Magnetism and electronics in quantum Hall bars

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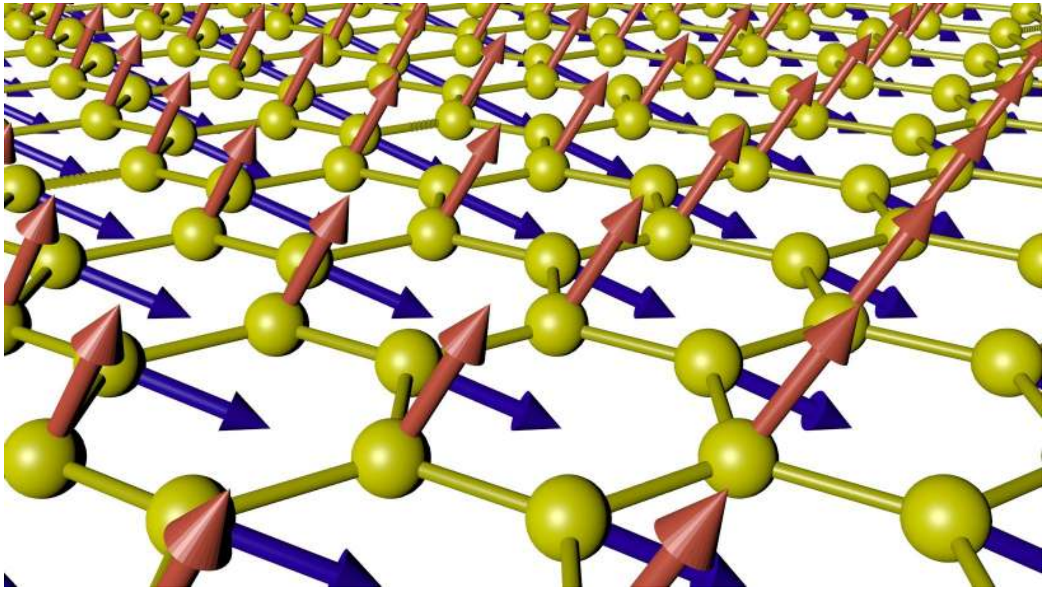


