# BARYON PRODUCTION IN $e^+e^-$-ANNIHILATION AT PETRA

JADE Collaboration

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Data on $\bar{p}$ and $\bar{\Lambda}$ production by $e^+e^-$-annihilation at CM energies between 30 and 36 GeV are presented. Indication for an angular anticorrelation in events with baryon–antibaryon pairs is seen.

So far little data exist on baryon production in $e^+e^-$-annihilation [1–5]. The models [6–8] interpreting jets usually take only mesonic cascades into account. New insight in the fragmentation process can be gained by studying baryon production. This letter presents data on the inclusive reactions $e^+e^- \to \bar{p} + X$ and $e^+e^- \to \bar{\Lambda}^0 + X$ and $e^+e^- \to \bar{p} + p + X$ at CM energies between 30 and 36 GeV.

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The experiment was carried out using the JADE detector at the $e^+e^-$ colliding beam facility PETRA at DESY. The detector, the trigger conditions and the criteria for the selection of the 3 300 hadronic events included in this analysis have already been described in ref. [9]. Within this sample, antiprotons ($\bar{p}$) are identified in a solid angle of 85% of $4\pi$ by means of a simultaneous measurement of momentum and energy loss ($dE/dx$) in the drift chamber, a special feature of the JADE detector [10].

$\bar{p}$ candidates are selected in the momentum range 0.3 to 0.9 GeV/$c$ where the only source of background is protons entering the jet-chamber from the outside and moving towards the centre of the detector and causing a misidentification as antiprotons. Such protons are either backscattered or produced through secondary interaction in the material outside the detector. They are readily removed by visual inspection of the event. After background subtraction a sample of 153 events with an unambiguous $\bar{p}$ is left. 131 $\bar{p}$-tracks satisfy $r_{min} < 20$ mm and $z_{min} < 100$ mm and are thus compatible with originating from the main vertex. The quantities $r_{min}$ and $z_{min}$ are the smallest radial and longitudinal distances between the interaction point and the measured particle trajectory. Any $\bar{p}$ tracks outside this cut either suffered an interaction in the material in front of the jet-chamber (3 g/cm$^2$ of Al) or originated from hyperon decays.

In order to obtain the momentum spectrum of the $\bar{p}$ sample, corrections are applied for acceptance (15%) assuming an isotropic angular distribution, for particle identification and pattern recognition efficiency (6%) and loss due to nuclear absorption (5–10% depending upon momentum [‡1]). Furthermore, the $\bar{p}$ momentum is corrected for ionisation loss in the material in front of the jet chamber. Fig. 1 shows the resulting differential cross section $d\sigma(e^+e^- \to \bar{p} + \text{anything})/dp$. The vertical scale has a systematic normalisation uncertainty of 11%. The solid curve is the prediction of a recent model from the Lund group [12], which shows reasonable agreement with the data. The basic new feature of this model is the inclusion of diquark antidiquark pairs in the fragmentation process. The normalisation of the Lund model was obtained from 4 GeV CM data [1,2]. In order to obtain the total yield of antiprotons

[‡1] The cross section $\bar{p}$ + Al was scaled from the $\bar{p}$ + d cross section with $A^{0.65}$ [11].

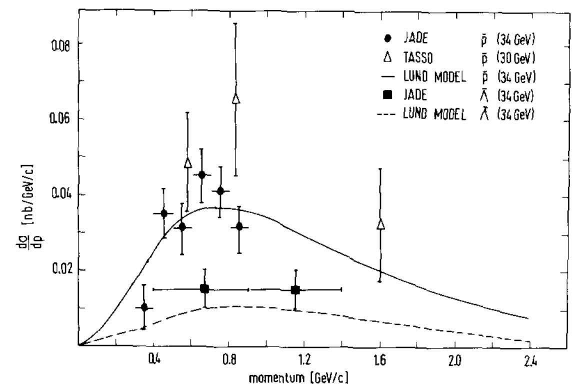


Fig. 1. Antiproton and antilambda momentum spectra. Errors are statistical only. The full and dashed curve is the prediction of the Lund model [12]. The TASSO points are from ref. [3].

outside the accepted momentum range 0.3–0.9 GeV/$c$, the momentum spectrum of the Lund model was used. The result is shown in table 1. It should be noted that the sample of antiprotons also includes contributions from hyperon and resonance decays.

