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Observations of Λ_c^+ semileptonic decay

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Direct observations of the semileptonic decay of Λ_c^+ in the decay channels $\Lambda_c^+ \to \Lambda e^+ X$ and $\Lambda_c^+ \to \Lambda\mu^+ X$ have been made using the ARGUS detector at the DORIS II e^+e^- storage ring. The cross section times branching ratio were found to be $\sigma(e^+e^- \to \Lambda_c^+ X)\cdot BR(\Lambda_c^+ \to \Lambda e^+ X) = 4.20 \pm 1.28 \pm 0.71$ pb and $\sigma(e^+e^- \to \Lambda_c^+ X)\cdot BR(\Lambda_c^+ \to \Lambda\mu^+ X) = 3.91 \pm 2.02 \pm 0.90$ pb.

There has been much effort lately given to theoretical calculations and experimental measurements of semileptonic decay rates of charmed and bottom mesons. The quark model has so far had reasonable success in describing these semileptonic processes [1–5]. From this work, one can eventually extract the KM-mixing angles and the quark structure of hadrons described by the various form factors. Thus, it is natural to extend this model to the decay of heavy quark baryons such as Λ_c^+. Just as in the semileptonic D meson decay, the semileptonic decay of Λ_c^+ is a spectator process where the Cabibbo-favored decay $c \to s\ell^+\nu_\ell$ dominates. This process occurs, to a good approximation, independently of the spectator u and d quarks. Differences from semileptonic meson calculations arise in parameterizing the hadronic wavefunctions. Recent theoretical work [6–8] has put the $\Lambda_c^+ \to \Lambda\ell^+\nu_\ell$ branching ratio between 1.4% and 4.2%, depending on the choice of various Λ_c^+ wavefunction models and the nature of the q^2 dependencies of the hadronic form factors. Thus, a detailed experimental measurement of the Λ_c^+ semileptonic rate should help to unravel the nature of such hadronic wavefunctions, form factors and their q^2 dependence.

In this paper, direct evidence for the semileptonic decay of the Λ_c^+ is presented and its $\sigma\cdot$BR and branching ratios are determined. The decay modes studied are $\Lambda_c^+ \to \Lambda e^+ X$ and $\Lambda_c^+ \to \Lambda\mu^+ X$ [#1], where X is any particle combination containing a neutrino. Because this associated neutrino cannot be detected, these decay channels are difficult to observe, with many possible contributing background processes. To data, only a few measurements [9–11] of the Λ_c^+ semileptonic decay have been made. These measurements either have low statistics or do not involve direct observation of the semileptonic decay channel. Therefore, improved measurements are of considerable interest.

The data presented here was collected using the ARGUS detector at the e^+e^- storage ring DORIS II at DESY. The ARGUS detector is a 4π solenoidal magnetic spectrometer detector, described in detail elsewhere [12]. The data sample comprises an integrated luminosity of 477 pb^{-1} on the $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(4S)$ resonances and the nearby continuum with an average center of mass energy of 10.4 GeV. Only multihadron events are selected, these being defined as having at least three charged tracks with either a common main vertex or a total energy deposit of at least 1.7 GeV in the shower counters. To suppress radiative Bhabhas and beam gas, only events that have $n_{ch} + n_\gamma/2 > 5$ are accepted, where n_{ch} is the number of charged tracks and n_γ is the number of photons with momentum above 100 MeV/c. To eliminate poorly measured particles, charged tracks must have a min-

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[#1] In this paper, all references to a specific charge state imply the charge conjugate state also, unless otherwise stated.

imum momentum transverse to the beam direction of 60 MeV/c and a polar angle, θ, with respect to the beam direction such that $|\cos\theta|<0.92$. Charged hadron identification is made on the basis of specific ionization in the drift chamber, time of flight measurements and shower counter and muon chamber information. This information is then used to calculate a likelihood ratio for all charged tracks. Only pions and protons with a likelihood ratio greater than 1% are accepted [12].