Aachen 2014, 9 December

Spinograph
Spintronics in Graphene

The team

Theory group at INL, Braga, Portugal

Jose Lado

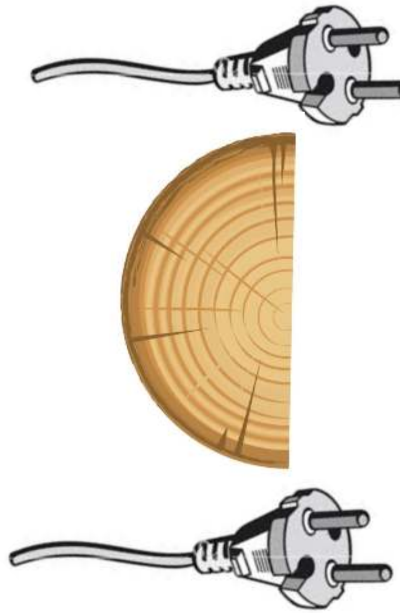
Joaquin
Rossier

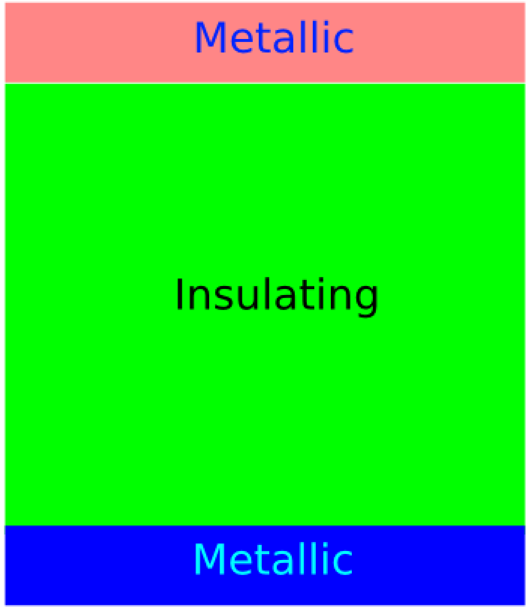
Topological state

Spin current

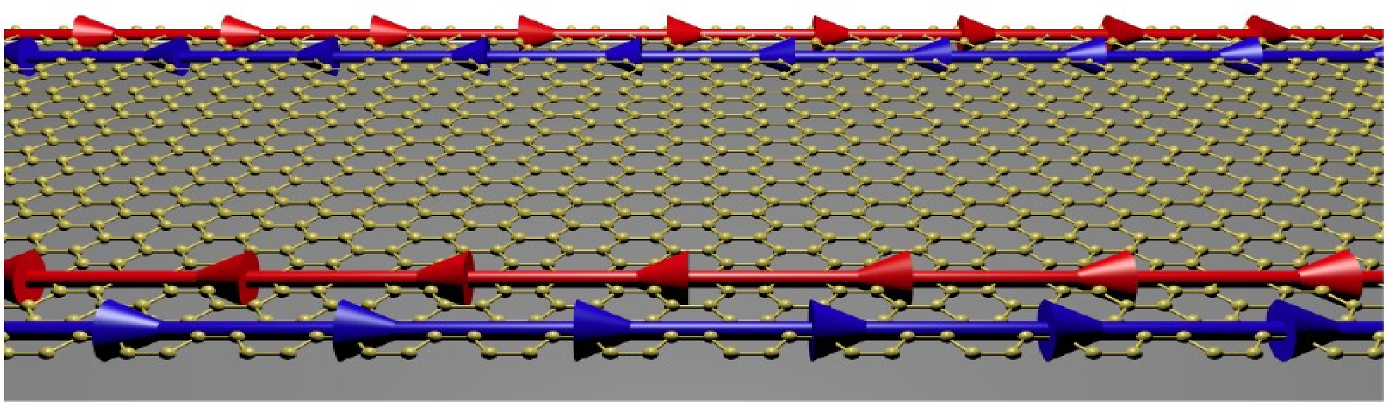
Insulator

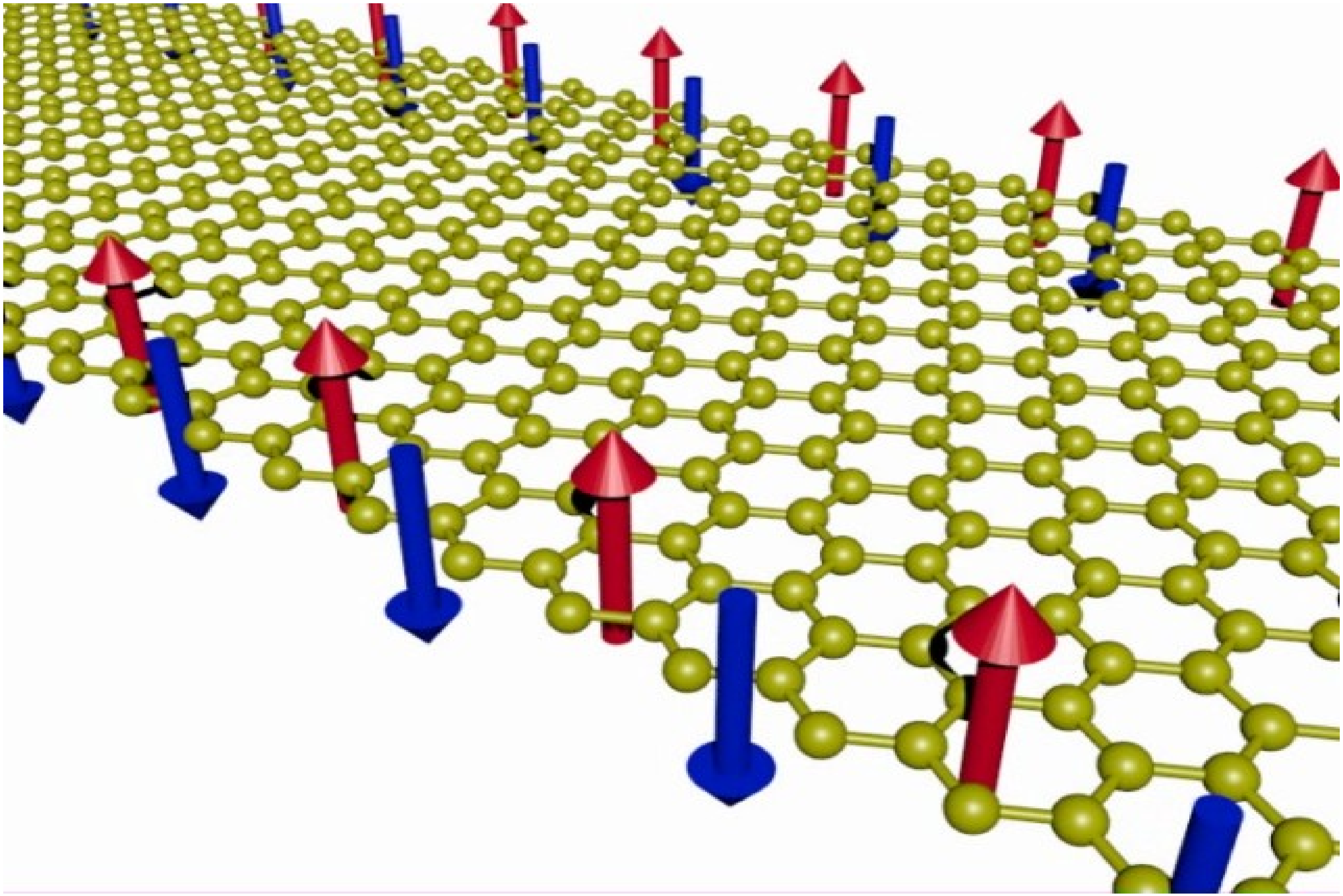
Spin current





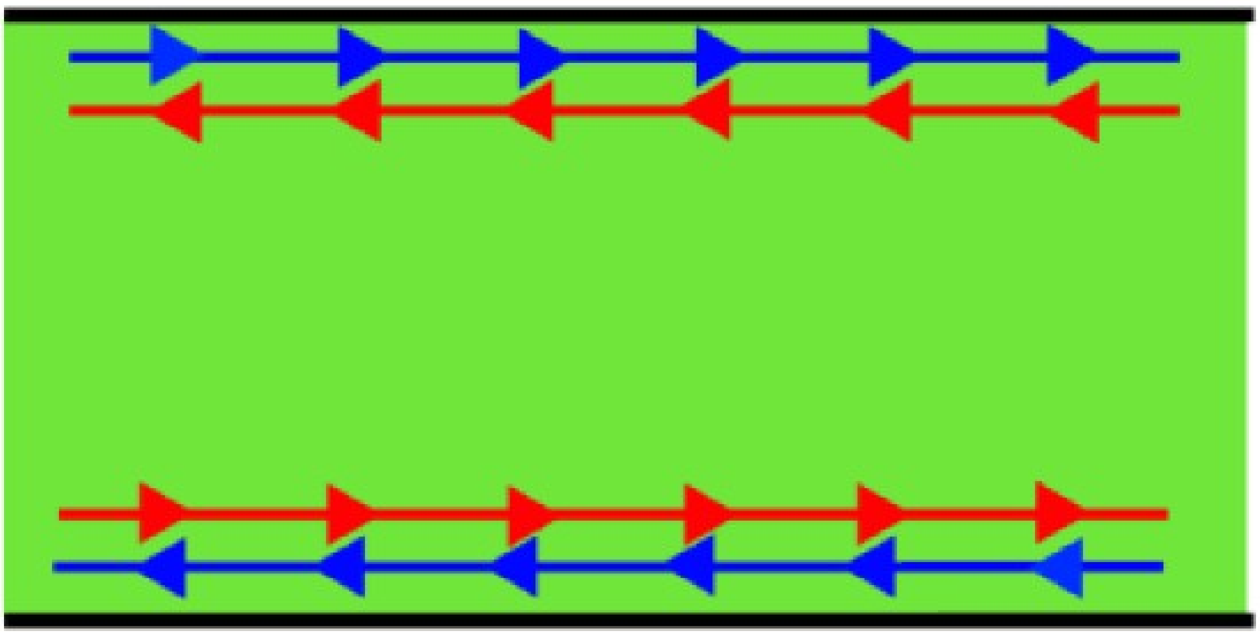
Same material





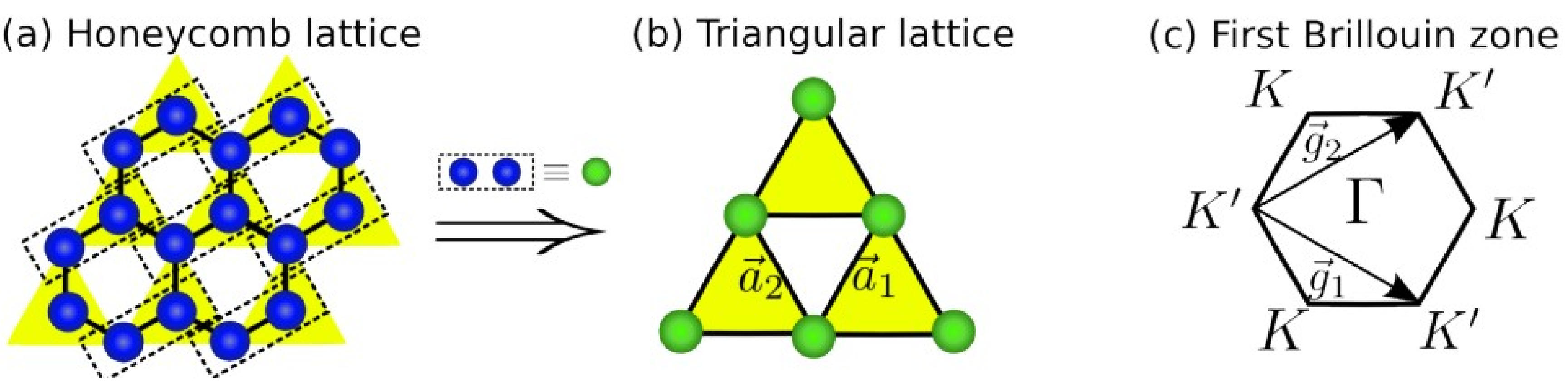
What is the quantum spin Hall effect

Counterpropagating spin polarized edge states

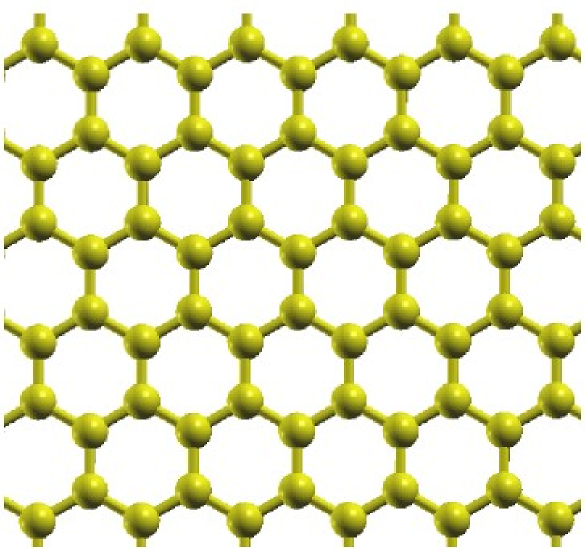


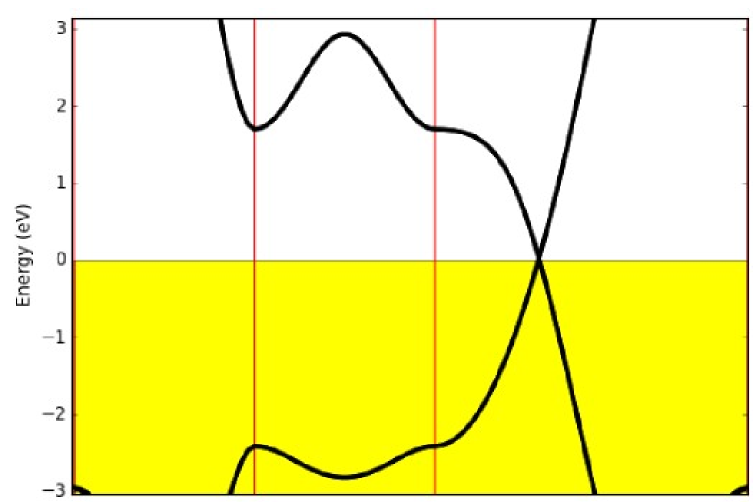
Spin current but no net current

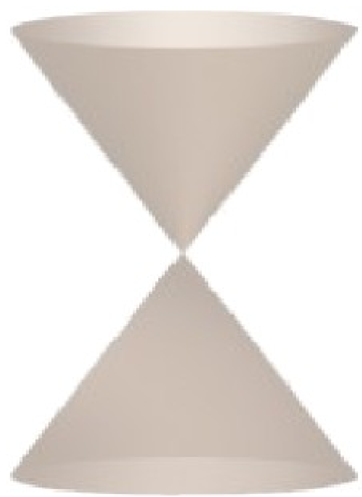
What is graphene



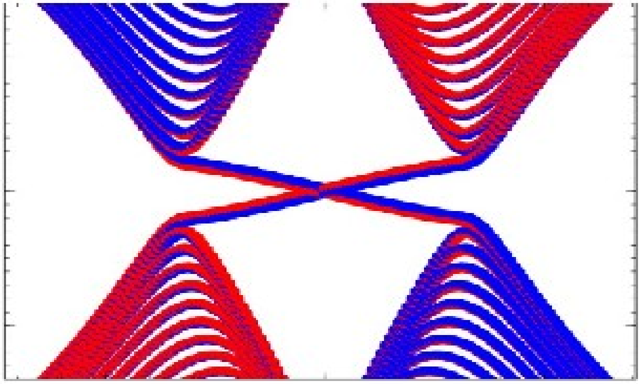
Low energy described by Dirac equation







Quantum Spin Hall in graphene



Z_2 topological insulator

Theory

Kane Mele PRL (2005)

Spin Chern insulator

Theory

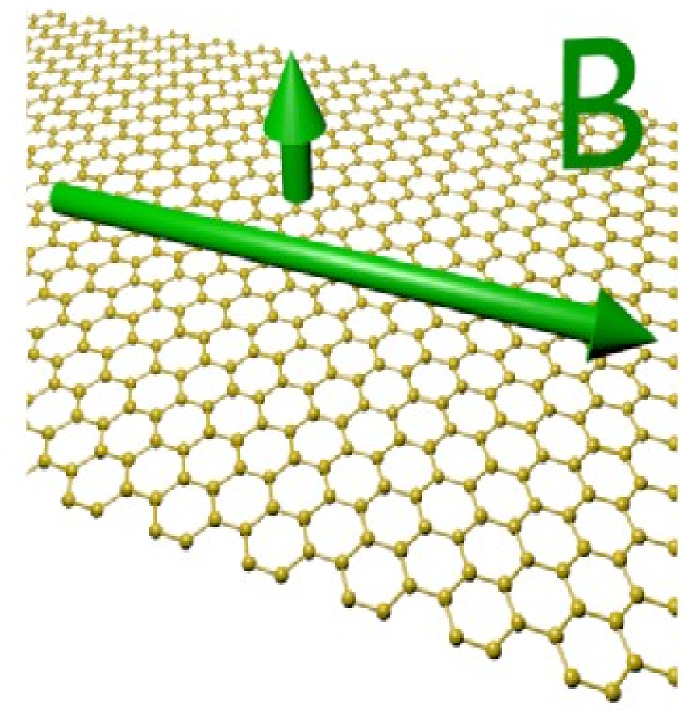
Abanin et al, PRL (2006)

