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Ellipse of Muon Dipole Moments

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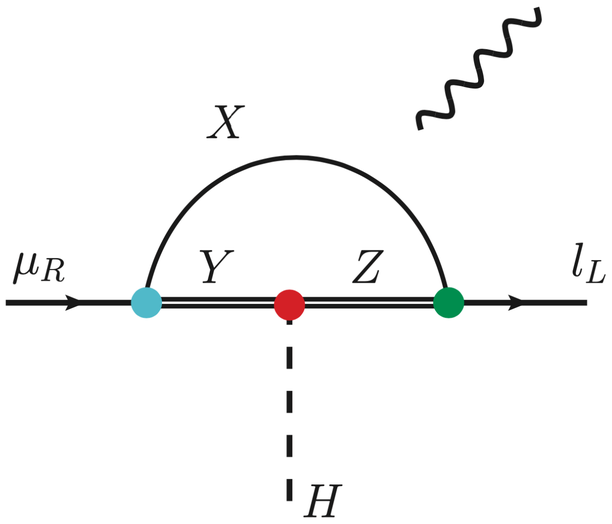
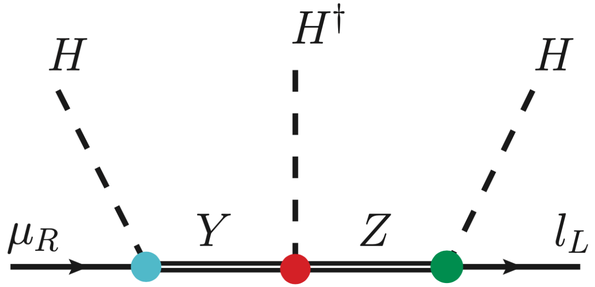
Outline

- Muon g-2 is one of the longest standing anomalies that needs to be explained
- There are many models that explain the anomaly. Examples include vectorlike leptons, SUSY, 2HDM, leptoquarks, …
- In models with chiral enhancement, New Physics scale can be as large as 50 TeV while explaining muon g-2 anomaly
- The same New Physics modifies the muon Yukawa coupling through higher dimensional operators, thus $h \to \mu^+\mu^-$ rate deviates from the SM value
- Furthermore, if all couplings are complex in general, then we expect μEDM
- We emphasize that, as we will show, since three observables, Δa_μ, $h \to \mu^+\mu^-$, and μEDM are highly correlated, complex couplings are not optional

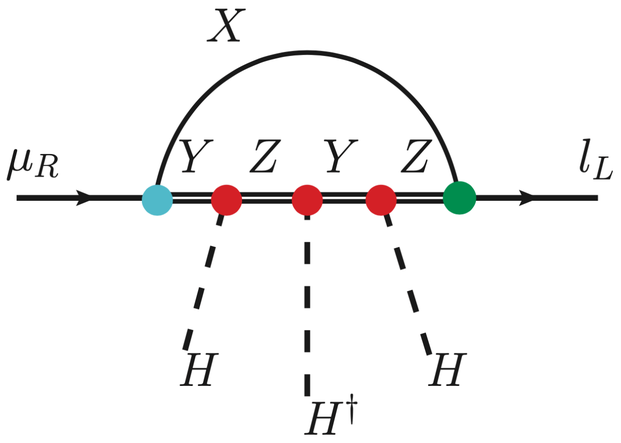
Intuitive picture





tree model

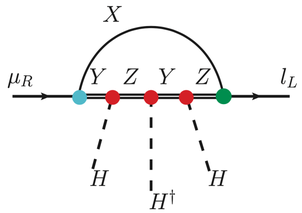
e.g. SM+VL
R. Dermisek, K. Hermanek and N. McGinnis, arXiv:2011.11812 [hep- ph]

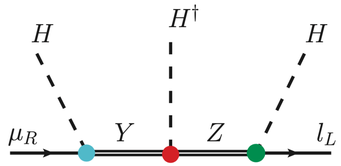


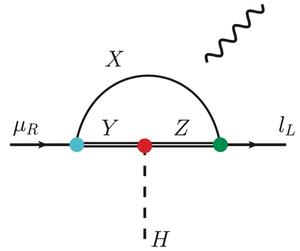
loop model

e.g. MSSM
A. Thalapillil and S. Thomas, arXiv:1411.7362 [hep-ph]

