‘Discussion’ session

Jordy de Vries, Nikhef, Amsterdam

Topical Lectures on electric dipole moments, Dec. 14-16

Solving the strong CP problem

$$+\theta \frac{g_s^2}{32\pi^2} \varepsilon^{\alpha\beta\mu\nu} G_{\alpha\beta} G^{\mu\nu} \quad \longleftrightarrow \quad -\left(\frac{m_u m_d}{m_u + m_d}\right)\theta\, \bar{q} i \gamma^5 q$$

- Remember: no strong-CP problem if $m_u = 0$

Questions:

- What happens to the mass of the proton or neutron if the **up and down** quarks were massless ?
- What would happen to the pion mass? And to the Kaon mass? And to the mass of the rho meson (vector meson)?
- Same questions but now only up quark mass is zero
- Do Yukawa masses matter at al ?

Varying the light quark mass: impact on the nuclear force and Big Bang nucleosynthesis

J.C. Berengut (New South Wales U.) , E. Epelbaum (Ruhr U., Bochum) , V.V. Flambaum (New South Wales U.) , C. Hanhart (Julich, Forschungszentrum & JCHP, Julich & IAS, Julich) , U.-G. Meissner (Julich, Forschungszentrum & JCHP, Julich & IAS, Julich & Bonn U., HISKP & Bonn U.) , J. Nebreda (Kyoto U., Yukawa Inst., Kyoto) , J.R. Pelaez (Madrid U.)

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e-Print: arXiv:1301.1738 [nucl-th] | PDF

The quark mass dependences of light-element binding energies and nuclear scattering lengths are derived using chiral perturbation theory in combination with nonperturbative methods. In particular, we present new, improved values for the quark mass dependence of meson resonances that enter the nuclear force. A detailed analysis of the theoretical uncertainties arising in this determination is presented. As an application, we derive from a comparison of observed and calculated primordial deuterium and helium abundances a stringent limit on the variation of the light quark mass, $\delta m_q/m_q=0.02\pm0.04$. Inclusion of the neutron lifetime modification, under the assumption of a variation of the Higgs vacuum expectation value that translates into changing quark, electron, and weak gauge boson masses, leads to a stronger limit, $|\delta m_q/m_q|<0.009$.

A crash course in loop diagrams

- I counted the number of loop diagrams in these lectures as 2123178184
- But we never discussed how to calculate them….
- Calculation diagrams is ‘straightforward’ but tedious .
- But estimating them is very very easy (apart from a O(1) factor)

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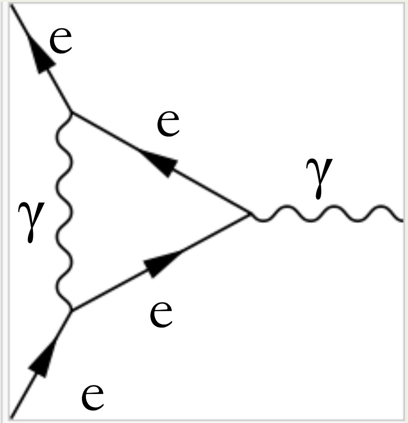

- 3 'rules'

- 1) multiply the vertices coupling strenghts
- 2) for each loop add $1/(4\,\pi)^2$
- 3) hardest step: 'adjust the dimension'

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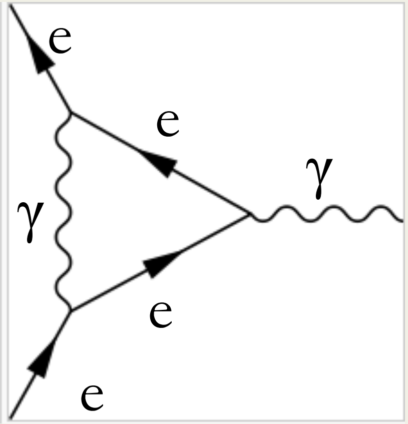

- Example 1: one-loop correction to electron magnetic moment (μ)

$$L_{dip} = -\frac{1}{2}\bar{e}\sigma^{\mu\nu}(\mu + i\gamma^5 d)eF_{\mu\nu}$$

- Step 1: ?
- Step 2: ?
- Step 3: ?

