SNN junction with mixed superconducting potential

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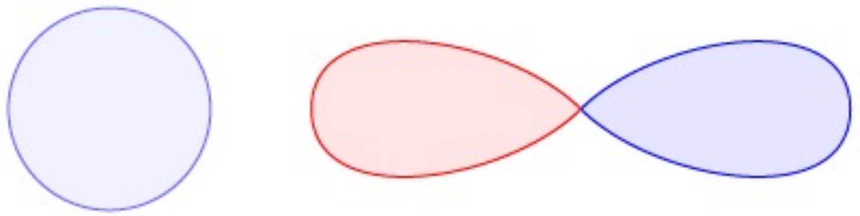
Mixed superconducting potentials

Noncentrosymmetric superconductors

Mixture of s and p

- Px $d = (0,0,\cos\phi)$
- Chiral $d = (0,0,e^{i\phi})$
- Helical $d = (\cos\phi, \sin\phi, 0)$



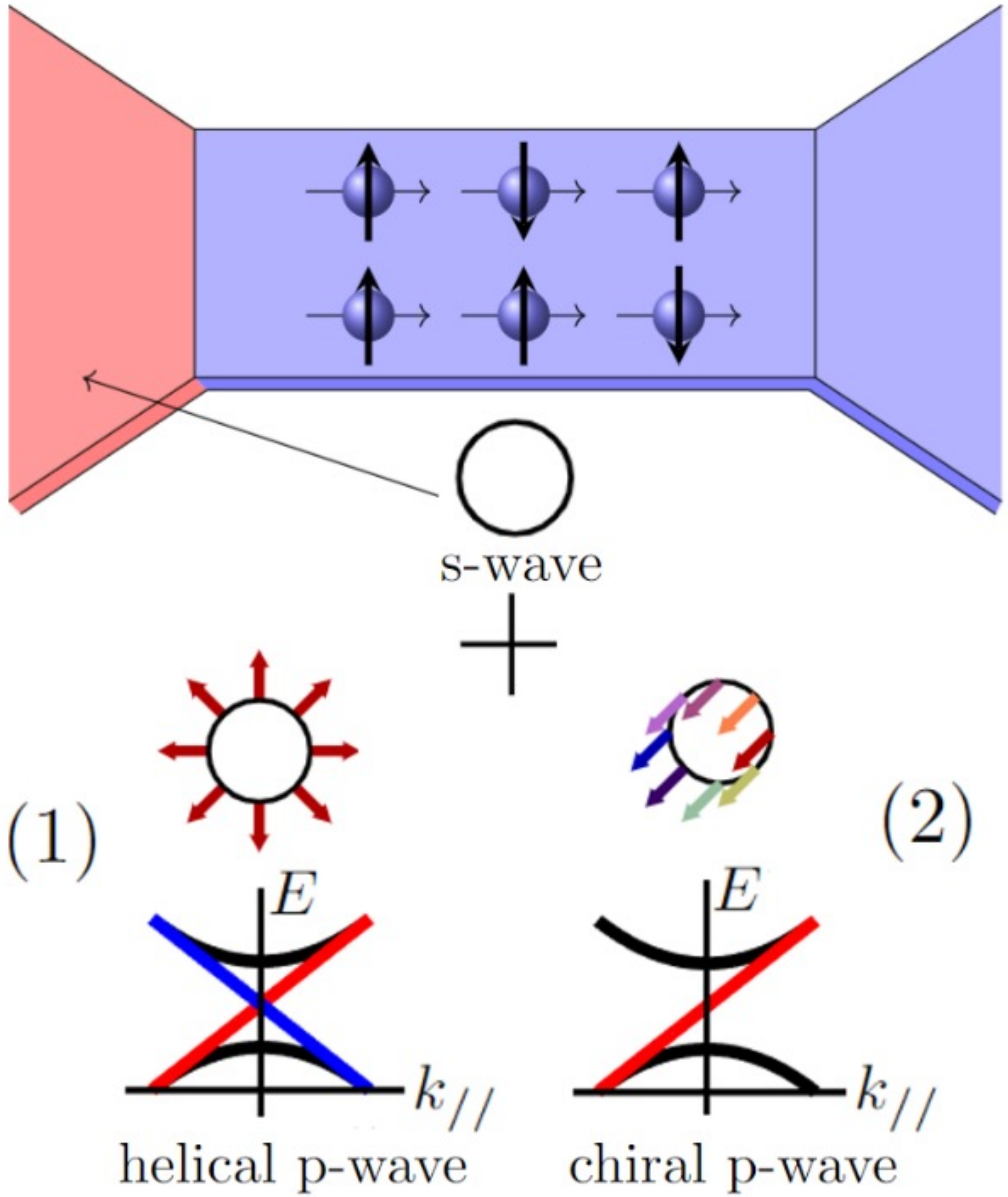
Mixture: $\Delta = \Delta_0 \left(\frac{1}{\sqrt{r^2+1}} + \frac{r}{\sqrt{r^2+1}} d(\phi) \cdot \sigma \right) i\sigma_y$

