Controlling topologically protected states by external fields and doping

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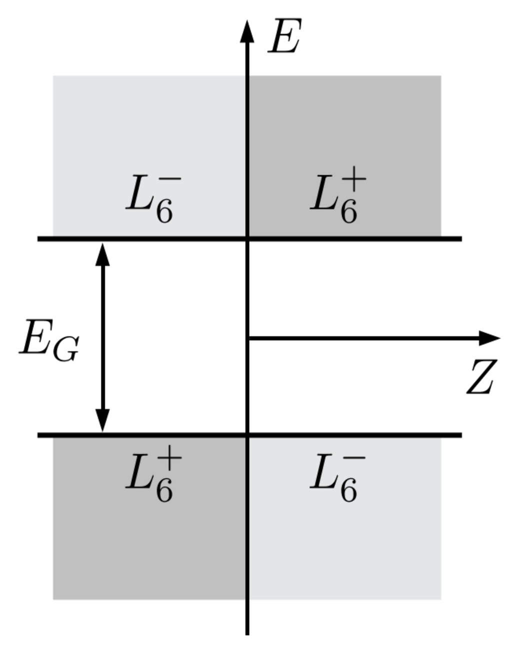
Motivation: Topologically protected surface states are foreseen to boost and reshape the current paradigm of electronics, spintronics, photonics and many other areas alike. It is therefore desirable to have a full control of their defining properties.

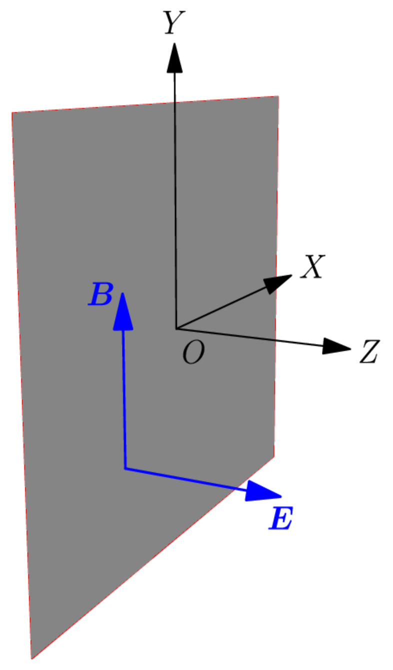
Systems: Three-dimensional topological insulators (e.g. Bi_2Se_3) and topological crystalline insulators (e.g. SnTe).

Main Results: External electric and magnetic fields allow to dynamically modify the Fermi velocity.
δ-doping induces a coexistence between a Rashba 2DEG and the topological surface states, altering the optical transitions.

Topological Boundary

External Fields





Spinful Two-Band Model

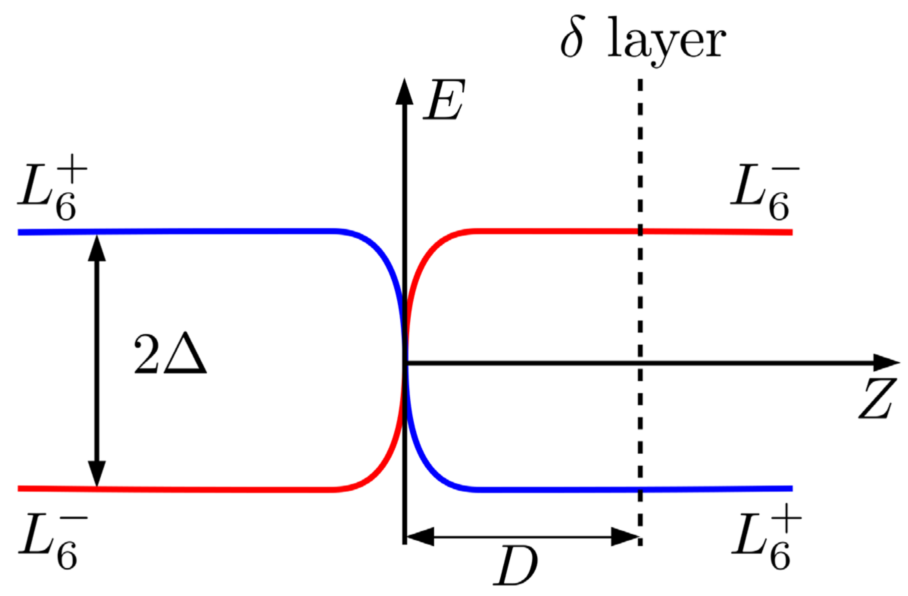
$$H = v_F \boldsymbol{\alpha} \cdot \boldsymbol{p} + \Delta(z)\beta + V(z)$$

