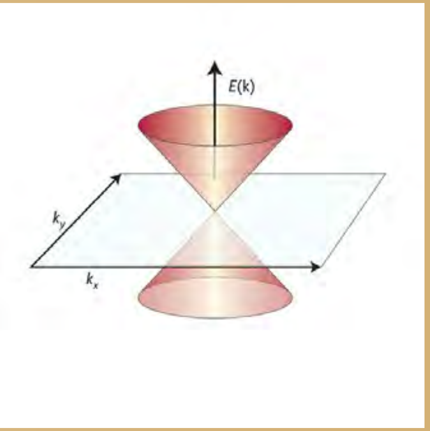
Weyl physics in superconducting junctions



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Outline

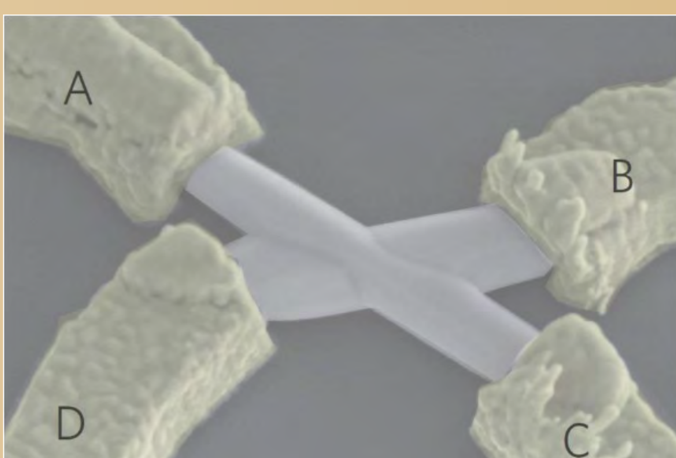
- MultiTerminal Superconducting Junctions
- MTSJ as (topological) material
- Weyl singularities in 4-terminal junction
- From 3D to 2D –flexible dimensionality
- Trasconductance quantization
- Vicinity of the singularity
  - Spin-orbit – spintronics!
  - Tricky interaction effect: from cones to pancakes

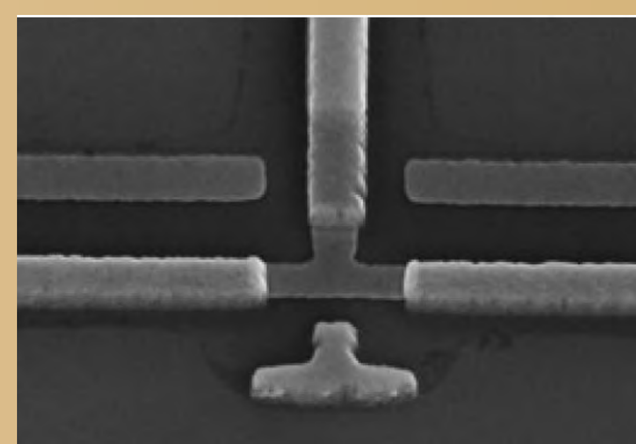
Multi-terminal superconducting junctions

- Josephson junction(2 terminals) $E = -E_J \cos\varphi$
- More transparent – Andreev bound states
- $E = -\frac{1}{2}\sum_p E_p$ $\quad E_p = \Delta\sqrt{1 - T_p \sin(\varphi/2)^2}$
- More terminals – more superconducting phases