SNN junction

No supercurrent

Dissipative current

Proximity effect



Model

Not material specific

Gorkov equation

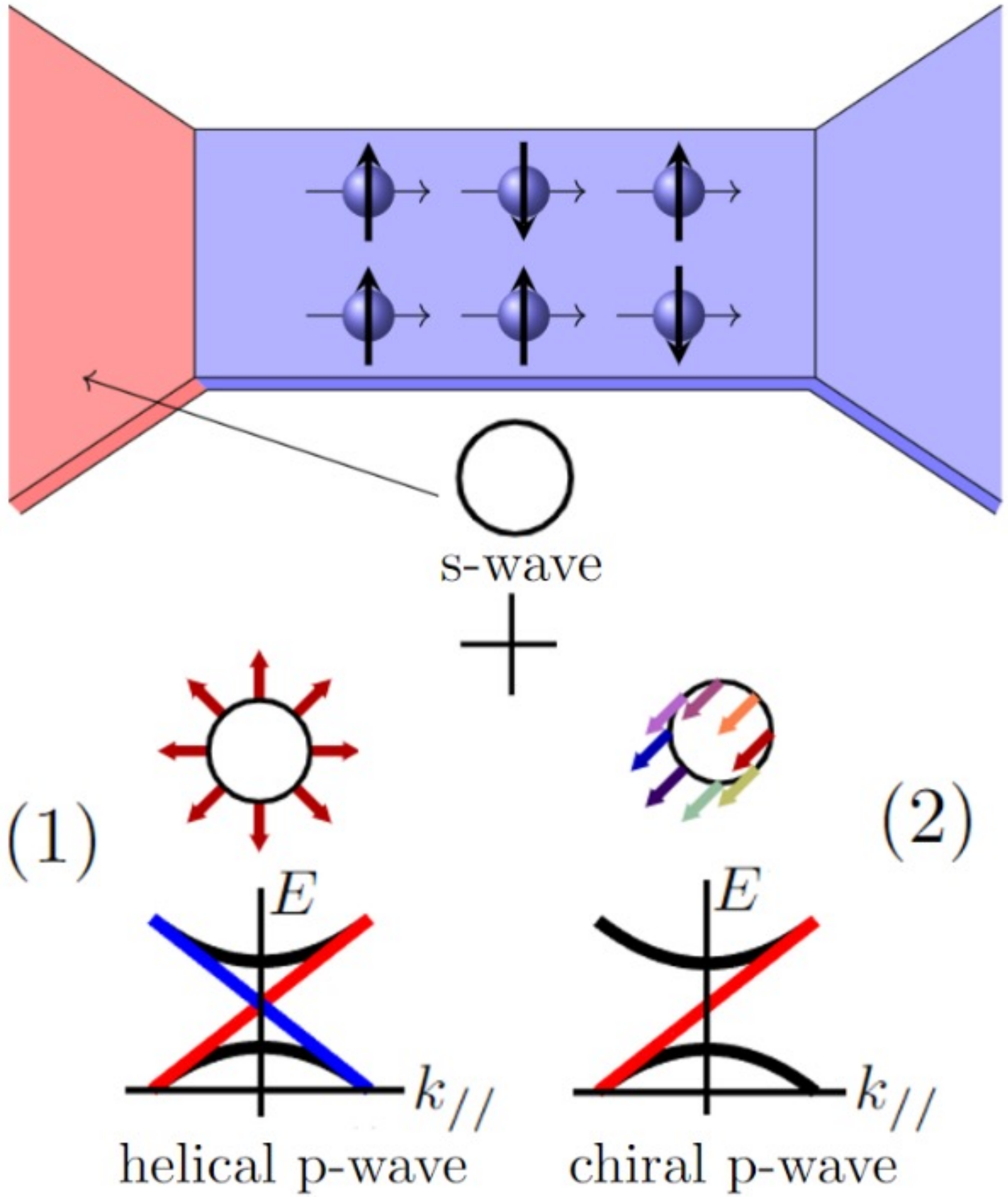
Quasiclassical approximation

Dirty limit

Usadel equation

Tanaka-Nazarov

- 2D: different modes



Belzig, W., Wilhelm, F. K., Bruder, C., Schön, G., & Zaikin, A. D. (1999). Quasiclassical Green's function approach to mesoscopic superconductivity. *Superlattices and microstructures*, *25*(5-6), 1251-1288.

Tanaka, Y., Nazarov, Y. V., & Kashiwaya, S. (2003). Circuit theory of unconventional superconductor junctions. *Physical review letters*, *90*(16), 167003.

