

# I. THE INTERFACE BETWEEN B PHYSICS, QCD AND HADRON SPECTROSCOPY

Hadron models and QCD needed to interpret B decay data

Peculiar systematics - clues to new physics and inadequacies in hadron models.

Experimental results challenge conventional wisdom

Anomalously high  $\eta'$  in charmless strange final states

Large branching ratios observed for decays to  $a_1(1260)^\pm$

"vector-dominance model"  $W \rightarrow \rho, \pi, a_1$

$D_{s1A} \rightarrow D^*K$  could be strongest excited  $c\bar{s}$  state seen in B decays

Branching ratios  $\approx 1\%$  for unobserved  $B \rightarrow D_{s1}(2536)$

Others around  $10^{-4}$

$$B_q(\bar{b}q) \rightarrow (W^+ \bar{c})q \rightarrow (\bar{c}q)D_{s1A} \rightarrow M(\bar{c}q)D_{s1A} \rightarrow M(\bar{c}q)D^*K$$

The Year 1967-68 at Princeton  
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1. Met young graduate student  
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Not very excited by dispersion  
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2. Invented use of FPR to measure  
 $\epsilon'$  in Kaon Decay (phi factory)

Yael Fitch: It's an experiment for the  
future - but publish it anyway.  
Not just spooky QM - useful!

3. Gave lectures on Quarks

Disregarded by Goldberger, Treiman et al  
Quarks were nonsense!

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## Important lesson learned at Princeton

With a few free parameters

I can fit an elephant.

With a few more I can make him  
wiggle his trunk! E. P. Wigner

Beware of ambulance-chasing theorists  
Running after one piece of data  
with many free parameters.

Example -

$J/\psi \rightarrow p\pi$  but  $\psi' \rightarrow p\pi$

### Yamaguchi Effect

Many calculations - No thought!

Where is the physics?

$J/\psi$  and  $\psi'$  are different!

How and why are they different?

Need more data! New input

Look at  $B \rightarrow J/\psi X$ ;  $B \rightarrow \psi' X$

Look for differences.

## THE $B \rightarrow K\eta$ - $B \rightarrow K\eta'$ PROBLEM

The large experimental branching ratio

$$BR(B^+ \rightarrow K^+\eta') = 6.5 \pm 1.7 \times 10^{-5}$$

Compared with

$$BR(B^+ \rightarrow K^+\eta) < 1.4 \times 10^{-5}$$

$$BR(B^+ \rightarrow K^0\pi^+) = 2.3 \pm 1.1 \times 10^{-5}$$

Still no completely satisfactory explanation

Considerable controversy

## FLAVOR TOPOLOGY APPROACH

Clear Experimental Tests - Two Classes of Diagrams

1. Flavor Singlet Dominance enhances only  $\eta'$  decays
2. s-u quark interference predicts parity-dependent  $\eta'/\eta$   
 $BR(K\eta'X) \gg BR(K\eta X)$  - - - for even parity final states  
 $BR(K\eta X) \gg BR(K\eta'X)$  - - - for odd parity final states

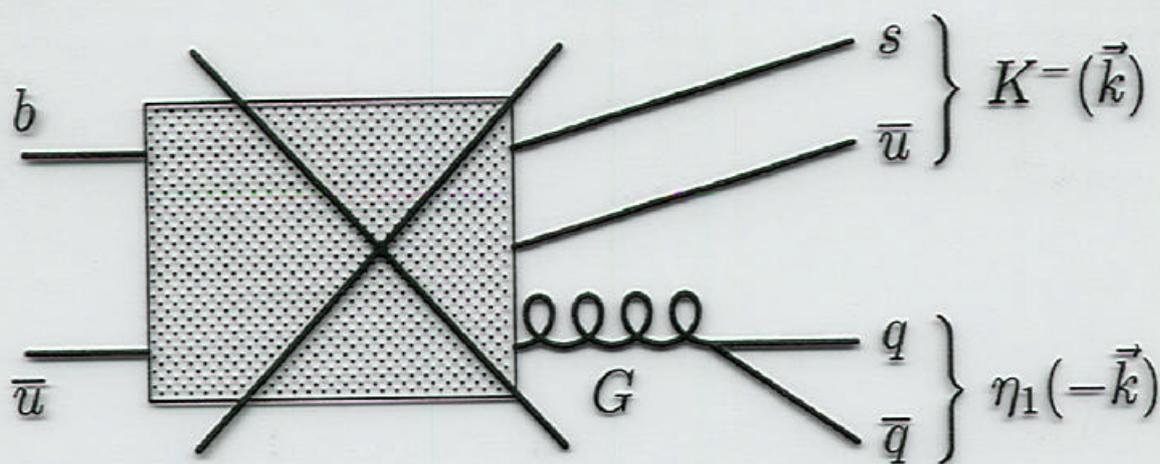


FIG. 1.

en "gluonic hairpin" diagram.  $G$  denotes any number of gluons.