$$E_p(\phi_1, \cdots, \phi_{n-1})$$

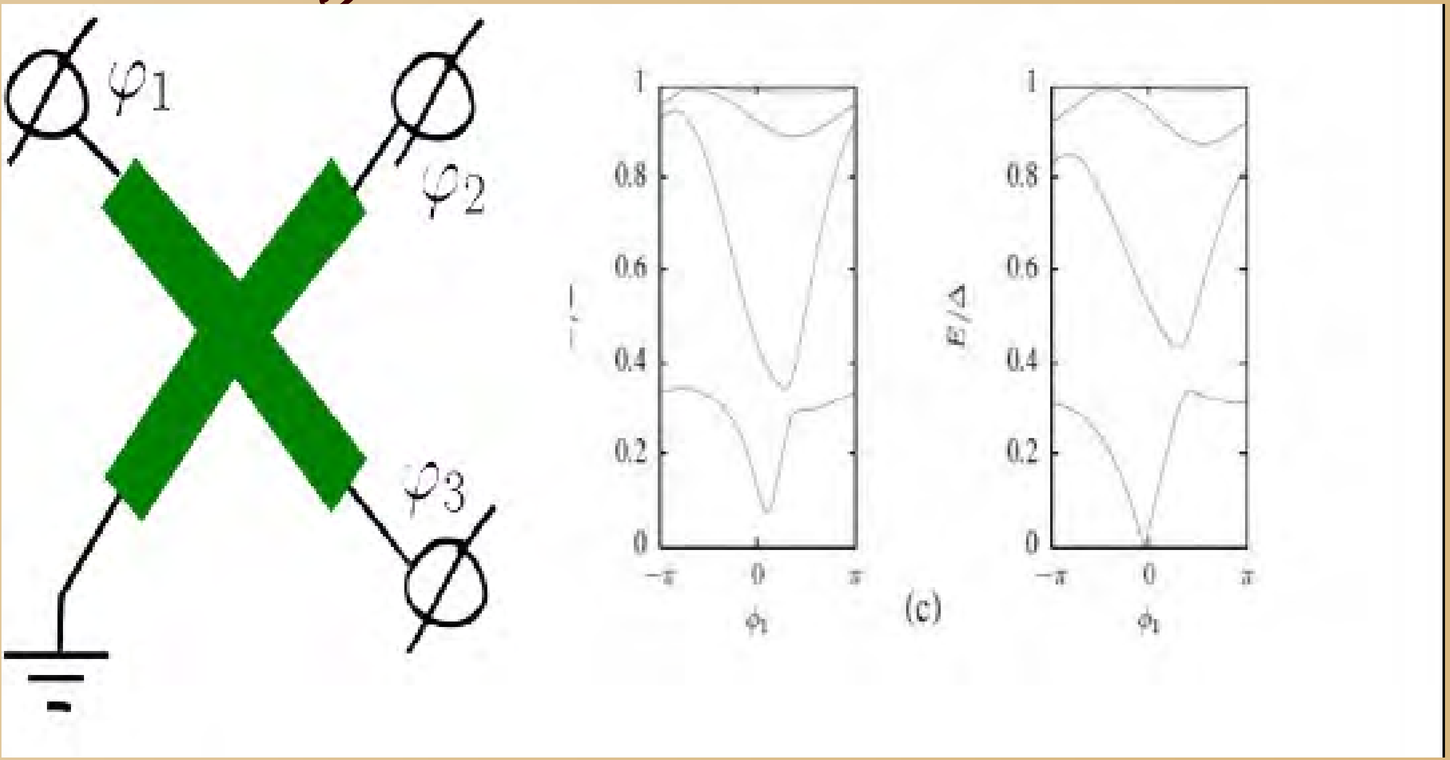
- same Andreev states





The analogy: junction – material

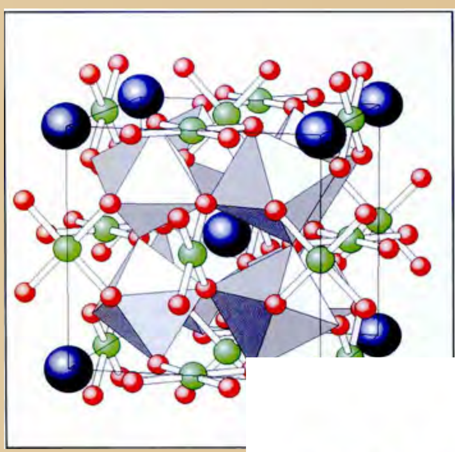
$$q_x, q_y, q_z \leftrightarrow \varphi_1, \varphi_2, \varphi_3$$



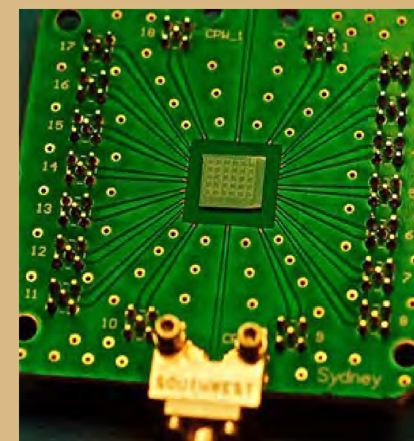
- Incomplete
  - Gap edge, continuous spectrum
  - Filling: all quasimomenta, phases - one

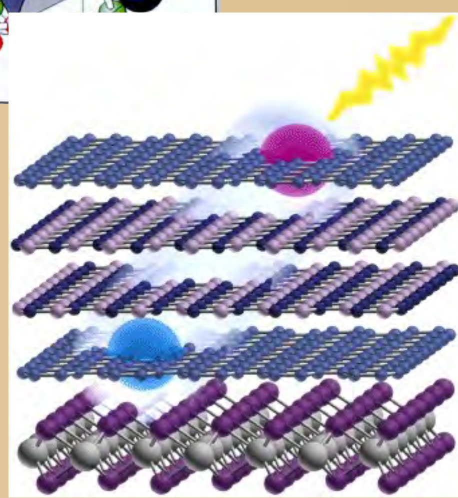
Breaktrough to higher dimensions

material



device





Nanodevice (multi-terminal sup.jun)

