$\beta(\phi_1)$ from B Decays with Charm:

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OUTLINE

• We already have measurement of $\sin 2\beta$ from $B_d \to J/\psi K_s$.
But 4 fold ambiguity:

$$(\beta, \frac{\pi}{2} - \beta) \quad (\beta + \pi, \frac{\pi}{2} - \beta + \pi)$$

• We want to measure the angle β in many processes to test the SM.
Also measure both $\sin 2\beta$ and $\cos 2\beta$.

• This talk is about measuring the CKM angle $\beta(\phi_1)$ from various B decays to charm final states.

• I will concentrate on $B \to J/\psi K_s^{(*)}$, $B \to D^{(*)}\bar{D}^{(*)}K_s$ - These are $b \to c\bar{c}s$ transitions.

• $B \to D^{(*)}\bar{D}^{(*)}$($b \to c\bar{c}d$) and $B \to D^{(*)}h^0$($b \to c\bar{u}d$)

$b \to c\bar{c}s$:

The general amplitude for $B^0 \to M_1 M_2$ involving $b \to c\bar{c}s$ transitions can be written as

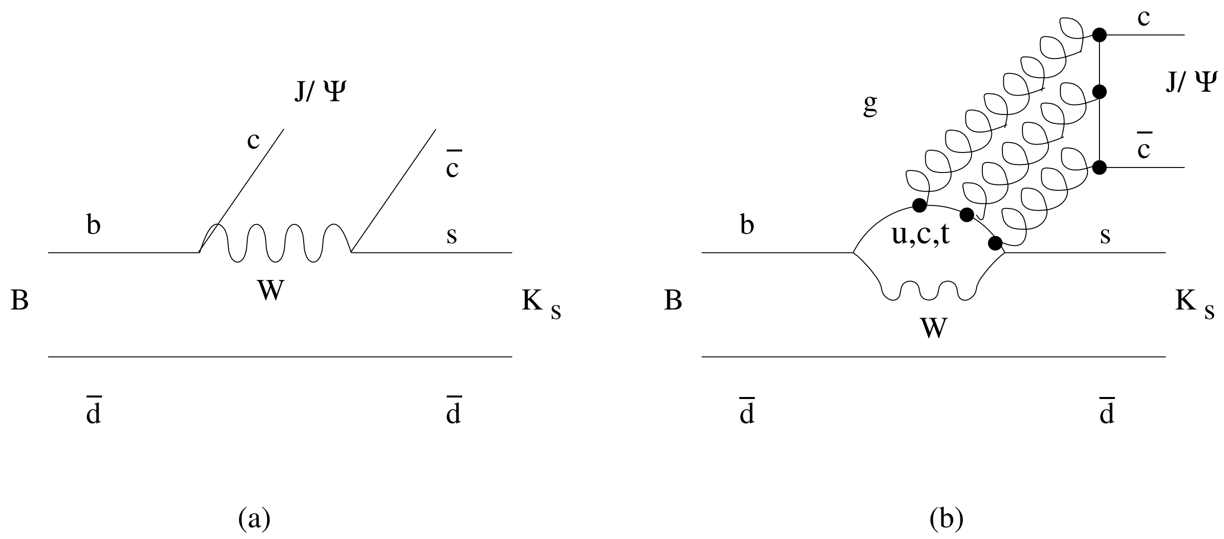
$$\begin{aligned} A(B^0 \to M_1 M_2) &= A_u V_{ub}^* V_{us} + A_c V_{cb}^* V_{cs} \\ &+ A_t V_{tb}^* V_{ts} \end{aligned}$$

- Use $V_{ub}^* V_{us} + V_{cb}^* V_{cs} + V_{tb}^* V_{ts} = 0$ to eliminate the $V_{tb}^* V_{ts}$ term

$$\begin{aligned} A &= (A_u - A_t) V_{ub}^* V_{us} + (A_c - A_t) V_{cb}^* V_{cs} \\ &\approx (A_c - A_t) V_{cb}^* V_{cs} \end{aligned}$$

$$\frac{V_{ub} V_{us}^*}{V_{cb} V_{cs}^*} \sim 2\%$$

$B \to J/\psi K_s(K^*)$:



$$
\begin{aligned}
A(B \to J/\psi K_s) &= V_{cb}V_{cs}^* C + V_{tb}V_{ts}^* P_t + V_{cb}V_{cs}^* P_c + V_{ub}V_{us}^* P_u \\
&= V_{cb}V_{cs}^*(C + P_c - P_t) + V_{ub}V_{us}^*(P_u - P_t) \\
&\approx V_{cb}V_{cs}^*(C + P_c - P_t)
\end{aligned}
$$

: Single amplitude decay- allows us to obtain $\sin 2\beta$.

$B(t) \to J/\psi K^*$

This is a VV decay and there are three amplitudes.

A_0, $A_{\|}$- CP even and $A_{\perp}$ which is CP odd.

The time dependent angular distribution allows us to measure both $\sin 2\beta$ and $\cos 2\beta$.

But time independent angular distributions are needed to fix the coefficients of $\sin 2\beta$ and $\cos 2\beta$ in the time dependent distributions.

$B(t) \to J/\psi K^*$

The time dependent differential decay rate is:

