NEW RESULTS ON CHARM HADRON DECAYS

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This is a review of new results on charm hadron decays. From the CLEO II experiment, there are new measurements of the branching fractions for $D^+ \to K_S K^+$ and $K_S \pi^+$, which are combined with other CLEO measurements to extract the isospin amplitude ratios and phase shifts for $D \to KK$ and $K\pi$. The Ξ_c^0 decay asymmetry parameter in the decay $\Xi_c^0 \to \Xi^- \pi^+$ has been measured for the first time. The result is $\alpha_{\Xi_c^0} = -0.72^{+0.40+0.28}_{-0.28-0.12}$. From the BES experiment, there are new absolute measurements on the decay branching fractions of the D_s meson, $B(D_s^+ \to \phi X) = (16.5^{+13.9+1.9}_{-\ 6.7-4.1})\%$ and $B(D_s^+ \to e^+ X) = (6.2^{+6.6+2.4}_{-4.8-2.1})\%$. All results are preliminary.

1 Introduction

This is a review of new results on charm hadron decays from two e^+e^- experiments, CLEO II at the Cornell Electron Storage Ring (CESR) and BES at Beijing Electron Positron Collider (BEPC). The CLEO II experiment collects data at the $\Upsilon(4S)$ ($\sqrt{s} \sim 10.6$ GeV) resonance and at energies just below $\Upsilon(4S)$. The data sample corresponds to an integrated luminosity of $4.8 fb^{-1}$. The BES experiment collects data at $\sqrt{s} = 4.03$ GeV, just above the $e^+e^- \to D_s^+ D_s^-$ threshold. The data sample corresponds to an integrated luminosity of $22.3 pb^{-1}$. In this paper, we first review [1] the CLEO II measurements of the branching fractions [2] for $D^+ \to K_S K^+$ and $K_S \pi^+$ and then combine the results with other CLEO measurements to extract the ratios of isospin amplitudes and phase shifts for $D \to KK$ and $K\pi$. We then present the first measurement of the Ξ_c^0 decay asymmetry parameter in the decay $\Xi_c^0 \to \Xi^- \pi^+$. This is followed by a review of the BES results on the absolute decay branching fractions for $D_s^+ \to \phi X$ and $e^+ X$.

2 Analyses of $D^+ \to K_S K^+$ and $K_S \pi^+$

In non-leptonic weak decays of hadrons, strong final state interactions complicate the interpretation of the underlying weak interactions. The problem is particularly acute for the D meson, as the mass lies in a resonance-rich region [3]. Elastic final state interactions such as $\pi\pi \to \pi\pi$ can introduce phase shifts by rotating the isospin amplitudes [4]. These isospin amplitudes may be calculated by combining measurements of branching fractions. The CLEO II experiment has reported new measurements of the branching fractions for $D^+ \to K_S K^+$ and $K_S \pi^+$.

The D^+ candidates are reconstructed using the decay chain $D^{*+} \to D^+ \pi^0$ to suppress the background. Candidates for the decay $D^+ \to K^- \pi^+ \pi^+$ are also reconstructed as the normalization mode. Figure 1 shows the $K_S K^+$ and $K_S \pi^+$ invariant mass spectra for combinations with reconstructed D^{*+} and D^+ mass difference that are within 2.5 MeV (3σ) of the known mass difference. A fit to the spectra yields a signal of 78.9 ± 12.8 and 471 ± 26 events, respectively. For the normalization mode, 5457 ± 110 events are reconstructed.

The final results are:

$$\frac{B(D^+ \to K_S K^+)}{B(D^+ \to K_S \pi^+)} = 0.250 \pm 0.044 \pm 0.018$$

$$\frac{B(D^+ \to K_S K^+)}{B(D^+ \to K^- \pi^+ \pi^+)} = 0.0432 \pm 0.0072 \pm 0.0039$$

$$\frac{B(D^+ \to K_S \pi^+)}{B(D^+ \to K^- \pi^+ \pi^+)} = 0.173 \pm 0.012 \pm 0.011$$

where the first error is statistical and the second error is systematic.

