EDMs in the Standard Model

+ speculations on recent state of affairs for NP vs EDMs

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(old papers + D. McKeen, A. Ritz, MP, in preparation)

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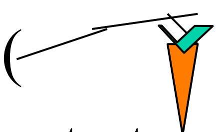
Points to Discuss

1. Intro: Why EDMs? EDMs and New Physics. Effective Lagrangian at 1 GeV.
2. EDMs from CKM – estimates for d_q, d_e, d_n, *etc*. More relevant question: suppose you see a non-zero EDM at 10^{-XX} e cm. *At what level of –XX are you no longer comfortable declaring it New Physics?* History lessons.
3. EDMs from the theta-term. Symmetries of the problem. Different ways of estimating the effect.
4. BAU from CKM and theta. *More sources of CP are likely needed but their scale can be anywhere from 100 to 10^{16} GeV*
5. *Hard realities for New Physics in 2013*. EDMs from 100 TeV SUSY. No kidding - might be a realistic goal ()
6. *Sweet dreams*: enhancement of Higgs branching to two photons via the FFdual (CP-odd channel) *Constraints from two-loop EDMs all but kill this possibility*, but there are exceptions.

Why bother with EDMs?

Is the accuracy sufficient to probe TeV scale and beyond?

Typical energy resoultion in modern EDM experiments

$$\Delta\text{Energy} \sim 10^{-6}\text{Hz} \sim 10^{-21}\text{eV}$$

translates to limits on EDMs

$$|d| < \frac{\Delta\text{Energy}}{\text{Electric field}} \sim 10^{-25}\text{e} \times \text{cm}$$

Comparing with theoretically inferred scaling,

$$d \sim 10^{-2} \times \frac{1\ \text{MeV}}{\Lambda_{CP}^2},$$

we get **sensitivity to**

$$\Lambda_{CP} \sim 1\ \text{TeV}$$

Comparable with the LHC reach! EDMs are one of the very few low-energy measurements sensitive to the fundamental particle physics.

Purcell and Ramsey (1949) ("How do we know that strong interactions conserve parity?" $\longrightarrow |d_n| < 3 \times 10^{-18} e\text{cm}$.)

$$H = -\mu \mathbf{B} \cdot \frac{\mathbf{S}}{S} - d\mathbf{E} \cdot \frac{\mathbf{S}}{S}$$

$d \neq 0$ means that both P and T are broken. If CPT holds then CP is broken as well.

CPT is based on locality, Lorentz invariance and spin-statistics = very safe assumption.

search for EDM = search for CP violation, if CPT holds

Relativistic generalization

$$H_{\text{T,P}-\text{odd}} = -d\mathbf{E} \cdot \frac{\mathbf{S}}{S} \to \mathcal{L}_{\text{CP}-\text{odd}} = -d\frac{i}{2}\overline{\psi}\sigma^{\mu\nu}\gamma_5\psi F_{\mu\nu},$$

corresponds to dimension five effective operator and naively suggests $1/M_{\text{new physics}}$ scaling. Due to $SU(2) \times U(1)$ invariance, however, it scales as m_f/M^2.

CKM model

$$\mathcal{L}_{cc} = \frac{g}{\sqrt{2}} \left(\bar{U}_L \not{W}^+ V D_L \, + \, (\text{H.c.}) \right) .$$

CP violation is closely related to flavour changing interactions.

$$\begin{pmatrix} d^I \\ s^I \\ b^I \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix} \equiv V_{\text{CKM}} \begin{pmatrix} d \\ s \\ b \end{pmatrix} .$$

CKM model of CP violation is independenly checked using nutral K and B systems. *No other sources of CP are needed to describe observables!*

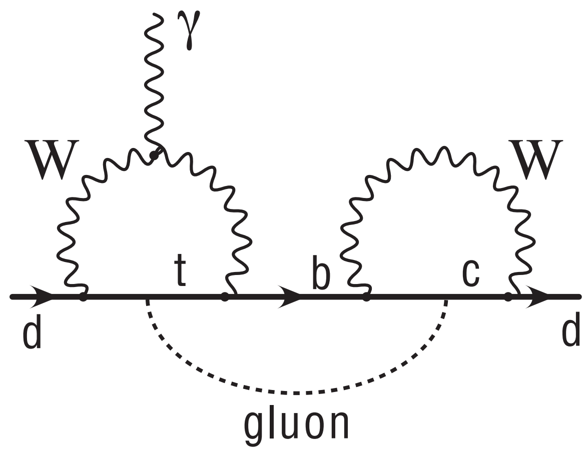
CP violation disappear if any pair of the same charge quarks is degenerate or some mxing angles vanish.

$$J_{CP} = \text{Im}(V_{tb} V_{td}^* V_{cd} V_{cb}^*) \times$$

$$(y_t^2 - y_c^2)(y_t^2 - y_u^2)(y_c^2 - y_u^2)(y_b^2 - y_s^2)(y_b^2 - y_d^2)(y_s^2 - y_d^2)$$

$$< 10^{-15}$$

EDMs from CKM



CKM phase generates tiny EDMs:

$$d_d \sim \mathrm{Im}(V_{tb}V_{td}^{*}V_{cd}V_{cb}^{*})\alpha_s m_d G_F^2 m_c^2 \times \text{loop suppression}$$

