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a_μ, a_e and Implications for a Muon EDM

Based on: AC, and M. Hoferichter and P. Schmidt-Wellenburg; arXiv:1807.11484

Outline

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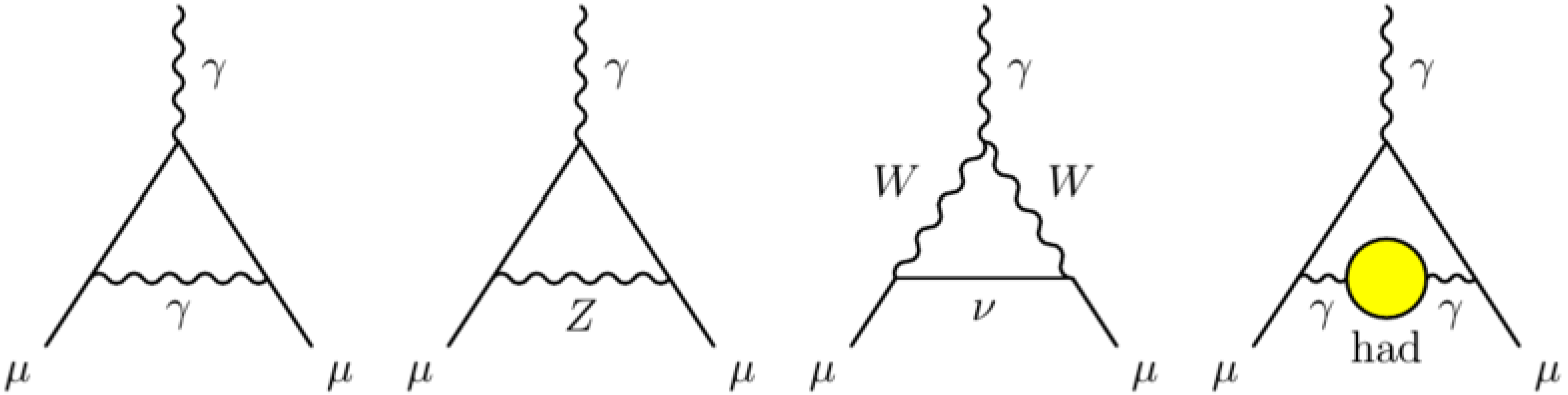
- Introduction: Searching for NP with flavour observables
- Experimental situation: Lepton Flavour Universality Violation
- Anomalous magnetic moments
  - a_μ
  - a_e
- Combined explanations
- A large muon EDM
- Conclusions

Muon Anomalous Magnetic Moment

- Single measurement from BNL
- Theory prediction sound but challenging because of hadronic effects.

$$\Delta a_{\mu} = (236 \pm 87) \times 10^{-11}$$

- Soon new experimental results from Fermilab



3σ deviation (order of SM-EW contribution)

Electron AMM

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- AMM usually used to determine α
- With *now* best determination of α from Cs atoms

$$a_e^{\mathrm{SM}}\big|_{\alpha_{\mathrm{Cs}}} = 1{,}159{,}652{,}181.61(23) \times 10^{-12}$$

- Compared to the electron AMM measurement

$$\Delta a_e = a_e^{\mathrm{exp}} - a_e^{\mathrm{SM}} = -0.88(36) \times 10^{-12}$$

- Normalized to the lepton mass

$$-3 \le \frac{\Delta a_\mu}{m_\mu} \Big/ \frac{\Delta a_e}{m_e} \le -130 \quad \text{or} \quad -0.006 \le \frac{\Delta a_\mu}{m_\mu^2} \Big/ \frac{\Delta a_e}{m_e^2} \le -0.26$$

2.5 σ deviation with opposite sign than a_μ

Dipoles in the EFT

- Effective Hamiltonian

$$\mathcal{H}_{\rm eff} = c_R^{\ell_f \ell_i}\, \bar{\ell}_f \sigma_{\mu\nu} P_R \ell_i F^{\mu\nu} + \text{h.c.}$$

