University of Zurich[UZH]

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Entanglement in
Strongly Correlated Systems

Benasque
17/02/2017

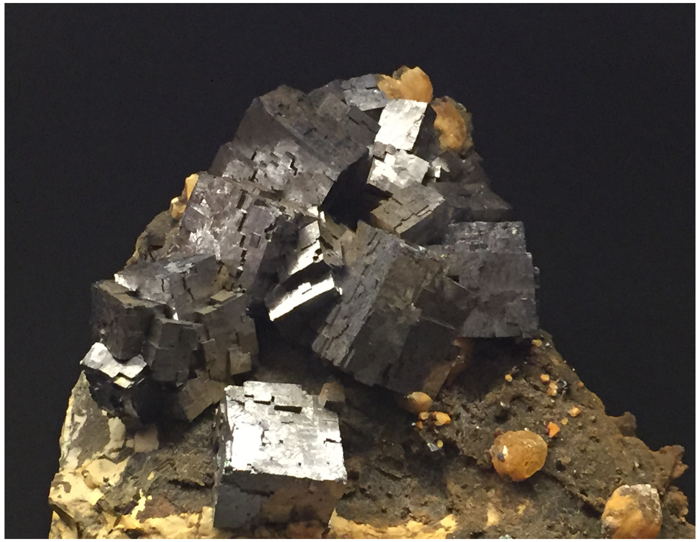
Higher-order Topological Insulators

A paradigm for topological states of matter

$$\partial(\partial M) = \emptyset$$

(the boundary of a boundary is empty)

… works for sufficiently smooth manifolds only.



Crystals have no smooth surface!

Outline

1. First-order topological insulators
2. Higher-order topological insulators
3. Models for second-order 3D TIs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Maia G. Vergniory
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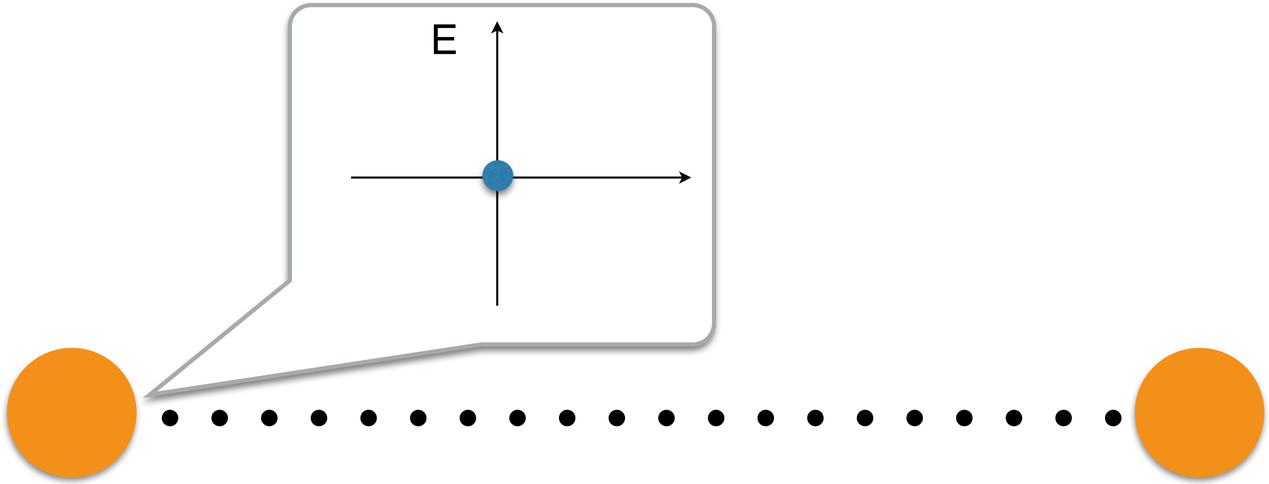
1. First-order Topological Insulators

