Towards Valley and Spin Injection in Graphene via Quantum Point Contacts

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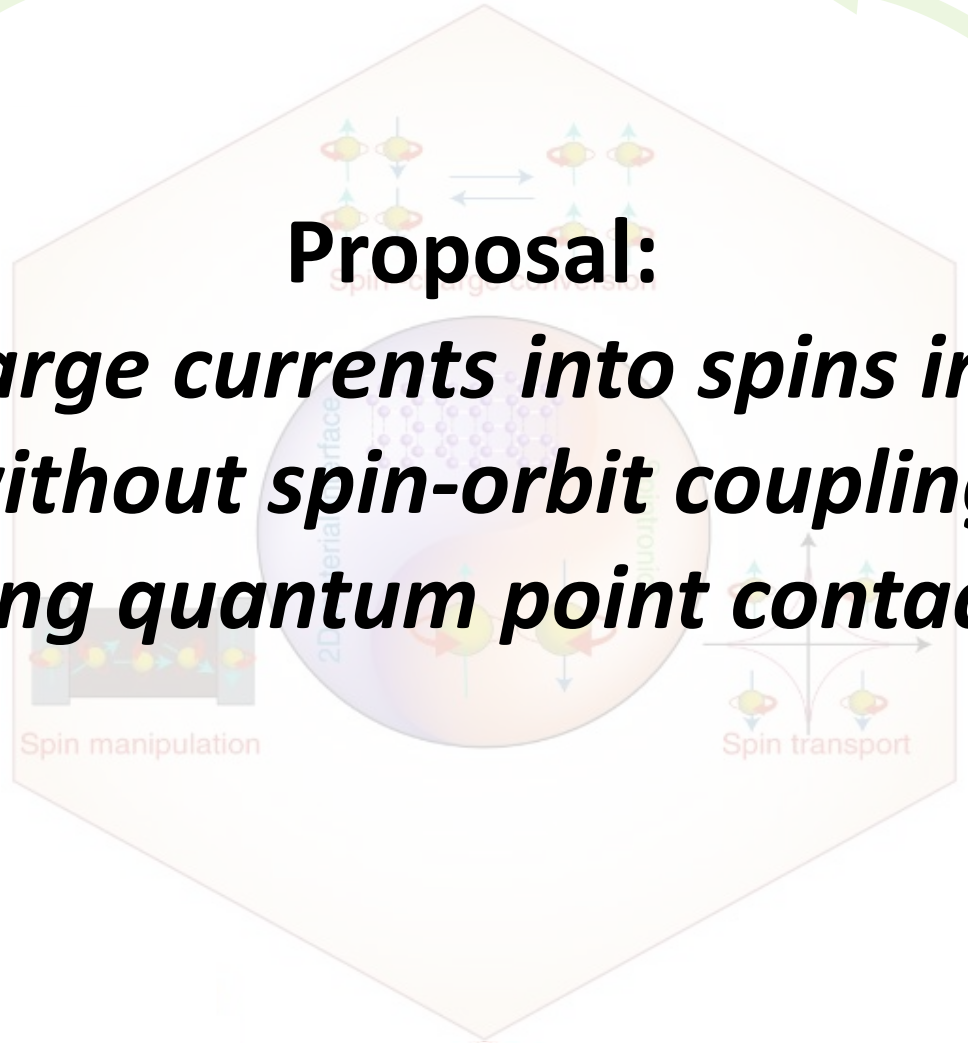
Graphene spintronics: all in ‘one’ material

Needs high spin-orbit coupling

Van der Waals heterostructures

Mutually exclusive



Spin-orbit or magnetic exchange proximity

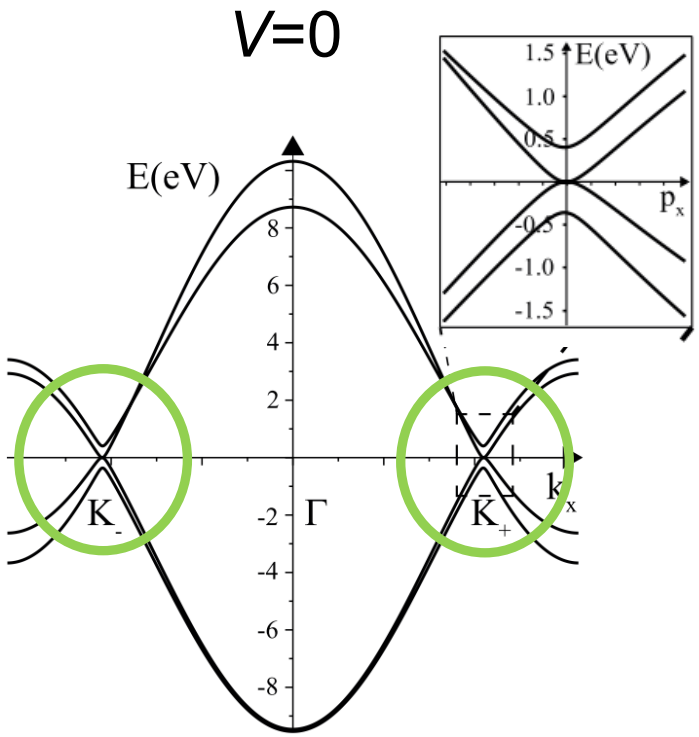
Pristine graphene needs low spin-orbit coupling

Proposal:

