Λ, $\bar{\Lambda}$ PRODUCTION IN e^+e^- ANNIHILATION AT 33 GeV CENTRE OF MASS ENERGY

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Differential cross sections for Λ, $\bar{\Lambda}$ production have been measured in e^+e^- annihilation at 33 GeV in the momentum range from 1 to 10 GeV/c. New results for K^0, $\overline{K^0}$ production at this energy are also presented and we show that the x-dependence of the scaling cross section $(s/\beta)\, d\sigma/dx$ is similar for lambdas and kaons over the whole x range measured. The sum of Λ and $\bar{\Lambda}$ production was found to be 0.28 ± 0.04 (statist. error) ± 0.04 (syst. error) per event which yields a value $R_{\Lambda,\bar{\Lambda}} = 1.12 \pm 0.15 \pm 0.17$.

Baryon production in e^+e^- annihilation is not yet understood although the evidence which exists for nucleon production [1,2] suggests that the majority of e^+e^- annihilations in the 30 GeV region will contain a baryon–antibaryon pair. Observations in this energy region have so far been restricted to low x, $x \lesssim 0.15$, where x is the fractional particle energy, $x = 2E/W$, W = total c.m. energy. In this letter we present evidence for copious Λ, $\bar{\Lambda}$ production up to large x values. The ratio of Λ, $\bar{\Lambda}$ to kaon production is roughly constant above $x \gtrsim 0.1$.

The experiment was performed with the TASSO [3] detector at PETRA for centre of mass energies between 29.9 GeV and 36.5 GeV. The average energy was 33.3 GeV. A sample of 3404 hadronic events was selected with standard cuts [3]: 5 or more charged particles with momentum component $p_T > 0.1$ GeV/c transverse to the beam direction and polar angles θ satisfying $|\cos\theta| < 0.87$. To avoid contamination from two-photon processes the total energy carried by charged particles was required to be larger than 0.27 times the centre of mass energy.

Candidates for $\Lambda \to p\pi^-$ and $\bar{\Lambda} \to \bar{p}\pi^+$ decays were selected by two procedures described below. In the following the term Λ will be used to refer to both Λ and $\bar{\Lambda}$.

Method 1.

(a) Only particles with $p_T > 0.1$ GeV/c and $|\cos\theta| < 0.87$ were considered.

(b) All pairs of oppositely charged trajectories were required to satisfy a three-dimensional fit which demanded that they intersect at a point in space. The higher momentum particle was considered to be the proton (antiproton).

(c) In the projection on a plane transverse to the beam direction, the closest distance d_0 between the particle trajectory and the primary vertex had to exceed 1.5 mm for the proton and 3 mm for the pion. The average error on d_0 due to track reconstruction is around 1 mm. The sensitivity of the Λ signal to these particular cuts is low but they reduce the background dramatically.

(d) The Λ decay point was required to be within a momentum dependent minimum and maximum distance from the primary vertex, corresponding to probabilities of 30% and 95%, respectively, for a Λ to decay before reaching that distance.

(e) Pairs consisting of tracks with more hits in the tracking chambers in front of the decay point than could be considered accidental or with more than 3 hits missing following the decay point were rejected.

(f) The direction of the line joining primary vertex and decay point had to agree with the direction of the Λ momentum vector within 3° in the projection perpendicular to the beam.

(g) The decay angle θ^* of the proton in the rest system of the Λ, measured with respect to the Λ direction of flight, had to satisfy $|\cos\theta^*| < 0.9$. Background from accidental combination of tracks is most concentrated at $|\cos\theta^*| > 0.9$.

(h) Electron pairs were removed from the sample by demanding that the effective mass of the pair be greater than 50 MeV if the particles were considered to be electrons.

(i) The majority of $K^0_S \to \pi^+\pi^-$ decays were removed by rejecting candidates with $|m_{\pi\pi} - m_{K^0}| < 15$ MeV where $m_{\pi\pi}$ is the effective mass if both tracks are considered to be pions. Any remaining K^0_S's contribute to a smooth background in the Λ region.

The effect of all these cuts was simulated in the Monte Carlo efficiency estimate described below.

There was a total of 345 events with at least one particle pair with momentum greater than 1 GeV/c satisfying the above cuts.

A scatter plot of the total momentum for particle pairs versus $m_{p\pi}$ is shown in fig. 1a. A clear concentration near the Λ mass is visible in all momentum intervals. The projections on the horizontal axis for Λ's and $\bar{\Lambda}$'s separately are shown in figs. 1b,c. They show a signal of 50 Λ's with masses within 25 MeV of the accepted Λ mass above a background of 23 and a signal of 54 $\bar{\Lambda}$'s above a background of 22. A gaussian fit to the mass peak of the combined sample gave a Λ mass, $M = 1.115 \pm 0.001$ GeV and a Λ mass resolution of $\sigma = 0.007$ GeV.