In this analysis we are only interested in Λ_c^+ events from continuum $c\bar{c}$ production. To reduce $\Upsilon(4S)$ resonance events, and hence possible Λ_c^+'s produced from B meson decay, a topological cut is applied. It is required that the second Fox–Wolfram moment [13] be larger than 0.35. Extensive Monte Carlo studies show that this results in (93 ± 3)% of the $\Upsilon(4S)$ resonance events been removed.

Λ candidates are reconstructed from identified $p\pi^-$ pairs having a common secondary vertex with a χ^2 less than 36 and the product of the proton and pion particle likelihood hypotheses greater than 5%. The identified Λ is required to have a reconstructed mass within 10 MeV/c^2 of the Λ mass [14] and a χ^2 of less than 25 for its mass hypothesis. These surviving combinations are then subjected to a mass constrained fit. A plot of the $p\pi^-$ mass shows a large peak at the Λ mass on a small linear background, demonstrating the purity of the Λ selection [12].

Electrons and muons are identified by a combined likelihood function which includes dE/dx, TOF, shower counter and muon chamber information. Only those leptons having a combined likelihood ratio greater than 80% are selected, with the further requirement that the muons must also have at least one hit in the outer muon chambers. Furthermore, electrons and muons are required to have a momentum greater than 0.4 GeV/c and 0.9 GeV/c, respectively. This is where reliable lepton identification begins. Finally, the electrons from reconstructed e^+e^- secondary vertices that are consistent with photon conversion are removed from the subsequent analysis.

The Λ's and leptons from semileptonic Λ_c^+ decay originate from the main interaction vertex. Thus, it is required that the leptons point to the main vertex with a χ^2 of less than 36. Also, Λ events are required to have the angle θ between the vector defined by the fitted main vertex and the Λ decay vertex and the vector defined by the reconstructed Λ momentum, such that $\cos\theta>0.995$.

Thus, the above selections result in a clean Λ and lepton data sample. There are 574 Λe^+ and 127 $\Lambda\mu^+$ pairs identified in the mass region of 1.115–2.285 GeV/c^2 (i.e. the kinematically allowed range from the $\Lambda\ell^+$ to Λ_c^+ mass). As will be explained later, the wrong-sign combination [#2] of a Λ and ℓ^- gives a measure of the background. Using the same selection procedure as above, there are 393 Λe^- and 52 $\Lambda\mu^-$ wrong-sign pairs in the same mass range. Fig. 1 shows the invariant mass plots for the two lepton channels and for both the right- and wrong-sign combinations.

The data is compared to $\Lambda_c^+\to\Lambda\ell^+\nu_\ell$ events gen-

[#2] In this paper, all references to $\Lambda\ell^+$ implies the right-sign combination of a Λ and a lepton while $\Lambda\ell^-$ implies the wrong-sign combination and $\Lambda\ell$ means both charged states.

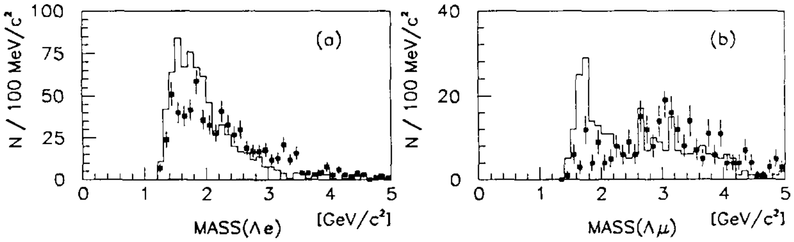

Fig. 1. Right-sign (histogram) and wrong-sign (solid squares) Λ+lepton invariant mass distributions for: (a) electron channel and (b) muon channel.

