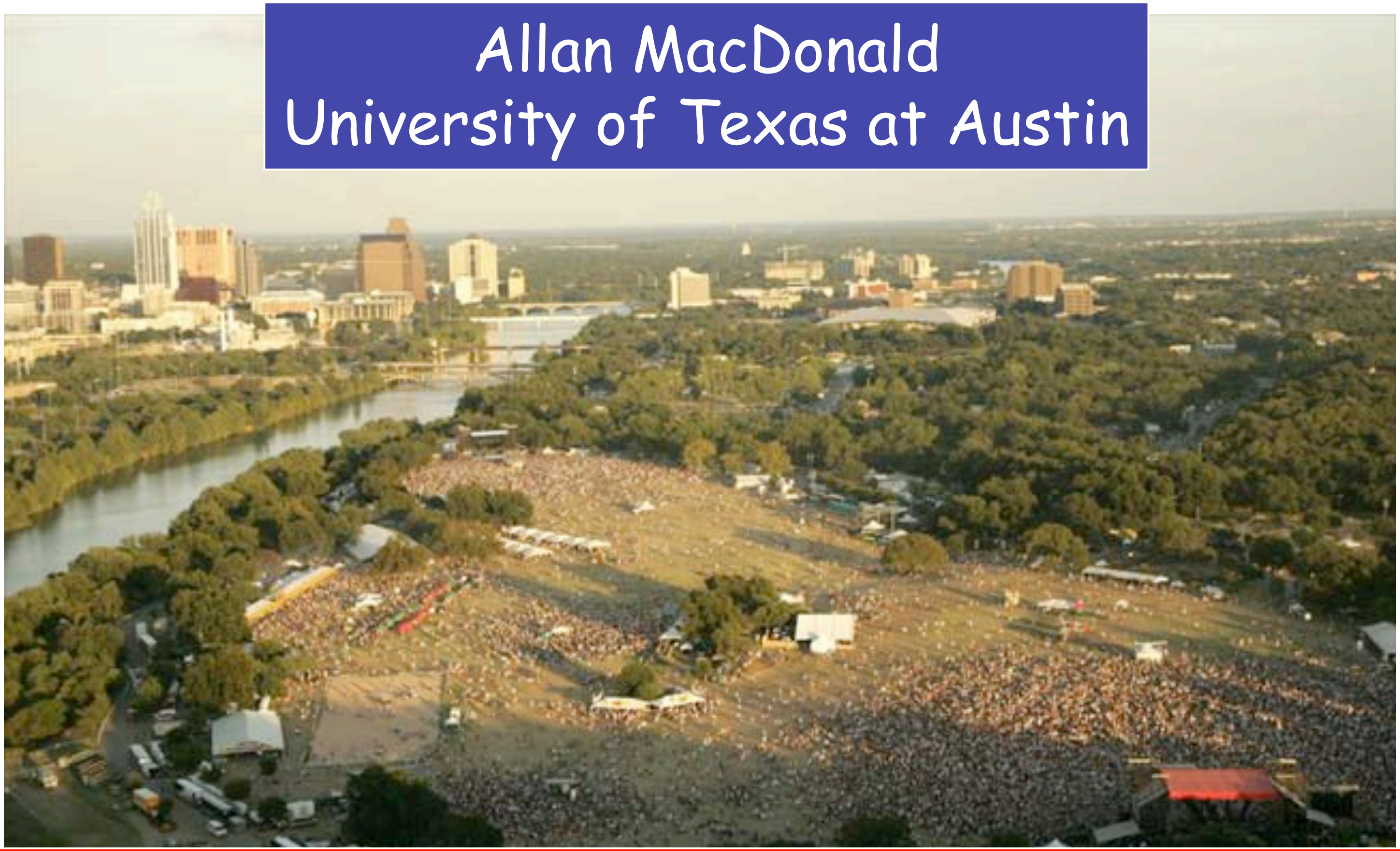
Pseudospintronics in Graphene

Allan MacDonald
University of Texas at Austin



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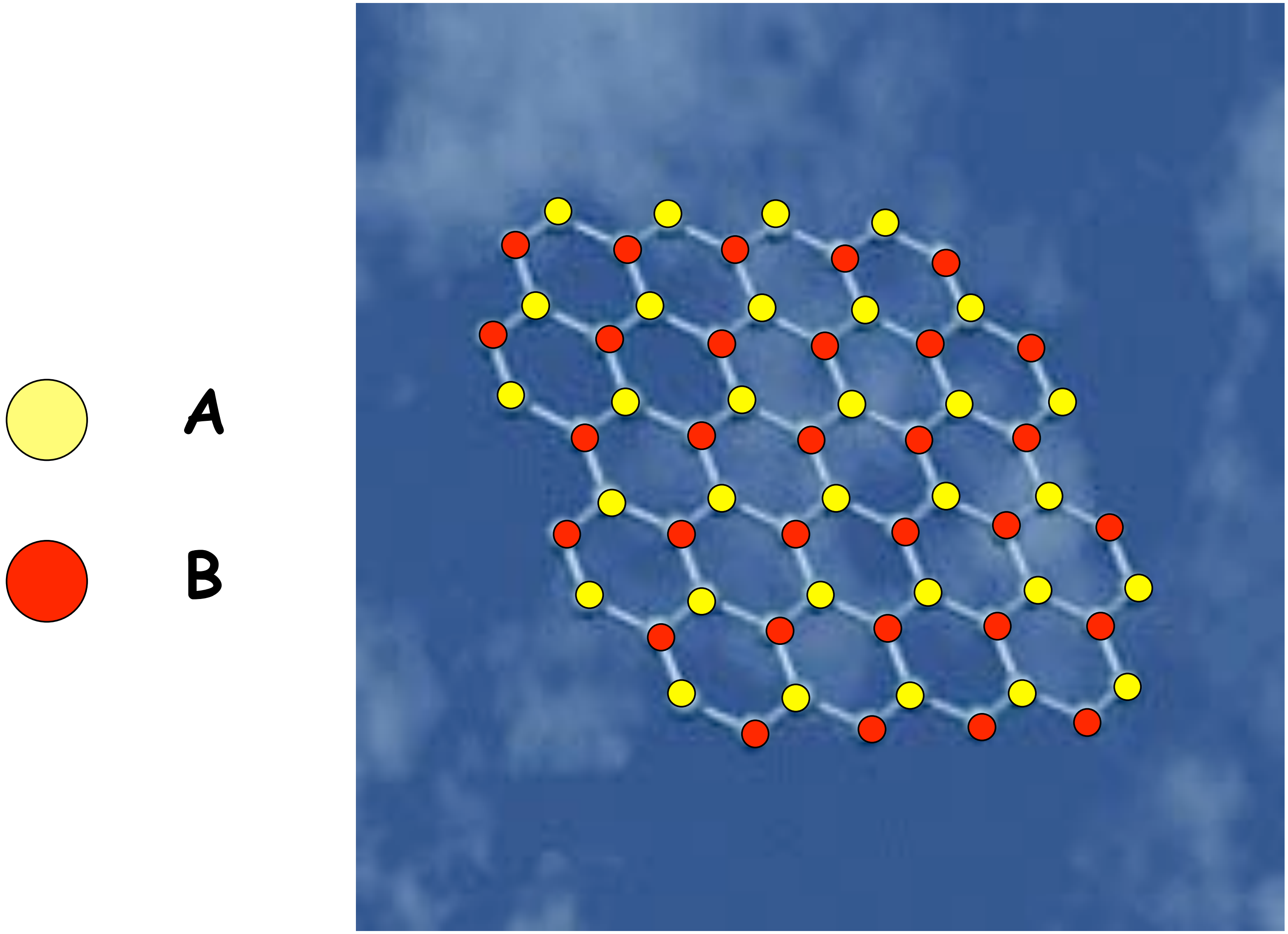
Spintronics & Pseudospintronics

Chiral 2DES

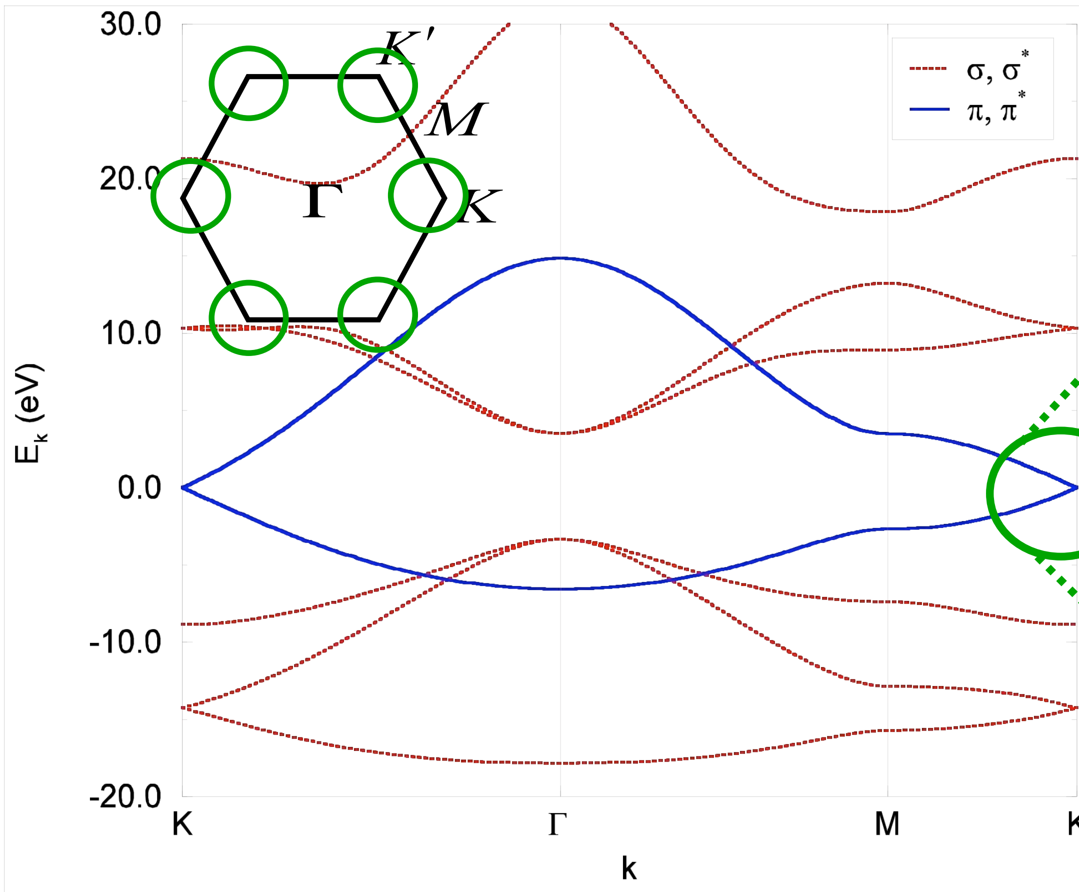
Bilayer Graphene: Pseudospin Ferromagnet?

