Diffusion of semi-Dirac excitations

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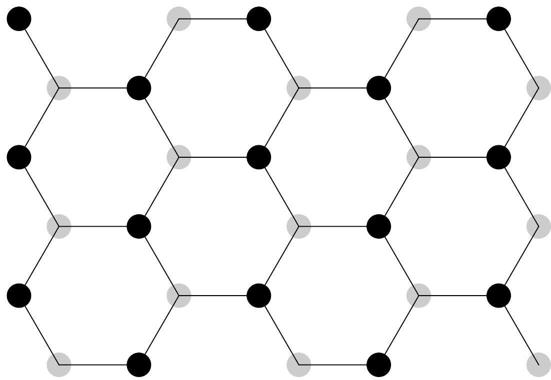
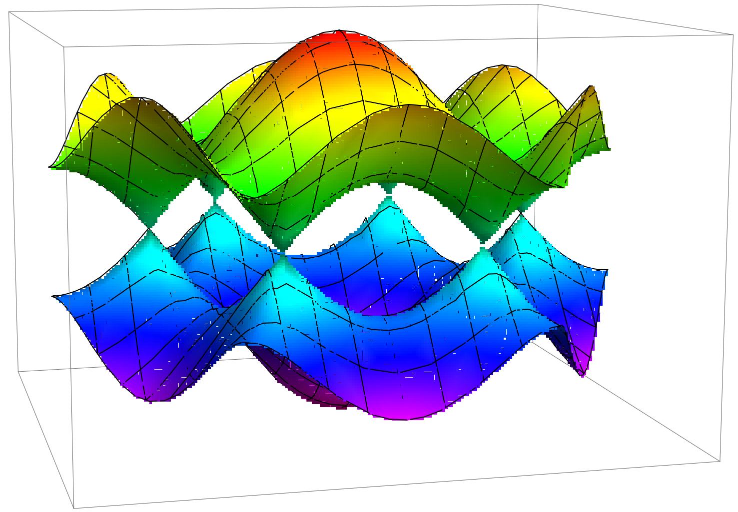
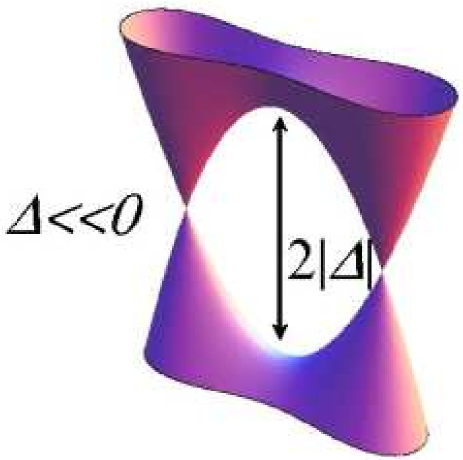
Semi-Dirac excitations

- Hexagonal lattice (graphene)