Experiment

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

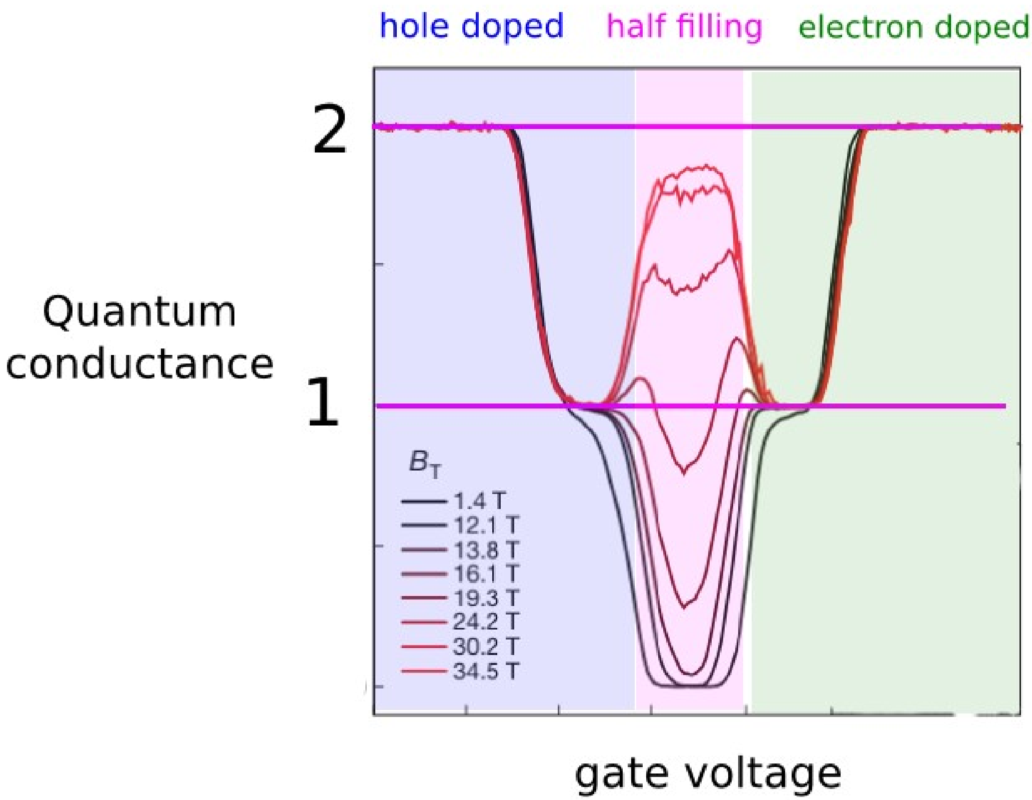
The experimental set-up

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

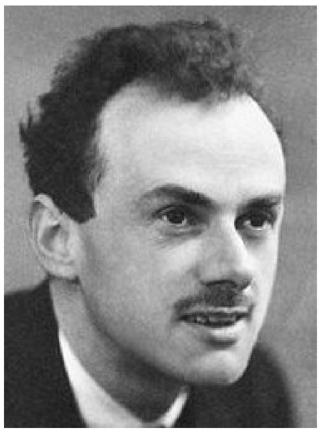


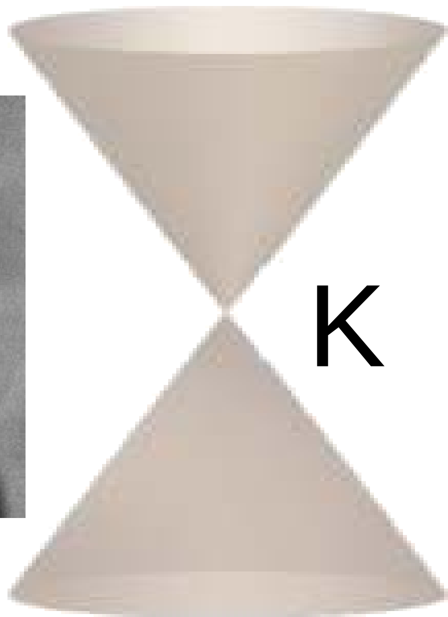
A. F. Young et al, Nature (2014)

Not perfect conductance???



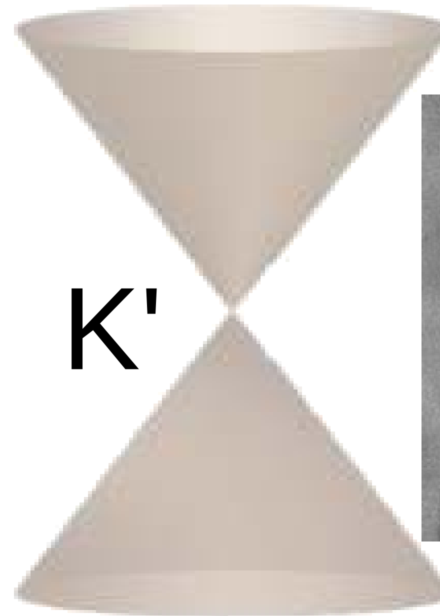
Low energy Hamiltonian





K

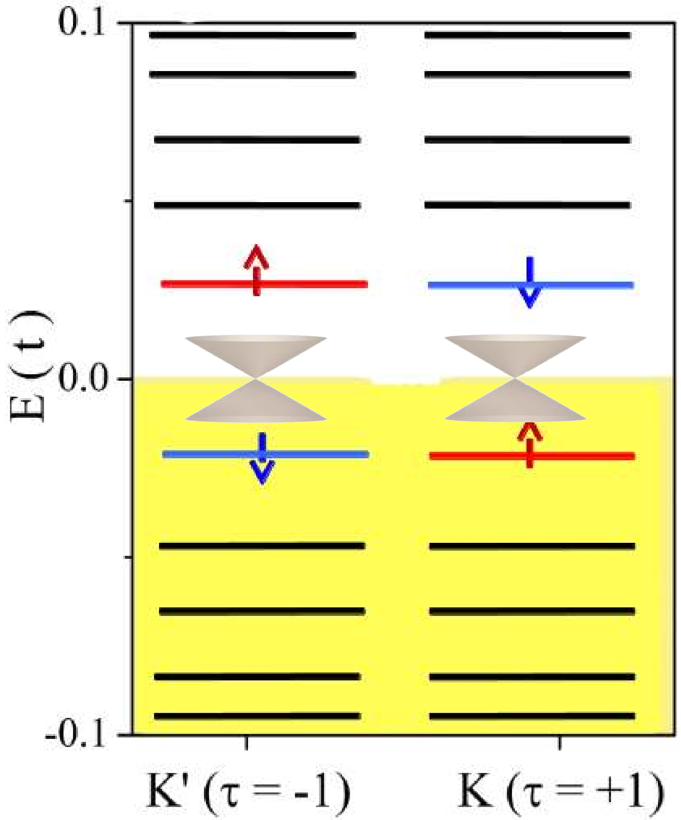
K'