erated by the LUND [15] Monte Carlo program [#3] and processed through the full detector simulation and reconstruction program [18] in order to identify various kinematical selections which discriminate against background. We determine the combined Λ and lepton momenta, $p=|\boldsymbol{p}_\Lambda+\boldsymbol{p}_\ell|$, and define x_p to be p/p_{max}, where $p_{max}=\sqrt{E_{beam}^2-M_{\Lambda_c^+}^2}$, and require this scaled momentum to be greater than 0.5. This selection is justified since Λ_c^+'s from the continuum have a hard momentum distribution [17], making this a good means of reducing combinatorial background. Furthermore, with the $x_p>0.5$ selection. Λ_c^+'s from the $\Upsilon(4S)$ resonance are eliminated since the decay products from B decay are kinematically restricted to be less than 2.3 GeV$/c^2$ (i.e. $x_p=0.48$). Coupled with the second Fox–Wolfram moment cut of 0.35, background Λ+lepton combinations from the $\Upsilon(4S)$ are severly reduced (as will be shown below from Monte Carlo studies). Thus, after the $x_p>0.5$ selection there remain 164 Λe^+ and 79 $\Lambda\mu^+$ right-sign events and 60 Λe^- and 27 $\Lambda\mu^-$ wrong-sign events in the mass range of 1.115–2.285 GeV$/c^2$. Their mass plots are shown in fig. 2.

The $\Lambda\ell^+$ signal within the desired mass range is strong, while the number of events beyond the Λ_c^+ mass is much smaller. Since the signal mass range is large, many background processes can contribute. These possible sources of background have to be considered and then analyzed to check their effect.

The presence of wrong-sign combinations demonstrates that a careful correction for background must be made. Corrections for processes that contribute equally to right and wrong-sign channels can be made simply by subtracting the latter distribution from the former. Such background includes: chance coincidence of a real Λ decay with a track that is misidentified as a lepton (fake lepton) or a coincidence of a fake Λ with a real lepton. Examples of this are electrons from misidentified hadrons, fake muons from hadron punch-throughs, muons from π or K decay and K_S^0 faking a Λ. These processes will populate the right-sign and wrong-sign distributions equally. As a check of this assumption, the expected number of events from these processes is calculated. The rate for hadrons misidentified as leptons is around 0.5% for electrons and 2.0% for muons per hadron track [12]. Multiplying this by the hadronic track multiplicity per event of 7.7, the number of Λ candidates and the various kinematical efficiencies, the number of right-sign real Λ and fake lepton events is calculated to be 56.0 ± 12.2 and 25.6 ± 6.9 for the electron and muon channels respectively. The number of right-sign events with a fake Λ and a real lepton is found to be 1.7 ± 0.8 for the electron channel and 0.9 ± 0.4 for the muon channel (this is calculated from the observed number of background events under the Λ mass peak). The sum of these numbers, for each channel, are consistent with the observed number of wrong-sign events, thus demonstrating an understanding of this background and validating the technique of wrong-sign subtraction.

Also considered as a source of background are events having randomly correlated Λ's and leptons. That is, real Λ and a real lepton from separate sources

[#3] The program parameters were set so that $\Lambda_c^+\to\Lambda\ell^+\nu_\ell$ decay calculations included the use of QED radiative and second order QCD corrections and simple weak decay matrix elements [15]. Also, the Λ_c^+ momentum spectrum was generated using a Peterson fragmentation function [16] with the fragmentation parameter as determined by ARGUS [17]. The above settings were used for all $\Lambda_c^+\to\Lambda\ell^+\nu_\ell$ Monte Carlo calculations that follow in this paper.

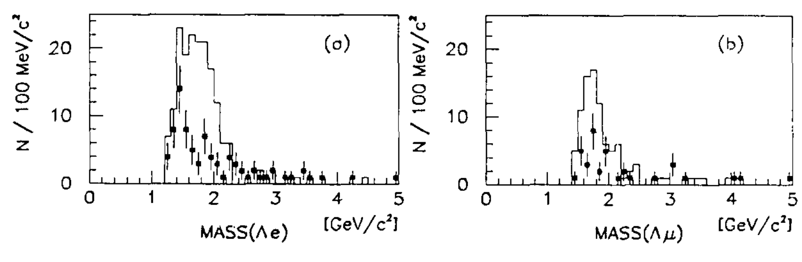

Fig. 2. Right-sign (histogram) and wrong-sign (solid squares) Λ+lepton invariant mass distributions with $x_p>0.5$ for: (a) electron channel and (b) muon channel (bins with zero contents are not displayed).

