Magnetism and electronics in quantum Hall bars

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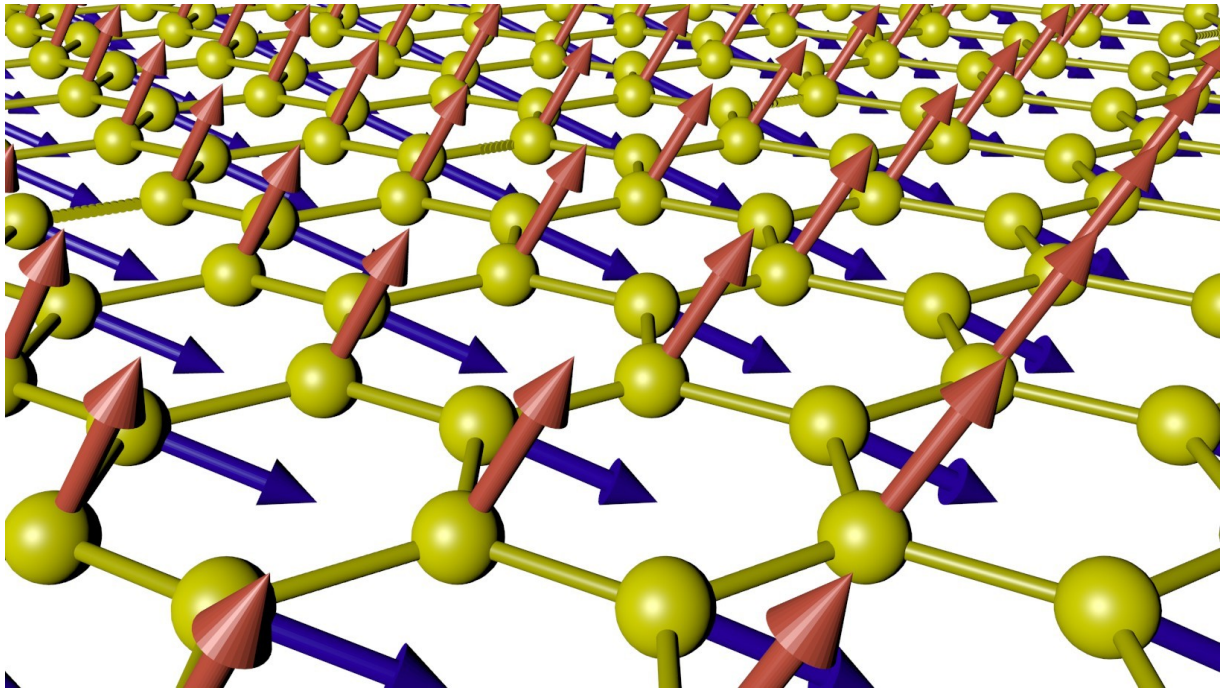
International Nanotechnology Laboratory (INL), Braga, Portugal