material : say, 5 d

Weyl singularity

- Massless particle with conical spectrum
- A missed paragraph in Landau and Lifshitz: Levels or bands do cross in 3-D parametric space
- In the vicinity of the crossing point: $\hat{H} = v_F \vec{\tau} \cdot \vec{p}$
- Occurrence in materials – **recently proved**
- **A monopole of the Berry curvature field -topstable**
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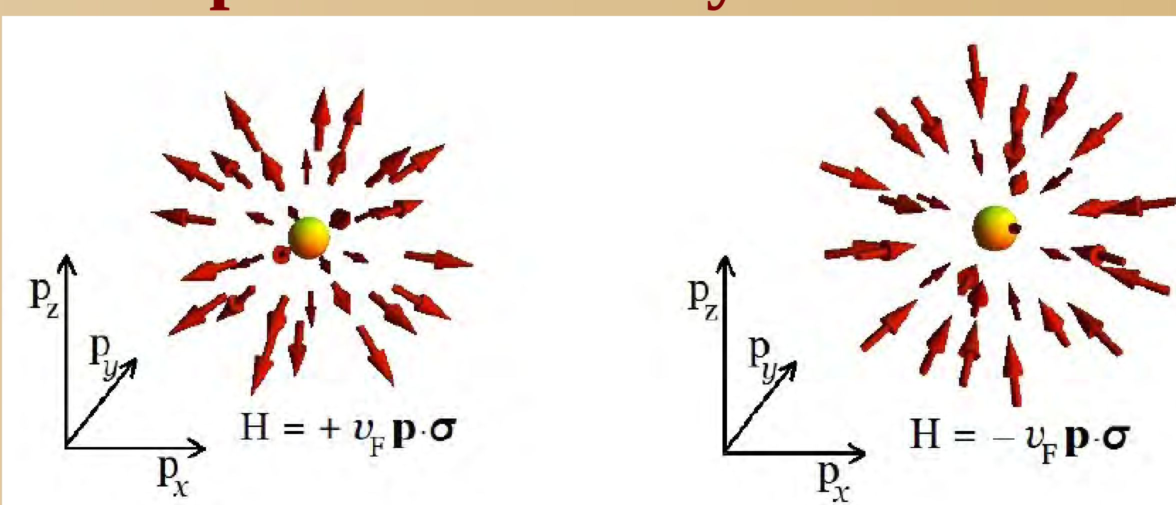
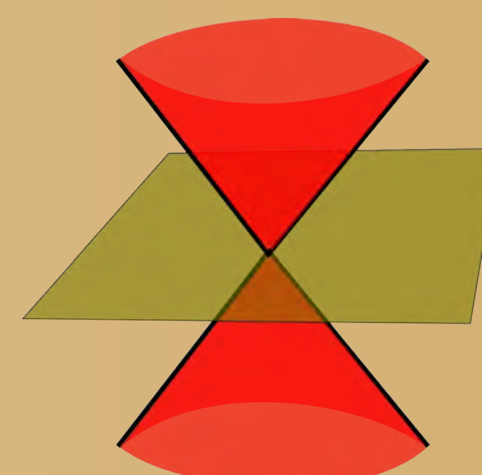
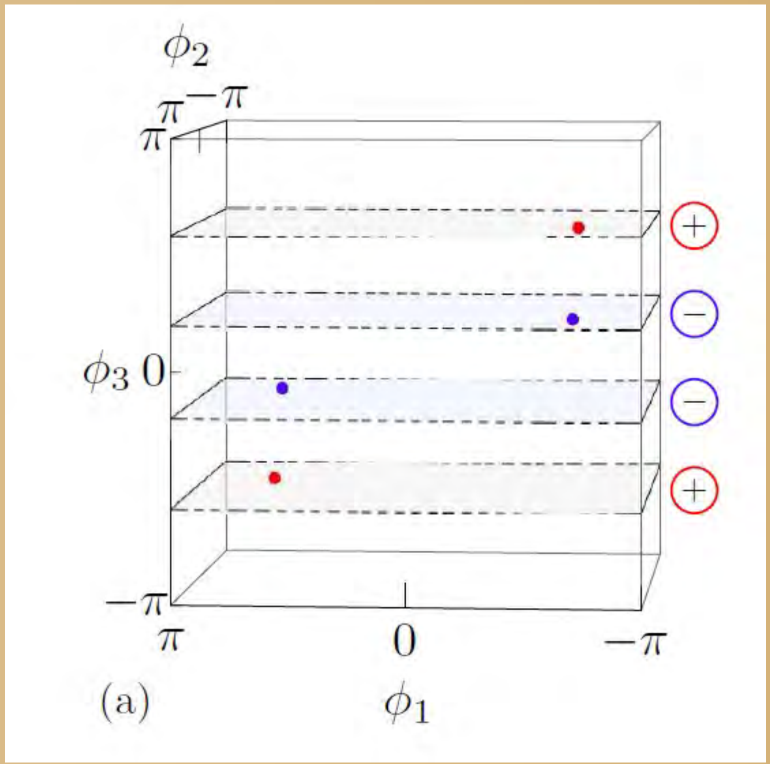


