Doped semimetals have a large anomalous magnetic moment

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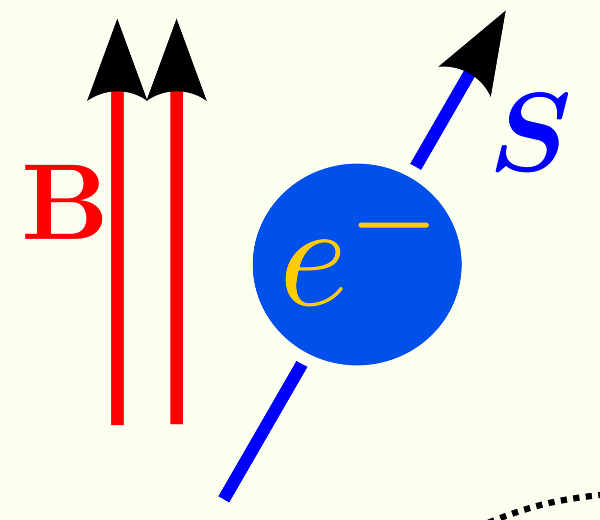
We investigate the effect of Coulomb interactions on the electromagnetic response of 3D Dirac and Weyl semimetals. In 1948 Schwinger did a similar calculation to calculate the anomalous magnetic moment of the electron using quantum electrodynamics. He considered the case of *massive* electrons in the vacuum coupling to *massless* photons. Instead, we consider a nonzero density of *massless* electrons around the band-touching points that couple to photons, This coupling gives the photons an effective mass and results in a screened Coulomb potential between the electrons. We find three physically distinct effects and an anomalous magnetic moment that is orders of magnitude larger than Schwinger's result.

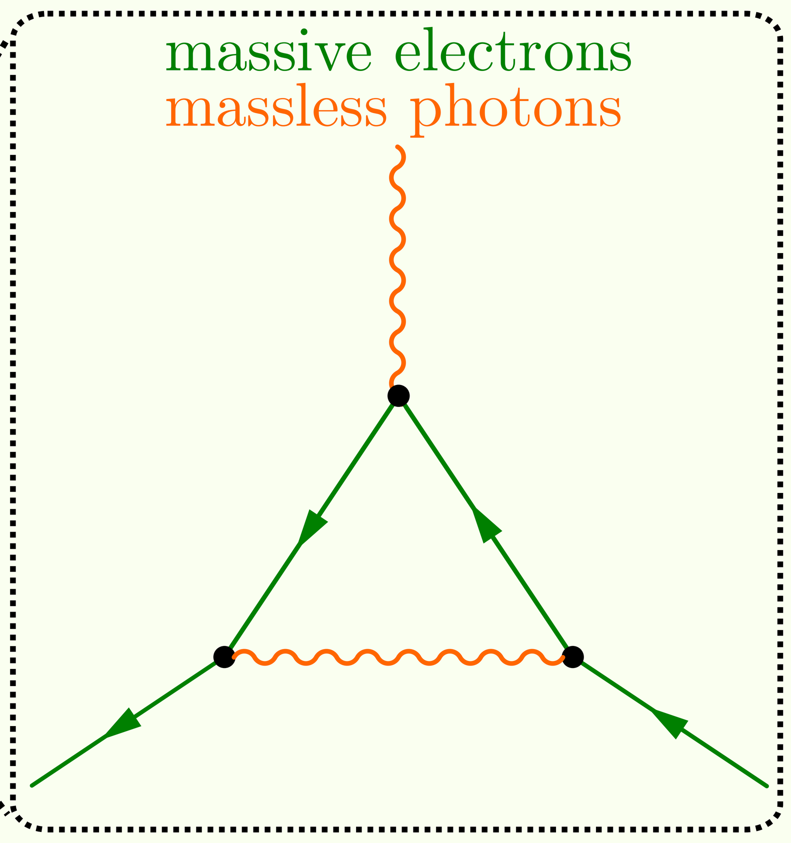
What is an anomalous magnetic moment?



