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# Factorization tests in hadronic B decays at BaBar

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On behalf of BaBar Collaboration





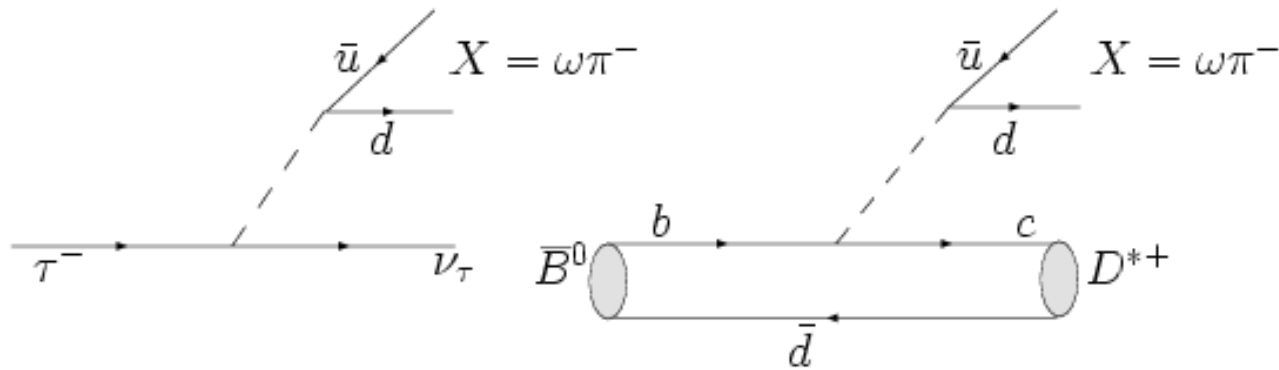
# Introduction

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- Frameworks to understand the hadronic decay of heavy mesons: HQET/SCET, Factorization hypothesis...
- $B \rightarrow D^{(*)} X$  ( $X$  = light hadronic state) is a good testing ground of factorization in hadronic  $B$  decay (examining decay rate as a function of the invariant mass of  $X$ ).
- $B \rightarrow D^* \omega \pi$  allows a precision study of the dependence of the corrections to factorization on the invariant mass of the light hadronic state (Ligeti, Luke, Wise, Phys. Lett. B 507, 142 (2001)).
- BF measurements of  $B \rightarrow D\pi$ ,  $D^*\pi$ ,  $D^{**}\pi$  can give useful information for factorization.
- We report the recent results of branching fraction measurements and analyses of decays  $B \rightarrow D^* \omega \pi$  and  $B \rightarrow D^{(*,**)} \pi$  with the BaBar data sample.

# $B \rightarrow D^* \omega \pi$

Factorization : compare  $B \rightarrow D^* \omega \pi$  with  $\tau$  decay



$$D^{*+} \rightarrow D^0 \pi^+$$

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

$$\omega \rightarrow \pi^+ \pi^- \pi^0$$

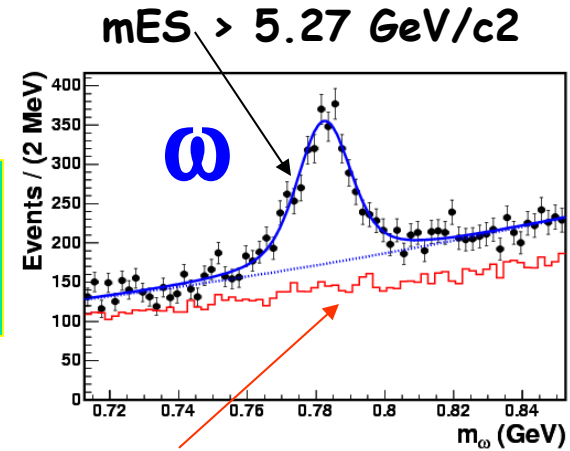
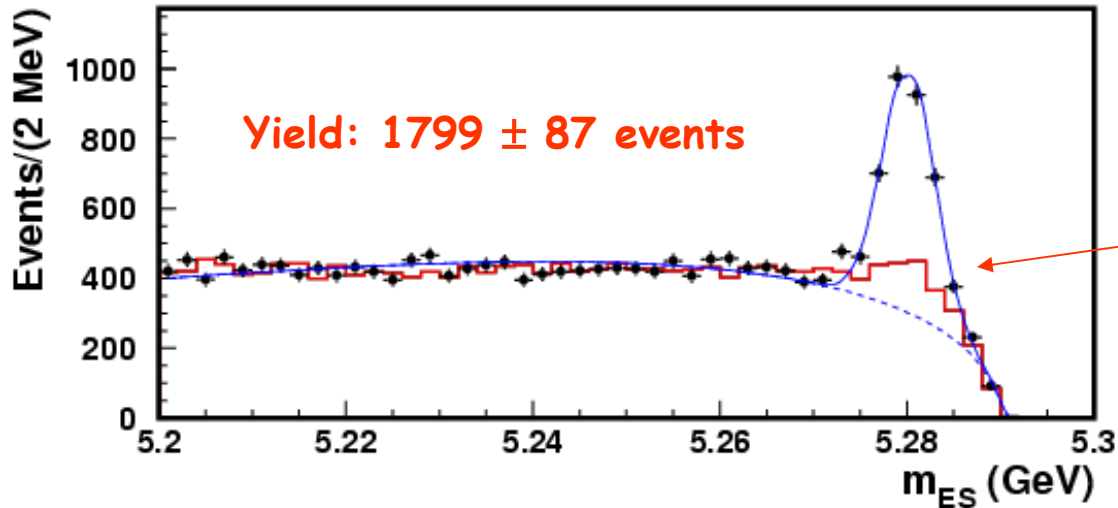
# B $\rightarrow$ D\* $\omega$ $\pi$