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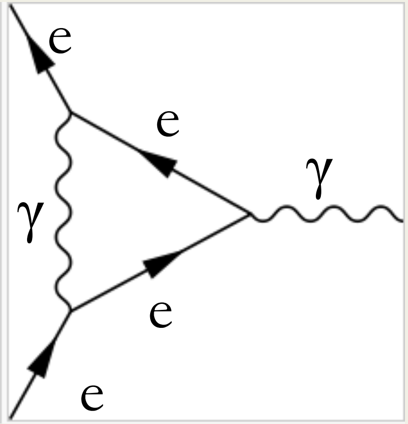

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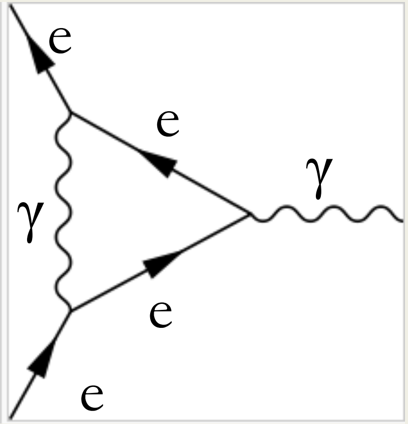

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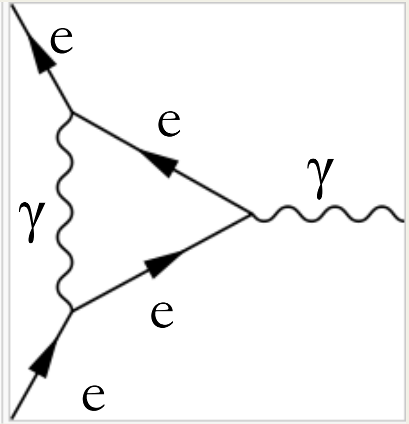

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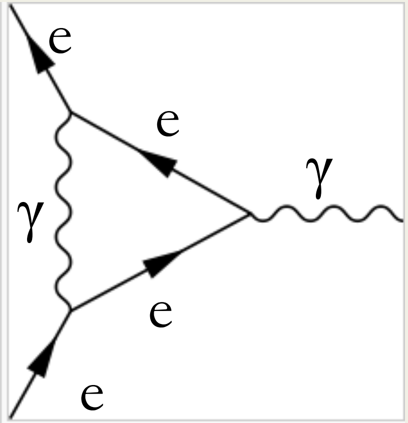

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$$\mu \propto e\frac{\alpha_{em}}{4\pi}\frac{1}{m_e}$$

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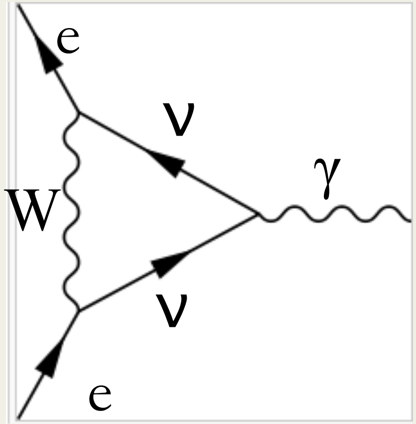

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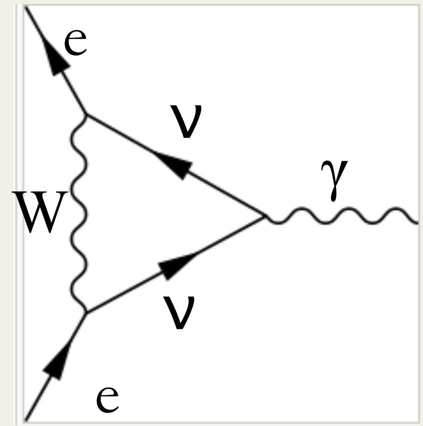

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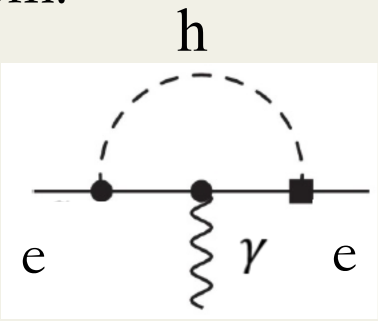
- What went wrong ? The chiral flip, if there is an even number of gamma matrices in the operator: it only connect left to right. But W only couples left-handed…. We need a mass insertion to flip it !

Now let's use this to do some real stuff

- We know in the SM, Higgs-fermion interactions are CP-even
- How well do we know this ?
- Question 1: How big is the electron EDM coming from:



$$L_{Higgs} = \frac{m_e}{v}\left(\bar{e}e + \tilde{y}_e \bar{e} i\gamma^5 e\right)h$$

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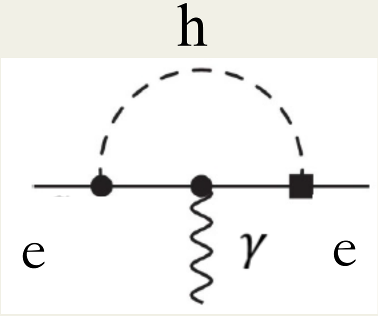