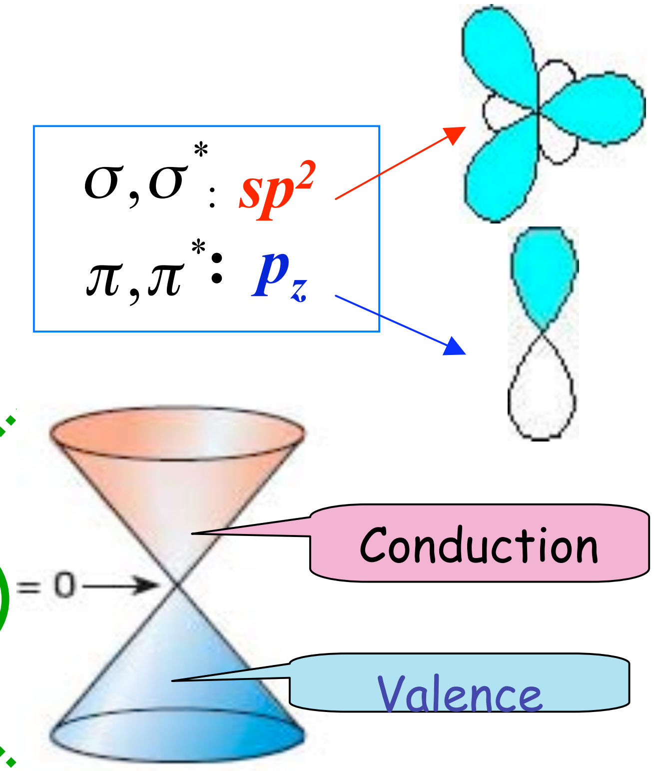
Graphene - Pseudospin



Graphene Bands

Phil Wallace - Physical Review - 1947





Presented at the PITP/SpinAps Asilomar Conference in June 2007

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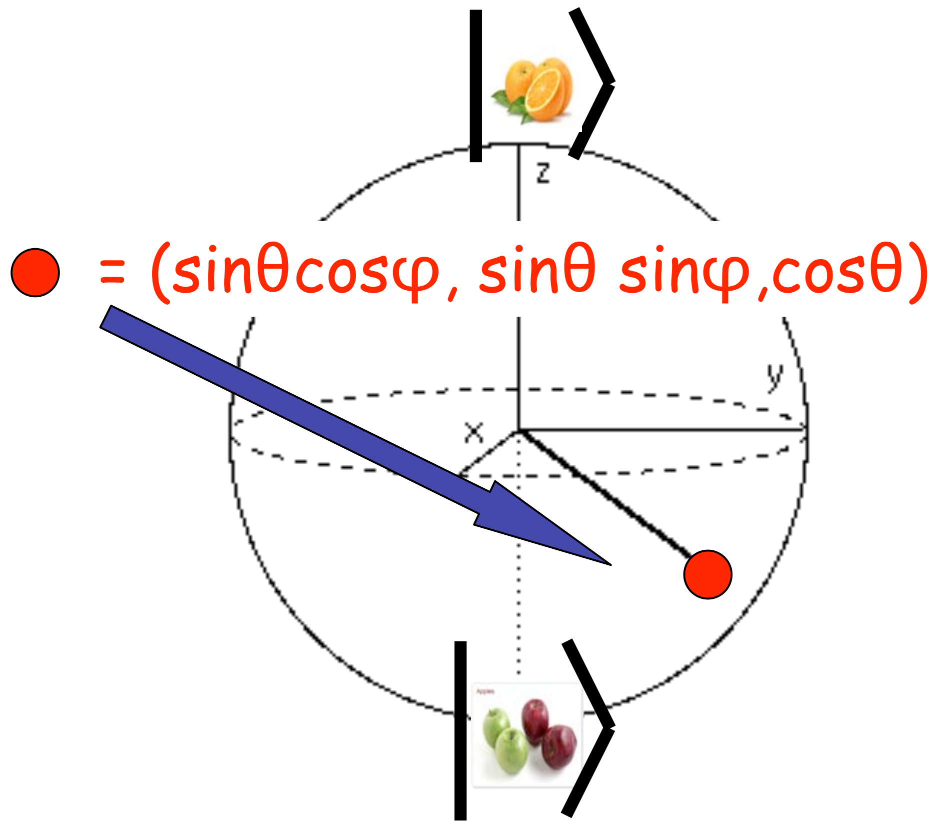
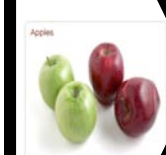
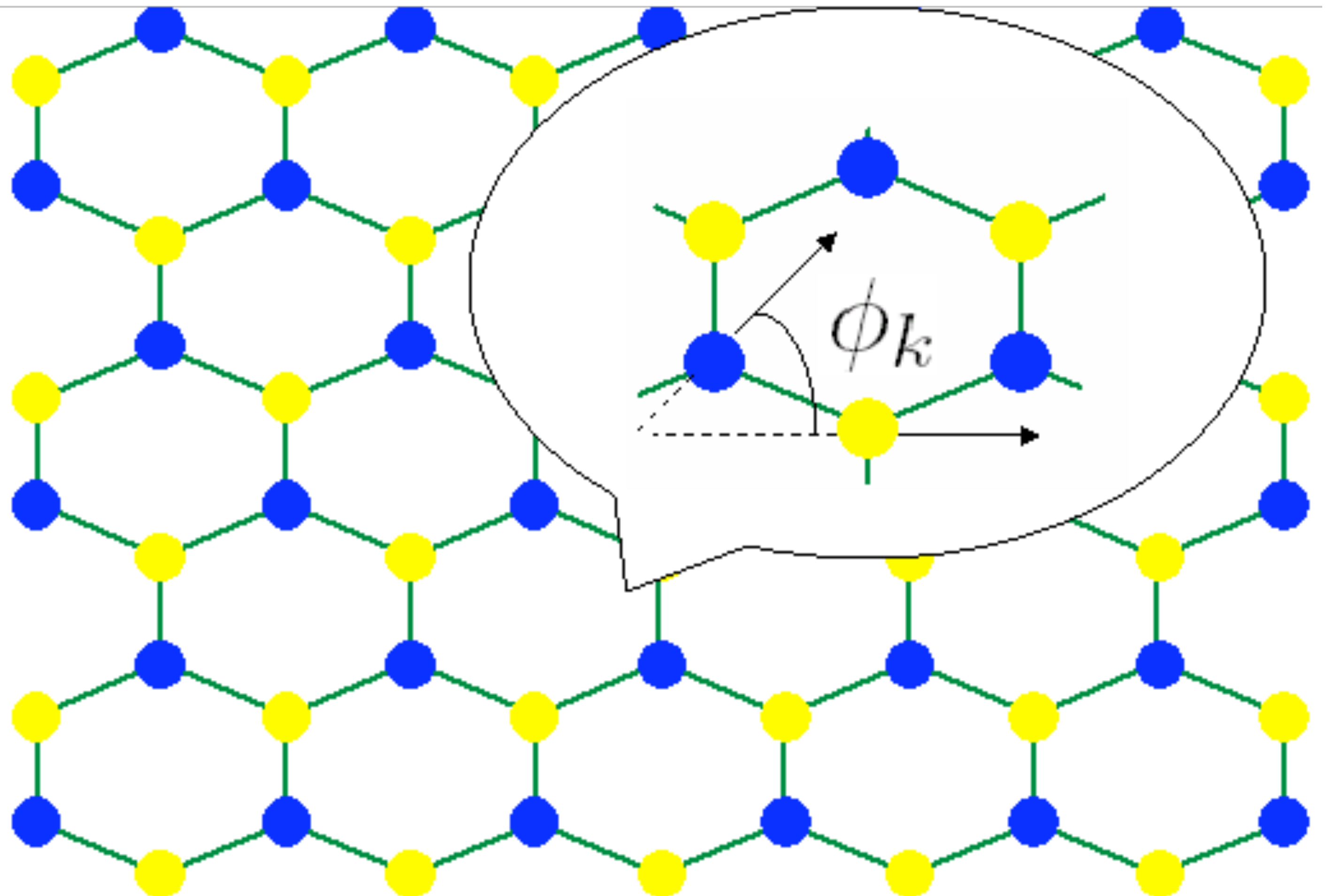
(Pseudo)Spin Coherent States



$\cos(\theta/2)\Big|$  $\Big\rangle + \sin(\theta/2)\, e^{i\varphi} \Big|$  $\Big\rangle$

Graphene Chiral Fermions



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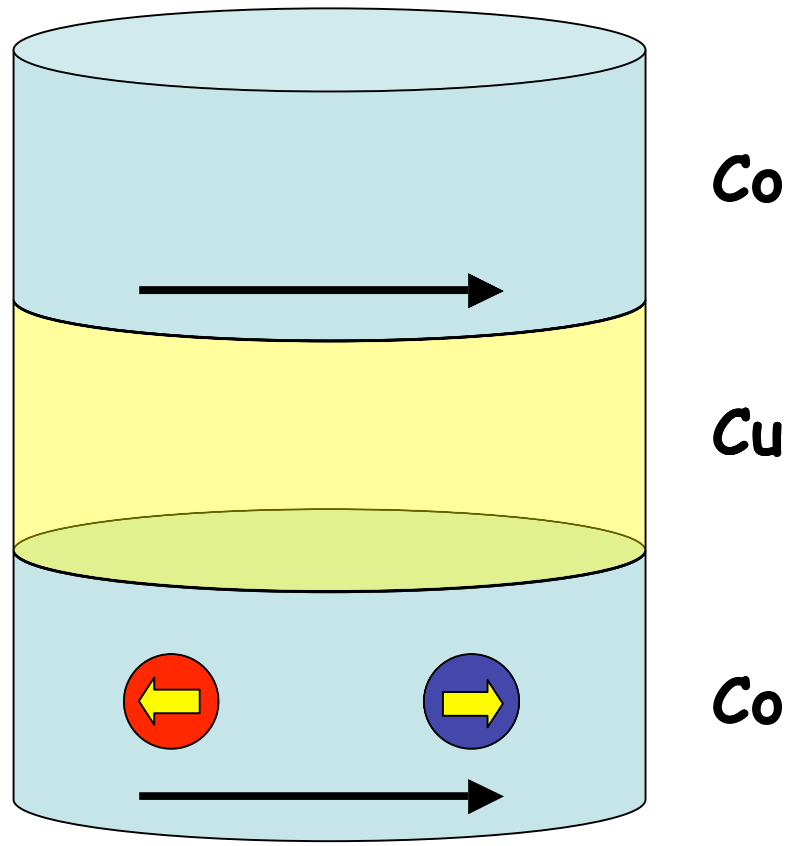
Two-Channel Conduction & CPP GMR