<u>Two Dirac equations</u>

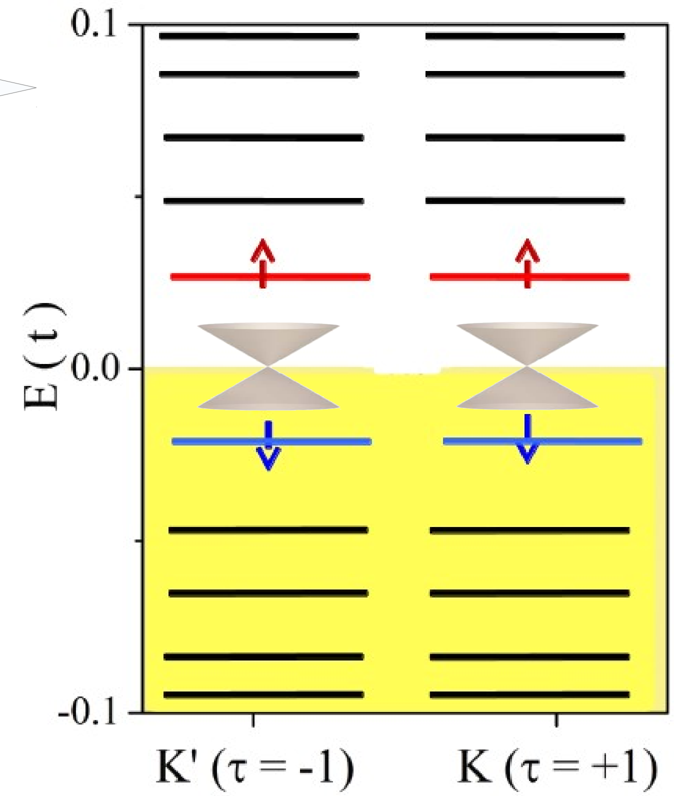
The Landau level picture

Antiferromagnetic



Increasing Zeeman

Ferromagnetic

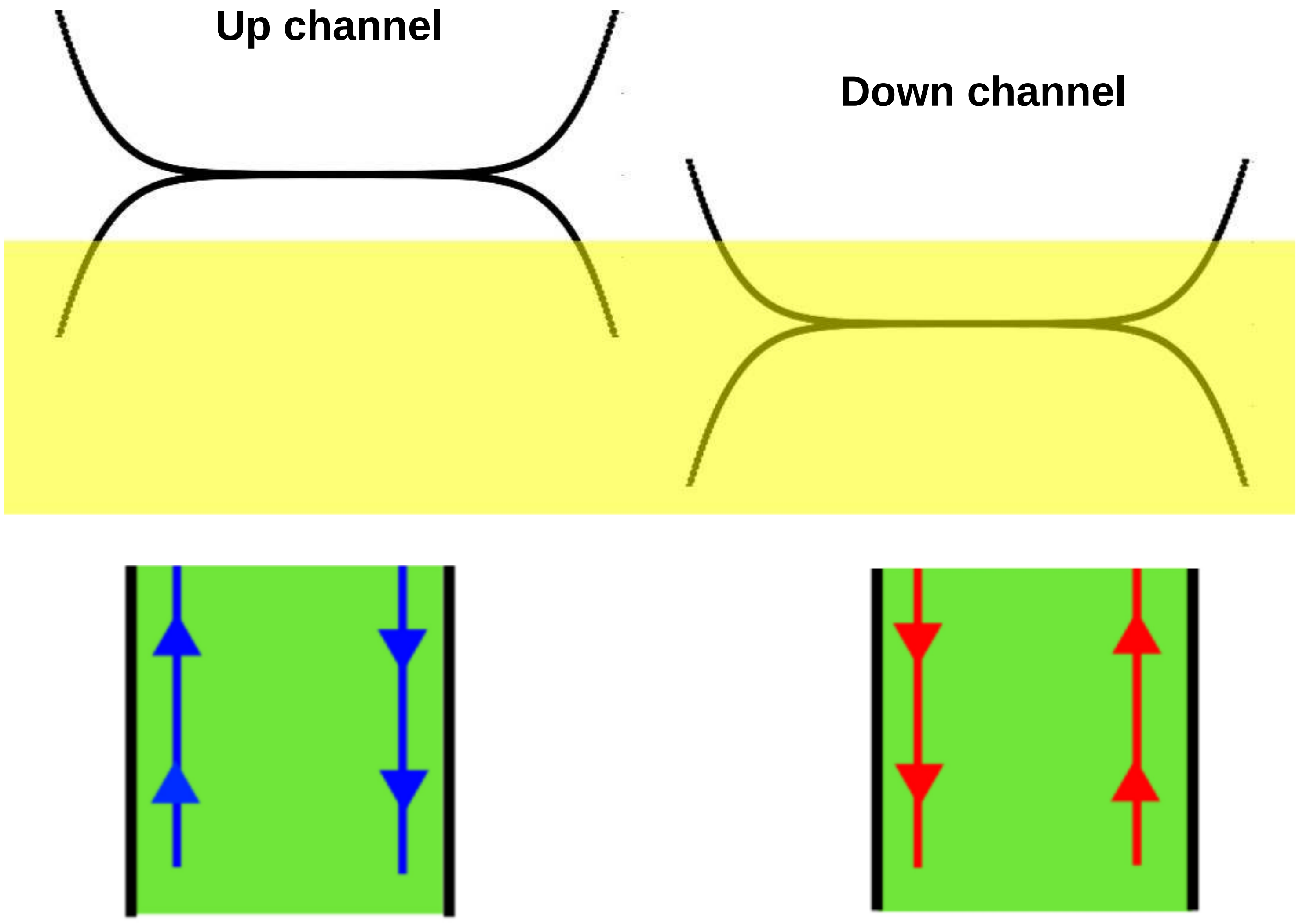


Spin Chern number = 0

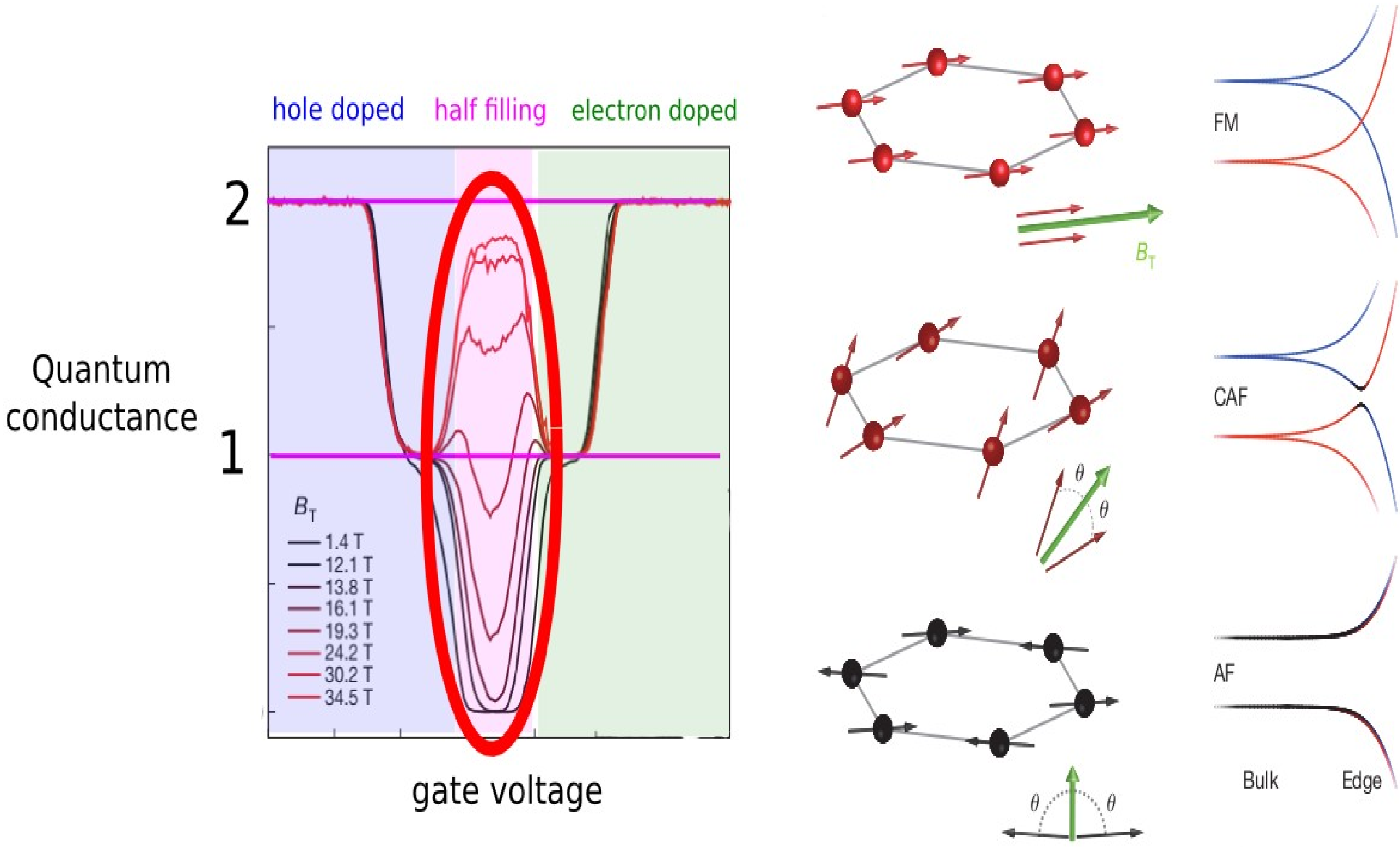
Spin Chern number = 2

Abanin et al, PRL (2006)

QSH in QH graphene



Canted magnetism



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

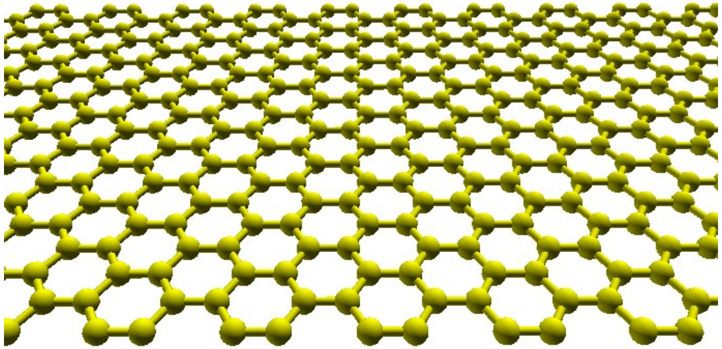
The model

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

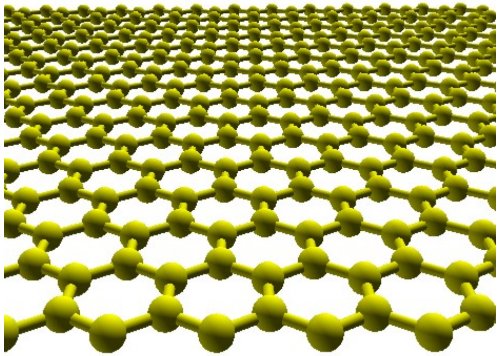
spin Zeeman field

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)

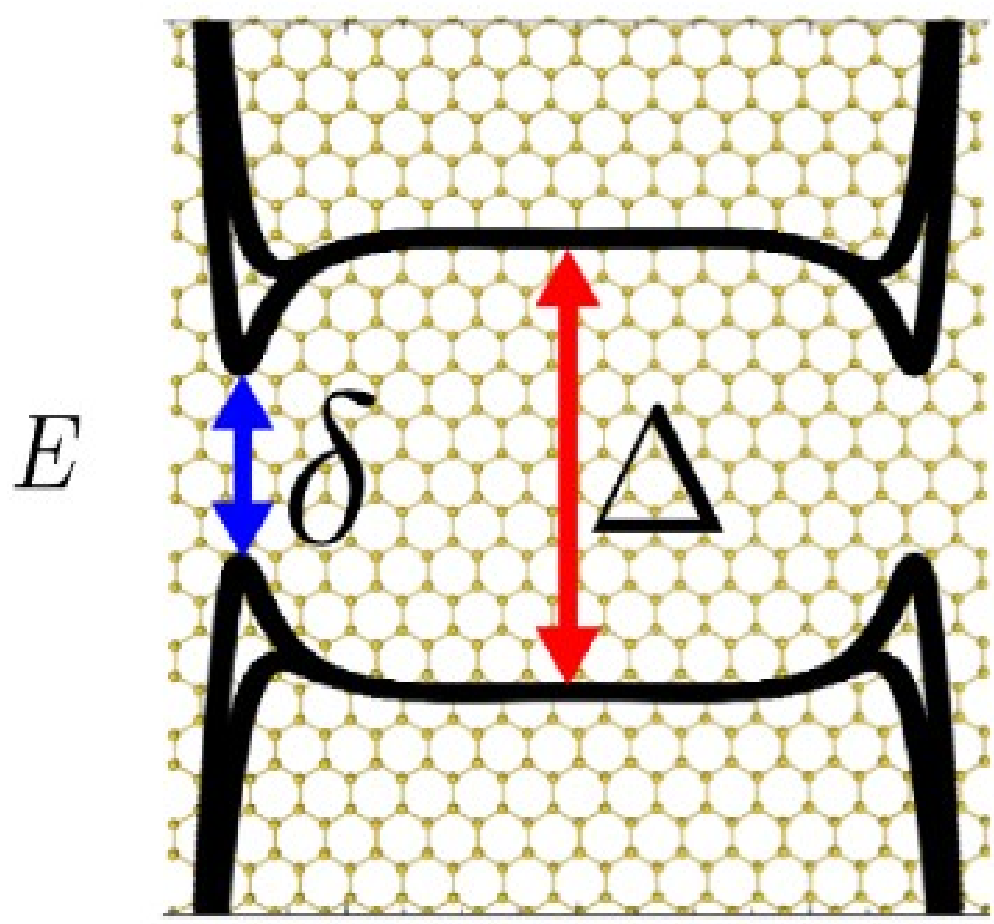
Exchange (Fock)

