

Title: TBA

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URL: <http://pirsa.org/18050004>

Abstract:

Strong CP problem
and UV instantons

w/ Kiel Howe

1710.04213

1712.05803

Introduction

$$\mathcal{L}_{\text{QCD}} = \frac{\theta \alpha_s}{8\pi} \mathbf{G} \tilde{\mathbf{G}} + Y_u \bar{Q} H U^c + Y_d \bar{Q} H \bar{D}^c$$

$$\bar{\theta} = \arg \det [e^{i\theta} Y_u^+ Y_d^+] \lesssim 10^{-10}$$

$$\delta_{\text{CKM}} = \arg \det [Y_u Y_u^+, Y_d Y_d^+] \approx \mathcal{O}(1)$$

Strong CP problem

$U(1)_{PQ}$
 Global symm.
 Anomalous w/ QCD.

a) $m_u = 0$
 $u^c \rightarrow e^{i\phi} u^c$
 $\theta \rightarrow \theta + \beta$

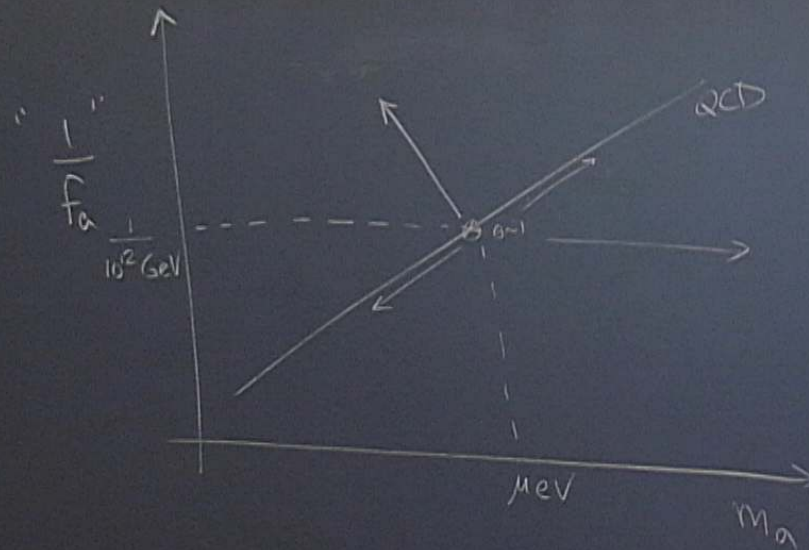
b) Spont Broken:
 Axion: $\left(\theta + \frac{a}{f_a} \right) \tilde{G}\tilde{G}$
 $\xrightarrow{\text{QCD}} m_\pi^2 \frac{f_\pi^2}{f} \approx \left(\frac{\alpha_s \bar{\theta}}{f} \right) f_a$

Strong CP problem and UV instantons

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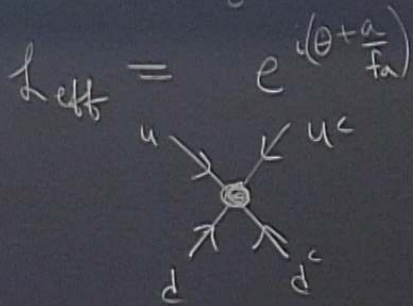
Warm up

uu^c, dd^c at Higgs vertex

— Λ_{uv}

— M

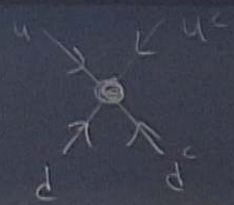
— Λ_{cd}



$$\int_0^1 \frac{d^4 z}{p^5} D(\alpha_s i \frac{1}{p}) \langle uu^c dd^c \rangle p^6$$

$$D(\alpha_s) \sim e^{-2\pi/\alpha_s} \left(\frac{2\pi}{\alpha_s}\right)^6$$

M
 λ_{QCD}



$$D(\alpha_s) \sim e^{-2\pi/\alpha_s} \left(\frac{2\pi}{\alpha_s}\right)^6$$

$$V_{SU}(\alpha) = \mathcal{O}\left(\frac{\alpha+\theta}{f}\right) M^4 D[\alpha_s(M)] \left(\frac{m_u m_d + \gamma_u \gamma_d}{M^2} \frac{1}{(4\pi)^2} \right)$$

uu^c, dd^c it Higgs vertex $\frac{1}{M} \int d^4z \frac{d^6f}{f^5} D(\alpha_s(\frac{1}{f})) \langle uu^c dd^c \rangle f^6$

