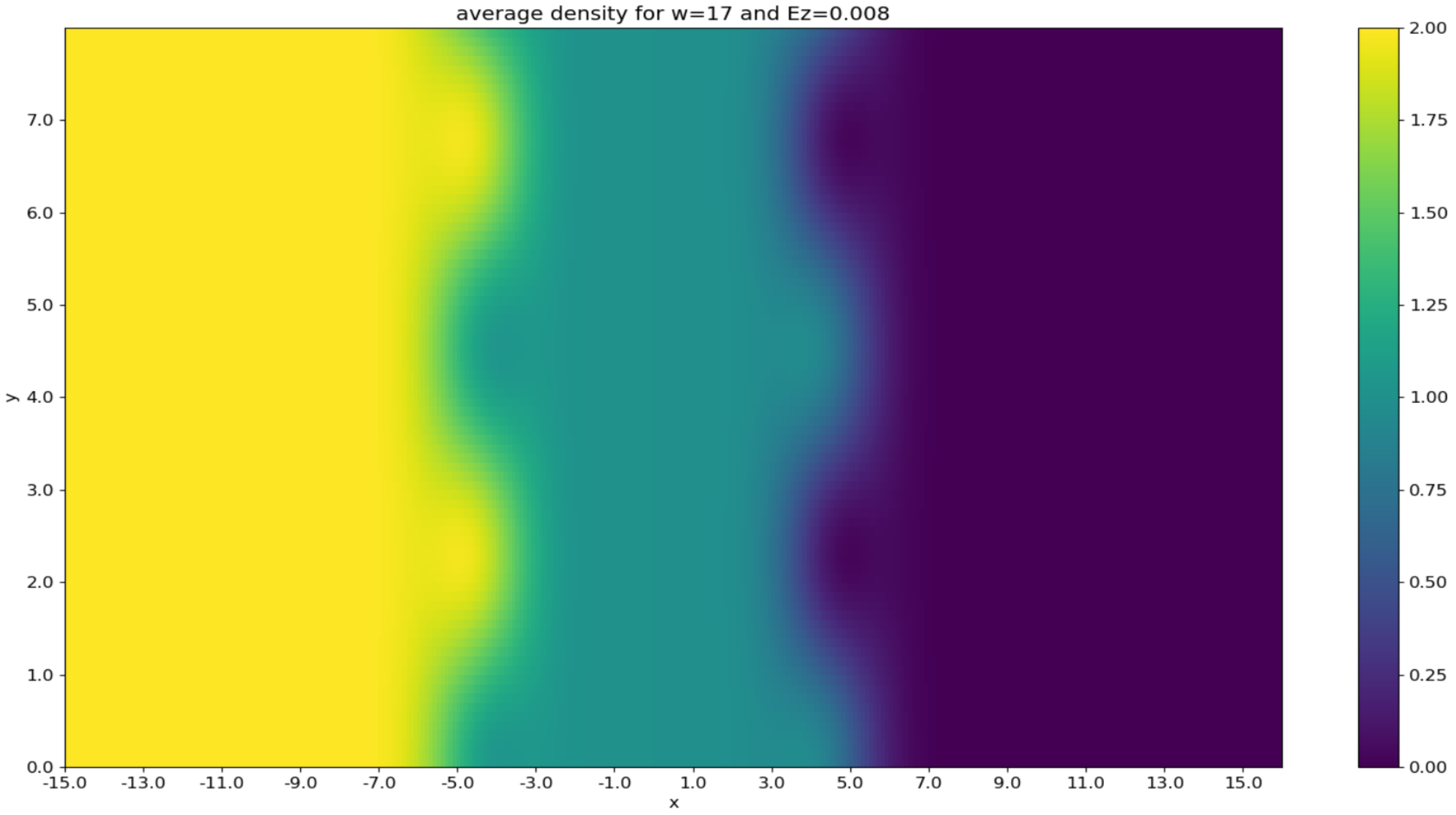
Charge density for W=17, E_z=0.002



S_x density for W=17, E_z=0.008



Charge density for W=17, E_z=0.008



Physical Signatures

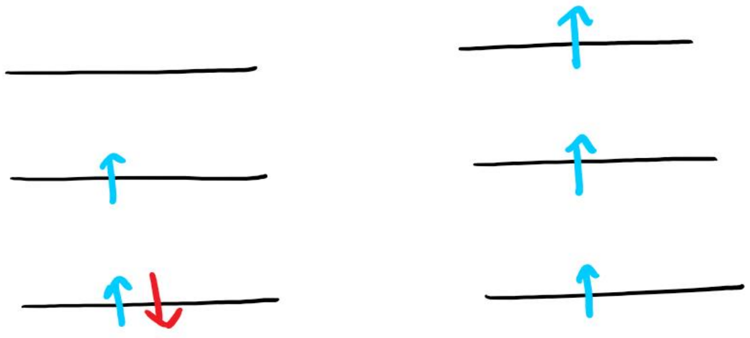
- Hartree-Fock can break translations in a 1D system, but this is a fake. The Mermin-Wagner theorem forbids it. The 1D “crystal” will melt at long distances with power law order of the crystalline correlations.
- We believe that the main consequence in either phase 2 or phase 3 will be the generation of a pair of counterpropagating neutral modes.
- Of course the two downstream charged chiral modes have to remain, but now their spin will not be pure.

