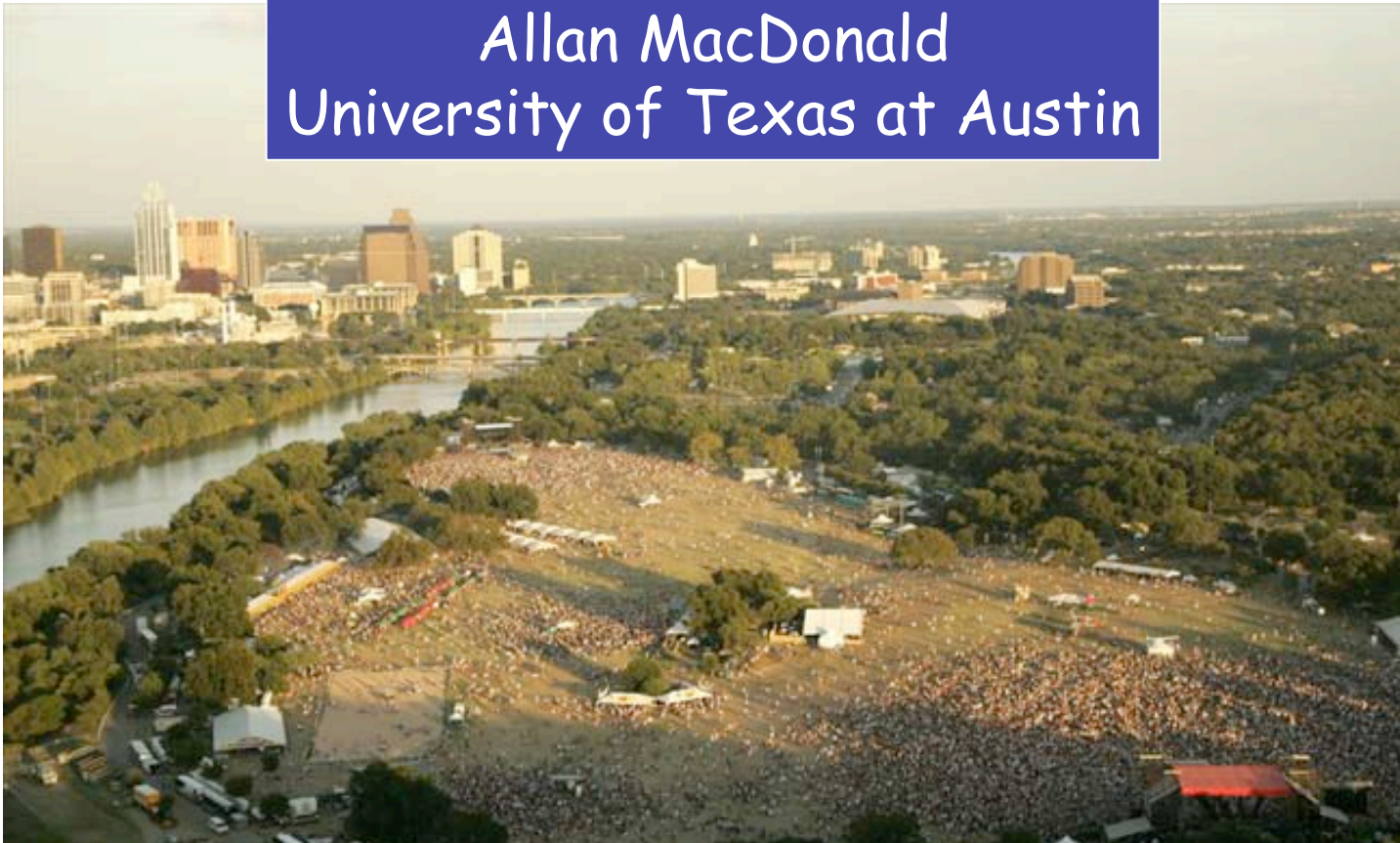
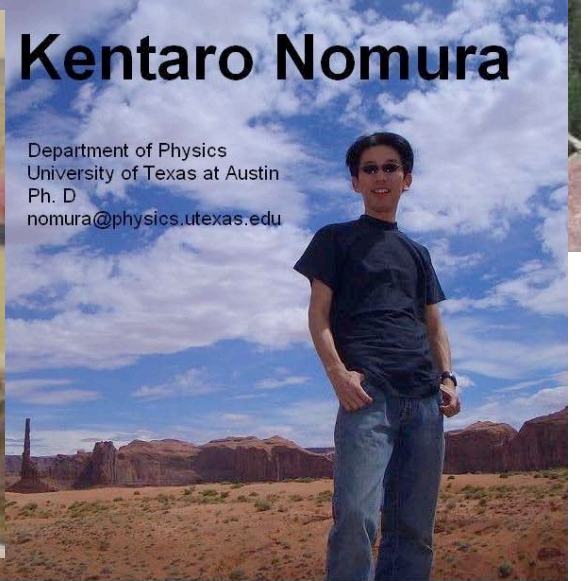
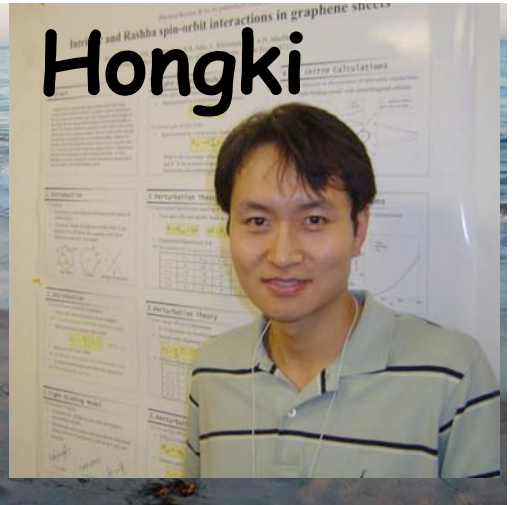


# Pseudospintronics in Graphene

Allan MacDonald  
University of Texas at Austin



arXiv:cond-mat/0701257 - to appear in PRL  
arXiv:0707.3786 - to appear in Solid State Comm.

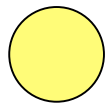


# Spintronics & Pseudospintronics

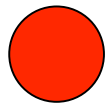
## Chiral 2DES

## Bilayer Graphene: Pseudospin Ferromagnet?

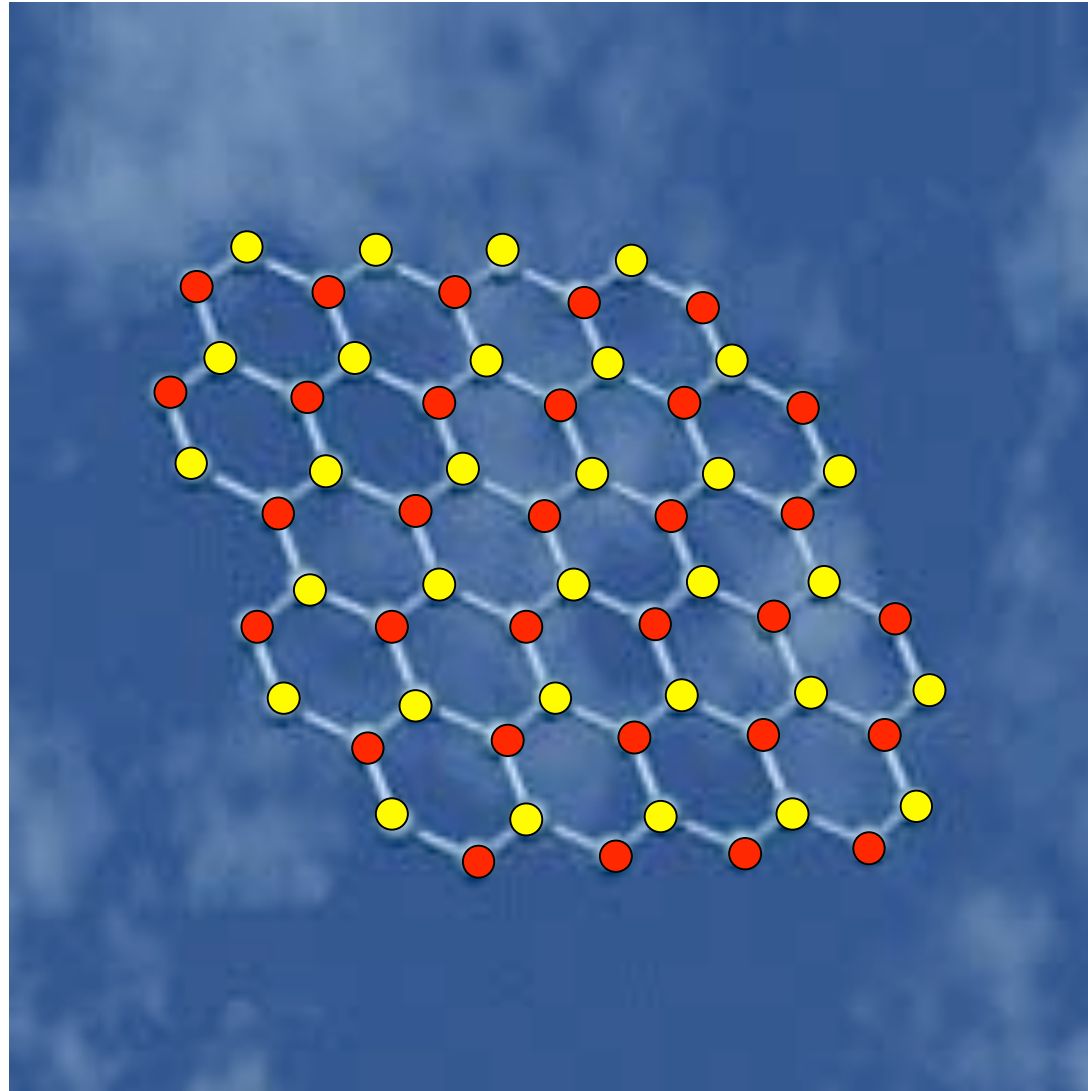
# Graphene - Pseudospin



**A**

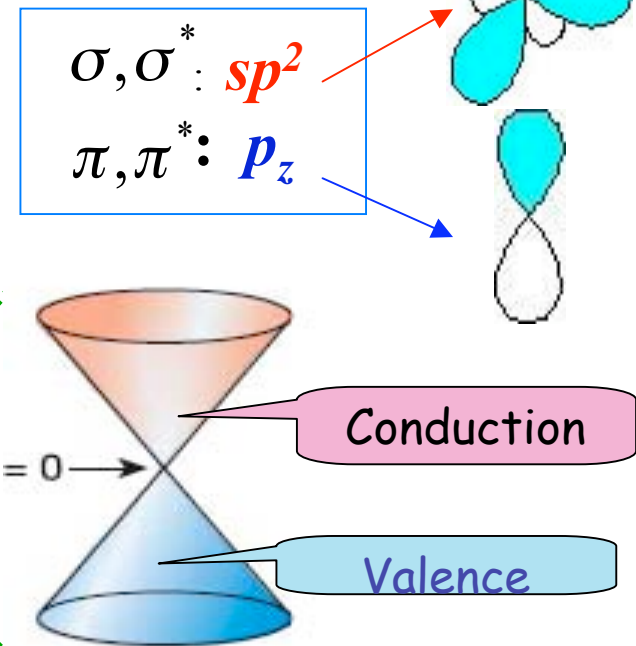
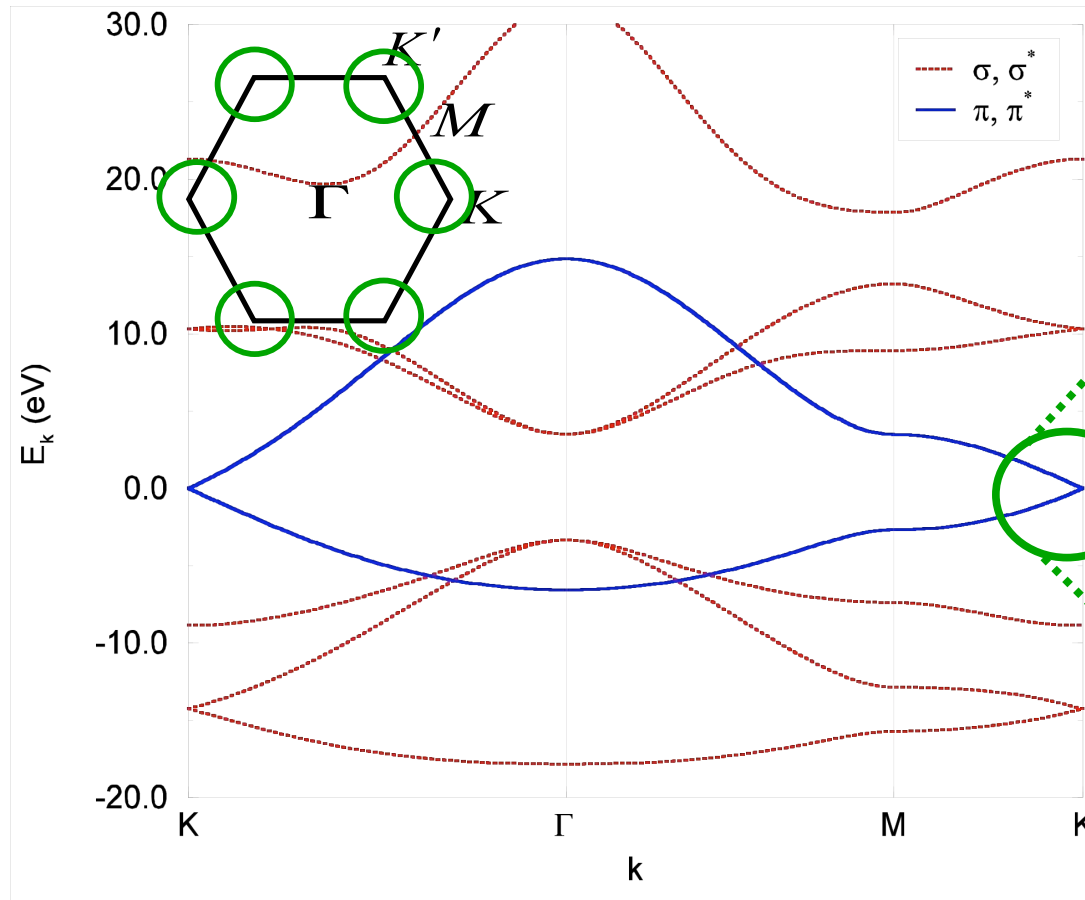


