



Extended Fractional Chern Insulators at High Fields in Twisted Bilayer Graphene Above the Magic Angle

Aaron Sharpe
Stanford University

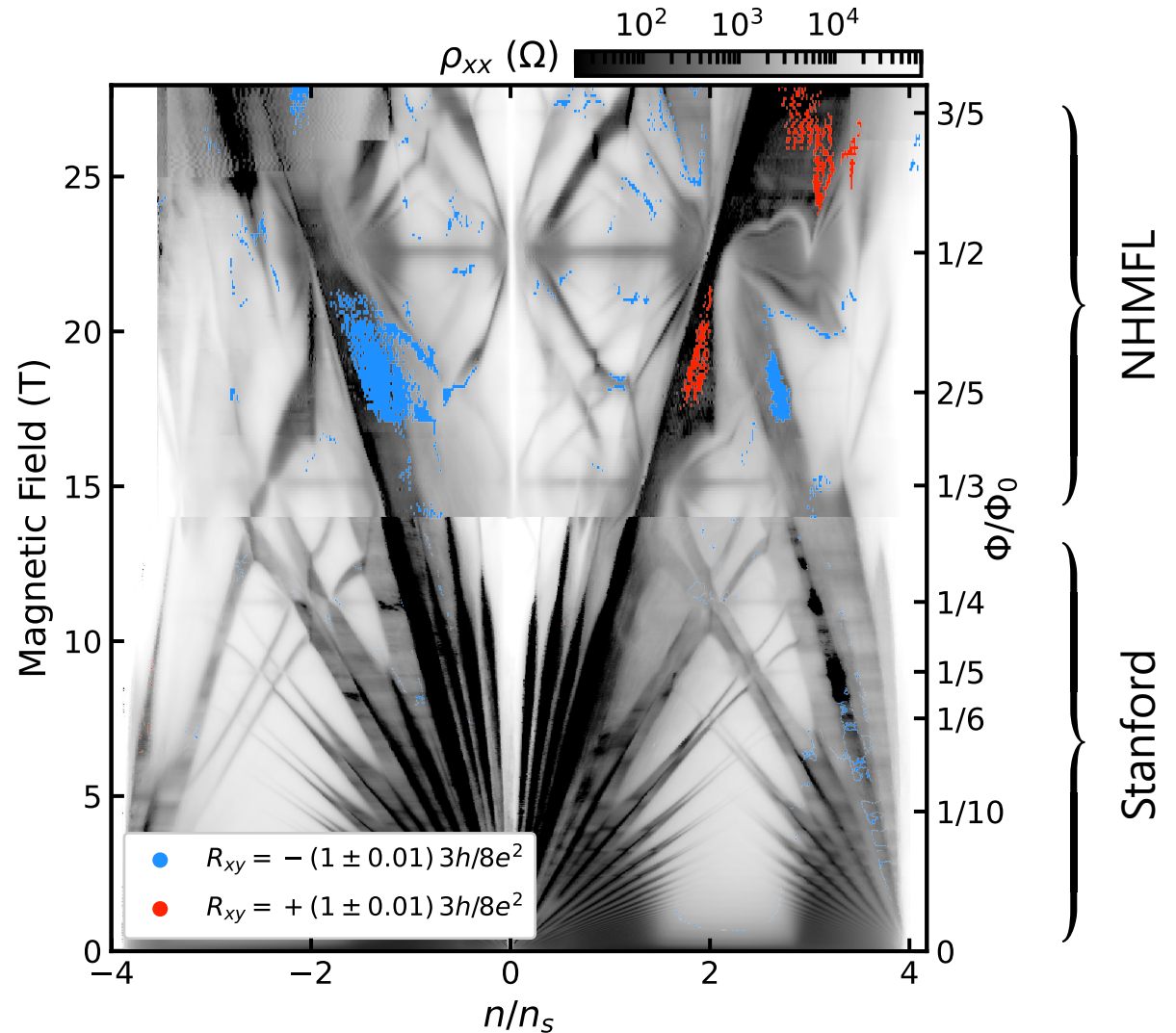
APS March Meeting
March 20th 2026

arXiv:2503.12819

Slides @ aaronsharpe.science

Bottom line

- **1.37° twisted bilayer graphene**
- From low field transport, **heterostrain** of:
 - Uniaxial: $0.24 \pm 0.02\%$
 - $\varphi_{\text{uni}} = 45 \pm 4^\circ$
 - Biaxial: $0.3 \pm 0.1\%$
- At high magnetic fields, we observe robustly quantized **fractional Chern insulators** (FCI)
- Some FCIs **extend** over a very broad range of density



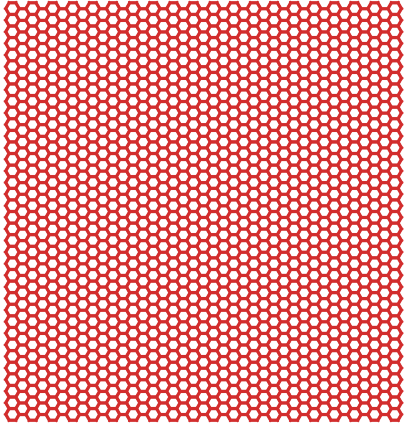
Outline

0. Introduction

1. Extracting Structural Parameters at Low Magnetic Fields

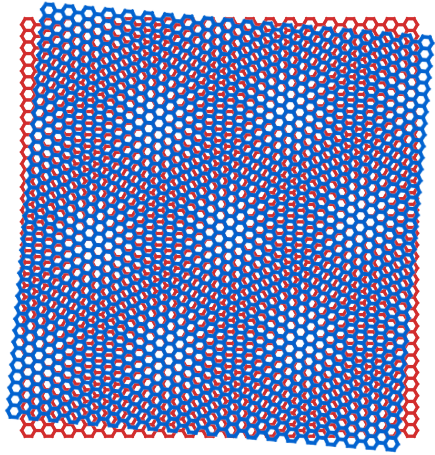
2. Fractional Chern Insulators at High Magnetic Fields

Bandstructure engineering with moirés



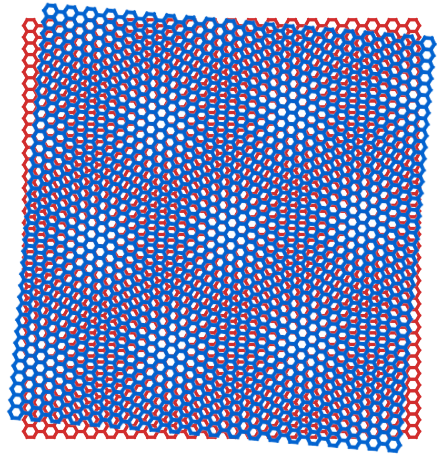
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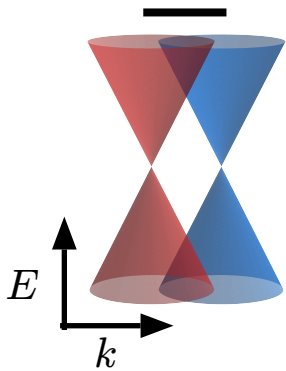


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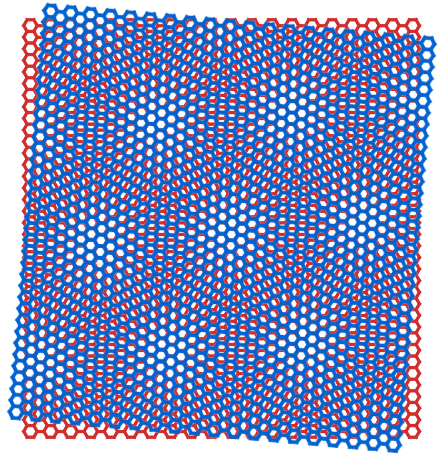


$$k_\theta \approx K\theta$$

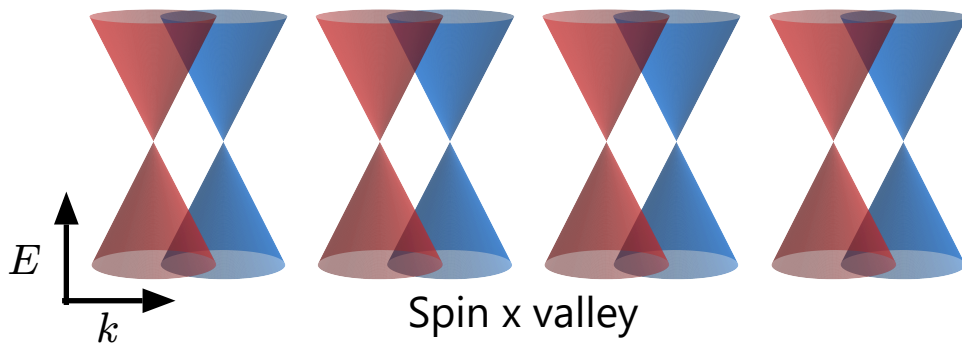


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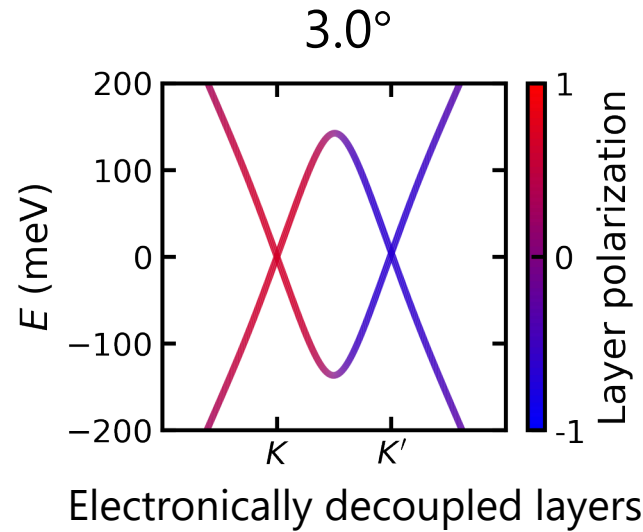
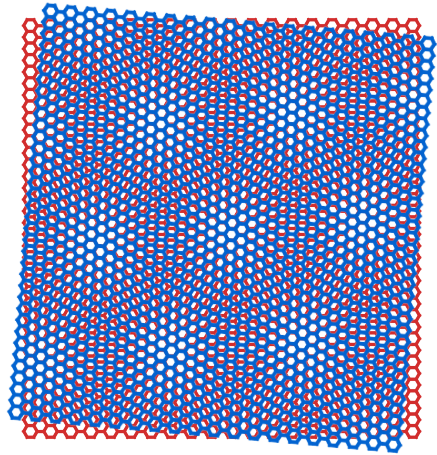


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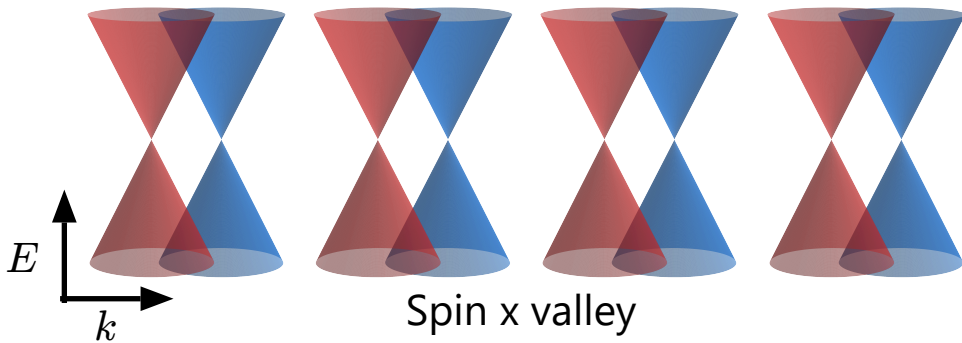


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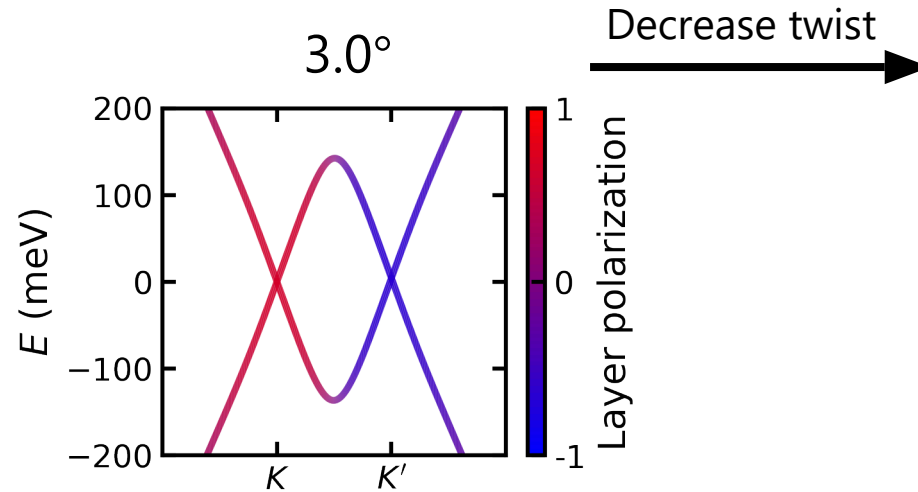
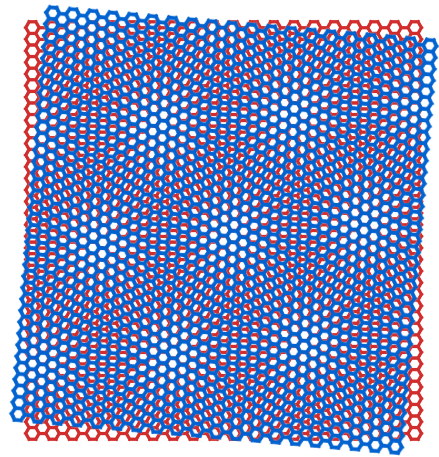


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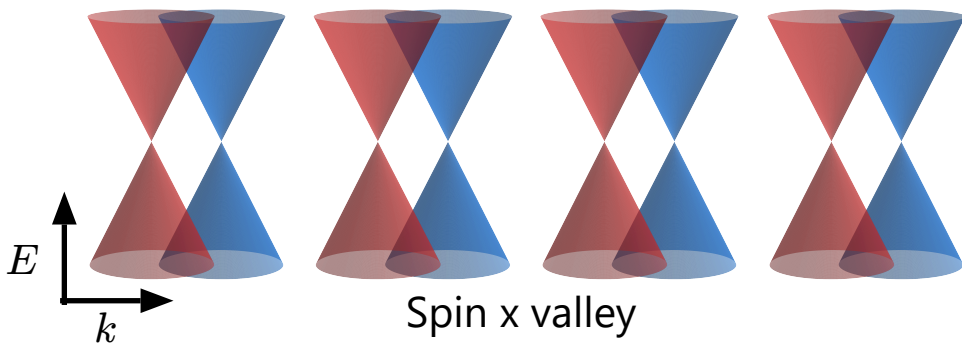
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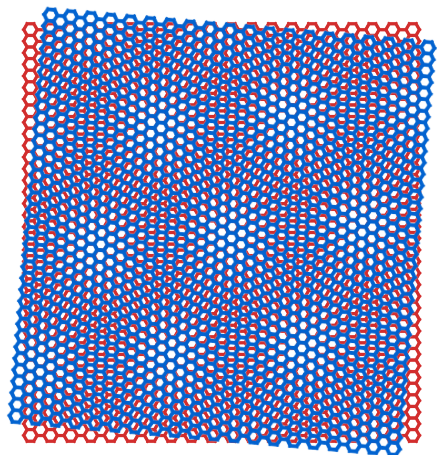
Electronically decoupled layers

$$k_\theta \approx K\theta$$



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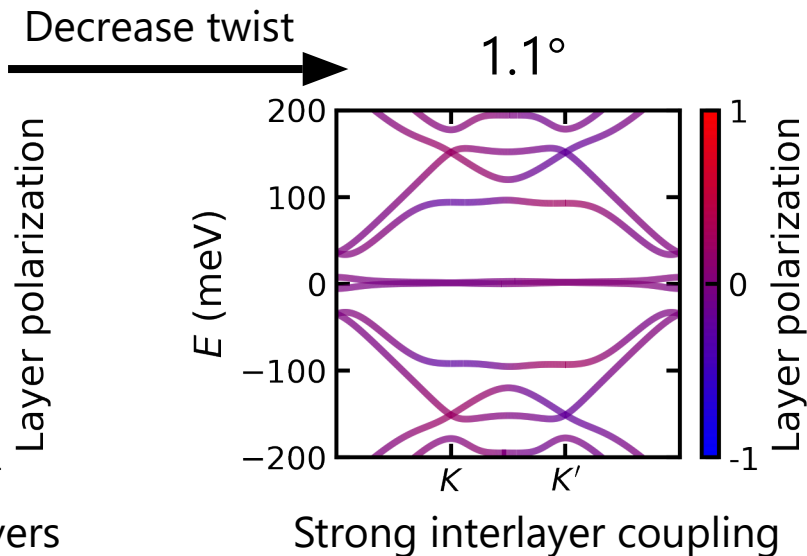
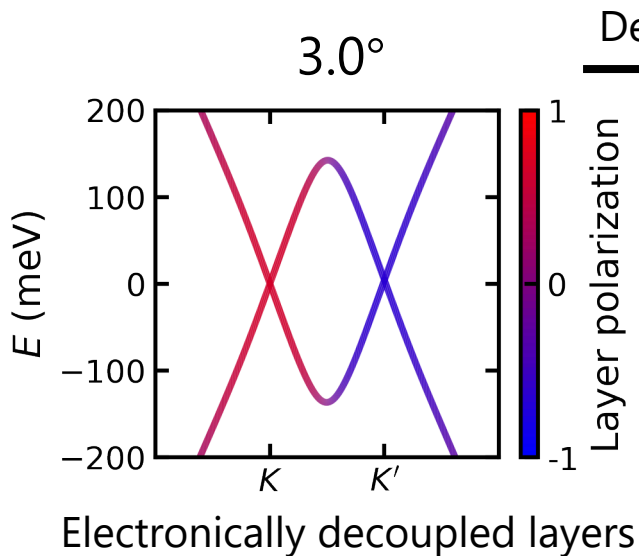
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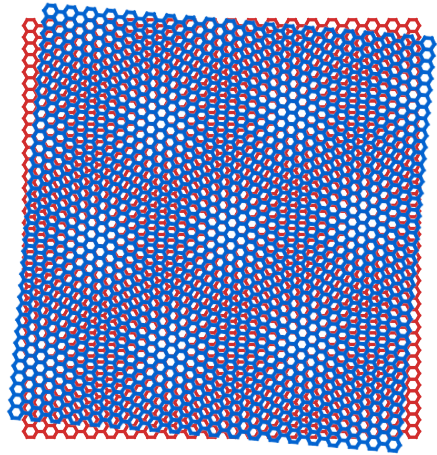


Spin x valley

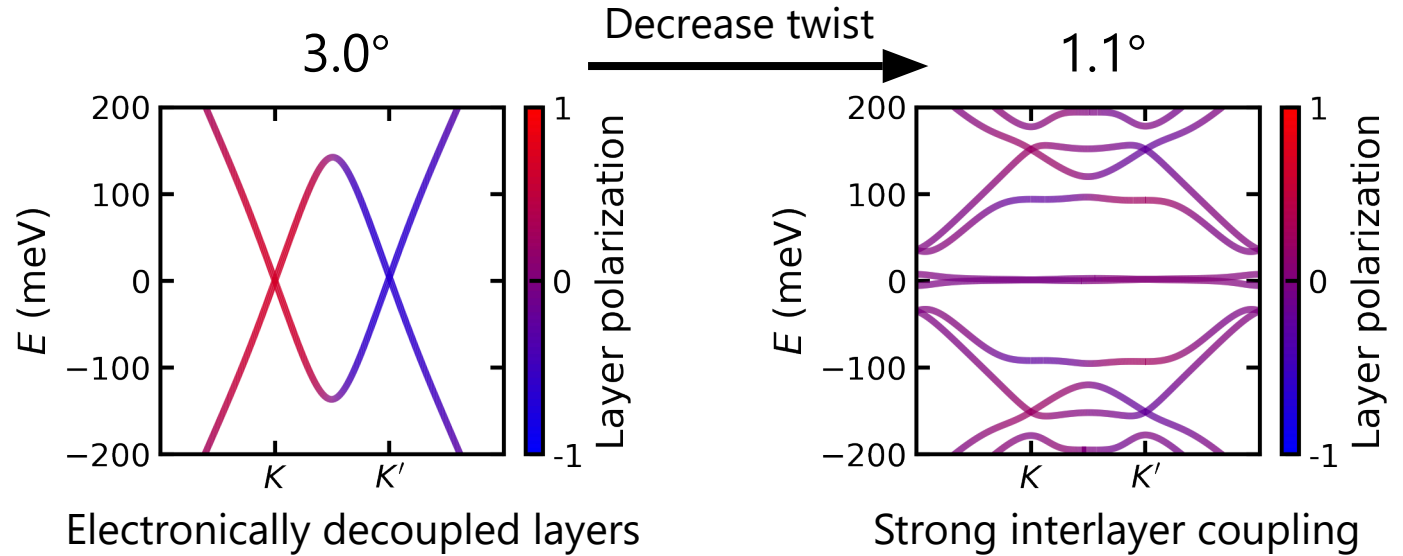
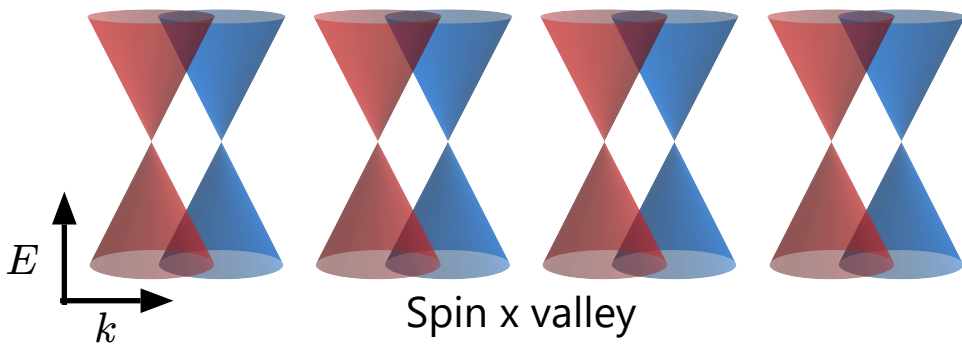


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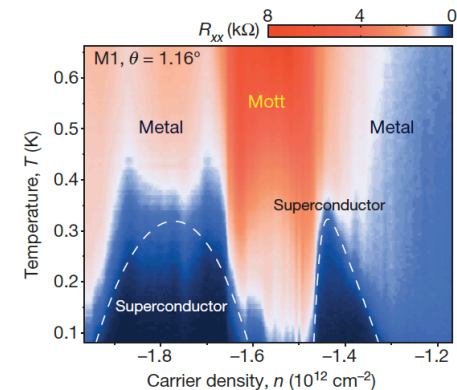
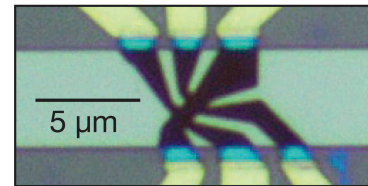
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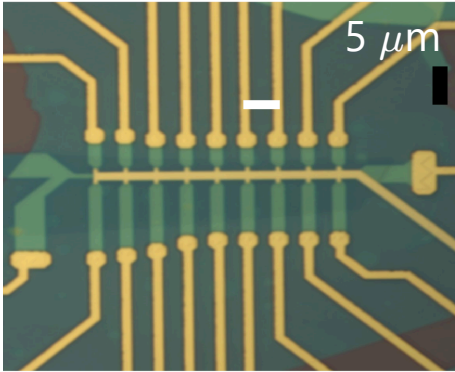


Experimental realization



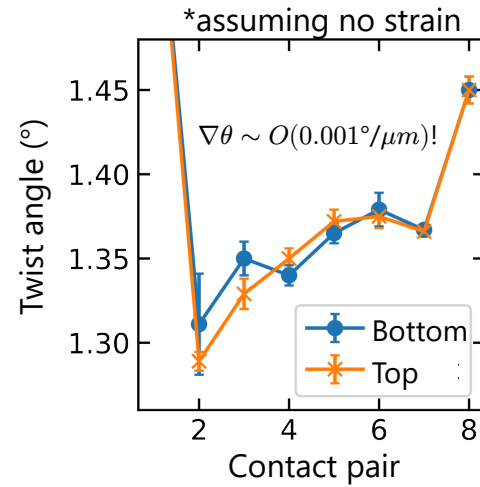
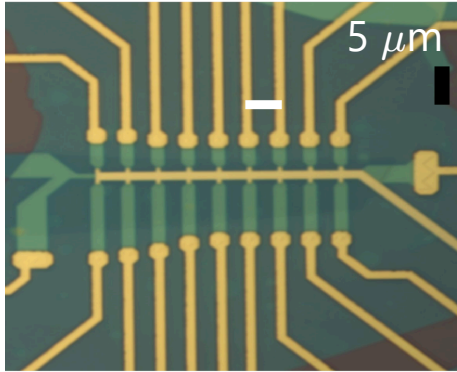
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Just above the magic angle

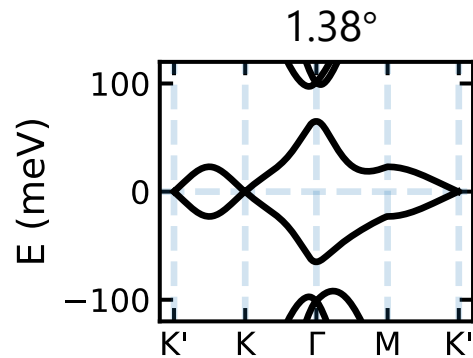
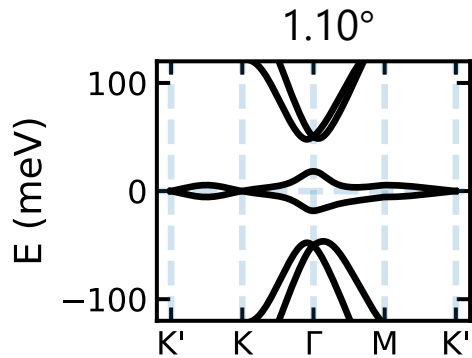
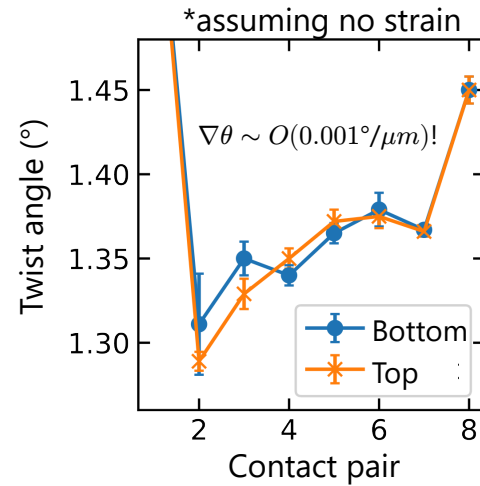
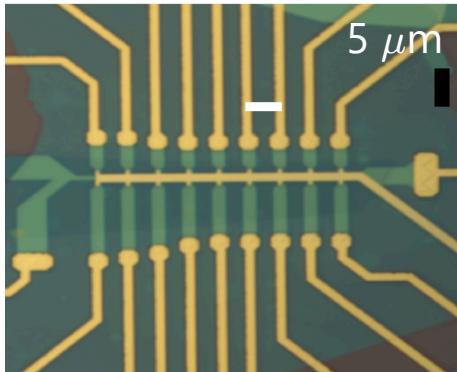


