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Abstract

Using the ARGUS detector at the e^+e^- storage ring DORIS II at DESY, we have observed parity violation in the decay $\Lambda_c^\pm \rightarrow \Lambda\pi^\pm$. We measure the coefficient of parity violation, α_{Λ_c}, to be -0.96 ± 0.42. In addition, we measure $\sigma\cdot\mathrm{BR}(\Lambda_c^+ \rightarrow \Lambda\pi^+)$ and $\sigma\cdot\mathrm{BR}(\Lambda_c^+ \rightarrow \Sigma^0\pi^+)$ to be, respectively, $(2.2 \pm 0.3 \pm 0.4)$ pb and $(1.8 \pm 0.5 \pm 0.3)$ pb.

Considerable progress has been made in attempts to understand the interplay of strong and weak interactions in weak decays of charmed hadrons [1]. Most attention has been paid to charmed mesons because of the extensive experimental data now available on their partial decay widths [2]. Charmed baryons offer possible new insights for two reason: firstly, because W-exchange diagrams can contribute without the helicity suppression that decreases their contributions to pseudoscalar meson decays and, secondly, parity violation effects due to interference between amplitudes with different orbital angular momentum values can be directly observed[3]. A recent revival of theoretical interest in charmed baryon decays [4][5][6] has heightened the interest in new experimental studies. The large samples of charmed baryons from e^+e^- annihilations collected by the ARGUS and CLEO collaborations have been used to study the properties of the Λ_c^+ baryon[7][8][9][10].

In this letter we report a measurement of the parity violating asymmetry in the decay $\Lambda_c^+ \rightarrow \Lambda\pi^{+*}$. The measurements of the production cross-section times branching ratio for this decay and for the decay $\Lambda_c^+ \rightarrow \Sigma^0\pi^+$ are also reported. The decay $\Lambda_c^+ \rightarrow \Lambda\pi^+$ followed by $\Lambda \rightarrow p\pi^-$ is exactly analagous to the well understood hyperon decay $\Xi^- \rightarrow \Lambda\pi^-, \Lambda \rightarrow p\pi^-$[11]. In both of these decays, the Λ is produced with a polarization equal to

$$\mathbf{P}_\Lambda = \frac{(\alpha_B + \hat{\Lambda}\cdot\mathbf{P}_B)\hat{\Lambda} - \beta_B(\hat{\Lambda}\times\mathbf{P}_B) - \gamma_B\hat{\Lambda}\times(\hat{\Lambda}\times\mathbf{P_B})}{(1+\alpha_B\hat{\Lambda}\cdot\mathbf{P}_B)} \tag{1}$$

owing to the interference between the S and P wave final states where $\mathbf{P}_B$ is the parent baryon polarization, α_B, β_B and γ_B are the parent baryon asymmetry parameters, and $\hat{\Lambda}$ is a unit vector along the Λ flight direction in its production frame [12]. Averaging over parent baryon polarization, one is left with

$$\mathbf{P}_\Lambda = \alpha_B\hat{\Lambda}. \tag{2}$$

Hence when the parent is unpolarized or when its polarization is not observed the Λ is produced with helicity equal to α_B. The angular distribution of the proton from the decay of the Λ is therefore

$$W(\theta) \propto 1 + \alpha_\Lambda\alpha_B cos\theta, \tag{3}$$

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*All references to a specific charge state imply the charge conjugate state unless otherwise stated where α_Λ is the Λ decay asymmetry parameter and θ is the angle between the Λ polarization and the proton flight direction. α_B is therefore determined by measuring the angular distribution of protons from the Λ decay since the Λ decay parameters are well known [2].

This analysis is based on a data sample of 386 pb^{-1} taken at an average centre-of-mass energy of 10.4 GeV/c^2 using the ARGUS detector at the e^+e^- storage ring DORIS II. The ARGUS detector is a 4π spectrometer described in detail elsewhere [13]. Charged particle identification is made on the basis of specific ionization in the drift chamber, time of flight measurements, energy deposits in the shower counters and muon chamber hits. This information is used to calculate, for all charged tracks, a normalized likelihood for each of the particle hypotheses (e, μ, π, K, p). All particle hypotheses with a normalized likelihood greater than 1% were accepted.

