Theoretical Review of γ/ϕ_3 Measurements with B_s Decays to Charm*

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- Setting the Stage
- Decays with Tree and Penguin Contributions
- Pure Tree Decays
- Concluding Remarks

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*I shall use the γ notation throughout my talk.

Setting the Stage

Introduction

- Tremendous progress in B physics during the recent years: [$\longrightarrow$ Ferroni]

Fruitful interplay between theory and experiment

  - e^+e^- B factories: have already produced $\sum \mathcal{O}(10^9)$ $B\bar{B}$ pairs;
  - Tevatron: observation of B_s^0–$\bar{B}_s^0$ mixing $\oplus$ first access to B_s^0 decays.

- Status @ CKM2006:

  - The data agree globally with the Kobayashi–Maskawa picture!
  - But we have also hints for discrepancies: $\longrightarrow$ first signals of NP??

- New perspectives for B studies @ LHC $\gtrsim$ autumn 2007: [$\longrightarrow$ Nakada]

  - Large statistics and full exploitation of the B_s physics potential, thereby complementing the physics programme of the e^+e^- B factories.
  - Precision determinations of γ: $\longrightarrow$ key ingredient for NP searches!

Let's have a closer look at B_s decays to charm $\longrightarrow$ topic of WG 5 ...

Basic Formulae & Notation

- Time-dependent rate asymmetry:

$$\frac{\Gamma(B_q^0(t)\to f)-\Gamma(\overline{B_q^0}(t)\to \bar{f})}{\Gamma(B_q^0(t)\to f)+\Gamma(\overline{B_q^0}(t)\to \bar{f})}=\left[\frac{\mathcal{A}_{\rm CP}^{\rm dir}\cos(\Delta M_q t)+\mathcal{A}_{\rm CP}^{\rm mix}\sin(\Delta M_q t)}{\cosh(\Delta\Gamma_q t/2)-\mathcal{A}_{\Delta\Gamma}\sinh(\Delta\Gamma_q t/2)}\right]$$

- CP-violating observables:

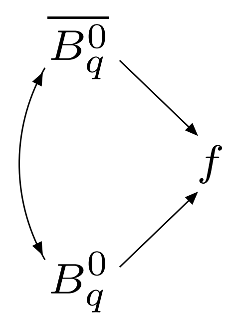
$$\mathcal{A}_{\rm CP}^{\rm dir} = \frac{1-|\xi_f^{(q)}|^2}{1+|\xi_f^{(q)}|^2}=\underbrace{\frac{|A(B_q^0\to f)|^2-|A(\overline{B_q^0}\to \bar{f})|^2}{|A(B_q^0\to f)|^2+|A(\overline{B_q^0}\to \bar{f})|^2}}_{\text{"direct" CP violation}}$$

$$\mathcal{A}_{\rm CP}^{\rm mix} = \frac{2\,\mathrm{Im}\,\xi_f^{(q)}}{1+|\xi_f^{(q)}|^2} \Rightarrow \boxed{\text{"mixing-induced" CP violation}}$$

$$\mathcal{A}_{\Delta\Gamma} = \frac{2\,\mathrm{Re}\,\xi_f^{(q)}}{1+|\xi_f^{(q)}|^2} \Rightarrow \boxed{(\mathcal{A}_{\Delta\Gamma})^2=1-(\mathcal{A}_{\rm CP}^{\rm dir})^2-(\mathcal{A}_{\rm CP}^{\rm mix})^2}$$

- Observables are governed by the following quantity:

$$\xi_f^{(q)} \sim e^{-i\phi_q}\left[\frac{A(\overline{B_q^0}\to f)}{A(B_q^0\to f)}\right]$$



The B_q^0–$\bar{B}_q^0$ Mixing Phases ϕ_q $\rightarrow$ Important Input

$$\phi_q \stackrel{\rm SM}{=} 2\arg(V_{tq}^* V_{tb}) = \left\{ \begin{array}{cc} +2\beta & (q=d) \\ -2\lambda^2\eta & (q=s) \end{array} \right.$$

- The "golden" decay $B_d^0 \rightarrow J/\psi K_{\rm S}$: $\mathcal{A}_{\rm CP}^{\rm mix} \Rightarrow \phi_d = (42.4 \pm 2)^\circ$
- B_s counterpart $B_s^0 \rightarrow J/\psi\phi$: $\rightarrow$ recent D0 analysis [Note 5144 ('06)]
  - Untagged, time-dependent three-angle $B_s \rightarrow J/\psi\phi$ distribution:

    $$\Rightarrow \phi_s = -0.79 \pm 0.56\,(\text{stat.}) \pm 0.01\,(\text{syst.}) = -(45 \pm 32 \pm 0.6)^\circ$$

    $\Rightarrow$ still not stringently constrained, but very accessible @ LHC:

    * LHCb: $\sigma_{\rm stat}(\sin\phi_s) \approx 0.031$ (1 year, i.e. 2 fb^{-1}) [0.013 (5 years)];
    * ATLAS & CMS: expect uncertainties of $\mathcal{O}(0.1)$ (1 year, i.e. 10 fb^{-1}).
- Determinations work also for CPV NP contributions to B_q^0–$\bar{B}_q^0$ mixing:
  - Requirement: negligible CPV NP contributions to decay amplitudes.
  - Very plausible for these modes, but can also be tested (see below)...