The absolute branching fractions can be obtained using CLEO measurements of $B(D^+ \to K^- \pi^+ \pi^+) = (2.35 \pm 0.16 \pm 0.16) B(D^0 \to K^- \pi^+)$ [5] and $B(D^0 \to K^- \pi^+) = (3.91 \pm 0.08 \pm 0.17)\%$ [6]. The results are,

$$B(D^+ \to \bar{K}^0 K^+) = (0.793 \pm 0.133 \pm 0.071 \pm 0.085)\%$$

$$B(D^+ \to \bar{K}^0 \pi^+) = (3.18 \pm 0.21 \pm 0.19 \pm 0.34 \pm 0.32)\%$$

where the third error is due to the uncertainty in the normalization branching fraction. The fourth error in $B(D^+ \to \bar{K}^0\pi^+)$ accounts for the possible interference [7] between the Cabibbo-favored $D^+ \to \bar{K}^0\pi^+$ and doubly-suppressed $D^+ \to K^0\pi^+$. A 10% uncertainty has been assigned due to the unknown phase δ in the interference amplitude, $\sim 2\tan^2\theta_C\cos\delta$. The ratio for $B(D^+ \to \bar{K}^0K^+)/B(D^+ \to \bar{K}^0\pi^+)$ is significantly higher than the Cabibbo suppression factor of $\tan^2\theta_C$, consistent with the expectation [8] that destructive interference suppresses the rate for $D^+ \to \bar{K}^0\pi^+$.

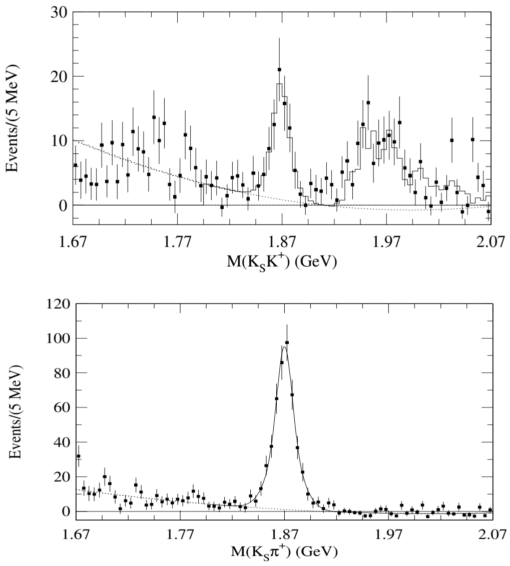

Figure 1: The observed K_SK^+ and $K_S\pi^+$ mass spectra. The solid lines show fits to the data.

The amplitudes for the three $D \to KK$ decays may be decomposed into isospin amplitudes:

$$A^{+-} = \frac{1}{\sqrt{2}}(A_1 + A_0)$$
$$A^{00} = \frac{1}{\sqrt{2}}(A_1 - A_0)$$
$$A^{+0} = \sqrt{2}A_1$$

where $A^{+-} \equiv \langle K^+K^-|H|D^0\rangle$, $A^{00} \equiv \langle K^0\bar{K}^0|H|D^0\rangle$, and $A^{+0} \equiv \langle K^+\bar{K}^0|H|D^+\rangle$. The Hamitonian responsible for these decays is assumed to have isospin structure $|\frac{1}{2}+\frac{1}{2}\rangle$. This is valid for all Standard Model decays, except for two: the $s\bar{s}$-popping W-exchange diagram of $D \to K^0\bar{K}^0$ and the annihilation diagram of $D^+ \to \bar{K}^0K^+$. The rates for these two decays are expected to be small because of helicity suppression and $s\bar{s}$ popping.

The ratio of isospin amplitudes and the isospin phase angle difference can be extracted from the

Table 1: Isospin analysis inputs and results. $\Gamma^{+-} \equiv |A^{+-}|^2$, $\Gamma^{00} \equiv |A^{00}|^2$, $\Gamma^{+0} \equiv |A^{+0}|^2$, and $\mathcal{B} = B(D^0 \to K^-\pi^+)$.