CPP = Current Perpendicular to Plane
GMR = Giant Magnetoresistance

Neville Mott
1905-1996

Minority

Majority

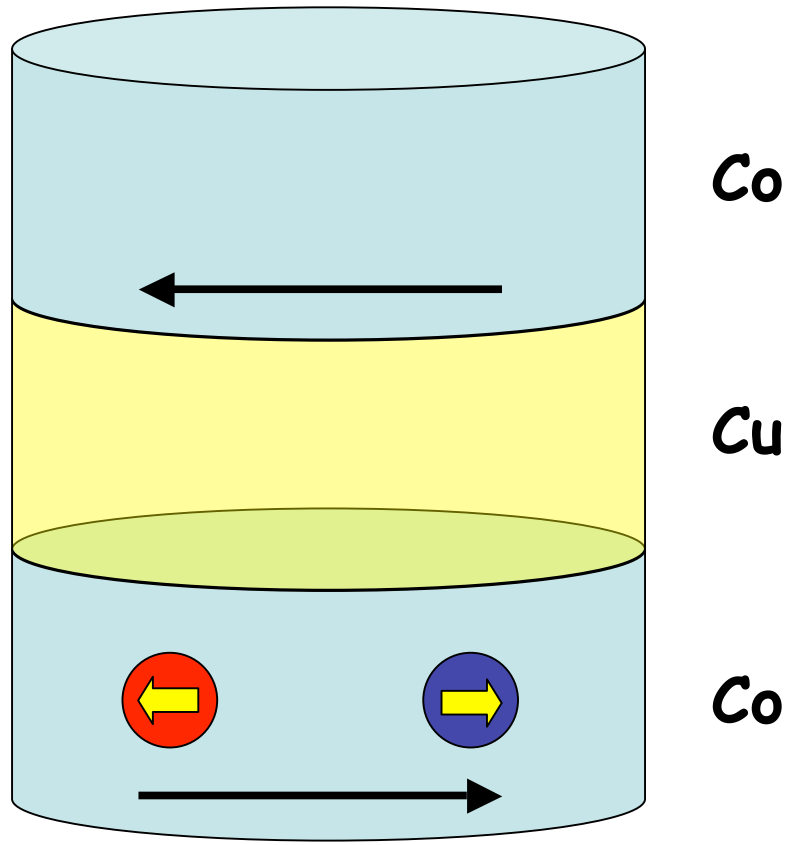


CPP GMR - High Resistance State

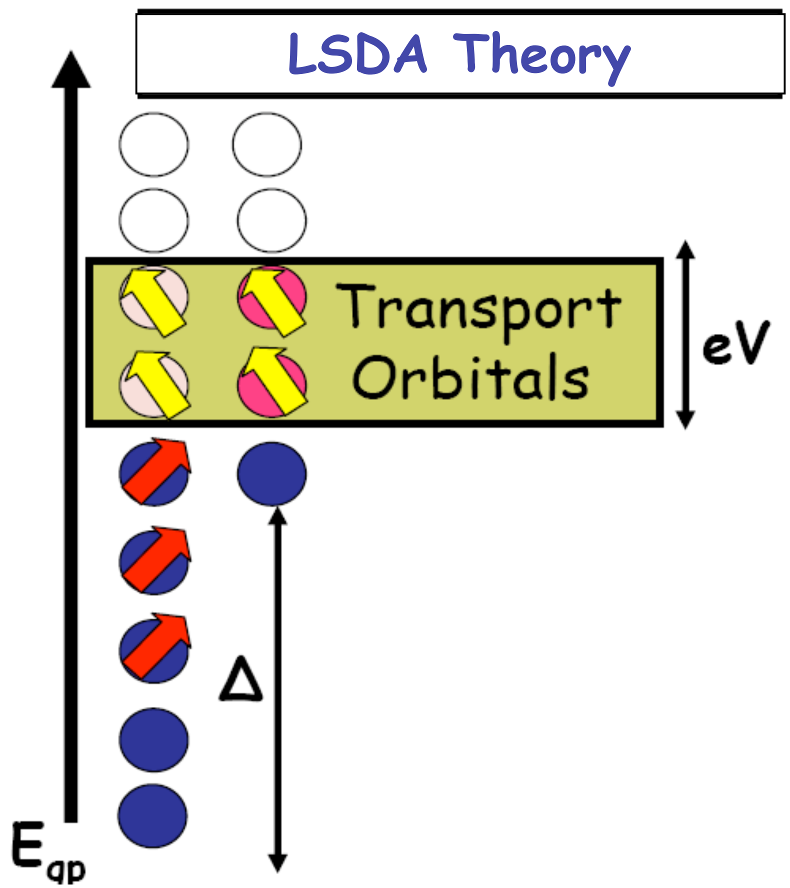
Majority

Minority

Neville Mott
1905-1996



Spin Transfer Torques



Spintronics & Pseudospintronics

Chiral 2DES

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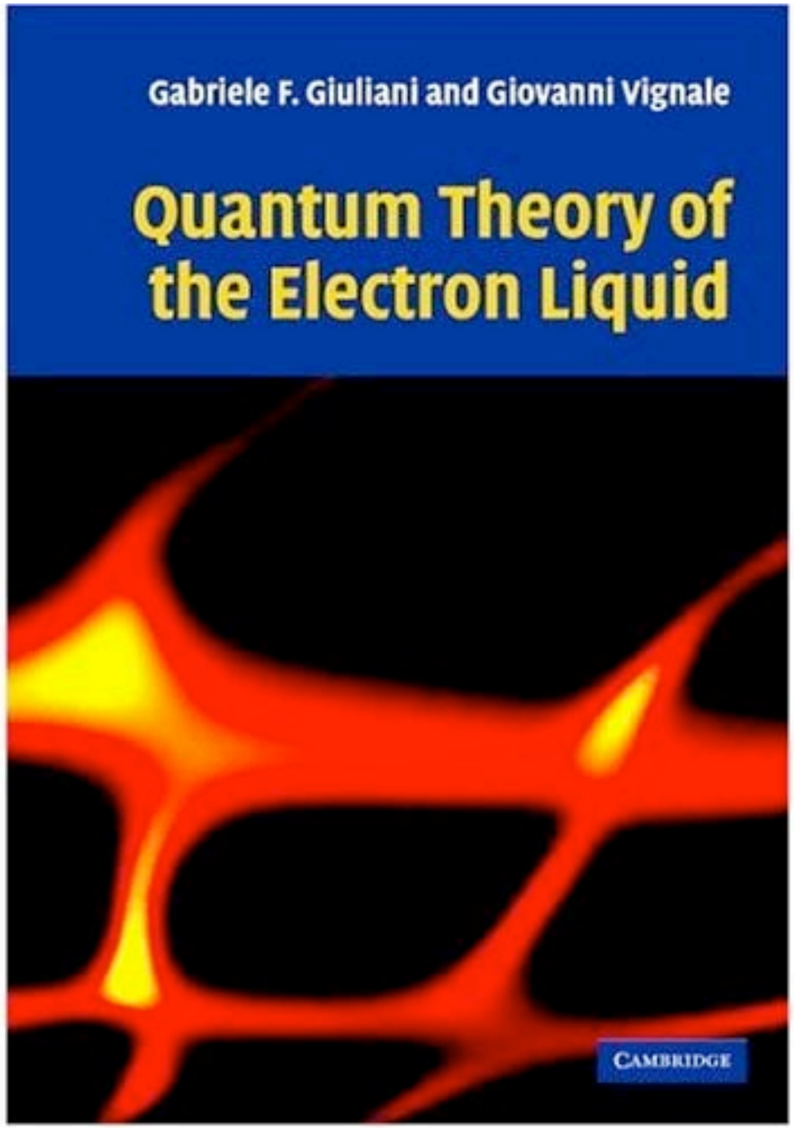
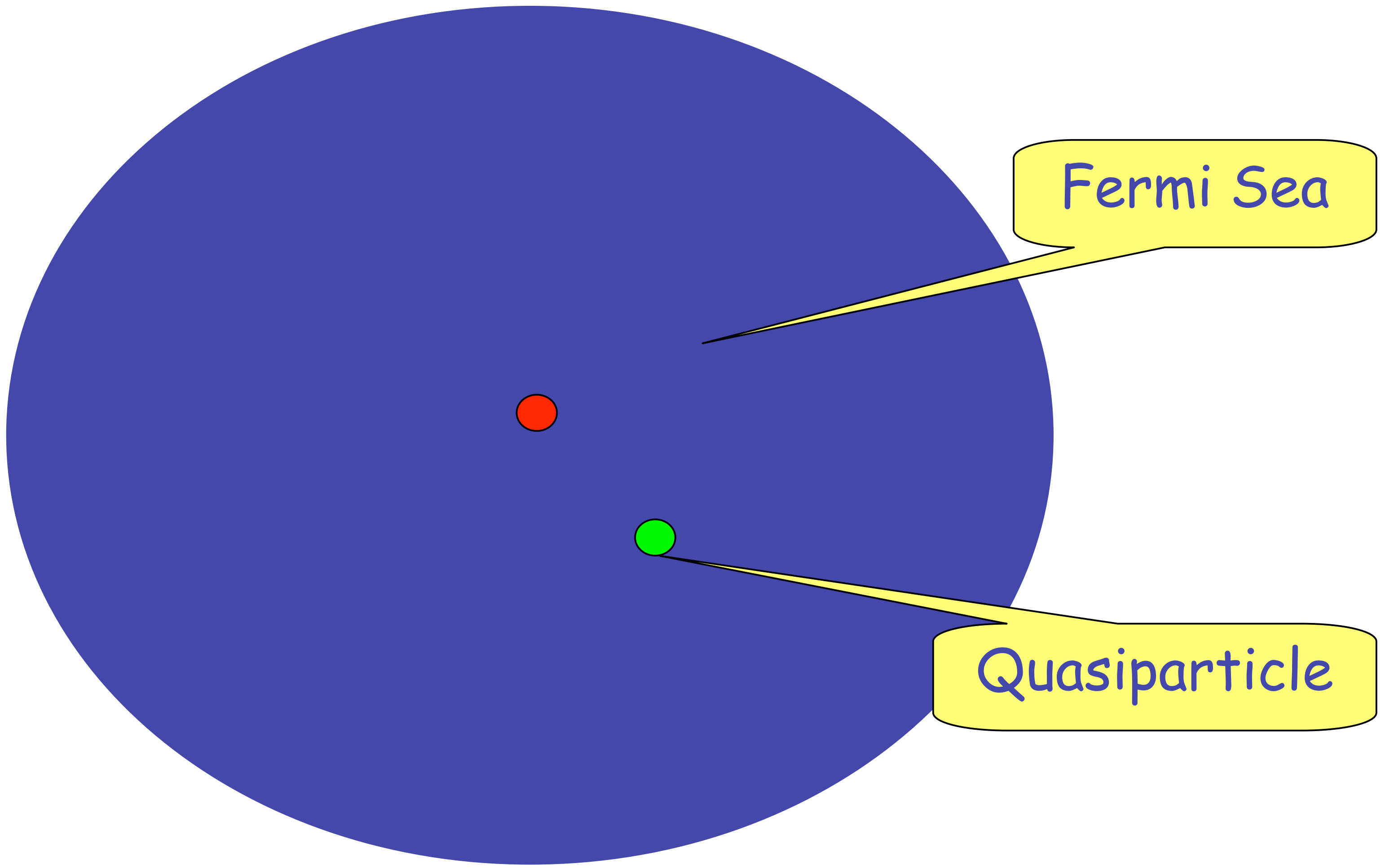
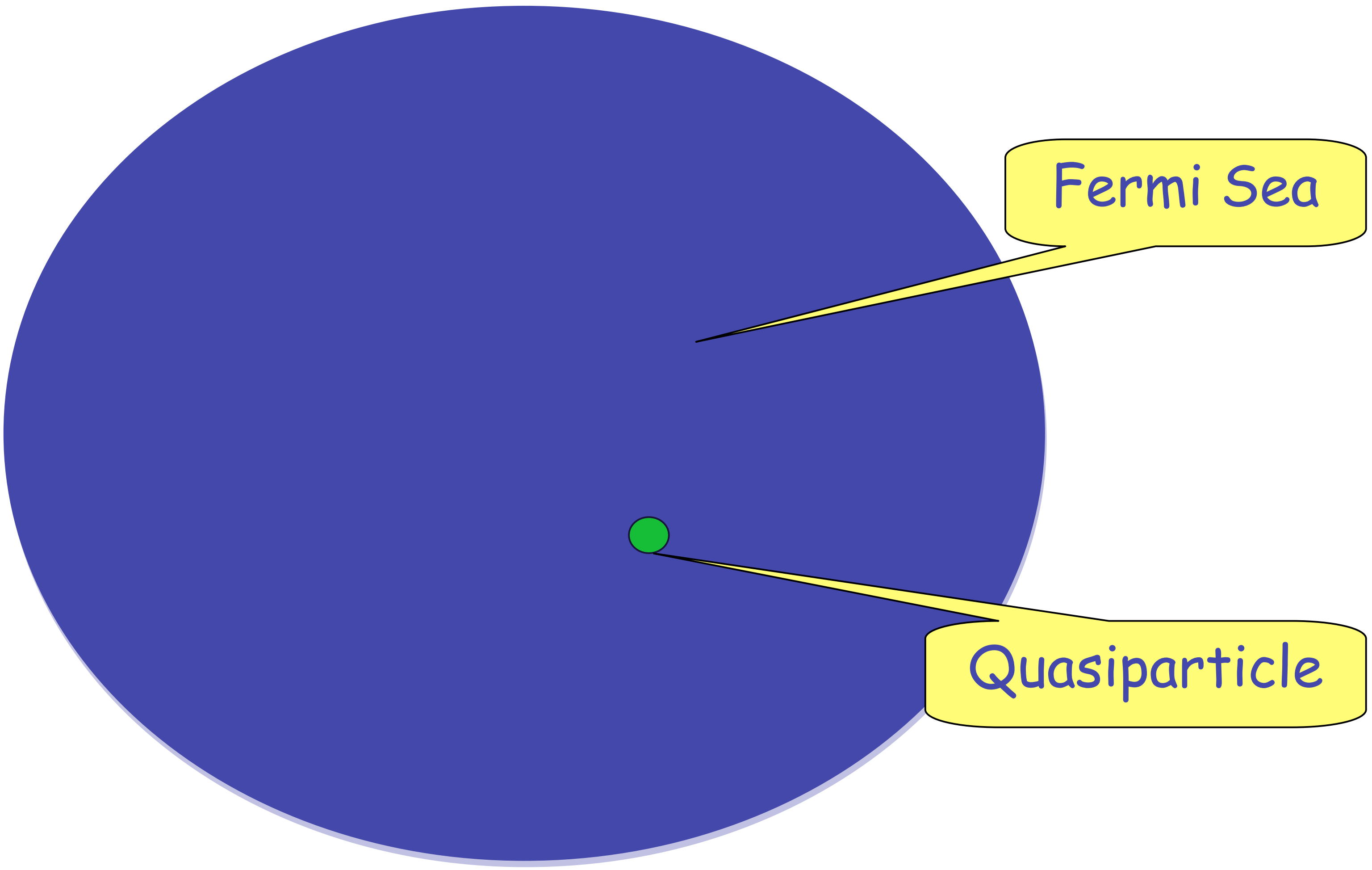
Electron Gas Theory



