Electron g-2 corrections from axion dark matter

18th Patras Worshop on Axions, WIMPs and WISPs

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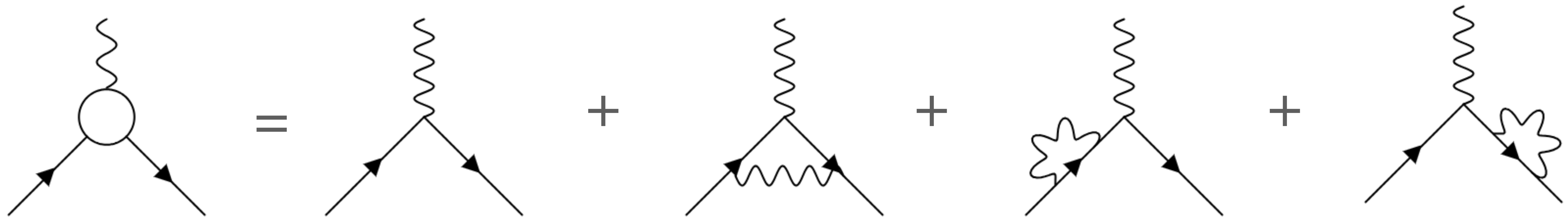
Electron g-2 in quantum electrodynamics

One loop



$$g - 2 = \frac{\alpha}{\pi}$$

We use

$$D_{\mu\nu}(k) = -\frac{\eta_{\mu\nu}}{k^2 + i\epsilon}$$

What happens if there is a photon background?

If there is a photon background with temperature T

$$D_{\mu\nu}(k) = -\eta_{\mu\nu}\left(\frac{1}{k^2 + i\epsilon} - 2\pi i f_\gamma(k,T)\delta(k^2)\right)$$

$$f_\gamma(k,T) = \frac{1}{e^{k/T} - 1}$$

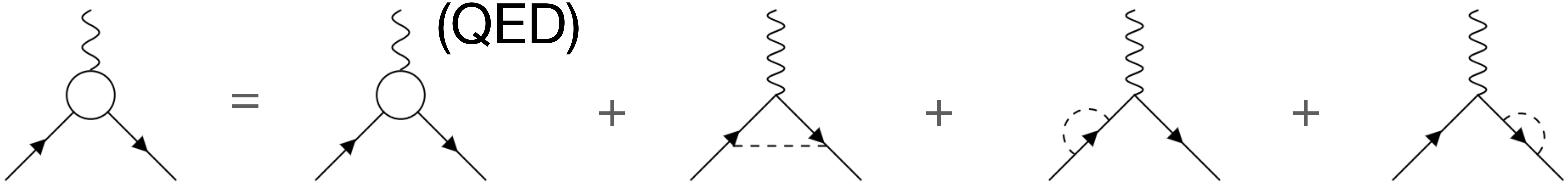
$$\boxed{g - 2 = \frac{\alpha}{\pi} - \frac{4\pi\alpha}{9}\frac{T^2}{m_e^2}}$$

This is discussed in detail by J. F. Donoghue, B. R. Holstein and R. W. Robinet in *Annals Phys.* 164 (1985) 233

In this work we follow the techniques exposed in *Annals Phys.* 164 (1985) 233 and *Phys.Rev.D* 28 (1983) 340

Adding ALPs

$$\mathscr{L}_I = \frac{g_{ae}}{2m_e}\partial_\mu a\,\bar{\psi}\gamma^\mu\gamma_5\psi$$



$$g-2 = \frac{\alpha}{\pi} + \boxed{\frac{g_{ae}^2}{16\pi^2}}$$

We use $\Delta_F(k) = \dfrac{1}{k^2 - m_a^2 + i\epsilon}$

The predicted and measured value agree about to:

$$\delta(g-2) \approx 1.4\times10^{-12}$$

$$\boxed{g_{ae} < 1.5\times10^{-5}}$$

$g_{ae} < 1.9\times10^{-12}$ (XENONnT)

$g_{ae} < 1.3\times10^{-13}$ (Red giants)

See [2209.13084] for an updated precise measurement of g-2

When a background of ALPs is present

$$\Delta_F(k) = \frac{1}{k^2 - m_a^2 + i\epsilon} - 2\pi i f_a(k)\, \delta(k^2 - m_a^2)$$