A sample of events with $\bar{p}$ candidates identified by ionisation loss in the enlarged momentum range 0.3–1.3 GeV/$c$ was scanned for antilambdas ($\bar{\Lambda}$) using the decay mode $\bar{\Lambda} \to \bar{p}\pi^+$. The enlarged sample contained particles of ambiguous mass assignment ($e^-$ or $\bar{p}$), but due to the narrow width of the lambda, these could eventually be subtracted from the lambda sample.

The following criteria had to be satisfied:

(i) Both tracks have $r_{min} > 2$ mm.

(ii) The momentum of the $\pi^+$-candidate is less than 40% of the momentum of the $\bar{p}$-candidate. This essentially removes any remaining $K^0$-candidates.

Table 1

Average number of $\bar{p}$ and $\bar{\Lambda}$ per hadronic event. For the extrapolation to all momenta the shape predicted by the Lund model [12] has been used.

| Particle type | Momentum range | Average number of $\bar{p}$ or $\bar{\Lambda}$ per hadronic event |
| --- | --- | --- |
| $\bar{p}$ | 0.3–0.9 GeV/$c$ | 0.062 ± 0.006 |
| $\bar{p}$ | extrapolated to all momenta | 0.27 ± 0.03 |
| $\bar{\Lambda}$ | 0.4–1.4 GeV/$c$ | 0.037 ± 0.010 |
| $\bar{\Lambda}$ | extrapolated to all momenta | 0.117 ± 0.032 |

(iii) The two tracks have a common origin in space.

(iv) The main vertex and the decay vertex are seperated by more than 10 mm and less than 200 mm in the plane perpendicular to the beam.

The invariant masses of the selected $\bar{\Lambda}$ candidates are shown in fig. 2a, where a prominent $\bar{\Lambda}$ signal is visible over a broad background. The mass distribution of the wrong charge combinations $\bar{p}\pi^-$ does not show any peak structure (fig. 2b) as expected. Thus the $\bar{\Lambda}$ parameters can be obtained by fitting a gaussian plus a background of the form

$$BG = a_1(m - m_T)^{0.5} + a_2(m - m_T) + a_3(m - m_T)^2 ,$$

to the measured spectrum. $m_T = m_{\bar{p}} + m_\pi$ is the threshold mass. The peak of the gaussian was found to be $m_{\bar{\Lambda}} = (1.120 \pm 0.003)$ GeV/$c^2$ and the width $\sigma = (0.011 \pm 0.003)$ GeV/$c^2$.

A fit to the $\bar{\Lambda}$-decay length distribution (fig. 3) yields

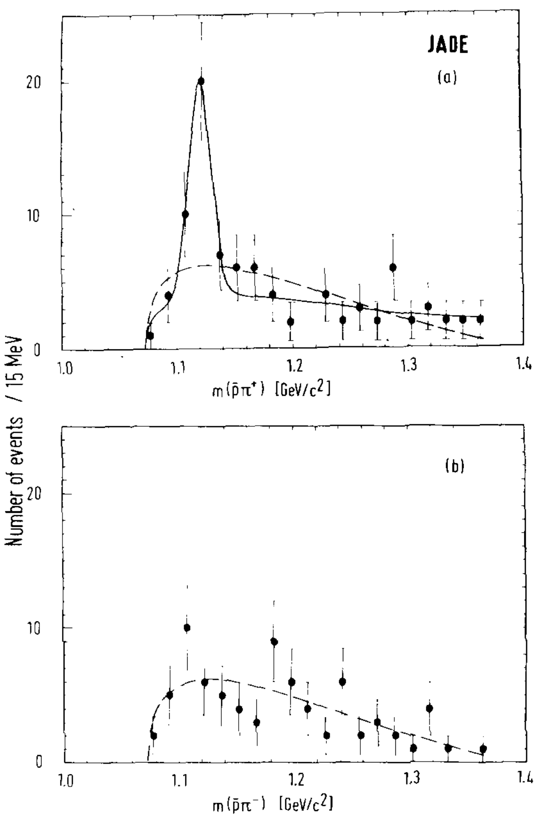


Fig. 2. Fit to the $\bar{p}\pi^+$ mass spectrum (a) and to the $\bar{p}\pi^-$ mass spectrum (b). The dashed line represents a fit to the $\bar{p}\pi^-$ spectrum and is shown on the $\bar{p}\pi^+$ spectrum for comparison.