**B**

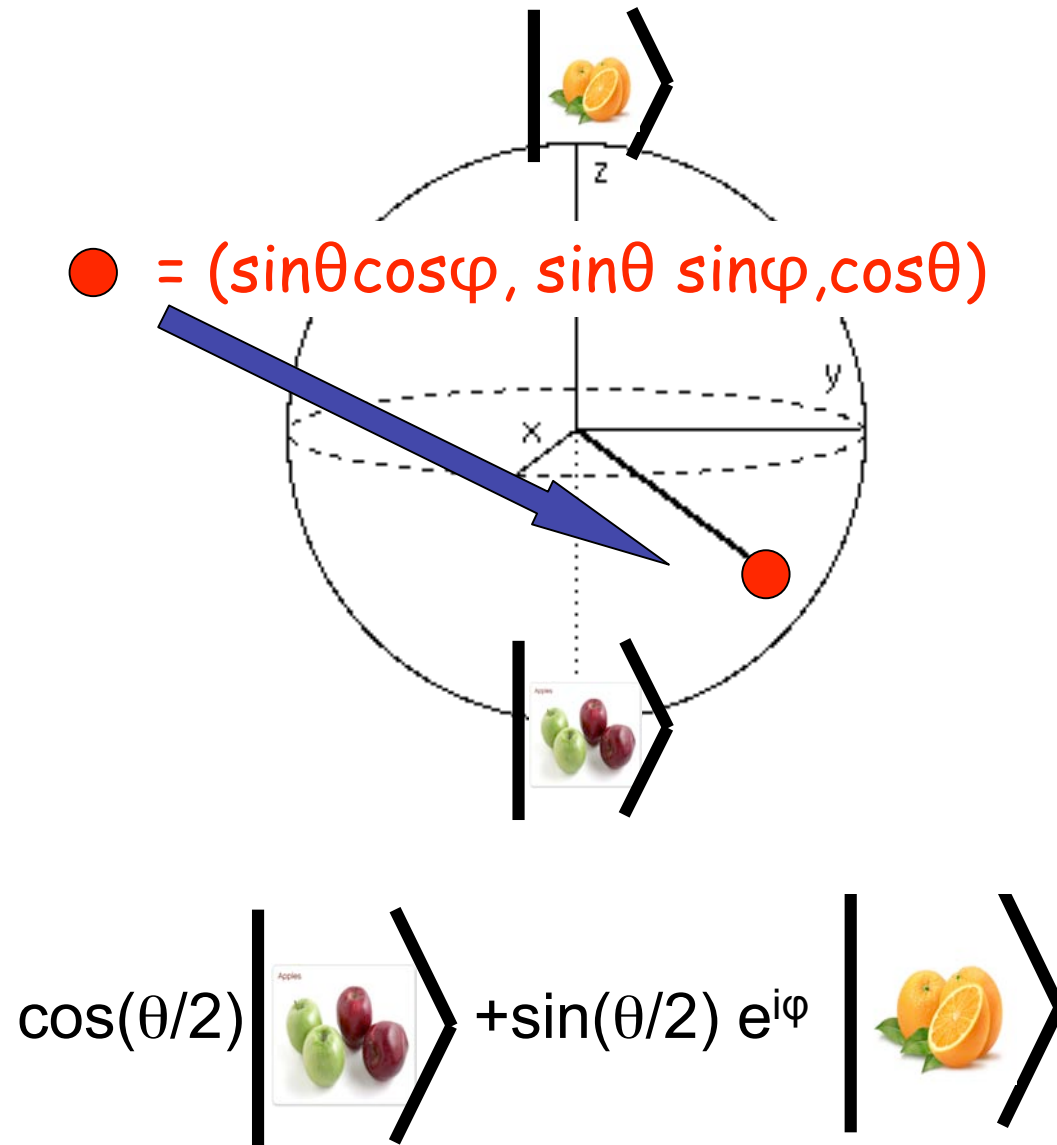


# Graphene Bands

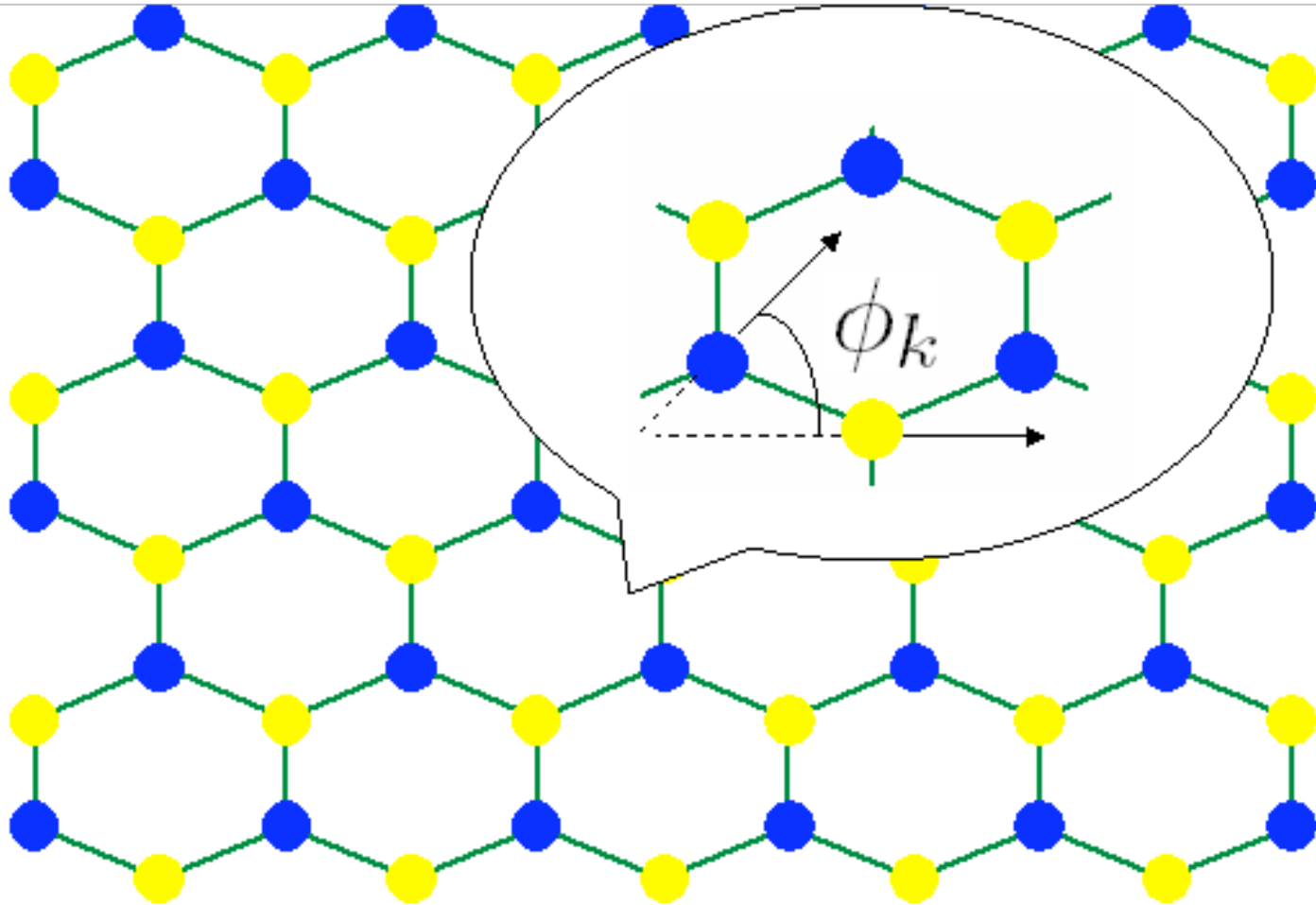
Phil Wallace - Physical Review - 1947



# (Pseudo)Spin Coherent States



# Graphene Chiral Fermions



# Two-Channel Conduction & CPP GMR

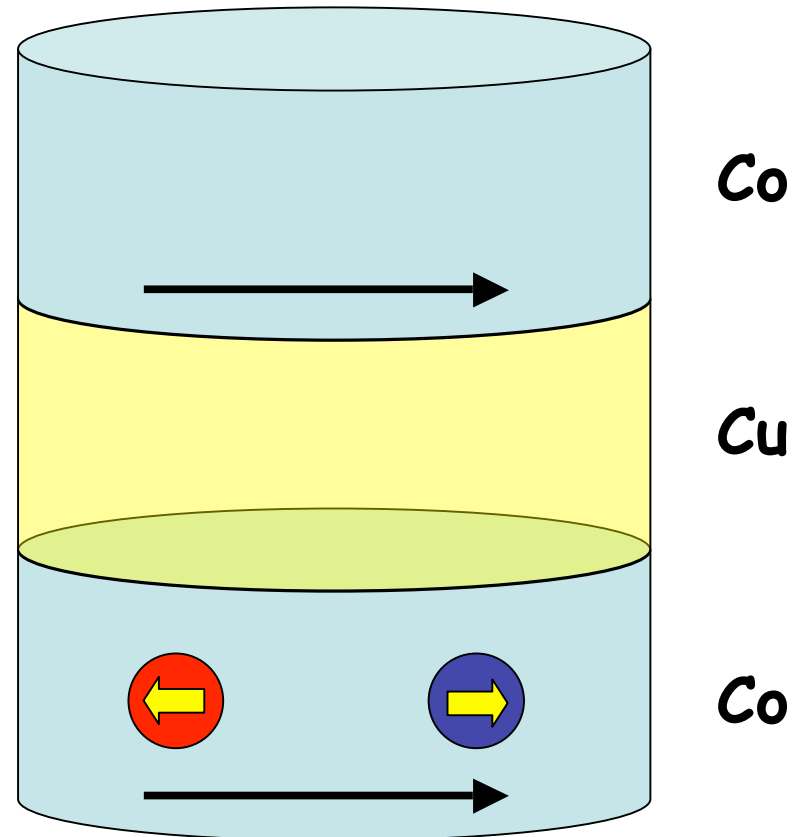
CPP = Current Perpendicular to Plane  
GMR = Giant Magnetoresistance