Finney, Sharpe, et al. PNAS (2022)
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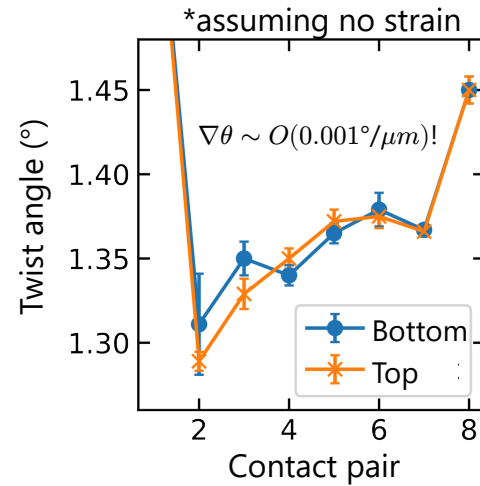
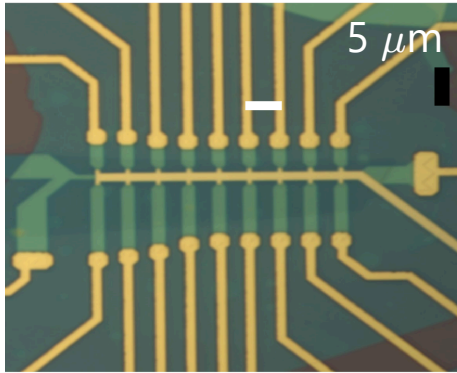


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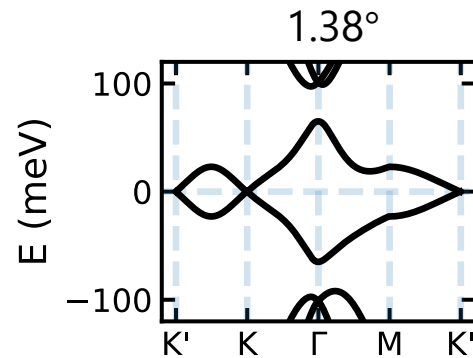
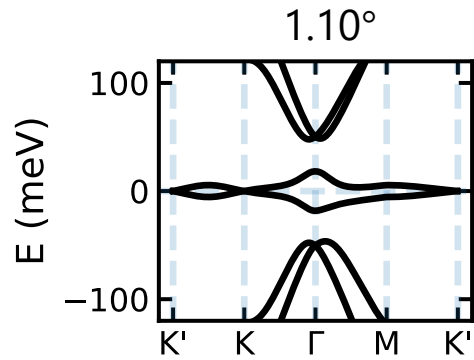
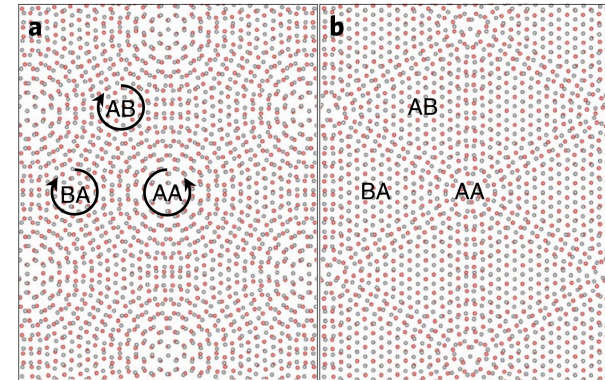


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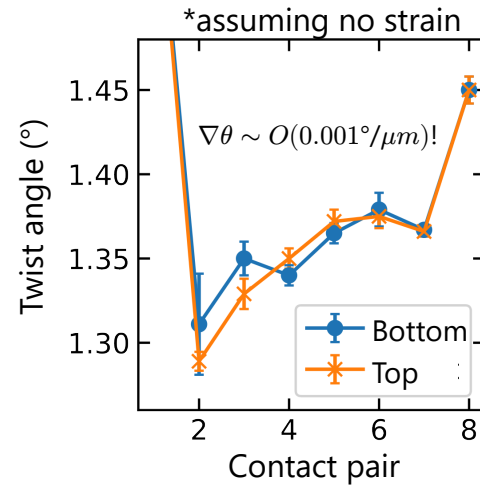
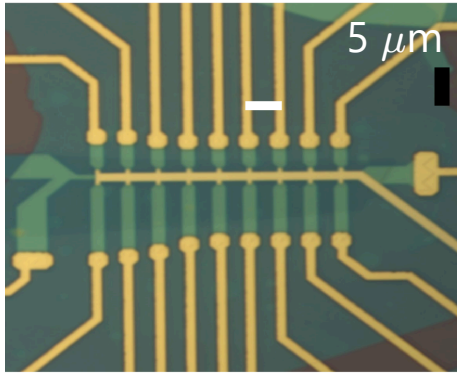
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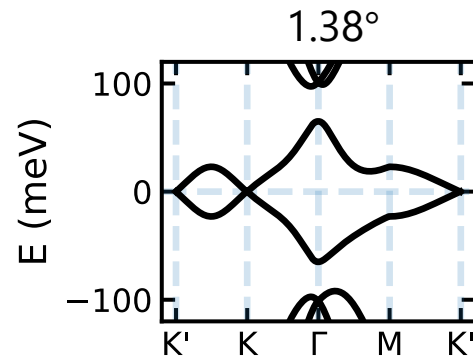
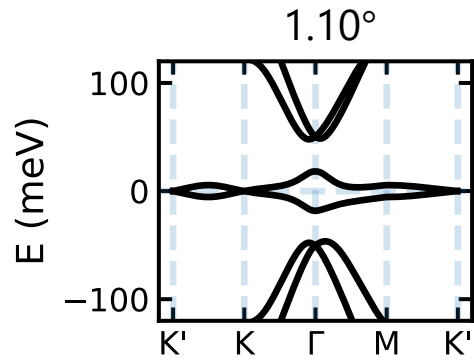
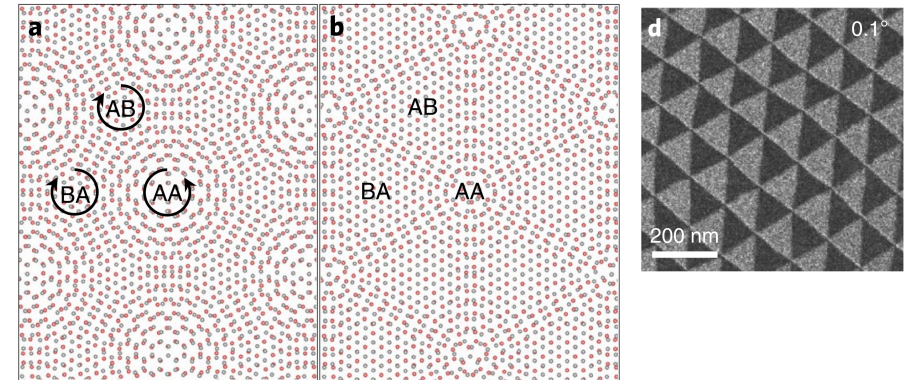
Lattice reconstruction



Just above the magic angle

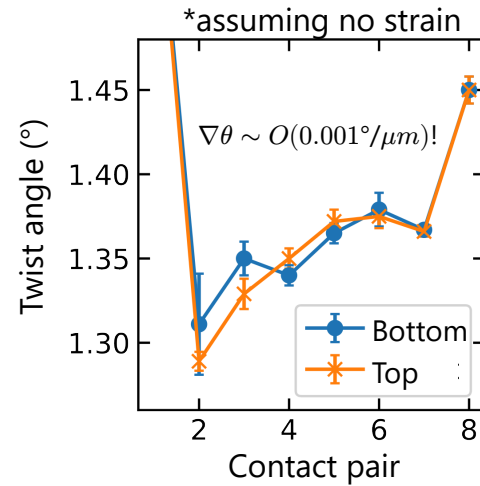
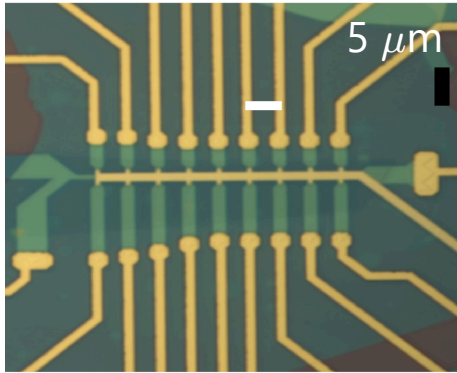


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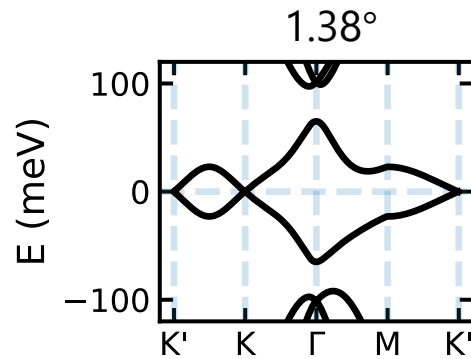
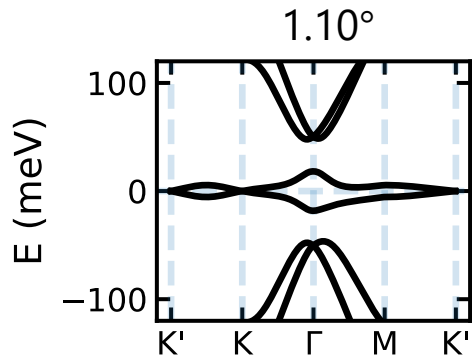
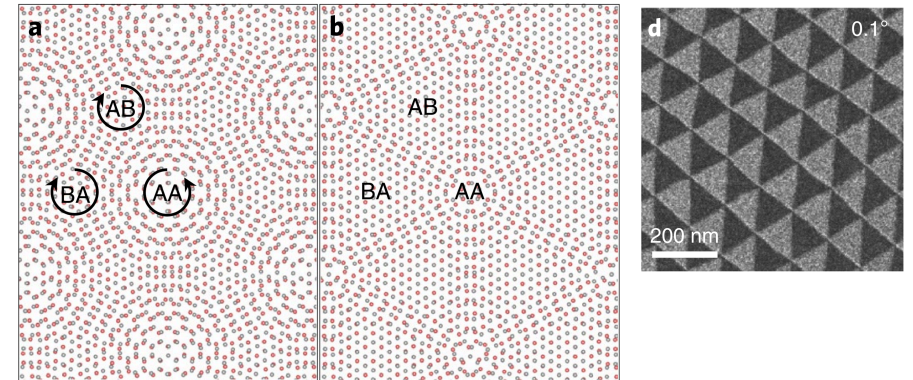


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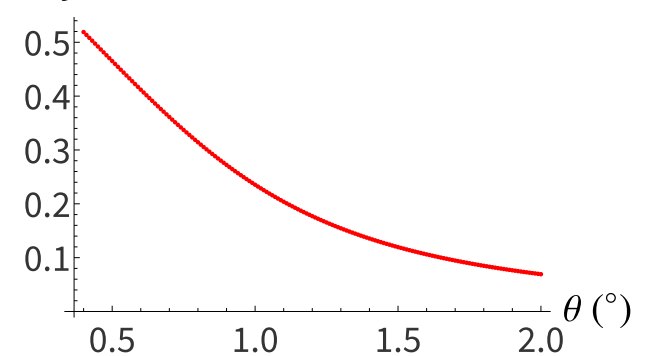
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Lattice reconstruction



$\zeta_1 \sim$ Amplitude of lattice relaxation



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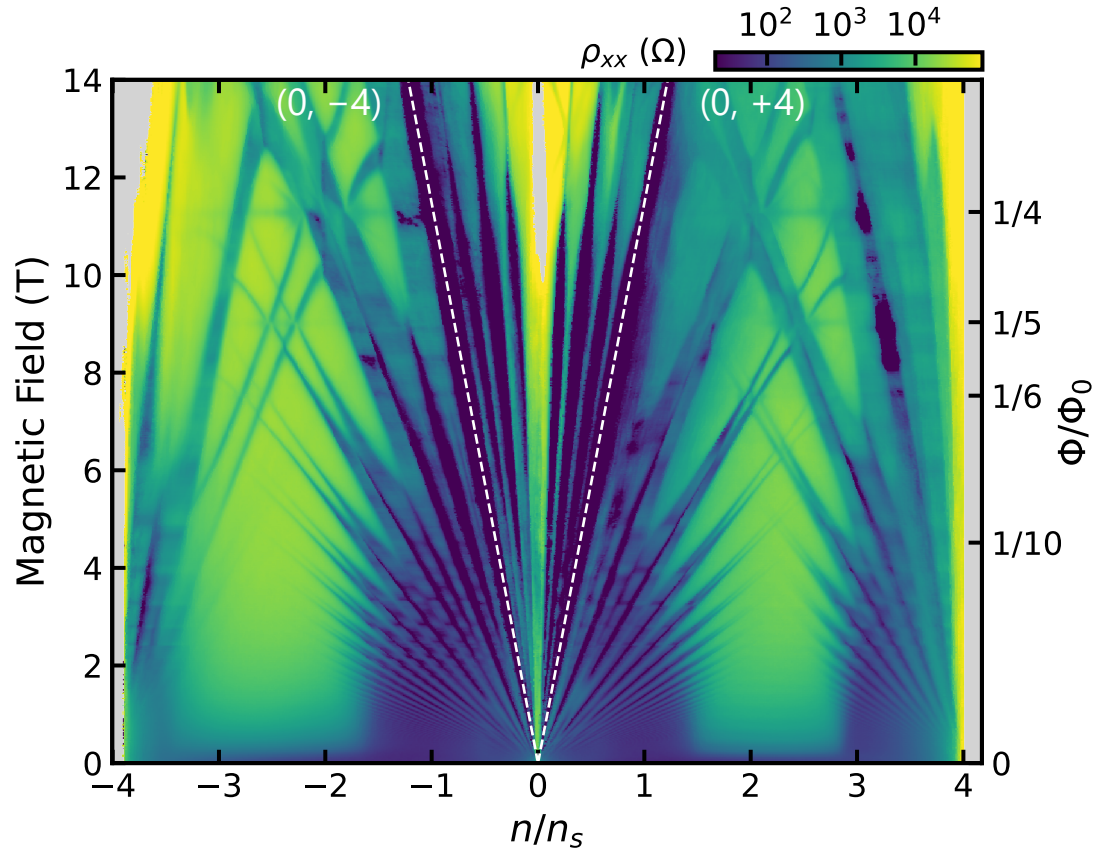
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1. Extracting Structural Parameters at Low Magnetic Fields

2. Fractional Chern Insulators at High Magnetic Fields

Quadratic magnetoresistance at low fields

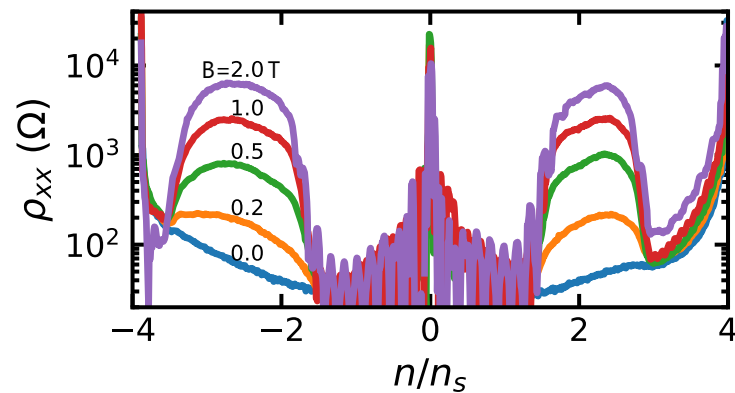
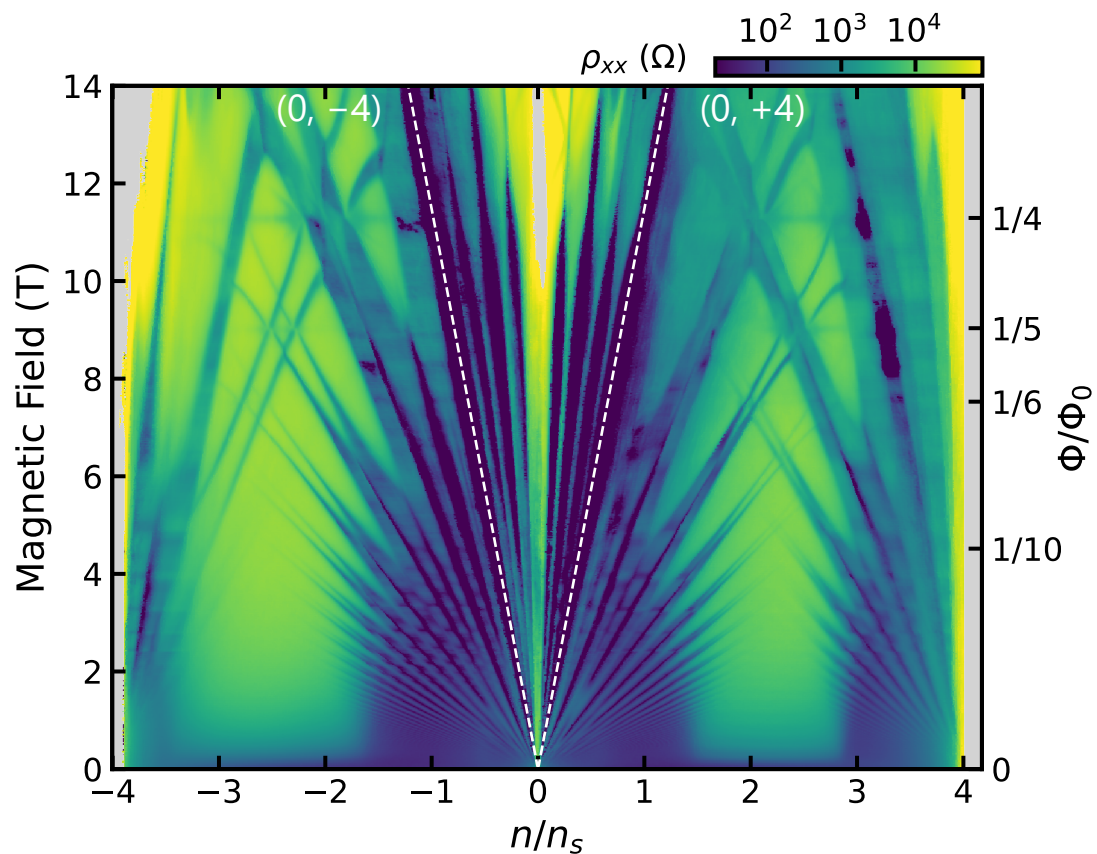


Finney, Sharpe, et al. PNAS (2022)
Wang, Finney, Sharpe, et al. PNAS (2023)

Diophantine: $n/n_s = s + t\Phi/\Phi_0 \rightarrow (s, t)$

Středa: $\sigma_{xy} = te^2/h$

Quadratic magnetoresistance at low fields

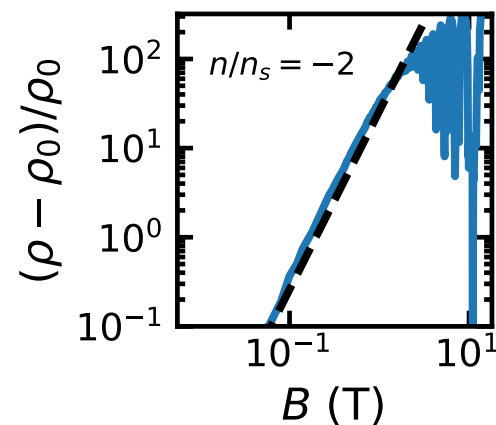
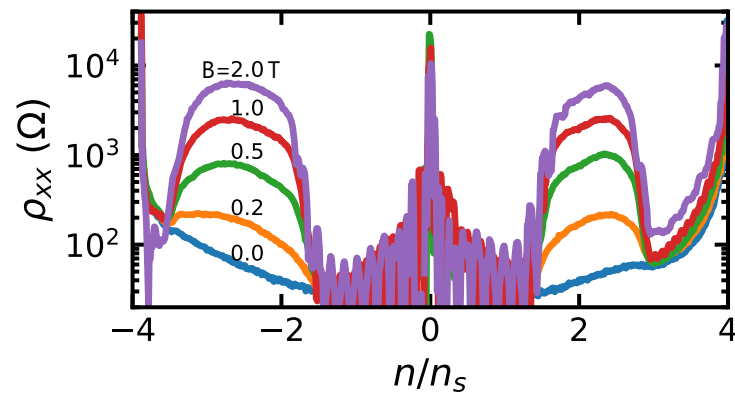
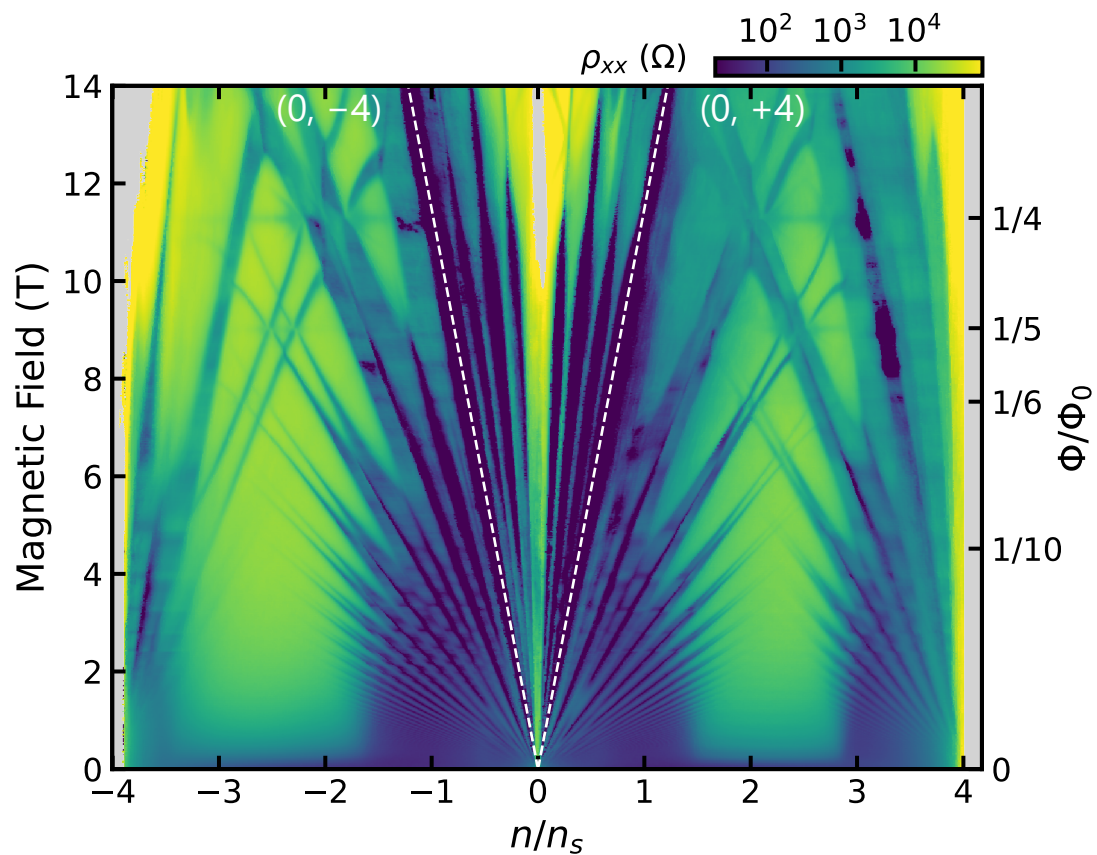


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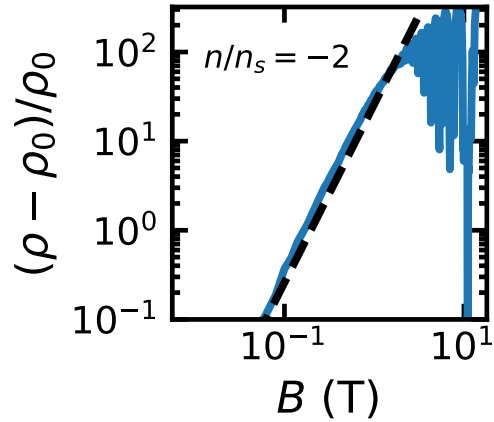


