CLEO Results on $B \to D^*\rho$ and $B \to D\pi$

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Introduction

CLEO Detector

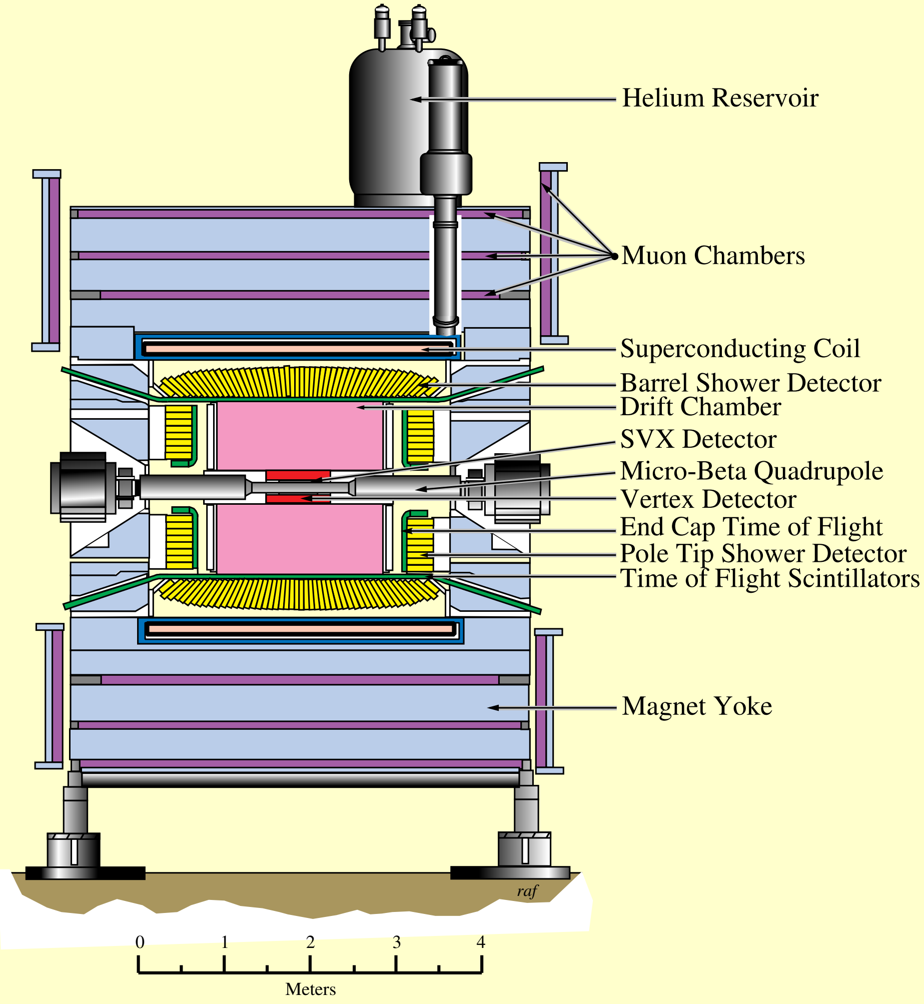
- ★ Operated at Cornell Electron Storage Ring (CESR)
- ★ Magnetic field: 1.5 T
- ★ Excellent tracking resolution and efficiency, as well as superb electromagnetic calorimetry
- ★ Two phases: CLEO II and CLEO II.V
  - ♦ Silicon detector
  - ♦ Argon-ethane $\longrightarrow$ Helium-propane

Data Sample

Analyses presented in this talk are based on CLEO II/II.V datasets of

- ★ An integrated luminosity of 9.1 fb^{-1} collected at the $\Upsilon(4S)$, corresponding to 9.7 M $B\bar{B}$ pairs
- ★ An integrated luminosity of 4.6 fb^{-1} off-resonance data: to eliminate continuum background

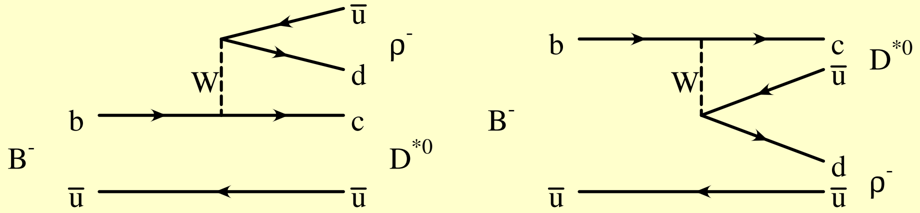
(More data from CLEO III)



