OBSERVATION OF Ξ^-, $\overline{\Xi}^-$ PRODUCTION IN e^+e^- ANNIHILATION

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We present evidence for the production of Ξ^-, $\overline{\Xi}^-$ in e^+e^- annihilation into hadrons. Our measurement yields: 0.026 ± 0.008 (stat.) ± 0.009 (syst.) Ξ^-, $\overline{\Xi}^-$ per hadronic event at $W \sim 34$ GeV. Using our previous measurements of Λ, $\overline{\Lambda}$ and p, $\overline{p}$ production we obtain the relative yields $(\Xi^-, \overline{\Xi}^-)/(\Lambda, \overline{\Lambda})$ = 0.087 ± 0.03 (stat.) ± 0.03 (syst.) and $(\Xi^-, \overline{\Xi}^-)/(p, \overline{p})$ = 0.033 ± 0.011 (stat.) ± 0.011 (syst.).

Recent measurements [1] have shown that baryons are produced at a substantial rate in high energy e^+e^- annihilation into hadrons and that their momentum distribution has a similar shape to that of mesons. To learn more about baryon production it is of considerable interest to measure the production of the different baryon species. In this letter we report on the first observation of Ξ^-, $\overline{\Xi}^-$ particles in e^+e^- annihilation. We refer to Ξ^-, $\overline{\Xi}^-$ production for simplicity as $\Xi^{\mp}$ production.

The experiment was performed with the TASSO detector [2] at PETRA for CMS energies W between 12 and 36.5 GeV. A sample of 26 115 hadronic events at average energies W = 14, 22 and 34 GeV, with the majority of 20 832 events at $W \gtrsim 30$ GeV, were selected using the charged particle information as described in ref. [3].

For reconstruction of the Ξ^- we used the cascade decay

$$\Xi^- \to \Lambda\pi^- \quad \hookrightarrow p\pi^- \,.$$

To select Λ candidates we calculated the invariant mass for each combination of two oppositely charged particles that fulfilled the following cuts:

each particle should have a transverse momentum p_t, with respect to the beam direction satisfying $p_t >$ 0.1 GeV/c and a polar angle θ with $|\cos\theta| < 0.87$;

each pair had to have a momentum greater than 1 GeV/c,

all pairs had to intersect in the plane transverse to the beam (R–φ plane), between 5 and 45 cm from the interaction point. A new fit for the z-components of both tracks was then made, constraining both tracks to have the same z value at the reconstructed decay point. The χ^2 of the fit had to satisfy χ^2/DOF < 5;

the direction of the line joining the average interaction point (as determined from Bhabha scattering events) and the decay point had to agree with the direction of the Λ momentum vector within 10° in the R–φ plane;

the higher momentum particle was considered to be the proton (antiproton). To reduce background the decay angle θ^* of the proton in the rest system of the Λ, measured with respect to the Λ direction had to satisfy $|\cos\theta^*| < 0.9$;

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;

in the R–φ plane the distance of closest approach of the pion track to the interaction point had to be greater than 3 mm if the decay point was less than 20 cm away from the interaction point (the first tracking chamber had a radius of 18.7 cm).

The resulting mass spectra of $p\pi^-$ and $\overline{p}\pi^+$ combinations are shown in fig. 1. Clear signals of about 240 Λ and 230 $\overline{\Lambda}$ are seen. The RMS Λ mass resolution obtained from a fit is $\sigma \approx 4$ MeV.

All particle combinations having an invariant mass within ±0.006 GeV of the Λ mass (1.116 GeV) were then considered to be Λ candidates. For the further analysis their mass was fixed to the nominal Λ mass.

To select Ξ^-'s we searched for an intersection of an additional charged track with the Λ. We required further that:

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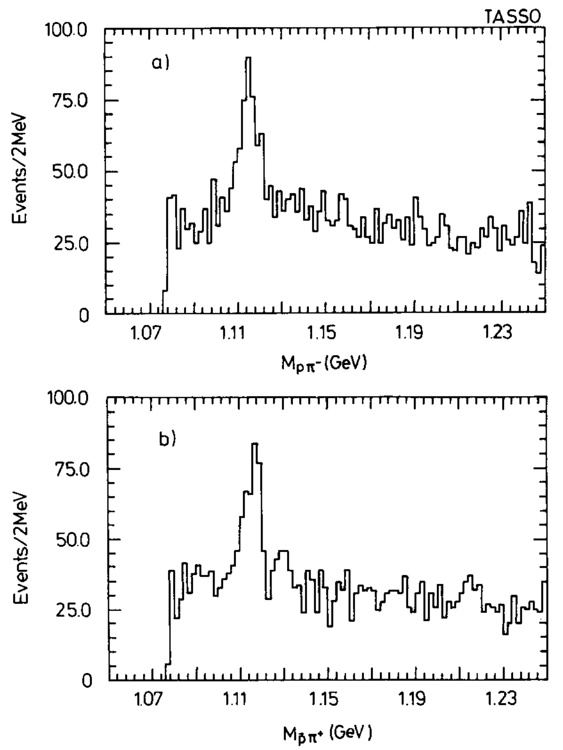

Fig. 1. The invariant $p\pi^-$ (a) and $\bar{p}\pi^+$ (b) mass spectra.