Λ candidates were identified in the decay mode $\Lambda \rightarrow p\pi^-$. All $p\pi^-$ combinations having a mass within ± 9 MeV/c^2 of the nominal Λ mass [2] and which fit to a secondary vertex with a χ^2 less than 36 were accepted as Λ candidates. Surviving combinations which satisfied the Λ mass hypothesis with a χ^2 of less than 25 were accepted and subjected to a mass constrained fit. Backgrounds from beam-wall and beam-gas interactions, in which many Λ's but no $\overline{\Lambda}$'s are produced, were removed by requiring that the momentum vector of the $p\pi^-$ combination point back to the main vertex. This condition was enforced by demanding that the cosine of the angle between the $p\pi^-$ momentum vector and the vector between main and secondary vertices be greater than 0.985. When reconstructing the Λ_c^+, the random backgrounds from combinations with slow Λ's or slow π^+'s are removed by requiring momenta greater than 0.8 GeV/c and 0.5 GeV/c respectively. Finally, the $\Lambda\pi^+$ combinations were required to have $x_p > 0.5$, where $x_p = p(\Lambda\pi^+)/p_{max}$, and $p_{max} = \sqrt{E_{beam}^2 - m^2(\Lambda\pi^+)}$.

The mass spectrum of all accepted $\Lambda\pi^+$ combinations is shown in Figure 1. A clear peak in the region of the Λ_c^+ mass is observed, as well as an enhancement at a slightly lower mass. A Monte Carlo study has shown that the latter is due to feeddown from the decay $\Lambda_c^+ \rightarrow \Sigma^0\pi^+$, where the photon from the decay of the Σ^0 is ignored. Superimposed on Figure 1 is the result of a fit to the spectrum using a Gaussian with width fixed to 18.1 MeV/c^2 for the Λ_c^+ signal, a Gaussian with mass and width fixed to 2191 MeV/c^2 and 36 MeV/c^2 respectively for the feeddown contribution and a third-order polynomial to model the background. All fixed parameters were determined by Monte Carlo studies. The fit yields 109 ± 17 events at a mass of 2288 ± 3 MeV/c^2, in excellent agreement with the accepted Λ_c^+ mass. In the feeddown signal there are 66 ± 20 events.

Figure 1(b) shows the wrong-sign spectrum, obtained by combining all Λ and π^- candidates. There is no signal in the region of the Λ_c^+ mass. The background is smooth over the entire range, and there is no excess in the $\Sigma^0\pi^+$ feeddown region.

To verify that the excess in the feeddown region was understood the decay $\Lambda_c^+ \rightarrow \Sigma^0\pi^+$ was studied. Λ's were selected using the same cuts as before with the exception that the cut on the angle between the vector between the main and secondary vertices and the Λ momentum was excluded. Photons were identified as neutral energy deposits in the shower counters. In reconstructing the Σ^0, the photon was required to have energy an between 50 and 140 MeV/c^2 with the lower cut imposed due to shower counter efficiency and the higher due to kinematics. All $\Lambda\gamma$ candidates having an invariant mass within $\pm$ 40 MeV/c^2 .of the particle data book mass were accepted and fit to the nominal Σ^0 mass[2]. To reduce background due to slow pions and Σ^0's, their momenta were required to be greater than than 0.4GeV/c^2 and 0.6GeV/c^2 respectively. Finally, due to considerable multiple counting in this channel, only one candidate per event was accepted, that being the one maximizing the total probability based on particle identification and intermediate fits.