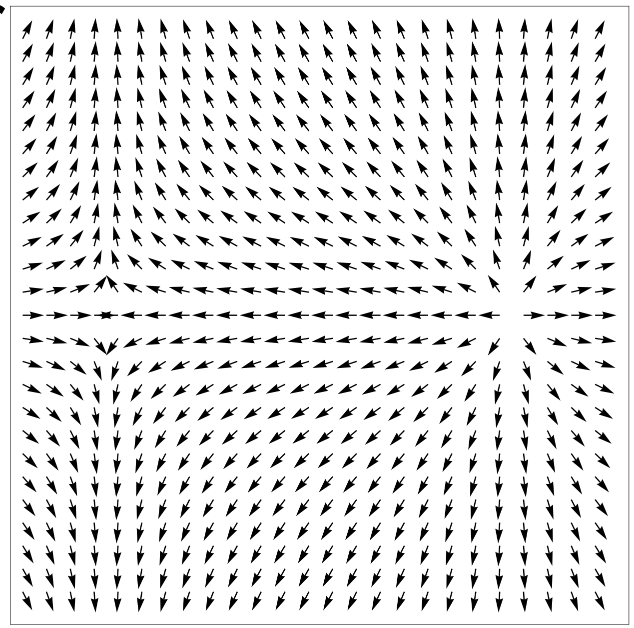




- 2 Dirac fermions, with topologic number



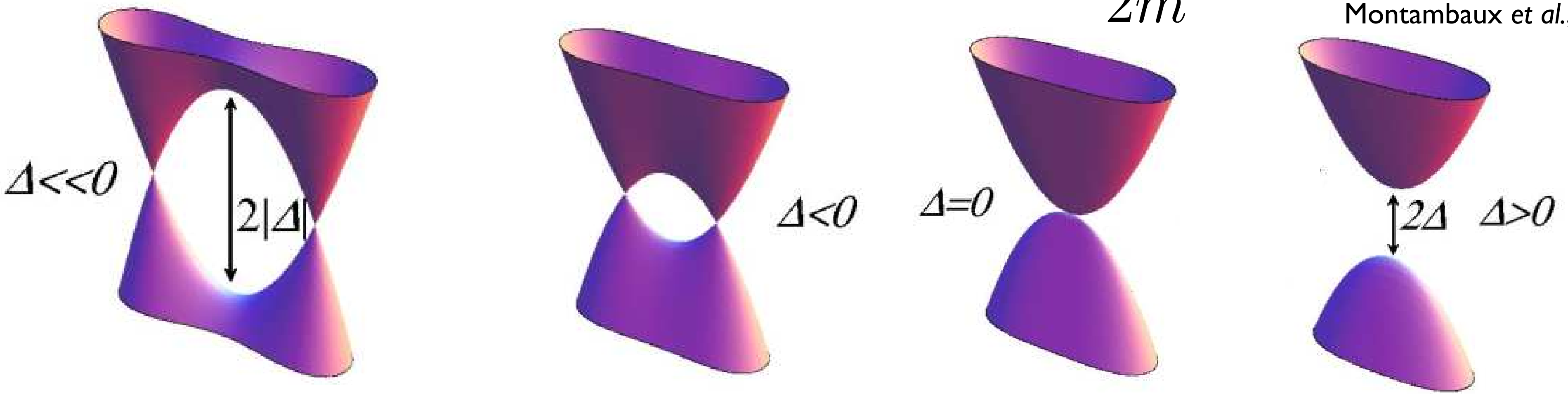
$$\mathcal{H} = \hbar v_F \vec{\sigma}.\vec{q}$$



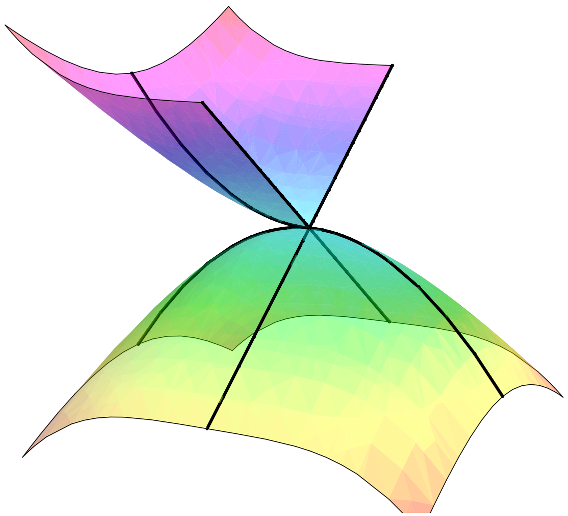
Semi-Dirac excitations

- Merging of the Dirac cones $\mathcal{H} = (\Delta + \frac{\hbar^2 q_x^2}{2m})\sigma^x + \hbar v_F \sigma^y q^y$