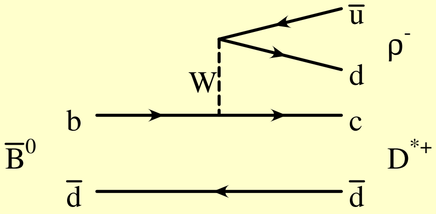
Measurements of the Branching Fractions and Helicity Amplitudes in $B \to D^* \rho$ Decays

Motivation

- Feymann Diagrams for $B \to D^* \rho$

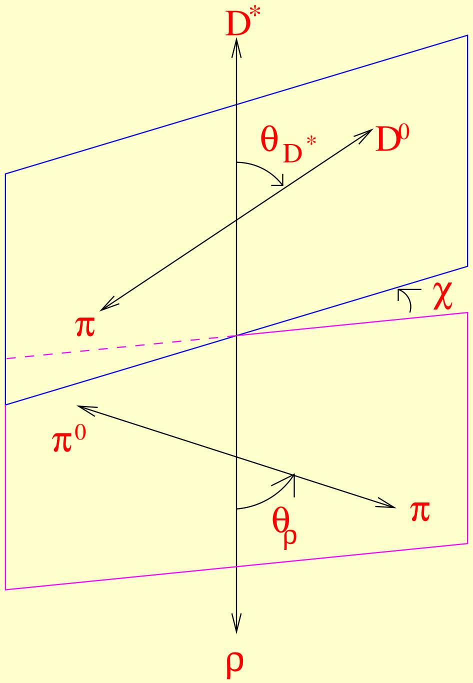


$B^- \to D^{*0} \rho^-$



$\bar{B}^0 \to D^{*+} \rho^-$

- Decay Angles



- Angular Distribution

$$\frac{d^3\Gamma}{d\cos\theta_{D^*}\, d\cos\theta_\rho\, d\chi} = \frac{9}{32\pi} \left| 2H_0 \cos\theta_{D^*} \cos\theta_\rho + (H_+ e^{i\chi} + H_- e^{-i\chi}) \sin\theta_{D^*} \sin\theta_\rho \right|^2 .$$

- Goal: Branching fractions, relative strength a_2/a_1
  Helicity amplitudes (and Γ_L/Γ)

- History:

★ CLEO (PRD50, 43(1994)): $(\cos\theta_{D^*}, \cos\theta_\rho)$, 0.89 fb^{-1} data
★ CLEO (CLEO CONF 98): $(\cos\theta_{D^*}, \cos\theta_\rho, \chi)$, 3.1 fb^{-1} data

Event Selection

- Charged tracks
  - ★ If $p > 250$ MeV
    - ♦ Coming from interaction point and well measured
    - ♦ Excluding identified leptons
    - ♦ 2.5σ consistency of dE/dx for K and π
  - ★ Soft tracks

    Only looser requirement of consistency with originating from interaction point
- π^0: pair of photons from barrel calorimeter
  - ★ $E_\gamma > 30 - 65$ MeV
  - ★ $|M_{\gamma\gamma} - M_{\pi^0}| \leq 2.5\sigma$
- D^0
  - ★ $|M_{D^0}^{cnd} - M_{D^0}| \leq 2.5\sigma$
  - ★ Use densely populated region of the Dalitz plane for $D^0 \to K^-\pi^+\pi^0$
- D^*: $|\Delta M - \Delta M_{PDG}| \leq 2.5\sigma$
- ρ^-: $|m - M_\rho| \leq 150$ MeV
- B: Use beam constrained mass $M = \sqrt{E_{beam}^2 - p_B^2}$
  - ★ $|\Delta E \equiv \sum_i E_i - E_{beam}| \leq 2.5\sigma$
  - ★ Suppress background from continuum
    - ♦ Ratio of Fox-Wolfram moments, $R_2 < 0.5$
    - ♦ $|\cos\theta_B| < 0.95$
    - ♦ $|\cos\Theta_S| < 0.7 - 0.8$

Unbinned Maximum Likelihood Fit

$$\mathcal{L} = \prod_{j=1}^{3} \frac{e^{-\nu_j}\nu_j^{n_j}}{n_j!} \prod_{i=1}^{n_j} \frac{n_j^S \cdot \mathcal{P}_{ji}^S(M, m, \cos\theta_{D^*}, \cos\theta_\rho, \chi) + n_j^B \cdot \mathcal{P}_{ji}^B(M, m, \cos\theta_{D^*}, \cos\theta_\rho, \chi)}{n_j^S + n_j^B}.$$

Signal Probability Distribution Function

- Gaussian function for $M = \sqrt{E_{beam}^2 - p_B^2}$
- BW with Blatt-Weiskopf form factor for m
- Angular distribution corrected by detector acceptance