Basis: $|\psi\rangle \in \mathcal{H}_{\text{orbital}} \otimes \mathcal{H}_{\text{spin}}$

Bulk Symmetries: $\mathcal{T}, \mathcal{P}$

$\mathbb{Z}_2$ topological index: $\nu = \text{sgn}(\Delta)$

Doping



External Fields

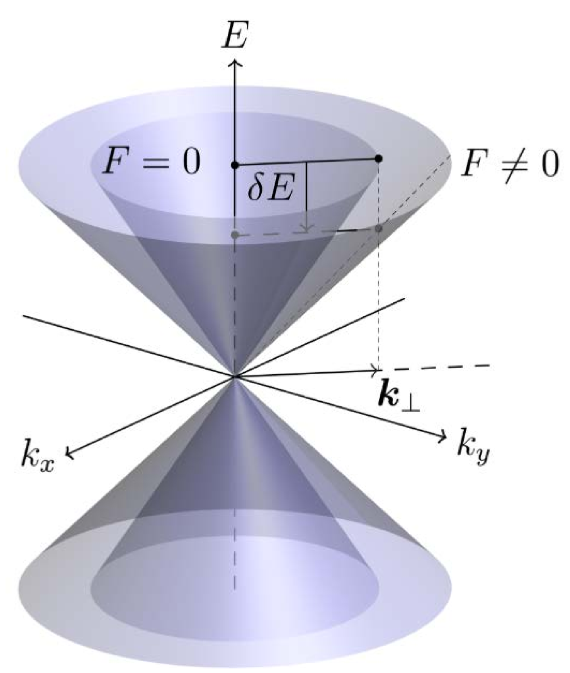
Electric Field

Isotropic Fermi velocity reduction

$$\frac{v_F(F)}{v_F(0)} = 1 - \frac{5}{8}\frac{F^2}{F_C}$$

$$eF_C d = \Delta$$

$$d = \frac{\hbar v_F}{\Delta}$$

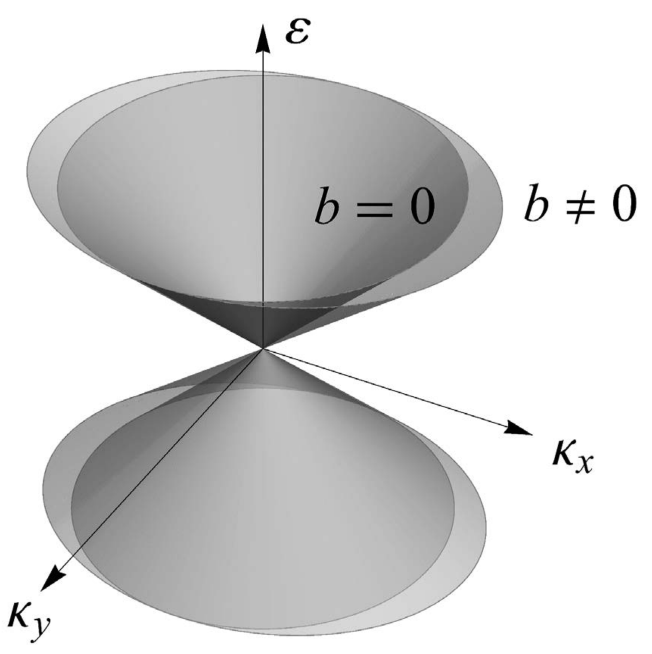


Magnetic Field