- Anomalous magnetic moment

$$a_{\ell_i} = -\frac{4 m_{\ell_i}}{e} \,\text{Re}\, c_R^{\ell_i \ell_i}$$

- Electric Dipole moment

$$d_{\ell_i} = -2\, \text{Im}\, c_R^{\ell_i \ell_i}$$

- Radiative Lepton decays

$$\text{Br}[\mu \to e\gamma] = \frac{m_\mu^3}{4\pi\, \Gamma_\mu}\left(|c_R^{e\mu}|^2 + |c_R^{\mu e}|^2\right)$$

Processes intrinsically connected

Explaining the Muon AMM

- Effect of the order of the EW-SM contribution needed

⇨ enhancement necessary

- Light particles
  - Neutral scalars
  - Neutral vector (Z' Dark Photon)
- Chiral enhancement: Chiriality flip does not come from the muon mass but rather from an NP mass inside the loop

Light particles or chiral enhancement

Light particles and the Muon AMM

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- Light particles: m_W^2 / m^2
  - Neutral scalars: Φ
  - Neutral vector (Z' Dark Photon): V

$$c_R^{\mu\mu} = \frac{e}{16\pi^2} m_\mu \left(\left|\Gamma^{\mu L}\right|^2 + \left|\Gamma^{\mu R}\right|^2 \right) \frac{f_{\Phi,V}\left(\frac{M_\Psi^2}{m^2}\right) + Qg\left(\frac{M_\Psi^2}{m^2}\right)}{m^2}$$

$Q =$ charge of the fermion $\quad f, g =$ loop functions

- Sime sign in muon and electron AMM
- Strong limits from direct searches for dark photons etc..

By construction real, i.e. no EDMs

Chiral enhancement

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- Enhancement by the mass of the fermion in the loop

$$c_R^{fi} = \frac{e}{16\pi^2} \Gamma_\Psi^{\mu L*} \Gamma_\Psi^{\mu R} M_\Psi \frac{f\left(\frac{M_\Psi^2}{M^2}\right) + Qg\left(\frac{M_\Psi^2}{M^2}\right)}{M^2}$$

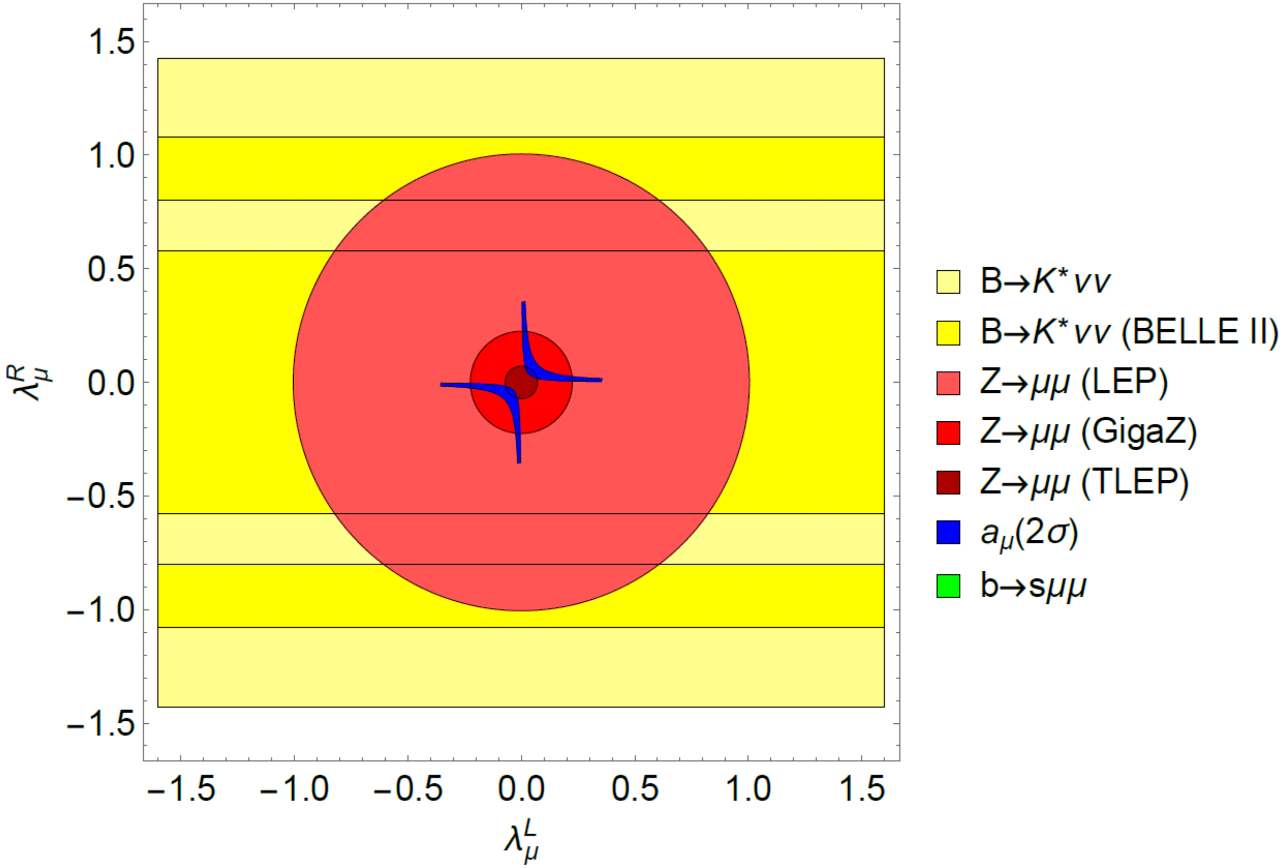
$Q, M_\Psi =$ charge, mass of the fermion $\qquad f, g =$ loop functions