Background Probability Distribution Function

- Argus-type background function
- Flat distribution for m
- $P_2(\cos\theta_{D^*})P_2(\cos\theta_\rho)P_1(\cos(\chi+\chi_0))$, parameterized with B sideband events

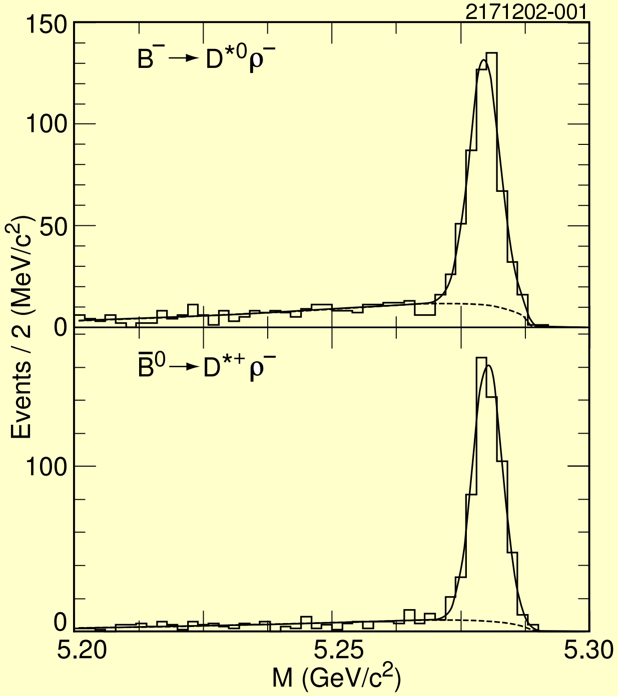
Acceptance

- Functional form: $\epsilon(\cos\theta_{D^*}, \cos\theta_\rho, \chi) = \epsilon_2(\cos\theta_{D^*}, \cos\theta_\rho) \cdot \epsilon_1(\chi)$
  - ★ Pretty flat along χ
  - ★ Coupling between $\cos\theta_{D^*}$ and $\cos\theta_\rho$
- Acceptance depends on helicity amplitudes
- Acceptance is determined from MC
- Iteration method is applied

Branching Fractions

$$\mathcal{B} = \frac{N^{\text{obs}}}{2N_{B\bar{B}} \cdot f \cdot \epsilon_j \cdot Br(D^*) \cdot Br(D^0)_j}.$$

- Algorithm
  - To get N^{obs}
    - All B candidates with $5.20 < M < 5.30$ GeV
    - Angular distributions are ignored



Number of signal events and efficiencies

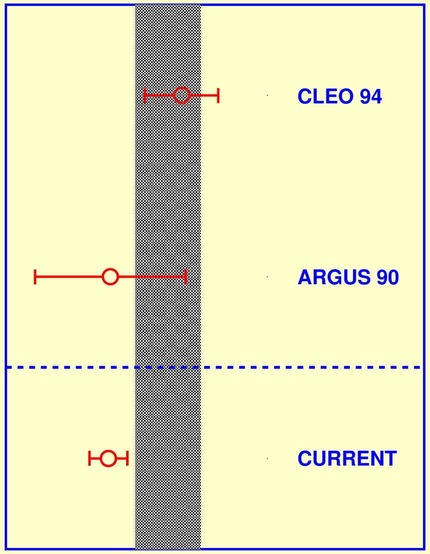
B	D^0 decay mode	n^S	ϵ (%)
B^-	$K^-\pi^+$	148.9 ± 13.8	6.56 ± 0.04
	$K^-\pi^+\pi^0$	177.4 ± 16.6	2.20 ± 0.02
	$K^-\pi^+\pi^-\pi^+$	136.0 ± 15.2	3.04 ± 0.03
$\bar{B}^0$	$K^-\pi^+$	196.3 ± 14.6	10.88 ± 0.05
	$K^-\pi^+\pi^0$	196.1 ± 16.4	3.67 ± 0.03
	$K^-\pi^+\pi^-\pi^+$	170.6 ± 13.9	4.46 ± 0.03

