Measuring β in $B \to D^{*+} D^{*-} K_s$ decays

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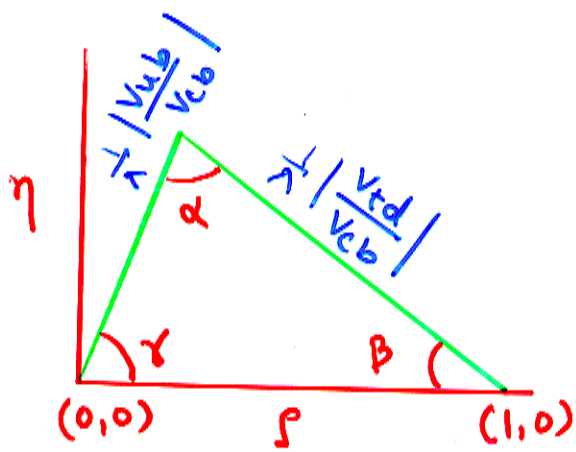
$$V_{CKM} = \begin{bmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{bmatrix} + O(\lambda^4)$$



- $\sin 2\beta$ can be measured via time dependent CP asymmetry

$$a_{cp}(t) = \frac{\Gamma[B^0(t) \to f_{cp}] - \bar{\Gamma}[\bar{B}^0(t) \to f_{cp}]}{\Gamma[B^0(t) \to f_{cp}] + \bar{\Gamma}[\bar{B}^0(t) \to f_{cp}]}$$

- $f_{cp} = J/\psi\, K_S\, [b \to c\bar{c}s]$, $D^+D^-\, [b \to c\bar{c}d]$, $\phi K_S\, [b \to s\bar{s}s]$

$a_{cp}(J/\psi K_S) = -\sin 2\beta \sin \Delta m t$ because $B \to J/\psi K_S$ is dominated by a single amp

- In SM $\quad A[B \to J/\psi K_S] = V_{cb}V_{cs}^* A_1 + V_{ub}V_{us}^* A_2$

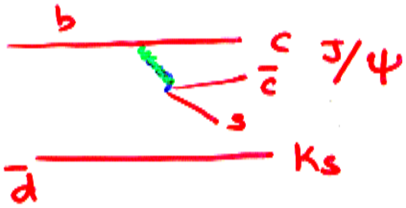
$$\frac{V_{ub}V_{us}^*}{V_{cb}V_{cs}^*} \sim \lambda^2 \quad (\lambda \sim 0.22)$$

Calculating $B \to J/\psi\, K_S$

$$A = \langle J/\psi\, K_S |\, H_{eff}\, | B \rangle$$

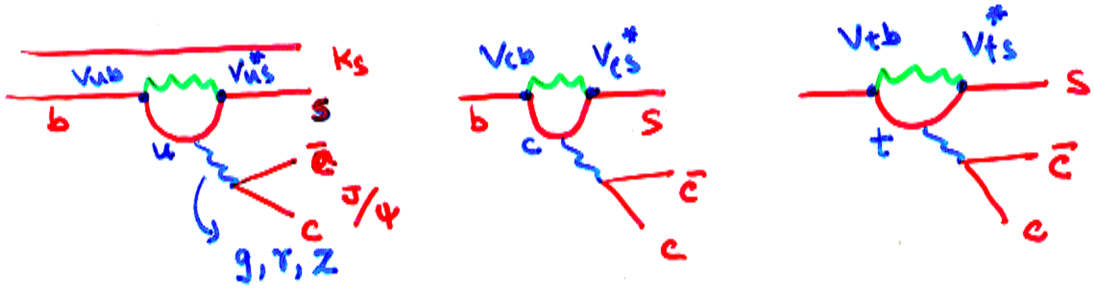
$$H_{eff} = \frac{G_F}{\sqrt{2}} \left[C_1 O_1 + C_2 O_2 \right] \underline{V_{cb} V_{cs}^*}$$

Tree
$$\begin{cases} O_1 = \bar{s}_\alpha \gamma_\mu (1-\gamma_5) c_\beta \; \bar{c}_\beta \gamma^\mu (1-\gamma_5) b_\alpha & C_1 = -0.307 \\ O_2 = \bar{s} \gamma_\mu (1-\gamma_5) c \; \bar{c} \gamma^\mu (1-\gamma_5) b & C_2 = 1.147 \end{cases}$$



$$+ \frac{G_F}{\sqrt{2}} \sum_{i=3}^{10} \left(V_{ub} V_{us}^* C_i^u + V_{cb} V_{cs}^* C_i^c + V_{tb} V_{ts}^* C_i^t \right) O_i$$

Penguins



$C_3^t = 0.017$ $\quad C_7^t = -1.24 \times 10^{-5}$

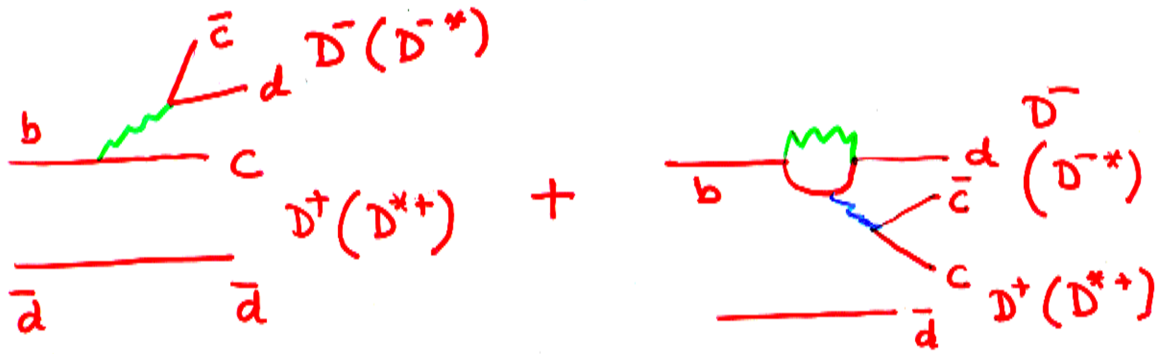
$C_4^t = -0.037$ $\quad C_8^t = 3.77 \times 10^{-4}$

$C_5^t = 0.010$ $\quad C_9^t = -0.010$

$C_6^t = -0.045$ $\quad C_{10}^t = 2.06 \times 10^{-3}$

- It is important to have different measurements of $\sin 2\beta$ as a check of the measurement in $B \to J/\psi K_S$

- For eg. $B \to D^+ D^-$ (Type II)



$$a_{cp}(t) = \frac{\Gamma(t) - \bar{\Gamma}(t)}{\Gamma(t) + \bar{\Gamma}(t)} = + \sin 2\beta \sin \Delta m t$$

Measurement of $\sin 2\beta$ in $B \to D^{(*)} \bar{D}^{(*)}$ could be a good check of systematic errors in the measurements.

However $B \to D^{(*)} \bar{D}^{(*)}$ is not necessarily dominated by a single amplitude.

$$A(B \to D^{(*)} \bar{D}^{(*)}) = V_{cb} V_{cd}^* A_1 + V_{ud}^* V_{ub} A_2$$

$$\frac{V_{ud}^* V_{ub}}{V_{cb} V_{cd}^*} \sim 1$$

Even if $\sin 2\beta$ is measured accurately in $B \to J/\psi K_S$ there is a 4-fold ambiguity in β

$$\sin 2\beta \Rightarrow \beta,\ \frac{\pi}{2} - \beta,\ \pi + \beta,\ \frac{3\pi}{2} - \beta$$

Two issues to consider

- Need better alternative (besides $B \to J/\psi K_S$) measurement of $\sin 2\beta$

- Need to resolve discrete ambiguity in β

Claim: The process $B \to D^{*+} D^{*-} K_S$ ($D^+ D^- K_S$)

- Provide better measurement of $\sin 2\beta$ than $B \to D^{*+} D^{*-}$ ($D^+ D^-$)

- May be used to measure both $\sin 2\beta$ and $\cos 2\beta$ which resolves the $\beta,\ \pi/_2 - \beta$ ambiguity and partly solves the discrete ambiguity problem.

