Charm input to B physics

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Technion

Introduction

What can we learn from D physics?

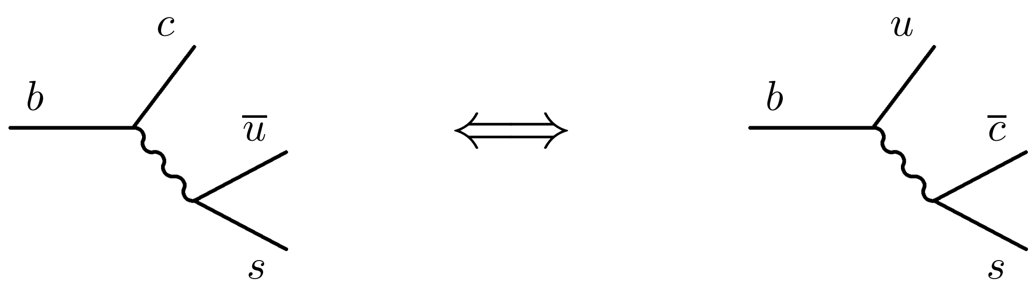
- D physics can provide input to B physics
  - Strong phases for γ in $B \to DK$
- D physics can be used to test the SM
  - $D - \overline{D}$ mixing

D physics input to γ

γ with $B \to DK$

Gronau and Wyler

Use interference between $b \to c\bar{u}s$ and $b \to u\bar{c}s$

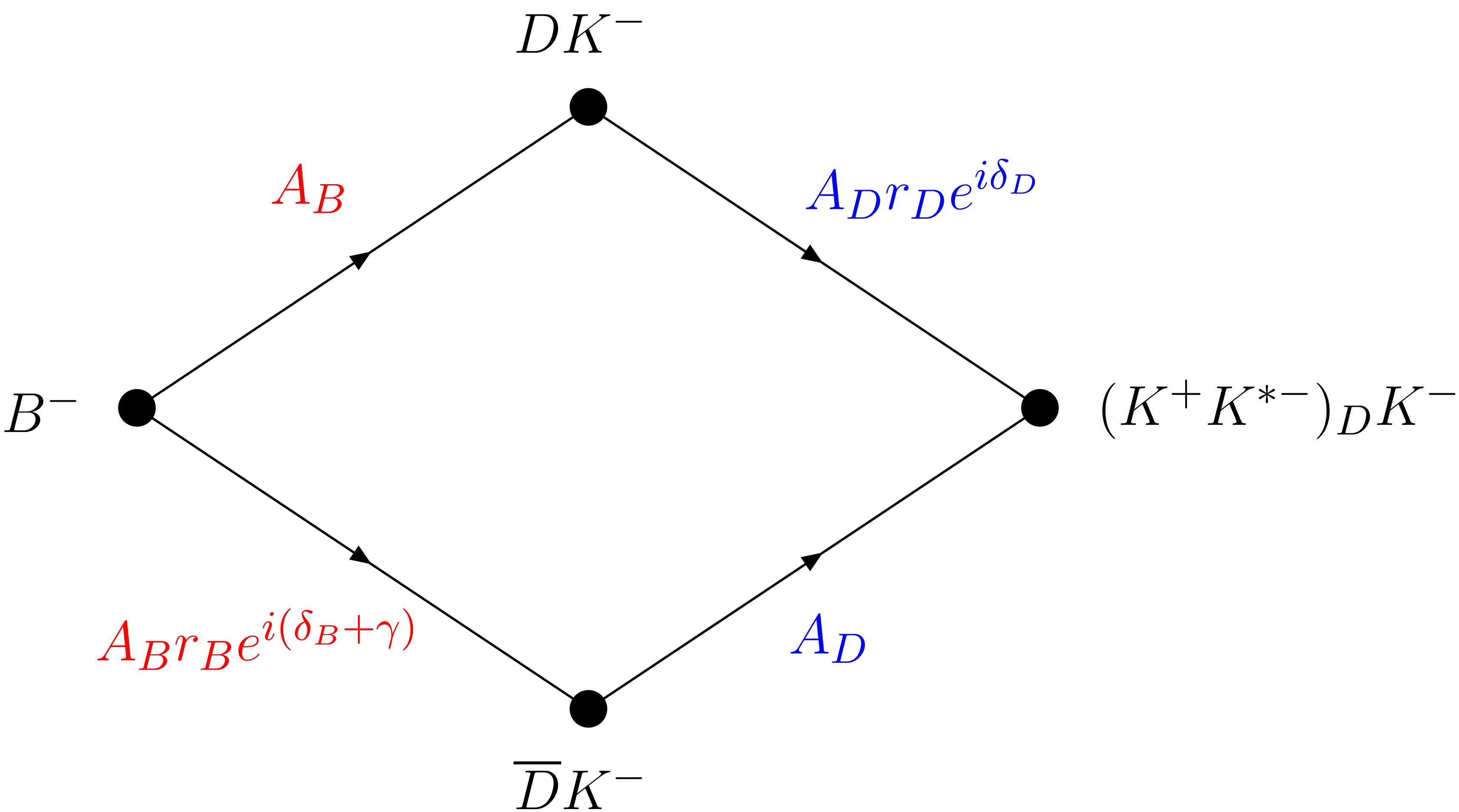


Interference between

$$B^+ \to DK^+ \quad \text{follows by} \quad D \to f$$
$$B^+ \to \overline{D}K^+ \quad \text{follows by} \quad \overline{D} \to f$$

f can be any common final state to D and $\overline{D}$

The path to γ



Common final state

In order to get a common final state we need either DCS or $K - \overline{K}$ mixing

- Double Cabibbo Suppression (DCS)
  - $D \to K^+\pi^-$ $\overline{D} \to K^+\pi^-$
  - $D \to K^+K^-$ $\overline{D} \to K^+K^-$
- $K - \overline{K}$ mixing
  - $D \to K_S\,\pi^0$ $\overline{D} \to K_S\,\pi^0$
  - $D \to K_S\,\pi^+\pi^-$ $\overline{D} \to K_S\,\pi^+\pi^-$

Charm input

In principle, we can get all the B and D decay hadronic parameters from the $B \to DK$ decays