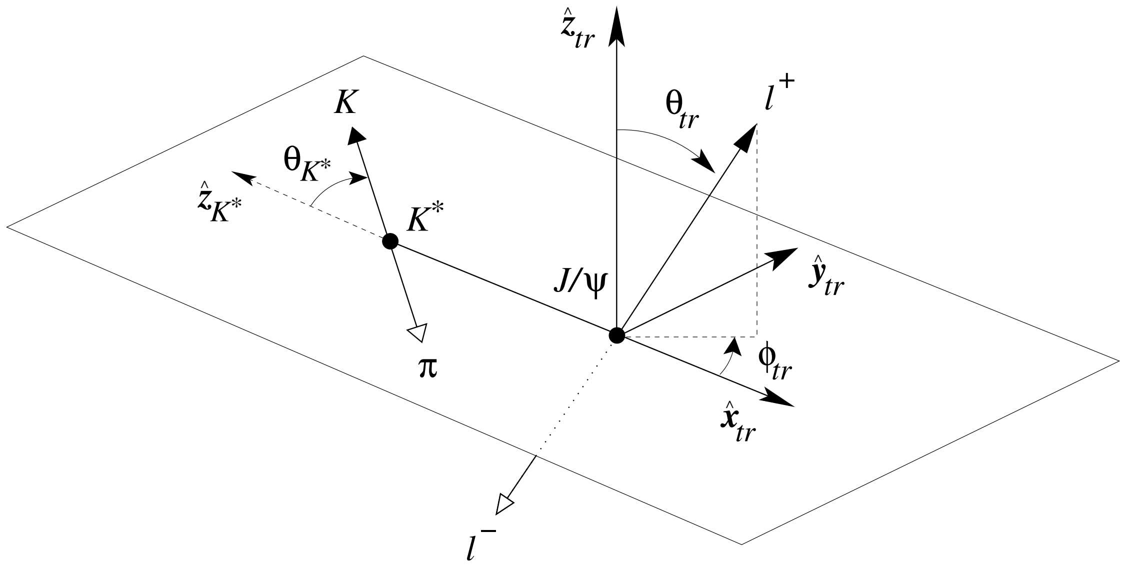
$$Dist = \frac{\Gamma_0}{2} e^{-\Gamma_0 t} \mathcal{A}(\boldsymbol{\omega}; \boldsymbol{A}) \times$$

$$\left\{ 1 + \eta \left[\cos \Delta m\, t \, \frac{\mathcal{P}(\boldsymbol{\omega}; \boldsymbol{A})}{\mathcal{A}(\boldsymbol{\omega}; \boldsymbol{A})} + \sin \Delta m\, t \left(\frac{\mathcal{S}(\boldsymbol{\omega}; \boldsymbol{A})}{\mathcal{A}(\boldsymbol{\omega}; \boldsymbol{A})} \sin 2\beta + \frac{\mathcal{C}(\boldsymbol{\omega}; \boldsymbol{A})}{\mathcal{A}(\boldsymbol{\omega}; \boldsymbol{A})} \cos 2\beta \right) \right] \right\},$$

with $\eta = +1$ ($\eta = -1$) for an initial B^0 ($\overline{B}^0$) meson.

$$\begin{aligned}
\mathcal{A}(\boldsymbol{\omega}; \boldsymbol{A}) &\equiv \quad f_1(\boldsymbol{\omega})|A_0|^2 + f_2(\boldsymbol{\omega})|A_{\|}|^2 + f_3(\boldsymbol{\omega})|A_{\perp}|^2 \\
&+ \quad f_5(\boldsymbol{\omega})|A_0||A_{\|}| \cos(\delta_{\|} - \delta_0), \\
\mathcal{P}(\boldsymbol{\omega}; \boldsymbol{A}) &\equiv \quad f_4(\boldsymbol{\omega})|A_{\|}||A_{\perp}| \sin(\delta_{\perp} - \delta_{\|}) + f_6(\boldsymbol{\omega})|A_0||A_{\perp}| \sin(\delta_{\perp} - \delta_0), \\
\mathcal{S}(\boldsymbol{\omega}; \boldsymbol{A}) &\equiv \quad f_1(\boldsymbol{\omega})|A_0|^2 + f_2(\boldsymbol{\omega})|A_{\|}|^2 - f_3(\boldsymbol{\omega})|A_{\perp}|^2 \\
&+ \quad f_5(\boldsymbol{\omega})|A_0||A_{\|}| \cos(\delta_{\|} - \delta_0), \\
\mathcal{C}(\boldsymbol{\omega}; \boldsymbol{A}) &\equiv -f_4(\boldsymbol{\omega})|A_{\|}||A_{\perp}| \cos(\delta_{\perp} - \delta_{\|}) - f_6(\boldsymbol{\omega})|A_0||A_{\perp}| \cos(\delta_{\perp} - \delta_0).
\end{aligned}$$

Angular distribution- $B \to J/\psi K^*$



$$\frac{1}{\Gamma}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_{K^*}\,\mathrm{d}\cos\theta_{tr}\,\mathrm{d}\phi_{tr}} = f_1(\boldsymbol{\omega})|A_0|^2 + f_2(\boldsymbol{\omega})|A_{\|}|^2 + f_3(\boldsymbol{\omega})|A_{\perp}|^2 + f_4(\boldsymbol{\omega})Im(A_{\|}^* A_{\perp}) + f_5(\boldsymbol{\omega})Re(A_{\|}A_0^*) + f_6(\boldsymbol{\omega})Im(A_{\perp}A_0^*),$$

$f_i(\boldsymbol{\omega})$ are known angular functions of $\boldsymbol{\omega} \equiv (\theta_{K^*}, \theta_{tr}, \phi_{tr})$

$B \to J/\psi K^*$

$A_i = |A_i|e^{i\delta_i}$. The angular analysis can fix $|A_i|$ and the relative strong phases through

$$
\begin{aligned}
Im(A_{\|}^* A_{\perp}) &= |A_{\|}||A_{\perp}|\sin(\delta_{\perp} - \delta_{\|}),\\
Re(A_{\|} A_0^*) &= |A_{\|}||A_0|\cos(\delta_{\|} - \delta_0),\\
Im(A_{\perp} A_0^*) &= |A_{\perp}||A_0|\sin(\delta_{\perp} - \delta_0),
\end{aligned}
$$

