Measurement of the Λ_c^+ Decay-Asymmetry Parameter

P. Avery,[1] D. Besson,[1] L. Garren,[1] J. Yelton,[1] K. Kinoshita,[2] F. M. Pipkin,[2] M. Procario,[2] Richard Wilson,[2] J. Wolinski,[2] D. Xiao,[2] Y. Zhu,[2] R. Ammar,[3] P. Baringer,[3] D. Coppage,[3] R. Davis,[3] P. Haas,[3] M. Kelly,[3] N. Kwak,[3] Ha Lam,[3] S. Ro,[3] Y. Kubota,[4] J. K. Nelson,[4] D. Perticone,[4] R. Poling,[4] R. Fulton,[5] T. Jensen,[5] D. R. Johnson,[5] H. Kagan,[5] R. Kass,[5] F. Morrow,[5] J. Whitmore,[5] P. Wilson,[5] D. Bortoletto,[6] W.-Y. Chen,[6] J. Dominick,[6] R. L. McIlwain,[6] D. H. Miller,[6] C. R. Ng,[6] S. F. Schaffner,[6] E. I. Shibata,[6] I. P. J. Shipsey,[6] W.-M. Yao,[6] M. Battle,[7] K. Sparks,[7] E. H. Thorndike,[7] C.-H. Wang,[7] M. S. Alam,[8] I. J. Kim,[8] W. C. Li,[8] V. Romero,[8] C. R. Sun,[8] P.-N. Wang,[8] M. M. Zoeller,[8] M. Goldberg,[9] T. Haupt,[9] N. Horwitz,[9] V. Jain,[9] M. D. Mestayer,[9] G. C. Moneti,[9] Y. Rozen,[9] P. Rubin,[9] V. Sharma,[9] T. Skwarnicki,[9] M. Thulasidas,[9] G. Zhu,[9] A. V. Barnes,[10] S. E. Csorna,[10] T. Letson,[10] J. Alexander,[11] M. Artuso,[11] C. Bebek,[11] K. Berkelman,[11] T. Browder,[11] D. G. Cassel,[11] E. Cheu,[11] D. M. Coffman,[11] G. Crawford,[11] J. W. DeWire,[11] P. S. Drell,[11] R. Ehrlich,[11] R. S. Galik,[11] M. Garcia-Sciveres,[11] B. Geiser,[11] B. Gittelman,[11] S. W. Gray,[11] A. M. Halling,[11] D. L. Hartill,[11] B. K. Heltsley,[11] K. Honscheid,[11] J. Kandaswamy,[11] N. Katayama,[11] D. L. Kreinick,[11] J. D. Lewis,[11] G. S. Ludwig,[11] J. Masui,[11] J. Mevissen,[11] N. B. Mistry,[11] S. Nandi,[11] E. Nordberg,[11] C. O'Grady,[11] D. Peterson,[11] M. Pisharody,[11] D. Riley,[11] M. Sapper,[11] M. Selen,[11] A. Silverman,[11] S. Stone,[11] H. Worden,[11] M. Worris,[11] and A. J. Sadoff[12]

[1] *University of Florida, Gainesville, Florida 32611*
[2] *Harvard University, Cambridge, Massachusetts 02138*
[3] *University of Kansas, Lawrence, Kansas 66045*
[4] *University of Minnesota, Minneapolis, Minnesota 55455*
[5] *Ohio State University, Columbus, Ohio 43210*
[6] *Purdue University, West Lafayette, Indiana 47907*
[7] *University of Rochester, Rochester, New York 14627*
[8] *State University of New York at Albany, Albany, New York 12222*
[9] *Syracuse University, Syracuse, New York 13244*
[10] *Vanderbilt University, Nashville, Tennessee 37235*
[11] *Cornell University, Ithaca, New York 14853*
[12] *Ithaca College, Ithaca, New York 14850*

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We report a measurement of Λ polarization in the two-body decay $\Lambda_c^+ \to \Lambda\pi^+$ in nonresonant e^+e^- interactions from data taken with the CLEO detector. Using these data we have determined the parity-violating asymmetry decay parameter α_{Λ_c} to be $-1.0^{+0.4}_{-0.0}$. We see no evidence for significant Λ_c^+ polarization.

