Topological states in bilayer graphene systems

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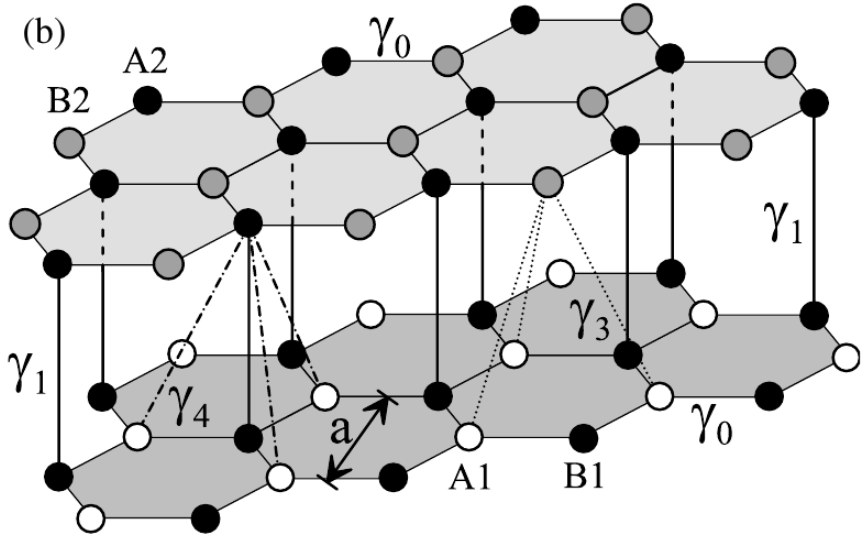
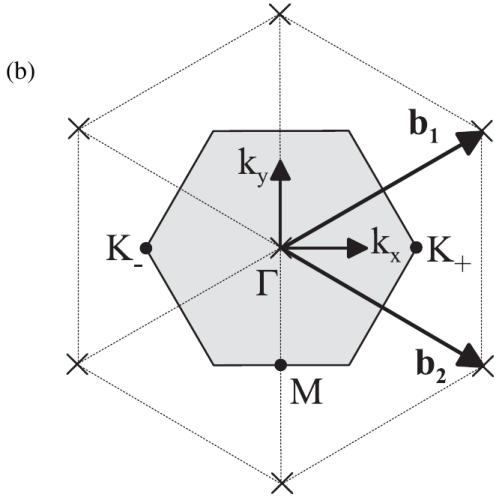
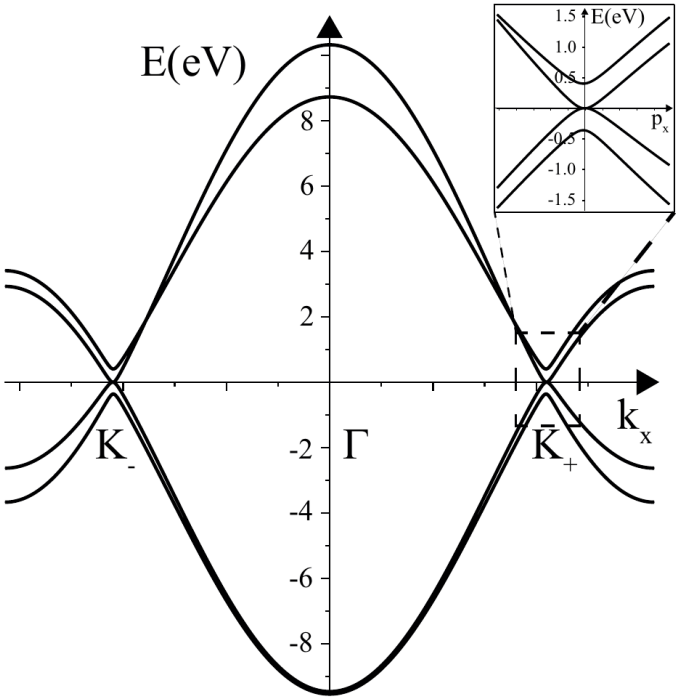
Ilink-2023, 5-6/6, 2023

Bilayer graphene (BLG)





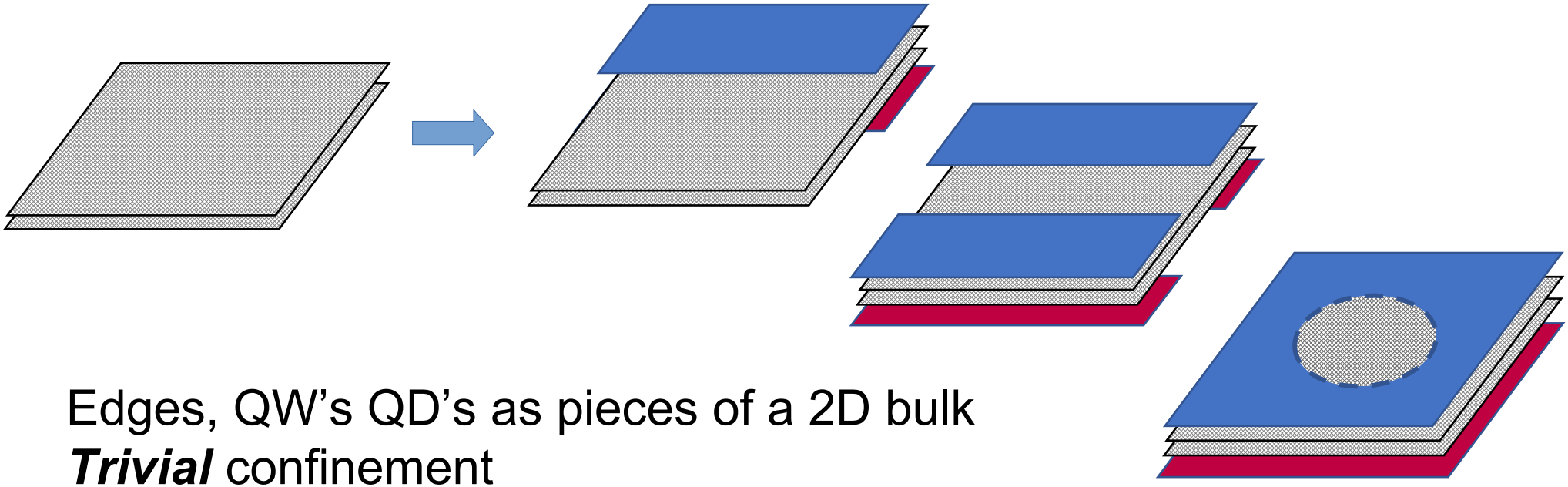


Gapless spectrum

Edward McCann and Mikito Koshino,
Reports on Progress in Physics **76**, 056503 (2013).

Electrostatic confinement in BLG

Graphene layer asymmetry potential $\pm V_a$
Top/bottom microelectrodes

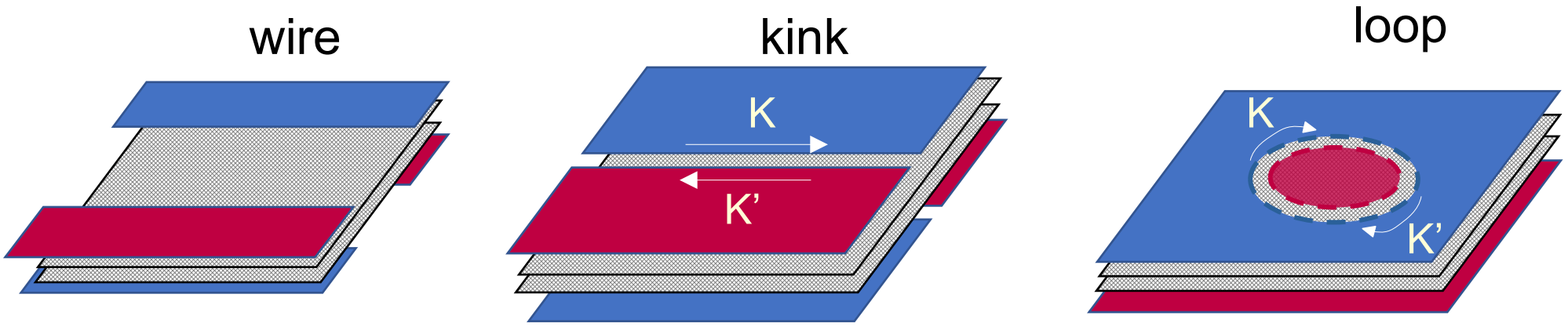


Edges, QW's QD's as pieces of a 2D bulk
Trivial confinement
similar to semiconductors, but ...
Schrödinger *vs* Dirac systems

Smooth edges atomic scale (reduced intervalley scattering)