- Assuming $f_{+-}/f_{00} = 1$
- Efficiencies depend on helicity amplitudes

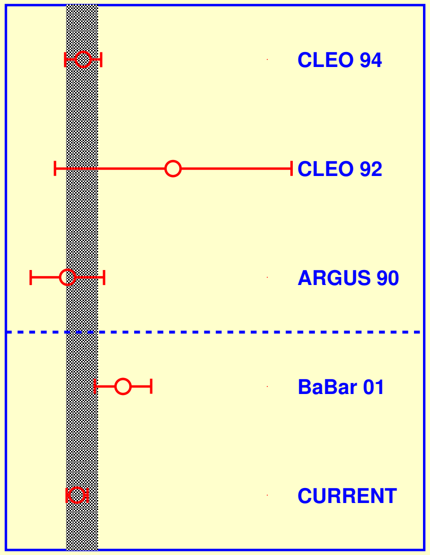
$B \to D^* \rho$

Branching fractions

$$\mathcal{B}(B^- \to D^{*0}\rho^-) = (0.98 \pm 0.06 \pm 0.16 \pm 0.05)\%,$$
$$\mathcal{B}(\bar{B}^0 \to D^{*+}\rho^-) = (0.68 \pm 0.03 \pm 0.09 \pm 0.02)\%.$$



$B^- \to D^{*0}\rho^-$



$\bar{B}^0 \to D^{*+}\rho^-$

Systematic uncertainties

- 1st systematic uncertainties
  - The number of $B\bar{B}$ pairs (2%)
  - The background shape (3%)
  - Monte Carlo statistics $(1-2\%)$
  - Detection efficiency $(10-18\%)$
- 2nd systematic uncertainties:
  Uncertainties in the D^* and D^0 decay branching fractions
- Others:
  - Non-resonant $D^*\pi\pi^0$ and non-ρ^- components:
    Appear small
  - Helicity amplitude dependence of the efficiency:
    Negligible

a_2/a_1

- Effective coupling strengths
  - ★ Color-enhanced: a_1
  - ★ Color-suppressed: a_2

  Together with factorization hypothesis predict non-leptonic decay rates
- Comparing hadronic B^- and $\bar{B}^0$ decays disentangles relative contributions from external and internal spectator decays

  BSW model predicts:

$$R_4 = \frac{\mathcal{B}(B^- \to D^{*0}\rho^-)}{\mathcal{B}(\bar{B}^0 \to D^{*+}\rho^-)} \approx (1 + 0.75 a_2/a_1)^2.$$

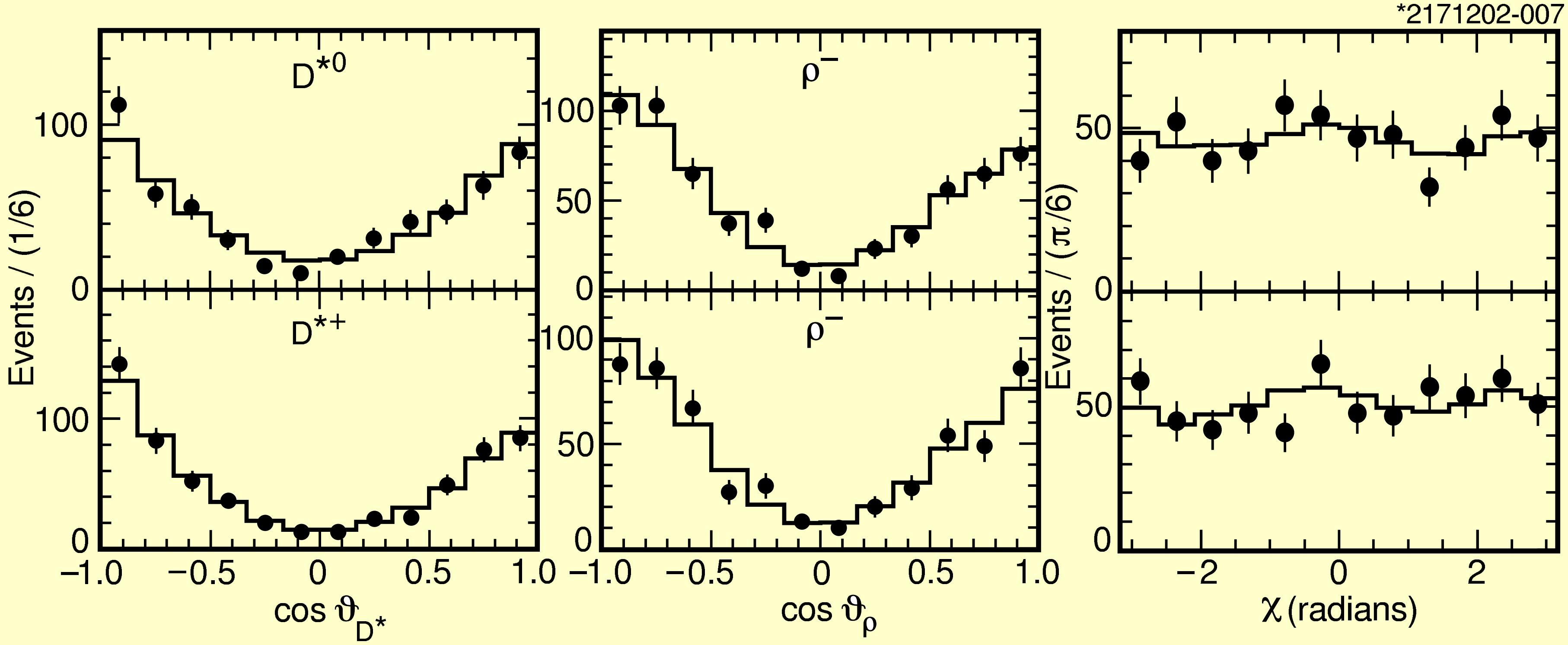
- Use $f_{+-}/f_{00} = 1.072 \pm 0.045 \pm 0.027 \pm 0.024$. (PDG 02)
- Results