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The Λ_c^+ (udc) is the lowest-mass baryon containing a charmed quark. Its spin is $\frac{1}{2}$, and its decays proceed via the weak interaction, usually resulting in strange-particle final states. As in hyperon decays, the weak decay of charmed baryons is expected to violate parity conservation. The decay $\Lambda_c^+ \to \Lambda\pi^+$ is analogous to the hyperon decays $\Xi^- \to \Lambda\pi^-$ and $\Lambda \to p\pi^-$, where the parity-violating asymmetry decay parameters have been measured to be $\alpha_\Xi = -0.456 \pm 0.014$ and $\alpha_\Lambda = 0.642 \pm 0.013$.[1] We present a measurement of the parity-violating asymmetry decay parameter α_{Λ_c} for the decay $\Lambda_c^+ \to \Lambda\pi^+$. A nonzero value of α_{Λ_c} indicates parity violation; in this decay, the parity violation takes the form of an up-down asymmetry in the decay Λ's direction relative to the Λ_c^+ spin. A nonzero α_{Λ_c} also gives rise to polarization of the daughter Λ, as we discuss below. Throughout this paper, unless noted otherwise, use of a particle or decay implies the use of its charge conjugate.

In a recent paper, Bjorken[2] argues that $\alpha_{\Lambda_c} \simeq -1$ for several Λ_c^+ decay modes including $\Lambda_c^+ \to \Lambda\pi^+$. Bjorken, making a factorization ansatz, writes the decay amplitude as

$$T = \bar{\chi}(p,s)(g_V\gamma_\mu + g_A\gamma_5\gamma_\mu)\chi(P,S)J^\mu ,$$

where T is the decay amplitude, $\bar{\chi}$, s, and p are the Dirac wave function, the spin, and momentum of the Λ, respectively; χ, P, and S are the Dirac wave function, momentum, and spin of the Λ_c^+, and J^μ is the pion weak current. The pion weak current is proportional to its momentum q^μ:

$$J^\mu \propto F_\pi q^\mu .$$

Since the π^+ is extremely relativistic, $\alpha_{\Lambda_c} \simeq -g_A/g_V$, which is naively -1.

The data sample used in this study was collected with the CLEO detector at the Cornell Electron Storage Ring (CESR). The CLEO detector and our hadronic event-selection criteria have been described in detail elsewhere.[3-5] These data comprise 101 pb^{-1} at energies just below the $B\bar{B}$ threshold ($\sqrt{s}=10.52$ GeV), 212 pb^{-1} at the $\Upsilon(4S)$ resonance ($\sqrt{s}=10.58$ GeV), and 117 pb^{-1} at the $\Upsilon(5S)$ resonance ($\sqrt{s}=10.86$ GeV).

Charged-particle tracking is performed inside a 1.0-T magnetic field, produced by a superconducting solenoid with a 1.0-m radius. A 64-layer drift chamber system is used for charged-particle tracking,[6] with a momentum resolution of $(\delta p/p)^2=(0.23\% p)^2+(0.7\%)^2$, where p is in GeV/c. The 51-layer central drift chamber provides an rms resolution in track ionization (dE/dx) of 6.5%. In addition, the 10-layer vertex detector provides a dE/dx resolution of 14%.

For reconstructing a Λ we use oppositely charged tracks which originate from a common vertex. We reduce backgrounds by requiring the point of intersection to be greater than 0.2 cm away from the beam line in the r-ϕ plane. In addition, we require the sum of momentum vectors to extrapolate back to the beam line and the invariant mass to be within ± 5.3 MeV/c^2 ($\pm 3\sigma$) of the Λ mass. To further reduce the background due to fake Λ candidates, particle identification is used to tag protons from the $\Lambda \to p\pi^-$ decays; the dE/dx measurement of the proton is required to be within $\pm 3\sigma$ of the expected value.

We search for Λ_c^+ baryons by forming the effective-mass spectrum $M(\Lambda\pi^+)$. To reduce the combinatorial background, we exclude from our sample Λ_c candidates with x less than 0.6, where $x=p/p_{\text{max}}$, and also candidates which have $|\cos\Theta_H|$ greater than 0.8, where Θ_H is tha angle between the Λ_c^+ flight path and the Λ direction in the Λ_c^+ rest frame.