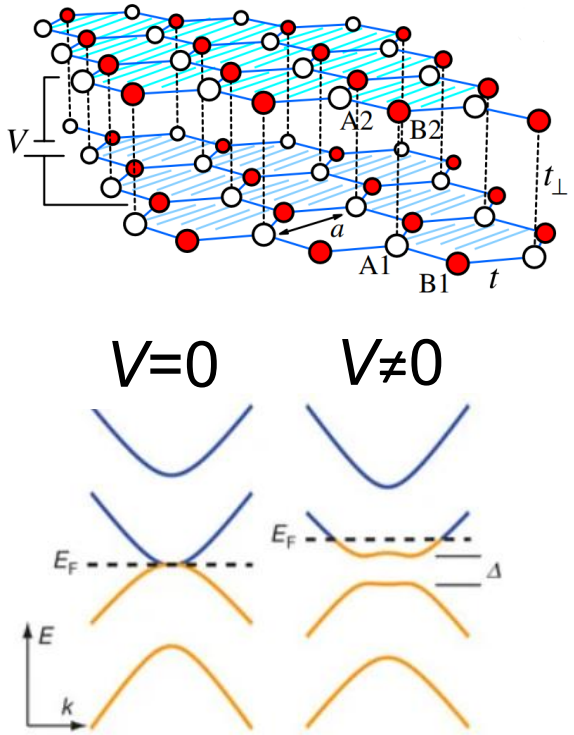
Convert charge currents into spins in graphene without spin-orbit coupling using quantum point contacts

Lin et al. Nature Electron. 2, 274 (2019)
Sierra et al. Nature Nanotech. 16, 856 (2021)

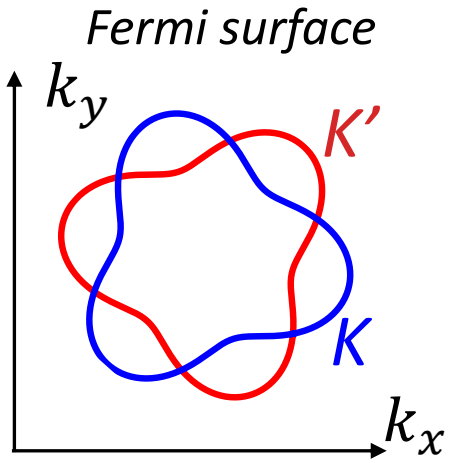
Bernal bilayer graphene (BLG): valleys and bandgap



degree of freedom:
valley degeneracy

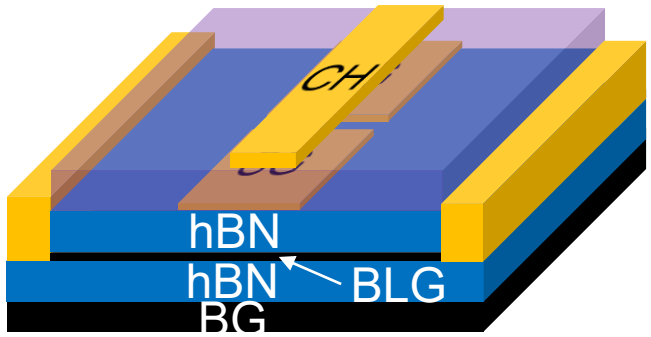


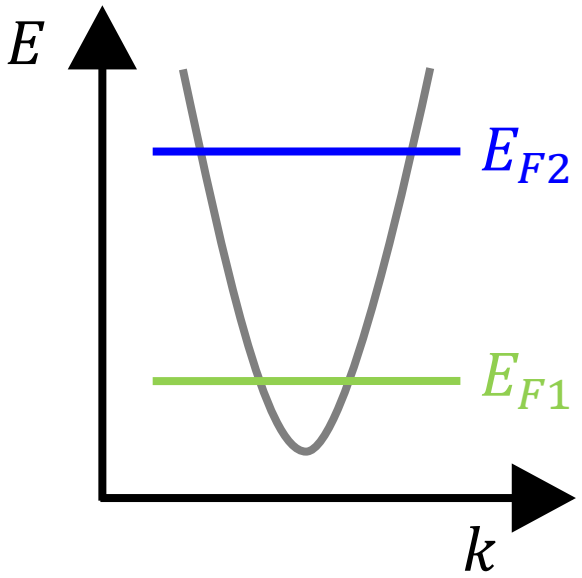
Trigonal warping

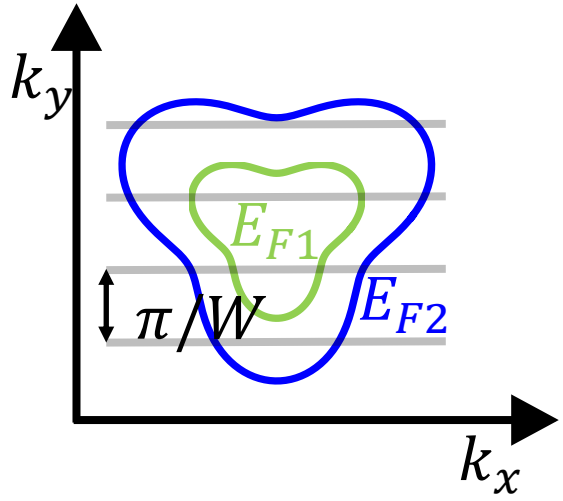


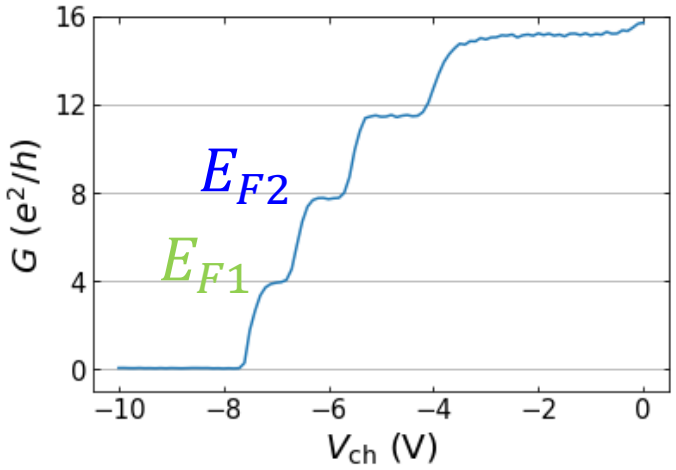
Icking et al. Adv. Elec. Mater. 8, 2200510 (2022)
Zhang et al. Nature 459, 820 (2009)

