Recent Charm Results From the CLEO Collaboration

Scott Menary
University of California at Santa Barbara

ABSTRACT

The excellent photon detection capabilities of the CLEO-II detector along with the record luminosity of the Cornell Electron Storage Ring, CESR, allow for very precise measurements of some important 'engineering' numbers associated with charm production and decay (e.g., the $D^{*o} - D^o$ mass difference) as well as the possibility of examining rarer and more subtle effects such as the role of final state interactions in charm decays. In this paper I will just give a flavour of the many new charm results from CLEO by discussing the following topics;

1) $D \rightarrow \pi\pi$ decays and the $\Delta I = 1/2$ rule in charm decays,
2) Model independent evidence for the spin-parity assignment of 1^+ for the $D^+_{s1}(2536)$,
3) Observation of W-exchange in Λ_c decays.

1 Introduction

The Cornell Electron Storage Ring, CESR, is an e^+e^- collider run at CMS energies around the $\Upsilon(4S)$ resonance ($\sim$ 10.6 GeV). While the primary reason for working at the $\Upsilon(4S)$ is that it decays 100% to $B\overline{B}$, there is also a sizeable continuum charm cross-section at this energy and the B mesons decay predominantly to charmed mesons. Hence, as well as being something of a B factory, CESR is also something of a charm factory. The results in this paper are extracted from a total of around 1.8 fb^{-1} of data collected at energies near the $\Upsilon(4S)$. This corresponds to some several million $e^+e^- \to c\overline{c}$ events.

The most significant recent upgrade to the CLEO detector[1] was the addition of a CsI calorimeter. The superb energy resolution of this detector,

$$\sigma_E/E(\%) = 0.35/E^{0.75} + 1.9 + 0.1E$$

allows for the reconstruction of π^o's with an efficiency and momentum resolution about half that for charged pions. This ability to use photons and π^o's with high efficiency and excellent resolution not only allows for the reconstruction of the $D^{*+} \to D^+\pi^o$ and $D^{*o} \to D^o\pi^o$ decay chains[2], which are crucial for B physics and for isolating clean samples of D^o's and D^+'s, but it also opens up a vast number of new charm decay channels. This is particularly true for charmed baryons where the Λ_c section of the next particle data group listings will be much expanded because of a slew of new decay modes from CLEO.

2 Charmed Mesons

The large data set collected with the CLEO II detector has allowed for many new and precise charmed meson measurements. In the realm of semi-leptonic decays, we have reported the first observation of the the Cabibbo suppressed decay $D^+ \to \pi^o l^+\nu$[2]. We also have high statistics measurements of all four $D \to K^{(*)}l\nu$ modes. Recently published results include precise measurements of the $D^* - D$ mass differences[3] and the D^* branching ratios[4] which are crucial 'engineering' numbers for minimizing the systematic errors in a vast number of B meson results. Finally, it has been possible to probe the effects of final state interactions through the examination of decay modes such as $D^o \to \overline{K}^{*o}\eta$[2].

[1] The so-called CLEO-II dectector[1].

[2] The charge conjugate state is implicitly included throughout this paper unless otherwise noted.

2.1 The $\Delta I = 1/2$ Rule and $D \to \pi\pi$ Decays

For the case of an $I = 1/2$ pseudoscalar (such as a K, D, or B meson) decaying to two pions,

$$|I = 1/2\rangle \longrightarrow |\pi^{+/o}\rangle\, |\pi^{-/o}\rangle$$

the final $\pi\pi$ state must be in either an $I = 0$ ($\Delta I = 1/2$) or an $I = 2$ ($\Delta I = 3/2$) state in order to satisfy Bose statistics. Hence, the transition amplitudes for the three $\pi\pi$ modes can be written in the form,

$$\begin{aligned} A^{+-} &= \sqrt{\tfrac{1}{3}}A_2 + \sqrt{\tfrac{2}{3}}A_0, \\ A^{00} &= \sqrt{\tfrac{2}{3}}A_2 - \sqrt{\tfrac{1}{3}}A_0, \text{ and} \\ A^{+0} &= \sqrt{\tfrac{3}{2}}A_2 \end{aligned}$$

where the superscript refers to the pion charges and the subscript to the isospin of the final state. Note that the $\pi^+\pi^o$ decay can proceed only via a $\Delta I = 3/2$ transition. It was found in kaon decay that $|A_2(\Delta I = 3/2)/A_0(\Delta I = 1/2)| \approx 0.05$ resulting in the formulation of the so-called '$\Delta I = 1/2$ Rule'. While models are not capable of explaining all of this suppression in the kaon system, it is not expected that there is a similar suppression in the D system.

