New bounds on heavy quark EDMs and implications for coloured scalar models

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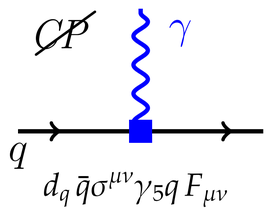
1. Electric Dipole Moments

The Standard Model (SM) cannot account for the observed **matter - antimatter imbalance** in the Universe. New sources of CP violation generate particle EDMs.

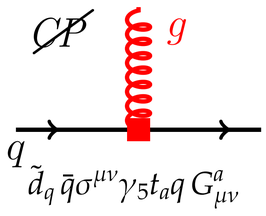
- With current sensitivity on EDMs, the **SM represents a negligible background**
- Relevant operators for hadronic EDMs:

Quark EDM



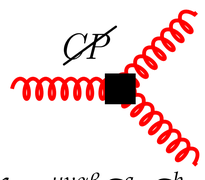
$d_q\,\bar{q}\sigma^{\mu\nu}\gamma_5 q\,F_{\mu\nu}$

Quark CEDM



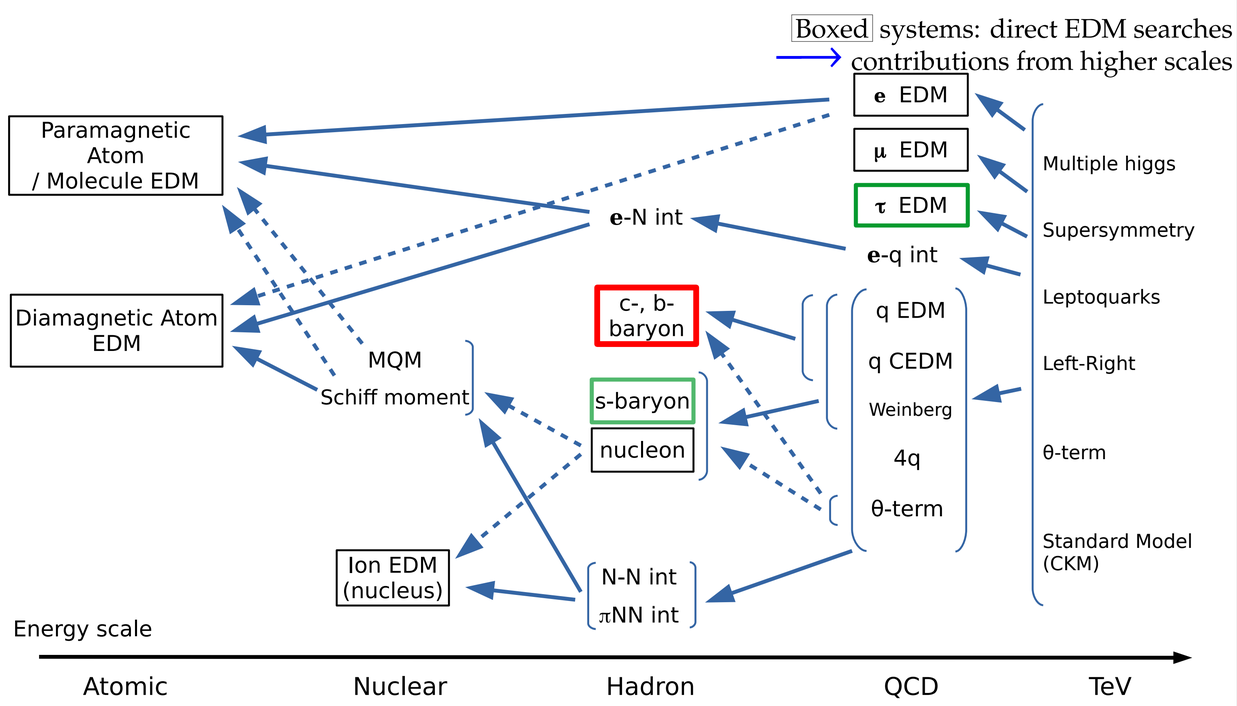
$\tilde{d}_q\,\bar{q}\sigma^{\mu\nu}\gamma_5 t_a q\,G^a_{\mu\nu}$

Weinberg op.