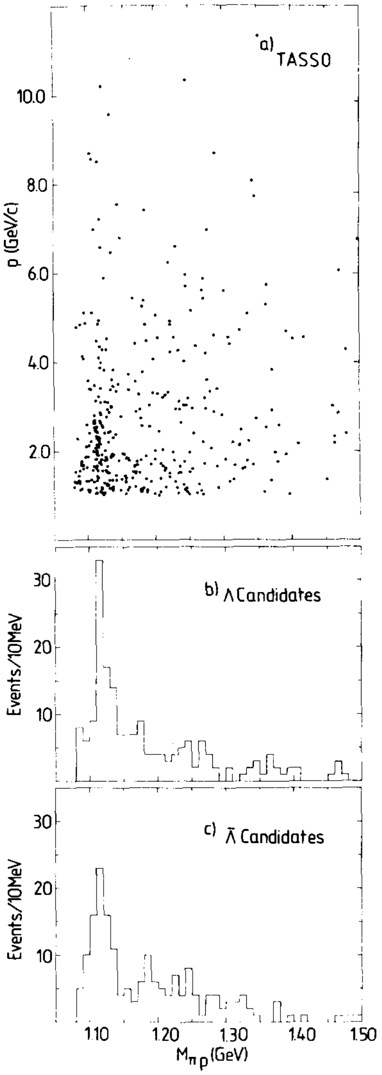

Fig. 1. (a) Total momentum for particle pairs versus the $p\pi$ invariant mass for pairs satisfying the cuts of method 1 (see text). (b) $M_{p\pi^-}$ projection for Λ candidates. (c) $M_{\bar{p}\pi^+}$ projection for $\bar{\Lambda}$ candidates.

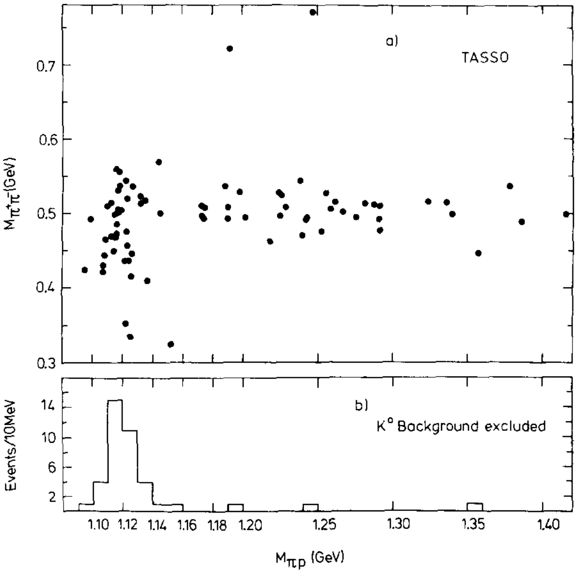

Fig. 2. (a) Invariant mass assuming pion masses versus invariant mass assuming $p\pi^-$ or $\bar{p}\pi^+$ masses for particle pairs satisfying the cuts of method 2 (see text). (b) Mass spectrum of $M_{p\pi^-}$ or $M_{\bar{p}\pi^+}$ with K^0 background excluded (see text).

Method 2.

This method provides a cleaner signal for the higher momentum Λ's. Criteria (a), (b), (e), (f), (h) above were again applied but with the additional requirement that the Λ decay point must be at a radius greater than 20 cm but less than 45 cm and hence be further from the primary vertex than the first tracking chamber. This assures that only genuine V^0's, i.e. track pairs not originating at the primary vertex, are accepted. The masses $m_{\pi\pi}$ and $m_{p\pi}$ for these candidates are displayed in fig. 2. Except for a very small background this sample consists of either $\Lambda \to \pi p$ or $K_S^0 \to \pi^+\pi^-$ decays. Extrapolating the $m_{p\pi}$ distribution of the K^0's into the Λ mass range ($m_{p\pi} < 1.15$ GeV) leads to a contamination of $8 \pm 3\,K^0$ decays under the Λ peak. They were subtracted from the Λ momentum distribution on a statistical basis. Λ candidates with $|m_{\pi\pi} - m(K^0)| < 50$ MeV were given a weight such as to reduce the total number of Λ's by 8. The remaining sample consists of 28 events. Another subtraction procedure, namely leaving out the 8 candidates with $m_{\pi\pi}$ closest to the K^0 mass, leads essentially to the same result since the momentum spectra of K's and Λ's in this sample are very similar.

The efficiency for both methods was estimated by generating events containing Λ, $\bar{\Lambda}$'s using a Monte Carlo program [4] which had been set up to produce baryons [5] in agreement with our earlier results on p, $\bar{p}$ production [1]. Hits in the tracking chambers were simulated from these events and hence losses due to geometric and tracking inefficiencies determined. A correction was also made for a loss of ~6% due to interaction of the Λ's or their decay products in the beam pipe. Finally the cuts described above were applied to the surviving members of the Monte Carlo sample.

