Quantum Magneto-transport in topological insulators with higher momentum contribution

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Abstract:

In this work we study the ultra-thin topological insulator (TI) placed in quantizing magnetic field with quadratic momentum contribution. We calculate the Landau-level (LL) spectrum, Hall conductivity and density of states (DOS) with the hybridization gap between top and bottom surfaces and Zeeman splitting. We show that with quadratic momentum term dispersion is not particle-hole symmetric which has significant consequences on the magneto-transport of the system. We calculate density of states and conductivity tensor using Kubo-formula. We observe that deviation from particle-hole symmetric behavior depend on the ratio of m/m_e. As $m\rightarrow\infty$, the system behaves as pure Dirac, whereas for small m Schrodinger behavior in transport properties is dominant. We explore that by the interplay of Zeeman and Hybridization energy, as the strength of magnetic field is increased the nature of n=0 LL is changed, due to this a quantum phase transition occur from a normal insulator state to a topological insulator state. The quadratic momentum term introduces new properties to the structure of Landau-level such as LL crossings.

Model:

Hamiltonian: $H = \int dr \psi^\dagger(r)(\frac{\hbar^2 k^2}{2m} + \hbar v_f \tau_z (z\times\sigma)\cdot p + \sigma_z\Delta_z + \Delta_t \tau^x)\psi(r)$

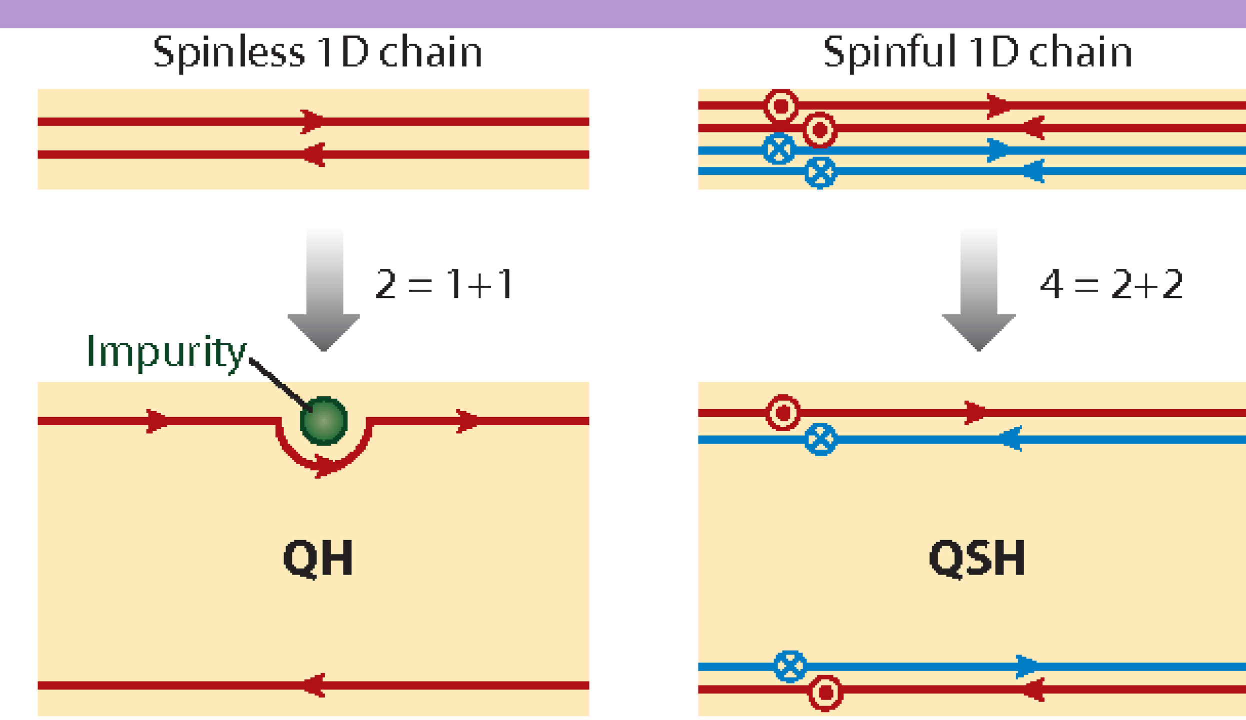
Eigen value: $E_{n\alpha s} = \frac{1}{2}[2n\omega_o + \alpha\sqrt{(2s(\Delta_t + s\Delta_z) - \omega_o)^2 + 8n\omega_b^2}]$