	$D \to KK$	$D \to K\pi$
$\frac{\Gamma^{+-}}{\Gamma_{D^+}}$	$(0.116 \pm 0.010)\mathcal{B}$	$\mathcal{B}$
$\frac{\Gamma^{00}}{\Gamma_{D^0}}$	$(0.014 \pm 0.004)\mathcal{B}$	$(0.620 \pm 0.126)\mathcal{B}$
$\frac{\Gamma^{+0}}{\Gamma_{D^0}}$	$(0.203 \pm 0.043)\mathcal{B}$	$(0.812 \pm 0.135)\mathcal{B}$
	$\left\lvert\frac{A_1}{A_0}\right\rvert = 0.66^{+0.12}_{-0.11}$	$\left\lvert\frac{A_{\frac{3}{2}}}{A_{\frac{1}{2}}}\right\rvert = 0.26 \pm 0.03$
$\cos\delta$	$0.85^{+0.09}_{-0.07}$	$-0.12^{+0.23}_{-0.21}$

measured branching fractions for $D \to KK$:

$$\left|\frac{A_1}{A_0}\right|^2 = \frac{\Gamma^{+0}}{2\Gamma^{+-} + 2\Gamma^{00} - \Gamma^{+0}}$$
$$\cos\delta_{KK} = \frac{\Gamma^{+-} - \Gamma^{00}}{\sqrt{\Gamma^{+0}}\sqrt{2\Gamma^{+-} + 2\Gamma^{00} - \Gamma^{+0}}}$$

where $\delta_{KK} \equiv arg(A_1/A_0)$.

In the Cabibbo-favored $D \to K\pi$ system, the Hamitonian has isospin structure $|1+1\rangle$. There are similar relationships [9] for the isospin amplitude ratio and phase angle difference, $|A_{\frac{3}{2}}/A_{\frac{1}{2}}|$ and $\delta_{K\pi} \equiv arg(A_{\frac{3}{2}}/A_{\frac{1}{2}})$.

CLEO has measured the six branching fractions [10,11,6] required to extract the amplitude ratios and phase shifts in $D \to KK$ and $K\pi$. All branching fractions are measured relative to $B(D^0 \to K^-\pi^+)$ using the CLEO measurement [5] $B(D^+ \to K^-\pi^+\pi^+) = (2.35 \pm 0.16 \pm 0.16)B(D^0 \to K^-\pi^+)$ and the PDG fit result [12] $B(D^0 \to \bar{K}^0\pi^+\pi^-) = (1.41 \pm 0.11)B(D^0 \to K^-\pi^+)$. This ensures that the uncertainty in $B(D^0 \to K^-\pi^+)$ cancels in the ratios. The results are listed in Table 1.

The isospin phase shift difference in $D \to KK$ is significantly smaller than that of both $D \to K\pi$ and $D \to \pi\pi$ ($\delta_{\pi\pi} = 0.14 \pm 0.16$) [13]. The phase shift is calculated based on simplified assumptions as stated above and ignoring inelastic FSI [14] such as $D^0 \to \phi\phi \to \bar{K}^0K^0$. The large rate for $D^0 \to \bar{K}^0K^0$ excludes models accounting for the decay through elastic FSI originating from non-exchange diagrams only or elastic rescattering from other modes through spectator or penguin diagrams.

3 Measurement of Ξ_c^0 Decay Asymmetry Parameter in the Decay $\Xi_c^0 \to \Xi^-\pi^+$

In charm baryon decays, the parity violation effects due to the interference between amplitudes with different angular momentum can be directly observed. The weak interactions underlying hadronic charm weak decay are well understood. However, the strong interactions between constituent quarks in the hadrons are difficult to calculate. Consequently, a variety of models are used to predict both the decay rate and degree of parity violation in the decay. To constrain the models it is important to provide as much experimental information as possible.

CLEO has measured for the first time parity violation in a charm strange baryon using the decay $\Xi_c^0 \to \Xi^-\pi^+$, with $\Xi^- \to \Lambda\pi^-$ and $\Lambda \to p\pi^-$. The angular distribution of the Ξ is given by,

$$\frac{d\Gamma}{d\cos\theta_\Xi} \propto 1 + \alpha_{\Xi_c^0}\alpha_\Xi \cos\theta_\Xi$$

where α_Ξ and $\alpha_{\Xi_c^0}$ are asymmetry parameters of Ξ and Ξ_c^0, and θ_Ξ is the angle between the Λ momentum vector in the Ξ rest frame and the Ξ direction in the Ξ_c^0 rest frame. Using the PDG compilation [12] of α_Ξ, $\alpha_{\Xi_c^0}$ can be extracted by measuring the angular distribution. In the massless fermion limit, the chirality of weak interaction corresponds to $\alpha_{\Xi_c^0} = -1$. The interplay between the strong and weak interactions modifies this value. The theoretical predictions cover a large range [15]: $-1 < \alpha_{\Xi_c^0} < -0.38$.

