Λ Production in e^+e^- Annihilation at 29 GeV

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(Received 9 October 1984)

The inclusive production cross section of $\Lambda,\bar{\Lambda}$ in e^+e^- annihilation at a c.m. energy of 29 GeV has been measured with the time-projection-chamber detector at PEP. The average $\Lambda,\bar{\Lambda}$ multiplicity has been measured to be $0.197 \pm 0.012(\text{stat.}) \pm 0.017(\text{syst.})$. Λ-$\bar{\Lambda}$ pairs have been observed in jets for the first time, and the average number of Λ-$\bar{\Lambda}$ pairs per event has been measured to be $0.042 \pm 0.017 \pm 0.014$.

PACS numbers: 13.65.+i

In the process of e^+e^- annihilation into jets, quarks and gluons fragment into hadrons. Various models to describe this process have been proposed. Meson formation from quark-antiquark pairs created in the color field is common to many hadronization models, while the implementation of baryon production differs significantly in these models. Examples are (1) the diquark model,[1] in which a baryon is produced by combining a diquark and a quark, (2) the color-singlet cluster model,[2] in which a baryon pair is produced as a two-body decay product of a low-mass color-singlet cluster, and (3) the popcorn model,[3] in which a baryon is produced by combining three independently produced quarks. While there exists some information on baryon production in e^+e^- annihilation,[4–7] further data, especially on baryon and antibaryon correlations, are required to test these models.

We present results on the inclusive production of Λ and $\bar{\Lambda}$ and on the production of Λ-$\bar{\Lambda}$ pairs in e^+e^- annihilation at a c.m. energy of 29 GeV. The data have been accumulated with the PEP4/TPC (time-projection-chamber) detector facility[8] at the SLAC PEP storage ring. The detector and the selection criteria for the hadronic events have been described elsewhere.[7,8] This analysis is based on 29 000 hadronic events. The capabilities of measuring three-dimensional coordinates of tracks and of identifying particles by ionization energy loss (dE/dx) make the TPC particularly suitable for the detection of Λ decays in complex hadronic events.

Λ and $\bar{\Lambda}$ were detected by reconstruction of $\Lambda \to \pi^- p$ and $\bar{\Lambda} \to \pi^+ \bar{p}$ decays, respectively. Hereafter, we refer to $\Lambda,\bar{\Lambda}$ production as Λ production for simplicity. To reconstruct a Λ decay, π^- and p were selected as charged tracks whose dE/dx and momentum measurements were consistent with the π and p hypotheses, respectively. A minimum momentum of 0.12 GeV/c was required for each track. All $\pi^- p$ pairs were subjected to secondary vertex finding routines. With the fitting error and multiple Coulomb scattering taken into account, the tracks had to be consistent with a common vertex within 3 standard deviations (s.d.) and the distance of closest approach in space of the orbits had to be less than 1.2 cm. The position of the secondary vertex formed by the π and p tracks had to be at least 1.4 cm or $(1.4\text{ cm}) \times p_{\pi p}/M_\Lambda$ (whichever is larger) away from the interaction point, and the momentum vector of the πp system had to point back to the interaction point within 15°. Contaminations in the Λ candidates due to misidentified e^+e^- pairs from photon conversions or $K_S^0 \to \pi^+\pi^-$ decays were reduced by removal of pairs consistent with either hypothesis. Backgrounds were further reduced by the requirement that the absolute value of the cosine of the angle between the Λ and the π in the Λ rest frame had to be less than 0.9. Each pair was assigned a probability to be a Λ based on the results of particle identification and of secondary-vertex reconstruction. This probability was required to be greater than the value necessary to retain 70% of the Λ's remaining at this stage.

The resulting πp-invariant mass spectrum is shown in Fig. 1. Fits based on the sum of a Gaussian peak and a smooth background give 272 ± 24 Λ and 292 ± 25 $\bar{\Lambda}$. The peak position is 1116.4 ± 0.6 MeV. The observed Λ mass resolution depends on the momentum p. It is 6 MeV (rms) at $p = 1-3$ GeV/c and 10 MeV at 6 GeV/c. These values are consistent with the result of a Monte Carlo simulation of the detector. The overall detection efficiency rises from 0 at 0.5 GeV/c and reaches a maximum of 15% at 2 GeV/c, then it decreases to 5% at 10 GeV/c.