Evora 2014, 8 October

The team

Theory group at INL, Braga, Portugal

Jose Lado

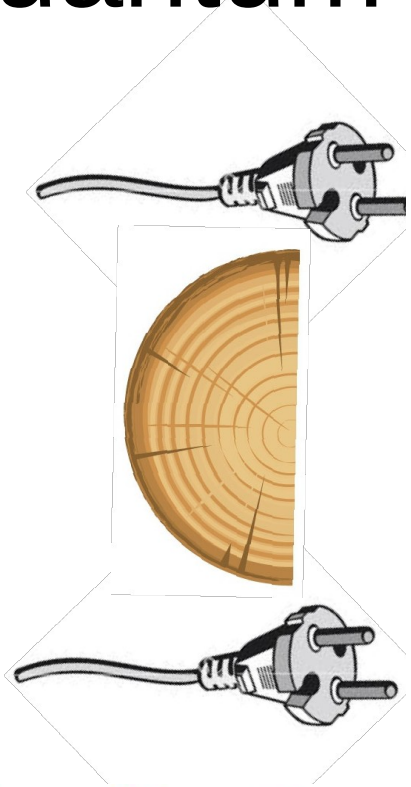
Joaquin Rossier

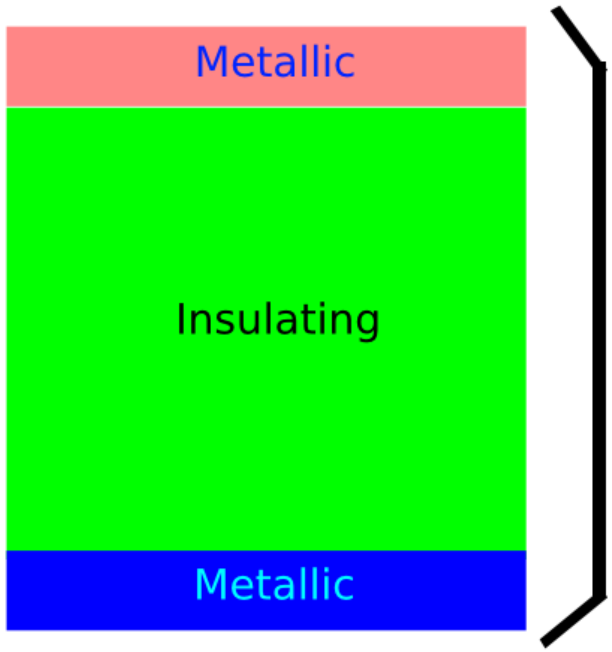
Quantum Spin Hall

Spin current

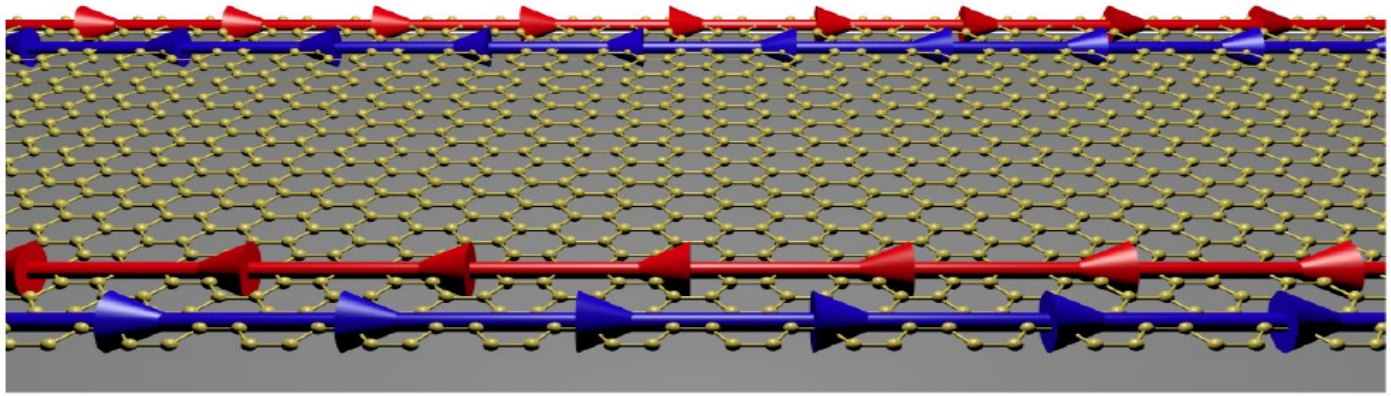
Insulator

Spin current

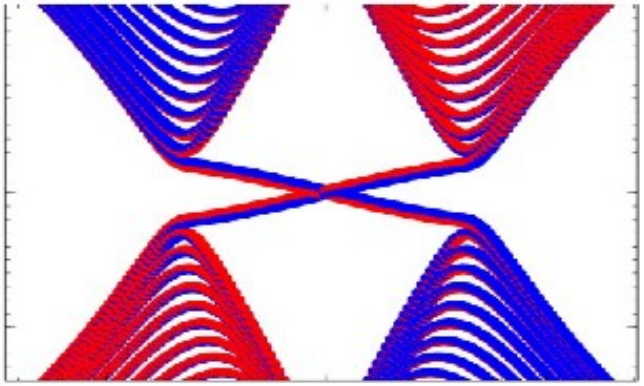




Same material



Quantum Spin Hall in graphene



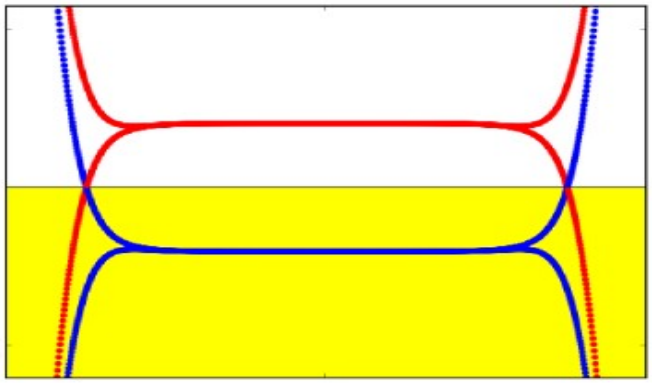
Z_2 topological insulator

Theory

Kane Mele PRL (2005)

Experiment

????????



Spin Chern insulator

Theory

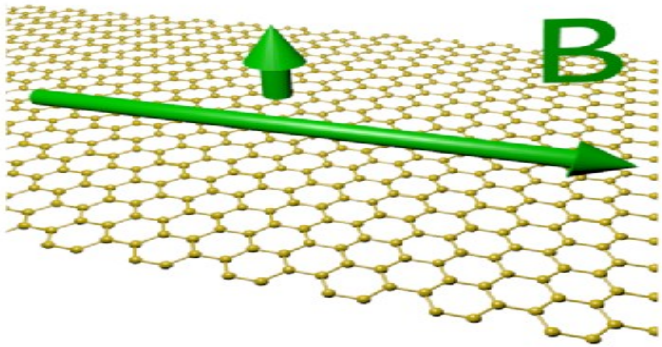
Abanin et al, PRL (2006)

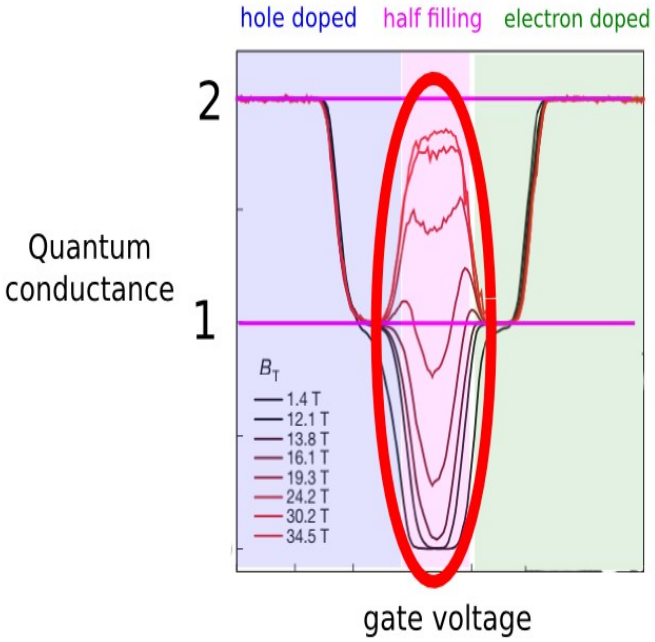
Experiment

A. F. Young et al, Nature (2014)

The experimental set-up

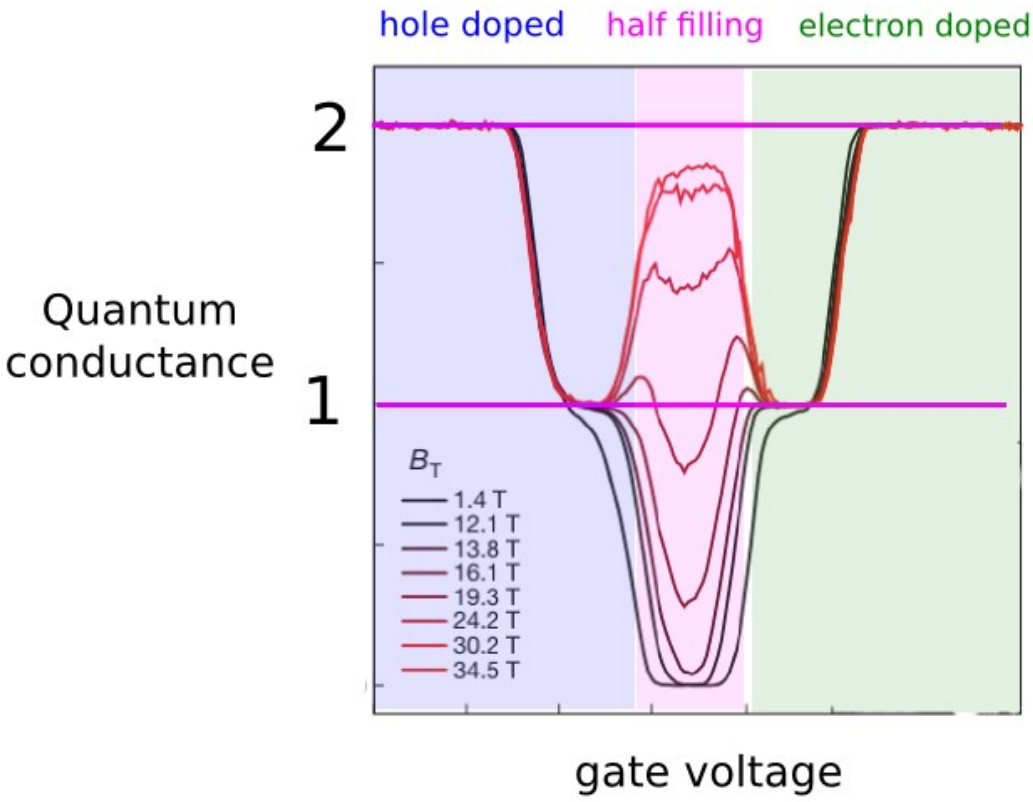
- High quality graphene
- Off-plane magnetic field
- In-plane magnetic field
- Variable doping via gate





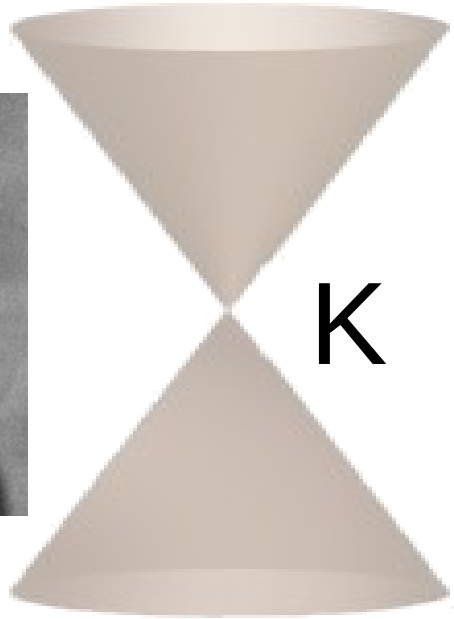
A. F. Young et al, Nature (2014)

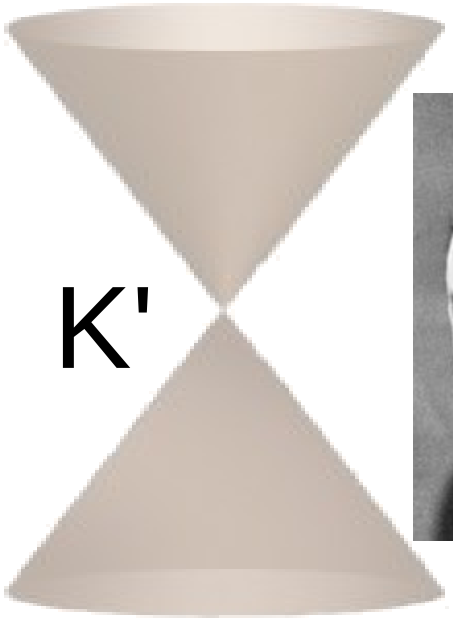
Not perfect conductance???