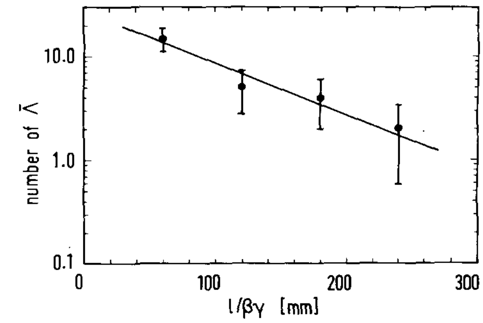


Fig. 3. $\bar{\Lambda}$-decay length distribution $l/\beta\gamma$. The curve represents a fit to the data, yielding a $\bar{\Lambda}$ lifetime of $\tau_{\bar{\Lambda}} = (2.8 \pm 0.6) \times 10^{-10}$ s.

$\tau_{\bar{\Lambda}} = (2.8 \pm 0.6) \times 10^{-10}$ s and is in good agreement with the world average of $\tau_\Lambda = (2.63 \pm 0.02)^{-10}$ s. The detection efficiency of the $\bar{\Lambda}$ satisfying the above criteria was determined by means of an isotropic distribution of simulated lambda particles. It ranged from 28% at 600 MeV/$c$ $\bar{\Lambda}$-momentum to 36% at 1.4 GeV/$c$ including the branching ratio of the unseen decay mode $\bar{\Lambda} \to \bar{n}\pi^0$ (36%). The corrected number of $\bar{\Lambda}$ in the observed momentum range 0.4–1.4 GeV/$c$ is 121 ± 28. The rates of $\bar{\Lambda}$ and $\bar{p}$ per hadronic event are given in table 1, and the differential cross section $d\sigma(e^+e^- \to \bar{\Lambda} + \text{anything})/dp$ is shown in fig. 1. The vertical scale for $\bar{\Lambda}$ has a systematic normalisation uncertainty of 14%.

To study a possible baryon–antibaryon correlation within the same event, the $\bar{p}$ and $\bar{\Lambda}$ sample was scanned for protons and lambdas. Typically one identified proton per event is observed. However, most of these are due to secondary interactions in the material in front of the jet chamber. Requiring both $\bar{p}$ and p with momenta between 0.3 and 0.9 GeV/$c$ to originate from the main vertex ($r_{min} < 20$ mm, $z_{min} < 100$ mm) and to show no possible secondary interaction, 6 events were found. Two additional events contain an antiproton lambda pair where the proton slightly violates the $r_{min}$ cut.

Fig. 4a shows the azimuthal angle $\phi$ formed by the baryon–antibaryon momenta projected onto the plane perpendicular to the event thrust axis versus the difference of the corresponding longitudinal momenta $|\Delta p_L|$. The error bar on $\phi$ in fig. 4a accounts for an uncertainty of 5° in the thrust axis. Due to the limited momentum acceptance no conclusion can be drawn from $|\Delta p_L|$ or a rapidity correlation. In the $\phi$-projec-