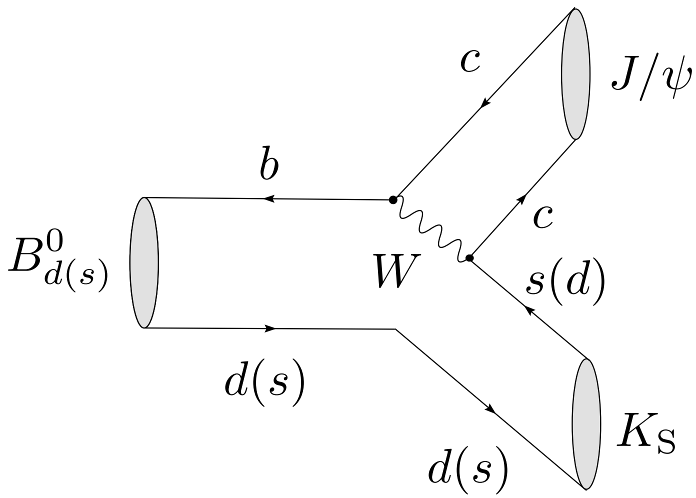
So let's assume that the ϕ_q are known $\rightarrow$

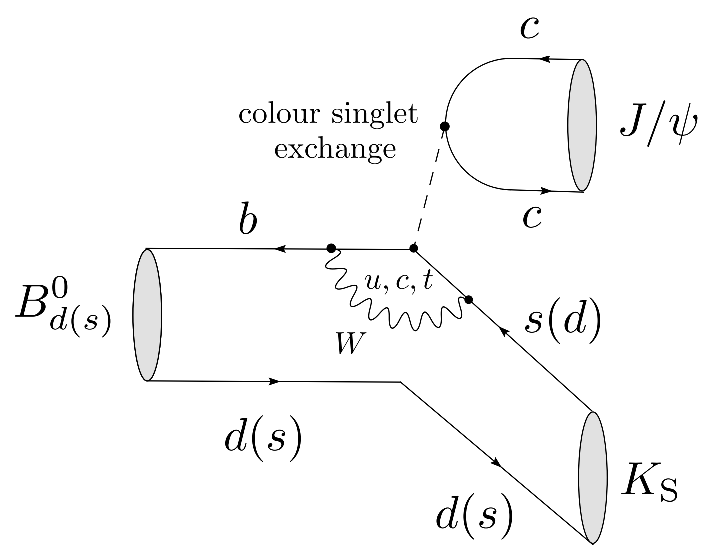
Decays with Tree and Penguin Contributions

[A fresh look at R.F., *Eur. Phys. J.* **C10** (1999) 299]

The $B_{d(s)} \to J/\psi K_{\rm S}$ System

- Decay topologies:





- Structure of the decay amplitudes (using CKM unitarity):

$$A(B^0_d \to J/\psi K_{\rm S}) = \left(1 - \frac{\lambda^2}{2}\right) \mathcal{A}' \left[1 + \left(\frac{\lambda^2}{1-\lambda^2}\right) a' e^{i\theta'} e^{i\gamma}\right]$$

$$A(B^0_s \to J/\psi K_{\rm S}) = -\lambda \mathcal{A} \left[1 - a e^{i\theta} e^{i\gamma}\right]$$

- Hadronic parameters: $\to$ CP-conserving strong quantities ...

$$\mathcal{A} = \text{“tree+pen”}, \quad a e^{i\theta} = \text{“pen/(tree+pen)”}$$

Observables

- "Untagged" rates:

$$\langle\Gamma(B\to f)\rangle \equiv \Gamma(B(t)\to f)+\Gamma(\bar{B}(t)\to f) \;\Rightarrow$$

$$H \equiv \mathsf{PhSp}\times\frac{1}{\epsilon}\left|\frac{\mathcal{A}'}{\mathcal{A}}\right|^2\frac{\langle\Gamma(B_s\to J/\psi K_{\rm S})\rangle}{\langle\Gamma(B_d\to J/\psi K_{\rm S})\rangle}=\frac{1-2a\cos\theta\cos\gamma+a^2}{1+2\epsilon a'\cos\theta'\cos\gamma+\epsilon^2 a'^2}$$

$$\epsilon\equiv\frac{\lambda^2}{1-\lambda^2}=0.05 \;\to\; \text{tiny parameter!}$$

- "Tagged" rates: ⇒ time-dependent CP-violating rate asymmetries ⇒

$$\begin{aligned}\mathcal{A}_{\rm CP}^{\rm dir}(B_s\to J/\psi K_{\rm S}) &= F_1(a,\theta,\gamma)\\ \mathcal{A}_{\rm CP}^{\rm mix}(B_s\to J/\psi K_{\rm S}) &= F_2(a,\theta,\gamma,\phi_s)\end{aligned}$$

$$\begin{aligned}\mathcal{A}_{\rm CP}^{\rm dir}(B_d\to J/\psi K_{\rm S}) &= F_1'(\epsilon a',\theta',\gamma)=0+\mathcal{O}(\epsilon a')\\ \mathcal{A}_{\rm CP}^{\rm mix}(B_d\to J/\psi K_{\rm S}) &= F_2'(\epsilon a',\theta',\gamma,\phi_d)=-\sin\phi_d+\mathcal{O}(\epsilon a')\end{aligned}$$