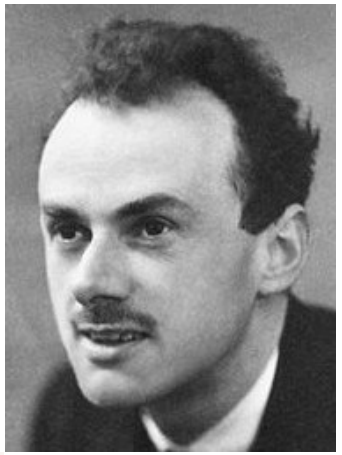


half filling

Low energy Hamiltonian



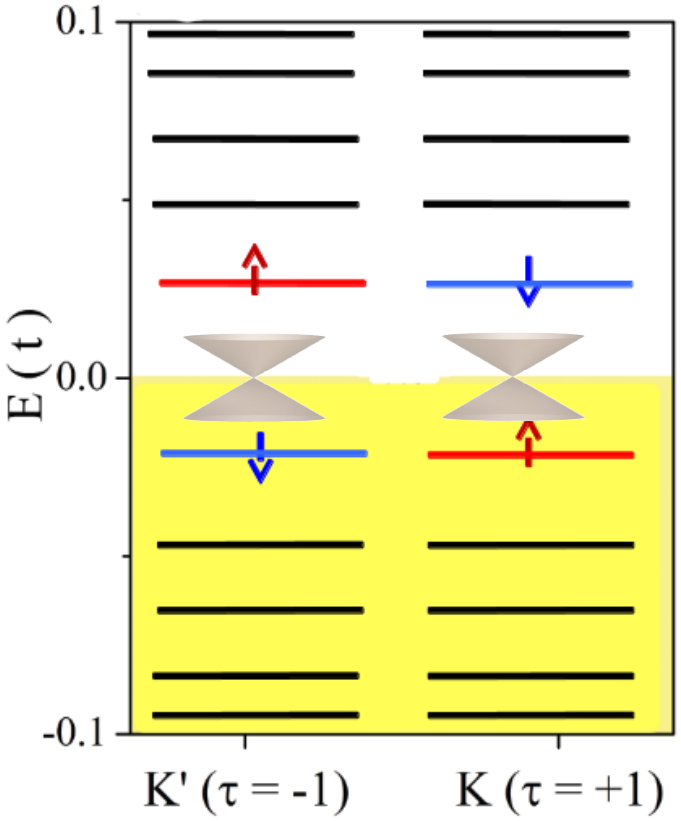




<u>Two Dirac equations</u>

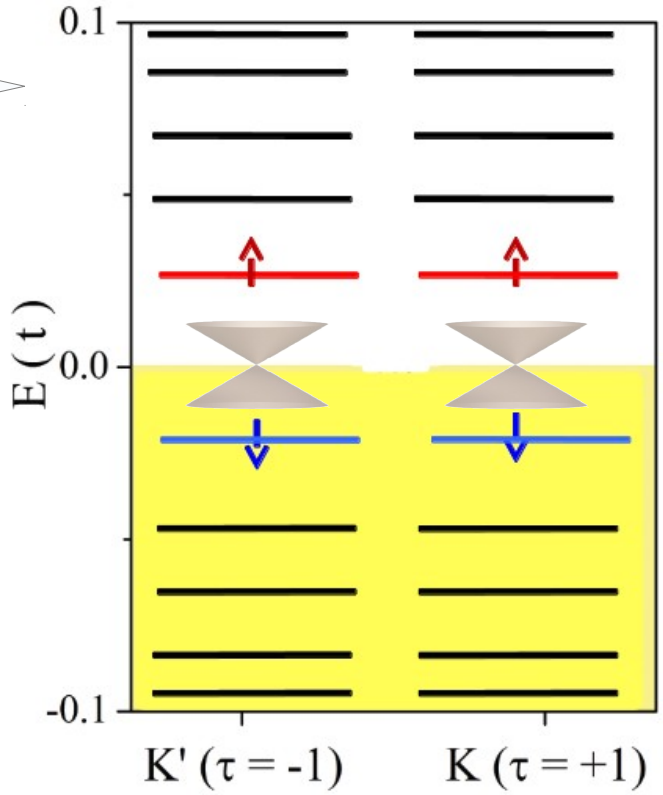
The Landau level picture

Antiferromagnetic



Increasing Zeeman

Ferromagnetic

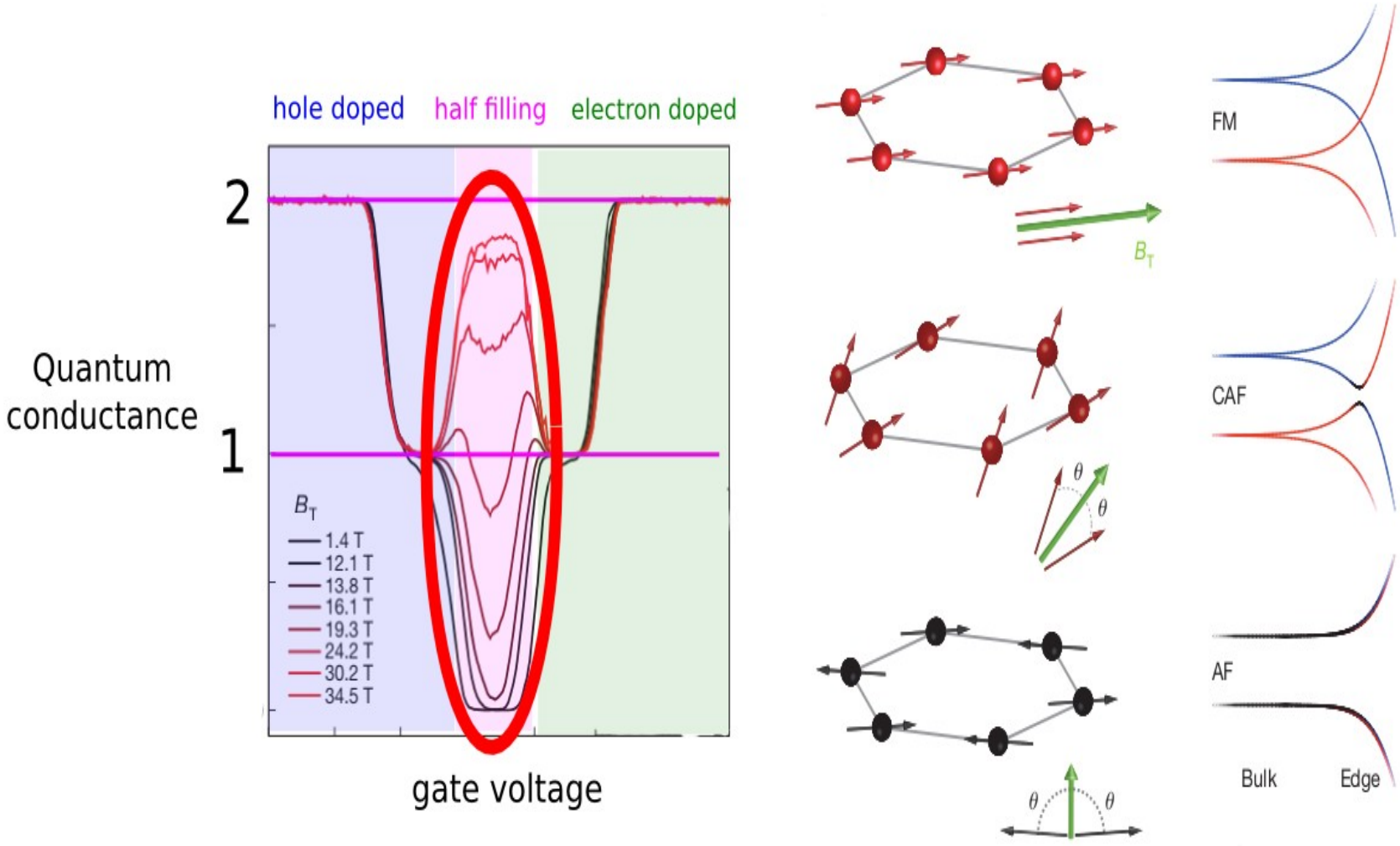


Spin Chern number = 0

Spin Chern number = 2

Abanin et al, PRL (2006)