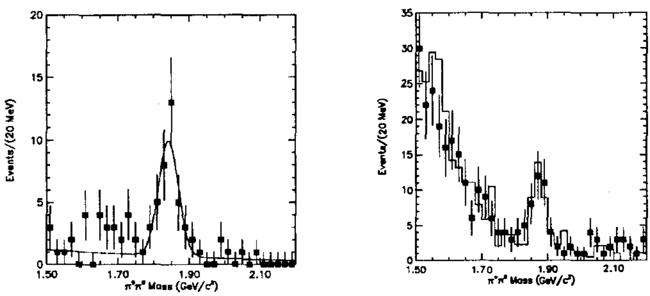

Figure 1: The $\pi^o\pi^o$ and $\pi^+\pi^o$ invariant mass plots. The points are the data while the fits to the spectra are shown as the solid lines.

All three Cabibbo suppressed $D \to \pi\pi$ decays have been measured by CLEO. The $\pi^o\pi^o$ and $\pi^o\pi^+$ invariant mass distributions are shown in Figure 1 where there are clear signals at the D mass. In order to reduce background, the D was required in all cases to have come from the decay of a D^{*+} (allowing for a 2.5σ $m(D^{*+}) - m(D)$ cut to be used). Also, to further clean up the signals, an $x_p = p/p_{max} > 0.6$ cut was applied to the D^{*+} candidates. The background shape is well modeled by the Monte Carlo which included a full simulation of the detector as well as the relevant physics background contributions such as Cabibbo favoured decays appearing in a $\pi\pi$ mass plot due to misidentification of a kaon as a pion.

It is possible to calculate the ratio of the magnitudes of these complex isospin amplitudes, as well as the relative phase, using the measured branching ratios. They are given for all three modes in Table 1 where the first error is statistical and the second is systematic. The result for the ratio of amplitudes is $|A_2/A_0| = 0.72 \pm 0.12 \pm 0.06$. Hence, unlike the case in kaon decay, there is no evidence for the suppression of the $I = 2$ amplitudes in D meson decay.

Table 1: The Measured $D \to \pi\pi$ Branching Ratios.

D Decay Mode	Yield (Events)	Branching Ratio (%)
$D \to \pi^+\pi^-$	227.2 ± 19.5	$0.126 \pm 0.011 \pm .011$
$D \to \pi^o\pi^o$	40.3 ± 7.6	$0.082 \pm 0.015 \pm .012$
$D \to \pi^+\pi^o$	34.4 ± 7.2	$0.23 \pm 0.05 \pm .05$

2.2 Measuring the Spin-Parity of the $D^+_{s1}(2536)$

The $D^+_{s1}(2536)$ was first observed by ARGUS in the mode $D^+_{s1} \to D^{*+}K_s$[5]. The parity was arrived at by simply assuming that the state was a P-wave meson. The spin assignment essentially came from models which were required to accomodate the narrowness (less than the detector resolution of around 2 MeV) of this strongly decaying resonance.

CLEO has observed the D_{s1} in both the $D^{*+}K_s$ and $D^{*o}K^+$ decay modes with yields of 44.1 ± 7.9 and 134 ± 22 events, respectively. The higher statistics $D^{*o}K^+$ channel allows for a model independent measurement of the spin-parity by using the helicity angle distribution of the decay. More precisely, defining the helicity angle, θ_h, as the angle between the D_{s1} and π^o directions in the D^{*o} center of mass system, then one has the possible $\cos\theta_h$ distributions listed in Table 2 for the various J^P assignments. The data rule out the second and third rows (confidence levels for fits to these distributions are less than 10^{-4}) leaving only the so-called 'unnatural' spin-parities, $1^+, 2^-, 3^+ \ldots$, as the possible assignments for the $D_s(2536)$. However, it is difficult to produce mesons in e^+e^- collisions with relative orbital angular momentum greater than 1 so the J^P assignment of 1^+ is strongly favoured by the data.

3 Charmed Baryons

It is in the charmed baryon sector that the excellent photon detection of the CLEO-II detector really becomes important. This is clear when one considers that the majority of charmed baryon decays result in there being either a Λ, Σ, or Ξ in the final state and, for example, the Ξ^o decays 100% of the time to $\Lambda\pi^o$

Table 2: The helicity angle distributions, $I(\cos\theta_h)$, for the various J^P assignments. The D^* helicity for each case, $\lambda_{D^{*o}}$, is also listed. $|A_{10}|$ and $|A_{00}|$ are helicity amplitudes.

J^P	$\lambda_{D^{*o}}$	$I(\cos\theta_h)$
0^+	Forbidden	
0^-	0	$\propto \cos^2\theta_h$
$1^-, 2^+, 3^- \ldots$	1	$\propto \sin^2\theta_h$
$1^+, 2^-, 3^+ \ldots$	0, 1	$\propto \|A_{10}\|^2 \sin^2\theta_h + \|A_{00}\|^2 \cos^2\theta_h$

while the the branching ratio for Σ^o to $\Lambda\gamma$ is also 100%! Hence, this improved photon and π^o resolution and detection efficiency opens up a vast number of previously inaccessible decay channels for examination.