The normalized cross sections, $(1/\sigma_h \beta)(d\sigma/dx)$, as a function of $x = 2E/\sqrt{s}$ are shown in Fig. 1 both for Λ and p.[7] The cross sections have been corrected for acceptance and for the effects of event selection and of initial-state radiation. The systematic errors result mainly from the uncertainties in the detection efficiency and in the fit of the invariant-mass spectra. Our data are consistent with the results of Bartel *et al.* (Jade collaboration)[4] and Brandelik *et al.* (Tasso Collaboration)[5] results. Included in Fig. 1 are predictions of the Lund model[1] (with standard parameters). The model gives a reasonable description of the data.

The Λ multiplicity was obtained by correction for the unobserved momentum regions $p < 0.5$ and > 10 GeV/c. According to the Lund model, these regions contribute 7% to the total Λ multiplicity. The resulting multiplicity of 0.197 ± 0.012(stat.) ± 0.017(syst.) is consistent with the result of Bartel *et al.* (0.234 ± 0.064)[4] and lower than that of Althoff *et al.* (0.31 ± 0.04).[6]

In the investigation of Λ-$\bar{\Lambda}$ correlations, two questions are addressed separately: (a) Are Λ's and $\bar{\Lambda}$'s usually produced close by in phase space, i.e., is baryon number conserved locally? (b) Does the fact that the Λ's carry strangeness introduce additional correlations beyond what is required by baryon number conservation?

To study Λ-$\bar{\Lambda}$ correlations, events which contain a Λ-Λ, Λ-$\bar{\Lambda}$, or $\bar{\Lambda}$-$\bar{\Lambda}$ pair were selected by requiring the πp invariant masses to fall within 2σ of the Λ mass. We observed the following number of events for each type of pair: Λ-$\bar{\Lambda}$ = 11 (1.4 ± 1.2), Λ-Λ = 3 (2.1 ± 0.9), and $\bar{\Lambda}$-$\bar{\Lambda}$ = 0 (0.6 ± 0.7), where the first figure is the number of observed pairs and the figure in parentheses is the background estimated from a Monte Carlo simulation. The error on the background includes the statistical and systematic errors of the simulation. While the numbers of Λ-Λ and $\bar{\Lambda}$-$\bar{\Lambda}$ pairs are consistent with 0, a statistically significant number of Λ-$\bar{\Lambda}$ pairs is observed. For these eleven Λ-$\bar{\Lambda}$ pairs, the distributions of the spatial opening angle ($\Theta_{\Lambda\text{-}\bar{\Lambda}}$) between Λ and $\bar{\Lambda}$ [Fig. 2(a)] and the absolute value of

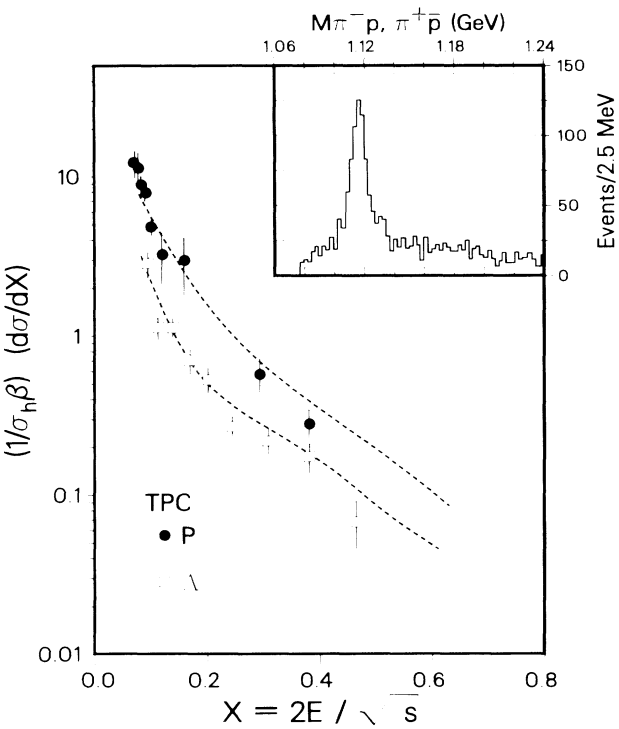

FIG. 1. Normalized inclusive cross sections of $\Lambda + \bar{\Lambda}$ and $p + \bar{p}$ (Ref. 7) and Lund-model predictions (Ref. 1). The inset shows the $\pi^- p$ and $\pi^+ \bar{p}$ invariant-mass spectrum.

