Probing the flavour of New Physics with dipoles

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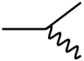
Outline

Moving beyond the flavour structure of the SM

→ Dipole effects: $\mathcal{L}_{dipole} = e\frac{v_{\rm EW}}{\sqrt{2}}\mathcal{C}^{\beta\alpha}_{\psi\gamma}\bar{\psi}_\beta\sigma^{\mu\nu}P_R\psi_\alpha F_{\mu\nu} + \mathrm{h.c.}$

E.M. form factors: *Magnetic Dipole Moment* (MDM),
Electric Dipole Moment (EDM)

Flavour transitions: $\mu \to e\gamma$, $\tau \to (e,\mu)\gamma$, $\nu' \to \nu\gamma$,
$s \to d\gamma$, $b \to (s,d)\gamma$, etc.



→ Multitask tool: **flavour structure (e.g., LFV) & CPV sources of the SM & BSM, in quark & lepton sectors** [Lomonosov: various talks]

eEDM: $|\mathrm{Im}[\mathcal{C}^{ee}_{e\gamma}]| \lesssim (8 \times 10^5\ \mathrm{TeV})^{-2}$ [ACME]

$\mu \to e\gamma$: $\sqrt{|\mathcal{C}^{e\mu}_{e\gamma}|^2 + |\mathcal{C}^{\mu e}_{e\gamma}|^2} \lesssim (4 \times 10^4\ \mathrm{TeV})^{-2}$ [MEG]

nEDM: $\left|\mathrm{Im}[\mathcal{C}^{dd}_{d\gamma}]\right|, \left|\mathrm{Im}[\mathcal{C}^{uu}_{u\gamma}]\right| \lesssim (2 \times 10^4\ \mathrm{TeV})^{-2}$ [nEDM]

→ **SM highly suppressed**: signs of NP are clearly identifiable

→ Possibly provide new insights to understand the origin of flavour

SMEFT: new heavy sector much above EW scale

$\rightarrow$ No discovery of non-SM particles below the EW scale

$\rightarrow$ Generic NP involving new heavy sector $\sim \Lambda \gg v_{\mathrm{EW}}$

$\rightarrow$ Consider operators $Q^{(n)}$ respecting SM local symmetries and containing SM d.o.f. only

$\rightarrow$ Non-SM interaction strengths $C^{(n)}$ among the d.o.f. that we know

$$\frac{C^{(5)} \times Q^{(5)}}{\Lambda}, \quad \frac{C^{(6)} \times Q^{(6)}}{\Lambda^2}, \quad \frac{C^{(7)} \times Q^{(7)}}{\Lambda^3}, \quad \frac{C^{(8)} \times Q^{(8)}}{\Lambda^4}, \text{ etc.}$$

$\rightarrow$ New weak sector: typically effects from lower-dimensionality operators are more important for low-energy observables

Dimension-six operators

→ Focus on operators of **dimension-six**

→ Equations Of Motion (EOMs) eliminate redundant cases:
59 linearly independent operators,
with 1350 CP-even + 1149 CP-odd couplings,
assuming SM global symmetries, $B_{\rm tot}$ and $L_{\rm tot}$

Warsaw: X^3, H^6, H^4D^2, ψ^2H^3, X^2H^2, ψ^2XH, ψ^2H^2D, ψ^4

[ψ fermions; D cov. derivative; X field strengths]

[Buchmüller, Wyler '86; Grzadkowski, Iskrzyński, Misiak, Rosiek '10]

$\underbrace{\psi^2XH \text{ class:}}_{\mathcal{L}_{dipole} \text{ @ tree}}$ $(\bar{q}\sigma^{\mu\nu}d)HB_{\mu\nu}$, $(\bar{q}\sigma^{\mu\nu}d)\tau^IHW^I_{\mu\nu}$, $(\bar{q}\sigma^{\mu\nu}T^Ad)HG^A_{\mu\nu}$, etc.