New CLEO charmed baryon results include: the first observation of all three $\Sigma_c^{++/+/o} \rightarrow \Lambda^+\pi^{+,o,-}$ decay channels in the same experiment, Λ_c decays with Σ^+ (e.g., $\Sigma\pi^o$) and Σ^o in the final state, $\Lambda_c \longrightarrow \Lambda\pi^+\pi^o$ decays, and new decay modes of the Ξ_c^o and Ξ_c^+[2].

3.1 Evidence for W-exchange in Λ_c decays

Unlike in charm meson decays, the W-exchange process is neither helicity nor colour suppressed in charmed baryon decays. A possible W-exchange decay is shown in Figure 2. Figure 3a shows the $\Sigma^+K^+K^-$ invariant mass plot

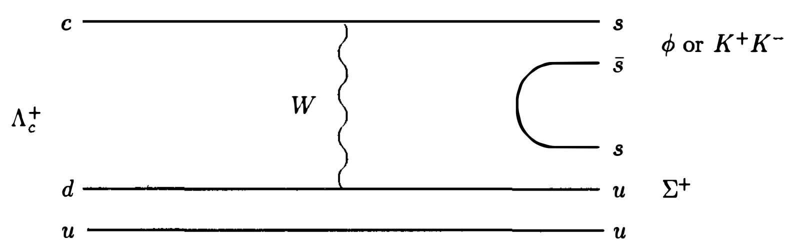

Figure 2: A Λ_c decay involving W-exchange.

where there is a clear peak at the Λ_c mass while Figure 3b shows the evidence for the φ meson in the K^-K^+ mass plot. As well as using vertex cuts to maximize signal to background for the long lived particles like the Σ^+, an x_p cut of 0.4 was applied to all Λ_c candidates. The final yields and branching ratios, relative to $\Lambda_c^+ \rightarrow pK^-\pi^+$, are listed in Table 3. These agree well with

Table 3: Branching ratios for candidate W-exchange decay modes.

Mode	Yield	Efficiency	Branching Ratio
$\Lambda_c^+ \to pK^-\pi^+$	5670 ± 210	35%	1.0
$\Lambda_c^+ \to \Sigma^+ K^+ K^-$	59 ± 10	5.2%	$0.070 \pm 0.011 \pm 0.011$
$\Lambda_c^+ \to \Sigma^+ \phi$	26 ± 9	2.3%	$0.069 \pm 0.023 \pm 0.016$
$\Lambda_c^+ \to \Xi^0 K^+$	56 ± 10	4.4%	$0.078 \pm 0.013 \pm 0.013$
$\Lambda_c^+ \to \Xi^- K^+ \pi^+$	61 ± 10	4.6%	$0.079 \pm 0.014 \pm 0.014$
$\Lambda_c^+ \to \Xi^{*0} K^+$	24 ± 7	2.8%	$0.053 \pm 0.016 \pm 0.010$

calculations which include a contribution from W-exchange and there does not appear to be a need to invoke final state interactions to explain the rates as is the case in charm meson decay.

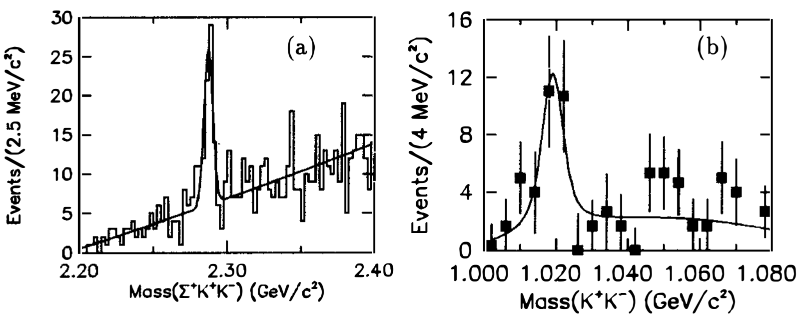

Figure 3: (a) The $\Sigma^+K^+K^-$ invariant mass distribution. (b) The K^+K^- mass distribution for for the $\Sigma^+K^+K^-$ signal region (2.275 – 2.295 GeV/c^2) with $\Sigma^+K^+K^-$ mass sideband subtracted.

References

[1] Y. Kubota *et al.*, Nucl. Instrum. Methods A**320** (1992) 66.

[2] See, for example, the proceedings of meeting of the Division of Particles and Fields of the American Physical Society, Fermilab, Oct., 1992.

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