that when combined, pass the above identification and kinematical selections. It is not obvious if they will populate the right- and wrong-sign distributions equally. To estimate the size of this background, a Monte Carlo study using the LUND event generator was performed. Processes from the continuum $e^+e^- \to c\bar{c}$, $s\bar{s}$, $d\bar{d}$, $u\bar{u}$ and from the $\Upsilon(1S)$, $\Upsilon(2S)$ resonances are analyzed. The $\Upsilon(4S)$ resonance was simulated by generating $B\bar{B}$ events using the MOPEK Monte Carlo generator [19]. The rates of production for the right- and wrong-sign correlations are determined and the results are scaled to the luminosity (including detector efficiency corrections). The scaled number of randomly correlated Λ+lepton events produced from the continuum are found to be $8.9\pm1.9 \Lambda e^+$ and $3.0\pm0.6 \Lambda\mu^+$ right-sign and $4.2\pm1.2\ \Lambda e^-$ and $1.1\pm0.3 \Lambda\mu^-$ wrong-sign combinations. Nothing is found from the $\Upsilon(1S)$ and $\Upsilon(2S)$ but from the $\Upsilon(4S)$ (including the second Fox–Wolfram moment cut) only 1 Λe^+ event is found. This leaves an excess of $5.7\pm2.5\ \Lambda e^+$ and $1.9\pm0.7\ \Lambda\mu^+$ right-sign events which means that the observed wrong-sign distribution does not completely represent this background. Thus, the Λ_c^+ semileptonic signal is corrected by subtracting this excess from the observed $\Lambda\ell^+$ distribution.

The only significant contribution to the randomly correlated Λ+lepton background comes from the process $e^+e^- \to c\bar{c}$. The enhanced right-sign background below the Λ_c^+ mass is attributed not to the excess production of right-sign over wrong-sign events, but to kinematic effects. Right-sign events originate more often in the same quark jet while wrong-sign events originate more often in opposite quark jets. An example of one process that contributes to this background is the production of a D^+ meson and a Λ in the same quark jet, with the D^+ producing a semileptonic ℓ^+, which results in a right-sign combination. Similarly, we have a D^- and a Λ produced in opposite quark jets, resulting in a wrong-sign combination. In general, the Λ's and leptons from right-sign events are produced with parallel momentum vectors, resulting in a high momentum and low mass combinations. While wrong-sign events are produced with antiparallel momentum vectors, resulting in a low momentum and high mass combinations. Thus, we would expect an excess of right-sign events at lower mass (as shown by the Monte Carlo analysis described in the preceding paragraph), and an excess of wrong-sign events at higher mass. This last effect can be seen in fig. 1, where the wrong-sign distribution is greater than the right-sign distribution above the Λ_c^+ mass. This excess is due to randomly correlated wrong-sign events since the background due to misidentified Λ's and leptons is assumed to populate both distributions equally. If the $x_p > 0.5$ selection is included, the Monte Carlo analysis predicts an excess of $10.0\pm3.4\ \Lambda e^-$ wrong-sign and $4.5\pm0.7\ \Lambda\mu^+$ right-sign events above the Λ_c^+ mass. From the data there is an observed excess of $13\pm6 \Lambda e^-$ wrong-sign and $6\pm5 \Lambda\mu^+$ right-sign events. This agreement in the excess number of events indicates that the Monte Carlo analysis describes the randomly correlated background reasonably. The lack of wrong-sign muon events at high mass is a kinematical effect due to the muon's high momentum cutoff. Since wrong-sign events are mostly back-to-back in the Λ and lepton momentum, and since only high momentum muons are detected, the resulting $\Lambda\mu^-$ momentum will be low and will be discriminated by the $x_p > 0.5$ selection.