Eigen vector: $U_{n\alpha s} = [\frac{-1}{2} i\alpha s f_{n\alpha s+}\,, \frac{-1}{2} s f_{n\alpha s-}\,, \frac{-1}{2} i\alpha f_{n\alpha s+}\,, \frac{1}{2} f_{n\alpha s-}]$

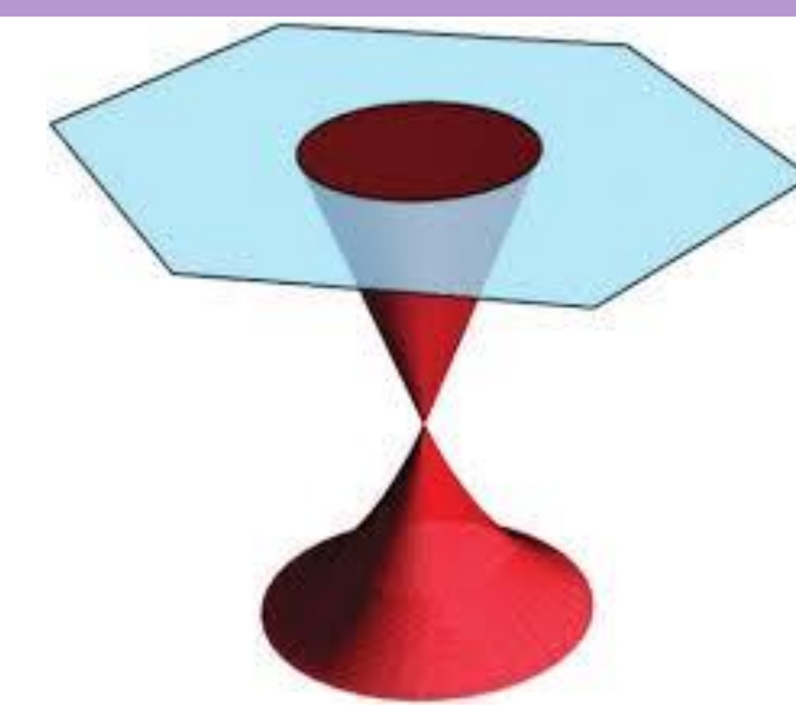
Density of states: $D(E_f) = \Sigma \frac{\Gamma}{(E_f - E_{n\alpha s})^2 + \Gamma^2}$

Hall Conductivity: $\sigma_{xy} = \frac{1}{2\pi l_b^2}\Sigma_{n\alpha s}\, Im\, [\langle n\alpha s|J_x|n'\alpha' s'\rangle * \langle n'\alpha' s'|J_y|n\alpha s\rangle] \frac{n_f(E_{n\alpha s}) - n_f(E_{n'\alpha' s'})}{(E_{n\alpha s} - E_{n'\alpha' s'})^2}$