Montambaux *et al.*, 2009



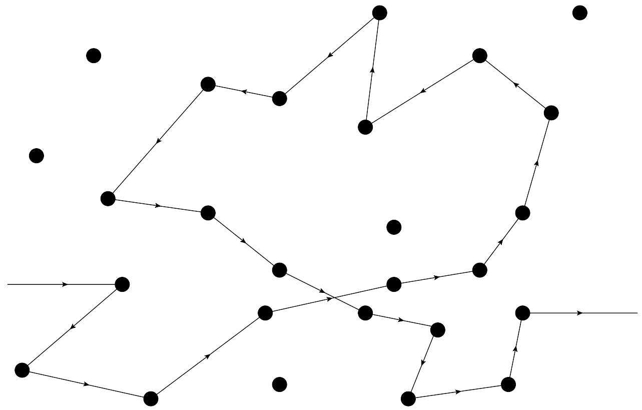
- Δ = 0 : Semi-Dirac excitation, $\mathcal{H} = \frac{\hbar^2 q_x^2}{2m}\sigma^x + \hbar v_F \sigma^y q^y$



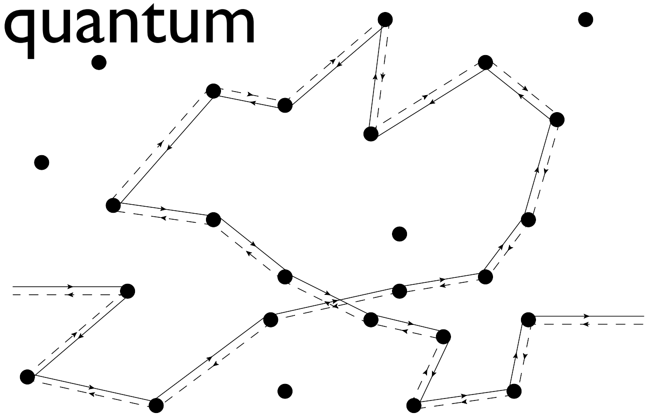
Also predited in VO_2/TiO_2 heterostructures