One more source of background which populates the right-sign distribution comes from the semileptonic decay of the charmed baryon $\Xi_c^0 \to \Xi^- \ell^+ \nu_\ell$, where $\Xi^- \to \Lambda\pi^-$. Recent theoretical work [6–8] has predicted the Ξ_c^0 semileptonic branching ratio to be similar to that of Λ_c^+. If the Ξ_c^0 production rate is comparable to Λ_c^+, then a large contamination from this process can be expected. LUND Monte Carlo gives a Λ_c^+ production rate which is about 14 times greater than Ξ_c^0. This would represent about a 7% contamination to the $\Lambda\ell^+$ signal, given that the reconstruction efficiency for this channel is similar to that for $\Lambda\ell^+\nu_\ell$. To check this background, $\Lambda\pi^-\ell^+$ combinations were selected such that the Λ and lepton are identified as above, and including the $x_p > 0.5$ selection to their combined momentum. Also, the π^- was not required to point back to the main interaction vertex since the Ξ^- can decay some distance from this vertex. The resulting $\Lambda\pi^-$ invariant mass distribution was fitted using a gaussian with the mass fixed at the Ξ^- mass [14] and width determined from Monte Carlo. The background was fitted with a first order polynomial. A signal of $12.4\pm4.3\ \Xi^- e^+$ and $6.5\pm3.4\ \Xi^-\mu^+$ events is observed. Wrong-sign combinations yielded a signal of $6.2\pm2.9\ \Xi^- e^-$ and

1.6 ± 1.4 $\Xi^- \mu^-$ events. Subtracting the wrong-sign from the right-sign and correcting for the Ξ^- reconstruction efficiency, the amount of contamination is estimated to be 7.3 ± 6.1 Λe^+ and 5.8 ± 4.4 $\Lambda\mu^+$ events. Not included in this analysis is the contribution from the other charged state $\Xi_c^+ \to \Xi^0 \ell^+ \nu_\ell$, where subsequently, $\Xi^0 \to \Lambda\pi^0$. This channel has low detection efficiency because the reconstruction of Ξ^0 involves the identification of π^0, which is difficult. However, it is expected to have the same exclusive semileptonic rate as for Ξ_c^0 [6]. Thus, the contribution of this background relative to that of Ξ_c^0 can be estimated by multiplying by the ratio of the experimentally determined lifetimes, $\tau(\Xi_c^+)/\tau(\Xi_c^0) = 2.44 \pm 1.68$ [20,21], giving a contamination of 17.8 ± 14.9 Λe^+ and 14.2 ± 10.7 $\Lambda\mu^+$ events.

The observed Λ_c^+ semileptonic signal is obtained by subtracting the wrong-sign, net randomly correlated and the semileptonic $\Xi_c^0 + \Xi_c^+$ background from the right-sign number of events. These results are summarized in table 1. After subtraction, this leaves 73.2 ± 22.1 Λe^+ and 30.1 ± 15.5 $\Lambda\mu^+$ events. Fig. 3 shows the $\Lambda\ell^+$ right-sign mass distribution, after wrong-sign subtraction, for both the electron and muon channels. Since the theoretical mass distribution is nearly gaussian [22], and because of the low statistics and detector smearing, the experimental mass distribution can be approximated as a gaussian. As a comparison, fig. 3 also shows the gaussian fitted $\Lambda\ell^+$ mass distributions resulting from the LUND simulated $\Lambda_c^+ \to \Lambda\ell^+\nu_\ell$ decay, with detector corrections applied and normalized to the data. The agreement between the experimental and Monte Carlo distributions is reasonable. As a further check of our results, fig. 4 shows the $\Lambda\ell^+$ right-sign x_p spectrum, after wrong-sign subtraction. Also shown is the x_p spectrum for $\Lambda\ell^+$ events generated from the LUND simulated $\Lambda_c^+ \to \Lambda\ell^+\nu_\ell$ decay, with detector corrections applied and normalized to the data. The agreement is reasonable, specifically for $x_p > 0.5$, since below this the assumptions about the background are no longer valid and low detection efficiencies cause large statistical errors in the observed signal. This agreement suggests that our assumptions regarding the wrong-sign subtraction and the parametrization of the Λ_c^+ momentum spectrum are reasonable.

Table 1
Sources of Λ + lepton signal and background events, with $x_p > 0.5$ and $M_{\Lambda\ell} < 2.285$ GeV/c^2.