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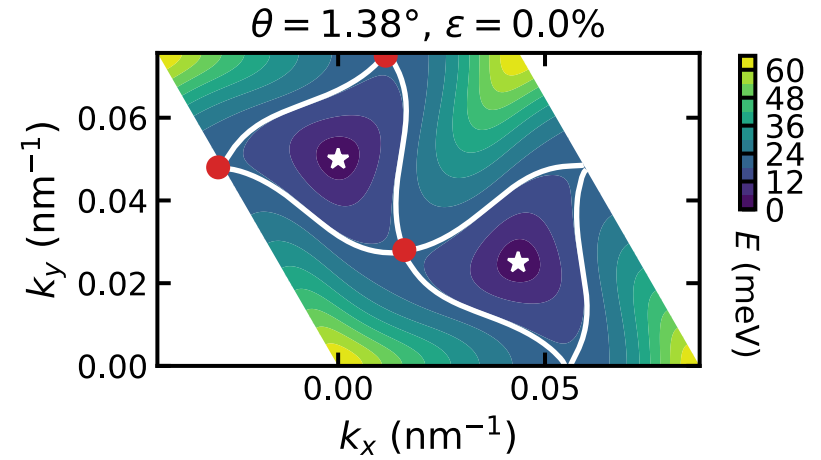
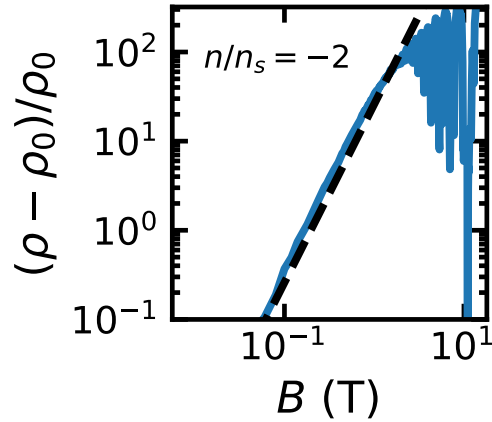
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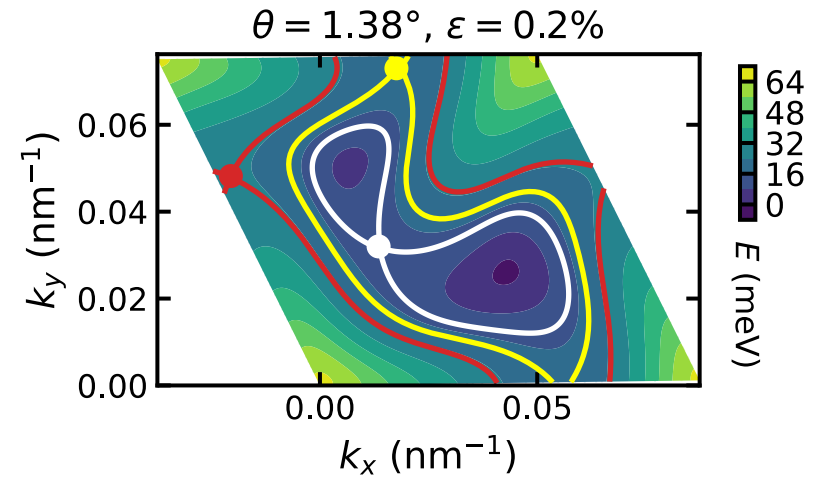
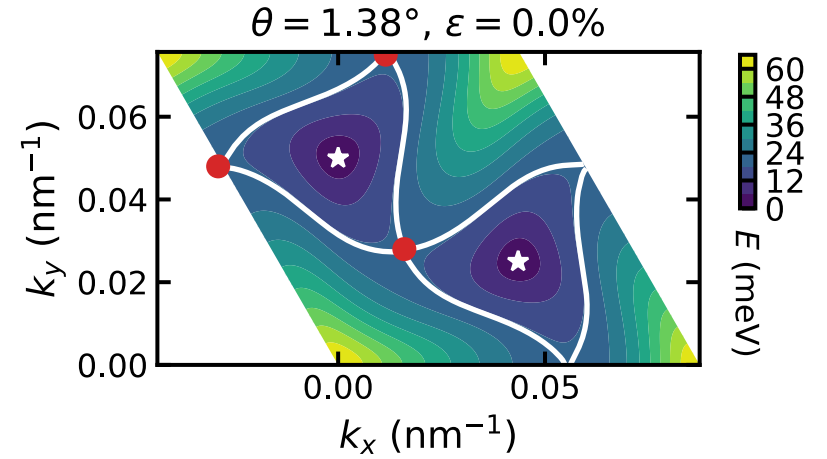
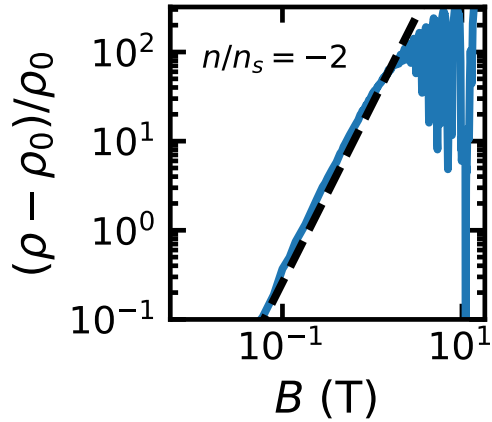
Uniaxial heterostrain breaks C_3 symmetry



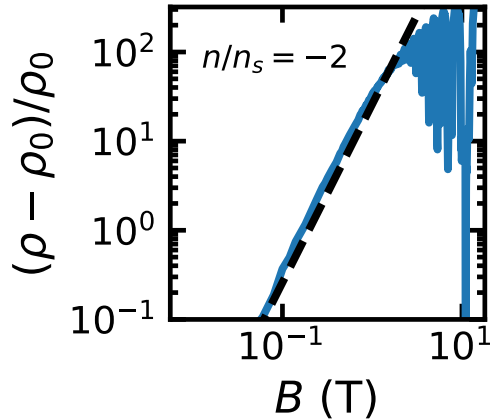
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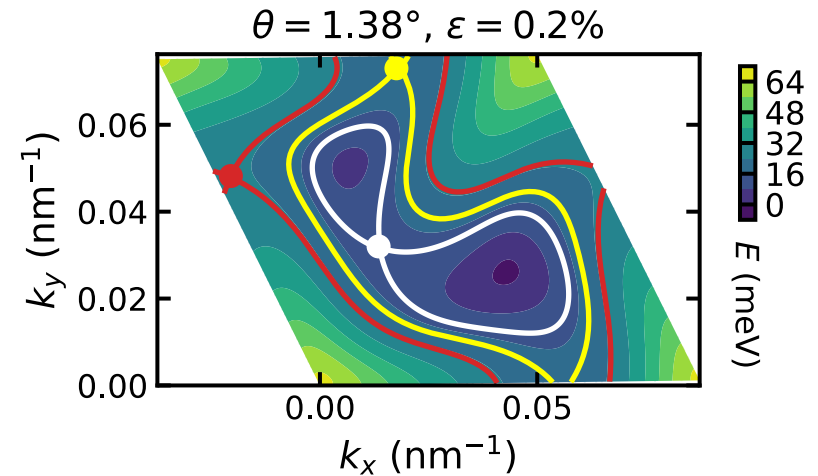
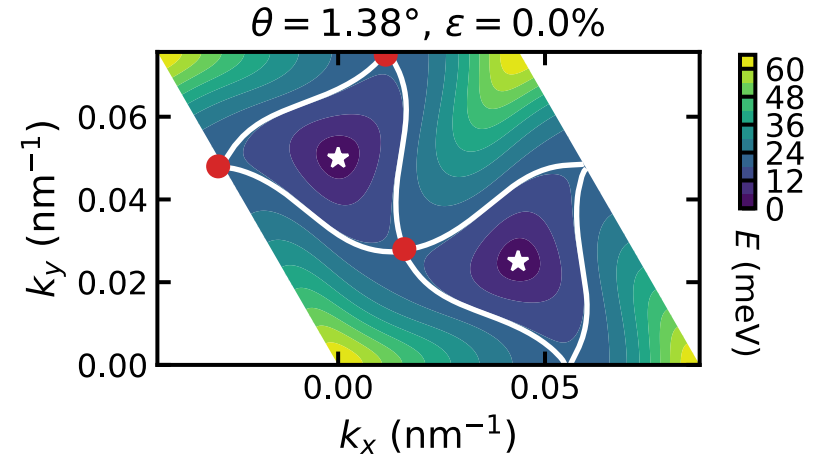
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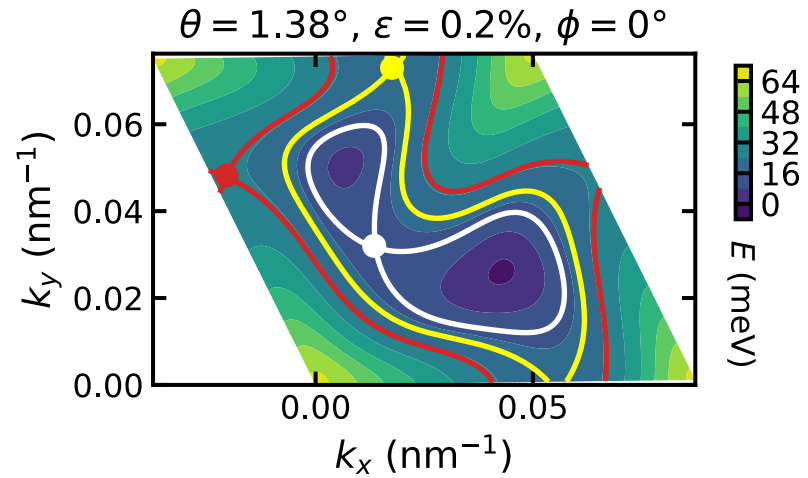
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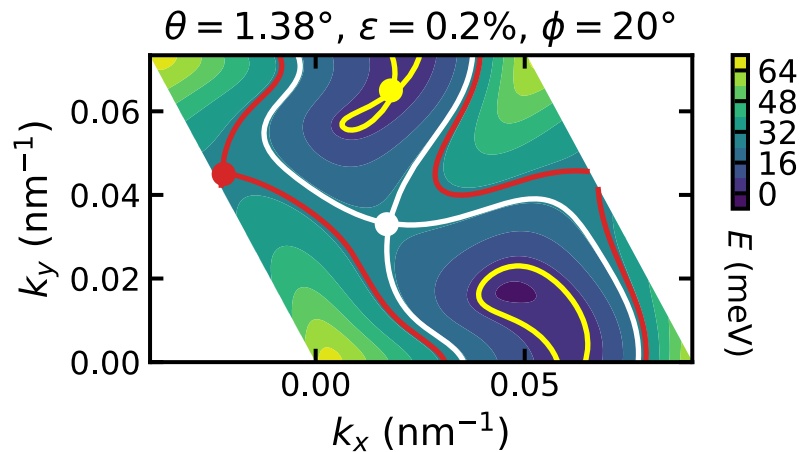
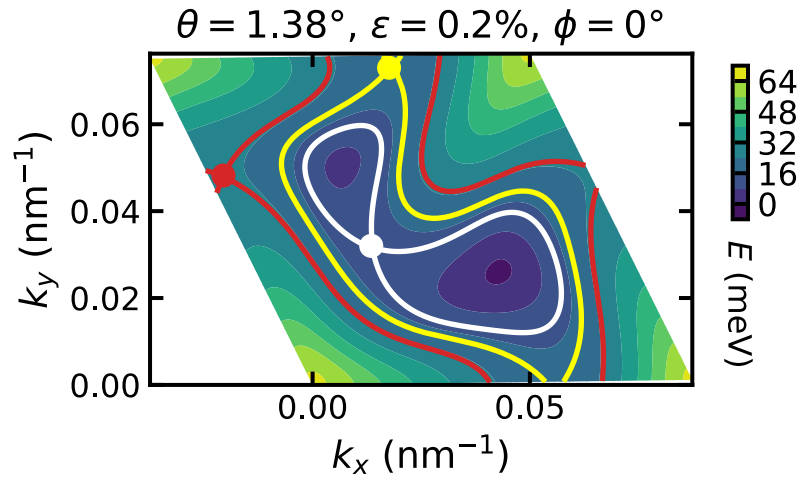
- Uniaxial heterostrain splits degeneracy of van Hove singularities
- Open orbits over a range of density: $\rho_{xx} \propto B^2$
- Expect highly anisotropic transport
- Can we fit the amount of strain and strain direction?



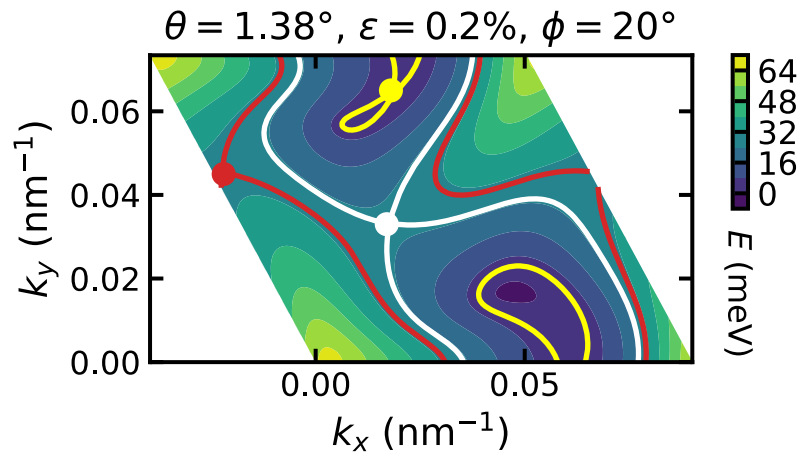
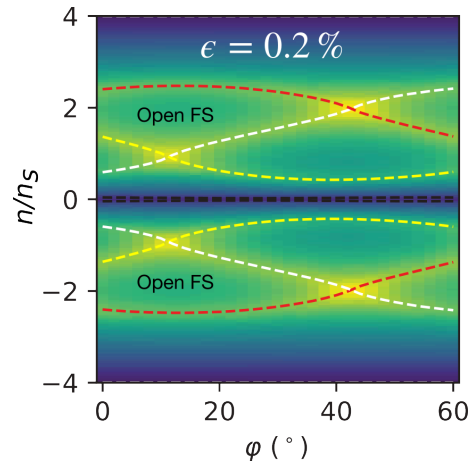
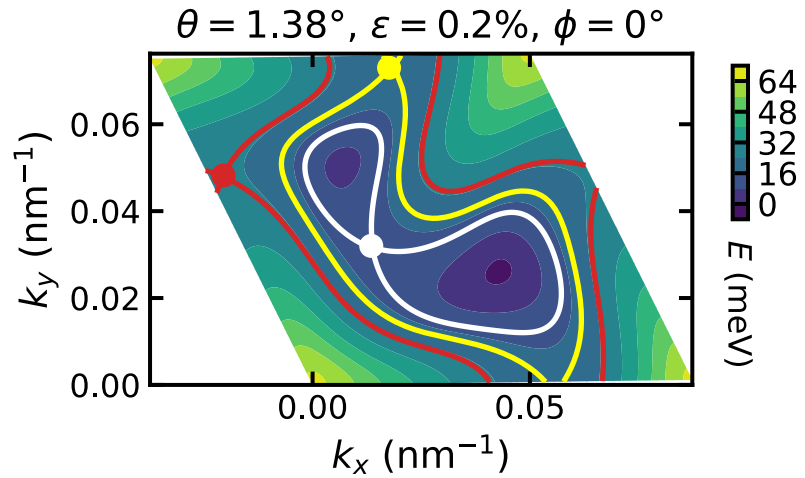
Fitting strain via Lifshitz transitions



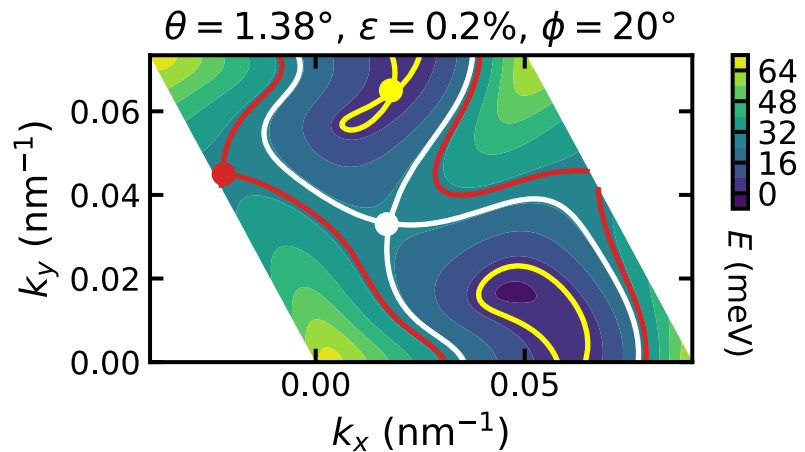
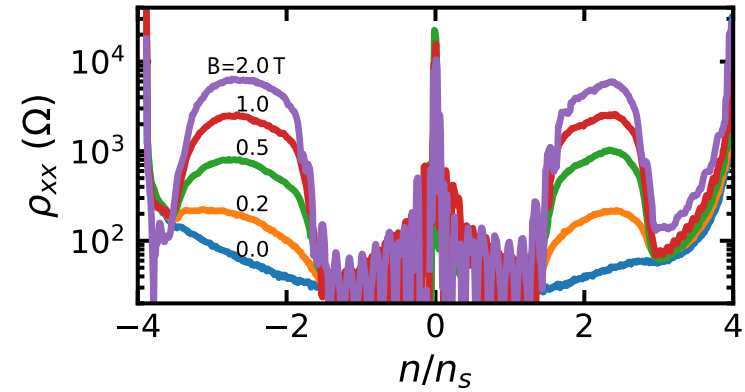
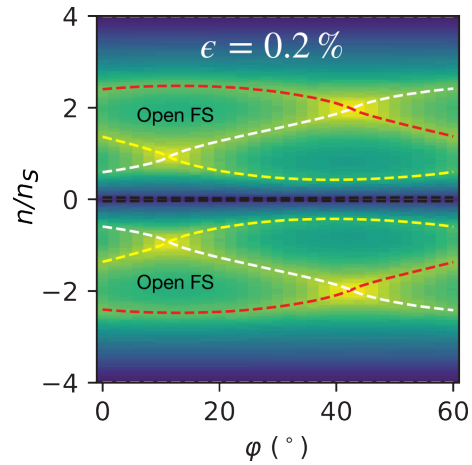
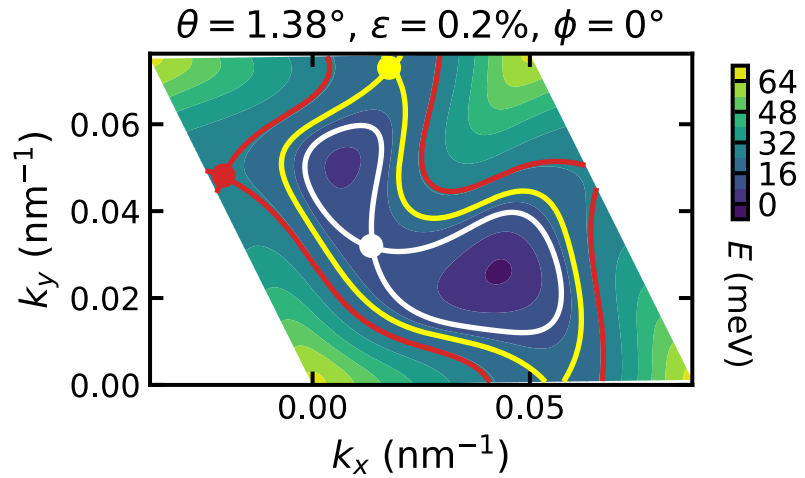
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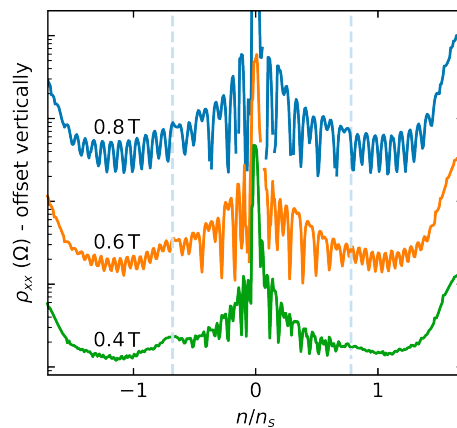
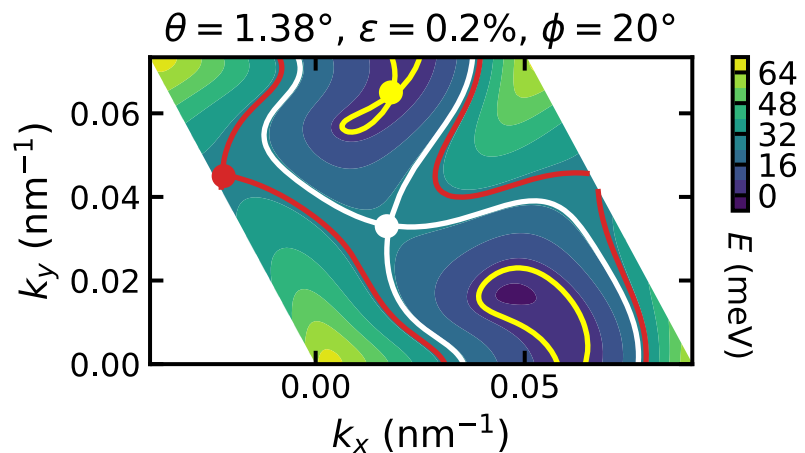
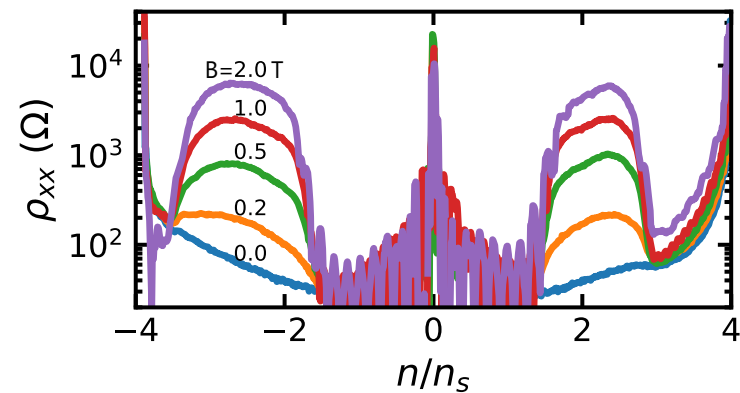
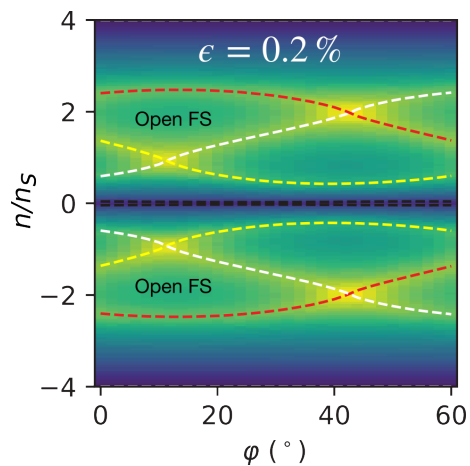
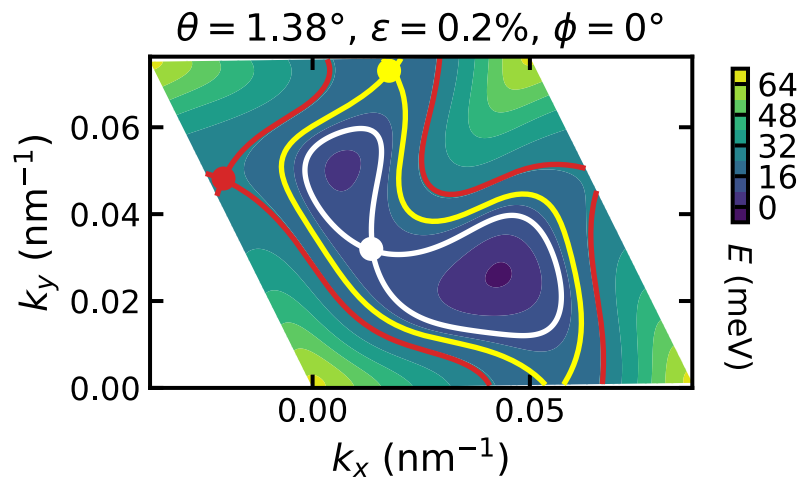
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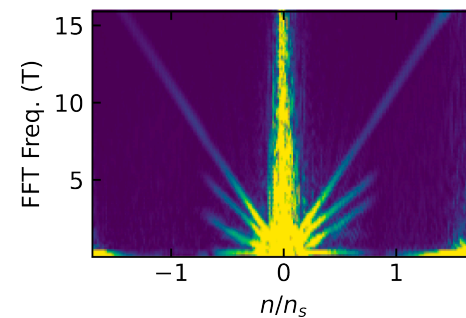
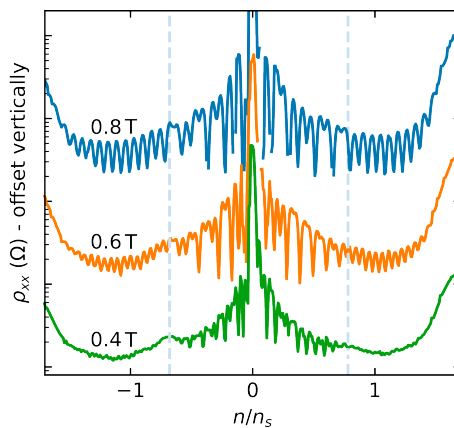
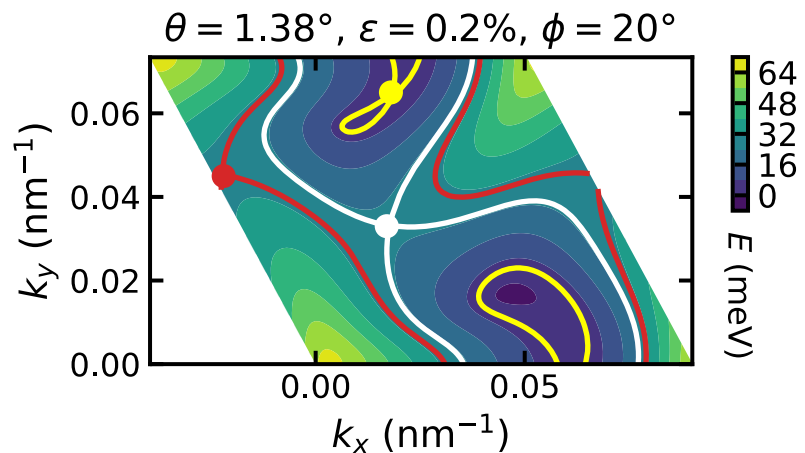
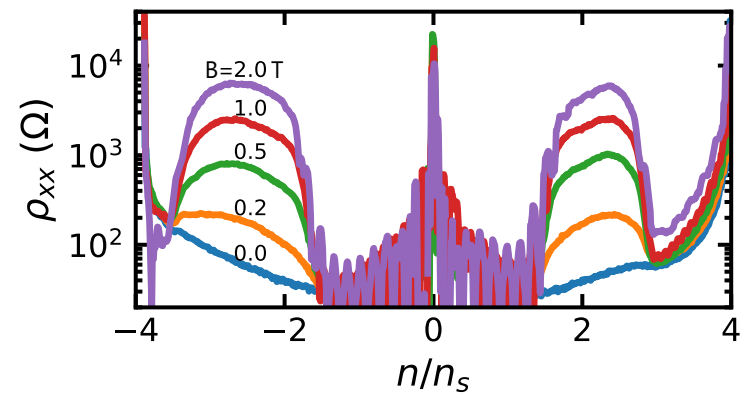
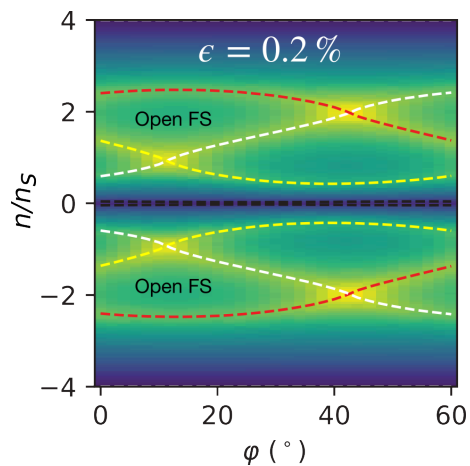
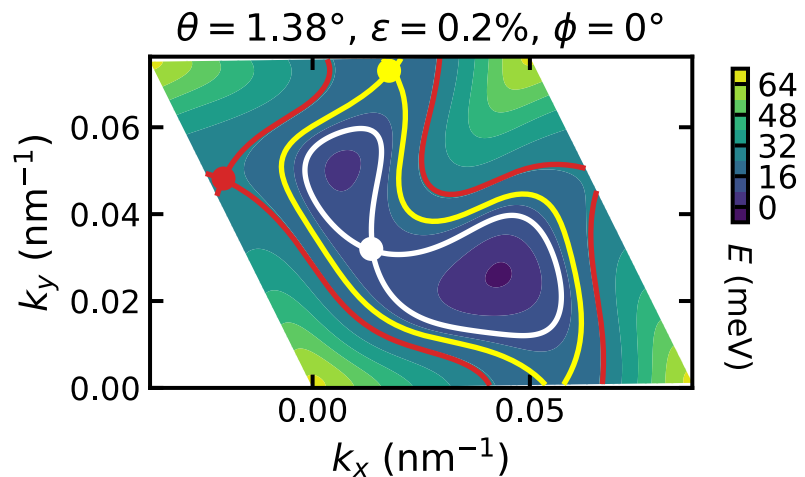
Fitting strain via Lifshitz transitions



