NEW CLEO RESULTS ON CHARMED BARYON SEMILEPTONIC DECAYS

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ABSTRACT

We report new results from CLEO on charmed baryon semileptonic decays, including the first observation of the decay modes $\Xi_c^+ \to \Xi^0 e^+ \nu_e$, the first absolute upper bounds on Ξ_c hadronic branching ratios, a measurement of the lifetime ratio of Ξ_c^+/Ξ_c^0 and the preliminary result on form factor ratio measurement in $\Lambda_c^+ \to \Lambda e^+ \nu_e$.

Charm semileptonic decays are important to test theoretical models as V_{cs} is known from unitarity. Within Heavy Quark Effective Theory (HQET), Λ-type baryons are more straightforward to treat than mesons as they consist of a heavy quark and a spin zero light diquark. The semileptonic decays of charmed baryons provide an interesting opportunity to test many of the predictions of HQET. We report here two new results from CLEO II, Ξ_c semileptonic decays[1] and form factor ratio measurement in $\Lambda_c^+ \to \Lambda e^+ \nu_e$[2].[3]

1. Ξ_c semileptonic decays and a measurement of the Ξ_c^+/Ξ_c^0 lifetime ratio

The naive spectator model of heavy quark decay predicts that the lifetimes of the charmed hadrons are equal. Experimentally this is not the case, as $\frac{\tau(D^+)}{\tau(D^0)} = 2.54 \pm 0.07$.[4] It is believed that the source of the lifetime difference is the hadronic width and destructive interference between the internal and external Cabibbo allowed spectator graphs is sufficient to decrease the hadronic width of the D^+ relative to the D^0 by about the amount required to explain the lifetime ratio.[5]

In the charmed baryon sector, destructive interference between the external and internal spectator graphs can occur when a spectator is a u quark. In addition, when a spectator quark is an s, constructive interference between two internal spectator graphs can occur. Finally, the W-exchange diagram is not helicity suppressed for baryons. The relative importance of these three effects leads to different predictions for the lifetime hierarchy of charm baryons [6].[7]

1.1. Search $\Xi_c^+ \to \Xi^0 e^+ \nu_e$ and $\Xi_c^0 \to \Xi^- e^+ \nu_e$

The data sample used in this study contains about 3 million $e^+e^- \to c\,\bar{c}$ events. We search for the decays $\Xi_c \to \Xi e^+ \nu_e$ by detecting a Ξe^+ (right sign) pair with $m_\Xi <$

$m_{\Xi e^+} < m_{\Xi_c}$. The Λ is reconstructed through its decay to $p\pi$. We reconstruct Ξ^0 and Ξ^- through the decay modes $\Lambda\pi^0$ and $\Lambda\pi^-$ respectively. The minimum allowed momentum for positrons is 0.5 GeV/c. The combined momentum of Ξ and positrons is required to be greater than 1.4 GeV/c to reduce background. To determine the number of events passing our cuts we fit the $\Lambda\pi$ invariant mass distributions, shown in Fig.1, and the fit results are given in Table 1.

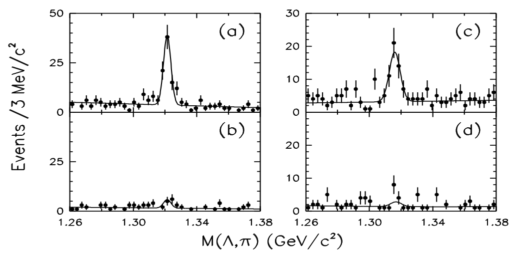

Fig. 1. The $\Lambda\pi$ invariant mass for right sign and wrong sign Ξe combinations;(a)$\Lambda\pi^-$ RS, (b)$\Lambda\pi^-$ WS;(c)$\Lambda\pi^0$ RS, (d)$\Lambda\pi^0$ WS.

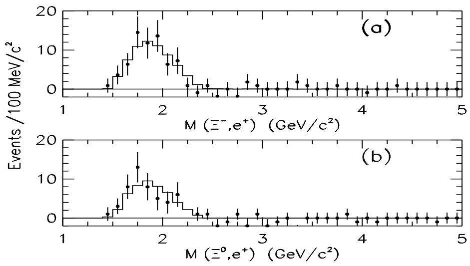

Fig. 2. The Ξe^+ invariant mass for: (a) $\Xi^- e^+$, (b)$\Xi^0 e^+$. The points are data and the solid lines are MC predictions.