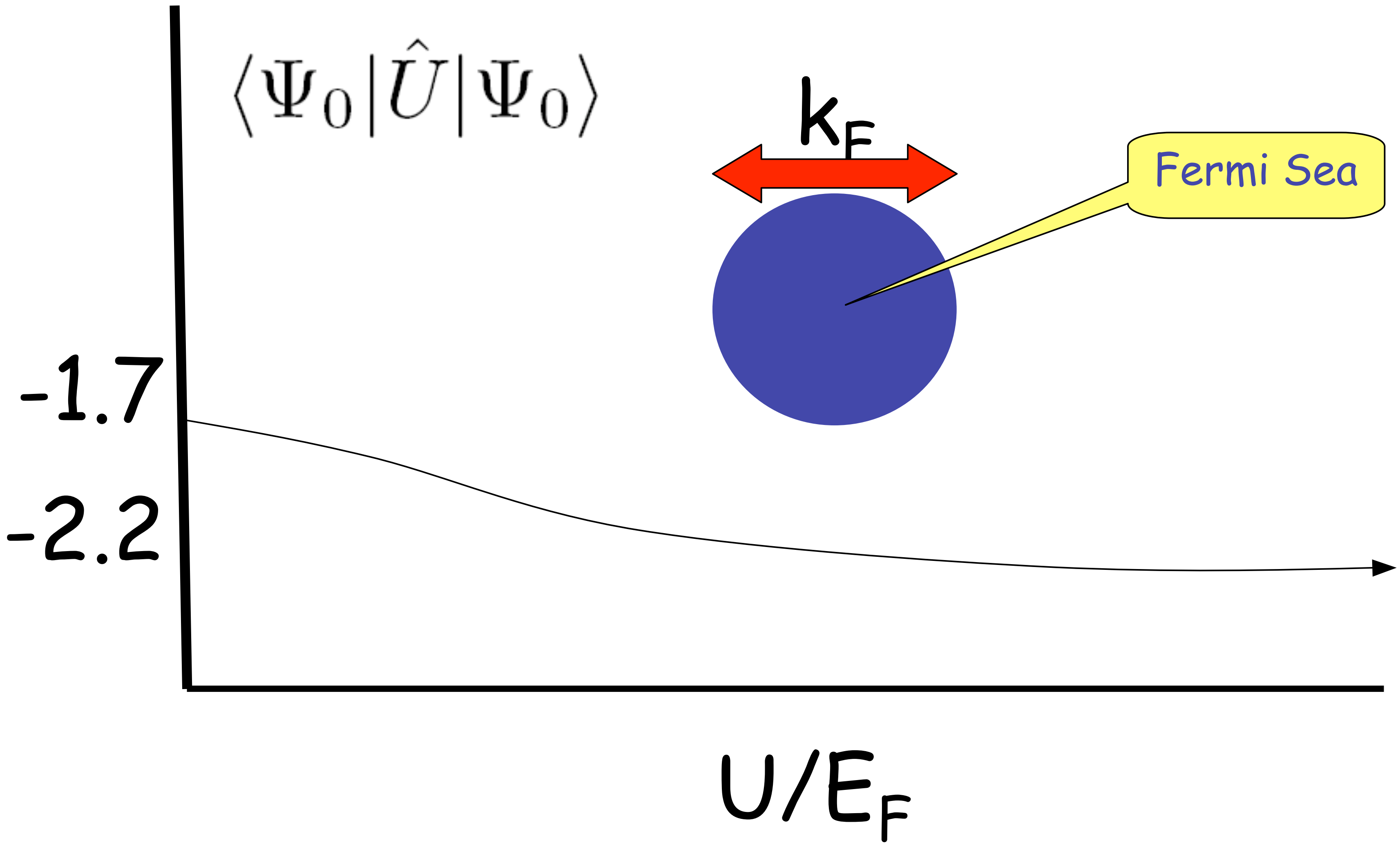
Exchange



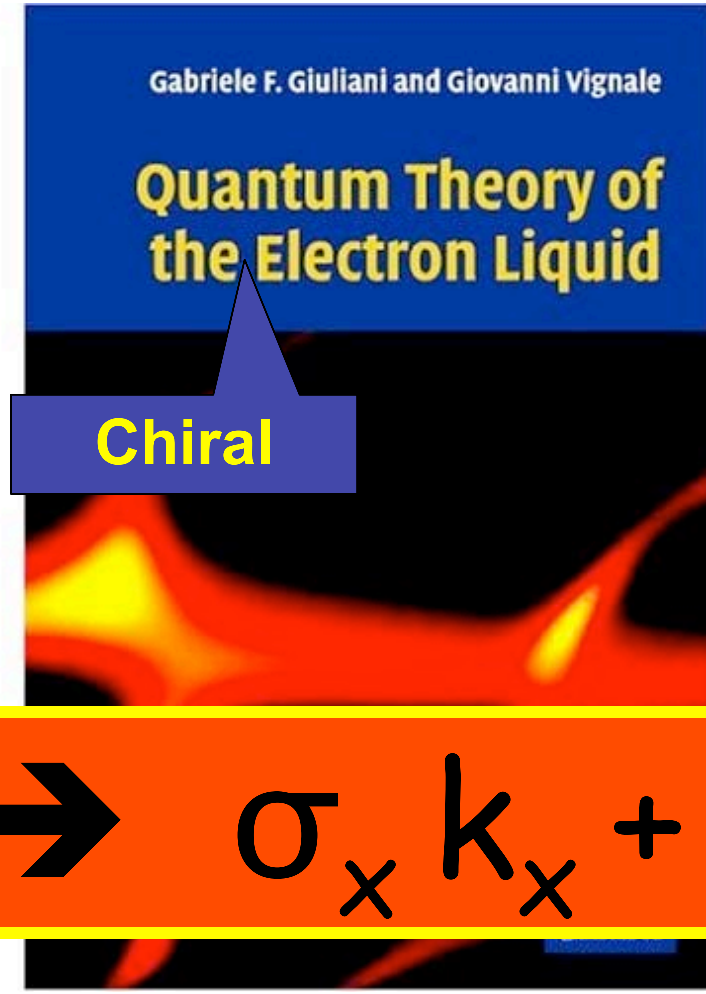
Correlation



Electron Gas Theory



Electron Gas Theory



New and improved

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

Graphene Continuum Model

$v_F = c/300$

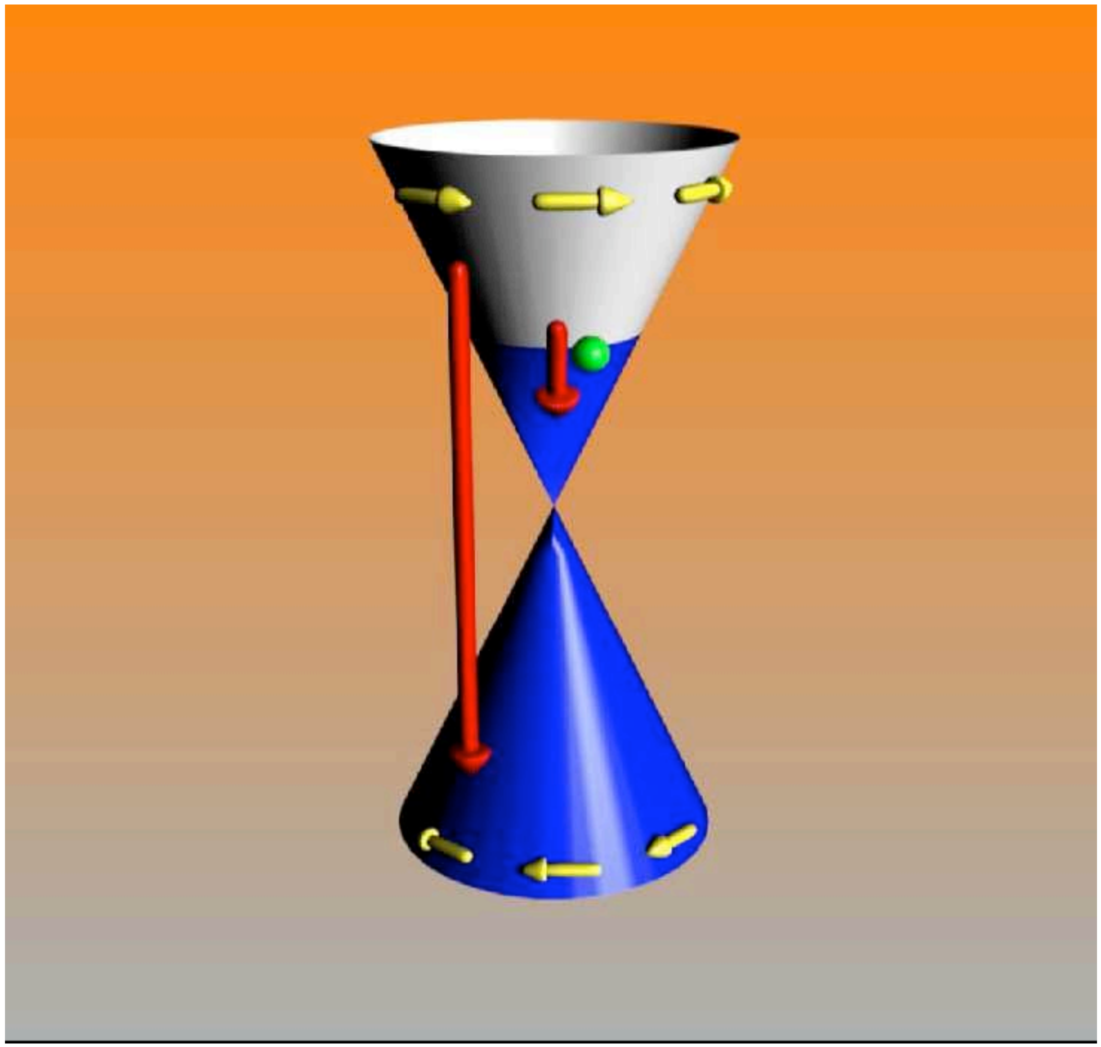
$$\mathcal{H} = \mathcal{H}_0 + \hat{V}$$

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

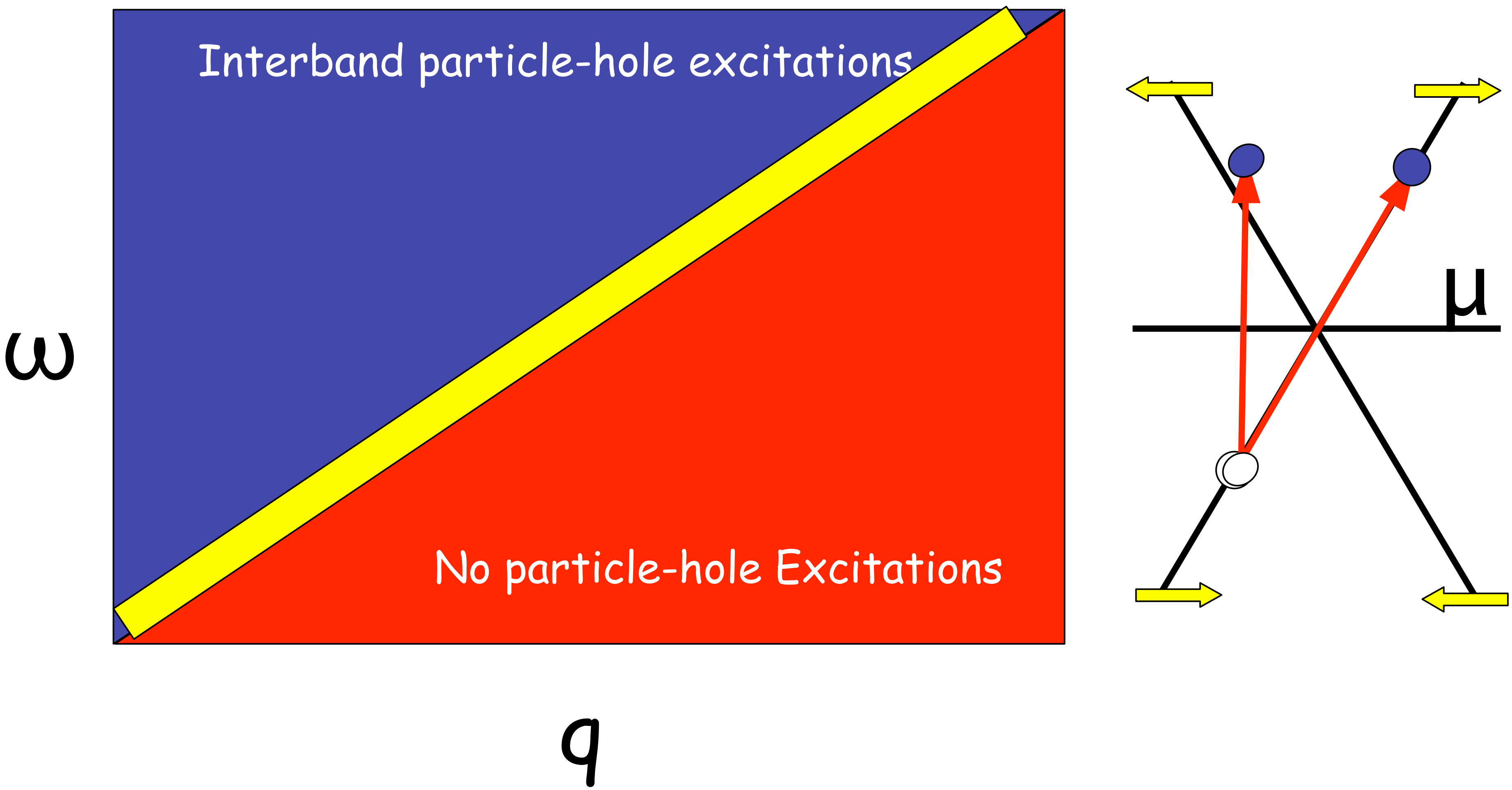
"relativistic"