Quantum point contacts in bilayer graphene



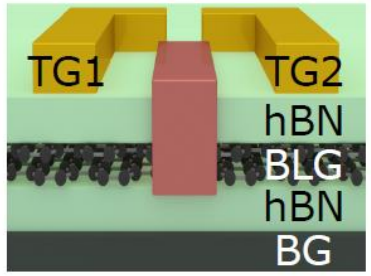


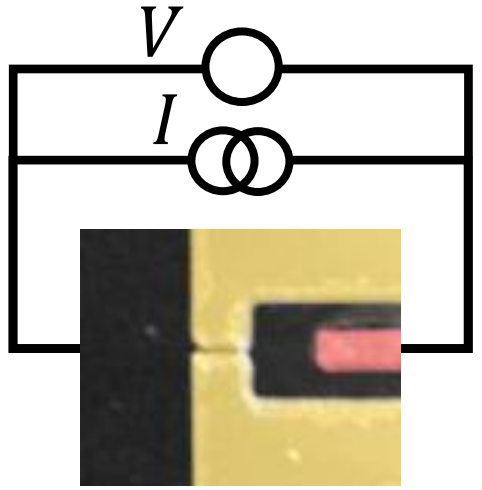


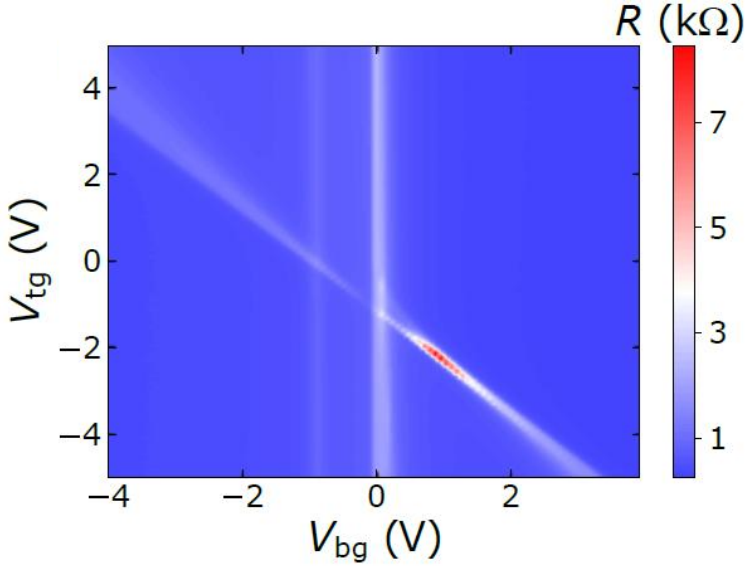


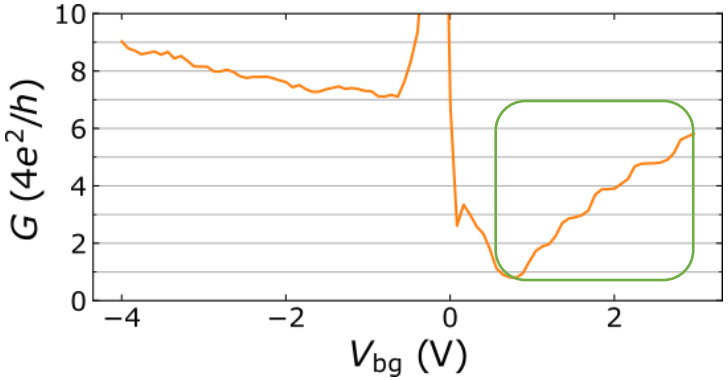
Overweg et al. Nano Lett. 18, 553 (2018)

Quantum point contacts for ballistic transport



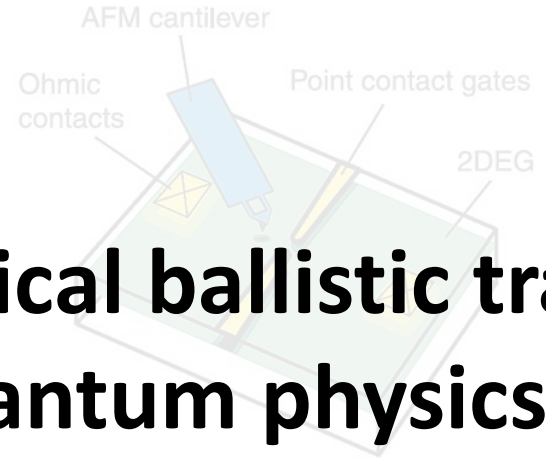






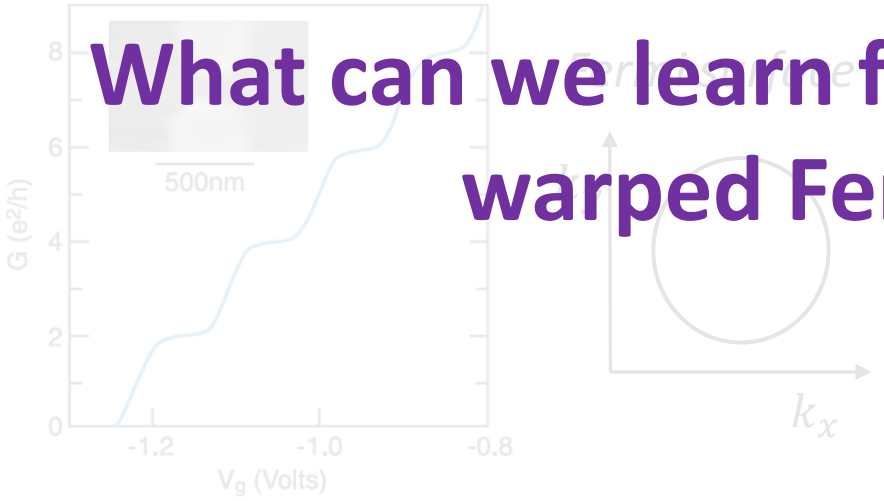
J. I-A et al. Nano Lett. 23, 5453 (2023)