The resulting mass spectrum is shown in figure 2(a). There is a peak at the Λ_c^+ mass, as well as one at a slightly higher mass. This feedup peak is due to combining Λ_c^+'s from the decay $\Lambda_c^+ \rightarrow \Lambda\pi^+$ with a soft photon. Monte Carlo studies predict the feedup signal's mass and width to be 2.372 GeV/c^2 and 36MeV/c^2 respectively and the Λ_c^+ signal to have a width of 16MeV/c^2. Superimposed on the plot is the result of a fit to the spectrum of the 2 Gaussians with the above parameters fixed to describe the signals and a third order polynomial to describe the background. The Λ_c^+ signal contains 42± 12 events at a mass of 2.291± 6 MeV/c^2 and the feedup 56 ± 16 events. Figure 2(b) shows the $\Sigma^0\pi^-$ mass spectrum. There is no enhancement in either the signal or the feedup region.

A Monte Carlo study was performed to determine the detector acceptance for both decay modes. Extrapolation to zero momentum was done using the fragmentation function of Peterson *et al.* [14]. An epsilon value of (0.24 ± 0.04) measured in the decay $\Lambda_c^+ \rightarrow pK^-\pi^+$ was used [15]. After correcting for acceptance and accounting for the $\Lambda \rightarrow p\pi^-$ branching ratio, the product of cross section times branching ratio for each decay mode is found to be $\sigma \cdot \mathrm{BR}(\Lambda_c^+ \rightarrow \Lambda\pi^+) = (2.2 \pm 0.3 \pm 0.4)$ pb and $\sigma \cdot \mathrm{BR}(\Lambda_c^+ \rightarrow \Sigma^0\pi^+) = (1.8 \pm 0.5 \pm 0.3)$ pb. If we calculate these branching ratios using the feedup and feeddown signals we get (2.2 ± 0.7) pb and (1.3 ± 0.4) pb respectively, in excellent agreement with those calculated from the signals, indicating that these secondary signals are well understood.

Using the updated ARGUS measurement for the $\sigma \cdot BR(\Lambda_c^+ \rightarrow pK^-\pi^+)$ of $(12.0 \pm 1.9 \pm 1.6)$ pb, the ratios of branching ratios $\mathrm{BR}(\Lambda_c^+ \rightarrow \Lambda\pi^+)/\mathrm{BR}(\Lambda_c^+ \rightarrow pK^-\pi^+)$ and $\mathrm{BR}(\Lambda_c^+ \rightarrow \Sigma^0\pi^+)/\mathrm{BR}(\Lambda_c^+ \rightarrow pK^-\pi^+)$ are $0.18 \pm 0.03 \pm 0.04$ and $0.15 \pm 0.05 \pm 0.03$[15] respectively. The systematic errors were determined by varying the cuts, the fit range, the width, the efficiency and the Peterson epsilon parameter.

Since the decay $\Lambda_c^+ \to \Lambda\pi^+$ proceeds through the weak interaction, the Λ is produced polarized. Although spin correlations are expected between $c\bar{c}$ pairs produced in e^+e^- annihilation, no net polarization of either member of the pair is predicted. The Λ_c^+ baryons produced in their fragmentation are, therefore, also expected to be unpolarized. Polarization may, however, be expected in the weak decays of B mesons to charmed baryons but the Λ_c^+'s from these decays have been excluded from the analysis by the x_p cut. Hence the final polarization of the Λ in our sample is simply α_{Λ_c}. The resulting distribution function for the proton is given by equation 3 with α_B replaced by α_{Λ_c}.

To determine α_{Λ_c}, the $\Lambda\pi^+$ spectrum is fitted in bins of $cos\theta$, and then normalized by the total number of events. It is important to note that the reconstruction efficiency is independent of $cos\theta$. For these fits, the mass of the $\Lambda\pi^+$ and width of the Λ_c^+ are fixed to 2285 MeV/c^2 and 18.1 MeV/c^2 respectively. The results are shown in Figure 3. The filled circles with error bars represent the distribution of the signal in bins of $cos\theta$ on which the result of a straight line fit is superimposed.

If parity were conserved, a flat distribution in $cos\theta$ would be expected (dotted line, Figure 3). On the other hand, parity violation leads to a distribution of the form given by Equation 3, with the slope equal to the product $\alpha_{\Lambda_c}\alpha_\Lambda$. Using a value for α_Λ of 0.642 ± 0.013 [2], we find α_{Λ_c} to be -0.96 ± 0.42.