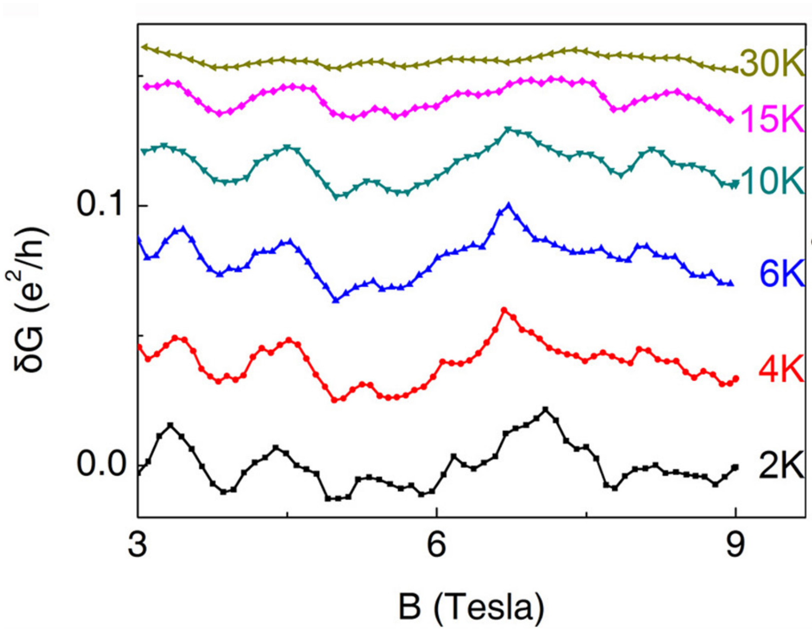
Pardo and Pickett, 2009

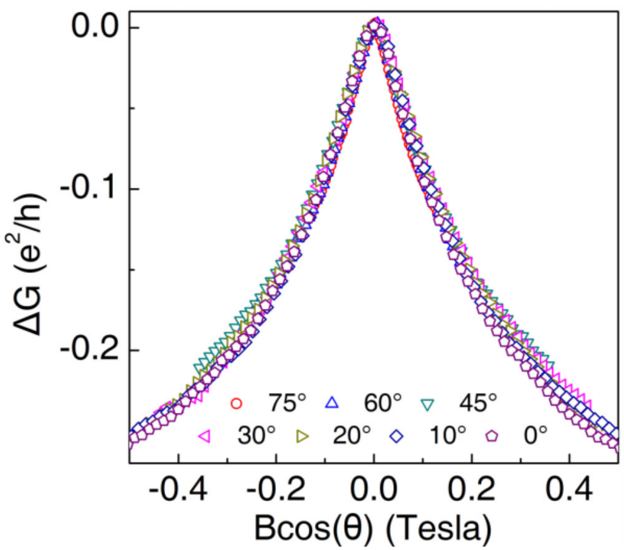
Diffusion



- Scattering processes
- Classically, $\langle \sigma \rangle \propto \sum_i p_i$
- Coherent regime, memory of the phase : quantum interferences $\delta\sigma \propto \sum_{i \neq j} a_i^* a_j$





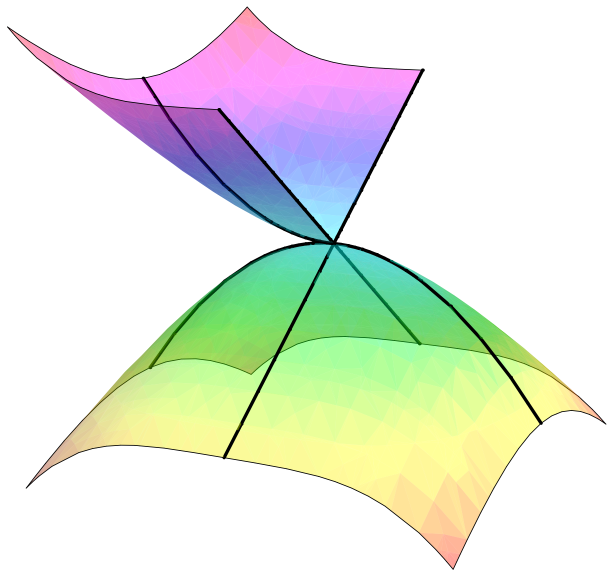


Regime of diffusive transport

- Semi classical approach, $\lambda_F \ll l_e$ (perturbative approach)
- Experimental regime : high Fermi energy (good metal)
- Hamiltonian : $\mathcal{H} = \dfrac{\hbar^2 q_x^2}{2m}\sigma^x + \hbar v_F \sigma^y q^y$

$$\langle V(\vec{r})\rangle = 0 \qquad \langle V(\vec{r})V(\vec{r'})\rangle = \gamma\delta(\vec{r}-\vec{r'})$$

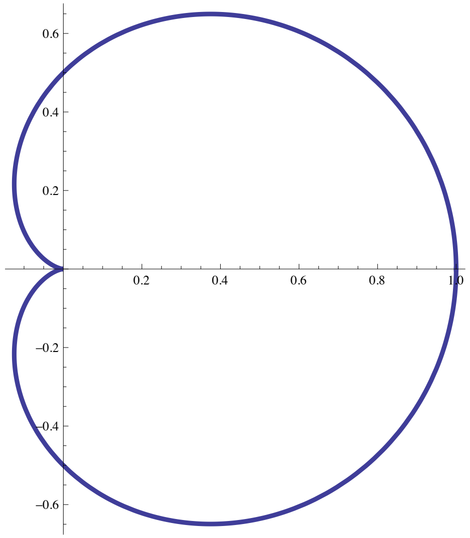
- Sample length $\gg$ mean free path l_e
- Weak disorder regime
  - Boltzmann equation
  - Diagrammatics