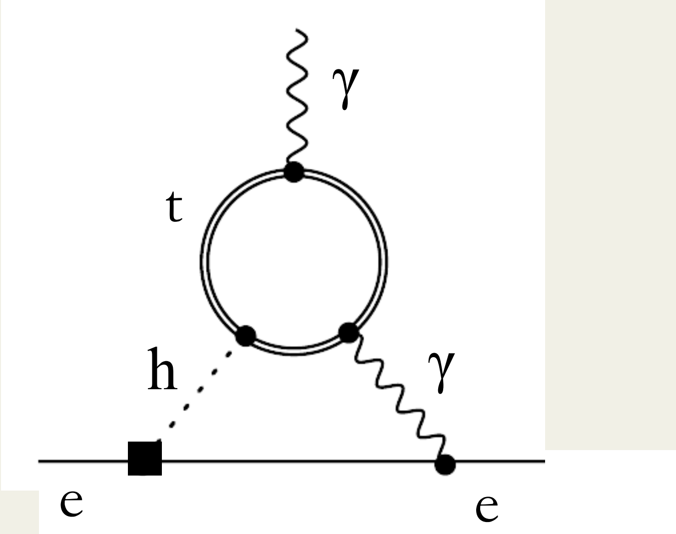

- Which diagram gives the largest contribution?
- Why ?

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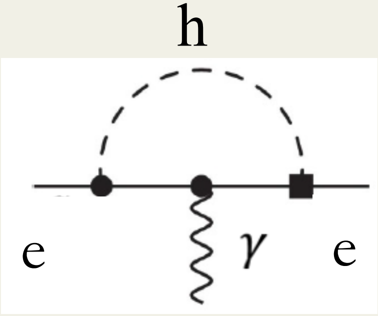
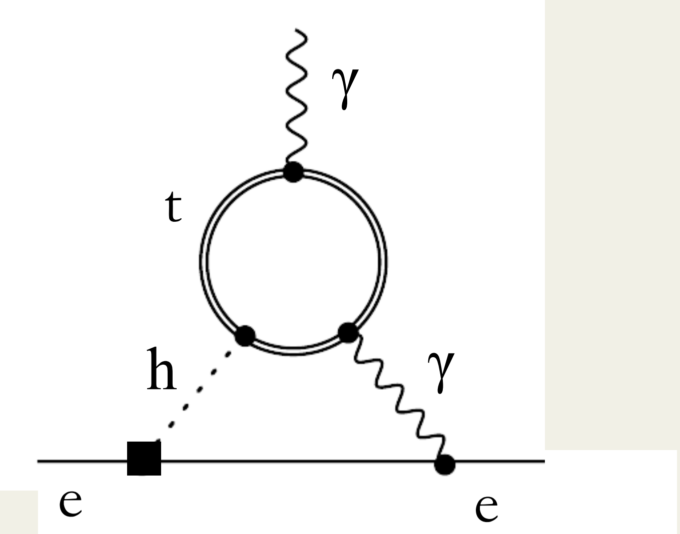


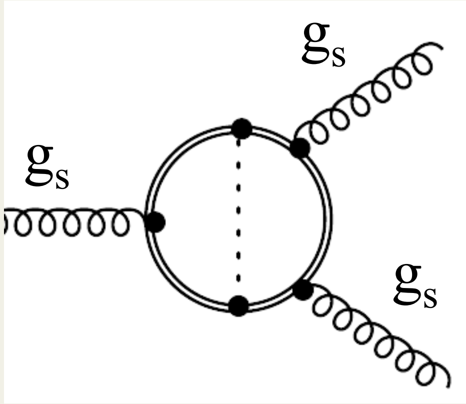


- We know that $d_e < 10^{-28}$ e cm = 10^{-15} e fm
- Use: hc = 1 = 200 MeV fm to constrain $\tilde{y}_e$

Final example

- If the top has a CP-odd Yukawa we can get the neutron EDM

$$L_{Higgs} = \frac{m_t}{v}\left(\bar{t}t + \tilde{y}_t \bar{t} i\gamma^5 t\right)h$$



- Effective operator

$$L_{Weinberg} = d_W G G \tilde{G}$$

- Estimate d_W in terms of $\tilde{y}_t$

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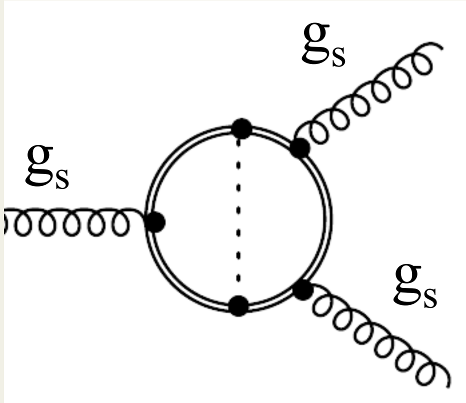

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- Estimate d_W in terms of $\tilde{y}_t$

- Estimate of the neutron EDM in terms of d_W give $d_n \propto (30\ MeV) d_W$
- We know: $d_n < 3*10^{-26}$ e cm = $3*10^{-13}$ e fm
- How much room for CPV is there in the top Yukawa ?