Sources of Λ + lepton events	$N_{\Lambda e}$	$N_{\Lambda\mu}$
right-sign	164.0 ± 12.8	79.0 ± 8.9
wrong-sign	60.0 ± 7.8	27.0 ± 5.2
net random correlation	5.7 ± 2.5	1.9 ± 0.7
$\Xi_c^0 + \Xi_c^+$ semileptonic decay	25.1 ± 16.1	20.0 ± 11.6
net $\Lambda\ell^+$ signal	73.2 ± 22.1	30.1 ± 15.5

To calculate $\sigma(e^+e^- \to \Lambda_c^+ X) \cdot BR(\Lambda_c^+ \to \Lambda\ell^+ X)$ and the branching ratios, we first have to correct the Λ_c^+ signal for detector efficiency, also including the topological and kinematical selections. From Monte Carlo studies, the reconstruction efficiencies are found to be 0.0353 ± 0.0012 for Λe^+ and 0.0156 ± 0.0006 for the $\Lambda\mu^+$ channel, where the given errors are statistical. Thus, the detector corrected Λ_c^+ semileptonic signals are computed to be 2074 ± 630 Λe^+ and 1930 ± 997 $\Lambda\mu^+$ events. Given an effective total luminosity of 493.6 pb^{-1}, which accounts for the enhanced continuum cross section from the electromagnetic decay of the $\Upsilon(1S)$ and $\Upsilon(2S)$ [23], we have for $\sigma \cdot$BR,

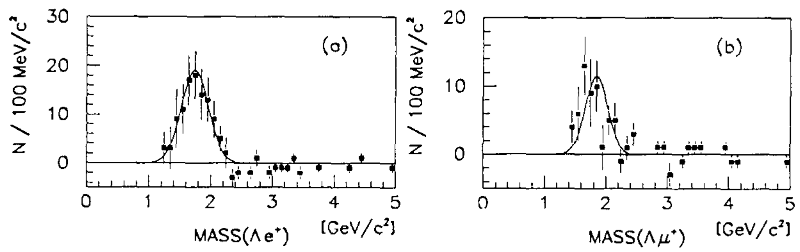

Fig. 3. The $\Lambda\ell^+$ right-sign invariant mass distribution, after wrong-sign subtraction (solid squares), and the $\Lambda\ell^+$ Monte Carlo generated invariant mass (line), both with $x_p > 0.5$ for: (a) electron channel and (b) muon channel (bins with zero contents are not displayed).

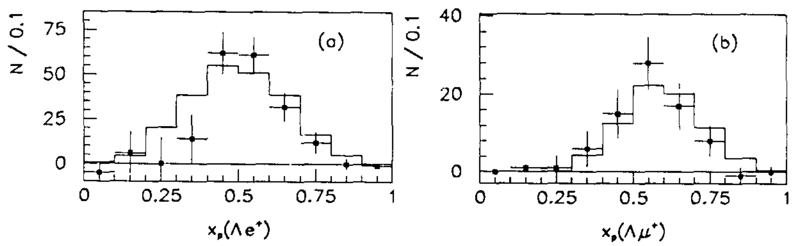

Fig. 4. The $\Lambda\ell^+$ right-sign x_p spectrum, after wrong-sign subtraction (solid squares), and the $\Lambda\ell^+$ Monte Carlo generated x_p spectrum (line), both with $M_{\Lambda\ell^+} < 2.285$ GeV/c^2, for: (a) electron channel and (b) muon channel.

$$\sigma(e^+e^- \to \Lambda_c^+ X)\cdot BR(\Lambda_c^+ \to \Lambda e^+ X) = 4.20 \pm 1.28 \pm 0.71 \text{ pb},$$
$$\sigma(e^+e^- \to \Lambda_c^+ X)\cdot BR(\Lambda_c^+ \to \Lambda \mu^+ X) = 3.91 \pm 2.02 \pm 0.90 \text{ pb}. \quad (1)$$

As expected from lepton universality in weak decay, the electron and muon channel branching ratios are in agreement with each other.