Background from the decays $\Xi_c \to \Xi(1530) e^+ \nu_e$ with $\Xi(1530) \to \Xi\pi$ is estimated to be 0.4 ± 3.3 events. Backgrounds produced from fake electrons, generic continuum and B decay are expected to have approximately equal number of Ξe^+ as Ξe^- (wrong sign) pairs. We therefore use the number of Ξe^- pairs in the data to estimate these backgrounds. The yield given in Table 1 is then obtained by subtracting the number of wrong sign events from the right sign events. Comparisons between data and Monte Carlo (MC) predictions for Ξe^+ invariant mass distributions are shown in Fig.2. Our results are: $\mathcal{B}(\Xi_c^+ \to \Xi^0 e^+ \nu_e) \cdot \sigma(e^+e^- \to \Xi_c^+ X) = (1.55 \pm 0.33 \pm 0.25)$pb and $\mathcal{B}(\Xi_c^0 \to \Xi^- e^+ \nu_e) \cdot \sigma(e^+e^- \to \Xi_c^0 X) = (0.63 \pm 0.12 \pm 0.10)$pb. This is the first observation of $\Xi_c^+ \to \Xi^0 e^+ \nu_e$.

Table 1. Signals and backgrounds

mode	$\Xi_c^+ \to \Xi^0 e^+ \nu_e$	$\Xi_c^0 \to \Xi^- e^+ \nu_e$
$N_{\Xi e^+}$ (right sign)	47 ± 8	62 ± 9
$N_{\Xi e^-}$ (wrong sign)	6 ± 3	8 ± 4
corrected yield	41 ± 9	54 ± 10
efficiency (%)	1.17 ± 0.02	3.80 ± 0.05
$\sigma \cdot \mathcal{B}$ (pb)	$1.55 \pm 0.33 \pm 0.25$	$0.63 \pm 0.12 \pm 0.10$

1.2. First model independent upper bounds on the absolute branching ratios of Ξ_c

Under the assumption that the semileptonic widths of all charmed particles are equal, we use the weighted average of the inclusive semileptonic widths of the D^0 and D^+, $\langle\Gamma_{SL}\rangle$[4] and the weighted average of the Ξ_c lifetime measurements of NA32[8] and E687[9] to setimate $\mathcal{B}_{\ell X}^{+(0)} = \mathcal{B}(\Xi_c^{+(0)} \to \ell^+ X) = \langle\Gamma_{SL}\rangle \cdot \tau(\Xi_c^{+(0)})$. We find $\mathcal{B}_{\ell X}^{+} = (4.8^{+1.3}_{-1.0})\%$ and $\mathcal{B}_{\ell X}^{0} = (1.6^{+0.4}_{-0.3})\%$. There exists no theoretical relationship between $\mathcal{B}(\Xi_c \to \Xi \ell^+ \nu_l)$ and $\mathcal{B}_{\ell X}$, however $\mathcal{B}(\Xi_c \to \Xi \ell^+ \nu_l) \leq \mathcal{B}_{\ell X}$.

We measure $R_0 = \frac{\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+)}{\mathcal{B}(\Xi_c^0 \to \Xi^- e^+ \nu_e)} = 0.32 \pm 0.10^{+0.05}_{-0.03}$ and $R_+ = \frac{\mathcal{B}(\Xi_c^+ \to \Xi^- \pi^+ \pi^+)}{\mathcal{B}(\Xi_c^+ \to \Xi^0 e^+ \nu_e)} = 0.44 \pm 0.11^{+0.11}_{-0.06}$. Therefore $\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+) \leq (5.2 \pm 1.6^{+1.4}_{-1.2}) \times 10^{-3}$ and $\mathcal{B}(\Xi_c^+ \to \Xi^- \pi^+ \pi^+) \leq (2.1 \pm 0.5 \pm 0.7) \times 10^{-2}$ where the first error is from the determination of $R_{0(+)}$ and the second error is from our estimate of the $\mathcal{B}_{\ell X}$. This is the first model independent absolute normalization of the hadronic decay mode of the charmed cascades.

1.3. Lifetime ratio of Ξ_c^+/Ξ_c^0

Since we measure both Ξ_c^+ and Ξ_c^0 semileptonic decays using similar cuts in one experiment, the lifetime ratio $R_\tau = \tau_{\Xi_c^+}/\tau_{\Xi_c^0}$ can be extracted from the ratio of our measurements under the following assumptions. We assume that semileptonic decay width (Γ_{sl}) of Ξ_c^+ and Ξ_c^0 are equal and $\Gamma(\Xi_c^+ \to \Xi^0 e^+ \nu_e) = \Gamma(\Xi_c^0 \to \Xi^- e^+ \nu_e)$. Both of these assumptions follow from isospin invariance. We also assume that the Ξ_c^+ and Ξ_c^0 are equally produced from e^+e^- annihilations at 10 GeV. This is reasonable because the Ξ_c^*'s are expected to decay to the ground state via pion emission, and to be sufficiently heavy that no channel related by isospin is excluded by phase space, and the Ξ_c' decays electromagnetically to a Ξ_c.[10] The lifetime ratio is then related to the ratio of branching ratios:

$$R_\tau = \frac{\mathcal{B}(\Xi_c^+ \to \Xi^0 e^+ \nu_e)}{\mathcal{B}(\Xi_c^0 \to \Xi^- e^+ \nu_e)} = \frac{\Gamma_{sl}(\Xi_c^+)\cdot\tau(\Xi_c^+)}{\Gamma_{sl}(\Xi_c^0)\cdot\tau(\Xi_c^0)} = \frac{\tau(\Xi_c^+)}{\tau(\Xi_c^0)} = 2.46 \pm 0.70^{+0.33}_{-0.23}$$