$$
\begin{aligned}
\mathcal{A}(\boldsymbol{\omega};\boldsymbol{A}) &\equiv f_1(\boldsymbol{\omega})|A_0|^2 + f_2(\boldsymbol{\omega})|A_{\|}|^2 + f_3(\boldsymbol{\omega})|A_{\perp}|^2\\
&+ f_5(\boldsymbol{\omega})|A_0||A_{\|}|\cos(\delta_{\|} - \delta_0),\\
\mathcal{P}(\boldsymbol{\omega};\boldsymbol{A}) &\equiv f_4(\boldsymbol{\omega})|A_{\|}||A_{\perp}|\sin(\delta_{\perp} - \delta_{\|}) + f_6(\boldsymbol{\omega})|A_0||A_{\perp}|\sin(\delta_{\perp} - \delta_0),\\
\mathcal{S}(\boldsymbol{\omega};\boldsymbol{A}) &\equiv f_1(\boldsymbol{\omega})|A_0|^2 + f_2(\boldsymbol{\omega})|A_{\|}|^2 - f_3(\boldsymbol{\omega})|A_{\perp}|^2\\
&+ f_5(\boldsymbol{\omega})|A_0||A_{\|}|\cos(\delta_{\|} - \delta_0),\\
\mathcal{C}(\boldsymbol{\omega};\boldsymbol{A}) &\equiv -f_4(\boldsymbol{\omega})|A_{\|}||A_{\perp}|\cos(\delta_{\perp} - \delta_{\|}) - f_6(\boldsymbol{\omega})|A_0||A_{\perp}|\cos(\delta_{\perp} - \delta_0).
\end{aligned}
$$

$B \to J/\psi K^*$

The differential decay rate is invariant under the transformation

$$(\delta_{\|} - \delta_0, \delta_\perp - \delta_0) \longleftrightarrow (\delta_0 - \delta_{\|}, \pi + \delta_0 - \delta_\perp).$$

This ambiguity translates into a sign ambiguity in the extraction of $\cos 2\beta$.
BABAR(hep-ex/0411016)

$$\begin{aligned} |A_0|^2 &= 0.566 \pm 0.012 \pm 0.005, \\ |A_{\|}|^2 &= 0.204 \pm 0.015 \pm 0.005, \\ |A_\perp|^2 &= 0.230 \pm 0.015 \pm 0.004, \end{aligned}$$

$$\begin{aligned} \text{Solution I} : (\delta_{\|} - \delta_0, \delta_\perp - \delta_0) &\simeq (2.7, 0.2), \\ \text{Solution II} : (\delta_{\|} - \delta_0, \delta_\perp - \delta_0) &\simeq (-2.7, \pi - 0.2). \end{aligned}$$

$B(t) \to J/\psi K\pi$

The $K\pi$ system originating from $B \to J/\psi(K\pi)$ can, in principle, have any integer spin.
Below 1.3 GeV, the S and P waves dominate (Aston 1987).

$$
\begin{aligned}
Dist(S+P) &\equiv \cos^2\lambda\, Dist(P) + \sin^2\lambda\, f_7(\boldsymbol{\omega}) \\
&+ \frac{1}{2}\sin 2\lambda \Big[\\
&\quad f_8(\boldsymbol{\omega})\cos(\delta_{\parallel} - \delta_S)|A_{\parallel}| \\
&\quad + f_9(\boldsymbol{\omega})\sin(\delta_{\perp} - \delta_S)|A_{\perp}| \\
&\quad + f_{10}(\boldsymbol{\omega})\cos(\delta_S - \delta_0)|A_0| \Big]. \\
\cos\lambda &\equiv \frac{A_P}{\sqrt{A_P^2 + |A_S|^2}}, \\
\sin\lambda &\equiv \frac{|A_S|}{\sqrt{A_P^2 + |A_S|^2}},
\end{aligned}
\qquad (1)
$$

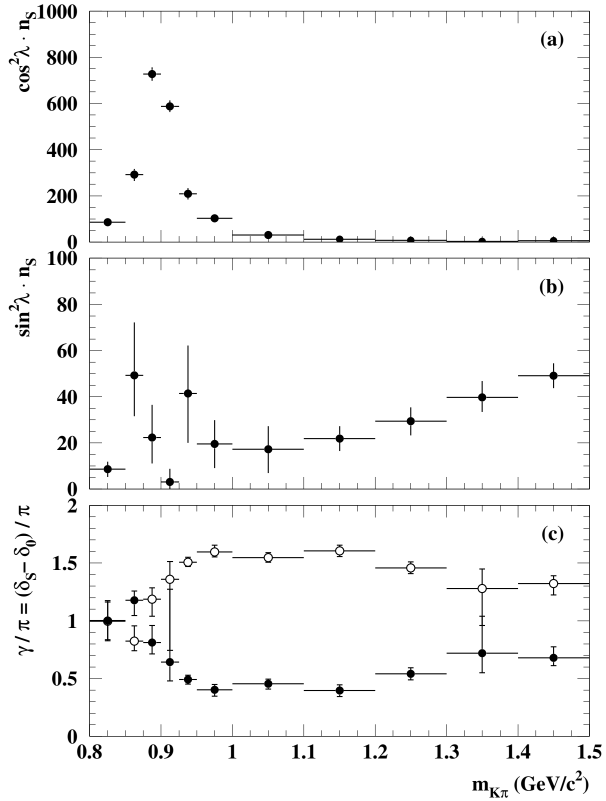
$B(t) \to J/\psi K\pi$

$$\begin{aligned}\delta_{\parallel} - \delta_S &= (\delta_{\parallel} - \delta_0) + (\delta_0 - \delta_S)\\ \delta_{\perp} - \delta_S &= (\delta_{\perp} - \delta_0) + (\delta_0 - \delta_S)\end{aligned}$$

Hence for the two possible solutions for $(\delta_i - \delta_0)$ with $i = \parallel, \perp$ we can fit for $\delta_S - \delta_0$. If we know how $\delta_S - \delta_0$ with $m_{K\pi}$ then we can choose the correct solutions for $(\delta_i - \delta_0)$.

As one goes through the K^* resonance δ_P will change rapidly (going through $\pi/2$ and increasing beyond K^* mass) while δ_s changes slowly. Hence S-P relative $\delta_S - \delta_0$ phase decreases in the region of the $K^*(892)$. Assume that the strong interactions of the $K\pi$ with the J/ψ do not alter this behavior- there is theory uncertainty here !