$f_a(k) \equiv$ Dark matter phase space distribution (occupancy number)

$$g - 2 = \frac{\alpha}{\pi} + \boxed{\frac{g_{ae}^2}{16\pi^2}(1 + \mathscr{A})}$$

$$\mathscr{A} \sim \frac{\rho_a}{m_a^2 m_e^2}$$

$\rho_a \equiv$ Dark matter energy density

$\mathscr{A} > 1$ for $m_a < 10^{-9}$ eV

The electron free propagation is affected

$$= \Sigma_0(k) + \Sigma_\beta(k)$$

$$\Sigma_\beta(k) = B(k) + C(k)(\gamma^\mu k_\mu - m_e) + \gamma^\mu D_\mu(k)$$

$\Sigma_0(k)$ results in the renormalization of the electron mass

$\Sigma_\beta(k)$ breakes Lorentz invariance and gives non-trivial effects

$$(\gamma^\mu k_\mu - m_e + \Sigma_\beta(k))u_\beta(k,s) = 0$$

$$\gamma^\mu k_\mu - m_e + \Sigma_\beta(k) = \gamma^\mu \tilde{k}_\mu - \tilde{m}_e$$

$$\boxed{(\gamma^\mu \tilde{k}_\mu - \tilde{m}_e)u_\beta(k,s) = 0}$$

$$u_\beta(k,s)^\dagger u_\beta(k,s') = \delta_{ss'}$$

$$\sum_s u_\beta(k,s)\bar{u}_\beta(k,s) = \frac{\gamma^\mu \tilde{k}_\mu + \tilde{m}_e}{2\tilde{E}}$$

$$\sum_s v_\beta(k,s)\bar{v}_\beta(k,s) = \frac{\gamma^\mu \tilde{k}_\mu - \tilde{m}_e}{2\tilde{E}}$$

It also implies a wave function renormalization constant

$$S_F^R(x-x') = \int \frac{d^4k}{(2\pi)^4} e^{-ik\cdot(x-x')} \frac{Z_2^{-1}}{\gamma^\mu \tilde{k}_\mu - \tilde{m}_e + i\epsilon}$$

Propagator definition

$$S_F^R(x-x') = -i \left\langle 0 \right| T[\psi_e(x)\bar{\psi}_e(x')] \left| 0 \right\rangle$$

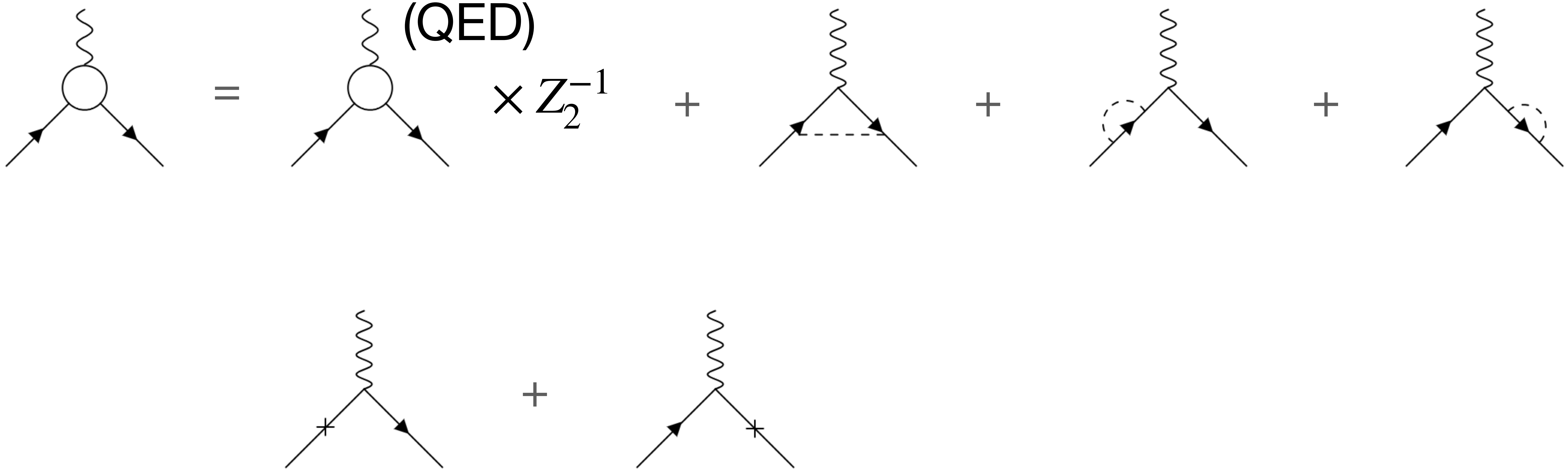
$$= -i \int \frac{d^3k}{(2\pi)^3} \left(\Theta(t-t') \frac{\gamma^\mu \tilde{k}_\mu + \tilde{m}_e}{2\tilde{E}} e^{-ip\cdot(x-x')} - \Theta(t'-t) \frac{\gamma^\mu \tilde{k}_\mu - \tilde{m}_e}{2\tilde{E}} e^{ip\cdot(x-x')} \right)$$