Canted magnetism



A. F. Young et al, Nature (2014)

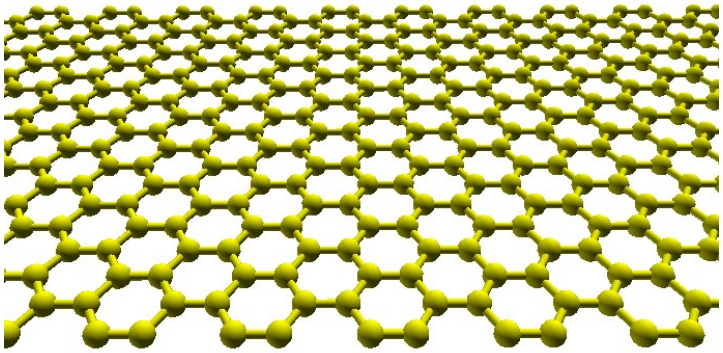
One ~~ring~~ model to rule them all

$$\mathcal{H} = \mathcal{H}_0(B_z) + g\mu_B \vec{B} \cdot \vec{S} + U \sum_i n_{i,\uparrow} n_{i,\downarrow}$$

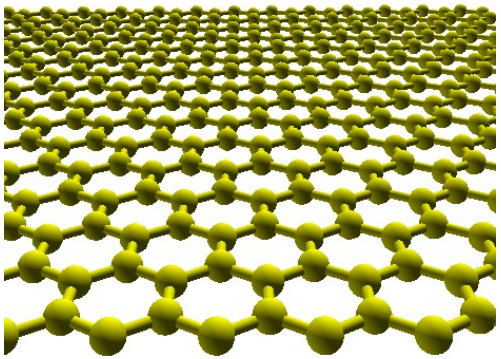
spin Zeeman field

nearest neighbor hopping
(with Peierls phase)

local e-e interaction
(Hubbard like)



ribbon geometry

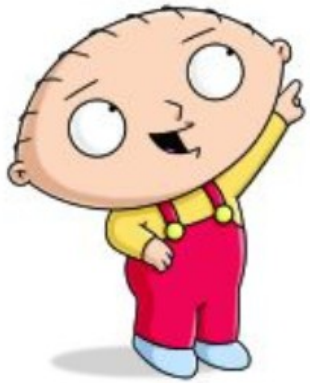


Solving the model

$$\mathcal{H} = \mathcal{H}_0(B_z) + g\mu_B \vec{B} \cdot \vec{S} + U \sum_i n_{i,\uparrow} n_{i,\downarrow}$$

Mean field antsaz

$$H^{MF} = H_0 + g\mu_B \vec{B} \cdot \vec{S} + H_H + H_F + E_{DC}$$



Collinear (Hartree)

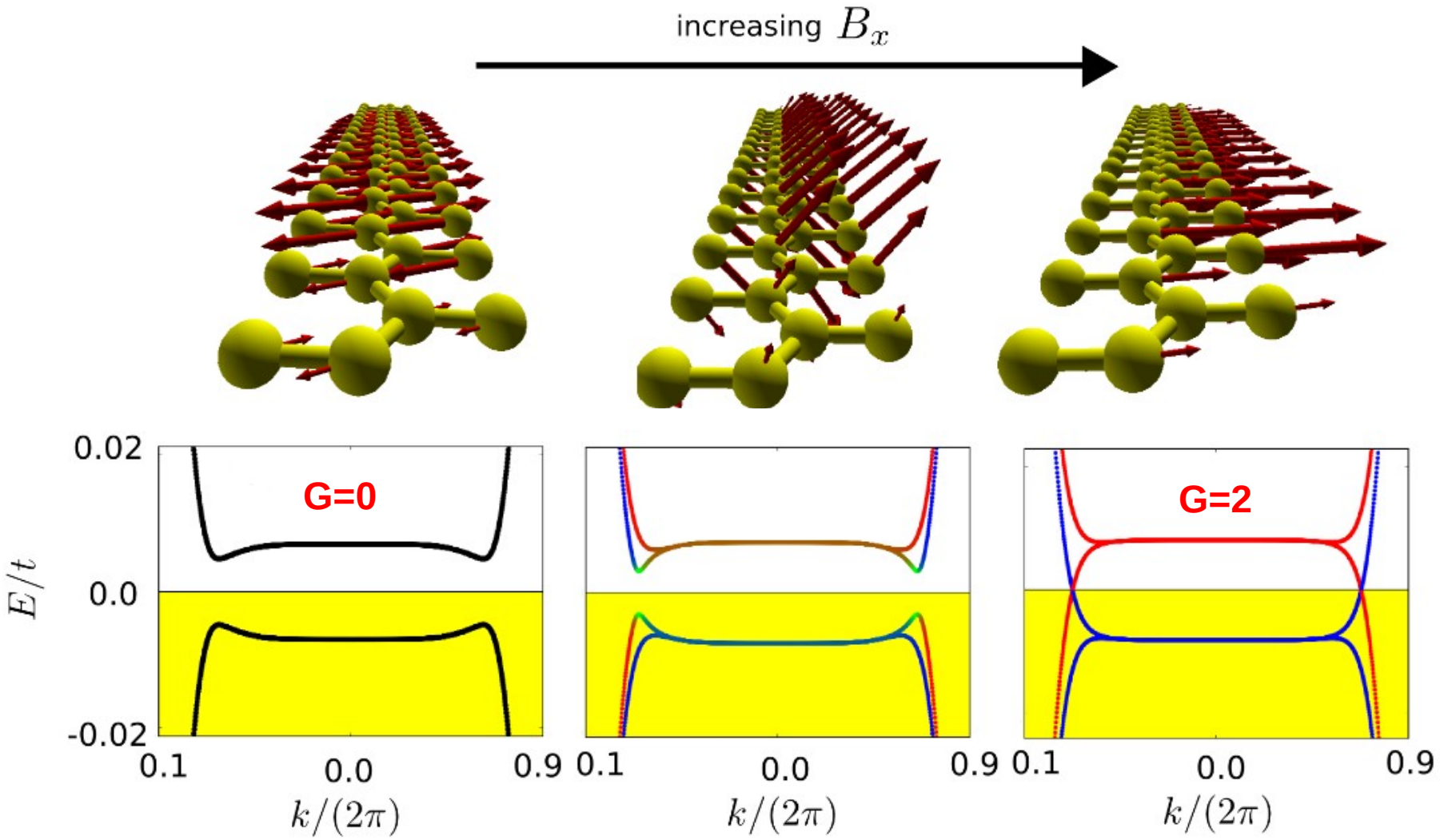
Exchange (Fock)

