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g-2 Beyond the Standard Model

La Thuile, 09.03.2023

Outline

- Explaining the anomalous magnetic moment of the muon with new physics
- a_μ and consequences for future measurements
- Lepton Flavour Universality Violating NP
- Explanations
- Conclusions

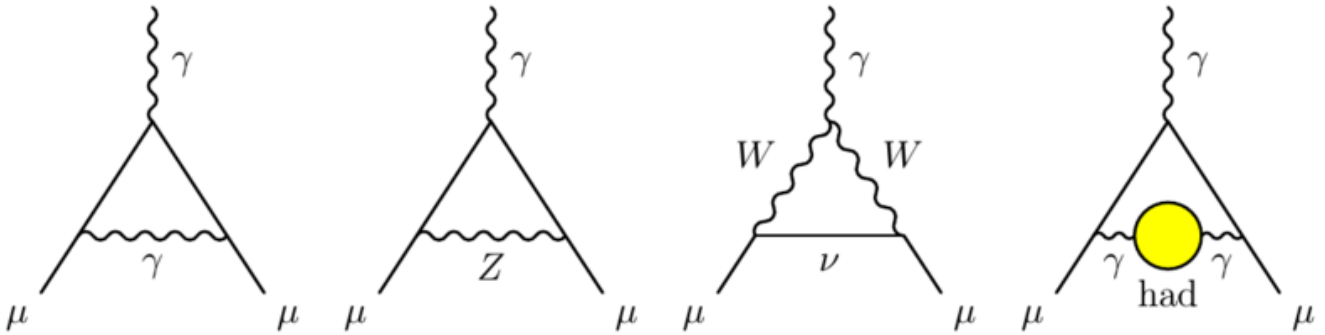
Physics Beyond the Standard Model

- Dark Matter existence established at cosmological scales
  - New weakly interacting particles
- Neutrinos not exactly massless
  - Right-handed (sterile) neutrinos
- Matter anti-matter asymmetry
  - Additional CP violating interactions

New particles and interactions exist!

The SM must be extended!
What is the underlying fundamental theory?

Muon Anomalous Magnetic Moment



- Theory prediction challenging (hadronic effects)

$$\Delta a_\mu = (251 \pm 49) \times 10^{-11}$$ T. Aoyama et al., arXiv:2006.04822

- Need NP of the order of the SM EW contribution
- Chiral enhancement necessary for heavy NP
- Soon more experimental results from Fermilab
- Vanishes for $m_\mu \to 0$ ⇨ **measure of LFUV**

4.2σ deviation from the SM prediction

Dipoles in the EFT

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- Effective Hamiltonian

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

- Anomalous magnetic moment

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

- Electric Dipole moment

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

- 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)
  - ALP (axion like particle)
- Chiral enhancement: Chirality flip does not come from the muon mass but rather from a NP mass inside the loop