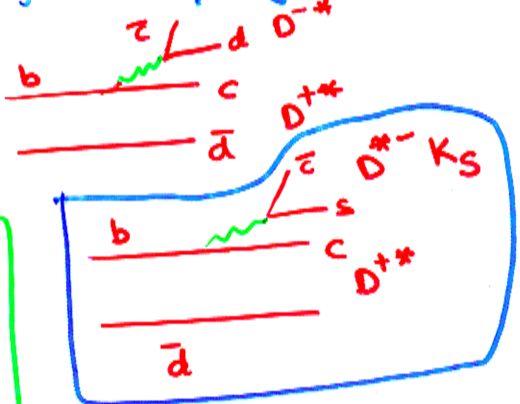
Why $B \to \bar{D}^* D^* K_S$ is better

- $B \to D^* \bar{D}^* K_S$ are $b \to c\bar{c}s$ decays [no penguin pollution]

- $$\frac{\Gamma(B \to D^* \bar{D}^* K_S)}{\Gamma(B \to D^* \bar{D}^*)} \sim \left|\frac{V_{cs}}{V_{cd}}\right|^2 \sim 20$$

- Similar to $B \to J/\psi K_S$ decays. Dominated by tree and small effects from penguins

- ALEPH, DELPI, CLEO have reconstructed $B \to D\bar{D}K$



- CLEO measurements.

$$BR(B^0 \to D^{*+} \bar{D}^{0*} K^-) \simeq 1.3\%$$
$$BR(B^- \to D^{*0} \bar{D}^{*0} K^-) \simeq 1.45\%$$
$$BR(B \to D^{+*} D^{-*}) = 6 \times 10^{-4}$$

Assume

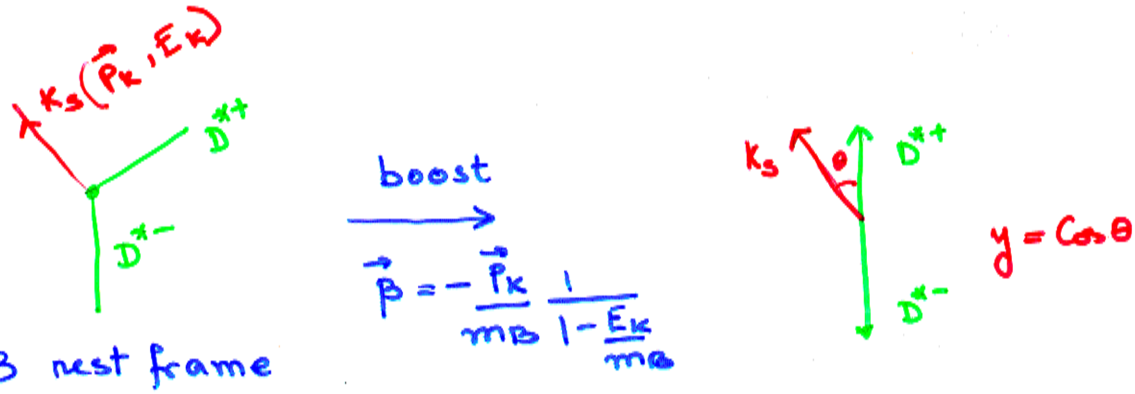
- $BR(K^0 \to K_S) = 0.5$ $\left[K_S = \frac{|K_0\rangle - |\bar{K}_0\rangle}{\sqrt{2}}\right]$
- $BR(K_S \to \pi^+\pi^-) = 0.667$
- Assuming K_S reconstruction efficiency ~ 0.5

$$\frac{\#\ \text{Tagged } B \to D^{*+} D^{*-} K_S \text{ events}}{\#\ \text{Tagged } B \to D^{*+} D^{*-} \text{ events}} \sim \underline{\underline{4}}$$

Same for $B \to D^+ D^- K_S$ vrs $B \to D^+ D^-$

$B \to D^{*+} D^{*-} K_S$

Extracting $\sin 2\beta$ and $\cos 2\beta$



$$a^{\lambda_1,\lambda_2} = \mathrm{Amp}\left[B^0 \to D^{*+}_{\lambda_1} D^{*-}_{\lambda_2} K_S\right]$$

$$\bar{a}^{\lambda_1,\lambda_2} = \mathrm{Amp}\left[\bar{B}^0 \to D^{*+}_{\lambda_1} D^{*-}_{\lambda_2} K_S\right]$$

- Time dependent amplitude is

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

- Square and sum over polarization

$$\left\{\begin{array}{l} |A|^2 \\ |\bar{A}|^2 \end{array}\right. = \frac{1}{2}\left[G_0(y,E_K) \pm G_c(y,E_K)\cos\Delta m t \mp G_s(y,E_K)\sin\Delta m t\right]$$

$$G_0 = |a|^2 + |\bar{a}|^2$$

$$G_c = |a|^2 - |\bar{a}|^2$$

$$G_s = -2\sin 2\beta\, G_{s1} + 2\cos 2\beta\, G_{s2}$$

$$G_{s1} = \mathrm{Re}(\bar{a}a^*) \qquad G_{s2} = \mathrm{Im}(\bar{a}a^*)$$

- If penguins are neglected then there is no direct CP

$$G_o(-y, E_K) = G_o(y, E_K)$$

$$G_c(-y, E_K) = -G_c(y, E_K)$$

$$G_{s1}(-y, E_K) = G_{s1}(y, E_K)$$

$$G_{s2}(-y, E_K) = -G_{s2}(y, E_K)$$

$$\Gamma(B^0 \to D^{*+} D^{*-} K_S) = \frac{1}{2}\left[I_o + 2 \sin 2\beta \sin \Delta m t \, I_{s1}\right]$$

$$\bar{\Gamma}\left[\bar{B}^0 \to D^{*+} D^{*-} K_S\right] = \frac{1}{2}\left[I_o - 2 \sin 2\beta \sin \Delta m t \, I_{s1}\right]$$

$$I_o = \int G_o \qquad I_{s1} = \int G_{s1} = \int \mathrm{Re}(\bar{a} a^*)$$

$$= \int \left[|a|^2 + |\bar{a}|^2\right]$$

$$a_{cp}(t) = \frac{\Gamma(t) - \bar{\Gamma}(t)}{\Gamma(t) + \bar{\Gamma}(t)} = D \sin 2\beta \sin \Delta m t$$

$D \to$ Dilution factor

$$D = \frac{2 I_{s1}}{I_o} = \frac{2 \int \mathrm{Re}(\bar{a} a^*)}{\int |a|^2 + |\bar{a}|^2}$$

What is D ?

$B \to D^{*+} D^{*-}$

$|D^{*+}, D^{*-}\rangle$ is a mixture of CP eigenstates.

- $B(J=0) = D^* \bar{D}^*$ $\begin{cases} J = S+L \text{ to } |S-L| \\ J=0 \Rightarrow S=L \end{cases}$

  $S = 2, 1, 0 \Rightarrow L = 2, 1, 0$

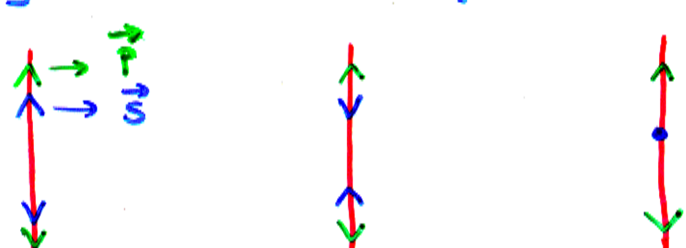
  $L \to$ relative angular momentum of $D^* \bar{D}^*$ system.