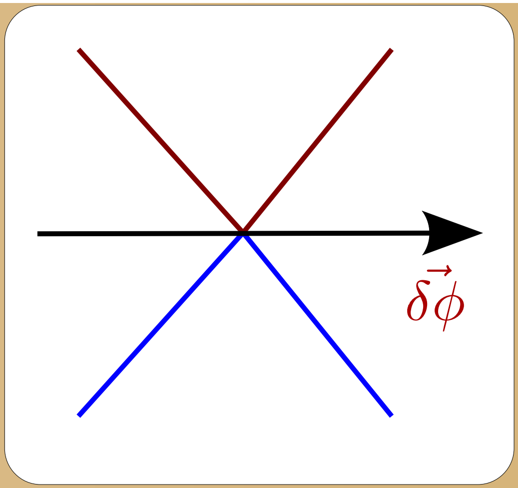


Weyl singularity in 4-terminal superjunctions

- At zero energy – important
- Three fields – three parameters – three phases – one-goal game?
- Beenakker formula – from scatt.matrix
- Come in pairs of 4
- (+ - charges and inversion (time-reversal) symmetry)



$$\hat{H} = I\vec{\tau} \cdot \delta\vec{\phi}$$

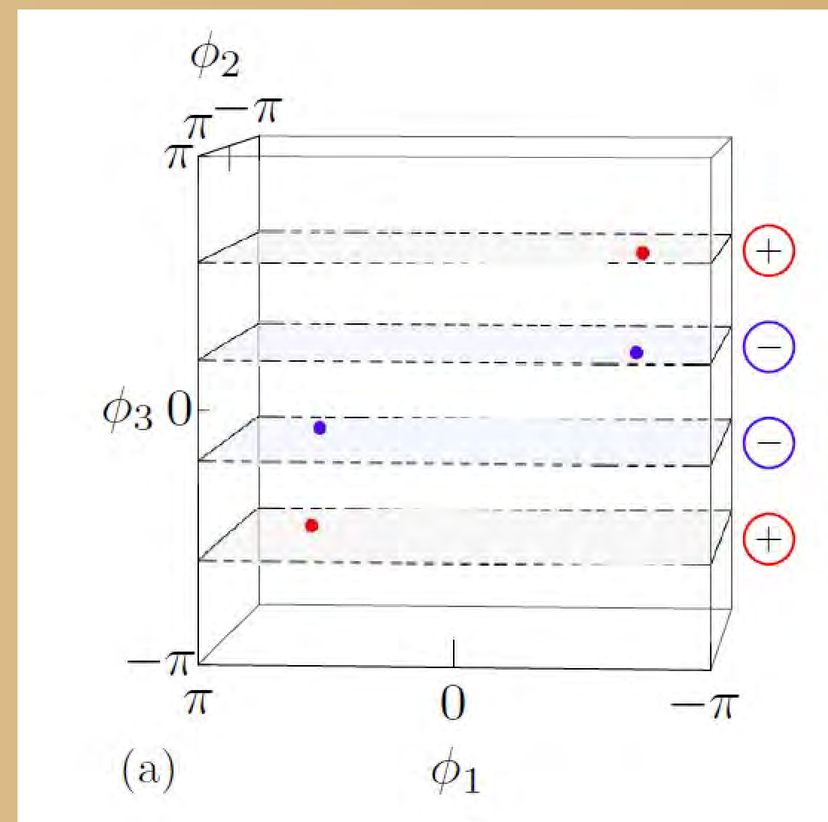


From 3D to 2D

- Flexibility of dimensions
- 2D bandstructure – a moving plane
- φ_3 – control parameter
- Plane passes a W.S =
- Change of Chern number
- Topologically non-trivial