Neville Mott  
1905-1996

Minority

Majority



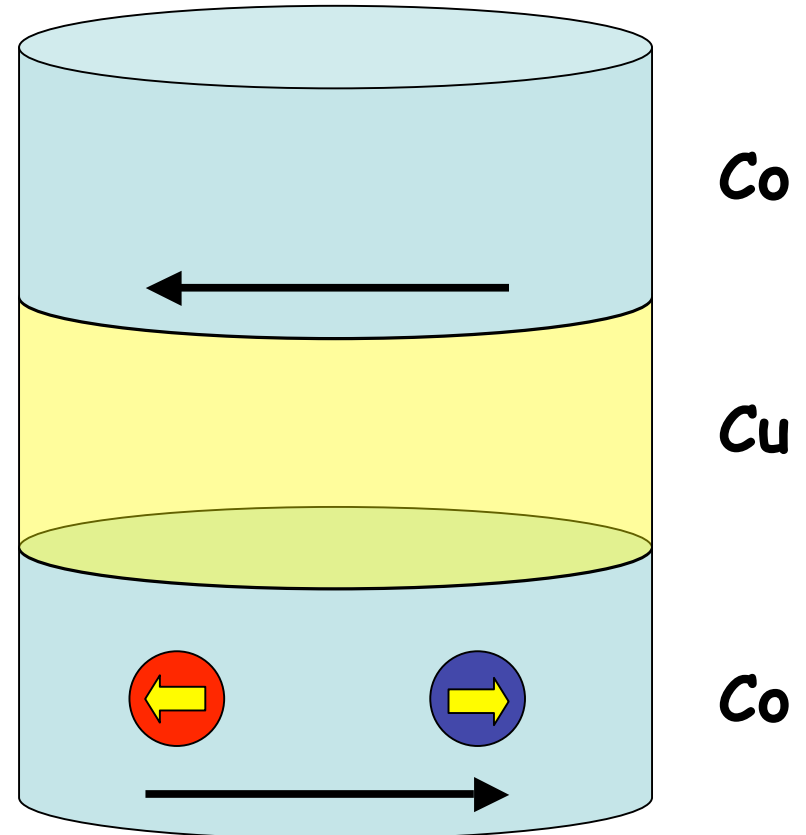
# CPP GMR - High Resistance State

Majority

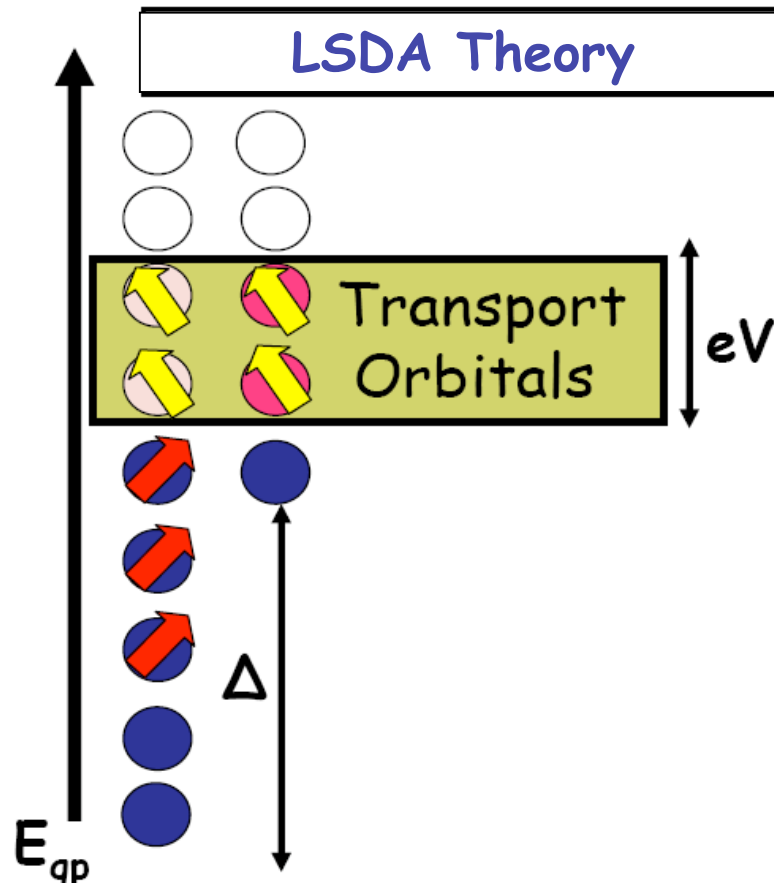
Minority



Neville Mott  
1905-1996



# Spin Transfer Torques

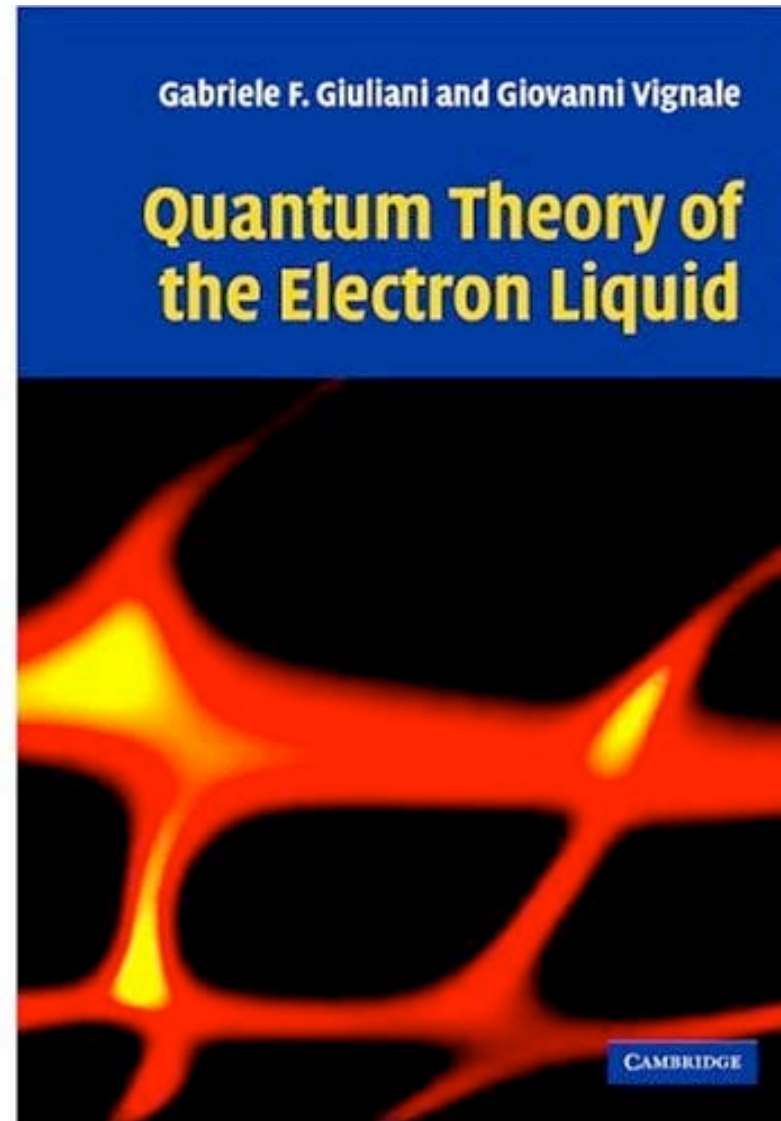


Spintronics & Pseudospintronics

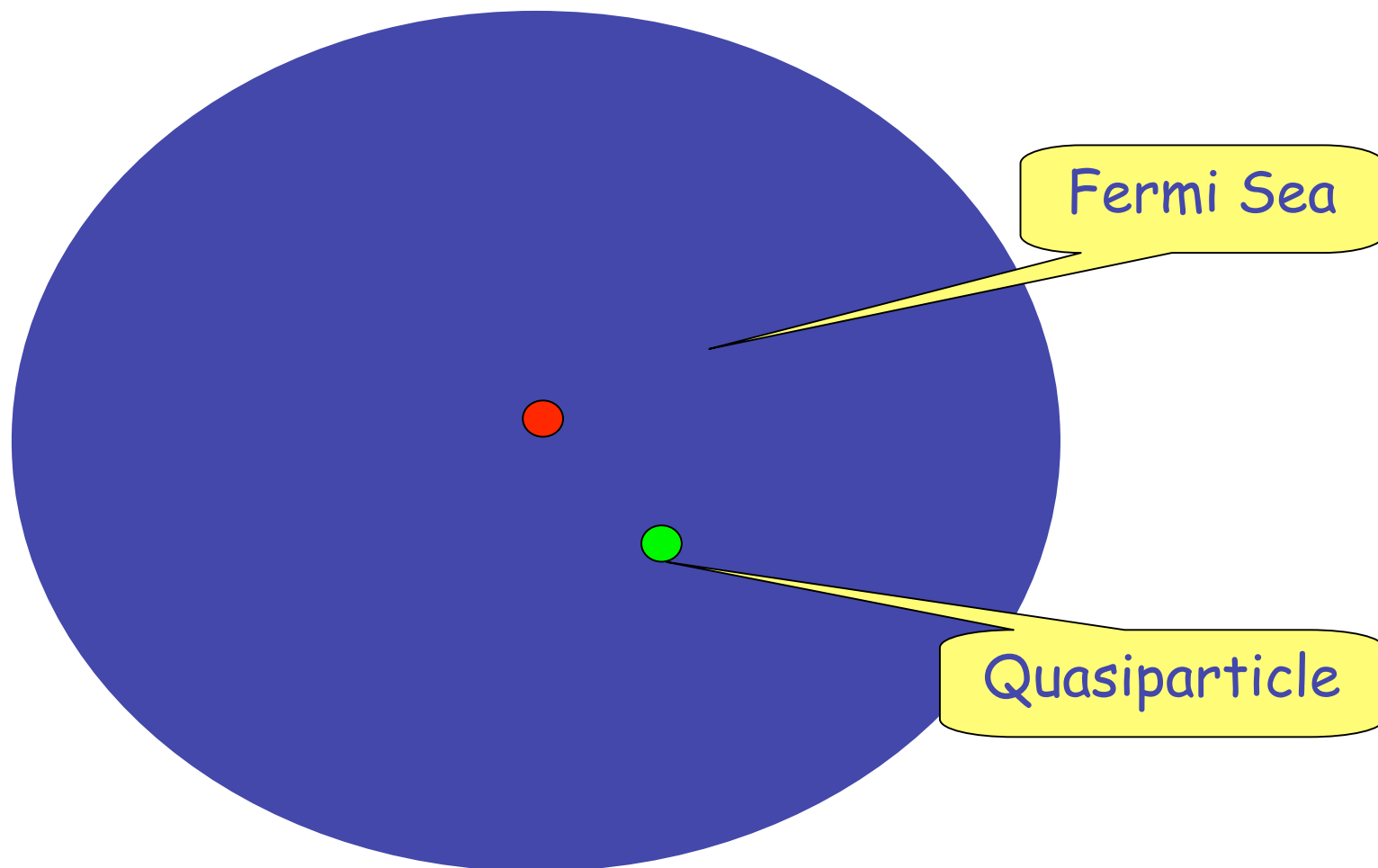
Chiral 2DES

Bilayer Graphene: Pseudospin  
Ferromagnet?

