Anomalous magnetic moments in asymptotically safe models

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based on [G. Hiller, CHF, D. Litim and T. Steudtner, arXiv:1910.14062]

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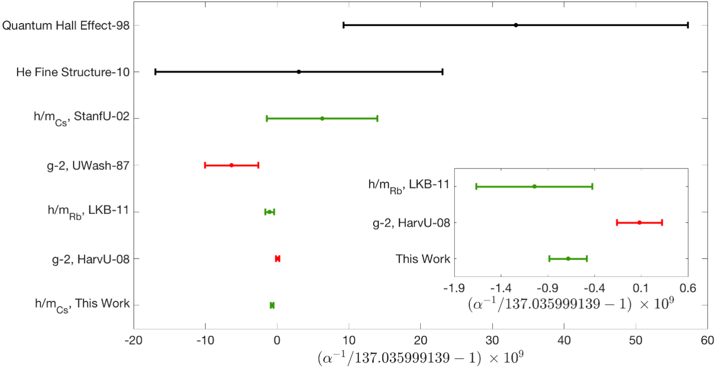
Outline

- Experimental status of lepton AMMs and anatomy of NP contributions
- AMMs in UV-safe models
- Signatures
- Safe trajectories

The electron AMM

Recent deviation from precision measurements of $\alpha_{\rm em}$ [Parker *et al* (2018)]

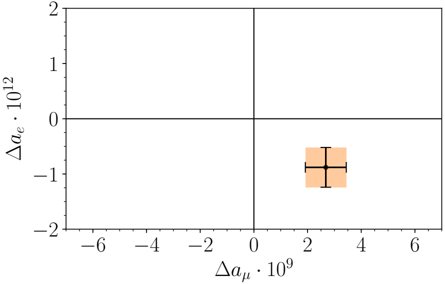


Lepton AMMs: experimental status

Deviations in $(g-2)_e$ and $(g-2)_\mu$

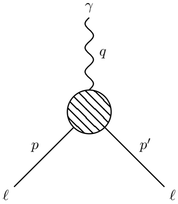
$$\Delta a_e = -88(28)(23) \cdot 10^{-14}$$ [Parker *et al* (2018)] $\sim 2.4\,\sigma$ from SM

$$\Delta a_\mu = 268(63)(43) \cdot 10^{-11}$$ [PDG (2018)] $\sim 3.5\,\sigma$ from SM



Anomalous magnetic moments: theory

Quantum corrections of the magnetic moment



$$\bar{u}(p')\left[e\gamma^{\mu}F_1(q^2) + ie\frac{\sigma^{\mu\nu}q_{\nu}}{2m}F_2(q^2) + ie\,\epsilon^{\mu\nu\sigma\rho}\sigma_{\rho\sigma}q_{\nu}F_3(q^2)\right]u(p)$$

- Anomalous magnetic moment: $a_{\ell} = \frac{(g-2)_{\ell}}{2} = F_2(0)$
- Arises from operator $\overline{\ell}_L\sigma^{\mu\nu}\ell_R \rightarrow$ chiral flip necessary

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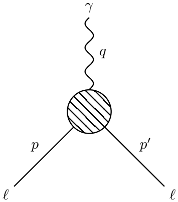

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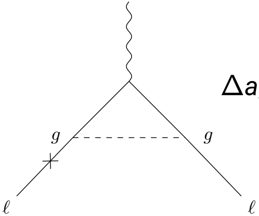
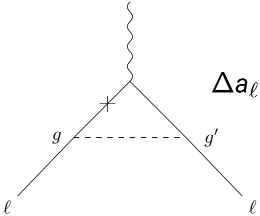
Scaling of *universal* New Physics contributions

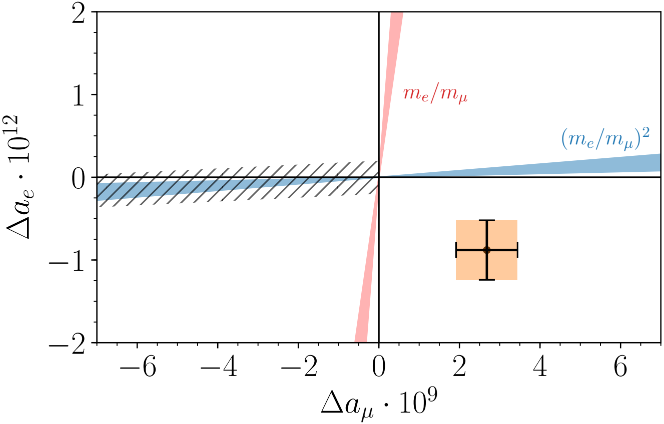


$$\Delta a_\ell \propto g^2 \frac{m_\ell^2}{M_{\rm NP}^2}$$



$$\Delta a_\ell \propto g\, g' \,\frac{m_\ell}{M_{\rm NP}}$$

Scaling from universal New Physics



→ without flavor structure in the couplings, different mass scaling in a_e^{NP}, a_μ^{NP} needed