Effective Lagrangian







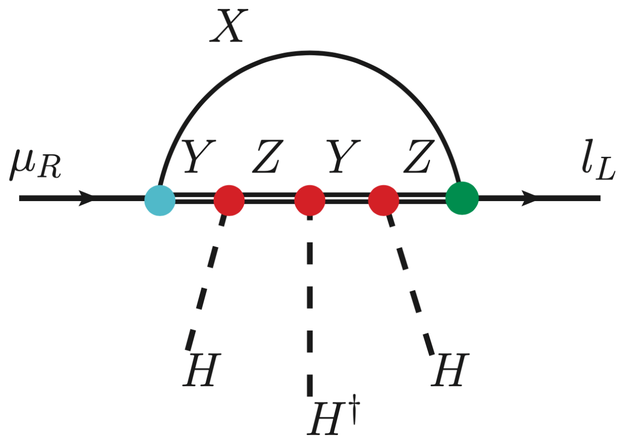
$$\mathcal{L} \supset -y_\mu \bar{l}_L \mu_R H - C_{\mu H} \bar{l}_L \mu_R H \left(H^\dagger H\right) - C_{\mu\gamma} \bar{l}_L \sigma^{\rho\sigma} \mu_R H F_{\rho\sigma} + h.c.,$$

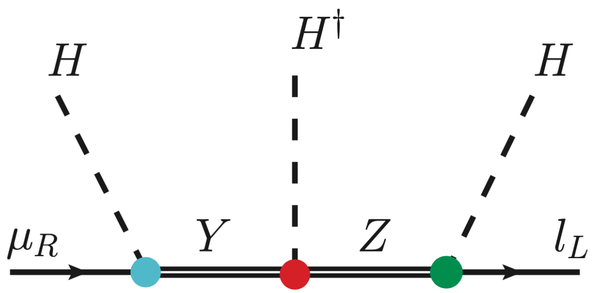
Real

Imaginary

$$h \to \mu^+ \mu^- \qquad \Delta a_\mu \qquad d_\mu$$

dimension-6 mass operator





$$C_{\mu H}\bar{l}_L\mu_R H(H^\dagger H)$$

Inserting 3 vevs

$$m_\mu = (y_\mu v + C_{\mu H} v^3)e^{-i\phi_{m_\mu}}$$

Inserting 2 vevs

$$\lambda^h_{\mu\mu} = (y_\mu + 3C_{\mu H} v^2)e^{-i\phi_{m_\mu}}$$

* $\lambda^h_{\mu\mu}$ can be complex

*3 appearing due to different combinations

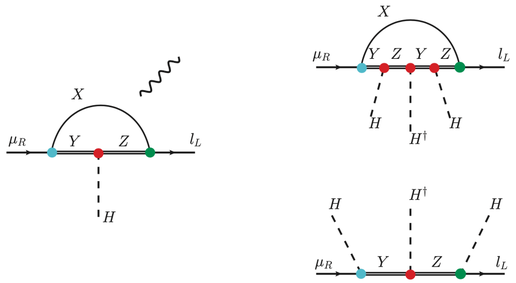
Modification of $h \to \mu^+\mu^-$ rate

The combinatorics lead to modifications of $h \to \mu^+\mu^-$

$$R_{h\to\mu^+\mu^-} \equiv \frac{BR(h \to \mu^+\mu^-)}{BR(h \to \mu^+\mu^-)_{SM}} = \left(\frac{v}{m_\mu}\right)^2 \left|\lambda^h_{\mu\mu}\right|^2$$

where $\lambda^h_{\mu\mu} = (y_\mu + 3C_{\mu H}v^2)e^{-i\phi_{m_\mu}}$

Complex couplings



- All couplings are in general complex
- Note that the same combination of phases appear both in $C_{\mu\gamma}$ and $C_{\mu H}$
- $C_{\mu\gamma}$ and $C_{\mu H}$ are related by a real factor k

$$C_{\mu H} = \frac{k}{e} C_{\mu\gamma}$$

- $R_{h\to\mu^+\mu^-}$ is not only correlated to Δa_μ but also highly to μEDM
- **If $h \to \mu^+\mu^-$ is not modified, then sizable μEDM is generated in many models**