Double counting

Variational wave function

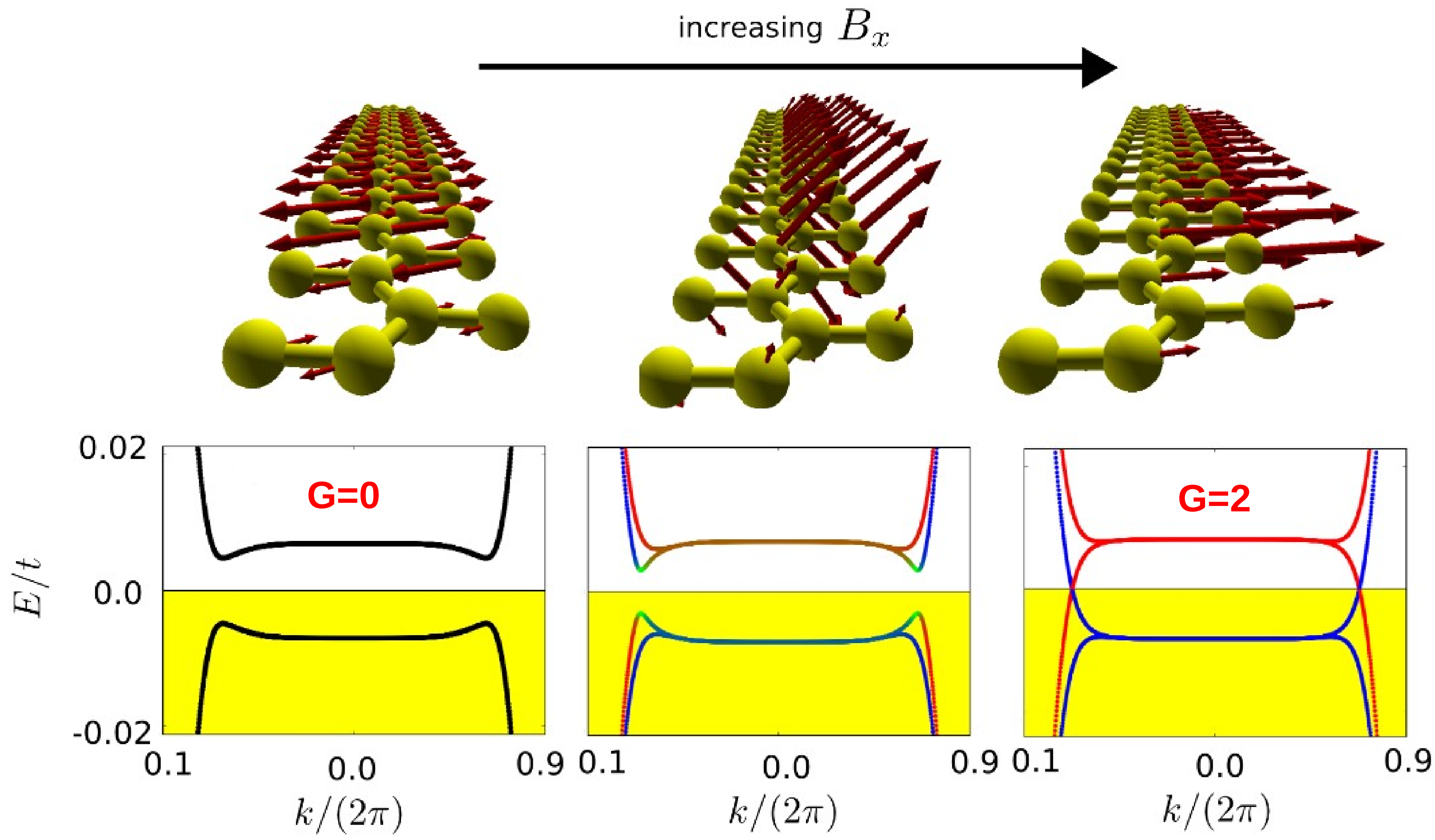
$$|\Omega\rangle = \prod_i \left(u_i c^\dagger_{i\uparrow} + v_i c^\dagger_{i\downarrow}\right)|0\rangle$$

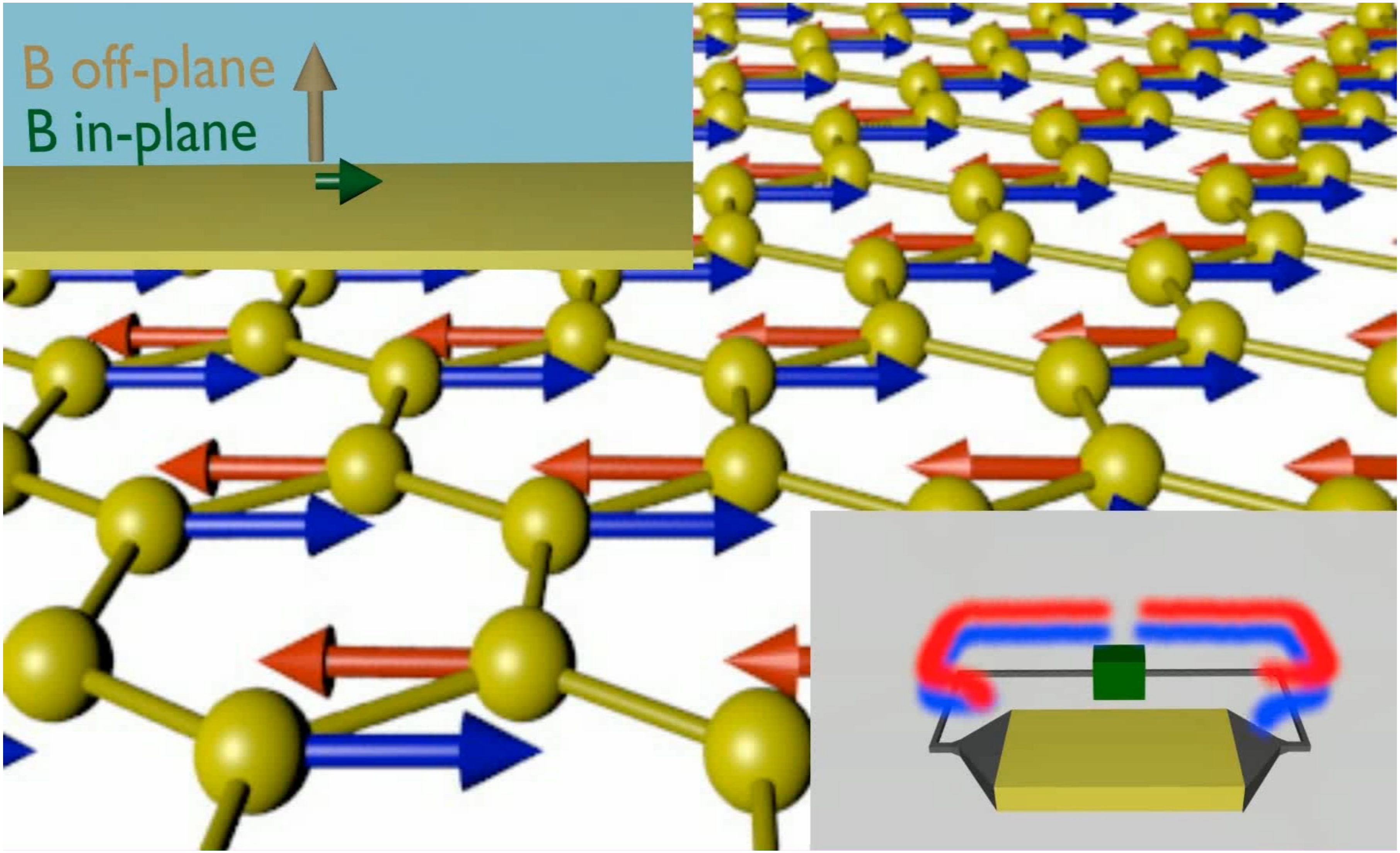
Bands of the system



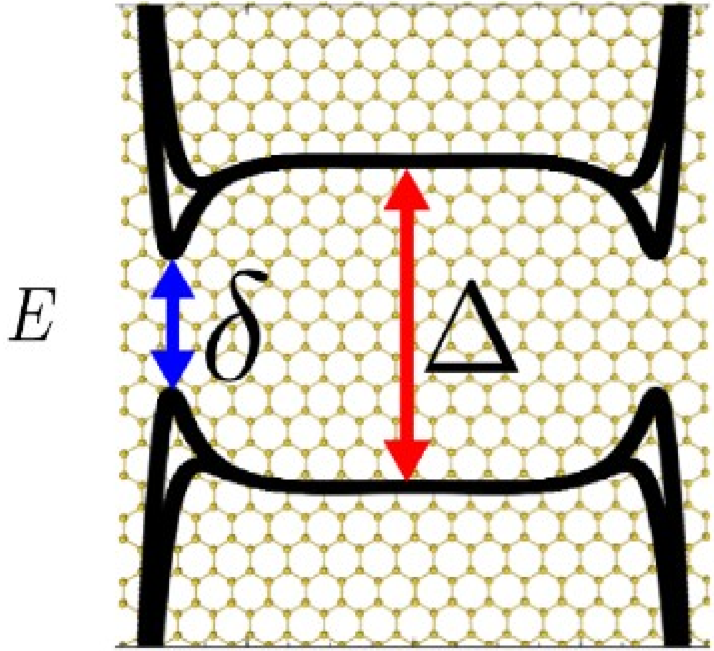
K-vector (and position across the ribbon)