Λ_{uv}
 M
 Λ_{cd}

$\text{Left} = e^{i(\theta + \frac{a}{f_a})}$

$D(\alpha_s) \sim e^{-2\pi/\alpha_s} \left(\frac{2\pi}{\alpha_s}\right)^6$

$V_{uv}(a) = \mathcal{O}\left(\frac{a+\theta}{f}\right) M^4 D[\alpha_s(M)] \left(\frac{m_u m_d + \gamma_u \gamma_d}{M^2} \frac{1}{(6\pi)^2} \right)$

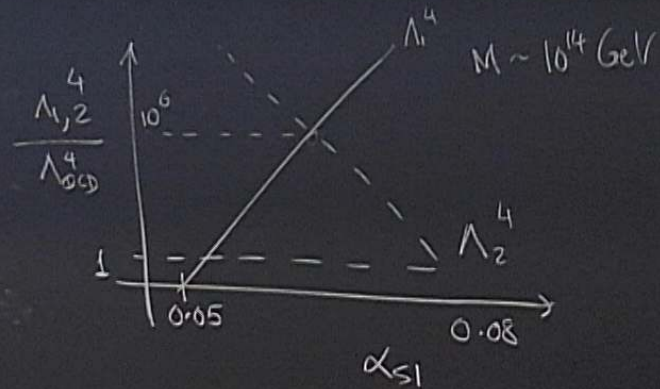
$$\mathcal{L}_{eff} = \frac{\alpha_s}{8\pi} \left(\frac{a_1}{f_1} + \frac{a_2}{f_2} + \theta_1 + \theta_2 \right) G \tilde{G}$$

$$+ \Lambda_1^4 \cos \left(\frac{a_1}{f_1} + \theta_1 \right)$$

$$+ \Lambda_2^4 \cos \left(\frac{a_2}{f_2} + \theta_2 \right)$$

$$\Lambda_1^4 \sim D(\alpha_{S1}(M)) M^4 \left(\frac{\prod y_i}{\sin \frac{4\pi}{5}} \right)$$

$$\Lambda_2^4 \sim D(\alpha_{S2}(M)) M^4$$



$$\underline{m_u = 0}$$

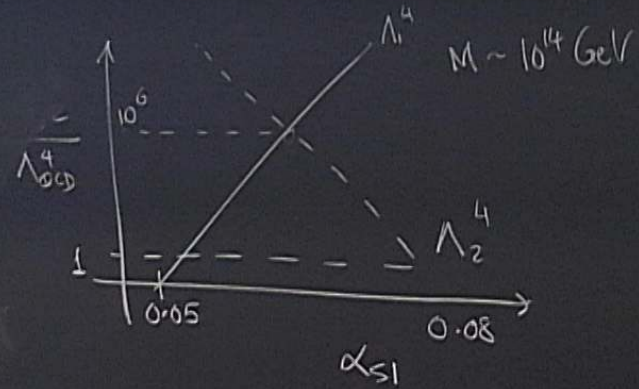
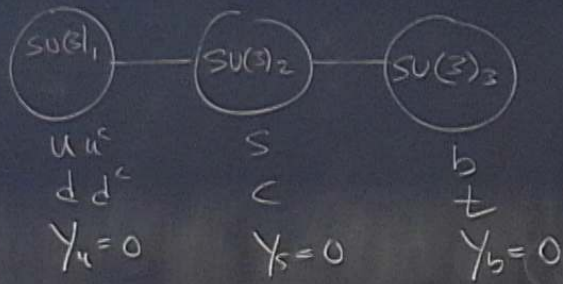
u, u^c, d, d^c