The $\Lambda\pi^+$ invariant-mass spectrum is shown in Fig. 1. A maximum-likelihood fit is performed using a Gaussian of fixed width above a second-order polynomial. The FWHM of the Gaussian is determined from Monte Carlo studies and fixed at 29 MeV/c^2. Monte Carlo studies have indicated that the two-body decay channel $\Lambda_c^+ \to \Sigma^0\pi^+$ followed by the decay $\Sigma^0 \to \Lambda\gamma$ would contribute an approximately Gaussian enhancement at 2.195 GeV. We have, therefore, allowed for this possibility in the fitting. Although the data prefer the presence of some $\Lambda_c^+ \to \Sigma^0\pi^+$, we do not consider the evidence strong enough to establish the channel. Our sample contains 86 ± 13 Λ_c events with $x>0.6$ and $|\cos\Theta_H|<0.8$.

We extract α_{Λ_c} from the angular distribution of the decay proton in the Λ rest frame, where the expected form of the distribution is given by[7]

$$\frac{dN}{d\cos\theta_1} = \tfrac{1}{2}(1+\alpha_\Lambda \alpha_{\Lambda_c}\cos\theta_1)\,,$$

where θ_1 is the angle between the Λ direction, in the Λ_c^+ rest frame, and the decay proton's line of flight in the Λ rest frame. This distribution is independent of Λ_c^+ polarization. Note that CP conservation requires $\alpha_{\Lambda_c} = -\alpha_{\bar{\Lambda}_c}$. Since the slope of the distribution depends on the product $\alpha_\Lambda \alpha_{\Lambda_c}$, which has the same sign for particle and antiparticle states, we combine particle and antiparticle distributions. The angular distribution is determined by

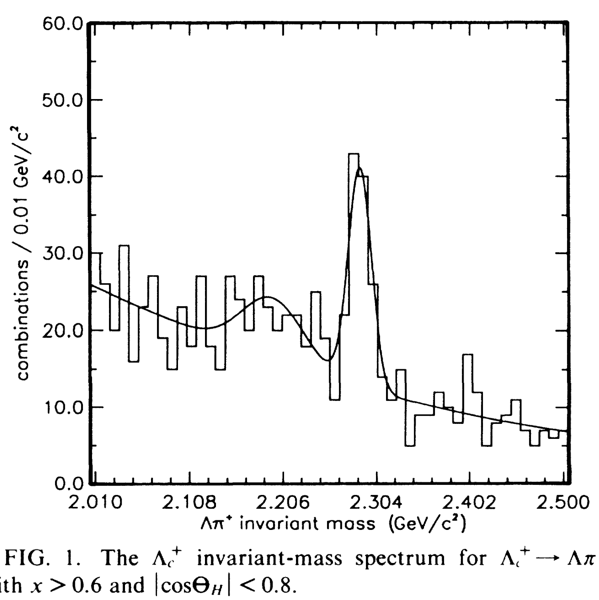

FIG. 1. The Λ_c^+ invariant-mass spectrum for $\Lambda_c^+ \to \Lambda\pi^+$ with $x>0.6$ and $|\cos\Theta_H|<0.8$.

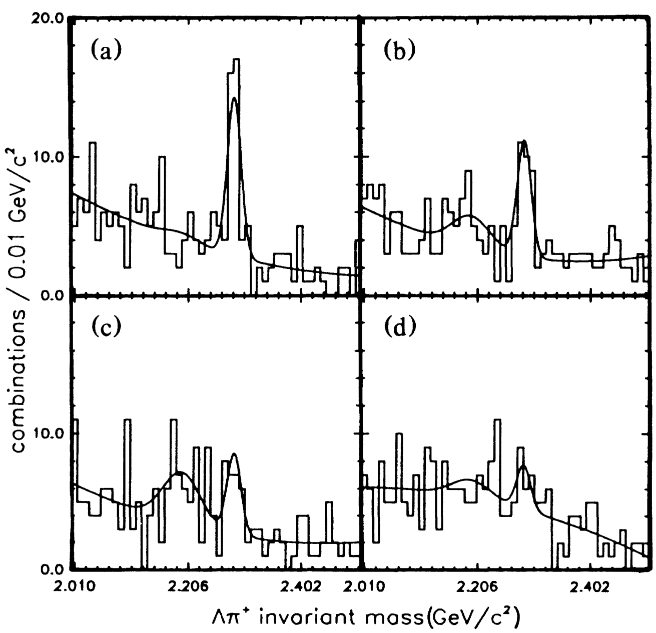

FIG. 2. Λ_c^+ invariant-mass distributions (a) $\cos\theta_1 < -0.5$, (b) $-0.5<\cos\theta_1<0.0$, (c) $0.0<\cos\theta_1<0.5$, and (d) $+0.5<\cos\theta_1$.

fitting for the number of Λ_c^+ in each of four equal-sized bins of $\cos\theta_1$.