UV-safe models: BSM Yukawa interactions

Flavor-blind sector

[Litim, Sannino (2014)]

- Vector-like fermions: $\psi^i_{L,R}$ (N_F, charged)
- Complex scalars: S^{ij} (N_F^2, uncharged)

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Extending the BSM Yukawa sector

[Bond, Hiller, Kowalska, Litim (2017)]

Choose $SU(3)_C \times SU(2)_L \times U(1)_Y$ reps. of ψ to couple with SM (L, E, H)

Singlet: $\psi(1, 1, -1), N_F = 3$

$$-\mathcal{L}^Y_{\rm sing} = y \,\mathrm{tr}\, \overline{\psi}_L S \psi_R + \kappa \overline{L} H \psi_R + \mathrm{tr}\, \kappa' \overline{E} S^\dagger \psi_L + h.c.$$

Doublet: $\psi(1, 2, -1/2), N_F = 3$

$$-\mathcal{L}^Y_{\rm doub} = y \,\mathrm{tr}\, \overline{\psi}_L S \psi_R + \kappa \overline{E} H^\dagger \psi_L + \mathrm{tr}\, \kappa' \overline{L} S \psi_R + h.c.$$

Vacuum Structure

Scalar potential

$$V_{\rm qrt} = \lambda (H^\dagger H)^2 + \delta\, H^\dagger H\, \mathrm{Tr}\left[S^\dagger S\right] + u\, \mathrm{Tr}\left[S^\dagger S S^\dagger S\right] + v\, \left(\mathrm{Tr}\left[S^\dagger S\right]\right)^2$$

Two stable vacua

- V^+: all S_{ii} acquire VEV $\left(u > 0, \quad u + 3\,v > 0\right)$
- V^-: only one component acquires VEV $\left(u < 0, \quad u + v > 0\right)$

Scalars with VEV mix with h through $\sin\beta \propto \delta\, m_h/m_s$

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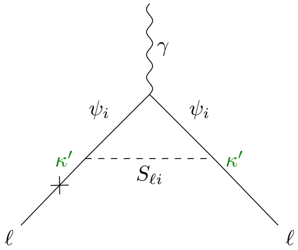
Effect in Yukawa terms

$$-\mathcal{L}^Y_{\rm sing} = \frac{\kappa}{\sqrt{2}} \cos\beta\, \overline{L}\, \psi_R\, h - \frac{\kappa'}{\sqrt{2}} \sin\beta\, \overline{E}^i\, \psi^i_L\, h + h.c.$$

flavors with scalar mixing $\rightarrow$ chirally enhanced contribution

Explaining Δa_μ



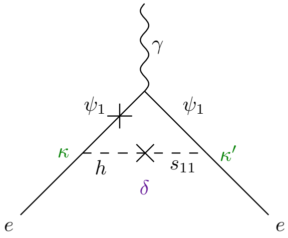
$$a_\mu^{\mathrm{NP}} \propto \kappa'^{\,2} \frac{m_\mu^2}{M_F^2}$$

$\kappa' \simeq 8.7 \left(\frac{M_F}{\mathrm{TeV}}\right)$ explains Δa_μ

with $m_h < M_S < M_F$

- $a_\mu^{\mathrm{NP}} > 0$
- Contributes to all flavors
  - $\kappa'^{\,2} \frac{m_e^2}{M_F^2} \ll |\Delta a_e|$
- Subleading contributions from $Z(W^\pm)$ exchange