  2D material

- Tunable by φ_3



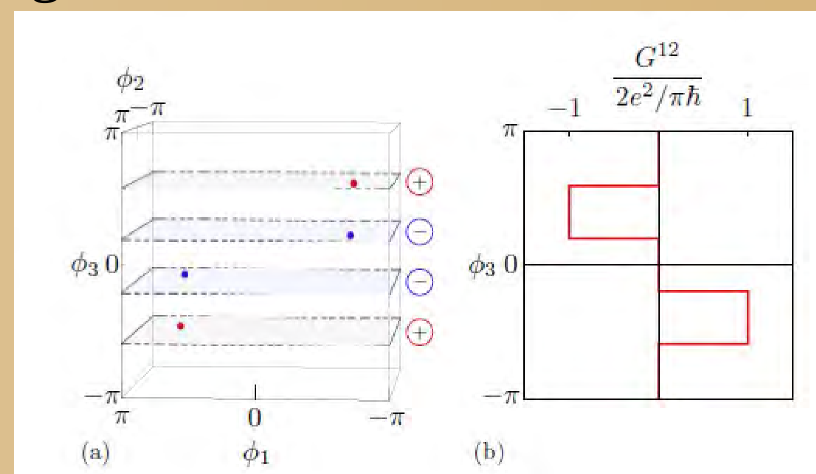
Transconductance quantization

- Berry curvature and ad.transport
- Sensitive to the local Berry curvature
- Apply (incommensurate) voltages
- Phases are swept over BZ
- Sup.current vanishes
- What remains?

$$I_\alpha(t) = \frac{2e}{\hbar}\frac{\partial E}{\partial \phi_\alpha} - 2e\dot{\phi}_\beta B^{\alpha\beta}$$