- $a^{\lambda_1 \lambda_2} = \langle D^{+*}(p_+, \varepsilon)\, D^{-*}(p_-, \mu) \,|\, H \,|\, B(p)\rangle$

$$= (\varepsilon^*_{\lambda_1} \cdot \mu^*_{\lambda_2}) f_S + \frac{(\varepsilon^*_{\lambda_1} \cdot p_-)(p_+ \cdot \mu^*_{\lambda_2})}{m^2_{D^*}} + i\, \varepsilon_{\mu\nu\rho\sigma}\, \varepsilon^{*\mu}_{\lambda_1} \mu^{*\nu}_{\lambda_2} p_-^{\rho} p_+^{\sigma} f_P$$

S D P

- Only three helicity states allowed



$|+,+\rangle$ $|-,-\rangle$ $|0,0\rangle$

$$a^{++} = \langle +,+ | H | B^0 \rangle$$

$$a^{--} = \langle -,- | H | B^0 \rangle$$

$$a^{00} = \langle 0,0 | H | B^0 \rangle$$

To construct states of definite CP we can go to the Partial wave basis or Transverse basis

Transverse basis: $A_{\parallel} = \frac{1}{\sqrt{2}}\left(a^{++} + a^{--}\right)$

$$A_0 = a^{00}$$

$$A_{\perp} = \frac{1}{\sqrt{2}}\left(a^{++} - a^{--}\right)$$

Partial wave: $S = \frac{1}{\sqrt{3}}\left(\sqrt{2}\, A_{\parallel} - A_0\right) \quad P = A_{\perp}$

$$D = \frac{1}{\sqrt{3}}\left(A_{\parallel} + \sqrt{2}\, A_0\right)$$

$CP|S,D\rangle = +|S,D\rangle \qquad CP|P\rangle = -|P\rangle$

$$D \text{ (Dilution Factor)} = \frac{2\,\mathrm{Re}\,(\bar{a}\, a^*)}{|a|^2 + |\bar{a}|^2} = \frac{|S|^2 + |D|^2 - |P|^2}{|S|^2 + |D|^2 + |P|^2}$$

$$= \frac{\Gamma_+ - \Gamma_-}{\Gamma_+ + \Gamma_-} \quad \left(\Gamma_\pm \rightarrow CP \begin{Bmatrix} \text{even} \\ \text{odd} \end{Bmatrix}\right)$$

$a_{cp} = D \sin 2\beta \sin \Delta m t$ [Note if $\Gamma_+ = \Gamma_-$, $a_{cp} = 0$]

Avoid Dilution

- Perform angular analysis to extract $A_\parallel$, $A_\perp$, A_0

- However, using factorization & HQET

$$\frac{\Gamma_0}{\Gamma} \sim 54\% \qquad \frac{\Gamma_\parallel}{\Gamma_0} \sim 40\% \qquad \frac{\Gamma_\perp}{\Gamma} \sim 6\%$$

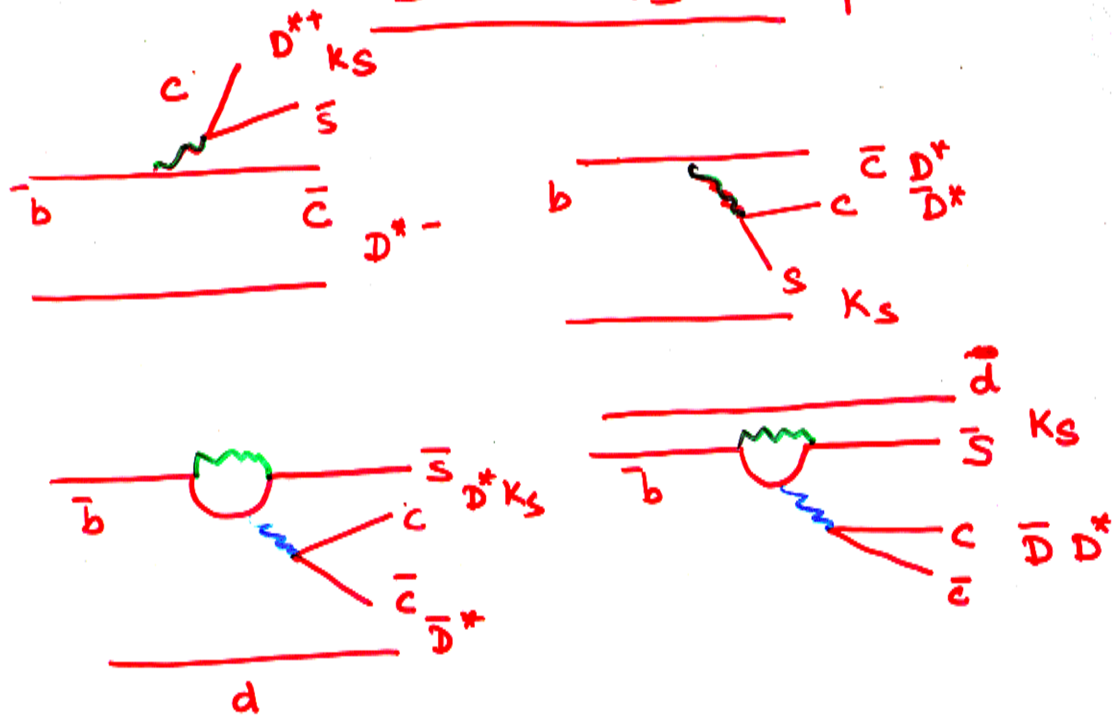
$$\Gamma_+ = \Gamma_0 + \Gamma_\parallel \sim 94\%$$
$$\Gamma_- \sim 6\%$$

$$D = \frac{\Gamma_+ - \Gamma_-}{\Gamma_+ + \Gamma_-} \simeq .89$$

ie $\sin 2\beta$ can be measured without angular analysis.

? Does similar result hold for $B \to D^* \bar{D}^* K_S$ decays.

How to study three body $B \to D^* \bar{D}^* K_S$ decays



- $p_K \lesssim 1\,\text{GeV}. \Rightarrow$ Chiral Pert Theory
- $m_b, m_c \to \infty$ HQET

Use Factorization & Heavy Hadron Chiral Pert Theory (HHCHPT)

- Particle Content in the Theory
- B
- D, D^* $(0^-, 1^-)$

$$D = c + \text{Light degrees of freedom } (j^P)$$

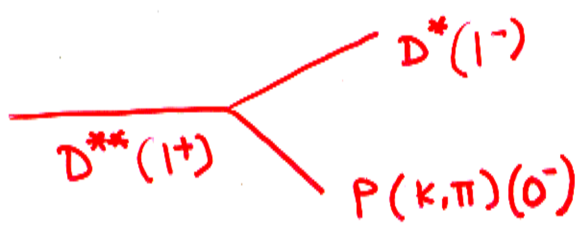
Ground state $\frac{1}{2} + l\left(\frac{1}{2}^-\right) \equiv \begin{matrix} 0^- \to D \\ 1^- \to D^* \end{matrix}$

P wave states

$$\ell(j^P) = \ell\left(\tfrac{1}{2}^+, \tfrac{3}{2}^+\right)$$

$$\ell\left(\tfrac{1}{2}^+\right) : \quad c\left(\tfrac{1}{2}\right) + \ell\left(\tfrac{1}{2}^+\right) < \left.\begin{matrix} 0^+ \\ 1^+ \end{matrix}\right\} D^{**}$$

$$\ell\left(\tfrac{3}{2}^+\right) : \quad c\left(\tfrac{1}{2}\right) + \ell\left(\tfrac{3}{2}^+\right) < \left.\begin{matrix} 1^+ \\ 2^+ \end{matrix}\right\} D^{***}$$



S wave decay

Γ is large $\Rightarrow$ broad states

Difficult to observe above background.

