Electrostatics of Chern insulator junctions

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INSTITUT QUANTIQUE

RQMP REGROUPEMENT QUÉBÉCOIS SUR LES MATÉRIAUX DE POINTE

Acknowledgements

Robin Durand (PhD Sherbrooke-Paris)

Pascal Simon (Paris-Saclay)

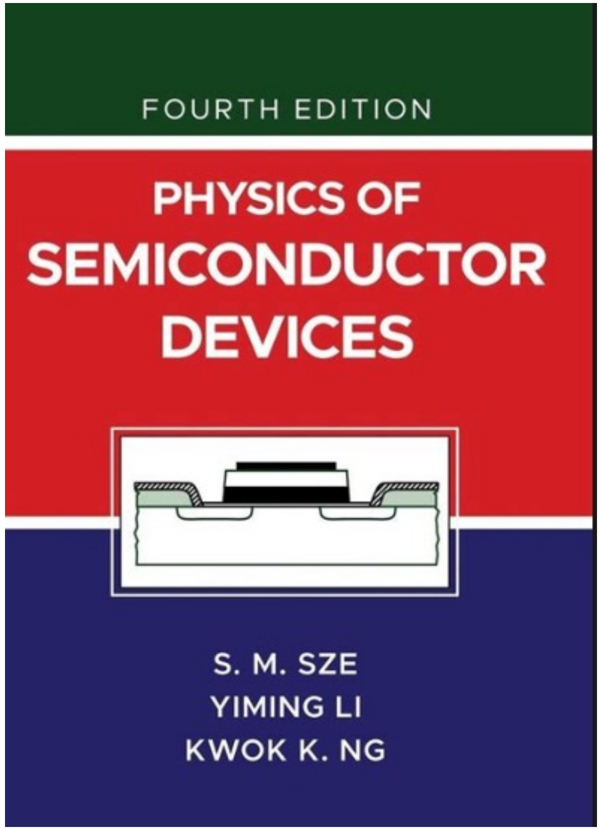
NSERC CRSNG

Fonds de recherche Nature et technologies Québec

irlfq

Motivation

- Today’s microelectronic devices rely on the physics of conventional semiconductors



Sze *et al*.,
Physics of semiconductor devices
(Wiley, 2007)

Motivation

- Emergence of topological materials.

B. Wieder et al., Nature Reviews Materials 7, 196 (2022).

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- Emergence of topological materials.

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- Prototype example: Chern insulator

(1) 2D material.
(2) Topological invariant (Chern number).
(3) Low-dissipation charge transport on the edge.

Motivation

- Some of tomorrow's microelectronic devices may rely on topological materials

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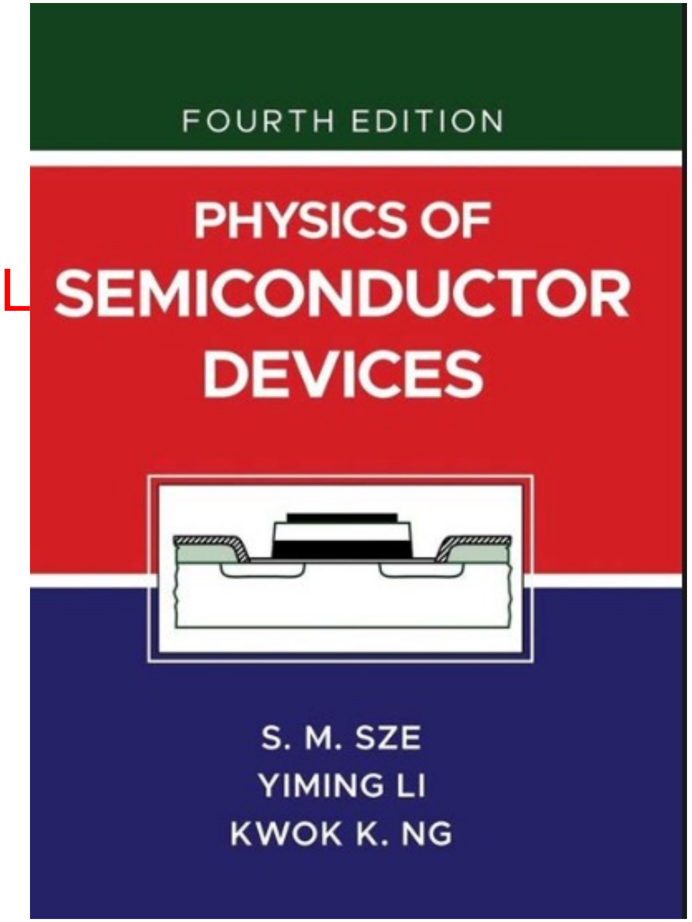

FOURTH EDITION

PHYSICS OF
SEMICONDUCTOR
DEVICES

S. M. SZE
YIMING LI
KWOK K. NG

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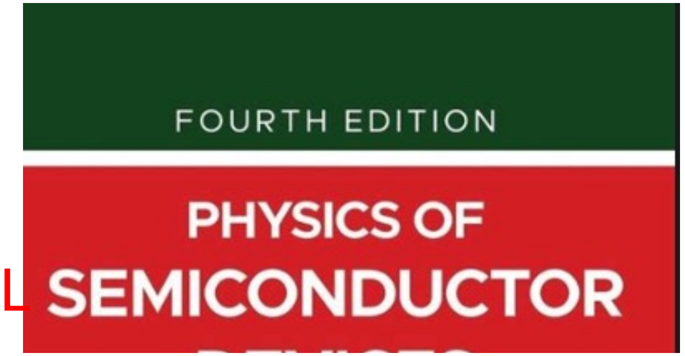

FOURTH EDITION

PHYSICS OF

TOPOLOGICAL SEMICONDUCTOR

Topological electronics

Matthew J. Gilbert

Communications Physics **4**, Article number: 70 (2021) | Cite this article

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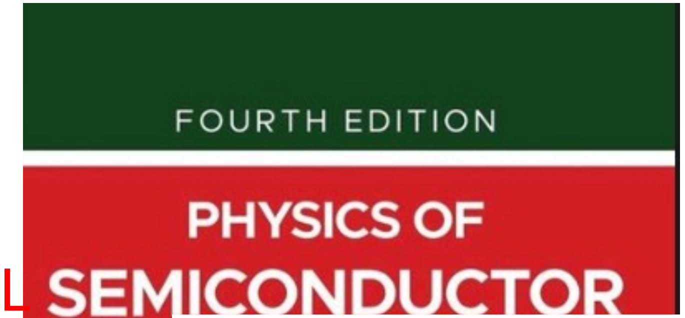

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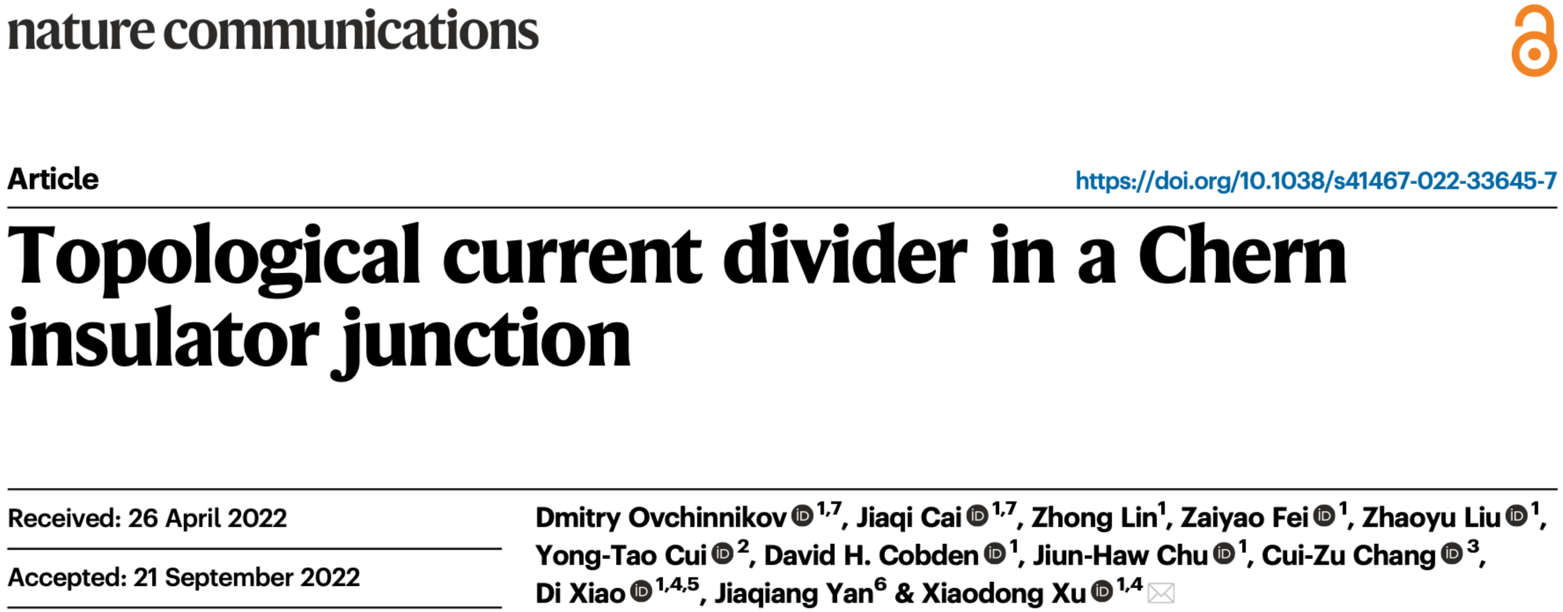

nature communications

Article

https://doi.org/10.1038/s41467-022-33645-7

Topological current divider in a Chern insulator junction

Received: 26 April 2022

Accepted: 21 September 2022

Dmitry Ovchinnikov[1,7], Jiaqi Cai[1,7], Zhong Lin[1], Zaiyao Fei[1], Zhaoyu Liu[1], Yong-Tao Cui[2], David H. Cobden[1], Jiun-Haw Chu[1], Cui-Zu Chang[3], Di Xiao[1,4,5], Jiaqiang Yan[6] & Xiaodong Xu[1,4]