Explaining Δa_e

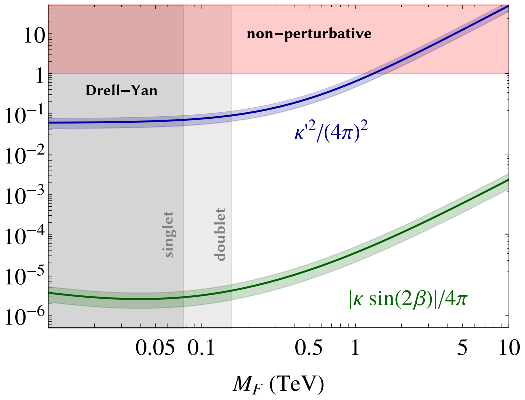


$a_e^{NP} \propto \kappa' \kappa \sin 2\beta \, \frac{m_e}{M_F}$

$-\kappa \sin 2\beta \simeq 2.9 \cdot 10^{-4} \left(\frac{M_F}{\mathrm{TeV}}\right)^2$ explains Δa_e

- a_e^{NP} can be > 0 or < 0
- Possible in V^+, electron-aligned V^-
  - $|\kappa' \kappa \sin 2\beta \, \frac{m_\mu}{M_F}| \ll \Delta a_\mu$
- Subleading contributions scaling as m_e^2/M_F^2

Explaining Δa_e and Δa_μ: parameter space

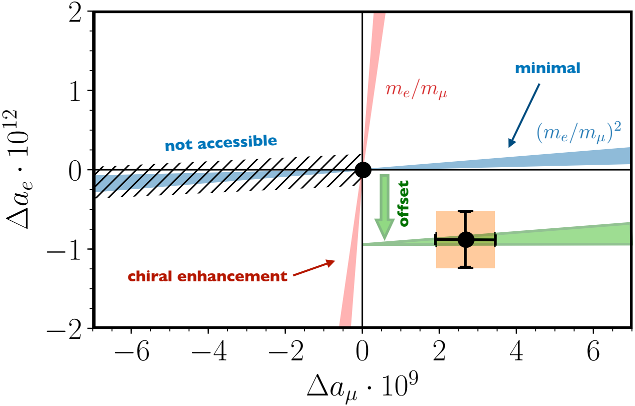


Bounds from [Farina *et. al.* (2017)]

EW precision parameters: $W, Y \propto \frac{\alpha_{2,1}}{10} \frac{M_W^2}{M_F^2} \Delta B_{2,1}^{\rm eff}$

change in 1-loop coefficient

Explaining Δa_e and Δa_μ: scaling



New Yukawas: mixing

- New coupling to Higgs ($\kappa \bar{L} H \psi_R$) and S ($\kappa' \bar{E} S^\dagger \psi_L$)
- After SSB $\to \psi_i - \ell_i$ mixing with $\kappa\, v_h$ and $\kappa'\, v_s$
- Same-generation mixing $\to$ no LFV

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- Same-generation mixing $\rightarrow$ no LFV

- For the singlet model

$$\bar{f}_L \mathcal{M}_\mathrm{s}\, f_R = \frac{1}{\sqrt{2}} \begin{pmatrix} \bar{\ell}_L \\ \bar{\psi}_L \end{pmatrix}^\mathrm{T} \begin{pmatrix} y_\ell v_h & \kappa\, v_h \\ \kappa'\, v_s & \sqrt{2} M_F \end{pmatrix} \begin{pmatrix} \ell_R \\ \psi_R \end{pmatrix}$$

$$\theta_L \simeq \frac{\kappa' v_s y_\ell + \sqrt{2}\kappa\, v_h M_F}{\bar{M}_F^2} \qquad \theta_R \simeq \frac{\kappa v_h y_\ell + \sqrt{2}\kappa' v_s M_F}{\bar{M}_F^2}$$

Constraints from mixing

- For the singlet model

θ_L - suppressed modifications

- Z vertex: $g_{V,A} = g_{V,A}^{\mathrm{SM}} + \frac{1}{2}\sin^2\theta_L$

  $g_{V,A}$ measured with permille accuracy

- Higgs couplings: $y_\ell = y_\ell^{\mathrm{SM}} + \sin\theta_L \Delta y_\ell$

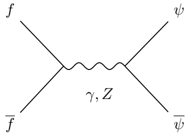
  Signal strength to leptons: $s_\ell \sim (y_\ell / y_\ell^{\mathrm{SM}})^2$

  Generally less restrictive ($s_\tau = 1.11 \pm 0.17$)

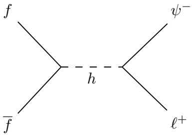
- $\theta_L < \mathcal{O}(10^{-2})$, fulfilled with small κ