The Second Tale

Suman De, Amartya Saha, Sumathi Rao, Yuval Gefen, and GM

$$E_c = \frac{e^2/\varepsilon \ell}{\hbar \omega_c}.$$

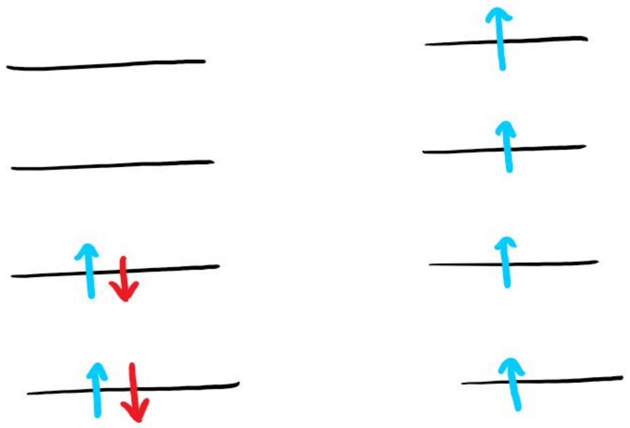
$\nu = 3$



Bulk transition

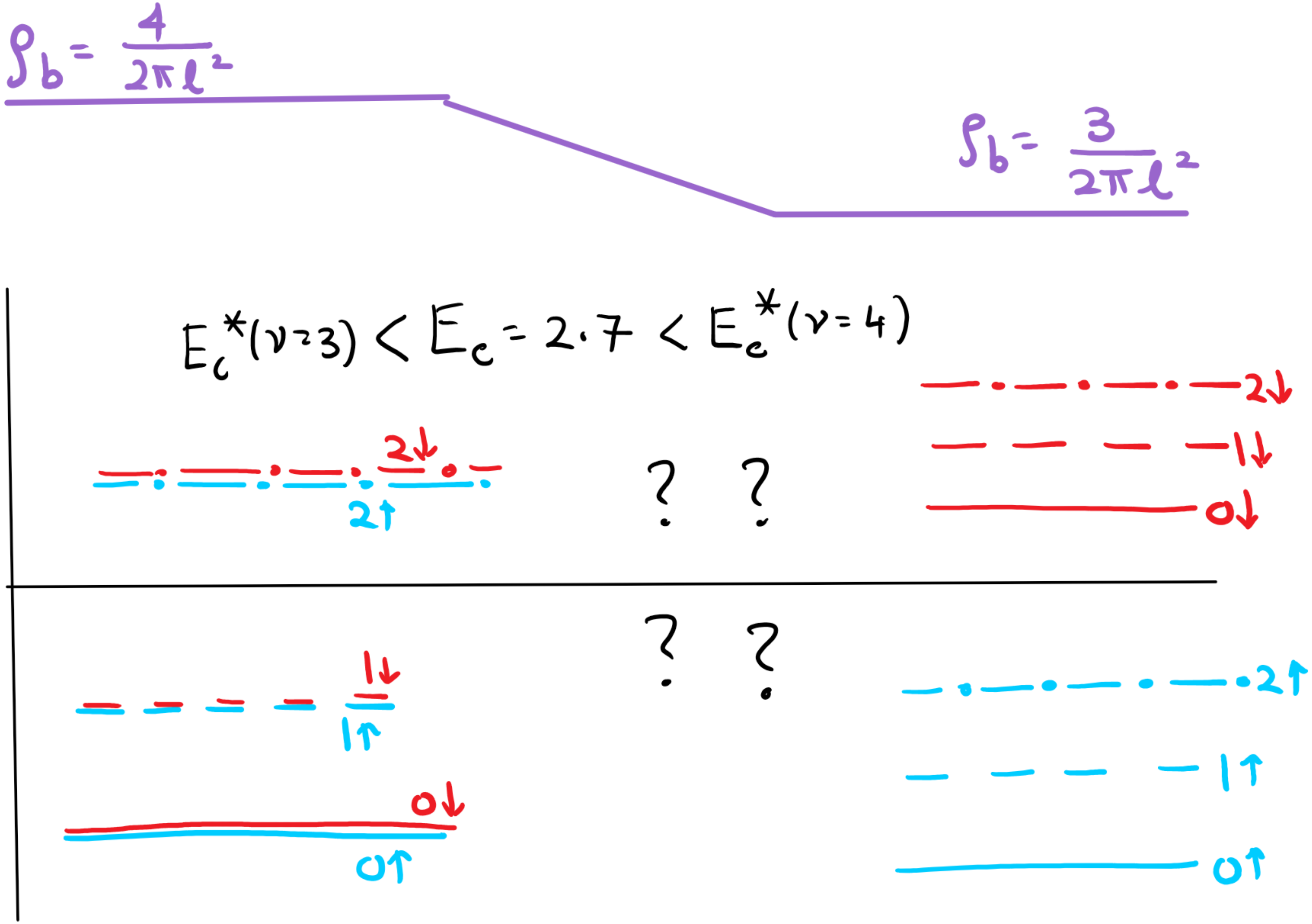
at $E_c^*(\nu=3) = 2.52$

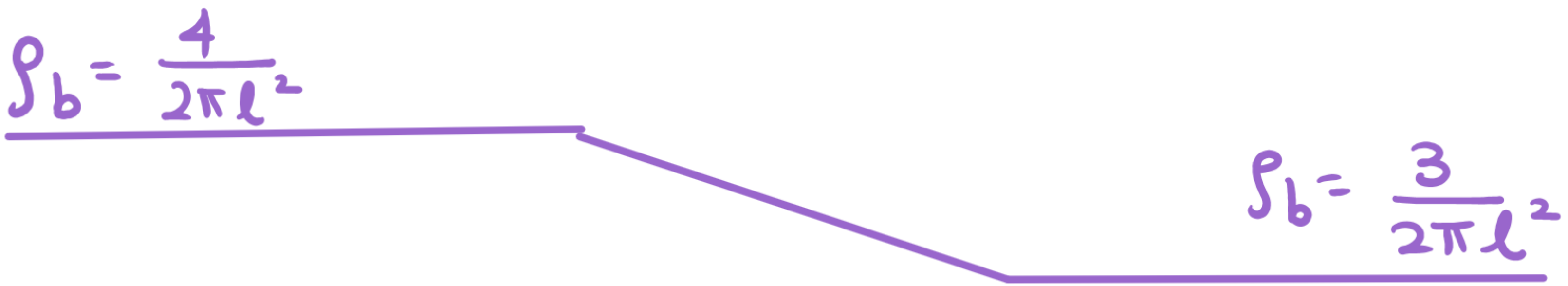