- MSSM: (tan(ß))
- Leptoquarks: m_t/m_μ
- Model with vector like fermions: m_Ψ/m_μ

A priori arbitrary phase

Leptoquarks in a_μ

- Chirally enhanced effects via top-loops



$\lambda_\mu^{L,R}$

Left-, right-handed muons-top coupling

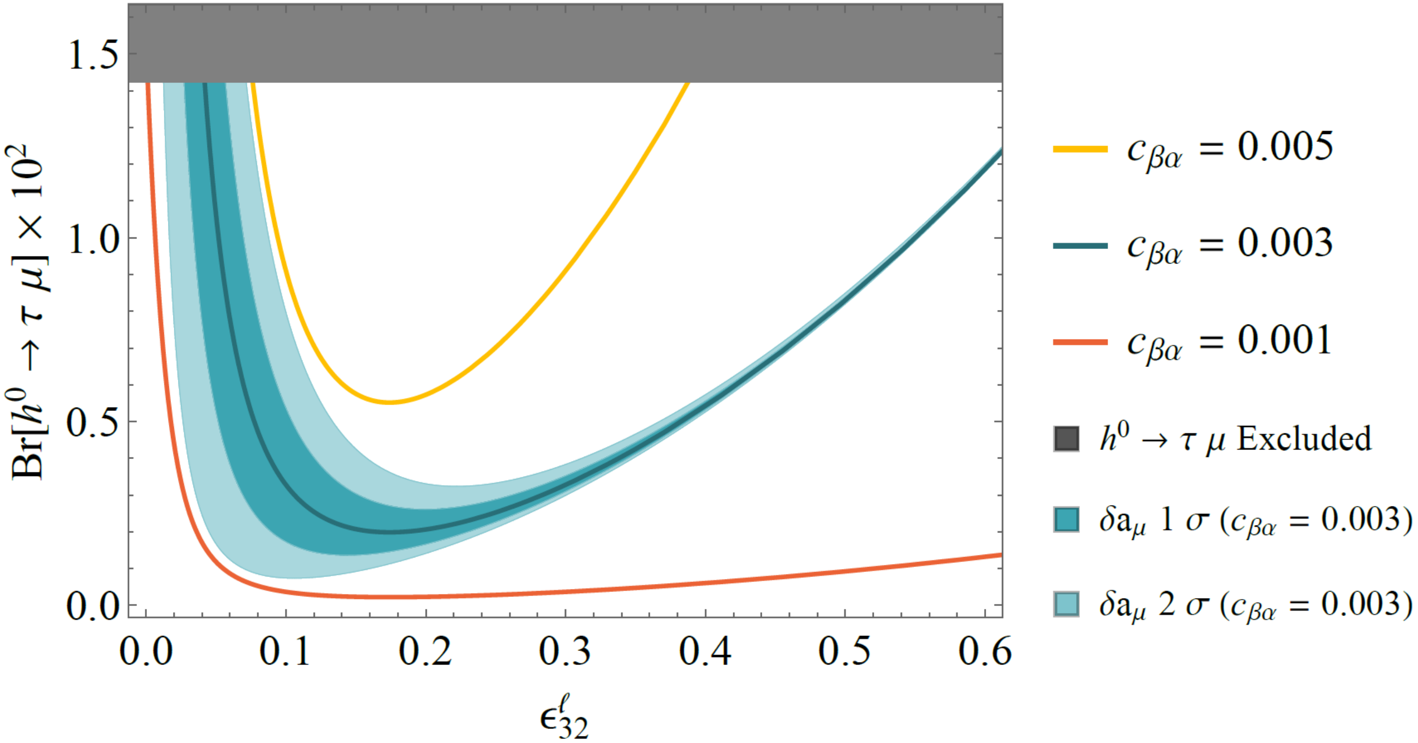
E. Leskow, A.C., G. D'Ambrosio, D. Müller arXiv:1612.06858

