Small violations of 3×3 unitarity, the phase in B_s^0–$\bar{B}_s^0$ mixing and visible $t \to cZ$ decays at the LHC

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arXiv:0805.3995[hep-ph]

Outline of the talk

Motivations

The Standard Model shows an outstanding consistency for an impressive list of flavour-related observables...
Nevertheless, recent times had brought

- Time-dependent, mixing induced, CP violation in $B_s \to J/\Psi\Phi$ measured at Tevatron,

  CDF Collaboration, *Phys. Rev. Lett.* **100**, 161802 (2008), arXiv:0712.2397

  DØ Collaboration, arXiv:0802.2255

- D^0–$\bar{D}^0$ mixing at B factories,

  Babar Collaboration, *Phys. Rev. Lett.* **98**, 211802 (2007), hep-ex/0703020

  Belle Collaboration, *Phys. Rev. Lett.* **98**, 211803 (2007), hep-ex/0703036

  Belle Collaboration, *Phys. Rev. Lett.* **99**, 131803 (2007), arXiv:0704.1000

- Hints from $b \to s$ penguin transitions.

  M. Artuso *et al.*, *Eur. Phys. J. C* **57**, 309-492 (2008), arXiv:0801.1833

What is this about?

Our main ingredient to tackle those issues:

One new $Q = 2/3$ isosinglet quark T

F. del Aguila, M. Bowick, *Nucl. Phys.* **B224**, 107 (1983)

G.C. Branco, L. Lavoura, *Nucl. Phys.* **B278**, 738 (1986)

. . . . . .

The CKM matrix is not 3×3 unitary anymore!

- New contributions to up-type quark loops,
- Tree level FCNC in the up sector.

Framework and notation

Charged Current Interactions:

$$\mathscr{L}_W = -\frac{g}{\sqrt{2}} \bar{\mathbf{u}}_L \gamma^\mu V \mathbf{d}_L W_\mu^\dagger + \text{H.C.}$$

Neutral Current Interactions:

$$\mathscr{L}_Z = -\frac{g}{2\cos\theta_W} \left[\bar{\mathbf{u}}_L \gamma^\mu (V V^\dagger) \mathbf{u}_L - \bar{\mathbf{d}}_L \gamma^\mu \mathbf{d}_L - 2\sin^2\theta_W J_{em}^\mu \right] Z_\mu$$

Where

$$\mathbf{u} = (u, c, t, T) \qquad \mathbf{d} = (d, s, b) \qquad V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \\ V_{Td} & V_{Ts} & V_{Tb} \end{pmatrix}$$

Framework and notation

- Mixing matrix $V \hookrightarrow U$

$$U = \left(\begin{array}{ccc|c} V_{ud} & V_{us} & V_{ub} & U_{14} \\ V_{cd} & V_{cs} & V_{cb} & U_{24} \\ V_{td} & V_{ts} & V_{tb} & U_{34} \\ V_{Td} & V_{Ts} & V_{Tb} & U_{44} \end{array}\right) \qquad 4 \times 4 \text{ unitary}$$

- FCNC controlled by $VV^\dagger$:

$$(VV^\dagger)_{ij} = \delta_{ij} - U_{i4}U^*_{j4}$$

For example, tcZ coupling:

$$\mathscr{L}_Z \supset -\frac{g}{2\cos\theta_W}\left[\bar{c}_L\gamma^\mu(-U_{24}U^*_{34})t_L + \bar{t}_L\gamma^\mu(-U_{34}U^*_{24})c_L\right] Z_\mu$$

Framework and notation

With no loss of generality one can rephase

$$\arg U = \begin{pmatrix} 0 & \chi' & -\gamma & \cdots \\ \pi & 0 & 0 & \cdots \\ -\beta & \pi + \beta_s & 0 & \cdots \\ \vdots & \vdots & \vdots & \ddots \end{pmatrix}$$

where

$$\beta \equiv \arg(-V_{cd}V_{cb}^*V_{td}^*V_{tb}) \qquad \gamma \equiv \arg(-V_{ud}V_{ub}^*V_{cd}^*V_{cb})$$
$$\beta_s \equiv \arg(-V_{ts}V_{tb}^*V_{cs}^*V_{cb}) \qquad \chi' \equiv \arg(-V_{cd}V_{cs}^*V_{ud}^*V_{us})$$