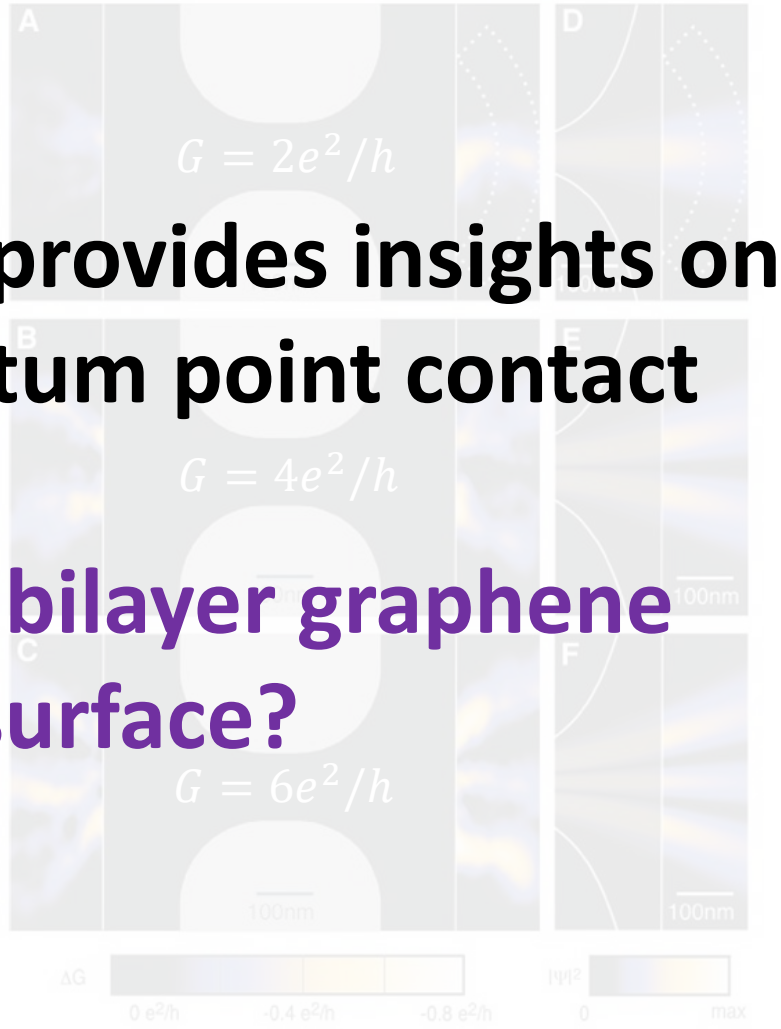
Mapping wave function of a quantum point contact using ballistic transport



Classical ballistic transport provides insights on quantum physics in quantum point contact

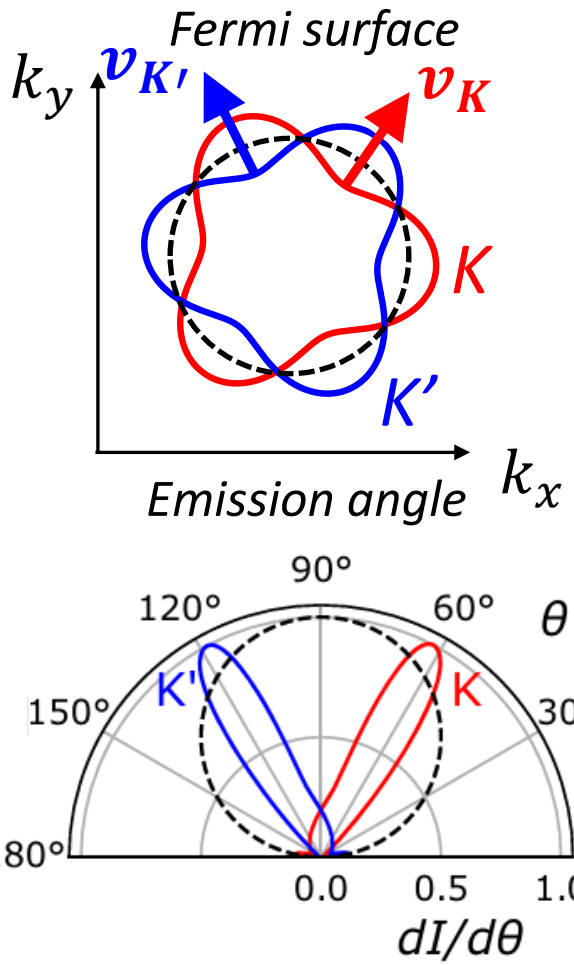
What can we learn from bilayer graphene warped Fermi surface?