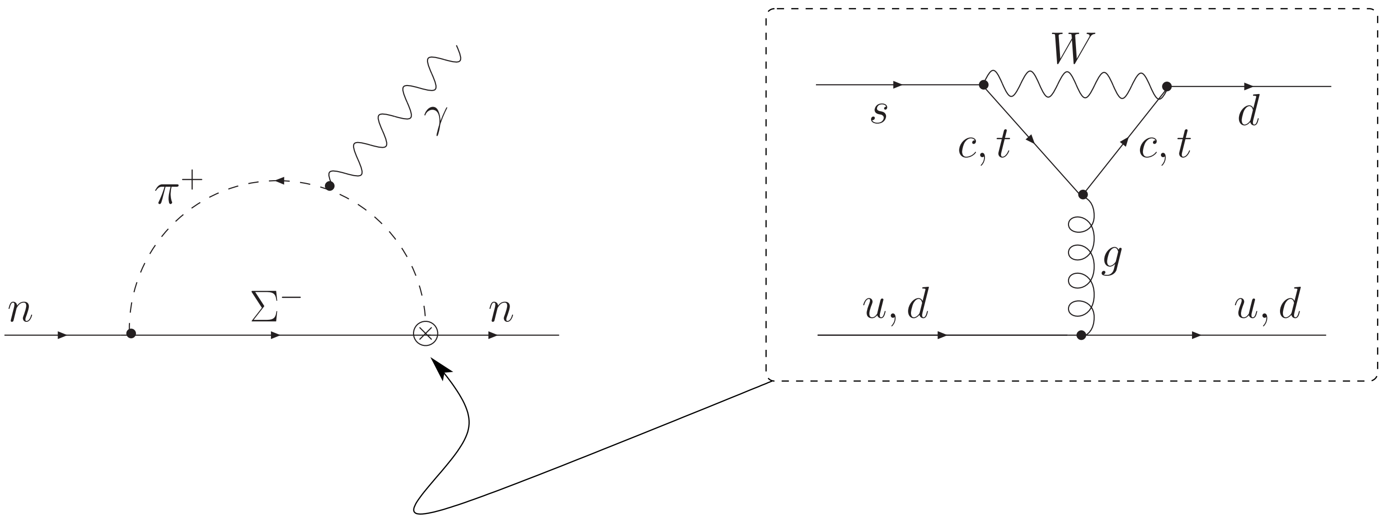
$$< 10^{-33} e\mathrm{cm}$$

Direct quark EDMs identically vanish at 1 and 2 loop levels (Shabalin, 1981). 3-loop EDMs are calculated by Khriplovich.

d_e first appears at 4 loops (Khriplovich, MP, 1991) < 10^{-37} cm

Long(er) distance contribution dominate

- Combination of ΔS =+1 and ΔS =-1 (and Δ charm = ± 1) gives a larger estimate to dn than just dq. Can be as large as 10^{-31} e cm (Khriplovich, Zhitnitskiy; Gavela et al). Charm contribution was recently looked at by Mannel, Uraltsev.
- EDMs of diamagnetic atomic species (closed e shells, nuclear spin) are generated by the CKM contribution to the nuclear Schiff moment. (Novosibirsk group; Donoghue, Holstein, Musolf)
- Direct contribution of de(CKM) to d_{Atom} is negligible compared to the semi-leptonic contribution (Schiff moment, nuclear CP-odd polarizability).



Bottom line: EDMs(CKM) are ~ 5 orders and more below current limits

One thing is to estimate EDM(CKM), another thing is to quantify our confidence in such estimate

History of past 2 decades have shown that many developments proceed along the following scenario:

1. Theorists quantify some important observable where strong interactions are important (ε'/ε; CP-violation in charm; Lamb shift in μH; lepton flavor dependence in B→D l ν…), and draw a line in the sand separating SM from New Physics.
2. Experimentalists measure something significantly different, e.g. much *larger* than original theory predictions – implying some NP if the theory calculations are taken too seriously.
3. [At least some parts of] theory community "flips", and admits that the SM effects could have been amplified [or errors on the original estimates must be inflated].
4. We end up at impasse: neither SM nor NP, and given any absence of direct NP at colliders, SM wins…

What is the "flipping benchmark" for EDMs?

Consider an outrageous overestimate for d_n that puts loop factors like $\alpha_s/4\pi$ to 1, and chooses constituent rather current quark mass scale

$d_n \sim \mathrm{Im(VVVV)}\, G_F^2 m_c^2 \times 100$ MeV $< 10^{-29}$ cm.

- Nonzero neutron EDM above 10^{-29} cm is guaranteed to be NP
- Nonzero n EDM in -29 to -31 range is either NP or SM.
- Nonzero n EDM at -31 and below will be consistent with the SM.