Light particles or/and chiral enhancement

Chiral enhancement

- Enhancement by the mass of the fermion in the loop

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

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

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

A priori arbitrary phase ⇒ muon EDM

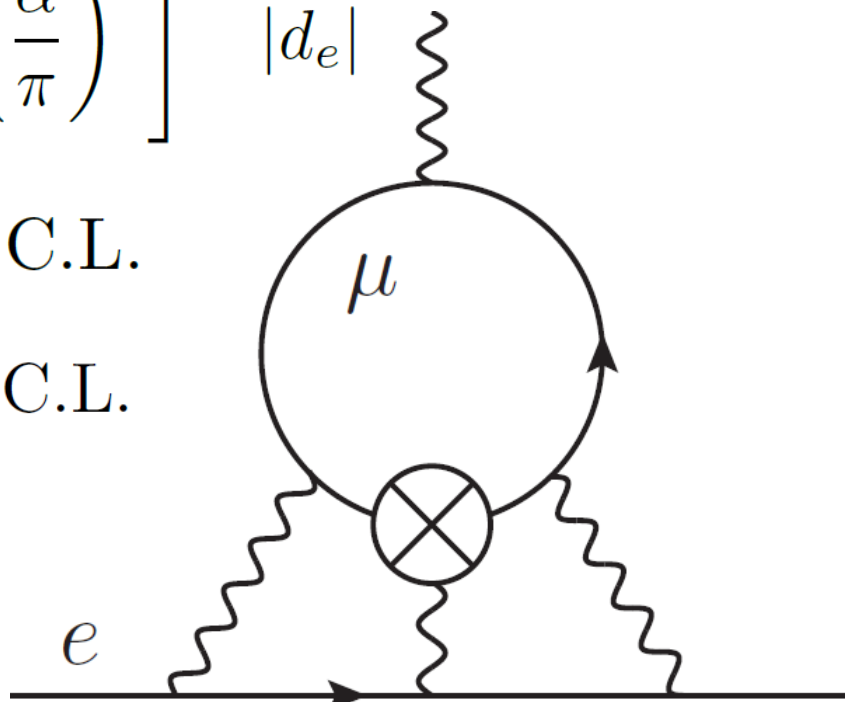
Indirect Limit on the Muon EDM

- MFV: $|d_\mu^{\mathrm{MFV}}| < 3.7 \times 10^{-24} e\,\mathrm{cm}$
- Contribution only starts at the 3-loop level