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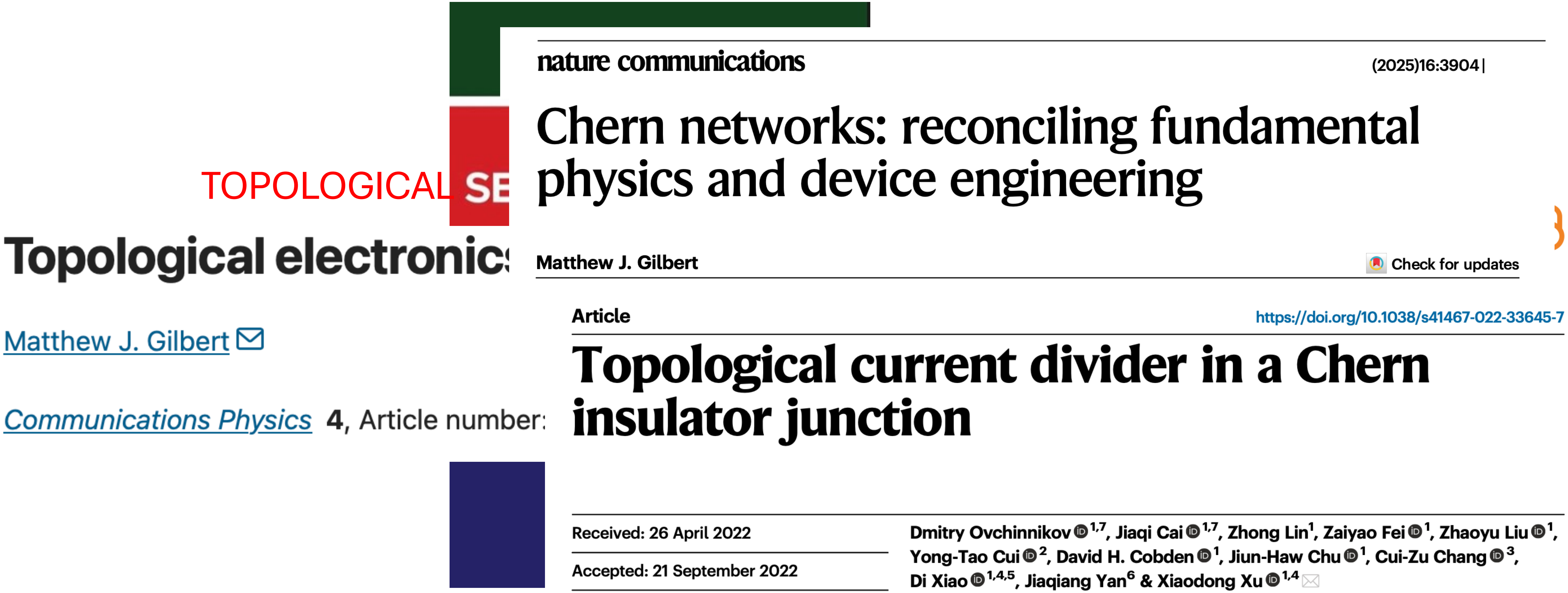

TOPOLOGICAL SE

Topological electronic

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Communications Physics **4**, Article number:

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nature communications (2025)16:3904 |

Chern networks: reconciling fundamental physics and device engineering

Matthew J. Gilbert

Check for updates

Article https://doi.org/10.1038/s41467-022-33645-7

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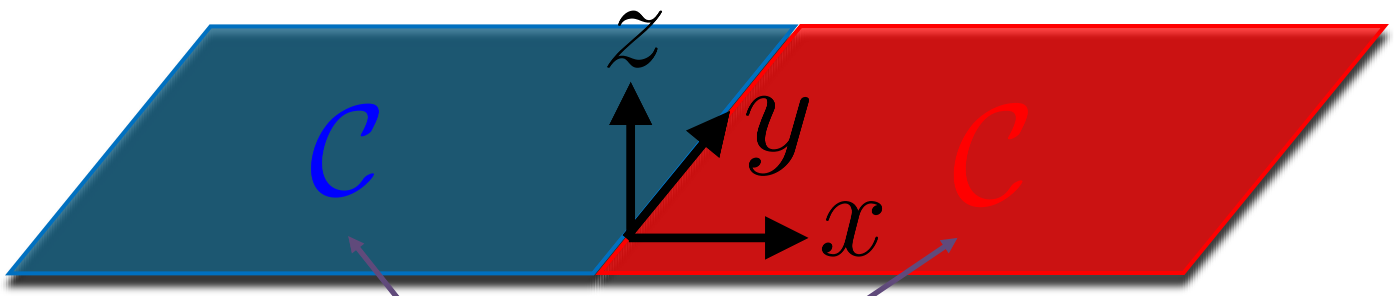
Motivation

- Main question of this talk:

Influence of Chern number in electrostatic properties of 2D junctions?



Chern numbers

What is special with electrostatics of 2D junctions

Sze *et al*. (Wiley, 2007)

Yu *et al*., Nano Lett. **16**, 5032 (2016)

3D junctions	Properties	2D junctions (conventional)
$c,\ \text{for}\ \lvert x\rvert < W$ $0,\ \text{for}\ \lvert x\rvert > W$	Charge density	

● Ionized dopant concentration

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$\propto 1/W$	Capacitance	$\propto \ln(L/W)$

System length

🔵 Ionized dopant concentration

🟥 Built-in potential

Role of magnetic field in Chern junctions

	Transformation under time-reversal
Chern number $\mathcal{C}$	odd
Electric potential ϕ	even
Magnetic field B	
$\mathcal{C}B$	

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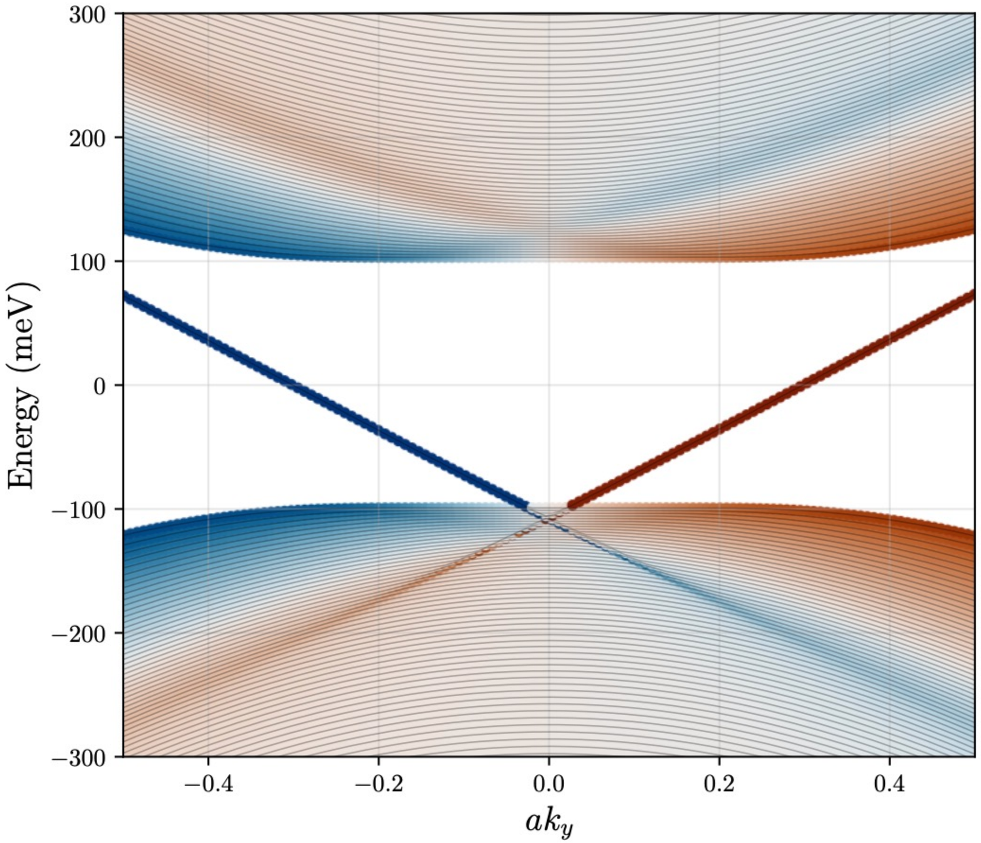
$\partial_x(\mathcal{C}B)$ influences electric field in Chern junctions.