CP violation from the Theta term

- If CKM gave too small an EDM, there is a much bigger source of CP violation in the flavor conserving channel - theta term

Energy of QCD vacuum depends on θ-angle:

$$E(\bar{\theta}) = -\frac{1}{2}\bar{\theta}^2 m_* \langle \bar{q}q \rangle + \mathcal{O}(\bar{\theta}^4, m_*^2)$$

where $\langle \bar{q}q \rangle$ is the quark vacuum condensate and m_* is the reduced quark mass, $m_* = \frac{m_u m_d}{m_u + m_d}$. In CP-odd channel,

$$d_n \sim e\,\frac{\bar{\theta} m_*}{\Lambda^2_{\rm had}} \sim \bar{\theta} \cdot (6 \times 10^{-17})\; e\,{\rm cm}$$

Strong CP problem = naturalness problem = Why $|\bar{\theta}| < 10^{-9}$ when it could have been $\bar{\theta} \sim O(1)$? $\bar{\theta}$ can keep "memory" of CP violation at Planck scale and beyond. Suggested solutions

Axions; clever symmetry for keeping theta=0; m_u=0…

More on strong CP

Topological susceptibility

$$E(\bar{\theta}) = \frac{1}{2}\bar{\theta}^2\chi(0) = -\frac{i}{8\pi^2}\bar{\theta}^2 \lim_{k\to 0} \int d^4x e^{ikx} \left\langle \frac{\alpha_s}{2\pi} G\tilde{G}(x), \frac{\alpha_s}{2\pi} G\tilde{G}(0) \right\rangle$$

naively should be zero.

Crewther, SVZ:

$$\chi(0) = -16 m_* \langle 0|\overline{q}q|0\rangle$$
$$-i \int d^4x \left\langle 0 \left| T \left\{ m_* \sum_{i=u,d} \bar{q}_i \gamma_5 q_i(x) \, , \, m_* \sum_{i=u,d} \bar{q}_i \gamma_5 q_i(0) \right\} \right| 0 \right\rangle . (1)$$

The remaining correlator is between two isoscalar pseudo-scalar densities. Can be saturated by the exchange of the singlet (eta for N_f=2)

If in chiral limit m^2_{eta} → $m^2_{pi} \sim m_q$, the quantity (1) vanishes. If on the other hand the mass of the singlet is heavy and does not go to zero in chiral limit, the second term is $O(m_q^2)$ and can be dropped.

Symmetries to be respected

- CP violation can reside in front of GGdual (θ_G) or qbar γ_5q (θ_q).

Any theta-dependent physical observables must depend on $\theta_G+\theta_q$

- Quark masses and quark mass phases must answer in a correct combination, $m_* \theta$

- When U(1) is restored by $m_{eta'} \rightarrow m_{pi}$, any theta dependence should disappear. And in particular, neutron EDM, pion-nucleon coupling constants etc must vanish.

It is possible to keep track of these symmetries in an analytic calculation (e.g. OPE in the external theta background), but [my understanding] they are difficult to fully implement on the lattice.

Various approaches to d_n(theta)

Chiral log estimates CDVW

$$d_n^{\chi\log} = \frac{e}{4\pi^2 M_n} g_{\pi NN} \bar{g}_{\pi NN}^{(0)} \ln \frac{\Lambda}{m_\pi},$$

QCD sum rules estimate (MP, Ritz)

$$d_n(\bar{\theta}) = (1 \pm 0.5) \frac{|\langle \overline{q} q \rangle|}{(225\text{MeV})^3} \bar{\theta} \times 2.5\ 10^{-16} e\,\text{cm},$$

In a simplified Ioffe-type estimate, using Vainshtein's value for the EM

Susceptibility of the QCD vacuum,

$$d_n^{\text{est}} = -\frac{e m_* \bar{\theta}}{2\pi^2 f_\pi^2},$$

So, the two results are very close

Comparison with chiral log estimate: $g_A \langle p | \bar{u}u - \bar{d}d | p \rangle \ln(\Lambda/m_\pi) \leftrightarrow 2.$

Cosmological reasoning for extra CP violation: Baryogenesis

Basic facts that are known about observable Universe:
1. $n_B \gg n_{\bar{B}}$
2. $\eta_B \equiv n_B/n_\gamma = 6.1 \pm 0.1 \times 10^{-10}$ (Any baryogenesis scenario would have mostly *theoretical* uncertainties.)
3. Fluctuations in the CMB spectrum give a strong support to an inflationary paradigm. The *initial* state of the Universe according to inflation was vacuum-like, and therefore B-$\bar{B}$ symmetric. Baryogenesis is needed!

Baryogenesis $\equiv$ a process that transfers intial baryo-symmetric state of the universe to a state with $n_B - n_{\bar{B}} > 0$.

Baryons can be generated dynamically ! (Sakharov, 1967)
Three Sakharov's conditions for baryogensis
1. Baryon number violation
2. C and CP violation
3. Departure from thermal equilibrium

First three conditions are *in principle* satisfied within Standard Model at $T \sim 100$ GeV.

SM by itself doesn't seem to work for BAU

Objection 1. There is not enough CP violation. $\eta_B(\delta_{CKM})$ is suppressed by $J_{CP} < 10^{-15}$. $\eta_B(\theta_{QCD})$ is suppressed by $m_u m_d m_s m_c m_b m_t / T^6$.

Objection 2. The departure from equilibrium is *very small* because the cosntraint from LEPII, $m_h > 114$ GeV necessarily implies the *absence* of the first order electroweak phase transition.