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

$$\leq 7.5 \times 10^{-19} e\,\mathrm{cm} \qquad 90\%\ \mathrm{C.L.}$$

$$|d_e| < 8.7 \times 10^{-29} e\,\mathrm{cm} \qquad 90\%\ \mathrm{C.L.}$$

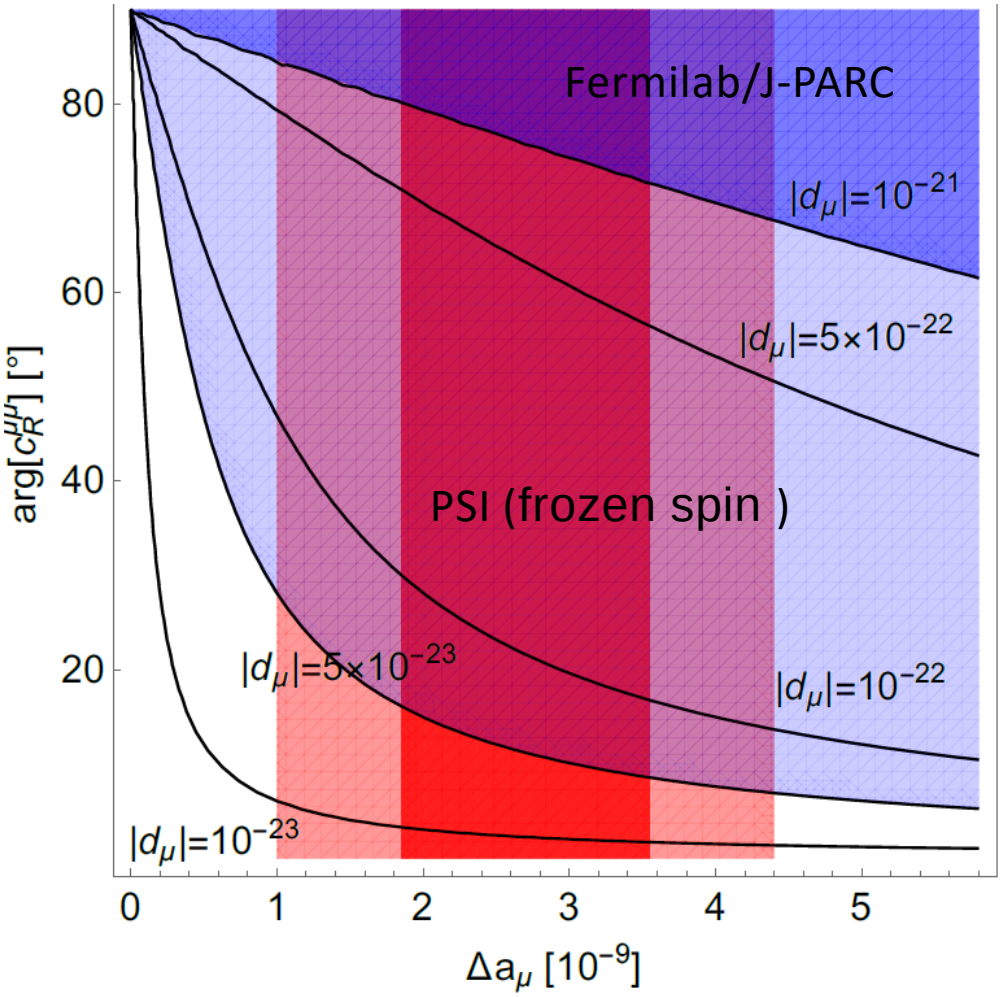


- Direct limit

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

Improvement of direct limit important

Future experimental sensitivity



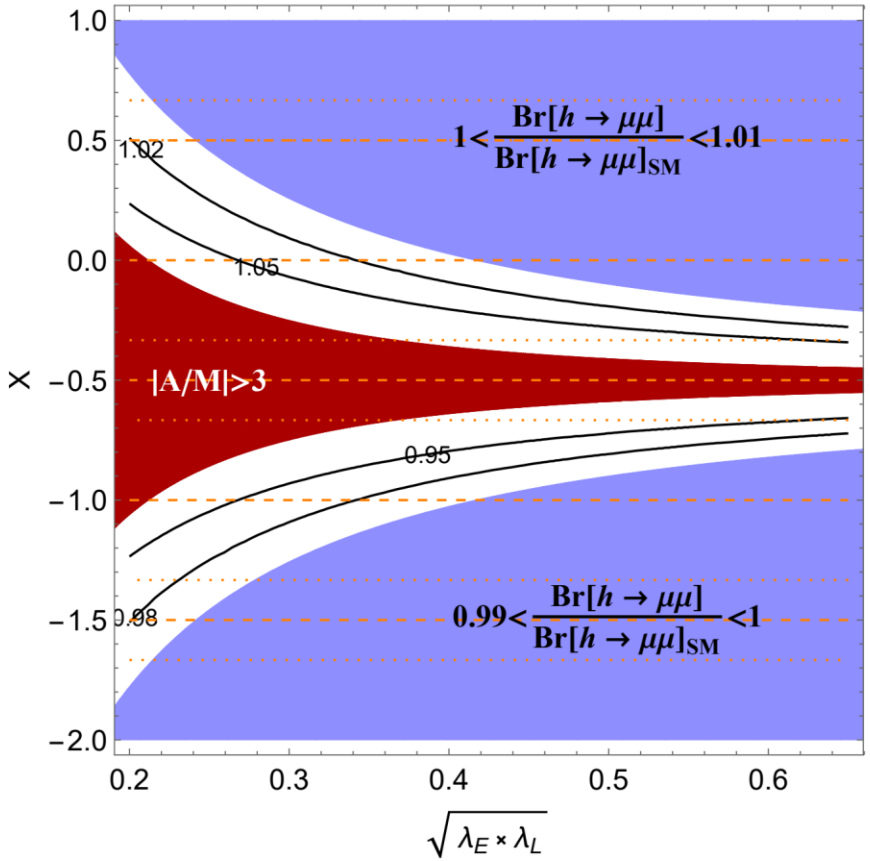
Dedicated experiment needed!

Heavy new scalars and fermions

- Chirally enhanced effects requires three fields

	R	Ψ, Φ	Φ_L, Ψ_L	Φ_E, Ψ_E	ϕ	ℓ	e
$SU(2)_L$	121	1	2	1	2	2	1
	212	2	1	2			
	323	3	2	3			
	232	2	3	2			
Y		X	$-\frac{1}{2} - X$	$-1 - X$	$\frac{1}{2}$	$-\frac{1}{2}$	-1