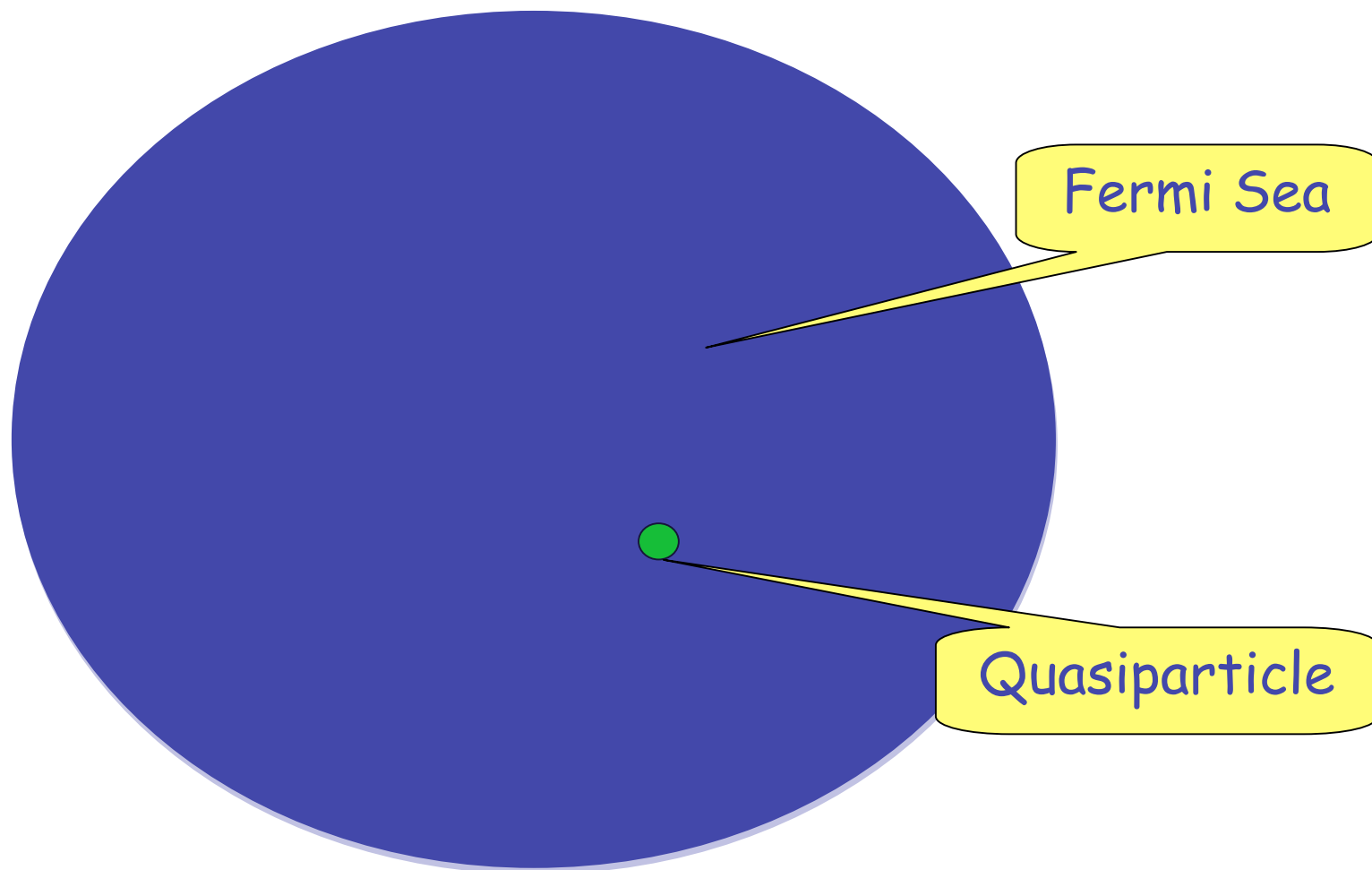
# Electron Gas Theory



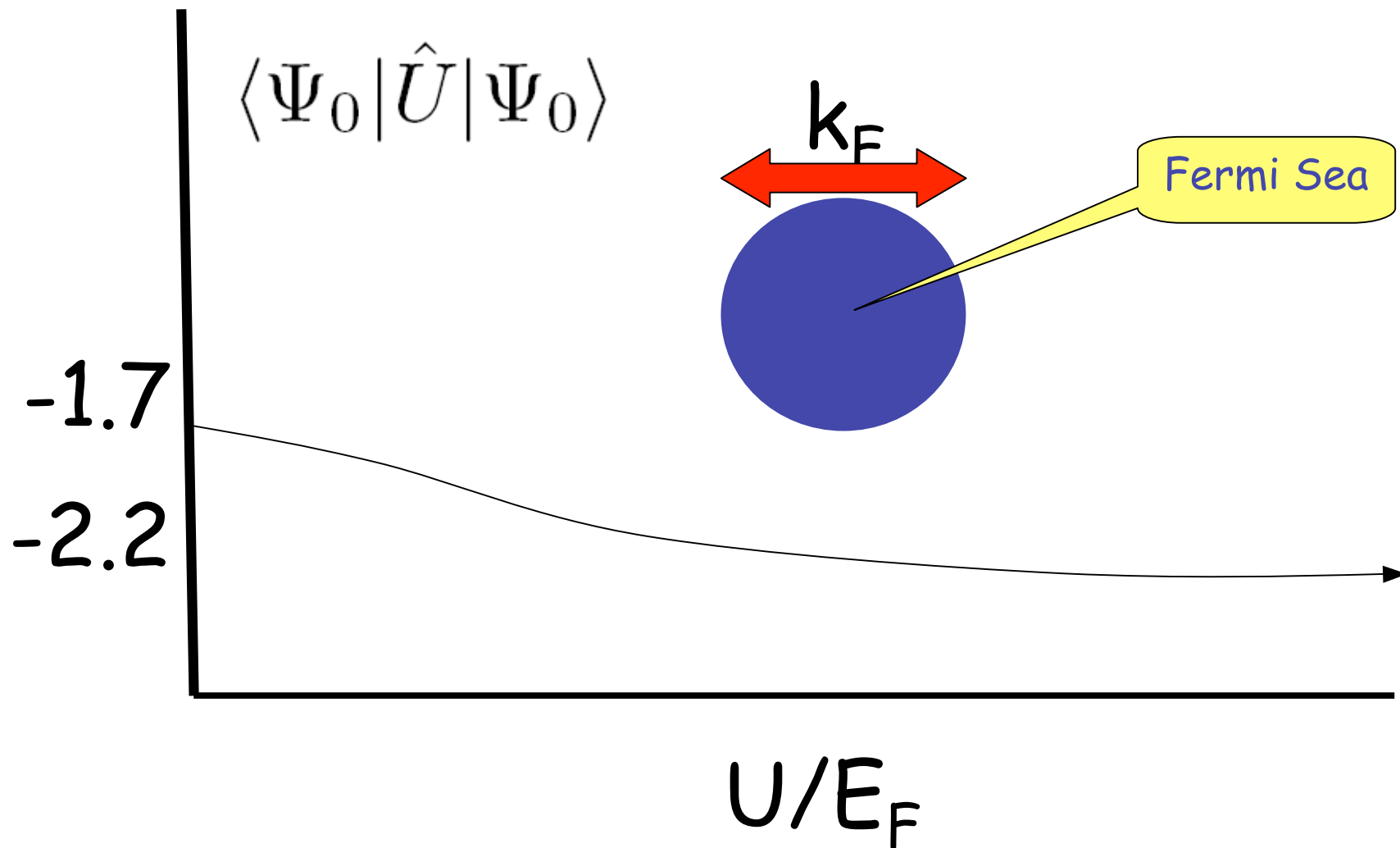
# Exchange



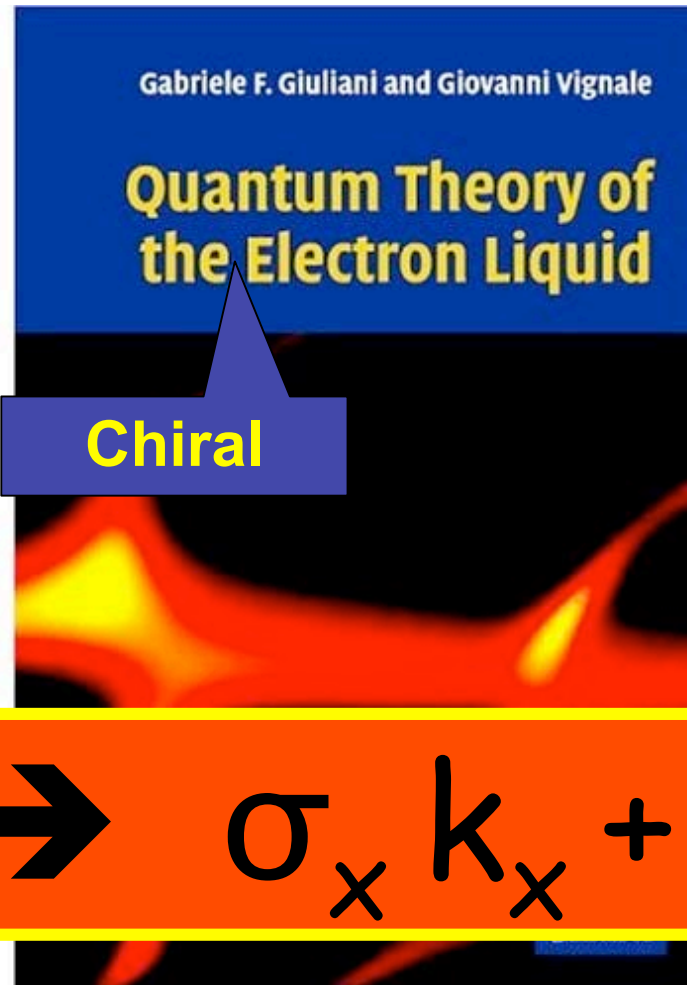
# Correlation



# Electron Gas Theory



# Electron Gas Theory



$$k^2 \Rightarrow \sigma_x k_x + \sigma_y k_y$$

# Graphene Continuum Model

$$v_F = c/300$$

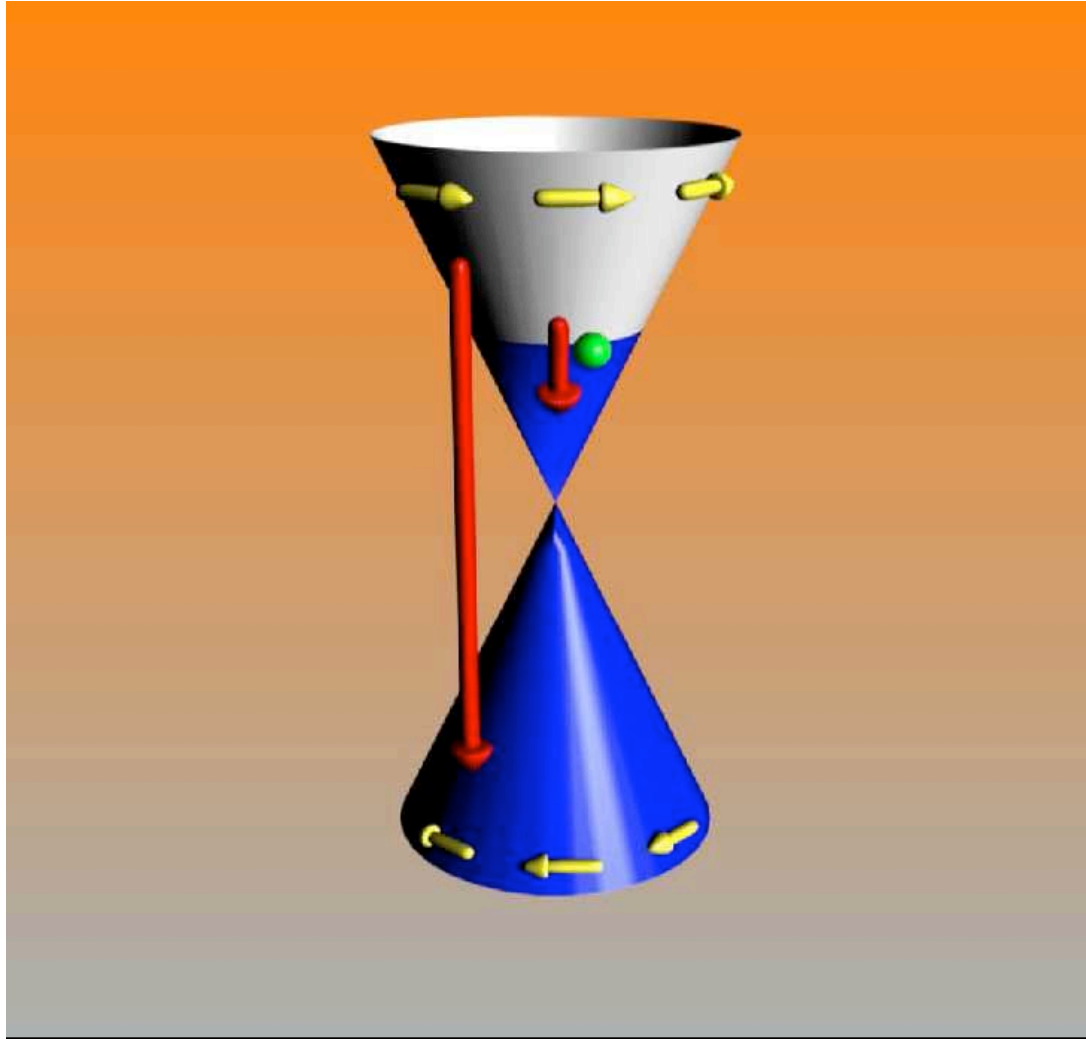
$$\mathcal{H} = \mathcal{H}_0 + \hat{V}$$

$$\mathcal{H}_0 = \sum_{j=1}^N \int d^2\mathbf{r} \left[ \psi_j^\dagger(\mathbf{r}) v_F \mathbf{p} \cdot \boldsymbol{\sigma} \psi_j(\mathbf{r}) \right]$$

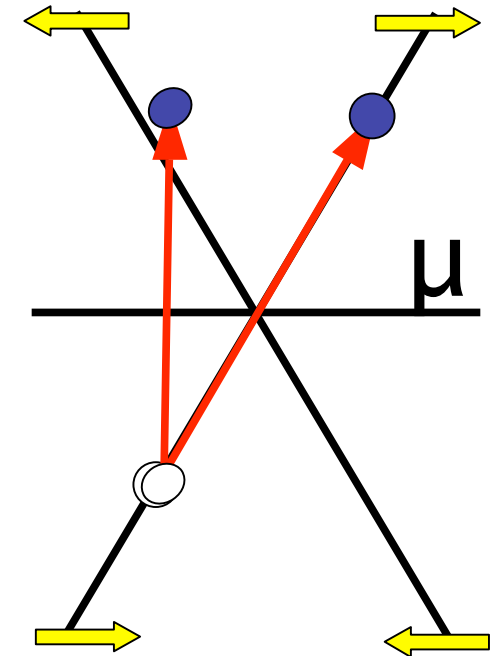
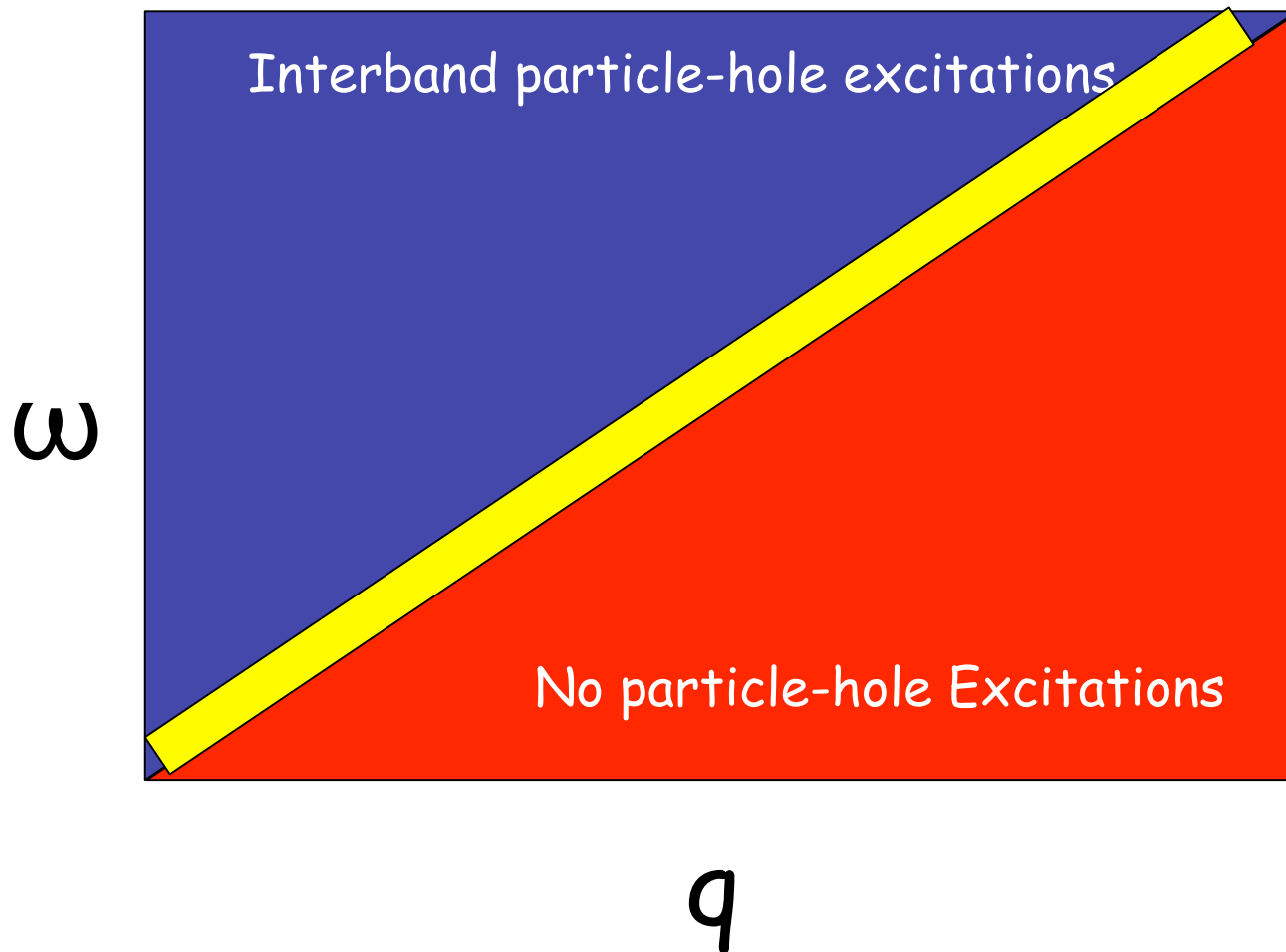
“relativistic”