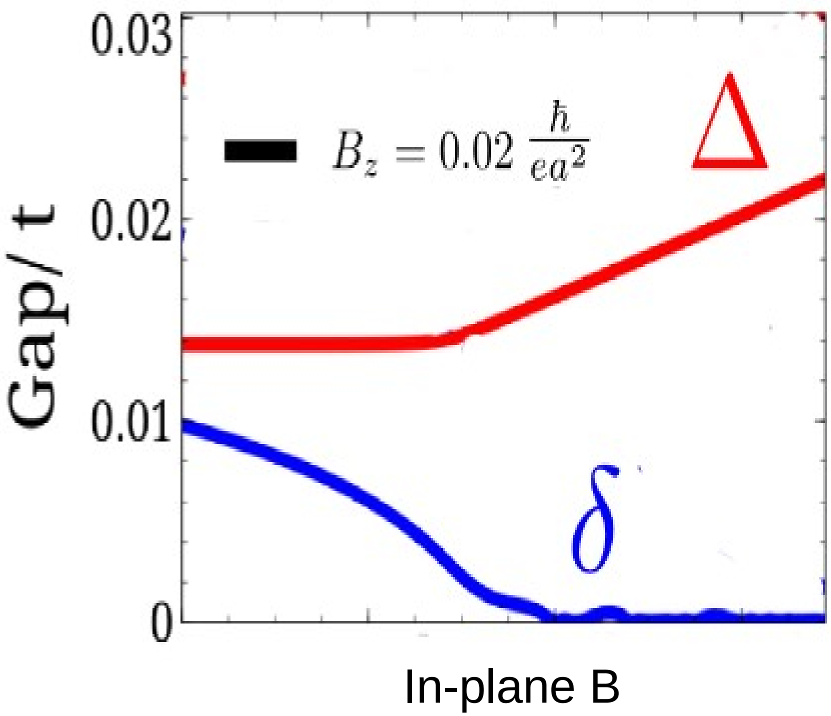
Transition at half filling with Bx




B off-plane
B in-plane

Transition at half filling with Bx

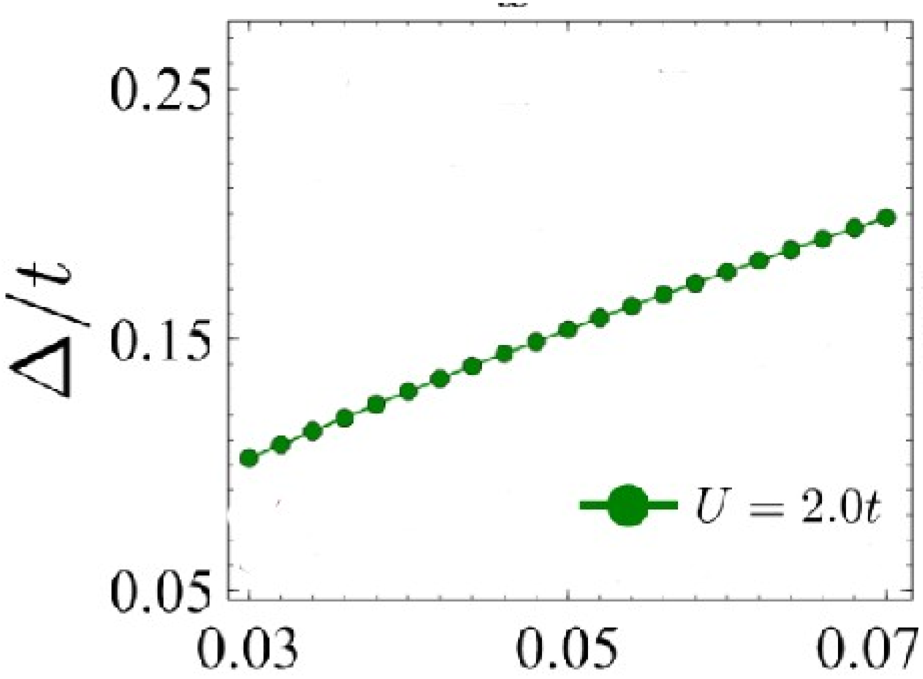




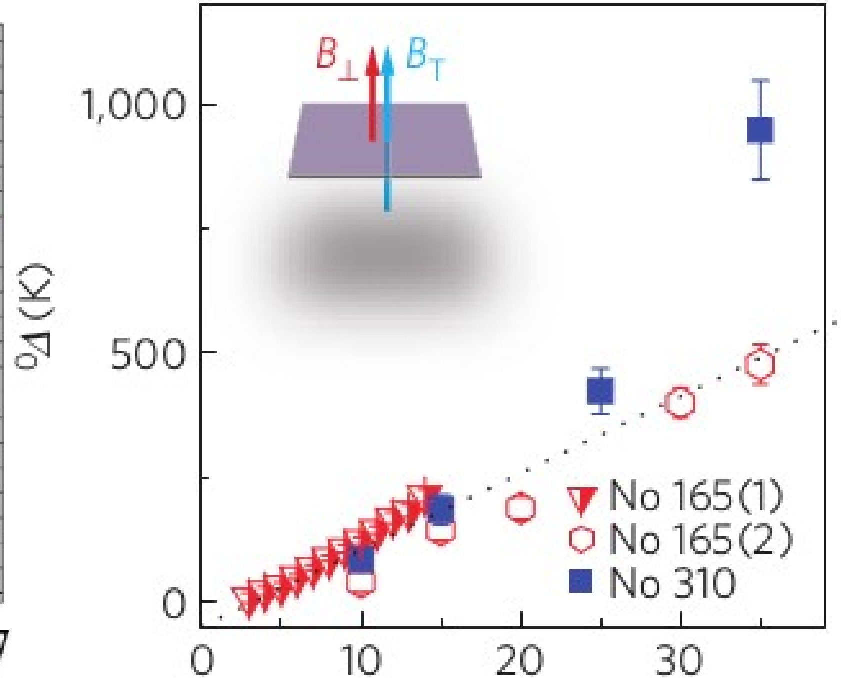
Edge gap closing without bulk gap closing

Gap increases at half filling

Gap in the bulk



Off-plane B



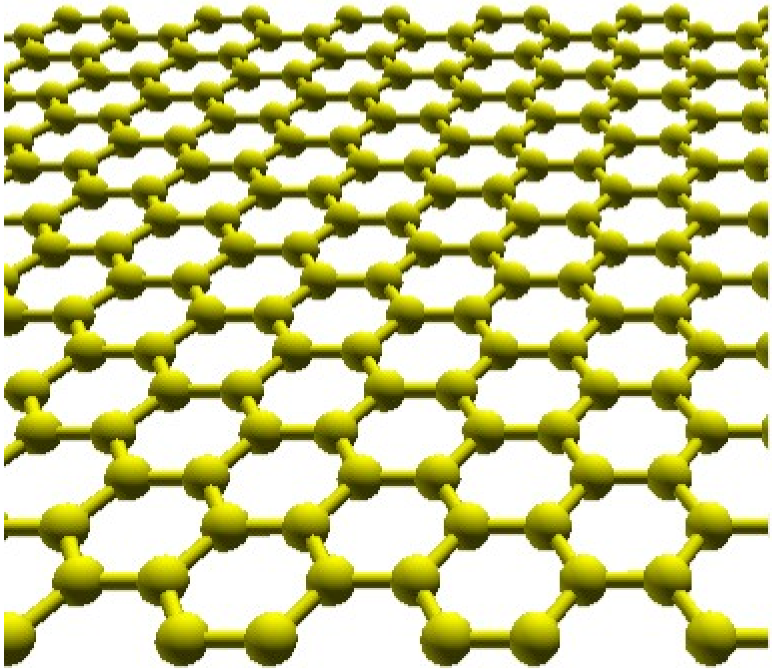
Off-plane B

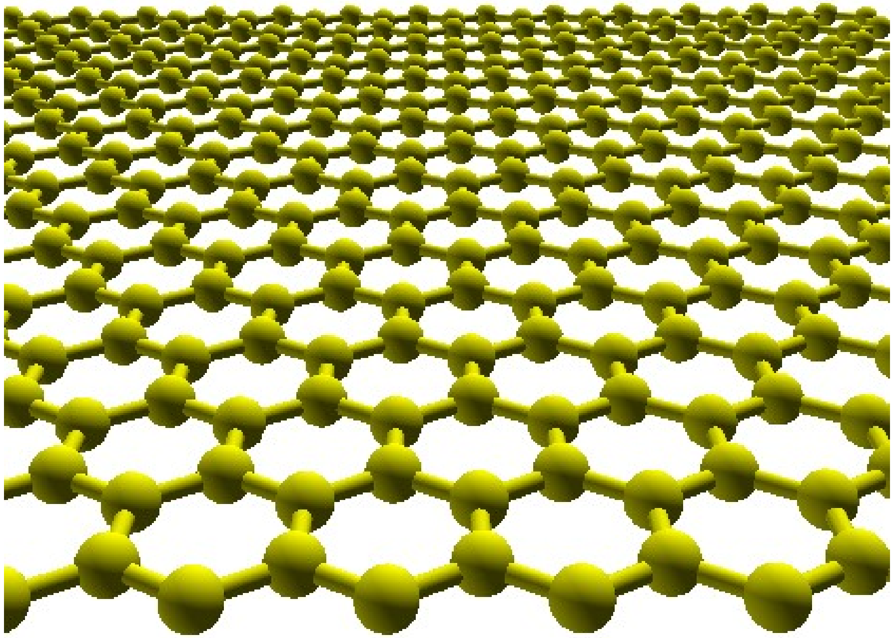
<u>Gap increases linearly with off-plane field</u>