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

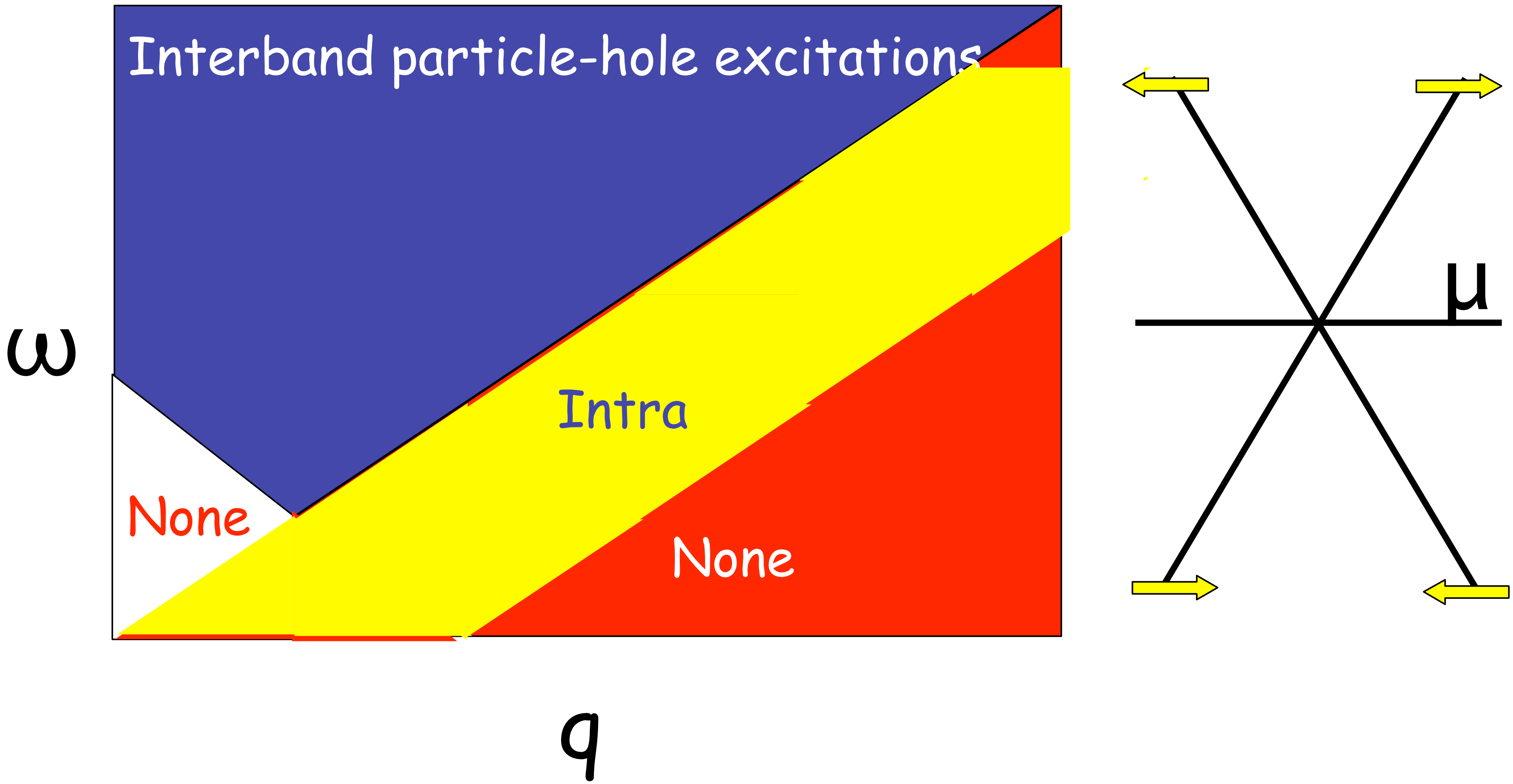
Chiral 2DES



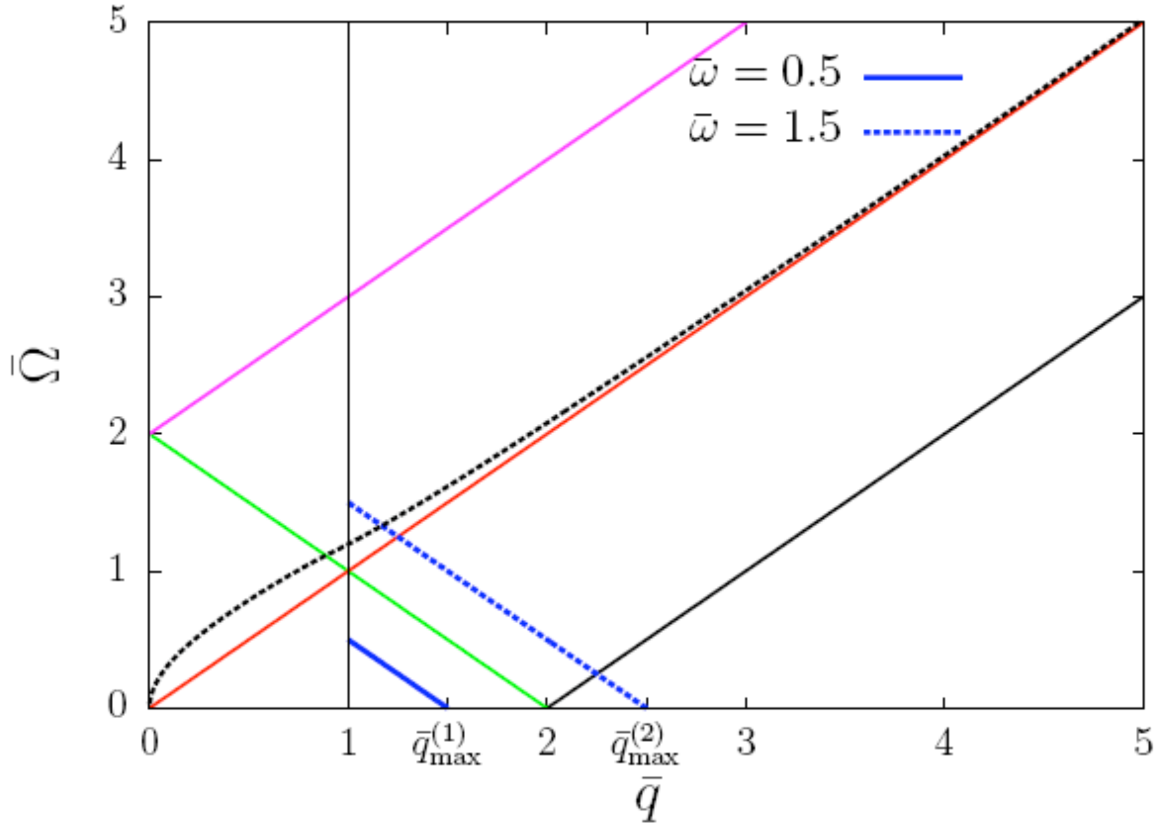
Neutral Graphene Fluctuations



Doped Graphene Fluctuations

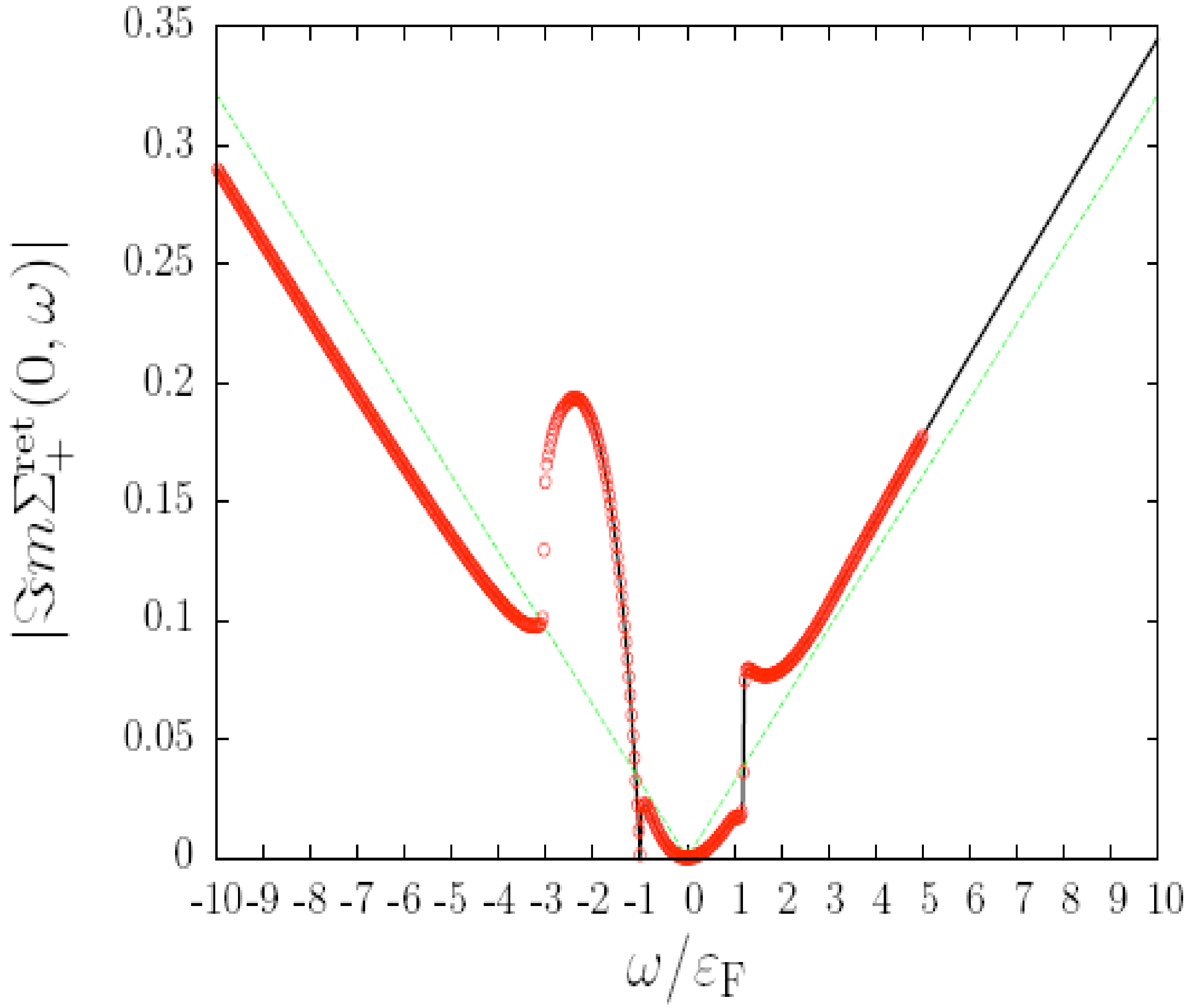


Plasmons

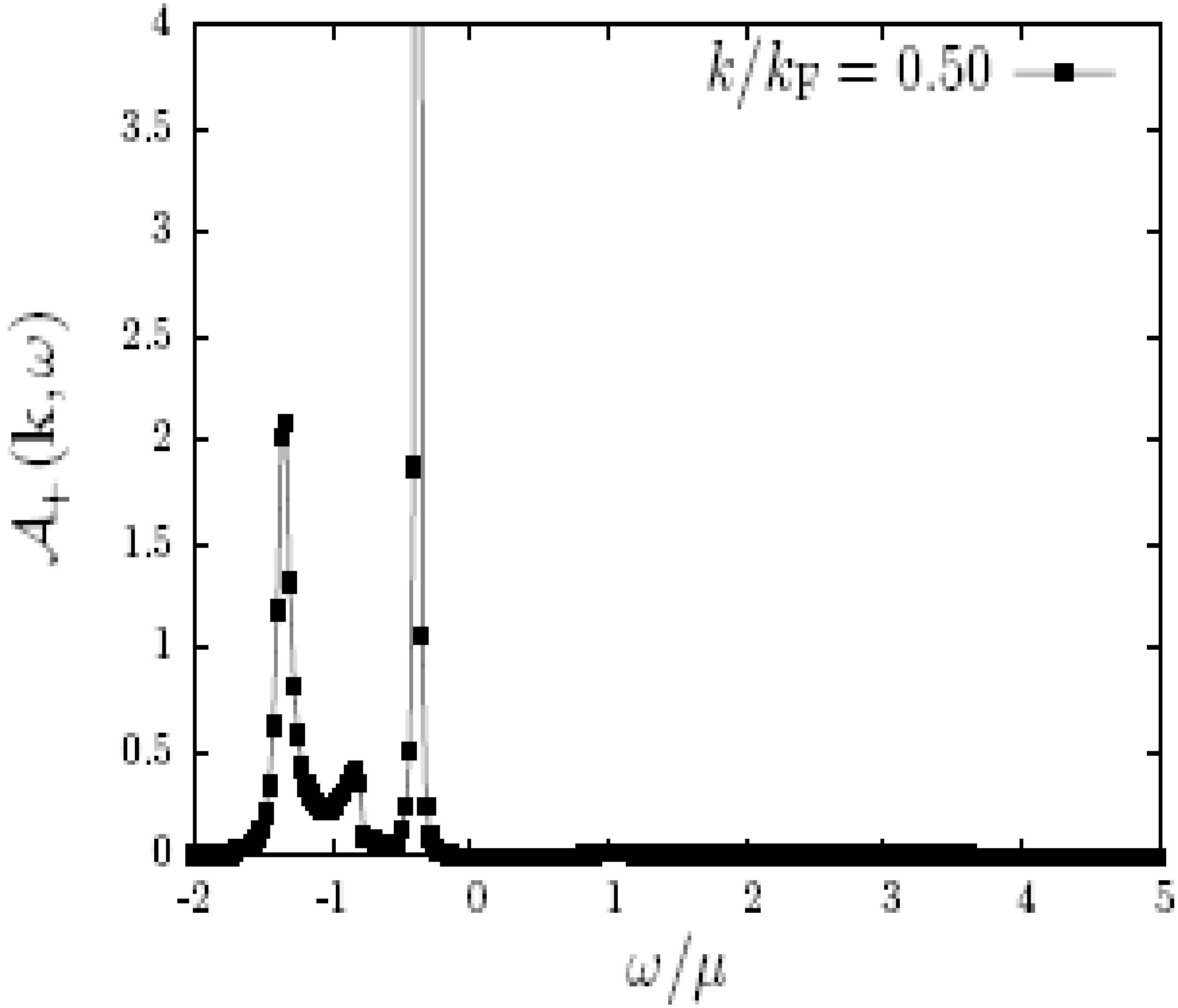


$\bar{\omega} = 0.5$
$\bar{\omega} = 1.5$
$\bar{\Omega}$
0
1
2
3
4
5
0
1
$\bar{q}^{(1)}_{\max}$
2
$\bar{q}^{(2)}_{\max}$
3
4
5
$\bar{q}$

Quasiparticle-Decay



ARPES



$k/k_F = 0.50$
$\mathcal{A}_+(\mathbf{k}, \omega)$
ω/μ
4
3.5
3
2.5
2
1.5
1
0.5
0
-2
-1
0
1
2
3
4
5