BSM sector production @ pp and $\ell\ell$ colliders

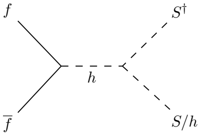
pp and $\ell\ell$



(a)

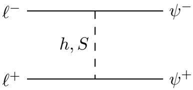


(b)

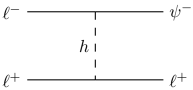


(c)

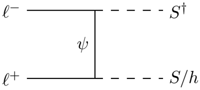
$\ell\ell$ only



(d)

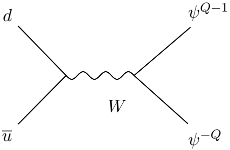


(e)



(f)

pp only



(g)

See talk by S. Bißman

Signatures

Decays

- Vector-like fermions: $\psi_i^- \to \ell^- h,\ \psi_i^0 \to \ell_i^- \ell_j^+ \nu_j$ (prompt decay)
- Singlet scalars: $S_{ij} \to \overline{\psi}_i \psi_j\ ,\ S_{ij} \to \psi_i^+ \ell_j^-\ ,\ S_{ii} \to GG$
  - LFV-like decays: $S_{ij} \to \ell_i^+ \ell_j^-$ through mixing

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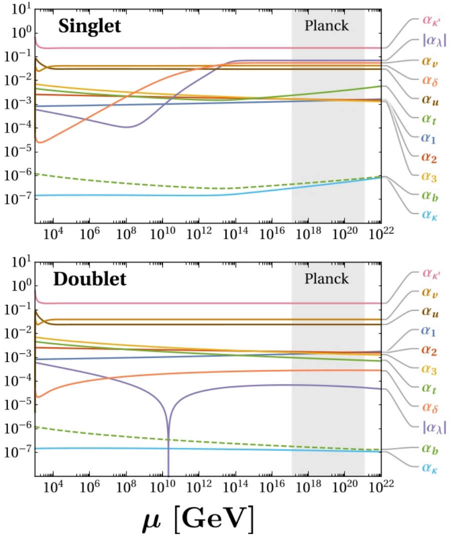
Anomalous magnetic moment of the τ

- Main BSM contribution $\propto \kappa'^2 m_\tau^2 / M_F^2$
- In V^-: $\Delta a_\tau = (7.5 \pm 2.1) \cdot 10^{-7}$

UV safety

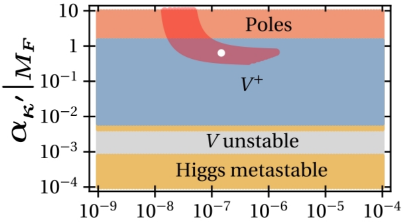
- Controlled 2-loop RG evolution of all couplings
  - Gauge: g_1, g_2, g_3
  - Yukawa: y, κ, κ' (y_t, y_b)
  - Scalar: λ, u, v, δ
- Stabilising Higgs quartic coupling possible



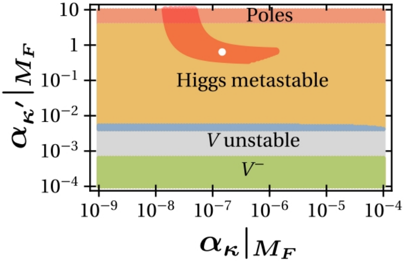
Vacuum stability

with BSM Yukawas $\kappa, \ \kappa'$ at matching scale

Singlet



Doublet



Summary

- NP contributions to a_e and a_μ with different mass scaling can accommodate the anomalies
- UV-safe models with additional Yukawa interactions give
  - chirally-enhanced contribution $\rightarrow \Delta a_e$
  - contribution $\propto \kappa'^2 \rightarrow \Delta a_\mu$
- No LFU breaking needed to explain both anomalies
- Signatures in BSM sector production and decay, AMM of the τ
- Fully controlled RG evolution

Outlook

- Collider study of ψ, S production and decay (with Stefan Bißman)
- Coloured ψ's (Tim Höne)

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Thank you

Extra slides

EDMs

Electron EDM bound

[ACME Collaboration (2018)]

$$|d_e| < 1.1 \cdot 10^{-29}\, e\, \mathrm{cm} \quad (90\%\ \mathrm{C.L.})$$

Constraint on relative CP-violating phases

$$\left|\sin 2\beta\, \mathrm{Im}\left[\kappa^* \kappa'\right]\right| < 8.8 \cdot 10^{-11}$$