Based on 232 M BB

$$B^0 \rightarrow D^{*-} \omega \pi^+$$

$$BR = 2.88 \pm 0.21 \text{ (stat)} \pm 0.31 \text{ (syst)} (10^{-3})$$

$$\text{CLEO: } 2.9 \pm 0.3 \pm 0.4 (10^{-3})$$



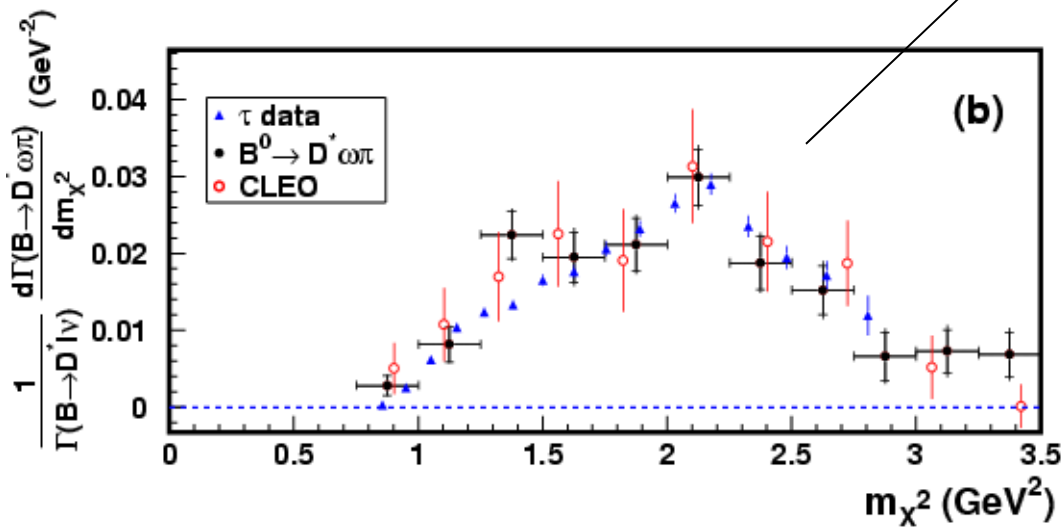
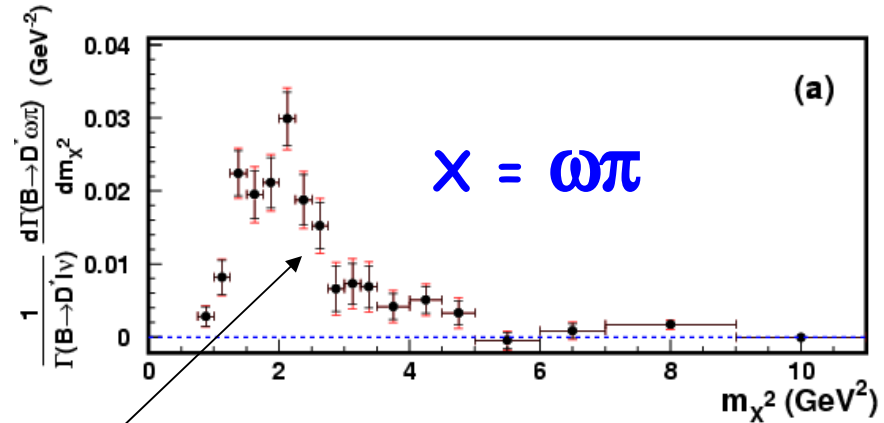
$m_{ES}: 5.20\text{-}5.25 \text{ GeV}/c^2$