$\nu = 4$



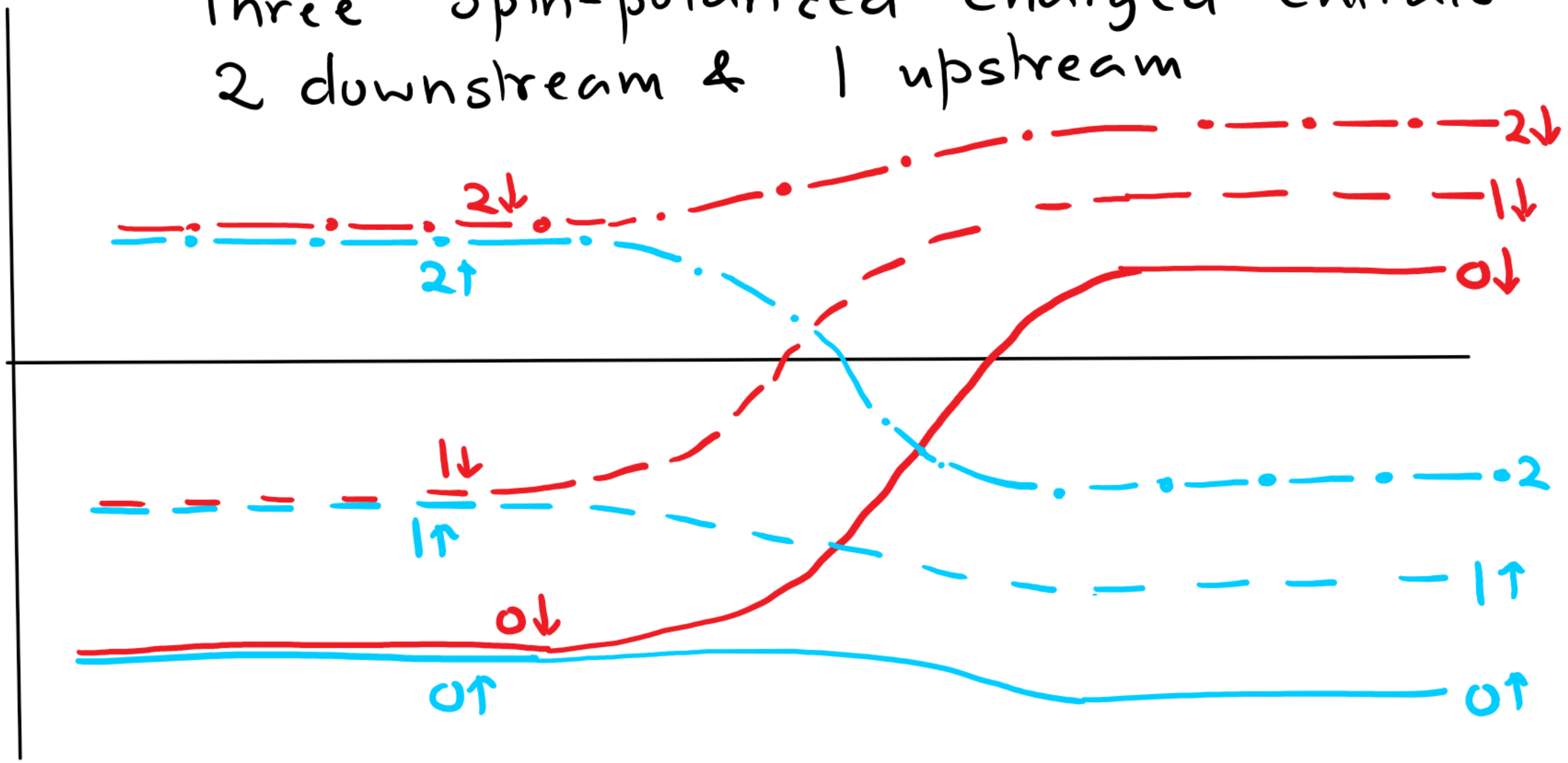
Bulk transition

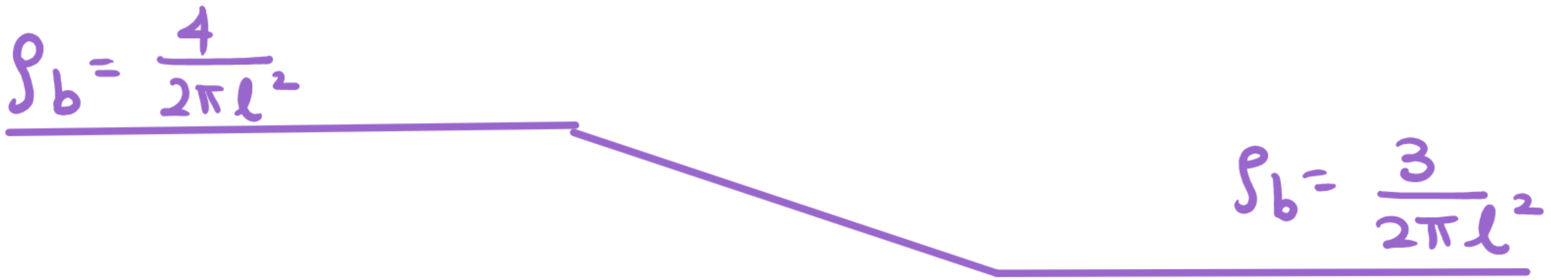
at $E_c^*(\nu=4) = 2.93$


$\rho_b = \frac{4}{2\pi \ell^2}$
$\rho_b = \frac{3}{2\pi \ell^2}$
$E_c^*(\nu=3) < E_c = 2.7 < E_c^*(\nu=4)$
2↓
2↑
1↓
1↑
0↓
0↑
? ?
? ?
2↓
1↓
0↓
2↑
1↑
0↑