Evidence of $D^{**}(1^+)$ reported by CLEO (CLEO-CONF 99-6)

$$B^- \rightarrow D^{**}(1^+)\,\pi^- \rightarrow D^{*+}\pi^-\pi^-$$

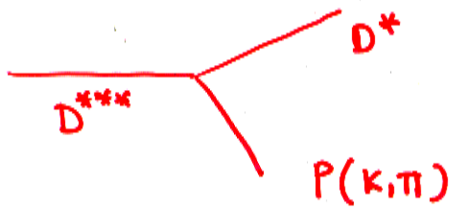
Preliminary: $m = 2461^{+41}_{-34} \pm 10 \pm 32$ MeV

$\Gamma = 290^{+101}_{-79} \pm 26 \pm 36$ MeV

Quark Model prediction $D^{**} \sim 2500$ MeV

$D_s^{**} \sim 2600$ MeV

$\Gamma_{D^{**}} \sim 150$ MeV (HHCHPT)

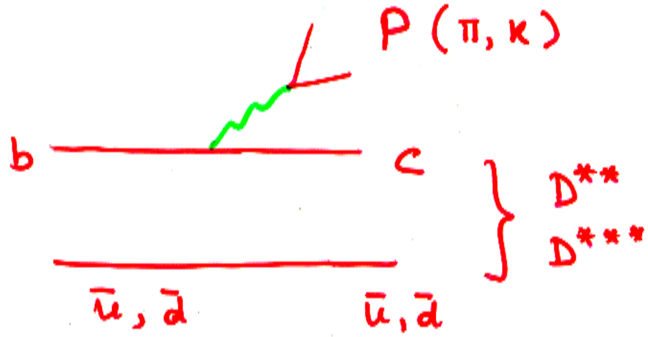


$\rightarrow$ D wave

Γ is small $\Rightarrow$ narrow states

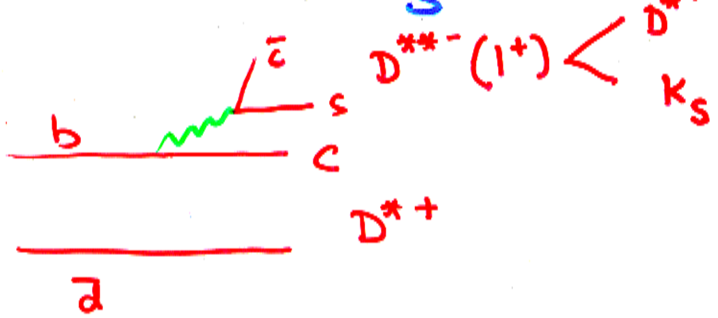
Has been seen $\left\{ \begin{array}{l} D_{s1}(2536)\ 1^+ \\ D_{sJ}(2573)\ 2^+ \end{array} \right\}$

Note all the resonant states discovered so far do not contain the s-quark. This is because B does not have a s quark.



To produce D_s^{**}, D_s^{***} need B_s meson

The process $B \rightarrow D^{*+} D^{*-} K_s$ can be used to discover the D_s^{**} at e^+e^- machines



HHCHPT

- Particle to work with

  B, D, D^*, $D^{**}(0^+, 1^+)$, K

- $$H_a = \left(\frac{1+\not v}{2}\right)\left[P^*_{a\mu}\gamma^\mu - P_a\gamma_5\right]$$ $Q\bar{q}_a$ Meson, $0^-, 1^-$, $a = 1, 2, 3\ (u, d, s)$

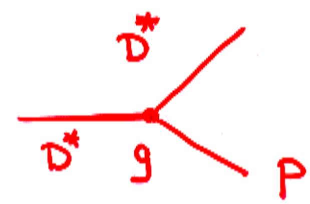
- $$S_a = \frac{1+\not v}{2}\left[D^*_\mu \gamma^\mu \gamma_5 - D_0\right] \quad [0^+, 1^+]$$

- $$M = \begin{bmatrix} \pi^0/\sqrt{2} + \eta/\sqrt{6} & \pi^+ & K^+ \\ \pi^- & -\frac{\pi^0}{\sqrt{2}} + \eta/\sqrt{6} & K^0 \\ K^- & \bar{K}^0 & -\sqrt{2/3}\,\eta \end{bmatrix}$$

$$\mathcal{L} = K.E + L_{int}$$

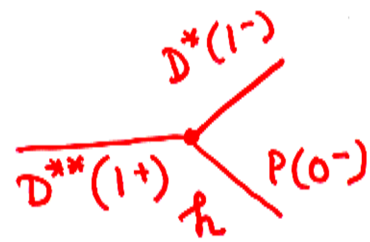
$$L_{int} \sim \underline{\underline{g}}\, Tr\left[H_b \gamma_\mu \gamma_5 A^\mu_{ba} \bar{H}_a\right]$$

$$+ \underline{\underline{h}}\, Tr\left[S_b \gamma_\mu \gamma_5 A^\mu_{ba} \bar{H}_a\right] + \cdots + h.c$$



$$A^\mu_{ba} = \frac{1}{2}\left(\xi^\dagger \partial_\mu \xi - \xi \partial_\mu \xi^\dagger\right)_{ba}$$

$$\xi = e^{iM/f_P}$$



Using the Factorization assumption

$$M\left[B \to D^{*+} D^{*-} K_S\right] \simeq \frac{G_F}{\sqrt{2}} C_+ V_{cb} V_{cs}^{*} \, J_\mu L^\mu$$

$$J_\mu = \left\langle D^*(v_1, m_1, \varepsilon_1) \right| \bar{c} \gamma_\mu^* (1-\gamma_5) b \left| B^0(v, m) \right\rangle$$

$$= \sqrt{m}\sqrt{m_1}\, \xi(v \cdot v_1) \Big[-i\, \varepsilon_{\mu\nu\alpha\beta}\, \varepsilon_1^{*\nu} v^\alpha v_1^\beta + v_{1\mu}\, \varepsilon_1^* \cdot v - \varepsilon_{1\mu}^* (v \cdot v_1 + 1) \Big] + O\left(\frac{1}{m}\right)$$

$\xi(v \cdot v_1) \to$ Isgur-Wise function.

$$L^\mu = \left\langle \bar{D}^* K_S \right| \bar{s} \gamma^\mu (1-\gamma_5) c \left| 0 \right\rangle$$

- No final state interactions are included (no FSI phases)

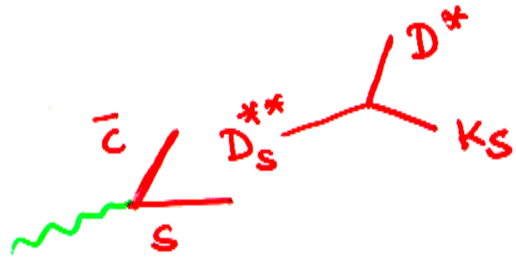
- However CP even phases can arise in L^μ when there is contribution from resonances.

$$L^{\mu} = \langle D^* K_s | \bar{s}\gamma^{\mu}(1-\gamma_5)\, c\, | 0 \rangle$$

can have two contributions

Non-Resonant

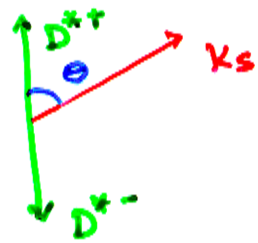
Resonant



- Pole contribution is dominated by $D_s^{**}(1^+)$
- Contribution from the other resonances are small
- D^{***} does not contribute in the lowest order in CHPT [$B \to D^{***}X < 0.95\%$ at 90% CL CLEO]
- $D_s^*(1^-)$ contribution is suppressed by small velocity of the D^*'s [S.V limit : $v(D^*) \to 0$ D_s^* contribution $\to 0$]

$B \to D^* D^* K_S$

Non-Resonant contribution



Non-resonant contribution can be calculated in HHCHPT

$$L^\mu = \langle D^* K_S | \bar{s}\gamma^\mu(1-\gamma_5)c|0\rangle$$

$$= \frac{i f_H \sqrt{m_H}}{2} \, Tr\left[\gamma^\mu(1-\gamma_5) H_b \xi^{+}_{ba}\right]$$

[Soft-Pion result]

- $a_{non-res}$ has no dependence on $y = \cos\theta$

K_S is in a S-wave configuration relative to the $D^* \bar{D}^*$ system

$\Rightarrow$ Partial wave (CP) analysis of $B \to D^* \bar{D}^* K_S$ (non-res) is identical to that for $B \to D^* \bar{D}^*$

i.e only 3 amp possible a^{++}, a^{--}, a^{00} $(A_{\parallel}, A_{\perp}, A_0)$ (S, P, D)

Dilution $D = 0.94$ (0.89 for $B \to D^* \bar{D}^*$)

$$a_{cp} = D \sin 2\beta \sin \Delta m t$$

If only non-res is present $\cos 2\beta$ cannot be extracted if factorization works