Resolving Ambiguity



$$\begin{aligned} \delta_{\parallel} - \delta_0 &= (-2.73 \pm 0.10 \pm 0.05), \\ \delta_{\perp} - \delta_0 &= (+2.96 \pm 0.07 \pm 0.05), \\ \cos 2\beta &= +2.72^{+0.50}_{-0.79} \pm 0.27 \end{aligned} \quad (2)$$

using $\sin 2\beta$ as an input.

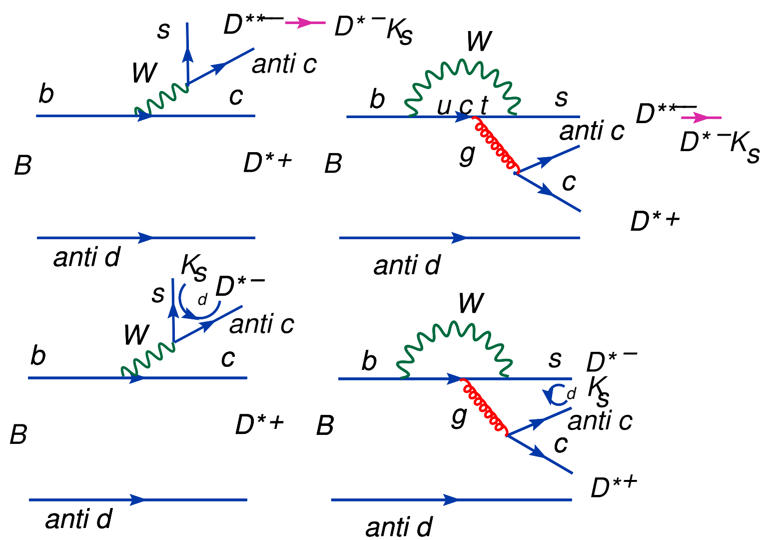
$B(t) \to D^{*+}D^{*-}K_s$(Browder et.al.)

- We define the following amplitudes

$$a^{\lambda_1,\lambda_2} \equiv A(B^0(p) \to D^{+*}_{\lambda_1}(p_+)D^{-*}_{\lambda_2}(p_-)K_s(p_k))$$

$$\bar{a}^{\lambda_1,\lambda_2} \equiv A(\bar{B}^0(p) \to D^{+*}_{\lambda_1}(p_+)D^{-*}_{\lambda_2}(p_-)K_s(p_k)$$

where B^0 and $\bar{B}^0$ represent unmixed neutral B and λ_1 and λ_2 are the polarization indices of the D^{*+} and D^{*-} respectively.



$B(t) \to D^{*+} D^{*-} K_s$

The time-dependent amplitudes for an oscillating state $B^0(t)$ which has been tagged as a B^0 meson at time $t = 0$ is given by

$$A^{\lambda_1,\lambda_2}(t) \quad = \quad a^{\lambda_1,\lambda_2} \cos\left(\frac{\Delta m\, t}{2}\right) + i e^{-2i\beta} \bar{a}^{\lambda_1,\lambda_2} \sin\left(\frac{\Delta m\, t}{2}\right),$$

and the time-dependent amplitude squared summed over polarizations and integrated over the phase space angles is:

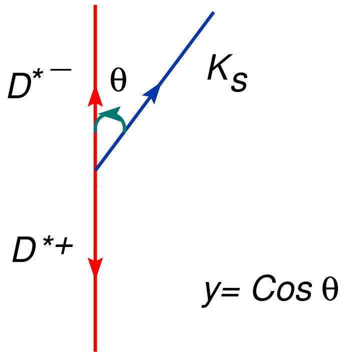
$$\begin{aligned}
|A(s^+, s^-; t)|^2 &= \frac{1}{2}\left[\mathrm{G}_0(s^+, s^-) + \mathrm{G}_\mathrm{c}(s^+, s^-) \cos \Delta m\, t - \right. \\
&\quad \left. \mathrm{G}_\mathrm{s}(s^+, s^-) \sin \Delta m\, t\right] \\
\mathrm{G}_0(s^+, s^-) &= |a(s^+, s^-)|^2 + |\bar{a}(s^+, s^-)|^2, \\
\mathrm{G}_\mathrm{c}(s^+, s^-) &= |a(s^+, s^-)|^2 - |\bar{a}(s^+, s^-)|^2, \\
\mathrm{G}_\mathrm{s}(s^+, s^-) &= 2\Im\left(e^{-2i\beta} \bar{a}(s^+, s^-) a^*(s^+, s^-)\right) \\
&= -2\sin(2\beta)\,\Re\left(\bar{a}a^*\right) + 2\cos(2\beta)\,\Im\left(\bar{a}a^*\right) \\
s^+ &= (p_+ + p_k)^2, \quad s^- = (p_- + p_k)^2.
\end{aligned}$$

$B(t) \to D^{*+} D^{*-} K_s$

The amplitude for $\bar{B}^0(t) \to D^{*-} D^{*+} K_s$ can be obtained with $s^+ \leftrightarrow s^-$, $a \leftrightarrow \bar{a}$ and $\beta \to -\beta$. Then:

$$|\bar{A}(s^-, s^+; t)|^2 = \frac{1}{2}\left[\mathrm{G}_0(s^-, s^+) - \mathrm{G}_c(s^-, s^+)\cos\Delta m\, t + \mathrm{G}_s(s^-, s^+)\sin\Delta m\, t\right] .$$

