nEDM limits on ALP couplings to fermions

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arXiv:2403.12133

Asymmetry
Essential Asymmetries of Nature

INVISIBLES24

Axion-like particles (ALPs)

Axions and ALPs are:

- **pseudo-Goldstone bosons of some new $U(1)$**
- **well motivated NP candidates**
- **targeted by an extensive experimental program**

	Axion	**ALPs**
Strong CP problem	✓	✗
Dark Matter	✓	✓
Cosmic Inflation	✓	✓
Baryogenesis	✓	✓

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The ALP Effective Field Theory

ALP couplings to up- and down-type quarks:

$$\mathcal{L}_a \supset \frac{1}{2}\partial_\mu a \partial^\mu a - \frac{1}{2} m_a^2 a^2$$
$$+ \left(\bar{u}_L \boldsymbol{M}_u u_R + \bar{d}_L \boldsymbol{M}_d d_R + \text{h.c.}\right) + \theta \frac{\alpha_s}{8\pi} G_{\mu\nu} \widetilde{G}^{\mu\nu}$$
$$+ \frac{\partial_\mu a}{f_a} \left(\bar{Q}_L \gamma^\mu \boldsymbol{C}_Q Q_L + \bar{u}_R \gamma^\mu \boldsymbol{C}_{u_R} u_R + \bar{d}_R \gamma^\mu \boldsymbol{C}_{d_R} d_R\right)$$

[Georgi, Kaplan, Randall, *Phys. Lett. B 169 (1986) 73-78*]

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related by anomalous $U(1)_{\text{Axial}}$

$\Longrightarrow$ **Physical combination is**

$$\bar{\theta} = \theta + \operatorname{Arg}\det(\boldsymbol{M}_u \boldsymbol{M}_d)$$

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CP-violation in flavor-nondiagonal entries

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CP-violation in flavor-nondiagonal entries

Will source CP violating observables e.g. the nEDM

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ALP contributions to the nEDM

How can C_Q, C_{u_R}, C_{d_R} contribute?