Extraction of γ

- Important feature of the $B_{s(d)} \to J/\psi K_S$ system:
  - Decays are related through the interchange of all d and s quarks!
  - The U-spin flavour symmetry of strong interactions hence implies:

$$|\mathcal{A}'| = |\mathcal{A}|; \tag{1}$$

$$a' = a, \quad \theta' = \theta. \tag{2}$$

- Consequently, Eqs. (1) and (2) allow us to determine H:
  - U-spin-breaking corrections to (1) have the most important impact:

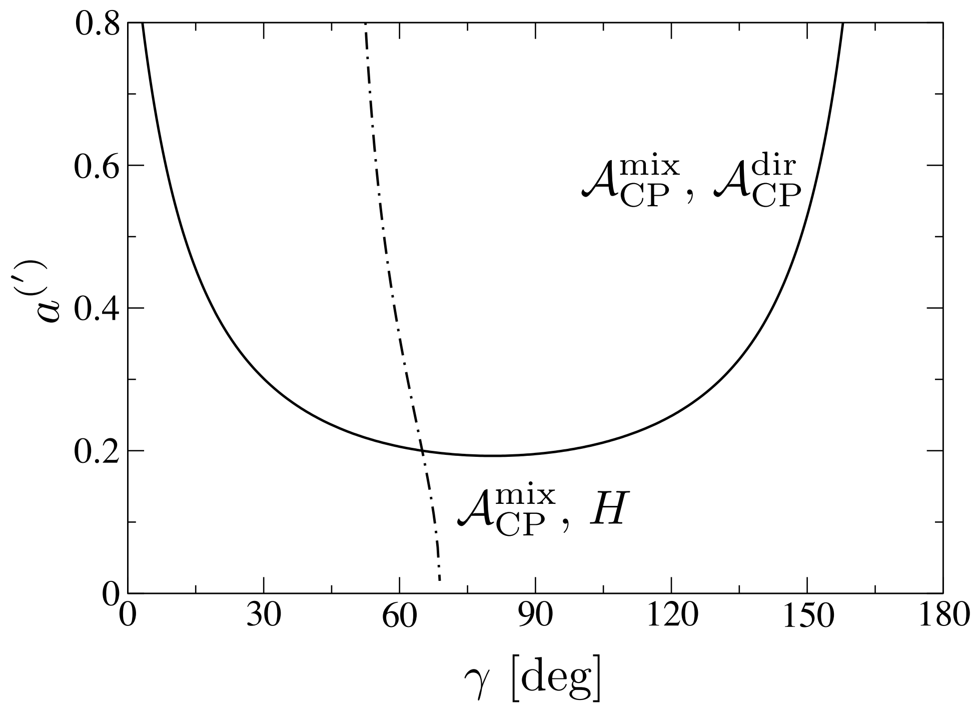
$$\left|\frac{\mathcal{A}'}{\mathcal{A}}\right|_{\rm fact} = \frac{F_{B_d^0 K^0}(M_{J/\psi}^2; 1^-)}{F_{B_d^0 \bar{K}^0}(M_{J/\psi}^2; 1^-)}.$$

  - Corrections to (2) have a minor impact because of the ϵ suppression.

- Finally: γ, a, θ from H, $\mathcal{A}_{\rm CP}^{\rm dir}(B_s \to J/\psi K_S)$, $\mathcal{A}_{\rm CP}^{\rm mix}(B_s \to J/\psi K_S)$.

Contours in the γ–$a^{(\prime)}$ Plane: An Example

- Input parameter:
  - $\gamma = 65^\circ$, $\phi_s = -2^\circ$, $a = a' = 0.2$, $\theta = \theta' = 30^\circ$.
- Observables:
  - $\mathcal{A}_{\rm CP}^{\rm dir}(B_s \to J/\psi K_{\rm S}) = 0.20$, $\mathcal{A}_{\rm CP}^{\rm mix}(B_s \to J/\psi K_{\rm S}) = 0.35$, $H = 0.89 \Rightarrow$



- Remarks:
  - Note that the contour following from $\mathcal{A}_{\rm CP}^{\rm dir}$, $\mathcal{A}_{\rm CP}^{\rm mix}$ is *theoretically* clean!
  - Additional solutions arise for unphysically large values of $a > 1$.

Another Interesting Aspect:

- Note: so far we have not used the B_d^0–$\bar{B}_d^0$ mixing phase ϕ_d!

$$\boxed{U\text{-spin relation:} \quad a' = a, \quad \theta' = \theta} \quad \Rightarrow$$

- γ and the hadronic parameters (a, θ) allow us to control the penguin uncertainties in the extraction of ϕ_d from $\mathcal{A}_{\rm CP}^{\rm mix}(B_d^0 \to J/\psi K_{\rm S})$:

$$\mathcal{A}_{\rm CP}^{\rm mix}(B_d \to J/\psi K_{\rm S}) = F_2'(\epsilon a', \theta', \gamma, \phi_d) = -\sin\phi_d + \mathcal{O}(\epsilon a')$$

  - These corrections received quite some attention [$\to$ Mishima; Ciuchini].
  - Use *data* to control them at the LHC!

- The U-spin relation given above implies the following relation:

$$\frac{\mathcal{A}_{\rm CP}^{\rm dir}(B_d \to J/\psi K_{\rm S})}{\mathcal{A}_{\rm CP}^{\rm dir}(B_s \to J/\psi K_{\rm S})} = -\epsilon H$$

Counterpart in the B_s System:

- Extraction of the B^0_s–$\bar{B}^0_s$ mixing phase ϕ_s from $B^0_s \to J/\psi\phi$:

  – Two vector mesons in the final state $\Rightarrow$ admixture of CP eigenstates...