R.Aleksan, B.Kayser, D.London, *Phys. Rev. Lett.* **73**, 18 (1994), hep-ph/9403341

Physical implications of (small) violations of 3×3 unitarity

- Potentially large β_s
- Rare top decays
- Contributions to D^0–$\bar{D}^0$ mixing
- Unitarity deviations in the first row of V and the size of χ'

Obtaining a large β_s

- Orthogonality of the s and b columns of V gives:

$$\sin\beta_s = \frac{|V_{ub}|\,|V_{us}|}{|V_{cb}|\,|V_{cs}|}\sin(\gamma-\beta_s+\chi') + \frac{|V_{Tb}|\,|V_{Ts}|}{|V_{cb}|\,|V_{cs}|}\sin(\sigma-\beta_s)$$

$$\sigma \equiv \arg(V_{Ts}V_{cb}V_{Tb}^*V_{cs}^*)$$

In the SM $\sin\beta_s = \mathcal{O}(\lambda^2)$
If instead we want to obtain β_s of order λ,
we must play with the couplings of T,
for example $V_{Tb} \approx \mathcal{O}(\lambda)$, $V_{Ts} \approx \mathcal{O}(\lambda^2)$

Obtaining a large β_s

- Orthogonality of the c and t rows of U gives:

$$\sin\beta_s = \frac{|V_{cd}|\,|V_{td}|}{|V_{cs}|\,|V_{ts}|}\sin\beta + \frac{|U_{24}|\,|U_{34}|}{|V_{cs}|\,|V_{ts}|}\sin\omega$$

$$\omega = \arg(V_{tb}^* U_{24}^* V_{cb} U_{34})$$

To have β_s of order λ,
$|U_{24}U_{34}|$ of order λ^3 is required,
for example $|U_{24}| \approx \mathcal{O}(\lambda^2)$, $|U_{34}| \approx \mathcal{O}(\lambda)$

Rare top decays

- We have just seen that $\beta_s \approx \mathcal{O}(\lambda)$ requires $|U_{24}U_{34}| \approx \mathcal{O}(\lambda^3)$
- ... but this is just what we have in the coupling

$$\frac{g}{2\cos\theta_W} U_{24}U_{34}^{*}\,\bar{c}_L\gamma^\mu t_L\, Z_\mu$$

- ... which leads to rare top decays $t \to cZ$ (at rates observable at the LHC)

That is,

a large value of β_s implies rare top decays $t \to cZ$

D^0–$\bar{D}^0$ mixing

- We also have tree level $\bar{c}_L \gamma^\mu u_L \, Z_\mu$ couplings
- To account for the observed size of D^0–$\bar{D}^0$ without having to invoke long-distance contributions to the mixing,
  $|U_{14} U_{24}|$ has to be of order λ^5

  E.Golowich, J.Hewett, S.Pakvasa, A.A.Petrov *Phys. Rev.* **D76**, 095099 (2007), arXiv:0705.3650
- With $U_{24} \approx \mathcal{O}(\lambda^2)$ for $\beta_s \approx \lambda$, $U_{14} \approx \mathcal{O}(\lambda^3)$
- However, $|U_{14}|$ has just an upper bound and, even for $\beta_s \approx \lambda$, this New Physics short-distance contribution to D^0–$\bar{D}^0$ mixing could be switched off (and thus long-distance contributions required)

Unitarity deviations in the first row of V and the size of χ'

- Most precisely measured elements of V

$$|V_{ud}| = 0.97408 \pm 0.00026 \qquad |V_{us}| = 0.2253 \pm 0.0009$$

imply the bound

$$1 - \left(|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2\right) = |U_{14}|^2 \lesssim (0.02)^2$$

Less restrictive than not overproducing short-distance contributions to D^0–$\bar{D}^0$ mixing