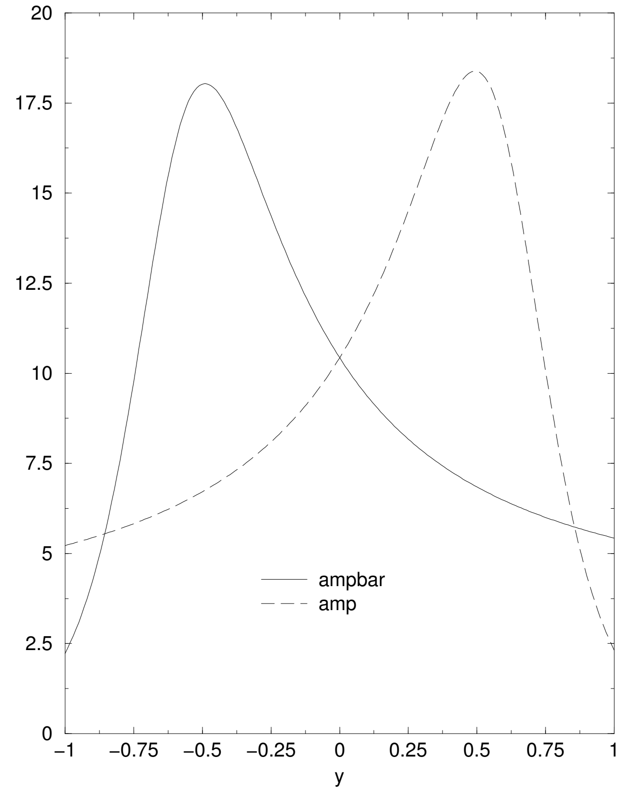
- Replace $(s^+, s^-) \to (y, E_k)$ where E_k is the K_s energy in the rest frame of the B.



- $y = \cos\theta$ with θ being the angle between the momentum of K_s and D^{*+} in a frame where the two D^* are moving back to back along the z-axis. $s^+ \leftrightarrow s^-$ corresponds to $y \leftrightarrow -y$.

$B(t) \to D^{*+}D^{*-}K_s$

To be sensitive to $\cos 2\beta$ the term $\Im\left(\bar{a}a^*\right)$ must be nonzero. This implies $\bar{a}$ and a have to be different with different strong phases.



The presence of an intermediate resonance makes $\bar{a}$ and a different.

$B(t) \to D^{*+} D^{*-} K_s$

In the approximation of neglecting the amplitude proportional to $V_{ub} V_{us}^*$ relative to $V_{cb} V_{cs}^*$ there is no direct CP violation. This leads to the relation

$$a^{\lambda_1,\lambda_2}(\vec{p}_{k1}, E_k) = \bar{a}^{-\lambda_1,-\lambda_2}(-\vec{p}_{k1}, E_k)$$

where $\vec{p}_{k1}$ is the momentum of the of the K_s in the boosted frame. The above relations then leads to

$$\begin{aligned} G_0(-y, E_k) &= G_0(y, E_k) \\ G_c(-y, E_k) &= -G_c(y, E_k) \\ G_{s1}(-y, E_k) &= G_{s1}(y, E_k) \\ G_{s2}(-y, E_k) &= -G_{s2}(y, E_k) \end{aligned}$$

where we have defined

$$\begin{aligned} G_{s1}(y, E_k) &= \Re\left(\bar{a}a^*\right) \\ G_{s2}(-y, E_k) &= \Im\left(\bar{a}a^*\right) \end{aligned}$$

$B(t) \to D^{*+}D^{*-}K_s$

Carrying out the integration over the phase space variables y and E_k one gets the following expressions for the time-dependent total rates for $B^0(t) \to D^{*+}D^{*-}K_s$ and the CP conjugate process

$$\Gamma(t) = \frac{1}{2}[I_0 + 2\sin(2\beta)\sin(\Delta m t) I_{s1}]$$
$$\overline{\Gamma}(t) = \frac{1}{2}[I_0 - 2\sin(2\beta)\sin(\Delta m t) I_{s1}]$$

where I_0 and I_{s1} are the integrated $G_0(y, E_k)$ and $G_{s1}(y, E_k)$ functions. One can then extract $\sin(2\beta)$ from the rate asymmetry

$$\frac{\Gamma(t) - \overline{\Gamma}(t)}{\Gamma(t) + \overline{\Gamma}(t)} = D\sin(2\beta)\sin(\Delta m t); \quad D = \frac{2I_{s1}}{I_0}$$

D is the dilution factor.

$$I_0 = 2\Gamma(0) = 2\overline{\Gamma}(0)$$

$B(t) \to D^{*+}D^{*-}K_s$

The $\cos(2\beta)$ term can be probed by integrating over half the range of the variable y which can be taken for instance to be $y \geq 0$ for B decay and $y \leq 0$ for $\bar{B}$ decay.

$$\frac{\Gamma(t, y \geq 0)}{I_0} = \frac{1}{2}[\frac{J_0}{I_0} + \frac{J_c}{I_0}\cos(\Delta m t) + 2\sin(2\beta)\sin(\Delta m t)\frac{J_{s1}}{I_0} - 2\cos(2\beta)\sin(\Delta m t)\frac{J_{s2}}{I_0}]$$

$$\frac{\overline{\Gamma}(t, y \leq 0)}{I_0} = \frac{1}{2}[\frac{J_0}{I_0} + \frac{J_c}{I_0}\cos(\Delta m t) - 2\sin(2\beta)\sin(\Delta m t)\frac{J_{s1}}{I_0} - 2\cos(2\beta)\sin(\Delta m t)\frac{J_{s2}}{I_0}]$$

where J_0, J_c, J_{s1} and J_{s2}, are the integrated $G_0(y, E_k)$, $G_c(y, E_k)$, $G_{s1}(y, E_k)$ and $G_{s2}(y, E_k)$ functions integrated over the range $y \geq 0$.

One can measure $\cos(2\beta)$ by fitting to the time distribution of $\frac{\Gamma(t)+\bar{\Gamma}(t)}{I_0}$.

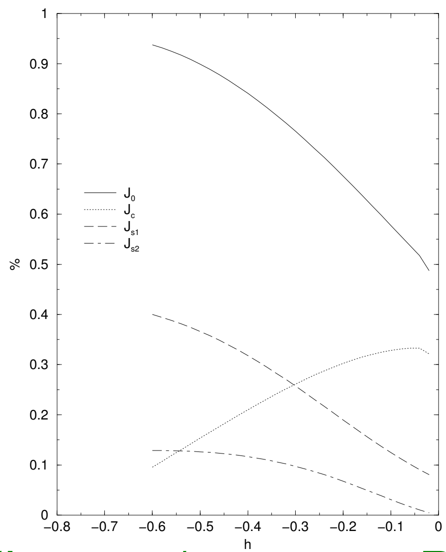
$B(t) \to D^{*+}D^{*-}K_s$

$a^{\lambda_1,\lambda_2}(y, E_k)$ and $\bar{a}^{\lambda_1,\lambda_2}(y, E_k)$ are calculated using factorization and chiral perturbation theory:

Experimentally factorization works well for $B \to D^{(*)}D^{(*)}$ and the K_s energy is small enough for chiral perturbation to be applicable.