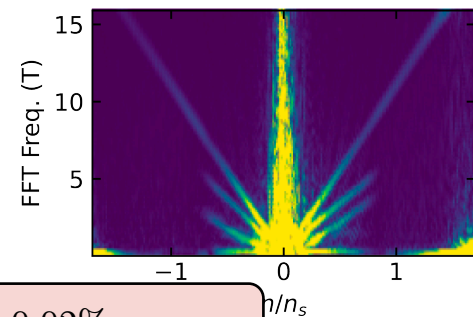
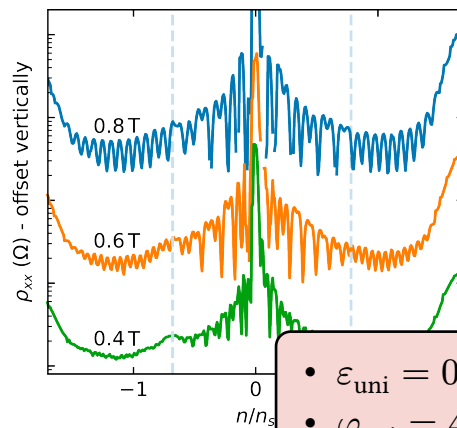
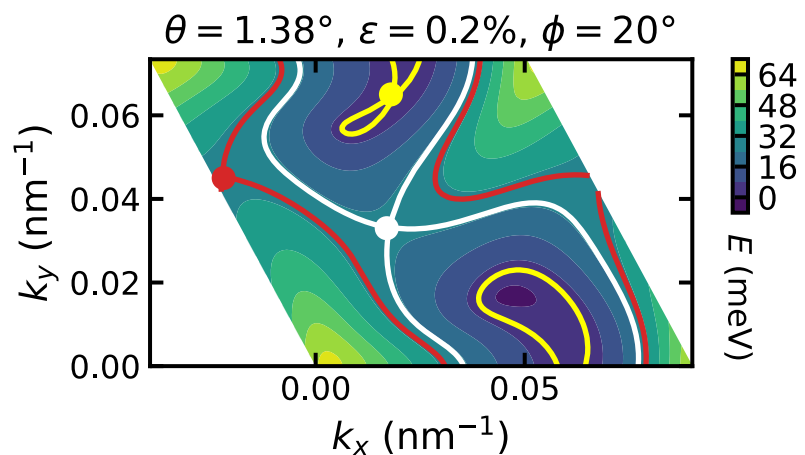
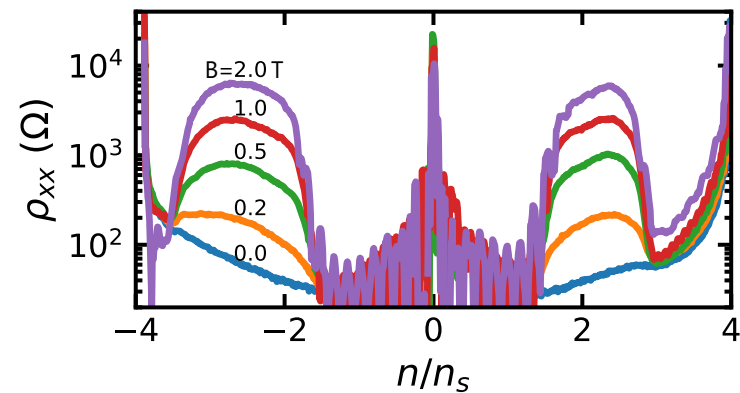
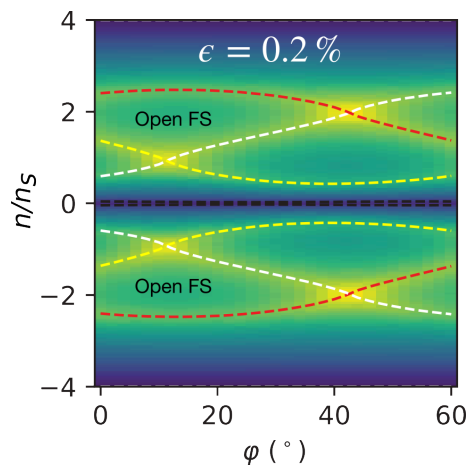
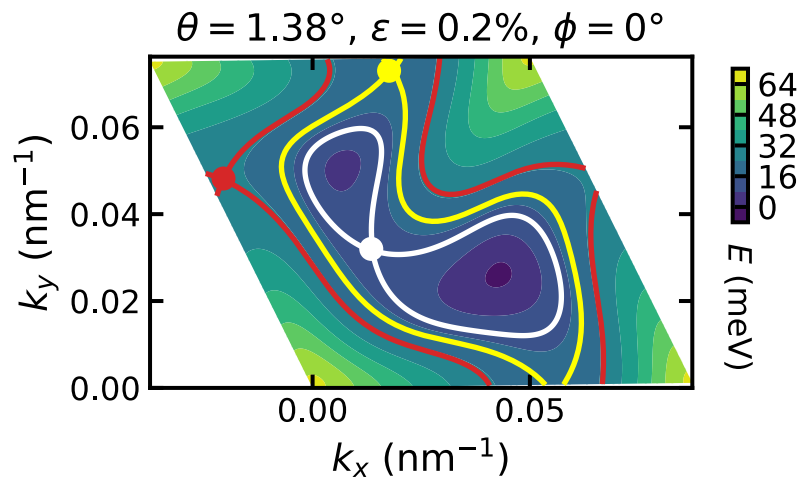
Fitting strain via Lifshitz transitions



Fitting strain via Lifshitz transitions



Fitting strain via Lifshitz transitions

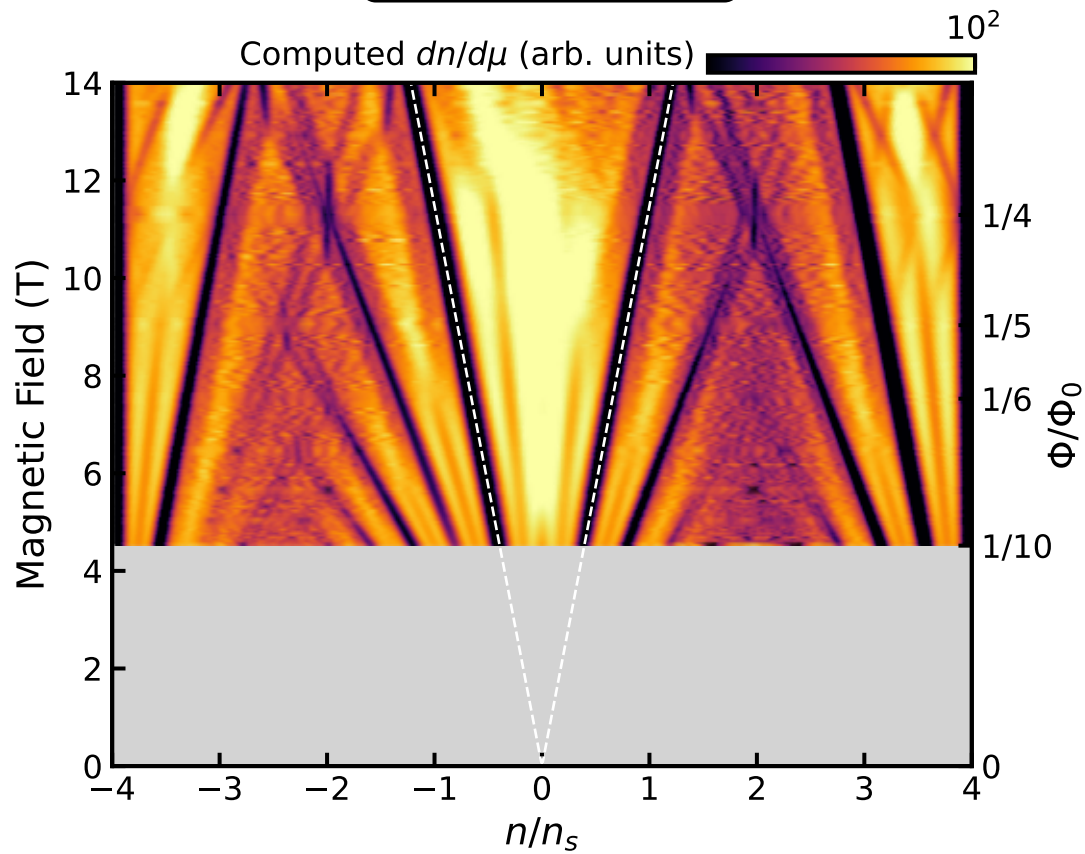
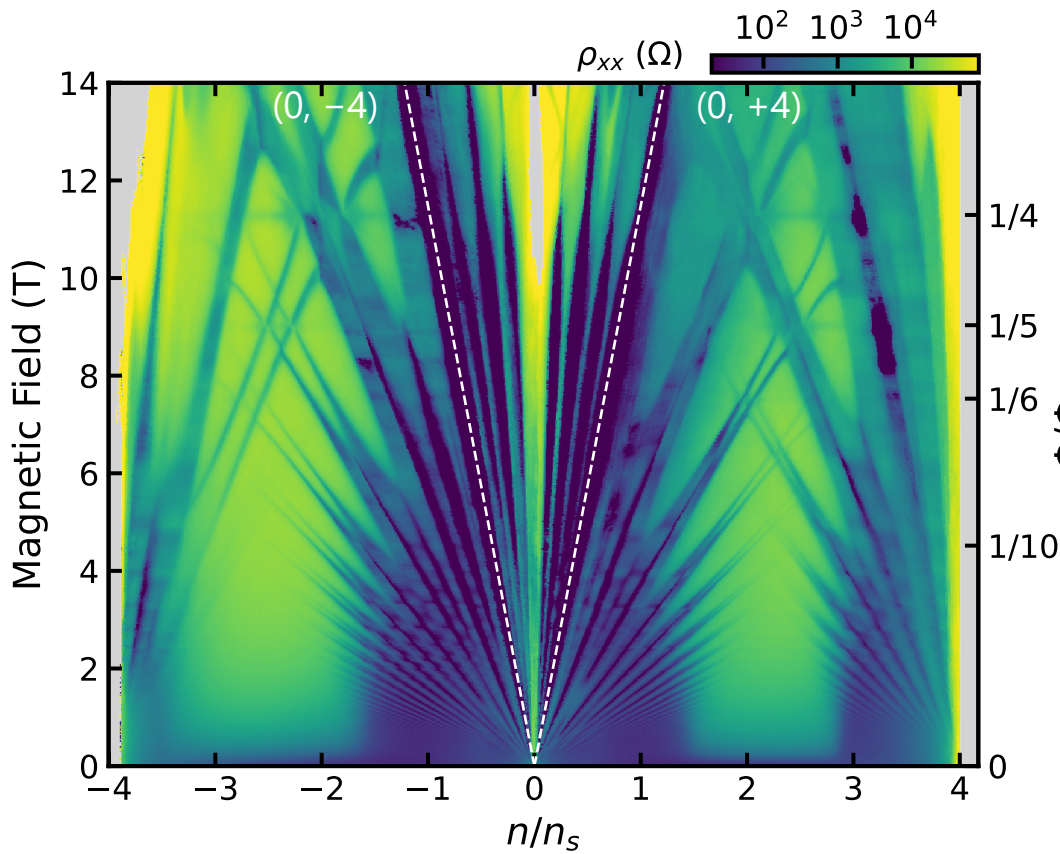


- $\epsilon_{\text{uni}} = 0.24 \pm 0.02\%$
- $\varphi_{\text{uni}} = 45 \pm 4^\circ$
- $\epsilon_{\text{bi}} = 0.3 \pm 0.1\%$

Finney, Sharpe, et al. PNAS (2022)

Wang, Finney, Sharpe, et al. PNAS (2023)

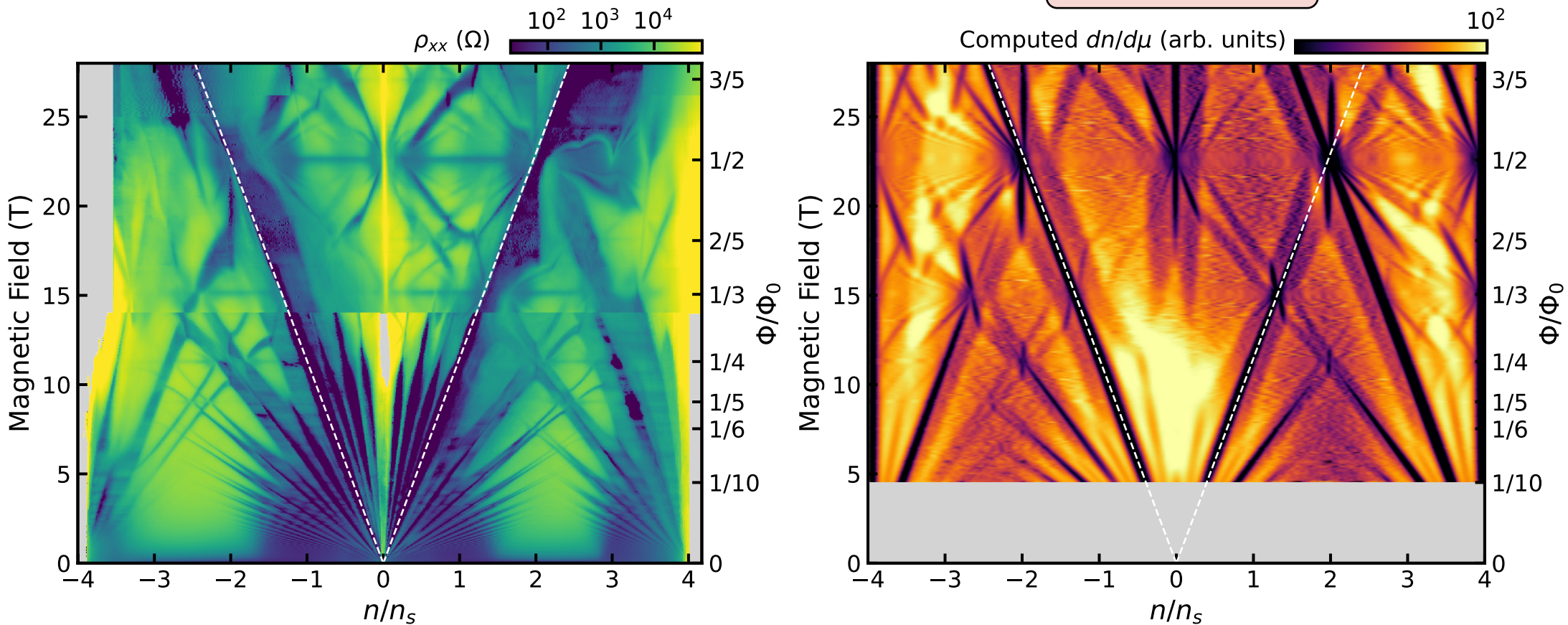
Hofstadter up to 14 T



- $\varepsilon_{\text{uni}} = 0.24 \pm 0.02\%$
- $\varphi_{\text{uni}} = 45 \pm 4^\circ$
- $\varepsilon_{\text{bi}} = 0.3 \pm 0.1\%$

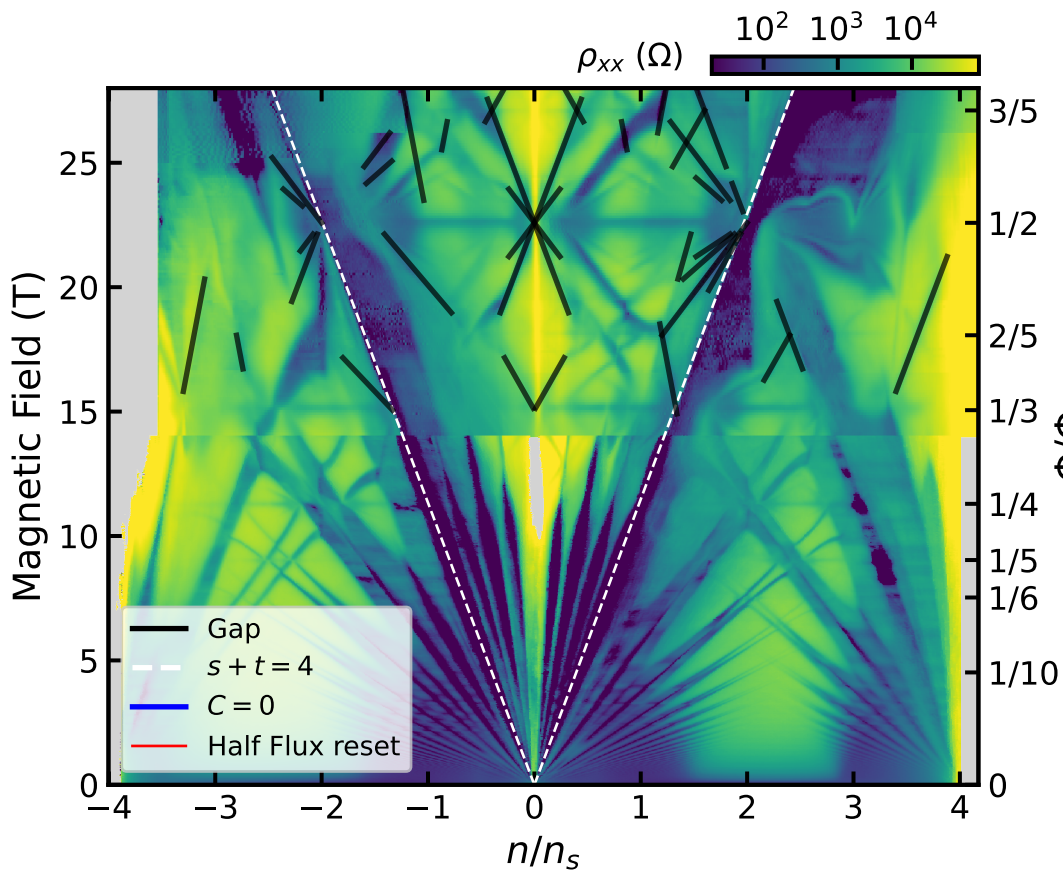
Finney, Sharpe, et al. PNAS (2022)
Wang, Finney, Sharpe, et al. PNAS (2023)
Finney, Sharpe, et al. arXiv:2503.12819

Hofstadter up to 28 T

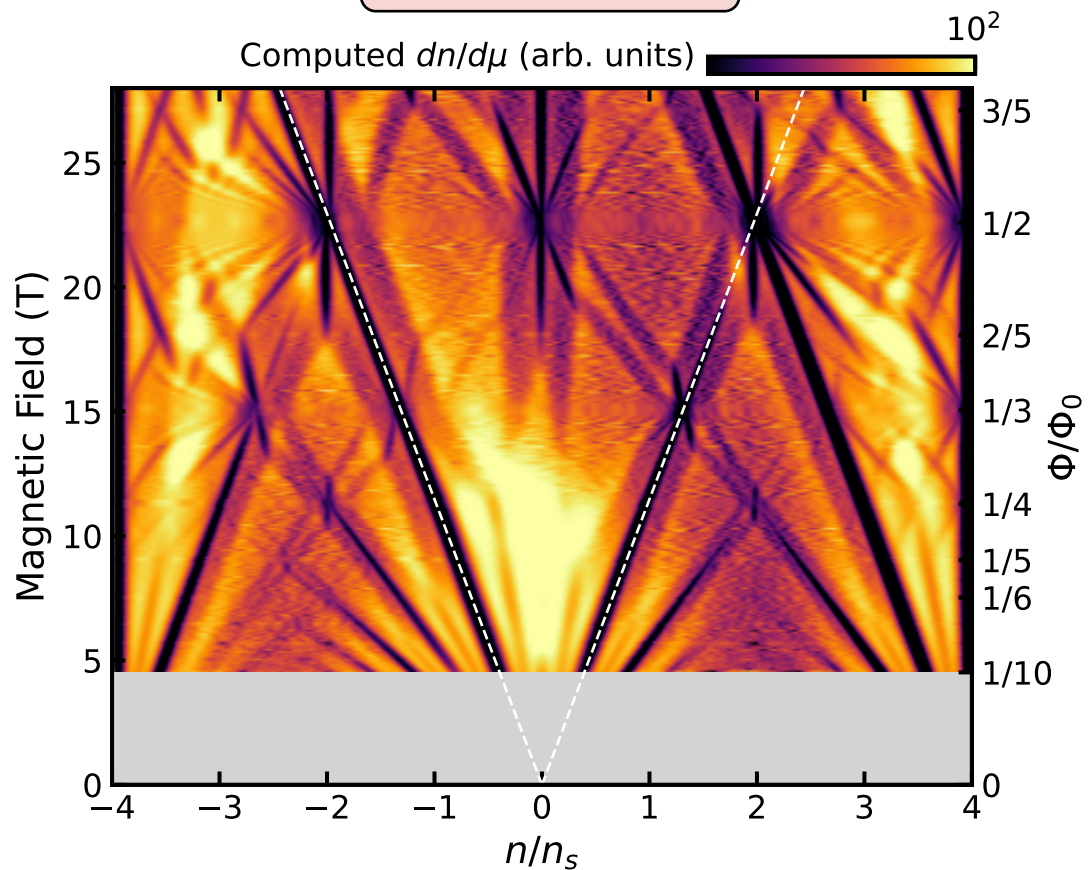


Finney, Sharpe, et al. PNAS (2022)
Wang, Finney, Sharpe, et al. PNAS (2023)
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Hofstadter up to 28 T

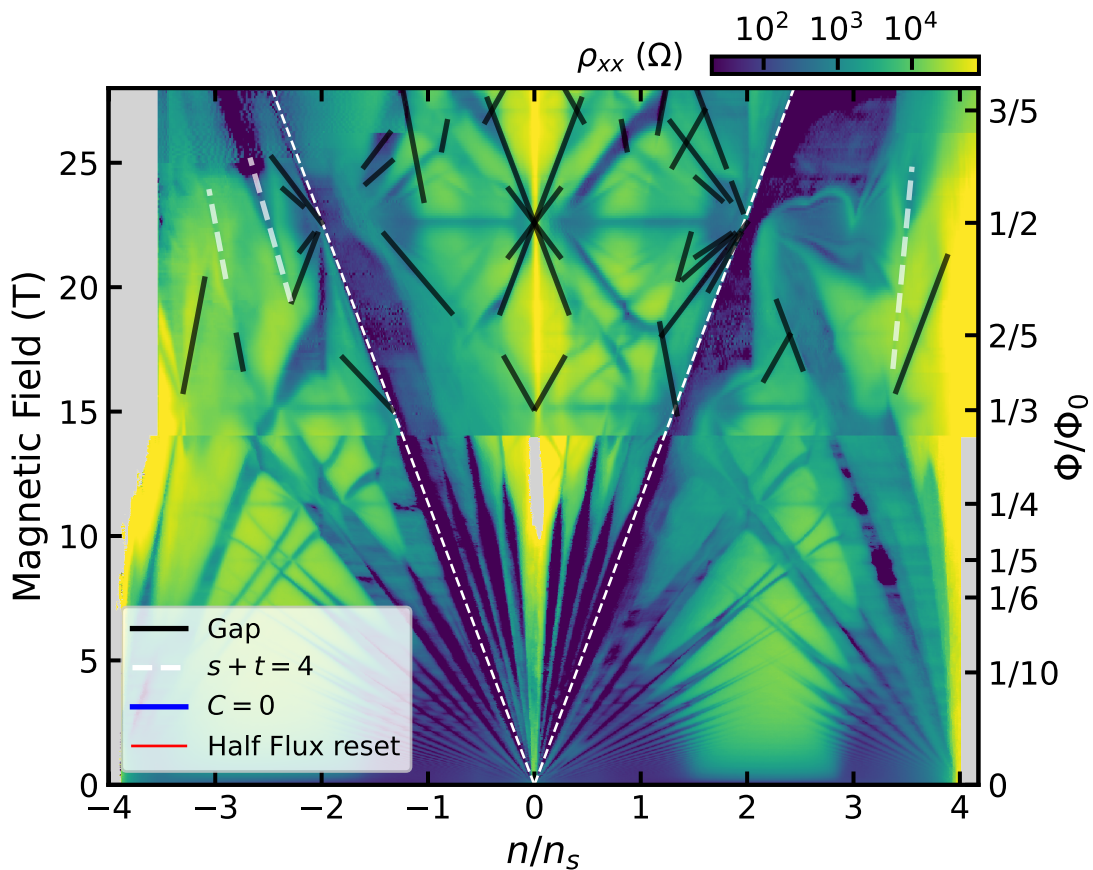


- $\varepsilon_{\text{uni}} = 0.24 \pm 0.02\%$
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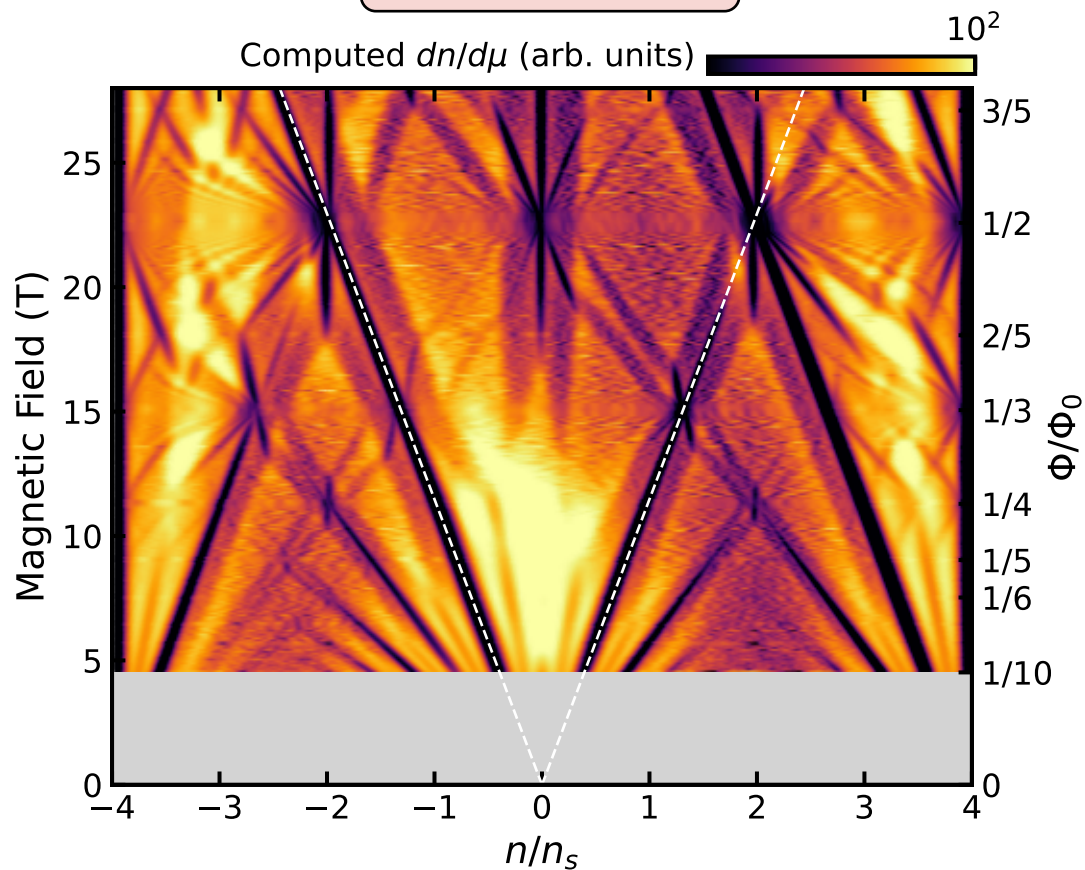