Agreement among the existing lifetime ratio measurements, 4.06 ± 1.26 (E687),[9] 2.44 ± 1.68 (NA32)[8] and this result, is good. As our result is not a direct measurement of the lifetimes, it has entirely different systematic errors than E687 and NA32 and therefore serves as valuable independent confirmation of the fixed target results.

2. Form factor ratio measurement in $\Lambda_c^+ \to \Lambda e^+ \nu_e$

In the limit of negligible lepton mass, the semileptonic decay $\Lambda_c^+ \to \Lambda e^+ \nu_e$ is usually parametrized in terms of four form factors: two axial form factors F_1^A and F_2^A, and two vector form factors F_1^V and F_2^V. Within the framework of HQET the heavy flavor and spin symmetries imply relations among the form factors which reduce their number to one when the decay involves only heavy quarks[11].[12] Treating the s quark as a light quark, two independent form factors f_1 and f_2 to $O(\bar{\Lambda}/m_s)$[11 13] are required to describe the hadronic current. In general f_2 is expected to be less than f_1. The relationship between these form factors and the standard form factors is: $F_1^V(q^2) = -F_1^A(q^2) = f_1(q^2) + \frac{M_\Lambda}{M_{\Lambda_c}} f_2(q^2)$ and $F_2^V(q^2) = -F_2^A(q^2) = \frac{1}{M_{\Lambda_c}} f_2(q^2)$. Here q^2 is the invariant mass squared of the virtual W. In order to extract the form factor ratio $R = f_2/f_1$ using all the data we follow the model of Körner and Krämer (KK)[14] and assume the dipole form of q^2 dependence of f_1 and f_2: $f(q^2) = \frac{f(q^2_{max})}{(1-q^2/m^2_{ff})^2}(1 - q^2_{max}/m^2_{ff})^2$. where the pole mass is chosen to be $m_{ff} = 2.11\mathrm{GeV/c^2}$.

The data sample used in this study contains about 4 million $e^+e^- \to c\,\bar{c}$ events. We search for the decay $\Lambda_c^+ \to \Lambda e^+ \nu_e$ by detecting a Λe^+ pair with $m_\Lambda < m_{\Lambda e^+} < m_{\Lambda_c}$. The minimum allowed momentum for positrons is 0.7 GeV/c. The Λ is reconstructed through its decay to $p\pi$. We require the momentum of the $p\pi$ pair to be greater than 0.8 GeV/c. The sum of Λ and e^+ momentum is required to be greater than 1.4 GeV/c. The number of events passing the cuts described above is 1101, of which 135^{+22}_{-14} are consistent with fake Λ background, 133 ± 40 are consistent with fake electron background and 116 ± 23 are $\Xi_c \to \Xi e^+ \nu_e$ feedthrough. In Fig. 3, we show the $m_{\Lambda e^+}$ distribution after fake Λ subtraction and comparisons between the data and MC predictions.

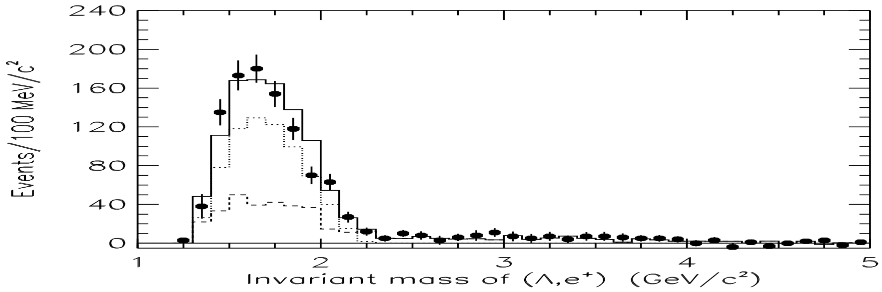

Fig. 3. Invariant Λe^+ mass for right sign combinations. The points are data after subtraction of fake Λs. The dashed line shows the backgrounds. The dotted line shows the MC prediction for the signal. The solid line shows the sum of the MC prediction and the backgrounds.