$$\boxed{a_2/a_1 = 0.21 \pm 0.03 \pm 0.05 \pm 0.04 \pm 0.04.}$$

- ★ Uncertainties are statistical, and three systematics in turn
- ★ The first two systematic uncertainties are corresponding to those in branching fractions
- ★ The third systematic uncertainty, from f_{+-}/f_{00}, is important here since other experimental systematics partially cancel

Helicity Amplitudes

- Use B candidates in B signal region ($5.27 < M < 5.30$ GeV)
  - ★ Only helicity amplitudes are allowed to float in the fit
  - ★ Other parameters inherited from previous fit
    - n_j^S from previous fit
    - n_j^B scaled from previous fit
    - ...
- Detector acceptance obtained by weighting with current helicity amplitudes. This is iterated until helicity amplitudes converge



$B \to D^*\rho$

- Helicity amplitudes

Quantity	$B^- \to D^{*0}\rho^-$	$\bar{B}^0 \to D^{*+}\rho^-$
$\lvert H_0 \rvert$	$0.944 \pm 0.009 \pm 0.009$	$0.941 \pm 0.009 \pm 0.006$
$\lvert H_+ \rvert$	$0.122 \pm 0.040 \pm 0.010$	$0.107 \pm 0.031 \pm 0.011$
α_+	$1.02 \pm 0.28 \pm 0.11$	$1.42 \pm 0.27 \pm 0.04$
$\lvert H_- \rvert$	$0.306 \pm 0.030 \pm 0.025$	$0.322 \pm 0.025 \pm 0.016$
α_-	$0.65 \pm 0.16 \pm 0.04$	$0.31 \pm 0.12 \pm 0.04$

★ Systematic errors

- Acceptance parameterization: different $\epsilon_2(\cos\theta_{D^*}, \cos\theta_\rho)$ and $\epsilon_1(\chi)$
- Detector smearing: increase smearing in nominal MC by 15% of itself
- Background level: increase n_j^B by 1σ
- Background shape: the largest, compare nominal fit (bkg from data sideband) with 3 other fits: bkg flat, bkg from MC sideband, bkg from MC non-signal under B peak
- Non-resonant $\pi^-\pi^0$: add an $S-$wave component in the angular distribution
- ρ^- mass: sensitivity to the q^2 dependence

★ Non-trivial helicity amplitude phases

- Our results indicate possible non-trivial amplitude phases (α_+ and α_-), with significances of

$$\begin{array}{ll} 3.19\sigma, & (B^- \to D^{*0}\rho^-) \\ 2.75\sigma, & (\bar{B}^0 \to D^{*+}\rho^-) \end{array}$$