The four mass distributions, corresponding to the four $\cos\theta_1$ regions, are shown in Fig. 2. A decrease in the number of Λ_c^+ is evident as a function of increasing $\cos\theta_1$. We use the fitted number of Λ_c^+ candidates in the four bins to obtain the $\cos\theta_1$ angular distribution. The $\cos\theta_1$ distribution is plotted in Fig. 3, after correction for efficiency. The efficiency as a function of $\cos\theta_1$ is determined by Monte Carlo simulation and is found to vary slowly from 35% at $\cos\theta_1 = -1.0$ to 31% at $\cos\theta_1 = +1.0$. The fit to the distribution shown in Fig. 3 yields -1.1 ± 0.4 for α_{Λ_c}.[8] By constraining the value of α_{Λ_c} to physically allowed values we find $\alpha_{\Lambda_c} = -1.0^{+0.4}_{-0.0}$. The error here is statistical. The systematic error is due to the corrections for efficiency and to the uncertainty in the shape of the background; we have estimated it by varying the background shape[9] and varying the value of α_{Λ_c} in Monte Carlo simulations. We generated Monte Carlo events at α_{Λ_c} values which spanned the physically allowed region -1 to $+1$; in every case we reproduced the generated value of α_{Λ_c} within the statistical errors of our Monte Carlo samples. We find the systematic error to be ± 0.1. Separate fits to the Λ_c^+ and $\bar{\Lambda}_c^-$ distributions yield -1.2 ± 0.7 and $+0.9 \pm 0.6$ for α_{Λ_c} and $\alpha_{\bar{\Lambda}_c}$, consistent with $\alpha_{\Lambda_c} = -\alpha_{\bar{\Lambda}_c}$. This result demonstrates parity violation in the decay $\Lambda_c^+ \to \Lambda\pi^+$ at the 99% confidence level.

Hyperons produced in strong interactions have been observed to be strongly polarized perpendicular to their production plane.[10,11] The mechanism producing polarized hyperons is not well understood. A paper by Lednicky[12] has pointed out that if the production processes for Λ_c^+ and Λ are analogous, the polarization of the Λ_c^+ should have the same sign as the polarization of the Λ. In addition, comparing the magnitude of polarization of the Λ_c^+ to that of the Λ would provide insight into the dependence of polarization on the mass of the leading quark, charm and strange, respectively. Most of our Λ_c^+ baryons are produced through electromagnetic annihilation, and parity conservation in electromagnetic interactions also requires Λ_c^+ polarization, if it exists, to be normal to the production plane. In addition, since C is a conserved quantum number for Λ_c^+ production, the polarization must be the same for particle and antiparticle states. We define the production normal as $\hat{\mathbf{n}} = \hat{\mathbf{p}}_{\Lambda_c} \times \hat{\mathbf{e}}^+$, the direction defined by the cross product of the Λ_c^+ momentum vector and the direction of the positron beam. In the Λ_c^+ rest frame the angular distribution of the Λ relative to $\hat{\mathbf{n}}$ has the form

$$\frac{dN}{d\cos\theta_2} = \tfrac{1}{2}(1 + P\alpha_{\Lambda_c}\cos\theta_2),$$

where P is the Λ_c polarization and θ_2 is the angle between $\hat{\mathbf{n}}$ and the Λ direction, in the Λ_c^+ rest frame. Since $\alpha_{\Lambda_c} = -\alpha_{\bar{\Lambda}_c}$, subtracting the $\bar{\Lambda}_c^- \cos\theta_2$ distribution from the $\Lambda_c^+ \cos\theta_2$ distribution yields a distribution of the form

$$\frac{dN}{d\cos\theta_2} = +P\alpha_{\Lambda_c}\cos\theta_2 .$$

The fit to this distribution, shown in Fig. 4, yields -0.2 ± 0.2 for P, assuming $\alpha_{\Lambda_c} = -1.0$. The error we quote is statistical. We do not have strong evidence for polarized Λ_c^+ production.

In summary, we have measured the parity-violating asymmetry decay parameter and the polarization of Λ_c^+ particles produced in nonresonant e^+e^- interactions through their decays to $\Lambda\pi^+$. Our measurements determine α_{Λ_c} to be $-1.0^{+0.4}_{-0.0}$. We do not observe evidence for the production of polarized Λ_c^+; the measured polarization being $P = -0.2 \pm 0.2$.