Leading order

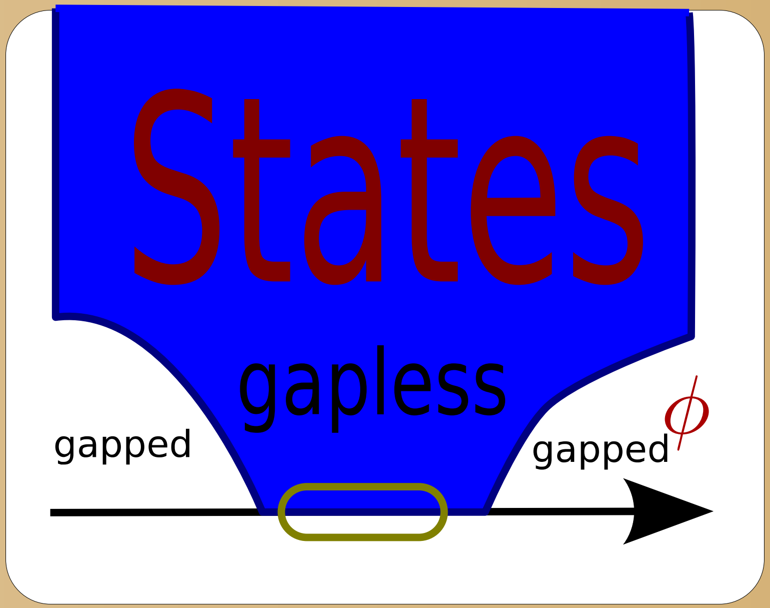
First correction

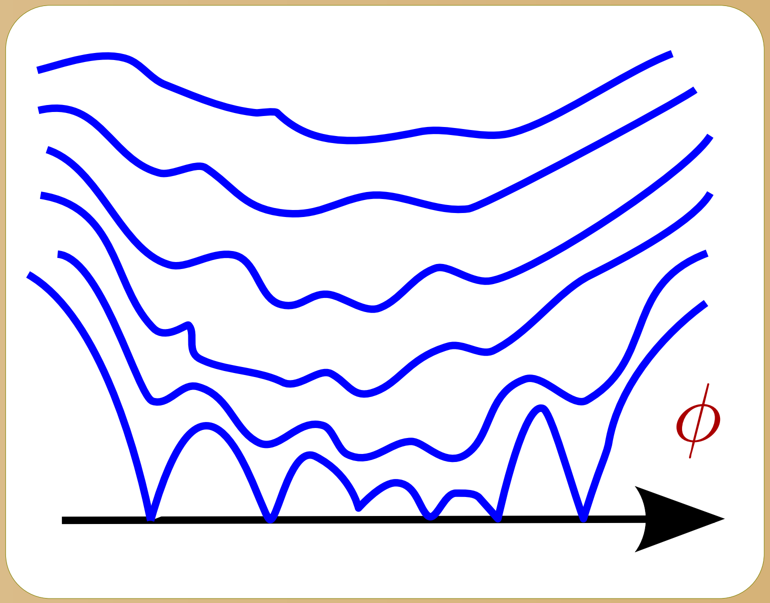


$$I_1 = G_{12}V_2;\ I_2 = -G_{12}V_1;\ G_{12} \equiv (2e^2/\pi\hbar)C$$

Semiclassical structures

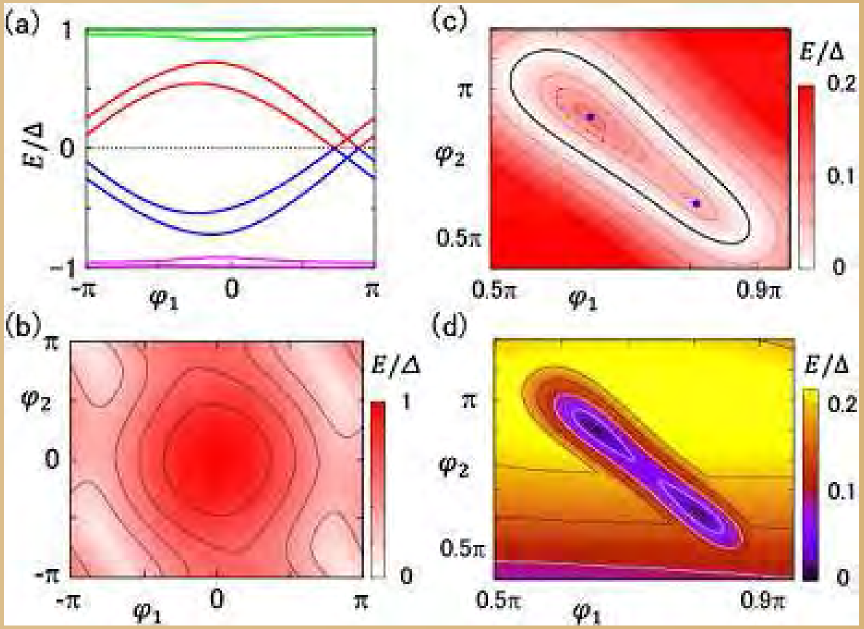
- Many channels
- Quasi-continous spectrum
- Gapped and Gapless phases
- Gappless – a vault of Weyl singularities