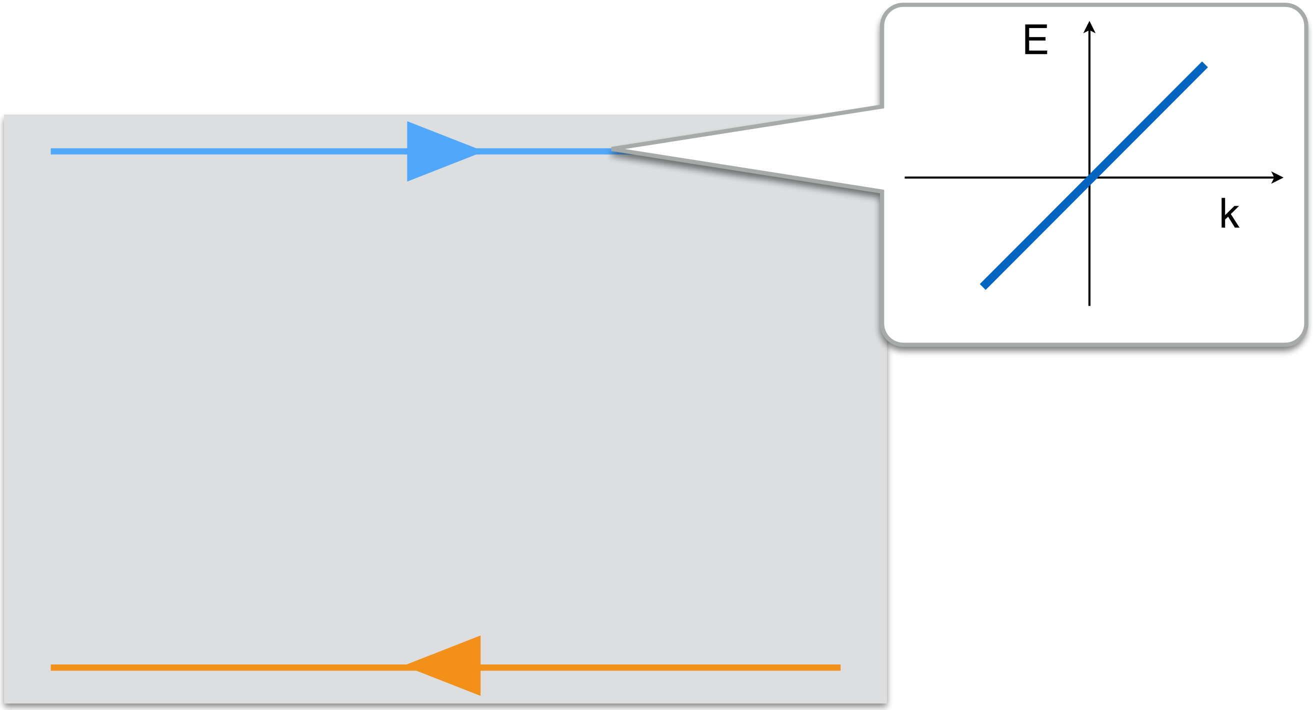
1D: Su-Schrieffer-Heeger Chain



Protected by chiral symmetry,

$\mathbb{Z}$ classification

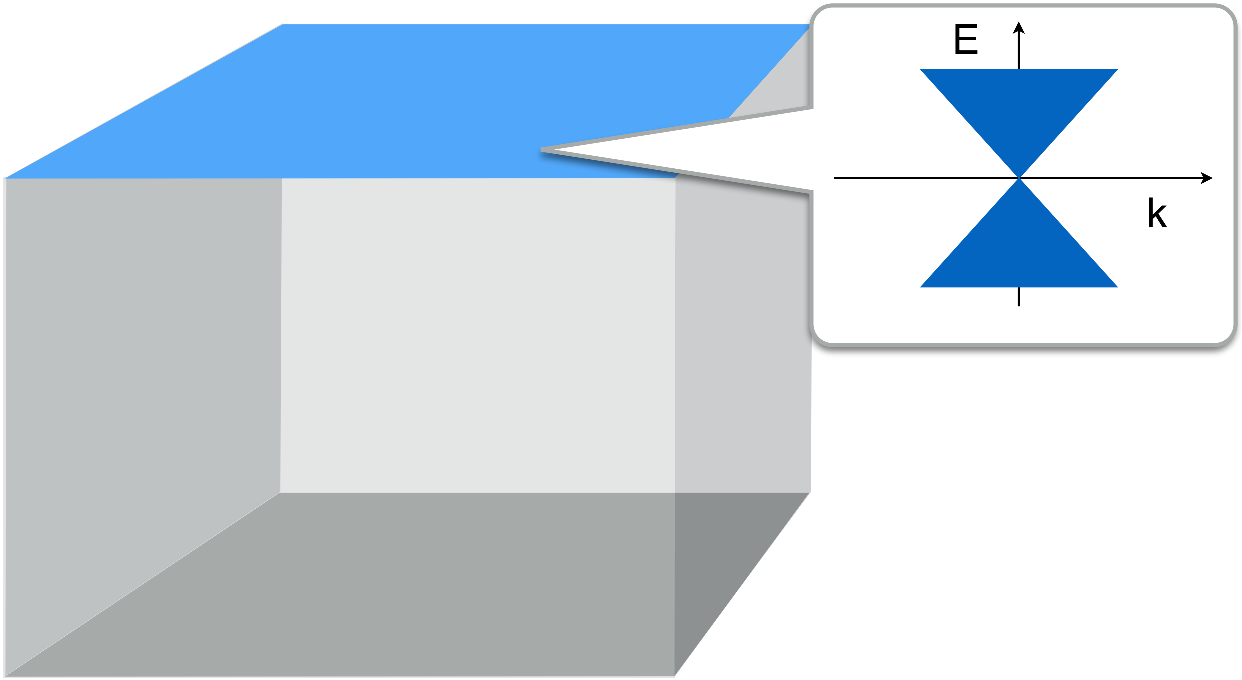
2D: Quantum Hall Effect



Protected without symmetry,

$\mathbb{Z}$ classification