Double counting

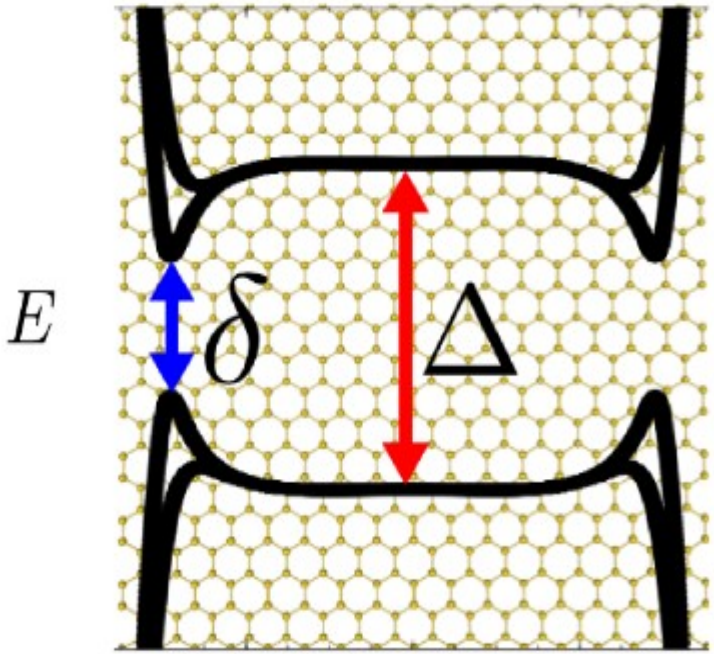
Variational wave function

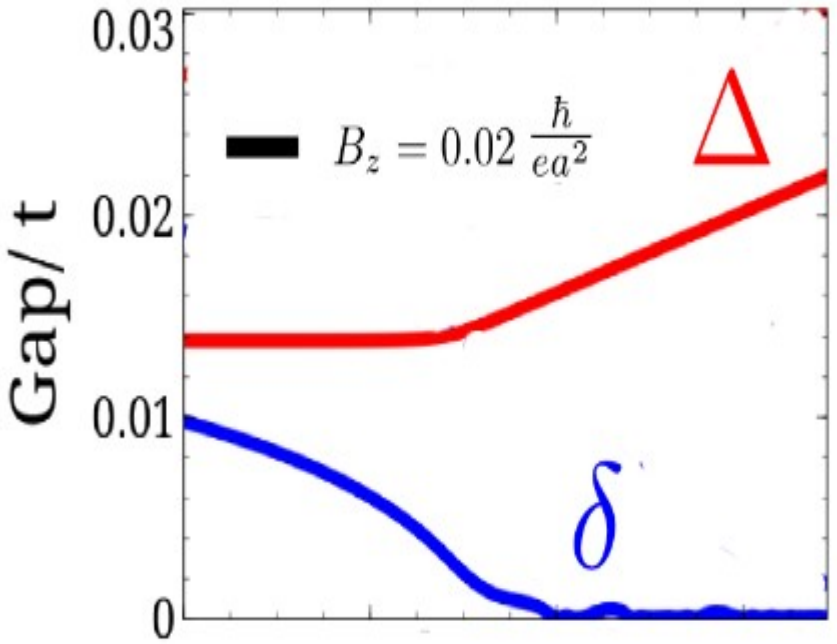
$$|\Omega\rangle = \prod_i \left(u_i c^\dagger_{i\uparrow} + v_i c^\dagger_{i\downarrow} \right) |0\rangle$$

Transition at half filling with Bx



Transition at half filling with Bx



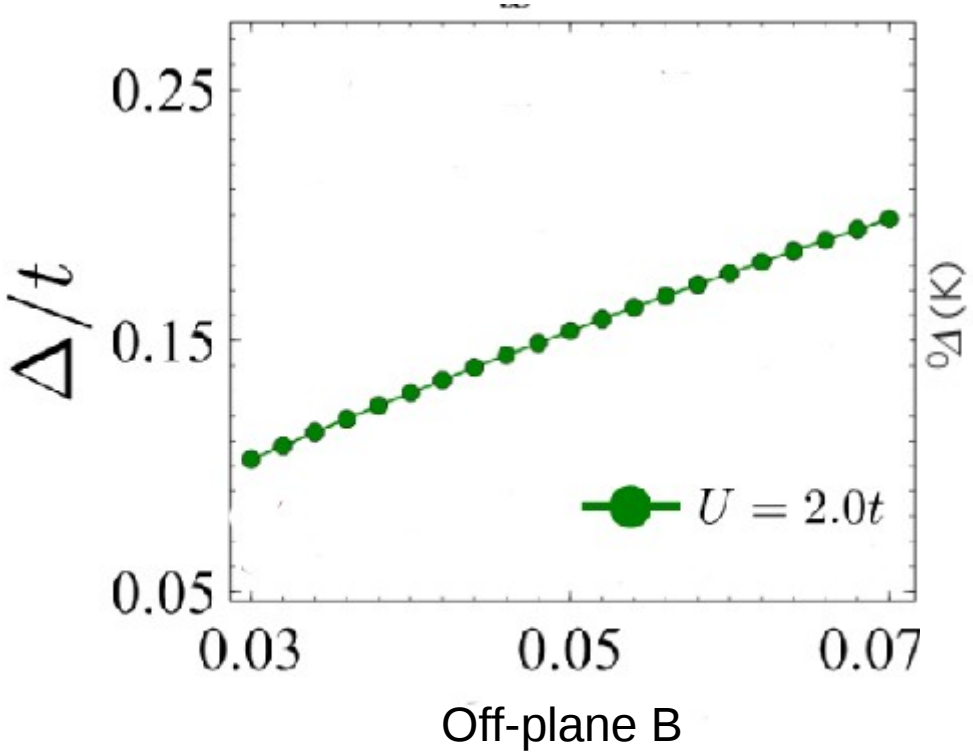


In-plane B

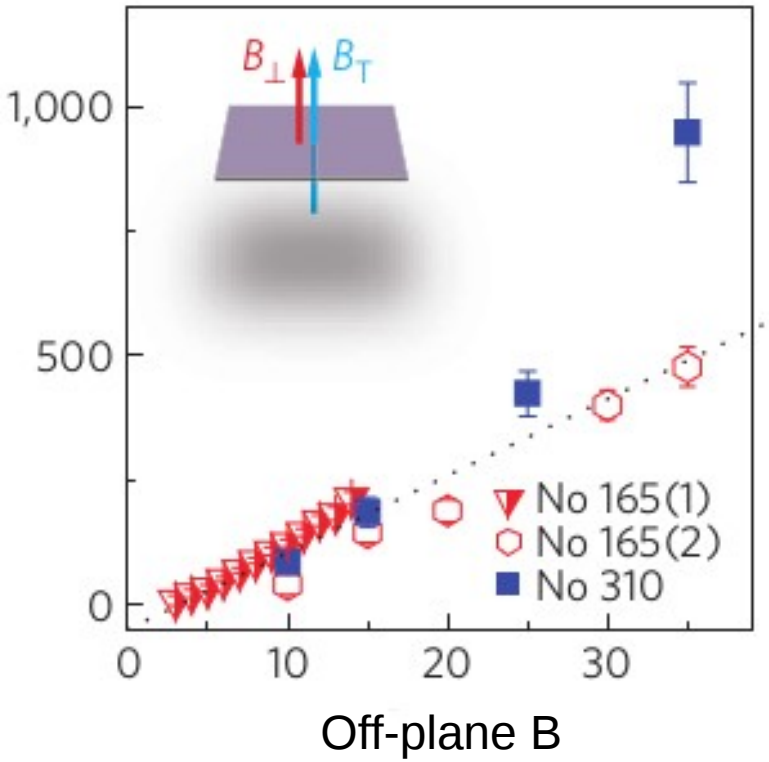
Only possible in the non-collinear formalism