In the vicinity

- Spin-orbit and spintronics
- interaction

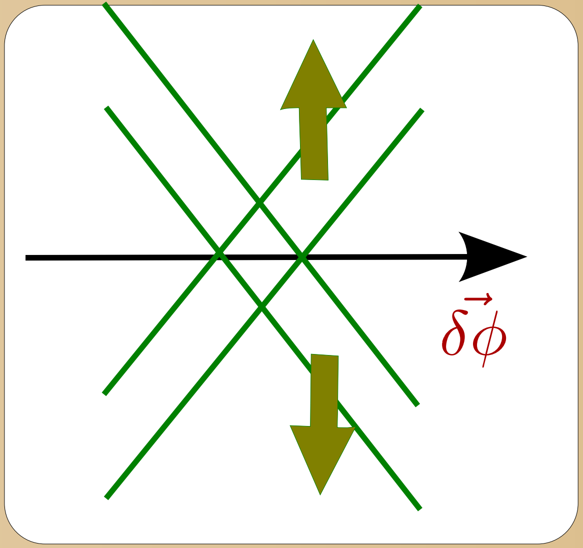


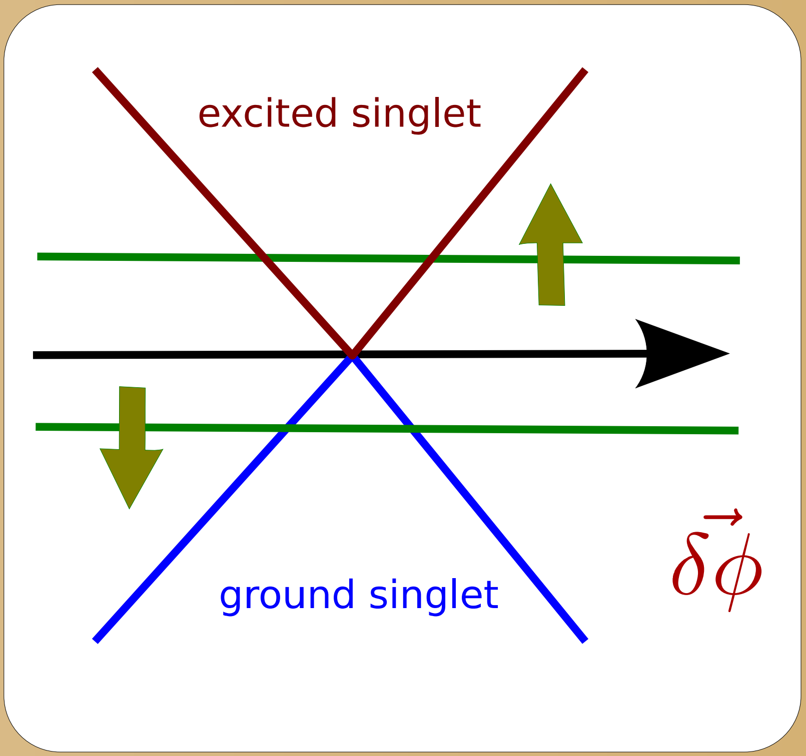
SO = spin splitting

- Since there is no time reversibility,

$$\hat{H} = I\vec{\tau}\cdot\delta\vec{\phi} + \vec{\sigma}\cdot\vec{B}$$

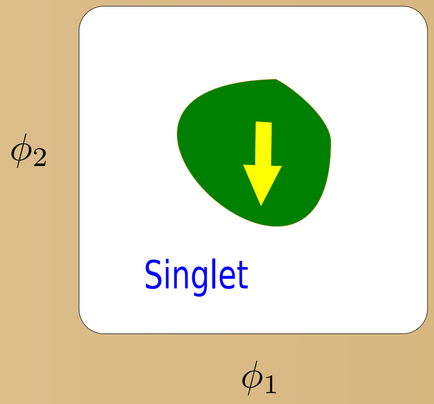
- Spin-split cone or flat spinful states
- Weyl singularity departs(?) from zero energy

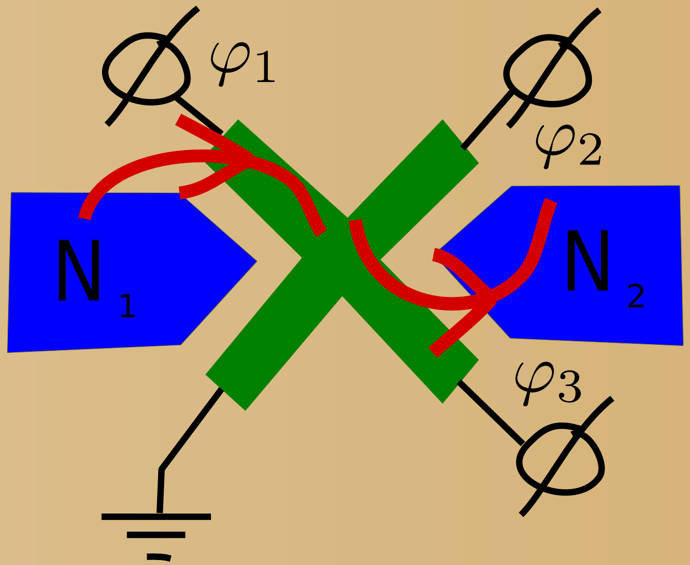




Spintronics

- Magnetic state in the vicinity
- Normal lead is needeed for equilibration
- With 2: spin filter driven by tiny phase differences