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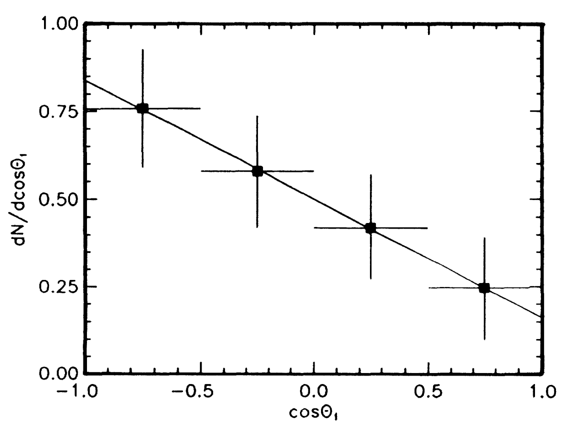

FIG. 3. The angular distribution of the decay proton ($dN/d\cos\theta_1$). The solid line is the fit to this distribution. The slope of the distribution is -0.34 ± 0.14 and represents $\alpha_\Lambda \alpha_{\Lambda_c}/2$.

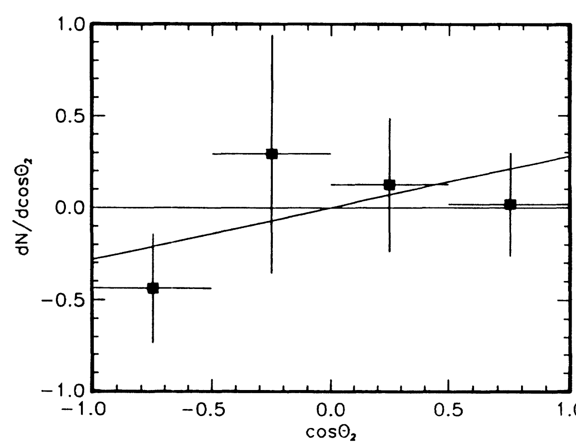

FIG. 4. The angular distribution $dN/d\cos\theta_2$. The solid line is the fit to this distribution. The slope of the distribution is $+0.24 \pm 0.24$ and represents $+P\alpha_{\Lambda_c}$.

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[1]G. P. Yost *et al.*, Phys. Lett. B **204**, 1 (1988).

[2]J. Bjorken, Phys. Rev. D **40**, 1513 (1989).

[3]D. Andrews *et al.*, Nucl. Instrum. Methods **211**, 47 (1983).

[4]C. Bebek *et al.*, Phys. Rev. D **36**, 690 (1987).

[5]S. Behrends *et al.*, Phys. Rev. D **31**, 2161 (1985).

[6]D. G. Cassel *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **252**, 325 (1986).

[7]For a review of a derivation of the decay distributions, see, for example, W. Koch, *Determination of the Ξ Decay Parameters,* Proceedings of the 1964 Easter School for Physicists, Herczeg-Novi, Yugoslavia (CERN Report No. 64-13), p. 75.

[8]The angular distribution of the satellite peak is different from the angular distribution of $\Lambda_c^+ \to \Lambda\pi^+$ events. If the satellite peak arises from the decay $\Lambda_c^+ \to \Sigma^0\pi^+$, we could evaluate the value of α_{Λ_c} for this decay mode as well. However, such a measurement would be statistically poor and we have not boosted into the correct reference frame for this decay mode, thus introducing an unknown rotation. Ignoring the unknown rotation introduced by the incorrect boosting, we obtain $\alpha = +0.6 \pm 0.8$ for this satellite peak. This does not exclude any of the range of allowed value (-1 to $+1$).

[9]We fit using many background shapes. We varied the order of the polynomial, fit with and without the Monte Carlo shape for the decay $\Lambda_c^+ \to \Sigma^0\pi^+$, used sideband subtraction, and subtracted the distribution of "wrong-sign" ($\Lambda\pi^-$) events. In every case the result was consistent with the value of α_{Λ_c} we determined using our method of fitting.

[10]S. A. Gourley *et al.*, Phys. Rev. Lett. **56**, 2244 (1986).

[11]R. Rameika *et al.*, Phys. Rev. D **33**, 3172 (1986).

[12]R. Lednicky, Yad. Fiz. **43**, 1275 (1986) [Sov. J. Nucl. Phys. **43**, 817 (1986)].