$$\alpha_{\text{Graphene}} = e^2 / \epsilon \hbar v_F \sim 1$$

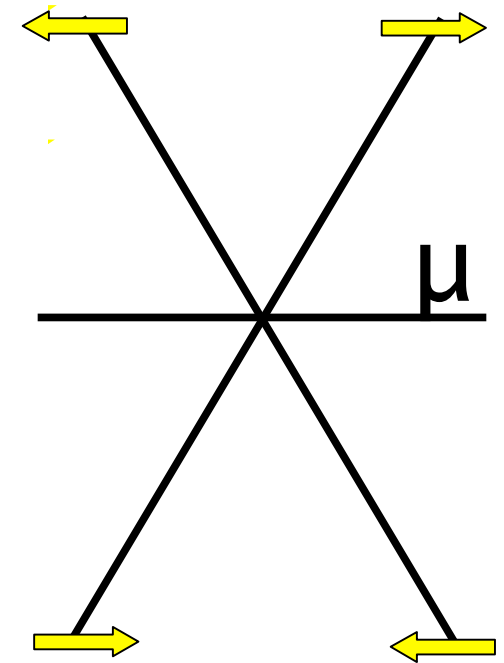
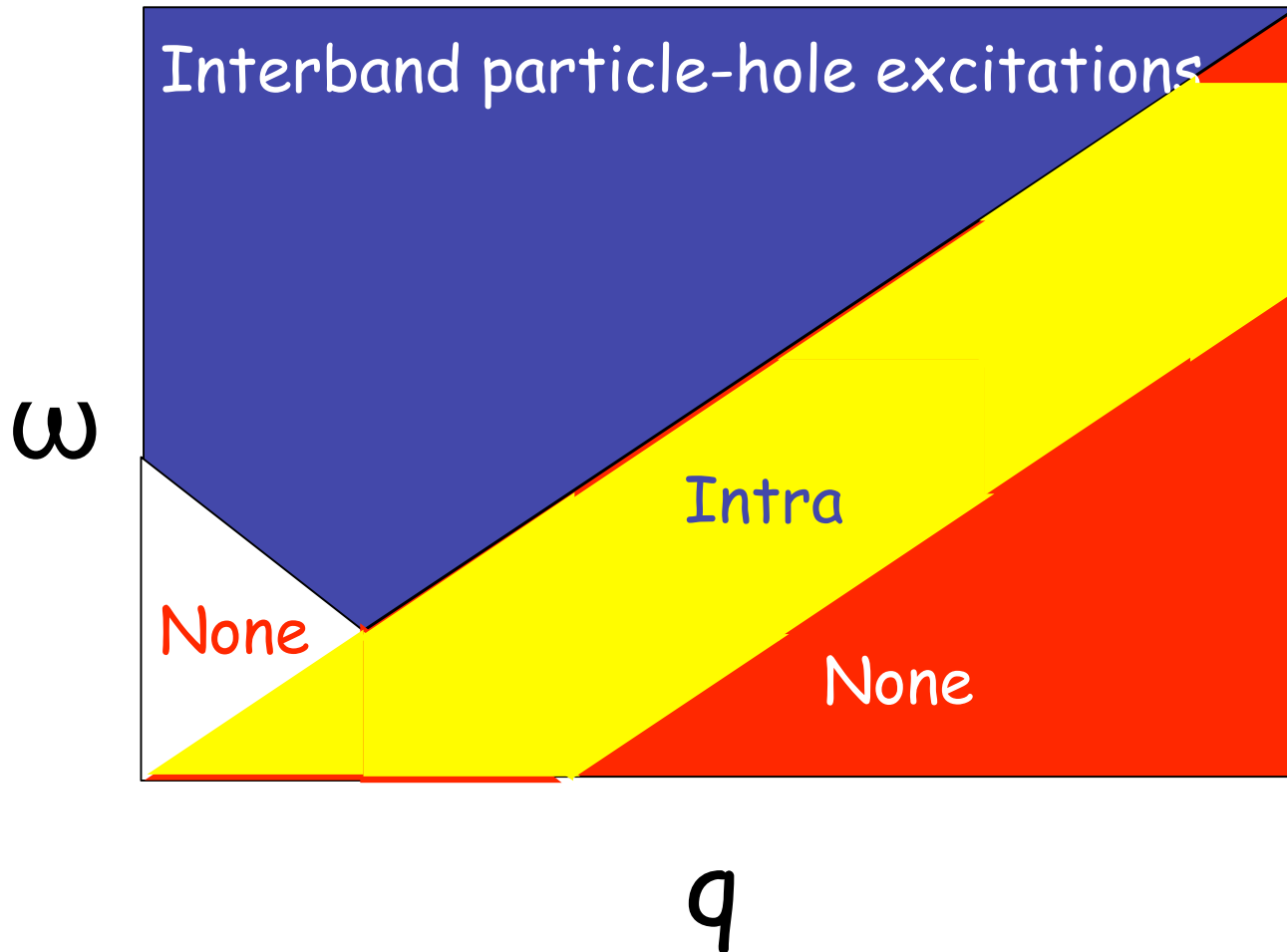
# Chiral 2DES