Chern insulator in a magnetic field

- Energy spectrum



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Chern insulator in a magnetic field

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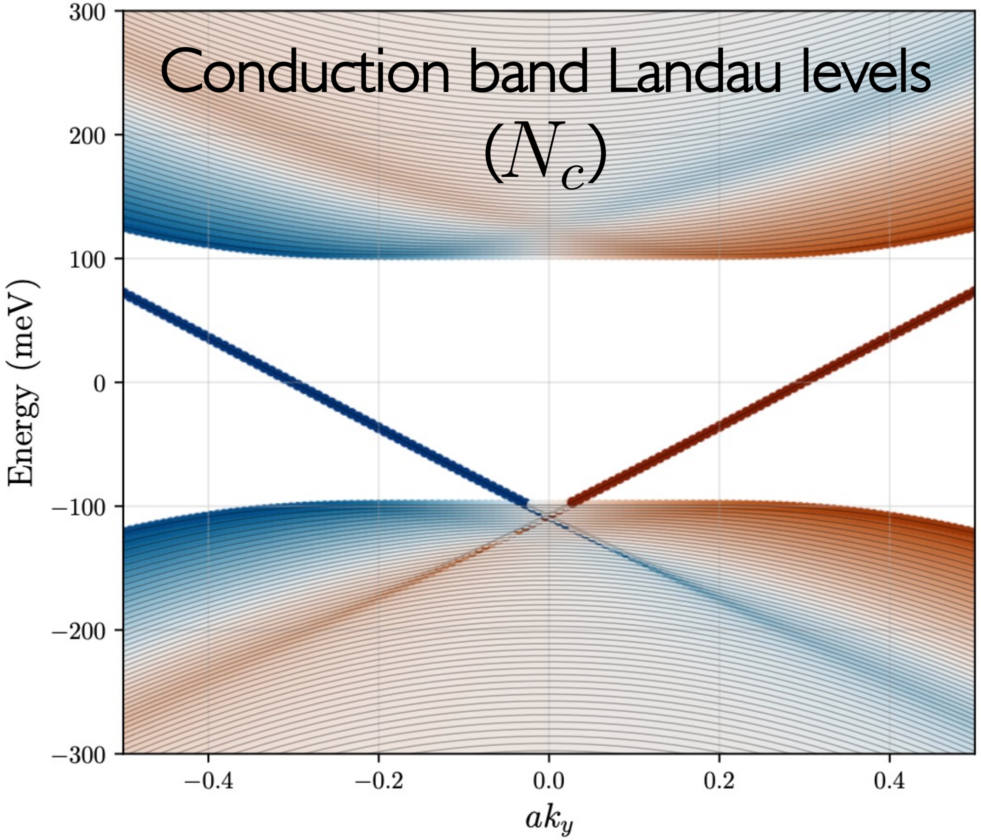

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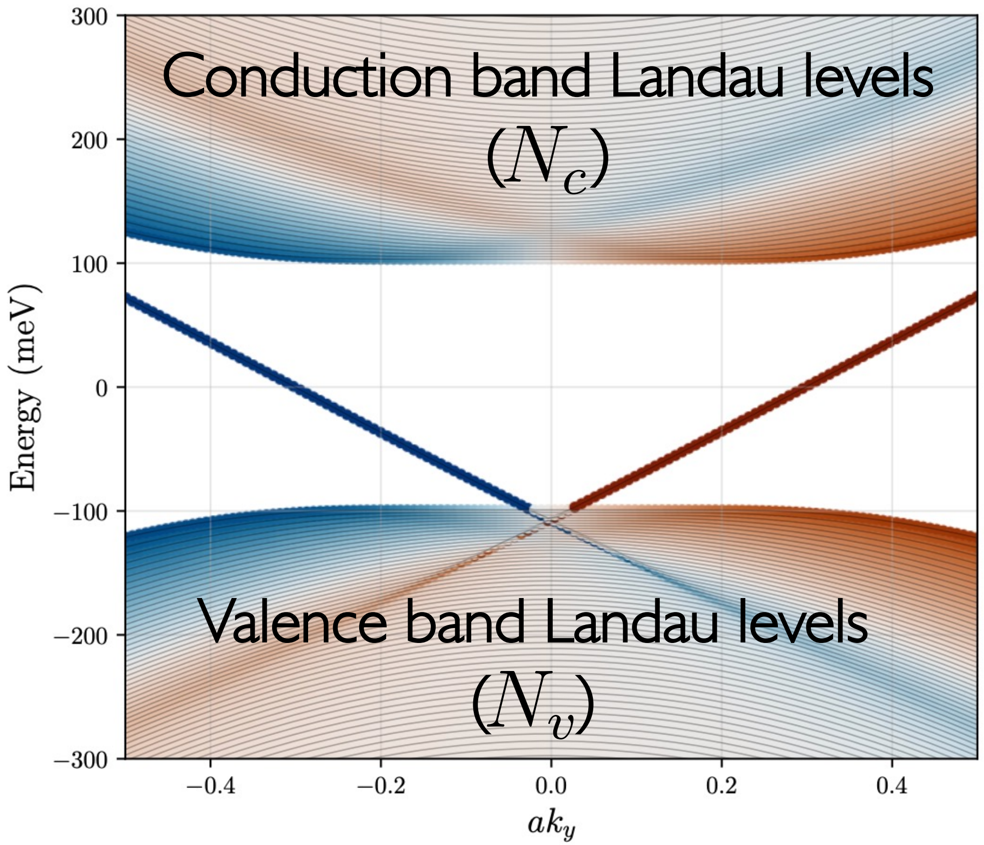

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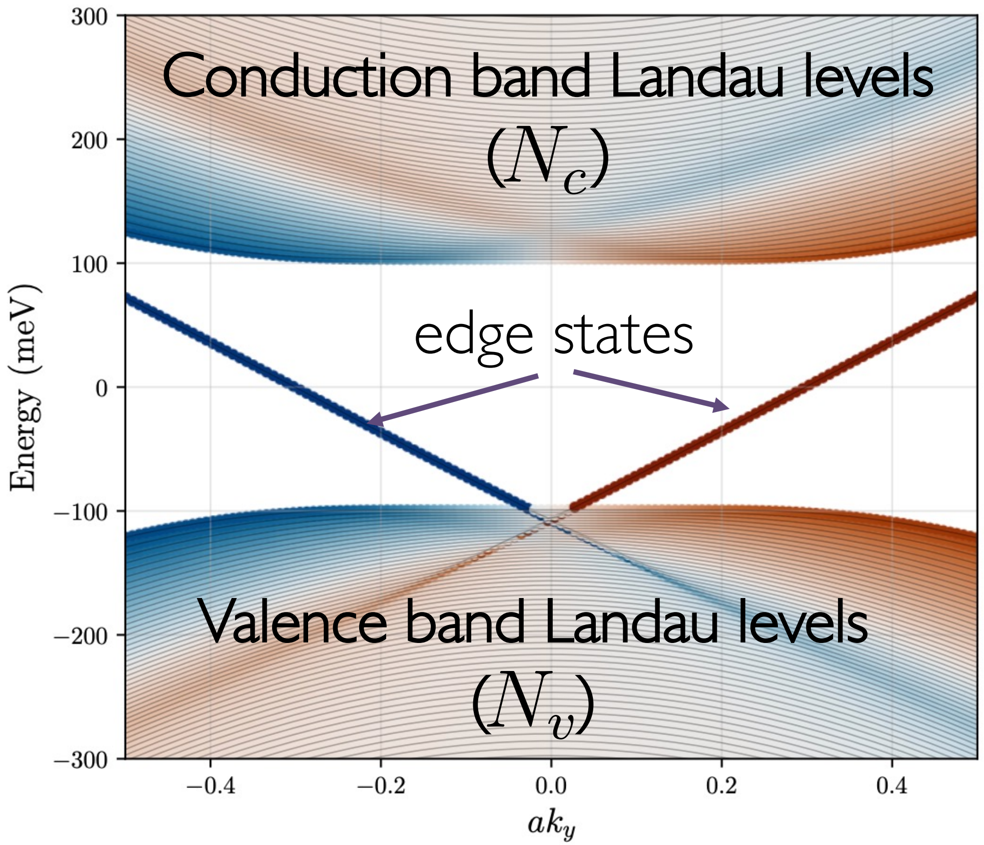