nEDM sourced by
- Quark EDMs and CEDMs
- **The $\bar{\theta}$ parameter**

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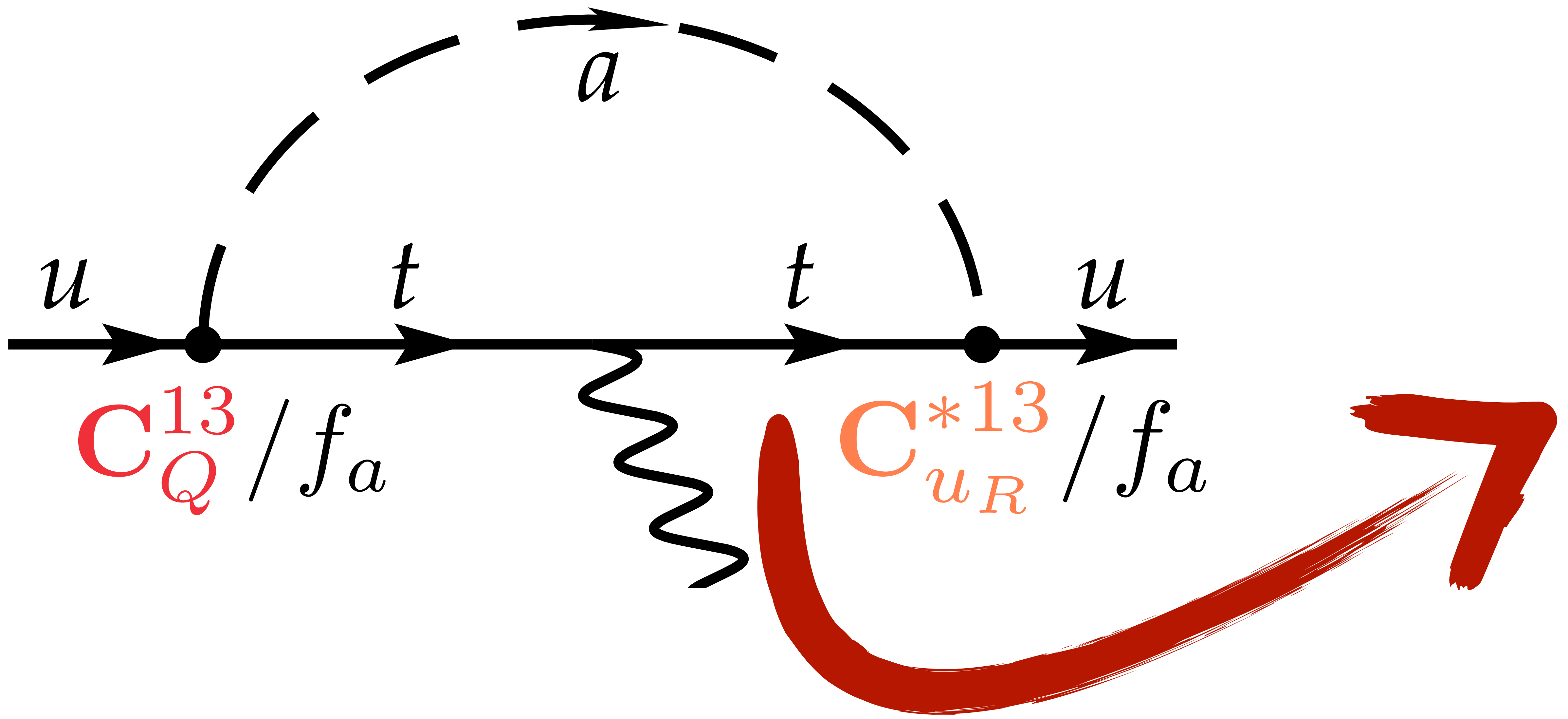

$$\frac{d_u}{e} \sim \frac{Q_u}{32\pi^2} m_t \frac{\text{Im}(C_Q^{13} C_{u_R}^{*13})}{f_a^2}$$

Corrections to the quark EDMs and CEDMs

[Di Luzio et al., 2010.13760]