Unitarity deviations in the first row of V and the size of χ'

- Orthogonality of the u and c rows of U gives:

$$\sin\chi' = \frac{|V_{ub}V_{cb}|}{|V_{us}V_{cs}|}\sin\gamma + \frac{|U_{14}U_{24}|}{|V_{us}V_{cs}|}\sin\rho$$

$$\rho \equiv \arg(V_{cd}U_{14}V_{ud}^{*}U_{24}^{*})$$

and thus, due to D^0–$\bar{D}^0$ mixing, the second term could be, at most, of order λ^4:

as in the SM case, $\sin\chi' \approx \lambda^4$

J.A.Aguilar-Saavedra, F.J.Botella, G.C. Branco, MN, *Nucl. Phys.* **B706**, 204 (2005)

hep-ph/0406151

Constraints

- Sizeable mixing induced, time dependent, CP-violating asymmetry in $B_s^0 \to J/\Psi\Phi$ (for the CP-even part of the final state)
$$A_{J/\Psi\Phi} \equiv \sin 2\beta_s^{\text{eff}}, \qquad 2\beta_s^{\text{eff}} = -\arg M_{12}^{B_s}$$
- The short-distance contribution to $x_D \equiv \Delta M_D/\Gamma_D$ in D^0–$\bar{D}^0$ from tree level FCNC mostly accounts for the observed value. As long-distance contributions might be important, examples with significantly smaller contributions to x_D are also considered.
- Agreement with purely tree level observables constraining V
$$|V_{ud}|, |V_{us}|, |V_{ub}|, |V_{cd}|, |V_{cs}|, |V_{cb}|, \gamma$$

Constraints

Agreement with the following observables potentially sensitive to New Physics

- Mixing induced, time dependent, CP-violating asymmetry in $B_d^0 \to J/\Psi K_S$
- Mass differences ΔM_{B_d}, ΔM_{B_s}, of the eigenstates of the effective Hamiltonians controlling B_d^0–$\bar{B}_d^0$ and B_s^0–$\bar{B}_s^0$ mixings
- Width differences $\Delta\Gamma_d/\Gamma_d$, $\Delta\Gamma_s$, $\Delta\Gamma_s^{CP}$ of the eigenstates of the mentioned effective Hamiltonians, related to $\mathrm{Re}\,(\Gamma_{12}^q/M_{12}^q)$, $q = d, s$
- Charge/semileptonic asymmetries $\mathcal{A}$, A_{sl}^d, controlled by $\mathrm{Im}\,(\Gamma_{12}^q/M_{12}^q)$, $q = d, s$

A. Lenz, U. Nierste *JHEP* **0706**, 072 (2007), hep-ph/0612167

Constraints

- Neutral kaon CP-violating parameters ϵ_K and ϵ'/ϵ_K

E. Pallante, A. Pich, *Phys. Rev. Lett.* **84**, 2568 (2000), hep-ph/9911233

Nucl. Phys. **B617**, 441 (2001), hep-ph/0105011

A. Buras, M. Jamin, *JHEP* **01**, 048 (2004), hep-ph/0306217

- Branching ratios of representative rare K and B decays such as $K^+ \to \pi^+ \nu\bar{\nu}$, $(K_L \to \mu\bar{\mu})_{SD}$ and $B \to X_s \ell^+ \ell^-$

FlaviaNet WG on Kaon Decays, arXiv:0801.1817

A. Buras, M. Gorbahn, U. Haisch, U. Nierste, *Phys. Rev. Lett.* **95**, 261805 (2005),

F. Mescia, C. Smith, *Phys. Rev.* **D76**, 034017 (2007), arXiv:0705.2025

$\cdots, \cdots$

Constraints

- Electroweak oblique parameter T, which encodes violation of weak isospin; the S and U parameters play no relevant rôle here.