Boltzmann equation

- Spinorial nature : Anisotropy of the scattering

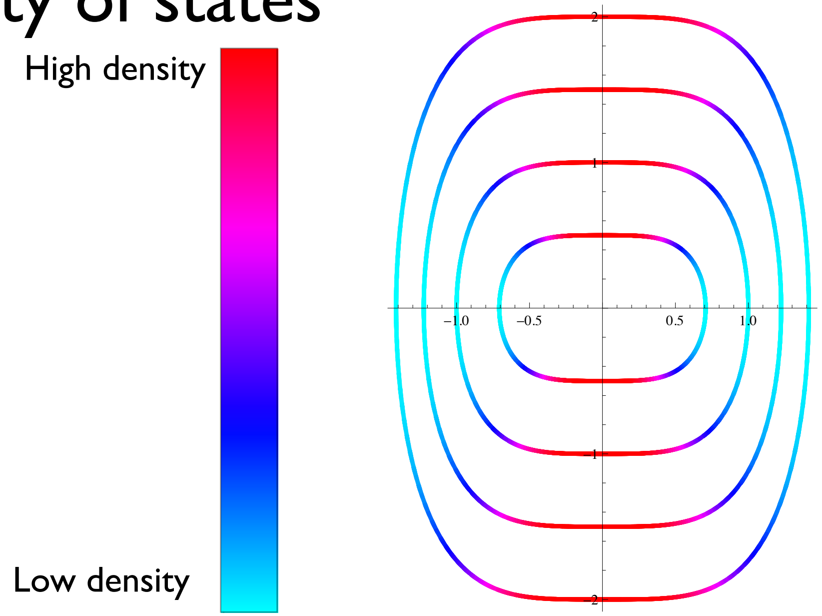
<u>Pure Dirac fermions</u>



$$|\psi(\vec{k})\rangle = \begin{pmatrix} 1 \\ e^{i\theta_{\vec{k}}} \end{pmatrix}$$

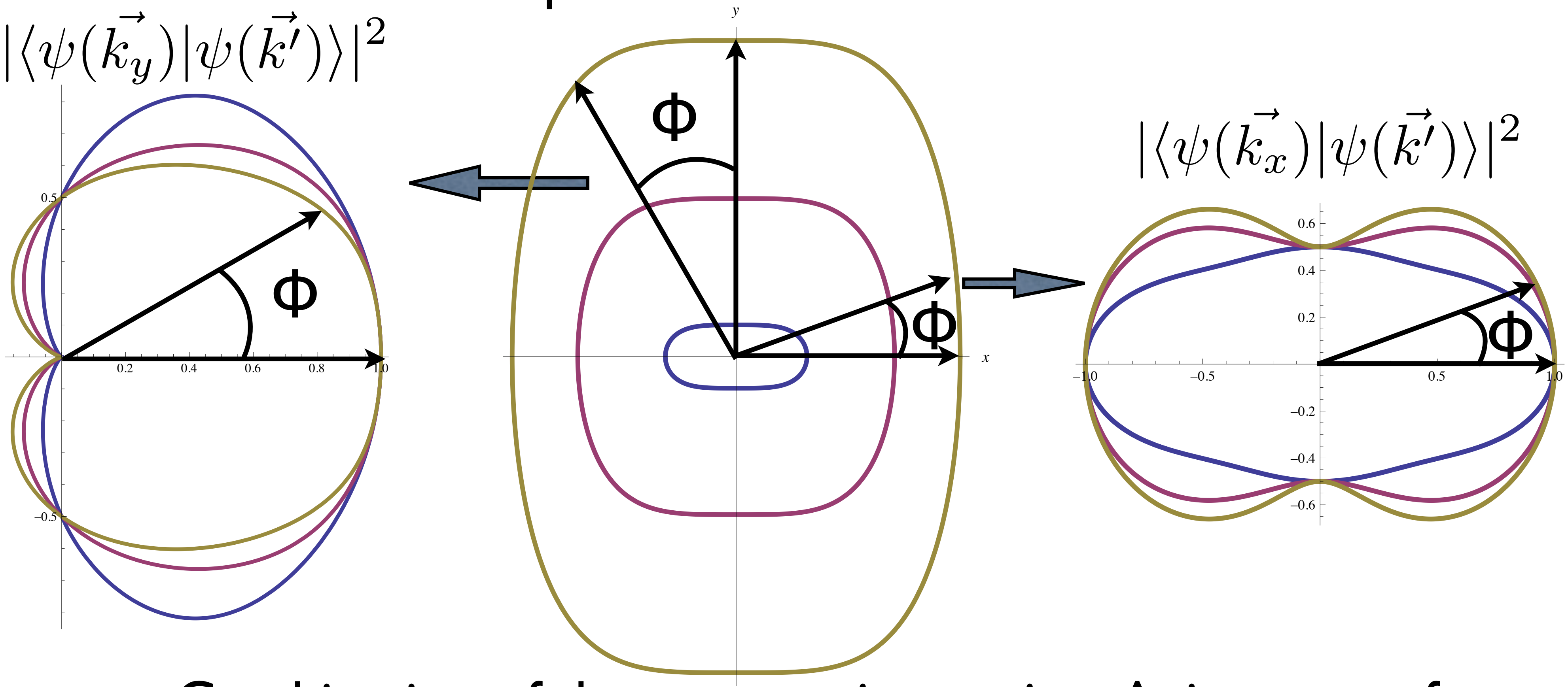
$$|\langle\psi(\vec{k})|\psi(\vec{k'})\rangle|^2 = \frac{1+\cos(\theta-\theta')}{2}$$