Z→μμ at future colliders

2HDMs

- Chirally enhancement of m_μ/m_e

AC, D. Müller, C. Wiegand
arXiv:1903.10440



Unavoidable constraints from $h \to \tau\mu$

Common explanation of a_μ and a_e

- Opposite sign: ⇨ no single light mediator
- Minimal Flavour Violation:

  $$\Delta a_\mu / \Delta a_e \neq m_\mu^2 / m_e^2$$

  ⇨ generic flavour structure
- Single new particle:

  $$\mathrm{Br}[\mu \to e\gamma] = \frac{\alpha m_\mu^2}{16 m_e \Gamma_\mu} |\Delta a_\mu \Delta a_e| \sim 8 \times 10^{-5}$$

  8 orders of magnitude too large

  ⇨ several new particles

Muon and electron sector must be decoupled

Models for a common explanation

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- MSSM
  - Constrained MFV does not work
  - With generic A-terms has problem with vacuum stability
  - With large tan(ß) and flavour violation
- 2HDMs & LQs: Problems with μ→eγ
- Extra dimensions
  - Can only explain the muon or the electron AMM because of μ→eγ

Most popular models do not work

Model with new vector-like leptons

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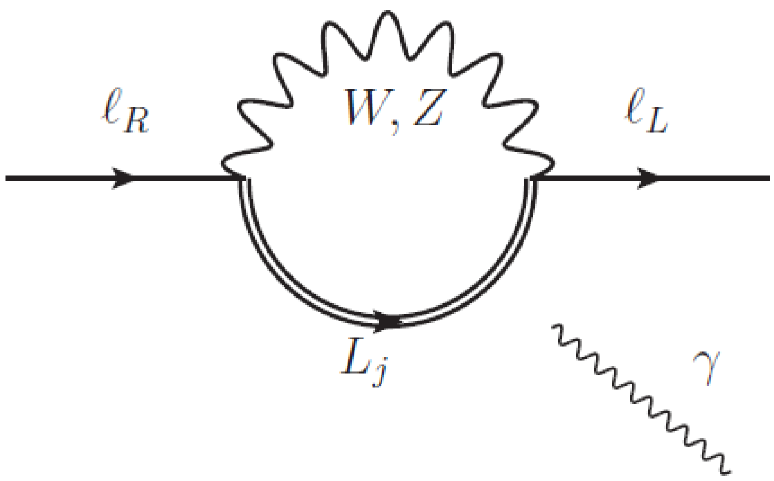
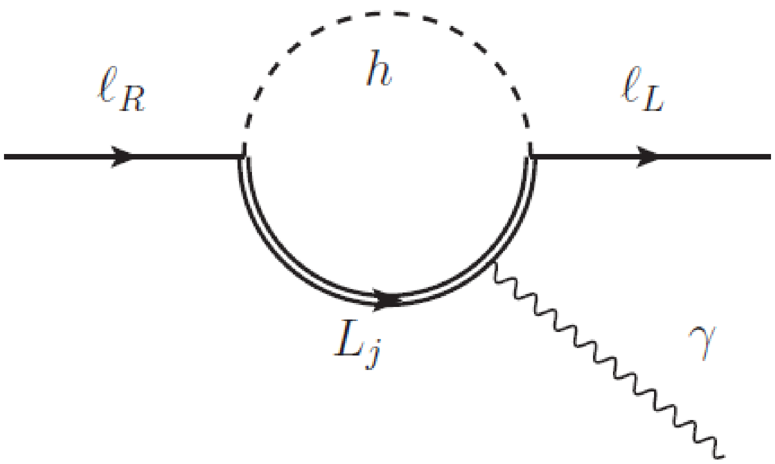
$$\mathcal{L}_M = -M_L \bar{L}_L L_R - M_E \bar{E}_L E_R + \text{h.c.},$$

$$\mathcal{L}_H = -\kappa_L \bar{L}_L H E_R - \kappa_E \bar{L}_R H E_L - \lambda_L \bar{L}_L \ell_R H - \lambda_E \bar{E}_R \tilde{H} \ell_L + \text{h.c.}$$





Chirally enhanced by $v\kappa_{L,R}/m_\mu$

Model with new vector-like leptons

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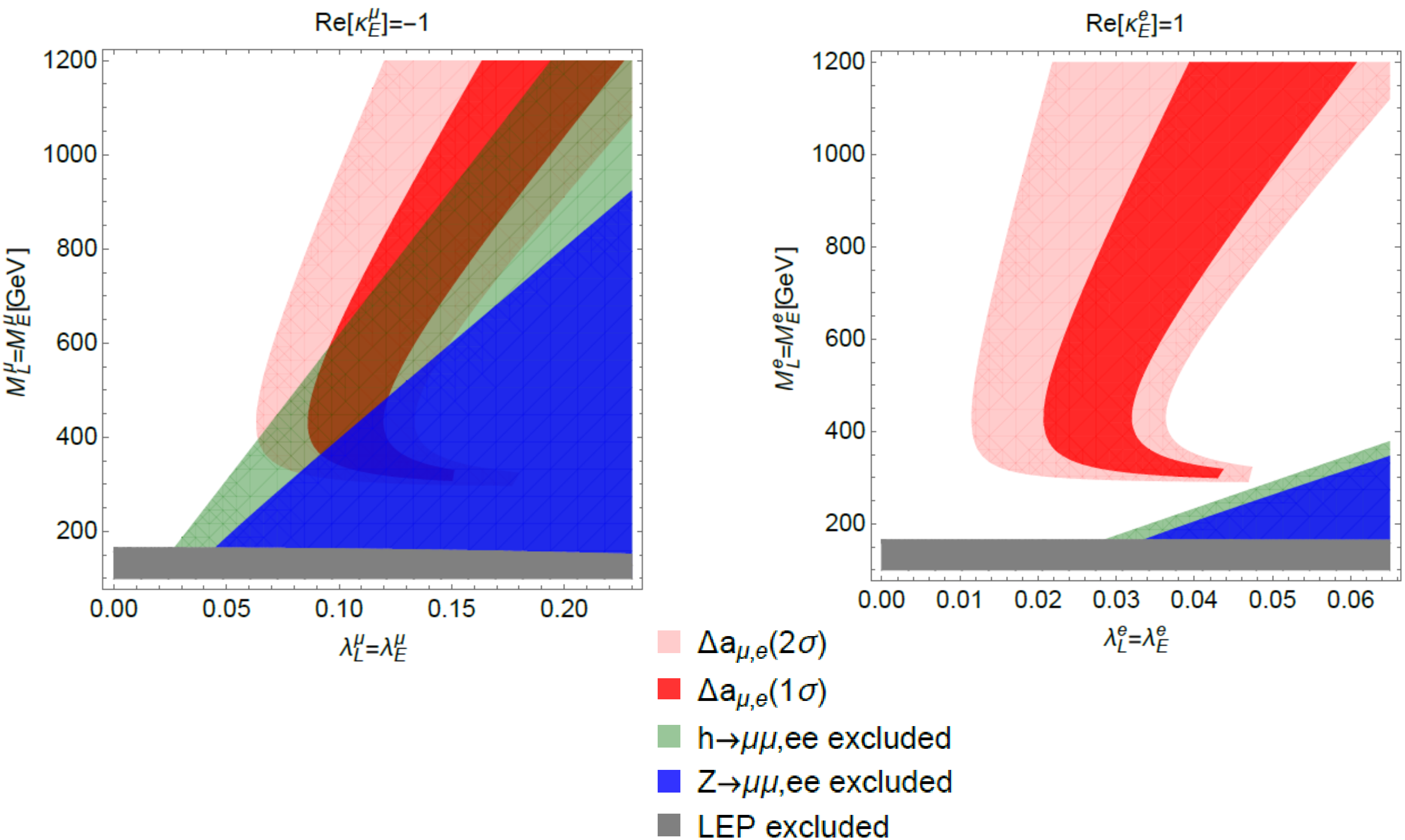