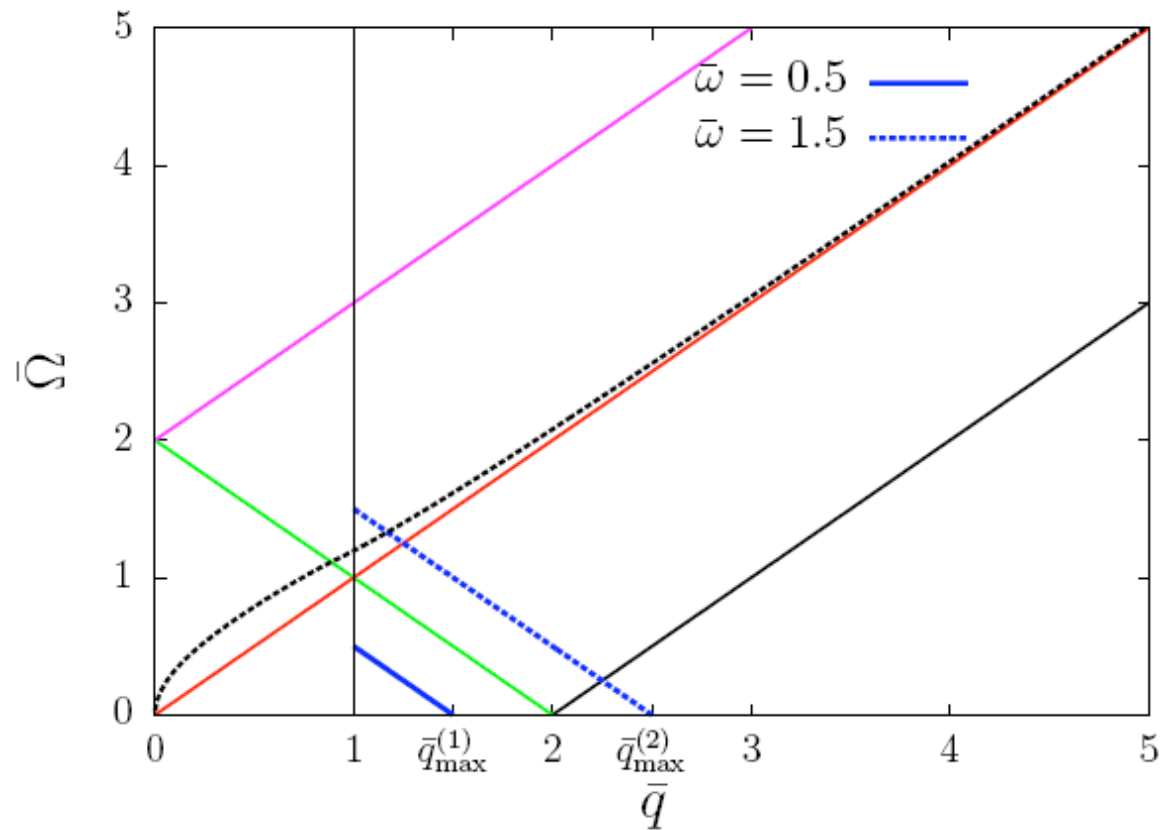
# Neutral Graphene Fluctuations



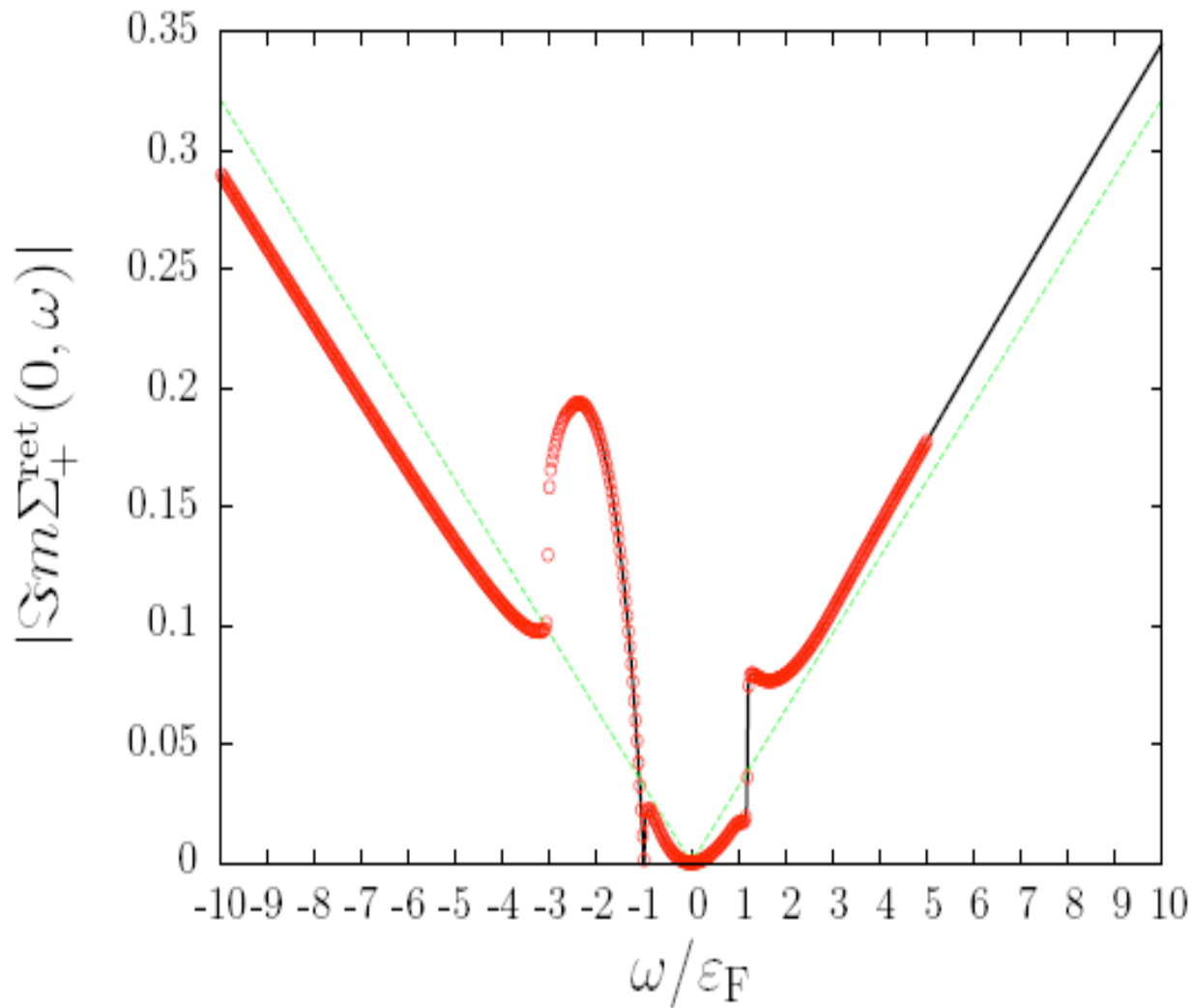
# Doped Graphene Fluctuations



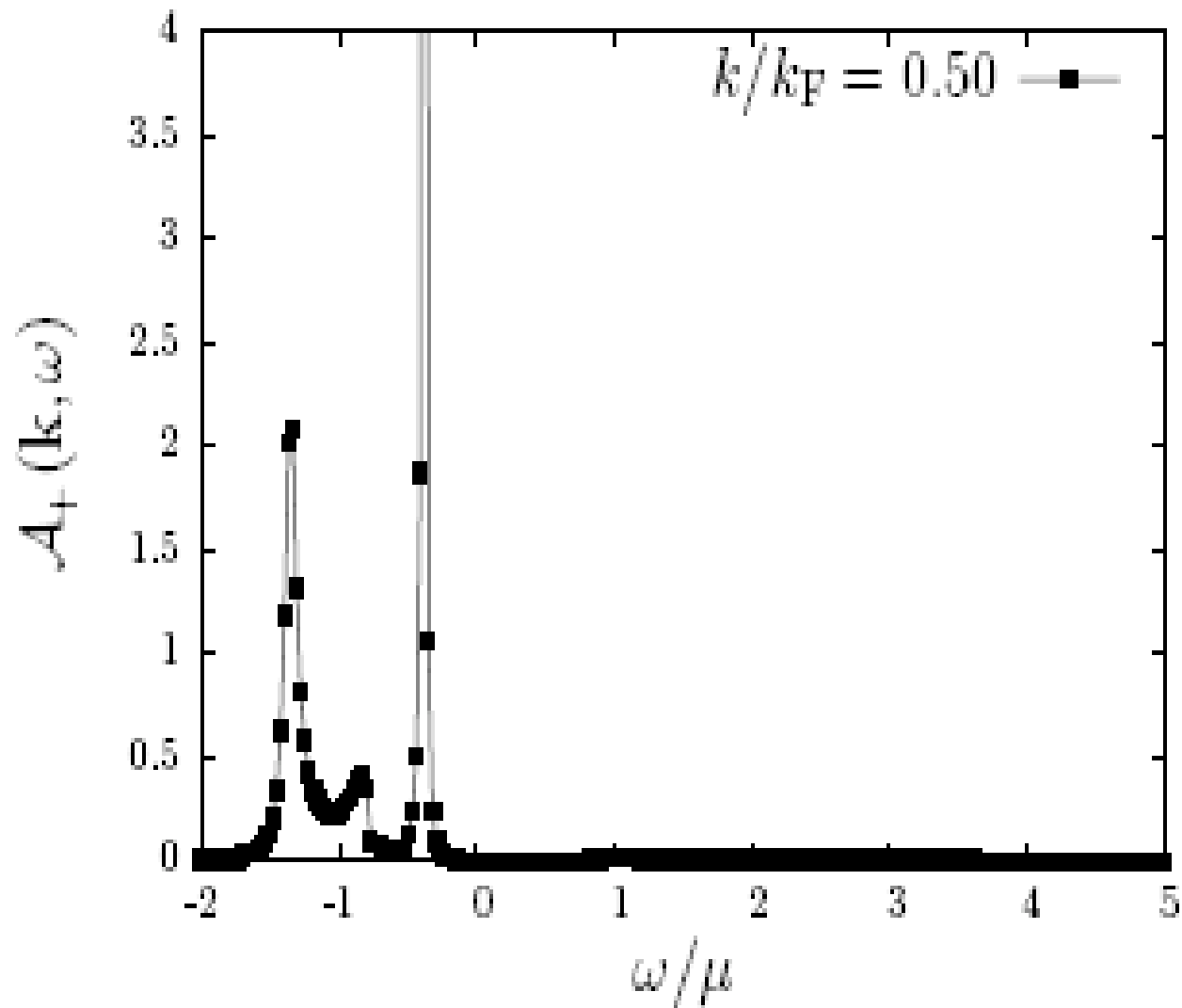
# Plasmons



# Quasiparticle-Decay



# ARPES



# Renormalized Velocity

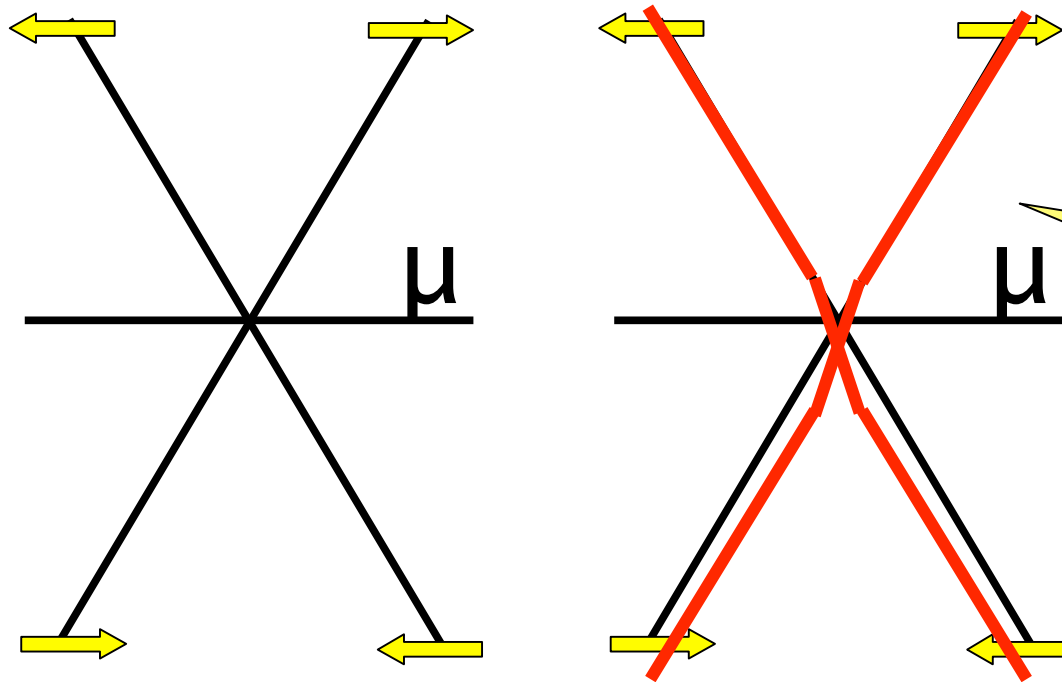
$$\Sigma_{\mathbf{k},s}^{(0)} = -\frac{1}{S} \sum_{\mathbf{k}',s'} V_{ss'}(\mathbf{k}, \mathbf{k}') n_{s'}^{(0)}(\mathbf{k}')$$

$\mu$

$$V_{s,s'}(\mathbf{k}, \mathbf{k}') = \frac{2\pi e^2}{|\mathbf{k} - \mathbf{k}'|} \left[ \frac{1 + ss' \cos(\theta_{\mathbf{k},\mathbf{k}'})}{2} \right]$$

Contribution  
to  
Band Energy

# Renormalized Velocity



Contribution  
to  
Band Energy

$$\Rightarrow v \rightarrow v \left[ 1 + \frac{f}{4g} \ln(\Lambda) \right]$$

Guinea et al. (1999) Katnelson,  
Mishchenko, DasSarma

# Chiral Electron Gas Properties

$$X/X_0 < 1$$

- $K/K_0 < 1$

- $v/v_0 > 1$

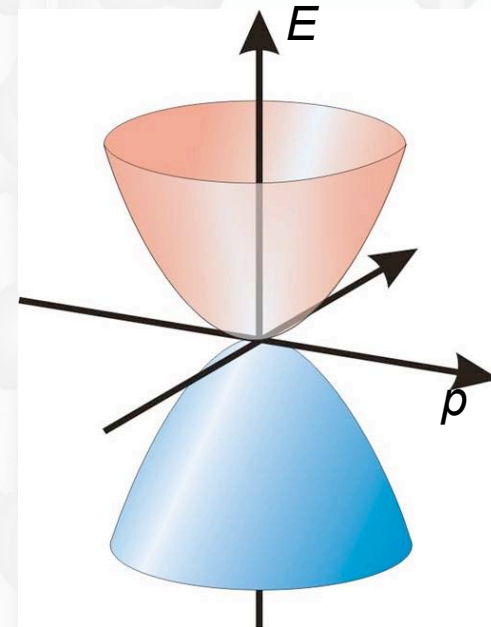
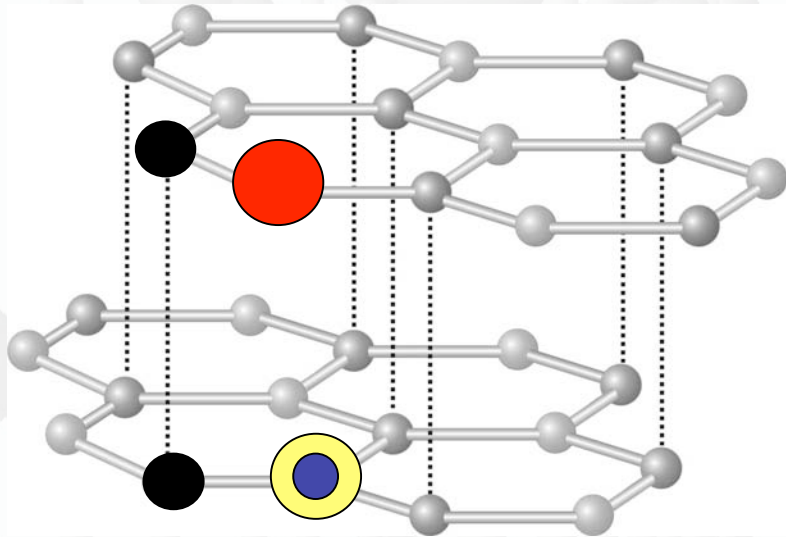
Barlas et al. cond-mat/0701257 + PRL to appear

Spintronics & Pseudospintronics

Chiral 2DES

Bilayer Graphene: Pseudospin  
Ferromagnet?

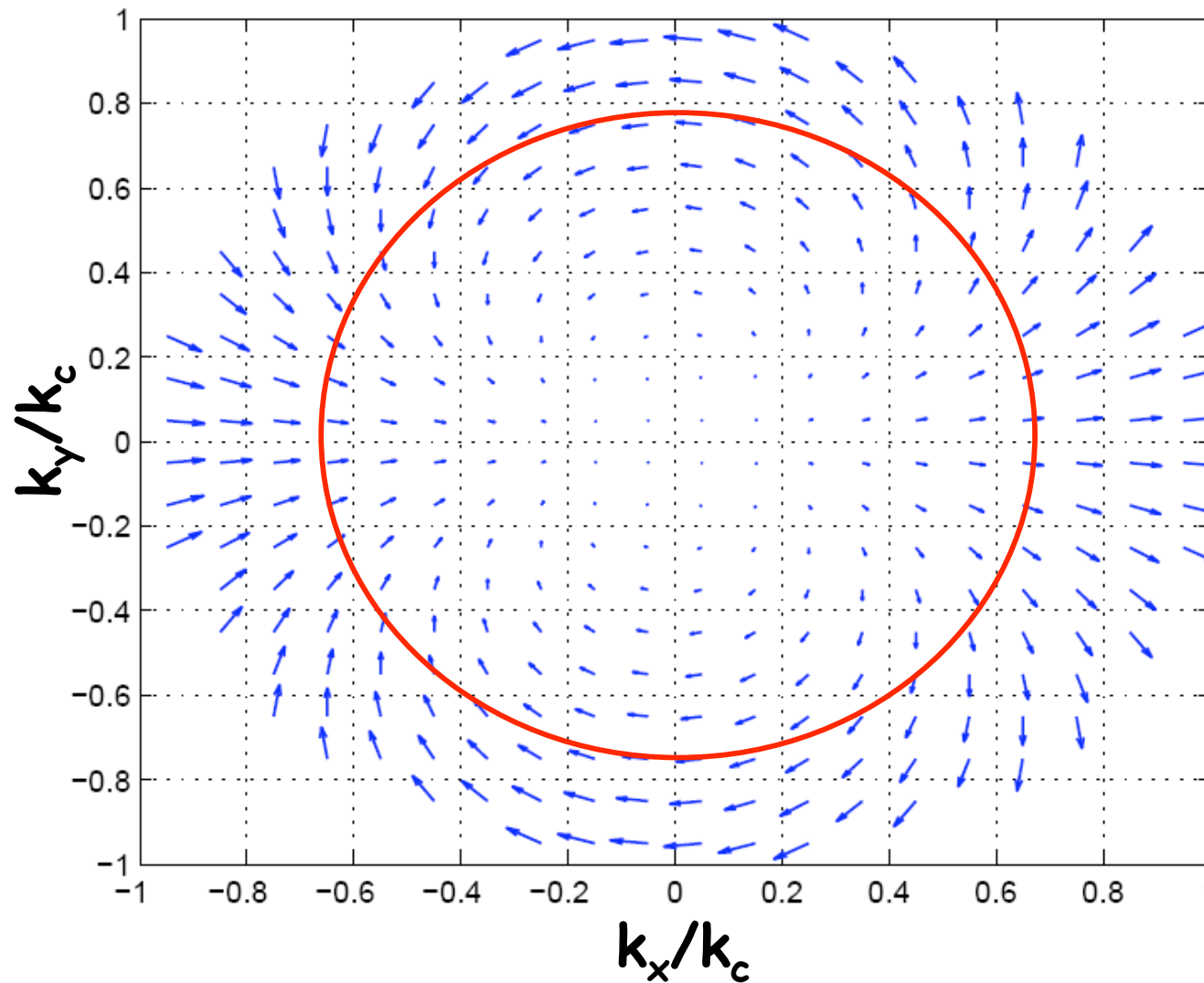
# BILAYER GRAPHENE



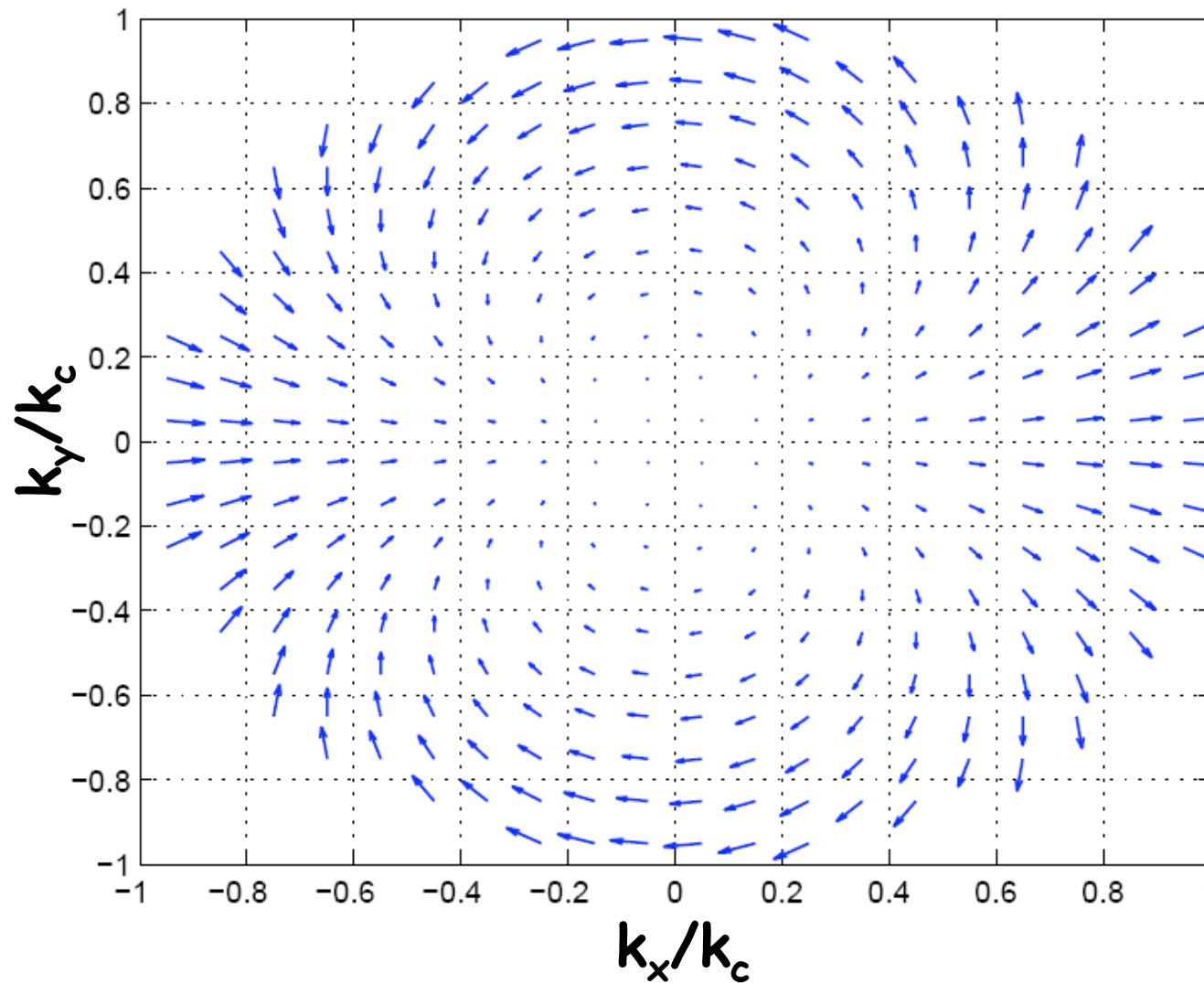
*Manchester Nature Phys 2, 177 (2006)*

$$\vec{B}_{\text{band}}(\vec{k}) = \frac{\hbar^2 k^2}{2m^*} (\cos(2\phi_{\vec{k}}), \sin(2\phi_{\vec{k}}), 0)$$