$B^0 \rightarrow D^* \pi \pi \pi \pi^0$   
non-resonant  
contamination

# B → D\* ω π

$m^2(\omega\pi)$  :

not associated with any narrow resonance. Wide range in  $m^2(\omega\pi)$  can be studied.

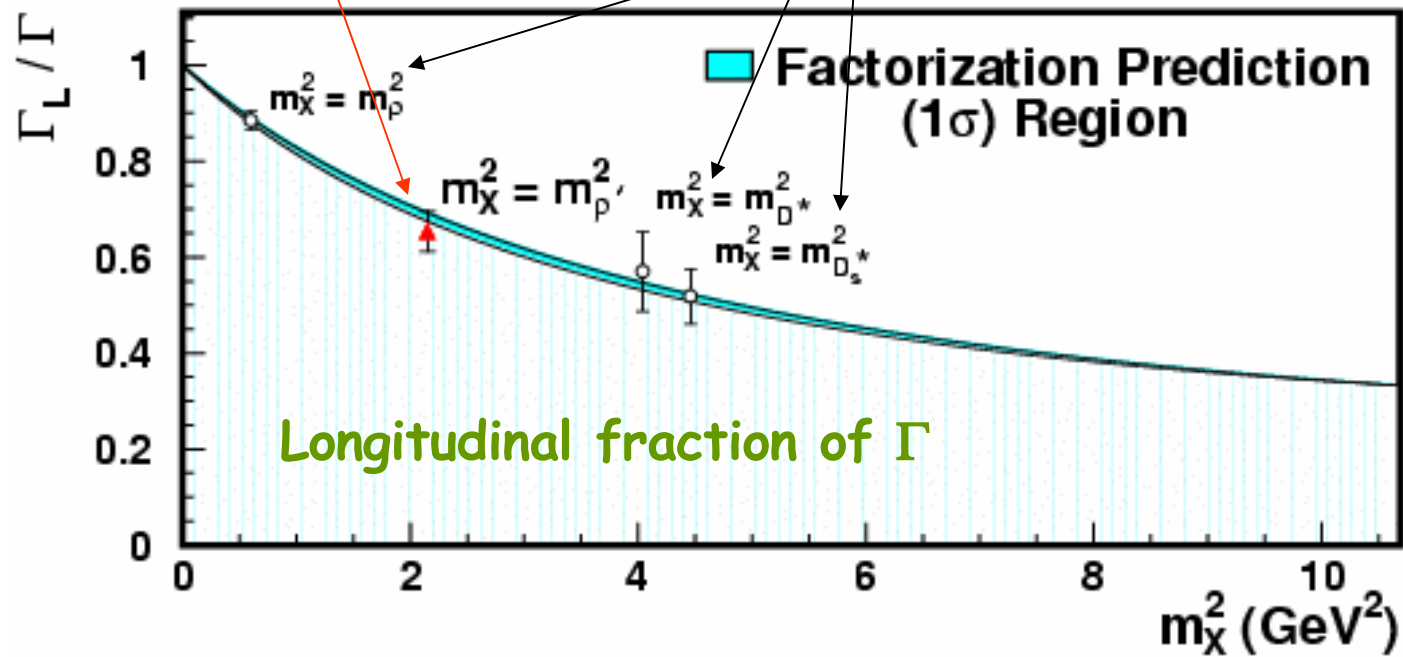


Distribution agrees well with predictions based on factorization in the region  $< 2.8 \text{ GeV}^2$  covered by the  $\tau$  decay