Renormalized Velocity

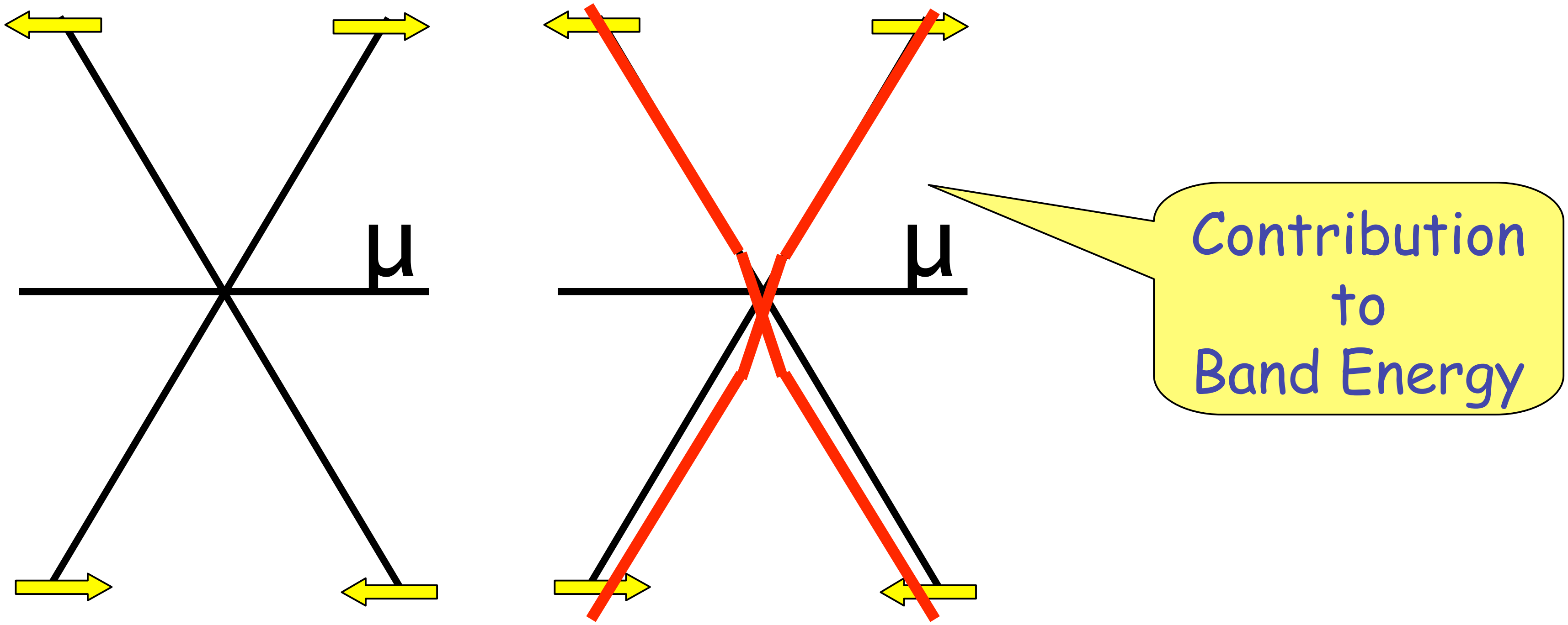
$$\Sigma^{(0)}_{\mathbf{k},s} = -\frac{1}{S}\sum_{\mathbf{k}',s'} V_{ss'}(\mathbf{k},\mathbf{k}')n^{(0)}_{s'}(\mathbf{k}')$$

μ

Contribution to Band Energy

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

Renormalized Velocity



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

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

Chiral Electron Gas Properties

$\chi/\chi_0 < 1$

- $\kappa/\kappa_0 < 1$
- $v/v_0 > 1$

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

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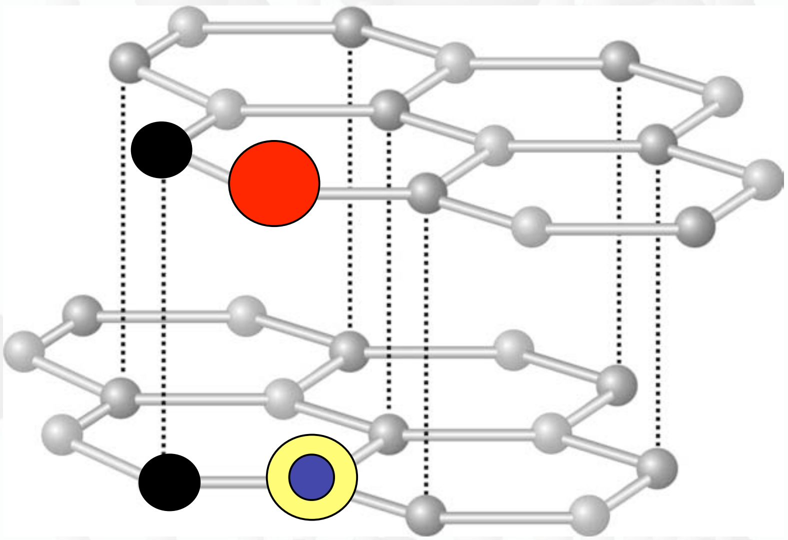
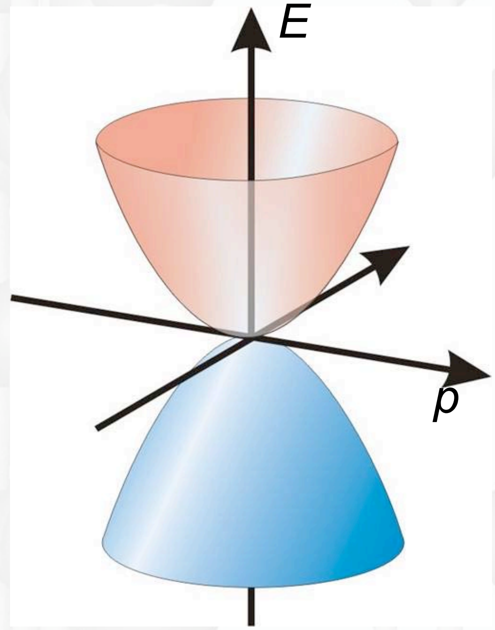
Bilayer Graphene: Pseudospin Ferromagnet?

BILAYER GRAPHENE

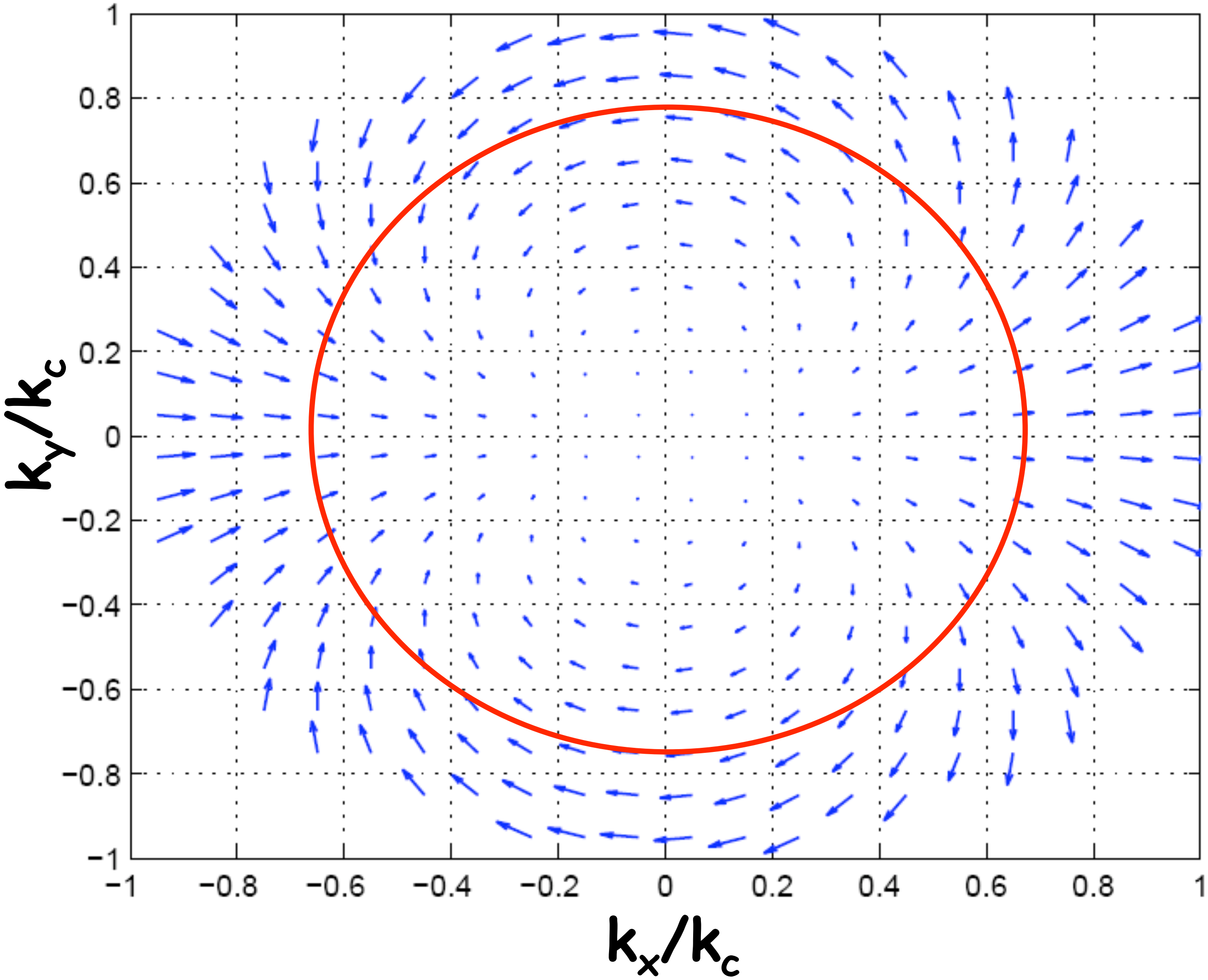




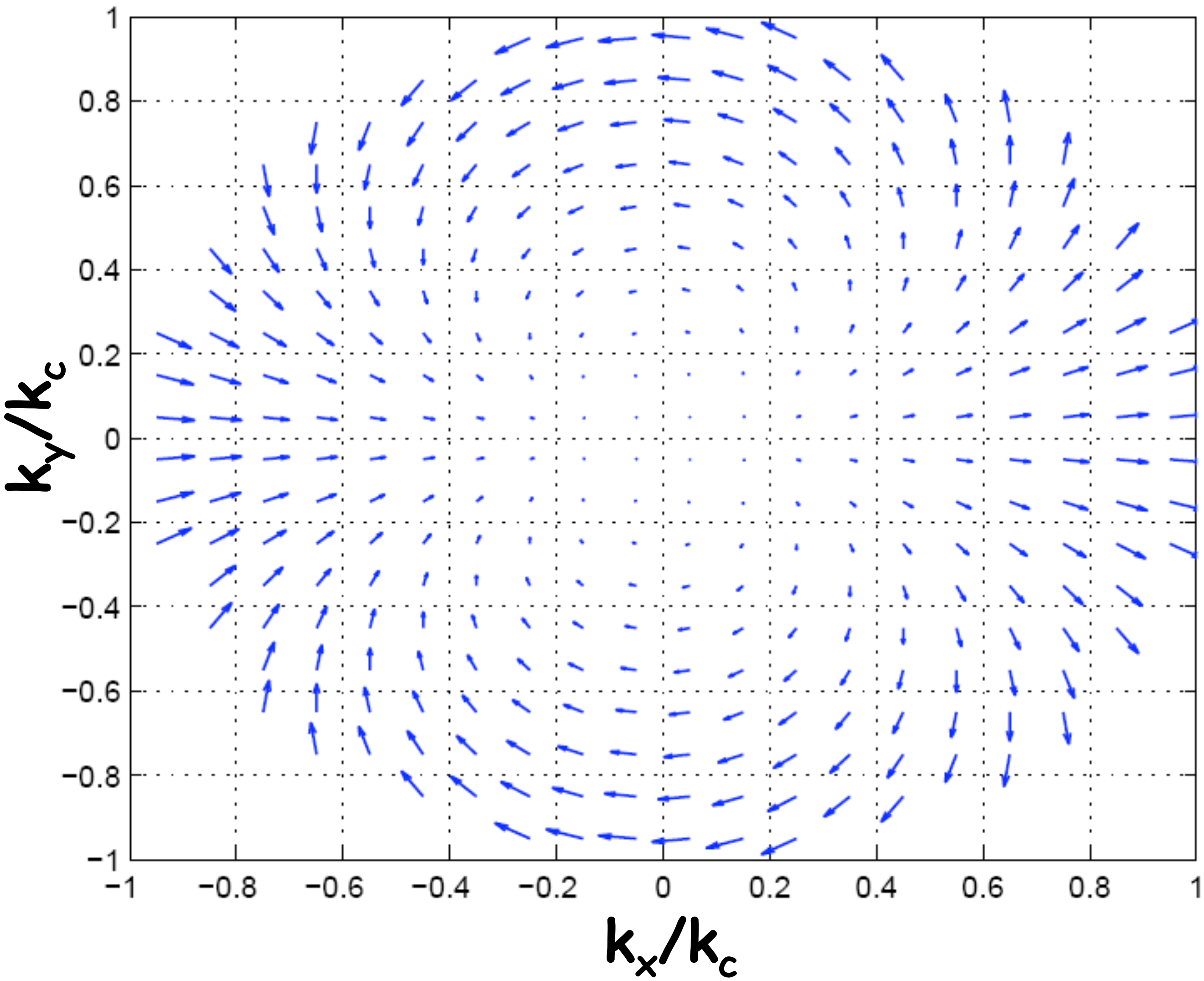
Manchester Nature Phys **2**, 177 (2006)