  L. Lavoura, J.P. Silva, *Phys. Rev.* **D47**, 1117 (1993)

  N.B. In the region we are interested in, other precision electroweak parameters like R_b give similar constraints to those obtained from T

  J. Alwall *et al.*, *Eur. Phys. J. C* **C49**, 791 (2007), hep-ph/0607115

  I.Picek, B.Radovcic, *Phys. Rev.* **D78**, 015014 (2008), arXiv:0804.2216

Beside experimentally based constraints, agreement is also required for every parameter entering the calculation of the observables: QCD corrections, lattice-QCD bag factors, etc.

The experimental values

Observable	Exp. Value	Observable	Exp. Value
$\|V_{ud}\|$	0.97408 ± 0.00026	$\|V_{us}\|$	0.2253 ± 0.0009
$\|V_{cd}\|$	0.230 ± 0.011	$\|V_{cs}\|$	0.957 ± 0.095
$\|V_{ub}\|$	0.00431 ± 0.00030	$\|V_{cb}\|$	0.0416 ± 0.0006
γ	$(76 \pm 23)^\circ$		
$A_{J/\psi K_S}$	0.675 ± 0.026	$A_{J/\Psi\Phi}$	0.540 ± 0.225
$\Delta M_{B_d}(\times\ \text{ps})$	0.507 ± 0.005	$\Delta M_{B_s}\ (\times\ \text{ps})$	17.77 ± 0.12
x_D	0.0097 ± 0.0029	ΔT	0.13 ± 0.10
$\epsilon_K(\times 10^3)$	2.232 ± 0.007	$\epsilon'/\epsilon_K(\times 10^3)$	1.67 ± 0.16
$\text{Br}(K^+ \to \pi^+ \nu\bar{\nu})$	$(1.5\ ^{+1.3}_{-0.9}) \times 10^{-10}$	$\text{Br}(K_L \to \mu\bar{\mu})_{SD}$	$< 2.5 \times 10^{-9}$
$\text{Br}(B \to X_s \ell^+ \ell^-)$	$(1.60 \pm 0.51) \times 10^{-6}$		
$\text{Br}(t \to cZ)$	$< 4 \times 10^{-2}$	$\text{Br}(t \to uZ)$	$< 4 \times 10^{-2}$
$\Delta\Gamma_s\ (\times\ \text{ps})$	0.19 ± 0.07	$\Delta\Gamma_s^{CP}\ (\times\ \text{ps})$	0.15 ± 0.11
$\Delta\Gamma_d/\Gamma_d$	0.009 ± 0.037		
A_{sl}^d	-0.003 ± 0.0078	$\mathcal{A}$	-0.0028 ± 0.0016

The different examples

- Example 1: $m_T = 300$ GeV, large x_D
- Example 2: $m_T = 300$ GeV, x_D not large
- Example 3: $m_T = 450$ GeV, large x_D
- Example 4: $m_T = 450$ GeV, x_D not large

Example 1, $m_T = 300$ GeV and large x_D

Moduli

$$|U| = \left(\begin{array}{ccc|c} 0.974186 & 0.225642 & 0.003984 & 0.005530 \\ 0.225559 & 0.972463 & 0.041676 & 0.041252 \\ 0.009002 & 0.047563 & 0.948582 & 0.312809 \\ 0.001666 & 0.033749 & 0.313759 & 0.948904 \end{array}\right)$$

Phases

$$\arg U = \left(\begin{array}{ccc|c} 0 & 0.000530 & -1.055339 & 1.071901 \\ \pi & 0 & 0 & 0.947622 \\ -0.472544 & \pi - 0.208060 & 0 & 0 \\ 1.795665 & -1.266410 & 0 & \pi + 0.004752 \end{array}\right)$$