New Physics is required

50+ scenarios have been put forward

Model of Baryogenesis	Axion required	EDMs are measurable	New Physics below TeV	$2\beta 0\nu$ decay	proton decay
GUT	$+$	$-$	$-$	$\pm$	$+$
Electroweak	$+$	$+$	$+$	$-$	$-$
Leptogenesis	$-$	$-$	$-$	$+$	$-$

Notice that not everyone gave up on BAU(CKM) – from time to time weird scenarios emerge that may have some hope, (e.g. initial conditions with vev=0, T=0 etc.)

EDMs and New Physics

- EDM observable ~

  ~ [some QCD/atomic/nuclear matrix elements] ×

SM mass scale (m_e, m_q) × (CP phase)$_{NP}$/Λ_{NP}^2

With some amount of work all matrix elements can be fixed. For the flavor blind NP, $d_i \sim m_i$. Unfortunately, we have no idea where actually Λ_{NP} is !!!

100 GeV, 1 TeV, 10 TeV, 100 TeV, 1000 TeV … GUT scale … M_P

After the LHC did not find the abundance of new states immediately above EW scale, "guessing EDMs" became even more difficult. *What shall we put in the denominator*? E.g. $(\text{TeV})^2$ or $(\text{PeV})^2$?

but may be the reason for pessimism is premature?

Thanks to the LHC experiments we now know that:

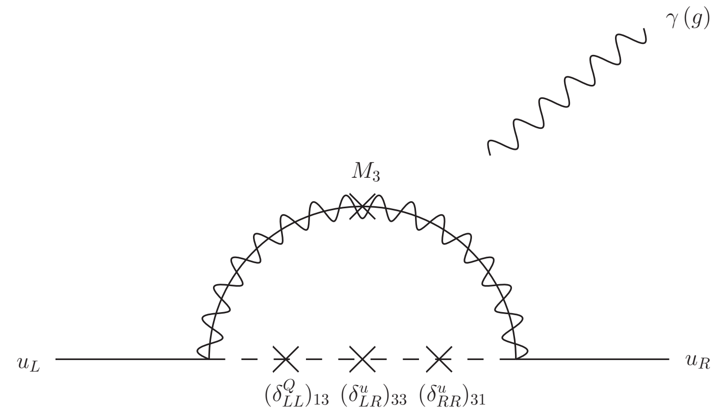
1. There is a new, [almost definitely] scalar resonance with high significance at about ~ 125 GeV that *on average* fits the SM Higgs boson description rather well.
2. While some of the exotic physics (new strongly-interacting states with advantageous decay channels, new heavy EW boson like resonances etc) is pushed to above TeV, there is plenty of room for new physics with EW strength interactions that can make appearance at few 100 GeV.
3. There is an intriguing discrepancy in $R_{\gamma\gamma}$ [for three more weeks?] and it could be a hint on something new and exciting right around the EW scale.
4. As to SUSY models, they became either "weird" or far less natural. *90% of 2001 Snowmass models is dead!*

EDMs from 100 TeV SUSY

- Measured Higgs mass value, ~126 GeV, may be pointing toward very heavy squark mass scale. The Higgs potential must be "tuned" to a considerable level.
- Such mass scale, 100 TeV-PeV allows [almost] not to worry about SUSY flavor issues [and about producing sfermions at the LHC]. Wells, 2003; …. Most recently Arkani-Hamed et al. 2012.
- Gaugino may be around EW scale, giving dark matter and allowing many models of SUSY breaking to easily explain such a scenario.
- Such a huge mass scale suppresses all EDMs, of course, but the absence of flavor-diagonal squark mass matrix can lead to a considerable enhancement via $d_i \sim m_{top}$, McKeen, MP, Ritz, *in preparation*.

Naturalness of masses and EDMs

$$\tilde{d}_u \simeq \frac{\alpha_s}{4\pi} M_3 \, (\delta^u_{LL})_{13} \, (\delta^u_{LR})_{33} \, (\delta^u_{RR})_{31} \times \frac{3}{M^2_{\rm sc}} \log\left(\frac{M^2_{\rm sc}}{M^2_3}\right) \sin\phi_{\tilde{u}\mu}$$
$$\sim 3 \frac{\delta m_u}{\Lambda^2_{\rm SUSY}} \log\left(\frac{\Lambda^2_{\rm SUSY}}{M^2_3}\right) \sin\phi_{\tilde{u}\mu}$$
$$\sim 1 \times 10^{-26}\ {\rm cm} \left(\frac{3}{\tan\beta}\right)\left(\frac{\theta^2_u}{1/3}\right)\left(\frac{M_3}{1\ {\rm TeV}}\right)\left(\frac{100\ {\rm TeV}}{\Lambda_{\rm SUSY}}\right)^3$$
$$\times \left[\log\left(\frac{\Lambda^2_{\rm SUSY}}{M^2_3}\right)/10\right]\left(\frac{\sin\phi_{\tilde{u}\mu}}{0.1}\right)$$