The open circles with error bars in Figure 3 show the angular distribution of the background, determined by summing the number of events in the regions from 1.9 -2.1 GeV/c^2 and 2.35 -2.55 GeV/c^2 in each angular range. Clearly the background distribution is uniform, in contrast to the Λ_c^+ behaviour. Similarly the wrong-sign spectrum was also examined and found to be flat in $cos\theta$. Finally, the angular distribution of the protons with respect to the Λ lab momentum was studied for the full sample of Λ decays. Again no asymmetry was observed.

Our result for α_{Λ_c} agrees well in magnitude with the recent prediction of Pakvasa *et al.* [5] and in excellent agreement with the predictions of Bjorken [4] and Mannel *et al.* [6] that α_{Λ_c} be around -1. CLEO [7] has also measured α_{Λ_c} and finds a value of $-1.0\pm^{0.4}_{0.0}$. A negative sign for α_{Λ_c} indicates that Λ's produced in Λ_c^+ decay have a negative helicity. In the so-called $\alpha\beta\gamma$ formalism, α is defined as $\frac{2ReS^*P}{|S|^2+|P|^2}$, where S and P are the S and P-wave amplitudes respectively [16]. Therefore, a magnitude of 1 for α could indicate that the S and P-wave amplitudes are equal implying that parity is maximally violated in this decay.

In summary, we have seen evidence for parity violation in the decay $\Lambda_c^+ \to \Lambda\pi^+$. The coefficient of parity violation, α_{Λ_c}, is -0.96 ± 0.42, in good agreement with the CLEO result and with the theoretical predictions. Together the two measurements indicate that parity is maximally violated in the decay $\Lambda_c^- \to \Lambda\pi^-$ with significance greater than 3 standard deviations. The product cross section times branching ratios, for $\sigma\cdot$BR($\Lambda_c^+ \to \Lambda\pi^+$) and $\sigma\cdot$BR($\Lambda_c^+ \to \Sigma^0\pi^+$) are (2.2 ± 0.3 ± 0.4)pb and (1.8 ± 0.5 ± 0.3)pb respectively, leading to the ratios of branching ratios BR($\Lambda_c^+ \to \Lambda\pi^+$)/BR($\Lambda_c^+ \to pK^-\pi^+$) = 0.18 ± 0.03 ± 0.04 and BR($\Lambda_c^- \to \Sigma^0\pi^+$)/BR($\Lambda_c^+ \to pK^-\pi^+$) = 0.15 ± 0.5 ± 0.3.