- Anisotropy of the density of states



Boltzmann equation

- Stronger anisotropy of the scattering for semi-Dirac excitations compared to Dirac fermions



- Combination of these two anisotropies : Anisotropy of the diffusion $D_x \neq D_y$

Diagrammatics

- Direction dependant elastic mean free time

$$-\Im\Sigma = \frac{1}{\tau_e} Id + \frac{\cos\theta}{\tau_e^*}\sigma^x$$

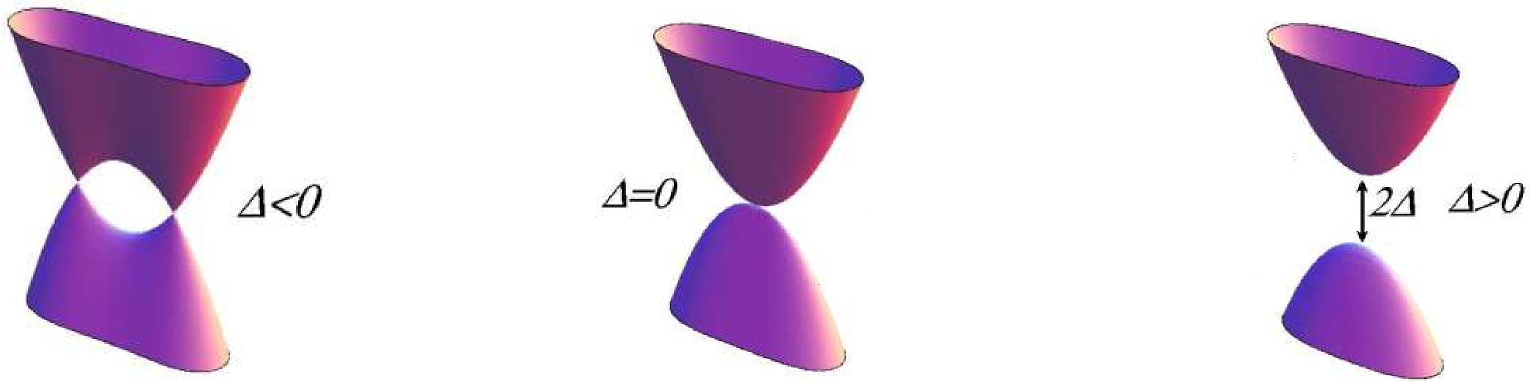
- 2 diffusive modes, 1 diffuson and 1 cooperon
- Drude conductivity tensor

$$\sigma_{xx} = \frac{e^2}{h}\frac{2E\hbar^2}{m\gamma}\frac{2e}{\tilde{a}} \qquad \sigma_{yy} = \frac{e^2}{h}\frac{\hbar^2 v_F^2}{\gamma}\frac{2c}{\tilde{a}} \qquad \sigma_{xy} = \sigma_{yx} = 0$$