3D: Topological Insulator (TI)



Protected by time-reversal symmetry,

$\mathbb{Z}_2$ classification

2. Higher-order Topological Insulators

Second-order 2D TI

Protected by mirror symmetries,

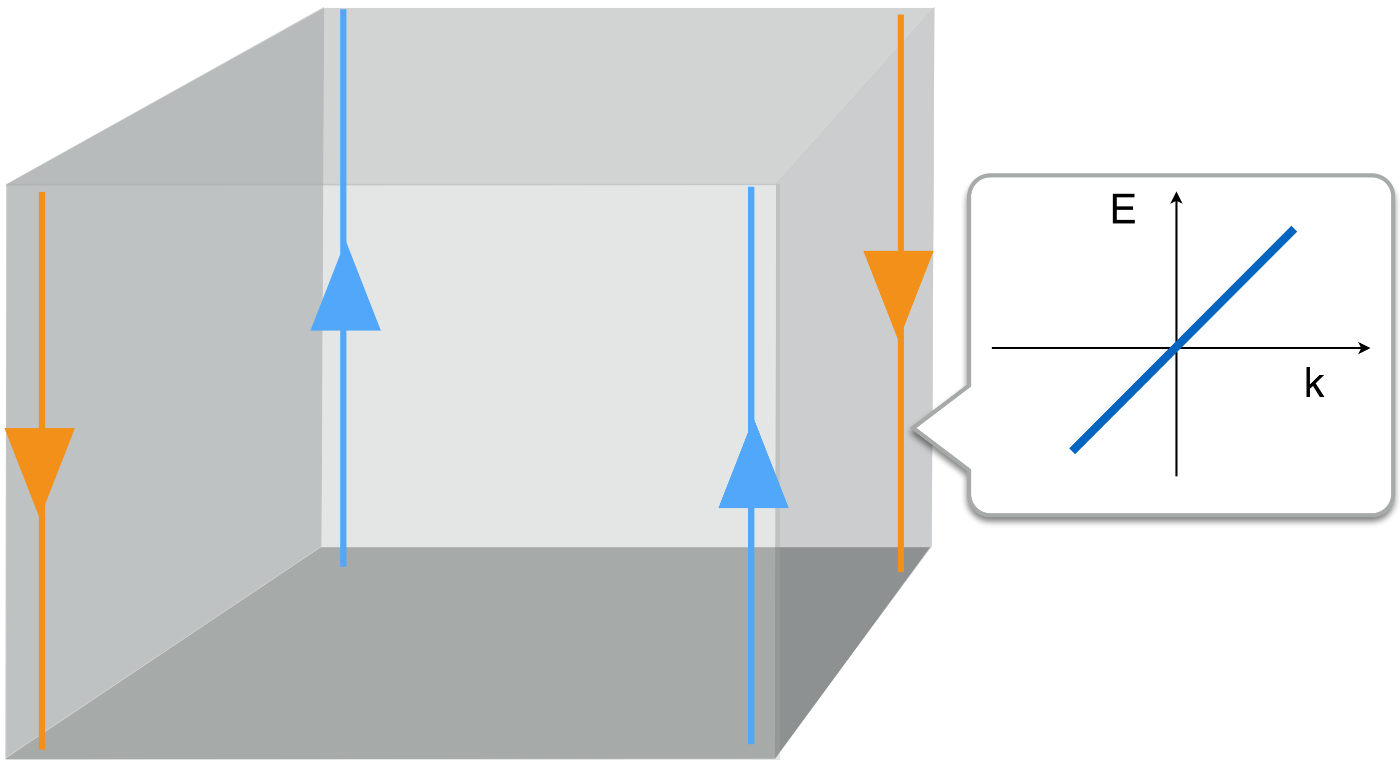
$\mathbb{Z}_2 \times \mathbb{Z}_2$ classification

