The neutron EDM vs up and charm flavour violation

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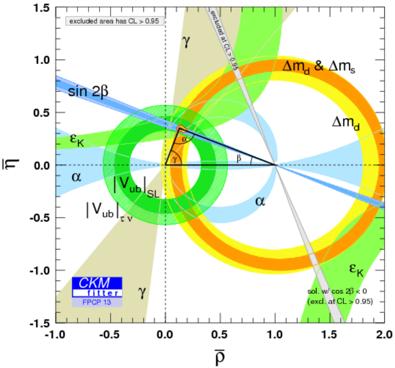
Moriond EW, La Thuile, 16 March 2014

based on: F.S. arXiv:1312.2589

Why is CKM description of flavour and CP so good?

Hierarchy problem: $m_h \approx \Lambda$ [Λ = highest scale h couples to]



$$\mathcal{L}_{\rm NP} = \sum_i \frac{1}{\Lambda_i^2}\mathcal{O}_i$$

"NP flavour problem" $\Downarrow$

$$\Lambda_i \gtrsim 10^4 \div 10^5\,\mathrm{TeV}$$

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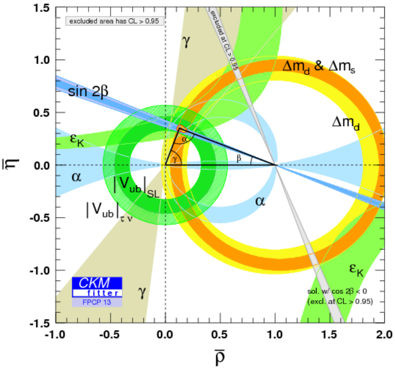

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Solution [insisting on naturalness] $\mathcal{L}_{\rm NP} = \sum_i \xi_i \frac{c_i}{\Lambda^2}\mathcal{O}_i \quad c_i \sim O(1) \quad \Lambda \sim \mathrm{TeV}$

ξ_i small due to some "feature", e.g. a flavour symmetry, partial compositeness

A class of solutions of NP flavour problem

Current constraints

Stronger ones: down sector [ϵ_K, $B - \bar{B}$ mixing, $B \to X_s \gamma$, ...]

Up sector: larger effects allowed! [$\Delta A_{\rm CP}$, ...]

Many examples realising this picture, like:

- $\to$ Flavour alignment [Nir Seiberg hep-ph/9304307, ...]
- $\to$ Partial compositeness [D.B. Kaplan, NPB (1991), ...]
- $\to$ Generic $U(2)^3$ [Barbieri Buttazzo S. Straub 1206.1327]

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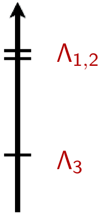
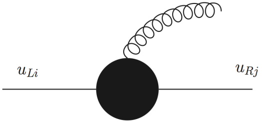


Separation of new physics scales

favoured by natural solution to hierarchy problem

Hot flavour observables



$$\mathcal{L}_{\rm NP} \supset c_{ij} \frac{m_t}{\Lambda^2} (\bar{u}_{Li} \sigma_{\mu\nu} T^a u_{Rj})\, g_s G^a_{\mu\nu}$$

Typical situation: up-quarks dipoles can be largish

Most sensitive observables

$$\Delta A_{\rm CP} = A_{CP}(D \to K^+K^-) - A_{CP}(D \to \pi^+\pi^-) \quad \propto \; c_{uc},\; c_{cu}$$

$$d_n = (1 \pm 0.5)\left[1.4(d_d - 0.25 d_u) + 1.1e(\tilde{d}_d + 0.5\tilde{d}_u)\right] \quad \propto \; c_{uu}$$

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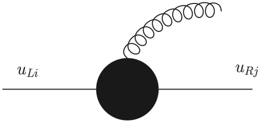

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Very general class of models

They realise $c_{uc} c_{cu} = c_{uu} c_{cc}$

$\Rightarrow$ one can have largish $\Delta A_{\rm CP}$, and respect d_n bound!

[big amount of literature exploiting this]

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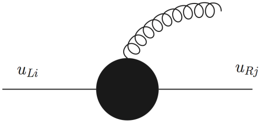

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This talk: point out d_n sensitive to c_{cc} $\Rightarrow$ now d_n constrains $\Delta A_{\rm CP}$!