Finney, Sharpe, et al. PNAS (2022)
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Hofstadter up to 28 T

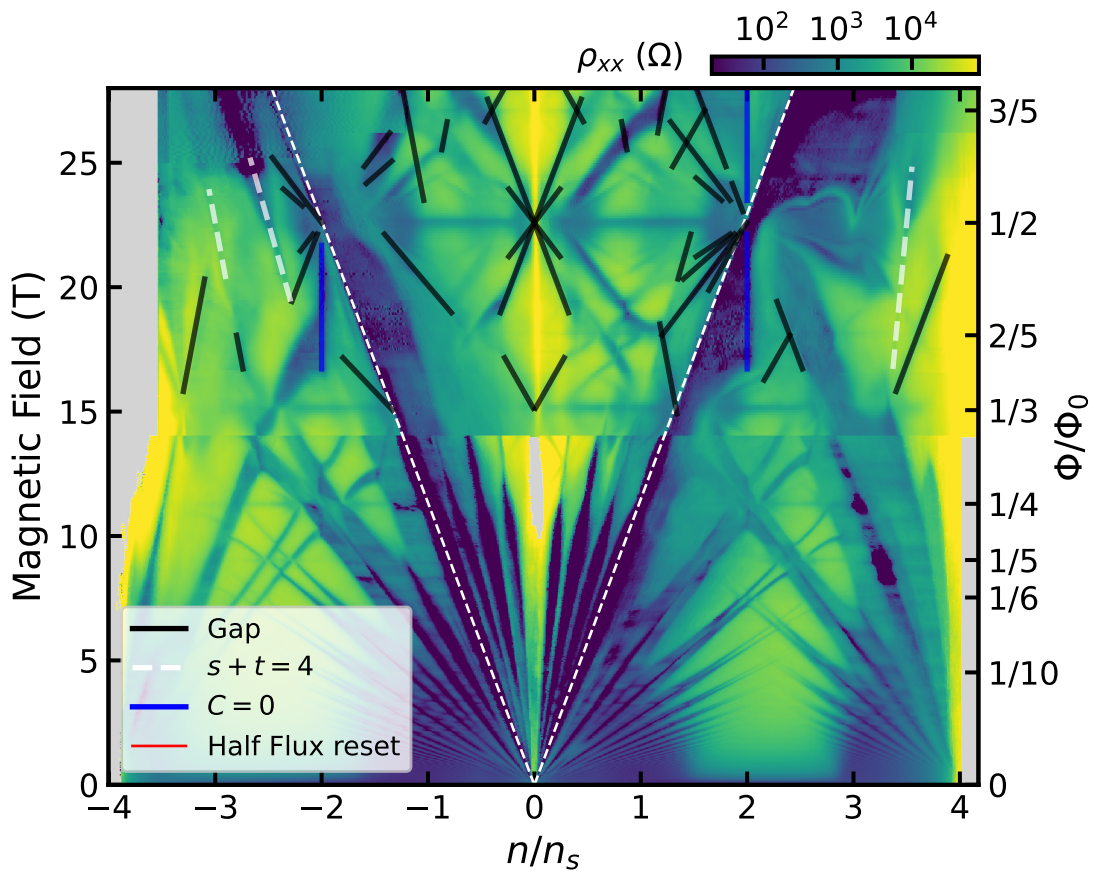


- $\epsilon_{\text{uni}} = 0.24 \pm 0.02\%$
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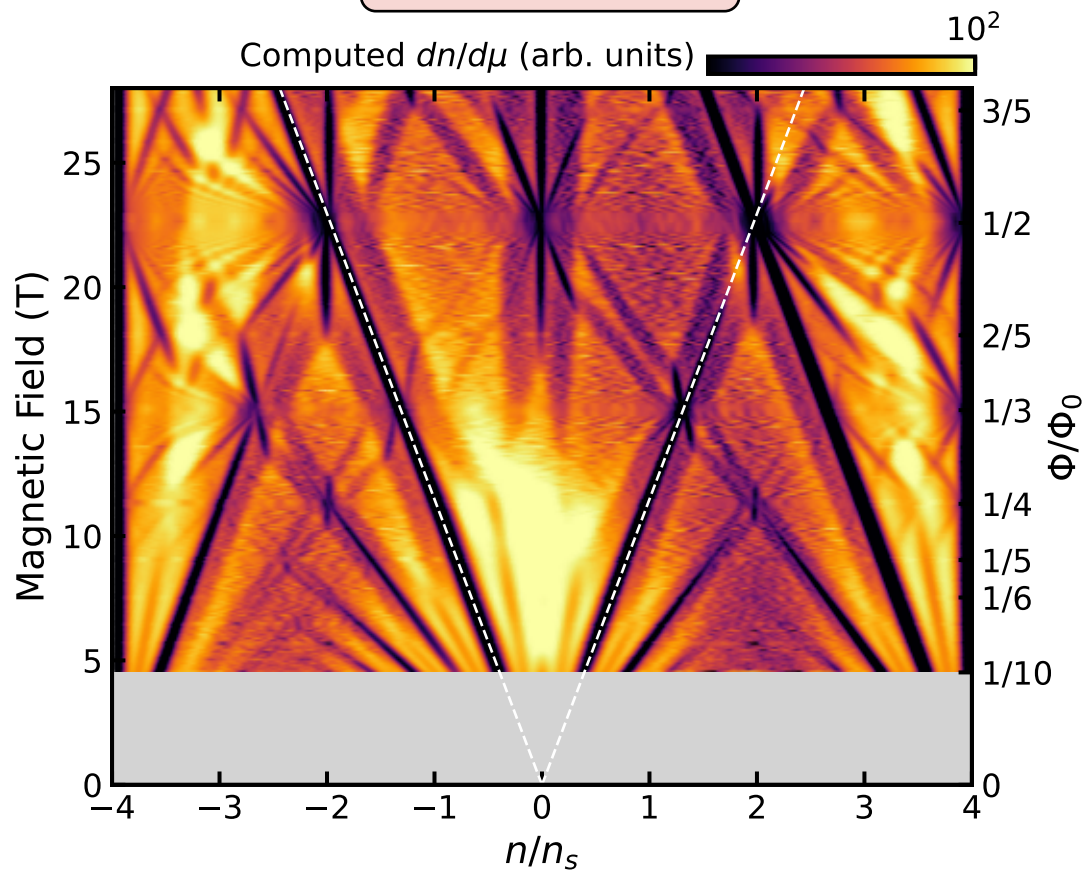


Finney, Sharpe, et al. PNAS (2022)
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Hofstadter up to 28 T

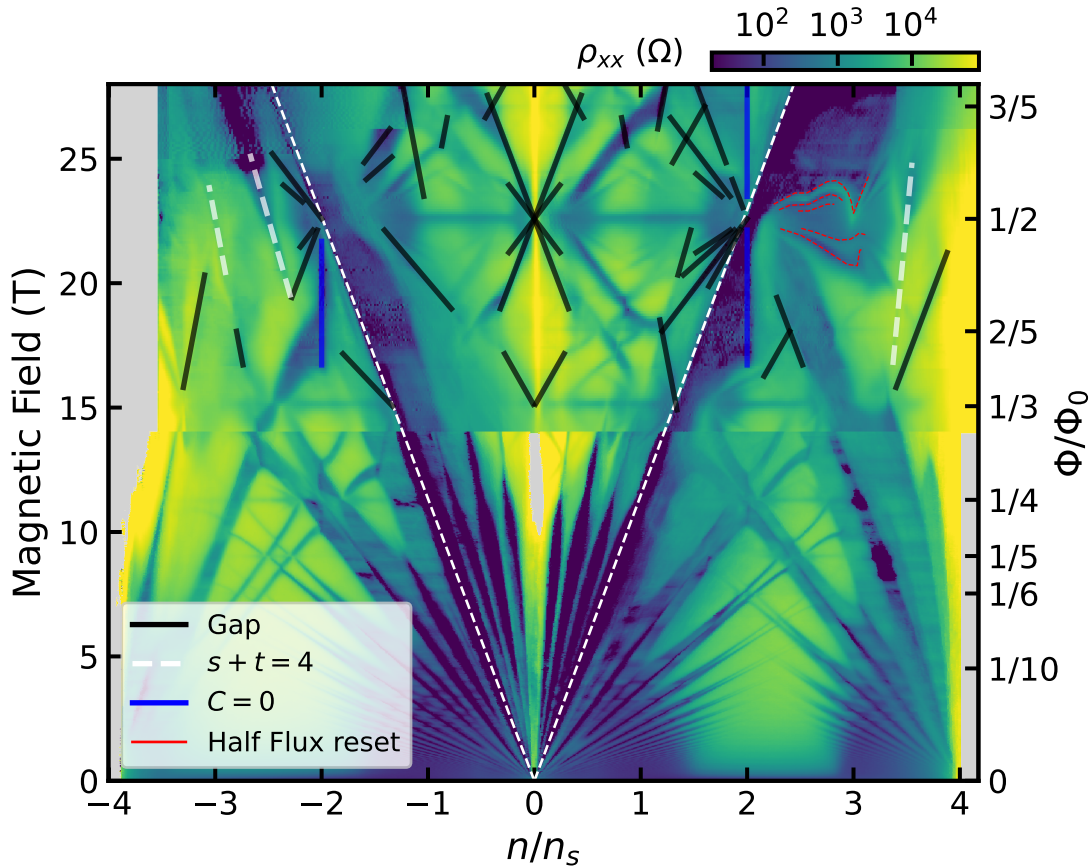


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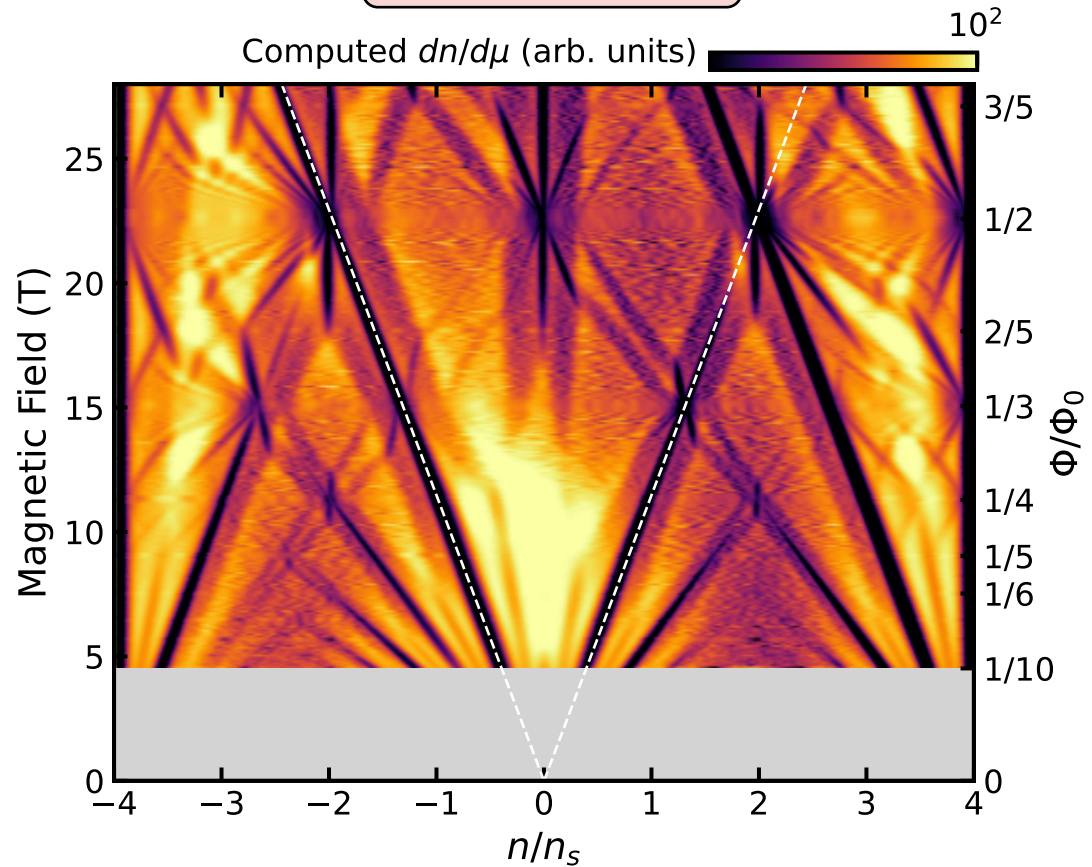


Finney, Sharpe, et al. PNAS (2022)
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Hofstadter up to 28 T



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Finney, Sharpe, et al. PNAS (2022)
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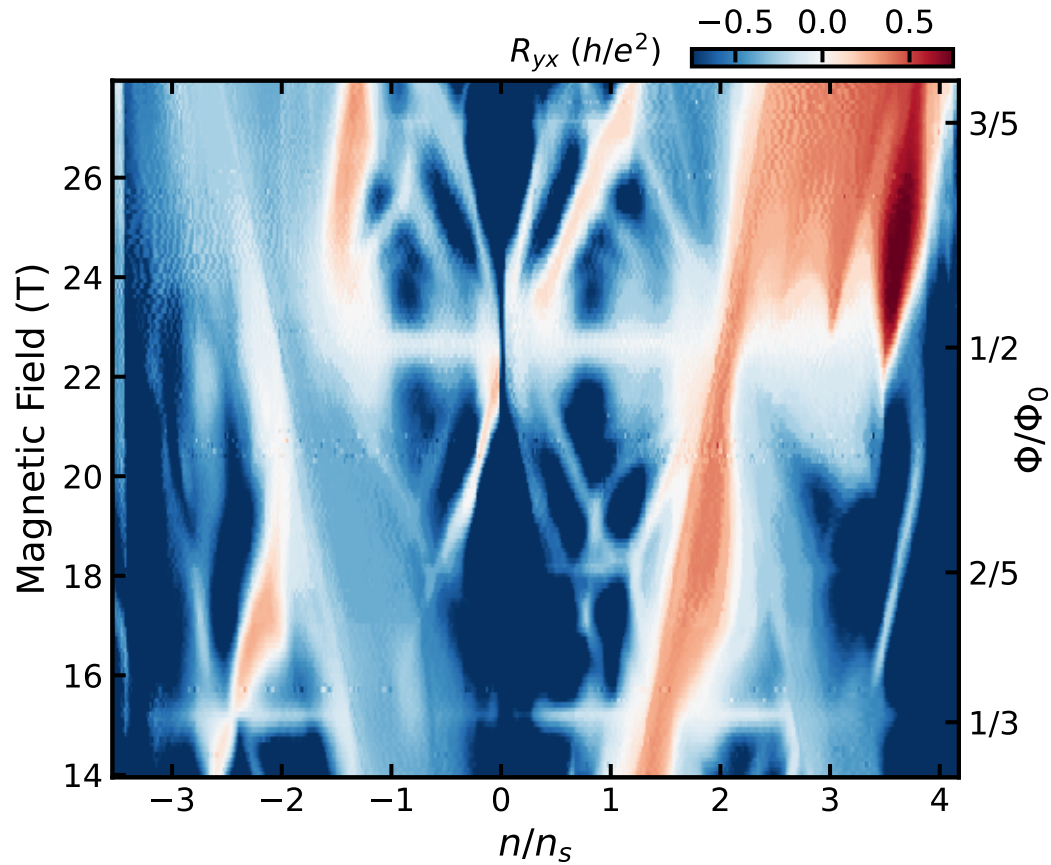
Outline

0. Introduction

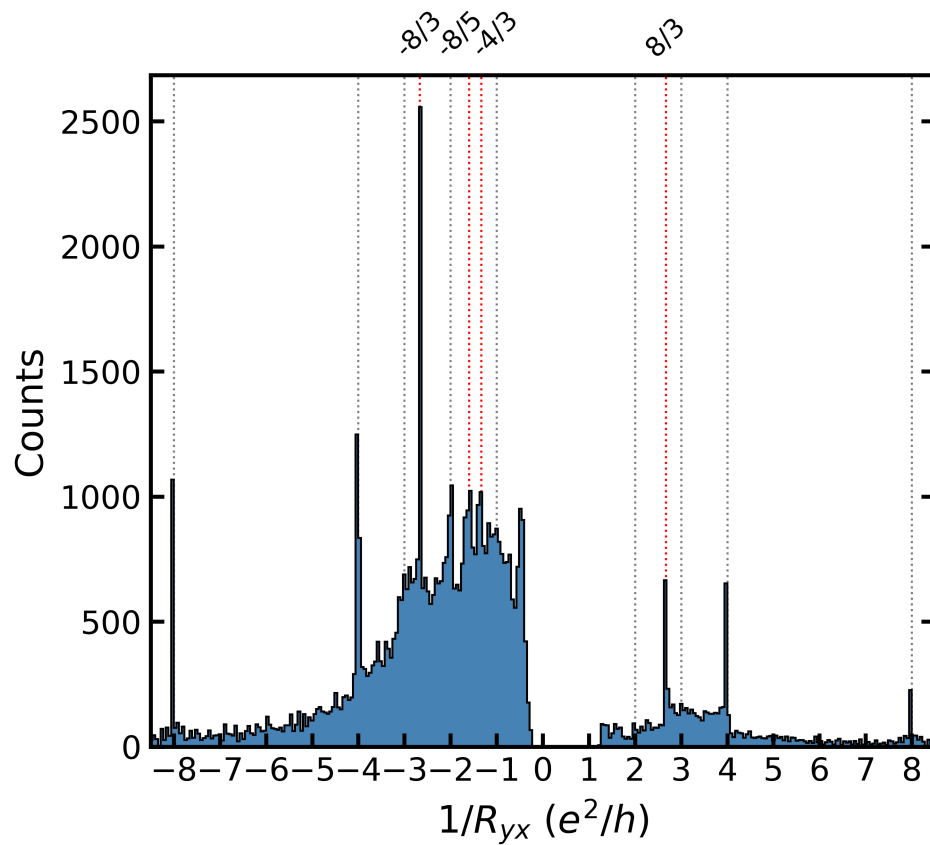
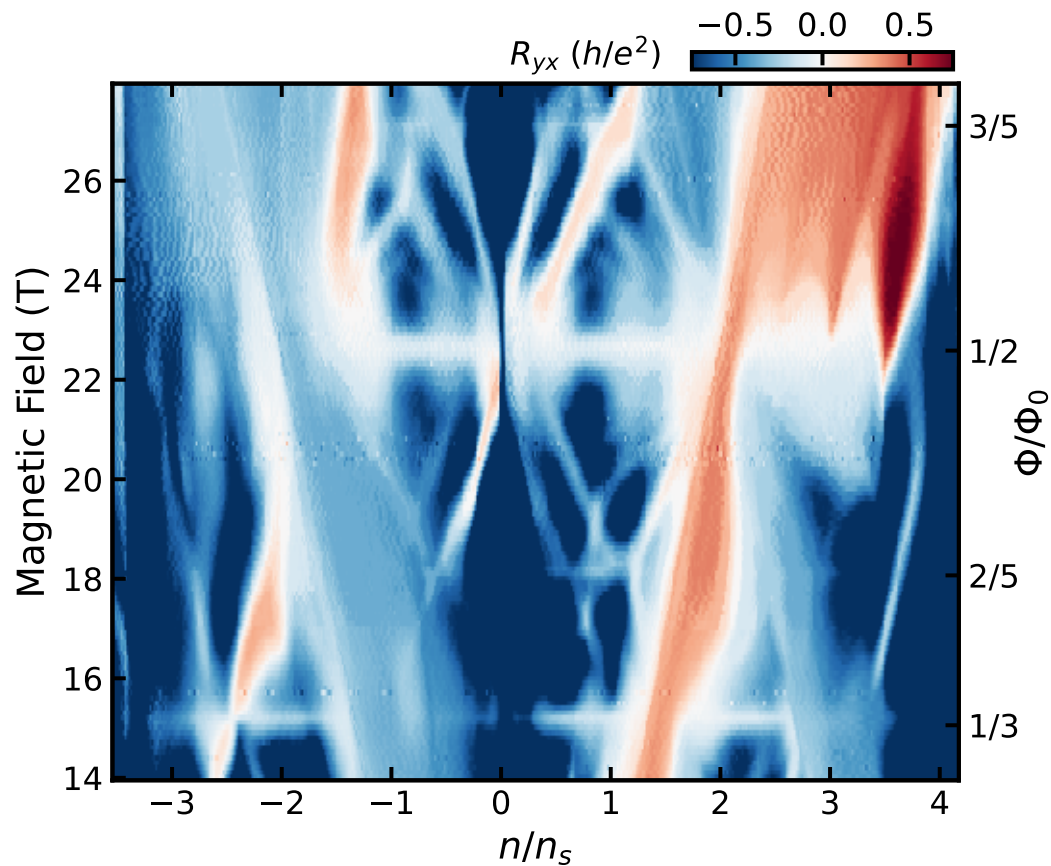
1. Extracting Structural Parameters at Low Magnetic Fields