- Presumably due to FSI.
- Implications for direct CP violation in B decays

Longitudinal Polarization

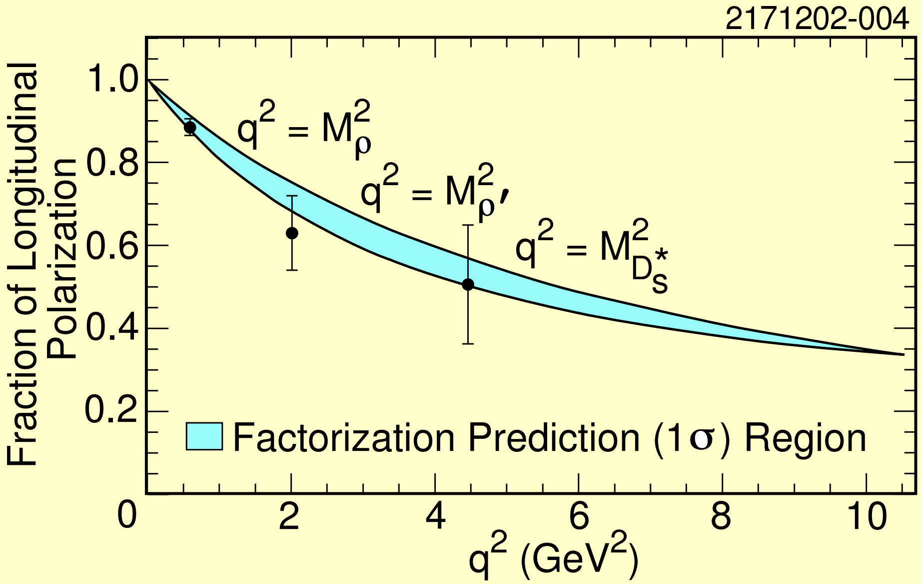
- Our measurements

$$\begin{cases} \frac{\Gamma_L}{\Gamma}(B^- \to D^{*0}\rho^-) & = & 0.892 \pm 0.018 \pm 0.016, \\ \frac{\Gamma_L}{\Gamma}(\bar{B}^0 \to D^{*+}\rho^-) & = & 0.885 \pm 0.016 \pm 0.012. \end{cases}$$

- Previous CLEO measurement

$$\frac{\Gamma_L}{\Gamma}(\bar{B}^0 \to D^{*+}\rho^-) = 0.93 \pm 0.05 \pm 0.05, \qquad \text{(CLEO 94)},$$
$$\frac{\Gamma_L}{\Gamma}(\bar{B}^0 \to D^{*+}\rho^-) = 0.878 \pm 0.034 \pm 0.030, \quad \text{(CLEO 98)}.$$

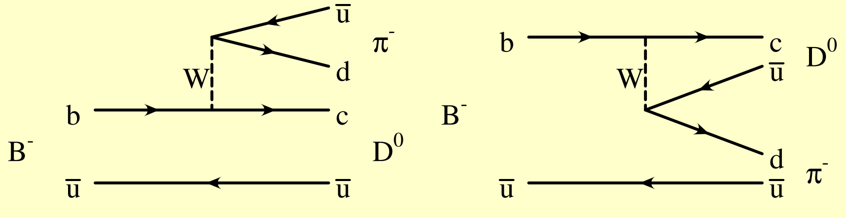
- HQET prediction



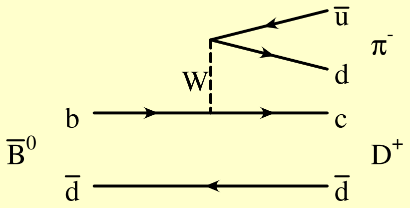
Measurements of $\mathcal{B}(\bar{B}^0 \to D^0\pi^0)$, $\mathcal{B}(B^- \to D^0\pi^-)$ and $\mathcal{B}(\bar{B}^0 \to D^+\pi^-)$,
Isospin Analysis of $B \to D\pi$ Decays

Motivation

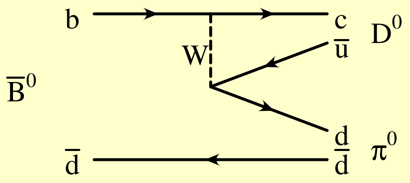
Feymann Diagrams for $B \to D\pi$



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



$\bar{B}^0 \to D^+\pi^-$



$\bar{B}^0 \to D^0\pi^0$

$B \to D\pi$ amplitude triangle

★ $\mathcal{B}(\bar{B}^0 \to D^0\pi^0)$ completes $B \to D\pi$ system

★ Two isospin amplitudes ($I = 1/2$ and $3/2$) contribute to $B \to D\pi$ decays, which can be written as:

$$\begin{cases} \mathcal{A}(B^- \to D^0\pi^-) & = & A_{3/2}, \\ \mathcal{A}(\bar{B}^0 \to D^+\pi^-) & = & \frac{2}{3}A_{1/2} + \frac{1}{3}A_{3/2}, \\ \mathcal{A}(\bar{B}^0 \to D^0\pi^0) & = & -\frac{\sqrt{2}}{3}A_{1/2} + \frac{\sqrt{2}}{3}A_{3/2}. \end{cases}$$

★ Triangle relation:

$$\mathcal{A}(B^- \to D^0\pi^-) = \mathcal{A}(\bar{B}^0 \to D^+\pi^-) + \sqrt{2}\mathcal{A}(\bar{B}^0 \to D^0\pi^0).$$