Method 1 had an overall efficiency of 20–23% for momenta between 1.0 and 4.0 GeV/c decreasing approximately linearly to ~7% at 10 GeV/c. The efficiency for method 2 rises from zero at 1.5 GeV/c to 15% at 3 GeV/c and then stays approximately constant up to 10 GeV/c. We estimate an overall systematic error of ± 15% on our efficiency determination. It results mainly from uncertainties in the tracking losses. No significant effect on the efficiency estimates was observed by small variations of the fragmentation parameters in the Monte Carlo generation program. The resulting cross sections from the two methods were in agreement and therefore were combined.

The Λ and $\bar{\Lambda}$ signals were found equal within errors. Corrections were made for the unobserved Λ, $\bar{\Lambda}$ decay modes to obtain differential cross sections for the sum of Λ and $\bar{\Lambda}$ production from the measured luminosity. Corrections for initial state radiation were applied [6].

In table 1 and fig. 3 we present the differential cross section $d\sigma/dp$ and the scaling cross section $(s/\beta)\, d\sigma/dx$ where $s = W^2$ and $\beta = p_\Lambda/E_\Lambda$. The errors do not include the 15% systematic uncertainty.

In fig. 3a the $d\sigma/dp$ results are shown together with two points at low momenta obtained by doubling values obtained by the JADE collaboration [2] for $\bar{\Lambda}$ production at effectively the same centre of mass energy. For comparison we also show values for p, $\bar{p}$ inclusive production at low x obtained by scaling our earlier 30 GeV results [1] with s^{-1} and by doubling results from JADE for $\bar{p}$ production [2]. In both cases the p, $\bar{p}$ results include protons and antiprotons from Λ and $\bar{\Lambda}$ decay. The p, $\bar{p}$ results are over a much more restricted range but it is apparent that in the 1 to 2 GeV/c region there are twice as many p, $\bar{p}$ as there are Λ, $\bar{\Lambda}$.

Table 1
Differential cross sections for $\Lambda + \bar{\Lambda}$ production at 33 GeV centre of mass energy.

Momentum (GeV/c)	$d\sigma/dp$ [a] (pb/GeV/c)
1.0– 2.0	26.7 ± 6.9
2.0– 3.0	21.2 ± 4.0
3.0– 5.0	6.8 ± 2.2
5.0– 7.0	4.1 ± 1.6
7.0–10.0	2.0 ± 0.9

[a] The errors do not include the 15% systematic uncertainty.

In fig. 3b we compare the inclusive scaling cross sections for Λ, $\bar{\Lambda}$ and K^0, $\overline{K^0}$ production. The K^0 data were obtained from the current data sample using the technique described in an earlier publication and are consistent with the values previously published [7]. They are based on a factor of 3.7 increase in statistics over our earlier results and this has allowed us to increase the measured x range to $x = 0.6$. The values shown are subject to a 15% systematic uncertainty arising predominantly from the efficiency determination. It can be seen from the figure that the x dependence of Λ and K^0 cross sections is very similar. The average ratio of the scaling cross sections

$$(s/\beta)\, d\sigma/dx(K^0)/(s/\beta)\, d\sigma/dx(\Lambda) = 3.0 \pm 0.4 \,.$$

The error is purely statistical. The systematic error in this ratio is less than 10%.

By integrating our cross sections and extrapolating to zero momentum we find

$$R_{\Lambda,\bar{\Lambda}} = \frac{\sigma(e^+e^- \to \Lambda X) + \sigma(e^+e^- \to \bar{\Lambda} X)}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

$$= 1.12 \pm 0.15 \pm 0.17 \,,$$

where $\sigma(e^+e^- \to \mu^+\mu^-) = 4\pi\alpha^2/3s$.

The contribution between 0 and 1 GeV/c was estimated by parameterising the invariant cross section $(E/4\pi p^2)\, d\sigma/dp$ in the form $a \exp(-bE)$ over the range from 1 to 5 GeV/c and then extrapolating this to zero momentum. The estimated contribution accounts for 13% of the above value of $R_{\Lambda,\bar{\Lambda}}$.

By integrating the K^0 differential cross section we find for

$$R_{K^0,\overline{K^0}} = \frac{\sigma(e^+e^- \to K^0 X) + \sigma(e^+e^- \to \overline{K^0} X)}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

$$= 5.5 \pm 0.4 \pm 0.8 \,,$$

which agrees well with our previous value [7] of 5.6 ± 1.0 ± 0.8.