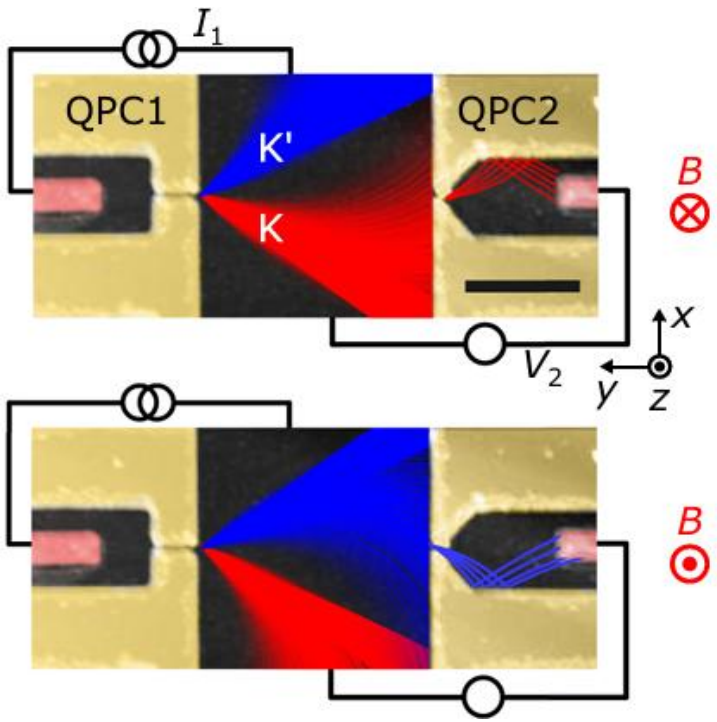




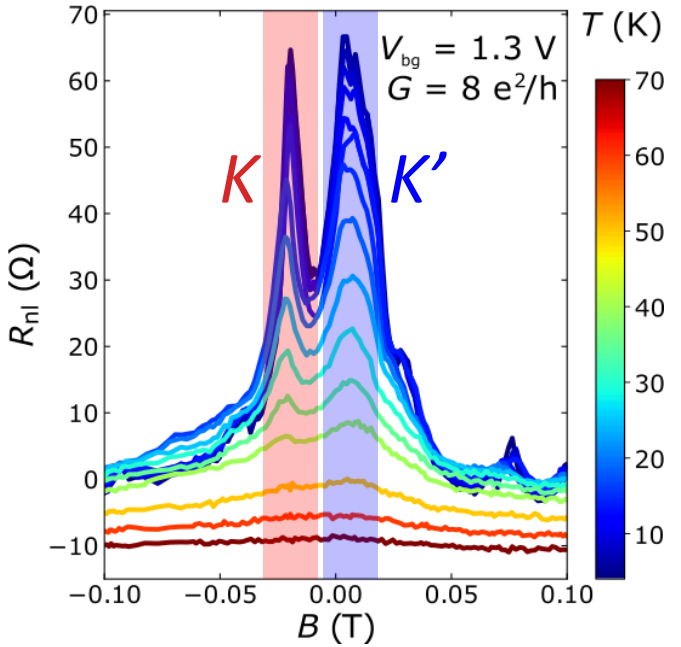
Topinka et al. Science 289, 5488 (2000)