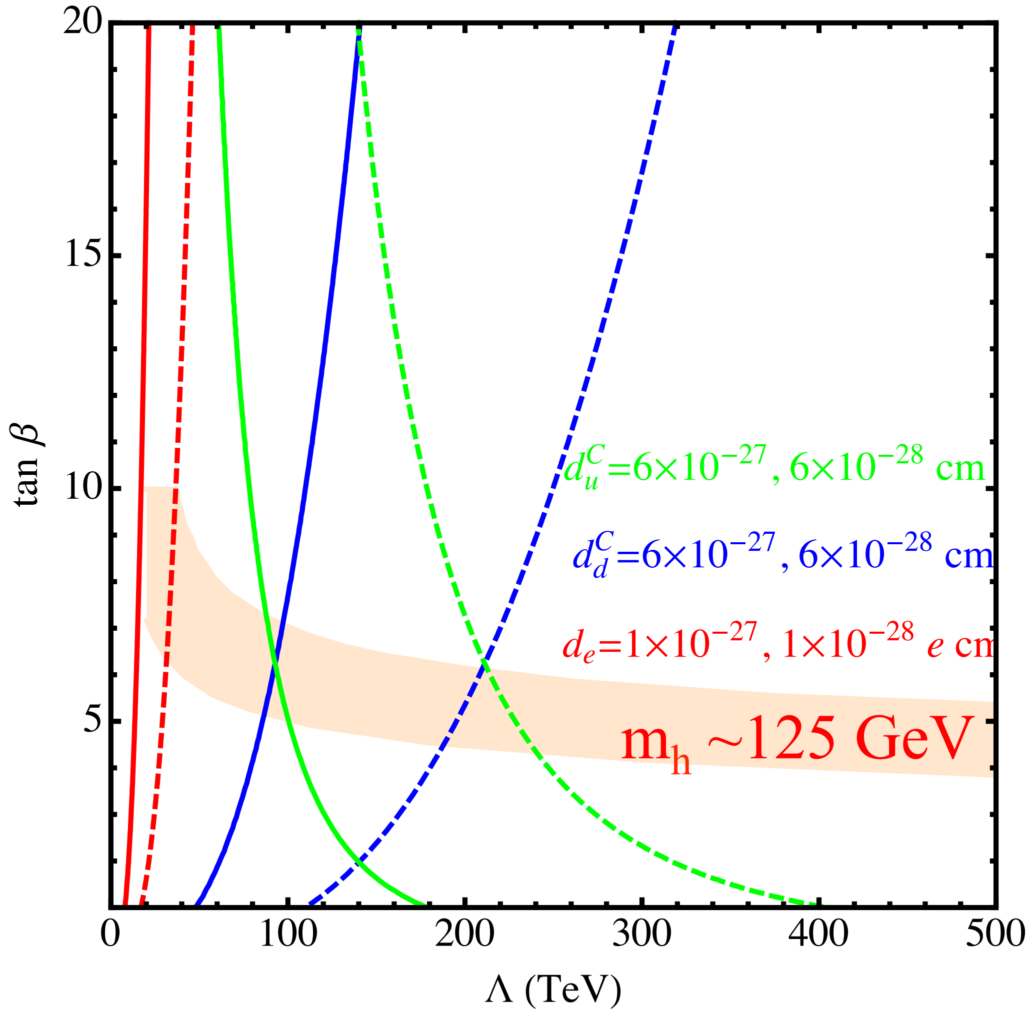
Common squark, Higgsino mass scale is assumed. Quark mass itself is also corrected and we require the tuning in m_u not be very large,

$$\delta m_u \sim \frac{\alpha_s}{4\pi} \theta^2_u \frac{m_t M_3}{\Lambda_{\rm SUSY} \tan\beta}$$
$$\sim 2\ {\rm MeV} \left(\frac{3}{\tan\beta}\right)\left(\frac{\theta^2_u}{1/3}\right)\left(\frac{M_3}{1\ {\rm TeV}}\right)\left(\frac{100\ {\rm TeV}}{\Lambda_{\rm SUSY}}\right)$$

Saturating naturalness in m_u allows fixing many free parameter in d_u.

Current bounds on d_{Hg} limit CEDM of up quark at ~ $5{\times}10^{-27}$ cm

Naturalness estimates for EDMs



Currently d_{Hg} probes ~ 100 TeV scale in this scenario. So sub-PeV SUSY is not hopeless for EDMs. But we may never learn that it is SUSY…