Status of d_n and ΔA_{CP}

Neutron EDM

Current bound: $d_n < 2.9 \cdot 10^{-26} e$ cm (90%CL) ILL, Grenoble

Future sensitivity: $d_n \sim 10^{-28} e$ cm ILL, PSI, TRIUMF...

Standard Model contribution: $d_n \sim 10^{-31} e$ cm [long distance effect]

CP asymmetry in D decays

Current world average: $\Delta A_{CP} = (-3.29 \pm 1.21) \times 10^{-3}$ LHCb

Standard Model contribution: a few $\times 10^{-3}$, big uncertainties!

LHCb will not increase sensitivity to NP (unless we understand SM)

Outline

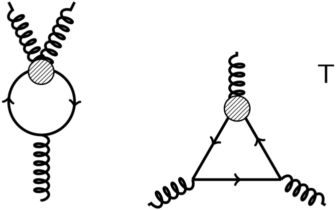
→ New bound on the charm chromo-EDM

→ Implications for phenomenology of new physics

Bound on the chromo-EDM of the charm quark

$$d_n = (1 \pm 0.5)\left[1.4(d_d - 0.25 d_u) + 1.1 e(\tilde{d}_d + 0.5\tilde{d}_u)\right] \pm (22 \pm 10)\,\text{MeV}\, w$$

$$\mathcal{L}_{\rm NP} \supset w\, \tfrac{1}{6} f^{abc} \epsilon^{\mu\nu\lambda\rho} G^a_{\mu\sigma} G^{b\,\sigma}_{\nu} G^c_{\lambda\rho}$$



Threshold effect $\quad w = \dfrac{\tilde{d}_q}{m_q}\dfrac{g_s^3}{32\pi^2}$ [known since 1990]

$$\tilde{d}_c < 1.0 \times 10^{-22} e \text{ cm}$$

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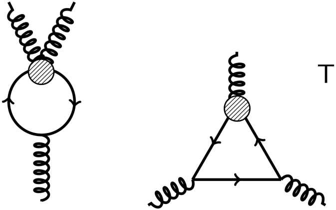

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$$\tilde{d}_q = 2 \frac{m_t}{\Lambda^2} \text{Im}(c_{qq})$$

$\text{Im}(c_{uu}) \lesssim 1.3 \times 10^{-8}\ (\Lambda/\text{TeV})^2$

$\text{Im}(c_{cc}) \lesssim 1.8 \times 10^{-5}$ "

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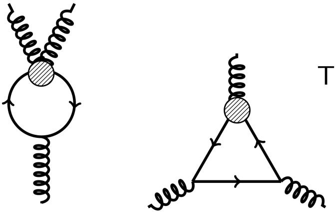

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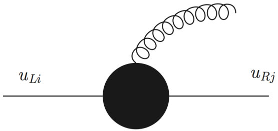
What if one ignores w in d_n? Still w runs in $d_{u,d}$, $\tilde{d}_{u,d} \Rightarrow \tilde{d}_c < 1.2 \times 10^{-20} e$ cm

Implications for New Physics

Reminder: i) largish flavour violation in up quark sector ii) $\Lambda_{1,2} \gg \Lambda_3$



$$c_{ij} = c\, W^L_{i3} W^R_{3j}$$

→ $W^{L,R}_{k3}$ = how much k^{th} generation of quarks communicates with Λ_3

→ Typically $W^L_{i3} \simeq V^{\mathrm{CKM}}_{ib}$

d_n	$\Rightarrow$	$\lvert W^R_{3c}\rvert < 4.4 \times 10^{-4}$	$\lvert W^R_{3u}\rvert < 3.7 \times 10^{-6}$
ΔA_{CP}	$\Rightarrow$	$\lvert W^R_{3c}\rvert < 1.1 \times 10^{-3}$	$\lvert W^R_{3u}\rvert < 9.2 \times 10^{-5}$

No bound on $\tilde{d}_c \Rightarrow$ largish W^R_{3c} allowed, without conflict with d_n!