Topological confinement in BLG

At borders between regions of opposite V_a

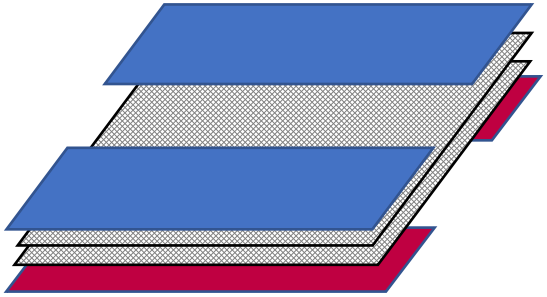


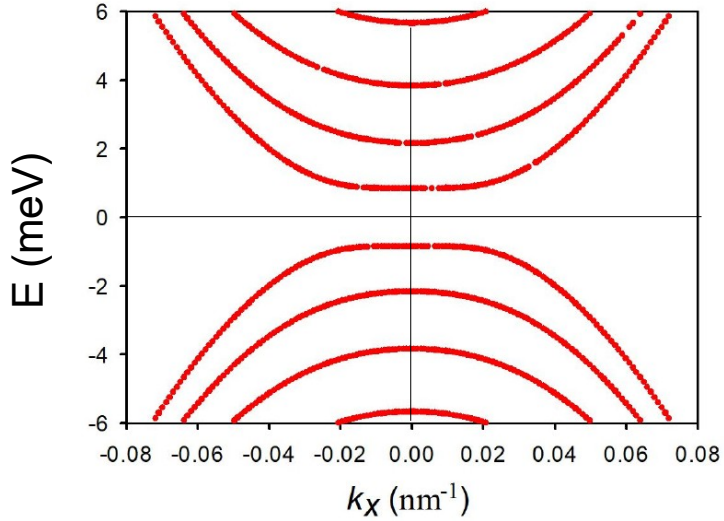
Kink is 1D-like confinement (no need of 2D bulk piece)

Topological confinement

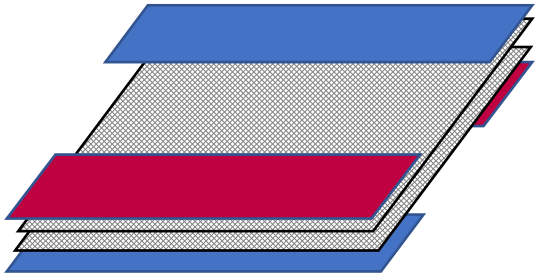
Chiral modes with valley-momentum locking

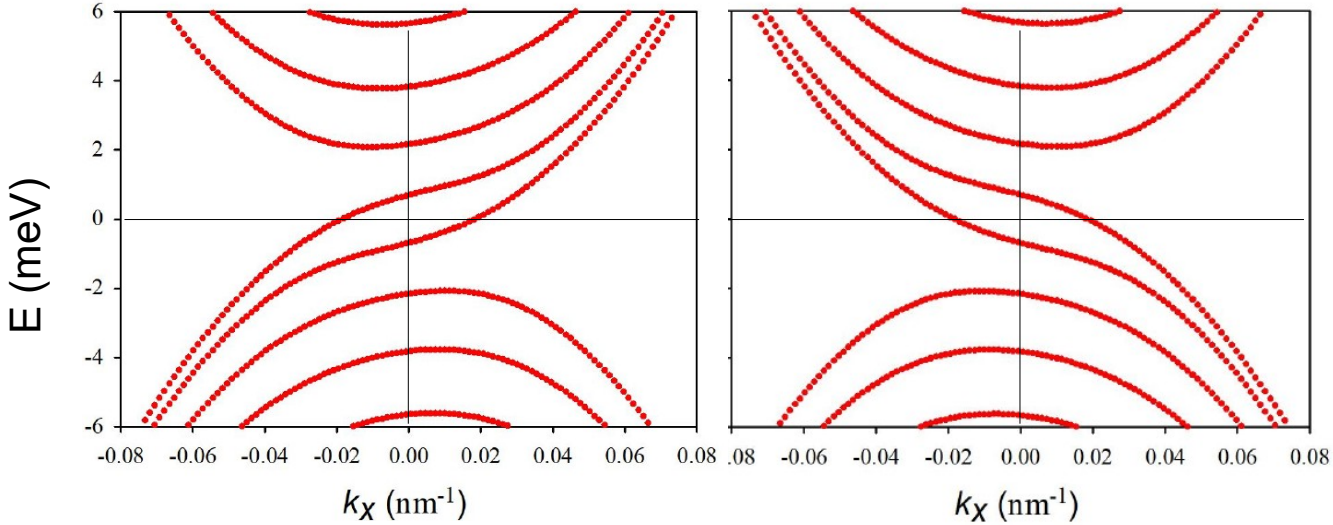
Trivial wire





Topological wire



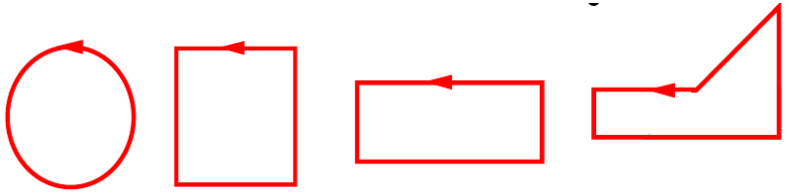


Overview of results

1.- Scattering of kink-antikink constrictions and loops

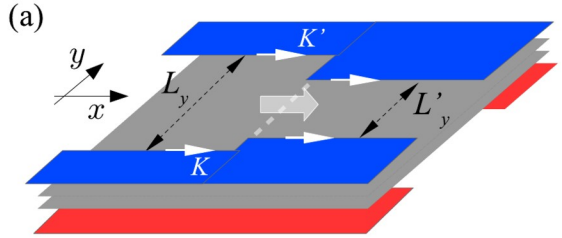
Phys Rev. B **104**, 155303 (2021)

2.- Trivial and topological finite bound states



New J. Phys. **24,** 013001 (2022)
Phys. Status Solidi B, 2200023 (2022)

3.- Junctions: trivial-trivial, trivial-topological



Phys Rev. B **106**, 035424 (2022)
Preprint

Low energy Hamiltonian

Reports on Progress in Physics **76**, 056503 (2013)

Near the Dirac points

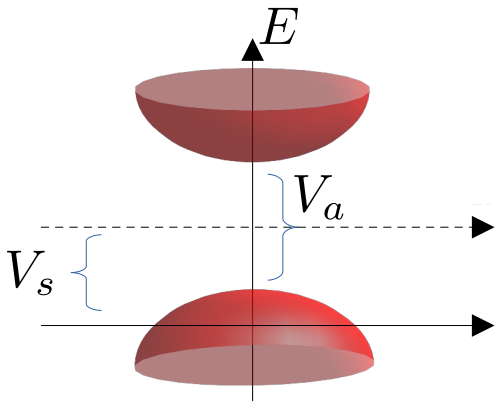
$$H = v_F \left(p_x - \hbar \frac{y}{l_z^2} \right) \tau_z \sigma_x + v_F \, p_y \sigma_y + \frac{t}{2} \left(\lambda_x \sigma_x + \lambda_y \sigma_y \right) + V_s + V_a \, \lambda_z \, ,$$

continuum: x, y, p_x, p_y

3 pseudospins: valley $\tau_{x,y,z}$; sublattice $\sigma_{x,y,z}$; layer $\lambda_{x,y,z}$