BR for the non-resonant contribution

depends on f_{D^*} and $\xi(\omega)$

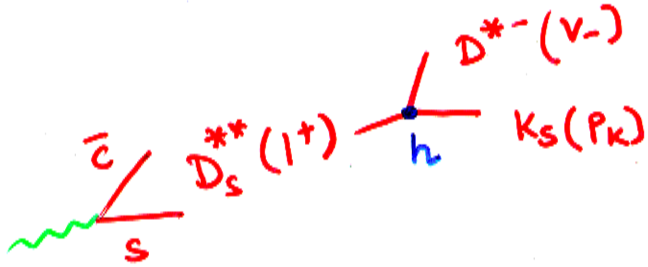
For $f_{D^*} \sim 200$ MeV Non-Res $\simeq$ 40% of Measured Rate

Note $D \propto \dfrac{2\,\mathrm{Re}(\bar{a}\, a^*)}{|a|^2 + |\bar{a}|^2}$ is independent

of f_{D^*} and $\xi(\omega)$

Resonance contribution

Since it appears that the non-resonant rate is smaller than the measured rate (BR) therefore there must be a significant resonant contribution.



$$a_{res} \sim a_{non\text{-}res}\left[\frac{h\, p_K\cdot v_-}{p_K\cdot v_- + m_{D^*} - m_{D_s^{**}} + i\frac{\Gamma_{D_s^{**}}}{2}}\right]$$

$\Gamma_{D_s^{**}} \propto h^2$

generates CP even phase

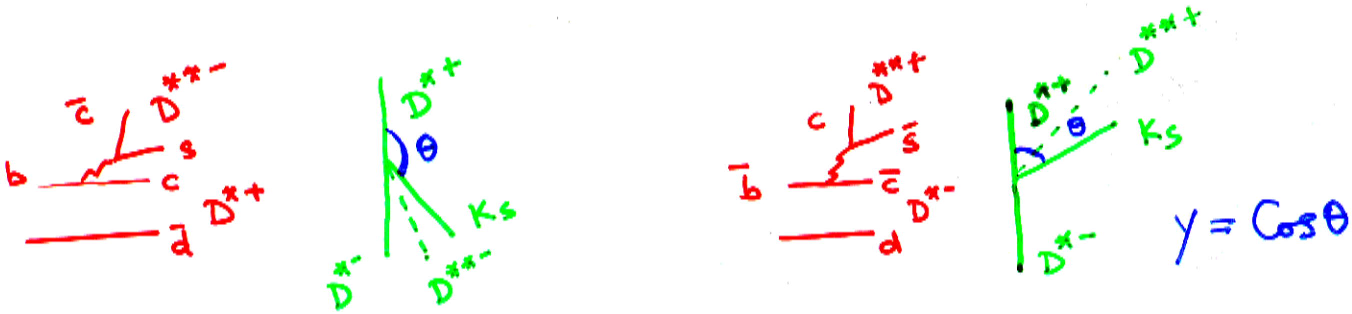
$$a_{cp}(t) = D \sin 2\beta \sin \Delta m t$$

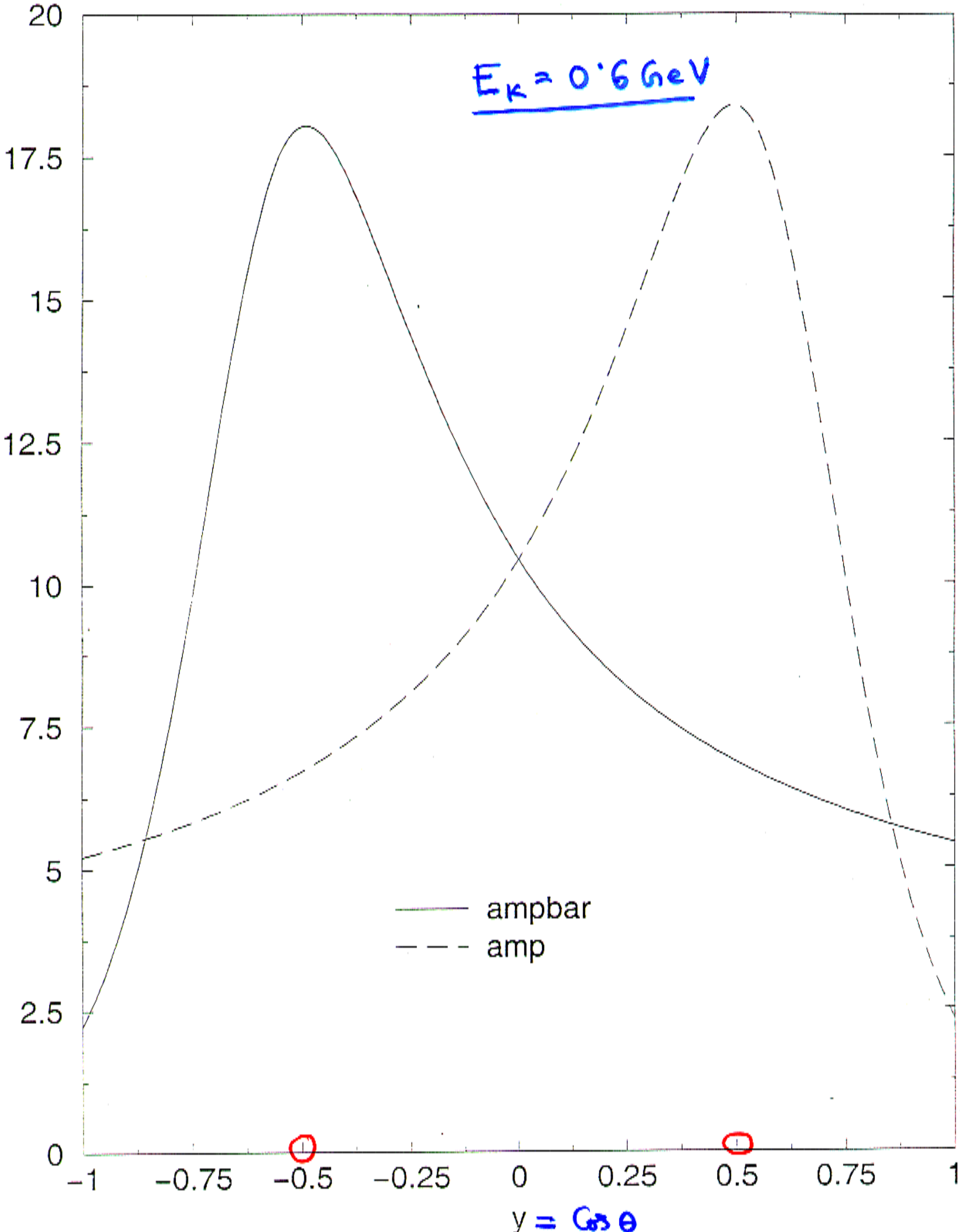
$D \sim \mathrm{Re}[a^* \bar{a}]$

$a = \mathrm{Amp}[B^0 \to D^* \bar{D}^* K_s]$

$\bar{a} = \mathrm{Amp}[\bar{B}^0 \to D^* \bar{D}^* K_s]$

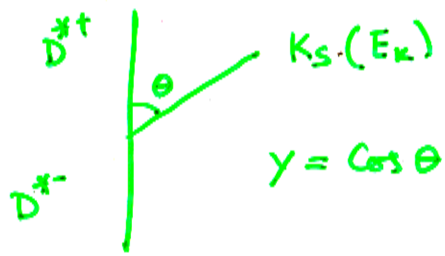
Presence of resonance reduces overlap of a and $\bar{a}$ and therefore decreases D (increases the dilution of a_{cp})





$D \propto \mathrm{Re}(\bar{a}\,a^*)$ measures overlap of the two amplitudes

One can try to increase D by trying to reduce the resonant contribution in the signal