Example 1, $m_T = 300$ GeV and large x_D

Observable	Value	Observable	Value
γ	60.5°	β_s	-11.9°
ΔM_{B_d}	0.507 ps^{-1}	ΔM_{B_s}	17.77 ps^{-1}
$A_{J/\psi K_S}$	0.692	$A_{J/\Psi\Phi}$	0.288
ϵ_K	2.232×10^{-3}	ϵ'/ϵ_K	1.63×10^{-3}
x_D	0.0085	ΔT	0.16
$\text{Br}(K^+ \to \pi^+ \nu\bar{\nu})$	1.3×10^{-10}	$\text{Br}(K_L \to \mu\bar{\mu})_{SD}$	1.86×10^{-9}
$\text{Br}(t \to cZ)$	1.4×10^{-4}	$\text{Br}(t \to uZ)$	2.5×10^{-6}
$\text{Br}(B \to X_s e^+ e^-)$	1.63×10^{-6}	$\text{Br}(B \to X_s \mu^+ \mu^-)$	1.58×10^{-6}
$\Delta\Gamma_d/\Gamma_d$	0.0042		
$\Delta\Gamma_s$	0.098 ps^{-1}	$\Delta\Gamma_s^{CP}$	0.094 ps^{-1}
A_{sl}^d	-0.0010	$\mathcal{A}$	-0.0006

Example 2, $m_T = 300$ GeV and x_D not large

Moduli

$$|U| = \left(\begin{array}{ccc|c} 0.974195 & 0.225663 & 0.004137 & 0.002015 \\ 0.225482 & 0.972938 & 0.041548 & 0.028688 \\ 0.009721 & 0.042034 & 0.945531 & 0.322660 \\ 0.002889 & 0.026471 & 0.322842 & 0.946078 \end{array}\right)$$

Phases

$$\arg U = \left(\begin{array}{ccc|c} 0 & 0.000569 & -1.204546 & 1.928448 \\ \pi & 0 & 0 & 1.267846 \\ -0.536152 & \pi - 0.189787 & 0 & 0 \\ 1.545539 & -1.774240 & 0 & \pi + 0.003725 \end{array}\right)$$

Example 2, $m_T = 300$ GeV and x_D not large

Observable	Value	Observable	Value
γ	$69.0°$	β_s	$-10.9°$
ΔM_{B_d}	0.507 ps^{-1}	ΔM_{B_s}	17.77 ps^{-1}
$A_{J/\psi K_S}$	0.686	$A_{J/\Psi\Phi}$	0.250
ϵ_K	2.232×10^{-3}	ϵ'/ϵ_K	1.66×10^{-3}
x_D	0.0005	ΔT	0.17
$\mathrm{Br}(K^+ \to \pi^+\nu\bar{\nu})$	1.2×10^{-10}	$\mathrm{Br}(K_L \to \mu\bar{\mu})_{SD}$	1.99×10^{-9}
$\mathrm{Br}(t \to cZ)$	0.72×10^{-4}	$\mathrm{Br}(t \to uZ)$	3.5×10^{-7}
$\mathrm{Br}(B \to X_s e^+ e^-)$	1.92×10^{-6}	$\mathrm{Br}(B \to X_s \mu^+ \mu^-)$	1.86×10^{-6}
$\Delta\Gamma_d/\Gamma_d$	0.0042		
$\Delta\Gamma_s$	0.088 ps^{-1}	$\Delta\Gamma_s^{CP}$	0.085 ps^{-1}
A_{sl}^d	-0.0013	$\mathcal{A}$	-0.0006

Example 3, $m_T = 450$ GeV and large x_D

Moduli

$$|U| = \left(\begin{array}{ccc|c} 0.974179 & 0.225657 & 0.004031 & 0.006073 \\ 0.225619 & 0.972525 & 0.041766 & 0.039324 \\ 0.008330 & 0.047219 & 0.966377 & 0.252620 \\ 0.001136 & 0.032304 & 0.253683 & 0.966747 \end{array}\right)$$

Phases

$$\arg U = \left(\begin{array}{ccc|c} 0 & 0.000570 & -0.957178 & 0.868831 \\ \pi & 0 & 0 & 0.816488 \\ -0.447359 & \pi - 0.140403 & 0 & 0 \\ 1.908192 & -1.055192 & 0 & \pi + 0.004977 \end{array}\right)$$