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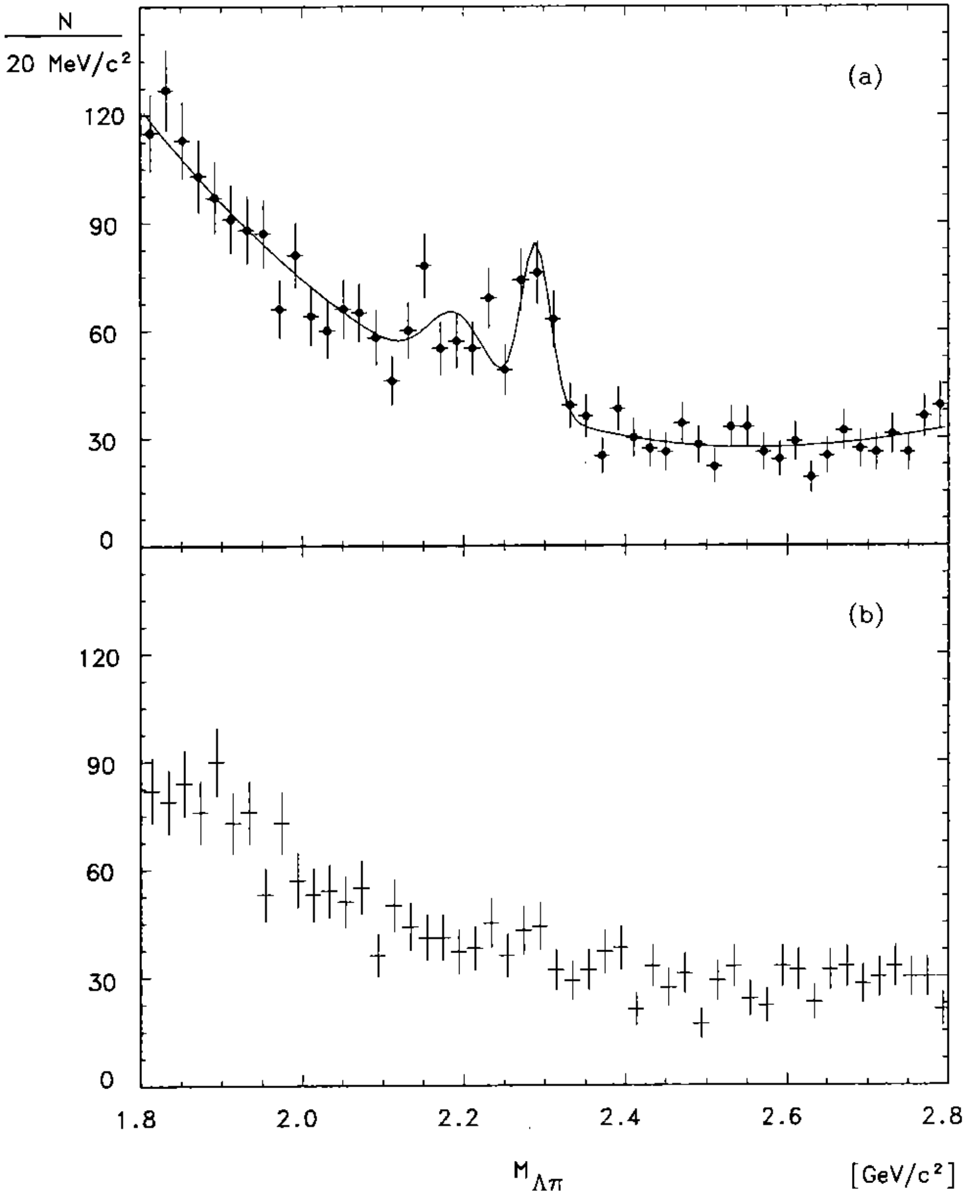

Figure 1: (a) Mass spectrum of accepted $\Lambda\pi^+$ candidates. The curve shows the result of the fit described in the text. (b) Mass spectrum of accepted $\Lambda\pi^-$ candidates. There is no enhancement in the $\Sigma^0\pi^+$ feeddown region and the background shape in similar to that for the right-charge distribution.