[q, ℓ, H (d, u, e) $SU(2)$ doublet (singlet)]

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[ψ fermions; D cov. derivative; X field strengths]

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$\underbrace{\psi^4 \text{ class}}_{\text{Fermi-like}}$: $(\bar{L}L)(\bar{L}L)$, $(\bar{R}R)(\bar{R}R)$, $(\bar{L}L)(\bar{R}R)$, $(\bar{L}R)(\bar{R}L)$, $(\bar{L}R)(\bar{L}R)$

[q, ℓ, H (d, u, e) $SU(2)$ doublet (singlet)]

Probing **non-dipole** operators

Consider $\mathcal{L} = \mathcal{L}_{\rm SM} + \sum_i C_i Q_i$, where C_i scales as Λ^{-2}

Mixing with dipole:

$$16\pi^2 \frac{d}{d\ell n(\mu)} C_{\psi^2 XH}(\mu) = \Sigma_i (C_{\psi^2 XH}, C_{\psi^4}, C_{X^3}, C_{X^2H^2})_i(\mu) \gamma^{(1\text{-loop})}_{i,\psi^2 XH}$$

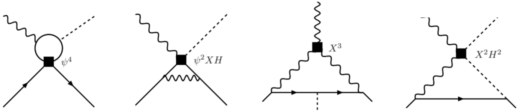
[1-loop, e.g.: Alonso, Jenkins, Manohar, Trott '13, Cirigliano, Crivellin, Dekens, de Vries, Hoferichter, Mereghetti '19, Aebischer, Dekens, Jenkins, Manohar, Sengupta, Stoffer '21]

$$\{\psi^2 XH, \psi^4, X^3, X^2H^2\} \xrightarrow[1Loop]{RGE} \psi^2 XH$$

Example: [ACME]

$$\left|{\rm Im}\,\tilde{C}^{(3),eett}_{\ell equ}\right| \lesssim (3 \times 10^5 \ {\rm TeV})^{-2}$$

$$Q^{(3)}_{\ell equ} = (\bar{\ell}^j \sigma_{\mu\nu} e)\epsilon_{jk}(\bar{q}^k \sigma^{\mu\nu} u)$$



[■: possible vertices]

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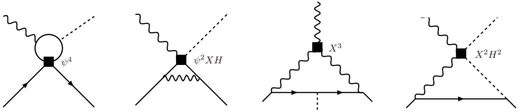


[■: possible vertices]

HERE: 4-fermion ops. for which $\gamma^{(\text{1-loop})}_{i,\psi^2 XH} = 0$ (i.e., no mix. at 1-loop)

→ Leading Order mixing with the dipole arriving at 2-loops

→ **Phenomenological implications**

Outline

$\rightarrow$ **Four-fermions**: only $Q^{(3)}_{\ell equ}$ mixes directly w/ dipoles at 1-loop

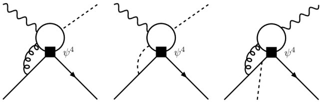
$$Q^{(1)}_{\ell equ} \xrightarrow[1Loop]{RGE} Q^{(3)}_{\ell equ} \xrightarrow[1Loop]{RGE} \psi^2 XH$$

LRLR operators

$$
\begin{aligned}
Q^{(1)}_{\ell equ}(prst) &= (\bar{\ell}^j_p e_r)\epsilon_{jk}(\bar{q}^k_s u_t)\\
Q^{(3)}_{\ell equ}(prst) &= (\bar{\ell}^j_p \sigma_{\mu\nu} e_r)\epsilon_{jk}(\bar{q}^k_s \sigma^{\mu\nu} u_t)\\
Q^{(1)}_{\ell\nu qd}(prst) &= (\bar{\ell}^j_p \nu_r)\epsilon_{jk}(\bar{q}^k_s d_t)\\
Q^{(3)}_{\ell\nu qd}(prst) &= (\bar{\ell}^j_p \sigma_{\mu\nu} \nu_r)\epsilon_{jk}(\bar{q}^k_s \sigma^{\mu\nu} d_t)
\end{aligned}
$$