# B $\rightarrow$ D\* $\omega$ $\pi$

This analysis

From study of B  $\rightarrow$  D\* $\rho$ , D\*D\*, D\*D<sub>s</sub>\*



Very good agreement with factorization prediction

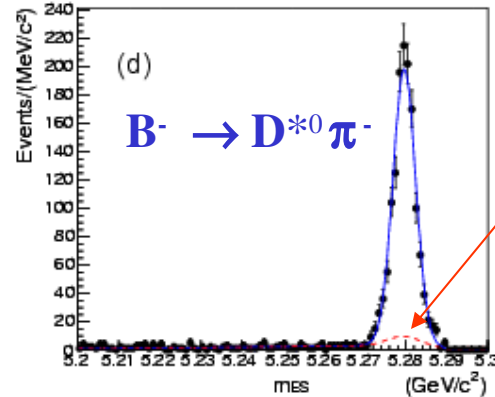
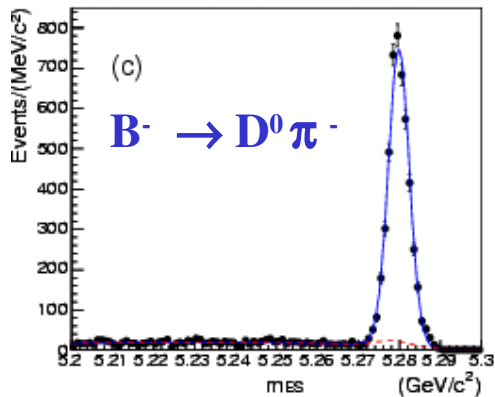
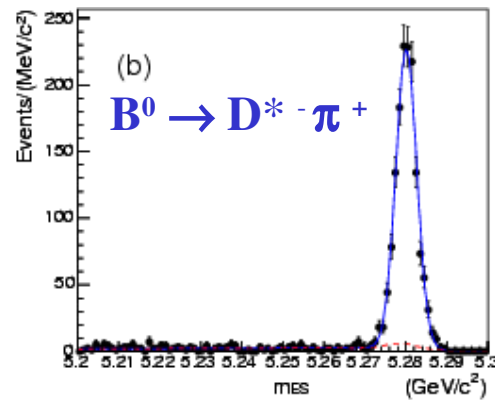
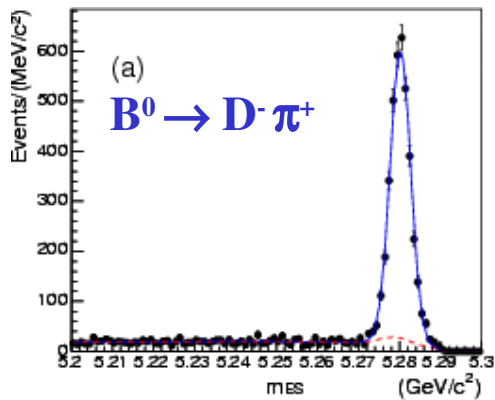

$$B \rightarrow D \pi, D^* \pi, D^{**} \pi$$

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- Color-favored two-body decay.
- Branching fractions:
  - known at ~10% (PDG), better precision is needed to test the factorization hypothesis.
  - Access to isospin strong phase difference, spin symmetry and factorization corrections in the HQET model.
- Two methods of measurements:
  - full reconstruction of B vs. missing mass method.

# $B \rightarrow D\pi, D^*\pi$ (full reconstruction method)

$m_{ES}$  distribution



Based on 65 M BB

Background is modeled by signal-removed MC.

Peaking background is about 2-4% depending on mode.





## $B \rightarrow D\pi, D^*\pi$ (full reconstruction method)

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Systematic errors are estimated from various sources



## B → Dπ, D\*π (full reconstruction method)

### Branching fractions:

<i>Mode</i>	<i>n</i>	<i>n<sub>pb</sub></i>	$\mathcal{B} (\times 10^{-3})$
$\bar{B}^0 \rightarrow D^+ \pi^-$	$3593 \pm 63$	$114 \pm 14$	$2.63 \pm 0.05 \pm 0.22$
$\bar{B}^0 \rightarrow D^{*+} \pi^-$	$1411 \pm 39$	$28 \pm 6$	$2.79 \pm 0.08 \pm 0.18$
$B^- \rightarrow D^0 \pi^-$	$4606 \pm 70$	$89 \pm 14$	$4.90 \pm 0.07 \pm 0.23$
$B^- \rightarrow D^{*0} \pi^-$	$1297 \pm 39$	$51 \pm 8$	$5.52 \pm 0.17 \pm 0.43$