Different edges

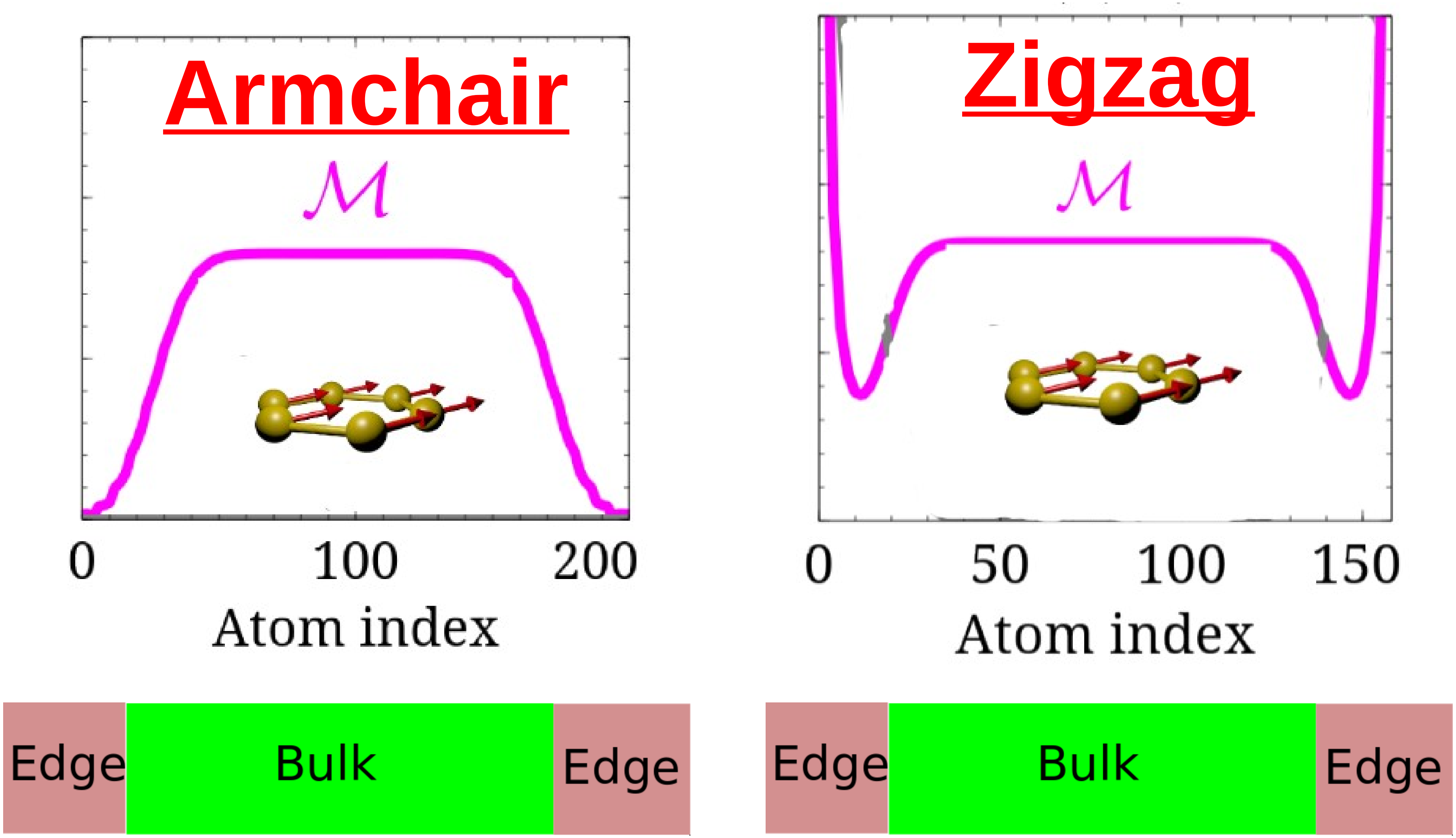
Armchair

Zigzag

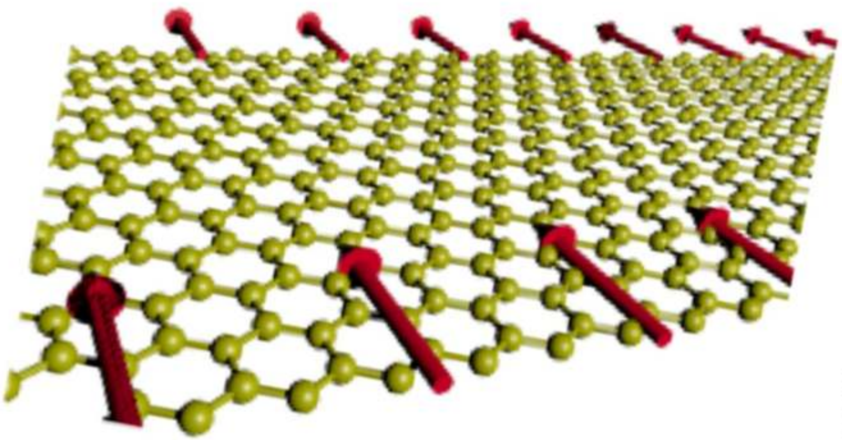


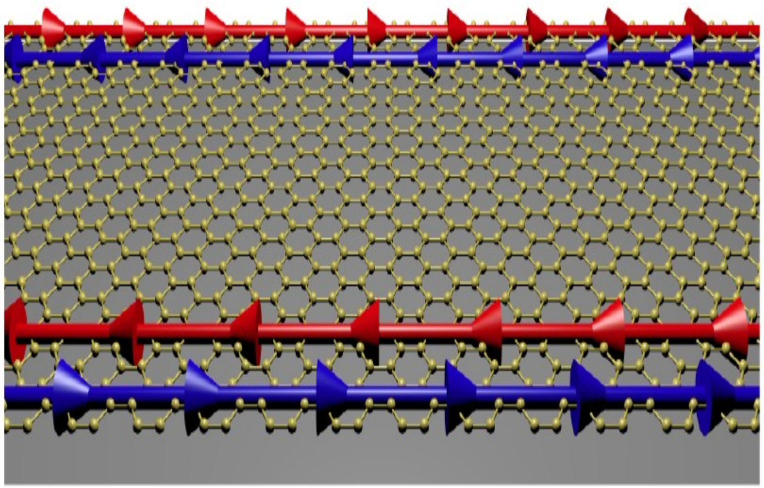


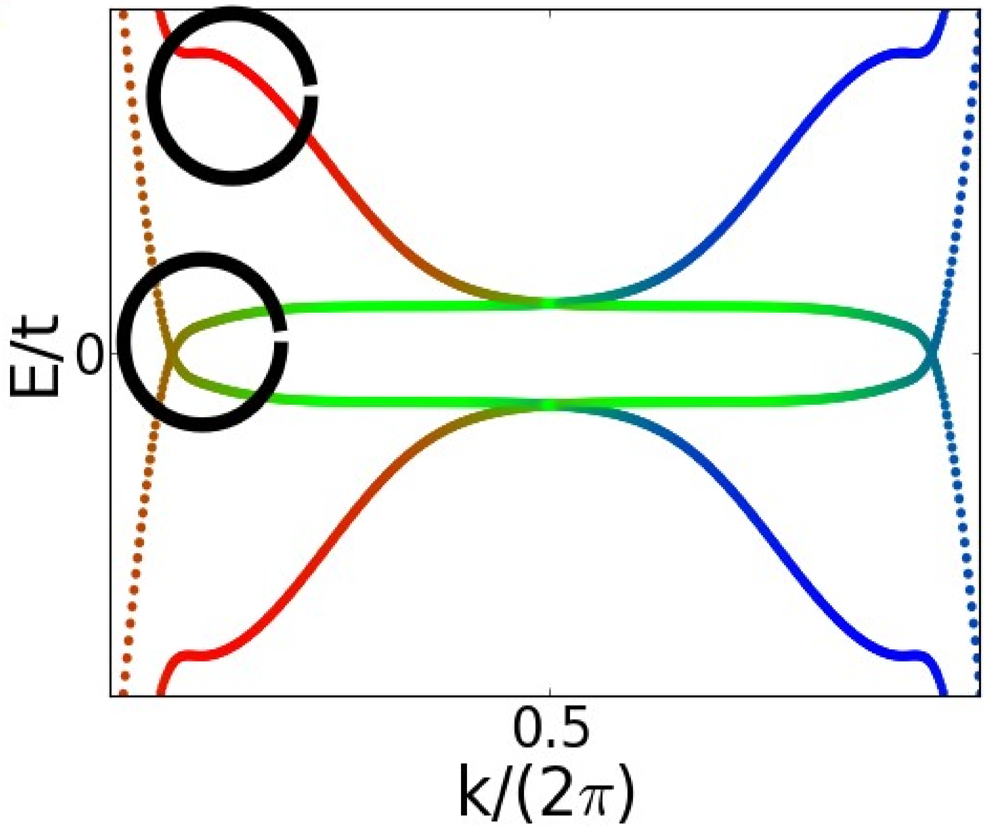
Edge dependent magnetism



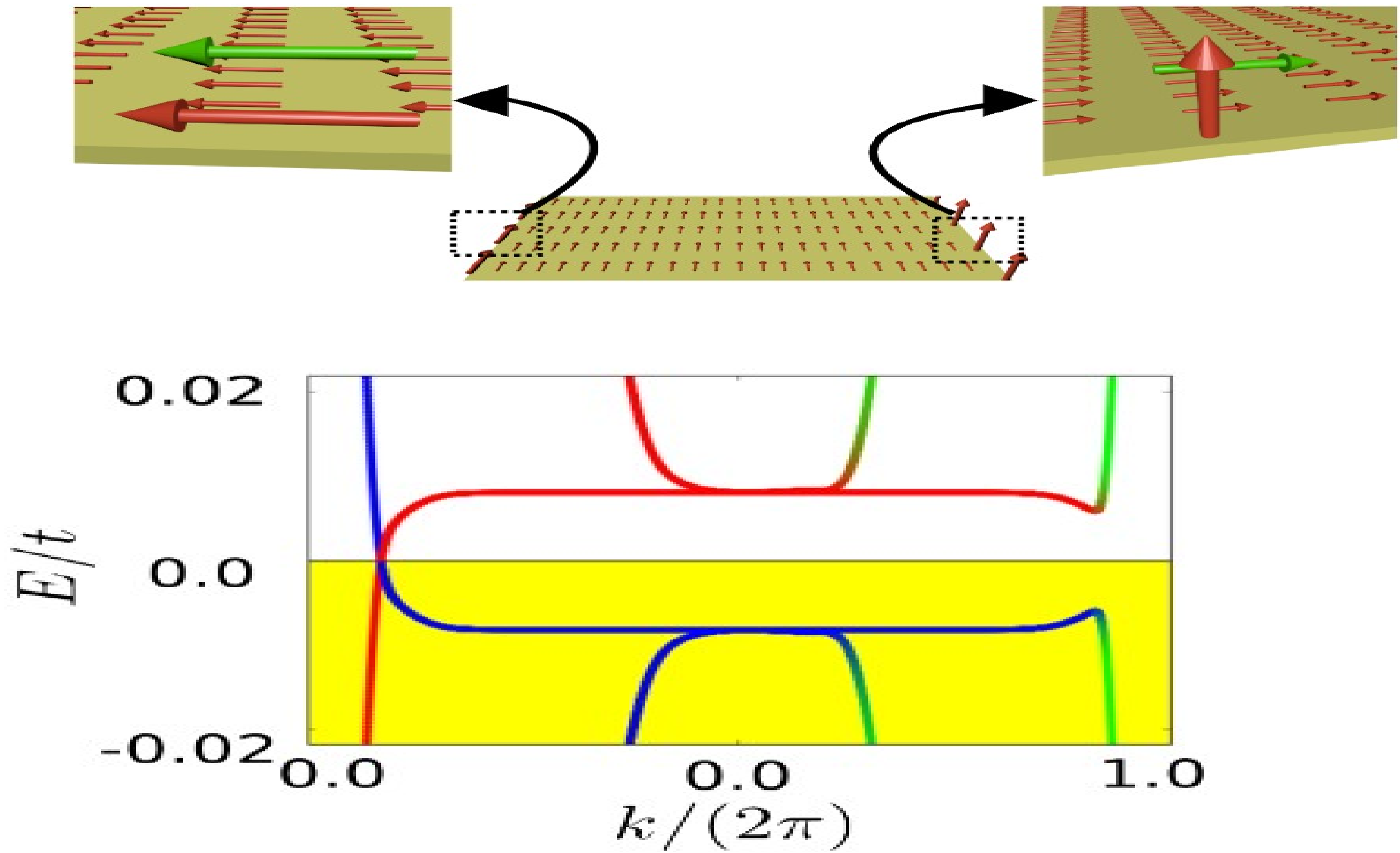
Two different edge states



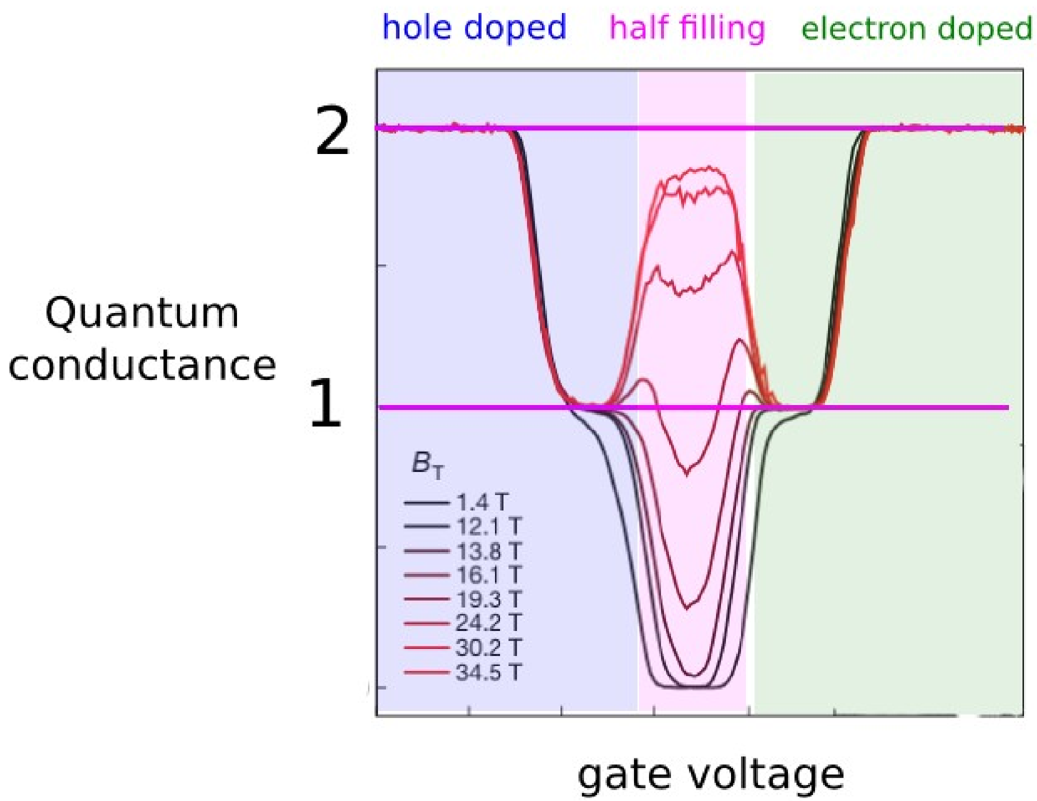




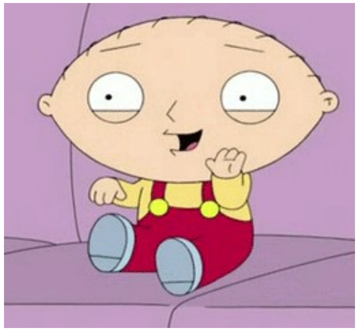
Electron-magnon coupling