Third-order 3D TI

Protected by mirror symmetries,

$\mathbb{Z}_2 \times \mathbb{Z}_2 \times \mathbb{Z}_2$ classification

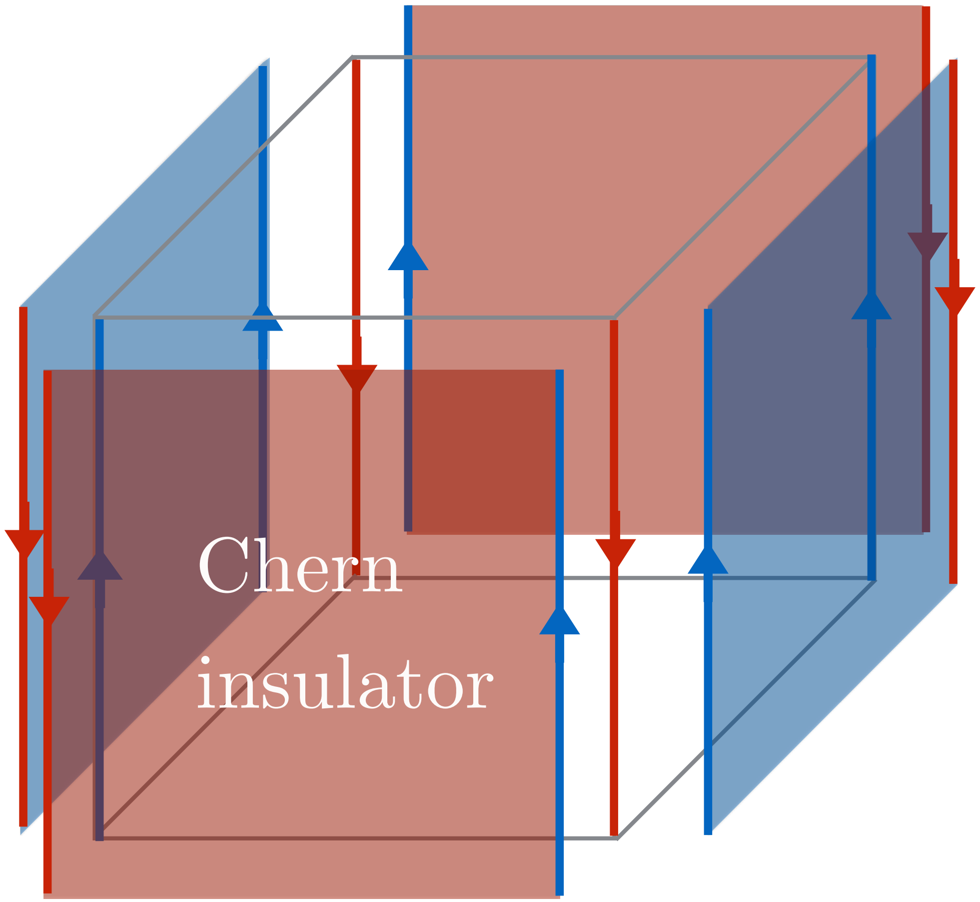
Second-order 3D TI: TRB case