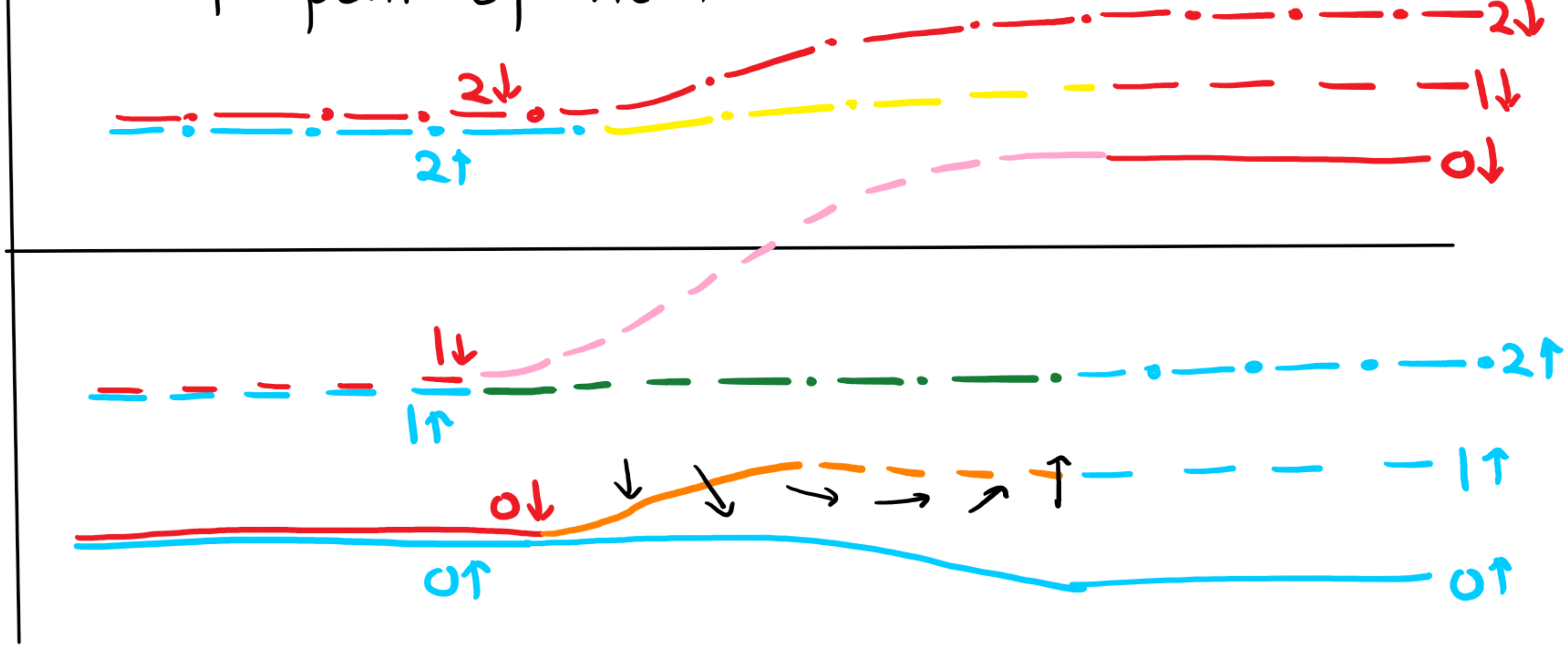


Three spin-polarized charged chirals
2 downstream & 1 upstream





Single downstream charged chiral + pair of neutral modes.