Expect corrections to theory input to change the numerical value of $\cos 2\beta$ somewhat but not the sign. Comparing the $\sin 2\beta$ value from this method with $B(t) \to J/\psi K_s$ will tell us about the reliability of the theory input.

Measurements



The fits to the data yield (hep-ex/0608016-BaBar)

$$\begin{aligned} \frac{J_c}{J_0} &= 0.76 \pm 0.18(stat) \pm 0.07(syst) \\ \frac{2J_{s1}}{J_0}\sin 2\beta &= 0.10 \pm 0.24(stat) \pm 0.06(syst) \\ \frac{2J_{s2}}{J_0}\cos 2\beta &= 0.38 \pm 0.24(stat) \pm 0.05(syst) \end{aligned} \quad (3)$$

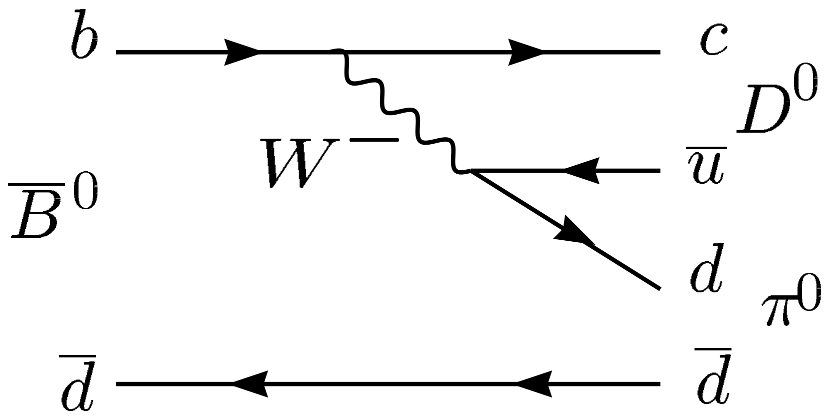
New Resonance ?

$\cos 2\beta$ is preferred to be positive at the 94 % confidence level as the theoretical parameter J_{s2}/J_0 is positive.

J_c/J_0 is significantly different from zero, this implies that there is a sizable resonant contribution to the decay from a unknown D_{s1}^+ state with large width.

$B(t) \to Dh^0$ (Bondar et al)

Consider the decays of the B meson to $Dh^0(\pi^0, \eta..)$. The dominant decay is through $b \to c\bar{u}d$



Next consider multibody D meson decay. As an example use $D \to K_S\pi^+\pi^-$.

$$Amp(\bar{D}^0 \to K_S\pi^+\pi^-) = f(m_+^2, m_-^2)$$

$$Amp(D^0 \to K_S\pi^+\pi^-) = f(m_-^2, m_+^2)$$

$$m_{+,-}{}^2 = (p_{K_s} + p_{\pi^\pm})^2$$

$B(t) \to Dh^0$ (Bondar et al)

The amplitude for the B decay at time $t_{\rm sig}$ is then given by

$$\begin{aligned} M_{\bar{B}^0}(\Delta t) &= [\bar{B}^0 \to D^0(K_s\pi^+\pi^-)h^0]\cos(\Delta m\Delta t/2) - \\ & i\frac{p}{q}\eta_{h^0}(-1)^l[B^0 \to \bar{D}^0(K_s\pi^+\pi^-)h^0]\sin(\Delta m\Delta t/2). \end{aligned}$$

$$M_{\bar{B}^0}(\Delta t) = f(m_-^2, m_+^2)\cos(\Delta m\Delta t/2) - i\frac{p}{q}\eta_{h^0}(-1)^l f(m_+^2, m_-^2)\sin(\Delta m\Delta$$

Then

$$\begin{aligned} M_{\bar{B}^0}(\Delta t) &= f(m_-^2, m_+^2)\cos(\Delta m\Delta t/2) - \\ & ie^{-i2\phi_1}\eta_{h^0}(-1)^l f(m_+^2, m_-^2)\sin(\Delta m\Delta t/2), \\ M_{B^0}(\Delta t) &= f(m_+^2, m_-^2)\cos(\Delta m\Delta t/2) - \\ & ie^{+i2\phi_1}\eta_{h^0}(-1)^l f(m_-^2, m_+^2)\sin(\Delta m\Delta t/2), \end{aligned}$$

Need to model $f(m_+^2, m_-^2)$ to extract the phase $2\phi_1(2\beta)$.

Modeling D Decay

Three body D decays is modeled as the coherent sum of two-body decay amplitudes plus non-resonant part:

$$f(m^2_{K_S\pi^+}, m^2_{K_S\pi^+}) = \sum_{J=1}^{N} a_j e^{i\alpha_j} A_j(m^2_{K_S\pi^+}, m^2_{K_S\pi^+}) + be^{i\beta},$$

where N is the number of resonances, $A_j(m^2_{K_S\pi^+}, m^2_{K_S\pi^+})$, a_j and α_j are the matrix element, amplitude and phase, respectively, for the j-th resonance, and b and β are the amplitude and phase for the non-resonant component.