### Ratio :

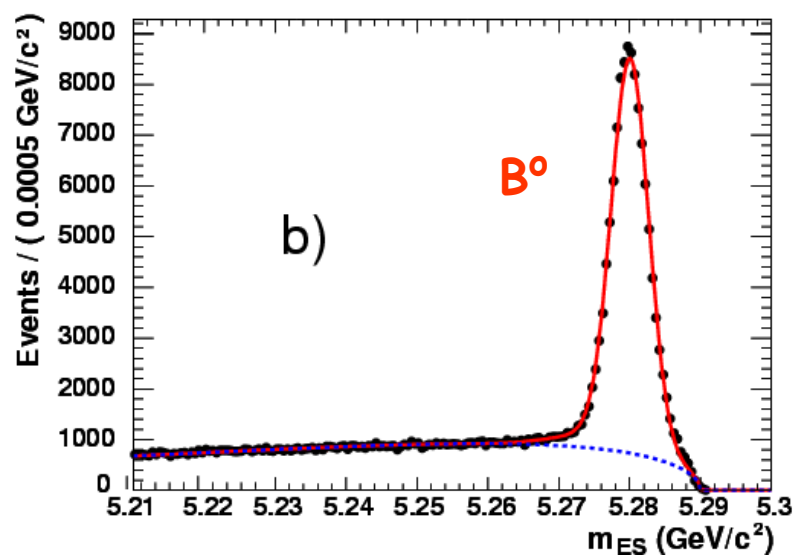
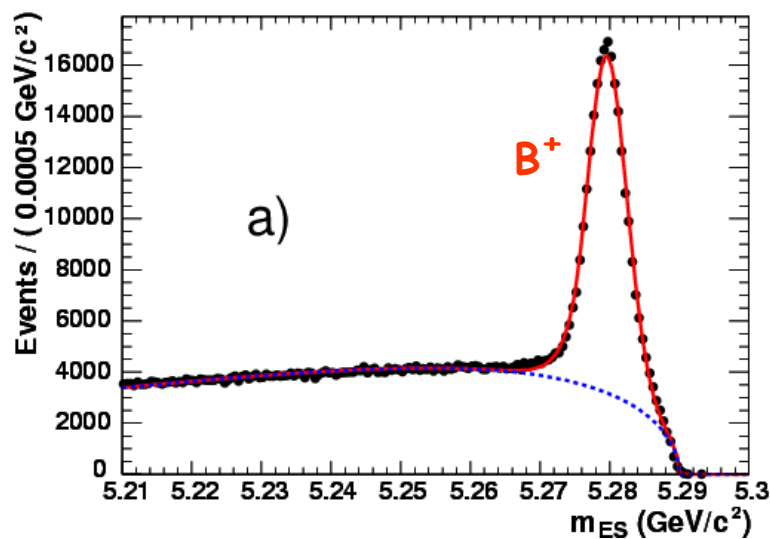
$$\mathcal{B}(B^0 \rightarrow D^{*-} \pi^+) / \mathcal{B}(B^0 \rightarrow D^- \pi^+) = 1.06 \pm 0.03 \pm 0.09$$

$$\mathcal{B}(B^- \rightarrow D^{*0} \pi^-) / \mathcal{B}(B^- \rightarrow D^0 \pi^-) = 1.12 \pm 0.04 \pm 0.09$$