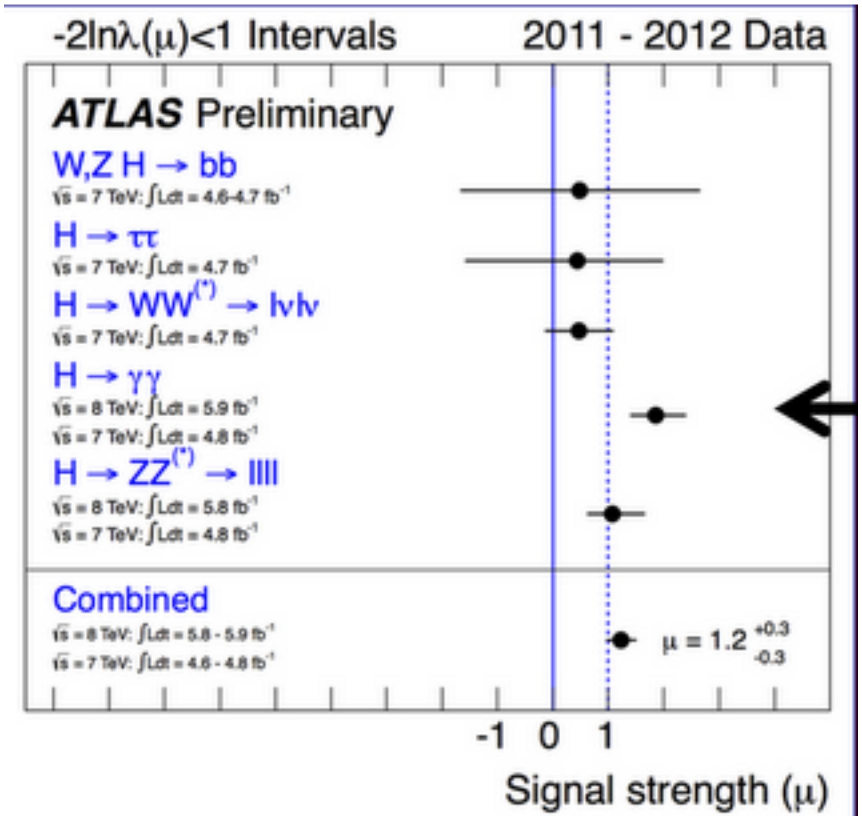
Constraining properties of 125 GeV Higgs-like particle with EDMs

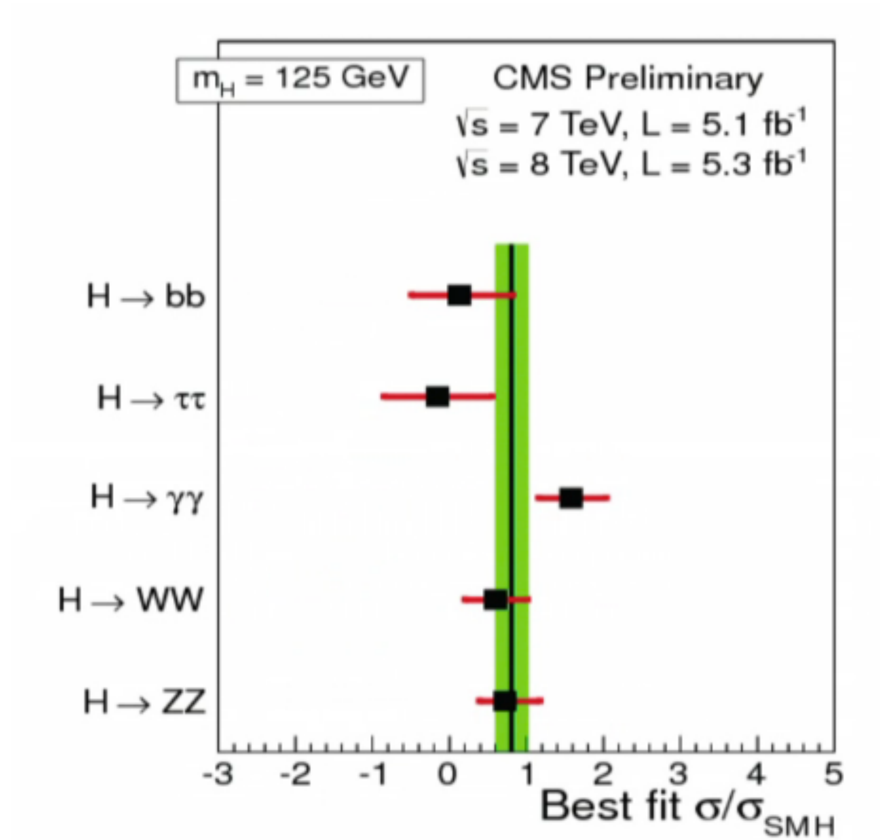
- New resonance discovered last year at the LHC may be exactly the SM Higgs or it may be a SM-Higgs-like with some deviations of its couplings from what's expected in the SM

- It is Tempting to speculate that the current enhancement in 2gamma channel comes from the CP-odd channel.

- If so, does it have any implications for the EDMs, and vice verse, do EDMs put certain constraints on the couplings and decay channels of this new resonance?

Recent results from ATLAS and CMS





Both collaborations show slight excess in $R_{\gamma\gamma}$ This may all go away, or may firm up to an interesting deviation from the SM

Reminder about $\Gamma_{\gamma\gamma}$

$$\Gamma^{\rm SM}_{\gamma\gamma} = \frac{m_h^3}{4\pi}\left(\frac{\alpha}{4\pi}\right)^2 \left|\frac{A_{\rm SM}}{2v}\right|^2 \simeq 9.1 \text{ keV},$$

which corresponds to branching of 0.0023. Top contribution to amplitude is positive, and W is negative and large,

$$A_{\rm SM}(m_h = 125 \text{ GeV}) \simeq A_W + A_t \simeq -6.5$$

Before the Higgs discovery, one could guess that if anything

$$R_{\gamma\gamma} = \frac{\Gamma_{\gamma\gamma}}{\Gamma^{\rm SM}_{\gamma\gamma}}$$

will go down because more heavy matter fields like tops is possibly out there.