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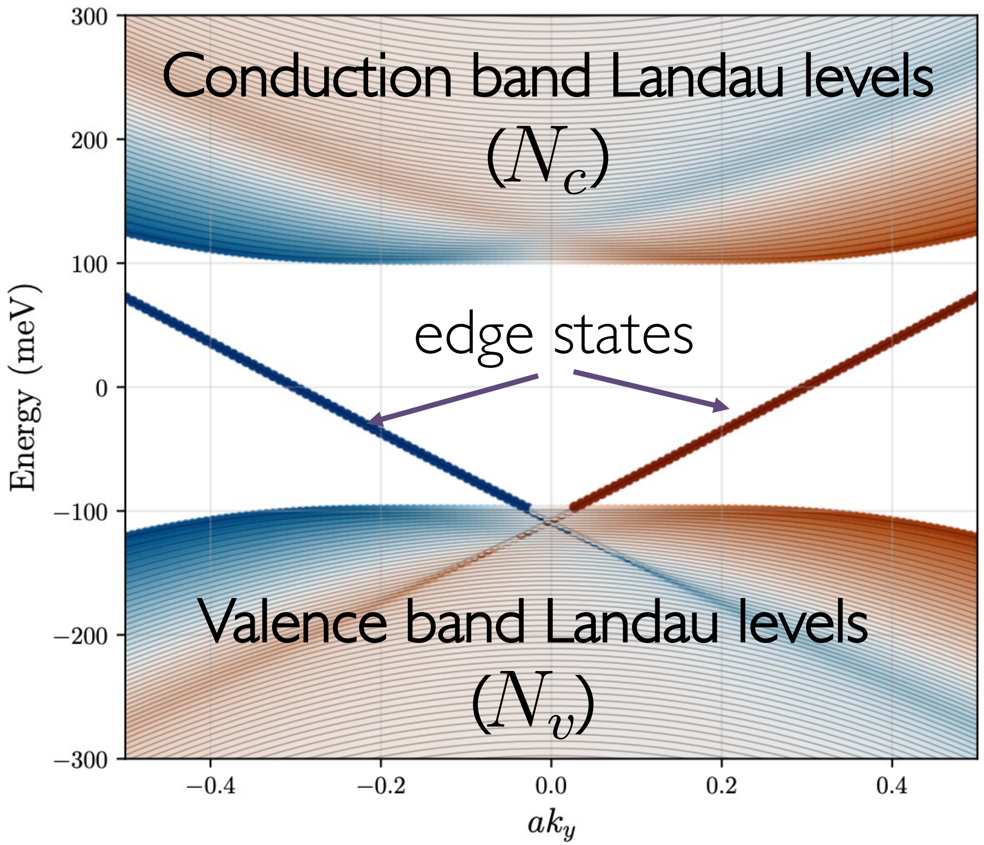

Spectral asymmetry:

$$\frac{N_c - N_v}{\text{area}} = \frac{2e}{h}\mathcal{C}B$$

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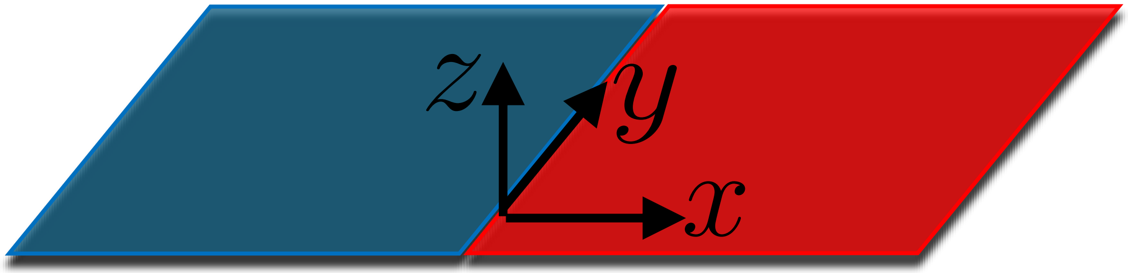
Electrostatics of Chern junctions

- 2D Poisson equation

$$\left(\partial_x^2 + \partial_z^2\right)\phi = e\frac{\sigma(x)}{\epsilon}\delta(z)$$



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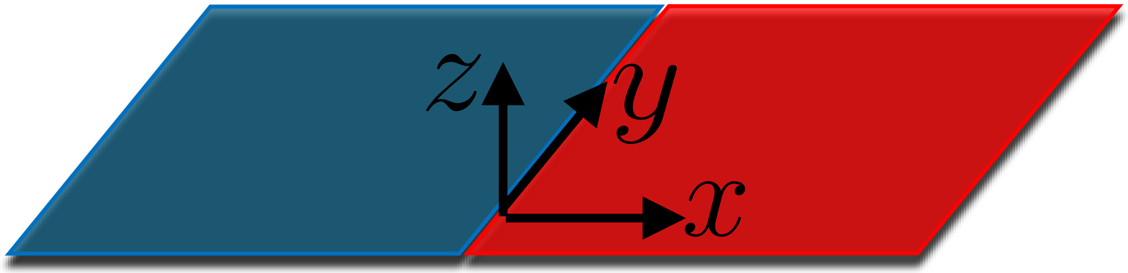

🟪 Net areal electron density

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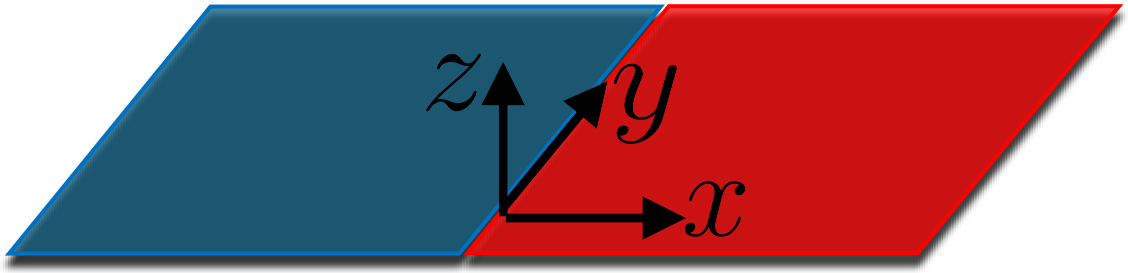

🟪 Net areal electron density

● Dielectric constant

Electrostatics of Chern junctions

- Net areal electron density

$$\sigma(x) = n(x) - p(x) + c_{\mathrm{eff}}(x)$$

Electrostatics of Chern junctions

- Net areal electron density

$$\sigma(x) = n(x) - p(x) + c_{\text{eff}}(x)$$

🟥 Density of conduction band electrons

Electrostatics of Chern junctions

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$$\sigma(x) = n(x) - p(x) + c_{\text{eff}}(x)$$

🟥 Density of conduction band electrons

🟦 Density of valence band holes

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Functions of ϕ

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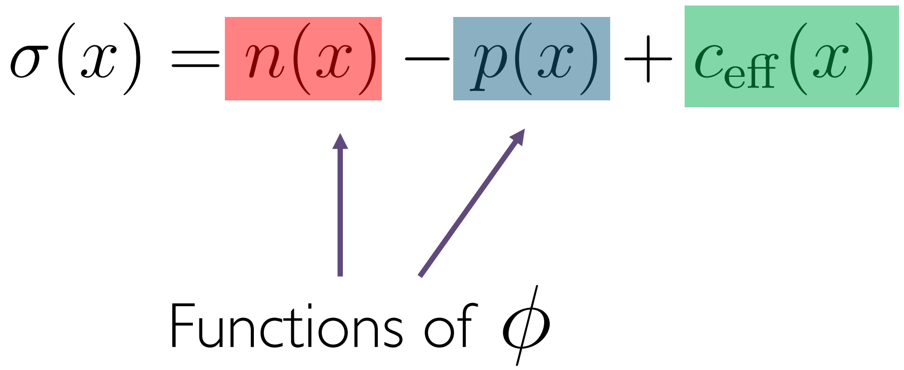
🟦 Density of valence band holes

Electrostatics of Chern junctions

- Net areal electron density



$$\sigma(x) = n(x) - p(x) + c_{\text{eff}}(x)$$

Functions of ϕ

🟥 Density of conduction band electrons

🟦 Density of valence band holes

🟩 Effective dopant density

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$$\sigma(x) = n(x) - p(x) + c_{\text{eff}}(x)$$

Functions of ϕ

🟥 Density of conduction band electrons

🟦 Density of valence band holes

🟩 Effective dopant density

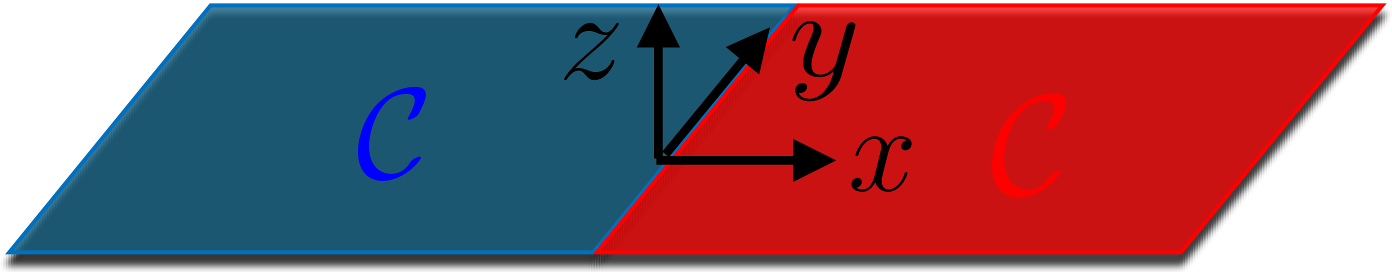
$$c_{\text{eff}} = c - \frac{e}{h}\mathcal{C}B$$