Works for a_e but tension with a_μ

Modifications to the model

- Add neutral scalar
  - Effect in a_μ possible without affecting $h \to \mu\mu$
- Impose abelian flavour symmetry (e.g. L_μ-L_τ) in order to avoid $\mu \to e\gamma$
- More minimal model with one generation of vector-like fermions possible if a_e is explained by the SM Higgs and a_μ via a new scalar
- New scalar could be L_μ-L_τ flavon

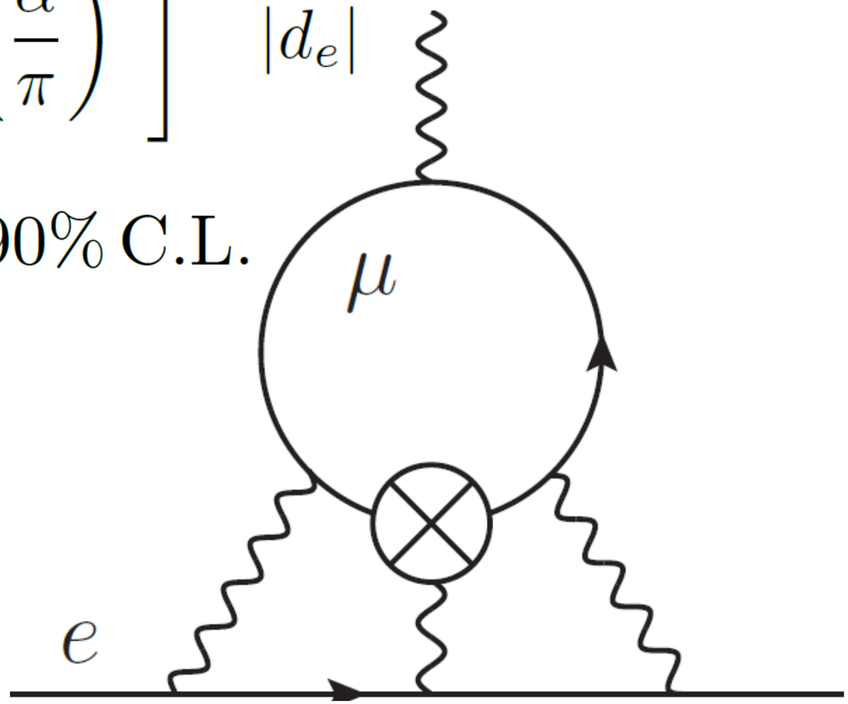
Many realizations possible

Limits on the Muon EDM

- MFV:
- Contribution only starts at the 3-loop level

$$|d_\mu| \leq \left[\left(\frac{15}{4}\zeta(3) - \frac{31}{12} \right) \frac{m_e}{m_\mu} \left(\frac{\alpha}{\pi} \right)^3 \right]^{-1} |d_e|$$