# B → D π, D\* π, D\*\* π (missing mass method)

Based on 231 M BB

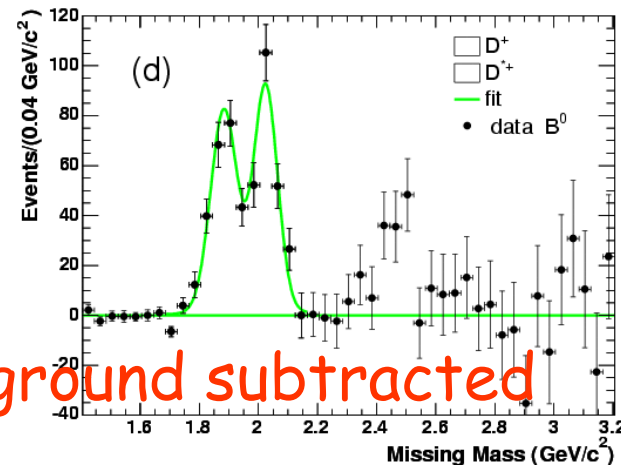
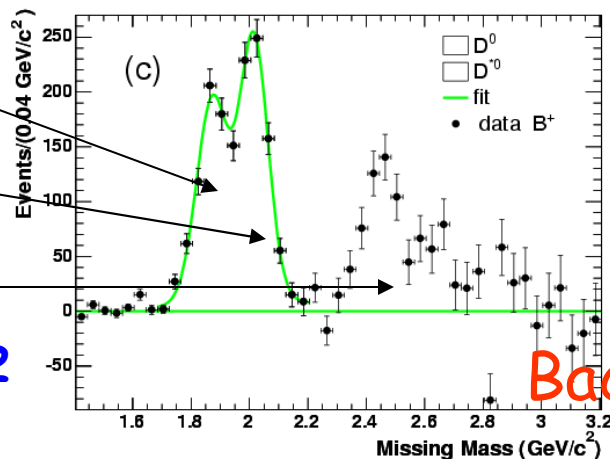
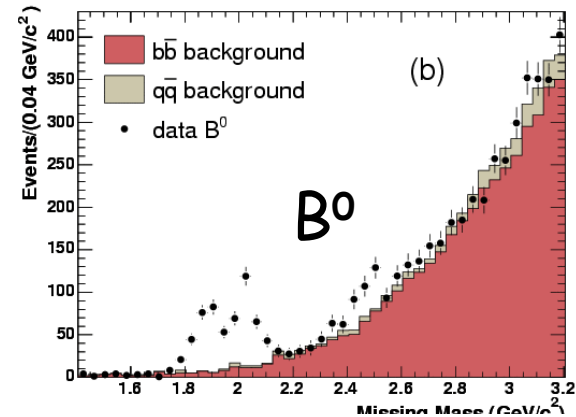
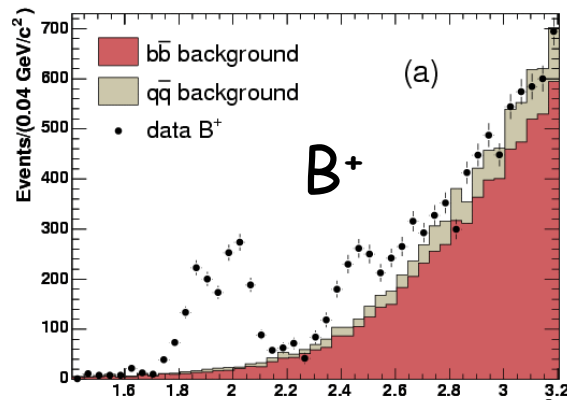
One B is reconstructed via  $B \rightarrow D^{(*)} \pi, D^{(*)} \rho, D^{(*)} a_1,$   
 The other  $B \rightarrow X\pi, X: D^{(*, **)}$  missing mass.



Reconstructed B

# $B \rightarrow D \pi, D^* \pi, D^{**} \pi$ (missing mass method)

Missing mass of X:



Background subtracted

## B → D π, D\*π, D\*\*π (missing mass method)

### Result:

$$\begin{aligned} \mathcal{B}(\bar{B}^0 \rightarrow D^+ \pi^-) &= 3.00 \pm 0.23 \pm 0.23 \times 10^{-3} \\ \mathcal{B}(\bar{B}^0 \rightarrow D^{*+} \pi^-) &= 2.97 \pm 0.23 \pm 0.24 \times 10^{-3} \\ \mathcal{B}(\bar{B}^0 \rightarrow D^{**+} \pi^-) &= 2.32 \pm 0.65 \pm 0.88 \times 10^{-3} \\ \mathcal{B}(B^- \rightarrow D^0 \pi^-) &= 4.49 \pm 0.21 \pm 0.23 \times 10^{-3} \\ \mathcal{B}(B^- \rightarrow D^{*0} \pi^-) &= 5.13 \pm 0.22 \pm 0.28 \times 10^{-3} \\ \mathcal{B}(B^- \rightarrow D^{**0} \pi^-) &= 5.50 \pm 0.52 \pm 1.04 \times 10^{-3} \end{aligned}$$

$$\begin{aligned} \mathcal{B}(B^- \rightarrow D^{*0} \pi^-) / \mathcal{B}(B^- \rightarrow D^0 \pi^-) &= 1.14 \pm 0.07 \pm 0.04 \\ \mathcal{B}(B^- \rightarrow D^{**0} \pi^-) / \mathcal{B}(B^- \rightarrow D^0 \pi^-) &= 1.22 \pm 0.13 \pm 0.23 \\ \mathcal{B}(\bar{B}^0 \rightarrow D^{*+} \pi^-) / \mathcal{B}(\bar{B}^0 \rightarrow D^+ \pi^-) &= 0.99 \pm 0.11 \pm 0.08 \\ \mathcal{B}(\bar{B}^0 \rightarrow D^{**+} \pi^-) / \mathcal{B}(\bar{B}^0 \rightarrow D^+ \pi^-) &= 0.77 \pm 0.22 \pm 0.29 \end{aligned}$$

## Isospin Analysis of $B \rightarrow D^{(*)}\pi$ System

Branching fractions of color-favored as well as color-suppressed can be used to determine the **relative strong-interaction phase  $\delta$**  between the isospin amplitudes  $A_{1/2}$  and  $A_{3/2}$  .