The muon ellipse

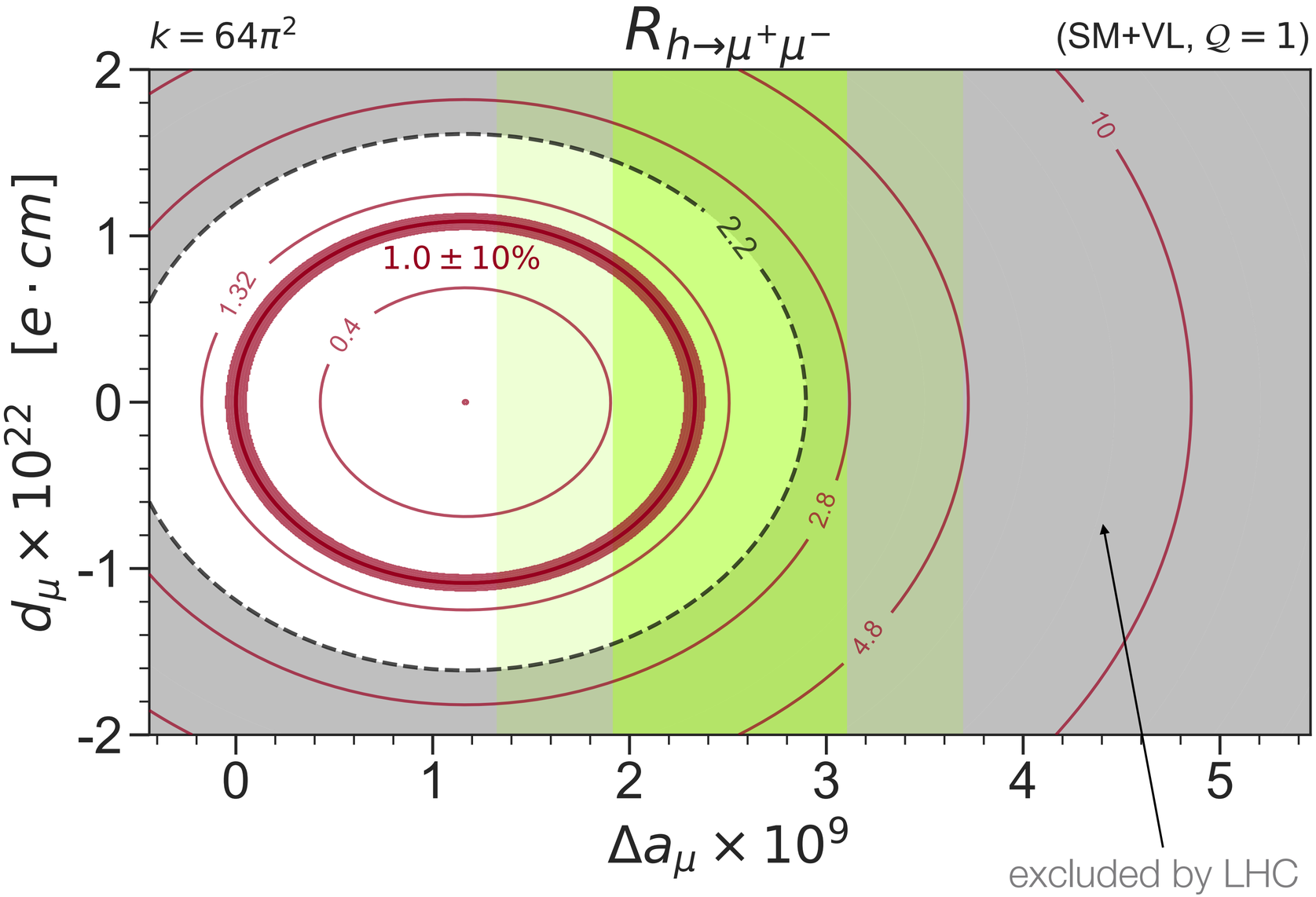
$$R_{h\to\mu^+\mu^-} = \left(\frac{\Delta a_\mu}{2\omega} - 1\right)^2 + \left(\frac{m_\mu d_\mu}{e\omega}\right)^2$$