  – Can be disentangled through the $J/\psi[\to \ell^+\ell^-]$, $\phi[\to K^+K^-]$ angular distribution, introduce linear pol. amplitudes $A_0(t)$, $A_{\|}(t)$, $A_\perp(t)$:

$$\xi^{(s)}_{(\psi\phi)_f} \propto e^{-i\phi_s}\left[1 - \underbrace{2\, i\, \lambda^2 a'_f e^{i\theta'_f} \sin\gamma + \mathcal{O}(\lambda^4)}_{\text{penguin effects}}\right] \to e^{-i\phi_s}$$

  – Since we have $\phi_s \approx -2^\circ$ in the SM, the penguin effects have a significant impact in this case, at least at the 20% level (FSI effects??).

$\Rightarrow$ how to control them (LHCb upgrade plans ...)? $\to$

- Simultaneous analysis of the $B_d \to J/\psi\rho^0$, $B_s \to J/\psi\phi$ system:

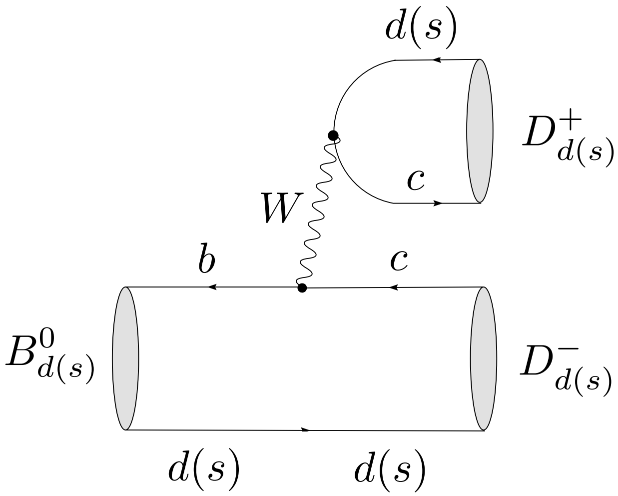
  – Using ϕ_d and the U-spin symmetry, γ and the (a'_f, θ'_f) can be extracted.

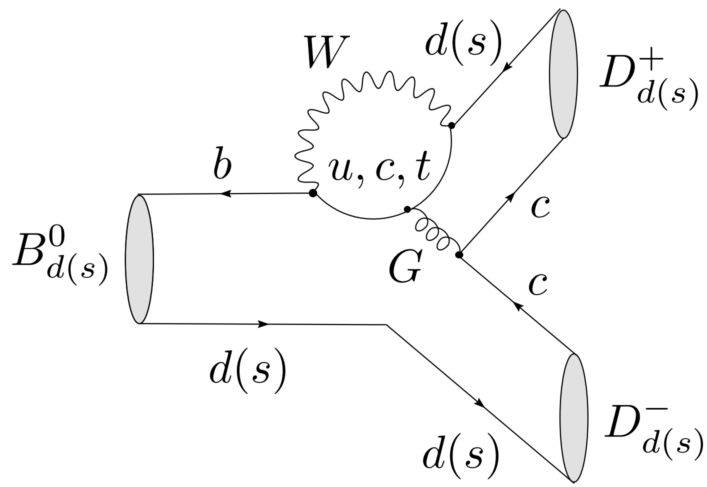
  – This allows us to control the penguin effects in the extraction of ϕ_s!

[R.F., *Phys. Rev.* **D60** (1999) 073008]

The $B_{d(s)} \to D^+_{d(s)} D^-_{d(s)}$ System

- Decay topologies:





- Structure of the decay amplitudes (using again the CKM unitarity):

$$A(B^0_d \to D^+_d D^-_d) = -\lambda \tilde{\mathcal{A}} \left[1 - \tilde{a} e^{i\tilde{\theta}} e^{i\gamma}\right]$$

$$A(B^0_s \to D^+_s D^-_s) = \left(1 - \frac{\lambda^2}{2}\right) \tilde{\mathcal{A}}' \left[1 + \left(\frac{\lambda^2}{1-\lambda^2}\right) \tilde{a}' e^{i\tilde{\theta}'} e^{i\gamma}\right]$$

- Hadronic parameters: $\to$ CP-conserving strong quantities ...

$$\tilde{\mathcal{A}} = \text{“tree+pen”}, \quad \tilde{a} e^{i\tilde{\theta}} = \text{“pen/(tree+pen)”}$$

Observables

- "Untagged" rates:

$$\langle\Gamma(B\to f)\rangle \equiv \Gamma(B(t)\to f)+\Gamma(\bar{B}(t)\to f) \;\Rightarrow$$

$$\tilde{H} \equiv \text{PhSp}\times\frac{1}{\epsilon}\left|\frac{\tilde{\mathcal{A}}'}{\tilde{\mathcal{A}}}\right|^2\frac{\langle\Gamma(B_d\to D_d^+D_d^-)\rangle}{\langle\Gamma(B_s\to D_s^+D_s^-)\rangle}=\frac{1-2\tilde{a}\cos\tilde{\theta}\cos\gamma+\tilde{a}^2}{1+2\epsilon\tilde{a}'\cos\tilde{\theta}'\cos\gamma+\epsilon^2\tilde{a}'^2}$$

$$\epsilon\equiv\frac{\lambda^2}{1-\lambda^2}=0.05 \;\rightarrow\; \text{tiny parameter!}$$