LRLR operators

$$
\begin{aligned}
Q_{\ell\nu\ell e}(prst) &= (\bar{\ell}^j_p \nu_r)\epsilon_{jk}(\bar{\ell}^k_s e_t)\\
Q^{(1)}_{quqd}(prst) &= (\bar{q}^j_p u_r)\epsilon_{jk}(\bar{q}^k_s d_t)\\
Q^{(8)}_{quqd}(prst) &= (\bar{q}^j_p T^A u_r)\epsilon_{jk}(\bar{q}^k_s T^A d_t)
\end{aligned}
$$



LRRL operators

$$
\begin{aligned}
Q_{\ell edq}(prst) &= (\bar{\ell}_p e_t)(\bar{d}_s q_r)\\
Q_{\ell\nu uq}(prst) &= (\bar{\ell}_p \nu_t)(\bar{u}_s q_r)
\end{aligned}
$$

[Fierzed] LLRR operators

$$
\begin{aligned}
Q_{\ell e}(prst) &= (\bar{\ell}_p e_t)(\bar{e}_s \ell_r)\\
Q_{\ell\nu}(prst) &= (\bar{\ell}_p \nu_t)(\bar{\nu}_s \ell_r)\\
Q^{(1)}_{qu}(prst) &= (\bar{q}^\alpha_p u^\beta_t)(\bar{u}^\beta_s q^\alpha_r)\\
Q^{(8)}_{qu}(prst) &= (\bar{q}^\alpha_p T^A_{\alpha\tilde{\alpha}} u^{\tilde{\beta}}_t)(\bar{u}^\beta_s T^A_{\beta\tilde{\beta}} q^{\tilde{\alpha}}_r)\\
Q^{(1)}_{qd}(prst) &= (\bar{q}^\alpha_p d^\beta_t)(\bar{d}^\beta_s q^\alpha_r)\\
Q^{(8)}_{qd}(prst) &= (\bar{q}^\alpha_p T^A_{\alpha\tilde{\alpha}} d^{\tilde{\beta}}_t)(\bar{d}^\beta_s T^A_{\beta\tilde{\beta}} q^{\tilde{\alpha}}_r)
\end{aligned}
$$

[Fierzed] LLRR operators

$$
\begin{aligned}
Q_{\ell u}(prst) &= (\bar{\ell}_p u_t)(\bar{u}_s \ell_r)\\
Q_{\ell d}(prst) &= (\bar{\ell}_p d_t)(\bar{d}_s \ell_r)\\
Q_{qe}(prst) &= (\bar{q}_p e_t)(\bar{e}_s q_r)\\
Q_{q\nu}(prst) &= (\bar{q}_p \nu_t)(\bar{\nu}_s q_r)
\end{aligned}
$$

LLLL operators

$$
\begin{aligned}
Q_{\ell\ell}(prst) &= (\bar{\ell}_p \gamma_\mu \ell_r)(\bar{\ell}_s \gamma^\mu \ell_t)\\
Q^{(1)}_{qq}(prst) &= (\bar{q}_p \gamma_\mu q_r)(\bar{q}_s \gamma^\mu q_t)\\
Q^{(3)}_{qq}(prst) &= (\bar{q}_p \gamma_\mu \tau^I q_r)(\bar{q}_s \gamma^\mu \tau^I q_t)\\
Q^{(1)}_{\ell q}(prst) &= (\bar{\ell}_p \gamma_\mu \ell_r)(\bar{q}_s \gamma^\mu q_t)\\
Q^{(3)}_{\ell q}(prst) &= (\bar{\ell}_p \gamma_\mu \tau^I \ell_r)(\bar{q}_s \gamma^\mu \tau^I q_t)
\end{aligned}
$$