where $\omega = m_\mu^2/kv^2$

Example: SM+Vectorlike Leptons

$$k = \frac{64\pi^2}{\mathcal{Q}}$$

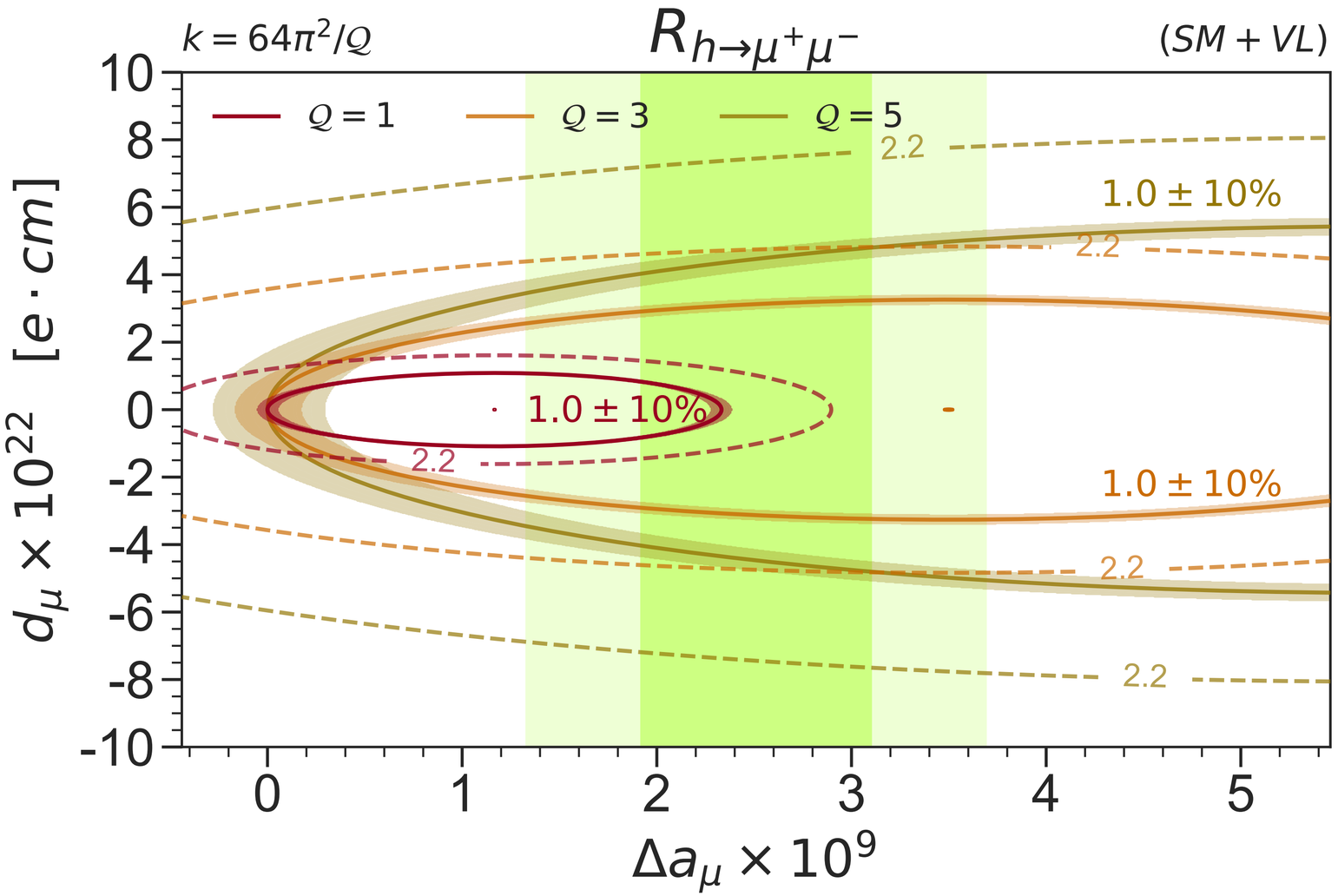
$\mathcal{Q}$ for different representations
For VL with same representations as SM ones,
$\mathcal{Q} = 1$



SM+VL, $\mathcal{Q} = 1, \mathcal{Q} = 3, \mathcal{Q} = 5$

The sensitivity at Paul Scherrer Institute (PSI): $|d_\mu| \sim 6 \times 10^{-23}\ ecm$

arXiv:2102.08838 [hep-ex]



$\mathcal{Q} = 3$:

$\mathbf{2}_{-3/2} \oplus \mathbf{1}_{-1}$

$\mathbf{2}_{-3/2} \oplus \mathbf{3}_{-1}$

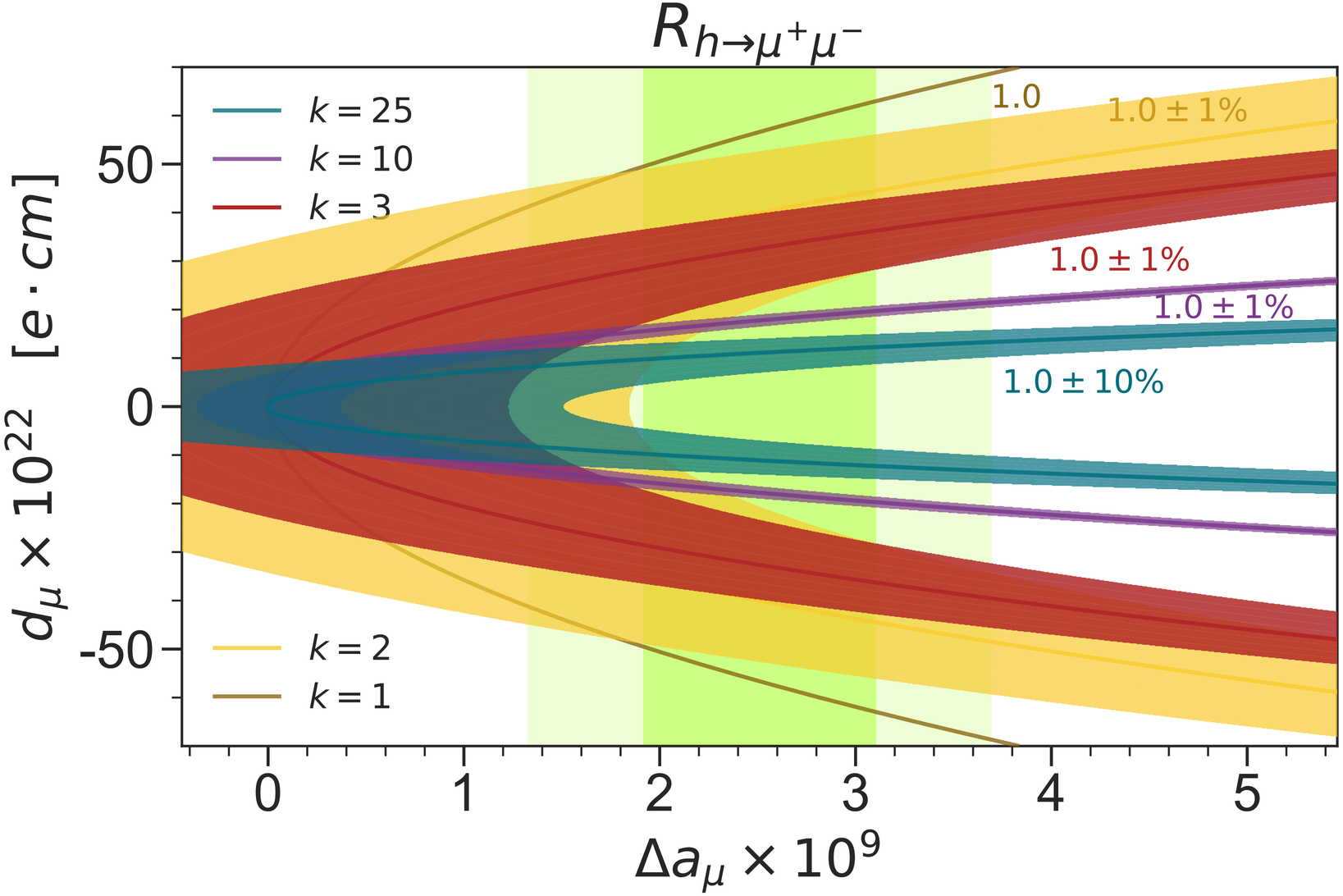
$\mathcal{Q} = 5$:

$\mathbf{2}_{-1/2} \oplus \mathbf{3}_{-1}$

Many models

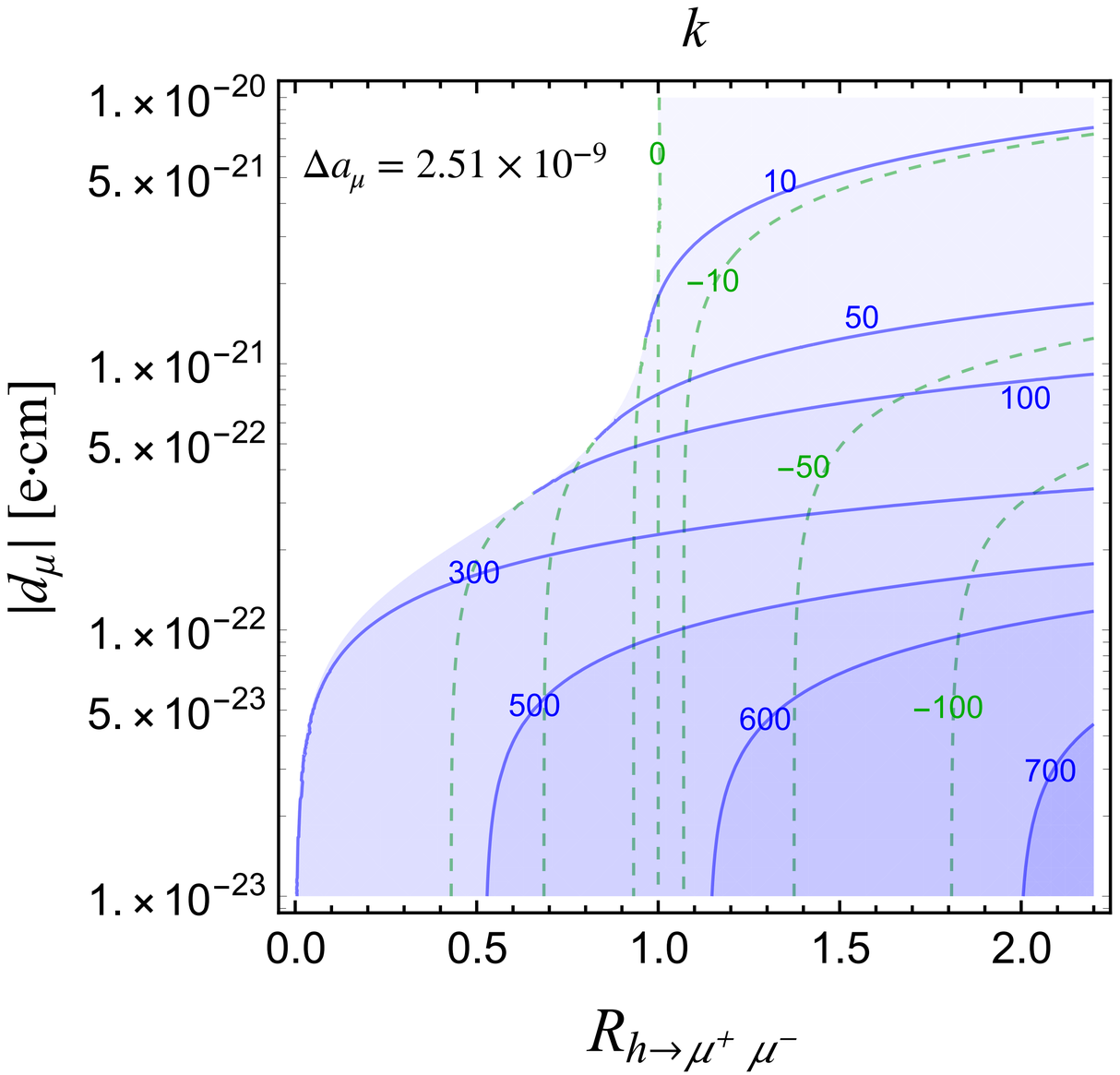
E.g., SM+VL, 2HDM, MSSM, leptoquarks, …

Many models will be tested in near future measurements



Any model that explains g-2 with chiral enhancement can be mapped to the plane

R. Dermisek and A. Raval, arXiv:1305.3522 [hep-ph]
M. Endo, K. Hamaguchi, T. Kitahara and T. Yoshinaga, arXiv:1309.3065 [hep-ph]
L. Calibbi, R. Ziegler and J. Zupan, arXiv:1804.00009 [hep-ph]
A. Crivellin, M. Hoferichter and P. Schmidt-Wellenburg, arXiv:1807.11484 [hep-ph]
K. S. Babu, S. Jana, M. Lindner and V. P. K, arXiv:2104.03291 [hep-ph]



Current experimental limit: $|d_\mu| \sim 1.8 \times 10^{-19}\ ecm$, arXiv:0811.1207 [hep-ex]

Expected reach at Fermilab: $|d_\mu| \sim 1 \times 10^{-21}\ ecm$, EPJ Web Conf. 118 (2016) 01005

Expected reach at PSI: $|d_\mu| \sim 6 \times 10^{-23}\ ecm$, arXiv:2102.08838 [hep-ex]

Summary

- Three observables, Δa_μ, $h \to \mu^+\mu^-$, and μEDM are highly correlated
- If $h \to \mu^+\mu^-$ is not modified, then sizable μEDM is necessarily generated in many models
- Near future measurements of $h \to \mu^+\mu^-$ will carve an ellipse, and together with μEDM, many models will be tested

Thank you for listening!