$$|d_\mu| \leq 0.9 \times 10^{-19} e\,\mathrm{cm} \qquad 90\%\ \mathrm{C.L.}$$

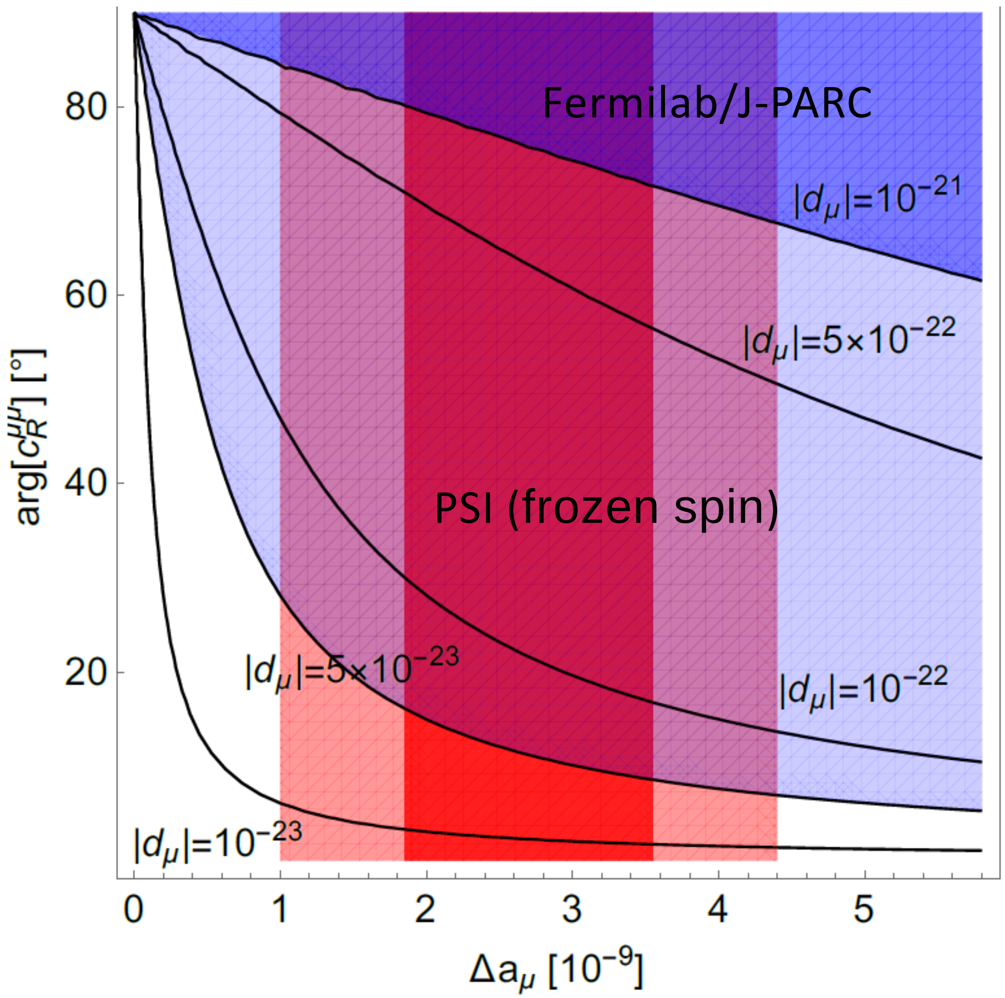


- Direct limit

$$|d_\mu| < 1.5 \times 10^{-19} e\,\mathrm{cm}$$

Improvement of direct limit important

Future experimental sensitivity



Dedicated experiment needed?

Conclusions