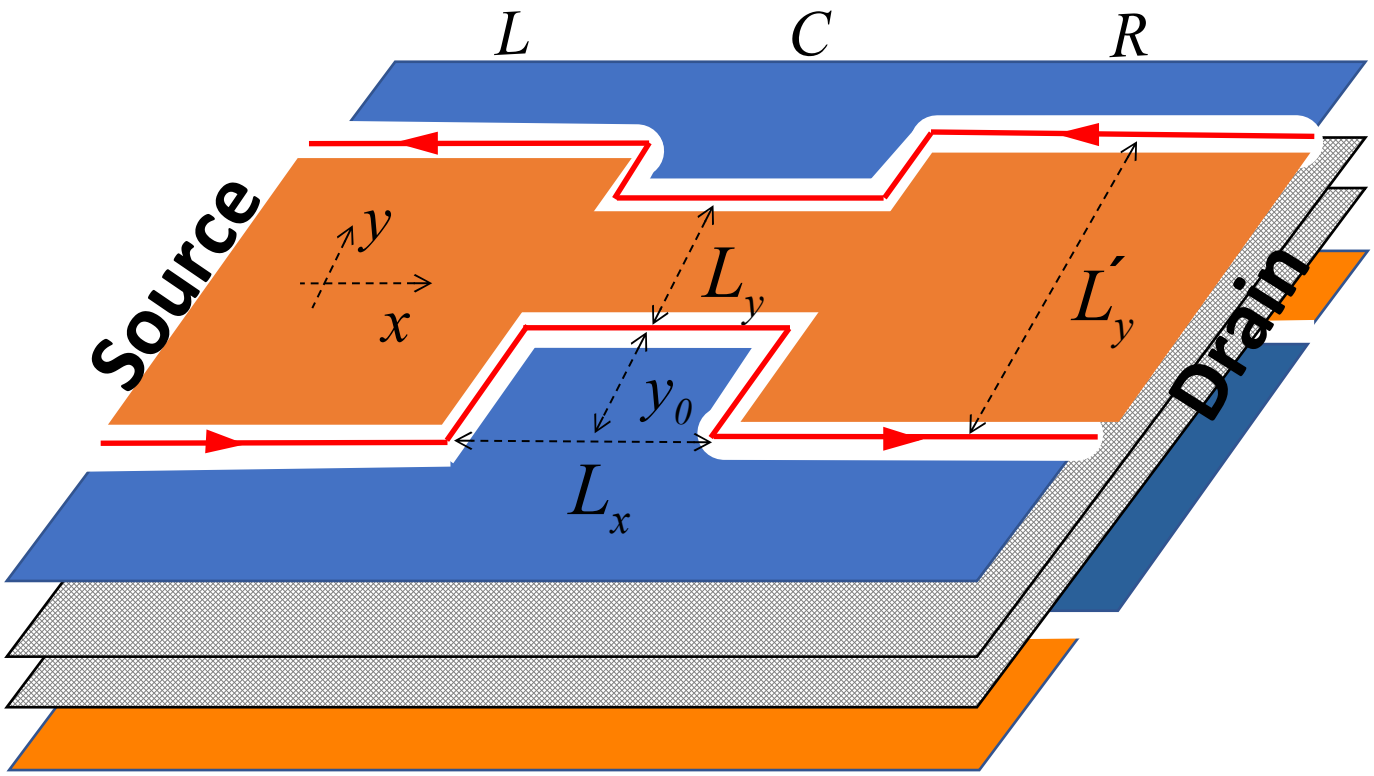
$\hbar v_F = 660\,\mathrm{meV nm}$; $t = 380\,\mathrm{meV}$; $l_z^{-2} = eB/\hbar c$

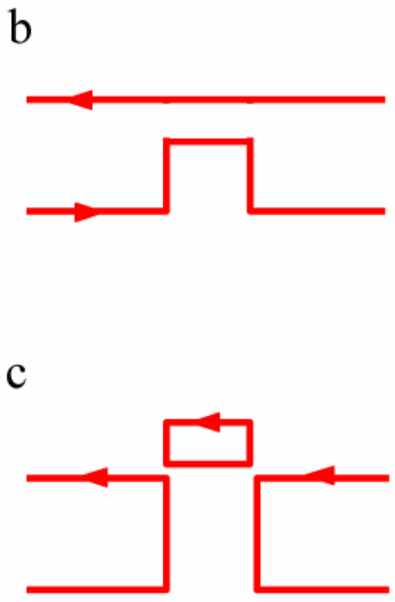
V_s ; V_a



Phys Rev. B **104**, 155303 (2021)

1.- Scattering of kink-antikink constrictions and loops





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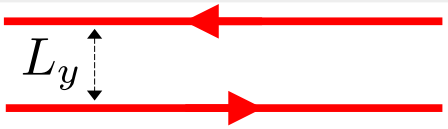
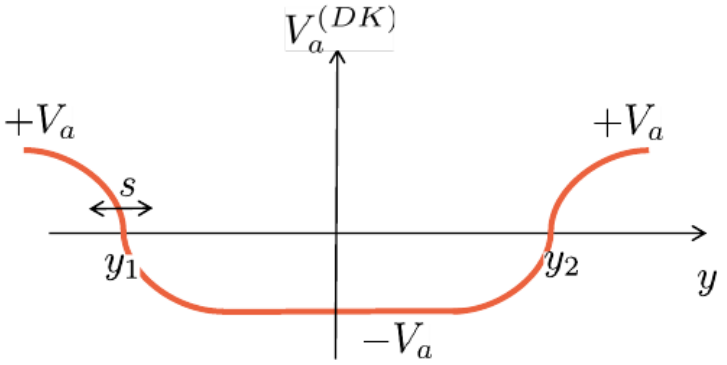
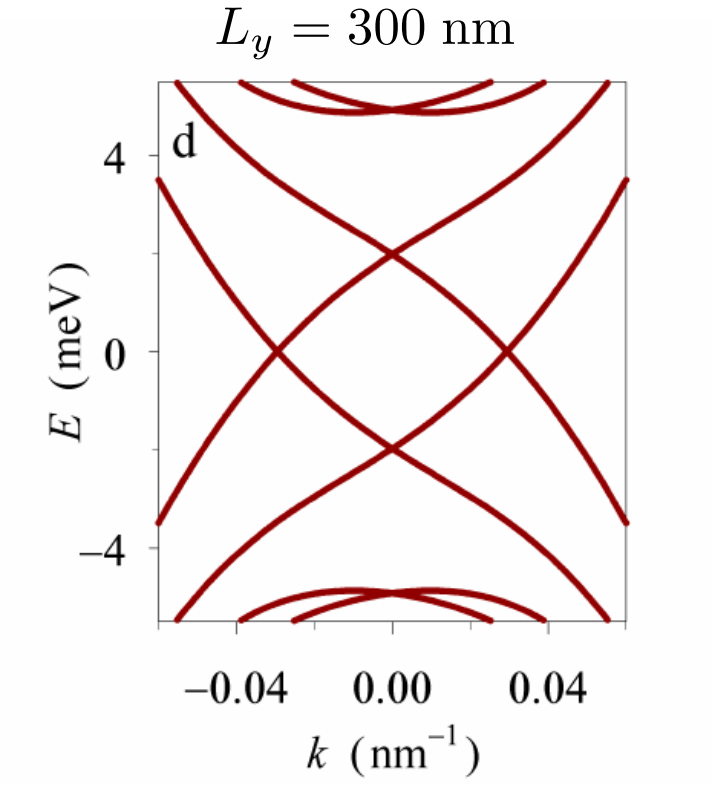
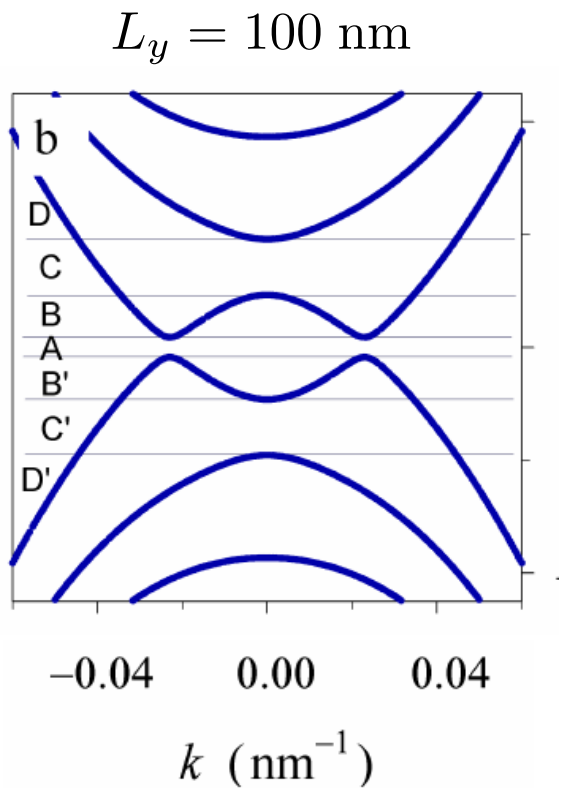
Kink-antikink system