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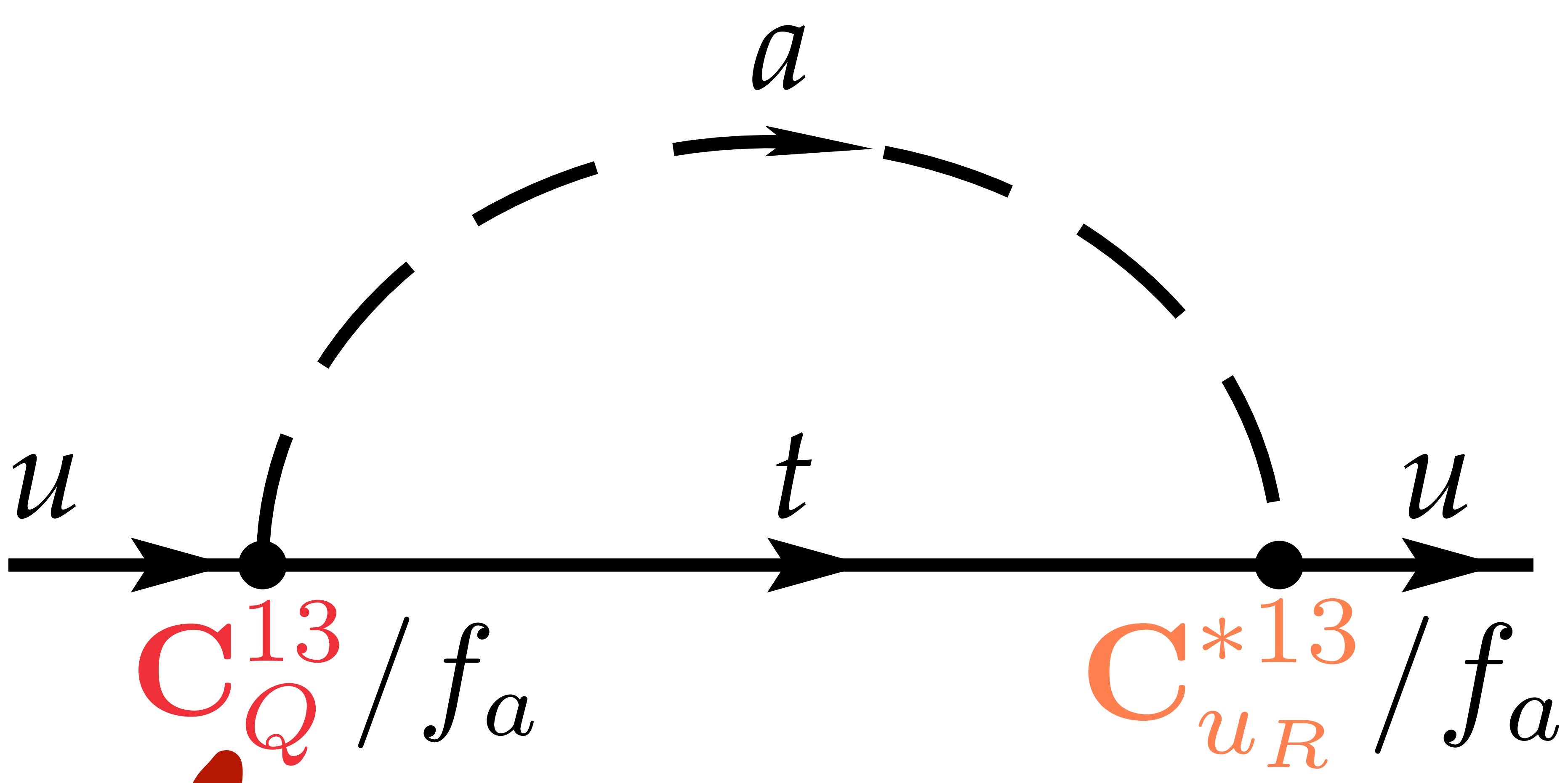

$$\Delta\bar{\theta}_{\mathrm{ALP}} \sim \frac{1}{16\pi^2}\left(\frac{m_t^3}{m_u}\right)\frac{\mathrm{Im}(C_Q^{13}\,C_{u_R}^{*13})}{f_a^2}$$