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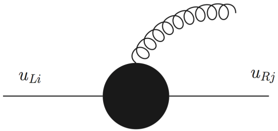

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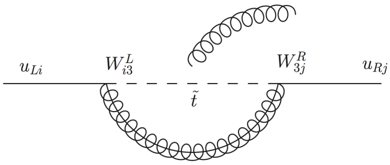
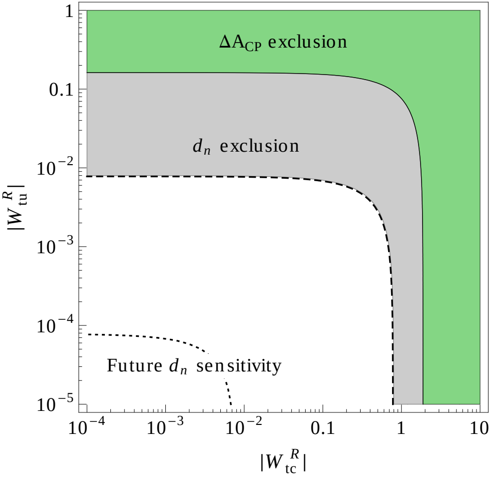
Supersymmetry with split families $[m_{\tilde{q}_{1,2}} \gg m_{\tilde{t},\tilde{b}}]$

Possible to consider all dominant contributions to both d_n and ΔA_{CP} *



$$\frac{c_{ij}}{\Lambda^2} = \frac{\alpha_s}{4\pi}\frac{1}{m_{\tilde{g}}^2}\frac{A_t - \mu\cot\beta}{m_{\tilde{t}}} f\left(\frac{m_{\tilde{g}}^2}{m_{\tilde{t}}^2}\right) W^L_{i3} W^R_{3j}$$



$[m_{\tilde{g}} = 1.5\,\text{TeV} = 2m_{\tilde{t}}]$

*down quark CPV strongly constrained by ϵ_k
Higgs and gaugino phases by d_e [Barbieri Buttazzo S Straub 1402.6677]

Composite Higgs models

Other main paradigm for natural solution to hierarchy problem

→ Higgs as pseudo-Goldstone boson

→ Simplified pheno: a composite state for every SM field (e.g. top partners T)

→ natural m_h + precision tests $\Rightarrow$ i) $m_T \lesssim \text{TeV}$ ii) strong coupling $Y^* \sim 1$

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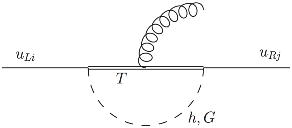


d_n	⇒	$m_T \gtrsim 2.1\, Y^*_u$ TeV	$m_T \gtrsim 1.2\, Y^*_c$ TeV
ΔA_{CP}	⇒	$m_T \gtrsim 1.3\, Y^*_8$ TeV	$m_T \gtrsim 0.26\, Y^*_{8'}$ TeV

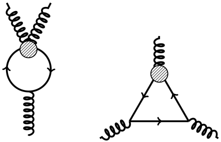
See also Konig Neubert Straub 1403.2756 for more detailed analysis:

Now d_n is giving the strongest bound on masses of up composite partners

Conclusions

- New bound on the charm chromo-EDM (via w)

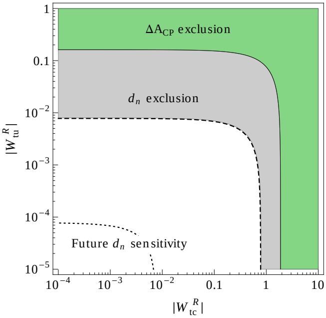
$$\tilde{d}_c < 1.0 \times 10^{-22} e \text{ cm}$$



- General class of models with

  i) largish flavour violation in up quark sector
  ii) $\Lambda_{1,2} \gg \Lambda_3$

  $\Rightarrow$ d_n constrains ΔA_{CP}



Future

- $\rightarrow$ Understand ΔA_{CP} in SM
- $\rightarrow$ Improve on w contribution to d_n
- $\rightarrow$ Long distance charm contribution to d_n?
- $\rightarrow$ Measure deuteron EDM