Trigonal warping: valley-polarized ballistic currents





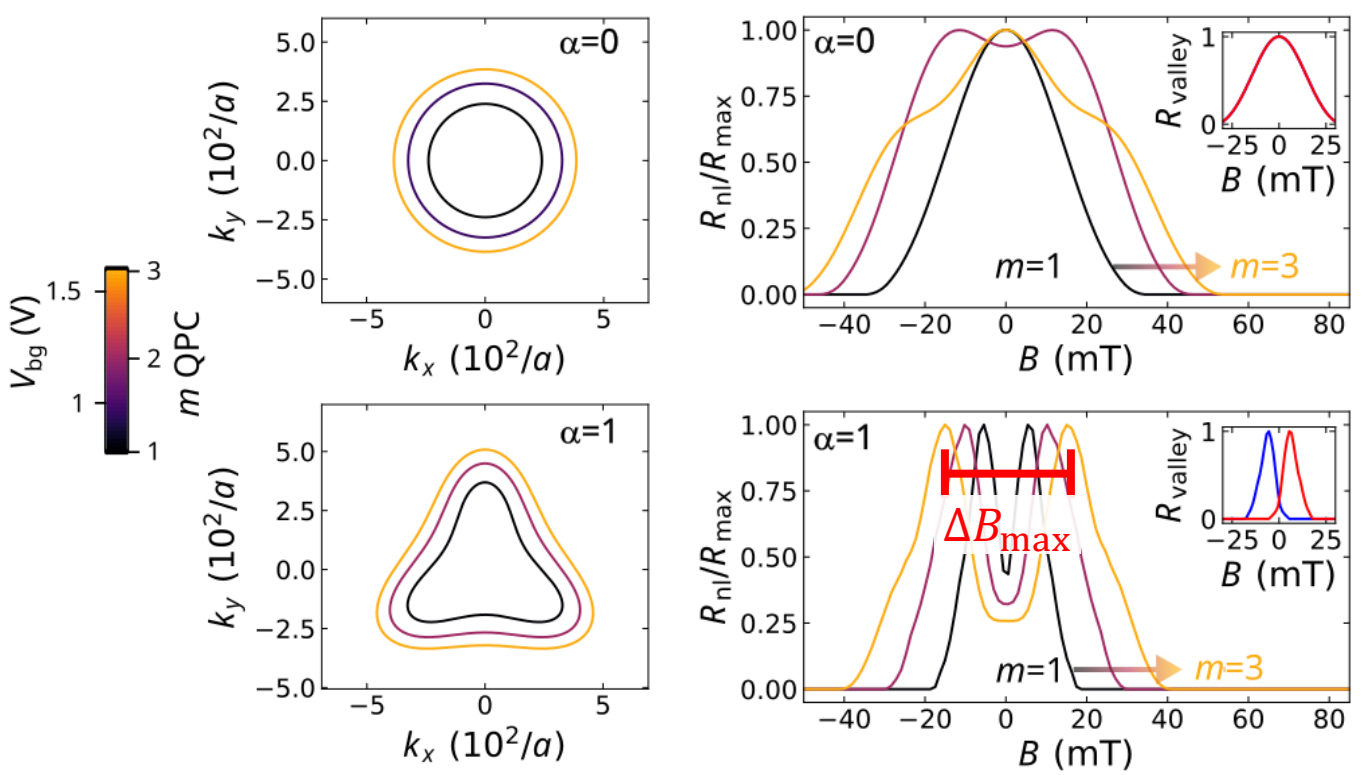
4 μm QPC separation



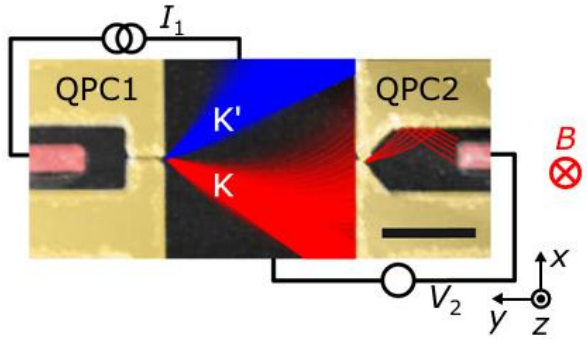
Gold et al. Phys. Rev. Lett. 127, 046801 (2021)
J. I-A et al. Phys. Rev. Lett. 133, 156301 (2024)

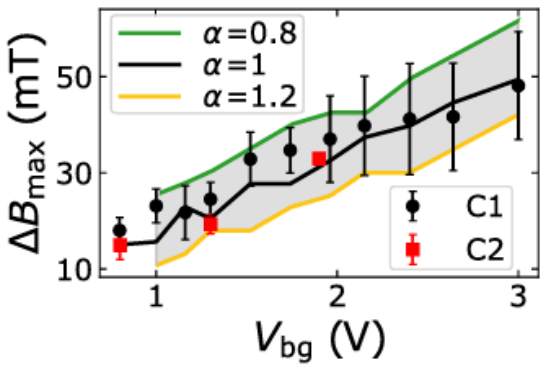
Quantum confinement effects

A. Manesco



$\alpha = 0$ no trigonal warping