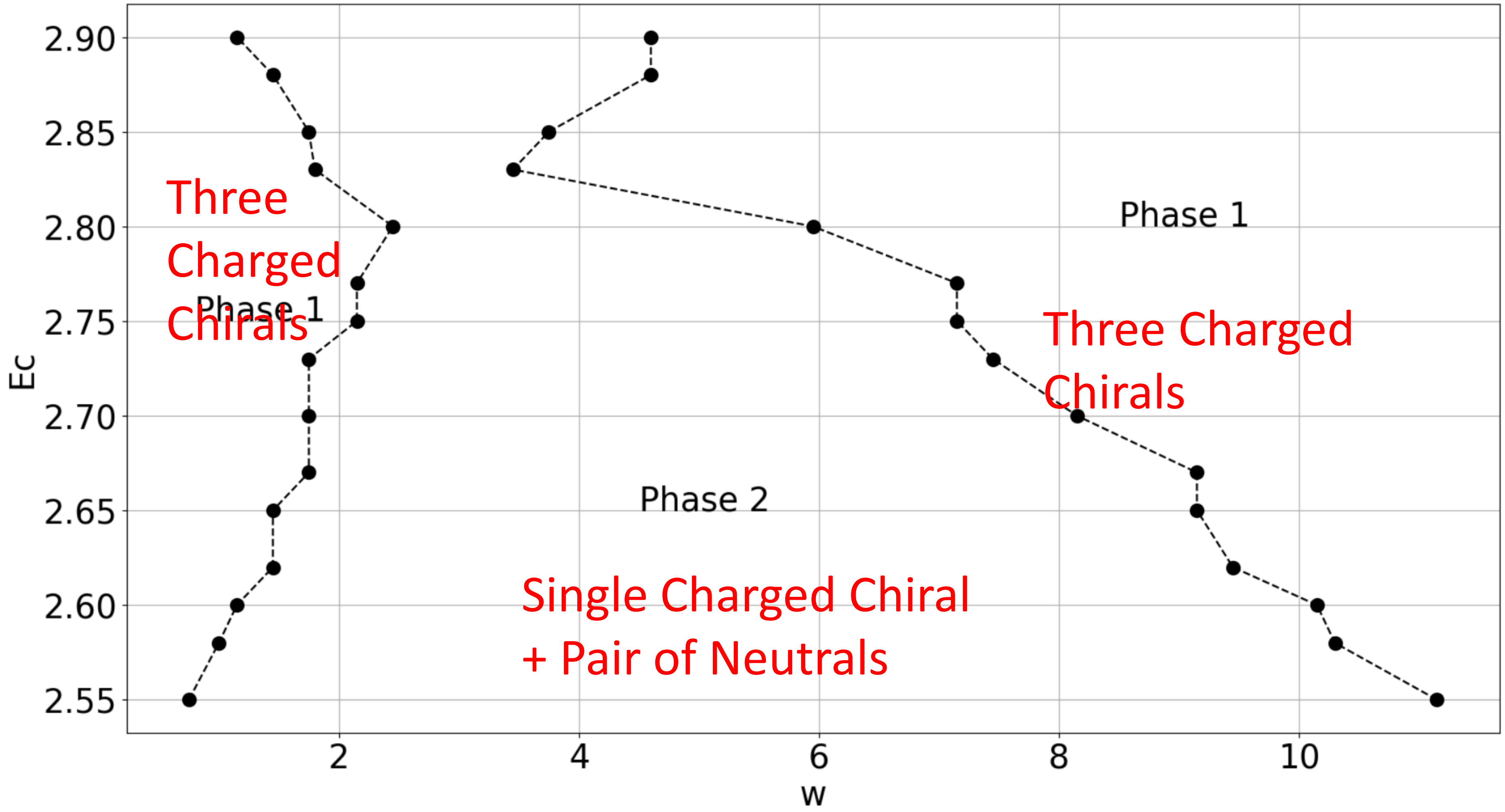
Features of the second phase

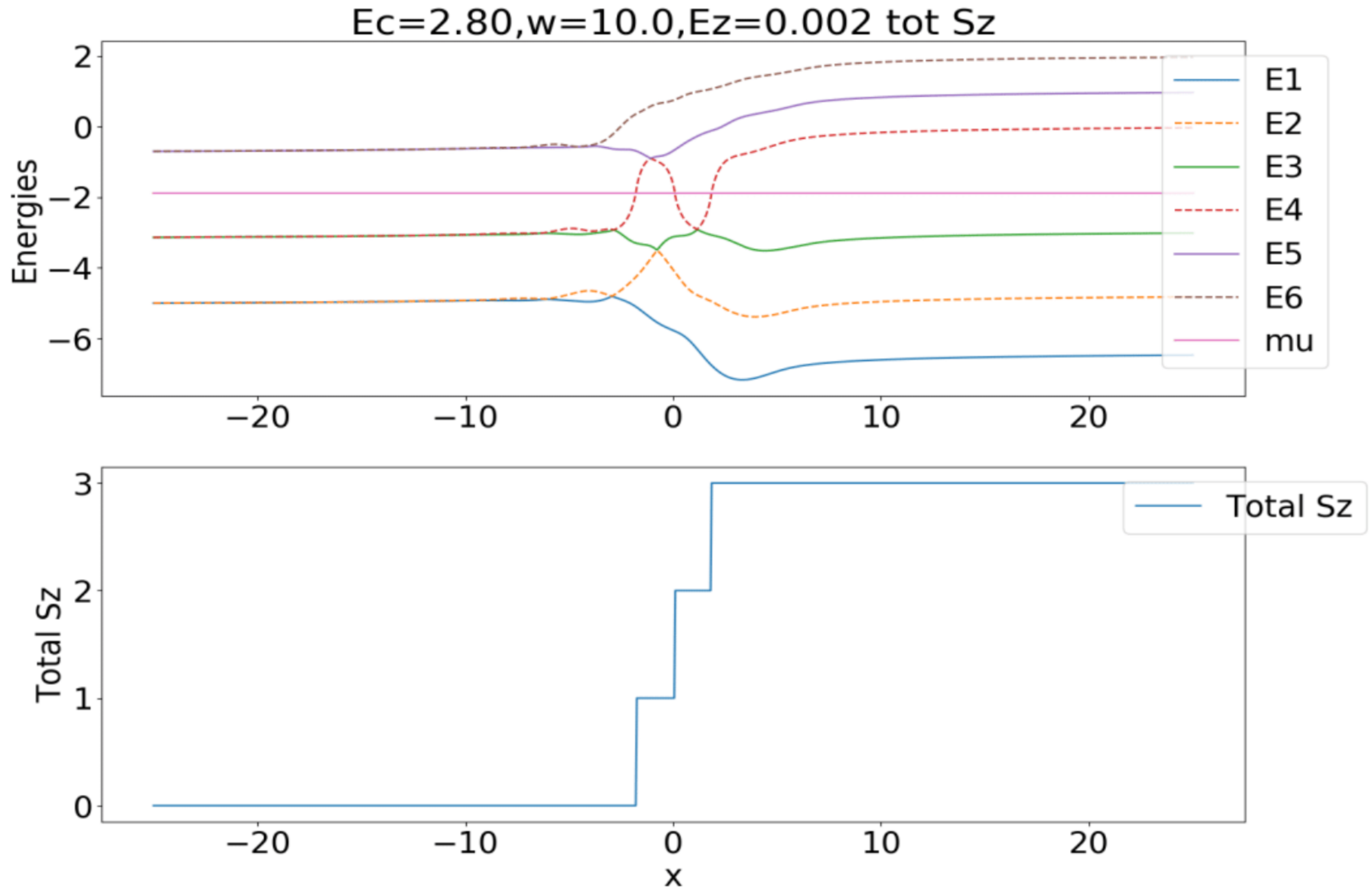
The second reconstruction breaks the U(1) spin-rotation symmetry of the Hamiltonian spontaneously, very similar to our previous work on nu=3 (Khanna, Murthy, Rao, & Gefen 2017). Again, Mermin-Wagner forbids it in a 1D system.