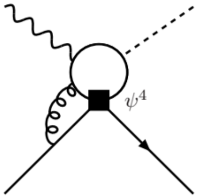
RRRR operators

$$
\begin{aligned}
Q_{ee}(prst) &= (\bar{e}_p \gamma_\mu e_r)(\bar{e}_s \gamma^\mu e_t)\\
Q_{\nu\nu}(prst) &= (\bar{\nu}_p \gamma_\mu \nu_r)(\bar{\nu}_s \gamma^\mu \nu_t)\\
Q_{uu}(prst) &= (\bar{u}_p \gamma_\mu u_r)(\bar{u}_s \gamma^\mu u_t)\\
Q_{dd}(prst) &= (\bar{d}_p \gamma_\mu d_r)(\bar{d}_s \gamma^\mu d_t)\\
Q_{eu}(prst) &= (\bar{u}_p \gamma^\mu u_r)(\bar{e}_s \gamma_\mu e_t)\\
Q_{ed}(prst) &= (\bar{e}_p \gamma_\mu e_r)(\bar{d}_s \gamma^\mu d_t)\\
Q_{\nu u}(prst) &= (\bar{\nu}_p \gamma_\mu \nu_r)(\bar{u}_s \gamma^\mu u_t)\\
Q_{\nu d}(prst) &= (\bar{\nu}_p \gamma_\mu \nu_r)(\bar{d}_s \gamma^\mu d_t)\\
Q_{e\nu}(prst) &= (\bar{\nu}_p \gamma_\mu \nu_r)(\bar{e}_s \gamma^\mu e_t)\\
Q^{(1)}_{ud}(prst) &= (\bar{u}_p \gamma_\mu u_r)(\bar{d}_s \gamma^\mu d_t)\\
Q^{(8)}_{ud}(prst) &= (\bar{u}_p \gamma_\mu T^A u_r)(\bar{d}_s \gamma^\mu T^A d_t)\\
Q_{du\nu e}(prst) &= (\bar{d}_p \gamma_\mu u_r)(\bar{\nu}_s \gamma^\mu e_t)
\end{aligned}
$$

$\rightarrow$ Focus on light external fermions: □ LRLR, □ LRRL, □ LRLR

$\rightarrow$ □ 1-loop, □ main focus here (preliminary), □ ongoing calculation

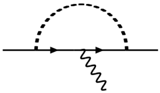
Contributions proportional to a large Yukawa

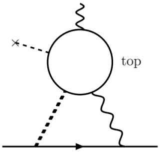


Possible enhancements: large Yukawa, strong coupling, color factor

→ Analogous to Barr-Zee diagrams

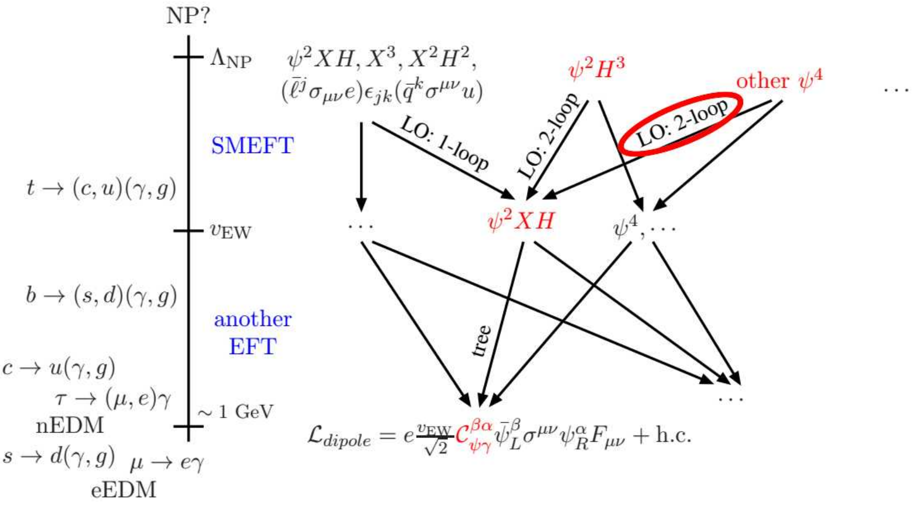
[Bjorken, S. Weinberg '77; Barr, Zee '90; see also Davidson '16]