It implies

$$Z_2 = 1 - C(k) - \frac{m_e}{E}\frac{d}{dE}\left(B(k) + \frac{k\cdot D(k)}{m_e} \right) + \frac{D_0(k)}{2E}$$

We should take into account the wave function renormalization constant as well as the counter term

$$\mathscr{L}_c = -\bar{\psi}(B(k) + \gamma^\mu D_\mu(k))\psi$$



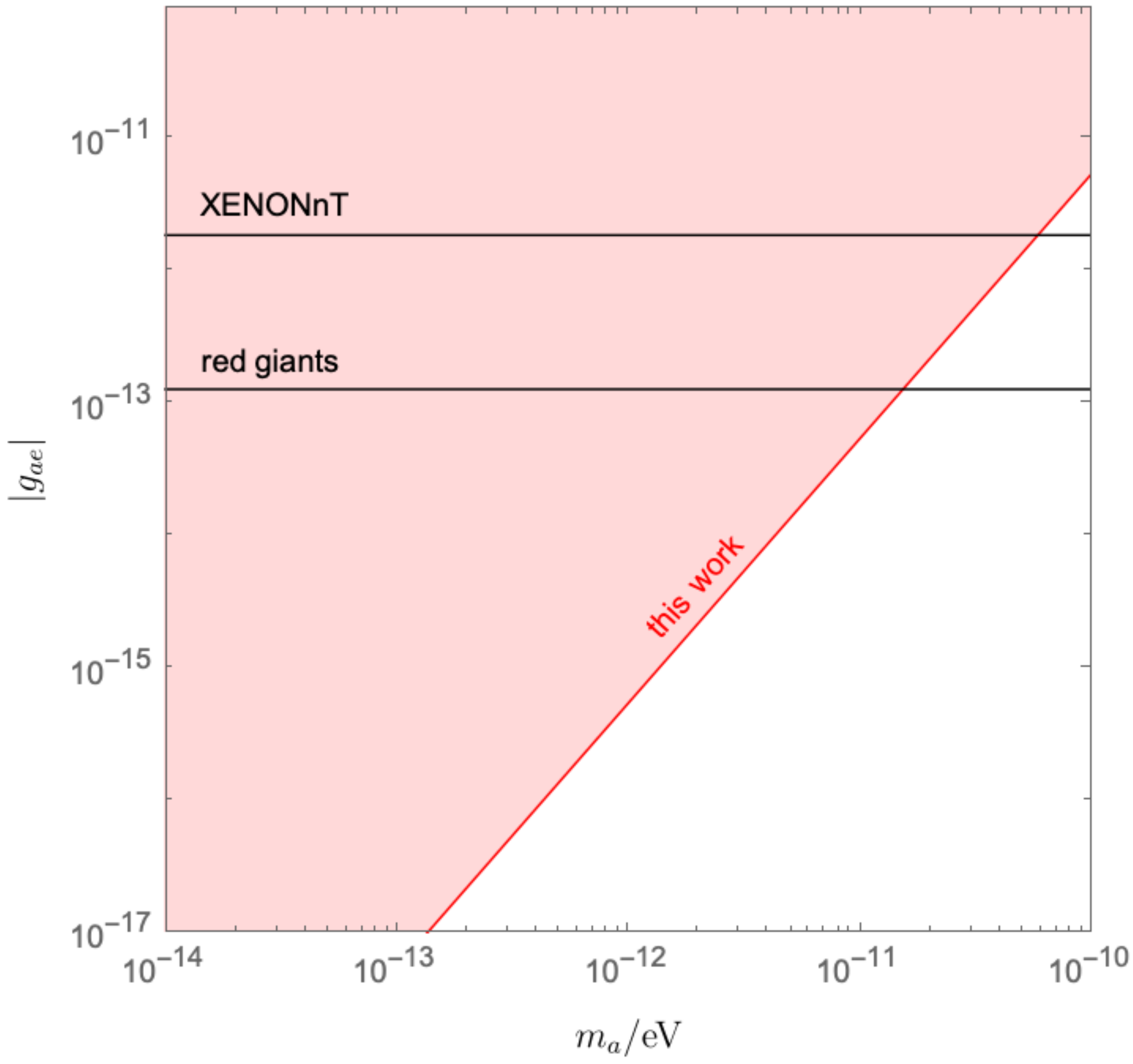
Results and constraints

$$g-2=\frac{\alpha}{\pi}+\frac{g_{ae}^2\rho_a}{4m_a^2m_e^2}$$

See [2209.13084] for an updated precise measurement of g-2

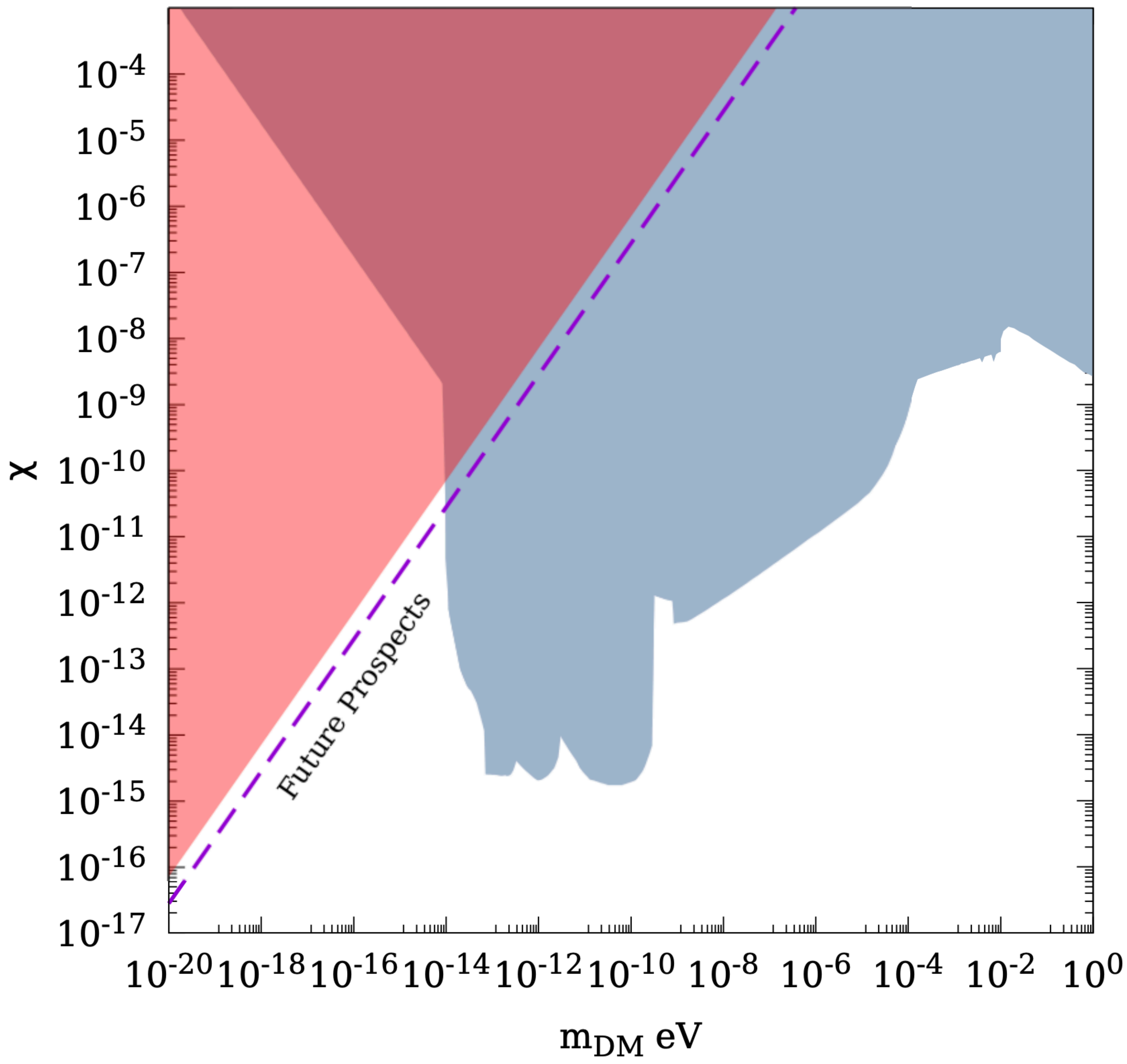
The predicted and measured value agree about to:

$$\delta(g-2)\approx 1.4\times 10^{-12}$$



hidden photon case

See J. L. Evans
[2302.08746]



Conclusions

1) We have calculated the effects of an ALP dark matter background on the g-2 of the electron

2) We put the strongest constraints on the axion dark matter-electron coupling for axion masses below 10^{-11} eV

3) The electron g-2 is a good example, but this idea can be extended to other SM processes, and also in astrophysics and cosmology