$\frac{w}{6} f_{abc}\varepsilon^{\mu\nu\alpha\beta} G^a_{\alpha\beta} G^b_{\mu\rho} G^{c\,\rho}_{\nu}$

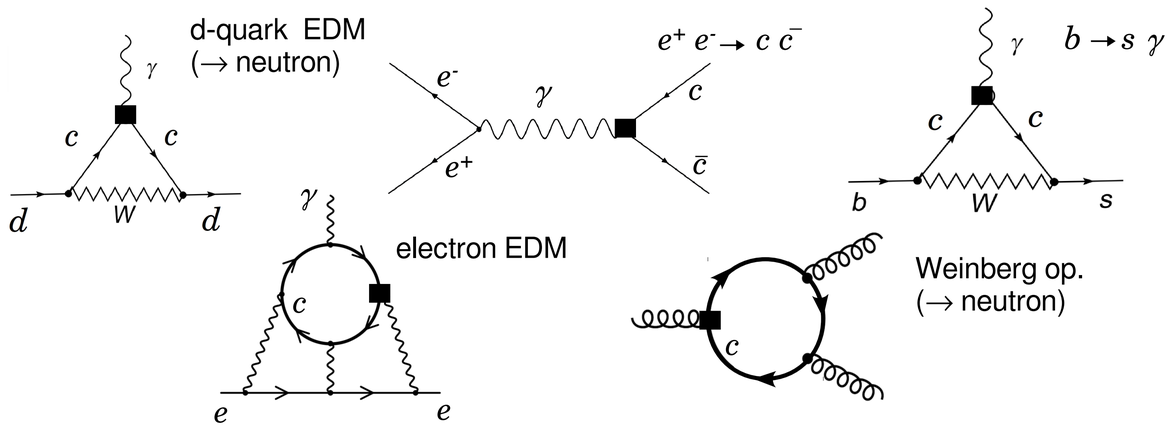
2. EDM: experimental status



- Stringest limits on electron and neutron EDM
- New experimental program on the search for **charm- and bottom-baryon EDM** ⇒ direct access to (chromo-)EDM of heavy quarks [1612.06769, 2010.11902 , ...]

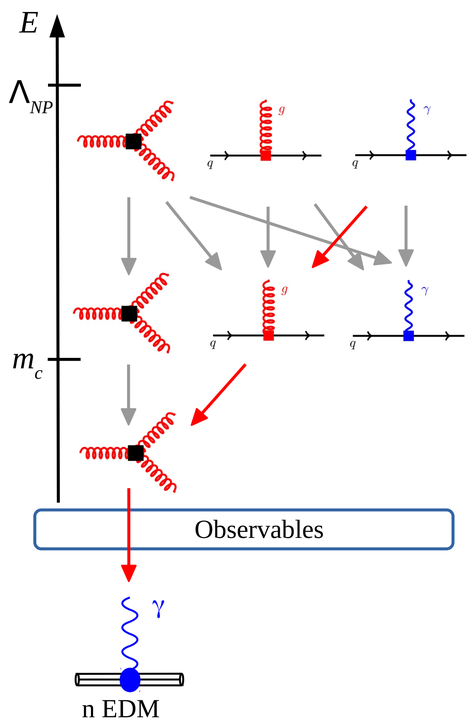
3. Heavy quarks: indirect limits

Attempts to put **limits to the dipole couplings of charm and bottom quarks** have used many different observables [1312.2589, 0902.3059, 0811.2380, hep-ph/9403304, 0712.0154]

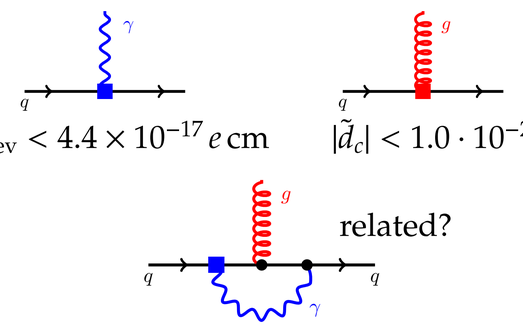


4. Heavy quarks: improved indirect limits

H.Gisbert, JRV, [1905.02513]



- Difference between EDM and CEDM bounds



$|d_c|_{\rm prev} < 4.4\times10^{-17}\,e\,{\rm cm}$ $\quad |\tilde{d}_c| < 1.0\cdot10^{-22}\,{\rm cm}$

- Related through **QED corrections** in RGEs. Overlooked due to *"larger"* QCD corrections

$$\mu\frac{d}{d\mu}\vec{C}(\mu) = \hat{\gamma}^T\vec{C}(\mu) \qquad \vec{C} = \begin{pmatrix} d_q \\ \tilde{d}_q \end{pmatrix}$$

- **Improvement of a factor 10^4** in charm EDM and 10^3 in bottom EDM

$$|d_c|_{\rm new} < 1.5\times10^{-21}\,e\,{\rm cm}$$
$$|d_b|_{\rm new} < 1.2\times10^{-20}\,e\,{\rm cm}$$

5. Implications for New Physics

SUSY

• **MSSM** • Updating predictions of [hep-ph/0204238] with LHC bounds on the masses, still $d_c \sim 10^{-20} e\,{\rm cm}$ ⇒ needs detailed analysis

• **BLMSSM** • Specially large predictions [1610.07314] from the new phases in this model, $d_c \sim 10^{-19} e\,{\rm cm}$. New analysis with our bounds [1910.05868].

• **R-parity violating SUSY** • Leading contribution at two loops [1406.3713]. Bounds useful to remove extended regions of fine-tuned cancellations.