The Ξ_c^0 candidates are identified by reconstructing the decay vertices of the Ξ^- and Λ. Any $p\pi^-$ combination with mass consistent with the Λ hypothesis is combined with another π^- track to search for an Ξ^- candidate. If the $\Lambda\pi^-$ combination satisfies the Ξ^- mass hypothesis, the Ξ^- candidate is combined with another π^+ track to search for an Ξ_c^0 candidate. Figure 2 shows the $\Xi^-\pi^+$ mass spectra for various angular region. The Ξ_c^0 yields are extracted by fitting the spectra and then correcting for detection efficiencies to obtain the angular distribution shown in Fig. 3. A fit to the angular distribution yields $\alpha_{\Xi_c^0}\alpha_\Xi = 0.33 \pm 0.18$. Using $\alpha_\Xi = -0.456 \pm 0.014$ from the PDG compilation [12], the final result is $\alpha_{\Xi_c^0} = -0.72^{+0.40+0.28}_{-0.28-0.12}$, where the second error is systematic. This is the first measurement of parity violation in a charm strange baryon. The result is consistent with the theoretical expectations but is not yet precise enough to discriminate between models.

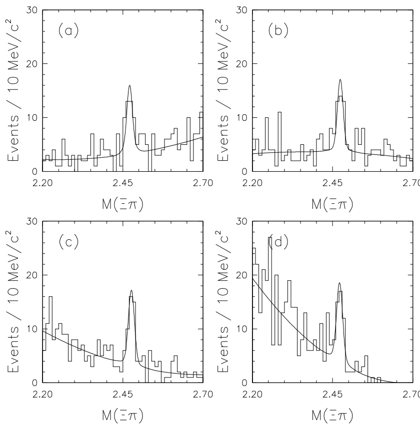

Figure 2: $\Xi^-\pi^+$ mass spectra: a) $-1 < \cos\theta_\Xi < -0.5$, b) $-0.5 < \cos\theta_\Xi < 0$, c) $0 < \cos\theta_\Xi < 0.5$, d) $0.5 < \cos\theta_\Xi < 1$.

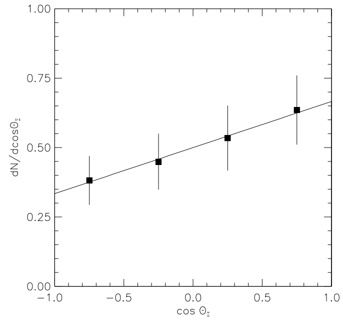

Figure 3: Efficiency corrected angular distribution for $\Xi_c^0 \to \Xi^-\pi^+$.

4 Direct Measurement of $B(D_s^+ \to \phi X)$

The absolute inclusive branching fraction of D_s^+ into ϕ is an important parameter in the study of heavy flavors. For example, the branching fraction is used in B_s^0 oscillation and mixing measurements at LEP and CDF. BES has measured the absolute branching fraction by measuring the fraction of events with a ϕ meson recoiling against a D_s^- meson in a sample of events containing D_s^- candidates. The experiment is performed at $\sqrt{s} = 4.03$ GeV, just above the $e^+e^- \to D_s^+D_s^-$ threshold. The D_s^- signal is detected via five hadronic decay modes, $D_s^- \to \phi\pi^-$, $\bar{K}^{0*}K^-$, K_sK^-, $f_0\pi^-$, and $K_sK^+\pi^-\pi^-$. A signal of 166.4 ± 31.8 D_s single tag events is found. Figure 4 shows the invariant mass of K^+K^- combinations recoiling against the kinematically fitted D_s^- mass. Three double tag events in the ϕ mass region are observed. This yields the first model-independent measurement of the branching fraction,

$$B(D_s^+ \to \phi X) = (16.5^{+13.9+1.9}_{-\ 6.7-4.1})\%$$

where the second error is systematic. The result is consistent with the sum of the indirect measurements of exclusive branching fractions [12] of $(18.2 \pm 5.2)\%$.