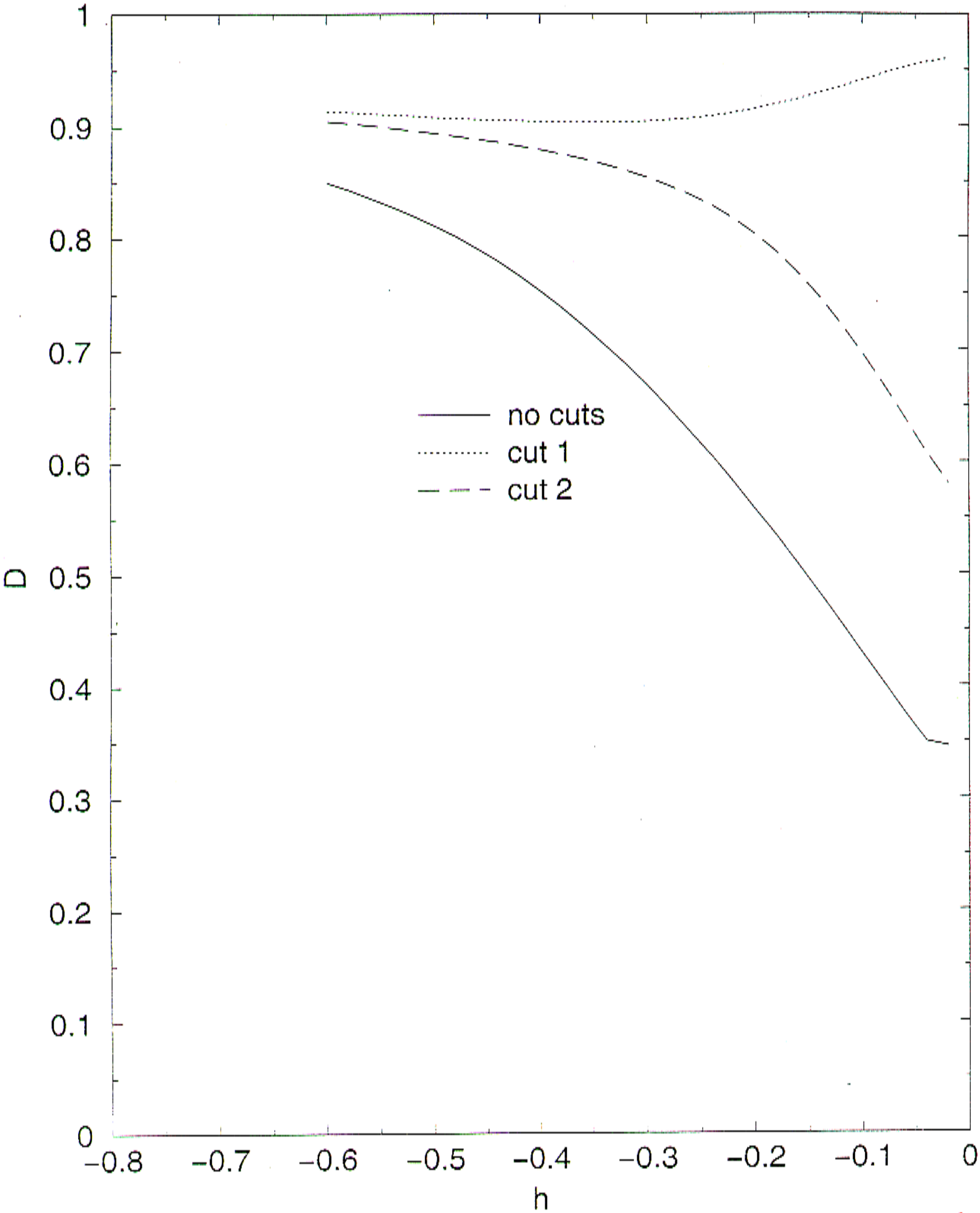
- Cut 1: Cut on E_K

  $E_K \geq E_{K0}$ ($\sim$ 0.76 GeV) Resonance is not formed

- Cut 2: For $E_K < E_{K0}$ $-\frac{1}{2} \leq y \leq \frac{1}{2}$ (Cut on y)

- As you reduce the dilution of a_{cp} you also loose the useable part of the signal.

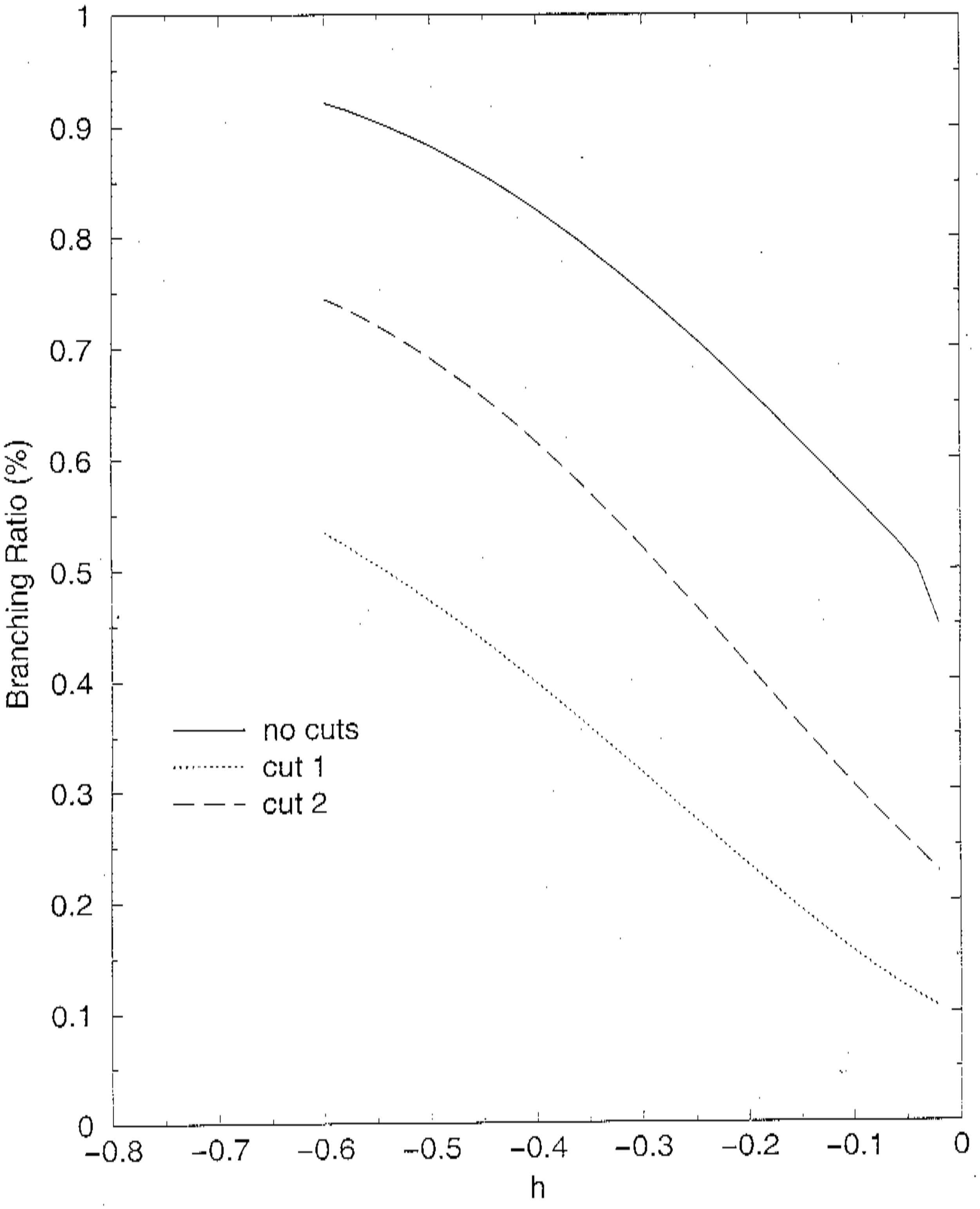
Cuts can be optimized after the resonance is discovered.