Ways to influence [and enhance] $R_{\gamma\gamma}$

1. More Higgs doublets: nHDM (where n=2,3… Preserve MFV)
2. New vector-like *charged* particles with mass *not* originating solely from the Higgs vev. Roughly you need
   $\mathbf{m_{VL} \sim m_0 + c(v+h)}$. If c is *negative*, then the sign of VL-matter-mediated amplitude is flipped relative to top.
3. Different CP channel for h→gg, so that amplitudes A_+ and A_- do not interfere, and $\Gamma_{\gamma\gamma} \sim |A_+|^2 + |A_-|^2$ gets bigger.

Let us look at option 3.

More on the CP-odd channel for Higgs
(McKeen, MP, Ritz)

Consider two effective operators from some physics that is integrated out:

$$\frac{c_h v}{\Lambda^2} h F_{\mu\nu} F^{\mu\nu} + \frac{\tilde{c}_h v}{\tilde{\Lambda}^2} h F_{\mu\nu} \tilde{F}^{\mu\nu}$$

Then, $$R_{\gamma\gamma} = \frac{\Gamma_{\gamma\gamma}}{\Gamma_{\gamma\gamma}^{\mathrm{SM}}} \simeq \left| 1 - c_h \frac{v^2}{\Lambda^2} \frac{8\pi}{\alpha A_{\mathrm{SM}}} \right|^2 + \left| \tilde{c}_h \frac{v^2}{\tilde{\Lambda}^2} \frac{8\pi}{\alpha A_{\mathrm{SM}}} \right|^2$$

and deviations are O(1) if c/Λ ~ 1/5 TeV.

Given that coefficients c and c_tilde are most likely perturbative, ~ alpha, then O(1) deviations are only if Lambda is relatively low.

The CP is probed rather well in many channels – is it reasonable to expect large contribution from the CP-odd channel?

Current sensitivity of electron EDM

Current limit on electron electric dipole moment,

$$|d_e| < 1.05 \times 10^{-27} e\,\mathrm{cm}$$

It was improved last year by the IC group (Hudson et al, Nature, 2011), the result is limited by the statistical error, and the experiment is on-going.

This is beyond the 2-loop benchmark from EW scale particles:

$$d_f^{(2l)} \equiv \frac{|e|\alpha m_f}{16\pi^3 v^2} \quad \Longrightarrow \quad d_e^{(2l)} \simeq 2.5 \times 10^{-27}\ e \cdot \mathrm{cm}.$$

Does the CP-odd amplitude that creates O(1) enhancement in $R_{\gamma\gamma}$ contribute to electron EDM at this level or larger?

Answer: **much larger**

Higgs-gamma loop is too big!

Integrating *h-gamma*, we end up with log-sensitivity to UV scale,

$$
\begin{aligned}
d_i &= \tilde{c}_h \frac{|e| m_f}{4\pi^2 \tilde{\Lambda}^2} \ln\left(\frac{\Lambda_{\rm UV}^2}{m_h^2}\right) \\
&= d_f^{(2l)} \times \frac{\tilde{c}_h}{\alpha/(4\pi)} \times \frac{v^2}{\tilde{\Lambda}^2} \ln\left(\frac{\Lambda_{\rm UV}^2}{m_h^2}\right)
\end{aligned}
$$

Cutting the log at the same scale, one ends up with

$$\tilde{\Lambda} \gtrsim 50\sqrt{\tilde{c}_h}\,\text{TeV}.$$

which is a lot *larger* than h→2 gamma rates "wants".

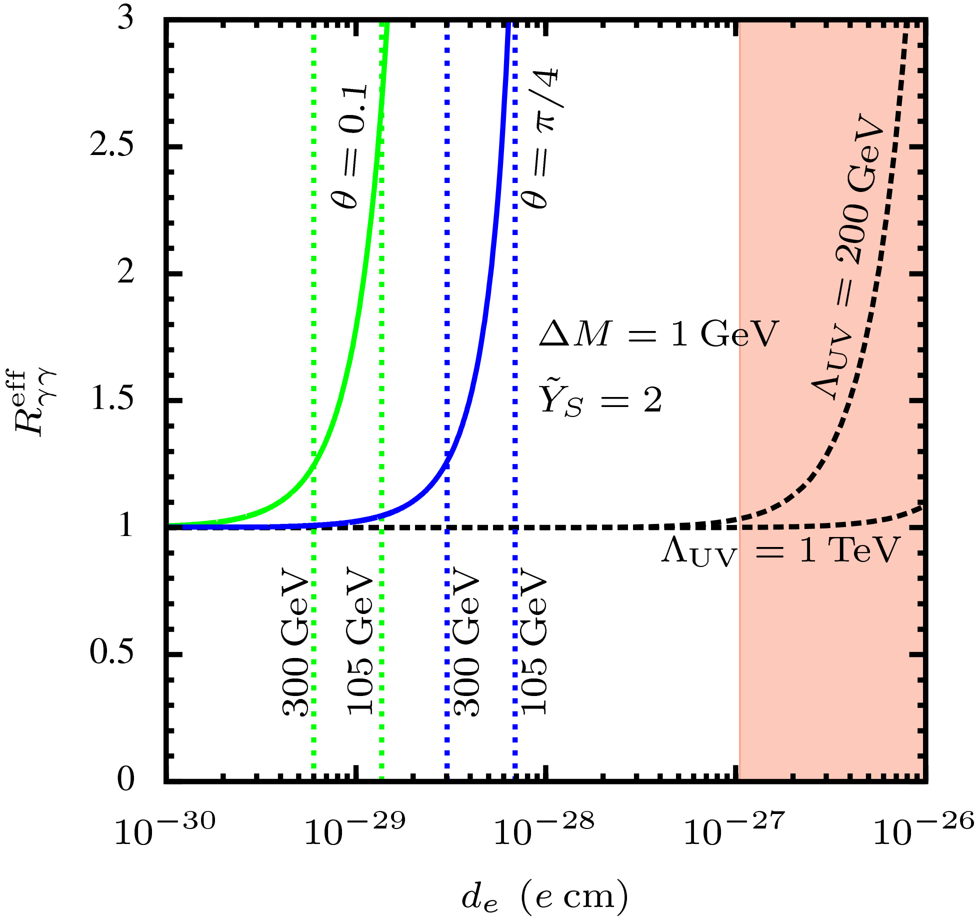
Consequently, once the EDM bound is imposed,