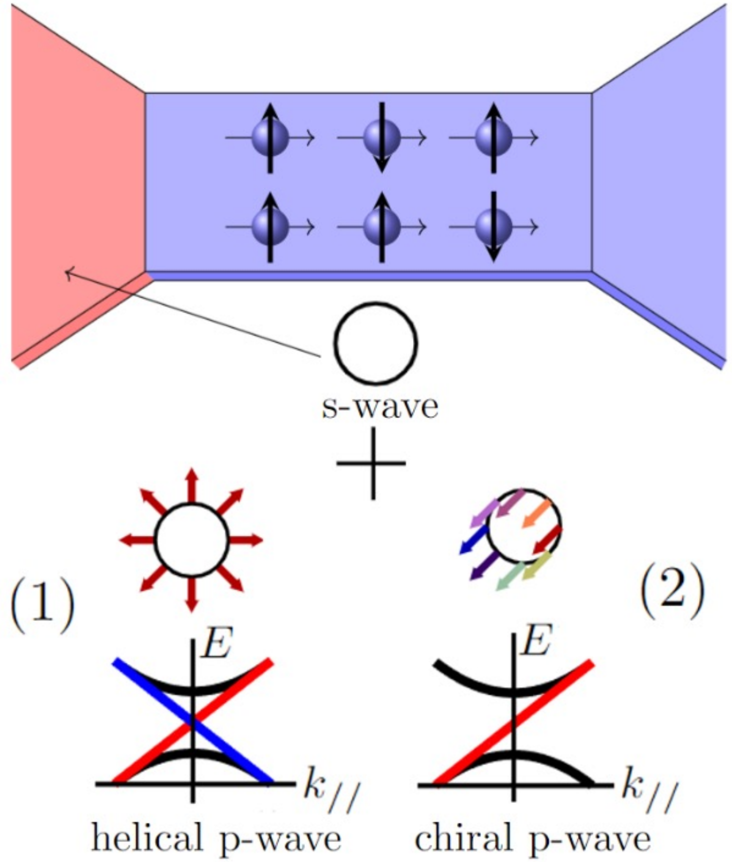
Quantities of interest

Density of states

- Near SN interface

Conductance

- Charge
- Spin



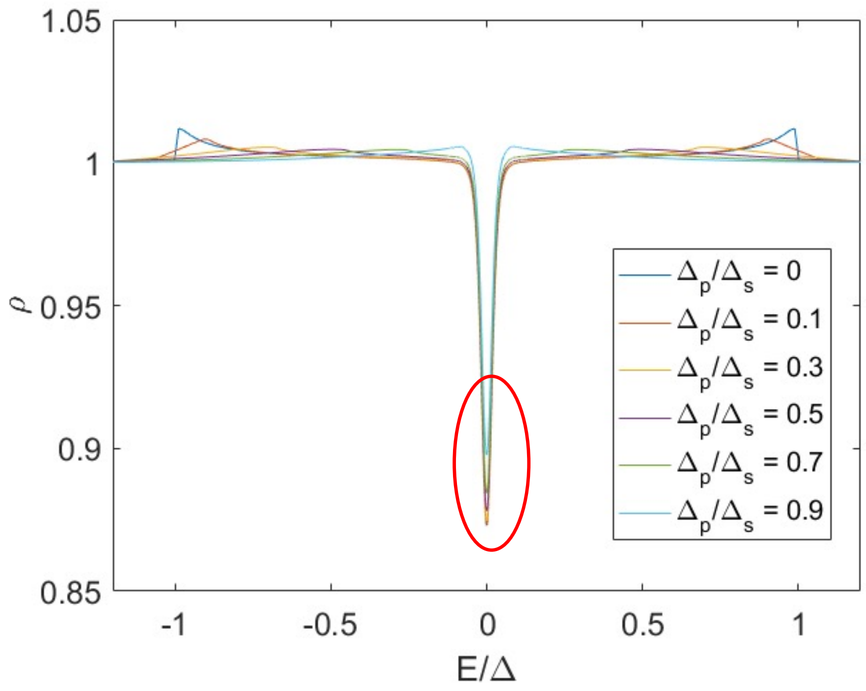
2D Chiral: $\Delta_p = \Delta_o e^{i\phi}$ Density of states