$$H = -g_m \mu_B \mathbf{S} \cdot \mathbf{B}$$

Bohr magneton

$$g_m = 2 + \alpha/\pi$$

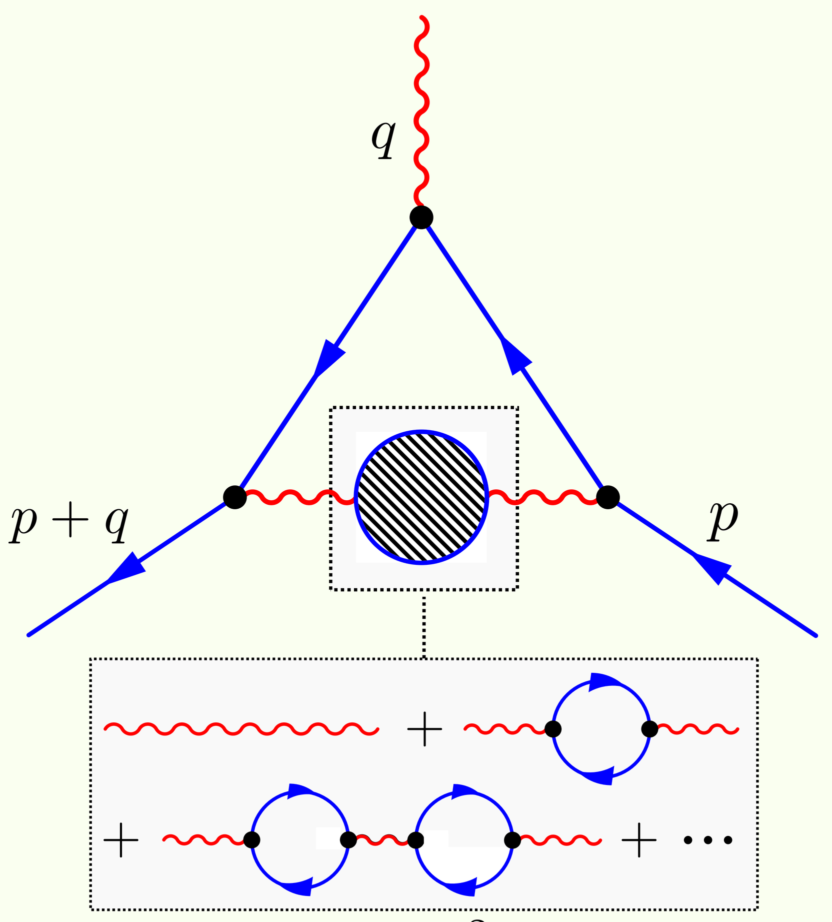


- 1947: measured by Rabi & Zacharias
- 1948: calculated by Schwinger with Quantum Electrodynamics
- small: $\alpha/\pi \approx 2 \cdot 10^{-3}$

Our calculation

massless electrons doped with k_F

massive photons with $m_{\rm ph} = 10^{-3} m_{\rm el}$



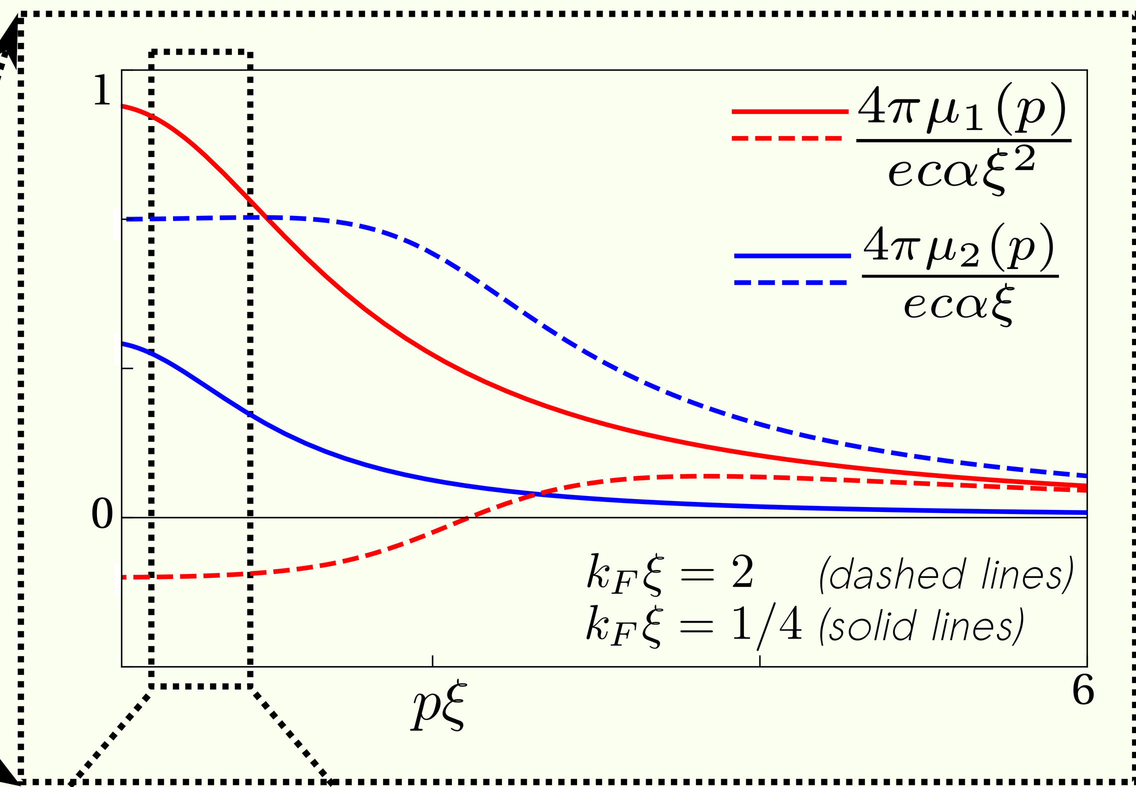
$$V_{\rm sc}(q) = \frac{e^2}{\epsilon_0} \frac{1}{q^2 + \xi^{-2}}$$