Gap increases at half filling

Hubbard model



Off-plane B

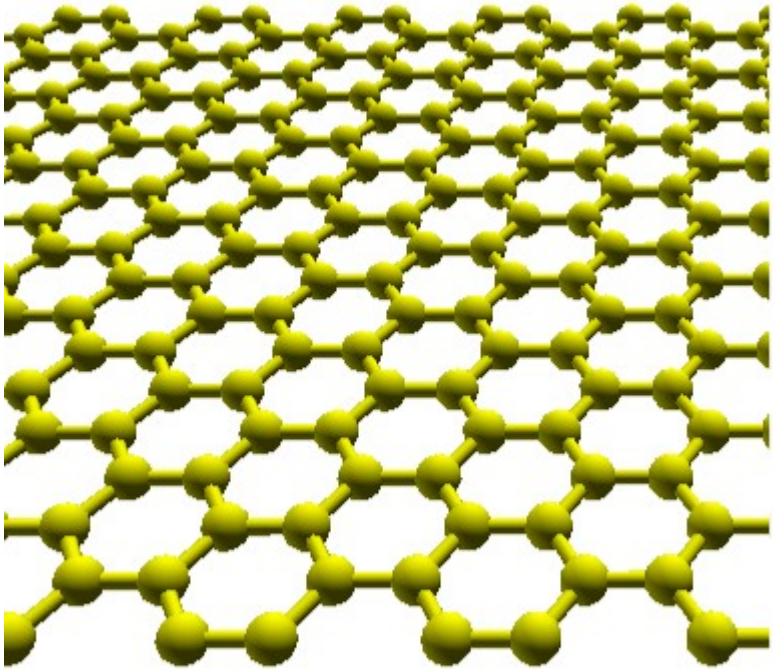


Off-plane B

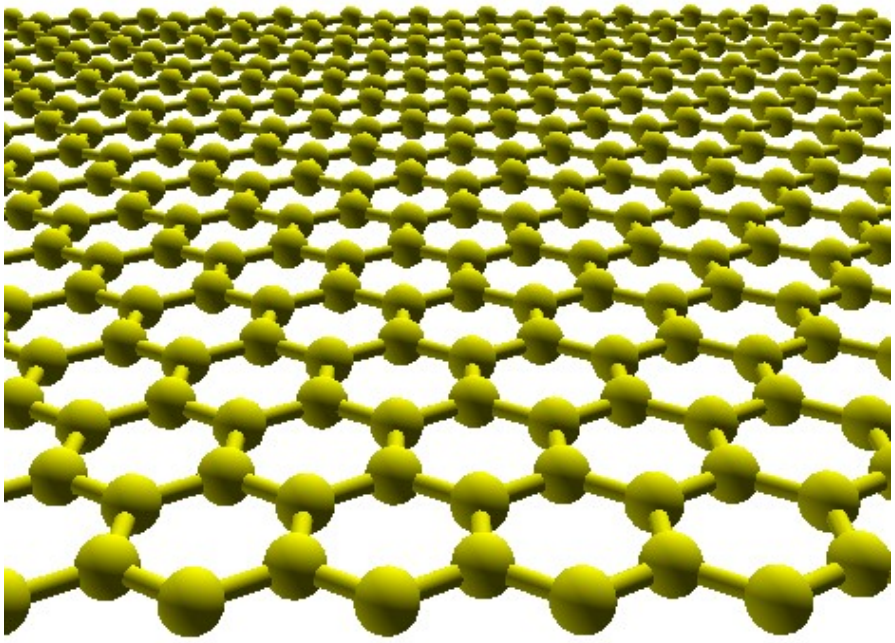
Gap increases linearly with off-plane field