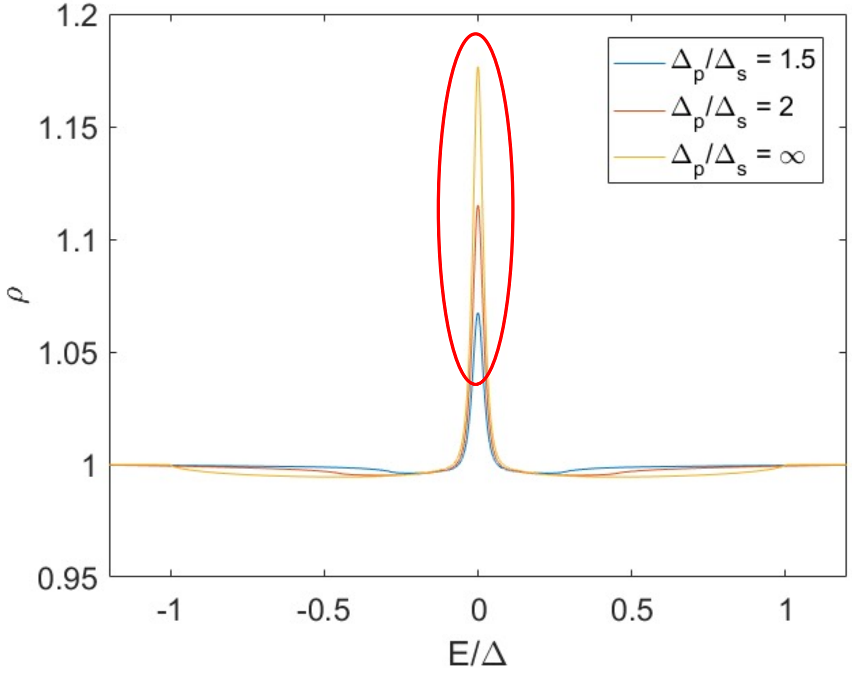
$\phi \in (-\frac{\pi}{2}, \frac{\pi}{2})$

$E = 0$ → No binary distinction

$$\Delta_{\pm} = \frac{1}{\sqrt{r^2+1}} \pm \frac{re^{i\phi}}{\sqrt{r^2+1}}$$

$$\frac{\Delta_+(\phi)}{|\Delta_+(\phi)|}, \frac{\Delta_-(\phi)}{|\Delta_-(\phi)|}$$