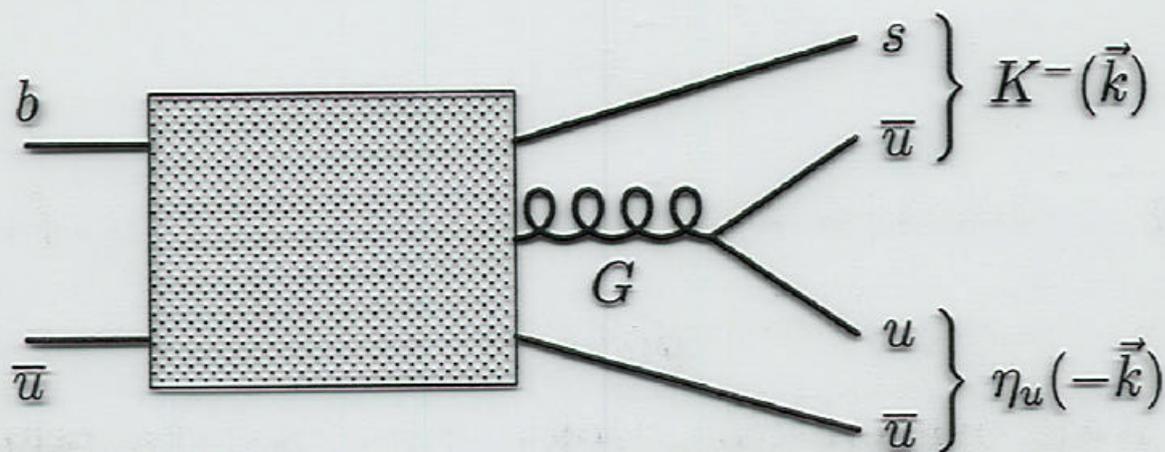


FIG. 2.

strong  $u\bar{u}$  pair creation.  $G$  denotes any number of gluons.

$$\varphi(\vec{k})$$

$$K^* = (-\vec{k})$$

$SU(3)$  says  $\left. \begin{aligned} K^0 &= \pi K^* \\ K^{*0} &= \rho K^* \end{aligned} \right\} \begin{array}{l} \text{How is} \\ SU(3) \text{ broken} \end{array}$