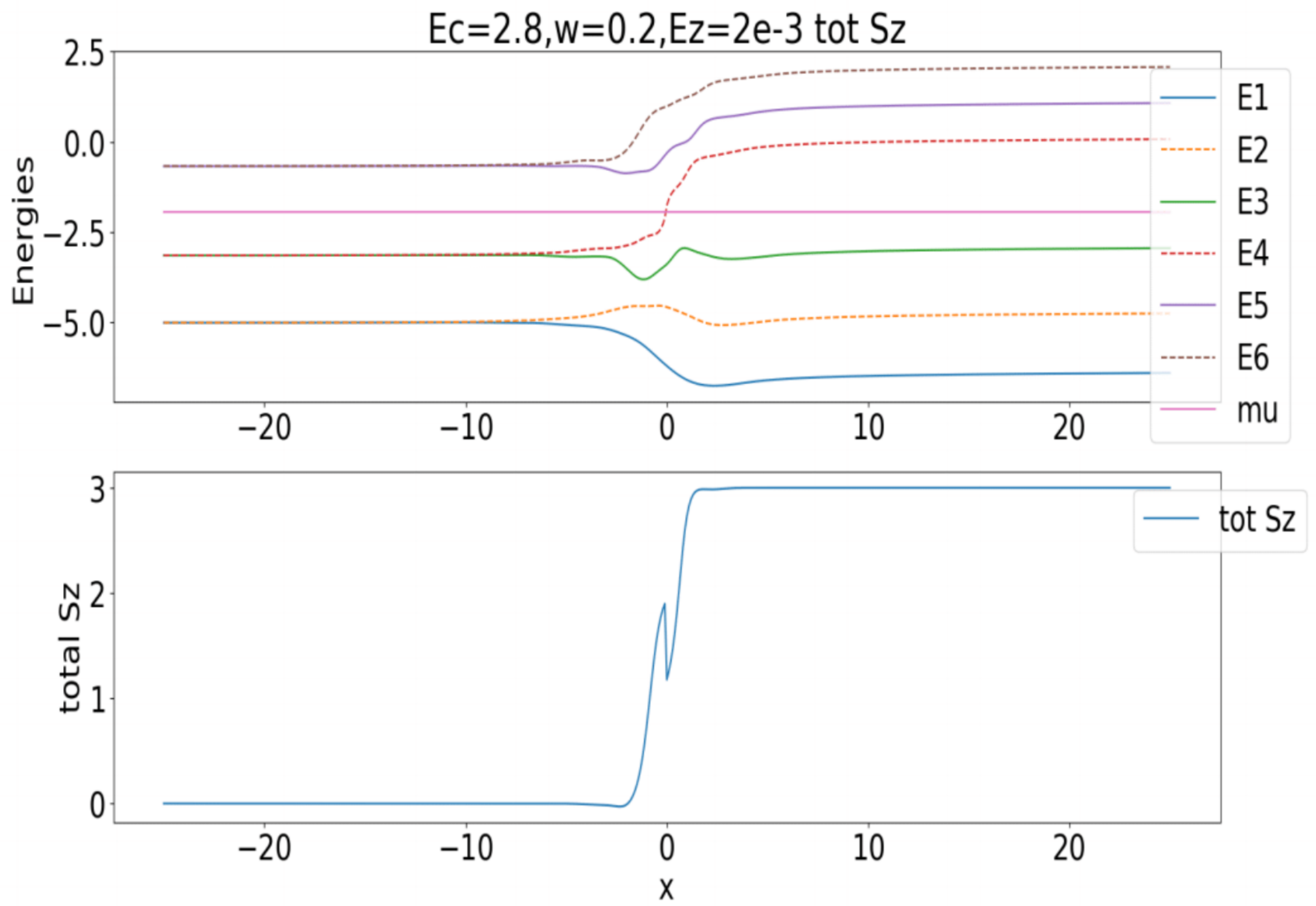
The spin part of the system can be modelled by an XXZ-like Hamiltonian, equivalent to a Luttinger liquid.