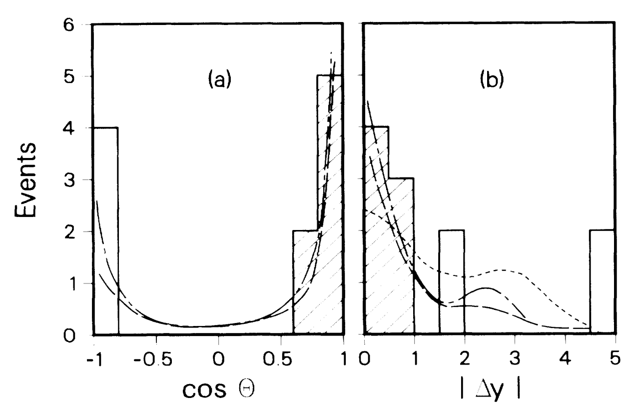

FIG. 2. Distributions of (a) opening angle between Λ and $\bar{\Lambda}$, and (b) absolute value of rapidity difference between Λ and $\bar{\Lambda}$. The hatched areas in (a) and (b) correspond to the same pairs. The distributions have not been corrected for acceptance and backgrounds. The dash-dotted line is the prediction of the Lund model for the distribution of Λ-$\bar{\Lambda}$ pairs with use of the same selection criteria as for the experimental data. The dashed line is the prediction of the model excluding background. The model prediction is based on an event sample 7 times larger than the data, and the distribution was scaled by this factor. The dotted line in (b) is the distribution expected for independent production of Λ and $\bar{\Lambda}$, the area being normalized to 11 (see text).

rapidity differences ($|\Delta y|$) between Λ and $\bar{\Lambda}$ [Fig. 2(b)] were obtained. For the calculations of rapidities, the sphericity axis was used. Included in Figs. 2(a) and 2(b) are the predictions of the Lund model, which are consistent with our data. We have also calculated a rapidity difference distribution assuming that Λ's and $\bar{\Lambda}$'s are generated independently according to the observed single-Λ rapidity distribution. This prediction is shown in Fig. 2(b) as a dotted line. The two Λ-$\bar{\Lambda}$ pairs at $|\Delta y| = 4.5$–5.0 have been investigated carefully, but no reason was found to reject these pairs as background. The observations of two Λ-$\bar{\Lambda}$ pair candidates in this $|\Delta y|$ region differs by 2 s.d. from the prediction of either the Lund model or the independent production assumption, and may indicate the coexistence of mechanisms which enhance long-range Λ-$\bar{\Lambda}$ correlation. Excluding these two pairs, we have performed a likelihood fit to compare the two models and find that the Lund model, both in its diquark and in its popcorn[3] version, is favored by 2 s.d. over the independent production assumption. Although the popcorn model predicts a slightly weaker short-range correlation between Λ and $\bar{\Lambda}$, it is impossible to distinguish the diquark model and the popcorn model on the basis of our data.

The mean number of Λ-$\bar{\Lambda}$ pairs per event (the Λ-$\bar{\Lambda}$ pair multiplicity) was determined to be $0.042 \pm 0.017 \pm 0.014$ for all pairs, $0.030 \pm 0.014 \pm 0.011$ for the pairs with $|\Delta y| < 1.4$, and $0.028 \pm 0.013 \pm 0.009$ for pairs with $\cos\Theta_{\Lambda\bar{\Lambda}} > 0$, after corrections for acceptance and for the effects of event selection and of initial-state radiation. Figure 3 shows the Λ multiplicity and the Λ-$\bar{\Lambda}$ pair multiplicity in comparison with models. The prediction of the Lund model[1] is shown as a function of $(us/ud)/(s/u)$, where us/ud is the ratio of the production rates of strange and ordinary diquark pairs from the vacuum and s/u is that of strange and ordinary quark pairs. For the present calculation, $s/u = 0.3$ and $qq/q = 0.09$, the diquark to quark pair-production ratio, were assumed as determined by the $K^{\pm}$ and $p + \bar{p}$ cross section,[7] respectively. The Lund model with $(us/ud)/(s/u) = 0.2$ gives a prediction in reasonable agreement with the Λ and Λ-$\bar{\Lambda}$ pair multiplicities. The prediction of the Webber model[2] is also shown in the same figure. While this model reproduces π, K, and p multiplicities, it predicts higher multiplicities for both Λ's and Λ-$\bar{\Lambda}$ pairs in disagreement with our data. The Λ cross section in the Webber model is around 50% larger than our data, and the short-range correlation between Λ and $\bar{\Lambda}$ is too strong. We did not try to optimize this model to reproduce these multiplicities.

