Two new physics paths to charm CP asymmetry

Cédric Delaunay
CERN-TH

[hep-ph/soon.!?!?]² with
J.F. Kamenik, G. Perez, L. Randall
&
L. da Rold, C. Grojean, G. Perez

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Introduction

- LHCb+CDF: \( \Delta a_{CP} = (-0.67 \pm 0.16)\% = 0 - 4.2\sigma = \text{SM??} \)

- if charm CPV is not SM-like, then 2 NP routes:
  - \( (uc)_{V+A}(qq)_{V+A} \) with \( \Lambda_{4f} \approx 15\text{TeV} \) | model dependent DDbar issue
  - \( g_s m_c u_L \sigma_{\mu\nu} G^{\mu\nu} c_R \) with \( \Lambda_8 \approx 20\text{TeV} \) | no DDbar thanks to chirality flip

- NP must solve the hierarchy problem
  - \( N_{\text{susy}} > 0 \): see Giudice, Isidori & Paradisi ’12 & Hiller, Hochberg & Nir ’12
  - \( N_{\text{susy}} = 0 \): warped extra dimension (or 4D composite models)

- \( \Lambda_8 \sim 20\text{TeV} \) arises in flavor anarchic strong TeV dynamics
  \( \rightarrow \text{implications?} \)

- \( \Lambda_{4f} \sim 15\text{TeV} \) possible if light RH-quarks are composite
  \( \rightarrow \text{does it pass present dijet constraints?} \)
The dipole way to charm CPV
RS + flavor anarchy
Warped essentials

RS'99: « Hierarchy problem is solved in AdS5 bckg: \[ ds^2 = e^{-2ky} dx^2 - dy^2 \] »

- EWPTs \( \rightarrow m_{KK} > 3 - 4 \text{ TeV} \)
- custodial symmetry @work

- SM flavor puzzle addressed
- NP flavor problem almost solved
  RSGIM @work, yet:

\[ \text{Im}[\epsilon_K] + \text{Im}[\epsilon'/\epsilon] \rightarrow m_{KK} > 5 \text{ TeV} \]

- a way out (supported by Daya bay):
  down alignment, but up anarchy
Charm CPV from a chromo-dipole operator

CD, Kamenik, Perez & Randall '12

- Flavor changing dipole induced at 1-loop by Yukawa int.
- Bulk Higgs: «wrong» chirality KK fermions dominate

\[
C_8 = \frac{\lambda_c Y_5^2}{16\pi^2 m_{KK}^2} [O_\beta] \quad H \text{ overlap corr.} \approx 0.1 \text{ for } \beta=0
\]

\[\Delta a_{CP} = 0.6\% \quad \text{for } m_{KK}=3 \text{TeV, } Y_5=6\]

- First implications:
  - overlap suppression requires a larger $Y$ than in generic 4D duals
    \[\Rightarrow \text{DDbar mixing in 5D is typically more suppressed}\]
  - gluon coupling is flavor blind
    \[a_{CP}(KK)=a_{CP}(\pi\pi)\]
The 4-fermion way to charm CPV RH quarks compositeness
Charm CPV from composite RH light quarks

- for $S$-channel mediated $u\bar{c} \rightarrow q\bar{q}$ transitions:
  \[
  \frac{l}{\Lambda_{uc}} \times \frac{l}{\Lambda_{qq}} \approx \frac{l}{(15 \text{ TeV})^2}
  \]

- The D meson see-saw:
  \[
  \Lambda_{c=2} \approx 1200 \text{ TeV} \gg \Lambda_{c=1} \approx 15 \text{ TeV}
  \]

- $200 \text{ GeV}$ implies strong coupling:
  \[
  \Lambda_{NDA} \sim 200 \text{ GeV} \times 4\pi \approx 2.5 \text{ TeV}
  \]

- $q=u,d$ excluded $\Lambda_{uu} \geq 3 \text{ TeV}$
  \[
  \rightarrow \text{ what if } q=s?\n  \]
Dijet searches & compositeness scale

- Dijet searches sensitive to 4F operators involving light quarks
- strategy:
  - QCD mostly produces forward jets through the exchange of massless particles in t-channel
  - Contact interactions produce more isotropic jets → dominates @ low y
  - construct angular variable $\chi = \exp(2y)$ to exploit the different kin.

$\sigma^{-1}d\sigma/d\chi$ from CMS

$F_\chi = \sigma(y<0.6)/\sigma(y<1.7)$ from ATLAS

![Graph showing CMS and ATLAS data for dijet searches and compositeness scale](image-url)
**Light quark compositeness vs. dijet searches**

\[ \Delta a_{CP} \text{ from s-channel FCNC } \rightarrow (s\bar{r}_R s_R)^2/(200\text{GeV})^2 \]

\[ \sigma^{-1}d\sigma/d\chi \text{ @CMS} \]

- **LO partonic level**

\[ \begin{align*} 
F_{\chi} \text{ @ATLAS} &= (u_R T^a u_R)^2/(3\text{TeV})^2 \\
&= (s_R T^a s_R)^2/(0.4\text{TeV})^2 \\
&= (u_R T^a u_R)(s_R T^a s_R)/(0.8\text{TeV})^2 
\end{align*} \]

- **mild tension but:**
  - **color octet favored** bounds for singlet is \( \sqrt{3} \) stronger
  - **negative Wilson coefficient induced**

- **NP matrix elem. for charm direct CPV are unknown**
- **NLO QCD corr. applied to NP weakens bounds by \( o(20\%) \)**
- **mostly strange jets are produced**
Conclusions/Outlook

• warped Xdim + up-type flavor anarchy induces $Q_8$ with the right size to explain charm CPV with $a_{CP}(KK) = a_{CP}(\pi\pi)$

• composite $s_R$ opens a 4F possibility for $\Delta a_{CP}$
  \textit{OK with dijets @LHC and predicts $a_{CP}(KK) \gg a_{CP}(\pi\pi)$}

• other ways to distinguish between the 2 NP routes:
  – CPV in radiative D decays from $Q_8$ induced $Q_7$ \textit{(see Gino’s talk)}
  – strange dijets @LHC should pop up from a 4F operator

• \textit{naturalness + $\Delta a_{CP} + \text{top } A_{FB}$ hints for an intriguing paradigm: partial compositeness + RH composite quarks}