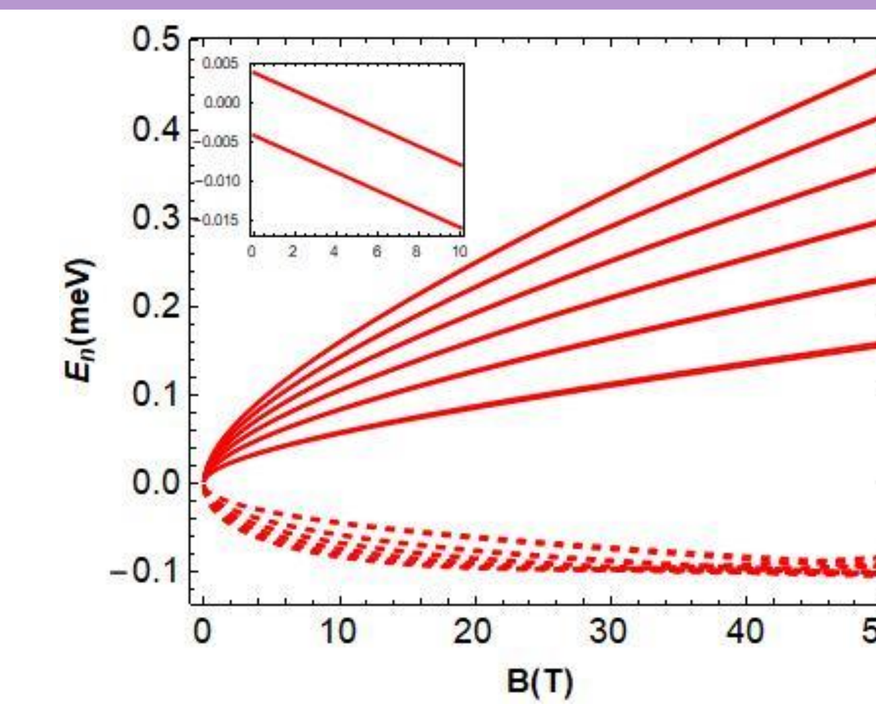
Collisional conductivity: $\sigma_{xx}^{col} = \frac{k_B T e^2}{L_x L_y}\Sigma_{\xi\xi'} f_\xi (1 - f_\xi) W_{\xi\xi'} (x_\xi - x_{\xi'})^2$



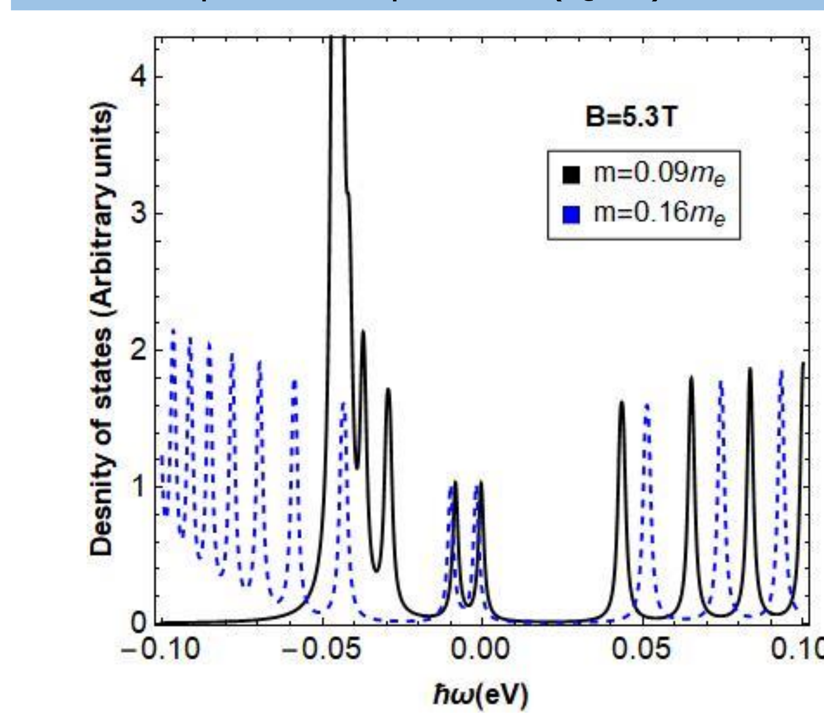
Spatial separation for the quantum Hall (QH) and the quantum spin Hall (QSH) effects.