A.C., M. Hoferichter, 2104.03202

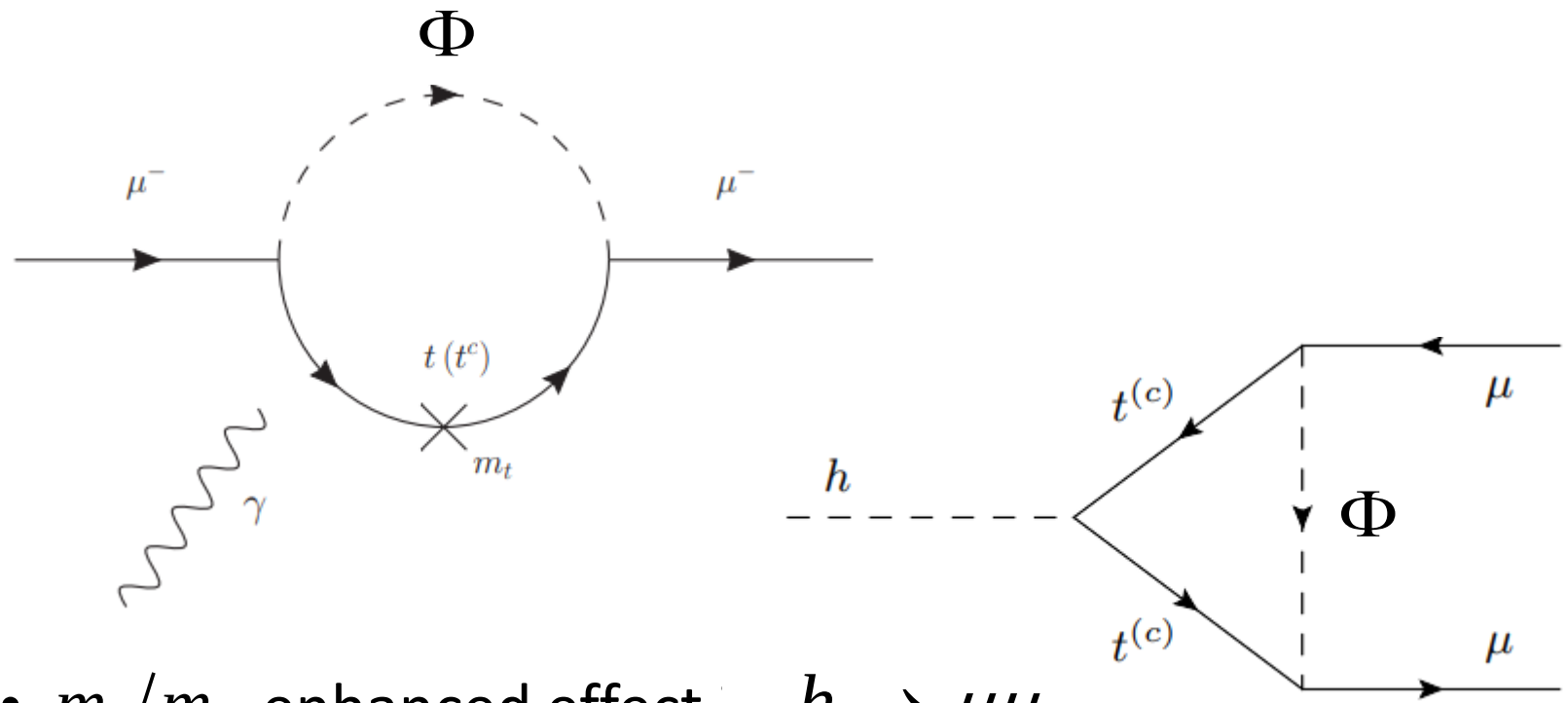


- SMEFT Matching
- Correlations with
  - Z→μμ
  - h →μμ

Z,h→μμ at future colliders

Leptoquarks in a_μ

- Chirally enhanced effects via top-loops

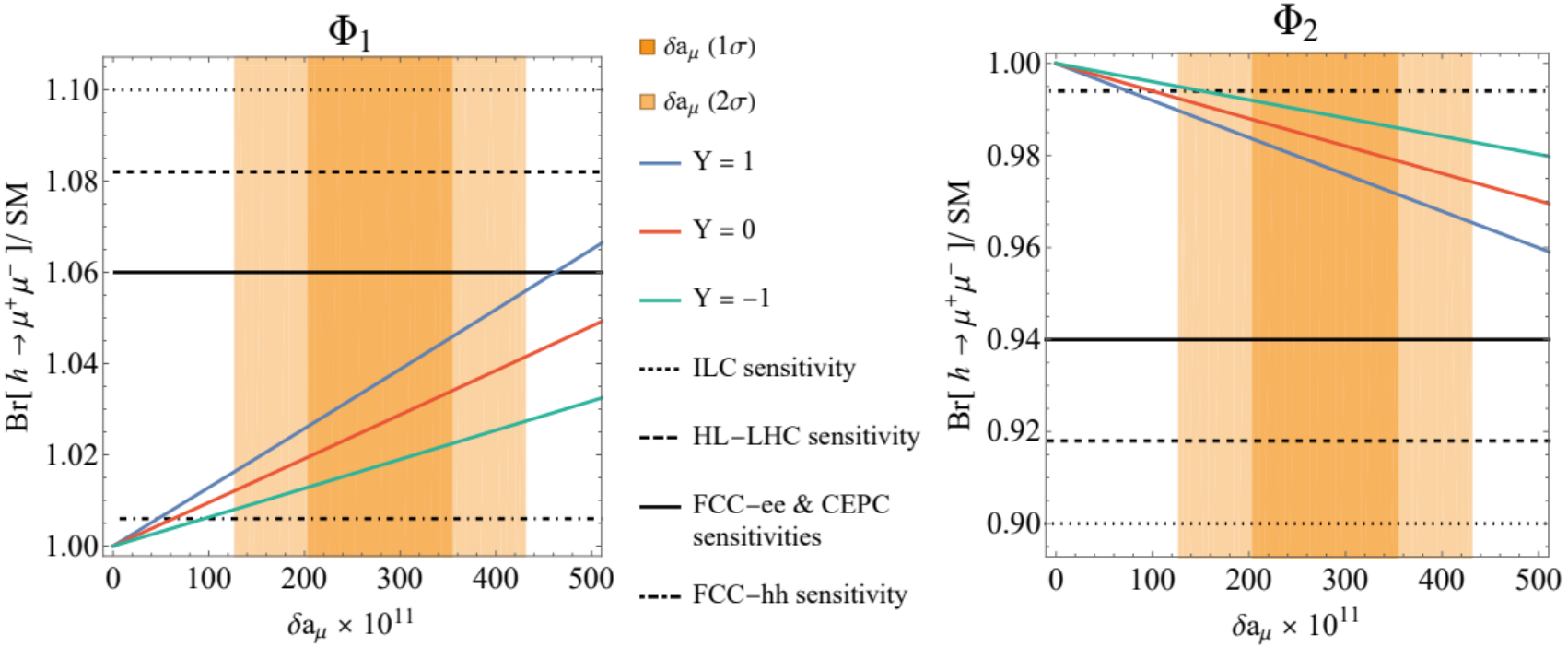


- m_t/m_μ enhanced effect $h \to \mu\mu$
- m_t^2/m_Z^2 enhanced effect in $Z \to \mu\mu$

Correlations with h→μμ and Z→μμ

a_μ vs h→μμ

- Chirally enhanced effects via top-loops
- Same coupling structure → direct correlation