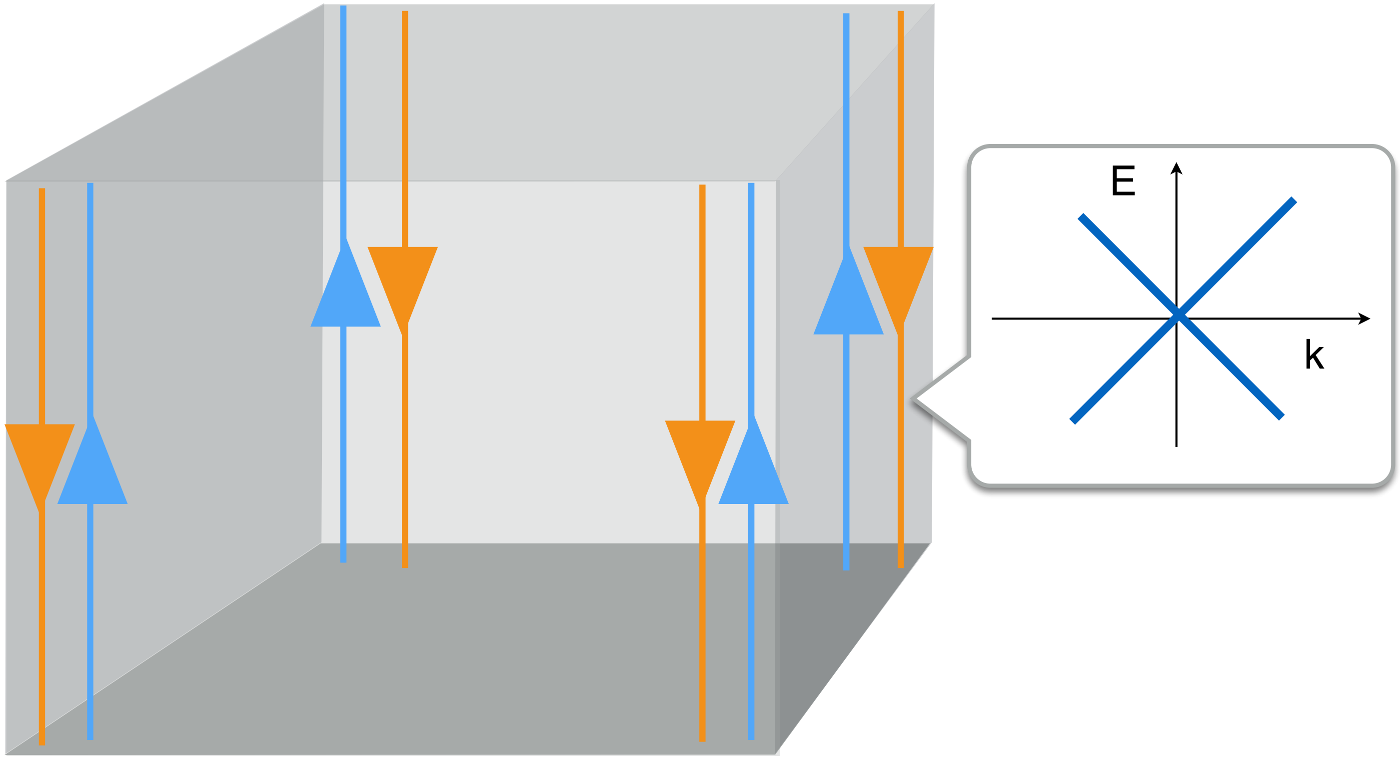
Protected by C_4T symmetry,

$\mathbb{Z}_2$ classification

Z_2 Classification



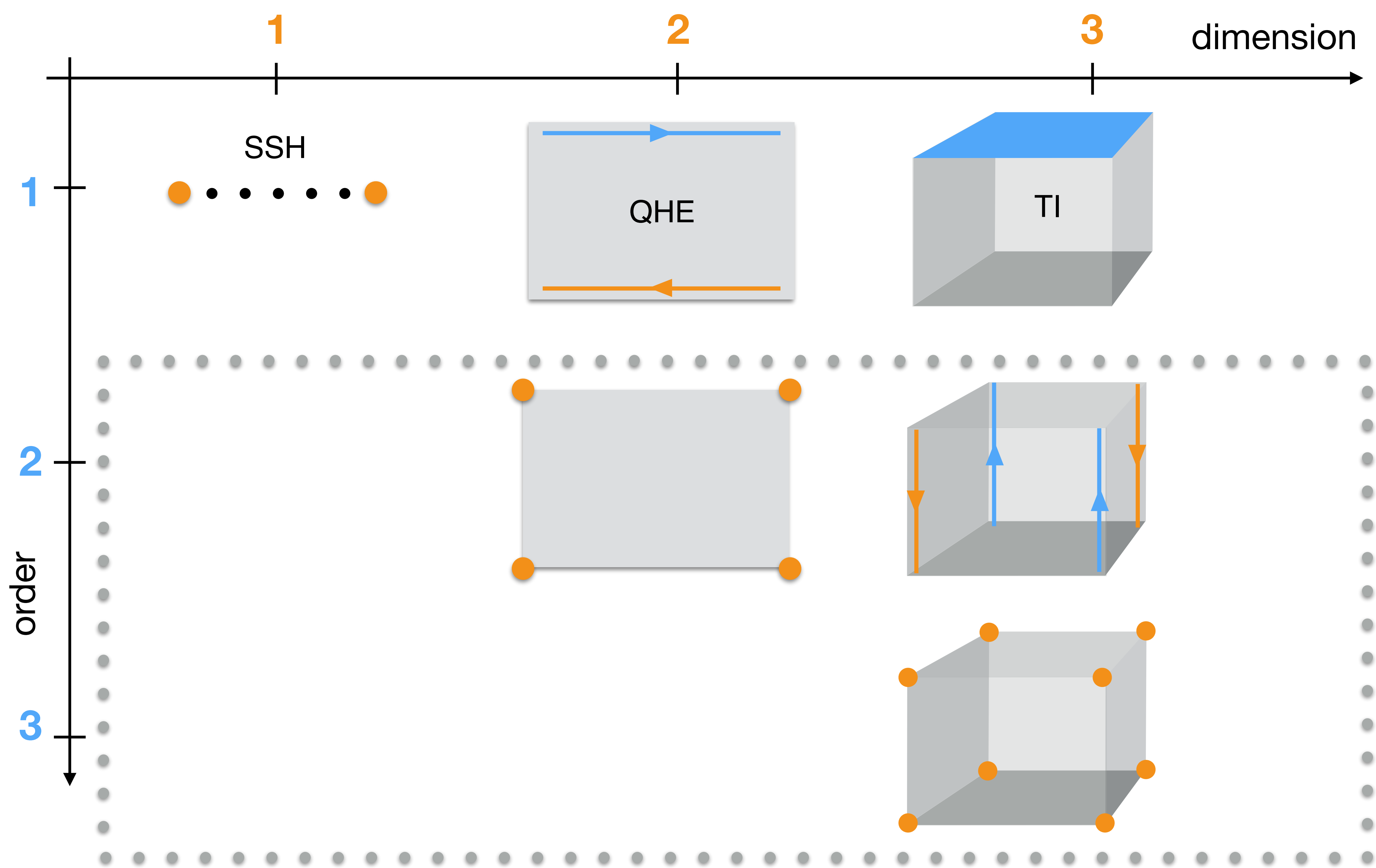
Second-order 3D TI: TRS case



Protected by mirror symmetries,