Measurements

Resonance	Amplitude	Phase (°)
$K^*(892)^+\pi^-$	1.418	170
$K_0^*(1430)^+\pi^-$	1.818	23
$K_2^*(1430)^+\pi^-$	0.909	194
$K^*(892)^-\pi^+$ (DCS)	0.100	341
$K_S\rho^0$	0.909	20
$K_S\omega$	0.034	134
$K_S f_0(980)$	0.309	208
$K_S f_0(1370)$	1.636	105
$K_S f_2(1270)$	0.636	328
$K_S\pi^+\pi^-$ non-resonant	1.0	0

$$\cos 2\beta = 0.54 \pm 0.54 \pm 0.08 \pm 0.18,$$
$$\sin 2\beta = 0.45 \pm 0.36 \pm 0.05 \pm 0.07.$$

$\bar{B}(t) \to D^{(*)}\bar{D}^{(*)}$

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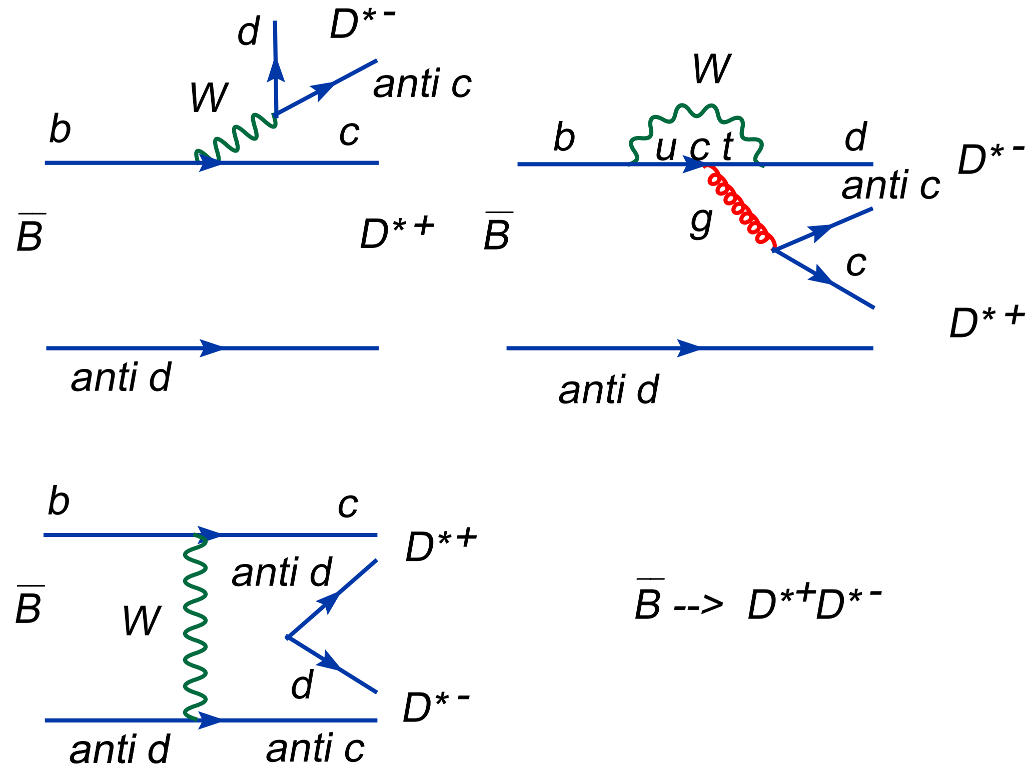


$$
\begin{aligned}
A^D &= (T + E + P_c)\, V_{cb}^* V_{cd} + P_u\, V_{ub}^* V_{ud} + (P_t + P_{EW}^C)\, V_{tb}^* V_{td} \\
&= (T + E + P_c - P_t - P_{EW}^C)\, V_{cb}^* V_{cd} + (P_u - P_t - P_{EW}^C)\, V_{ub}^* V_{ud} \\
&\equiv \mathcal{A}_{ct}\, e^{i\delta^{ct}} + \mathcal{A}_{ut}\, e^{i\gamma} e^{i\delta^{ut}} ,
\end{aligned}
$$

$\bar{B}(t) \to D^{(*)}\bar{D}^{(*)}$

• The time-dependent measurement of $B^0(t) \to M_1 M_2$ allows one to obtain the three observables

$$
\begin{aligned}
B &\equiv \frac{1}{2}\left(|A|^2 + |\overline{A}|^2\right) = \mathcal{A}_{ct}^2 + \mathcal{A}_{ut}^2 \\
&+ 2\mathcal{A}_{ct}\,\mathcal{A}_{ut}\cos\delta\cos\gamma \\
a_{dir} &\equiv \frac{1}{2}\left(|A|^2 - |\overline{A}|^2\right) = -2\mathcal{A}_{ct}\,\mathcal{A}_{ut}\sin\delta\sin\gamma \\
a_{indir} &\equiv \mathrm{Im}\left(e^{-2i\beta}A^*\overline{A}\right) \\
&- \mathcal{A}_{ct}^2\sin 2\beta - 2\mathcal{A}_{ct}\,\mathcal{A}_{ut}\cos\delta\sin(2\beta+\gamma) \\
&- \mathcal{A}_{ut}^2\sin(2\beta+2\gamma)
\end{aligned}
$$

• The three independent observables depend on five theoretical parameters: $\mathcal{A}_{ut}$, $\mathcal{A}_{ct}$, δ, β, γ.