(J.L.Rosner, Phys. Rev. D 60 074029 (1999))

$$\cos \delta = \frac{3\Gamma(D^+\pi^-) + \Gamma(D^0\pi^-) - 6\Gamma(D^0\pi^0)}{6\sqrt{2}|A_{1/2}A_{3/2}|}$$

$$|A_{3/2}|^2 = \frac{1}{3}\Gamma(D^0\pi^-)$$

$$|A_{1/2}|^2 = \Gamma(D^+\pi^-) + \Gamma(D^0\pi^0) - \frac{1}{3}\Gamma(D^0\pi^-)$$

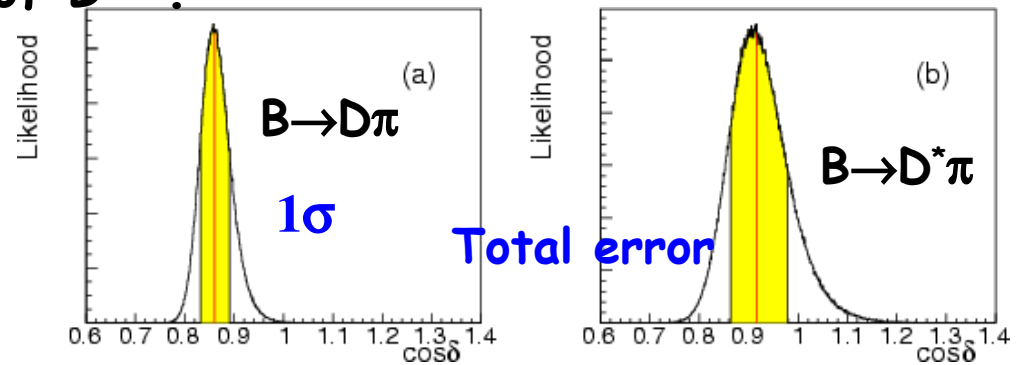
(notation modified)

Non-zero  $\delta \Rightarrow \cos(\delta)$  differs from 1  $\Rightarrow$  Final states interaction

# Isospin Analysis of $B \rightarrow D^{(*)}\pi$ System : $\delta$

Based on the BFs from full reconstruction of B and PDG color-suppressed modes of  $B^0$ .

We use  $10^6$  Monte Carlo experiments to treat the total systematic error (and total error).



Suggest final state interaction in  $B \rightarrow D \pi$

$$B \rightarrow D\pi \quad \cos \delta = 0.860^{+0.007+0.029}_{-0.006-0.028}$$

$$B \rightarrow D^*\pi \quad \cos \delta^* = 0.917^{+0.018+0.059}_{-0.016-0.051}$$

$$\text{CLEO: } B \rightarrow D \pi : \cos\delta = 0.877 \pm 0.03^{+0.046}_{-0.044}$$

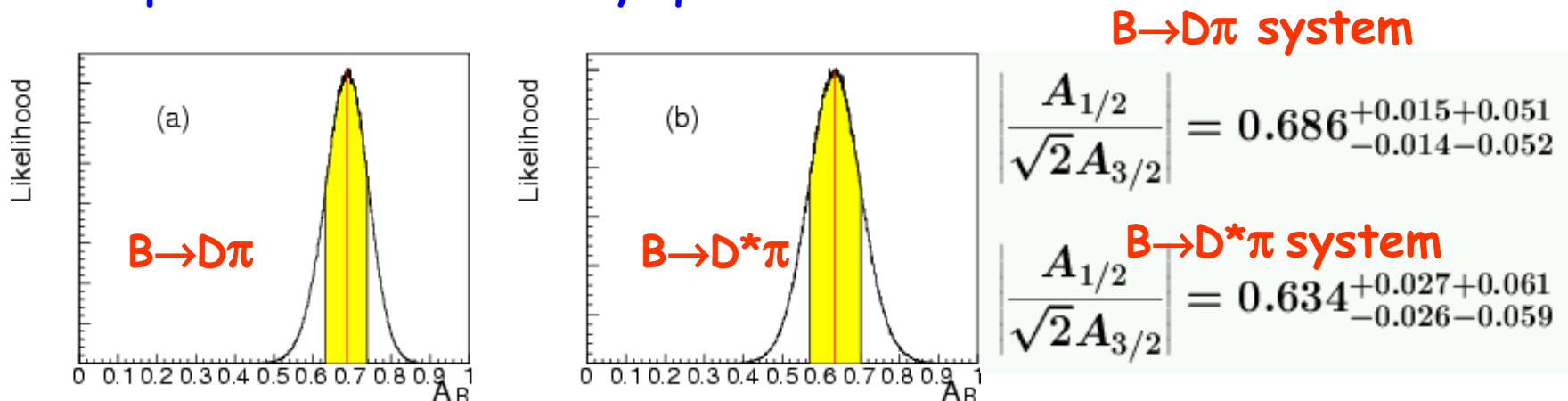
(S. Ahmed et al., Phys. Rev. D 66 031101 (2002).)