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

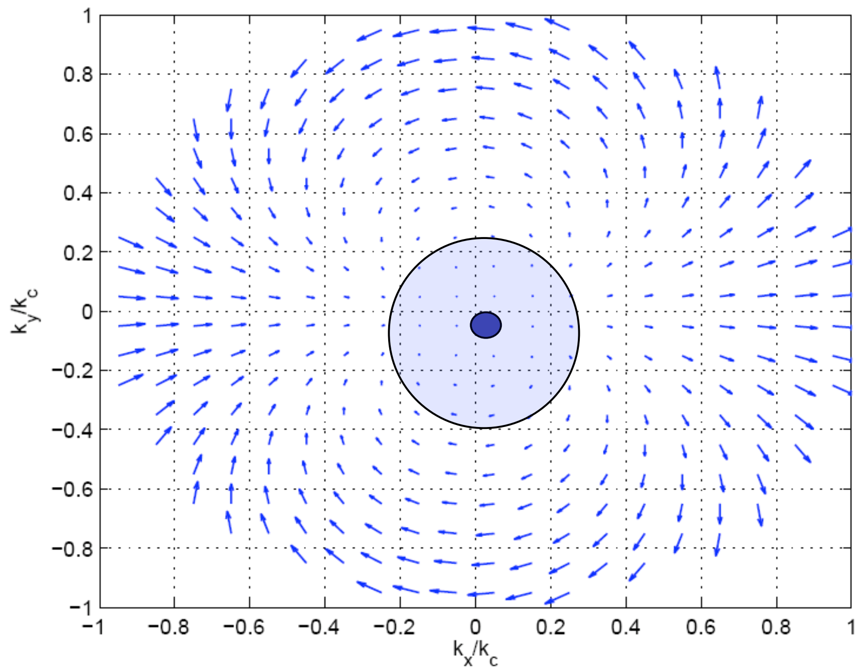
Bilayer Pseudospin Orientations



Bilayer Pseudospin Orientations

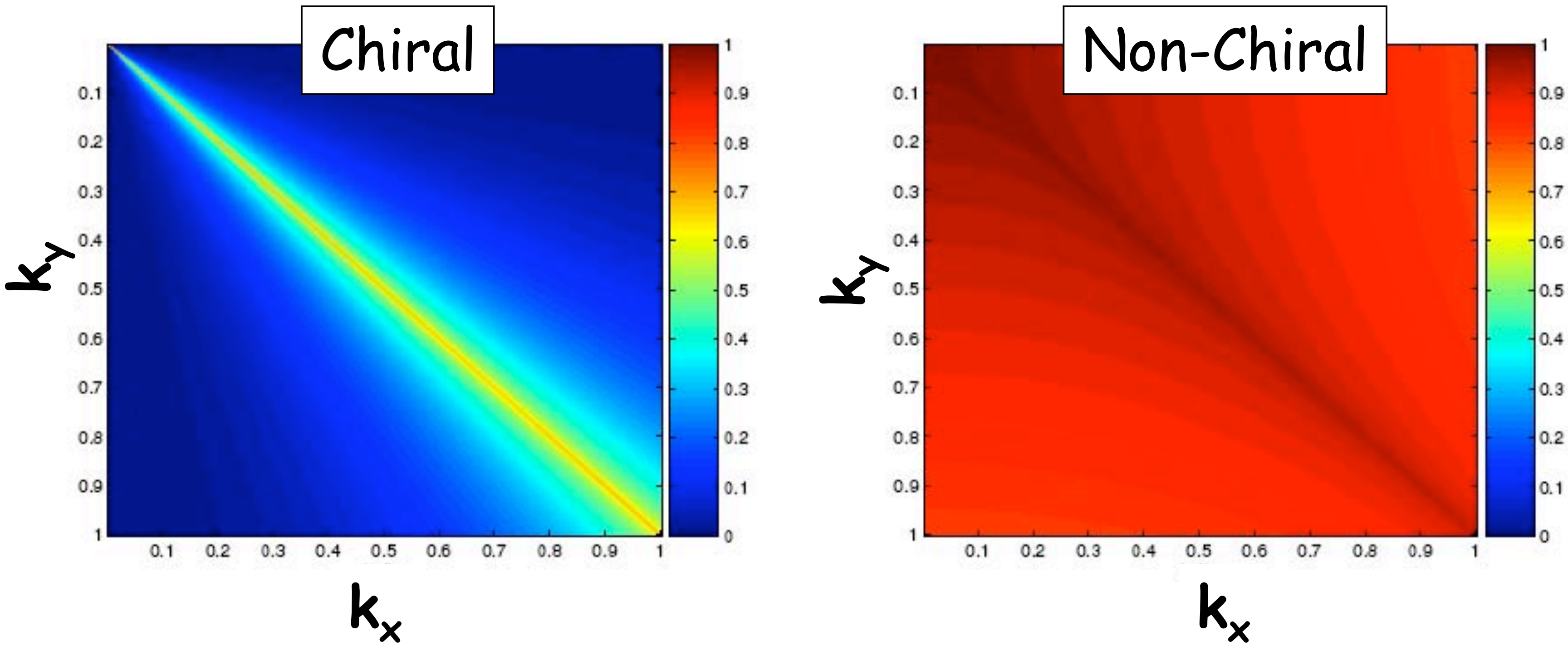


Pseudospin Exchange Fields



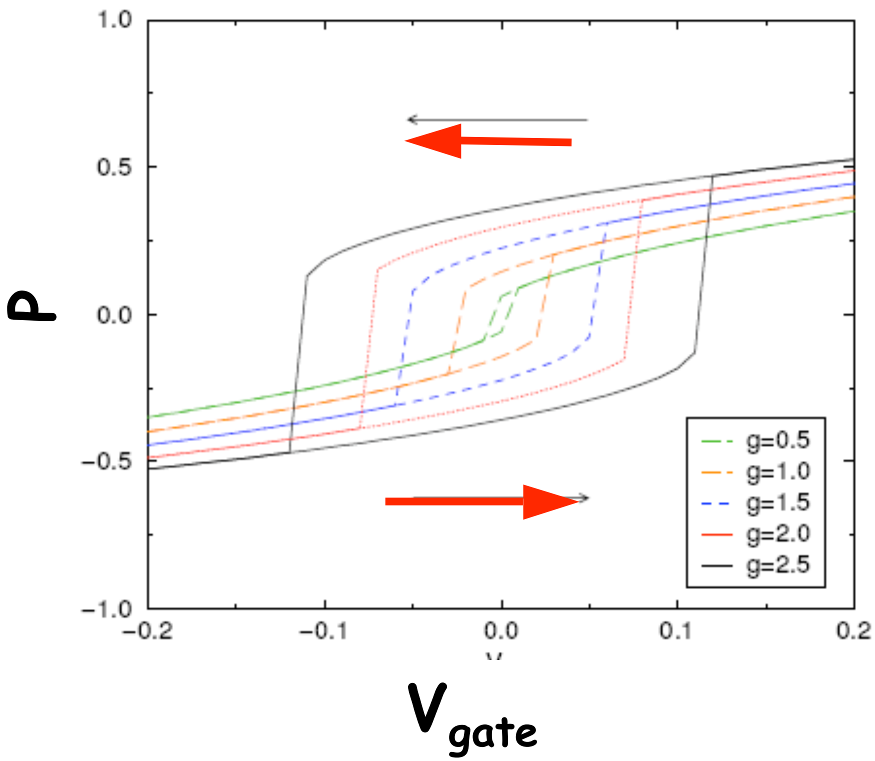
$$\vec{B}_{\mathrm{x}}(\vec{k}) = \frac{1}{2A} \sum_{\vec{k}'} V(\vec{k} - \vec{k}')\ \hat{n}(\vec{k}')$$

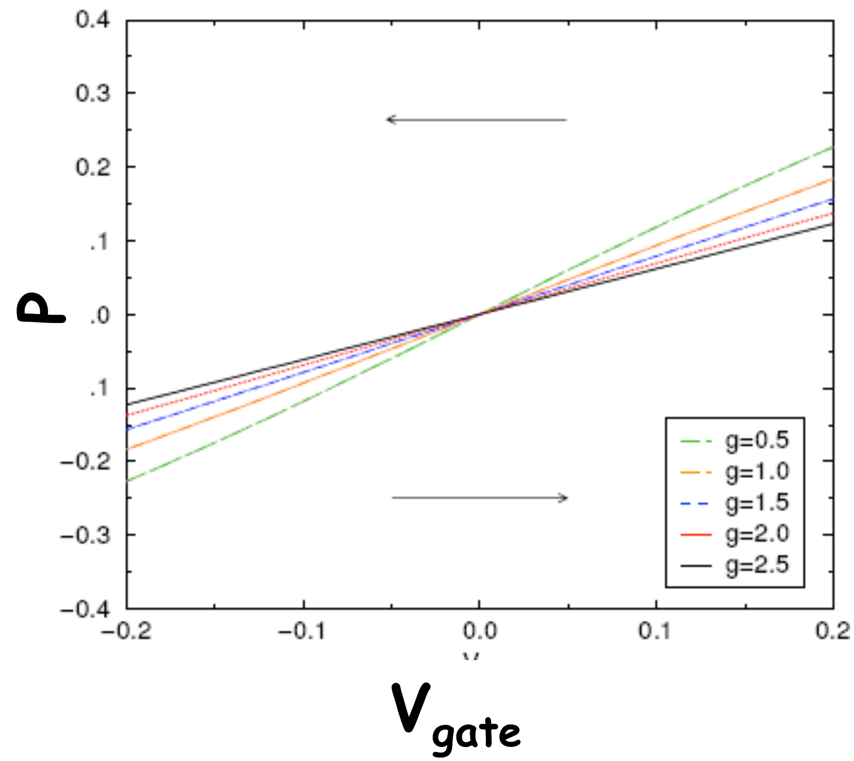
Self-Consistent HF Theory



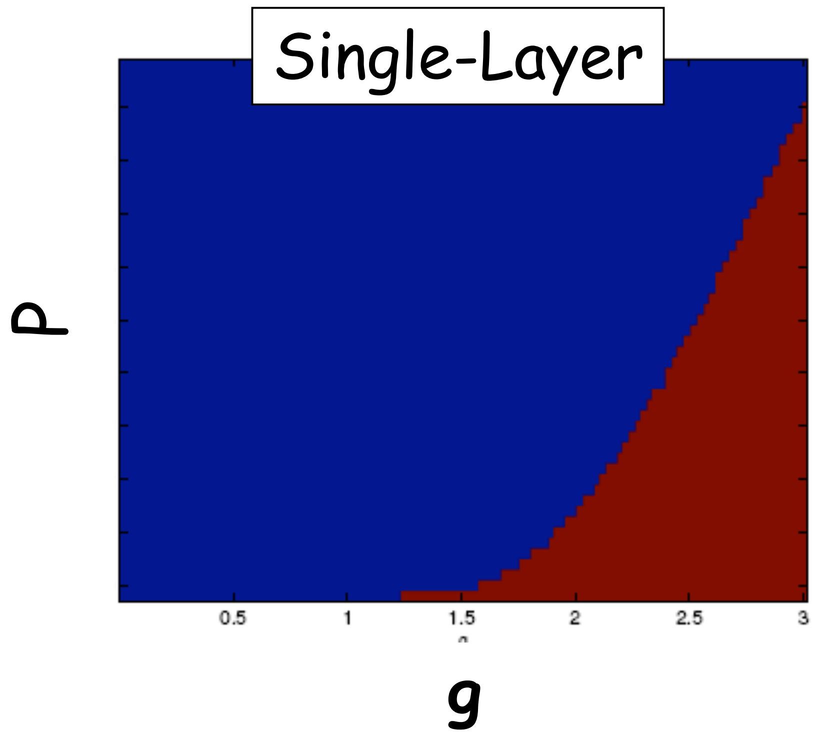
$$\left[\vec{B}_{\rm band}(\vec{k}) + \vec{B}_{\rm x}(\vec{k})\right] \times \hat{n}(\vec{k}) = 0$$