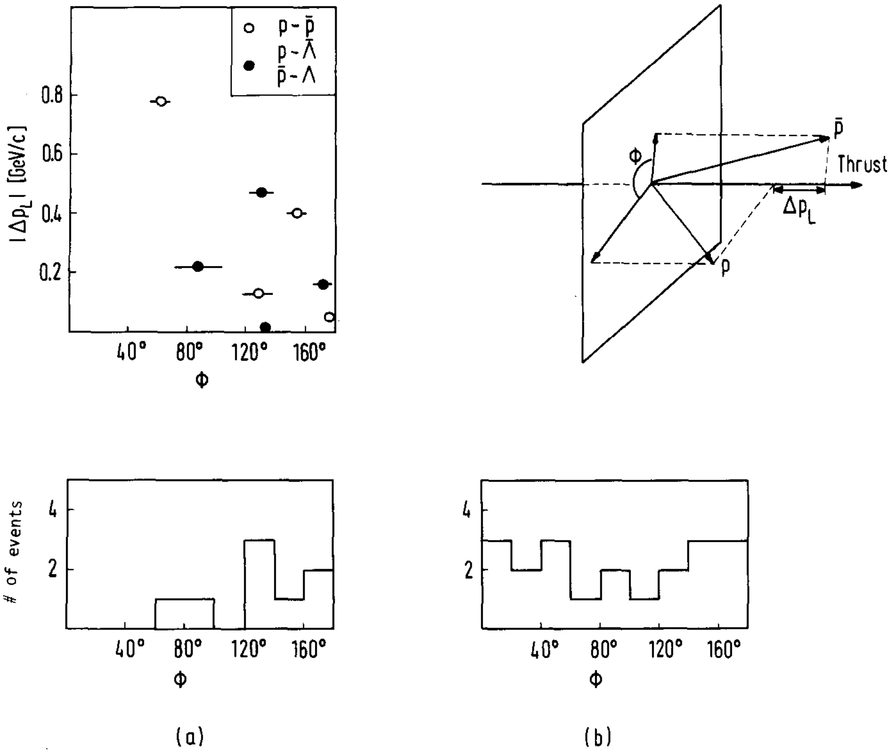


Fig. 4. The distribution of the measured angle $\phi$ between the projected momenta in the plane perpendicular to the thrust axis for baryon–antibaryon (a) and for $\bar{p}$ and an arbitrary negative charged particle (b). In (a) for each point also the difference of their longitudinal momenta is given.

tion, the baryon–antibaryon pairs, however, show an angular anticorrelation, i.e. they are produced with transverse momenta preferentially opposite to each other. A flat distribution in $\phi$ would be expected from an uncorrelated pair, as is borne out in fig. 4b, where all negative charged tracks in the given momentum range were combined in turn with each $\bar{p}$. The weighted mean of angle $\phi$ in fig. 4a is $\overline{\phi} = (140 \pm 14)^\circ$ compared to a flat $\phi$-distribution containing the same number of events $\phi = (90 \pm 18)^\circ$.

In conclusion, baryon production plays a substantial role in $e^+e^-$-annihilation: We estimate that 27% of all multihadronic events contain an antiproton either direct or from hyperon or resonance decays and 12% an antilambda, using the Lund model [12] to extrapolate the data to all momenta. The fraction of multihadron events with a $\bar{p}$ increases from the highest SPEAR and DORIS energies to PETRA energies by about a factor of 2, whereas the ratio of $\bar{\Lambda}$ to $\bar{p}$ production appears to be constant. The data indicate an angular anticorrelation of the baryon–antibaryon pairs.

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*References*

[1] M. Piccolo et al., Phys. Rev. Lett. 39 (1977) 1503;
G.S. Abrams et al., Phys. Rev. Lett. 44 (1980) 10.

[2] DASP-Collab., R. Brandelik et al., Nucl. Phys. B148 (1979) 189.
[3] TASSO-Collab., R. Brandelik et al., Phys. Lett. 94B (1980) 444.
[4] D. Pandoulas, Rapporteur talk 20th Intern. Conf. on High energy physics (Madison, WI, 1980).
[5] DASP-II Collab., H. Albrecht et al., DESY 81-011.
[6] R.D. Field and R.P. Feynman, Nucl. Phys. B136 (1978) 1.
[7] P. Hoyer et al., Nucl. Phys. B161 (1979) 349.
[8] B. Andersson, G. Gustafson and T. Sjöstrand, Phys. Lett. 94B (1980) 211.
[9] JADE-Collab., W. Bartel et al., Phys. Lett. 88B (1979) 171.
[10] JADE-Collab., W. Bartel et al., Z. Phys. C6 (1980) 296.
[11] R.J. Abrams et al., Phys. Rev. D4 (1971) 3235.
[12] B. Andersson, G. Gustafson and T. Sjöstrand, Lund Univ. preprint LU TP 81-3.