$\mathbb{Z}_2$ classification

Higher-order topological insulators



3. Models for second-order 3D Topological Insulators

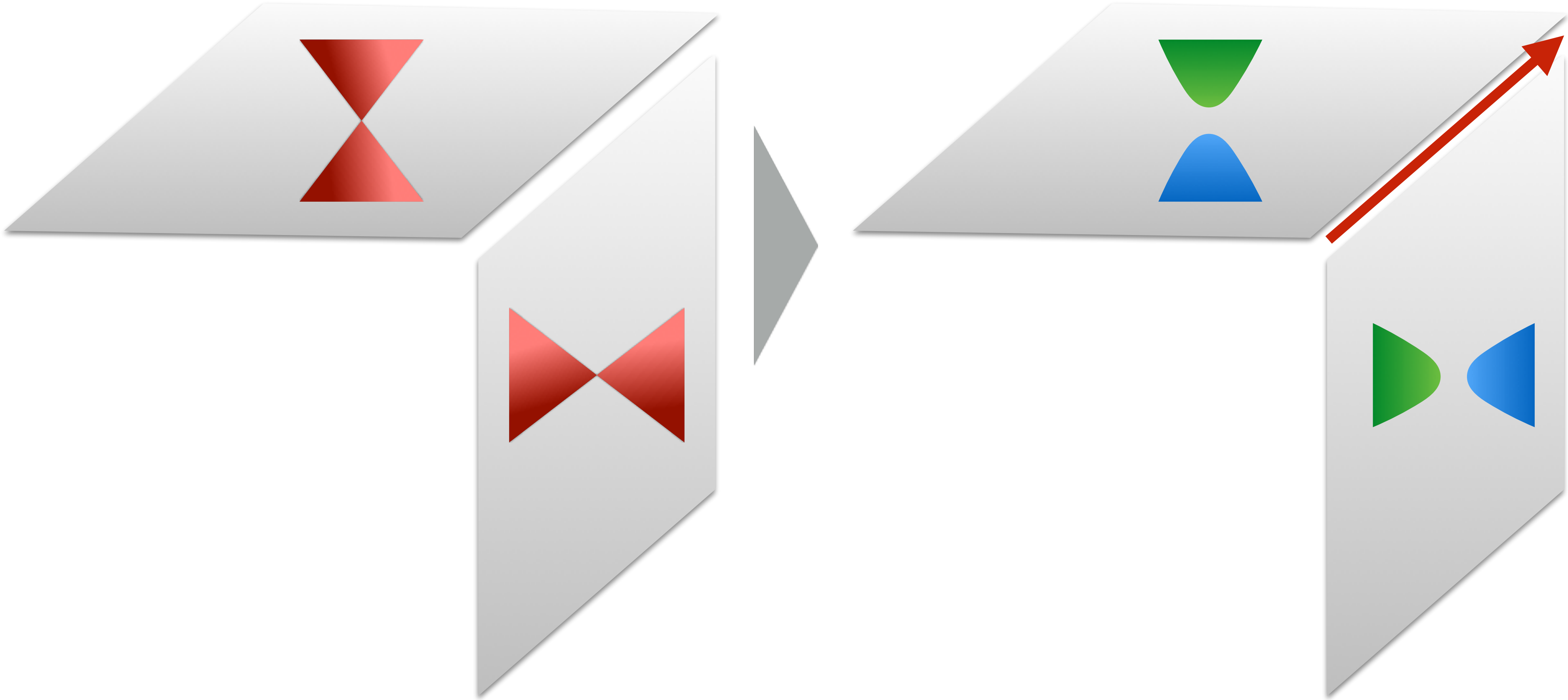
Construction of a TRB second-order order 3D TI