NEW

Corrections to $\bar{\theta} = \theta + \mathrm{Arg}\,\det(\,M_u M_d)$

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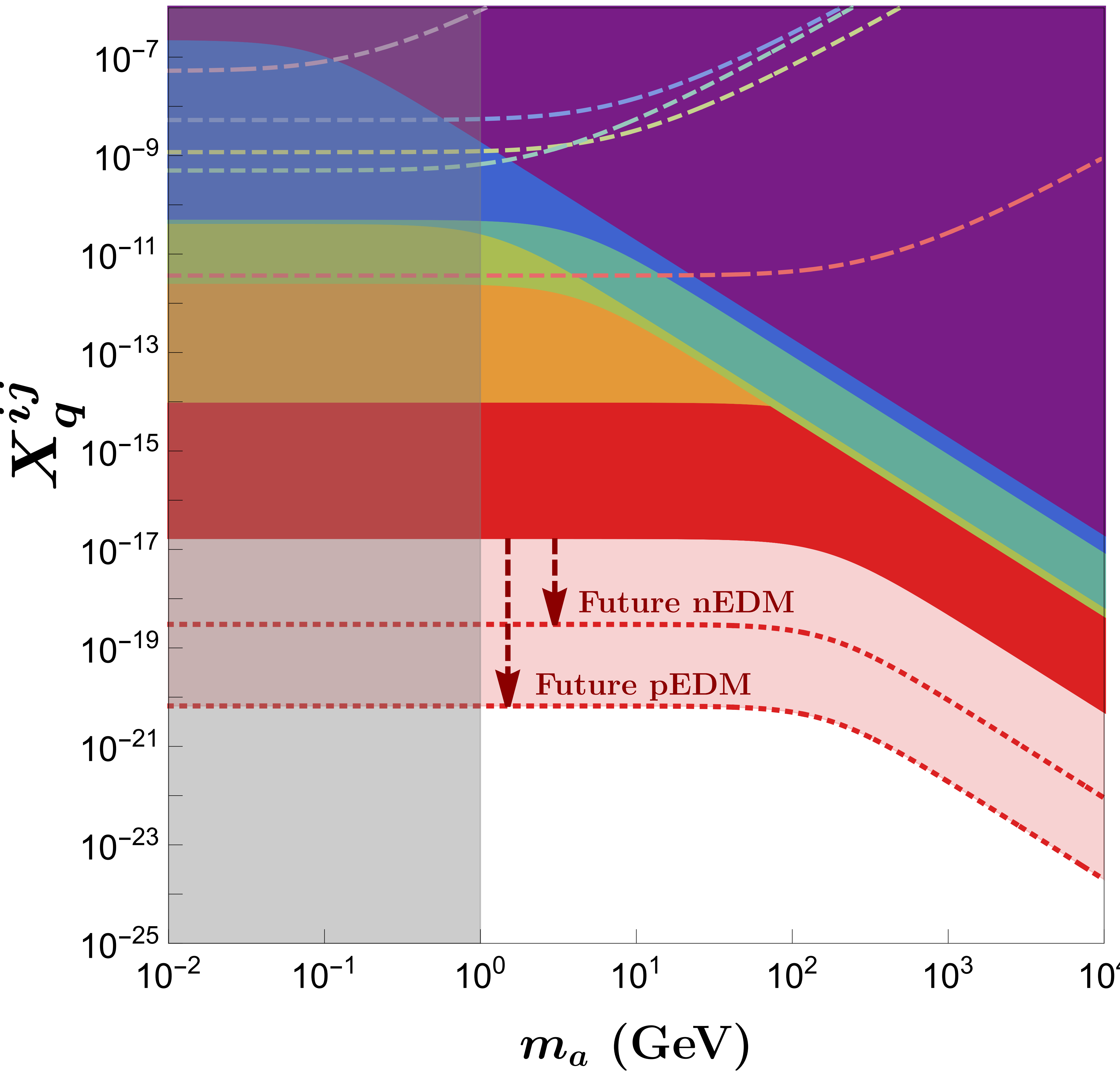
nEDM limits on ALP-fermion couplings



$$X_q^{ij} = \mathrm{Im}(C_L^{ij} C_{q_R}^{*ij})/f_a^2 \; (\mathrm{GeV}^{-2})$$

X_u^{13}, X_u^{23}, X_d^{13}, X_u^{12}, X_d^{23}, X_d^{12}

Dotted lines:

$$\left.\frac{d_n}{e}\right|_{d_q, \tilde{d}_q} \sim \mathcal{O}(1) \times \frac{Q_u}{32\pi^2} m_t \frac{\mathrm{Im}(\mathrm{C}_Q^{13} \mathrm{C}_{u_R}^{*13})}{f_a^2}$$

OLD

Solid regions:

$$\left.\frac{d_n}{e}\right|_{\bar{\theta}} \sim \frac{\mathcal{O}(10^{-3}\ \mathrm{GeV}^{-1})}{16\pi^2} \times \left(\frac{m_t^3}{m_u}\right) \frac{\mathrm{Im}(C_Q^{13}\, C_{u_R}^{*13})}{f_a^2}$$