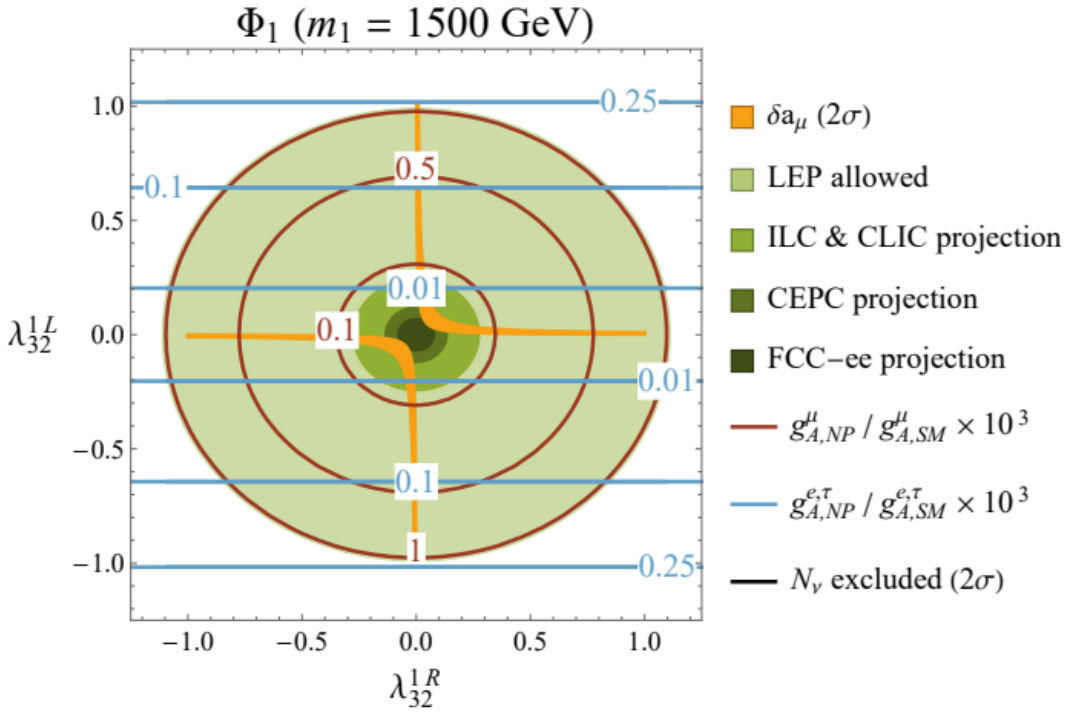


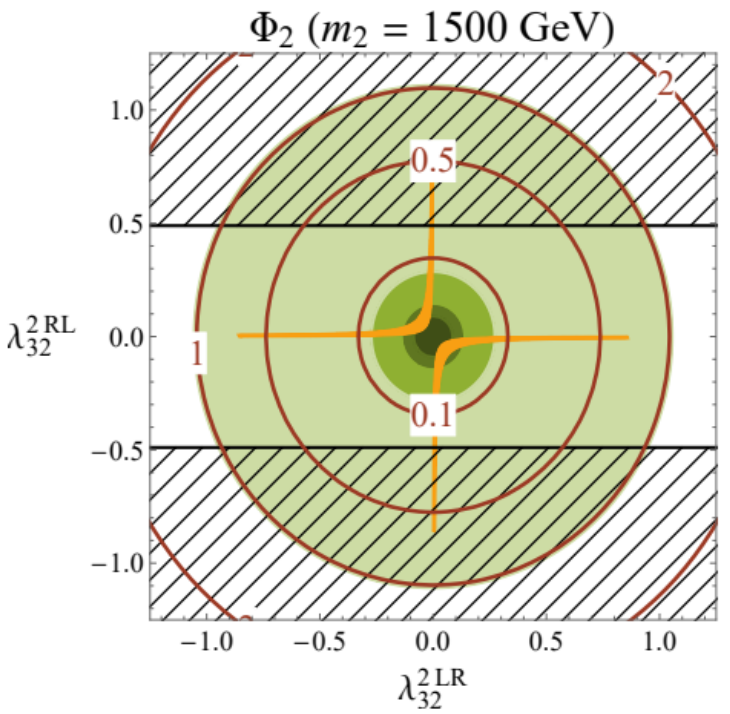
A.C., D. Mueller, F. Saturnino, 2008.02643