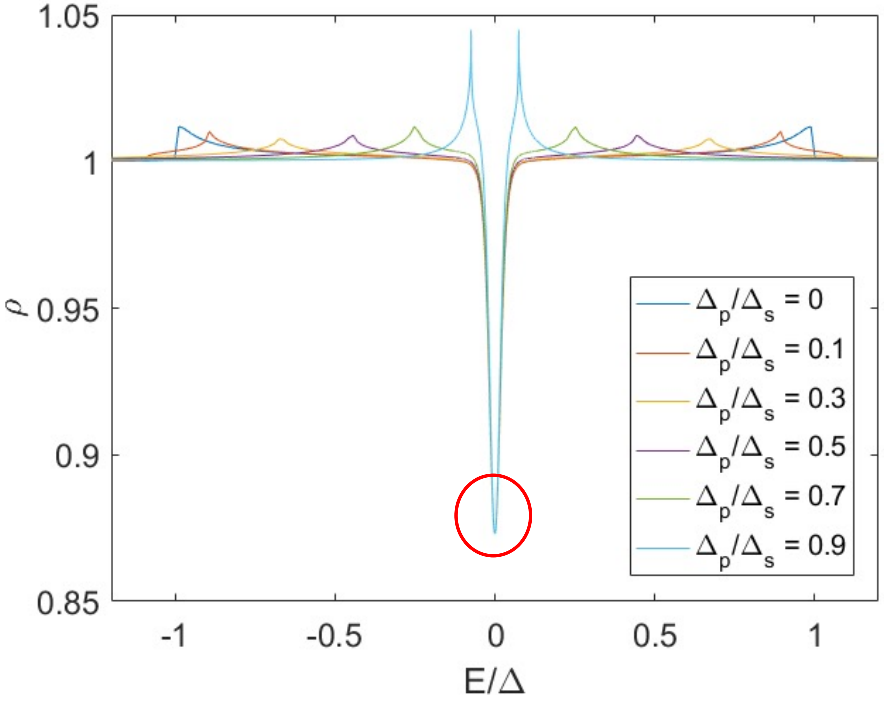


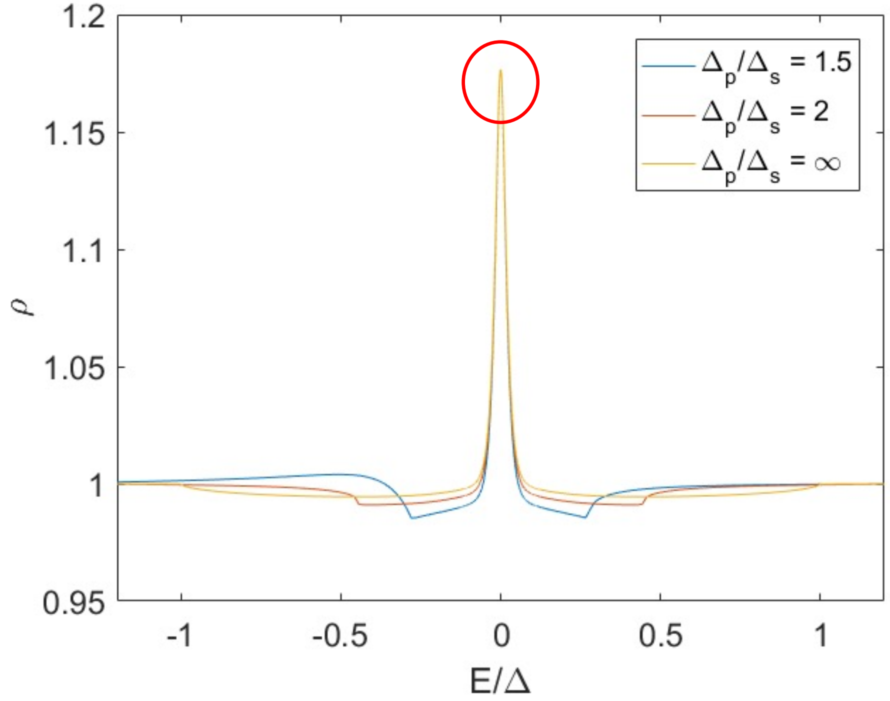
2D Helical: Density of states

Binary splitting

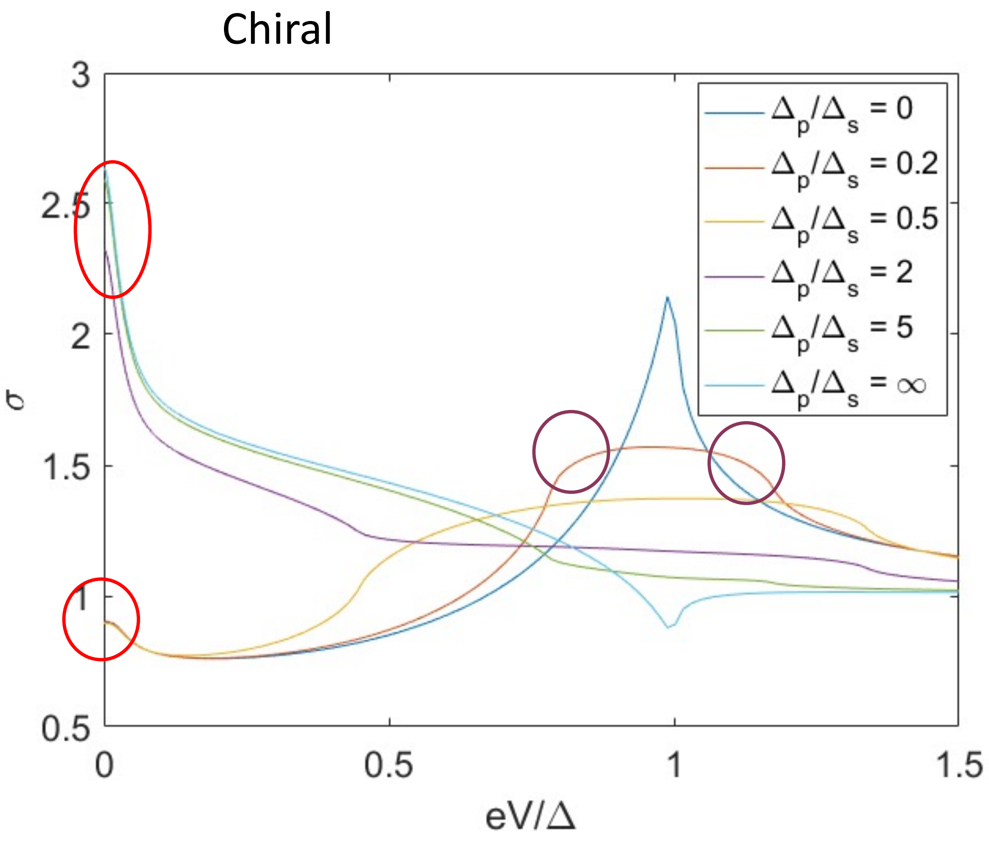
$$\Delta_{\pm} = \frac{1}{\sqrt{r^2+1}} \pm \frac{r}{\sqrt{r^2+1}}$$