$\alpha = 1$ tight-binding band structure





Peak separation determined by trigonal warping

Introduction

Ballistic transport

Valley current source

Conclusions and outlook

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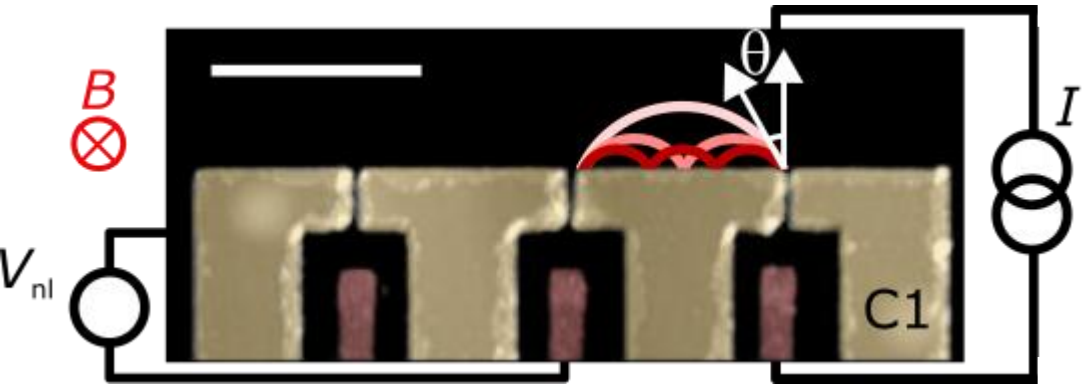
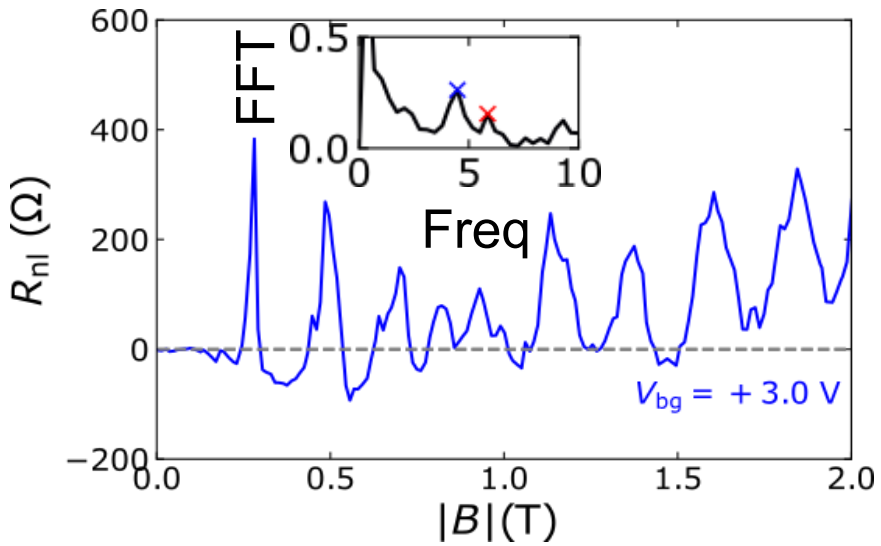
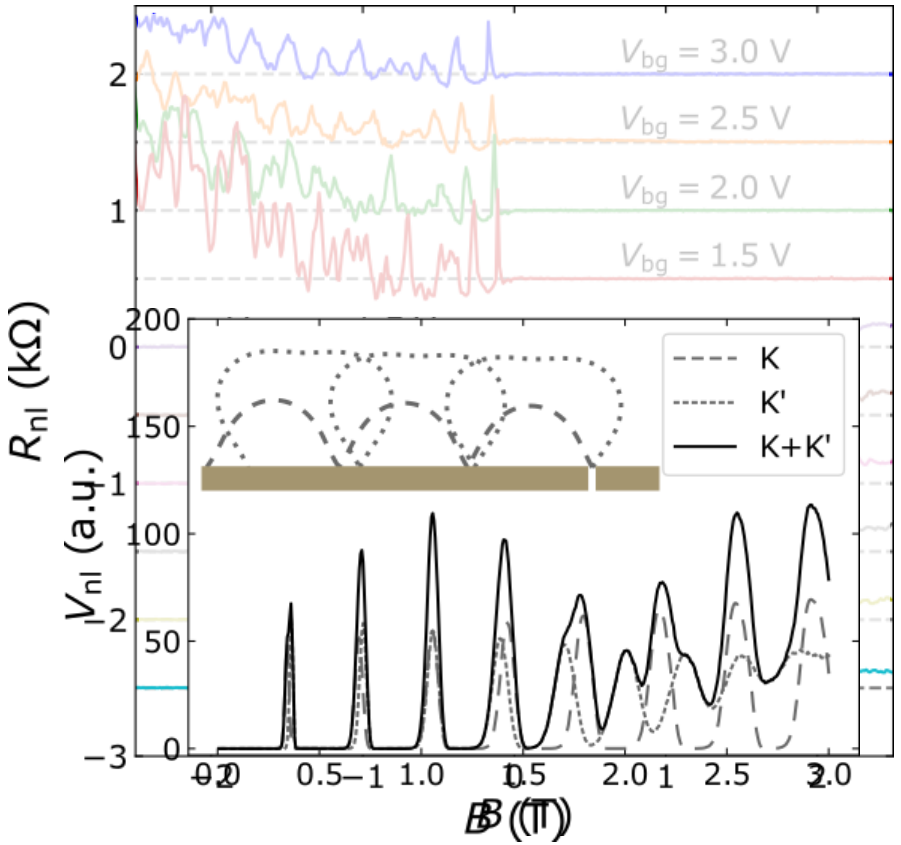
Trigonal warping and transverse electron focusing