$\delta$   $K^*$

$d$

$\pi^-$   
 $\rho^-$

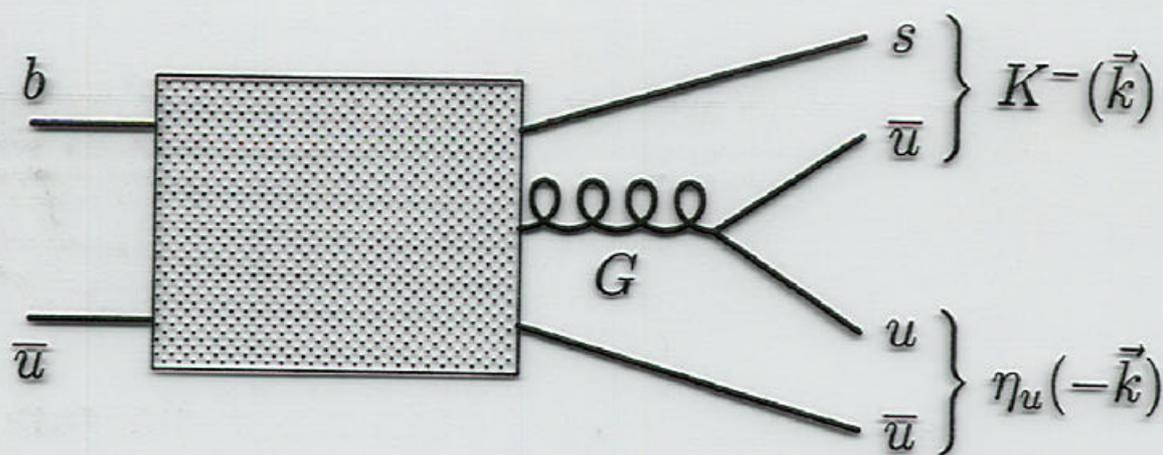


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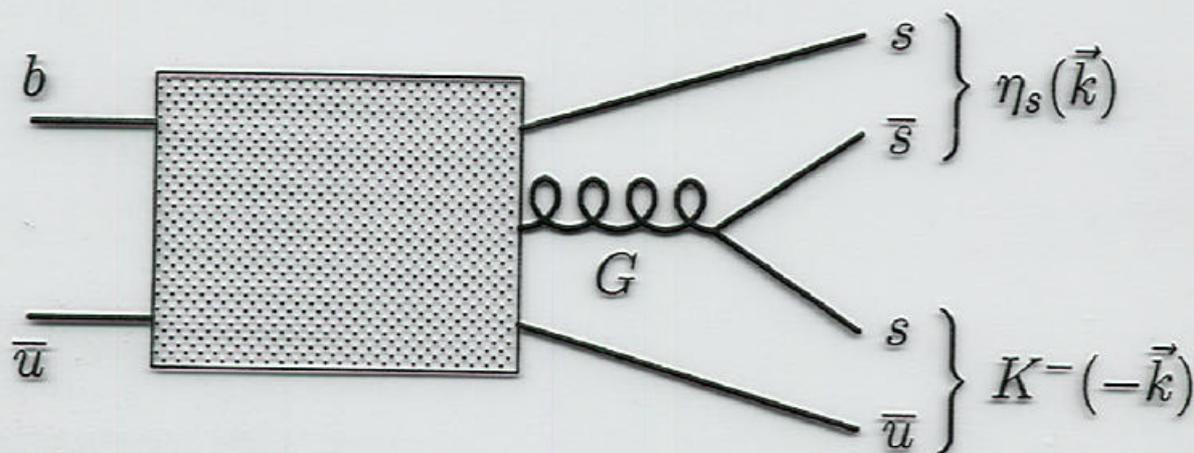


FIG. 3.

Strong  $s\bar{s}$  pair creation.  $G$  denotes any number of gluons.

$$A[\eta_s(\vec{k})K^-(-\vec{k})] \equiv A[\eta_u(-\vec{k})K^-(\vec{k})] \equiv P \cdot A[\eta_u(\vec{k})K^-(-\vec{k})]$$

## Other Experimental consequences of Parity Selection Rules

1.  $K\pi\eta$  and  $K\pi\eta'$  states all have odd parity, even when  $K\pi$  not in  $K^*$ .  
s-u quark interference models predict  $BR(K\eta\pi) \gg BR(K\eta'\pi)$   
when summed over all final states. CLEAR TEST!
2.  $BR(K\eta X) \gg BR(K\eta' X)$  for all cases where missing mass  $M(X) < 2m_\pi$   
Simplifies  $K\eta' X$  data analysis by ruling out large contributions from  
scalar  $K_0(1430) = (93\% - K\pi)$   
tensor  $K_2(1430) = (50\% - K\pi)$   
higher resonances like  $K^*(1680) = (39\% - K\pi)$ .
3. TRANSVERSITY in  $\eta\rho K$ ,  $\eta'\rho K$ ,  $\eta\pi K^*(892)$  and  $\eta'\pi K^*(892)$ .  
Polarization of the vector meson in normal to VPP plane gives PARITY
4. State with  $\eta$  or  $\eta'$  recoiling against  $K^*$  resonance  
State with NATURAL parity  $K^*$  has odd parity - favors  $\eta$  over  $\eta'$ .  
State with UNNATURAL parity  $K^*$  has even parity - favors  $\eta'$  over  $\eta$ .
5. States  $K\eta X$  and  $K\eta' X$  containing  $K\eta$  and  $K\eta'$  resonances  
Even parity resonances favor the  $\eta'$ ;  
odd parity resonances favor the  $\eta$ .

### Possible new physics and CP violation

Parity selection rule violation - Anomalously large  $\eta' X$  decays  
might indicate new physics - New source of CP violation.