Contribution from spectral asymmetry

Contribution from impurities (zero in pristine semiconductors)

Electrostatics of Chern junctions

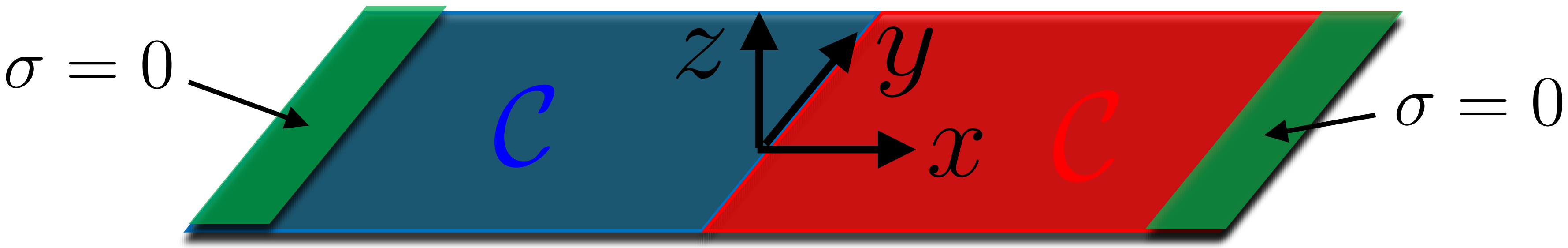
- Boundary conditions



Vanishing electric field at large |z|. Charge neutrality at contacts.

Electrostatics of Chern junctions

- Boundary conditions



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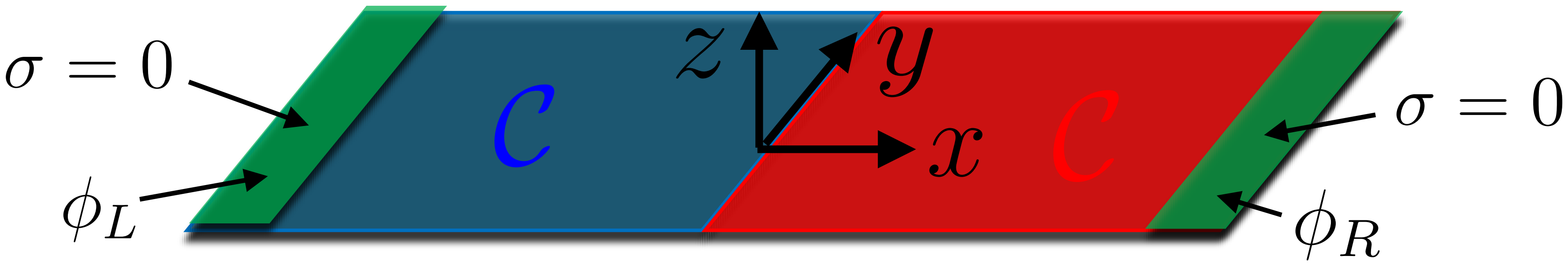

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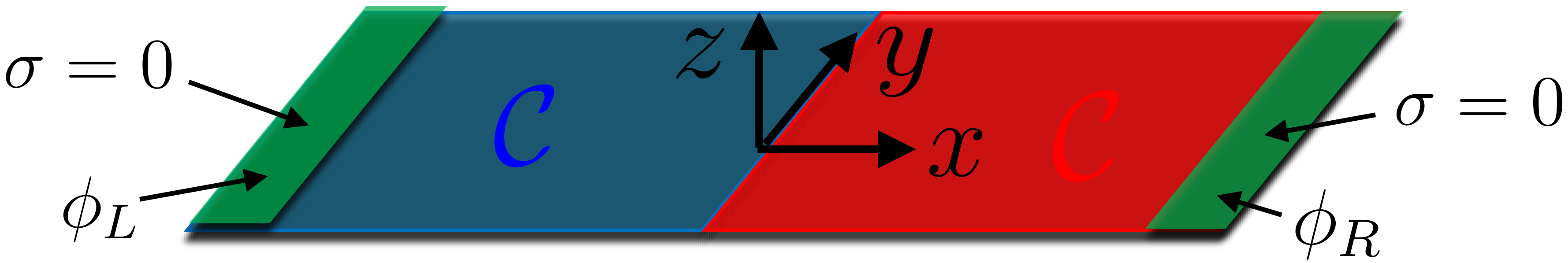

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Spectral asymmetry → ϕ_L and ϕ_R depend on $\mathcal{C}$ and $\mathcal{C}$, respectively

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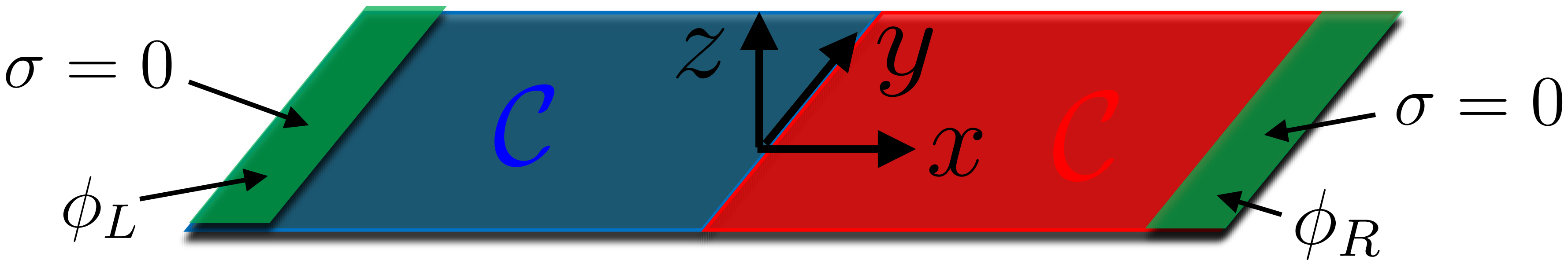

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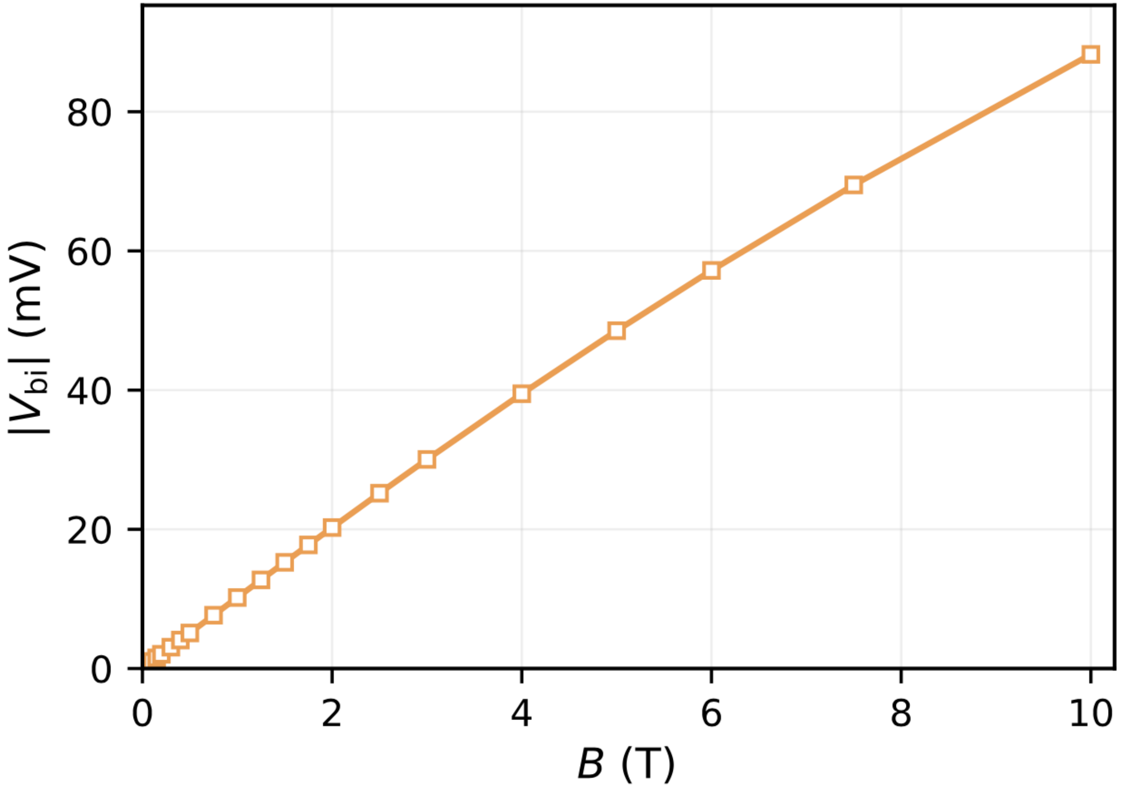
Spectral asymmetry → ϕ_L and ϕ_R depend on $\mathcal{C}$ and $\mathcal{C}$, respectively