The problem with γ is statistics

- Use many methods with many B and D decay modes
- Use D decays to extract the D decay hadronic parameters

Example: GW+ADS

Atwood, Dunietz and Soni; Soffer

Beside the $B^- \to DK^-$ rate we need the rates

$$B^\pm \to (K^\pm \pi^-)_D K^\pm \qquad B^\pm \to D_{\rm CP} K^\pm$$

Hadronic parameters

$$\frac{A(B^- \to \overline{D}K)}{A(B^- \to DK)} \equiv r_B e^{i(\delta_B+\gamma)} \qquad \frac{A(D \to K^+\pi^-)}{A(\overline{D} \to K^+\pi^-)} \equiv r_D e^{i\delta_D}$$

- $r_D \ll 1$ is needed from D decay
- 4 measurements and 4 unknowns (δ_D, r_B, δ_B, γ) $\Rightarrow$ γ

Can we also get δ_D from D data?

Example: $B^+ \to (KK^*)_D K^+$

Atwood, Dunietz and Soni; Grossman, Ligeti and Soffer

Beside the $B^- \to DK^-$ rate we need the rates

$$B^\pm \to (K^\pm K^{*\mp})_D K^\pm$$

Hadronic parameters

$$\frac{A(B^- \to \overline{D}K)}{A(B^+ \to DK)} \equiv r_B e^{i(\delta_B+\gamma)} \qquad \frac{A(D \to K^+K^{*-})}{A(\overline{D} \to K^+K^{*-})} \equiv r_D e^{i\delta_D}$$

- $r_D \sim 1$ is needed from D decay
- 4 measurements and 4 unknowns (δ_D, r_B, δ_B, γ) $\Rightarrow \ \gamma$

Can we also get δ_D from D data?