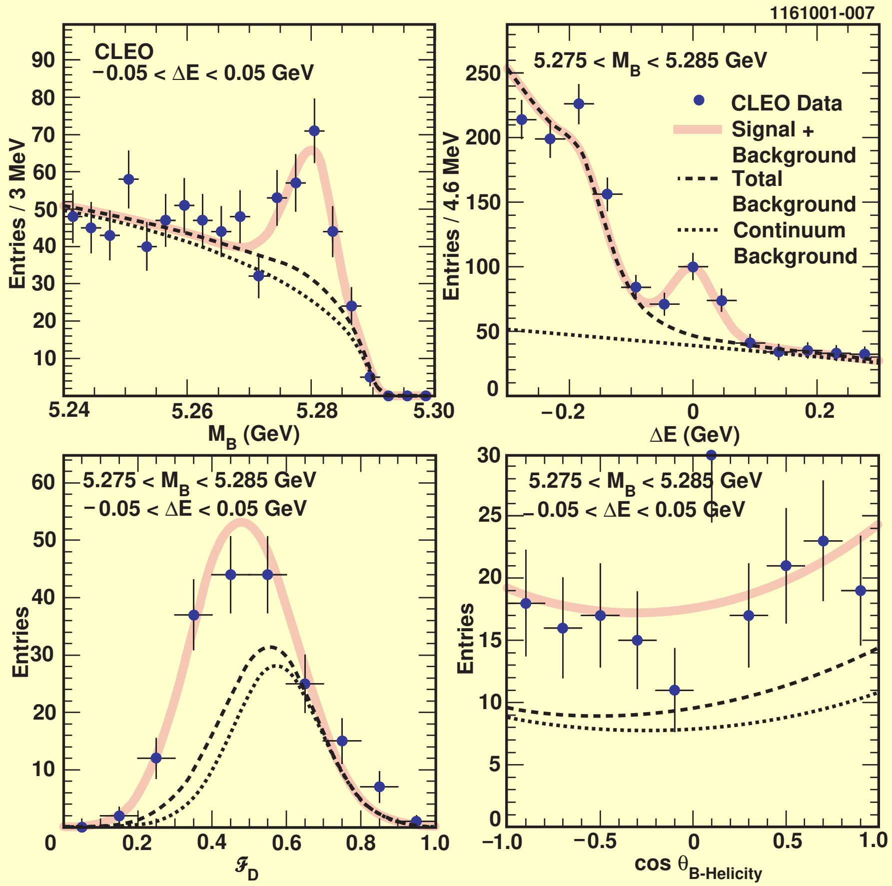
★ Phase difference between isospin amplitudes

$$\cos\delta_I = \frac{3\Gamma(D^+\pi^-) + \Gamma(D^0\pi^-) - 6\Gamma(D^0\pi^0)}{4|A_{1/2} \cdot A_{3/2}|}.$$

($\cos\delta_I \neq 1 \quad \longrightarrow$ FSI)

Color Suppressed Decays $\bar{B}^0 \to D^0\pi^0$

- **Event selection** based on high momentum D^0 and π^0 mesons
  - ★ D^0
    - ◆ D^0 in 3 decay modes $K^-\pi^+, K^-\pi^+\pi^0, K^-\pi^+\pi^-\pi^+$
    - ◆ $|M^{cnd}_{D^0} - M_{D^0}| \leq 2.5\sigma$
    - ◆ Dalitz cut for $D^0 \to K^-\pi^+\pi^0$
    - ◆ $p_{D^0} > 1.65$ GeV
  - ★ π^0
    - ◆ Isolated shower with $E_\gamma > 30$ MeV (Barrel) or 50 MeV (EC)
    - ◆ $|M_{\gamma\gamma} - M_{\pi^0}| \leq 2.5\sigma$
- **Event yields** obtained using extended unbinned maximum likelihood fit
  - ★ 3 free par's: n^S, n^B_{cont}, $n^B_{B\bar{B}}$
  - ★ 4 input var's: M, ΔE, $\mathcal{F}_D$, $\cos\theta_{B-hel}$