$\mathcal{C} \neq \mathcal{C}$ contributes to $\phi_L \neq \phi_R$, i. e. to the built-in potential

Electrostatics of pristine Chern junctions

- Built-in potential of topological origin



$\mathcal{C} = -1$

$\mathcal{C} = 1$

Energy gap ~ 30 meV

Temperature ~ 300 K

Electrostatics of pristine Chern junctions

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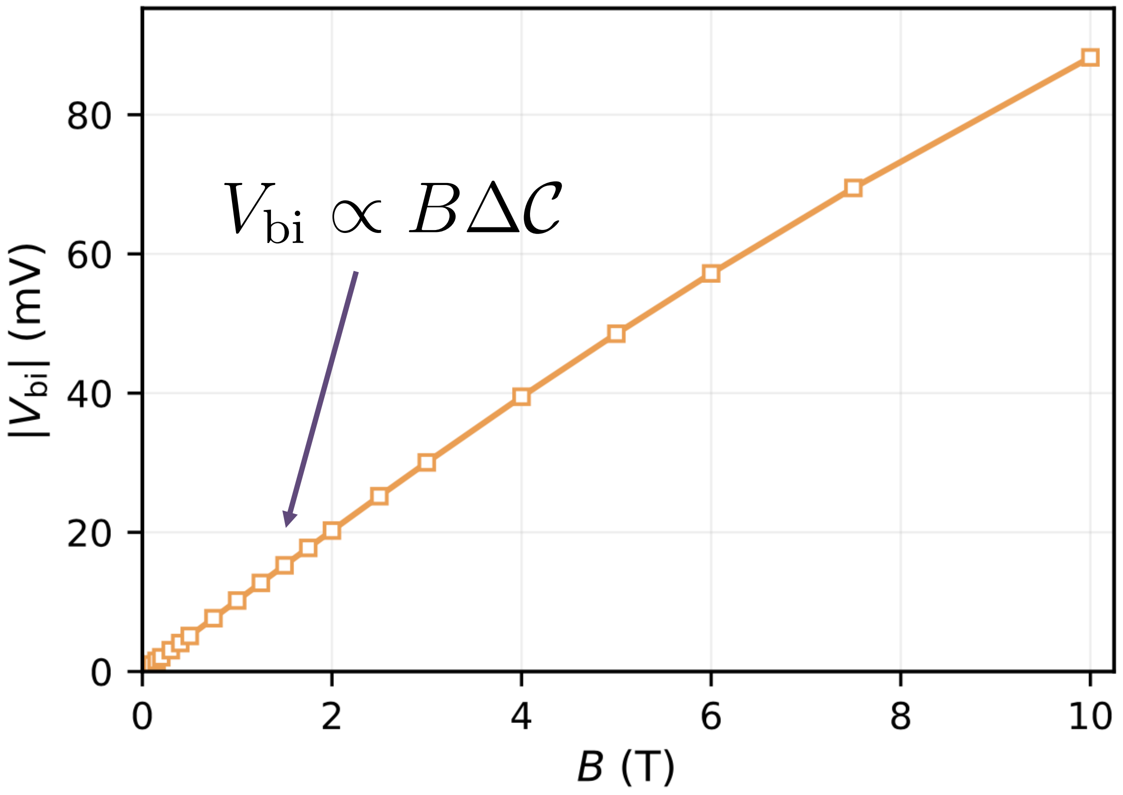

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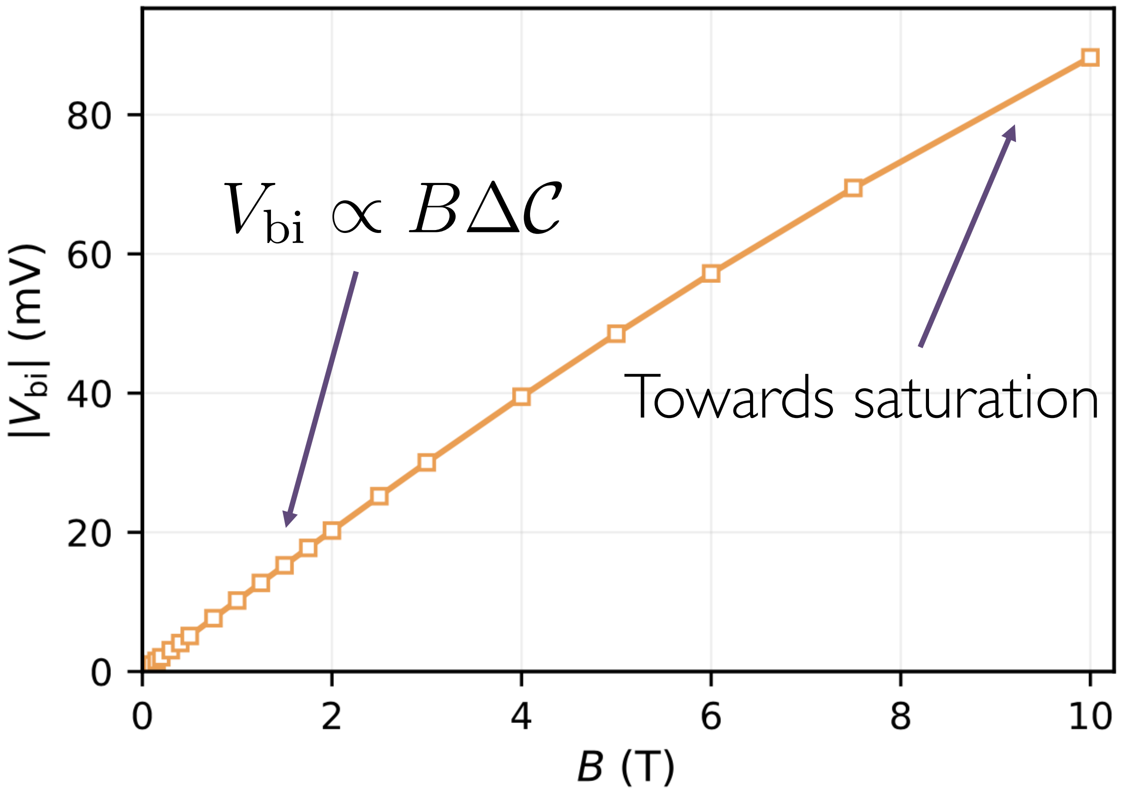

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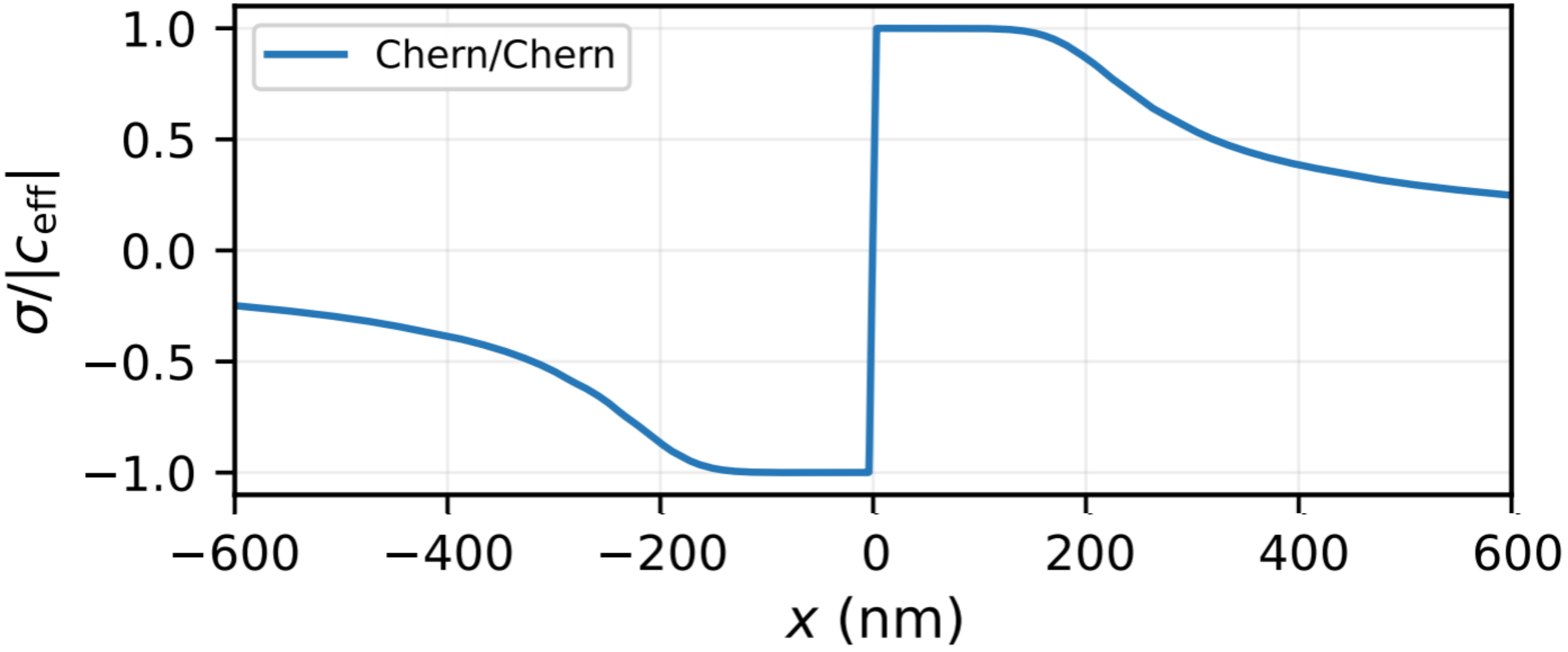
- Charge density