QCD sum rule give $h \sim -0.4 \Rightarrow D \sim 0.75$

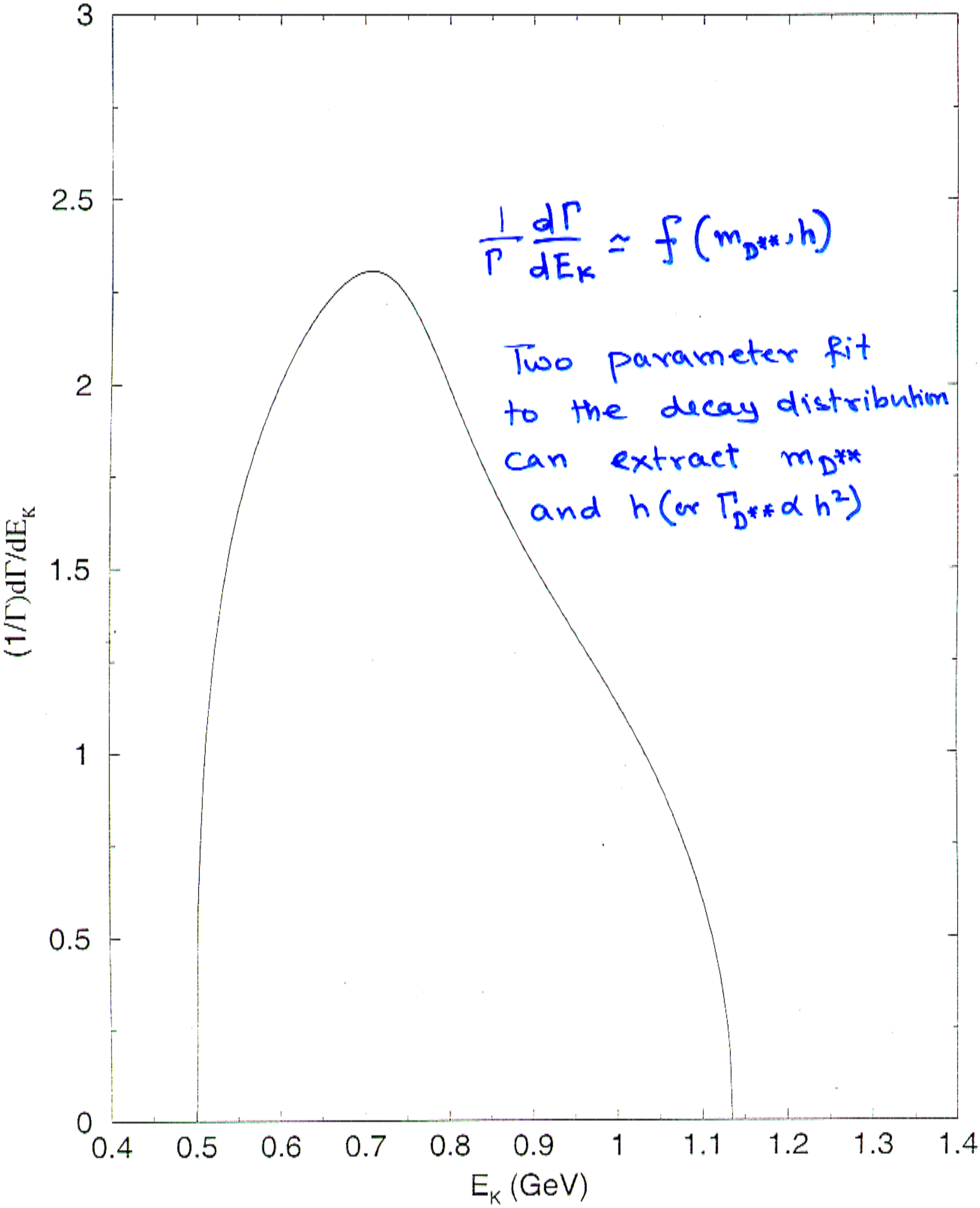
$D \sim 0.88 - 0.91$ with cuts

$\Gamma_{D^{**}} \propto h^2$



Branching Ratio (%)
h
no cuts
cut 1
cut 2
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
−0.8
−0.7
−0.6
−0.5
−0.4
−0.3
−0.2
−0.1
0

Discovering the resonance $D^{**}(1^+)$



$$\frac{1}{\Gamma}\frac{d\Gamma}{dE_K} \simeq f(m_{D^{**}}, h)$$

Two parameter fit to the decay distribution can extract $m_{D^{**}}$ and h (or $\Gamma_{D^{**}} \propto h^2$)

Extracting $\cos 2\beta$

Integrating over half the range of y
($y \geq 0$ or $y \leq 0$)

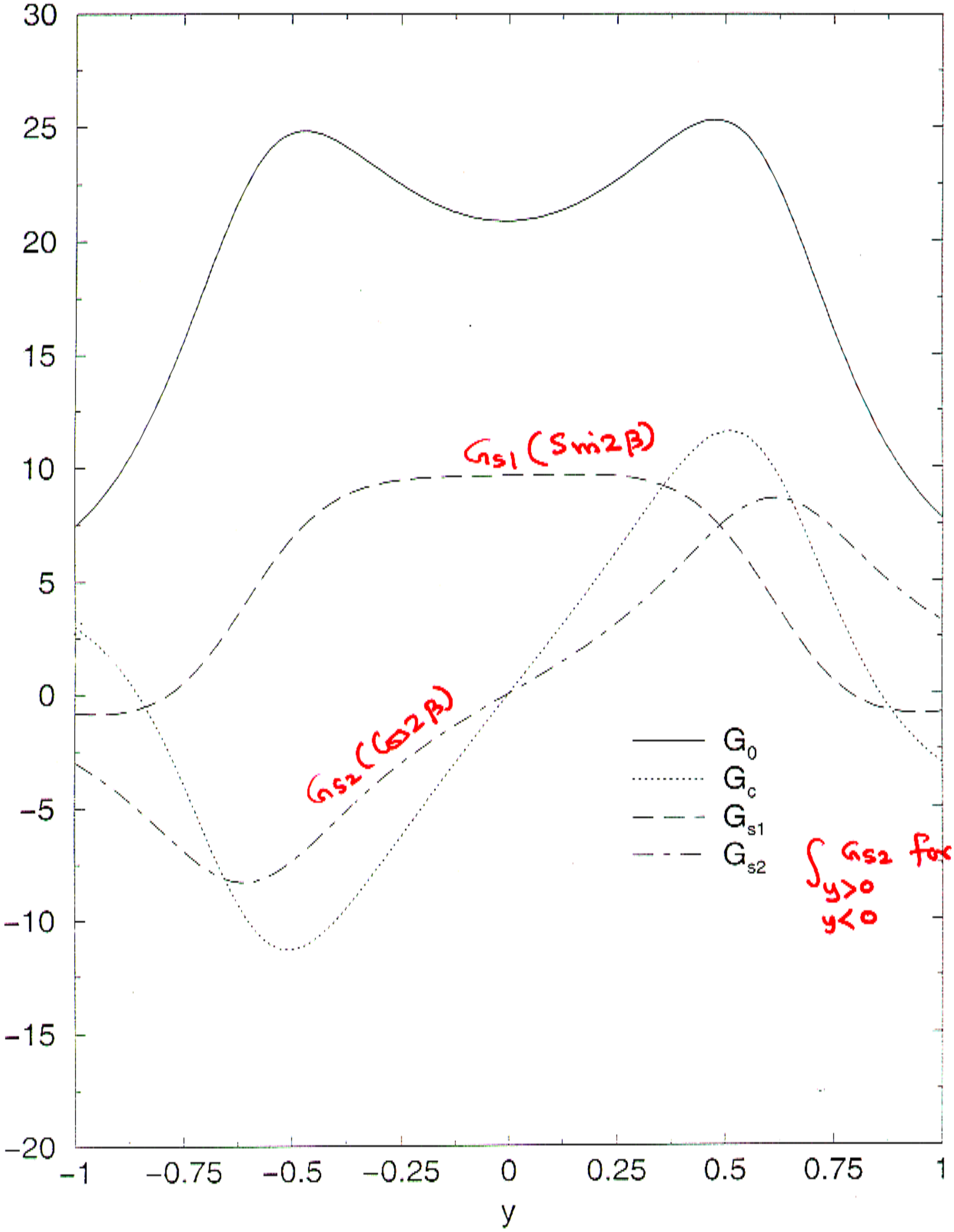
$$\begin{cases} \Gamma[B^0 \to D^* \bar{D} K_S] = \frac{1}{2}\Big[J_0 + J_c \cos\Delta m t \pm 2\sin 2\beta \sin\Delta m t\, J_{S1} \\ \qquad\qquad\qquad\qquad - 2\cos 2\beta \sin\Delta m t\, J_{S2}\Big] \\ \bar{\Gamma}[\bar{B}^0 \to D^* \bar{D}^* K_S] \end{cases}$$

$$\Gamma + \bar{\Gamma} = J_0 + J_c \cos\Delta m t - 2\cos 2\beta \sin\Delta m t\, J_{S2}$$