- screening length $\xi = \hbar / m_{\rm ph} c$
- relation to doping $\xi = \sqrt{\pi / 2 \alpha_{\rm eff} k_F^2}$

Transversal vertex correction:

$$H = -\mu_1(p)(\mathbf{p} \times \boldsymbol{\sigma}) \cdot \mathbf{E}/v_F - [\mu_2(p)\boldsymbol{\sigma} \mp \mu_1(p)\mathbf{p}] \cdot \mathbf{B}$$

1) Rashba spin-orbit coupling
2) Zeeman-like effect



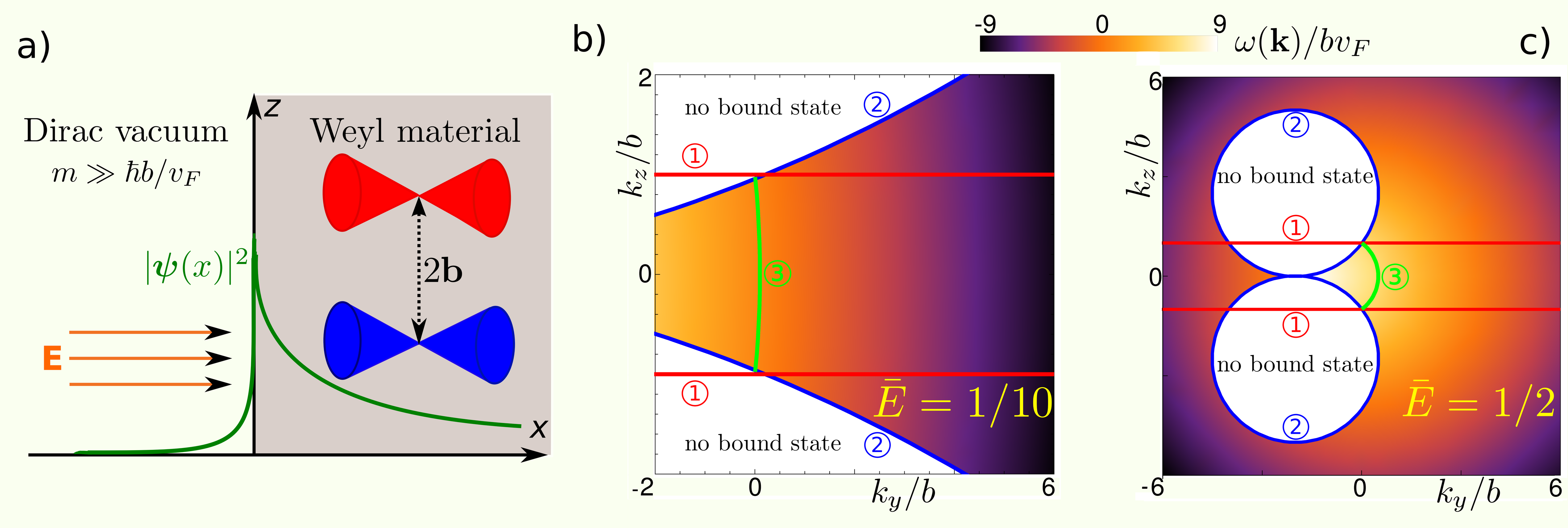
$$\mu_1 k_F \approx 0.25 \mu_B$$
$$\mu_2 \approx 0.85 \mu_B$$

Substantial magnitude!

- Vertex correction finite because doping induces photon mass, yielding infrared cut-off.
- Result of order one because proportional to $(m_{\rm el}/m_{\rm ph})(\alpha/\pi)$ with $m_{\rm el} \gg m_{\rm ph}$

Are there experimental signatures?

- Interface between Weyl semimetal and Dirac vacuum [Fig. a)].
- Apply perpendicular electric field, yields anomalous Rashba spin-orbit coupling.
- Bound states have peculiar dispersion relation $\omega(\mathbf{k})$ & special Fermi arc [Fig. b) & Fig. c)].



- *White regions: no bound states.*
- *Red lines: boundary of area which supports bound states for $\bar{E} = 0$*
- *Blue lines: boundary of area which supports bound states for $\bar{E} \neq 0$*
- *Green lines: Fermi arc.*