Example: $B^+ \to (K_S\pi^+\pi^-)_D K^+$

Giri, Grossman, Soffer and Zupan; Atwood and Soni

Beside the $B^+ \to DK^-$ rate we need the Dalitz plot of

$$B^\pm \to (K_S\pi^-\pi^+)_D K^\pm$$

B hadronic parameters

$$\frac{A(B^+ \to \overline{D}K)}{A(B^+ \to DK)} \equiv r_B e^{i(\delta_B+\gamma)}$$

D hadronic parameters

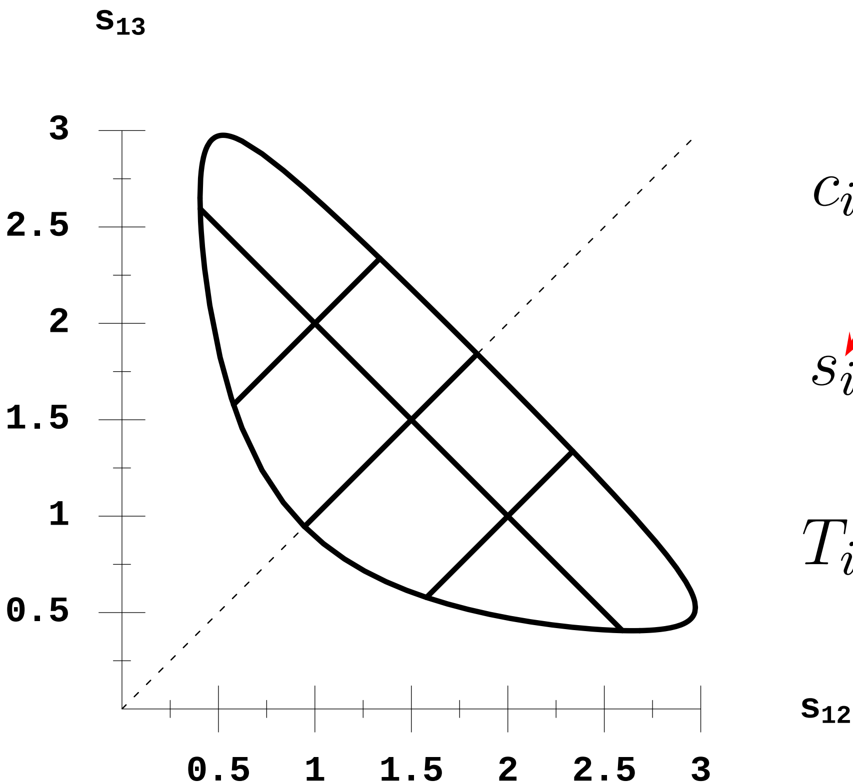
unknowns

$$A_D(s_{12}, s_{13}) \equiv A_{12,13}\, e^{i\delta_{12,13}} \equiv A(D \to K_S(p_1)\pi^-(p_2)\pi^+(p_3))$$
$$= A(\overline{D} \to K_S(p_1)\pi^+(p_2)\pi^-(p_3))$$

measurable

The method - definitions

- Partition the Dalitz plot in $2k$ bins
- Label bins below symmetry axis i, above axis $\bar{i}$



unknowns

$$c_i \equiv \int_i dp\, A_{12,13}\, A_{13,12} \cos(\delta_{12,13} - \delta_{13,12})$$

$$s_i \equiv \int_i dp\, A_{12,13}\, A_{13,12} \sin(\delta_{12,13} - \delta_{13,12})$$

$$T_i \equiv \int_i dp\, A^2_{12,13}$$

measurable from tagged D

$$c_{\bar{i}} = c_i, \qquad s_{\bar{i}} = -s_i$$

$s_{12} = m^2_{K_s\pi^-}$ and $s_{13} = m^2_{K_s\pi^+}$

Determining γ

- A set of $4k$ equations
- The k equations for the i bins

$$\hat{\Gamma}_i^- \equiv \int_i d\hat{\Gamma}(B^- \to (K_S\pi^-\pi^+)_D K^-) =$$
$$T_i + r_B^2 T_{\bar{i}} + 2r_B[\cos(\delta_B - \gamma)c_i + \sin(\delta_B - \gamma)s_i]$$

- $2k+3$ unknowns: $c_i,\ s_i,\ r_B,\ \delta_B,\ \gamma$
- Solvable for $k \geq 2$

Can we also get c_i and s_i from D data?