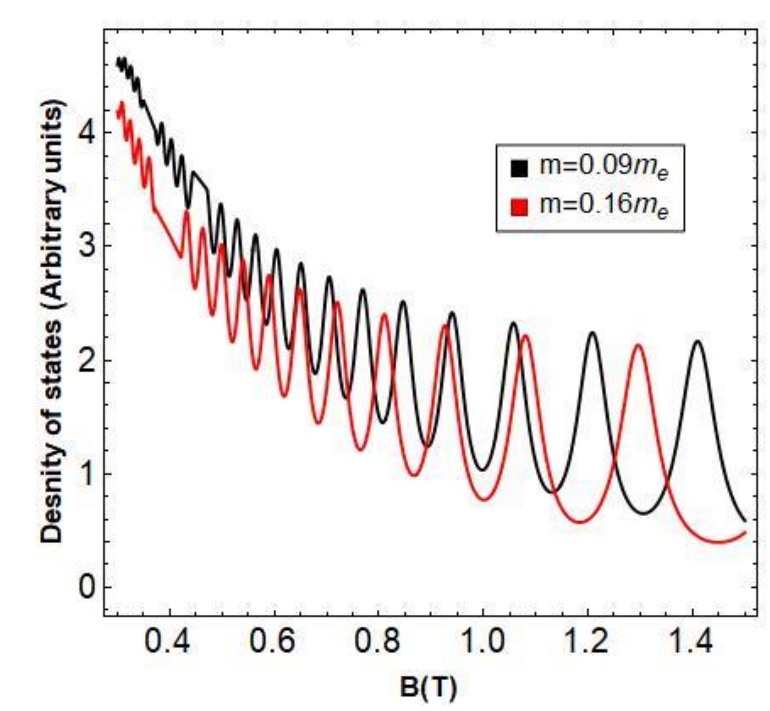
Schematic of Dirac cone



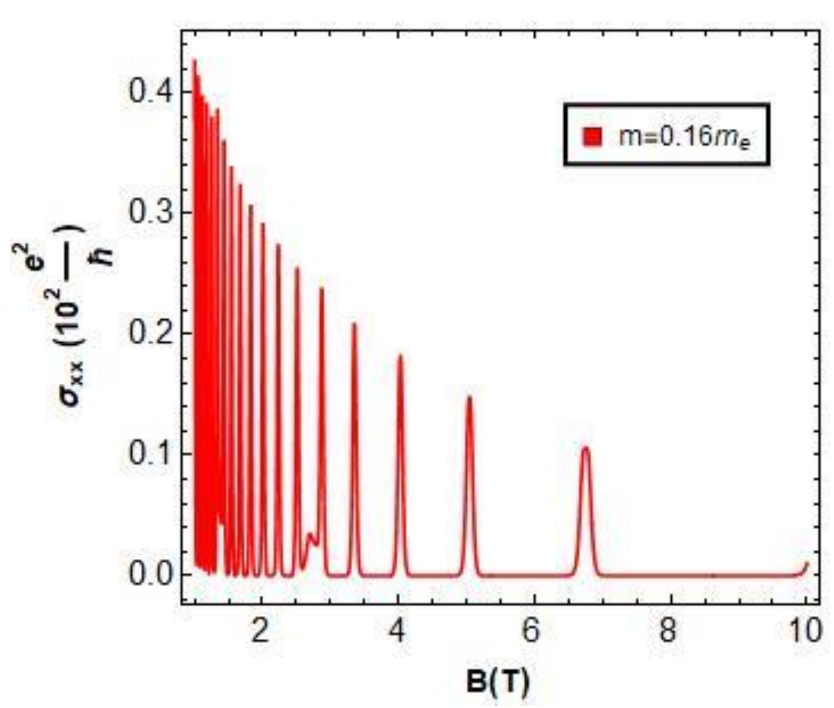
Energy spectrum of LLs



Density of states against Fermy energy



Density of states against magnetic field



Collisional conductivity

Conclusion:

We used Kubo-formula and derived analytical expression for the longitudinal and Hall conductivities in the linear response regime. We study the magneto-transport properties of these conductivities and highlight the non-trivial behavior of Hall plateaus. We show that due to quadratic in momentum term, Hall conductivity deviates from the conventional two dimensional systems with the filling factor 2(n+1/2) to non-trivial quadratic filling factor. We also show SdH oscillations.