Toy model with only C_4T in *z*-direction

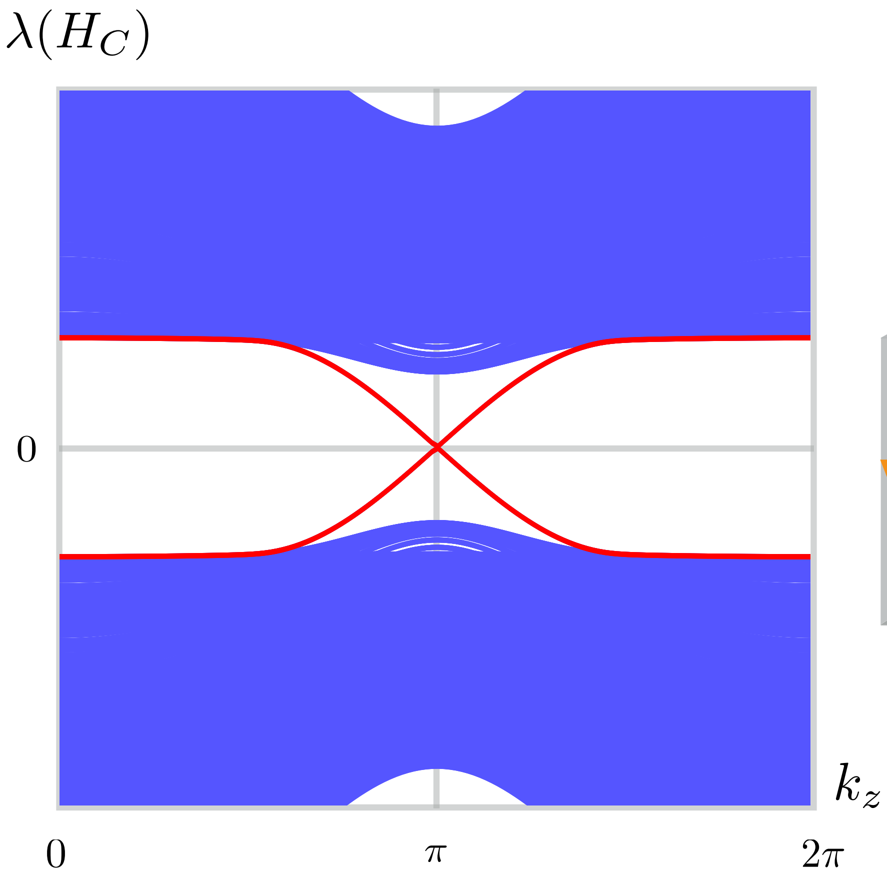
$$H_4(\vec{k}) = \underbrace{\left(M + \sum_i \cos k_i\right) \tau_z\sigma_0 + \Delta_1 \sum_i \sin k_i \, \tau_y\sigma_i}_{\text{3D TI}} + \underbrace{\Delta_2(\cos k_x - \cos k_y)\, \tau_x\sigma_0}_{\text{T, } C_4 \text{ breaking term}}$$

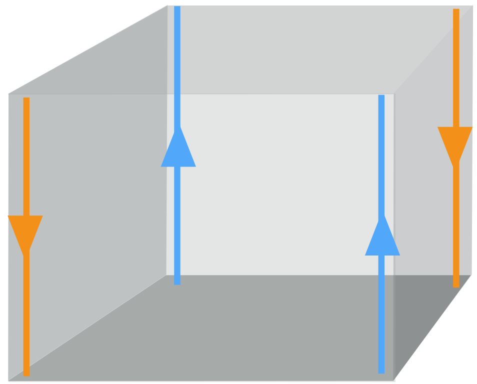
C_4T is still preserved!