Interference for:
Small separations $|y_1\text{-}y_2|$
Large diffusivity s

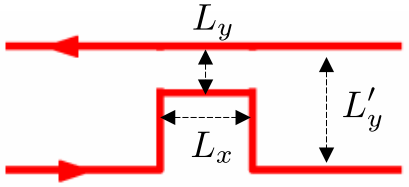


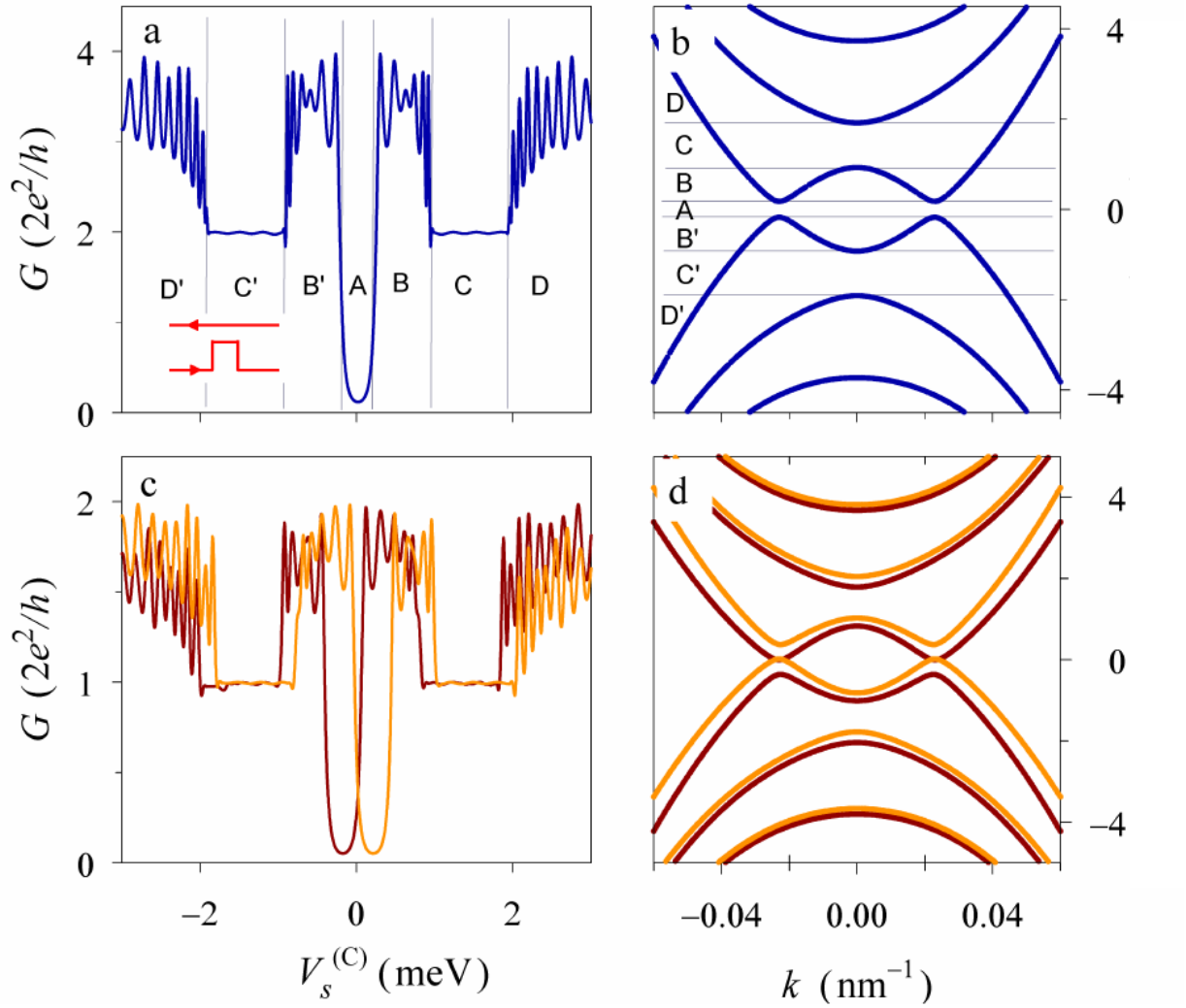




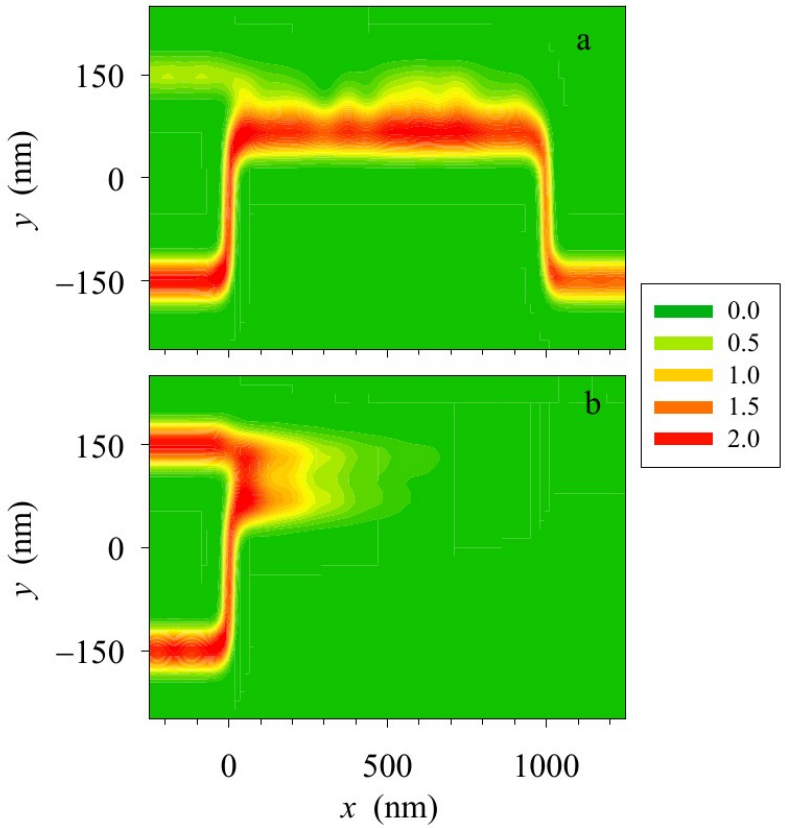
constriction

$L_y = 100$ nm
$L_x = 1\ \mu$m
$L'_y = 300$ nm





$B = 50$ mT



$B = 50$ mT
$V_s^{(C)} = 0.2$ meV

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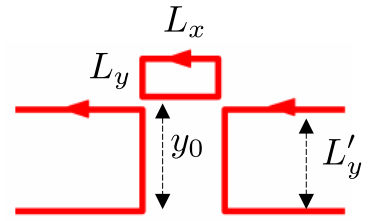
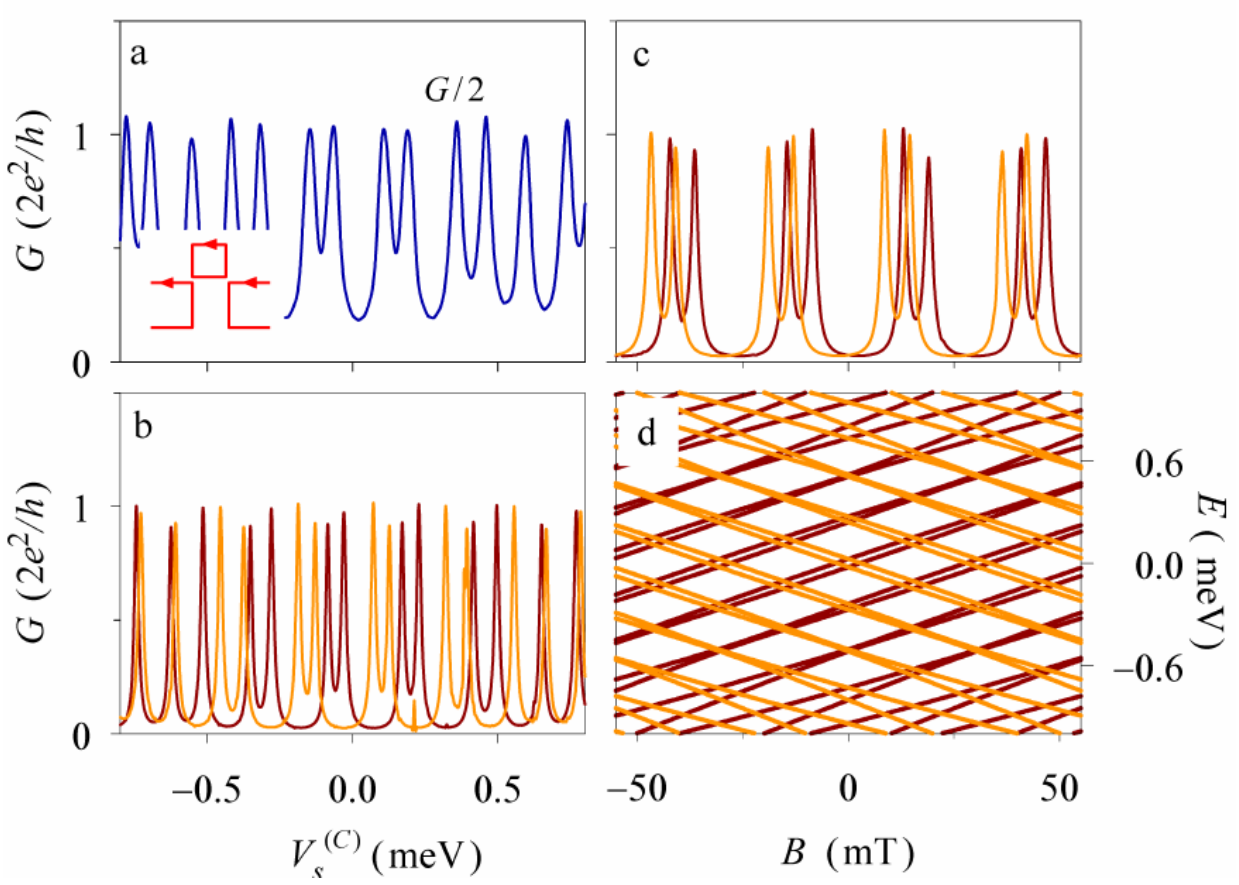
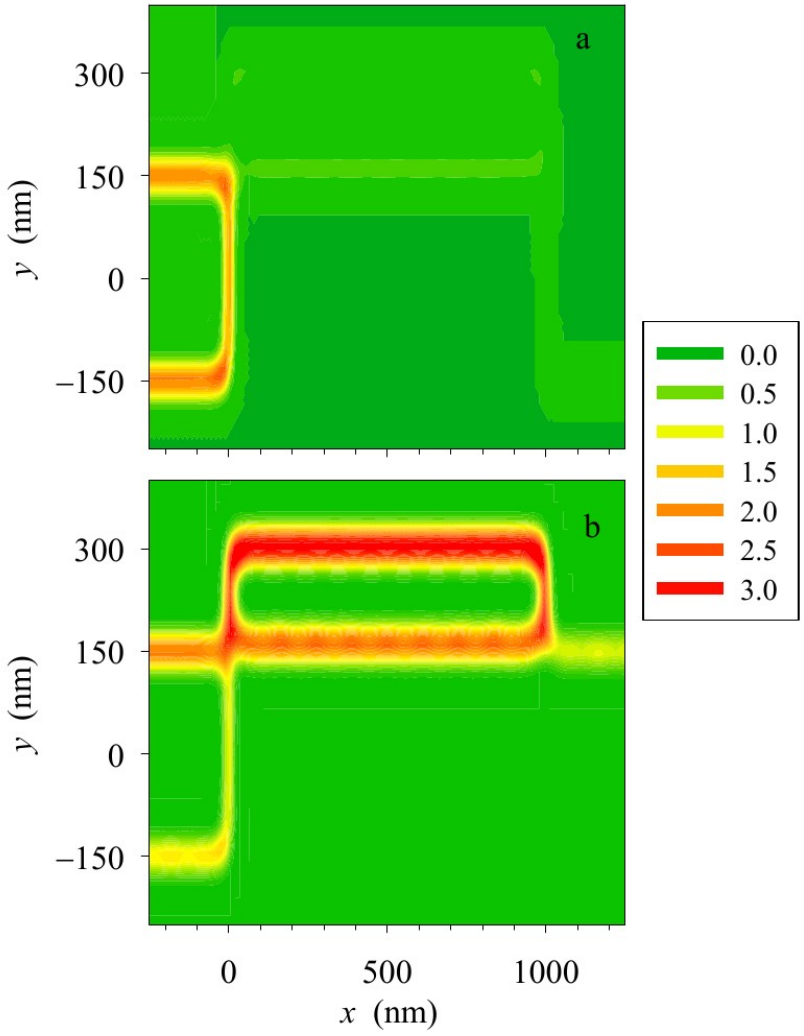
side loop