Measuring hadronic D parameters

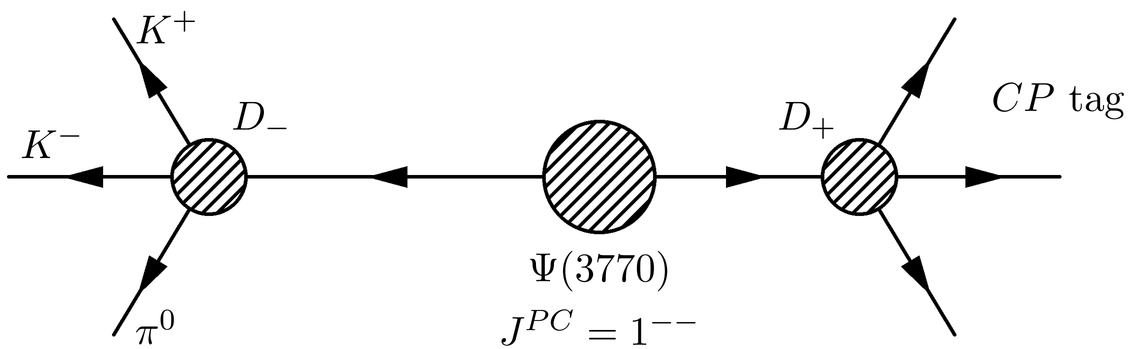
- In all the above examples the B physics parameters are the same: $r_B,\ \delta_B,\ \gamma$
- The D decay amplitudes are different in each example
  - Their magnitudes are assumed to be known from D data
  - Their phases are extracted using B decay data

Can we measure strong phases of D decays using D decay data?

Measuring $\cos\delta_D$ in a charm factory

Soffer; Soffer and Silva; Gronau, Grossman and Rosner

- Charm factory, $\psi(3770) \to D\overline{D}$
- Use CP eigenstates $D_\pm \equiv (D \pm \overline{D})/\sqrt{2}$



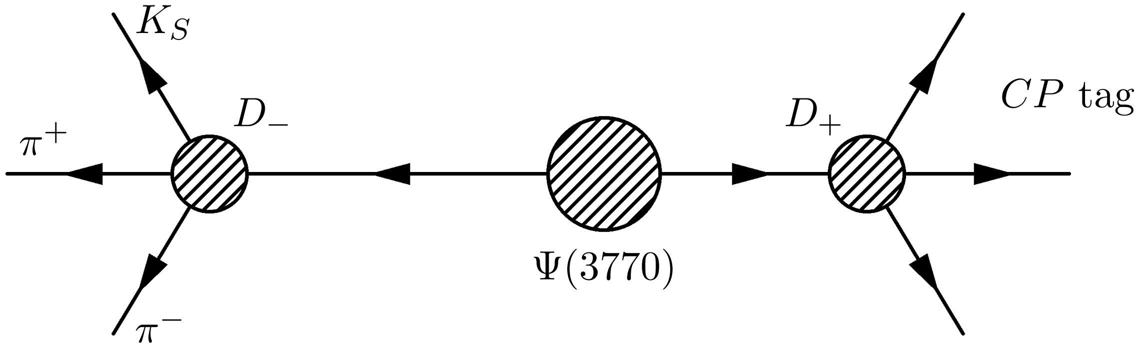
$$\Gamma(D_\pm \to K^+K^{*-}) \propto |A(D \to K^+K^{*-}) \pm A(\overline{D} \to K^+K^{*-})|^2 \propto$$
$$1 + r_D^2 \pm 2r_D\cos\delta_D$$