Different edges

Armchair

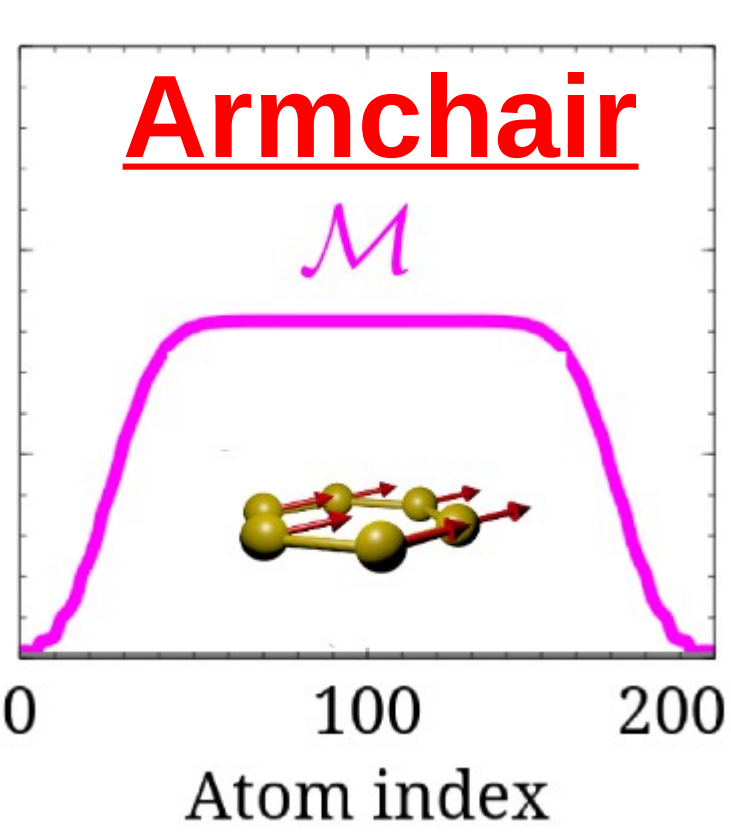


Zigzag

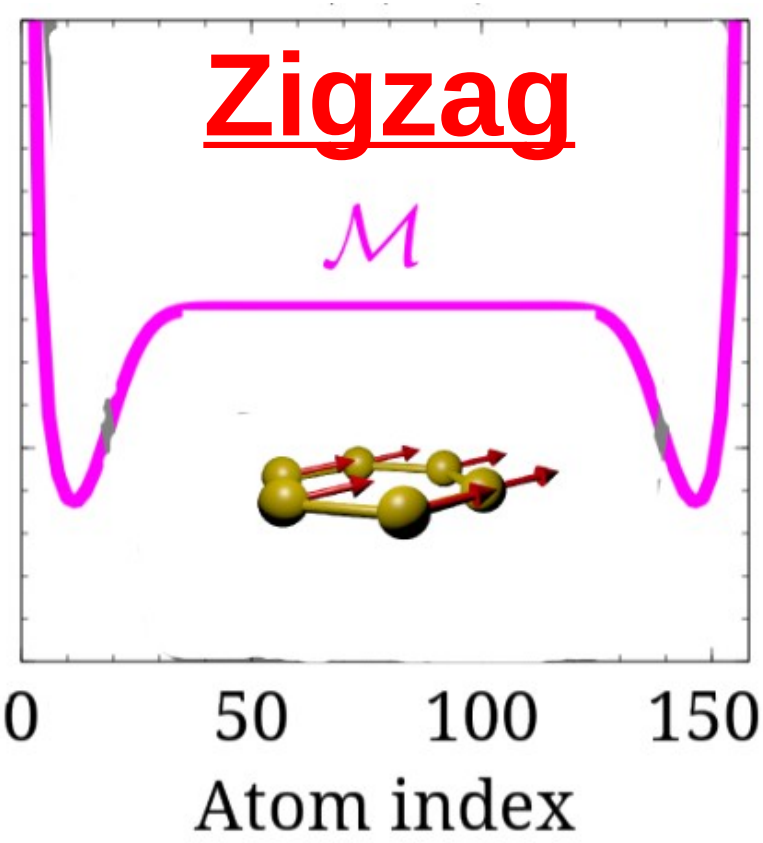


Edge dependent magnetism

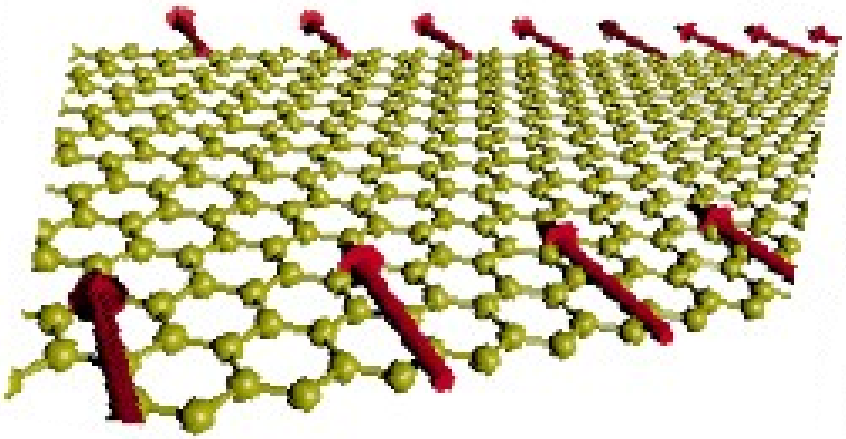
Armchair

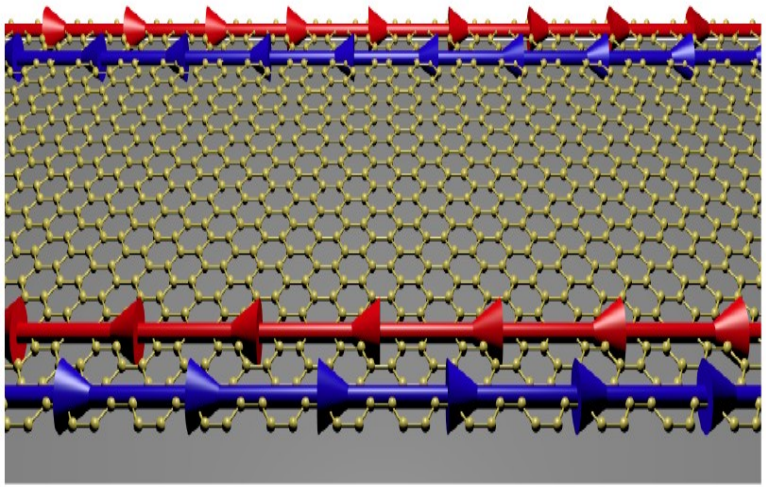


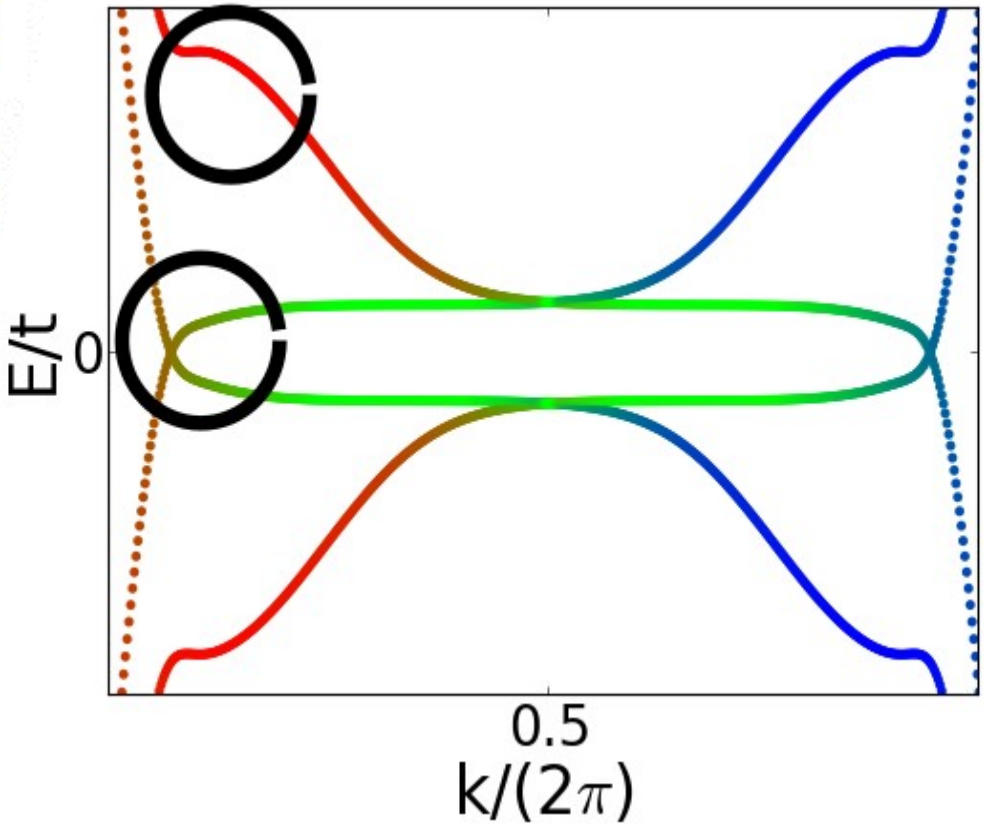
Zigzag



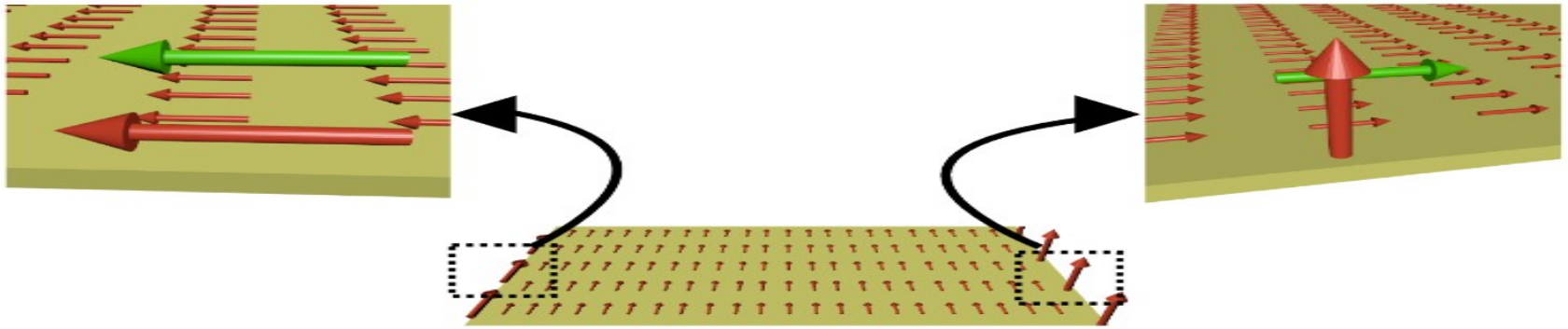
Two different edge states

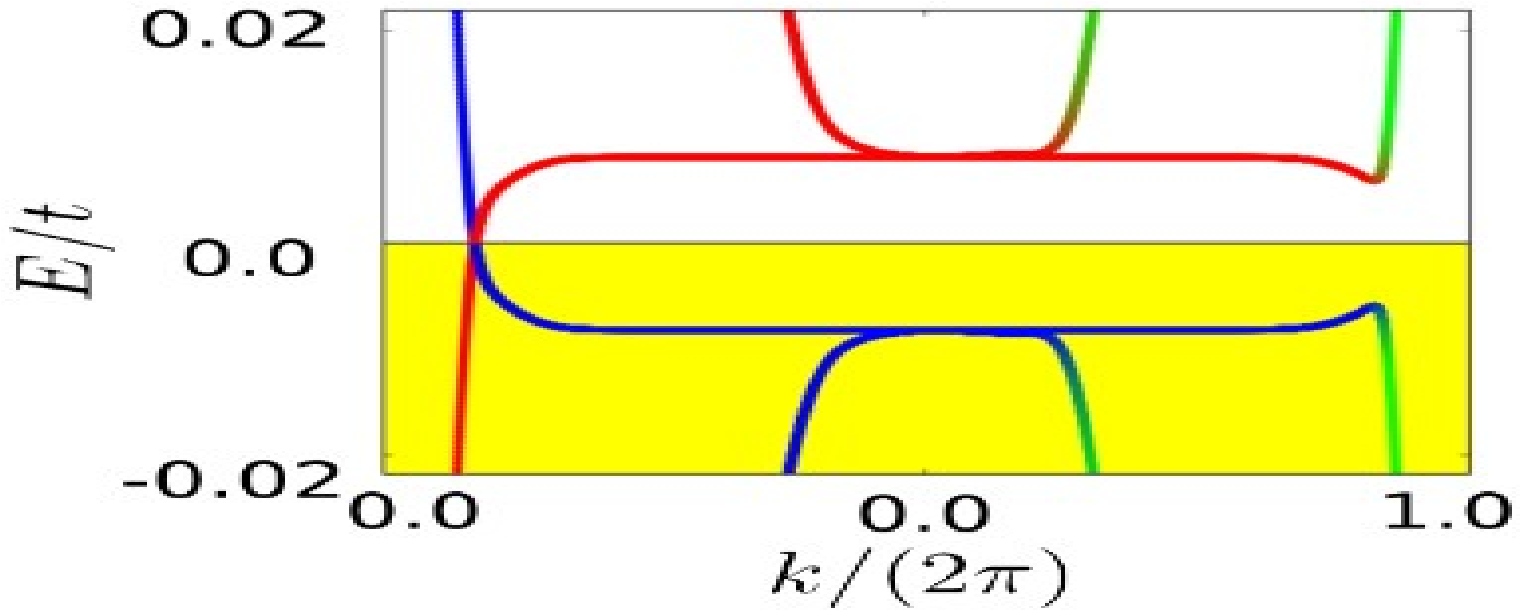