$L_y = 100$ nm
$L_x = 1\ \mu$m
$L'_y = 300$ nm
$y_0 = 310$ nm





$B = 50$ mT



$B = 50$ mT
$V_s^{(C)} = 0.3$ meV

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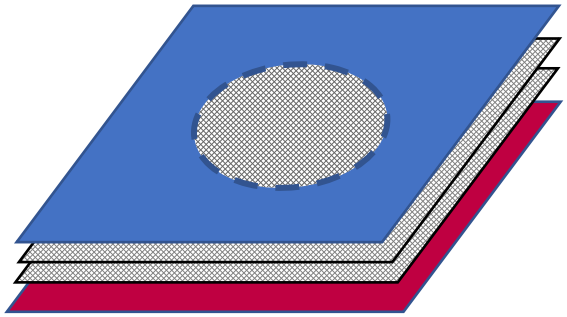
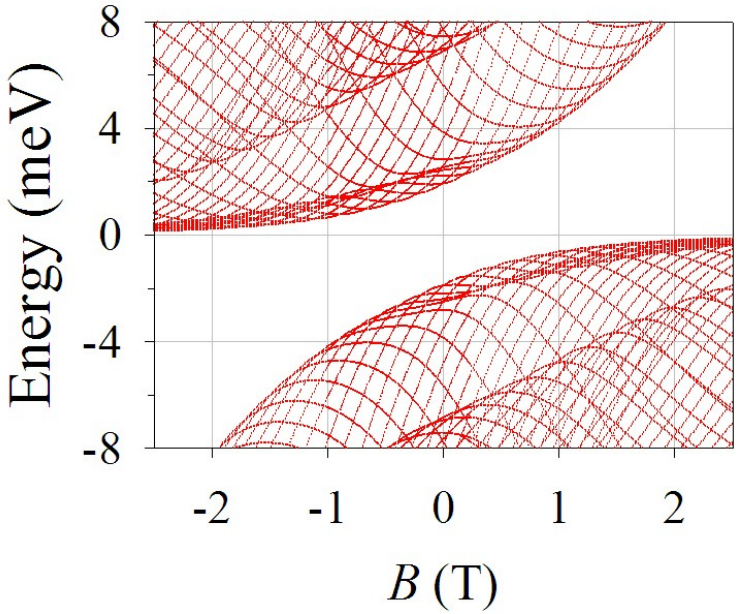
2.- Trivial and topological finite bound states