To provide another reference for the strength of the Λ-$\bar{\Lambda}$ correlations, we compare the data with predictions based on two extreme assumptions: (1) that the flavors of the baryon (B) and the antibaryon ($\bar{B}$) of a B-$\bar{B}$ pair are completely uncorrelated, and (2) that Λ's and $\bar{\Lambda}$'s are always produced as Λ-$\bar{\Lambda}$ pairs. The first assumption corresponds to the minimum Λ-$\bar{\Lambda}$ correlation, whereas the second describes the maximum possible correlation, given that the baryon number has to be conserved. In the former case, strangeness is compensated, if necessary, by strange mesons in the event. Both for (1) and for (2), the detailed predictions depend on the distribution in the number of baryons per event. The bands in Fig. 3 indicate the range from a model with Poisson distribution in the number of baryons per event to a model where at most one baryon pair per event is produced. In the calculation, the mean baryon plus antibaryon multiplicity per event was taken as twice the $p + \bar{p}$ multiplicity.[7] Our Λ-$\bar{\Lambda}$ pair multiplicity is more than two s.d. below the band predicted by the second assumption of maximum correlation, and is slightly above (but consistent with) the band corresponding to minimum correlation.

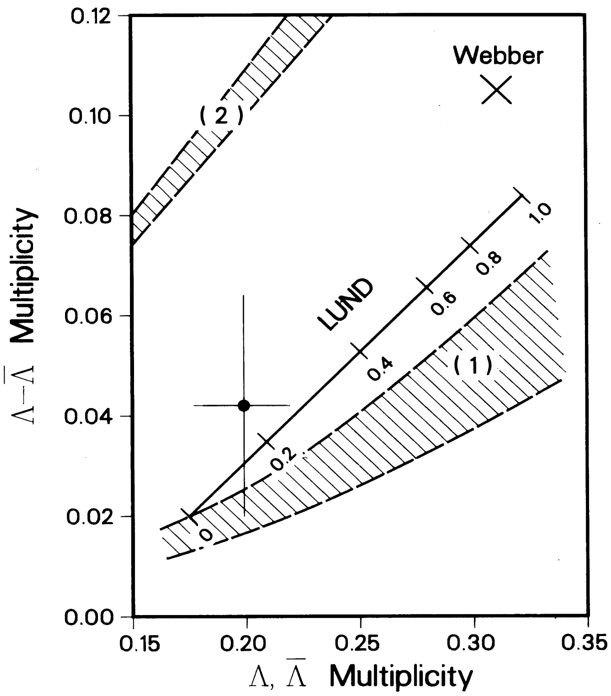

FIG. 3. $\Lambda, \bar{\Lambda}$ multiplicity and Λ-$\bar{\Lambda}$ pair multiplicity. The dot with error bars is the present data. The solid line shows the prediction of the Lund model as a function of $(us/ud)/(s/u)$. The cross gives the Webber model prediction. Band (1) is the range of predictions if the flavors of the baryon and antibaryon of a baryon-antibaryon pair are uncorrelated and band (2) is the range of predictions if Λ and $\bar{\Lambda}$ are always pair produced. The upper bounds of these bands correspond to the model with Poisson distribution in the baryon multiplicity and the lower bounds to the model with at most one baryon pair per event. See text for details.

In summary, we have measured the inclusive cross section for Λ and $\bar{\Lambda}$ production in e^+e^- annihilation at a c.m. energy of 29 GeV. The $\Lambda,\bar{\Lambda}$ multiplicity is $0.197 \pm 0.012 \pm 0.017$, and Λ-$\bar{\Lambda}$ pair multiplicity is $0.042 \pm 0.017 \pm 0.014$, close to the limit of vanishing correlation between baryon flavors. The observed Λ-$\bar{\Lambda}$ correlation favors mechanisms where baryon number is locally conserved.

We would like to thank the PEP staff and the engineers, programmers, and technicians of the collaborating institutions who made this work possible. This work was supported by the Department of Energy under Contracts No. DE-AC03-76SF-00098, No. DE-AM03-76SF00034, and No. DE-AC02-76ER03330, by the National Science Foundation, and by the Joint Japan–US Collaboration program in High Energy Physics. One of us (W.H.) acknowledges an A.P. Sloan Fellowship.

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