→ In the following: preliminary bounds from $\mu \to e\gamma$, EDMs

Roadmap to phenomenology

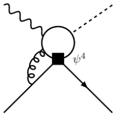


CP violation in light quark dipoles

→ One-loop ADM: $Q_{\ell equ}^{(1)}$, $Q_{\ell equ}^{(3)}$

→ Two-loop, y_t-enhancement: $Q_{qu}^{(1)}$, $Q_{qu}^{(8)}$, $Q_{ququd}^{(1)}$, $Q_{ququd}^{(8)}$

→ Two-loop: $Q_{qd}^{(1)}$, $Q_{qd}^{(8)}$, $Q_{\ell edq}$



$$(16\pi^2)^2 \frac{d}{d\ell n(\mu)} C_{\psi^2 XH}(\mu) = \left(g_Y^2 \gamma_Y^X + g_L^2 \gamma_L^X + g_C^2 \gamma_c^X + Y^2 \gamma^X\right) \times Y \times C_{\psi^4}(\mu)$$

$$Q_{qu}^{(1)} = (\bar{q}_p^\alpha u_t^\beta)(\bar{u}_s^\beta q_r^\alpha)$$

ext → int ↓	$X = B$	$X = W$	$X = G$
γ_Y^X	$-\frac{1655}{6912}$	$+\frac{701}{2304}$	$+\frac{7}{72}$
γ_L^X	$+\frac{587}{768}$	$-\frac{923}{768}$	$+\frac{5}{8}$
γ_c^X	$-\frac{20}{9}$	$-\frac{4}{3}$	$+\frac{11}{3}$

$$Q_{qu}^{(8)} = (\bar{q}_p^\alpha T^A_{\alpha\tilde{\alpha}} u_t^{\tilde{\beta}})(\bar{u}_s^\beta T^A_{\beta\tilde{\beta}} q_r^{\tilde{\alpha}})$$

ext → int ↓	$X = B$	$X = W$	$X = G$
γ_Y^X	$-\frac{1655}{1296}$	$+\frac{701}{432}$	$-\frac{679}{576}$
γ_L^X	$+\frac{587}{144}$	$-\frac{923}{144}$	$-\frac{935}{192}$
γ_c^X	$+\frac{\mathbf{760}}{\mathbf{27}}$	$+\frac{\mathbf{152}}{\mathbf{9}}$	$+\frac{\mathbf{446}}{\mathbf{9}}$

→ $X = G$: Chromo-Magnetic Dipole Moment

Light quark dipole moments, pheno

→ Electric Dipole Moment:

$$\mathcal{C}_{u\gamma}(\mu) \simeq \frac{1}{(16\pi^2)^2} \times \ell n\left(\frac{\Lambda^2}{\mu^2}\right) \times \mathbf{y_{top}} \times \left\{ C_{qu}^{(1)}(\Lambda)\left(-0.9 \times g_L^2 + 0.4 \times g_c^2\right) + C_{qu}^{(8)}(\Lambda)\left(-4.8 \times g_L^2 - 5.6 \times g_c^2\right)\right\}$$

→ Chromo-MDM generates a CPV πNN coupling [see, e.g., Pospelov, Ritz '05]

$$\mathcal{C}_{uG}(\mu) \simeq \frac{1}{(16\pi^2)^2} \times \ell n\left(\frac{\Lambda^2}{\mu^2}\right) \times \mathbf{y_{top}} \times \left\{ C_{qu}^{(1)}(\Lambda)\left(-0.3 \times g_L^2 \mathbf{-1.8} \times g_c^2\right) + C_{qu}^{(8)}(\Lambda)\left(2.6 \times g_L^2 \mathbf{-24.8} \times g_c^2\right)\right\}$$

	$y_{top} \times \lvert \mathrm{Im}\{\tilde{C}_{qu}^{(1)}(\Lambda)\}\rvert$	$y_{top} \times \lvert \mathrm{Im}\{\tilde{C}_{qu}^{(8)}(\Lambda)\}\rvert$
$\lvert d_N \rvert$	$\mathcal{O}(10^{-4})\,\mathrm{TeV}^{-2}$	$\mathcal{O}(10^{-5})\,\mathrm{TeV}^{-2}$
$\lvert d_{Hg} \rvert$	$\mathcal{O}(10^{-6})\,\mathrm{TeV}^{-2}$	$\mathcal{O}(10^{-7})\,\mathrm{TeV}^{-2}$