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$k_B T \ll \text{energy gap}$

Electrostatics of pristine Chern junctions

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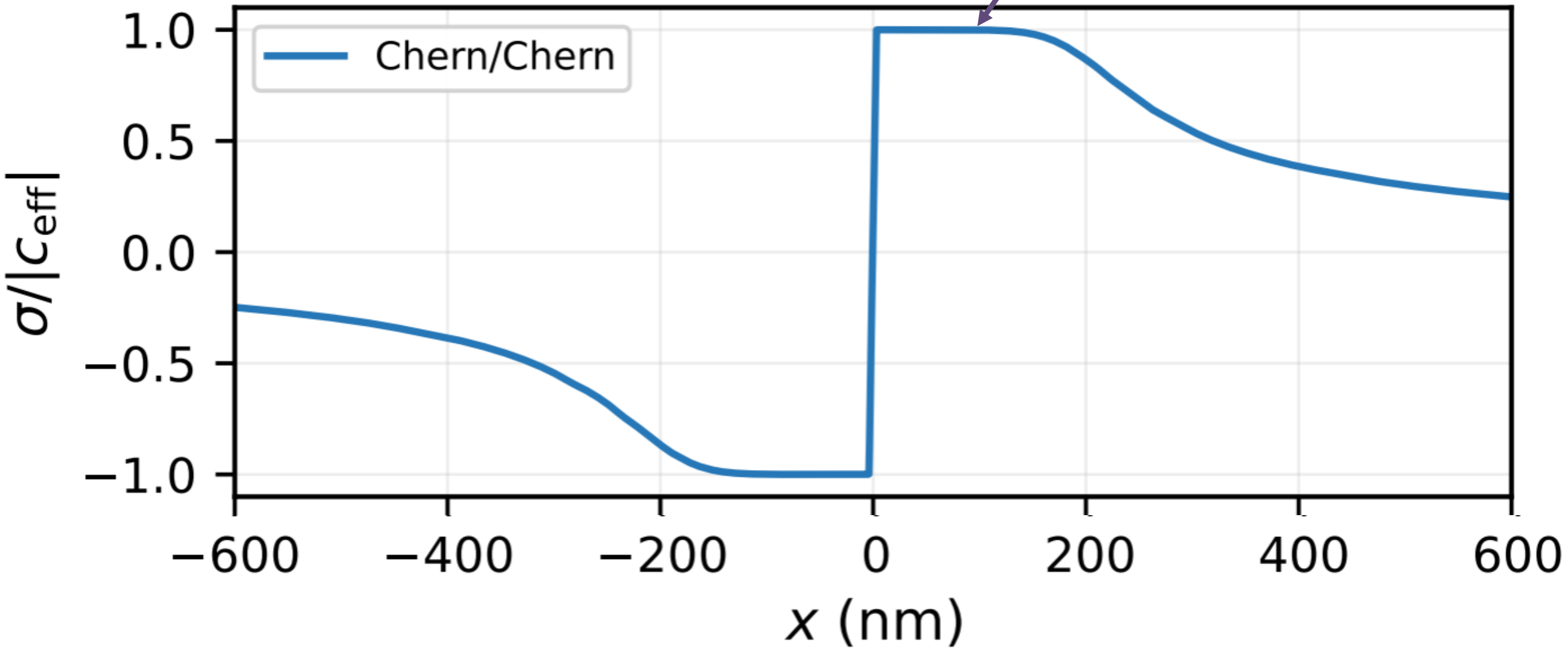
$\sigma = c_{\rm eff}$



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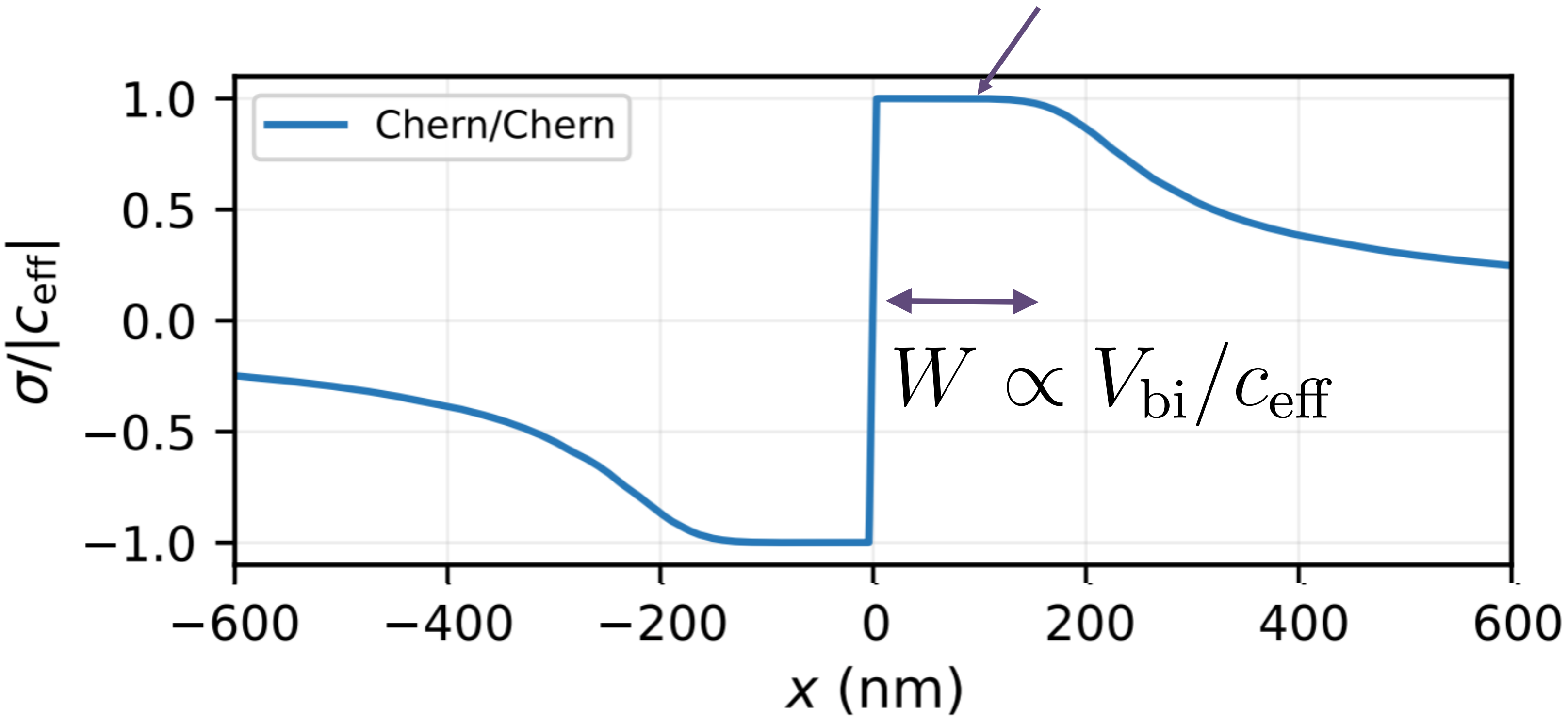