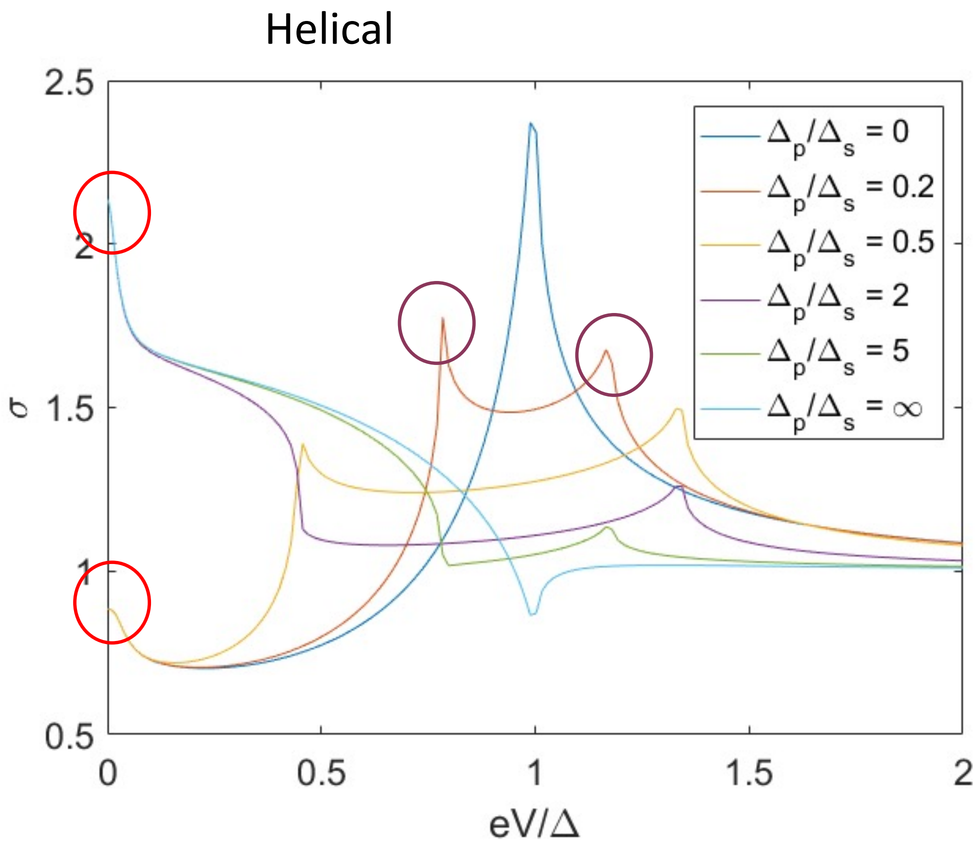
Eigenvalues $\cos\phi\sigma_x + \sin\phi\sigma_y$