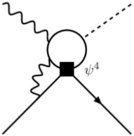
→ Wilson coefficients $\lesssim (700\ \mathrm{TeV})^{-2} - (3000\ \mathrm{TeV})^{-2}$

→ No dynamical tops below EW scale: effects from mix in SMEFT

Charged light lepton dipoles

→ One-loop ADM: $Q^{(1)}_{\ell equ}$, $Q^{(3)}_{\ell equ}$

→ Two-loop, y_τ, y_b-enhanced: $Q_{\ell e}$, $Q_{\ell edq}$



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$$Q_{\ell e} = (\bar{\ell}_p e_t)(\bar{e}_s \ell_r)$$

ext → int ↓	$X = B$	$X = W$	$X = G$
γ_Y^X	$+\frac{185}{256}$	$+\frac{331}{768}$	0
γ_L^X	$-\frac{249}{256}$	$-\frac{923}{768}$	0
γ_c^X	0	0	0

$$Q_{\ell edq} = (\bar{\ell}_p e_t)(\bar{d}_s q_r)$$

ext → int ↓	$X = B$	$X = W$	$X = G$
γ_Y^X	$-\frac{135}{256}$	$+\frac{619}{768}$	0
γ_L^X	$-\frac{345}{256}$	$-\frac{923}{768}$	0
γ_c^X	0	0	0

$$\mathcal{C}_{e\gamma}(\mu) \simeq \frac{1}{(16\pi^2)^2} \times \ell n \left(\frac{\Lambda^2}{\mu^2}\right) \times \{-0.2 \times C_{\ell e}(\Lambda) \times \mathbf{y}_\tau + 0.3 \times C_{\ell edq}(\Lambda) \times \mathbf{y_b}\} \times g_L^2$$

Charged light lepton dipoles, pheno

$\rightarrow$ Mixing below EW scale, e.g., $(\bar{\ell} P_L \ell')(\bar{f} P_R f)$, $\ell, \ell' = \mu, e$, $f = b, \tau$

[Estimate of RGE below EW scale: Crivellin, Davidson, Pruna, Signer '17]

eEDM: $Q_{\ell e}$

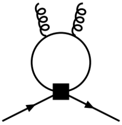
$$|\mathrm{Im}\{\tilde{C}_{\ell e}^{e\tau\tau e}(\Lambda)\}| \times y_\tau \lesssim \mathcal{O}(10^{-7})\,\mathrm{TeV}^{-2}$$

[Similar bounds found by Panico, Pomarol, Riembau '18]

$\mu \rightarrow e\gamma$: $Q_{\ell e}$

$$|\tilde{C}_{\ell e}^{\mu\tau\tau e}(\Lambda)| \times y_\tau \lesssim \mathcal{O}(10^{-5})\,\mathrm{TeV}^{-2}$$

$\rightarrow$ Wilson coefficients $\lesssim (10\,\mathrm{TeV})^{-2} - (400\,\mathrm{TeV})^{-2}$