- $\cos\delta_D$ can be extracted

Measuring c_i

Giri, Grossman, Soffer and Zupan; Atwood and Soni

- Similar analysis holds for multibody D decay to get c_i



$$d\Gamma(D_\pm \to K_S(p_1)\pi^-(p_2)\pi^+(p_3)) \propto$$
$$\left(A_{12,13}^2 + A_{13,12}^2\right) \pm A_{12,13}A_{13,12}\cos(\delta_{12,13} - \delta_{13,12})dp$$

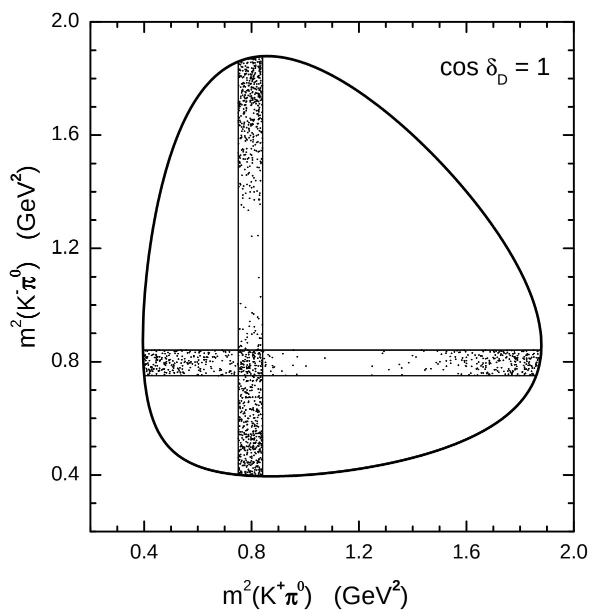
$$c_i = \frac{1}{2}\left[\int_i d\Gamma(D_+ \to K_S\pi^-\pi^+) - \int_i d\Gamma(D_- \to K_S\pi^-\pi^+)\right]$$

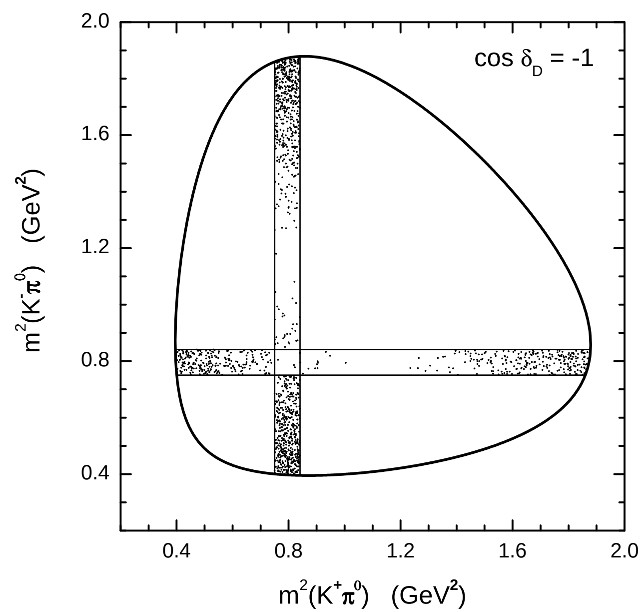
$\cos\delta_D$ from D^* decays

Rosner and Suprun

- Tagged D from $D^* \to D\pi$
- $\cos\delta_D$ can be extracted from the overlap region

$$\Gamma \propto \ |A(D \to K^+K^{*-}) + A(D \to K^-K^{*+})|^2 \propto$$
$$1 + r_D^2 + 2r_D \cos\delta_D$$