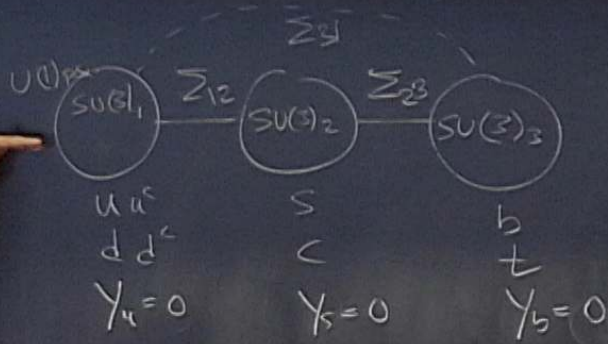
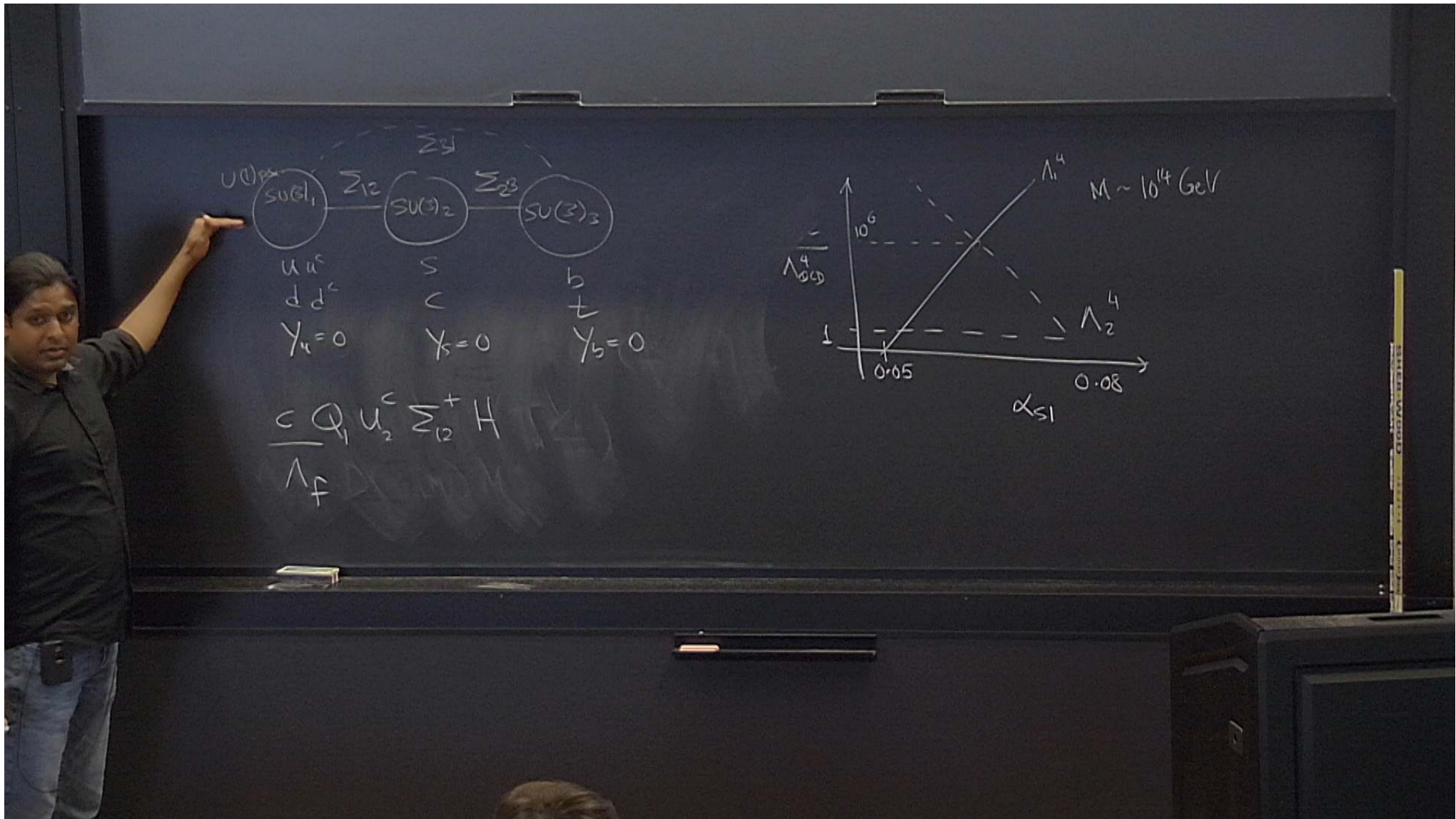


$$\frac{m_u}{m_d} \text{ (current alg)} \sim 0.5$$

$$Y_u \approx Y_d^* e^{i\theta} D(\alpha_s(M))$$

$$m_u \approx 2.3 \begin{matrix} 0.7 \\ -0.5 \end{matrix} \text{ MeV @ 2 GeV}$$





$$\frac{c Q_1 U_2^c \Sigma_{12}^+ H}{\Lambda_f}$$