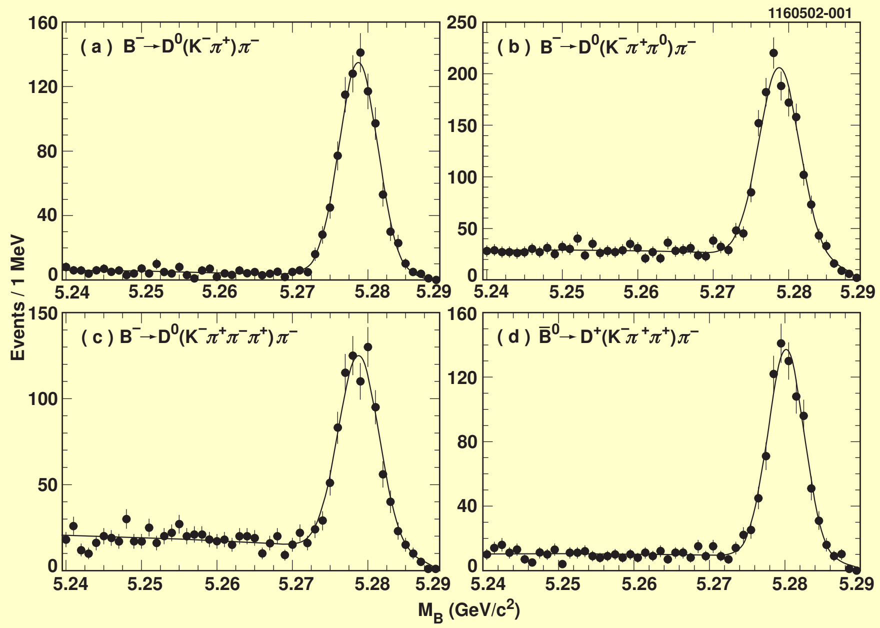


$$\mathcal{B}(\bar{B}^0 \to D^0\pi^0) = (2.74^{+0.36}_{-0.32} \pm 0.55) \times 10^{-4},$$
$\cos\delta_I = 0.89 \pm 0.08$, (Using PDG $\mathcal{B}(D^0\pi^-)$ and $\mathcal{B}(D^+\pi^-)$).

Isospin Analysis of $\bar{B} \to D\pi$

Previous measurements show $\cos\delta_I$ consistent with 1 but with large error. CLEO re-measured the two color-favored $\bar{B} \to D\pi$ decays

- D^0 reconstructed as before in 3 modes ($K^-\pi^+, K^-\pi^+\pi^0, K^-\pi^+\pi^-\pi^+$), and D^+ in one ($K^-\pi^+\pi^+$)
- Event yields obtained using simple binned maximum likelihood fit



$$
\begin{cases}
\mathcal{B}(B^- \to D^0\pi^-) = (49.7 \pm 1.2 \pm 2.9 \pm 2.2) \times 10^{-4}, & (53 \pm 5) \times 10^{-4} \text{ (PDG)}, \\
\mathcal{B}(\bar{B}^0 \to D^+\pi^-) = (26.8 \pm 1.2 \pm 2.4 \pm 1.2) \times 10^{-4}, & (30 \pm 4) \times 10^{-4} \text{ (PDG)}.
\end{cases}
$$

- Improved precision WRT the current PDG averages
- Systematic errors dominate: Individual D branching fractions, f_{+-} and f_{00}
- Phase difference ($\cos\delta_I$ differs from 1 by $\sim 2.3\sigma$)

$$
\begin{array}{lll}
\cos\delta_I = 0.877 \pm 0.030^{+0.046+0.039}_{-0.044-0.031}, & 13.6^\circ < \delta_I < 38.3^\circ & \text{(90\%CL, CLEO)} \\
\cos\delta_I = 0.863^{+0.024+0.036+0.038}_{-0.023-0.035-0.030}, & 16.5^\circ < \delta_I < 38.1^\circ & \text{(90\%CL, CLEO + Belle)}
\end{array}
$$

Summary

- We have presented new results for $B \to D^* \rho$
  hep-ex/0301028 (Submitted to PRD)
  - ★ Branching fractions of $B^- \to D^{*0}\rho^-$ and $\bar{B}^0 \to D^{*+}\rho^-$, and therefore a_2/a_1 for the $D^*\rho$ final state
  - ★ The helicity amplitudes for both $B^- \to D^{*0}\rho^-$ and $\bar{B}^0 \to D^{*+}\rho^-$, and therefore the fractions of longitudinal polarization (Γ_L/Γ), that of $\bar{B}^0 \to D^{*+}\rho^-$ is consistent with prediction from factorization hypothesis
  - ★ Our results indicate non-trivial amplitude phases

- We have presented CLEO results for $B \to D\pi$
  - ★ CLEO has observed the color-suppressed decay $\bar{B}^0 \to D^0\pi^0$
    Phys. Rev. Lett. **88**, 062001 (2002)
  - ★ CLEO re-measured the color-allowed decays $B^- \to D^0\pi^-$ and $\bar{B}^0 \to D^+\pi^-$
    Phys. Rev. D. **66**, 031101(R) (2002)
  - ★ The measurement of $\cos\delta_I$ based on the two above measurement indicates final state interaction