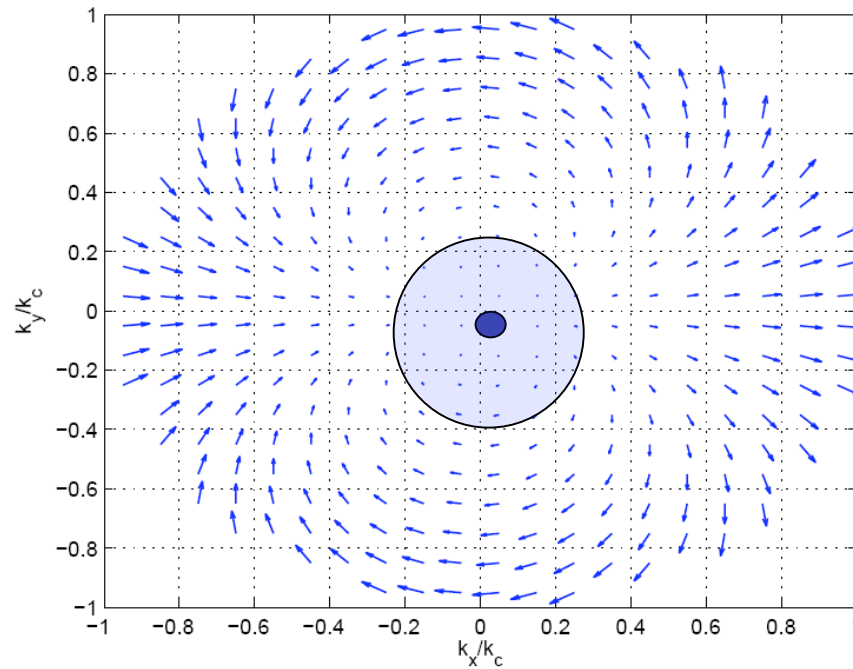
# Bilayer Pseudospin Orientations



# Bilayer Pseudospin Orientations

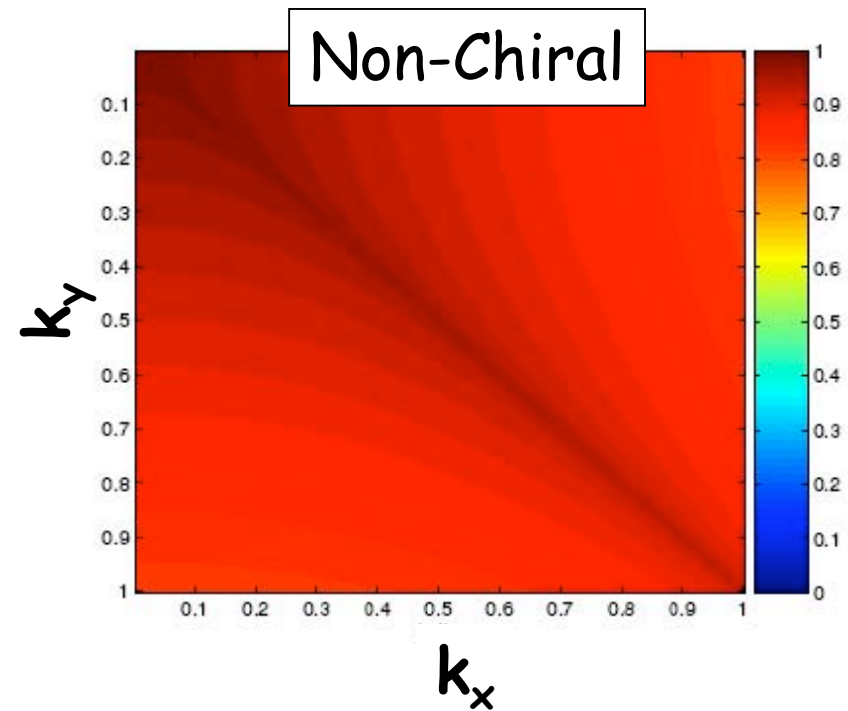
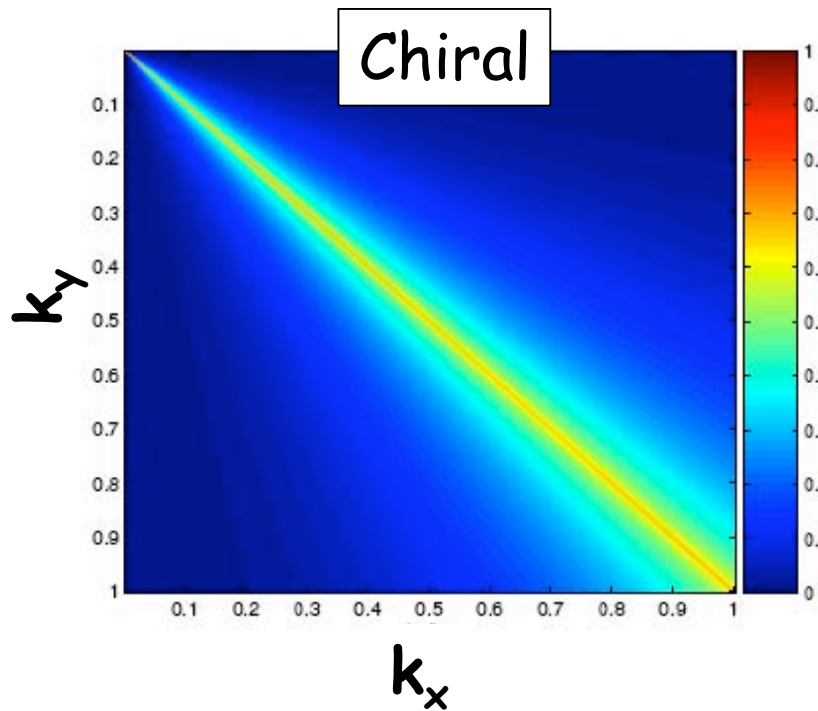


# Pseudospin Exchange Fields



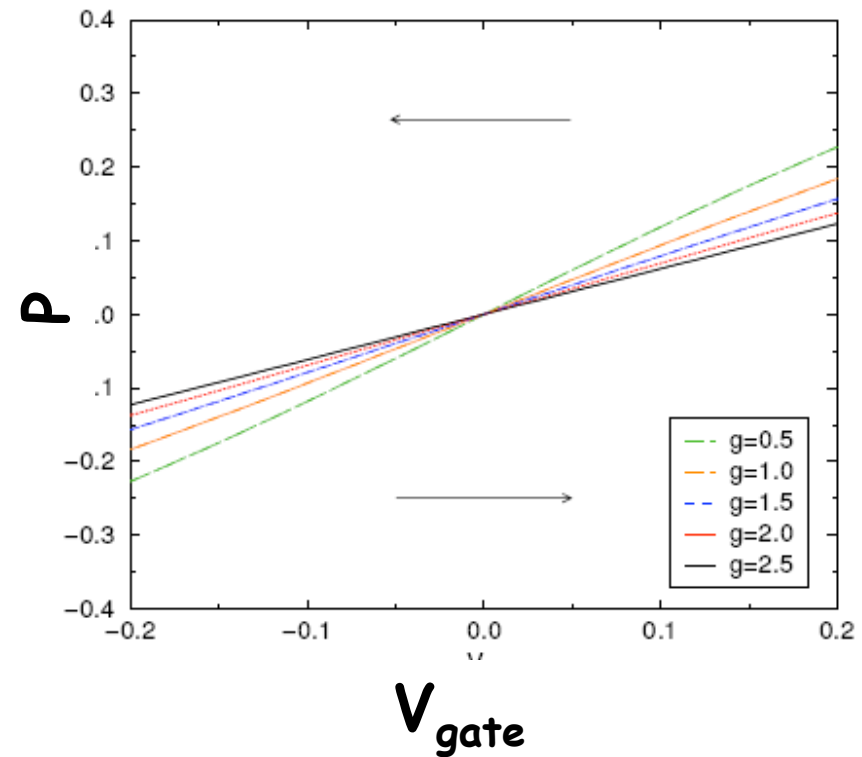
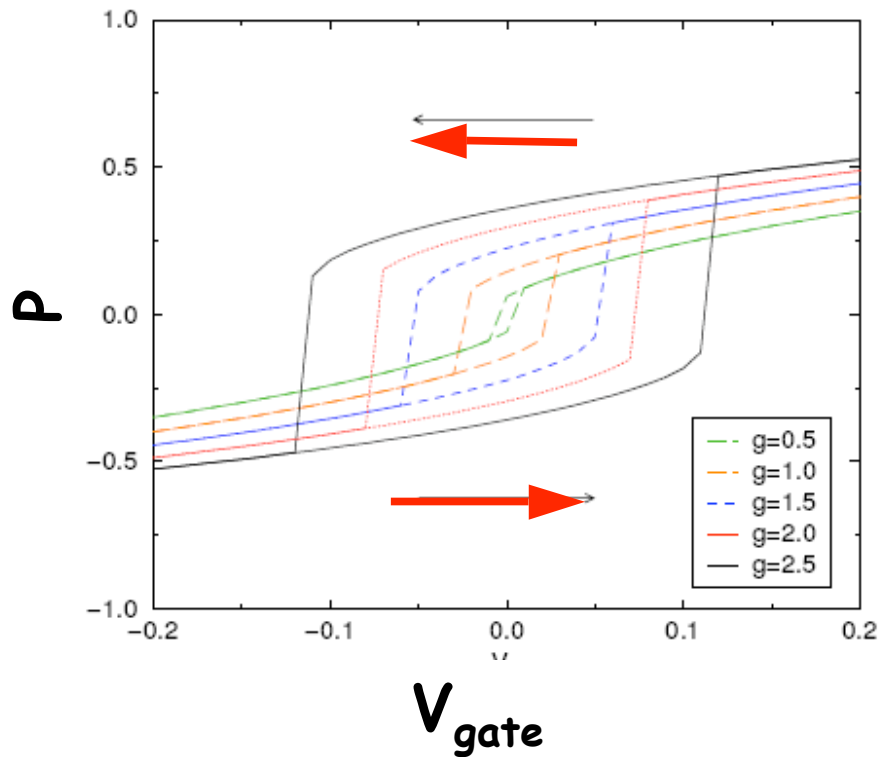
$$\vec{B}_x(\vec{k}) = \frac{1}{2A} \sum_{\vec{k}'} V(\vec{k} - \vec{k}') \hat{n}(\vec{k}')$$

# Self-Consistent HF Theory

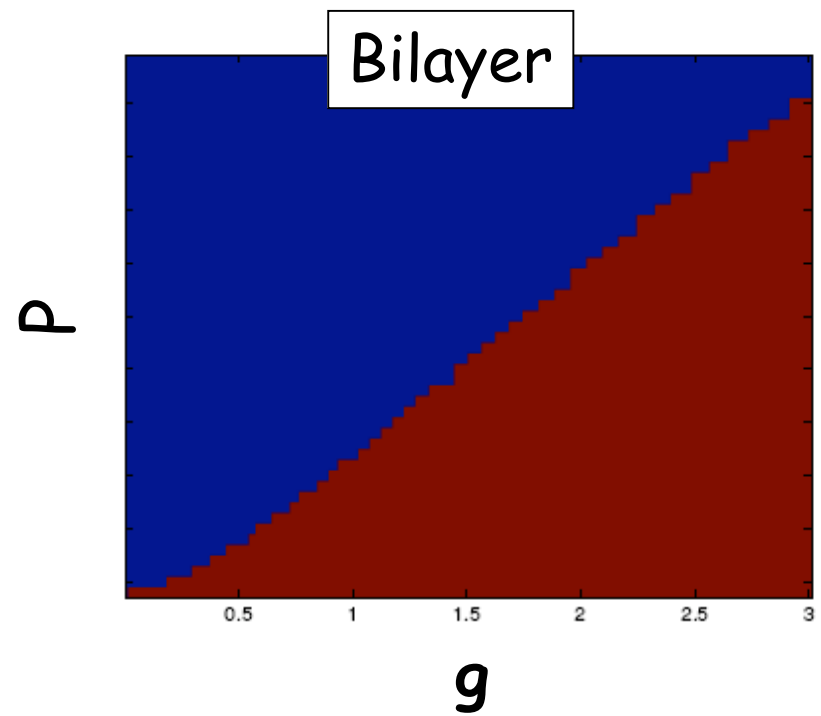
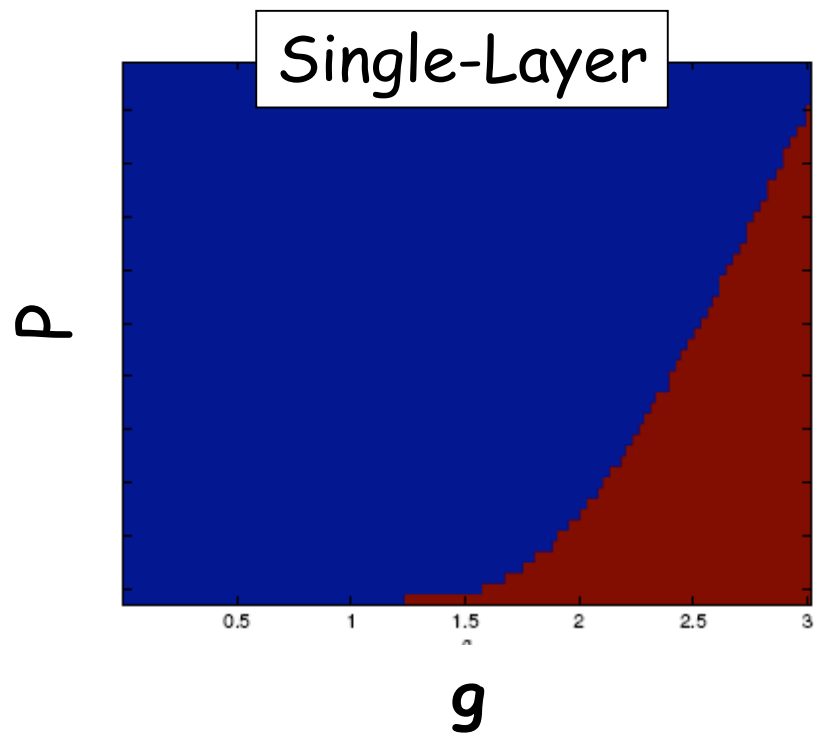


$$\left[ \vec{B}_{\text{band}}(\vec{k}) + \vec{B}_X(\vec{k}) \right] \times \hat{n}(\vec{k}) = 0$$