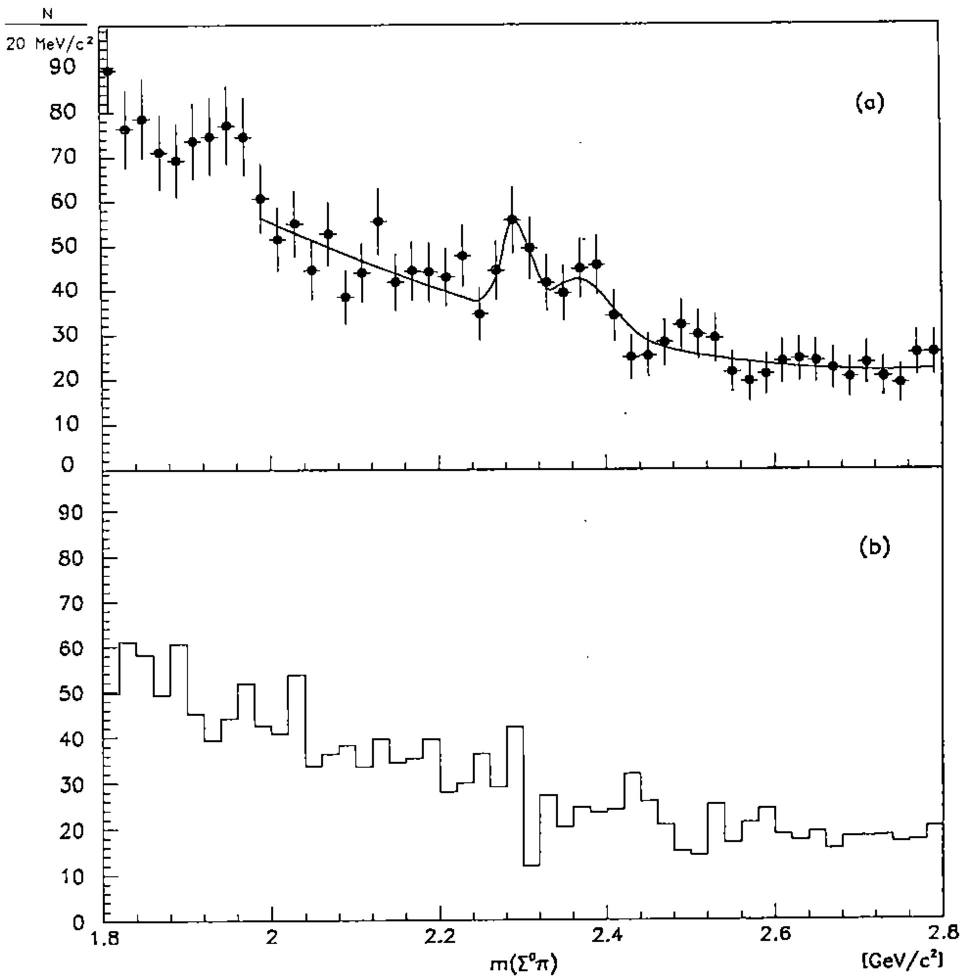

Figure 2: (a) Mass spectrum of accepted $\Sigma^0\pi^+$ candidates. The curve shows the result of the fit described in the text. (b) Mass spectrum of accepted $\Sigma^0\pi^-$ candidates. There is no enhancement in the $\Lambda\pi^+$ feedup region and the background shape in similar to that for the right-charge distribution.

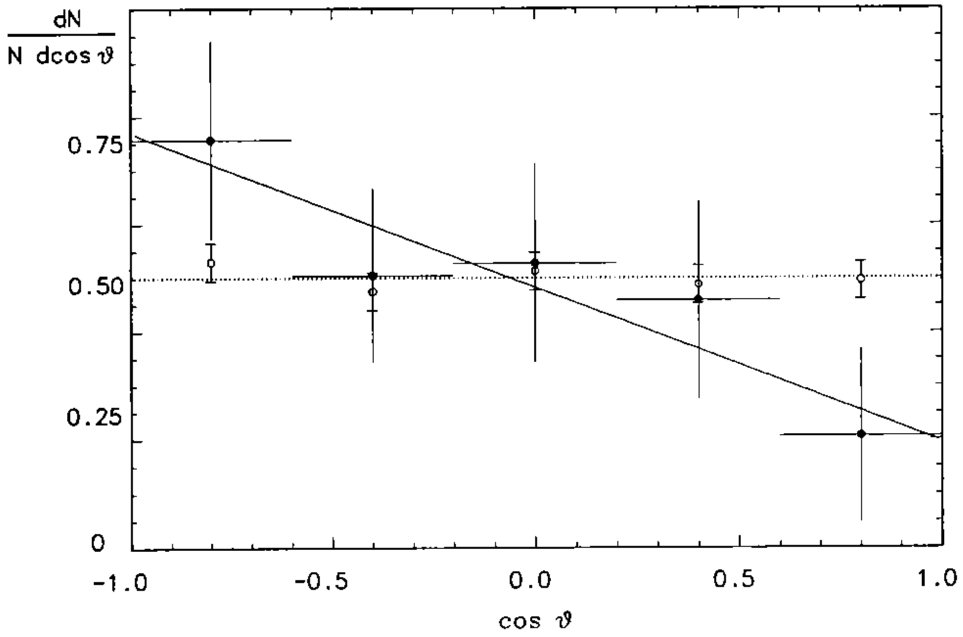

Figure 3: (a) Number of events as a function of $cos\theta$. The shape is well parametrized by the fit described in the text.

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