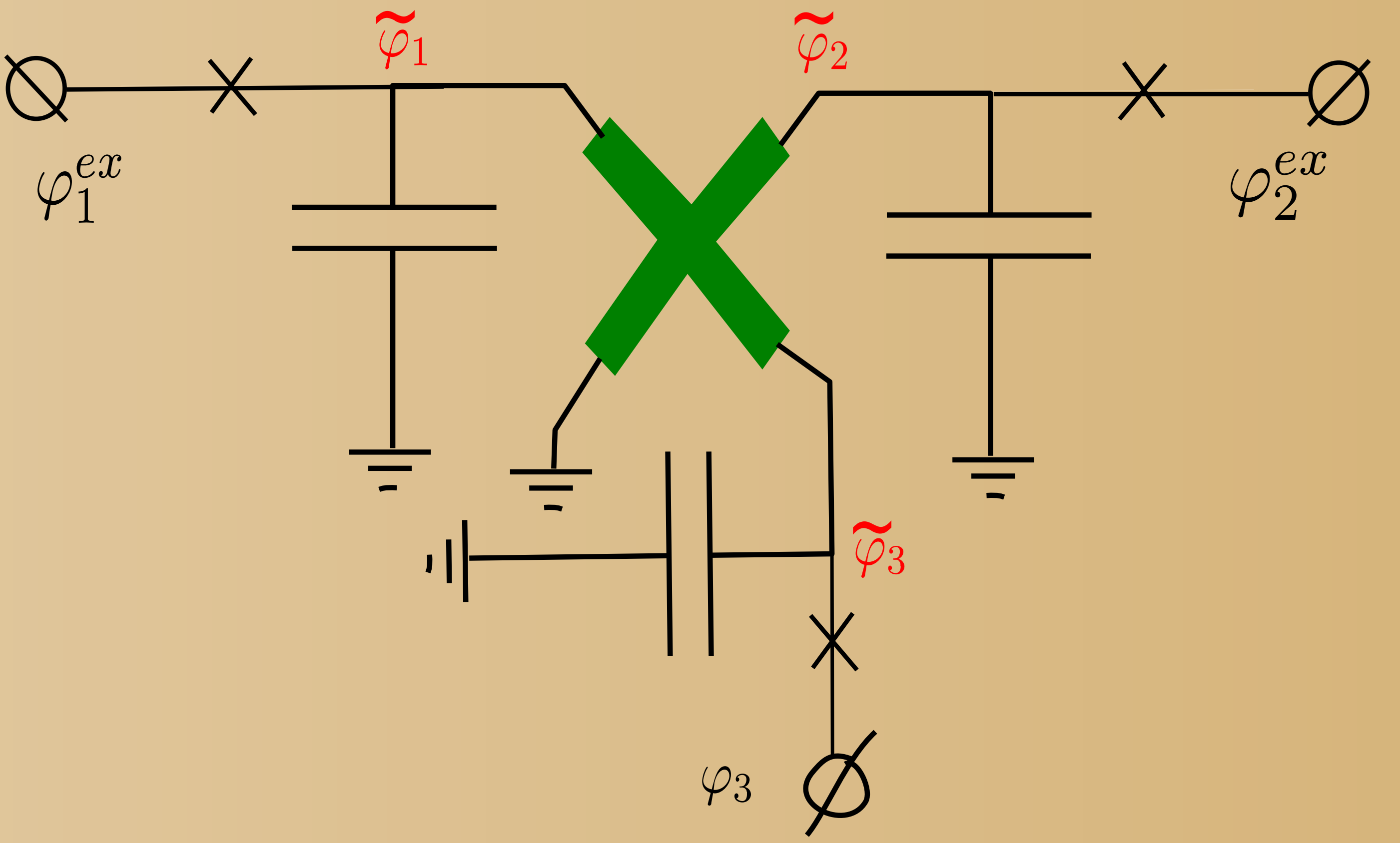




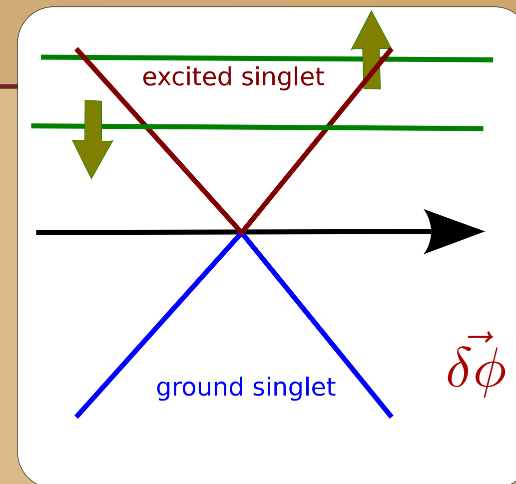
Interaction? Interaction!

- Deviations and fluctuations of the phases

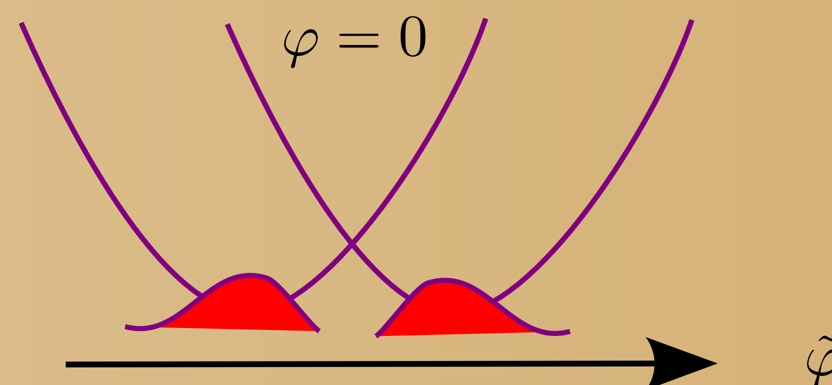
$$\hat{H} = \sum_k E_k^J \frac{\left(\varphi_k - \tilde{\varphi}_k\right)^2}{2} + E_k^C \frac{\tilde{q}_k^2}{2}$$



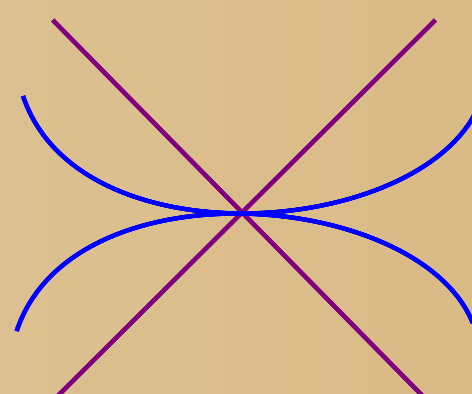
What does the interaction do?



- Conical point survives :)
- Even states are favoured
- Small quantum fluctuations
  - Strongly anistotropic cone
  - 2D region of almost degenerate levels:



pancake



Conclusions

- Weyl physics – in MSJ
  - Higher (flexible) dimensions
  - Superconducting QHE
- In the vicinity of the singularity
  - Spintronics
  - pancake
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