EDM calculations

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EDM experiments

Can measure:

- EDM of neutron,
$$|d_n/e| \lesssim 3.0 \times 10^{-26}\ \mathrm{cm}.$$
- $\rightarrow$ Famously implies $|\theta_{QCD}| < 10^{-10}$.
- EDMs of heavy atoms Hg (diamagnetic) and Tl (paramagnetic). EDMs of most atoms $\sim$ vanish due to Schiff screening theorem, these violate the assumptions.
- EDM of electron (ACME expt):

$$d_e < 1.1 \times 10^{-29} e\ \text{cm} = 0.6 \times 10^{-15} e\ \mathrm{GeV}^{-1}.$$

EDM operators are CP violating. In the SM the CPV is small $\rightarrow$ very sensitive to new physics! Fits very nicely with EFT approach, too!

EDM calculations

We'll hear about the theory of EDM calculations from Ramsey-Musolf's talk.
In BSM, need to calculate the operators:

$$\mathcal{L}_{d=4,5} \supset \theta_s \frac{g_s^2}{32\pi^2} G^a_{\mu\nu} \tilde{G}^{a\,\mu\nu} + \frac{1}{4} \sum_f \overline{\psi}_i [\gamma^\mu, \gamma^\nu] \gamma_5 \left(d_i F_{\mu\nu} + g_s \tilde{d}_i G_{\mu\nu} \right) \psi_i$$

and also

$$\mathcal{L}_{d=6} \supset \frac{1}{3} d_W f^{abc} G^a_{\mu\nu} \tilde{G}^{b\,\nu\beta} G^{c\,\mu}_{\beta} + \sum_{ij} C_{ij} (\overline{\psi}_i \psi_i)(\overline{\psi}_j i \gamma_5 \psi_j) + \ldots$$

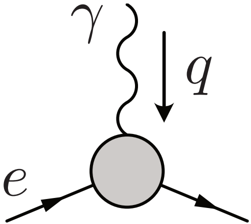
These can then be matched to electron/neutron/atom EDMs at low energies, e.g.

$$|d_n/e| \sim 4 \times 10^{-26}\ \mathrm{cm} \times \left[d_W \times 10^{10} \times (\mathrm{GeV})^2 \right].$$

Clearly, the cleanest is the electron EDM.

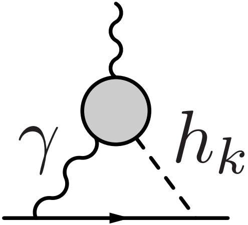
Status of EDM calculations

Operators can be calculated at one loop:



In SARAH, can compute all the operators at the BSM scale at one loop automatically, for any theory.

But for specific models, we know we need two-loop contributions, e.g. (in particular) Barr-Zee diagrams:



Until recently, only partial sets of these were known for specific theories.

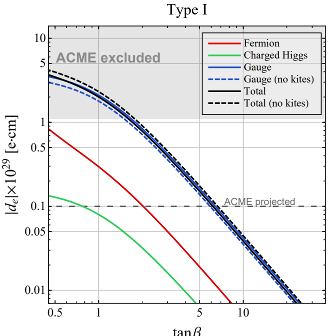
Example: SUSY theories

- In SUSY theories, have lots of extra sources of CPV, and an extended Higgs sector
- At one loop, for electron EDM only have fields that couple to the electron, e.g. selectrons/Higgs/electroweakinos.
- Strongly constrains phases in Higgs sector (B_μ), electroweakino mass phases.
- Gluino phase, stop mixing phase do not enter at one loop $\rightarrow$ naively relatively unconstrained (neutron EDM/atomic EDMs less constraining than electron EDM).
- Also: if first two generations of squarks heavy, third generation appears unconstrained at one loop.

Non-SUSY extended Higgs sectors

- In non-SUSY theories, good motivation for extended Higgs sectors is to allow EW baryogenesis $\rightarrow$ and also lamppost principle!
- Similar situation though: quartic CPV couplings in e.g. THDM appear really at two loops in EDMs.

Recently though [2009.01258] performed a complete calculation in the THDM for the electron EDM, with easily-implementable formulas. Idea of one of the projects was to implement these and apply for THDM extensions ... such as the MSSM.



Pipeline for generic theories

- The missing two-loop effects might also partially reappear through operator mixing after RG running.
- Can calculate all the operators at one-loop in SARAH at the BSM scale, export in WXCF format.
- Other tools can then handle the running in the SMEFT/WET $\rightarrow$ calculate the EDMs at low energy, constrain with Flavio.

In principle all the pieces exist already for this, but I do not know if it has been applied to examples.
Making the pipeline “automatic” and trying it out was the other idea for a simple hands-on project.
Clearly in an ideal world we’d really have the genuine two-loop matching too ...

Future collaboration/directions

- In an ideal world, would have fully-automatic calculation/approximation of leading two-loop contributions ... I suspect even the one-loop matching can still be improved.
- Would be interesting if there are still things to improve in the low-energy/running part.
- My own interest started with interplay between constraints on phases and their contribution to other observables, e.g. Higgs mass. Maybe identifying other correlations in favourite benchmark theories?