2. Fractional Chern Insulators at High Magnetic Fields

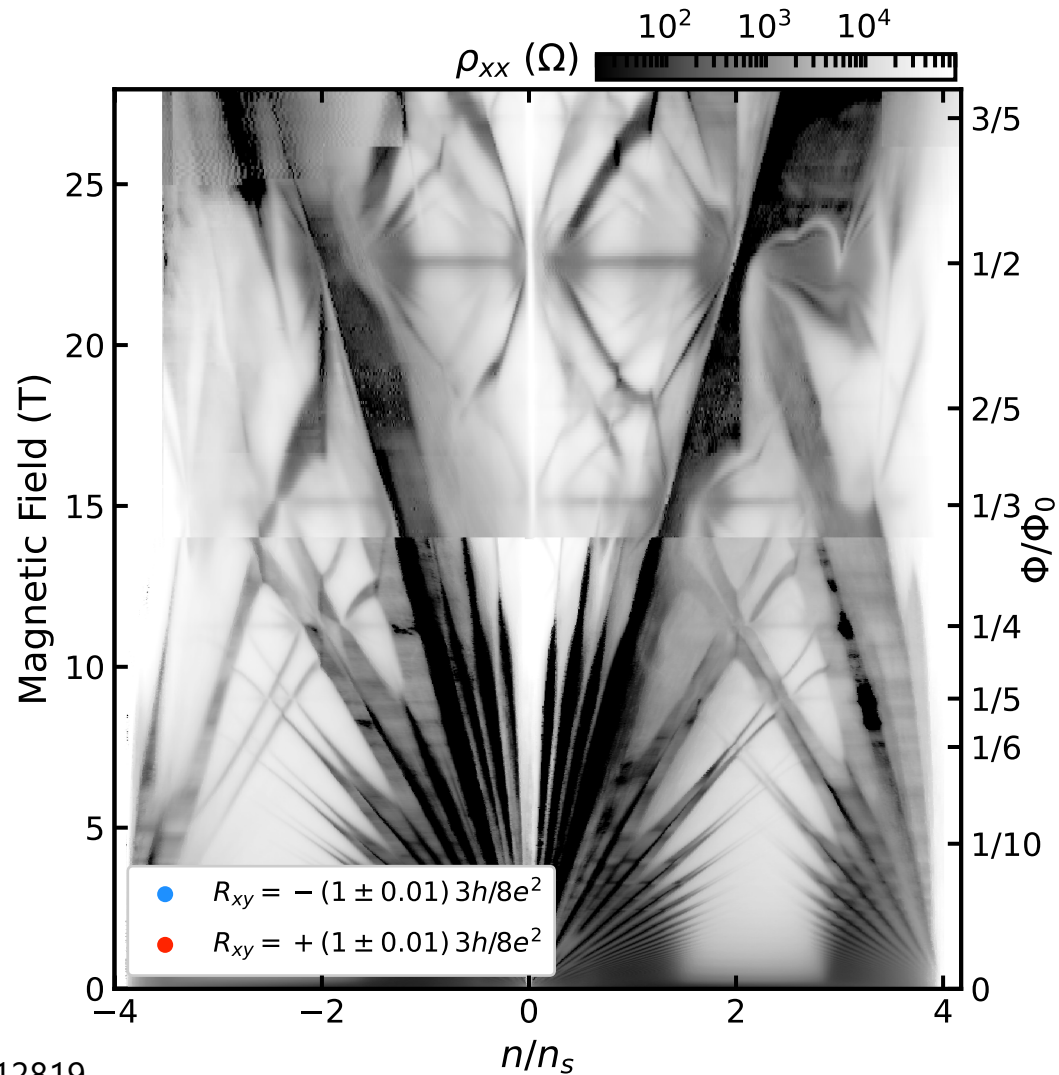
Hall resistance at high fields



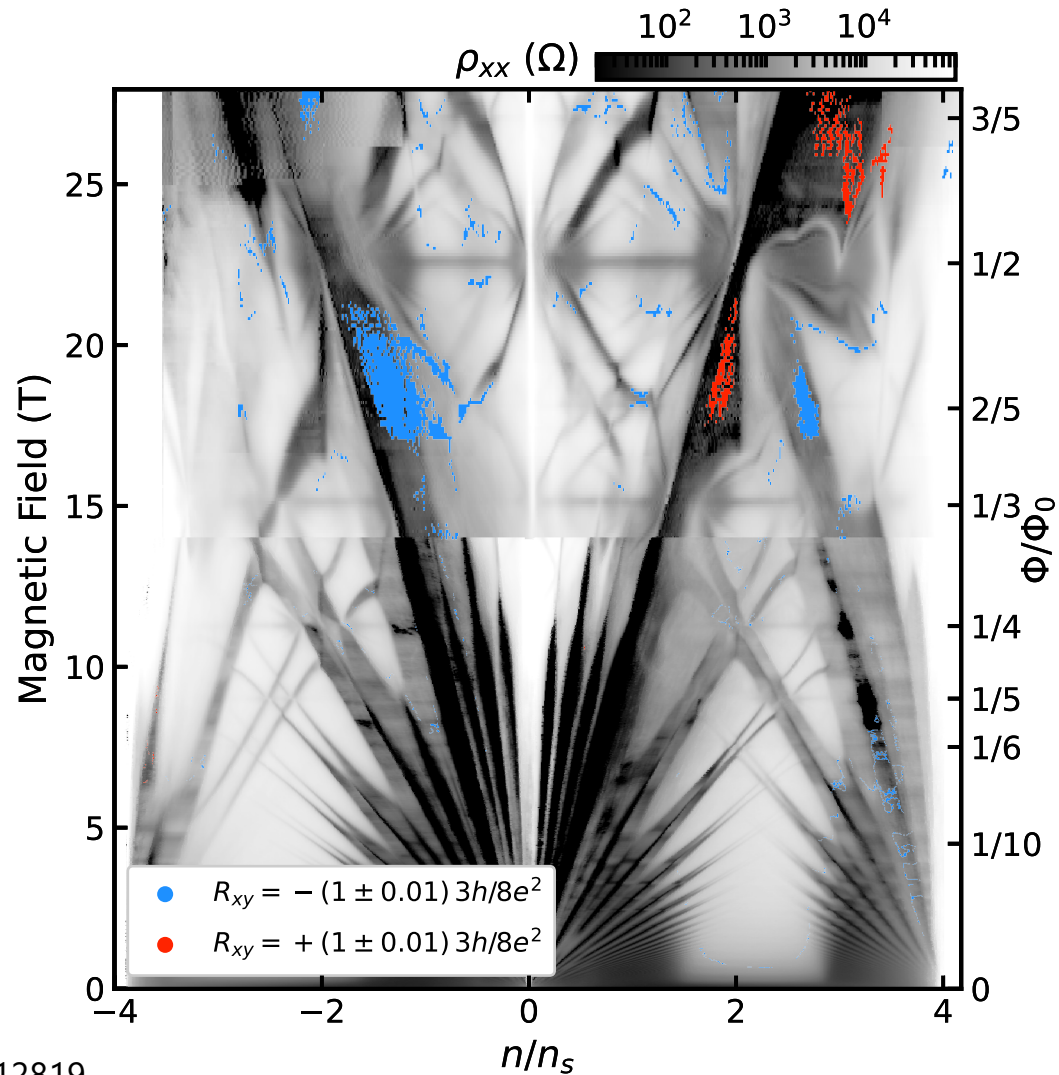
Hall resistance at high fields



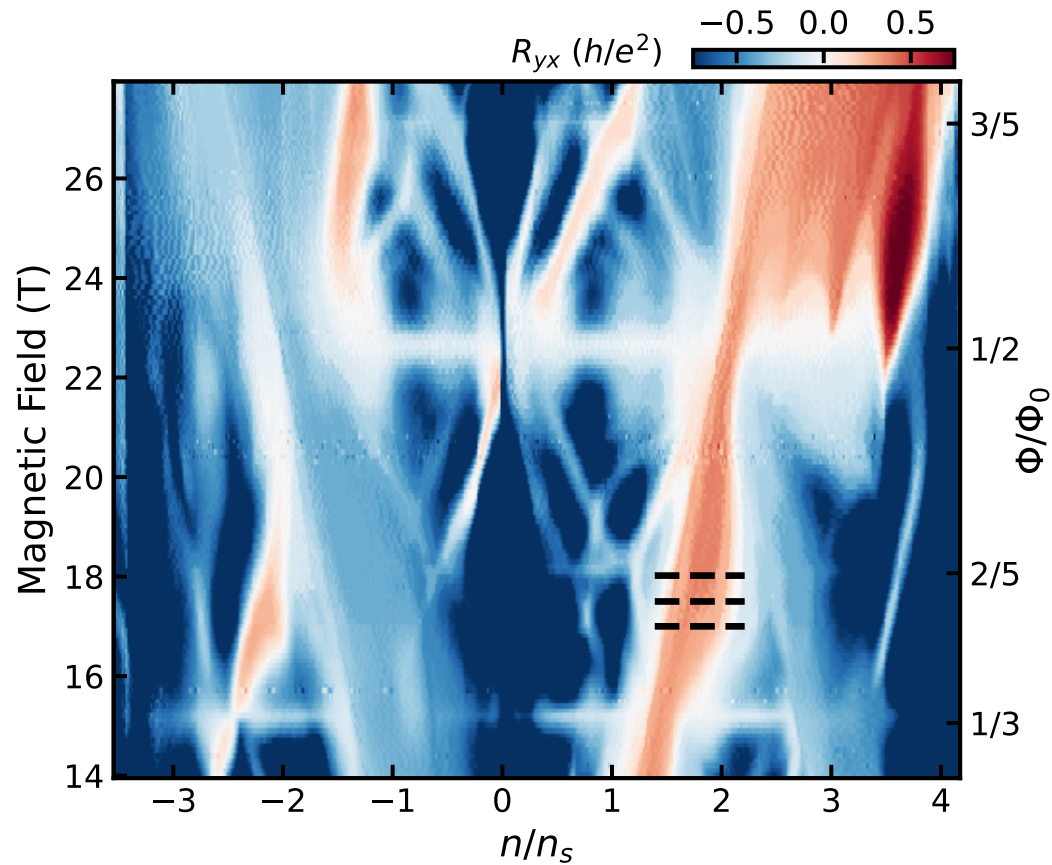
8/3 fractional Chern insulator



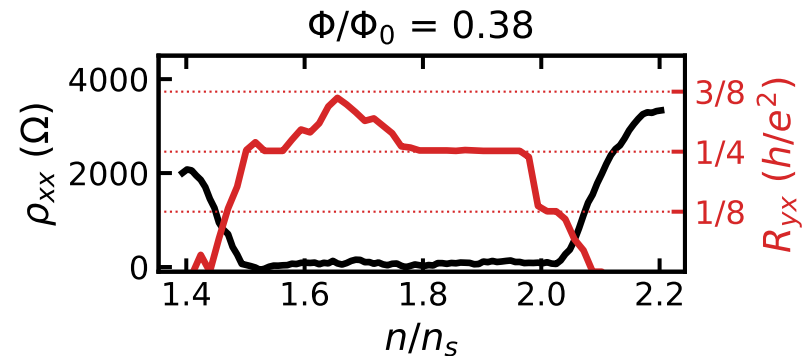
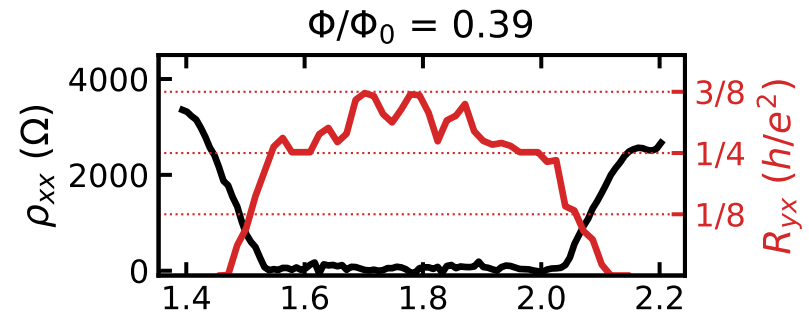
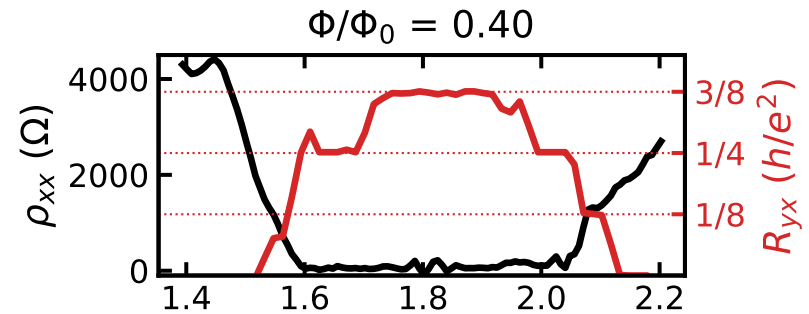
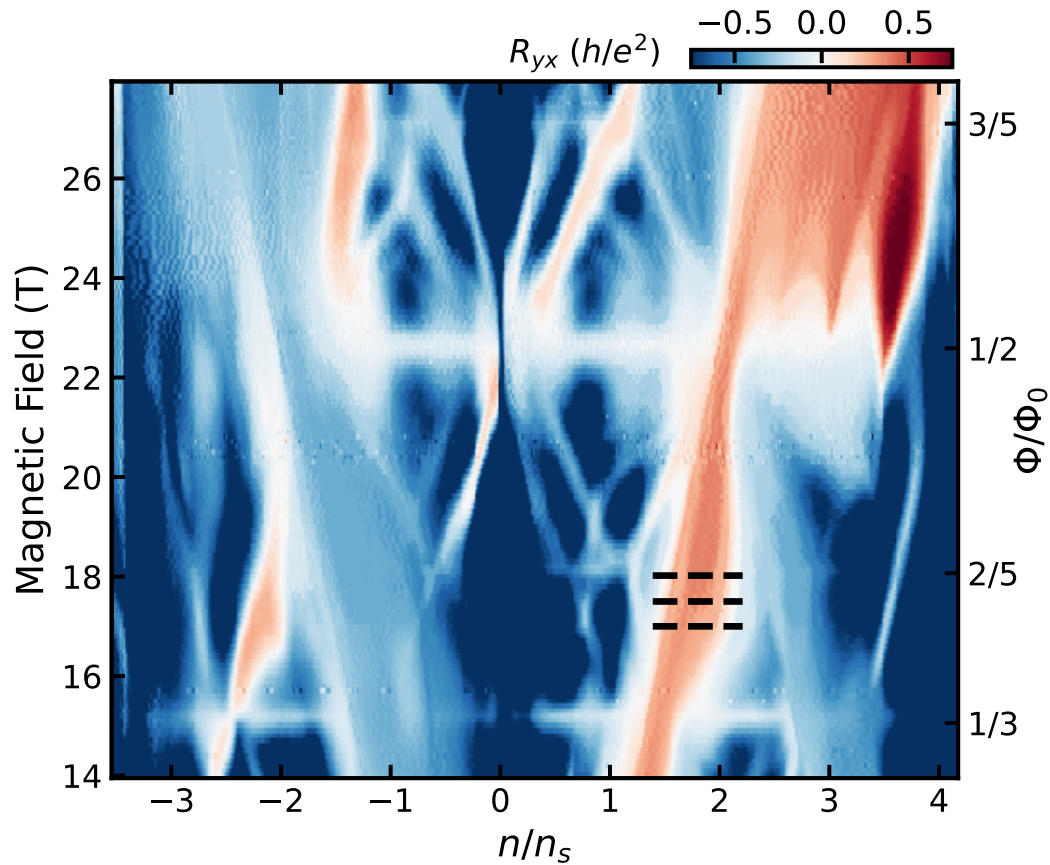
8/3 fractional Chern insulator



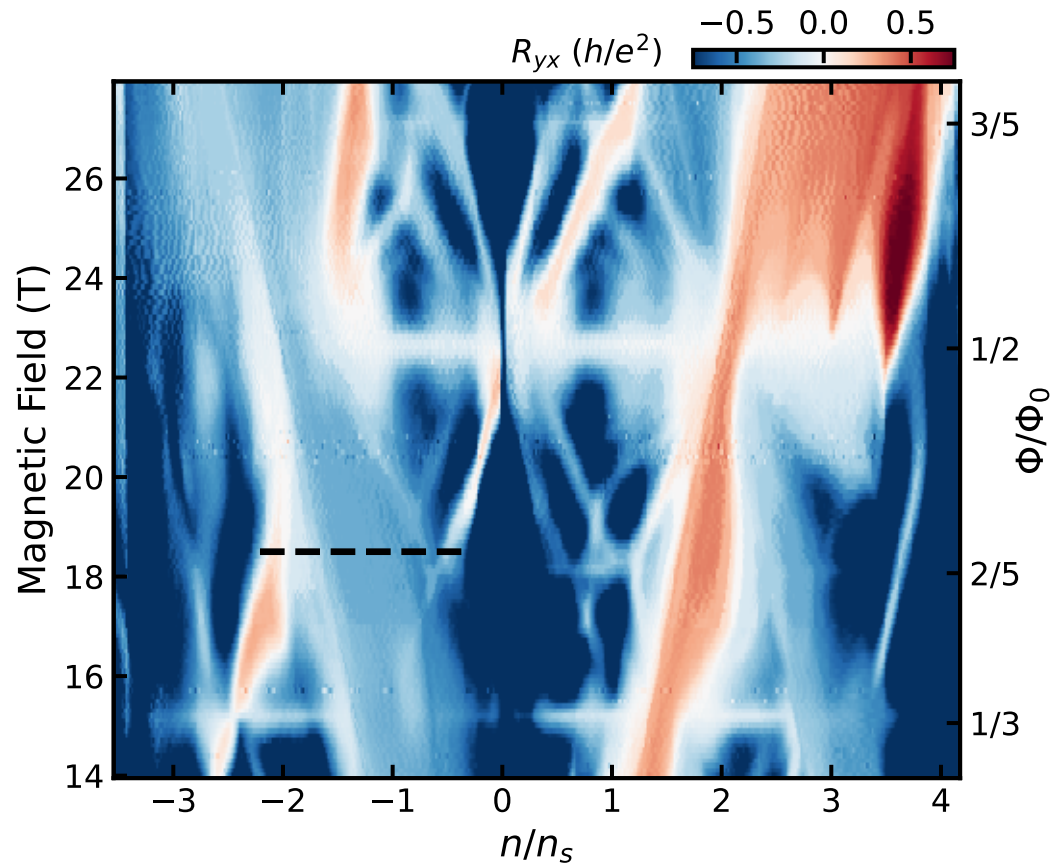
Line cuts near $\Phi/\Phi_0 = 2/5$



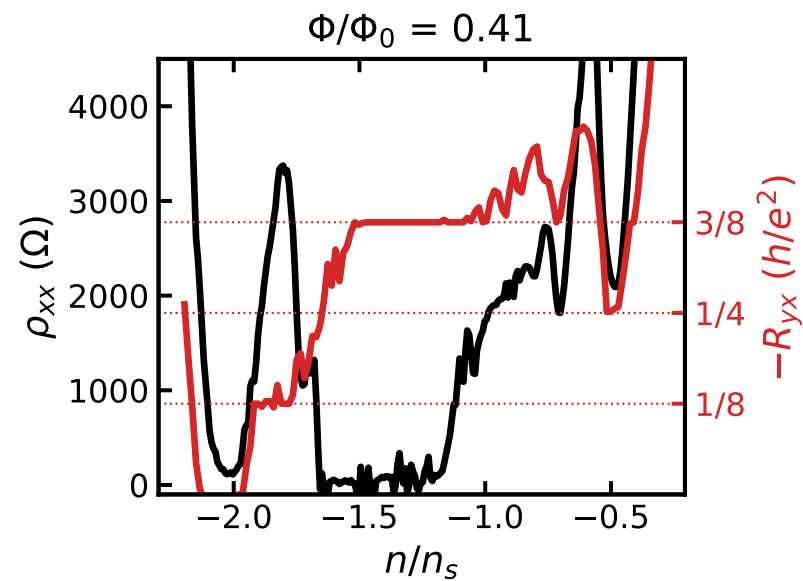
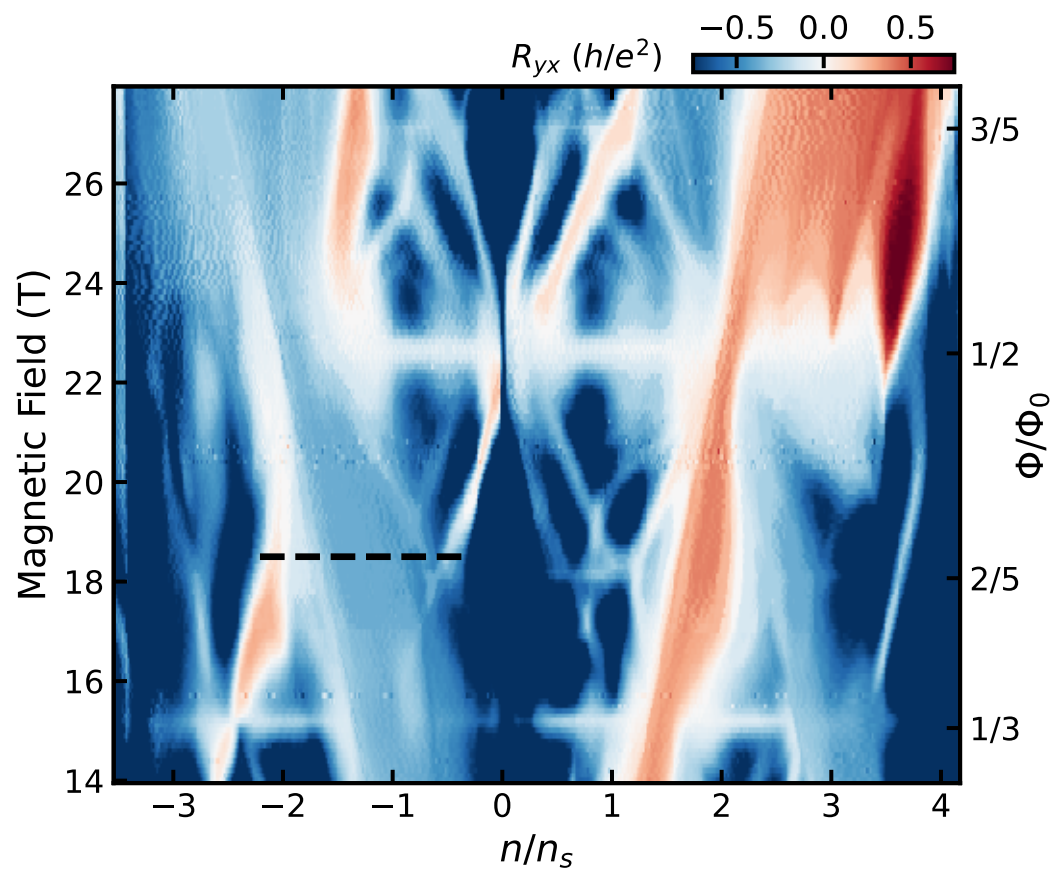
Line cuts near $\Phi/\Phi_0 = 2/5$



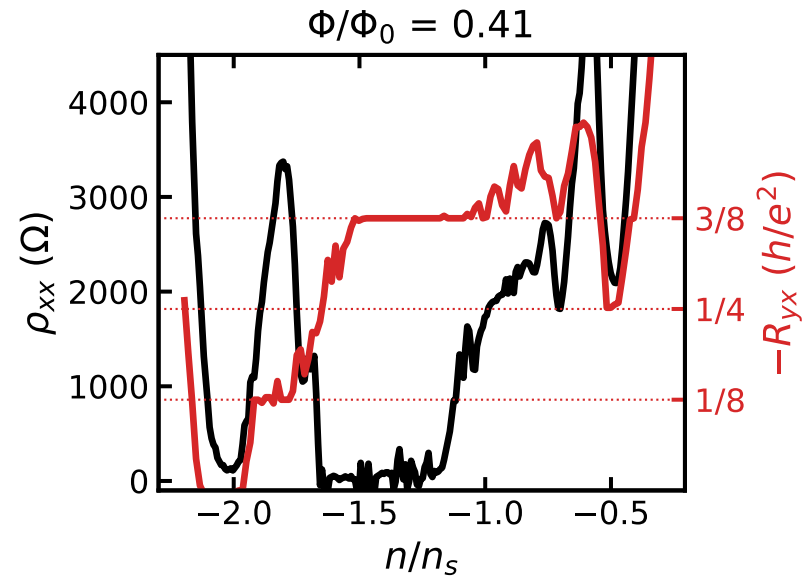
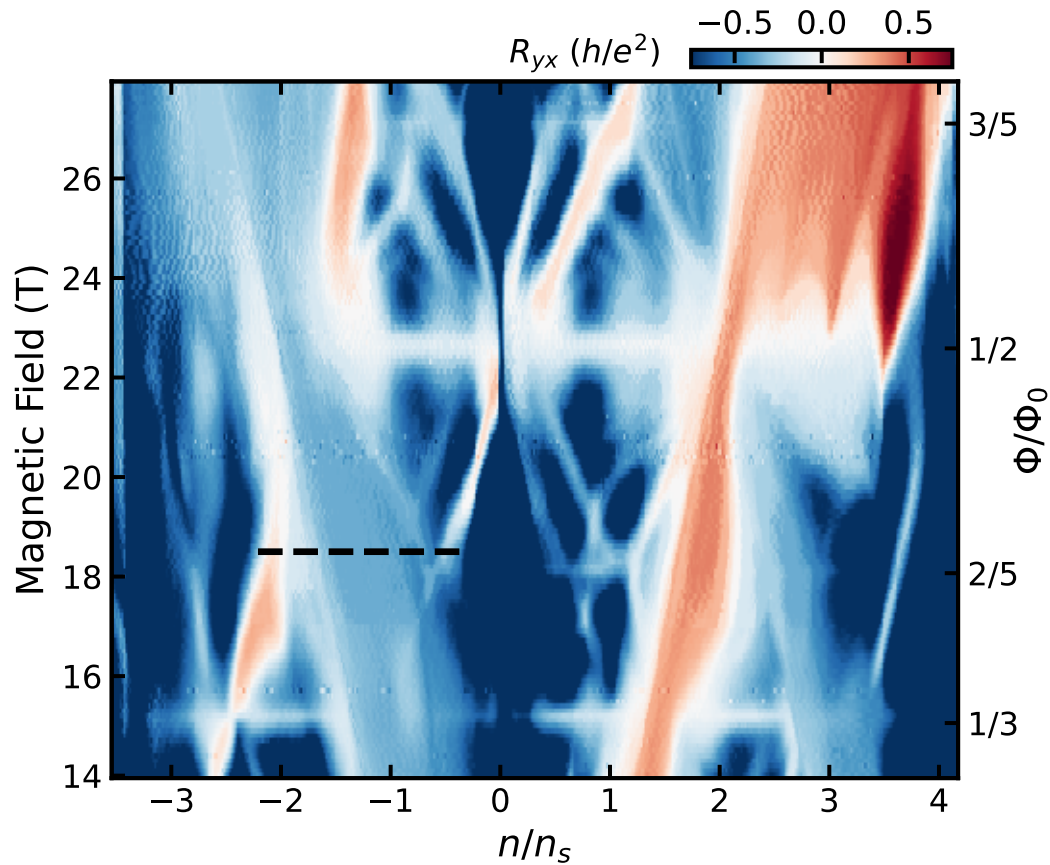
Line cuts near $\Phi/\Phi_0 = 2/5$



Line cuts near $\Phi/\Phi_0 = 2/5$

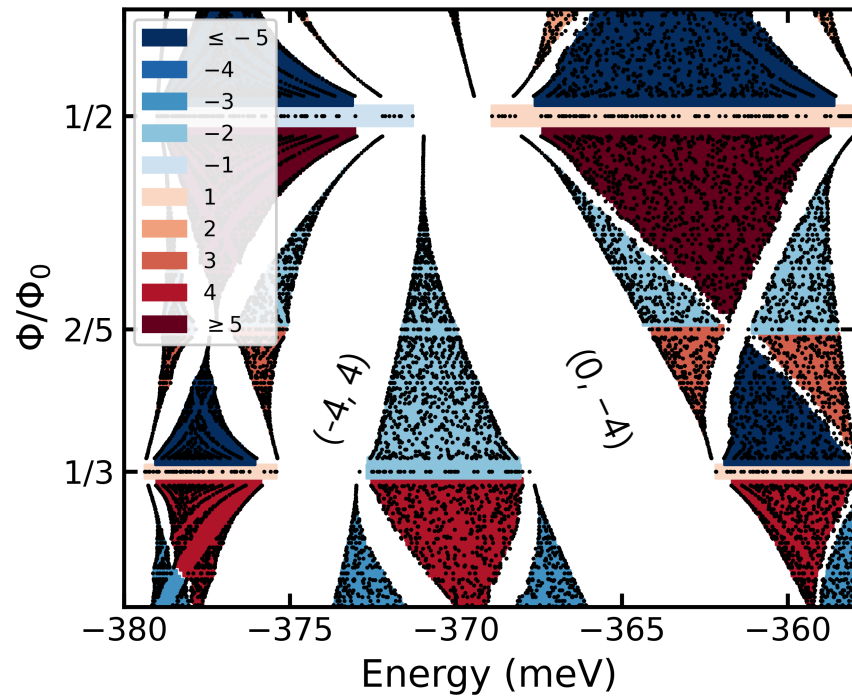


Line cuts near $\Phi/\Phi_0 = 2/5$

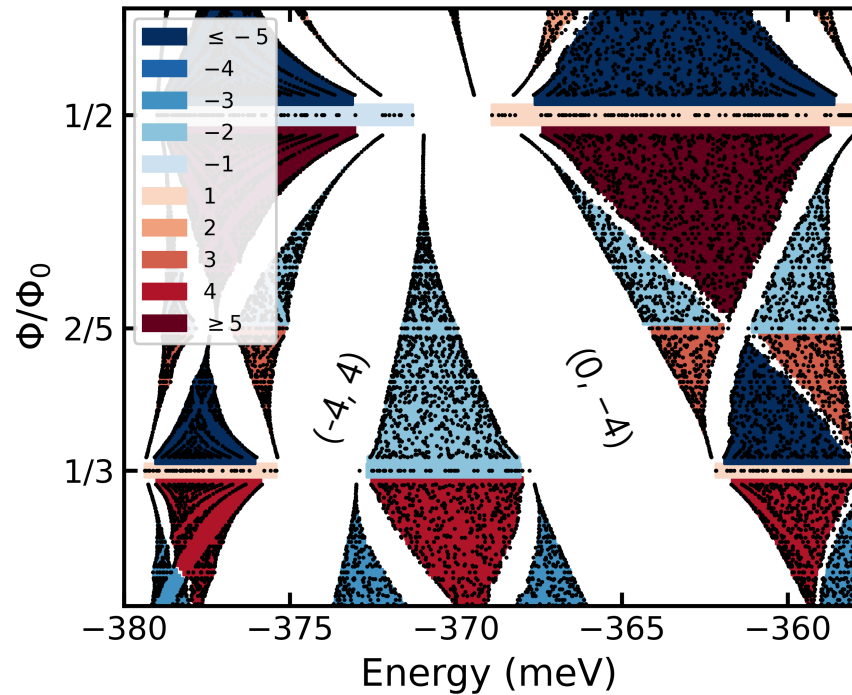


Robust quantization over roughly 0.5 n/n_s !