The systematic error in the measurement of $\sigma\cdot$BR comes from a number of sources. The value of the collected luminosity is known to a 1.8% accuracy. The efficiency for the reconstruction of three tracks in the drift chamber is known within 3.5%. The Monte Carlo lepton identification efficiency is known to within 4% and 6% for the electrons and muons respectively. The error on the parametrization of the x_p spectrum for the production of Λ_c^+ results in an uncertainty of 5%. The error in the Monte Carlo simulation of the randomly correlated Λ + lepton background has been estimated at 3%. By varying the x_p cut, the wrong-sign background subtraction error has been estimated at 8%. Finally, the error in the ratio of lifetimes for the two charged states of Ξ_c gives a semileptonic Ξ_c^+ background subtraction error of 12.5% for the electron channel and 19.5% for the muon channel. Adding all of these sources of error in quadrature, gives a total systematic error of 16.9% and 23.0% for the electron and muon channels, respectively.

To calculate branching ratios, one requires the knowledge of Λ_c^+ production from $e^+e^- \to c\bar{c}$ continuum events for $\sqrt{s}$ around 10.4 GeV. We only have to concern ourselves with Λ_c^+ production from the continuum since there is no direct production of Λ_c^+'s from the $\Upsilon(1S)$ and $\Upsilon(2S)$ resonances [23] and Λ_c^+'s from the $\Upsilon(4S)$ are greatly reduced by the second Fox–Wolfram moment and x_p selections. To date, no such measurement of the Λ_c^+ production has been made. Thus, we compare our measured value of $\sigma\cdot$BR with that for the decay channel $\Lambda_c^+ \to pK^-\pi^+$, which is the best measured Λ_c^+ decay channel. The measurements of $\sigma(e^+e^- \to \Lambda_c^+ X)\cdot BR(\Lambda_c^+ \to pK^-\pi^+)$, at $\sqrt{s}$ near 10.4 GeV, from ARGUS [17] and CLEO [24] are $12.0 \pm 1.0 \pm 1.3$ pb and $10.0 \pm 1.5 \pm 1.5$ pb respectively, and their weighted average is $\sigma(e^+e^- \to \Lambda_c^+ X)\cdot BR(\Lambda_c^+ \to pK^-\pi^+) = 11.3 \pm 0.8 \pm 1.0$ pb. Using this result and eq. (1), we get for the ratio of branching ratios

$$BR(\Lambda_c^+ \to \Lambda e^+ X)/BR(\Lambda_c^+ \to pK^-\pi^+) = 0.37 \pm 0.11 \pm 0.08,$$
$$BR(\Lambda_c^+ \to \Lambda \mu^+ X)/BR(\Lambda_c^+ \to pK^-\pi^+) = 0.35 \pm 0.18 \pm 0.09. \quad (2)$$

The $\Lambda_c^+ \to \Lambda\ell^+ X$ branching ratio can now be calculated using the knowledge of the $\Lambda_c^+ \to pK^-\pi^+$ branching ratio. The most recent measurements of $BR(\Lambda_c^+ \to pK^-\pi^+)$, made by ARGUS [25] and CLEO [24], are $(4.2 \pm 1.2 \pm 1.0)$% and $(4.4 \pm 1.1 {}^{+1.2}_{-1.0})$%, respectively. These results are based on the assumption that all baryons produced in B decay come from Λ_c^+ decay. If this is not true, then the $\Lambda_c^+ \to pK^-\pi^+$ branching ratio increases. The weighted average of these branching ratios is $BR(\Lambda_c^+ \to pK^-\pi^+) = (4.3 \pm 1.1)$%. Using this result and eq. (2), one finds for the Λ_c^+ semileptonic branching ratio

$$BR(\Lambda_c^+ \to \Lambda e^+ X) = (1.6 \pm 0.5 \pm 0.5)\%,$$
$$BR(\Lambda_c^+ \to \Lambda \mu^+ X) = (1.5 \pm 0.8 \pm 0.5)\%. \quad (3)$$