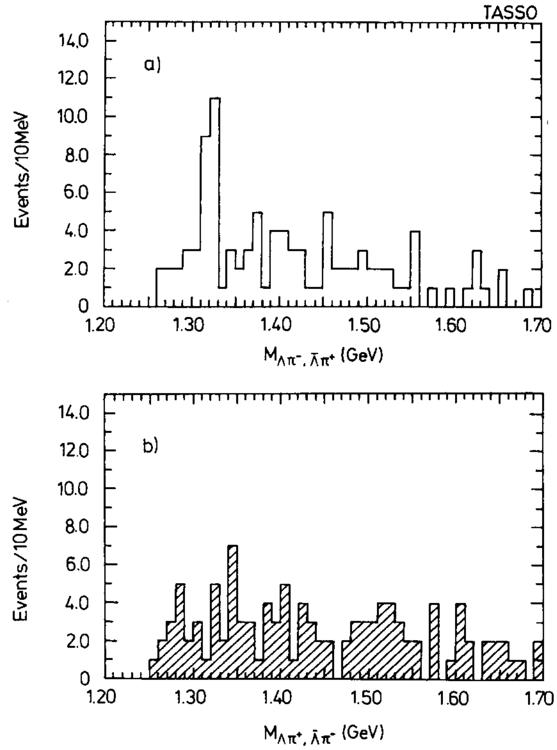

Fig. 2. The invariant $\Lambda\pi^-$, $\bar{\Lambda}\pi^+$ (a) and $\Lambda\pi^+$, $\bar{\Lambda}\pi^-$ (b) mass spectra.

the additional charged track satisfied $p_t > 0.1$ GeV/c and $|\cos\theta| < 0.87$;

the intersection of the additional track with the Λ should be more than 1 cm away from the interaction point in the R–φ plane and in front of the Λ decay point. The z component of the additional charged track was refitted with respect to the position of the Λ at the reconstructed Ξ^- decay point. The χ^2/DOF of the fit had to be smaller than 10. In order to reduce background, Ξ^- candidates which decayed close to the interaction point were rejected. We accepted Ξ^- candidates which satisfied the condition $\exp(-mr/(p_T c\tau)) < 0.8$ where m is the Ξ^- mass, r the distance between interaction point and decay point and p_T the Ξ^- momentum component in the R–φ plane, and τ the Ξ^- lifetime;

the angle between the reconstructed direction of flight of the $\Lambda\pi^-$ combination and its momentum vector had to be smaller than 5°;

the momentum of the $\Lambda\pi^-$ combination had to be greater than 1 GeV/c.

The resulting $\Lambda\pi^-$ mass spectrum is shown in fig. 2a. A narrow peak around the Ξ^- mass (1.321 GeV) is visible. No similar structure is visible in fig. 2b where the Λ's are combined with tracks of the wrong charge ("Ξ^{+}"). Furthermore we checked thta assigning the kaon mass to the additional charged track and computing the ΛK mass spectrum no enhancement in the Ω^- region is seen. The width of the Ξ^- signal in fig. 2a is in agreement with the expected RMS resolution of σ = 8 MeV obtained from Monte Carlo calculations. From fig. 2a we obtain 20 candidates (16Ξ^-, $\overline{\Xi^-}$ above a background of 4) with a mass 1.310 GeV $< M(\Lambda\pi) <$ 1.330 GeV. Separating our sample of 20 Ξ^- candidates into baryons and antibaryons we find 11 Ξ^- and 5 $\overline{\Xi^-}$ above background.

For the further analysis we only considered the 14 of the 20 candidates observed at a CMS energy $W >$ 30 GeV, the average energy being $\bar{W}$ = 34.4 GeV. The efficiency for Ξ^- detection was determined by generating Monte Carlo events for $e^+e^- \to q\bar{q}, q\bar{q}g$ [4,5] and simulating hits in the tracking chambers as well as decays, nuclear absorption and scattering. Also included were radiative effects. The simulated events were subjected to the same chain of analysis programs as the real data. The efficiency was defined by

$\epsilon = (n_1/N_1)/(n_0/N_0)$,

where n_0 is the number of Ξ^- in N_0 events generated at the nominal energy W and n_1 is the number of reconstructed Ξ^- in N_1 events after radiative effects and after all cuts were applied. The efficiency for detection of $\Xi^- \to \Lambda\pi^- \to p\pi^-\pi^-$ increased from 2% at a Ξ^- momentum of 1 GeV/c to 7% at 2 GeV/c and decreased to 1.9% at 6 GeV/c. In addition we corrected for the unseen decay modes of Λ and Ξ^-.