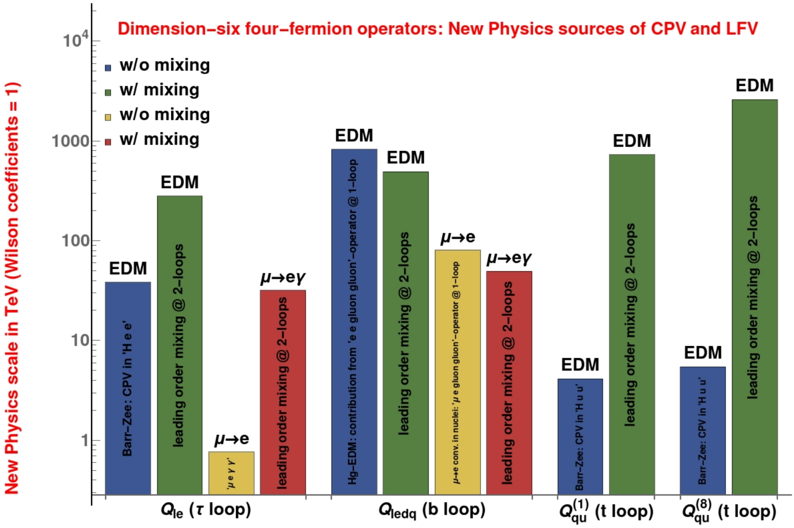


$(\bar{e} P_X \mu) G^A_{\nu\rho} G^{\nu\rho}_A$

$Q_{\ell edq}$, effect at 1-loop: stronger bound on $\tilde{C}_{\ell edq}^{\mu bbe, ebbe}(\Lambda)$

[Shifman, Vainshtein, Zakharov '78; Crivellin, Davidson, Pruna, Signer '17; $\gamma\gamma$: Davidson, Kuno, Uesaka, Yamanaka '20]

Summary, pheno



Outline

Conclusions

→ Dipoles: probe very high energy scales, e.g., EDMs, $\mu \to e\gamma$

→ **Generic tool** for improving our understanding of flavour and CPV

→ SMEFT: systematic approach to deal with new heavy sector

→ Here: Leading-Order 2-loop effects generated by operator mixing

→ Present measurements already allow strong bounds on NP

Thanks! (luizva -*- ific.uv.es)

Backup

Painting: Moscow by Alexander Pervukhin

Summary ψ^4

$\rightarrow$ 2-loops in many cases: better bounds than tree and 1-loop

[e.g., (semi-)leptonic, low-energy + LHC: Falkowski, González-Alonso, Mimouni '15 '17]

$\psi^4 \xrightarrow[2Loop]{RGE} \psi^2 XH$, preliminary

	Observable	Coupling	Bound
$Q_{qu}^{(1)}$	Hg-EDM	$y_{top} \times \lvert\mathrm{Im}[\tilde{C}_{qu}^{(1),uttu}(\Lambda)]\rvert$	$\lesssim \mathcal{O}(10^{-6})\,\mathrm{TeV}^{-2}$
$Q_{qu}^{(8)}$		$y_{top} \times \lvert\mathrm{Im}[\tilde{C}_{qu}^{(8),uttu}(\Lambda)]\rvert$	$\lesssim \mathcal{O}(10^{-7})\,\mathrm{TeV}^{-2}$
$Q_{\ell e}$	$\mu \to e\gamma$	$y_\tau \times \sqrt{\lvert\tilde{C}_{\ell e}^{e\tau\tau\mu}(\Lambda)\rvert^2 + \lvert\tilde{C}_{\ell e}^{\mu\tau\tau e}(\Lambda)\rvert^2}$	$\lesssim \mathcal{O}(10^{-5})\,\mathrm{TeV}^{-2}$
	eEDM	$y_\tau \times \lvert\mathrm{Im}[\tilde{C}_{\ell e}^{e\tau\tau e}(\Lambda)]\rvert$	$\lesssim \mathcal{O}(10^{-7})\,\mathrm{TeV}^{-2}$
$Q_{\ell edq}$	$\mu \to e$ conv.	$y_b \times \sqrt{\lvert\tilde{C}_{\ell edq}^{ebb\mu}(\Lambda)\rvert^2 + \lvert\tilde{C}_{\ell edq}^{\mu bbe}(\Lambda)\rvert^2}$	(*1Loop*)
	Hg-EDM	$y_b \times \lvert\mathrm{Im}[\tilde{C}_{\ell edq}^{ebbe}(\Lambda)]\rvert$	(*1Loop*)

(ongoing analysis for further operators, channels, and couplings)