2D Chiral and Helical: Conductance





Spin conductance

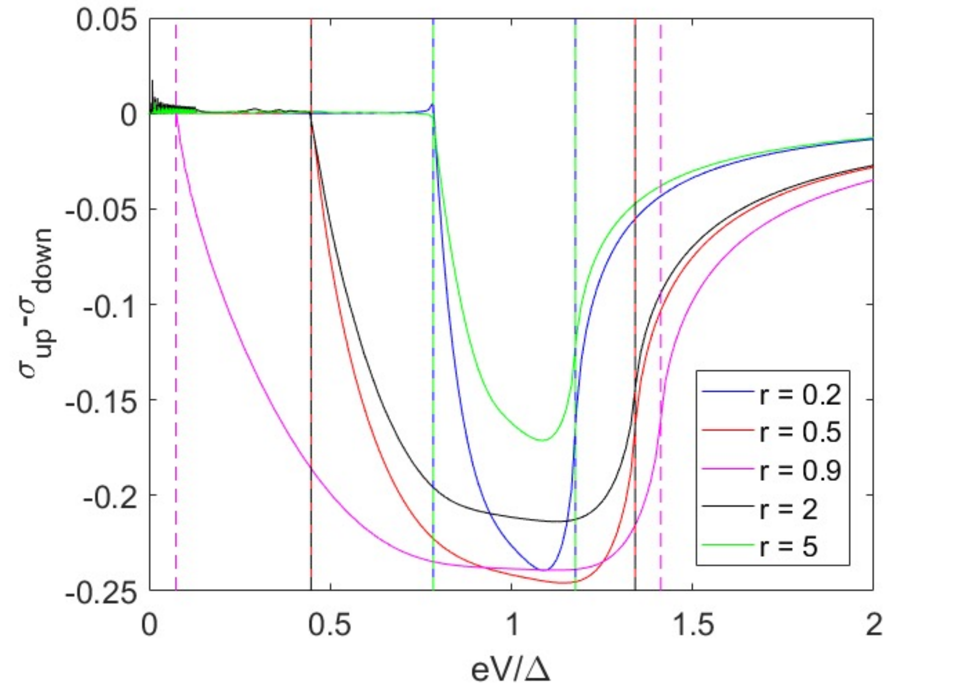
Distribution functions not equal

Minor modification of charge conductance

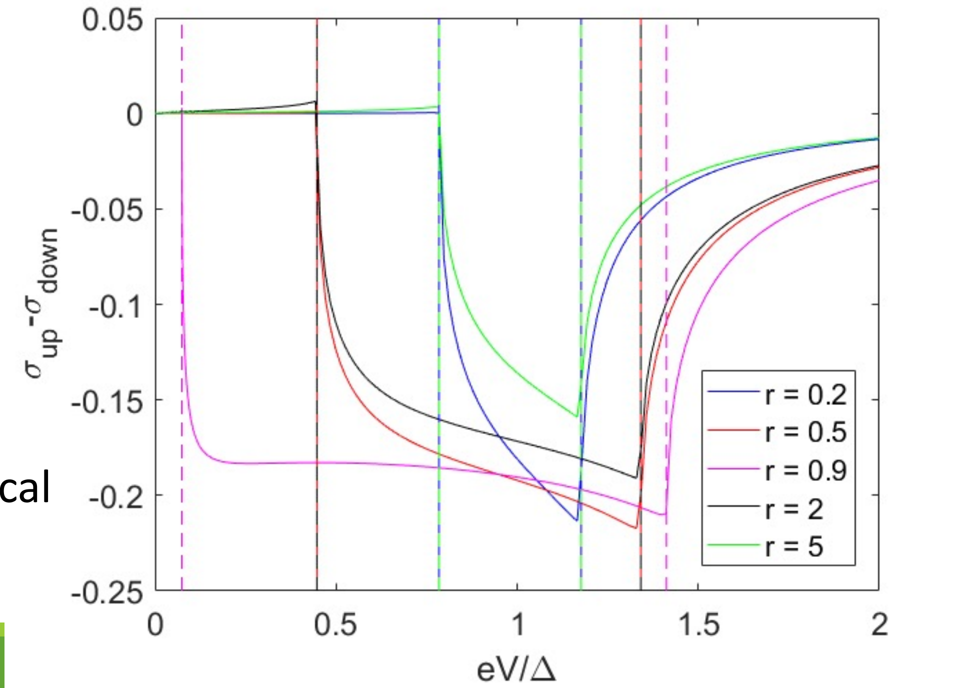
Confirmed in ballistic case

$$\Delta = \Delta_0 \left(\frac{1}{\sqrt{r^2+1}} + \frac{r}{\sqrt{r^2+1}} d(\phi) \cdot \sigma \right) i\sigma_y$$