Trivial



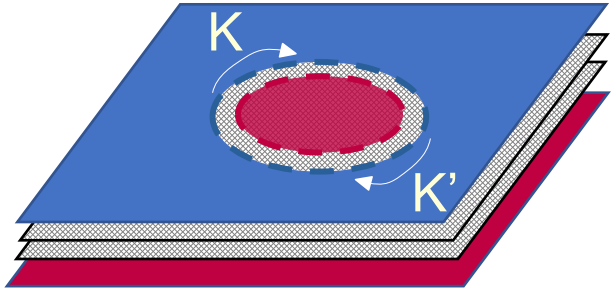


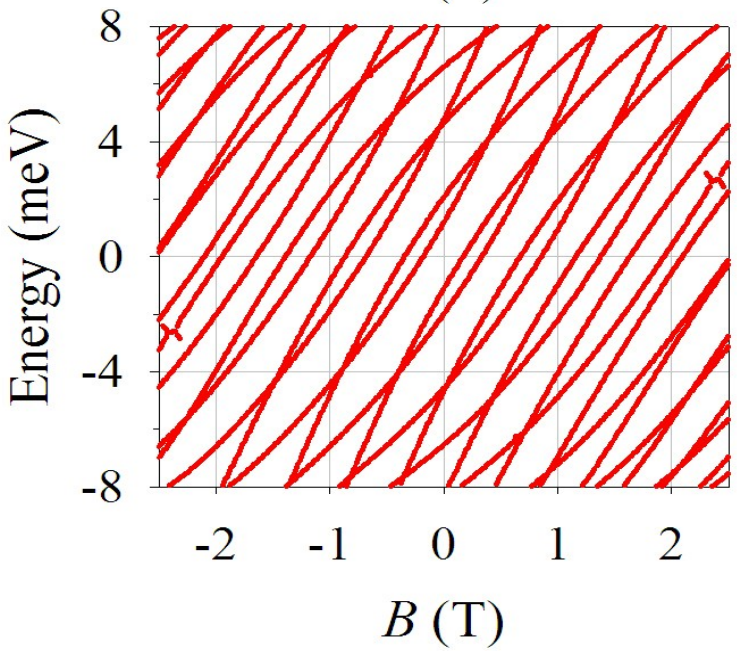
Landau gap

$$[0, \sqrt{2}\,\hbar\omega_c]$$

$$\omega_c = \frac{2eB\,v_F^2}{t}$$

Topological





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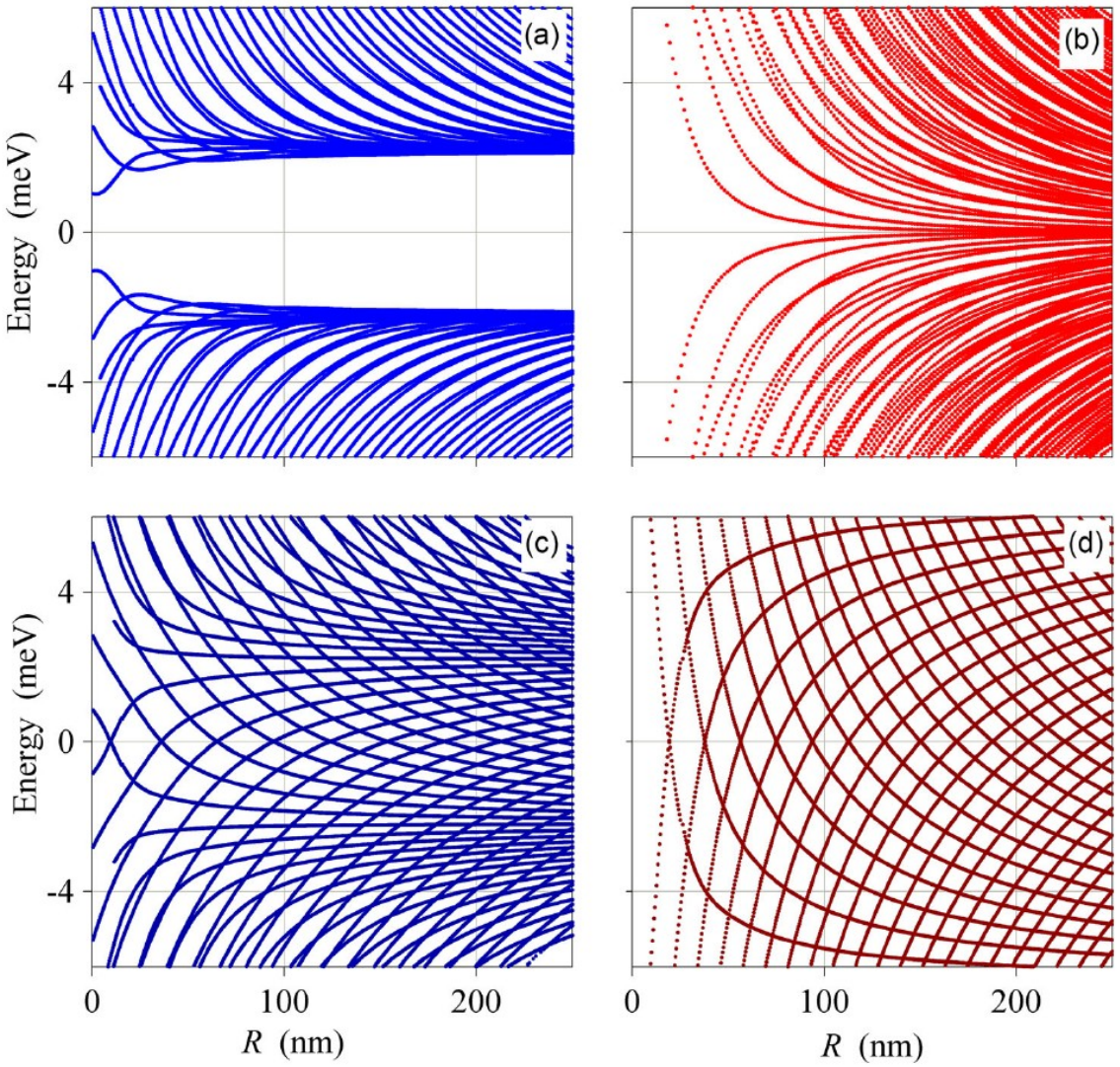
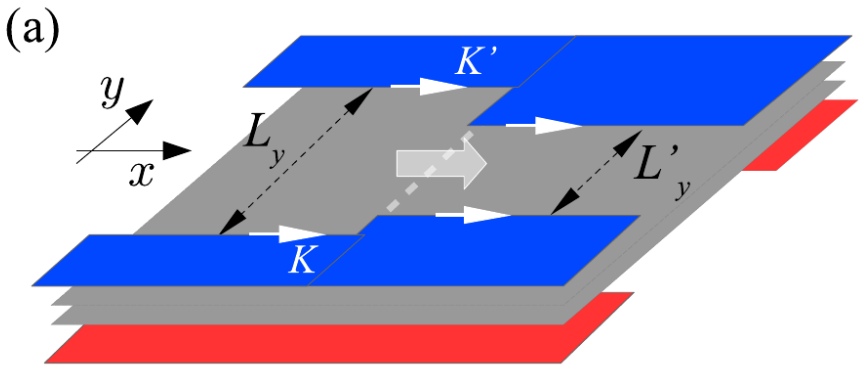
Size dependence

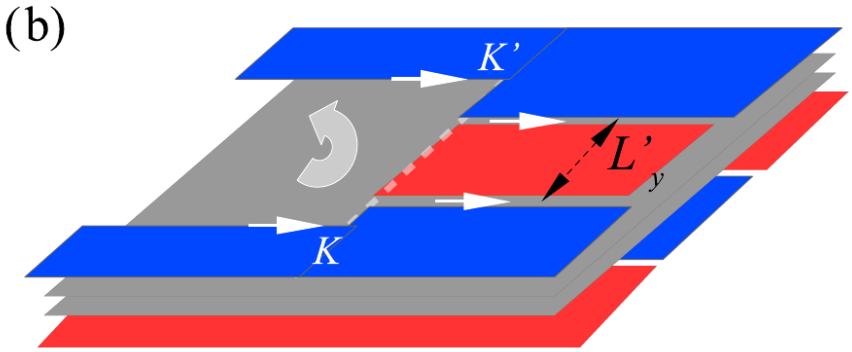


Electrostatic wire junctions

trivial-trivial



trivial-topological



A *novel* chiral edge mode in trivial confinement

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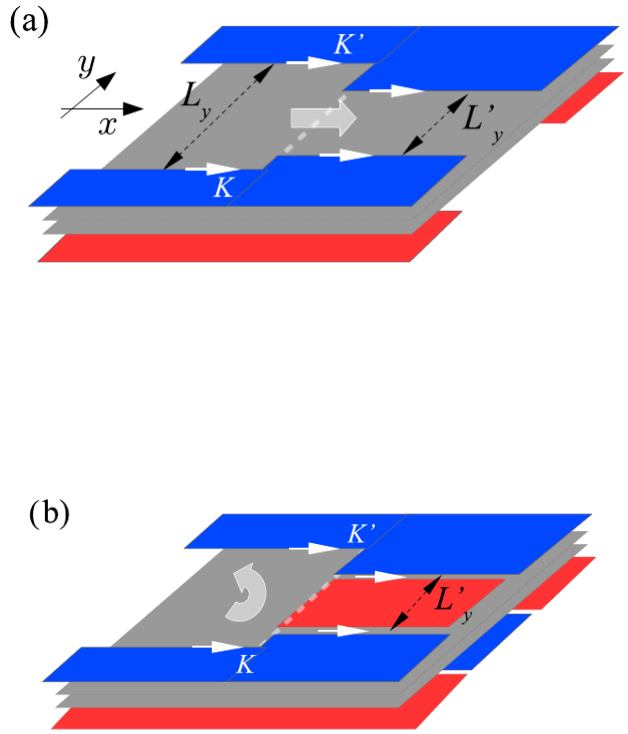
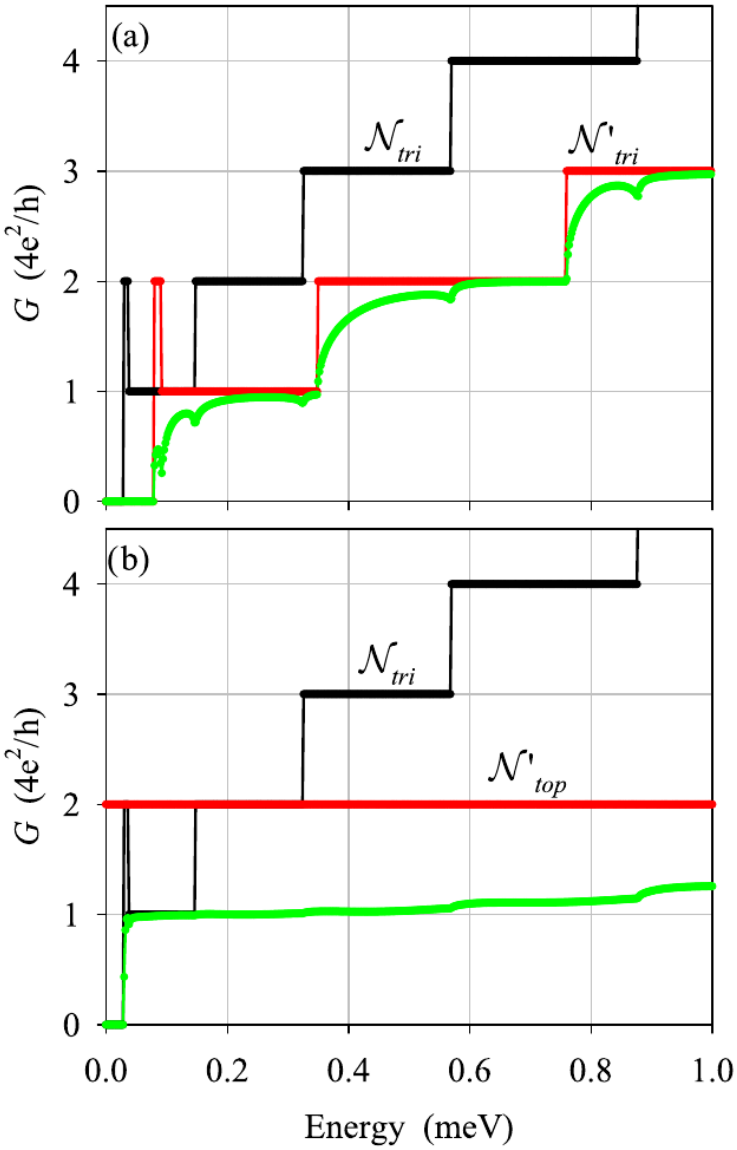
Single-junction conductances