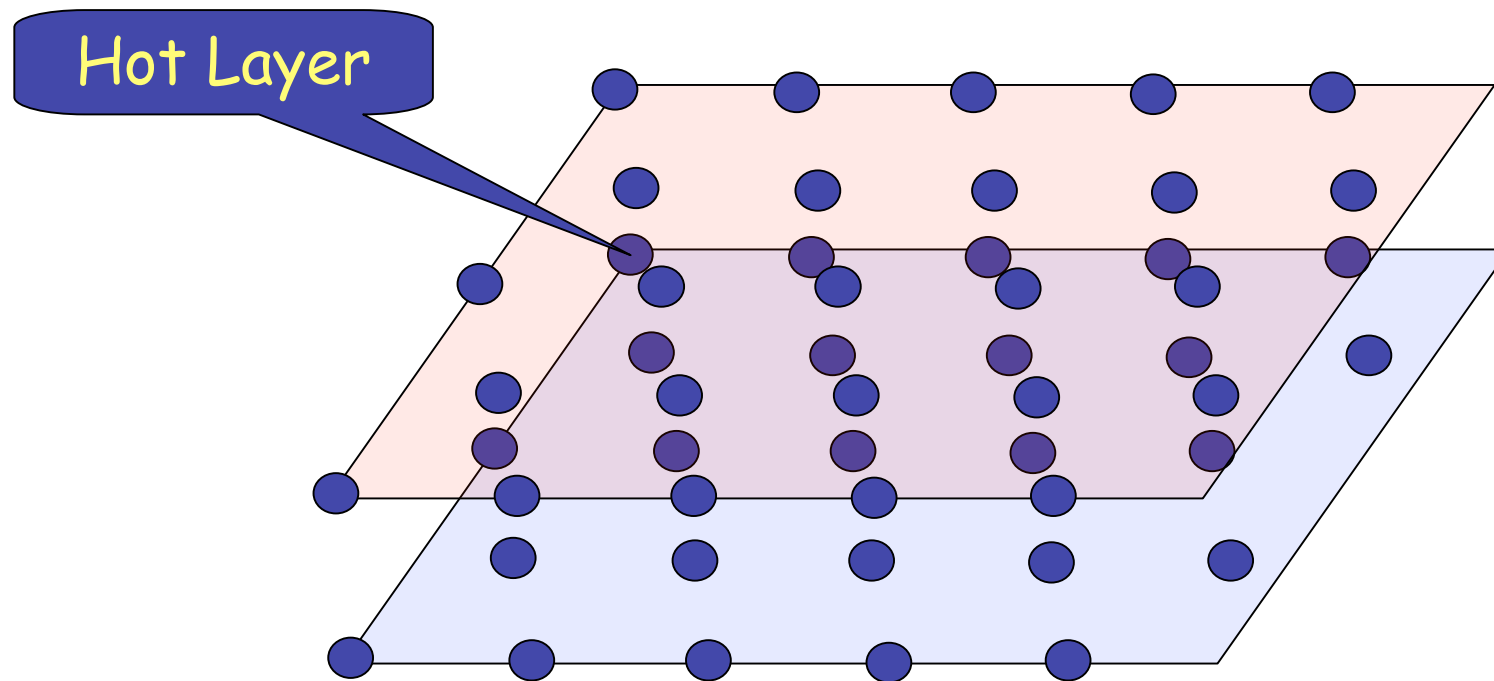
# Pseudospin Ferromagnetism



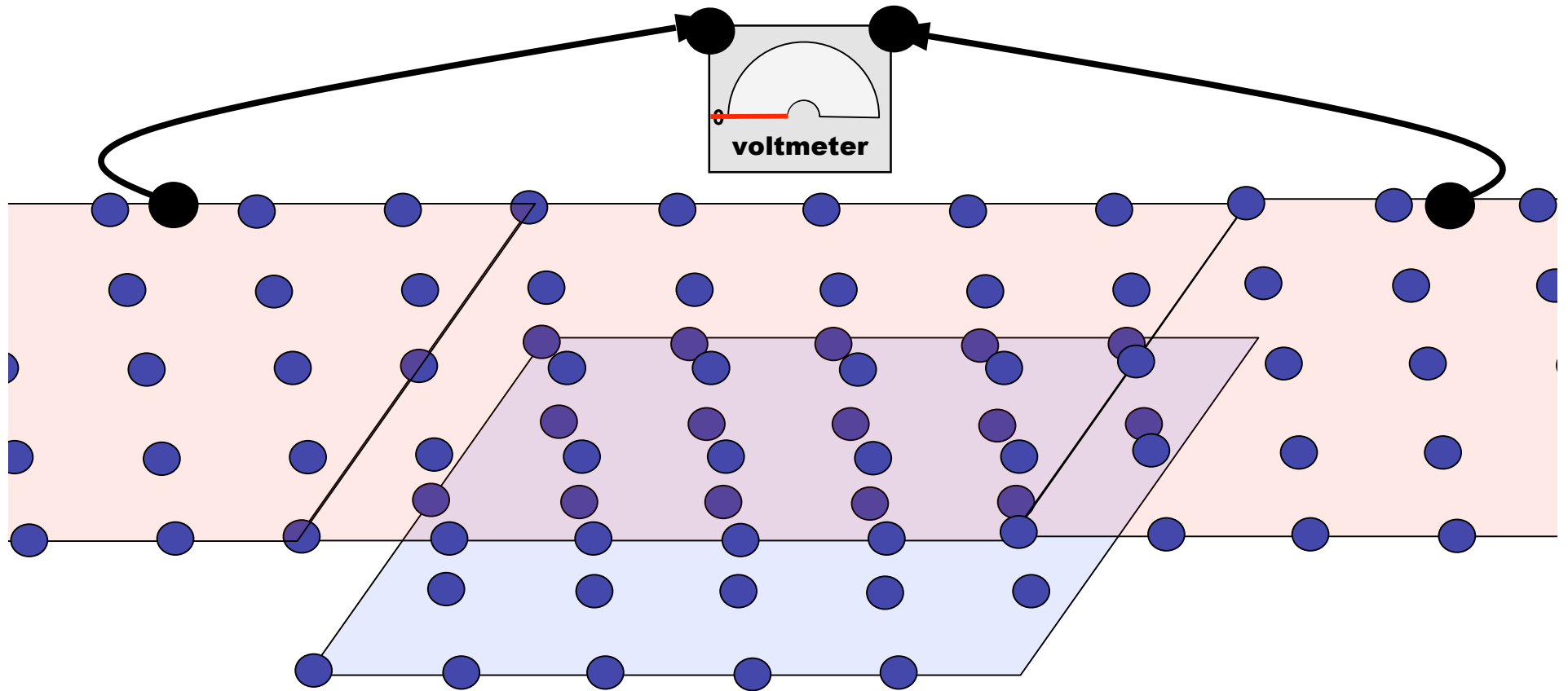
# Phase Diagram



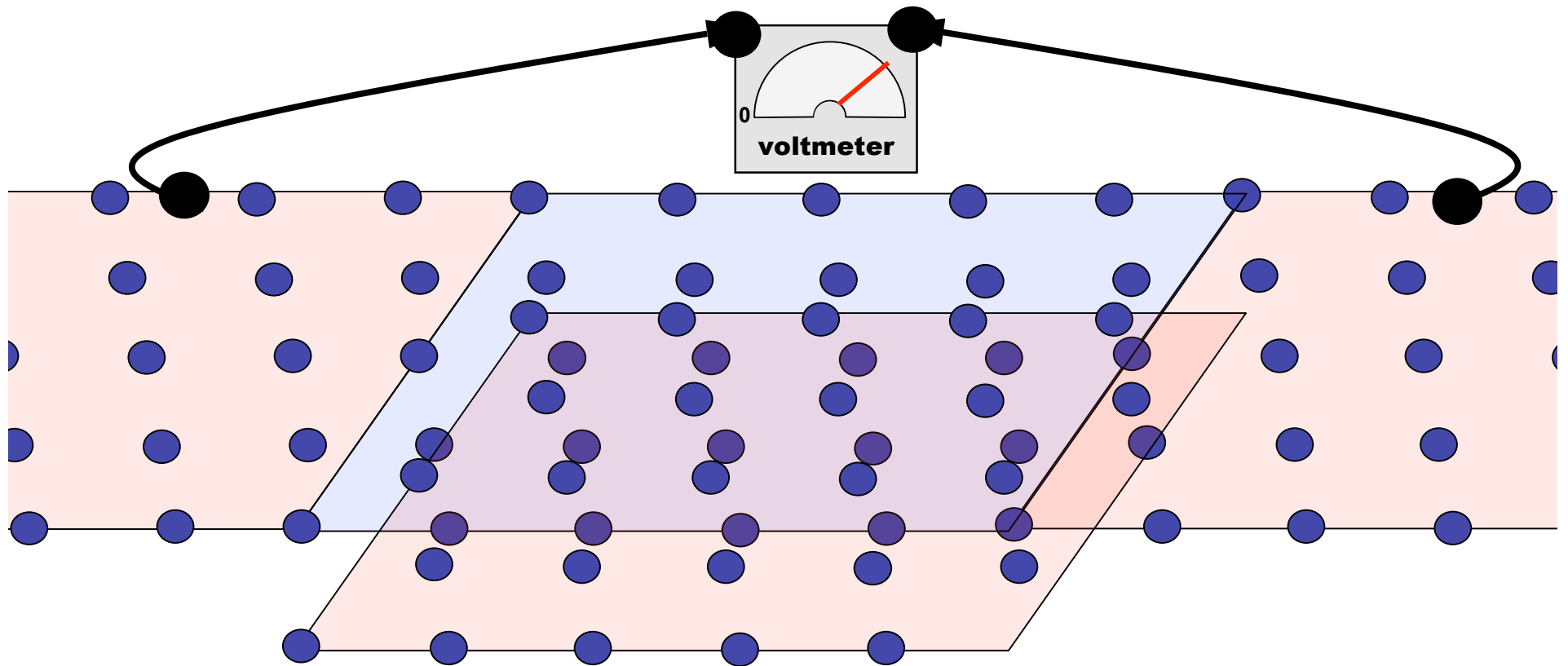
# Giant *Electro-resistance*



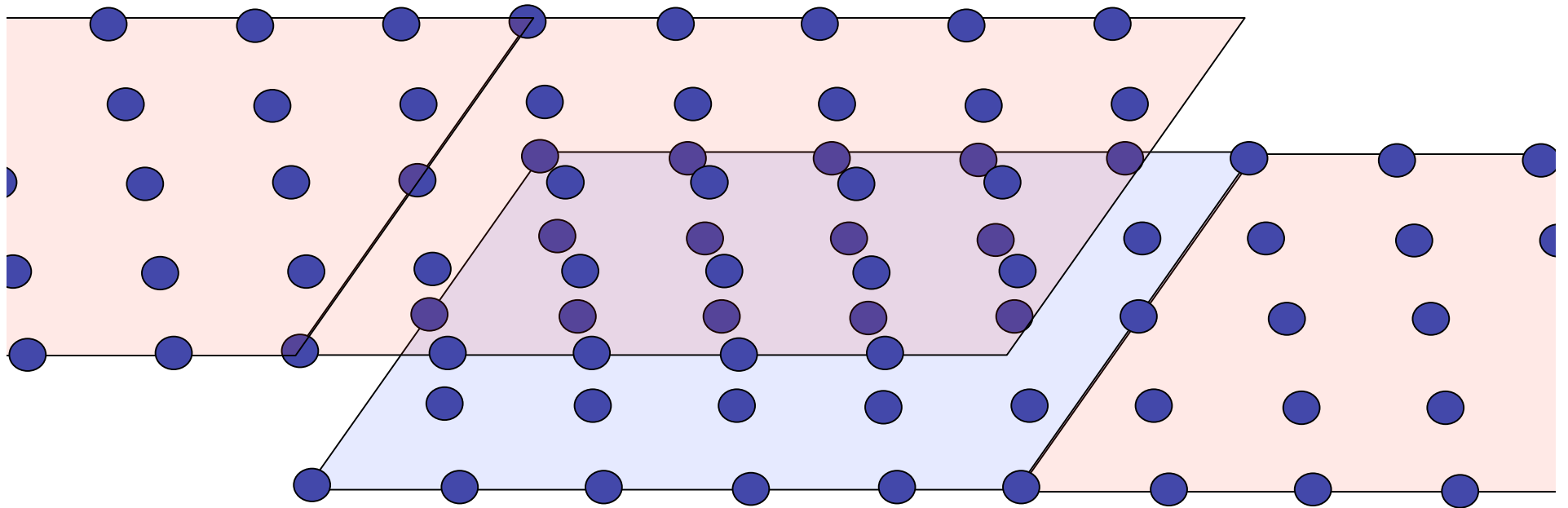
# Giant Electro-resistance



# Giant *Electro-resistance*



# Pseudospin Transfer



**no hands!**



# Pseudospintronics in Graphene

- Pseudospin Chirality important for graphene correlations
- Graphene bilayer band state unstable
- Pseudospin ferromagnetism is a possibility and would lead to interesting 'electro-transport' effects