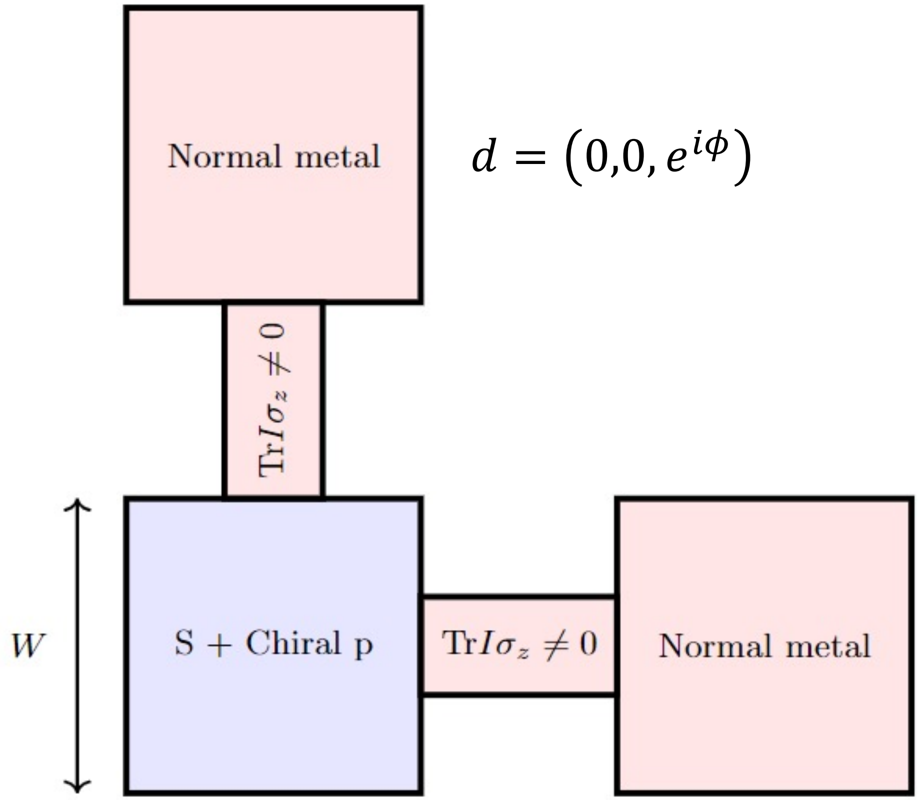
Chiral



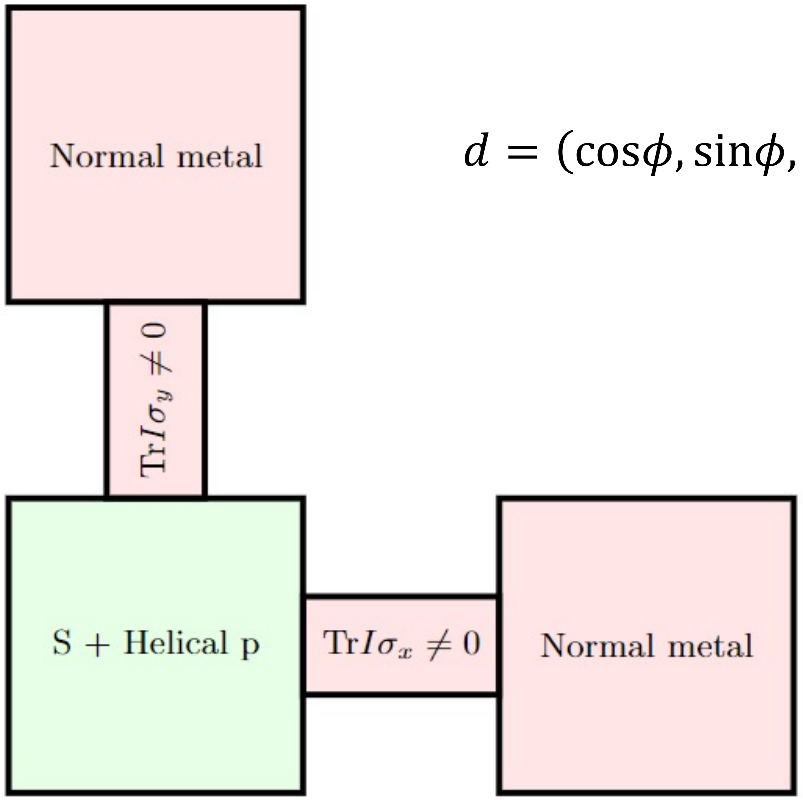
Helical



Distinguish chiral and helical



$d = (0, 0, e^{i\phi})$



$d = (\cos\phi, \sin\phi, 0)$

Conclusion

Sharp distinction between $\frac{\Delta_p}{\Delta_s} < 1$ and $\frac{\Delta_p}{\Delta_s} > 1$

Chiral Helical

LDOS

Charge conductance

Spin conductance

Acknowledgements

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Spin

Singlet: Reverse Δ

Triplet: Same Δ

$$H = \begin{bmatrix} E & 0 & 0 & \Delta_s + \Delta_p \\ 0 & E & -\Delta_s + \Delta_p & 0 \\ 0 & -(-\Delta_s + \Delta_p) & -E & 0 \\ -(\Delta_s + \Delta_p)^* & 0 & 0 & -E \end{bmatrix}$$

Chiral/Px:
$d_x = d_y = 0$

$\Delta_s i\sigma_y, \Delta_p \sigma_z i\sigma_y$

Decouple

Helical: $\mathrm{d}_x d_y \neq 0,$ angular dependent → No decoupling?

$$Y = \begin{bmatrix} 1 & 0 & & \\ 0 & -1 & & 0 \\ & 0 & -1 & 0 \\ & & 0 & 1 \end{bmatrix}$$

$$YHY = H$$

Helical p-wave

Spin momentum correlation

$d_x = \cos\phi, d_y = \sin\phi, d_z = 0$

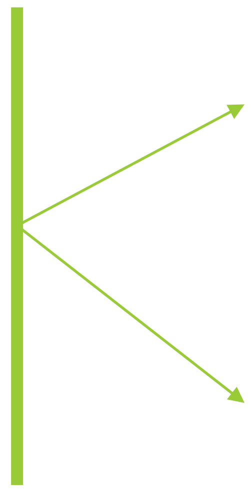
Symmetry: transform to $\uparrow_x, \downarrow_x$

- $U = \frac{1}{\sqrt{2}}\begin{bmatrix} \begin{matrix} 1 & 1 \\ 1 & -1 \end{matrix} & 0 \\ 0 & \begin{matrix} 1 & 1 \\ 1 & -1 \end{matrix} \end{bmatrix}$

$YI(\phi)Y = I(-\phi)$

$\rightarrow Y\langle I\rangle Y = \langle I\rangle$

$\rightarrow$ Two by two matrices, but with harder boundary condition



Interface:
Averaging over $(-\frac{\pi}{2}, \frac{\pi}{2})$

$\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \sin(\phi)\, d\phi = 0$