The scaled cross-section $(s/\beta)\,\mathrm{d}\sigma/\mathrm{d}x$ ($s = W^2$, $\beta = P/E$ where P, E are the Ξ^- momentum and energy, $x = 2E/W$) obtained for the reaction $e^+e^- \to \Xi^-(\overline{\Xi^-}) + X$ at $W > 30$ GeV is shown in fig. 3. For comparison our measured $\Lambda, \bar{\Lambda}$ and $p, \bar{p}$ cross sections are also shown. In order to obtain the total $\Xi^-, \overline{\Xi^-}$ yield, the cross section measured in the Ξ^- momentum interval $1 < P < 6$ GeV/c was extrapolated to zero and to the maximum possible momentum using the shape of the momentum spectrum predicted by the Lund Monte Carlo [6]. The fraction of the Ξ^- yield outside the measured momentum interval was estimated to be 26%. The total yield of $\Xi^-, \overline{\Xi^-}$ per hadronic event at $W = 34.4$ GeV was found to be 0.026 ± 0.008 (stat.) $\pm\, 0.009$ (syst.). The systematic error stems mainly from uncertainties in the efficiency and in the extrapolation to low momenta. Together with our measured $\Lambda, \bar{\Lambda}$ and $p, \bar{p}$ rates we obtain the ratios: $(\Xi^-, \overline{\Xi^-})/(\Lambda, \bar{\Lambda}) = 0.087 \pm 0.03$ (stat.) $\pm\, 0.03$ (syst.) and $(\Xi^-, \overline{\Xi^-})/(p, \bar{p}) = 0.033 \pm 0.011$ (stat.) $\pm\, 0.011$ (syst.).

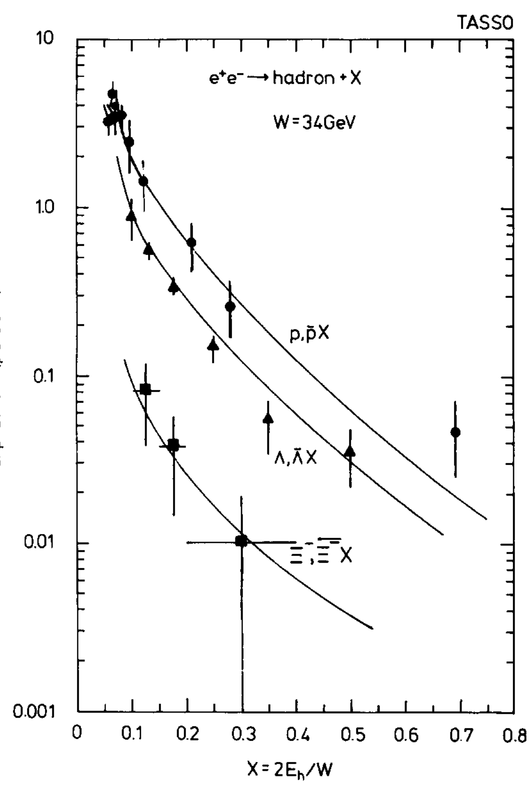

Fig. 3. The scaled cross section $(s/\beta)\,\mathrm{d}\sigma/\mathrm{d}x$ for $e^+e^- \to p, \bar{p}X$, $\Lambda, \bar{\Lambda}X$ and $\Xi^-, \overline{\Xi^-}X$ at $W = 34.4$ GeV. The curves show the prediction of the Lund model (see text).

Baryon production in e^+e^- annihilation has been studied theoretically by many groups. We compared our data with the predictions of the Lund group [6] and of Meyer [5]. In both models baryon production proceeds via diquark formation. Both models contain certain parameters which can be optimized by comparison with the data. Assuming a u : d : s quark production ratio of $P(\mathrm{s})/P(\mathrm{u}) = P(\mathrm{s})/P(\mathrm{d}) = 0.4$ (in agreement with our $K^0, K^\pm$ data), a diquark to quark rate of 0.11 (in agreement with our $p, \bar{p}$ and $\Lambda, \bar{\Lambda}$ data), we used the Ξ^- cross section data to estimate the parameter d in the Lund model, which yields an extra suppression factor for the s-quark in diquark pairs,

$$d = P(\mathrm{us})P(\mathrm{d})/P(\mathrm{ud})P(\mathrm{s}) \,.$$

The Lund model is in reasonable agreement with the p, Λ and Ξ^- data for $0.2 < d < 0.5$, with $d = 0.3$ being the preferred value. This may be compared with the value of $d = 0.2$ assumed in ref. [6]. The curves in fig. 3 show the predictions of the Lund model with $d = 0.3$. A similar agreement with the data could be obtained in the Meyer model.

To summarize we have observed Ξ^- production in e^+e^- annihilation. At $W \approx 34$ GeV we measure $0.026 \pm 0.008 \pm 0.009$ $\Xi^-, \overline{\Xi^-}$/event and obtain the ratios $(\Xi^-, \overline{\Xi^-})/(\Lambda, \bar{\Lambda}) = 0.087 \pm 0.03 \pm 0.03$ and $(\Xi^-, \overline{\Xi^-})/(p, \bar{p}) = 0.033 \pm 0.011 \pm 0.011$.

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