Simple cheap test for far-out idea - Compare corresponding  $B^\pm \rightarrow \eta' X$  decays  
Other suspicious cases  $D_s \rightarrow \pi\eta'$  and  $D_s \rightarrow \rho\eta'$ .

TABLE I

Branching Ratios for D Decays into Vector Dominance Modes

	<i>D</i> <sup>0</sup> Decay	<i>D</i> <sup>+</sup> Decay	<i>D</i> <sup>0</sup> Decay	<i>D</i> <sup>+</sup> Decay
<i>M</i> <sup>+</sup>	<i>BR</i> ( <i>K</i> <sup>-</sup> <i>M</i> <sup>+</sup> )	<i>BR</i> ( <i>K̄</i> <sup>0</sup> <i>M</i> <sup>+</sup> )	<i>BR</i> ( <i>K</i> <sup>*-</sup> <i>M</i> <sup>+</sup> )	<i>BR</i> ( <i>K̄</i> <sup>*0</sup> <i>M</i> <sup>+</sup> )
<i>a</i> <sub>1</sub> (1260) <sup>+</sup>	7.3 ± 1.1%	8.0 ± 1.7%		
<i>a</i> <sub>2</sub> (1320) <sup>+</sup>	< 0.3%	< 0.2%		
<i>ρ</i> <sup>+</sup>	10.8 ± 1.0%	6.6 ± 2.5%	6.1 ± 2.4%	2.1 ± 1.3%
<i>π</i> <sup>+</sup>	3.85 ± 0.9%	2.89 ± 0.26%	5.0 ± 0.4%	1.90 ± 0.19%
<i>e</i> <sup>+</sup> <i>ν</i> <sub><i>e</i></sub>	3.66 ± 0.18%	6.7 ± 0.9%	2.02 ± 0.33%	4.8 ± 0.5%
<i>μ</i> <sup>+</sup> <i>ν</i> <sub><i>μ</i></sub>	3.23 ± 0.17%	7.0 ± 3.0%		4.4 ± 0.6%

TABLE II

Branching Ratios for B Decays into Vector Dominance Modes

	<i>B</i> <sup>0</sup> Decay	<i>B</i> <sup>+</sup> Decay	<i>B</i> <sup>0</sup> Decay	<i>B</i> <sup>+</sup> Decay
<i>M</i> <sup>+</sup>	<i>BR</i> ( <i>D</i> <sup>-</sup> <i>M</i> <sup>+</sup> )	<i>BR</i> ( <i>D̄</i> <sup>0</sup> <i>M</i> <sup>+</sup> )	<i>BR</i> ( <i>D</i> <sup>*-</sup> <i>M</i> <sup>+</sup> )	<i>BR</i> ( <i>D̄</i> <sup>*0</sup> <i>M</i> <sup>+</sup> )
<i>a</i> <sub>1</sub> (1260) <sup>+</sup>	0.60 ± 0.33%	0.5 ± 0.4%	1.30 ± 0.27%	1.9 ± 0.5%
<i>ρ</i> <sup>+</sup>	0.79 ± 0.14%	1.34 ± 0.18%	0.68 ± 0.34%	1.55 ± 0.31%
<i>π</i> <sup>+</sup>	0.3 ± 0.04%	0.53 ± 0.05%	0.276 ± 0.021%	0.46 ± 0.04%
<i>ℓ</i> <sup>+</sup> <i>ν</i> <sub><i>ℓ</i></sub>	2.10 ± 0.19%	2.15 ± 0.22%	4.60 ± 0.27%	5.3 ± 0.8%
<i>D</i> <sub>s</sub>	0.8 ± 0.3%	1.3 ± 0.4%	0.96 ± 0.34%	1.2 ± 0.5%
<i>D</i> <sup>*</sup>	1.0 ± 0.5%	0.9 ± 0.4%	2.0 ± 0.7%	2.7 ± 1.0%