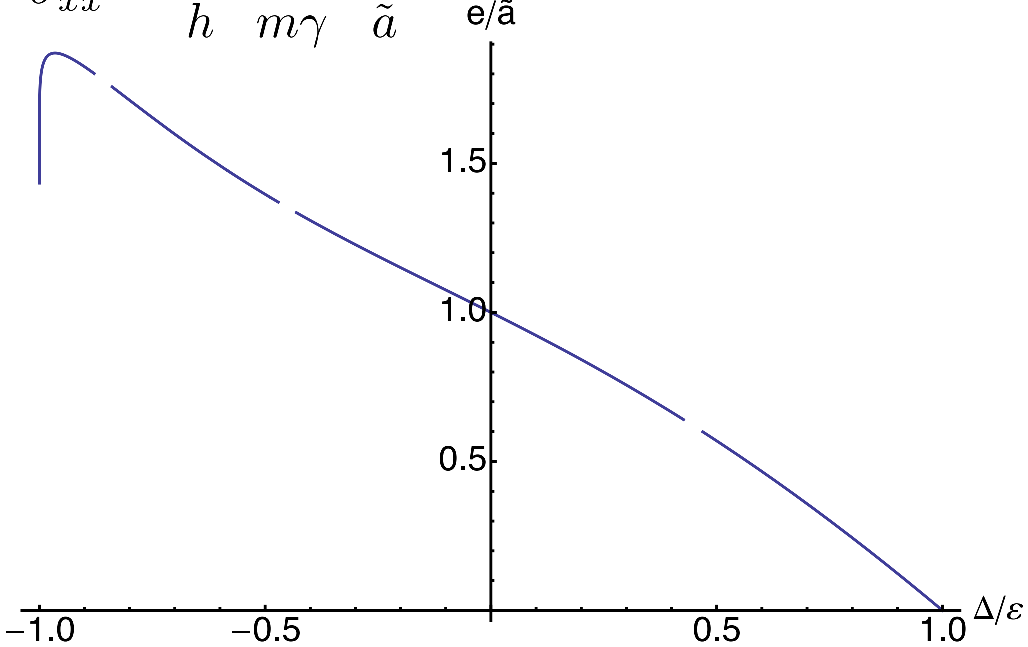
- Weak anti-localization (Quantum interferences)