$D-\overline{D}$ mixing

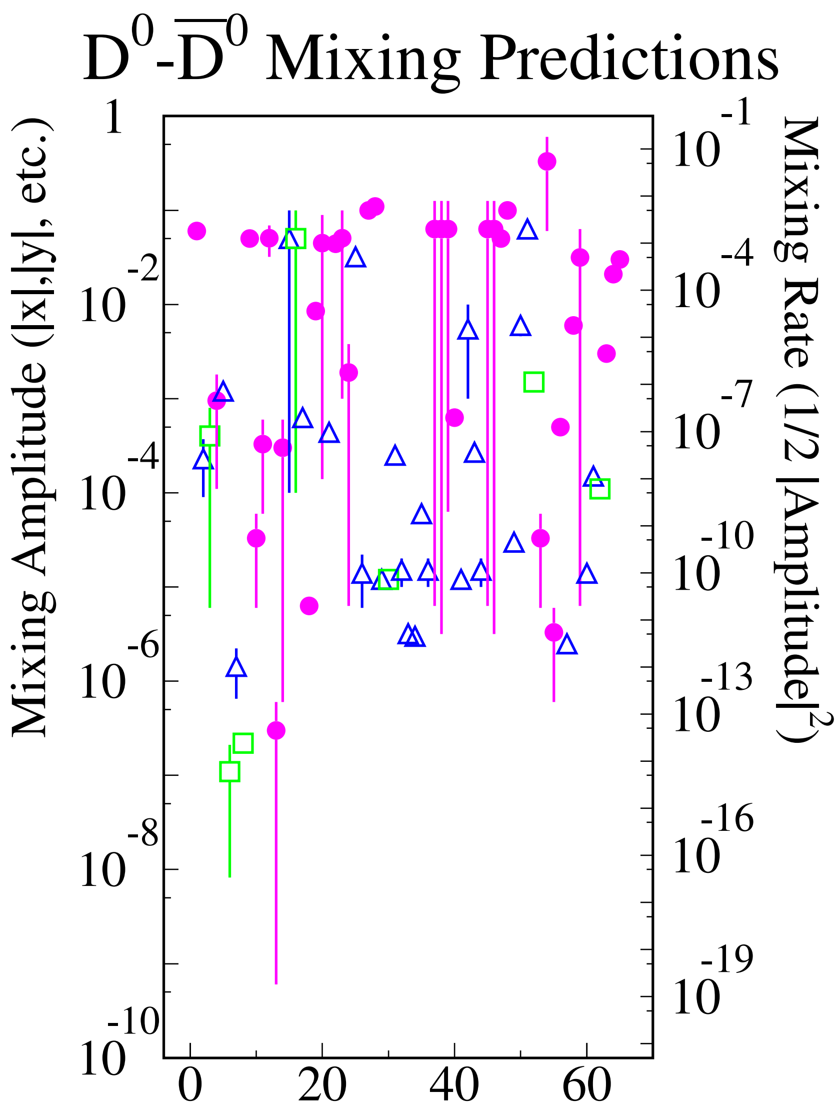
$D - \overline{D}$ mixing

$$x \equiv \frac{\Delta m}{\Gamma} \qquad y \equiv \frac{\Delta\Gamma}{2\Gamma}$$

What are the values of x and y?

- Experimentally: $x, y <$ few $\times 10^{-2}$
- In the SM: $x, y < 10^{-2} - 10^{-3}$
- With new physics, up to experimental bound

$D - \overline{D}$ mixing predictions



H. Nelson, hep-ex/9908021

- ● : NP predictions for x
- △ : SM predictions for x
- □ : SM predictions for y

$\mathrm{SU}(3)$ breaking

- Neglecting the third generation
- $D - \overline{D}$ mixing vanishes in the flavor $\mathrm{SU}(3)$ limit (GIM mechanism)
- It arises only at second order in $\mathrm{SU}(3)$ breaking

$$x, y \sim \sin^2\theta_C \, \varepsilon^2_{\mathrm{SU}(3)}$$

What is the value of $\varepsilon_{\mathrm{SU}(3)}$?

$\varepsilon_{\rm SU(3)}$

In general

$$\varepsilon_{\rm SU(3)} \sim \frac{m_s}{\Lambda}$$

What is Λ?

- $\Lambda \sim m_c \;\Rightarrow\; \varepsilon^2_{\rm SU(3)} \sim 10^{-2} \;\Rightarrow\; x, y \lesssim 10^{-3}$
- $\Lambda \sim Q < m_c \;\Rightarrow\; \varepsilon^2_{\rm SU(3)} \sim 10^{-1} \;\Rightarrow\; x, y \lesssim 10^{-2}$

Can we get better estimates?