$$\Delta R_{\gamma\gamma}(\tilde{c}_h) \lesssim 1.6 \times 10^{-4}.$$

This is very restrictive and one wonders if this would hold outside of the contact operator approximations. *We need UV completions*.

I will consider a representative VL model.

Correlation between EDM and $R_{\gamma\gamma}$



UV completion with VL fermions and new singlet

$$\mathcal{L}_{SH\psi} = \bar{\psi} i\gamma^\mu (i\partial_\mu - eQ_\psi A_\mu)\psi + \bar{\psi}\left[m_\psi + \hat{S}(Y_S + i\gamma_5 \tilde{Y}_S)\right]\psi + \mathcal{L}_{HS}.$$

SU(2) singlet Psi is charged under the SM U(1). Scalar mixes with the Higgs:

$$V_{HS} = -\mu_H^2 H^\dagger H + \lambda_H (H^\dagger H)^4 + \frac{1}{2}\hat{m}_S^2 \hat{S}^2 + AH^\dagger H\hat{S} - B\hat{S} + \frac{\lambda_S}{4}\hat{S}^4\,.$$

The scalar eigenstates are given by

$$\begin{pmatrix} \hat{h} \\ \hat{S} \end{pmatrix} = \begin{pmatrix} c_\theta & s_\theta \\ -s_\theta & c_\theta \end{pmatrix} \begin{pmatrix} h \\ S \end{pmatrix}, \qquad \tan 2\theta = \frac{2Av}{\hat{m}_S^2 - 2\lambda_H v^2},$$

The EDM result is given by contributions from both scalar mass eigenstates,

$$d_f = d_f^{(2l)} \times Q_\psi^2 \tilde{Y}_S \frac{v}{m_\psi} \sin(2\theta)\left[g(m_\psi^2/m_h^2) - g(m_\psi^2/m_S^2)\right]$$

The version of the model that allows escaping EDM constraints involves nearly degenerate scalars.

$$d_f = d_f^{(2l)} \times Q_\psi^2 \tilde{Y}_S \frac{v}{m_\psi} \sin(2\theta) \left[g(m_\psi^2/m_h^2) - g(m_\psi^2/m_S^2) \right]$$

If $m_S \rightarrow$ large, then of course everything comes back to the contact operator case, and log cutoff is m_S.

The degenerate case is interesting because one can achieve large mixing with small A-term, but EDMs cancel.

$$\sin(2\theta)(m_S^2 - m_h^2) \to 2Av,$$

and the EDM becomes

$$d_f = d_f^{(2l)} \times Q_\psi^2 \tilde{Y}_S \frac{2Av^2 m_\psi}{m_h^4} g'(m_\psi^2/m_h^2)$$

$$\longrightarrow \; d_f^{(2l)} \times Q_\psi^2 \tilde{Y}_S \frac{Av^2}{m_h^2 m_\psi},$$

An ~ 1GeV mass splitting between h and S allows having $\frac{Av^2}{m_h^2 m_\psi}$ as small as 10^{-2}-10^{-3}, theta~O(1) and EDMs safely within bounds

Conclusions

1. CKM phase gives too small an EDM, and before experimentally we cross 10^-29 cm, we can be sure that we are probing new physics.
2. EDMs generated by theta term is too large – one needs to remove theta from the theory by some adjustment mechanism. Chiral loop and QCD SR give close estimates for d_n(theta).
3. Neither θ_{QCD} nor ϕ_{CKM} look as viable sources for BAU. Likely, there are more sources of CP breaking but its scale is unknown.
4. Main uncertainty in the EDM business comes not from QCD or nuclear physics, but from us not knowing where New Physics is and how it looks like. But even if it is very heavy – I argue – EDMs are capable of probing scales as high as several 100 TeV. (Example = "minimally unnatural SUSY")
5. CP-violating channel works to enhance $R_{\gamma\gamma}$, but avoiding the electron EDM constraints is a challenge.