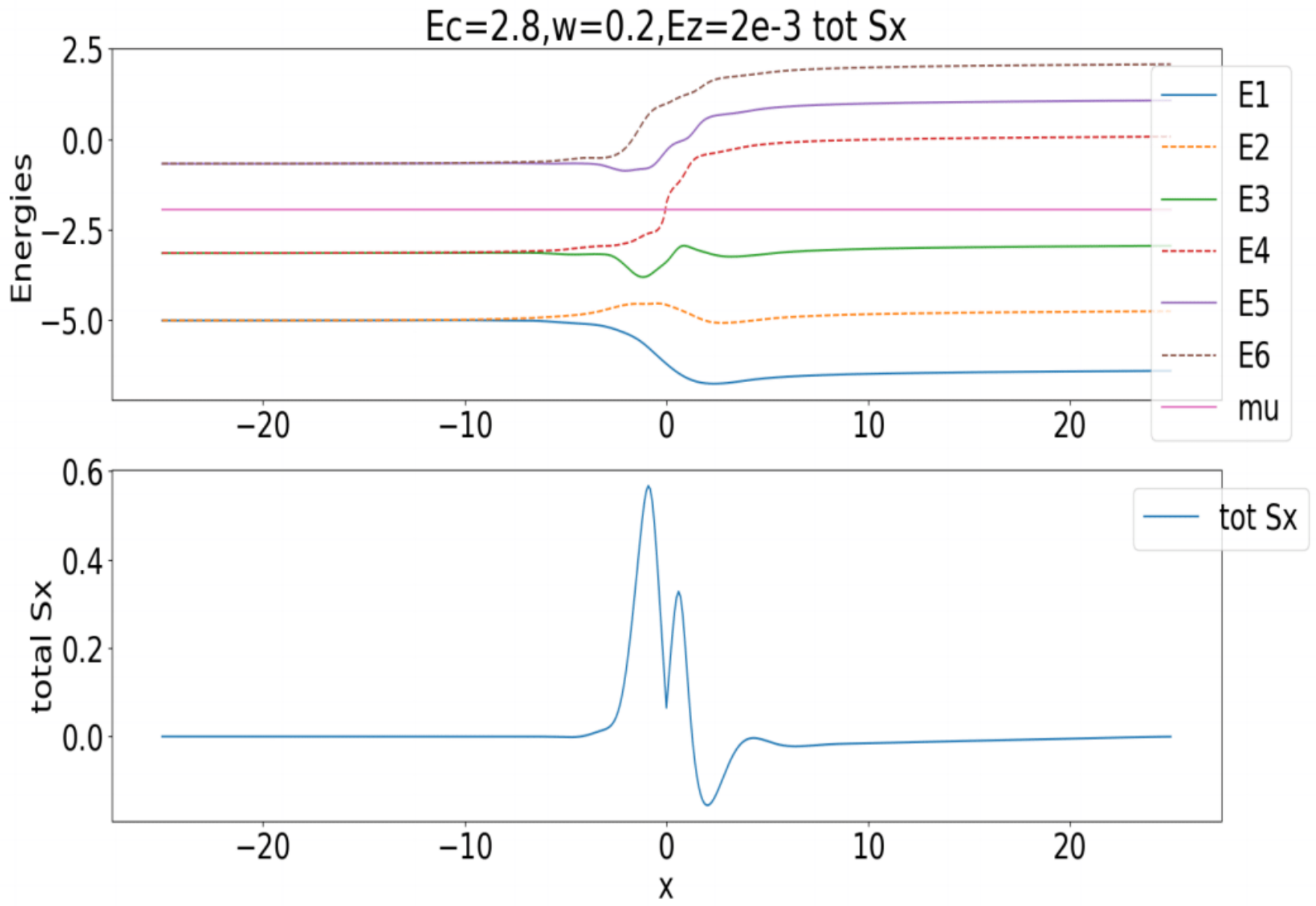
So in addition to the charged chiral mode, there will be a pair of counterpropagating neutral modes, essentially spin waves.

Our Tentative Phase Diagram




Ec=2.80,w=10.0,Ez=0.002 tot Sz
Energies
E1
E2
E3
E4
E5
E6
mu
Total Sz
Total Sz
x


Ec=2.8,w=0.2,Ez=2e-3 tot Sz
Energies
2.5
0.0
−2.5
−5.0
−20
−10
0
10
20
E1
E2
E3
E4
E5
E6
mu
total Sz
3
2
1
0
tot Sz
x


Ec=2.8,w=0.2,Ez=2e-3 tot Sx
Energies
2.5
0.0
−2.5
−5.0
E1
E2
E3
E4
E5
E6
mu
−20
−10
0
10
20
total Sx
0.6
0.4
0.2
0.0
tot Sx
−20
−10
0
10
20
x

Conclusions

- Even integer quantum Hall systems can show very interesting edge reconstructions.
- These reconstructions can break many symmetries at mean field, but these will be restored by quantum fluctuations (Mermin-Wagner).
- However, the mean-field broken U(1) symmetries leave behind pairs of counterpropagating neutral modes. This seems to be a fairly generic mechanism for generating “unnecessary” neutral modes.
- Disorder along the edge can be expected to nucleate small regions of such phases, perhaps leading to lots of localized low-energy modes.