h→μμ at future colliders

a_μ vs $Z\to\mu\mu$

- Chirally enhanced effects via top-loops



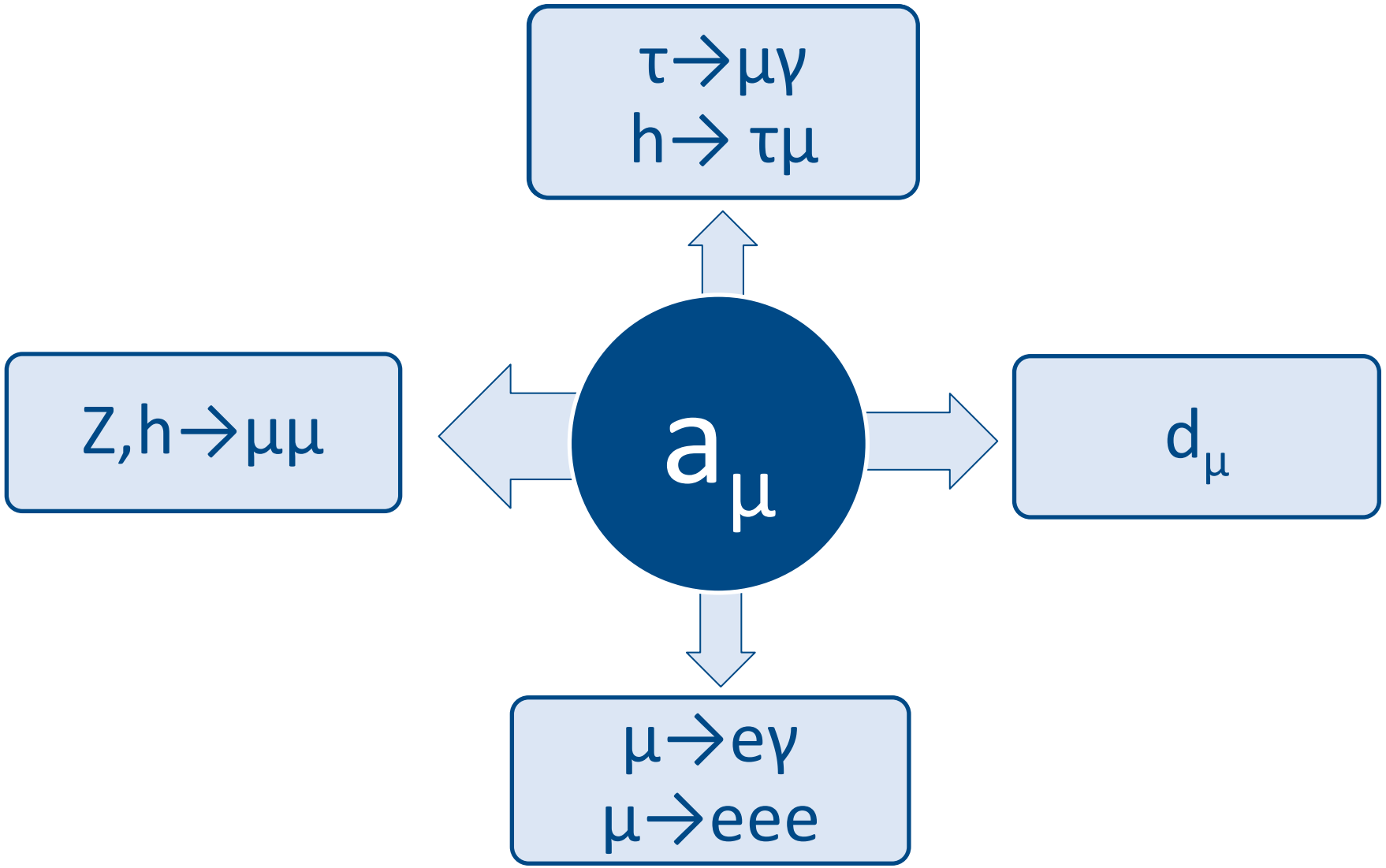


$\lambda_\mu^{L,R}$ Left-, right-handed muon-top coupling

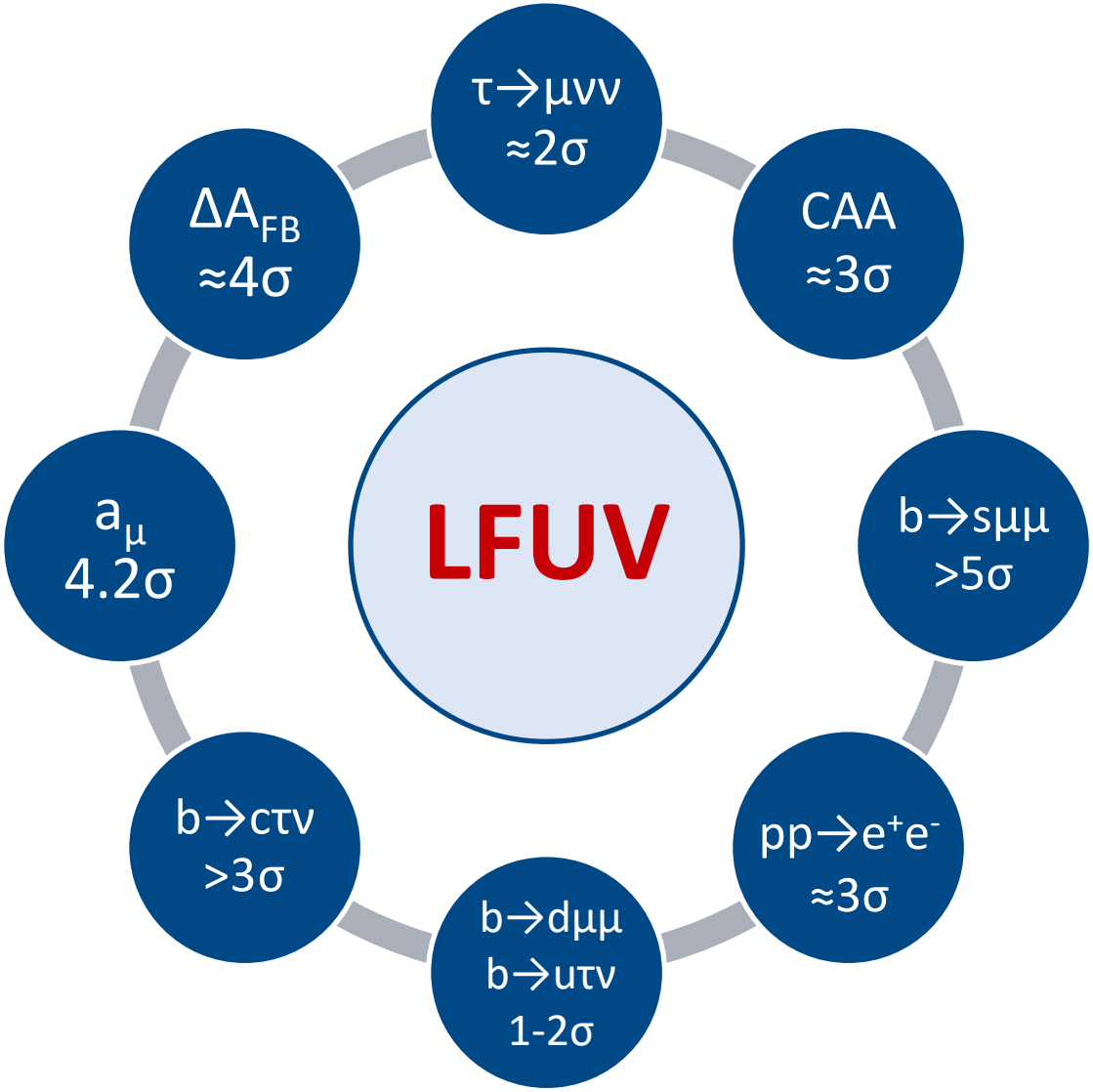
E. Leskow, A.C., G. D'Ambrosio, D. Müller 1612.06858
A.C, C. Greub, D. Müller, F.Saturnino, 2010.06593

$Z\to\mu\mu$ at future colliders

Future Implications of a_μ



Flavour Anomalies



Conclusions