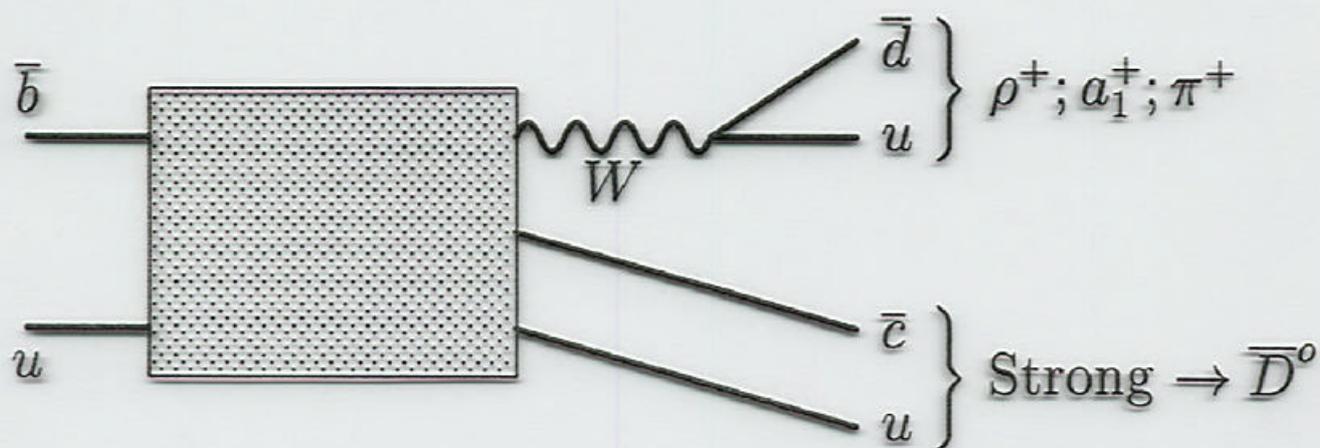


FIG. 2.

Weak vector dominance -  $W \rightarrow u\bar{d}$  diagram.

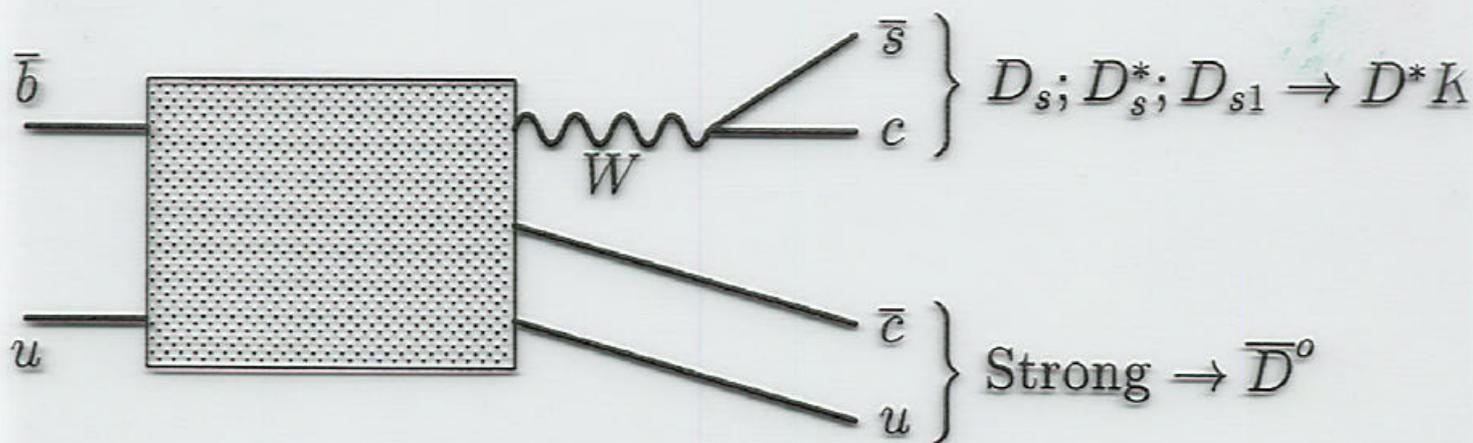


FIG. 3.

Weak vector dominance -  $W \rightarrow c\bar{s}$  diagram.

all  $\swarrow$  seen

$\bar{u}$

$\rightarrow \pi^0, D^+$

seen  $\begin{matrix} 2 \\ 9 \\ 8 \end{matrix}$

$\bar{u}$

$\rightarrow \pi^0$   
 $q_1^0$

$q_1^+ \pi^0$  and  $q_1^0 \pi^+$  —  $I=1$  and  $I=2$   
If  $q_1^0$  is suppressed by strong form factor  
 $I=1$  and  $I=2$  amplitudes cancel.