Example 3, $m_T = 450$ GeV and large x_D

Observable	Value	Observable	Value
γ	54.8°	β_s	-8.0°
ΔM_{B_d}	$0.507\ \text{ps}^{-1}$	ΔM_{B_s}	$17.77\ \text{ps}^{-1}$
$A_{J/\psi K_S}$	0.693	$A_{J/\Psi\Phi}$	0.317
ϵ_K	2.232×10^{-3}	ϵ'/ϵ_K	1.63×10^{-3}
x_D	0.0092	ΔT	0.20
$\text{Br}(K^+ \to \pi^+ \nu\bar{\nu})$	1.0×10^{-10}	$\text{Br}(K_L \to \mu\bar{\mu})_{SD}$	1.87×10^{-9}
$\text{Br}(t \to cZ)$	0.80×10^{-4}	$\text{Br}(t \to uZ)$	1.88×10^{-6}
$\text{Br}(B \to X_s e^+ e^-)$	1.60×10^{-6}	$\text{Br}(B \to X_s \mu^+ \mu^-)$	1.55×10^{-6}
$\Delta\Gamma_d/\Gamma_d$	0.0041		
$\Delta\Gamma_s$	$0.110\ \text{ps}^{-1}$	$\Delta\Gamma_s^{CP}$	$0.104\ \text{ps}^{-1}$
A_{sl}^d	-0.0010	$\mathcal{A}$	-0.0007

Example 4, $m_T = 450$ GeV and x_D not large

Moduli

$$|U| = \left(\begin{array}{ccc|c} 0.974192 & 0.225675 & 0.004015 & 0.002260 \\ 0.225535 & 0.972984 & 0.041642 & 0.026487 \\ 0.009033 & 0.044207 & 0.961556 & 0.270876 \\ 0.001741 & 0.020444 & 0.271403 & 0.962247 \end{array}\right)$$

Phases

$$\arg U = \left(\begin{array}{ccc|c} 0 & 0.000622 & -1.092316 & 1.085654 \\ \pi & 0 & 0 & 0.885746 \\ -0.467721 & \pi - 0.108029 & 0 & 0 \\ 1.920727 & -1.329417 & 0 & \pi + 0.003299 \end{array}\right)$$

Example 4, $m_T = 450$ GeV and x_D not large

Observable	Value	Observable	Value
γ	62.6°	β_s	-6.2°
ΔM_{B_d}	0.507 ps^{-1}	ΔM_{B_s}	17.77 ps^{-1}
$A_{J/\psi K_S}$	0.688	$A_{J/\Psi\Phi}$	0.265
ϵ_K	2.232×10^{-3}	ϵ'/ϵ_K	1.66×10^{-3}
x_D	0.0006	ΔT	0.23
$\mathrm{Br}(K^+ \to \pi^+ \nu\bar{\nu})$	1.0×10^{-10}	$\mathrm{Br}(K_L \to \mu\bar{\mu})_{SD}$	2.10×10^{-9}
$\mathrm{Br}(t \to cZ)$	0.42×10^{-5}	$\mathrm{Br}(t \to uZ)$	3.0×10^{-7}
$\mathrm{Br}(B \to X_s e^+ e^-)$	1.75×10^{-6}	$\mathrm{Br}(B \to X_s \mu^+ \mu^-)$	1.70×10^{-6}
$\Delta\Gamma_d/\Gamma_d$	0.0043		
$\Delta\Gamma_s$	0.098 ps^{-1}	$\Delta\Gamma_s^{CP}$	0.094 ps^{-1}
A_{sl}^d	-0.0012	$\mathcal{A}$	-0.0006

B_s^0–$\bar{B}_s^0$ mixing phase

- Remember $A_{J/\Psi\Phi}$ *is not* $\sin 2\beta_s$ *but* $\sin 2\beta_s^{\text{eff}}$
- The examples provide values of $A_{J/\Psi\Phi}$ in the range [0.25;0.32], *significantly* larger than the SM expectation 0.04
- However, the model does not allow for much larger values of $A_{J/\Psi\Phi}$, even if larger values of m_T are considered: difficulties with non-decoupling contributions to flavour changing rare decays arise

D^0–$\bar{D}^0$ mixing

- The examples could account for x_D just through the short-distance contributions available in this framework (tree level Z-mediated)
- ... or not, it is not compulsory
- The crucial test to disentangle the origin of D^0–$\bar{D}^0$ mixing, short or large distance, could come from CP violation; the present model produces new CP-violating phases