- "Tagged" rates: $\Rightarrow$ time-dependent CP-violating rate asymmetries $\Rightarrow$

$$\begin{aligned}
\mathcal{A}_{\rm CP}^{\rm dir}(B_d\to D_d^+D_d^-) &= F_1(\tilde{a},\tilde{\theta},\gamma)\\
\mathcal{A}_{\rm CP}^{\rm mix}(B_d\to D_d^+D_d^-) &= F_2(\tilde{a},\tilde{\theta},\gamma,\phi_d)
\end{aligned}$$

$$\begin{aligned}
\mathcal{A}_{\rm CP}^{\rm dir}(B_s\to D_s^+D_s^-) &= F_1'(\epsilon\tilde{a}',\tilde{\theta}',\gamma)=0+\mathcal{O}(\epsilon\tilde{a}')\\
\mathcal{A}_{\rm CP}^{\rm mix}(B_s\to D_s^+D_s^-) &= F_2'(\epsilon\tilde{a}',\tilde{\theta}',\gamma,\phi_s)=-\sin\phi_s+\mathcal{O}(\epsilon\tilde{a}')
\end{aligned}$$

Extraction of γ

- Important feature of the $B_{s(d)} \to D^+_{s(d)} D^-_{s(d)}$ system:
  - Decays are related through the interchange of all d and s quarks!
  - The U-spin flavour symmetry of strong interactions hence implies:

$$|\tilde{\mathcal{A}}'| = |\tilde{\mathcal{A}}|; \tag{3}$$

$$\tilde{a}' = \tilde{a}, \quad \tilde{\theta}' = \tilde{\theta}. \tag{4}$$

- Consequently, Eqs. (3) and (4) allow us to determine $\tilde{H}$:
  - U-spin-breaking corrections to (3) have the most important impact:

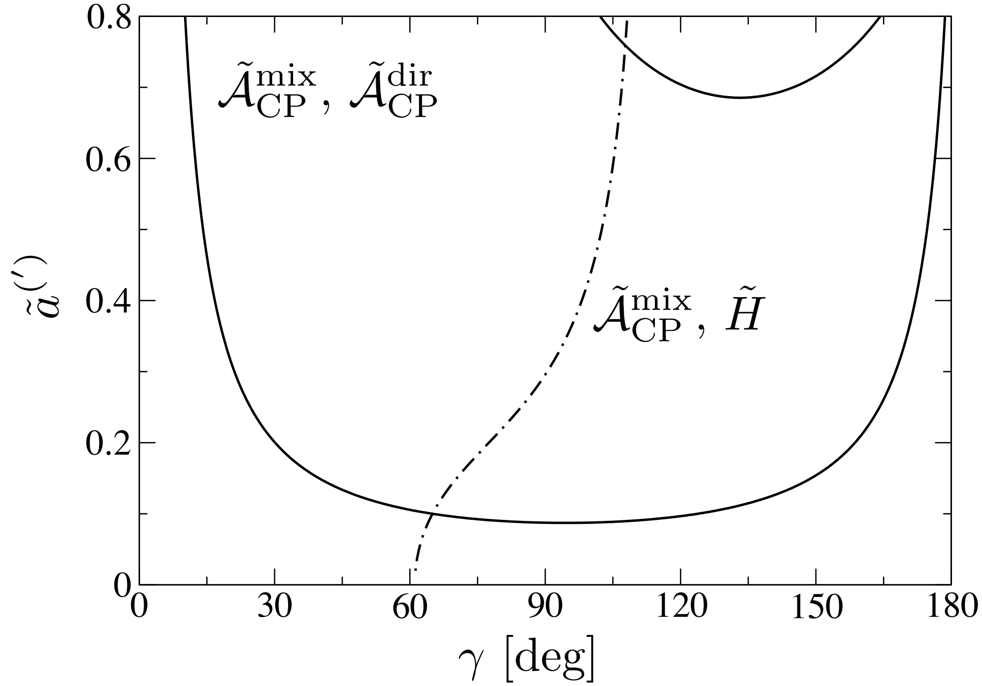
$$\left|\frac{\tilde{\mathcal{A}}'}{\tilde{\mathcal{A}}}\right|_{\rm fact} \approx \frac{(M_{B_s} - M_{D_s})\sqrt{M_{B_s}M_{D_s}}\,(w_s+1)}{(M_{B_d} - M_{D_d})\sqrt{M_{B_d}M_{D_d}}\,(w_d+1)}\frac{f_{D_s}\,\xi_s(w_s)}{f_{D_d}\,\xi_d(w_d)}.$$

  - Corrections to (4) have a minor impact because of the ϵ suppression.

- Finally:
  - Extract γ, $\tilde{a}$, $\tilde{\theta}$ from $\tilde{H}$, $\mathcal{A}_{\rm CP}^{\rm dir}(B_d \to D_d^+ D_d^-)$, $\mathcal{A}_{\rm CP}^{\rm mix}(B_d \to D_d^+ D_d^-)$.
  - We can then also control the penguin effects in the extraction of ϕ_s from $\mathcal{A}_{\rm CP}^{\rm mix}(B_s \to D_s^+ D_s^-)$ $\Rightarrow$ interesting alternative to $B_s \to J/\psi\phi$.