We estimate the direction of the Λ_c from the event thrust axis. The magnitude of the Λ_c momentum is then obtained by solving the equation $\vec{P}^2_{\Lambda_c} = (\vec{P}_\Lambda + \vec{P}_e + \vec{P}_{\nu_e})^2$. After the Λ_c momentum is estimated, the four kinematic variables are obtained by working in Λ_c center-of-mass frame. The resolutions (RMS) on $t = q^2/q^2_{max}$, $\cos\Theta_\Lambda$, $\cos\Theta_W$ and χ determined by MC are 0.25, 0.25, 0.2 and 45^0 respectively. Due to poor resolution on χ, this angle is not used here to extract the form factor ratio.

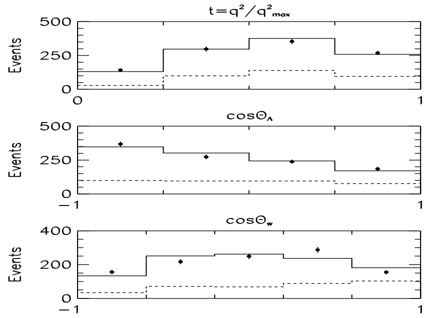

Fig. 4. Projections of the data (points) and the fit (solid lines) for t, $\cos\Theta_\Lambda$ and $\cos\Theta_W$. The dashed lines show the background.

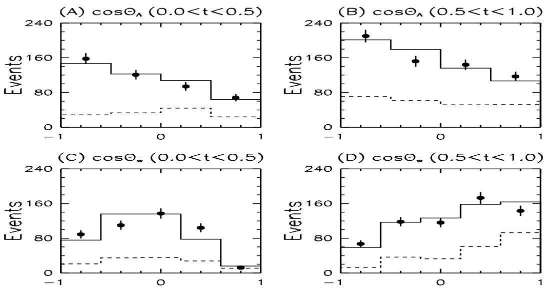

Fig. 5. Projections of the data and the fit onto $\cos\Theta_\Lambda$ and $\cos\Theta_W$ for two t regions. (A) and (C) for $0.0 < t < 0.5$, and (B) and (D) for $0.5 < t < 1.0$. The dashed lines show the background.

Using t, $\cos\Theta_\Lambda$ and $\cos\Theta_W$, we perform a 3-dimensional unbinned maximum likelihood fit in a manner similar to that developed by E691.[15] This technique enables a multi-dimensional likelihood fit to be performed to variables modified by experimental acceptance and resolution, and is necessary for this analysis due to the substantial smearing of the kinematic variables. Fig. 4 and Fig. 5 show the projections of the t, $\cos\Theta_\Lambda$ and $\cos\Theta_W$ distributions for the data and for the fit. The confidence level of the fit is determined to be 23% by the K nearest neighbors method[16] and by comparing the likelihood of the fit with the distribution of likelihoods obtained by fitting many MC samples of the same number of events as the data sample. The systematic error on R arises from MC statistics, volume size used in the likelihood fit, uncertainties in the background normalization and the method of background incorporation into the fit. Our preliminary result is:

$$R = -0.33 \pm 0.15 \pm 0.16$$

3. Summary

CLEO II is carrying out a systematic study of the semileptonic decays of charmed baryons. New results on Ξ_c semileptonic decays and form factor ratio in $\Lambda_c^+ \to \Lambda e^+ \nu_e$ are reported here. We have measured $\mathcal{B}(\Xi_c^+ \to \Xi^0 e^+ \nu_e) \cdot \sigma(e^+e^- \to \Xi_c^+ X) = (1.55 \pm 0.33 \pm 0.25)$ pb and $\mathcal{B}(\Xi_c^0 \to \Xi^- e^+ \nu_e) \cdot \sigma(e^+e^- \to \Xi_c^0 X) = (0.63 \pm 0.12 \pm 0.10)$ pb. We set upper bounds on absolute branching ratios of Ξ_c decays, $\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+) \leq (5.2 \pm 1.6^{+1.4}_{-1.2}) \times 10^{-3}$ and $\mathcal{B}(\Xi_c^+ \to \Xi^- \pi^+ \pi^+) \leq (2.1 \pm 0.5 \pm 0.7) \times 10^{-2}$. Assuming the Ξ_c^+ and Ξ_c^0 are equally produced in e^+e^- annihilation events at 10 GeV, the lifetime ratio of Ξ_c^+ / Ξ_c^0 is found to be $2.46 \pm 0.70^{+0.33}_{-0.23}$. From a 3-dimensional unbinned maximum likelihood fit we obtain a preliminary result on form factor ratio in $\Lambda_c^+ \to \Lambda e^+ \nu_e$, $R = f_2/f_1 = -0.33 \pm 0.15 \pm 0.16$.

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