Inclusive calculation

- Using quarks to calculate
- The box diagram

$$x \propto m_s^4 \to 10^{-5} \qquad y \propto m_s^6 \to 10^{-7}$$

  - m_s^2 from $\mathrm{SU}(3)$ breaking
  - m_s^2 to compensate the chirality flip of the first insertion
  - (For y only) m_s^2 to lift the helicity suppression of the decay of a scalar meson to two massless fermions

OPE based calculation

Georgi; Bigi and Uraltsev

- Perform an OPE assuming $\Lambda/m_c \ll 1$ with $\Lambda \sim 1$ GeV
- The box diagram is the leading term (4 quark operators)
- Higher order terms have fewer powers of m_s. 8 quark operators have only the minimum m_s^2.
- With some assumptions

$$x, y \lesssim 10^{-3}$$

Exclusive calculation

Falk, Grossman, Ligeti and Petrov

- Using hadrons to calculate
- Assume that there are only small number of final states and sum their contributions to x and y
- It is hard since we need very precise experimental data
- Phase space effects are a calculable source of $\mathrm{SU}(3)$ breaking
- They can be important since large fraction of D decays is to final states close to threshold

Example: PP

Consider only the charged mesons U spin triplet

$$y_U = \sin^2\theta_C \times$$
$$\left[\Phi(\pi^+,\pi^-) + \Phi(K^+,K^-) - \Phi(K^+,\pi^-) - \Phi(K^-,\pi^+)\right]$$

- y_U is the “would-be" value of y, if D only decays to these four states
- We assume that $\mathrm{SU}(3)$ breaking enters only via the phase space function Φ
- The result is explicitly proportional to $\sin^2\theta_C$ and vanishes in $\mathrm{SU}(3)$ limit as m_s^2
- Similar calculations were done for other $\mathrm{SU}(3)$ multiplets

Two–body final states

Final state	$\varepsilon^2_{\mathrm{SU(3)}}$
(PP)s-wave	-0.011
(PV)p-wave	0.14
(VV)s-wave	-0.14
(VV)p-wave	-0.24
(VV)d-wave	1.1

- Only $\mathrm{SU}(3)$ breaking in phase space
- Contribution of PP is “anomalously" small
- Larger $\mathrm{SU}(3)$ breaking for heavier multiplets

Conclusions from this analysis

Fraction of the D width rounded to nearest 5%:

Final state	fraction	$\varepsilon^2_{\mathrm{SU(3)}}$
PP	5%	$O(10^{-2})$
PV	10%	$O(10^{-1})$
VV	10%	$O(1)$
$3P$	5%	$O(1)$
$4P$	10%	$O(1)$

- We expect $y \sim \sin^2\theta_C\, \varepsilon^2_{\mathrm{SU(3)}} \sim 1\%$
- Moral: It would require cancellations to suppress y much below $\sim 1\%$

Inclusive vs exclusive calculations

	inclusive	exclusive
Assumption	heavy charm	light charm
$\mathrm{SU}(3)$ breaking	amplitudes	phase space
Uncertainty	matrix elements	decay rates
Conclusion	$x, y \lesssim 10^{-3}$	$x, y \lesssim 10^{-2}$

Inclusive vs exclusive calculations

	inclusive	exclusive
Assumption	heavy charm	light charm
$\mathrm{SU}(3)$ breaking	amplitudes	phase space
Uncertainty	matrix elements	decay rates
Conclusion	$x, y \lesssim 10^{-3}$	$x, y \lesssim 10^{-2}$

My conclusions:

- The exclusive calculation seems to give a reasonable estimation of y
- It might be that the charm is too light for this OPE

Conclusions

- The problem with γ is statistics. We can use D decay to help in determining all the D hadronic parameters
- We do not know the $D - \overline{D}$ mixing parameters. It is likely that their SM values are close to the current experimental bound. Yet, CP violation in $D - \overline{D}$ mixing is a robust signal of new physics