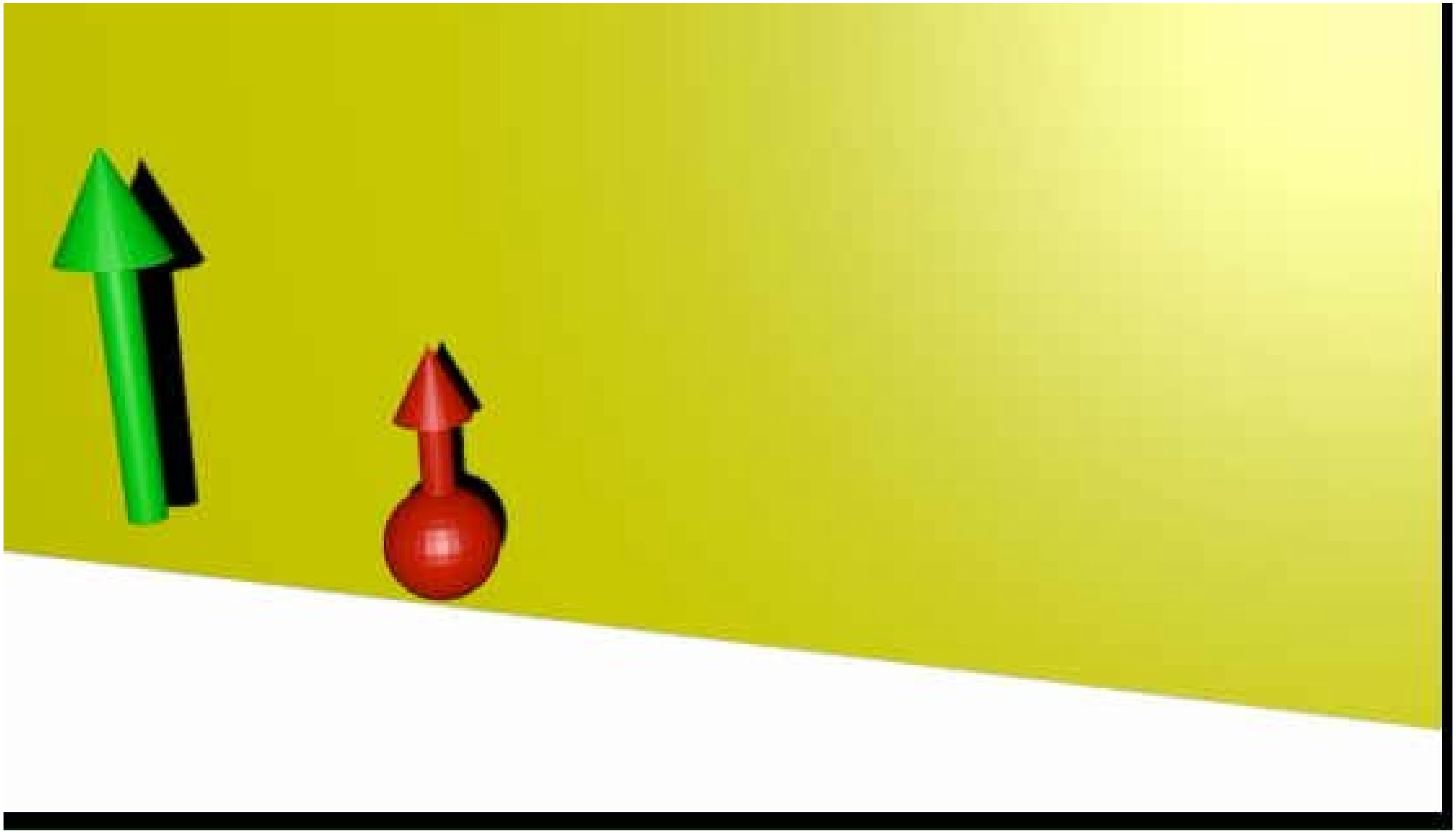


Back scattering channel

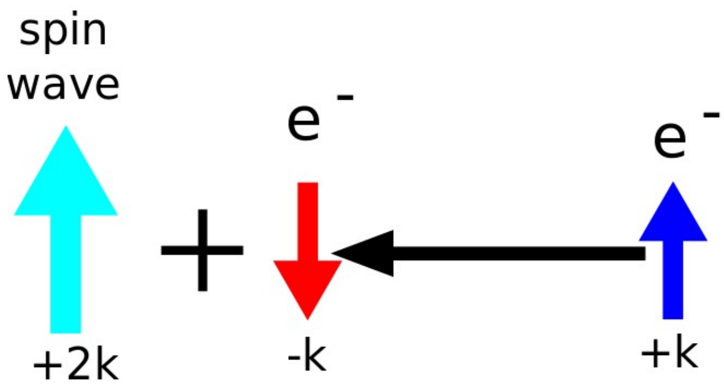


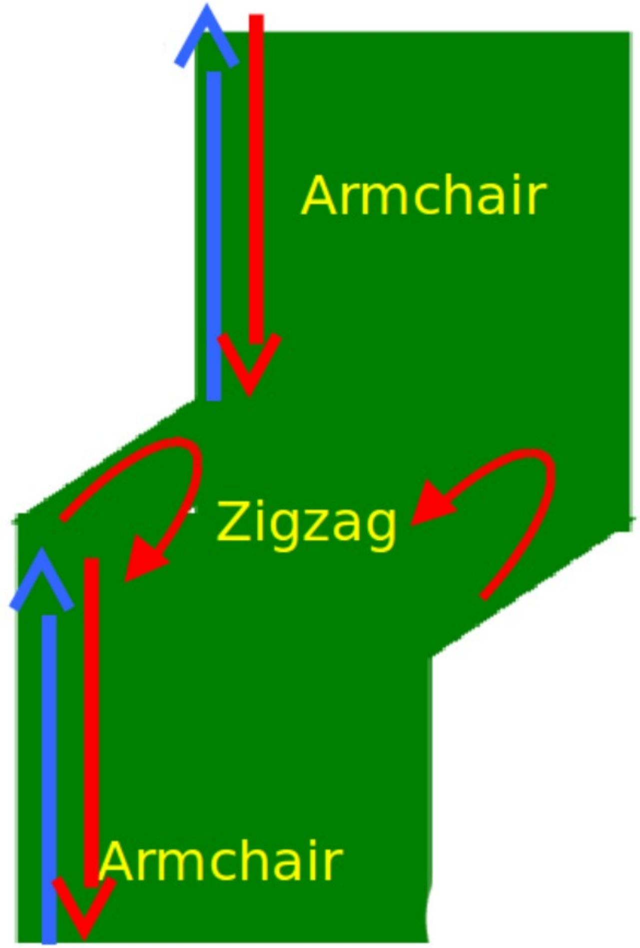
half filling





Mixed edges





Backscattering channel in zigzag part

Take home

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

<u>But before finishing...</u>

Funded by

Spinograph
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Thank you!!!