The value of $R_{\Lambda,\bar{\Lambda}}$ is much higher than the value measured at 7 GeV centre of mass energy [8], $R_{\Lambda,\bar{\Lambda}} = 0.24 \pm 0.02$ with an estimated systematic error of 25%. This increase in Λ production between 7 GeV and 33 GeV centre of mass energy is larger than the increase of K^0 [7,9] production from $R_{K^0,\overline{K^0}} = 2 \pm 0.2$ to

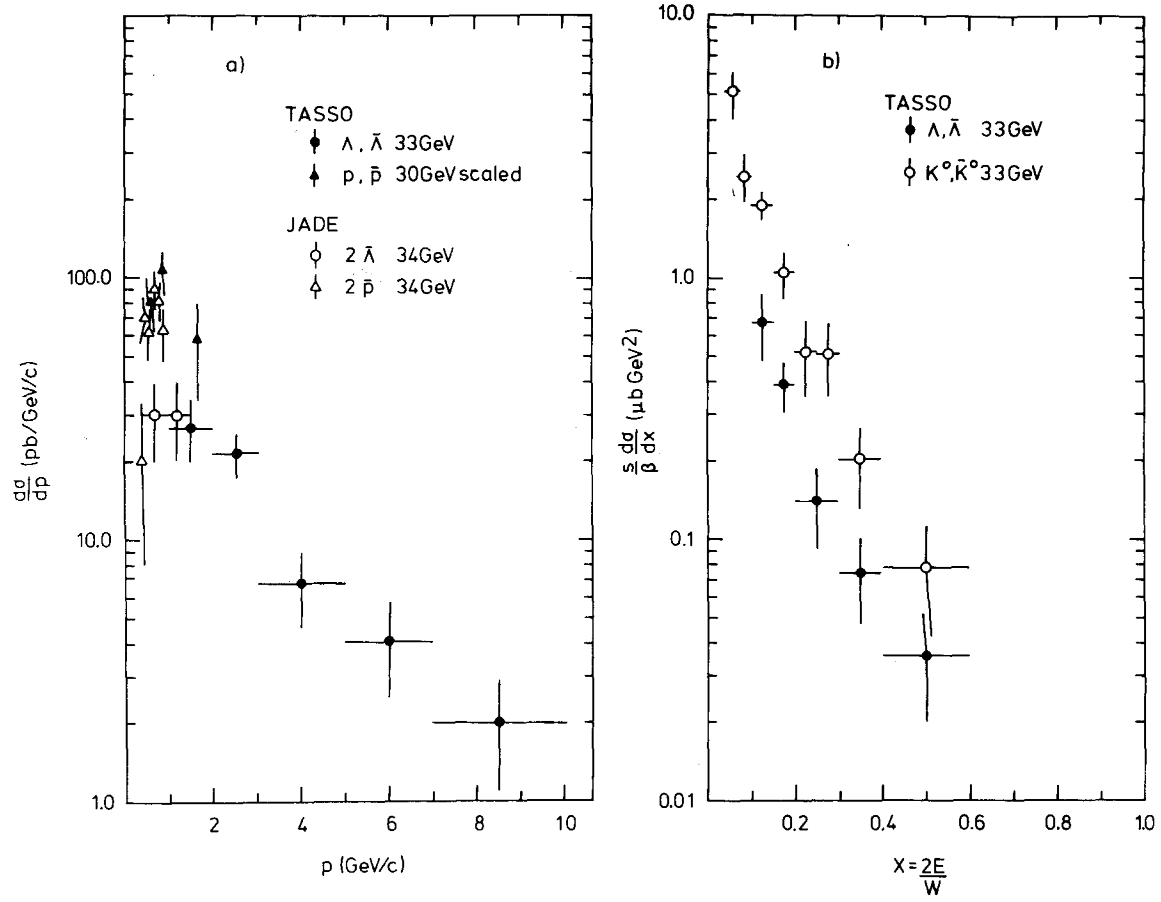

Fig. 3. (a) Differential momentum cross section for the sum of Λ, Λ̄ production. Also shown are JADE results on Λ̄ and p̄ production [2] multiplied by a factor of two and TASSO results on p, p̄ production at 30 GeV [1]. The 30 GeV points have been scaled with s^{-1} to the mean energy of 33.3 GeV. (b) The scaling cross section $(s/\beta)\, d\sigma/dx$ for the sum of Λ, Λ̄ production. Also shown are the K^0 data at 33.3 GeV centre of mass energy from this experiment.

$R_{K^0,\bar{K}^0} = 5.5 \pm 0.4 \pm 0.8$ which is similar to the increase of charged particle multiplicity [10].

To summarize we have measured inclusive Λ and Λ̄ production in e^+e^- annihilation at 33 GeV over a large momentum range. We find that Λ, Λ̄ production plays an important role in e^+e^- annihilation at this energy and that the scaling cross section is similar to that of kaons. We conclude that the dynamics of baryon and meson production in high-energy e^+e^- annihilation appear to be very similar.

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