Construction of a TRB second-order order 3D TI



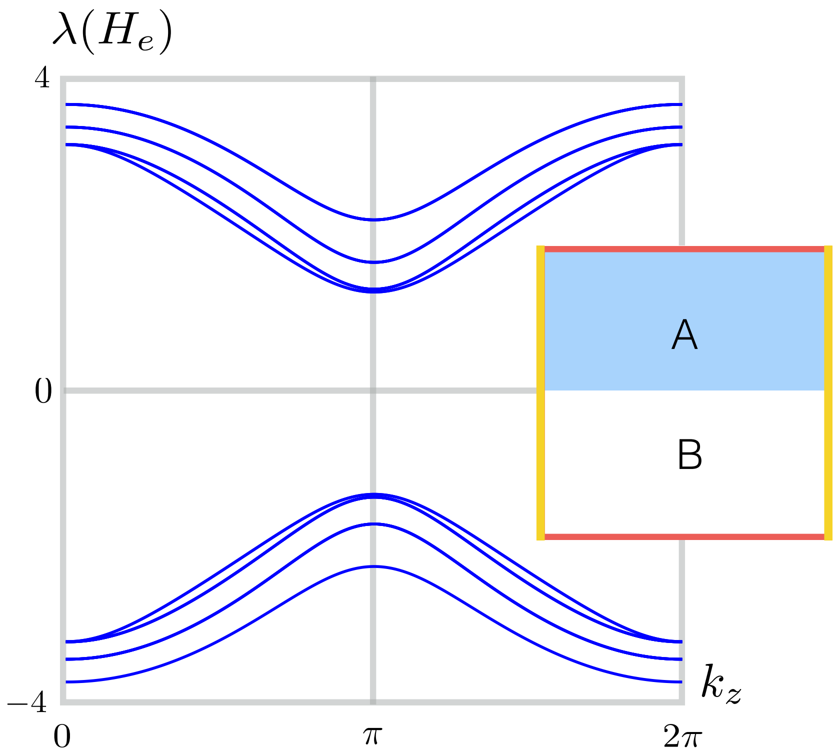
Spectrum in column geometry





Nested entanglement spectrum

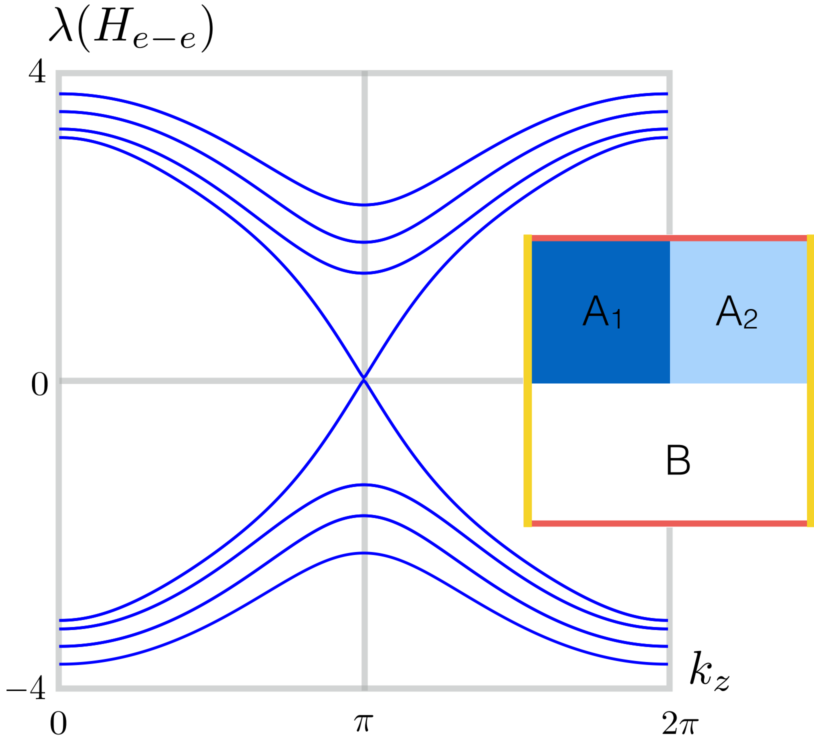
$$\rho_A = \mathrm{Tr}_B |\Psi\rangle\langle\Psi| \equiv \frac{1}{Z_\mathrm{e}} e^{-H_\mathrm{e}}$$



Nested entanglement spectrum

Define: entanglement spectrum of entanglement Hamiltonian

$$\rho_{\mathrm{e};A_1} = \mathrm{Tr}_{A_2} |\Psi_\mathrm{e}\rangle\langle\Psi_\mathrm{e}| \equiv \frac{1}{Z_{\mathrm{e-e}}} e^{-H_{\mathrm{e-e}}}$$



Take-Home Message

new paradigm for hierarchical topological phases protected by spatial symmetries

- edge modes protected by a 3D bulk invariant
- single edge has same properties as that of QSHE or QHE
- possibility of lossless transport in an intrinsically 3D system