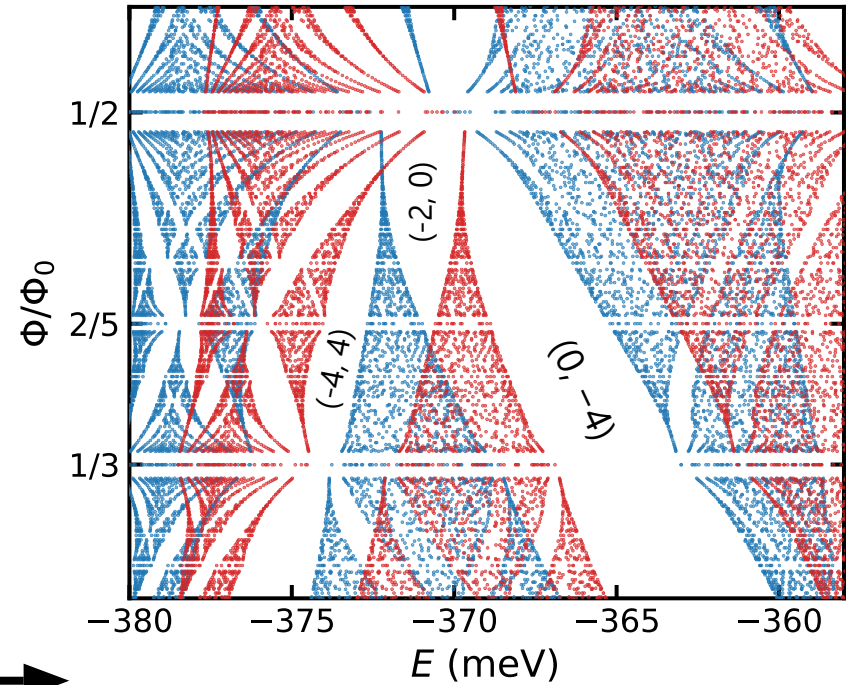
Where in the spectrum is this state?



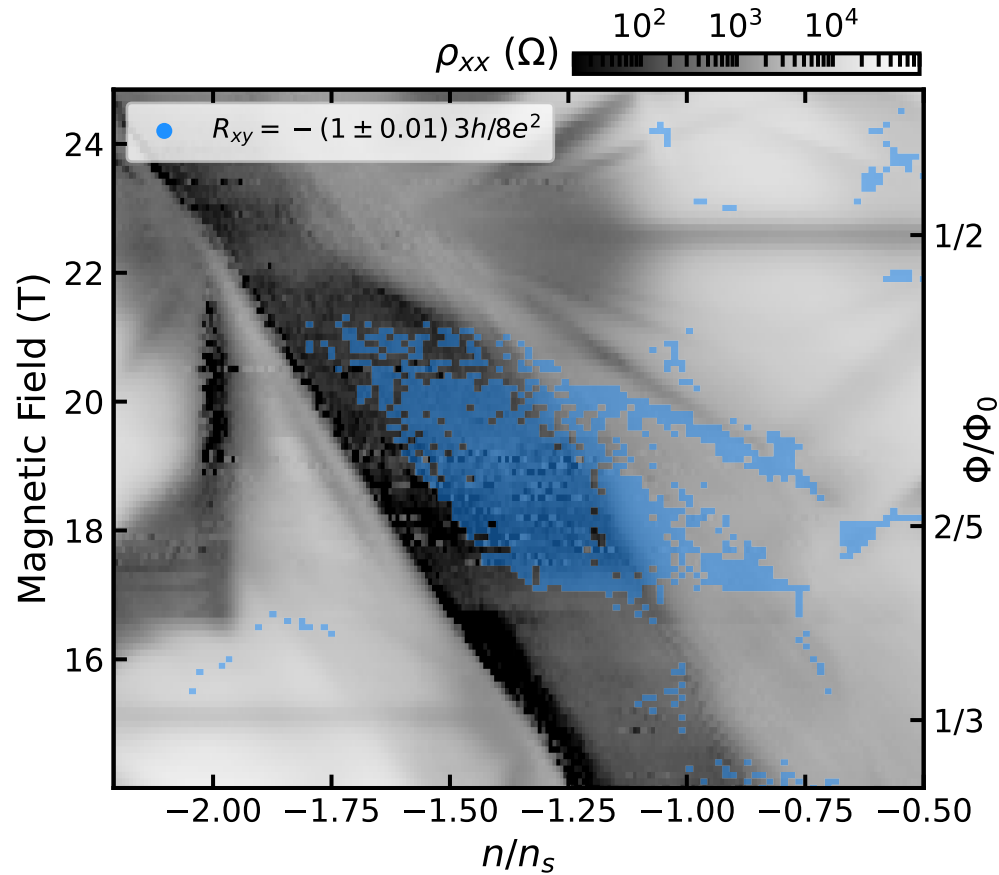
Where in the spectrum is this state?



→
Incorporate spin Zeeman



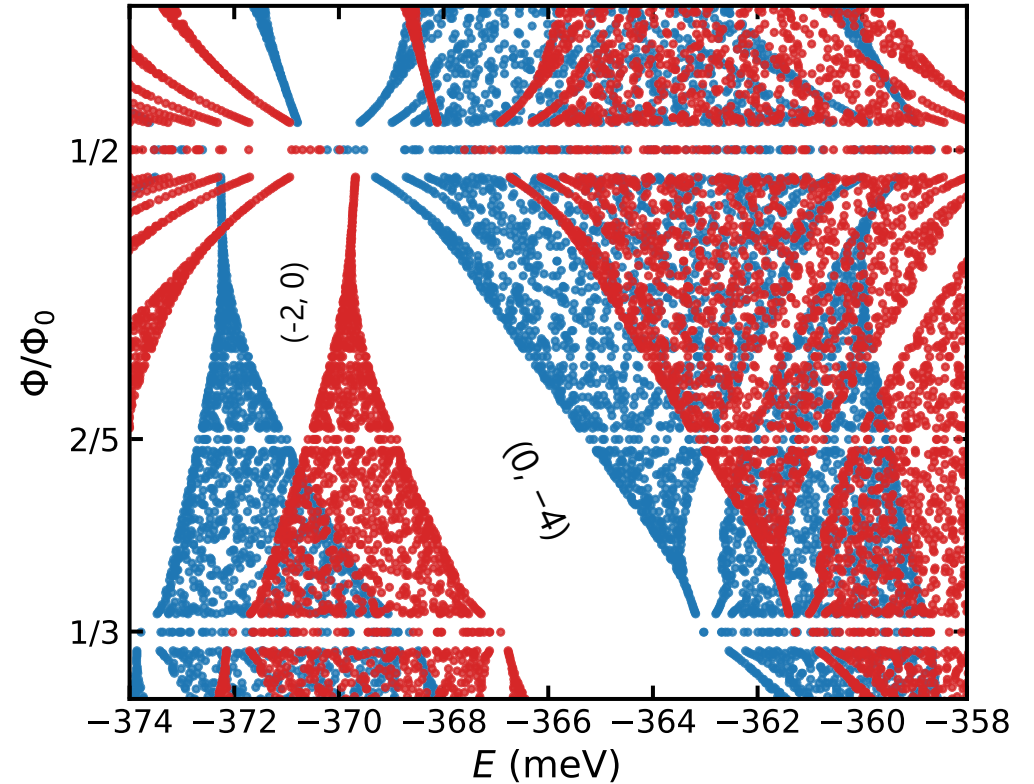
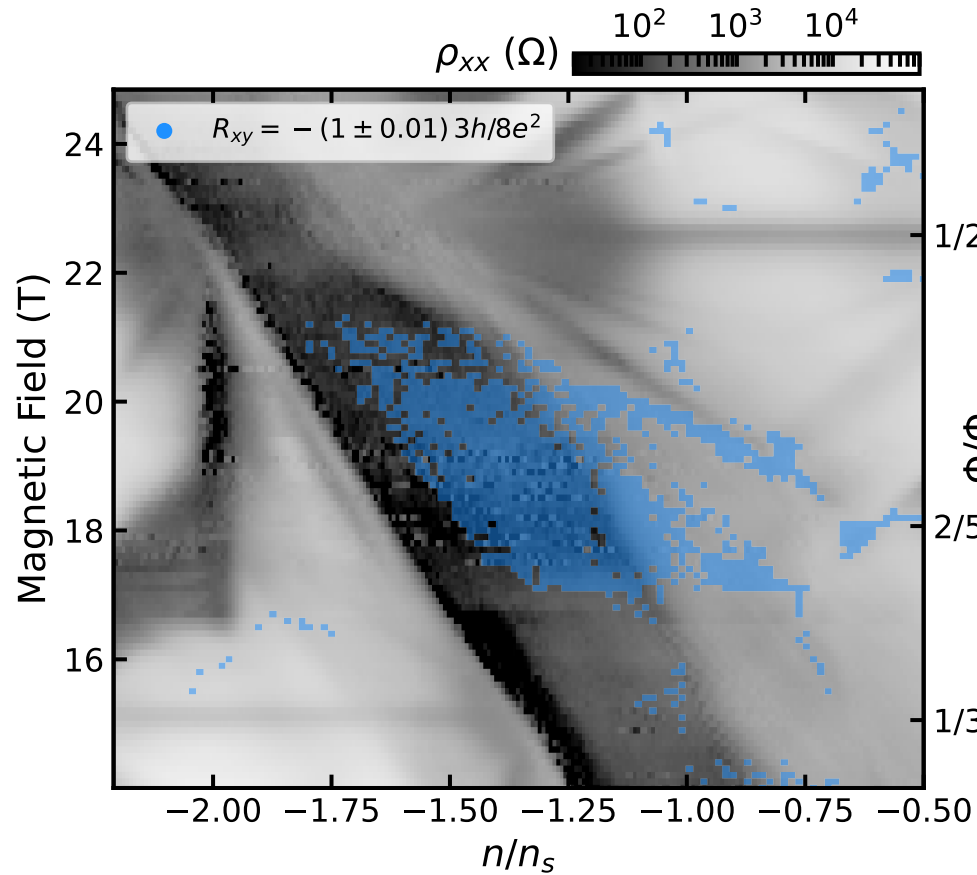
Where in the spectrum is this state?



Diophantine: $n/n_s = s + t\Phi/\Phi_0 \rightarrow (s, t)$

Štředa: $\sigma_{xy} = te^2/h$

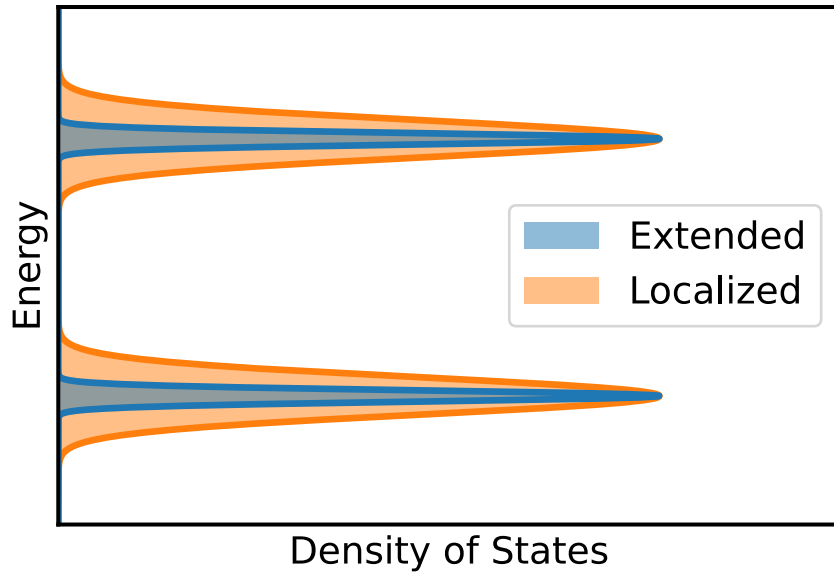
Where in the spectrum is this state?



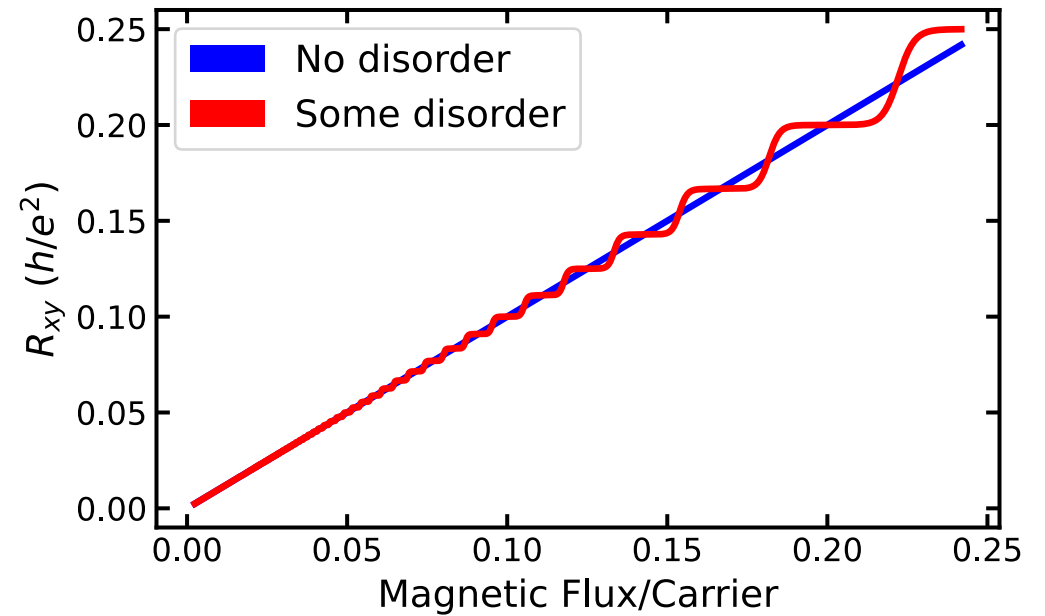
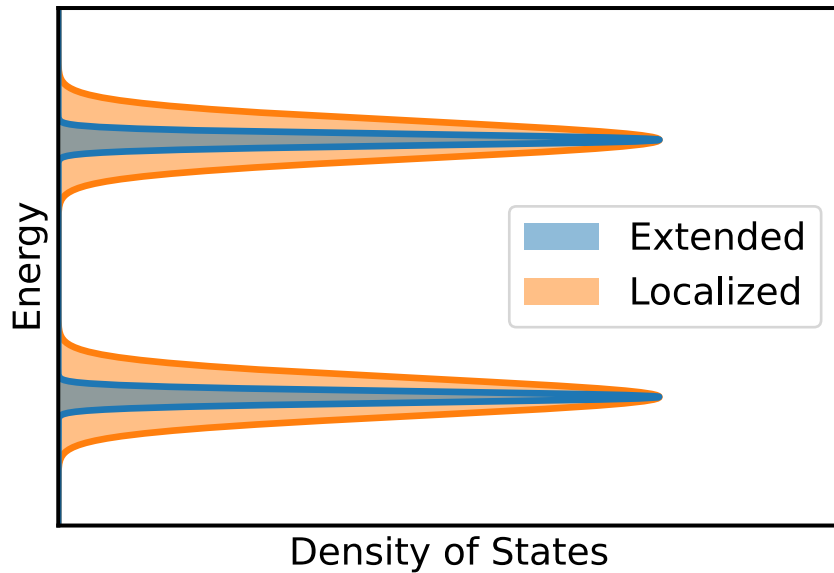
Diophantine: $n/n_s = s + t\Phi/\Phi_0 \rightarrow (s, t)$

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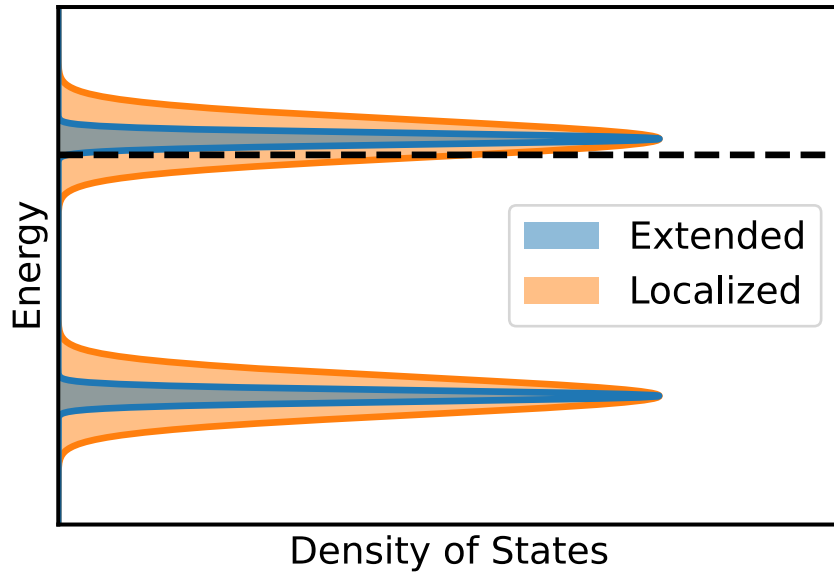
Landau levels and disorder



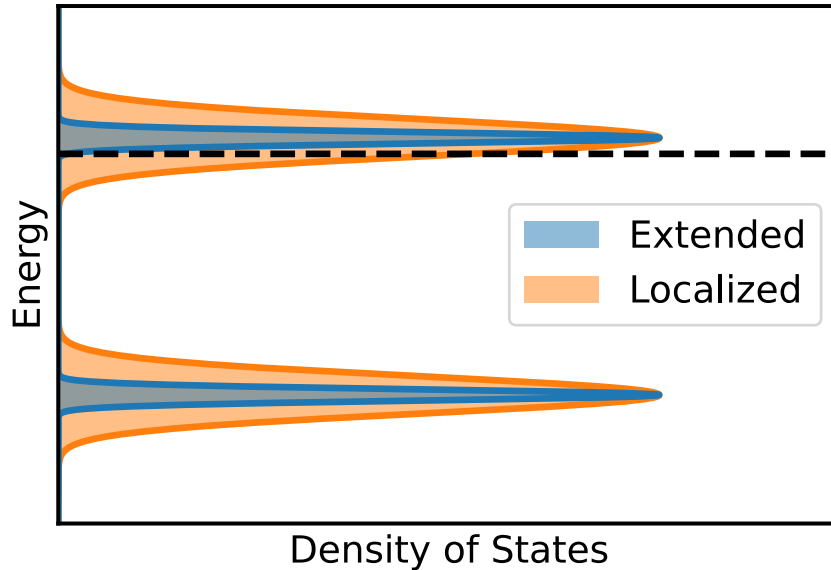
Landau levels and disorder



Landau levels and disorder



Landau levels and disorder



Metallic state:

- Finite R_{xx} and unquantized R_{xy}

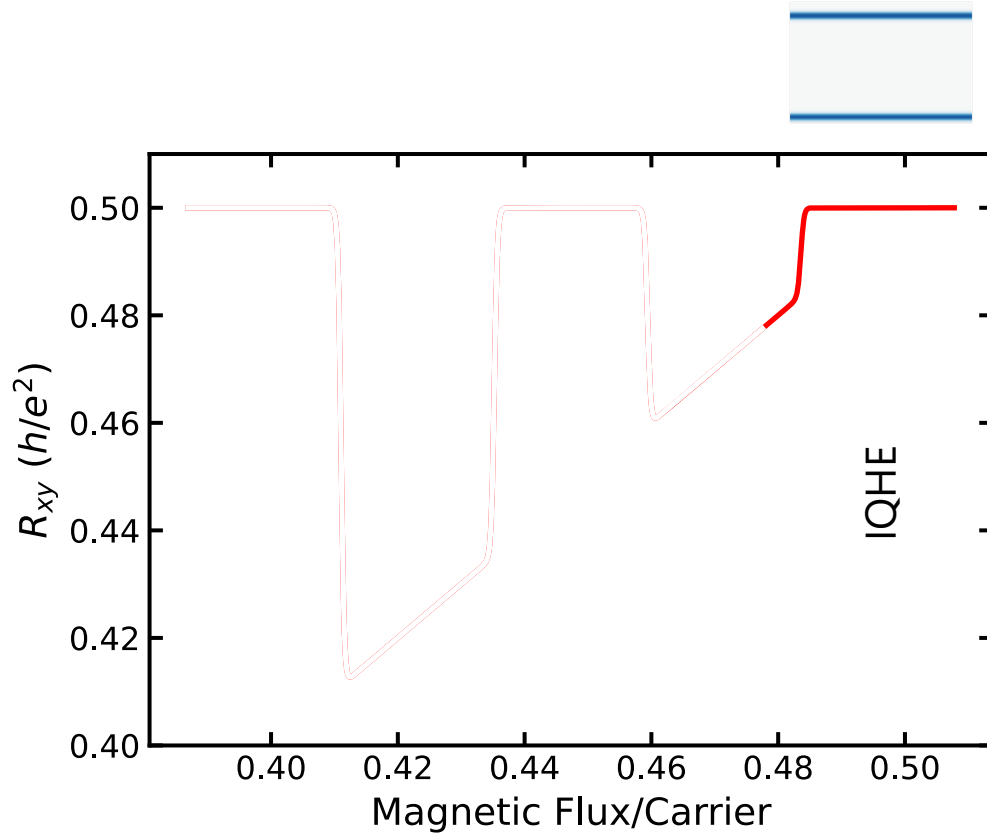
Incompressible FQH Liquid:

- At rational filling
- Zero R_{xx} and quantized R_{xy}
- Very sensitive to disorder

Charge ordered state:

- Wigner crystal, stripes, bubbles
- Reentrant quantum Hall

Reentrant quantum Hall



Finney, Sharpe, et al. arXiv:2503.12819

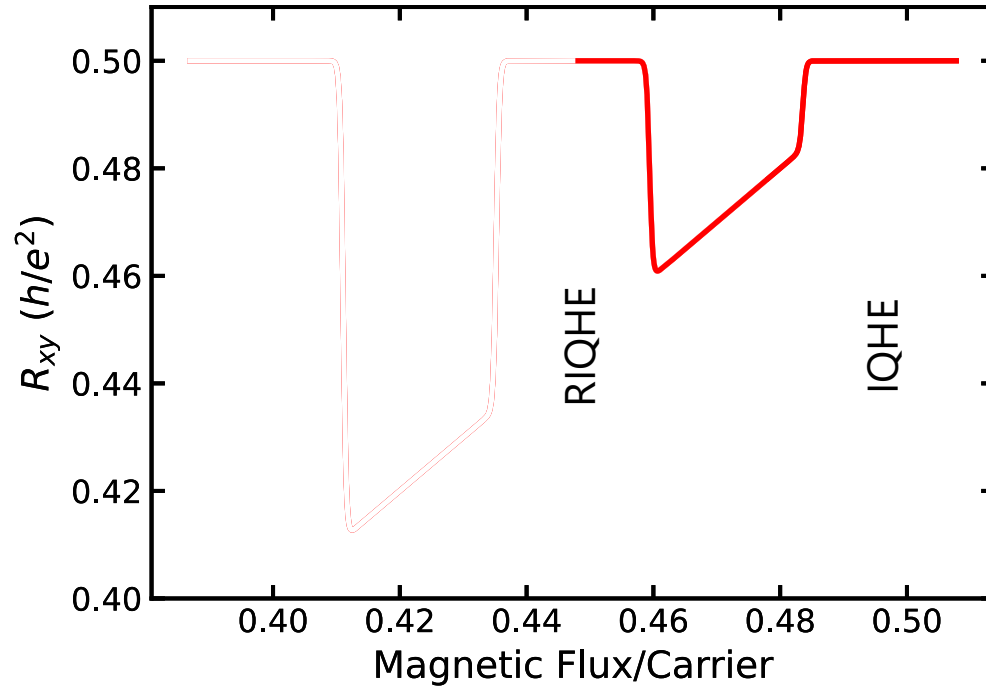
Tešanović, et al. PRB (1989)

Kumar, et al. Phys. Rev. Lett. (2010)

Shingla, et al. Nat. Phys (2023)

See also: Lu, et al. Nature (2024)

Reentrant quantum Hall



Finney, Sharpe, et al. arXiv:2503.12819

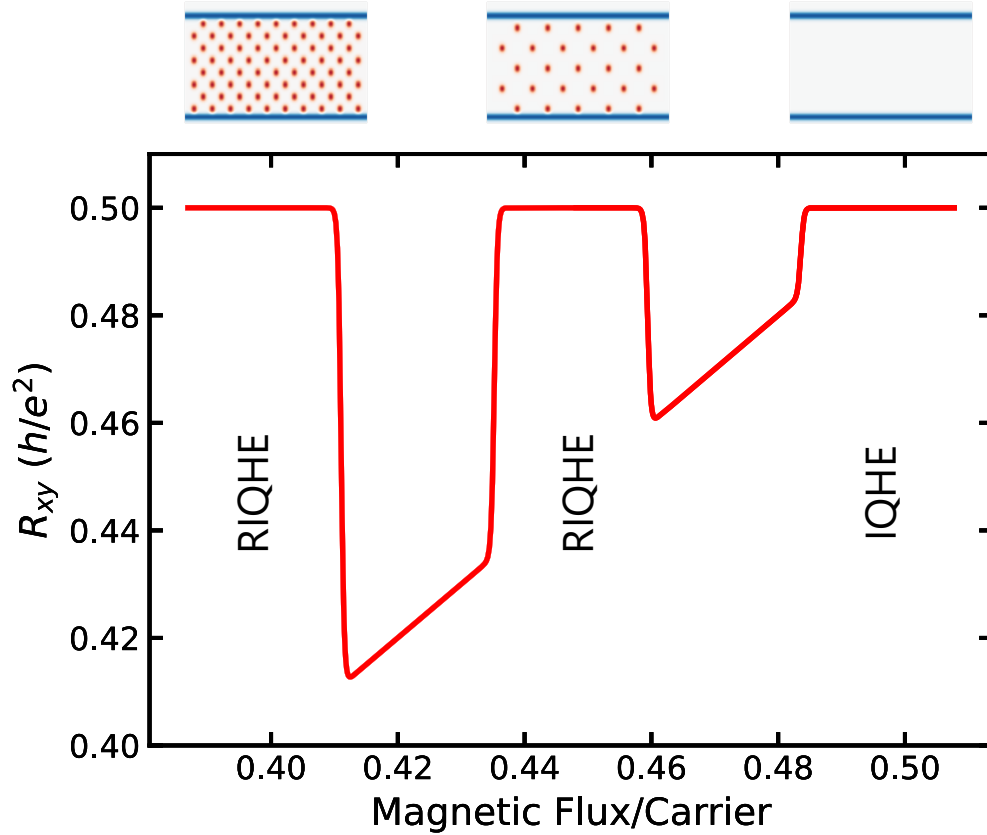
Tešanović, et al. PRB (1989)