Contours in the γ–$\tilde{a}^{(\prime)}$ Plane: An Example

- Input parameter:
  - $\gamma = 65°$, $\phi_d = 42.4°$, $\tilde{a} = \tilde{a}' = 0.1$, $\tilde{\theta} = \tilde{\theta}' = 210°$.
- Observables:
  - $\mathcal{A}_{\rm CP}^{\rm dir}(B_d \to D_d^+ D_d^-) = -0.08$, $\mathcal{A}_{\rm CP}^{\rm mix}(B_d \to D_d^+ D_d^-) = 0.78$, $\tilde{H} = 1.1 \Rightarrow$



- Remarks:
  - Note that the contour following from $\tilde{\mathcal{A}}_{\rm CP}^{\rm dir}$, $\tilde{\mathcal{A}}_{\rm CP}^{\rm mix}$ is *theoretically* clean!
  - Additional solutions arise for unphysically large values of $\tilde{a} \gtrsim 0.8$.

Comments

- CP asymmetries of $B_d^0 \to D_d^+ D_d^-$ from BaBar [PRL 95 (2005) 131802]:

$$\mathcal{A}_{\rm CP}^{\rm dir}(B_d^0 \to D_d^+ D_d^-) = 0.11 \pm 0.35 \pm 0.06;$$
$$\mathcal{A}_{\rm CP}^{\rm mix}(B_d^0 \to D_d^+ D_d^-) = 0.29 \pm 0.63 \pm 0.06.$$

- Observation of $B_s^0 \to D_s^+ D_s^-$ at the Tevatron:
  - CDF Note 7925 (06-03-16):

$$\frac{\text{BR}(B_s^0 \to D_s^+ D_s^-)}{\text{BR}(B^0 \to D_s^- D^+)} = 1.67 \pm 0.41 \pm 0.12 \pm 0.24(f_s/f_d) \pm 0.39(\text{BR}).$$

  - D0 Note 5068-CONF (06-03-21):

$$\text{BR}(B_s^0 \to D_s^{(*)+} D_s^{(*)-}) = 0.071 \pm 0.035(\text{stat})^{+0.029}_{-0.025}(\text{syst}).$$

- The strategy can also straightforwardly be applied to the projections on the CP eigenstates of $B_{s(d)}^0 \to D_{s(d)}^{(*)+} D_{s(d)}^{(*)-}$ $\oplus$ other variants ...

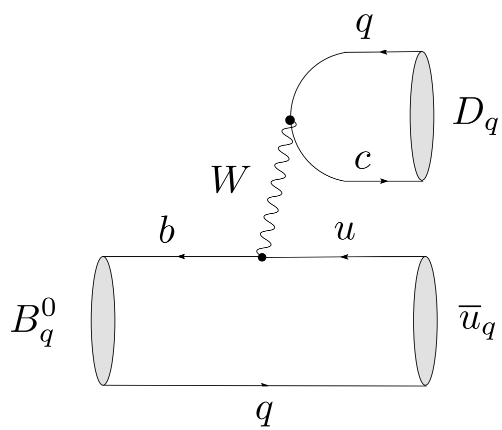
Pure Tree Decays

- B-factory data:

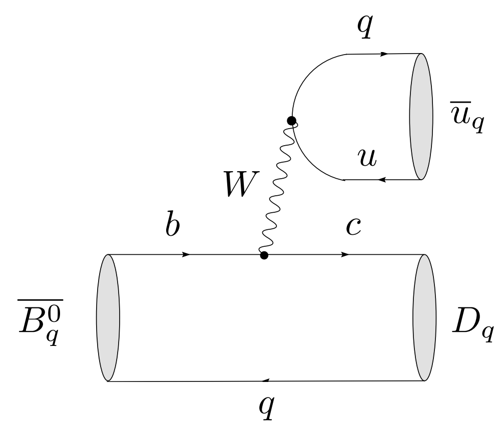
$$\gamma|_{D^{(*)}K^{(*)}} = \left\{ \begin{array}{ll} (62^{+38}_{-24})^\circ & \text{(CKMfitter)} \\ (82 \pm 20)^\circ & \text{(UTfit)} \end{array} \right\} \Rightarrow \text{large uncertainty ...}$$

The $B_s \to D_s^{\pm} K^{\mp}$, $B_d \to D^{\pm}\pi^{\mp}$ System

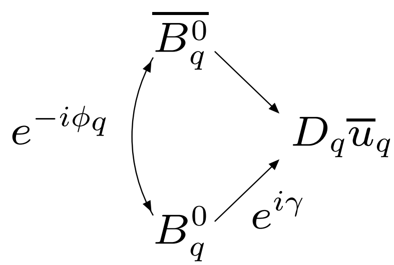
- General case:



$\propto e^{i\gamma}$



no weak phase



$$\boxed{\phi_q + \gamma}$$

- $q = s$: $D_s \in \{D_s^+, D_s^{*+}, ...\}$, $u_s \in \{K^+, K^{*+}, ...\}$:

  $\to$ hadronic parameter $X_s e^{i\delta_s} \propto R_b \Rightarrow$ *large* interference effects!

- $q = d$: $D_d \in \{D^+, D^{*+}, ...\}$, $u_d \in \{\pi^+, \rho^+, ...\}$:

  $\to$ hadronic parameter $X_d e^{i\delta_d} \propto -\lambda^2 R_b \Rightarrow$ *tiny* interference effects!