$\sigma = c_{\rm eff}$

$W \propto V_{\rm bi}/c_{\rm eff}$

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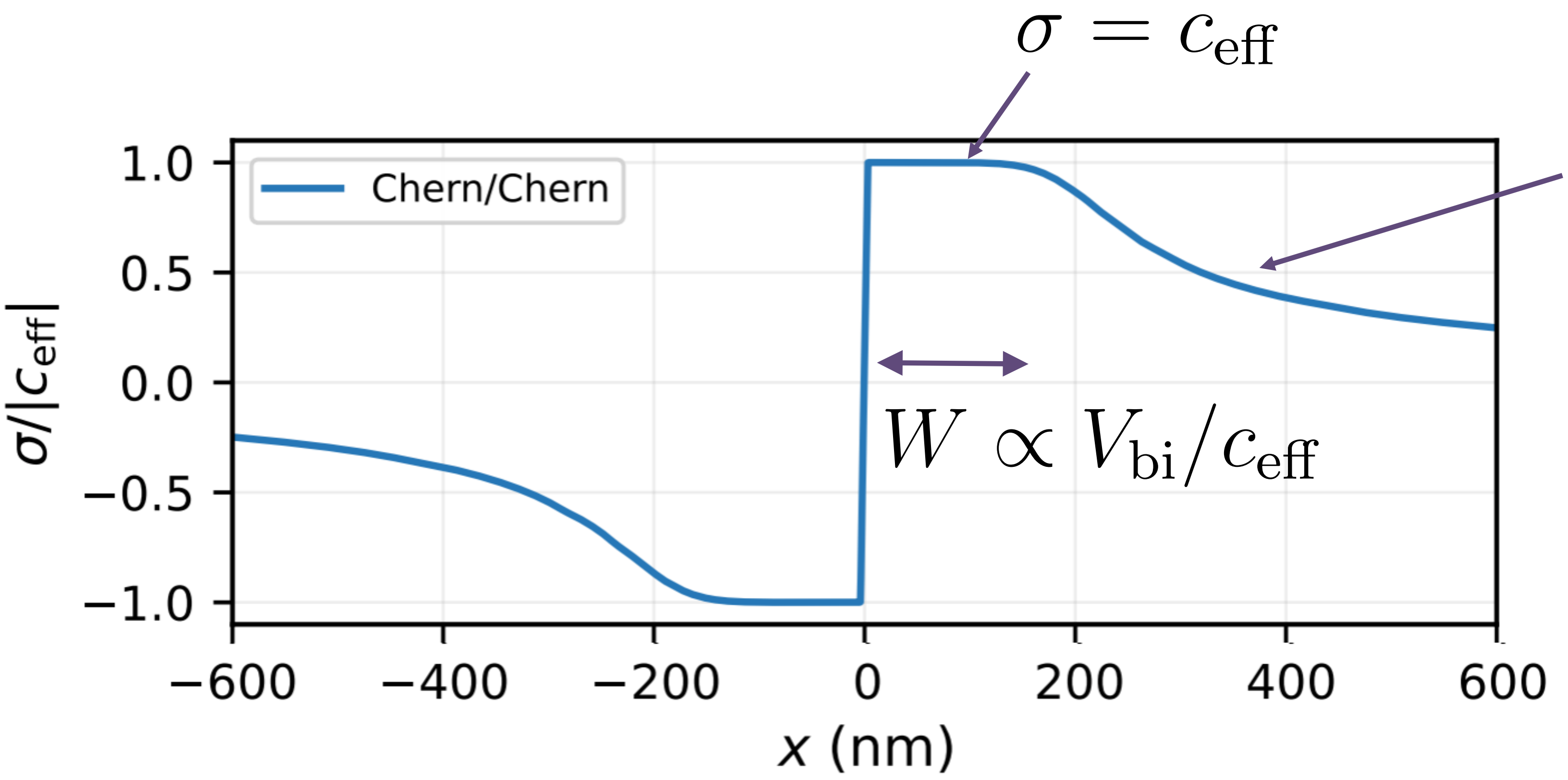

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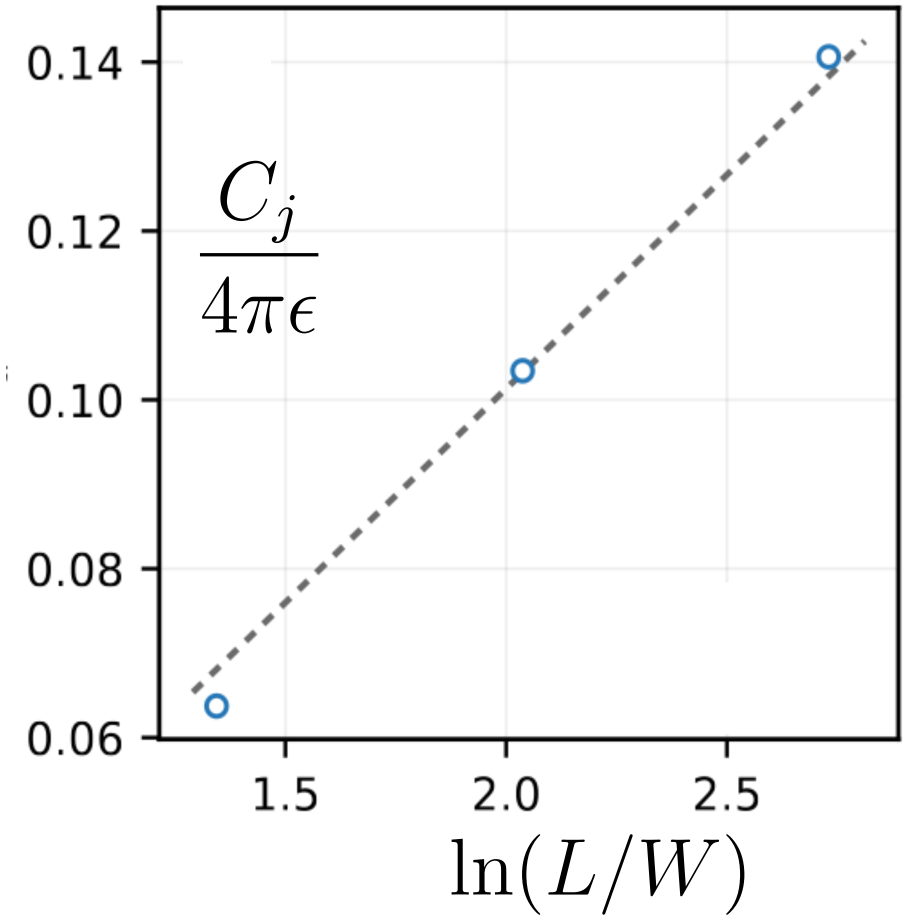
Electrostatics of <u>pristine</u> Chern junctions

- Junction capacitance

$$C_{\rm j} = \frac{\partial}{\partial V_{\rm bi}} \int_0^L (-e\sigma)dx$$



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  1) Modified doping parameter: $c \to c_{\mathrm{eff}} = c - \frac{e}{h}\mathcal{C}B$

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REGROUPEMENT QUÉBÉCOIS SUR LES MATÉRIAUX DE POINTE

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  2) Transport across junction.

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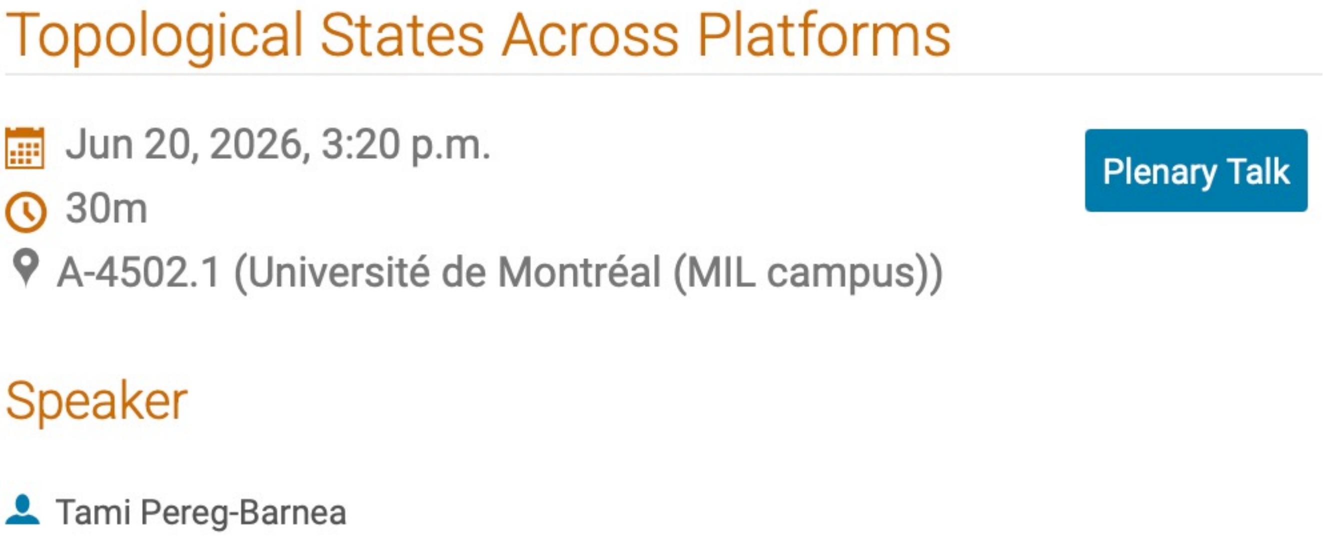

Topological States Across Platforms

Jun 20, 2026, 3:20 p.m.
30m
A-4502.1 (Université de Montréal (MIL campus))

Speaker

Tami Pereg-Barnea

- Electronic bands with nonzero topological invariants (e.g. the Chern number):

(1) Quantized responses.
(2) Low(er)-dissipation charge transport.
(3) Exotic quasiparticles (e.g. axions, Majorana fermions, Weyl fermions).