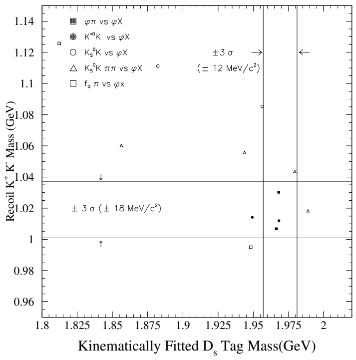

Figure 4: K^+K^- recoil mass vs. D_s tag mass.

5 Direct Measurement of $B(D_s^+ \to e^+ X)$

The D^+ lifetime is measured [12] to be about twice that of the D^0 and D_s^+, contrary to the prediction of the spectator model. The inequality is probably due to the final state interference in hadronic D^+ decays. However, the semileptonic decays widths are expected to be approximately equal, $\Gamma_{SL}(D^+) \approx \Gamma_{SL}(D^0) \approx \Gamma_{SL}(D_s^+)$. Experimentally [12], this prediction is respected between D^+ and D^0. If this relation is extended to D_s^+, then $B(D_s^+ \to e^+ X)$ is expected to be $\sim$8%.

BES has measured the inclusive branching fraction using a technique similar to the inclusive ϕ measurement. The D_s tag is detected via its hadronic decay into $\phi\pi^-$, $\bar{K}^{0*}K^-$, K_sK^-, or $K_sK^+\pi^-\pi^-$, and a sample of 147 ± 19 D_s's were reconstructed. By fitting the reconstructed D_s mass recoiling against an electron candidate in the sample, the branching fraction is estimated to be

$$B(D_s^+ \to e^+ X) = (6.2^{+6.6+2.4}_{-4.8-2.1})\%$$

where the second error is systematic. The result is consistent with the Mark III measurement [16], which has a larger error. The result also reaffirms the prediction of the spectator model of equal semileptonic widths for D^+, D^0, and D_s^+.

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References

1. For more details, see the papers submitted to this conference (PA05-090, 089, 111, 113).
2. In this paper charge conjugate states are implied.
3. D.G. Sutherland, Phys. Lett. B **90**, 173 (1980); H.J. Lipkin, Phys. Rev. Lett. **44**, 710 (1980); J.F. Donoghue and B.R. Holstein, Phys. Rev. D **21**, 1334 (1980).
4. A.N. Kamal, Int. J. Mod. Phys. A **7**, 3515 (1992).
5. R. Balest *et al.*, Phys. Rev. Lett. **72**, 2328 (1994).
6. D.S. Akerib *et al.*, Phys. Rev. Lett. **71**, 3070 (1993).
7. I.I. Bigi and H. Yamamoto, Phys. Lett. B **349**, 363 (1995).
8. B. Guberina *et al.*, Phys. Lett. B **89**, 111 (1979).
9. M. Bauer, B. Stech, and M. Wirbel *et al.*, Z. Phys. C **34**, 103 (1987).
10. D.M. Asner *et al.*, Phys. Rev. D **53**, 1039 (1996).
11. M. Procario *et al.*, Phys. Rev. D **48**, 4007 (1993).
12. Particle Data Group, R.M. Barnett *et al.*, Phys. Rev. D **54**, 1 (1996).
13. M. Selen *et al.*, Phys. Rev. Lett. **71**, 1973 (1993).
14. A.N. Kamal and T.N. Pham, Phys. Rev. D **50**, 1832 (1994).
15. Q.P. Xu and A.N. Kamal, Phys. Rev. D **46**, 270 (1992); P. Zencykowski, Phys. Rev. D **50**, 410 (1994); J.G. Korner and M. Kramer, Z. Phys. C **55**, 659 (1992); H. Cheng and B. Tseng, Phys. Rev. D **48**, 4188 (1993).
16. Z. Bai *et al.*, Phys. Rev. Lett. **65**, 686 (1990).