NEW

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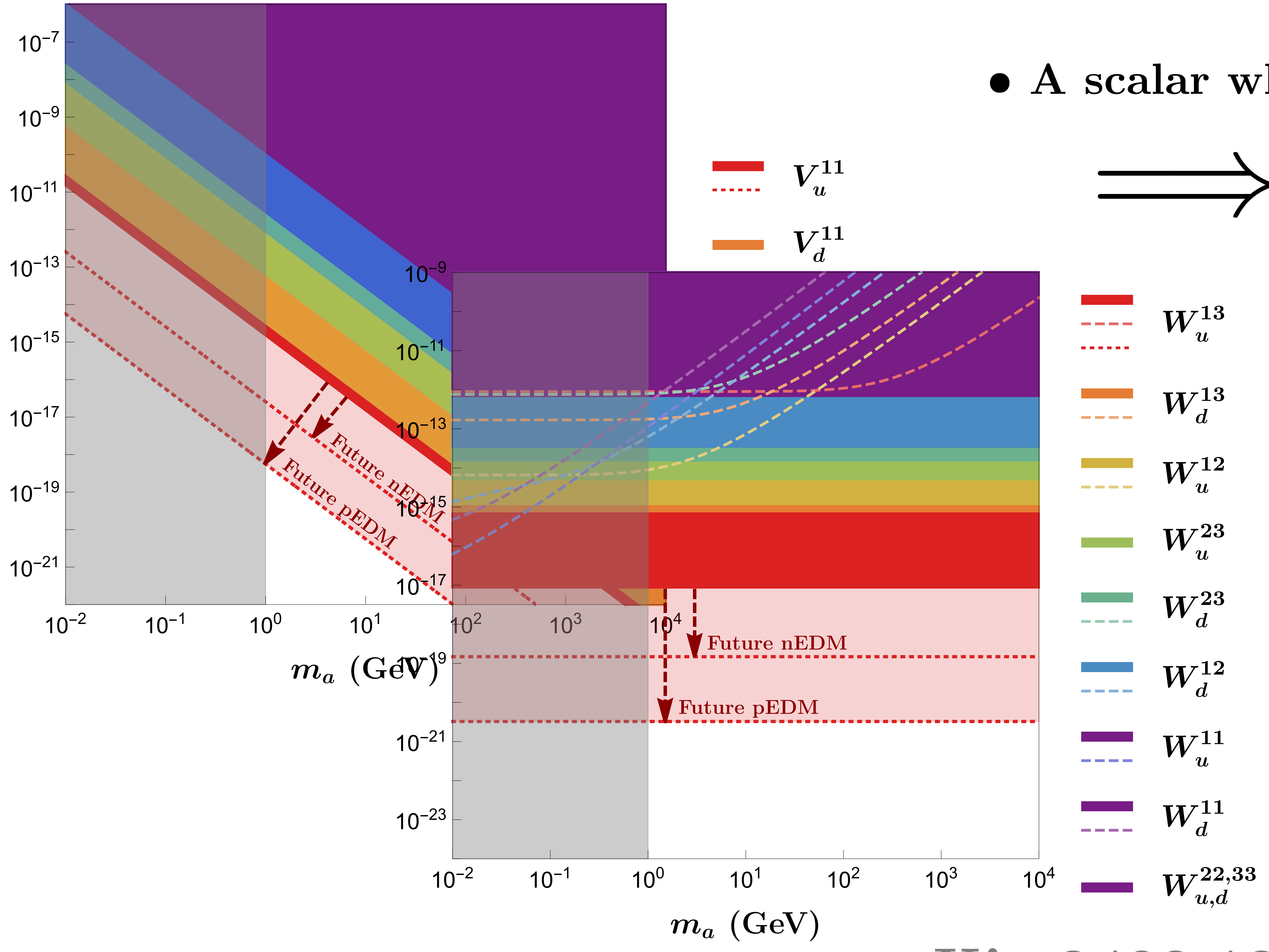
General scalar theory



- **A scalar which may not be a pseudo-Goldstone**

$\Longrightarrow$ **More parametric freedom**

We also

- **Improved existing bounds**
- **Established new bounds**

MORE IN OUR PAPER

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