Finally, the nature of X in $\Lambda_c^+ \to \Lambda\ell^+ X$ is to be considered here. The only contributions to X can come from other Λ_c^+ semileptonic decay modes such as: $\Lambda^* \ell^+ \nu_\ell$, $\Lambda\pi^0\ell^+\nu_\ell$, $\Lambda(\pi\pi)^0\ell^+\nu_\ell$, $\Sigma^0\ell^+\nu_\ell$, $\Sigma^{*0}\ell^+\nu_\ell$, and $\Sigma^0\pi^0\ell^+\nu_\ell$, where subsequently, $\Lambda^* \to \Sigma^0\pi^0$, $\Sigma^0 \to \Lambda\gamma$ and $\Sigma^{*0} \to \Lambda\pi^0$. A detailed discussion of these modes is done in ref. [11] (except the channel involving Λ^*), where it was concluded that they are all negligible. For instance, the channels involving the hadrons Σ^0, Σ^{*0} and $\Lambda\pi^0$ are isospin 1, whereas the Λ_c^+ is isospin 0, thus these modes are isospin-suppressed [6]. Also, decay modes involving multihadrons should be suppressed because of the required creation of a $u\bar{u}$ or $d\bar{d}$ quark pair. This is supported by the observation that the dominant semileptonic decay modes of D mesons are to single-particle hadronic final states [26]. Also, theoretical calculations of $\Lambda_c^+ \to \frac{1}{2}^+ 0^- e^+\nu_e$ transitions, using the phenomenological chiral lagrangian method [27], puts these partial rates at two or three orders of magnitude less than single-hadron modes.

Considering decays involving Λ^*, the most probable mode would be $\Lambda_c^+ \to \Lambda^*(1600)\ell^+\nu_\ell$, since this is the lowest mass J^P: $\frac{1}{2}^+ \to \frac{1}{2}^+$ transition. The $\Lambda^*(1600)$ baryon can further decay to $(\Sigma\pi)^0$, with a maximum branching ratio of 60% [14]. Only the mode involving a Σ^0, which occurs 50% of the time can be a source of Λ's. Furthermore, the efficiency for reconstruction of $\Lambda\ell^+$ pairs from this source of background, determined from Monte Carlo, is 50% of that from $\Lambda_c^+ \to \Lambda\ell^+\nu_\ell$, thus contamination from $\Lambda^*(1600)$ can be at most 15% of the observed $\Lambda\ell^+$ signal. It is most likely less than this since the $\Lambda_c^+ \to \Lambda^*\ell^+\nu_\ell$ mode has less phase space available than $\Lambda_c^+ \to \Lambda\ell^+\nu_\ell$, thereby reducing its rate.

Thus, we conclude that other possible Λ_c^+ semileptonic modes involving a Λ in the final state have rates that are negligible compared to $\Lambda_c^+ \to \Lambda\ell^+\nu_\ell$ or that their contribution to the observed $\Lambda\ell^+$ signal is minimal. Therefore, the signal is dominanted by the decay $\Lambda_c^+ \to \Lambda\ell^+\nu_\ell$. However, because of possible contributions from other sources, only the branching ratio for $\Lambda_c^+ \to \Lambda\ell^+ X$ is given.

Finally, to put the measurements made here in perspective, a comparison with other semileptonic Λ_c^+ results is in order. MARK II at SPEAR has measured [9] $BR(\Lambda_c^+ \to e^+X) = (4.5 \pm 1.7)\%$ and $BR(\Lambda_c^+ \to \Lambda e^+ X) = (1.1 \pm 0.8)\%$. The Fermilab 15 foot bubble chamber neutrino experiment measures [10] $BR(\Lambda_c^+ \to \Lambda e^+ X) < 2.2\%$ at a 90% confidence level. These measurements are in agreement with the observations made here.

In summary, direct observation of the decay $\Lambda_c^+ \to \Lambda\ell^+\nu_\ell$ has been made. The sources of background have been studied and the data subsequently corrected, leaving only $\Lambda\ell^+$ events that are attributed to Λ_c^+ semileptonic decay. This allowed a determination of $\sigma(e^+e^- \to \Lambda_c^+ X) \cdot BR(\Lambda_c^+ \to \Lambda\ell^+ X)$. This was compared with $\sigma(e^+e^- \to \Lambda_c^+ X) \cdot BR(\Lambda_c^+ \to pK^-\pi^+)$ as measured by ARGUS and CLEO, and using the $\Lambda_c^+ \to pK^-\pi^+$ branching ratio as measured by ARGUS and CLEO, the Λ_c^+ semileptonic branching ratio $BR(\Lambda_c^+ \to \Lambda\ell^+ X)$ was determined. These measurements are the most definitive, to data, of this decay channel.

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