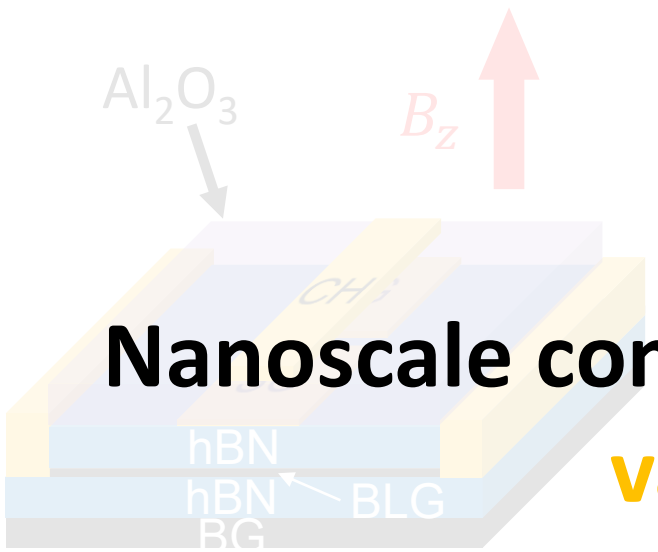


$$R_{nl} = V_{nl}/I$$

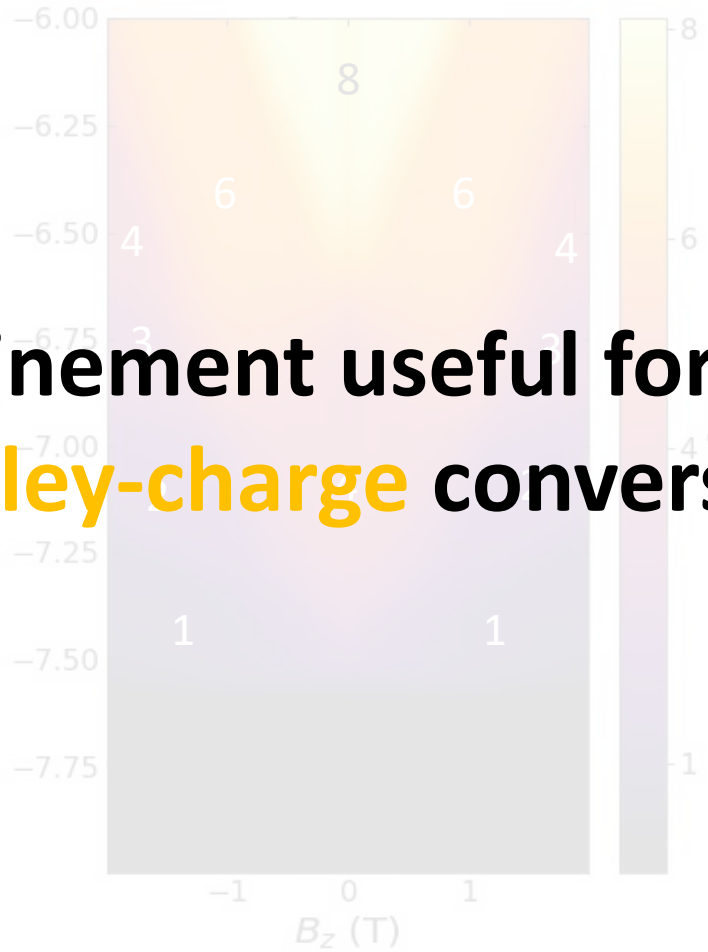


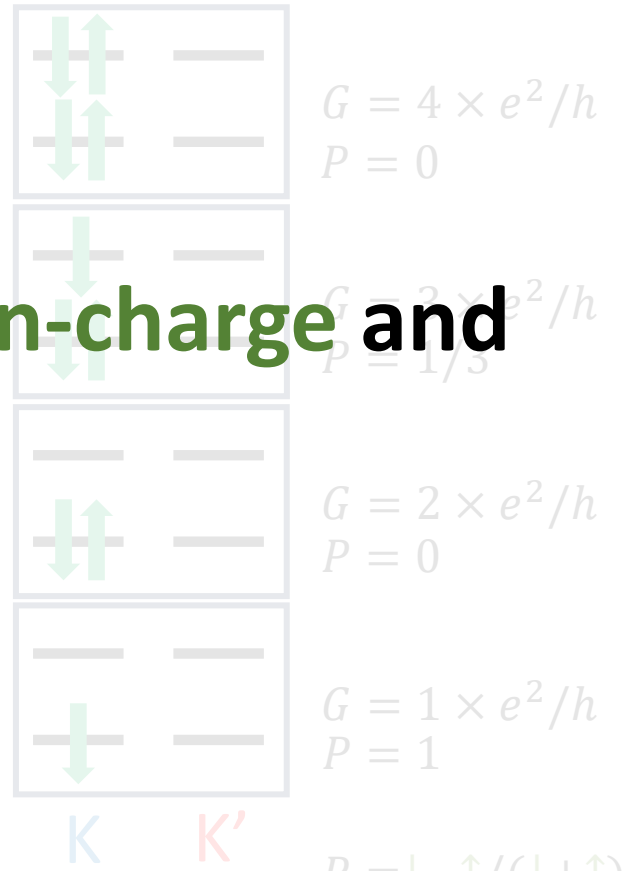
J. I-A et al. Nano Lett. 23, 5453 (2023)

Spin and valley split Fermi surfaces in quantum point contact



BLG: bilayer graphene
hBN: boron nitride
SG: split gates
BG: back gate
CH: channel gate





Nanoscale confinement useful for spin-charge and valley-charge conversion

- Introduction
- Ballistic transport
- Valley current source
- Conclusions and outlook

Overweg et al. PRL 121, 257702 (2018), Kraft et al. PRL 257703 (2018)
Lee et al. PRL 124, 126802 (2020)

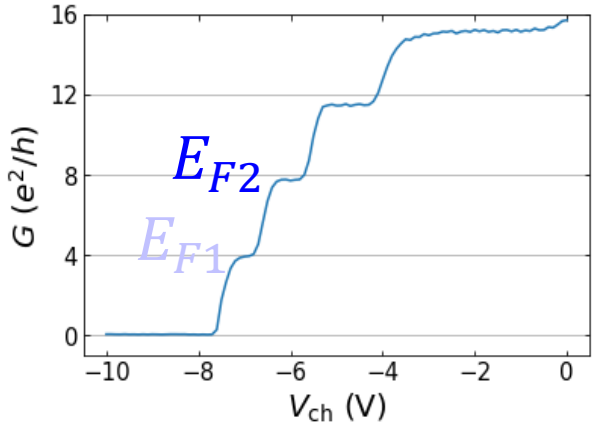
Conclusions

Spin-charge conversion
(high spin-orbit coupling)

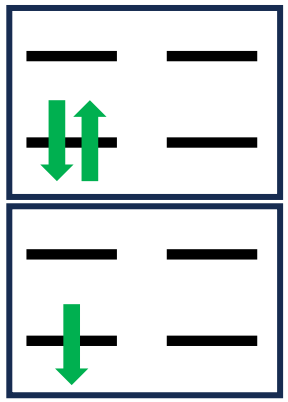
+ = **Challenge**

Long distance spin transport

Quantum point contacts have discrete subbands



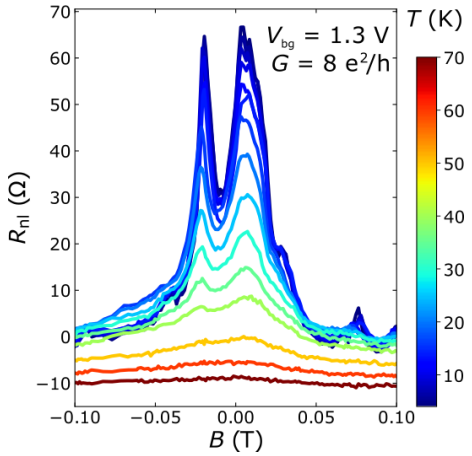
That allows for creating spin and valley polarized currents

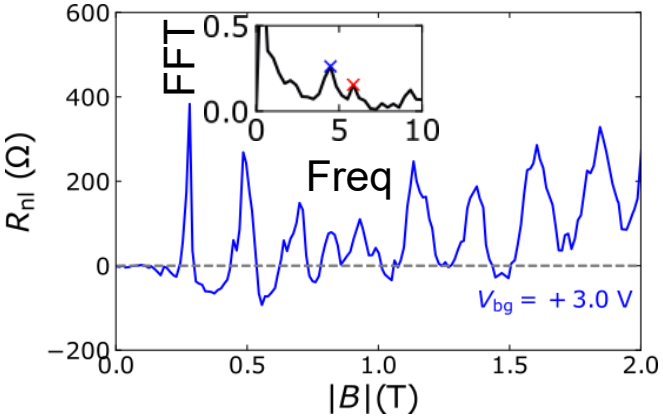


$G = 2 \times e^2/h$

$G = 1 \times e^2/h$

And enable the observation of unique effects on ballistic transport





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K K’

Vila et al. Phys. Rev. Lett. 124, 196602 (2020)

J. I-A et al. Nano Lett. 23, 5453 (2023)
J. I-A et al. Phys. Rev. Lett. 133,156301 (2024)