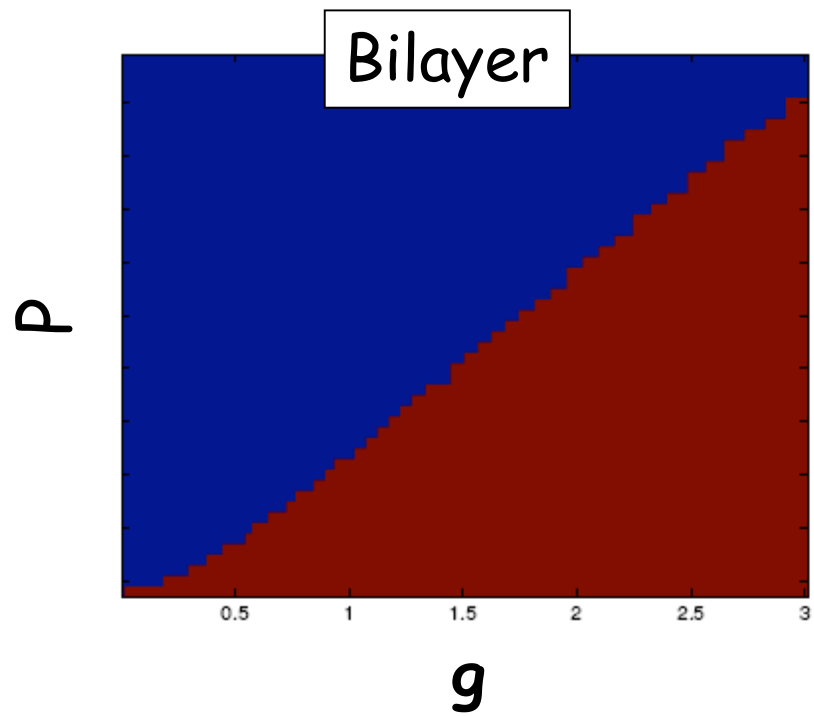
Pseudospin Ferromagnetism



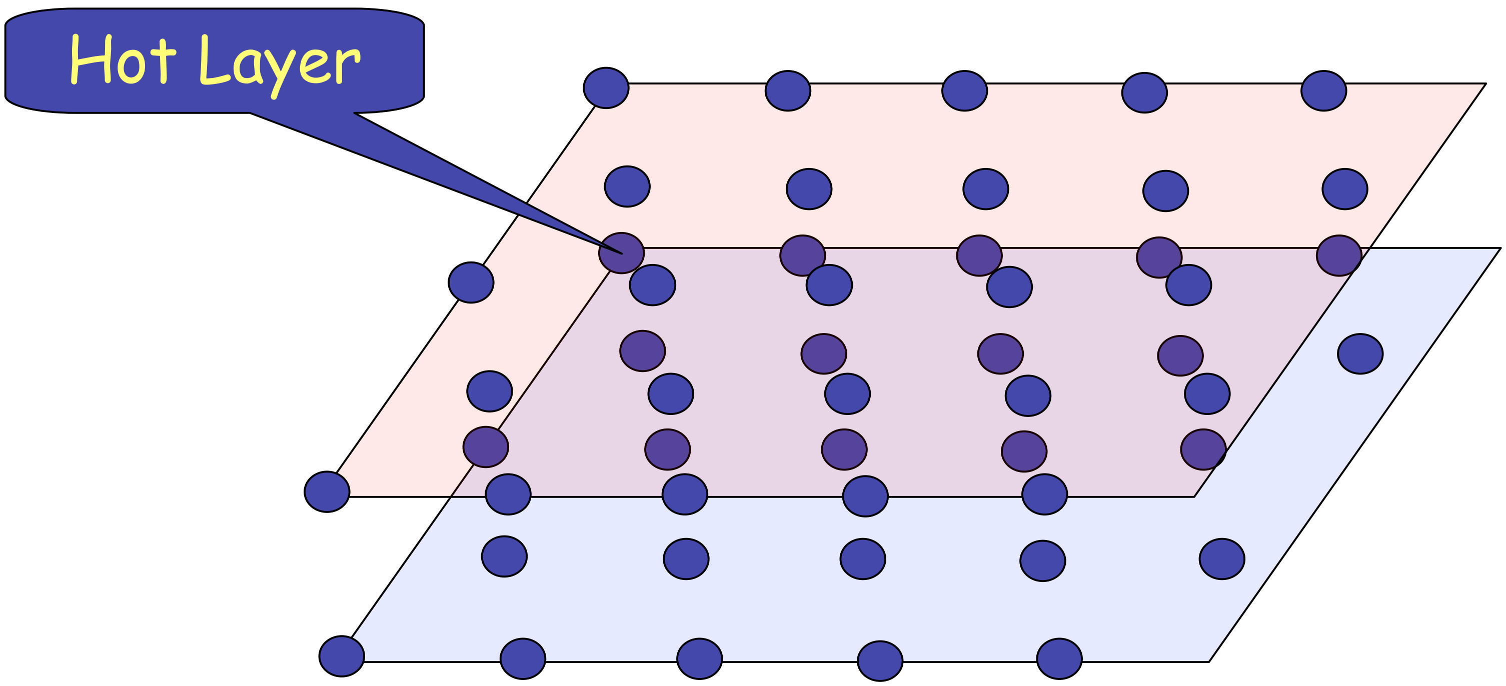


Phase Diagram

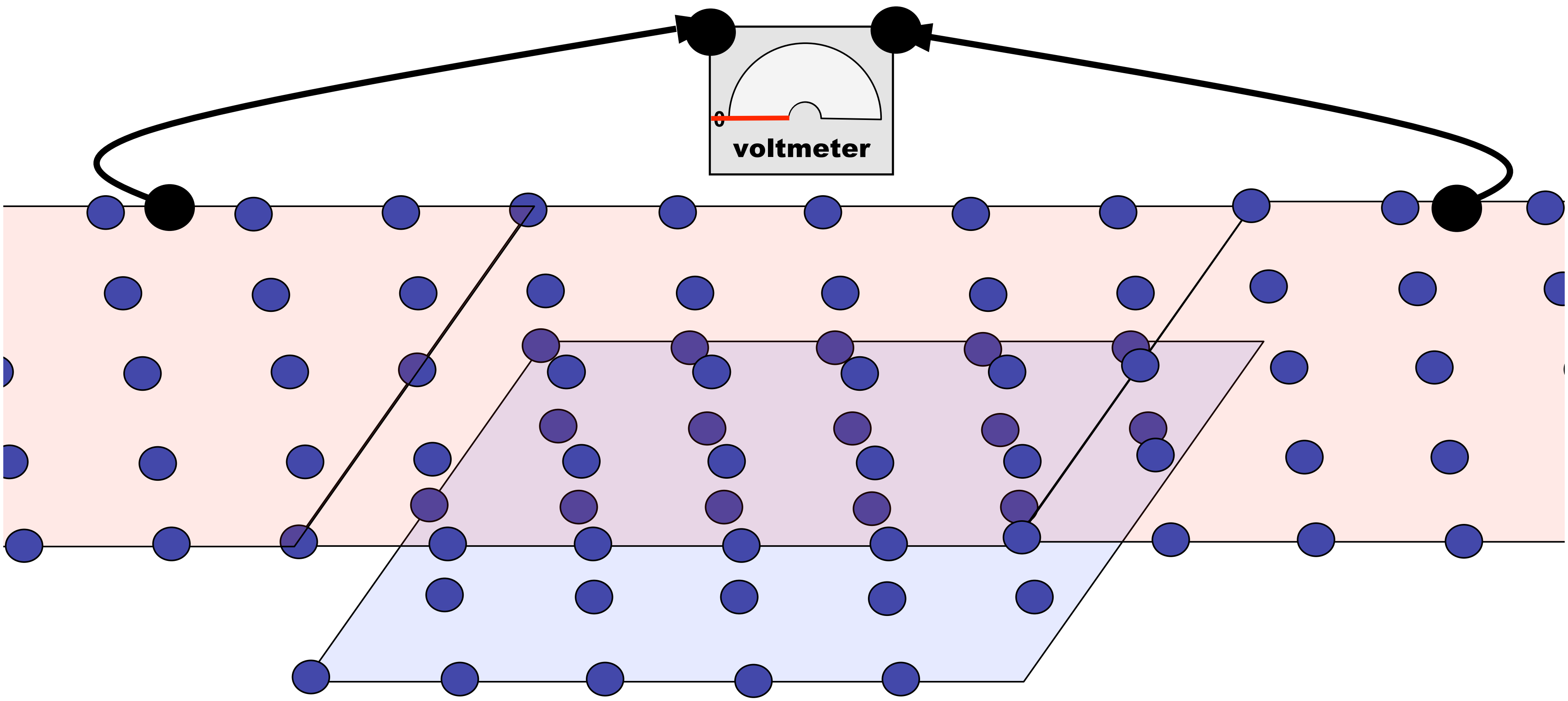




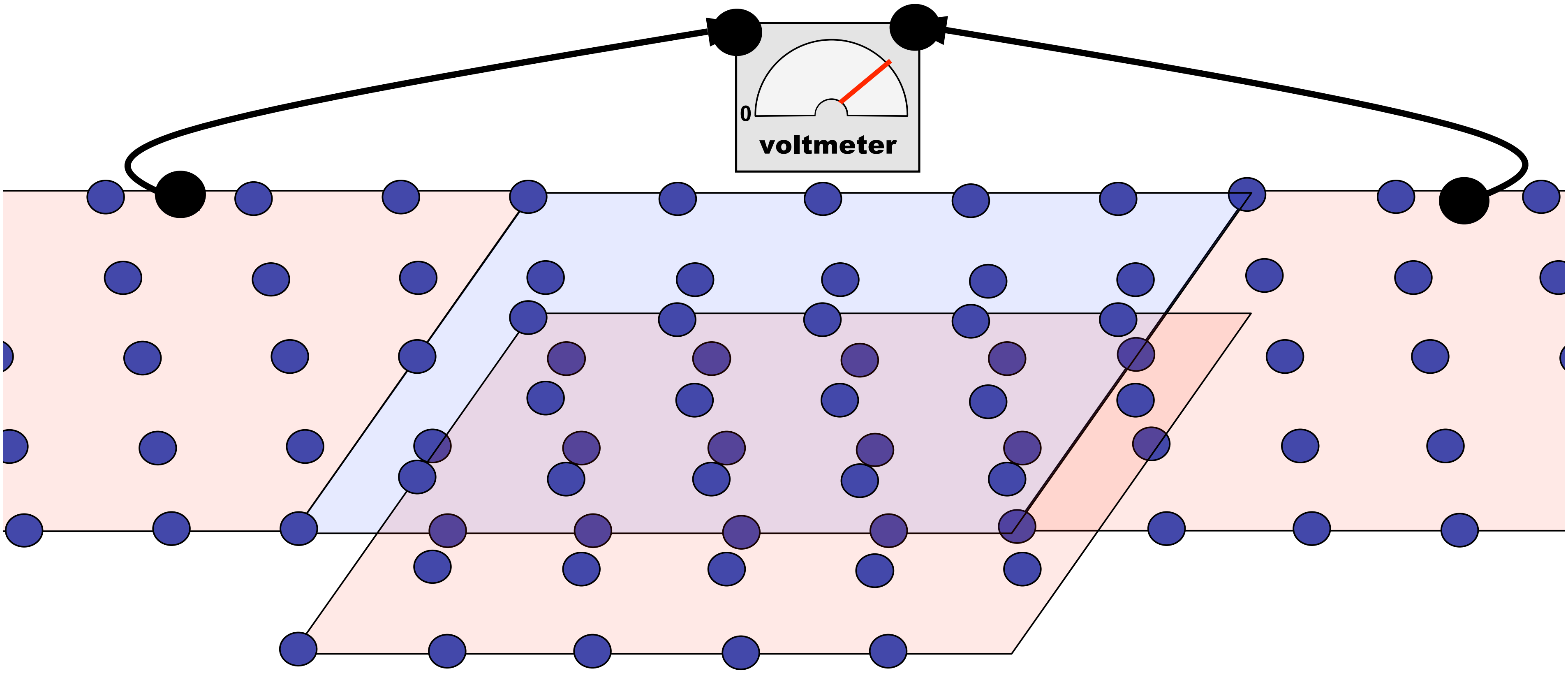
Giant *Electro*-resistance



Giant *Electro*-resistance



Giant *Electro*-resistance



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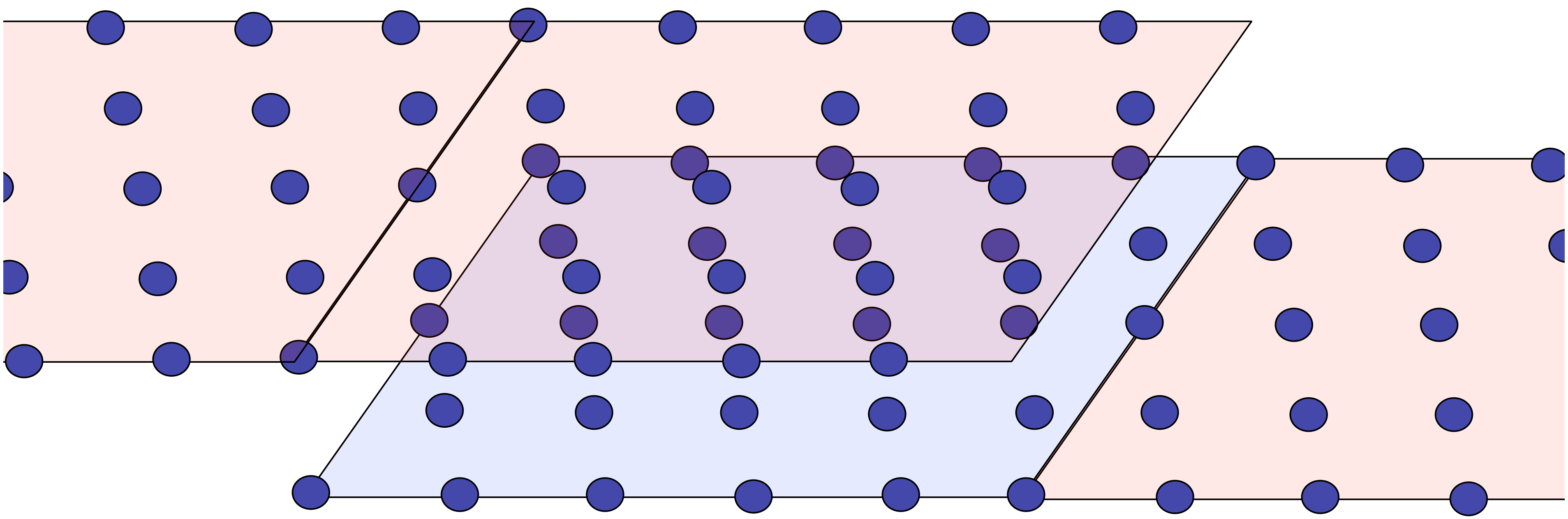
Pseudospin Transfer




no hands!
CAUTION!

Pseudospintronics in Graphene

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