$L_y = 600$ nm

$L'_y = 400$ nm

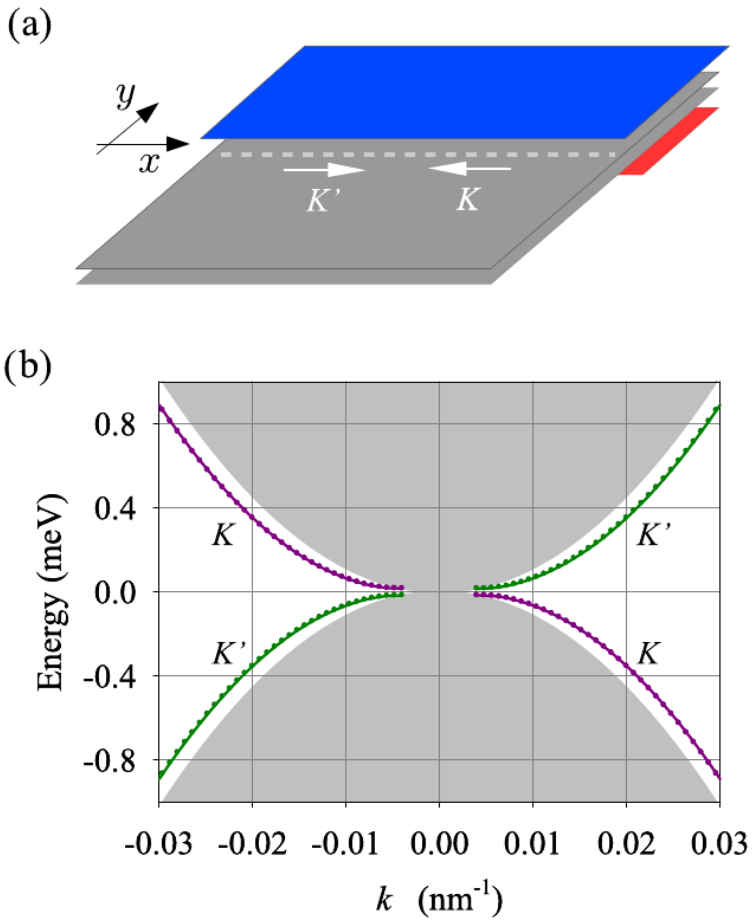




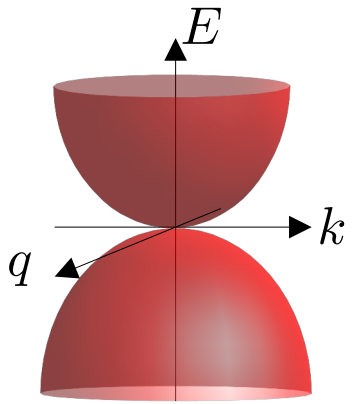
Follows *staircase*

Reduced cond.

One (trivial *gapped-ungapped*) edge

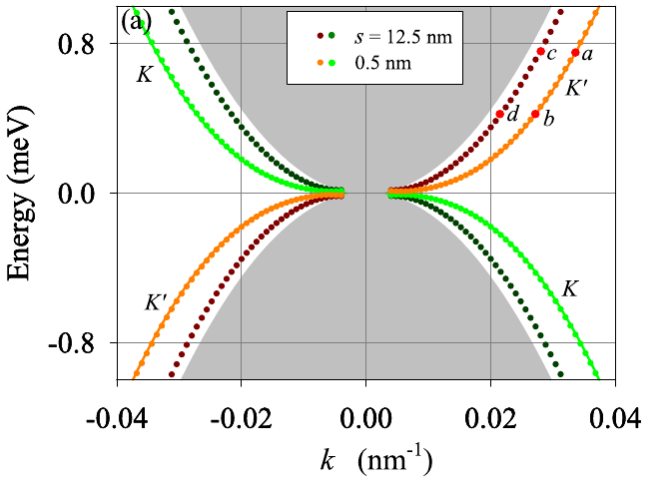


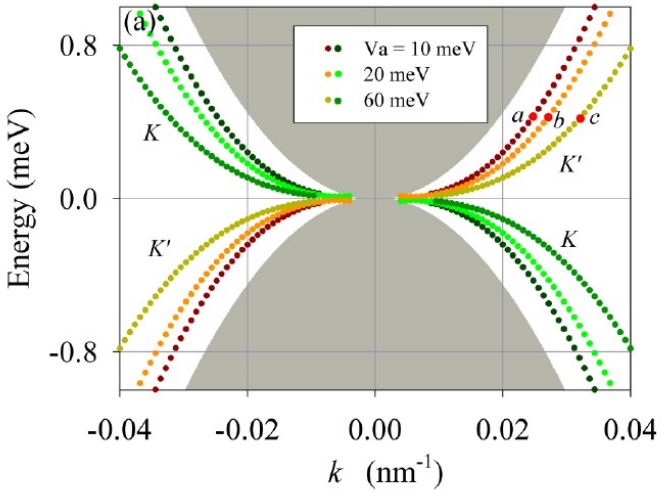
2D continuum: k < kc

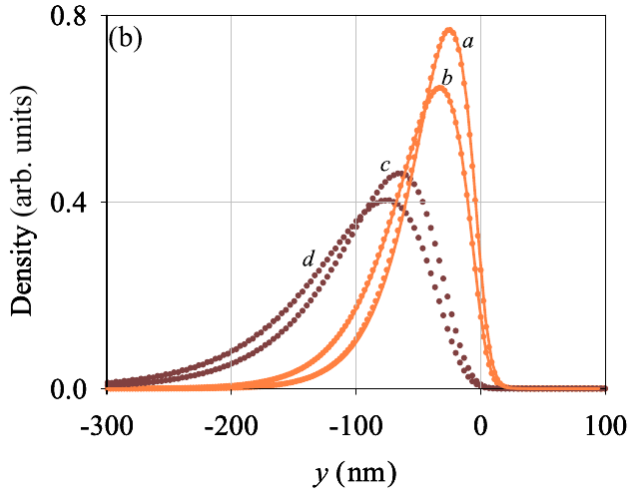


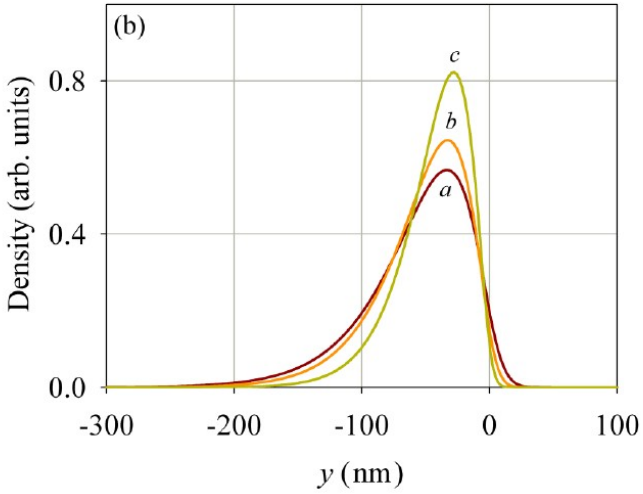
$$k_c = \frac{1}{\hbar v_F}\sqrt{|E|\,(|E|+t)}.$$