Leptoquarks

• **Scalar leptoquark R_2 (3,2,7/6)** • Recently motivated by the anomalies in $b \to c\tau^-\bar{\nu}$ transitions.

- Needs imaginary coupling ${\rm Im}(g_{S_L})$ to simultaneously explain R_D and R_{D^*} ⇒ **generates a charm EDM** [1809.09114]
- Future sensitivity on neutron ($d_n < 10^{-27} e\,{\rm cm}$) can rule out the model through our connection neutron ↔ charm EDM

MFV / Coloured Higgs

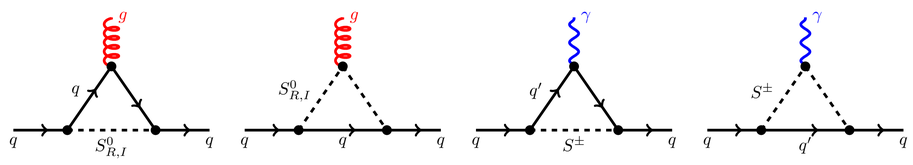
• **Manohar-Wise model (8,2,1/2)** • Adheres to Minimal Flavor Violation [hep-ph/0606172]. Emerges in GUTs.

- Most restrictive flavor observable $\mathcal{B}(B \to X_s\gamma)$ [1504.00839]
- New bottom EDM bound competes in the same plane of parameter space
- Are the light-quark EDMs even more restrictive?
- **Needs complete analysis of EDM bounds** ... and loops

6. Full EDM analysis in color-octet scalar model

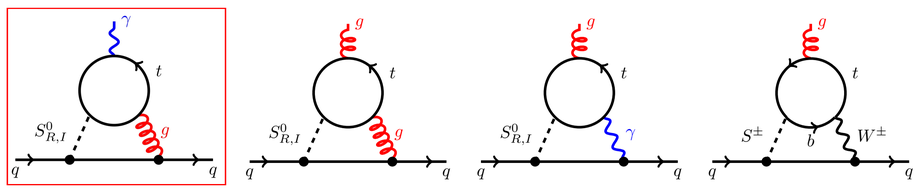
H.Gisbert, V.Miralles, JRV, [2111.09397]

■ Dipoles (1-loop) [1905.02513]



- Suppressed by light-quark masses in Yukawa couplings
- Neutral scalars cancel out, $d_q(S^0_I) \approx -d_q(S^0_R)$
- Charged-scalar ($S^\pm$) contributions dominate bottom quark EDM

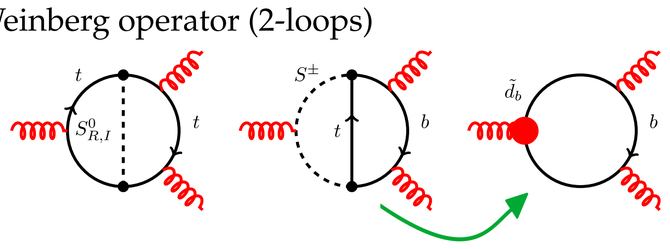
■ Dipoles (2-loops)



* enhanced contribution wrt colorless THDM

- Barr-Zee diagrams dominate light-quark (C)EDM

■ Weinberg operator (2-loops)



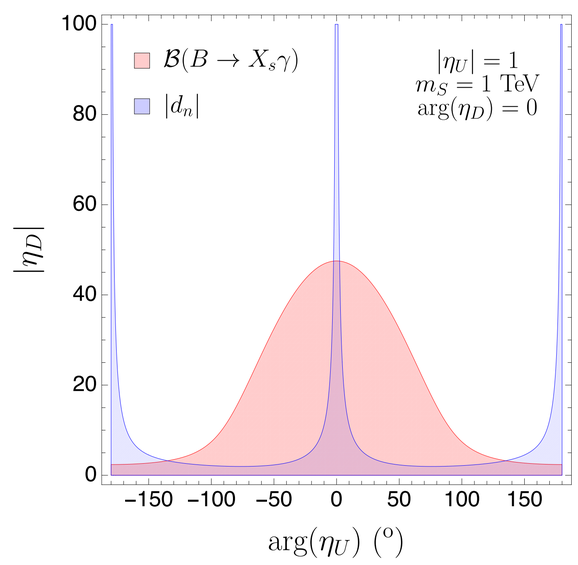
- Charged scalar dominates via effective $\tilde{d}_b$
- Described method to recover analytic expressions

Conclusions

★ Current **neutron and mercury EDM** limits provide **best restrictions** on the Yukawa phases of this model

★ Complementary to flavor obs. (*e.g.* $\mathcal{B}(B \to X_s\gamma)$)

Future work: exploit interplay of model parameters through global-fit analysis



- Allowed regions for up (η_U) and down (η_D) Yukawa couplings
- Powerful restrictions from neutron EDM for non-zero phases $\arg(\eta_{U,D}) \neq 0$