$\Xi$

$\rightarrow \begin{matrix} K_1 (1270) \\ K_1 (1400) \end{matrix}$

No  $b_1^+$

Two Axial Vector Kaons  
Not How are They mixed —  
SU(3)  
HQET?



## II. UNIVERSALITY OF VECTOR DOMINANCE COUPLINGS

$$R(if\pi) \equiv \frac{BR[i \rightarrow f\pi^+]}{BR[i \rightarrow f\rho^+]} \approx \left| \frac{W^+ \rightarrow \pi^+}{W^+ \rightarrow \rho^+} \right|^2$$

$$R(ifa) \equiv \frac{BR[i \rightarrow fa_1(1260)^+]}{BR[i \rightarrow f\rho^+]} \approx \left| \frac{W^+ \rightarrow a_1^+}{W^+ \rightarrow \rho^+} \right|^2$$

for all states  $i$  and  $f$  with corrections for phase space.

$$(D^+\bar{K}^0\pi) \approx R(D^0K^-\pi) \approx R(B^0D^-\pi) \approx R(B^0D^{*-}\pi) \approx R(B^+\bar{D}^0\pi) \approx R(B^+\bar{D}^{*0}\pi)$$

$$.44 \pm .17 \approx .35 \pm .09 \approx .38 \pm .08 \approx .41 \pm .20 \approx .40 \pm .06 \approx .30 \pm .07$$

$$(D^+\bar{K}^0a) \approx R(D^0K^-a) \approx R(B^0D^-a) \approx R(B^0D^{*-}a) \approx R(B^+\bar{D}^0a) \approx R(B^+\bar{D}^{*0}a)$$

$$1.2 \pm .5 \approx .68 \pm .12 \approx .8 \pm .4 \approx 1.9 \pm 1.0 \approx .37 \pm .30 \approx 1.2 \pm .4$$

Errors large for the  $a_1$  data

Experimental values all consistent with 0.7

More than order of magnitude higher than other upper limits

That such widely different decays should agree so well is impressive

Suggests further investigation.

$$R(D^0K^-a_2^+) < 0.019 \pm 0.002; \quad R(D^+\bar{K}^0a_2^+) < 0.045 \pm 0.017$$

### III. RELATIONS FROM ISOSPIN INVARIANCE

Strong form factors  $[(\bar{c}q) \rightarrow M(\bar{c}q)]_S$  conserve isospin

Vector-dominance predicts equal widths  $\Gamma$  for neutral and charged decays

$$BR[B^+(\bar{b}u) \rightarrow M(\bar{c}u)^0 M(c\bar{s})^+] \approx BR[B^0(\bar{b}d) \rightarrow M(\bar{c}d)^- M(c\bar{s})^+]$$

Exact consequences of isospin invariance

Satisfied by semileptonic and the charmed-strange decays

$$BR[B^+(\bar{b}u) \rightarrow M(\bar{c}u)^0 M(u\bar{d})^+] \approx BR[B^0(\bar{b}d) \rightarrow M(\bar{c}d)^- M(u\bar{d})^+]$$

Can be violated by final state interactions

Satisfied with large errors by  $a_1$  decays

Disagreements for  $\rho$  and  $\pi$  decays.

Sharpening disagreements by reducing experimental errors

Can shed light on strength of final state interactions

$$A(B^0 \rightarrow \bar{D}^0 \rho^0) = \sqrt{\frac{2}{3}} \cdot A_3 - \sqrt{\frac{1}{3}} \cdot A_1; \quad A(B^0 \rightarrow D^- \rho^+) = \sqrt{\frac{1}{3}} \cdot A_3 + \sqrt{\frac{2}{3}} \cdot A_1$$

For estimate and upper bound on strong phase difference  $\phi$

Assume observed neutral decay amplitude arises from phase difference

Vanishes when  $\phi = 0$

$$\sqrt{2} \cdot A_3 = e^{i\phi} \cdot A_1; \quad \sin^2 \frac{\phi}{2} = \frac{9}{8} \cdot \frac{BR(B^0 \rightarrow \bar{D}^0 \rho^0)}{BR(B^0 \rightarrow \bar{D}^0 \rho^0) + BR(B^0 \rightarrow D^- \rho^+)}$$

Experimental the upper limit is 0.06.

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