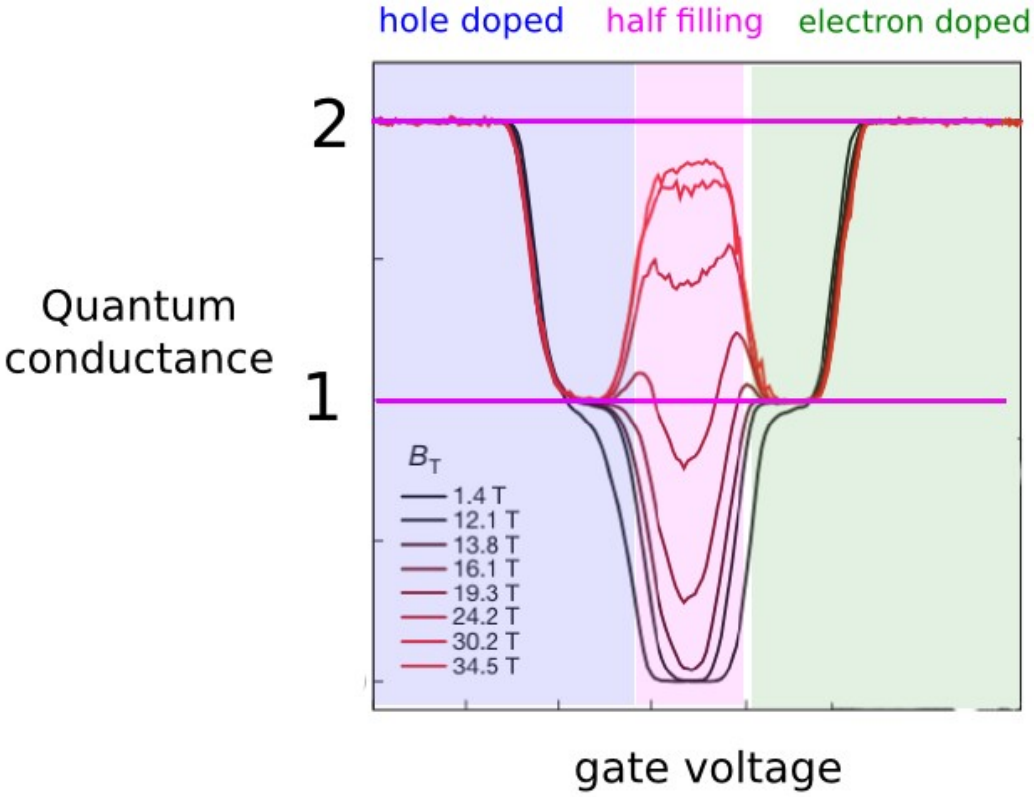


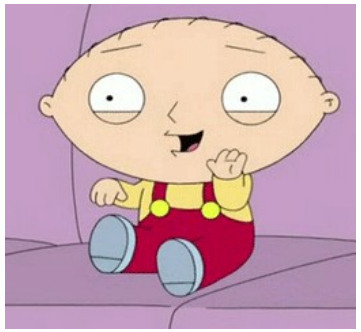
Electron-magnon coupling





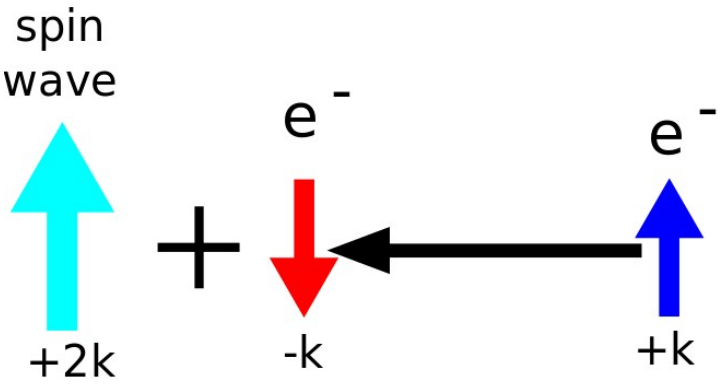
Back scattering channel

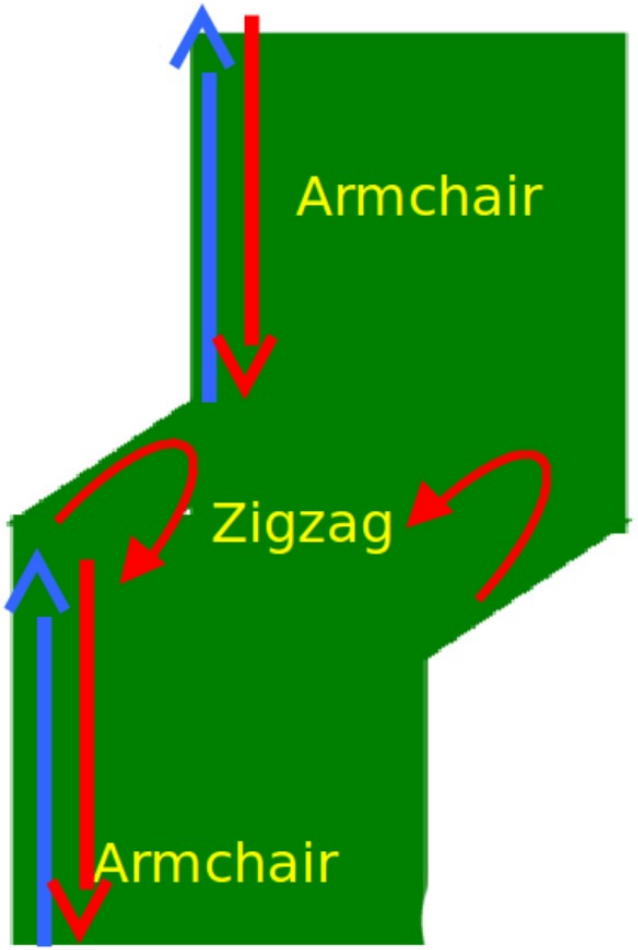




half filling

Mixed edges





Backscattering channel in zigzag part

Take home

- Interaction of different edge states opens up a channel for backscattering

But before finishing...

Funded by

Thank you!!!