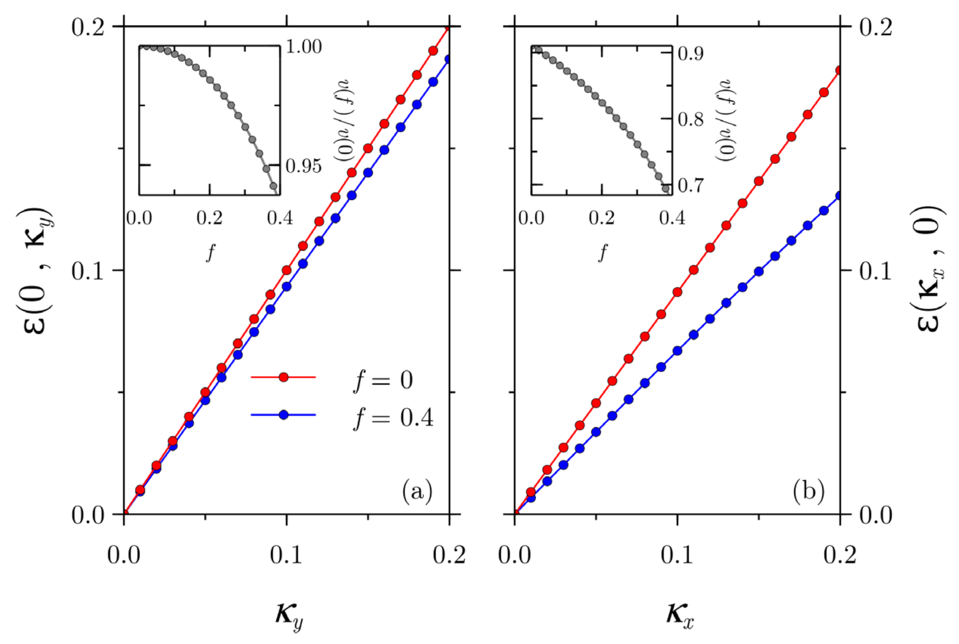
Anisotropic Fermi velocity reduction

$$\frac{v_F^x(B)}{v_F^x(0)} = 1 - \frac{5d^2}{\ell_B^2}$$

$$\ell_B = \sqrt{\frac{\hbar}{eB}}$$

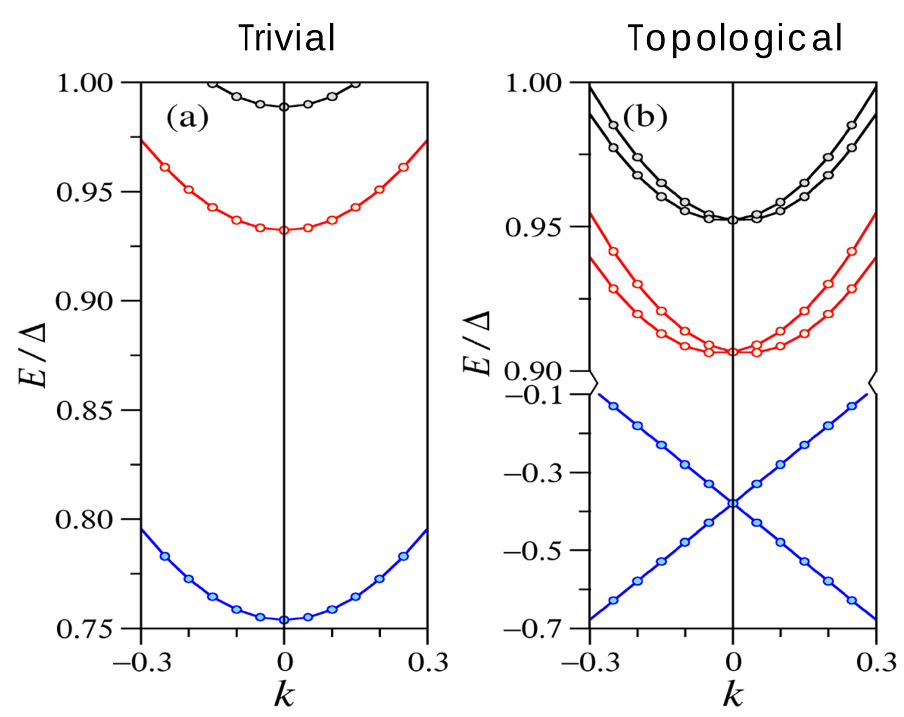


Crossed Fields

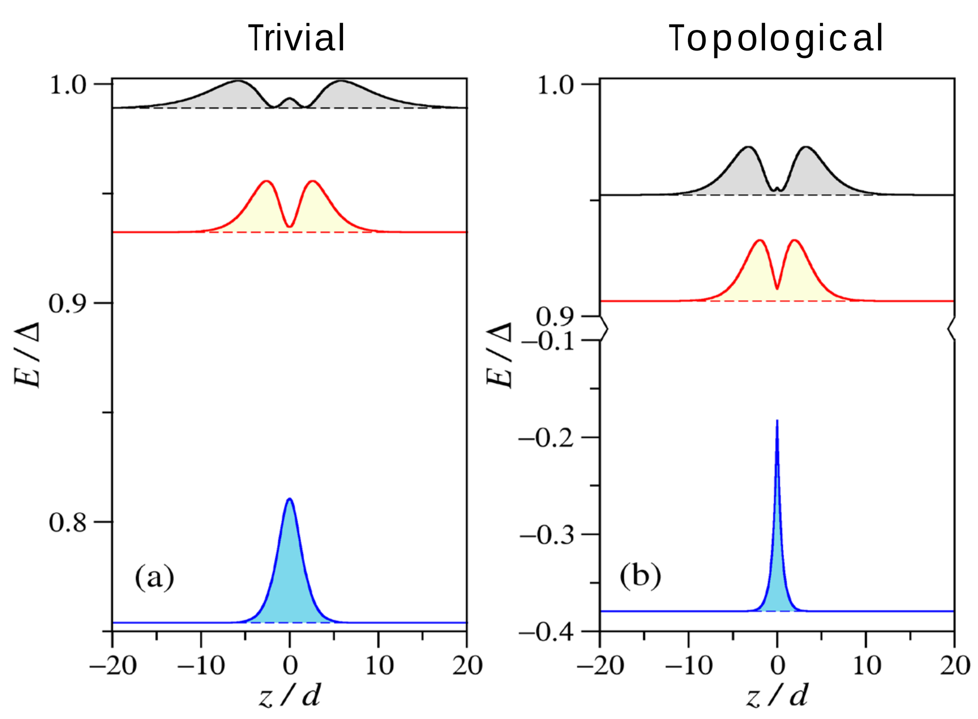


δ-doping

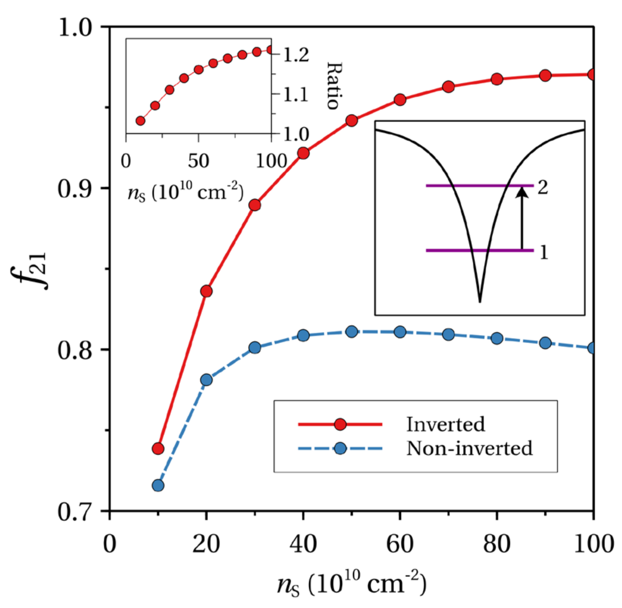
Spectrum



States



Optical Transitions



Reshaped oscillator strength

$$f_{ji} = \frac{E_j - E_i}{\Delta} \left| \left\langle j \left| \frac{z}{d} \right| i \right\rangle \right|^2$$

Conclusions

- Topological surface states are robust against perturbations.
- Dirac dispersion can be modified externally.
- Rashba-like 2DEG coexists with topological surface state.
- Linear optical response is reshaped by the topological state.

References

Topological Boundary:
- Volkov and Pankratov, JETP Lett. **42**, 178 (1985)
- F. Zhang *et al.*, PRB **86**, 081303 (2012)

External Fields:
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δ-doping:
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