Topological phase transition

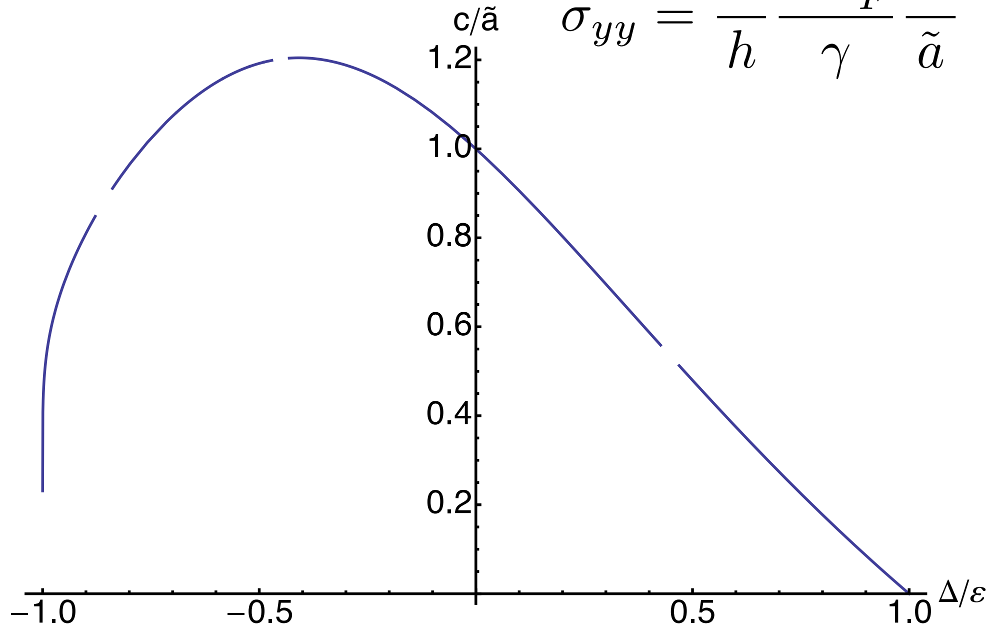
- Dependance in Δ of the conductances



$$\sigma_{xx} = \frac{e^2}{h}\frac{2E\hbar^2}{m\gamma}\frac{2e}{\tilde{a}}$$

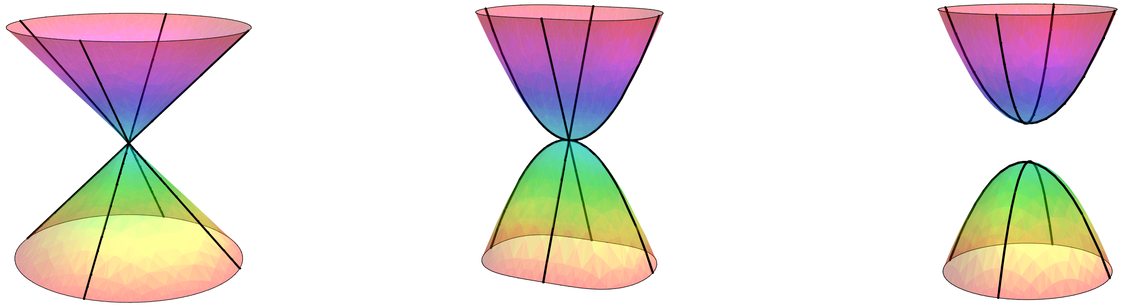


$$\sigma_{yy} = \frac{e^2}{h}\frac{\hbar^2 v_F^2}{\gamma}\frac{2c}{\tilde{a}}$$

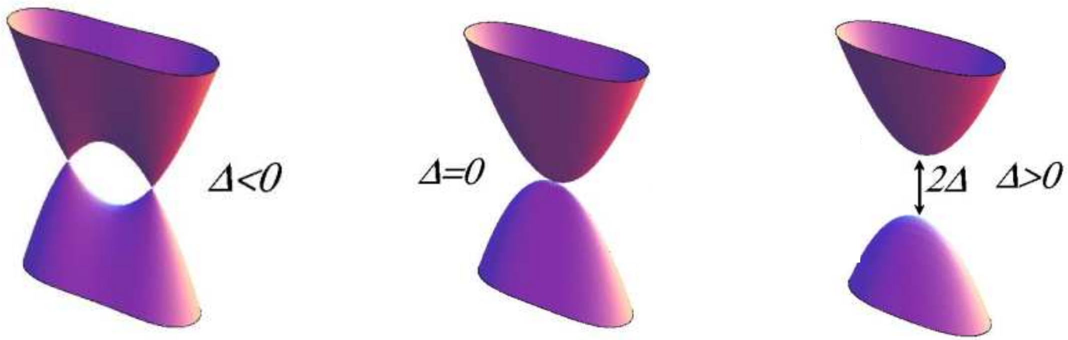


Conclusion

- Significative difference with Dirac or non-relativistic excitations : anisotropic diffusion



- Study of the topological phase transition



- Weak antilocalization (symplectic class)
- Details soon on ArXiv