One (trivial *gapped-ungapped*) edge



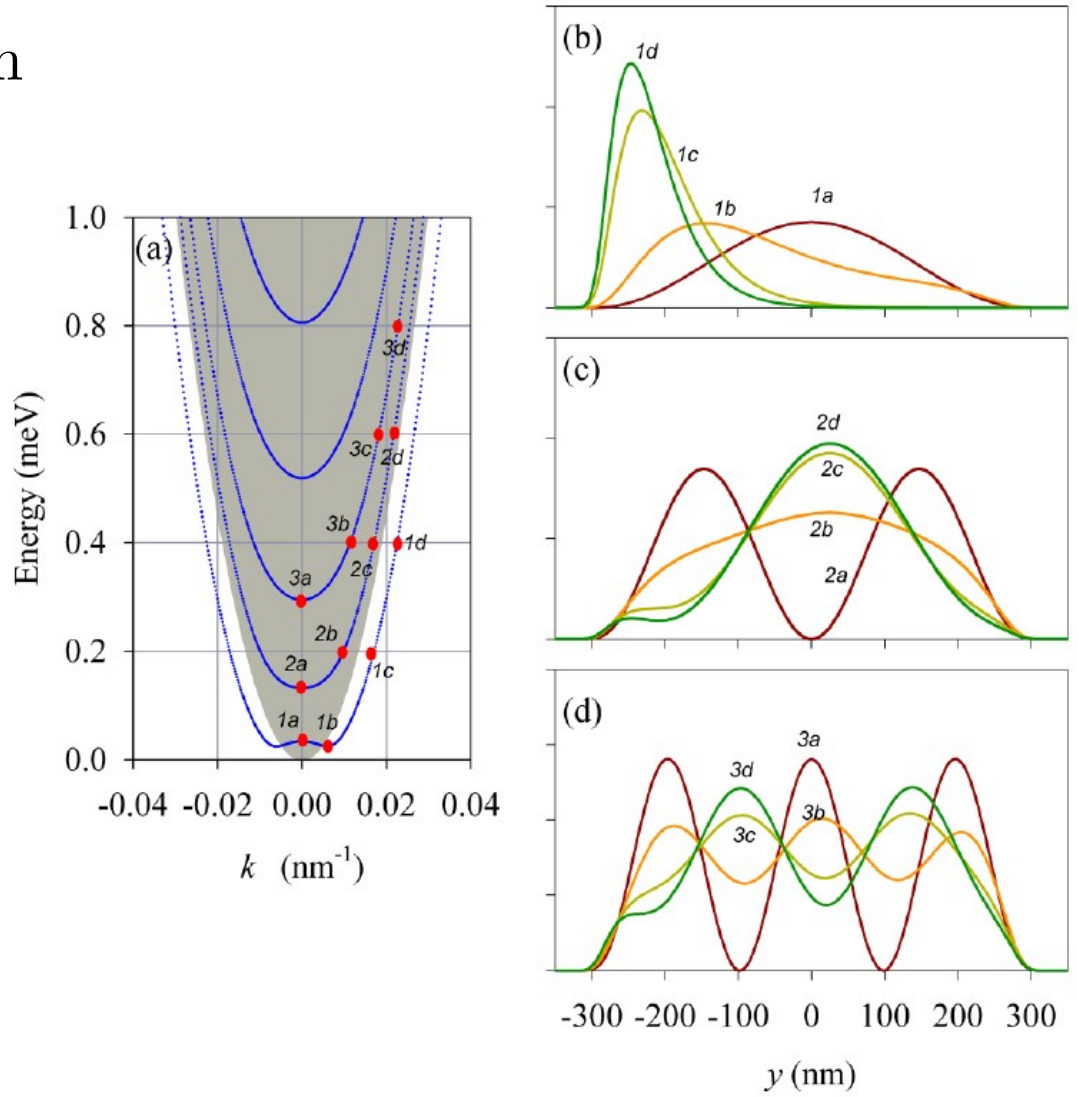






Two trivial edges (wire)

$$L_y = 600 \text{ nm}$$



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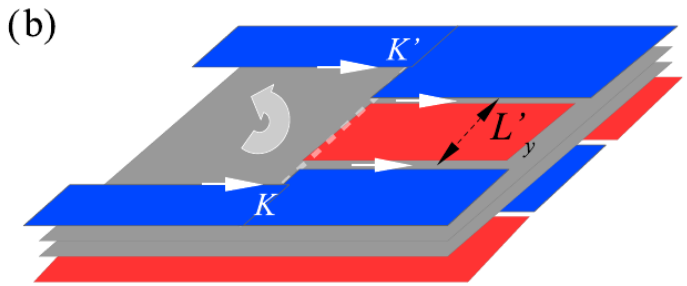
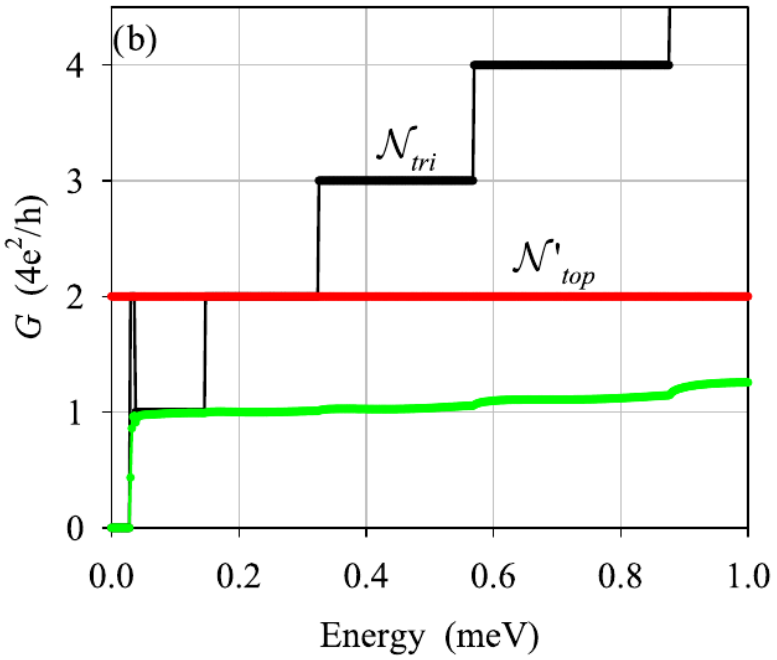
Explaining reduced conductance:

Backscattered bulk modes

Transmitted edge mode





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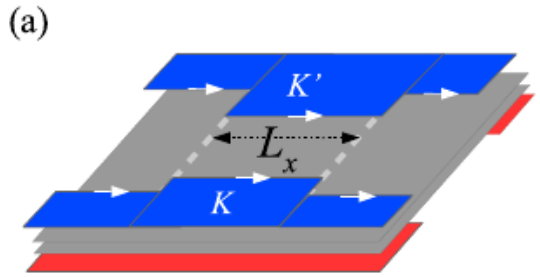
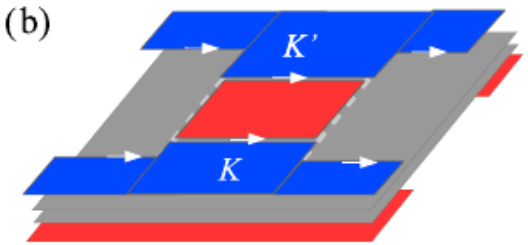
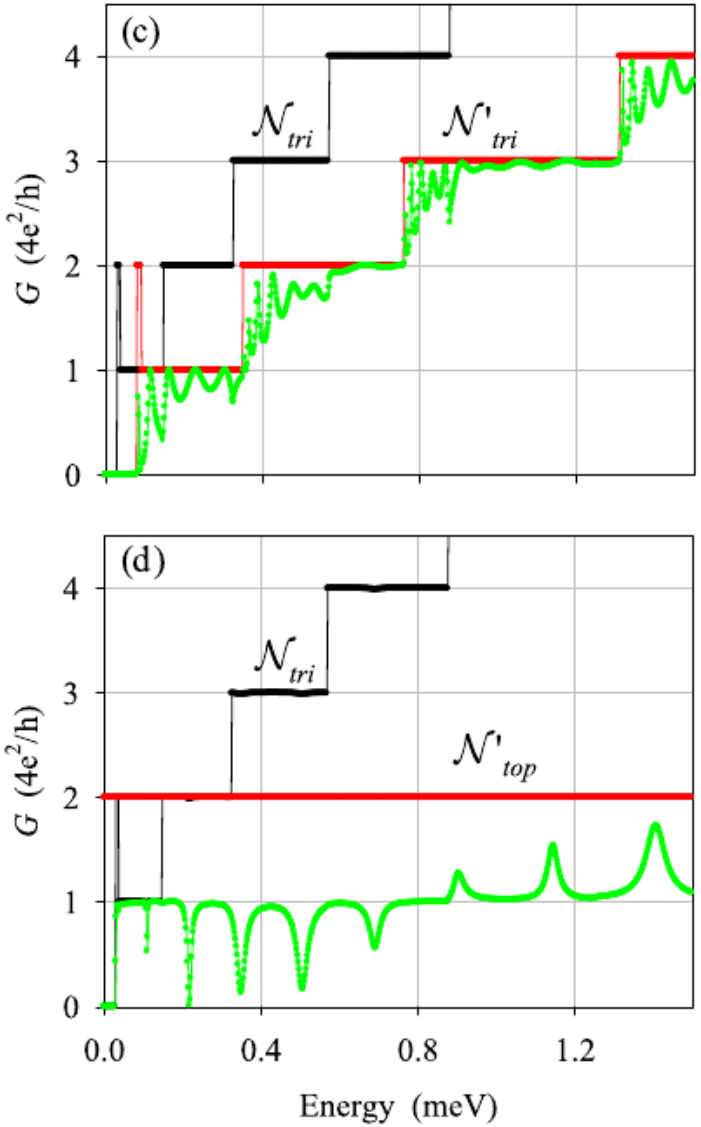
Double junction conductances







oscillations

Fano dips/peaks

Summary

- Versatile nanodevices in quantum valley transport
  * working with robust topological states (vanishing E)

- Kink-antikink constrictions and loops
  * anomalous quantized conductances
  * valley filtering in tiny magnetic fields (50 mT)
  * chiral quasibound states
  * valley accumulations

- Differneces of trivial and topological finite bound states

- Junctions: trivial-trivial vs trivial-topological
  * A gapped-ungapped edge hosts a discrete chiral mode
  * Quantized conductance of the trivial-topological junction
  * Resonances (conductance dips-peaks) in wire double junctions

THANK YOU