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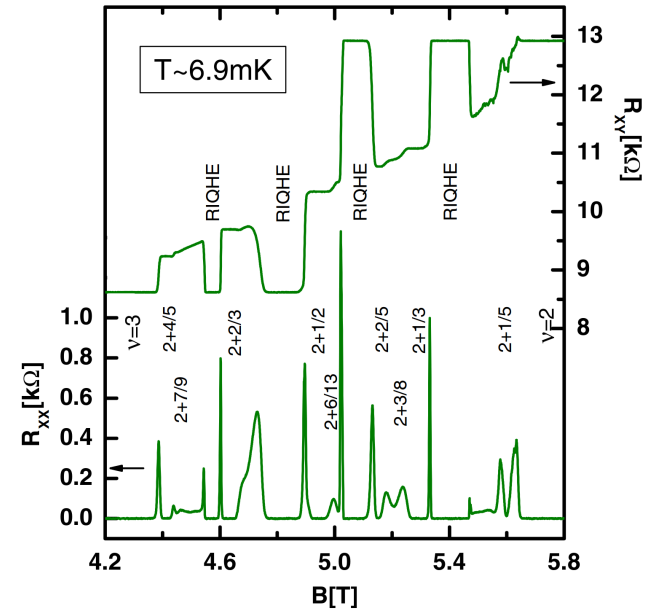
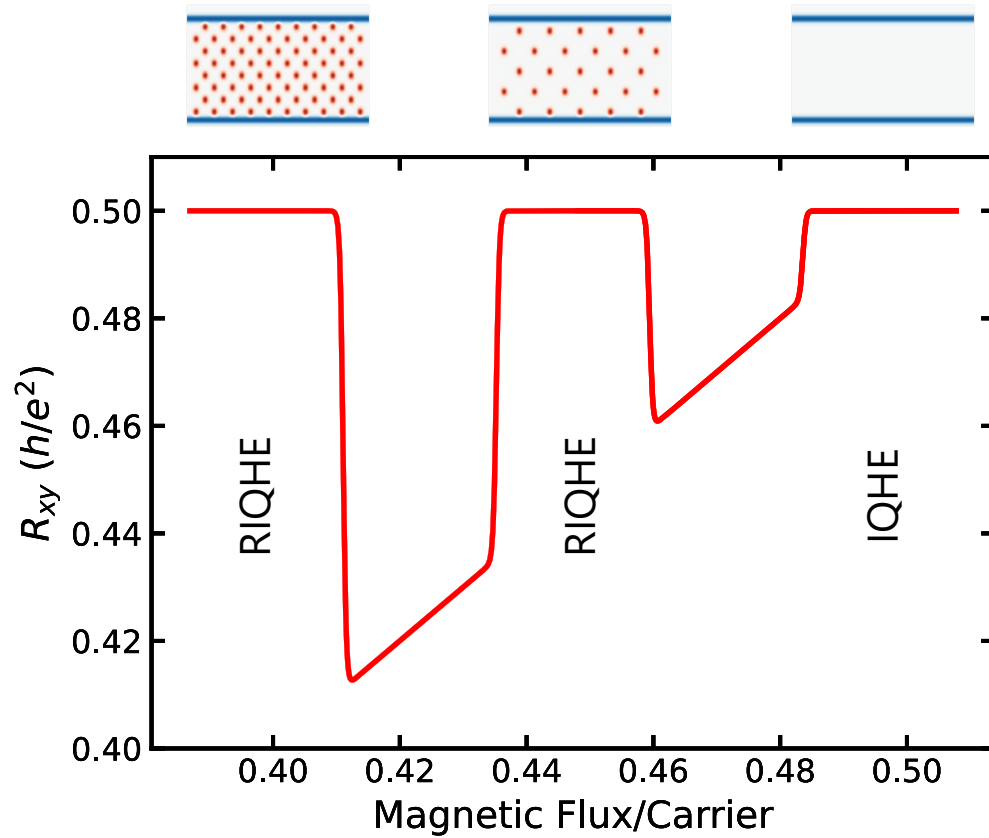
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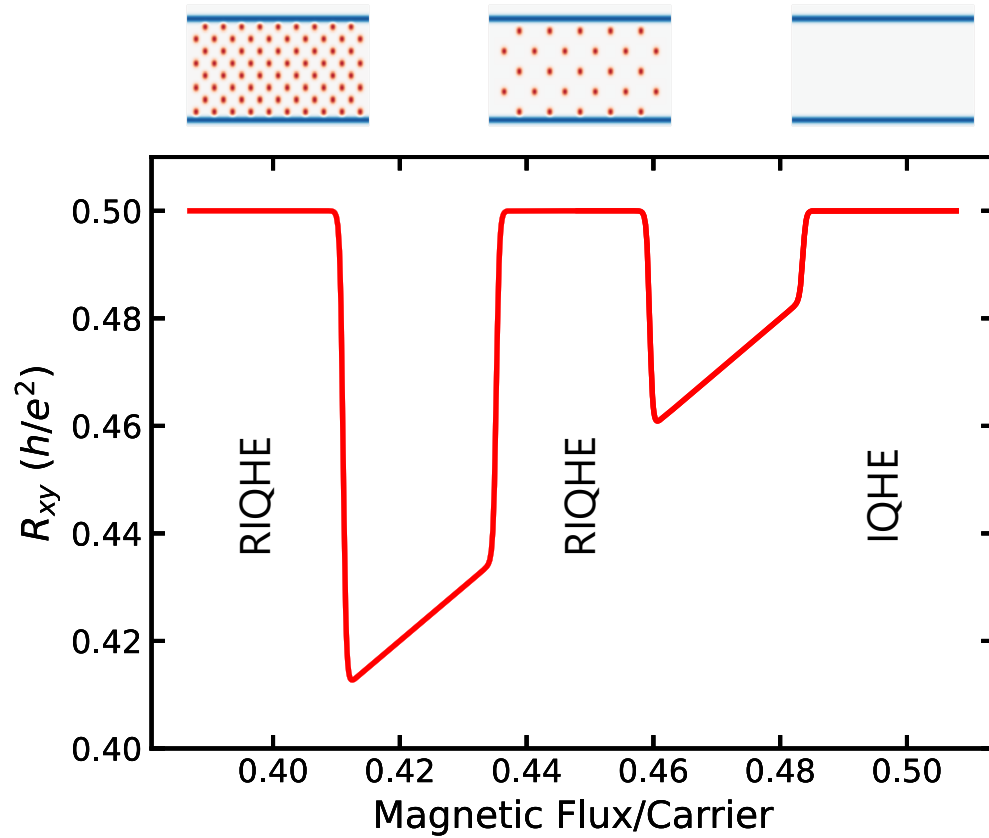
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Reentrant quantum Hall

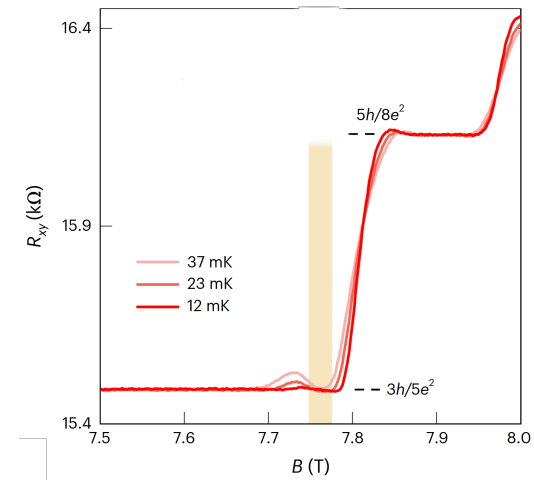
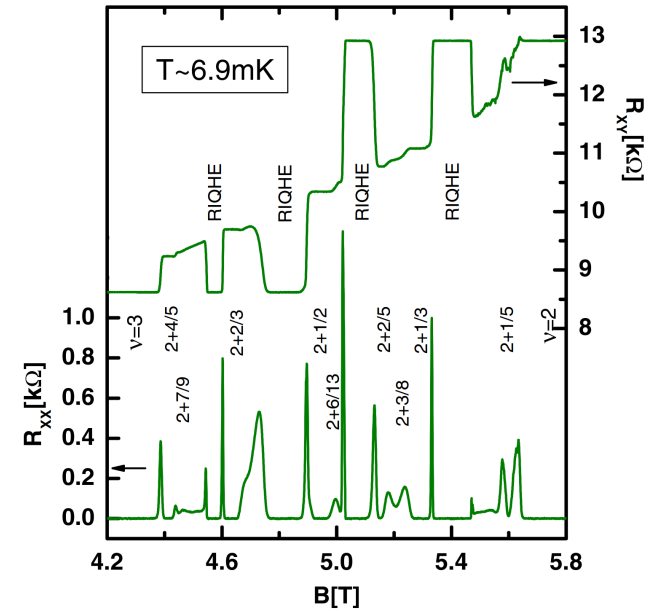


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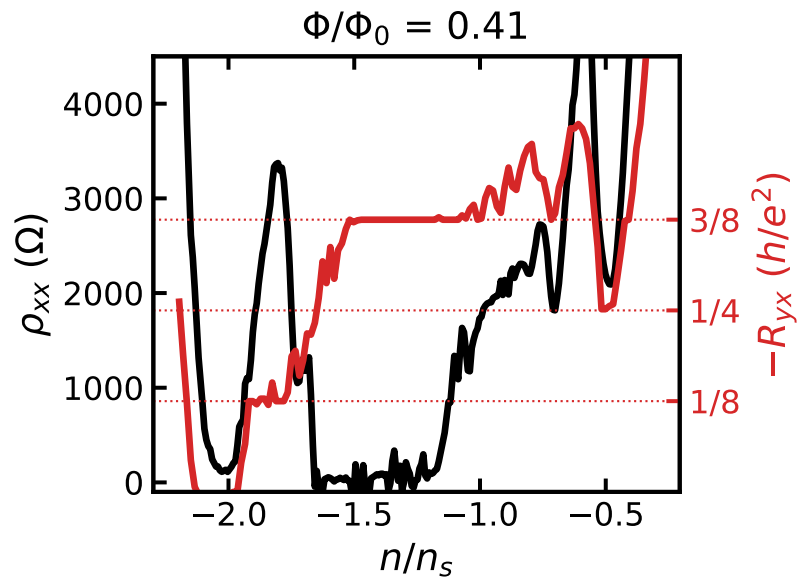
Reentrant quantum Hall



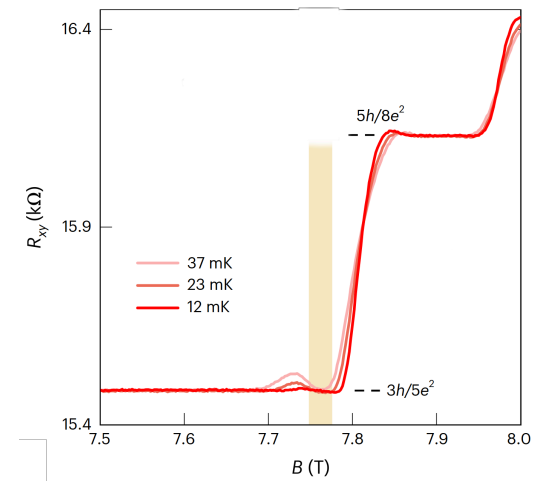
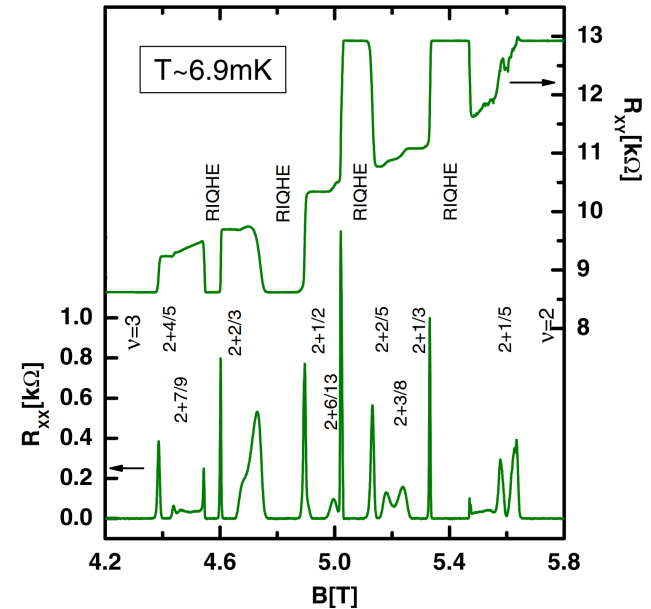
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Reentrant quantum Hall



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Acknowledgements



Joe Finney



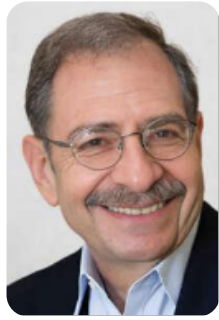
Xiaoyu Wang



Jian Kang



David Goldhaber-Gordon



Marc Kastner



Oskar Vafek

Thanks

Linsey Rodenbach, Connie Hsueh

Takashi Taniguchi, Kenji Watanabe

National High Magnetic Field Laboratory

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Steve Kivelson, Julian May-Mann, Trithep Devakul,

Yves Kwan, Tomohiro Soejima, Patrick Ledwith,

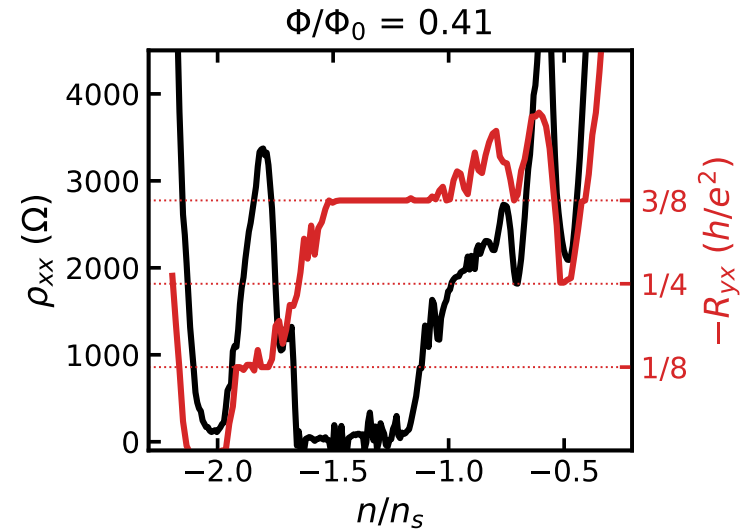
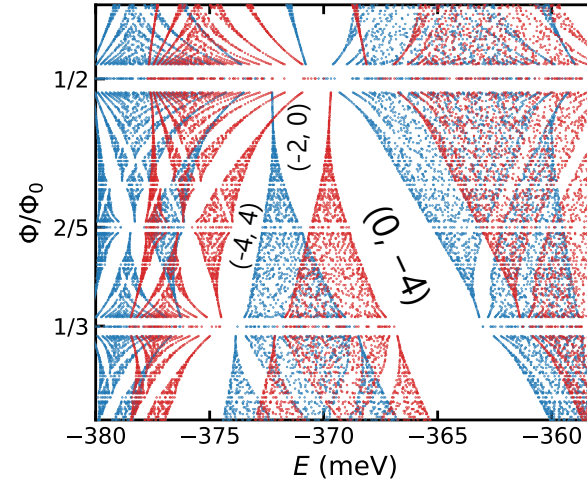
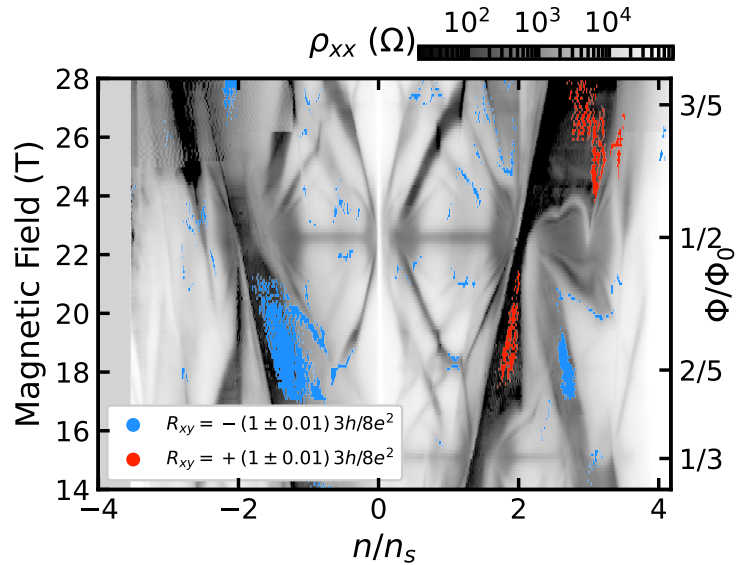
Ben Feldman, Matt Yankowitz, Jonah Herzon-Arbeitman,

Nisarga Paul, Sayak Bhattacharjee



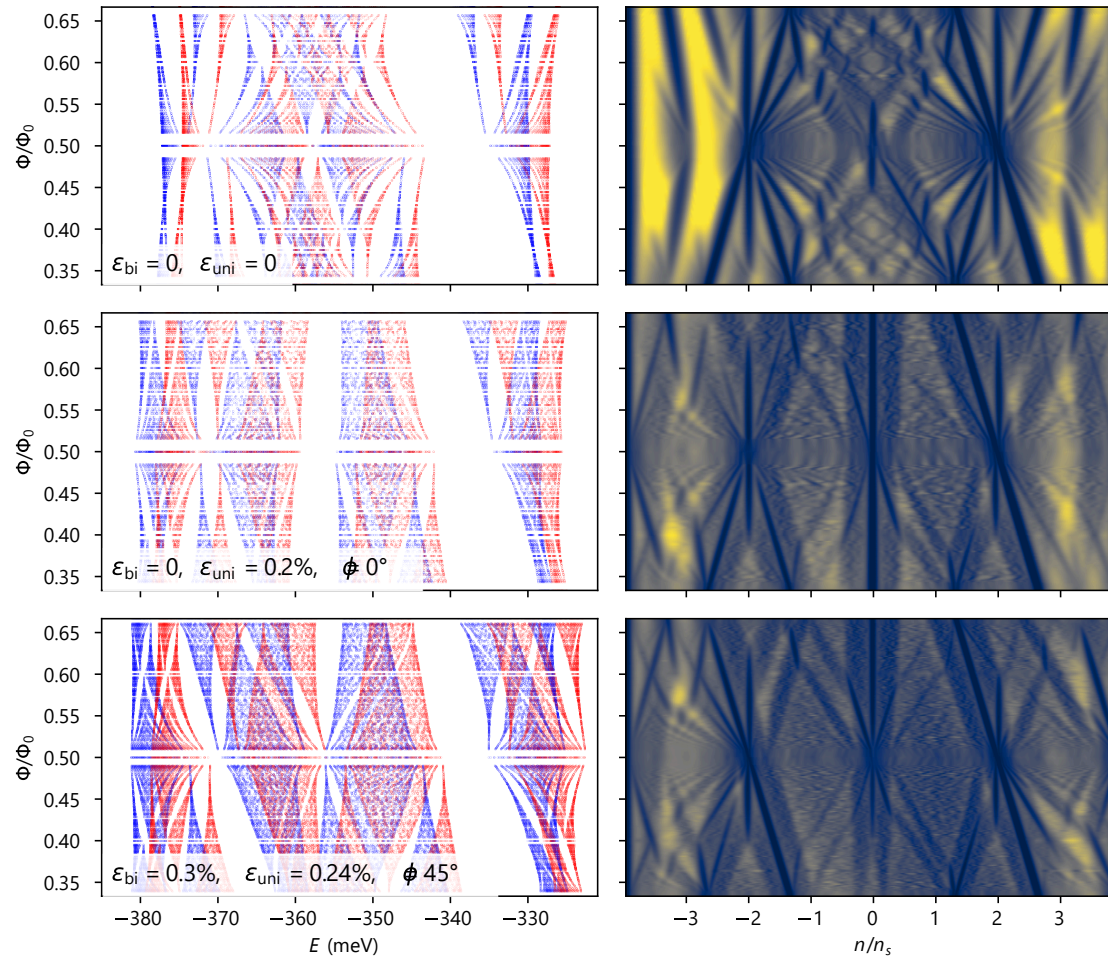
nano @
stanford

Summary

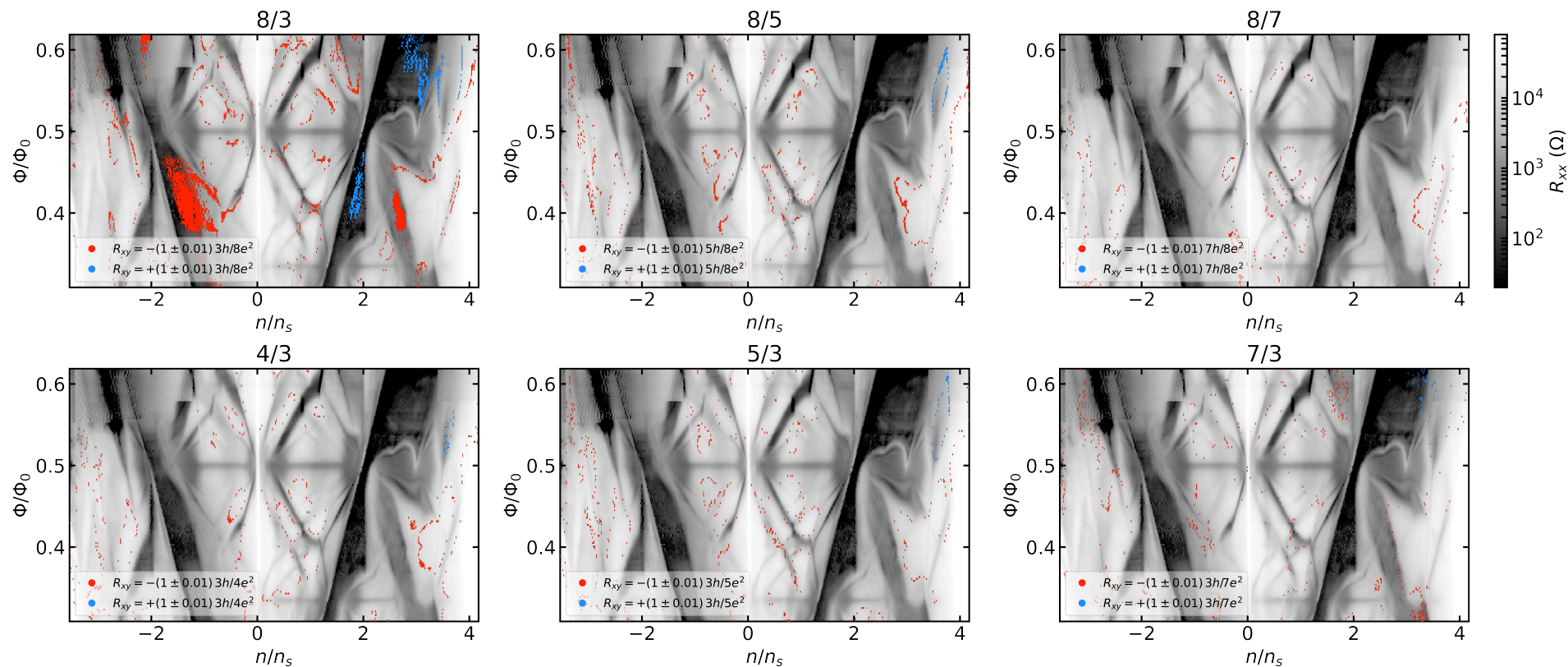


- 1.37° TBG, $\varepsilon_{\text{uni}} = 0.24 \pm 0.02\%$, $\varepsilon_{\text{bi}} = 0.3 \pm 0.1\%$
- FCIs at high fields, including $8/3$ state in $C = 2$ and 3 bands
- Quantized over roughly $0.5 n/n_s$!
- Likely not due to disorder
 - More robust than nearby integers
- Fractional partial Hall crystal?

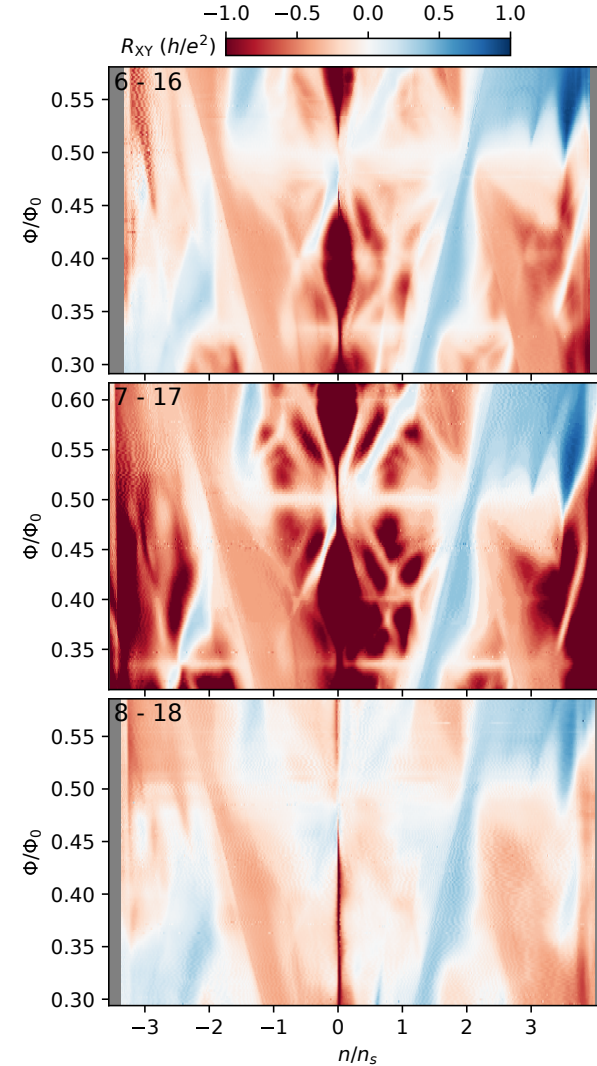
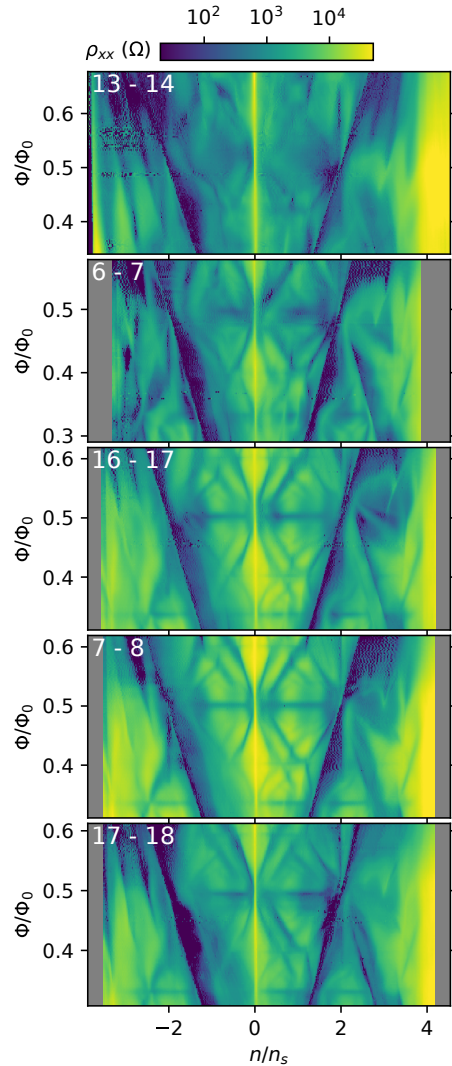
Hofstadter spectrum with strain



Other fractions



All contact pairs



QGT