Observable $t \to cZ$ decays at the LHC and $|V_{tb}| \neq 1$

- The branching ratio of $t \to cZ$ decays has, in the examples, values $10^{-4} - 10^{-5}$
- ...typically within reach of the LHC detectability expectations, this branching ratio can be explored down to 3.1×10^{-4} for an integrated luminosity 10 fb^{-1}, down to 6.1×10^{-5} for 100 fb^{-1}

  J. Carvalho *et al.*, *Eur. Phys. J. C* **C52**, 999 (2007), arXiv:0712.1127

  T. Han, arXiv:0804.3178
- $t \to uZ$ decays are also of potential interest but the resulting branching ratio is much smaller, typically $\mathcal{O}(10^{-6})$

Observable $t \to cZ$ decays at the LHC and $|V_{tb}| \neq 1$

- Once again, these branching ratios are not unavoidably obtained with such a size.
  However, it is true that once we focus on the possibility of obtaining significant phases in B_s^0–$\bar{B}_s^0$ mixing, sizable values of $\mathrm{Br}(t \to Zc)$ follow
- By the same token, $|V_{tb}|$ is sizeably different from unity, and this affects observables at hadron machines like, for example, single top production

Conclusions

- Through a new isosinglet $Q = 2/3$ quark and associated small violations of 3×3 unitarity, we can accommodate a large ($\mathcal{O}(\lambda)$) value of β_s^{eff}, partially accounting for the observed CP violation in $B_s \to J/\Psi\Phi$
- The mass of the T quark should not exceed ~ 500 GeV
- One distinctive feature of this framework, with respect to supersymmetric extensions, Little Higgs models, four generations, etc, is the fact that a large β_s implies significant $t \to cZ$ branching ratios
- Potential explanation for the observed D^0–$\bar{D}^0$ mixing
- More detailed analysis in progress

$A_{J/\Psi\Phi}$ and the contribution of β_s

$$
\begin{aligned}
\frac{M_{12}^s}{|[M_{12}^s]_{SM}|} &= r_s^2 e^{-i2\beta_s^{\mathrm{eff}}} \\
&= e^{-i2\beta_s}\left\{1+2\,\frac{S(x_t,x_T)}{S(x_t)}\frac{V_{Ts}^*V_{Tb}}{V_{ts}^*V_{tb}}+\frac{S(x_T)}{S(x_t)}\left(\frac{V_{Ts}^*V_{Tb}}{V_{ts}^*V_{tb}}\right)^2\right\} \\
&= e^{-i2\beta_s}\ r_s^2\ e^{-i2\varphi}
\end{aligned}
$$

- Screening

$$
\lim_{m_T\to m_t}\beta_s+\varphi=\arg\left(1+\frac{V_{ub}^*V_{us}}{V_{cb}^*V_{cs}}\right)\leq \arcsin\left(\frac{|V_{ub}^*V_{us}|}{|V_{cb}^*V_{cs}|}\right)\sim\mathcal{O}(\lambda^2)
$$

So in the limit $m_T\to m_t$, φ is either order $-\beta_s$ (for $\beta_s\sim\lambda$), or very small (for $\beta_s\sim\lambda^2$)

$A_{J/\Psi\Phi}$ and the contribution of β_s

- φ is dominated by the imaginary part of $-\frac{S(x_t,x_T)}{S(x_t)}\frac{V_{Ts}^* V_{Tb}}{V_{ts}^* V_{tb}}$. (The ratio of CKM matrix elements is at most of order λ)
- The x_T dependence of the Inami-Lim function $S(x_t, x_T)$ destroys the cancellation as soon as we move away from $m_T = m_t$. For example, $S(x_t, x_T) \simeq 1.5 S(x_t)$ for $m_T = 300$ GeV, and growing with m_T

To have β_s^{eff} of order λ, we have to pick β_s of order λ and, as soon as the mass of the new quark T grows, we will get β_s^{eff} of the same order and opposite size