- $\cos(\Delta M_q t)$ and $\sin(\Delta M_q t)$ terms of the time-dependent decay rates:

$$\Rightarrow \boxed{\text{theoretically } \mathit{clean} \text{ determination of } \phi_q + \gamma} \quad \xrightarrow{\phi_q \text{ known}} \quad \boxed{\gamma}$$

[Dunietz & Sachs (1988); Aleksan, Dunietz & Kayser (1992); Dunietz (1998); ...]

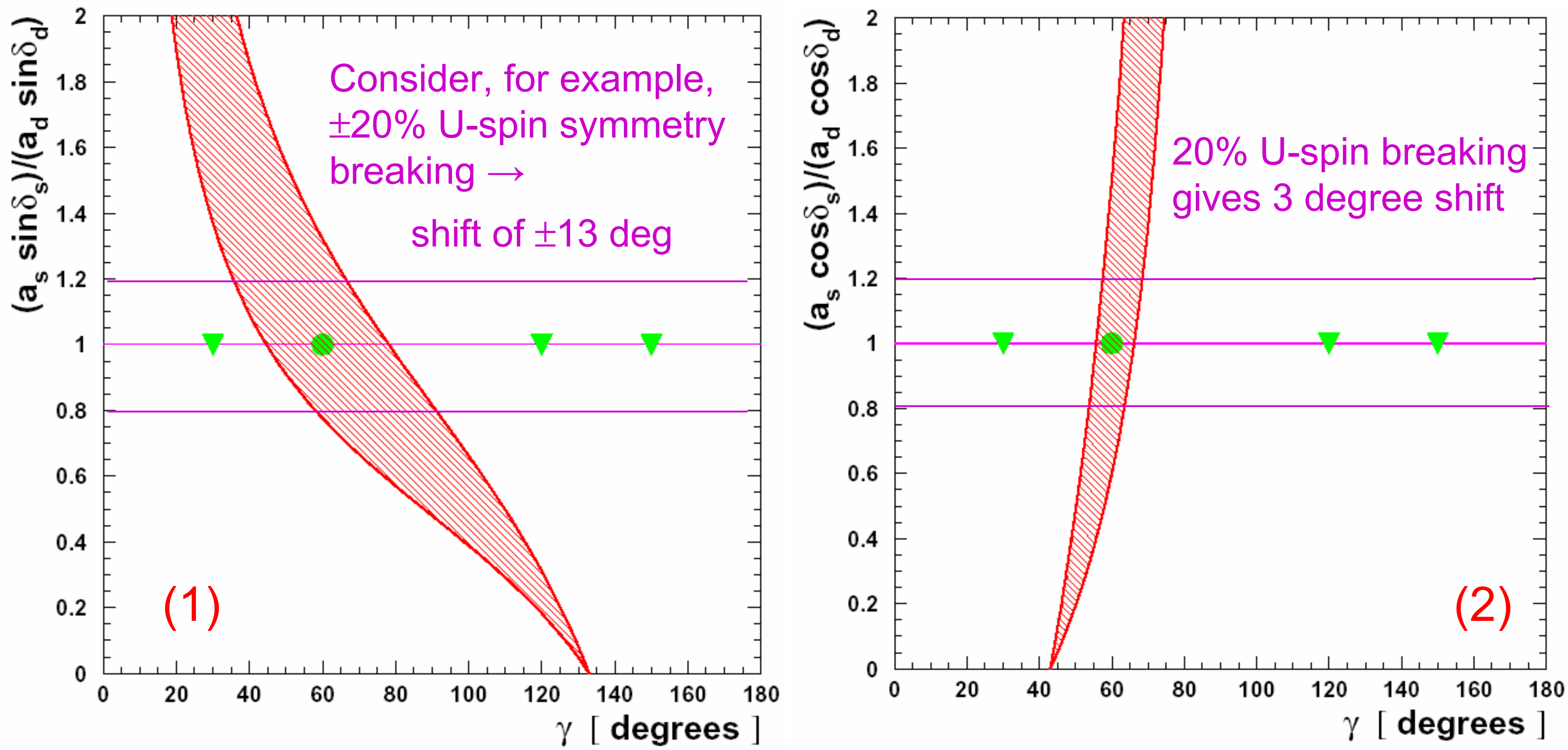
- However, there are also problems:
  - We encounter an *eightfold* discrete ambiguity for $\phi_q + \gamma$!?
  - In the $q = d$ case, an additional input is required to extract X_d since $\mathcal{O}(X_d^2)$ interference effects would have to be resolved $\rightarrow$ *impossilbe* ...

- Combined analysis of $B_s^0 \to D_s^{(*)+} K^-$ and $B_d^0 \to D^{(*)+} \pi^-$: [R.F. (2003)]

$$\boxed{s \leftrightarrow d} \quad \Rightarrow \quad U\text{-spin symmetry provides an interesting playground:}$$

  - An *unambiguous* value of γ can be extracted from the observables!
  - To this end, X_d has *not* to be fixed, and X_s may *only* enter through a $1 + X_s^2$ correction, which is determined through *untagged* B_s rates!
  - Promising first studies by LHCb: $\boxed{\rightarrow}$

Full U-Spin Symmetry: 5 years



Both expressions now giving very interesting precision on γ .
Right hand plot has precision of 5 degrees, and small systematic.
Ambiguous solutions now excluded.