# Isospin Analysis of $B \rightarrow D^{(*)}\pi$ System

QCD factorization gives:

$$A_R \equiv \frac{A_{1/2}}{\sqrt{2}A_{3/2}} = 1 + O(\Lambda_{QCD}/m_b)$$

The deviation of  $A_R$  from 1 is a measure of the departure from the heavy-quark limit



CLEO: S. Ahmed et al., Phys. Rev. D 66 031101 (2002).

$B \rightarrow D\pi$  :  $A_R = 0.69 \pm 0.03 \pm 0.06 \pm 0.06$ ,





## Summary

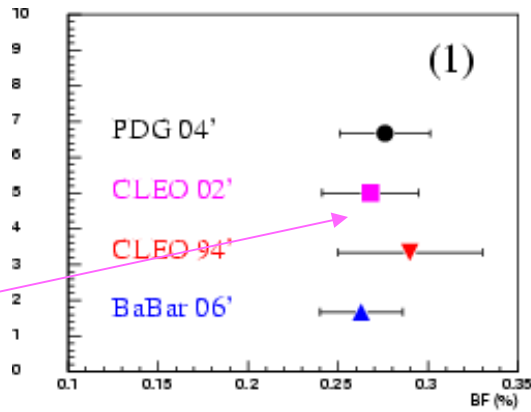
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- We measured the BF of  $B^0 \rightarrow D^{*0} \omega \pi$  and the result is in good agreement of the factorization prediction.
- We measured the BF of color-favored  $B \rightarrow D\pi$ ,  $D^*\pi$  and  $D^{**}\pi$  with better precision.  
The isospin analysis suggest the final state interactions in  $B \rightarrow D\pi$  system.

# (Backup) Branching Fraction Comparison

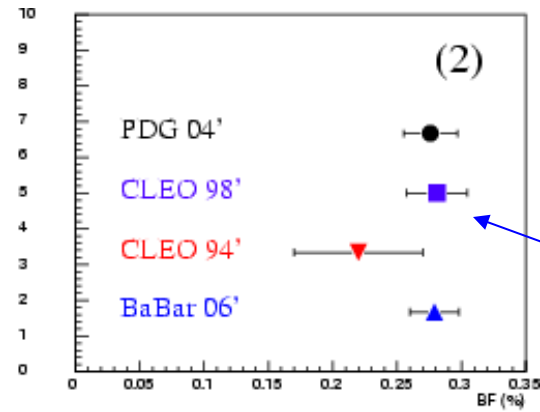
$B^0 \rightarrow D\pi^+$

Full rec.

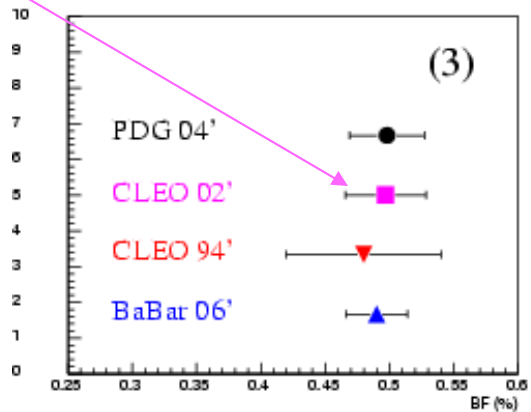


$B^0 \rightarrow D^*\pi^+$

Partial Rec.



$B^- \rightarrow D^0\pi^-$



$B^- \rightarrow D^{*0}\pi^-$