2-Loop effects set most important bounds in many cases

Summary $\psi^2 H^3$

$\psi^2 H^3 \xrightarrow[2Loop]{RGE} \psi^2 XH$, preliminary

Observable	Coupling	Bound
$\mu \to e\gamma$	$\sqrt{\lvert\tilde{C}_{eH}^{e\mu}(\Lambda)\rvert^2 + \lvert\tilde{C}_{eH}^{\mu e}(\Lambda)\rvert^2}$	$\lesssim 0.02 \times \frac{\sqrt{2m_e m_\mu}}{v_{\rm EW}^3}$
eEDM	$\lvert\mathrm{Im}[\tilde{C}_{eH}^{ee}(\Lambda)]\rvert$	$\lesssim 0.002 \times \frac{\sqrt{2}m_e}{v_{\rm EW}^3}$
$h \to e\tau$	$\sqrt{\lvert\tilde{C}_{eH}^{e\tau}\rvert^2 + \lvert\tilde{C}_{eH}^{\tau e}\rvert^2}$	(tree)
$h \to \mu\tau$	$\sqrt{\lvert\tilde{C}_{eH}^{\mu\tau}\rvert^2 + \lvert\tilde{C}_{eH}^{\tau\mu}\rvert^2}$	(tree)
$h \to ee$	$\lvert\tilde{C}_{eH}^{ee}\rvert$	(tree)
$h \to \mu\mu$	$\lvert\tilde{C}_{eH}^{\mu\mu}\rvert$	(tree)
nEDM	$\left\lvert\mathrm{Im}[\tilde{C}_{\psi H}^{\psi\psi}(\Lambda)]\right\rvert_{(\psi=u,d)}$	$\lesssim 3 \times \frac{\sqrt{2}m_d}{v_{\rm EW}^3}$
$\lvert\Delta q'\rvert, \lvert\Delta q\rvert = 2$ $(q, q' = u, d, s, c, b)$	$\lvert\tilde{C}_{\psi H}^{qq'}\rvert^2 + \lvert\tilde{C}_{\psi H}^{q'q}\rvert^2$	(tree)

2-Loop effects set most important bounds in many cases

$$\mathcal{B}(h \to e\mu) < 6.1 \times 10^{-5} \text{ (95\% CL)}$$ [Aad:2019ojw]

$$\mathcal{B}(h \to e\tau) < 4.7 \times 10^{-3} \text{ (95\% CL)}$$ [Aad:2019ugc]

$$\mathcal{B}(h \to \mu\tau) < 2.5 \times 10^{-3} \text{ (95\% CL)}$$ [Sirunyan:2017xzt]

$$\mathcal{B}(\mu \to e\gamma) < 4.2 \times 10^{-13} \text{ (90\% CL)}$$ [TheMEG:2016wtm]

$$\mathcal{B}(\tau \to e\gamma) < 3.3 \times 10^{-8} \text{ (90\% CL)}$$ [Aubert:2009ag]

$$\mathcal{B}(\tau \to \mu\gamma) < 4.4 \times 10^{-8} \text{ (90\% CL)}$$ [Aubert:2009ag]

$$\Delta a_e = a_e^{\rm exp} - a_e^{\rm SM} = -0.88(0.36) \times 10^{-12} \text{ @ } 1\sigma$$ [Parker:2018]

$$\Delta a_\mu = a_\mu^{\rm exp} - a_\mu^{\rm SM} = 268(63)(43) \times 10^{-11} \text{ @ } 1\sigma$$ [Tanabashi:2018oca]

$$|d_e|/e < 1.1 \times 10^{-29} \text{ cm (90\% CL)}$$ [Andreev:2018ayy]

$$|d_\mu|/e < 1.8 \times 10^{-19} \text{ cm (95\% CL)}$$ [Bennett:2008dy, PDG]

$$d_\tau/e \in [-2.2, 4.5] \times 10^{-17} \text{ cm (95\% CL)}$$ [Inami:2002ah]

$$|d_N|/e < 1.8 \times 10^{-26} \text{ cm (90\% CL)}$$ [Abel:2020gbr]

$$|d_{\rm Hg}|/e < 7.4 \times 10^{-30} \text{ cm (95\% CL)}$$ [Graner:2016ses]