[G. Wilkinson (2005); further studies in progress by G. Wilkinson & V. Gligorov ...]

$B_s \to D\eta^{(\prime)}$, $B_s \to D\phi$, ... (and $B_d \to DK_{\mathrm{S(L)}}$)

- Colour-suppressed counterparts of the $B_s \to D_s^{\pm} K^{\mp}$ channels!
- Consider CP eigenstates of the neutral D system: $B_q^0 \to D_{\pm} f_s$.
- Observables:[1]
  - *Untagged* rate asymmetry:

$$\Gamma_{+-}^{f_s} \equiv \frac{\langle\Gamma(B_q \to D_+ f_s)\rangle - \langle\Gamma(B_q \to D_- f_s)\rangle}{\langle\Gamma(B_q \to D_+ f_s)\rangle + \langle\Gamma(B_q \to D_- f_s)\rangle} \Rightarrow |\cos\gamma| \geq |\Gamma_{+-}^{f_s}|$$

  - $\cos(\Delta M_q t)$, $\sin(\Delta M_q t)$ coefficients $C_{\pm}^{f_s}$, $S_{\pm}^{f_s}$ of CP asymmetries:

$$\langle C_{f_s}\rangle_{\pm} \equiv \left[C_+^{f_s} \pm C_-^{f_s}\right]/2, \quad \langle S_{f_s}\rangle_{\pm} \equiv \left[S_+^{f_s} \pm S_-^{f_s}\right]/2.$$

- Extraction of γ: [$\eta_{f_s} \equiv (-1)^L \eta_{\mathrm{CP}}^{f_s}$, where L is angular momentum of $D f_s$]

$$\tan\gamma\cos\phi_q = \left[\frac{\eta_{f_s}\langle S_{f_s}\rangle_+}{\Gamma_{+-}^{f_s}}\right] + \left[\eta_{f_s}\langle S_{f_s}\rangle_- - \sin\phi_q\right]$$

$\to$ *unambiguous* determination of γ $\to$ interesting for NP!

[R.F. (2003)]

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[1] Look challenging for LHCb, but could be interesting for a super-B factory @ $\Upsilon(5S)$: $\to$ synergy!?

$B_s \to D_\pm K_{\mathrm{S(L)}}$ and $B_d \to D_\pm \pi^0, D_\pm \rho^0, \ldots$

- $b \to d$ counterparts of $B_s \to D\eta^{(\prime)}$, $B_s \to D\phi$, ... and $B_d \to DK_{\mathrm{S(L)}}$:
  - Description through the following parameters:

$$x_{f_d} e^{i\delta_{f_d}}\Big|_{\mathrm{fact}} = +\left(\frac{\lambda^2 R_b}{1-\lambda^2}\right) \approx 0.02$$

$\Rightarrow$ **tiny interference effects, i.e. not promising for γ!**

- However: $\eta_{f_d} \langle S_{f_d} \rangle_- = \sin\phi_q + \mathcal{O}(x_{f_d}^2) = \sin\phi_q + \mathcal{O}(4 \times 10^{-4})$

$\Rightarrow$ **_extremely clean_ extractions of $\sin\phi_q$!**

  - Theoretical accuracy is one order of magnitude better than in the conventional $B_s \to J/\psi\phi$ and $B_d \to J/\psi K_{\mathrm{S}}$ determinations.
  - Moreover, as we have *no penguin contributions*, the determinations are very robust with respect to NP effects at the amplitude level:

$\to$ interesting topic in view of low $(\sin 2\beta)_{\psi K}$ and UTfit "tension"!

[R.F. (2003)]

Concluding Remarks: Various γ Determinations ...

- Decays with tree and penguins: U-spin symmetry useful tool[2] $\to$
  - $B_s \to J/\psi K_S \quad \oplus \quad B_d \to J/\psi K_S$
  - $B_s \to D_s^+ D_s^- \quad \oplus \quad B_d \to D_d^+ D_d^-$

- Pure tree decays:
  - $B_s \to D_s^{\pm} K^{\mp} \quad \oplus \quad B_d \to D^{\pm}\pi^{\mp}$: U-spin symmetry $\to$ advantages!
  - $B_s \to D\eta^{(\prime)}, D\phi$: very challenging @ LHCb, but super-B factory?

- Interesting "by-products" for the B-physics programme @ LHC:
  - The $B_s \to J/\psi K_S$ channel allows us to control the hadronic penguin uncertainties in the extraction of ϕ_d from CPV in $B_d \to J/\psi K_S$.
  - In analogy, $B_d \to J/\psi \rho^0$ allows us to control the hadronic penguin uncertainties in the extraction of ϕ_s from CPV in $B_s \to J/\psi\phi$.
  - $B_d \to D_d^+ D_d^-$ allows us to control the penguin effects in the extraction of ϕ_s from CPV in $B_s \to D_s^+ D_s^-$: alternative to $B_s^0 \to J/\psi\phi$!

- The cleanest determinations of ϕ_s and ϕ_d are offered by the pure *tree* decays $B_s \to D_{\pm} K_{S(L)}$ and $B_d \to D_{\pm}\pi^0, D_{\pm}\rho^0, \ldots$, respectively:

$\to$ interesting for NP searches, but challenging for LHCb! Super-B factory?

[2] Even more powerful for the extraction of γ from $B_s \to K^+K^-$, $B_d \to \pi^+\pi^-$ (different dynamics)!