Fit to $\Gamma + \bar{\Gamma}$ can be used to extract $\cos 2\beta$

- $J_{S2} \sim \mathrm{Im}(\bar{a}a^*)$. Non-zero J_{S2} is generated by the Breit-Wigner structure of the resonant contribution
- J_{S2} increases with $\Gamma_{D^{**}}$. So a broad resonance like the $D_s^{**}(1^+)$ is favourable for $\cos 2\beta$ determination.
- Based on the work of Quinn and Snyder for $B \to \rho\pi$
- Extraction of $\cos 2\beta$ in $B \to D\bar{D}\pi^0$ ($B \to D\bar{D}K_S$) was first discussed by charles et. al (PLB)

$$|A|^2 = \frac{1}{2}\Big[G_0 + G_c \cos \Delta m t + 2 \sin 2\beta \sin \Delta m t \; G_{s1} - 2\cos 2\beta \sin \Delta m t \; G_{s2}\Big]$$



$\int_{y>0}^{y<0} G_{s2}$ for $\cos 2\beta$

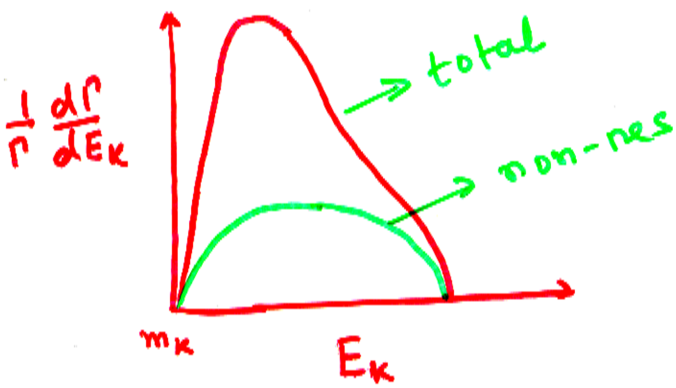
Differences between Charles et. al. (X) and present work (o)

X Only includes resonant contribution

o Includes both resonant and non resonant contribution

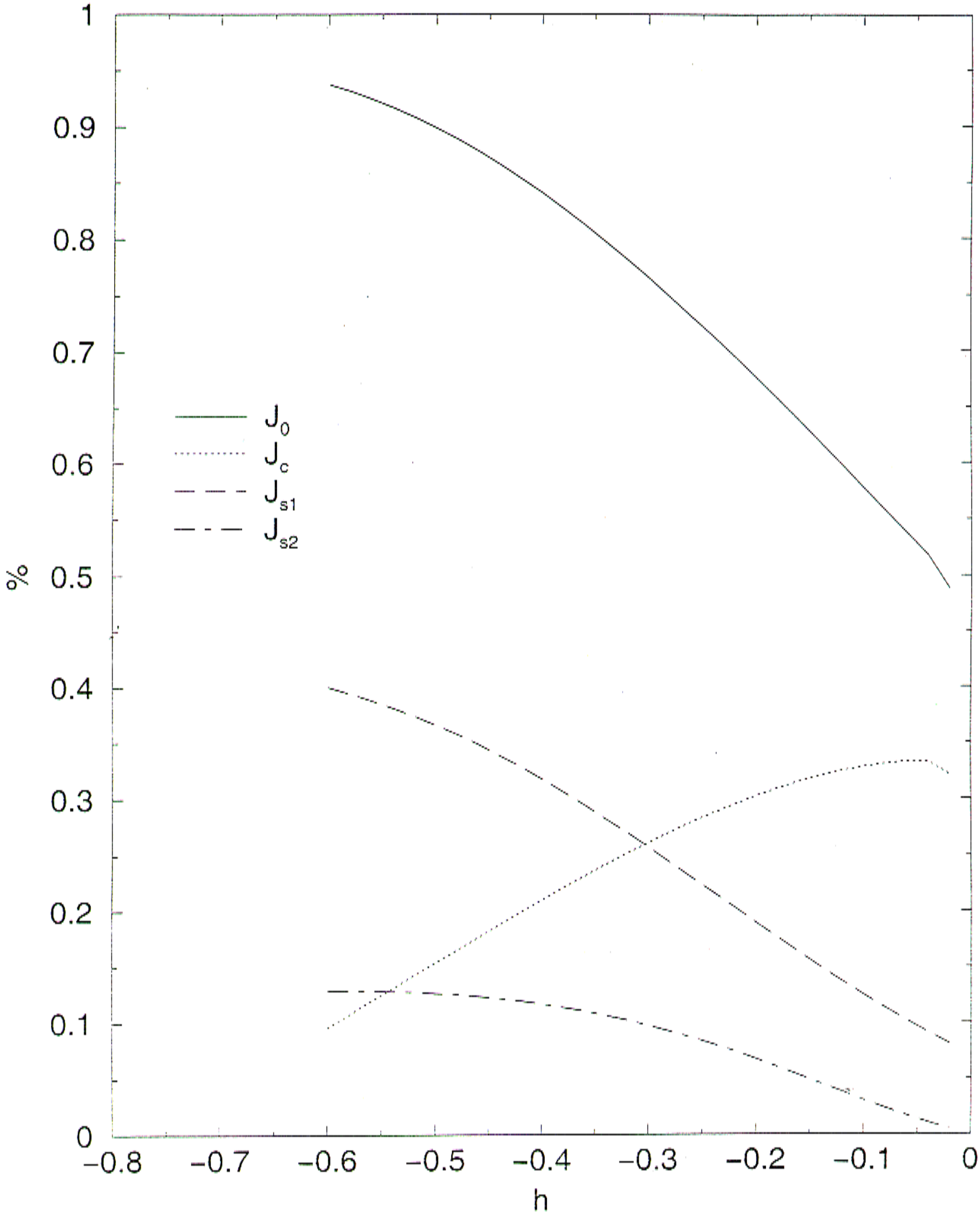
- Non-res contribution depends on f_{D^*} and $\xi(\omega)$

$f_{D^*} \sim 200\,MeV$ Non Res $\simeq$ 40% observed rate



X Assumed D_s^{**} resonance was below $D^* K$ threshold so they did not consider $B \to D^* \bar{D}^* K_s$

o We use $m_{D_s^{**}} = 2600\,MeV$: above $D^* K_s$ threshold. This is reasonable given the discovery of $m_{D^{**}} \simeq 2500\,MeV$



$\Gamma_{D^{**}} \propto h^2$

Expt ~~[illegible]~~ Prospects

- Eric Heenan working on M.C for $B \to D^* \bar{D}^* K_S$ at Belle
  - Trying to increase D^* reconstruction efficiency

In e^+e^- machine the low momenta of the pions from the D^* reduce the reconstruction efficiency.

In hadron machines the final state is boosted $\Rightarrow$ decay products are more energetic and easier to reconstruct

Hence $B \to D^* \bar{D}^* K_S$ is very relevant for hadron machines

Conclusion

$B \to D^* \bar{D}^* K_S$ can be a good way to measure $\sin 2\beta$ (especially in hadron machines BTeV)

If the broad $D_s^{**}(1^+)$ contribute significantly to this process one can also measure $\cos 2\beta$ and resolve the β, $\pi/2 - \beta$ discrete ambiguity.