$\bar{B}(t) \to D^{(*)}\bar{D}^{(*)}$

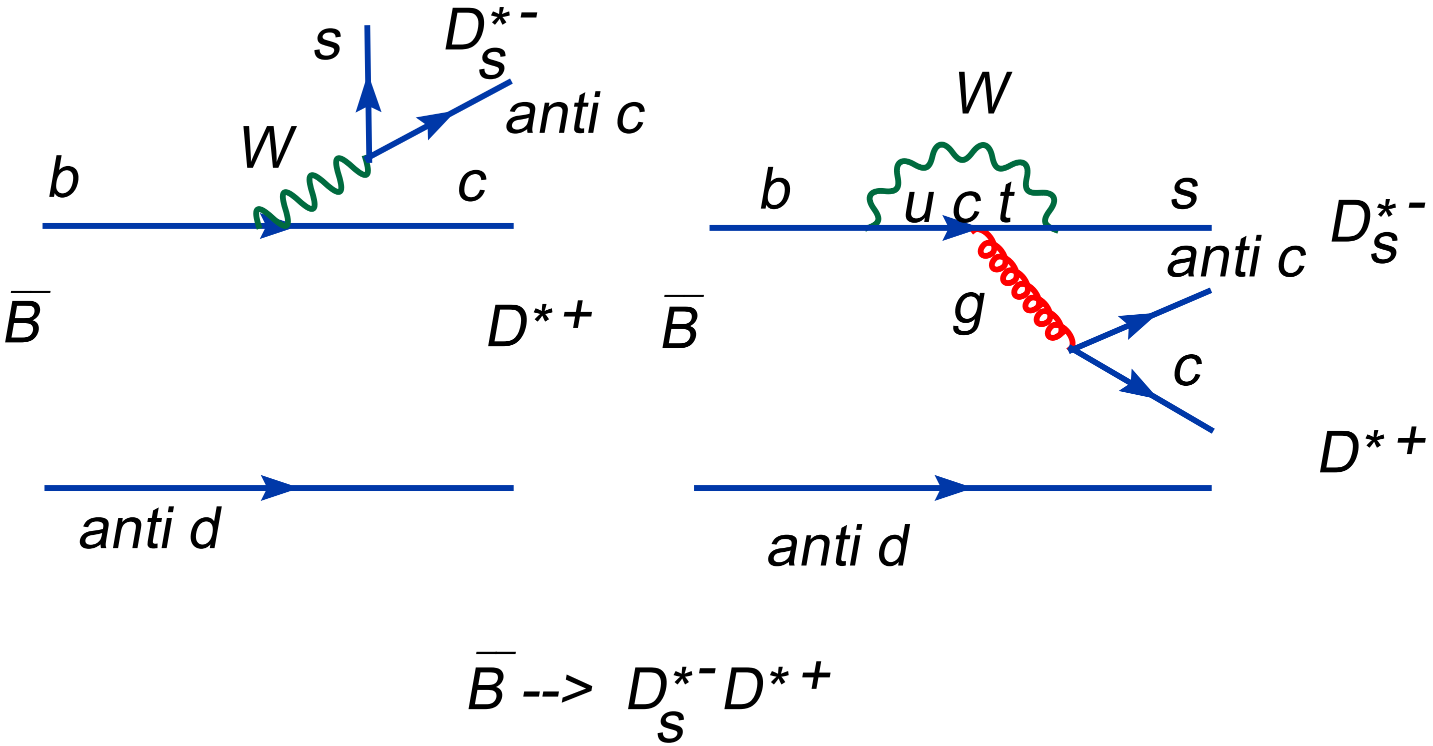
Therefore one cannot obtain CP phase information from these measurements- Penguin Pollution. Hence theoretical input is necessary to get the CKM phase information

$$
\begin{aligned}
\mathcal{A}_{ct}^2 &= \frac{a_R \cos(2\beta + 2\gamma) - a_{indir}\sin(2\beta + 2\gamma) - B}{\cos 2\gamma - 1} \\
a_R^2 &= B^2 - a_{dir}^2 - a_{indir}^2 \, .
\end{aligned}
$$

Obtain $\mathcal{A}_{ct}$ from a partner process and use it as a theory input. We can then obtain γ if given β and vice versa.

$\bar{B} \to D^{(*)} \bar{D}_s^{(*)}$

Partner process is $\bar{B} \to D^{(*)} \bar{D}_s^{(*)}$



$$
\begin{aligned}
A^{D_s} &= (T' + P'_c)\, V_{cb}^* V_{cs} + P'_u\, V_{ub}^* V_{us} + (P'_t + P'^C_{EW})\, V_{tb}^* V_{ts} \\
&= (T' + P'_c - P'_t - P'^C_{EW})\, V_{cb}^* V_{cs} + (P'_u - P'_t - P'^C_{EW})\, V_{ub}^* V_{us} \\
&\approx (T' + P'_c - P'_t - P'^C_{EW})\, V_{cb}^* V_{cs} \equiv \mathcal{A}'_{ct} e^{i\delta'^{ct}} \;.
\end{aligned}
$$

Theory Input

Note the measurement of the total rate for $\bar{B} \to D^{(*)} \bar{D}_s^{(*)}$ yields $\mathcal{A}'_{ct}$

Theory input(SU(3))

$$\Delta \equiv \frac{\sin\theta_c \, \mathcal{A}'_{ct}}{\mathcal{A}_{ct}} \quad = \quad \frac{\sin\theta_c |(T' + P'_c - P'_t - P'^C_{EW})V^*_{cb}V_{cs}|}{|(T + E + P_c - P_t - P^C_{EW})V^*_{cb}V_{cd}|} = 1 \; ,$$

$$\mathcal{A}^2_{ct} \quad = \quad (\sin\theta_c \, \mathcal{A}'_{ct})^2 = \frac{a_R \cos(2\beta + 2\gamma) - a_{indir} \sin(2\beta + 2\gamma) - B}{\cos 2\gamma - 1}$$

Neglecting exchange diagrams we can estimate SU(3) breaking as

$$\Delta \equiv \frac{\sin\theta_c \, \mathcal{A}'_{ct}}{\mathcal{A}_{ct}} \quad = \quad \frac{f_{D^*_s}}{f_{D^*}}$$

Conclusions

- I discussed the extraction of $\sin 2\beta$ and $\cos 2\beta$ from $B \to J/\psi K_s^{(*)}$, $B \to D^{(*)}\bar{D}^{(*)}K_s$ - these are $b \to c\bar{c}s$ transitions and from $B \to D^{(*)}h^0$($b \to c\bar{u}d$)

- All methods require some modeling of hadronic decays. But measurement for all three decays give the same positive sign for $\cos 2\beta$.

- The decay $\bar{B} \to D^{(*)}\bar{D}^{(*)}$($b \to c\bar{c}d$) cannot be used to obtain CP phase information. However with a partner process $\bar{B} \to D^{(*)}\bar{D}_s^{(*)}$ and theory input (SU(3)) one can obtain γ with β as input and vice versa.